Hot Dust in Debris Disks

Rachel Akeson
NASA Exoplanet Science Institute (NExScI)
Caltech

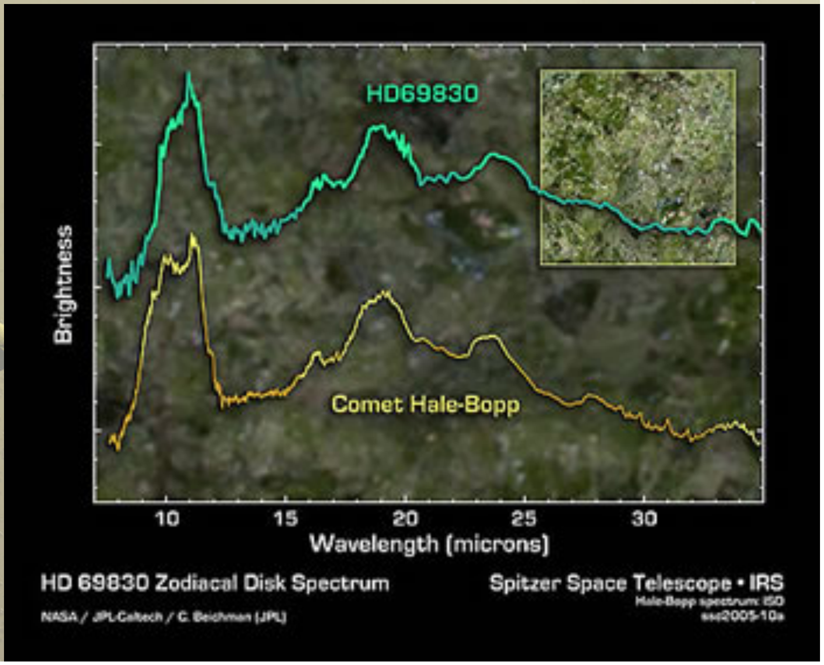
D.R. Ciardi, R. Millan-Gabet, A. Merand, E. Di Folco, J.D. Monnier, C.A. Beichman, O. Absil, J. Aufdenberg

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

Image: T. Pyle

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 (also see poster #109)

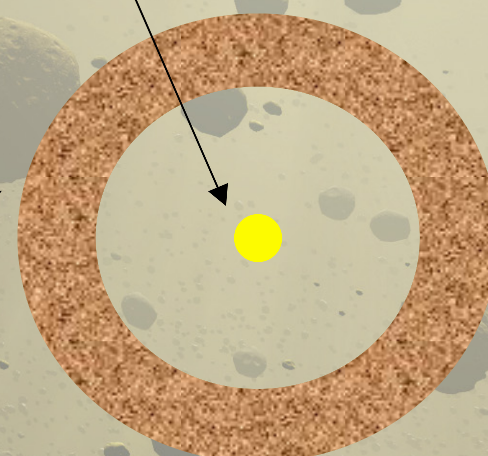


- What about hot dust?

Why interferometry?

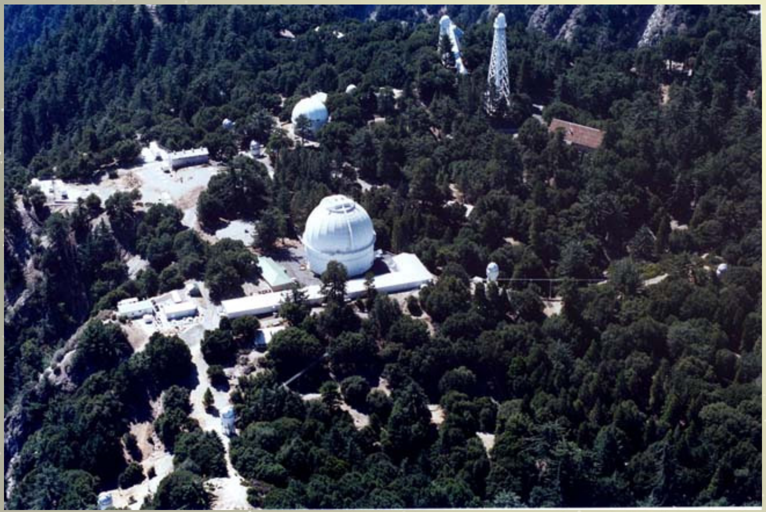
- Debris disk emission is a small fraction of stellar flux
  - The problem is not detecting the disk flux but in having the dynamic range
- Interferometry measures the flux as a function of spatial frequency

Stellar photopshere ~ few mas
• resolved on baselines > 100 meters



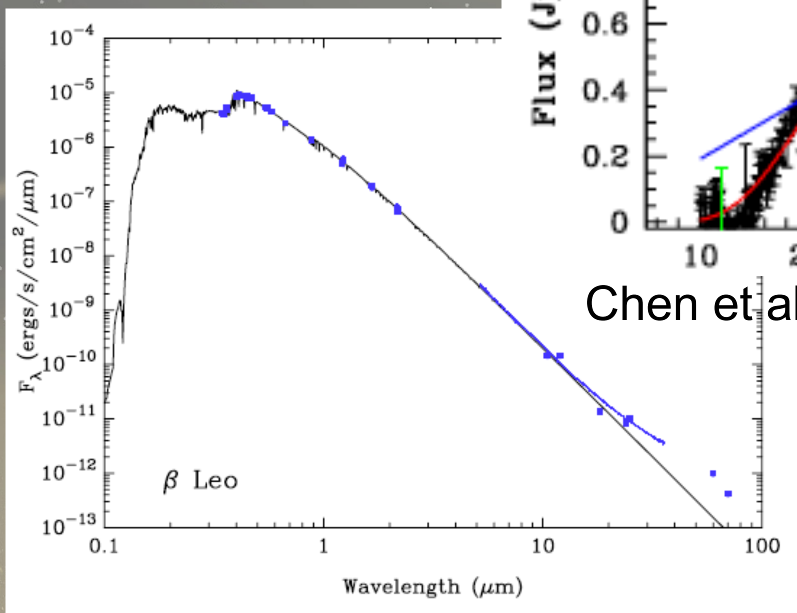
Dust ring > 10’s mas
• resolved on baselines ~ 10 meters

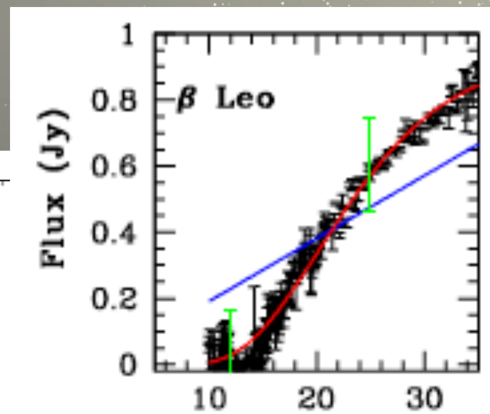
CHARA observations



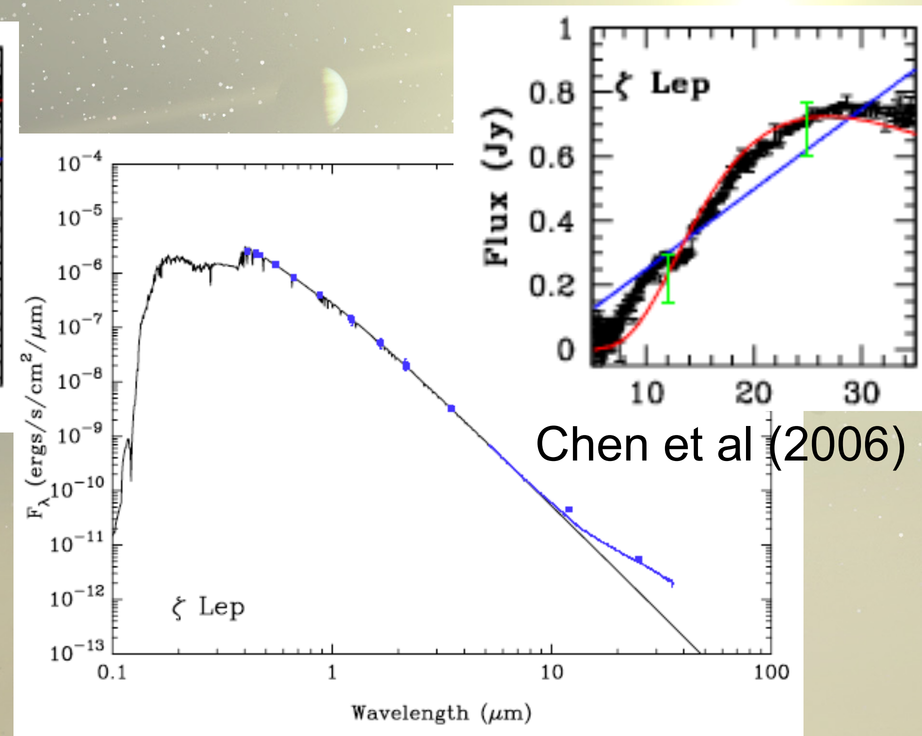
- Center for High Angular Resolution Array on Mt. Wilson; built and operated by Georgia State University
  - 6 telescopes with baseline from 30 to 300 meters
  - Used precision fiber combiner FLUOR (Coude du Foresto et al 2003) at K band (2.2 microns)
- Method
  1. Use long baseline (high spatial frequencies) to accurately measure stellar diameter
  2. Compare short baseline (low spatial frequencies) observations to expected value from star alone
  3. Any additional emission component larger than the star itself will ***decrease*** the measured visibility

Observed sources





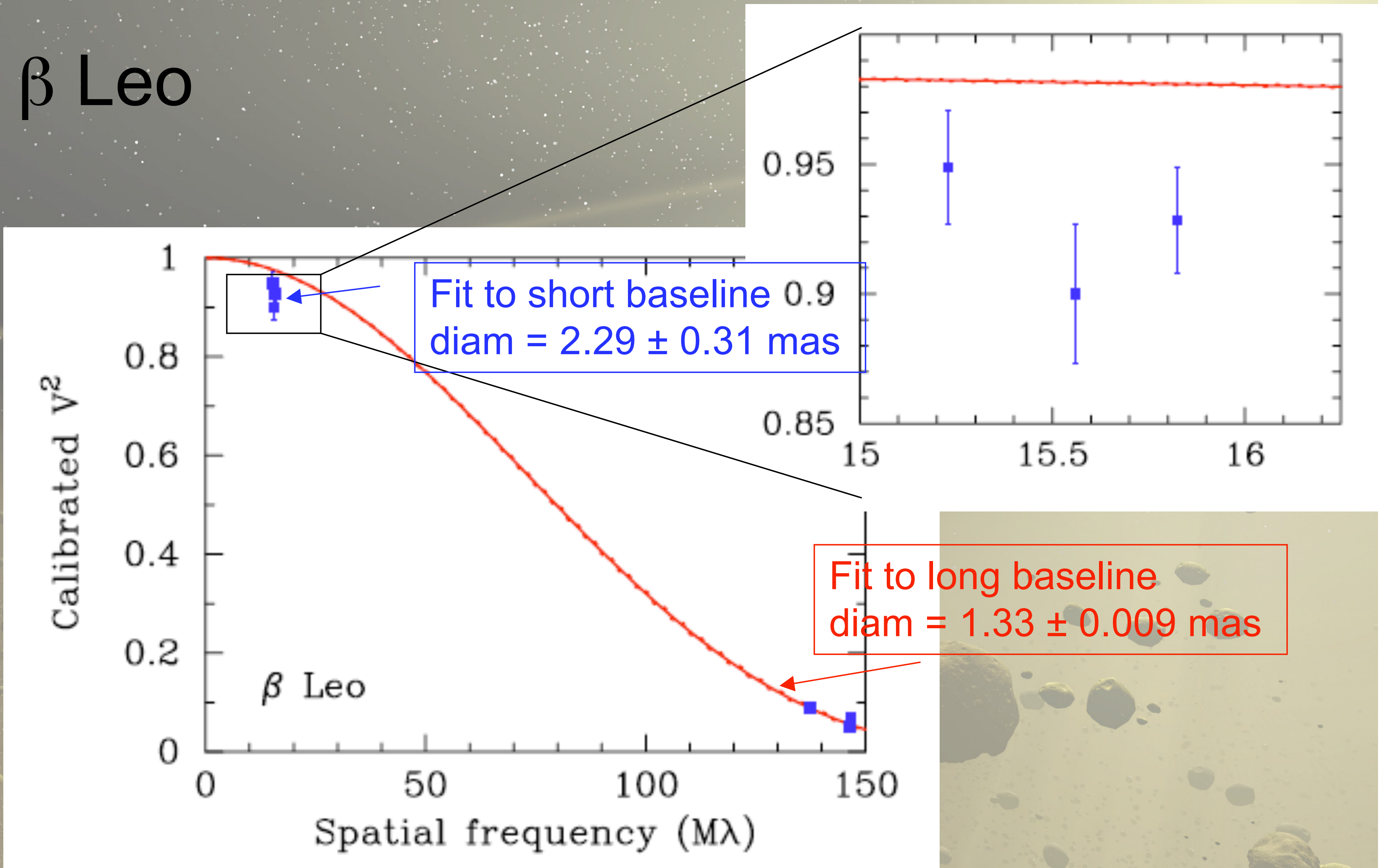
Chen et al (2006)



Chen et al (2006)

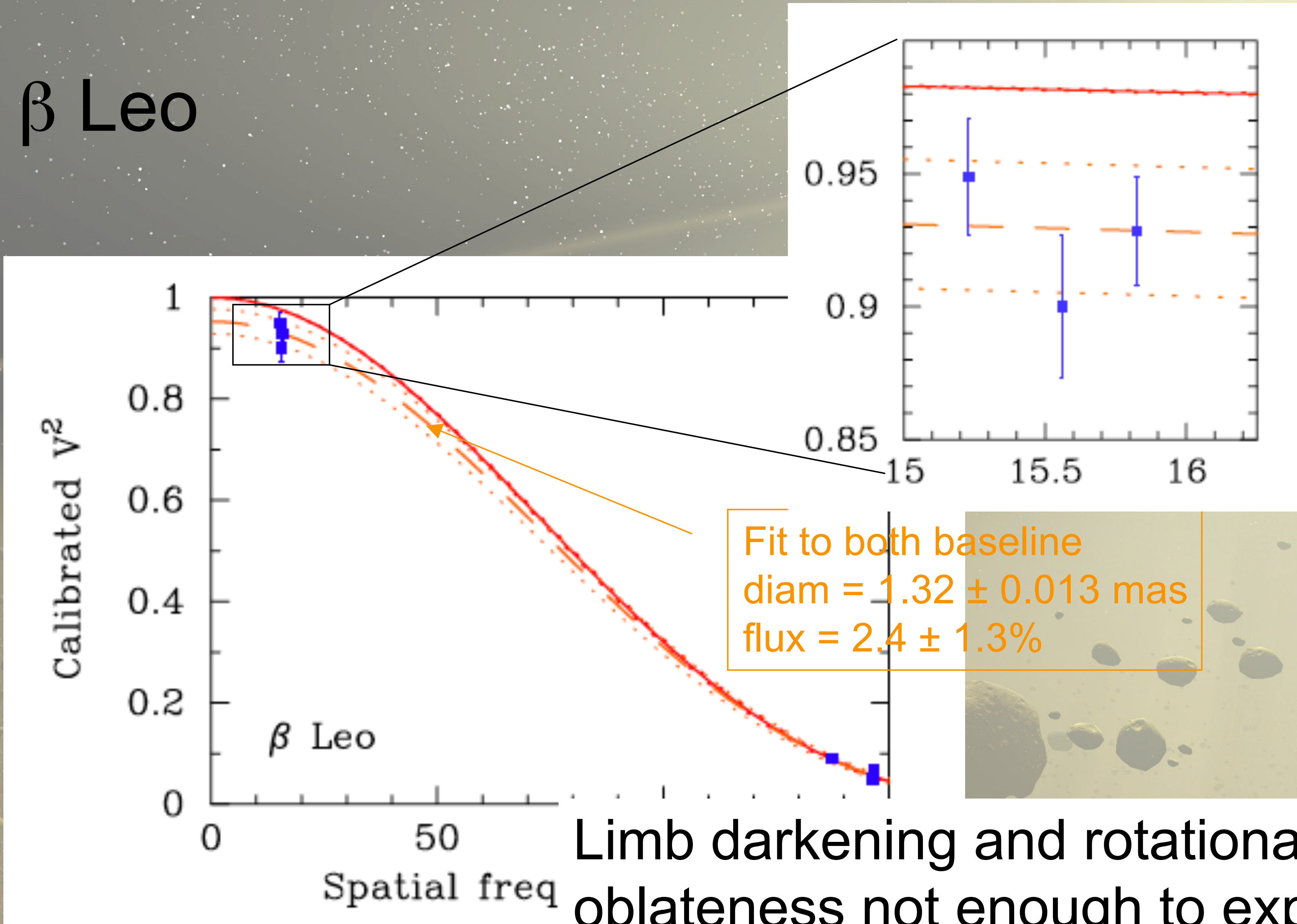
- β Leo
  - A3 star at 11 pc
  - IRAS discovered, featureless IRS excess
  - T ~ 120 K, radius ~ 19 AU
- ζ Lep
  - A2 star at 20 pc
  - IRAS discovered, featureless IRS excess
  - Resolved at 18 microns (Moerchen et al 2007)
  - T ~ 300 K, radius 2 - 8 AU

β Leo



Akeson et al, 2009, see astro-ph

β Leo

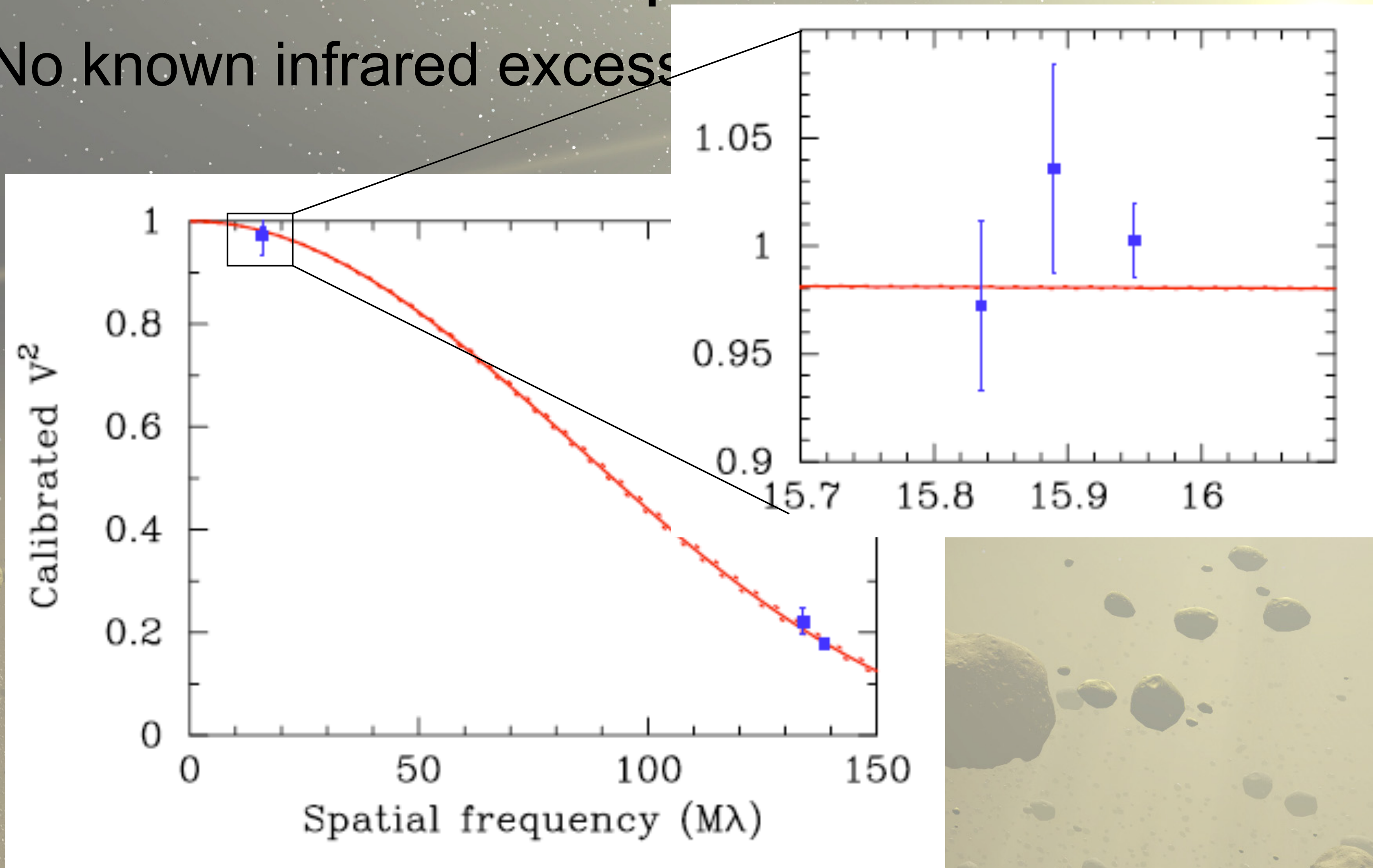


Limb darkening and rotational oblateness not enough to explain difference

Akeson et al, 2009, see astro-ph

δ Leo: A5 star at 17 pc

No known infrared excess



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

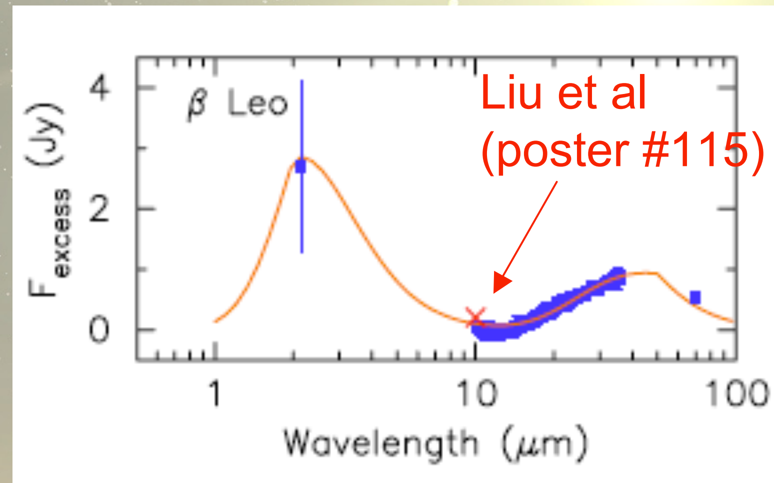
- Small grains generated by collisions in id-IR producing b , drift inward with P drag

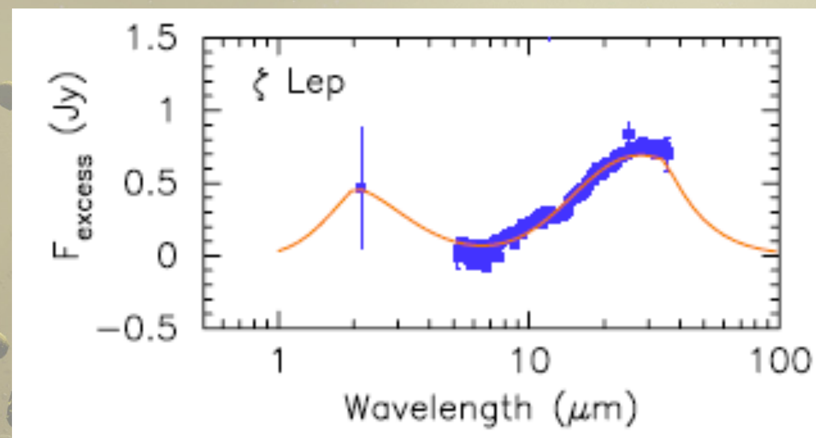
- Inner dust ring
- Can match 2 and 10 micron flux with emission from small grains near the dust sublimation radius

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

Simple dust distribution model

- 2 optically thin rings
- Grain emission efficiency $\propto (\lambda_o/\lambda)^q$
- 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

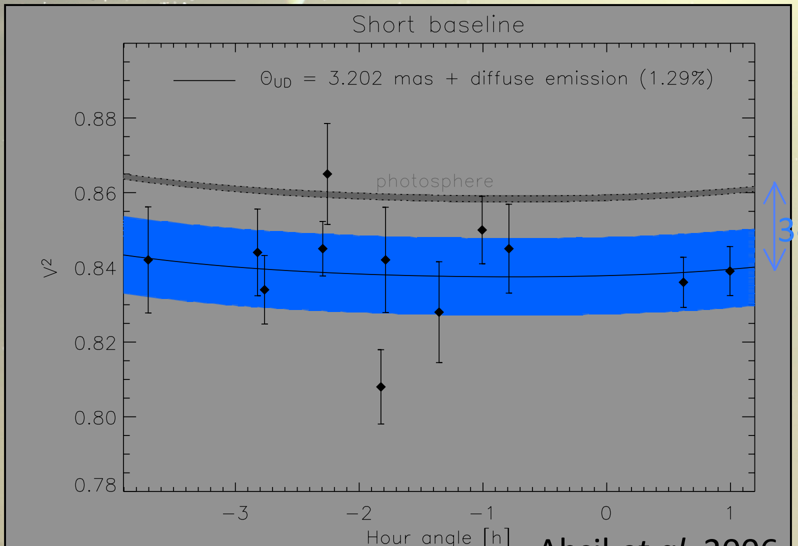
Where does the hot dust come from?

- 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

Vega



Absil *et al.* 2006

Current statistics on hot dust:

•3/8 AF stars

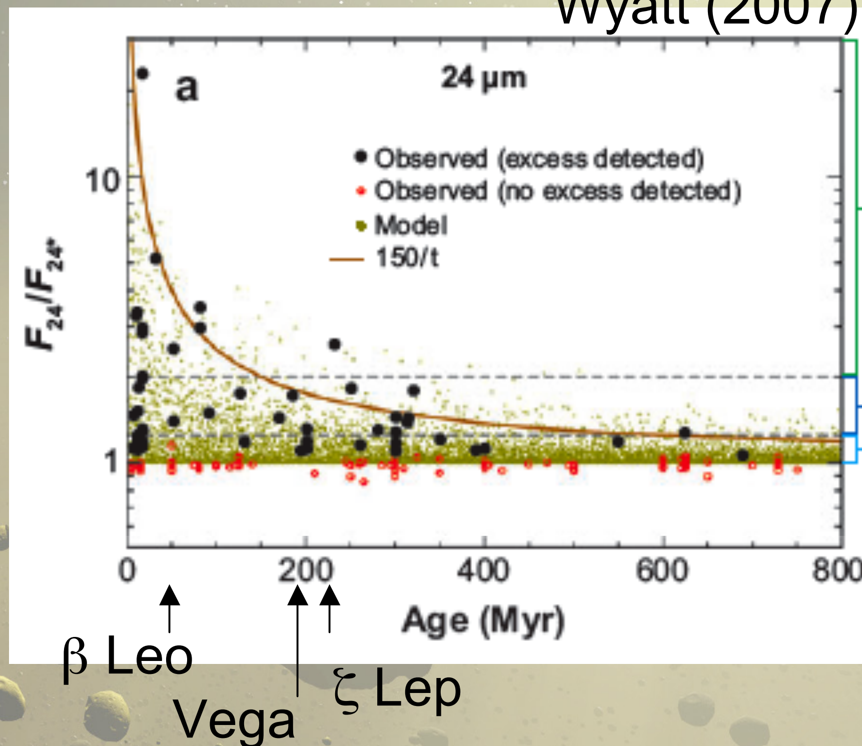
•1/2 GK stars

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 $f/f_{max} \sim 10^6$!

Future directions

- Observe more objects
  - What is the fraction of A stars with hot dust?
    - Does this vary with age?
  - What about FGK stars?
- Constrain the dust composition and distribution
  - Observations with shorter baselines to directly measure size
  - Observations at other wavelengths: H and N (nulling interferometry with Keck and MMT)

- Current project at Palomar Testbed Interferometer using IONIC camera (from IOTA) to observe at H (1.6 microns)
  - Includes β Leo and Vega
- Survey of more targets at CHARA (Absil, in progress)


Courtesy of National Geographic

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