A VLTI/AMBER closure-phase search for low-mass companions in nearby young moving groups

First results on β Pictoris

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Why young moving groups?

- "Main sequence"
  - Thick circumstellar disks have disappeared
  - Planetary systems mostly formed
- "Young"
  - Planets are still warm and luminous → easier
  - Cooling models poorly constrained
- "Moving groups" (or associations)
  - Nearby (~ 20 – 50 pc) → bright, good resolution
  - Ages relatively well defined (~ 8 to 200 Myr)

Why VLTI/AMBER?

- Example: young MS star at 40 pc
- VLTI/AMBER complementary to VLT/NACO
  - Search region ~ 200 mas in radius (ATs)
- Could replace RV for inappropriate stars
  - Young, active, inappropriate spectral type, …

VLTI/AMBER	VLT/NACO

0.1   1   10   100

Distance [AU]
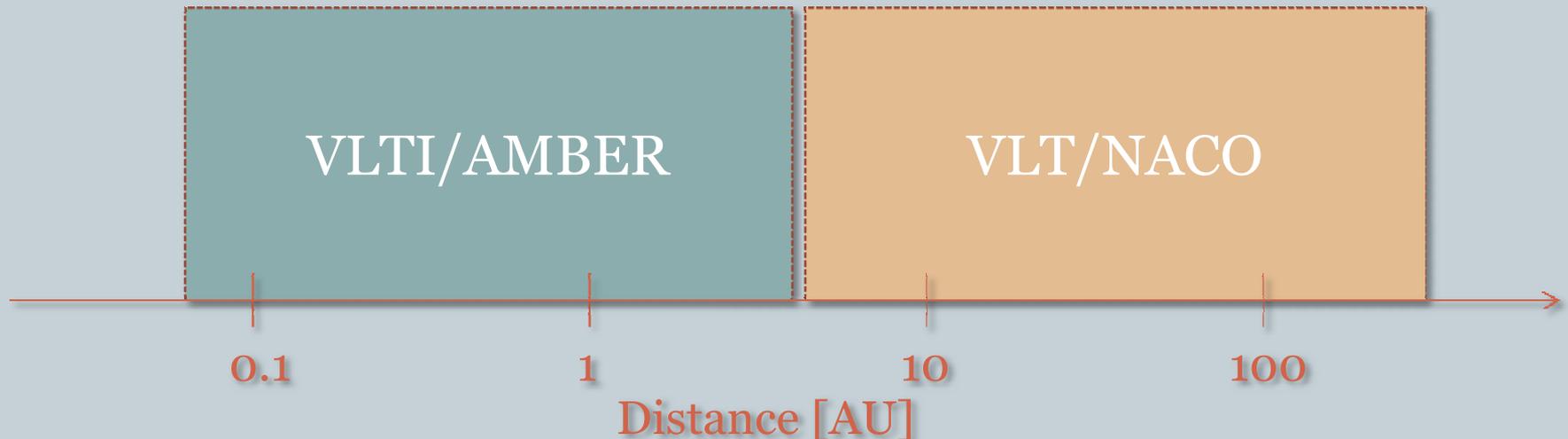
Search method: interferometric phases

- Star and planet → 2 fringe packets
  - Resulting packet shifted wrt "star only"
- Problem: atmospheric turbulence
  - Absolute phase not preserved

$\lambda/2B$

B
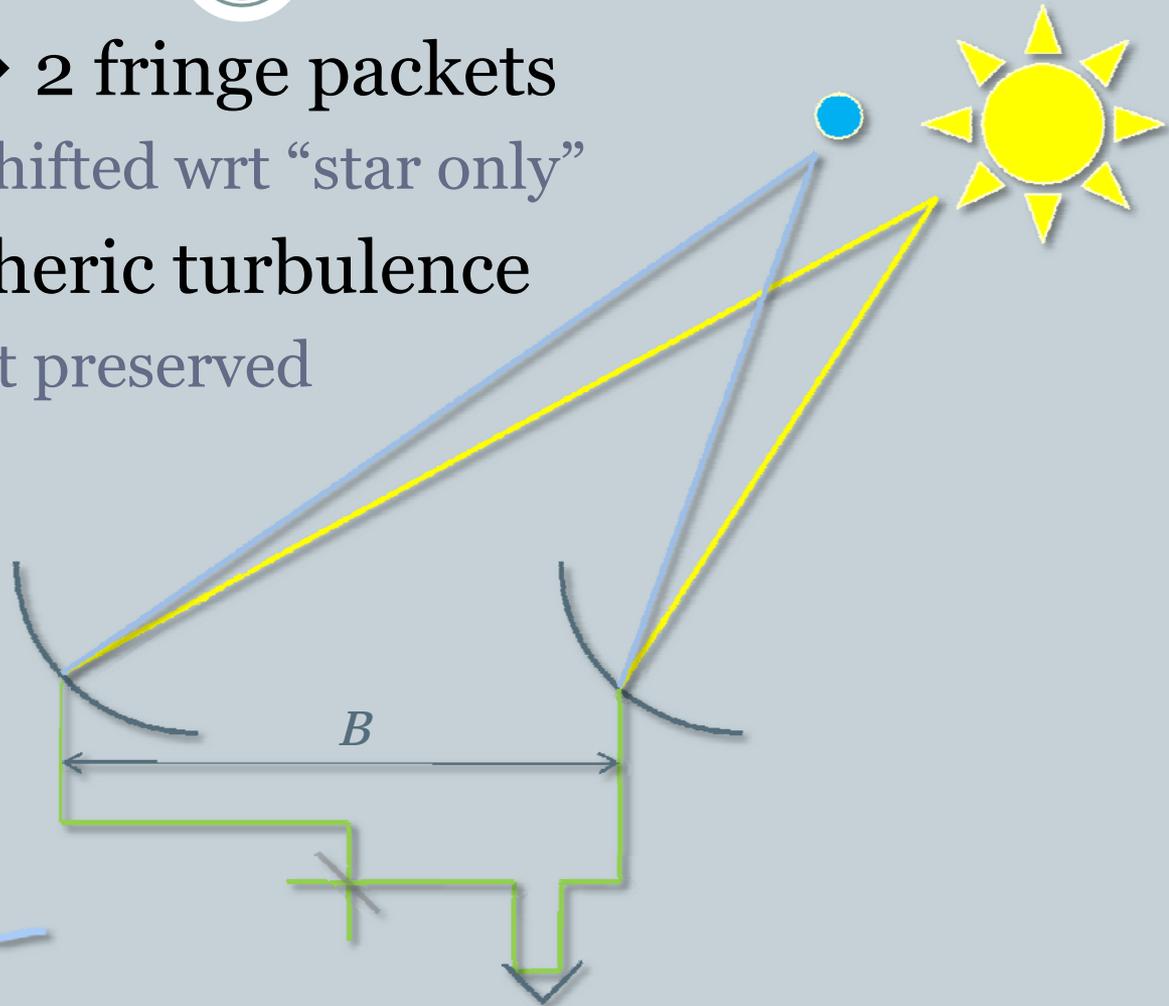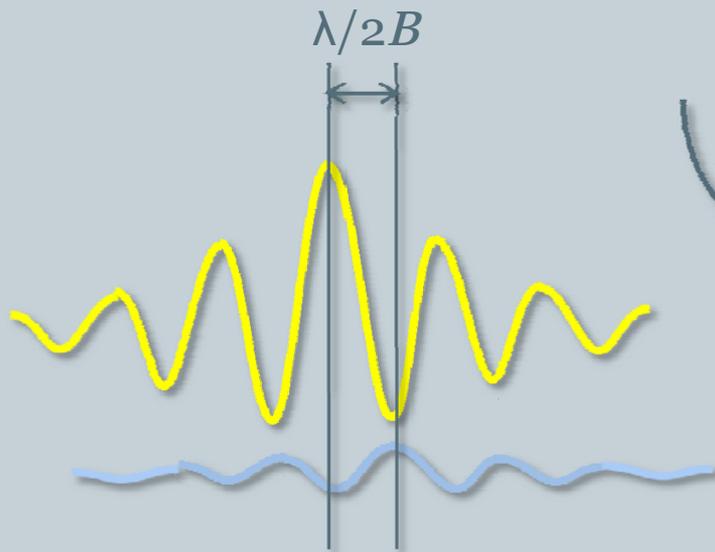
A solution: closure phase

- Closure phase (CP)
  - $\Psi_{123} = \varphi_{12} + \varepsilon_1 + \varphi_{23} + \varphi_{31} - \varepsilon_1$
  - External perturbation removed
  - $\neq 0$ only when object departs from point-symmetry
- Case of a binary object
  - $\Psi_{123} = \rho \, (\sin \alpha_{12} + \sin \alpha_{23} + \sin \alpha_{31})$
    - where $\alpha_{ij} = 2\pi \mathbf{B}_{ij} \cdot \boldsymbol{\theta} / \lambda$
  - CP proportional to flux ratio ρ
    - Contrast of 1:100 $\rightarrow$ CP $\sim 1°$
  - VLTI/AMBER CP stability $\sim 0.2°$

turbulence

ε_1

1

$\varphi_{12} + \varepsilon_1$

$\varphi_{31} - \varepsilon_1$

2

3

φ_{23}
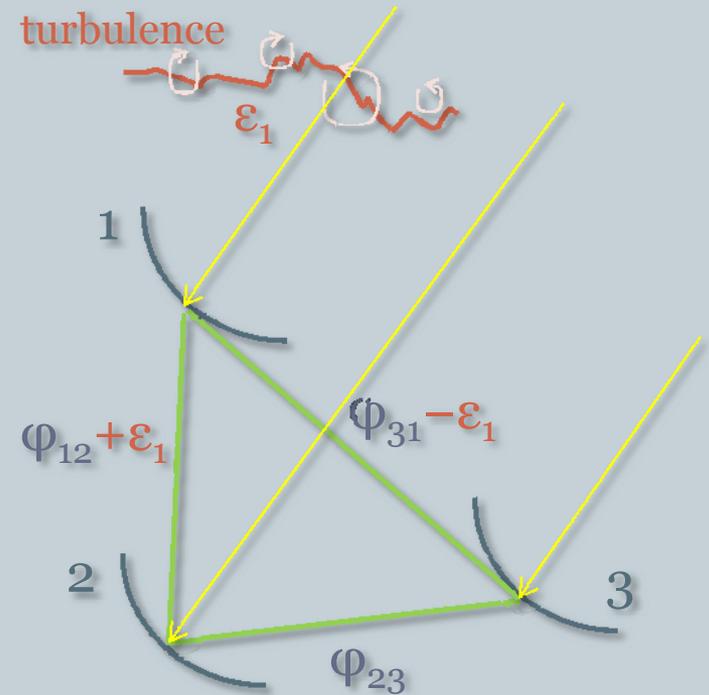
Our VLTI/AMBER observing program

- Moving groups / associations
  - Eta Chameleontis (5 Myr, ~100 pc)
  - TW Hydra (8 Myr, ~50 pc)
  - Beta Pictoris (12 Myr, ~40 pc)
  - Tucana-Horlogium (30 Myr, ~40 pc)
  - AB Doradus (70 Myr, ~30 pc)
  - Hercules-Lyra (200 Myr, ~20 pc)
- Constraints
  - K < 5, Southern hemisphere
- P81: 11 early-type dwarfs (PI: Chauvin)
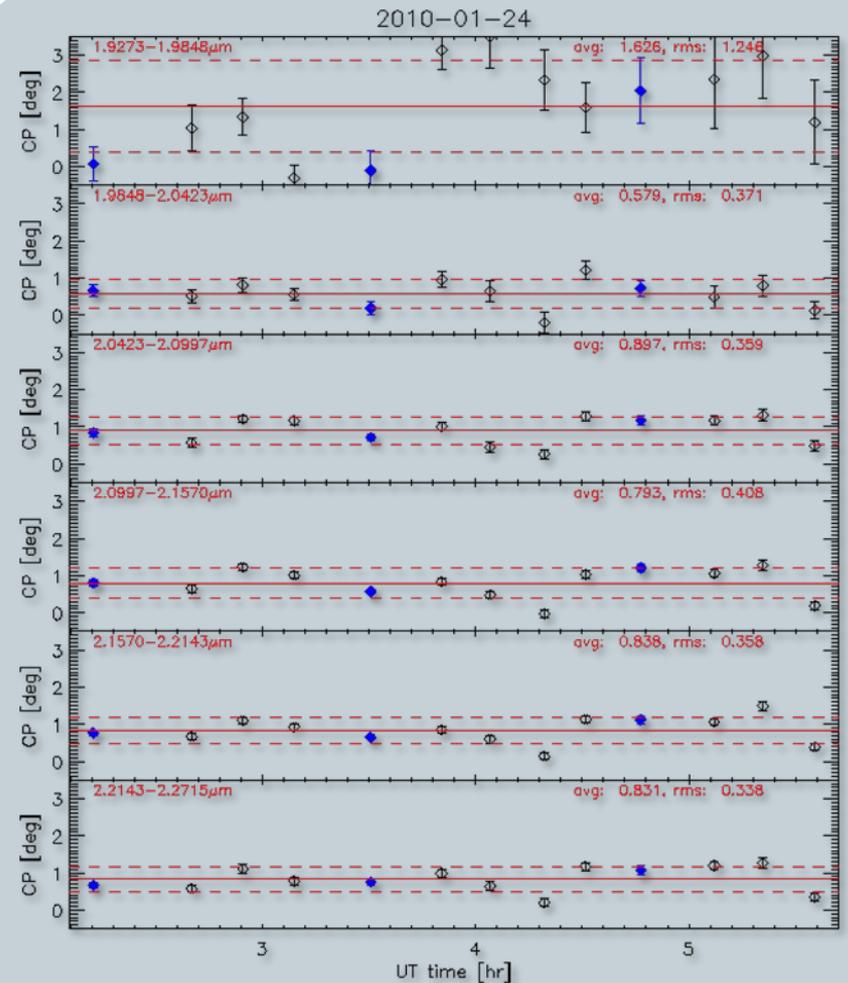- P85-P87: 23 early- and late-type dwarfs (PI: Hanot)

Observations of β Pictoris

- 24 – 28 January 2010
  - 13 Observing Blocks in total
- VLTI
  - ATs: A0 – G1 – K0
  - Good seeing (0.8")
- AMBER
  - MedRes (R = 1500)
  - K1 band (1.93 – 2.27 μm)
  - FOV ~ 420 mas FWHM
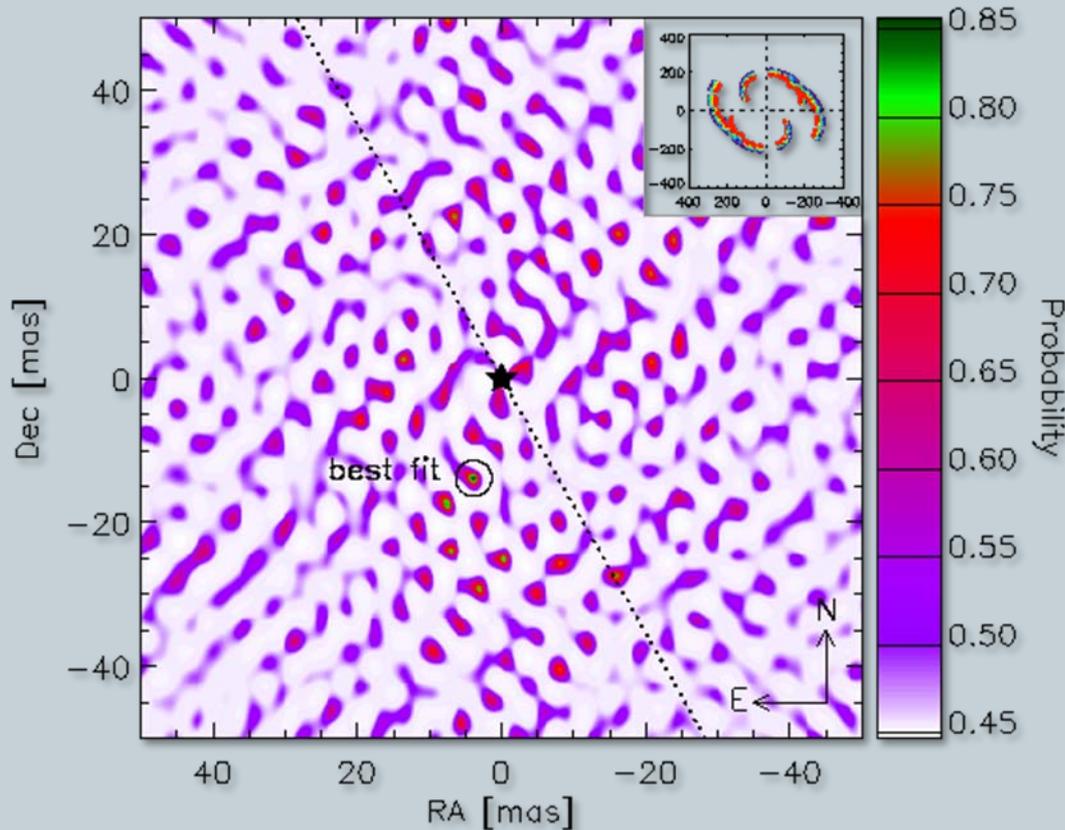   - Radius ~ 4 AU for β Pic
- FINITO
  - Fringe tracking
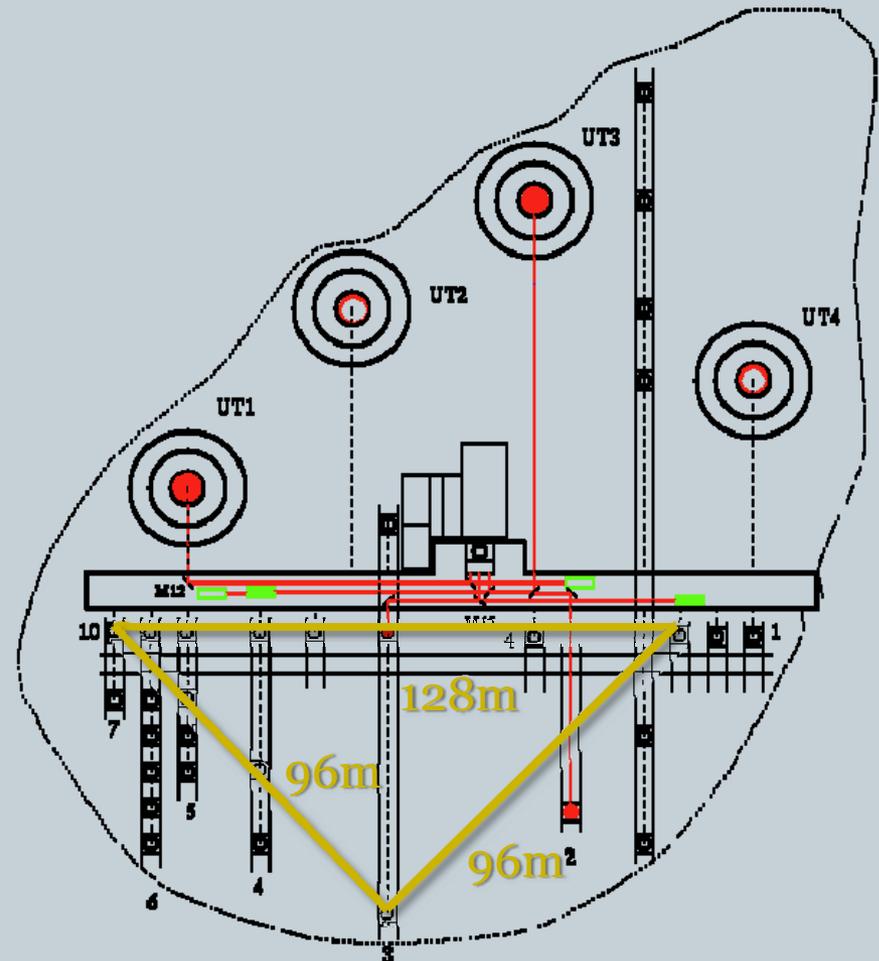
Closure phase stability

- ## Calibration star
  - HD 39640 (G8III, K=3)
    - At 1.2° on sky
    - Unresolved (V²~0.9)
- ## Data reduction
  - Amdlib 3.0
  - No special options/scripts
- ## CP stability
  - ~0.3° in 2.00 – 2.27 μm

2010-01-24

1.9273–1.9848μm   avg: 1.626, rms: 1.246
1.9848–2.0423μm   avg: 0.579, rms: 0.371
2.0423–2.0997μm   avg: 0.897, rms: 0.359
2.0997–2.1570μm   avg: 0.793, rms: 0.408
2.1570–2.2143μm   avg: 0.838, rms: 0.358
2.2143–2.2715μm   avg: 0.831, rms: 0.338
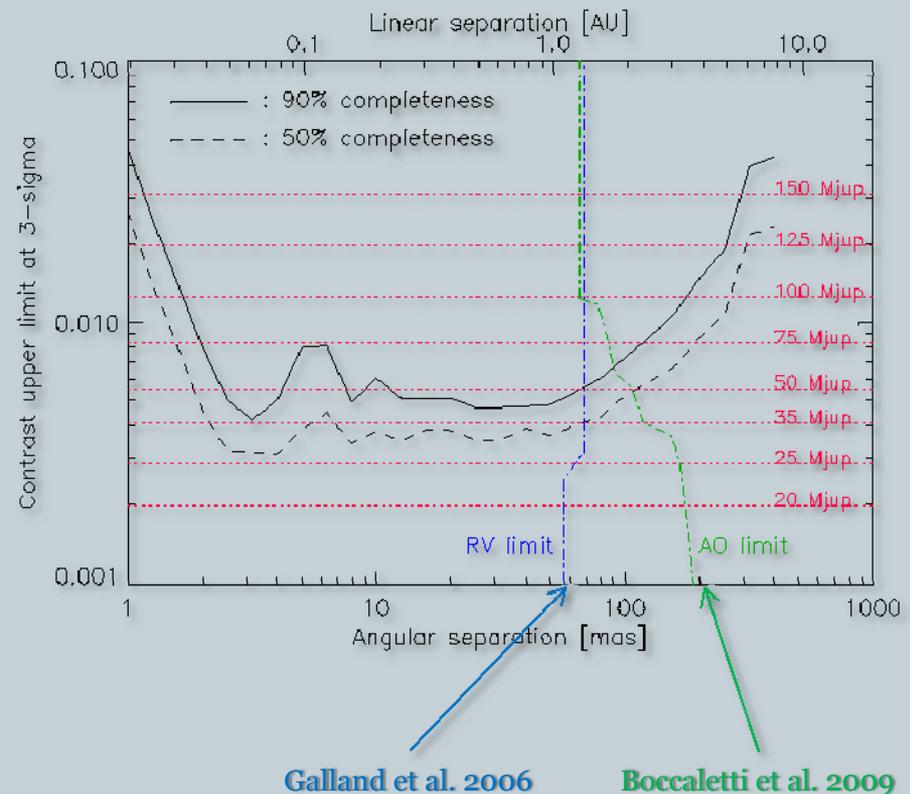
Fitting a (high-contrast) binary model

Best fit: $1.8 \times 10^{-3} \pm 1.1 \times 10^{-3}$ at 14 mas ($\chi_r^2 = 0.87$)
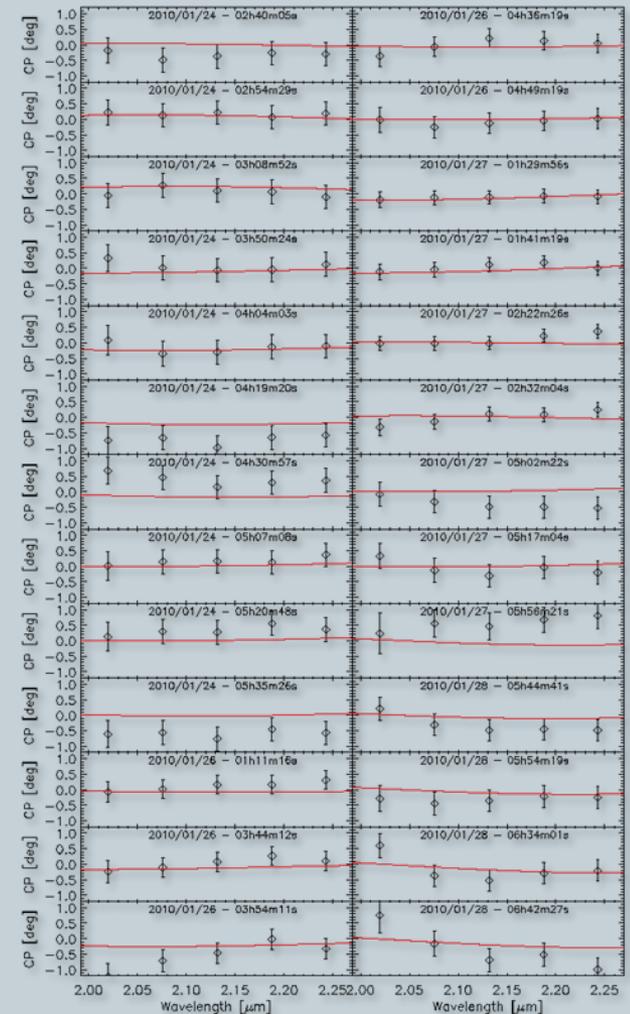
VLTI/AMBER sensitivity profile

- Optimal search zone
  - 2 – 60 mas
  - Median error bar = 1.2×10^{-3}
  - 3σ limit at 50% completeness
    - 3.5×10^{-3} (= 29 M_{Jup})
  - 3σ limit at 90% completeness
    - 5.0×10^{-3} (= 47 M_{Jup})
- Reduced perf → 300 mas
  - Time smearing
  - FOV limitation
- Confirmed by double-blind test

Galland et al. 2006   Boccaletti et al. 2009

Outlook

- ## VLTI/AMBER observing program
  - Search for tight brown dwarfs around ~ 30 stars
    - Typical search region from 0.1 to 10 AU
    - Short periods → masses accessible
  - Need 10× better accuracy to reach giant planet regime
- ## Starting P88: program extension on VLTI/PIONIER
  - Visitor instrument (1st fringes last night)
  - 4-telescope instrument
    - Better efficiency and completeness
  - Integrated Optics beam combiner
    - Improved magnitude limit (K~6-7, ATs)
    - Excellent CP stability (<0.1°?)
  - Goal: enter the planetary regime