Infrared Observations of Young Stellar Objects at CHARA

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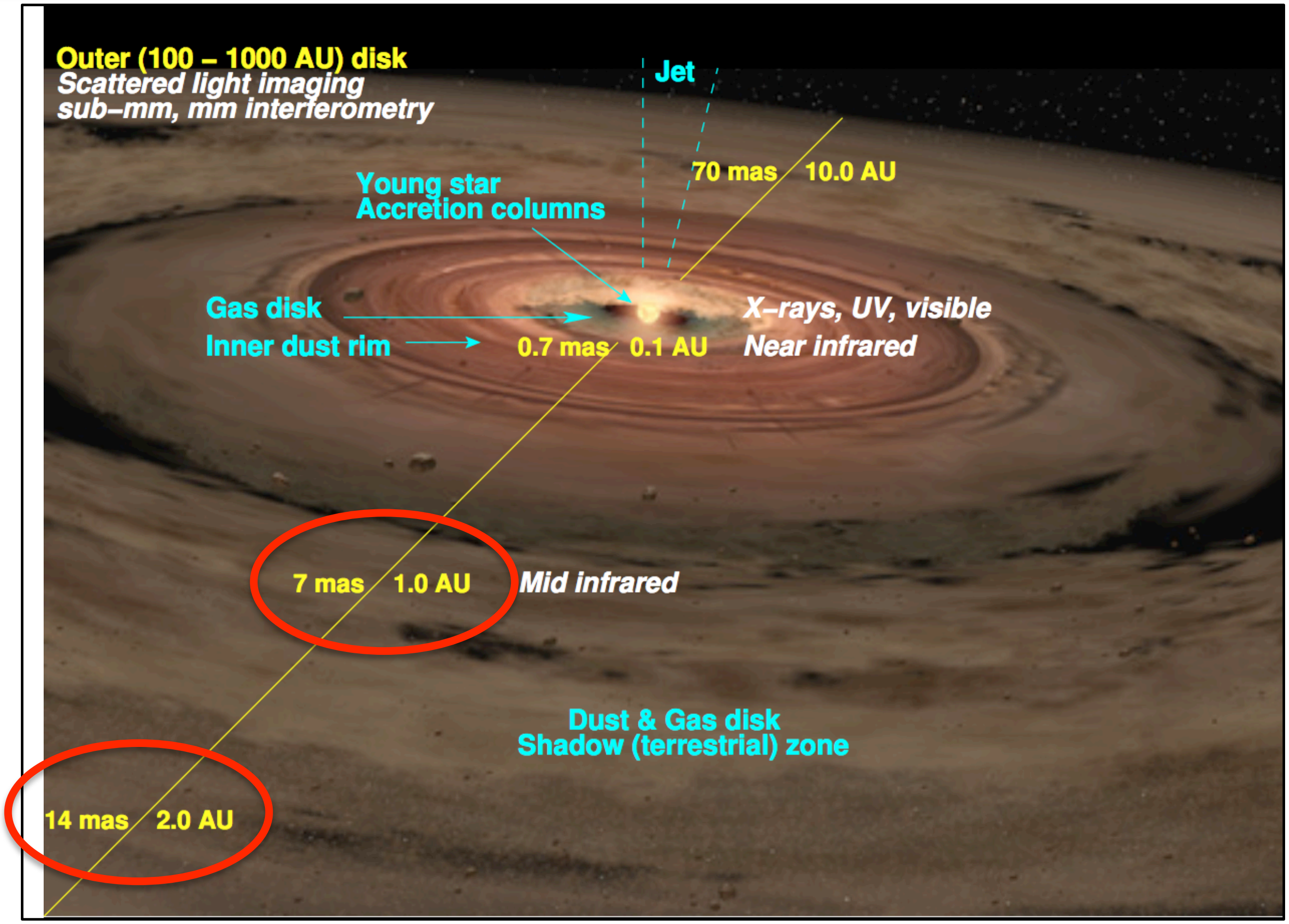
Goals of Classic Observations

1. Improve on what is known about the disk morphology (beyond the characteristic sizes) by using Classic and the longest baselines (beyond the 1st visibility lobe).

2. Identify prime targets for imaging studies enabled by CHAMP (MIRC).

Motivation

Millan-Gabet et al. ASTRO2010 white paper



Based on artist's conception by D. Darling.

Interesting scales for the planet formation problem: location of Solar System rocky planets, exo-hot-Jupiters, habitable zone, snowline … all unresolvable by conventional imaging!

Background:
First generation interferometry results

Main results:

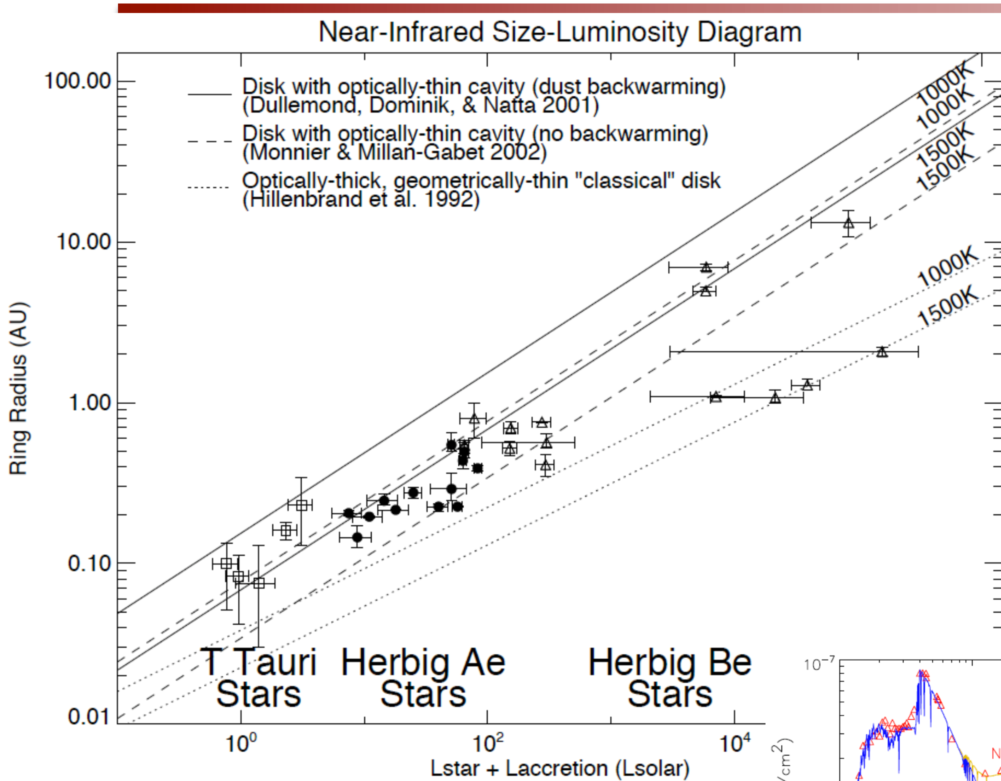
- Measured NIR disk sizes; established disk-like morphology (IOTA, PTI, KI).
- Emergence of new paradigm for the inner disk: the "puffed-up" inner dust rim (independently motivated also to explain the NIR SED, and by aperture masking imaging of extreme case LkHa101).
- First probes of second order inner disk morphology via Closure Phases (strong CPs expected from simplest models not seen…) (IOTA/IONIC).
- Measured MIR sizes; correlations with outer disk shadowing and flaring (SED classifications); dust mineralogy & disk gradients (VLTI/MIDI).

Caveats:

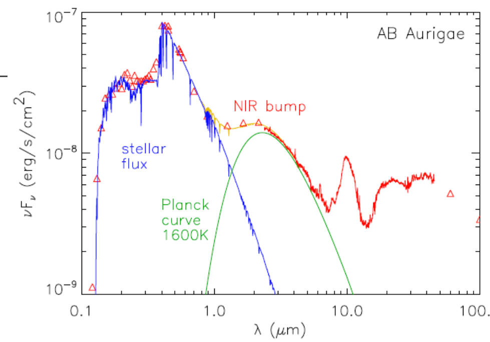
- Sparse data, in λ and uv.
- Small sample sizes, limited by sensitivity.
- Interpretation based mostly on simple geometrical models.

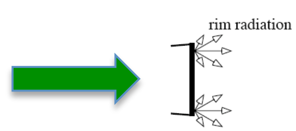
Some recent reviews:
Millan-Gabet et al. PPV review 2007
Dullemond & Monnier ARA&A, in preparation

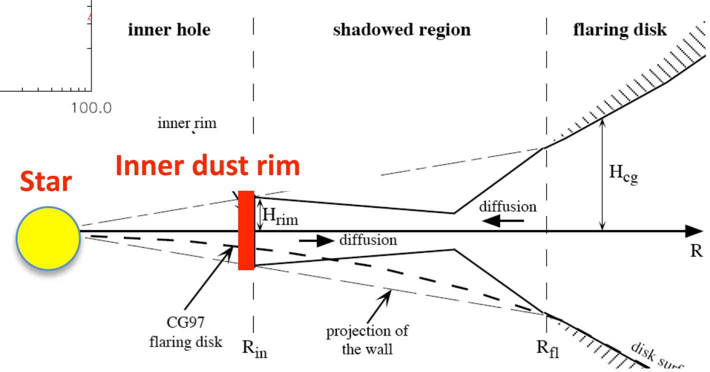
Size-Luminosity relations & The inner disk



- For most objects, reveals dominant mechanism for setting the NIR sizes (dust sublimation).
- SED NIR "bump" explained by the same model.
- the NIR SED bump is a very important (energetic) feature! (even for TTS)
- High L objects require different model.
- TTS need better accuracy.
- Large scatter.







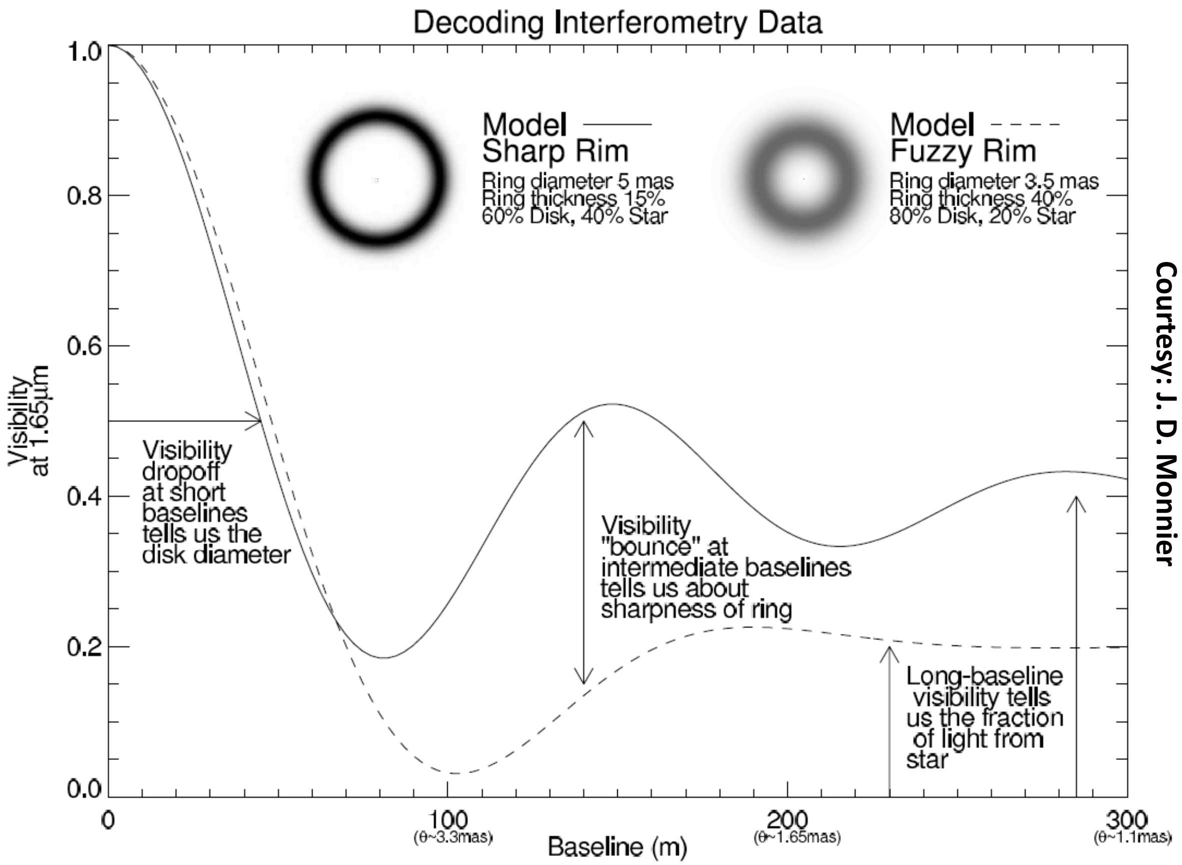
New Questions

- Does the inner dust wall really exist?
- If so what are its precise structure & physical properties?
- What is inside the dust sublimation radius?
- Disk structure (dust & gas) as a function of stellar type.

Methods

- New observables:
  - CPs and visibilities over wide uv coverage.
  - More wavelength coverage.
  - Spectro-interferometry.
- Theory:
  - Self-consistent physical models
    (a complex 3D radiative transfer problem …).
- Integrated modelling of complex datasets using realistic models.

Detailed tests of the inner wall with very long baselines



Curved inner dust rims (fuzzier brightness) are expected theoretically:

+ Inner rim "puffing" (Dullemond 2001).
+ Dust sublimation temperature dependence on vertical gas density (Isella 2005).
+ Dust settling to mid-plane & growth (Tannirkulam 2007).

Status of observing campaigns (2004 – 2009)

Herbig Ae/Be

	V	K	
AB Aur	7.1	4.2	Hae
MWC275	6.9	4.8	HAe
v1295 Aql	7.8	5.8	HBe
MWC361	7.4	4.7	HBe binary
HD158352	5.4	4.8	HAe
HD142666	8.8	6.1	HAe
MWC147	8.8	5.7	HBe
MWC758	8.3	5.8	HAe

(AB Aur, MWC275: published)

(v1295 Aql, MWC361: next publications)

T Tauri

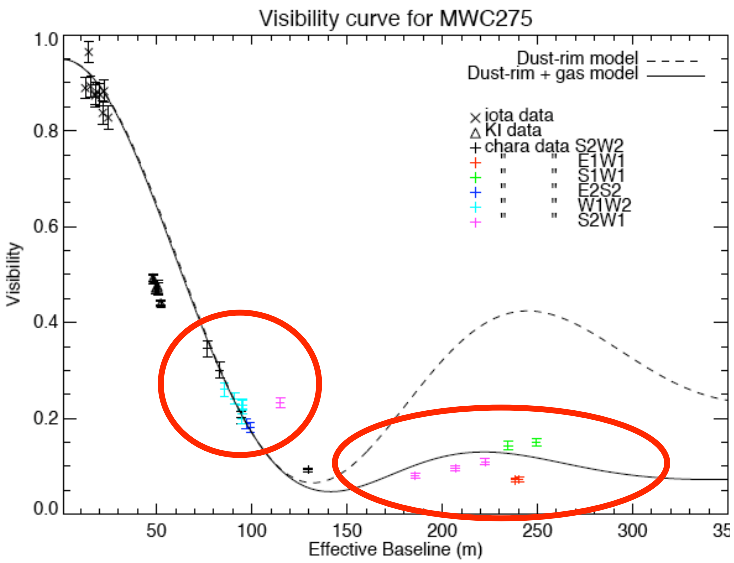
	V	K	
FU Ori	8.9	5.2	G3I
RY Tau	10.2	5.4	F8V binary
SU Aur	9.4	6.0	G2III
RW Aur	10.3	7.0	G5V binary
BP Tau	12.0	7.7	K5V

- Mostly K-band data, started H-band too.
- Fainter objects enabled by recent improvements in TT & NIRO sensitivity.
- If CHAMP limit is K~8, all can be imaged with MIRC too.

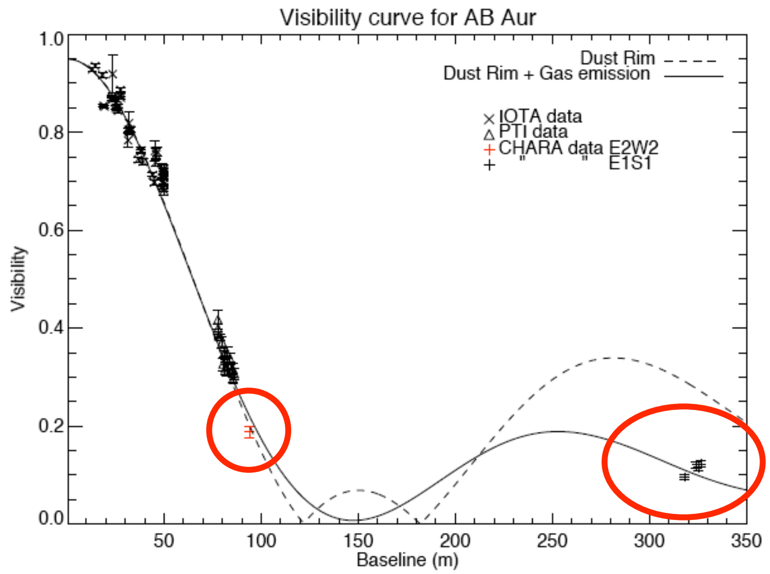
CHARA first results

Tannirkulam et al. 2008.

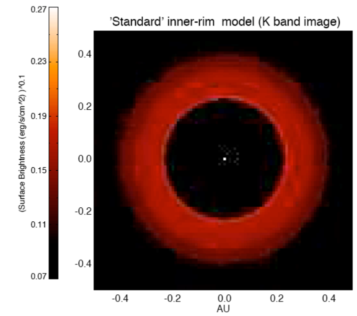
MWC275: K=4.7, A1 Herbig Ae



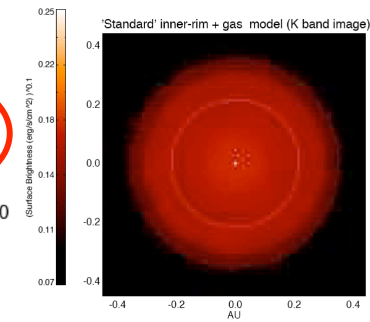
AB Aur: K=4.4, A0 Herbig Ae



Inner dust rim only



Rim + Inner Gas

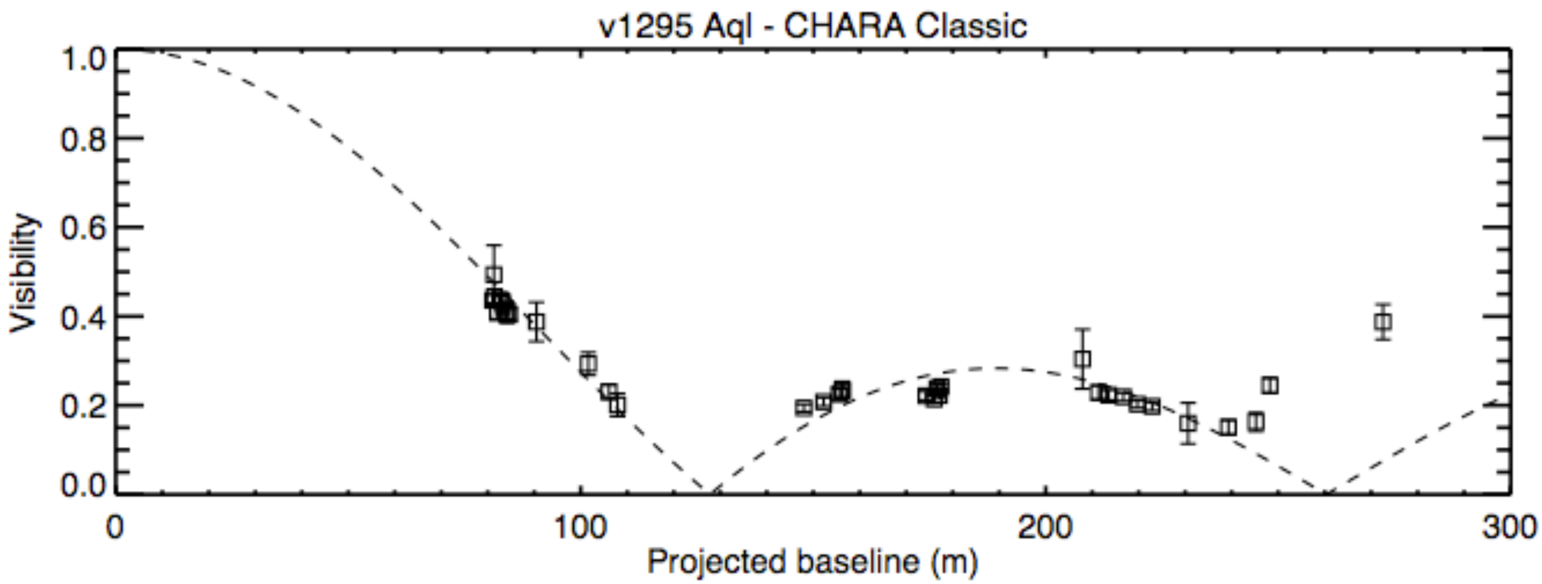


- Very "fuzzy" rims, not reproducible by any physical smoothing mechanism
  ➔ another disk component is required.
- Large amount of NIR excess (~50% at K) originates in this new component.
- Origin of this new hot emission not yet conclusively established: gas accretion energy? refractory dust? inner wind/envelope?
- How general is this result? (so far only brightest HAe/Be observed)

New object

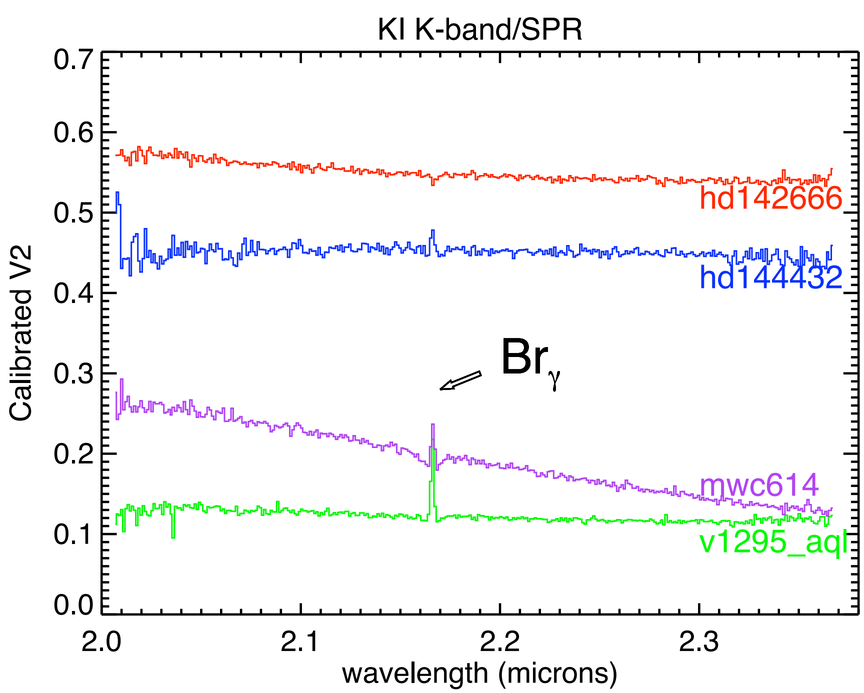
V1295 Aql: K=5.9, A2 Herbig Ae

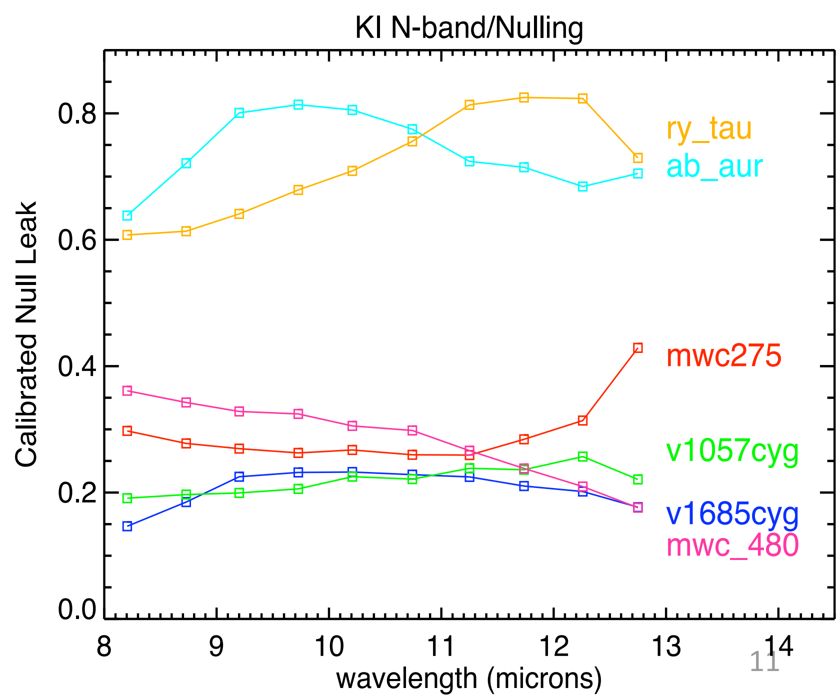
- Much better baseline coverage Bp = 80 – 275 m
- Investigating data reduction for these low SNR data (faint & low visibility).
    - reduceir & Michigan Classic pipeline generally give similar results.
    - Some differences with the lowest SNR data.
- Disk inclination very uncertain ➔ additional modelling complication …
    - 0 – 65 deg from IR interferometry (Eisner04, Isella06).
    - Low rotation velocity –(v sini = 9 km/s) > low inclination (Acke04, Catala07).
    - No mm maps (e.g. CARMA) data!



Relation to other projects

- KI YSO program:
  - Spectro-interferometry of selected objects observable in the 3 modes: MIR (Nulling, R=100), NIR (R=1700) & L-band (R=60).
  - Contemporaneous IRTF spectro-photometry (with M. Sitko, SSI).
  - KI Nuller observations require K<6, so it is the same sample as CHARA.

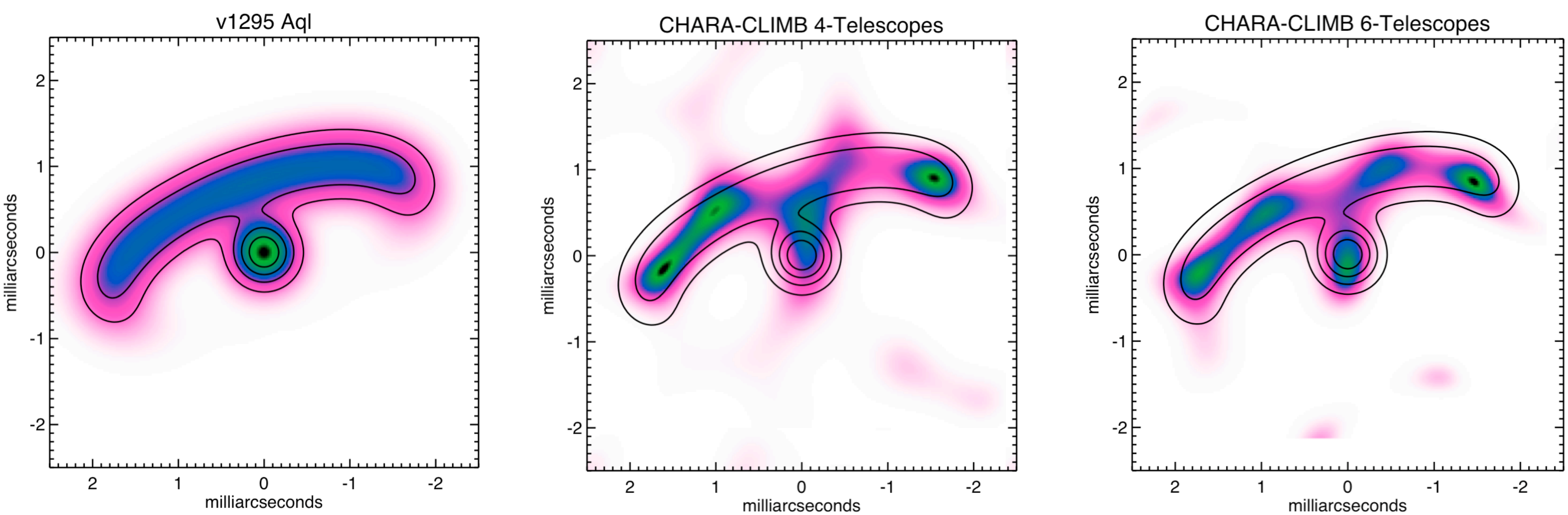




Relation to other projects

- Identify "good" targets for future imaging studies.
  - Hopefully will start CLIMB campaign in Summer 2010.
  - Then, CHAMP+MIRC.

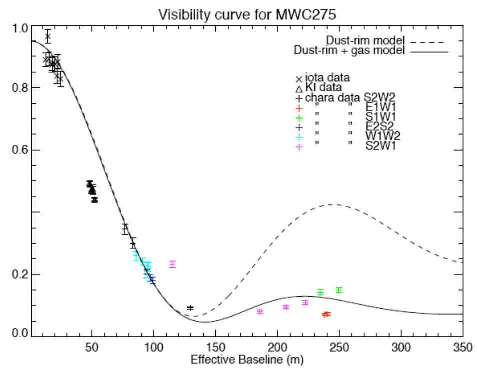
Courtesy: F. Baron

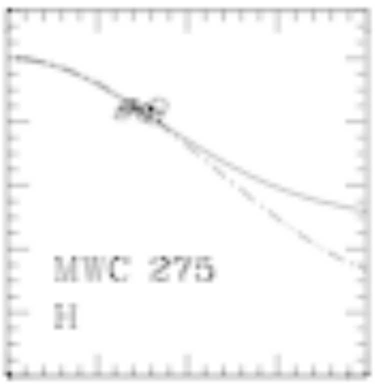


Example evolution of uv coverage: MWC275

CHARA (+KI)

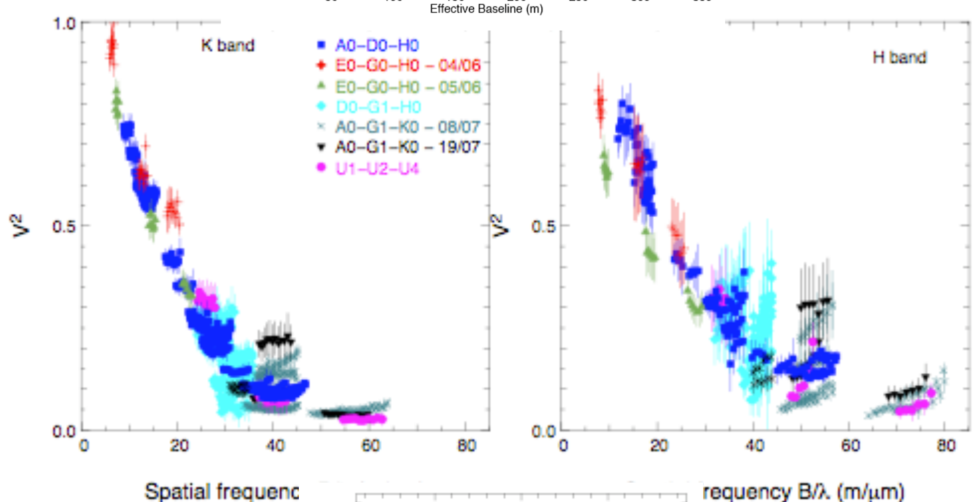
Tannirkulam et al. 2008

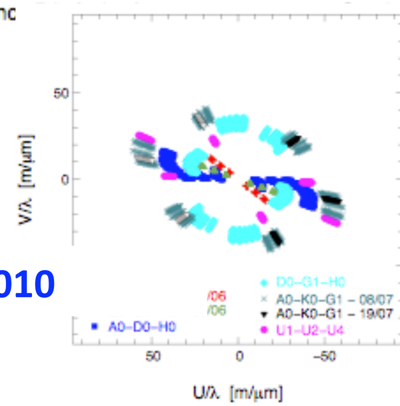




IOTA

Millan-Gabet et al. *1999*





VLTI

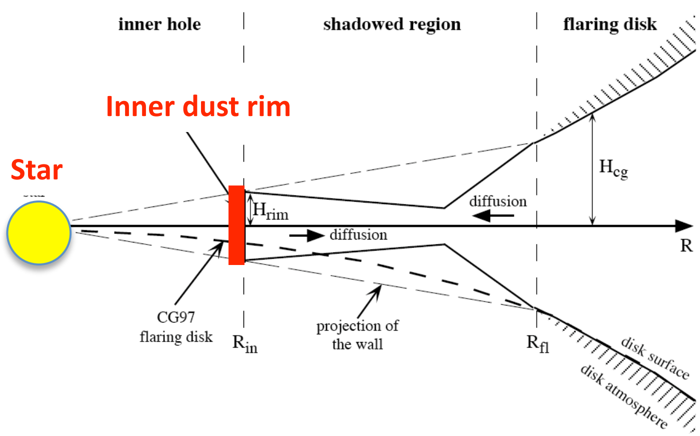
Benisty et al. 2010

??

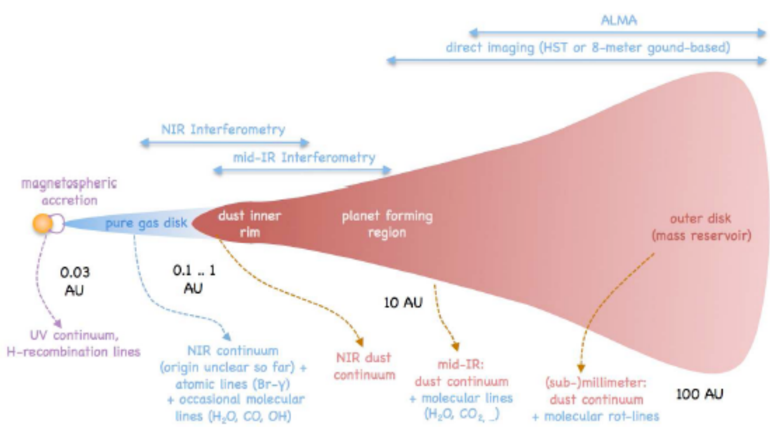
What will we find with images at this resolution?

Evolution of the inner disk picture (or how life gets complicated)

SED only motivated



SEDs + simple interferometer data. (add a 1500K blackbody at the dust sublimation radius)



Physical (smooth) inner dust rims (still do not fit the SED bump very well).

Inner gas (opacity, line & continuum emission).

Extended envelopes (few % NIR flux).

Conclusions

- CHARA/Classic contributes fundamentally new science in the area of YSO disk studies, primarily exploring disk structure beyond the 1^{st} lobe.
- Combining data from multiple instruments (wavelength and uv coverage), detailed studies of individual objects will reveal the disk structure for each type of object.
- Approaching the era of mas imaging: confront our basic paradigms and the likely complexity of disk morphologies.