Observational Studies of Protoplanetary Disks at Mid-Infrared Wavelengths

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I. Introduction

For my (Dan Li) PhD thesis research, I have used mid-infrared cameras on 8-to-10 m class telescopes to explore the properties of young circumstellar disks. Here I highlight some of my thesis work and results, including the commissioning of CanariCam (§II), mid-IR data reduction (§III), imaging polarimetry of AB Aur (§IV), high-spatial-resolution imaging and spectroscopy of the β Pic disk (§V), and a mid-IR imaging study of MWC 1080 (§VI). This research has been supported in part by NSF grants AST-0903672 and AST-0908624 to CMT.

II. Commissioning of CanariCam

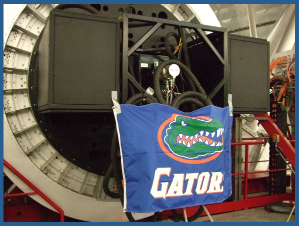

Fig. 1. CanariCam mounted at the GTC Nasmyth-A focal station.

I participated in the commissioning of CanariCam, a new mid-IR facility imager and spectrograph built by the University of Florida for the 10.4 m Gran Telescopio Canarias (GTC) on La Palma, Canary Islands, Spain. CanariCam is an **imager** with **spectroscopic**, **polarimetric**, and **coronagraphic** capabilities, with the dual-beam polarimetry being a unique mode introduced by CanariCam for the first time to a 10 m telescope at mid-IR wavelengths.

III. iDealCam – Interactive Data Reduction for CanariCam

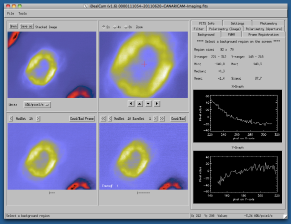

Fig. 2. iDealCam GUI.

iDealCam provides a one-stop solution for reducing the standard imaging and polarimetric imaging data acquired by CanariCam. Using the graphical user interface (GUI) of iDealCam, one can reduce and analyze the CanariCam data without IDL programming. The polarization maps of AB Aur shown in §IV illustrate iDealCam's capabilities.

IV. Mid-IR Polo-imaging of AB Aur

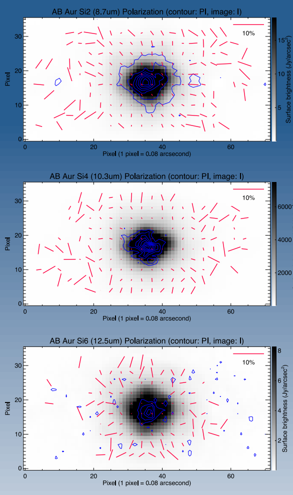

Fig. 3. Imaging polarimetry of AB Aur at 8.7, 10.3, and 12.5 µm. The gray-scale image is the total intensity (Stokes I). The blue contours are the polarized intensity.

Measurements of polarization, originating from aligned dust grains in the disks and their environments, have the potential to shed light on the morphologies of the magnetic fields (B-fields) in these regions. Mid-IR imaging polarimetry can help distinguish between models that have been proposed from theoretical studies of B-fields in YSOs and disks. Figures shown here are preliminary results from a pilot program of mid-IR polo-imaging of Herbig Ae/Be disks. By analyzing the polo-images of AB Aur and a polo-standard, AFGL 2591, we found that the instrument polarization (IP) of CanariCam is not negligible at 8.7 µm, thus requiring further calibration. Adding a non-polarized standard star to the baseline calibration will help characterize the IP for future observations. No net polarization was detected at 10.3 and 12.5 µm, in agreement with the model proposed by Pudritz & Norman (1986), which predicts an hourglass shaped B-field, and thus no net polarization for face-on disks. To what degree this result is influenced by the IP is still under investigation, and therefore we present no quantitative information at this time.

V. Inner Disk of β Pictoris

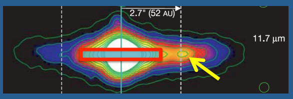

Fig. 4. Mid-IR image of β Pic disk. Yellow arrow points at the "SW Clump", and red rectangle indicates the slit position we used in our spectroscopy observation in 2010.

We (Li et al. 2012) observed β Pictoris, an archetypal debris-disk star with a known planet (β Pic b), using 10-µm-band imaging and spectroscopy to clarify and extend some of the previous observations and conclusions about this system, specifically, those given by Okamoto et al. 2004 (O4) and Telesco et al. 2005 (T5).

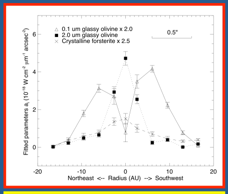

Fig. 5. Spatial resolution of multiple dust components in the β Pic disk. By modeling the 10-µm silicate feature, we confirm that dust populations with different compositions and/or sizes are distributed differently in the disk, as observed by O4. We found strong evidence that the distribution of sub-micron amorphous grains is double-peaked, while that of larger grains is not. This may indicate the presence of a planetesimal belt, or it may result from stellar heating; sub-micron grains can be heated by the central star to temperatures that are significantly higher than those of the big grains. As a result, dust sublimation can create a region extending out to several AU and deficient in small grains.

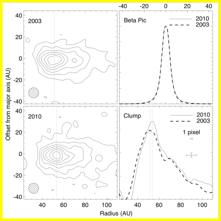

Fig. 6. Two-epoch imaging of the β Pic disk confirming the existence of the "SW dusty clump" discovered by T5. In addition, we have detected a projected radial shift in the clump's position of 2.0±0.6 AU between 2003 and 2010, a value consistent with the assumption that the clump is orbiting around β Pic in a Keplerian orbit of radius 54.3 (+2.0/-1.2) AU.

VI. Environments of MWC 1080

MWC 1080 is a Herbig Be star and the center of a small cluster of young stars at a distance of 2.2 kpc. Within 0.3 pc, it is surrounded by more than 40 young low-mass stars and 32 dense gas clumps. To gain insight into MWC 1080's complex environment, we imaged this system in the mid-IR N and Q bands and computed the distributions of optical depth and temperature. These analyses will be presented elsewhere.

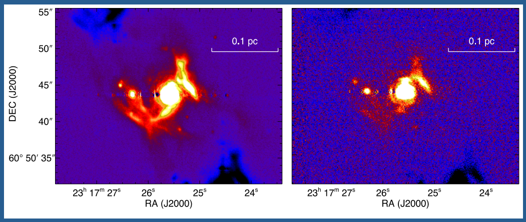

Fig. 7. N (left) and Q (right) images of MWC 1080 and its environment. An hourglass-shaped structure with complex emitting filaments is visible at both wavelengths. The central star is not resolved, implying that the radius of the MWC 1080 disk is <92 AU. This measurement agrees well with the estimate by Alonso-Albi et al. (2009) via SED modeling, and it is 10 times tighter than constraints from previous observations.

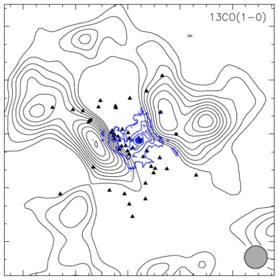

Fig. 8. N image contours (blue) overlap on BIMA array ^{13}CO contours (black; Wang et al. 2008). Comparisons with other data like these reveal the origin of the mid-IR morphology around MWC 1080: the complex filaments are not parts of a disk or envelope. Rather, they appear to trace the emission from the internal surfaces of a gas cavity (outlined by ^{13}CO contours) cleared by the bipolar outflow of MWC 1080. Analyses of the temperature and optical depth distributions suggest that MWC 1080 is the dominant heating source, with some near-IR-identified stars (black triangles) also heating parts of the filaments around them.

References Cited

Alonso-Albi et al. 2009, A&A, 497, 117; Li et al. ApJ, 759, 821, 2012; Okamoto et al. 2004, Nature, 431, 660; Pudritz & Norman 1986, ApJ, 301, 571; Telesco et al. 2005, Nature, 433, 133; Wang et al. 2008, ApJ, 673, 315.

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