FLUOR Science
Recent results, ongoing projects

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+ CHARA team!
+ J.-C. Augereau, D. Defrère, F. Thévenin + …
FLUOR science papers since last CHARA Meeting (2007-2009)


Topic 1: 61 Cyg A&B diameters and evolutionary status of asteroseismology targets (Kervella, Thévenin et al. 2008)

\[
\theta_{\text{LD}}(A) = 1.775 \pm 0.013 \text{ mas and } \theta_{\text{LD}}(B) = 1.581 \pm 0.022 \text{ mas}
\]
61 Cyg A & B: fundamental parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>61 Cyg A</th>
<th>61 Cyg B</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi ) (mas)</td>
<td>286.9 ± 1.1</td>
<td>285.4 ± 0.7</td>
</tr>
<tr>
<td>[Fe/H]</td>
<td>-0.20 ± 0.10</td>
<td>-0.27 ± 0.19</td>
</tr>
<tr>
<td>( R(R_\odot) )</td>
<td>0.665 ± 0.005</td>
<td>0.595 ± 0.008</td>
</tr>
<tr>
<td>( T_{\text{eff}} ) (K)</td>
<td>4 400 ± 100</td>
<td>4 040 ± 80</td>
</tr>
<tr>
<td>( L(L_\odot) )</td>
<td>0.153 ± 0.010</td>
<td>0.085 ± 0.007</td>
</tr>
<tr>
<td>Initial He content ( Y_{\text{ini}} )</td>
<td>0.265</td>
<td>0.265</td>
</tr>
<tr>
<td>Initial [Z/H] (dex)</td>
<td>-0.10</td>
<td>-0.10</td>
</tr>
<tr>
<td>Final [Z/H] (dex)</td>
<td>-0.15</td>
<td>-0.15</td>
</tr>
<tr>
<td>Age (Gyr)</td>
<td>6.0 ± 1.0</td>
<td>6.0 ± 1.0</td>
</tr>
<tr>
<td>Mass ( (M_\odot) )</td>
<td>0.690</td>
<td>0.605</td>
</tr>
<tr>
<td>( \alpha ) (MLT convection)</td>
<td>1.2</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Stellar atmosphere modeling constraints the age (6Gyr), mixing length
Asteroseismic observations \( \rightarrow \) Small and large frequency separations
\( \rightarrow \) accurate **Masses** and evolutionary status
Topic 2 - Cepheids: distance and envelopes

- A key-role in the determination of distances in the Universe

1 AU → Parallax → 10 pc → Céphéides RR Lyr → 10 Mpc → W Vir → Statistical methods → 1 Gpc → Supernovae → Redshift
Calibrating the Period-Luminosity relationship

- \( \log(L) = a \cdot \log(P) + b \)
- The slope \( a \) is constrained (SMC, LMC)
- The \textit{zero-point} \( b \) is the Graal
- Requires several independent measurements
  (a handful of high-precision observations of Cepheids with interferometry available today)

  \textbf{Typical precision achieved on} \( b \sim 0.06 \text{ mag} \)
Pulsation parallax method

- Radial velocity monitoring
- Interferometry

\[
\theta_{UD}(T) - \theta_{UD}(0) = -2 \frac{k \rho}{d} \int_0^T v_{\text{rad}}(t) \, dt
\]

Pulsation along the line of sight and in the sky plane
Cepheids and Interferometry: 1997-2007

- Zeta Gem
- Delta Cep
- eta Aql

NPOI (2002)
PTI (2001)
VINCI/VLTI (2003)
CHARA (2005)
CHARA (2007)
SUSI (2003)
Cepheids: circumstellar envelopes

δ Cep (Mérand et al. 2006)

\[ R_{\text{CSE}} \sim 3 \, R_{\text{star}} \]

Bias = f(baseline length)

Y Oph (Mérand et al. 2007)

\[ D = 472 \pm 18 \, \text{pc} \]

\[ D = 491 \pm 18 \, \text{pc} \text{ unbiased (=4% !)} \]
Cepheids: circumstellar envelopes

Flux_{CSE} \sim 2-5\% 

Period-Luminosity relationship

Envelopes found around 4/4 Cepheids …
Link with mass-loss, Correlation F_{CSE} vs. Period?

Adapted from Kervella 2004, after debiasing for CSE
Cepheids: distance and envelopes

Y Oph (Mérand et al. 2007)

Y Oph = low-amplitude Cepheid, P~17d (crossing the instability strip for 3rd time)

Derived **Linear radius**:
R = 67.8 ± 2.5 R_0

Expected from P-R relationship:
R = 100 ± 8 R_0!

Y Oph:
- probably not a fundamental-mode pulsator
- shows phase-shift (1d) between RV and angular diameter variations…
=> should be excluded from P-L calibration

More to come: the most precise distance estimation so far for a Cepheid (Mérand et al. 2009 in prep)
Topic 3  Exozodiacal disks: the quest for hot dust
Why look for warm exozodi?

Dust grains distribution -> dynamics of the parent bodies

How common is our own solar system?
How do planetary systems evolve?

Requires information on:
  - morphology of dust exo zodi
  - composition of dust (multi-\(\lambda\))

Prepare future missions to directly detect earth-like planets
TPF-like missions -> Feasibility? Target selection?

Cash et al. 2008
Coronagraph, visible
Exozodiacal light as an «issue»

Source: DARWIN CV proposal
The quest for exo-zodiacal warm dust

Spitzer photometry (Trilling 07, Bryden 06, Beichman 06, Chen 06)
- Positive detections < 2.5% of 1-10Gyr GK stars @10 µm
  4%@24mic, 16%@70µm.
- Sensitivity threshold ~ 1000 Zodi 8 < λ < 24 µm
- Absolute accuracy ~ 4% photospheric flux
- Statistics: majority of exozodii 0.1 zodi < Lum < 10 zodi

Direct Imaging

Needs: small FOV, high spatial resolution, high dynamics
A survey of debris discs with CHARA/FLUOR

CHARA Array (Mt Wilson, CA)
6 1m-telescopes

FLUOR instrument
2-T combiner, 2.2 µm fiber-filtered
high precision visibility

Strategy
Short 30m baseline (CSE)
Long (>200m) baseline (photosphere)

Survey of MS stars (K < 5) with known, cold debris discs

ε Eri, τ Cet, σ Boo, η Crv, β UMa, α CrB, γ Oph, Vega, ζ Aql, α A0V

34 m, 330 m
IR interferometry: towards high contrast imaging

-> Rachel’s talk
FLUOR FOV ~ 0.8 arcsec  (few AU @ nearby stars)
Dusty disk extended emission induces a Visibility drop, best detected at short baselines

Direct measurement of the contrast

Disc / star contrast
Constraining the morphology

- Lift modeling degeneracy through:
  - Spatial characterization (need fine (u,v) sampling)
  - Spectral characterization (FLUOR+prism; H band?)


5x the detected amplitude!
Vega: fast rotating A0V
7.7 pc \sim 300 \text{ Myr}

Detected excess:
$f_K = 1.29 \pm 0.2 \times 10^{-2}$

Origin:
- background object ?
- bound companion ?
- stellar wind ?
- hot dust grains ?
Vega: modeling the hot dust grains

Model Augereau (1999)

- Sub-micron grains
- Steep distribution close to sublimation distance
- Carbon/Si > 50%
- \( M_{dust} \sim 10^{-8} M_\odot \)

Large amount of small grains: 10 Hale-Bopp comets/day !?

Origin? LHB-like phenomenon ? (see also Wyatt 07)
Hot stars program

Absil et al. 2008

α Crb – A0V

Disc/star contrast: \(-0.14 \pm 0.57 \pm 0.10 \%\)

\(\chi^2 = 1.87\)

ζ Aql – A0V

Disc/star contrast: \(1.69 \pm 0.27 \pm 0.15 \%\)

\(\chi^2 = 0.97\)

γ Oph – A0V

Disc/star contrast: \(0.25 \pm 0.48 \pm 0.03 \%\)

\(\chi^2 = 1.23\)

β UMa – A1V

Disc/star contrast: \(-0.05 \pm 0.16 \pm 0.03 \%\)

\(\chi^2 = 0.40\)
Zet Aql: dust or low-mass companion? Complementary observations are crucial.

Not yet conclusive for this star! Stronger constraints are needed...
Zet Aql: no more cold debris?

Re-analysis of Spitzer IRS+MIPS data (Chen06): no longer warm/cold excess!
τ Ceti & ε Eridani: two sun-like stars

τ Ceti
G8V
3.6 pc, ~10 Gyr
RV stable over 6yr

ε Eridani
K2V (active)
3.2 pc, ~0.5 Gyr
+1 eccentric Jupiter (Hatzes00, Benedikt06)

SCUBA: resonant structures? Poulton et al.06

Spitzer: 3AU + 20AU asteroid belts
Backman et al 2009

Spitzer 8-24 μm:
Consistent with photospheric (Chen et al. 06)
Hot zodiacal dust around $\tau$ Ceti
Di Folco et al. 2007

$\sigma_{LD} = 2.015 \pm 0.004$ mas
$f_{\text{obs}} = 0.98 \pm 0.21 \times 10^{-2}$

$\delta_{LD} = 2.126 \pm 0.009$ mas
$f_{\text{obs}} < 0.6 \times 10^{-2}$
Dust properties: from observation to modeling

**Spitzer upper limits**

- Excess $\sim 10^3$ Zodi at 2$\mu$m (+6yr RV stability) $\Rightarrow$ safely attributed to dust
- 10/2$\mu$m excess $\rightarrow$ grain size, composition, distribution
  - Modeling: **Small grains** are favored (but degeneracy)
  - Density as steep as $r^{-d}$ (solar system: $r^{-0.4}$ with 10-100$\mu$m grains)
  $\Rightarrow$ dust confined in an **annulus** ($T_{\text{evap}} \sim 1500$K)
  - **Origin** of the hot dust production? (transient events)

**The zodiacal cloud around $\tau$ Ceti clearly departs from solar system scheme**

**Does it represent ...**
Lessons learned & conclusions

Detections:
\[ f_{\text{det}} \sim 1-2\% ; \sigma_i \sim 0.2\% \sim \text{few } 10^2 \text{ zodi} \]
10 x better than 2\(\mu\)m-photometry
visibility accuracy is the key
Not all stars show IR excesses
6-10 measurements for a robust detection
complementary (RV) observations to identify the nature
of the excess

A « niche » for interferometry and a « niche » for CHARA/FLUOR (so far) !!

Statistics:
very preliminary rate \(\sim\)20-30% of reliable detections
search for correlations with SP Type, warm/cold dust,
presence of planets ?
On-going program with increased sensitivity
Nov. 2008 campaign very successful (slow seeing !)
(12 more targets, 2-3 detections, reached K=5.8)
planetay systems become accessible (hd69830)
Sample \(\sim\) 45 targets with K < 5
Open questions

- Origin of the hot dust production?
- Frequency =f(ampitude) of 2µm excess
- Time variation of the hot dust excess?
- Connection hot/warm/cold dust?
  - Link 2-10-24µm excess (if any?)
- How can we constrain the emission in the habitable zone from our 2µm detections?
- What impact on the direct detection or characterisation of earth-like planets?