Infrared Long Baseline Interferometry of Circumstellar Disks

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

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

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.
  – New wavelengths (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)

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

MWC275: $K=4.7$, A1 Herbig Ae object

AB Aur: $K=4.4$, A0 Herbig Ae object

V1295 Aql: $K=5.9$, A2 Herbig Ae object

New object:

- Very “fuzzy” rims, not reproducible by any physical smoothing mechanism $\Rightarrow$ 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:
  - $K=6 \Rightarrow K=8$.
  - 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.