



EPICS – high-contrast imaging of Exoplanets with the E-ELT

Markus Kasper

AO4ELT2, Victoria, Sep 2011



Phase-A study



Mission statement from SOW:

“...Conceptual Design for a **feasible instrument** ...
...**implication on telescope requirements** should be addressed“

Major Milestones:

- | | |
|-----------------|----------------|
| 24 Oct 2007: | Kick-off |
| 24 Sep 2008: | Phase-1 review |
| 16/17 Mar 2010: | Final review |

Funding and manpower:

Funded in parts by ESO and by the European Framework
Programme 7 (FP7)

About **20 FTEs** were invested by the consortium.



Consortium



ESO: Markus Kasper, Emmanuel Aller-Carpentier, Norbert Hubin, Florian Kerber, Natalia Yaitskova, Patrice Martinez, Enrico Fedrigo

LAOG: Jean-Luc Beuzit, Christophe Verinaud, Visa Korkiaskoski, Patrick Rabou, Jacopo Antichi, Olivier Preis

Padova Observatory: Raffaele G. Gratton, Mariangela Bonavita, Dino Mesa

ASTRON: Lars Venema, Ronald Roelfsema, Rieks Jager, Hiddo Hanenburg

University of Oxford: Niranjan Thatte, Mattias Tecza, Graeme Salter

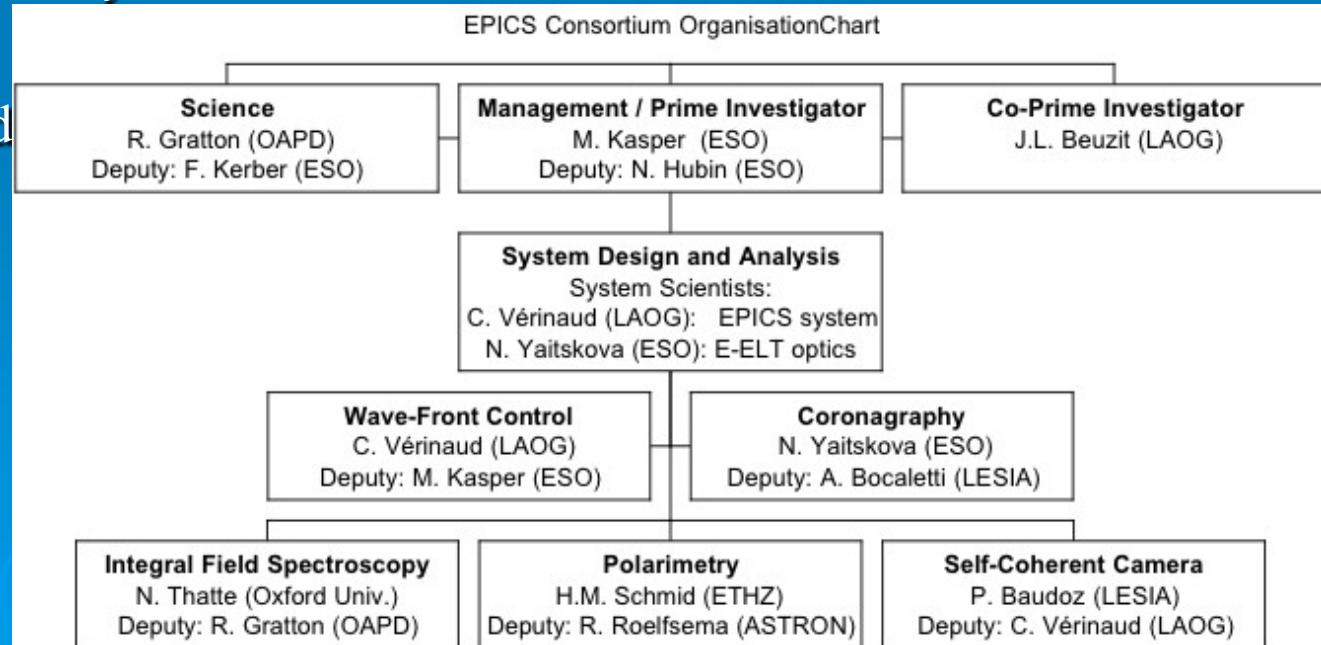
LESIA: Pierre Baudoz, Anthony Boccaletti

NOVA: Christoph Keller

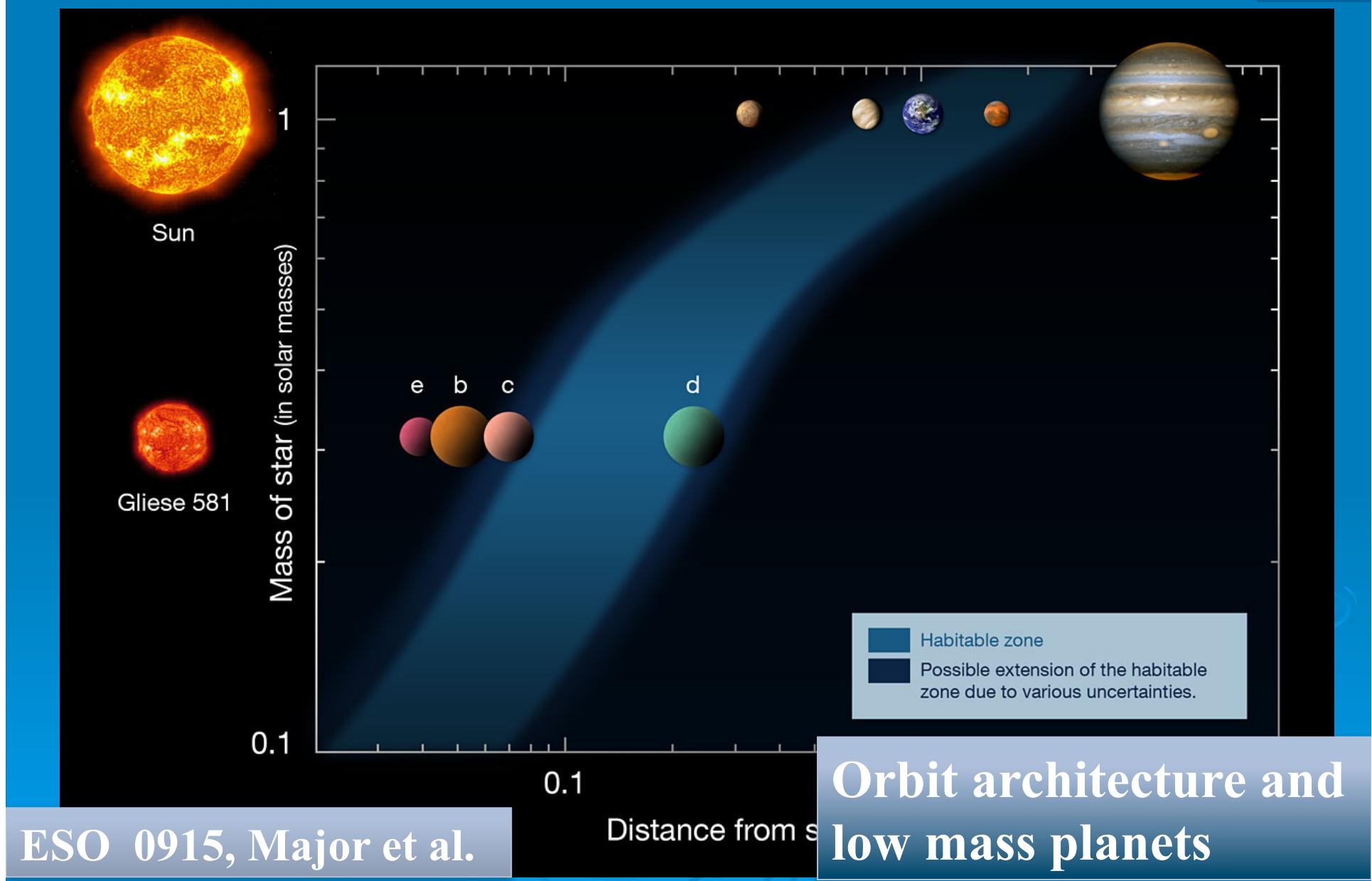
ETH Zürich: H.M.Schmid

FIZEAU: Lyu Abe

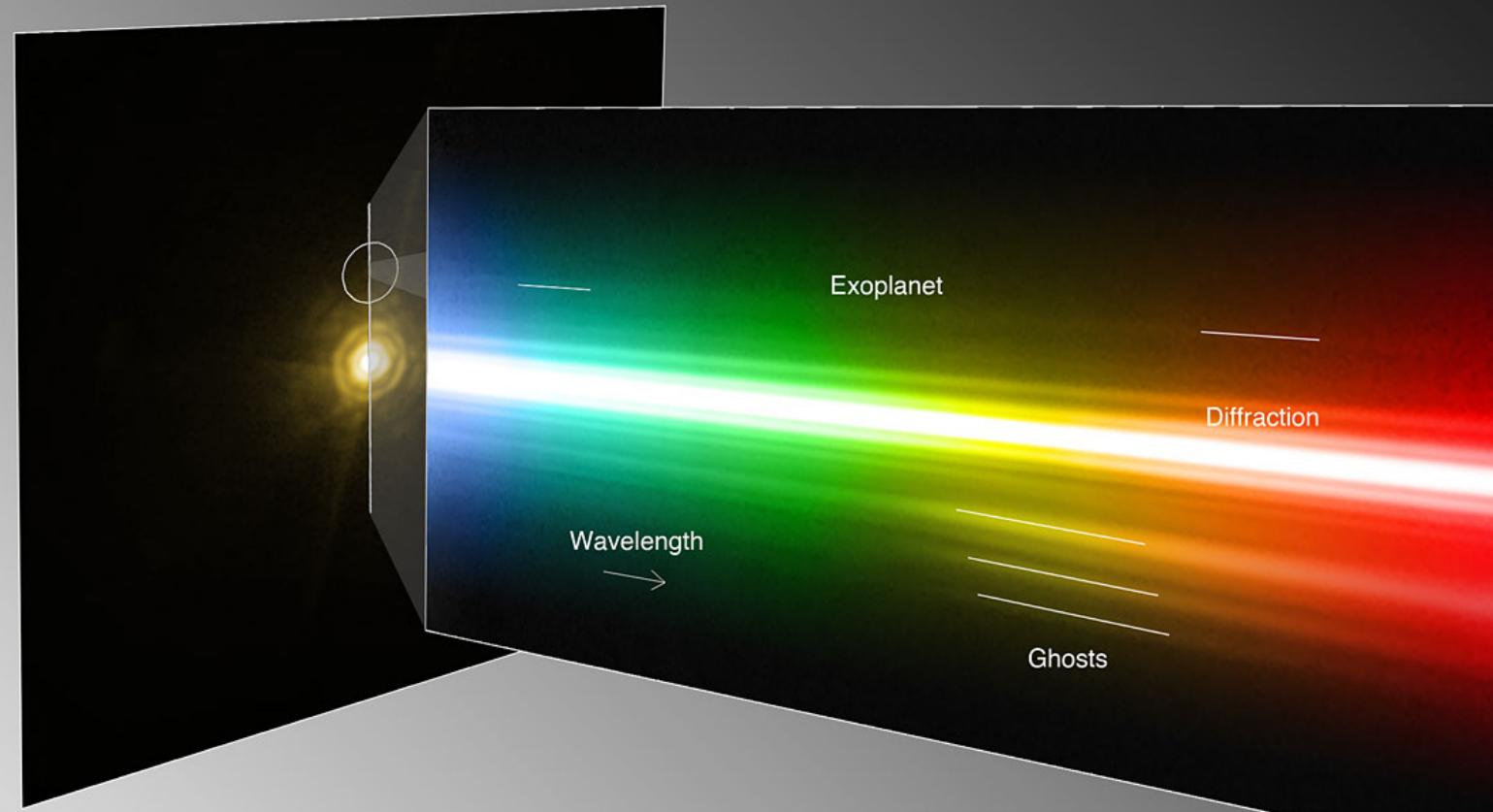
LAM: Kjetil Dohlen



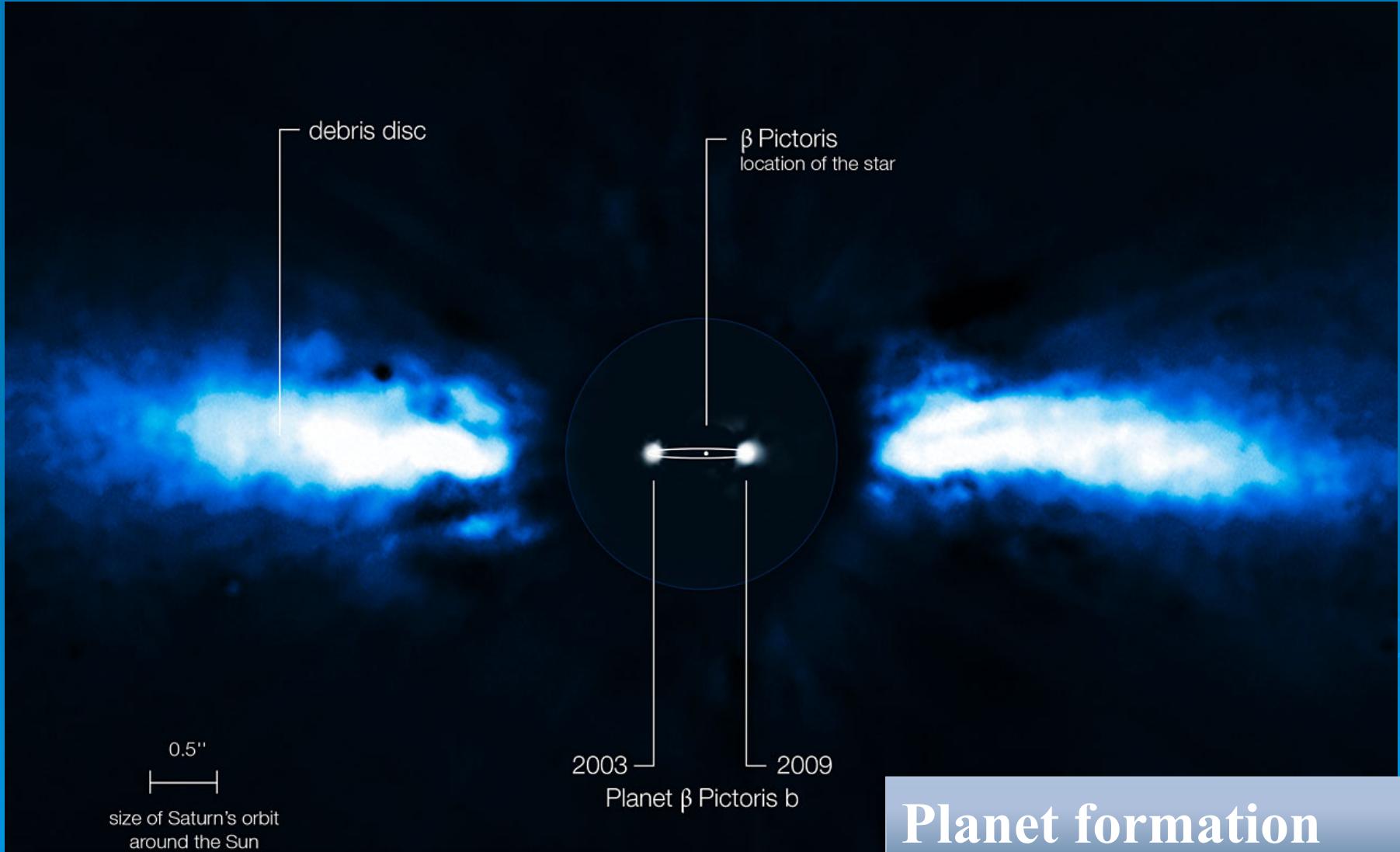
Science Goals



Science Goals



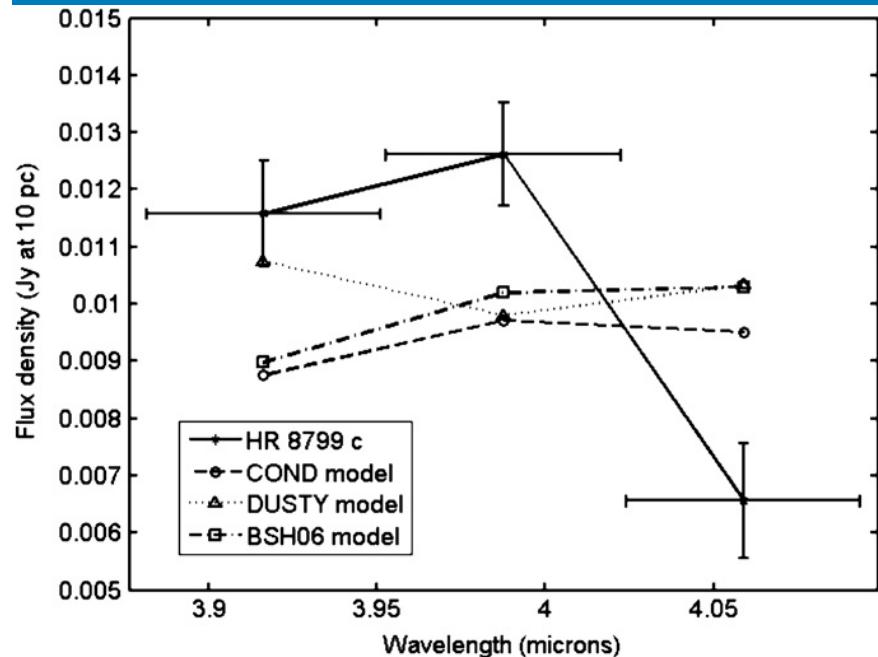
Science Goals



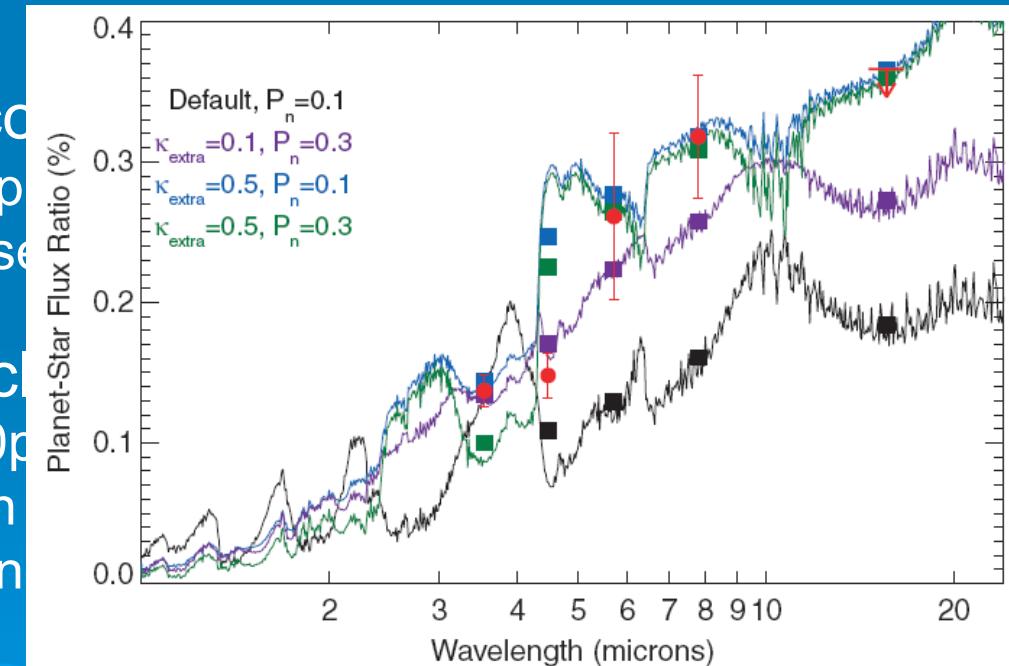
**Planet formation
and evolution, disks**

Why direct imaging with E-ELT?

- 1. Most efficient in detecting exoplanets**
 (low-mass in HZ, giant planets beyond ice-line)
 - A single detection in a couple of nights.
 - Measure dynamic mass combining data from RV and imaging



Janson et al. 2010



Knutson et al. 2009

Contrast requirements

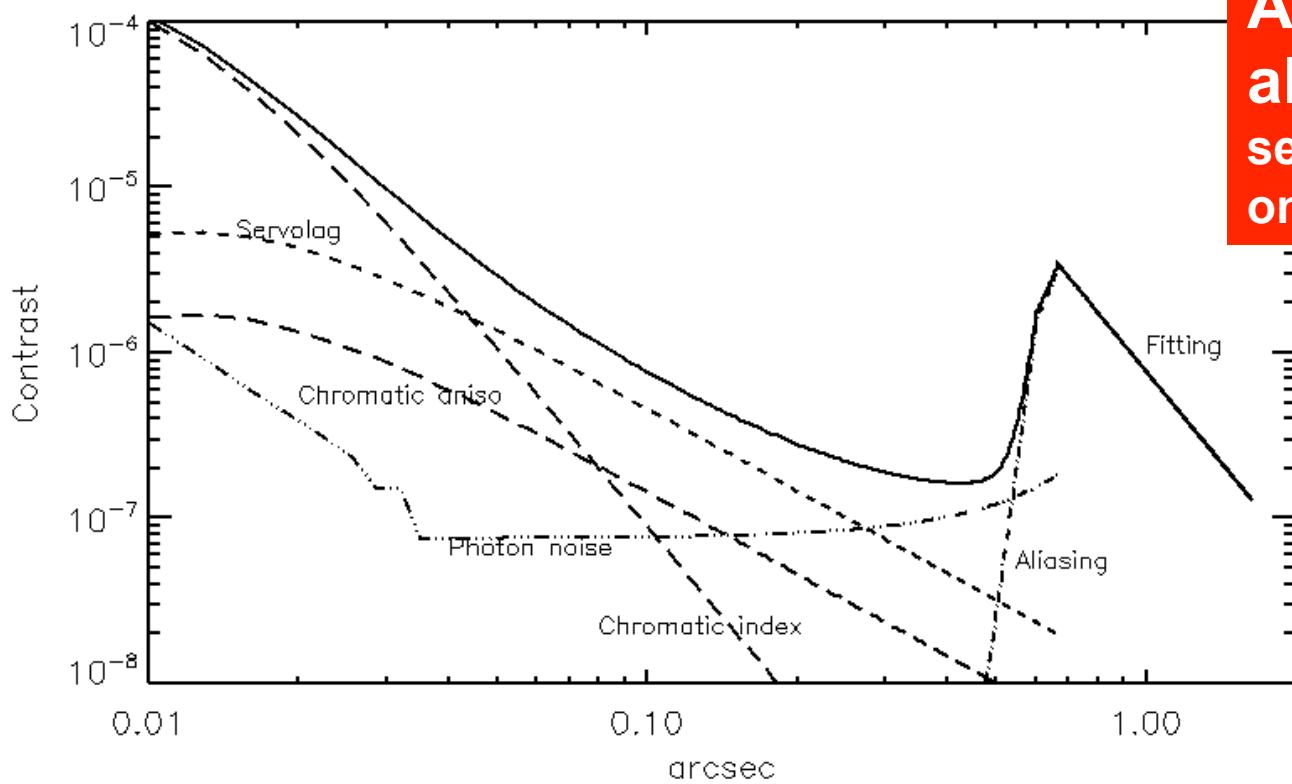
6. a) **Contrast requirements Y-H band** (10h telescope time, reference seeing conditions, 5σ detection):

Brightness ratio at distance: [mas]	30	100	300	Limiting stellar Magnitude I band:
Science Case 1	10^{-6}	10^{-6}	10^{-6}	9 (goal: 10)
Science Case 2		$2 \cdot 10^{-9}$ (goal 10^{-9})	10^{-9} (goal $4 \cdot 10^{-10}$)	7 (goal: 8)
Science Case 3	10^{-8}	10^{-9}	10^{-8}	7 (goal: 8)
Science Case 4	$2 \cdot 10^{-9}$ (goal 10^{-9})	10^{-9} (goal $4 \cdot 10^{-10}$)	$5 \cdot 10^{-10}$ (goal $2 \cdot 10^{-10}$)	5 (goal: 6)

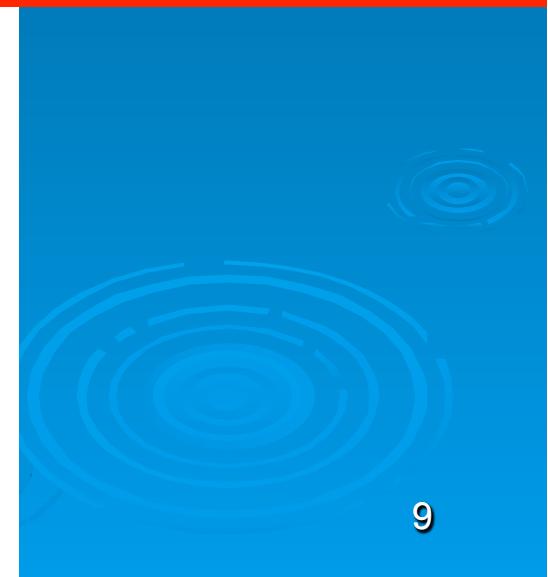
- b) **Contrast requirements I band** (10h telescope time, reference seeing conditions, 5σ detection, for differential signal contrast $(I_1(\text{planet}) - I_2(\text{planet})) / (I_1(\text{star}) + I_2(\text{star}))$ where I_1 and I_2 are fluxes in two spectral bands (on/off CH₄ absorption) or $I(\text{parallel})$ and $I(\text{perpendicular})$ for polarimetry):

Brightness ratio at distance: [mas]	30	100	300	Limiting stellar Magnitude I band:
Science Case 2		$2 \cdot 10^{-9}$ (goal 10^{-9})	10^{-9} (goal $4 \cdot 10^{-10}$)	7 (goal: 8)
Science Case 4	$2 \cdot 10^{-9}$ (goal 10^{-9})	10^{-9} (goal $4 \cdot 10^{-10}$)	$5 \cdot 10^{-10}$ (goal $2 \cdot 10^{-10}$)	5 (goal: 6)

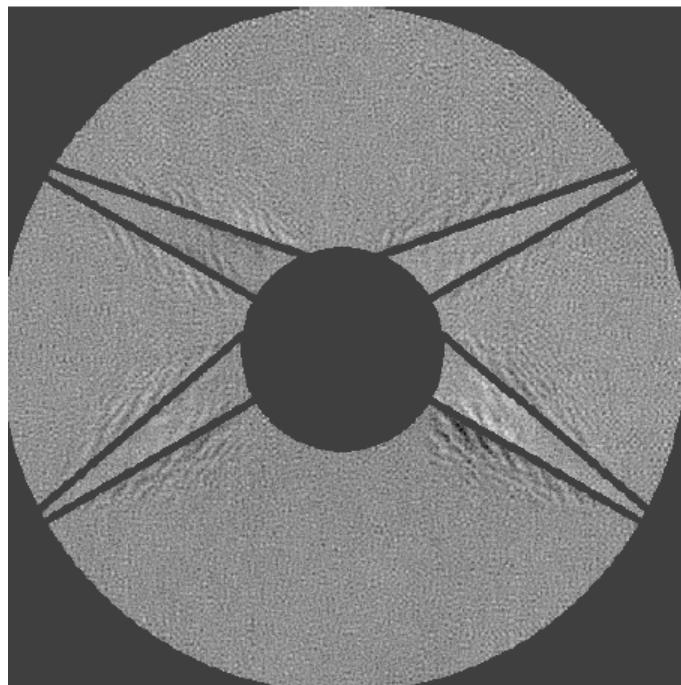
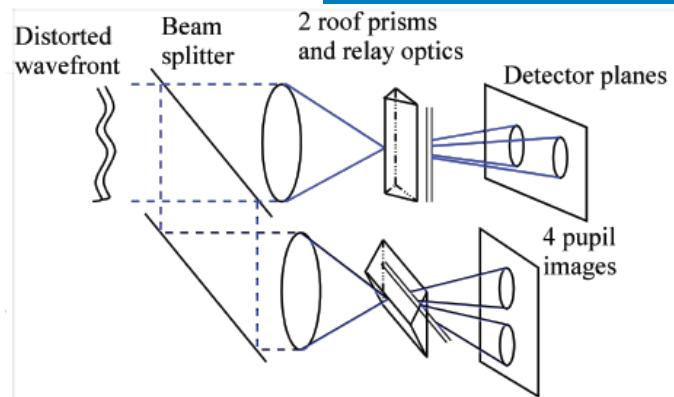
- Two-stage AO system in series:
SCAO with M4
XAO with internal DM
- XAO: roof PWS at 825 nm, 3 kHz
- 200x200 actuators (20 cm pupil spacing)



**Advanced RTC
algorithms needed
see e.g. talk by R. Ramlau
on Sep 29**

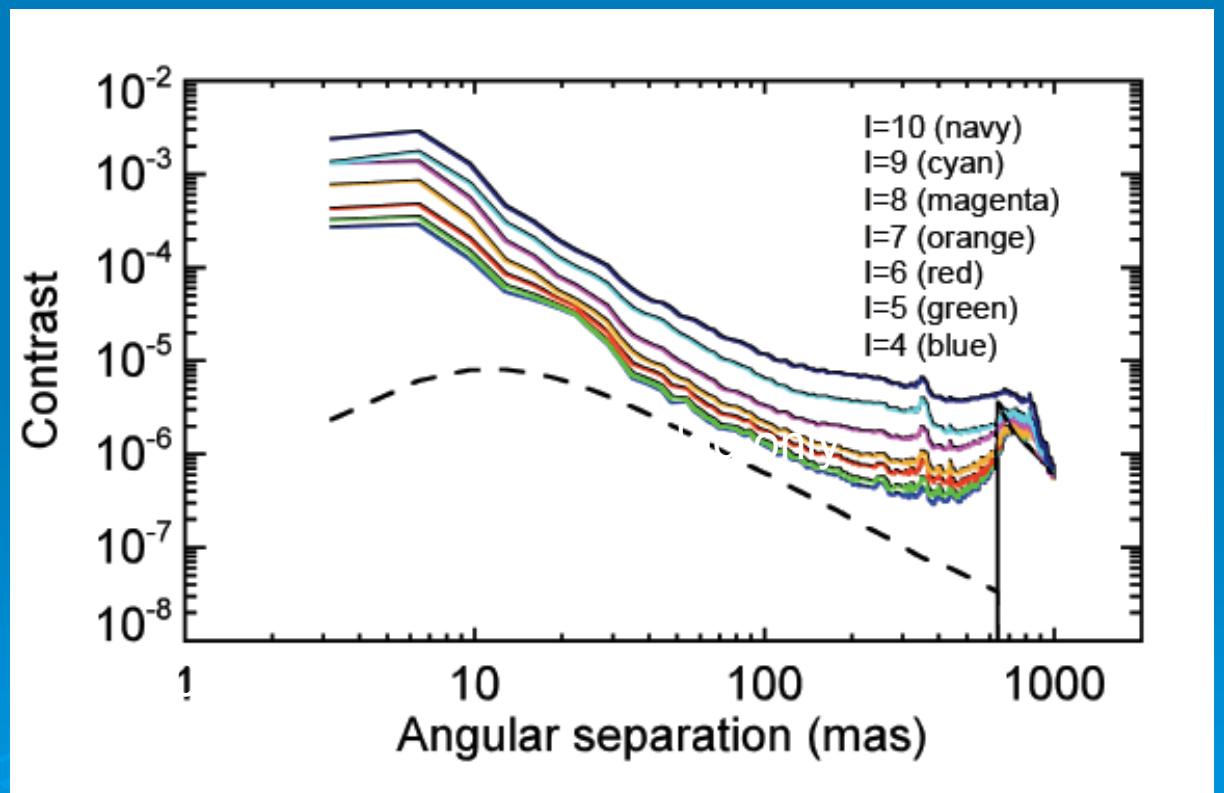


XAO End-to-end simulations



Example: WF map, spider disturbance not calibrated

Roof PWS: Phase-like sensor
Good noise propagation (Verinaud, MNRAS, 2005, Guyon, ApJ 2005, PASP 2010)

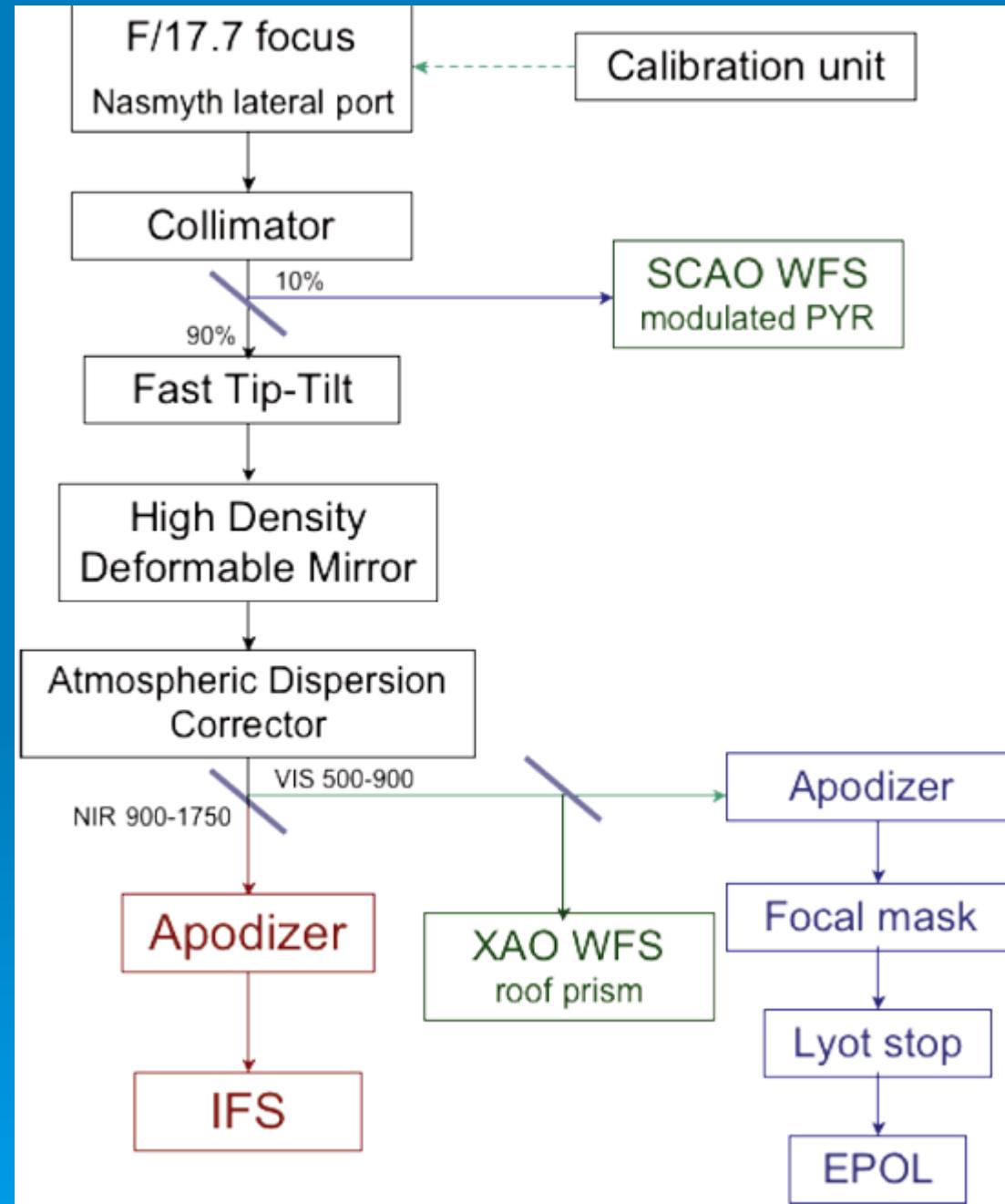


Photon Noise

- AO Halo: 10^{-6} , ExoPlanet: 10^{-9} $\rightarrow N_H \approx 1000 N_{EP}$
- $N_{EP}/\sqrt{1000 N_{EP}} > 5 \Rightarrow N_{EP} > 25000$
(Jupiter@10pc with 10% BW in V: ~0.5h on 40-m telescope)

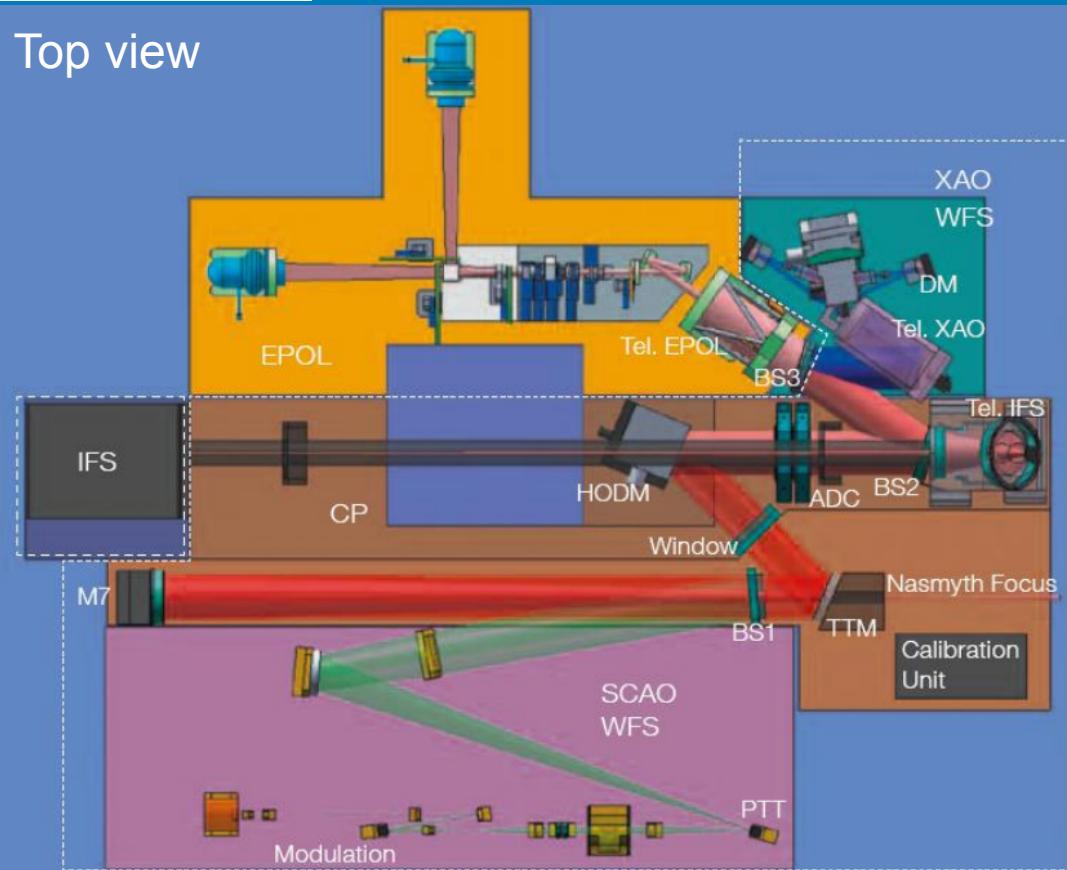
Systematic Residuals

- Suppress QSS to $< 10^{-7}$ (goal 10^{-8}) at $5 \lambda/D$
- Use chromatic and polarimetric differential techniques for speckle calibration at 0.5% level
- Good temporal instrument stability for temporal calibrations as a bonus

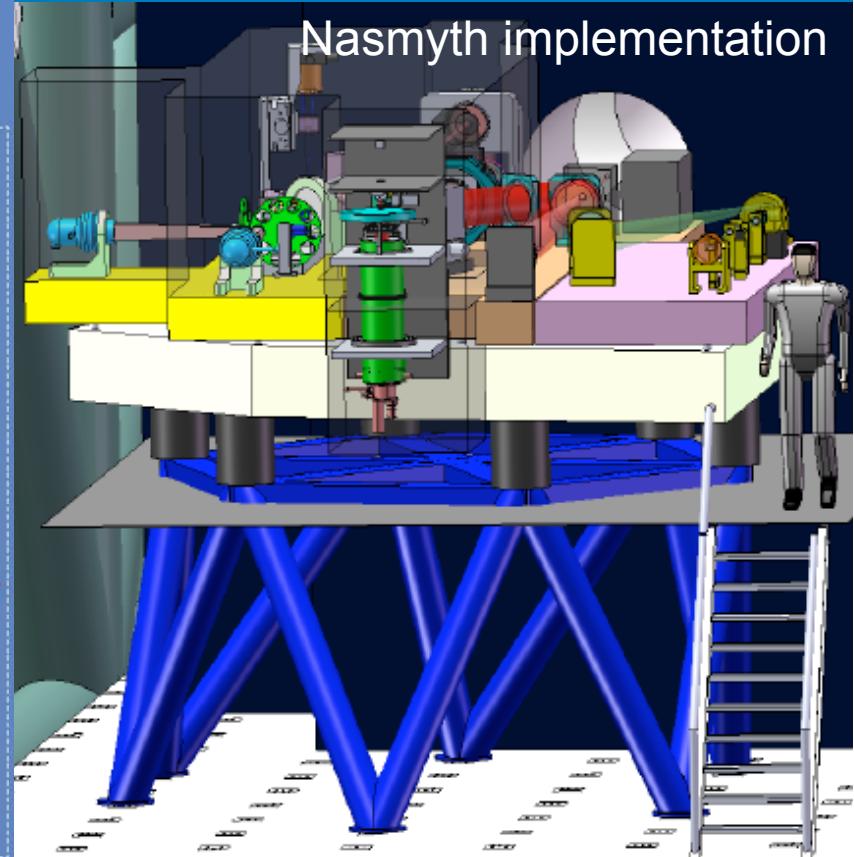


Concept

Top view



Nasmyth implementation



NIR imaging:

NIR IF spectroscopy:

Vis imaging:

Vis polarimetry

950-1650 nm, 0.8" FoV, 2.33 mas/px

R = 125, 1400, 20.000

600-900 nm, 2" FoV, 1.5 mas/px

Concept Highlights

1. Superb XAO and wave-front control

- Turbulence residual halo $\sim 10^{-5}$ at 30mas $< 10^{-6}$ further out
- QSS about 10x below AO residuals

2. Good temporal stability

- All moving or rotating optics are in the common path.
- Cover providing thermal inertia and dust protection.

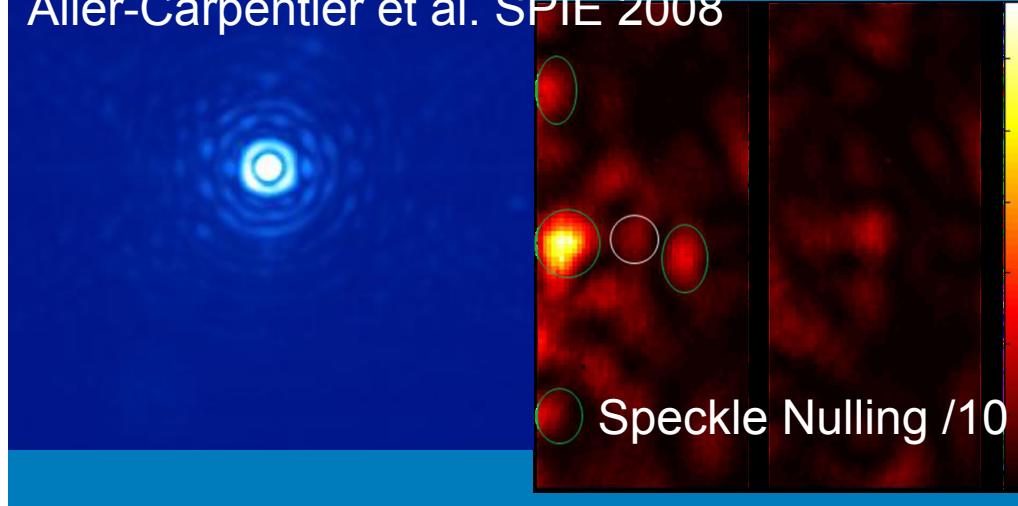
2. Very efficient calibration of PSF residuals

- Small and known chromaticity for spectral deconvolution (see poster by S.Gladysz)
- Small instrumental polarization and efficient calibration for differential polarimetry

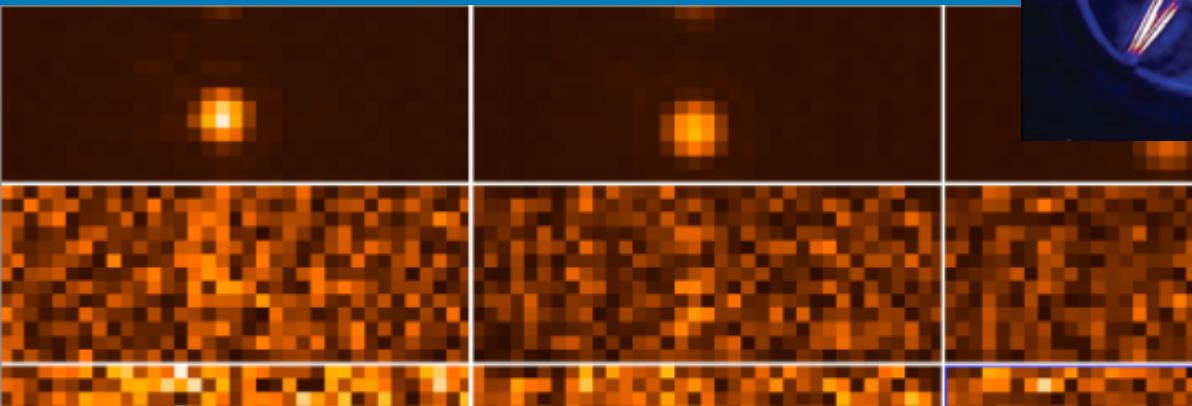
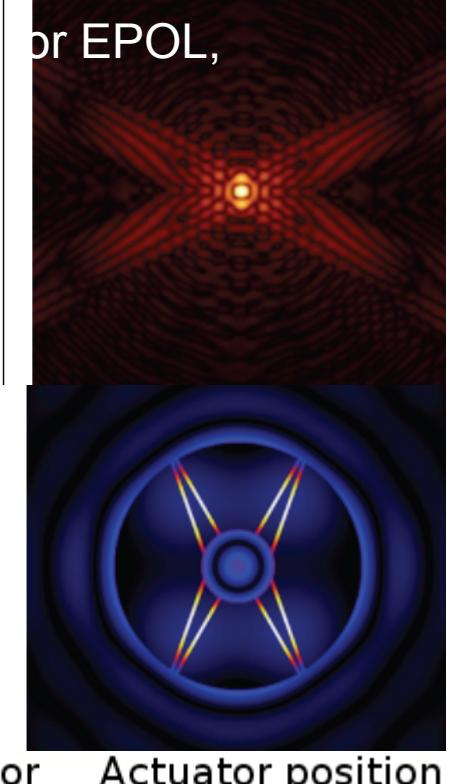
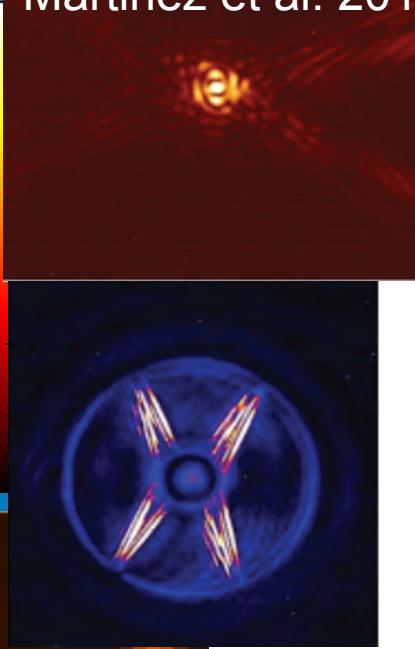
=> EPICS is photon noise limited

Demonstration experiments

XAO with 90% H-band Strehl,
Aller-Carpentier et al. SPIE 2008



APLC coronagraph for EPOL,
Martinez et al. 2010



Spectral deconvolution with 250x speckle rejection,
Salter et al. SPIE 2010, see Sep 30

AO4ELT2, Victoria, S

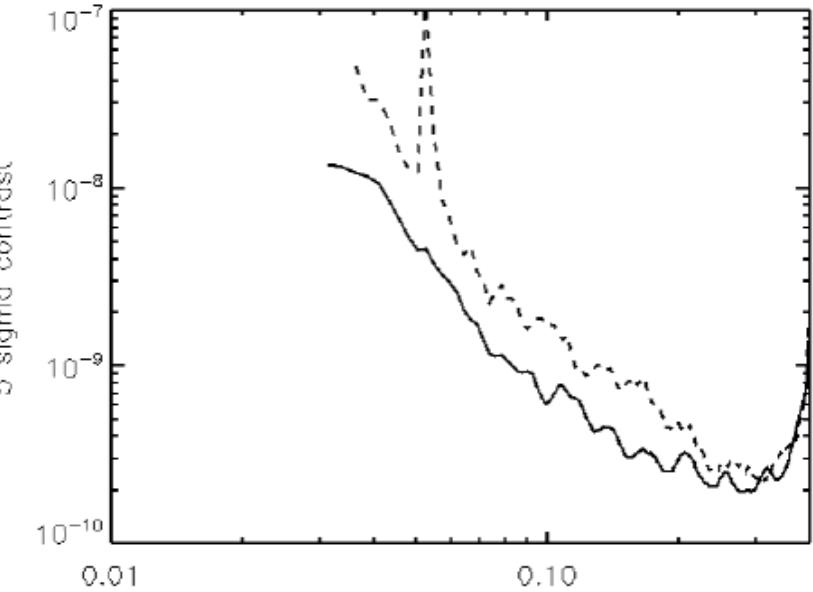
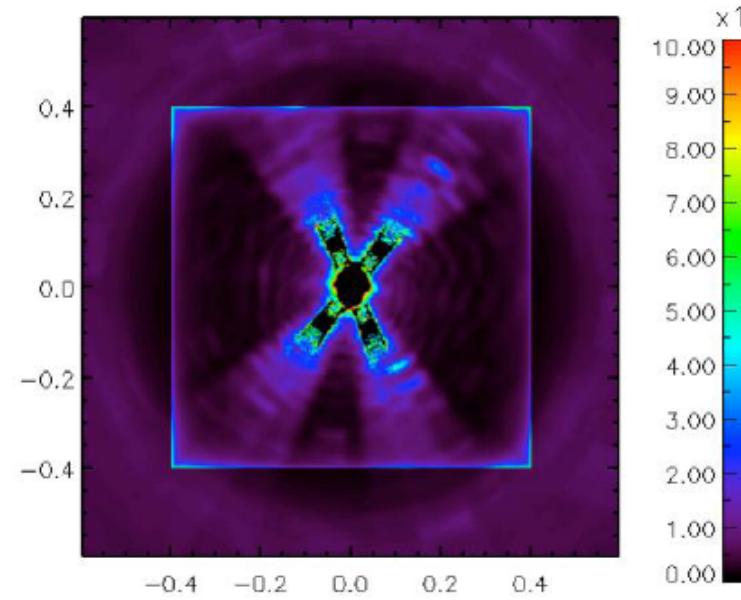
Coherence camera/WFS,
Baudouz et al. SPIE 2010, see Sep 28



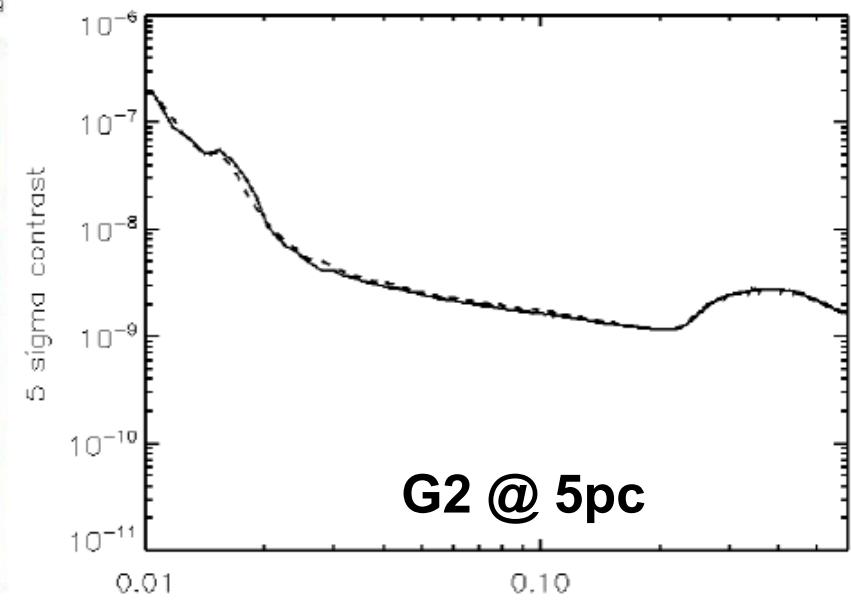
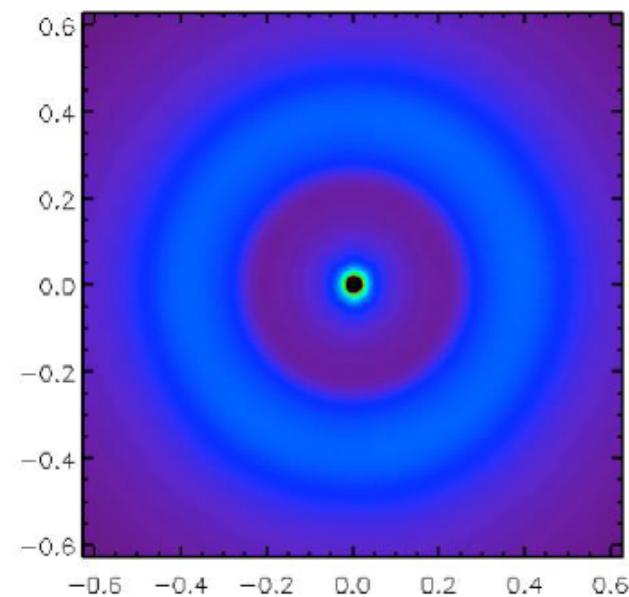
Analysis (E2E)



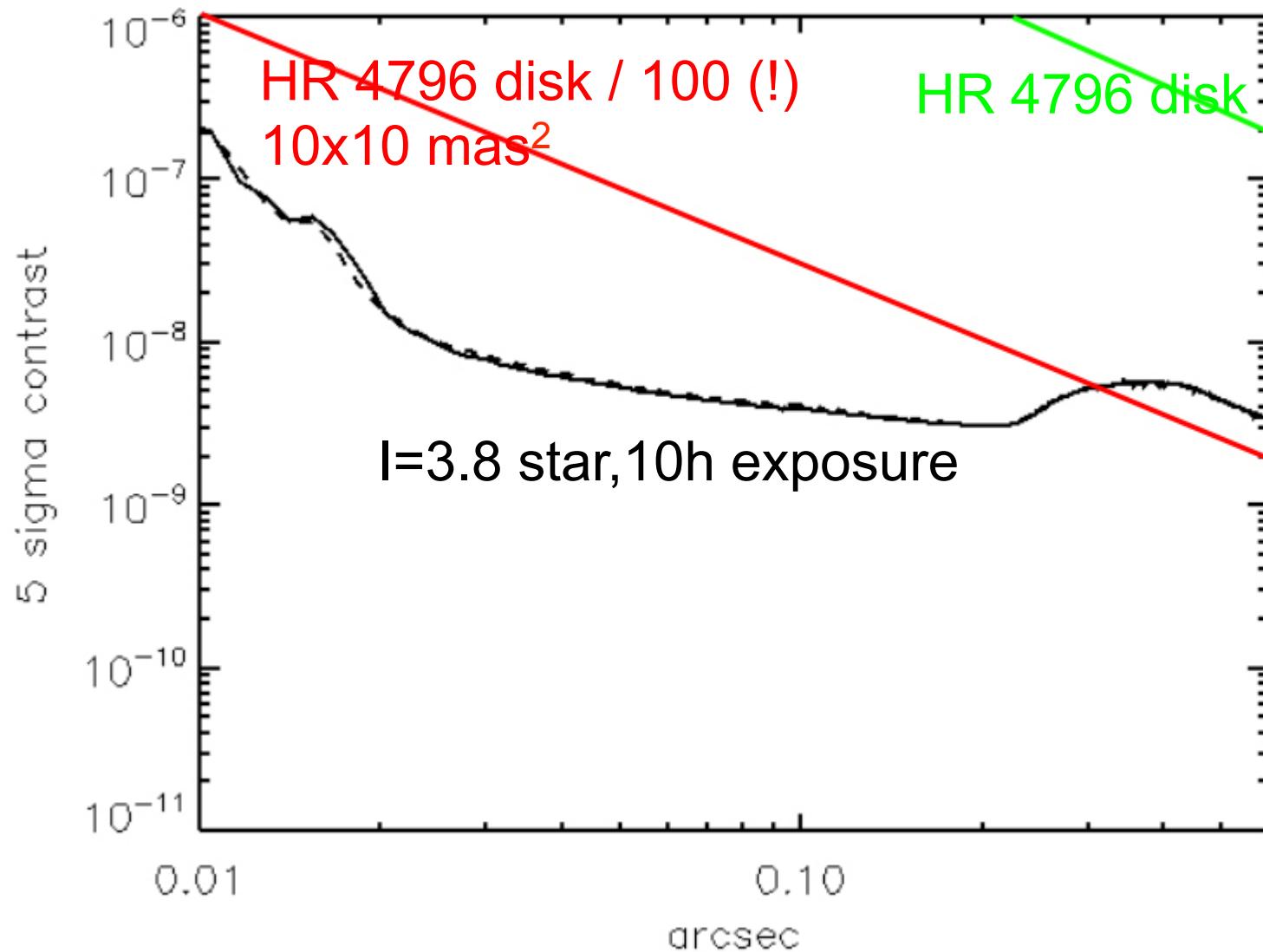
IFS

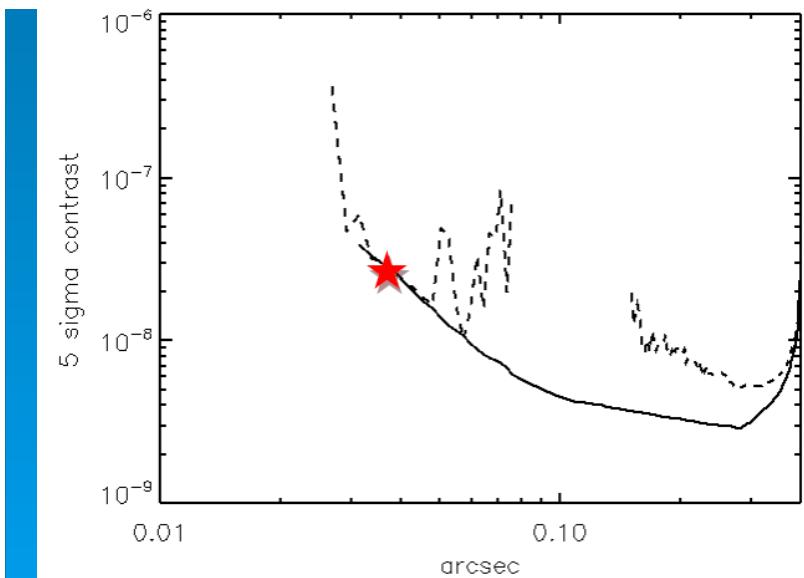
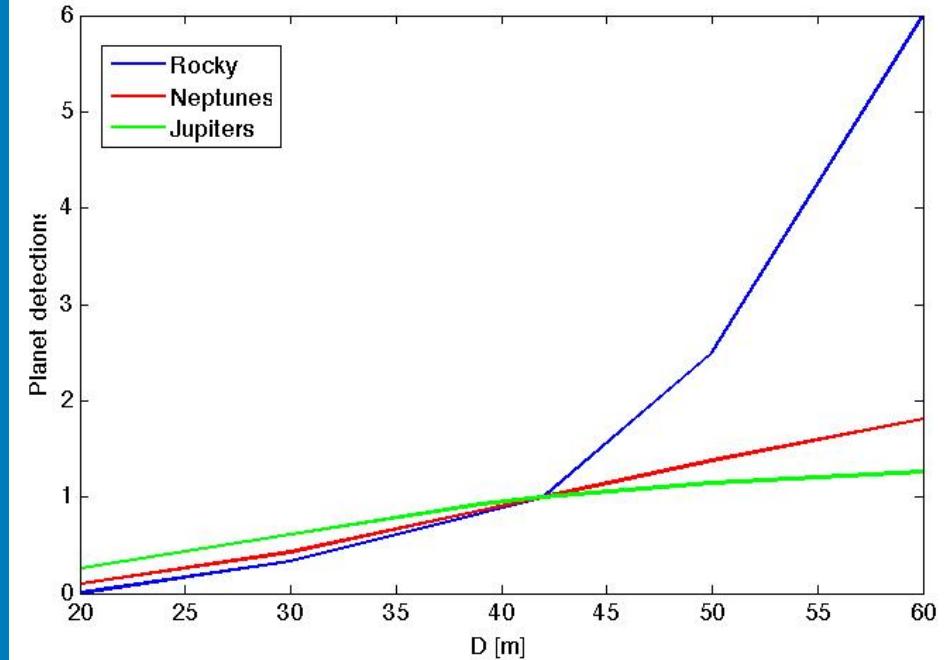
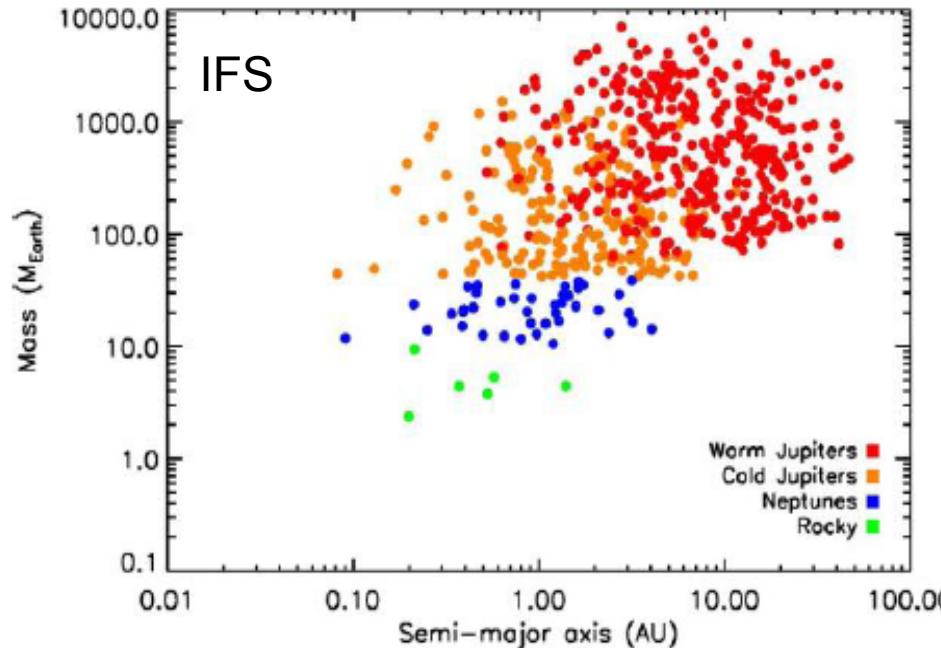


EPOL



Disks with EPOL





Rocky Planets detections benefit most from larger telescope apertures

Imaging of a rocky planet in the HZ
(Gliese 581 d)



Summary



1. EPICS is the Exoplanet imager for the E-ELT
2. EPICS provides direct imaging contrasts down to 10^{-9} at $0.1''$...
3. ... and it provides it with the E-ELT baseline design