# Formation of Extrasolar Planets

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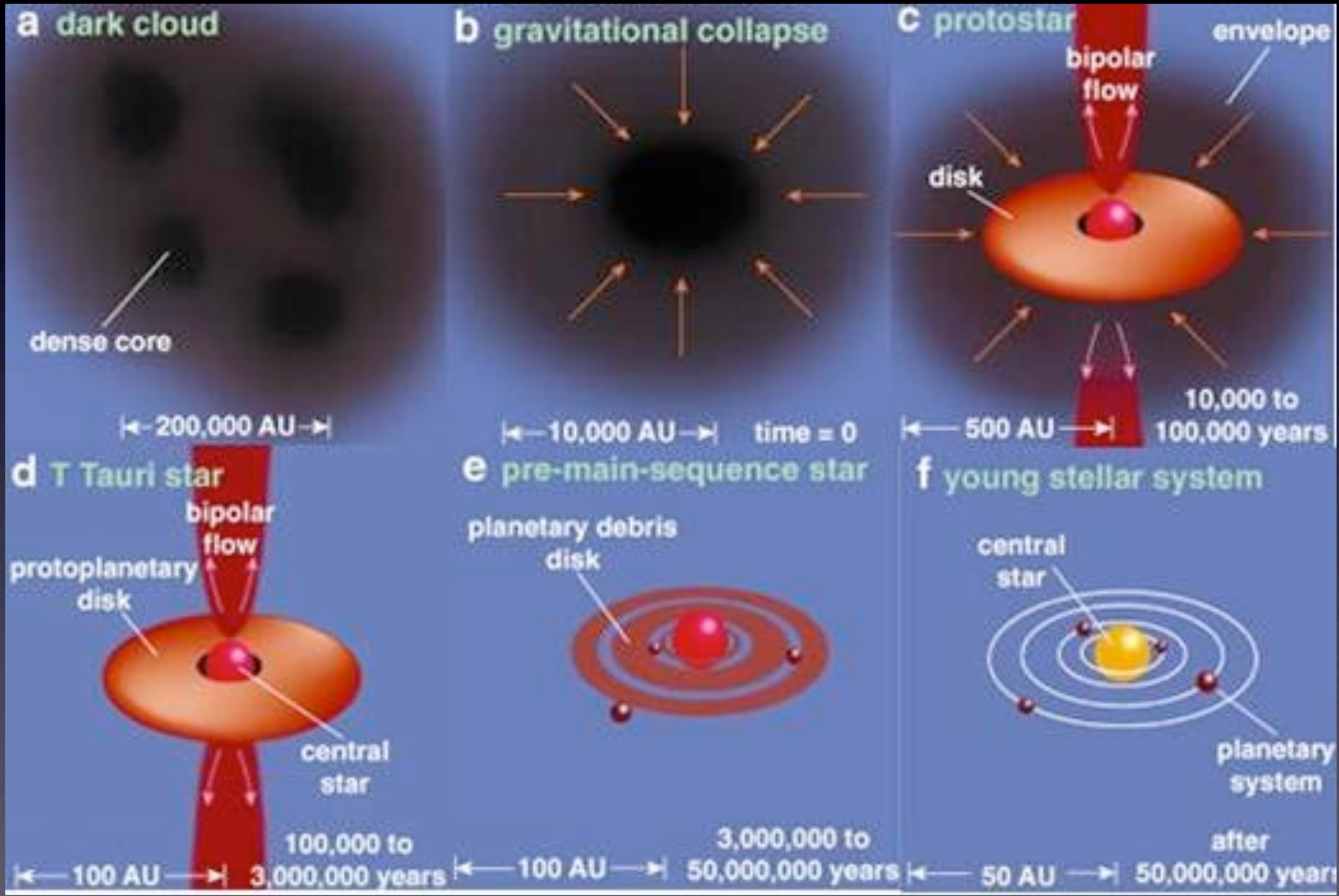
Gemini North Adaptive Optics Workshop
2012-6-20

# Planet Formation



# Planet Formation

The history planet formation processes is imprinted on the nature and distribution of circumstellar solids.

# Circumstellar Disks & Debris

- Asteroid and Kuiper Belts contain primitive remnant bodies
- Collisions and evaporation of these bodies create fresh dust
- Forces alter grain trajectories, creating a disk
- ~15% of nearby stars have detectable dust debris

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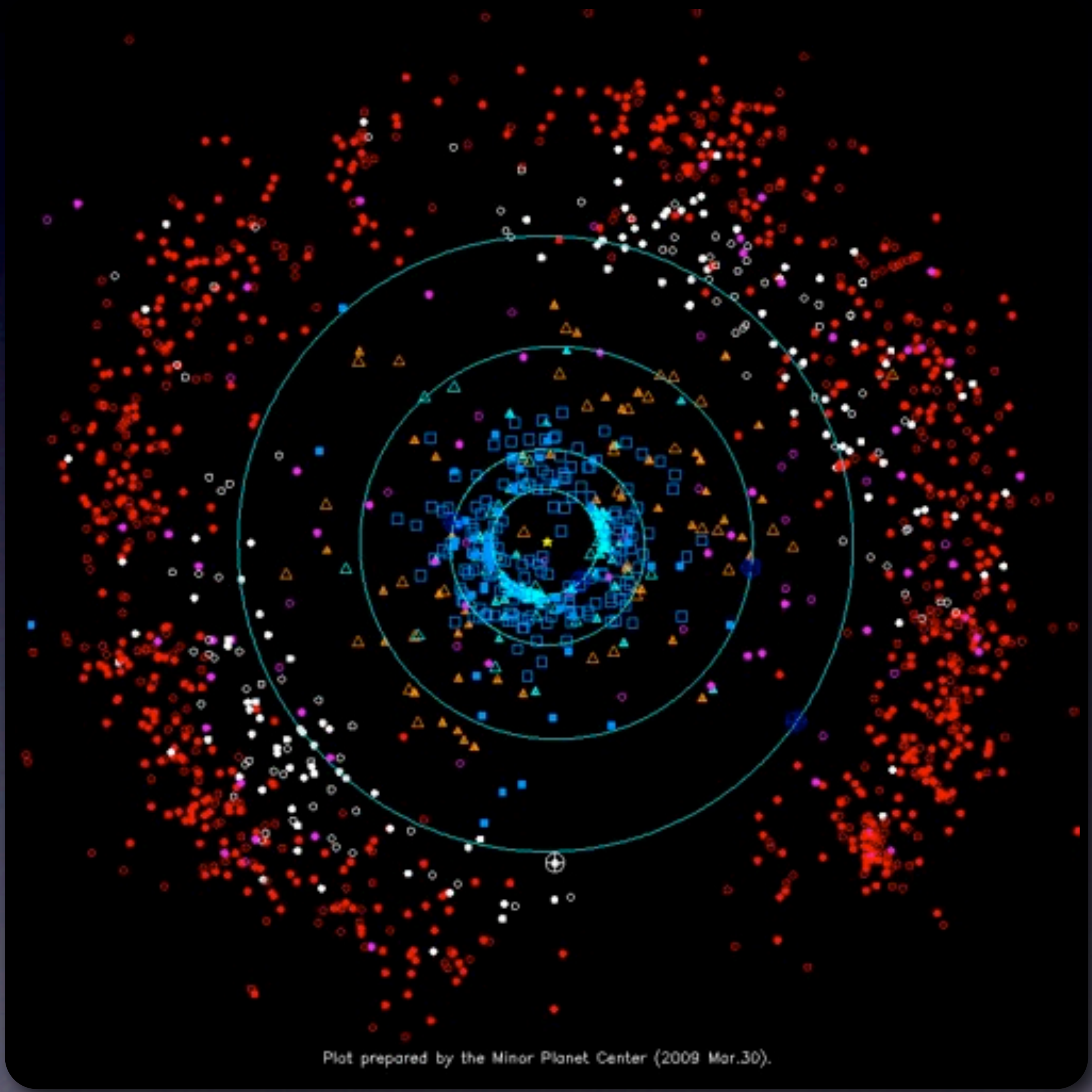
P. Kalas

# Planetesimal Dynamics

- Grain growth and solid transport initially tied to gas disk
  - expect compositional gradients
- Dust production is enhanced by stirring
  - recently formed Pluto-sized bodies (e.g. Kenyon & Bromley 2008)
  - inner giant planets' secular perturbations (e.g. Wyatt 2005)
- Migration of planets



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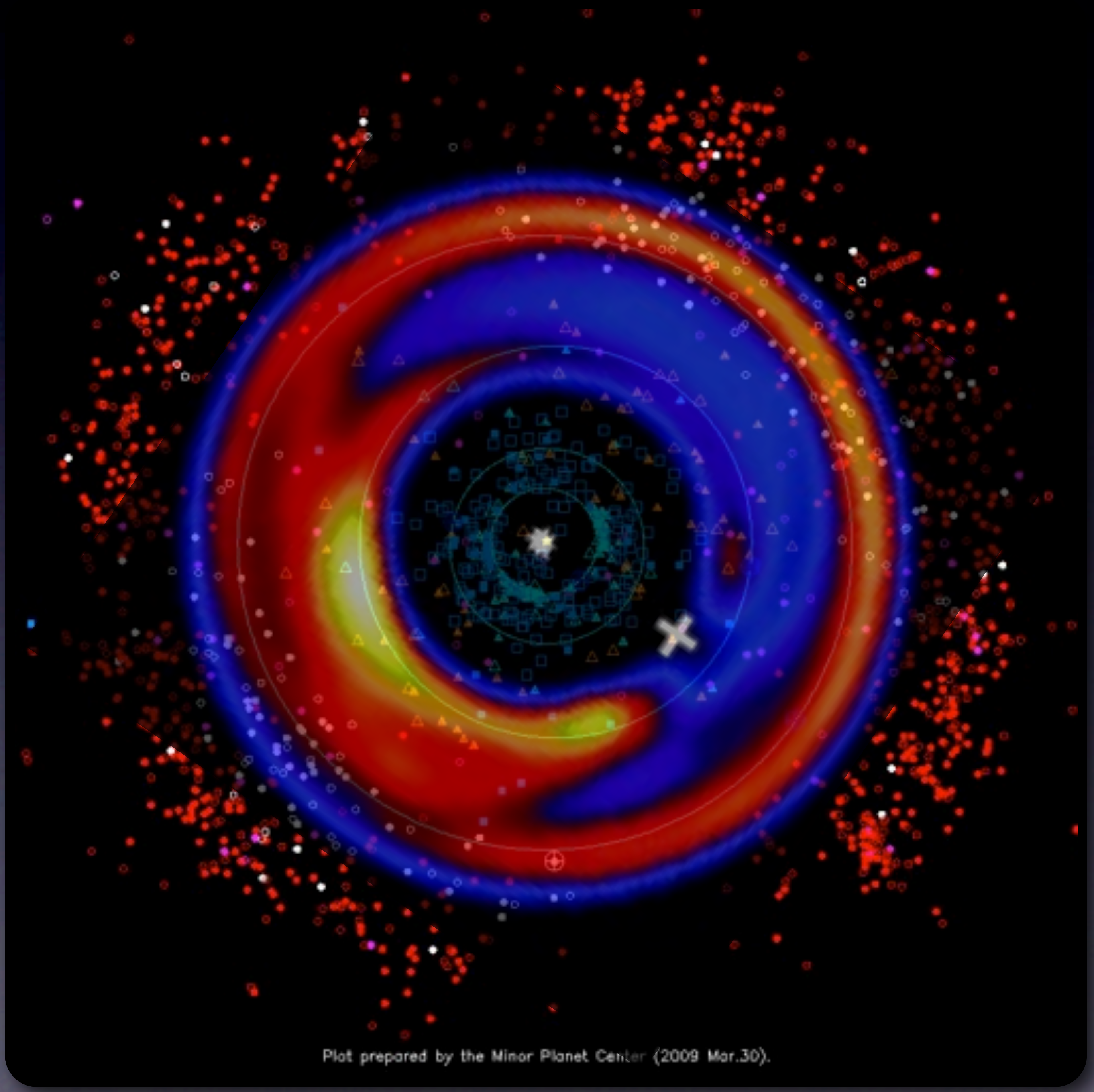
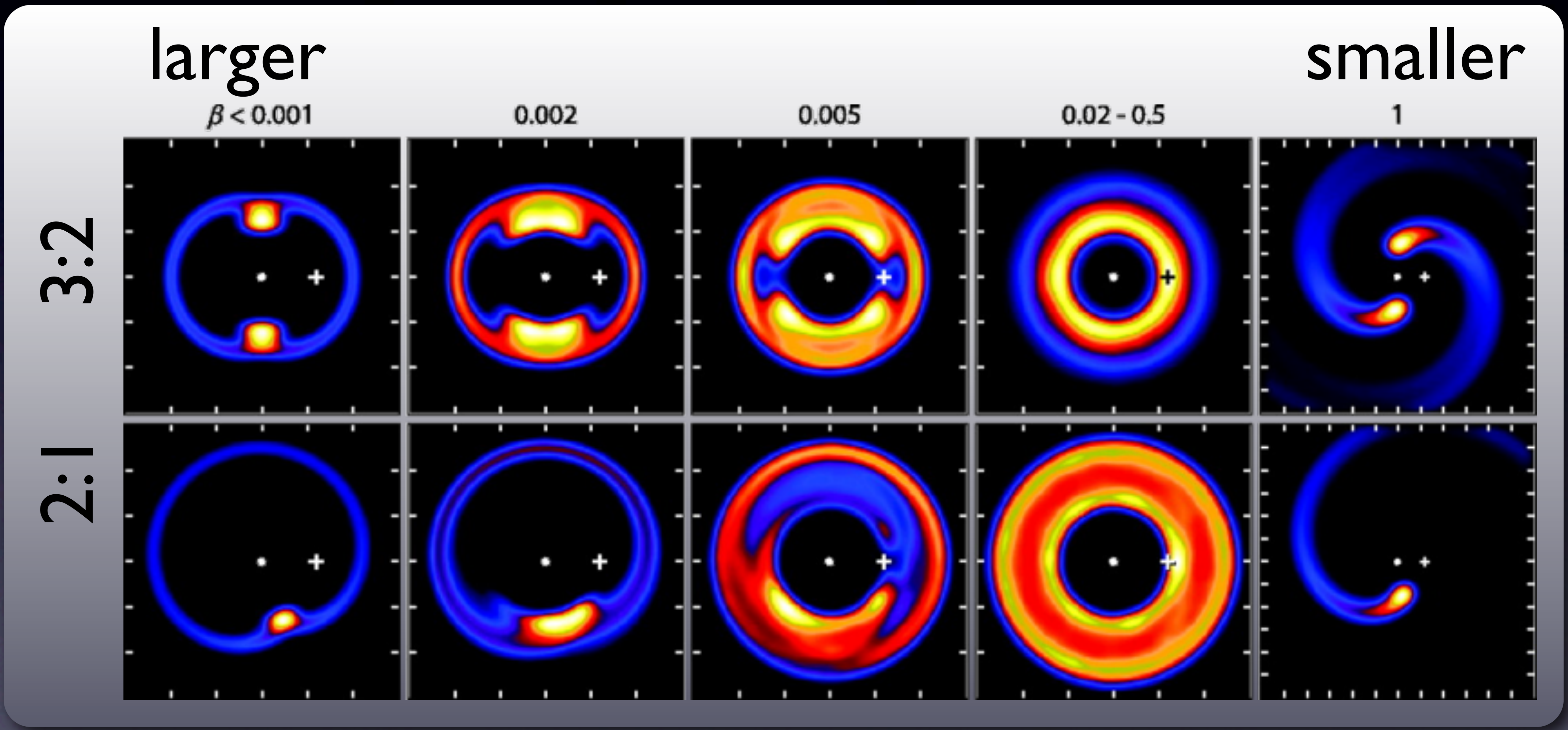


# Gravitational Perturbations

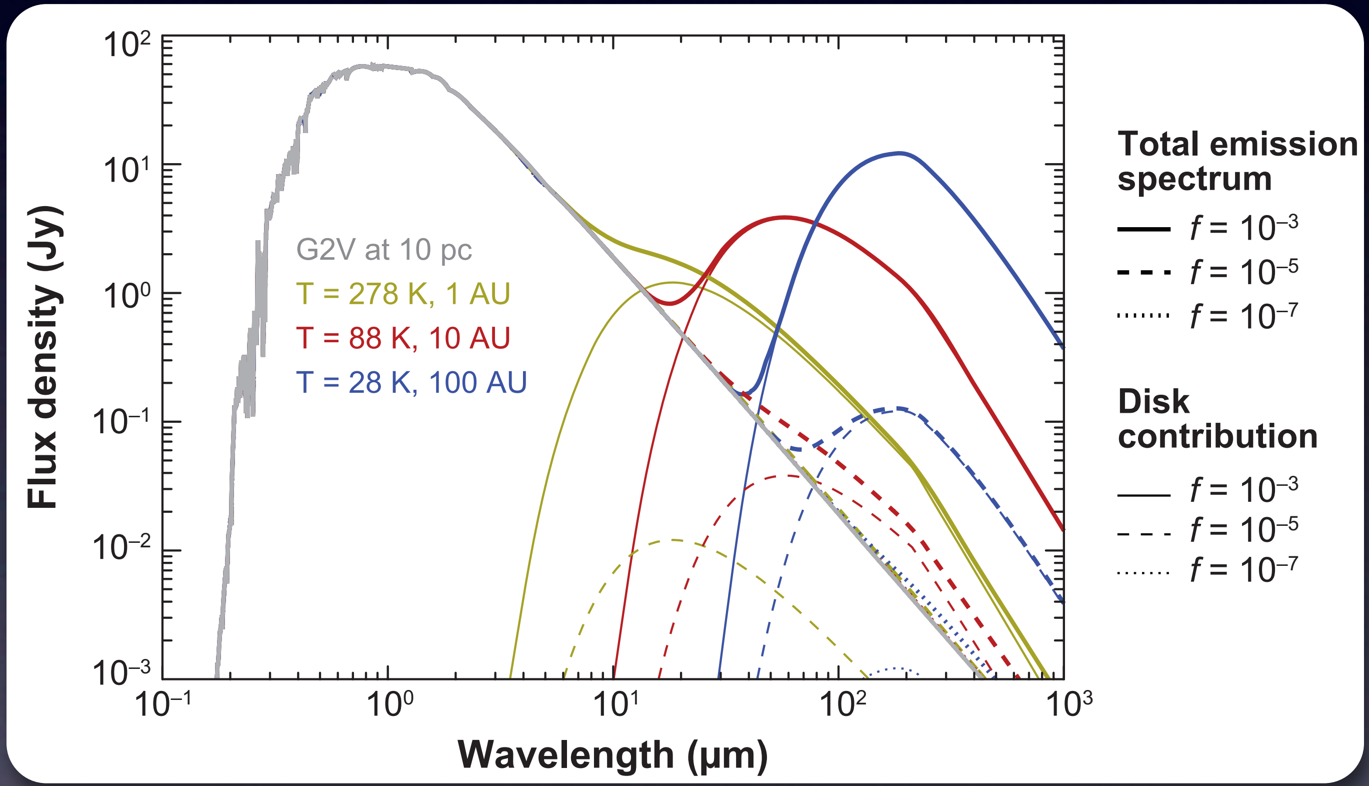



Wyatt (2006)

Planetesimal trapping in Mean-Motion Resonances

# Debris Disk Detection

- Infrared Excess around main-sequence star
- Most excesses can be characterized by single-T blackbody
- Hundreds detected, few resolved in scattered light or thermal emission
- Scattered light is dominated by star




Wyatt (2008)

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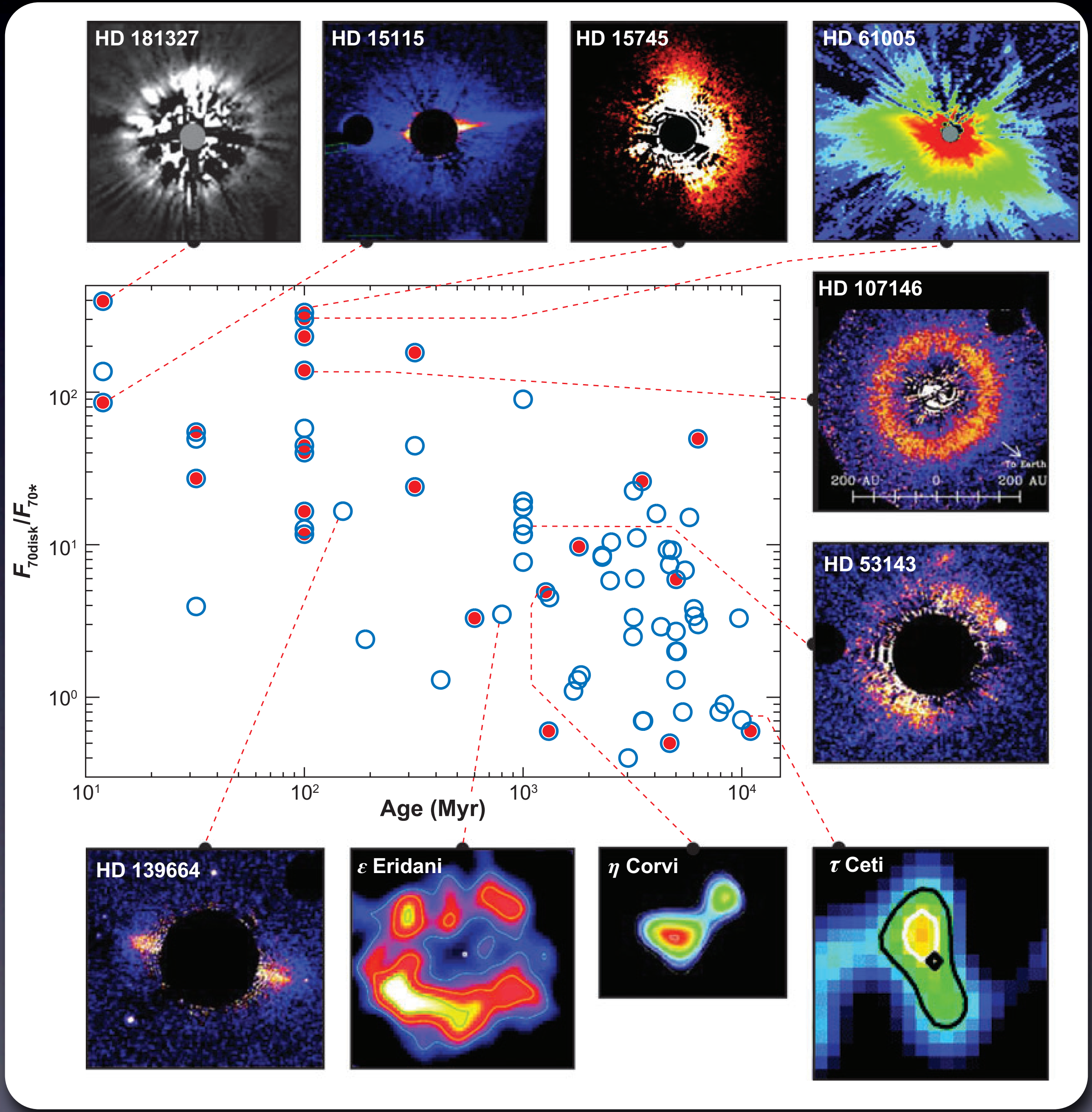
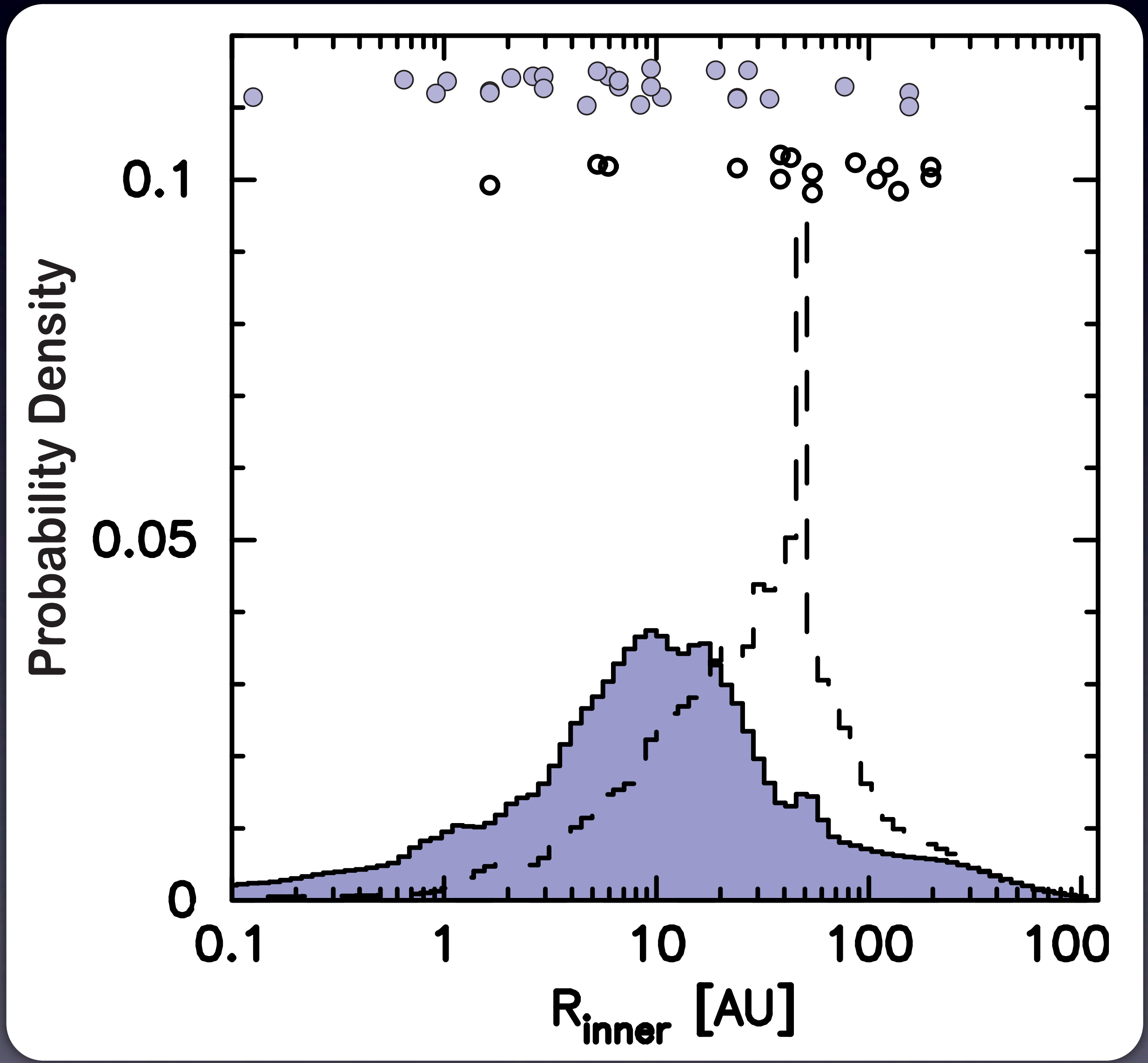



Wyatt (2008)

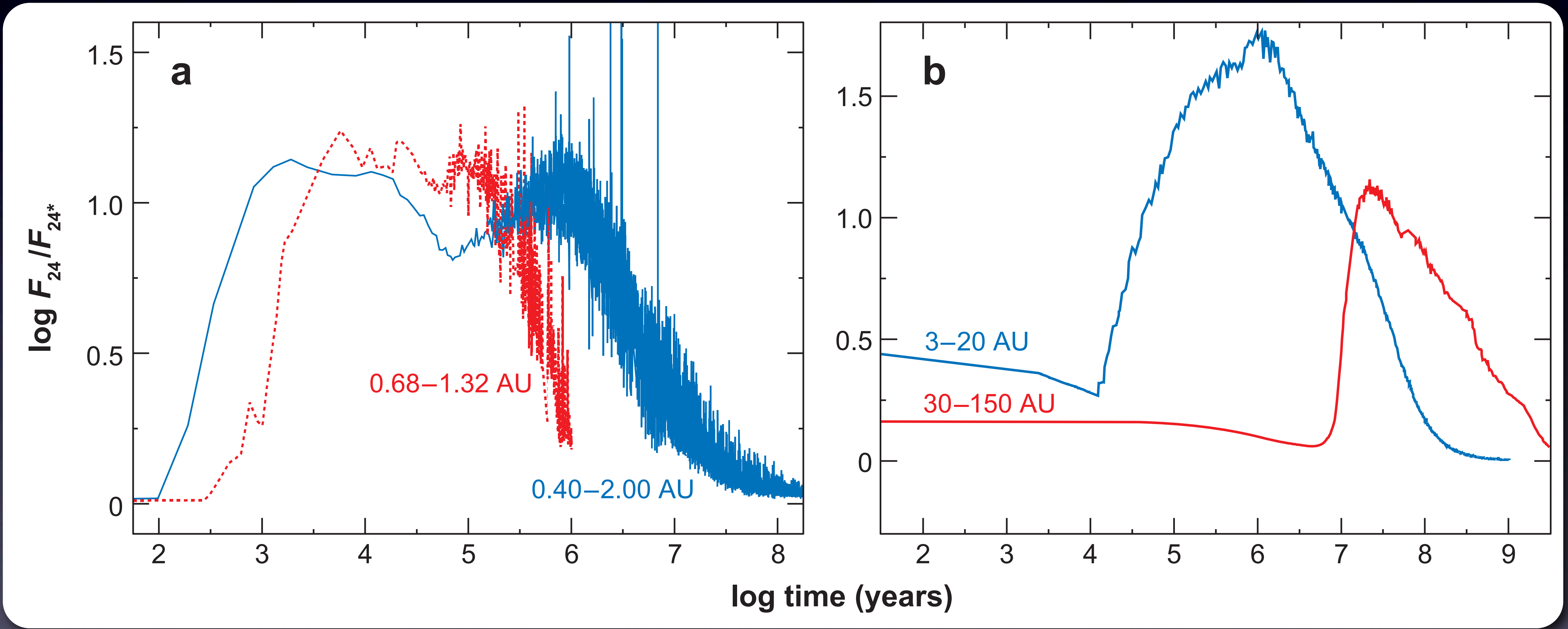
# Sizes of Dust Belts

- Inferred sizes around FGK stars span Solar System scales
    - both asteroidal and cometary type dust
- Sizes inferred from IR excesses often underestimate by factor of ~3




Jewitt et al., Carpenter et al.

# Dust Production by Stirring




Kenyon & Bromley (2004)

# Debris Disk Structure

- Resolved imaging to break degeneracies between grain properties and disk structure
- Scattered-light imaging requires high contrast
- Thermal imaging requires good sensitivity and angular resolution

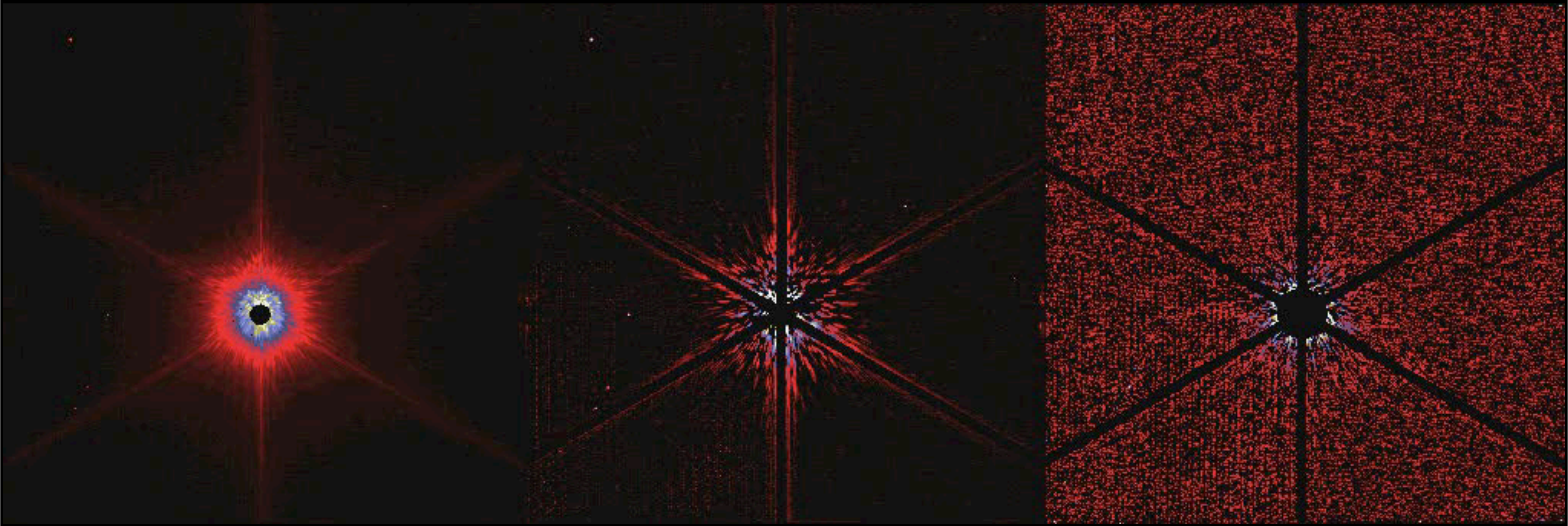
# Topics Addressed with AO

- Location and timing of planet formation
- Composition and structure of solids
- Giant planet migration mechanisms

# Current AO Work

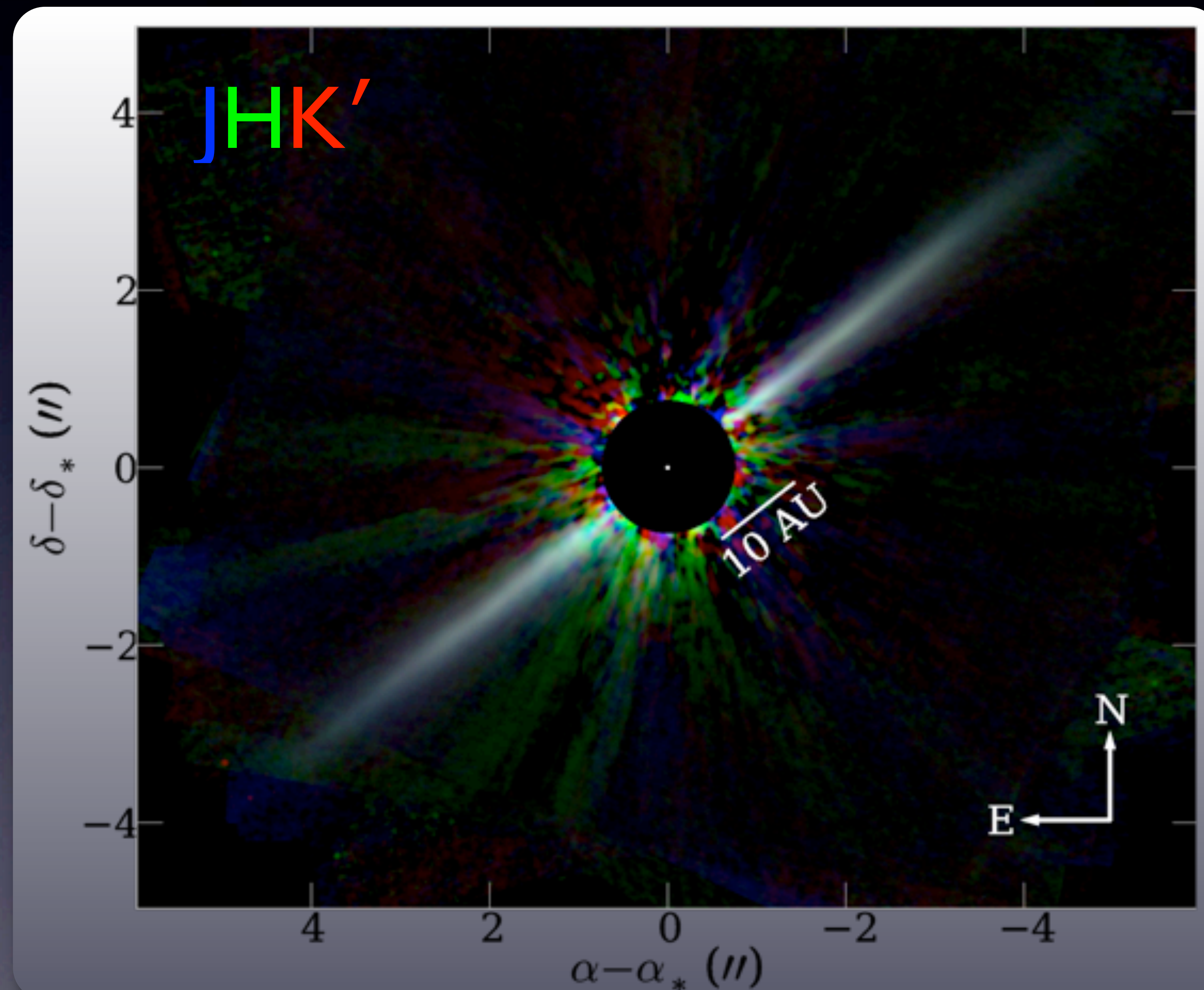
- Imaging in scattered light
  - only bright, dusty systems
  - previously resolved
  - sharp features amenable to PSF subtraction
- Only a handful resolved with AO

Observations Filtered PSF Subtracted

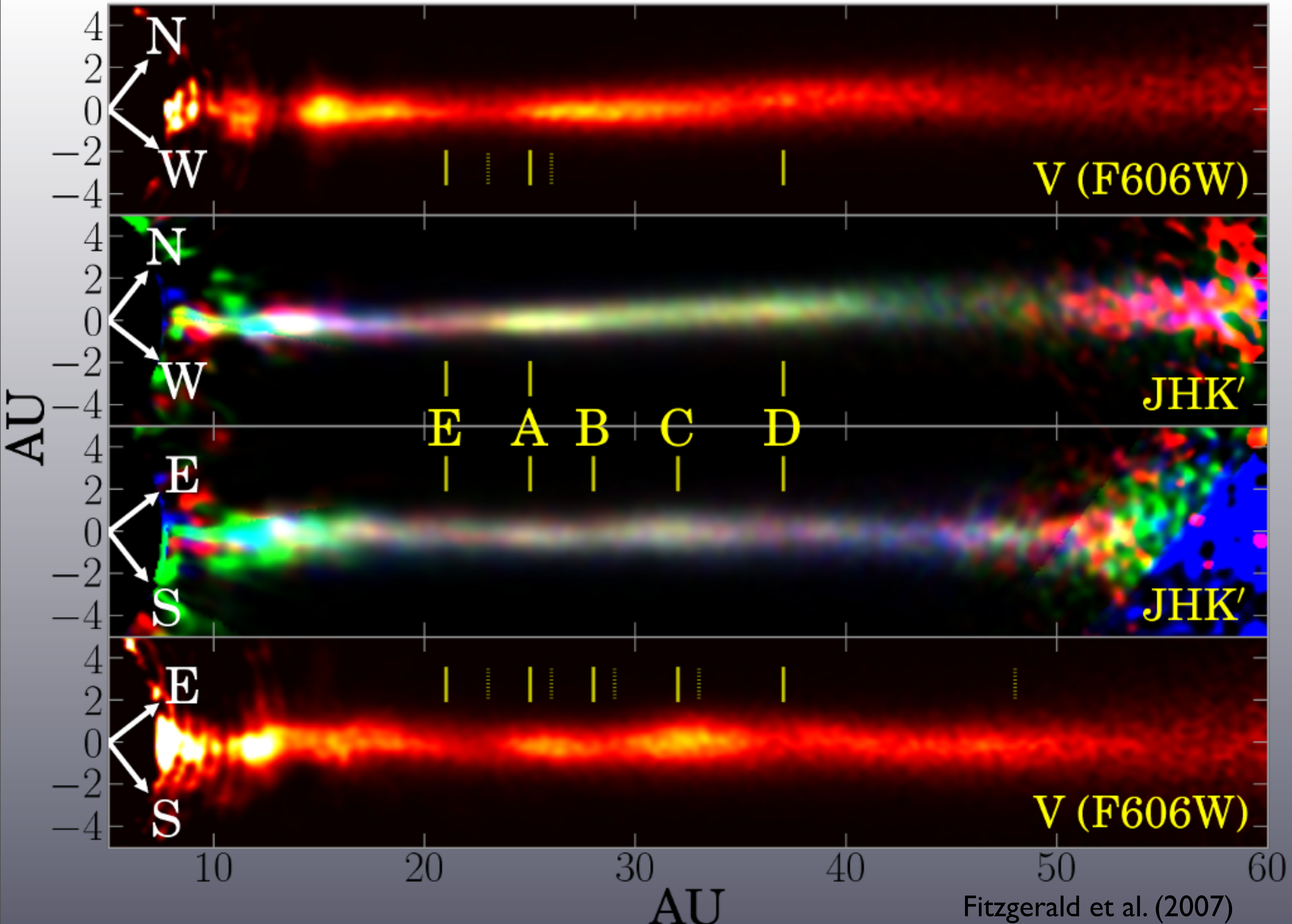


# AU Mic

- MIV
- 10 pc
- β Pic Moving Group
- 12 Myr (Zuckerman et al 2001)
- $L_{IR}/L_{*} \sim 5\times10^{-4}$



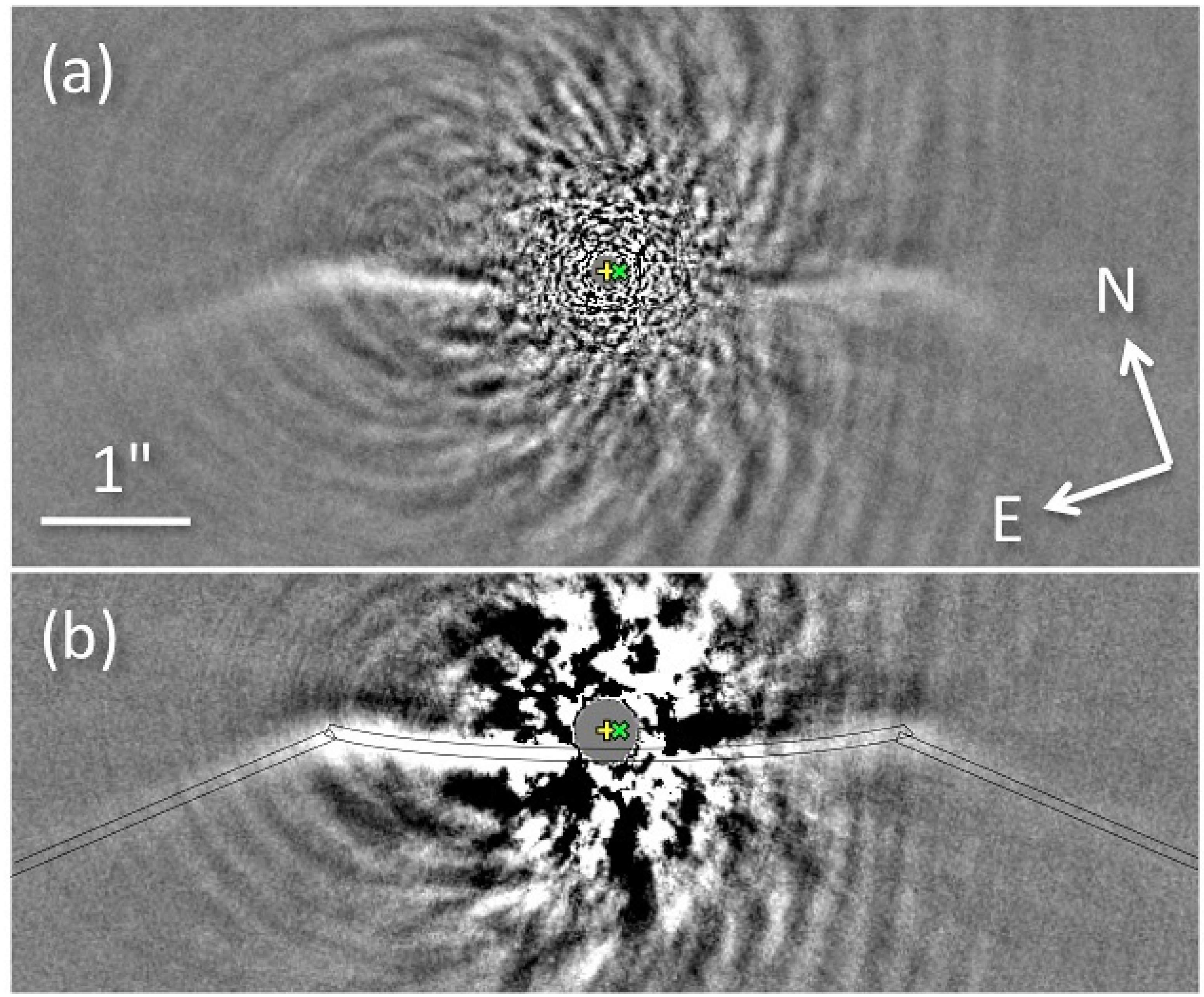

Fitzgerald et al. (2007)




Wednesday, June 20, 2012

# HD 61005

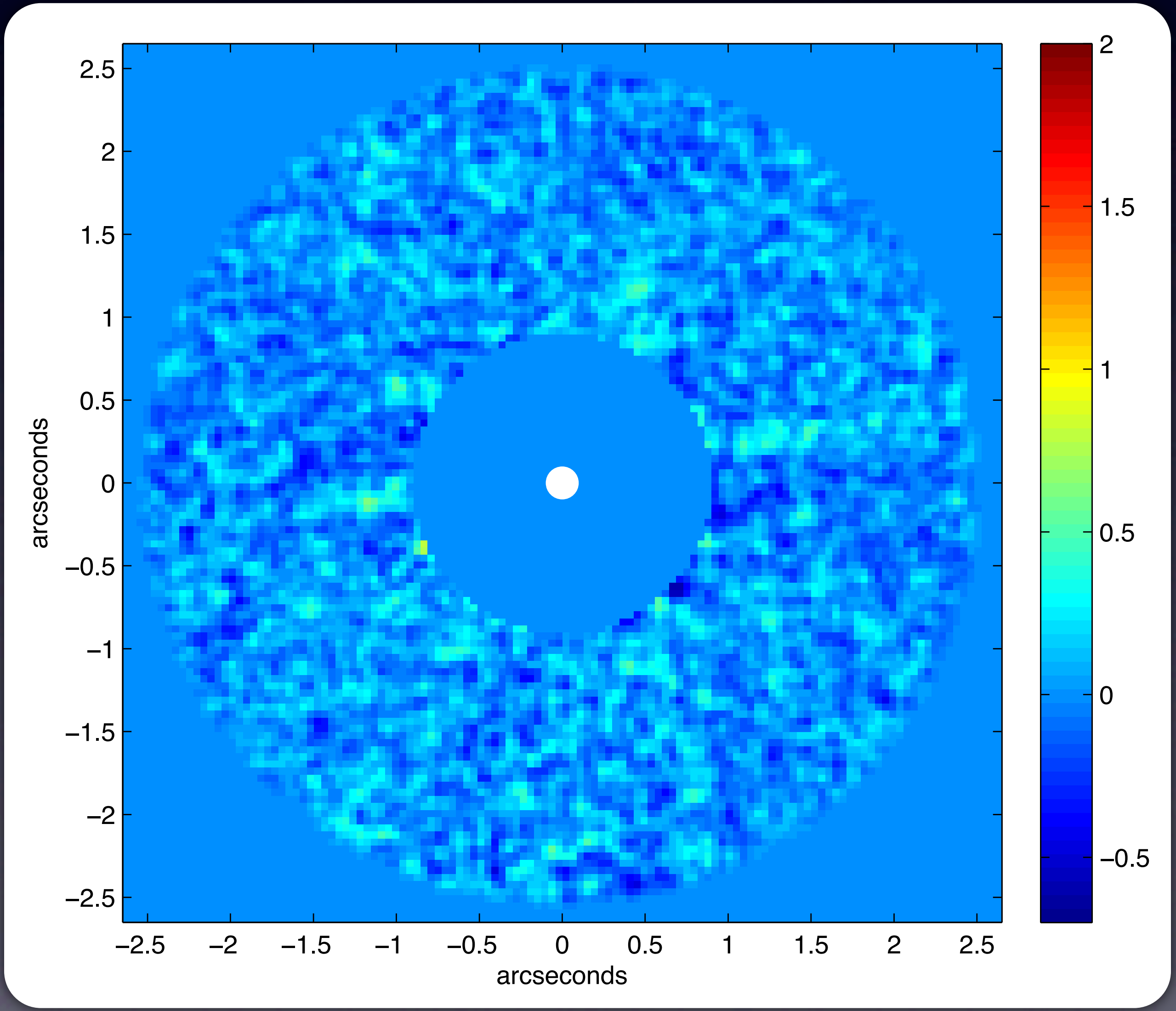
- G3/G5 V
- 35 pc
- 40 - 120 Myr
- $L_{IR}/L_* \sim 2\times10^{-3}$
- VLT/NaCo - *H* band
- Detected offset




Buenzli et al. (2011)

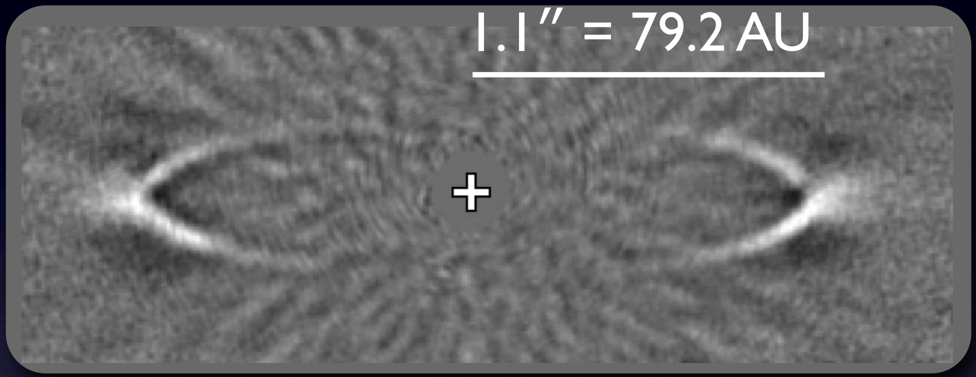
# HD 15115

- LBT/LMIRcam - $L'$ band
- $L_{IR}/L_* \sim 5\times10^{-4}$




Rodigas et al. (2012)

# HR 4796A




Thalmann et al. (2012)

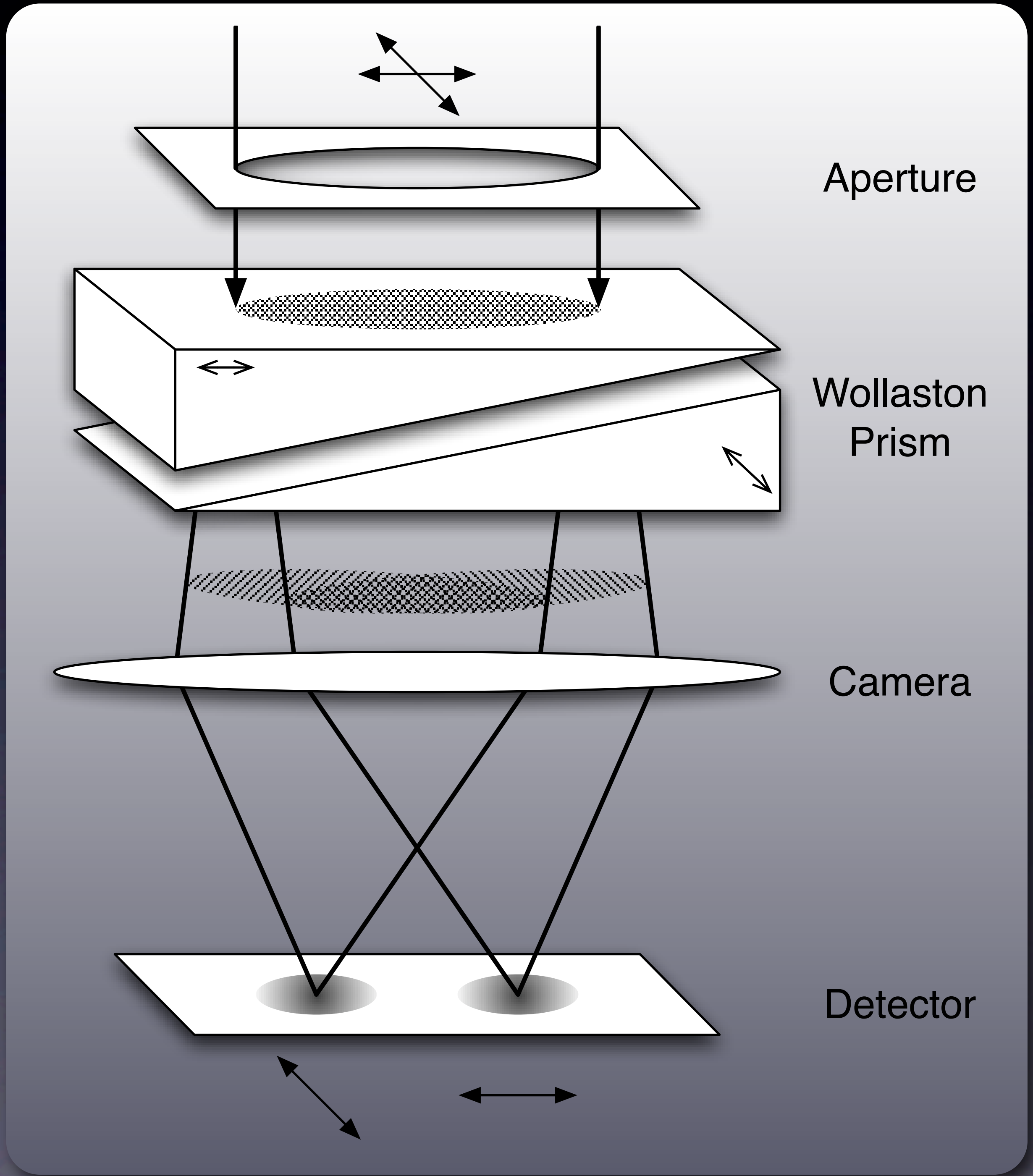
- Subaru/HiCIAO - *H* band
- $L_{IR}/L_* \sim 5\times10^{-3}$
- Detected offset

# ExAO Systems (Coming Soon)

- GPI, SPHERE, etc.
  - low WFE
  - bright NGS
  - polarimetry
  - GPI J-K, SPHERE/ZIMPOL 0.5-0.9 um

# Dual-Channel Polarimetry

- Simultaneous measurement of two polarization states
- Upstream modulation
- Calibration of instrumental polarization
- Break degeneracies between scattering phase function and dust spatial distribution



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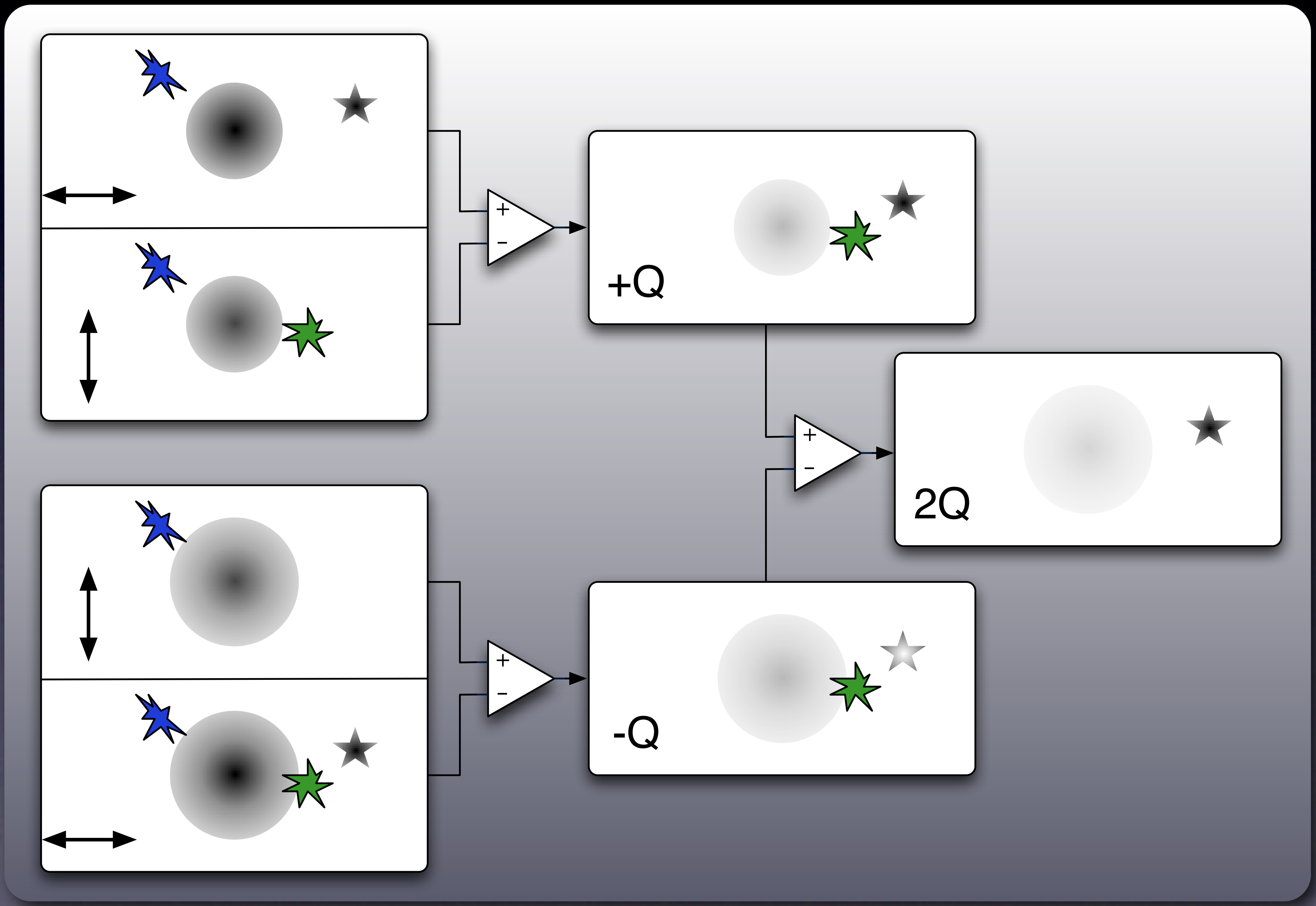
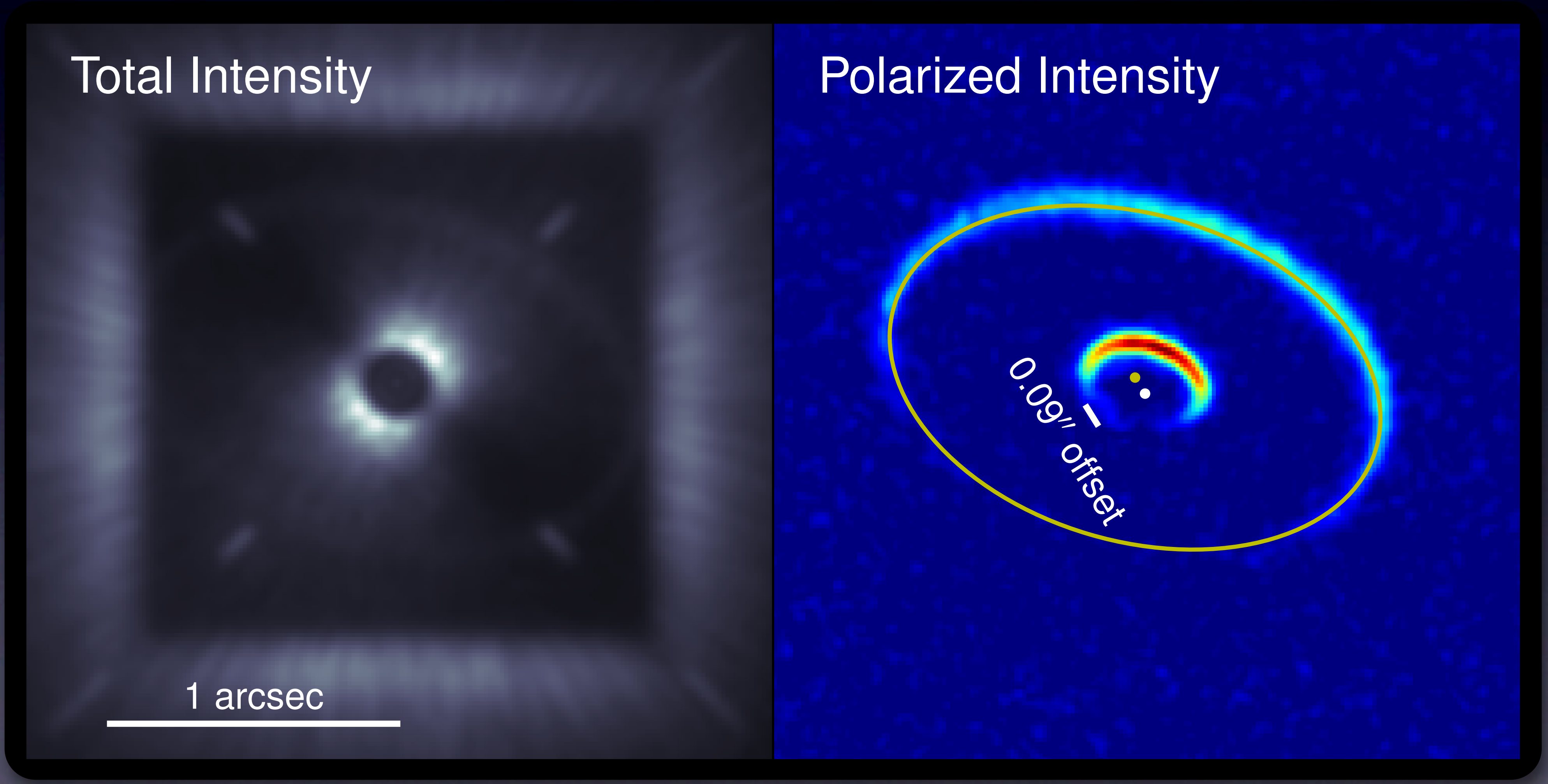
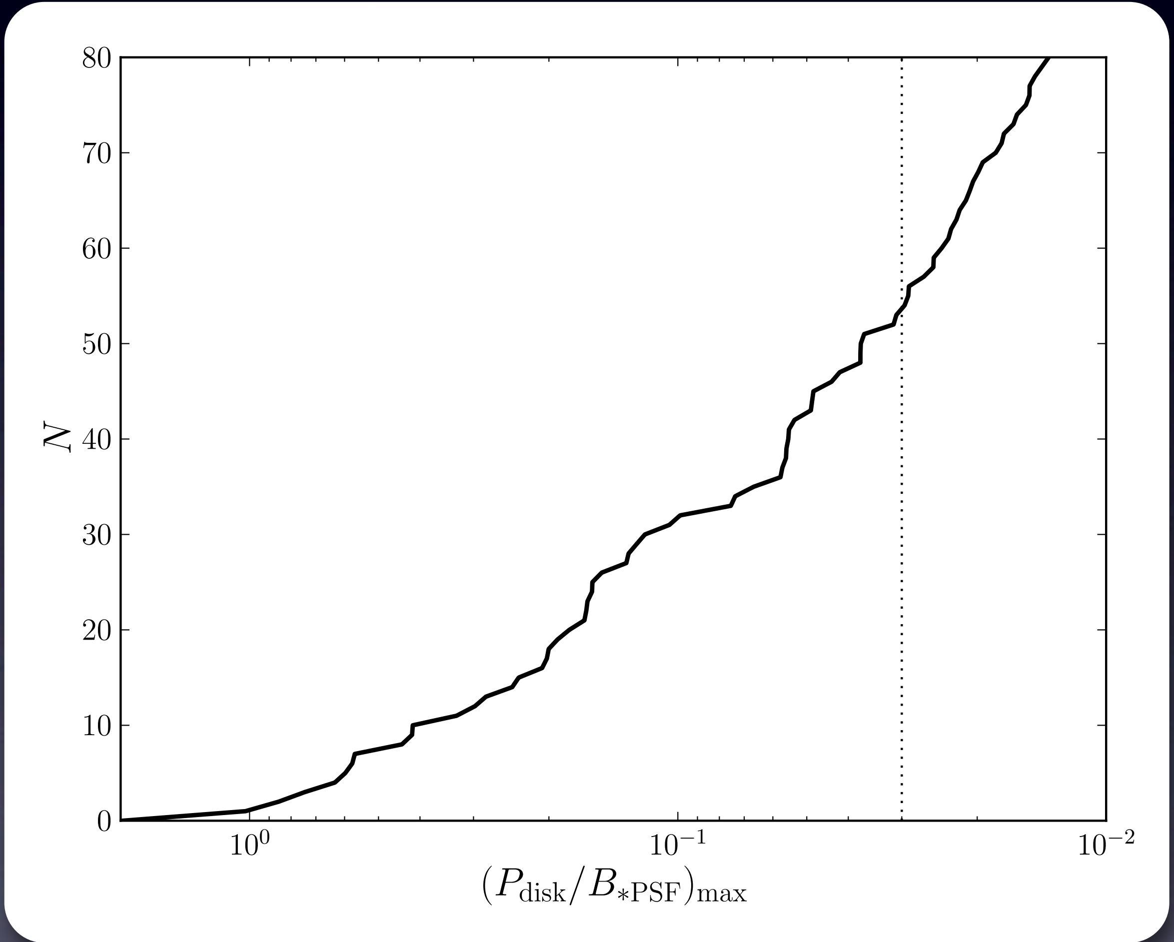


# GPI Debris Disks



# GPI Debris Disks

- contrast gains due to high-order AO and APLC
- increase in contrast by looking in polarized light
- decrease in IWA increases number of accessible systems
- $L_{\rm IR}/L_* \sim 3 \times 10^{-6}$ can produce detectable polarized light

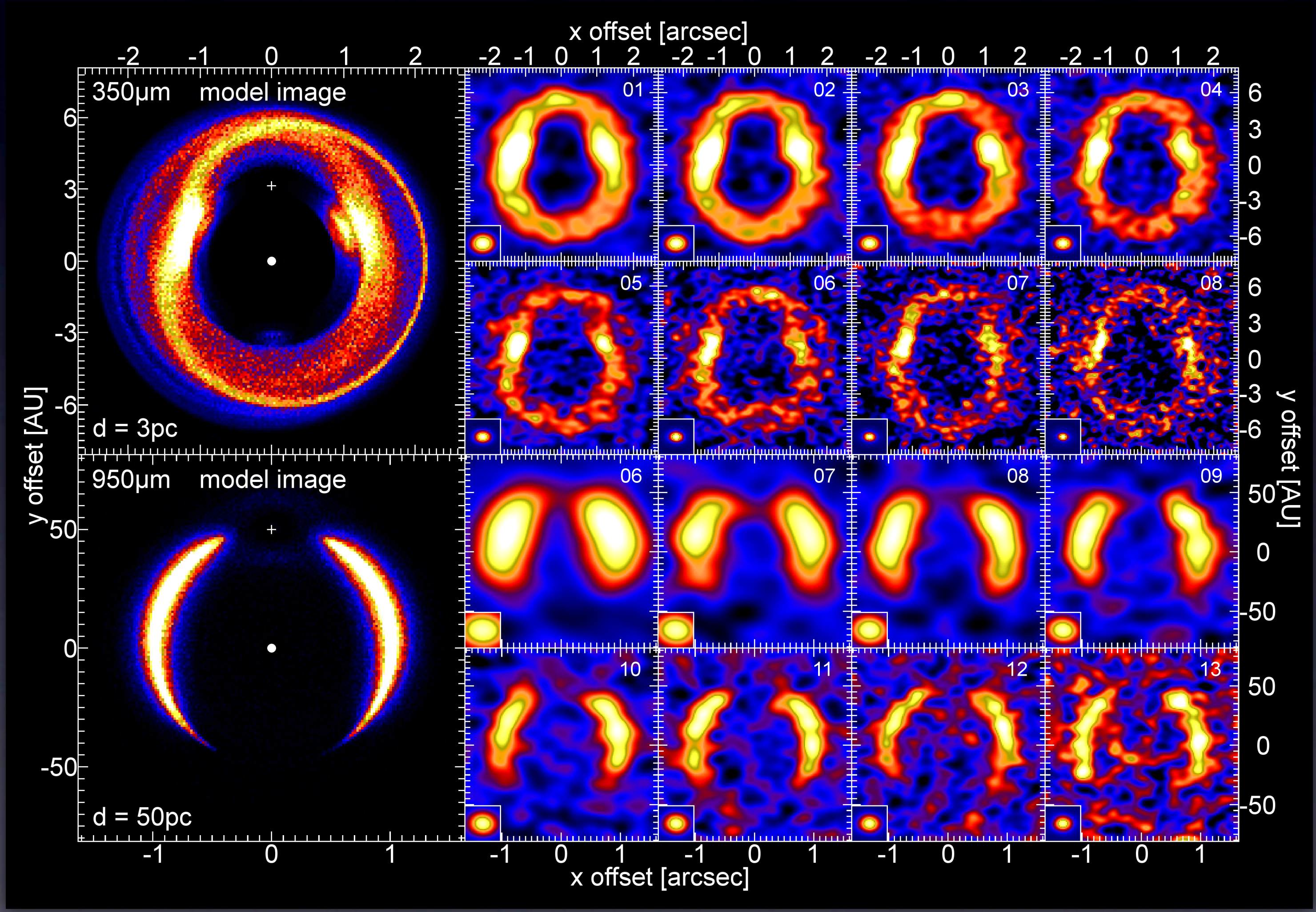


# AO Disk Imaging Summary

- High Contrast enables detection
  - low WFE
  - PSF stability
- Scattered light traces dust properties and location
  - 0.5 to 10s of arcseconds

# Future Facilities

- ALMA
  - 0.03″ resolution on longest baselines (1 AU @ 30 pc)
  - mapping structures traced by mm grains
  - sensitivity to resolved structure will be roughly limited to *Spitzer*-detected sample




Ertel et al.

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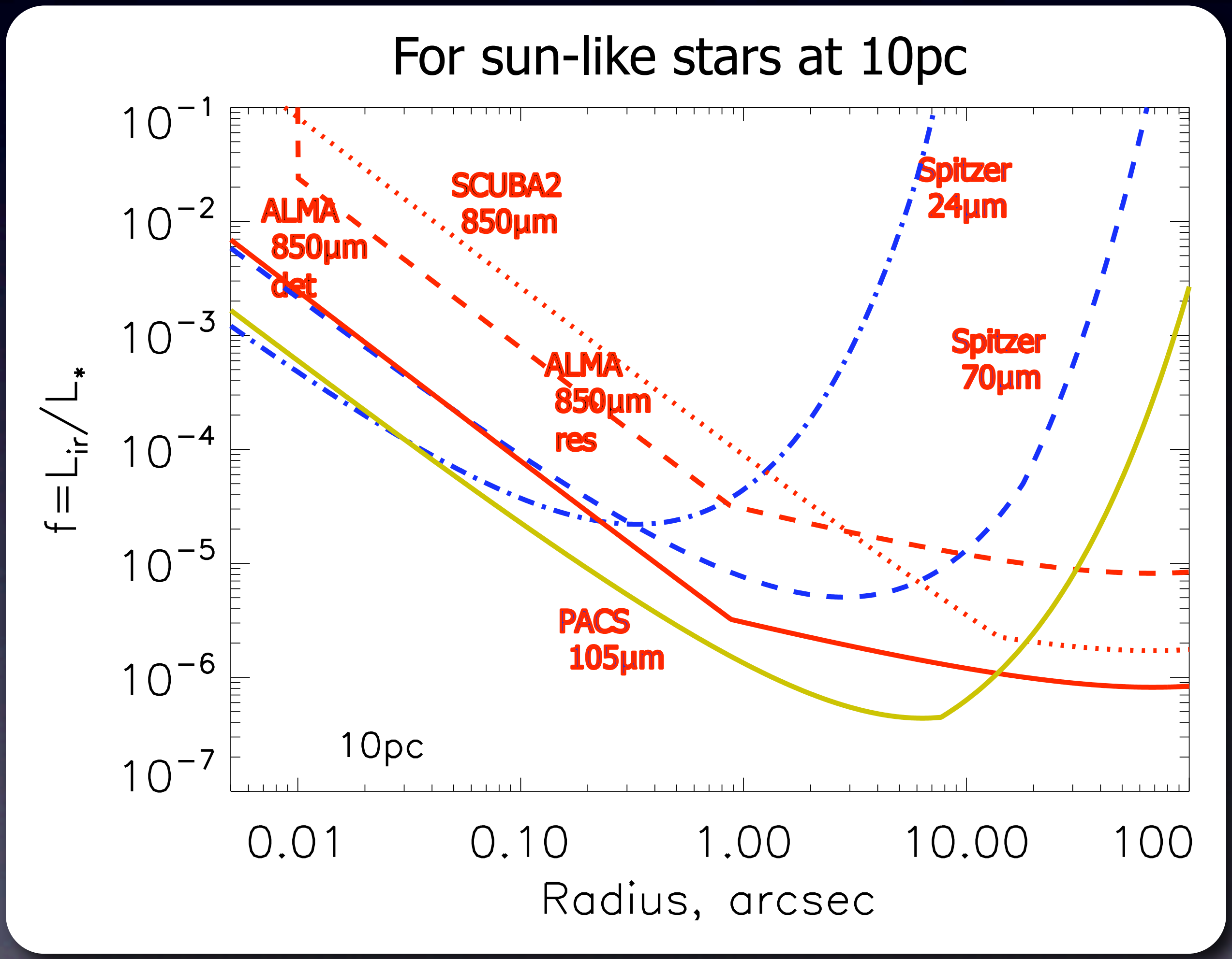


Wyatt et al.

# Connection to Future GNAO

- Optimize for:
    - relatively narrow field (<10″)
    - NGS
    - low WFE
- Highest contrast with ExAO-like system
    - Save money: bring GPI to GN, or GPI upgrades
    - Exploit 3-5 µm regime
        - 100 nm WFE @ 1.6 µm ⇔ 200 nm WFE @ 3 µm
        - also advantageous for emission from young gas giants
        - better angular resolution than *HST*

# Connection to Future GNAO

- Polarimetry is important for contrast
  - up-looking port
  - waveplate before any high-incidence optics (M3) or transmissive optics (dichroic)
- Push toward shorter wavelengths
  - better angular resolution
  - however smaller grains more strongly affected by dynamical perturbations, e.g. radiation pressure
  - poor PSF stability compared to *HST*