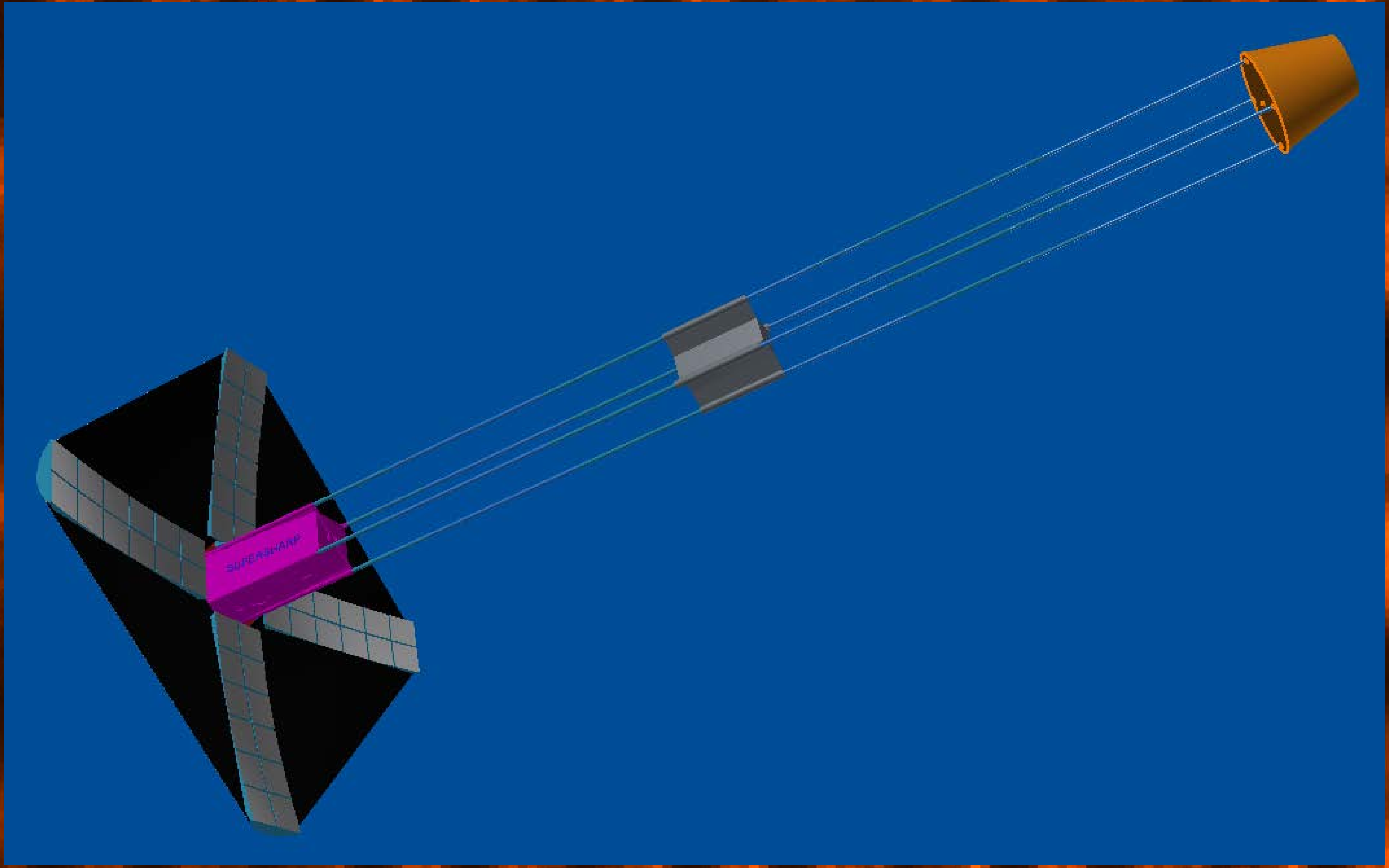
SUPERSHARP – a proposal to ESA

Segmented Unfolding Primary for Exoplanet Reconnaissance via Spectroscopic High Angular Resolution Photography



Ian Parry (IoA Cambridge)

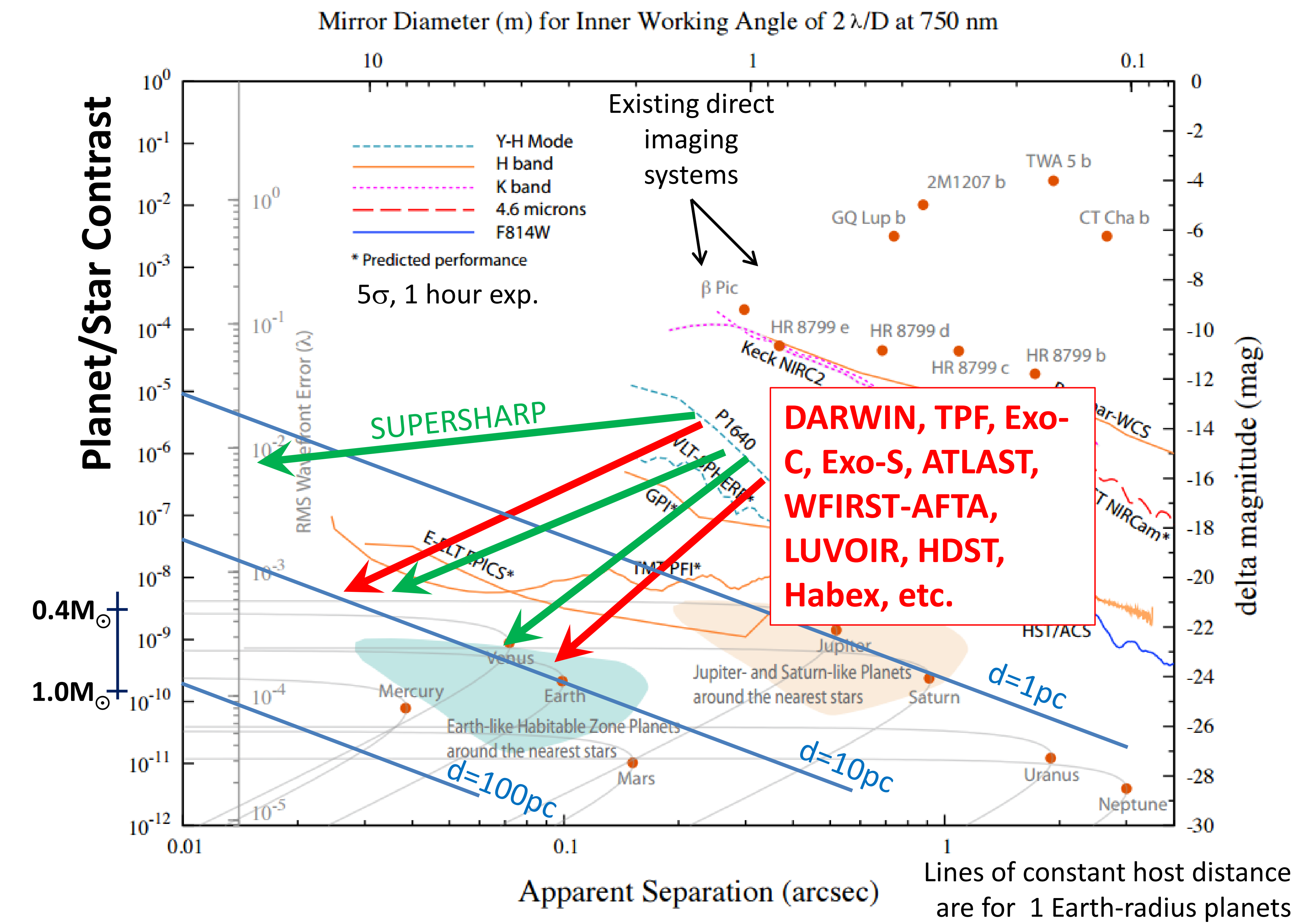
Main Motivation – Exo-Earths with bio-signatures

General Question:

How common is life in the Universe? Current observations constrain this to somewhere between 1 life-bearing planet in the entire universe to ~3 life-bearing bodies per star. So we really don't know the answer to this question at all!

Specific Questions:

1) How common are Earth-like exoplanets in the habitable zone (HZ) that show the O_2 A-band (762nm) bio-signature in their spectra?
2) What telescope design(s) enables us to observe a large enough sample (say 50 – 100 targets) to robustly address this question in a 5 year observing program? [I'm trying to introduce new affordable and feasible designs]
3) Can we build such a telescope within ESA's mission constraints (budget, mass, volume, TRL requirements)?



Underlying figure from Lawson 2012 (JPL Document D-77698)

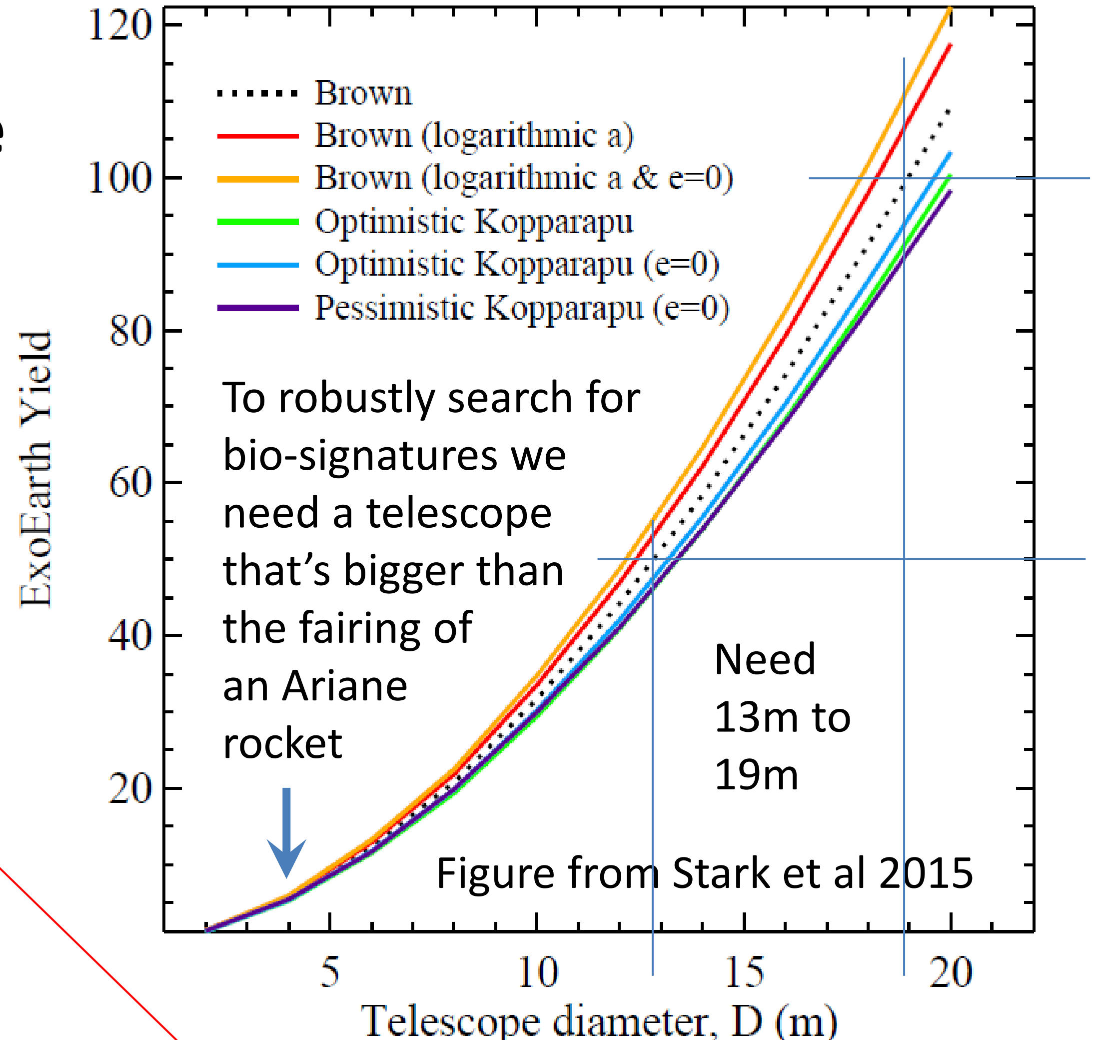
Number of targets (yield) v telescope size

Approximately
Yield $\propto D^3$

Figure shows yield for one year of observation time in total. Assumes a circular primary mirror

Reducing IWA by ×0.5 increases yield by ×2

10^{-7} instrument contrast reduces yield by ×2



Scaling law from Stark et al 2015

$$\text{Yield} \approx 25 \left[\frac{D}{10\ \text{m}}\right]^{1.97} \times \left[\frac{T_{\text{exp}}}{1\ \text{yr}}\right]^{0.32} \times \left[\frac{\text{IWA}}{3.5\ \lambda/D}\right]^{-0.98} \times \left[\frac{\text{Throughput}}{0.20}\right]^{0.35} \times \left[\frac{\Delta\lambda}{0.10\mu}\right]^{0.30} \times \left[\frac{\text{Contrast}}{10^{-10}}\right]^{-0.10} \times \left[\frac{\eta_{Earth}}{0.10}\right]^{0.89} \times \left[\frac{\text{Bkgd}}{3.0\ \text{zodi}}\right]^{-0.23}.$$

Biosignature Missions Past and present

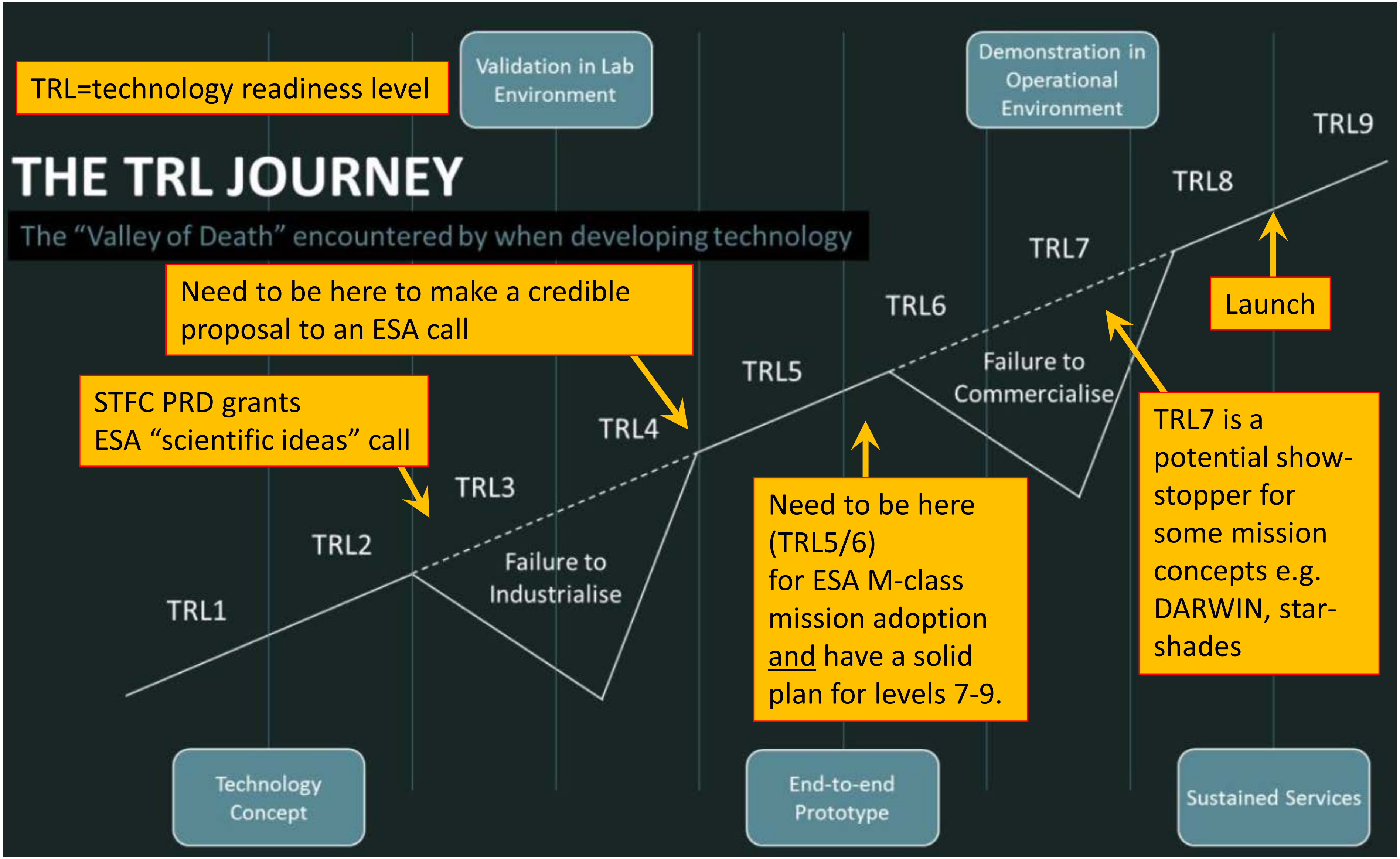
- Many detailed studies since ~2000 which did not go forward to an actual mission: e.g. DARWIN, TPF-I, TPF-C, ATLAST, EXO-C, EXO-S.
- WFIRST will have a coronagraph but it’s only a 2.5m telescope.
- In the US, flagship concepts (LUVOIR, HABEX, HDST) are being studied in preparation for the 2020 decadal review.
- At the moment, the widely accepted view is that a direct imaging/spectroscopy biosignature search mission will need a 13-19m telescope and cost at least $2B!

ESA's Cosmic Vision Program

- ESA M-class missions are ~€750M and L-class ones are up to ~€1.5B (includes typical consortium contributions).
- Next available M (medium) slot is M5 for launch in ~2029. M6 probably will launch around 2034.
- Next available L (large) slot is L4 for launch in ~2039(?)
- Apparently, based on the US studies, it looks like a biosignature mission is too expensive for the ESA program.

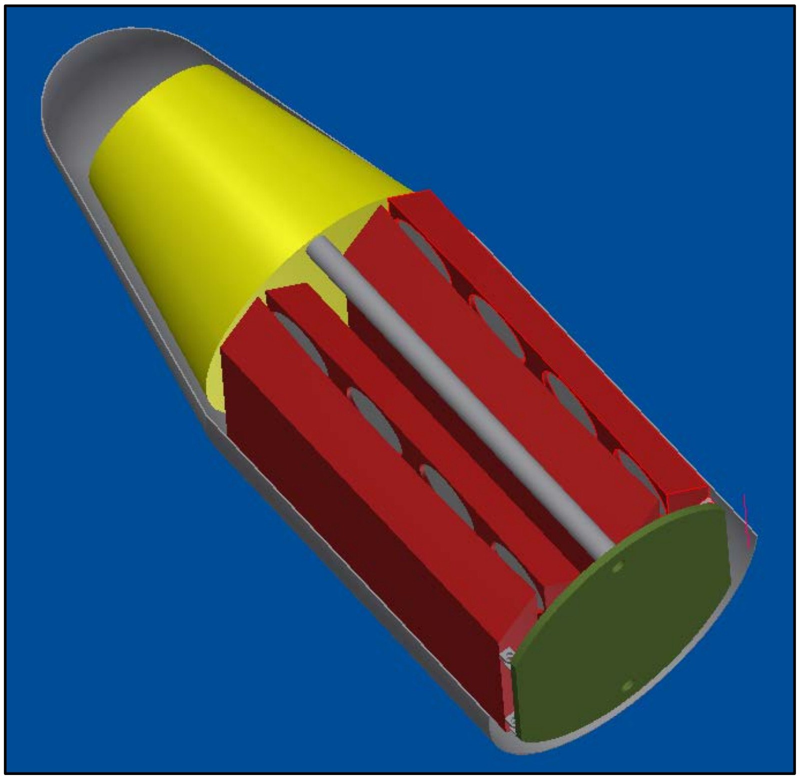
How can we make SUPERSHARP affordable?

- **Build it in Europe:** If you compare like-for-like, ESA missions are probably less expensive than NASA ones.
- **Relax the instrument contrast requirement**: US studies argue that a speckle contrast of 10^{-10} is needed but recent ground based observations suggest that this can be relaxed by ~100-1000x by accepting longer exposure times and eliminating systematic errors.
- **Abandon the circular mirror:** Primary mirror only has to be big (~15m) in one dimension not two. Baseline is more important than diameter/area.
- **Use spherical primary segments.** Need fewer actuators and easier to make.
- **Continuously and rapidly align the primary segments:** Relaxes the requirements on telescope stability (so we don't need a complicated thermal management system or a separate sun shield).
- **Dedicate it only to exoplanets:** SUPERSHARP is not a flagship so it doesn't have to have instruments and design features for a broad range of science goals. Can still be time-shared and used for non-exoplanet observations.
- **Keep it simple where possible:** Wavelength range 110 – 980nm. Small FOV (1.2 arcsec). R~100. Relatively inexpensive coronagraphs feeding integral field spectrographs. Very few detectors. No IR detectors. No cryogens. Telescope not cooled. No DM if alignment drifts are slow.

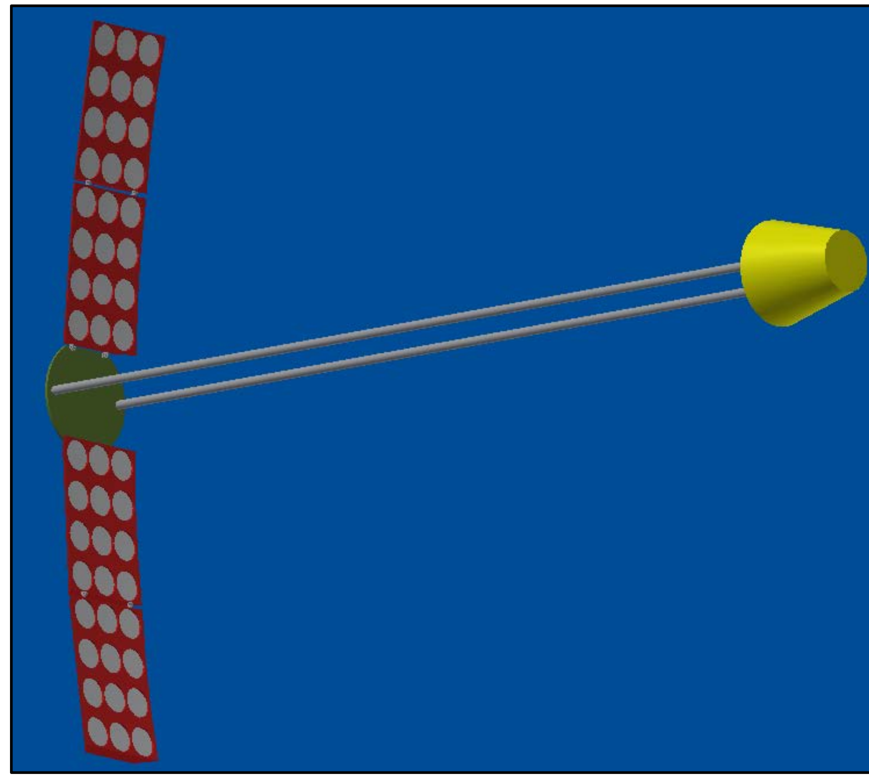


Underlying figure from white paper "SMALL IS THE NEW BIG"
Anderson, Brunskill, and Guillo, Satellite Applications Catapult, UK , May 2014
Yellow labels added later.

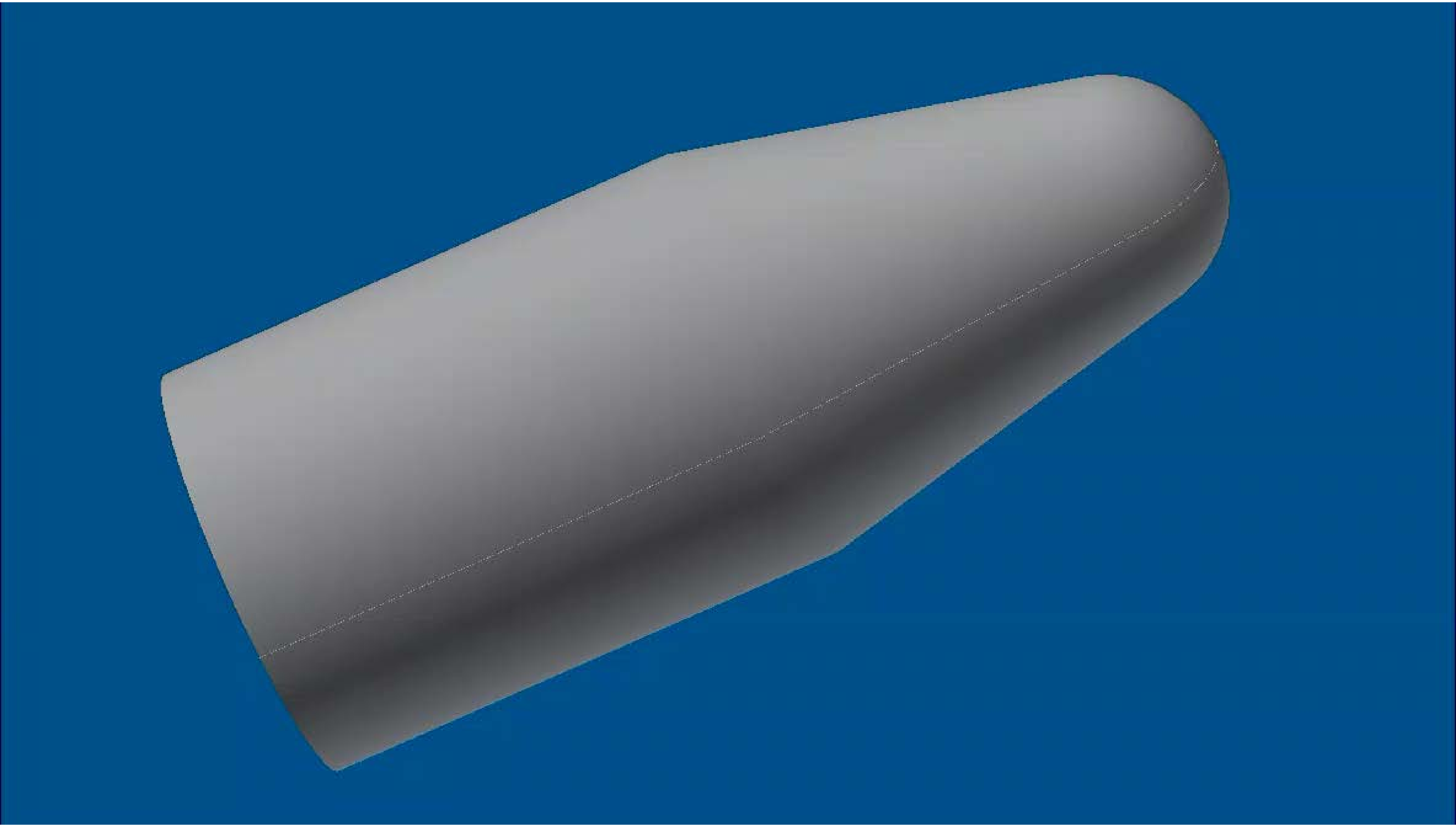
SUPERSHARP – Soyuz version as presented in the M5 Statement Of Interest (Version for future proposals will be for Ariane 6)



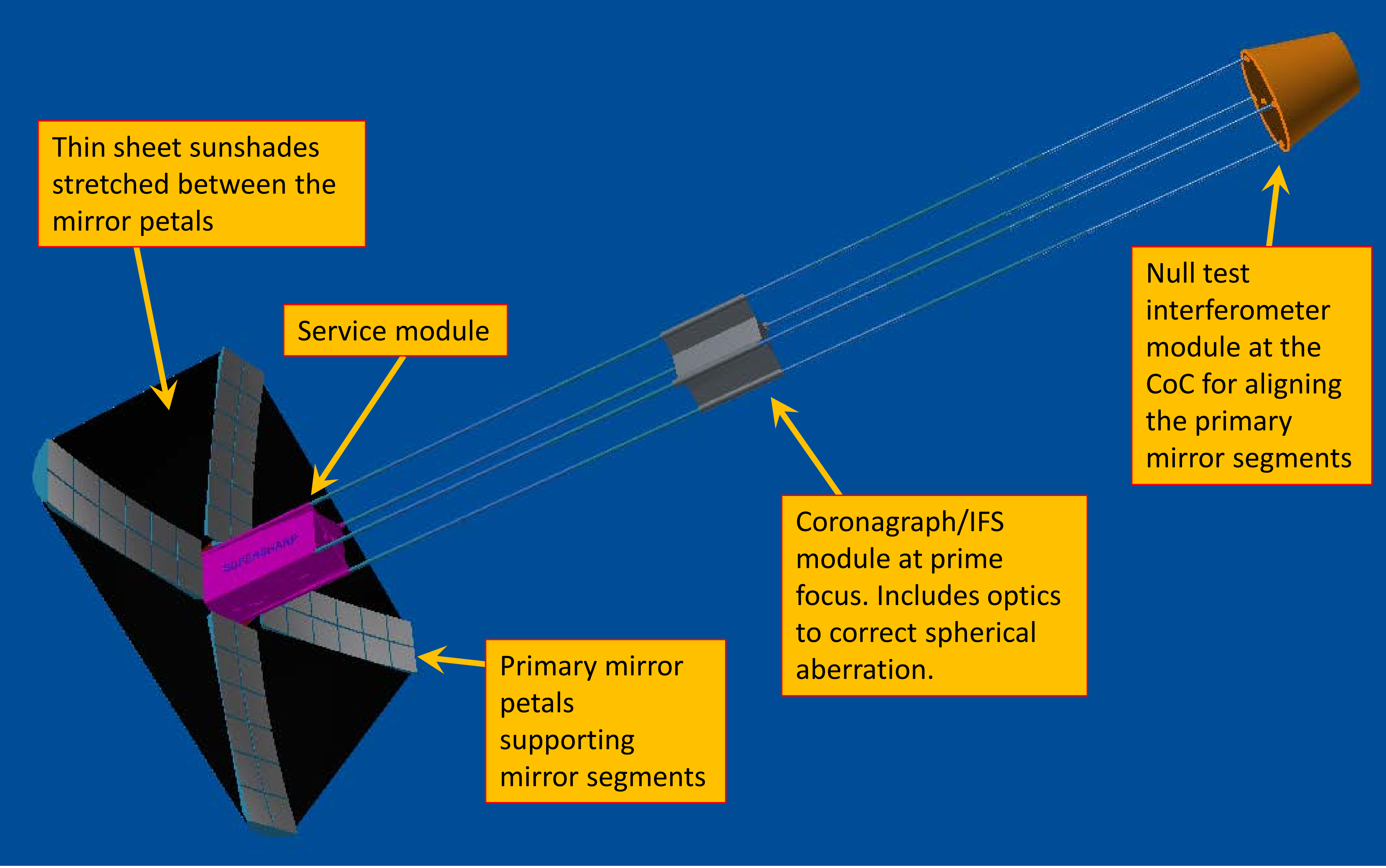
Folded inside a Soyuz fairing



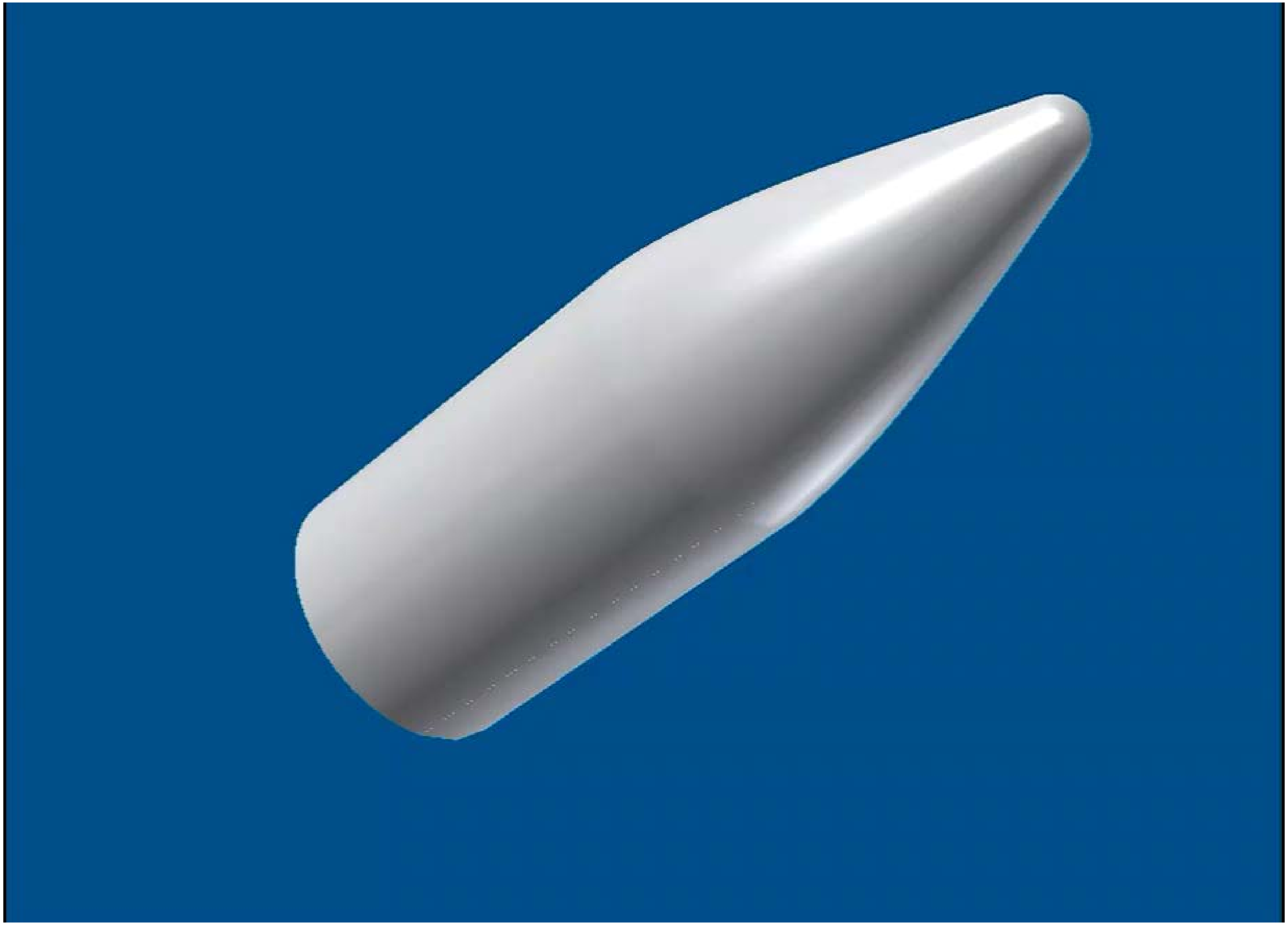
Fully deployed. The primary mirror is 24m×3.4m and the telescope structure is 30m long.



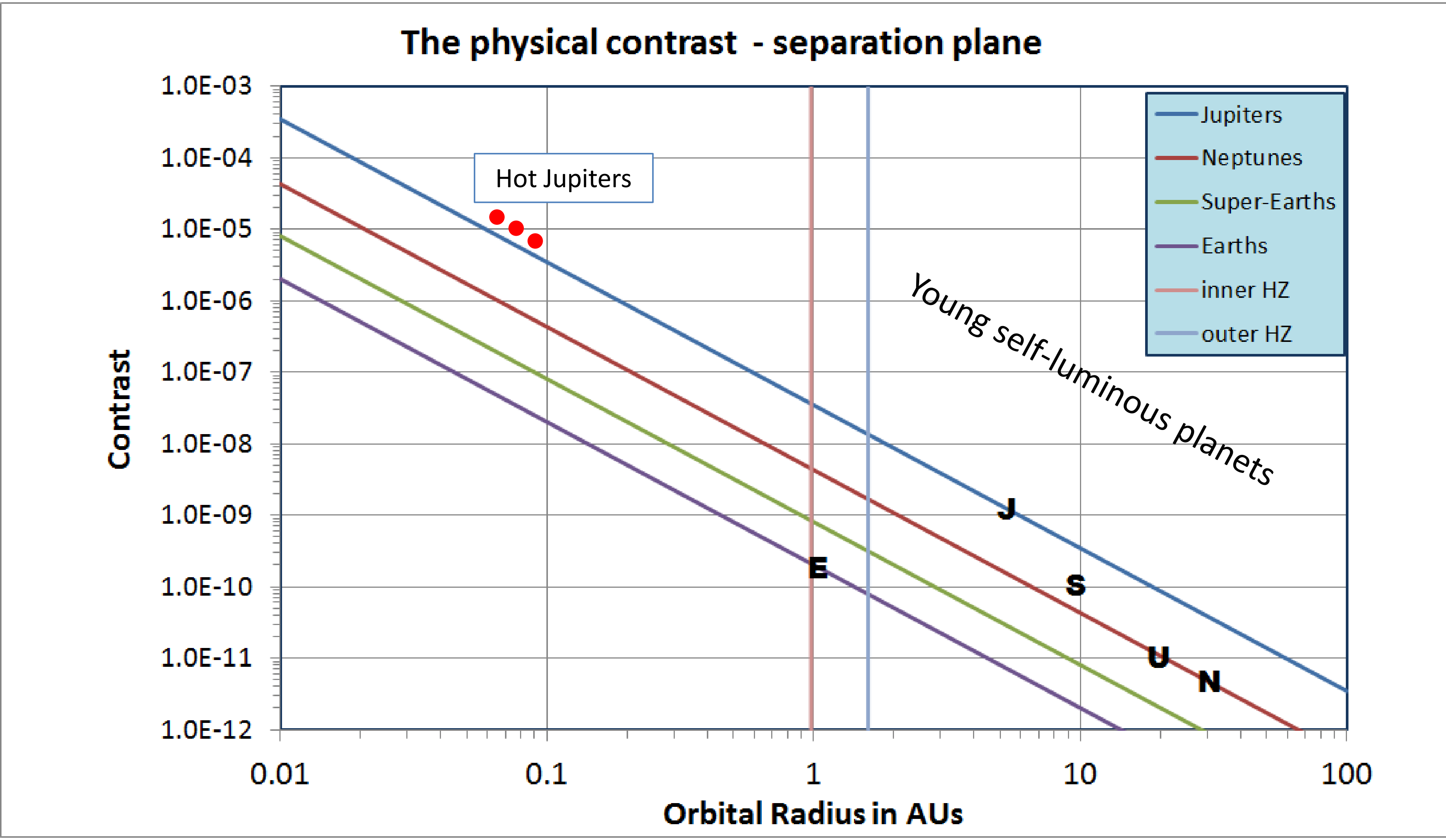
Extremely simple CAD movie concept showing how a 24m telescope can be stowed inside a Soyuz fairing and then deployed to its full extent. Much more work needed of course! https://www.youtube.com/watch?v=1G4r3RYZVwI&feature=youtu.be



When deployed, this Ariane 6 version of the SUPERSHARP concept is 50m long and 19mx19m wide. The primary mirror baseline is 24m.



Another simple CAD movie concept showing how a 24m telescope can be stowed inside an Ariane 6 fairing and then deployed to its full extent.
https://youtu.be/aTdvO1adhNA

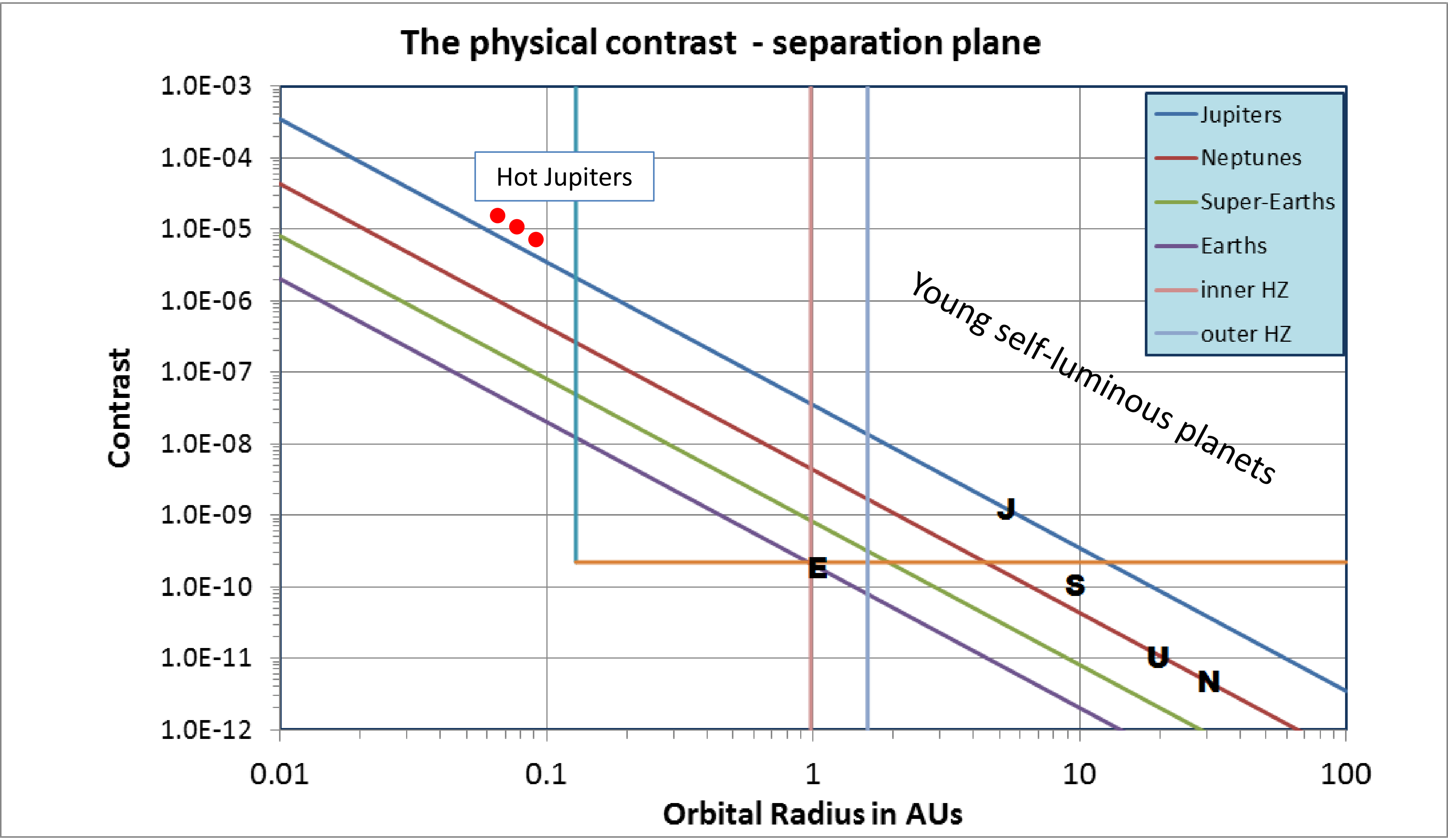


Diagonal lines are for reflected light at half phase.

Contrast = I_{planet}/I_{star} :not instrument (speckle) contrast.

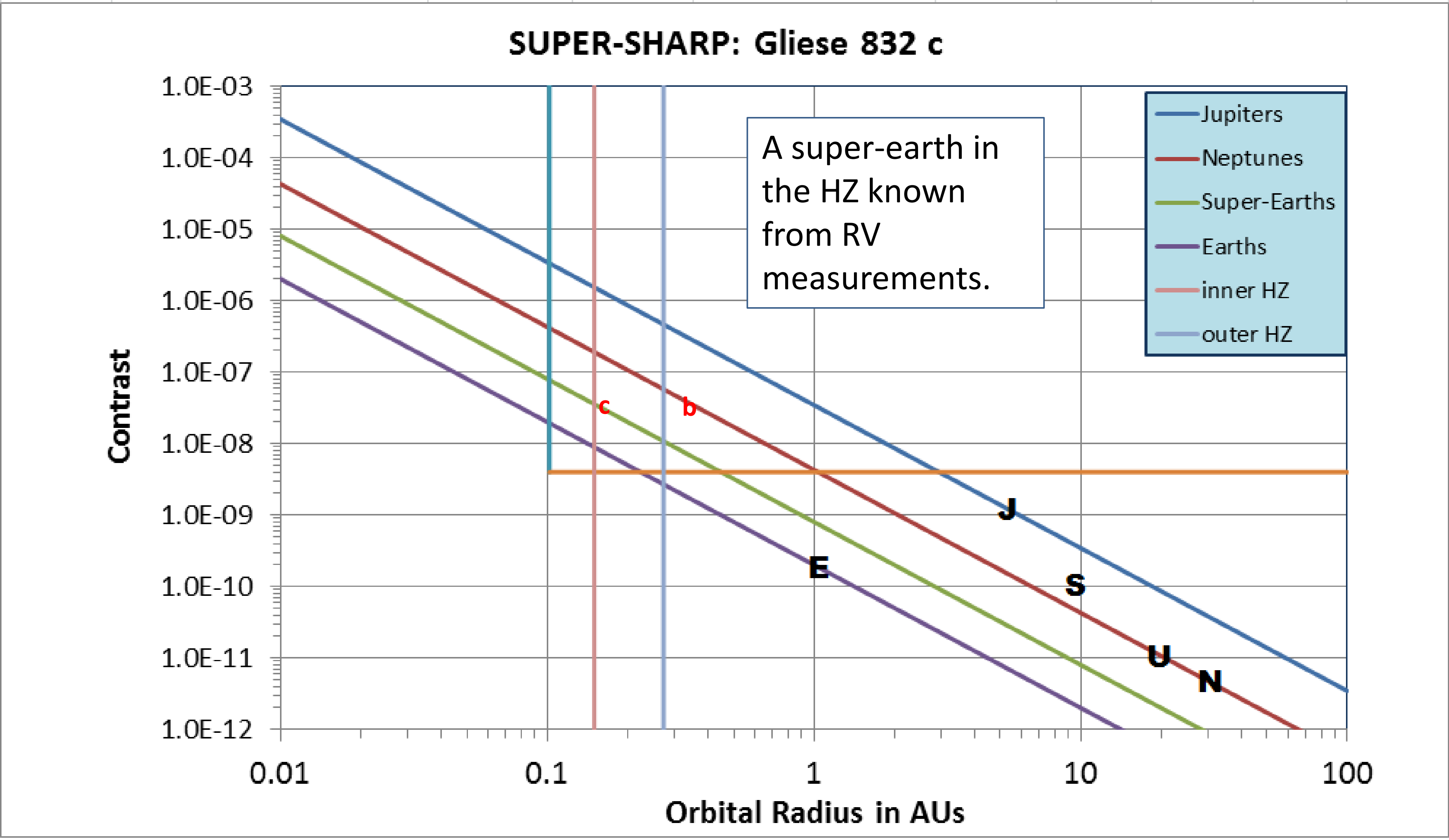
Vertical lines show the HZ for a 1 solar mass MS star.

Nothing in this plot depends on the observing parameters (e.g. distance, D_{tel}, λ, etc.)



For a set of observing parameters we can plot the smallest resolvable scale (related to the inner working angle) and the faintest detectable planet (limiting contrast).

15	telescope mirror length (baseline) in metres	0.15	throughput	400	FOV width in pixels
1.8	telescope mirror width in metres	750	wavelength in nm	6.11	FOV half width in AU
5	required signal-to-noise ratio	7.5	bandwidth in nm		
4.94	distance in pc	0.4	star's mass in solar units		approx sp type
100.0	exposure time in hours	1.00E-07	speckle contrast	M	2

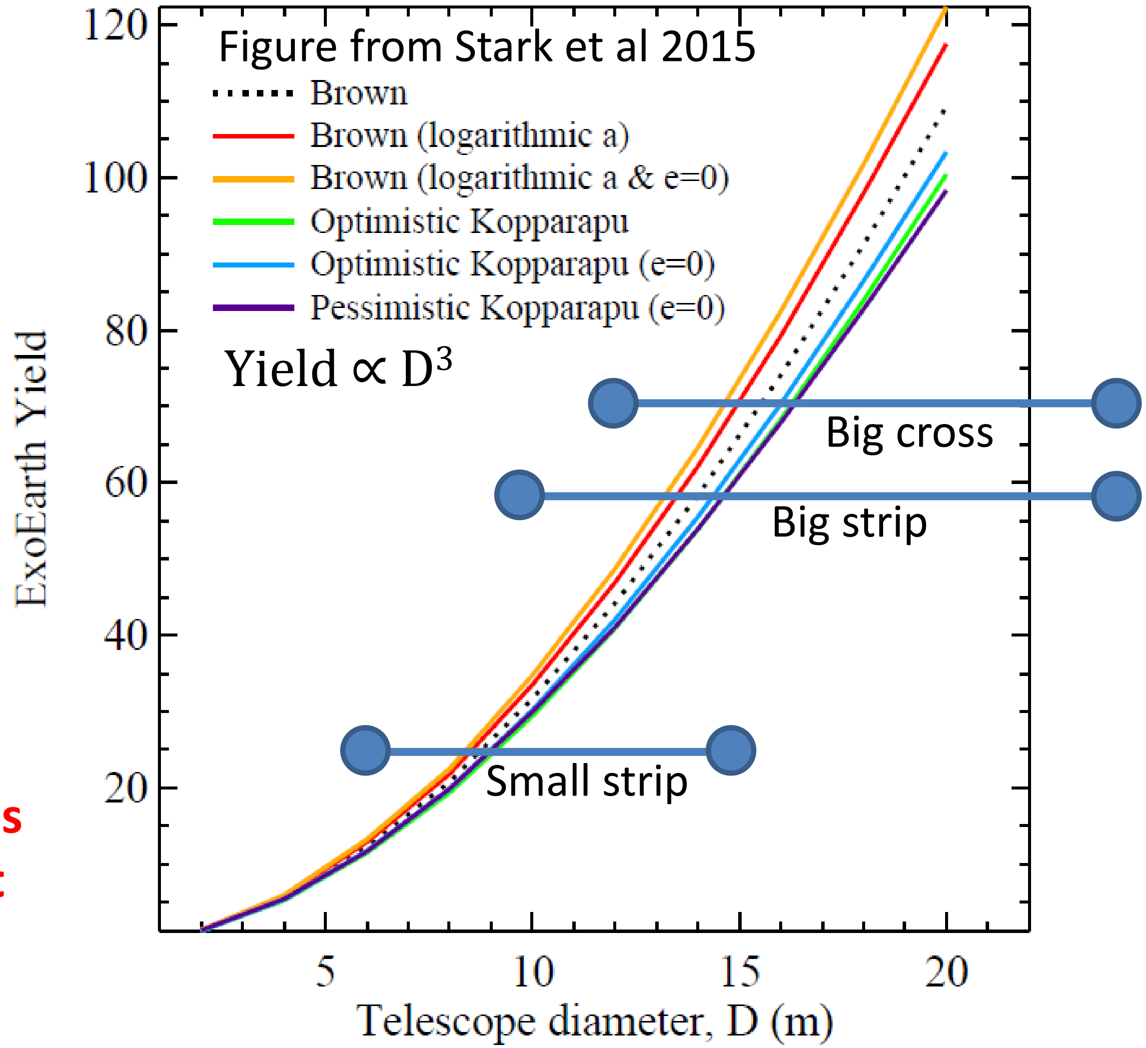


Number of targets (yield) v telescope size

SUPER-SHARP	Primary mirror	Effect. Diam.	Base-line	yield
Big cross	4x10x2.8	11.9m	24m	71
Big strip	2x10x3.4	9.0m	24m	58
Small strip	2x7.5x1.8	5.8m	15m	26

SUPERSHARP yields are for
$\Delta\lambda = 0.0076$
$T_{exp} = 5$ years
Throughput = 0.15
Contrast = 10^{-7}

Non-circular geometry improves the yield! More targets per unit area of primary mirror.



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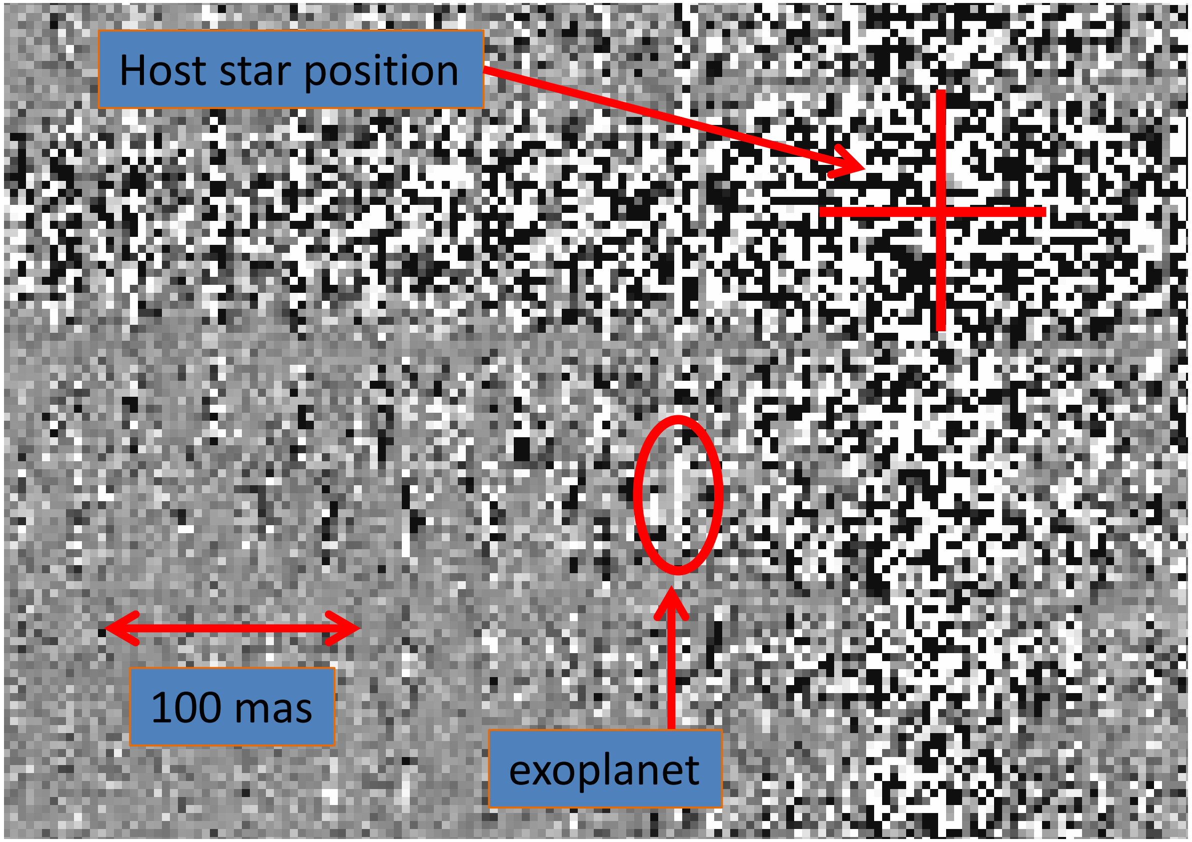
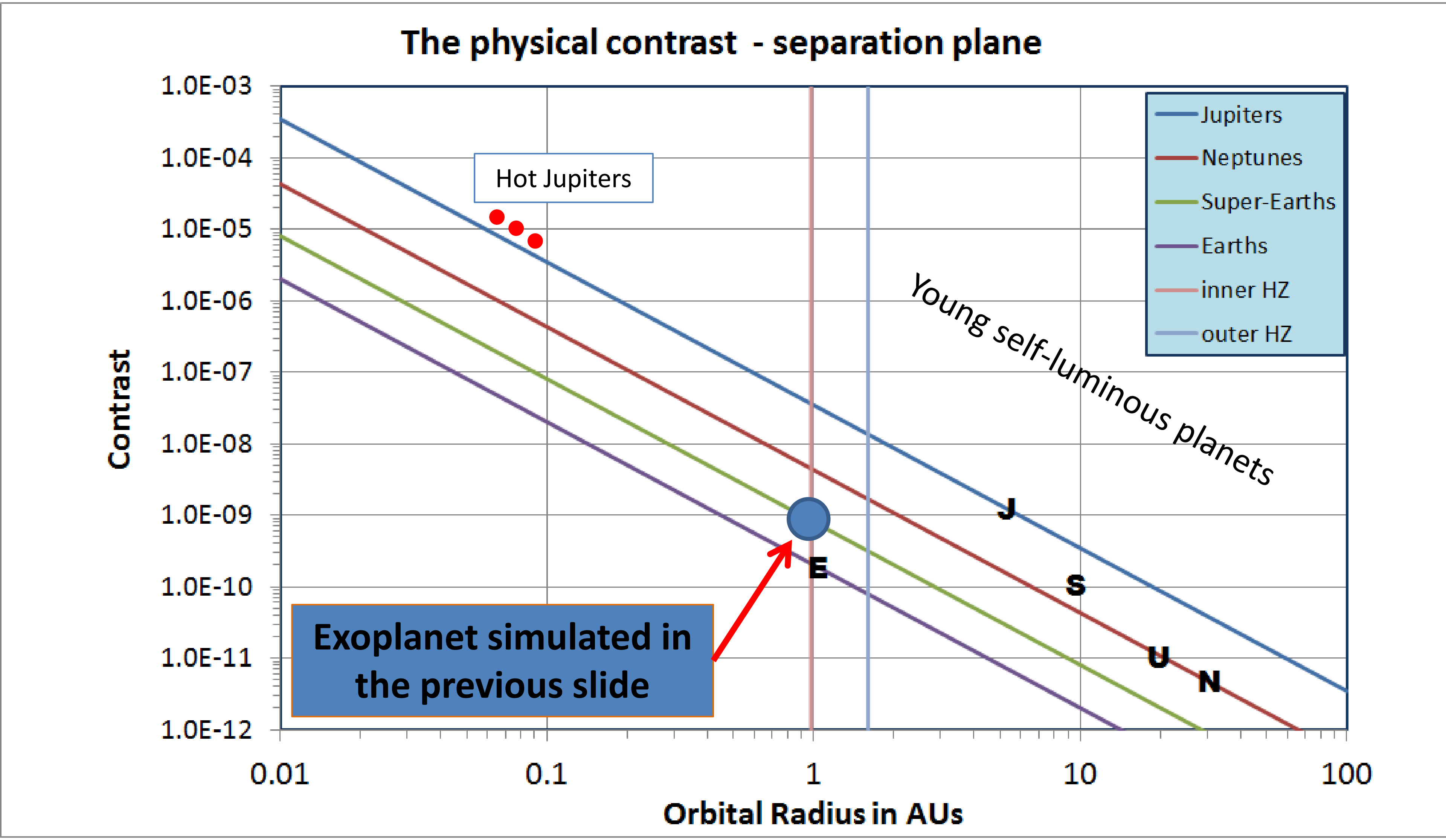


Simulated HZ super-earth

Host: 3rd mag G-star
Distance: 5pc
Exoplanet: 25.5mag
Contrast: 1×10^{-9}
Exposure time=500hr
R=100 at 750nm
ADI subtraction
Big strip design
24mx3.4m

Work in progress – a single channel in the data cube (7.5nm bandpass)

Proper end to end (telescope + coronagraph) wavefront propagation modelling using John Krist's PROPER IDL library.



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Vertical lines show the HZ for a 1 solar mass MS star.

Summary

- SUPERSHARP is a design concept for a very large space telescope dedicated to exoplanet science and targeted at the ESA cosmic vision programme (M6 or L4).
- The O_2 A-band spectrum for ~60-70 Earth-sized HZ exoplanets could be observed with S/N=5 in ~5 years with a 24m version of SUPERSHARP.
- SUPERSHARP will be proposed as a "New Science Idea" ESA proposal. Consortium is growing. Proposal deadline is Sept 14^{th} 2016.
- The successor to JWST (LUVOIR/HABEX/HDST) will be a US-led flag-ship observatory serving the whole astronomical community and not a survey instrument. It will cost several billion dollars and be launched no earlier than 2035.
- SUPERSHARP is a less expensive European alternative to search for exo-life which could launch as early as 2034.