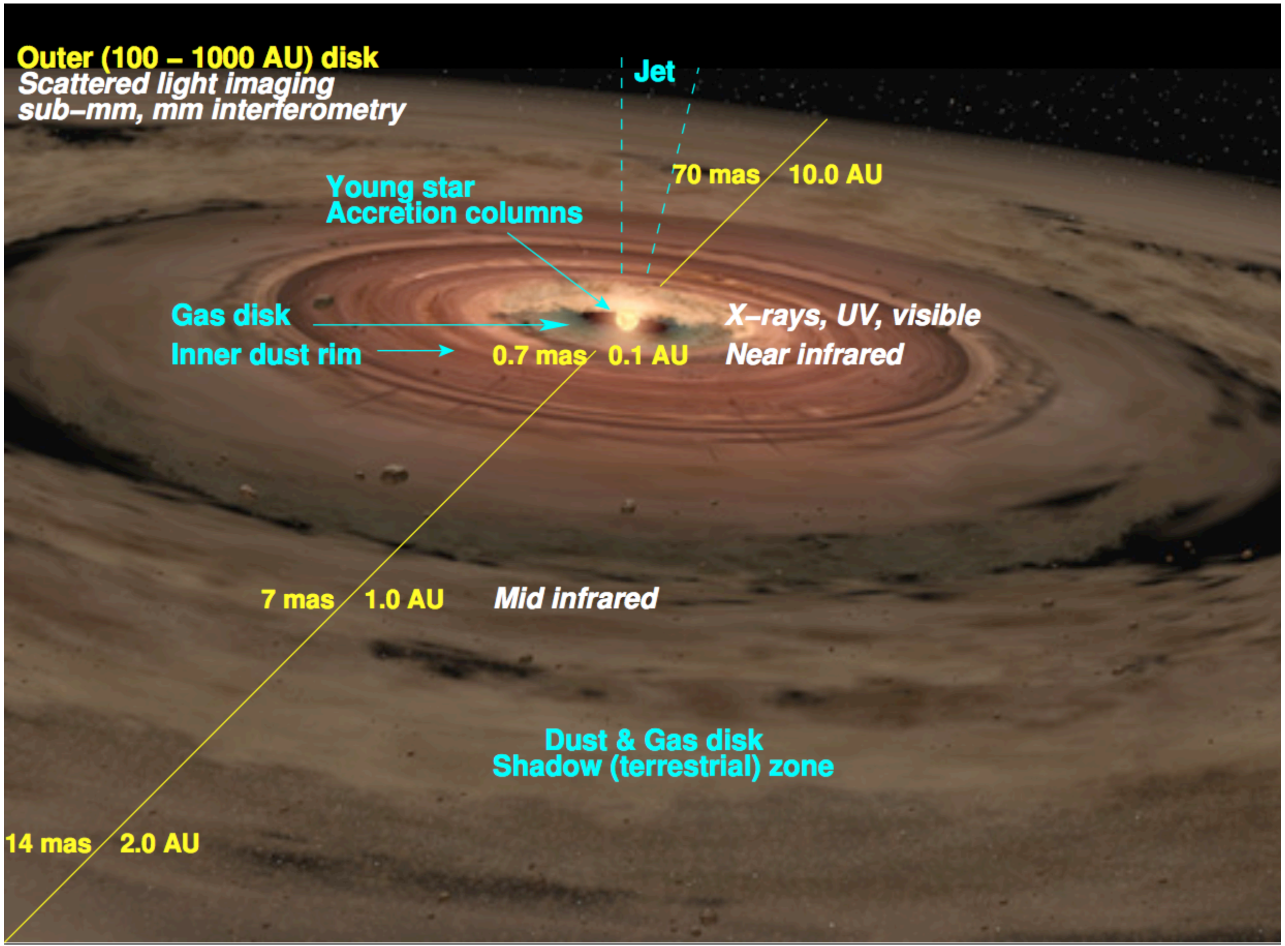
Infrared Long Baseline Interferometry of Circumstellar Disks

Rafael Millan-Gabet
CalTech/NExScI

Michelson/Sagan Fellows Symposium
Pasadena CA, November 12-13 2009

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!

First generation results

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

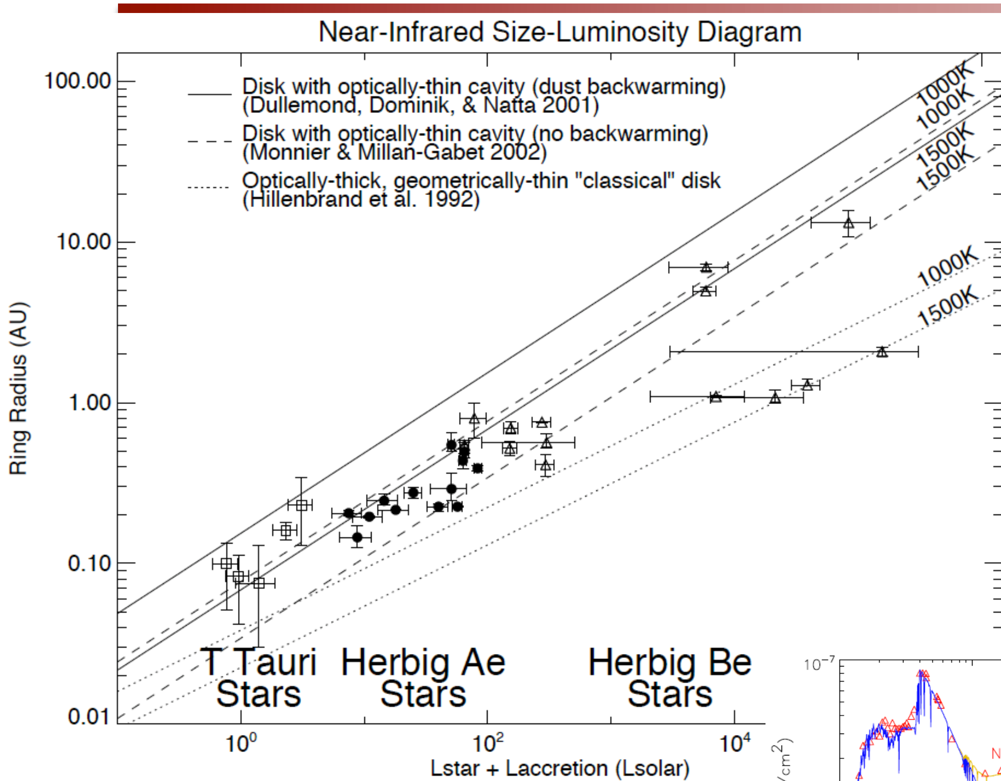
Main results:

- 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).

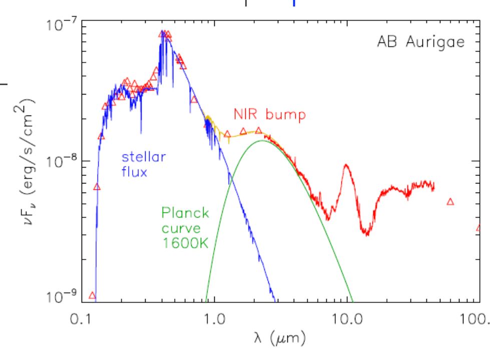
Caveats:

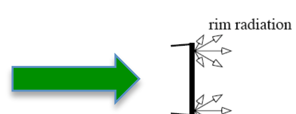
- Sparse data, in λ and uv.
- Small sample sizes, limited by sensitivity.
- Interpretation based mostly on simple geometrical models.

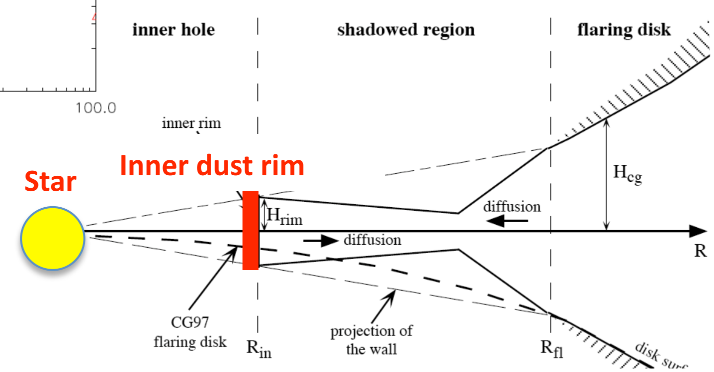
Size-Luminosity relations & The inner disk



- 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.







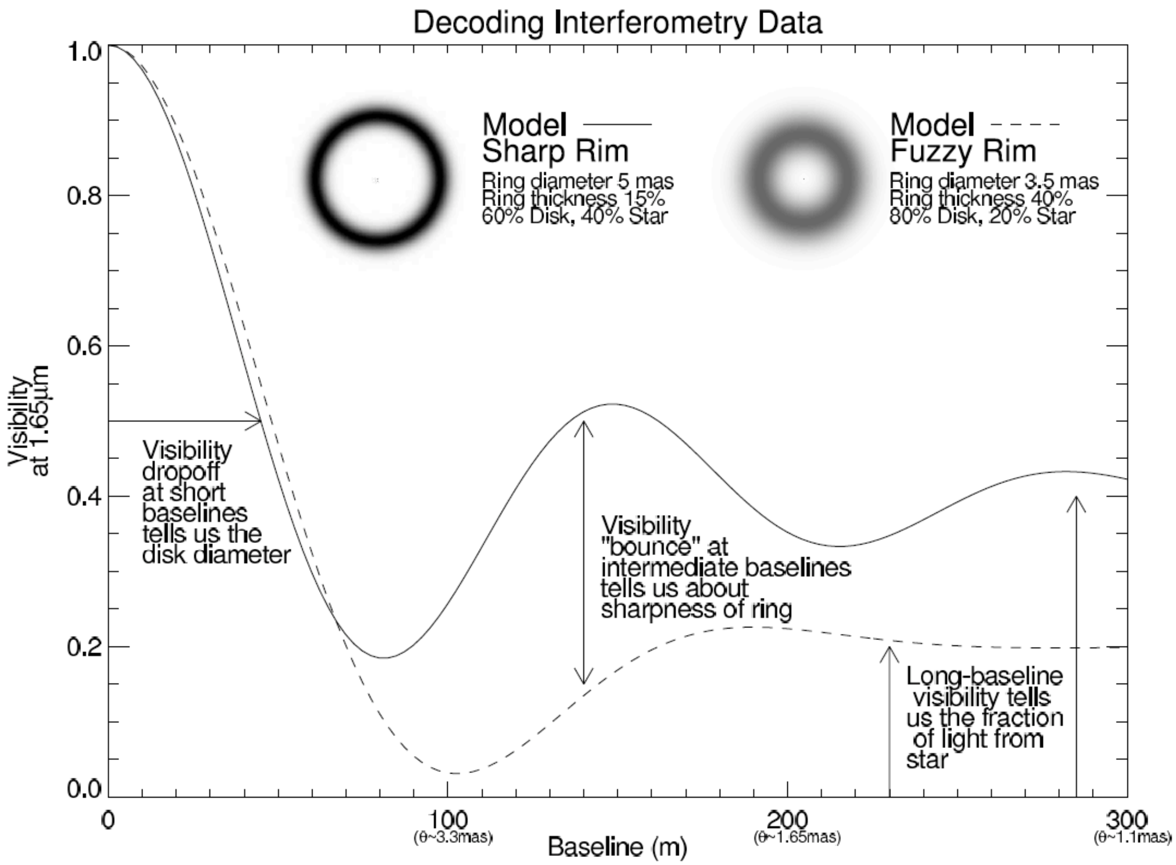
New Questions

- 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.
  - New wavelenghts (e.g L-band – see talk by S. Ragland).
  - Spectro-interferometry.
- Theory:
  - Self-consistent physical models
    (a complex 3D radiative transfer problem …).
- Integrated modelling of complex datasets (e.g. S. Kraus talk).

Detailed tests of the inner wall with very long baselines



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

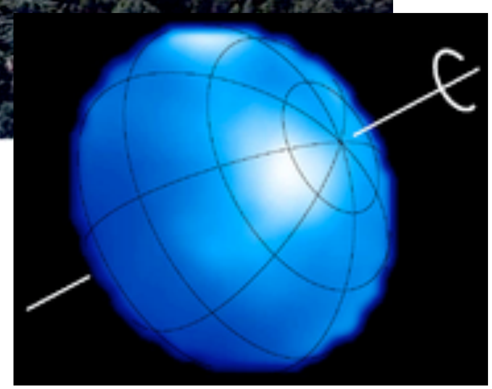
+ Inner rim "puffing" (Dullemond 2001).
+ Dust sublimation temperature dependence on vertical gas density (Isella 2005).
+ Dust settling to mid-plane & growth (Tannirkulam 2007).

CHARA
(Mt. Wilson, CA)

ten Brummelaar T. A. SPIE 2008.

Now has 6 beam combiners, including NIR and VIS *imaging* combiners.

Improved YSO sensitivity with CHAMP fringe tracker (on-sky commissioning started this year).



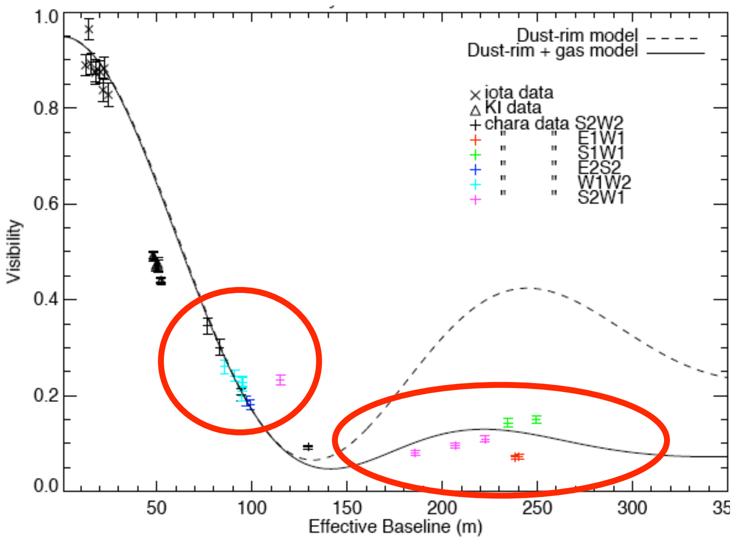
Imaging the surface of Altair, Monnier et al. Science 2007.

(see M. Zhao talk for more examples of CHARA/MIRC imaging).

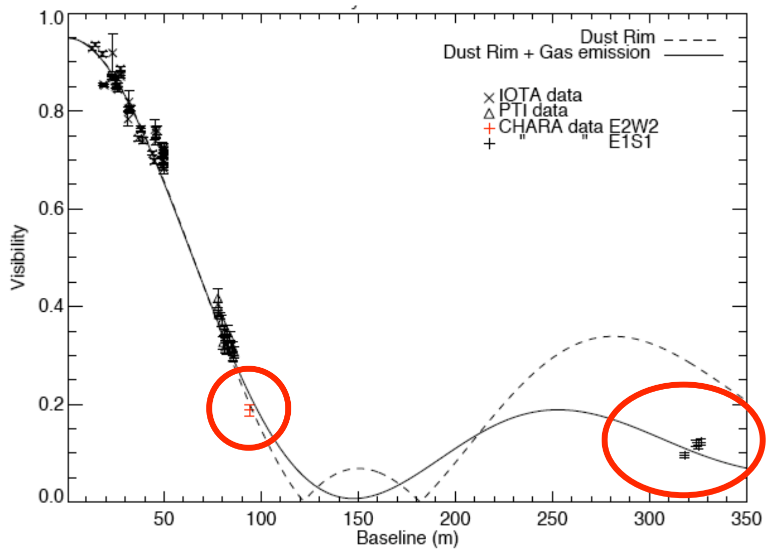
CHARA results

Tannirkulam et al. 2008.

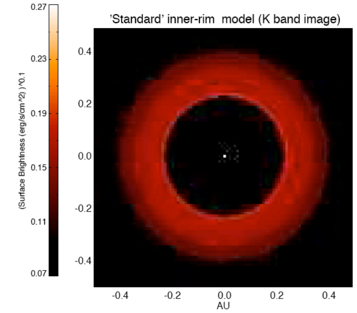
MWC275: K=4.7, A1 Herbig Ae object



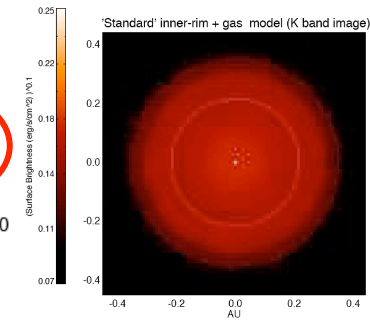
AB Aur: K=4.4, A0 Herbig Ae object



Inner dust rim only

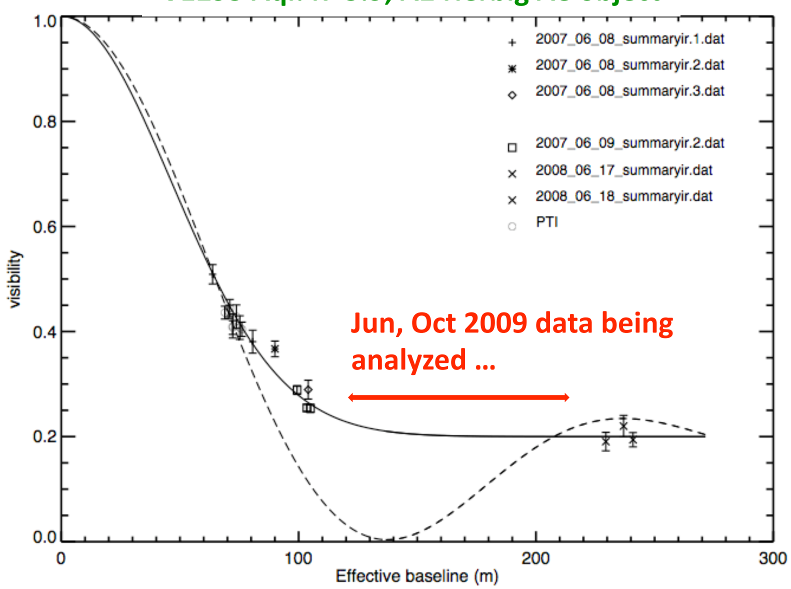


Rim + Inner Gas



New object:

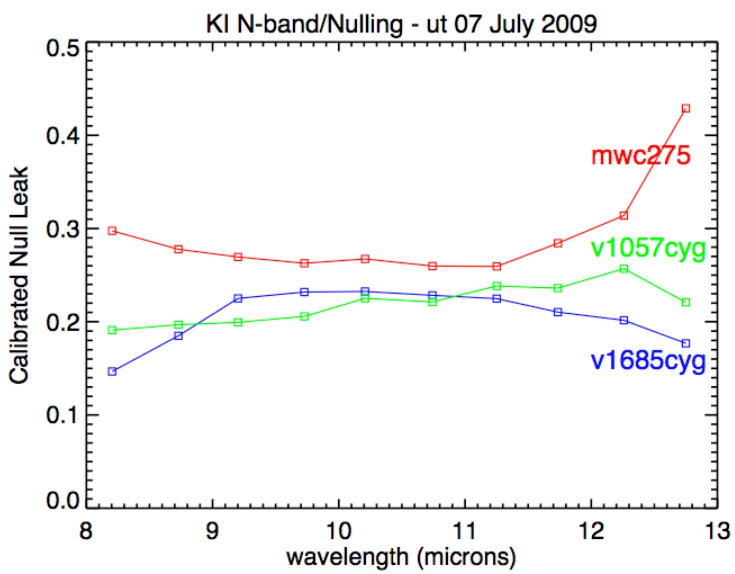
V1295 Aql: K=5.9, A2 Herbig Ae object

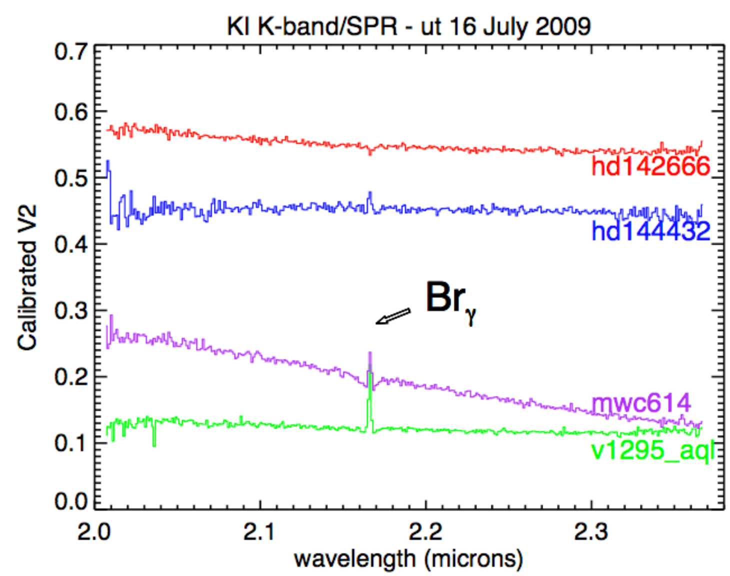


- Very "fuzzy" rims, not reproducible by any physical smoothing mechanism ➔ another disk component is required.
- Large amount of NIR excess (~50% at K) originates in this new component.
- Origin of this new hot emission not yet conclusively established: gas accretion energy? refractory dust? inner wind/envelope?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

Other lines of attack

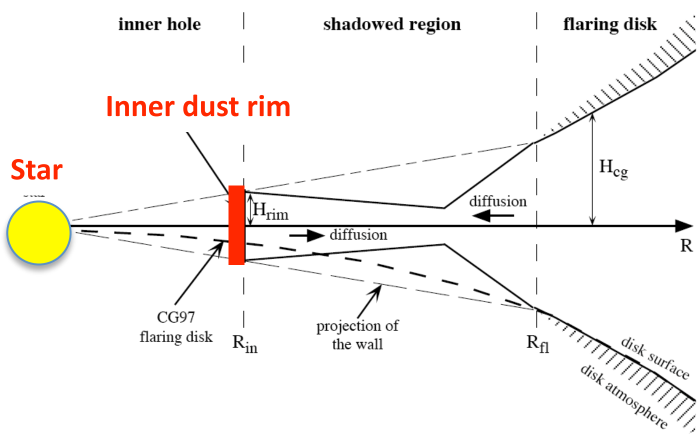
- Thanks to recent CHARA sensitivity improvements:
  - K=6 ➔ K=8.
  - Expanded the survey of HAeBe objects with long baselines.
  - Initiated T Tauri "pilot" study (Fall 09, 2 nights, 5 objects).
  - Bonus: Identify "good" targets for future imaging studies.
- KI YSO program:
  - Spectro-interferometry of selected objects: MIR (R=20), NIR (R=1900) & L-band (R=60).
  - 3.5 nights so far, 10 objects, no good "mode coverage" yet …
  - Contemporaneous IRTF spectro-photometry (with M. Sitko, SSI).



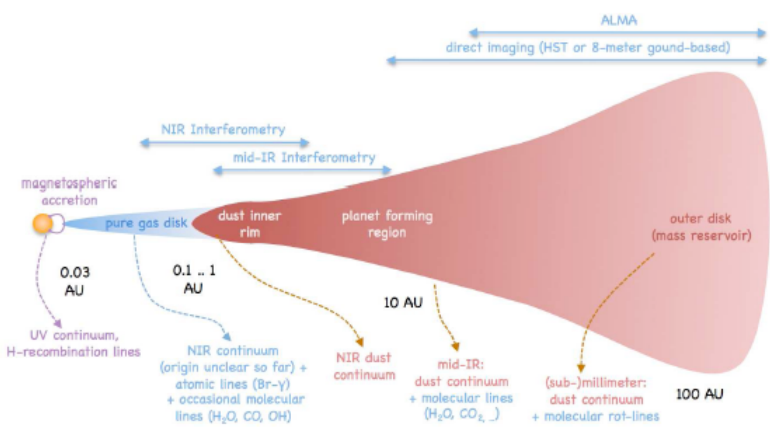


Evolution of the inner disk picture (or how life gets complicated)

SED 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

- Towards a "second unification": Detailed studies of individual objects will reveal the disk structure for each type of object.

- Golden age for interferometric studies, promise to (continue to) contribute fundamentally new knowledge in this field. Enabled by unprecedented capabilities: sensitivity, spectral coverage, uv coverage, phases (KI-ASTRA, CHARA, VLTI).

- Approaching the era of mas imaging: confront our basic paradigms and the likely complexity of disk morphologies.