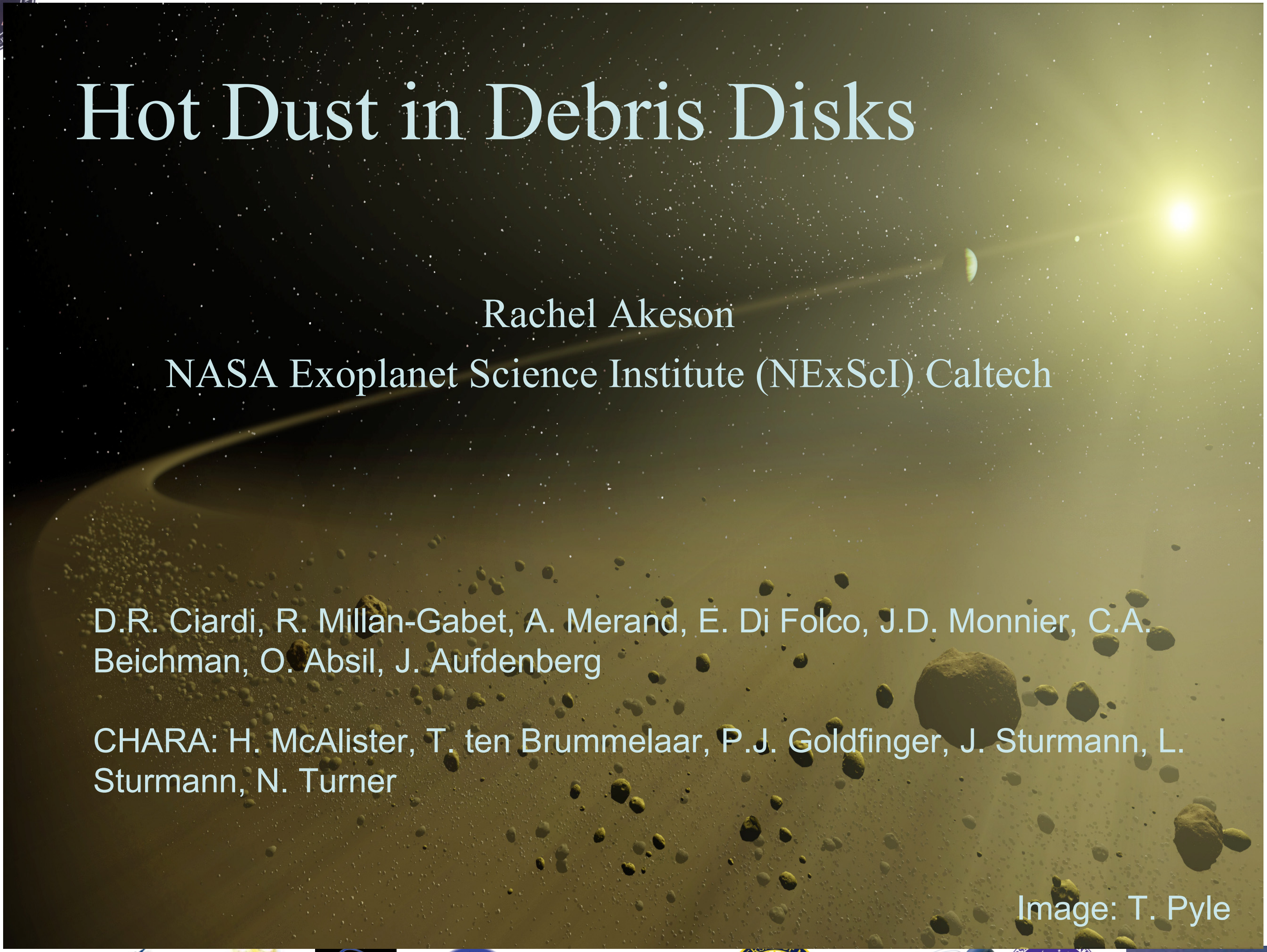

# Hot Dust in Debris Disks

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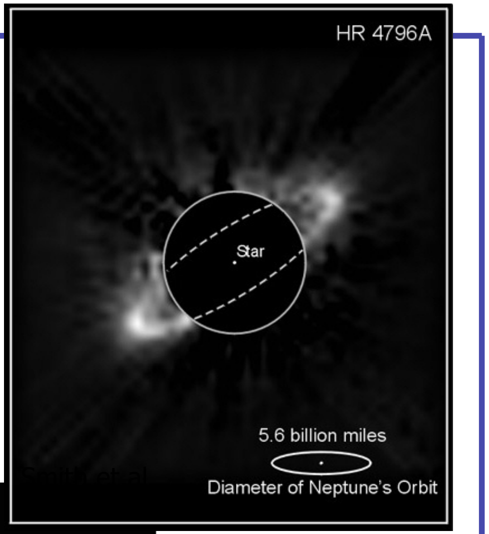
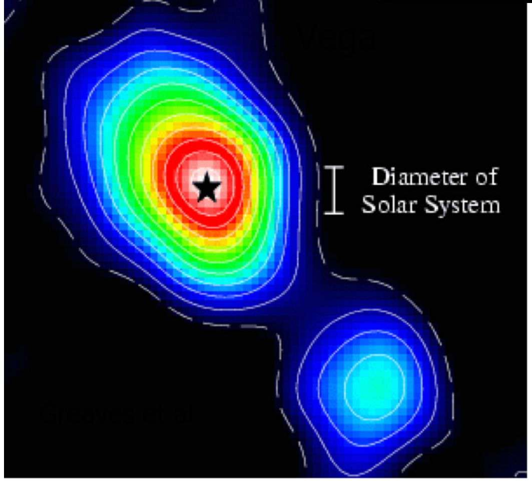
CHARA: H. McAlister, T. ten Brummelaar, P.J. Goldfinger, J. Sturmann, L. Sturmann, N. Turner

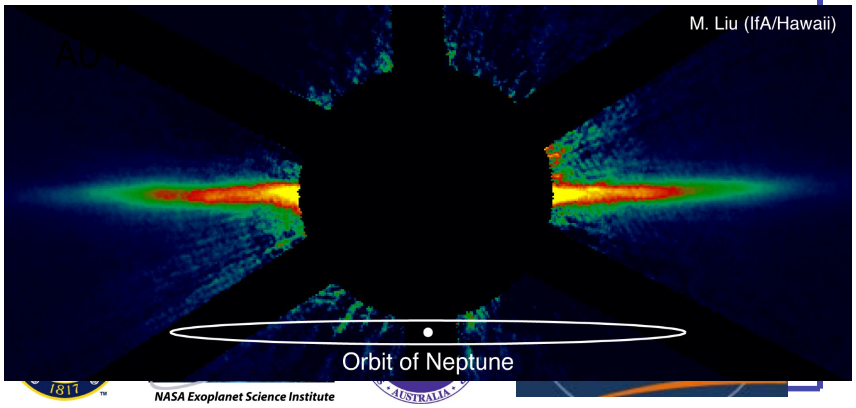
Image: T. Pyle

# Debris disks

- Circumstellar material around main sequence stars
  - First observed by IRAS, now imaging from optical to sub-millimeter
  - Dust grain survival time scales can be used to argue that material is not primordial, but must be generated from collisions of larger bodies
  - Spitzer observations are greatly expanding the number of known sources, but can not directly measure spatial distribution
  - Structures in images debris disks have been used to infer planetary sized bodies

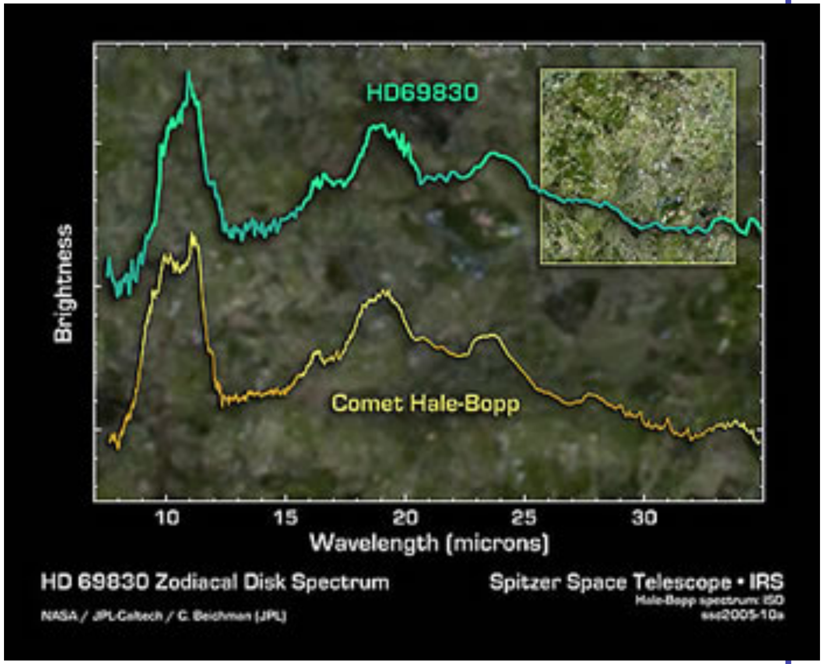






# Warm dust in debris disks

- The majority of known debris disks have dust located tens of AU from the star with temperatures < 100 K
- A small fraction have excess shortward of 30 microns (Rieke et al 2005, Beichman et al 2006, Su et al 2006)
  - Age dependant
    - FGK stars: 9-19% for t < 300 Myr, 2-4% t > 1 Gyr
    - A stars: 33% for t < 190 Myr, 2% t > 400 Myr
  - A few exceptional sources with dust within the central few AU have been discovered through spectral features and imaging



HD 69830 Zodiacal Disk Spectrum

Spitzer Space Telescope • IRS

Hale-Bopp spectrum: ISO

NASA / JPL-Caltech / C. Beichman (JPL)

ssc2005-10a

What about hot dust?

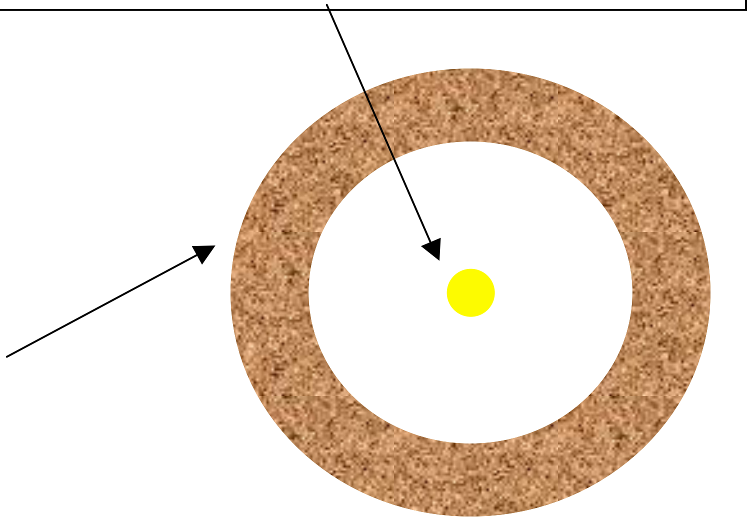
# Interferometry and debris disks

- Interferometry can determine the spatial distribution of the material close to the star
  - Much more sensitive to small amounts of emission than SED modeling
    - Bright stars
  - Use the interferometer to compare emission on short and long baselines
    - Short baselines = large spatial scales (star + disk)
    - Long baselines = small spatial scales (star only)
- First observations of this type: Vega (Ciardi et al 2001, PTI; Absil et al 2006, CHARA)
  - Emission at 2 microns in excess of the stellar photosphere
  - Multiple models for the spatial distribution

# Multiple baselines key

- Debris disk emission is a small fraction of stellar flux
  - The problem is not detecting the disk flux but in having the dynamic range

Interferometry measures the flux as a function of spatial frequency



Stellar photosphere ~ few mas
- resolved on baselines > 100 meters

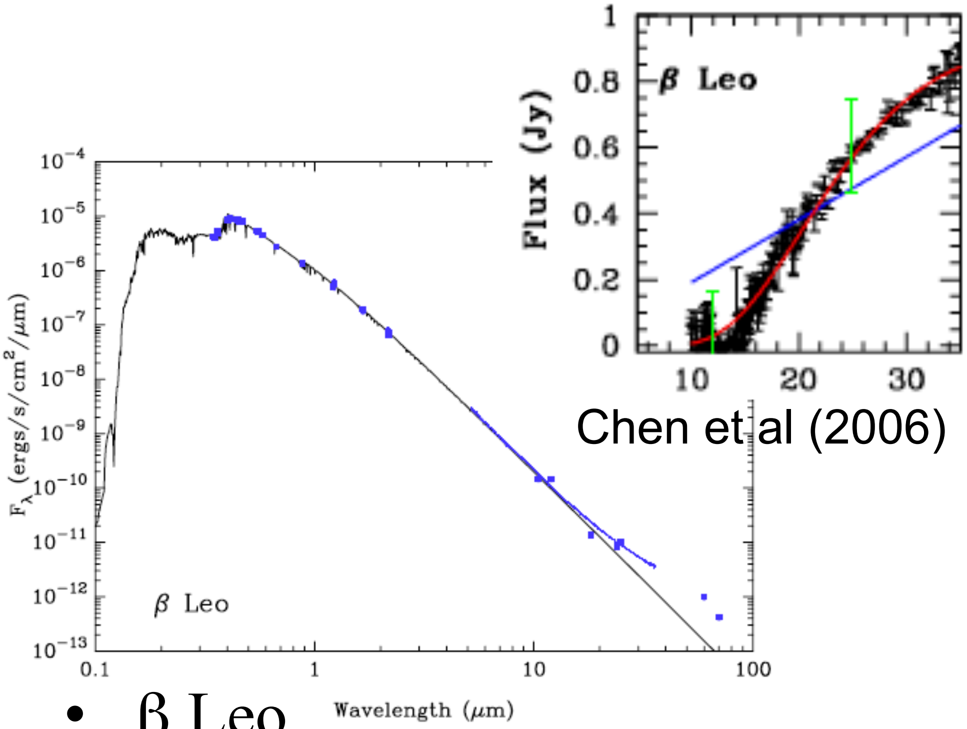
Dust ring > 10’s mas
- resolved on baselines ~ 10 meters

# CHARA observations

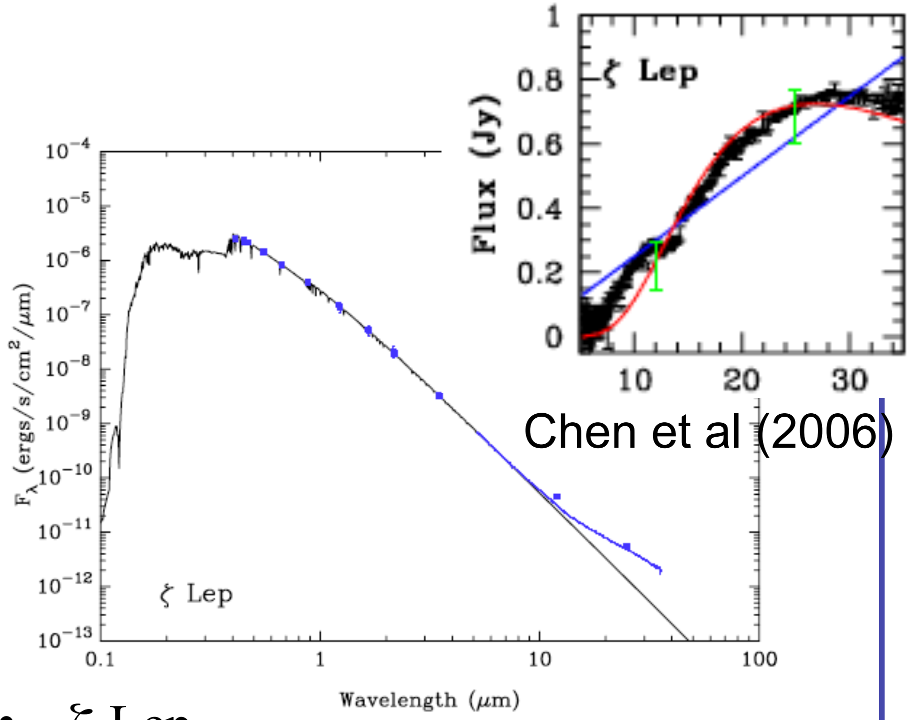
- S1S2 baseline was crucial to provide sufficiently short spacing

- Method
  - Use long baseline (high spatial frequencies) to accurately measure stellar diameter
  - Compare short baseline (low spatial frequencies) observations to expected value from star alone
  - Any additional emission component larger than the star itself will ***decrease*** the measured visibility

# Observed sources



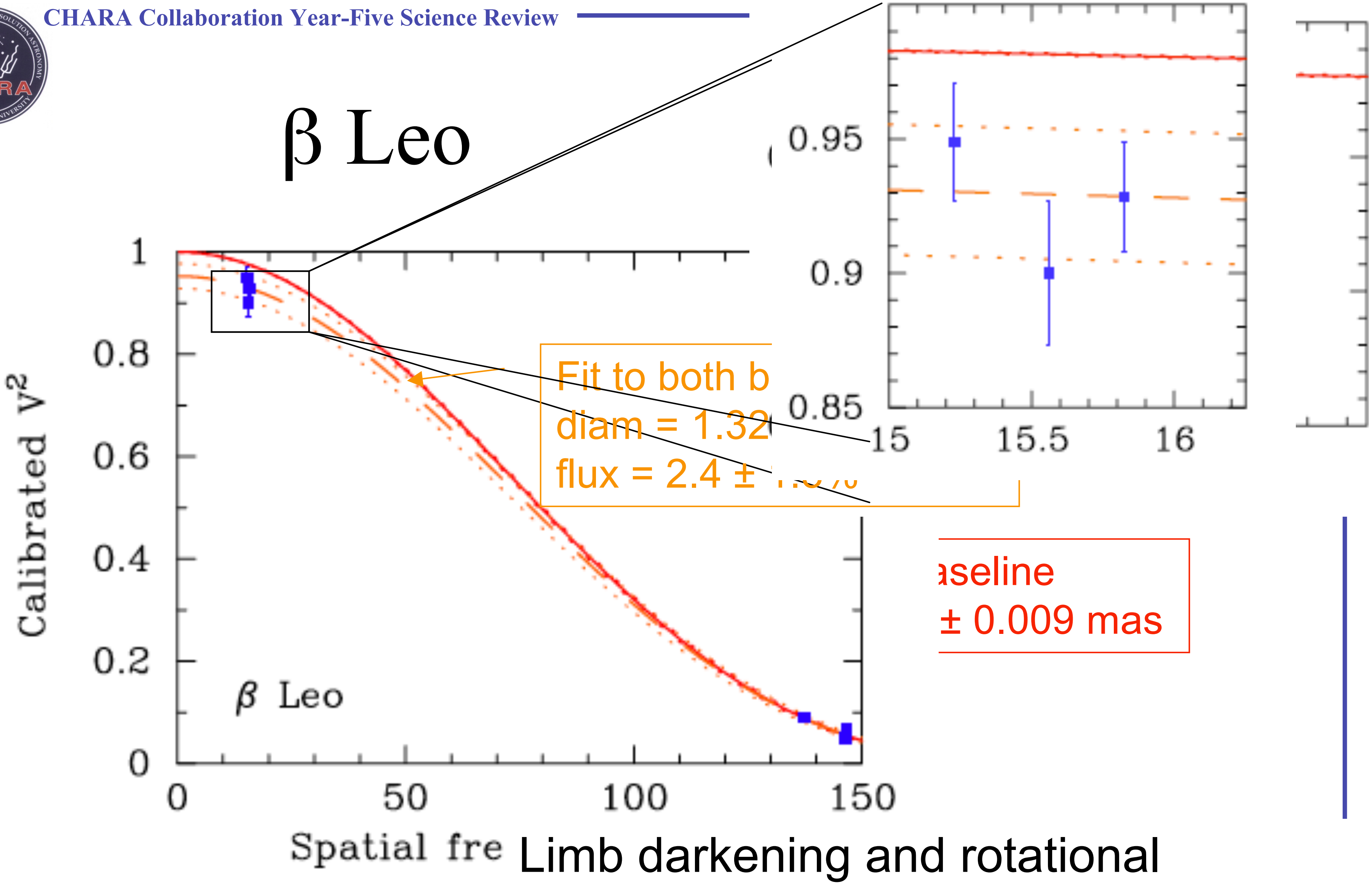
Chen et al (2006)



Chen et al (2006)

- β Leo
  - A3 star at 11 pc
  - IRAS discovered, featureless IRS excess
  - T ~ 120 K, radius ~ 19 AU
- ζ Lep
  - A2 star at 20 pc
  - IRAS discovered, featureless IRS excess
  - Resolved at 18 microns (Moerchen et al 2007)
  - T ~ 300 K, radius 2 - 8 AU

# β Leo



Fit to both b
diam = 1.32
flux = 2.4 ±

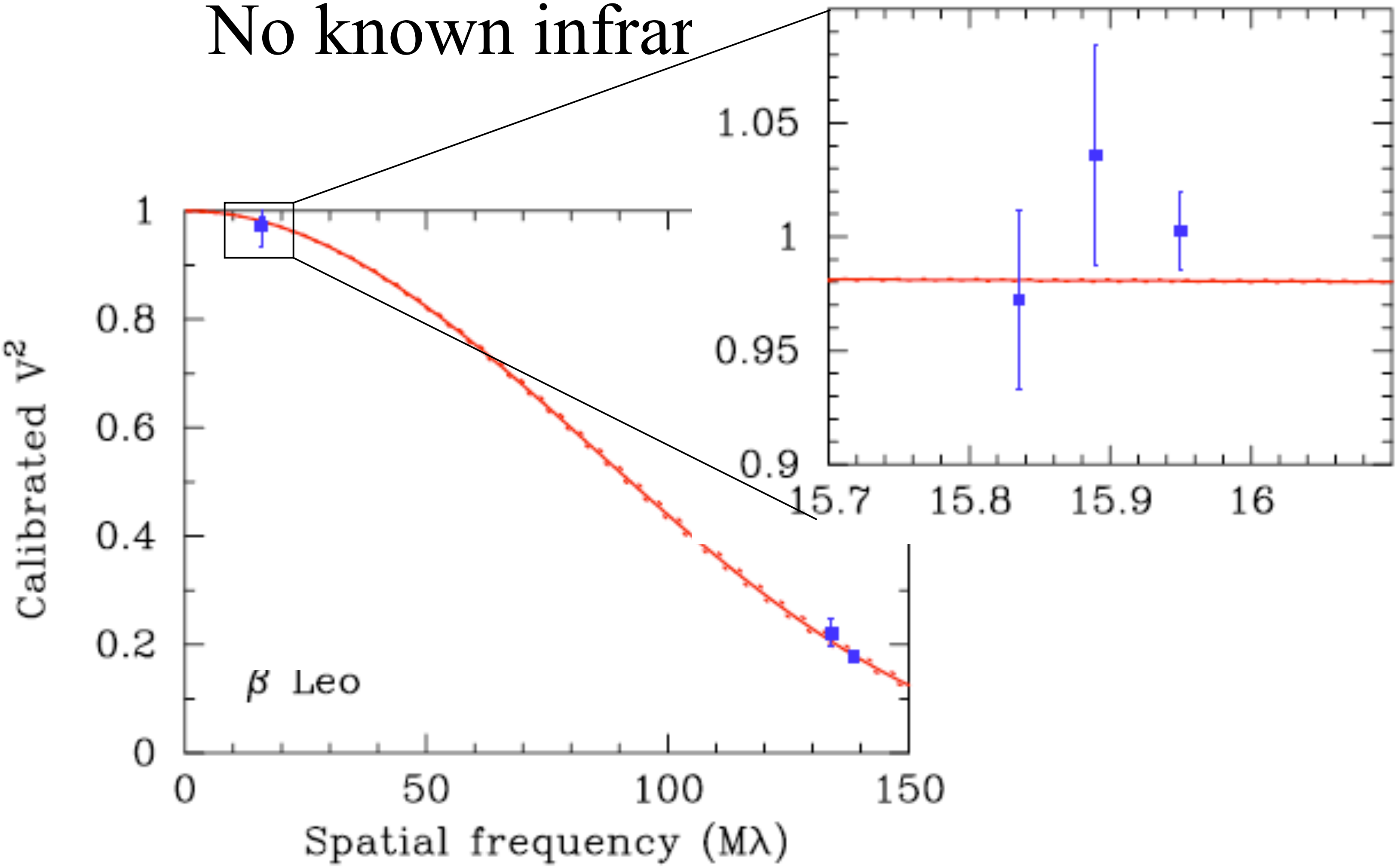
aseline
± 0.009 mas

Limb darkening and rotational oblateness not enough to explain difference

Akeson et al, 2009

# δ Leo: A5 star at 17 pc

No known infrar



# Interferometry results

- Near-infrared excess emission detected at 1-2% level toward both β Leo and ζ Lep (marginal detection)
- Interferometry data consistent with stellar photosphere + excess flux
- Possible origins of flux
  - Companion
    - Would have M spectral type
    - Hipparcos data rules out periods from tens of days to the edge of the FOV
      - Could be long period but passing within CHARA 0.8” FOV
      - Shorter period would have large (> 5 km/sec) RV signature
  - Emission or scattering from dust
    - Constrained by FOV (radius ~ 5 AU for β Leo, 9 AU for ζ Lep) and spectral energy distribution

# Dust morphology

Mid-IR belt

- Small grains gener[illegible] by collisions in mid[illegible] producing belt, [illegible]ft inw[illegible]d with PR drag

**Too much 10 micron flux**

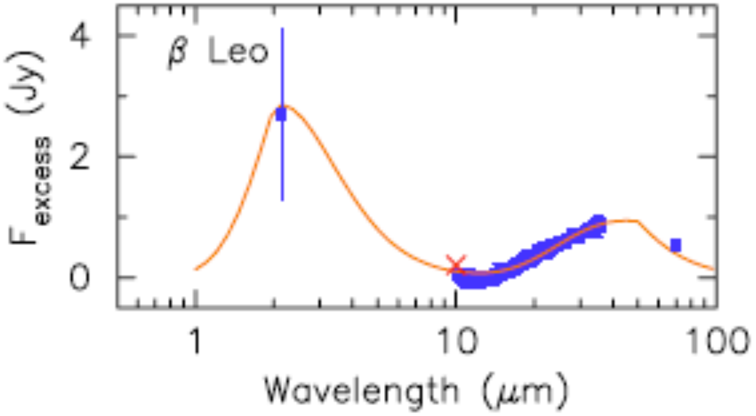
Inner dust ring

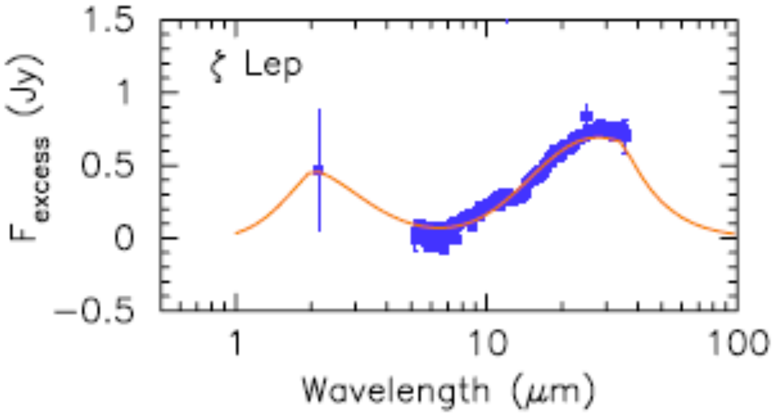
•Can match 2 and 10 micron flux with emission from small grains near the dust sublimation radius

•Excess flux dominated by scattering produces too much mid-infrared flux

# Simple dust distribution model

- 2 optically thin rings
- Grain emission efficiency ∝ $(\lambda_o/\lambda)^q$
- Inner ring
    - Inner radius < 0.2 AU
    - Sublimation temp ~ 1600 K
    - $q \sim 2$
    - $\lambda_o < 2$ microns
    - Mass > several x $10^{-9}$ $M_{Earth}$





Observations can not constrain detailed morphology of inner dust

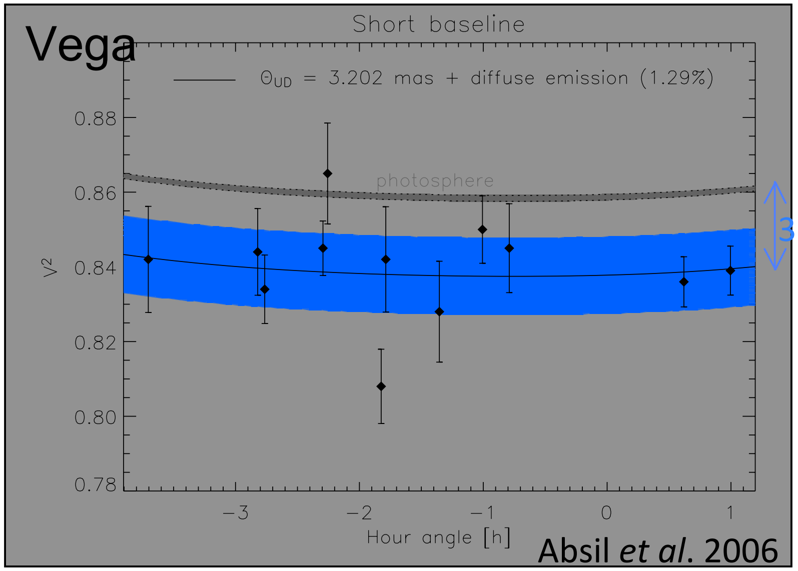
Could be geometrically thin and vertically thick

# Where does the hot dust come from?

- 2 to 10 micron flux ratio requires small, hot, non-silicate grains
  - Grain size is below nominal radiation pressure blowout radius →lifetime problem?
    - But clearing may not be absolute (Krivov et al 2000)
- Transient event (comet sublimation, recent asteroid collision)
  - Minimum mass necessary in inner disk can be generated by breakup of single 10 km radius body
  - Dust needs to be near sublimation radius
- Generated by collisions in planetesimal belt at < 1 AU

# Other interferometry results

- Vega (Ciardi et al 2001, Absil et al 2006, 2008)
- ζ Aql (probable binary) and 5 non-detections (Absil et al 2008)
- Two lower-mass stars (di Folco et al 2007): τ Ceti (G8) detected, ε Eri (K2) not



Absil *et al.* 2006

Current statistics on hot dust:

•3/8 AF stars

•1/2 GK stars

# Can the inner ring be steady-state?

- Steady-state collisional cascade (Wyatt et al 2007)

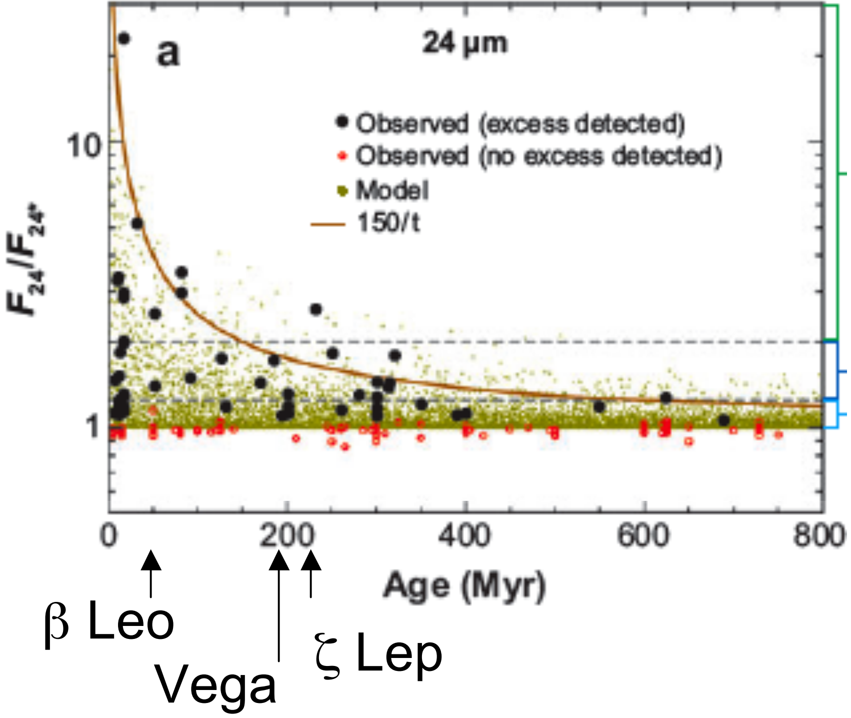
Collisions are destructive

$f_{max} \propto age^{-1} * radius^{7/3}$

In a sample of 46 A star disks, all but 4 have $f/f_{max} < 10$ for the mid-infrared excess

ζ Lep is one of the exceptional sources

Wyatt (2007)



The near-infrared dust for Vega, β Leo and ζ Lep all have $f/f_{max} \sim 10^6$ !

# More on β Leo

- Recent MMT nulling observations (Liu, Stock, Hinz et al) have shown a 10 micron excess between 0.1” and 1.0” (1.1 - 11 AU) at levels between 1% and 2% of the photospheric flux
  - This size scale is intermediate between the CHARA observations and the likely radius for the “cold” Spitzer disk
  - Models from Arizona group require multiple bands of emission
    - Unknown what dynamics are required to maintain this structure or could be more evidence for a transient origin

# Summary

- A moderate fraction of A stars with cool debris disks also have near-infrared excess emission
  - The near-infrared flux is most consistent with emission from small, hot grains in 3 cases
    - Vega and β Leo have gap between hot and cool dust
  - The hot dust is highly anomalous when compared to evolutionary models
    - Transient origin?
      - These stars are relatively young
  - Need larger sample and expansion to later spectral types