Direct Imaging of Alpha Centauri A and B with the Gemini Planet Imager

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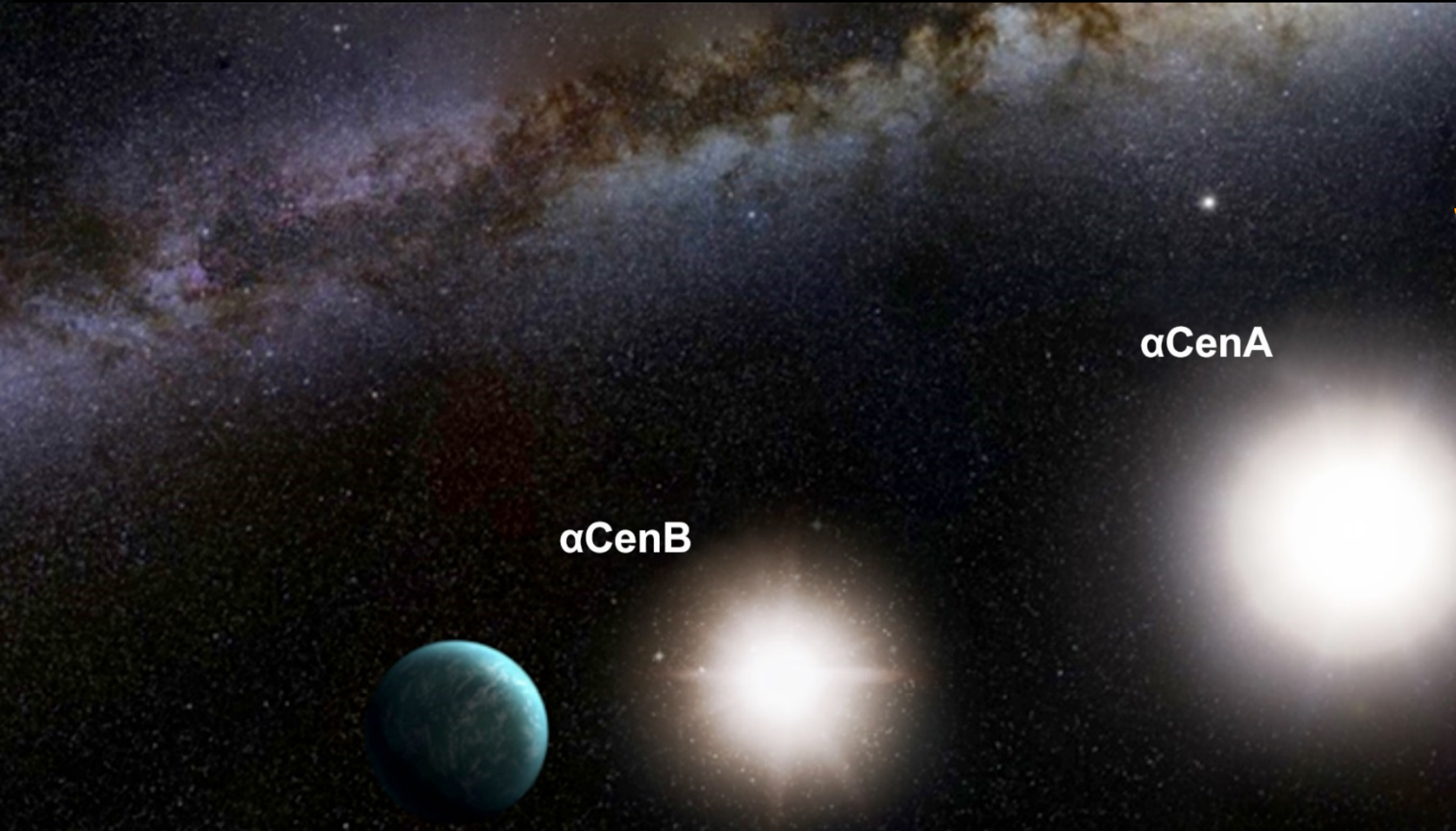
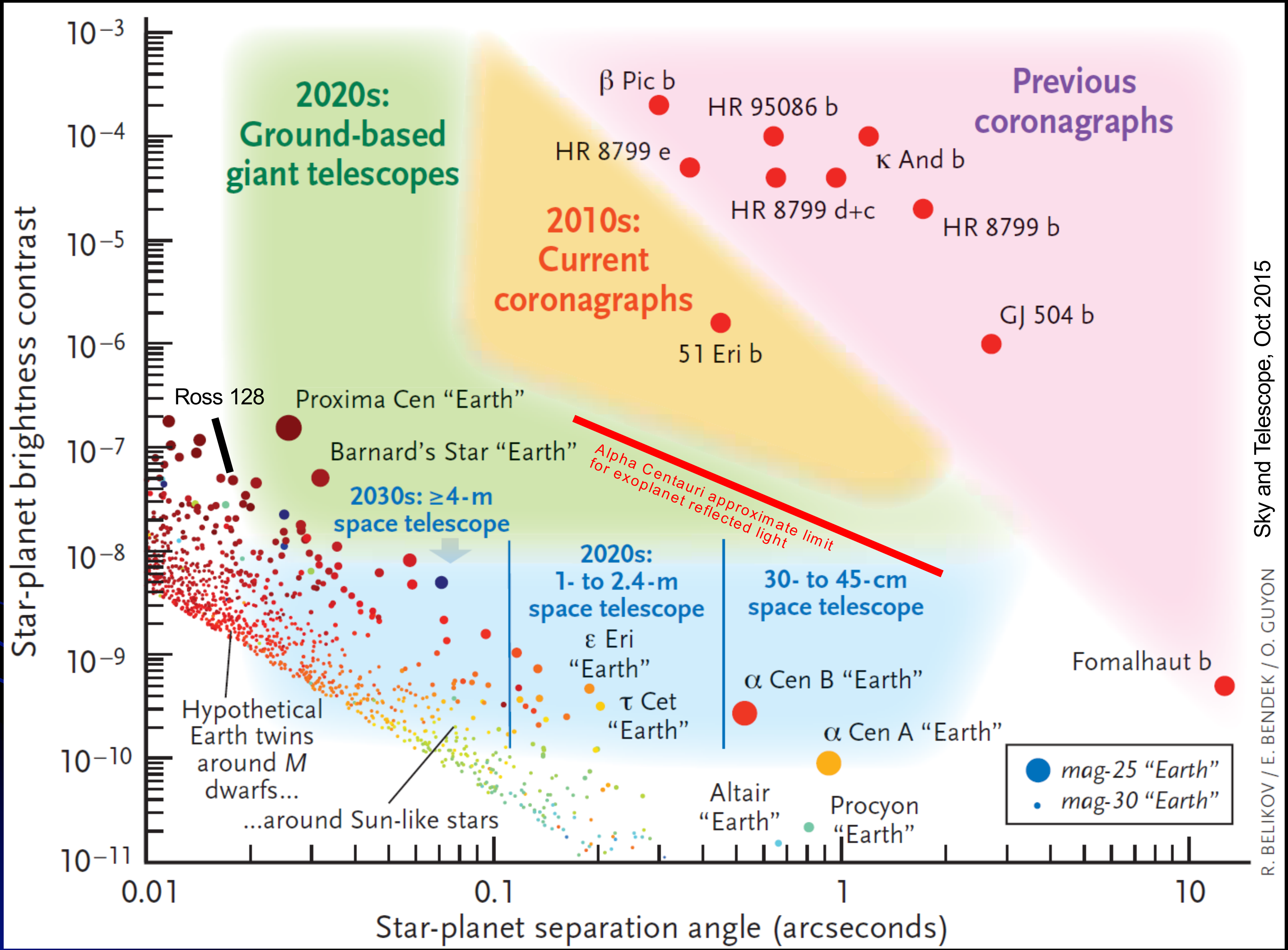
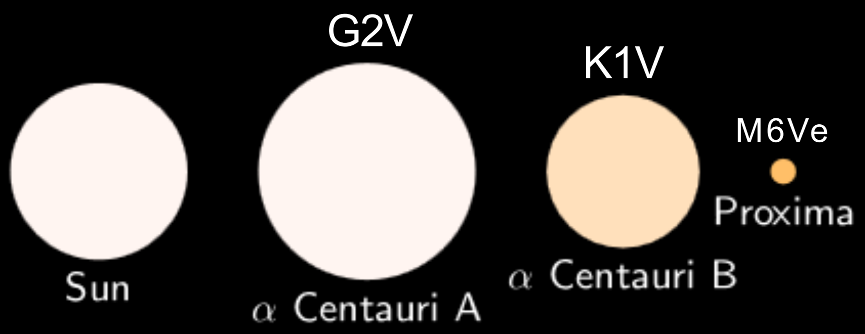


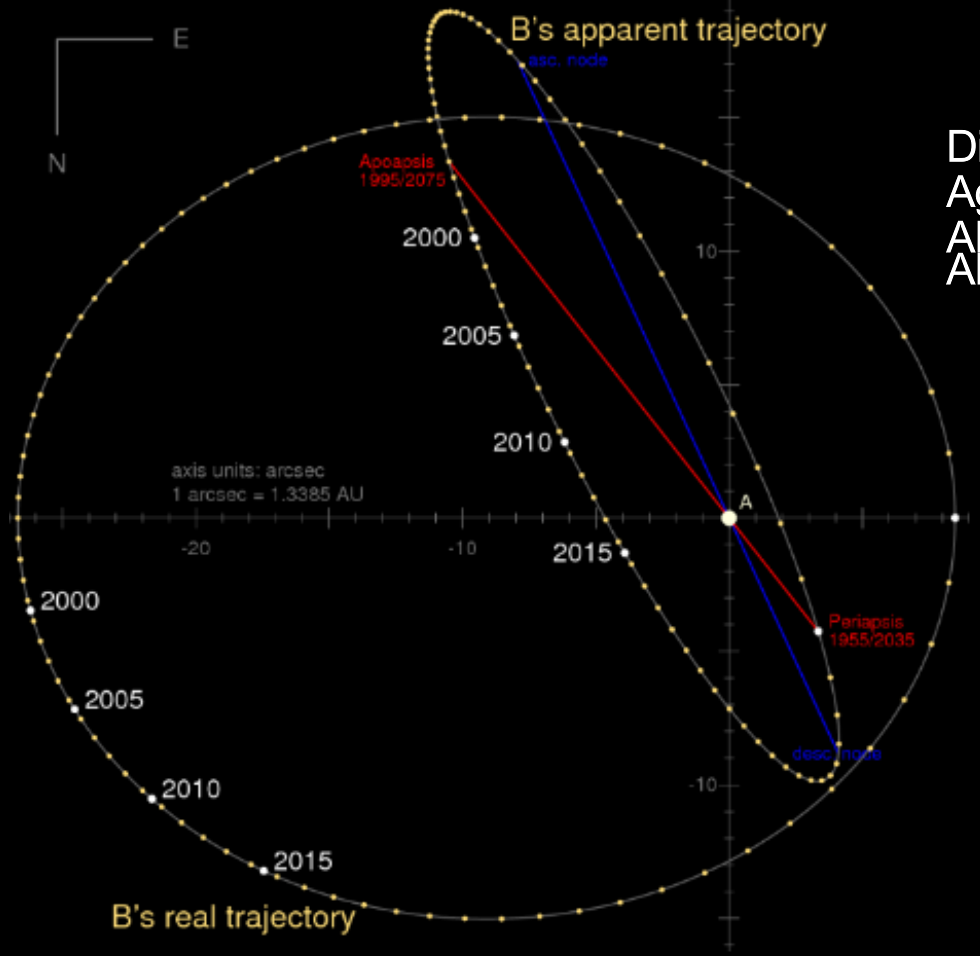
Science and Evolution of Gemini Observatory, San Francisco, 7/23/2018



Star-planet brightness contrast
Star-planet separation angle (arcseconds)
2020s: Ground-based giant telescopes
2010s: Current coronagraphs
Previous coronagraphs
2030s: ≥4-m space telescope
2020s: 1- to 2.4-m space telescope
30- to 45-cm space telescope
β Pic b
HR 95086 b
HR 8799 e
κ And b
HR 8799 d+c
HR 8799 b
GJ 504 b
51 Eri b
Ross 128
Proxima Cen "Earth"
Barnard's Star "Earth"
Alpha Centauri approximate limit for exoplanet reflected light
ε Eri "Earth"
τ Cet "Earth"
α Cen B "Earth"
α Cen A "Earth"
Fomalhaut b
Altair "Earth"
Procyon "Earth"
Hypothetical Earth twins around M dwarfs...
...around Sun-like stars
mag-25 "Earth"
mag-30 "Earth"
Sky and Telescope, Oct 2015
R. BELIKOV / E. BENDEK / O. GUYON

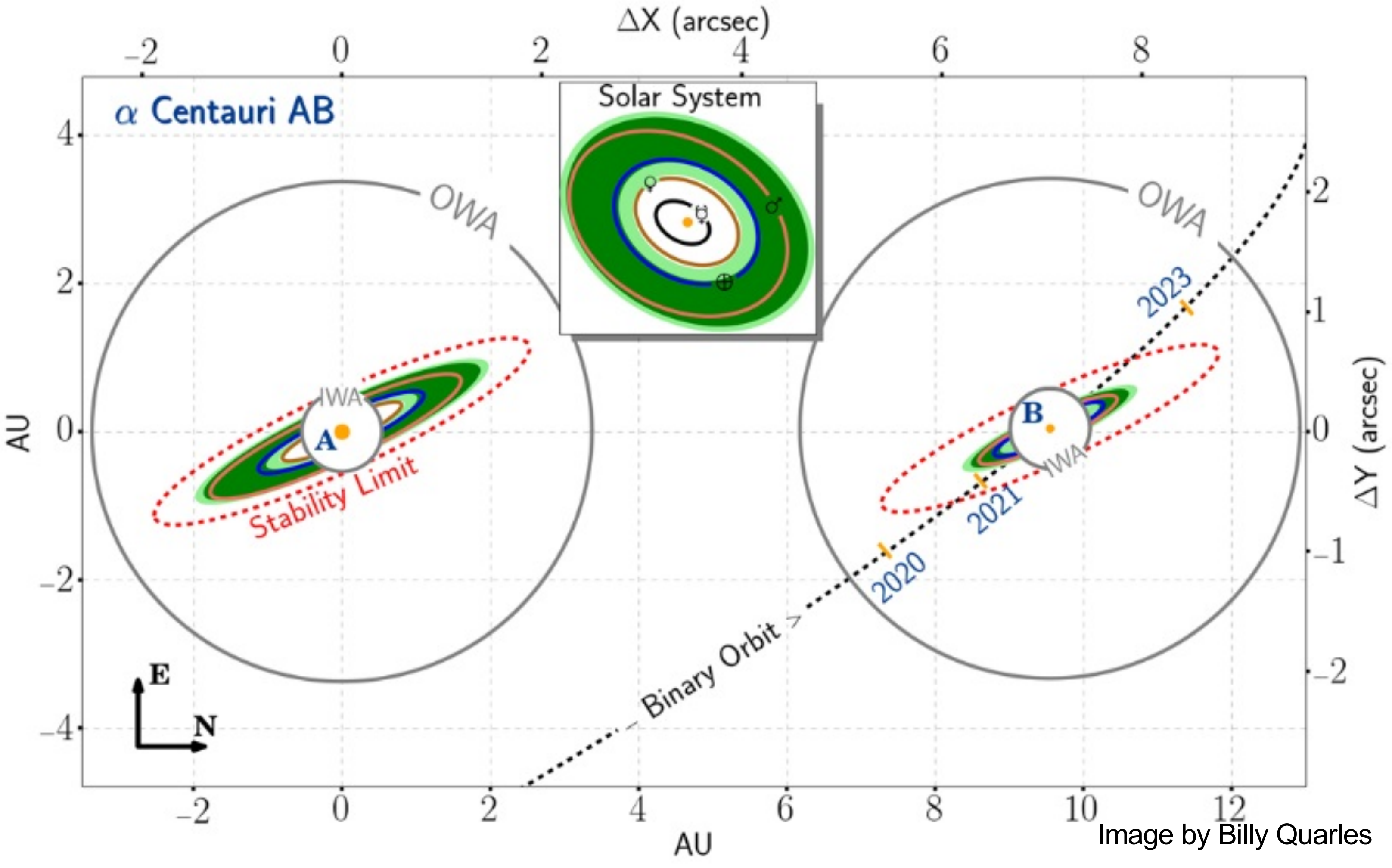
α Cen System Overview





Distance: 1.3pc
Age: ~4.5 – 7 Gy
AB Period: 79.91y
AB SMA: 17.57 AU

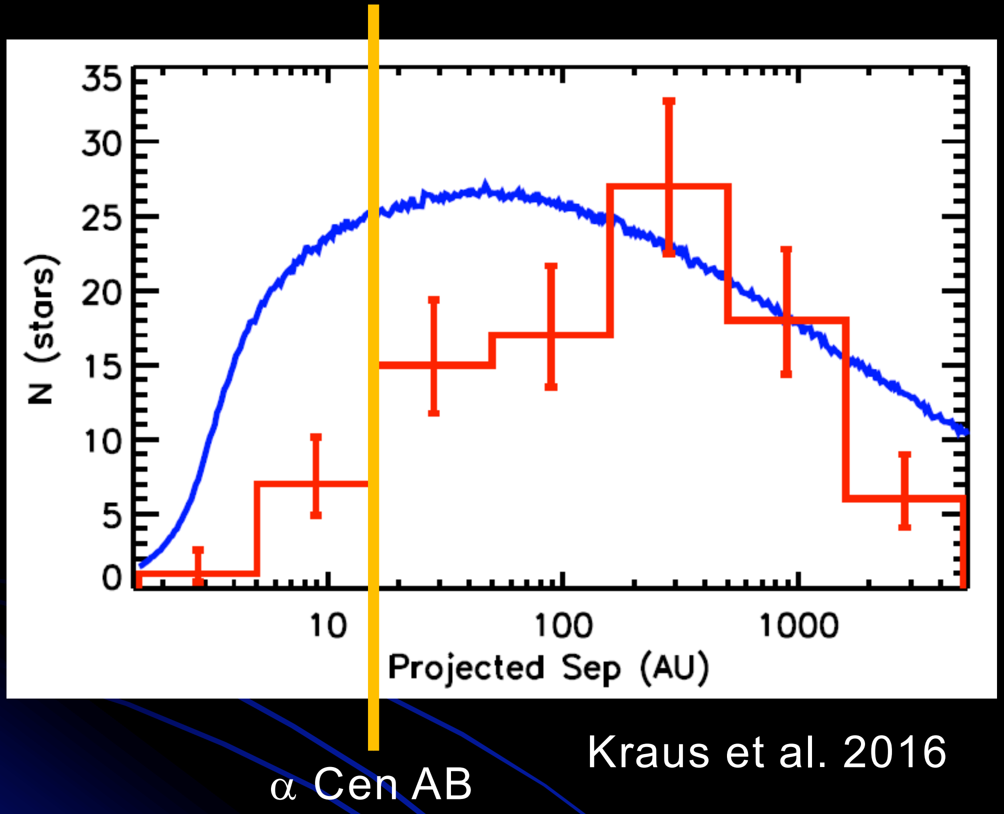
Habitable Zones of αCen AB



see Quarles and Lissauer 2016 for aCen stability
https://arxiv.org/abs/1604.04917

- Both HZs are fully accessible with a 0.4” (0.5AU) inner working angle (IWA)
- Orbits are stable out to ~ 2.5 AU (Holman & Wiegert 1999, Quarles and Lissauer 2016)

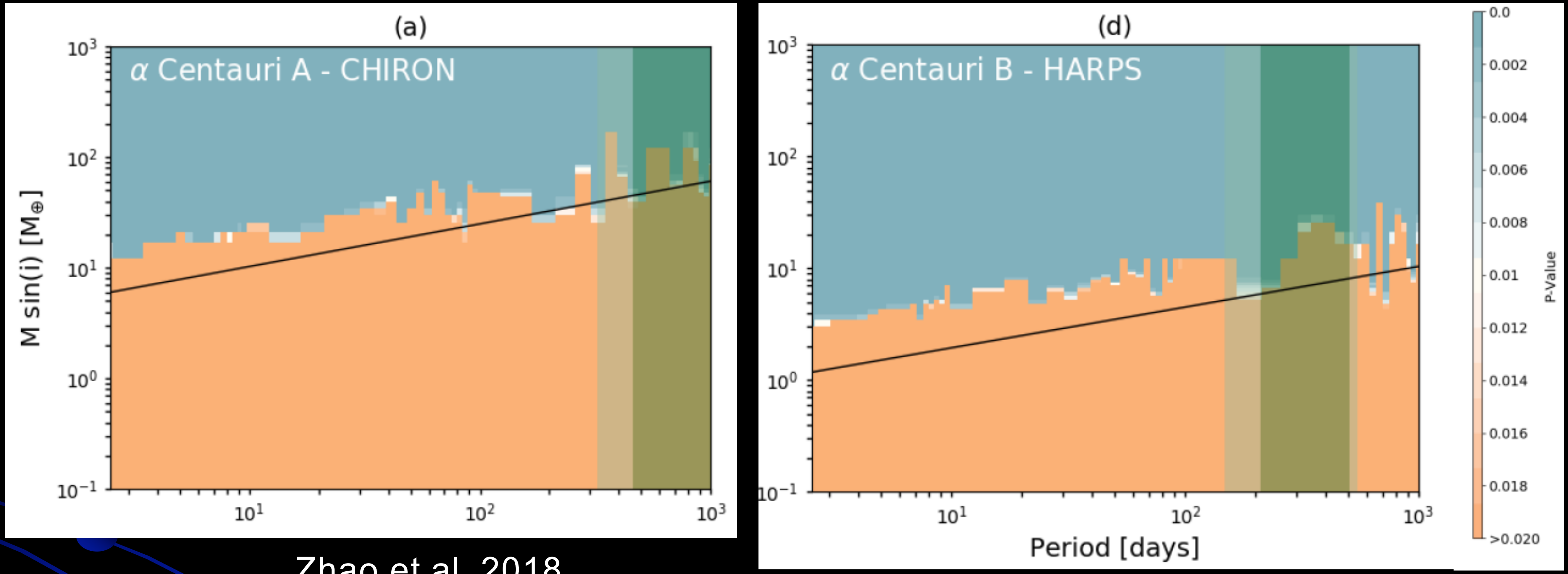
Effects of binarity on planet occurrence



Kraus et al. 2016

- Kepler space telescope has detected planets around binaries (with separations comparable to Alpha Centauri)
- Kraus et al. 2016 suggests planet formation around binaries with SMA < 47^{+59}_{-23} is suppressed by a factor of $0.34^{+0.14}_{-0.15}$
- However, Matson et al. 2018 “do not see evidence of companion suppression”

m sin(i) limits from RV non-detections



Zhao et al. 2018

- Limits for habitable zone (p-value = 0.01)
  - 53 M_Earth (0.17M_Jup) for aCen A
  - 8.4 M_Earth (0.026M_Jup) for aCen B
  - (For reference, Neptune mass: ~17 Earths)

Do RV mass constraints impose a strong radius constraint?

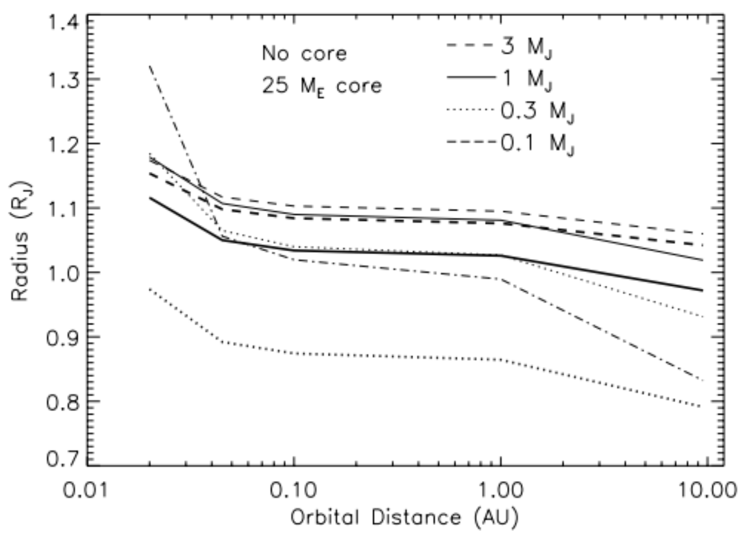


FIG. 6.—Planetary radii at 4.5 Gyr as a function of orbital distance from the Sun. Models are calculated at 0.02, 0.045, 0.1, 1.0, and 9.5 AU. Masses are 0.1, 0.3, 1.0, and 3.0 M_J. Coreless planets (*thin lines*) and planets with a core of 25 $M_\oplus$ of heavy elements (*thick lines*) are shown. Note the shape of these radius curves and the flattening between 0.1 and 1.0 AU. The 0.1 M_J planet with a 25 $M_\oplus$ core is off the plot at ~0.5 R_J.

Fortney et al. 2007.

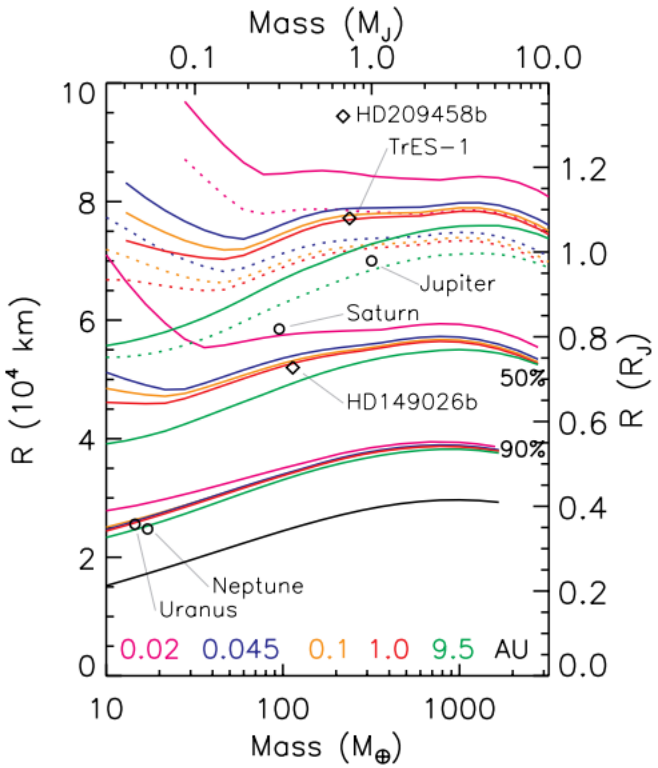
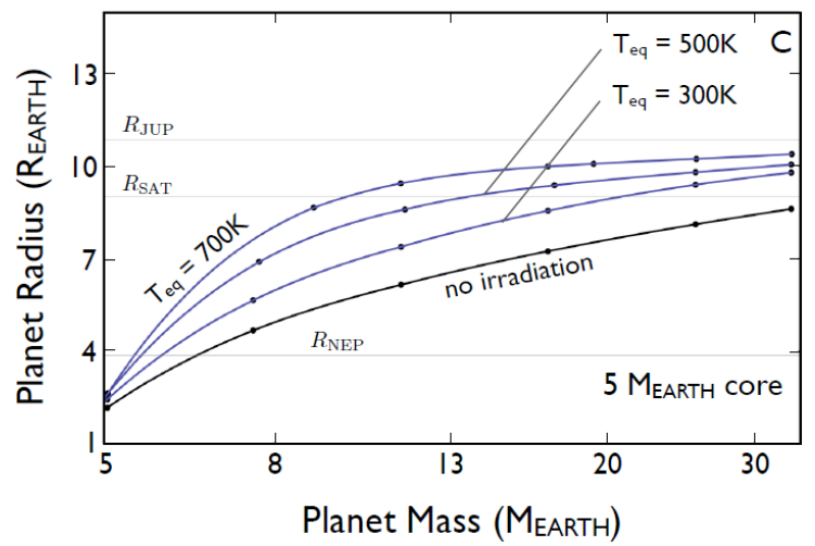


FIG. 7.—Planetary radii at 4.5 Gyr as a function of mass. Models are calculated at 0.02, 0.045, 0.1, 1.0, and 9.5 AU and are color coded at the bottom of the plot. The black curve is for a heavy element planet of half ice and half rock. The group of five colored curves above the black curve is for planets that are 90% heavy elements. The next higher set of five colored curves are for planets that are 50% heavy elements. The next higher set, shown in dotted lines, are 10% heavy elements. The highest set are for core-free planets of pure H/He. The open circles are solar system planets and the diamonds are extrasolar planets.



Batygin & Stevenson (2013). Mass-Radius relationship for a low-mass, gas-dominated planetary model (for a 5 MEarth core).

8 M_Earth planets at 1AU can still have radius comparable to Jupiter

What do we know about aCen exozodi?

How dusty is α Centauri? ⋆ ⋆⋆

Excess or non-excess over the infrared photospheres of main-sequence stars

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(Affiliations can be found after the references)

Recieved ... / Accepted ...

ABSTRACT

Context. Debris discs around main-sequence stars indicate the presence of larger rocky bodies. The components of the nearby, solar-type binary α Centauri have higher than solar metallicities, which is thought to promote giant planet formation.
Aims. We aim to determine the level of emission from debris around the stars in the α Cen system. This requires knowledge of their photospheres. Having already detected the temperature minimum, $T_{\rm min}$, of α Cen A at far-infrared wavelengths, we here attempt to do so also for the more active companion α Cen B. Using the α Cen stars as templates, we study possible effects $T_{\rm min}$ may have on the detectability of unresolved dust discs around other stars.
Methods. We use *Herschel*-PACS, *Herschel*-SPIRE, and APEX-LABOCA photometry to determine the stellar spectral energy distributions in the far infrared and submillimetre. In addition, we use APEX-SHeFI observations for spectral line mapping to study the complex background around α Cen seen in the photometric images. Models of stellar atmospheres and of particulate discs, based on particle simulations and in conjunction with radiative transfer calculations, are used to estimate the amount of debris around these stars.
Results. For solar-type stars more distant than α Cen, a fractional dust luminosity $f_{\rm d} \equiv L_{\rm dust}/L_{\rm star} \sim 2 \times 10^{-7}$ could account for SEDs that do not exhibit the $T_{\rm min}$-effect. This is comparable to estimates of $f_{\rm d}$ for the Edgeworth-Kuiper belt of the solar system. In contrast to the far infrared, slight excesses at the $2.5\,\sigma$ level are observed at $24\,\mu$m for both α Cen A and B, which, if interpreted to be due to zodiacal-type dust emission, would correspond to $f_{\rm d} \sim (1-3) \times 10^{-5}$, i.e. some 10^2 times that of the local zodiacal cloud. Assuming simple power law size distributions of the dust grains, dynamical disc modelling leads to rough mass estimates of the putative Zodi belts around the α Cen stars, viz. $\lesssim 4 \times 10^{-6}\,M_{☾}$ of 4 to $1000\,\mu$m size grains, distributed according to $n(a) \propto a^{-3.5}$. Similarly, for filled-in $T_{\rm min}$ emission, corresponding Edgeworth-Kuiper belts could account for $\sim 10^{-3}\,M_{☾}$ of dust.
Conclusions. Our far-infrared observations lead to estimates of upper limits to the amount of circumstellar dust around the stars α Cen A and B. Light scattered and/or thermally emitted by exo-Zodi discs will have profound implications for future spectroscopic missions designed to search for biomarkers in the atmospheres of Earth-like planets. The far-infrared spectral energy distribution of α Cen B is marginally consistent with the presence of a minimum temperature region in the upper atmosphere of the star. We also show that an α Cen A-like temperature minimum may result in an erroneous apprehension about the presence of dust around other, more distant stars.

Summary of GPI aCen observations

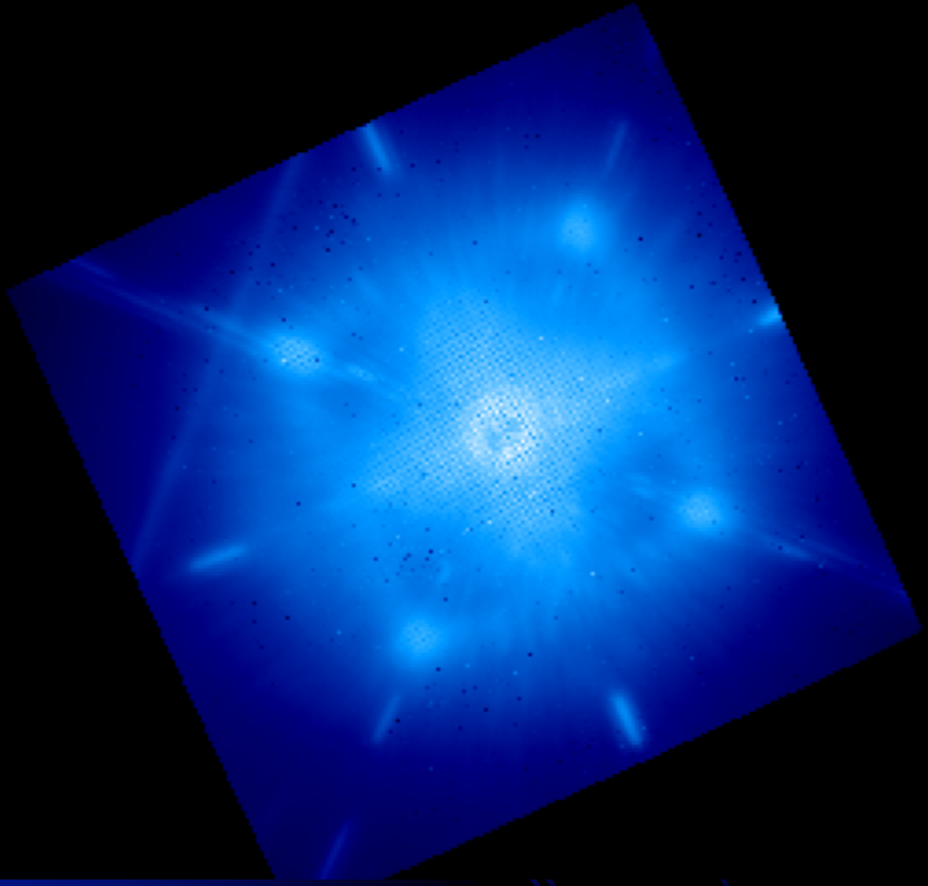
- 3/12/2018
  - GPI Wollaston (polarization mode), Y-band
  - Alpha Centauri B
  - 2:40 minutes of science (38 minutes of open shutter)

- 4/09/2018
  - GPI Wollaston (polarization mode), Y-band
  - Alpha Centauri B
  - 1:51 minutes of science (22 minutes of open shutter)

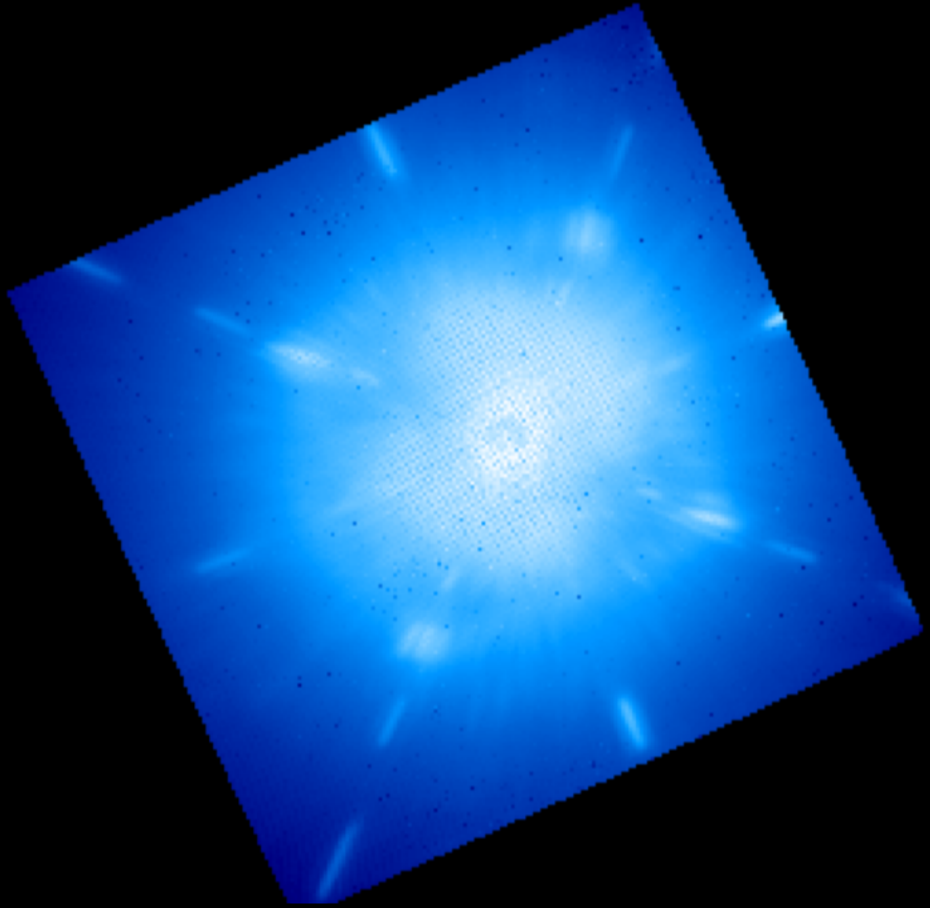
- 5/20/2018
  - GPI Coronagraph (Spectroscopy mode), Y-band
  - Alpha Centauri A
  - 1:10 minutes of science (17 minutes of open shutter)

Polarization mode raw images

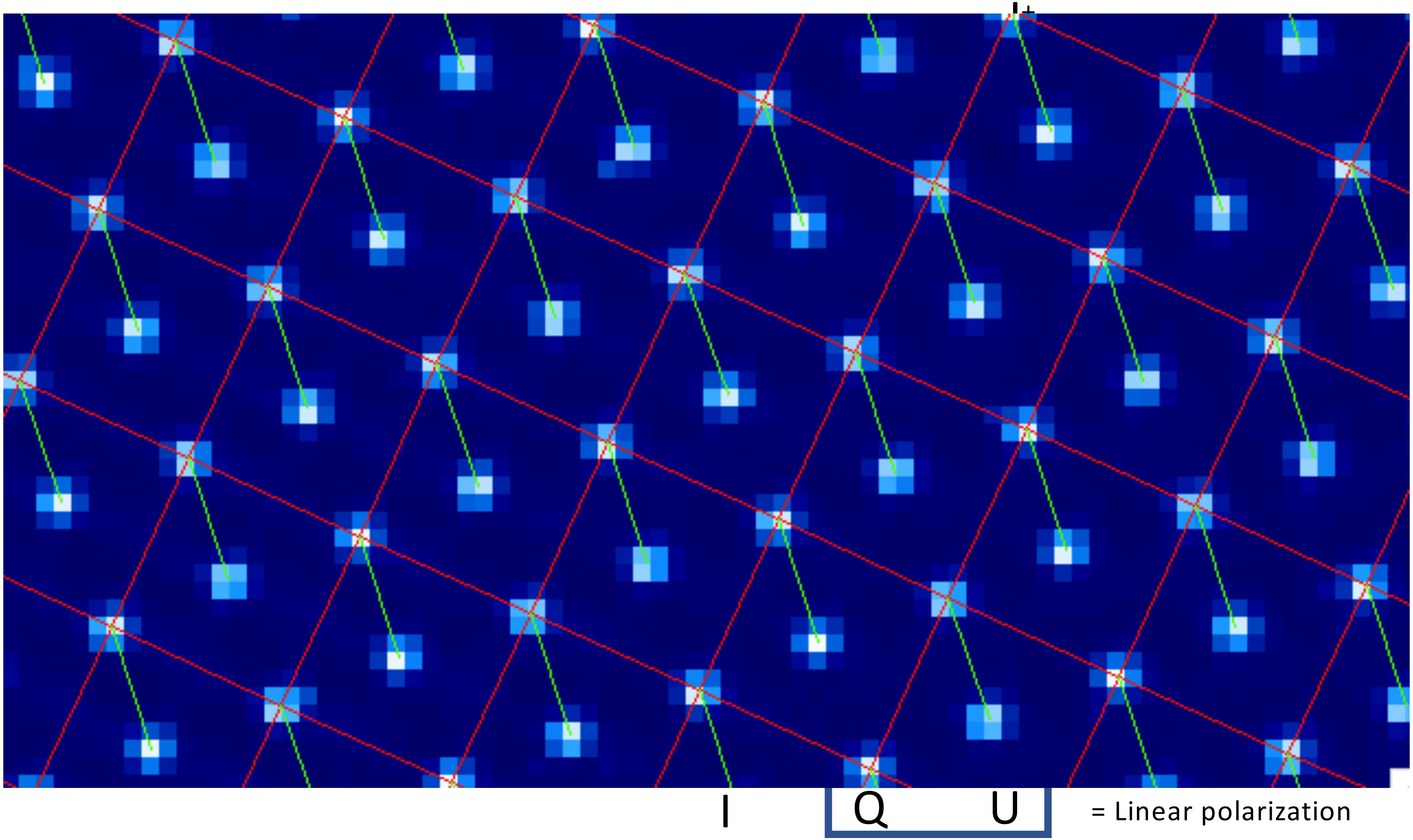
March 12, 2018



April 9, 2018

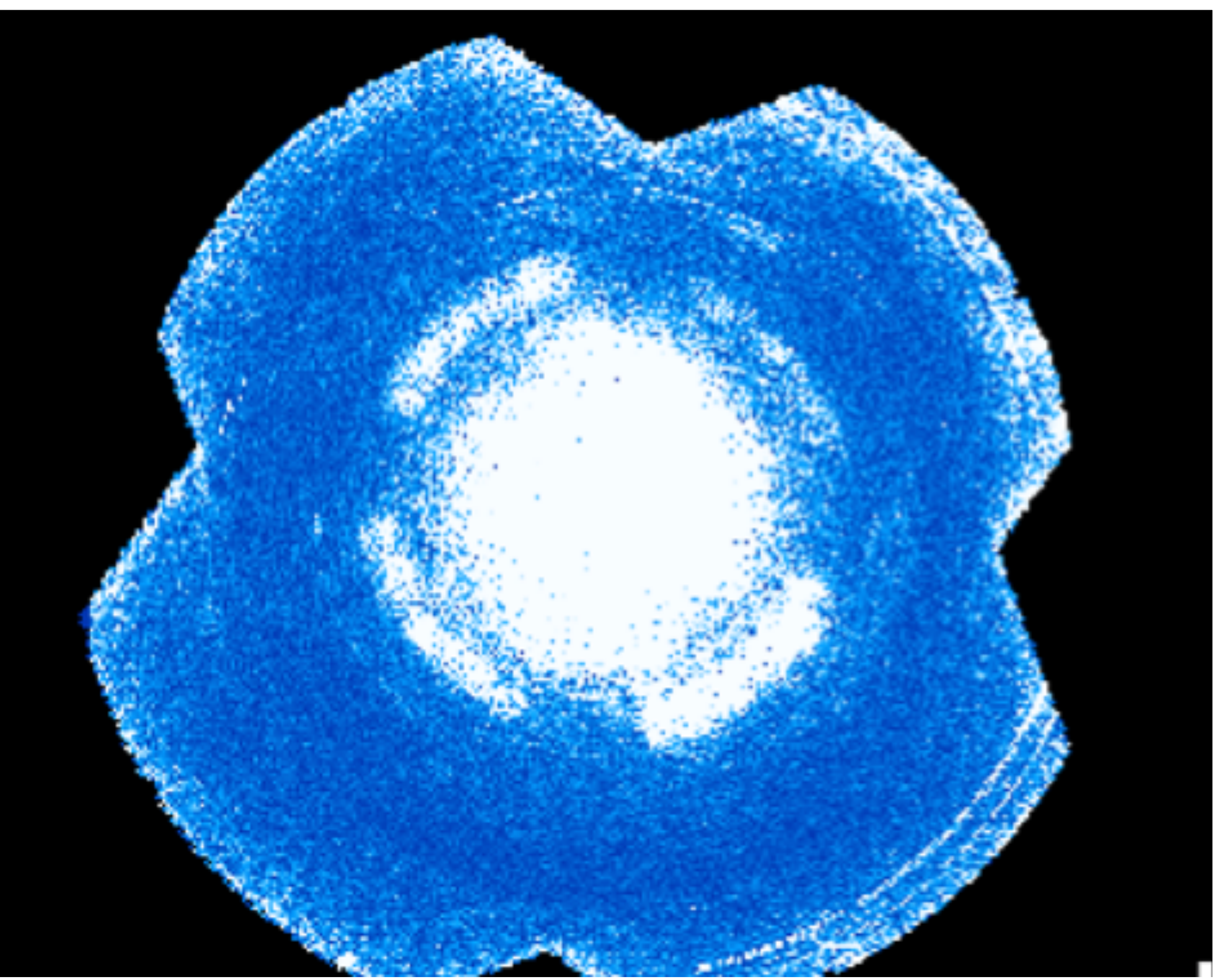


Polarimetry with GPI

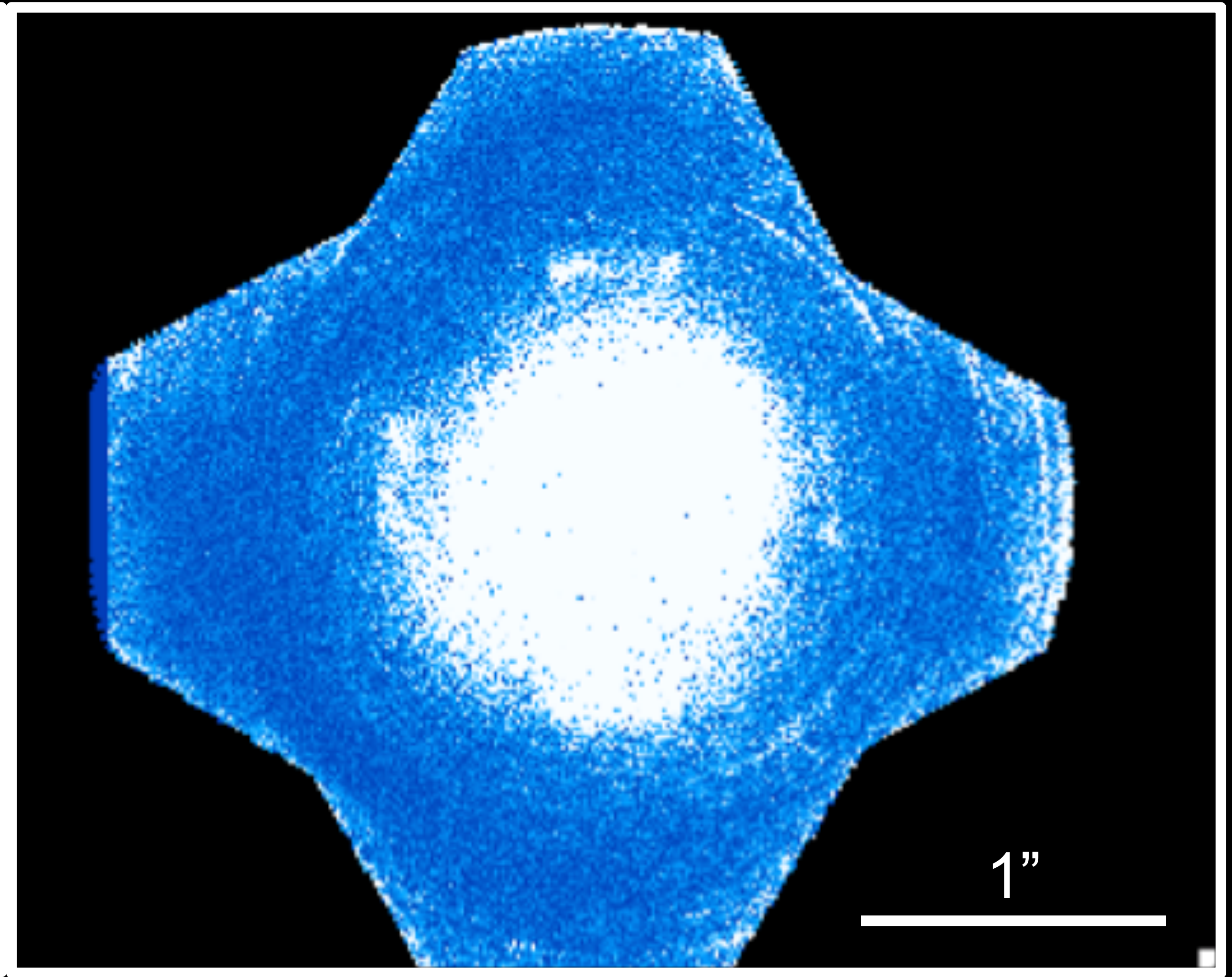


Reduced Polarization Intensity Contrast Images

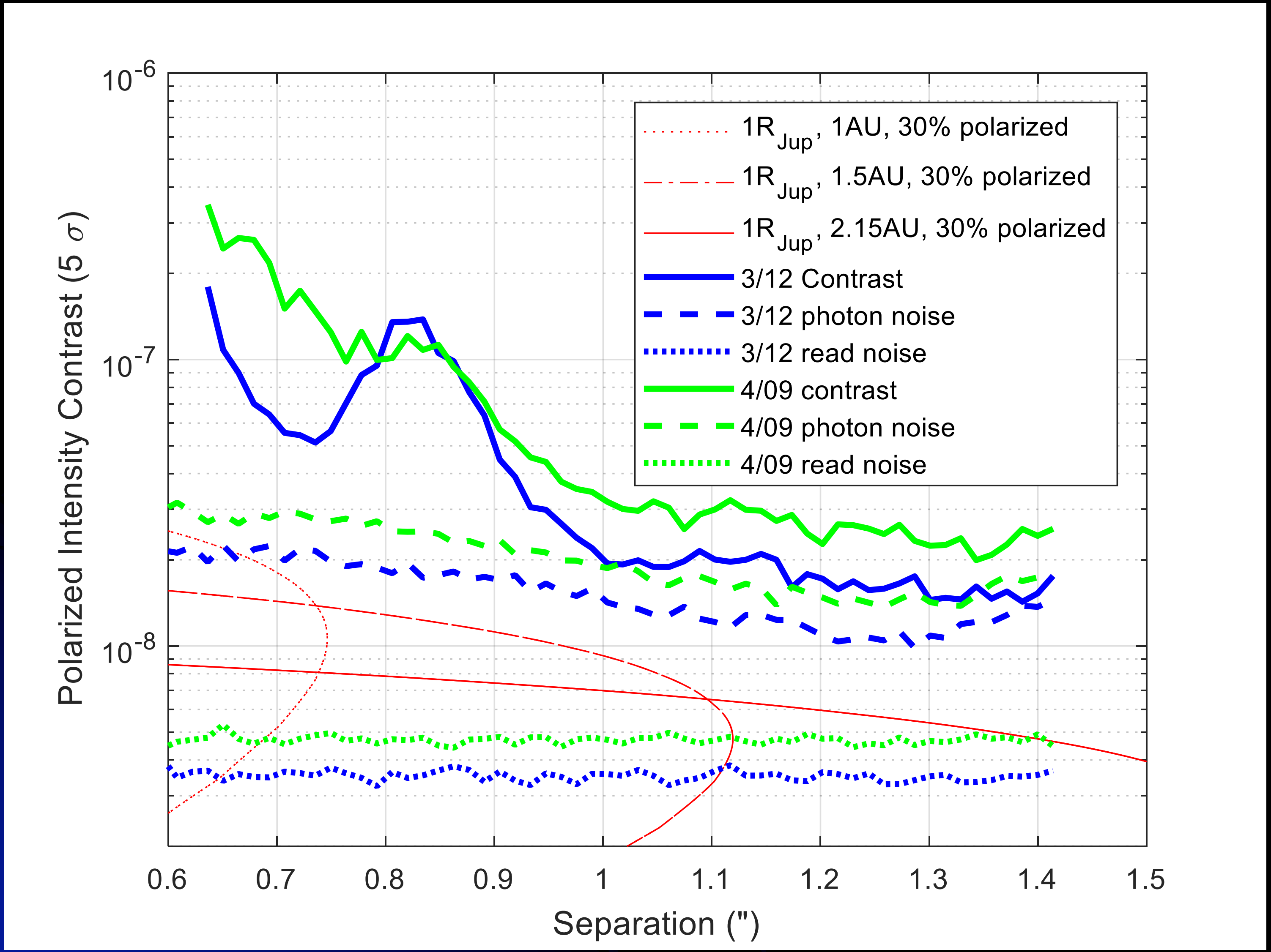
March 12, 2018



April 9, 2018



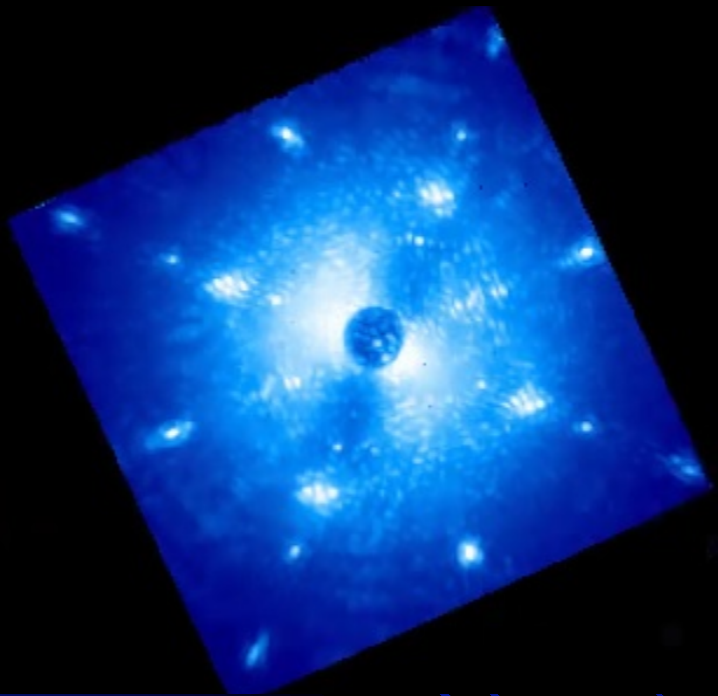
Polarization mode contrast curves (aCen B)
(analysis by Max Millar-Blanchaer)



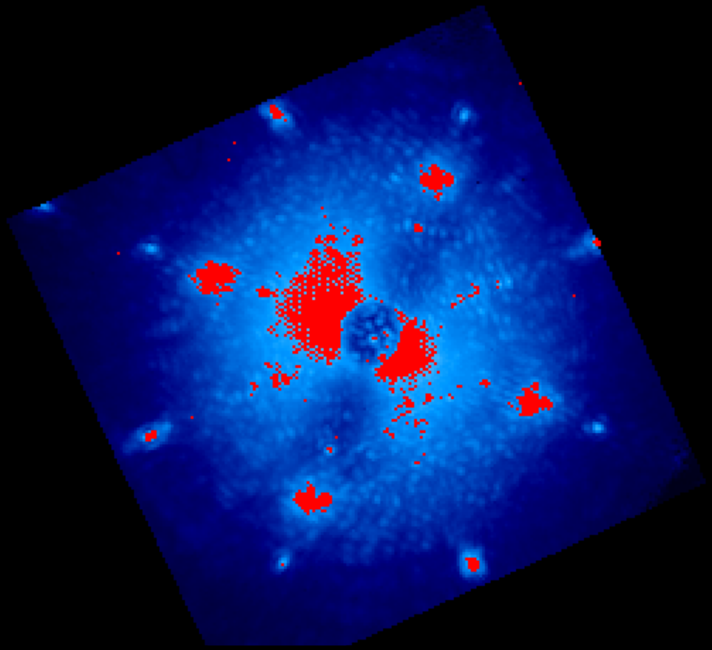
- Deepest contrast GPI achieved in pol mode
- Not yet sensitive to R_Jup planets, but can rule out very bright rings
- Contrast comparable to photon noise, which suggests we can go deeper by
  - Improving open shutter duty cycle
  - Longer observations
- Caveats:
  - Instrument curves at separations < 1" may not be accurate because of partial saturation
  - Planet models are based in part on Cahoy et al. 2010, but smaller separations are extrapolations and are possibly optimistic
  - 30% may be a bit optimistic

Spectroscopy mode raw images (aCen A)

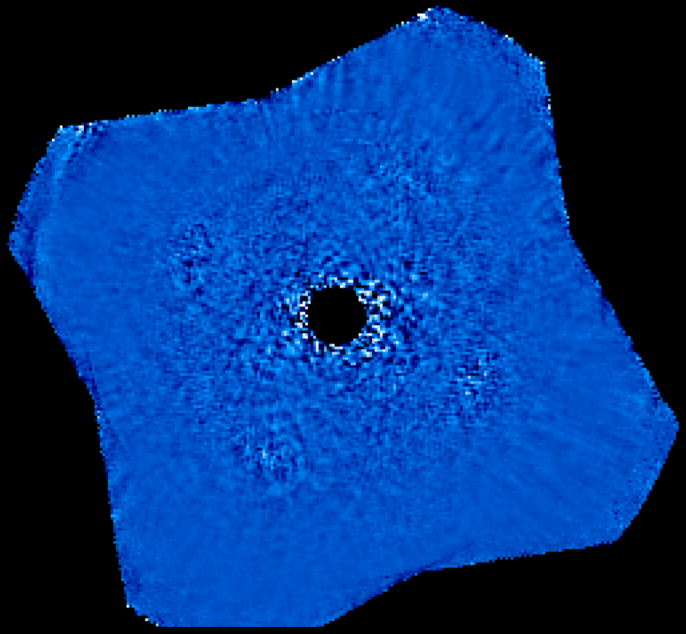
Raw image



Saturation highlighted

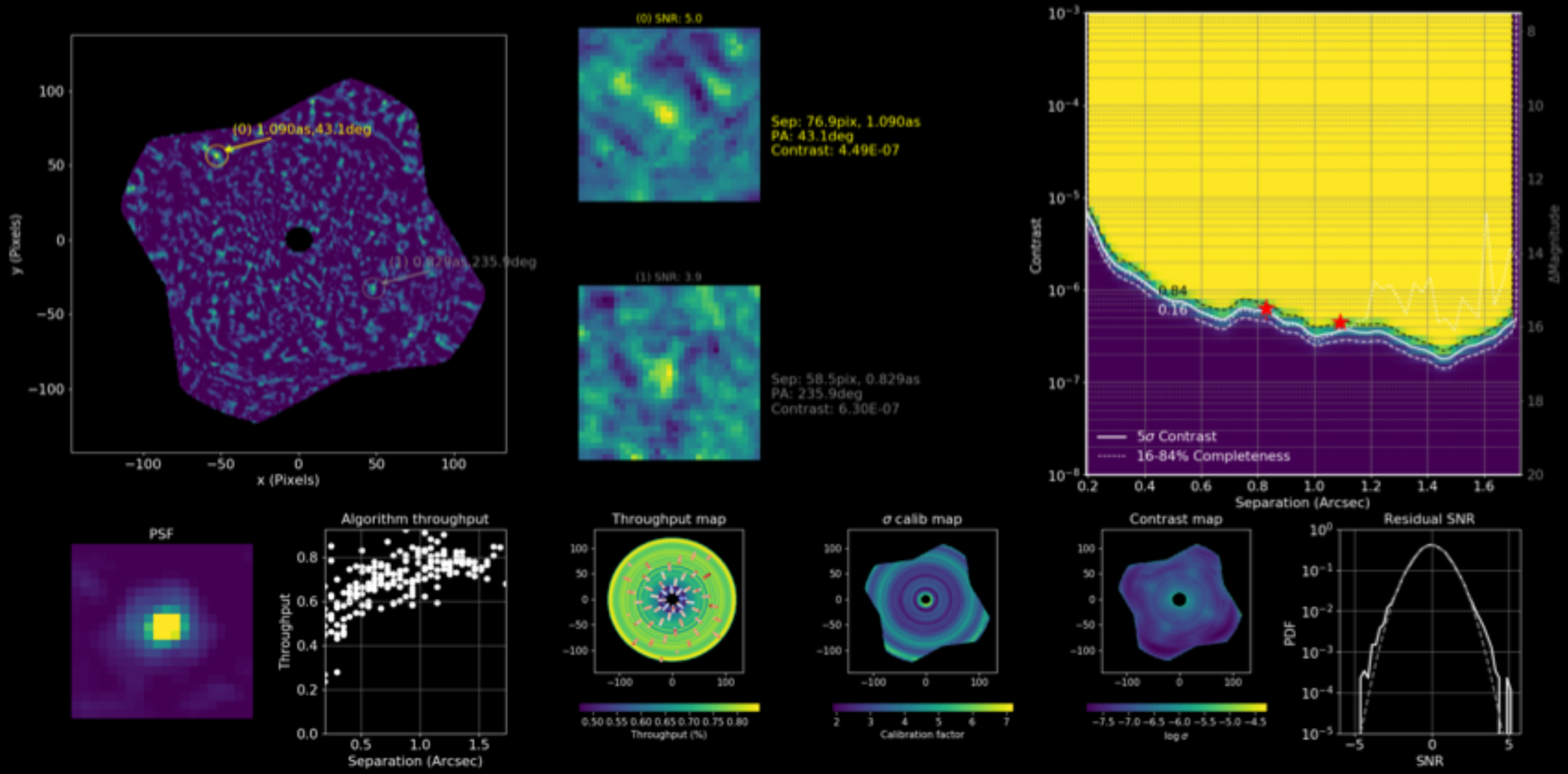


Processed



Spectroscopy mode analysis (aCen A)
(analysis by J-B Ruffio)

Alpha_Centauri_A 20180520, Filter: Y, Cubes: 32, Template: t600g100nc/t1000g100nc



Conclusions

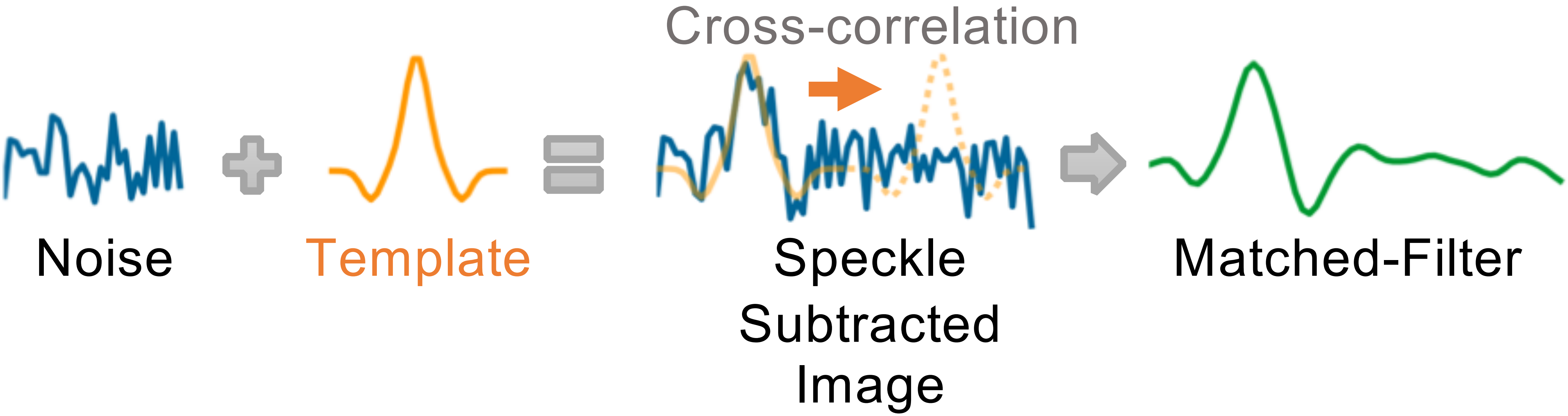
- Alpha Centauri is a particularly attractive target for direct imaging, and represents a possibility (albeit optimistic) of detecting exoplanets by reflected light with the current generation of high contrast imaging instruments

- GPI has achieved:
  - deepest pol-mode contrast to date: ~1-2e-8 between ~1 and ~1.4”, which corresponds to the vicinity around 1.5AU on Alpha Centauri B.
  - ~2e-7 contrast (spectroscopy mode) at 1.4” around Alpha Centauri A.

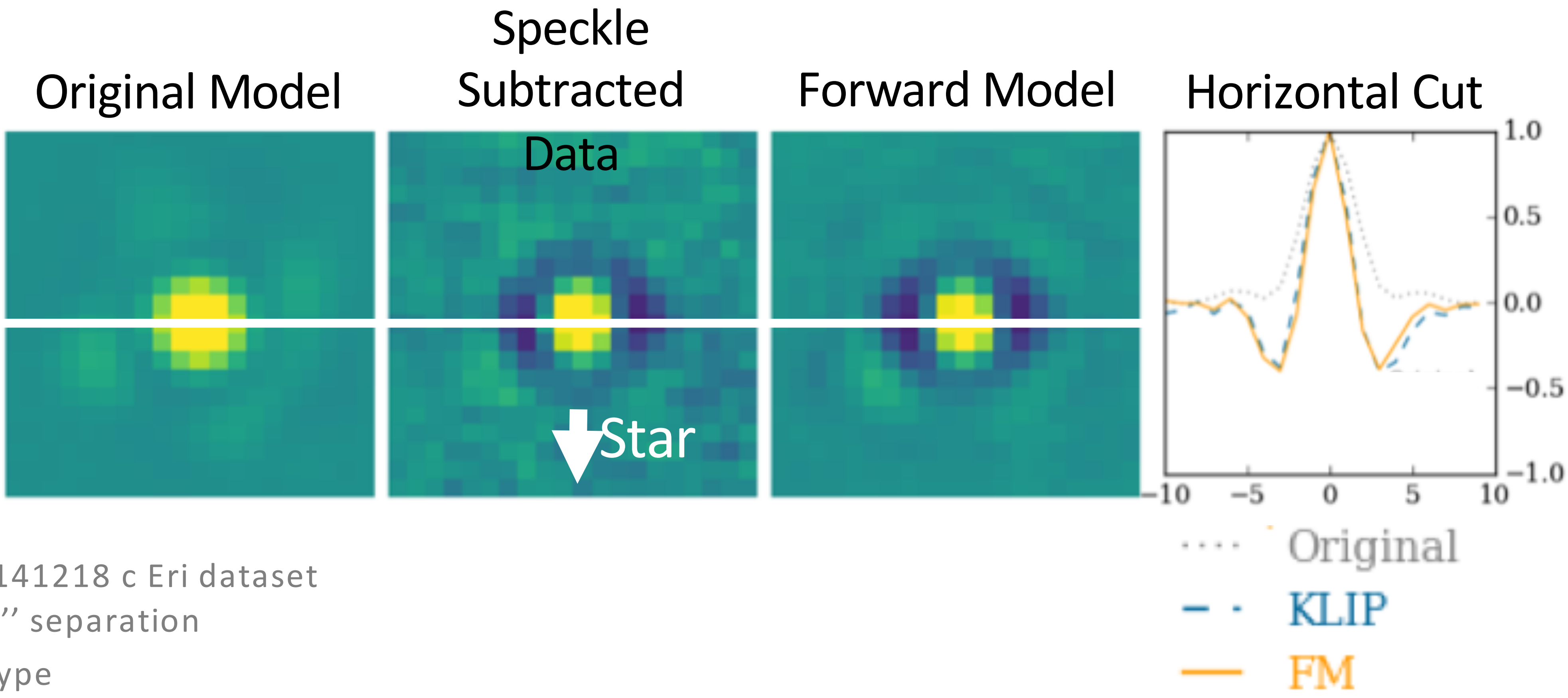
- Can rule out planets with very bright rings, but not yet Jupiter radius planets. However, sensitivity on pol mode appears to be limited by photon noise, so longer exposure times or better exposure duty cycle can reach deeper

BACKUP SLIDES

Matched Filter Concept

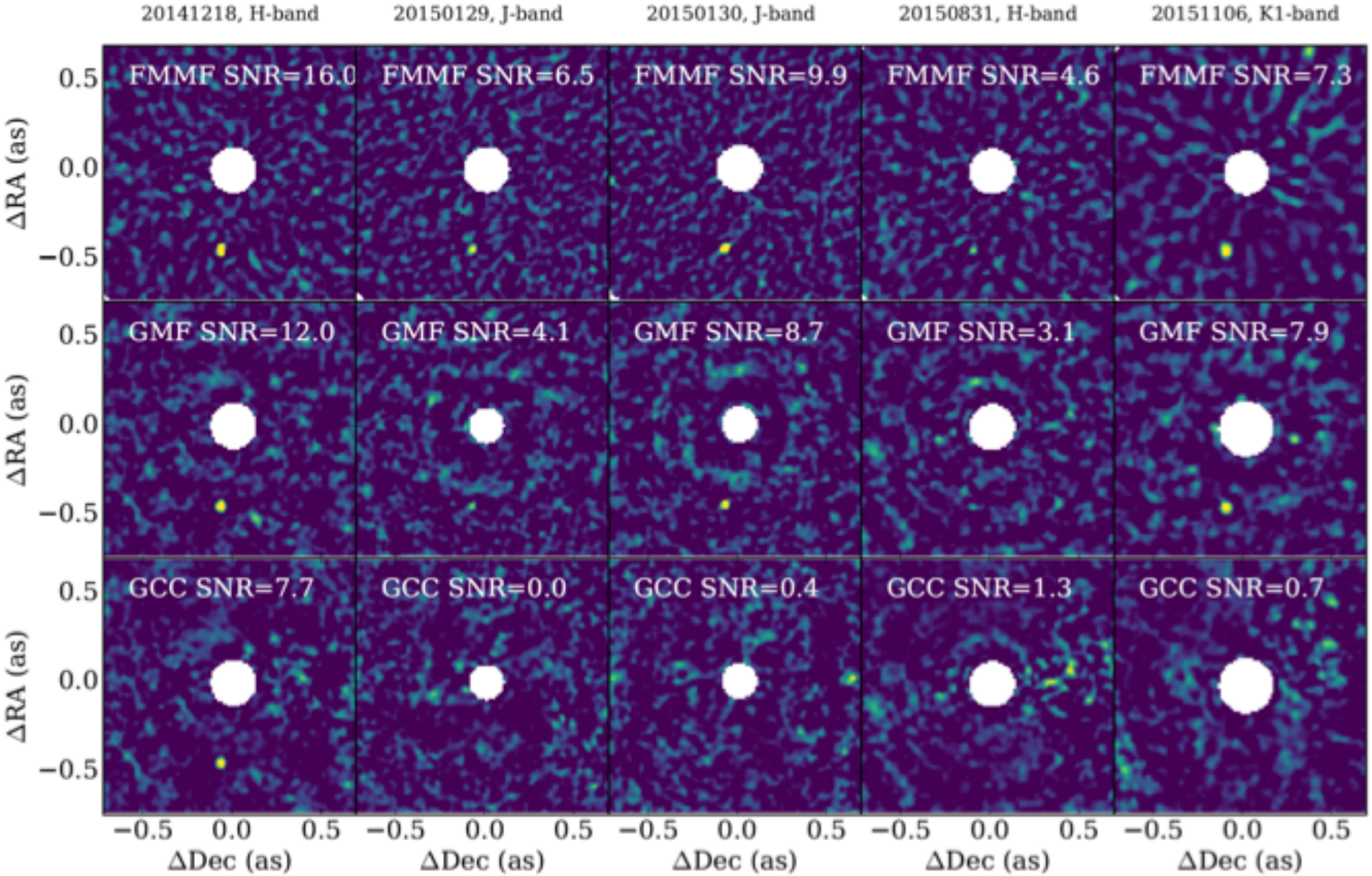


Planet Forward Model (cf. Pueyo 2016)

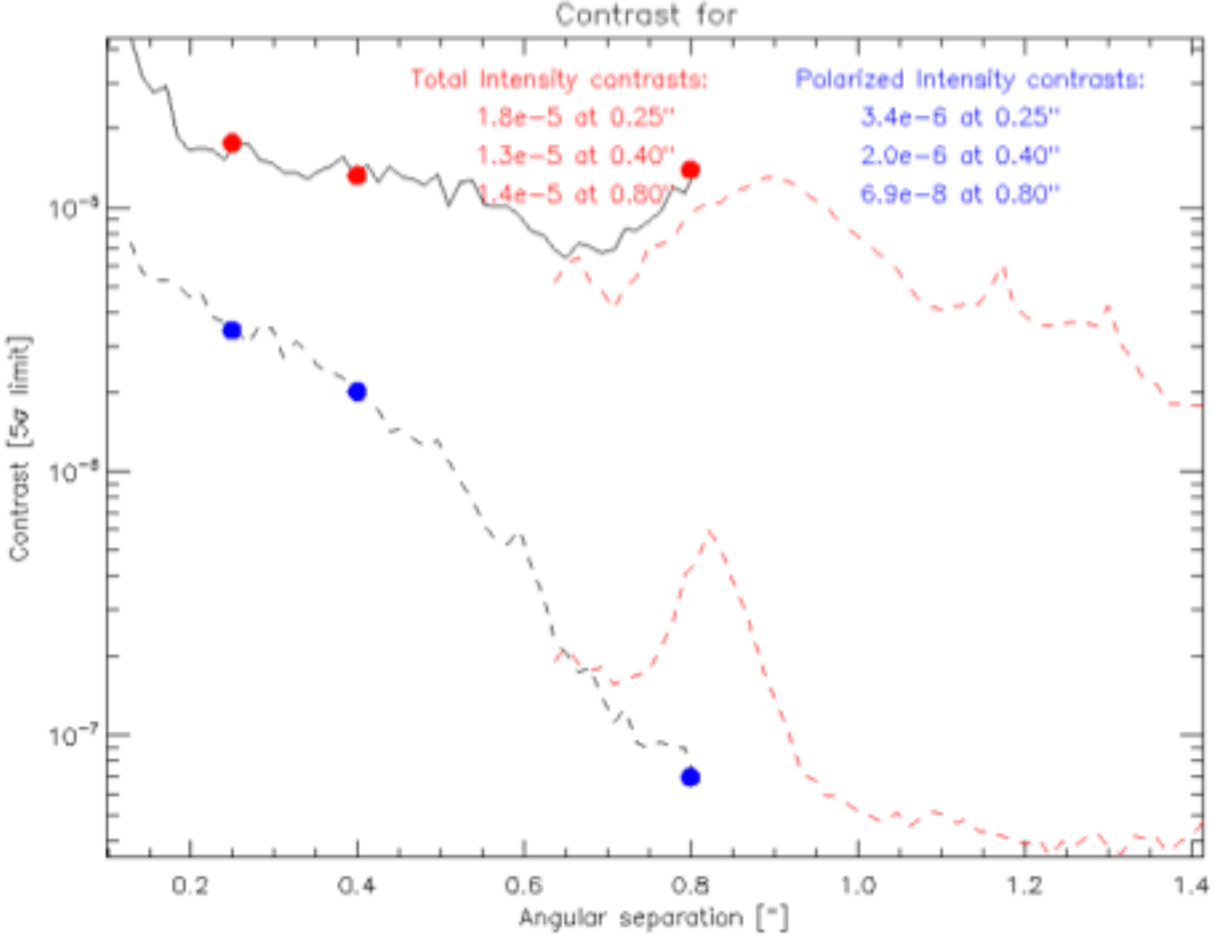


- 20141218 c Eri dataset
- 0.4’’ separation
- T-type
- SNR≈10

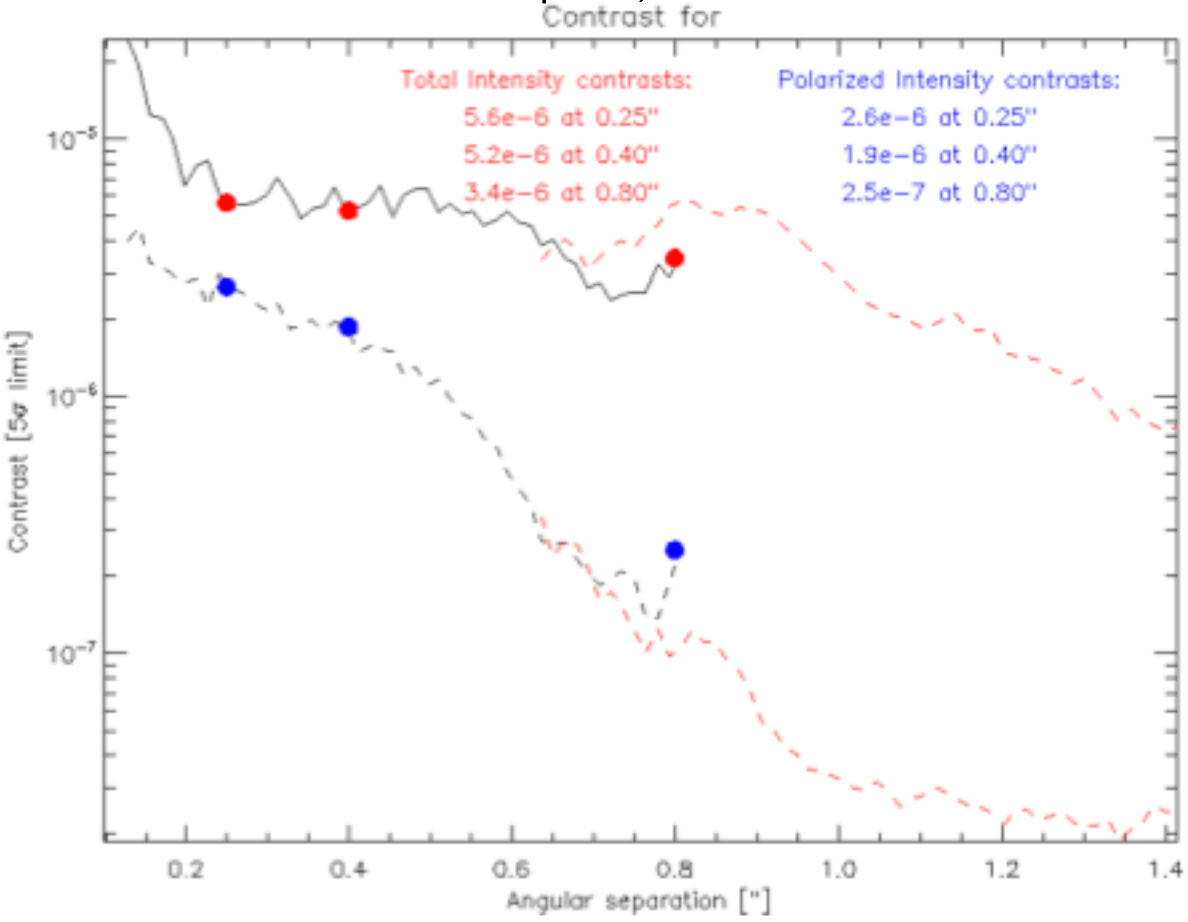
The Forward Model Matched Filter yields a better SNR.

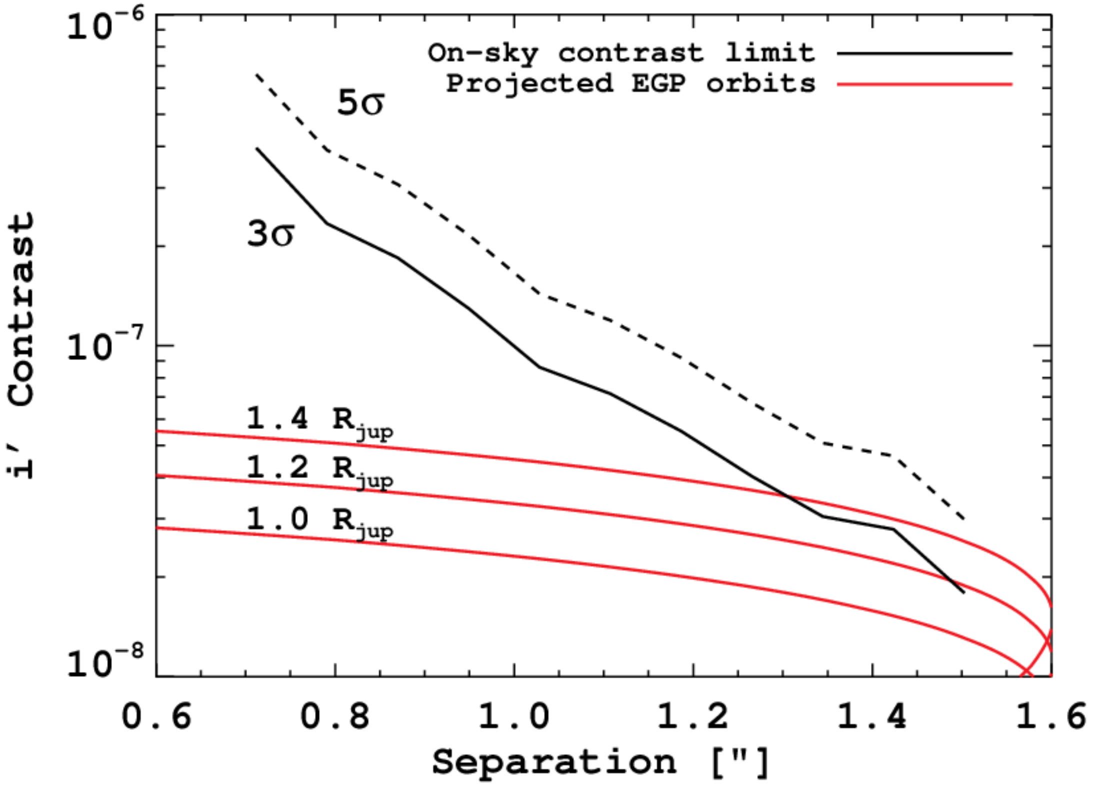


March 12, 2018



April 9, 2018





On-sky contrast limit
Projected EGP orbits
5σ
3σ
1.4 R_jup
1.2 R_jup
1.0 R_jup
10^-6
10^-7
10^-8
i' Contrast
0.6
0.8
1.0
1.2
1.4
1.6
Separation ["]