Recognizing and characterizing terrestrial exoplanets

Pathways towards habitable planets II
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And thanks to the entire Exo-S team!

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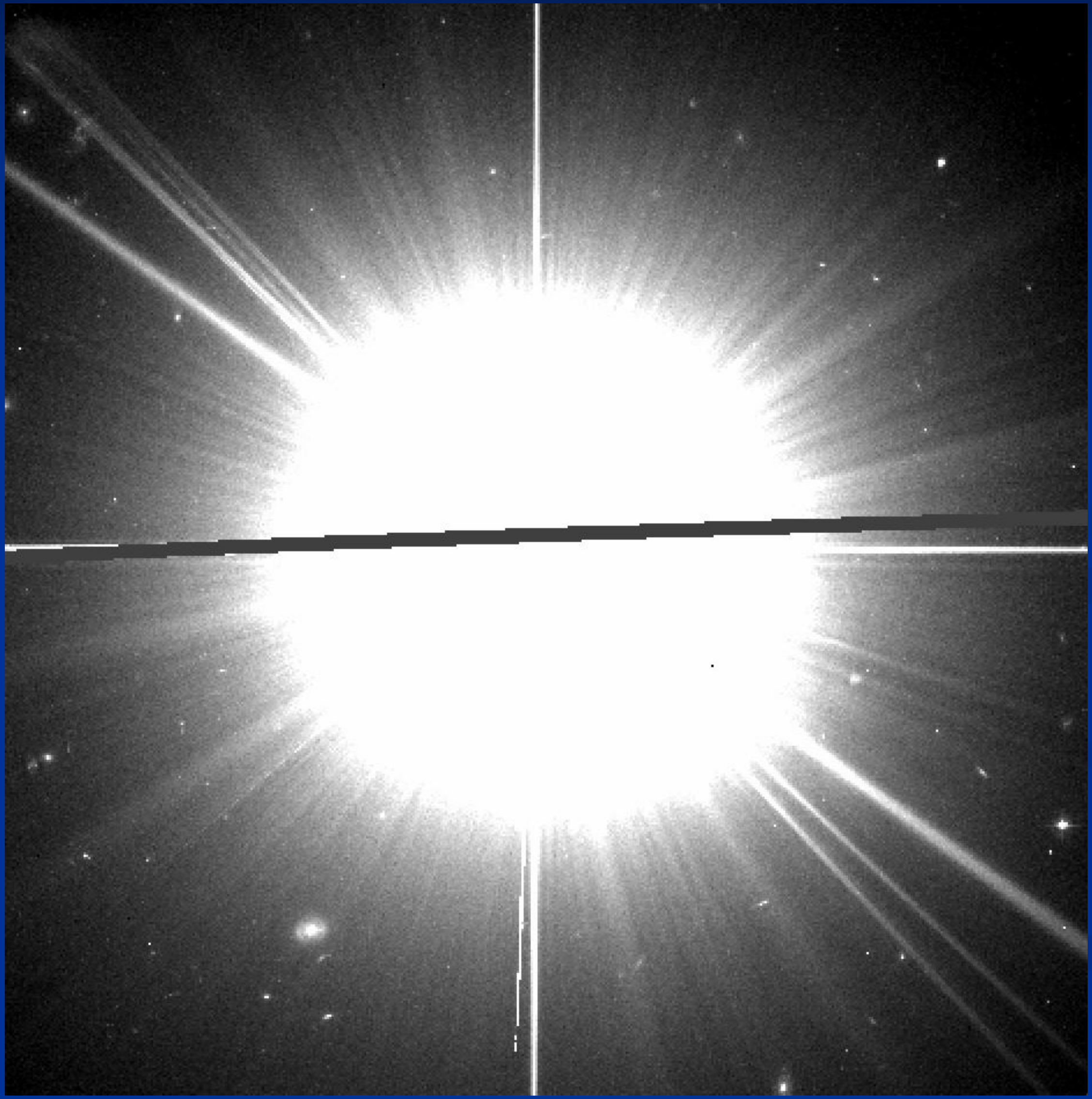
SPACE TELESCOPE SCIENCE INSTITUTE

Where's the planet?

ε Eridani

HST ACS/WFC

200×200 arcsec



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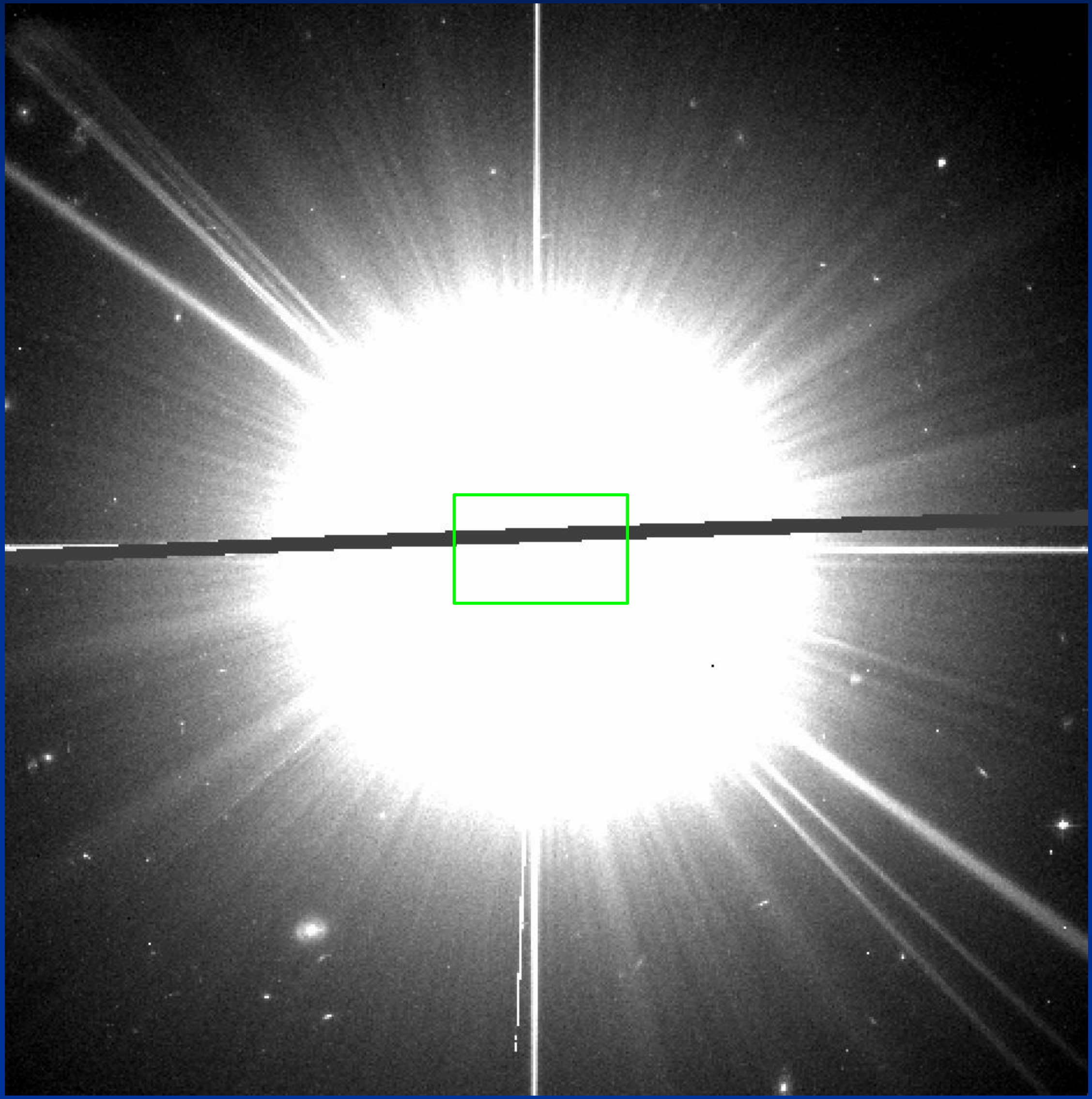
Box 30 ×20 arcsec



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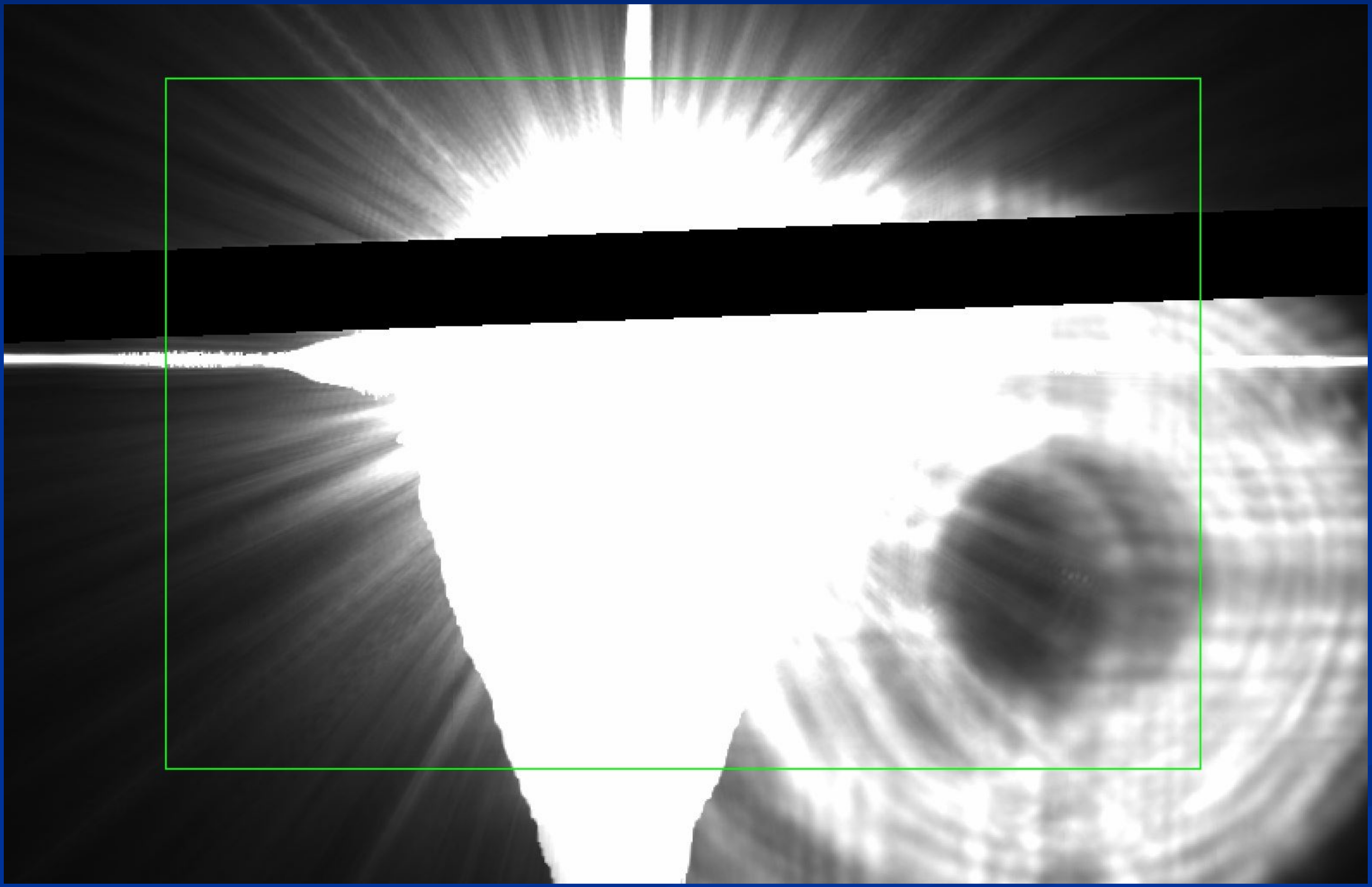


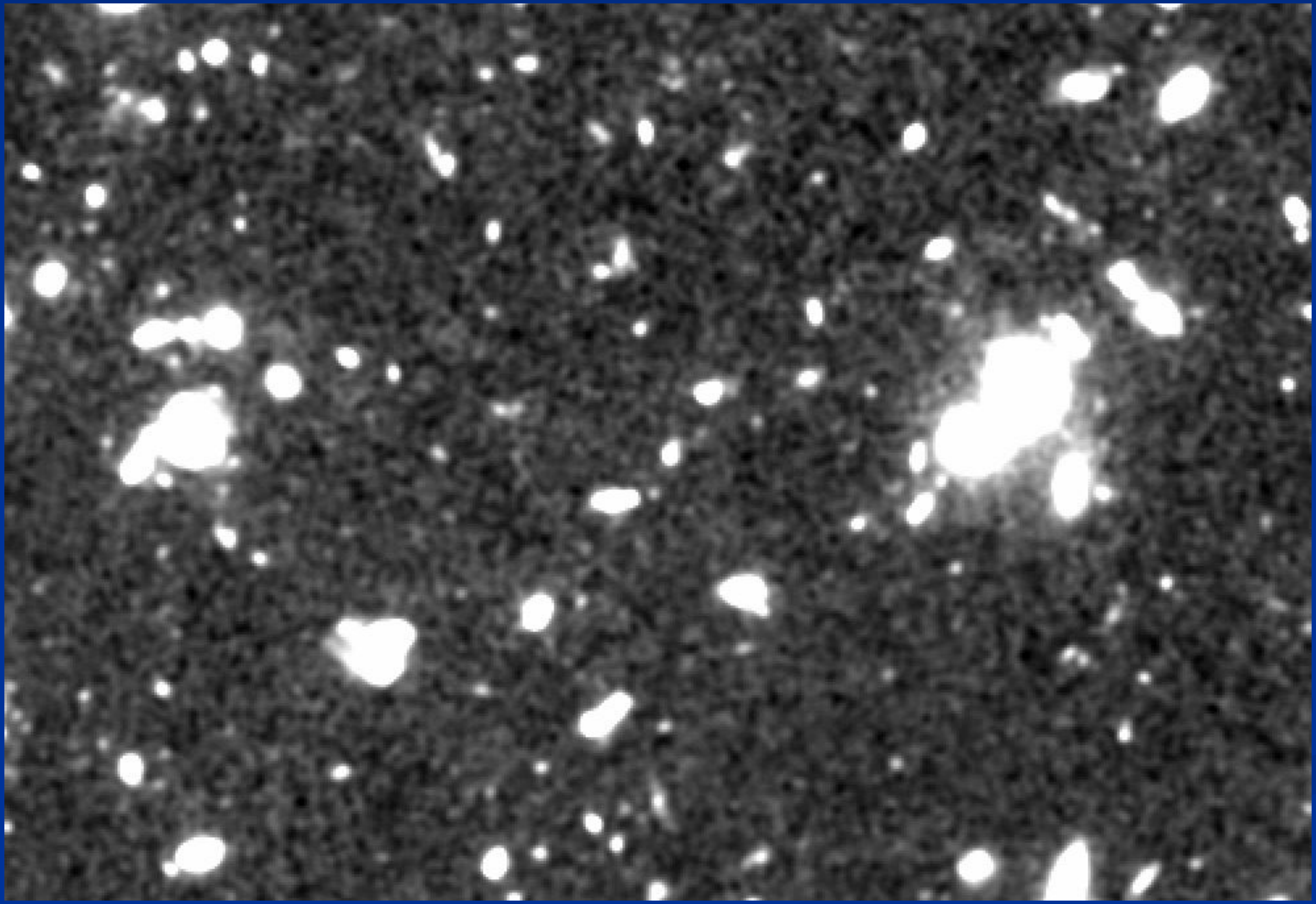
Where's the planet?

Hubble Extreme Deep Field (Illingworth et al 2013) ~10^6s total

HST ACS/WFC

F606W 174ks

Box 30 ×20 arcsec



Where's the planet?

Hubble Extreme Deep Field (Illingworth et al 2013) ~10^6s total

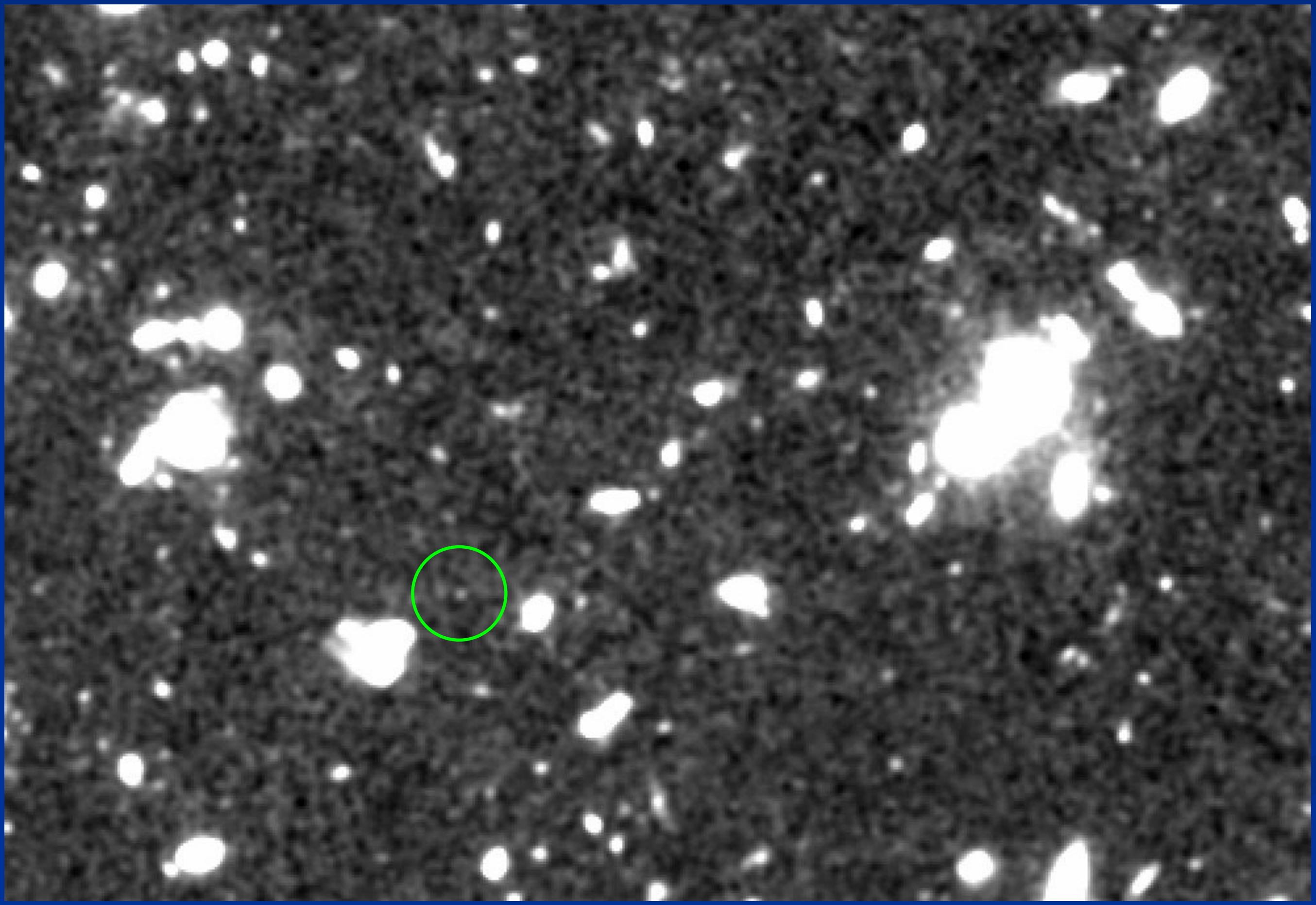
HST ACS/WFC

F606W 174ks

Box 30 ×20 arcsec

30th mag object

Circle radius 1 arcsec



Extragalactic Background

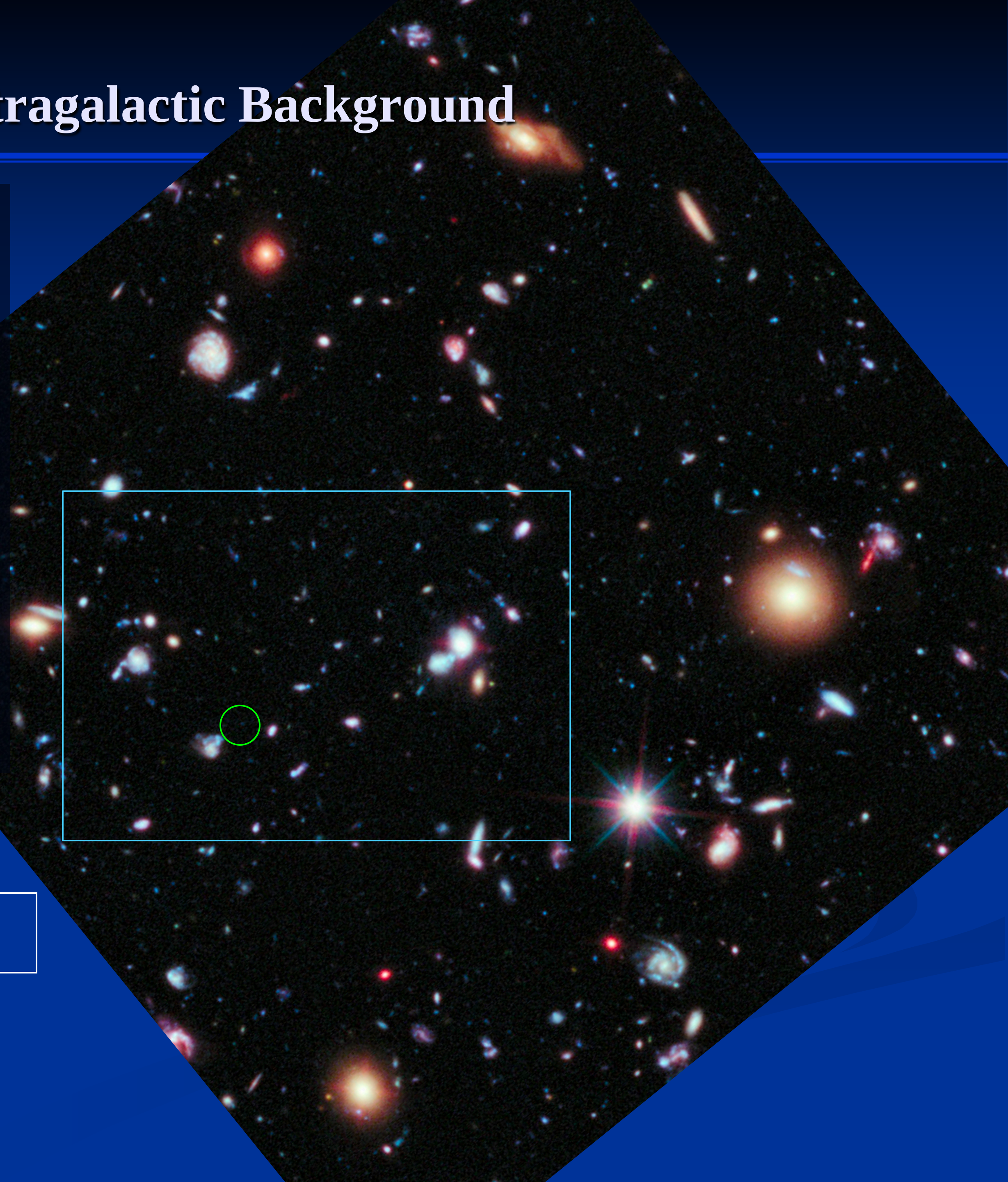
The deepest part of the XDF has a limiting magnitude near V ~ 31

7,121 galaxies above the 5-sigma significance level in ~4.7 arcmin^2.

Significant image crowding at V ~ 30, where 45% of the pixels contain galaxy light (Koekemoer et al. 2013).

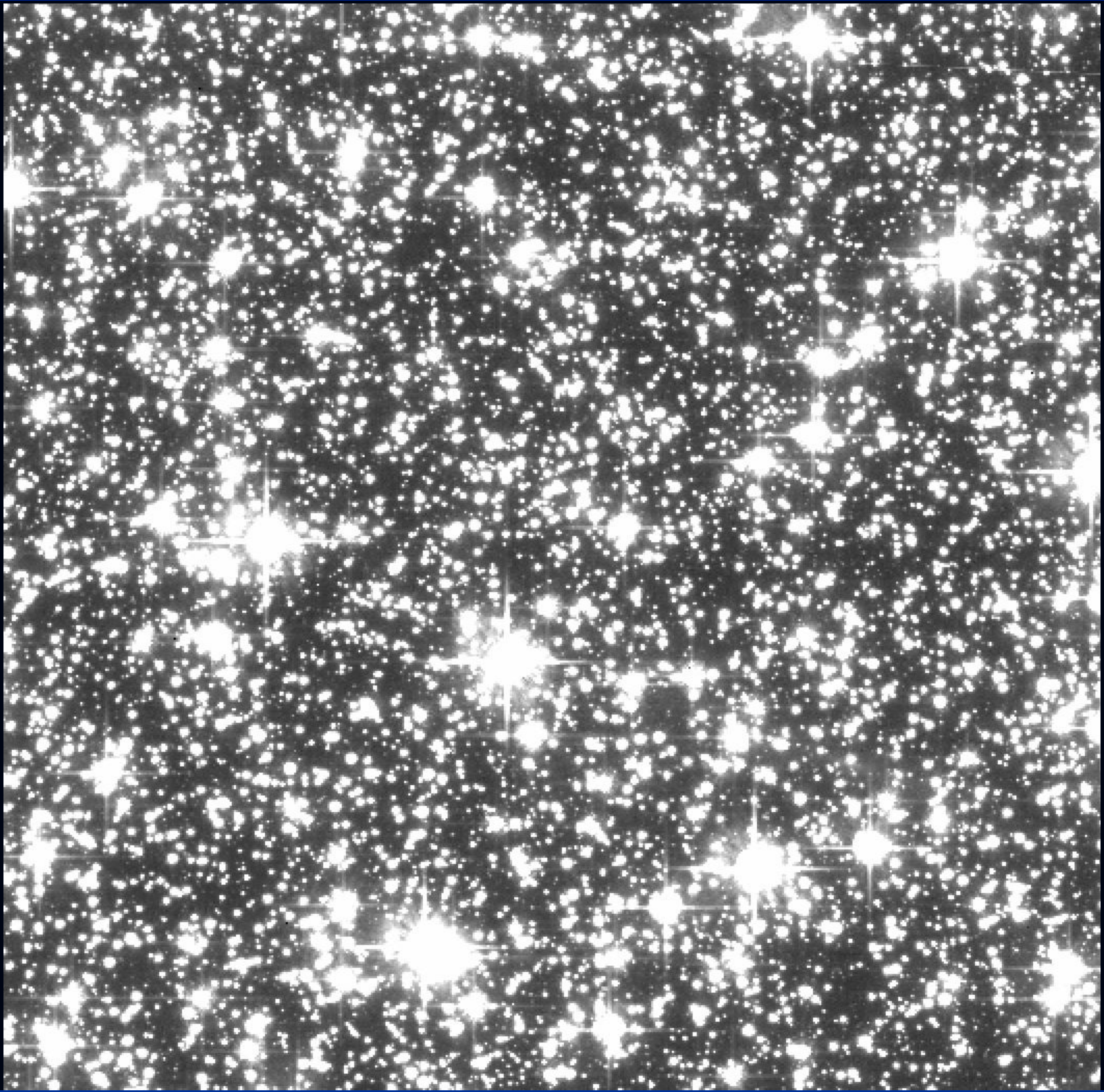
Faint extragalactic sources appear unresolved

Other surveys (e.g. Windhorst et al. 2011) indicate we should expect a few dozen galaxies per arcmin^2 at V < 25: brighter, extended, galaxies will make planet detection difficult wherever they dominate the FOV.

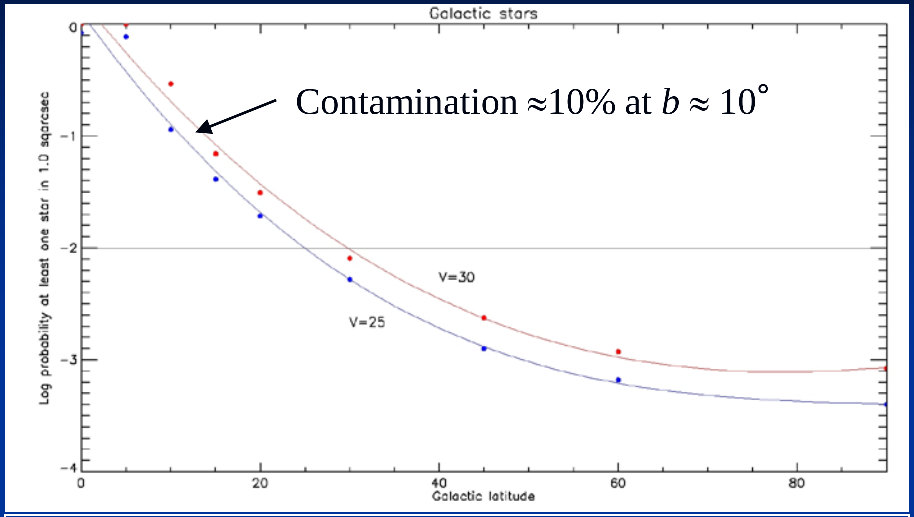


1 arcmin^2 field from the Hubble XFD Extreme Deep Field (Illingworth et al. 2013).

Galactic Stars



Galactic Stars



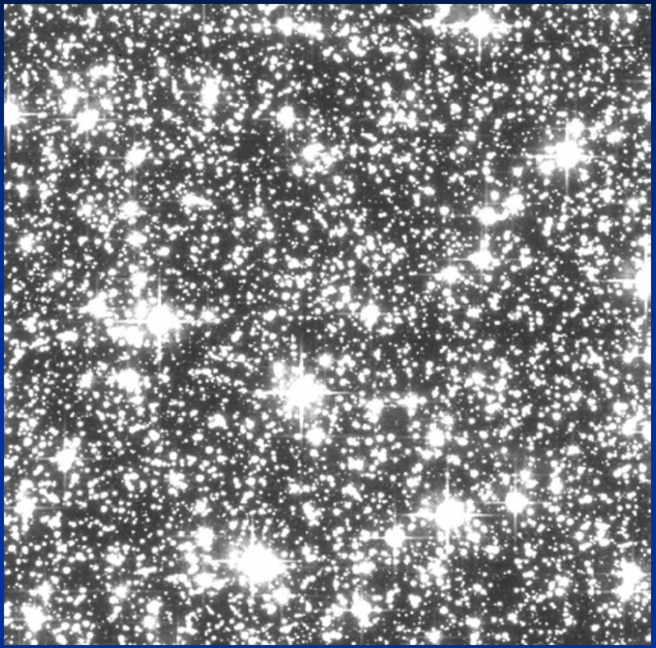
Probabilities derived from:
Besançon model of the Galaxy l= 0° http://model.obs-besancon.fr

For Galactic latitudes above 30° (or below -30°) the probability of a contamination by a galactic star is less than 1%

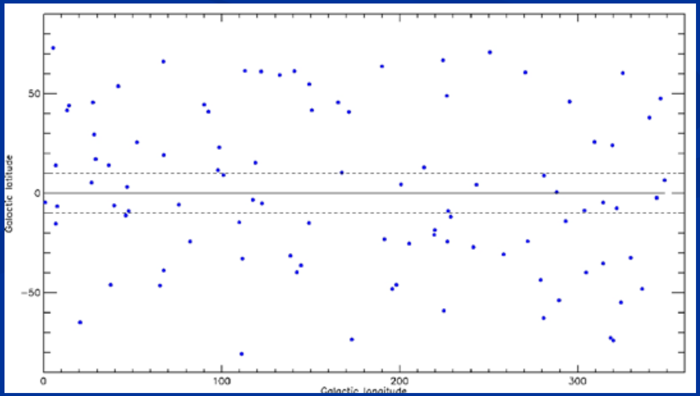
However, at all galactic latitudes, the probability remains greater than 10^{-3}

Within 10° of the galactic plane, the probability of finding a Galactic star in 1 $arcsec^2$ is >10%.

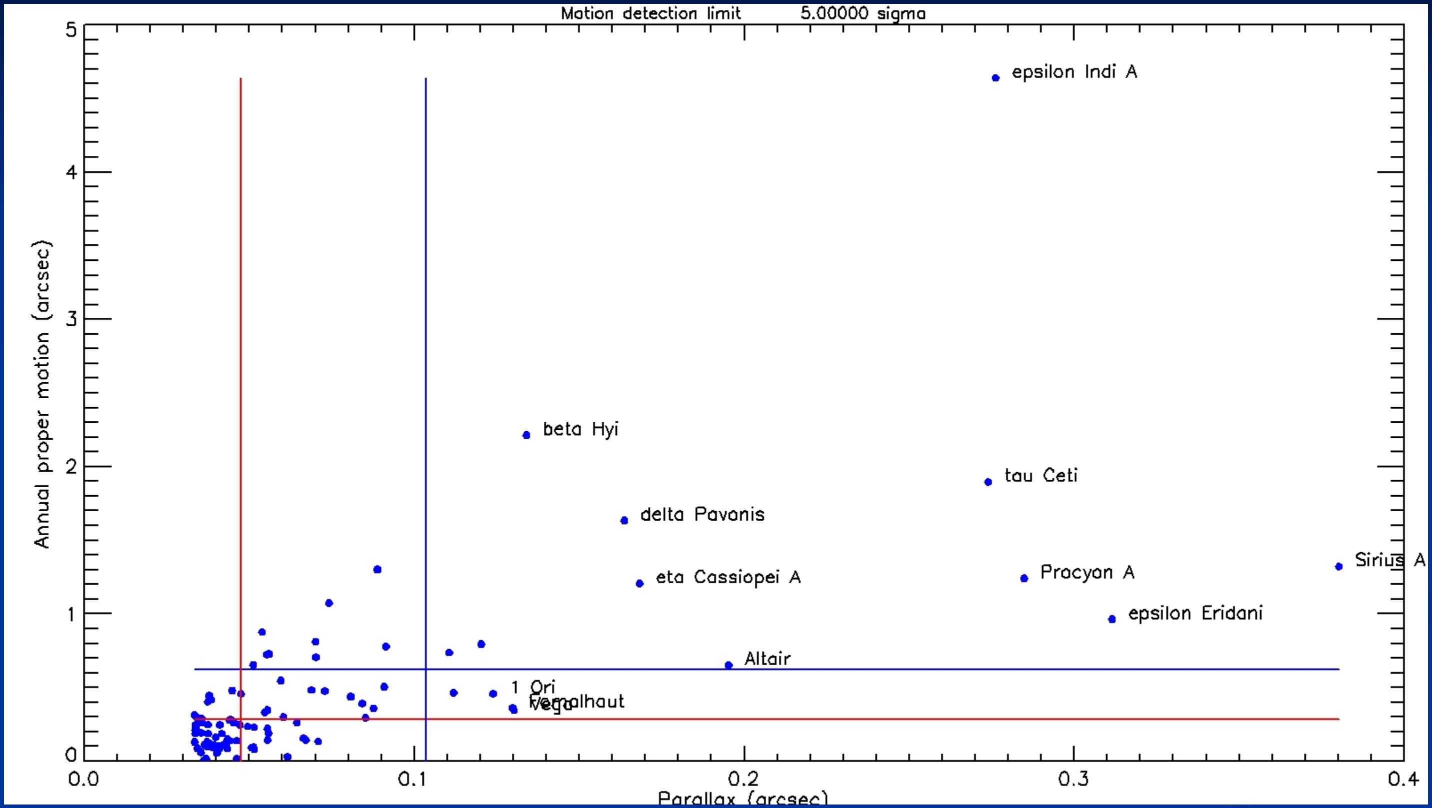
Almost one third, 26/96, of the Rendezvous target sample is within 10° of the galactic plane



ACS image (one orbit) 50×50 arcsec from SWEEPS Galactic bulge field, Sahu et al (2006) near the Galactic Center



Mitigation: in motion, sooner rather than later



Red lines: Rendezvous (WFIRST+starshade): limit after one month

Blue lines:
1-m Exo-S

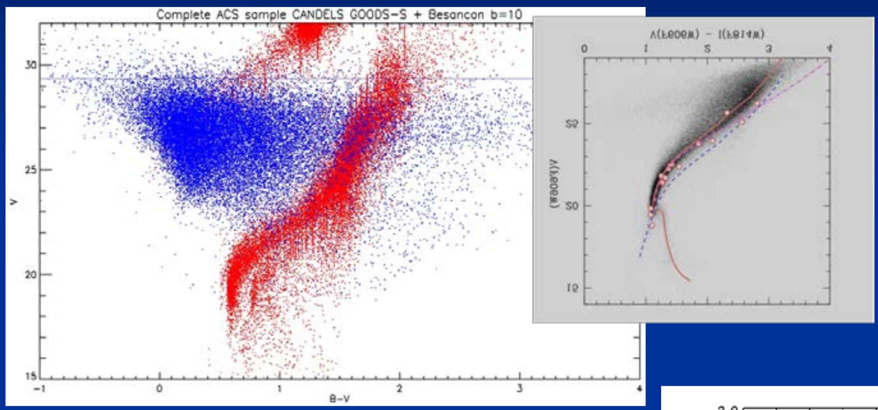
Proper motion: Proper motion can discriminate between planets and background objects for ***all*** in sampe after a year.
Parallax: about half the sample have easily measured parallax (~1-6 month but may not be compatible with mission constraints)

Orbital motion: Earth analog potentially detectable to 20 pc in 1 month (30° orbital longitude change). A significant but unknown, number of planets are likely to exhibit detectable orbital motion within a month.

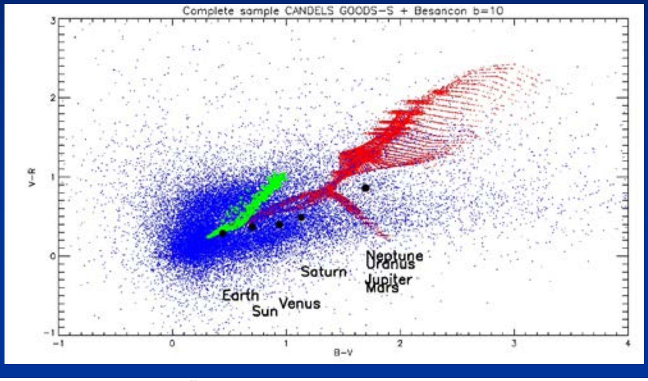
For the majority of the highest priority targets, confirmation of a planet candidate can be done after a month or less using either common proper motion, parallax, or both

Mitigation: photometric

Colour-magnitude (B-V) & V



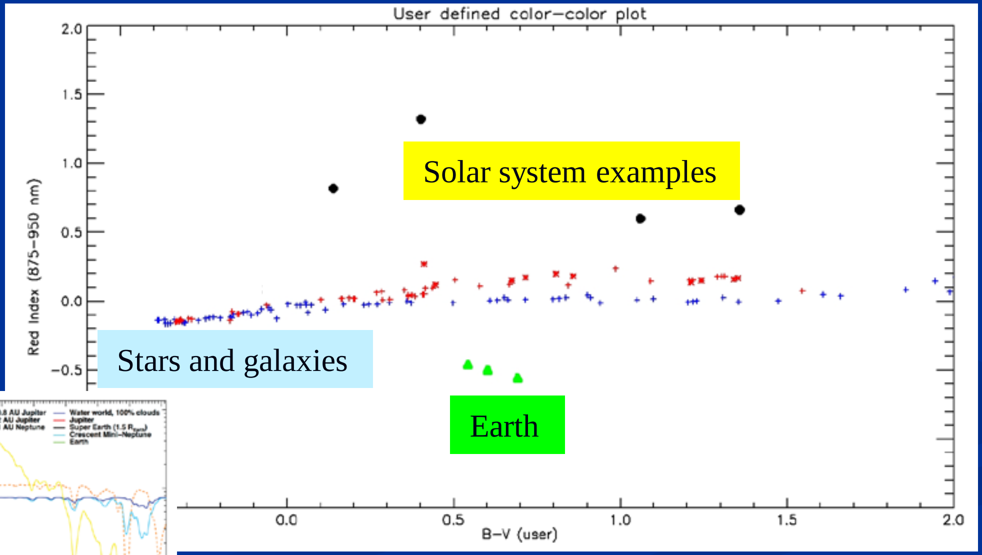
Colour-colour (B-V) & (V-R)



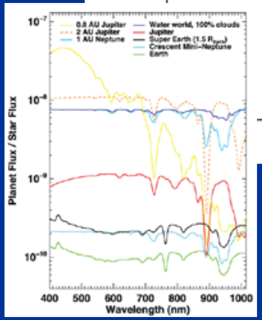
Stars red, galaxies blue

Earth (green), colours change due to diurnal rotation, cloud, phase

> >Planets are unremarkable in conventional colour/magnitude systems



IFU allows post-facto definition of photometric bandpasses



Post-facto colour indices (example): (450–625) vs (875–950): ***clean separation of planets***

Besançon model of the Galaxy *l*= 0° *b*=10°; s
http://model.obs-besancon.fr/
CANDELS GOODS-S extragalactic source

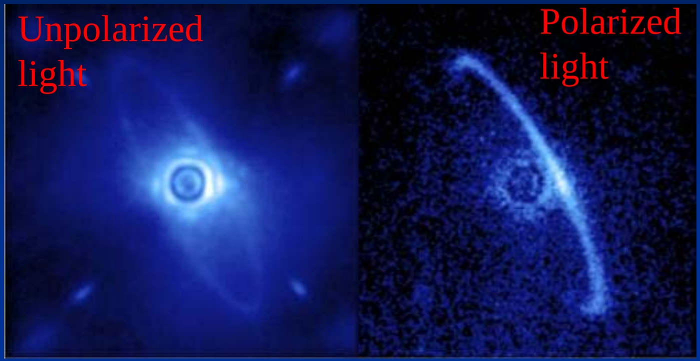
Mitigation: polarimetric

Planets shining by scattered light of host star are expected to be polarized – few to tens %

- The density of background polarized sources is not known, but certainly much lower than the density of all background sources. P.A.within 5° of tangent vector, reduces additional 18×
- Uncertainty on polarization % scales with the SNR, uncertainty on P.A. scales with product of polarization and SNR (Miller, Robinson & Goodrich 1987)
- P.A. uncertainty 10°, requires 3σ detection of polarization degree leading to source 4–8 × brighter than faintest detection (assuming 5σ flux detection limit).

*Hence polarimetry candidate detection (PDI) & identification can be applied to planets which are modestly brighter than the faintest detectable**

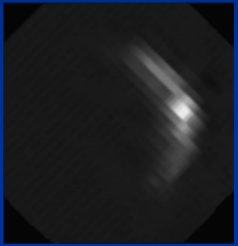
*For polarimetric detection the entire spectrum can be used; hence improvement by about a factor 2 in favorable circumstances



Advantages of including polarization spectroscopy

Mission design:

- Wavefront correction
- ***Detection - differential method, PDI***
- ***Identification of candidates without revisit***
- ***Geometry - exozodi disks***
- ***Characterization***



Beware! polarization affecting appearance of spectrum

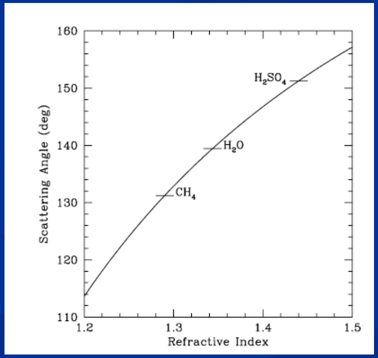
everything is scattered light, could be polarized ~50%

Characterization includes:

- Rayleigh scattering in atmosphere
- Surfaces, ices, rock, oceans, cirrus, clouds
  - Stam 2008; Zugger et al 2010 – terrestrial; Kolokolova 2010 – ices show glints
  - Seager 2000; Stam et al 2004; Marley & Sengupta 2011 – giant planets

Remote sensing of **liquids**

- Specular reflection from **oceans**; glint. Max P% Brewster's angle.
  - For Earth, brightness significant near crescent (Robinson et al 2011, 2014)
  - Cloud-free ***ocean world, glint dominates***, high P% (Williams & Gaidos 2008).
- **Rainbows**; aerosols; clouds
  - Classic Venus analysis, sulfuric acid rainbow Hansen & Hovenier 1974
  - See also Bailey 2007; Karalidi et al 2011



Peak rainbow phase angle versus refractive index (Bailey 2007)

A simple strategy: accept what is there

Observe for a predetermined integration time

- *useful S/N* on Earth twin => ***large aperture telescope***

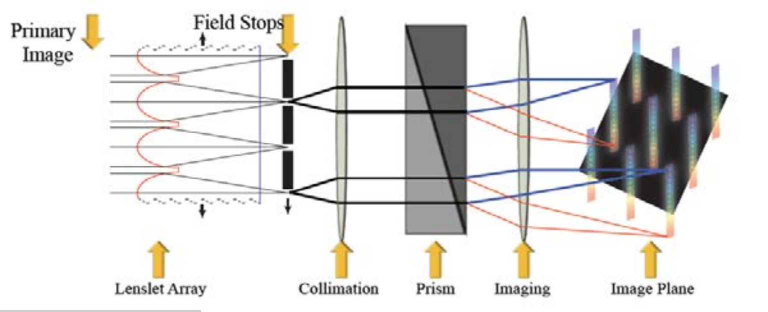
High contrast suppression system (coronagraph or starshade) with:

Integral Field Spectrograph

- ***Spectra of all sources in field***
  - ***no concerns over "choosing", or acquisition, multiple systems the norm***
- ***Post-facto band definition/PCA***
- ***Speckle discrimination (some architectures)***

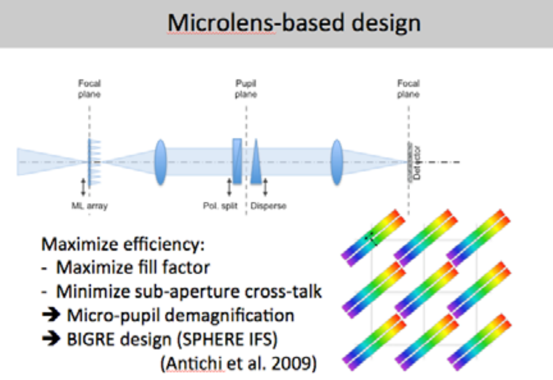
include polarization capability

- ***Detection***
- ***Identification***
- ***Geometry***
- ***Additional characterization***



Simple option:

- ***Just observe every target star for predetermined time - unbiassed inventory of local planetary demographics***
- ***Revisit most interesting***



Examples: above Kasdin et al
left: Rodenhuis (2011) in Polarimetry with Extremely Large Telescopes

Conclusions

- The problem and probabilities
  - Galactic
  - Extragalactic
- Solutions:
  - Proper motion, parallax, orbital motion
  - Post facto spectroscopy/photometry/PCA
  - Polarimetry
- Instrumentation can affect mission design
  - IFU, polarimetry
    - Take inventory of local neighborhood
  - Lets not skimp on the instrumentation
    - ***Do we really need 10^{-10} suppression?***
- Need photons, S/N – large telescope – to do it right: identification, photometry, spectroscopy, timing, polarimetry

- *Advert: HST GO/AR-14320 Characterizing the Galactic and Extragalactic Background of Exoplanet Direct Imaging Targets P.I. M. Turnbull*