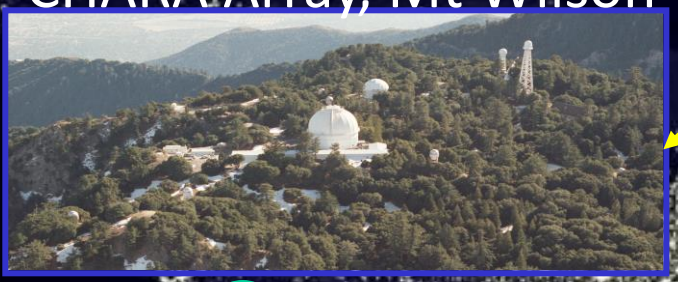
VEGA/CHARA High spatial and spectral resolution (0.3mas et R=6000/30000)

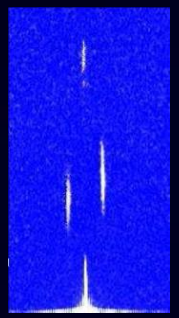
Remote, Nice

CHARA Array, Mt Wilson



09-2007: Integration
07-2008: First light
10-2009: 3T Mode
10-2010: 4T Mode

Since 2011 :
3T VEGA + IR in // (CLIMB, MIRC)
~20 programs, 60 nights per year

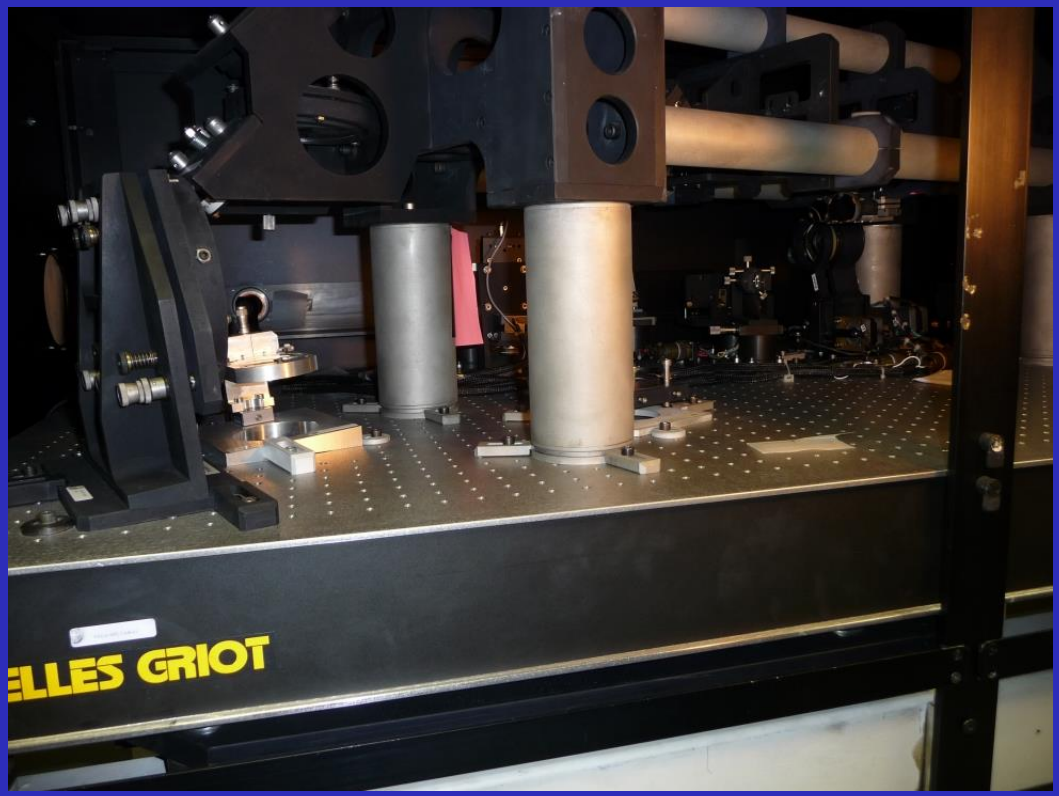


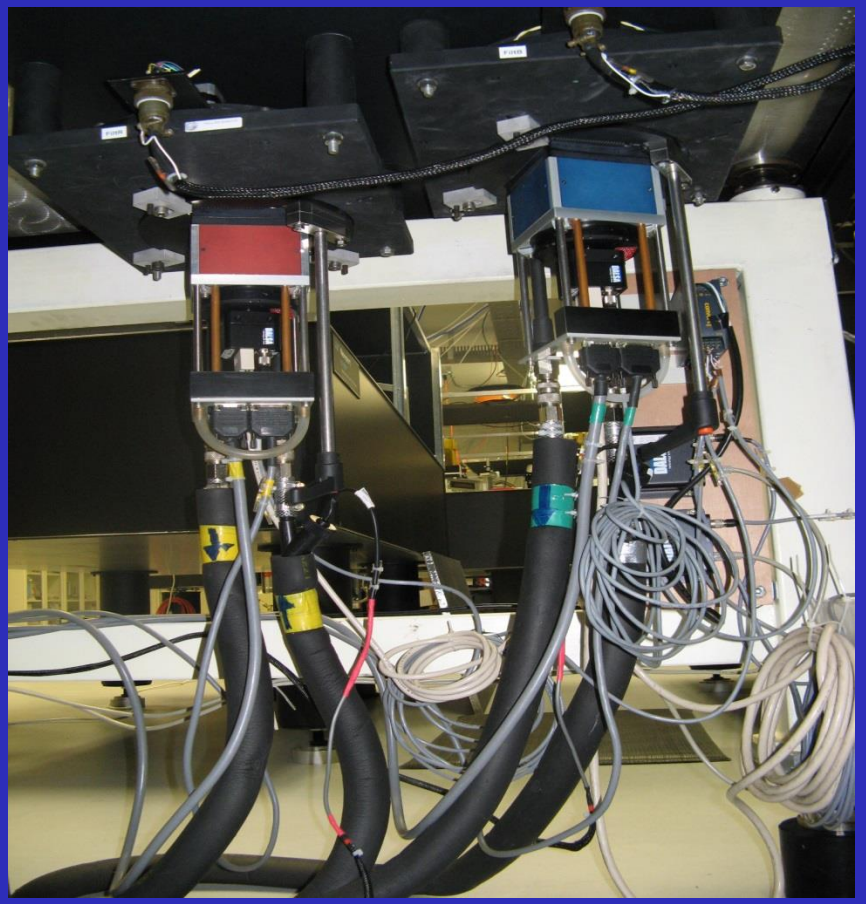
Mode 3T

Mode 4T

VEGA in images

VEGA in images





Main characteristics of VEGA/CHARA

Mourard et al. A&A 2009, 508 (for 2T) & Mourard et al. 2011, 531 (for 3T/4T)

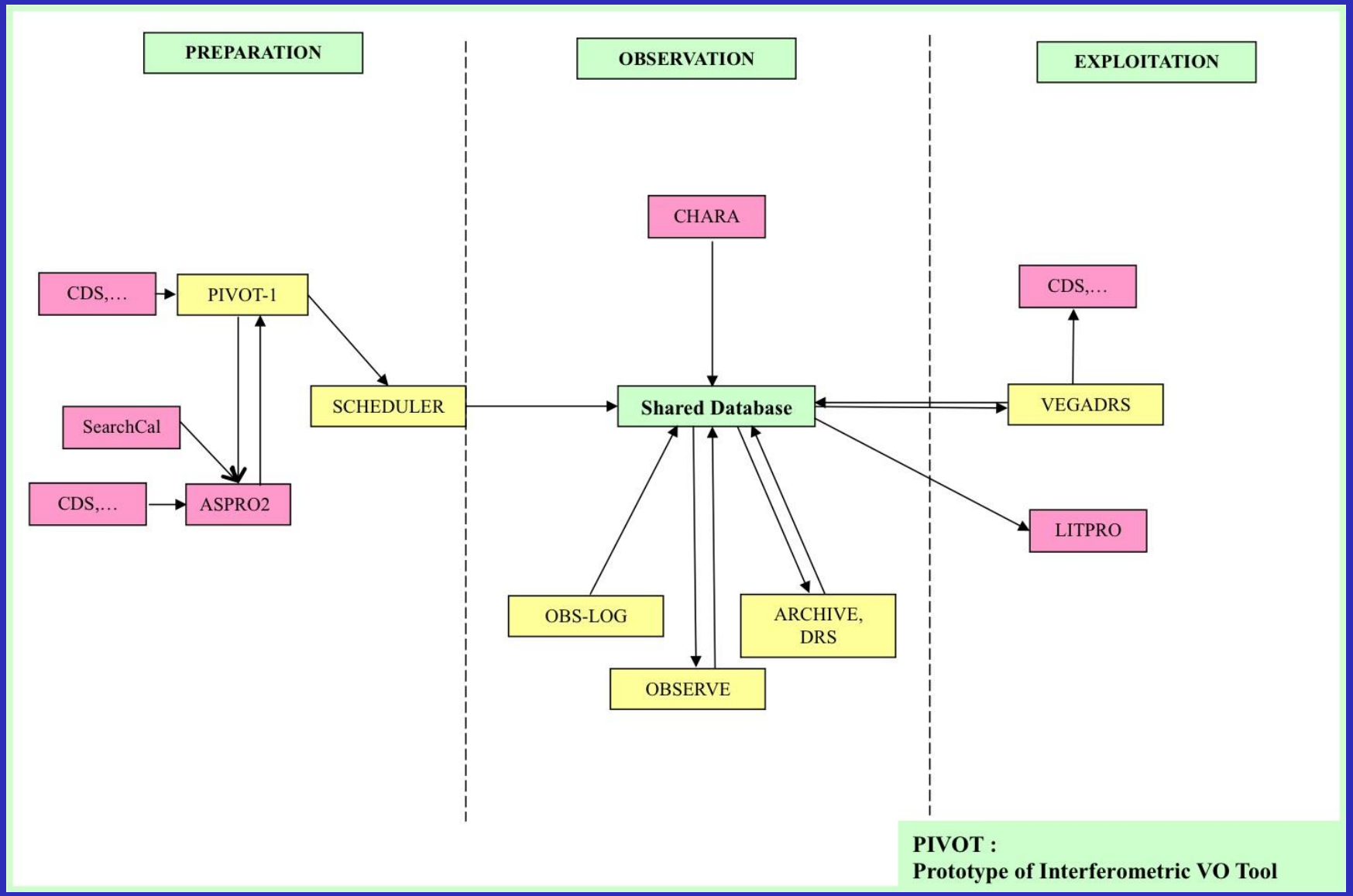
Spectrograph Characteristics

Grating	R	$\Delta\lambda$ (Blue)	$\Delta\lambda$ (Red)	$\lambda_R - \lambda_B$
R1: 1800 gr/mm	30 000	5 nm	8 nm	25 nm
R2: 300 gr/mm	5000	30 nm	45 nm	170 nm
R3: 100 gr/mm	1700	100 nm	150 nm	not possible

Limiting magnitude **R0=8cm** **R0=15cm**

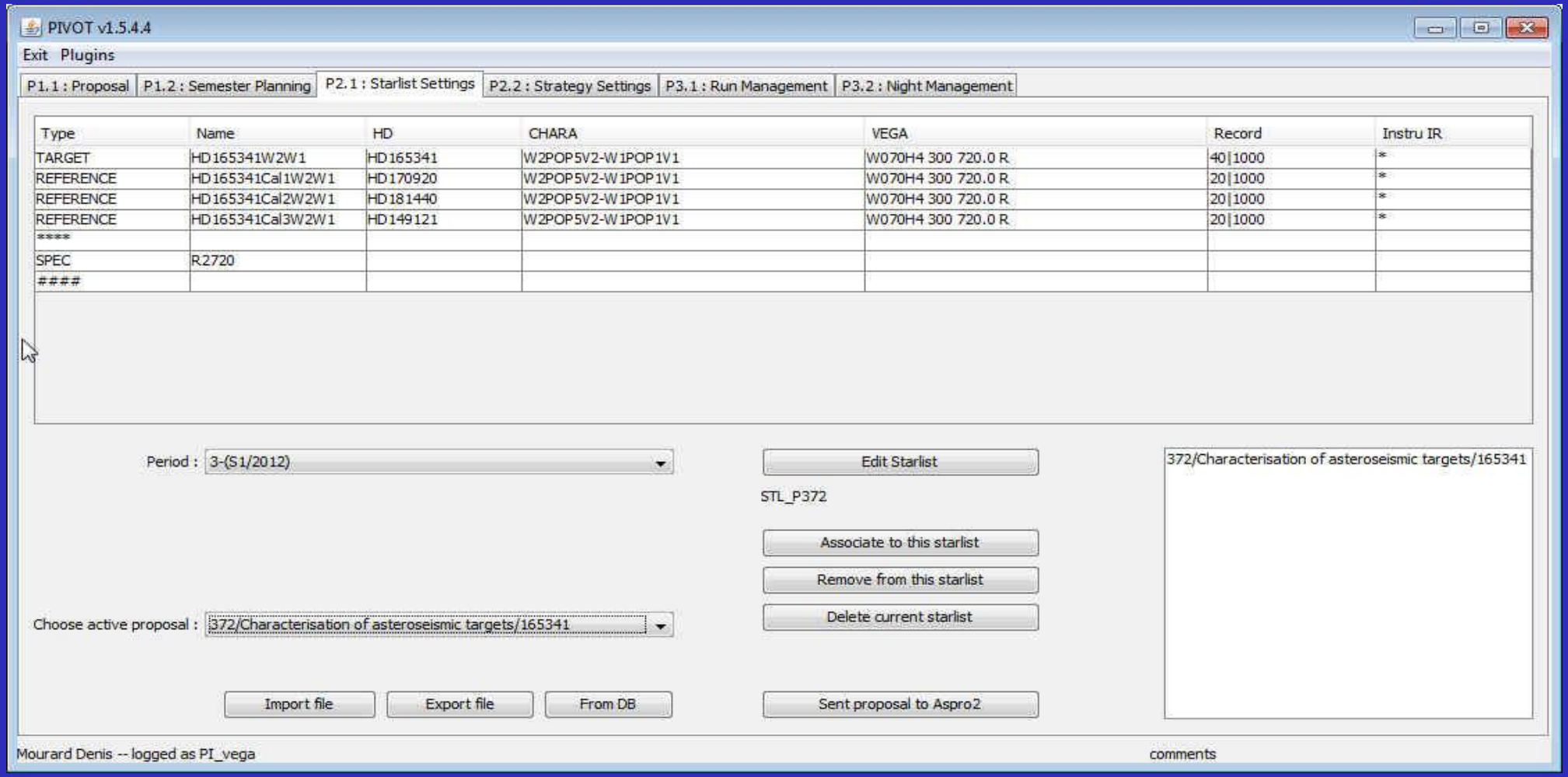
Resolution	R	Typical lim. magnitude	Best perf.
Low	1700	6.8	7.5
Medium	6000	6.5	**8.0**
High	30 000	4.2	5.5

Interferometric toolbox

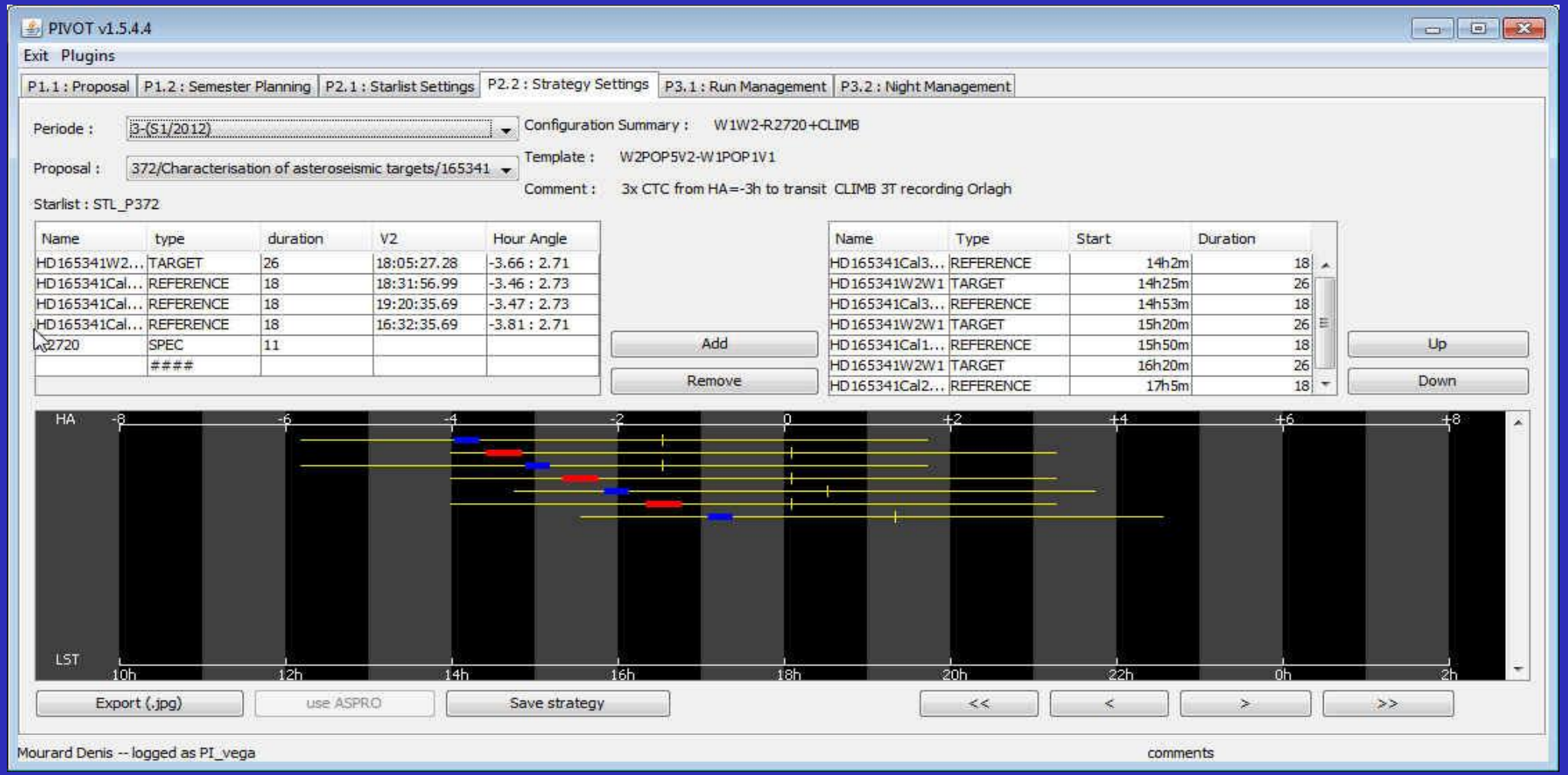


PIVOT: proposals and runs management

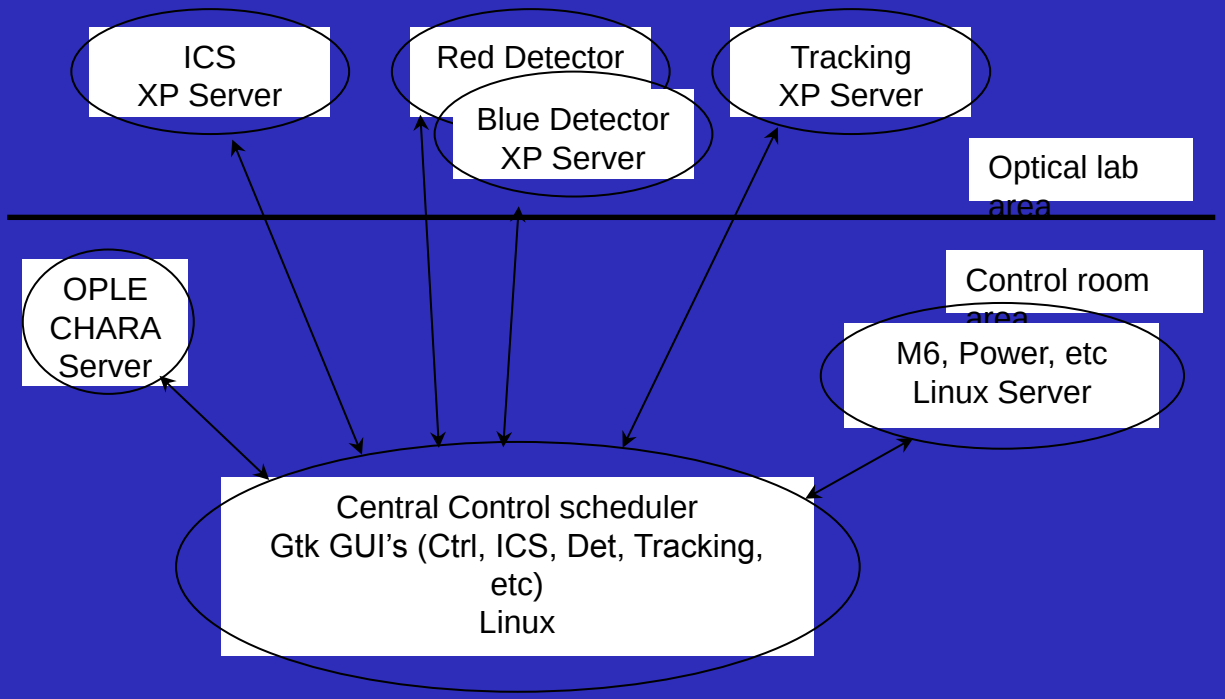
web service, interoperability

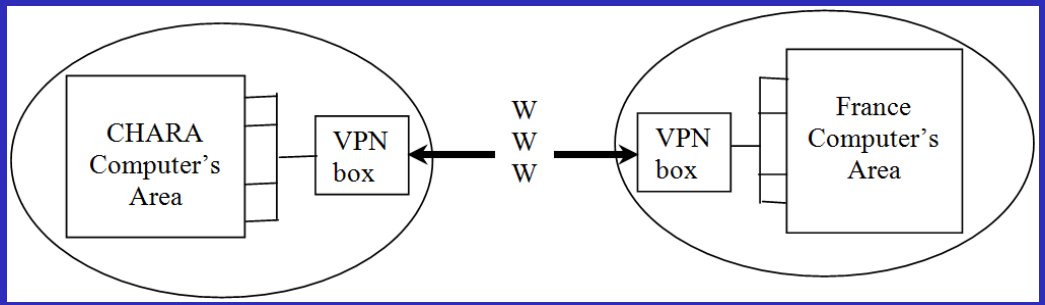


PIVOT: defining observing's strategy

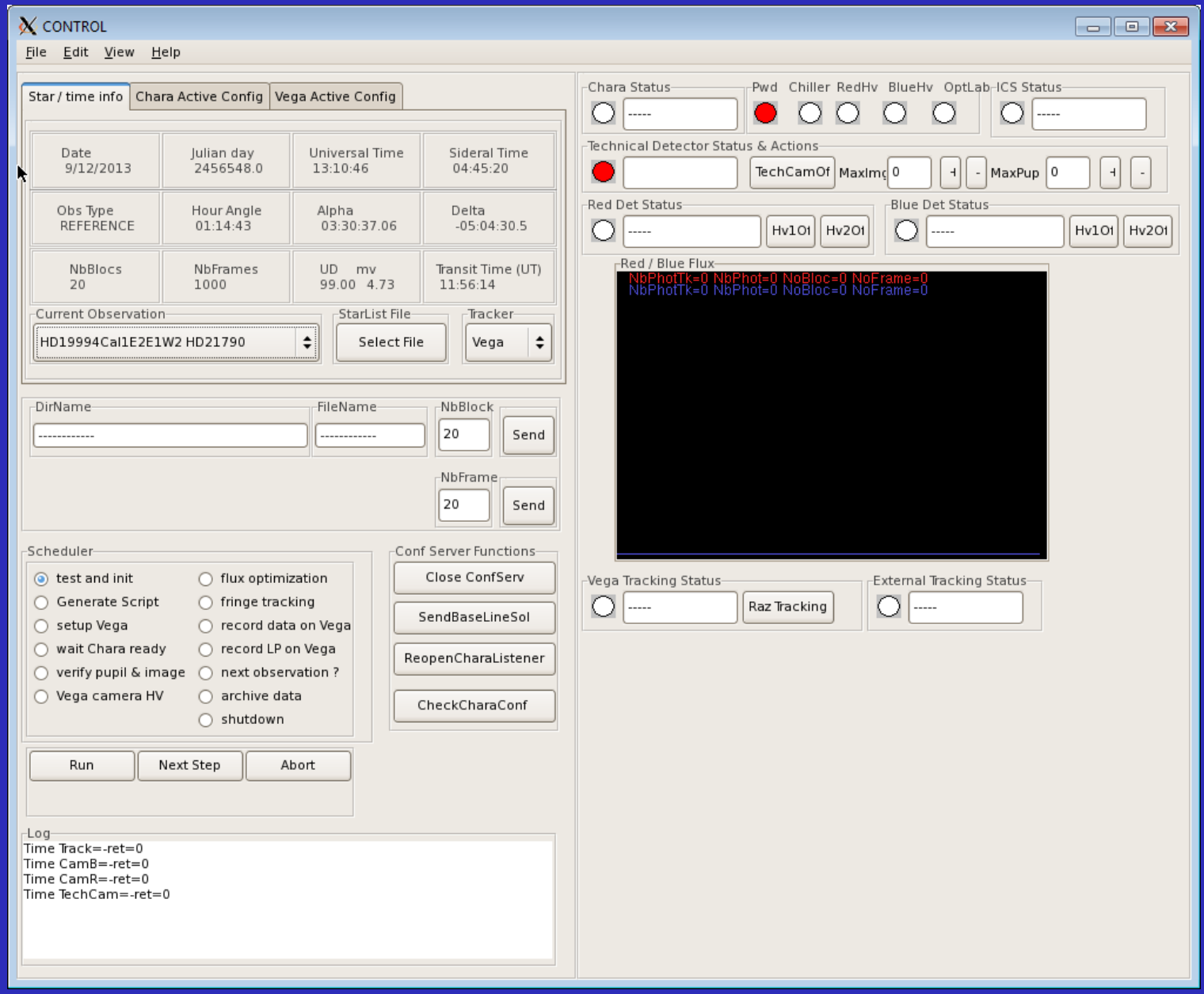


VEGA Control system

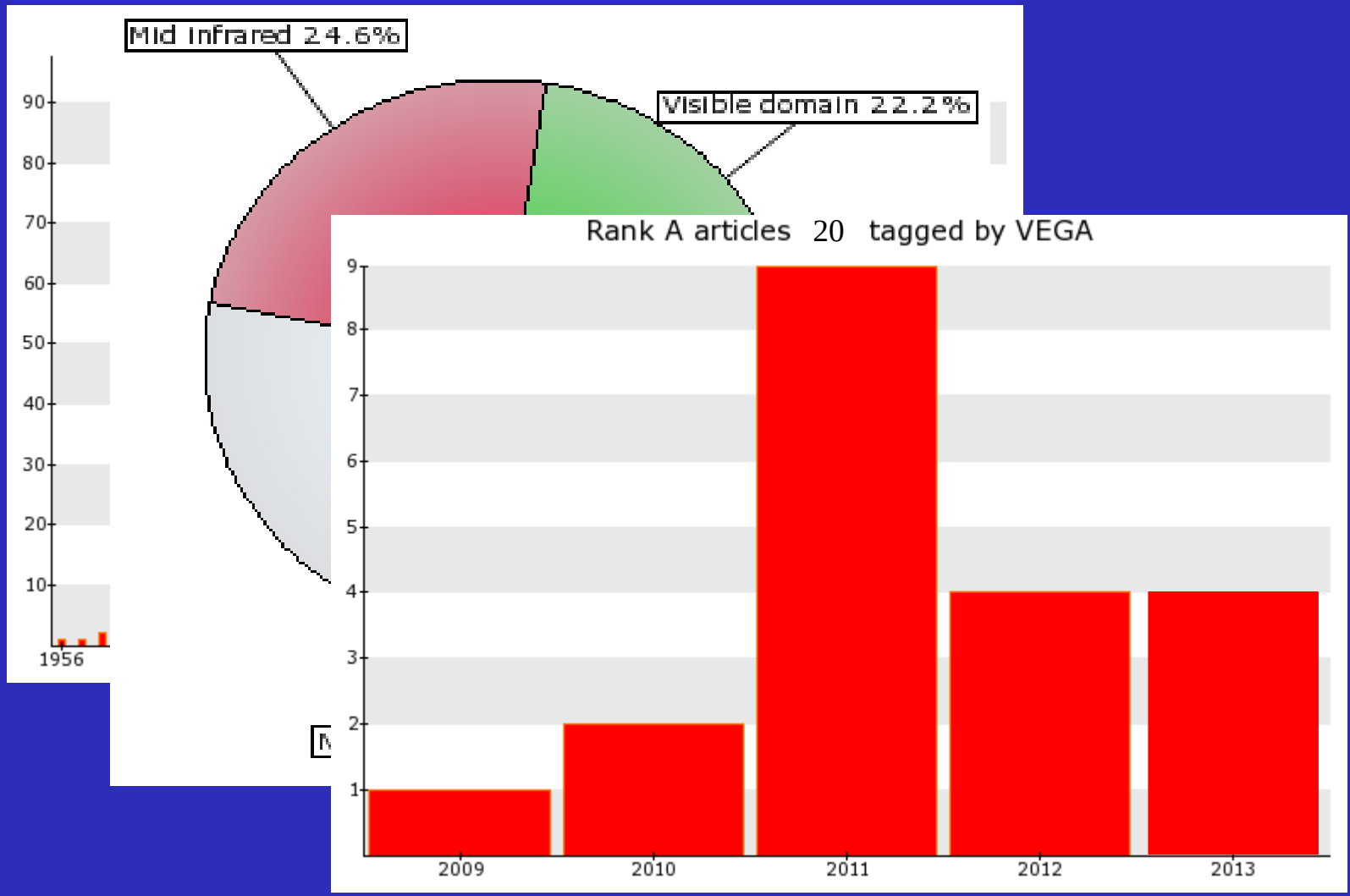




VEGA Control System



Some statistics



Main VEGA/CHARA programs

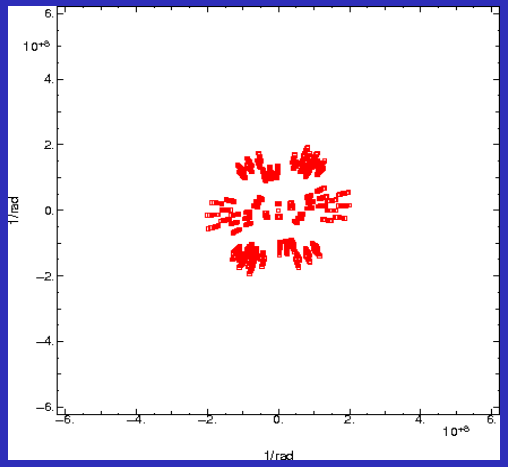
http://www-n.oca.eu/vega/en/publications/index.htm

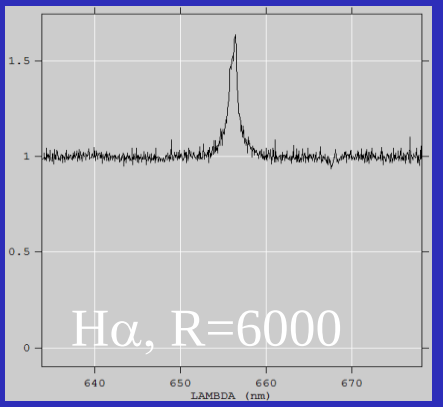
- **Circumstellar environments: high spectral resolution**
  - A/B Supergiants (wind): Chesneau et al, A&A 521 (2010)
  - β Cep (disk): Nardetto et al. , A&A 525 (2011)
  - Be stars
    - Wind studies: Delaa et al. A&A 529 (2011), Stee et al. A&A (2012)
    - Interactive massive stars: Bonneau et al., A&A 432 (2011), Meilland et al. A&A 532 (2011)
  - The chromosphere of K giants: Berio et al. A&A (2011)
  - Eps Aur : Mourard et al., A&A 2012
  - Young Stellar objects (MWC361, AB Aur, ...): Perraut et al., Benisty et al.,
  - Rotation of stars and interaction with environment
- **Fundamental parameters: Visible + 300m baseline + IR coherencing**
  - roAp stars: Perraut et al., A&A 526 (2011)
  - CoRoT Targets: HD49933: Bigot et al., A&A (2011)
  - Exoplanet host stars: Ligi et al., A&A (2012)
  - Surface brightness relationships
- **Spectral imaging**

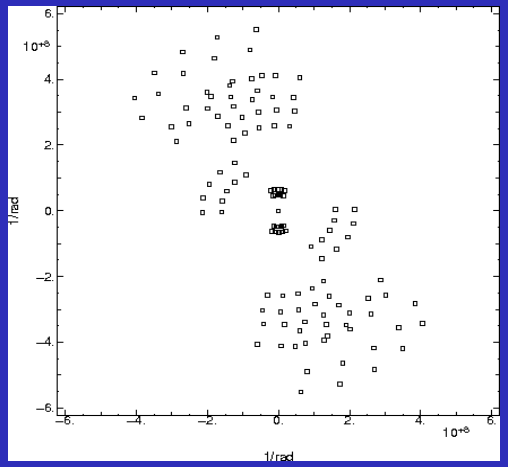
Spectral imaging VEGA+MIRC

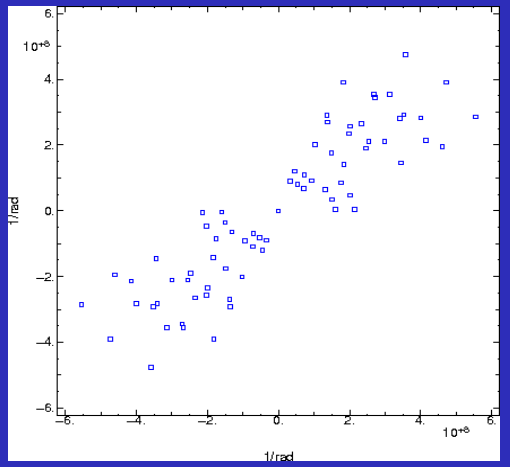
2012 October 18th and 19th on CHARA ϕ Persei (Be + subdwarf-HST)

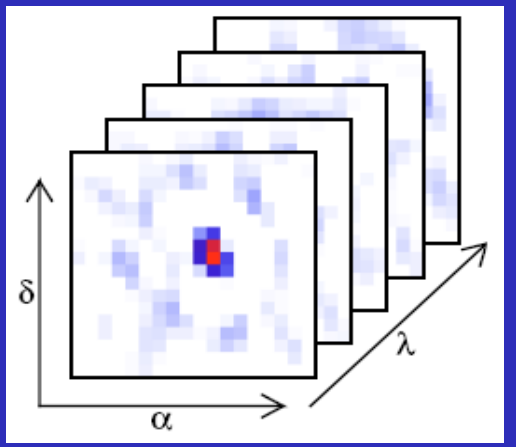
MIRC 6T @ 1.6μm, VEGA 4T @ 656-487nm











Summary of *'known'* facts on phi Per (1) Be star for sure!

- Slettebak 1966, Abt 2002
  - Vsini= 450 – 410km/s, 85% of the equatorial breakup velocity
  - The highest projected velocity among B stars
- Distance
  - Hipparcos 2007: π=4.54±0.2mas, ie d=220pc±10pc
  - Megier 2009 (indicator CaII), d=195±32pc
- Compagnon
  - Gies 1998 HST: subdwarf Teff=53000K, logg=4.2, flux ratio 0.165/0.154 @ 137.4/164.7nm
- Polarization
  - Clarke 1998: polar&binary but no detection of variatins
  - Ghosh 1999: Spectral dependence on polarisation
    - P_B 1.57% P_V=1.36% P_R=1.19% P_I=0.98%
    - PA=27°±2°
    - ➔ electron-scattering disks with attenuative hydrogen opacitiess, combined with dilution due to the visible central star

Summary of *'known'* facts on phi Per (2)
Spectroscopic and photometric studies

- Bozic-Harmanec 1995:
  - Linear ephemeris and true orbital elements + masses
  - Period for the spectroscopic binary: 127d
  - B0.5e for the primary, sdO6 for the secondary
  - Secular variations in the RV curves + orbital light variations
- Stefl 2000:
  - Study of the He lines: outer regions of the circumstellar (primary) disk and excited by the O-type secondary
  - Emission line assymetry due to the global density pattern in the inner regions
- Hummel 2001:
  - Axisymetric disk R=10Rp. Keplerian rotation in question
  - Complex structure of emission lines due to external illumination

Summary of *'known'* facts on phi Per (3)
Previous interferometric studies

- Quirrenbach MarkIII 1997
  - Equator-on. Disk MajorAxis=2.67mas, r=0.46, PA disk 62+-5°
  - Bande large sur Halpha
- Tycner NPOI 2006
  - Gaussian model: 2.89mas, r=0.27, phi=-61.5°
  - Inclination >75°, half-opening angle <8°
  - Bande large sur Halpha
- Gies, CHARA K' 2007
  - 2.30mas, r=0+-0.2, phi=-44

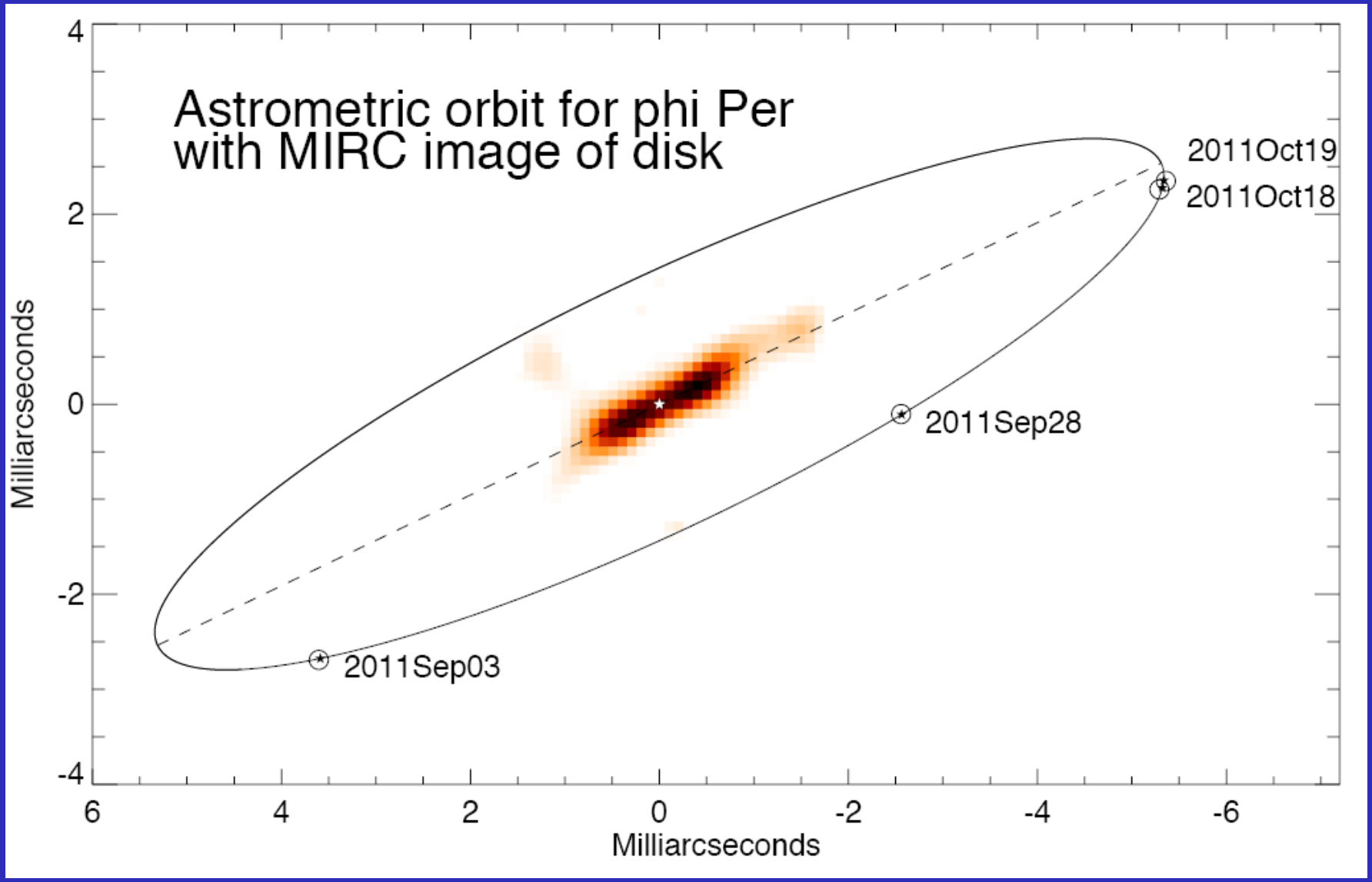
Starting points

- Be star, very elongated disk, see equator-on
- Vsini=450km/s
- Spectroscopic binary with 127d period
- Companion UV ➔ 5% of flux in V, 8% in H band

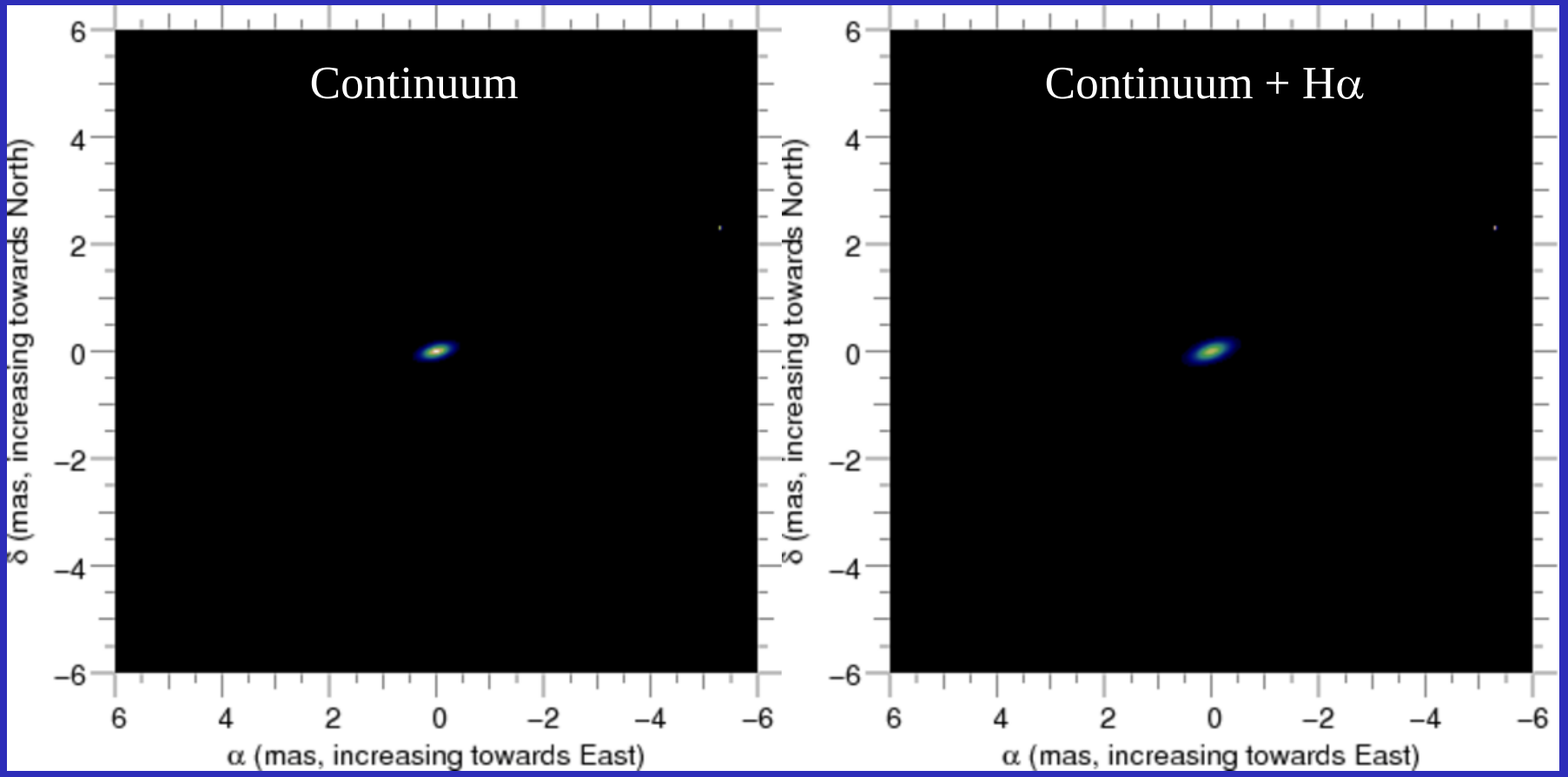
- Maximum uv coverage
- H band and V band continuum observation
- Halpha spectrally resolved interferometry
- 2 dates for companion identification

- Goals
  - Detection and Spectral type of the companion (never seen in optical)
  - Disk geometry + kinematics. Spectral study, influence of secondary
  - Stellar disk geometry

MIRC 6T H band (done by J. Monnier, X. Che)



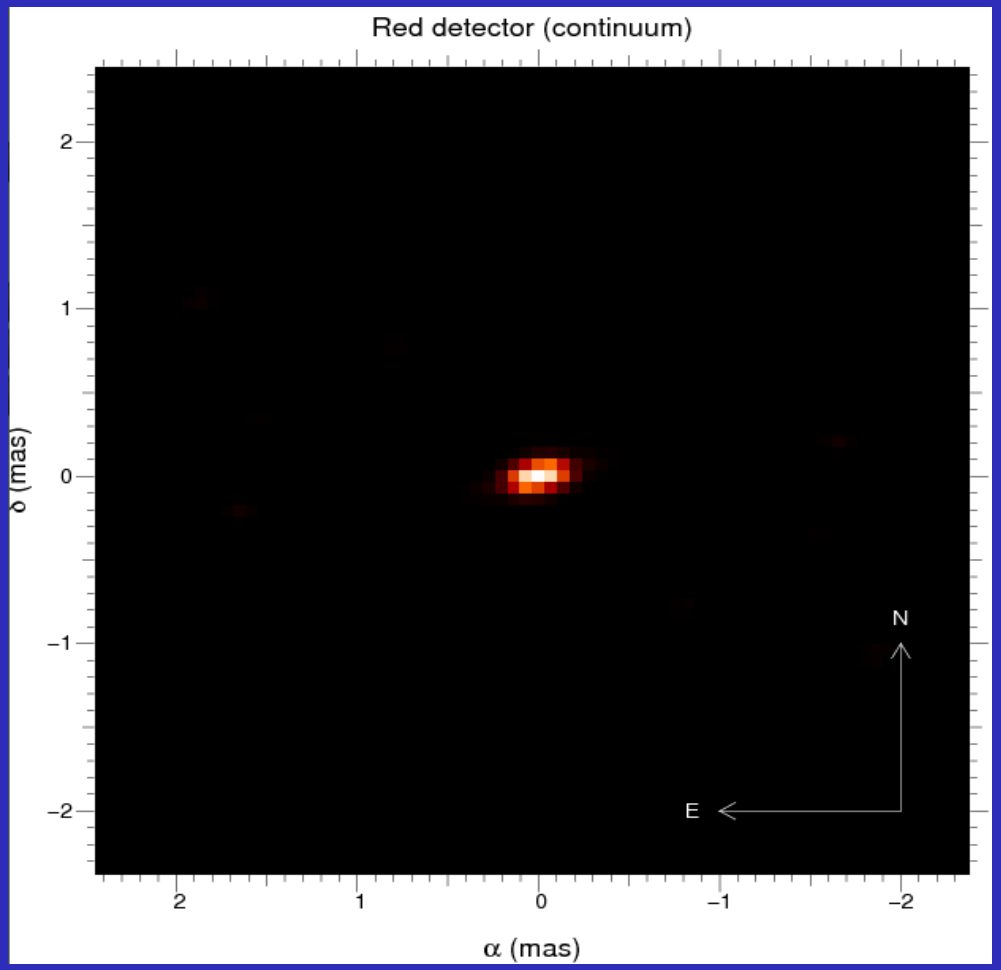
Model fitting, V^2 VEGA only
(done with JMMC/LitPro software)

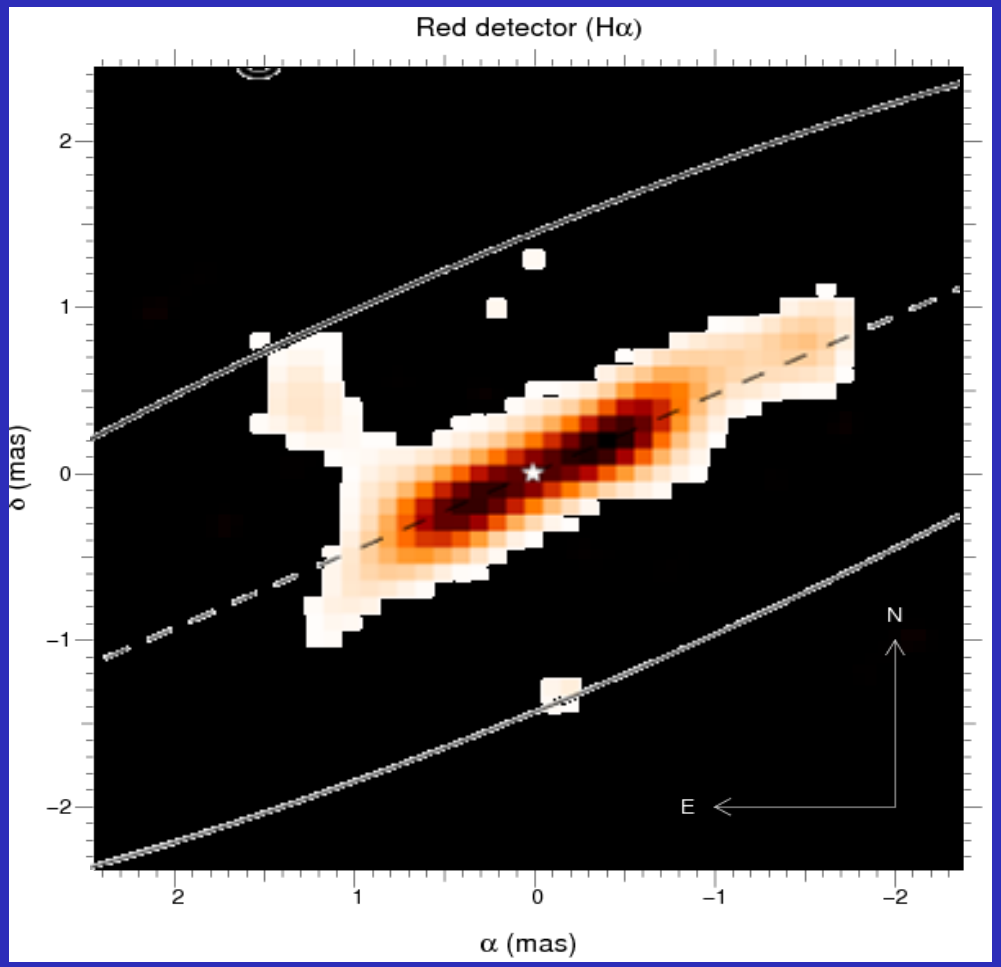


Very low contribution of the disk in the continuum
Stellar disk elongated by a factor more than 2
~10° tilt between the continuum and continuum+Hα region

Image reconstruction VEGA V^2 only

(done by F. Millour, OCA)





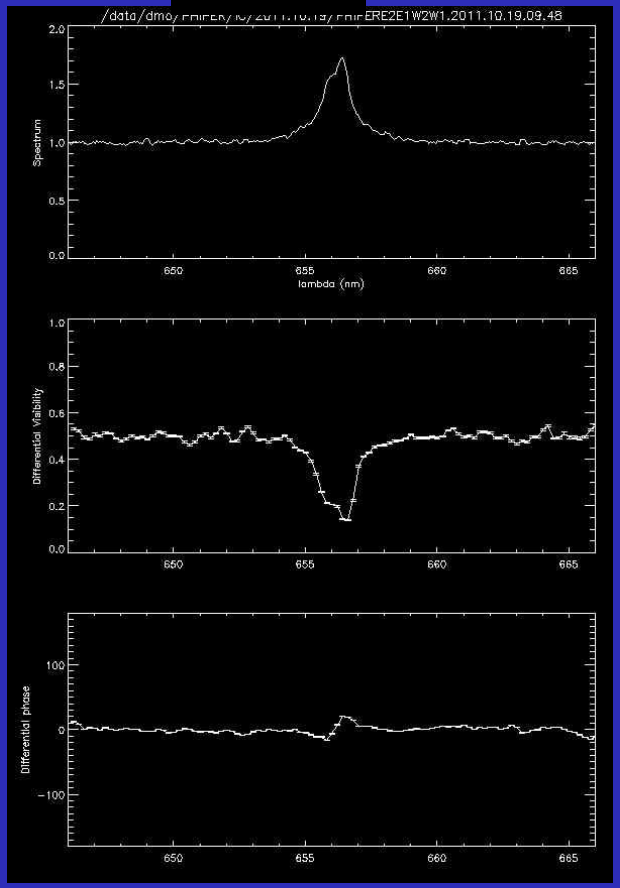
First image VEGA/CHARA in the visible

Disk orientation ok with MIRC

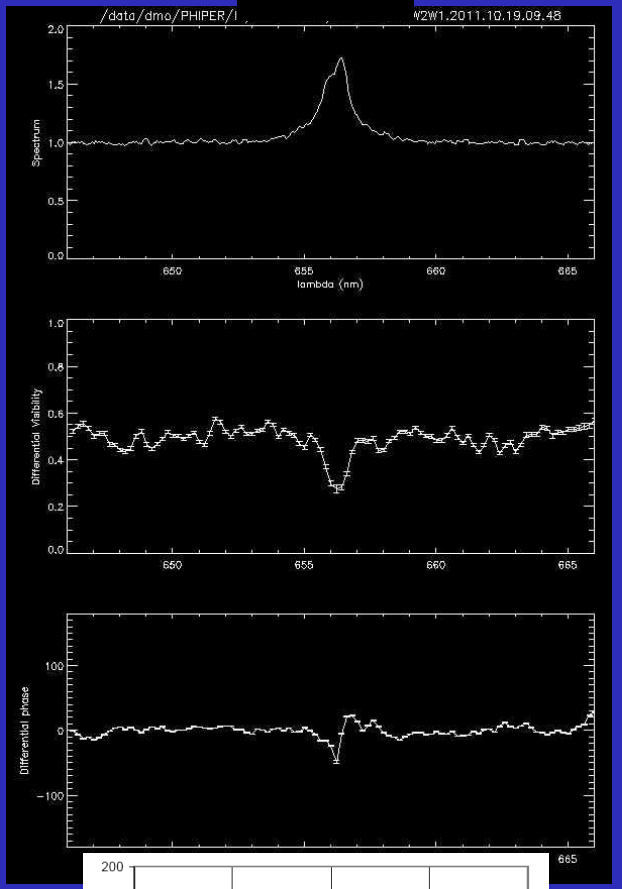
Quantitative analysis in progress: central star, disk

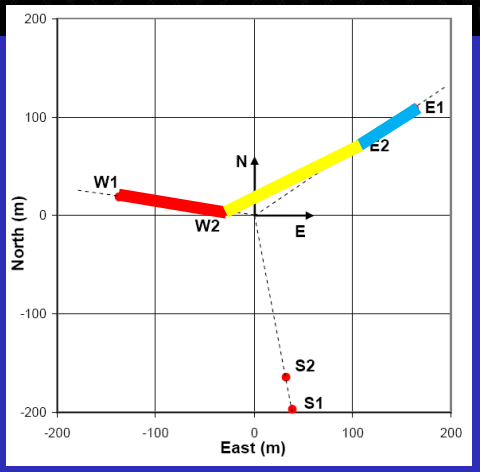
Exemples of V_DIFF

W1W2

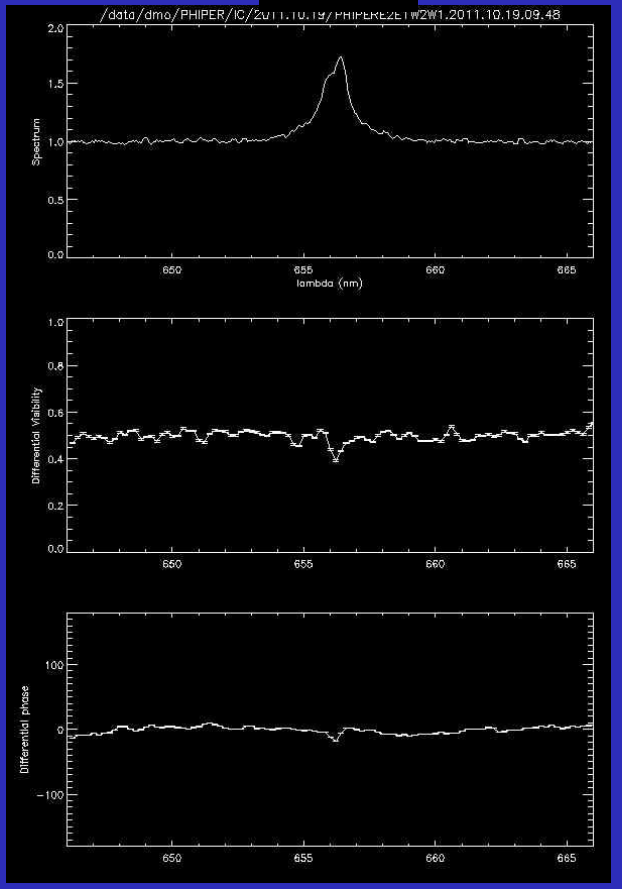


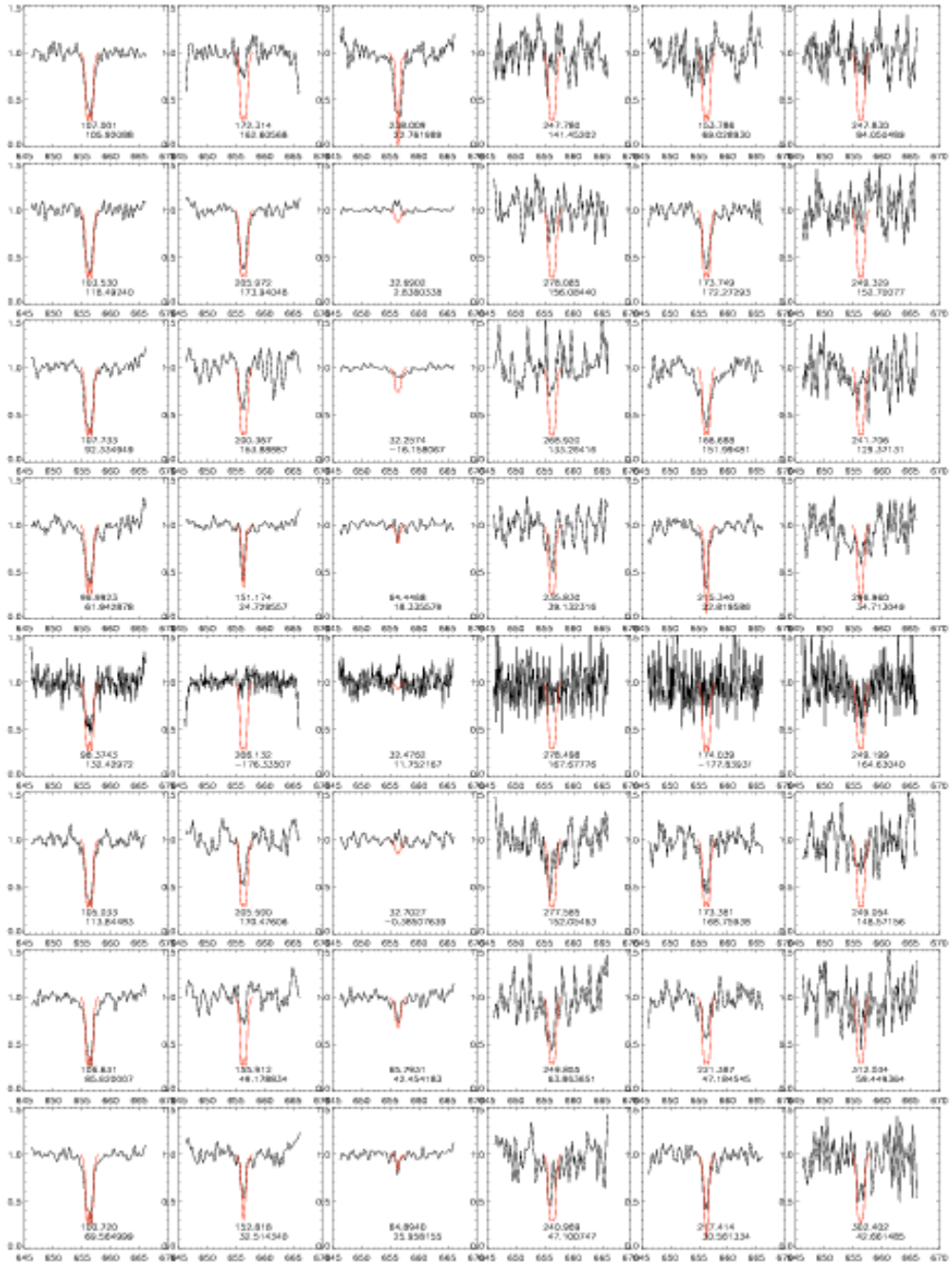
W2E2

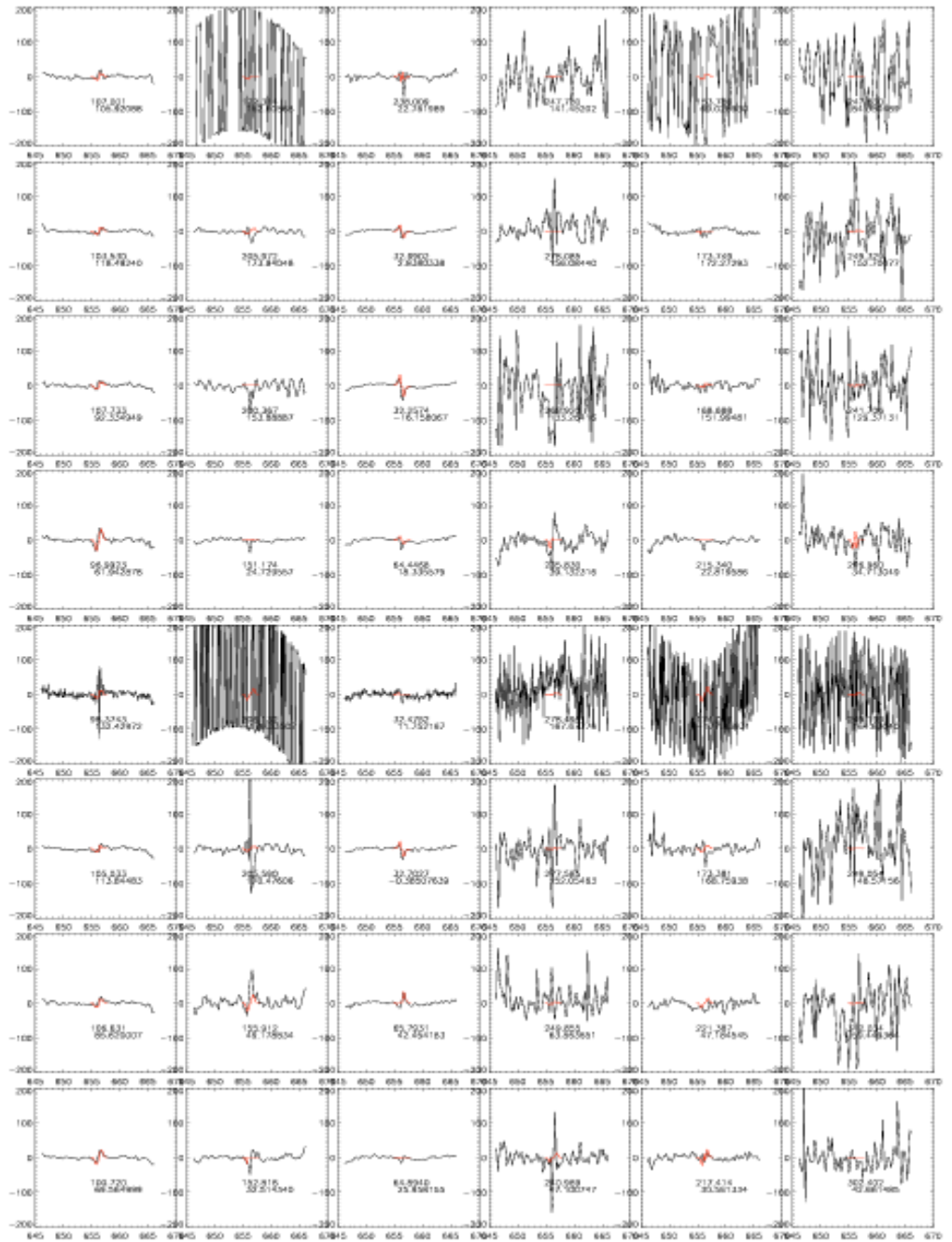




E2E1

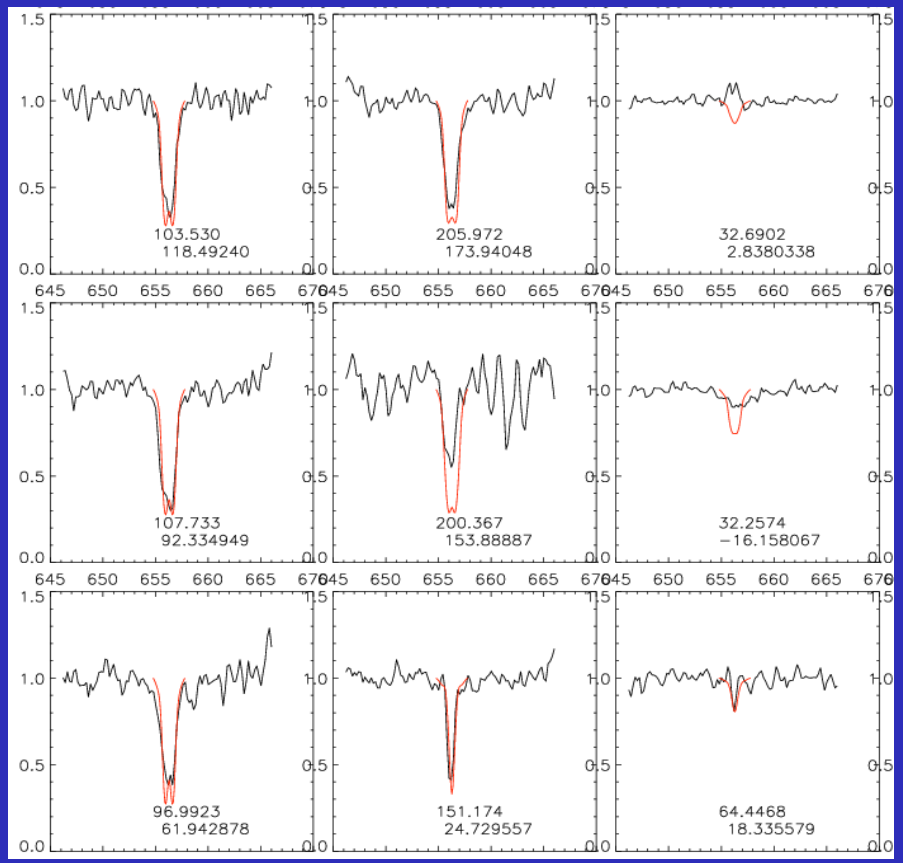


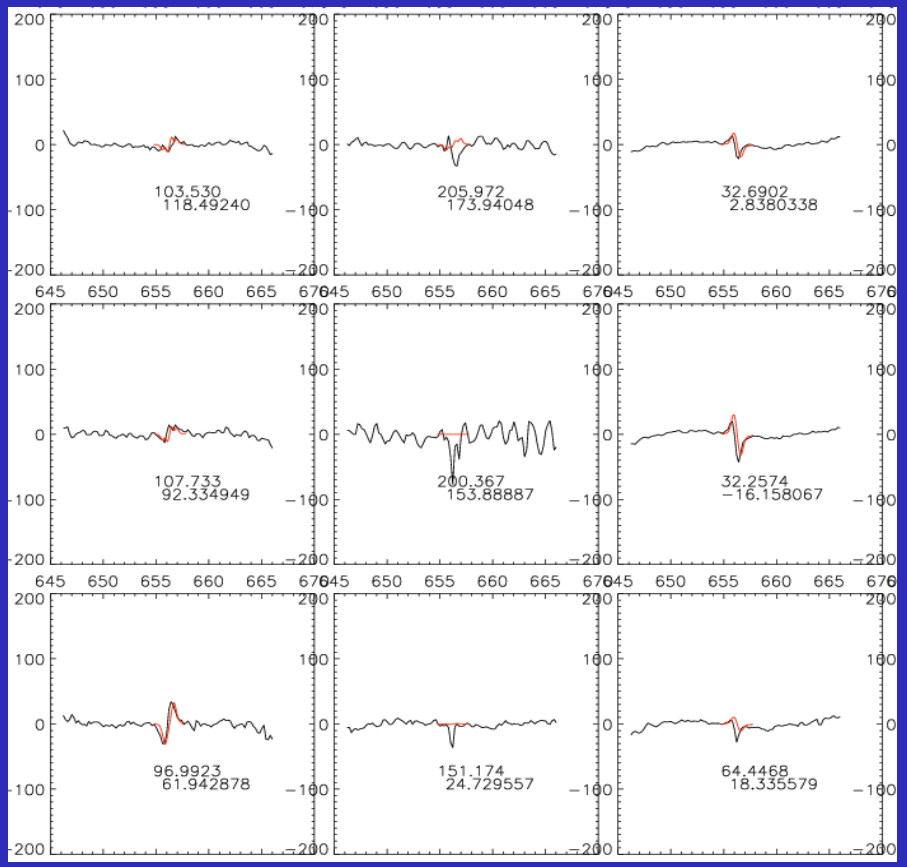




Rotating disk modeling Hα line profile + VIS(λ) + PHI(λ)

(done by A. Meilland, OCA)





FWHM disk = 4 stellar diameters, PA=-65°.

Vrot~500kms^{-1} keplerian rotation

Why an instrument of second generation ?

- Installation of OA system in the next 2 or 3 years
- Saturation problems with photon counting detectors (high flux or small D/r0)

Low noise analog detectors

- Low visibilities measurements are difficult
- Increase the limiting magnitude
- Increase the measurements precision

Single-mode spatial filters

- Combine 6 telescopes simultaneously

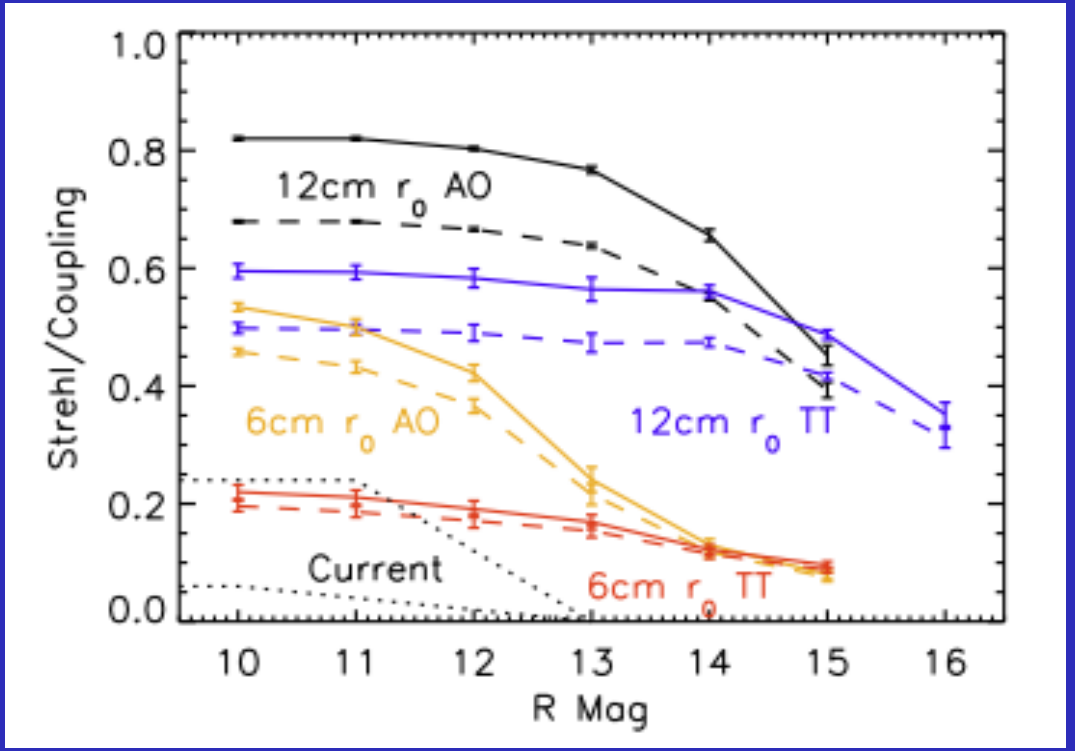
OA characteristics

- OA installed in the telescopes
- Shack-Hartmann sensors
- Modal correction
- 30 sub-pupils / 19 actuators

Scheduling

- PDR 60 days after funding agreement
- Systems should be ready for scientific observations 2 years after PDR

Performances attendues en bande H



Expected performances in the visible (700nm)

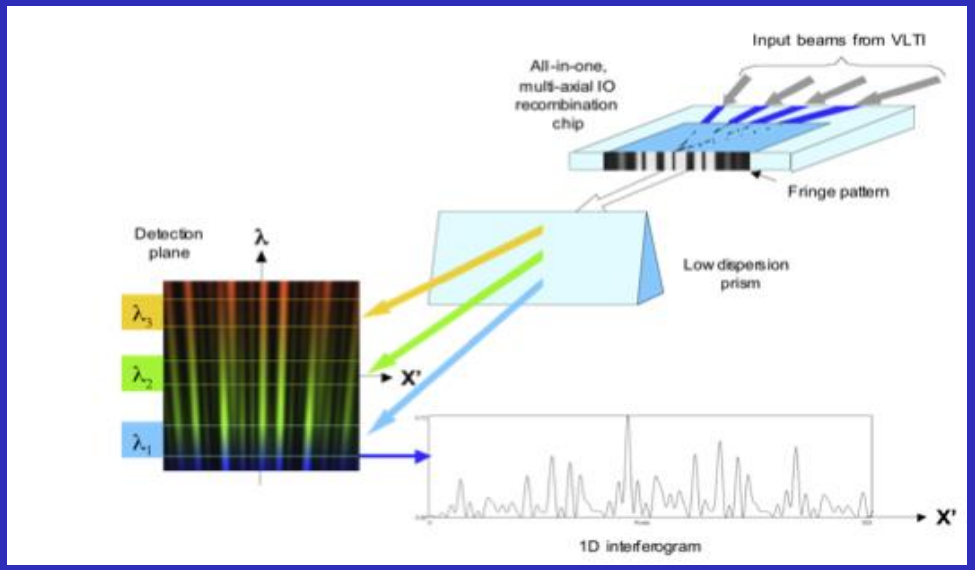
- Strehl ≈30% for r0=12cm
  => coupling ≈25%
- Strehl ≈6% for r0=6cm
  => coupling ≈5%

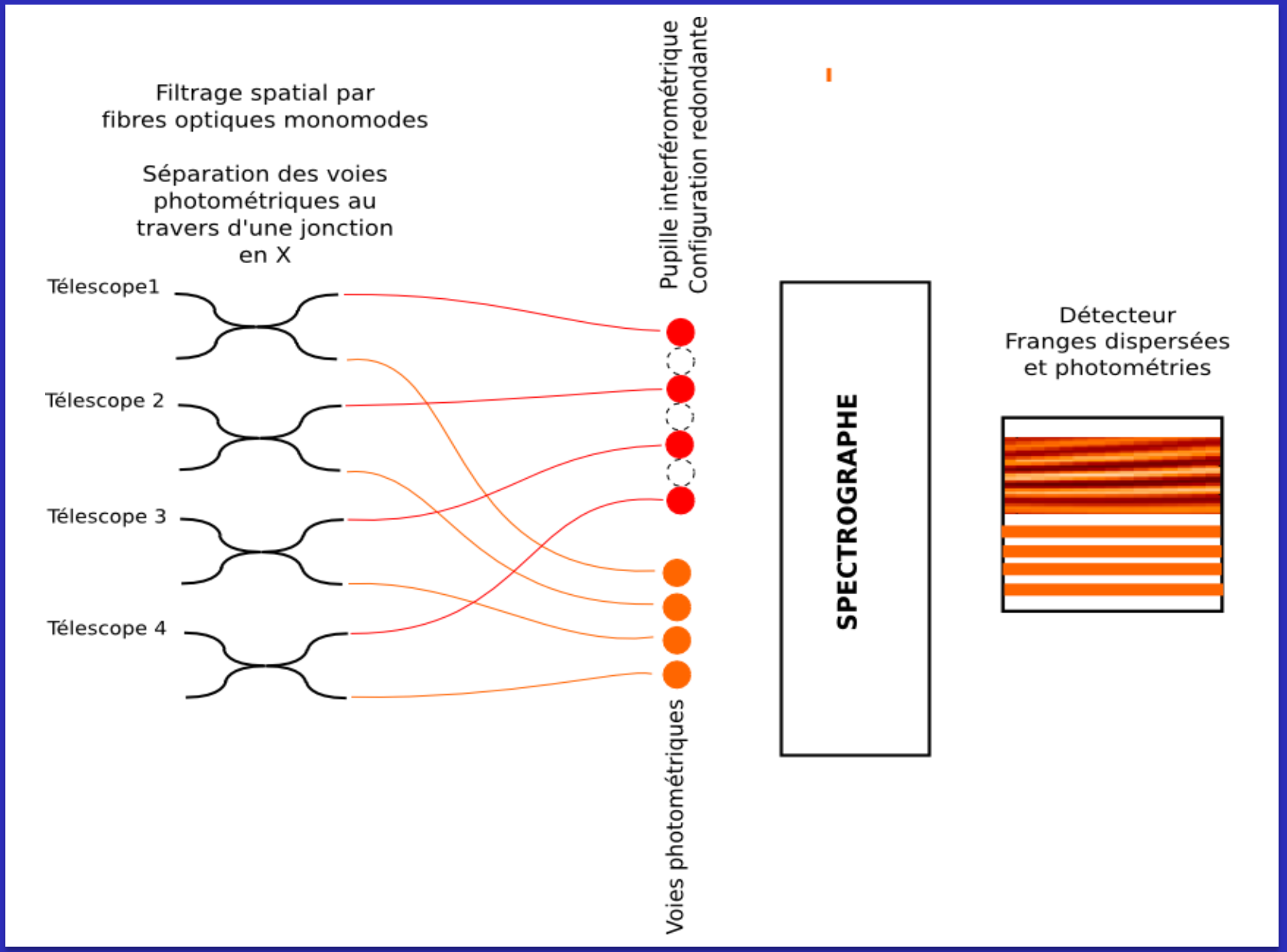
3 possible solutions :

- **with single mode optical fibers**
  - easy transportation
  - good transmission over $\Delta\lambda$<100nm

- **with integrated optics**
  - Compact system (multi-axial combiner)
  - active modules (OPD modulation, …)
  - transmission loss (2-3dB)

- **with pinholes**
  - not studied

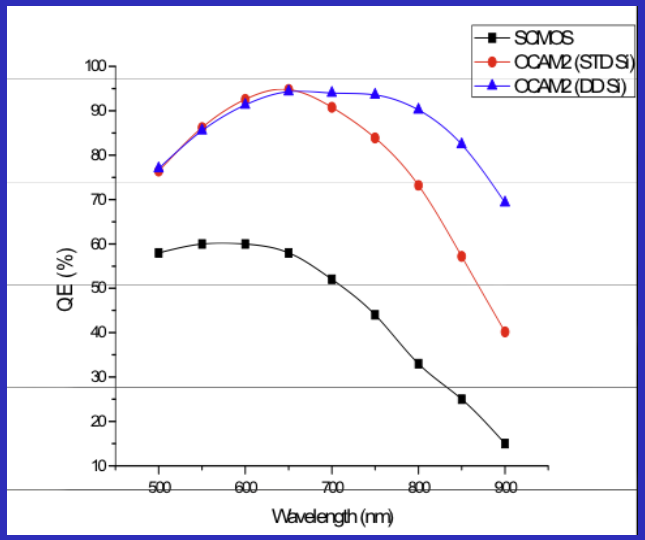



Filtrage spatial par
fibres optiques monomodes
Séparation des voies
photométriques au
travers d'une jonction
en X
Télescope1
Télescope 2
Télescope 3
Télescope 4
Pupille interférométrique
Configuration redondante
Voies photométriques
SPECTROGRAPHE
Détecteur
Franges dispersées
et photométries

OCAM2:

Low noise camera developped by IPAG-LAM

- 1500 frames par second maximum
- quantum efficiency> 90% between 600nm and 800nm
- RON ~ 0.13 e^-
- 240x240 pixels



VEGA prospective

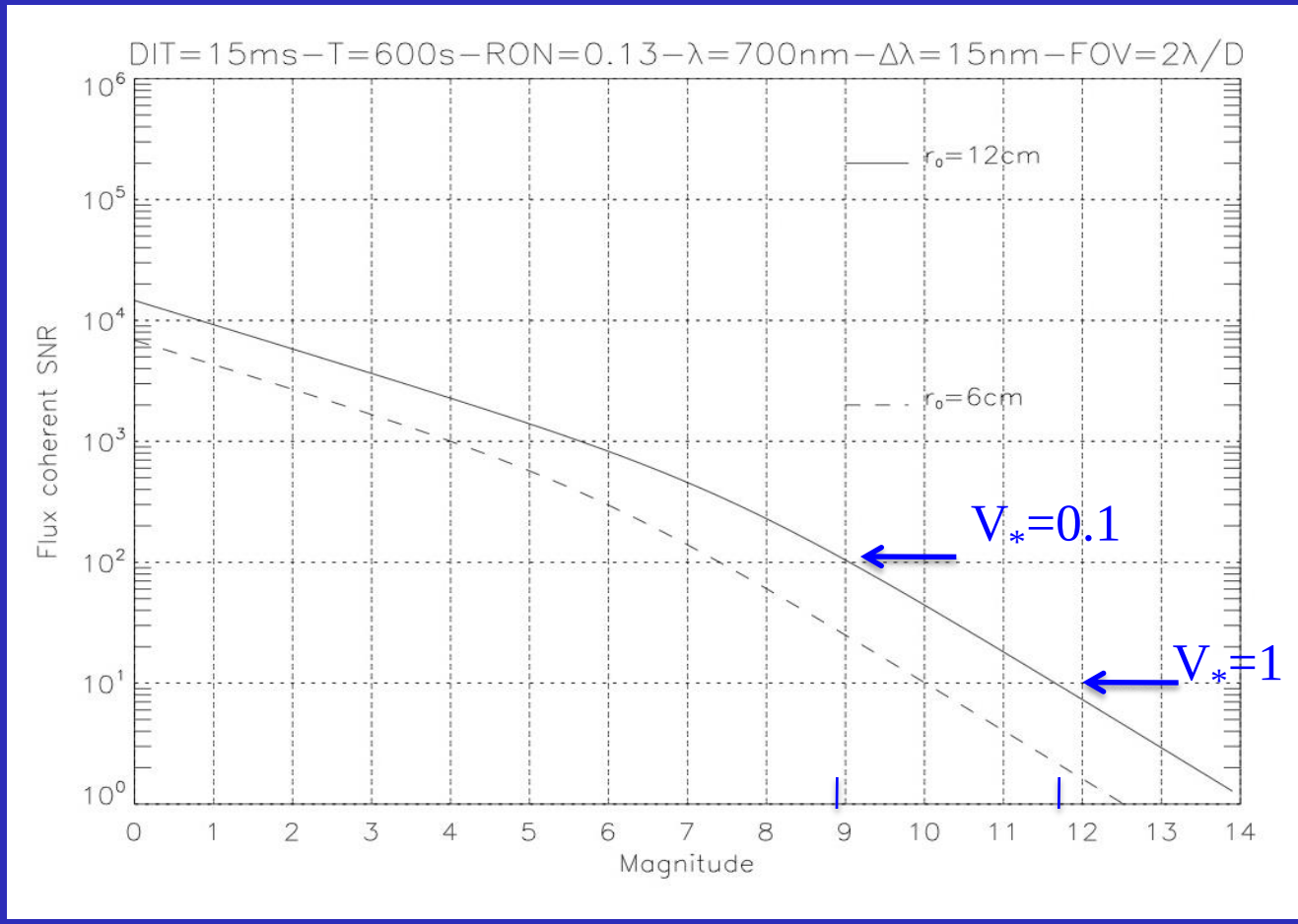
Expected performances with OCAM2

SNR expression

$$SNR_V = \frac{\sqrt{M} N V_{inst} V_*}{\sqrt{n_{tel} N + n_{pix} RON^2}}$$

Parameters:

- Quatum efficiency: 90%
- CHARA Transmission : 3%
- Spectro Transmission : 46%
- OA Transmission : 80%
- Polar Transmission : 50%
- RON : 0.13
- 4 pixels per fringe
- FOV: 2λ/D
- Δλ: 15nm @ 700nm
- n_{pix}: 48x214
- DIT: 15ms
- M: 40000 (10 minutes)
- V_{inst}: 0.7
- RatioPhot: 20%



=> Gain of 4 magnitudes wrt current VEGA

Tests of the OCAM detector on VEGA/CHARA (Nov. 2012)

Test de la caméra OCAM au foyer de l'instrument CHARA/VEGA

- 4 demi nuits d'observation en Novembre 2012 (2 nuits exploitables)
- Installation et observation réalisées par S.Lagarde, P.Feautrier et P.Balard
- 10 étoiles observées :
  - Magnitude de m_V=0 à m_V=5.5
  - Mode 2T (S1S2) et 3T (E1E2W2)
  - Moyenne résolution spectrale (R=5000) autour de Hα et à 800nm
  - Temps de pose testés : 1ms – 2ms -5ms – 10ms – 20ms - 40ms

➔ Franges détectées sur toutes les étoiles dans toutes les configurations

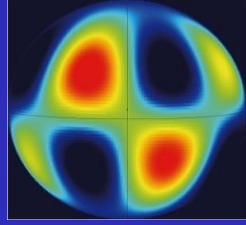
Towards a VLTI visible instrument

- Progresses of VLTI + VEGA/CHARA bring unique opportunities for key astrophysical questions.

- Imaging at very high angular and spectral resolution for asteroseismic sources, exoplanet's host stars and general stellar physics.

- Main features:
  - 4T/6T beam combiner + spectrograph
  - IR group delay tracking
  - VISA infrastructure: *well-optimized for imaging in the visible.*
    - # of ATs, AO on ATs: *denser than CHARA (more short baselines)*
    - longest baselines, fast reconfiguration.

Perspective : pulsating star / asteroseismology

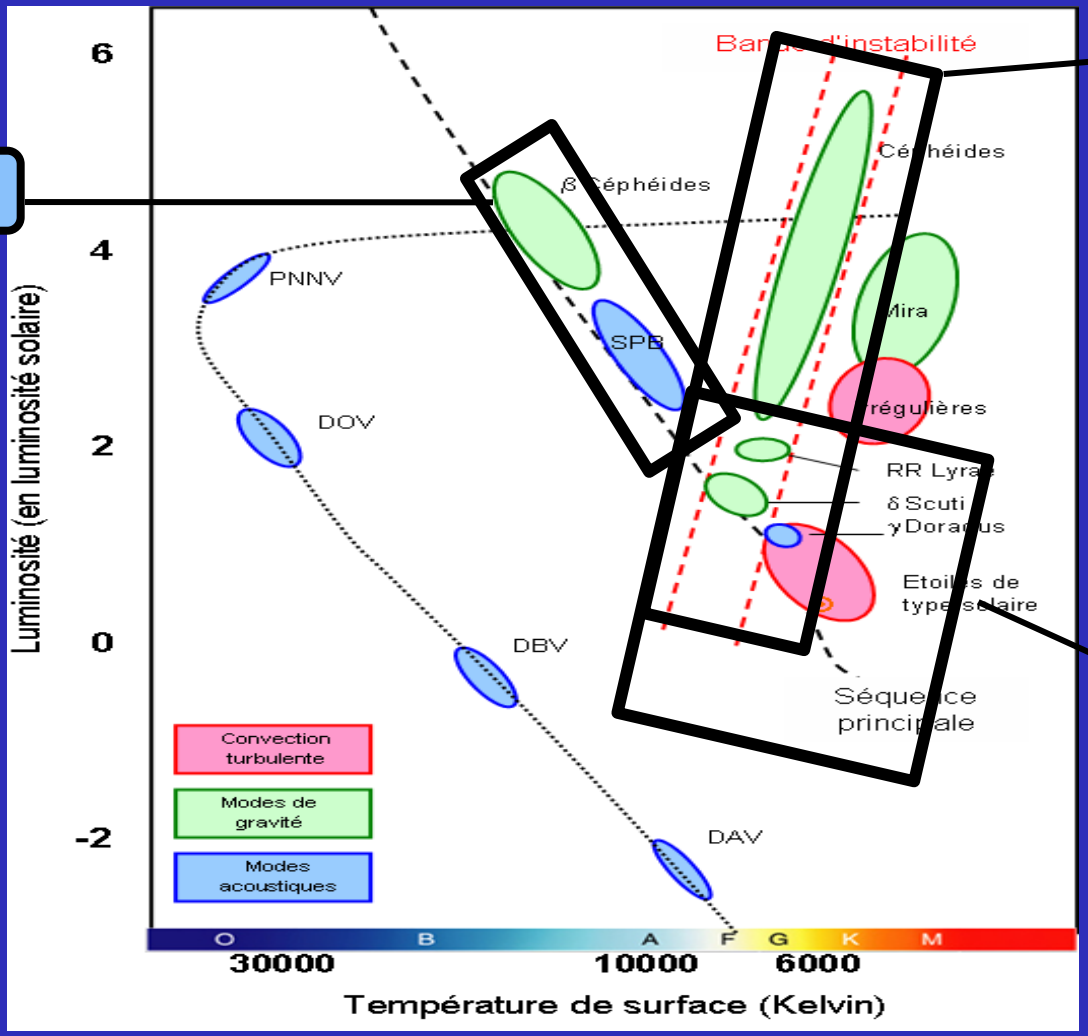


1- distances IBW : Cepheids + HADS
2- asteroseismology : Solar types/γ Dor/δ-Scuti/RR Lyrae/roAp/β-Cepheids
3- environment : β-Cepheids, ...

1- Δθ (φ)

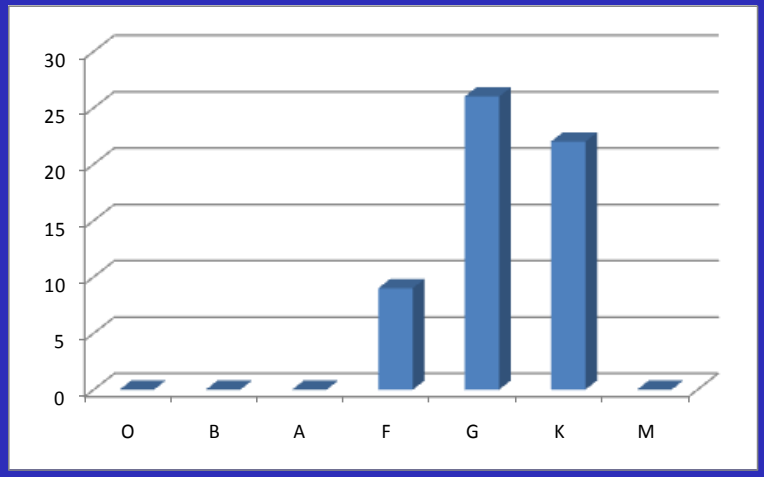
2- <θ>

3- <θ> & CSEs



Exoplanet's host stars

- Angular diameter @ 1% of relative uncertainty
- Direct limb darkening characterization



- Example of VEGA/CHARA possibilities

- Science Goals
  - Better determination of planet's parameters
  - Removal of stellar noise due to activity (spots, pulsation) for RV systems
  - Direct removal of limb darkening bias for transit systems

- Importance of the definition of a large program: study in progress at VEGA consortium level.

You can propose VEGA programs…
Please join and be part of the future!