Astrometry with PRIMA
first commissioning results

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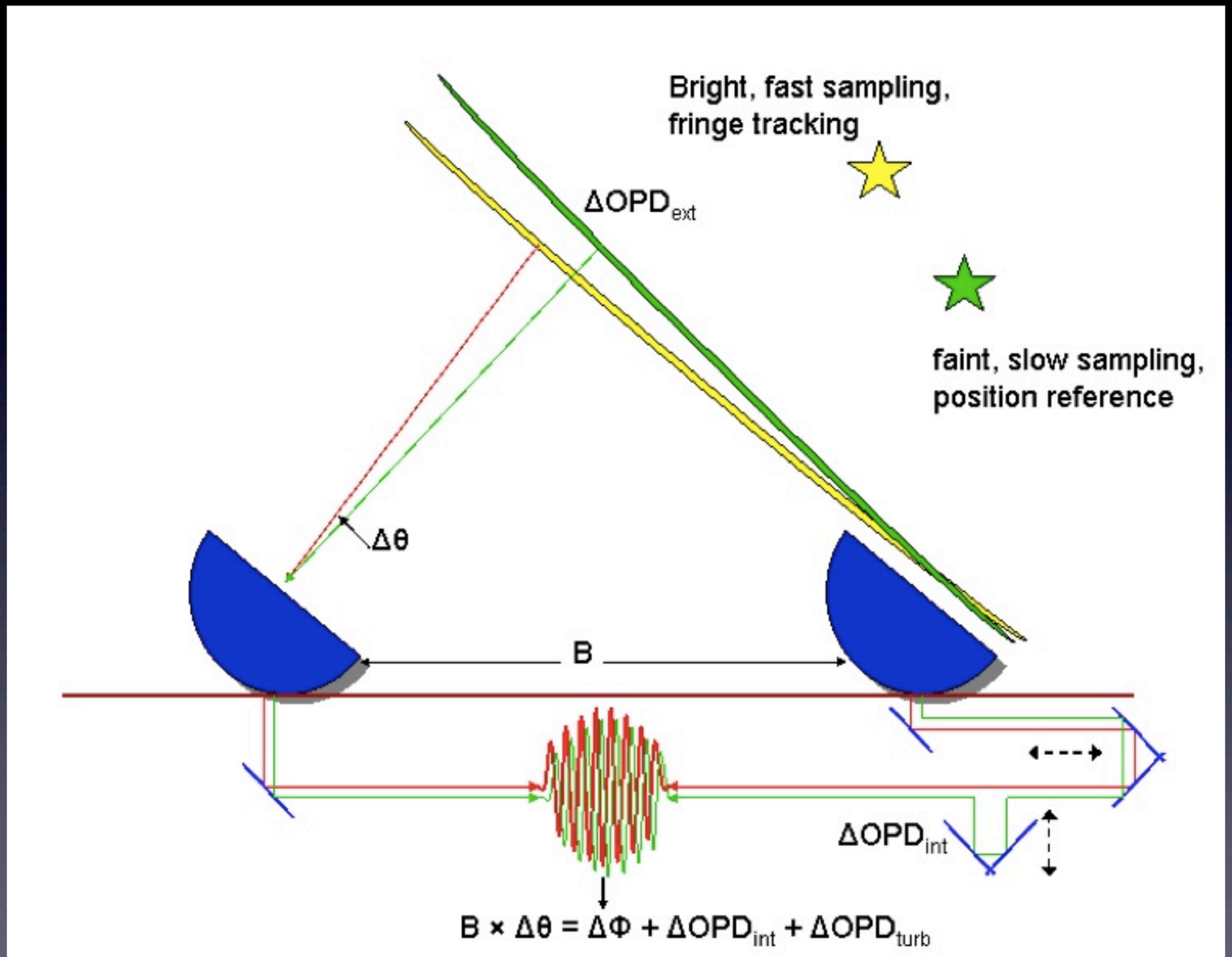
ESPRI Consortium

OAU-Geneva, MPIA-Heildelberg, Sternwarte-Heidelberg

Data Analysis Working Group

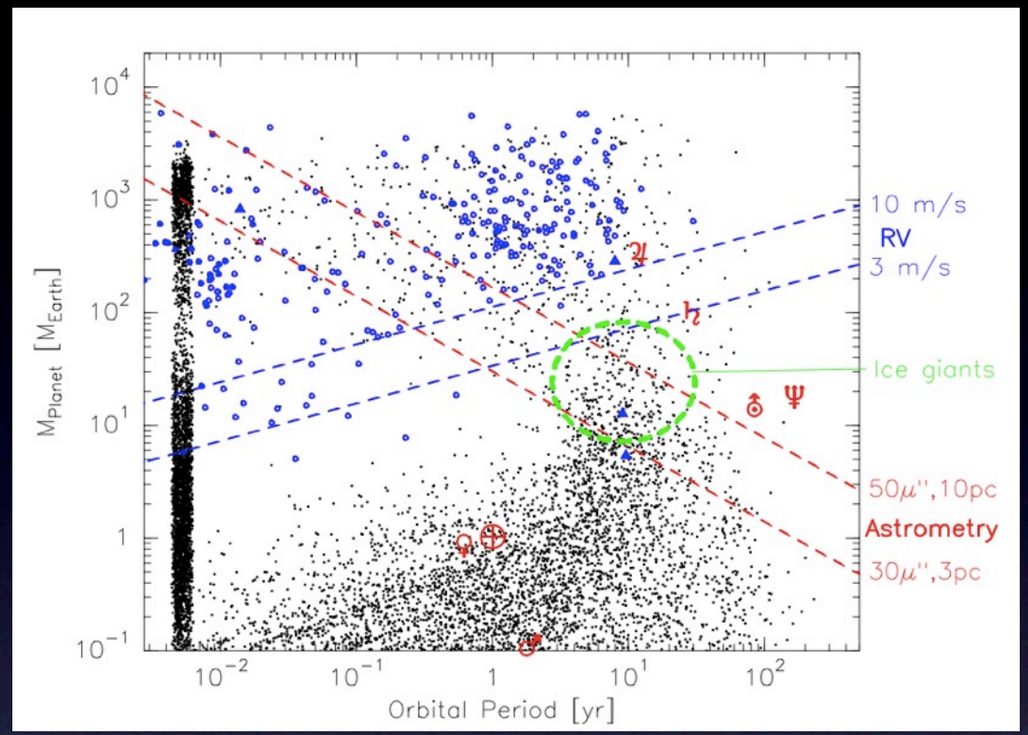
ESPRI, ESO-Garching, ESO-Paranal

Narrow Angle Astrometry Principles



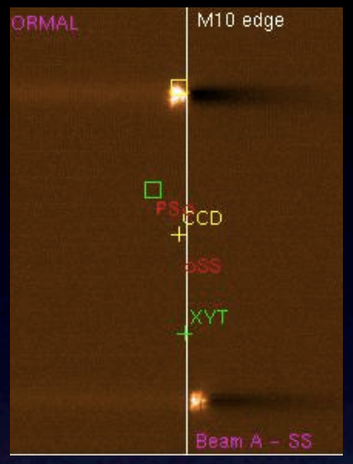
Project Overview

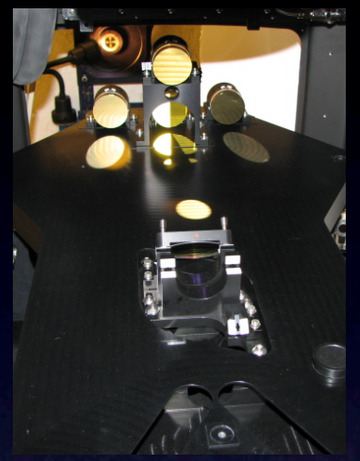
- PRIMA-astrometry requirements
  - Bright targets (K<8)
  - Ref star within 2-30 arcsec and K<13-14
  - Expected Astrometry accuracy : 10 muas
- ESPRI Consortium
  - OAU-Geneva, MPIA-Heildelberg, LSW-Heidelberg
  - PIs : D. Queloz, T. Henning, A. Quirrenbach; PM : F. Pepe; PS: R. Laundhardt
- Timeline
  - Kick-off, June 2004; PDR, June 2005; FDR, Apr 2007; PAE, June 2008
  - Hardware Procurement, installation, testing
  - Data Analysis Working Group : November 2010
  - PRIMA Astrometry first light : January 2011
  - Astrometry-COM 1&2 : July & August 2011

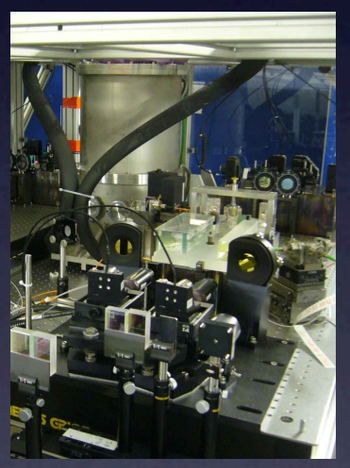


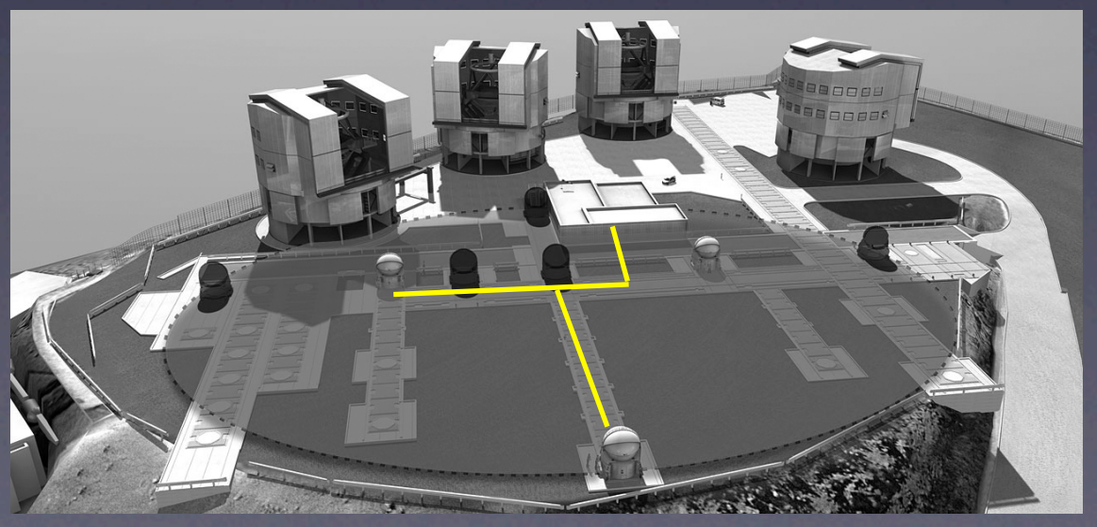
Project Overview : Hardware

- ATs
- STS : Star separators
- Delay Lines
- Differential Delay Lines
- 2 Fringe Sensor Units
  - Spatial filtering after recombination. No photometric channels. 5 spec. channels in K. Simultaneous ABCD (no time delay).
  - Fringe Tracking, Fringe Scanning. Allow to measure phase shifts (ABCD vs lambda) + group delay
- Metrology : PRIMET









Exoplanet Search program with **PRI**ma

- Stars with known radial velocity planets (d<200pc)
  - Massive planets - BD Transition (Sahlman, 2011)
  - Multi-planetary systems (Dynamics, Kozai)
  - Dynamical masses
- Nearby Stars (d<15pc)
  - Best detectability
  - All type of stars (active, young, fast rotator, early type)
- Young Stars (d<100pc, age<300 Myr)
  - cf. W. Benz talk

Exoplanet Search program with **PRI**ma

- Stars with known radial velocity planets (d<200pc)
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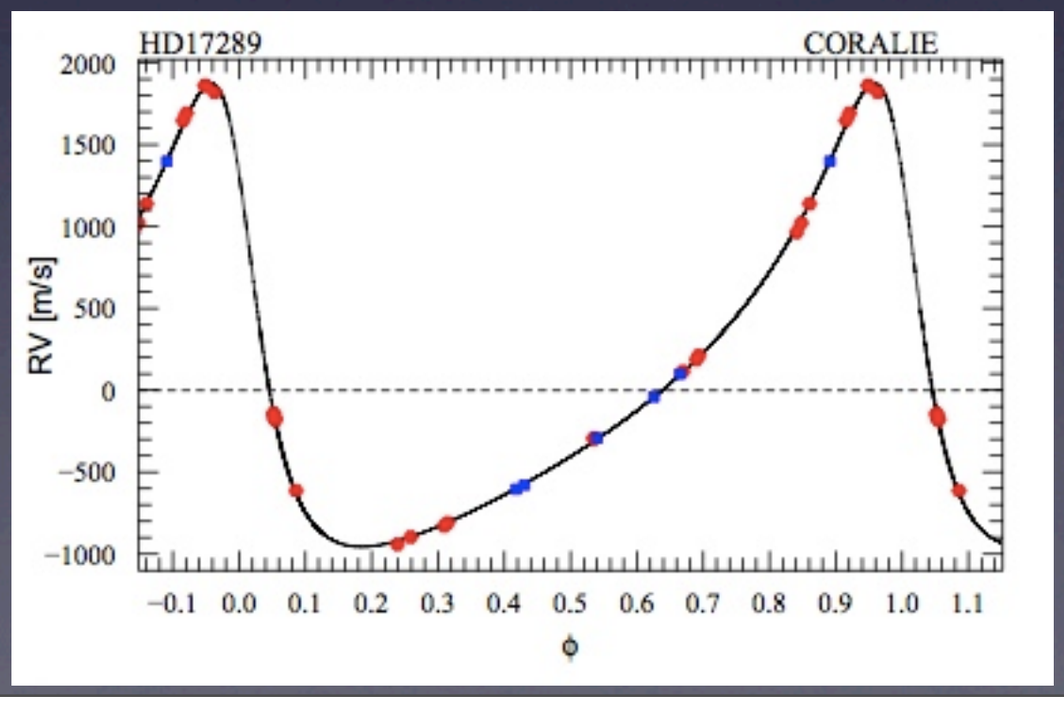
  - Multi-planetary systems : Full geometry of the orbit (Dynamics)
  - Dynamical masses

P = 562 days

m.sin(i) = 49 M_{Jup}



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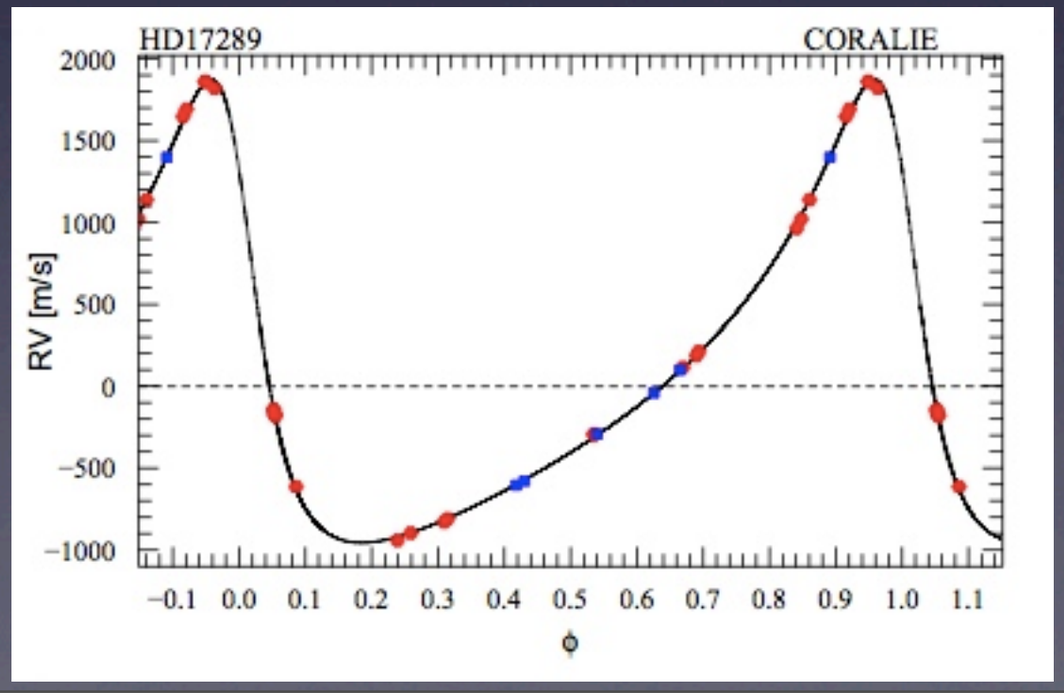

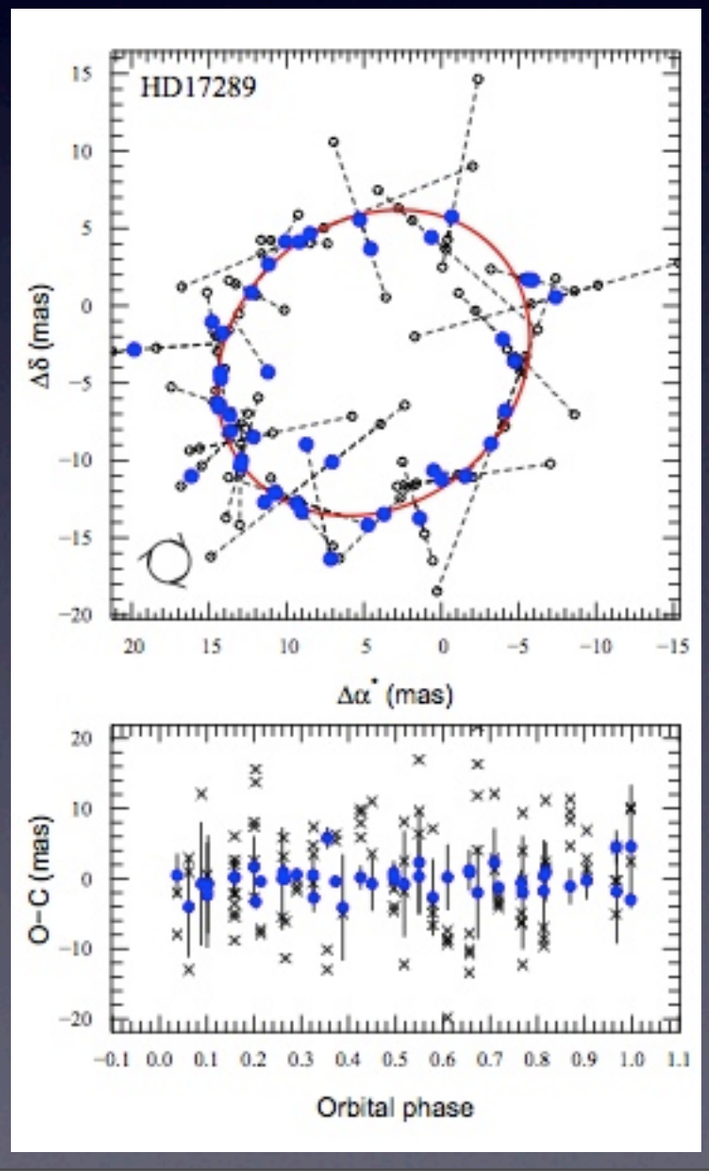

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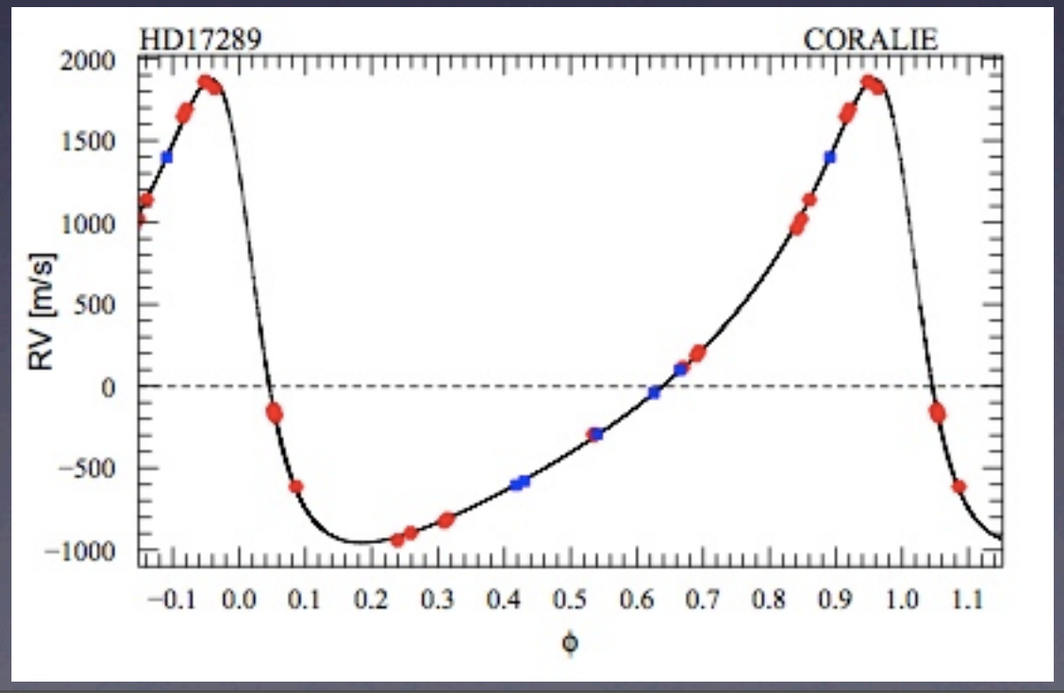
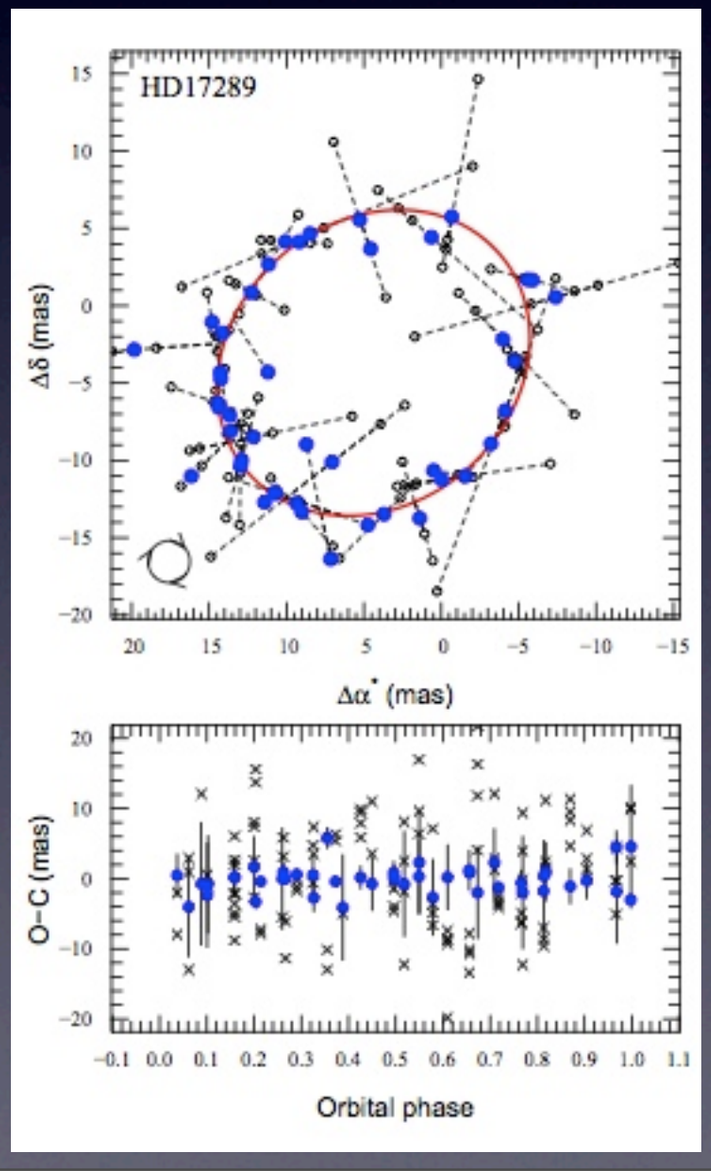


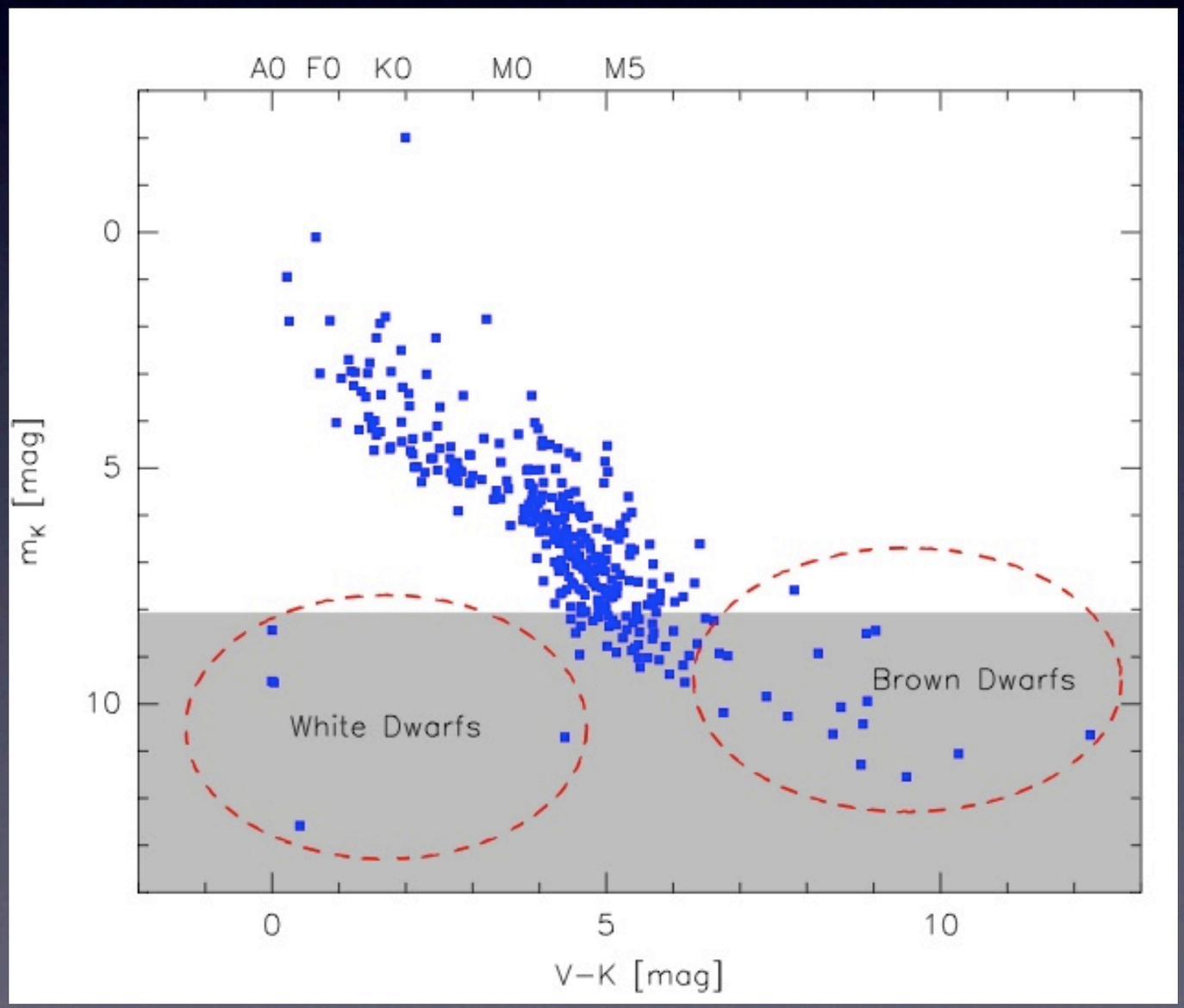


i=173 deg.

m = 547 M_{Jup}

Exoplanet Search program with **PRI**ma

- Nearby Stars (d<15pc)
  - Best detectability (astrometric signature)
  - All type of stars (active,fast rotator)



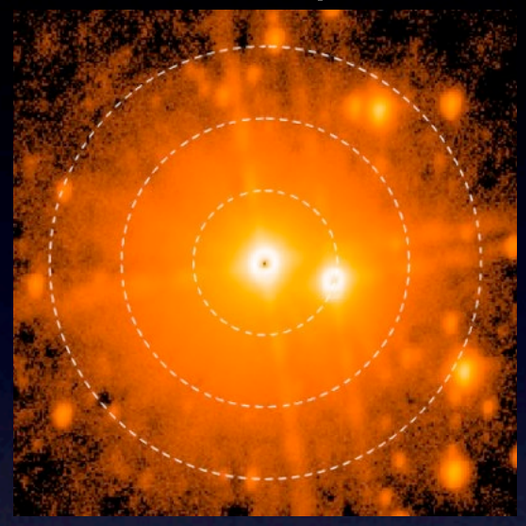
ESPRI : Preparation program

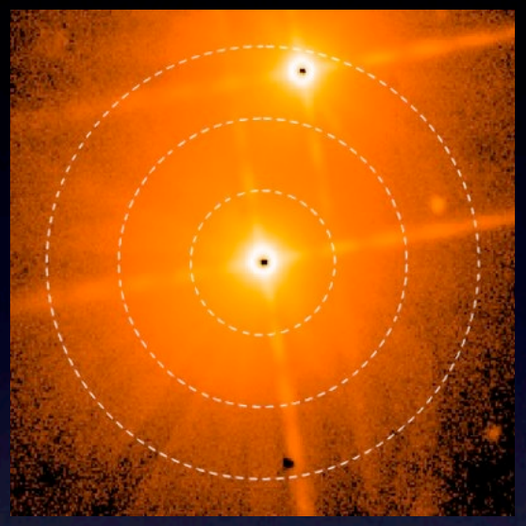
Search for reference stars (ρ=2..30 as, K<13-14)

15 observing runs over 6 years (NTT-SOFI +MPIA time Calar Alto)

1000 stars observed. All data reduced

>100 good targets with references

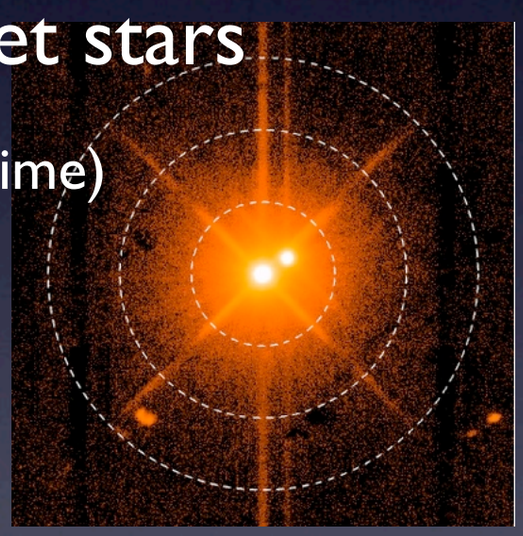


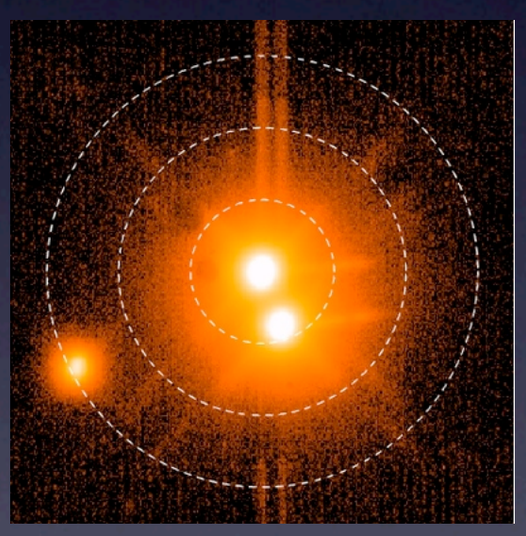


Spectroscopic characterization of target stars

All qualified targets observed with FEROS (MPIA time)

All data reduced, stellar parameter derived





Selecting good science targets

Top 100 target list with (1/3 RV planets, 1/3 Nearby stars, 1/3 Young stars)
Need to refine criteria (isoplanatic angle, limiting mags, crowding, ...)

Let's go back to PRIMA subsystems ...

- ATs
- STS : Star separators
- Delay Lines
- Differential Delay Lines
- 2 Fringe Sensor Units
  - Spatial filtering after recombination. No photometric channels. 5 spec. channels in K. Simultaneous ABCD (no time delay).
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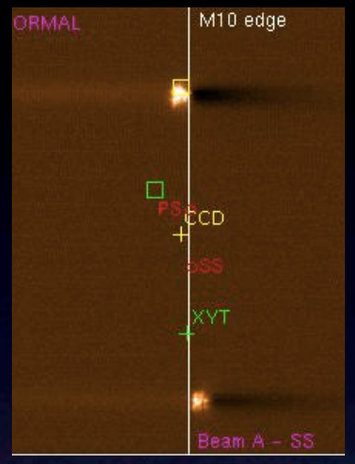
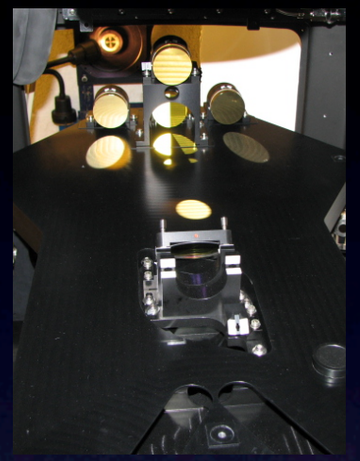
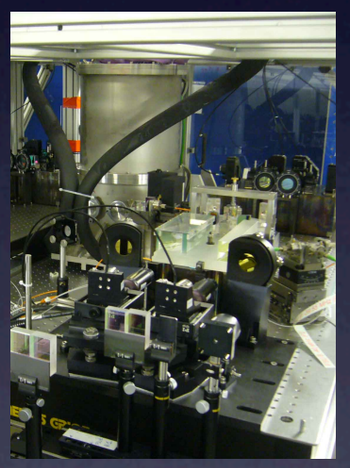
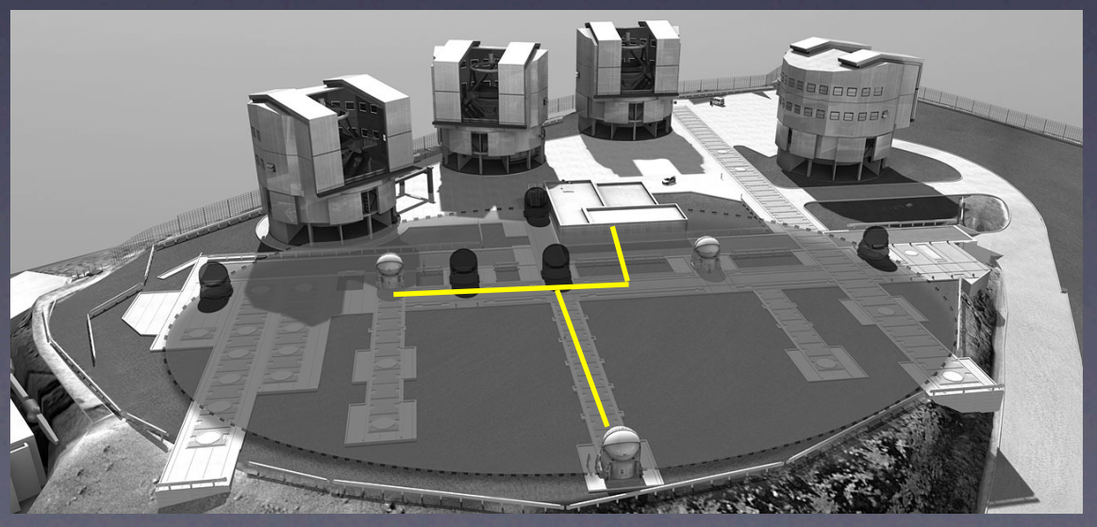








Data Analysis Working Group : DAWG

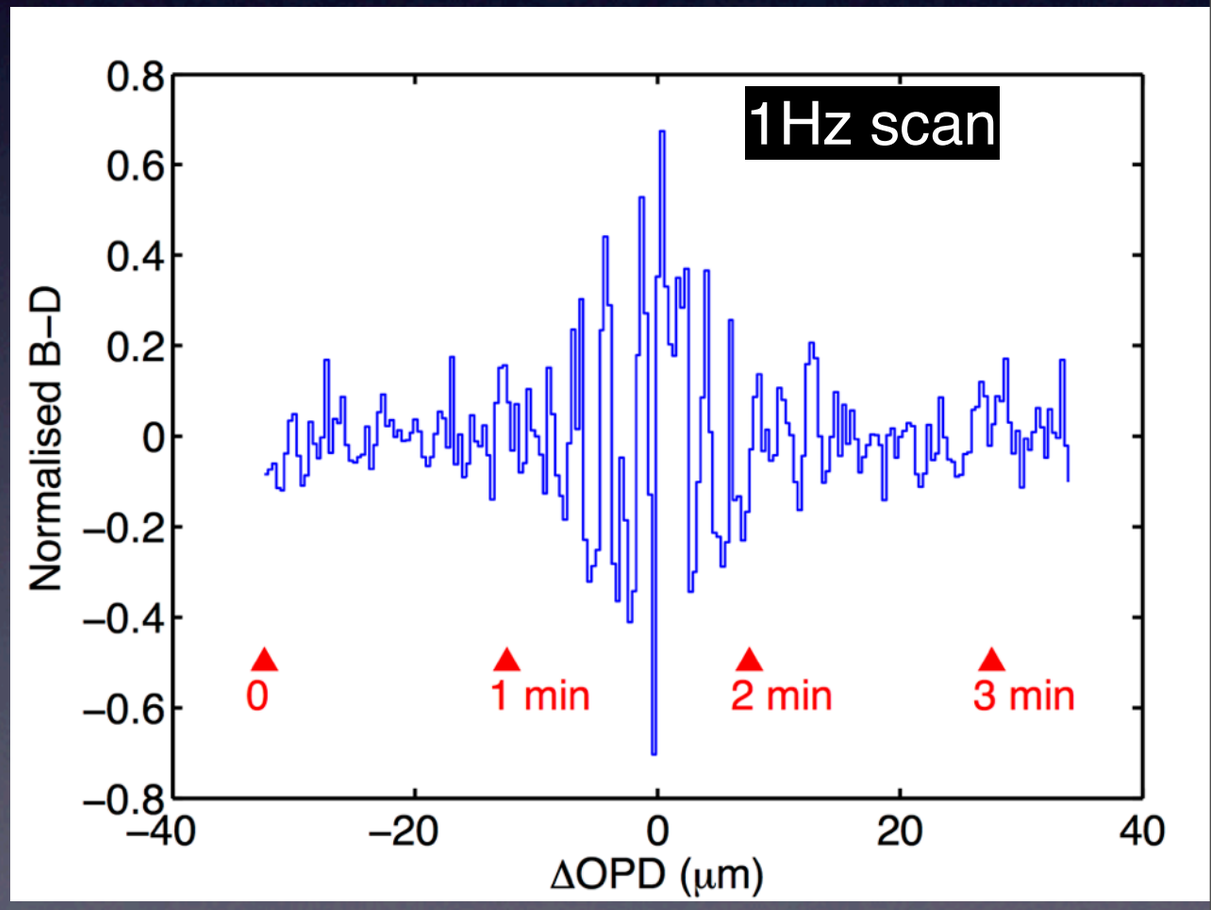
- Coordinator : D. Ségransan
- 20 members of ESPRI; ESO-Garching&Paranal
  - Astronomers, Phd students, Engineers (soft, optics, control)
- Analyze data & Develop new algorithms
- Provide feed-back to
  - Hardware / Control Software / Templates/ Operations
  - COM team
  - Pipeline
  - ESPRI Consortium

First Light : January 2011

- For several targets : FT, FS with both FSU, on both targets. Beam swap with metrology.

- Fringe Scanning while FT on bright targets.

- Fringe Tracking :
  - 1 KHz on HD87640 (K=4.8)
- Fringe Scanning :
  - 1 Hz on SAO221759 (K=7.1, rho=6.6")
- 3 minute coherent integration



Functionalities OK! System is Robust

Data Reduction

ΔOPD is reconstructed by using :

- Fringe Tracking and/or Scanning data
- Real time Primet B-A
- Real time FSU Group delay computation (Sahlmann, 2009)

Data clean-up :

- Fringe Tracking status
- Outliers
- Interpolation
- Averaging

In parallel, DAWG working on new algorithm to :

- Improve real time fringe detection
- Improve ABCD phase shift computation
- Improve Group delay computation

ΔOPD model

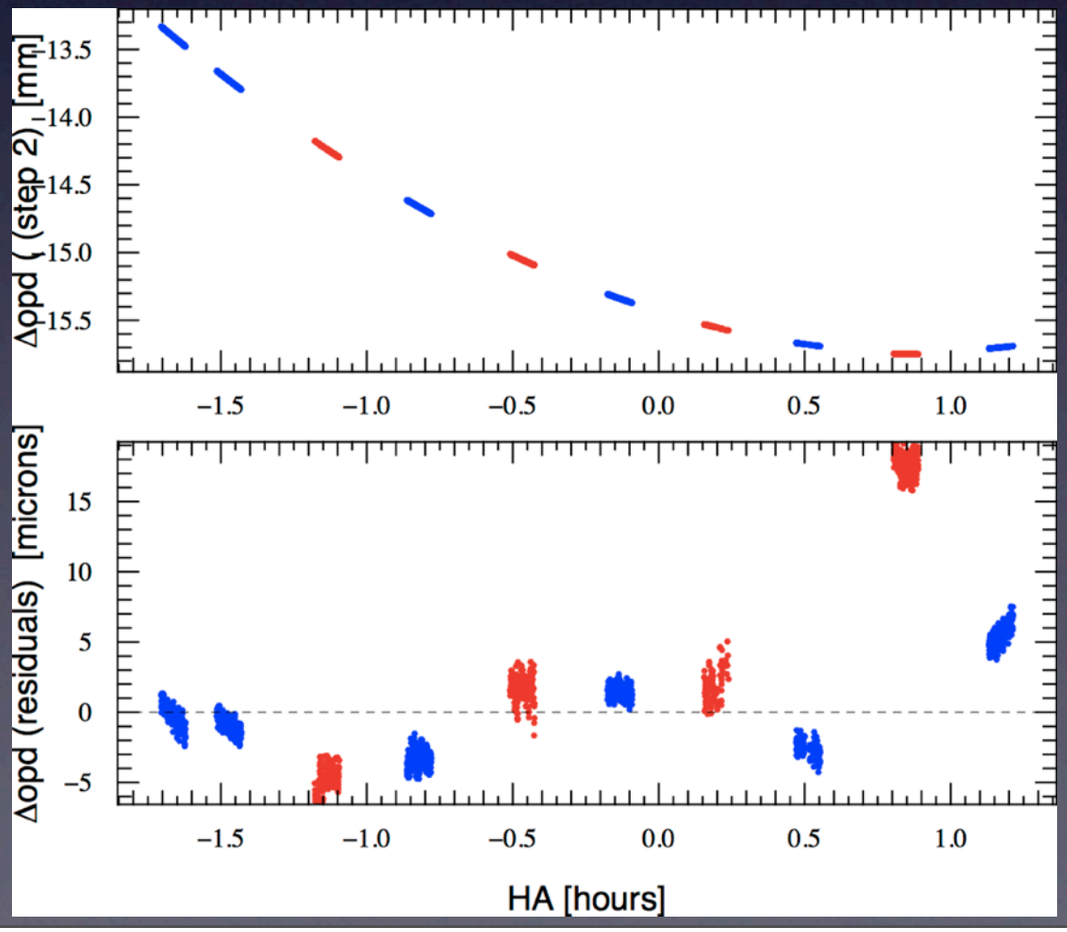
$$\Delta OPD = \sum_{i=1}^{N_{\mathrm{nights}}} Z_i + S\left(A_0 + A_1\cos\left(t_s\right) + A_2\sin\left(t_s\right)\right)$$

$A_{j=1..3}$ is a function of $(\alpha_0, \delta_0, \Delta\alpha, \Delta\delta, \mathbf{B})$

To study ΔOPD stability, a linear fit in Z, A_0, A_1 and A_2 is good enough.

HD66598, K=3.04, ϱ = 36 arcsec
1 night January 2011
Peak-to-Peak [microns] ≈ 25

Super large structure on ΔOPD Residuals !



Tracking down the origin of the ΔOPD residual Structure

In the 6 months that separated the First light from the first ACOM, we investigated :

- Derotators un-recorded motion in the star separators
- Baseline systematic errors
- Anysoplanetism effects...

We designed specific tests for ACOM1, July 2011

At ACOM1 (July 2011):

Poor weather conditions

A bug was found in PRIMET

Short separation targets were observed

At ACOM2 (August 2011):

Good weather conditions

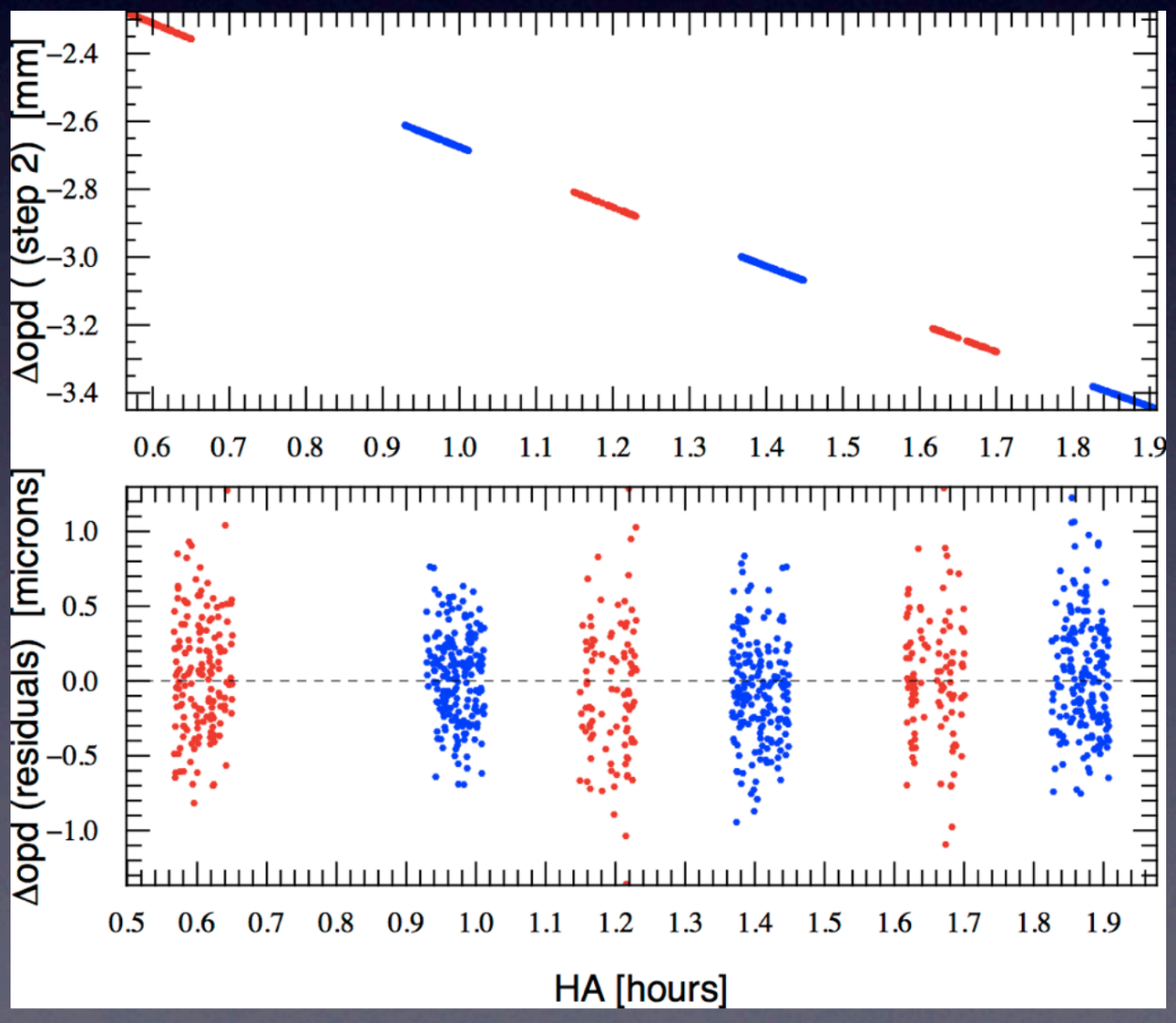
Short separation targets

AND ....

ΔOPD Short time scale stability

HD10360
PS K5V, K=3.56, d=6.8pc
SS K=3.51

ϱ = 11.5 as
1 night august 2011
No obvious Systematics

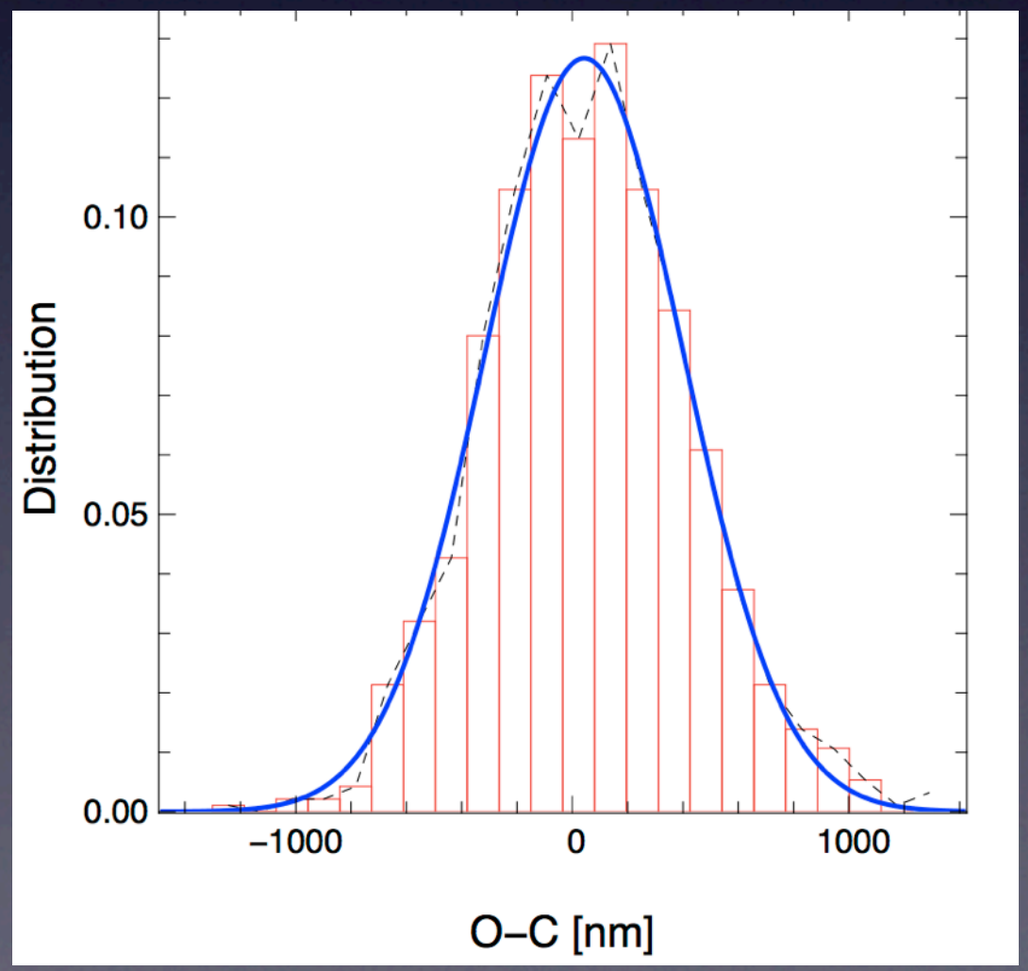


Statistics

Nmeas : 937 ; ΔT : 1.4 hour

Residuals	100%	99%	95%
Peak-to-Peak [microns] :	2.6	2.0	1.4
RMS [nm] :	372	356	320

Expected precision :
Red Noise : 849 [muas]
Gaussian White Noise : 28 [muas]



ΔOPD long time scale stability

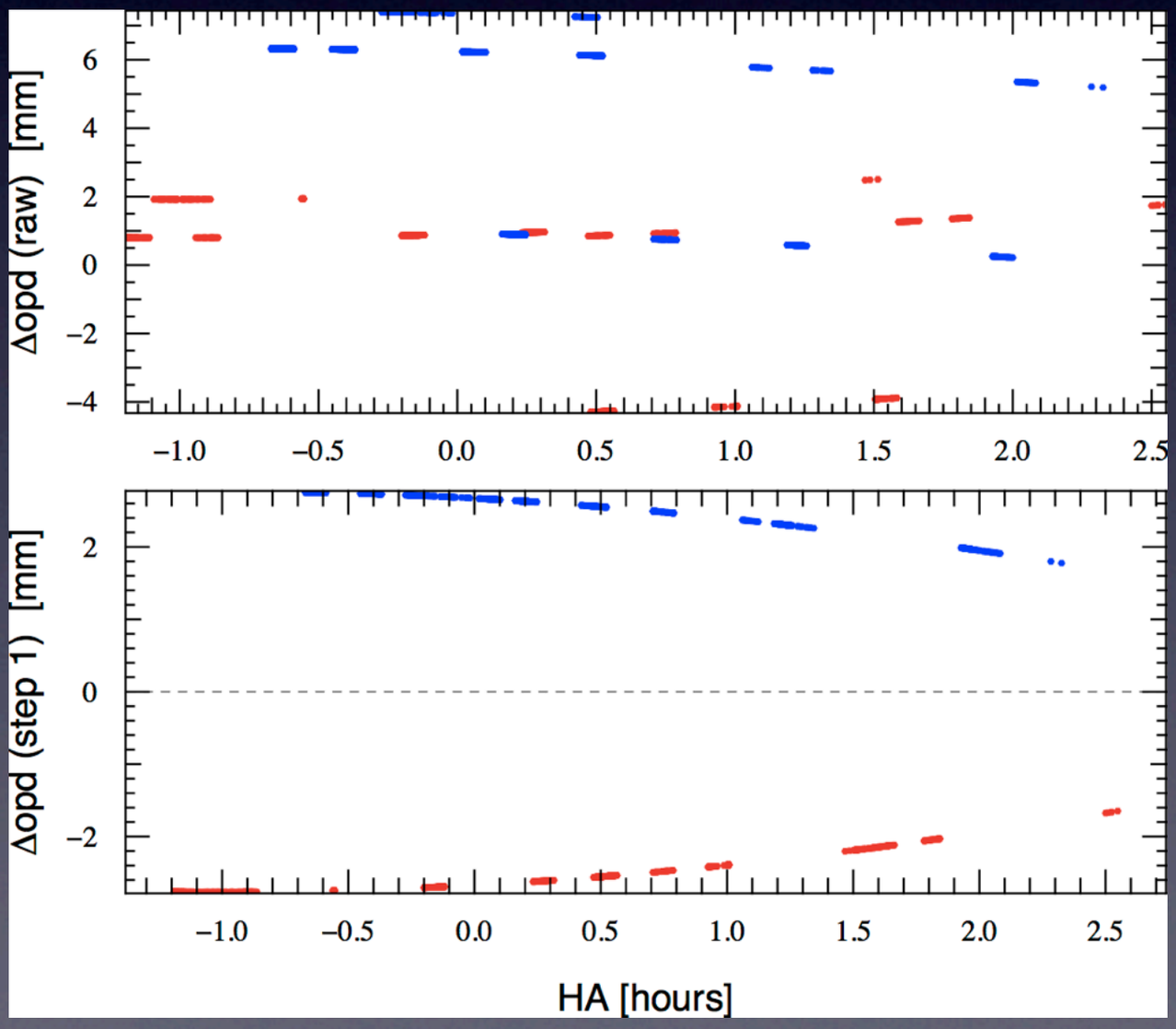
HD202730

PS A5V, K=5.42, d=30pc; SS K=5.42; ϱ = 7.2 as

4 night over 40 days, July/August 2011

No obvious Systematics

$$\Delta OPD = \sum_{i=1}^{4} Z_i + S\left(A_0 + A_1 \cos\left(t_s\right) + A_2 \sin\left(t_s\right)\right)$$



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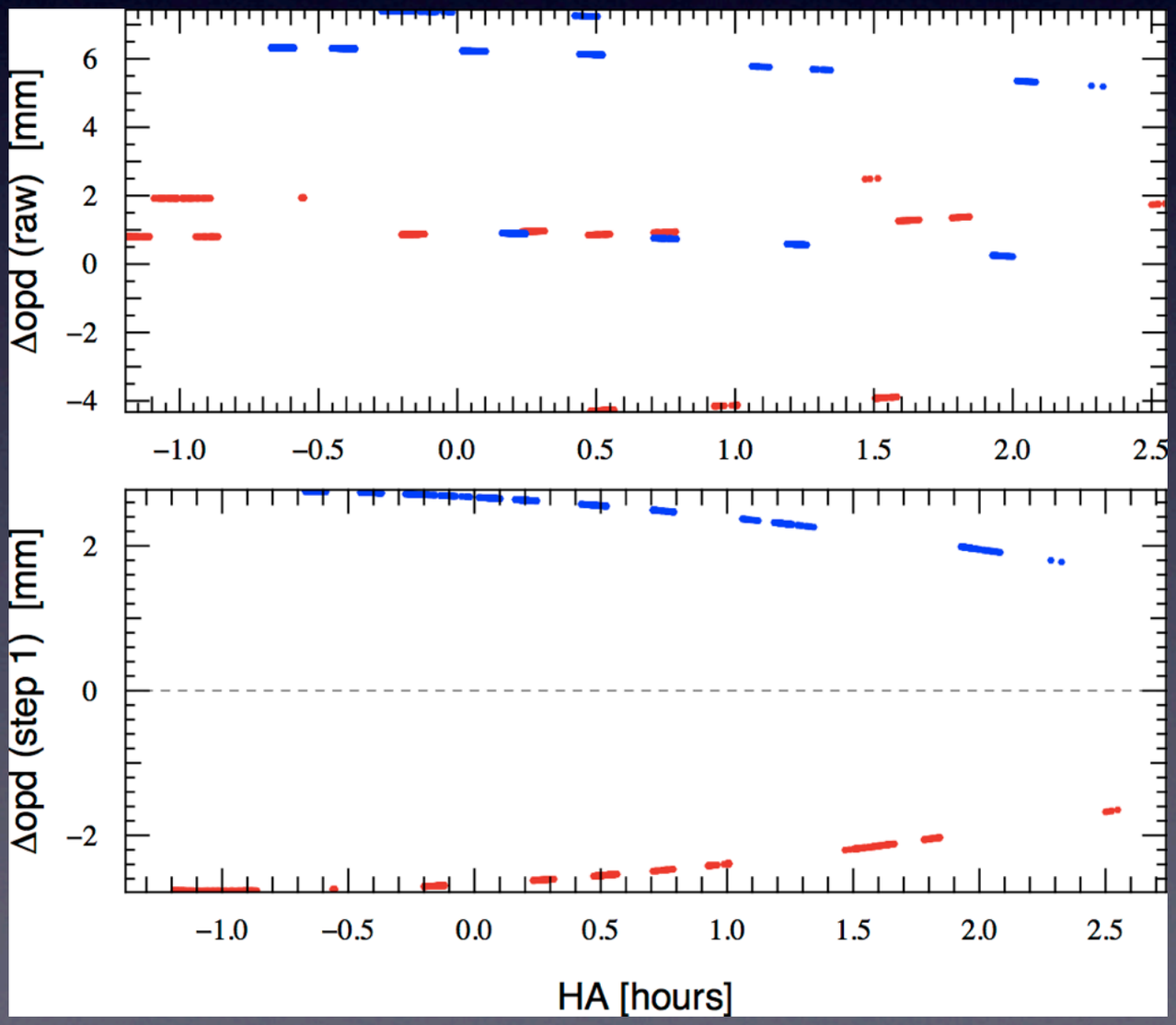
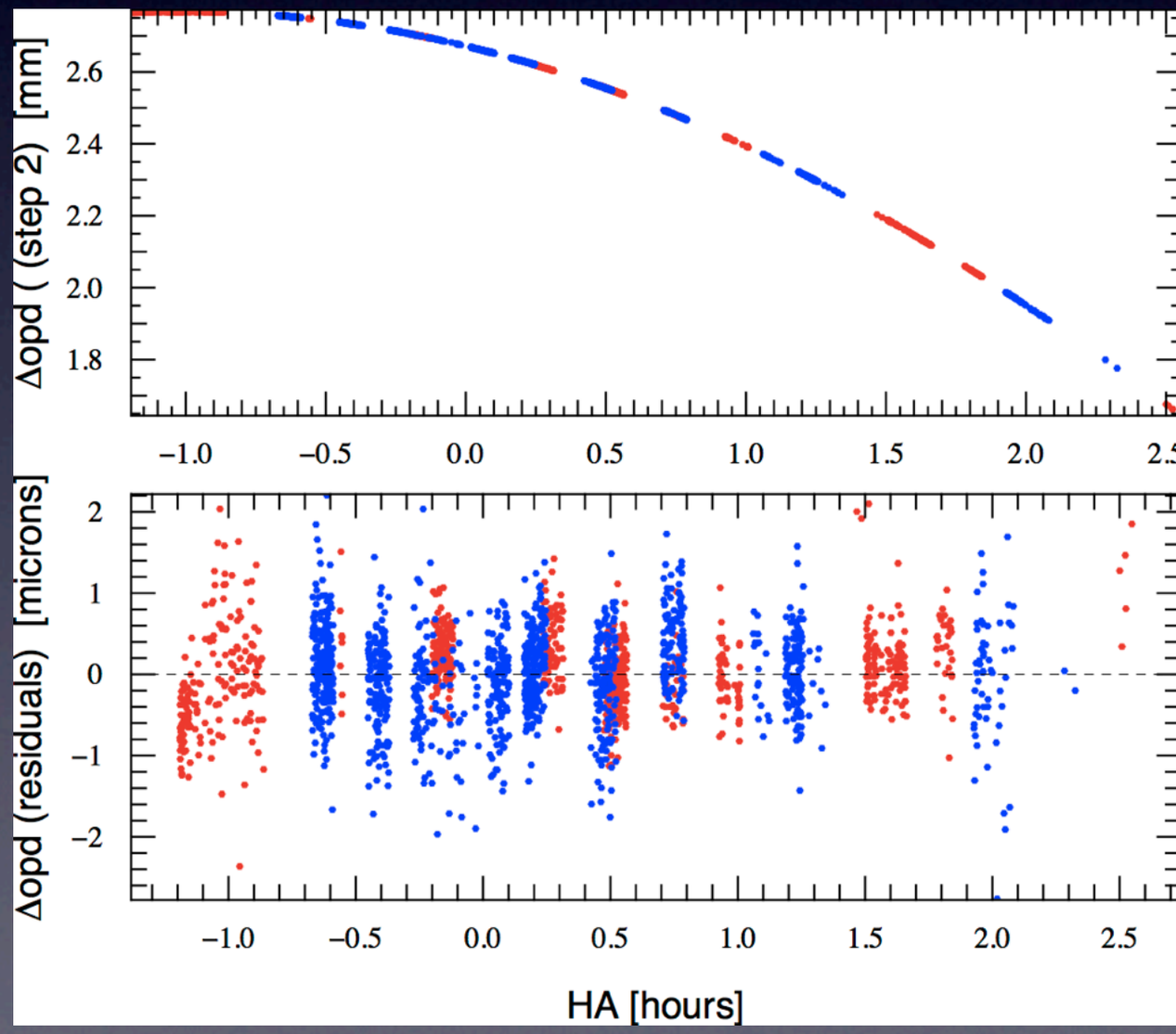




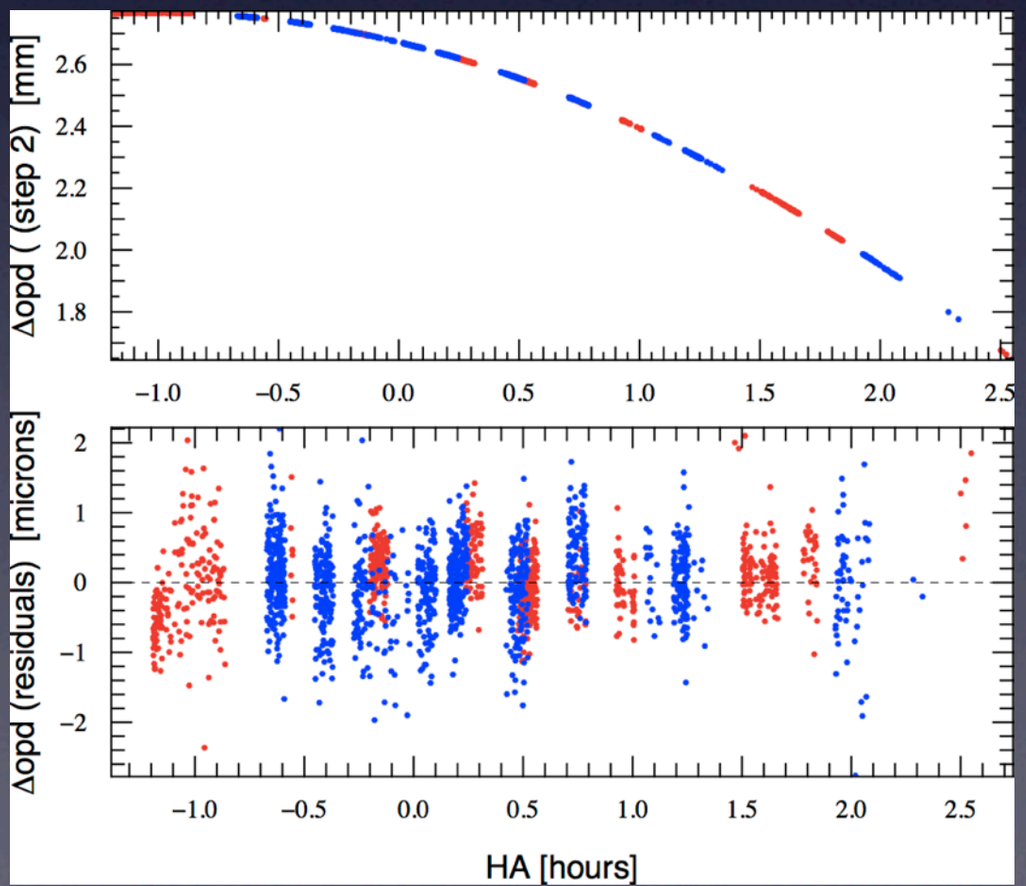
$$\Delta OPD = \sum_{i=1}^{4} Z_i + S\ (A_0 + A_1 \cos(t_s) + A_2 \sin(t_s))$$

Statistics

Nmeas : 2106 ; ΔT : 40 days

Residuals	100%	99%	95%
Peak-to-Peak [microns] :	5.0	3.3	2.2
RMS [nm] :	544	512	447

Expected precision :
Red Noise ≈ 1266 [muas]
Gaussian White Noise : 28 [muas]

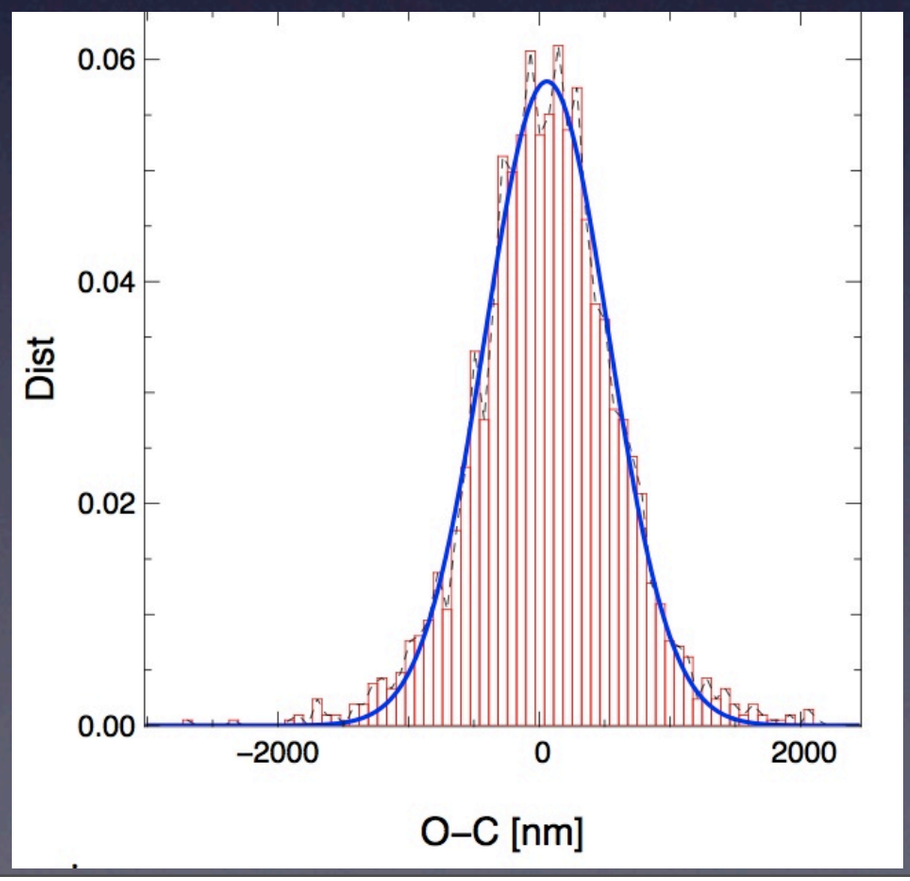


Instrumental Δopd offsets

Z1 = 4.6871**56** [mm] ± 40 [nm]
Z2 = 3.413**258** [mm] ± 37 [nm]
Z3 = 3.567**676** [mm] ± 17 [nm]
Z4 = -1.733**695** [mm] ±16 [nm]

Targets related Δopds

A0(α_0,δ_0,Δα,Δδ,**B**) = -4.**146** [microns] ±114 [nm]
A1(α_0,δ_0,Δα,Δδ,**B**) = 398.**563** [microns] ± 95 [nm]
A2(α_0,δ_0,Δα,Δδ,**B**) =-570.**536** [microns] ± 67 [nm]



HD10268, K=4.61

ϱ = 19 arcsec

1 night agust 2011

Systematics

Residuals	100%	99%	95%
Peak-to-Peak [microns] :	6.2	5.8	4.1

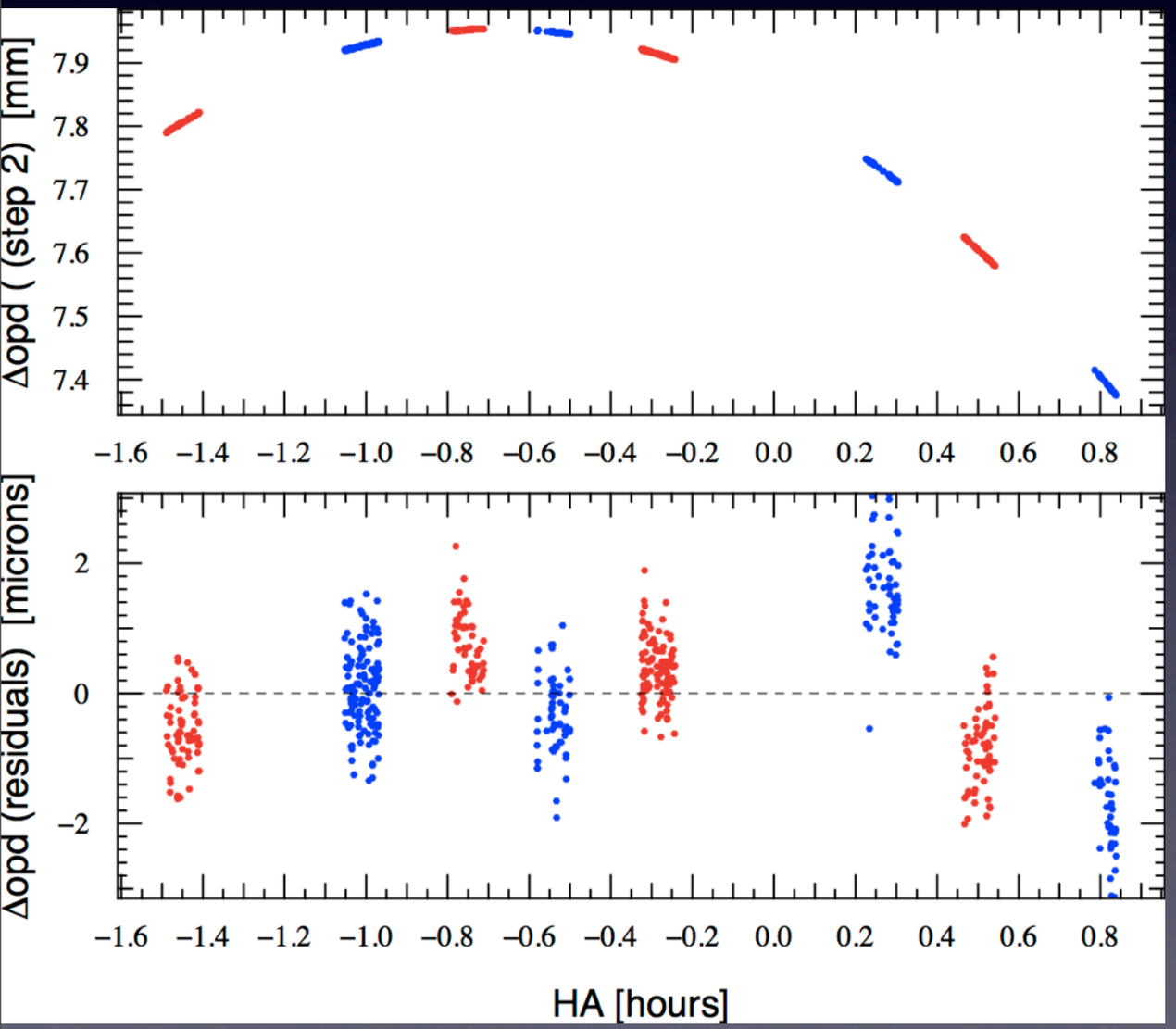
HD66598, K=3.04

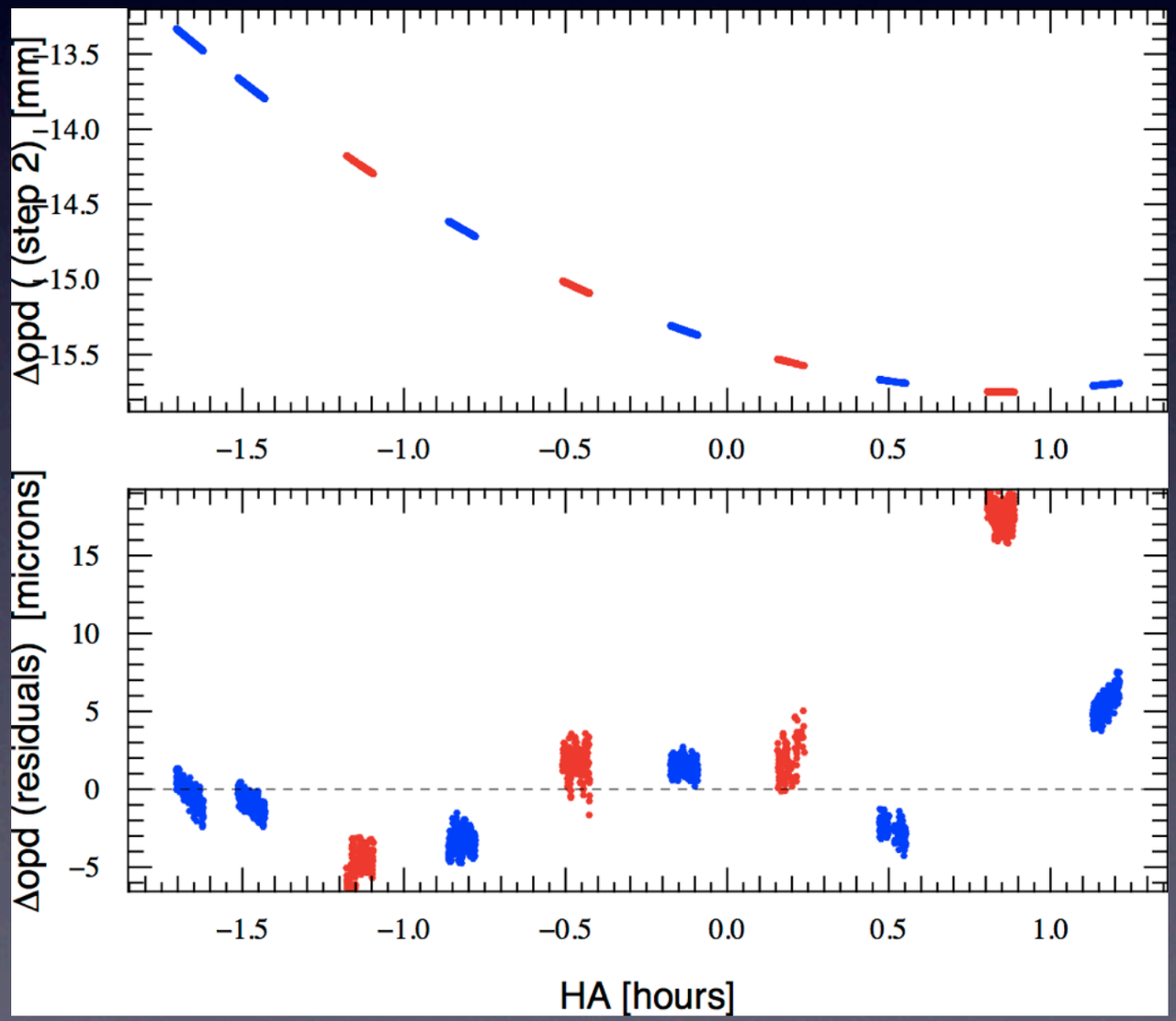
ϱ = 36 arcsec

2 nights January 2011

Huge Systematics

Residuals	100%
Peak-to-Peak [microns] :	26





Doing Astrometry with PRIMA
work in progress...

$$\Delta OPD = \sum_{i=1}^{N_{\mathrm{nights}}} Z_i + S\left(A_0 + A_1\cos\left(t_s\right) + A_2\sin\left(t_s\right)\right)$$

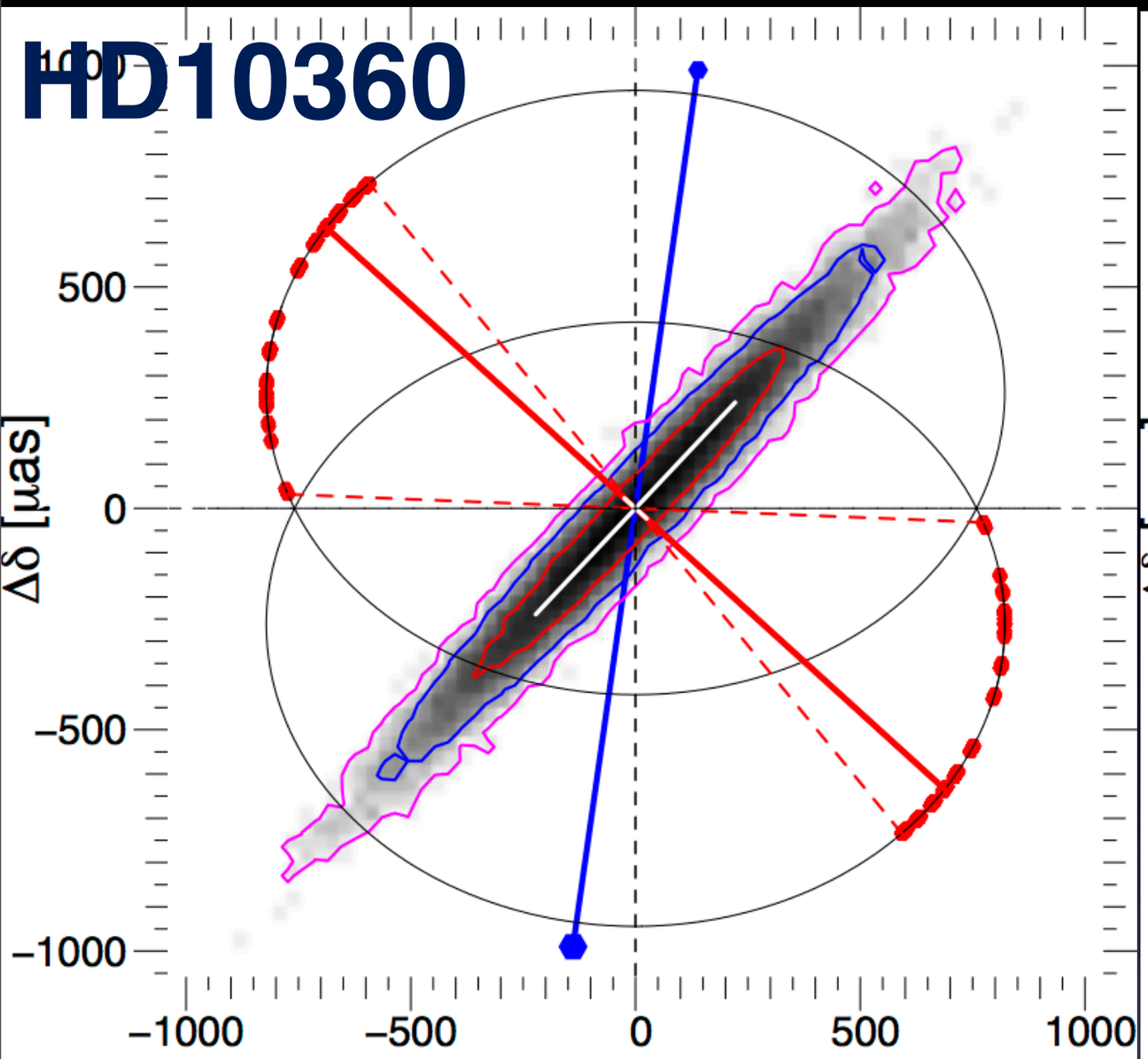
$A_{j=1..3}$ is a function of $(\alpha_0, \delta_0, \Delta\alpha, \Delta\delta, \mathbf{B})$

Model no longer linear, parameters are less correlated

Assumptions :

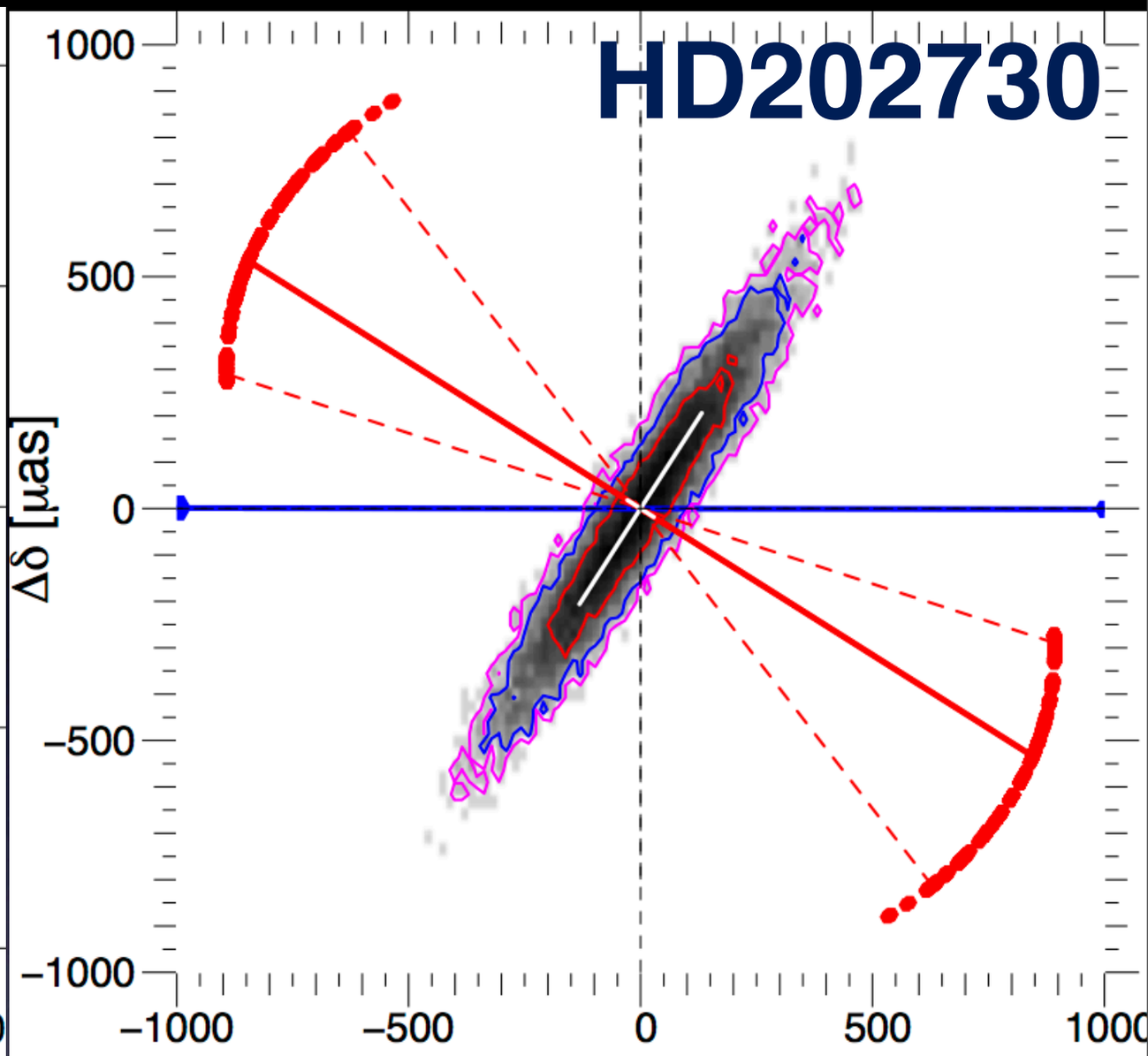
Baseline is known with the required accuracy

Relative position is not changing over the time of the observations



$\Delta\alpha^*$: −1.590050 +− 0.000223 [arcsec] ie. 223 [μas]
$\Delta\delta$: −11.325557 +− 0.000240 [arcsec] ie. 240 [μas]
ρ : 11.436630 +− 0.000254 [arcsec] ie. 254 [μas]
PA −172.0082 +− 0.0011 [deg]

Principal Component Analysis (PAC) :
Std(C1) : 326 [μas]
Std(C2) : 34 [μas]



$\Delta\alpha^*$: −7.209613 +− 0.000135 [arcsec] ie. 135 [μas]
$\Delta\delta$: 0.010994 +− 0.000207 [arcsec] ie. 207 [μas]
ρ : 7.209621 +− 0.000135 [arcsec] ie. 135 [μas]
PA −89.9126 +− 0.0008 [deg]

Principal Component Analysis (PAC) :
Std(C1) : 245 [μas]
Std(C2) : 34 [μas]

Conclusions (1st)

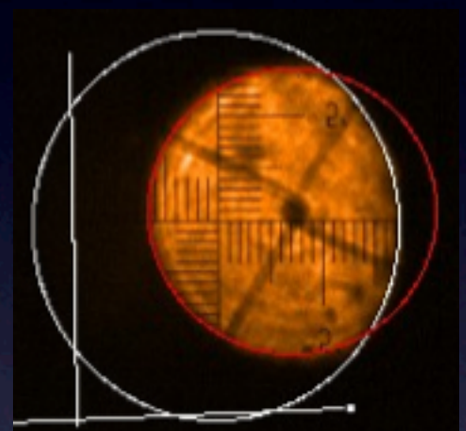
- DAWG is important to understand and improve such a complex system as PRIMA
- Astrometry 1st light Jan 2011. Functionalities ok.
- Astrometry Commissionings (July & August 2011)
- ΔOPD Stability is very encouraging (550-750nm over 40 days)
- Data analysis still in progress but astrometry below 100 muas is within reach and one could seriously consider 50 muas in the near future.
- Real time data reduction is validated (primetB-A, group delay).

Conclusions (2nd)

However, ...

Efforts remains to be done

- **Sensitivity issues (ATs differential focus)**
- **Pupil vignetting in the beam train!!**
- Stability with large separations
- Long term stability
- Data reduction Algorithm (phase shifts, group delay)
- Performances with targets of different magnitudes
- Operation of PRIMA with faint targets (FT, FS, intermediate)



Which is the goal of the forthcoming ACOM's

Thanks to :

OAU-Geneva

J. Sahlmann
B. Chazelas
F. Pepe
D. Queloz

MPIA-Heidelberg

R. Launhardt
T. Henning
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J. Setiawan
P. Weise
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LSW-Heildeberg

A. Kaminski
R. Koehler
A. Quirrenbach
I. Stilz
S. Reffert

ESO-Garching

F. Delplancke
R. Abuter
C. Hummel
S. Lévêque
S. Menardi
R. Palsa
I. Percheron
C. Schmid
et al.

ESO-Paranal

A. Mérand
S. Brilland
P. Haguenauer
N. Schuhler
et al.