ExTrA-design considerations for precise ground-based (spectro)photometry

Xavier Bonfils (IPAG/CNRS/UJF, Grenoble)
ESO Garching
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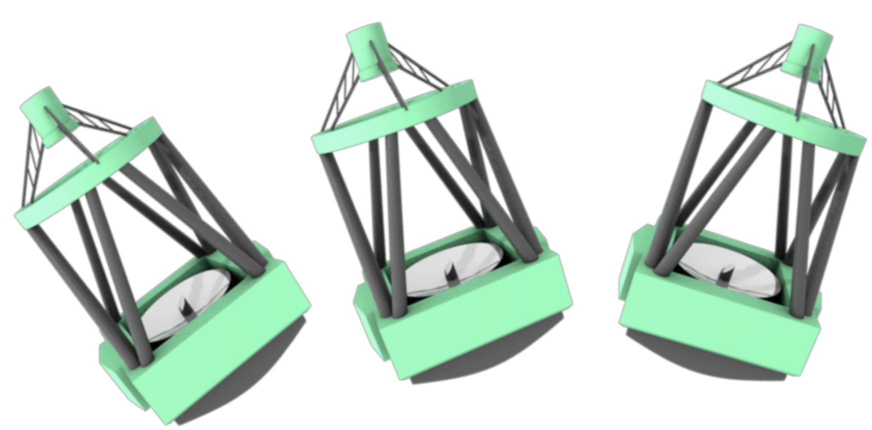
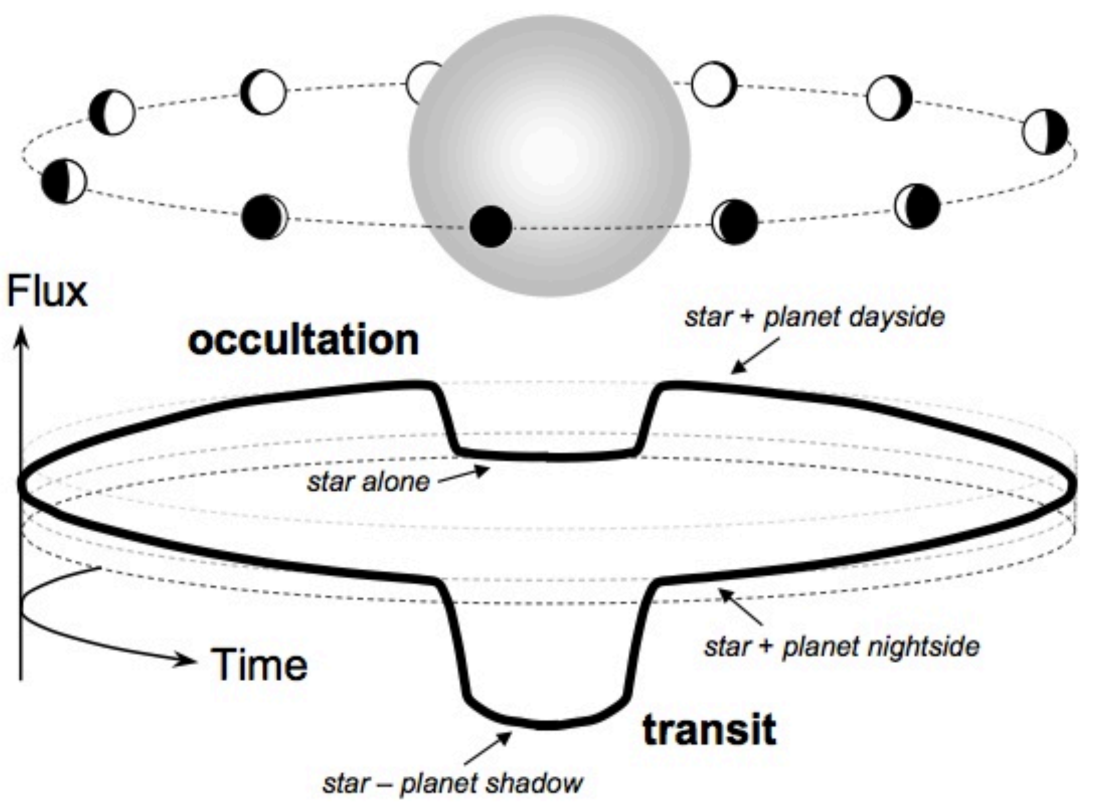
& the ExTrA Team (IPAG) : P. Kern , L. Jocou, E. Stadler, Y. Magnard, Th. Moulin, L. Gluck, S. Lafrasse, S. Rochat, P. Feautrier, X. Delfosse, T. Forveille, ...

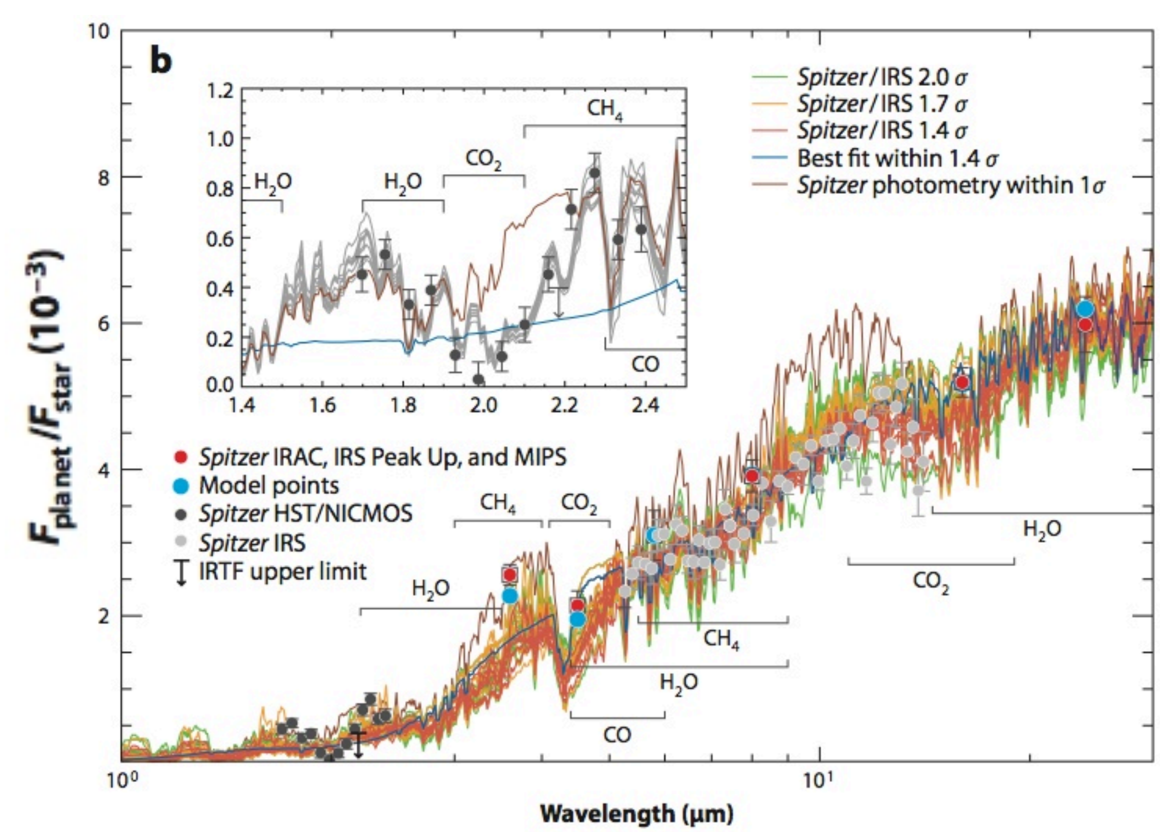


Transiting planets

- ~1/2 known exoplanets (~450/1050, +thousands candidates)
- open up a wealth of physical properties
  radius, true mass (+RV), density, structure, eccentricity, tilt star/orbit, chemical composition, clouds and hazes, T-P profile, winds, climate, ...
- characterization needs very high S/N observations



after Winn (2010)



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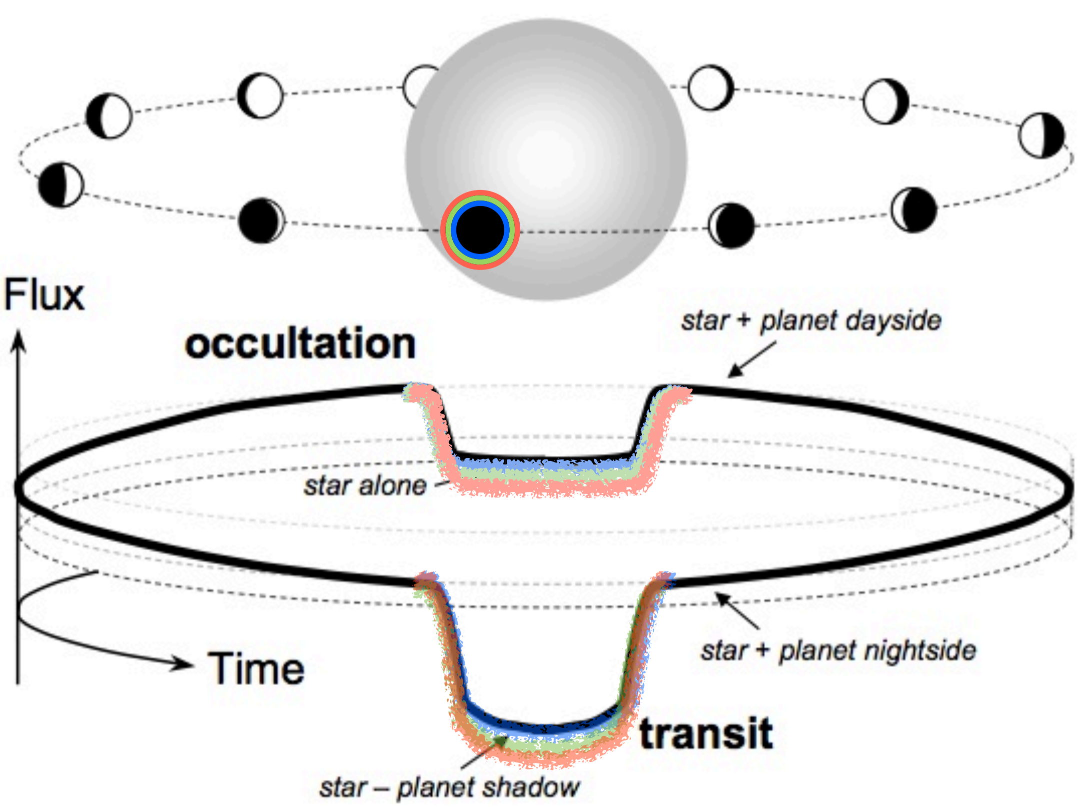

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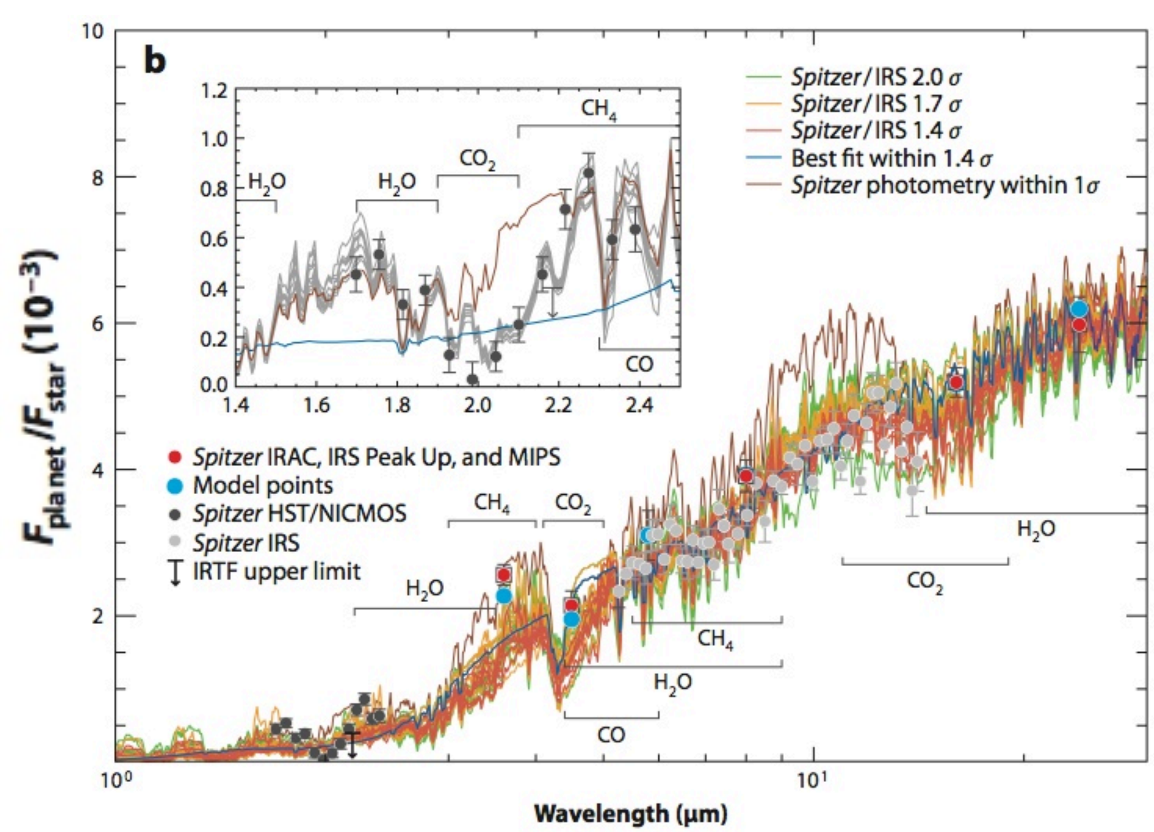

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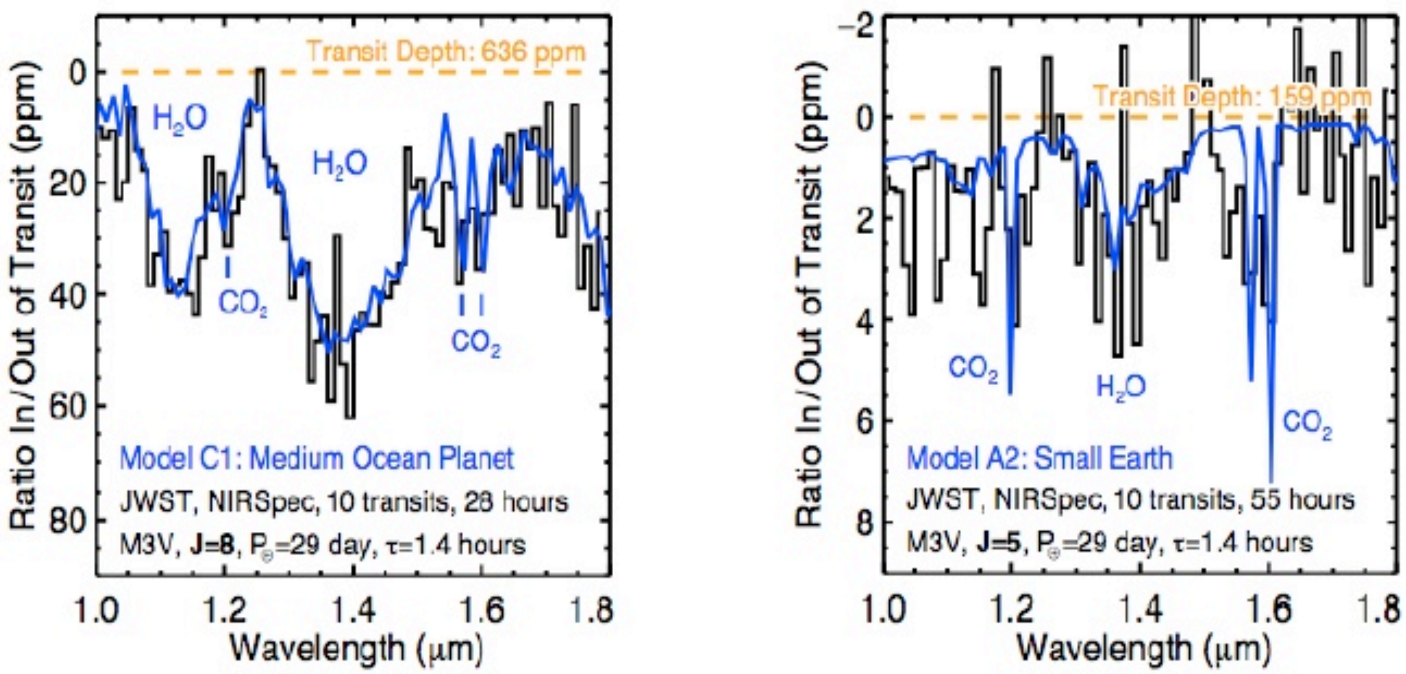
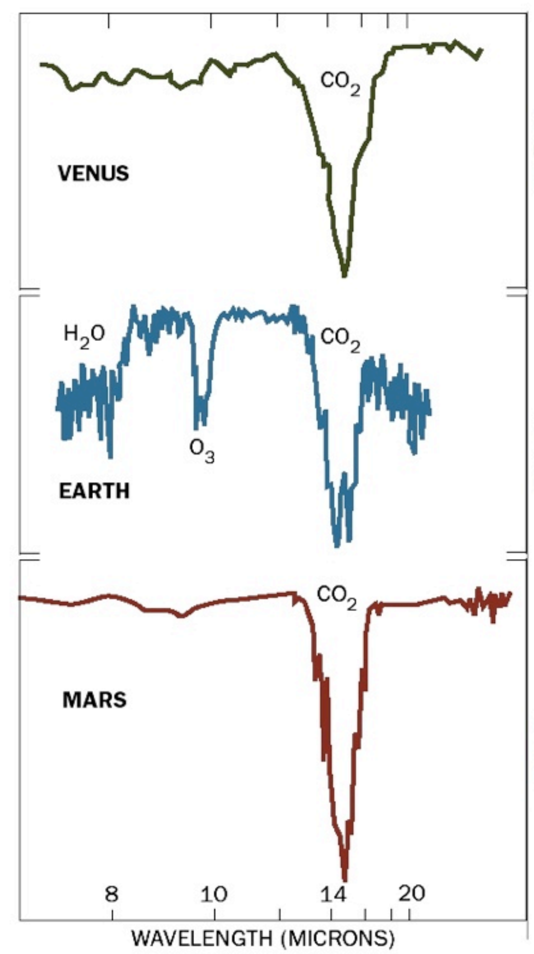
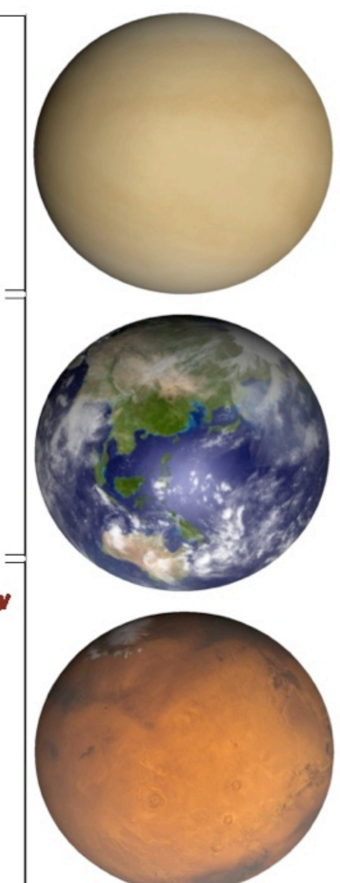


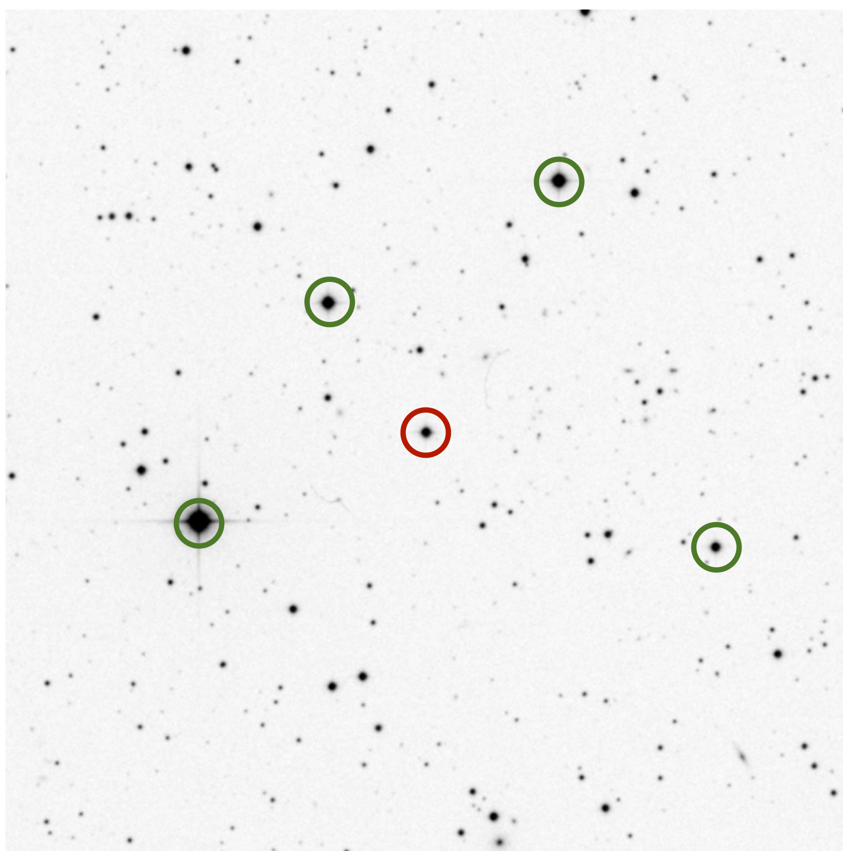
Seager & Deming (2009)

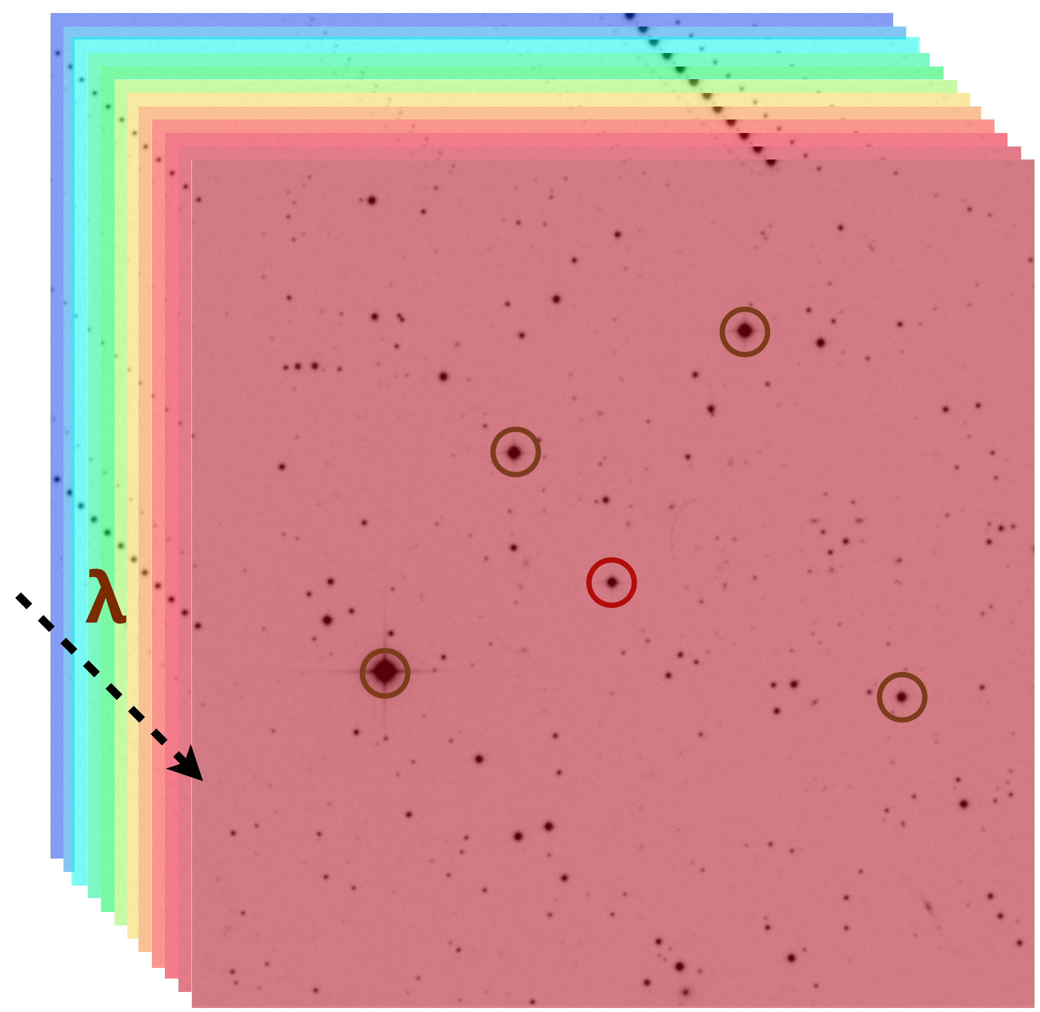




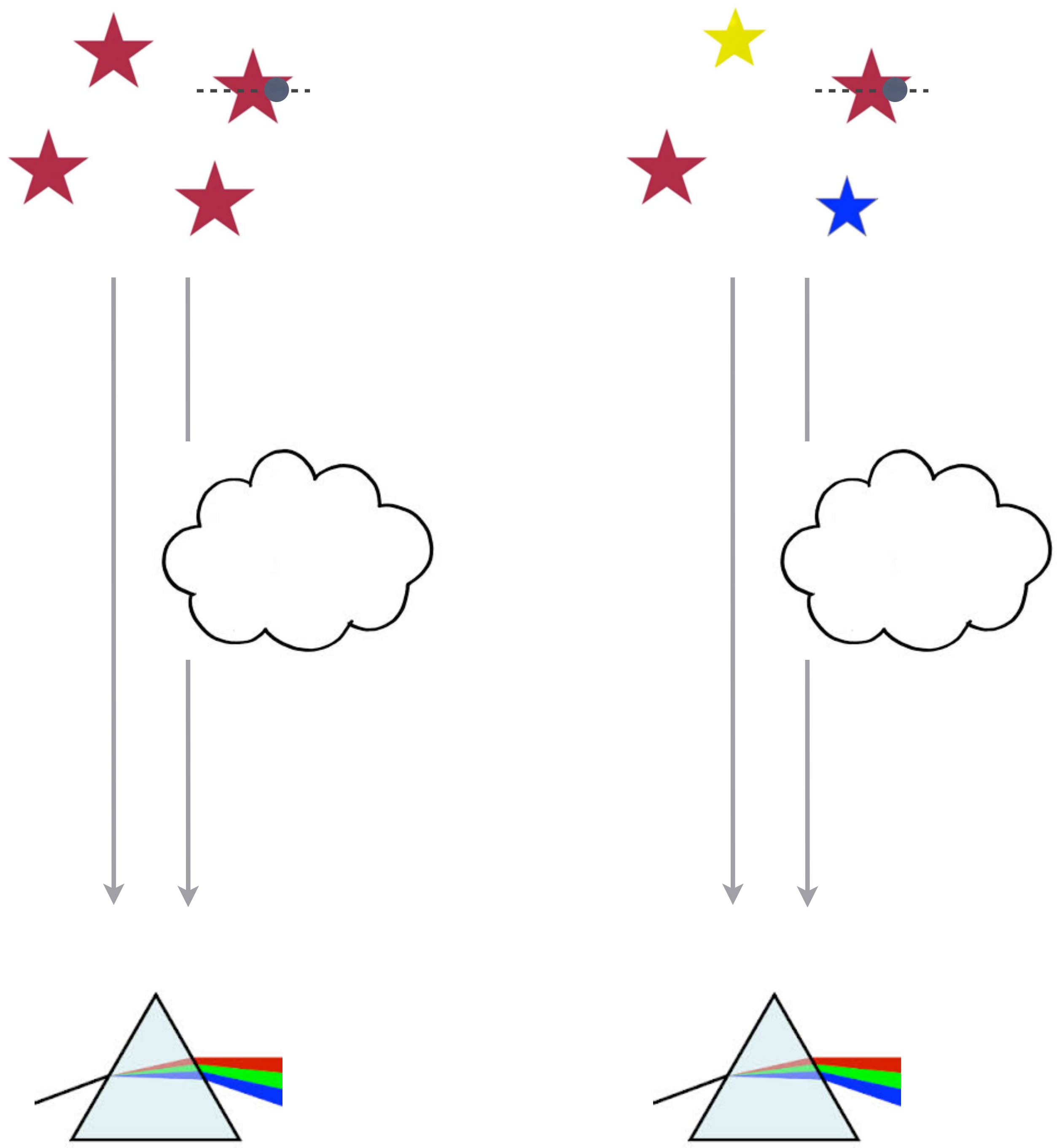
Methods (ground based)

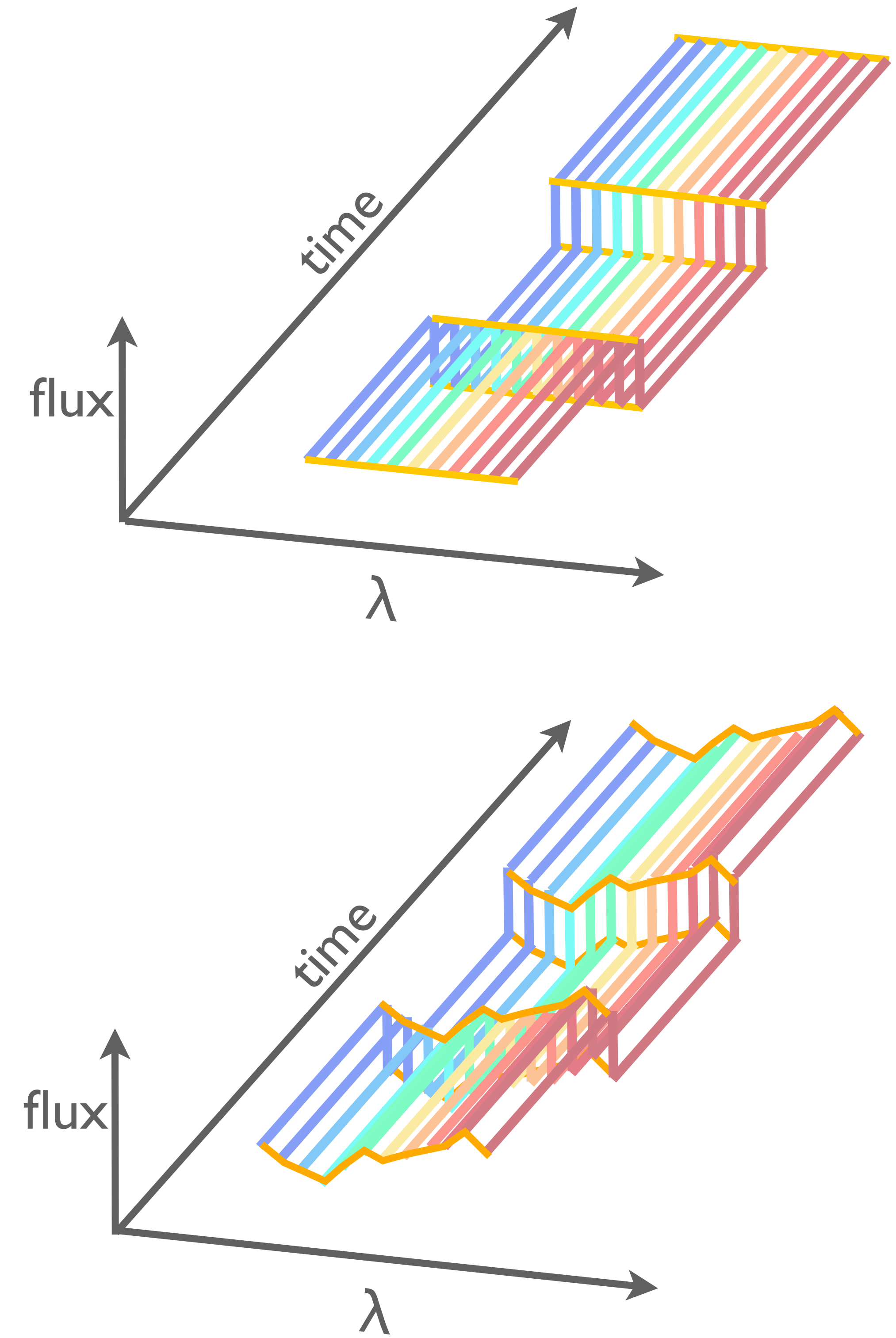
- multi-band differential photometry (broad or short band)
- high-res spectro
  + efficient, self calibrated - loose spectral continuum, rely on line list knowledge
- <u>multi-object spectroscopy</u>





Systematics illustrated :





High spectral resolution resolves correlated noise.
Enables correction before eventually degrading that spectral resolution, to boost S/N.

First results

FORS2

mask w/ large slits

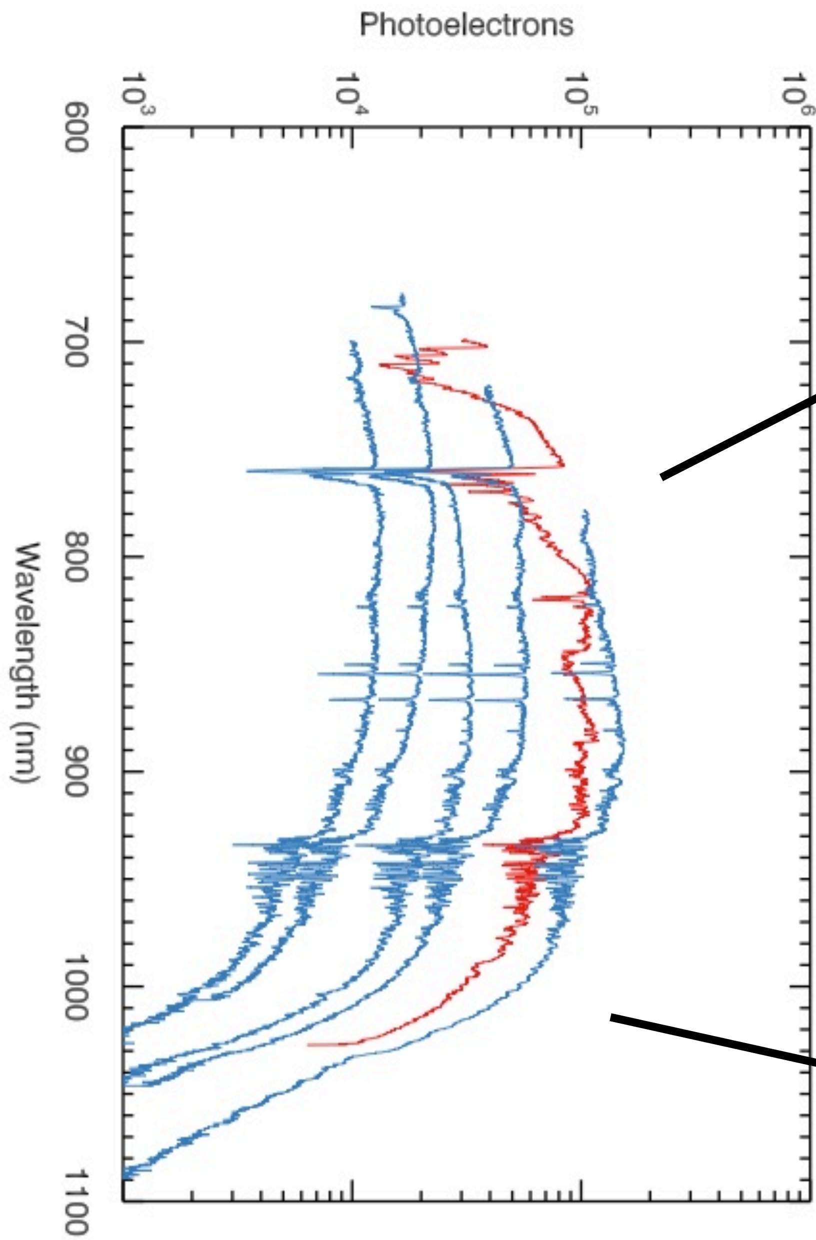
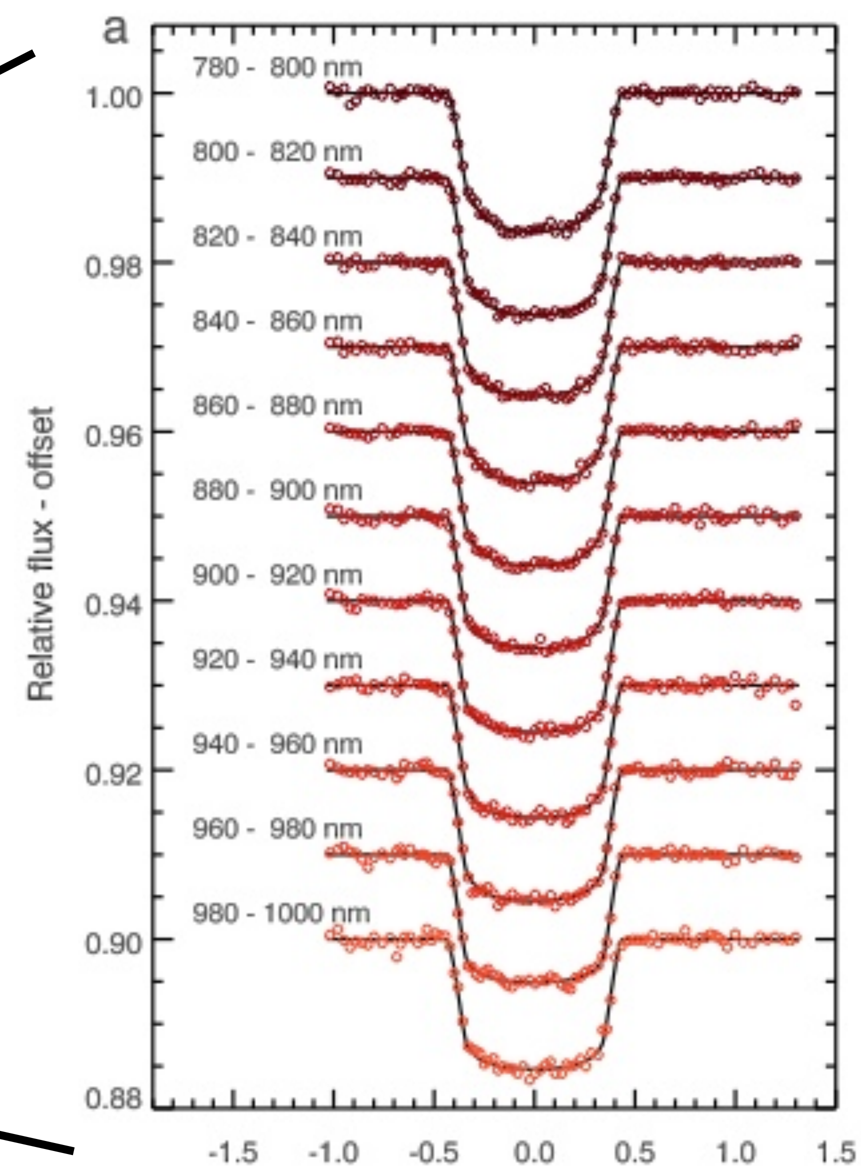


Figure 3: Example extracted spectra for GJ 1214 (red) and the five reference stars utilized for the relative photometric calibration (blue). The different wavelength coverage for the objects is a result of parts of their spectra not falling on the detector due to their distribution on the sky in the dispersion direction.

R~1000



by Bean et al. (2010, Nature 470, 669)

also w/ GMOS (Gibson et al. 2012; Crossfield et al. 2013)

Context Method Design Extra

First results

2380 *P. L. Wood et al.* (2011)

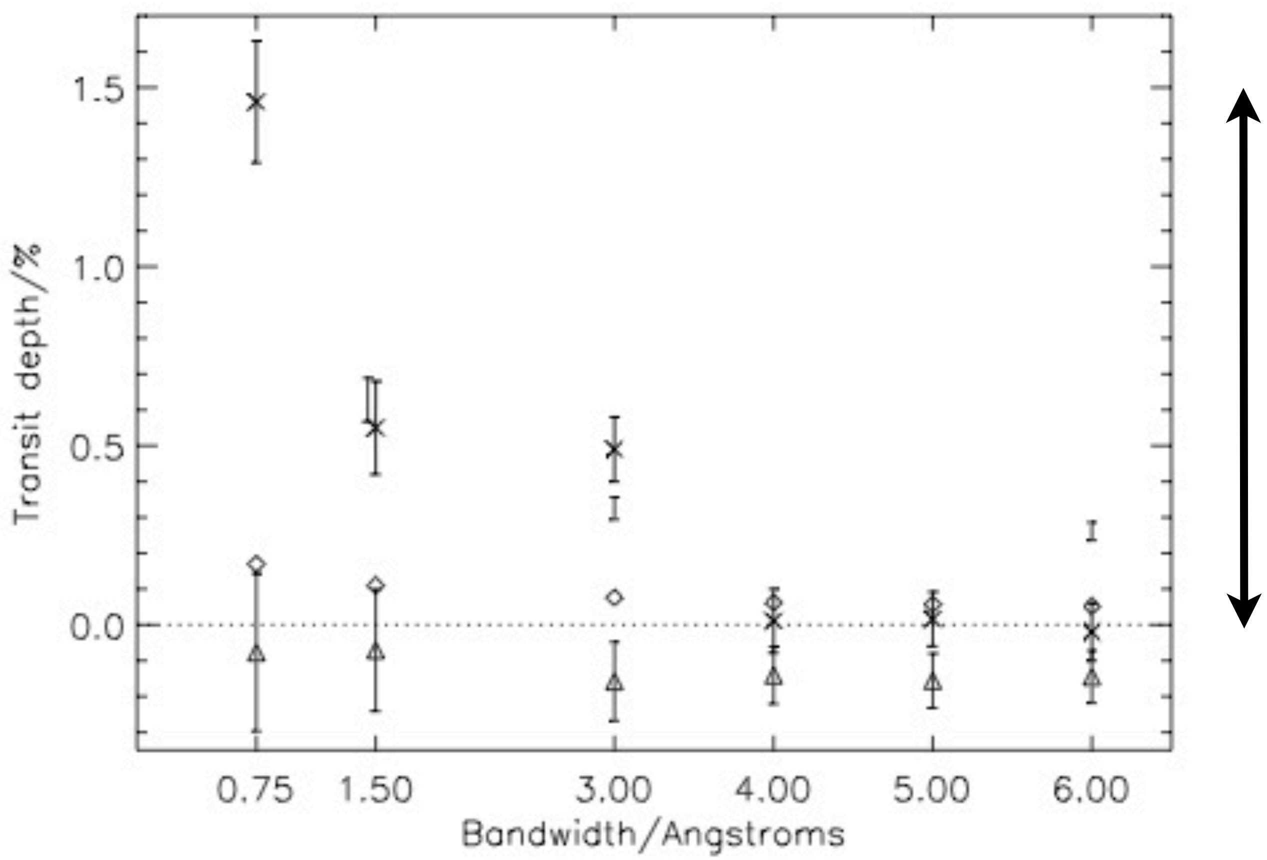
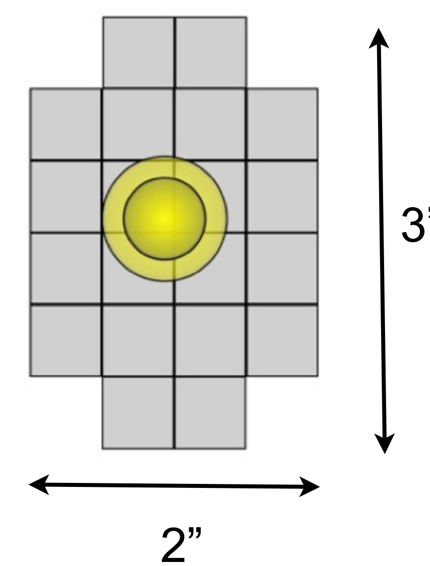


Figure 6. Transit depths for WASP-17b shown as crosses with error bars. S08 values for HD 209458b, scaled up by factors 4.2–5.1, are shown as plain error bars; transit depths for the comparison star are shown as triangles with error bars. Diamonds represent the uncertainties due to photon noise.

FLAMES

9-σ detection of Na absorption

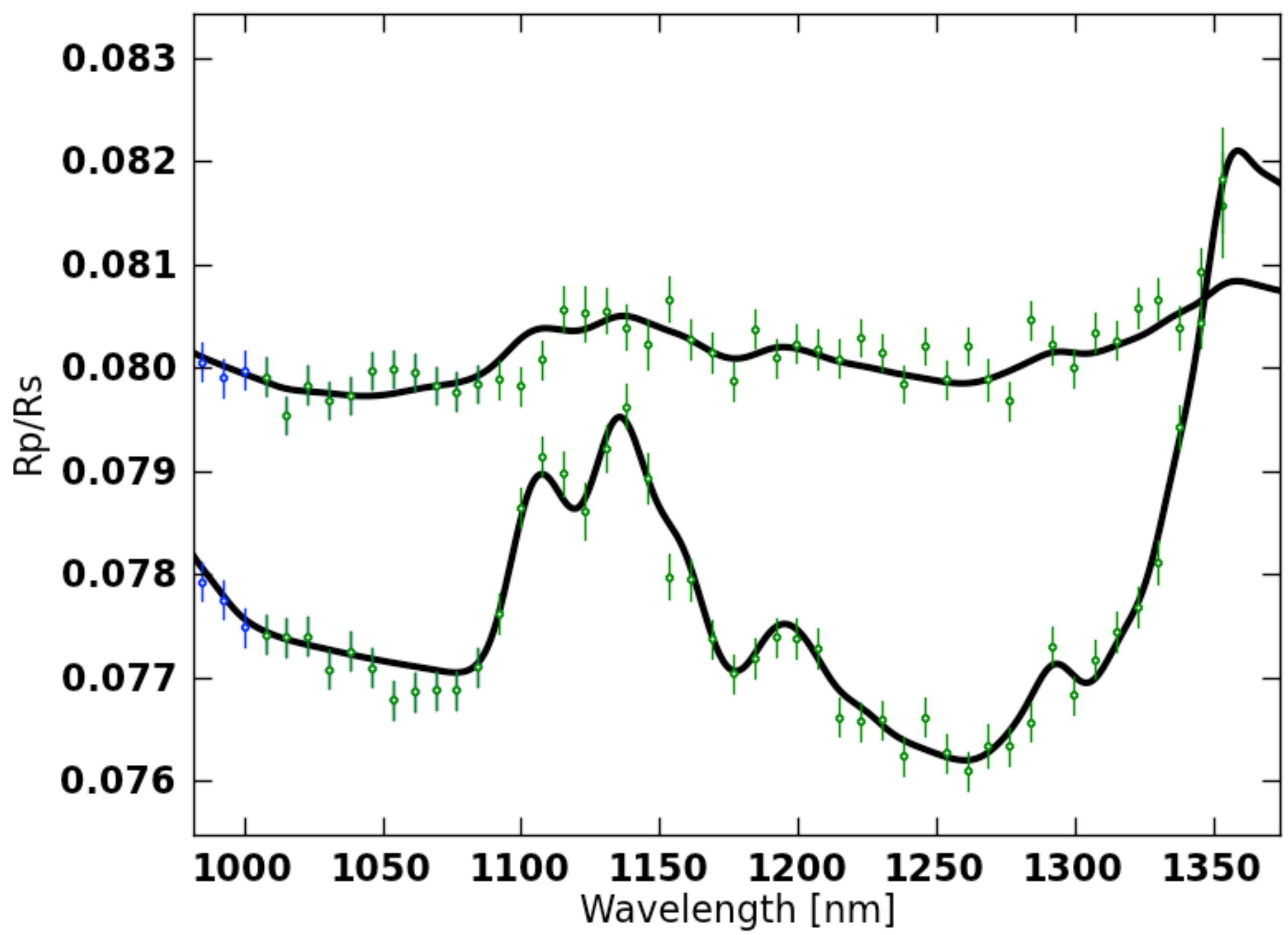


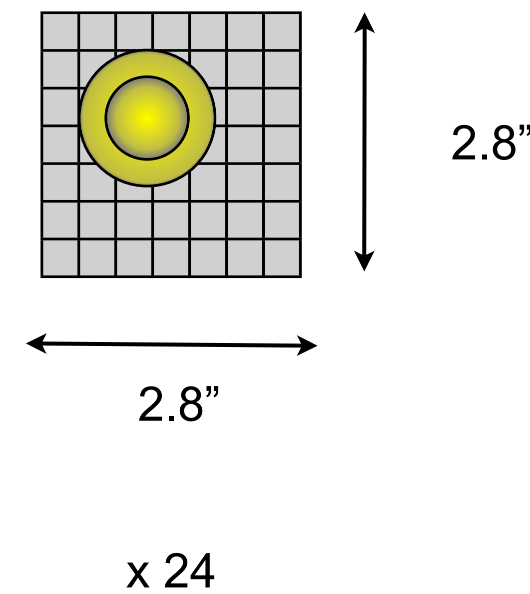
x 14

no further results so far... perhaps because of the imperfect micro-lens transmission...

KMOS ?

Simulations for GJ3470b :



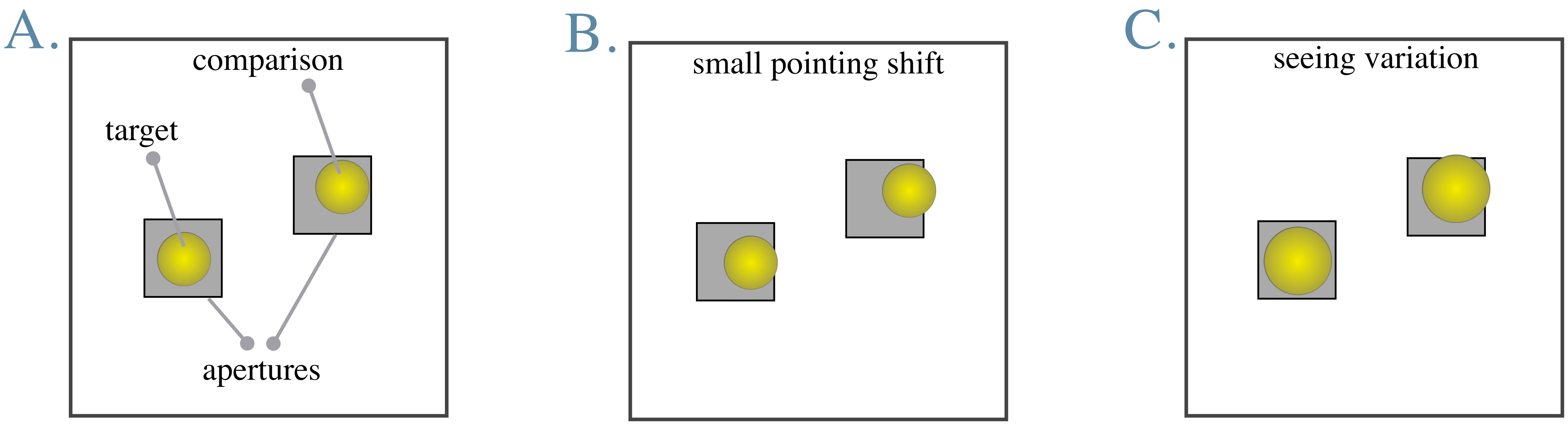


Several on-going programs with K-MOS
=> experience that can inform MOS design

model thanks to D. Ehrenreich

ongoing observations (Saglia et al.)

Injection



Systematics

- tracking (case B) or seeing variations (case C) induces flux losses
- bad centering induces differential flux losses

Injection design

- large “apertures” (or field of view), but not too large because of the sky
- precisely centered on star PSF
- minimal repositioning error
- precise guiding

Context
Method
Design
Extra

Injection

Aperture values

(simulations used by the Science Team to define the TLRs)

case : precision = 10^-4

- seeing=1.5”, seeing variation=10%
  - aperture > 5”x5”
  - centering precision < 0.2” (pTp)
  - integrated tracking precision < 0.05” (pTp)

case : precision = 10^-6

- seeing<1.0”, seeing variation=30%
  - aperture > 5”x5”
  - centering precision < 0.05” (pTp)
  - integrated tracking precision < 0.05” (pTp)

seeing var = 10%

centering < 0.1” (pTp)

- star positions do change ! (e.g. field geometry or differential refraction)
- can be accommodate by (unnecessarily) larger apertures
- ‣ active centering should be preferred

The ExTrA facility

Cassegrain Units

5 movable field units
(1 target + 4 comp. stars)

each field unit injects
star & sky flux
in 2x4 fibers

positionners are
piezo-electric
stages assemblies

Telescopes

numbers	3
diameter	60cm
f-ratio	f/8
fov	57‘x57’

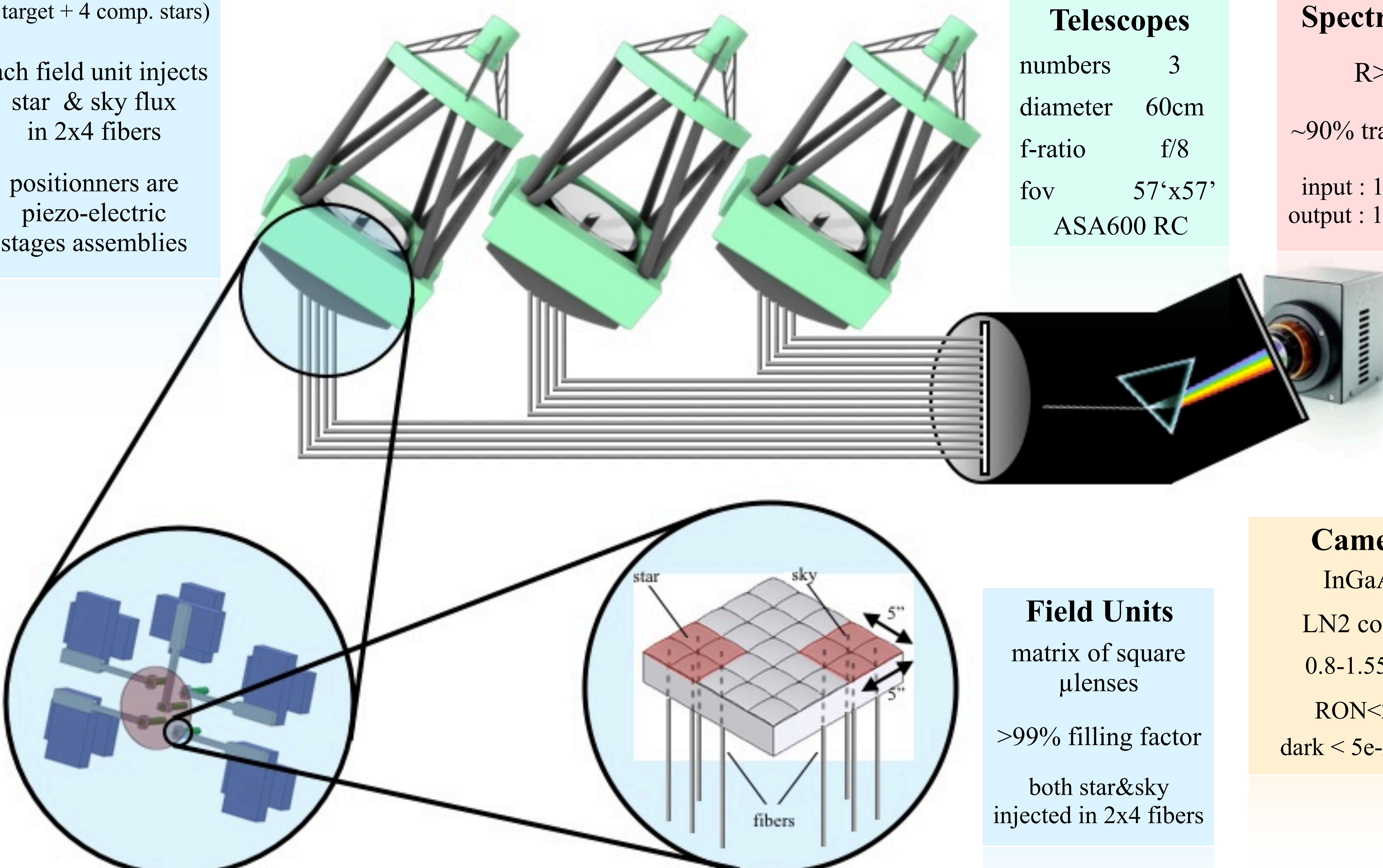
ASA600 RC

Spectrograph

R>200

~90% transmission

input : 120 fibers
output : 120 spectra



Field Units

matrix of square
μlenses

>99% filling factor

both star&sky
injected in 2x4 fibers

Camera

InGaAs

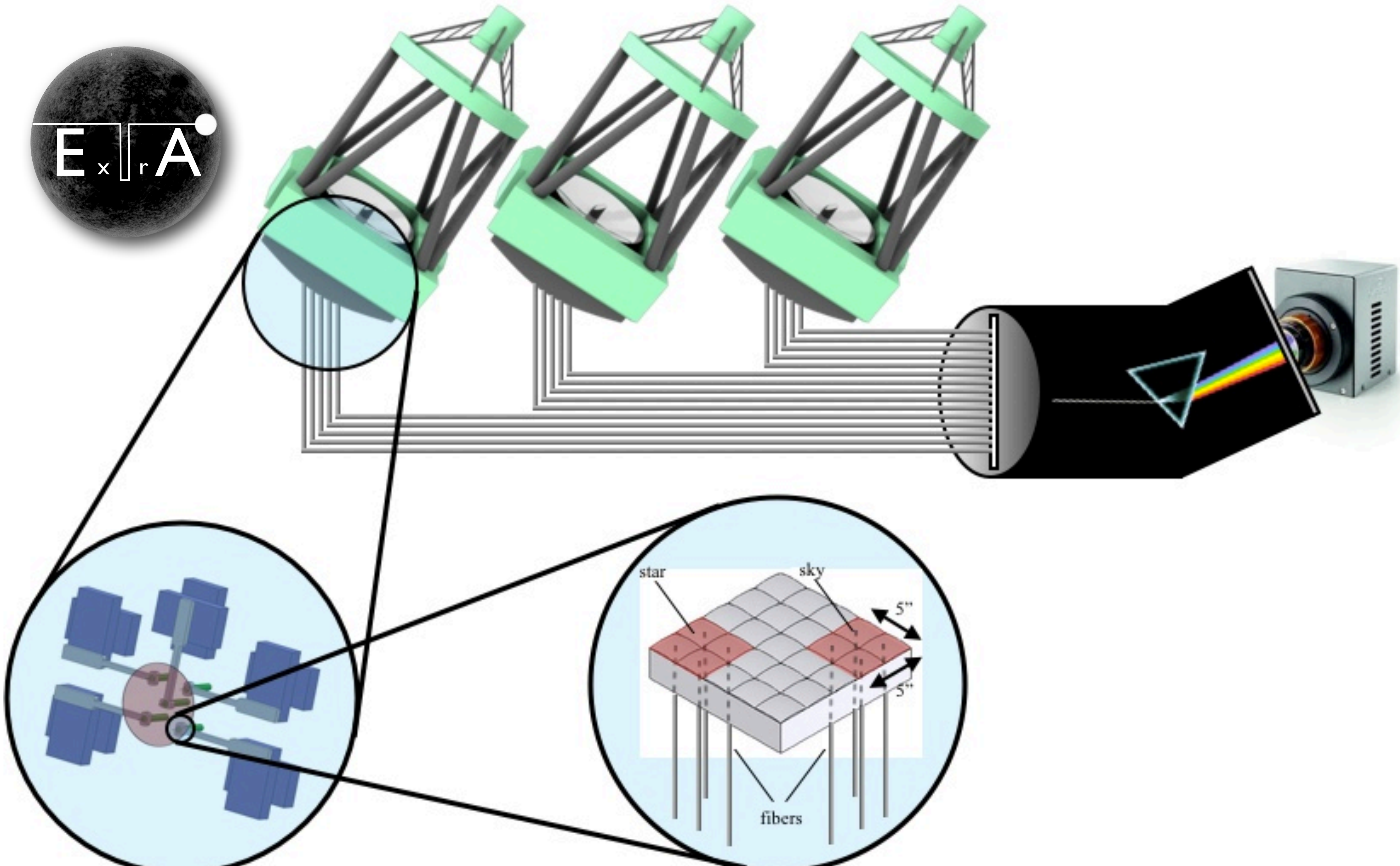
LN2 cooled

0.8-1.55μm

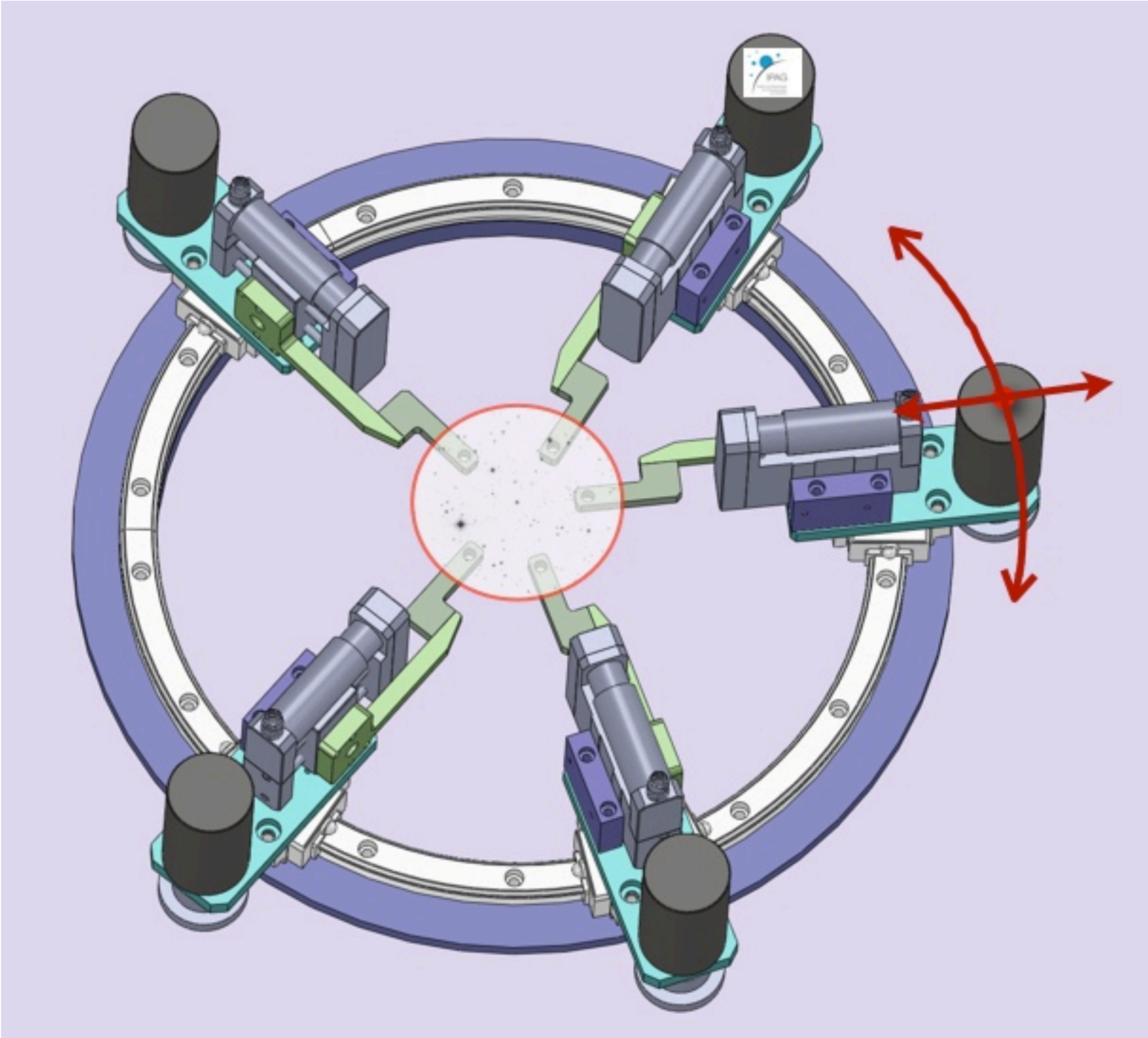
RON<20e-

dark < 5e-/pix/sec

The ExTrA facility



Injection



- active positioning   23.3µm <-> 1 arcsec (600mm, f/8)

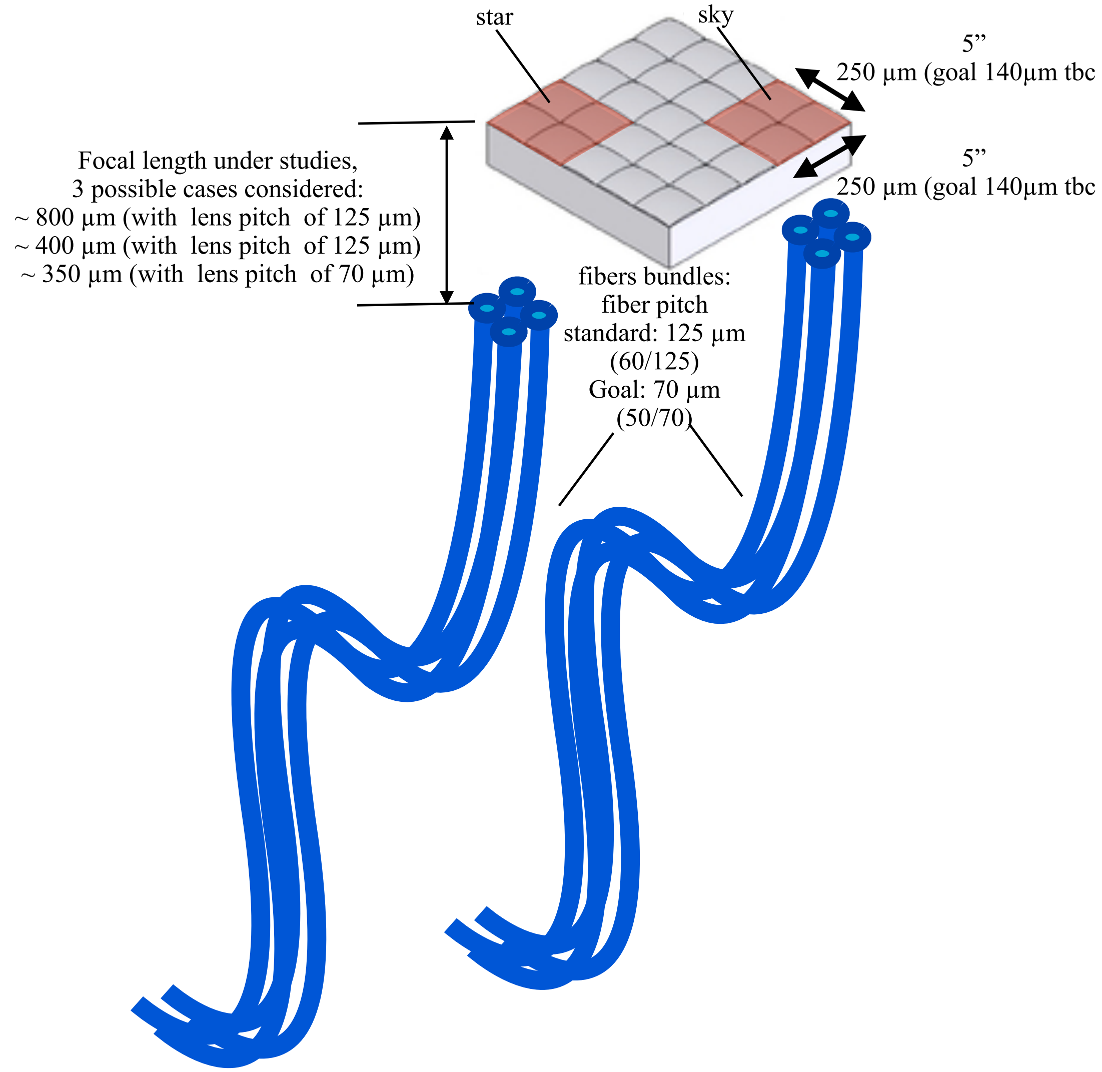
Injection

Filed Unit Design

+ active centering

+ measure of photocenter position

= stable illumination



- sky measured next to each object to remove OH emission

- large FOV (5-10” width)

If filling factor <100% ?

- 1µm dead zone => defocus = 2”, aperture=10”x10”, centering < 0.1”
- alt/ : perform dithering or PSF shaping w/ active positioning
- lab. tests foreseen

Alt/ design ?

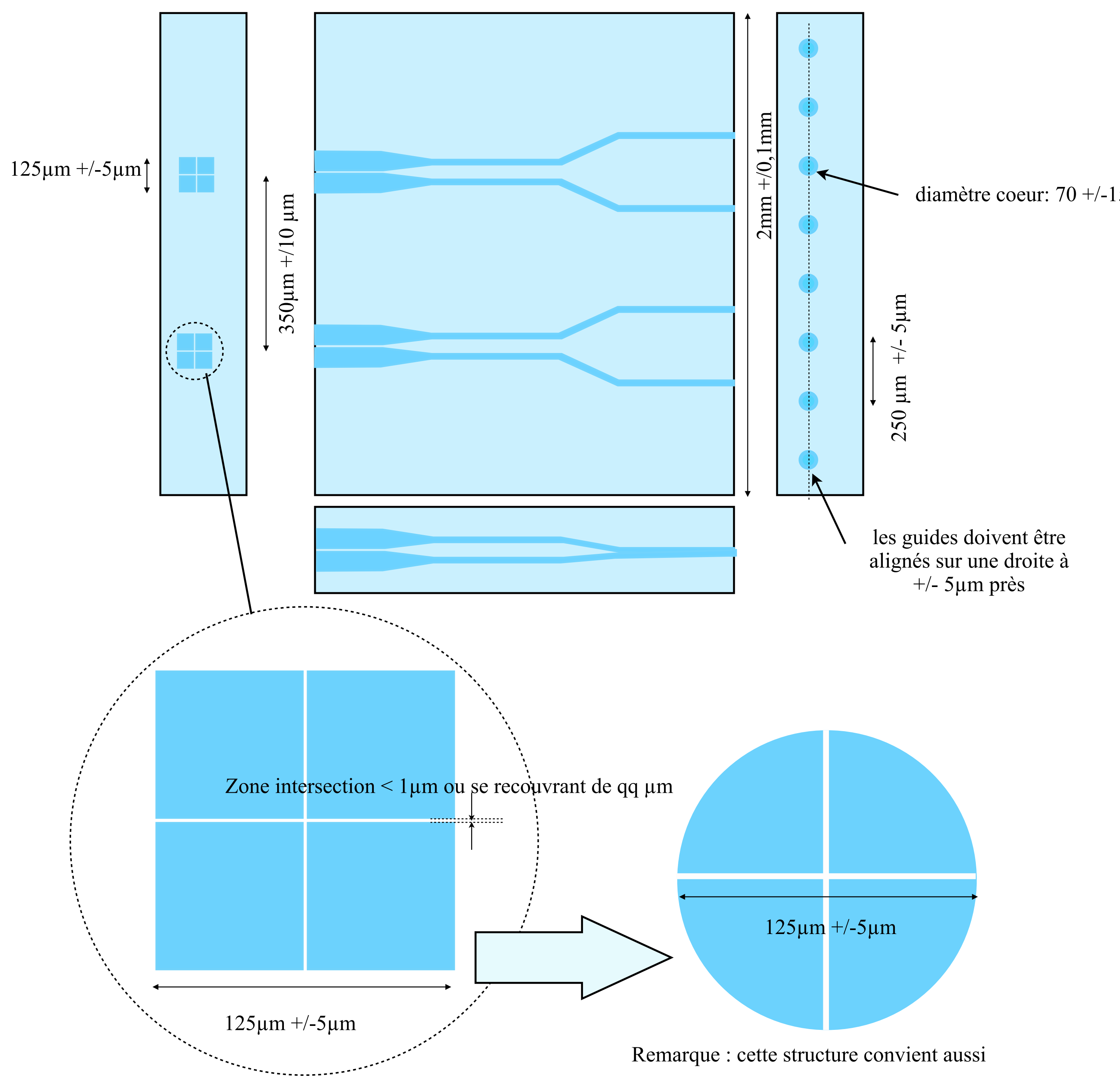
Injection

Alt/ design ?

P. Kern
L. Jocou
R. Stoian

Structure Lanterne pour 4 quadrants

Ouverture numérique : F/5 => Δn correspondant ?
Δn = 4.10-2 ou 5.10-2



Similar to :

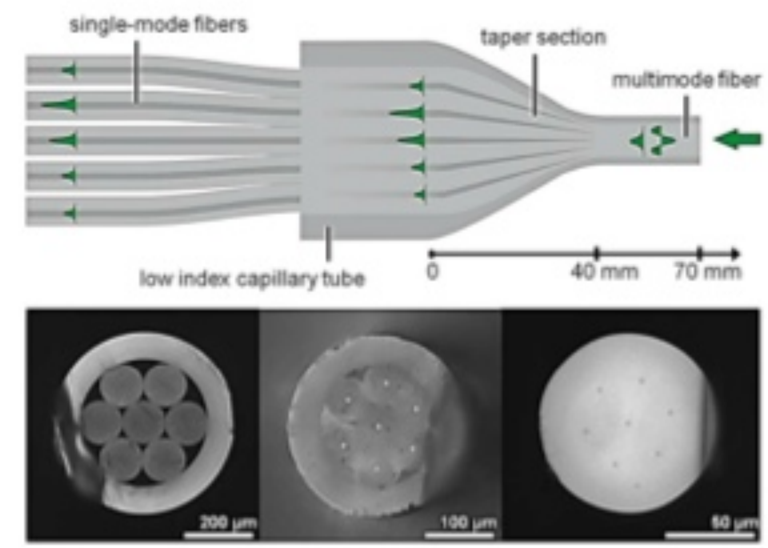
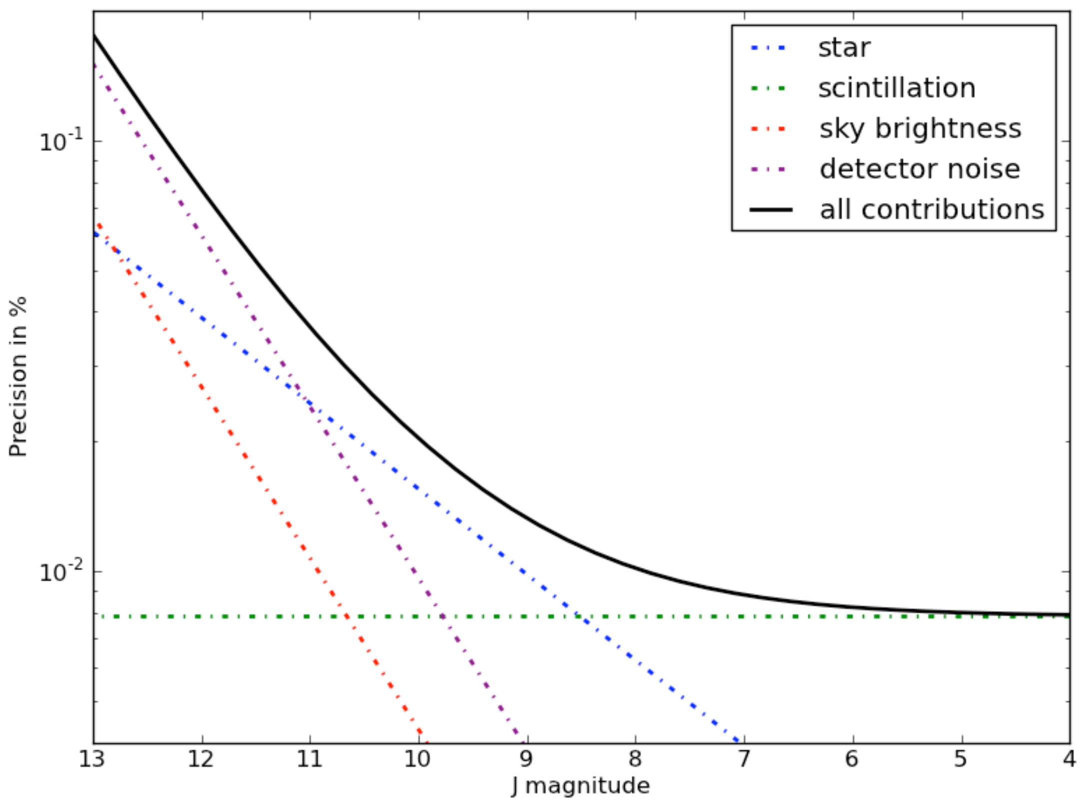


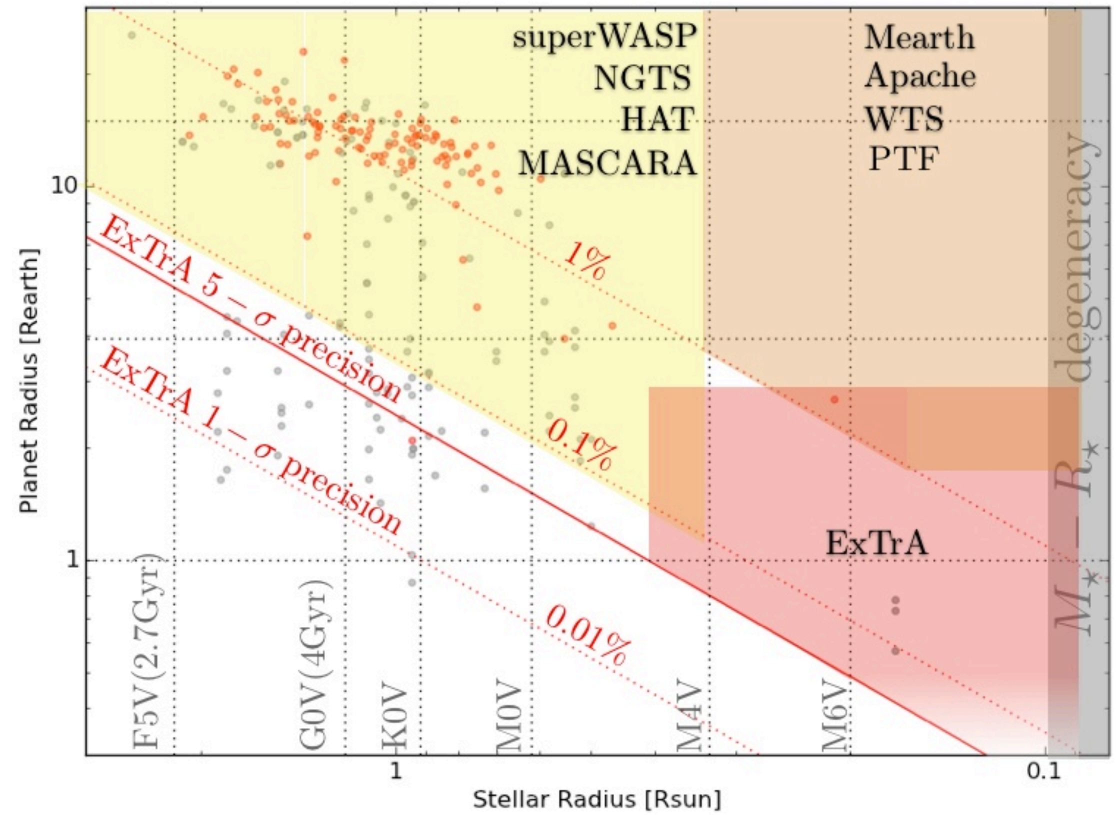
Figure 1. (top panel) Schematic illustration of the photonic lantern. (bottom panel) Microscope pictures at different positions along the down taper transition.

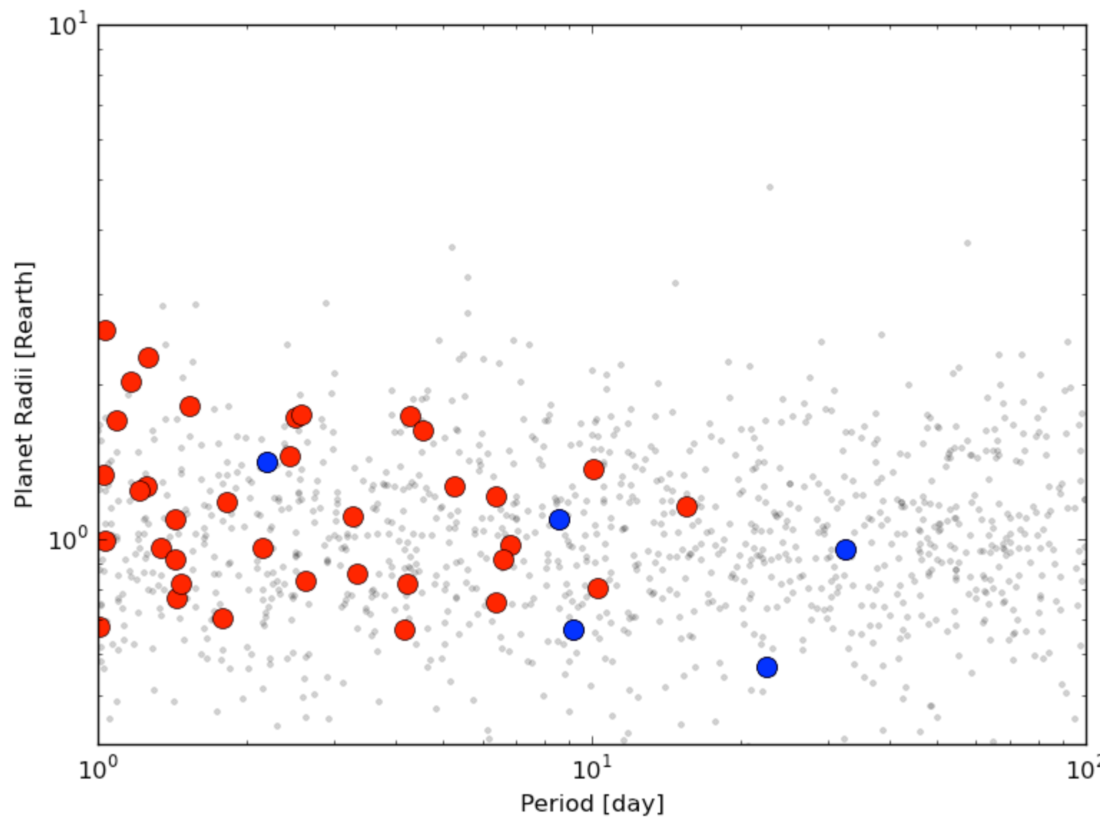
C. Schwab's poster

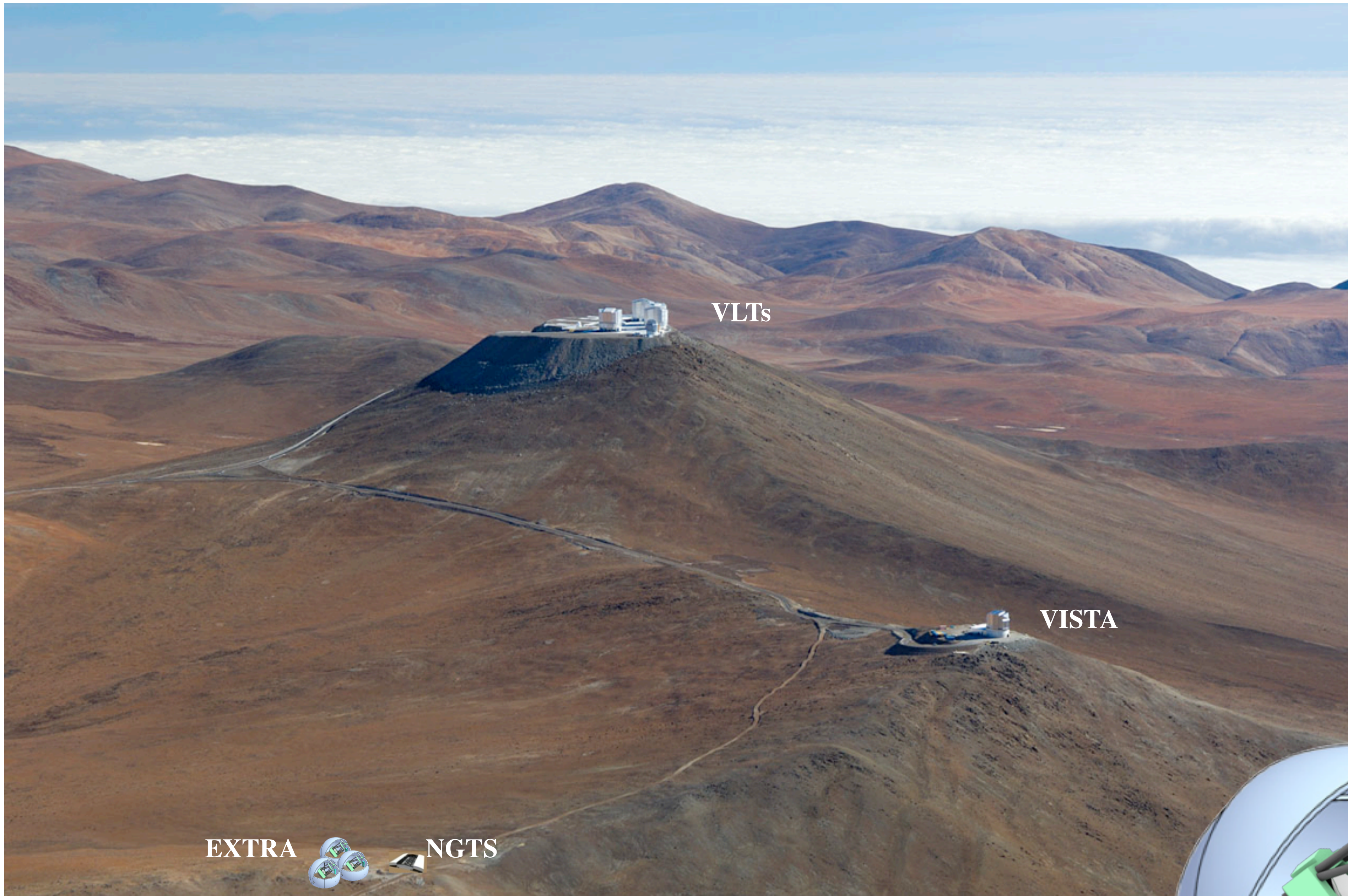
Expected performances

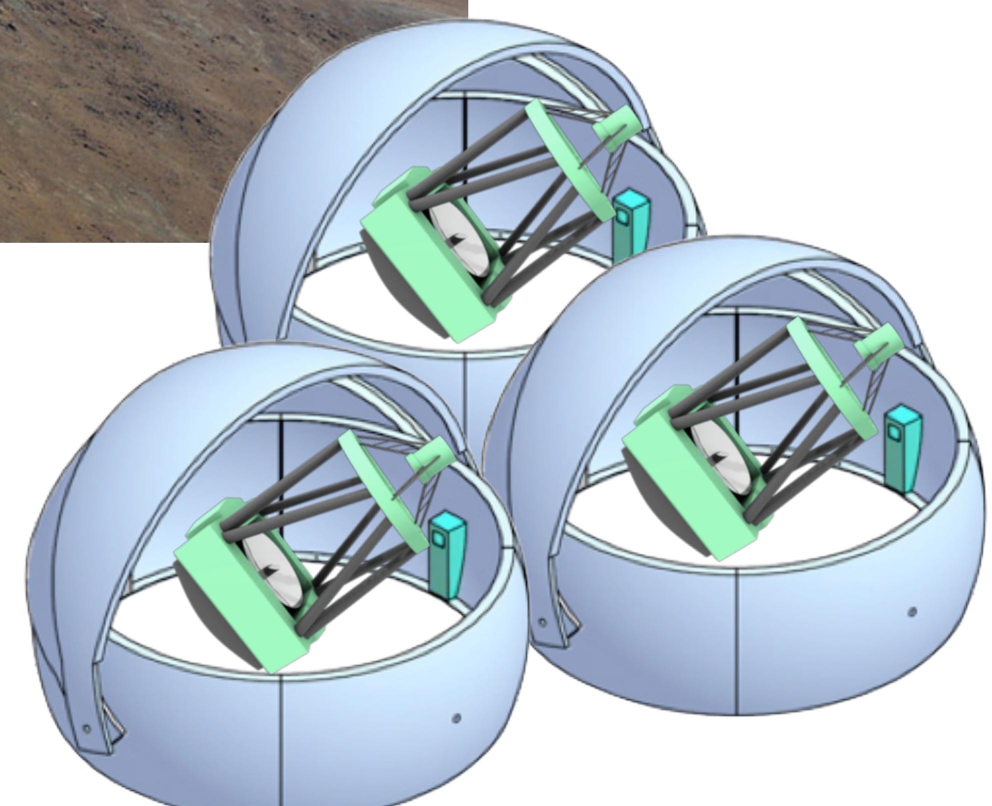
precision = 0.01% in 240s for J=8











- Paranal ?
- 1st light foreseen ~fall 2015

Other requirements

Precision also affected by detector non-linearities (pixel response, charge transfer efficiency, intra-pixel response, remanence...) :

- spread spectra over many pixels to average down the systematics
- full a priori characterization

Multiplexing :

- goal : 10x more flux on comparison stars than on target
- comparisons are better if the same brightness as the target

=> mux ~ a few

Wavelength:

	0.4-1 μm	1-5 μm	5-11 μm	11-16 μm
R, baseline	~Few tens	300	≥30	20
R, desired	300	300	300	300
*H_2O	0.51, 0.57, 0.65, 0.72, 0.82, 0.94	1.13, 1.38, 1.9, **2.69**	6.2	continuum
*CO_2	-	1.21, 1.57, 1.6, 2.03, **4.25**	-	**15.0**
C_2H_2	-	1.52, **3.0**	7.53	**13.7**
HCN	-	**3.0**	-	**14.0**
C_2H_6	-	3.4	-	**12.1**
O_3	0.45-0.75 (the Chappuis band)	4.7	9.1, **9.6**	14.3
HDO	-	2.7,3.67	7.13	-
*CO	-	1.57, 2.35, **4.7**	-	-
O_2	0.58, 0.69, 0.76, 1.27	-	-	-
NH_3	0.55, 0.65, 0.93	1.5, 2, 2.25, 2.9, **3.0**	6.1, **10.5**	-
PH_3	-	4.3	8.9, 10.1	-
*CH_4	0.48, 0.57. 0.6, 0.7, 0.79, 0.86,	1.65, 2.2, 2.31, 2.37, **3.3**	6.5, **7.7**	-
CH_3D	?	3.34, **4.5**	6.8, 7.7, **8.6**	-
C_2H_4	-	**3.22**, 3.34	6.9, **10.5**	-
H_2S	-	2.5, 3.8 ...	7	-
SO_2	-	4	**7.3**, 8.8	-
N_2O	-	2.8, 3.9, **4.5**	7.7, 8.5	-
NO_2	-	3.4	**6.2**, 7.7	13.5
H_2	-	2.12	-	-
H_3^+	-	2.0, 3-4.5	-	-
He	-	1.083	-	-
*Na	0.589	1.2	-	-
*K	0.76	-	-	-
TiO	0.4-1	1-3.5	-	-
VO	0.4-1	1-2.5	-	-
FeH	0.6-1	1-2	-	-
TiH	0.4-1	1-1.6	-	-
Rayleigh	0.4-1	-	-	-
Cloud/haze	yes	possible	silicates, etc.	-
H Hα	**0.66**			
H Hβ	0.486			
Ca	0.8498, 0.8542, 0.8662		-	-

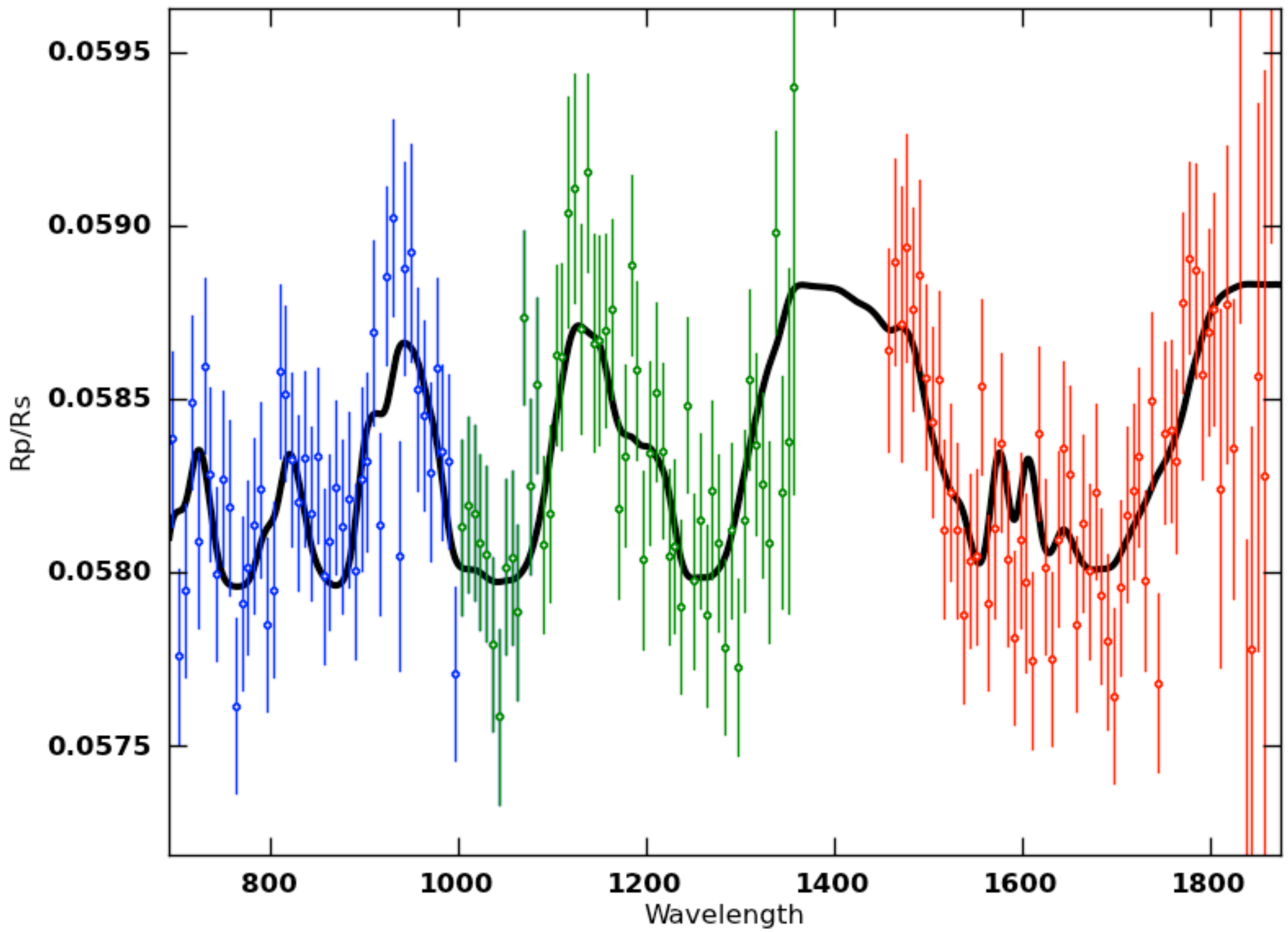
Tinetti et al. (2012)

Conclusion

- MOS were not conceived w/ exoplanets in mind so far...
- large apertures => success of large-slit mask MOS
- better IFUs & active positioning should be considered
- forthcoming feedback from the ExTrA project

E-ELT scaled

Transmission spectra for a single transit of an ocean planet of 2 Rearth transiting a 0.33-Rsun M dwarf



model thanks to D. Ehrenreich