Glenn Schneider – Curriculum Vitae: Table of Contents

(21 July 2021)

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Glenn Schneider – Curriculum Vitae

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Citizenship: United States

Education: Ph.D. in astronomy, August 1985, University of Florida.
B.S. in physics (cum laude), June 1976, New York Institute of Technology.

Professional Employment / Appointments:

[1994 – present] The University of Arizona, Steward Observatory
- Astronomer/Research Professor (2008-present)
- Associate Astronomer (2003-2008)
- NICMOS Project Instrument Scientist (1994-2003)

[1985 – 1994] Computer Sciences Corporation at the Space Telescope Science Institute
Operations Astronomer:
- Staff Scientist (1992-1994)
- Senior Member of the Technical Staff (1988-1992)
- Member of the Technical Staff-A (1985-1988)

[1987 – 1989] Catonsville (Maryland) Community College – Adjunct Teaching Faculty
[1978 – 1985] University of Florida
- Department of Astronomy – Research Assistant (1984 – 1985)
- Space Astronomy Laboratory – Research Assistant (1982 – 1984)
- Department of Astronomy – Teaching/Research Assistant (1978 – 1982)

Professional/Research Positions Held:

[2007 – 2018] Principal Investigator (PI) for the EXCEDE Project at UofA
[1994 – 2021] PI for 17 HST GO/AR, NASA, JPL, SSC-sponsored Research Programs
[1994 – 2021] UofA PI or Co-Investigator on 41 HST GO/AR or NASA-sponsored Programs
[1994 – 2003] Near Infrared Camera and Multi-Object Spectrometer Project:
- Instrument Definition Team (IDT) key member
- Guaranteed Time Observing (GTO) Team key member
- Environments of Nearby Stars (EONS) program lead
- Instrument Scientist

[1985 – 1994] Operations Astronomer at the Space Telescope Science Institute:
- WFPC-1, FGS, WF/PC-2, NICMOS instruments & observatory

Professional Experience:

SCIENCE: Circumstellar (CS) disks; extrasolar planets; formation, evolution, characterization, architectures, and diversity of extrasolar planetary systems; stellar/galactic astronomy; planetary transits; VIS/IR astronomy; eclipse, transit, occultation studies.

INSTRUMENTATION AND TECHNIQUES: Coronagraphy & high contrast/high spatial resolution imaging; polarimetry; photometry; astrometry; space instrumentation; spacecraft and mission operations.

SYNOPSIS: Over the past quarter century, Dr. Schneider has led and actively engaged in a diversity of galactic, extragalactic, and solar system investigations; in particular (but not limited to) developing and levering the unique high-contrast (coronagraphic) imaging and polarimetry capabilities of the Hubble Space Telescope (HST) in the pursuit of exoplanetary science (see Externally Sponsored Research – Awards). His scientific and technical interests have focused on the formation, evolution, properties, architectures and diversity of extrasolar planetary systems in the context of their host-star CS environments. In concert with his scientific investigations of dusty CS material and bodies (of all size scales) orbiting their host-stars, he has played leading scientific, technical, and programmatic roles in the development of very high contrast space-based coronagraphic imaging systems and techniques with HST (see Positions Held), resulting in spatially resolved scattered-light discovery and follow-up imaging, and interpretive analysis of disks of nascent CS material, evolutionarily evolved (and optically thin) exoplanetary debris systems, and sub-stellar companions (e.g., see Publications). As PI for the EXoplanetary Circumstellar Environments and Disk Explorer (EXCEDE), he devoted much of his time and effort to the advancement of its science and mission concept and to its hardware maturity - very recently successfully completing its NASA-sponsored technology maturation and demonstration program. Prior, during his decadal tenure as the Project Instrument Scientist for HST's Near Infrared Camera and Multi-Object Spectrometer (NICMOS), he was a leading member of its Instrument Definition and Guaranteed Time Observing teams. In his GTO role, he led the NICMOS Environments of Nearby Stars (EONS) programs with the first imaging discoveries and characterization of circumstellar disks since β Pictoris, and of brown dwarf substellar companions. In his IDT role, his functional, programmatic, and managerial responsibilities included providing science-driven end-to-end science, systems engineering, operations, and calibration oversight with the development, advancement, tracking, and implementation of mission-goal oriented requirements and recommendations to: (a) PI/science team, (b) external agencies (NASA/GSFC, HST Project Office, STScI), (c) instrument construction personnel, and (d) operations contractors and subs, during all project phases. Prior, for 9.5 years, Dr. Schneider served as an Operations Astronomer in the Science and Engineering Systems Division at STScI; see CV Appendix I for details.

Externally Sponsored Research Programs – Awards to G. Schneider as P.I. at UofA

Title (see appendices II& III for project research summaries)	Spon.	Start	End	Award
1. A Search for Stellar Duplicity and Variability from FGS Guide Star Acquisitions and Guiding Data	STScI	04/01/1995	06/30/1998	$37,346
2. Direct Imaging of a Circumstellar Disk: β Pictoris, a Case Study	STScI	09/01/1995	09/30/1999	$9,921
3. Near-IR Photometry of a Candidate companion to Proxima Centauri	STScI	11/01/1998	10/31/2000	$11,296
4. Duplicity and Variability in HST Guide Stars: An FGS Serendipitous Survey	STScI	02/01/1999	01/31/2002	$39,615
5. Confirmation and Characterization of Brown Dwarfs and Giant Planets from NICMOS 7226/7227	STScI	09/01/1999	08/31/2003	$69,092
6. Imaging and Spectroscopy of Dusty Circumstellar Disks	STScI	11/01/2000	10/31/2003	$32,273
7. Enabling Coronagraphic Polarimetry with NICMOS	STScI	02/01/2004	01/30/2007	$37,188
8. Solar Systems in Formation: A NICMOS Coronagraphic Survey of Protoplanetary and Debris Disks	STScI	07/01/2004	06/30/2009	$347,450
9. Coronagraphic Survey for Giant Planets Around Nearby Young Stars	STScI	09/01/2004	08/31/2008	$102,900
10. Imaging Polarimetry of Young Stellar Objects with ACS and NICMOS: A Study in Dust Grain Evolution	STScI	09/01/2004	06/30/2008	$46,552
11. High Spatial Resolution Imaging Polarimetry with TPF-C	JPL	10/01/2005	06/30/2007	$25,000
12. Imaging of Ices in Circumstellar Disks	STScI	03/01/2005	02/28/2007	$41,691
13. Spitzer Observations of a Newly-Discovered Edge-On Debris Disk About HR 32297	SSC	02/17/2006	05/21/2008	$5,513
14. Imaging Scattered Light from Debris Disks Discovered by the Spitzer Space Telescope Around 20 Sun-like Stars (I)	STScI	04/01/2006	03/31/2009	$173,911
15. Near-IR Spectrophotometry of 2MASSWJ 1207334-393254B: An Extra-Solar Planetary Mass Companion to a Young Brown Dwarf	STScI	05/01/2006	06/30/2009	$136,989
16. NICMOS Polarimetric Calibration	STScI	09/01/2006	08/31/2009	$44,363

17. Coronagraphic Polarimetry of HST-Resolved Debris Disks	STScI	09/01/2006	08/31/2011	$69,461
18. Coronagraphic Polarimetry with NICMOS: Dust Grain Evolution in T Tauri Stars	STScI	09/01/2006	08/31/2011	$55,775
19. Imaging Scattered Light from Debris Disks Discovered by the Spitzer Space Telescope around 21 Sun-like Stars (II)	STScI	09/01/2006	08/31/2011	$220,222
20. Mapping the Gaseous Content of Protoplanetary and Young Planetary Systems with ACS	STScI	05/01/2007	04/30/2011	$47,346
21. Dust Grain Evolution in Herbig Ae Stars: NICMOS Coronagraphic Imaging and Polarimetry	STScI	09/01/2007	08/31/2012	$87,354
22. NICMOS Imaging Survey of Dusty Debris Around Nearby Stars Across the Stellar Mass	STScI	09/01/2007	08/31/2012	$147,624
23. A Legacy Archive PSF Library and Circumstellar Environments (LAPLACE) Investigation	STScI	08/01/2007	07/31/2012	$197,035
24. A Paschen-α Study of Massive Stars and the ISM in the Galactic Center	STScI	05/01/2008	04/30/2011	$19,105
25. Structure and Chemistry of Planet-Building Disks: A Synoptic Study	NASA	01/01/2009	06/30/2010	$3,242
26. A STIS NUV Search for Shocked-Interstellar and Circumstellar Gas Towards the Debris System HD 61005	STScI	01/01/2010	12/31/2013	$19,646
27. PRONOUNCED – Polarimetry Reduction of NICMOS Observations Using New Calibrations and Enhanced Data	STScI	01/01/2010	10/31/2014	$78,802
28. Probing for Exoplanets Hiding in Debris Disks: Inner (<10 AU) Disk Imaging, Characterization, and Exploration	STScI	12/01/2010	11/30/2015	$246,970
29. Exoplanet Search in the HST NICMOS Coronagraphic Archive	STScI	11/01/2011	10/31/2016	$45,481
30. WFC3 Imaging of z=6 QSO Hosts: Zooming in on the First L>L* Galaxies and their Surroundings	STScI	04/01/2011	03/31/2015	$42,678
31. The EXoplanetary Circumstellar Disk Environments and Disk Explorer (Category III Technology Development)	NASA	04/01/2012	09/27/2015	$600,000
32. The Jovian Transit of Venus – A 'Truth Test' for Atmospheric Characterization of Earth-Size Planets in Habitable Zones	STScI	10/01/2012	09/30/2017	$139,068
33. Crossing the Snow Line: Mapping Ice Photodesorption Products in the Disks of Herbig Ae-Fe Stars	STScI	02/01/2013	01/31/2017	$27,963
34. WFC3IR Imaging of UV-Faint z=6 Quasars: Star-Forming Host Galaxies of AGN in the Early Universe	STScI	07/01/2013	06/30/2016	$15,000
35. SMACK: A New Tool for Modeling Images of Debris Disks	STScI	10/01/2013	09/30/2017	$24,839
36. STIS Coronagraphy of Four Young Debris Disks Newly Uncovered from the NICMOS Archive	STScI	12/01/2013	11/30/2017	$33,011
37. Confirmation and Characterization of Young Planetary Companions Hidden in the HST NICMOS Archive	STScI	02/01/2014	01/30/2018	$8,034
38. Quick Study of Science Return from Direct-Imaging Exoplanet Missions	NASA	07/01/2014	06/30/2016	$22,000
39. Decoding Debris System Substructures: Imprints of Planets/Planetesimals and Signatures of Extrinsic Influences on Material in Ring-Like Disks	STScI	01/01/2015	03/31/2019	$279,420
40. Pushing to 8 AU in the archetypal protoplanetary disk of TW Hya	STScI	05/01/2015	04/30/2018	$28,464
41. Decoding the Origin, Structure, and Composition of Exoplanetary Debris Systems Through Multi-Wavelength Studies	NASA	02/17/2016	02/16/2020	$81,780
42. An Extinction Probe Through the HD 107146 Debris Ring: Taking Unique Advantage of a Background Galaxy Transit (Long Term Program)	STScI	04/01/2017	03/31/2022	$283,787
43. Super-Keplerian Motions in the AU Mic Circumstellar Debris System	STScI	11/01/2017	02/29/2020	$69,250
44. Debris Disk Dust Characterization through Spectral Types: Deep Visible-Light Imaging of Nine Systems	STScI	07/01/2018	06/30/2021	$38,973
45. High Contrast Imaging of Exoplanets and Exoplanetary Systems with JWST (DD-ERS program)	STScI	02/01/2019 Q4/20-Q1/21	01/31/2022 Q4/22-Q2/23	prep: $16,061 (+pending)
46. Time Domain Coronagraphy: Diagnosing the Stripping of AU Mic's Debris Disk (Long Term Program)	STScI	12/01/2019	11/31/2023 +CY29	$76,363 (+long term)
47. A planet is Born: Investigating the Accretion Rate of PDS70b with WFC3/UVIS Direct Imaging Observations	STScI	02/01/2020	01/31/2023	$61,793
48. Revealing Structure in the HD 53143 Debris Disk	STScI	09/01/2020	08/31/2022	$45,667 (pending)
49. Confirming a Wide-Separation Directly-Imaged Infant Planet around a Young, Dusty Star	STScI	03/01/2021	02/29/2024	$91,334
Total Sponsored Project Funding Awarded (less pending awards on approved programs)				**$4,293,314**

Notes: STScI = Space Telescope Science Institute, JPL = Jet Propulsion Laboratory, SSC = Sptizer Science Center
Listed by start date. Concurrent UA appointments: Instrument Scientist #1-#6, Associate Astronomer #7-#23, Astronomer #24- #47

Publications

Summary: Refereed Journal Papers: 132, Conference Proceedings: 74, Meeting Paper & Presentation Abstracts: 192, NASA/STScI Reports: 24, Catalogs: 5, Other: 7; (h-index: 47, i10-index: 104)

Selected First Author/Oft-Cited Papers:

Schneider, G., et al. 2018, "The HR 4796A Debris System: Discovery of Extensive Exo-Ring Dust Material", *AJ*, 155, 177

Schneider, G., et al. 2016, "Deep HST-STIS Visible-Light Imaging of Debris Systems around Solar Analog Hosts", *AJ*, 152, 64

Schneider, G., Hines, D. C. 2016, "Detection and Characterization of Circumstellar Material with a WFIRST or EXO-C Coronagraphic Instrument: Simulations and Observational Methods", *JATIS*, 2(1), 011022

Schneider, G., et al. 2014, "Probing for Exoplanets in Dusty Debris Disks: Disk Imaging, Characterization, and Exploration with HST/STIS Multi-Roll Coronagraphy", *AJ*, 148, 59

Schneider, G., et al. 2009, "STIS Imaging of the HR 4796A Circumstellar Debris Ring", *AJ*, 137, 53

Schneider, G., Pasachoff, J. M., and Willson, R. 2006, "The Effect of the Transit of Venus on ACRIM's Total Solar Irradiance Measurements: Implications for Transit Studies of Extrasolar Planets", *ApJ,* 641, 565

Schneider, G., Silverstone, M. D., and Hines, D. C. 2005, "Discovery of a Nearly Edge-On Disk Around HD 32297", *AJ*, 639, L227

Schneider, G., Pasachoff, J. M., and Golub, L. 2004, "TRACE Observations of the 15 November 1999 Transit of Mercury and the Black Drop Effect for the 2004 Transit of Venus", *Icarus*, 168, 249

Schneider, G., et al. 2003, "NICMOS Coronagraphic Observations of the GM Aurigae Circumstellar Disk", *AJ*, 125, 1467

Schneider, G., et al. 1999, "NICMOS Imaging of the HR 4796A Circumstellar Disk", *AJ*, 513, 127

See PUBLICATION LIST (CV Appendix IV) for Complete Bibliography

Professional Service:

- Hubble Space Telescope Post-SM4 Scientific Review Panel (panel member)
- NASA/GSFC NICMOS Dewar Anomaly Review Board (board member)
- HST/NICMOS & Ground-based/AO Independent Study Report to STScI (study lead)
- Steward Observatory Time Allocation Committee (committee member)
- Publications referee: ApJ, AJ, PASP, A&A, Icarus
- IAU Interdivision 2 C-E Working Group on Solar Eclipses (working group member)
- HST Allocation Committees (panel member and large program reviewer, multiple cycles)
- Decadal Survey Astro 2010/2020 Science and Technology White Papers and RFI Contributions
- Exoplanet Exploration Program Analysis Group (ExoPAG)/Study Analysis Group (15)

Observing Experience:

Platforms/Instruments - Space:

- Hubble Space Telescope: Near Infrared Camera & Multi-Object Spectrometer, Wide Field/Planetary Cameras (1 & 2), Wide Field Camera 3, Fine Guidance Sensors (astrometric interferometry), Space Telescope Imaging Spectrograph, Advanced Camera for Surveys
- Spitzer Space Telescope: IRAC, IRS, MIPS
- Transition Region Coronal Explorer (TRACE): WL and EUV
- Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSAT)

Facilities/Instruments - Ground:

- MMT with Adaptive Optics System: Aries, Pisces
- Steward Observatory Bok 90" telescope: B&C spectrograph
- Heinrick Hertz Sub-Millimeter Telescope
- Palomar/PHARO Adaptive Optics System
- Big Bear Solar Observatory: New Solar Telescope
- A wide range of small (≤ 1 m) fixed, and portable optical telescopes/CCD imaging systems

Image/Data Analysis from: Chandra, IRTF, Keck-II, VLT, GPI, SPHERE, and Lick AO

Teaching Experience:

- *University of Florida:* Taught laboratory and lecture sections of introductory general undergraduate astronomy, astronomy for astronomy majors, astronomical (observing and data analysis) techniques, and digital electronics. Planned, supervised and evaluated in-class exercises in astronomy, data reduction, analysis, and instrumentation. Taught and trained students in observational methods in astronomical imaging and photometry at Rosemary Hill Observatory (76 cm telescope) and on-campus student observatory. Taught seminar series on computer programming for astronomy and physical sciences with APL.
- *Catonsville Community College (Maryland):* Taught laboratory and lecture sessions of introductory astronomy for undergraduate, associate degree candidate, and "nontraditional" (returning) students. Planned and executed curricula, lesson plans and in-class observing exercises. Developed, and implemented planetarium based and augmented education program.
- *University of Arizona:* No formal teaching responsibilities. Service since 2004 on graduate student mentoring and thesis committees. Occasional substitute lectures for AST 300 (Astronomy & Astrophysics) / AST 400 (Theoretical Astrophysics).

Selected Invited/Review/Keynote/Research Talks:

• NASA Goddard Space Flight Center	*Exploring the Environments of Nearby Stars*
• American Museum of Natural History – Rose Center	*Dust-Busters: When Worldletts Collide*
• Custer Institute	*Stars, Galaxies and HST/NICMOS: A Tale of Birth, Death and Resurrection*
• 2nd TPF/Darwin Conference	*High Contrast/High Resolution Imaging of Circumstellar Disks*
• 2nd Int'l Solar Eclipse Conference (SEC; UK)	*EFLIGHT 2003 – The Umbra on Ice from 35,000 ft.*
• STScI	*NICMOS & VLT Imaging of 2M1207: A Planetary Mass Companion to a Young Brown Dwarf*
• U. Hawaii/IfA	*Probing Planetary System in Formation with HST*
• Gemini Observatory	*Scattered Light Imaging of Circumstellar Disks: HST Coronagraphy and Polarimetry*
• 3rd Int'l SEC – Griffith Obs.	*Up, up, and away: Chasing the Umbra Into the Stratosphere (and Beyond)*
• STScI 2014 Calibration Workshop	*Coronagraphic Imaging with HST*
• l'Observatoire de Paris/Beta Pic 30	*Other Debris Disks/Differences with β Pic through Scattered-Light Imaging*
• Lyot Conference 2015/Montreal	*Revealing the Outer Reaches of the HR 4796A Debris System*
• Starfest 2017 (Bays Mountain)	*In Quest of Astronomical Shadows: On Earth, in our Solar System and Beyond*
• NCBA 2018 Dean's Lecture Series	*Exploring the Universe with the Hubble Space Telescope*

Professional Honors/Awards:

- ASP Maria & Eric Muhlmann Award (NICMOS IDT)
- NASA/GSFC Science Leadership Group
- STScI Individual Achievement Award
- NASA Public Service Achievement Award
- NASA HST Project Achievement Awards
- JPL WF/PC-2 Project Award (SLTV/Calibration)

Professional Society Affiliations:

- International Astronomical Union
- American Astronomical Society
- American Association for the Advancement of Science
- Society of Photo-Optical Instrumentation Engineers
- Sigma Pi Sigma (National Physics Honor Society)
- Association for Computing Machinery (SIGAPL)

CV APPENDIX I — Prior Employment, Functional Positions and Appointments

1. The University of Arizona – Steward Observatory (1994 – 2003)

Appointment/Functional Responsibility: Served for nine years as the NICMOS Project Instrument Scientist at Steward Observatory, The University of Arizona. **Supervisor:** Prof. Rodger Thompson.

General Responsibilities: As the NICMOS Project Instrument Scientist, Dr. Schneider saw the instrument through its final pre-launch design, implementation, integration and test, on-orbit calibration, science/operational, and post-mission recommissioning phases while taking on a number of pivotal leading and supervisory hardware, software, and programmatic responsibilities. The compression of the observational phase of the GTO program into a single (but protracted) HST observing cycle posed many unanticipated challenges in maintaining coherence in data calibration and analysis, as well as in reformulating many aspects of those investigations. In accomplishing the completion of those programs he worked with and for the NICMOS science team in many diverse aspects of planning (and replanning) GTO observations while continuing to serve as the Project's technical interface under the PI to the STScI, and Goddard Space Flight Center's (GSFC) codes 440, 441 and 512. During the pre-launch and commissioning phases of the NICMOS mission he worked closely with Ball Aerospace & Technology Corporation's (BATC) integrated product teams leading to the successful emergence of NICMOS as a facilities class instrument aboard HST. His responsibilities included frequent interaction with the aforementioned agencies in the development and implementation of ground and flight systems, procedures, software, interfaces, supporting on-orbit and ground calibration methodologies and data, on-orbit test procedures and detailed observing proposals to assure that the primary goals of NICMOS science programs were carried to successful conclusion. Concomitant with these activities were his daily interactions with software and technical support staff lending guidance and supervision on a diverse variety of team-support tasks. With the advent and rapid acquisition of NICMOS data, particularly in the coronagraphic science programs, his labors were successfully divided between science and functional support.

With the instruments' SN_2 cryogen depletion, a significant portion of his efforts were devoted not only to post-mission calibration, characterization, and performance evaluation but in support of a large integrated systems engineering effort readying NICMOS for "resurrection" with the installation of an active cooling system (successfully installed on HST servicing mission 3B). In that regard, Dr. Schneider led test teams both at the NICMOS Detector Laboratory at Steward Observatory and at the EMI/EMC facility at GSFC in conducting comprehensive experiments with a flight spare array replicating the on-orbit performance of the NICMOS detectors under on-orbit thermal conditions and integrated with the to-be-flown NICMOS cooling system. During that era his responsibilities extended to detailed end-to-end instrumental systems evaluations, in collaboration with GSFC and STScI personnel, in preparation for both serving mission (SM)3B and the Cycle 11 Observatory Verification (SMOV) program to follow, including leading the planning and analyses of key elements of the NICMOS recommissioning activities (e.g., detector performance, optical alignment and focus, target acquisition reactivation, etc.), which were completed successfully as a precursor to re-enabling post-SM3B near-IR science on HST.

• **Science Team Support.** The complex process of developing viable observational strategies for carrying out near-IR astronomical investigations with HST did not relax as the mission evolved. Indeed, the rapid acceleration of the program demanded a closer and more detailed level of involvement in the monitoring, execution, and evaluation of observations than if the observing programs were played out over three cycles as originally envisioned. This was exacerbated with a new instrument whose characteristics were changing on short time scales. Dealing with this required vigilance in shepherding many of our needs through the "system", which Dr. Schneider attacked with success. He attributes this to the fact that he has worked closely in numerous aspects of HST operations and planning for nineteen years and, through trial-by-fire, gained first-hand intimate knowledge of both the HST and NICMOS systems. Together these afforded him the ability to assist team members, and the larger community of HST/NICMOS users, in dealing with unrelenting minutiae associated with the implementation of their scientific programs. He has seen this as a pivotal aspect of this position. Thus, he had directed his efforts toward making NICMOS as scientifically a productive instrument as possible (often, in the face of seemingly adversarial external forces to be overcome, but with full support and direction of the project PI). The emergence of the continuing stream of NICMOS GTO and follow-on science, is demonstrative of his success in working toward that goal.

• **Instrument Operations, Data Reduction, Processing and Analysis.** Dr. Schneider worked on a daily basis as the UofA/IDT technical interface with STScI's "Project to Re-Engineer Space Telescope Operations" [PRESTO], Instrument Commanding/Engineering Support Branch, Systems Engineering, and NICMOS Instrument support groups. In addition to identifying and resolving proposal planning, execution, and instrument operations problems, he has recommended specific strategies to improve on-orbit efficiency, instrument stability and calibratability to expand the scope of NICMOS capabilities both in solid cryogen (Cycle 7) and NICMOS Cooling System (NCS; Cycle 11 and beyond) eras. Such recommendations resulted from an expenditure of a considerable effort to understanding the on-orbit characteristics of NICMOS (as interfaced with HST) enabling the extraction of photometric and astrometric data from NICMOS images unbiased of systematic effects to the greatest extent possible. In doing so he iterated many times with both STScI's NICMOS support group, and NICMOS Project software and database personnel, in improving calibration reference files as well as reduction and analysis software. He had also worked with STScI in planning for, and analyzing the results of the NICMOS warm-up in light of the concerns of an independent science review committee established by NASA (the Harwitt committee), and for post SM-3B science operations. He assumed the lead role in coordinating the "warm up anomaly" testing in the NICMOS detector lab based upon test goals discussed with the HST Project at GSFC and STScI as well as the responsibility for supervising the integrated test team and laboratory personnel.

- **Pre-launch Instrument Testing (SLTV[1], RAS/HOMS[2], EMI/EMC[3] testing).** To explore and evaluate the operating characteristics of NICMOS, Dr. Schneider took a leading role in the definition, execution and analysis of some pre-launch calibration programs at BATC. Working closely during round-the-clock shifts with BATC project management, hardware, S/W, and test team personnel he investigated anomalous behaviors, which led to both a better understanding of the instrument, and changes in the methods and philosophy of instrument operation.

  [1]System Level Thermal Vacuum, [2]Refractive Aberration Simulation/Hubble Opto-Mechanical Simulator, [3]Electro-Magnetic Interference/Electro-Magnetic Compliance

- **HST Systems Level Integration, Test, and Verification (VEST[1], STOCC[2], SOGS[3]/SPSS[4].** The exercise of pre-deployment validation of a new HST science instrument required extensive sub-system and integrated tests to be run with both ground and flight hardware and software. Dr. Schneider supported these efforts by defining, contributing to, and participating in numerous ground system and functional tests (unit and end-to-end) and simulations. To validate the command generation capability of the HST ground system for NICMOS, and the response to those command requests by the instrument, he worked with STScI ESB/Commanding personnel in creating test proposals, calendars, and Science Mission Specifications used in these series of tests and subsequently analyzed resulting image data and engineering telemetry. He worked with BATC Integration & Test and MOSES[5] personnel in reviewing Real-Time command and operations procedures required for these tests and in preparation for flight. In addition, he monitored and evaluated the ground system and instrument behavior during test execution, and participated in real-time hardware and software anomaly analysis and resolution.

  [1]Vehical Electrical Simulation and Test, [2]Space Telescope Operations Control Center, [3]Space Operations Ground System, [4]Science Planning and Scheduling System, [5]Mission Operations & Systems Engineering Support

- **SM[1]-2 and SM-3B On-Orbit Instrument Checkout (AT[2]/FT[3] Planning and Execution).** Dr. Schneider was an active member of the SM-2 and 3B flight preparation and operations teams defining and improving procedures for the NICMOS on-orbit installation and checkout. He participated in defining the NICMOS requirements and implementation details of the Servicing Missions Integrated Timeline, Command Plan, on-orbit Aliveness and Functional tests, developed evaluation/acceptance criteria and real-time analysis S/W for the latter. This included on-console at the STOCC for all SMGT[4]s, JIS[5]s, and during the mission as the IDT science support representative.

  [1]Servicing Mission, [2]Aliveness Test, [3]Functional Test, [4]Science Mission Ground Test, [5]Joint Integrated Simulation

- **SM OV[1] 2 and 3B Program Planning, Implementation, and Analysis.** Dr. Schneider served as the UofA/IDT representative and technical lead for the NICMOS Servicing Mission Observatory Verification programs. This engendered defining the NICMOS SMOV plans and requirements in concert with HST and STScI project management. As Principle Investigator for many of the SMOV programs (and co-I on most others), he developed and implemented on-orbit check-out, engineering, and calibration proposals, operations procedures and analysis plans in consultation and association with STScI and the BATC I&T teams. Post-launch he worked extensively at STScI to support near-RT analysis and a dynamically evolving and changing SMOV program in light of unexpected instrumental performance anomalies.

  [1]Observatory Verification

HST/NICMOS On-Orbit Calibration and Engineering Programs; P.I. unless noted

Cy	Title	ID	Cy	Title	ID
7	Internal Parallel (Electrical Cross Talk)	7032/7136	11	Filter Wheel/Mechanisms Functional Test	8944
7	Transfer Function Verification	7037	11	SMOV3B Transfer Function Verification	8976
7	Target Acquisition Test	7038	11	Coronagraphic Focus Optimization	8979
7	Coarse Optical Alignment	7041/7150	11	Mode-2 Target Acquisition Test	8983
7	Fine Optical Alignment; coI	7042	11	Coronagraphic Performance Assessment I	8984
7	Focus Monitor	7043	12	Enabling Coronagraphic Polarimetry; co-I	9768
7	Coronagraphic Performance Verification	7052	12	Coronagraphic Performance Assessment II	9693
7	Pre-Alignment Check-out	7134	13	Two-gyro Coronagraphic Performance Assessment	10448 10464
7	Intermediate Focus/Alignment	7135	17	DC Transfer Function Test	11406
7	Coronagraphic Hole Monitor	7156	17	NICMOS Filter Wheel Test; co-I	11407
7	Coronagraphic Focus Determination	7151	17	Focus and PAM Grid Tilt Test; co-I	11408
7	Coronagraphic Hole Location	7808/7924	17	Mode-2 Coronagraphic Acquisition Test	11413
17	Optimum Coron. Focus Determination	11414	17	Coronagraphic Performance Assessment	11415

2. Computer Sciences Corporation: Operations Astronomer at STScI (1985 – 1994)

Appointment/Functional Responsibility: Served for nine years as an Operations Astronomer in the Operations, and Science and Engineering Support Divisions at STScI. **Supervisor:** Dr. Rodger Doxsey (deceased).

General Responsibilities: Appointed as a member of the Instruction Management (Science Instrument Commanding) Task Group. Designed, implemented, and tested science commanding instructions (for the Science Planning and Scheduling System (SPSS) /Science Commanding Subsystem of the Hubble Space Telescope Science Operations Ground System (SOGS)). Developed operational procedures, science instrument command groups and supportive file structures for inclusion in the HST Project Data Base (PDB) for operating the Wide Field/Planetary Camera (WFPC), Fine Guidance Sensors (for astrometric science), Wide Field/Planetary Camera-2 (WFPC-2), as well as other Science Instruments and spacecraft subsystems. Participated in the validation of low-level and atomic command constructs tested during Assembly and Verification for all HST Science Instruments. Adapted these for use in the SOGS and Payload Operations Control Center/Applications Support Software (PASS) ground systems. Designed and built higher-level logic to control the use of these command structures. Developed requirements and software interfaces for driving flow-down control logic from a structured Proposal Management Data Base (PMDB) and calendars of time-ordered events. Developed and implemented reconfiguration instructions and associated table driven logic to allow for automatic setup and transitioning of the science instruments to/from various defined operational states. Generated detailed requirements for the proposal Transformation software. Contributing author to HST Proposal Instructions and Instrument Handbooks.

WFPC-2: In preparation for the on-orbit installation of WFPC-2 was responsible for working with the WFPC-2 Science, Instrument Development, and Integration & Test teams in both pre-launch testing of the hardware and ground system software. This effort engendered gaining specific first-hand knowledge of the workings of the instrument by participating a series of ground system, thermal vacuum, hardware, and system functional tests. This also encompassed participation in the SMOV Proposal Implementation Team. Assisted in defining the overall implementation requirements for WFPC-2 SMOV and performed detailed reviews of those proposals, implementation plans, calendars and SMSs. Supported the HST servicing mission by first participating in a number of pre-launch simulation and training exercises, and later performing real-time monitoring, data collection and evaluation during the servicing mission itself.

- **Command Development:** Developed ground system command constructs which were required for testing and operating the WFPC-2, both pre-launch and on-orbit. The scope of this activity was sufficiently broad so involvement went beyond just creating executable procedures and software, but lent itself to active participation in and contributing to development efforts across many groups at STScI, MOSES, JPL and the WFPC-2 Science team. The need to be responsive to ever changing demands and requirements were met as the operational methodologies and instrument characteristics evolved and/or solidified during the long series of ground tests which occurred during this period.
- **SLTV:** Actively participated in the WFPC-2 System Level Thermal Vacuum Test and Instrument Calibration as the STScI/Science Commanding on-site representative at JPL. Worked closely during round-the-clock shifts with JPL hardware, S/W, instrument and science team personnel. Defined, modified, executed and analyzed real-time tests designed to explore and evaluate the operating characteristics of the WFPC-2. Investigated anomalous behaviors which led to both a better understanding of the instrument, and to changes in the methods of operating and commanding it. Information and knowledge that was acquired during SLTV was transferred to other STScI and WFPC-2 project personnel and incorporated in the implementation of the WFPC-2 stored command instructions. Worked with the ESB WFPC-2 engineer on obtaining the SLTV engineering data in a timely manner from JPL and porting it to a data archive at STScI.
- **Tests and Simulations:** The exercise of pre-deployment validation of a new science instrument required extensive sub-system and integrated tests to be run both ground and flight hardware and software. Supported this effort by contributing to, and participating in the various ground system and functional tests, discrete simulations, and joint integrated simulations. In particular, to validate the command generation capability of the ground system for the WFPC-2, and the response to those command requests by the instrument created test proposals, calendars, and SMS's used in these series of tests. Worked with the MOSES SI personnel in reviewing new Real-Time command procedures that were needed in support of these tests, and the servicing mission. Monitored the ground system and instrument behavior during execution, and participated in real-time hardware and software anomaly analysis and resolution. Worked with other members of flight team, through the real-time simulations, to define and improve procedures to be used during the servicing mission.
- **Servicing Mission:** Assisted in preparing and configuring the ESB/commanding work site at the OSS facility by setting up the hardware and S/W interfaces to permit real-time analysis on the engineering data. Developed adjunct data collection and analysis tools, and set up automated data reduction and network transfer processes. During the Servicing mission participated in the 24-hour commanding shift coverage - monitoring instrument and spacecraft sub-

system changeouts. Key subsystem parameters were watched and trended and, for the WFPC-1 and 2 in particular, thermal considerations were constantly addressed and discussed with other project elements - as were contaminant and other issues of real-time concern.

• **Serving Mission Observatory Verification:** Served as a member of the SMOV Proposal Implementation Team. Worked on the development and implementation of engineering, calibration, and ERO proposals for the SMOV program in consultation and association with the WFPC-2 IDT and I&T teams. Identified the need for special commanding and/or structuring of the PMDB through a series of proposal implementation meetings and reviews. Built, tested, and delivered non-standard commanding for early operations of the WFPC-2. Test, and later flight, calendars and SMS's were microscopically reviewed for any deficiencies - and proposals reworked as needed when problems were found. During execution monitored all first-time operations, and was prepared to responded to unanticipated anomalies. Throughout this era worked with the WFPC-2 engineering and science teams (JPL and SIB) to evaluate the instrument's performance and provided information on commanding related activities to these groups through regular calibration and team meetings. Worked with the with the WFPC-2 science team to develop a coherent transition plan to the Cycle 4 calibration program. Worked with both the IDT and STScI/SIB on defining additional on-orbit and laboratory tests to better characterize and calibrate the photometric performance of the instrument, based upon on-orbit data.

WFPC-1: Participated in the planning and implementation of all ground system simulation, throughput, and vehicle tests. Prepared special commanding instructions and structured inputs for the WFPC-1. Worked on the production, and reviewed the content, of the WFPC-1 commanding on Calendars, Science Mission Specifications (SMS's) and command loads used in all Ground System Tests (GST's). Supported real-time monitoring of the use of the WFPC-1 during integrated system GST's. Participated in the development and implementation of many special WFPC engineering operations, procedures, and instructions including the implementation and redefinition of the UV Flood, CCD decontamination procedures, integration of the NASA Standard Spacecraft Computer-1 (NSSC-1) soft safing capability and Real Time safing recovery plans. Worked with GSFC Flight Software Group (Code 512) in defining special executive flight software requirements, and WFPC/NSSC-1 command interfaces for special operations. Provided “emergency” support for unplanned safing events, WFPC instrument anomalies and unforeseen Target of Opportunity observations. Worked with WFPC engineers (both contractor and in-house) and representatives of the Telescope Instrument Branch in assessing general post-launch instrument performance, operational use trending, and in response to directed technical inquiries. Worked with the WFPC on-site Instrument Development Team (IDT) representative to help assure that new WFPC command capabilities (not originally specified by the IDT) were implemented and assimilated into the ground systems in a faithful and efficient manner. Created new instructions, data base definitions, and supported ground testing and validation of these capabilities, which included: the on-board WFPC Idle checking (and bay 5 temperature regulation) software; suppression of CCD erasure following preflashes; issuance of autoerase commands following pyramid rotations; allowing Kspot, Bias, Dark and exposures to be preflashed and CR-Splitting of the latter two; and permitting subsetted CCD reads with efficient use of the onboard tape recorder and/or communications downlink.

• **Observatory Verification:** Member of the Orbital Verification (OV) Planning/Implementation Team. Reviewed and identified technical problems in OV proposals. Developed solutions to these problems and worked with the IDTs to reach closure on those items. Wrote detailed implementation plans used by personnel involved in defining science and engineering objectives, planning and scheduling of activities, developing, testing, and implementing special science instrument and spacecraft subsystem commanding, identifying required real-time support, and supplying specific database constructs and entries needed to carry out these proposals.

HST/WFPC On-Orbit Calibration and Engineering Program

Cy	Title	Cy	Title
4	WFPC-2 SOFA Partial Stepping Test, Co-Investigator	1	WF/PC Calibration: UV Flood Test, Co-Investigator
2	WF/PC K-Spot Reflectivity Test, Principle Investigator	1	WF/PC Light-Pipe Throughput Test, Co-Investigator

FGS/Astrometry: Served, for two years, as the STScI Operation Division's technical representative to the Space Telescope Astrometry Team. Worked with the team on defining baseline functional astrometric requirements. Developed command constructs and procedural logic for using the HST Fine Guidance Sensors (FGS's) to carry out astrometric science observations, and special Orbital Verification focus and alignment tests. Oversaw the creation of test calendars, and SMS's used to validate FGS commanding. Participated in ground-system simulation, unit level hardware, and vehicle testing of Fine Guidance Electronics/FGS commanding. Developed and provided software to assist in the Real-Time analysis of FGS, Pointing Control System and Optical Telescope Assembly telemetry during early on-orbit operations.

Operations Support: Reviewed proposals scheduled for execution and resulting commanding on flight SMS's. Participated in iterative SMS analysis/rerun cycling during the OV, SMOV, Science Verification epochs, and Science Assessment and Early Return Observations. Uncovered and reported numerous problems, developed and offered solutions to SPSS, User Support and Science Planning Branches (SPB) as appropriate. Worked with SPSS personnel on fixing many problems related to improper PMDB population or proposal structure, and interpreting PASS mission scheduler and command loader products. Often consulted with the proposer (directly or through SPB) to recommend proposal changes to enable his/her scientific or engineering goals to be accomplished when the proposal itself was improperly or incompletely specified. Developed many software tools which were provided to various branches of the Operations and Systems Engineering divisions to assist in validating the integrity of transformation products, the PMDB, and flight SMS's and to facilitate engineering data analysis.

3. Catonsville Community College (1987-1989)

Appointment: Adjunct Faculty in Astronomy. **Supervisor:** Dr. Robert Sopka.

General Responsibilities: Taught laboratory and lecture sessions of introductory astronomy for undergraduate, associate degree candidate, and "nontraditional" (returning) students. Planned and executed curricula, lesson plans and in-class observing exercises. Developed planetarium based and augmented education program. Typical class size: 30 – 40. Typical teaching load: 2 classes per semester.

4. University of Florida – Department of Astronomy (1984-1985)

Appointment: Research Assistant. **Supervisor:** Prof. John P. Oliver (deceased).

South Pole Telescope: Designed, implemented and tested the firmware program for the automated operation of the University of Florida's multi-color photometric South Pole Telescope. Developed process control, data acquisition and calibration management software. Assisted in telescope, photometer, and control system mechanical and electronic design, fabrication, and telescope calibration. Performed instrument installation, photometric calibration and operational field check at the Amundsen-Scott South Pole Station. Performed instrument anomaly analysis during observing season. Returned to the South Pole for post-season instrument performance evaluation and engineering diagnostics. Reduced and analyzed photometric data as part of a quantitative site survey program, as well as astronomical studies of γ^2 Velorum and HR 2554. This work was supported by National Science Foundation grants DPP 82-17830 and DPP 84-14128.

5. University of Florida – Space Astronomy Laboratory (1982-1984)

Appointment: Research Assistant. **Supervisor:** Dr. Frank Giovane.

Giotto/Halley Optical Probe Experiment (HOPE): Ground System data acquisition and real-time analysis S/W lead for HOPE, a multi-band photo-polarimeter employing a multi-anode micro-channel array (MAMA) detector, flown on the European Space Agency's Giotto Mission to Halley's Comet. Designed, developed and programmed ground support equipment and real-time spacecraft simulator. Assisted in optical calibration, electronic circuit board design, fabrication, and calibration of engineering and flight model units. Performed flight unit engineering checkout during spacecraft/payload Assembly & Verification at British Aerospace. Worked with project mission planners and scientists at the European Space Agency (Noordwijc, Netherlands) and Service d'Aeronomie-Centre National de la Recherche Scientifique (Paris, France) on many payload interface and operational issues. This work was supported in part by NASA grant AGW-1289.

Additional Instrumental Work: Specified, designed, and programmed a microcomputer interface for an optical vignetting test table for photometric and radiometric calibration of spacecraft instrumentation as part of a collaborative project between the Space Astronomy Laboratory and Ruhr-Universitat, Bereich Extraterrestrische Physik (Bochum, W. Germany).

6. University of Florida – Department of Astronomy (1978-1982)

Appointment: Teaching Assistant/Research Assistant. **Supervisors:** Prof. Howard Cohen/Prof. John Oliver.

Teaching Responsibilities & Experience: Taught laboratory and lecture sections of introductory general undergraduate astronomy, astronomy for astronomy majors, astronomical (observing and data analysis) techniques, and digital electronics. Planned, supervised and evaluated in class exercises in astronomy, data manipulation and analysis, instrumentation. Taught and trained students in observational methods in photographic and photoelectric photometry at the Rosemary Hill (76 cm telescope) and on-campus student observatories. Maintained and rebuilt facilities and telescopes at on-campus student observatory. Taught seminar series on APL programming for physical sciences and computer programming with APL.

Instrumentation: Designed, fabricated, and installed a new Cassagrain light baffle and offset guiding systems for the Rosemary Hill Observatory 76 cm telescope. Designed and built a multi-channel digital data acquisition system to be used by several photometric instruments. Redesigned and put into working service a 3-color flare star photometer. Designed and constructed coelostat fed flash spectrograph employing a U.T.-synchronous high speed camera used for obtaining time resolved spectra of the solar chromosphere and inner corona during the inner tangential contacts of solar eclipses. Interfaced an Ebert-Faste scanning spectrograph to a microprocessor based control system (and used this system to determine the size of the H-alpha emission region of several B-emission (shell) stars, including ζ Tauri). Performed maintenance and repairs on historic Alvin Clark 20 cm. refractor and Celestron telescopes at UF's student observatory.

7. Warner Computer Systems, Inc. (1976-1980)

Appointment (1977-1980): APL Technical Analyst. **Supervisor:** Mr. Alan Krieger.

S/W Systems Design, Implementation, Training: Developed turn-key end-user directed software systems. Products created included: software for econometrics forecasting, statistical analysis, laser/resonant-cavity design, message and packet switching, and inventory and process control. Conducted APL programming classes and handled technical inquires from time-sharing clients.

Appointment (1978-1980): APL Technical Consultant. **Supervisor:** Mr. Ben Adenbaum.

Project-based technical consultation and programming: Maintained public and development system workspace libraries. Wrote system specific application functions and integrated them into the libraries. Developed plotting/graphics display software for Tektronix, Versatek, and Diablo/Spintronic devices. Supervised creation of documentation of APL software libraries by technical writing staff.

CV APPENDIX II — CURRENT Research Projects (Summaries)

Dr. Schneider's current scientific interests and pursuits are primarily (but not exclusively) focused on studying the formation, evolution, properties, architectures, and diversities of extra-solar planetary systems and the planet-forming/hosting circumstellar (CS) environments from which they arise. I.e., advancing our understanding, through observationally and theoretically informed investigations, of the evidence for, and evolutionary pathways of, exoplanet presence in CS protoplanetary, transitional, and debris systems (studying the forests) - symbiotic with the goals of characterizing individual exoplanets (studying the trees) within. To this end, he is currently engaged in eight new-start or on-going externally sponsored research investigations: 7 as UofA Principal Investigator (mapped to grant award table on CV page 3), and 4 as co-Investigator, in exoplanetary systems science with thematically symbiotic programmatic goals and objectives. In concert he is also an unfunded collaborator in the GPI-ES consortium. These projects are summarized below.

Externally Sponsored Research [numbering per CV sponsored programs list] (inverse start-date chronology)

[49] HST/GO 16447 (8 orbits). ***Confirming a Wide-Separation Directly-Imaged Infant Planet around a Young, Dusty Star.*** Near infrared ground-based data sets obtained over multiple recent epochs suggest a wide-separation protoplanet around AB Aur whose colors/spectrum are posited as distinguishable from scattered starlight and whose astrometry hints at orbital motion. HST visible-light imaging, roughly contemporaneous with ground-based extreme AO observations, are required to confirm and characterize this candidate protoplanet. Only optical imaging can conclusively rule out the alternate hypothesis: that this signal is a due to a static disk feature. STIS, with its ability to yield unbiased detections of disk sub-structures and point sources, is unmatched by any ground or space-based facility and is the only suitable optical high-contrast imaging instrument for this task. Our analysis will decisively point to one of three interpretations: 1) thermal emission from a protoplanet formed by disk instability, 2) an orbiting disk region heated and puffed up by an unseen planet, or 3) a non-rotating disk feature whose pathological colors and near-IR variability can be mistaken for an orbiting protoplanet. Our STIS multi-roll PSF-template subtracted coronagraphic imaging will achieve the required contrast to arbitrate between these scenarios. If interpretations 1) or 2) are supported, this candidate would be HST's first bona fide exoplanet direct imaging discovery (given the recent controversy over Fomalhaut b). Moreover, if 1) is correct, this investigation will rewrite the field's understanding of planet formation, decisively demonstrating the existence of multiple mechanisms for forming jovian planets: core accretion AND disk instability.

[48] HST/GO 16202 (15 orbits). ***Revealing Structure in the HD 53143 Debris Disk.*** The solar analog star HD 53143 hosts a tenuous disk of cold material analogous to a more massive version of our solar system's Kuiper Belt. Puzzlingly, unlike every other debris disk observed thus far, existing low-S/N visible wavelength images of HD 53143 show that the micron-sized dust around HD 53143 does not resemble a circumstellar ring--rather, it looks like two isolated clumps of material. New ALMA observations show that the underlying distribution of larger planetesimals is indeed ring-like, but very eccentric and mis-aligned with the visible wavelength clumps. Further, the ALMA observations reveal 5-sigma excesses just interior to the circumstellar ring, suggesting structure in the planetesimal population that may be connected to the visible wavelength clumps. High-S/N coronagraphic imaging of HD 53143 using HST STIS will reveal the peculiar nature of this unique debris disk and enable a search for signs of planet-induced disk structure or collisional activity. In addition to revealing the structure of the disk, these high-S/N images will allow us to measure the optical properties of the debris disk dust to constrain its composition, size distribution, and provide critical measurements of debris disk properties that will inform future exoplanet-imaging missions.

[47] HST/GO 15830 (18 orbits). ***A Planet is Born: Investigating the Accretion Process of PDS70b with WFC3/UVIS Direct Imaging Observations***. Recent direct imaging detection of Hα emission from PDS70b, a giant young planet, revealed its rapid ongoing accretion. This discovery offers an exciting opportunity for constraining PDS70b's mass accretion rate, a critical parameter for studying its formation process. However, the correlation between the hydrogen line luminosity and the total accretion luminosity has not been established for Jovian mass objects. Therefore, both hydrogen line and continuum accretion luminosity for PDS70b are required to derive its mass accretion rate accurately. We are obtaining WFC3/UVIS direct imaging observations of PDS70b. Using HST's unique capability of high-contrast observations in the ultraviolet (UV) and optical wavelengths, we measure the accretion-induced excess emissions of PDS70b in the F336W (Balmer break, UV continuum) and F656N (Hα) bands to derive its mass accretion rate. The observations are optimized to enable KLIP-based angular differential imaging data reduction and maximize HST's high-contrast imaging capacity. This goals of this investigation are to: 1) directly measure the total accretion luminosity of PDS70b and accurately derive its mass accretion rate. 2) enable the comparison of accretion luminosity in the UV and the Hα bands to advance our understanding of the accretion process of PDS70b. 3) compare the measured mass accretion rate to the empirical mass vs. accretion rate relationship and assess the formation pathway of PDS70b.

[46] HST/GO 15907 (21 orbits; Long-Term Program). ***Time Domain Coronagraphy: Diagnosing the Stripping of AU Mic's Debris Disk.*** Boccaletti et al. (2015) discovered features moving within the AU Mic debris disk at super-Keplerian tangential velocities in spatially resolved imagery of the AU Mic debris disk. To date, these are the only moving structures seen in spatially resolved imagery of debris disks. The surface brightness, number, morphology, and velocities of these moving features constrains their physical location and mass, and thus are critical quantities needed to constrain the origin of this phenomenon. In this investigation we are monitoring the evolution of these debris disk sub-structures over three HST cycles (27, 28, 29) to determine: a) What is the surface brightness of all features, and how does the surface brightness and morphology of features change over time?; b) What is the detailed vertical motion of features, and does the amplitude of this motion depend on stellocentric separation?; and c) What is the motion of the newly found features (NW-gamma and NW-delta) on the NW-side of the disk? These data will be used to test hypotheses that predict features are caused by the stellar wind expelling grains originating from a parent body that orbits at 8±2 au (Sezestre et al. 2017) or by interaction between the star's wind and repeated dust avalanche events (Chiang & Fung 2017).

[45] JWST/ERS 1386 (38.8 hours; pending JWST launch**).** ***High Contrast Imaging of Exoplanets and Exoplanetary Systems with JWST.*** JWST will transform our ability to characterize directly imaged planets and circumstellar debris disks, including the first spectroscopic characterization of directly imaged exoplanets at wavelengths beyond 5 microns, providing a powerful diagnostic of cloud particle properties, atmospheric structure, and composition. To lay the groundwork for these science goals, we proposed a 39-hour ERS program to rapidly establish optimal strategies for JWST high contrast imaging. We will acquire: a) coronagraphic imaging of a newly discovered exoplanet companion, and a well-studied circumstellar debris disk with NIRCam & MIRI; b) spectroscopy of a wide separation planetary mass companion with NIRSPEC & MIRI; and c) deep aperture masking interferometry with NIRISS. Our primary goals are to: 1) generate representative datasets in modes to be commonly used by the exoplanet and disk imaging communities; 2) deliver science enabling products to empower a broad user base to develop successful future investigations; and 3) carry out breakthrough science by characterizing exoplanets for the first time over their full spectral range from 2-28 microns, and debris disk spectrophotometry out to 15 microns sampling the 3 micron water ice feature. Our team represents the majority of the community dedicated to exoplanet and disk imaging and has decades of experience with high contrast imaging algorithms and pipelines. We have developed a collaboration management plan and several organized working groups to ensure we can rapidly and effectively deliver high quality Science Enabling Products to the community. (Dr. Schneider is the investigation co-lead for data quality assurance for project deliverables as well as a scientific co-investigator.)

[44] HST/GO 15218 (39 orbits). ***Debris Disk Dust Characterization through Spectral Types: Deep Visible-Light Imaging of Nine Systems***. We are obtaining STIS coronagraphy of 9 debris disks recently seen in the near-infrared from our re-analysis of archival NICMOS data. STIS coronagraphy provides complementary visible-light images that enable characterizing disk colors needed to place constraints on dust grain sizes, albedos, and anisotropy of scattering of these disks. With 2-3 times finer angular resolution and better sensitivity, our STIS images will improve upon the NICMOS discovery images, and more clearly reveal disk local structures, cleared inner regions, and test for large-scale asymmetries in the dust distributions possibly triggered by co-orbiting planets in these systems. The exquisite sensitivity to visible-light scattering by submicron particles uniquely offered by STIS coronagraphy will let us detect and spatially characterize the diffuse halo of dust blown out of the systems by the host star radiative pressure. Our sample includes disks around 3 low-mass stars, 3 solar-type stars, and 3 massive A stars; together with our STIS+NICMOS imaging of 6 additional disks around F and G stars, our sample covers the full range of spectral types and will let us perform a comparative study of dust distribution properties as a function of stellar mass and luminosity. Our sample comprises ~ 1/4 of all debris disks imaged in scattered light to date, and offers a homogeneous characterization of the visible-light to near-IR properties of debris disk systems over a large range of spectral types. Our program will allow us to analyze how the dynamical balance is affected by initial conditions and star properties, and how it may be perturbed by gas drag or planet perturbations.

[42] HST/GO 14714+15221+15501 (30 orbits; Long-Term Program). ***An Extinction Probe Through the HD 107146 Debris Ring: Taking Unique Advantage of a Background Galaxy Transit*****.** We are conducting a 3-cycle GO program to directly measure and map the line-of-sight optical depth through the brightest sector of the HD 107146 solar-analog debris ring by ring-transit differential photometry of a bright (compared to the disk), spatially extended, background galaxy. We will advantageously exploit its serendipitously unique and experiment-enabling high proper motion reflex trajectory w.r.t. the galaxy back-lighting a sectional slice the exoplanetary debris system (EDS) with a 2D grid of multiple sight-lines through the nearly face-on disk over six observational epochs spanning ≥ 3 years. These measures (the only opportunity for such in remaining HST lifetime) will uniquely provide unambiguous extinction/optical depth constraints to better elucidate the physical properties of the debris particles in this otherwise well studied EDS. With these and prior data we will: (a) disambiguate inferred particle spatial, size, and mass density distributions otherwise conflated with debris material optical property dependencies, (b) better constrain the posited pathways for planetary debris dust production mechanisms in EDSs (e.g., catastrophic collisions of parent bodies, dust-production cascades, cratering events, etc.) and (c) search for and discriminated between "clumps", "bumps", and "clouds" of collisional debris of varying particle (and mass) densities. This investigation was enabled in forethought by mapping the galaxy surface brightness out-of-transit in a comprehensive 2011 precursor study (HST GO/12228) using exactly the same STIS instrumental configuration with multi-roll PSF template subtracted coronagraphy we use for the ring transit.

Dr. Schneider is also a co-investigator four Hubble Space Telescope General Observer programs:

HST/GO 16174 (3 orbits). ***Imaging Planet-Disk Interactions in the β Pictoris Disk.*** Debris disks are readily detectable tracers of embedded planetary systems; however, their complex internal structures are often challenging to interpret as most debris disks do not harbor known exoplanets. The prototypical debris disk around β Pic and its two relatively short-period super-Jupiter planets offer a unique laboratory for studying planet-disk interactions. Five mechanisms have been identified through models in which β Pic b may shape the complex disk structure and may perturb planetesimals into an inclined orbit, giving rise to the secondary disk discovered with HST. Structures shaped by the planet's resonances can introduce large-scale azimuthal asymmetries in the disk that orbit on timescales similar to that of the planet (~18 yr). With STIS images from 1997 and 2012 a uniquely long baseline is available for identifying the temporal evolution of the disk, which is predicted to evolve on comparable Keplerian timescales. We will revisit and continue monitoring the β Pic disk with STIS to characterize its temporal evolution. By repeating the earlier observations we will detect variations as small as 1% at 0.5". In comparison, models of radiation-pressure driven small grains freed from planetesimals trapped in resonance with the planet predict variations up 300% in this component. We will identify disk structures and dust grain populations resulting from interactons with the two giant planets, directly testing models explaining the disks' complex structure. These observations will provide an entirely new set of constraints on the 3D structure and dynamics of the only known disk/planet system where such measurements are possible.

HST/GO 15905 (8 orbits). ***Resolving the Asteroid-belt of the Fomalhaut Planetary System.*** As we celebrate the discovery of thousands of exoplanets, we need to reflect on virtually all of them lying in planetary systems vastly different than our own. The initial architectures of planetary systems must reflect laws of physics and chemistry, such as the influence of H2O and CO ice lines. How do similar beginnings evolve into dissimilar ends? Answers demand a detailed understanding of all the constituents of planetary systems, of which debris disks are the most readily studied. The most favorable opportunity lies with Fomalhaut. Not only is it the second-closest bright debris disk system (tied with Vega), but the level of observable details is aided by the high luminosity of the star, resulting in disk features lying four times further out than they would around a solar-type star at the equivalent stellar insolation. HST imaging, space IR missions, and ground-based radio observations have resolved the outer Kuiper-belt-analog of the system exquisitely well. However, evolution in these outer orbits proceeds slowly. We must bore into the regions interior to the snow line to further study planetary system evolution. Due to the technical challenges, there are no resolved images of these inner regions around any stars (other than the Sun). Herein we observe to spatially resolve this domain of the Fomalhaut system, one of only three where this is possible with current technology. With these data we aim to: (1) test whether there is an Asteroid-analog belt near Fomalhaut's H_2O ice line; (2) search for the influence of unseen planets; and (3) constrain grain properties, providing new inputs to debris disk theory.

HST/GO 15906 (8 orbits). ***Imaging Planetary Perturbations in the Epsilon Eridani Debris Disk.*** With a Jupiter-like exoplanet in an orbit similar to that of Jupiter itself (Mawet et al. 2019) and an asteroid-analog belt just interior to it (Su et al. 2017), Eps Eridani (0.8 M_{sun}, 400-800 Myr old) has a fascinating resemblance to our expectations for a much younger Solar System. It also has an unusual intermediate debris belt, with characteristics deduced from modeling the spectral energy distribution of the entire star-plus-debris-disk system in the mid-infrared. This belt appears to extend over the region from ~ 8 to ~ 20 au, corresponding to the orbits of Uranus and Neptune in the solar system, but it is currently unresolved. There is also an outer belt at ~ 60 au seen in the far infrared and mm-wave. At a distance of only 3.2 pc, this system offers a unique opportunity to study an exoplanetary system at high physical resolution. Herein we image the intermediate and outer belts at high SNR and spatial resolution of ~ 0.2 au. These HST/STIS images will probe the gravitational influence of unseen planets on the intermediate and outer belts, and constrain the grain properties at these locations. The intermediate belt in particular is likely to be highly structured due to sculpting by unseen planets in orbits between that of the Jupiter-like one and the outer Kuiper-like belt. This investigation tests indirectly for the presence of planets far below our current limits for direct detection and substantially advance our understanding of debris disks in general, as well as revealing processes that may have shaped the early Solar System.

HST/GO 16666 (32 orbits). ***A Deep and Complete Characterization of the Vega Debris Disk in Scattered Light.*** The discovery of the Vega debris disk (the first of its kind) predates the discovery of our own Kuiper Belt by almost a decade, and yet it has never been resolved in scattered light. Systems where we can achieve au (or even sub-au) resolution hold the keys to understanding evolved planetary system architectures. At 7.7 parsecs, Vega enables one of the highest spatial resolution imaging opportunities of all exoplanetary systems. For example, its Kuiper-belt analog ring peaks at r=11" (85 au) and extends out to ~ 20" (150 au). The sharp inner edge (as seen by ALMA) indicates the presence of as yet undetected planetary companions, but remains to be confirmed with higher resolution observations. At these angular distances, the STIS coronagraph has excellent imaging contrast. Furthermore, the luminous host star provides ample flux at optical wavelengths for the dust in the system to scatter. Despite these attributes, the Vega disk has never been imaged with HST. We propose a single heritage HST program that will provide a deep and complete characterization of the Vega debris disk system. Our program is designed to image the disk components outward of 30 au to investigate the dust properties and morphological signatures of shepherding planets. Our HST observations will complement JWST GTO Cycle 1 observations of the system with NIRCam and MIRI.

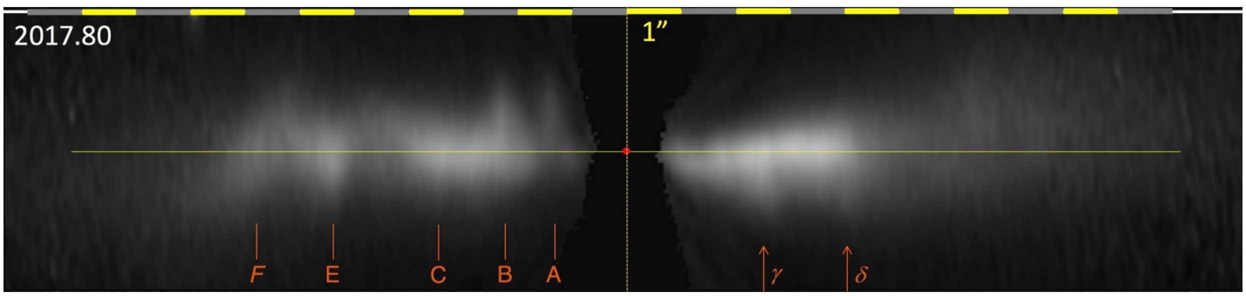
Dr. Schneider is a also a UofA co-Investigator on a technology and science mission concept development investigation externally supported by the Gordon and Betty Moore Foundation (with supplemental UA funding):
Ultralight Very Large Aperture Space Telescopes using MODE Lens Technology (T. Milster, PI). This investigation will establish feasibility and demonstrate a paradigm-shifting space telescope technology enabled by multiple-order-diffraction engineered material (MODE) lenses. MODE lenses are ultralightweight, transmissive, and fabricated economically by compression molding very large aperture lenses directly or by molding segments that are assembled into large apertures. In future space missions, matured MODE-based optics will replace mirror systems to provide: 1) lighter weight; 2) lower cost for a given aperture size; and 3) higher transmission due to the unobscured optical path of MODE lenses. Preliminary plastic MODE components have been successfully constructed and tested at UA. Herein we will conduct a credible demonstration with glass MODE lenses for space telescopes with the design, fabrication, and testing of a diffraction-limited, 0.24-m diameter aperture, nine-segment (two mold) MODE-lens telescope that is optimized for the astronomical R-band wavelength range. The successful demonstration of low-cost, low-weight, scalable MODE technology will revolutionize future space telescope architecture and design. This is a first step in conjunction with the maturation of a science and mission plan for the conceptual Nautilus Unit Telescope and Space Observatory (see Publications List, appendix IV: [1S] – Astro 2020 Decadal Survey "white paper"; BAAS, 51, 141)

Dr. Schneider is also a collaborator on a large Gemini Planet Imager program:
GPI-ES: ***Characterizing Dusty Debris in Exoplanetary Systems*** **(C. Chen, PI).** Studying debris disks is one of the frontiers of exoplanet science because observations of these objects provide direct constraints on planetary system formation and planet migration around other stars. At the onset of this investigation, twenty-four debris disks have been spatially resolved in scattered light, revealing the location of the dust and the albedos of the grains when compared with thermal emission measurements. Although these observations help break some of the degeneracies between composition, size, porosity, and shape, the detailed grain properties are still not well understood. A key limitation is that the previous generation of ground-based instruments lacked the contrast and image fidelity to detect dust disks within a ~1.5 arcsec radius. Therefore the thermally emitting dust detected close to the star is not the same cold grain population detected by scattered light observations far from the star. Thus, we are obtaining GPI Integral Field Spectroscopy (IFS) and Polarimetry of all of the debris disks spatially resolved in scattered light observable from Gemini South. GPI offers an unprecedented discovery space by virtue of its small inner working angle and sensitivity using dual channel polarimetry in the near-IR. IFS observations will be sensitive to spectral features and better constrain the color of the scattered light and therefore the particle composition and size. Polarimetry will allow us to break the degeneracy in forward scattering between particle size and porosity. Our team will combine the proposed GPI observations with complementary high contrast imaging and thermal mapping data from *HST*, MagAO, and ALMA to develop holistic models that will significantly improve our understanding of the materials available during the late stages of planetary system formation.

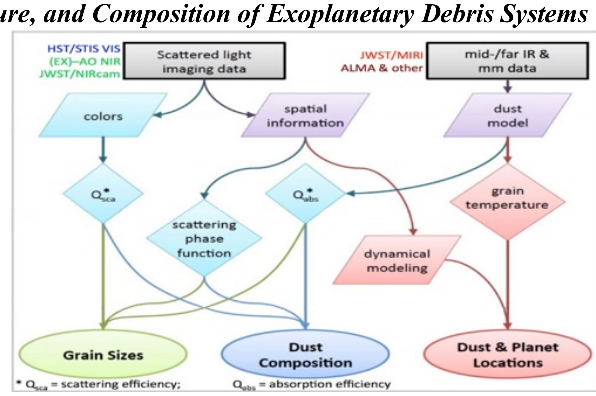
CV APPENDIX III — COMPLETED Research Projects (Summaries)

A. Externally Sponsored Research [numbering per CV sponsored programs list] (inverse start-date chronology)

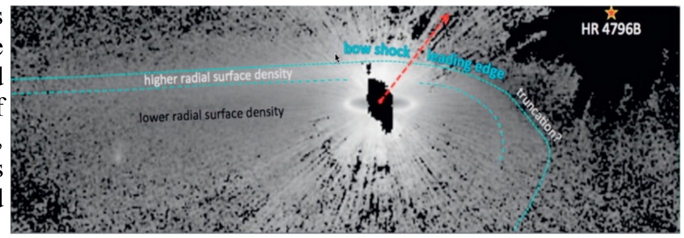
[43] HST/GO 15219 (12 orbits). ***Super-Keplerian Motions in the AU Mic Circumstellar Debris System.*** We found enigmatic, few-au-scale features in spatially resolved near-IR scattered light observations of the AU Mic debris disk system obtained with VLT/SPHERE in 2014. We recovered these structures in re-analysis of HST/STIS imagery from 2010/2011, and discovered that they are moving away from the star at super-Keplerian speeds, possibly escaping the system. To-date, these are the only moving features seen in resolved imagery of debris disks. To help diagnose the origin of this phenomenon and in concert with multi-wavelength diagnostics being pursued with other facilities, we use 12 orbits of HST/STIS to re-image the AU Mic scattered light disk from 0.2" (2 au) to 13" (130 au) ~8 years after the previous epoch of HST/STIS imagery. HST/STIS provides the only means to trace the motion of structures that have already moved outside the FOV of ground-based extreme-AO imagers, the best means to accurately diagnose the morphological and kinematic evolution of these moving features, and the best means to trace the evolution of small grains in the system. Our optical STIS coronagraphy observations are critically needed to establish the locations and shapes of the blobs, establish their optical fluxes at high photometric fidelity, and therefore enable (IR - optical) colors of disk features to be measured in JWST's cycle-1, using NIRCAM's and MIRI's coronagraphs. These data will constrain the grain size distribution, hence mass, of the moving features and by extension the magnitude of the force that is expelling the features, enabling us to test whether mechanisms like the stellar wind or coronal-mass ejections are responsible for the newly observed phenomenon.



[41] NASA/ADAP (3 year). ***Decoding the Origin, Structure, and Composition of Exoplanetary Debris Systems Through Multi-Wavelength Studies.*** We are combining optical/near-IR imaging from HST with mid-IR spectra and photometry from the *Spitzer* Space Telescope to investigate planet formation in association with exoplanetary debris disks (DDs). DDs represent the last stages of planet formation, after the gas left over from the star formation process has largely or completely dissipated. DDs consist of dust produced by collisions between planetesimals orbiting the star whose presence around young stars is ubiquitous. This late phase in planet formation may be analogous to the period of the Late Heavy Bombardment in our own Solar System. By studying the DD stage in exoplanetary system evolution, we gain important new insights into planet formation processes. Resolved images of DDs obtained by *HST* reveal and map their spatial structure. When combined with images across multiple wavelengths of visible and near-IR light, we can study dust properties by examining how the brightness varies with color. Such photometric analysis alone provides useful, but limited, information the scattering and inferred physical properties of the disk grains. IR data from *Spitzer* do not yield images of these disks, but the spectra and IR photometry of the disk grains reveal the absorption and emission properties of the disk. While neither *HST* nor *Spitzer* gives a complete picture of the dust in DDs individually, by combining the two, we can fill in the gaps and develop a more holistic view and better understanding of DDs and planet formation processes. The dust properties of DDs will be able to help inform where planets form, when they form, and what they are made of. We use data from both *HST* and *Spitzer* to decode the properties of the grains in these disks in order to study the origin, composition and structure of DDs.



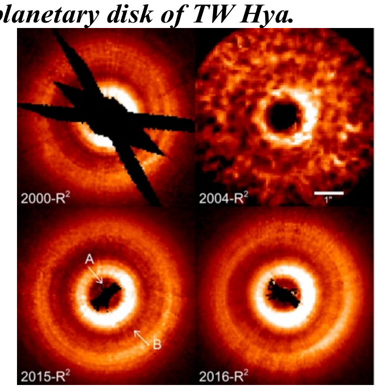
[39] HST/GO 13786 (40 orbits). ***Decoding Debris System Substructures: Imprints of Planets/Planetesimals and Signatures of Extrinsic Influences on Material in Ring-Like Disks***. How do circumstellar (CS) disks evolve and form planetary systems? Is our solar system's two-component debris disk (DD) typical? Are planets implicated by evidence of dynamical stirring in disks? Are DD architectures correlated with stellar mass? To address these highly-compelling questions of fundamental astrophysical import, we proposed follow-up STIS coronagraphy of five intermediate-inclination ring-like DDs. These images provide unprecedented clarity, sensitivity, and photometric efficacy to: 1) Study the spatial distribution of dust as close as 0.2" from the host stars enabling us to infer the existence and properties of unseen co-orbiting planets, and to probe disk-planet interactions across stellar ages and spectral types; 2) Provide spatially resolved imaging within DD regions previously unsampled to significantly improve constraints on disk grain properties and radial segregation of grain populations as a function of stellocentric distance (and thus temperature); 3) Produce high-fidelity images of DD substructures for dynamical interpretation, constraining the possibilities for planetary system architectures; 4) Obtain deep images of regions beyond the primary, bright, debris features to study small-grain populations that might be unbound from the system



and affected by both extrinsic and intrinsic forces planetesimal belt; 5) Provide, through the HLA, the highest quality and most complete, value-added data products for a seminal legacy data set of spatially resolvable light-scattering debris disks, thus enabling multi-wavelength investigations with new and future ground- and space-based facilities.

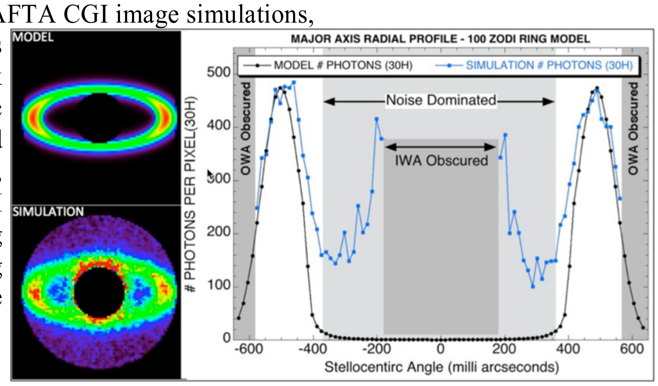
[UA coI] HST/GO 14241 (112 orbit Treasury program; D. Apai, PI). ***Cloud Atlas: Vertical Cloud Structure and Gravity in Exoplanet and Brown Dwarf Atmospheres.*** Condensate clouds play a fundamental role in all three types of substellar ultracool atmospheres: (1) transiting planets, (2) directly imaged exoplanets, and (3) brown dwarfs. The primary parameter influencing the spectra of these atmospheres is temperature. Observations, however, demonstrate the presence of a second key parameter that is often assumed, but not verified, is surface gravity. Members of this team pioneered *HST* rotational phase mapping of brown dwarfs and exoplanets, providing new insights in the heterogeneity, longitudinal and vertical structure, and dynamical evolution of condensate clouds on a small set of targets. In this high-photometric-precision HST/WFC3 Treasury survey we investigate the effect of gravity on cloud structure in ultracool atmospheres with longitudinal and vertical cloud maps for brown dwarfs and exoplanets to sample their atmospheres. By probing the variability amplitude in J, H, and 1.4 μm water absorption bands we test model predictions on the connection between gravity, temperature, and vertical cloud structure. The observations provide a homogeneous and uniquely rich set data from 10 ultracool atmospheres (including brown dwarfs and planetary mass companions). These observations and our analyses complement those of the small sample of the six brown dwarfs observed prior to this investigation, and enable new, powerful comparative atmospheric studies, including cloud tomography. We apply a novel technique, unique to *HST*, to address questions fundamental to the atmospheres of transiting planets, directly imaged exoplanets, and brown dwarfs. Our survey has resulted in an information-rich data set with very high legacy value.

[40] HST/GO 13753 (8 orbits). ***Pushing to 8 AU in the archetypal protoplanetary disk of TW Hya.***



With HST/STIS coronagraphy, utilizing the new bent finger occulter commissioned in our GO 12923 program, we probed, for the first time in visible scattered light, the protoplanetary disk of TW Hya at stellocentric distances as close as 8 – 13 au (0.15" – 0.24") from its host star. That distance is a factor of three improvement in inner working Imager (GPI), SPHERE, and polarimetric observations of this disk. angle compared to previous STIS images of this disk taken in 2000. HST/STIS provides a unique window through visible wavelengths at inner working angles on Solar System scales and at a spatial resolution comparable to the highest resolution modes of ALMA in its Cycle 2 configuration. Previous scattered light observations show that the surface brightness of the disk abruptly changes its character interior to 50 au, which could be indicative of a gap opened by a forming planet, a large opacity change, or shadowing from the inner disk. We probe the inner disk at high fidelity,with the goal of discriminating between these three possibilities. We also will look for disk surface brightness variations and Keplerian motion of structures in the outer disk during the 15-year baseline between observational epochs. These legacy observations of TW Hya's small dust grain population will provide an anchor for future JWST, ALMA, Gemini Planet Imager (GPI), SPHERE, and polarimetric observations of this disk.

[38] **JPL/EXEP (1.5 year).** ***A Quick Study of Science Return from Direct Imaging Exoplanet Missions: Detection and Characterization of Circumstellar Material with an AFTA* or EXO-C/S CGI***. The capabilities of a high (~ 10^{-9} resel^{-1}) contrast, narrow-field, coronagraphic instrument (CGI) on a space-based AFTA-C or probe-class EXO-C/S mission, conceived to study the diversity of exoplanets now known to exist into stellar habitable zones, are particularly and importantly germane to symbiotic studies of the systems of circumstellar (CS) material from which planets have emerged and interact with throughout their lifetimes. The small particle populations in disks of co-orbiting materials can trace the presence of planets through dynamical interactions that perturb the spatial distribution of the light-scattering debris, detectable at optical wavelengths and resolvable with an AFTA-C or EXO-S/C CGI. In this study we: (1) develop the science case to study the formation, evolution, architectures, diversity, and properties of the material in the planet-hosting regions of nearby stars, (2) evaluate how a CGI under current conception can uniquely inform and contribute to those investigations, (3) consider the applicability of CGI anticipated performance for CS debris system (CDS) studies, (4) investigate, through AFTA CGI image simulations, the anticipated interpretive fidelity and metrical results from specific, representative, zodiacal debris disk observations, (5) assess the utility of specific observational modes and methods germane to, and augmenting, CDS observations, (6) consider, in detail, the case for augmenting the currently conceived CGI two-band Nyquist sampled (or better) imaging capability with a full linear-Stokes imaging polarimeter of great benefit in characterizing the material properties of CS dust.
{*subsequently renamed: WFIRST.}



[37] HST/GO 13331 (40 orbits). ***Confirmation and Characterization of Young Planetary Companions Hidden in the HST NICMOS Archive.*** We conducted a WFC3 high contrast imaging program of six faint exoplanetary companion candidates orbiting young (1 to 100 Myrs) stars that we identified from reprocessed archival *HST* NICMOS coronagraphic data as part of our *HST* AR-12652 and 11279 programs. Such rare objects are of the utmost importance to comparative exoplanetology as their physical properties reflect the initial conditions of still poorly constrained planetary formation mechanisms. Moreover, directly imaged exoplanets are foundational for investigations of the expanding exoplanetary menagerie, providing high-priority follow-up targets for spectroscopic characterization. Our statistical analyses, that combine population synthesis models and empirical inspections of the entire NICMOS field of view for all sources observed in coronagraphic mode, indicate with very high probability that at least one of these six faint candidates is physically associated with its putative stellar host. We carried out our photometric observations in four WFC3 near-IR spectral bands: F125W and F160W to establish the baseline luminosity of our candidates, and in F127M and F139M to probe the depth their water absorption features that are characteristic of substellar- and exoplanetary-like atmospheres.

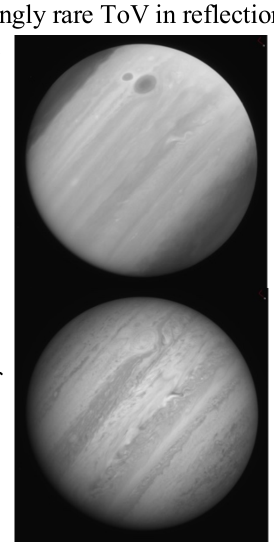
[36] HST/GO 13381 (15 orbits). ***STIS Coronagraphy of Four Young Debris Disks Newly Uncovered from the NICMOS Archive.*** We obtained STIS coronagraphic observations of four debris disks, each recently prior seen in scattered light for the first time in our archival reanalysis of NICMOS coronagraphy using LAPLACE (AR 11279; G. Schneider, PI) reprocessed data and template PSFs. Our targets are young (< 30 Myr) solar type (G2 – F3) stars; observing them will triple the number of debris disks imaged around Sun-like stars at ages comparable to when terrestrial planets were forming in our solar system. Follow-on STIS coronagraphy surpass the NICMOS discovery images with 2x better angular resolution, improved image contrast, and sensitivity to circumstellar light-scattering debris. These observations allow us to measure in detail the disk geometries, determining whether parent bodies are constrained in "birth rings" analogous to the Kuiper Belt, and to search for the signatures of unseen planets gravitationally stirring the disks, potentially leading to stochastic giant collisions that might produce observable signatures in disk and dust properties.

[35] HST/AR 13257 (4 year). ***SMACK: A New Tool for Modeling Images of Debris Disks***. *HST* and *JWST* images of planetary signatures in debris disks are important tools for finding hidden exoplanets and constraining their properties when the images are interpreted via numerical models. But current models cannot yet model the time-dependent interplay between planetesimal collisions and dynamics. For example, they fail to accurately model patterns like the ubiquitous warps and eccentric rings, which are interactions between collisional and secular dynamical phenomena. Thus, we developed a new numerical tool called "SMACK" that models the locations of planetesimal collisions that release the dust in debris disks, the dynamical effects of these collisions, and the evolving planetesimal size-velocity distribution in thee dimensions. We applied this code to derive new constraints on the masses of planets orbiting Beta Pictoris and Fomalhaut, and to study the latest debris disk images from the GO 12228 and 13786 STIS imaging surveys. SMACK was made available to the community in the form of new modules for the popular, publicly available, REBOUND code.

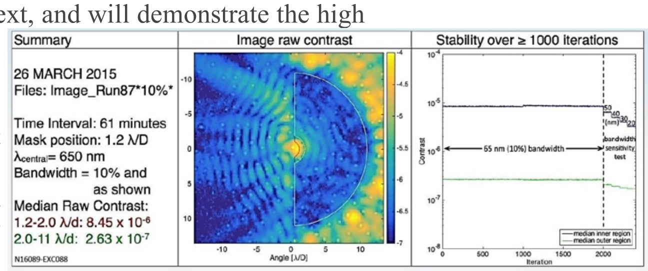
[34] **HST/GO 12974 (25 orbits).** ***WFC3IR Imaging of UV-Faint z = 6 Quasars: Star-Forming Host Galaxies of AGN in the Early Universe.*** We studied star-forming host galaxies of AGN at z ~ 6 with WFC3/IR in F125W and F160W. Recently, far-infrared (FIR) continuum was detected in five UV-faint (rest-frame $m_{1450} > 20.2$) quasars at z ~ 6, suggesting that they have star formation rates (SFRs) of ~ 1000 M_{sun} yr^{-1}, comparable to UV-bright z ~ 6 quasars. Such SFRs imply a significant young, UV-bright, stellar population. However, starlight from these host galaxies has not yet been detected since light from the AGN still dominates the rest-frame UV emission. In HST program 12332 [#30], we successfully subtracted the point source in the UV bright ($m_{1450} = 19.03$) quasar 1148+5251 down to $m_J >$ 24.4, $m_H > 24.9$ mag $arcsec^{-2}$, giving upper limits of $m_{1680} > 22.5$, $m_{2160} > 23.0$ mag for its host galaxy. Uncertainties in the PSF model remain the dominant source of residuals. Since these uncertainties scale with brightness, low-contrast quasars with UV-faint point sources and UV-bright hosts are the best targets for this method. Using the observing and subtraction methods we developed, we observed five FIR-detected, UV-faint, z ~ 6 quasars with WFC3/IR in F125W and F160W. Observations of these host galaxies are critical to determine: (a) The existence of a luminous stellar component, (b) Luminosity and color profiles, to constrain star formation histories, (c) Morphologies and sizes, to look for mergers and hierarchical formation processes (d) Stellar mass, to understand formation and co-evolution of SMBHs and galaxy bulges.

[33] HST/GO 13032 (9 orbits). ***Crossing the Snow Line: Mapping Ice Photodesorption Products in the Disks of Herbig Ae-Fe Stars***. Water is a key constituent of protoplanetary disks. In our Solar System, small, icy grains are thought to have boosted the disk solid surface density, setting the stage for icy planetesimal formation and ultimately the growth of gas giant planets, while water vapor warms the disk, facilitating chemistry. Survival of water, in either phase, is sensitive to the UV radiation field. Intermediate-mass PMS stars, the Herbig Ae stars, straddle the temperature range where icy grains can survive within 10 au of the star to systems where ice is photodesorbed at the disk surface to beyond 100 au. Far-IR studies with *Herschel* have shown that, while water vapor is rarely detected for Herbig Ae stars, its dissociation products such as OH and O I are common. Such data lack the spatial resolution to directly constrain where water in any phase is located. An alternate approach exploits *HST*'s superb angular resolution and disk-to-star contrast in the FUV with *HST* STIS long-slit spectroscopy. Such observations can map the spatial distribution of water's other dissociation product, H I at Lyman alpha, with 7 au resolution. The same spectra also simultaneously trace H_2 and dust, enabling an additional test of whether the HI traces the dust or the molecular gas in these stratified disks. Thus, with STIS G140M spectra at Lyman alpha for 4 otherwise well-studied Herbig Ae-Fe stars we test the hypothesis that spatially extended H I in these systems provides a fossil record of where ice was located in the disk which can be compared with where giant planets are found in these disks.

[32] HST/GO 13067 (15 Orbits). ***The Jovian Transit of Venus: A 'Truth Test' for Atmospheric Characterization of Earth-Size Planets in Habitable Zones.*** Following the June 2012 Transit of Venus (ToV) visible from Earth (E/ToV2012), we proposed for HST Directory's Discretionary time to observe an exceedingly rare ToV in reflection from Jupiter, as an exoplanet-transit analog in our own solar system. Using Jupiter as an integrating sphere, the g is spatially unresolved, allowing us to analogously test the ability to characterize Earth-size planetary atmospheres in stellar habitable zones with foreknowledge of the Cytherian atmosphere. By imaging in two key WFC3/UVIS diagnostic bands, we collected ~10^{12} photons from the entire disk of Jupiter in time-resolved imaging over the transit duration (in principle) enabling ppm differential detection of Venus's atmosphere. Our observation and data analysis plans are designed to reduce systematic errors to a comparable or lesser level and assess the impact of refractive atmospheric lensing (the Cytherian aureole) on the discernment of Earth-size exoplanet atmospheres. The color-dependent evolution of the aureole with photospheric impact distance was studied as a key goal of the now-completed E/ToV2012, ground, and space-based observing campaign. Those data suggest the possibility of optical amplification of the atmospheric absorption signal, enhancing its detectability, a possibility this proposal will test. These observations directly inform on performance requirements for future Exo-Earth detection and characterization missions. We further exploit these data concert with the goals of *HST*/GO 12314 in inverting spatially unresolved brown dwarf and exoplanet light curves to map brightness anisotropies in their cloud-deck/surfaces.

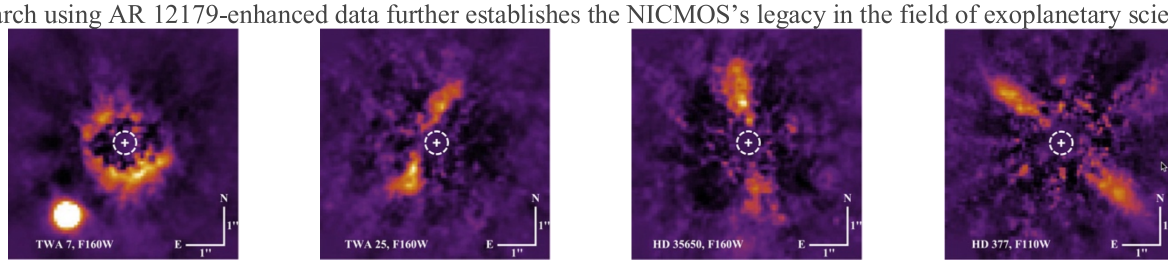


[31] NASA/{MIDEX} EXPLORER (4 years). ***The EXoplanetary Circumstellar Environments and Disk Explorer (EXCEDE).*** EXCEDE was selected by NASA as a category III program for technology development and maturation under the agency's Explorer and Exoplanet Exploration Program with new-start funding in CY 2012. EXCEDE will study the formation, evolution, architectures, and diversity of exoplanetary systems, and characterize circumstellar (CS) environments into stellar habitable zones. EXCEDE provides contrast-limited scattered-light detection sensitivities 1000x greater than HST or JWST coronagraphs at a much smaller effective inner working angle (IWA), thus enabling the exploration and characterization of exoplanetary CS disks in currently inaccessible domains. EXCEDE will utilize a laboratory demonstrated high-performance Phase Induced Amplitude Apodized Coronagraph (PIAA-C) integrated with a 70 cm diameter unobscured aperture visible light telescope. The EXCEDE PIAA-C will deliver star-to-disk augmented image contrasts of < 10^{-8} resel^{-1} and a 1.2 λ/D IWA of 0.14" with a wavefront control system utilizing a 2000 element MEMS DM, Low Order Wavefront Sensor, and fast steering mirror in an integrated starlight suppression system. EXCEDE will provide 144 mas spatial resolution at 0.4 μm with dust detection sensitivity to levels of a few tens of zodis with two-band imaging polarimetry. EXCEDE is a science-driven technology pathfinder that will advance our understanding of the formation and evolution of exoplanetary systems, placing our solar system in broader astrophysical context, and will demonstrate the high contrast technologies required for larger-scale follow-on and multi-wavelength investigations on the road to finding and characterizing exo-Earths in the years ahead. EXCEDE underwent technology development and maturation using laboratory and test facilities at the NASA Ames Research Center and the Lockheed Martin Advanced Technology center with partnership funding contributed by those institutions as well as by UofA.



[30] HST GO/12332 (20 orbits). ***WFC3 imaging of z = 6 QSO hosts: Zooming in on the First L > L* Galaxies & their Surroundings***. With this pilot project (upon which GO 12974 was subsequently built), we studied the first massive galaxies and their surroundings at z = 6. In WMAP cosmology, there is just enough time (< 0.5 – 0.8 Gyr) since z = 10 – 20 to collapse such a galaxy by z = 6. The brightest SDSS QSOs at z = 6 may have been hosted by the most massive and luminous galaxies with L > L*. Surprisingly, recent CO studies suggest relatively large masses, and IR-spectra suggest solar Fe/H and significant stellar processing. However, the z = 6 host galaxies have not yet been found. We investigate the technical feasibility of doing so with WFC3 J+H band imaging in the rest frame UV-flux of the luminous host galaxies of two SDSS QSOs at z = 6 and careful PSF subtraction. Such galaxies likely have AB ~ 23 – 24 mag and half-light radii ~ 0.3" – 0.5" (~ 2 – 3 kpc). With aggressive observation and image processing techniques, WFC3 can detect > 60% of the host galaxy flux outside the central peak of the PSF at > 20 sigma, and surrounding fainter structures at z = 6. A significant detection of even a few very luminous galaxies at z ~ 6 is critical to constrain: (a) their luminosity & color-profiles, and their physical properties; (b) the process of hierarchical galaxy formation; and (c) the formation history of supermassive black holes.

[29] HST/AR 12652 (5 years). ***Exoplanet Search in the HST NICMOS Coronagraphic Archiv*e**. The HST NICMOS coronagraphic archive is a rich repository of data that has not yet been systematically mined for the presence of planets and circumstellar disks using the most current image processing techniques. Recent improvement in optimal PSF subtraction algorithms, combined with a complete recalibration of the NICMOS coronagraphic archive (AR 12179, G. Schneider, PI), enabled an order of magnitude improvement in contrast compared to the data processing previously performed. Herein we reprocessed imaging data from a selection of survey-type programs that included interesting targets for potential exoplanet and disk detections. Our study delivered to the community a list of exoplanet candidates with precise astrometry and photometry so they can be followed up and fully characterized, and discovered debris disk previously unseen. Importantly our ensemble of non-detection provides a database of sensitivity maps spanning a wide range of host star spectral types and ages. This effort established a standard framework for such high-level data products, which will contribute to future high-contrast imaging instruments and missions. This ambitious archival search using AR 12179-enhanced data further establishes the NICMOS's legacy in the field of exoplanetary science.



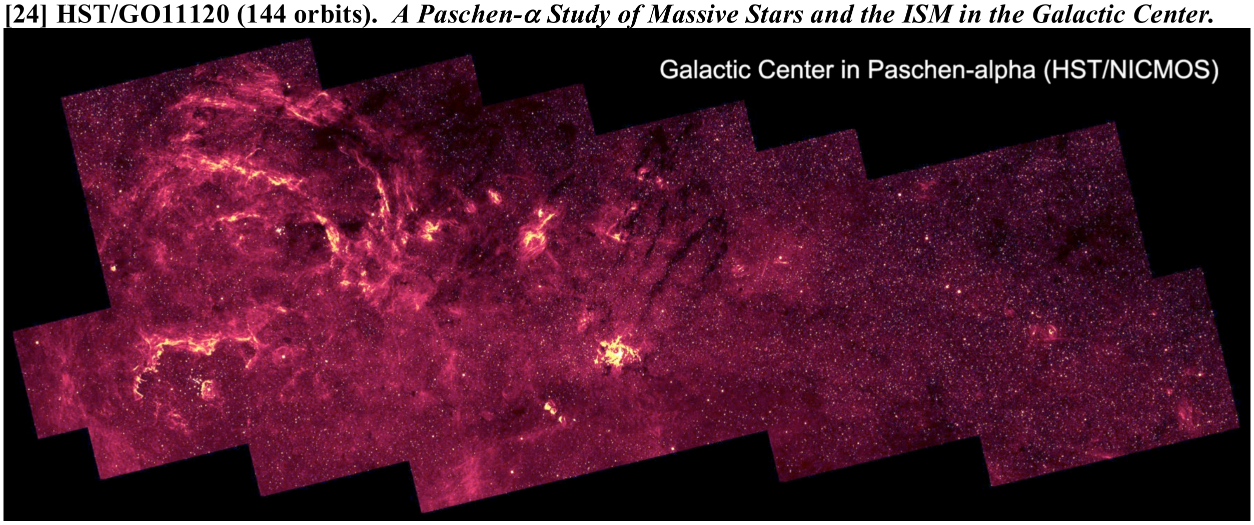
[28] HST/GO 12228 (88 orbits). ***Probing for Exoplanets Hiding in Dusty Debris Disks: Inner {<10 AU} Disk Imaging, Characterization, and Exploration.*** We obtained visible-light observations of a well-selected sample of circumstellar (CS) debris disks, all with HST pedigree, using STIS PSF-subtracted multi-roll coronagraphic imaging. Our new observations probes the interior CS regions of these debris systems (with inner working distances of < approximately 8 au for half the stars in this sample), corresponding to the giant planet and Kuiper belt regions within our own solar system. These images enable the directly inter-comparison of the architectures of these exoplanetary debris systems in the context of our own Solar System. These observations also permit, for the first time, the characterization of material in these regions at high spatial resolution while searching for sub-structures within the disks that are the sign posts of planetary formation and evolution; in particular, asymmetries and non-uniform debris structures signal the presence of co-orbiting perturbing planets. All of our objects were observed previously at longer wavelengths (but with lower spatial resolution and imaging efficacy) with NICMOS, but with an inner working angle comparable to STIS multi-roll coronagraphy. The combination of new optical and existing near-IR imaging enables the placement of strong constraints on the dust properties, thus providing better context to assess grain processing and planetesimal populations. These results directly inform upon the posited planet formation mechanisms that occur after the ~ 10 My epoch of gas depletion, at a time in our solar system when giant planets were migrating and the terrestrial planets were forming, and directly test theoretical models of these processes. The outer reaches (only) of most of these systems were previously observed with a much larger (~ 6x on average), spatially limiting, effective inner working angle of the ACS coronagraph (inadequate to address our science goals of imaging the inner structures of these CS disks). Our investigation, enabled only with HST STIS visible-light coronagraphy, uniquely probes into the interior regions of these systems for the first time with spatial resolution comparable to ACS and with augmenting NICMOS near-IR disk photometry in hand.

[27] HST/AR 12132 (4 years). ***PRONOUNCED – Polarimetry Reductions of NICMOS Observations Using New Calibrations and Enhanced Data.*** We engaged in a rigorous, systematically complete, and consistent recalibration of all raw NICMOS polarimetric science imaging data in the MAST archive to enable science deferred or unachieved by many diverse approved investigation teams. The NICMOS instrument intrinsically provides powerful, and unique polarimetry capabilities that are not possible with ground-based instrumentation, and will not be replicated by any space-based facility in the foreseeable future (e.g., none of the JWST instruments have polarimetric capabilities). Knowing this, HST TACs have wisely allocated significant numbers of orbits to NICMOS polarimetry programs over the past decade. However, various issues with ground data processing and calibration {not the raw data themselves}, especially in those data acquired in the pre-NCS era that represent the majority of near-IR polarimetry programs attempted, have impeded these various investigators in analyzing and interpreting these otherwise valuable data sets. Here, as a service to the astronomical community at large, we remedy this situation by enabling the recovery of science until now lost by a rigorous re-calibration of all archived raw NICMOS polarimetric data from which we create high-level analysis-quality data sets (e.g., Stokes images, polarization maps, polarized and total intensity mages) with quantitative error estimation to return and enter into the MAST for public dissemination. These value-added data products assist investigators to meet and complete their initial science goals, and enable new science that was not anticipated previously.

[26] HST/GO 11674 (2 orbits). ***A STIS NUV Search for Shocked-Interstellar and Circumstellar Gas Towards the Debris System HD 61005.*** Circumstellar debris disks provide the principle window for investigating planet formation and evolution on timescales of 10 – 100 Myr. Unlike their younger counterparts, debris disks no longer contain primordial material. The dust observed in these objects is instead produced by collisional erosion of larger parent bodies in the developing planetary system. At the time of this investigation, only five confirmed debris disks were known to have circumstellar gas (studied primarily through UV absorption spectroscopy), poorly constraining the exact production mechanisms for gas replenishment. However, the few objects studied prior revealed a wide range of intriguing properties, including a stable Keplerian gas disk maintained by its high carbon abundance (β Pic), and a rapidly expelled population of gas produced in collisions between unstable planetesimals (σ Her). To add to this important set of observations, we obtained NUV STIS spectroscopy of the debris disk host, HD 61005, a nearly edge-on debris disk notable for its swept asymmetric morphology. These observations allowed the detection of circumstellar gas, making HD 61005 the first solar-type debris disk host with gas detected in this way. Such new observations provide the unique opportunity to study gas in a debris disk analogous to our early solar system. In addition to potentially detecting circumstellar gas associated with this system, HD 61005 offered the possibility of tracing interstellar bow-shocked gas. The HD 61005 debris disk is prototypical in terms of its significant interaction with the interstellar medium. These observations, therefore, were the first to spectroscopically probe the interaction between a debris disk and its surrounding interstellar material directly. STIS was ideally suited for this experiment, providing sensitive NUV spectra with the required balance between spectral resolution and wavelength coverage.

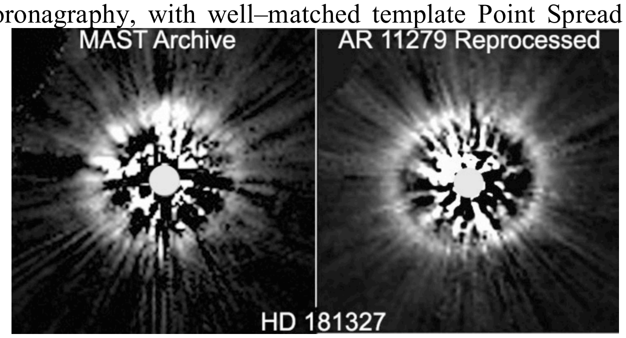
[25] NASA/08-ADP08-0036 (1.5 yr archival research/data analysis). ***Structure and Chemistry of Planet-Building Disks: A Synoptic Study.*** Studies of exo-planetary systems provide important information about the current structure of mature systems, but do not address many issues related to their formation, the production and processing of organic molecules necessary for life, and how these will be distributed within the habitable zones around stars. It is now clear, through the analysis of the Stardust samples from Comet Wild 2 that even the most "primitive" objects in the solar system contain highly processed material, most likely formed close to the Sun and transported radially outward to the planet-forming zone. Within the past few years preceding this study, a new class of young disk systems had been recognized: the transition disk, which includes an inner zone largely free of material, possibly cleared out by newly-formed planets. The prior detection of a probable planet in the prototypical transition disk system, TW Hya, began to cement the relation between planet formation and disk architecture. It also became apparent that the inner disk regions are highly dynamic places whose structure can change on time scales of a year or less. Such changes have been observed in near-IR interferometry measurements, spectral energy distributions, and detailed spectral structure. Such activity may be related to the processing of both refractory and organic materials in young planet-building systems. While such activity is now well-documented in bone fide pre-main sequence disks, the situation in the transition disks was yet to be thoroughly investigated. In this study we carried out an analysis of existing data from NASA missions, supplemented by both archival (when available) and limited new ground-based observations (when not) of a select sample of such systems. We investigate the nature of the changes occurring, and outline the consequences of these changes to the geochemistry of the disk.

[24] HST/GO11120 (144 orbits). ***A Paschen-α Study of Massive Stars and the ISM in the Galactic Center.***



The Galactic center (GC) is a unique site for a detailed study of a multitude of complex astrophysical phenomena, which may be common to nuclear regions of many galaxies. Observable at resolutions unapproachable in other galaxies, the GC provides an unparalleled opportunity to improve our understanding of the interrelationships of massive stars, young stellar clusters, warm and hot ionized gases, molecular clouds, large scale magnetic fields, and black holes. We obtained the first large-scale hydrogen Paschen alpha line survey of the GC using NICMOS on the Hubble Space Telescope. This survey produced a high resolution and high sensitivity map of the Paschen alpha line emission in addition to a map of foreground extinction, made by comparing Paschen alpha to radio emission. This survey of the inner 75 pc of the Galaxy provides for unprecedented and complete searches for sites of massive star formation. In particular, we are able to (1) uncover the distribution of young massive stars in this region, (2) locate the surfaces of adjacent molecular clouds, (3) determine important physical parameters of the ionized gas, (4) identify compact and ultra-compact HII regions throughout the GC. When combined with existing Chandra and Spitzer surveys as well as a wealth of other multi-wavelength observations, the results allow us to address such questions as where and how massive stars form, how stellar clusters are disrupted, how massive stars shape and heat the surrounding medium, and how various phases of this medium are interspersed.

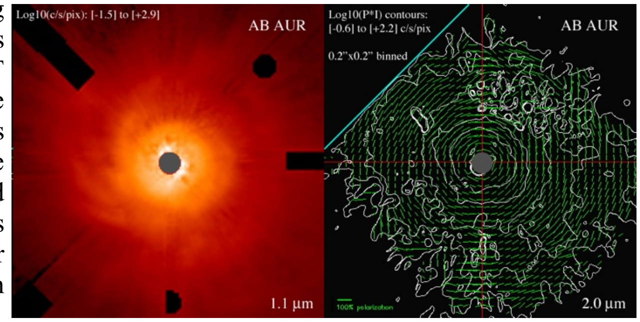
[23] HST/AR 11279 (5 year Legacy Archival Research). ***A Legacy Archive PSF Library And Circumstellar Environments (LAPLACE) Investigation.*** NICMOS coronagraphy, with well–matched template Point Spread Function (PSF) subtraction, probes the closest environments of occulted targets with the highest imaging sensitivity in intrinsically high contrast fields at the smallest radial distances afforded, uniquely, by HST. NICMOS PSF-subtracted coronagraphy has been invoked in a wide variety of HST programs with science themes as divergent as detecting and characterizing disks of circumstellar material in neo-natal stellar environments, to studying faint nebulosity associated with luminous active galaxies, to searching for planetary-mass compan-



ions in extrasolar planetary systems recently born and in the "stellar graveyard". The investment in HST time in the execution of these and other programs has met with mixed returns. Stunning (but infrequent) successes, importantly advancing their fields highlight much more frequent, unfortunately common, failures arising from highly compromised technically-achievable performance due to the lack of suitable template PSFs required to produce high-fidelity, photometrically robust, high contrast coronagraphic images. We addressed this situation by undertaking a rigorous, homogeneous, and complete recalibration and analysis of the full archival set of ~ 8450 raw NICMOS coronagraphic images previously obtained and residing in the MAST to create a parametrically diverse Legacy library of template PSFs, enabling the recovery of the large body of science otherwise lost. We delivered this PSF library to the Hubble Legacy Archive, along with generically applicable analysis software to: (1) critically augment the needs of future observational programs reliant on high fidelity PSF subtractions, (2) increase their yields and photometric efficacy, (3) reduce the observing time (HST orbit allocations) otherwise required for near-contemporaneous reference PSF observations, and (4) greatly enrich the yet-unrealized potential of the many NICMOS coronagraphic observations already acquired from the broad spectrum of science programs previously executed. Using the enabling power of the PSF library enables a re-reducing and re-analysis of all archival NICMOS coronagraphic observations of circumstellar disk and VLM stellar, brown dwarf, and EJP companion candidate stars (~ 400 targets) to probe for previously undetected circumstellar disks. Through image analysis and modeling the physical properties of newly-discovered disks and their constituent grains can be ascertained. With a very large and homogeneously contrast-limited sample of optimally PSF-subtracted images, spatially resolved flux density limits on dust-scattered starlight can be set from non-detections to constrain the properties of the many IR-excess (and other) sources in this sample.

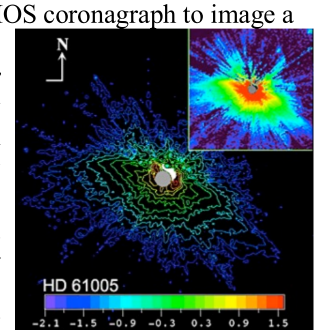
[22] HST/GO 11157 (48 Orbits). ***NICMOS Imaging Survey of Dusty Debris Around Nearby Stars Across the Stellar Mass Spectrum.*** Association of planetary systems with dusty debris disks is now quite secure, and advances in our understanding of planet formation and evolution can be achieved by the identification and characterization of an ensemble of debris disks orbiting a range of central stars with different masses and ages. Imaging debris disks in starlight scattered by dust grains remains technically challenging so that only about a dozen systems at the time of this investigation had thus far been imaged. Further advancing in the field required increasing number of imaged debris disks. However, the technical challenge of such observations, even with the superb combination of HST and NICMOS, requires the best targets. Recently prior HST imaging investigations of debris disks were sample-limited, not limited by the technology used. We performed a search for debris disks from a IRAS/Hipparcos cross correlation which involved an exhaustive background contamination check to weed out false excess stars. Out of ~140 identified debris disks, we selected 22 best targets in terms of dust optical depth and disk angular size. Our target sample represented the best then-available target set in terms of both disk brightness and resolvability; e.g., these targets have higher dust optical depth, in general, than then-newly identified Spitzer disks. Also, our targets covered a wider range of central star ages and masses than previous debris disk surveys, thus expanding the domain of investigations of planetary system formation and evolution across the stellar mass spectrum.

[21] HST/GO 11155 (14 Orbits). ***Dust Grain Evolution in Herbig Ae Stars: NICMOS Coronagraphic Imaging and Polarimetry.*** We took advantage of the sensitive coronagraphic capabilities of NICMOS to obtain multiwavelength coronagraphic imaging and polarimetry of primordial dust disks around young intermediate-mass stars (Herbig Ae stars), in order to advance our understanding of how dust grains are assembled into larger bodies. Because the polarization of scattered light is strongly dependent on scattering particle size and composition, coronagraphic imaging polarimetry with NICMOS provides a uniquely powerful tool for measuring grain properties in spatially resolved circumstellar disks. It is widely believed that planets form via the gradual accretion of planetesimals in gas-rich, dusty circumstellar disks, but the connection between this suspected process and the circumstellar disks that we can now observe around other stars remains very uncertain. Our observations, together with powerful 3-D radiative transfer codes, enable quantitative determination of dust grain properties as a function of location within disks, and thus testing whether dust grains around young stars are in fact growing in size during the putative epoch of planet formation. HST imaging polarimetry of Herbig Ae stars complements and extends existing polarimetric studies of disks around lower-mass T Tauri stars and debris disks around older main-sequence stars. When combined with these previous studies, this research helps establish the influence of stellar mass on the growth of dust grains into larger planetesimals, and ultimately to planets. Our results permit calibrating models of the thermal emission from these disks, a critical need for validating the properties of more distant disks inferred on the basis of spectral information alone.

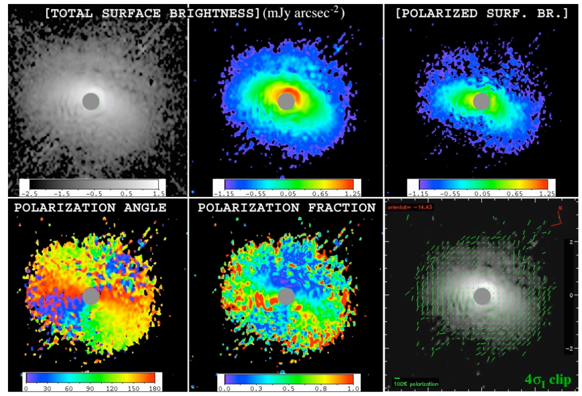


[20] HST/GO 10864 (19 Orbits). ***Mapping the Gaseous Content of Protoplanetary and Young Planetary Systems with ACS/SB.*** One of the key problems in planetary system formation is understanding how rapidly, and over what time interval, Jovian planets can form. Dust in the protoplanetary disk is critical in planetesimal formation, but it is the gas which produces giant planets, and which is essential for their migration. However, compared to data on the circumstellar dust, information on the gas component is sparse, especially in the planet-formation zone. This severely limits our ability to put observational constraints on giant planet formation, except to note that the process must be largely complete by 12 Myr, given the paucity of Herbig Ae or classical T Tauri stars older than 10 – 12 Myr. In the FUV, photo-excited molecular hydrogen transitions have the requisite contrast to the stellar photosphere, accretion shock, and reflection nebulosity, and can be traced 50 – 100 au from the exciting stars in both envelopes and outflow cavities and protoplanetary disks. Central disk cavities, an expected consequence of planet formation, larger than 0.1" are directly detectable in HST FUV spectra, while smaller cavities may be detected by comparison with protoplanetary disks which are still accreting onto their stars. In GO 10846 we augmented existing HST coronagraphic imagery of six Herbig Fe and T Tauri disks with ACS Solar-Blind Channel Lyman alpha imagery and slitless spectroscopy, simultaneously sampling the disk in molecular hydrogen and small-grain reflection nebulosity. These data are used to quantify the amount of vertical stratification in these disks, to map the mass-loss geometry from their central stars, and to determine whether removal of molecular material precedes, lags, or is contemporary with clearing of the dust.

[19] HST/GO 10849 (44 Orbits). ***Imaging Scattered Light from Debris Disks Discovered by the Spitzer Space Telescope around 21 Sun-like Stars***. We used the high contrast capability of the NICMOS coronagraph to image a sample of then-newly discovered circumstellar disks associated with Sun-like stars. These systems were identified by their strong thermal infrared emission with the *Spitzer* Space Telescope. Modeling of the thermal excess emission in the form of spectral energy distributions alone cannot distinguish between narrowly confined high opacity disks and broadly distributed low opacity disks. Our NICMOS observation, however, can by imaging the light scattered from this material. Non-detections of low surface brightness disks place significant constraints on disk geometries, ruling out models with high optical depth. Unlike previous disk imaging programs, this well-defined sample of solar mass stars covers a range of ages from ~ 10 Myrs to a few Gyrs, allowing us to study, for the first time, the evolution of disks from primordial to debris. These results greatly improve our understanding of debris disks around Sun-like stars at stellar ages nearly 10 times older than any previous investigation. Through this investigation, we are providing a crucial, but now missing, piece of the puzzle concerning the formation and evolution of our own solar system.

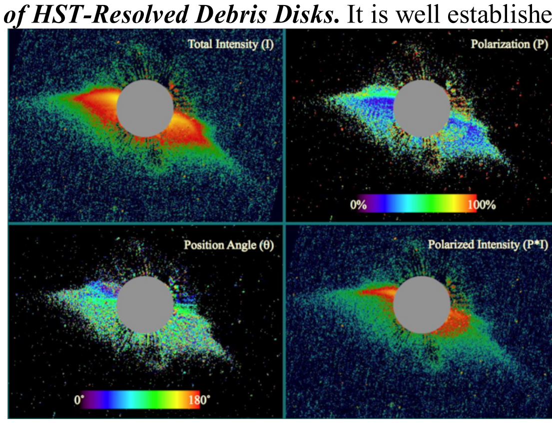


[18] HST/GO 10852 (14 Orbits). ***Coronagraphic Polarimetry with NICMOS: Dust Grain Evolution in T Tauri Stars.*** The formation of planetary systems is intimately linked to the dust population in circumstellar disks. Thus, understanding dust grain evolution is essential to advancing our understanding of how planets form. In GO 10852, we, the first time combined: (*a*) the coronagraphic polarimetry capabilities of NICMOS recently enabled and demonstrated in HST/GO 9768), (*b*) powerful 3-D radiative transfer and modeling codes, and (*c*) observations of objects (previously observed in unpolarized light with NICMOS coronagraphy in GO 10177/GTO 7233) known to span protoplanetary disk Class II-III stellar evolutionary phases With these, we gain crucial insight into dust grain growth – a necessary precursor to the formation of planetary systems. With spatially resolved polarimetric obser vations of T–Tauri disks, representative of an evolutionary sequence of YSOs, investigate how dust grain populations evolve in size and spatial distribution during the crucial transition from a star–plus-disk system to a system containing planetesimals. When combined with our concurrent study on dust grain evolution of Class I–II disks (GO 10178), and our symbiotic coronagraphic polarimetric investigation of debris disks (GO 10847), this study helps establish the fundamental time scales for the depletion of ISM-like grains. This investigation bridges the first step in understanding the transformation from small submicron sized dust grains, to large millimeter sized grains, and eventually to planetary bodies.

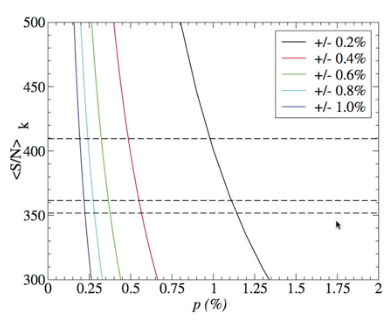


GM Auriage – 2 μm coronagraphic polarimetry

[17] HST/GO 10847 (39 Orbits). ***Coronagraphic Polarimetry of HST-Resolved Debris Disks.*** It is well established that stars form in gas-rich protostellar disks, and that the planets of our own solar system formed from a circum-solar disk. However, the connection between the (largely gas depleted) circumstellar disks that we now observe around other stars and the processes of planet formation is still very uncertain. Mid-IR spectral studies have suggested that disk grains grow in the environments of young stellar objects during the putative epochs of the formation of planetary embryos. Structures revealed in well resolved images of older circumstellar disks, by light scattered from their constituent grains (such as we have uniquely obtained with HST broadband coronagraphy in our previously reported investigations), suggest gravitational influences on the disks from co-orbital bodies of planetary masses. Such imaging data, while of critical importance in establishing the existence and the basic properties of the light–scattering disks in these systems, provides only limited information about the disk grain properties and their environments. Key insights into disk/planet evolutionary scenarios may be realized, and the field of inquiry significantly advanced, by spatially resolved imaging polarimetric observations of our well-selected sample of circumstellar debris disks. Our target characteristics were well established through our previous HST non-polarimetric coronagraphic observations. Here, we took full advantage of ACS and NICMOS coronagraphic capabilities to obtain polarimetric imaging of circumstellar debris disks that were imaged previously without polarizing optics. These observations enable quantitative determination of the sizes of the grains and optical depths as functions of their location within the disks (i.e., detailed tomography). Armed with these well-determined physical and geometrical systemic parameters allows the development a set of self-consistent models of disk structures to investigate possible interactions between unseen planets and the disks from which they formed. Together with our then-concurrently executing coronagraphic polarimetric investigation probing the putatively earlier, T-Tauri, evolutionary stages of circumstellar disks (GO 10852), and (non-coronagraphic) NICMOS-plus-ACS polarimetric study of more deeply embedded Class I-II sources and their protoplanetary disks (GO 10178), we fully probe the posited epochs of planet building. Our results also help calibrate models of the thermal emission from these disks, that in turn enable the inference of the properties of other debris disks that cannot be spatially resolved with current or planned instruments and telescopes.

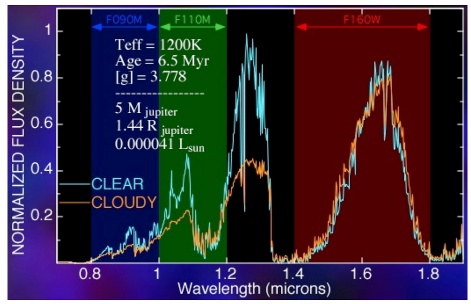


[16] HST/GO 10839 (9 Orbits). ***NICMOS Polarimetric Calibration.*** It has been shown that NICMOS possesses a residual instrumental polarization at a level of 1.2%. This completely inhibits the data reduction in significant numbers of previous HST programs, and hampers the ability of the instrument to perform very high accuracy polarimetry. We have now pushed the NICMOS polarimetric calibration to the ultimate levels that residual instrumental systematics will allow. This investigation, and the resulting calibrations, have enabled near-IR imaging polarimetric investigations of astronomical sources with (*a*) intrinsically very low near-IR polarization fractions (P% < 1%; previously appx. the detection floor), and (*b*) higher precision recovery of polarization than is now achievable for sources with larger intrinsic polarizations.



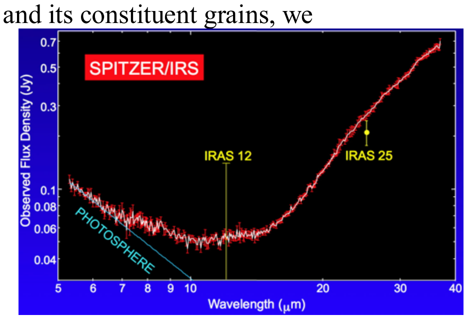
Polarimetric analysis at P% < 1% (and commensurate accuracies for higher P% sources) require very high precision, and pedigree tracking -- with fully propagated error statistics (both "random" and systematic) -- in the derivation of instrumental count-rate images, and their later combinations and cross-calibrations to derive proper instrumental calibrations. These calibrations have enabled new classes of investigations requiring very high near-IR precision polarimetry.

[15] HST/GO 10538 (30 Orbits). ***Near-IR Spectrophotometry of 2MASSWJ 1207334-393254B - An Extra-Solar Planetary Mass Companion to a Young Brown Dwarf***. We obtained "short" wavelength near-IR diagnostic and characterizing spectra of the extra-solar giant planet (EGP) companion to 2MASSWJ 1207334-393254 (2M1207), a young brown dwarf and TW Hydrae Association member. NICMOS camera 1 multi-band photometric imaging (obtained in our HST/GO 10177 program) of the EGP companion, 0.77" (54 au projected) from 2M1207 implicate an object of several Jupiter masses based on cooling models of EGPs and the ~ 8 Myr likely age of 2M1207. Through our HST observations, physical companionship of the EGP candidate with 2M1207 has now been established at the 16 σ level of confidence. Diagnostic spectra in the 0.8 – 1.9 μm region (unobtainable from the ground and overlapping the NICMOS imaging observations) can (*a*) critically inform on the physical nature of the EGP, (*b*) provide currently non-existing information to test/constrain theoretical models of EGP properties and evolution, and (*c*) unequivocally confirm the imaging of a bone fide EGP. This prototypical spectrum serves to test and improve upon current models of young EGPs that predict flux suppression by molecular absorption in their atmospheres.



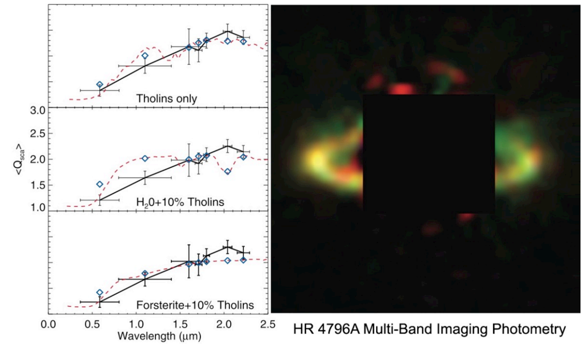
[14] HST/GO 10527 (42 Orbits). ***Imaging Scattered Light from Debris Disks Discovered by the Spitzer Space Telescope Around 20 Sun-like Stars.*** Continuing as investigation HST GO/10849; see [19] above.

[13] SPITZER/DD 225 (1.1 hours). ***Spitzer Observations of a Newly-Discovered Nearly Edge-On Disk About HD 32297***. We obtained obtain IRAC and MIPS imaging photometry and IRS low resolution spectroscopy of nearly edge-on, light-scattering debris disk about HD 32297 discovered in our HST 10177 survey program, extending at least 3.3" (400 au) from the star along its major axis with a 1.1 micron flux density of 4.81 ± 0.57 mJy beyond 0.3" from the star. Our HST imagery provided crucial information on the disk morphology and dust scattering efficiency, but cannot inform unambiguously upon the physical properties of the dust in this potentially planet-forming, optically thin, environment. To further elucidate the physical characteristics of the disk and its constituent grains, we combine our HST high spatial resolution 1.1μm scattered light imagery with photometry and spectra from 3.6 –160 μm that we obtained with Spitzer, and 2 micron imaging polarimetry we obtained in HST GO 10849. The Spitzer data allows us to develop a well-sampled spectral energy distribution (SED) for both the star and the disk emission, including mid-IR spectral coverage sufficient to characterize mineralogical features that will place strong constraints on the dust constituents. As one of only a small handful of disks resolved in both thermal and scattered light, these observations provide a crucial laboratory for understanding disks and planet formation.



[12] HST/GO 10167 (15 Orbits). ***Imaging of Ices in Circumstellar Disks.*** The link between the material of the interstellar medium and the ultimate composition of planets lies in the way gas and dust are processed in circumstellar disks. Planet formation models rely upon knowledge of the disk constituents and temperature profiles to predict how small grains may eventually combine into terrestrial planets and gas giant cores. Disks around other stars may be analogs for our own early Solar System and thus allow the direct measurement of such phenomena.

Preceding this study several well-resolved images of dust disks around several late T Tauri or main sequence stars been secured. HST provides a uniquely stable platform for making such sensitive high dynamic range images. Now, for those handful of disks already resolved, we are going beyond the discovery phase and making astrophysical measurements with color-diagnostic data to deepen our understanding of the course of disk evolution. With our multi-wavelength near-IR images we are searching for and study the spatial distribution of two common Solar System materials – CH_4 and H_2O ices – in other potentially planet-forming systems.

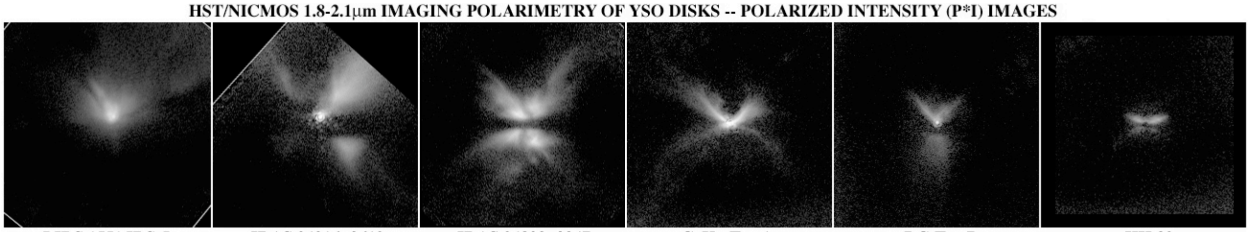


HR 4796A Multi-Band Imaging Photometry

[11] JPL/1278115 (Concept Study). ***High Spatial Resolution Imaging Polarimetry with TPF-C.*** As difficult as the challenge will be, TPF-C (before mission cancellation) was being designed to detect Earth-like planets in stellar habitable zones. Subsequent characterization of those planets, and of the environments in which they have formed, is an even more daunting challenge. Many avenues of approach have been considered and suggested. Polarimetric analysis of light scattered by circumstellar grains in the active and residual planet-forming environments of stars, and reflected by planetary surfaces (and atmospheres) once formed, can both constrain the physical properties of the constituent particles and elucidate the geometries of such systems. Polarimetric coronagraphy can very significantly lower a polarimetric sensitivity floor by rejection of stellar light which, if unsuppressed, may become instrumentally polarized in a spatially dependent (and uncalibratable) fashion, thus otherwise limiting the ultimate achievable sensitivity. Here, in concert with the TPF-C Technology Plan we conducted a study to: (*a*) define and delineate the key science drivers for a TPF-C polarimetric capability; (*b*) establish the core instrument and system performance requirements for a polarimetric system to meet the needs of *a*; (*c*) evaluate key elements of system requirements to enable the development of an effective polarimeter within the envisioned scope of the TPF-C program.

[10] HST/GO 10178 (19 Orbits). ***Imaging Polarimetry of Young stellar Objects with ACS and NICMOS: A Study in Dust Grain Evolution***. The formation of planetary systems is intimately linked to the dust population in circumstellar disks. Thus, understanding dust grain evolution is essential to advancing our understanding of how planets form. By combining: (*a*) the high resolution imaging polarimetry capabilities of ACS and NICMOS, (*b*) 3-D radiative transfer codes and light-scattering models, and (*c*) observations of objects known to span the earliest stellar evolutionary phases, we gain crucial insight into the initial phases of dust grain growth: evolution away from an ISM distribution. Fractional polarization is a strong function of wavelength. Therefore, by comparing

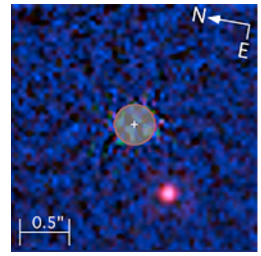
HST/NICMOS 1.8-2.1μm IMAGING POLARIMETRY OF YSO DISKS -- POLARIZED INTENSITY (P*I) IMAGES



LIRS 1551 IRS-5 | IRAS 04016+2610 | IRAS 04302+2247 | CoKu Tau 1 | DG Tau B | HH 30

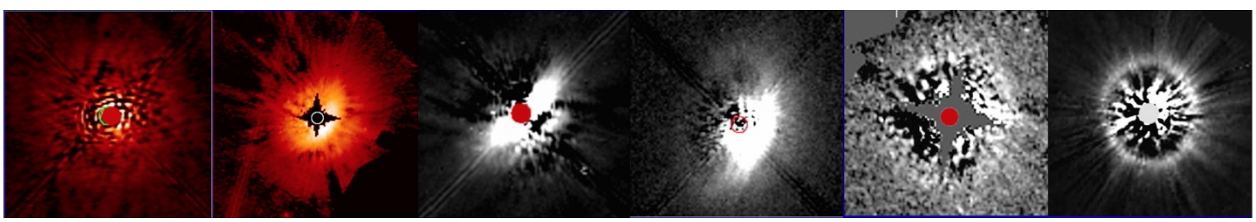
polarimetric images in the optical (with ACS) and infrared (with NICMOS), we can sensitively constrain not only the geometry and optical depth of the scattering medium, but also the grain size distribution. By observing objects representative of the earliest evolutionary sequence of YSOs, we investigate how the dust population evolves in size and distribution during the crucial transition from a disk+envelope system to a disk+star system during an evolutionary epoch where significant variabilities are seen in YSO disks. The study helps to establish the fundamental time scales for the initial depletion of ISM-like grains: the first step in understanding the transformation from small submicron sized dust grains, to large millimeter sized grains, "rocks", and untimely to planetary bodies.

[9] HST/GO 10176 (116 Orbits) ***Coronagraphic Survey for Giant Planets Around Nearby Stars.*** Predicated on the success of our earlier imaging surveys, and recent progress in identifying "young stars near Earth", we conducted a systematic imaging search for extra-solar Jovian planet candidates with HST/NICMOS coronagraphy. Jupiter-mass planets can be imaged as close as a few tens of AUs from the primary stars for most of our young (≤ 30 Myrs) and nearby (≤ 60 pc) targets. This represented the first time that potential analogs of our solar system – planetary systems with giant planets having semi-major axes comparable to those of the giant planets in our Solar System – within the grasp of existing, then state-of-the-art, instrumentation. Many of our targets are even younger, and closer to the Earth than the selected members of the TW Hya association previously studied with HST/NICMOS. Considering the success of our path-finding observations in imaging low mass brown dwarfs and planetary disks among members of the TW Hydrae Association, a significant fraction of our targets may possess low mass brown dwarf or giant planets companions, or dusty planetary disks. Follow-up astrometric (common proper motion) and multi-band photometric imaging observations of newly discovered candidates (e.g., 2M1207) confirm companionship and provide initial physical characterization of newly identified gravitationally–bound planetary–mass companions.



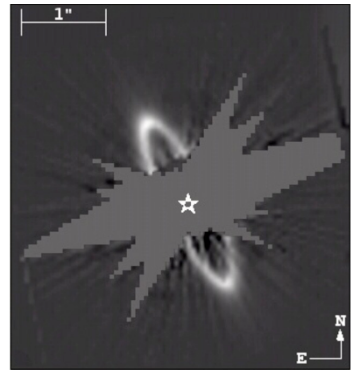
2M1207b ~ $5M_{Jupiter}$

[8] HST/GO 10177 (56 Orbits). ***Solar Systems in Formation: A NICMOS Coronagraphic Survey of Protoplanetary and Debris Disk.*** Despite decades of concerted effort applied to understanding the formation processes that gave birth to our solar system, until recently, the detailed morphology of CS material that must eventually form planets has been virtually impossible to discern. The advent of high contrast, coronagraphic imaging as implemented with the HST instruments has dramatically enhanced our understanding of natal planetary system formation. Even so, only a handful of evolved disks (~ 1 Myr and older) have been imaged and spatially resolved in light scattered from their constituent grains. To elucidate the physical processes and properties in potentially planet-forming CS disks, and to understand the nature and evolution of their grains, a larger spatially resolved and photometrically reliable sample of such systems *must* be observed. Thus, we conducted a highly sensitive CS disk imaging survey of a well-defined and carefully selected sample of YSOs (1–10 Myr T Tau and HAeBe stars) and (> app 10 Myr) main sequence stars, to probe the posited epoch of planetary system formation, and to provide this critically needed imagery. Our high spatial resolution HST/NICMOS coronagraphic images are shedding light on the spatial distributions of the dust in these thermally emissive disks. In combination with their long wavelength SEDs, the physical properties of the grains are being discerned or constrained by our photometrically accurate surface brightness sensitivity limits for thermally emissive disks that elude scattered-light detection. Our sample provides the highest detection sensitivity to the smallest disks around bright stars that can be imaged with HST. The imaging data permits discriminating between proposed evolutionary scenarios and provides a legacy of cataloged morphologies for interpreting mid- and far-IR SEDs that the Spitzer Space Telescope has delivered.



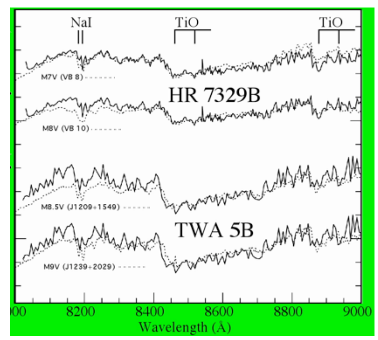
[7] HST/GO-CAL 9768 (6 Orbits). ***Enabling Coronagraphic Polarimetry with NICMOS.*** Through this observing mode enabling and instrumental characterization program, with demonstration science content, we enabled a new observing mode for HST that combines the powerful diffracted light rejection of the NICMOS coronagraph with the diagnostic power of near-IR (2 μm) polarimetry. This new capability, now available to all HST observers, will open a new regime in high contrast imaging that has not been possible before. The enabled science included, but was not limited to, detection and imaging of circumstellar debris in polarized light, the polarized emission surrounding bright planetary nebulae, and the extended structure around bright active galaxies. A complementary capability is possible with the ACS. With the added capability of NICMOS coronagraphic polarimetry, HST (at this era) provided the only platform for this extremely high contrast imaging polarimetry covering the entire near-UV, optical and near-infrared wavelength regime. Only the combined HST NICMOS system has the combined resolution and stability (especially with the NCS) to provide high spatial resolution, coronagraphic, near-infrared polarimetry in the foreseeable future. The technique was absolutely unique to HST (while NICMOS and ACS/HRC were co-operational) and enabled a new regime in high contrast imaging. With the success of this enabling program we were granted time to carry out three new polarimetric investigations in HST Cycle 15: HST GO 10847, and 10839.

[6] HST/GO-8624 (17 Orbits). ***Imaging and Spectroscopy of Dusty Circumstellar Disks.*** Understanding the properties and evolution of dusty disks in the circumstellar environments of young stars is a key element in furthering our concepts of the formation mechanisms of extra-solar planetary systems. The then-recent advent of NICMOS and STIS coronagraphy has given rise to the first reflected light imaging, other than for β Pictoris, of dusty circumstellar disks with spatially resolved morphological structures. NICMOS has taken a first step in imag-

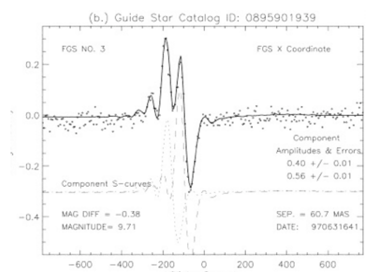


ing these new disks elucidating their geometries, morphologies, and bulk photometric properties, while increasing the number of such known systems from one to half a dozen. These dusty disks vary in physical size by over two orders of magnitude and exhibit radial anisotropies in their brightness distributions that may be indicative of dynamical confinement or sculpting of the disk particles by unseen planetary bodies. STIS follow-on imaging and spectroscopy provide further insight into the nature of the disk particles. With spectra, we measure the albedo of the disk dust and search for complex molecules and water ice. With coronagraphic images, we investigate the scattering phase function and hence the composition of the disk dust as well as measure the disk sizes and shapes with high precision. Such observations are of fundamental importance in establishing the physical basis for emergent theories of disk evolution and planet-building.

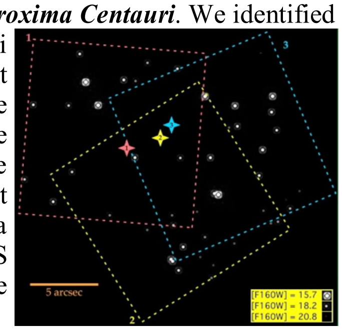
[5] HST/GO-8176 (20 Orbits). ***Confirmation and Characterization of Brown Dwarfs and Giant Planets from NICMOS 7226/72277.*** A systematic search for giant planet and brown dwarf companions to stars in the solar neighborhood is a cornerstone of the NICMOS IDT's Environments of Nearby Stars programs. A carefully selected candidate list of 74 stars was observed using the NICMOS coronagraph at 1.6 µm. We have found possible sub-stellar companions as faint as H = 22, 10 to ~ 15 magnitudes fainter than their primaries at separations of ~ 0.8" to 5.0" corresponding to minimum physical separations of less than 10 au for some of the stars in the sample. The lower mass limit depends on age, distance, and spectral type, but can be as low as 3 – 5 M(Jupiter) for many of our targets. Following the initial search-phase, second epoch spectrographic observations are required to characterize the physical nature of the putative companions. STIS spectra allow us to compare the atomic line and molecular band strengths of key tracers for very low mass M and L stars (TiO, VO, and FeH bands), brown dwarfs similar to GL 229B (LiI 8216 Å, CsI 8521 Å and 8944 Å, H_2O 9300Å and 9500 Å bands), RbI 7800 Å and 7948 Å, CrH 8611 Å and 8800 Å for hotter BDs, and 8890 Å in giant-Jupiters. Ground-based atmospheric absorption of CH_4 compromises the ability to obtain high quality spectra in the broad H_2O vapor bands in the ~ 9300 Å – 9600 Å spectral region. With such observations, we address questions as fundamental as: Is here a continuity of objects across the sub-stellar mass spectrum bridging the main sequence to planetary objects? What is their frequency of occurrence? At what distances will they be found from their primaries? What implications will these discoveries have for our understanding of stellar/planetary formation mechanisms?



[4] HST/GO-8370 (ENG/Archival Research). ***Duplicity and Variability in HST Guide Stars – An FGS Serendipitous Survey.*** Subsequent to the publication of our first-epoch catalog we continued the serendipitous search for close double stars (separations > 20 mas) in the magnitude range 9 to 14.5 using interferometric guiding data from the HST Guidance Sensors. In this second epoch follow-on phase to our GO 5811 [#1] investigation, we have more than doubled our initial sample size and temporal baseline of 13,979 acquisitions on 4882 stars observed over 22 months, and with the inclusion of additional FGS1R data improve the sensitivity limits and detection thresholds of the variability study for all observed HST guide stars with sampling rates up to 40 overall sample. In addition, we have conducted a differential photometric Hz and milli-magnitude photometric precision. (Results from 5811 and 8370 results have been released as a special astrometric catalog available through CDS J/PASP/110/1012;
Ancillary data on-line: http://nicmosis.as.arizona.edu:8000/pub/gsdoubles.html

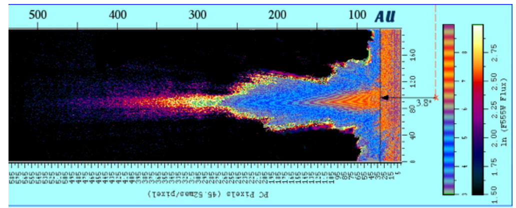


[3] HST/GO-7847 (4 Orbits). ***Near-IR Photometry of a Candidate companion to Proxima Centauri***. We identified a candidate low luminosity companion to the closest star to the Sun, Proxima Centauri (dist. ~1.3 pc) from data obtained in HST Cycle 6 using the Faint Object Spectrograph (GO program #6059) in a pseudo-coronagraphic imaging mode. The candidate companion was found within 0.4" of Proxima Cen, thus too close to be detected with WFPC2 direct imaging. It's apparent motion on the sky is similar to the parallactic motion of Proxima Cen, which makes its effect upon Proxima Cen difficult to detect with FGS astrometry. If the candidate companion is in orbit about Proxima Cen, modeling indicates the orbital period would be ~ 1 year. Here we used NICMOS camera 1 PSF-subtracted imaging observations to investigate the nature of the putative companion, determine IR magnitudes, and to constrain orbital elements.

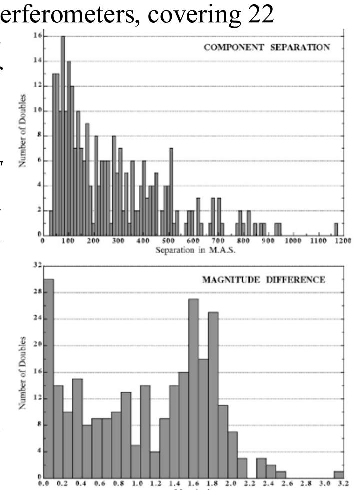


Our new observations informed of the likelihood of the FOS-identified candidate being a background object, but revealed several additional candidates to be vetted with future common proper motion observations.

[2] **HST/GO-6058 (8 Orbits).** ***Direct Imaging of a Circumstellar Disk: β Pictoris, a Case Study.*** We employed the unique imaging capabilities of HST/WFPC2 to obtain high resolution PC1 images of the dust disk about β Pictoris, the best known candidate then known for an extrasolar proto-planetary system or massive Kuiper Belt. With accurate photometry of the disk we investigated the reported morphology (gaps) and variable disk thickness. The diffraction-limited image resolution of WFPC2 provides information needed to delineate more clearly the optical properties and size distribution of the circumstellar dust. It is the only circumstellar disk that was then detectable with optical imaging techniques due to the large differences in brightness between the central star (V = 3.9) and the disk (V ~16 mag arcsec^{-2}) with a ground-based coronagraph. With HST/WFPC2 we place the core of the stellar PSF for β Pic in WF3, isolating the blooming and saturation from overexposure to this frame. Details of the dust disk normally masked by the extended halo of the PSF core are revealed in the adjacent CCD frame PC1, and enhanced with similarly-observed PSF template subtraction.



[1] HST/GO-5811 (ENG/Archival Research). ***Search for Stellar Duplicity and Variability from FGS Guide Star Acquisitions and Guiding Data.*** Data from the HST Fine Guidance Sensor (FGS) interferometers, covering 22 months of guide-star acquisition operations, were analyzed for evidence of stellar duplicity and variability. The data comprise a survey of observed guide stars, all of which are taken from the *HST* Guide Star Catalog (9 ≤ V ≤ 14). The survey results cover a parameter space for the newly found doubles, for the fainter stars, which are of smaller limiting angular separations than in any previous surveys. The normal *HST* engineering telemetry data from 13,979 acquisitions on 4882 stars have been processed. The FGS guidance data can reveal duplicity with separations ranging from approximately 0.03", for the brighter stars, with small magnitude differences, up to the neighborhood of 0.5", and in some cases to 1.0". The fraction of guide stars indicating duplicity is a function of the statistical criteria used but is over 5% at a very high level of confidence. It is possible that if some of the brighter and closer pairs could be identified as nearby, then their orbital motions would be rapid enough to allow a mass and distance determination on a timescale of a decade if followed with ground-based interferometric and spectroscopic instruments. A catalog of double stars is provided, nearly all of which are of certain duplicity. Information for accessing on-line catalogs of large numbers of stars with lesser, but nevertheless strong, probabilities of duplicity and also for the solutions for duplicity from all acquisitions is provided. (Also see [4] GO-8370, above).



Dr. Schneider was also an externally funded UofA co-I on two HST programs:

[UA coI] HST*/GO 13418 (12 orbits*; D. Apai UA PI*). Patchy Clouds and Rotation Periods in Directly Imaged Exoplanets.* Directly imaged exoplanets offer unique insights into weakly-irradiated planetary atmospheres and into the architecture of outer planetary systems. They also raise two pivotal questions: 1) How do their atmospheres compare to brown dwarfs? and 2) How did these large-separation massive planets form? Atmospheric modeling of directly imaged planets is complicated by the presence of condensate clouds; many successful models assume patchy cloud cover, a combination of two different atmospheres (e.g. cloudy and cloud-free). Heterogeneous cloud covers are common in brown dwarfs and led to rotational photometric variability. In addition, different planet formation models proposed for large-separation exoplanets led to different typical rotation rates. We pioneered *HST* and *Spitzer* rotational mapping of brown dwarfs and in a series of studies that showed this technique provides very important and unique constraints on the composition and structure of brown dwarf atmospheres and their cloud layers. Herein we will apply high-contrast, high-precision photometry to two prototypical directly imaged exoplanets (or planetary mass companions) and search for photometric variations. The observations: 1) verify the prediction of patchy cloud cover and allow quantitative comparisons to cloud properties observed in brown dwarfs; and, 2) provide the first direct measurements of the rotation periods of wide-separation exoplanets, an important constraint on their formation mechanism. Furthermore, the observations demonstrated a new observing technique on two low-risk targets, opening a new window on directly imaged exoplanets.

[UA coI] HST/GO 12923 (6 orbit HST calibration/mode enabling program; A. Gaspar UA PI): ***Pointing the Finger: Calibrating the Hidden Features of STIS and Enabling Coronagraphy at Separations of 0.15 arcseconds.*** We conducted a STIS calibration program enabling *HST* coronagraphy at its ultimate inner working angle (IWA) limit, with greater than previously possible contrast performance, well characterized at IWAs as small as 0.15", at optical wavelengths that cannot be broached from the ground even with AO augmented telescopes. Observations enabled by our calibrations advance exoplanetary science by revealing the currently-unexplored inner regions of circumstellar protoplanetary and debris disks, and detect and resolve close orbit substellar companions to nearby stars. Extragalactic studies of host galaxies of bright QSOs, damped Lyman alpha absorbers, and feedback mechanisms in the bulges of AGN can be pursued at distances closer to their hosts than ever before. The STIS occulting wedges A & B provide IWAs to > 0.3" before aperture edge intrusion and cut-off. Our calibration program mitigates this unintended deficiency unplanned in the STIS design to, for the first time on orbit, explore the "finger" occulter - unfortunately bent on the ground but quite likely still a functional, small IWA, focal plane occulter. We also explored the BAR10 occulter corners, unused in this fashion on-orbit, to comparatively demonstrate the merits of both with new capabilities for optical coronagraphy with sufficient time will before *HST* end of mission to exploit this potentially unmatched capability in unexplored observational domains required for high contrast science and uniquely at visible light wavelengths.

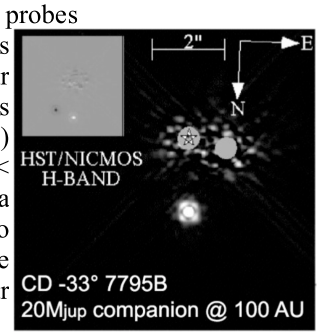
B. HST/NICMOS GTO Research Programs

HST/NICMOS Guaranteed Time Observing Programs (Schneider: PI/coI) – Completed

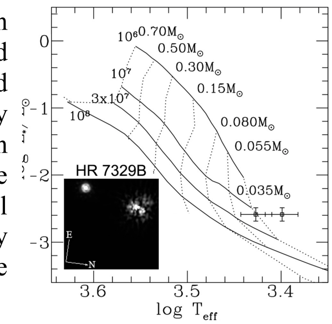
Title (see Research Project Summaries by ID number for details)	ID	Role
1. EONS-I: A Search for Low Mass/Sub-Luminous Companions to M-Stars	7227	PI
2. EONS-II: A Search for Massive Jupiters	7226	Lead/CoI
3. EONS-III: Dust Disks Around Main Sequence Stars	7233	Lead/CoI
4. EONS-IV: (Spectroscopy and) Polarimetry of the β Pictoris Disk	7248	CoI
5. EONS-V: NICMOS Spectrophotometry and High Resolution Imaging of HD 98800	7232	CoI
6. High Spatial Resolution Imaging of Comet Hale-Bopp (C/1995 O1)	7240	CoI
7. Spectrophotometry and Imaging of Pluto and Charon	7223	CoI
8. Astrometry and nIR Photometry of Neptune's Inner Satellites and Stability of the "Ring Arcs"	7242	CoI
9. High Spatial Resolution Observations of Markarian 231.	7038	PI
10. The Core and Circumnuclear Star Clusters in the Galaxy Merger NGC 6240	7219	CoI
11. Imaging of Quasar Host Galaxies	7220	CoI

B.1. Environments of Nearby Stars Programs

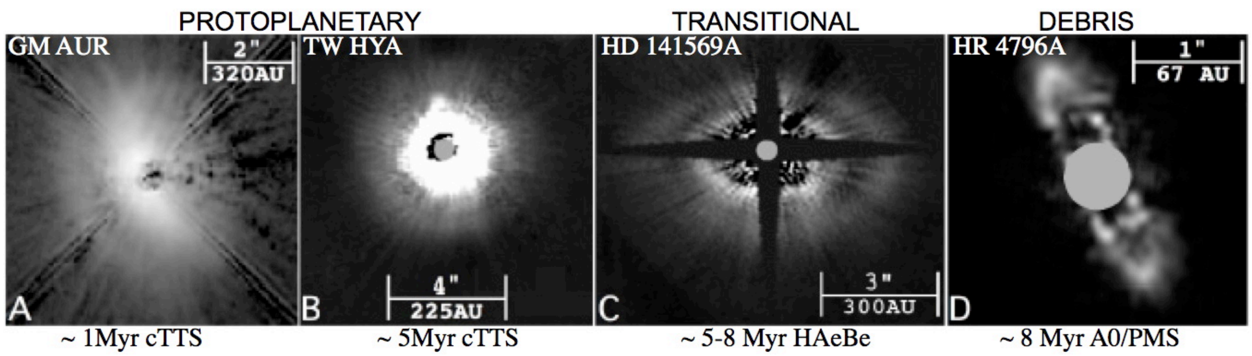
1. HST/NICMOS GTO-7227 (32 Orbits; PI). ***EONS-I: A Search for Low Mass/Sub-Luminous Companions to M-Stars.*** Knowledge of stellar and sub-stellar masses and luminosities at and below the ~ 0.08 M_{sun} hydrogen burning limit is of fundamental importance in many inter-related areas such as the determination of the stellar mass function at the lowest masses, the theory of stellar evolution, the study of the end of the main sequence, the search for galactic missing mass, and the resolution of age/evolution issues. Yet, this transition region between low-mass stars and giant planets is poorly understood and ill-observed. Until very recently, with the discovery of the brown dwarf companion to GL 229, the very existence of such objects remained in the conjectural realm. To make further progress at the low end of the mass function, additional objects must first be found. NICMOS uniquely probes the potentially fruitful hunting grounds in which to search for such transitional objects over parameter spaces that do not overlap with ground-based capabilities. Our investigation carries out a coronagraphic imaging program to discover close companions to M-dwarfs which are (a) nearby (d < 6 pc) with spectral types later than ~ M3.5, (b) young (age < 100 Myr) with d < 25 pc, and (c) spectrally the latest known (types < M8.5). With these findings, one may address such fundamental questions as: Is there a continuity of objects across the sub-stellar mass spectrum bridging the main sequence to planetary objects? What is their frequency of occurrence? At what distances will they be found from their primaries? And, what implications will these discoveries have for our understanding of stellar/planetary formation mechanisms.



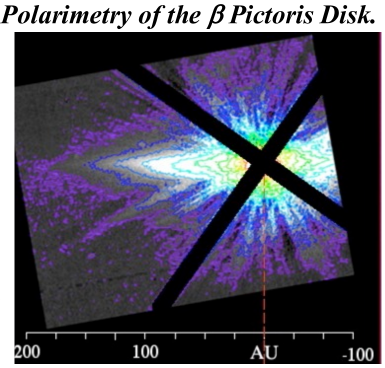
2. HST/NICMOS GTO-7226 (45 Orbits; coI). ***EONS-II: A Search for Massive Jupiters.*** We used NICMOS camera 2 coronagraphy to search for massive planets around nearby, young main sequence stars from 0.3" < r < 3" in the wavelength band 1.4 – 1.8 μm that corresponds to strong emission in the brown dwarf candidates GL 229B and GD 165B as well as to strong reflections in Jupiter and Titan. Because of the extreme youth of these objects, any low-mass brown dwarf and planetary companions will still be in a higher luminosity phase and thus easily detectable. The lower mass limit depends on age, distance, and spectral type, but can be as low as 3 – 5 $M_{jupiter}$ for targets in our sample. Follow-up observations of candidate companions provide proof of true physical association with the primary. Typical separations observable with NICMOS are near the empirical maximum in the binary distribution of stars (~ 20 – 40 au), which also corresponds to the mean distance of the giant planets in our own solar system.



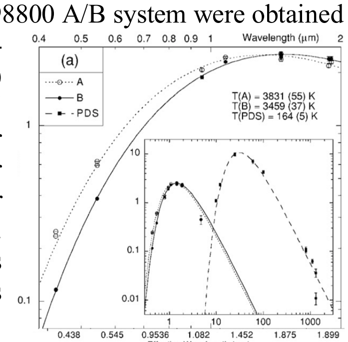
3. HST/NICMOS GTO-7233 (23 Orbits; coI). ***EONS–III: Dust Disks Around Main Sequence Stars.*** We surveyed a selection of mostly main sequence stars with IR determined $\tau_{dust} \geq 10^{-3}$ or other characteristics that suggest the presence of circumstellar dust disks. The observations were made with the NICMOS camera 2 coronagraph to minimize the effects of glare from the bright central star and employ a "rotational dither" about the occulted target stars by means differential spacecraft roll angles for best background subtraction. As a primary objective, all images were examined for the presence of dust disks. An important secondary objective was to search of all images for possible brown dwarfs or high-mass planets. Follow-up observations for many detections were made to characterize the physical properties of those objects found.



4. HST/NICMOS GTO-7248 (4 Orbits; coI). ***EONS–IV: (Spectroscopy and) Polarimetry of the β Pictoris Disk.*** (At the onset of this investigation) little was known about the β Pictoris disk within 50 au of the central star. No near-IR spectrophotometry or polarimetry existed within this dynamically interesting region, which is about the same size as our own solar system. We obtained NICMOS observations of the disk from ~ 5 au of the star to the outer regions of the disk limited by the total integration time to help to characterize the chemical and physical properties of the disk particles as a function of their distance from the star. By moving the star close to the edge of the coronagraphic hole, in that imaging mode, we attempted to observe as close as 2 au from the star to provide photometric, color and morphological properties of the innermost regions of the disk detectable by starlight-scattering dust.

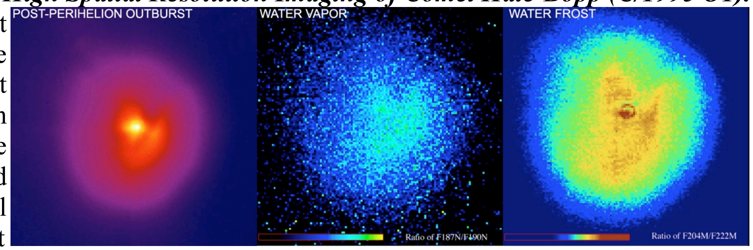


5. HST/NICMOS GTO-7248 (2 Orbits; coI). ***EONS-V: NICMOS High Resolution Imaging of HD 98800.*** NICMOS multi-band imaging photometry of the individual components of the HD 98800 A/B system were obtained and combined with other data to create ***s***pectral energy distributions (SEDs) from 0.4 to 4.7 μm. A third major component, is an extensive planetary debris system (PDS) that emits more than 20% of the luminosity of star B in a blackbody SED at 164±5 K extending from mid-IR to millimeter wavelengths. At 0.95 μm, a preliminary upper limit of less than 0.06 is obtained for the ratio of reflected light to the total from star B. This result limits the albedo of the PDS to less than 0.3. Values are presented for the temperature, luminosity, and radius of each major systemic component. Remarkable similarities are found between the PDS and the interplanetary debris system around the Sun as it could have appeared a few million years after its formation.

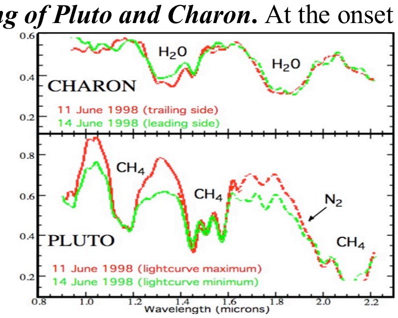


B.2. Solar System Programs

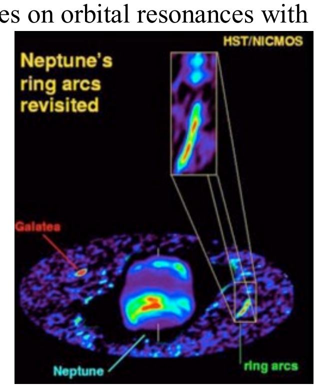
6. HST/NICMOS GTO-7240 (1 Orbit; coI). ***High Spatial Resolution Imaging of Comet Hale-Bopp (C/1995 O1).*** Comet Hale-Bopp provided an excellent opportunity for high-resolution imaging of the nuclear and inner coma regions of a bright comet soon after perihelion. Observations in the near-IR offer high contrast between the coma and nucleus since reflected sunlight and fluorescence are at a minimum and thermal emission from coma dust is important only at longer wavelengths. With multi-band imaging we probe gas and dust production in the inner coma very near the nucleus and imaged activity from jet structures. Near-IR images were obtained in and out of diagnostic spectral bands to detect both C_2 and to map water production and discriminate a discriminate between its gaseous and ice states.



7. HST/NICMOS GTO-7223 (3 Orbits; coI). ***Spectrophotometry and Imaging of Pluto and Charon.*** At the onset of this investigation detailed spectra of the individual members of the Pluto–Charon system were not known. Different surface compositions were suggested by some evidence obtained during previously mutual eclipse events. In this program, we obtained NICMOS grism spectrophotometry of Pluto–Charon, which were deblended to provide a direct comparison of the surface materials of each member of the double planet with Charon's leading (orbital direction), trailing, Pluto-facing and non-Pluto-facing hemispheres. These observations revealed striking different surface ice features on the two bodies.

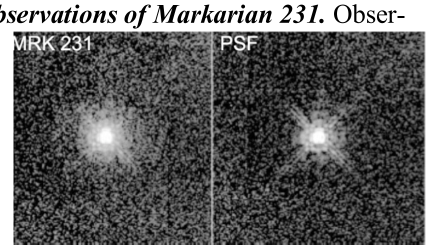


8. HST/NICMOS GTO-7242 (1 Orbit; coI). ***Astrometry and Near-Infrared Photometry of Neptune's Inner Satellites and Stability of the "Ring Arcs".*** (a) Although all four of the gas-giant planets in the Solar System have ring systems, only Neptune exhibits "ring arcs" – stable clumps of dust that are discontinuous from each other. Two basic mechanisms for confining the dust to these arcs have been proposed. The first relies on orbital resonances with two shepherding satellites, while the second invokes a single satellite (later suggested to be Galatea) to produce the observed ring arc structures. Here we report observations of the ring arcs and Galatea, that show a mismatch between the locations of the arcs and the site of Galatea's co-rotation inclined resonance. (b) With 1.87 μm photometry and astrometry of the inner satellites (Proteus, Larissa, Galatea, and Despina) and ring arcs. From comparison with the Voyager data at visible wavelengths, the small bodies orbiting within the ring region of Neptune have a near-infrared albedo consistently low, but higher than at visible wavelengths for most of the satellites. The ring arcs display a reddish spectral response similar to the satellites' in the 0.5 to1.9 μm wavelength range. Considering an earlier K-band photometry of Proteus the satellite's albedo shows a depression at 2.2 μm that could be the first spectral evidence for the presence of CH or CN bearing material on its surface.

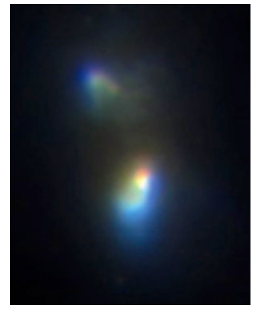


B.3. High Resolution/High Contrast Imaging/Photometry Programs

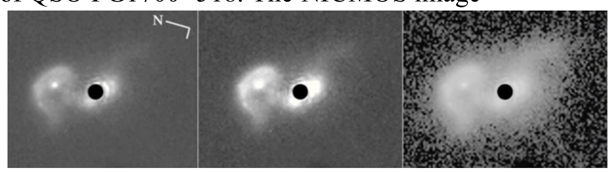
9. HST/NICMOS SMOV-7038 (3 Orbits, PI*). High Spatial Resolution Observations of Markarian 231.* Observations of the ultra-luminous galaxy Markarian 231 (z = 0.042) at 1.1 μm were obtained with HST/NICMOS. The brightness of the object in the near-infrared, and the inherent short-term stability of the NICMOS optical and instrumental system, enables the application of special observational and analysis techniques that effectively increase high spatial resolution. By these means, we set an upper limit on the size of the core of the active galactic nucleus at 8 mas, corresponding to a radial projected distance of ~ 3 pc from the center of Markarian 231.



10. HST/NICMOS GTO-7219 (& archival, co-I*). The Core and Circumnuclear Star Clusters in the Galaxy Merger NGC 6240 Observed with HST/NICMOS and Keck/AO.* We present results from near-infrared imaging of the disk-galaxy merger NGC 6240 using HST/NICMOS and adaptive optics on the Keck II telescope. Both active galactic nuclei (AGN) are clearly elongated each with considerable substructure within. We identify the southwestern point source within the northern nucleus as the position of one of the AGN. Within the southern nucleus, the northern "sub-nucleus" is more highly reddened and has strong H_2 1-0 S(1) line emission (contrary to the conclusions of previous seeing-limited observations). Narrowband H_2 emission line images show that a streamer or ribbon of excited molecular hydrogen connects the northern and southern nuclei, suggesting a bridge of gas connecting the two nuclei, as seen in computer simulations of mergers. Many point-like regions are seen around the two nuclei; we suggest young star clusters course of the merger. We examine these in detail and estimate that most of the clusters are consistent with being ~15 Myr old and mass from 7×10^5 to 4×10^7 M_{solar}. The total contribution to the star formation rate (SFR) from these clusters is approximately 10 M_{solar} yr^{-1}, ~10% of the total SFR in the nuclear region. We use these newly discovered clusters to estimate the extinction toward NGC 6240's double nuclei and find values of A_V as high as 14 mag along some sight lines, with an average extinction of A_V = 7 toward sight lines within appx. 3" of the double nuclei.



11. *HST/NICMOS GTO-7220 (25 Orbits, co-I). Imaging of Quasar Host Galaxies* — Molecular Gas and the Host Galaxy System of the z ~ 0.3 QSO PG 1700+518. New WFPC–2 direct and NICMOS coronagraphic images provide the highest resolution view yet of the host and companion of QSO PG1700+518. The NICMOS image reveals the underlying, apparently tidally disrupted structure seen previously will less clarity from high-resolution ground-based optical imaging. Light from the host galaxy is overwhelmed by the central point source in the WFPC–2 images, but the companion galaxy is well resolved in both data sets, and the WFPC–2 provides for the first time a clear picture of the visible ring structure in the optical. We speculate that we may be witnessing the fueling event in progress that resulted from a collision between the QSO host and the companion galaxy, and that there is an accompanying expulsion of material along our line of sight in the form of broad absorption line gas.



C. Other HST/GTO & General Observer Programs (collaborator/contributing co-author)

Title (see Publications by reference number for results)	ID	Pub List #
1. NICMOS Observations of the Hubble Deep Field	7235	19R, 32R
2. Imaging of Quasar Absorber Systems	7221	25R, 34R, 12P, 13P, 27P, 33M
3. Survey of Three Young Clusters	7217	28R
4. Imaging and Polarimetry of YSO's	7228	35R
5. Deep Imaging of the UDF	9803	43R
6. The Origins of Sub-stellar Masses: Searching for the "End" of the IMF	9846	49R, 77M, 88M

D. HST/NICMOS GTO Early Release Observation Programs (G. Schneider: co-I)

Title (see Publications by reference number for results)	ID	Pub List #
1. NGC 2264 IRS Evidence for Triggered Star Formation	7128	11R
2. High-Resolution Near-Infrared Imaging of the Orion 114-426 Silhouette Disk	7114 7363	12R
3. NICMOS Imaging of the Nuclei of ARP 220	7116	13R
4. Unveiling the Hidden Nucleus of IC 5063 with NICMOS	7119	14R
5. NICMOS 2 µm Continuum and H2 Images of OMC-1	7111	15R, 11M
6. The Structure of the Prototype Bipolar Protoplanetary Nebula CRL 2688	7115	16R
7. 2.12 µm Molecular Hydrogen Emission from Circumstellar Disks Embedded in the Orion Nebula	7111	17R

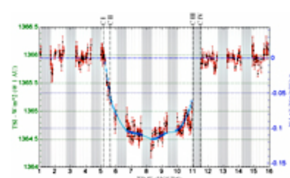
E. Other Previously Completed Studies and Research Projects:

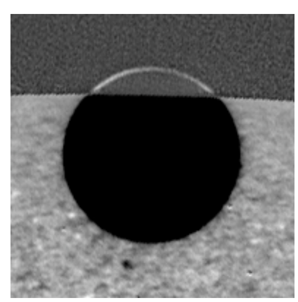
Title (see Publications by reference number for results)	Pub List #
1. Space Imaging of Cytherian and Mercurian Transits with TRACE	40R, 38P, 57M, 66M, 69M
2. Radiometric Detection of Inner Planetary Transits in Our Solar System – A Kepler Mission Analog	46R, 78M, 94M, 113M
3. Lunar Occultations & Stellar Angular Diameters (Ph. D. Dissertation, U. Florida)	3O, 8R
4. Asteroidal Photometry	1M, 3R, 4R, 7R
5. Numerical Modeling of White Dwarf Stars	2P
6. Night Time In-Situ Cloud Cover/Opacity Study at the Geographic South Pole	2M, 2O, 6R, 1P, 3M

E.1 & E.2: Space-Based Observations of Inner Solar System Planet Transits:

• ***Liaison to the Past.*** Historically, the visual manifestation of the "Black Drop effect," the appearance of a band linking the solar limb to the disk of a transiting planet near the point of internal tangency, had limited the accuracy of the determination of the Astronomical Unit and the scale of the solar system in the 18th and 19th centuries. This problem was misunderstood in the case of Venus during its rare transits due the presence of its atmosphere. In preparation for the rare opportunities later presented by the 2004 and 2012 transits of Venus, observations of the 15 Nov 1999 transit of Mercury were obtained, without the degrading effects of the Earth's atmosphere, with the Transition Region and Coronal Explorer (TRACE) spacecraft. In spite of the telescope's location beyond the Earth's atmosphere and the absence of a significant Mercurian atmosphere, a faint Black Drop effect was detected. The observed black drop was fully attributable solar photospheric limb-darkening back-lighting the Mercurian disk, and blurred by the instrumental point-spread function. These effects (and those of atmospheric turbidity) were elaborated upon in light of earlier ground-based observations of inner planet transits to explain the historical basis for the Black Drop effect. The methodologies developed for improving upon space-based transit imagery are applicable to ground-based (adaptive optics augmented) and space-based observations of the 8 June 2004 and 5-6 June 2012 transits of Venus, providing a path to achieving high-precision measurements of transit phenomenon. (Pub. List 40R, 38P, 57M, 66M, 69M)

• ***Contemporary Extra-Solar Planet Studies & Liaison to the Future.***
Coordinated space and ground-based observations of the 08 June 2004, and 05 June 2012 transits of Venus were obtained to: (a) test observing methods, strategies and techniques which were being contemplated for future space missions to detect and characterize extrasolar terrestrial planets as they transit their host stars; (b) investigate, in detail, the properties of the circum-Cytherian "aureola" (sunlight scattered by aerosols and refracted in the back-lit planetary atmosphere via the "Venus Twilight Experiment" – Pub. List 138M, 139M, 140M, 141M); (c) study the (detectability of) optical absorption by sulfur allotropes and other species by the upper atmosphere of Venus. Combining high spatial and temporal resolution broadband imaging (with TRACE), very high precision time-resolved radiometry (with ACRIMSAT), and ground-based lunar reflectance differential spectroscopy, and narrow-band imaging from a variety of telescopes, inferences for the detectability and possibilities for characterization of extra-solar planets by space-transit measurements were assessed. This study was partially funded by the National Geographic Society Committee for Research and Exploration in collaboration with Prof. Jay Pasachoff of Williams College. In addition to their continued scientific use, the resulting images and data[1] have been (and continue to be) used in education and public outreach activities.

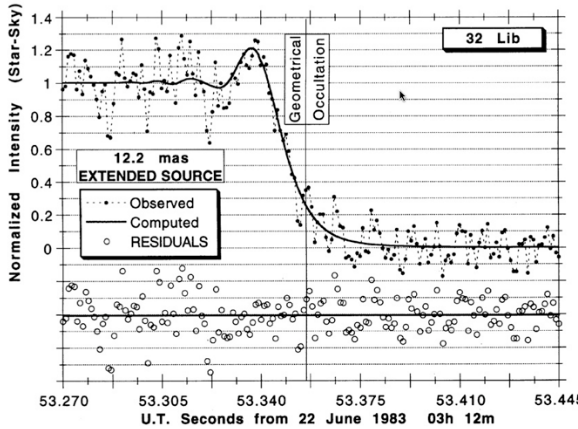




[1] See: http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/TRANSIT_04/TRACE/TOV_TRACE.html and http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/TRANSIT_04/ACRIMSAT/ACRIMSAT_TOV.html

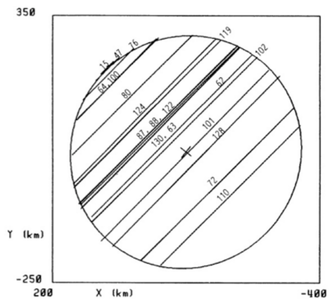
E.3 – E.6. Dissertation and Graduate Research at the University of Florida (Gainesville)

E.3. Lunar Occultations & Stellar Diameters (Dissertation Research, Department of Astronomy, U. of Florida): The observation and analysis of lunar occultations. A systematic program of fast photometric observations of lunar occultations of selected stars was carried out to measure stellar diameters, obtain better astrometric positions of stars, search for previously unsuspected stellar duplicity and provide fundamental data for the determination of time based upon corrections and checks to the lunar theory. Fast photometric data acquisition instrumentation was designed and developed to carry out a systematic study of selected stellar targets that were occulted by the moon. New numerical techniques for data reduction and analysis, including the introduction of probabilistic constraints into a non-linear least-squares differential-correction model fitting process, were investigated and implemented.

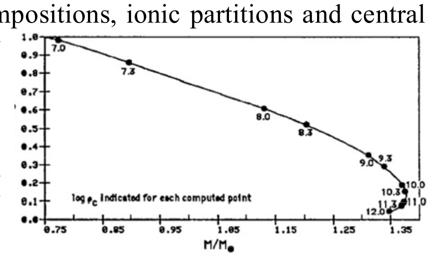


Physical parameters (including diameters) for many stars and stellar systems were successfully determined. Chairman: Dr. John P. Oliver (deceased). (Pub. List 8R, 3O)

E.4 Asteroidal Photometry: Initiated a collaborative program of multi-color asteroidal photometry and fast photometric observations of asteroidal occultations of stars to determine the size, shape and density of selected minor planets, and to search for asteroidal duplicity. Designed and constructed portable photoelectric photometers, electrometer amplifiers, time-code converters and digital data acquisition electronics for remote-site observations. Deployable field stations were used for independent observations, and in conjunction with observations made at Rosemary Hill Observatory and other fixed observatory sites. Profiles, diameters, densities, and other physical and photometric properties of many asteroids including Nemausa, Pallas, and Ceres were determined. This program was conducted under a grant from the University of Florida's Division of Sponsored Research. (Pub. List 3R, 4R, 7R).

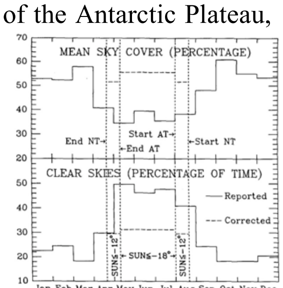


E.5. Numerical Modeling of White Dwarf Stars: Developed a computational model for investigating dynamical instabilities in the structure of white dwarf stars of varying chemical compositions, ionic partitions and central densities, applicable over a wide range of partial and total degeneracy regimes. The model included such affects as Coulomb interactions between electrons and nucleons, inverse beta decays, the effects of the general theory of relativity on the condition on hydrostatic equilibrium (local and global), stellar rotation, mass accretion in binary systems and interactions with external magnetic fields. This work was supported by a grant from Warner Computer Systems, Inc. (Pub. List 2P)



E.6. Polar Atmospheric / Climatological Research: The integrity of the synoptic meteorological record of the South Pole (SP) is important both to the continuing effort to understand the climatology of the Antarctic Plateau, and to a number of interdisciplinary studies aimed at discovering the details of the mechanism responsible for the depletion of upper atmospheric ozone. An analysis of the nighttime synoptic meteorological record from the SP station was undertaken, and a systematic error in the sky cover observations was discovered. As a result it was determined that the seasonal variations in sky cover, as inferred from these observations, are not nearly as significant as previously believed.


GS and colleagues at the SP



This project was partially supported under National Science Foundation grant DPP 86-14550. (Pub. List 6R, 3M)

F. Total Solar Eclipses (Prior and Ongoing)

Dr. Schneider is a member of the International Astronomical Union's Interdivision 2 C-E Working Group on Solar Eclipses. He is recognized as a leading expert in the high-precision numerical calculation of eclipse circumstances and the application of those computations in planning and carrying out observations of total solar eclipses. (e.g., Pub. List: 33P, 40P, 55M, 73M, 120M, 125R, 1O; Invited Talks: SEC 2004, 2007, 2011, 2014, 2018[2]).

For over four decades, Dr. Schneider has led expeditionary groups and conducted such observations on land, sea and air of thirty-five (of thirty-eight) total solar eclipses (TSEs) occurring since 7 March 1970 from remote locations across the globe conducting direct, polarimetric, and spectrophotometric imaging programs[2].

Recently, for TSE 2017 (the "Great American Eclipse"), he was deeply engaged with: (a) the international "pro/am" eclipse chasing community, providing technical and logistical eclipse-observation information through the (internet based) Solar Eclipse "Mailing List", and (b) the public at large through numerous E/PO events, activities, and information dissemination through TV, radio, print, and inter-net based media. Dr. Schneider (conducting a high-resolution coronal imaging program) organized an observing site for a group of approximately 100 other observers, cooperatively using facilities of the Oregon State University at Madras[3].

For TSE 2019, Dr. Schneider secured the use of a Boeing 787-9 aircraft to extend the duration of totality to ~ 8m 27s minutes at 41,000 ft. above the mid-Pacific Ocean[4]. Therein he deployed a near-IR imaging spectrograph to study chromospheric and coronal emission from ~ 0.7 to 1.0 μm.

He currently has planned two sunrise airborne central eclipse intercepts: ASE 2021[5] using an Airbus 319-100 aircraft over southern Canadian airspace launched from Minneapolis for Sky&Telescope/AAS, and for TSE 2021[6] using three A321-200 aircraft launched from Punta Arenas, Chile, to 39,000 ft over the Scotia Sea.

Dr. Schneider has personally executed nine, and provided planning details for many other additional, high-altitude, high-precision centerline eclipse intercepts with jet aircraft including:

Date (UTC)	Status*	Aircraft	Altitude	Duration	Location	Comments
03OCT1986	Executed	Citation II	44,000 ft	Instant-aneous	N. Atlantic	highly technically challenging navigationally critical intercept
30JUN1992	Executed	DC-10	41,000 ft	6m 15s	S. Atlantic	in situ cockpit, PAX seats removed
21JUN2001	Planned Canceled	Concorde	60,000 ft	55 min	E. Atlantic	cancelled due to grounding of the Concorde fleet after AF 4590 crash
23NOV2003	Executed	B747-400	35,000 ft	2m 30s	Antarctica	in situ cockpit instrumented
23NOV2003	Planned	A340	38,000 ft	2m 26s	Antarctica	Lan Chile 8001 executed per plan
29MAR2006	Planned	Hawker400	40,000 ft	4m14s	Turkey	weather contingency – unused
01AUG2008	Executed	A330-200	36,000 ft	2m 52s	82°N	In situ cockpit instrumented
22JULY2009	Planned	B737-400	41,000 ft	3m 28s	India	executed per plan – SPACE
11JUL2010	Executed	A319 CRJ	39,000 ft	9m 23s !	S. Pacific	in situ cockpit, PAX seats removed
03NOV2013	Executed	Cessna208B	10,800 ft	10.7s	Turkana, Kenya	backup flight – escaped sandstorm
20MAR2015	Executed	B737-800	34,000 ft	3m 39s	Norwegian Sea	+2 other A320 aircraft
08MAR2016	Planned	B737-800	35,000 ft	1m 53s	N. of Hawaii	AS: reprogrammed commercial flt.
21AUG2017	Planned	B737-900	37,000 ft	1m 43s	NE Pacific	AS: "Great American Eclipse" flight
02JUL2019	Executed	B787-9	41,000 ft	8m 27s !	S. Pacific	+3 other (A321) aircraft
10JUN2021	Planned	A319-100	39,000 ft	4m 02s	S. Canada	Near-Sunrise Annular, S&T/AAS
04DEC2021	In prep	A321-200	39,000 dt	1m45s	Scotia Sea	Near-Sunrise TSE, 3 aircraft

* Executed = Developed detailed plans and implemented in-situ in flight. Planned: Developed detailed plans for other missions.

The planning of these airborne observations is rooted in the use of the EFLIGHT S/W[7], created by Dr. Schneider, specifically to address the problem and optimization of intercepting the moon's shadow from a moving aircraft. The core algorithms were developed for the highly technically challenging 1986 eclipse intercept and were first augmented for the 1992 eclipse flight to provide greater flexibility for real-time use on the DC-10 flight deck. The S/W was

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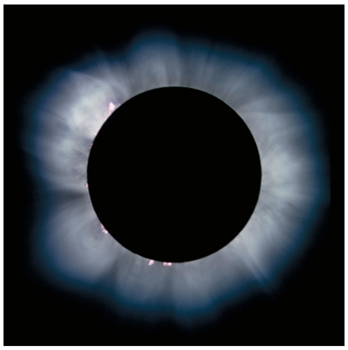
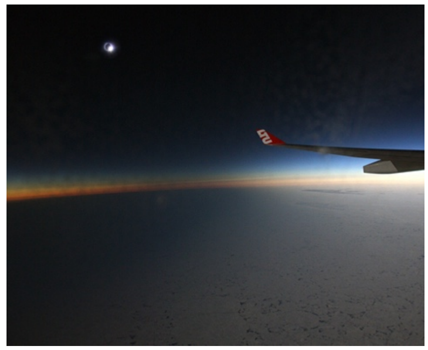
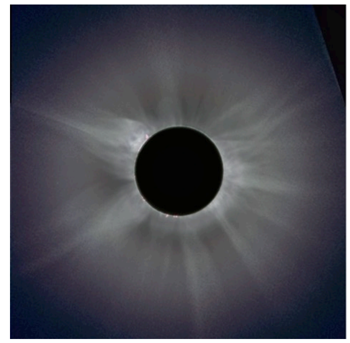
[2] See: http://nicmosis.as.arizona.edu:8000/UMBRAPHILLIA.html and links therein.
[3] http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/ECLIPSE_17/TSE2017_REPORT.html#TSE_2017_IN_THE_NEWS
[4] https://www.youtube.com/watch?v=NdojOZQ4O50
[5] https://skyandtelescope.org/astronomy-travel/2021-annular-eclipse-flight/
[6] http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/TSE2021/TSE2021WEB/EFLIGHT2021.html
[7] See: http://nicmosis.as.arizona.edu:8000/ECLIPSE_WEB/SEC2011/SEC2011_EFLIGHTSW_SCHNEIDER.pdf

modified in preparation for the 2001 Concorde eclipse flight, for consideration of an intercept in the supersonic regime where the instantaneous speed of the aircraft was greater than that of the lunar umbra given the geometrical circumstances of that eclipse.

The EFLIGHT S/W was again modified specifically for the “over the pole” approach geometry of the lunar shadow for the 23 Nov 2003 Antarctic eclipse and tailored for real-time use given the manual input requirements of the Boeing 747-400 ER flight management system, to enable an on-board imaging program in co-ordination with contemporaneous observations of the LASCO/C2 coronagraph on the SOHO spacecraft. EFLIGHT has subsequently been used to plan many solar eclipse flight missions since.







CV APPENDIX IV: Glenn Schneider – Publication List

(21 July 2021)

Refereed Journals (132)

1R. **Schneider, G.** 1982, "Fourier Transformation by Harmonic Analysis", *APL Quote Quad*, **11-2**, 19

2R. **Schneider, G.** 1982, "Inverse Fourier Transformation", *APL Quote Quad*, **11-2**, 21

3R. Dunham, E. W., Baron, R. L., Conner, S., Dunham, D. W., Dunham, J. B., **Schneider, G.**, Cohen, H. L., Helms, V. T. III, Croom, M., & Safko, J. 1984, "Results from the Occultation of 14 Piscium by (51) Nemausa", *Astronomical Journal,* **89**, 1755

4R. Millis, R. L., Wasserman, L. H., Franz, O. G., Nye, R. A., Oliver, R. C., Kreidl, T. J., Jones, S. E., Hubbard, W., Lebofsky, L., Goff, R., Marcialis, R., Sykes, M., Fecker, J., Hunten, D., Zellner, B., Reitsema, H., **Schneider, G.**, Dunham, E., Klavetter, J., Meech, K., Oswalt, T., Rayfert, J., Strothers, E., Smith, J., Povenmire, H., Jones, B., Kornbluh, D., Reed, L., Izon, K., A'Hearn, M. F., Schnurr, R., Osborn, W., Klemola, A., Rios, M., Sanchez, A., Pirronen, J., Mooney, M., Ireland, S., Parker, D., Douglas, W. T., Beish, J. D., & Leibow, D. 1987, "The Size, Shape, Density, and Albedo of Ceres from Its Occultation of BD+08 471", *Icarus*, **72**, 507

5R. **Schneider, G.** 1989, "The Jurkevich Periodogram", *APL Quote Quad*, **19-2**, 23

6R. **Schneider, G**., Paluzzi, P., & Oliver, J. P. 1989, "Systematic Error in the Synoptic Sky Cover Record of the South Pole", *Journal Of Climate*, **2**, 295

7R. Dunham, D. W., Dunham, J. B., A'Hearn, M. F., Schnurr, R., Binzel, R. P., Henry, G., Frueh, M., Evans, D. S., Bowell, E., Wasserman, L. H., Nye, R., Chapman, C. R., Dietz, R. D., Moncivais, C., Douglas, W. T., Parker, D. C., Beish, J. D., Martin, J. O., Monger, D. R., Hubbard, W. B., Reitsema, H. J., Klemola, A. R., Lee, P. D., McNamara, B., Maley, P. D., Manly, P., Markworth, N. L., Nolthenius, R., Povenmire, H., Purrington, R. D., Durham, F. E., Trenary, C., Jenevin, W., Dauns J., **Schneider, G.**, Schuster, W. J., Moreno, M. A., Guichard, J., Sanchez, G. R., Strothers, E., Taylor, G. E., & Upgren, A. 1989, "The Size and Shape of (2) Pallas from the 1983 Occultation of 1 Vulpeculae", *Publication of the Astronomical Society of the Pacific*, **99**, 1663

8R. **Schneider, G.,** & Anderson, C. 1993, "Rosemary Hill Observatory Lunar Occultation Summary for 1983-1984", *Publication of the Astronomical Society of the Pacific*, **105**, 367

9R. McCarthy, D., Stolovy, S., Kern, S., **Schneider, G.**, Ferro, A., Spinrad, H., Black, J., & Smith, B. 1999, "NICMOS/HST Post-Perihelion Images of Comet Hale-Bopp in Outburst", *Earth, Moon and Planets*, **78**, 243

10R. Thompson, R. I., Rieke, M., **Schneider, G.**, Hines, D. C., & Corbin, M. 1998, "Initial On-Orbit Performance of NICMOS", *Astrophysical Journal*, **492**, L95

11R. Thompson, R. I., Corbin, M., Young, E., **Schneider, G.**, & Rieke, M. 1998, "NGC 2264 IRS Evidence for Triggered Star Formation", *Astrophysical Journal*, **492**, L177

12R. McCaughrean, M. E., Chen, H., Bally, J., Erickson, E., Rieke M., **Schneider, G.**, Stolovy, S., Thompson, R., & Young, E. 1998, "High-Resolution Near-Infrared Imaging of the Orion 114-426 Silhouette Disk", *Astrophysical Journal*, **492**, L157

13R. Scoville, N. Z., Evans, A. S., Dinshaw, R., Thompson, R., Rieke, M., **Schneider, G.**, Low, F. J., Hines, D., Stobie, B., Becklin, E., & Epps, H. 1998, "NICMOS Imaging of the Nuclei of ARP 220", *Astrophysical Journal*, **492**, L107

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