PCS – Planetary Camera and Spectrograph for the E-ELT Roadmap

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&

EPICS consortium

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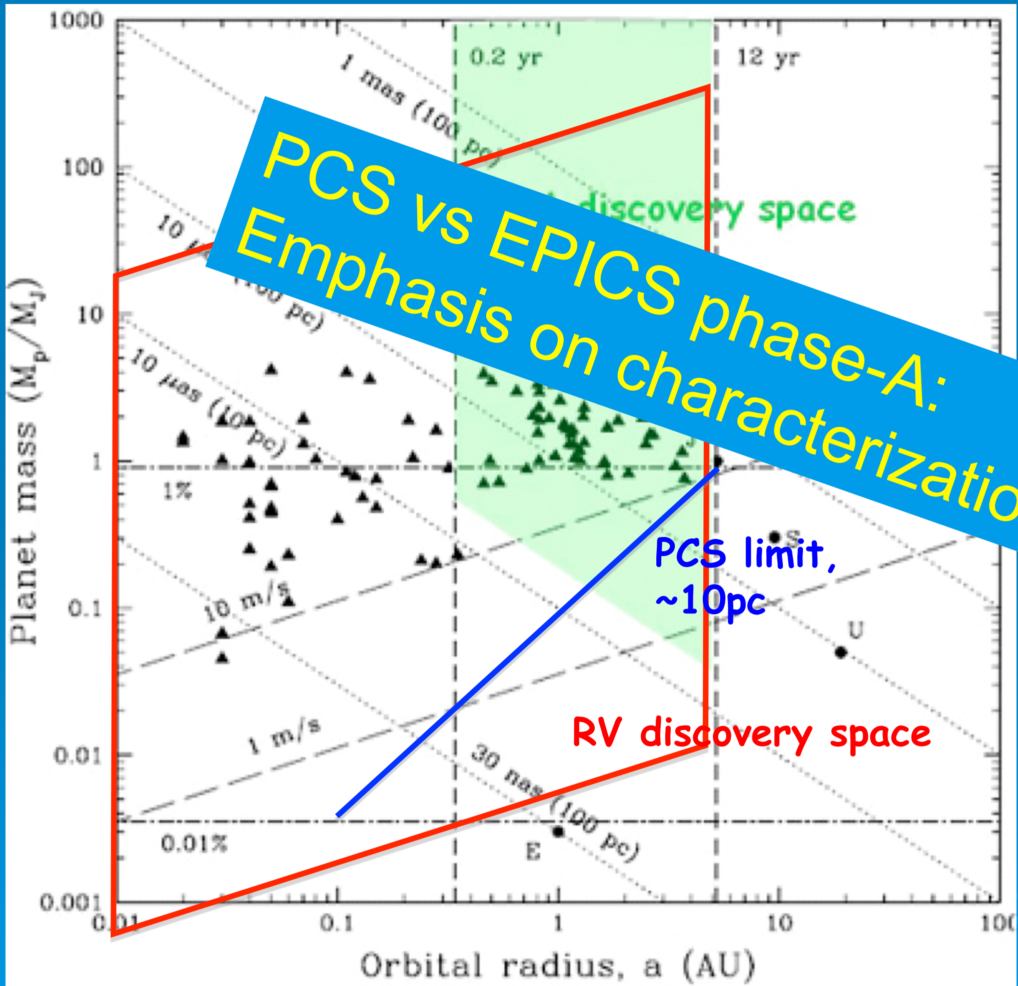
Outline

- Scientific context and goals
- O_2 detection on an Exoplanet with the E-ELT?
- PCS concept and technological challenges
- Timeframe for E-ELT high-contrast imaging

Scientific context in 2025+

GAIA: Know orbits all Giant Exoplanets out to 5 AU within 50 pc (**V_{star} > 5-6 !**)
RV: Know orbits (but not orientation on-sky) of a number of rocky planets in the solar neighborhood out to ~0.5 AU, incl. in HZ for M-stars



Perryman et al., 2005

PCS vs EPICS phase-A: Emphasis on characterization rather than discovery

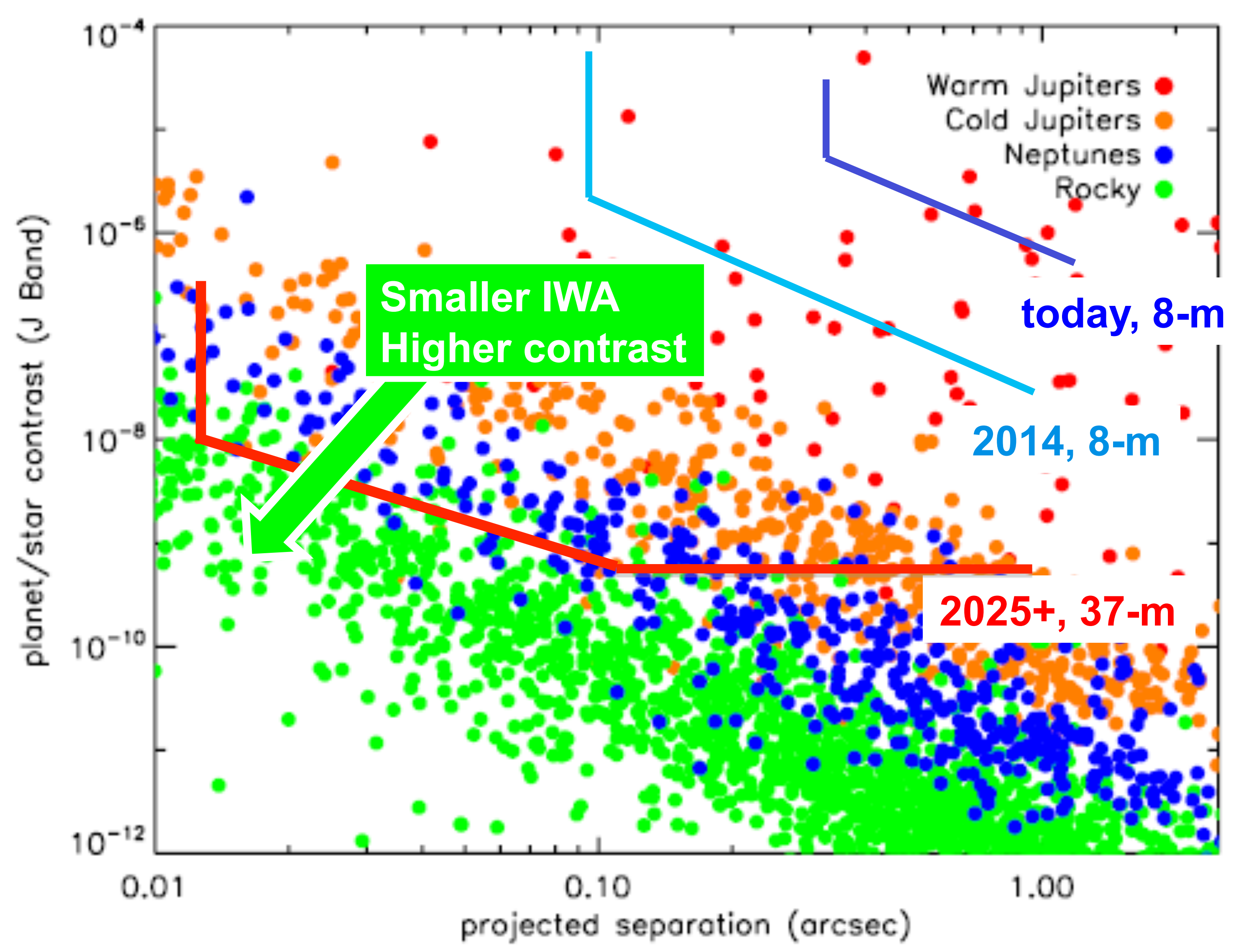
NIR Contrast, reflected light

Rocky @ 0.1 AU is 10^{-8} (HZ M-star)
Jupiter @ 5 AU is 10^{-9}
≈ PCS photon noise limit for stars J~4-6
...me hrs observing time

...jectives

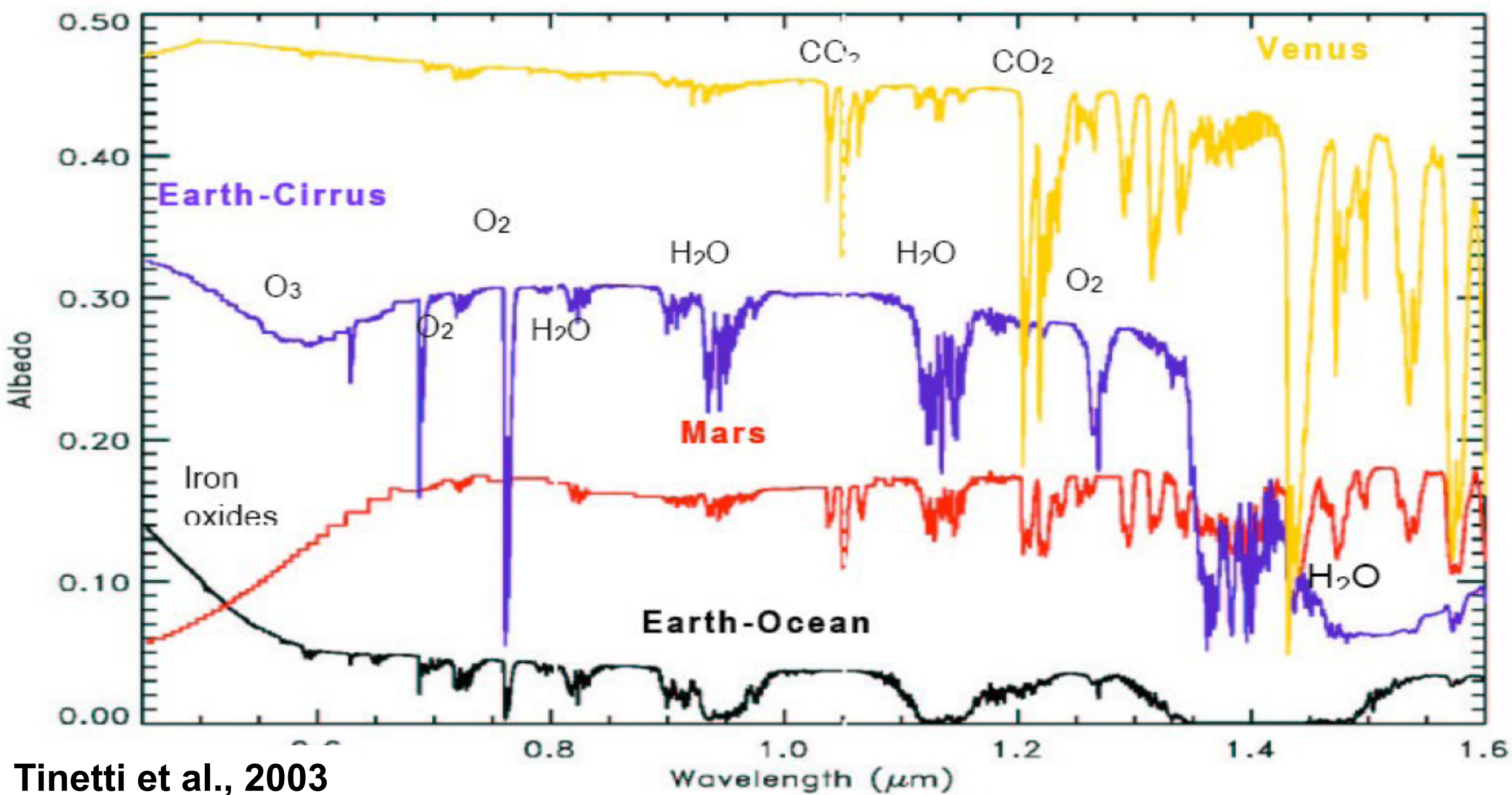
1. Biosignatu... planets
2. Characterization ... irradiated planets – Rocky planets to Gas Giants
3. Survey of self-luminous Exoplanets (SFR, forming beyond snow-line)

Contrast requirements



Bonavita et al. 2012

Spectral diagnostics



Tinetti et al., 2003

Oxygen on an Earth-like planet, idealized

Model EP: Earth-like, O_2 at 760nm (50% average transmission, 10 nm spectral bandwidth), O_2 at 1.27mu (80%, 30 nm), O_3 at 9.6 mu (60%, 1000nm)

Observation: E-ELT, 30% transmission to science detector

$\mathbf{N_{\gamma,star}}$ = Absolute photon flux of star in O_2/O_3 line window

x (10/6)^2 Remark: Star @ 6 pc

x 0.3 Remark: 30% transmission

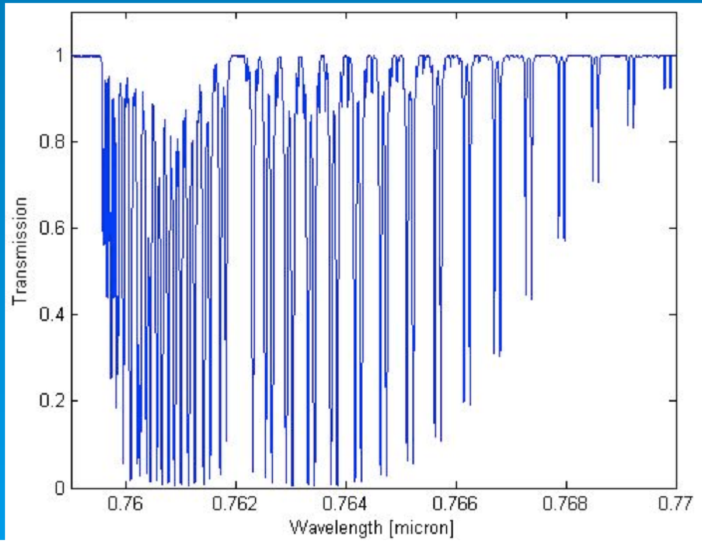
x 0.8 Remark: Fraction of flux within core of Airy PSF

x Strehl Remark: Fraction of overall flux in Airy pattern

$\mathbf{N_{\gamma,EP}}$ is derived like N_γ Star assuming photon flux of Exoplanet

$N_{\gamma,Sky}$ uses the following magnitudes / arcsec^2: I = 19.71, J = 16.5, N = -2.1, x T% in NIR

$N_{\gamma,XAOhalo}$ scales N_γ Star by the XAO halo contrast at the given distance



O_2 on an Earth-like planet, idealized

Star 1: M4V, 6 pc, 0.09 AU (HZ) = 15 mas (~70 M-stars within 6 pc)

760 nm: XAO halo: 3e-5, SR ~0.6

1270 nm: XAO halo: 3e-5, SR ~0.8

10000 nm: not resolvable

Method	N_γ EP /hr	N_γ Star /hr	N_γ Sky /hr	N_γ XAO halo/hr	SNR (1hr) $O_{2/3}$	t(3σ, $O_{2/3}$)
2^{nd} transit, J-band	1.2e4	6.3e11	4.3e4		0.015 (w AO)	> 1e4 transits
2^{nd} transit, N-band	2e6	1.3e11	2.4e13		0.41 (w AO)	27 transits (~8 yrs)
Transmission, 760nm					~1 (Snellen 2013)	~10 transits (~3 yrs)
Transmission, 1270nm					~0.6 (Snellen 2013)	~30 transits (~8 yrs)
HCI, N-band						
HCI, 760nm	1.7e3	5.7e10	<1e4 (negl.)	1.7e6	50% x 1.7e3 / sqrt(1.7e6) = 0.65	20 hrs
HCI, 1270nm	1.2e4	4e11	2.55e4	1.2e7	20% x 1.2e4 / sqrt(1.2e7) = 0.69	20 hrs
HCI+HRS, 760nm	1.7e3/2	5.7e10/2	Negl.	1.7e6/2	0.92	10 hrs
HCI+HRS, 1270nm	1.2e4/5	4e11/5	2.55e4/5	1.2e7/5	1.54	4 hrs

O_2 on an Earth-like planet, idealized

Star 2: G2V, 6 pc, 1 AU (HZ) = 150 mas (3 G-, 15 K-stars <6 pc)

760 nm: XAO halo: 1e-6, SR ~0.6

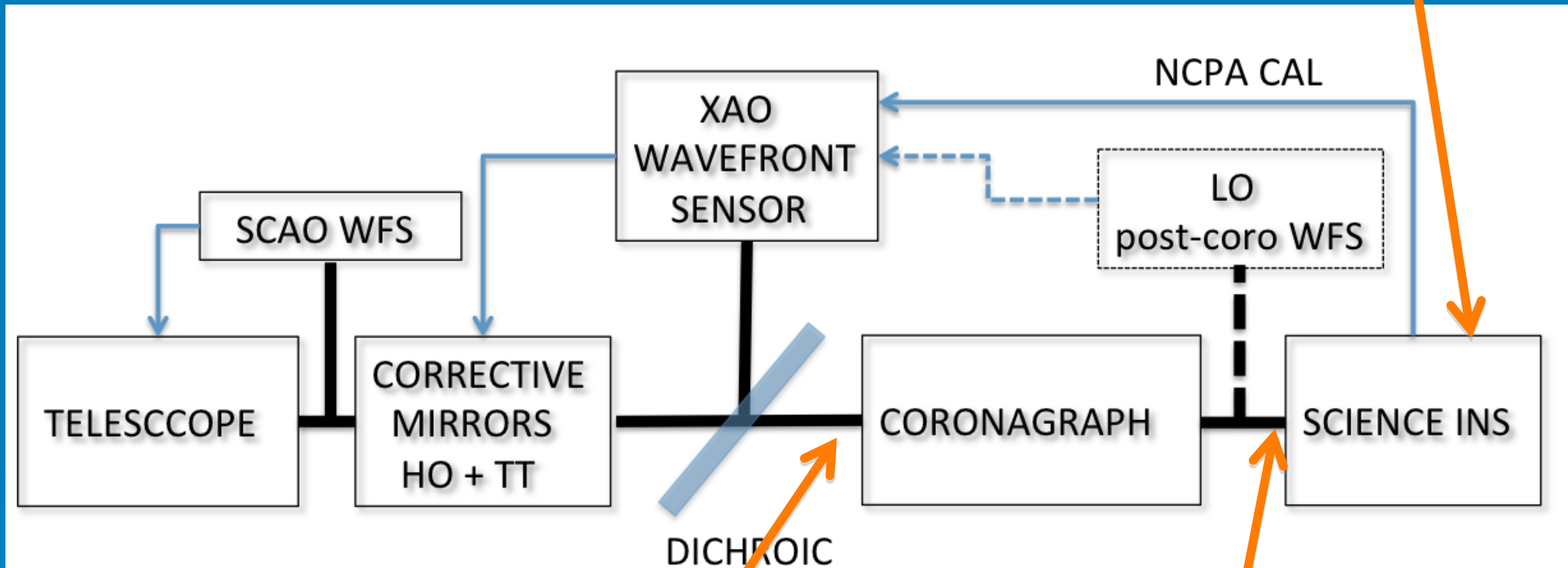
1270 nm: XAO halo: 1e-6, SR ~0.8

10000 nm: AO halo: 1e-5, SR ~1

Method	N_γ EP /hr	N_γ Star /hr	N_γ Sky /hr	N_γ XAO halo/hr	SNR (1hr) $O_{2/3}$	t(3σ, $O_{2/3}$)
Transit and transmission						not feasible
HCI, 760nm	2.7e3	1.9e13	Negl.	1.9e7	0.31	94 hrs
HCI, 1270nm	7.7e3	3.9e13	2.55e4	3.9e7	0.25	148 hrs
HCI, N-band	1.6e6	8.2e12	2.4e13	<1e8	0.33	84 hrs
HCI+HRS, 760nm	2.7e3/2	1.9e13/2	Negl.	1.9e7/2	0.44	47 hrs
HCI+HRS, 1270nm	7.7e3/5	3.9e13/5	2.55e4/5	3.9e7/5	0.55	29.6 hrs

PCS concept, 1st order specs for 10^{-8} - 10^{-9} @ 15-400 mas

QSS Calibration: 10%-1%
(CDI @ small IWA, SD/PDI/ADI)



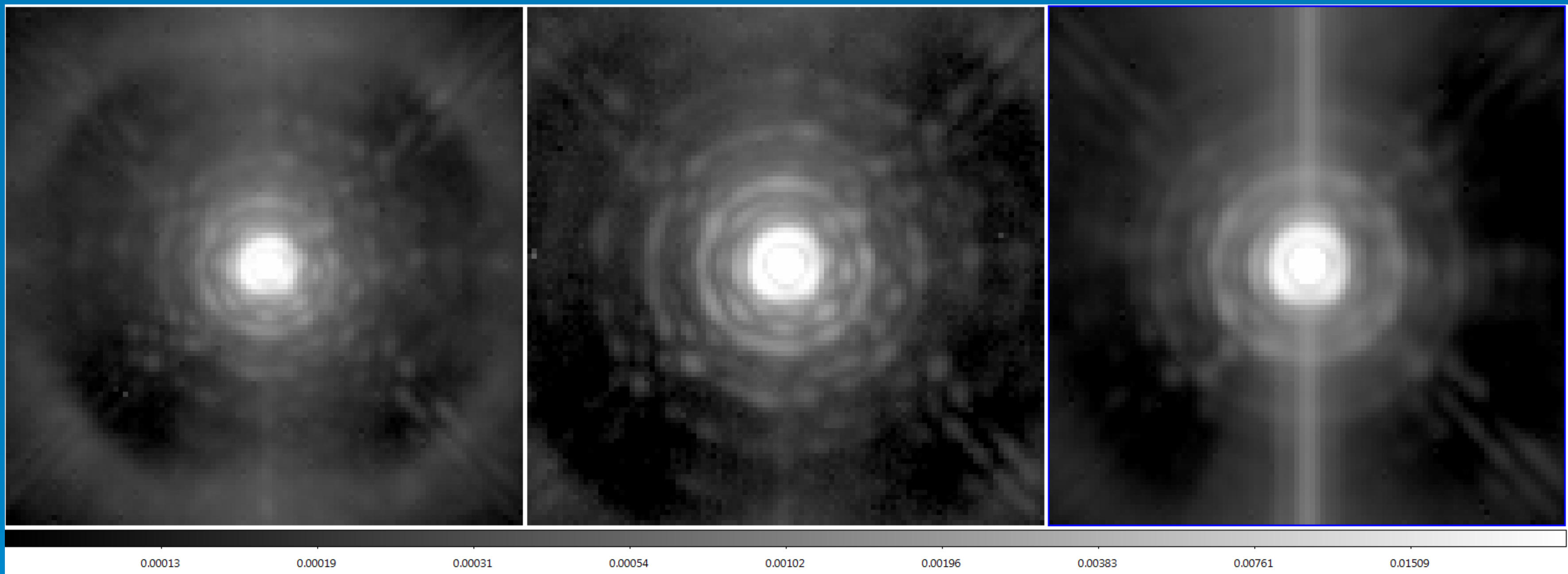
XAO Turbulence residual halo
~10^{-5} @ 15mas
~10^{-6} @ 100 mas

Pointing: 10^{-2}-10^{-3} λ/D

Coro leakage halo (Θ_{star} < ~0.05 λ/D): 10^{-5} (~XAO halo)
QSS (coro + WF control residuals): 10^{-7} - 10^{-8}

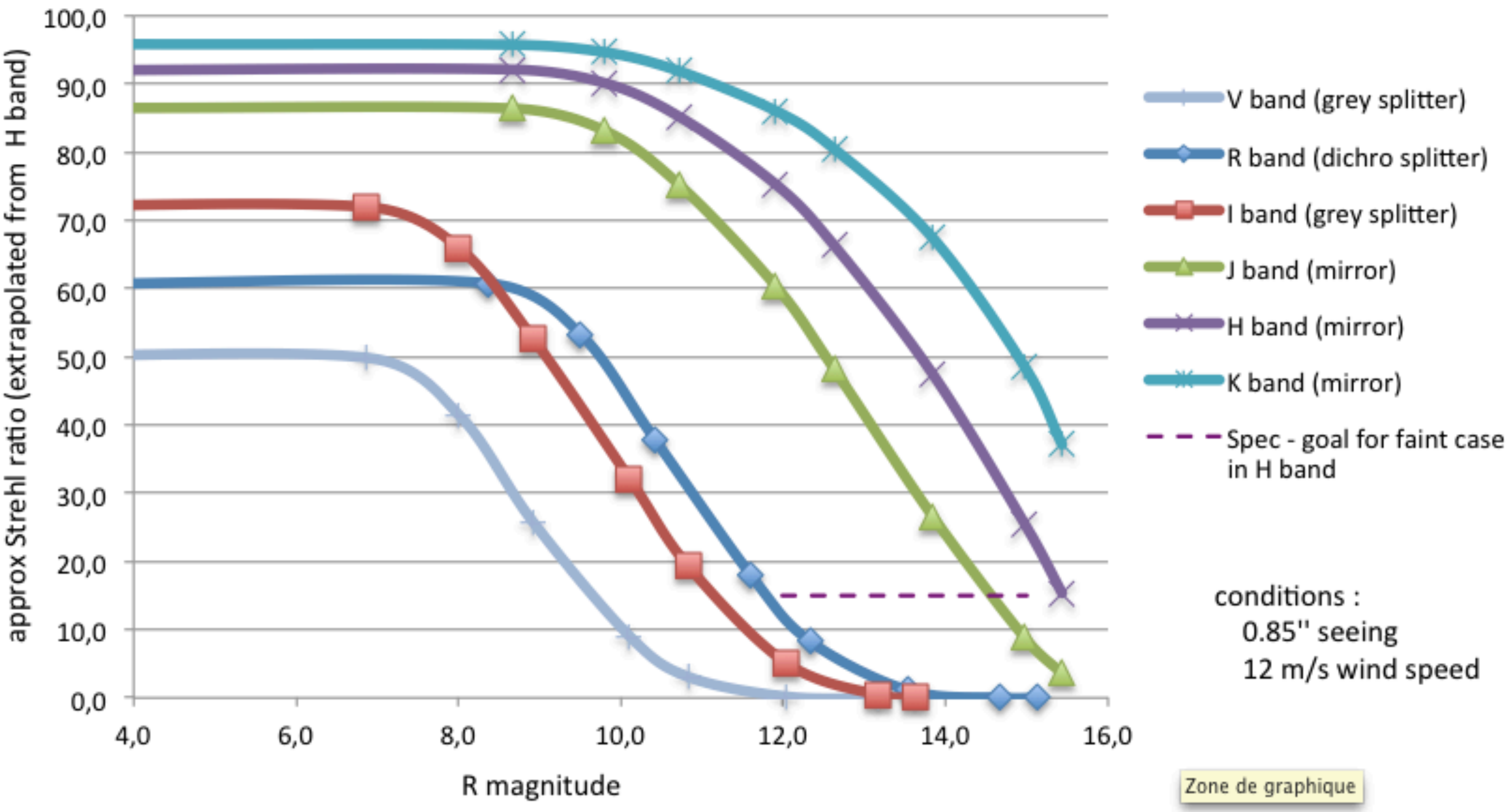
SPHERE XAO in the visible

Filter NR (625-685 nm) | Filter NI (780-860 nm) | Filter VBB (600-900 nm)



Seeing: 0.85", Wind Speed: 10 m/s
Strehl ratios of 50%-70%

SPHERE / SAXO



approx Strehl ratio (extrapolated from H band)
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
4,0
6,0
8,0
10,0
12,0
14,0
16,0
R magnitude
V band (grey splitter)
R band (dichro splitter)
I band (grey splitter)
J band (mirror)
H band (mirror)
K band (mirror)
Spec - goal for faint case in H band
conditions :
0.85'' seeing
12 m/s wind speed
Zone de graphique

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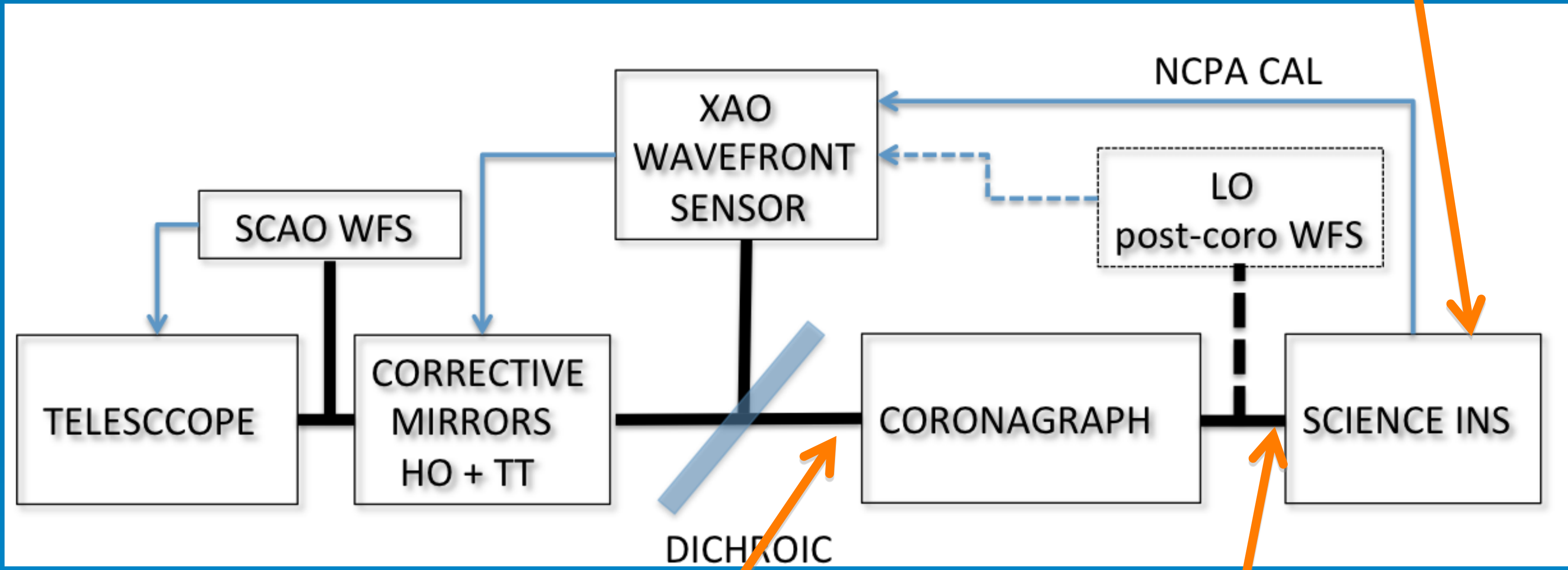
QSS Calibration: 10%-1%
(CDI @ small IWA, SD/PDI/ADI)



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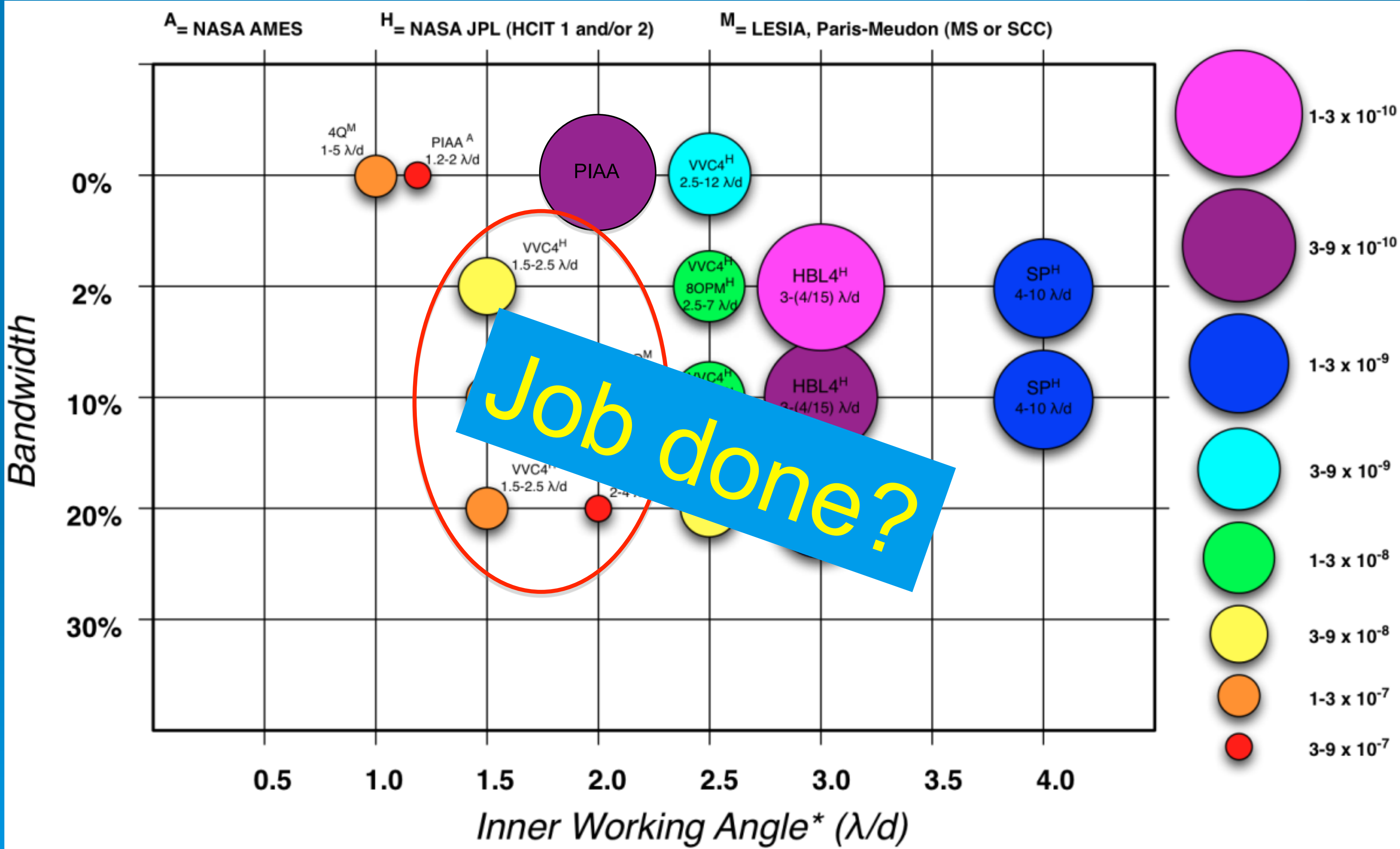
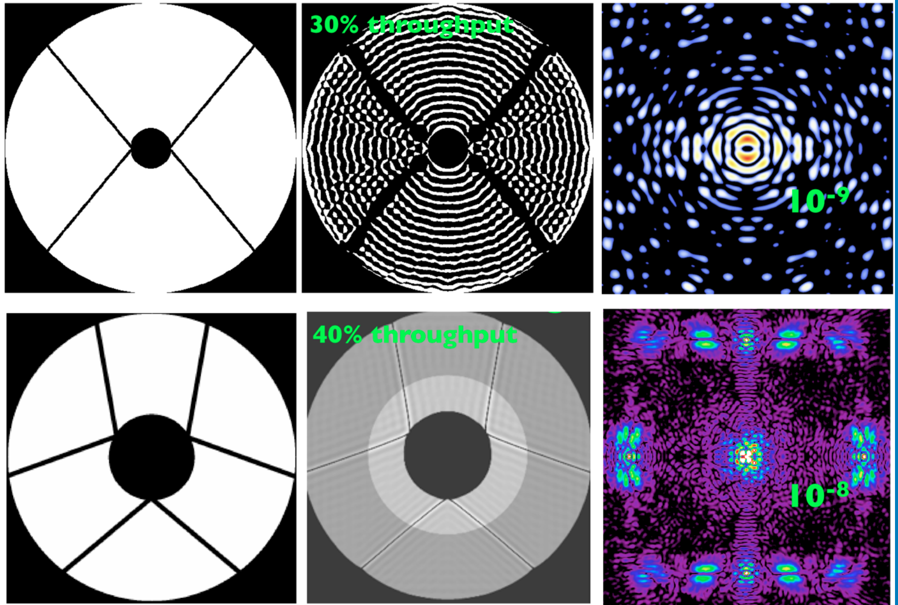
QSS (coro + WF control residuals): 10^{-7} - 10^{-8}

Coronagraph technological maturity

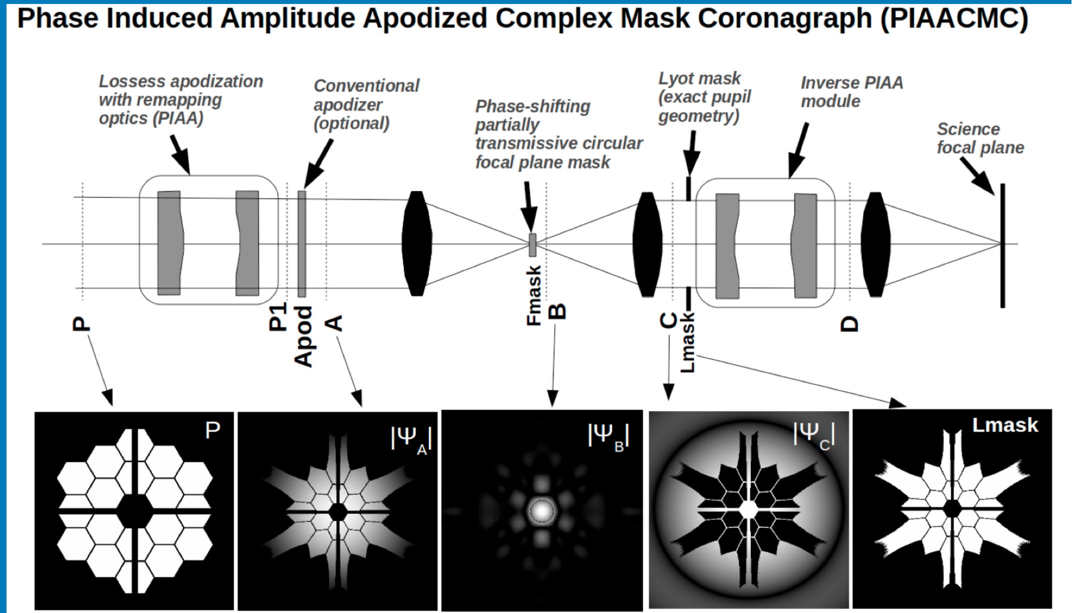


Mawet et al. SPIE 2012

Coronagraph options to deal with ELT irregular aperture



Apodized VVC4 (Mawet, Carlotti)

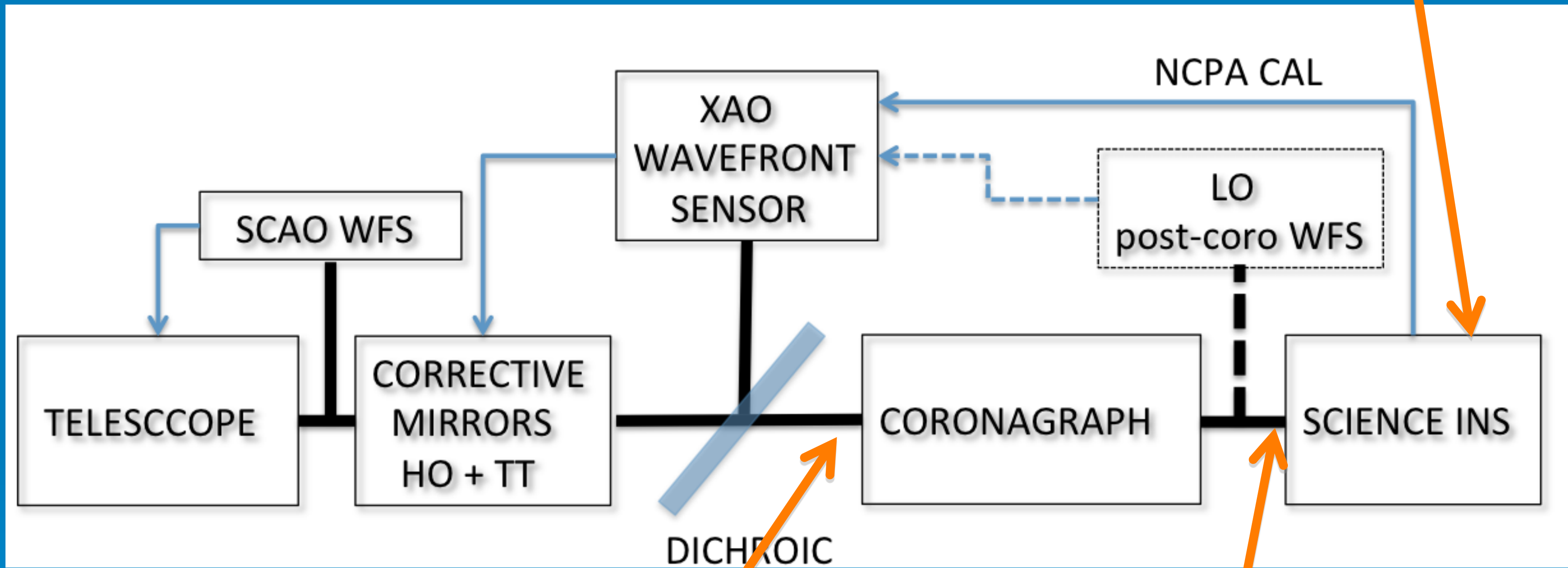


PIAACMC (Guyon)

- Both design fulfill the source extension leakage requirement with IWA of 1.23 λ/D (PIAACMC for a/2 = 2) and 1.75 λ/D (VVC4)
- R&D: demonstrate contrast requirements with E-ELT aperture incl. spiders and gaps for both options

PCS concept, 1st order specs for 10^{-8} - 10^{-9} @ 15-400 mas

QSS Calibration: 10%-1%
(SD/ADI, PDI/CDI/HRS @ 2λ/D)



XAO Turbulence residual halo
~10^{-5} @ 15mas
~10^{-6} @ 100 mas

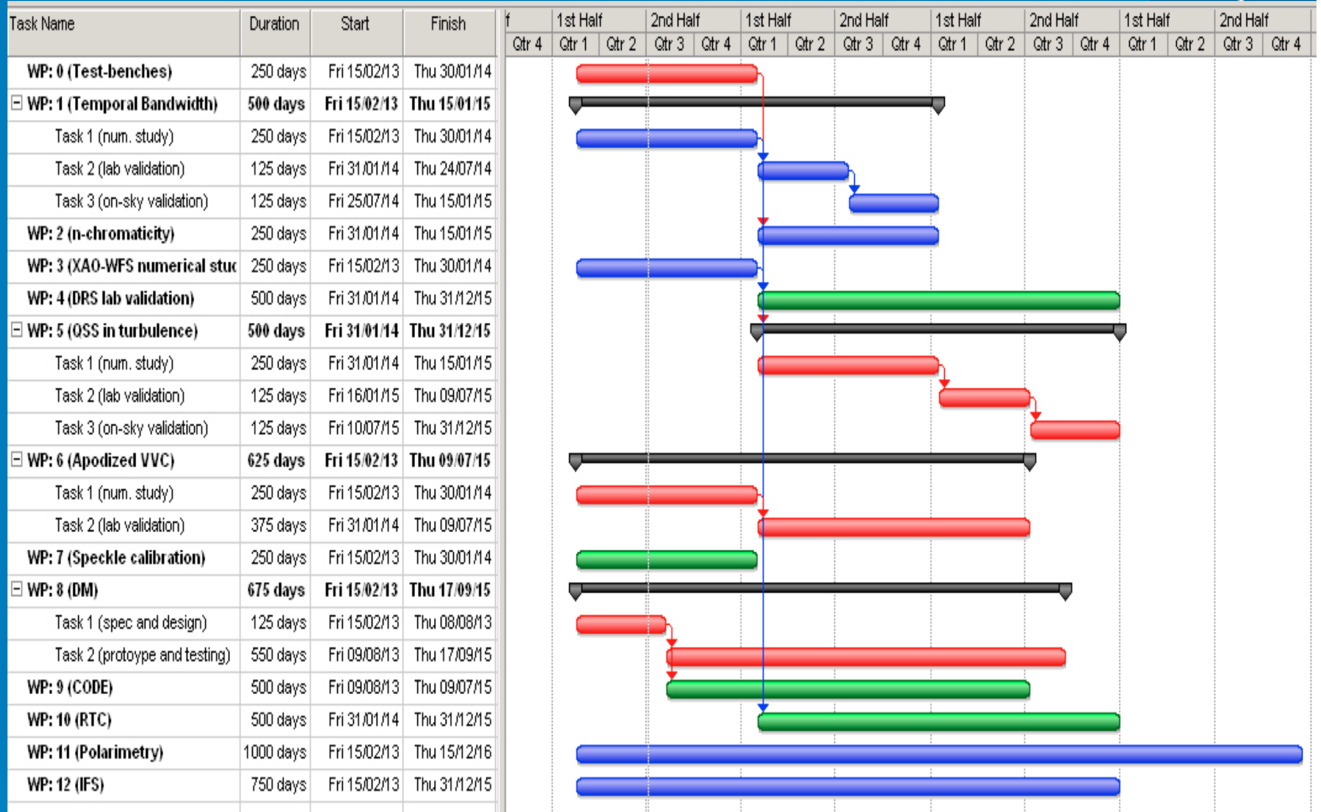
Pointing: 10^{-2}-10^{-3} λ/D

Coro leakage halo (Θ_{star} < ~0.05 λ/D): 10^{-5} (~XAO halo)
QSS (coro + WF control residuals): 10^{-7} - 10^{-8}

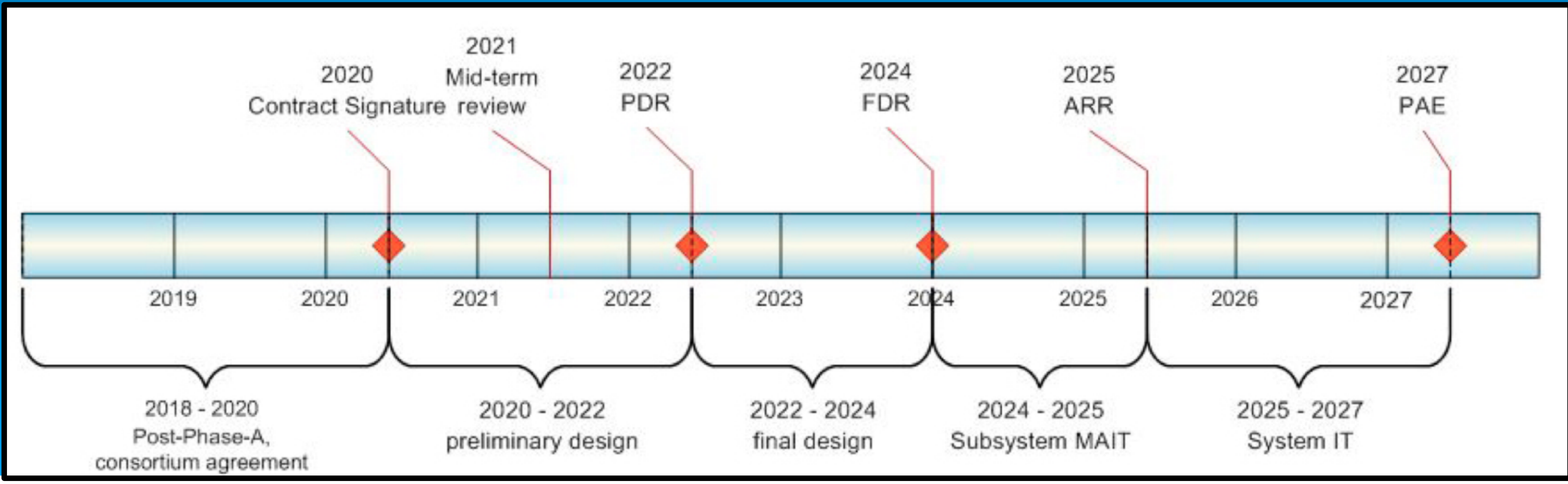
Schedule

2015:
SPHERE operation
E-ELT start of
construction

2015/16: R&D start
2020: TRL demo,
Project start



Task Name	Duration	Start	Finish
WP: 0 (Test-benches)	250 days	Fri 15/02/13	Thu 30/01/14
WP: 1 (Temporal Bandwidth)	**500 days**	**Fri 15/02/13**	**Thu 15/01/15**
Task 1 (num. study)	250 days	Fri 15/02/13	Thu 30/01/14
Task 2 (lab validation)	125 days	Fri 31/01/14	Thu 24/07/14
Task 3 (on-sky validation)	125 days	Fri 25/07/14	Thu 15/01/15
WP: 2 (n-chromaticity)	250 days	Fri 31/01/14	Thu 15/01/15
WP: 3 (XAO-WFS numerical stuc	250 days	Fri 15/02/13	Thu 30/01/14
WP: 4 (DRS lab validation)	500 days	Fri 31/01/14	Thu 31/12/15
WP: 5 (QSS in turbulence)	**500 days**	**Fri 31/01/14**	**Thu 31/12/15**
Task 1 (num. study)	250 days	Fri 31/01/14	Thu 15/01/15
Task 2 (lab validation)	125 days	Fri 16/01/15	Thu 09/07/15
Task 3 (on-sky validation)	125 days	Fri 10/07/15	Thu 31/12/15
WP: 6 (Apodized VVC)	**625 days**	**Fri 15/02/13**	**Thu 09/07/15**
Task 1 (num. study)	250 days	Fri 15/02/13	Thu 30/01/14
Task 2 (lab validation)	375 days	Fri 31/01/14	Thu 09/07/15
WP: 7 (Speckle calibration)	250 days	Fri 15/02/13	Thu 30/01/14
WP: 8 (DM)	**675 days**	**Fri 15/02/13**	**Thu 17/09/15**
Task 1 (spec and design)	125 days	Fri 15/02/13	Thu 08/08/13
Task 2 (protoype and testing)	550 days	Fri 09/08/13	Thu 17/09/15
WP: 9 (CODE)	500 days	Fri 09/08/13	Thu 09/07/15
WP: 10 (RTC)	500 days	Fri 31/01/14	Thu 31/12/15
WP: 11 (Polarimetry)	1000 days	Fri 15/02/13	Thu 15/12/16
WP: 12 (IFS)	750 days	Fri 15/02/13	Thu 31/12/15



Summary

1. PCS is a versatile EELT instrument for
   - discovery of biosignatures of M-star HZ planets
   - characterization of cold and faint Exoplanets down to Earth-mass
   - discovery and study of forming planets
2. High-R spectrograph would make a powerful science instrument
3. Concept technological choices are advanced and require a 3-5 years R&D programme
   - XAO (incl. DM! Consider risk mitigation)
   - Small IWA Coronagraphy/Wave-front control
4. 1st light >2027