Near-IR Interferometry of YSO Disks

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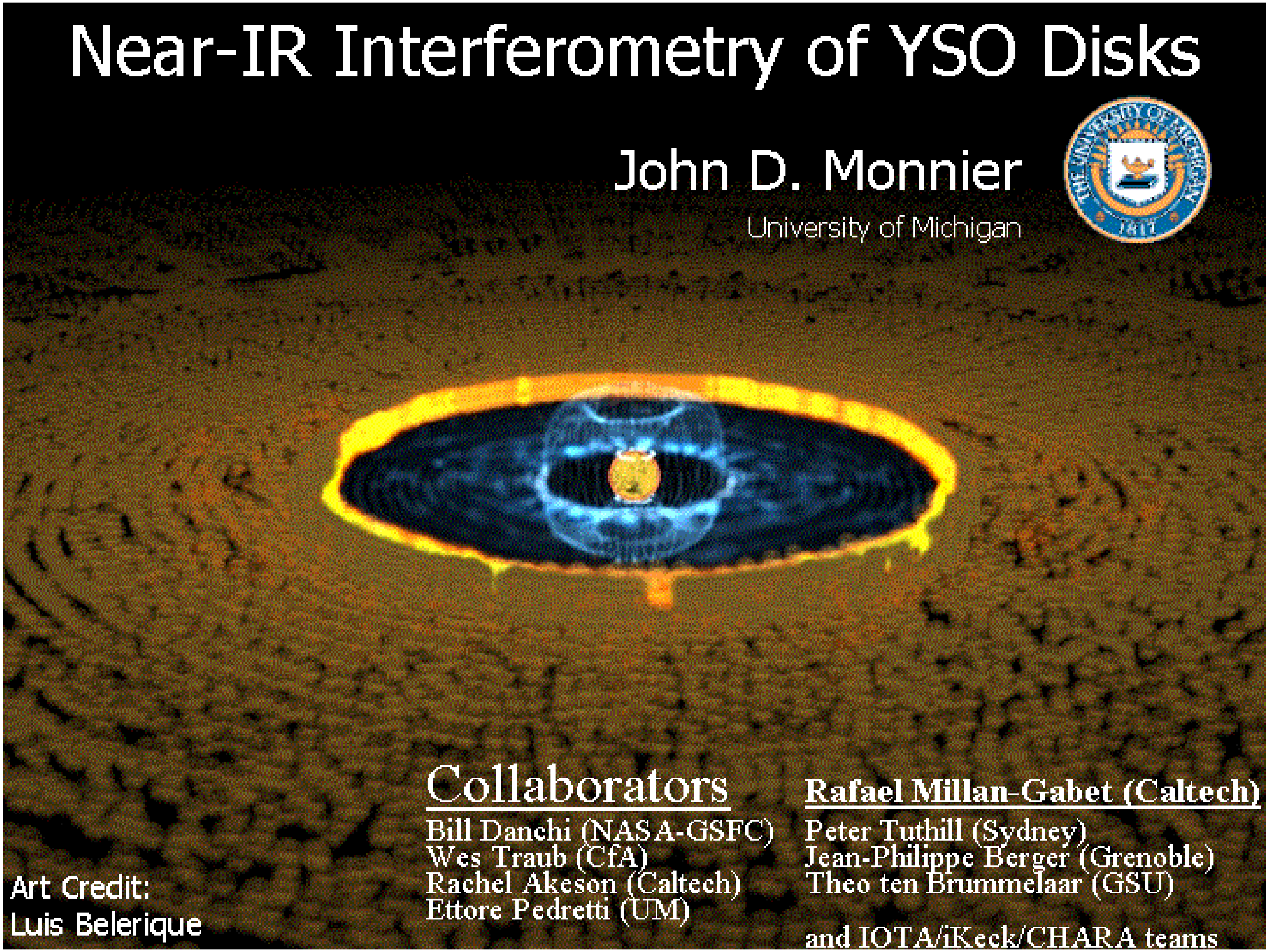

Art Credit:
Luis Belerique

Collaborators

Rafael Millan-Gabet (Caltech)

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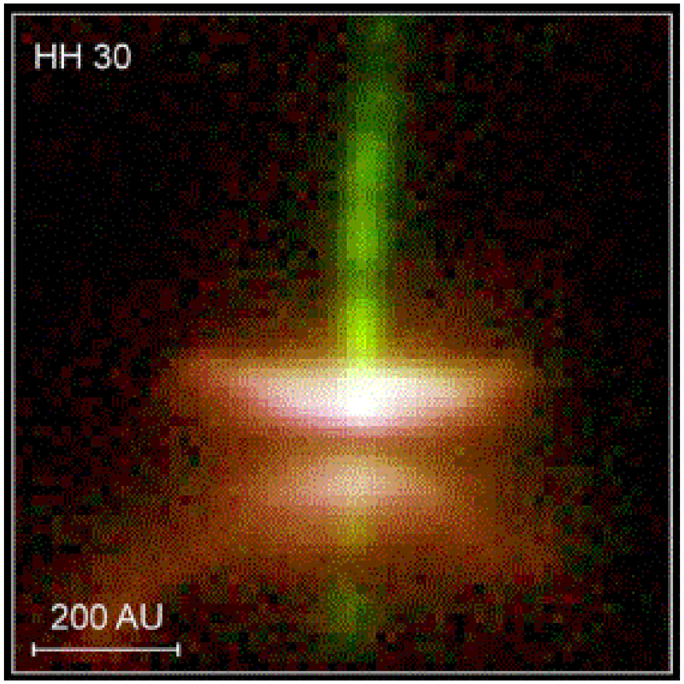
Wes Traub (CfA)
Rachel Akeson (Caltech)
Ettore Pedretti (UM)
Peter Tuthill (Sydney)
Jean-Philippe Berger (Grenoble)
Theo ten Brummelaar (GSU)

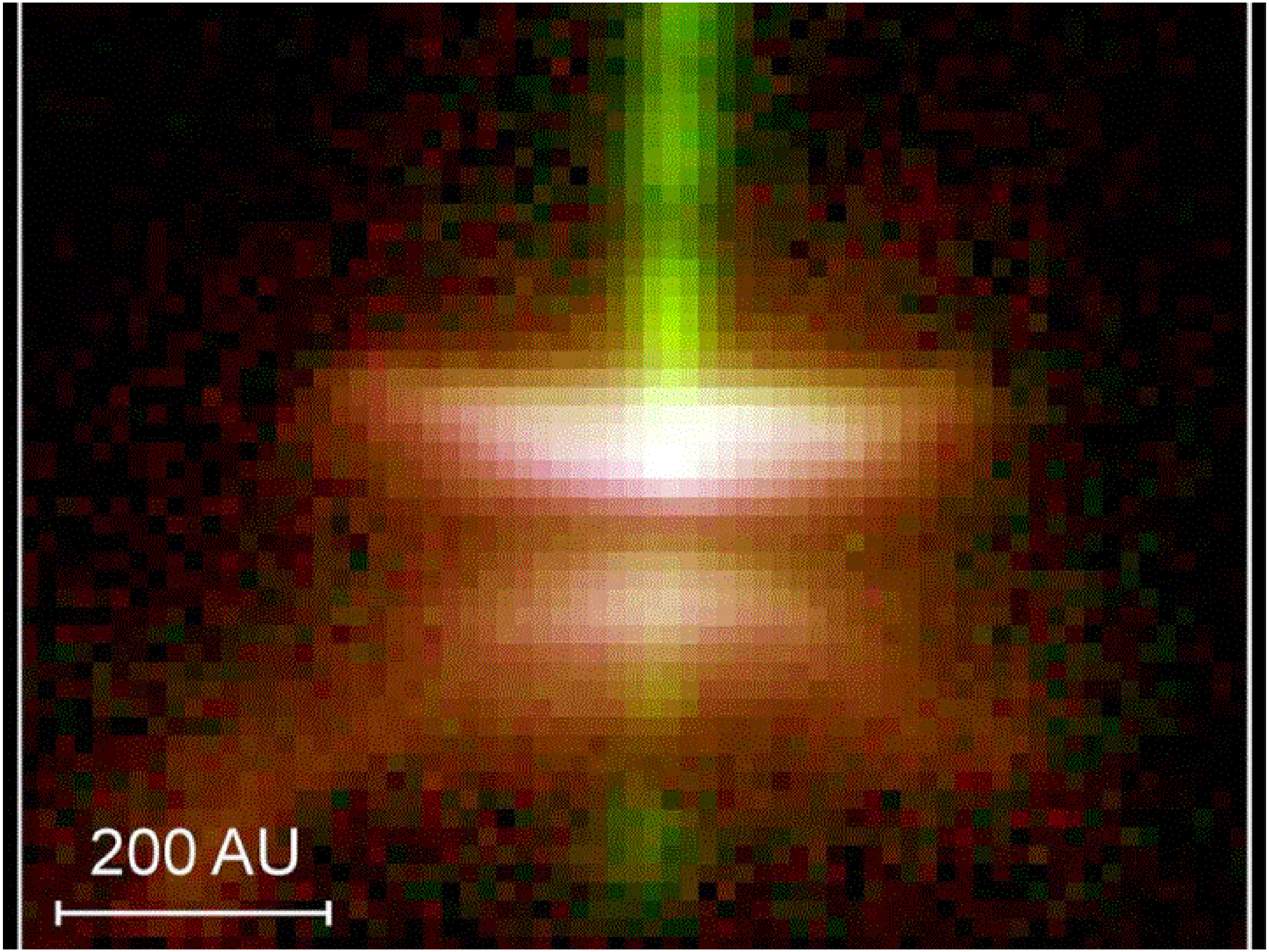
and IOTA/iKeck/CHARA teams

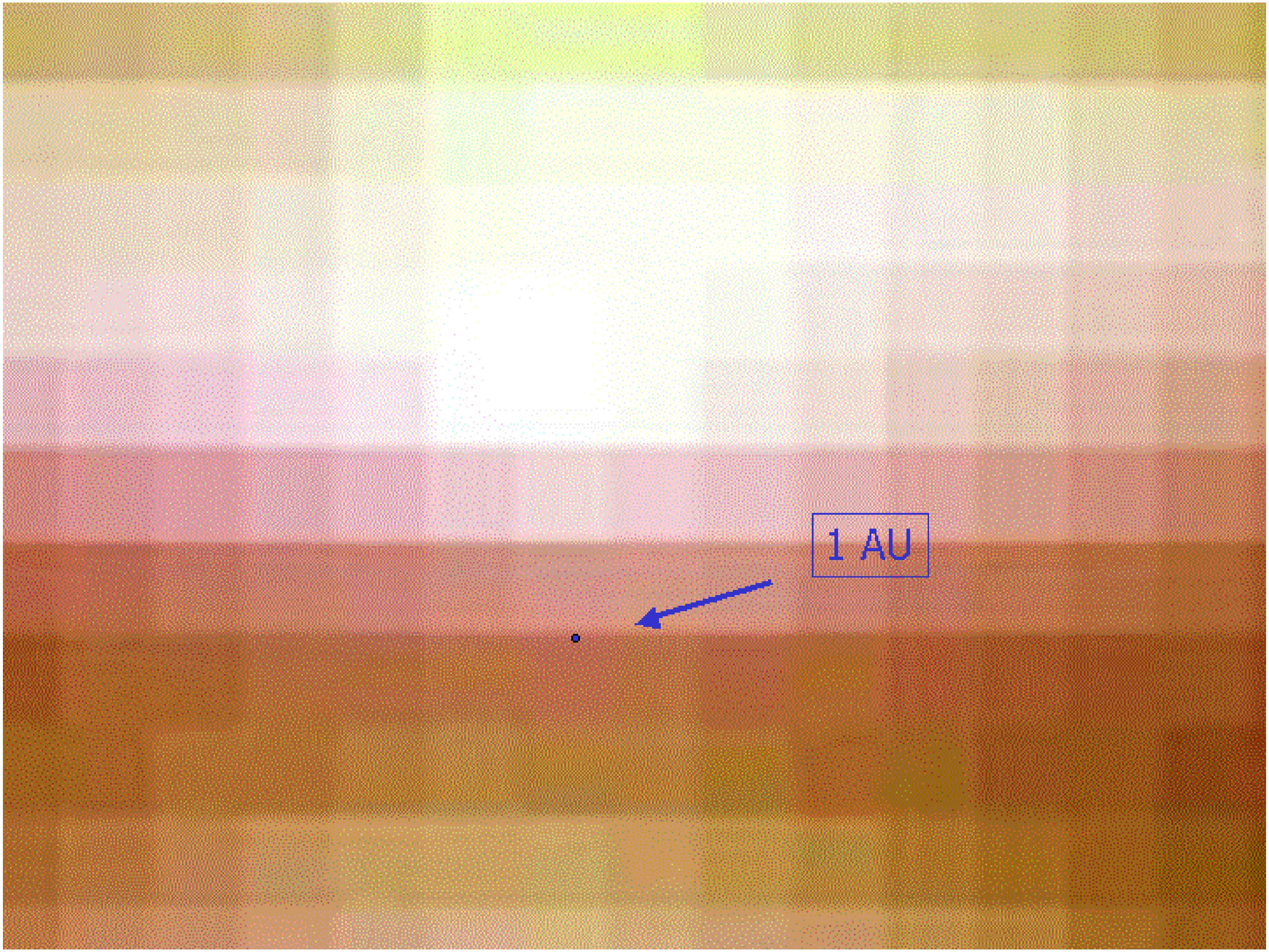
Need for High Angular Resolution

- Challenging Angular Resolution: 1 AU @ 100 pc: 10 mas
- Only long-baseline optical interferometers can resolve the inner disk for most sources
- Scientific Interest
  - Initial conditions of planet formation
  - Disk inhomogenieties (motion)
  - Region of disk where terrestrial planets form
  - Direct detection of extrasolar planets



HST/WFPC2 Credit: C. Burrows (STScI)


200 AU


1 AU

Young Stellar Objects (Near-IR)

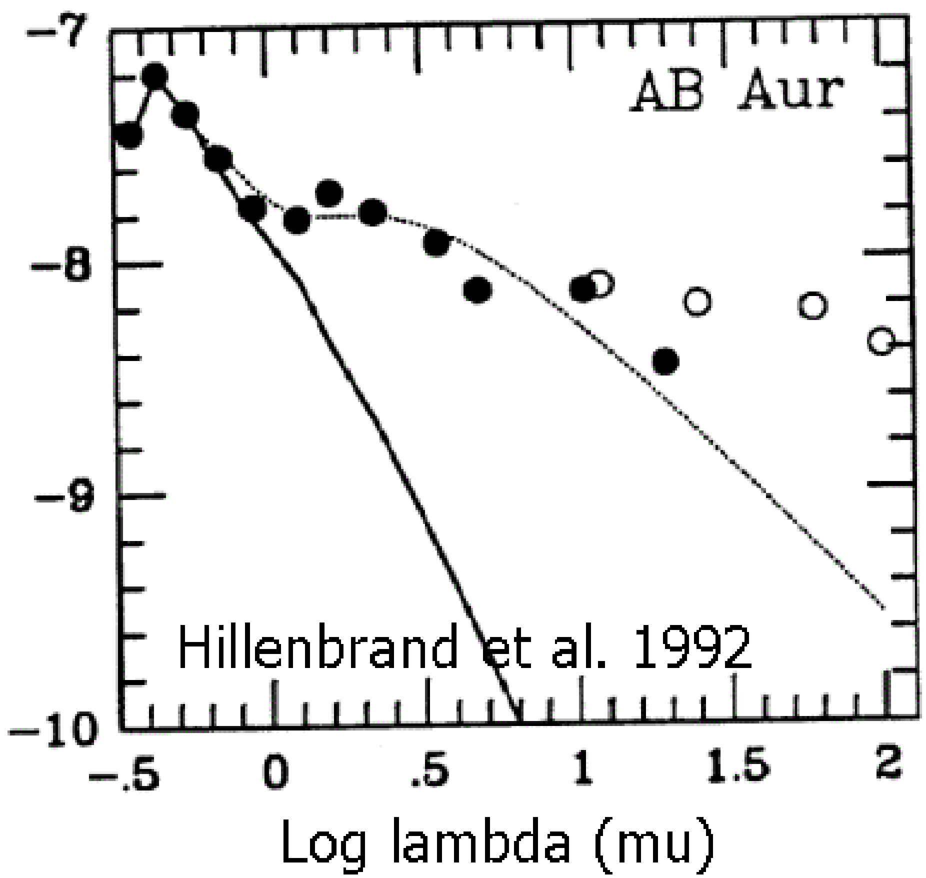
- In the early 1990s, our story begins with the progenitors of intermediate-mass stars:

  <u>the Herbig Ae/Be stars</u>

  - Just the higher-mass counterparts to T Tauri stars (solar-type progenitors)
  - T Tauri disks were relatively "well understood"
    - Geometrically thin
    - Optically thick
    - Possible Accretion Luminosity

- Physical Process: thermal emission from hot dust accreting onto young stars

In the beginning…
astronomers created SEDs…



- Hillenbrand et al. 1992
  - Re-processed radiation + accretion luminosity
  - Temp: $T \propto r^{-\frac{3}{4}}$
  - Central hole!
- SED fits were ok
  - Required (too) high accretion rates (Hartmann)

Pre-Interferometry (NIR): Summary of Herbig Models

- Hillenbrand et al 1992 successfully fit SEDs with optically thick, geometrically thin accretion disk models (with central holes)
- Miroshnichenko et al 1997 successfully fit SEDs with spherically symmetric envelopes of dust (Halos – not disks?)
- Mannings & Sargent 1997 detect (outer) disks using millimeter interferometry

- **Inner disks or (spherical) halos? Or both?**
  - New data needed to break the theoretical logjam..

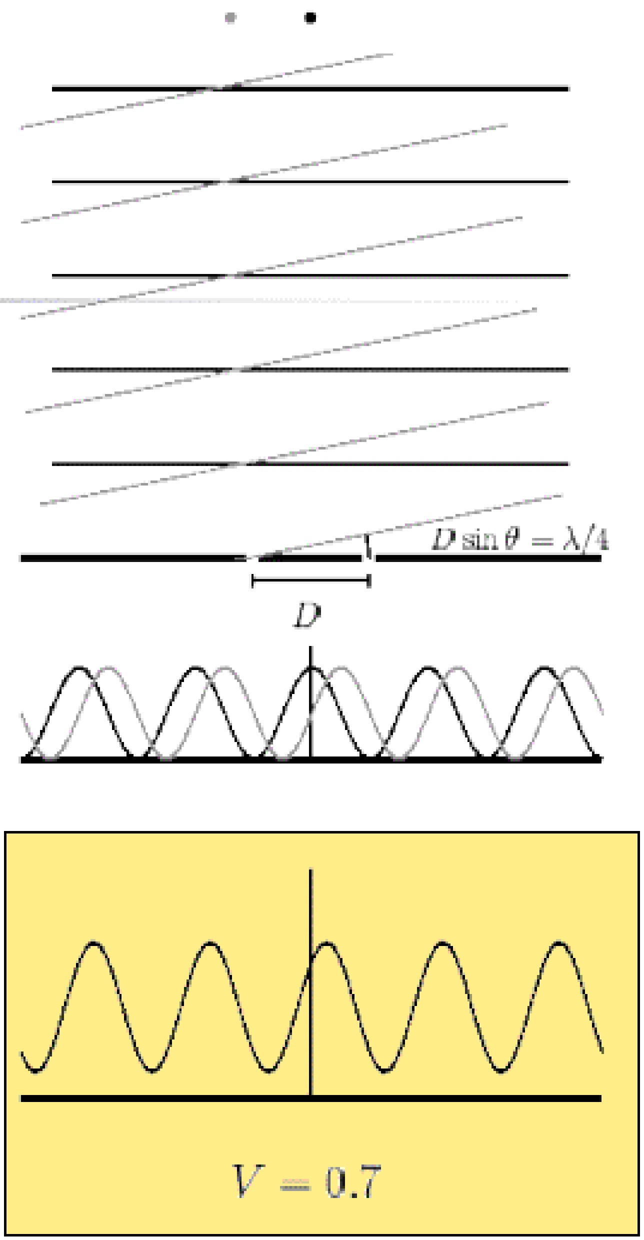
Interferometry

- Fringe **Visibility** (or contrast) depends on source size
- Angular resolution depends on telescope separation and PA

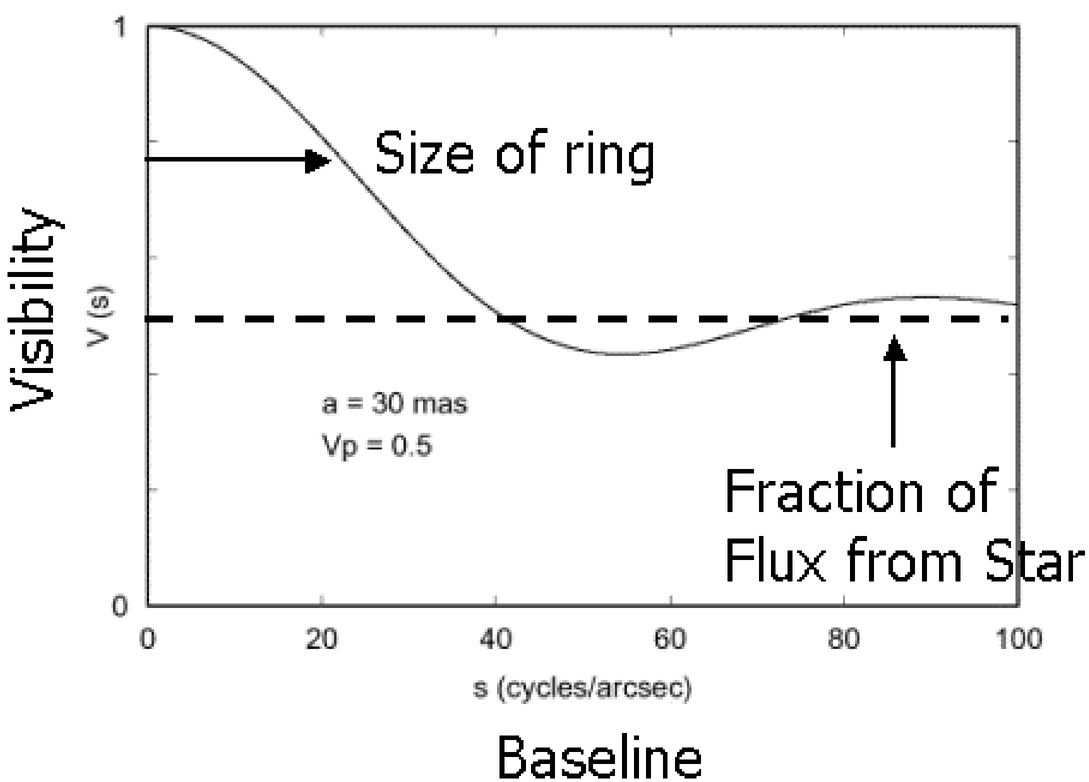
Example (λ/2D)

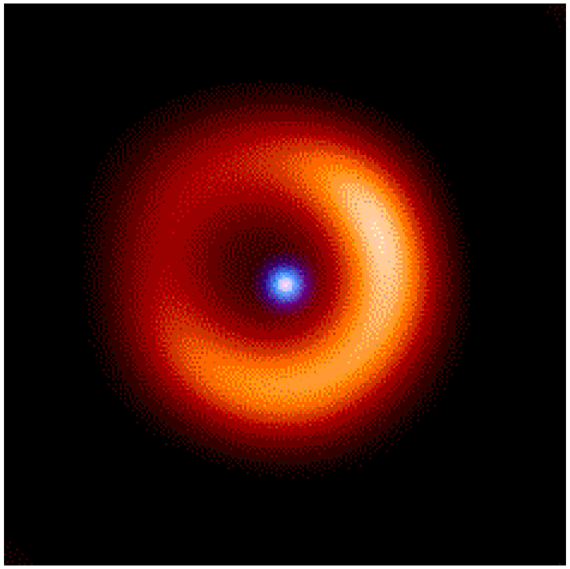
100 m baseline @ 1 μm:

1.0 mas (0.1 AU @ 100pc)

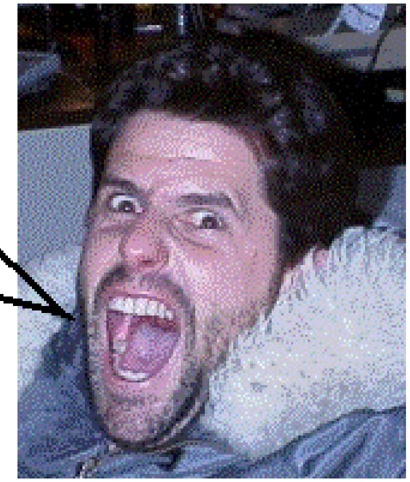


Visibility: Star + Dust Shell



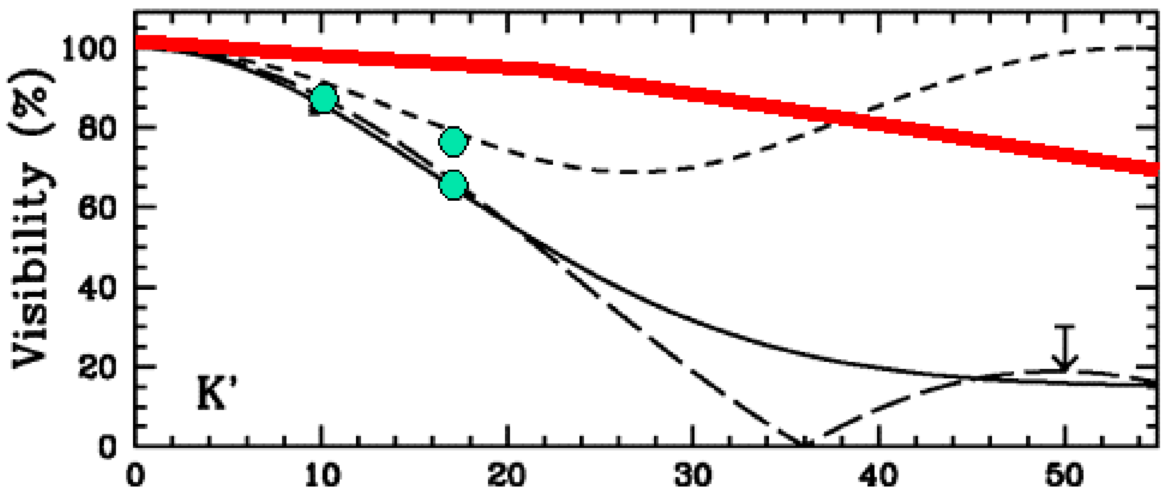


Surprise:
AB Aurigae TOO BIG!



Rafael @ IOTA

- Accretion disk model, used for SED fitting, is RULED OUT by IOTA!



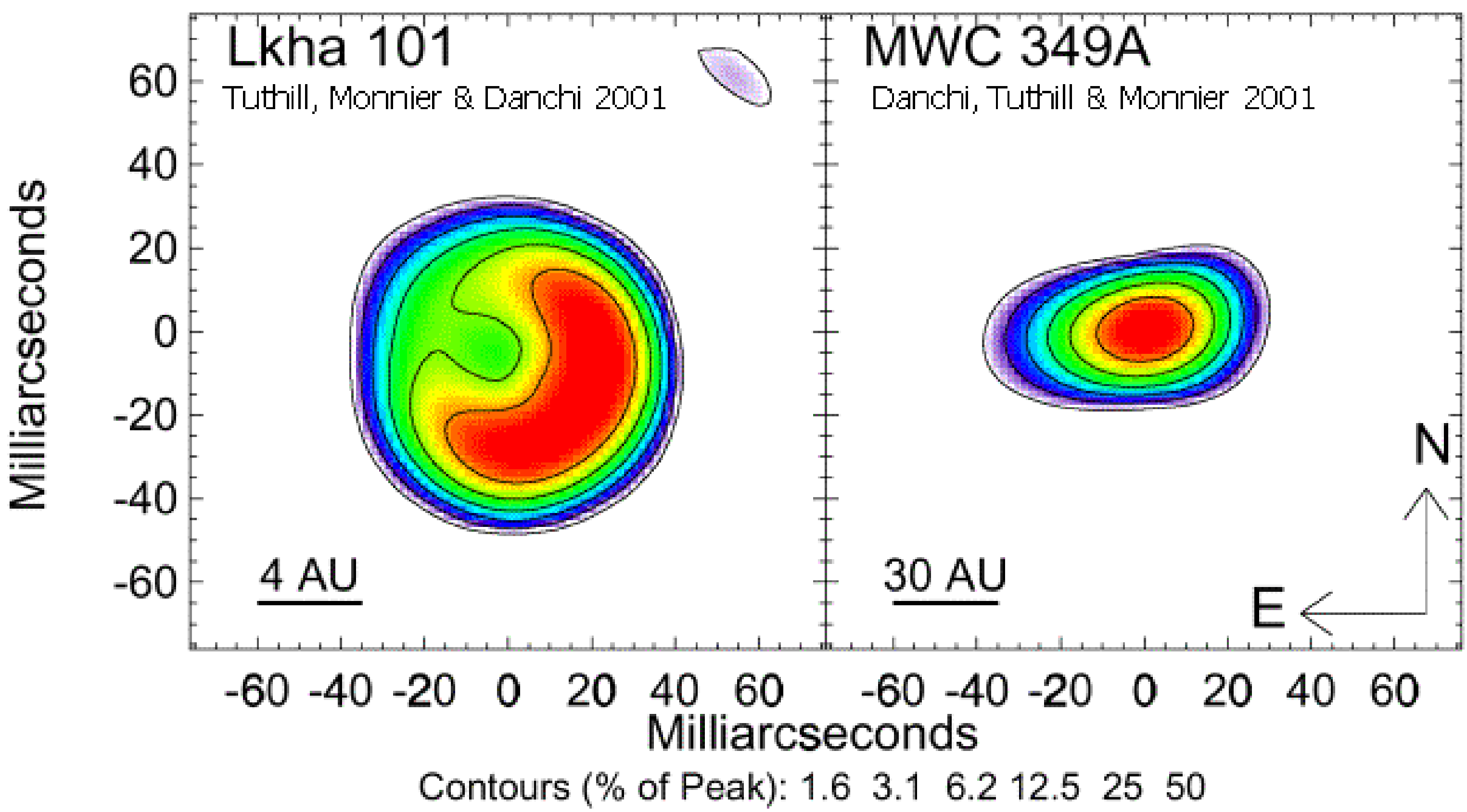
Millan-Gabet et al. 1999

Baseline (M-lambda)

IOTA Survey Results

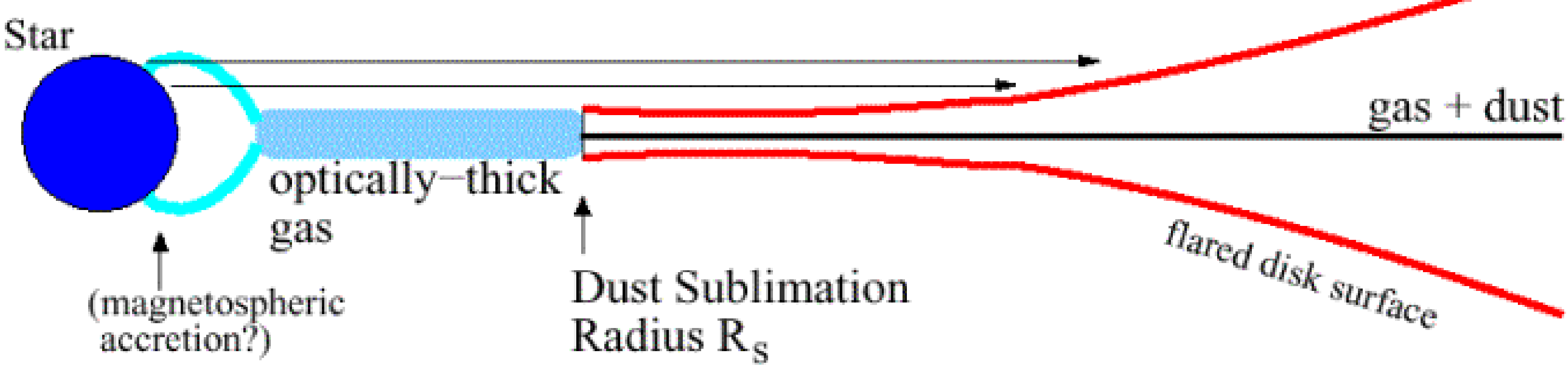
- Millan-Gabet, Traub & Schloerb 2001 reported characteristic sizes of sample of Herbig Ae/Be stars
  - Much larger than expected based on “standard” accretion disk models (optically-thick disks)
  - Although no obvious disk asymmetries were found, most sources were probed at limited position angles

Disks Around Herbig Ae/Be Stars (with Keck aperture masking)



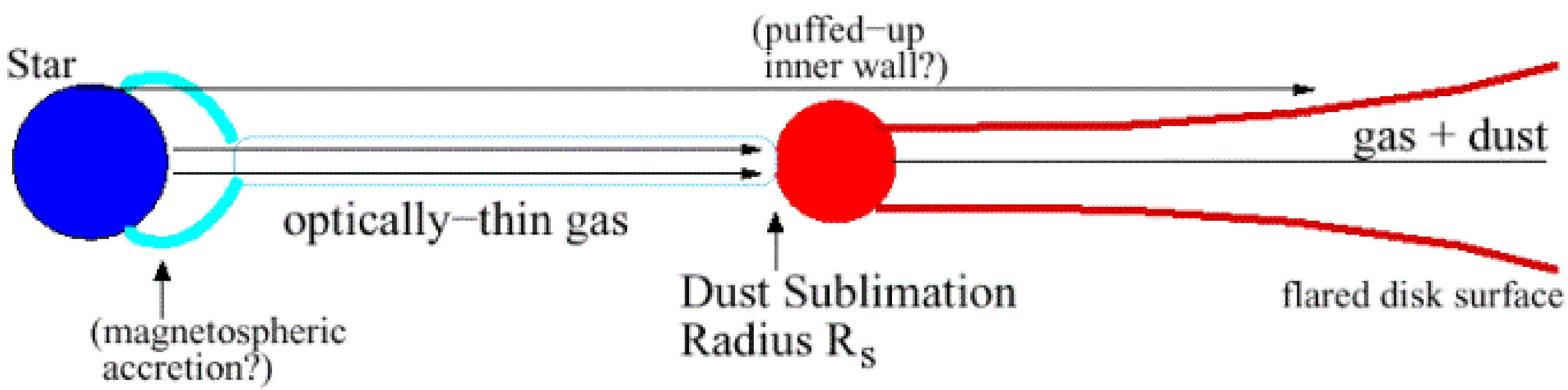
(e.g., Hillenbrand et al. 1992
+ flaring)

"Classical" Disk Model

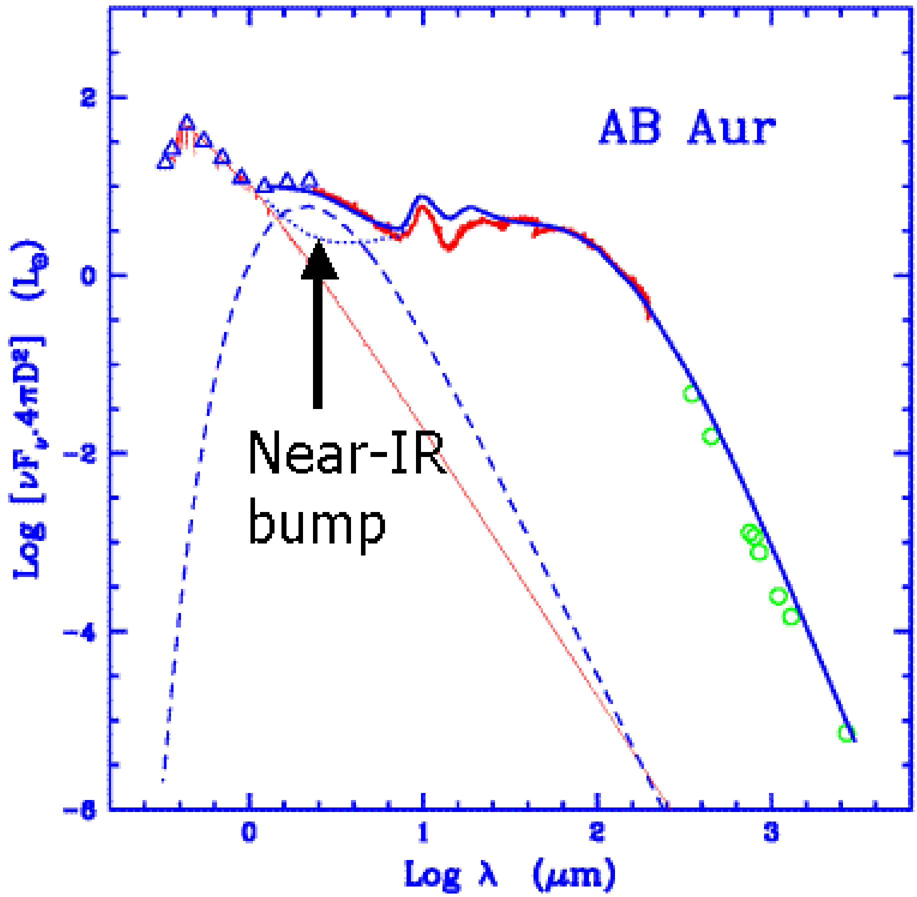


(e.g., Tuthill et al 2001;
Natta et al. 2001)

"Optically−thin Cavity" Disk Model



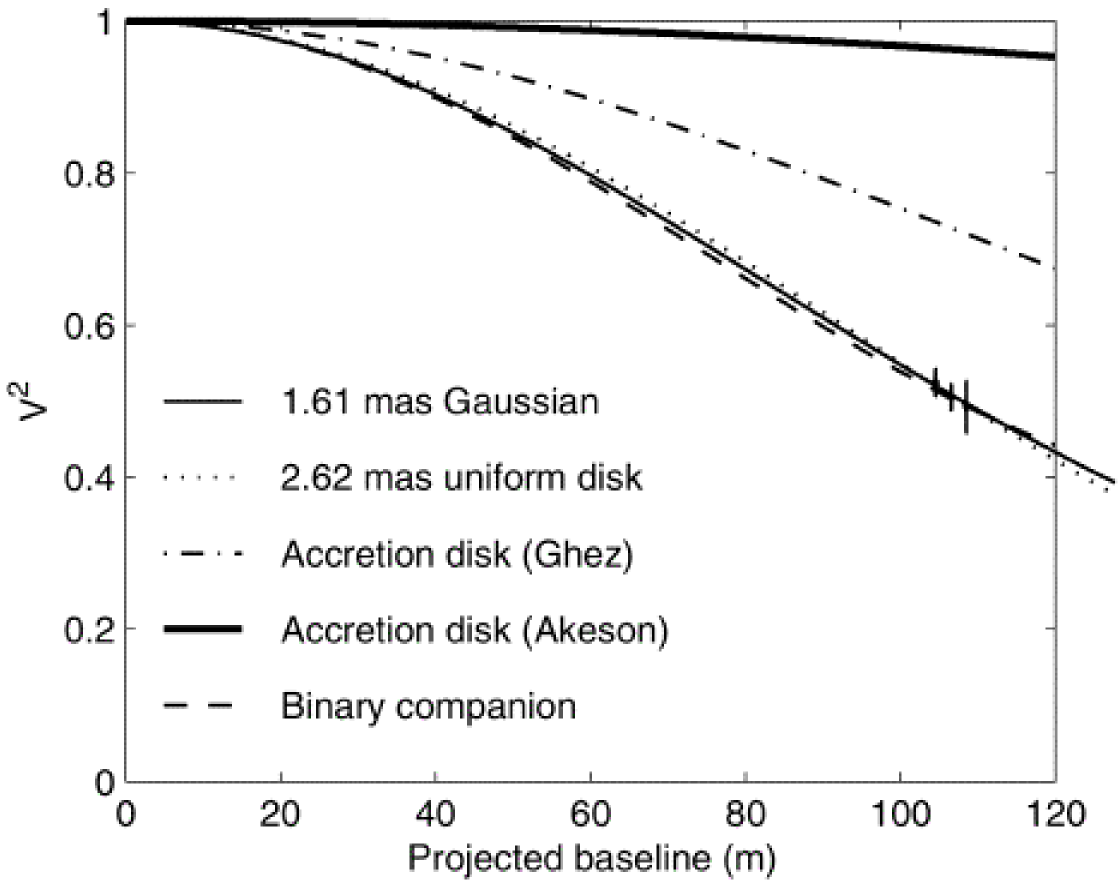
Infrared Luminosity Problem? Solved.



- Natta et al. 2001
  - Flaring increases mid-IR (e.g., Chiang & Goldreich 1997;
  - HOT INNER WALL increases near-IR
- Expanded upon by Dullemond, Dominik, et al.

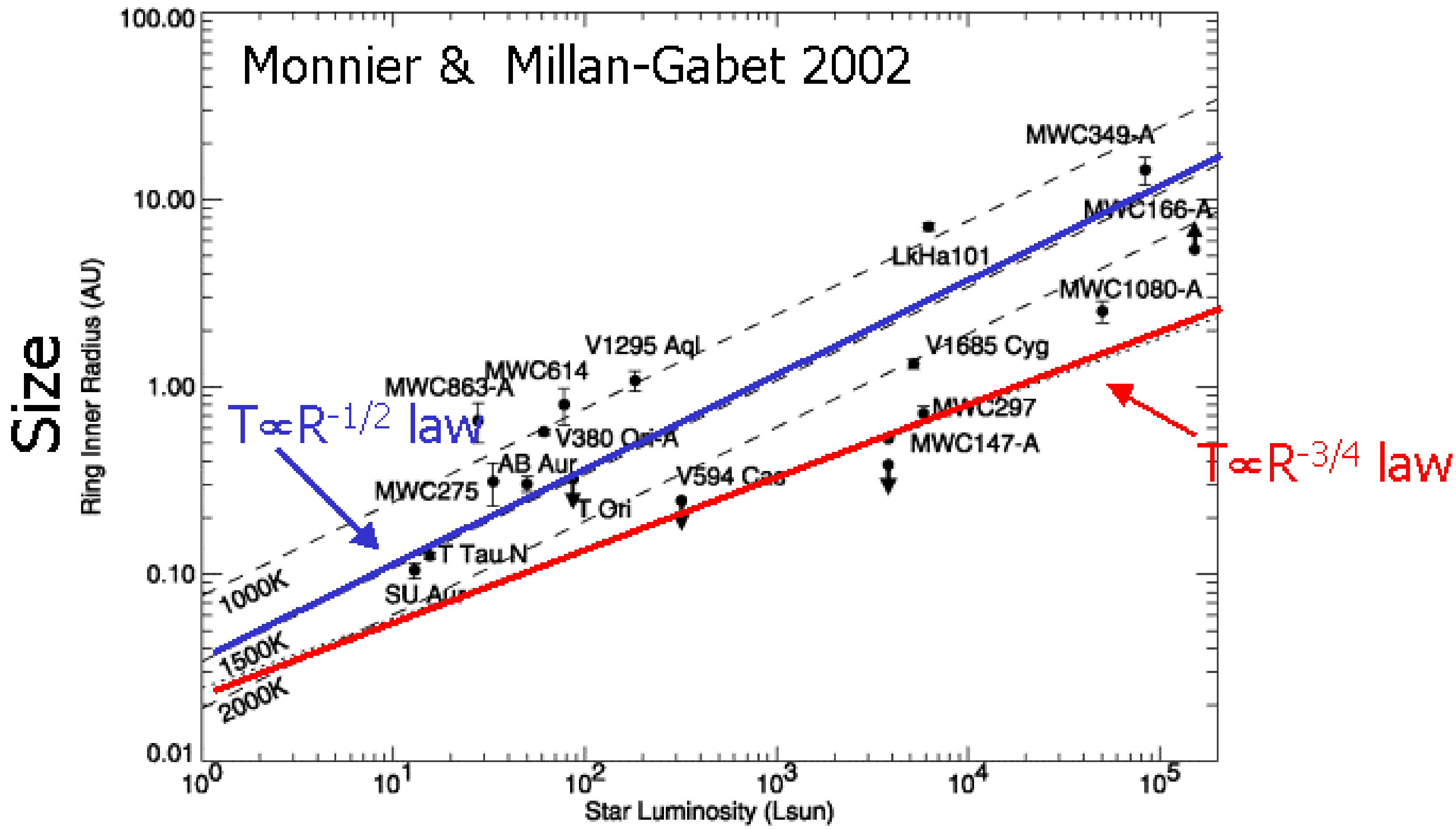
T Tauri Disks are too big too!

- PTI resolves T Tauri N
- TTS are just the low-mass counterparts to the Herbigs (!)



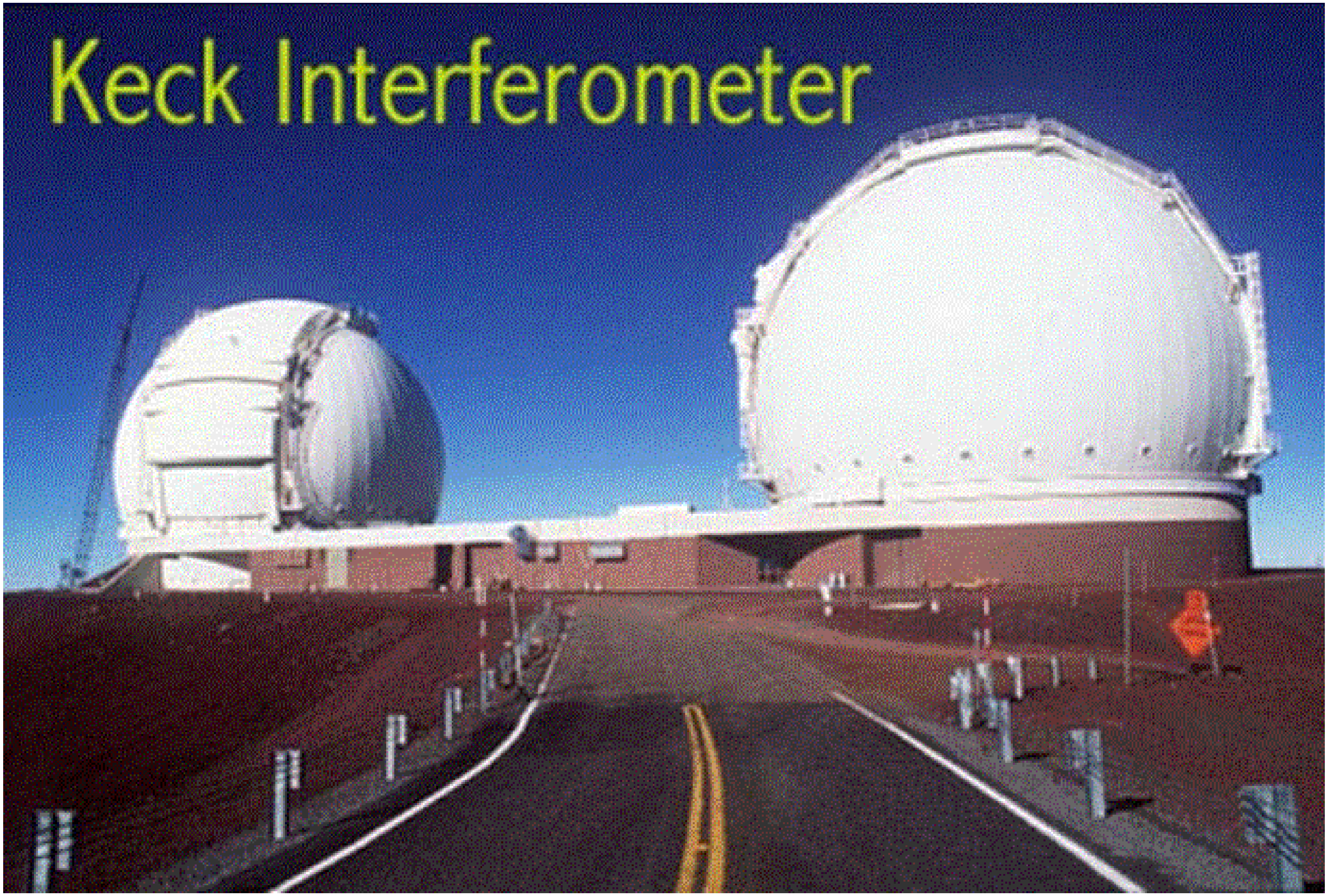
Akeson et al 2000

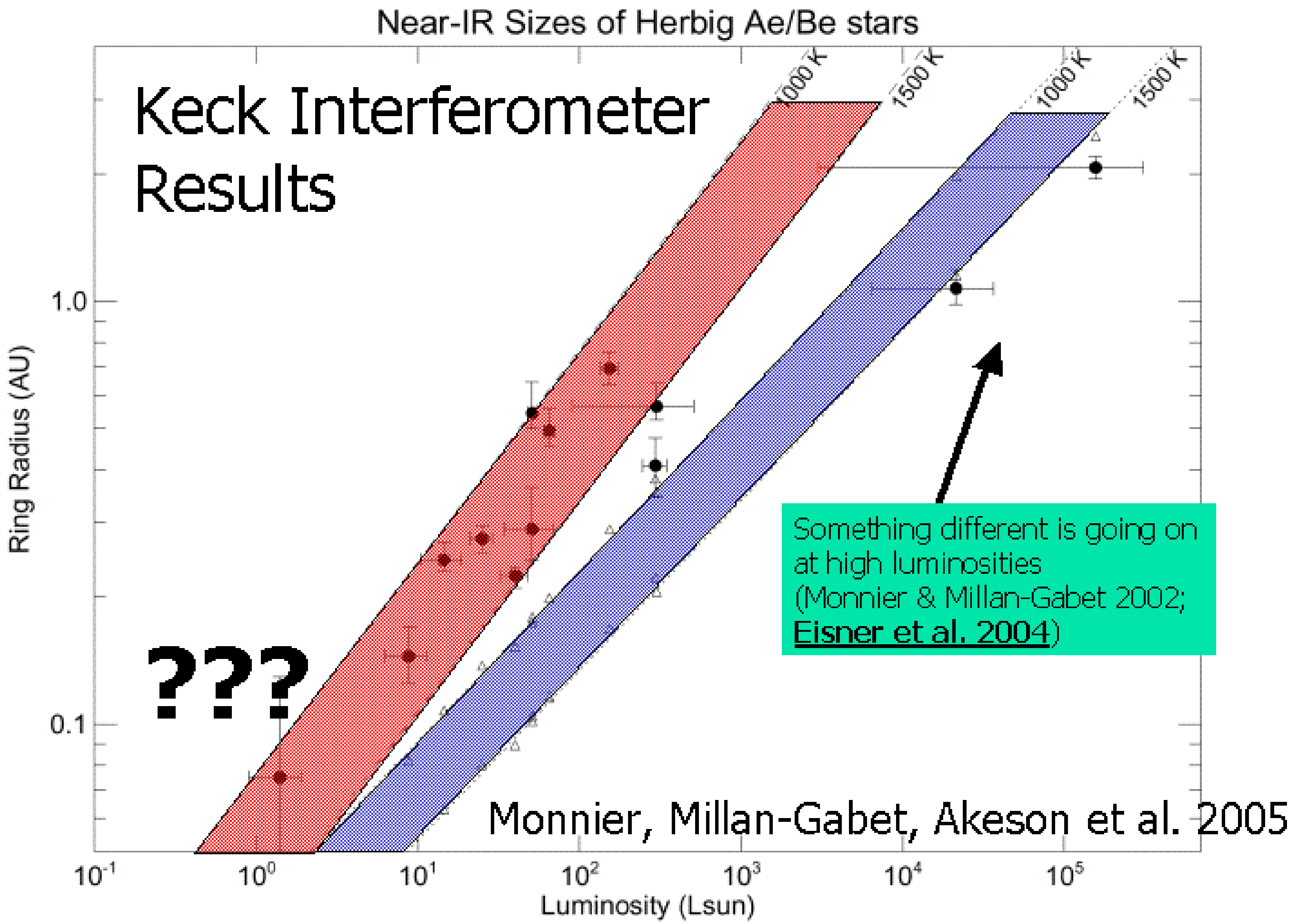
Test of Optically-thin Cavity Model: The Size-Luminosity Diagram

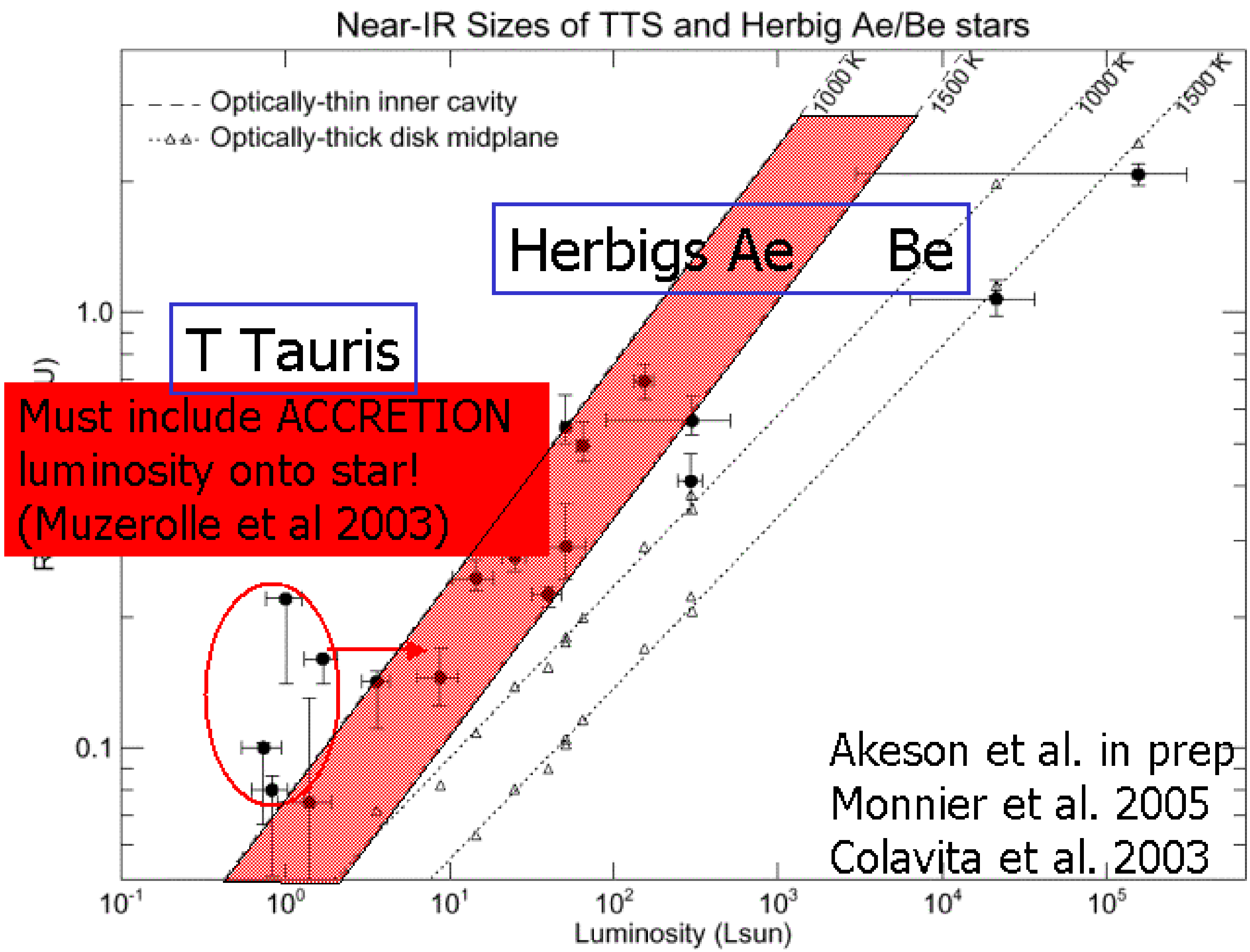


The next big questions

- Why so much scatter in size-luminosity relation?
- What happens at lower and higher luminosities?


Keck Interferometer


Near-IR Sizes of Herbig Ae/Be stars
Keck Interferometer
Results
???
1000 K
1500 K
1000 K
1500 K
Something different is going on at high luminosities (Monnier & Millan-Gabet 2002; Eisner et al. 2004)
Monnier, Millan-Gabet, Akeson et al. 2005
Ring Radius (AU)
1.0
0.1
10-1
100
101
102
103
104
105
Luminosity (Lsun)

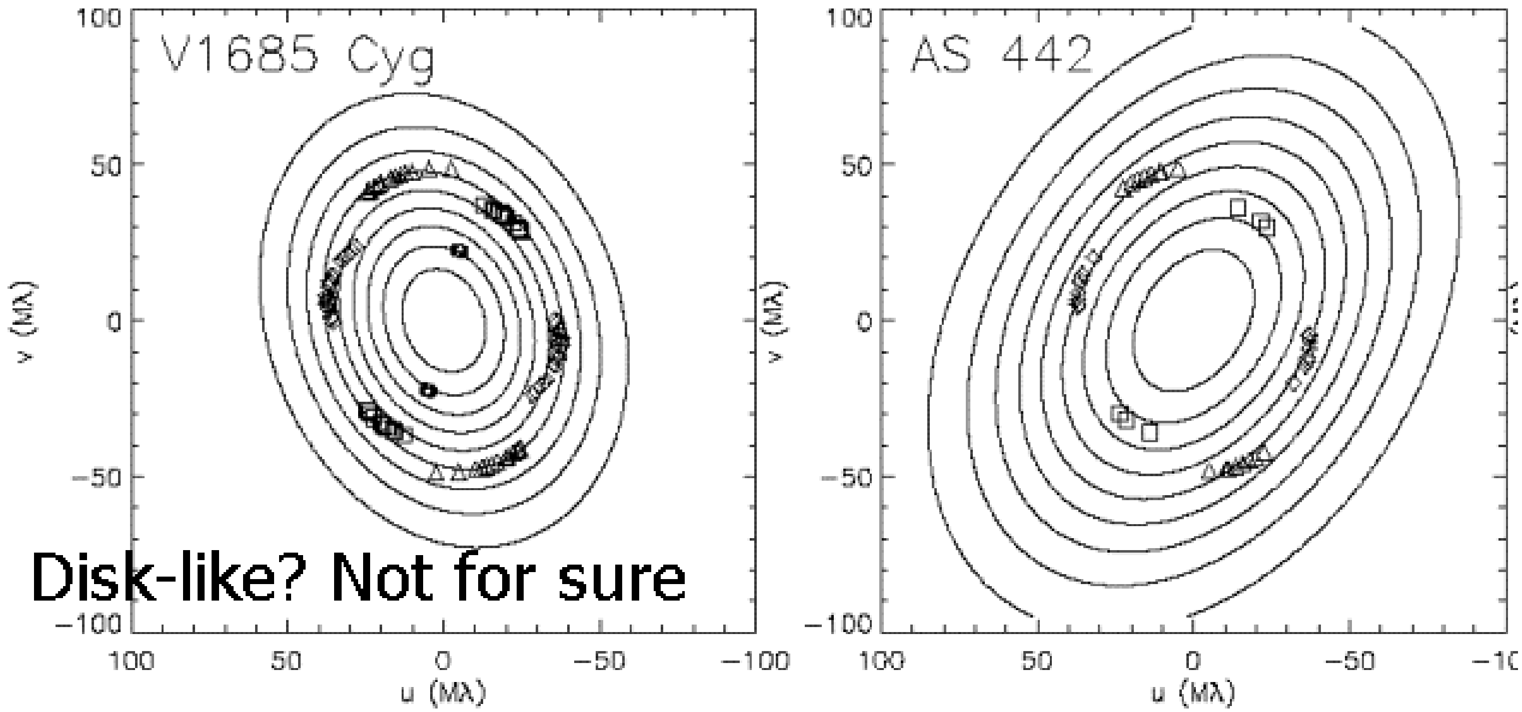

Near-IR Sizes of TTS and Herbig Ae/Be stars
Optically-thin inner cavity
Optically-thick disk midplane
1000 K
1500 K
1000 K
1500 K
Herbigs Ae
Be
T Tauris
Must include ACCRETION
luminosity onto star!
(Muzerolle et al 2003)
1.0
0.1
Akeson et al. in prep
Monnier et al. 2005
Colavita et al. 2003
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
Luminosity (Lsun)

The next big questions

- Why so much scatter in size-luminosity relation?
- What happens at lower and higher luminosities?
- What is the actual geometry of the near-infrared emission?
  - Disk, halo, other?

Near-IR emission is often ELONGATED

- Elongations now well-established for MANY sources (PTI; Akeson et al. 2002; Eisner et al. 2003, 2004)
  - Explains residual x2 scatter in size-luminosity diagram

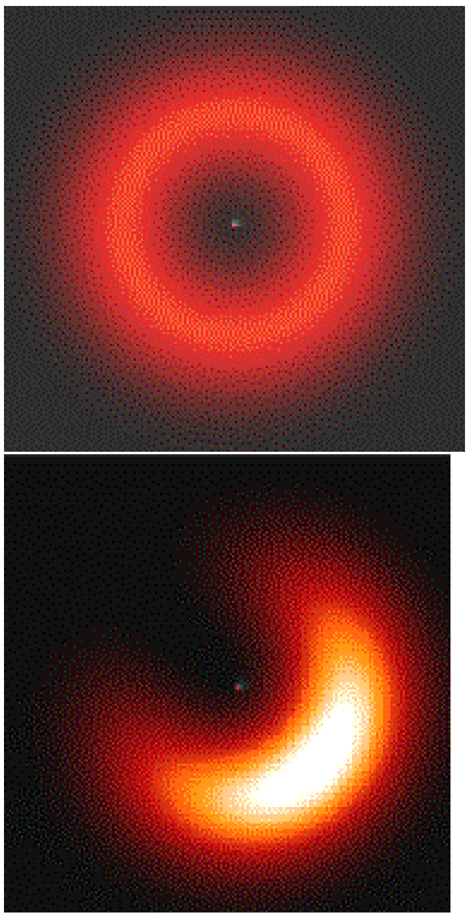


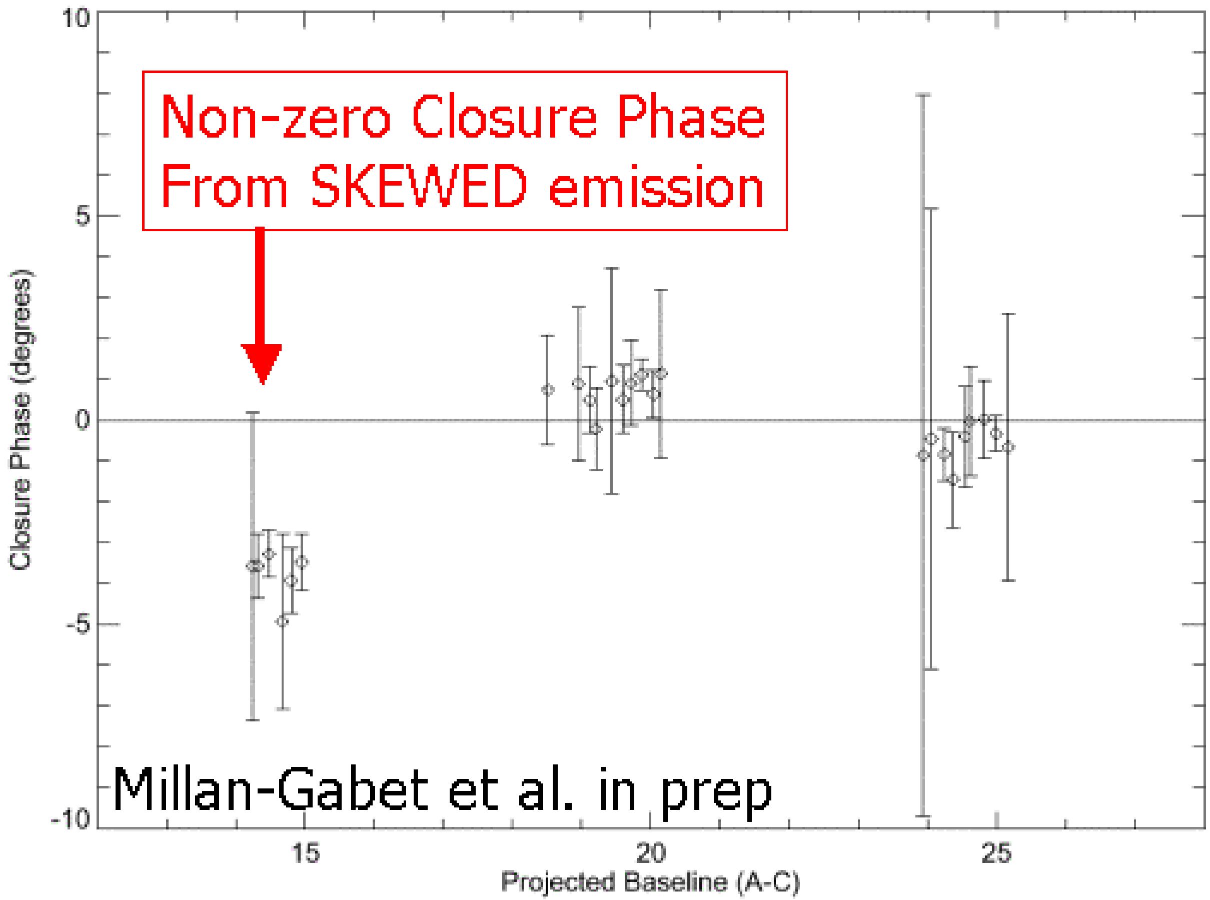
- Disk-like? Not for sure

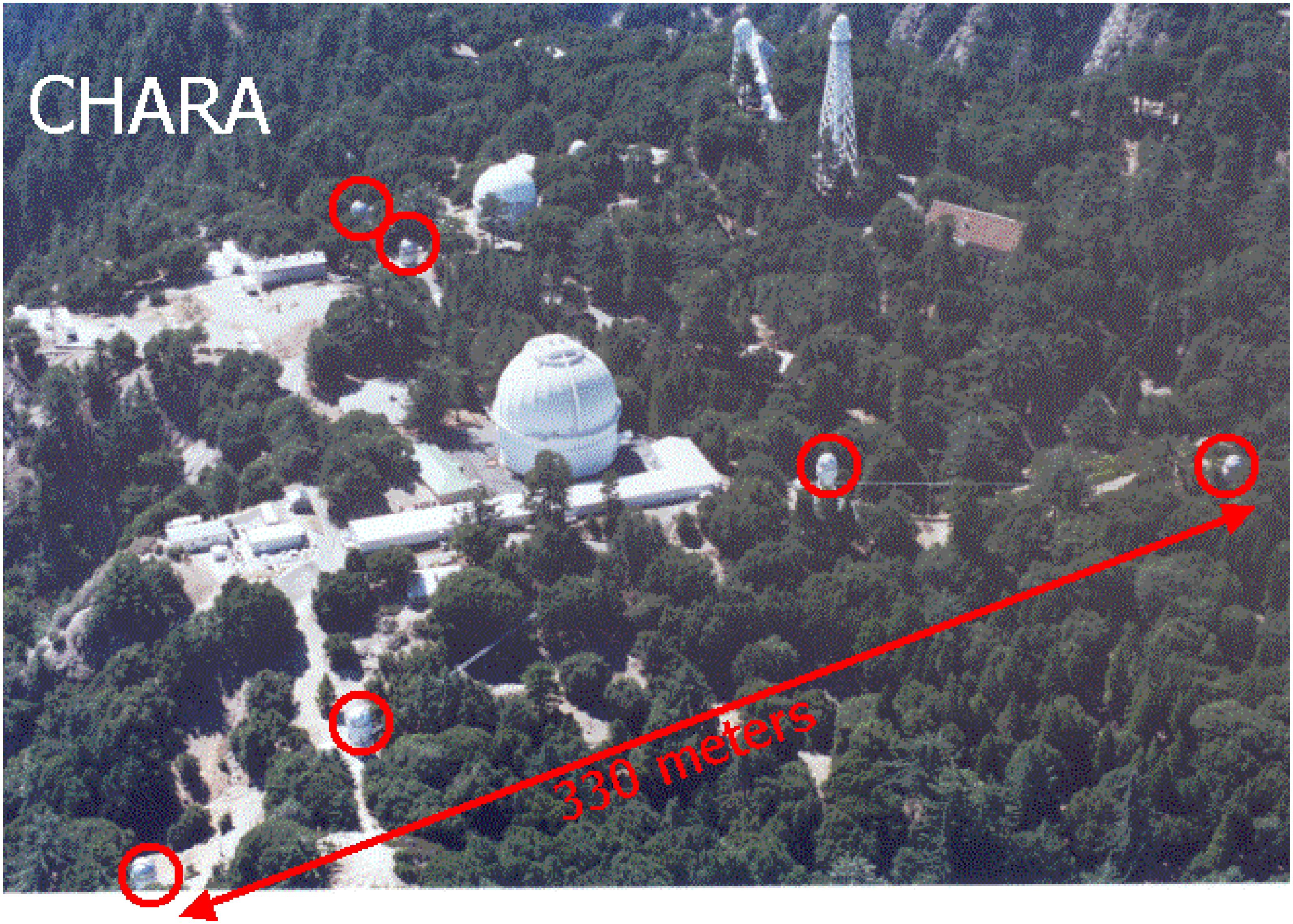
Imaging Disks with IOTA3

Traub
Berger
Monnier
Millan-Gabet
Pedretti
Schloerb
Carleton
And more

First closure phases for YSOs: AB Aur (!)

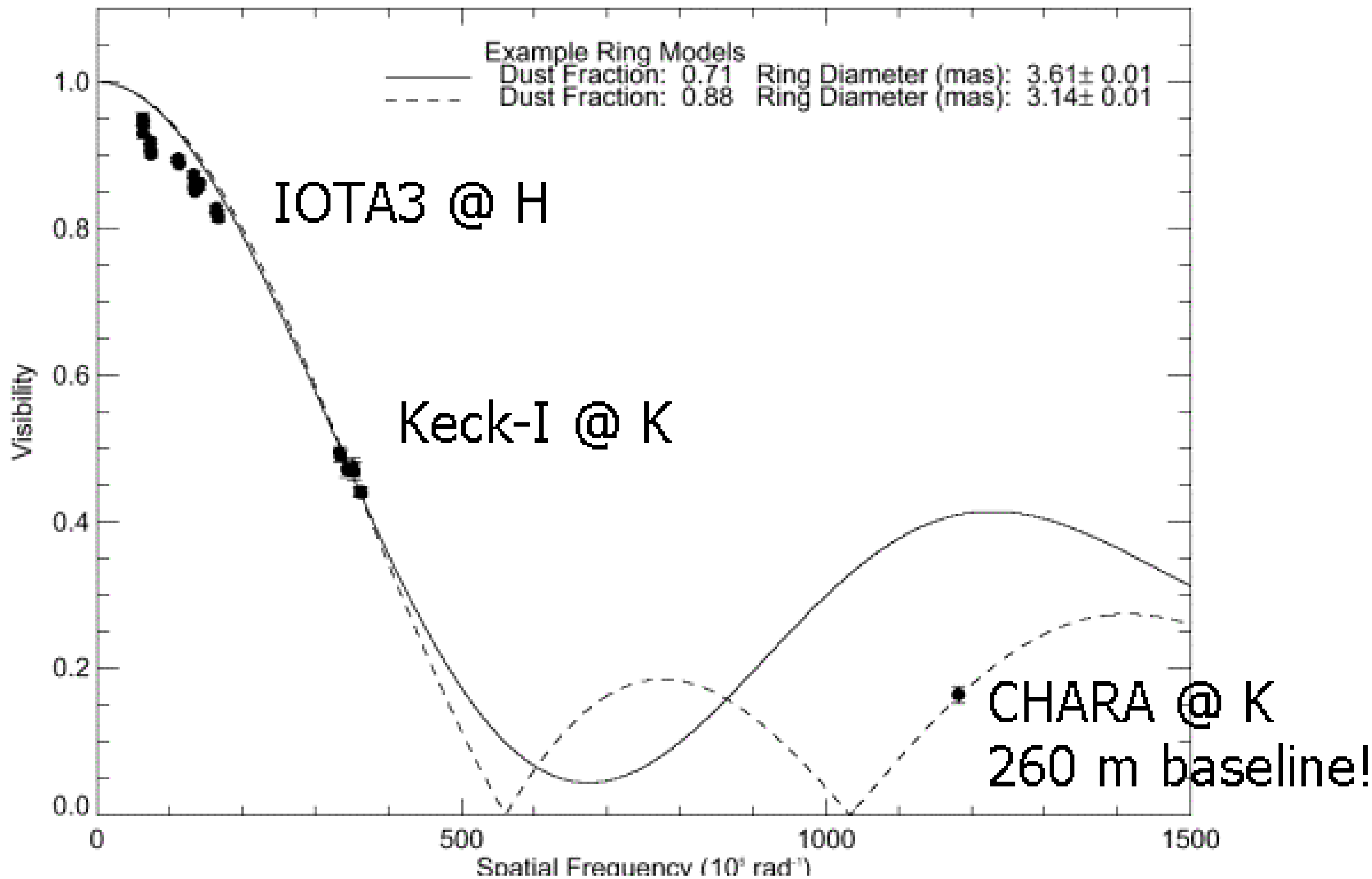




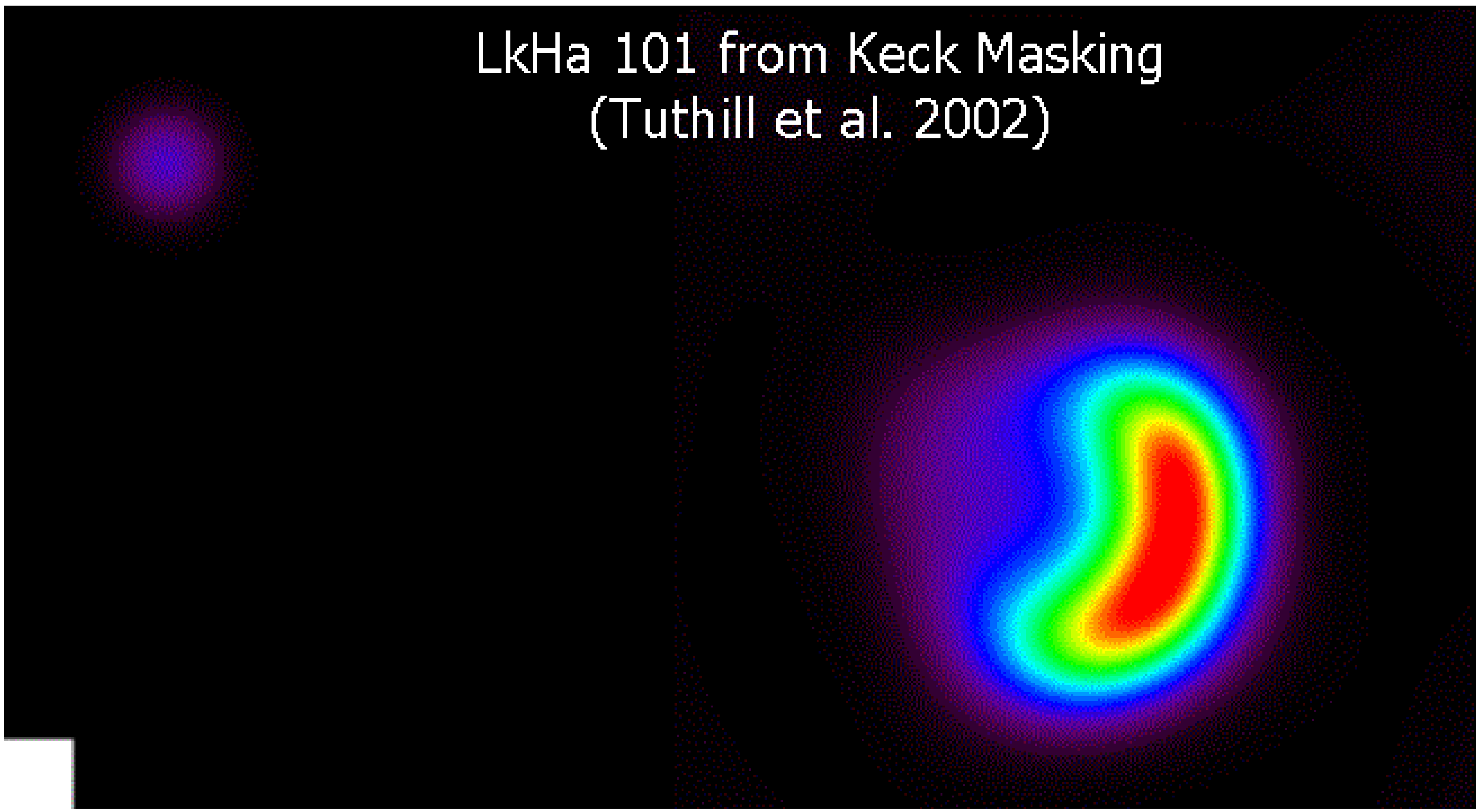


1 milliarcsecond resolution at K band

MWC 275 with IOTA3, Keck-I, CHARA

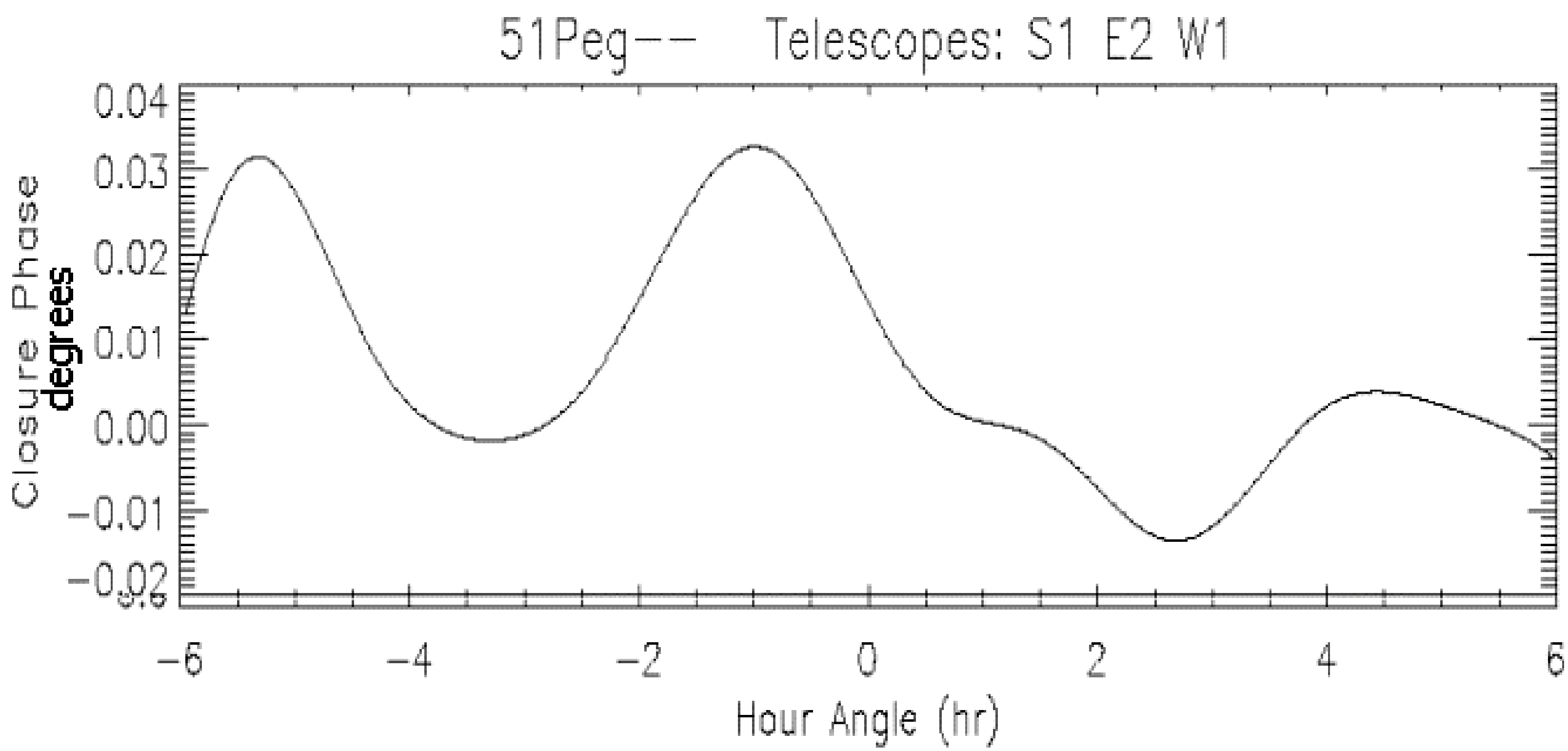


Potential of IR Imaging at CHARA: YSO Disk Dynamics

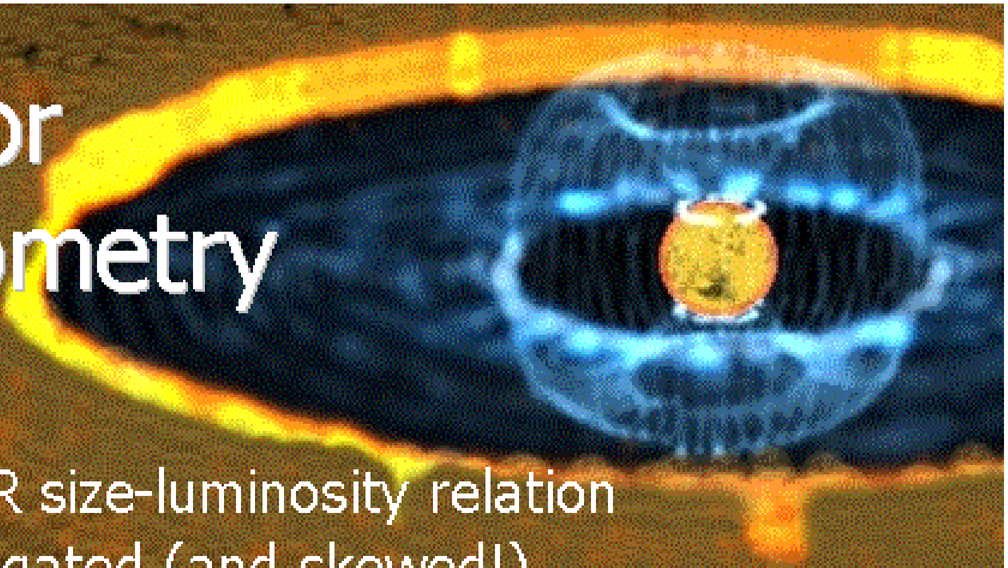


Hot Jupiters at CHARA

-- and KI/VLTI



Golden Age for YSO Interferometry



- Herbig Ae/Be
  - Well-defined near-IR size-luminosity relation
  - Some disks are elongated (and skewed!)
  - Imaging is next logical step with CHARA & VLTI
- T Tauris
  - New development of "hot inner rim"
  - Observed sizes are <u>still</u> too big
  - More sizes to come from KI & VLTI
- With 45 YSO sizes, it's now time for tailored models!
- FU Orionis Objects
  - Ask me…

Art Credit:
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