

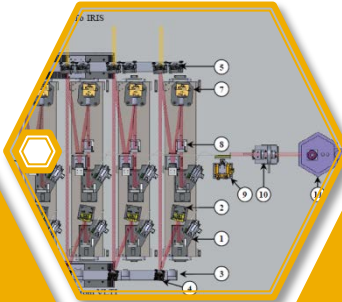
Olivier Absil

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Detecting faint companions with PIONIER

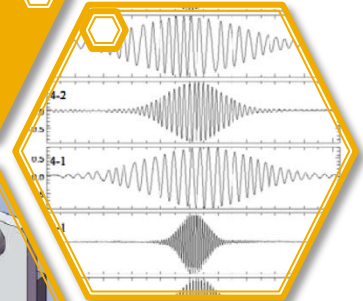
PIONIER in a nutshell

6 baselines

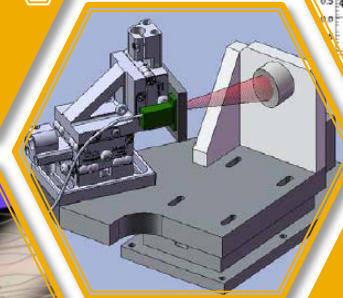


Single-mode fibers

Low spectral resolution



Integrated optics

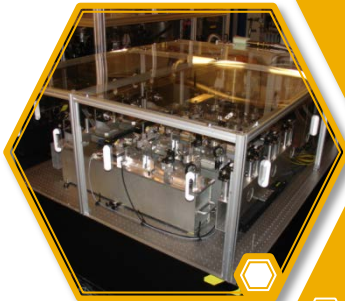
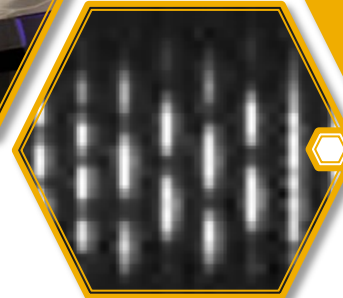


3 closure phases

Magnitude limit $H=8$

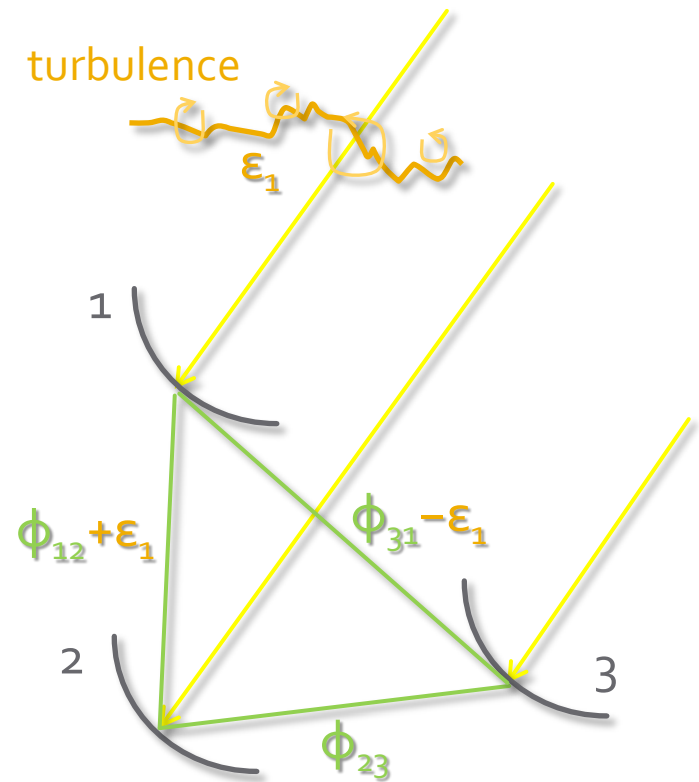


Fringe scanning



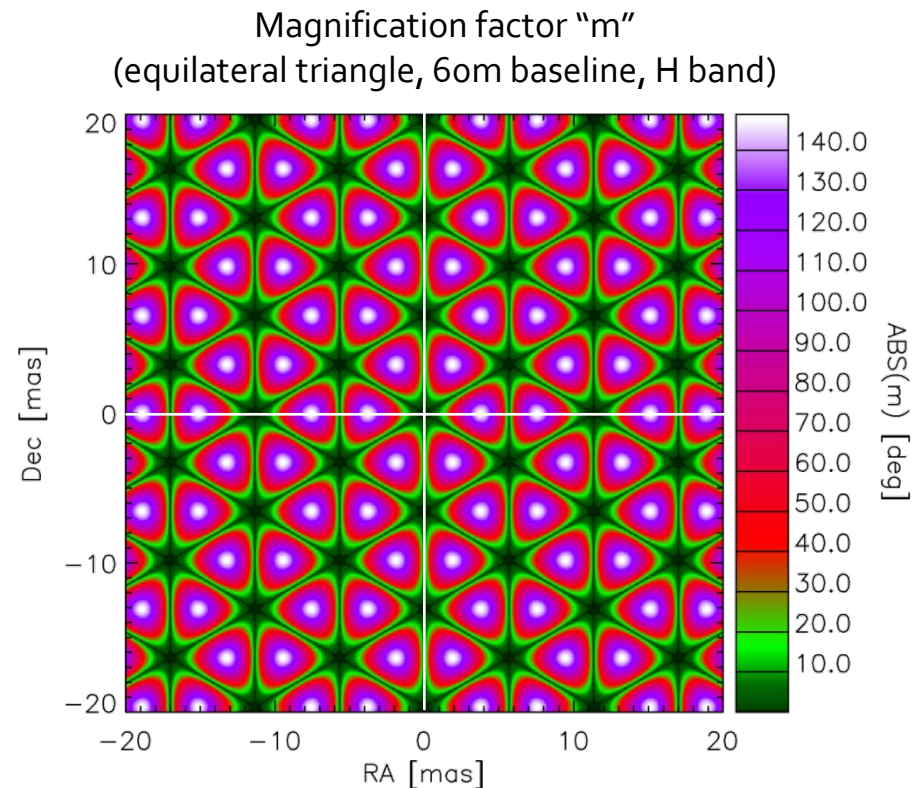
Benefits of closure phase

- Not affected by telescope-specific errors
 - $\psi_{123} = \phi_{12} + \epsilon_1 + \phi_{23} + \phi_{31} - \epsilon_1$
 - Not biased by turbulence
- $\psi_{123} = 0$ for point-symmetric objects
 - Sensitive to off-axis companions
 - Not sensitive to stellar model at 1st order

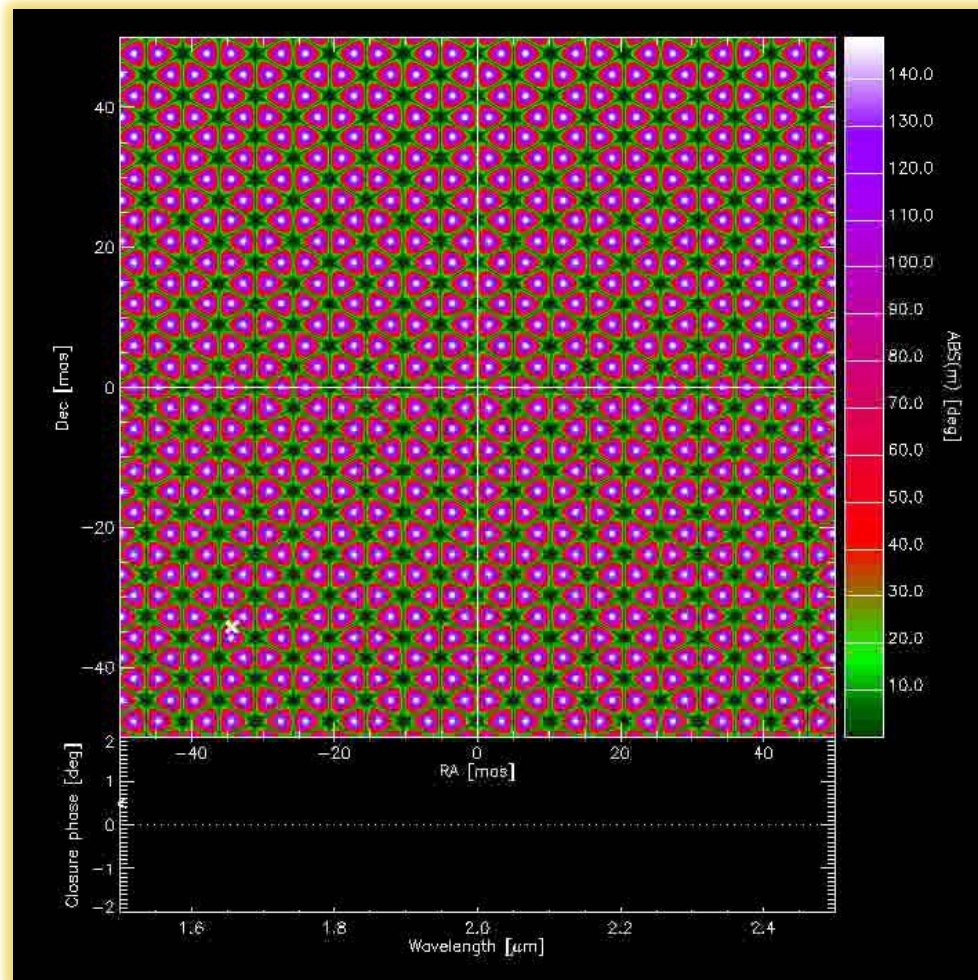


The faint companion regime

- Unresolved individual objects with contrast ρ
 - $\psi = \rho m$
 - $m = \sin \alpha_{12} + \sin \alpha_{23} + \sin \alpha_{31}$
 - $\alpha_{ij} = 2\pi \mathbf{B}_{ij} \cdot \boldsymbol{\theta} / \lambda$
 - Magnification factor “ m ” ranges from 0° to 149°
 - Ex: $\rho = 1\% \rightarrow \psi \sim 1^\circ$
- Resolved primary
 - ψ strongly enhanced
 - “Closure phase nulling”

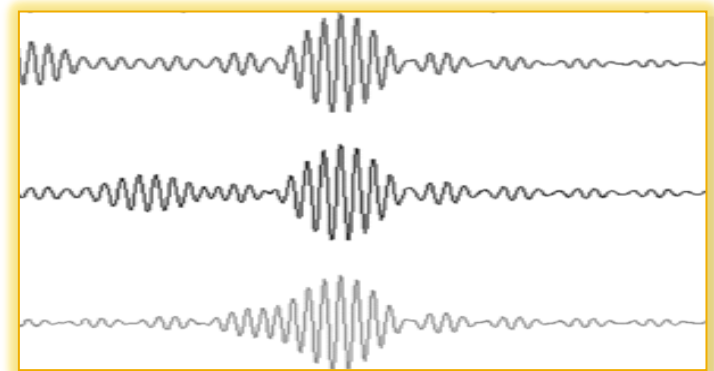
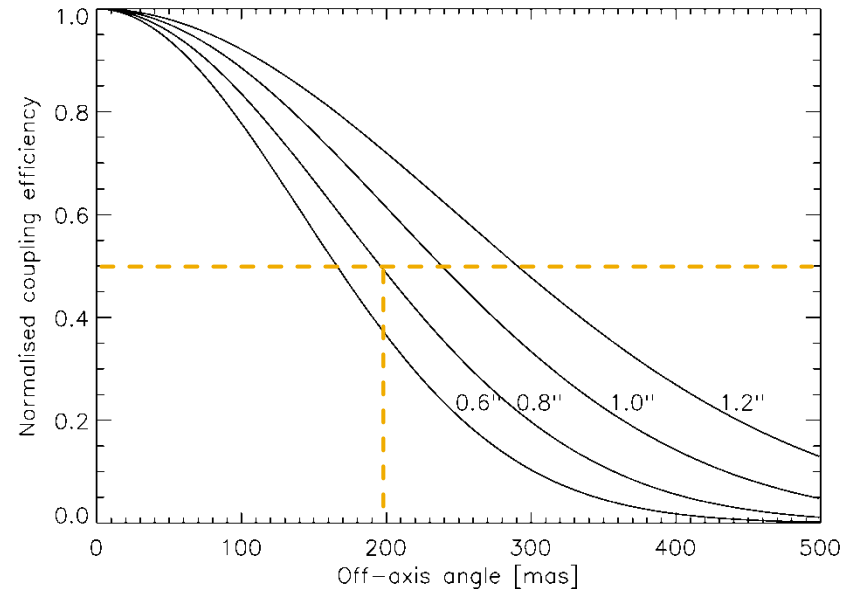


The wavelength-differential ψ



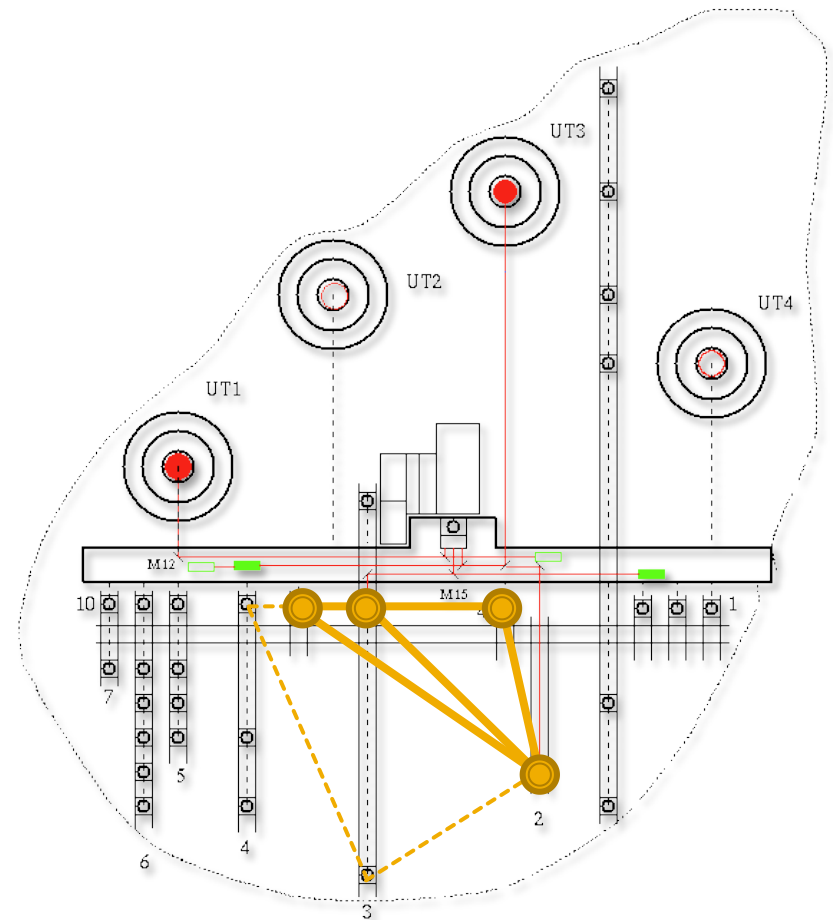
Field-of-view limitations

- Single-mode fibers
 - Gaussian injection efficiency
 - Affected by seeing
 - FWHM ~ 400 mas
- Two fringe packets
 - Within scan window
 - Mostly superposed
 - Equivalent to good sampling of differential ψ
 - 50m baseline \rightarrow max separation ~ 100 mas



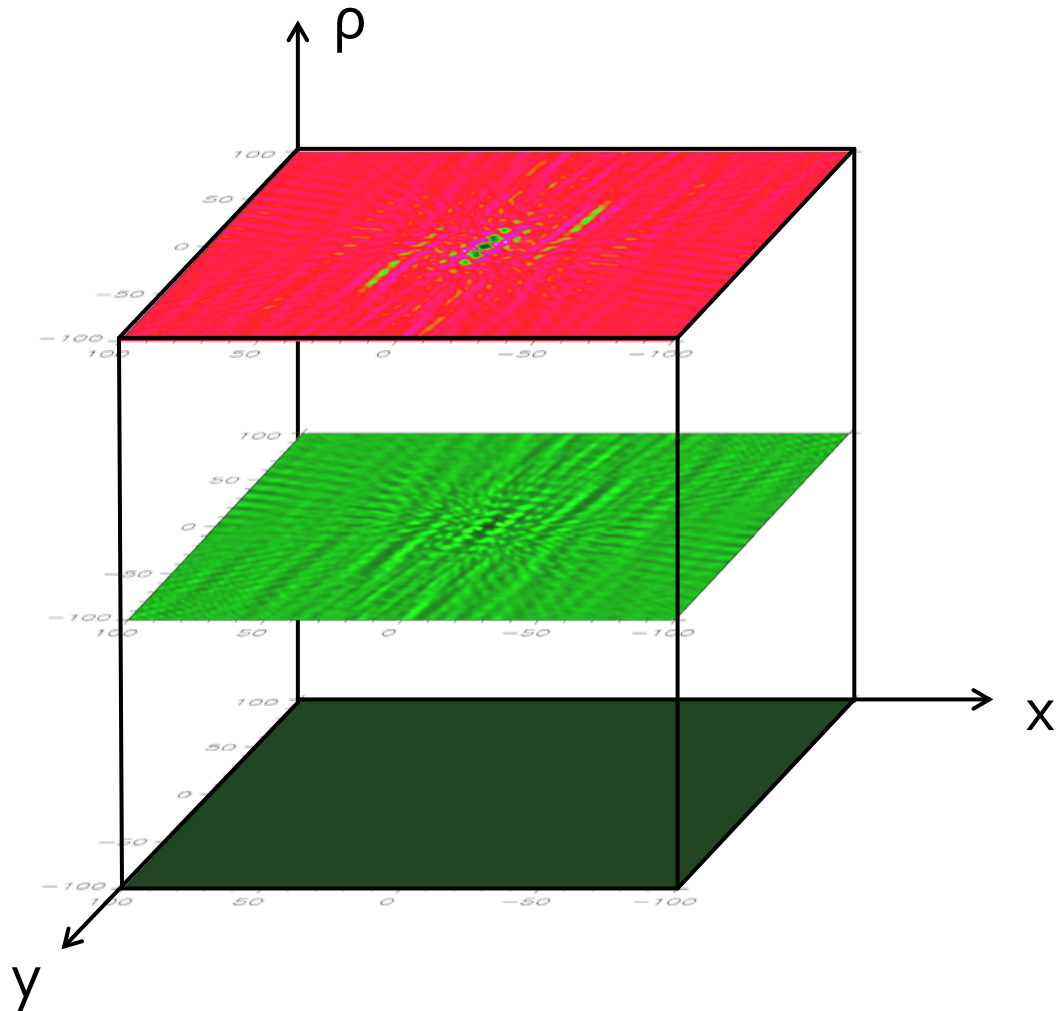
The PIONIER observations

- Oct-Dec 2010
 - Commissioning run
 - First scientific runs
- Deep integrations
 - Fomalhaut (7 OBs)
 - τ Cet (6 OBs)
- Snapshots
 - δ Aqr (1 OB)
 - Regulus (3 OBs)
- 7 spectral channels
- ~50m baselines



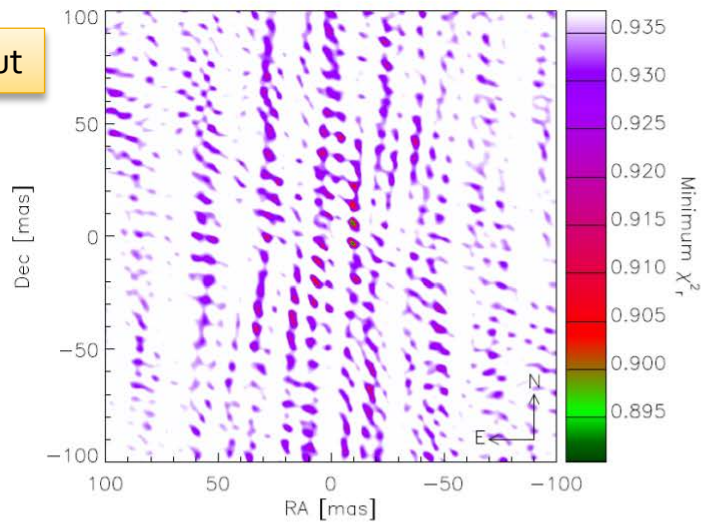
Companion search method

- χ^2 cube
 - Series of binary models compared to $\psi(\lambda)$ data
- Search minimum
- Evaluate significance
 - Renormalise so that $\chi^2_{\min} = 1$
 - Probability of null hypothesis?

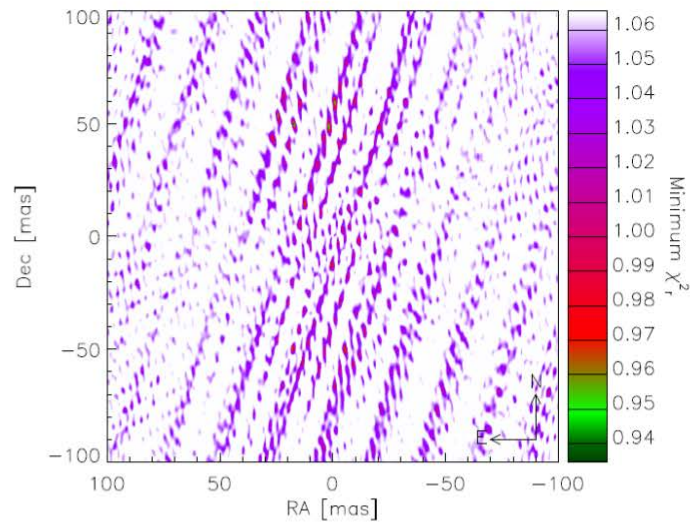


Minimum χ^2 maps

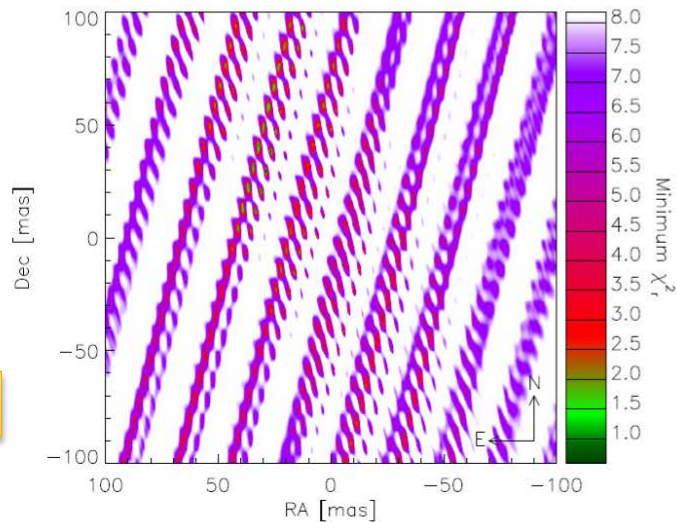
Fomalhaut



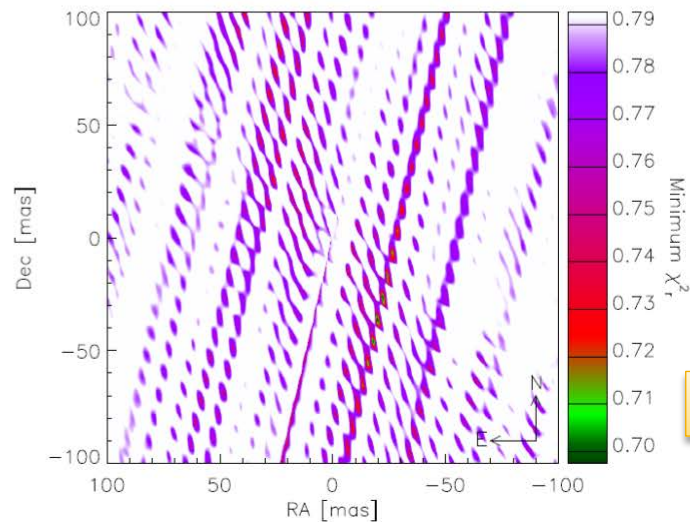
τ Cet



δ Aqr

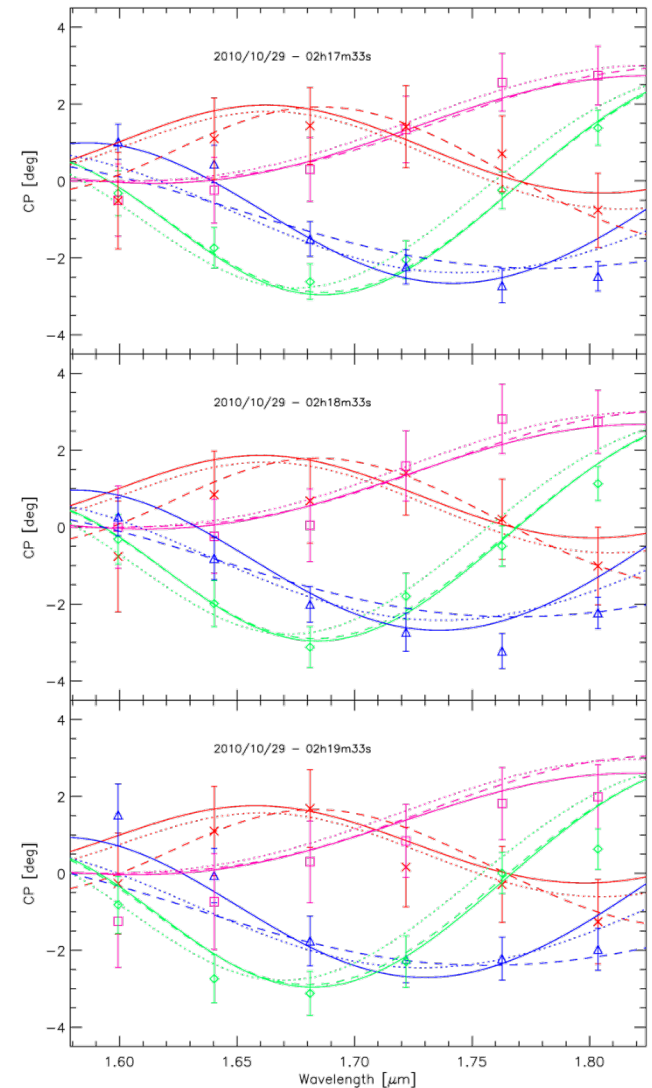
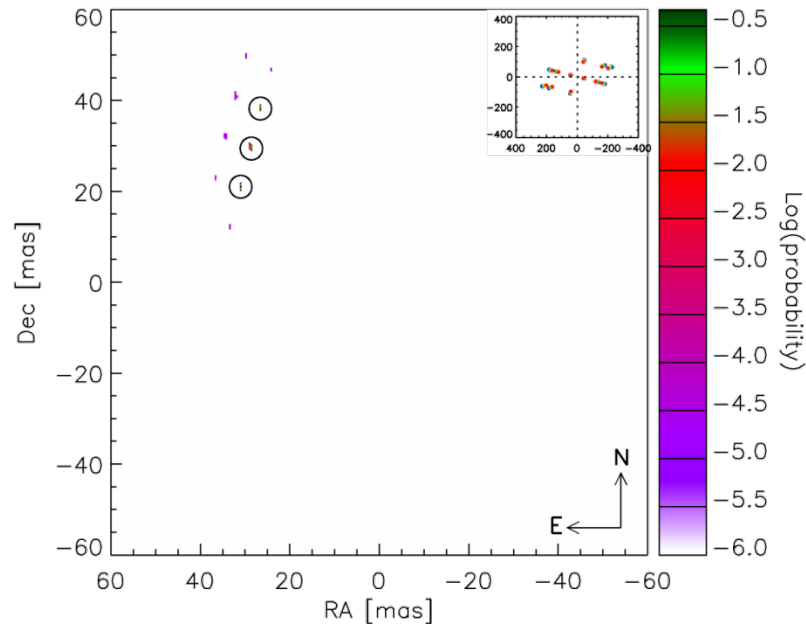


Regulus



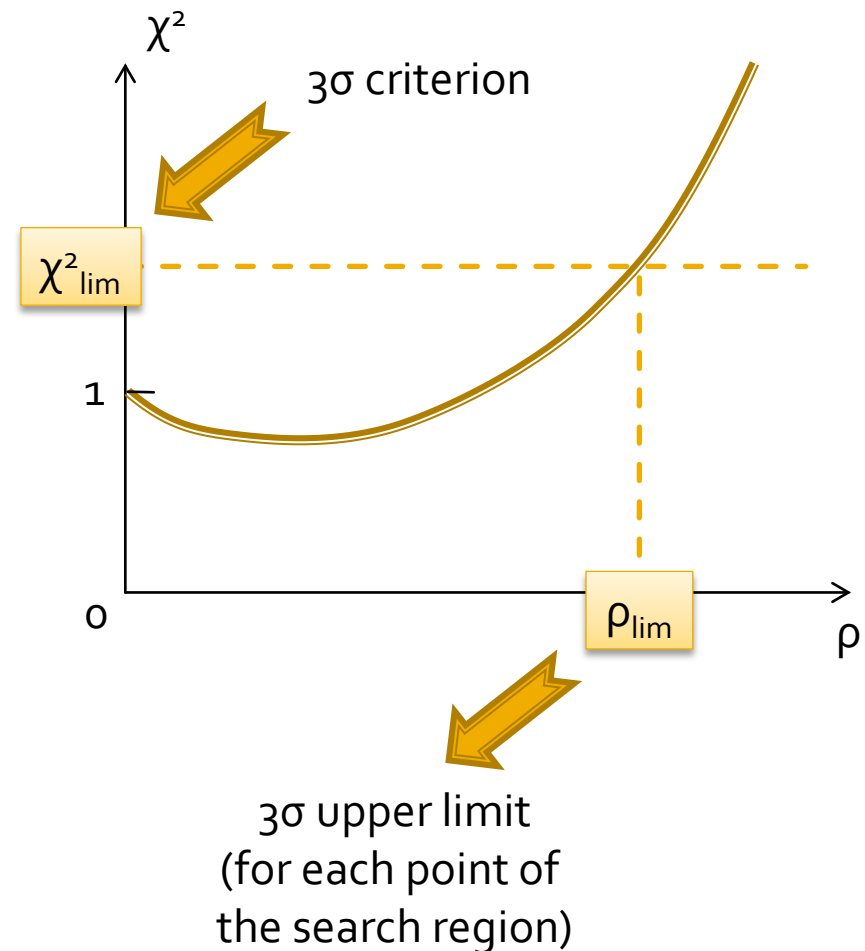
A companion around δ Aqr

- Long period RV + astrometry
- Contrast $2.05\% \pm 0.16\%$
 - A₃V + G₅V system
- Position ambiguous



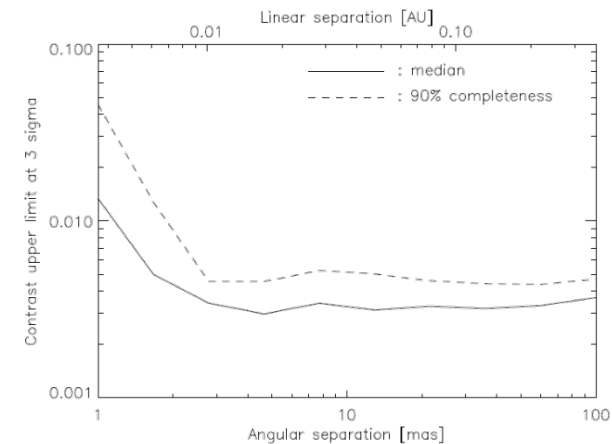
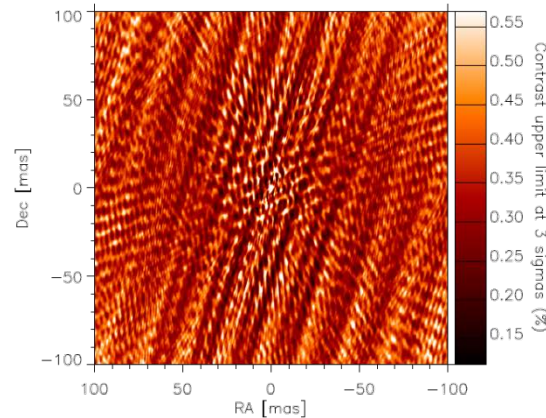
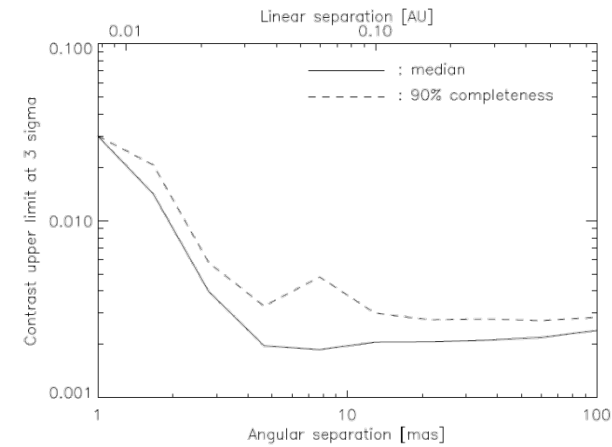
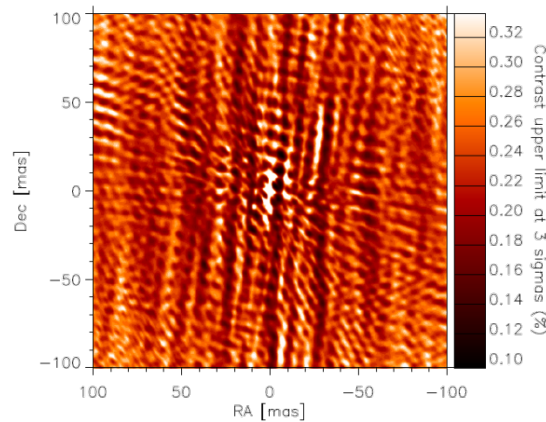
Deriving upper limits

- Based on χ^2 cube
 - Renormalise $\chi^2|_{\rho=0} = 1$
 - Find ρ such that model at more than 3σ from data
- Double blind test
 - Fake companions inserted into calibrated ψ data
 - Count the fraction of good detections vs ρ



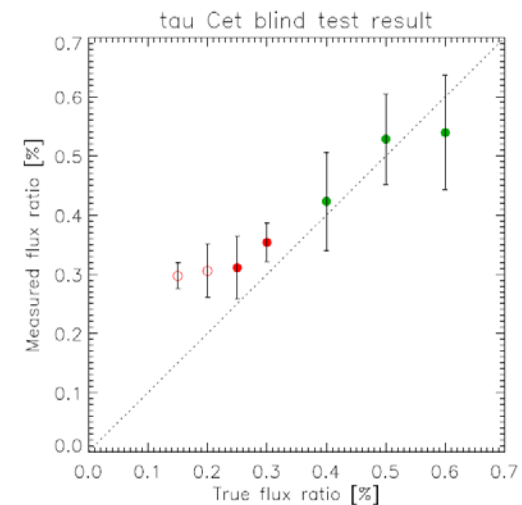
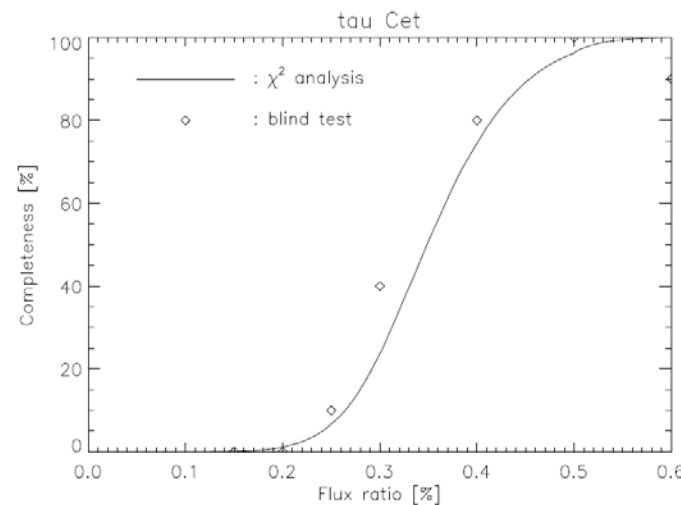
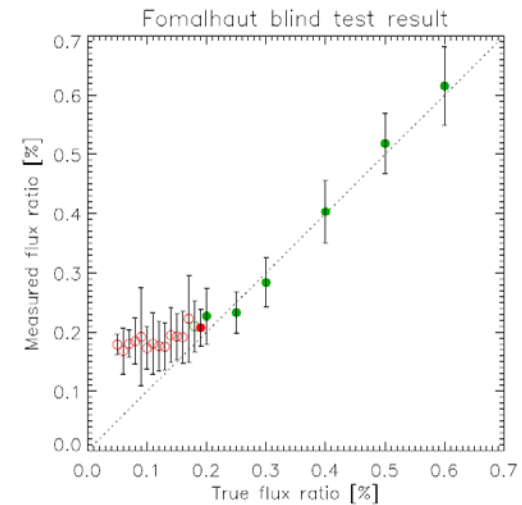
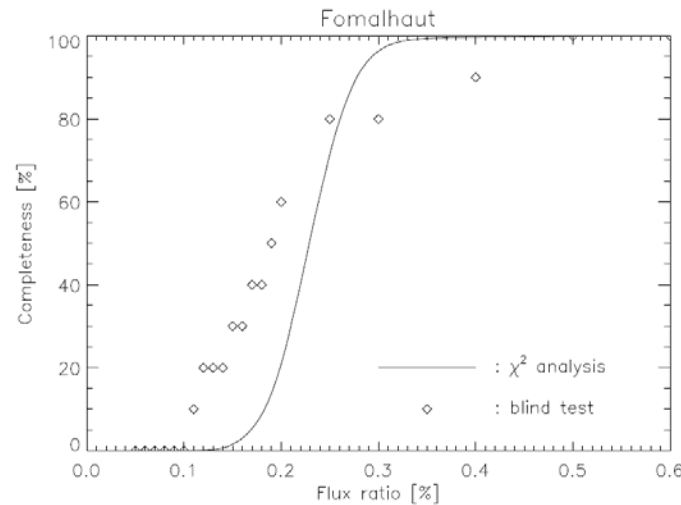
Deep search: χ^2 cube results

- 3σ sensitivity on 100 mas region
 - Fom: 2.3×10^{-3}
 - τ Cet: 3.5×10^{-3}
- 90% upper limit
 - $0.17 M_{\text{SUN}}$ (\sim M6V)
 - $0.09 M_{\text{SUN}}$ (\sim BD)
- Exclude companion as source of near-infrared excess



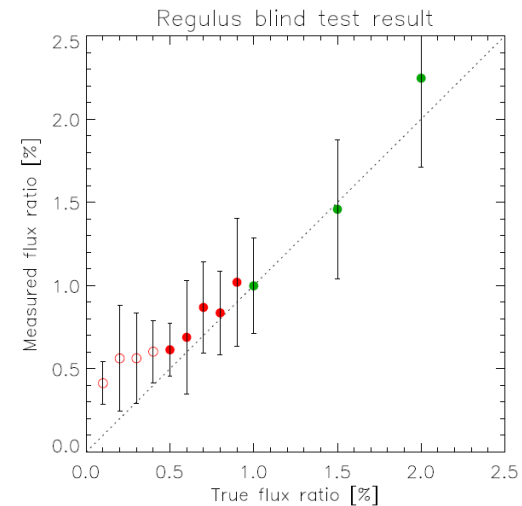
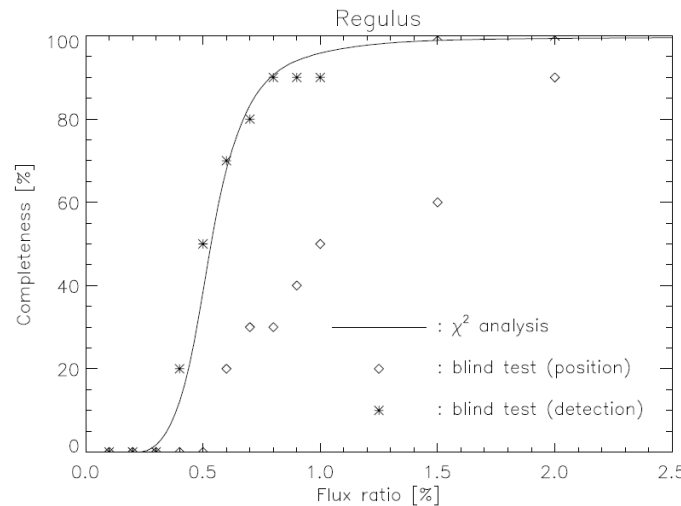
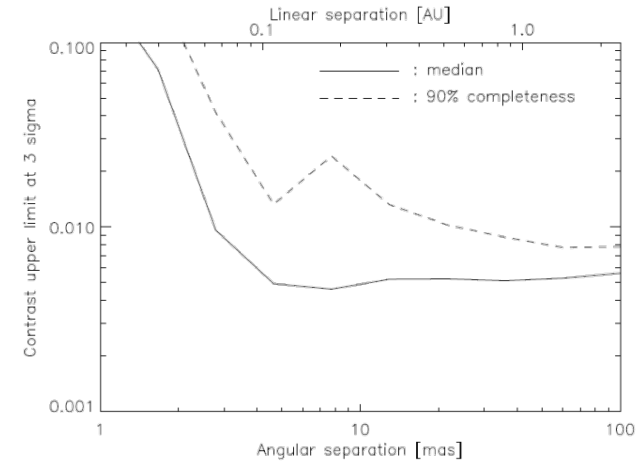
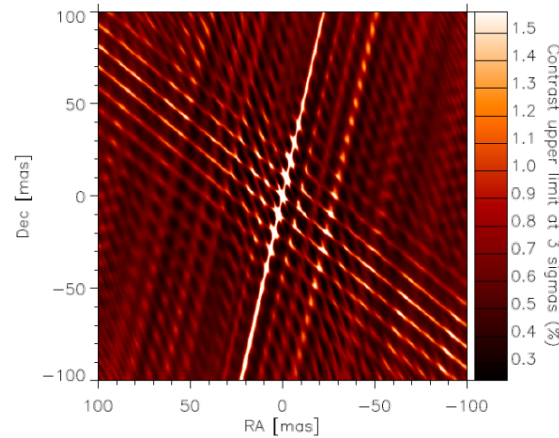
Deep search: blind test results

- Confirms the χ^2 results
- Median sensitivity
 - Fom: 1.9×10^{-3}
 - τ Cet: 3.2×10^{-3}
- False detections
 - $\leq 2.3 \times 10^{-3}$
 - $\leq 3.5 \times 10^{-3}$



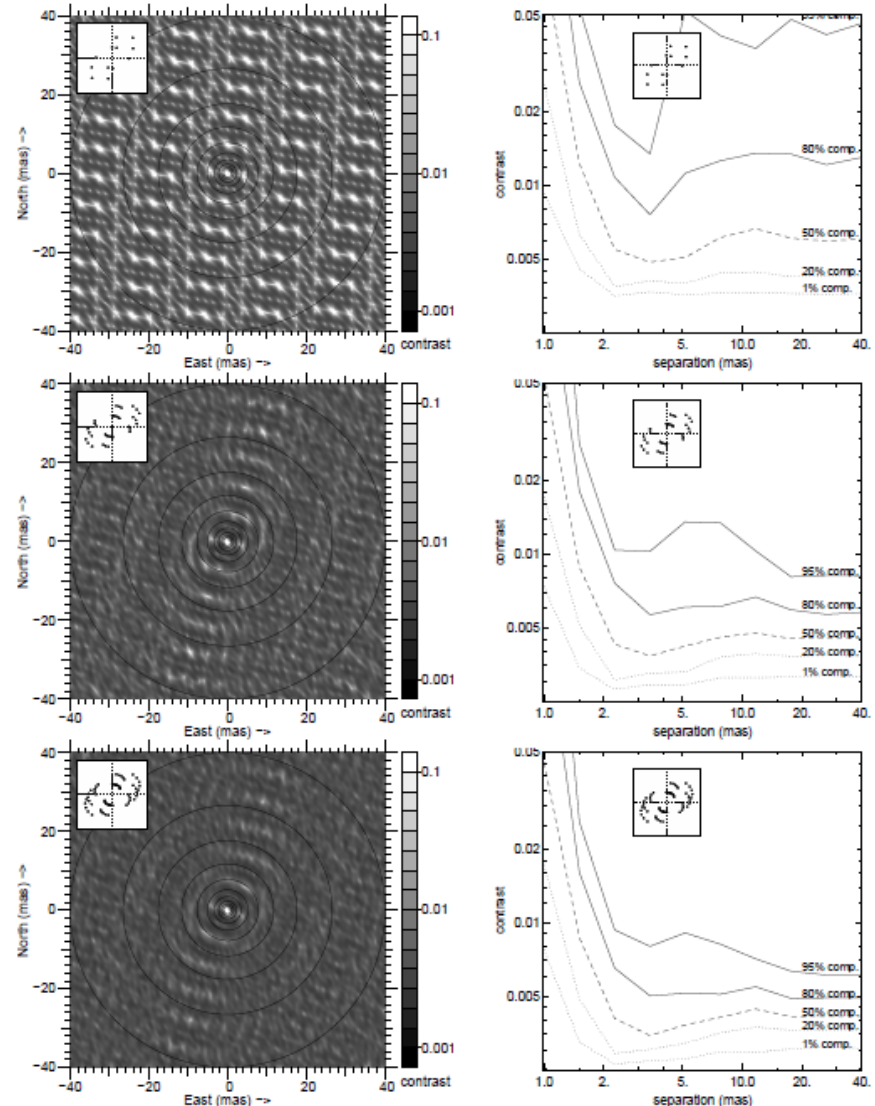
Snapshot results (Regulus)

- Median sensitivity: 5.4×10^{-3}
- Poor uv plane coverage \rightarrow zones with low sensitivity
- Blind test ok for contrast but not for position
 - "Side lobes" of instrument PSF



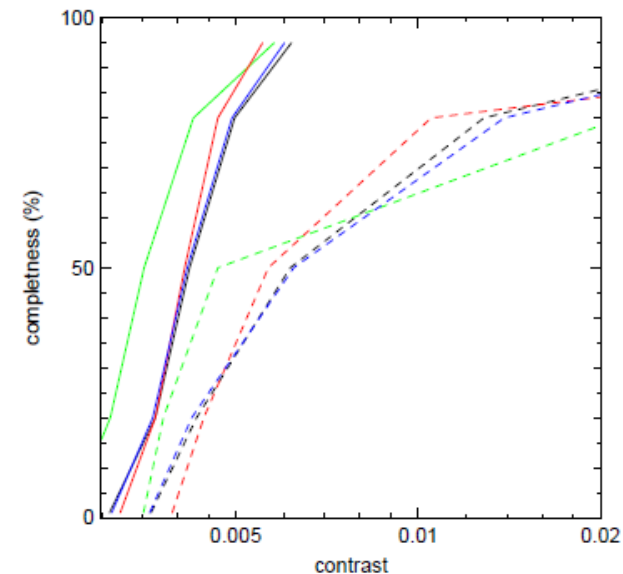
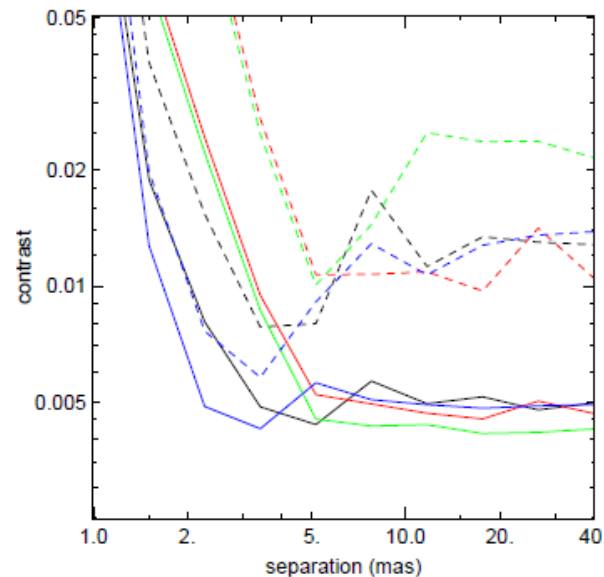
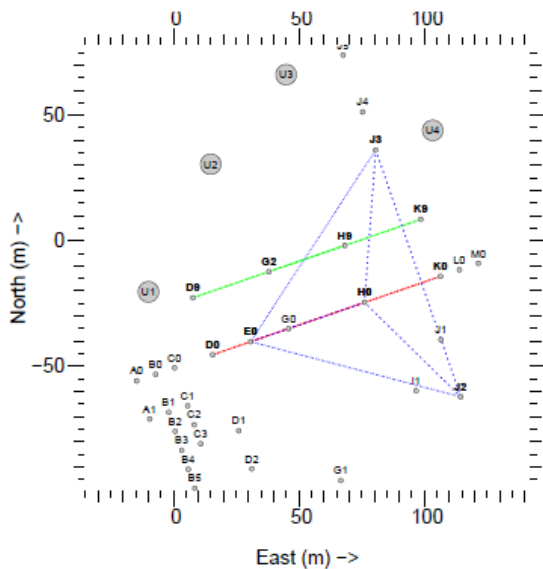
Sensitivity vs number of OBs

- Assume accuracy of 0.25° on A1-G1-I1-Ko
- Pointings at hour angles
 - oh
 - -1h, oh, 1h
 - -2h, -1h, oh, 1h, 2h
- Median sensitivities
 - 6×10^{-3} , 4.5×10^{-3} , 4.0×10^{-3}
 - Huge improvement in completeness
- 3 pointings ok for survey



Sensitivity vs configuration

- Sensitivity does not depend on configuration
- Configuration size still matters
 - Sets inner working angle and FOV size
- Companion search = ideal filler program!



Astrophysical applications

- Performance summary
 - Noise floor $\sim 0.2^\circ$
 - Dynamic range $\Delta H \sim 6$
 - Valid up to $H \sim 6$ (?)
- Warm BD/planets
 - Transition objects
 - Moving groups
 - Hot Jupiters ... not yet
- Binary fraction of massive stars
 - Mass ratio up to ~ 15

Age	AoV	GoV	MoV
10 Myr	$0.09 M_{\text{sun}}$	$0.017 M_{\text{sun}}$	$0.012 M_{\text{sun}}$
50 Myr	$0.22 M_{\text{sun}}$	$0.043 M_{\text{sun}}$	$0.013 M_{\text{sun}}$
200 Myr	$0.35 M_{\text{sun}}$	$0.08 M_{\text{sun}}$	$0.030 M_{\text{sun}}$

