Observations and models of dust stratification in T Tauri circumstellar disks

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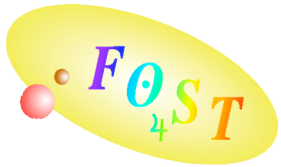
Disk stratification

- Dust grains are expected to grow by coagulation and to settle by gravity
  - Disks should have a stratified structure
- Physical models predict extremely short timescales (<10^5 yrs) for both phenomena
  - Disks around 10^6 yr-old T Tauri stars could already show evidence for these effects

The search for stratified disks is on !



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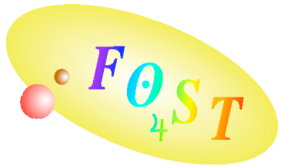
Indirect evidence so far

- SED analyses suggest both growth and settling, though with ambiguities and/or uncertain free parameters
- Silicate emission and optical scattered light reveal small grains in surface whereas radio thermal emission suggests large grains in the disk midplane

Quantitative analyses are difficult



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Multi-λ scattered light images

- Dust opacity decreases with increasing λ
  - Images in the thermal IR probe deeper into the disks than optical/NIR images
- Scattering depends on grain size and λ, and is most sensitive to $2\pi a \approx \lambda$ grains
  - Optical/NIR ⇔ 0.1-0.5 μm dust grains
  - Thermal IR ⇔ 1-5 μm dust grains

A powerful tool to probe stratification

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Scattered light models

- Images must be quantitatively compared to numerical simulations
- We use a Monte Carlo code that includes a dust grain size distribution
  - It now includes a parametrized stratification of dust grains, with $H_0(a) \propto a^{\eta}$
  - Set-up to run thousands of models at several wavelengths for simultaneous multi-λ fit

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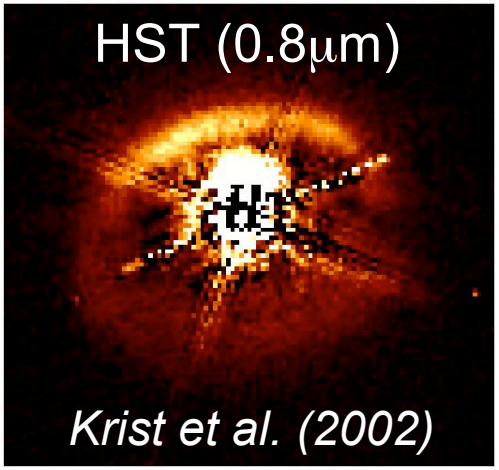
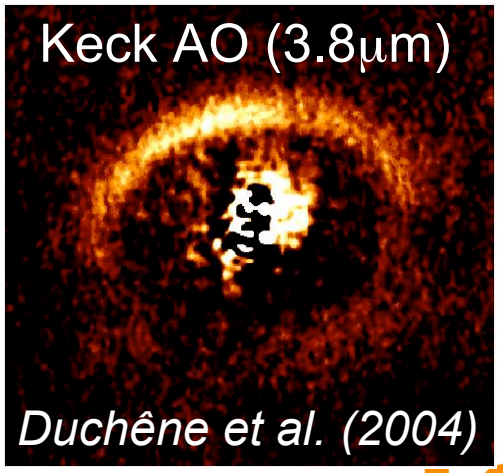
The case of GG Tau

- A 0.13$M_{\odot}$, 180AU-radius circumbinary ring
- We have obtained the first thermal-IR image
  - Clear detection of the ring in scattered light
  - Morphology extremely similar to visible image

ISM dust models match the visible Image with i ≈ 40°





1”

The case of GG Tau

- Interstellar-like, submicron grains would produce a dramatically different image
  - Clearly shows the presence of a substantial amount of grains with radius beyond 1μm
- However, it is virtually impossible to find a single size distribution for the entire disk
  - No high-polarization, λ-independent scattering
  - Evidence for disk stratification?

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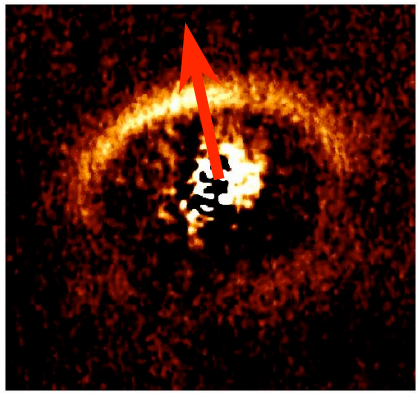
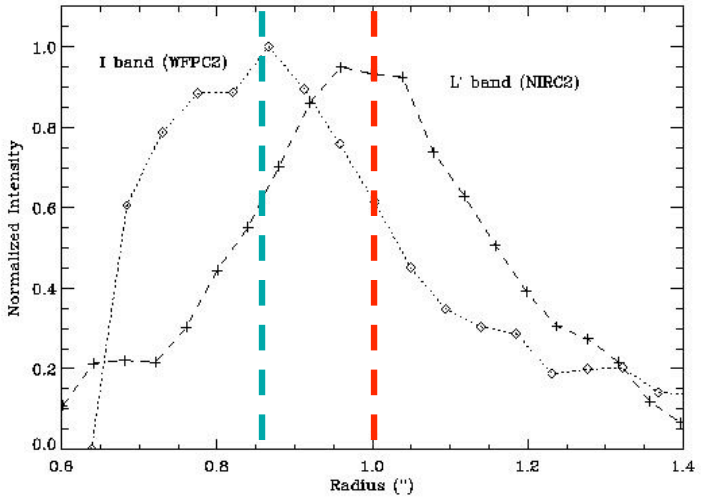
A first direct evidence

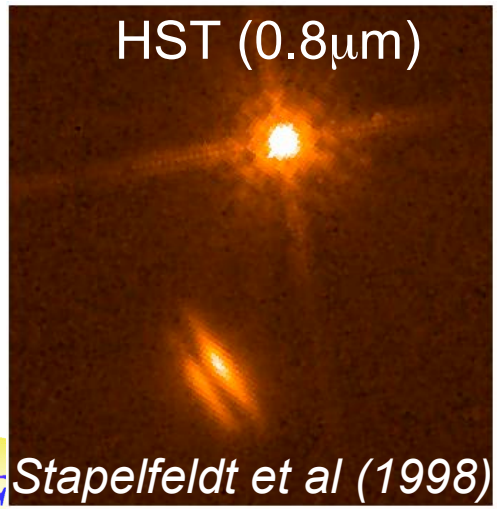
- Scattered light at L' comes from 25AU above the midplane; I band, 50AU above
- Arguably the most direct evidence of dust stratification to date
  - Settling and/or growth?

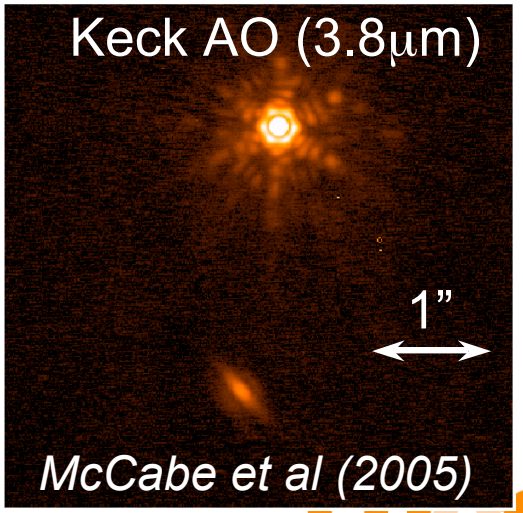




The case of HK Tau B

- 105AU-radius optically thick edge-on disk
  - mm emission suggests layered structure
- IR images reveal an increasingly forward-scattering morphology at longer wavelengths

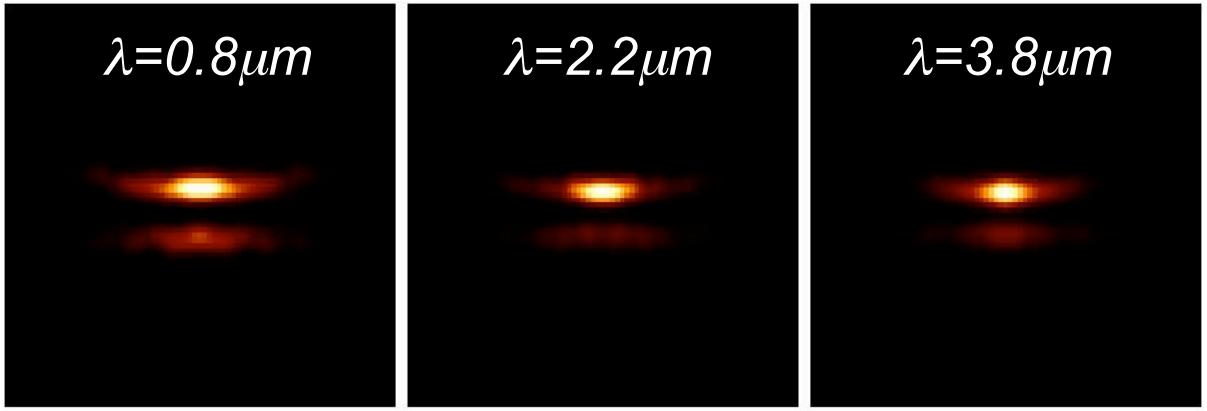




It could be stratification …

- Supra-μm grains are needed (deeper)
- Monte Carlo simulations with stratification provide a decent fit to all images
  - But it's not a perfect fit (e.g., low contrast)

$M_D = 3\ 10^{-3}\ M_\odot$
$a_{max} = 100\ \mu m$
$H_0(a) \propto a^{-0.1}$



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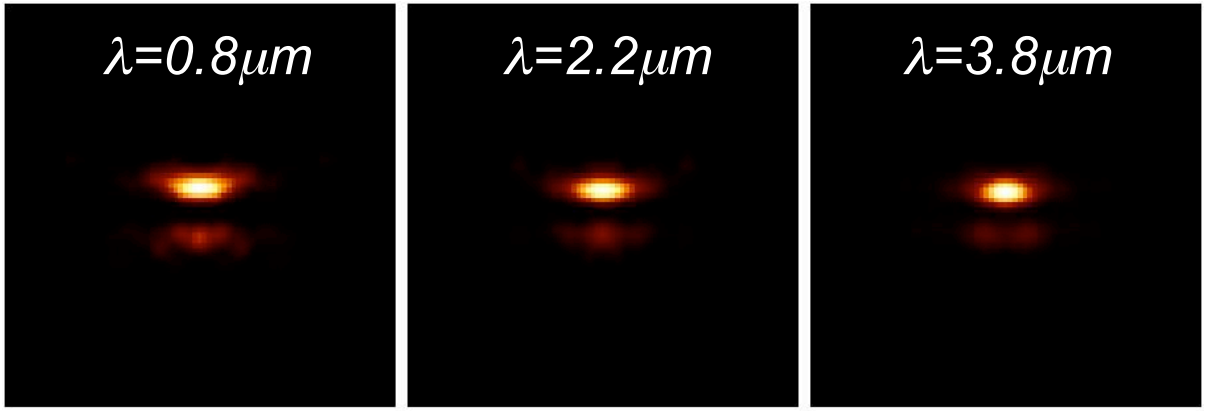
… but it's not clear yet

- Fitting the images without stratification yields only slightly poorer results
  - Still an open question for this object
  - Edge-on disks may not be the best test-cases

$M_D = 10^{-3}\ M_\odot$
$a_{max} = 10\ \mu m$
$H_0(a) = cst$



Summary

- Stratification is predicted by models but not directly evidenced by SED studies
- Scattered light images can yield such direct evidence (see the case of GG Tau)
- Ultimately, the combination of scattered light images and SED will be critical
  - Quantitative tests of growth and settling models

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