THE GEOMETRY OF ACCRETION AND MASS LOSS ON PMS STARS THROUGH THE EPOCH OF JOVIAN-MASS PLANET FORMATION: A MULTI-WAVELENGTH STUDY

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2 Scientific, Technical and Management

2.1 Project Summary

Accretion-related and mass-loss activity are some of the most spectacular signatures of stellar youth and are tied to the magnetic field geometry of the pre-Main Sequence stars. Direct magnetic field mapping is resource intensive and is not easily extensible to large numbers of stars, or those with smaller magnetic fields. However, plasma associated with accretion can be mapped as a function of stellar latitude using photoelectric absorption data from archival X-ray observations if the system inclination and disk or remnant envelope contributions to the absorption are known. Inclination data can be derived either from HST coronagraphic imagery of the disk, or jet imagery and spectroscopy extracted from HST and Goddard Fabry-Perot data. The disk and envelope contribution to N(H) can be estimated from Monte-Carlo Radiative Transfer modeling of the IR spectral energy distribution. A pilot study using these techniques has found a peak in photoelectric absorption near 50 degrees stellar latitude (40 degrees inclination from pole-on) for both 2-2.5 $M_\odot$ Herbig Ae stars and a small sample of classical T Tauri stars. We propose extending our multi-wavelength approach to a larger and statistically significant sample of stars, including disks with developing central cavities, the transitional disks, to determine whether the pilot study results are typical, and to search for changes in the accretion geometry as a function of stellar mass, age, and disk clearing.

2.2 Problem Statement and Relevance to NASA's Strategic Goals

NASA has identified "learning how the Sun's family of planets and minor bodies originated and evolved" (sub-Goal 3C.1) and "understanding how individual stars form and how those processes ultimately affect the formation of planetary systems" (sub-Goal 3D.3) as important strategic goals for the Agency in its 2006 Strategic Plan[1]1. Both of these goals not only relate to placing our planetary system into context, but also contribute to understanding the frequency and diversity of exo-planetary systems (Goal 3D.4).

Excess light, enhanced emission features, and outflow features are some of the most flamboyant signatures of stellar youth. For young, late-type stars, material accretes onto the star from the circumstellar disk along magnetic field lines. The magnetic coupling between star and disk and the point at which it does ultimately establishes how rapidly the star rotates, and sets the Main Sequence FUV and X-ray activity level of the star. In turn the activity level has implications both for survival of terrestrial planet atmospheres and the habitability of the corresponding planetary surfaces (Engle et al. 2009; Guinan et al. 2009). Before the protoplanetary disk clears, accretion-related activity and associated FUV and X-ray flows drive chemistry in the disk, and may be important in the removal of the disk gas (Gorti & Hollenbach 2009; Bergin et al. 2007).

The detailed geometry of accretion and mass loss from the star are still uncertain for many PMS stars (Gómez de Castro 2009). In particular, the latitude range of the accretion footprint is also important in establishing, for T Tauri stars, which magnetic field components are implicated in accretion. Jets and bipolar outflows, which are believed to be magnetocentrifugally launched from either the star or the inner 1-1.5 AU of the disk (Tatulli

[1]www1.nasa.gov/pdf/142302main_2006_*NASA_Strategic_Plan.pdf*

et al. 2007) are some of the most conspicuous signatures of mass loss from the star. While jet activity is most conspicuous in young stars, it has been detected in older T Tauri and Herbig Ae stars as old as 5-7 Myr (Cox et al. 2005; Stecklum et al. 2009), but not in any of the recently identified transitional disks, even those, such as GM Aur, which still are accreting at rates $\geq 10^{-8}$ $M_{\odot}$ yr^{-1}. The lack of a correlation with accretion rate suggests that changes in the magnetic field strength or geometry may occur as the disk begins to clear. The development of central cavities, which are present in some systems t by 2 Myr, and is more common by 5 Myr, is consistent with recent age estimates for the formation of massive planets like Saturn. If we are to understand the environment of young, gas giant planets we need to know how the coupling between the disk and star change as a function of stellar mass, age, stellar rotation, and degree of central disk clearing.

2.3 Background

Over the past 3 decades the combination of X-ray emission and flaring, detection of large-scale, bipolar outflows, broad optical and UV emission lines, and measurement of kG magnetic fields on many T Tauri stars has prompted a number of authors, beginning with Uchida & Shibata (1984) to consider that the circumstellar disks associated with young stars are truncated by the stellar magnetic field near the co-rotation radius, and plasma is then funneled at free-fall velocities toward the star along magnetic field lines. The observation that optical and NIR line profiles with associated red-shifted absorption features or profile asymmetries suggestive of infalling material are observed in a large fraction of classical T Tauri spectra, and when synoptic observations are made, are routinely present (Edwards et al. 1994, 1996; Fischer et al. 2008) suggested that the field lines connect to the star at sufficiently "high" latitude that they are not routinely occulted by the circumstellar disk. Early modeling efforts used dipole field geometries, with the magnetic axis coincident with the stellar rotation axis. More recent efforts based on tomographic modeling of starspots and polarization data have considered more complex field geometries for T Tauri stars, including dipole components which are offset from the stellar rotation axis (Bouvier et al. 2007; Donati et al. 2008; Gregory et al. 2007; Strassmeier et al. 2005). The few stars with detailed modeling have suggested that it is the dipole field component that threads the disk at or near the co-rotation radius, and thus should be implicated in accretion, while the more compact field lines of the higher order multipole components may be associated with coronal activity. While extremely valuable, these tomographic studies are sufficiently time and data intensive that they are not easily extensible to large surveys of PMS stars in the near term. Moreover, while accretion-related activity is now known for both higher mass (2.5$M_{\odot}$ Herbig Ae stars; Devine et al. 2000; Wassell et al. 2006; Grady et al. 2004; Grady et al. 2009a, b) and for lower mass brown dwarfs (Mohanty et al. 2005; Whelan et al. 2009), these stars have weaker magnetic fields, typically $\sim$ a few hundred Gauss (Wade et al. 2007; Hubrig et al. 2007; 2009; Reiners et al. 2009;Alecian et al. 2008) making them less amenable to detailed tomographic studies. What is needed is an alternate set of accretion signatures which can be tracked over a wider range of central object mass, luminosity, and age to map the coupling between star and disk, accretion and mass loss.

2.3.1 An Alternate Approach Which is Extensible to A Larger Number of Stars

Fortunately, there are other accretion signatures which are detectable at other wavelengths which can be used to probe the accretion geometry. At X-ray energies, emission from the accretion shock at or near the stellar photosphere is produced by in-falling plasma with velocities sufficiently high to produce soft X-ray emission. If other infalling plasma lies between the star and the observer, it can absorb the soft X-rays through photoelectric absorption, which can be detected if a sufficiently large column of overlying material is in the line of sight. Güdel et al. (2008) interpret excess photoelectric absorption in the spectrum of DG Tau A as arising from such accretion funnels. An alternate opacity source can be provided by any wind or outflow launched from the star. Rorbrade & Schmitt (2007) note that for pole-on systems like RU Lup, where a bipolar outflow is expected to be in the line of sight, or for systems driving a massive, wide-angle wind, the absorbing column is consistent with the expected mass loss rate.

These two, distinct models have different geometrical implications: a wide angle wind would be expected to be detectable via excess absorption for any inclination where the disk doesn't obscure the star. Absorption via a collimated outflow (e.g. jet) would be expected to be preferentially observed for inclinations where the jet is in the line of sight (e.g. low inclinations from pole-on) The photoelectric absorption should also correlate with mass loss rate from the system for both mass loss geometries. In contrast, photoelectric absorption due to accretion funnels should be preferentially detected at intermediate inclinations, while a soft X-ray emission excess should be seen at inclinations where the funnel is not in the line of sight. Identifying photoelectric absorption due to these, competing mechanisms requires a suite of stars with known foreground extinction, and where the amount of circumstellar absorption can be independently estimated from knowledge both of the disk and/or any remnant infalling envelope and how we view the star (system inclination).

These data are best derived with different observation techniques and with different instruments. For example, extinction data are traditionally measured in the optical as long as the star is optically detected (Hartigan et al. 1995), but can be derived from moderate resolution NIR or high resolution mid-IR spectra covering water and CO_2 ice features and the 9.7μm silicate features when the star is not optically visible (Terada et al. 2007), as can occur for viewing geometries where the circumstellar disk occults the star. Such data are now available as a result of IRTF/SPEX and Spitzer/IRS observations. System inclination constraints can be derived from millimeter and sub-millimeter interferometry of circumstellar disks, or from direct (high inclinations i$\sim$80-90°) or coronagraphic (lower inclinations, $0 \leq i \leq 75°$) observations of disks in scattered-light such as have been produced by HST. For disks which are small or which are shadowed by material lying close to the star and thus dark in scattered-light, multi-epoch observations of jet proper motion and spectral measurements of radial velocities can yield disk inclinations, if we assume that the jet is orthogonal to the disk, and traces the stellar rotation axis. This is is true of the jets imaged in the course of HST coronagraphic imaging of the disks. High spatial resolution jet observations are available for a number of T Tauri stars from HST direct imaging, while high contrast jet data at lower spatial resolution have been routinely obtained using the Goddard Fabry-Perot at the Apache Point Observatory 3.5m telescope. The availability of IR data, such as that obtained with *Spitzer* and soon to be obtained with *Herschel* and SOFIA, in tandem with older data means that the IR SED can be fit with minimal degeneracy using the inclination data, and disk size or surface brightness data using state-of-the-art Monte Carlo Radiative Transfer Codes. In turn, such codes can predict the line-of-sight extinction due to the disk and any remnant envelope. We illustrate the power of these techniques for diagnosing the source of the soft X-ray absorption excess for the Herbig Ae star MWC 480.

2.3.2 An Intermediate-Mass Worked Example: MWC 480

The Herbig Ae star MWC 480 was the first Herbig Ae star to have its disk spatially resolved using millimeter interferometry (Mannings et al. 1997), and has subsequently been well-studied from FUV through mid-IR wavelengths. The star is variable, but lightly reddened (E(B-V)=0.02-0.09 using A3V and photometry from Beskrovnaya & Pogodin (2004)). In the FUV, the photosphere is not detected by FUSE but the accretion luminosity is visible down to 1000 Å, again indicating modest foreground selective extinction. The line-of-sight $N(H_2)$ is comparable to that of AB Aur (Roberge et al. 2001) and is insufficient to account for the N(H). A *Chandra* ACIS-S observation from 2008 April was unexpectedly faint, resulting in 130 counts in 10 ks, with a CCD resolution spectrum above 0.7 keV consistent with L_X=2x10^{29} erg/s, typical of older, accreting Herbig Ae stars (fig. 1, Grady et al. 2009b). However, the photoelectric absorption N(H)=0.57x10^{22} cm^{-2} was a factor of between 9 and 40 times more than expected based on foreground extinction, that expected through the disk based on the SED and scattered-light imagery (A_V=0.415 for i=38° Grady et al. 2009b using the SED of Sitko et al. (2008)) or the measured $N(H_2)$.

Having excluded absorption by dust or molecular gas, the remaining option is atomic gas or plasma. For MWC 480 the measured N(H) corresponds to plasma with a basal density of a few x10^{-10} cm^{-3}, consistent with detection of O III] emission in IUE SWP 53929 and with the suspected presence of Si III] emission in the lone saturated portion of the same spectrum. If associated with mass loss, the column corresponds roughly to a mass loss rate of $\sim$5x$10^{-9}M_\odot$ yr^{-1} which is plausible in terms of the FUV accretion luminosity. While MWC 480 drives a jet (Stecklum et al. 2009), at i=38° the bulk of the jet is not in the line of sight. The origin of the excess absorption can be diagnosed by comparing MWC 480 with other Herbig Ae stars, including those which also drive jets (Devine et al. 2000; Wassell et al. 2006;Grady et al. 2004). Neither HD 163296 nor HD 104237 shows a large elevation in N(H) compared to that predicted from the optical extinction data, and in particular, the effect is not seen in the case of the i=18° HD 104237, where it should be most conspicuous. This rules out a jet origin for the elevated N(H). Moreover, AB Aur,, HD 163296, and HD 104237 all have higher accretion rates than MWC 480, which should result in elevated N(H) in the wind model. This is not seen (fig. 2). Instead, when the few Herbig Ae stars with secure inclination estimates and good X-ray data (the real limiting factor here), instead of a polar concentration or no dependence on inclination as predicted by Rorbrade & Schmitt (2007), we find a peak near 40°, corresponding to accretion funnels being in the line of sight at 50° latitude.

We have extended this study to a pilot sample of classical T Tauri stars with N(H) from the XEST survey (available from Vizier) and inclinations largely derived from HST coronagraphic imagery. We confirm Gúedel et al. (2008)'s finding of elevated N(H) for DG Tau A (fig. 3), and further find a general correlation between N(H) and increasing inclination. Interestingly the local peak in N(H) is also near i=40°. The amplitude of the effect is larger for the 1-2 Myr old classical T Tauri stars compared to the older (4<t<7 Myr) Herbig Ae sample. At this time we do not know whether this reflects evolution in the gas to dust ratio in the disks, or the weaker magnetic fields typical of Herbig Ae stars relative to classical T Tauri stars. Exploring such effects will require a larger sample of stars, and extension of the inclination data to older stellar associations. In the meantime, the fact that N(H) correlates with inclination for the T Tauri stars demonstrates that the bulk of the absorption is due to the disk, and not to either remnant envelopes or foreground molecular cloud material.

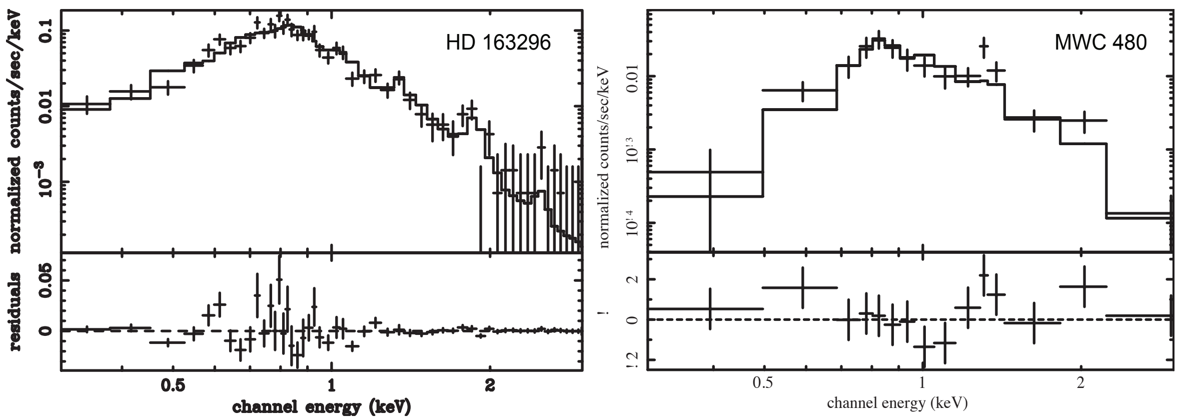
2.4 Scientific Objectives

While promising, the trend with inclination in both the Herbig Ae stars and the classical T Tauri stars is based on very small numbers of stars which may or may not be typical. While the Herbig Ae stars with good X-ray data are limited by the availability of X-ray data, the same limit does not apply to classical T Tauri stars.

- We propose extending the dataset of classical T Tauri stars with securely determined inclinations by combining inclination measures from coronagraphic imaging with inclinations derived from multi-epoch jet observations, and will compare these with interferometric measurements (where available in the literature). One byproduct of this exercise will be a direct measure of the equatorial rotation velocity for the stars which is useful for angular momentum evolution studies. This exercise will also produce disk size estimates based on the scattered light data, or the closest approach to the star of any counterjet which can in turn further constrain disk models. The inclination measures will also allow us to establish over what inclination range as a function of stellar properties that ice (water and other volatile species) and silicate absorption are found. YSO models assuming well-mixed gas and dust, and particle size distributions typical of the ISM predict that absorption features begin to be detectable for inclinations higher than 60° (Crapsi et al. 2008). Comparison of our pilot sample with silicate emission spectra from *Sptizer* (Watson et al. 2009) suggests that the onset of routine detection of silicate absorption occurs for i≥76°. Such a restriction of the absorption features to inclinations closer to edge-on provides additional evidence for grain growth and settling toward the disk midplane, complementing disk photosphere radial surface brightness profile data and SED fits (e.g. Furlan et al. 2005), but needs to be extended to a larger sample of disks.

- We will uniformly treat the X-ray data, using target acquisition data (ACA for *Chandra*, and OM for XMM-*Newton (see Audard et al. 2007 for the XEST surevey)* observations, if available with suitable filters) to estimate V at the epoch of the X-ray observations, and produce an N(H) survey for the program stars. For the optically visible stars, lacking good contemporary photometry we will make use of data from the literature, other archives (e.g. IUE FES data), and more recent photometric monitoring programs. In any case, we calculate A_V for our stars using E(B-V) data from the literature and the target acquistion data, and predict N(H) assuming a) ratios of

Fig. 1: X-ray CCD-resolution spectra of the accreting star HD 163296 (left after Günther & Schmitt (2009) together with a short, 10ks Chandra ACIS-S spectrum of MWC 480 (right). Both stars are lightly reddened, and have FUV data from FUSE. MWC 480 shows an unexpectedly large soft X-ray absorption, a factor of between 9 and 40 times that expected from the selective extinction, or the molecular hydrogen column seen by FUSE. Chandra ACA data taken immediately before the ACIS-S observation indicate that the star was at its average V level, suggesting that the absorption arises in a dust-free region.



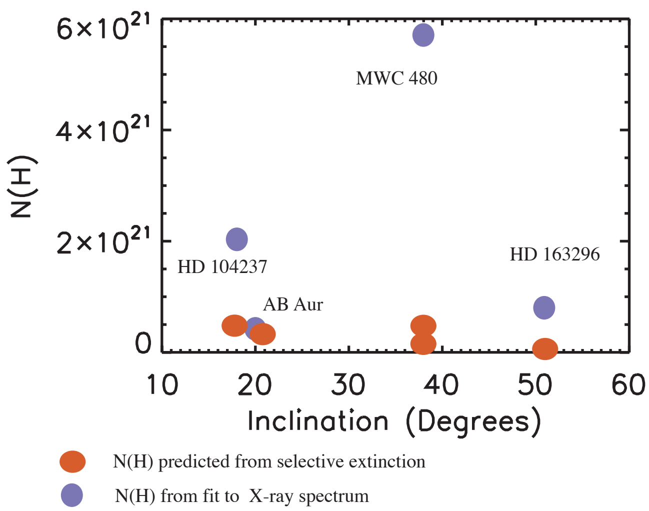


Fig. 2: When compared to other Herbig Ae stars with high-quality X-ray observations from Chandra or from XMM-Newton, with secure inclination measurements either from coronagraphy, jet data, or millimeter interferometry, N(H) for MWC 480 is elevated compared to other known jet-driving Herbig Ae stars HD 104237 (Grady et al. 2004) and HD 163296 (Devine et al. 2000; Wassell et al. 2006), and to higher mass accretion rate systems such as AB Aur. This excludes a wind or jet-based enhanced absorption as suggested by Rorbrade & Schmitt (2007).

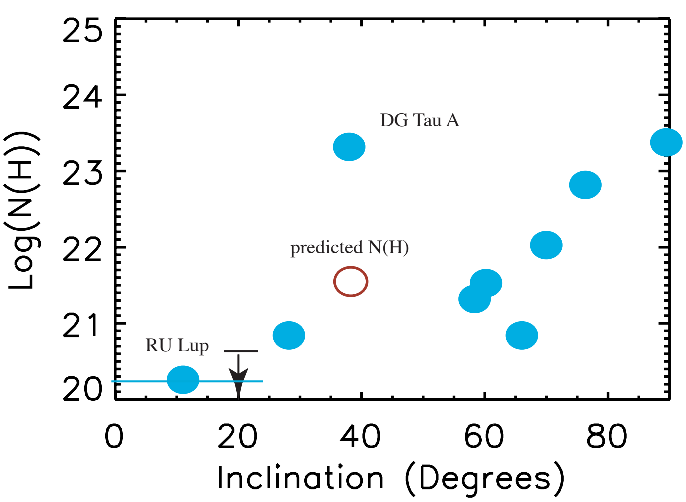


Fig. 3: A preliminary comparison of the few T Tauri stars with N(H) in the literature or on Vizier and secure disk inclination measures confirms Güdel et al. (2008)'s claim of elevated N(H) for DG Tau and further demonstrate for the stars shown here that the bulk of the N(H) is from the disk since envelope and foreground absorption would not be correlated with system inclination. A major goal of this proposal is to determine whether DG Tau A and MWC 480 are anomalies or are typical of stars in their inclination range.

total to selective extinction typical of the diffuse ISM (R=3.1) and b) under conditions more typical of molecular clouds (R=5) for all of the optically detected stars.

- For stars lacking optical detections we will use archival (or new, as needed) NIR or mid-IR spectra to estimate the equivalent A_V following Terada et al. (2007).
- Using fits to the IR SED we will estimate the circumstellar disk and any remnant envelope contribution to the extinction. This step will make use of either custom-fits to the SED using the Whitney et al. (2003, 2004a,b) Monte Carlo Radiative Transfer code or will use pre-computed libraries of models calculated with the same code (see Robitaille et al. 2007) where the model parameters are a good fit to particular targets.
- Next we will identify stars with excess N(H) for the line-of-sight extinction, and compare their distribution in inclination, stellar mass, system age, and whether or not they have independently been classified as a transitional disk. The observed excess distribution as a function of inclination will be compared with 3 models: absorption in uniform wind (no inclination dependence for sight lines with minimal disk extinction), absorption concentrated at latitudes where the line of sight to the star preferentially passes through the jet (low inclination for known jet systems), and the inclination dependence expected for accretion funnels associated with inclined dipole magnetic field components.

2.5 Technical Plan

2.5.1 Data Availability

To test the photoelectric absorption models we need a) a sample of coeval T Tauri stars which are roughly equally distributed by spectral type (F-G, K, M), and spanning the full inclination range, and b) select groups of older stars. After more than a decade of HST, jet, and X-ray observations, together with the wealth of data provided by *Spitzer*, inclination estimates are either available, or can be rather easily derived for at least 60 classical T Tauri and currently for an additional ∼10 transitional disk systems. As a result of large X-ray and IR surveys of star forming regions similar to the XMM Extended Survey of Taurus (XEST, Güdel et al. 2007) and its IR counterpart, the majority of these stars have both good X-ray data and IR data needed to constrain the SED. We therefore have the critical mass of data needed to test the models of Güdel et al. (2008) and Rorbrade & Schmitt (2007). Extension to other star-forming regions is feasible, but will depend upon the pace of new inclination determinations. However, at this time we have identified ∼60 T Tauri stars and an additional ∼10 transitional disk systems which have data from which inclination measures can be derived. ≈3/4 of these have archival X-ray data in hand which can be used to derive N(H). Since both XMM-*Newton* and *Chandra* continue to operate, we expect the X-ray archival data to continue to grow. New inclination measures are also expected, both as a result of reprocessing efforts and improvements in data reduction for HST archival data (see §2.5.4 below) and as a result of new ground-based coronagraphic surveys such as the *Subaru Strategic Exploration of Exoplanets and Disk Systems (SEEDS)*, which should begin to produce data in 2009.

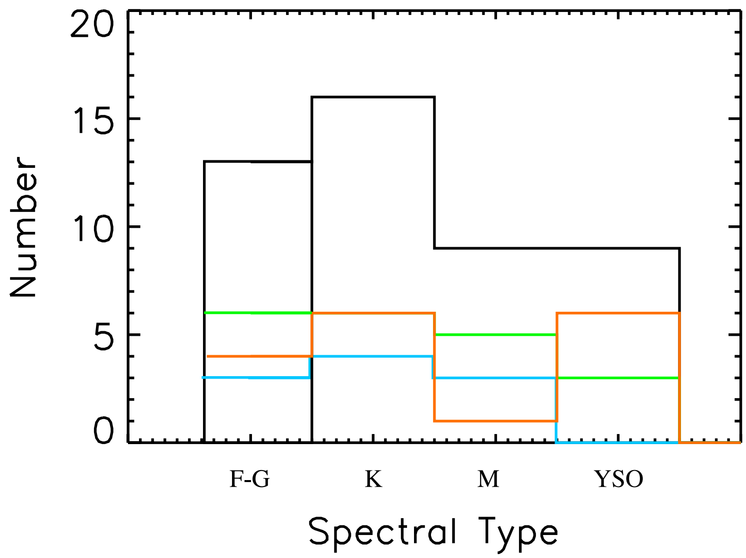


Fig. 4: Distribution of program stars with known inclinations as a function of spectral type and in inclination bins (0-30 degrees, blue, 30-60 degrees, green, 60-90 degrees, orange).

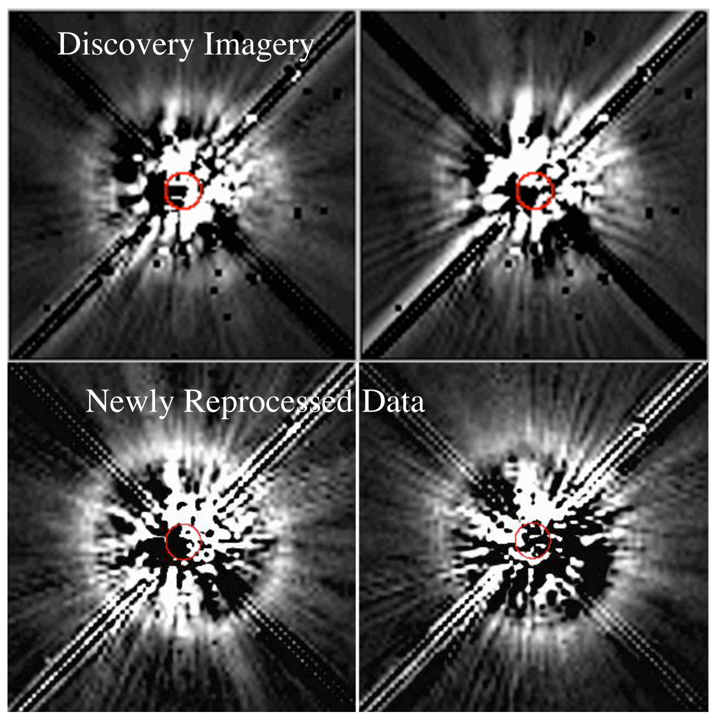


Fig. 5: Improvement in NICMOS coronagraphic data reduction using both recently and uniformly reprocessed data and color and artifact-match PSF template stars is illustrated for the mid-F debris disk HD 181327. Data for two visits with the orientation on the sky rolled by 30 degrees are shown left to right. The top row shows the discovery imagery (Schneider et al. 2006), while the lower roll shows the reprocessed data. With improvements in data handling, an order of magnitude improvment in sensitivity is realized, a level of improvement historically realized for HST with the installation of new instrumentation. The ring now clearlyhas a crisp inner edge and steep radial surface brightness drop off to larger radii. The NICMOS 0.3" radius coronagraphic obscuration is indicated by the red circle in each frame.

Table 1: Available Data

CTT Stars	with Existing Inclination Measurements	46
HAe Stars	with Existing Inclination Measurements	15
Transitional Disks	with Existing Inclination Measurements	~10
Stars with Data	for which Inclinations can be Determined	70
CTT Stars	with Inclinations Needing X-ray Data	10
HAe Stars	with Inclinations Needing X-ray Data	5
CTT Stars	with X-ray Data needing inclinations	10
Transitional Disks	Needing higher S/N X-ray Data	

At present, there are at least 46 T Tauri stars with inclination data, primarily from Tau-Aur and ρ Oph. The distribution of these stars by spectral type is shown in fig. 4. The roughly equal distribution in 4 bins (F-G, K, M, and YSO) means that we can begin to look for systematic differences as a function of stellar mass in roughly co-eval populations, and can compare the behavior with the Herbig Ae stars. Coarser spectral type binning is now feasible to explore systematic differences with inclination, or mass loss rate, and will become more statistically significant as the sample with measured inclinations grows.

2.5.2 Need for New Observations

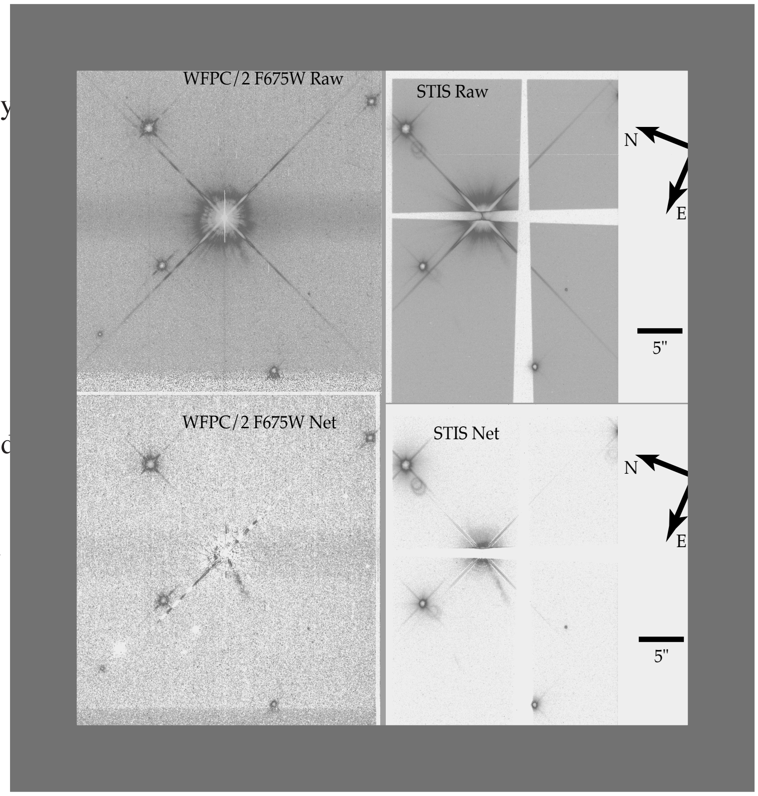
Not all of the current set of targets have X-ray data, inclination measures, or optical/NIR measures of extinction. We will therefore propose new X-ray observations (XMM observation analysis will be costed to this effort), as well as second-epoch jet observations using the Goddard Fabry-Perot at Apache Point Observatory. For stars lacking good photometric coverage we will seek additional optical/NIR photometry to be able to place the X-ray data in context. We will also propose for additional 1-5μm moderate resolution spectral observations (e.g. IRTF/SpeX) extend the spectral coverage provided by *Sptizer* IRS data to include ice features. SpeX data can be obtained with remote observing, minimizing travel costs.

2.5.3 X-ray Data Analysis

We are requesting funding for analysis of the X-ray data not included in the XEST release, using the same models to produce a homogeneous catalog of N(H) data for both the archival data and any new XMM observations that either become available during the study period, or which we obtain as the result of dedicated proposals. XMM-*Newton* data reduction will follow Güdel et al. (2007), while *Chandra* data reduction will make use of the current version of CIAO and use standard analysis threads. Spectral modeling will be carried out using the XSPEC package (Arnaud 1996) using *vapec* and the photoelectric absorption model *wabs* which uses absorption cross-sections by Morrison & McCammon (1983) to ensure uniform handling and minimize the need for re-reduction of the XEST sources.

Both XMM-*Newton* and *Chandra* have on-board optical monitoring capabilites. For *Chandra* the Aspect Camera Assembly photometry for the science target, either acquired during the X-ray observation, or immediately prior as part of target acquisition verification

Fig. 5: Example of Jet Detections in HST raw and PSF-subtracted data. The jet of DL Tau is marginally detectedin a WFPC2 direct image (upper left), and is clearer in STIS raw coronagraphic imagery (upper right). Thejet visibility is improved by PSF subtraction for both instruments (lower panel), while side-by-side comparison of the data reveals the jet proper motion. The counterjet is detected in the STIS data and can be followed at larger distance from the star in GFP imagery (fig. 6). The jet data for DL Tau, independent of the disk detection by STIS is sufficient to constrain the inclination of this system to 38 degrees.



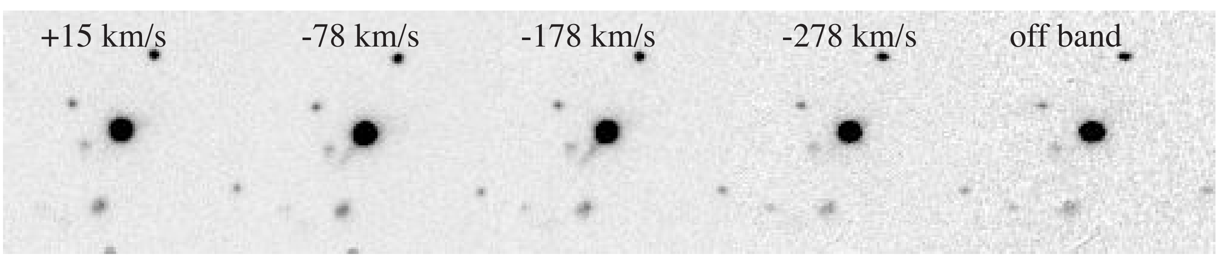
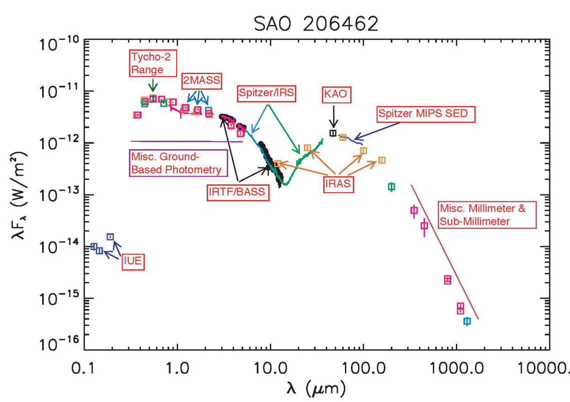


Fig. 6: Velocity data for jets can be obtained either from conventional long-slit spectroscopy or velocity scans with GFP., here shown for DL Tau in [S II].

Fig. 7: Assembly of an IR SED typically requires combining data from several different NASA or ESA missions with ground-based observations at different wavelengths. Shown is an example for the Herbig F star SAO 206462 (Grady et al. 2009) with the data sources indicated. For SED assembly we anticipate literature searches, archival data analysis (Spitzer, possibly ISO) in tandem with use of new observations (IRTF/SpeX) and possibly Herschel data as available.



will be used in tandem with B-V data in the literature or from SIMBAD to estimate the V magnitude at the epoch of the X-ray observation. XMM-*Newton* has an Optical Monitor (OM) with user-specified filters. Where appropriate, we will make use of these data, and will also explore the availability of target acquisition data to derive V. Where these are not availabie, we will make use of data from the literature, going back, where feasible to the photometry rather than relying on tablulated A_V data of uncertain pedigree. For some targets, we can use IUE FES magnitudes, again converted to V, or Hipparcos data to establish a representative range of V to place the light level at the epoch of the X-ray observations into context. Some of the transitional disks are the subject of current photometric monitoring programs, which will be available to us at no cost to this effort.

2.5.4 Reanalysis of HST Coronagraphic Data

The start of this project will coincide with the first data delivery to the MAST of uniformly reprocessed NICMOS coronagraphic data (higher photometric accuracy and cosmetic efficiacy than is now in the archive) from the HST Legacy Archive program Legacy Archive PSF Library and Circumstellar Environments Investigation (LAPLACE HST- AR-11279). That program will create a high-quality and systematically re-processed PSF Library (with pedigree, photometry, astrometry and other information), and will reprocess all NICMOS coronagraphic data through cycle 15 (mid-2008) at the visit and visit-combined level to enable archival research programs using all previously approved NICMOS GO/CAL/engineering programs. Using both the reprocessed data, and coronagraphic observations of PSF template stars which are matched in the presence (or absence) of NICMOS artifacts, have similar HST focus properties, have the cold mask at similar locations in the imagery, and where the target star and template differ in J-H or H-K by $\leq$0.2 results in an order of magnitude improvement in the straylight background (fig. 5) at r$\leq$1.7". This is comparable to the improvement historically achieved for HST by the installation of a new coronagraph, and based on our experience with coronagraphic imagery, may result in a doubling of the scattered-light disk detections from the current archival pool (e.g. Grady et al. 2007, Grady et al. 2009a). The timeline for the LAPLACE reprocessing effort is compatible with our needs, since some data will be in the archive in the summer of 2009, while the bulk of the reprocessing is expected to be completed by mid-2010, only 6 months into our proposed study. We will explore a reanalysis of the ACS and STIS coronagraphic imagery, but fewer candidate PSFs are available for these instruments, which may limit our ability to make new disk detections.

As part of this effort we will also explore the suitability of the Locally Optimized Combination of Images (LOCI) algorithm (Lafreniére et al. 2009) used to detect planets in HR 8799, for the disk non-detections. We will use LOCI to identify the closest point sources near our PMS stars, and where multi-epoch HST imagery is available determine whether they are co-moving with the target or are background objects. An abrupt drop in the local density of background objects in the vicinity of the target can then be used to place upper limits on the size of the disk, for use in the SED modeling. Any wide, co-moving objects that result from this effort will be analyzed separately.

2.5.5 Analysis of HST Jet Observations

Multi-epoch jet observations can be used to constrain the disk inclination, with the simple assumption that jets launch orthogonal to the circumstellar disk, which can be tested from the disk detections in our sample. Bipolar jet detections, and in particular, the counter-jet can be used to place a firm upper bound on the size of the disk along the disk semi-minor axis. HST has observed a number of T Tauri stars as part of jet studies, and while the jets have been studied in detail, the data have typically not been PSF subtracted and analyzed for the disk properties. The analysis of the direct imagery includes subtraction of a suitably matched, registered, and scaled PSF template observation in a bandpass (F606W or F675W for WFPC2) which contains strong jet emission lines (fig. 6). The principal use of the HST jet imagery will be to establish jet proper motion. We will augment these data with HST spectroscopy and/or spectral imagery.

2.5.6 Goddard Fabry-Perot Narrow-band Imaging of Jets

The Goddard Fabry-Perot interferometer, based at the Apache Point Observatory 3.5m telescope combines a larger field of view (3.7' in diameter) with the ability image with a variety of filters ranging from broad-band (UBVRI), medium-band blocking filters (FWHM 115 Å) and Fabry-Perot etalons with resolutions ranging from 15 Ådown to 3.25 Åwith and without a coronagraph in the line of sight. This instrument can achieve emission-line contrast gains relative to HST high contrast imagery of anywhere between a factor of 600 to 3000, enabling detection of any jets which are extended more than a few arcseconds from their star. As part of ongoing observations begun to support the HST coronagraphic imaging programs, we have data for some of the program T Tauri stars at 1 or more epochs, and the capability to obtain current epoch data for jets with only literature data, or which are newly identified from the analysis of the archival HST data. Due to the lower spatial resolution of the GFP (natural-seeing imagery) compared to HST, second epoch imagery needed to measure proper motions of knots in microjets or more discrete HH-knots typically needs to follow (ground-based) discovery imagery by 5-10 years. For this study we will make use of our existing archive, with new observations planned only for 2nd epoch imagery (fig. 7).

2.5.7 Spectral Energy Distribution Assembly

The spectral energy distributions of the target objects will be assembled from a wide variety of sources. These will include, but are not limited to: ultraviolet spectra form the International Ultraviolet Explorer (IUE), low-resolution PHT-40 spectrophotometry form the Infrared Space Observatory (ISO), infrared spectroscopy from the Infrared Spectrograph (IRS) of the Spitzer Space Telescope (SST), broad-band infrared photometry from the InfraRed Astronomical Satellite (IRAS), 2MASS photometry, available ground-based optical and infrared photometry , and any available submillimeter and millimeter observations, including data from *Herschel* and/or SOFIA as they become available. An example of an SED assembled for the pre-transitional disk system SAO 206462 (Grady et al. 2009a) is shown in Fig. 7. Because these systems are variable, a proper appraisal of the material to be used in this study will be required. For the purposes of simply illustrating the actual range of flux densities exhibited by the stars and their disk emission, multiple epochs of data will be shown. However, the SED material to be included in the modeling will have to be selected carefully, especially as they will (except on rare occasions) rarely be nearly simultaneous.

2.5.8 Monte-Carlo Radiative Transfer Modeling of Disks

Fitting of the IR spectral energy distribution in tandem with constraints on disk size and inclination provides powerful insight into disk structure, predicted color, and the degree of grain growth and settling toward the disk mid-plane (Grady et al. 2007; 2009a). A number of Monte-Carlo Radiative transfer codes are in use in the astronomical community. Two approaches toward this modeling are in use: a) computation of a suite of generic models at a number of different inclinations (Robitaille et al. 2007), and b) custom computation of models when there are no suitable library models available. The former approach works best when there is at least a reasonable match between the disk parameters and the library models, and may work best for the youngest members of our sample. Our experience with older disks, where significant settling has occurred, is that custom computation of models works best (Grady et al. 2007; 2009a). To ensure that we can exploit the pre-computed models, we propose using the Whitney et al. (2003a,b, 2004) MCRT code used by Robitaille and by co-I Sitko in our previous studies. This process, however, is resource intensive and will be carried out only for those disks where we need to unambiguously separate the disk and/or envelope contribution to the line-of-sight extinction from foreground material.

2.5.9 Follow-On Science Enabled By This Effort

A large, homogeneously processed multi-wavelength dataset of the kind we propose to work with will enable many other science investigations. First, knowledge of the system inclination plus v *sin* i data will allow us to know which sample members are rapid rotators, and to track the angular momentum evolution of stars from the age of Tau-Aur through to the epoch of the debris disks. This effort will form the PhD thesis of Thompson LeBlanc (Vanderbilt U.) who is supported by a NASA Graduate Student Research Program fellowship beginning in September 09 at no cost to this effort. We anticipate that he will expand the modeling effort led by co-I Sitko to a larger sample of our program stars, complementing our proposed work.

As part of the SED assembly effort we will be acquiring IRTF/SpeX and BASS data covering 0.8-13μm which can be used to search for the onset of detectable ice (water and other species) and silicate absorption as a function of system inclination, disk size and local stellar environment, following Terada et al. (2007).

Further, the majority of our program stars are planned *Herschel* or SEEDS targets. The inclination data we assemble in this effort will faciliate interpretation of the *Herschel* gas data, any follow-on SOFIA observations (such as an HD survey). The NICMOS scattered-light imagery, especially at 1.1μm will complement the SEEDS H-band data and expand the suite of disks for which disk color data are available, which ultimately will feed in to constraining the time and/or UV radiation dose required to redden the outer disk, and to other disk chemistry studies.

2.6 Why an ADA proposal and Why Now?

All of the component datasets, analysis techniques, and modeling tools needed for this study are currently available, enabling us to carry out the goals of our study. However, a good analysis effort should make predictions which can be tested with follow-on observations. Exploiting this predictive power requires that the study results are available while we continue to have access to the X-ray, and high-contrast imaging from space. Both *Chandra* and XMM continue to operate. After SM4, at least some of HSTs coronagraphs are expected to be operational, while ground-based high contrast imaging surveys are beginning on 8-10m telescopes, and will produce a large volume of disk inclinations during our study period. Thus the time is right, not only to carry out a large-scale data mining effort of the kind proposed here, but to obtain the follow-on observations.

This study will also provide constraints needed to model data from new missions. Many of our program stars are targets on *Herschel* Open Time Key Projects, while other stars are natural targets for detailed study by SOFIA and ALMA. A uniform X-ray library for many of these stars is essential for chemical modeling of the disks, while the geometrical insight this study can provide in terms of what portions of the disk are routinely illuminated as a function of wavelength is needed not only to account for the diversity in disk imagery, but also to understand typical conditions in disks both prior to the formation of Jovian-mass planets, during their formation, and during the period of central disk clearing. Such insight is critical in optimizing the scientific return from the remainder of the HST and *Chandra* missions, and also for planning for JWST. This is an intrinsically multi-wavelength project which goes well beyond the scope of studies traditionally funded through archival studies associated with NASA's Great Observatories, but which has the potential to provide powerful insight into the data obtained with *Chandra*, HST, or with *Spitzer*, and with new facilities such as SOFIA or *Herschel*. As a result, we are requesting support through the Astrophysics Data Analysis opportunity.

2.7 Work Plan

2.7.1 The Team

Our team members have collaborated previously, and have extensive experience both in the analysis of the individual components of our study, and also in multi-wavelength studies of particular objects. Grady as PI will provide overall project management, is responsible for getting things written up, and will take the lead with the re-analysis of the HST direct imagery, but will also be actively involved in the coronagraphic analysis, the analysis of any new Goddard Fabry-Perot data, and the X-ray data. Hamaguchi, is an experienced X-ray astronomer and will lead the X-ray reanalysys. Schneider is expert in coronagraphic data analysis, and is PI of the LAPLACE NICMOS data reprocessing effort: he will lead the coronagraphic data analysis. Woodgate is PI of the Goddard Fabry-Perot, and will lead the acquisition of 2nd epoch jet data. Sitko is not only expert in IR observing, but has been actively involved in study of transitional disks which are variable in the near to mid-IR. He will lead the SED assembly and the WMCRT modeling of the disks.

2.7.2 Schedule

We will begin our work in this area prior to the start of funding for this studyl by focussing on the stars with known inclinations and literature N(H), as shown in fig. 3, under Woodgate's current APRA funding. Having identified stars which are missing X-ray data, but which have secure inclination measures (e.g. DL Tau), we will propose for XMM-*Newton* observations at the first available opportunity, and then follow with the other stars needing X-ray data with *Chandra* and/or XMM-*Newton*. We will also begin to acquire the 2nd epoch jet data with GFP in the late 2009, under our existing GFP APRA funding, at no cost to this effort. We will propose for IRTF/SpeX observations beginning in mid-2009.

Year 1: FY10: In this year we will begin the re-analysis effort, starting with stars which have all of the suitable archival data, but which are missing either measured N(H) or inclination data. SED Assembly and modeling will begin for systems like DG Tau A which show elevated N(H) (fig. 3). Re-analysis of the NICMOS data will be coordinated with LAPLACE data deliveries to MAST. If we are successful in acquiring X-ray data for stars with good inclinations in the 30-50° range, we will be able to establish whether DG Tau A and MWC 480 are representative, and to test the model predictions of Güdel et al. 2008 and Rorbrade & Schmitt (2007).

Year 2: FY 11: We will continue the effort begun in FY10, folding in stars with new X-ray or inclination data as they become available, and will continue to acquire the 2nd epoch jet data with GFP. We expect that the bulk of the NICMOS data reanalysis will be complete during this year.

Year 3: FY12: By FY12 we anticipate that surveys like SEEDS will have produced a large sample of inclination data which can be directly combined with the N(H) measures from the X-ray data. The focus for the NICMOS work will shift to establishing whether features of interest in the SEEDs data can be recovered in the earlier NICMOS observations. We will continue to fill in gaps in our data coverage. and will start our analysis of the full sample.

Year 4: FY 13 In the final year of the project we will focus on trends in N(H) as a function of inclination, age, stellar properties and the degree of central clearing of the disk. In this year we will explore whether there is a change in the star-disk coupling for the transitional disks compared to the jet-driving systems and whether this change follows or is contemporary with the earliest indication of Jovian-mass planets resident in the disks (as determined from other large surveys such as SEEDS).

Dissemination Plans: We plan a phased publication effort with at least one paper exploring the origin of the elevated N(H), one focussing on differences and similarities in behavior of accretion activity as a function of spectral type in a coeval population, and then an evolutionary study including the transitional disks. We plan to make the N(H) data available via Vizier. Many of our targets are in common with the *Herschel* Open Time Key Project GASPS (Grady is a co-I). GASPS has planned a VO-compliant archive both of the *Hershel* data and ancillary data. We will make our full dataset available via this portal.

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4 Biographical Sketches

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    - Eureka Scientific (3/96-6/98) on NASA LTSA funding, J. Vallerga, supervisor
    - Applied Research Corporation (93-96) NASA LTSA funding, R. Harms, supervisor
    - The Catholic University of America (11/89-93) F. Bruhweiler, supervisor
    - Computer Sciences Corporation, (9/84-11/89) IUE Observatory, N. Oliversen, supervisor; 12/82-9/84 Space Telescope Science Institute, A. Holm, supervisor
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- **Graduate Students Supervised**: Grady has supervised students at the Masters level (U. Louisville 2008), and the PhD. Level (Catholic University of America 2008).

- **Service to the Astronomical Community**: FUSE Observer's Advisory Committee 2006-2008, Subaru Observing Time Peer Review 2008-2009. NSF and NASA Reviews

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- **Team Member:** member *Herschel Open Time Key Project "Gas in Protoplanetary Systems"* awarded 400 hours of telescope time, member *Subaru Strategic Exploration of Exoplanets and Disks (SEEDS)* awarded 120 nights of Subaru 8.3m time

- **Professional Societies:** AAS, IAU, ΦΒΚ

- **Recent Invited Reviews:**
    - Grady, C.A. 2009, "Planetary System Formation and Evolution: The FUSE Legacy and Future FUV Potential", in *Future Directions in Ultraviolet Spectroscopy* AIP Conference

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- **Recent Applicable Refereed Publications:**
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Most Relevant Publications

1. "Variability of Disk Emission in Pre-Main Sequence and Related Stars. I. HD 31648 and HD 163296 - Isolated Herbig Ae Stars Driving Herbig-Haro Flows", **M.L. Sitko**, W.J. Carpenter, R.L. Kimes, J.L. Wilde, D.K. Lynch, R.W. Russell, R.J. Rudy, S.M. Mazuk, and C.C. Venturini, R.C. Puetter, C.A. Grady, E.F. Polomski, J.P. Wisnewski, S.M. Brafford, H. B. Hammel, R.B. Perry, ApJ, 678, 1070-1087 (2008).
2. "The Disk and Environment of a Young Vega Analog: HD 169142", C.A. Grady, G. Schneider, K. Hamaguchi, **M.L. Sitko**, W.J. Carpenter, D. Hines, K.A. Collins, G.M. Williger, B.E. Woodgate, Th. Henning, F Ménard, D. Wilner, R. Petre, P. Palunas, A. Quirrenbach, J.A. Nuth, III, M.D. Silverstone, and J.S. Kim. ApJ 665, 1391 (2007).
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Circumstellar disks, extrasolar planets, coronagraphy, high contrast and high spatial resolution imaging, infrared astronomy, space instrumentation, spacecraft/mission/science operations, photometry, polarimetry, astrometry

Employment:

Steward Observatory, Univ. of Arizona: Astronomer (2007-present), Associate Astronomer (2003-2007)
NICMOS Project Instrument Scientist (1994-2004)

CSC at Space Telescope Science Institute, Operations Astronomer & Staff Scientist (1985-1994)

Selected Current/Recent Scientific Investigations (Principal Investigator):

HST/AR 11279:	"A Legacy Archive PSF Library and Circumstellar Environments Investigation"
HST/GO 10852:	"Coronagraphic Polarimetry with NICMOS: Dust Grain Evolution in T Tauri Stars"
HST/GO 10538:	"Near-IR Spectrophotometry of 2M1207B"
HST/GO 10177:	"A NICMOS Coronagraphic Survey of Protoplanetary and Debris Disks"
HST/AR 8370/5811:	"A Search for Stellar Duplicity and Variability in HST Guide Stars"
JPL/SSC 229:	"Spitzer Observations of a Newly Discovered Nearly Edge-On Disk HD 32297"
JPL/DRDF:	"High Spatial Resolution Imaging Polarimetry with TPF"

Selected Professional Honors/Awards:

ASP Maria and Eric Muhlmann Award (NICMOS IDT)
NASA/GSFC Science Leadership Group
STScI Individual Achievement Award
NASA Public Service, Achievement, & Project Awards

Professional Society Affiliations:

International Astronomical Union, American Astronomical Society, American Association for the Advancement of Science, Society of Photo-Optical Instrumentation Engineers

Recent 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: Astrophysical Journal, Astronomical Journal, Pub. Astr. Soc. Pacific
IAU Division 2 WGSE (working group member)

Recent Selected Publications: (additional: see http://nicmosis.as.arizona.edu:8000/Publications.html)

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

Schneider, G., et al., 2006, "Discovery of an 86 AU Radius Debris Ring around HD 181327", *ApJ*, 650, 414

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

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

Dr. Bruce E. Woodgate

Position: Senior Astrophysicist, Astrophysical Sciences Division, NASA/GSFC

Education: 1961 - B.S. in Physics, University College, London.
1965 - Ph.D. in Astronomy, University College, London.

Professional specialties:

Formation of planetary systems, high redshift galaxies and clusters, dark energy, supernova remnants, solar and stellar flares, UV, visible and IR instrument development.

<u>Previous positions</u>:

1974 - 1974	Goddard Institute for Space Studies, Senior Scientific Systems Analyst
1971 - 1974	Columbia Astrophysics Laboratory, Columbia University, Associate Director
1965 - 1971	Mullard Space Science Laboratory, University College, London, Research Associate

Project responsibilities:

Principal Investigator, HST/Space Telescope Imaging Spectrograph
GSFC lead for Joint Dark Energy Mission/ SuperNova Acceleration Probe

Awards:

1985 NASA Exceptional Scientific Achievement Medal – for Solar Maximum Mission
1997 Inducted into Space Technology Hall of Fame
1998 NASA Exceptional Scientific Achievement Medal – for HST/STIS
1999 GSFC Award of Merit

Publications: 176 publications, including:

1. Lowenthal, J. D., Hogan, C. J., Green, R. F., Caulet, A., Woodgate, B. E., Brown, L. and Foltz, C. B. 1991, "Discovery of a Lyman-α galaxy near a damped Lyman-α absorber at z =2.3" Ap.J. Lett., 377, L73.
2. Woodgate, B. E. et al., 1998, "The STIS Instrument Design", PASP, 110,1183.
3. Woodgate, B. E. and Blades, J. C., (2003), "Ultraviolet and Visible detectors", ASP Conference Series, Vol 291, 271.
4. Palunas, P, Teplitz, H.I., Francis, P.J., Williger, G.M., Woodgate, B.E., 2004, "The distribution of Lyman-α emitting galaxies at z=2.3", Ap.J., 602, 545.
5. Francis, Paul J.; Palunas, Povilas; Teplitz, Harry I.; Williger, Gerard M.; Woodgate, Bruce E., 2004 "The Distribution of Lyman alpha-emitting Galaxies at z=2.38. II. Spectroscopy", ApJ, 614, 75.
6. Woodgate, B., Mentzell, E., Hilton, G. and Lindler, D., 2005, "An Integral Field Spectrograph design concept for the Terrestrial Planet Finder Coronagraph", Durham conference proceedings, eds Allington-Smith, J., and Robinson, New Astronomy
7. Colbert, J. W. Teplitz, H. Francis, P. Palunas, P. Williger, G. M. Woodgate, B., 2008, "Mystery of the Lyman Alpha Blobs", Astronomical Society of the Pacific, 2008., p.468.
8. Bonfield, David G., Woodgate, Bruce E., Grady, Carol A., Hilton, George M., White, Larry A., McCleary, Jacqueline E., 2008, "GFP-IFS: a coronagraphic integral field spectrograph for the APO 3.5-meter telescope", Proc. SPIE, Vol 7014, W-11.
9. Grady, C. A. et al., 2009 "The Disk and Environment of a Young Altair Analog: SAO 206462" AIP Conf. Proc. Vol 1094, 385-388.

CURRENT AND PENDING SUPPORT

PRINCIPAL INVESTIGATOR	Person-mos./yr or % of Effort Committed to the Project		
MICHAEL SITKO	ACAD.	SUMM.	CAL.
Current Support			
1. Agency: JPL - Subcontract 1287505 (PI) Title: IR Spectroscopy of Comet 73P Total Funding: $42,399 Period Covered: 8/7/2006 – 9/1/2009 Co-I.'s: B. Whitney, M. Wolff Location: Space Science Institute			2%
2. Agency: Space Telescope Science Institute Grant No. HST-GO-10864.02-A (PI) Title: Mapping the Gaseous Content of Protoplanetary and Young Planetary Systems with ACS Total Funding: $14,999 Period Covered: 5/1/2007 – 4/30/2010 Location: Space Science Institute			2%
3. Agency: NASA Astrophysics Data System (Co-I) Title: Environments and Evolution of Young Stars and Planetary Systems Total Funding: $75,000 (subcontract to larger grant of PI) Period Covered: 3/1/2006 - 2/28/2010 Co-I.'s: C. Grady (PI) Location: University of Cincinnati		0.25 mo.	
4. Agency: NASA Astrophysics Data Analysis (PI) Title: The Structure and Chemistry of Planet-Building Disks Total Funding: $335,696 ($102,586 to Co-Is) Period Covered: 1/1/2009 – 12/31/2012 Co-I.'s: C. Grady, G. Schneider Location: University of Cincinnati		1.0 mo.	
Pending Support			
2. Agency: NASA Astrophysics Data Analysis (Co-I) - **THIS PROPOSAL** Title: The Geometry of Accretion and Mass Loss on PMS Stars Through the Epoch of Jovian-Mass Planet Formation Total Funding: $117,636 Period Covered: 1/1/2010 – 12/31/2013 Co-I.'s: C. Grady (PI) Location: Space Science Institute			8%

Glenn Schneider (University of Arizona)

Current and Pending Research Grants and Proposals (Title, Funding Period, Amount)

Programs continuing/completed and pending by most recent start date

#	CURRENT - Title	Funding Period	Amount	Status
1	A Paschen-alpha Study of Massive Stars and the ISM in the Galactic Center (*HST* GO 11120)	05/01/2008 04/30/2010	$19,105	Cont.
2	A Legacy Archive PSF Library and Circumstellar Environments Investigation (*HST* AR 11279)	09/01/2007 08/31/2009 [a]	$161,436	Cont.
3	NICMOS Imaging Survey of Dusty Debris Around Nearby Stars Across the Stellar Mass Spectrum (*HST* GO 11157)	09/01/2007 08/31/2009 [a]	$147,624	Cont.
4	Dust Grain Evolution in Herbig Ae Stars: NICMOS Coronagraphy and Polarimetry (*HST* GO 11155)	09/01/2007 08/31/2009 [a]	$87,354	Cont.
5	Mapping the Gaseous Component of Protoplanetary and Young Planetary Systems with ACS (*HST* GO 10846)	05/01/2007 04/30/2010	$47,346	Cont.
6	Coronagraphic Polarimetry with NICMOS: Dust Grain Evolution in T Tauri Stars (*HST* GO 10852)	09/01/2006 08/31/2009 [a]	$55,775	Cont.
7	Imaging Scattered Light from Debris Disks Discovered by the Spitzer Space Telescope Around 21 Sun-Like Stars (*HST* GO 10849)	09/01/2006 08/31/2009 [a]	$220,222	Cont.
8	Coronagraphic Polarimetry of *HST* Resolved Debris Disks (*HST* GO 10847)	09/01/2006 08/31/2009 [a]	$86,826	Cont.
9	The NICMOS Polarimetric Calibration (*HST* GO 10839)	09/01/2006 08/31/2009	$55,453	Comp.
10	Near-IR Spectrophotometry of 2MASSWJ-1207334-393254B: An Extrasolar Planetary Mass Companion to a Young Brown Dwarf (*HST* GO 10538)	05/01/2006 06/30/2009	$136,989	Cont.
11	Solar Systems in Formation: A NICMOS Coronagraphic Survey of Protoplanetary and Debris Disks (*HST* GO 10177)	07/01/2004 06/30/2009	$347,450	Comp.
#	PENDING - Title			
12	A STIS NUV Search for Shocked-Interstellar and Circumstellar Gas Towards the Debris Disk System HD 61005 (HST GO 11674)	TBD [b] + 2 yrs	$19, 646	PEND
13	Structure and Chemistry of Planet-Building Disks: A Synoptic Study (NASA 08-ADP08-0036)	06/01/09 06/30/10	$4,895	PEND
14	A Paschen-alpha Study of Massive Stars and the ISM in the Galactic Center (*HST* GO 11120)	05/01/2009 04/30/2011	$19,585 [c]	Cont. PEND

[a] In process No-Cost Extension requests to current closing dates for ≥ + 1 yr in process; approval anticipated

[b] Subject to STIS re-enabling in HST/SM-4. Anticipated start now ≥ 07/2009

[c] Supplemental budget request currently under review by STScI

Dr. Bruce E. Woodgate

Current

"Emission Line Astronomy – Fabry-Perot and Coronagraphic Integral Field Spectrograph",
PI: Bruce Woodgate (NASA/GSFC)
ROSES/APRA2 2006
0.17 WY for FY08 - FY10
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov

"ACCESS"
PI: Mary-Elizabeth Kaiser, proposed to the NASA Research Announcement NNH06ZDA001N-APRA (ROSES/APRA 2007)
~0.02 WY for FY08-10
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov

"High Quantum Efficiency Wide Band Gap Photocathodes for Photon-Counting Ultraviolet Detectors ", PI: Bruce Woodgate (NASA/GSFC)
ROSES/APRA 2007
0.1 WY for FY08-FY10 Total Budget FY08 FY09 FY10
$470 K $480 K $460K
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov

Pending *(This proposal)

Kinematic Imaging Traiblazer Experiment
PI: Charles Joseph (Rutgers University) ROSES/APRA 2008
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov

"Ultraviolet Electron Bombarded CMOS detector development"
PI: Charles Joseph (Rutgers University) ROSES/APRA 2008
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov

"All-reflective integral field spectrograph for far ultraviolet astrophysics",
PI: Dennis Ebbets (Ball Aerospace) ROSES/APRA 2008
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov

"Knots in the Cosmic Web"
PI: Bruce Woodgate (NASA/GSFC) ROSES/APRA 2008
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov

*"The Geometry of Accretion and Mass Loss on PMS Stars through the Epoch of Jovian-mass Planet Formation: A Multi-wavelength Study"
PI : Carol Grady (Eureka) ROSES/ADP 2009
Contact: Dr. Mario Perez, 202-358-1535, mario.perez@nasa.gov