Imaging Polarimetry of Young Stellar Objects with ACS and NICMOS: A Study in Dust Grain Evolution

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Abstract

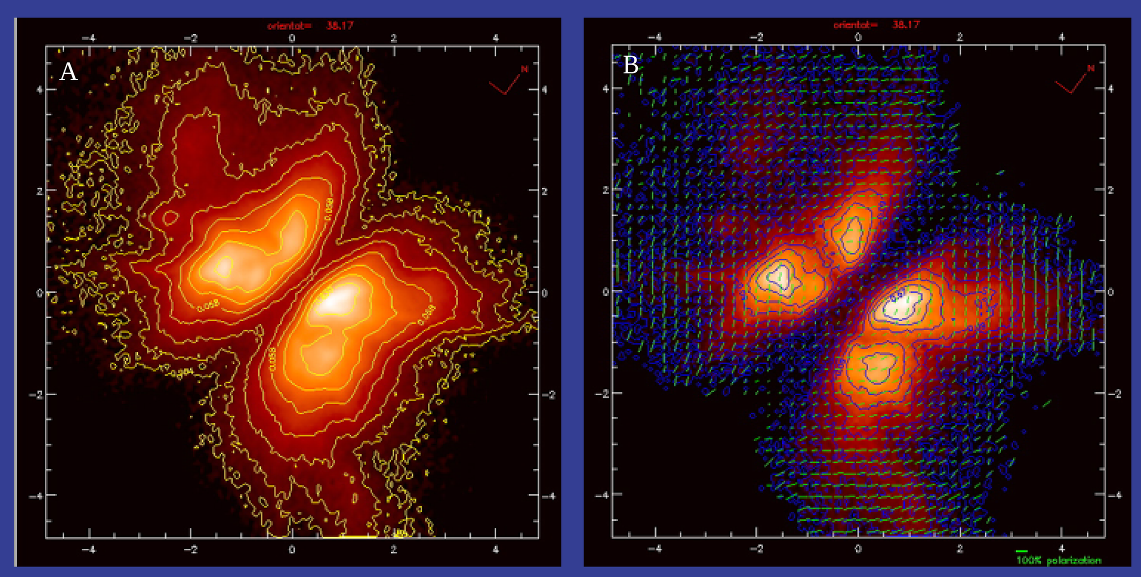
We present the first results from our near-IR and optical polarimetric imaging study utilizing NICMOS and ACS on HST. We have selected five Class I and five Class II YSOs to investigate dust grain evolution and segregation as a function age. Most of our targets also have earlier broad band HST images which allows for an intriguing study of time variability in the scattered light morphology. The YSOs observed to date indicate that the polarized light - scattered from dust grains in the disk - has a strong spatial dependence, with the polarization decreasing dramatically toward the disk midplane for some targets. When combined with radiative transfer models of the circumstellar disks, our observations will enable us to explore the scattering geometry of these systems and place constraints on the grain size distributions. During these early stages of low mass star formation, the circumstellar dust grow from the small grains typical of dust in the interstellar medium (ISM), to planetesimals (and eventually planets); constraining the evolution of the dust grain distribution can provide crucial insight into the formation of Solar type planetary systems. Future investigations will seek to extend this investigation to Class III and full fledged debris disk systems, where the emergence of the star from the envelope will require use of the newly commissioned coronagraphic polarimetry mode on NICMOS.

Introduction

Over the past ten years, high resolution HST observations have enabled investigations of the circumstellar environment around young stellar objects (YSOs) down to spatial scales of 100--150 AU: the approximate size of our Solar System. In turn, these observational studies have stimulated impressive advances in theoretical studies of circumstellar disks. Since any planets must form out of the dust and gas already present in the disks of YSOs, understanding the early evolution of these objects is critical to our understanding of planet formation. Specifically, the dust grains within the circumstellar disk must grow from the small grains typical of the interstellar medium (ISM), to planetesimals, to planets, over very short time scales (<1 Myr). Previous searches for evidence of such grain growth (e.g. Cotera et al. 2001; Wood et al. 2002; Wolf et al. 2003), although provocative, are preliminary; and none have systematically explored an evolutionary sequence. Specifically, the time scale for the first step in this evolution, the aggregation of the small ISM grains to intermediate size grains, has not been addressed.

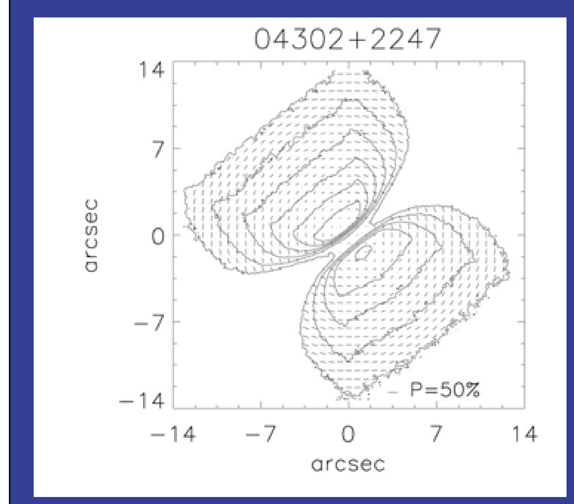
The combined polarimetry cabilities of ACS and NICMOS provide a unique opportunity to investigate the early evolution of dust grain properties via multiwavelength polarimetry. Since grains (<0.1 μm) have a much larger fractional polarization and a steeper wavelength dependence than larger grains, observations of the variation of polarized light as a function of wavelength are a sensitive probe for determining the size distribution of the sampled grain population.

IRAS 04302+2247 (NICMOS)



A: and B: as above. IRAS 04302+2247 is a very young Class I object embedded in the Taurus L1536 molecular cloud. Low resolution imaging polarimetry (Whitney et al. 1997) led to a proposed inclination close to edge-on, which was confirmed by later HST NICMOS images (Padgett et al. 1999). The source drives a small molecular outflow, with a nearby associated string of HH objects exhibiting a morphology indicative of time-varying outflow. Irregular bright and dark streamers seen in previous HST observations may possibly indicate material infalling onto the disk. As can be seen by comparing the NICMOS polarization results with the model (right), the models already reproduce the spatial distribution well and mak a good estimate of the percent polarization. Additional modeling will address whether the assumed grain distrubution can also reproduce the polarization as seen with ACS.

Model

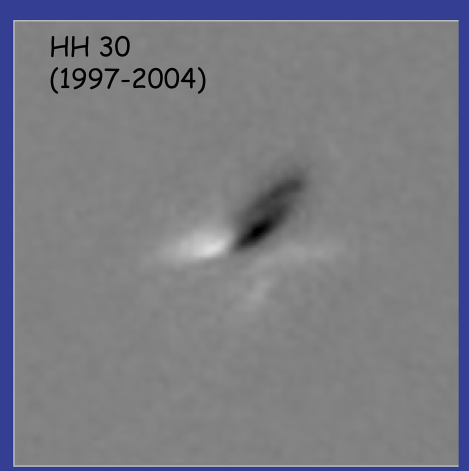


Variability

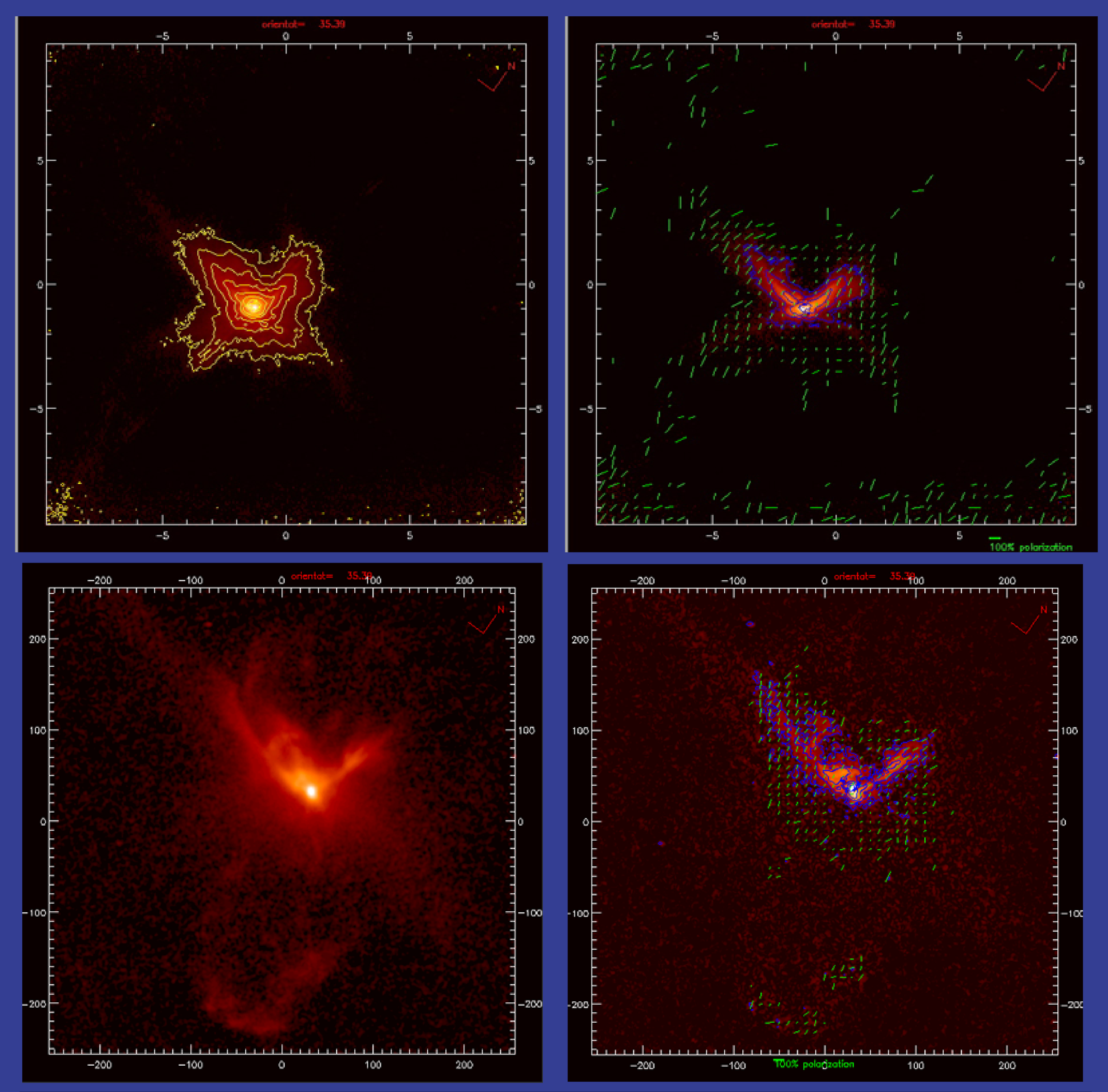
T Tauri stars are renown for their variability. The exact timescales for this varibility and the mechanism(s) responsible, are not well known. Wood et al. (2000) demonstrated by ground based VRI monitoring of HH 30, that variability on the order of 1.5 mag occurs over timescales of a few days. The models (see above right) already allow for rotating magnetic accretion hot spots, which successfully predicted a variation in the scattered light image of HH 30 (Wood & Whitney 1998) subsequently observed during differnet epochs with HST WFPC2 (Stapelfeldt et al. 1999).

All of the objects observed as part of this program were previously observed with NICMOS in the F160W filter (GTO 7228, PI: Young; GO 7418, PI: Padgett). We have retrived the Cycle 7 data from the archive and reprocessed it using the latest calibration data. Taken together, the Cycle 7 and Cycle 13 observations provide much needed data with which to test the hot spot models, and investigate other possible mechanisms such as light scattered off a clumpy inner disk. The current data set, however, has a random timescale, and high resolution scattered light images over a well established timescale are need to discriminate between the various mechanisms and improve the models.

Below (on the laptop), we blink the 1997 and 2004 F160W images for the six objects reduced to date. We see variability (often striking) in the scattered light pattern for all of these objects.



CoKu Tau 1



A: NICMOS false color total intensity (I) image. B: Polarization (P)*I image, overlayed with the polarization vectors. The NICMOS data has been calibrated (Hines et al., in preparation), and the length of the polarization vector equals the percent polarization, based on the 100% polarization length given. C: ACS false color total intensity (I) image. D: P*I for ACS. Although the ACS polarizing filter angles have been calibrated (HST ISR 04-10), the percent polarization is not well understood for this observing mode at this time. Future calibration observations are scheduled. Therefore, although the angle of the polarization vectors are most likely correct, the percent polarization is only an estimate at this point. Importantly, the polarization morphology is well correlated between the NICMOS and ACS observations of CoKu Tau 1.

Observations

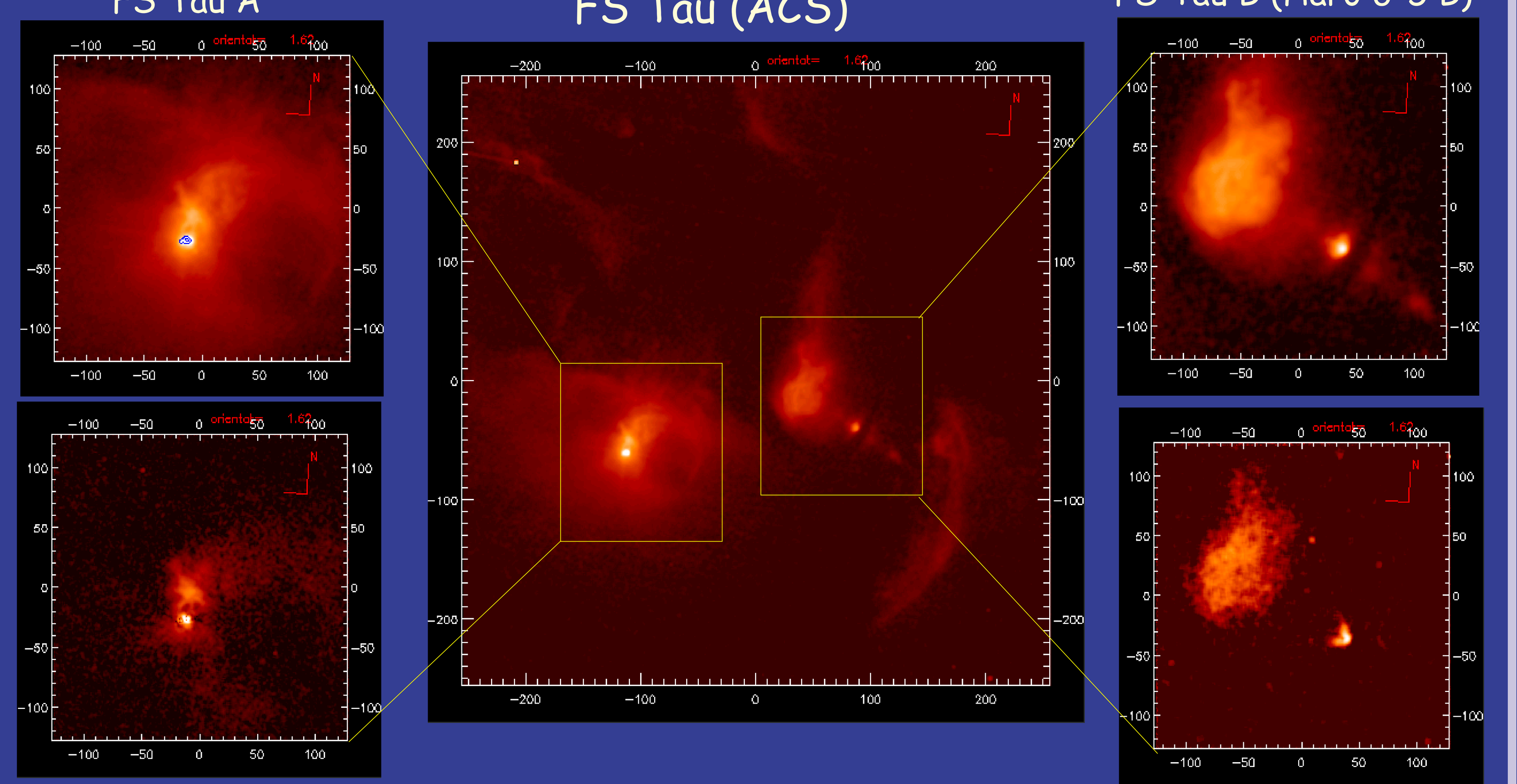
The observations for this project are being obtained as part of HST Cycle 13 GO 10178 . The table below lists the program objects, and gives the observation date for all objects which have been completed as of this meeting. All ACS observations are made with the WFC camera, with nominal plate scale of 0.05" / pixel. The filter combination F606W / POLV is being used for all ACS observations. The NICMOS observations are being made with the NIC2 camera, which has a nominal plate scale of 0.075". Polarization measurements on NIC2 are taken with the POLL filters. In addition, we have obtained an F160W image for each object, allowing for a preliminary investigation into the variability of the objects since all have been previously observed with NICMOS with this filter during Cycle 7.

Objects	ACS	NICMOS
L1551 IRS5	2004 Sep 02	2004 Oct 7
IRAS 04302+2247	TBS	2004 Aug 24
IRAS 04016+2610	2004 Nov 23	2004 Aug 24
CoKu Tau 1	2004 Aug 22	2004 Aug 24
DG Tau B	TBS	2004 Aug 25
HH 30	2005 Jan 2	2005 Oct 7
Haro 6-5B (FS Tau B)	2004 Aug 17	2004 Dec 17
HK Tau B	2004 Sep23	2004 Dec 30
HV Tau C	2004 Oct 5	2004 Nov 19
HL Tau	2005 Jan 4	Cycle 7

Data Reduction

The NICMOS Cycle 13 data was partally processed using STSDAS CALNICA, with additional processing done using a APL based analog to CALNICA. STScI model darks were used, with flats created from archival calibration data. Cycle 7 data (see "Variability") were reprocessed using the APL analog, with darks and flats created by the NICMOS IDT Team. ACS flat fielded data were obtained from STScI, and additional processing was done using the latest version of PyRAF / Multidrizzle. Polarization results utilize the IDL program POLARIZE developed by the NICMOS IDT Team (see "Acknowledgements"): NICMOS polarization calibration was performed as part of GO 9644 (PI: Hines), ACS calibration was taken from ISR 04-09 and ISR 04-10.

FS Tau (ACS)



Upper and Middle: Total intensity (I) image from ACS. **Lower:** P*I images. FS Tau A is a close binary with a projected separation of ~250 mas. FS Tau B is associated with the jet HH 157, which can be seen in the images. Examination of the images shows scattered light in apparent "streamers" connecting the binaries in FS Tau A with the clump of dust located to the north; the clump is clearly seen in the P*I image. The jet disappears in the P*I image of FS Tau B as expected.

Acknowledgements

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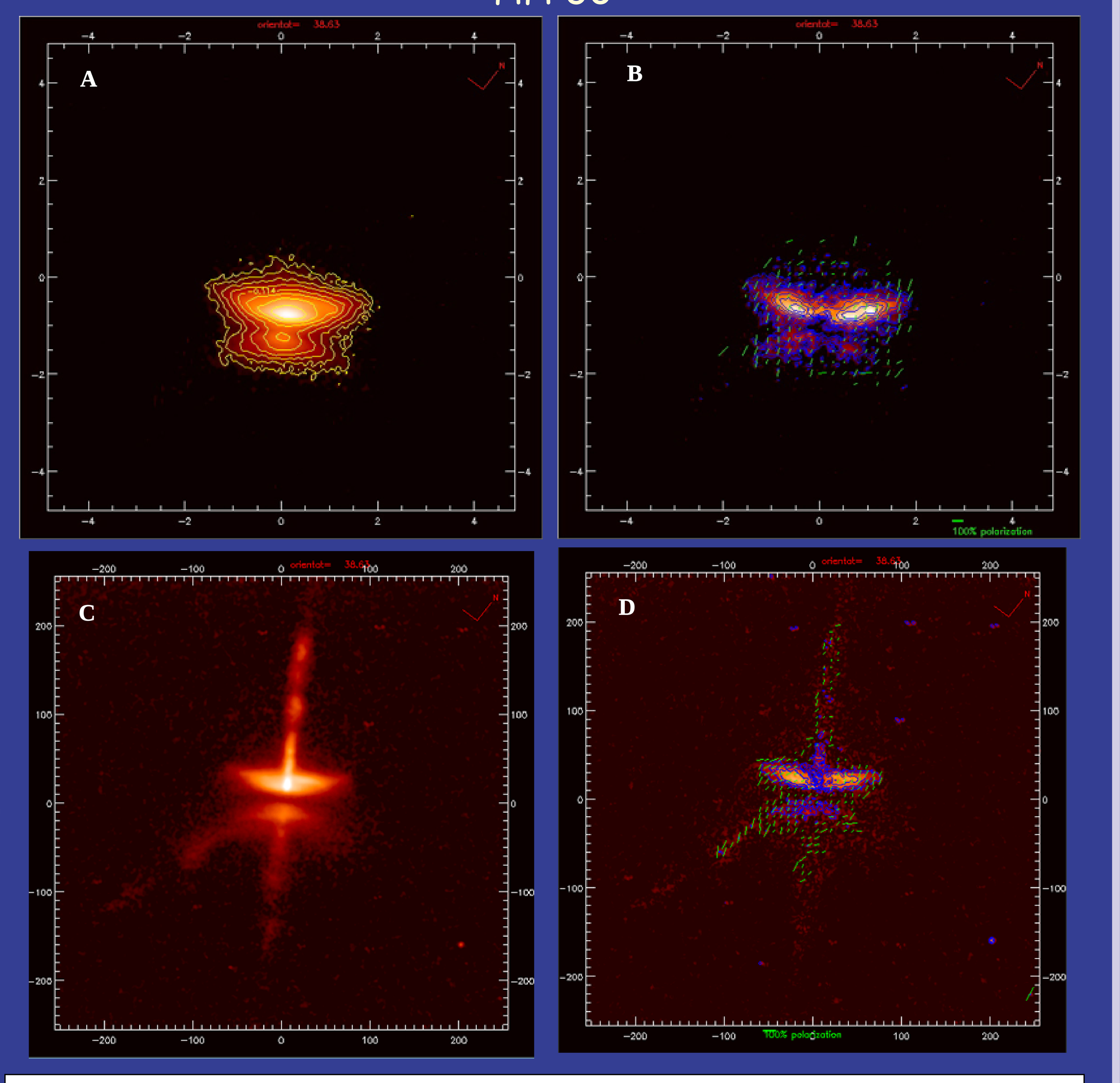
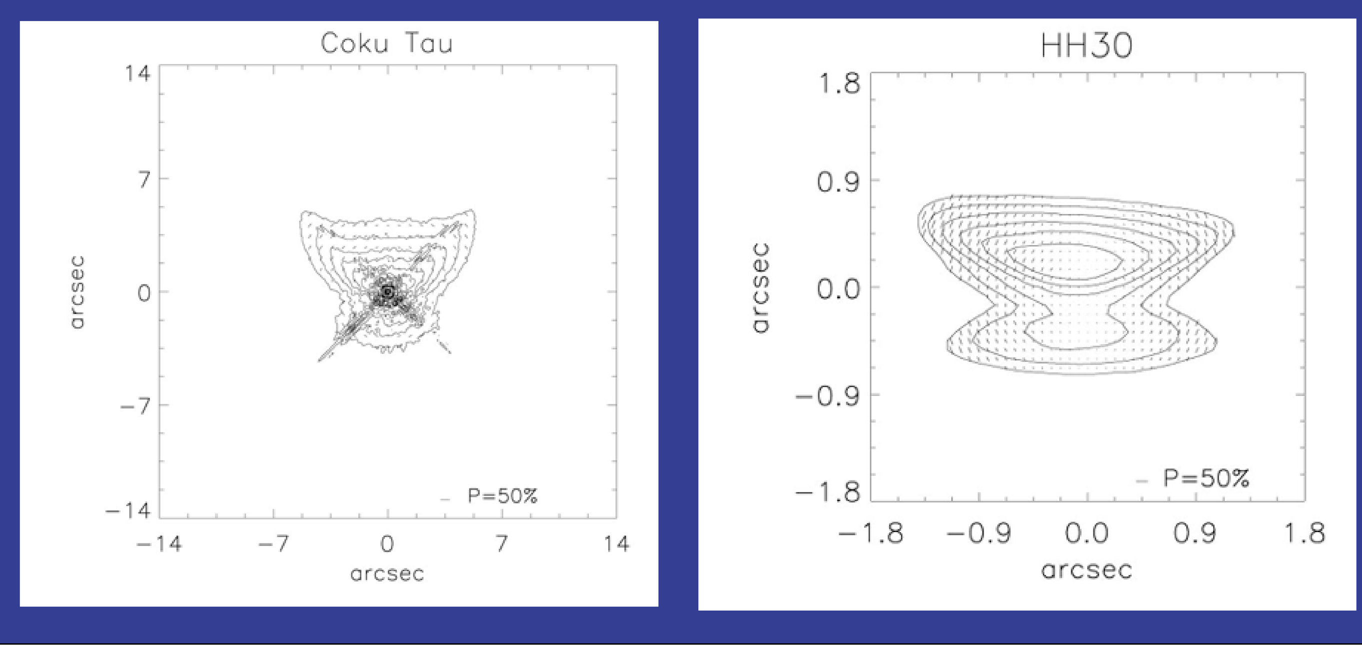
HH 30



A: NICMOS false color total intensity (I) image. B: Polarization (P)*I image, overlayed with the polarization vectors. C: ACS false color total intensity (I) image. D: P*I for ACS. HH 30 is a well studied edge-on Class II object, where the circumstellar disk occults the star. Models of previous HST data (e.g . Cotera et al. 2001), assuming a flared accretion disk, indicated a wavelength dependent variation in the observed dustlane which required the disk dust grains to be 2.1 times larger than standard interstellar medium grains. These results will be tested using the more sensitive grain size discriminant available from these multiwavelength polarization maps.

Models



Polarization models for CoKu Tau 1 and HH 30. For disks where the density structure is reasonably well-known -- such that a flared disk geometry can be assumed -- the models needed to analyze the dust grain distribution are currently available (e.g. Whitney et al. 2003, Wolf et al. 2003). To date, however, the spatially resolved polarization maps produced by the models, such as those shown to the above for CoKu Tau 1 and HH 30, have not yet been tested against high resolution polarization maps. Whitney et al. (2002) calculated model polarization maps assuming non-spherical grains aligned by an axial magnetic field, which successfully produced a higher net polarization, providing a better match to the observations, but also gave polarization vectors in the disk midplane in a direction opposite to the observations. Recently, the models have been extended to include arbitrary magnetic field directions, and show that toroidal fields in the disk may become axial outside of the disk. At this point, the theoretical models are ahead of the observational data; therefore in addition to effectively probing the grain size distribution, these HST polarization observations will be invaluable in testing and informing these models.

The Next Step

The observations presented here are part of a program to understand the evolution of the dust grain population from the small ISM grains to larger grains; the first step in developing a planetary system. The program objects are all Class I–Class II. The next step is to obtain similiar polarization data for Class III and Debris Disk systems, to determine if and when the smallest grain population disappears. In addition, the small grain population may be replenished as we reach older evolutionary states due to collisionaly destruction of larger grains. To reach these evolutionary states, however, requires an evolution in observing techniques. For all of the object studied here, the central star is still obscured, either because of age (in the case of the Class I objects), or by a fortuitous viewing angle, such that the circumstellar disk blocks the light from the star. For Class III and Debris Disk systems we must provide our own obscuration in the form of coronagraphic polarimetry. NICMOS coronagraphic polarimetry is now well calibrated (Poster 5.04 at this meeting), and we will propose to use this mode to continue this fruitful investigation along the evolutionary sequence in Cycle 14. When the ACS coronagraphic polarimetry mode is calibrated, the valuable color lever obtained for the program presented here will also be extended to the Class III and DD objects.

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