SCATTERED LIGHT IMAGES OF PROTOPLANETARY AND DEBRIS DISKS

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From circumstellar disks to planetary systems – Garching – Nov 4 2009

Why scattered light imaging?

- High spatial resolution can be achieved
  - Typically better than 0.1”
  - Resolve structures down to a few AU
- Independent of the star properties
  - Images scale with illuminating flux; use $F_{disk}/F_\star$
  - Location of star is most important

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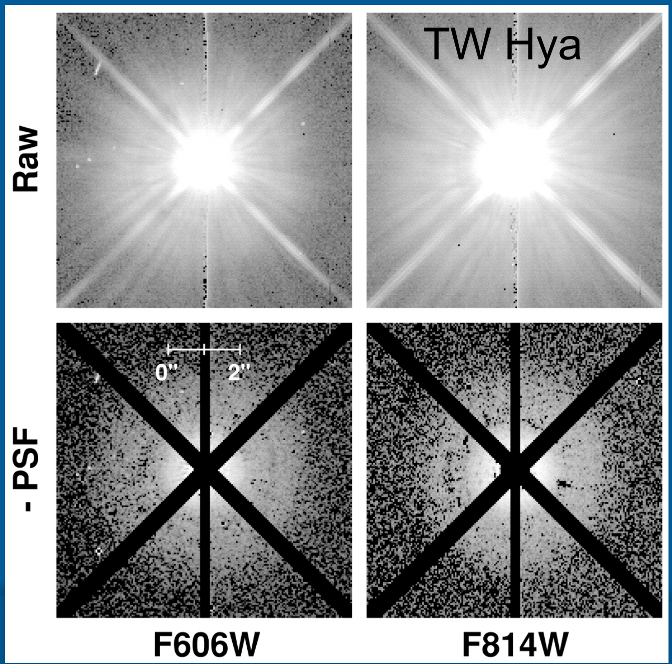
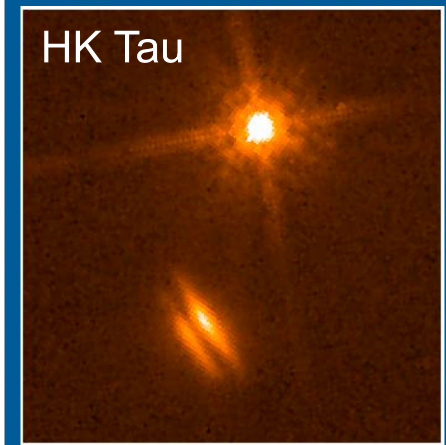
  - Location of star is most important
- Available wavelength range:
  - “Routine”: 0.4 to 2.2 μm (best instrumentation)
  - Challenging but informative: 3 to 10 μm

From a practical standpoint…

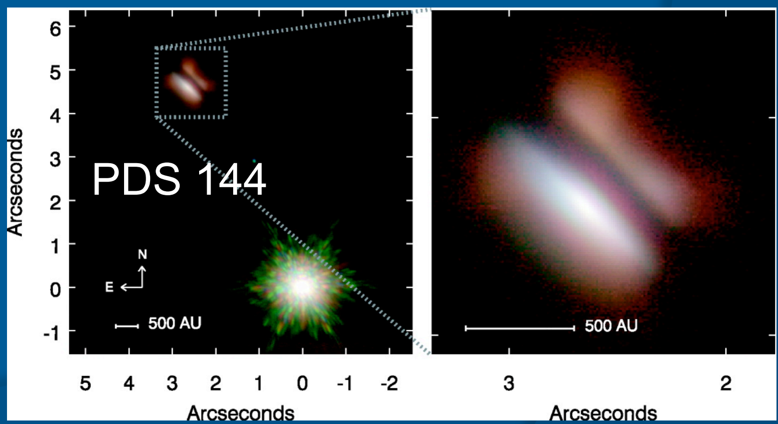
- Major facilities: HST, ground-based AO
- High contrast required in most cases
  - Accurate PSF subtraction mandatory
  - Coronography helps a lot (but hides inner disk!)



Krist et al. (2000)



Stapelfeldt et al. (1998)



Perrin et al. (2006)

Scattering 101

- Scattering off dust has dependencies on
  - the grain size, shape and composition … and λ!

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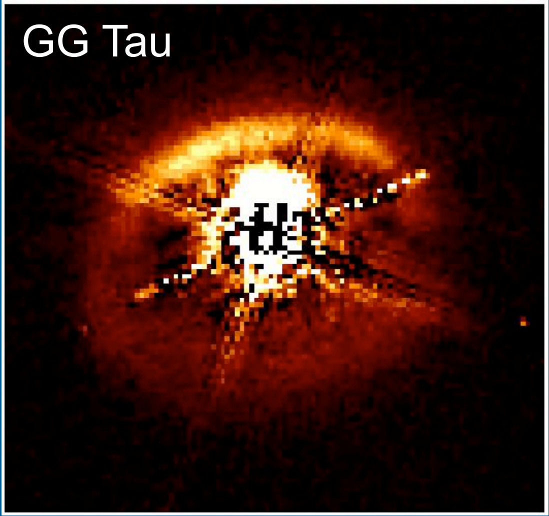
  - Not sensitive to mm-size pebbles
- Single scattering induces linear polarization
- Polychromatic, multi-technique approach can be used to solve for ambiguities

  ➔ ***disk geometry and dust properties***

Constraining disk geometry

Constraining disk geometry

- Scattered light images can help determine
  - the disk radial extent



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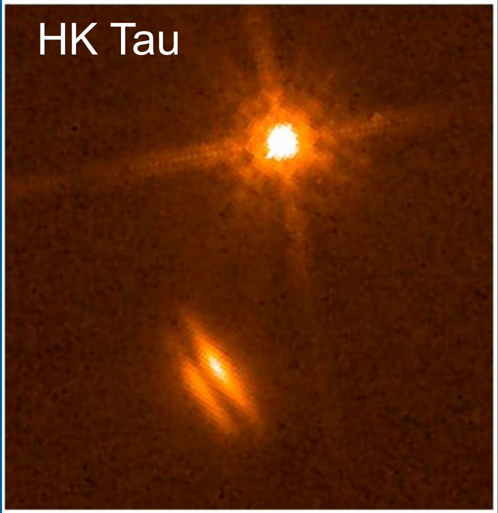

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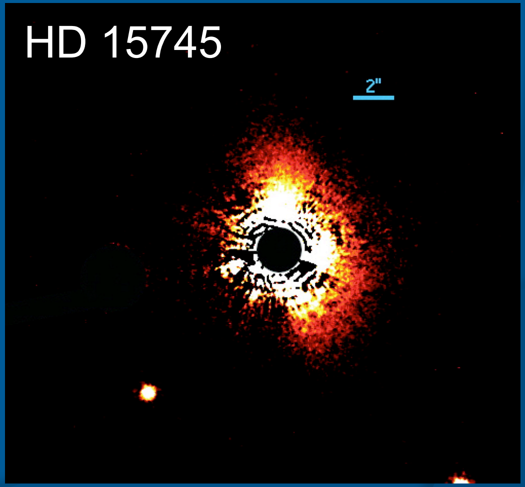
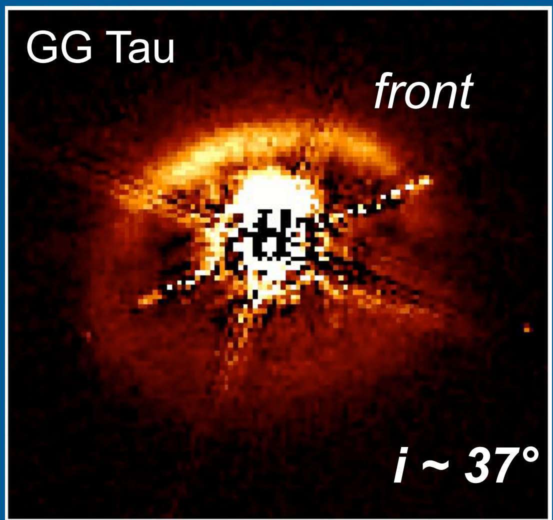


Kalas et al. (2007)

Constraining disk geometry

- Scattered light images can help determine
  - the disk radial extent
  - the line-of-sight inclination (via the phase function, slightly model-dependent)



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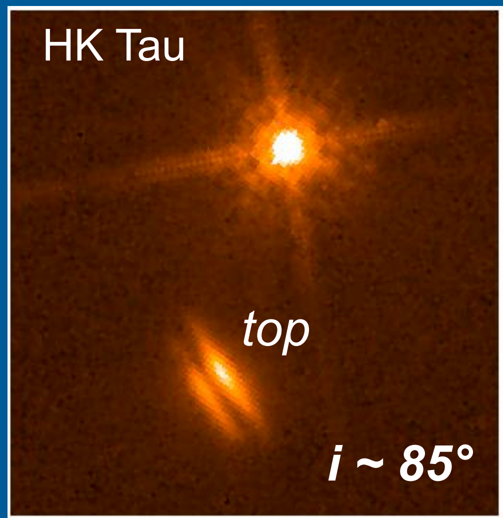
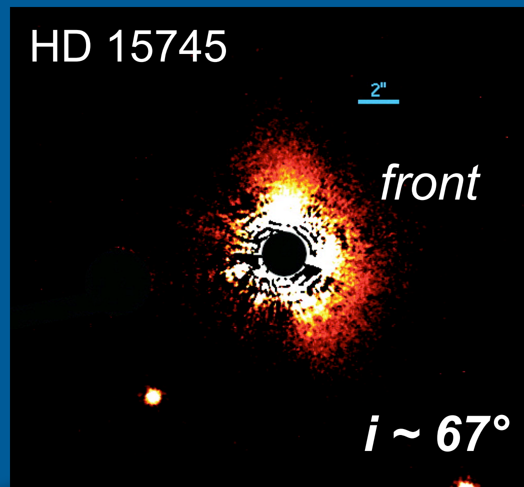


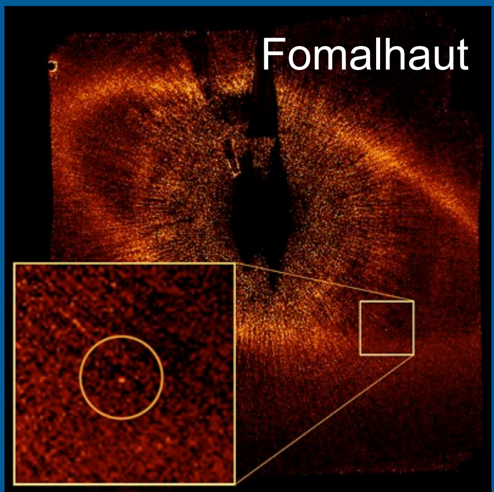
Stapelfeldt et al. (1998)



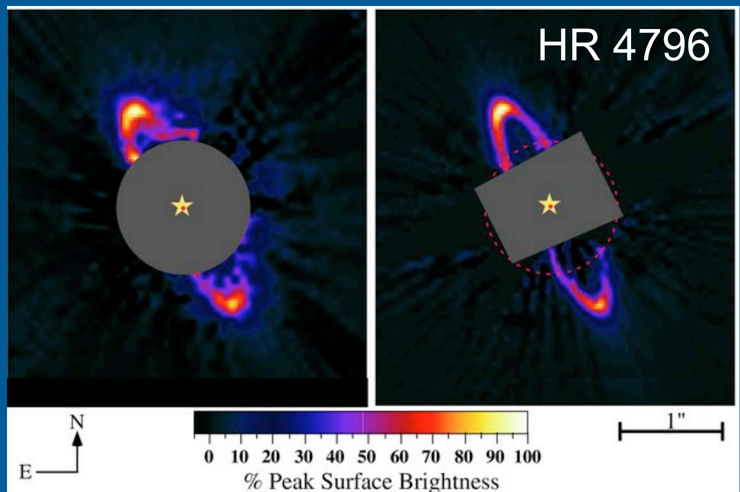
Kalas et al. (2007)

Constraining disk geometry

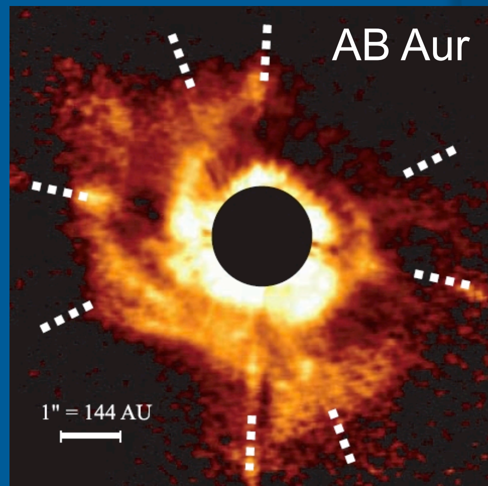
- Scattered light images can help determine
  - the presence of large scale structures
    - related to the presence of planets?



Kalas et al. (2008)



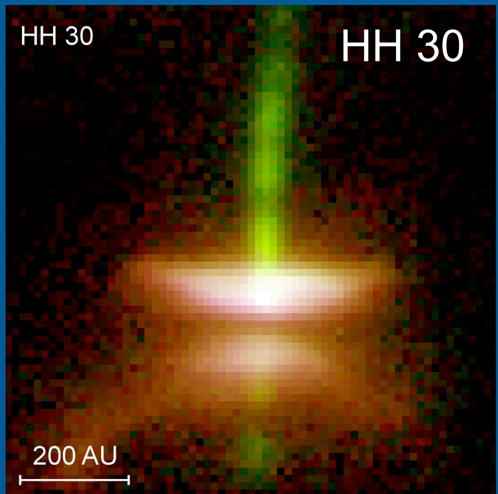
Schneider et al. (1999, 2009)



Fukagawa et al. (2004)

Constraining disk geometry

- Scattered light images can help determine
  - the disk vertical structure
    - Disks are not geometrically flat



Burrows et al. (1996)

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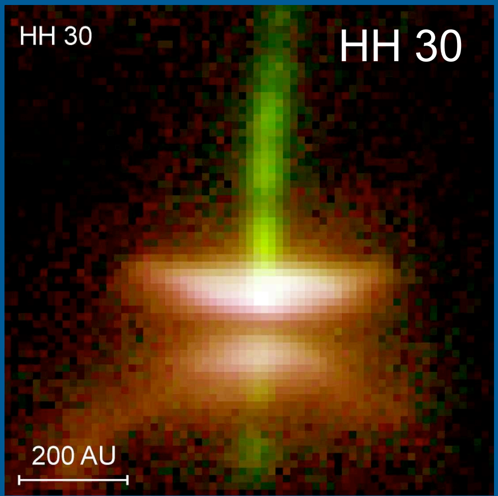
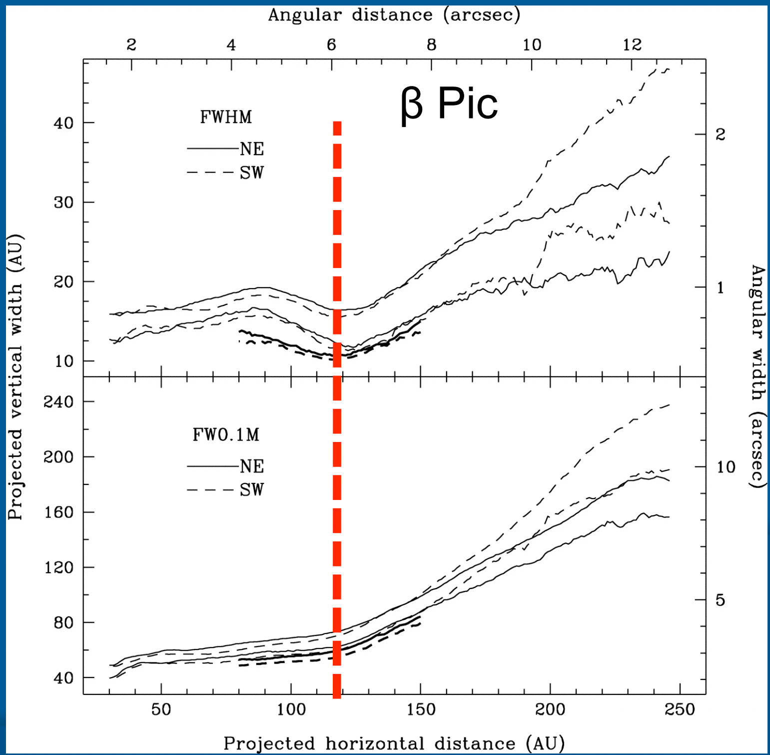


Burrows et al. (1996)



Not a simple surface density feature! Location of birth ring…

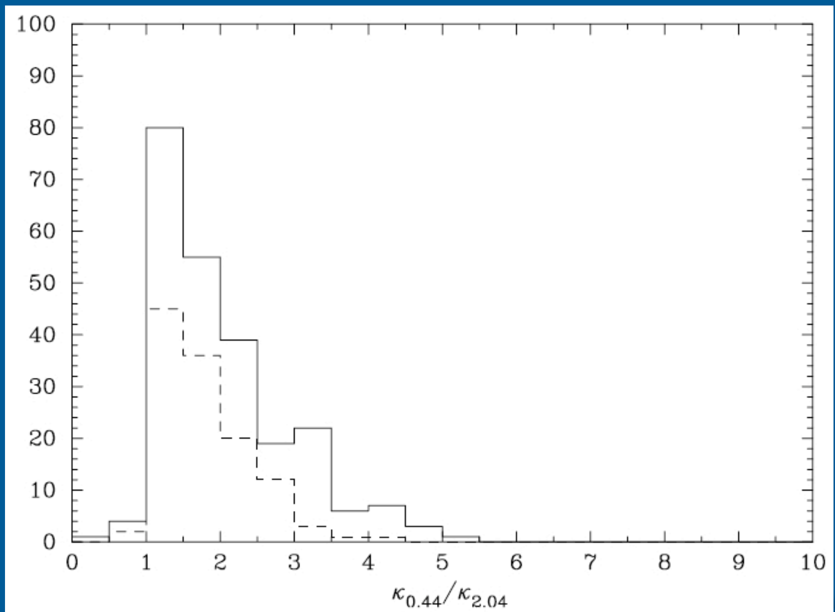
Golimowski et al. (2006)

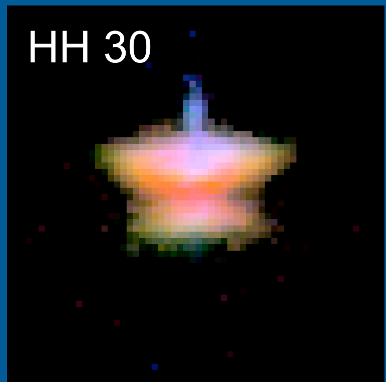
Probing the dust content

Probing the dust content

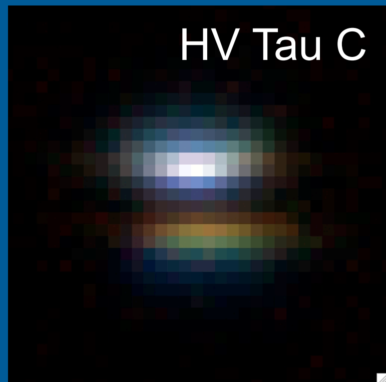
- Multi-wavelength images constrain the dust opacity (or albedo) law

Visible/near-infrared opacity law





Watson & Stapelfeldt (2004)

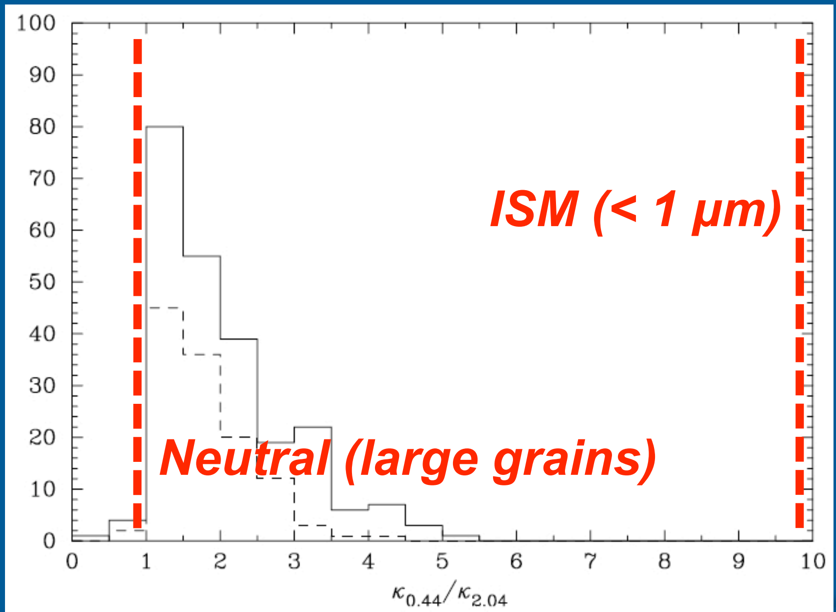


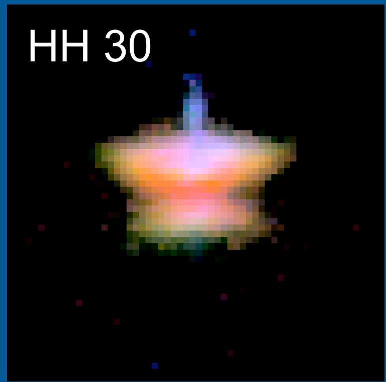
Duchêne et al. (2010)

Probing the dust content

- Multi-wavelength images constrain the dust opacity (or albedo) law
  - Grain growth in protoplanetary disks (to a few μm)

Visible/near-infrared opacity law





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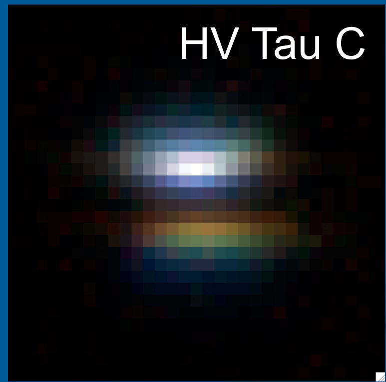
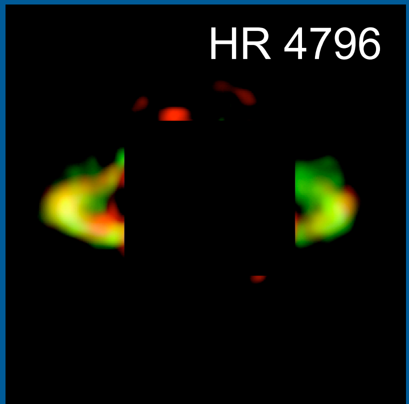


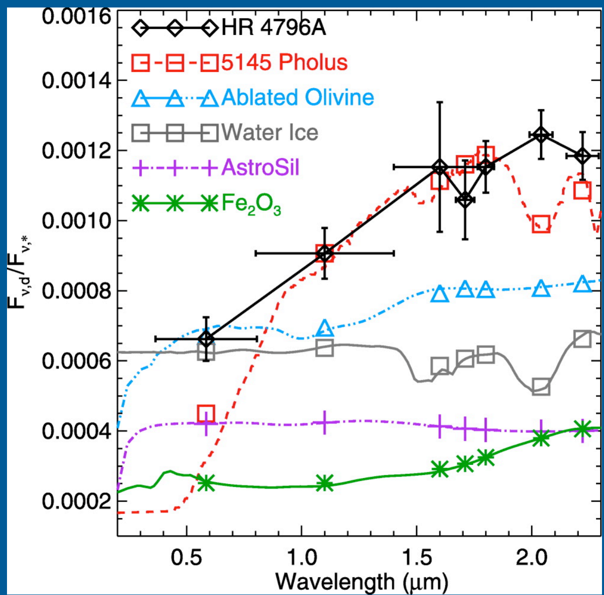
Duchêne et al. (2010)

Probing the dust content

- Multi-wavelength images constrain the dust opacity (or albedo) law
  - Peculiar (organic) composition



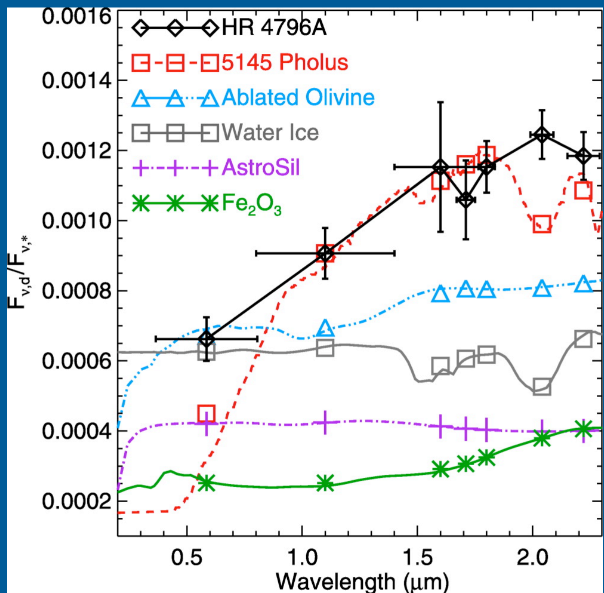
Debes et al. (2008)

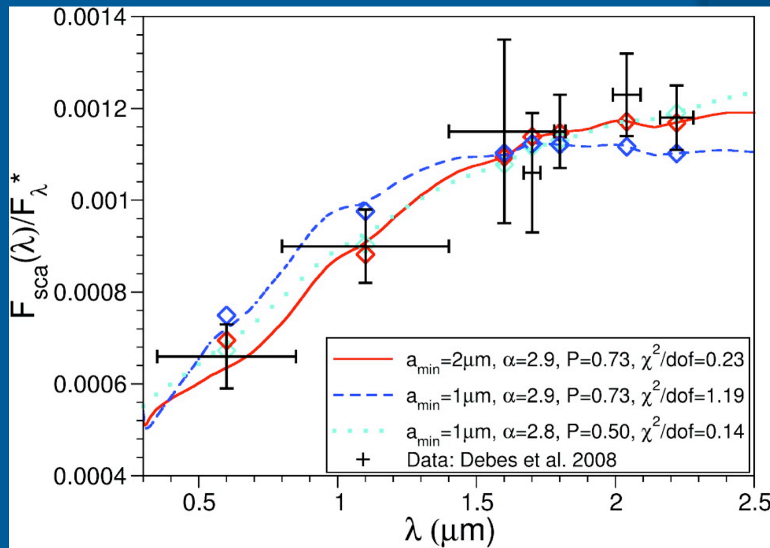


Probing the dust content

- Multi-wavelength images constrain the dust opacity (or albedo) law
  - Peculiar (organic) composition (or porosity?)

Debes et al. (2008)





Köhler et al. (2008)

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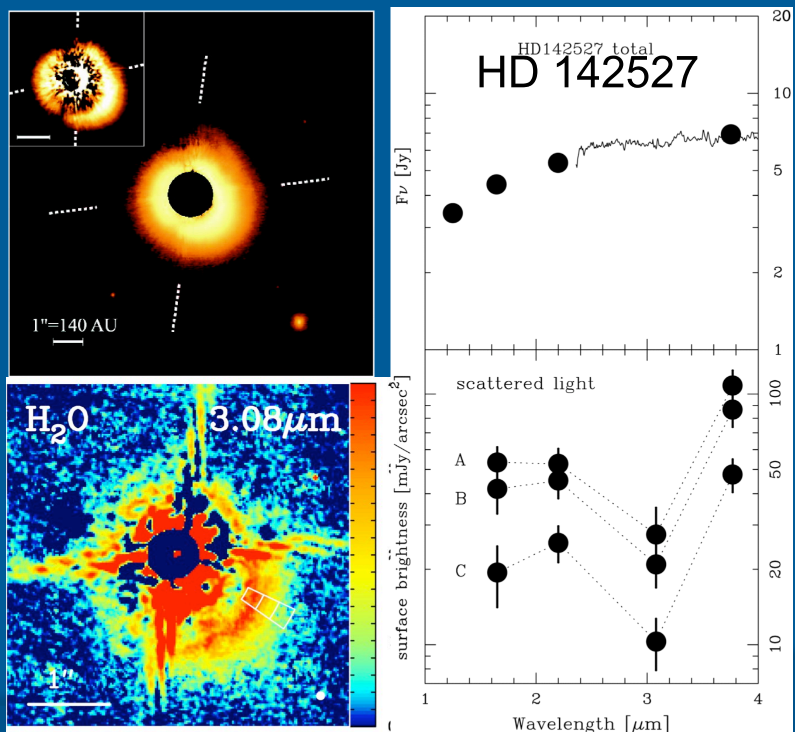
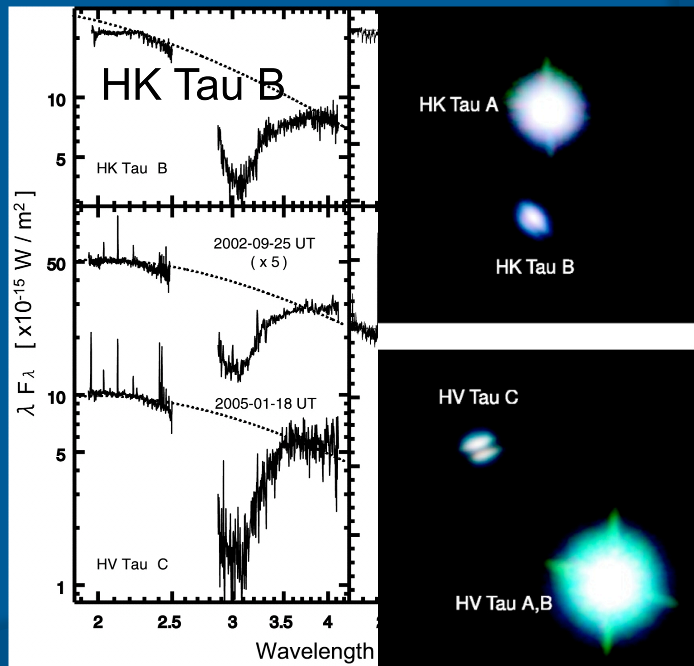
Fukagawa et al. (2004)

Honda et al. (2009)





Terada et al. (2007)

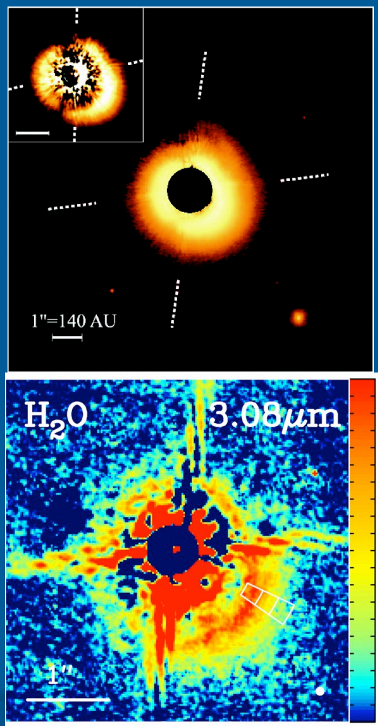
Probing the dust content

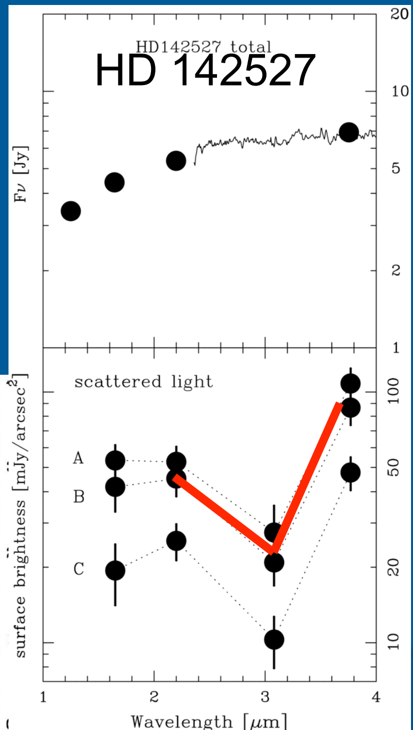
- Multi-wavelength images constrain the dust opacity (or albedo) law
  - Water ice coating of dust grains

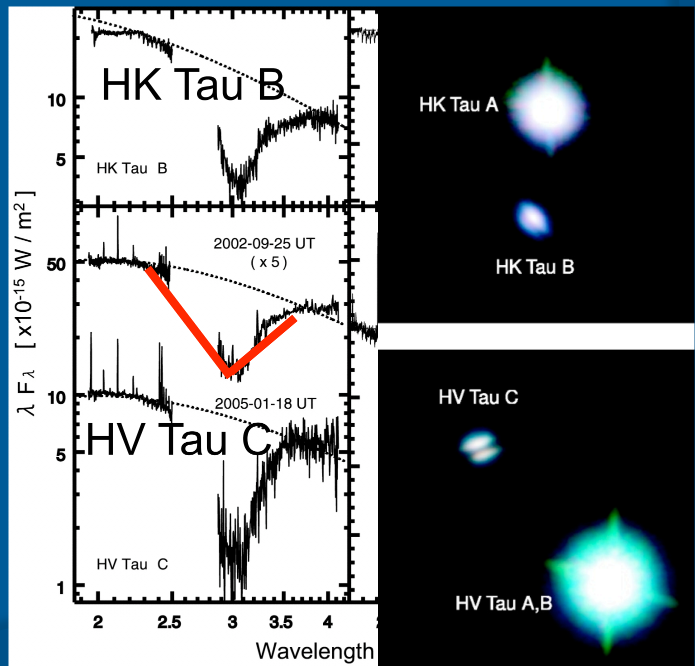
Fukagawa et al. (2004)

Honda et al. (2009)

see also Malfait et al. (1999)







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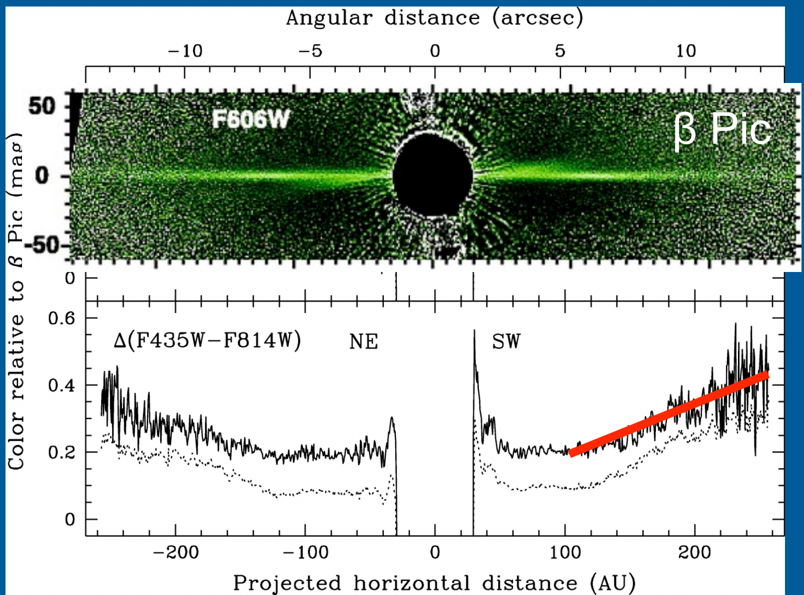
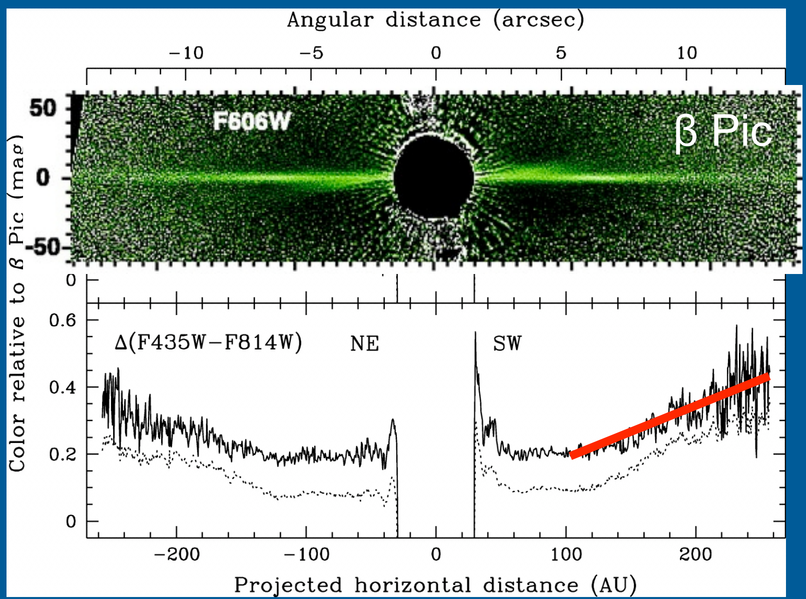


Golimowski et al. (2006)

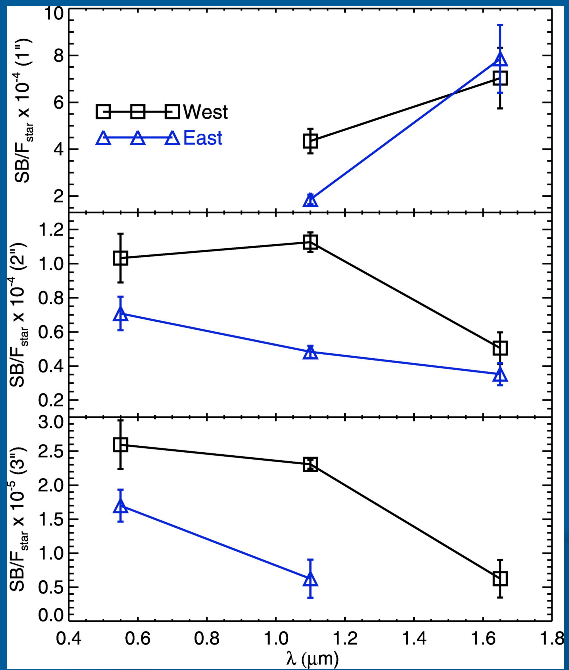
But AU Mic is incresingly bluer!

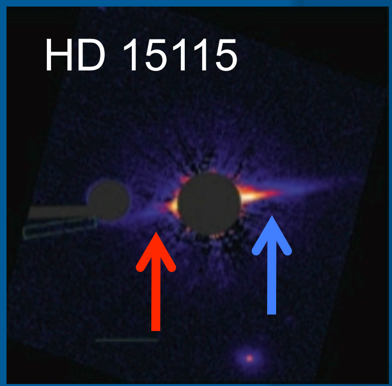
Probing the dust content

- Multi-wavelength images constrain the dust opacity (or albedo) law
  - Spatial variations of dust properties (grain size?)



Golimowski et al. (2006)



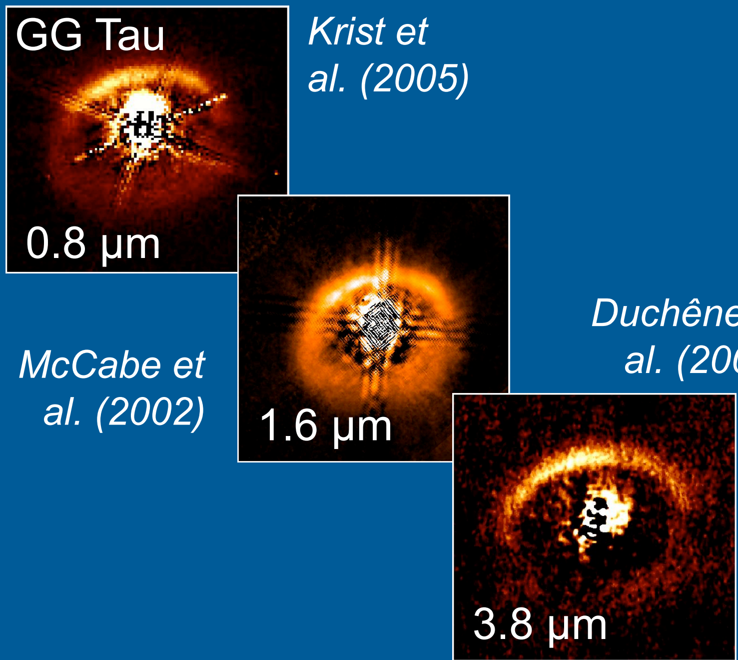


Debes et al. (2008)

But AU Mic is incresingly bluer!

Probing the dust content

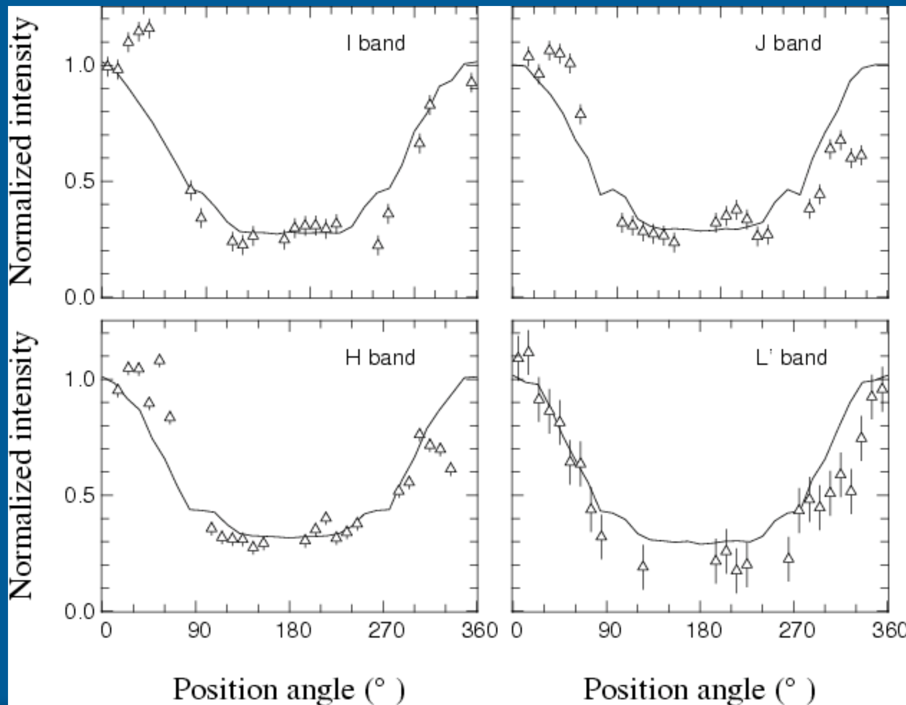
- Scattered light images constrain the dust (wavelength-dependent) phase function



Krist et al. (2005)

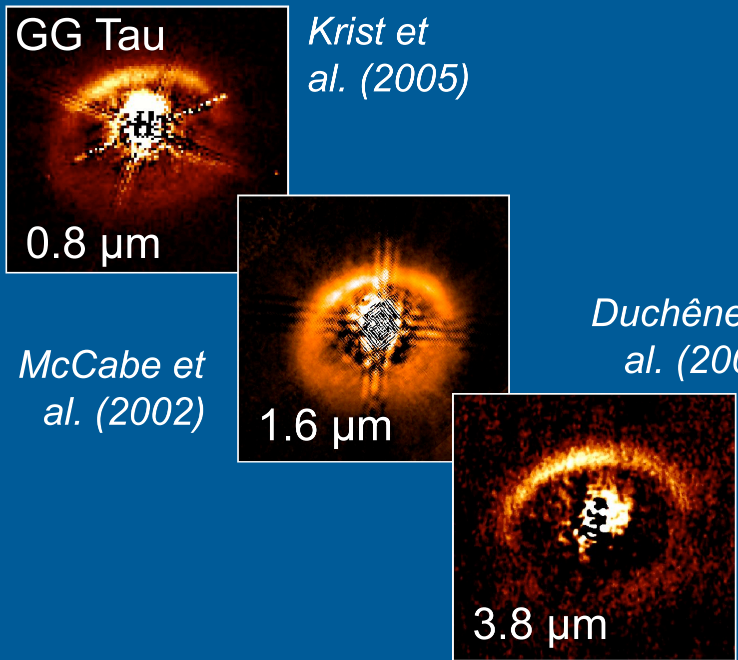
McCabe et al. (2002)

Duchêne et al. (2004)



Probing the dust content

- Scattered light images constrain the dust (wavelength-dependent) phase function
  - Grain growth *and* sedimentation



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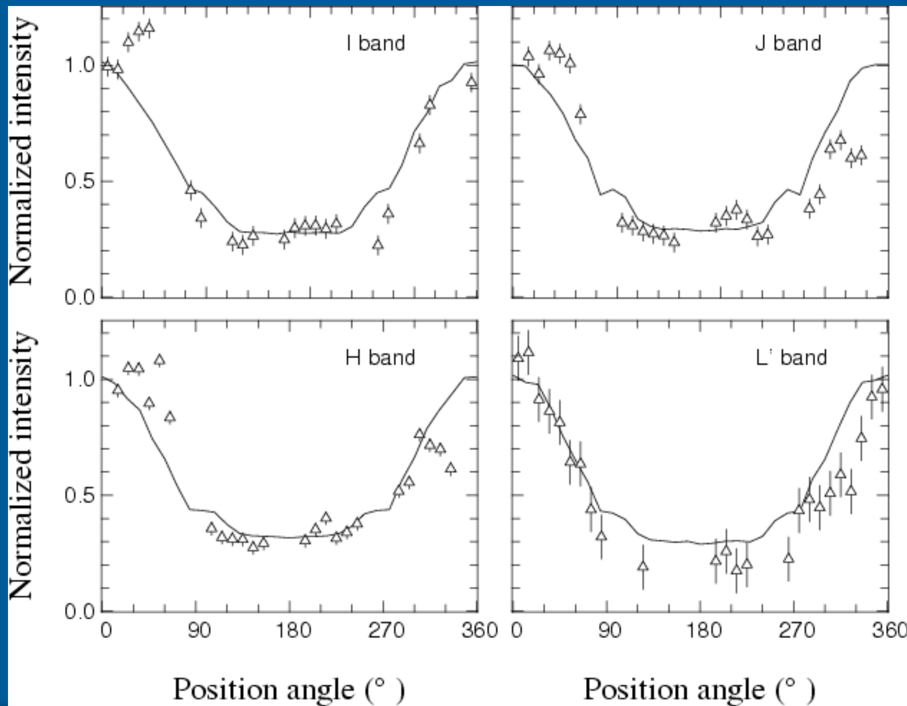

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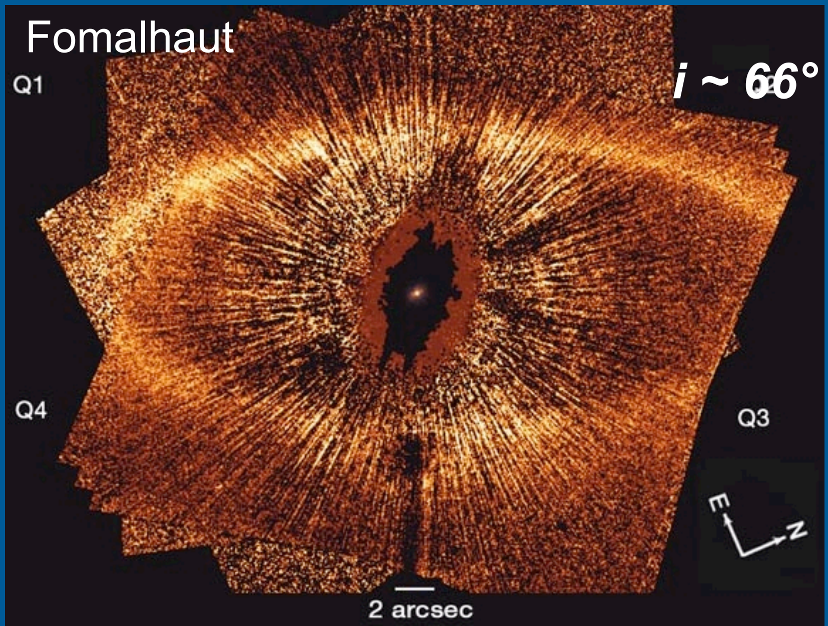


Kalas et al. (2005)

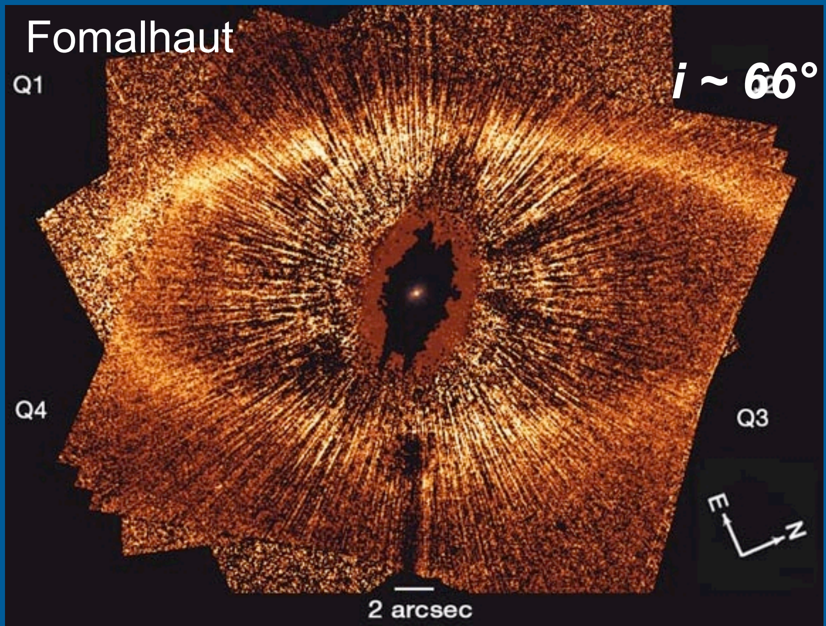
Phase function is roughly isotropic (g~0.2)

↓

Typical of submicron grains

Probing the dust content

- Scattered light images constrain the dust (wavelength-dependent) phase function
  - Non-spherical aggregates?



Kalas et al. (2005)

Phase function is roughly isotropic (g~0.2)

↓

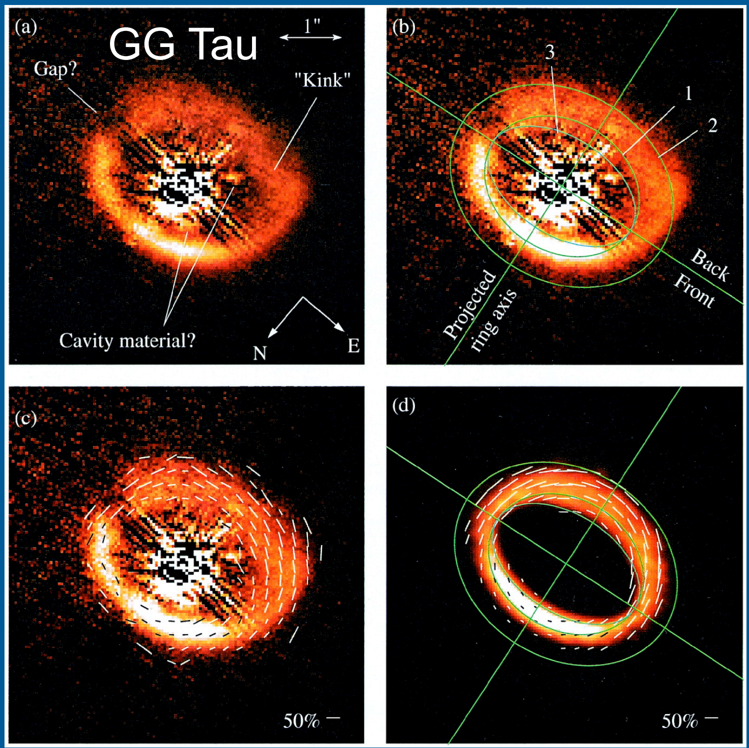
Typical of submicron grains

Yet gains are several microns in size!
Same contradiction in Solar System…

Probing the dust content

- Polarization constrains the dust properties

ISM-like dust at the surface



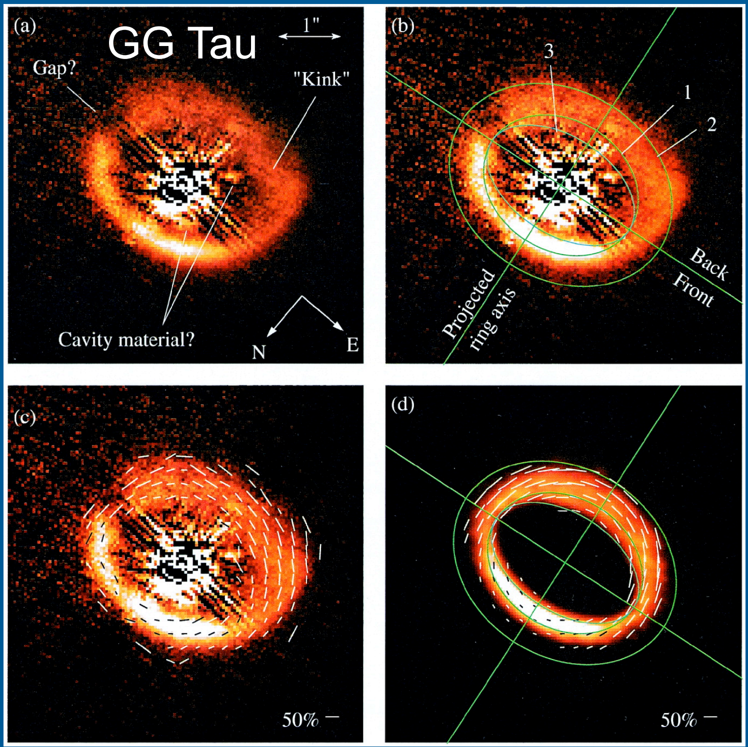
Silber et al. (2000)

Probing the dust content

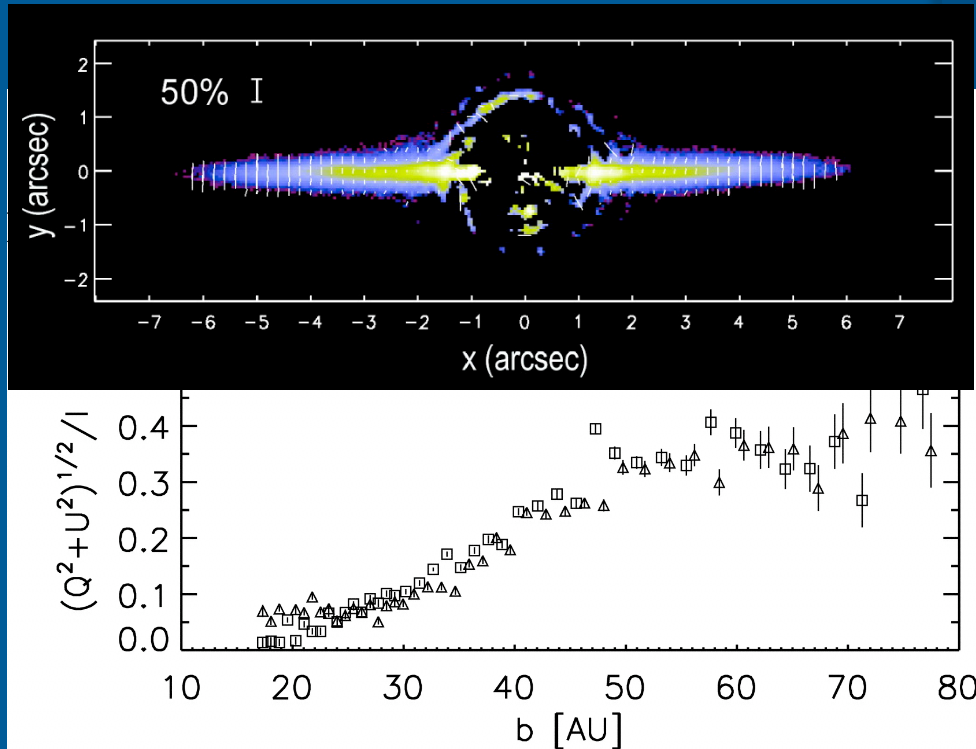
- Polarization constrains the dust properties

ISM-like dust at the surface

High-porosity dust (~ 70-80%)



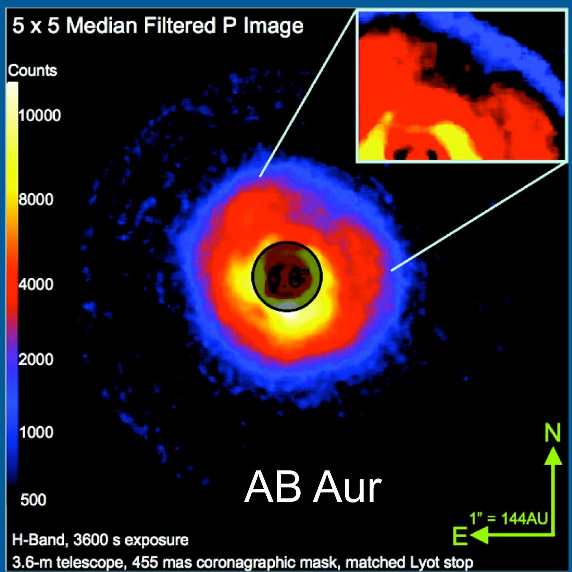
Silber et al. (2000)



Graham et al. (2007)

Probing the dust content

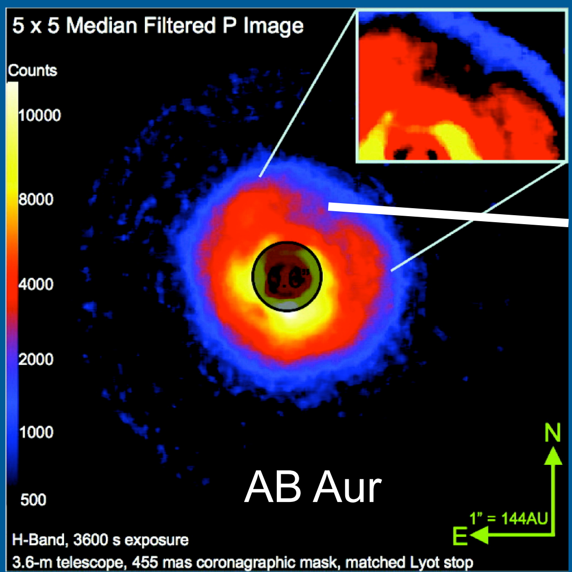
- Polarization offers a natural "rejection factor" that makes scattered light imaging easier
  - Detect finer, closer-in details



Oppenheimer et al. (2008)

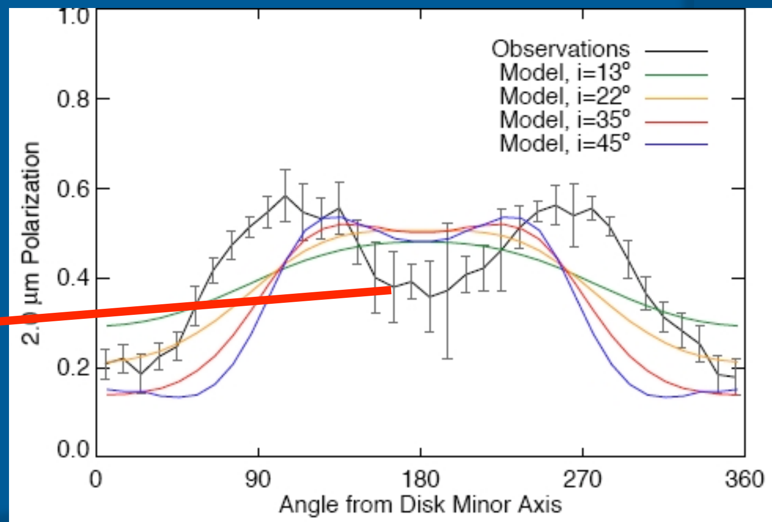
Probing the dust content

- Polarization offers a natural "rejection factor" that makes scattered light imaging easier
  - Detect finer, closer-in details
    - Interpretation depends on dust polarization rate



Oppenheimer et al. (2008)

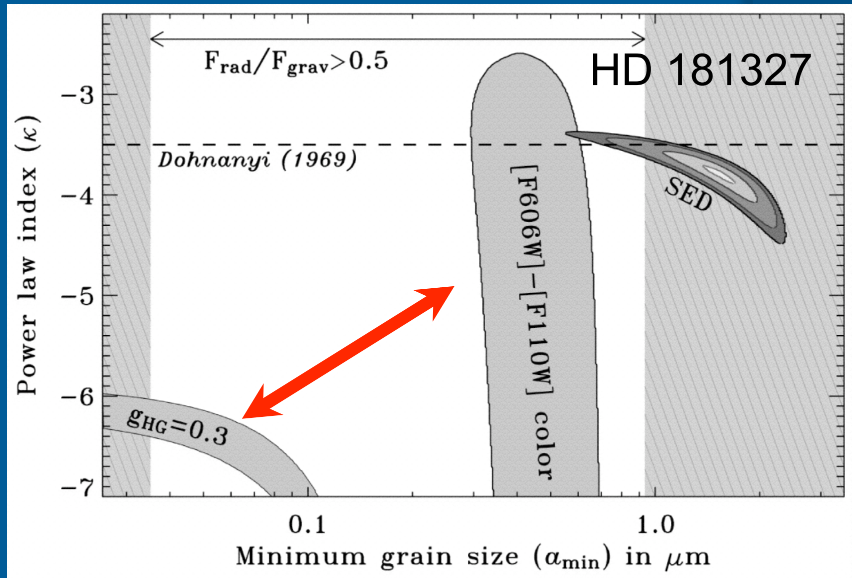
Not a planet-induced gap, but a region of lower polarization



Perrin et al. (2009, in press)

Bringing it all together

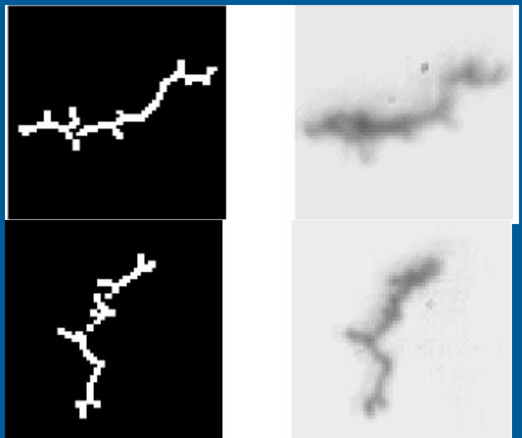
- Attempting to simultaneously reproduce several scattered light datasets is
  - challenging but a great way to probe the complexity of the disk



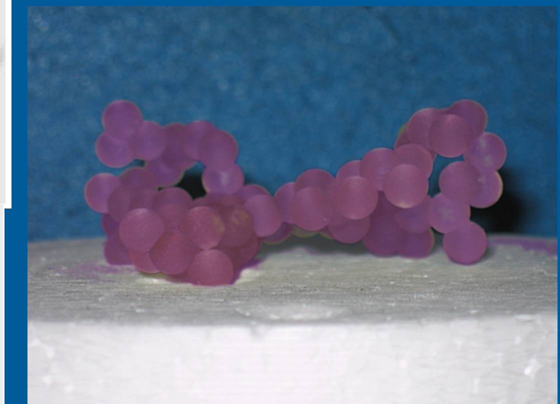
Schneider et al. (2006)

Bringing it all together

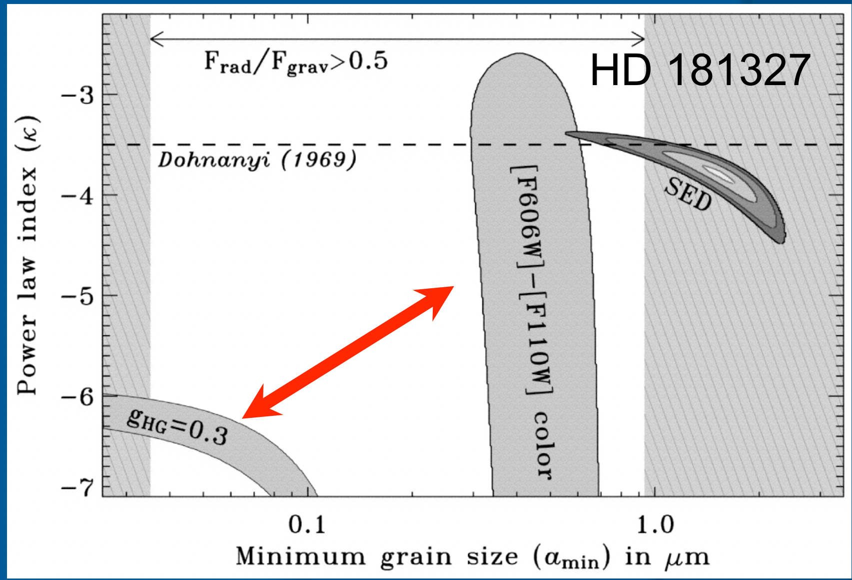
- Attempting to simultaneously reproduce several scattered light datasets is
  - challenging but a great way to probe the complexity of the disk
- Porosity/aggregates



Blum et al. (2000)



J.-M. Geffrin, P. Labouroux (Marseille)



Schneider et al. (2006)

Summary & perspective

- Scattered light images are great to constrain
  - the global and fine scale structure of disks
  - the dust properties
    - Grain sizes (and evolution)
    - Grain composition
    - Grain structure (porosity, aggregates)
    - Spatial differentiation

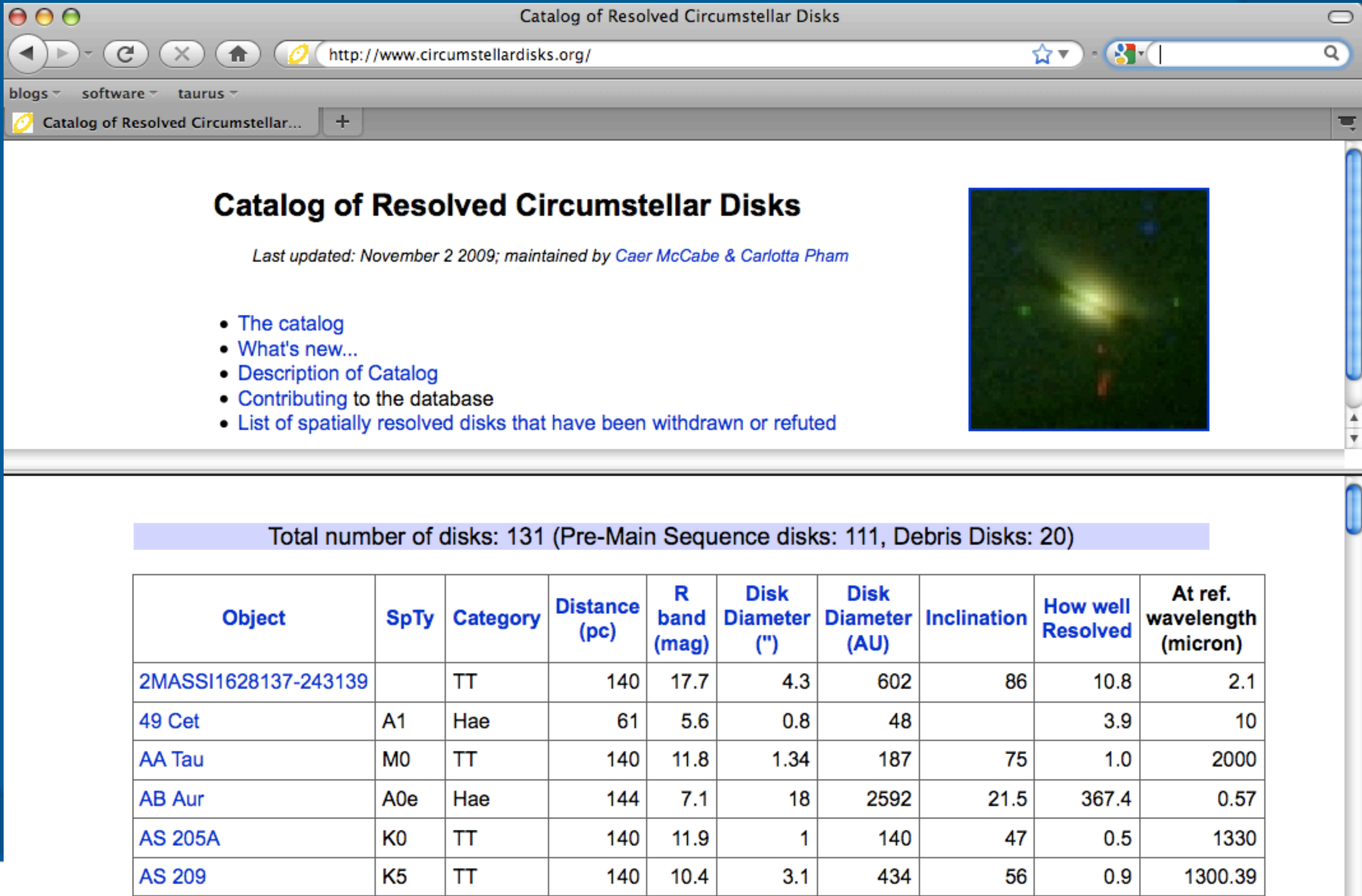
Summary & perspective

- Scattered light images are great to constrain
  - the global and fine scale structure of disks
  - the dust properties
    - Grain sizes (and evolution)
    - Grain composition
    - Grain structure (porosity, aggregates)
    - Spatial differentiation
- That information should be merged with input from SED, mm/NIR interferometry, and full radiative transfer modeling

Also at this conference...

- Talks by
  - C. Pinte, P. Kalas, M. Wyatt
- Posters
  - A24 (Debes et al.)
  - A35 (Fukagawa et al.)
  - B10 (Maness et al.)
- And probably more…

Circumstellardisks.org



Catalog of Resolved Circumstellar Disks

http://www.circumstellardisks.org/

blogs software taurus

Catalog of Resolved Circumstellar...

Catalog of Resolved Circumstellar Disks

Last updated: November 2 2009; maintained by Caer McCabe & Carlotta Pham

- The catalog
- What's new...
- Description of Catalog
- Contributing to the database
- List of spatially resolved disks that have been withdrawn or refuted

Total number of disks: 131 (Pre-Main Sequence disks: 111, Debris Disks: 20)

Object	SpTy	Category	Distance (pc)	R band (mag)	Disk Diameter (")	Disk Diameter (AU)	Inclination	How well Resolved	At ref. wavelength (micron)
2MASSI1628137-243139		TT	140	17.7	4.3	602	86	10.8	2.1
49 Cet	A1	Hae	61	5.6	0.8	48		3.9	10
AA Tau	M0	TT	140	11.8	1.34	187	75	1.0	2000
AB Aur	A0e	Hae	144	7.1	18	2592	21.5	367.4	0.57
AS 205A	K0	TT	140	11.9	1	140	47	0.5	1330
AS 209	K5	TT	140	10.4	3.1	434	56	0.9	1300.39