

Xavier Bonfils (IPAG/CNRS/UJF, Grenoble) ESO Garching Feb. 4th, 2013

& 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



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Method

Design

Extra

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Tuesday, February 4, 14

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CO,

1.8

1.6

characterization needs very high S/N observations



Seager & Deming (2009)



# Methods (ground based)

- Method
- Design
- Extra

# 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>





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High spectral resolution resolves correlated noise.

Enables correction before eventually degrading that spectral resolution, to boost S/N.



Context

Method

Design

Extra

dispersion direction.



mask w/ large slits



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

# First results

Context

Method

Design

Extra

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



# FLAMES

#### $9-\sigma$ detection of Na absorption



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.

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

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# KMOS?







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

model thanks to D. Ehrenreich

ongoing observations (Saglia et al.)

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Methoo

Design

Extra



# **Systematics**

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

# **Aperture values**

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

#### case : precision = 10<sup>-4</sup>

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

### case : precision = 10<sup>-6</sup>

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

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
- <u>active</u> centering should be preferred

Context

Method

Design

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# 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

ASA600 RC

3

60cm

f/8

57'x57'

numbers

diameter

f-ratio

fov

### Spectrograph

R>200

~90% transmission

input : 120 fibers output : 120 spectra

Camera InGaAs LN2 cooled 0.8-1.55µm RON<20edark < 5e-/pix/sec

#### **Field Units** matrix of square µlenses

>99% filling factor

both star&sky injected in 2x4 fibers

fibers

The ExTrA facility Context Method E x r A Design WWWWWW Extra fibers

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

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# **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"</li>
- alt/ : perform dithering or PSF shaping w/ active positioning
- lab. tests foreseen

# Alt/ design ?

Context

Method

Design

Extra



#### Similar to :

taper section

multimode fiber

45

low index capillary tube 0 40 mm 70 mm

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

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# Expected performances

#### precision = 0.01% in 240s for J=8







# Other requirements

Precision also affected by <u>detector</u> 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

#### <u>Multiplexing</u>:

- goal : 10x more flux on comparison stars than on target

- comparisons are better if the same brightness as the target

=> mux ~ a few

#### Wavelength:

$R, desime       ~Few       300       ≥30       20         R, desime       300       300       300       300       300         *H_2O       0.51, 0.57, 0.57, 0.53       1.13, 1.38, 0.62       conti-muum         *CO2       -       1.21, 1.57, 0.57, 0.52, 0.34       -       15.0         *CO2       -       1.21, 1.57, 0.57, 0.52, 0.34       -       15.0         C2H2       -       1.52, 3.0       -       14.0         C2H4       -       3.4       -       12.1         O3       0.45-       4.7       9.1, 9.6       14.3         O3       0.45-       4.7       9.1, 9.6       14.3         D0       -       2.7, 3.67       7.13       -         HDO       -       2.7, 3.67       7.13       -         M3       0.55, 0.65, 0.59, 0.29, 0.25, 0.29, 0.30       -       -       -         NH3       0.55, 0.65, 0.59, 0.29, 0.30       -       -       -         NH3       0.55, 0.65, 0.7, 0.33       8.9, 10.1       -       -         VCH4       0.48, 0.57, 0.5, 1.65, 2.2, 0.5, 7.7       -       -       -         NB3       0.55, 0.65, 0.7, 0.3.3       -       -    $		$0.4-1\mu\mathrm{m}$	1-5 µm	5-11 µm	11-16 µm
base- line         tens         initial         sead         sead $R, de-sired         300         300         300         300           *H2O         0.51, 0.57,0.65, 0.72,0.82, 0.94         1.13, 1.38,0.65, 0.72,0.82, 0.94         6.2         conti-nuum           *CO2         -         1.21, 1.57,0.6, 2.03,4.25         -         15.0           C2H2         -         1.52, 3.0         7.53         13.7           HCN         -         3.00         -         14.0           O2H6         -         3.4         -         12.1           O3         0.45-0.75         (theChappuisband)         -         14.3           HDO         -         2.7,3.67         7.13         -           VCO         -         1.57, 2.35,4.7         -         -           NH3         0.55, 0.65,0.76, 1.27         2.25, 2.9,3.0         -         -           NH3         0.55, 0.65,0.76, 1.27         1.65, 2.2,0.93         6.5, 7.7         -           Ref         -         3.34, 4.5         6.8, 7.7,8.6         -           CH3D         -         -         -         -           NSQ         -         2.5, 3.8         7<$	<i>R</i> ,	$\sim$ Few	300	$\geq 30$	20
line         and         descent         and         and         and $R, de_s$ 300         300         300         300         300 $sired$ 0.51, 0.57, 1.13, 1.38, 0.62         continuum         nuum         nuum $0.82, 0.94$ 1.9, 2.69         6.2         continuum         nuum $0.82, 0.94$ 1.21, 1.57, -         15.0         1.50         nuum $C_2H_2$ -         1.52, 3.0         7.53         13.7           HCN         -         3.0         -         12.1 $O_3$ 0.45-         4.7         9.1, 9.6         14.3 $0.75$ (the         Chappuis         -         -         - $band$ -         1.57, 2.35, -         -         - $0.76, 1.27$ -         -         -         - $0.76, 1.27$ -         -         -         - $0.78, 0.85, 0.65, 0.25, 0.25, 2.2, 2.5, 2.9, 3.0         -         -         -           0.79, 0.86, 3.3         -         -         -         -           CH_3D         -         3.34, 4.5         6.8, 7.7, -      $	base-	tens			
R, de- sired       300       300       300       300       300         *H <sub>2</sub> O       0.51, 0.57, 0.65, 0.72, 0.82, 0.94       1.13, 1.38, 1.9, 2.69       6.2       conti- nuum         *CO <sub>2</sub> -       1.21, 1.57, 1.6, 2.03, 4.25       -       15.0         C <sub>2</sub> H <sub>2</sub> -       1.52, 3.0       7.53       13.7         HCN       -       3.0       -       14.0         C <sub>2</sub> H <sub>6</sub> -       3.4       -       12.1         O <sub>3</sub> 0.45- 0.75 (the Chappuis band)       4.7       9.1, 9.6       14.3         HDO       -       2.7, 3.67       7.13       -         O <sub>2</sub> 0.58, 0.69, 0.76, 1.27       -       -       -         NH <sub>3</sub> 0.55, 0.65, 0.93       2.25, 2.9, 3.0       6.1, 10.5       -         NH <sub>3</sub> 0.59, 0.69, 0.79, 0.86, 3.3       -       -       -         CH <sub>4</sub> D       -       3.34, 4.5       6.8, 7.7, 8.6       -         CH <sub>3</sub> D       ?       3.34, 4.5       6.8, 7.7, 8.6       -         NO <sub>2</sub> -       3.4       6.2, 7.7       13.5         N <sub>2</sub> O       -       3.4       6.2, 7.7       13.5         Res       -       - </td <td>line</td> <td></td> <td></td> <td></td> <td></td>	line				
sired $   -$ *H <sub>2</sub> O         0.51, 0.57, 0.65, 0.72, 0.65, 0.72, 1.9, <b>2.69</b> 1.9, <b>2.69</b> nuum           *CO <sub>2</sub> -         1.21, 1.57, 1.6, 2.03, 4.25         -         15.0           C <sub>2</sub> H <sub>2</sub> -         1.22, 3.0         7.53         13.7           HCN         -         3.0         -         14.0           C <sub>2</sub> H <sub>6</sub> -         3.4         -         12.1           O <sub>3</sub> 0.45-         4.7         9.1, 9.6         14.3           O <sub>75</sub> (the Chappuis band)         -         1.57, 2.35, -         -           PHO         -         2.7,3.67         7.13         -           O <sub>2</sub> 0.58, 0.69, 0.76, 1.27         -         -         -           NH <sub>3</sub> 0.55, 0.65, 0.2, 2.2, 0.50, 0.5         -         -         -           NH <sub>3</sub> 0.55, 0.65, 1.5, 2.2, 0.5, 7.7         -         -         -           NH <sub>3</sub> 0.57, 0.86, 3.3         -         -         -           CH <sub>4</sub> D         0.48, 0.57, 0.5, 3.3, 3.4         6.9, 10.5         -           CH <sub>3</sub> D         ?         -         -         -           N	R, de-	300	300	300	300
*H <sub>2</sub> O 0.51, 0.57, 0.65, 0.72, 0.82, 0.94 *CO <sub>2</sub> - 1.21, 1.57, - 15.0 *CO <sub>2</sub> - 1.21, 1.57, - 15.0 C <sub>2</sub> H <sub>2</sub> - 1.52, 3.0 C <sub>2</sub> H <sub>2</sub> - 1.52, 3.0 C <sub>2</sub> H <sub>4</sub> - 3.4 - 12.1 O <sub>3</sub> 0.45 band) - 12.1 O <sub>3</sub> 0.45 C <sub>1</sub> C <sub>1</sub>	sired				
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$^{\circ}$ CO2       -       1.21, 1.57, 1.6, 2.03, 4.25       -       15.0         C2H2       -       1.52, 3.0       7.53       13.7         HCN       -       3.0       -       14.0         C2H6       -       3.4       -       12.1         O3       0.45-       4.7       9.1, 9.6       14.3         O3       0.45-       4.7       9.1, 9.6       14.3         O3       0.45-       4.7       9.1, 9.6       14.3         O45       4.7       9.1, 9.6       14.3       -         O45       4.7       9.1, 9.6       14.3       -         PH0       -       2.7, 3.67       7.13       -       -         O2       0.58, 0.69, 0.76, 1.27       -       -       -       -         NH3       0.55, 0.65, 1.5, 2, 2, 2.5, 2.9, 3.0       6.1, 10.5       -       -         PH3       -       4.3       8.9, 10.1       -       -         *CH4       0.48, 0.57, 0.5       1.65, 2.2, 0.5, 7.7       -       -       -         0.6, 0.7, 2.31, 2.37, 0.79       3.34, 4.5       6.8, 7.7, 8.6       -       -         C2H4       -       3.22, 3.34       6.9		0.65, 0.72,	1.9, 2.69		nuum
		0.82, 0.94			
1.6, 2.03, 4.25         1.52, 3.0         7.53         13.7           C2H2         -         3.0         -         14.0           C2H6         -         3.4         -         12.1           O3         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         -         -           02         0.58, 0.69, 0.76, 1.27         -         -         -           NH3         0.55, 0.65, 0.76, 1.27         1.5, 2, 0.93         6.1, 10.5         -           NH3         0.55, 0.65, 0.7, 2.31, 2.37, 0.6, 0.7, 2.31, 2.37, 0.6, 0.7, 2.31, 2.37, 0.79, 0.86, 3.3         8.9, 10.1         -           CH <sub>4</sub> 0.48, 0.57. 1.65, 2.2, 3.8         7         -         -           CH <sub>3</sub> D         ?         3.34, 4.5         6.8, 7.7, 8.6         -         -           CH <sub>3</sub> D         ?         4.5         -         -         -           NQ0         -         4.5         -         -         -           NQ2         -         3.4         6.2, 7.7         13.5         -           H <sub>2</sub> -	*CO2	-	1.21, 1.57,	-	15.0
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$O_3$ 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 <sub>3</sub> 0.55, 0.65, 0.93       1.5, 2, 2.25, 2.9, 3.0       6.1, 10.5       -         PH <sub>3</sub> -       4.3       8.9, 10.1       -         *CH4       0.48, 0.57, 0.6, 0.7, 2.31, 2.37, 0.79, 0.86, 3.3       6.5, 7.7       -         CH <sub>4</sub> D       ?       3.34, 4.5       6.8, 7.7, 8.6       -         Cyappe       -       2.5, 3.8       7       -         NO <sub>2</sub> -       4.5       -       -         NO <sub>2</sub> -       3.4       6.2, 7.7       13.5         H <sub>2</sub> -       2.8, 3.9, 7.7, 8.5       -       -         NO <sub>2</sub> -       3.4       6.2, 7.7       13.5         H <sub>2</sub> -       -       -       -         H <sub>2</sub> -       -       -       -         NO <sub>2</sub> -       3.4       6.2, 7.7       13.5         H <sub>4</sub> -	C <sub>2</sub> H <sub>6</sub>		3.4	-	12.1
0.75 (the Chappuis band)         2.7,3.67         7.13         - $^{*}CO$ - $1.57, 2.35,$ -         - $O_2$ $0.58, 0.69,$ -         -         - $O_2$ $0.58, 0.69,$ -         -         - $NH_3$ $0.55, 0.65,$ $1.5, 2,$ $6.1, 10.5$ - $NH_3$ $0.55, 0.65,$ $1.5, 2,$ $6.1, 10.5$ - $PH_3$ - $4.3$ $8.9, 10.1$ -           *CH4 $0.48, 0.57,$ $1.65, 2.2,$ $6.5, 7.7$ - $0.79, 0.86,$ $3.3$ -         -         -           CH_3D         ? $3.34, 4.5$ $6.8, 7.7,$ -           SO <sub>2</sub> -         4         7.3, 8.8         -           N <sub>2</sub> O         - $2.8, 3.9, 7.7, 8.5$ -         -           N <sub>2</sub> O         - $3.4$ $6.2, 7.7$ $13.5$ N <sub>2</sub> O         - $3.4$ $6.2, 7.7$ $13.5$ H <sub>2</sub> - $3.4$ $6.2, 7.7$ $13.5$	03	0.45-	4.7	9.1, 9.6	14.3
Chappuns band)         2.7,3.67         7.13         -           *CO         -         1.57, 2.35, 4.7         -         -           O2         0.58, 0.69, 0.76, 1.27         -         -         -           NH3         0.55, 0.65, 0.93         1.5, 2, 2.25, 2.9, 3.0         6.1, 10.5         -           PH3         -         4.3         8.9, 10.1         -           *CH4         0.48, 0.57, 0.6, 0.7, 2.31, 2.37, 0.79, 0.86,         1.65, 2.2, 3.34, 4.5         6.8, 7.7, 8.6         -           CH3D         ?         3.34, 4.5         6.8, 7.7, 8.6         -         -           SO2         -         4         7.3, 8.8         -         -           N2O         -         3.4         6.2, 7.7         13.5         -           N2O         -         3.4         6.2, 7.7         13.5         -           N2O         -         3.4         6.2, 7.7         13.5         -           Hg <sup>+</sup> -         1.083         -         -         -           N2O         -         3.4         6.2, 7.7         13.5         -           Hg <sup>+</sup> -         1.083         -         -         -		0.75 (the			
band)         2.7,3.67         7.13         -           *CO         -         1.57, 2.35, 4.7         -         - $O_2$ 0.58, 0.69, 0.76, 1.27         -         -         -           NH <sub>3</sub> 0.55, 0.65, 0.55, 0.22, 2.9, 0.30         -         -         -           PH <sub>3</sub> -         4.3         8.9, 10.1         -           *CH <sub>4</sub> 0.48, 0.57, 0.65, 0.7, 2.31, 2.37, 0.79, 0.86, 0.7, 0.76, 0.86, 0.7, 0.76, 0.46, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.46, 0.76, 0.7, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0.46, 0.76, 0.7, 0.76, 0		Chappuis			
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	upo	band)	0 7 9 67	7.19	
$1.57, 2.35, 4.7$ -       - $0_2$ $0.58, 0.69, 0.76, 1.27$ -       - $NH_3$ $0.55, 0.65, 0.22, 2.9, 3.0$ 6.1, 10.5       - $PH_3$ -       4.3       8.9, 10.1       -         *CH4 $0.48, 0.57, 0.65, 0.7, 2.31, 2.37, 0.6, 0.7, 0.231, 2.37, 0.79, 0.86, 3.3$ 6.5, 7.7       -         CH_3D       ?       3.34, 4.5       6.8, 7.7, -       -         SO2       -       4       7.3, 8.8       -         NQ2       -       2.8, 3.9, 7.7, 8.5       -         NO2       -       2.4, 5       -       -         NO2       -       2.12       -       -         NQ2       -       3.4       6.2, 7.7       13.5         H2       -       2.12       -       -         NQ2       -       3.4       6.2, 7.7       13.5         H2       -       1.083       -       -         NO2       -       3.4       6.2, 7.7       13.5         H2       -       -       -       -       -         NO2       -       3.4       6.2, 7.7       13.5       -         H2 </td <td>*00</td> <td>-</td> <td>2.7,3.07</td> <td>1.13</td> <td>-</td>	*00	-	2.7,3.07	1.13	-
$0_2$ $0.58, 0.69, 0.76, 1.27$ $  -$ NH <sub>3</sub> $0.55, 0.65, 0.93$ $1.5, 2, 2.25, 2.9, 3.0$ $6.1, 10.5$ $-$ PH <sub>3</sub> $ 4.3$ $8.9, 10.1$ $-$ *CH <sub>4</sub> $0.48, 0.57, 0.65, 2.2, 0.65, 7.7$ $6.5, 7.7$ $ 0.6, 0.7, 2.31, 2.37, 0.79, 0.86, 3.3$ $6.8, 7.7, 8.6$ $-$ CH <sub>3</sub> D $?$ $3.34, 4.5$ $6.8, 7.7, 8.6$ $-$ CH <sub>3</sub> D $?$ $3.34, 4.5$ $6.8, 7.7, 8.6$ $-$ No <sub>2</sub> $ 2.5, 3.8 \dots$ $7$ $-$ NO <sub>2</sub> $ 2.8, 3.9, 7.7, 8.5$ $ -$ NO <sub>2</sub> $ 2.4, 3.4$ $6.2, 7.7$ $13.5$ H <sub>2</sub> $ 2.0, 3.4.5$ $ -$ NO <sub>2</sub> $ 3.4$ $6.2, 7.7$ $13.5$ H <sub>2</sub> $ 2.0, 3.4.5$ $ -$ NO <sub>2</sub> $ 3.4$ $6.2, 7.7$ $13.5$ H <sub>3</sub> $-$	.00	-	1.57, 2.35,	-	-
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	0	0.58.0.60	4.7		
NH3 $0.55, 0.65, 0.93$ $1.5, 2, 2.9, 3.0$ $6.1, 10.5$ $-$ PH3       - $4.3$ $8.9, 10.1$ $-$ *CH4 $0.48, 0.57, 0.6, 0.7, 2.31, 2.37, 0.79, 0.86, 3.3$ $6.5, 7.7$ $-$ CH3D       ? $3.34, 4.5$ $6.8, 7.7, 8.6$ $-$ CH4D       ? $3.34, 4.5$ $6.8, 7.7, 8.6$ $-$ C2H4 $ 3.22, 3.34$ $6.9, 10.5$ $-$ H2S $ 2.5, 3.8 \dots$ $7$ $-$ SO2 $ 4$ $7.3, 8.8$ $-$ NQ0 $ 2.8, 3.9, 7.7, 8.5$ $-$ NO2 $ 3.4$ $6.2, 7.7$ $13.5$ H2 $ 2.0, 3-4.5$ $ -$ H2 $ 2.12$ $ -$ H3 $ 2.0, 3-4.5$ $ -$ H4 $ 1.083$ $ -$ H4 $ 1.083$ $ -$ H6 $    -$	02	0.58, 0.69,	-		<u> </u>
NH3       0.33, 0.35, 0.35, 0.43, 0.5, 2.2, 0.4, 10.3       0.41, 10.3 $\sim$ 9H3       -       4.3       8.9, 10.1       -         *CH4       0.48, 0.57, 0.65, 0.7, 0.6, 0.7, 0.31, 0.37, 0.79, 0.86, 0.33       6.5, 7.7       -         0.79, 0.86, 0.7, 0.79, 0.86, 0.7, 0.79, 0.86, 0.33       3.34, 4.5       6.8, 7.7, -       -         C2H4       -       3.22, 3.34       6.9, 10.5       -         H2S       -       2.5, 3.8       7       -         SO2       -       4       7.3, 8.8       -         N2O       -       2.8, 3.9, 7.7, 8.5       -         H2       -       2.12       -       -         H2       -       2.12       -       -         NO2       -       3.4       6.2, 7.7       13.5         H2       -       1.083       -       -         H4       -       1.083       -       -         H4       -       1.2       -       -         H5       -       -       -       -         H2       -       -       -       -       -         H2       -       -       -       -       -	NH.	0.55 0.65	15 9	61 10 5	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	NH3	0.03, 0.05,	1.0, 2,	0.1, 10.5	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		0.95	2.20, 2.9,		
*CH4       0.48, 0.57. 0.6, 0.7, 2.31, 2.37, 0.79, 0.86,       1.65, 2.2, 3.34, 4.5       6.5, 7.7       -         CH <sub>3</sub> D       ?       3.34, 4.5       6.8, 7.7, 8.6       -       -         C2H4       -       3.22, 3.34       6.9, 10.5       -         H <sub>2</sub> S       -       2.5, 3.8       7       -         SO <sub>2</sub> -       4       7.3, 8.8       -         N <sub>2</sub> O       -       2.8, 3.9, 4.5       7.7, 8.5       -         NO <sub>2</sub> -       3.4       6.2, 7.7       13.5         H <sub>2</sub> -       2.12       -       -         H <sup>+</sup> <sub>3</sub> -       2.0, 3-4.5       -       -         He       -       1.083       -       -       -         *K       0.76       -       -       -       -         VO       0.4-1       1-3.5       -       -       -         VO       0.4-1       1-2.5       -       -       -         FeH       0.6-1       1-2       -       -       -         TiO       0.4-1       1-1.6       -       -       -         QU       0.4-1       -       -       -	PH.		4.3	8 9 10 1	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	*CH.	0.48 0.57	1.65 2.2	65 77	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	CIII	0.6 0.7	2.31. 2.37	0.0, 1.1	C
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		0.79 0.86	3.3		
$C_2H_4$ -       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,       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       -       - $H_3^+$ -       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       -       -         TiH       0.6-1       1-2       -       -         TiH       0.4-1       1-1.6       -       -         Cloud/       yes       possible       silicates,       -	CH <sub>2</sub> D	2	3 34 4.5	68 77	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Chigo		0.04, 410	8.6	
$H_2S$ -       2.5, 3.8       7       - $SO_2$ -       4       7.3, 8.8       - $N_2O$ -       2.8, 3.9,       7.7, 8.5       - $NO_2$ -       3.4 <b>6.2</b> , 7.7       13.5 $H_2^+$ -       2.12       -       - $H_3^+$ -       2.0, 3-4.5       -       - $H_3^+$ -       1.083       -       -         *Na       0.589       1.2       -       -         *K       0.76       -       -       -         TiO       0.4-1       1-3.5       -       -         VO       0.4-1       1-2.5       -       -         TiH       0.6-1       1-2       -       -         Cloud/       yes       possible       silicates,       -	C <sub>2</sub> H <sub>4</sub>	-	3.22. 3.34	6.9, 10.5	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	H <sub>2</sub> S	-	2.5. 3.8	7	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	SO <sub>2</sub>	-	4	7.3.8.8	
4.5 $NO_2$ -       3.4       6.2, 7.7       13.5 $H_2$ -       2.12       -       - $H_3^+$ -       2.0, 3-4.5       -       - $H_8^+$ -       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       -       -         Cloud/       yes       possible       silicates,       -	N <sub>2</sub> O	-	2.8, 3.9,	7.7. 8.5	-
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$			4.5		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	NO <sub>2</sub>	-	3.4	6.2, 7.7	13.5
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	H <sub>2</sub>	-	2.12	-	-
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         -         -           Cloud/         yes         possible         silicates,         -	$H_3^+$	-	2.0, 3-4.5	-	-
*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/ yes possible silicates	He	-	1.083	-	-
*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/ yes possible silicates	*Na	0.589	1.2	-	-
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/         yes         possible         silicates,         -	*K	0.76	-	-	-
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/         yes         possible         silicates,         -	TiO	0.4-1	1-3.5	-	-
FeH         0.6-1         1-2         -         -           TiH         0.4-1         1-1.6         -         -           Rayleigh         0.4-1         -         -         -           Cloud/         yes         possible         silicates,         -	VO	0.4-1	1-2.5	-	-
TiH         0.4-1         1-1.6         -         -           Rayleigh         0.4-1         -         -         -           Cloud/         yes         possible         silicates,         -	FeH	0.6-1	1-2	-	-
Rayleigh 0.4-1	TiH	0.4-1	1-1.6	-	-
Cloud/ yes possible silicates, -	Rayleigh	0.4-1	-	-	
	Cloud/	yes	possible	silicates,	-
haze etc.	haze	100 A		etc.	
Η Ηα 0.66	H Ha	0.66			
Η Ηβ 0.486	$H H\beta$	0.486			
Ca 0.8498,	Ca	0.8498,		-	-
0.8542,		0.8542,			

Tinetti et al. (2012)

exoELT 2014 @ ESO Garching

Method

- 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





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







