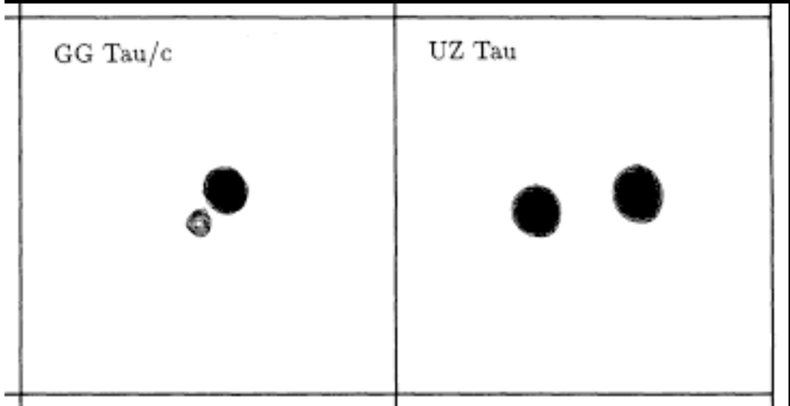
The Role of Multiplicity in Protoplanetary Disk Evolution

Adam Kraus (Hawaii)

Michael Ireland (Sydney)
Frantz Martinache, James Lloyd (Cornell)
Lynne Hillenbrand (Caltech)

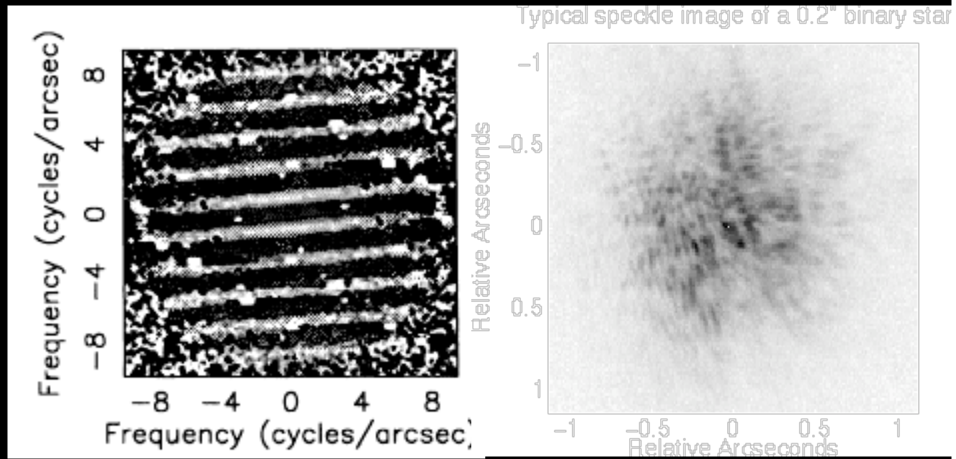
Review: Multiplicity of Young Stars



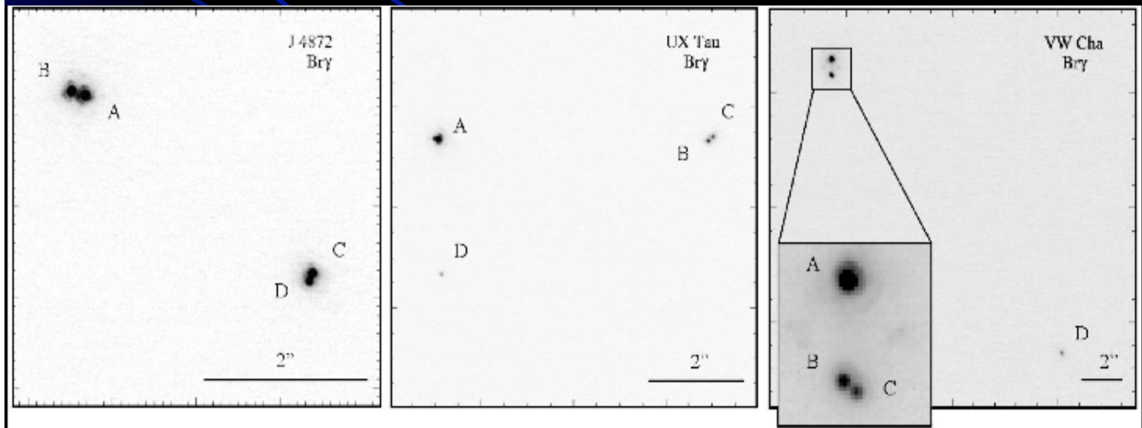
Reipurth & Zinnecker (1993)

1980s-1990s: Seeing-limited imaging of wide binary systems
(1”; 150 AU @150 pc)

1990s: Speckle interferometry on ~3-5m telescopes
(100 mas; 15 AU @150 pc)
plus lunar occultation



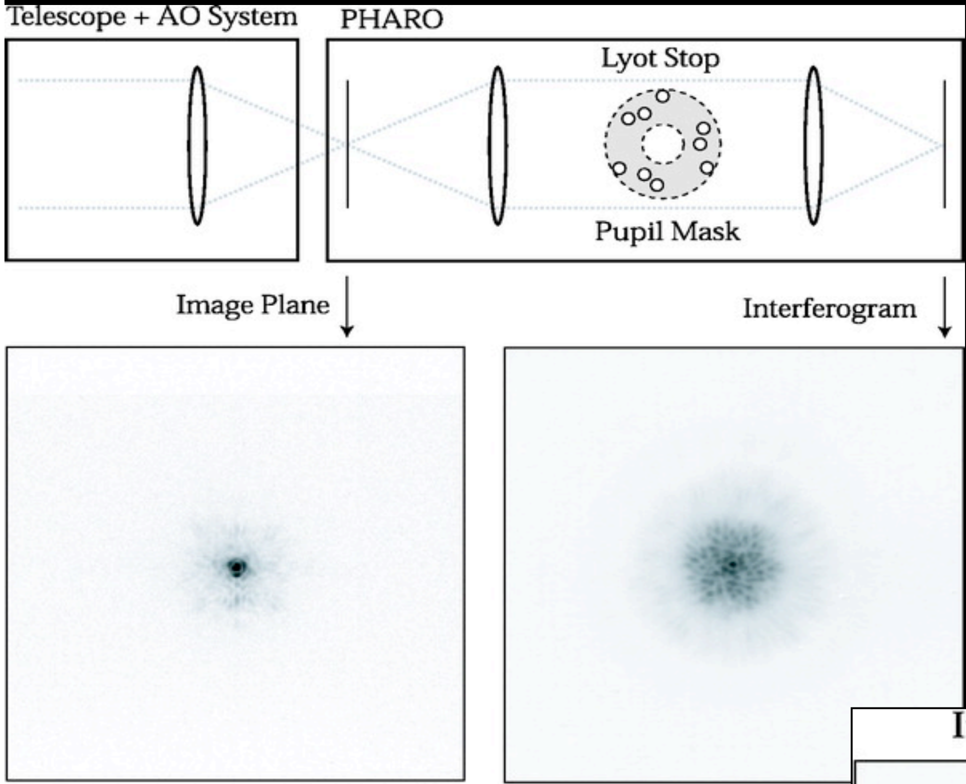
Ghez et al. (1993,1995)



2000s: AO imaging on 8-10m telescopes
(60 mas; 10 AU @150 pc)

Correia et al. (2006)

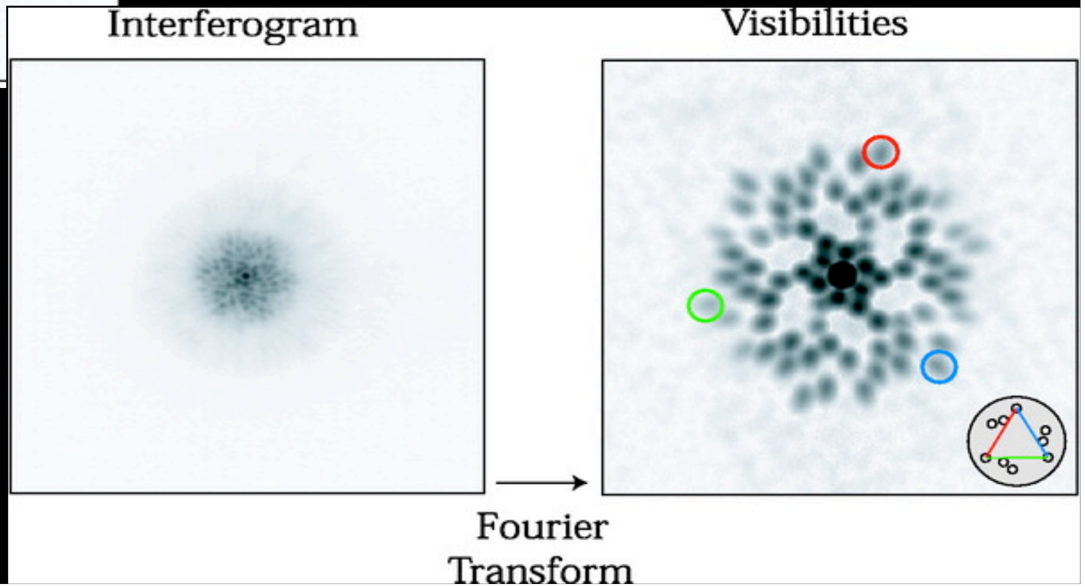
Aperture Mask Interferometry



Placing an aperture mask in the pupil plane allows calibration of atmospheric turbulence on scales larger than the subapertures. Coupled with AO (for overall wavefront stabilization), it filters almost all noise from turbulence and AO errors. This yields very stable performance.

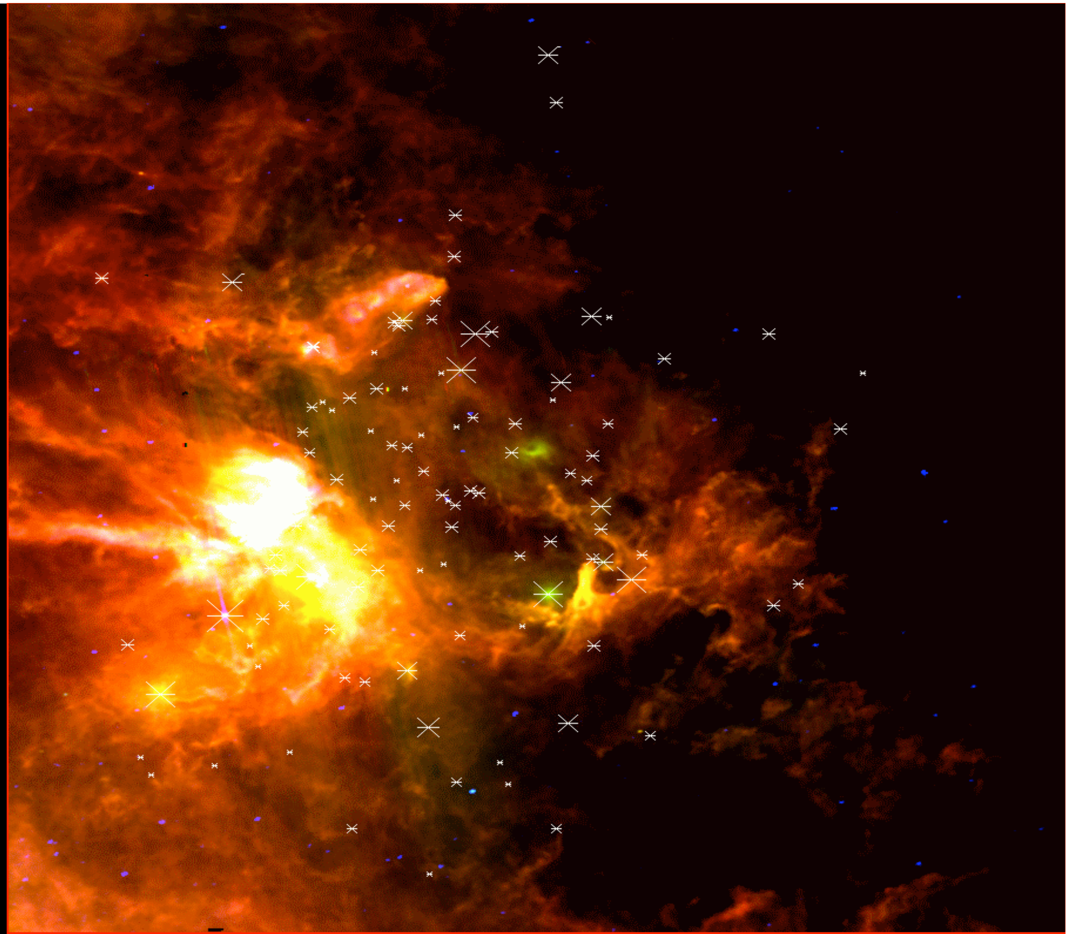
2010s (15 mas; 2 AU @150 pc)

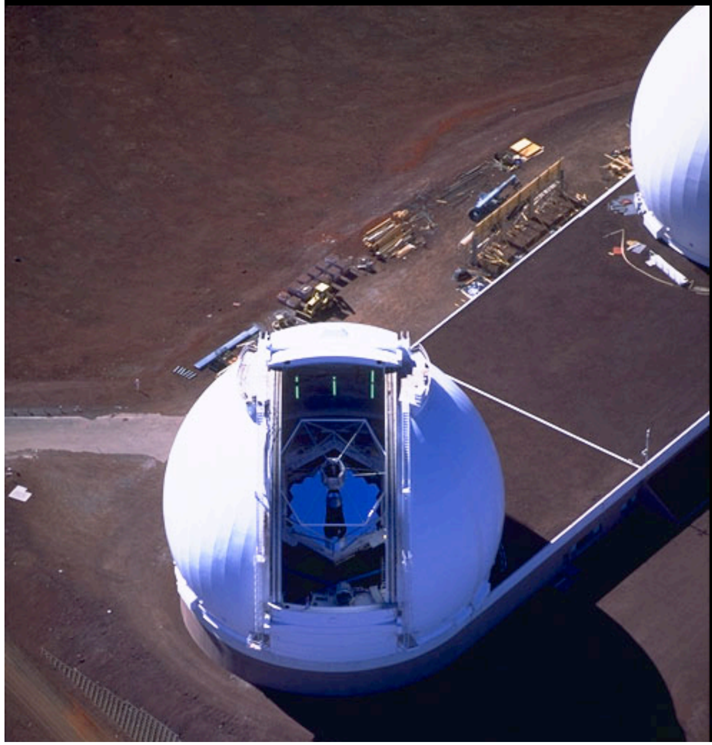
The end result is an interferogram. The Fourier transform of that interferogram yields the visibilities, which measure the angular structure of the source.



Observations

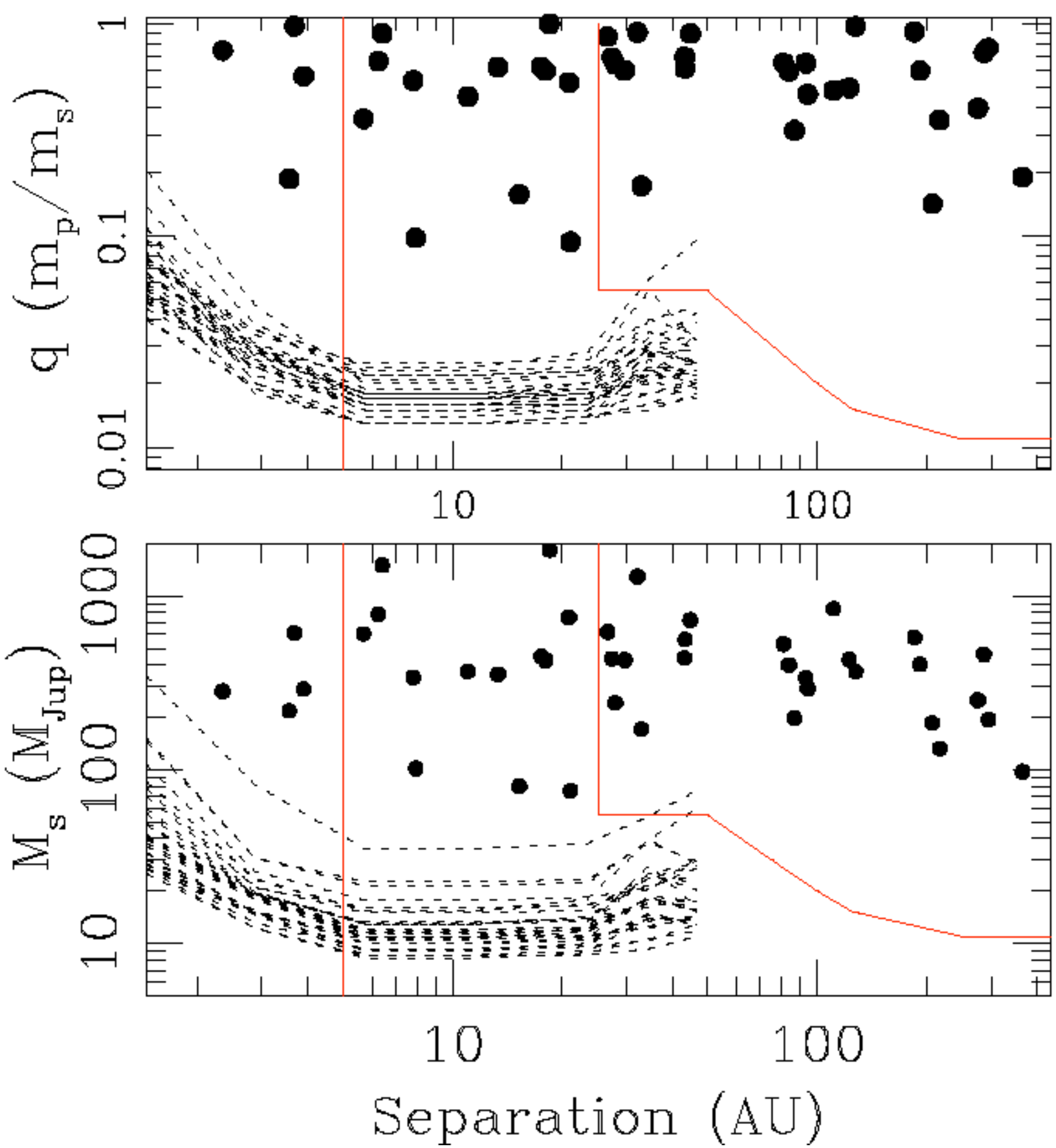
We've observed ~100 members each for Taurus and Upper Sco, plus a smaller sample in Ophiuchus. Each sample spans masses of 0.5-2.0 M_{sun}.





Most of our survey is being conducted with Keck, though some observations were obtained at Palomar. Each target is observed in ~20 minutes, for a survey rate of ~25 stars per night. We could detect equal-brightness companions at ~1/4 λ/D and the best sensitivity is at ~λ/D.

Results for Upper Sco



Binary Population

We found many new companions, but none with ΔK>3. Our limits extend to ΔK~6 for Keck, so this is a big range of empty parameter space. The brown dwarf desert is looking pretty dry so far.

(Note: Many of our detection limits extend to ~6-10 M_{Jup}, and even lower for Taurus!)

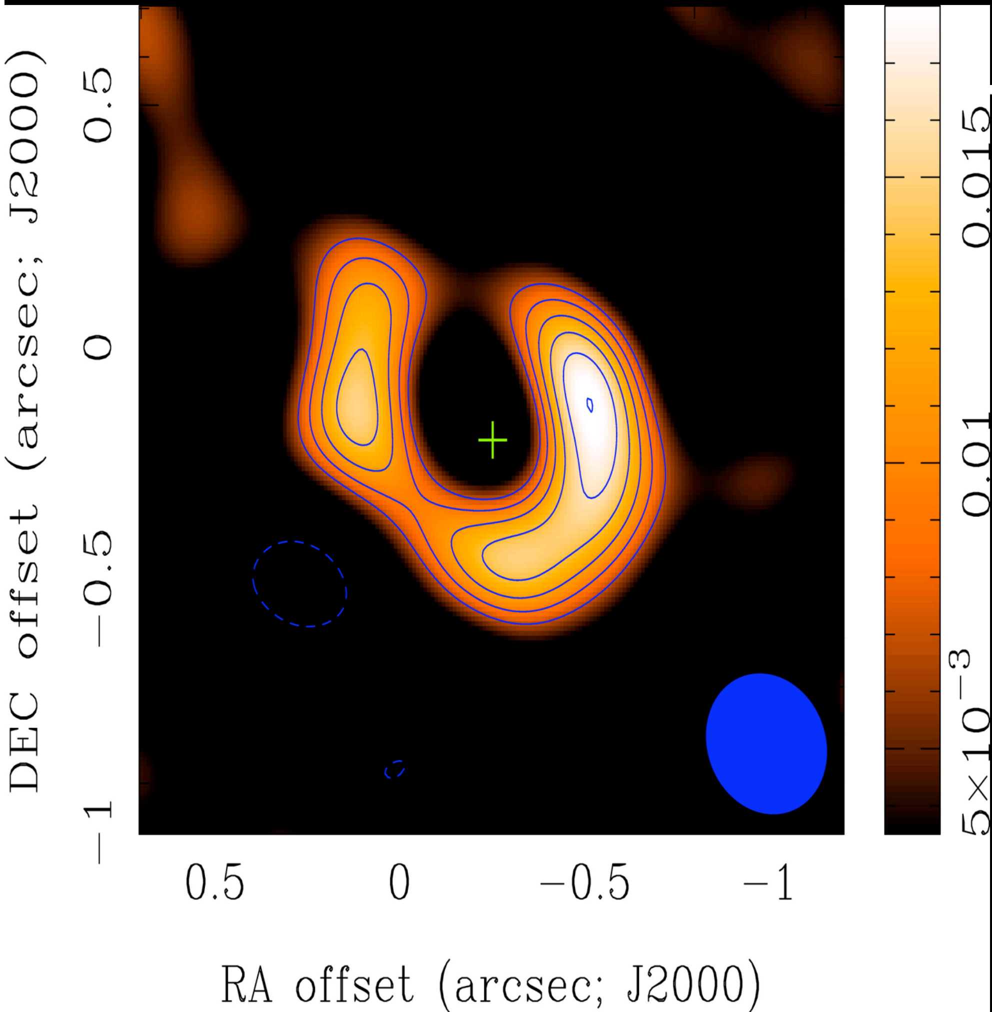
Left: Detections and detection limits for Upper Scorpius.

Filled circles: Companions

Dashed lines: 99.5% Detection Limits

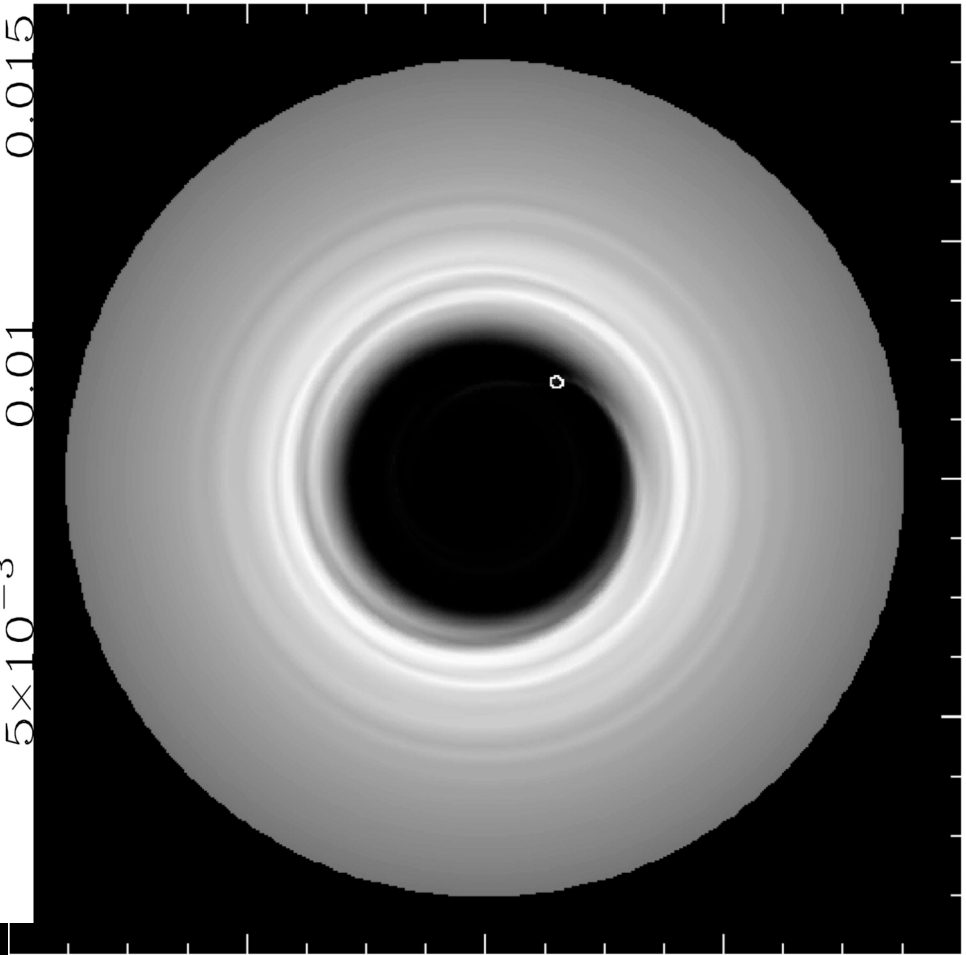
Red Lines: Limits for RV and Coronagraphic Imaging Surveys

Transitional Disks



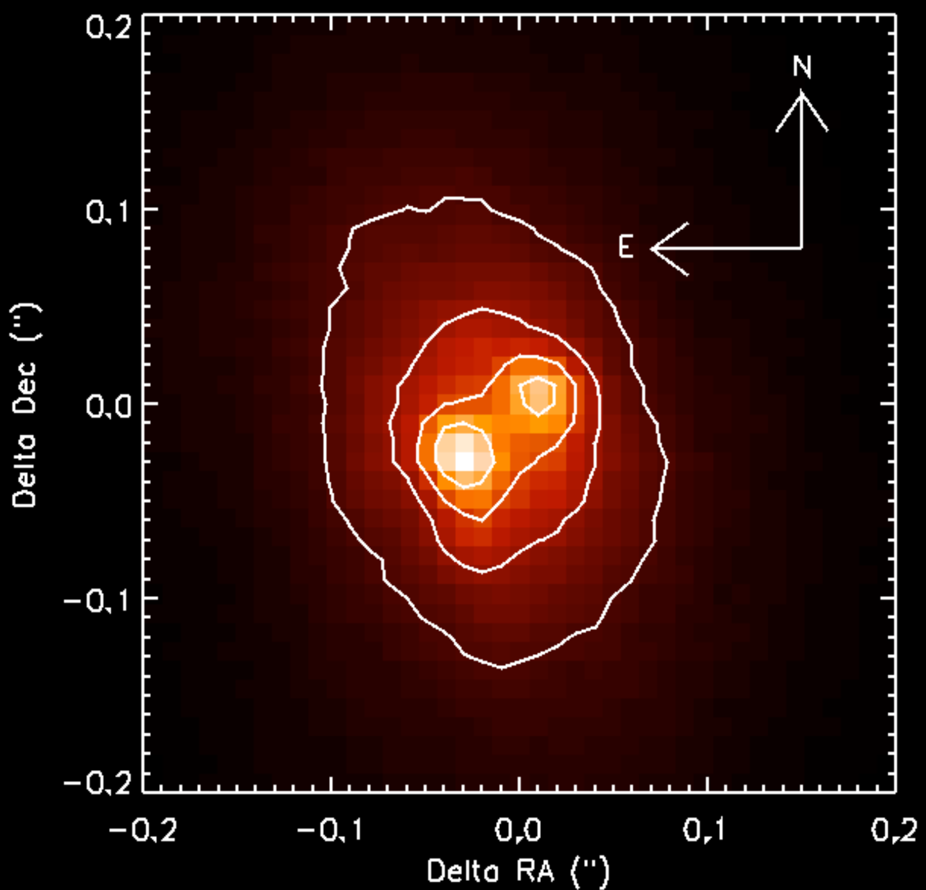
LkHa330 (sub-mm; Brown et al. 2008)

CoKu Tau/4 (Model; Quillen et al. 2004)



Transitional disk hosts are prime targets for a planet search!

The Disk around CoKu Tau/4



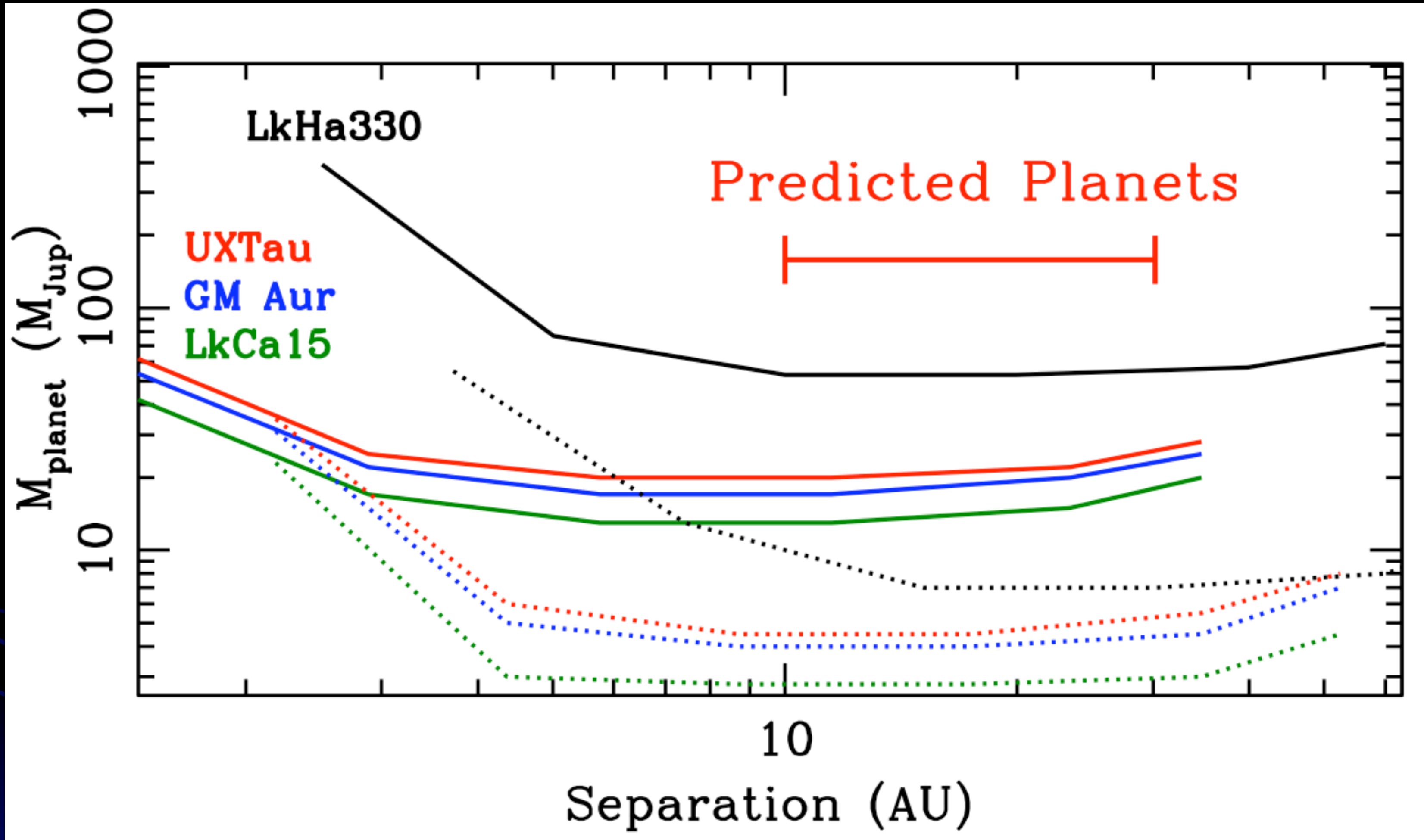
SED modeling suggests that the inner 10-15 AU of the disk around CoKu Tau/4 have been cleared; this has been attributed this to active planet formation.

However, we actually found that CoKu Tau/4 an ~8 AU binary; the disk truncation is therefore a natural result of tidal truncation and not planet formation.

(CS Cha might be another example of a faux transitional disk; Guenther et al. 2007)

Troubling Question: Many of the other hosts for “transitional” disks haven’t been thoroughly surveyed for multiplicity. How many are actually circumbinary disks?

Circumbinary “transitional” disks?



Detection limits (K-band multiplicity survey; solid lines) for GM Aur, UX Tau, LkCa15, and LkHa330 from Keck (Kraus et al., in prep); shallower VLT limits exist for southern targets (Ireland et al., in prep). Next step is a deep L-band survey of these targets to directly search for planetary-mass companions.

Circumbinary "transitional" disks?

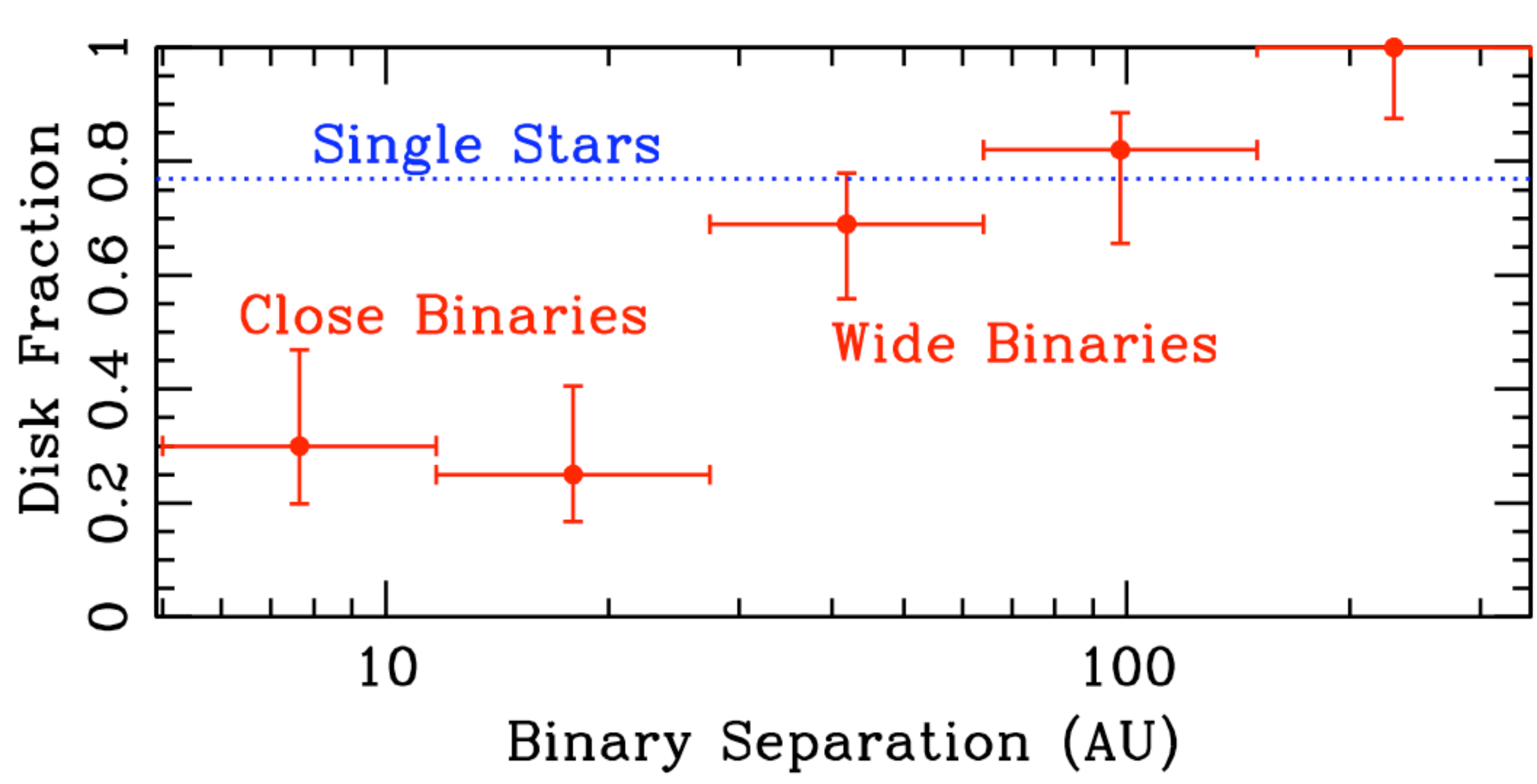
But wait a minute…

20% of all solar-type stars appear to be 1-20 AU binary systems, so why don't we see ~20 "fake" transitional disks in places like Taurus? Maybe this says something about protoplanetary disk evolution?

Many of the disk-free stars in Taurus are turning out to be close binaries! (Hubble 4, LkCa4+5+21, V827 Tau, almost anything with CIDA in its name)

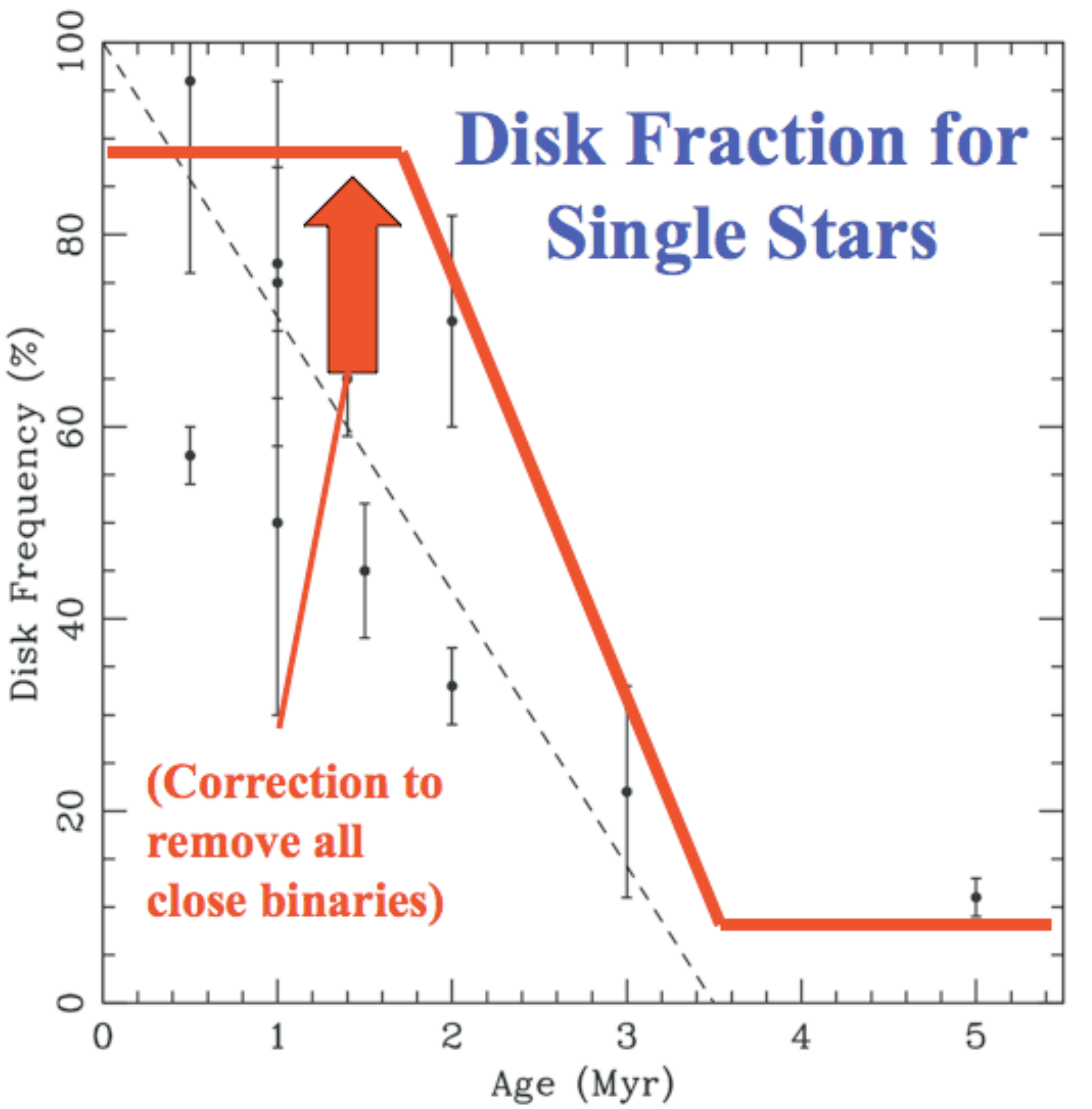
This isn't a new idea (Ghez et al. 1997; White & Ghez 2001; Cieza et al. 2008), but remember the sensitivity limits I quoted for past binary surveys – this is the first time we can see more than a hint of this trend.

Binaries and Disks



The disk fraction as a function of separation for Taurus solar-type stars in binary systems. Disk hosts were identified from IRAC, IRS/MIPS, or submm; disk-free stars identified from IRS or MIPS. The disk location (primary, secondary, or circumbinary) hasn't been determined for most systems).

The Multiplicity Correction

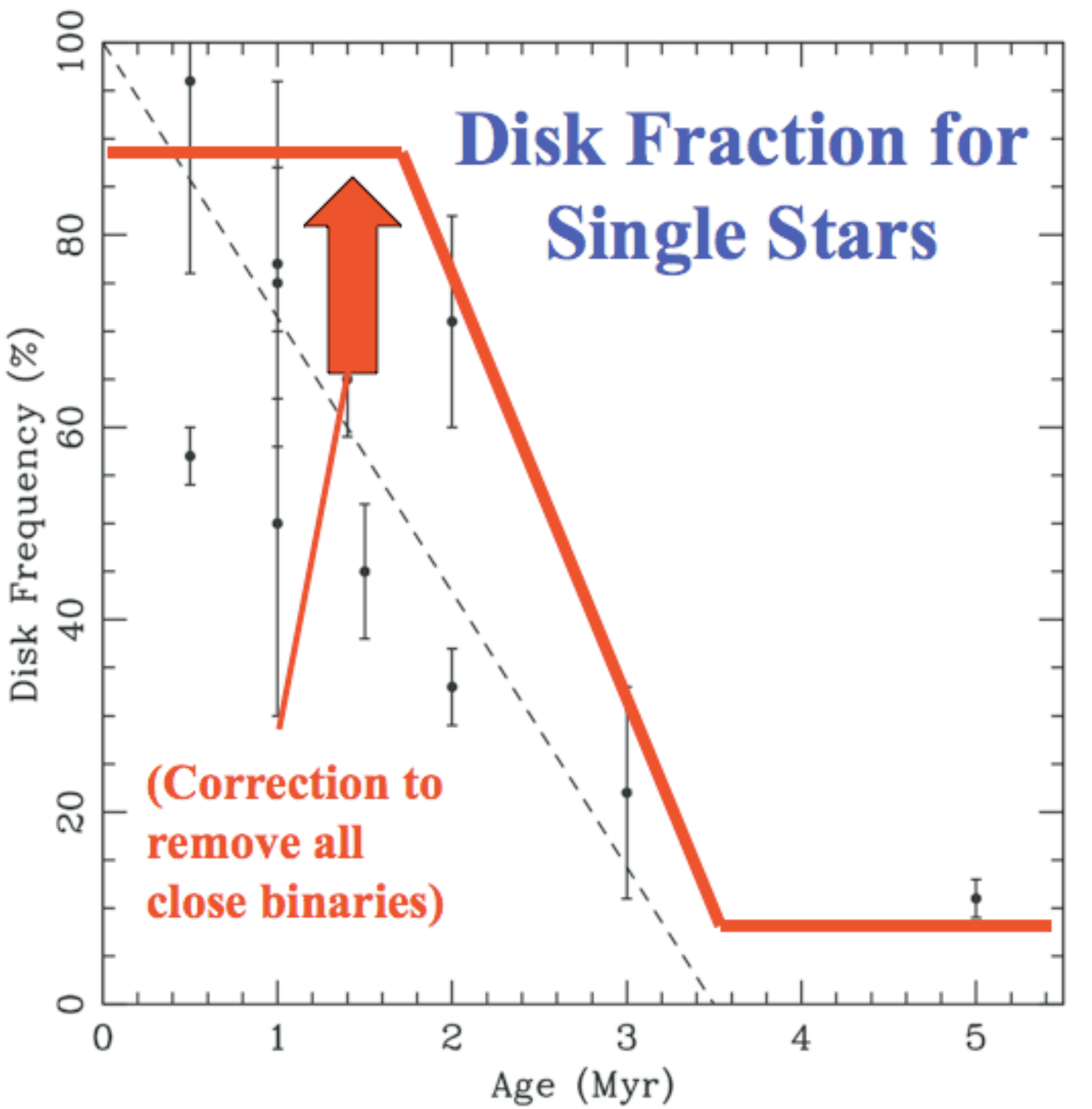


It seems that many of the disk-free stars in these 1-2 Myr associations are binaries; if we remove them, the disk fraction of genuinely single stars goes up by ~10-20%.

Open question: What happens inside 3-5 AU?

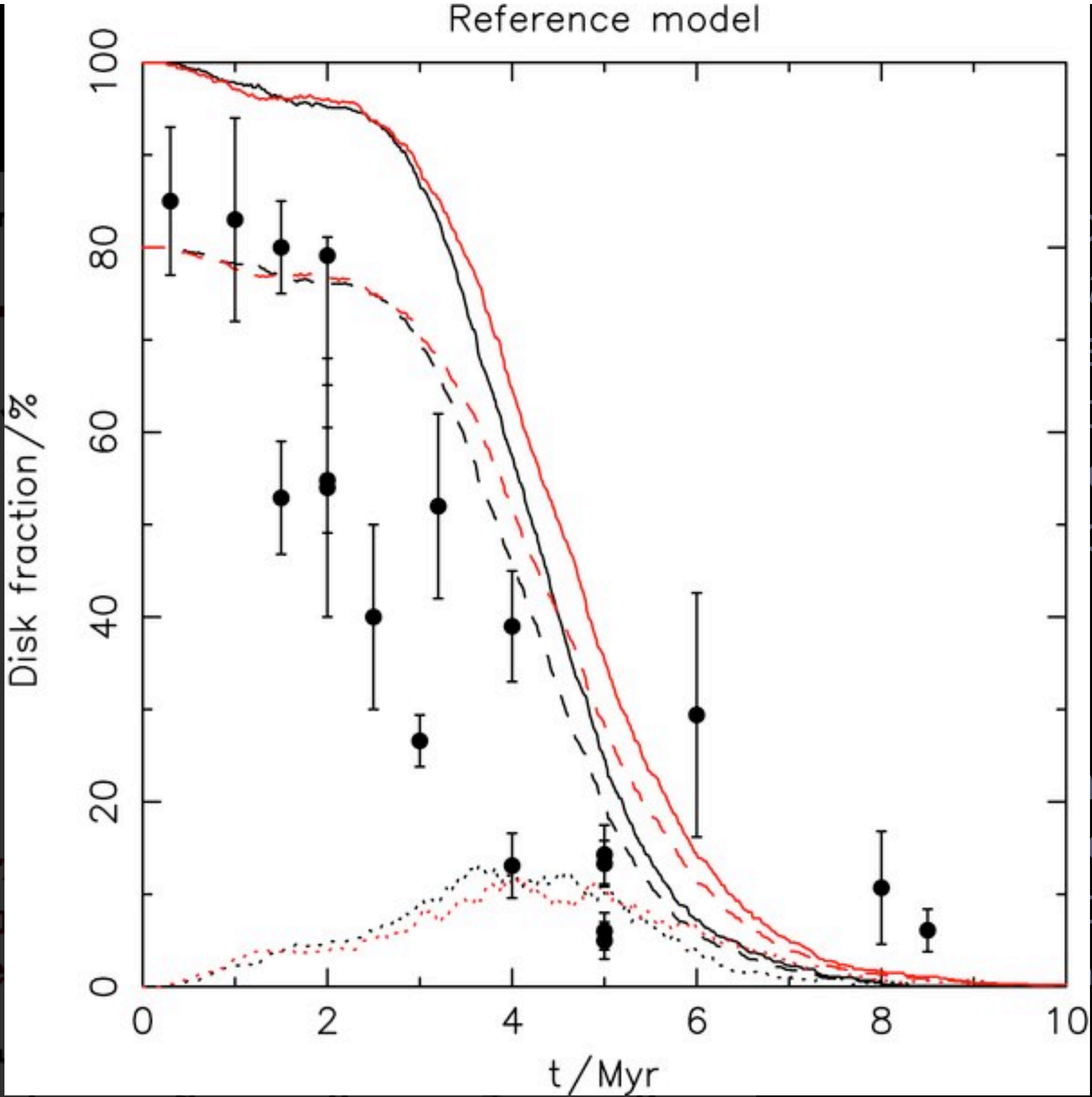
(Disk fractions from Hillenbrand 2005).

Disk Lifetimes



Under this picture, most circum*stellar* disks last at least 1-2 Myr; most circum*binary* disks, on the other hand, seem to disperse promptly.

Numerous surveys have found that even circumstellar disks are mostly gone by 5 Myr, though. (Carpenter et al. 2006)



cture,
tellar
east 1-2
cum*binary*
other
disperse

rveys
at even
disks are
by 5 Myr,
ter et al. 2006)

(Figure from Alexander & Armitage 2009)

Implications for Planet Formation

Most single stars should have at least 1-2 Myr within which to form planets (but not much more than 5), while close binary systems have <1 Myr.

(This doesn't bode well for planet searches around close binaries…)

Note: There are variable outcomes. Judging by the SEDs,
DP Tau has a full disk, CoKu Tau/4 has a circumbinary disk, and Hubble 4 has no disk. Why?

Many of the disks that do survive (CoKuTau/4, ST 34, GG Tau) seem to be in binary systems with equal mass components and/or circular orbits. Are these the criteria for circumbinary disk longevity?

Summary

- Aperture masking interferometry is an excellent method for probing the multiplicity for distant young stars, offering superior resolution and sensitivity (Keck, VLT, Palomar)
- Some "transitional disk" systems are close binaries, but they are probably a small minority
- We aren't swamped by "fake transitional disks" because the majority of close (<30 AU) binaries lose their protoplanetary disks extremely quickly (<1 Myr)
- This prompt dispersal of circum*binary* disks suggests that disk fractions for true single stars are higher, and removing binaries obviates the need for prompt dispersal of circum*stellar* disks
  - Planet formation around single stars usually has >2 Myr to occur
  - Planet formation around close binaries has to occur quickly (<1 Myr)
  - Some binary systems keep their disks for a long time, perhaps because they're in dynamically stable configurations where accretion is difficult