SCExAO/CHARIS High-Contrast Integral Field Spectroscopy and Polarimetry of Planet-Forming Disks

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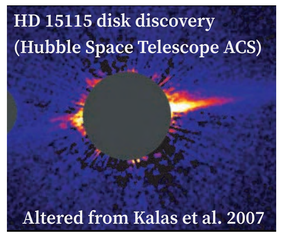
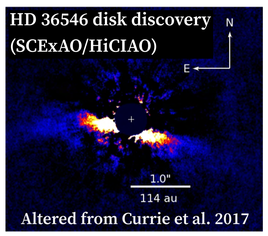
SCExAO / CHARIS

- SCExAO is the coronagraphic and "extreme adaptive optics" (ExAO) system (Strehl ratios of 70-90%) for the Subaru Telescope.
- CHARIS is a near-IR integral field spectrograph, collecting simultaenous spatial and spectral data in its 2" × 2" FOV
- Coupled, SCExAO and CHARIS allow impressive high contrast imaging and spectral characterization of circumstellar environments
- Low-res broadband mode exposures produce image cubes of 22 wavelength channels spanning J, H, and K

Debris Disks

- Dust dominated circumstellar disks
- Replenished by planetesimal collisions
- Features (e.g. gaps, asymmetries) may reveal clues about unseen planets





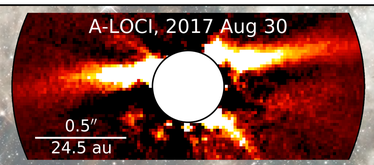
HD 15115

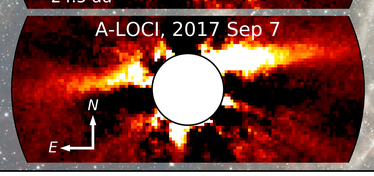
- F2V star, d=49pc, nearly edge-on debris disk with large east-west flux asymmetry
- Recent evidence of a distinct inner ring (Engler et al. 2019, MacGregor et al. 2019)
- Observed HD 15115 on 2017 Aug 30 (81 min) & 2017 Sep 7 (55 min) with SCExAO/CHARIS in ADI mode
- PSF subtractions for disk recovery performed using A-LOCI and KLIP algorithms separately
- PSF-subtracted image cube for each set is averaged over wavelength to reach a final image

HD 15115 Imagery with SCExAO/CHARIS

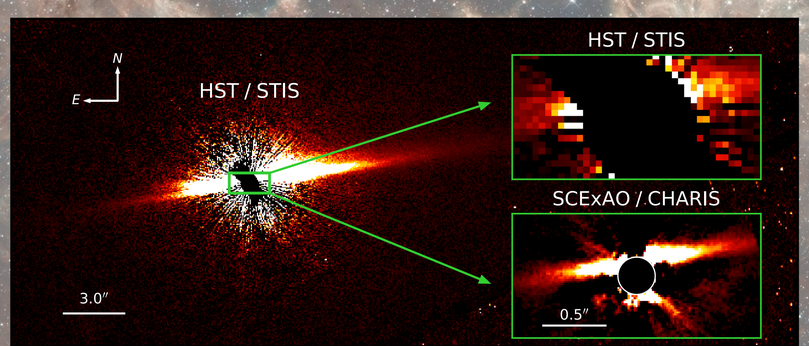
- Recover the northern side of the disk from ~1" to 0.2" (closest detection to date)
- No obvious sign of a distinct second disk spine (as posited by Engler et al. 2019)
- Separate planet-sensitive reductions yield no compelling planet candidates
- Disk color suggests minimum dust grain size of ~ 0.25 – 1.0 μm (less than blowout size)

Full results: Lawson, K. et al. 2020, AJ, 160, 163





CHARIS HD15115 imagery vs HST/STIS

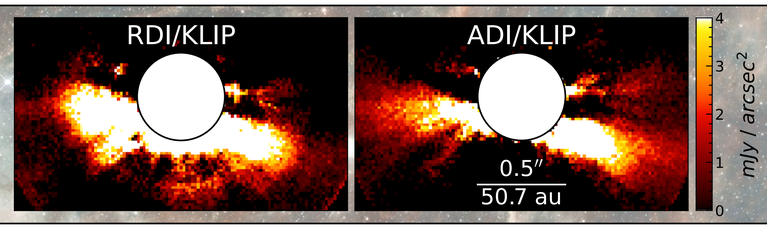


HD 36546

- AOV star, d=101pc, with highly inclined (i~80°) debris disk
- Very young (3–10 Myr), providing rare look at a debris disk in epoch of Jovian planet formation
- Observed HD 36546 on 2019 Jan 12 (50 min) with SCExAO/CHARIS in ADI mode
- Also observed a reference star (HR 2466) to enable reference star differential imaging (RDI)
- PSF subtractions performed using ADI-KLIP and RDI-KLIP separately

HD 36546 Imagery with SCExAO/CHARIS

- Recover the southern side of the disk to 0.25" (closest detection to date)
- No clear evidence of new disk features (gaps, cavities, etc.)
- Separate planet-sensitive reductions yield no compelling planet candidates

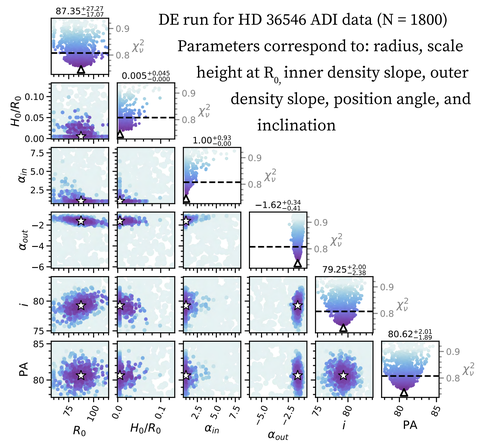


Forward Modeling with Differential Evolution

Use "forward modeling" to assess disk geometry and correct photometry for disk flux lost in PSF subtraction:

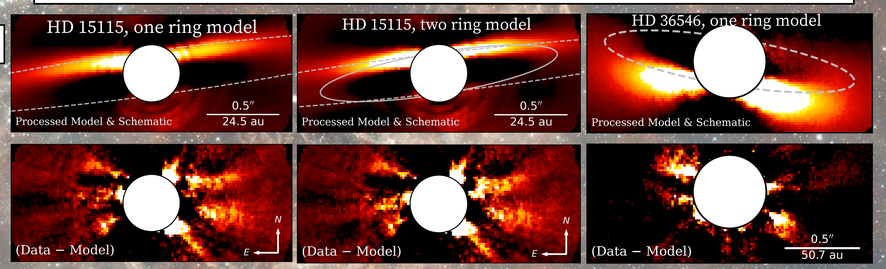
- Create synthetic disk model images (Augereau et al. 1999)
- Simulate attenuation, and compare with data to get reduced chi-squared metric
- Explore models of one and two ring geometries for HD 15115, and one ring for HD 36546

Given our expensive model evaluations (~10 minutes per model), we use "differential evolution" (DE; Storn & Price 1997) to quickly optimize params



- DE is a global optimization algorithm that needs only parameter bounds to operate effectively.
- DE tends to identify a strong solution in many fewer model evaluations than alternatives such as Markov Chain Monte Carlo or grid searches.

Model Results



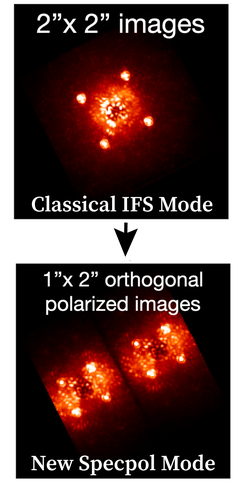
HD 15115:
- Strong, comparable fits for one and two ring models
- Acceptable two ring models only when rings aligned along line-of-sight
- No support for clearly misaligned two-ring geometry

HD 36546:
- Best-fit consistent with Currie et al. 2017 model
- DE favors a disk with slow fall-off (small α params)
- Two independent RDI modeling runs and one ADI run converge to close agreement

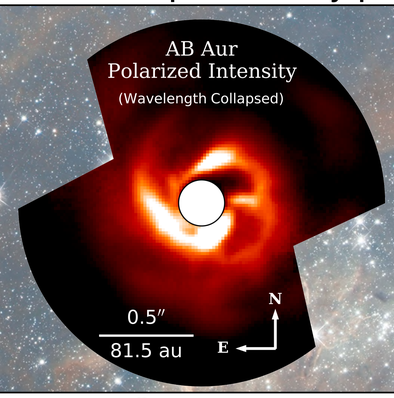
CHARIS Integral Field Spectropolarimetry Mode

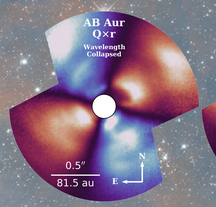
CHARIS has recently implemented a new "integral field spectropolarimetry" mode (or "PDI Mode")

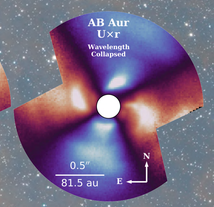
- Enables high-contrast polarimetry at the same array of wavelengths as classical mode (22 for low-res broadband)
- Comparison of total and polarized intensity can help distinguish self-luminous signals, such as protoplanets, from disk structure
- Fractional polarization measurements spanning the NIR spectrum can enable novel assessment of dust grain populations in disks
- For description of upcoming Mueller Matrix solution for PDI-mode calbration, see: **van Holstein, R. G., et al. 2020, Proc. SPIE, 11447, 114475B**
- AB Aurigae (A0, 163 pc, 2-3 Myr) disk system observed in new PDI mode on 2020 Oct 3 (76 min)
- Small scale disk structures recovered across all 22 channels in pol. intensity

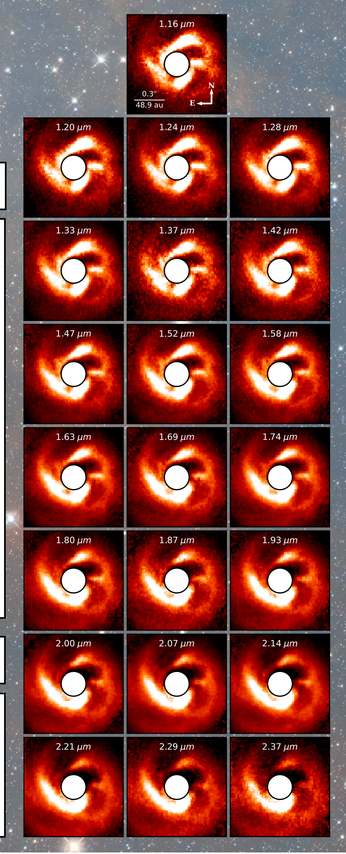


AB Aur preliminary polarimetric imagery









Summary

- Using SCExAO/CHARIS, we recover the debris disks of HD 15115 and HD 36546 to the smallest separations to date
- We efficiently explore possible disk models using differential evolution, a technique we suggest for groups facing similar optimization challenges
- Through modeling, we find results for HD 15115 consistent with one ring or two aligned rings, and for HD 36546 consistent with Currie et al. 2017
- We show preliminary science results or AB Aur with CHARIS's new PDI mode
- **CHARIS's PDI mode provides a powerful new tool for groups studying planet-forming disks**

Acknowledgments

We wish to acknowledge the very significant cultural role and reverence that the summit of Mauna Kea has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain.

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