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Circumstellar Emission from Young Stars

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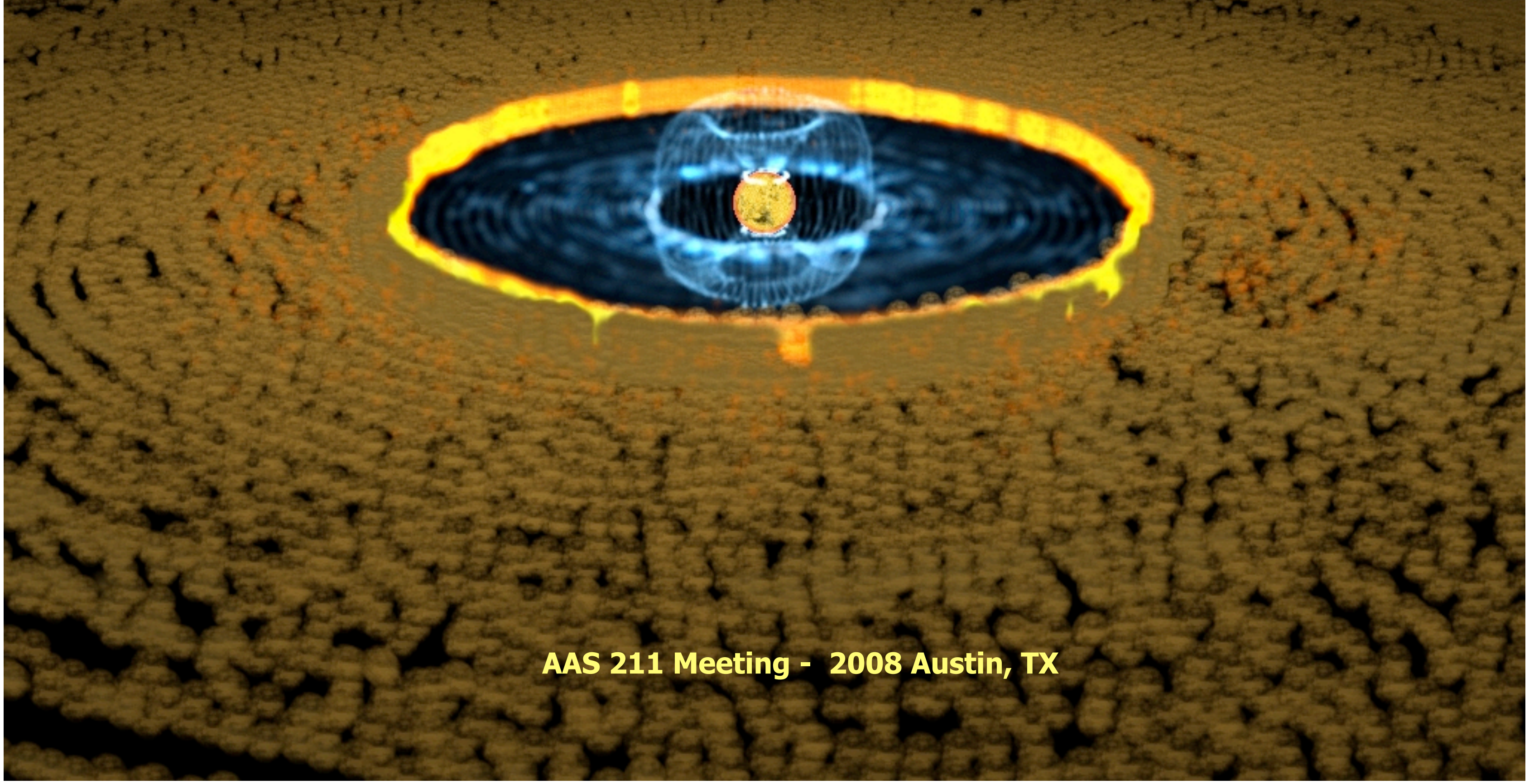


AAS 211 Meeting - 2008 Austin, TX

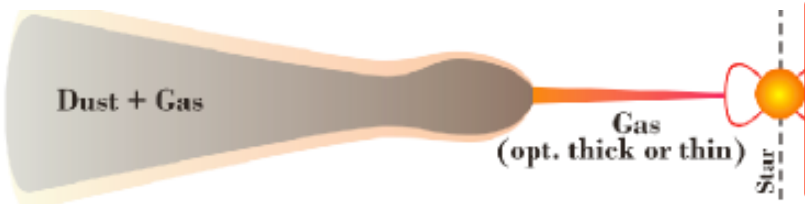
Introduction

- Motivation: spatially resolve the inner regions of disks around young stars.
  - $\lambda/2B$ = 4mas for B=100m λ=2.2μm or 0.4 AU @ 100pc
  - $\lambda/2B$ = 21mas for B=100m λ=10μm or 2 AU @ 100pc
  - Break the degeneracies inherent to SED modeling alone.
  - Help establish the disk geometry and physical properties of the dust & gas from near the star to few AU (initial conditions for planet formation).
- A young and productive field: since 1998, ~45 refereed, YSO science papers.
- (Arguably?) Highlights of first generation results:
  - Measured characteristic NIR sizes (IOTA, PTI, KI).
    - Larger than expected
    - Motivated a new class of models for the inner dust disk (dust rim models)
  - Measured characteristic MIR sizes (VLTI/MIDI) & spectrally resolved interferometry
    - Established correlation between MIR sizes and degree of outer disk flaring
    - Detected radial gradients in dust chemistry (grain size & composition).
  - Measured the first closure phases (IOTA/IONIC)
    - Strong CP signatures expected from sharp inner disk edges not seen

See the review in 2005 Protostars and Planets V (Millan-Gabet et al. 2007)

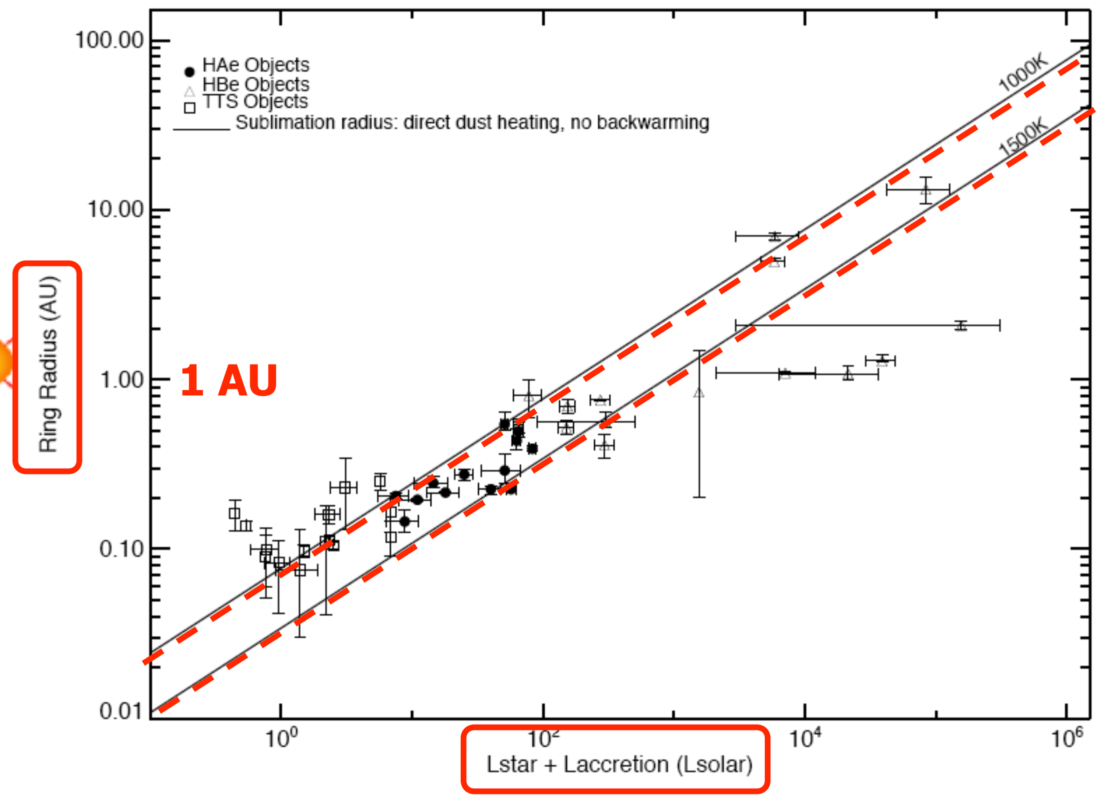
Highlights since 2005

The Inner Dust Rim and Its Problems



Sketch from Kraus07

Refs: Tuthill01, Natta01, Dullemond01, Monnier&Millan-Gabet02, Isella05 …

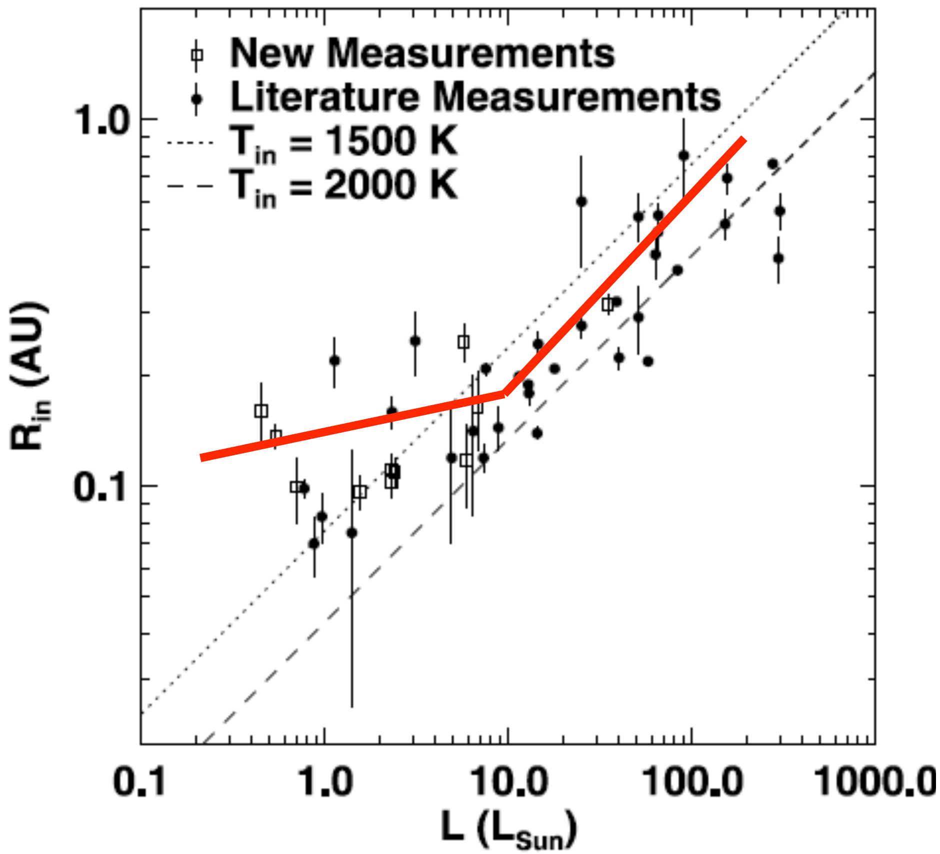


- Describes well the essential characteristics of the SEDs & measured NIR characteristic sizes across a large range of Lstar.
- But, must not be the whole story …
  - There is large scatter in the relation
  - Some T Tauris objects are “too large”
  - Some high luminosity HABe objects are “too small”
  - For some objects detailed radiative transfer calculations do not reproduce the measured sizes

T Tauri Objects

- A significant fraction (~50%) of TTS NIR sizes measured (PTI, KI; Akeson00,05; Eisner07a) are much larger (~x2-3) than predicted by inner rim models.

  -- Eisner 07a also used NIR spectroscopy to infer Fstar/Ftotal (veiling) and the accretion luminosity (Brγ).

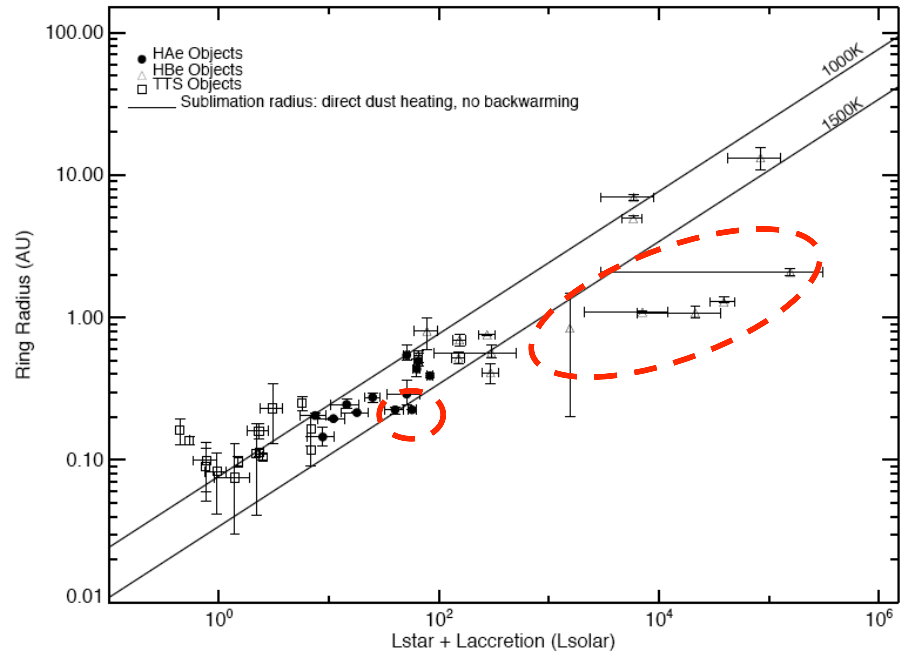


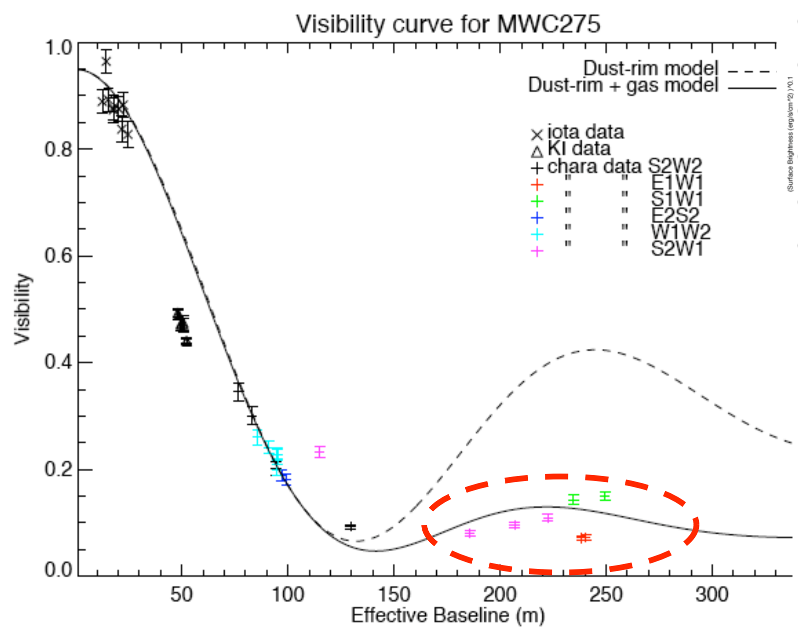
Interpretations:

- Dust disk truncated by stellar magnetosphere, not dust sublimation (Eisner 07a).
- For the cooler stars especially, (stellar & disk) light scattered by disk contributes significantly to the measured visibilities (Pinte 07).

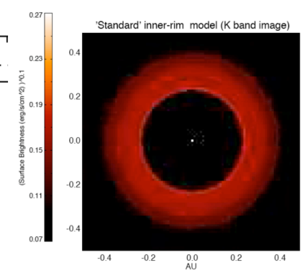
Herbig Ae and Be Objects

- Some very high L objects have NIR sizes much smaller than dust sublimation radius.
  - Shielding of dust wall by UV gas opacity (Monnier&Millan-Gabet02)
  - "standard" flat disk (Eisner04)
- Also, for some intermediate Lstar objects, detailed rim models fail to reproduce the measured NIR sizes (too large by x2-4): ABAur, MWC275, MWC147 - Isella06, Kraus07, Tannirkulam thesis talk Friday AM (145.03D).
- Main additional (come-back) ingredient needed appears to be NIR emission by hot inner gas (also postulated by Eisner07b based on V(λ) for 5 PTI channels)
- Confirmation probing detailed inner disk morphology with CHARA very long baselines (ABAur,MWC275; Tannirkulam08).

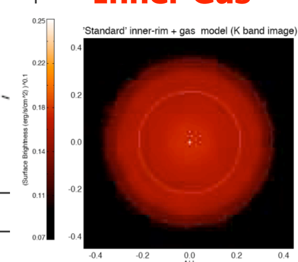




Inner dust rim only



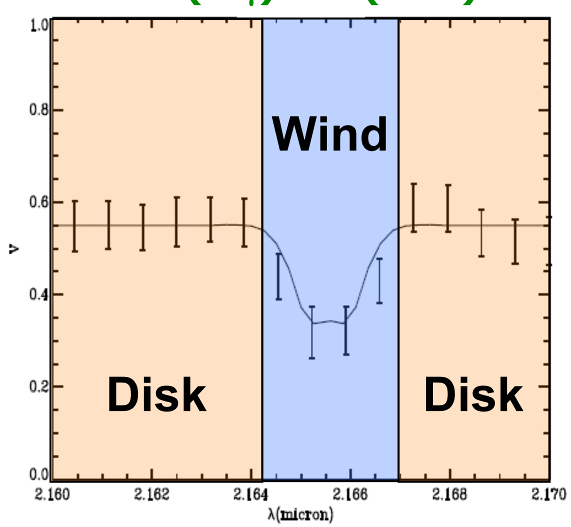
Rim + Inner Gas



Interferometry of Gas Spectral Lines

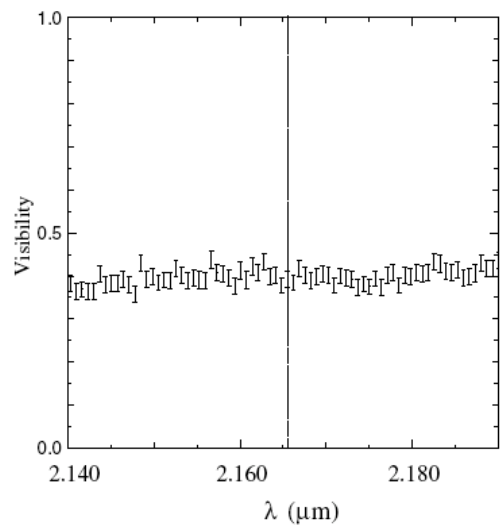
- Emission lines are used to infer the physical properties of CS gas, and to constrain its geometry & dynamics. Their exact origin, however, is not known.
- Low-medium spectrally & spatially resolved visibility measurements (KI, VLTI/MIDI, VLTI/AMBER) provide powerful additional constraints on the location of the gas emission.
- H-gas lines have been detected, and can be found to arise at spatial scales that are larger, smaller, or same as the (dust) continuum: accreting or outflowing components, perhaps depending on the relative importance of Lstar vs. Lacc.
- Also detection of H2O vapor (Eisner07c) and CO gas (51 Oph - HBe, Tatulli08).

V(Brγ)<<V(cont)



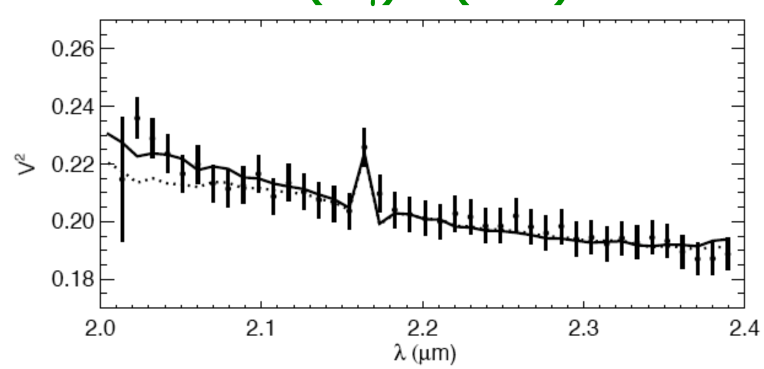
MWC297 HAe - Stellar wind (Malbet05)

V(Brγ)=V(cont)



HD104237 HAe - Base of disk wind (Tatulli07)

V(Brγ)>V(cont)



MWC480 (HAe) - Hot inner gas (Eisner07c)

decreasing Lstar

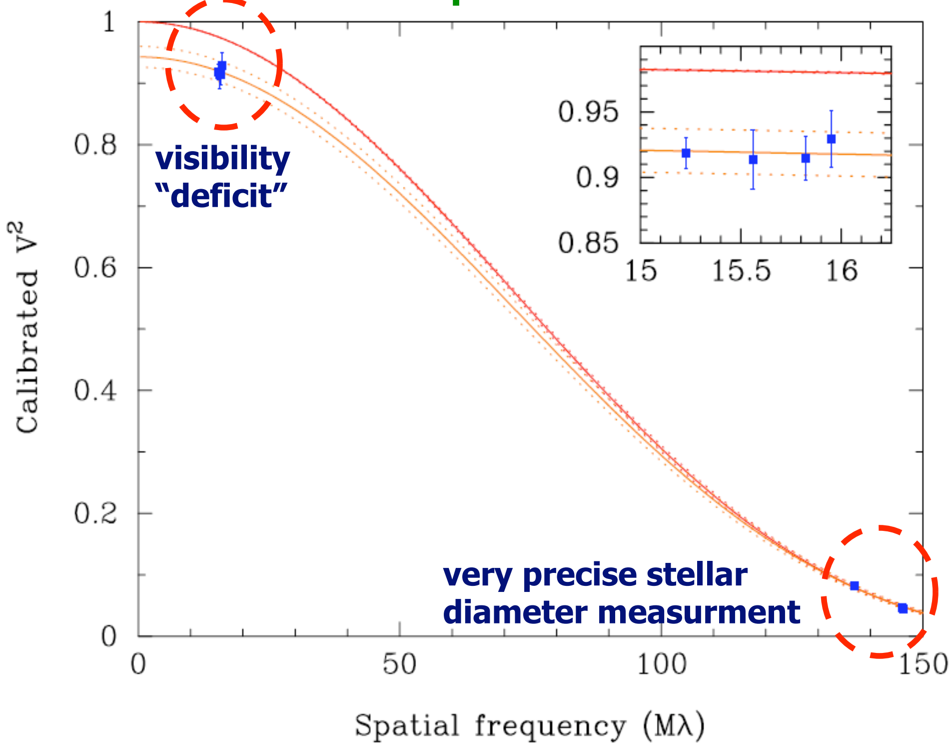
Additional Recent Young Disks Results

- The few-AU "outer" disk:
  - HAe: MIR sizes well correlated w. degree of flaring (MMT & Magellan Nulling, Liu06).
  - HBe: MWC349-A - simple disk model work well, also many gas line detections. (VLTI/MIDI, Vis and DP!, Quirrenbach poster 057.10).
  - TTS: RY Tau - adding envelope works better than simple flared disk (VLTI/MIDI, Schegerer07).
  - FU Oris: Standard flared disk models work well (FU Ori, v1647Ori; VLTI/MIDI; Quanz06; Abraham06).
- Transition object TW Hya: smaller inner hole than previously inferred; inward-out dispersal rather than planet clearing? (VLTI/MIDI, Ratzkal07).
- HD5999 (HAe): companion-truncated disk? (2-3AU) (VLTI/MIDI, Preibisch06).
- Very massive YSO W33A (VLTI/MIDI, de Wit07): revised Lstar required.
- Circumbinary disks: HD98800B disk warping (KI, Akeson07); DQTau emission well inside circumbinary disk (KI, Boden poster 057.02).
- Young star dynamical masses: HD98800B (KI, Boden05), v773 Tau A (KI, Boden07), DQ Tau (KI, Boden08); see also G. Schaefer poster 057.03 on Haro 1-14c.

Debris Disks Systems - Hot Dust in Exo-Zodi Clouds

- Observations (IRAS, Spitzer, JCMT) have established the existence of debris disks of "second generation" dust; primarily distant 10s-100s AU cold (50K) dust (Kuiper analog).
- Much less is known about warmer (300K) dust near the habitable zone.
- Presence of such exo-zodi clouds at levels > 10 SSZ would prevent detection by planned Terrestrial Planet Finder missions.
- Spectrophotometric techniques are limited in sensitivity to ~1000 SSZ.
- Nulling techniques (KI, LBTI) will improve to 30-100 SSZ.

Example from CHARA:



Interferometers are now revealing a new population of even hotter (>1000K) close-in dust:

- Vega (PTI, Ciardi01; CHARA/FLUOR Absil06)
- τ Ceti (CHARA/FLUOR, Di Folco07)
- β Leo (CHARA/FLUOR, Akeson poster 057.09)
- more in the CHARA pipeline …

Conclusion

We continue to learn a great deal about circumstellar disks around young stars from long baseline optical (infrared) interferometry. In recent years, greatest progress has come about as a result of starting to use multi-technique (interferometry, photometry, spectroscopy …) and multi-facility (e.g. interferometry observables from more than one instrument and more than one interferometer) datasets, in conjunction with realistic models that take into account all the possible emission components (dust disk, gas disk, wind, envelopes - thermal and scattering emission).

Exciting Prospects! (USA)

- **KI:**
  - Nuller Key Science survey of TPF stars (2008).
  - See R. Barry poster 057.05 on first result from the Nuller (RS Oph nova).
  - ASTRA: Phase referencing for increased sensitivity to disk objects.
  - L-band: New (and unique) λ (and disk) regime.
- **CHARA** imaging combiners (MIRC+CHAMP, see Monnier talk next).
- **LBTI**- wide field “Fizeau” nulling.
- **MROI** - tremendous direct imaging potential (see M. Creech-Eakman poster 057.21).

CHARA

KI

LBTI

MROI