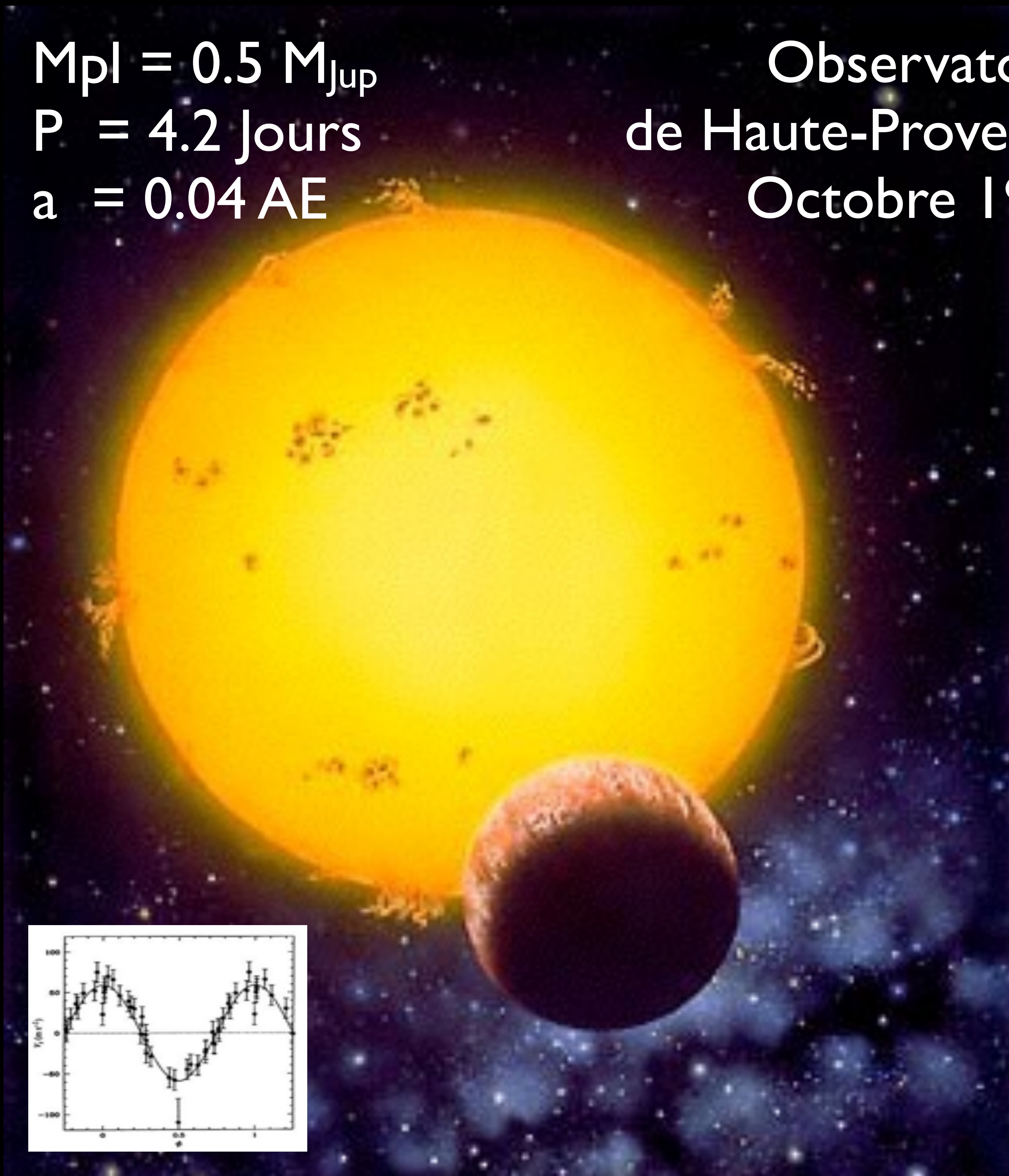
Le vitesses radiales à haute précision

Francesco Pepe
Université de Genève
Departement d'Astronomie

51 Peg b: La première

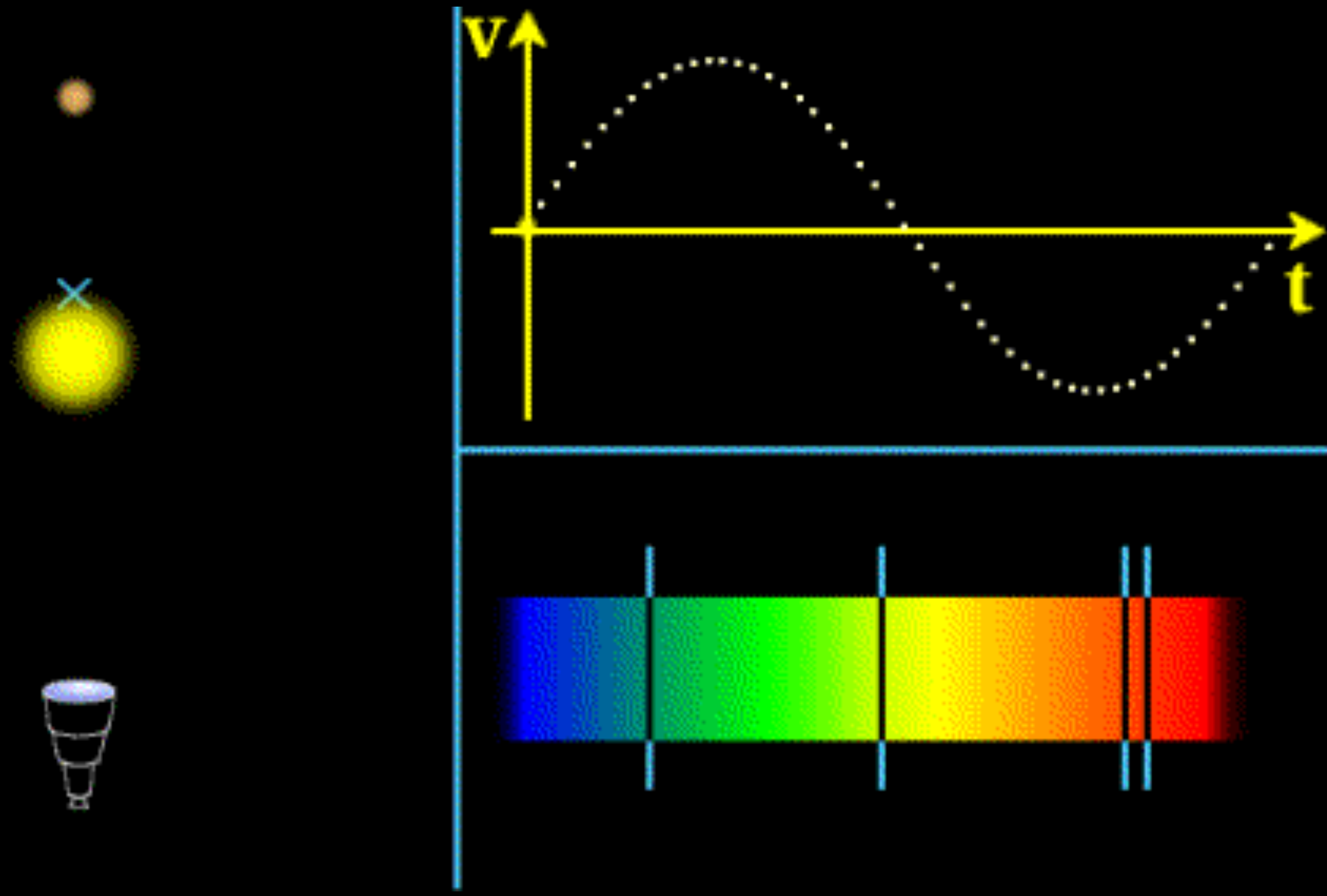
$M_{pl} = 0.5\ M_{Jup}$
$P = 4.2$ Jours
$a = 0.04$ AE

Observatoire
de Haute-Provence
Octobre 1995

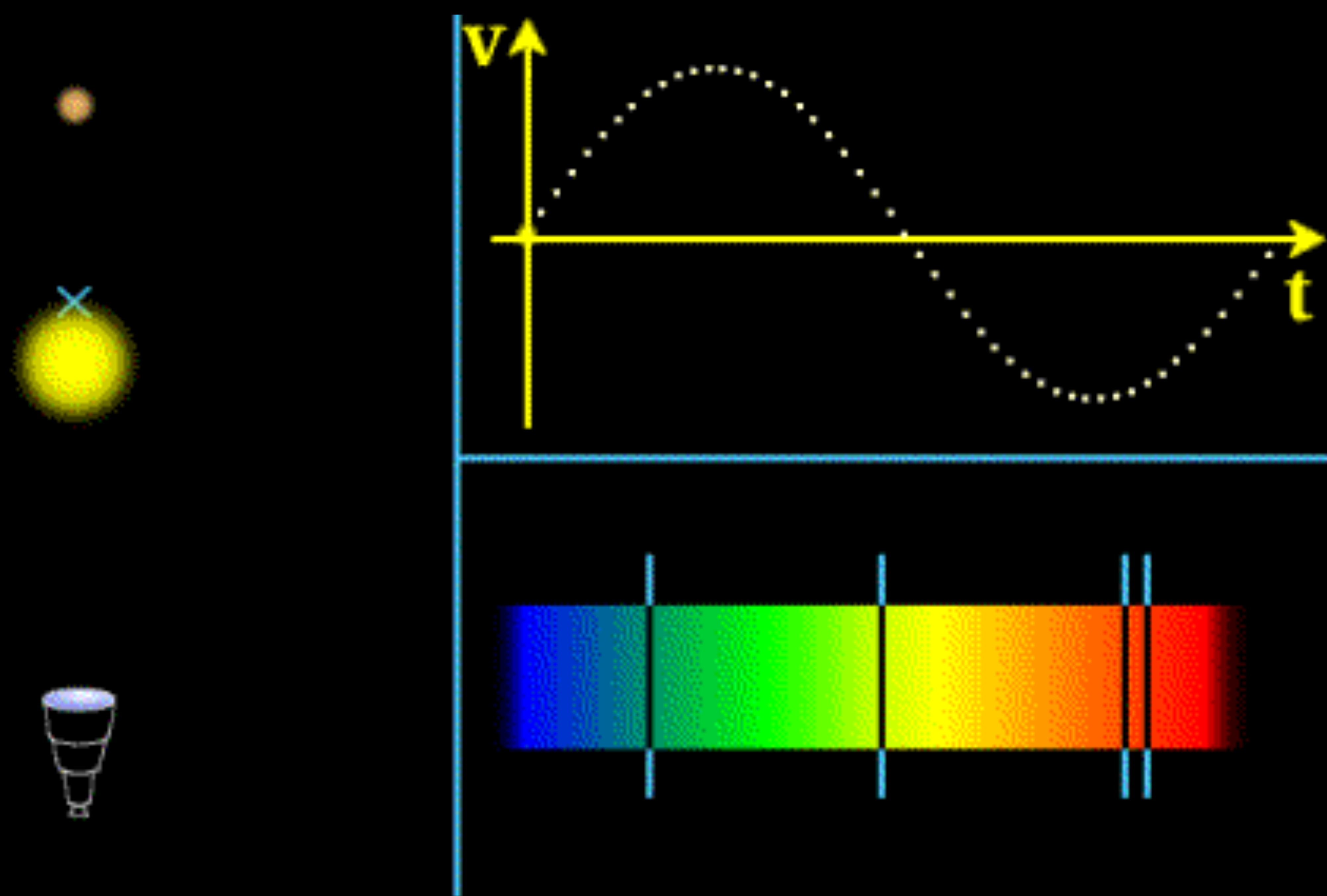


Michel Mayor – Didier Queloz

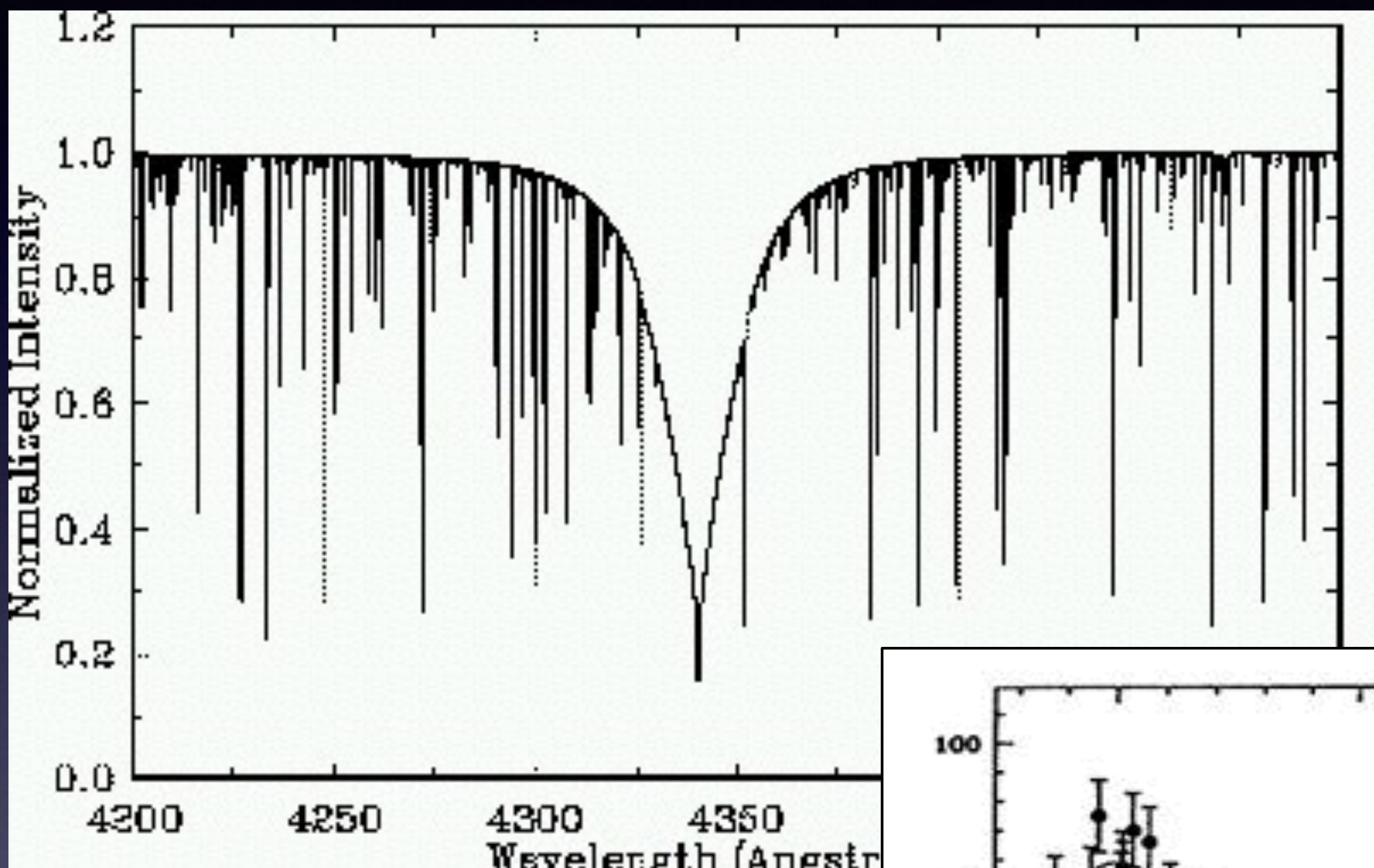
Effet Doppler - Vitesses Radiales

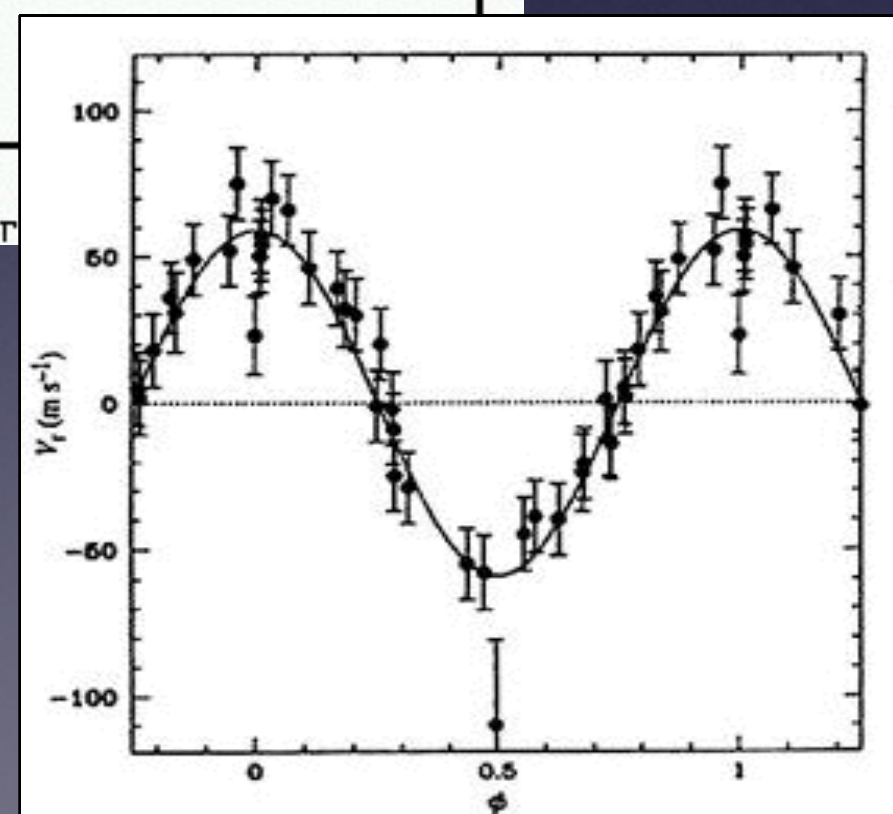


Effet Doppler - Vitesses Radiales



La mesure Doppler



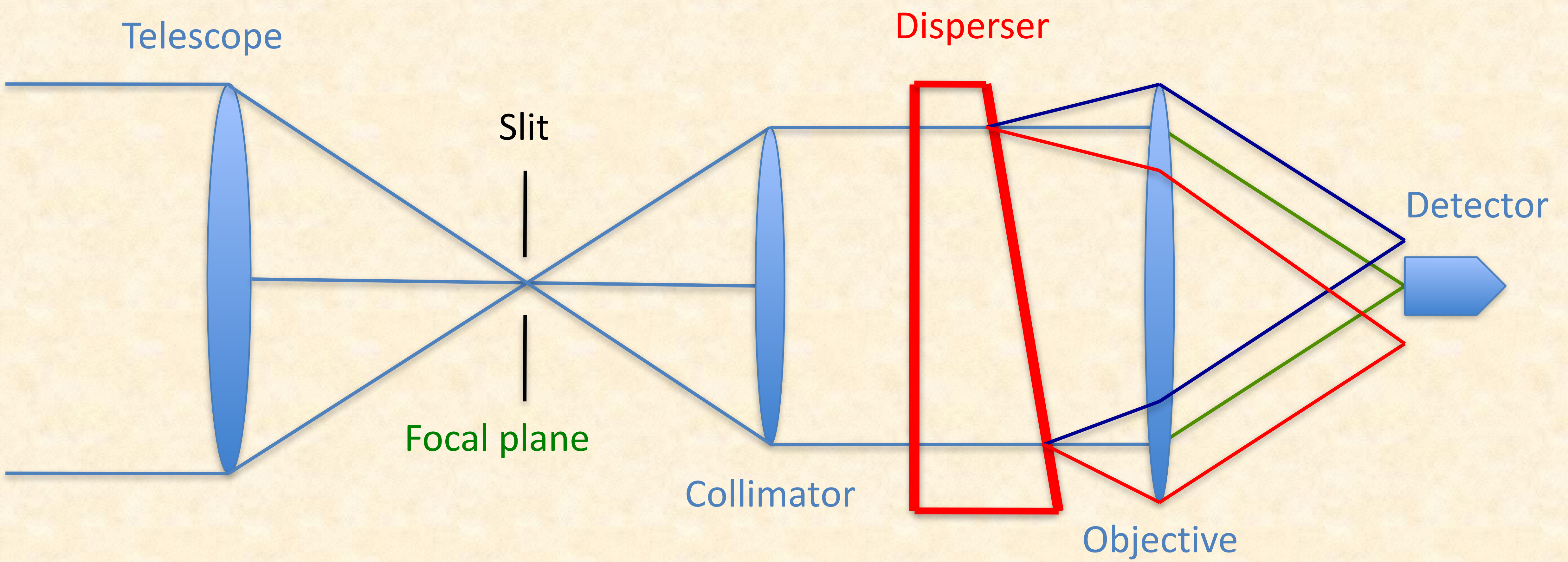


m sin(i)

Période

Eccentricité

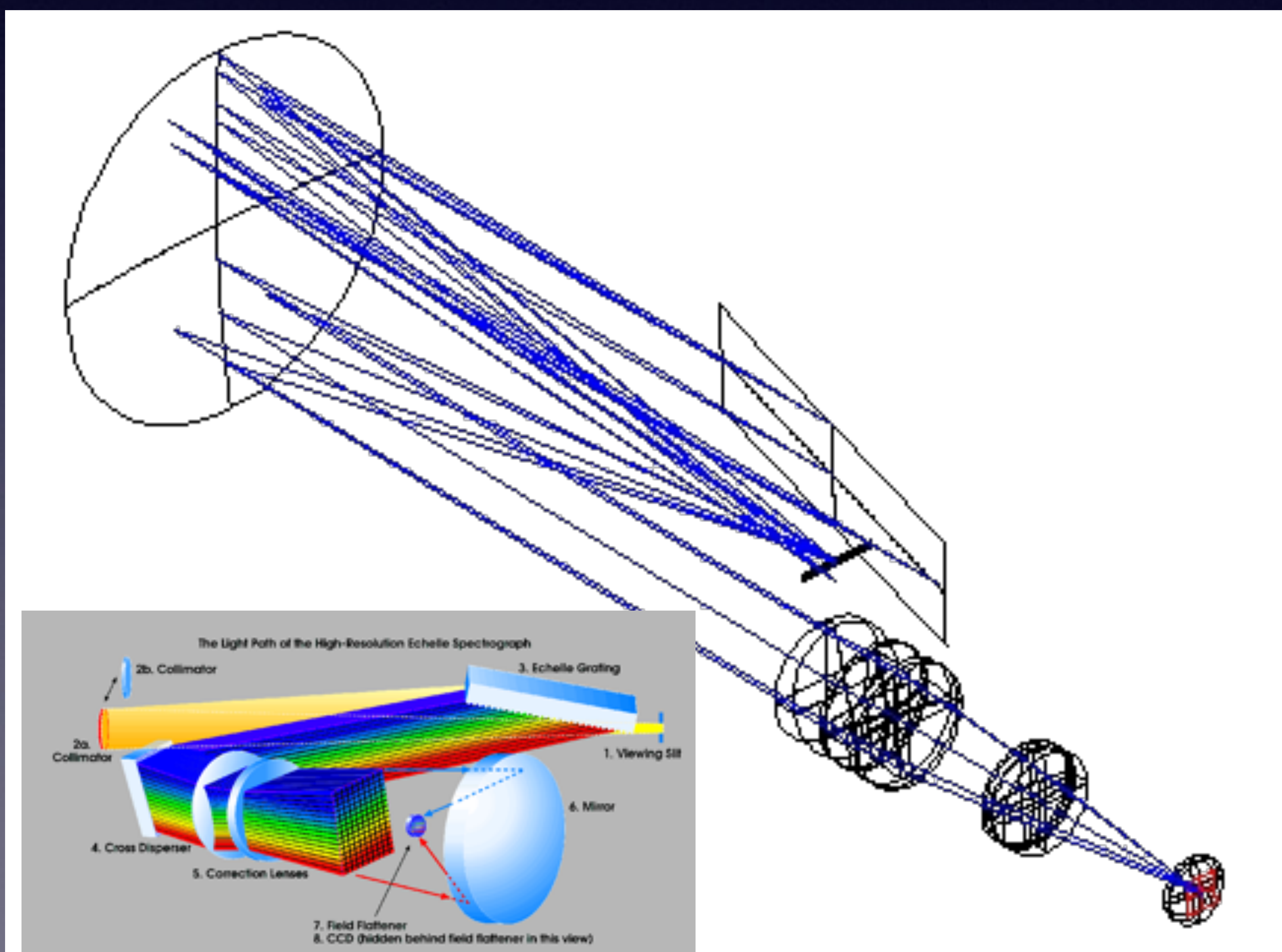
Principes d'un spéctrographe



1 pixel -> monochromatezr (balaiage en longueur d'onde)

Trame de pixels -> spectrograph (tout le spectre simultanément)

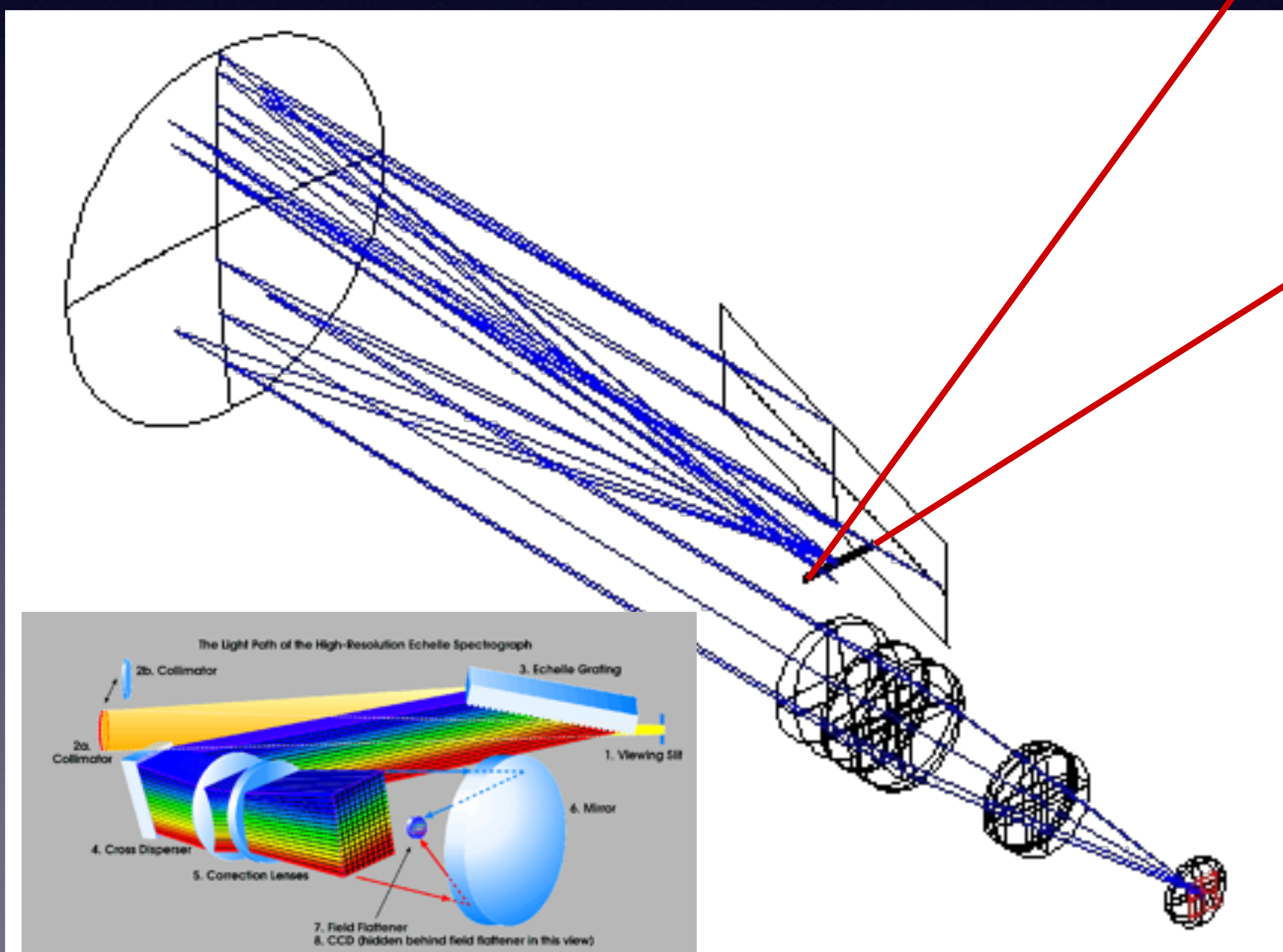
La ‘construction’ d’un spectre à échelle



La ‘construction’ d’un spectre à échelle

Plan focal intermédiaire
‘le spectre blanc’

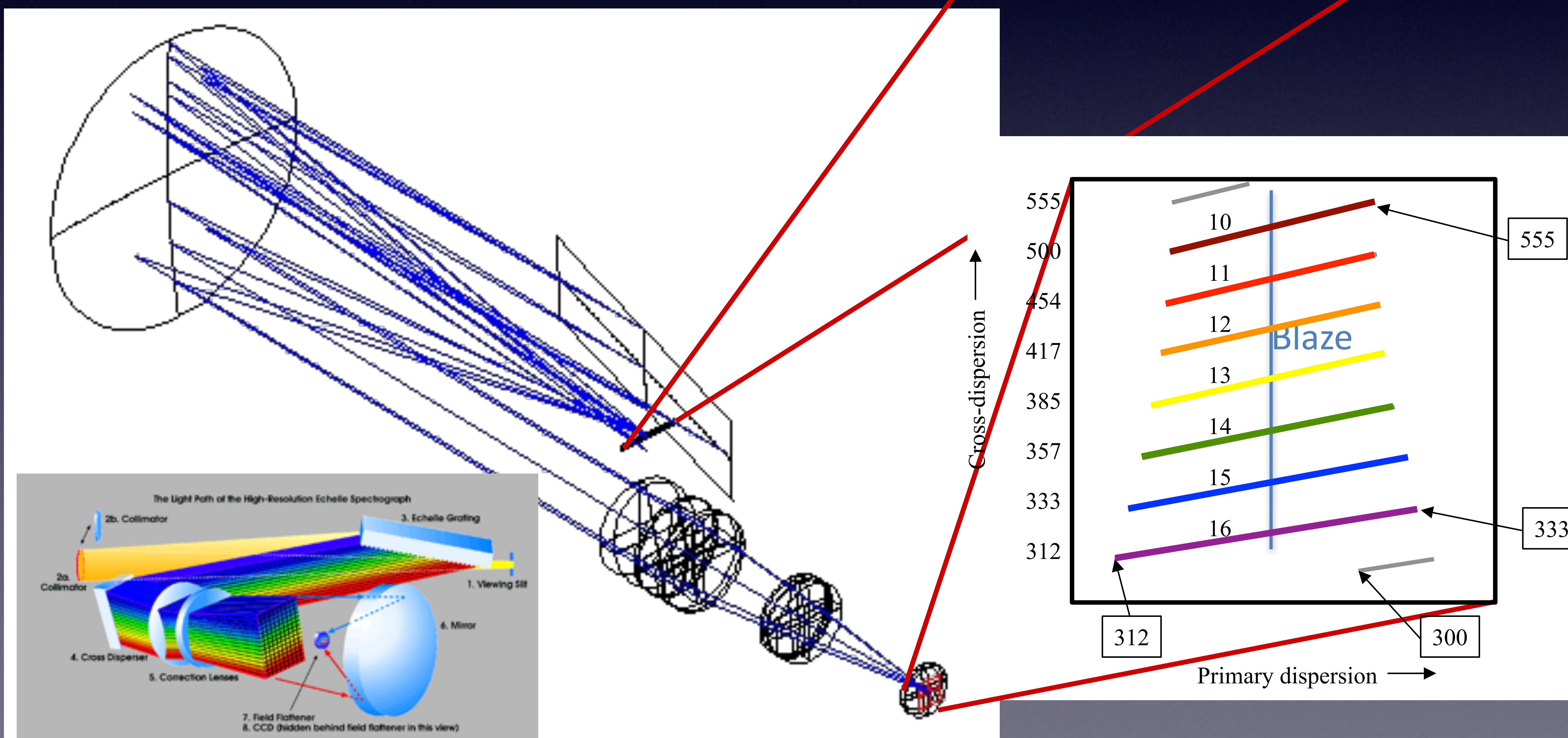
Tous les ordres superposés



La ‘construction’ d’un spectre à échelle

Plan focal intermédiaire
‘le spectre blanc’

Tous les ordres superposés



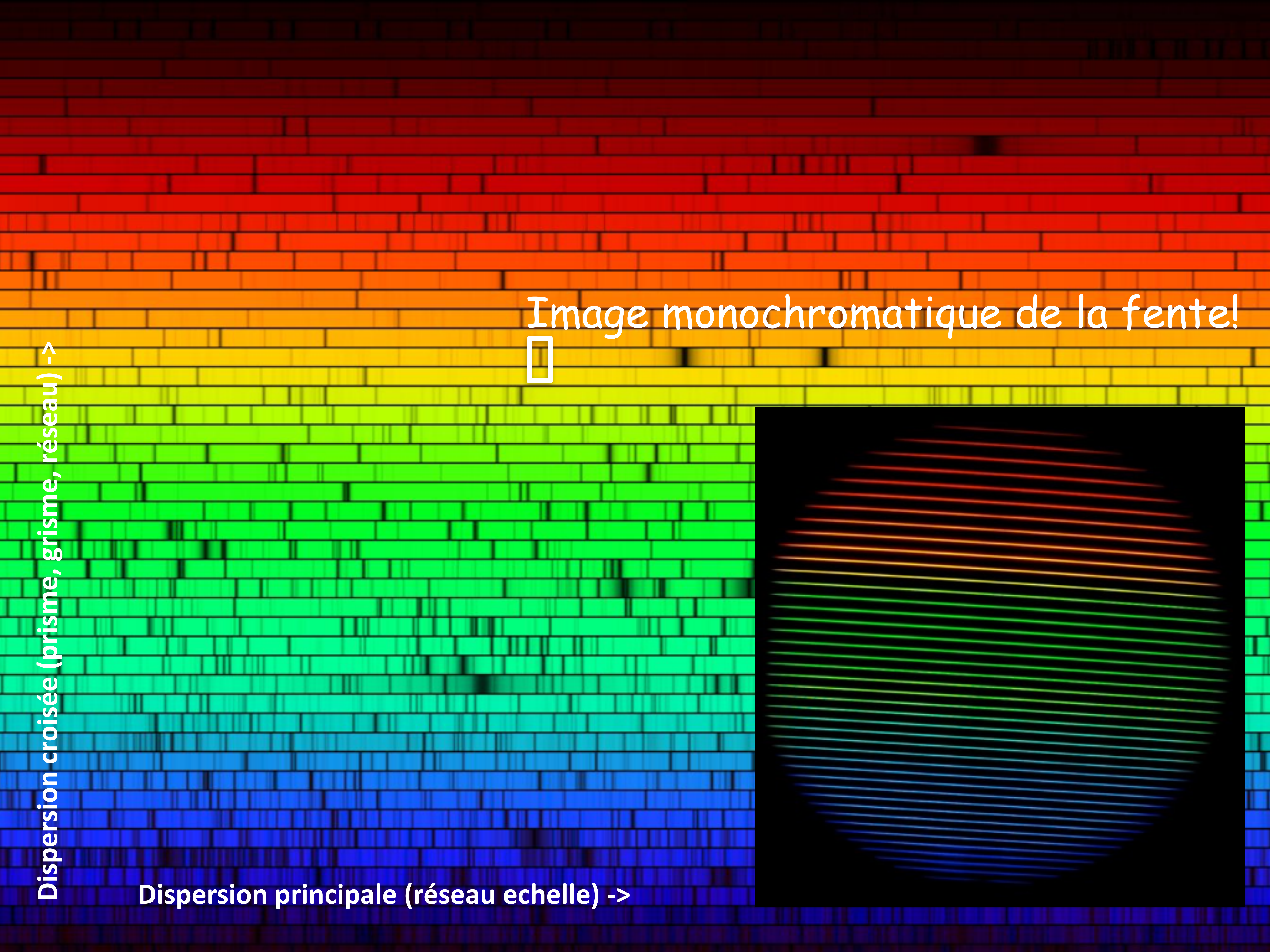
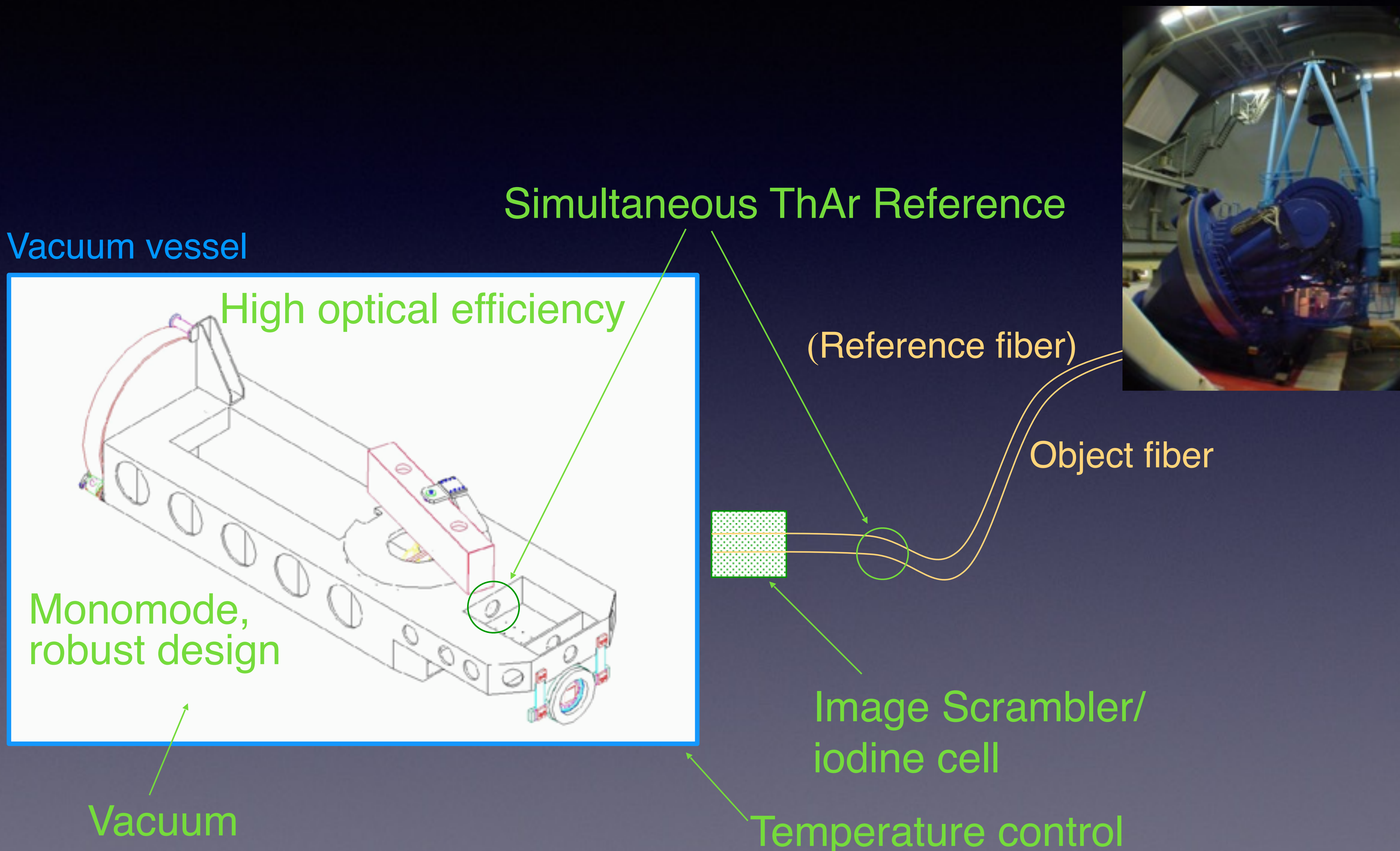


Image monochromatique de la fente!
Dispersion croisée (prisme, grisme, réseau) ->
Dispersion principale (réseau echelle) ->

Configuration de HARPS



La stabilité, une nécessité

$\Delta RV = 0.1$ m/s

⇕

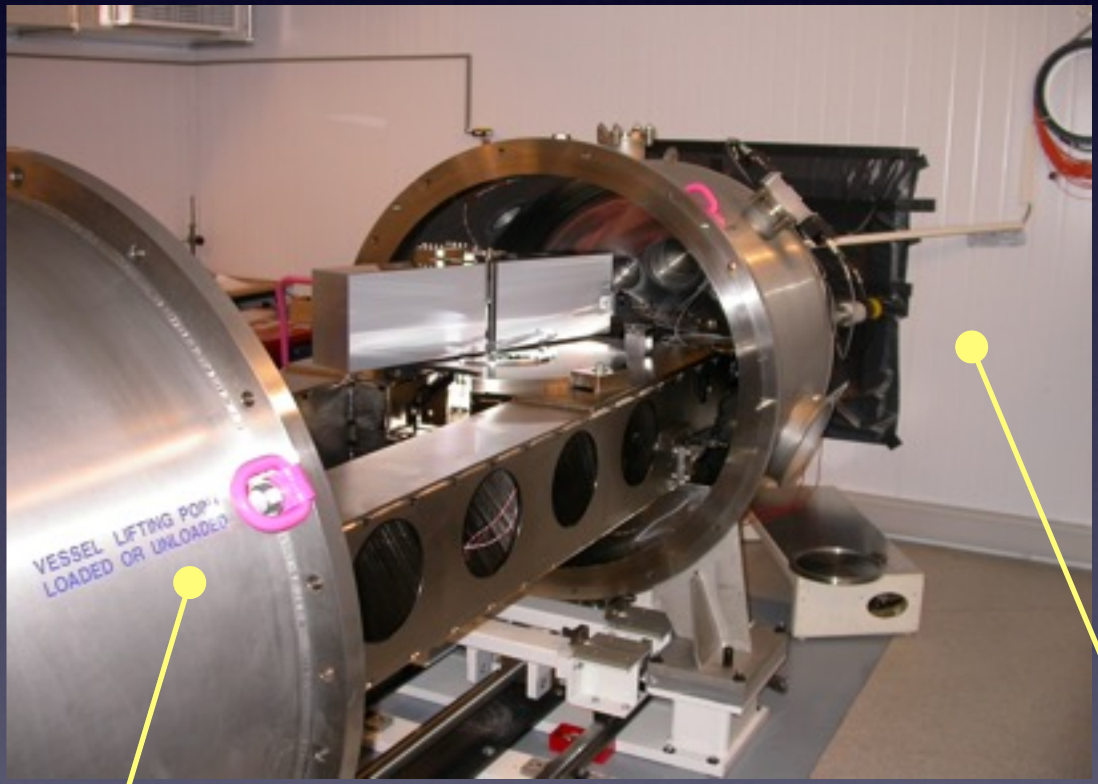
$\Delta\lambda = 0.000001$ A

⇕

1.5 nm

⇕

1/10'000 pixel



$\Delta RV = 0.1$ m/s

⇕

$\Delta T = 0.001$ K

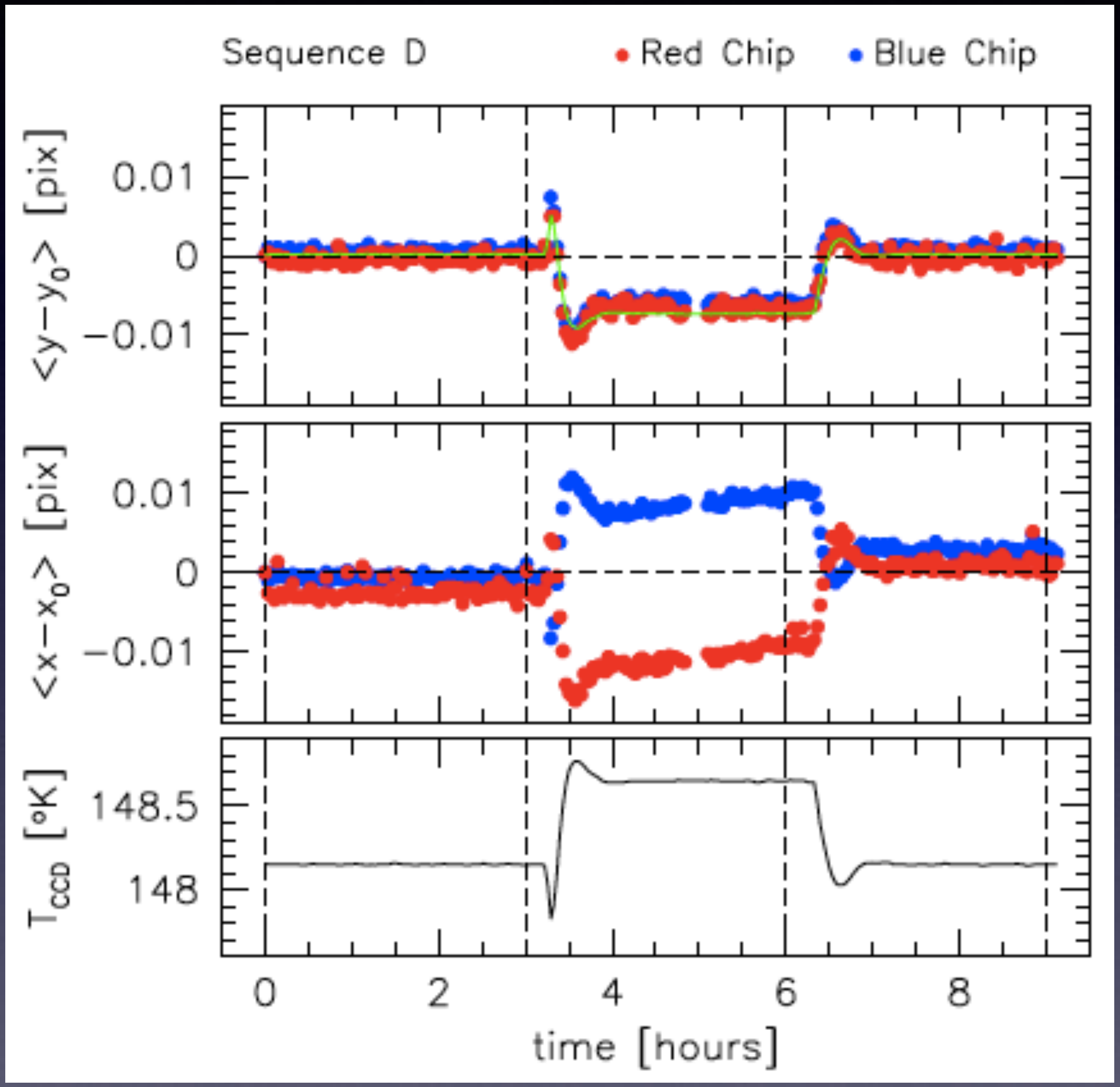
⇕

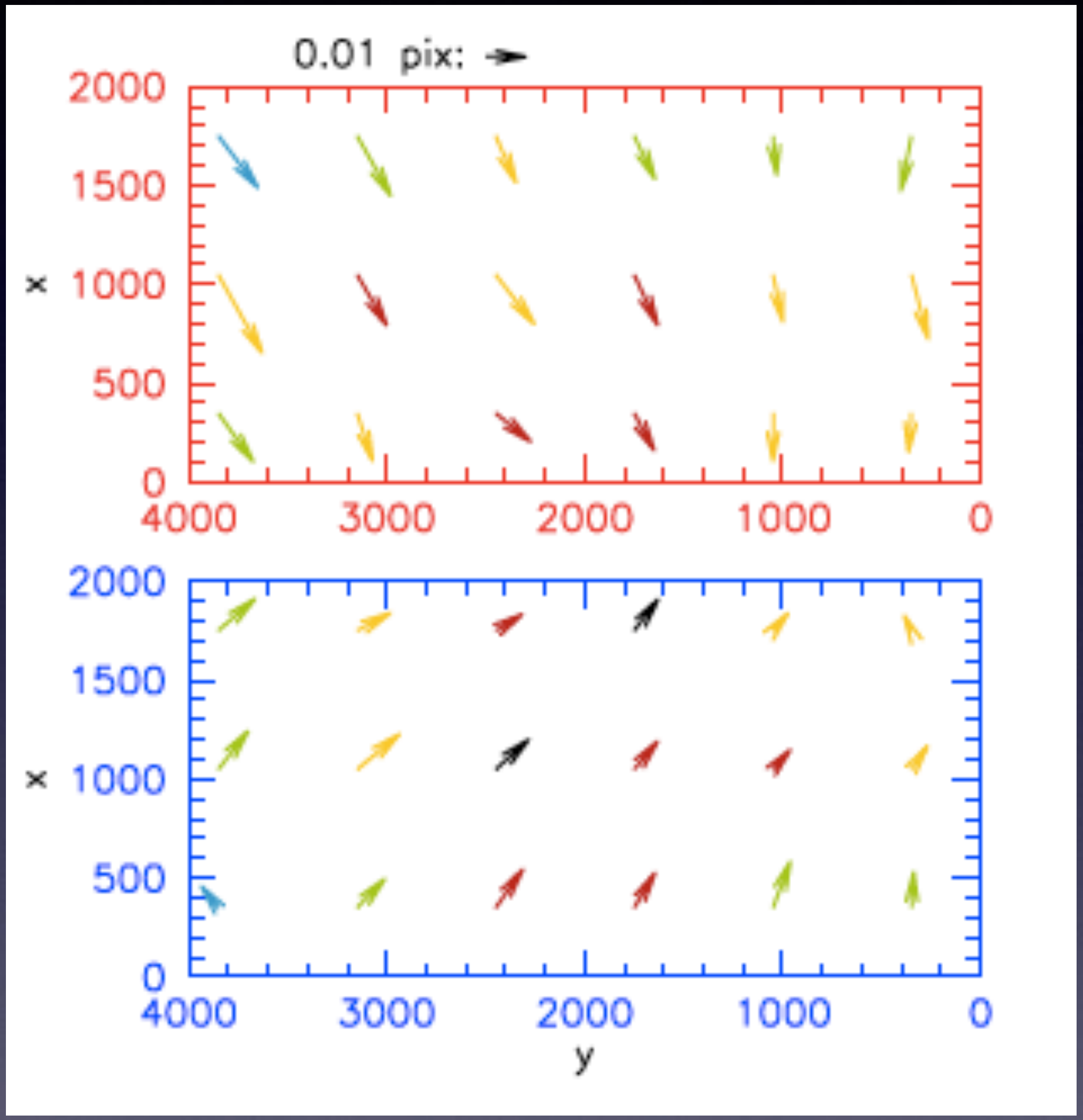
$\Delta p = 0.001$ mBar

Vacuum operation

Temperature control

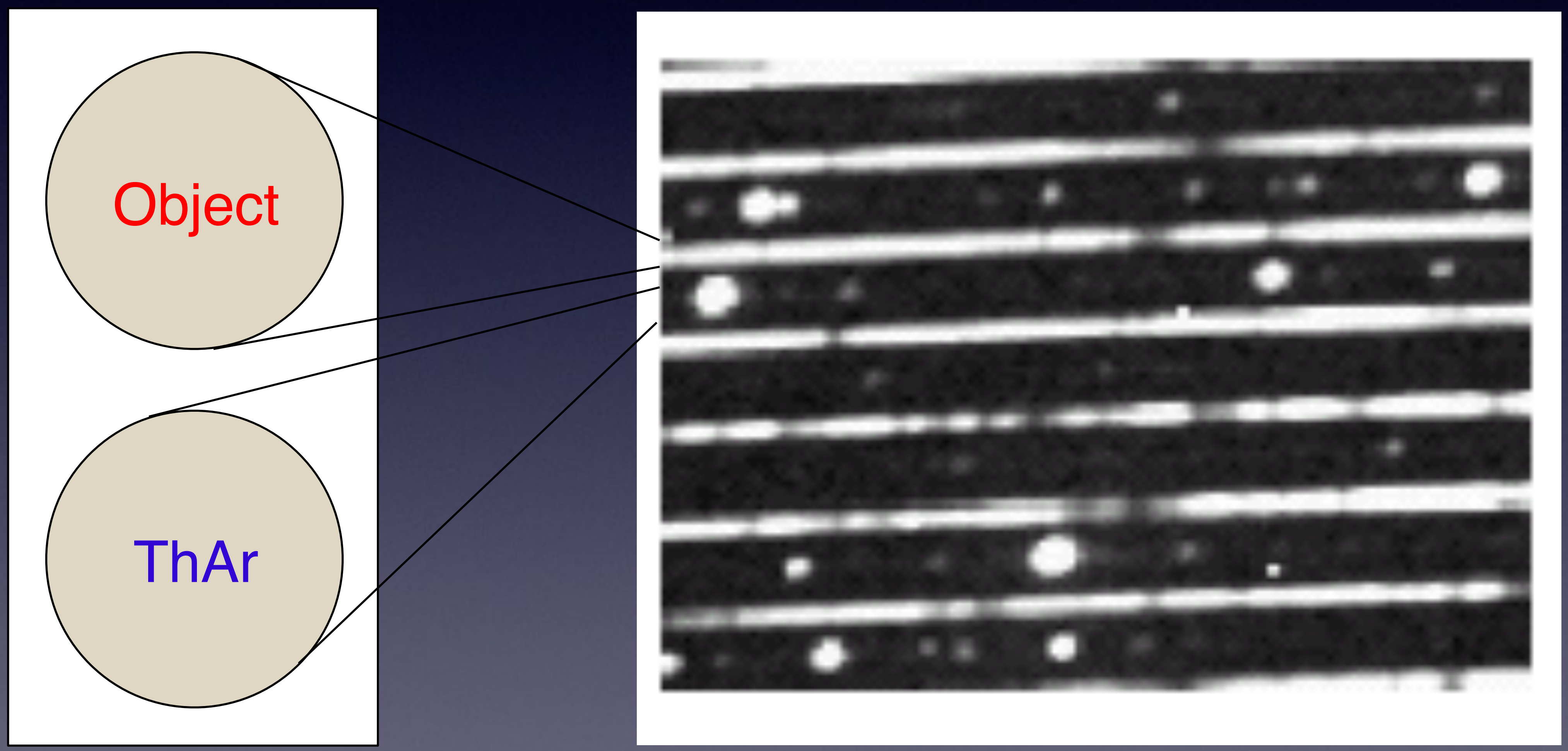
Expansion thermique du CCD

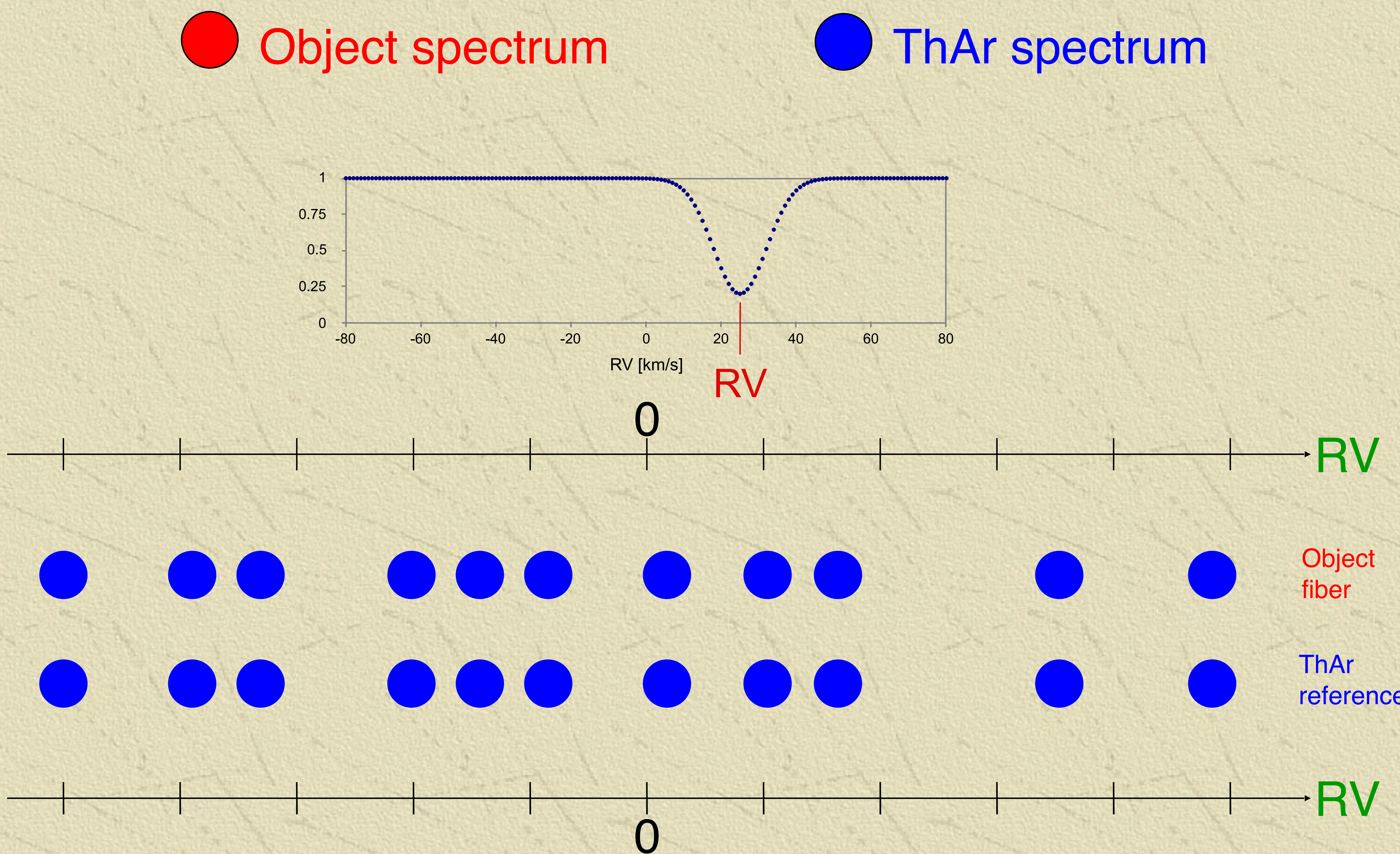




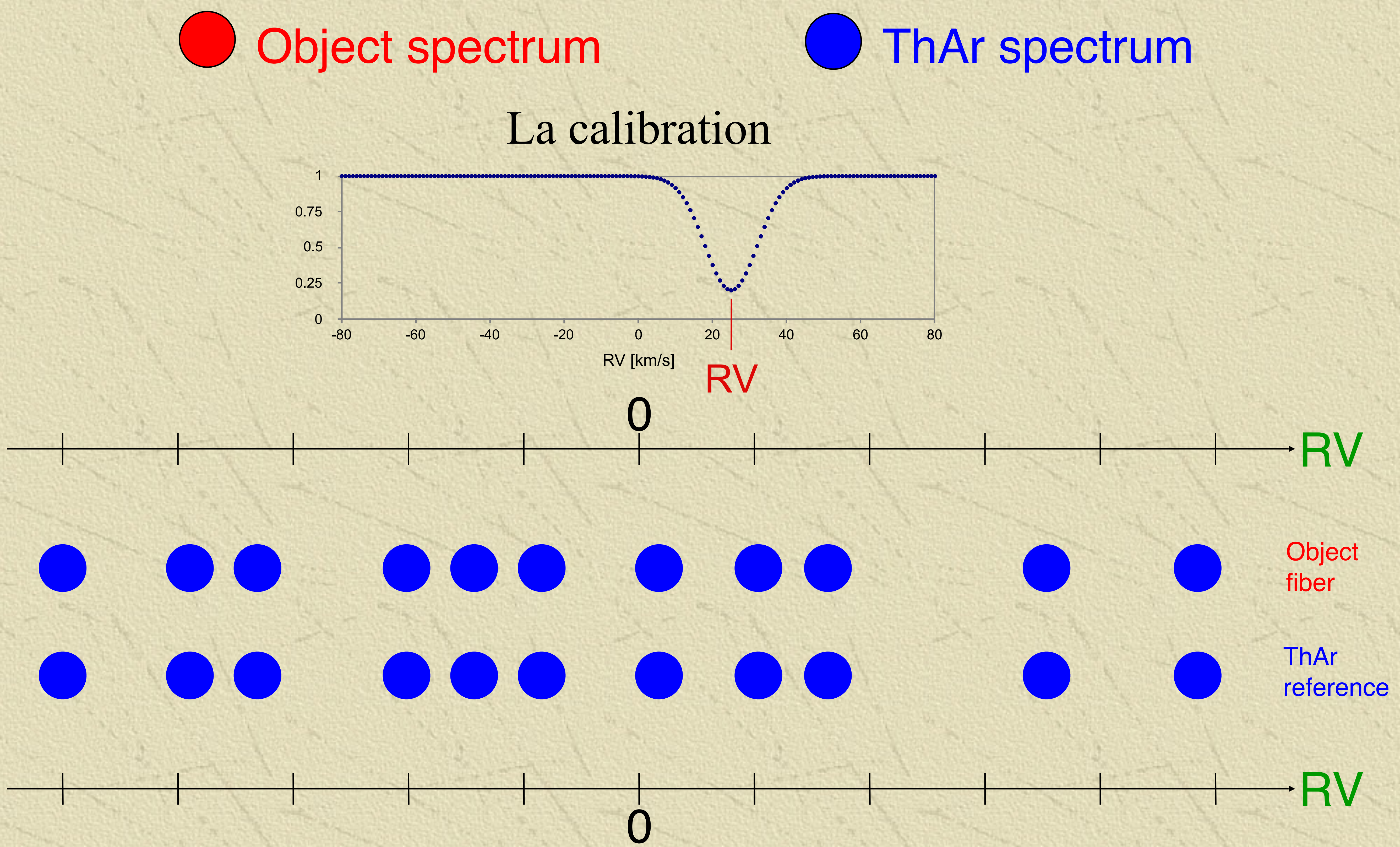
Marco Gullieuszik, ESO

La technique de la référence simultanée





Object spectrum
ThAr spectrum
1
0.75
0.5
0.25
0
-80
-60
-40
-20
0
20
40
60
80
RV [km/s]
RV
0
RV
Object
fiber
ThAr
reference
RV
0

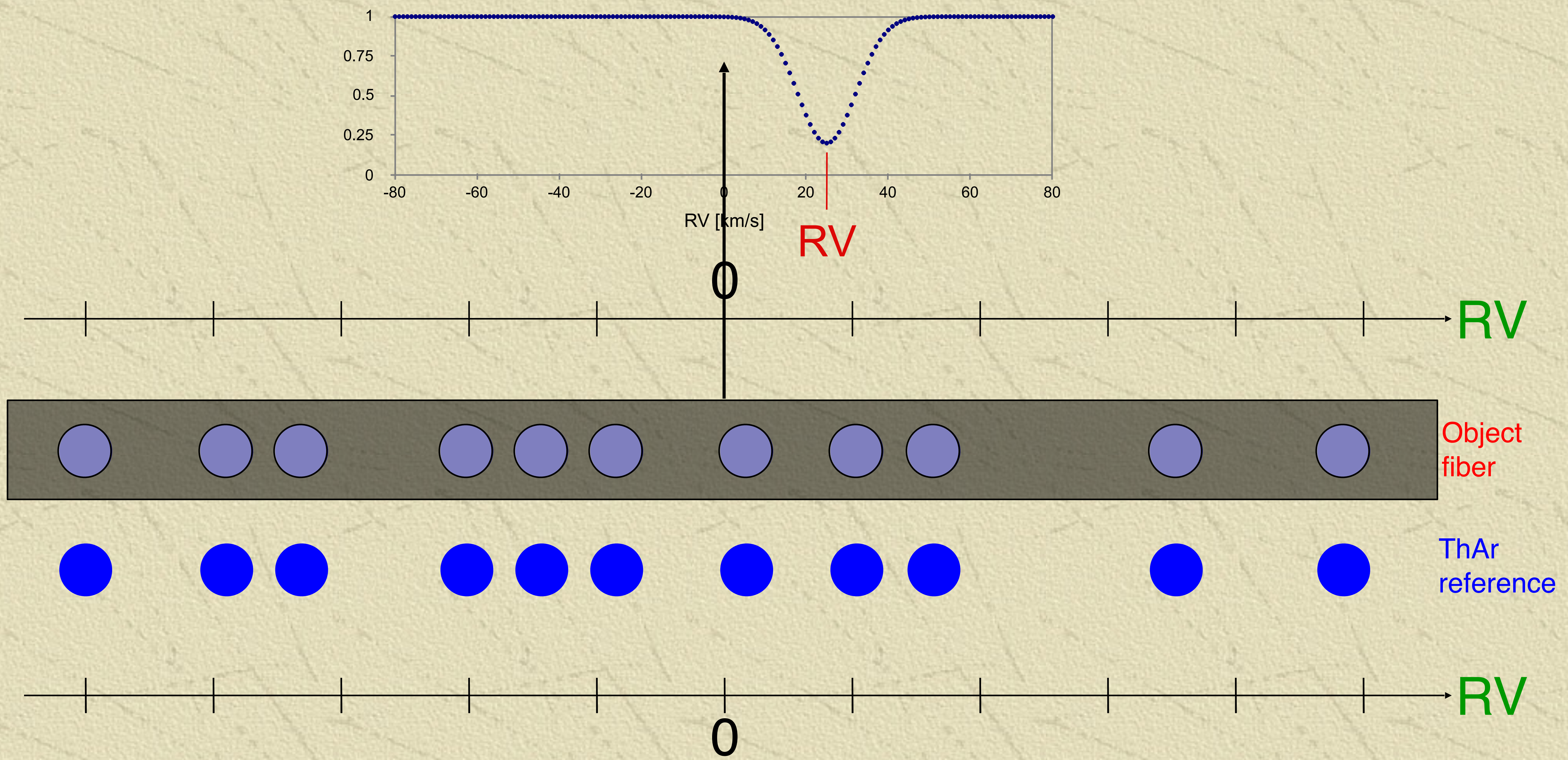


Object spectrum
ThAr spectrum
La calibration
1
0.75
0.5
0.25
0
-80
-60
-40
-20
0
20
40
60
80
RV [km/s]
RV
0
RV
Object fiber
ThAr reference
RV
0

Object spectrum

ThAr spectrum

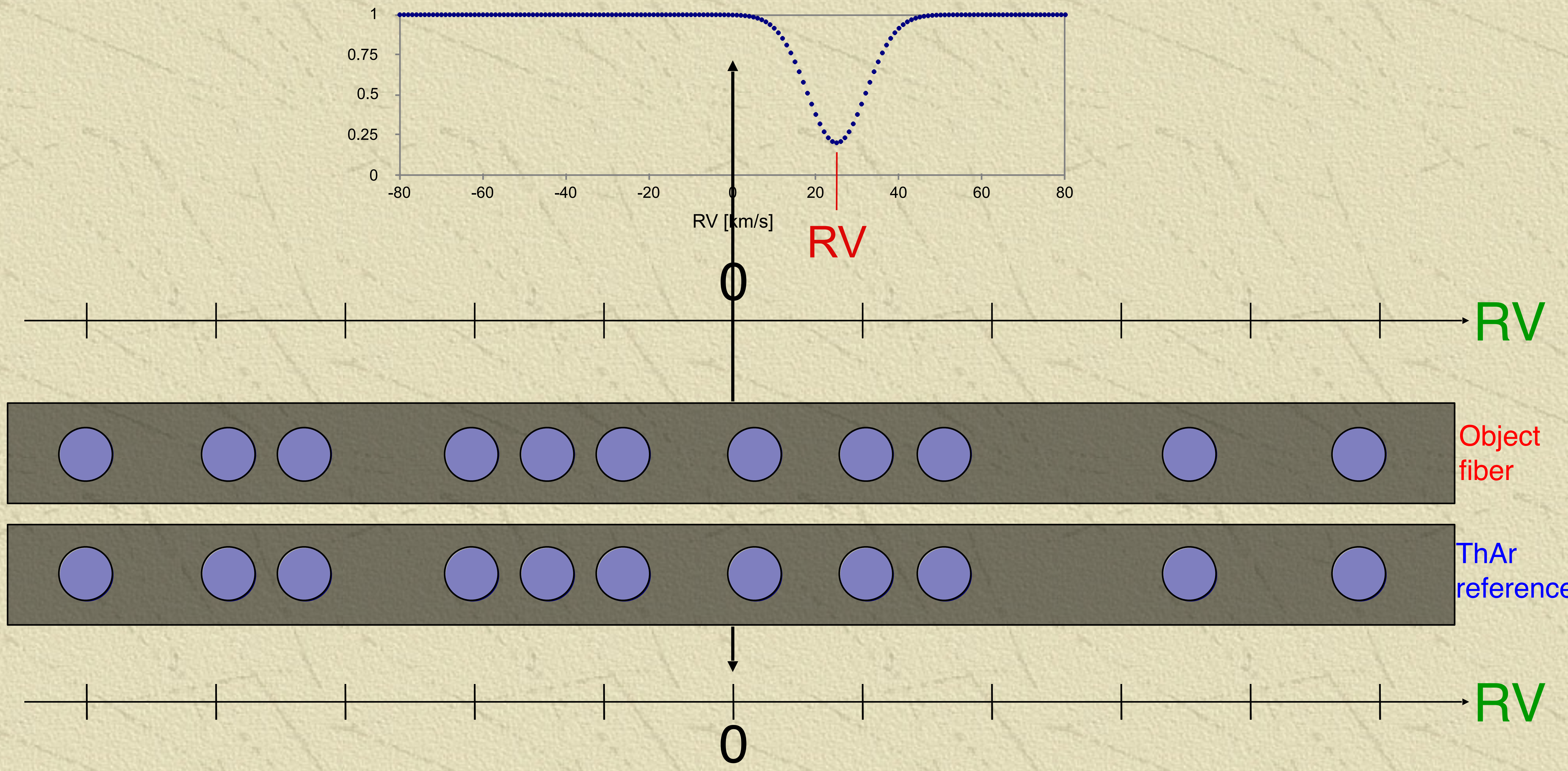
La calibration



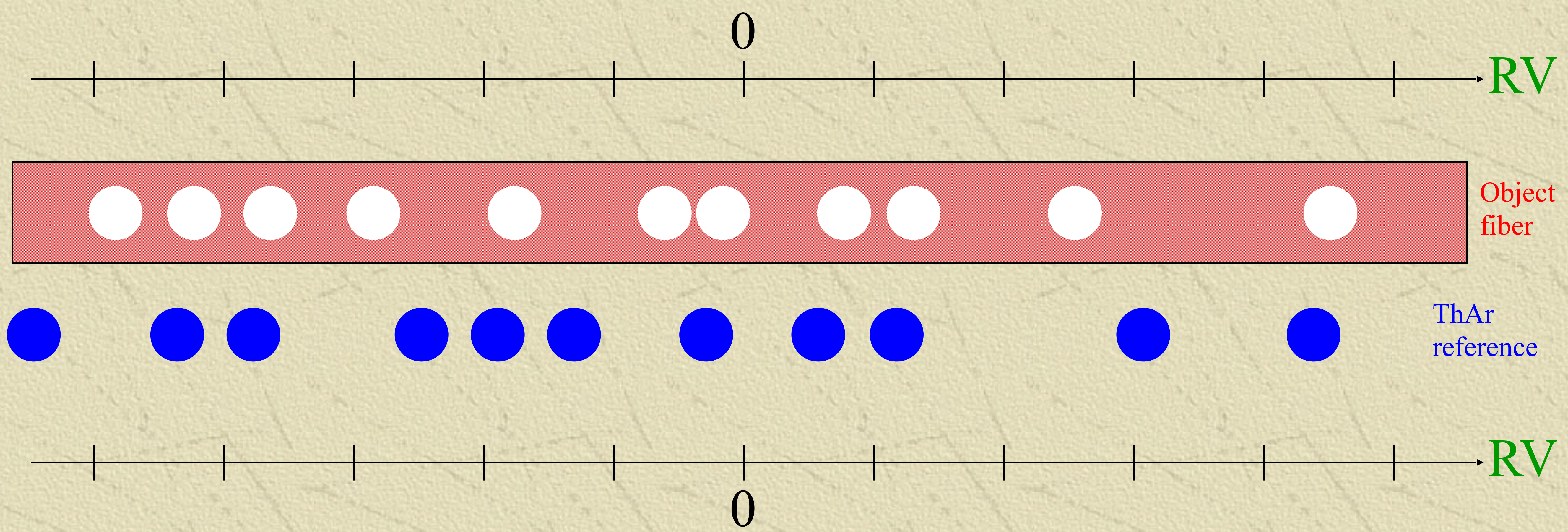
Object spectrum

ThAr spectrum

La calibration

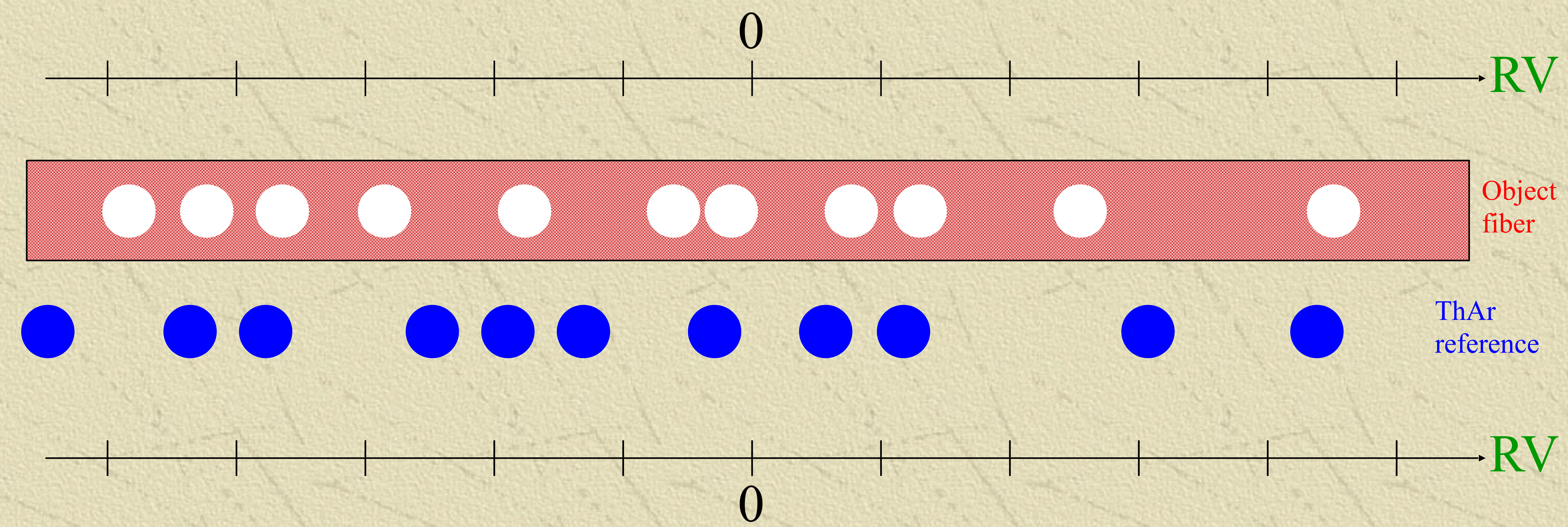


Object spectrum ThAr spectrum



Object spectrum ThAr spectrum

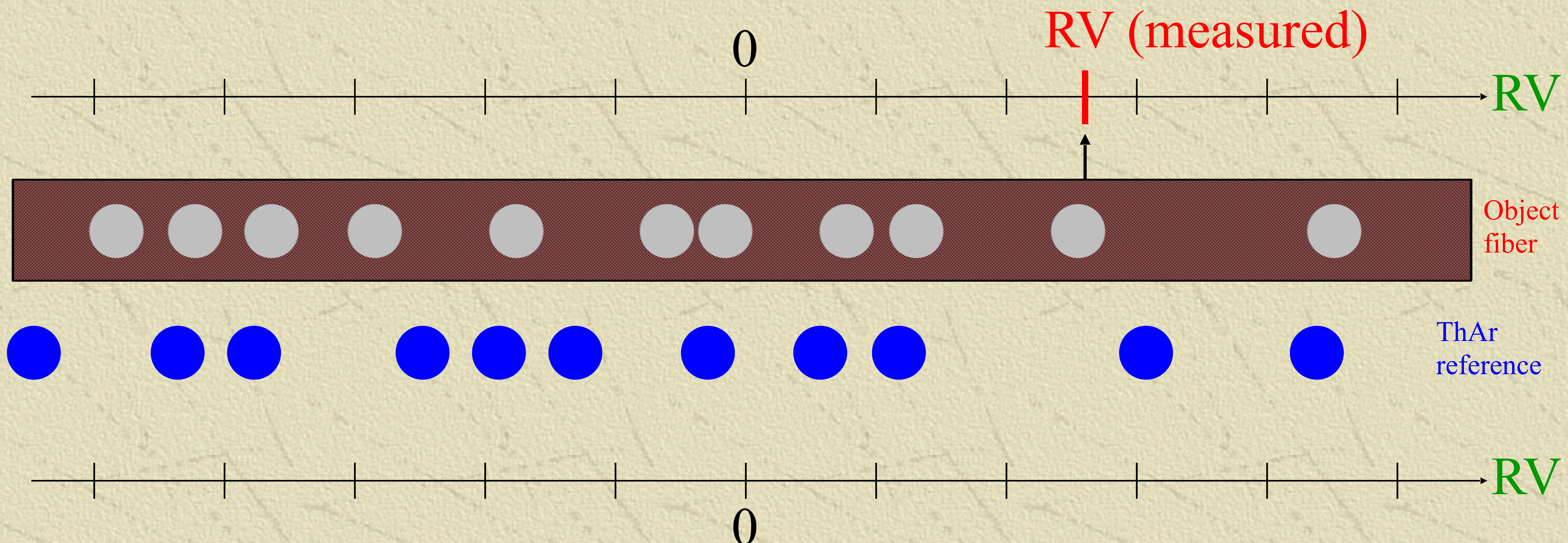
La mesure scientifique



Object spectrum ThAr spectrum

La mesure scientifique

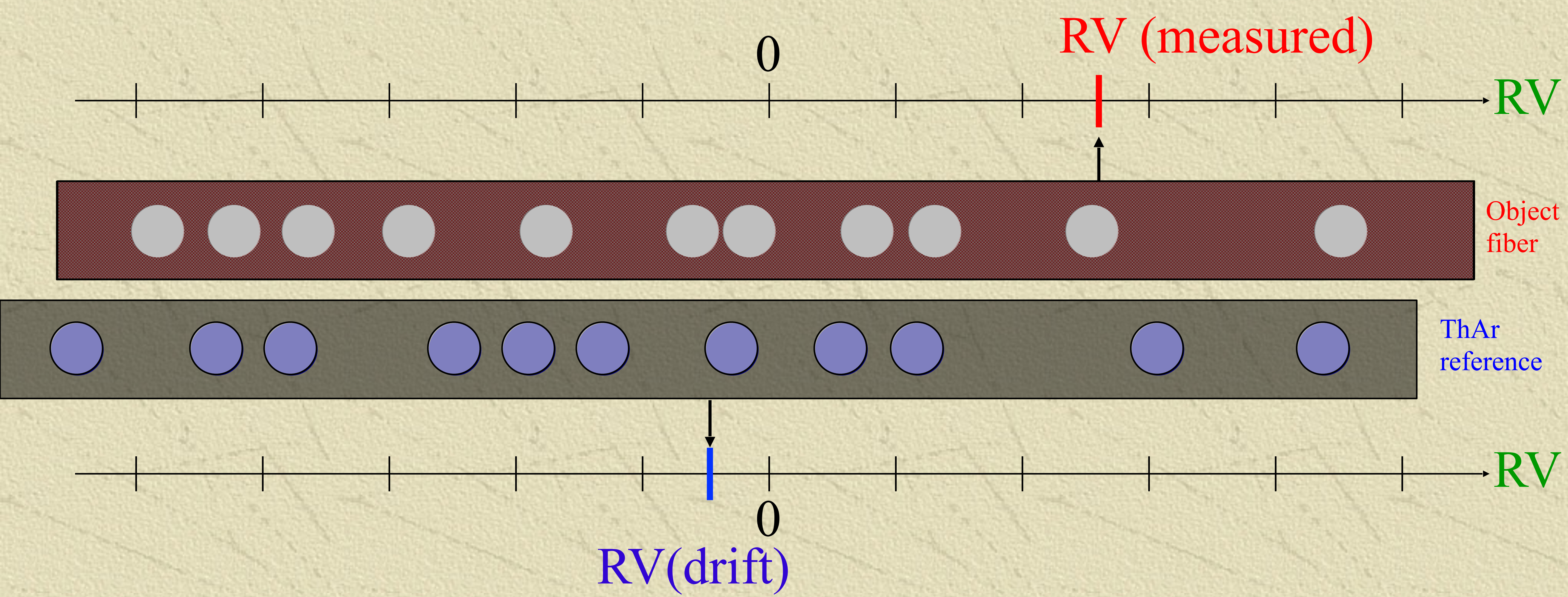
RV (measured)



Object spectrum ThAr spectrum

La mesure scientifique

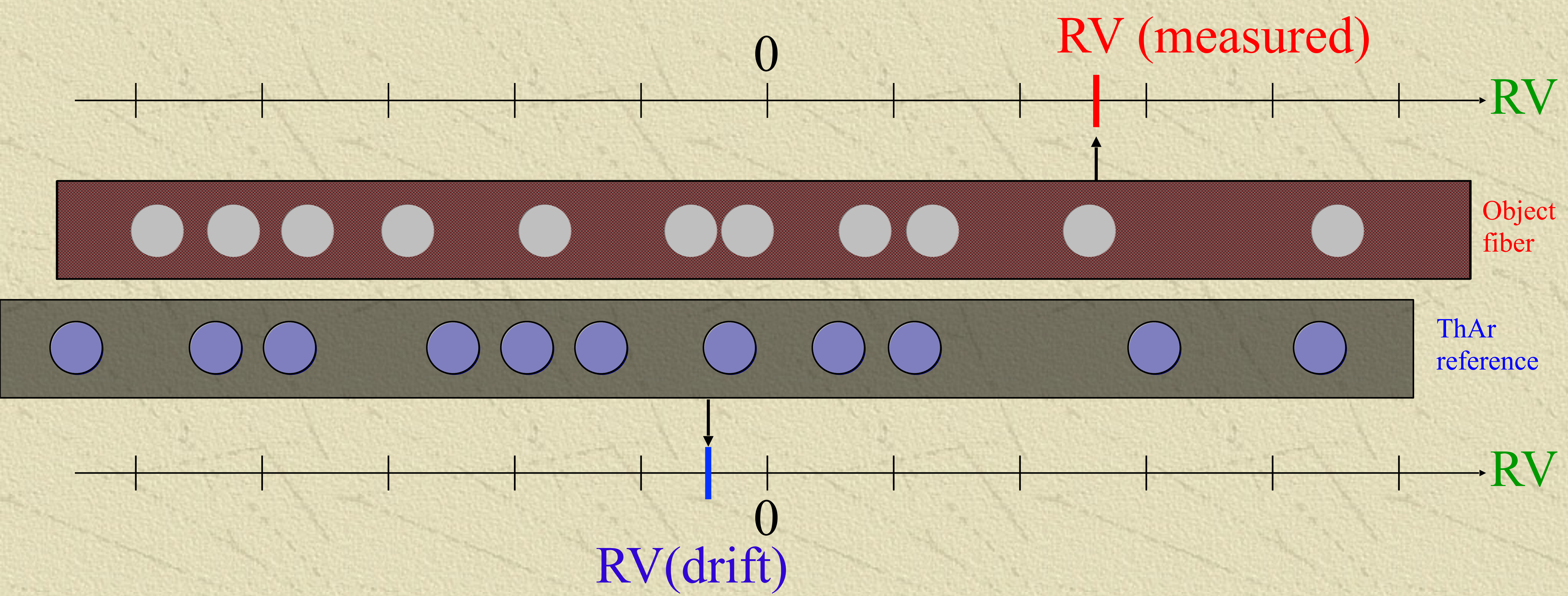
RV (measured) RV(drift)



Object spectrum ThAr spectrum

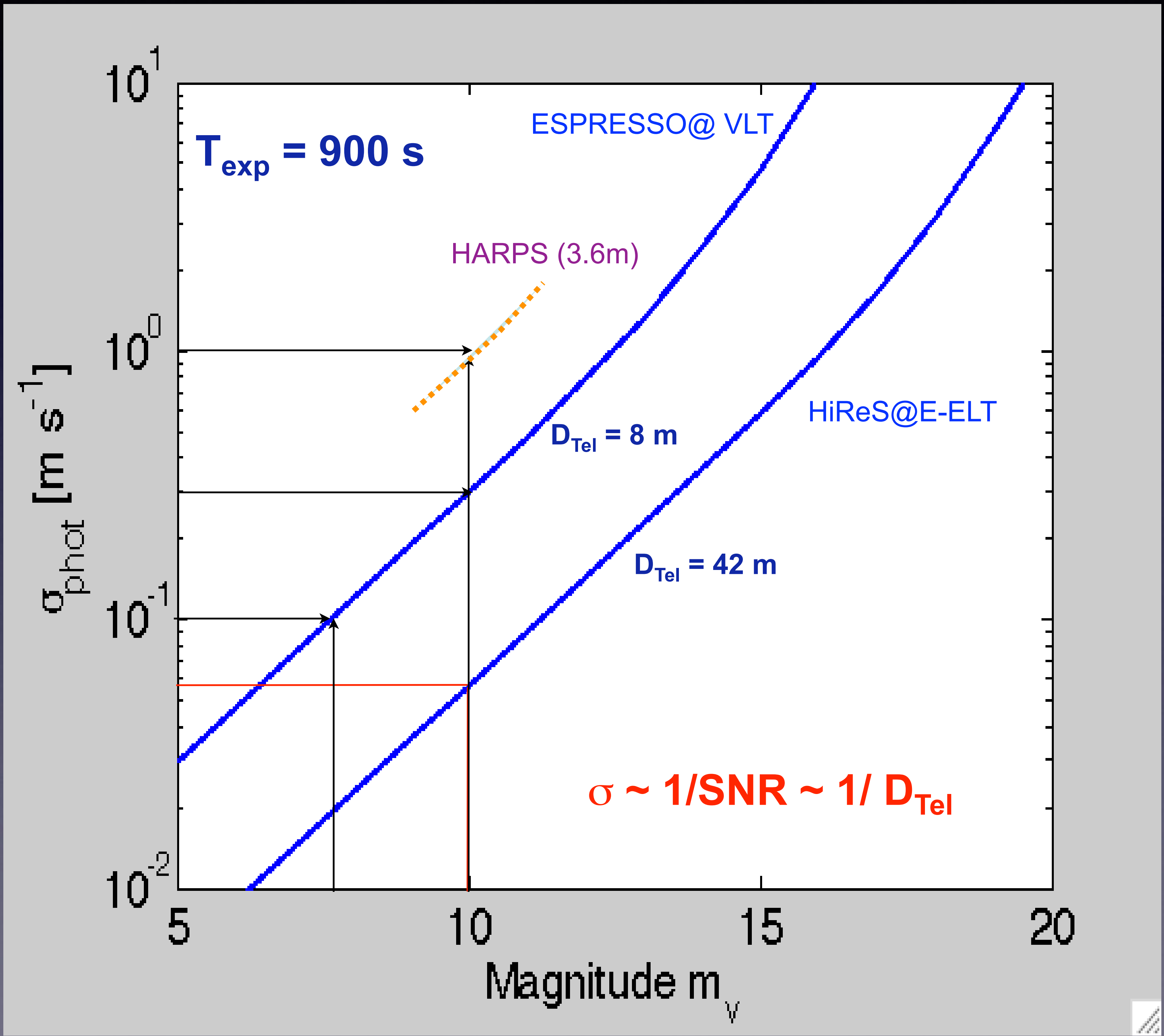
La mesure scientifique

RV (object) = RV (measured) - RV(drift)



Le bruit photonique

Pour un spectrographe style HARPS: R > 100'000, ε_{Tot} = 6%

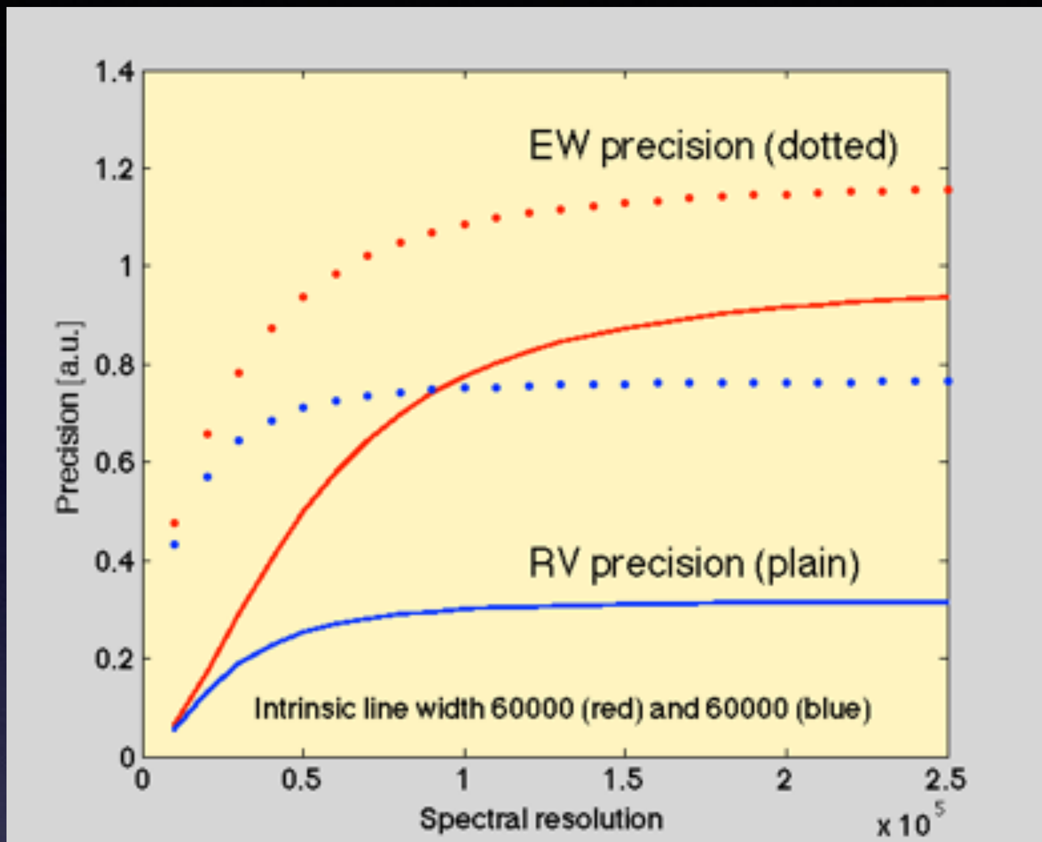


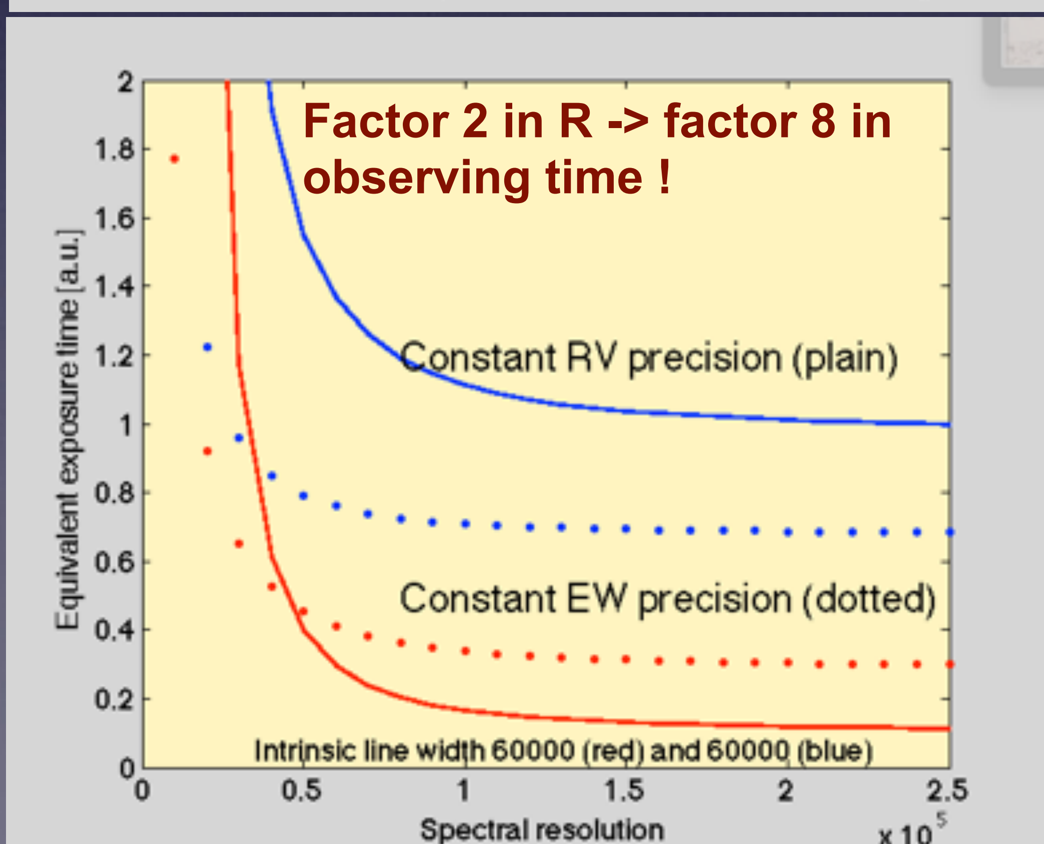
1) HARPS/ 3.6m
   1 m/s in 15' on V=10 star
   -> ~50 cm/s on VLT
   -> ~10 cm/s on E-ELT

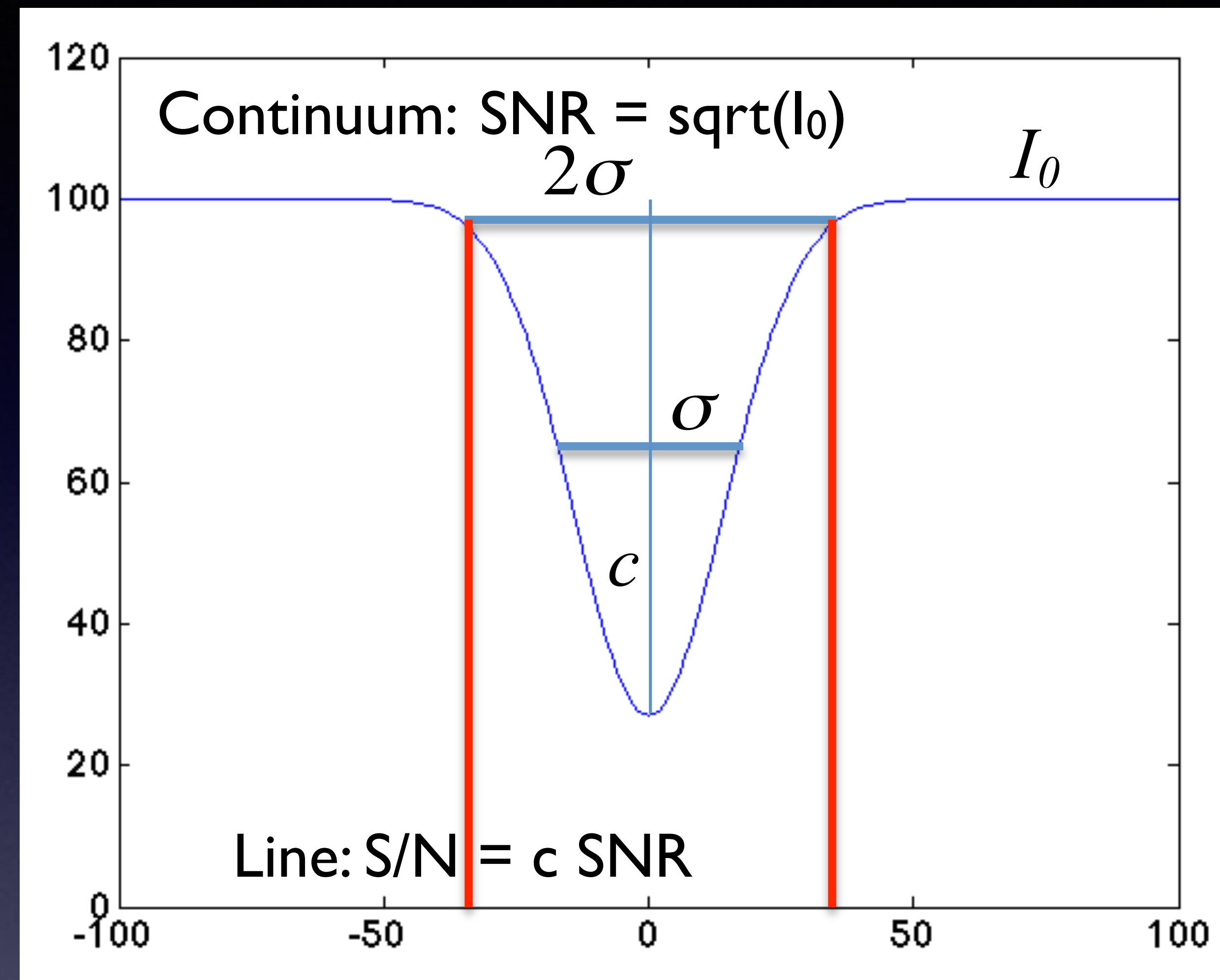
2) ESPRESSO/VLT
   Vlim = ~8 for 10 cm/s in 15'
   => Many solar-type stars
   ~700 non-active stars
   => Earth twin search
   TRANSITS (TESS/CHEOPS)

3) HIRES/E-ELT
   1 cm/s on star with V<6
   10 cm/s on V=11-12 stars
   TRANSITS (PLATO)

SNR, précision & Co.







$$\varepsilon_x = \frac{\sqrt{\sigma_{ix}^2 + \sigma_{Rx}^2}^{\,1.5}}{\sqrt{2I'_0} \cdot EW_x} \cdot \sqrt{\left(1 - \frac{c}{2}\right) + n_c \cdot \left(\frac{I_D}{I'_0} \cdot t + \frac{1}{b_c \cdot b_R} \cdot \frac{RON^2}{I'_0}\right) + \frac{I'_S}{I'_0}}$$

$$\varepsilon_{EW} = \frac{\sqrt{2}\sqrt{\sigma_{ix}^2 + \sigma_{Rx}^2}^{\,0.5}}{\sqrt{I'_0} \cdot EW_x} \cdot \sqrt{\left(1 - \frac{c}{2}\right) + n_c \cdot \left(\frac{I_D}{I'_0} \cdot t + \frac{1}{b_c \cdot b_R} \cdot \frac{RON^2}{I'_0}\right) + \frac{I'_S}{I'_0}}$$

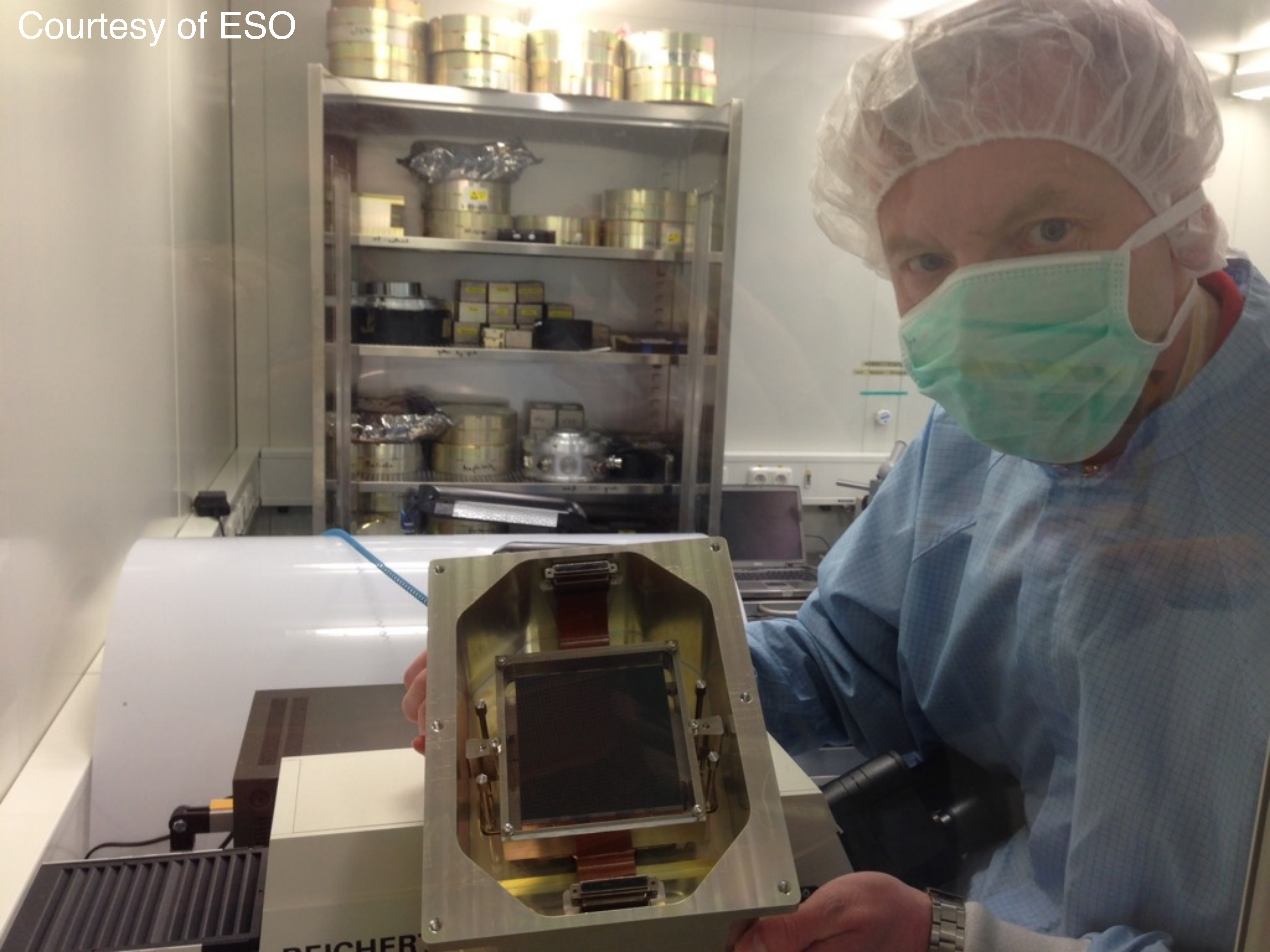
Conservation of the ‘étendue’

The étendue is defined as E=A x O, where A is the area of the beam at a given optical surface and O is the solid angle under which the beam passes through the surface.

When following the optical path of the beam through an optical system, E is constant, in particular, it cannot be reduced

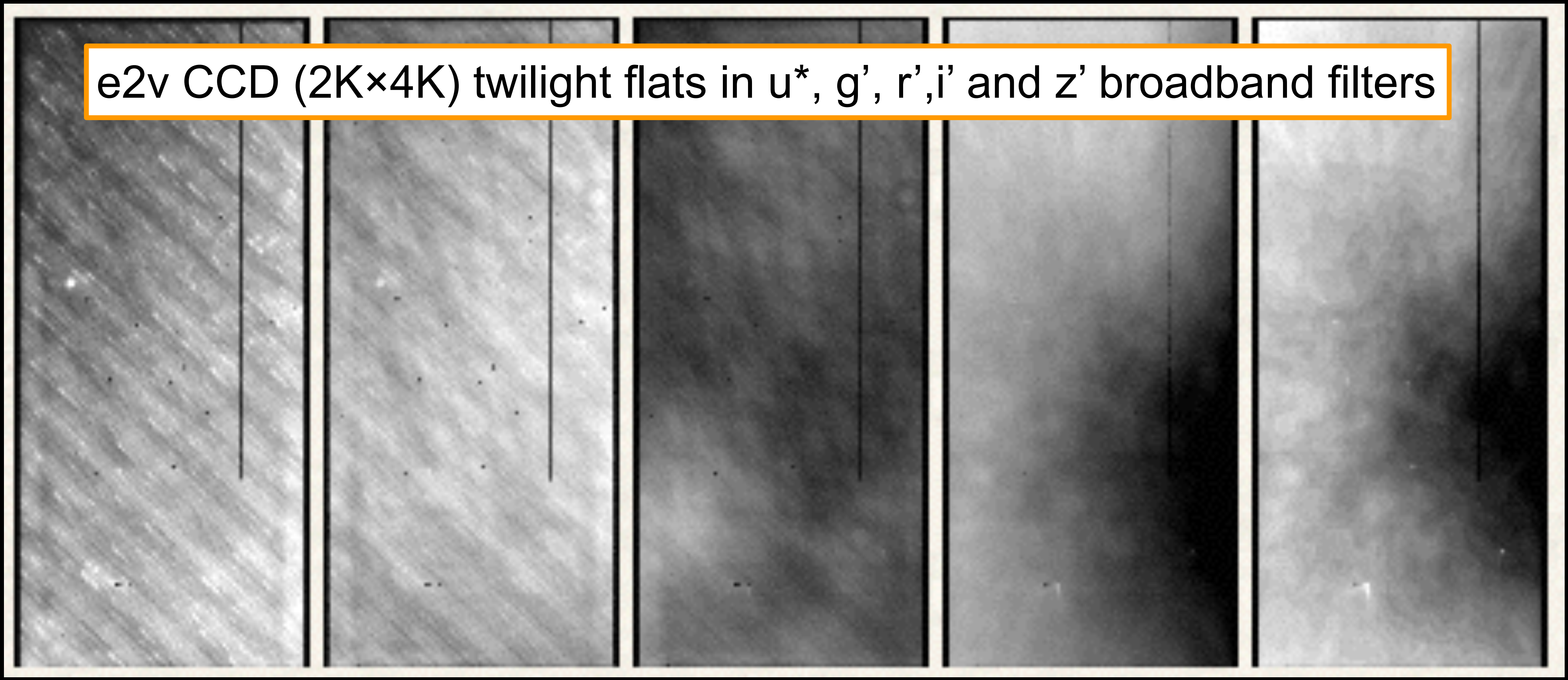
For a telescope, E is the product of the primary mirror surface and the two-dimensional field (in sterad) transmitted by the optical system. Normally, the transmitted field is defines a slit width. When entering spectrograph, the slit x beam aperture at the slit is equal to the etendue E of the telescope. This implies that at fixed spectral resolution, the slit width and the beam diameter cannot be chosen independently, since dΘ depends on both.

$$R \cdot \frac{D_T \cdot FOV}{D_C \cdot \tan\beta} = const \qquad N_{Pixels} \propto \frac{D_T^2 \cdot FOV^2}{D_C^2 \cdot \tan\beta}$$


Courtesy of ESO

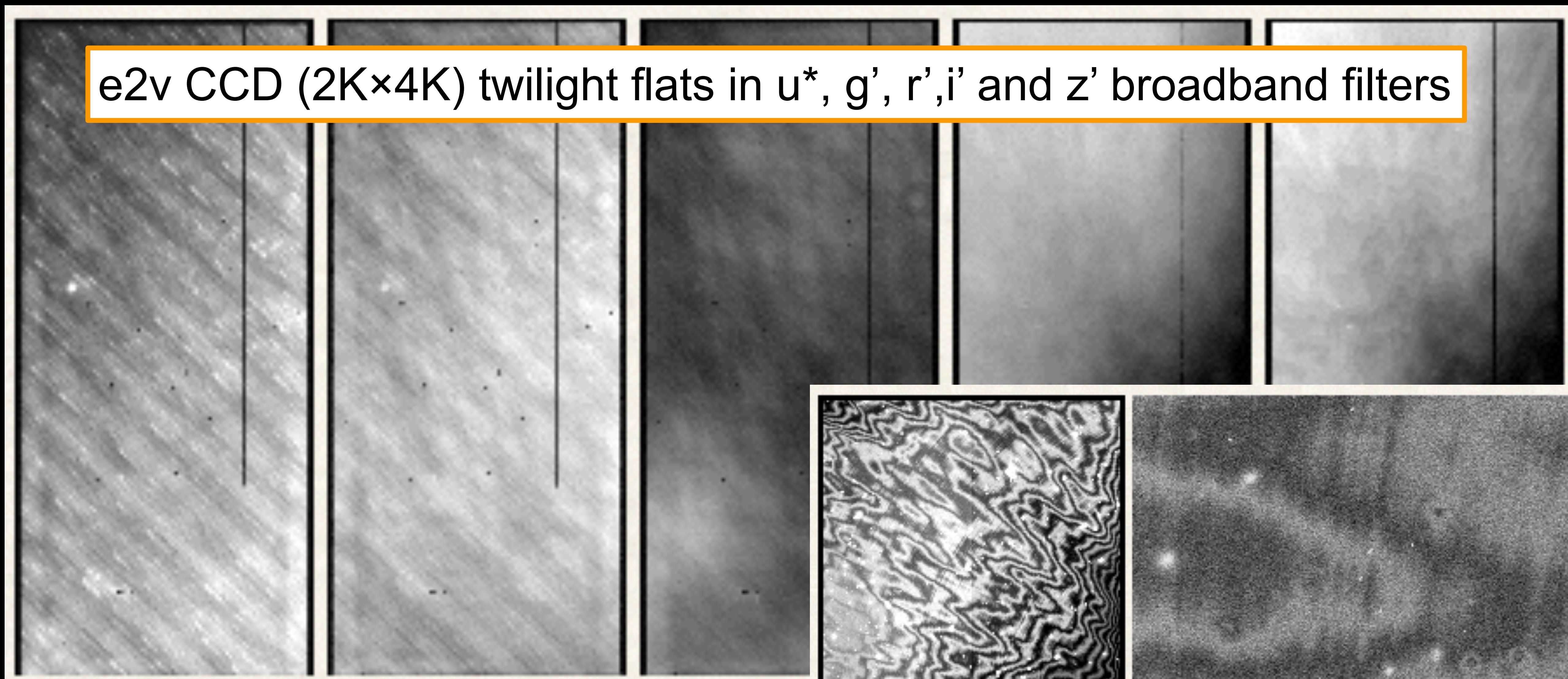
QE variations

Boron implant / laser anneal (blue end), and fringing (red)

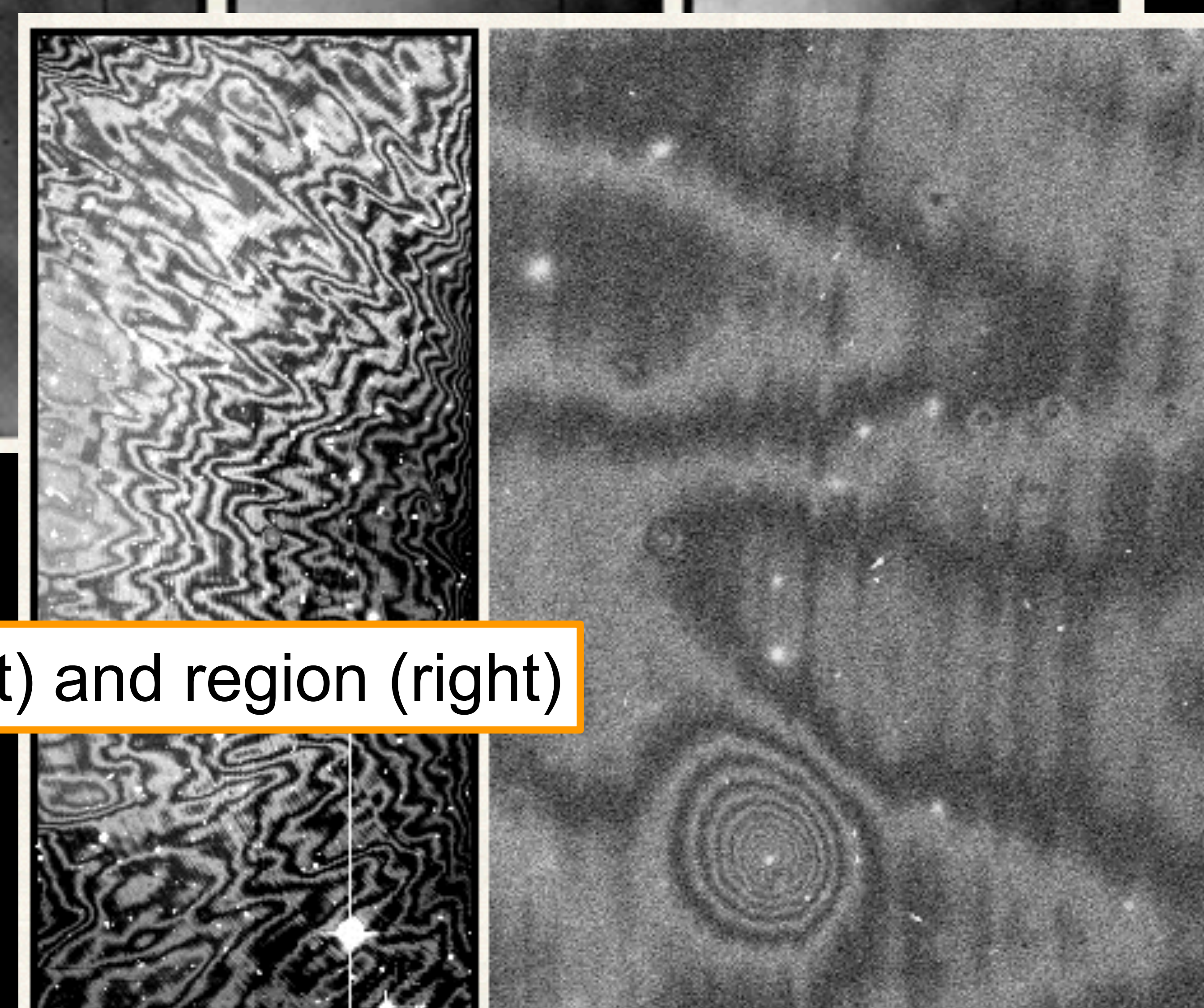


QE variations

Boron implant / laser anneal (blue end), and fringing (red)

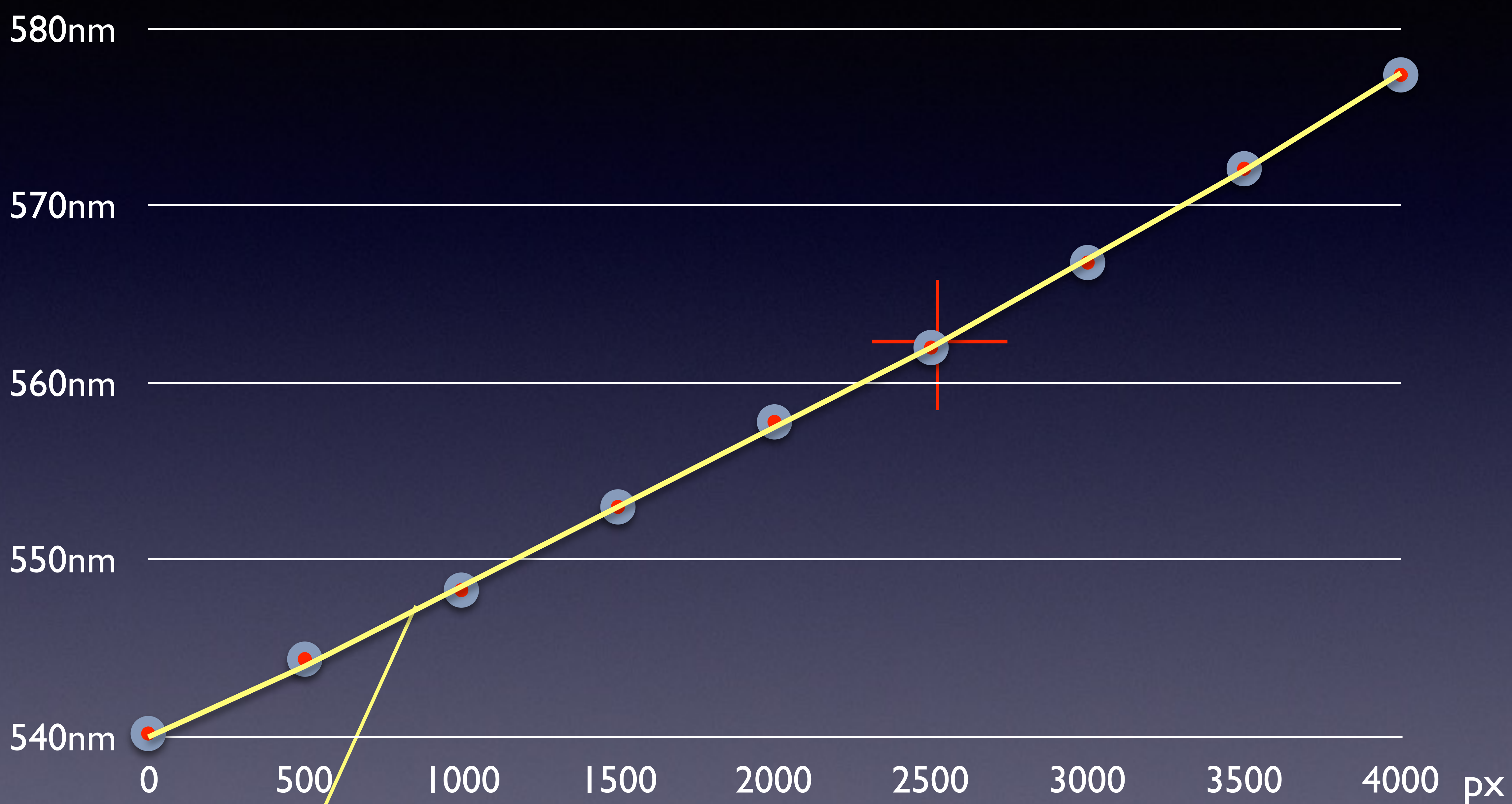


e2v CCD (2K×4K) twilight flats in u*, g’, r’,i’ and z’ broadband filters



Fringes in the i’ band: full CCD (left) and region (right)

La calibration

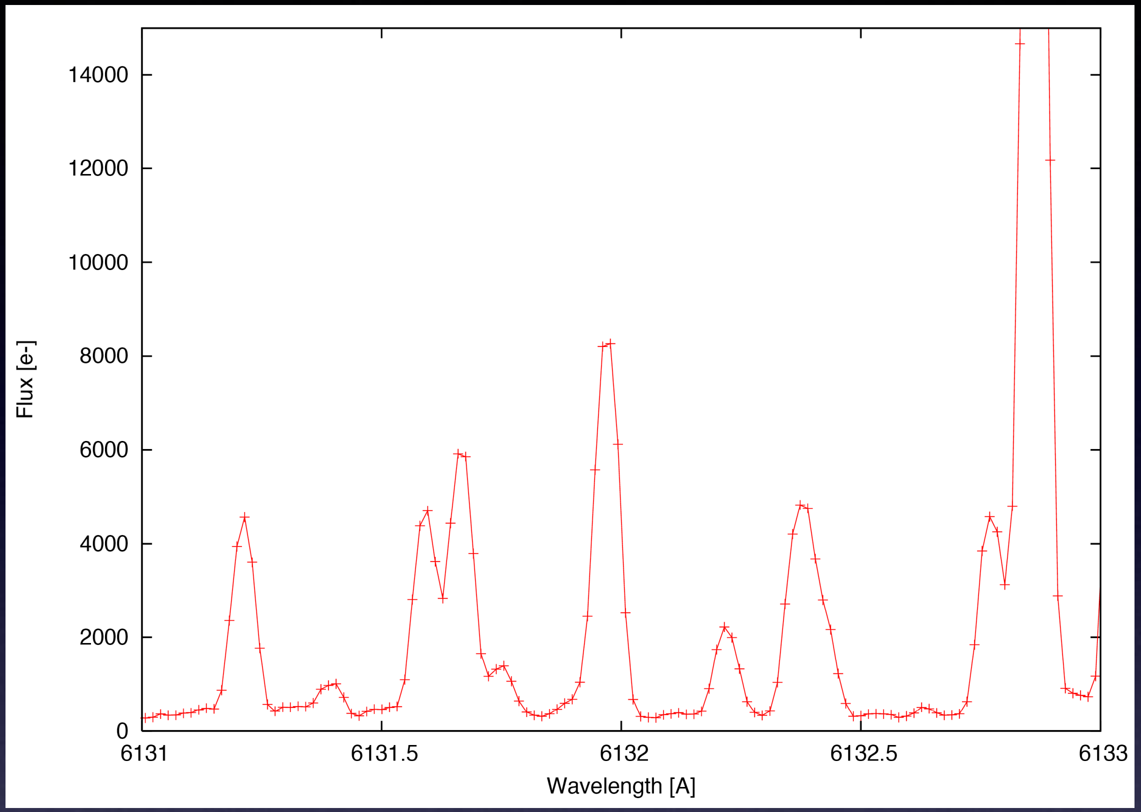


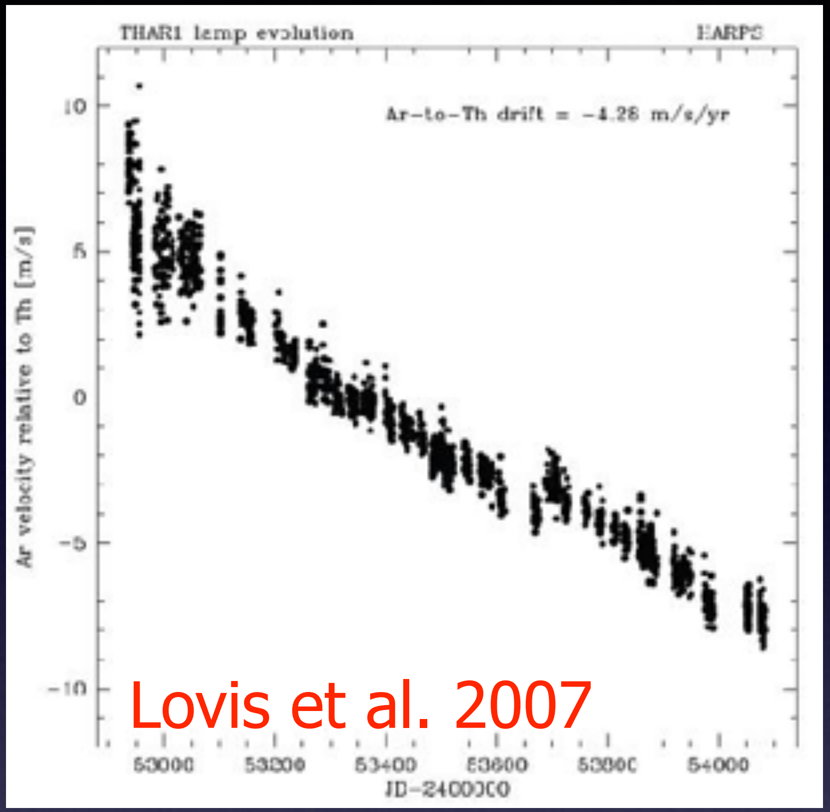
Achieved $\Delta\lambda/\lambda$: (Absolute) accuracy: 1×10^{-7} 5×10^{-8}

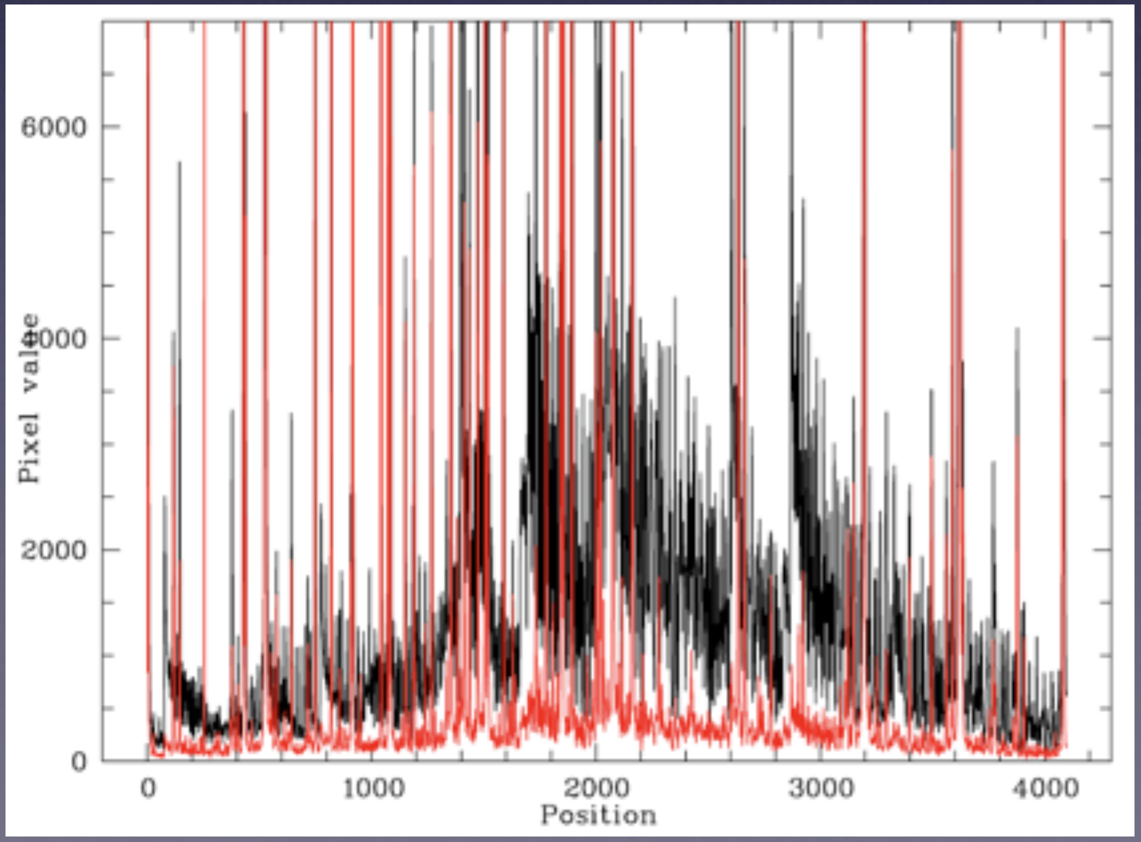
Aimed $\Delta\lambda/\lambda$: Scale factor: 3×10^{-8} 5×10^{-8}

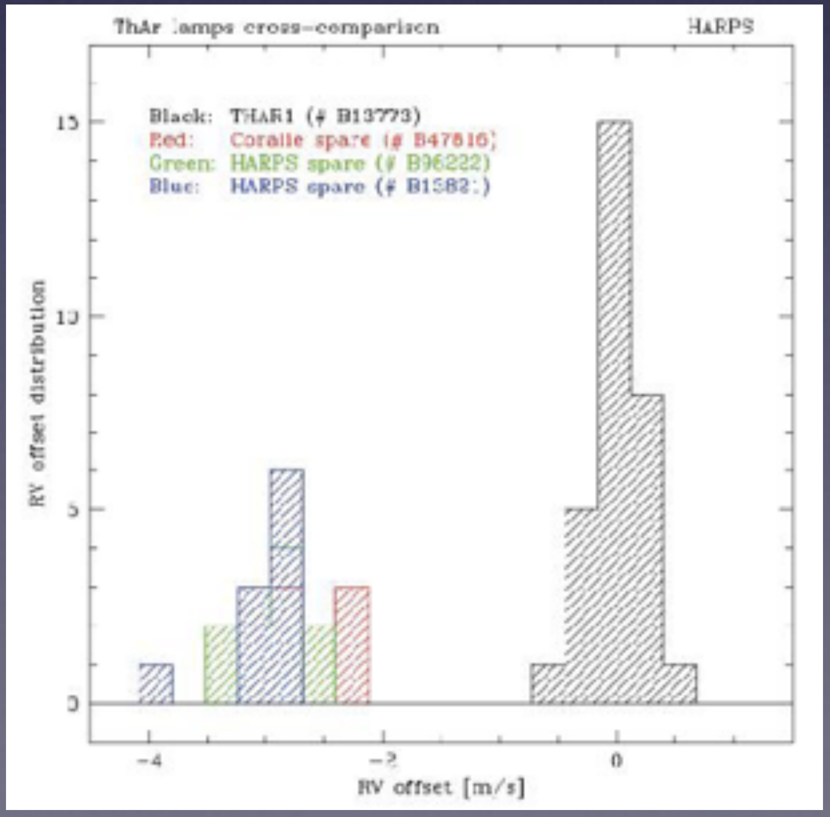
Repeatability: 1×10^{-9} 3×10^{-11}

Limites de la lampe ThAr

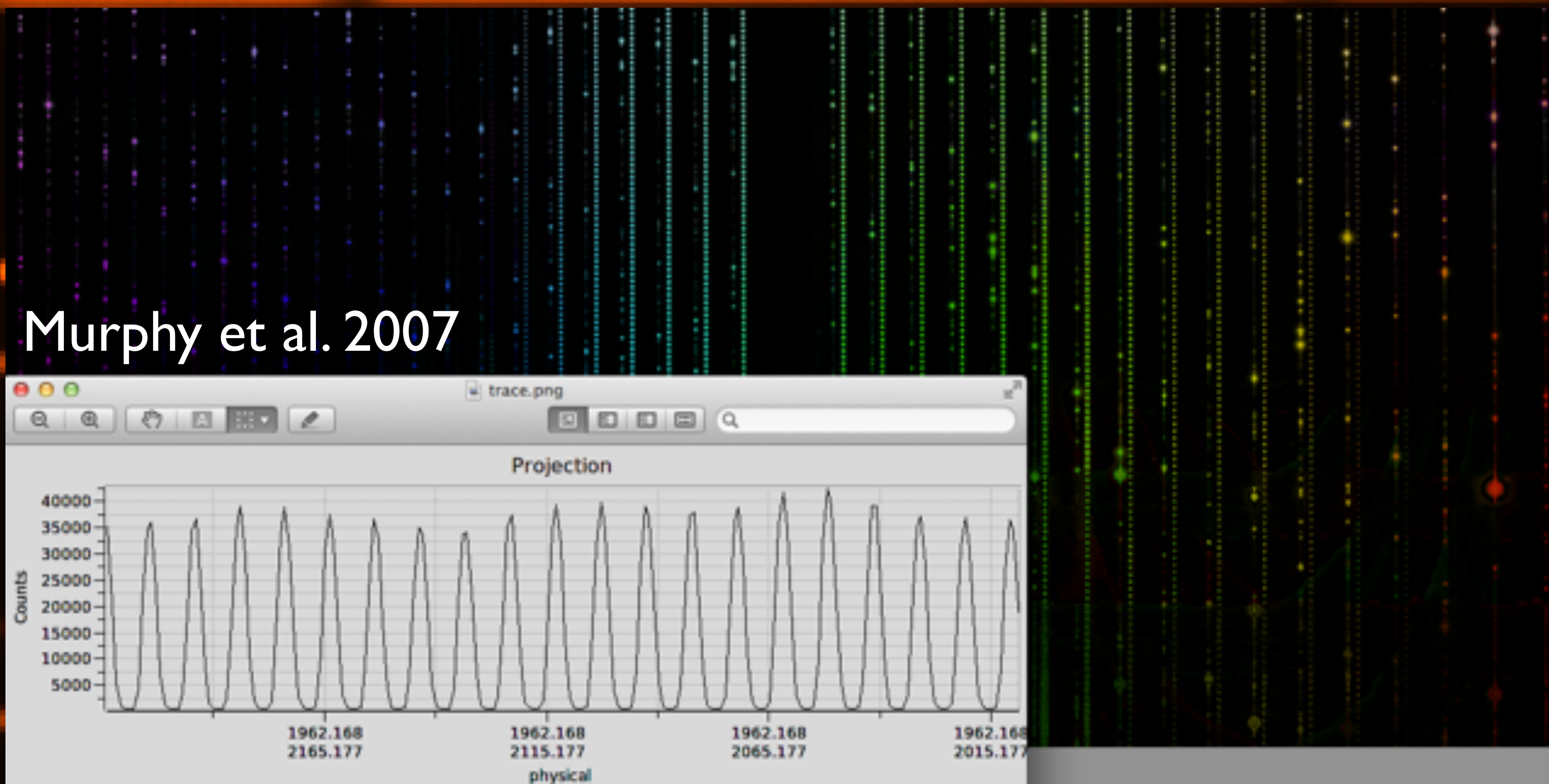


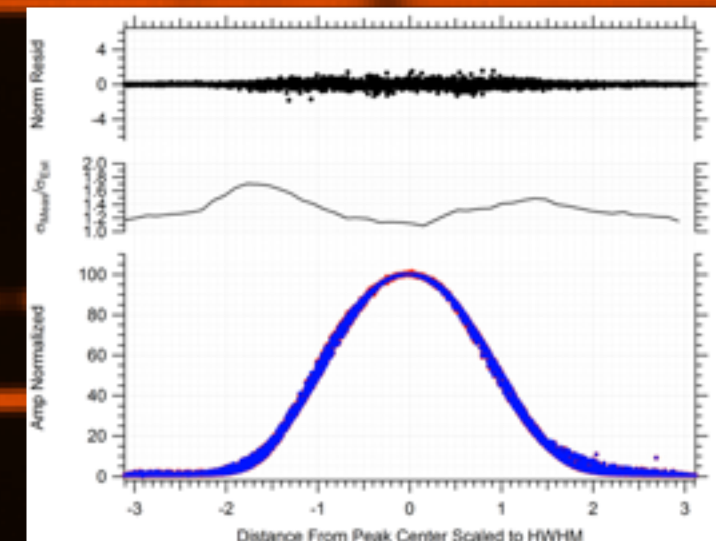






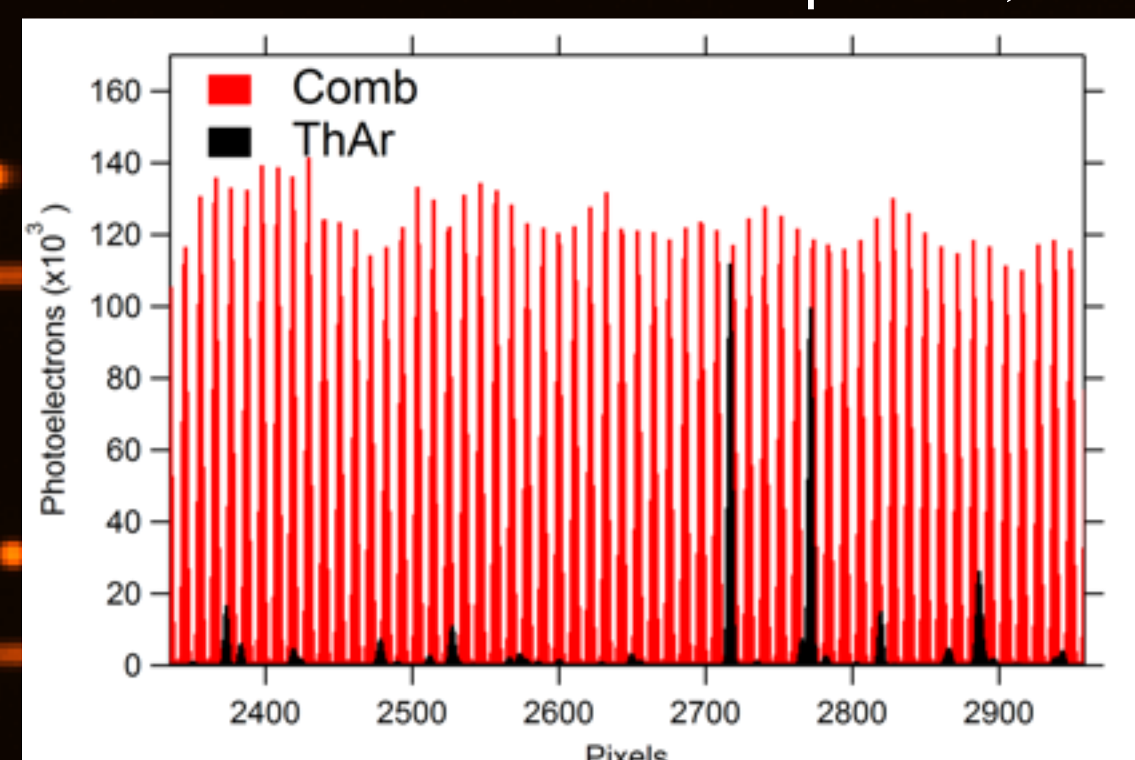
The HARPS-N LFC





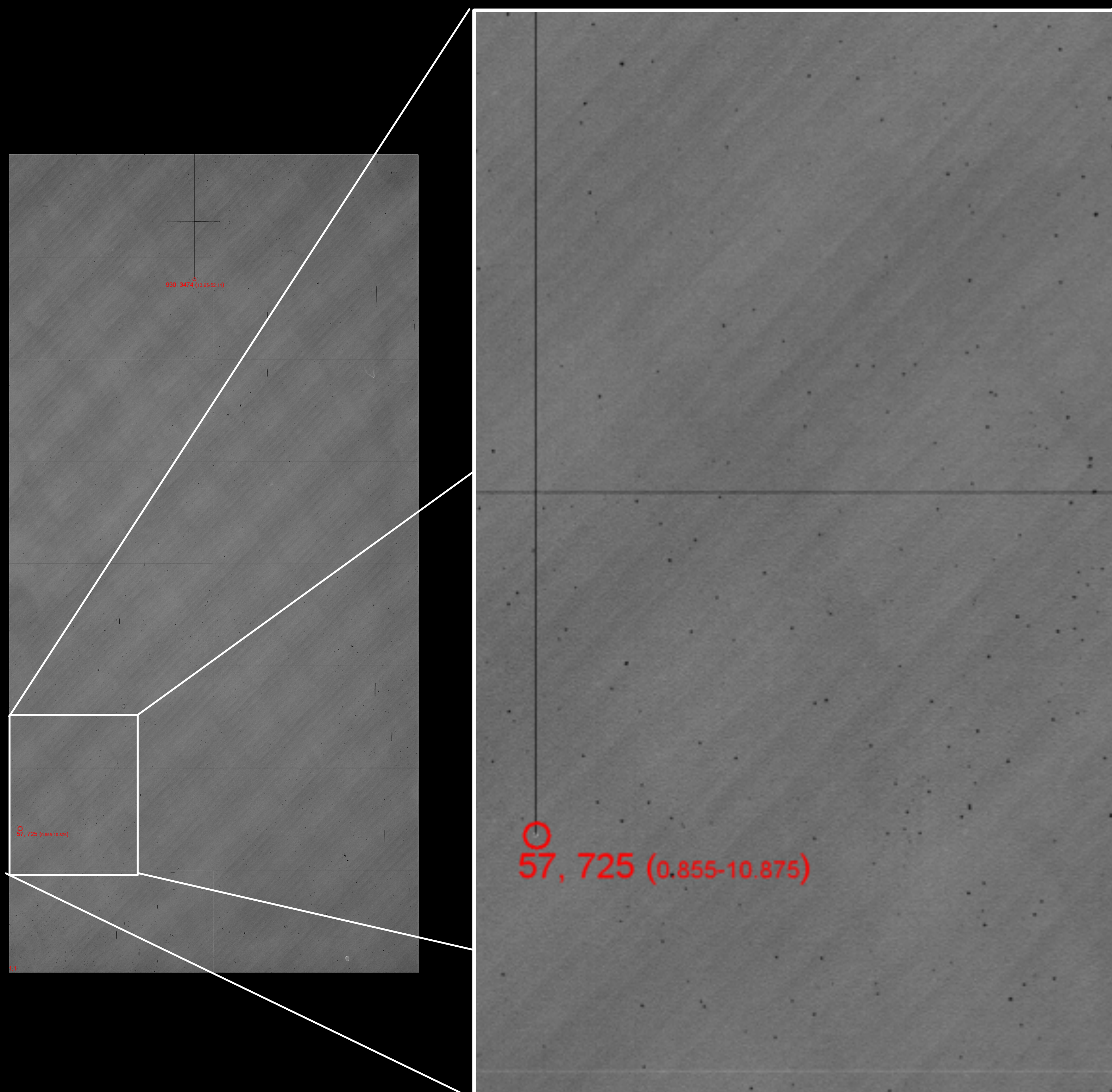
Courtesy of Alex Glenday, CfA

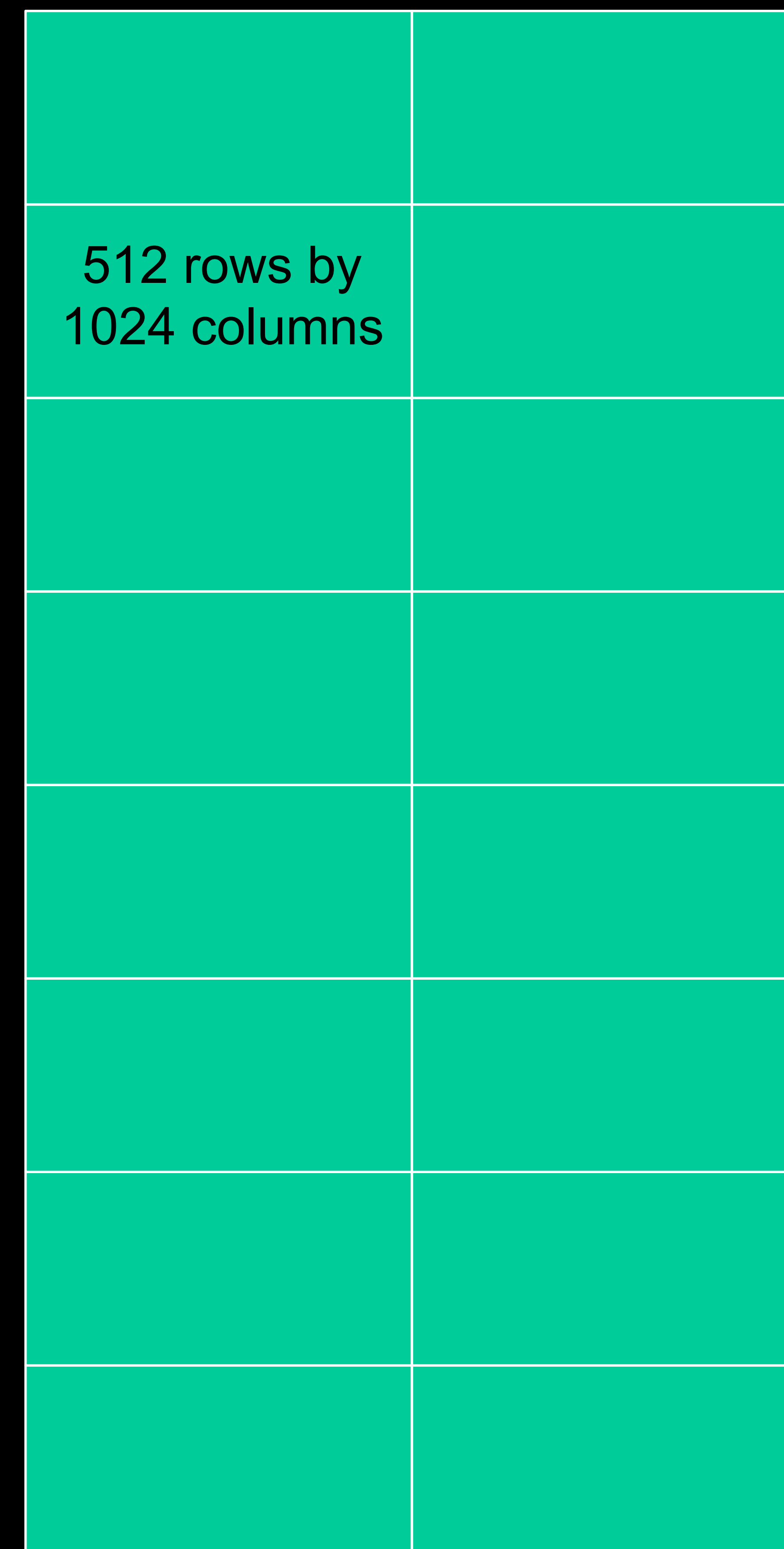
Phillips et al., 2012



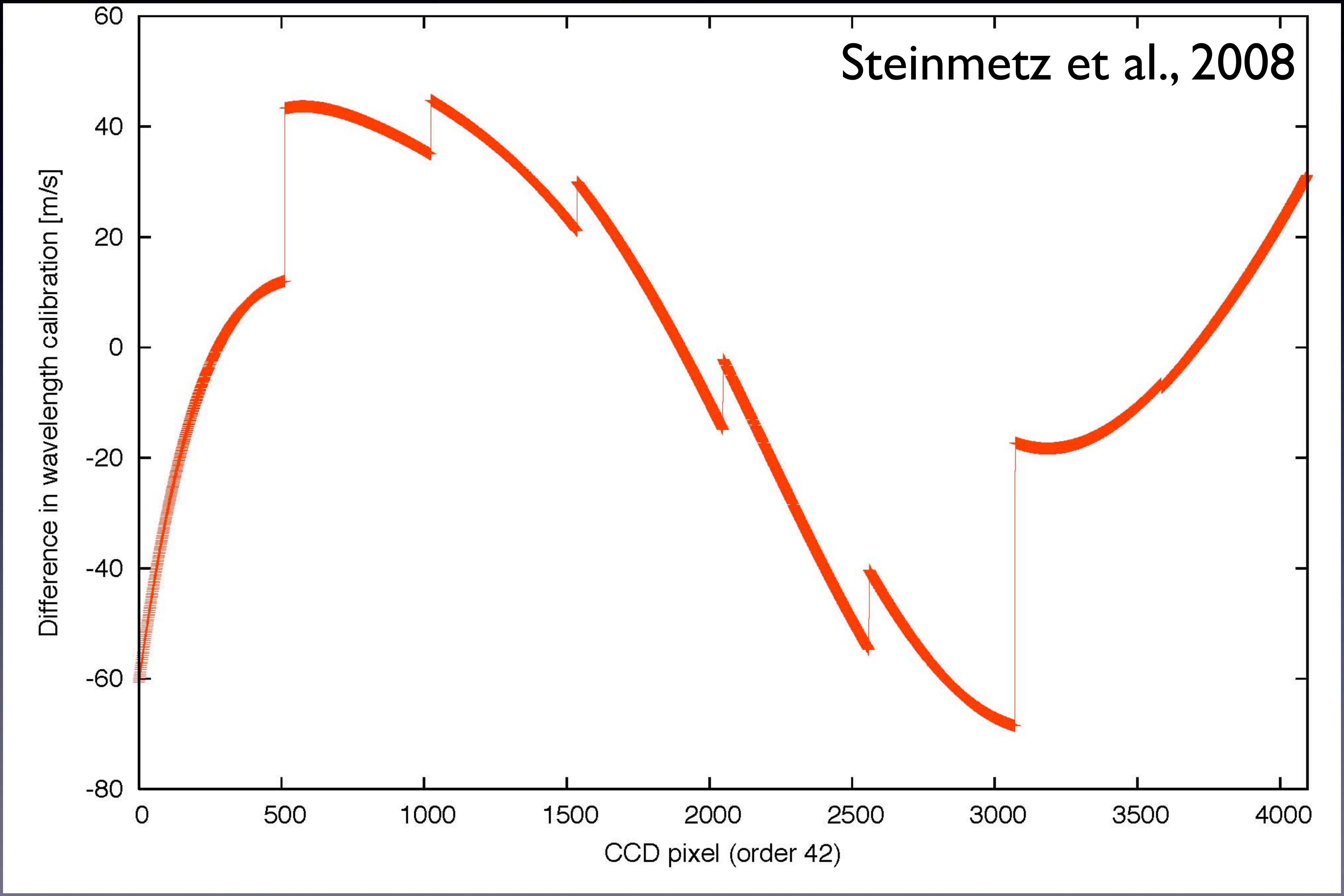
HARPS CCD stitch boundary effect

e2v has provided us with new information to state that they now have a new stepper for stitching with 100 nm precision, and this stitch issue should no longer be an effect.

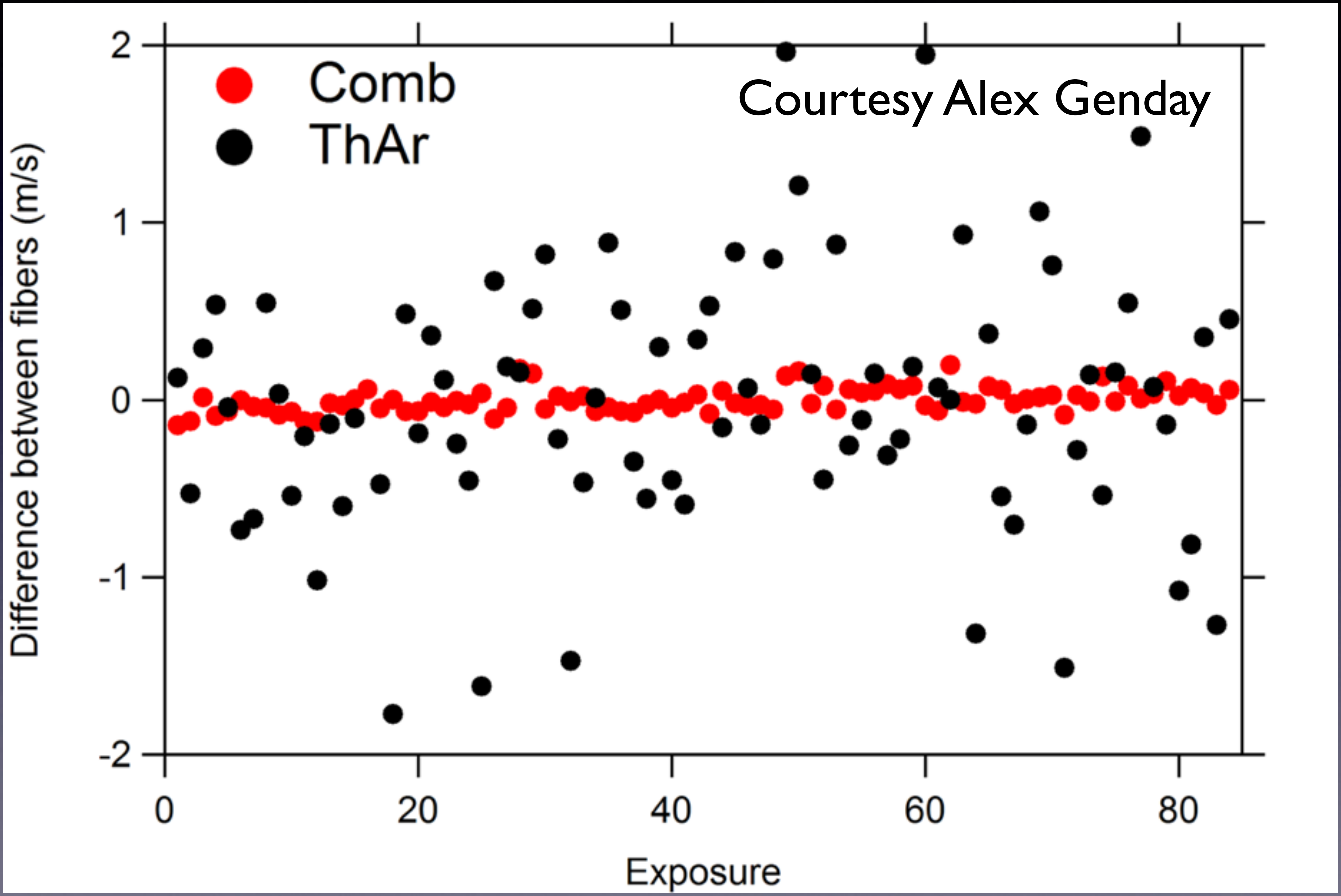




Erreur de calibration et repétibilité

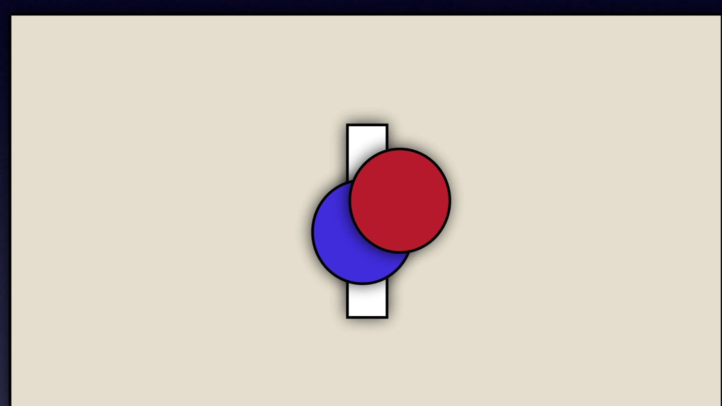


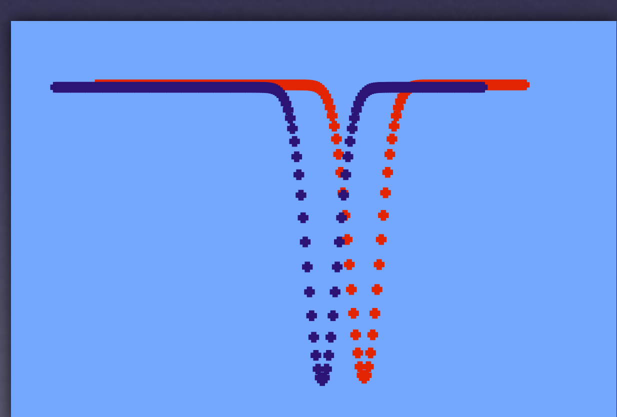
Erreur de calibration et repétibilité



Illumination effects

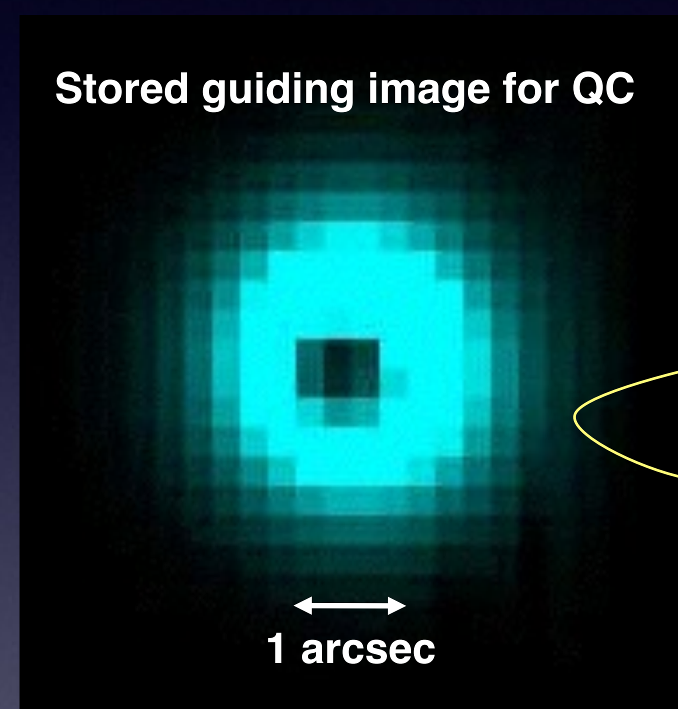
Slit-fed spectrograph

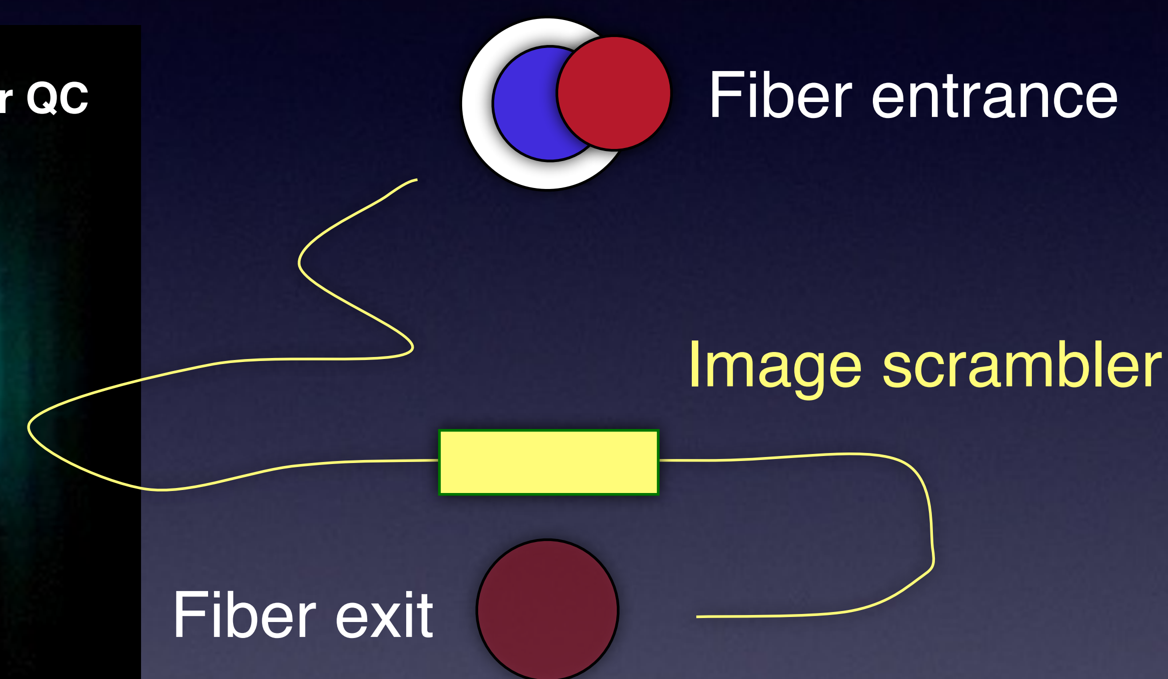


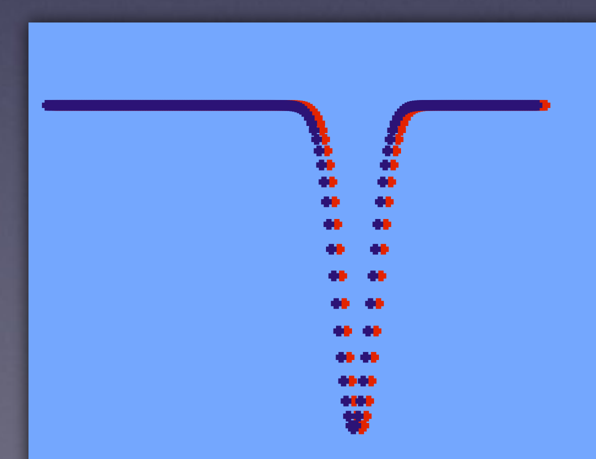


Δ RV

Fiber-fed spectrograph



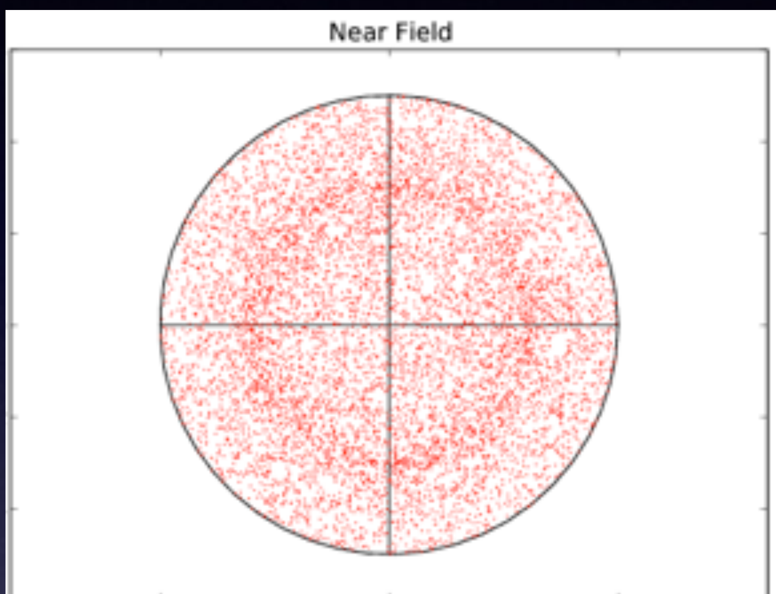


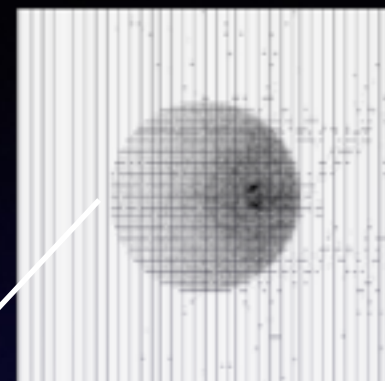


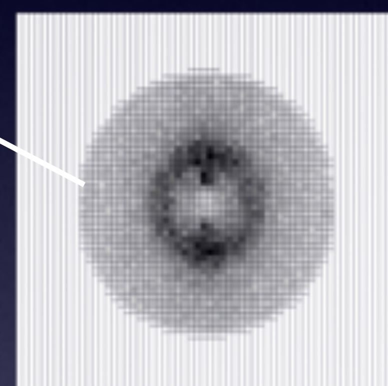
Δ RV

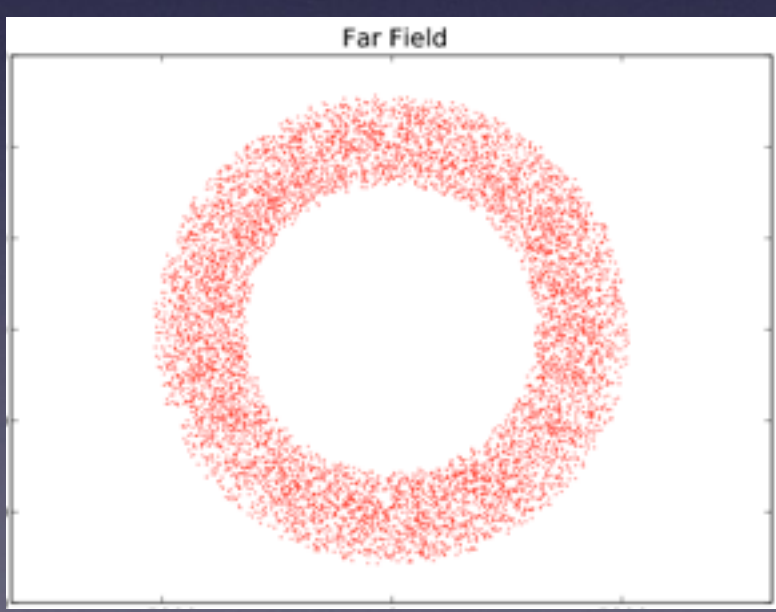
Guiding error:
0.5” → 2-3 m/s
for a fiber-fed spectrograph

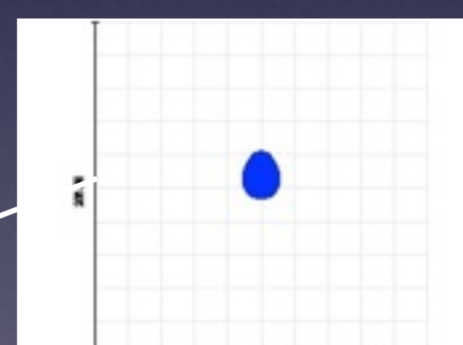
Circular fibers alone do not scramble enough ...

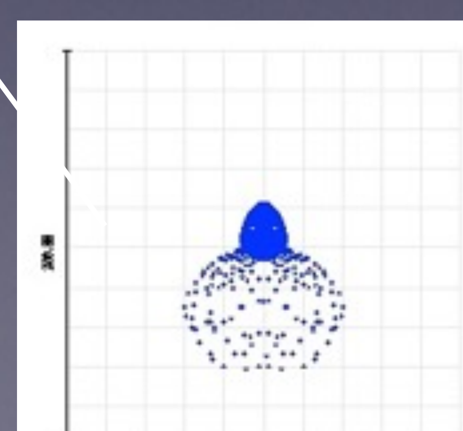


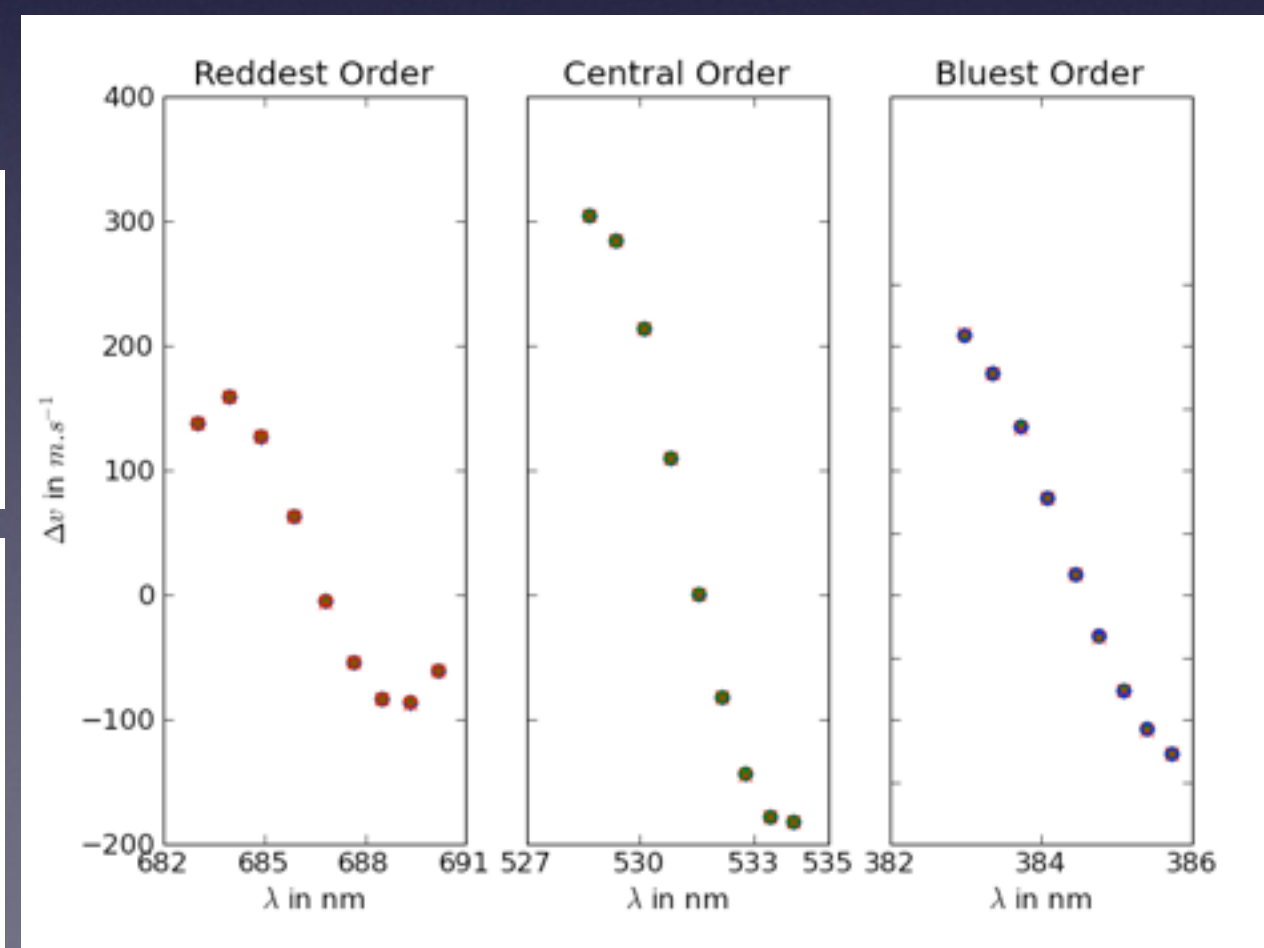




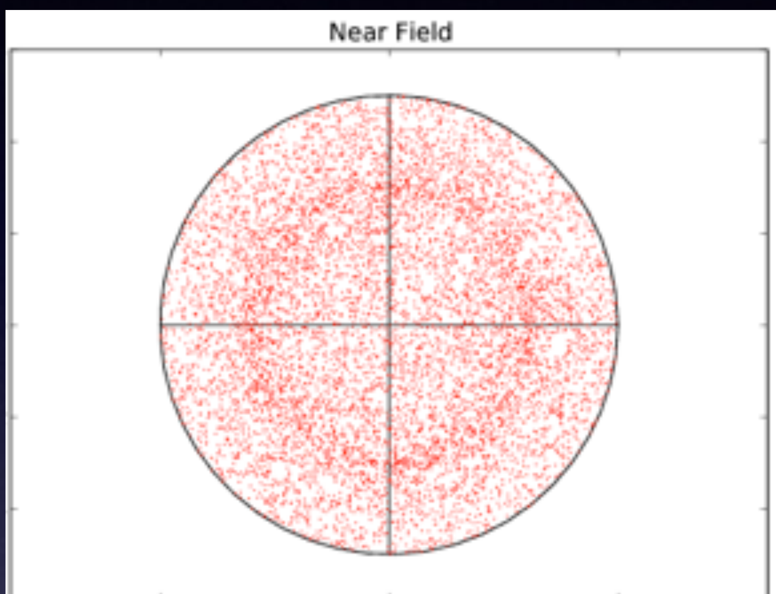


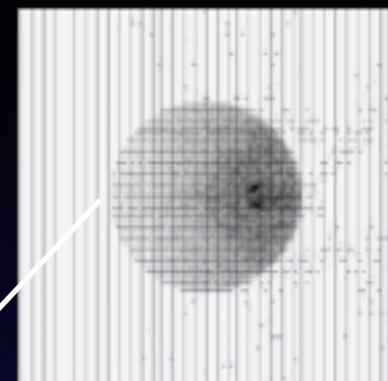


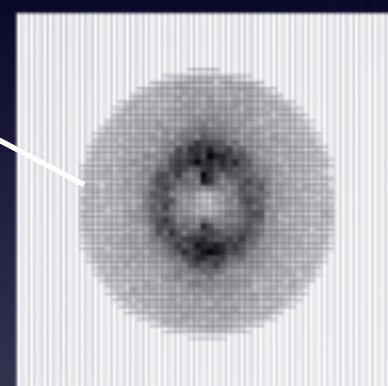


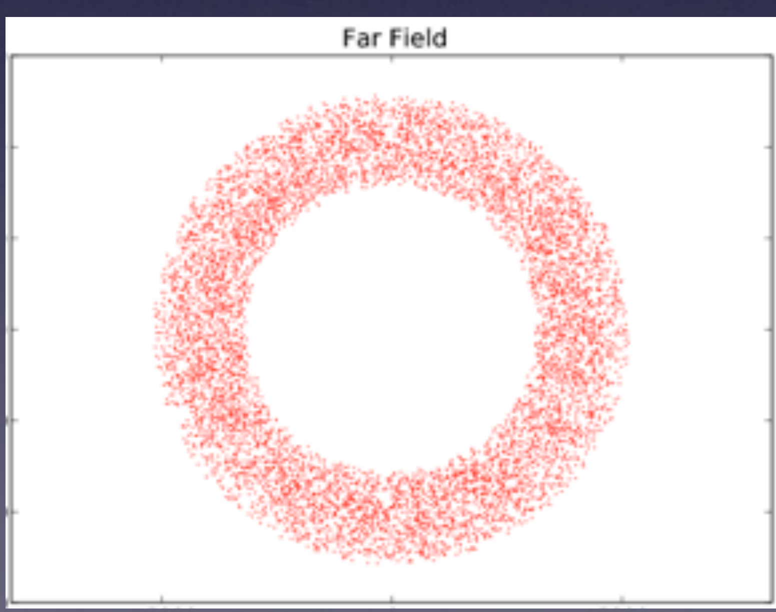


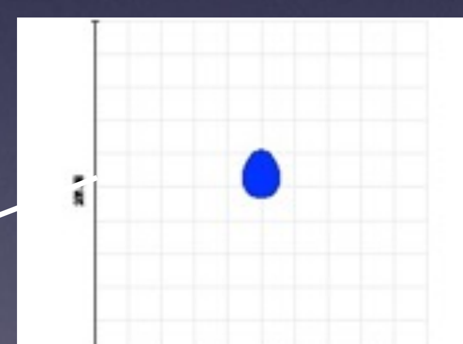
Circular fibers alone do not scramble enough ...

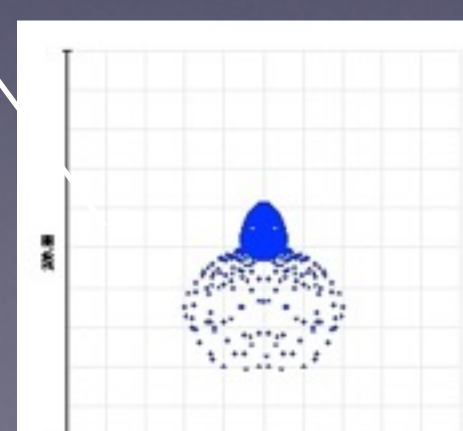




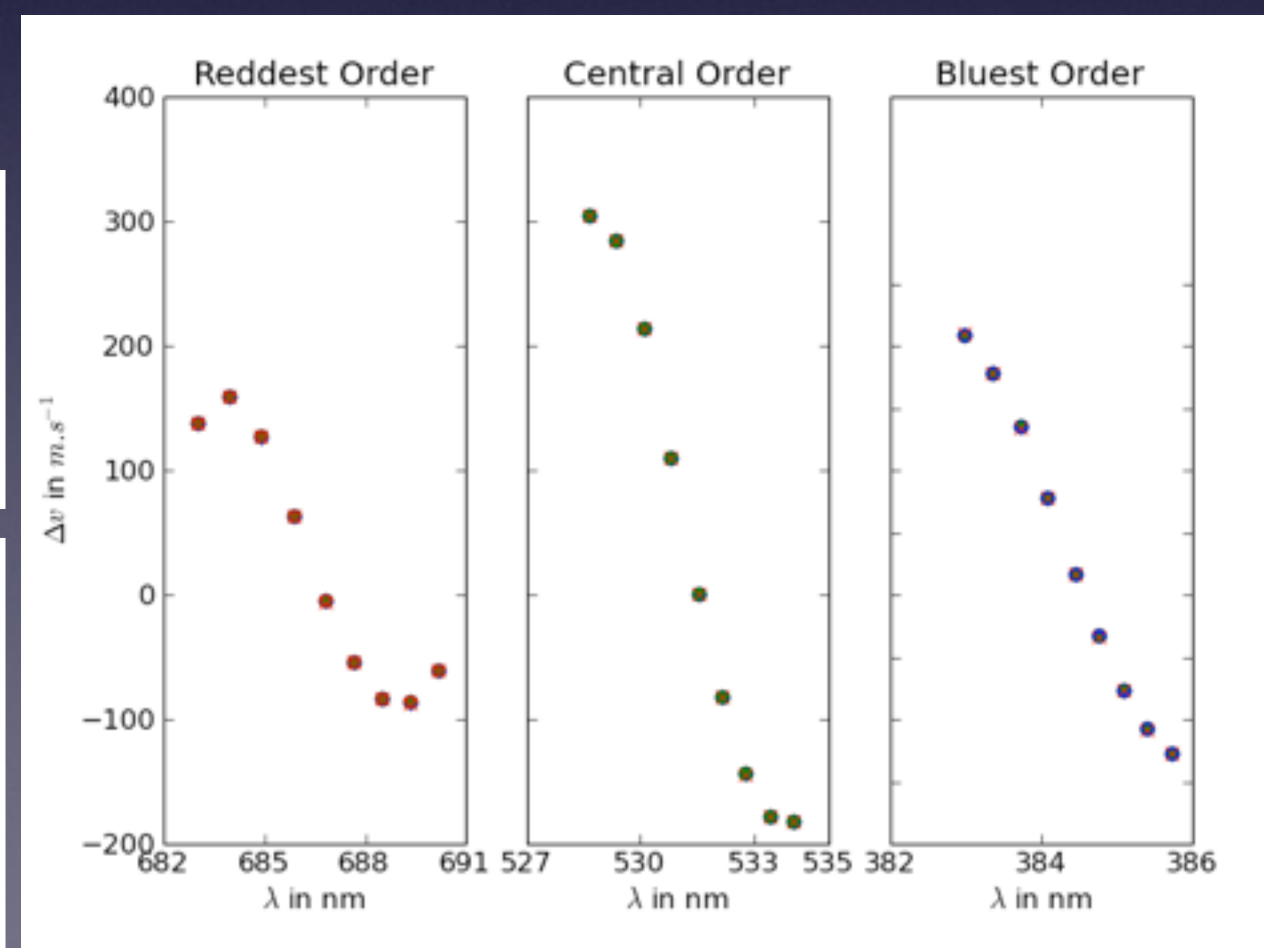




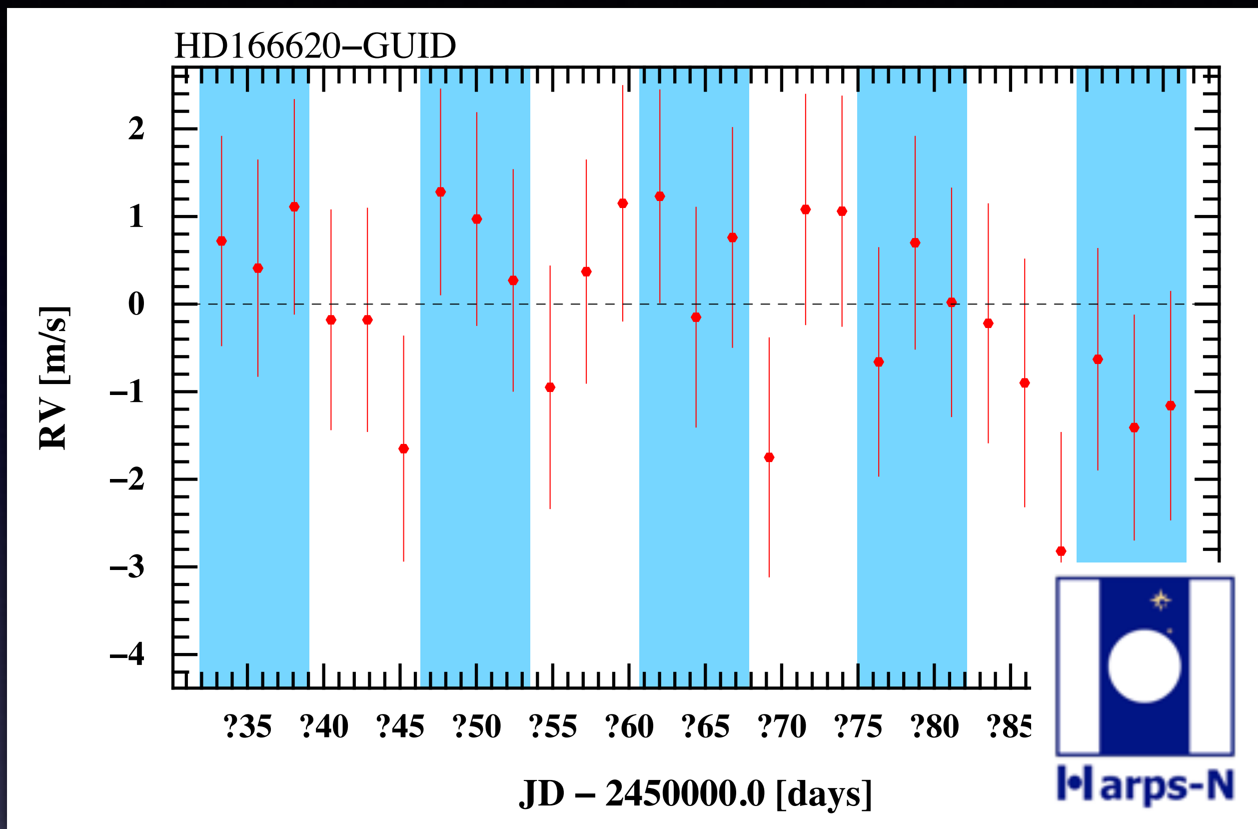


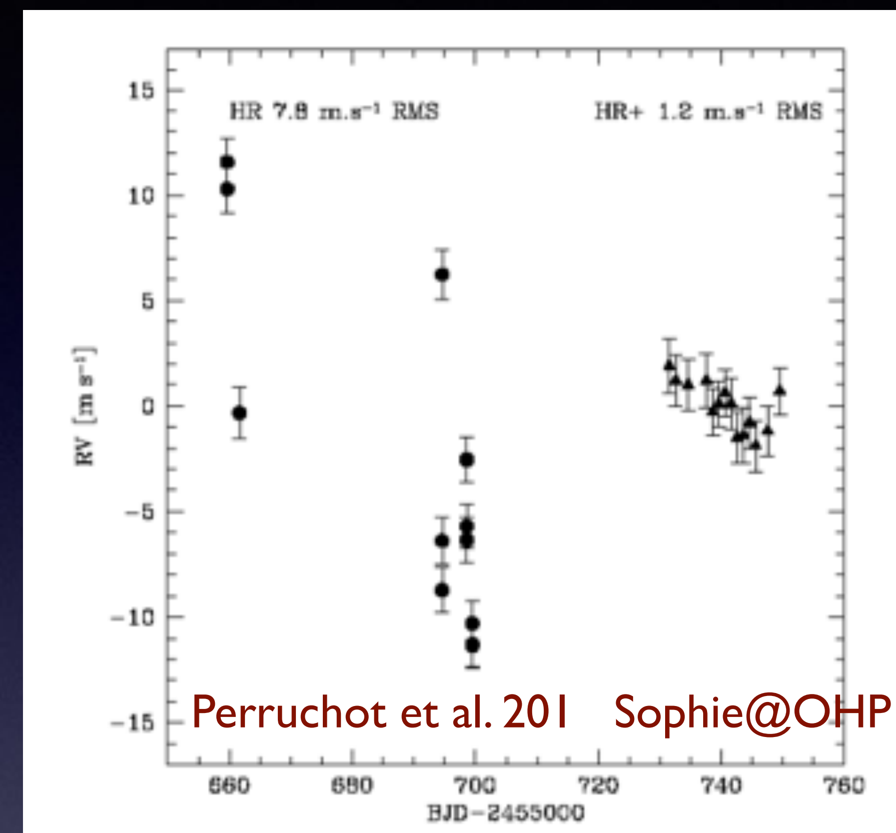


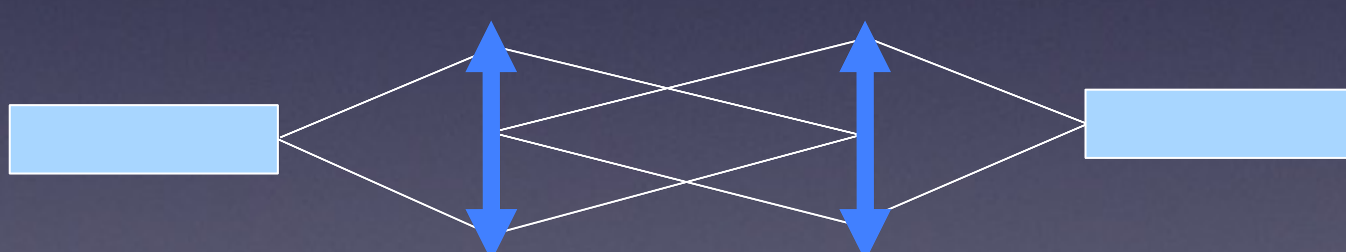
Chazelas et al., 2011
Avila et al. 2011
Perruchot et al. 2011



Illumination effects: guiding tests





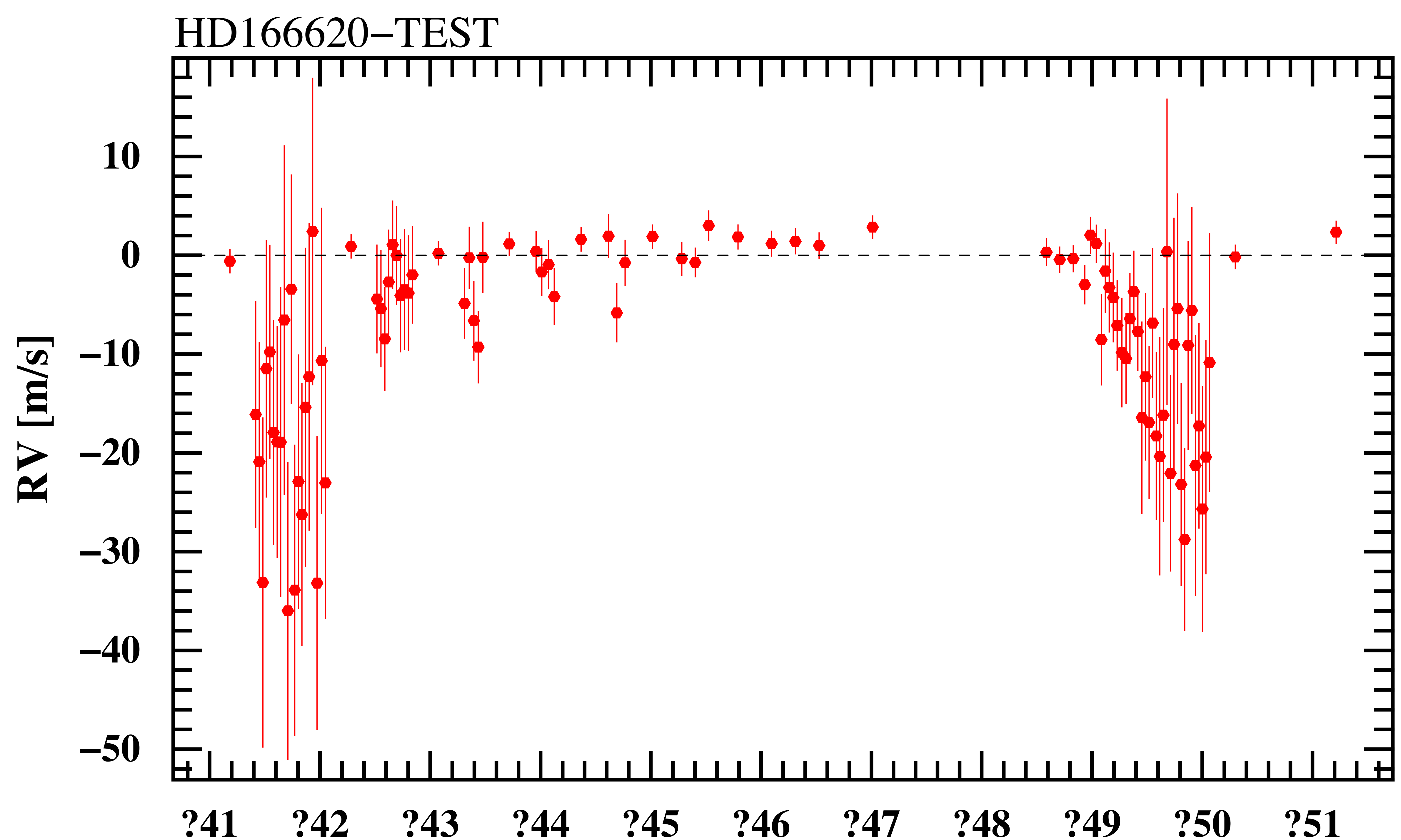


1) Scramble stellar image

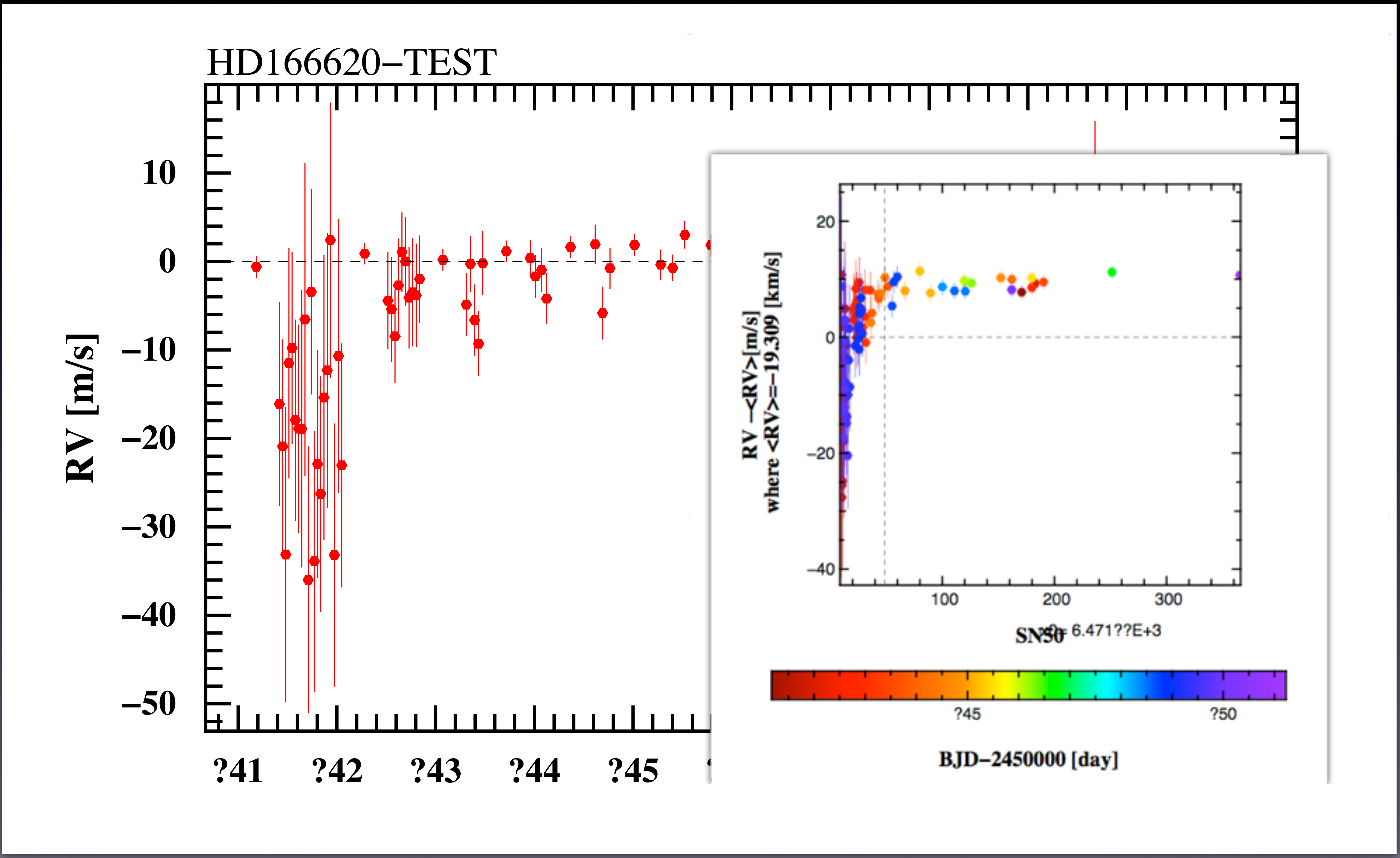
2) Use telescope pupil as new entrance illumination

3) Use octagonal fibers

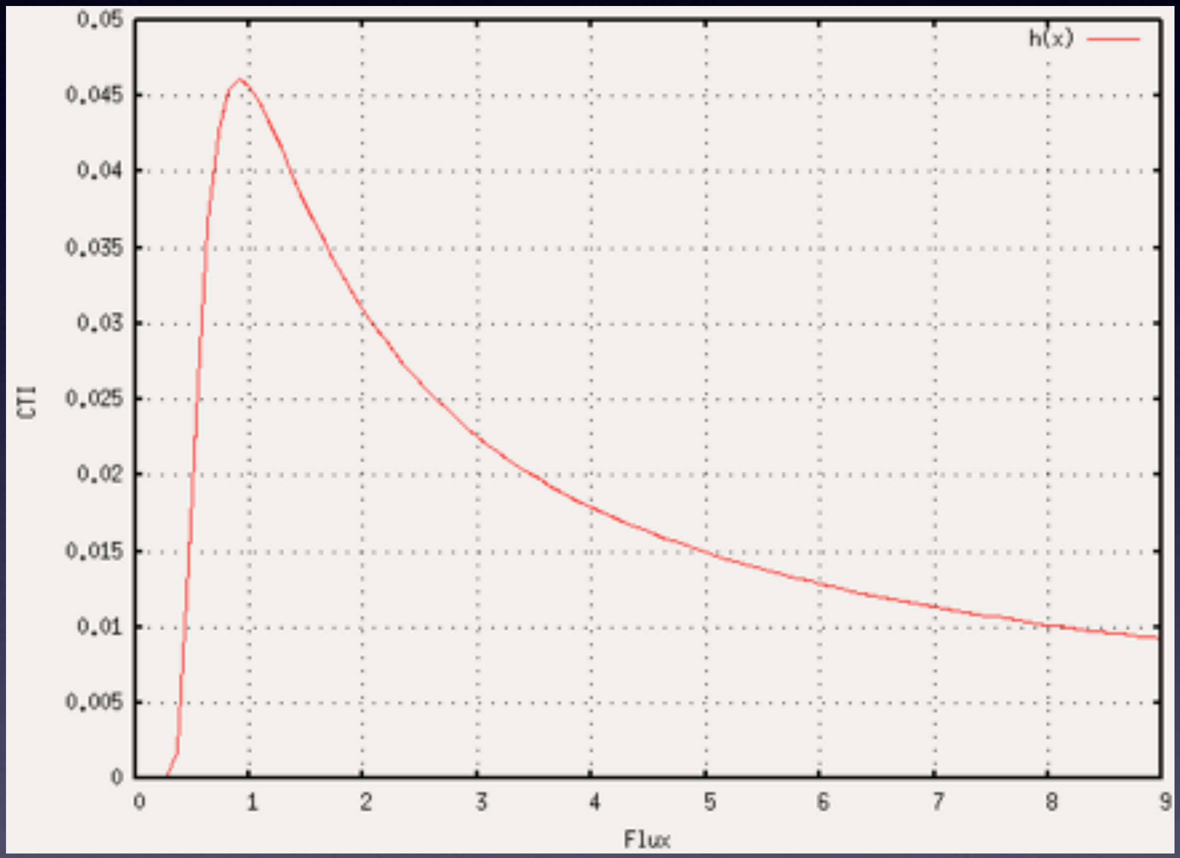
CTE Problem: SNR test

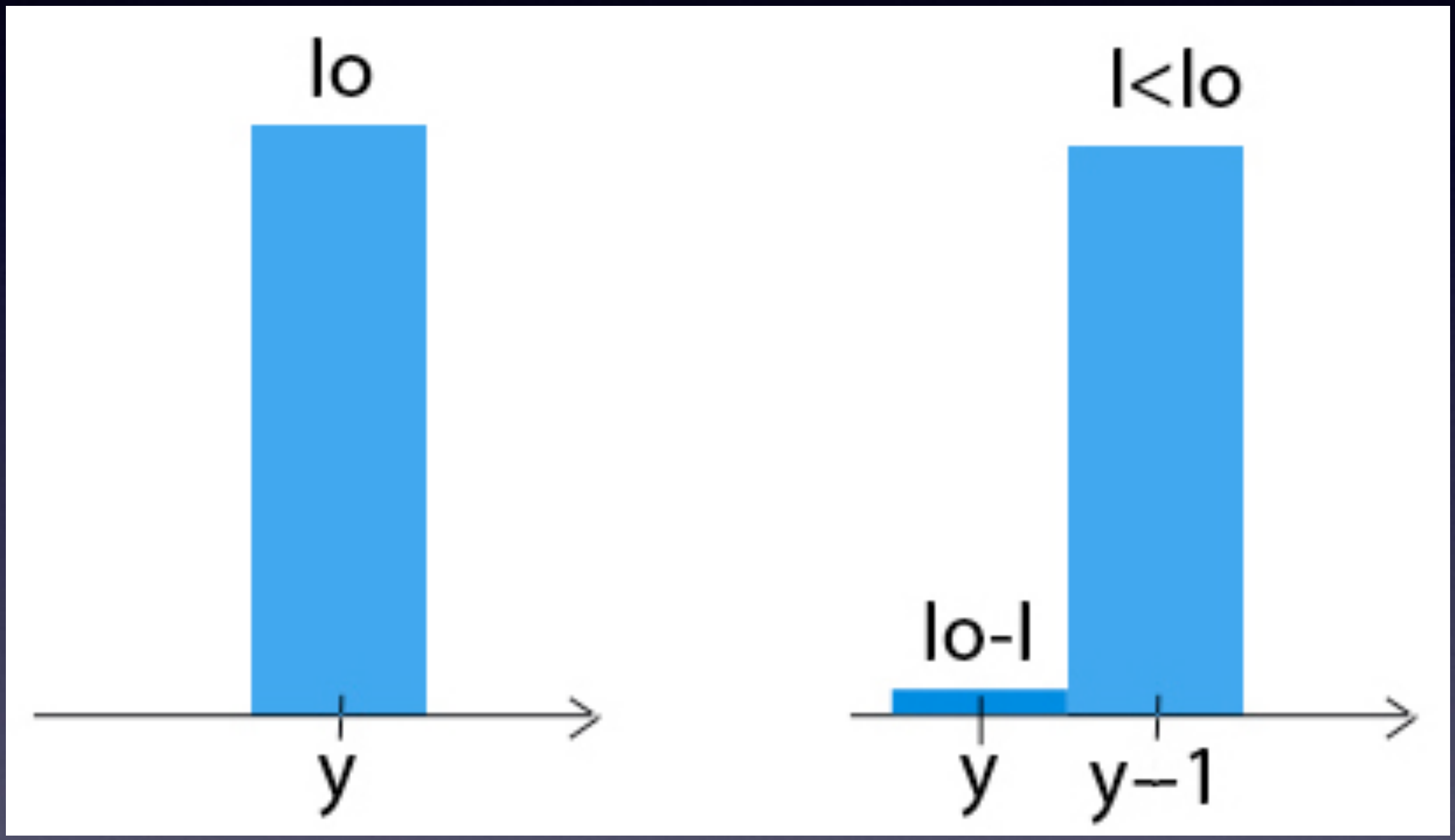


CTE Problem: SNR test



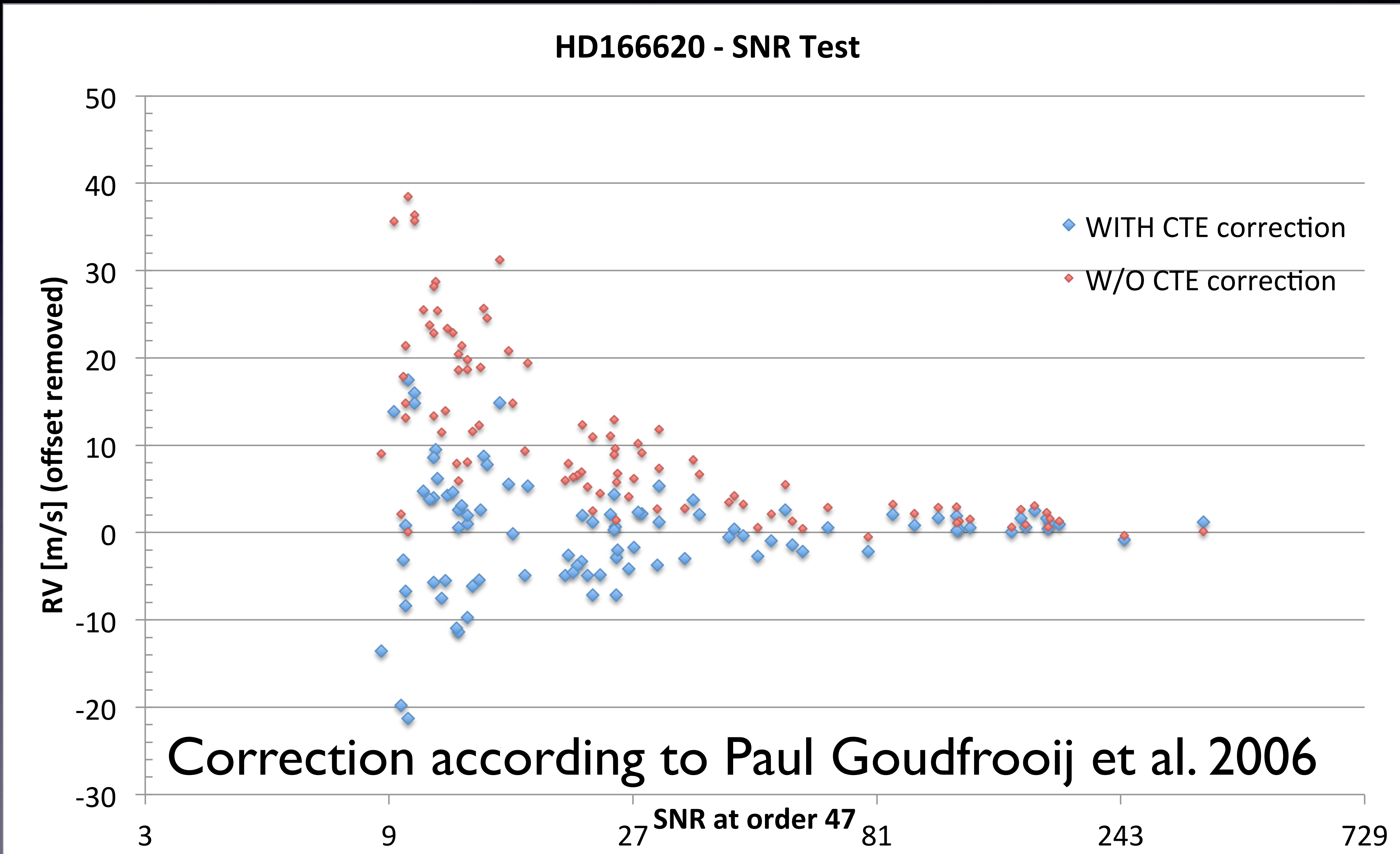
CTE Problem: SNR test





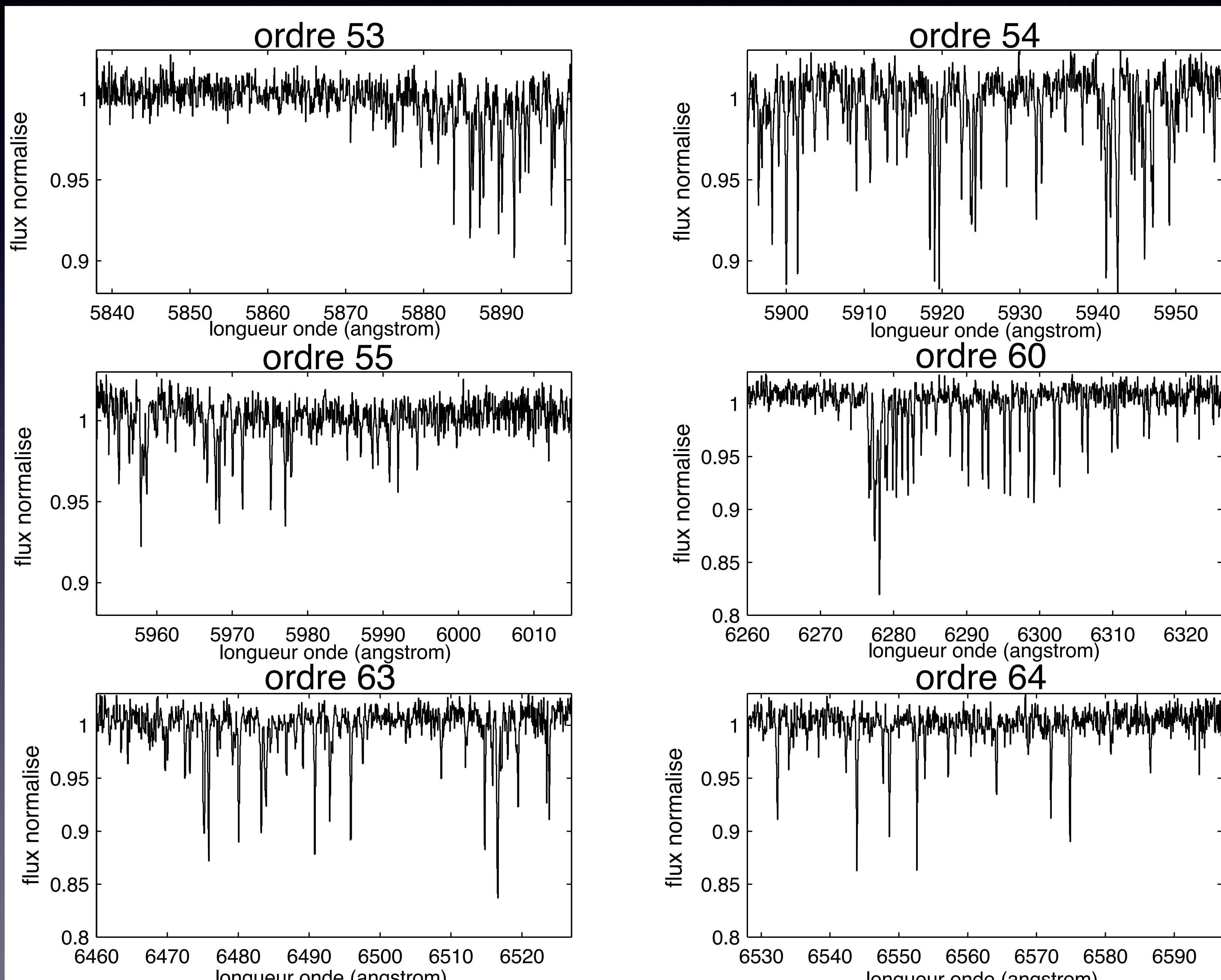
CTI(Flux)

CTE Problem: solution

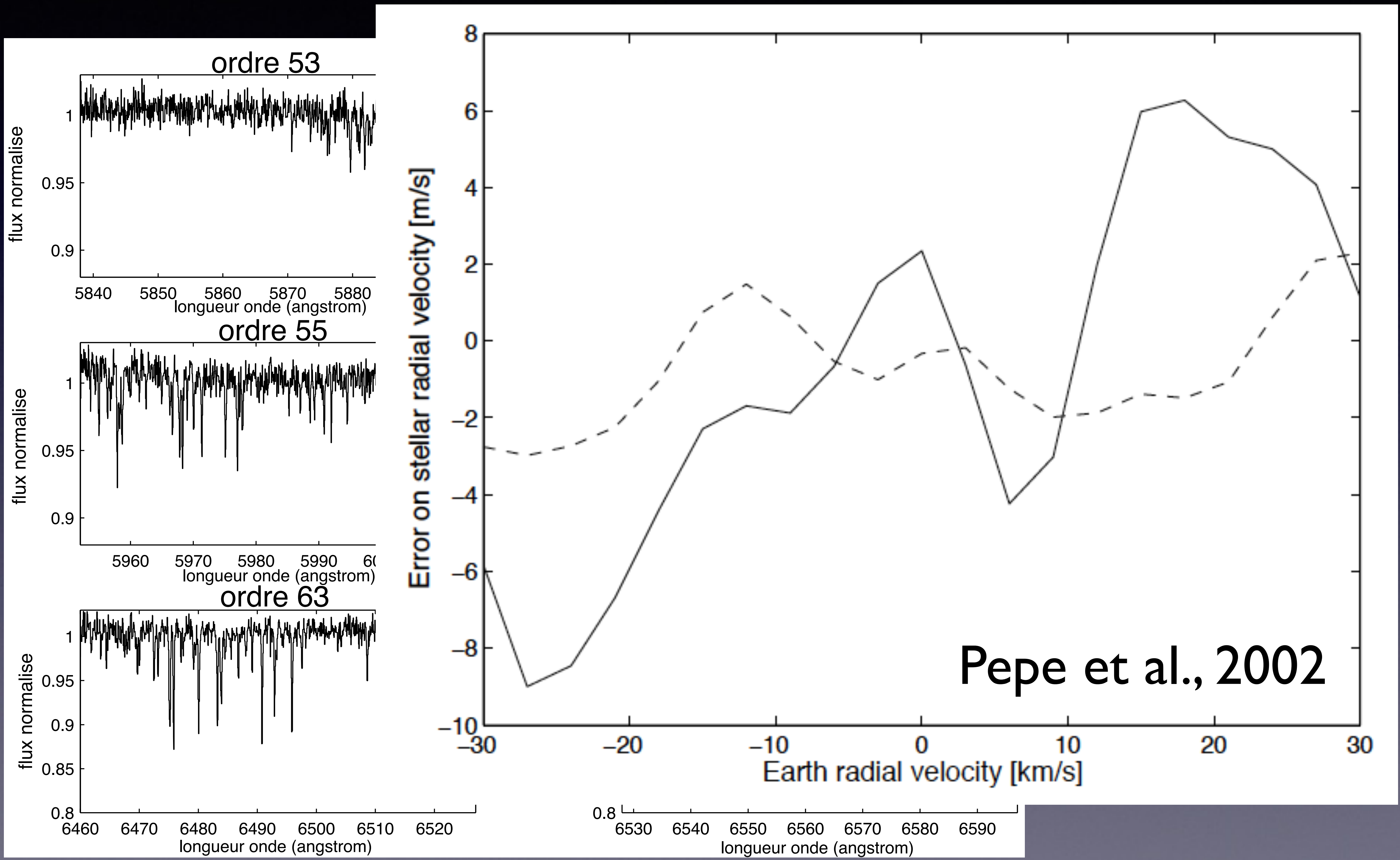


Correction according to Paul Goudfrooij et al. 2006

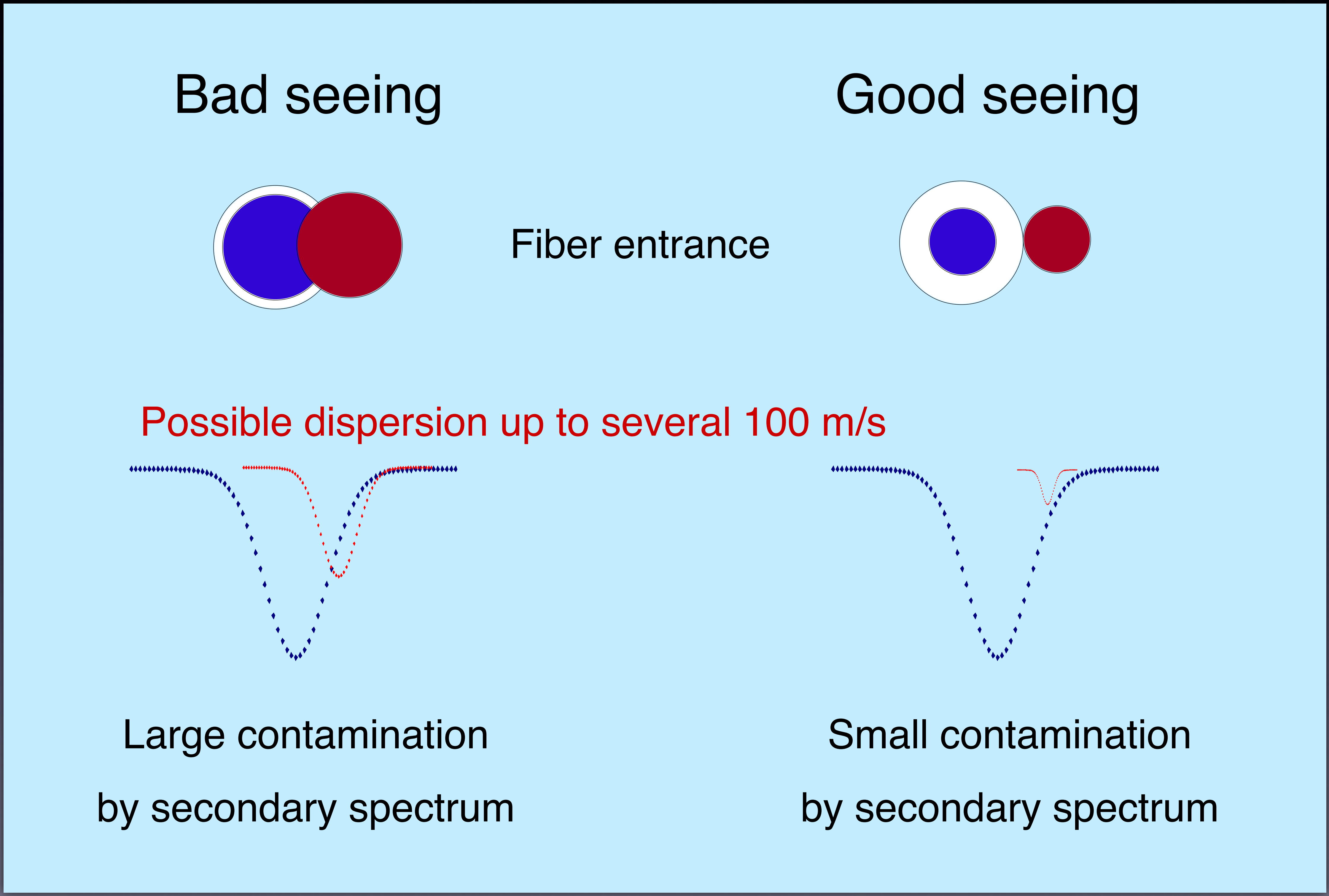
Contaminants: Atmosphere



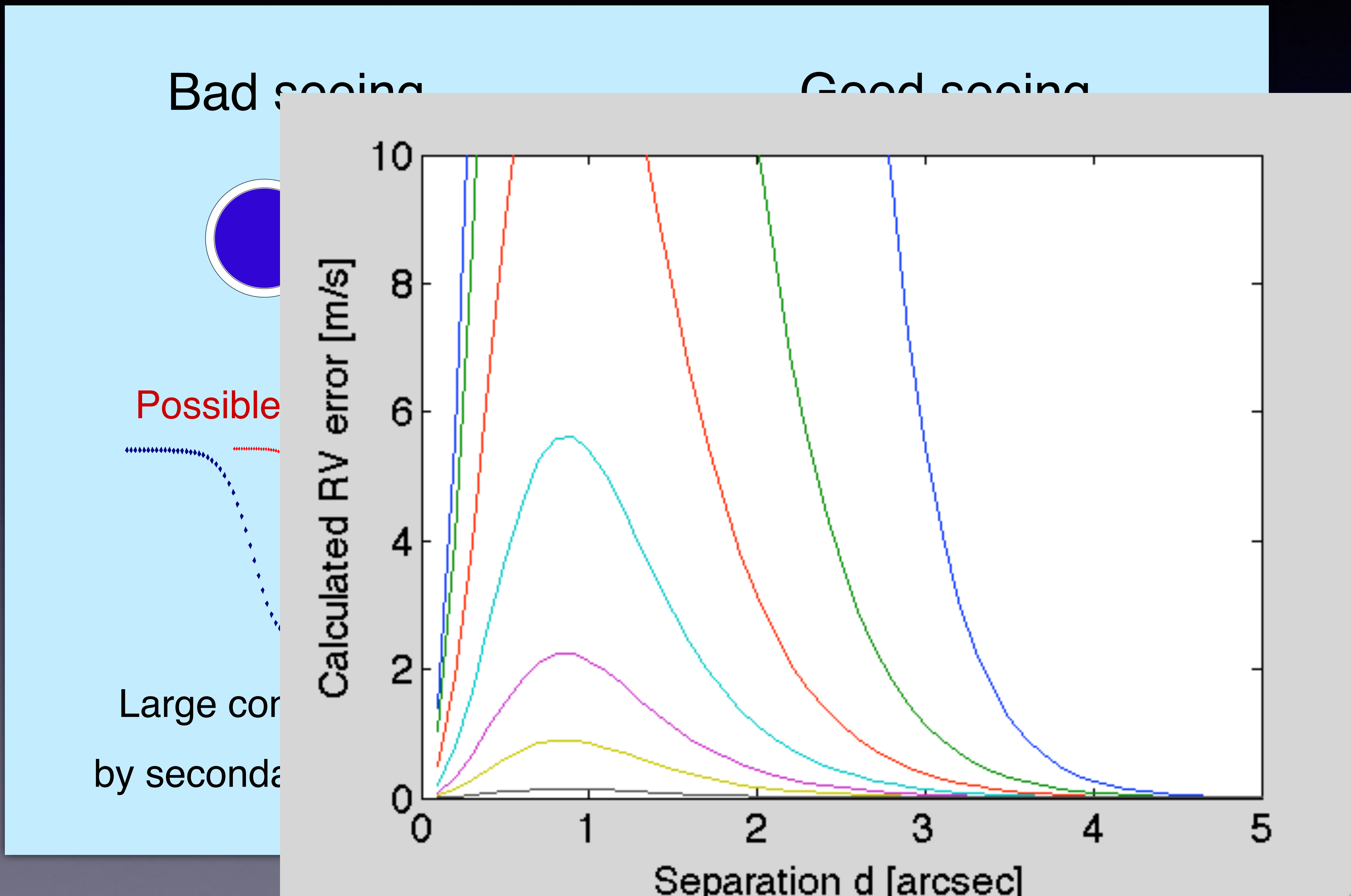
Contaminants: Atmosphere



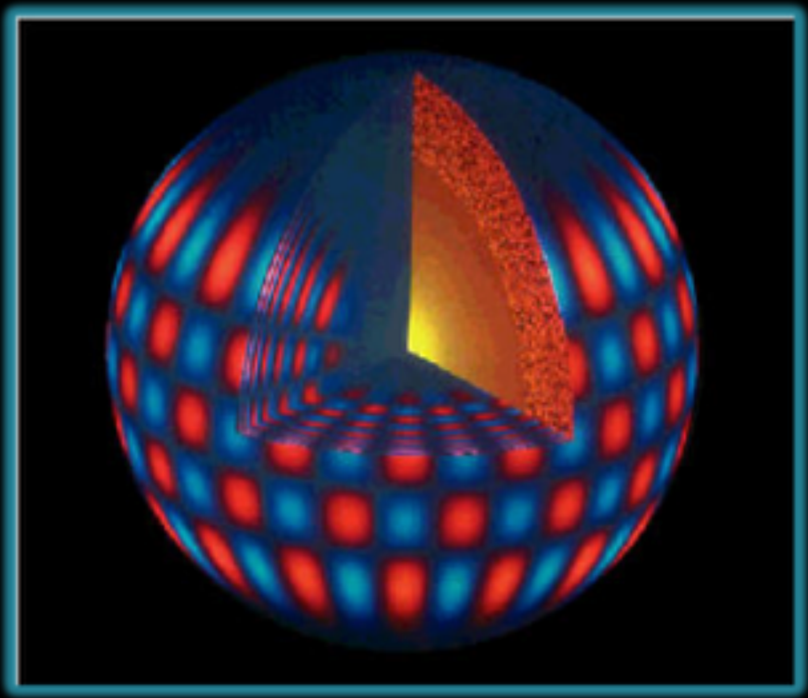
Contaminants: Close-by objects

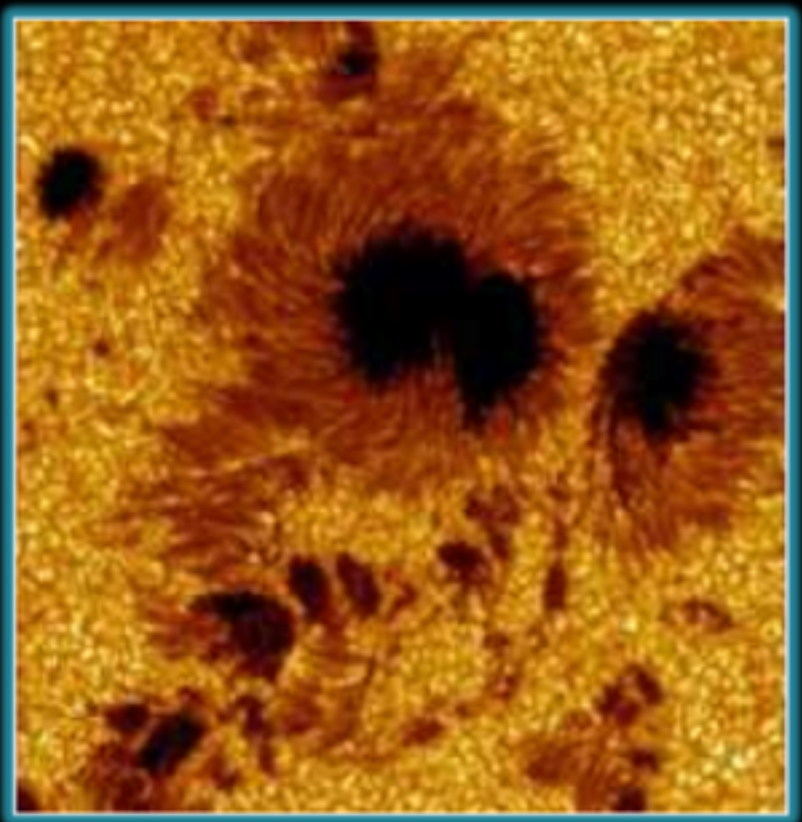


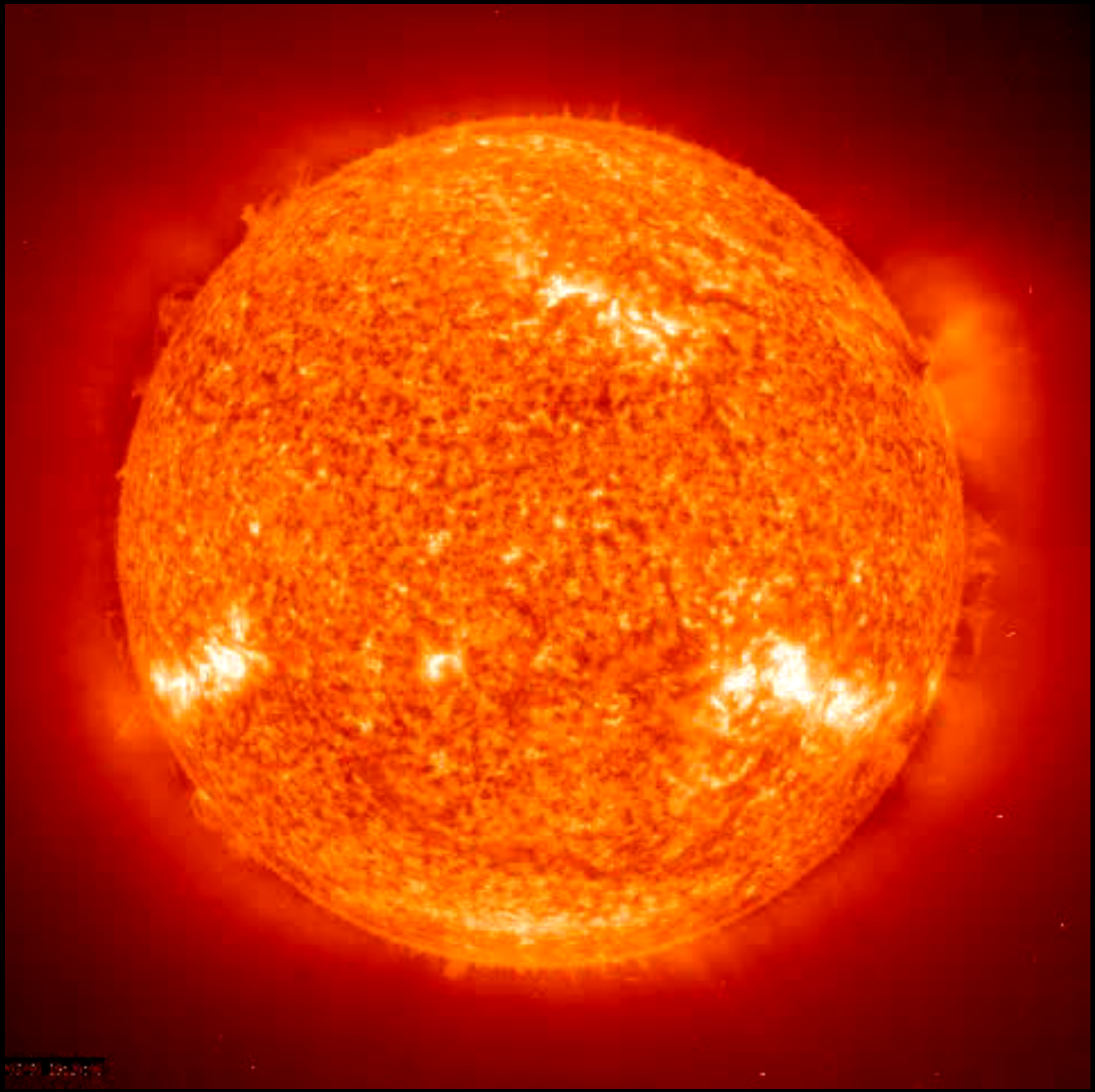
Contaminants: Close-by objects



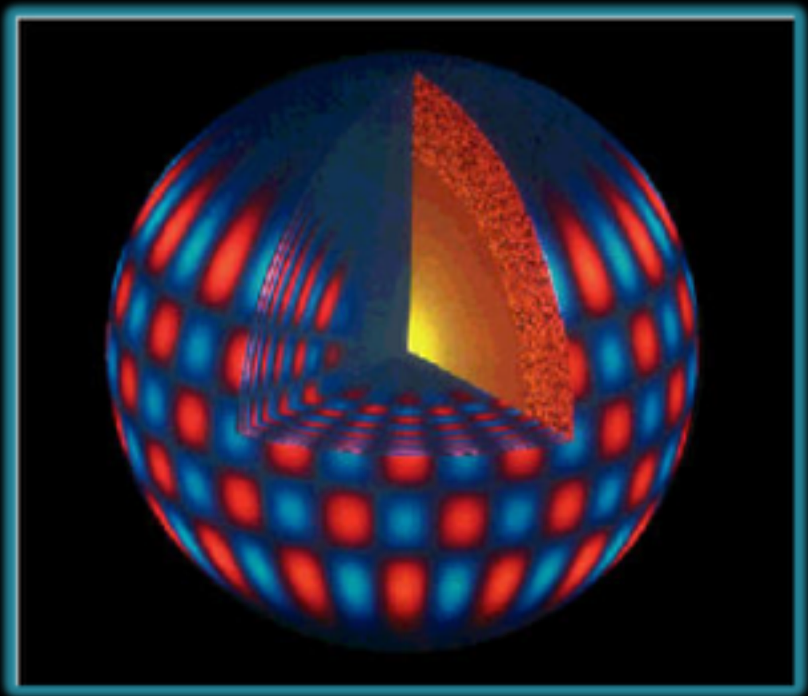
Stellar intrinsic limitations

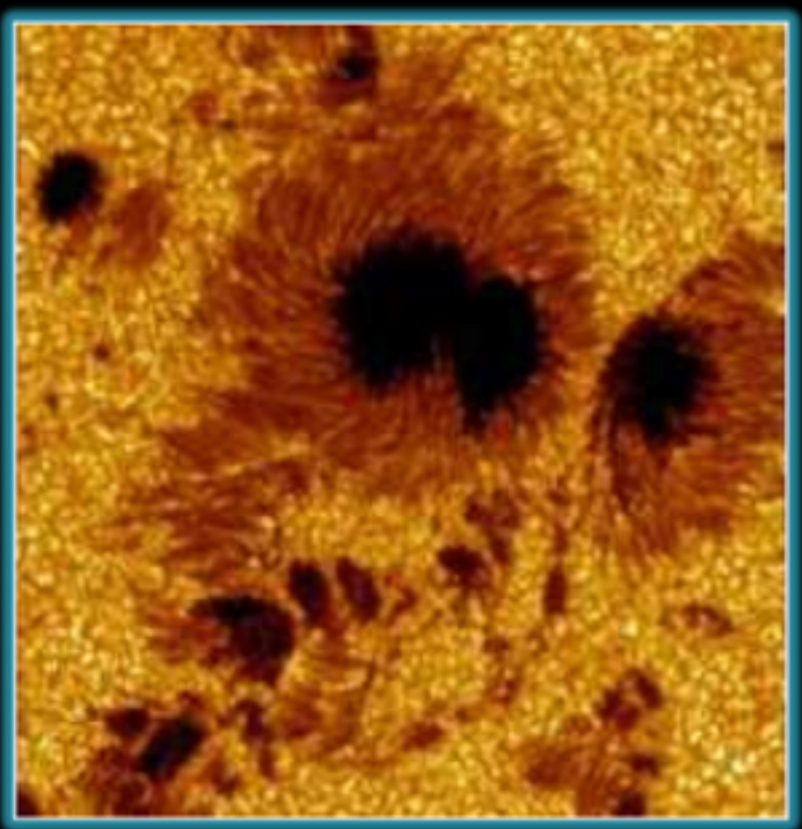


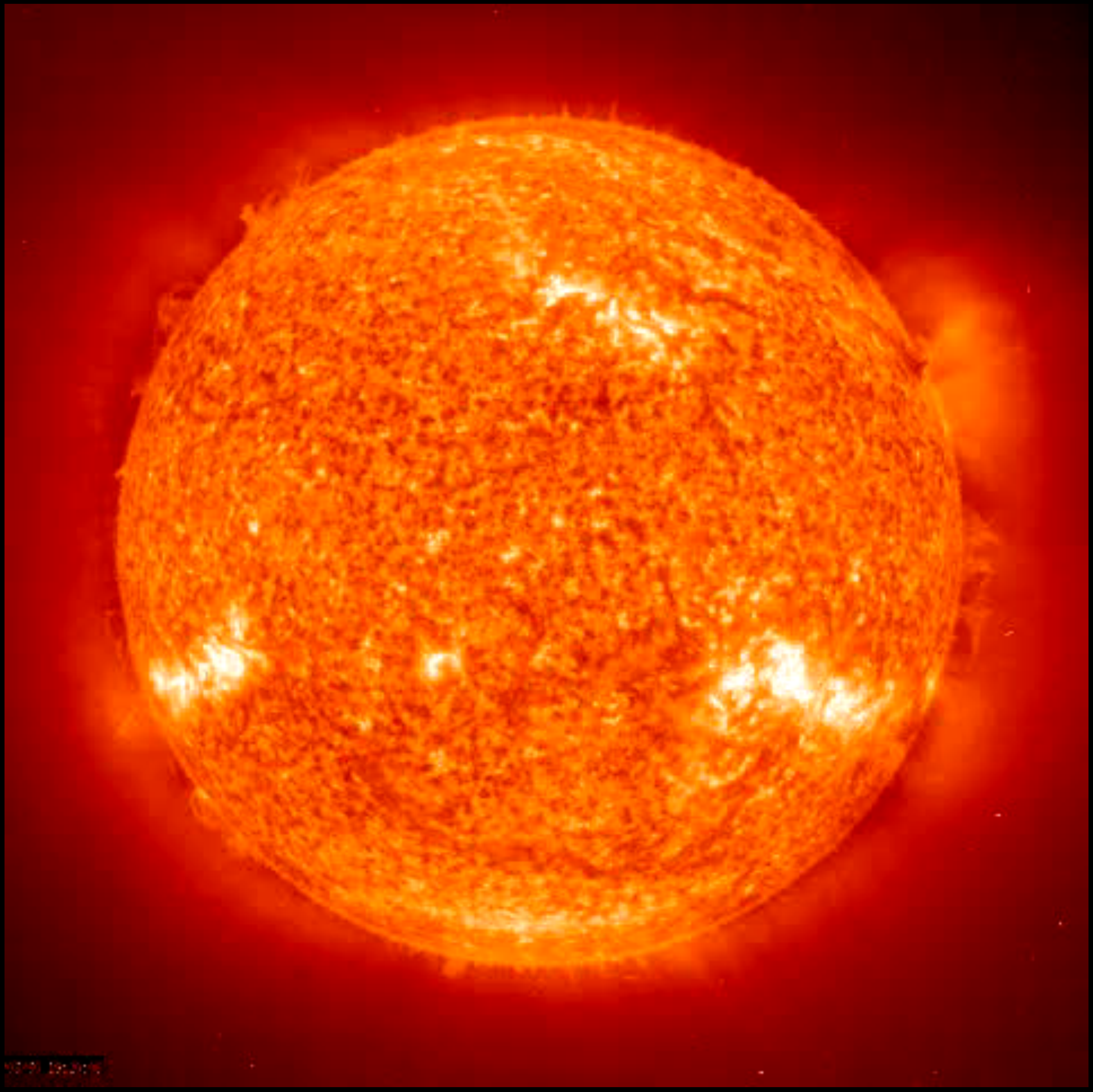




Stellar intrinsic limitations

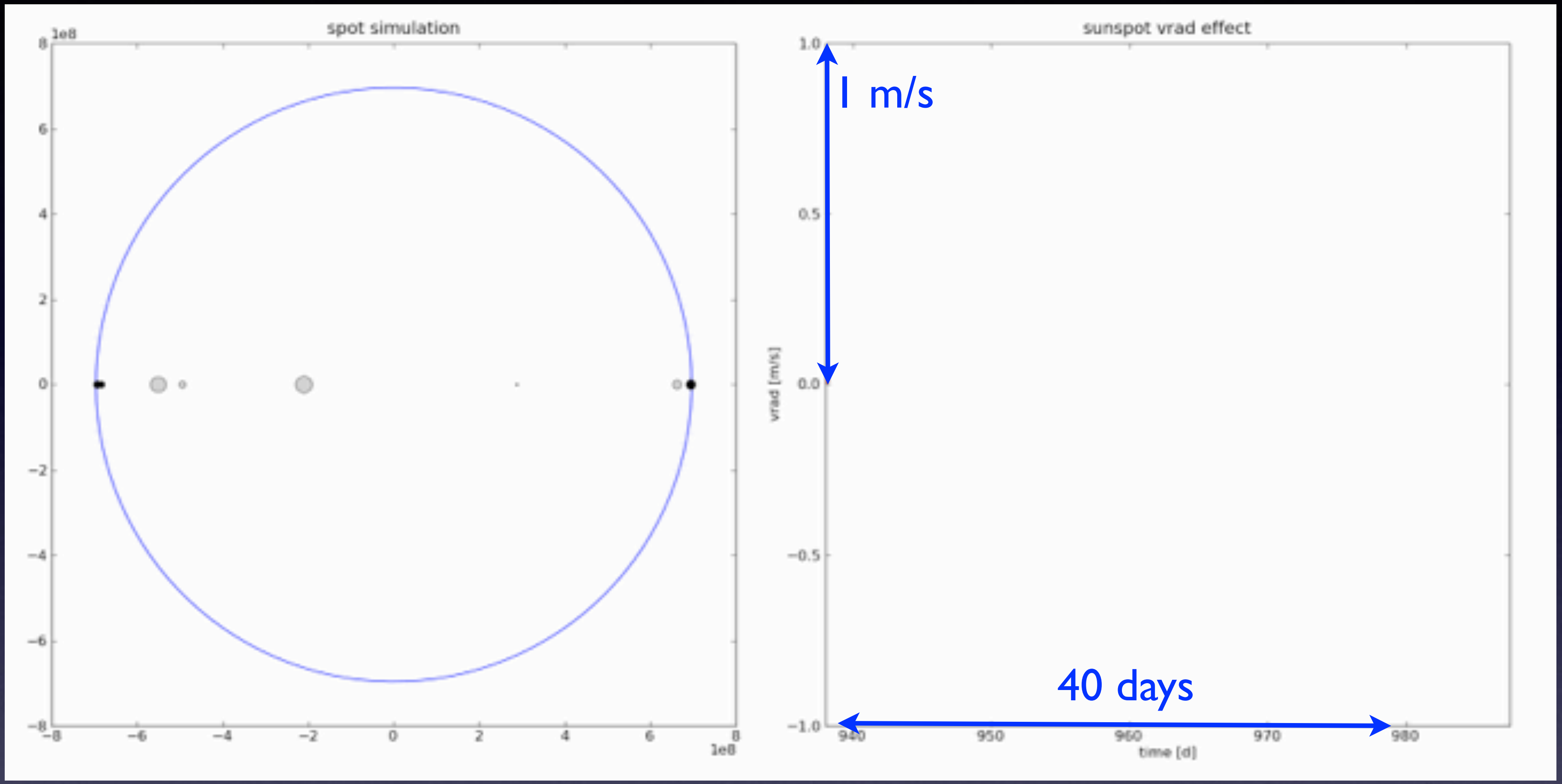






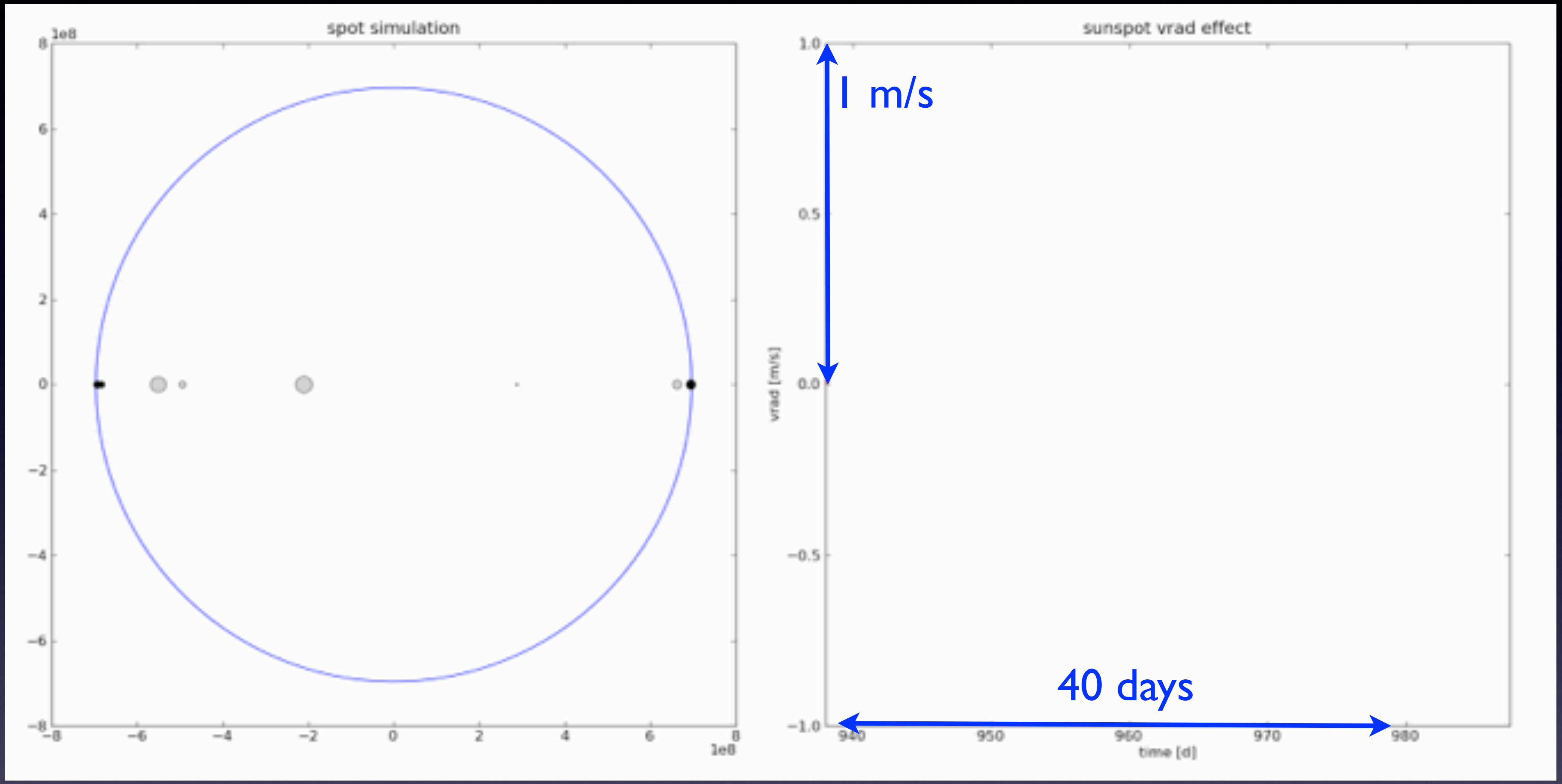
Simulations of spot effects on radial velocities

Effect of realistic spot models: case for $\log(R'_{HK})=-4.9$



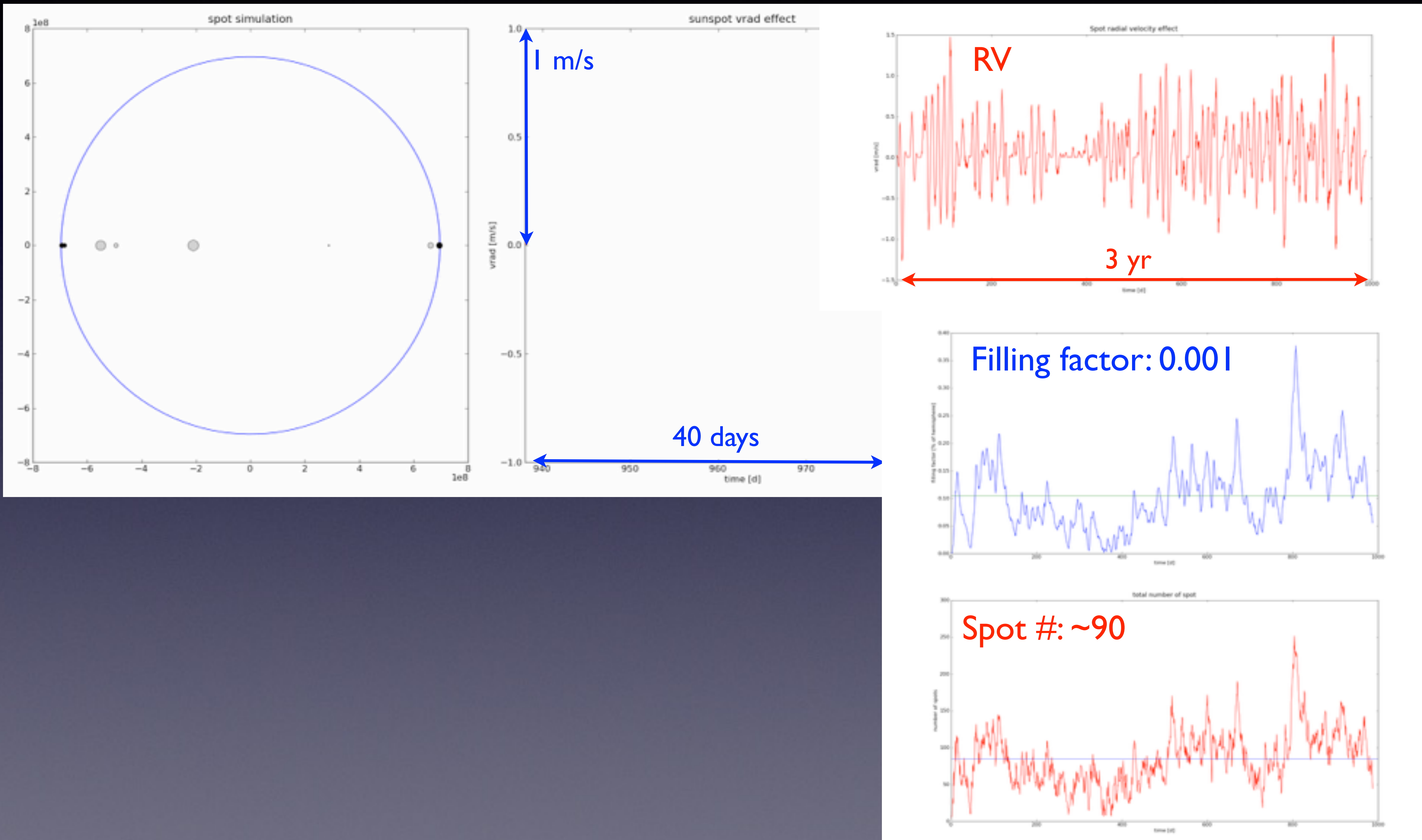
Simulations of spot effects on radial velocities

Effect of realistic spot models: case for $\log(R'_{HK})=-4.9$



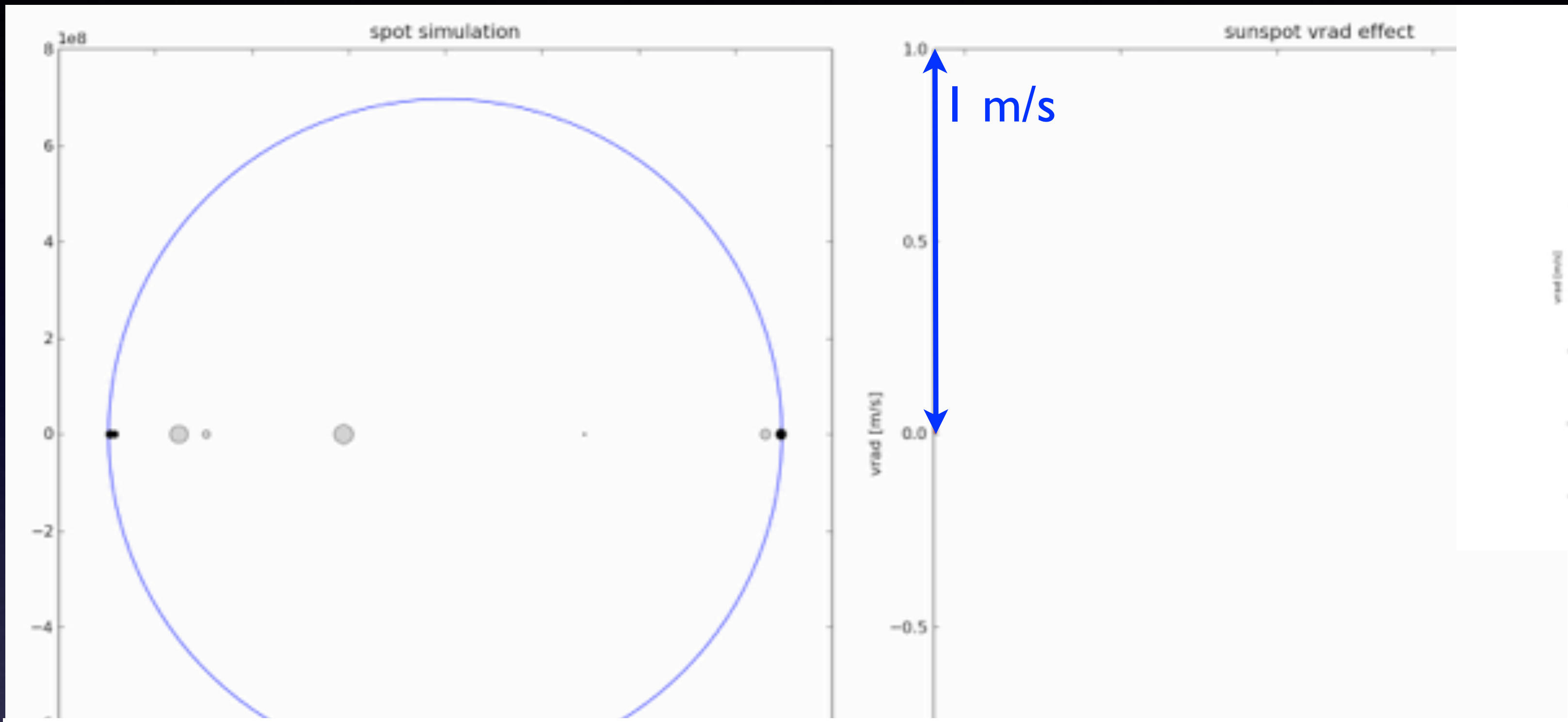
Simulations of spot effects on radial velocities

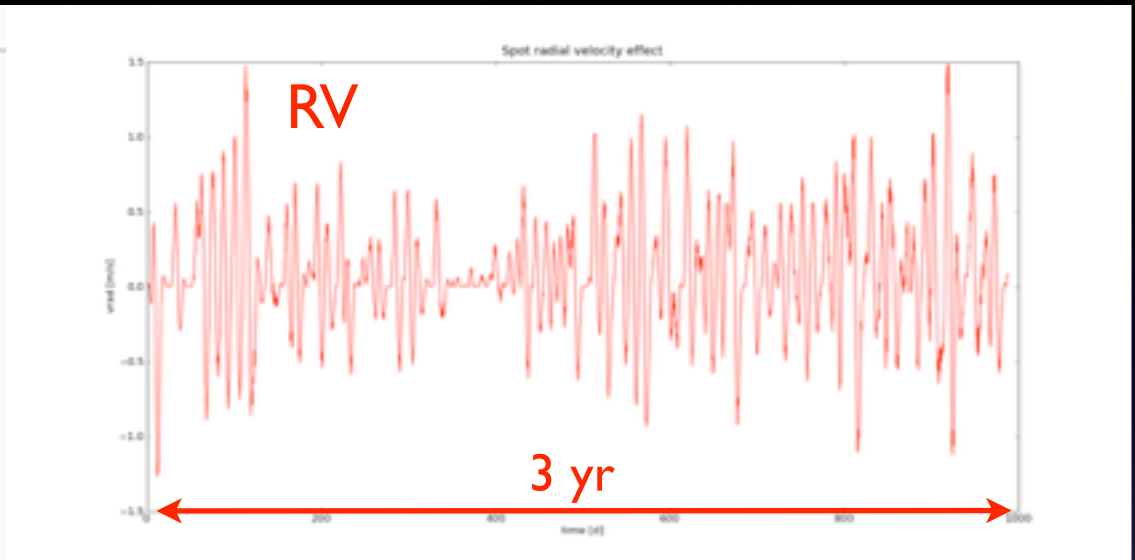
Effect of realistic spot models: case for $\log(R'_{HK})=-4.9$

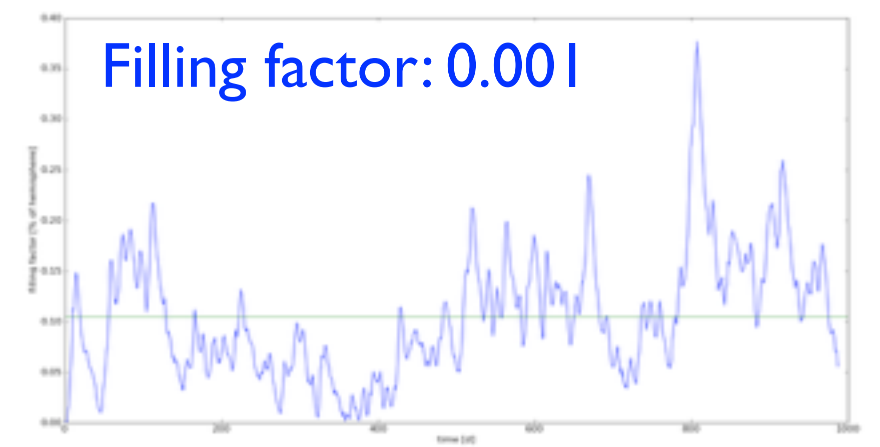


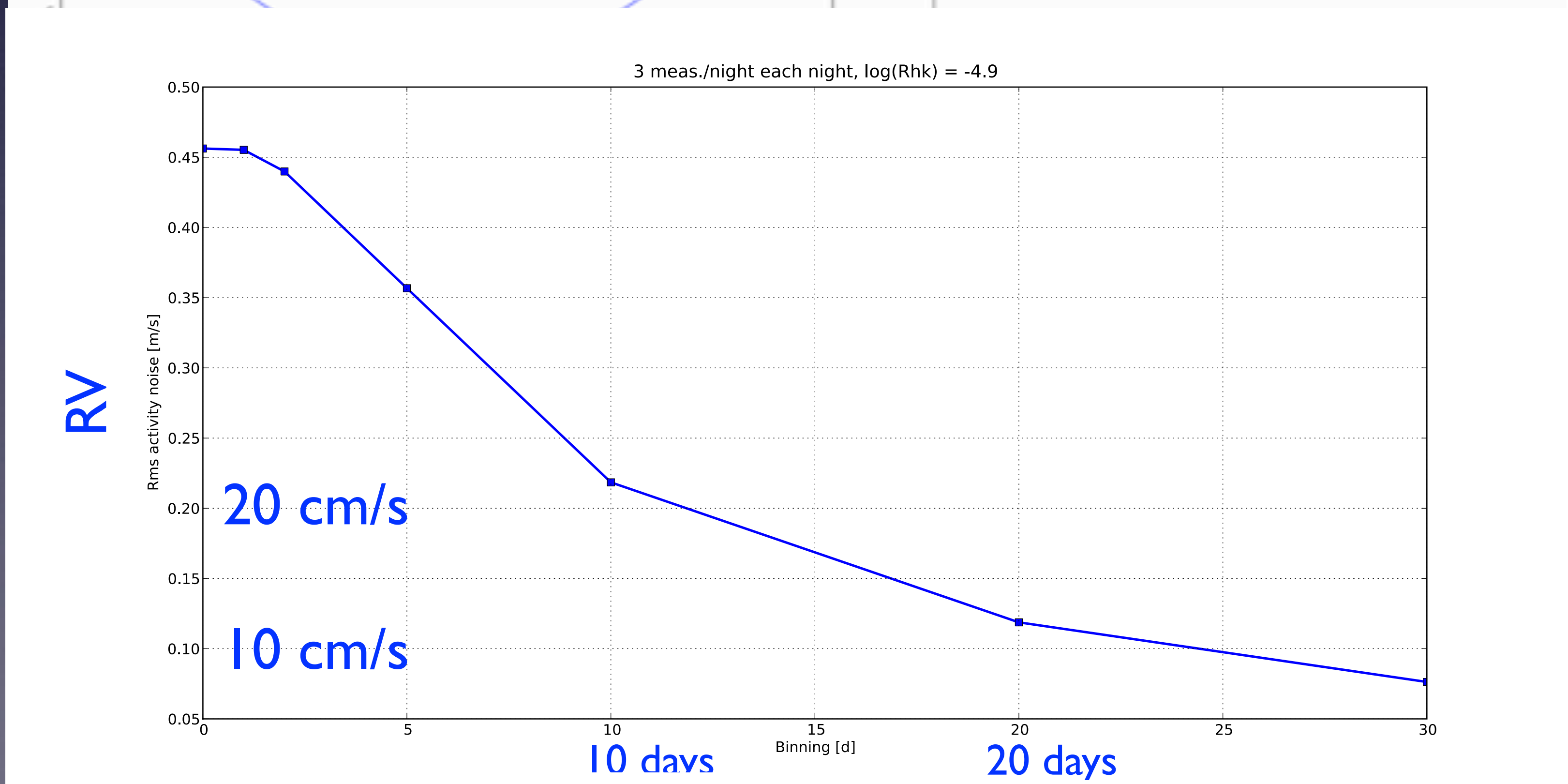
Simulations of spot effects on radial velocities

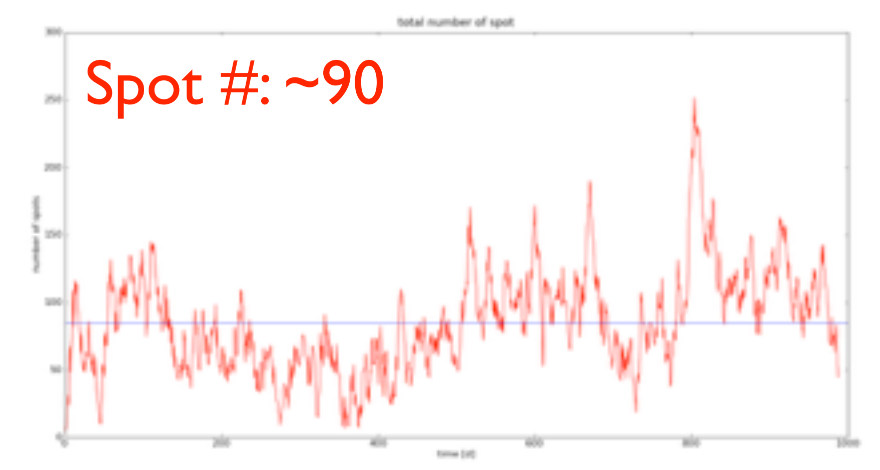
Effect of realistic spot models: case for $\log(R'_{HK})$=-4.9



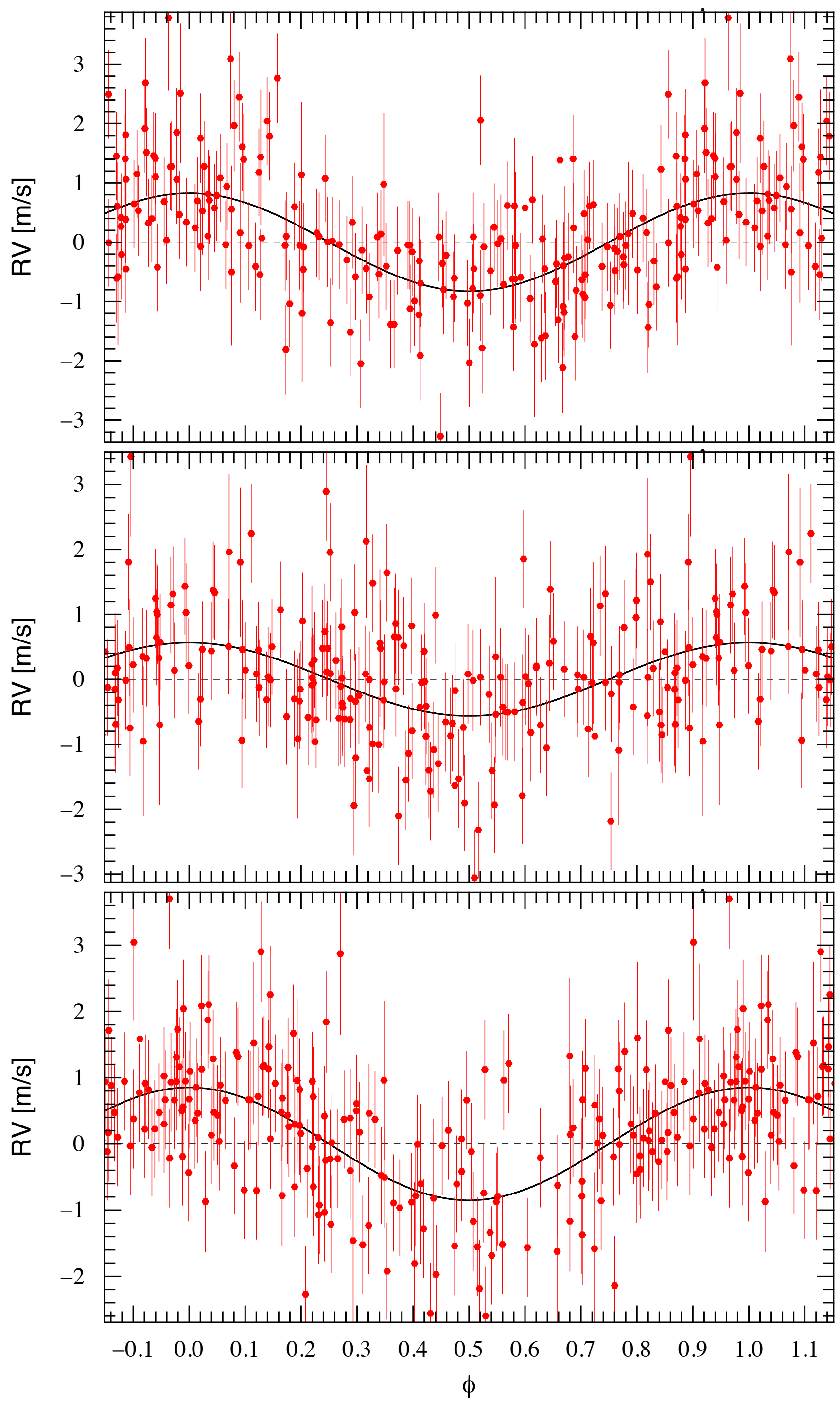






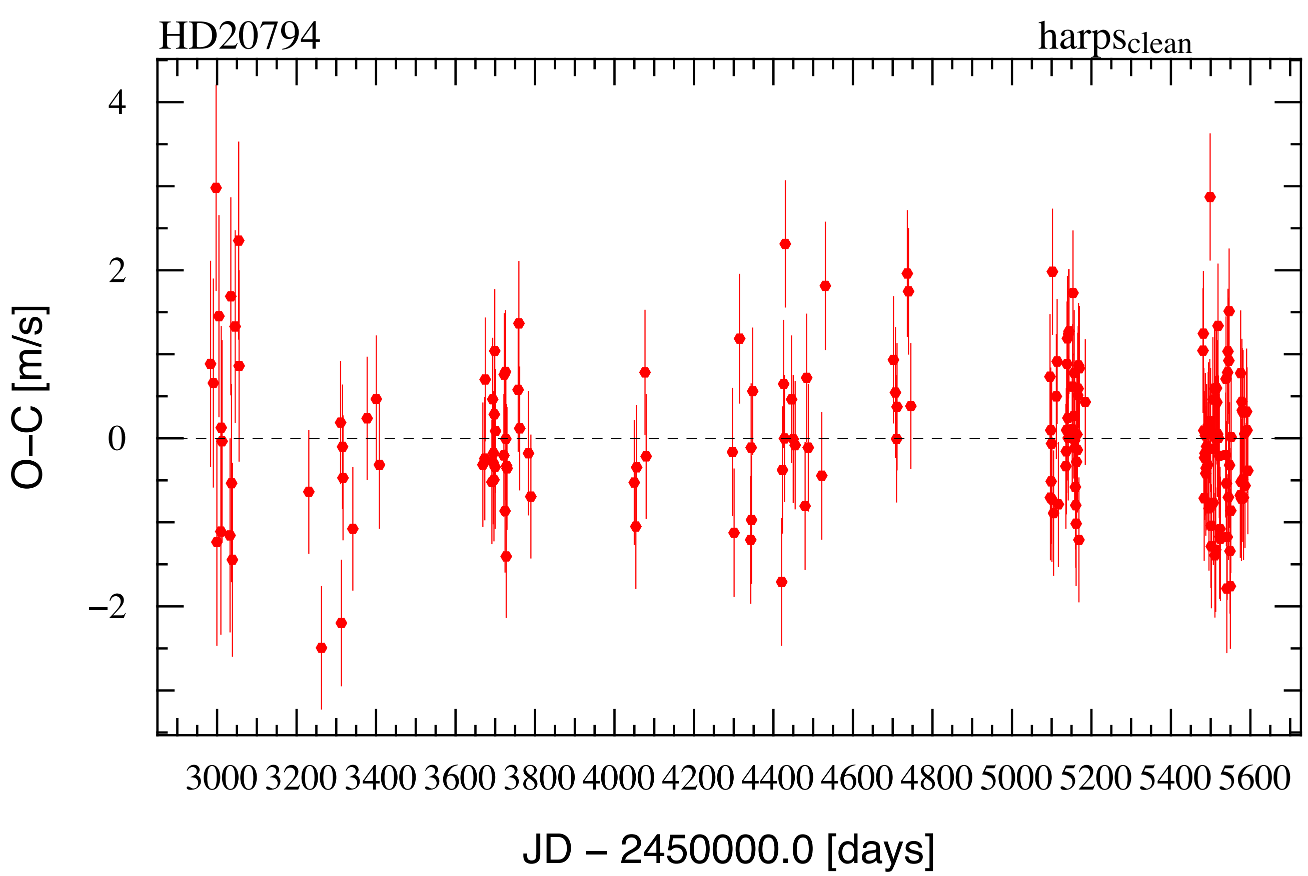


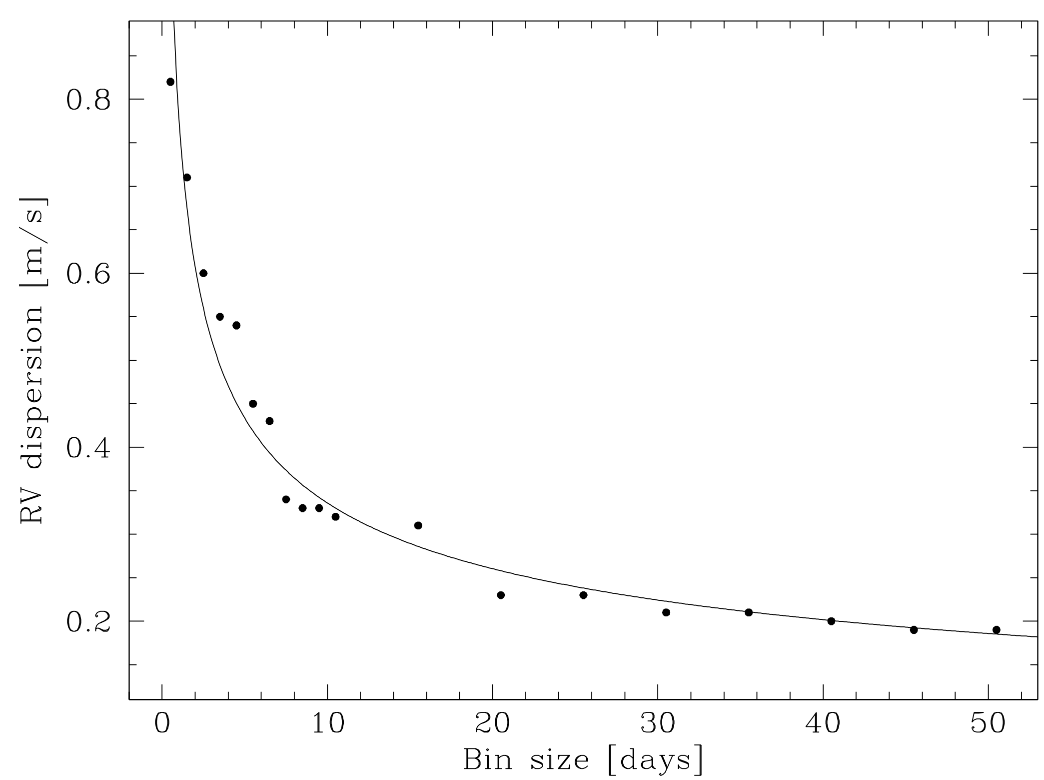
HD20794: Three Earth-mass planets



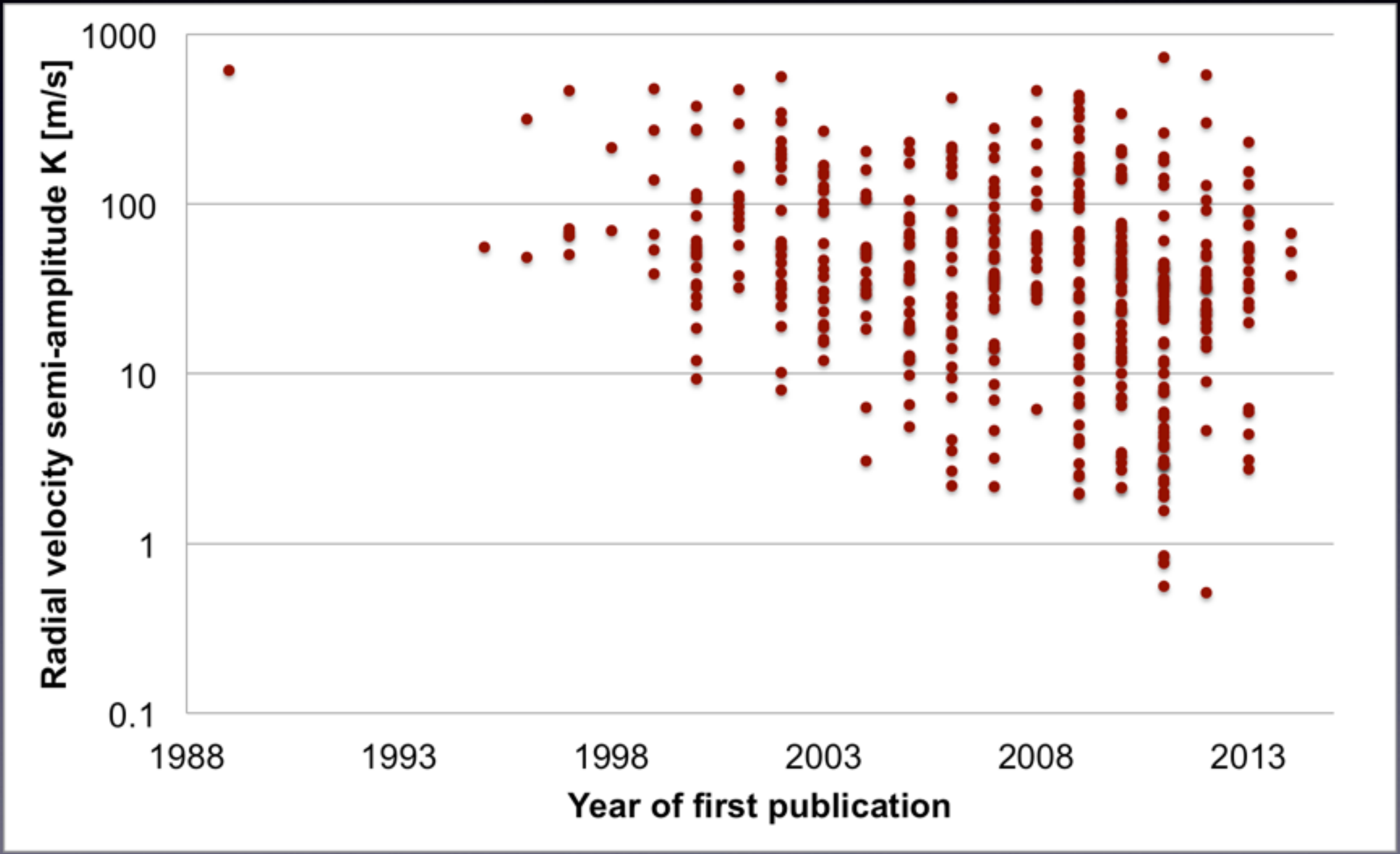
Parameter	[unit]	HD 20794 b	HD 20794 c	HD 20794 d
Epoch	[BJD]		2'454'783.40362208	
i	[deg]		90 (fixed)	
V	[km s^{-1}]		87.9525 (±0.0001)	
P	[days]	18.315	40.114	90.309
		(±0.008)	(±0.053)	(±0.184)
λ	[deg]	169.0	149.4	16.2
		(±6.7)	(±10.0)	(±6.8)
e		0.0	0.0	0.0
		(fixed)	(*fixed*)	(*fixed*)
ω	[deg]	0.0	0.0	0.0
		(fixed)	(*fixed*)	(*fixed*)
K	[m s^{-1}]	0.83	0.56	0.85
		(±0.09)	(±0.10)	(±0.10)
$m \sin i$	[$M_\oplus$]	2.7	2.4	4.8
		(±0.3)	(±0.4)	(±0.6)
a	[AU]	0.1207	0.2036	0.3499
		(±0.0020)	(±0.0034)	(±0.0059)
T_{eq}	[K]	660	508	388
N_{meas}			187	
Span	[days]		2610	
rms	[m s^{-1}]		0.82	
χ^2_r			1.39	

Précision au sub-m/s

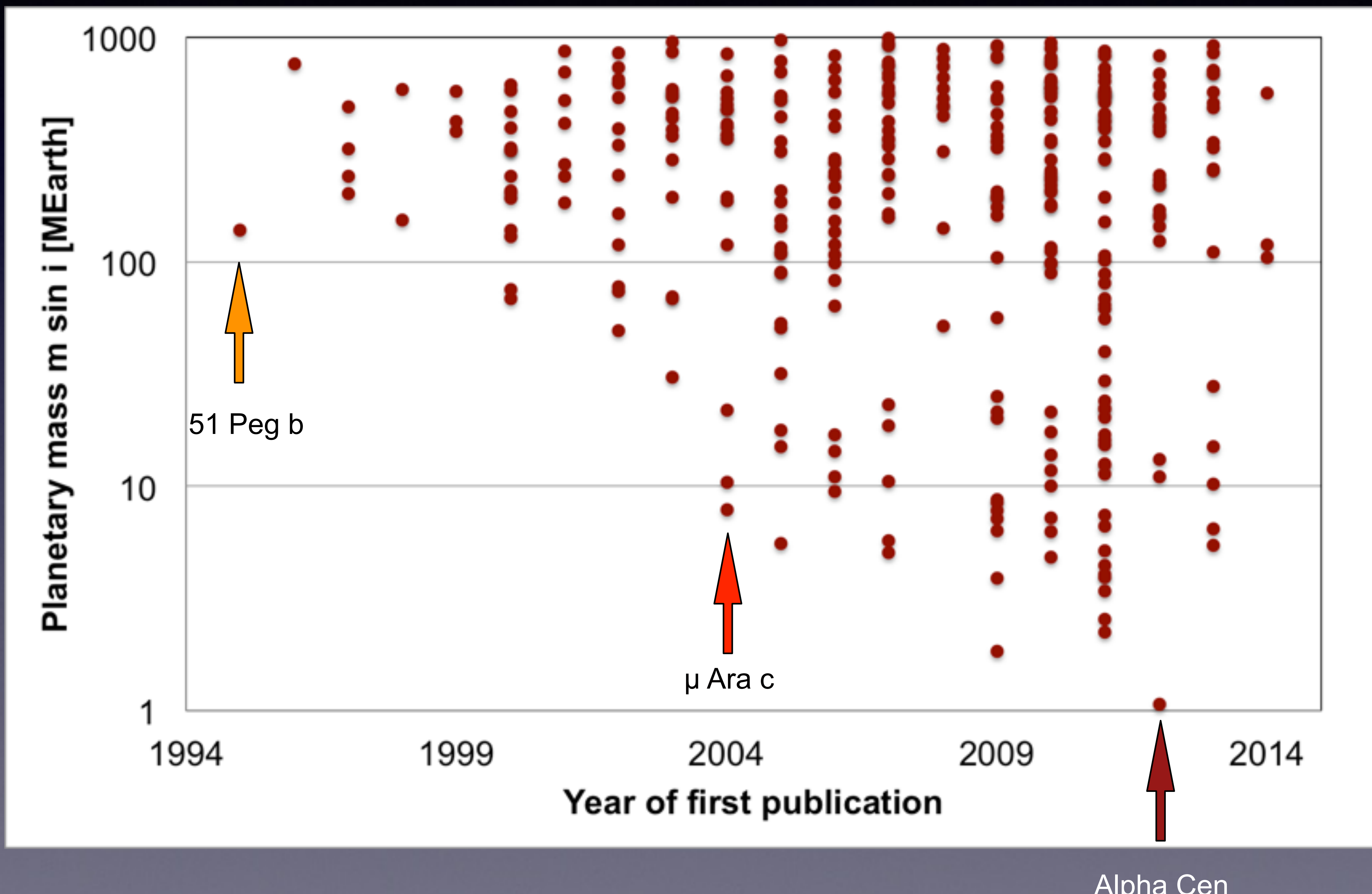




En améliorant la précision



En améliorant la précision



La sensibilité des vitesses radiales

$$k_1 = \frac{28.4\ \mathrm{m\,s^{-1}}}{\sqrt{1-e^2}} \frac{m_2 \sin i}{M_{\mathrm{Jup}}} \left(\frac{m_1 + m_2}{M_{\mathrm{Sun}}}\right)^{-2/3} \left(\frac{P}{1\ \mathrm{yr}}\right)^{-1/3}$$

(M_1 = Sun)

Jupiter	@ 1 AU	: 28.4 m s^{-1}
Jupiter	@ 5 AU	: 12.7 m s^{-1}
Neptune	@ 0.1 AU	: 4.8 m s^{-1}
Neptune	@ 1 AU	: 1.5 m s^{-1}
Super-Earth (5 $M_\oplus$)	@ 0.1 AU	: 1.4 m s^{-1}
Super-Earth (5 $M_\oplus$)	@ 1 AU	: 0.45 m s^{-1}
Earth	@ 1 AU	: 9 cm s^{-1}

La sensibilité des vitesses radiales

$$k_1 = \frac{28.4\ \mathrm{m\ s^{-1}}}{\sqrt{1-e^2}} \frac{m_2 \sin i}{M_{\mathrm{Jup}}} \left(\frac{m_1 + m_2}{M_{\mathrm{Sun}}} \right)^{-2/3} \left(\frac{P}{1\ \mathrm{yr}} \right)^{-1/3}$$

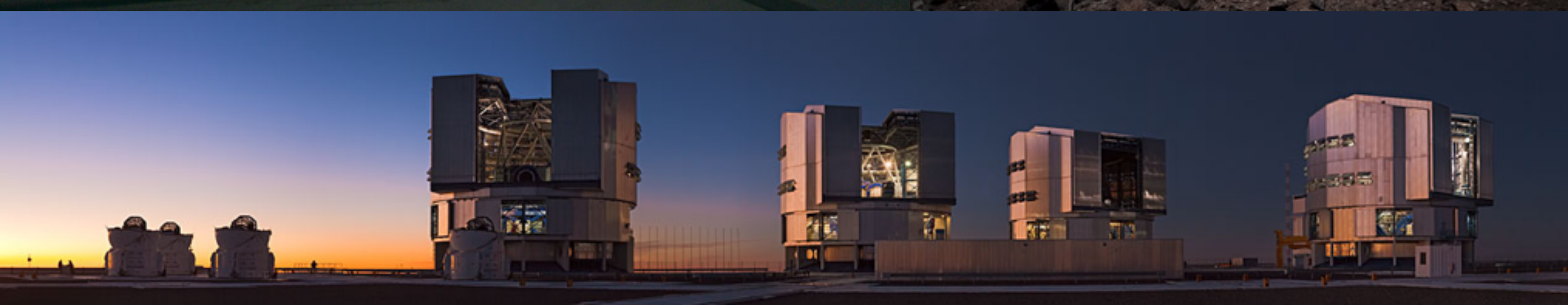
(M_1 = Sun)

Jupiter	@ 1 AU	: 28.4 m s^{-1}
Jupiter	@ 5 AU	: 12.7 m s^{-1}
Neptune	@ 0.1 AU	: 4.8 m s^{-1}
Neptune	@ 1 AU	: 1.5 m s^{-1}
Super-Earth (5 $M_\oplus$)	@ 0.1 AU	: 1.4 m s^{-1}
Super-Earth (5 $M_\oplus$)	@ 1 AU	: 0.45 m s^{-1}
Earth	@ 1 AU	: 9 cm s^{-1}

Planètes géantes
Premières exoplanète
e.g. Jupiters jusqu'à 5 AU

Neptunes et Superterres
Accessibles avec HARPS

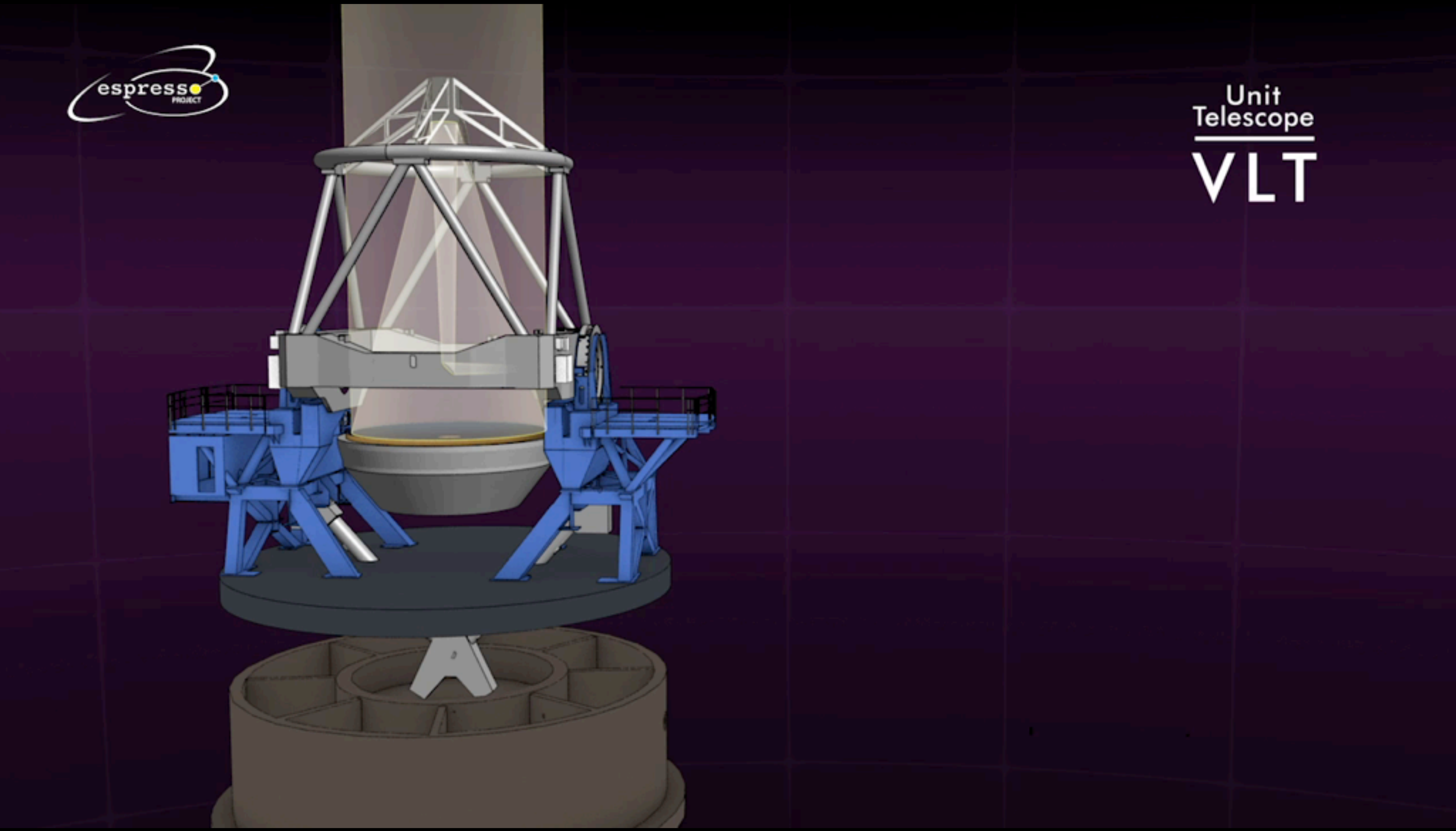


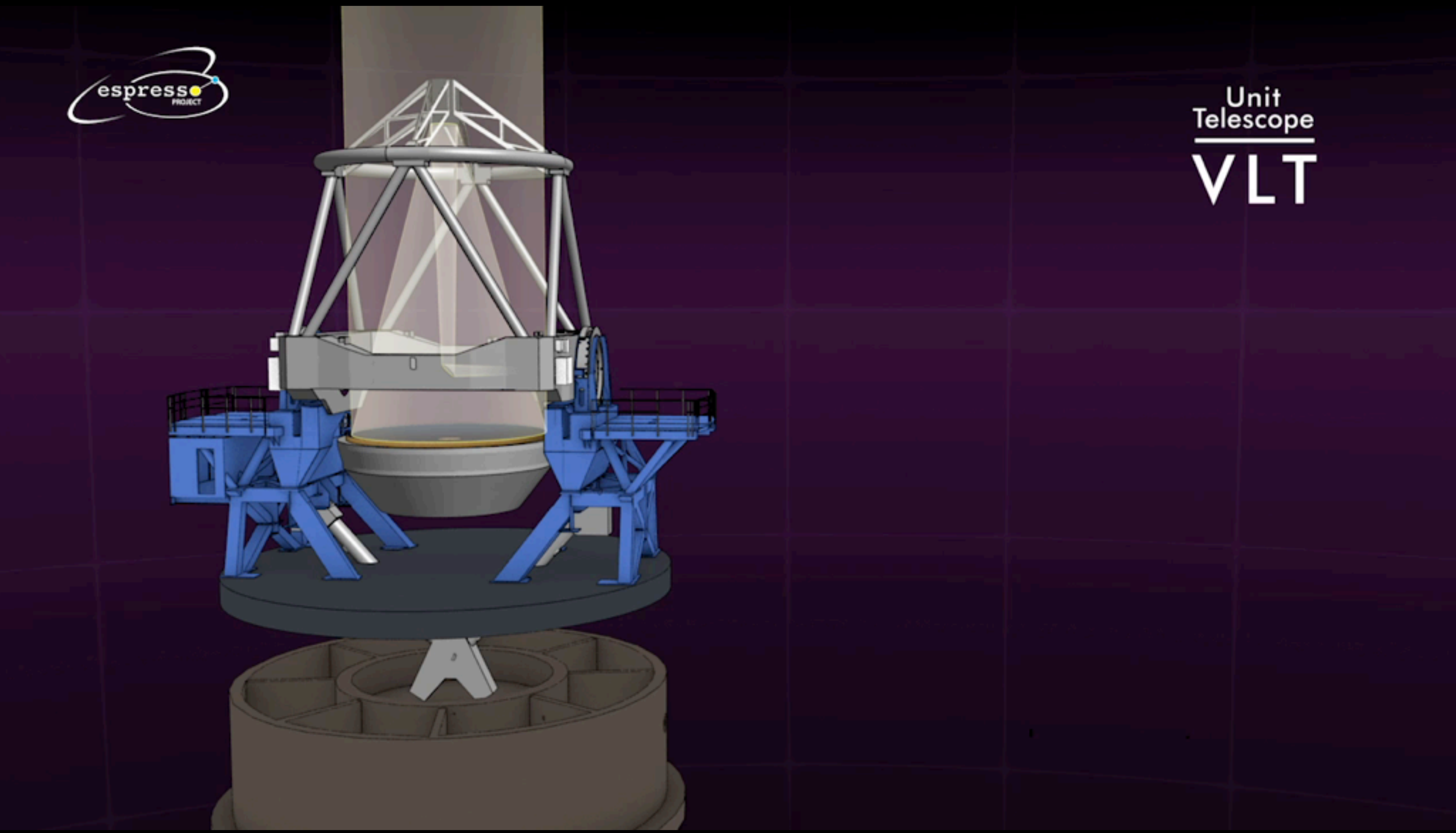



Pourquoi ESPRESSO serait meilleur?

Pourquoi ESPRESSO serait meilleur?

- Télescope plus grand (dont jusqu'à 4! Wow!)
- Capteurs monolithique et stabilisés (9k9 e2v)
- Fibres octogonal (ex-limitation dans HARPS!)
- Source de calibration adaptés (LFC/FP)
- Une pipeline de réduction puissante
- Flexibilité opérationnelle (4 télescope au choix, changement rapide)! -> Efficacité, échantillonnage en t


espresso
PROJECT
Unit
Telescope
VLT


espresso
PROJECT
Unit
Telescope
VLT