The inner debris disc of Vega as seen by CHARA / FLUOR

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The quest for warm dust

- Until now:
  - Cold and distant (~100 AU)
  - Massive (~10^{-2} M_{⊕})
  - Similar to Kuiper belt
  - Evidences for inner holes

- Detected by:
  - Far-IR excess flux
  - Sub-mm imaging
  - Visible imaging

- First hints for warm dust with Spitzer

- Final goal: detect debris discs similar to our zodiacal disc
  - Towards Darwin / TPF…

Stapelfeldt et al. 2004

\[ T \approx 75 \text{ K} \]

Marsh et al. 2005 (350 μm)

Kalas et al. 2005 (0.8 μm)

(150 AU ≈ 20” at 7.7 pc)
Are the inner holes for real?

- Two major difficulties
  - High contrast (>1:100)
  - Small angular separation
    - Inner disc: a few 10 mas
    - Requires IR interferometry

Macintosh et al. 2003 (Keck AO)
van Cittert-Zernike theorem: each baseline gives one component of the Fourier transform of the source

\[ V = \frac{I_{\text{max}} - I_{\min}}{I_{\text{max}} + I_{\min}} \]

Model: stellar disk

\[ V = \frac{2J_1(\pi b \theta / \lambda)}{\pi b \theta / \lambda} \]

Spatial frequency: $b/\lambda$
Debris discs by interferometry

- Disc larger than angular resolution ($\lambda/b$) $\Rightarrow$ incoherent flux
- Induces a visibility deficit at all baselines
- Best detected at short baselines

\[ V^2 \approx (1 - 2f) \left( \frac{2J_1(\pi b \theta / \lambda)}{\pi b \theta / \lambda} \right)^2 \]

Flux ratio

Needs very good accuracy (~1%)
### Previous attempts

**Near-IR (K band)**
- **Ciardi et al. 2001**
  - Vega with PTI
  - Baseline too long
  - Suggest possible excess of 3-6%
- **Di Folco et al. 2004**
  - 5 stars at VLTI
  - Upper limit of a few % on the inner disc emission

**Mid-IR (N band)**
- **Liu et al. 2004**
  - Vega by nulling interferometry (MMT)
  - Very short baseline (4m)
  - Observation restricted to radius > 1 AU
  - Upper limit of 2.1% on mid-IR excess
CHARA - FLUOR

Centre for High Angular Resolution Astronomy
Fibre Linked Unit for Optical Recombination

- 1m collectors
- FoV: 1 arcsec (8 AU)
The Fourier Vega

- Pole-on → no azimuthal dependence
- Stellar diameter (150 m)
- Limb darkening (>200 m)
- Circumstellar dust (30 m)
Fitting a uniform stellar model

\[ \theta_{ud} = 3.217 \pm 0.013 \; \text{mas} \]

\[ \chi_r^2 = 3.36 \]
Fitting star + debris disc

Absil et al. 2006, A&A 452

\[ \theta_{UD} = 3.202 \pm 0.005 \text{ mas} \]

Disk/star contrast: \[ 0.0129 \pm 0.0019 \]

\[ \chi^2 = 1.10 \]
Modelling the inner disc

- Spectral Energy Distribution constrained by:
  - Photometric data, from 1 to 12 μm
  - Interferometric data, at 2.2 and 10.6 μm
- Caveat: Vega is a rapid rotator!

Aufdenberg et al. 2006
SED fitting procedure

- SED fitted with model of Augereau et al. (1999)
  - Various density power laws, size distributions & compositions
  - 2 fit parameters: minimum grain size ($a_{\text{min}}$) and inner radius ($r_0$)
Properties of the inner disc

- Small grains (mostly < 1 µm) at distances ~ 0.1 – 0.5 AU
- Highly refractive grains, no silicate feature → carbons > 50%
- Steep density power law: $\Sigma(r) \sim r^{-4}$ (or steeper)
Our new view of Vega

Outer debris disc

- $3 \times 10^{-3} M_\oplus$
- $3 \times 10^{-5} L_\star$

Inner debris disc

- $6 \times 10^{-8} M_\oplus$
- $5 \times 10^{-4} L_\star$

Holland et al. 1998
Origin of the dust

- Radiation pressure $\rightarrow$ grains blown out in $\sim 10$ yr
  - High replenishment rate needed ($\sim 10^{-8}$ M$_\oplus$/yr)
- Cometary origin is favoured
  - Grain size distribution ($dn \propto a^{-3.7}$ da)
  - Steep density distribution
  - $\sim 10$ Hale-Bopp per day!
- Dynamical perturbations
  - See also poster 44 by Rèche
Towards a global scenario?

- Late Heavy Bombardment scenario
  - Triggered by late migration of giant planets
  - Compatible with age of Vega (~350 Myr)

- Could explain at the same time
  - Asymmetry of outer disc
  - Small grains in outer disc
  - Dust in inner disc

Su et al. 2005

![Vega Debris Disk at 70 μm](image)
What’s next?

- Further observations of Vega
  - Confirm the excess in H/K with IOTA/IONIC
  - VISIR: mid-IR spectroscopy
- Interferometric survey of bright Vega-type stars (K<5)
  - 6 more targets at CHARA in 2006
    - Preliminary result: 3 of them seem resolved
  - First observations with VLTI (MIDI + AMBER)
- Multi-wavelength approach
- More short baselines for morphology