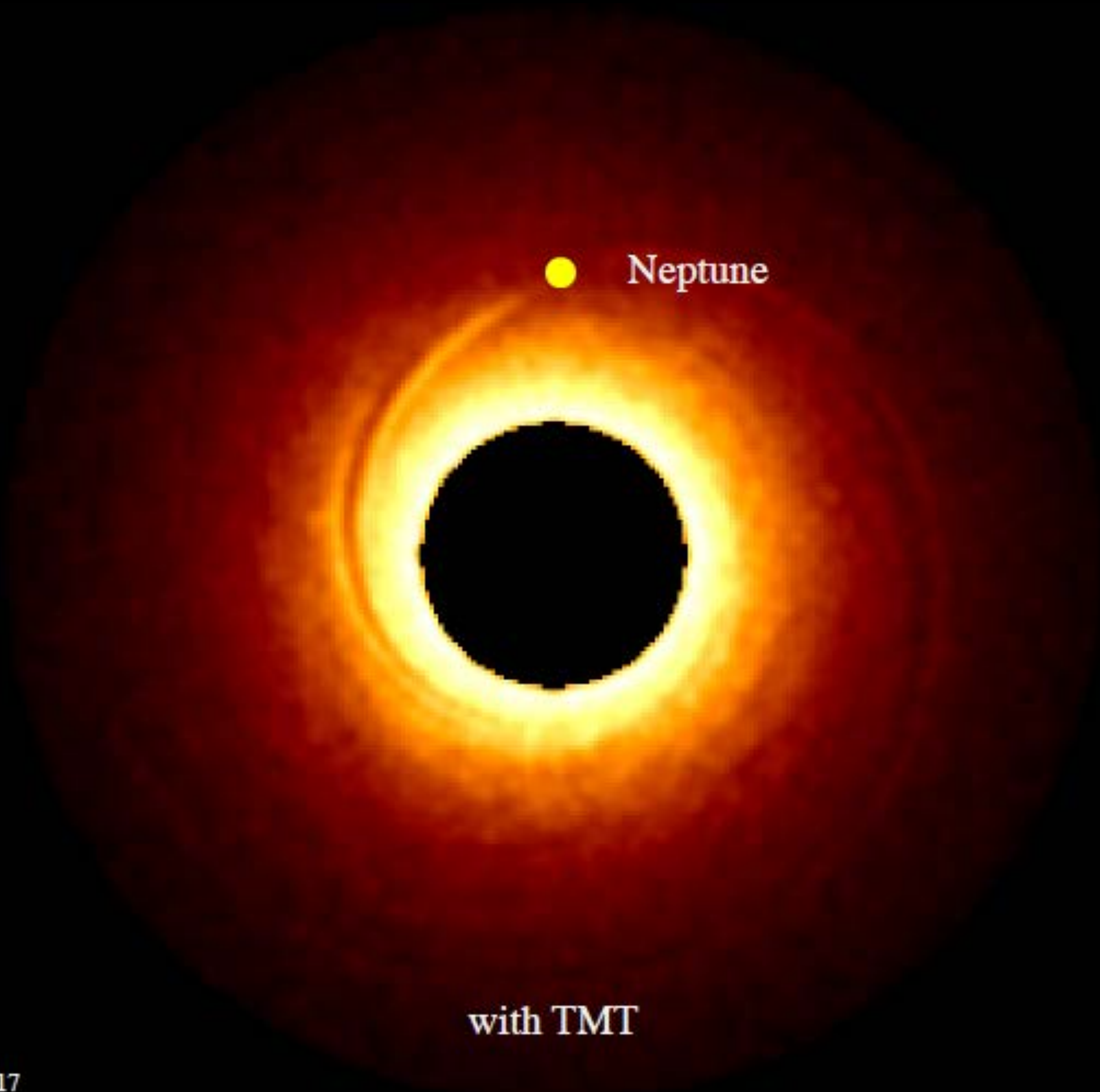
High-Contrast Imaging at TMT

Gas giants, ice-giants, terrestrial planets, exomoons, polarization, transits, weather, surface mapping, biomarkers, disks, planet formation, …

High-Contrast/ExAO breakout session

Wednesday November 8th 2017			
Time	Theme	Speaker	Comments
14:00	Goals + round table	Christian/Chris	Overview of the breakout session
14:05	Science	Andy Skemer	L/M-band Imaging/spec.
14:20	Science	Ruobing Dong	Young disks/exoplanets
14:35	Science	Honda-San	protoplanetary Disks
14:50	Science	Christian Marois	Exoplanet thermal
15:05	Science	Dimitri Mawet	Science hires spectroscopy
15:20	Science	all	Discussions
15:50	BREAK	-	-
16:00	Science	Eric Nielson	What we/will know about exoplanets cont. talk
16:10	Science	Sujan Sangupta	Polarization
16:20	Science	Stanimir Metchev	Variability
16:30	Science	Etienne Artigau	Synergy of various obs techniques
16:40	Science	Norio Narita	Transit
16:50	Science	Jun Hashimto	SEEDS, PSI
17:00	Science	Stanimir Metchev	Discussions

Thursday November 9th 2017			
Time	Theme	Speaker	Comments
9:00	Inst.	Chris Packham	MICHI
9:10	Inst.	Mark Chun	MIRAO
9:20	Inst.	Michael Fitzgerald	PSI
9:30	Inst.	Dimitri Mawet	High-Res. Spect. + AO
9:40	Inst.	Olivier Guyon	SCExAO as a prec. TMT inst.
9:50	Inst.	Andy Skemer	L/M-band imaging/spec
10:00	Inst.	all	**Round table discussions**
10:15	BREAK	-	-
10:30	Inst.	Benjamin Mazin	MKIDS cont. talk
10:40	Inst.	Prashant Pathak	TMT dispersion cont. talk
10:50	Inst.	Olivier Guyon	**Round table discussions**
11:15	Inst.	Olivier Guyon	**Round table discussions**
11:30	Inst.	Olivier Guyon	**Round table discussions**
11:45	White papers org.	Sujan Sangupta	**White papers**
12:00	Lunch	-	-
13:30	Prep time	Christian Marois	Finalizing Presentation Preparation
13:45	Prep time	Christian Marois	Finalizing Presentation Preparation



Dong & Fung 2017

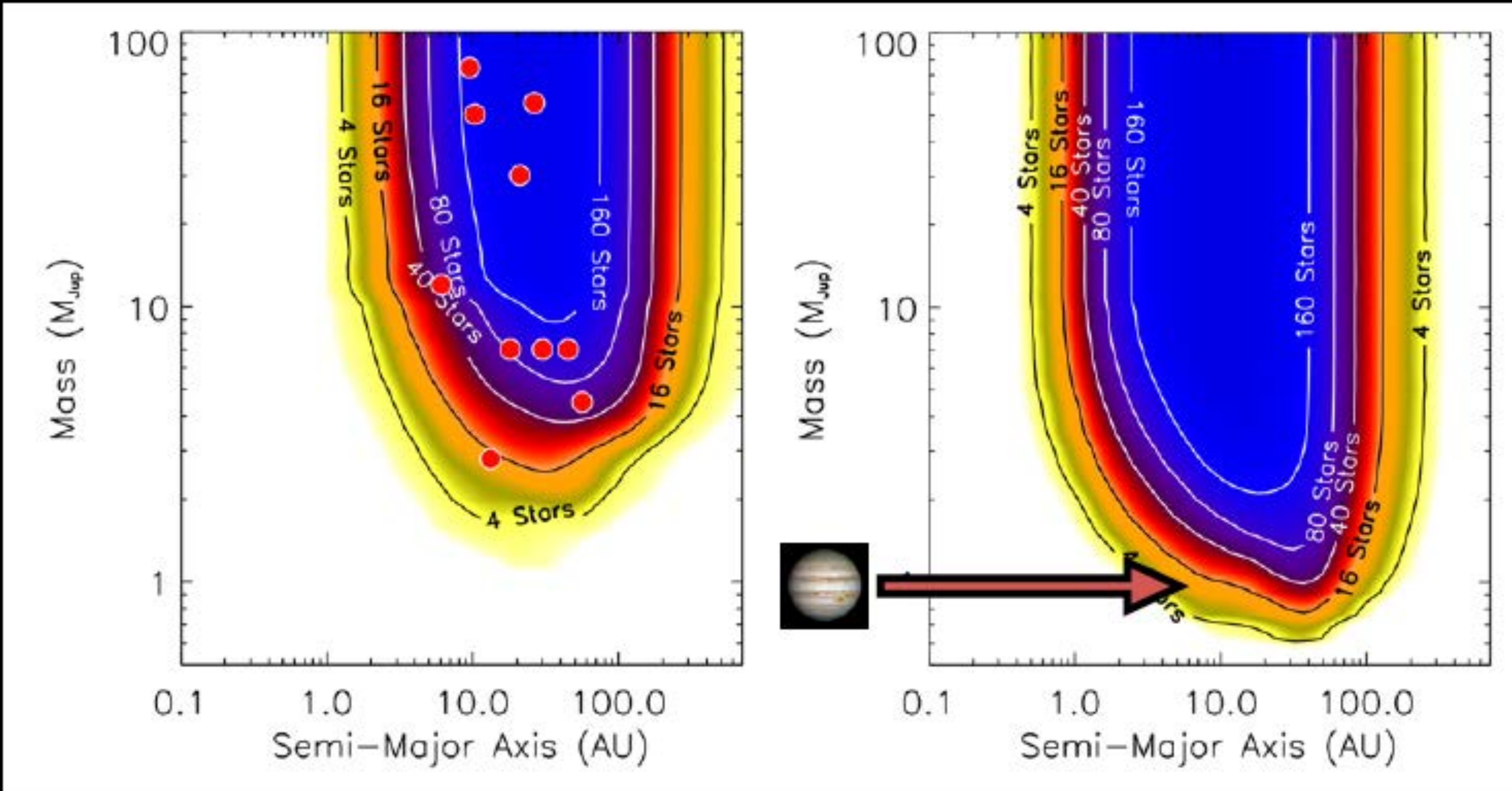
Inner Working Angle 0.025"
Angular Resolution 0.01"

Looking ahead to TMT

Eric Nielsen

GPIES: 380 stars

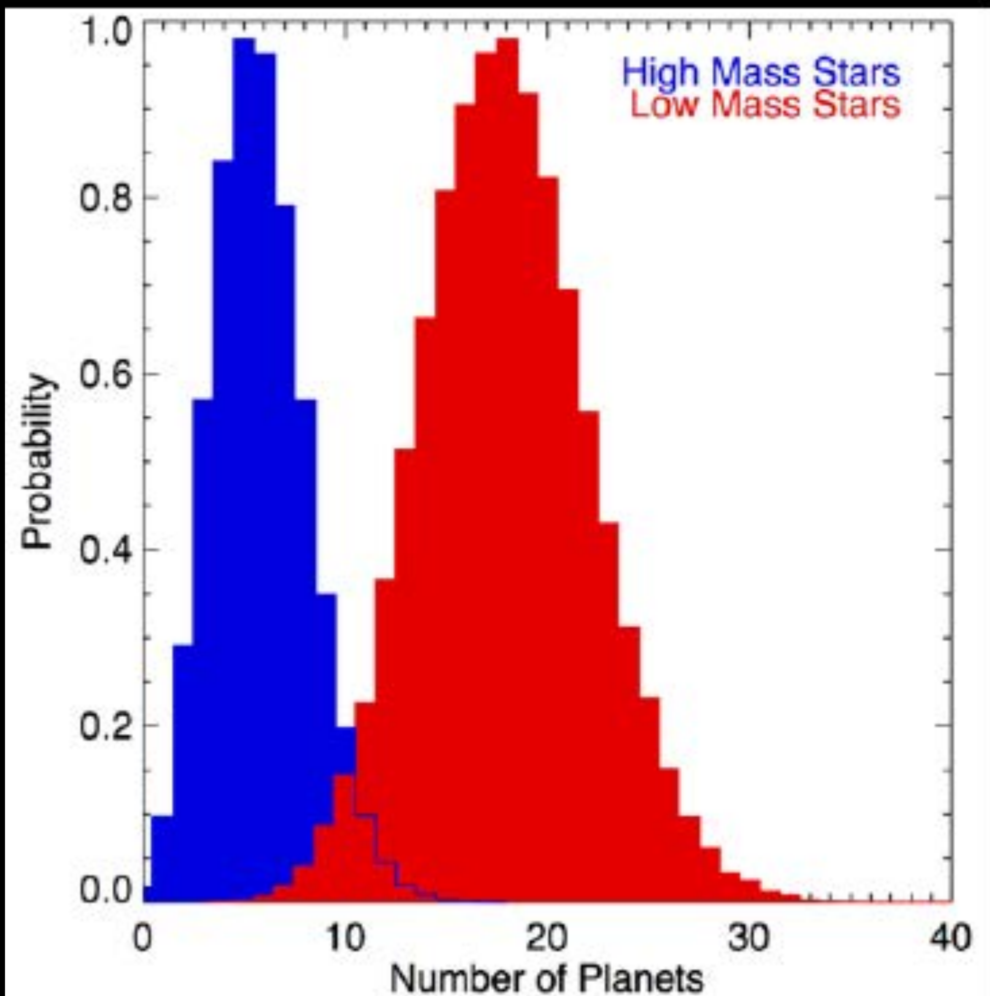
TMT: 500 stars



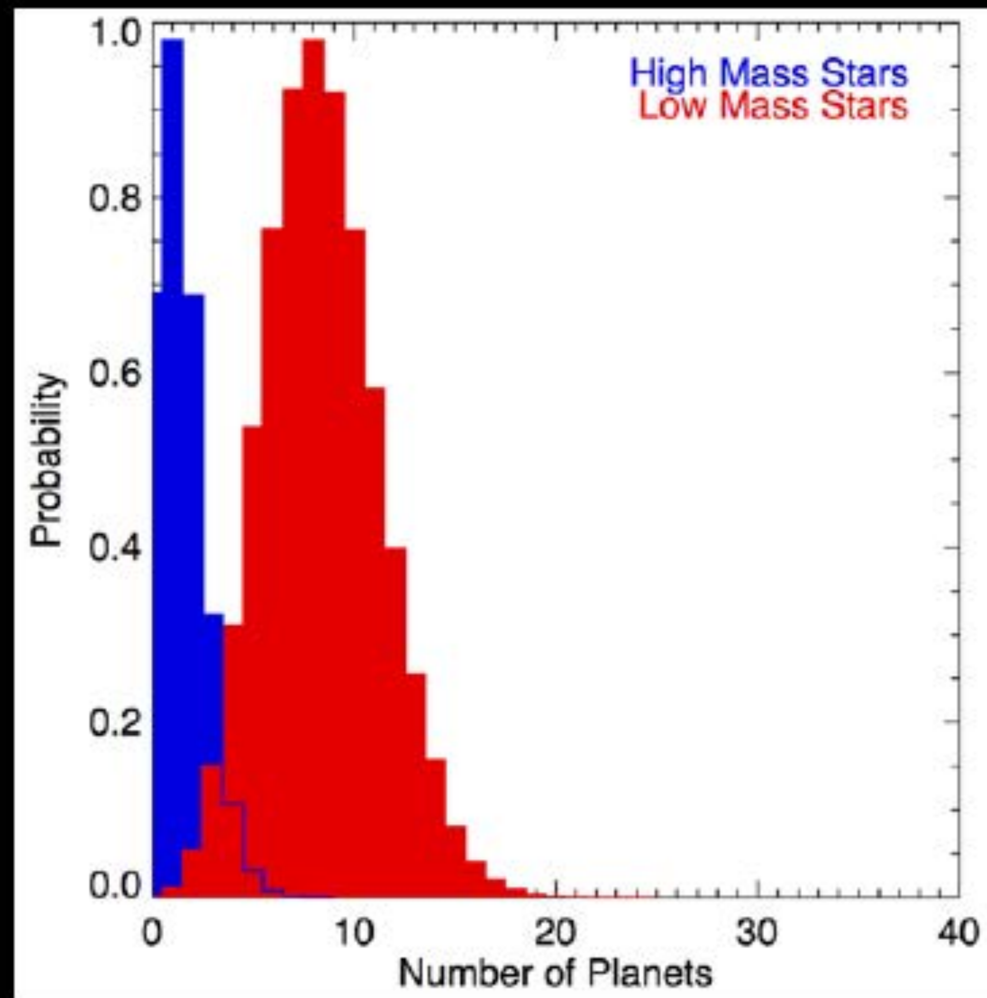
Looking ahead to TMT

Eric Nielsen

Planets within 30 AU



Planets within 10 AU



Conclusions

Eric Nielsen

For high-mass stars (>1.5 $M_\odot$), GPIES looks to be probing outer edge of RV planet populations

Strong dependence on stellar mass for high mass, wide-separation giant planets

Conservative estimate for performance of a TMT planet-imager at first light gives about a dozen new planets

TMT will let us directly probe the extent of the giant planet region as a function of stellar mass

Exoplanet (and brown dwarf) variability with TMT

- **IRMS**
  - multi-object 0.9–2.5 micron spectroscopy enables simultaneous calibration of telluric variations
  - Y dwarfs: the most characterizeable exoplanets
- **PSI**
  - high-dispersion spectroscopy for exoplanet tomography, Doppler imaging
  - 0.9–2.5 micron polarimetry probes the peak of the condensate size distribution
- **MICHI / bMICHI**
  - 3–20 micrton spectroscopy for direct cloud composition measurements
  - Y dwarfs

Stanimir Metchev, UWO

S. Sengupta

Polarimetric Detection of Exoplanets and Exo-moons

Thermal radiation of L- Brown Dwarfs and Self-luminous exoplanets gets scattered by cloud particles giving rise to local polarization at optical and infra-red wavelengths.

The disc averaged net observable polarization is zero or negligibly small if the object is spherical or almost spherical.

Asymmetry introduced by rotation-induced oblateness ortransit of exoplanets/exomoons can give rise to detectable amount of linear polarization in the optical and infrared bands.

Time resolved image polarimetry by TMT can detect Earth-size Exoplanets around cloudy Brown Dwarfs and Exo-moons around self-luminous Exoplanets. Image Polarimetry will also probe cloud in the atmosphere.

Imaging and Characterizing Habitable Planets with TMT...

… will requires ~1000x gain in raw contrast over state-of-the-art
New promising tools, but relatively low system-level maturity

→ If we built "to-print" a facility instrument designed TODAY, we would almost certainly fail to reach this ambitious goal

Solutions:

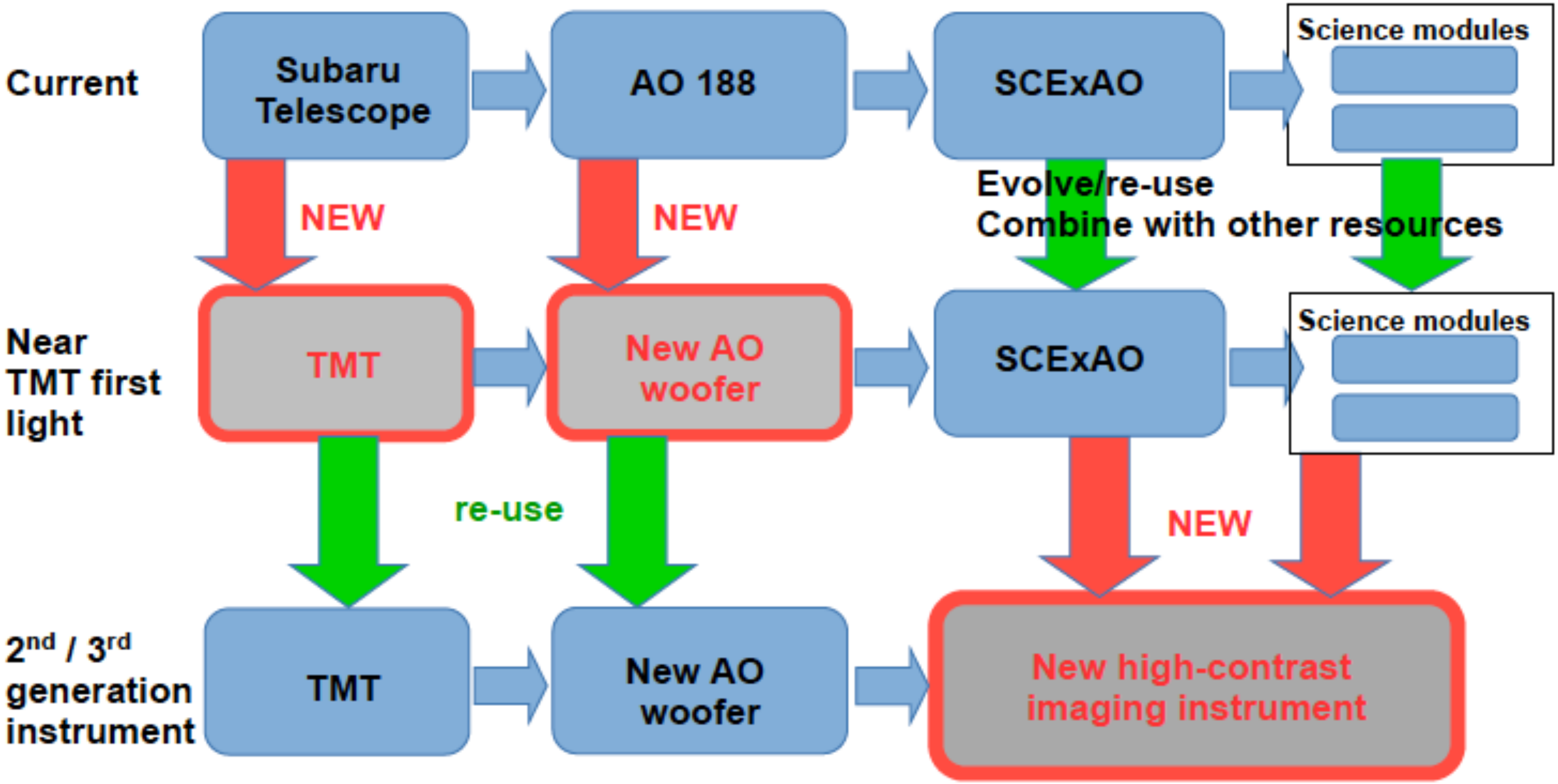
[1] For the most challenging science goal (hab planets), adopt flexible/ modular approach to TMT instrument. Do our best at first light, improve and solve issues as we go.

[2] Need to demonstrate and validate performance in labs and on current telescopes prior to deployment on TMT. Find out what architecture works, develop algorithms.
→ Subaru/SCExAO provides path to quickly integrate/validate new technologies on-sky, possible hardware transfer to TMT

O. Guyon

Notional plan toward TMT instrument

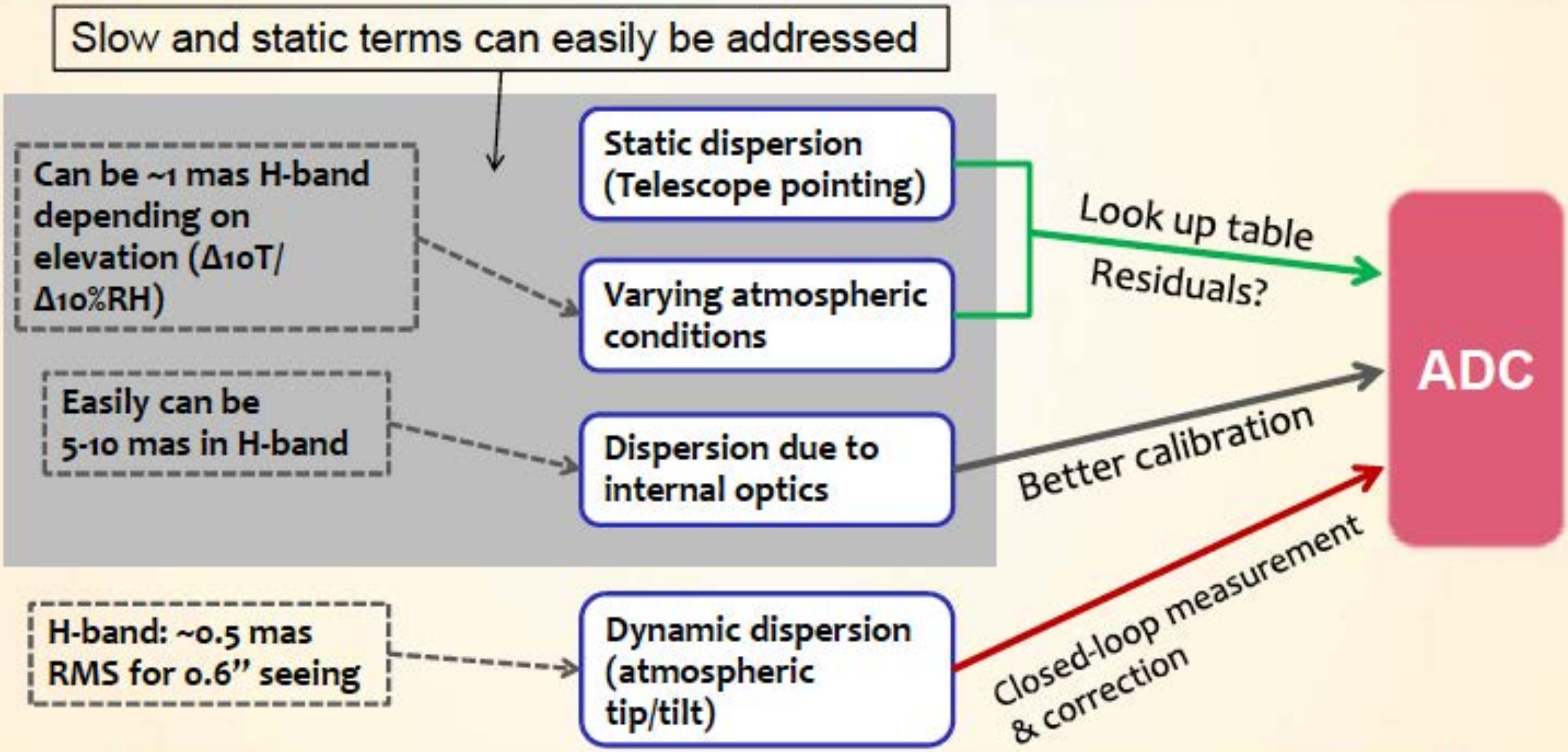
Path to TMT requires new AO woofer (~120x120 DM elements) to be built.



O. Guyon

Fixing Atmospheric Dispersion

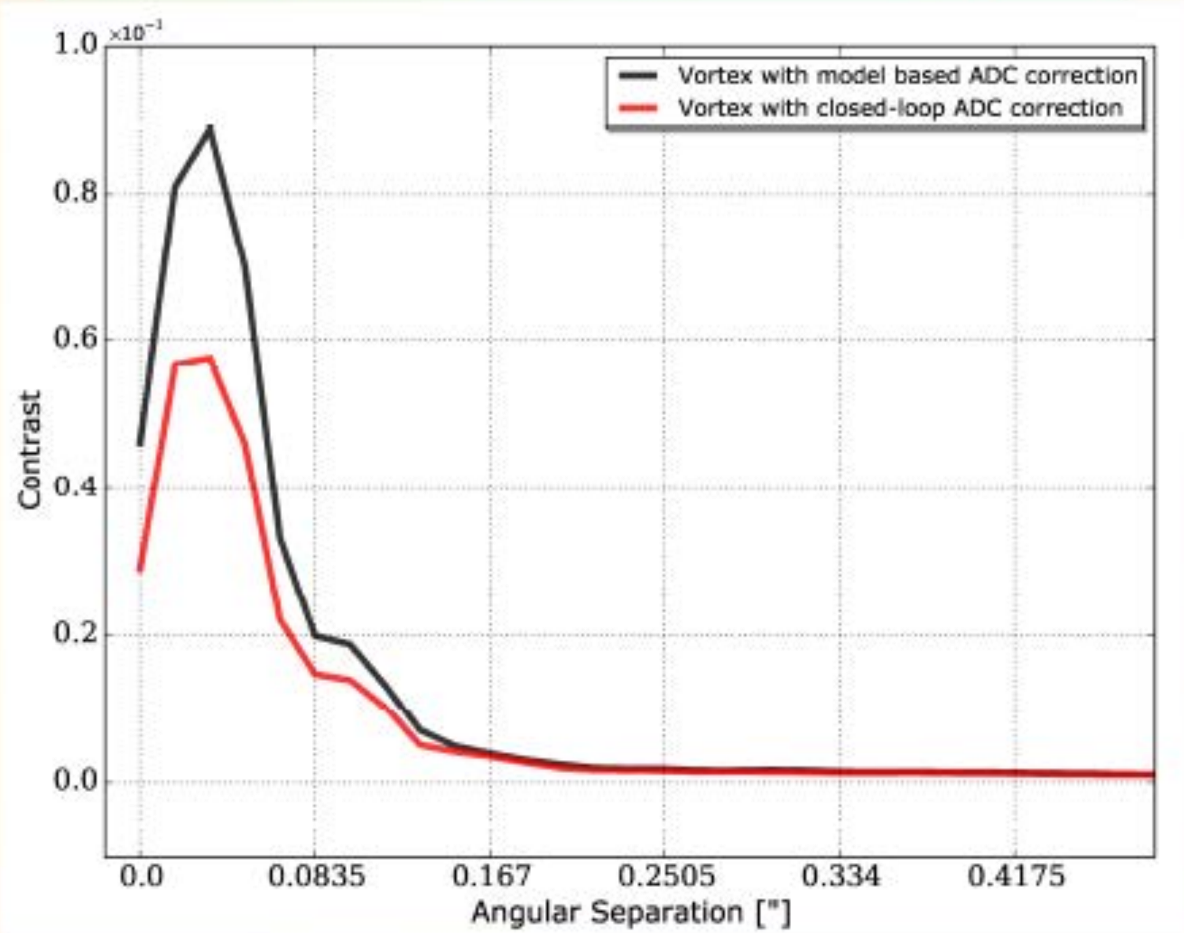
Using focal plane based technique, dispersion can be measured and corrected in a closed-loop manner to a high-precision (Pathak et al. 2016, 2017)



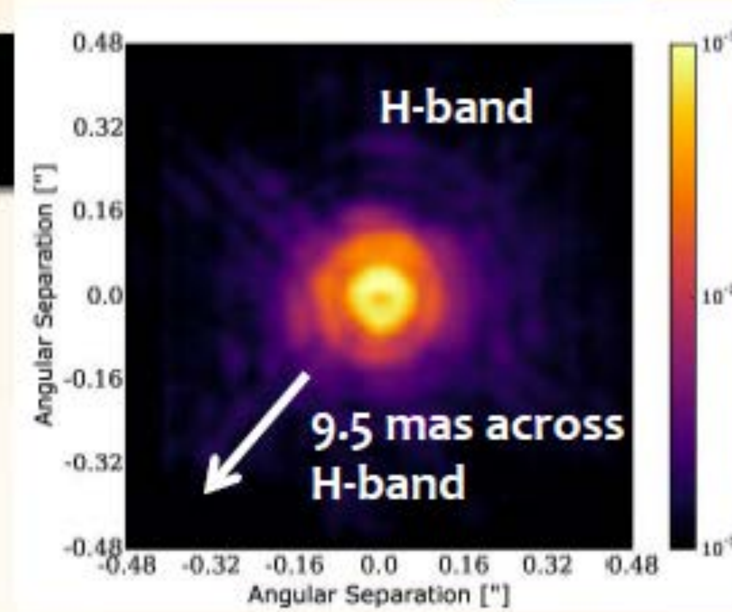
In H-band residual dispersion reduced from: 7.99 mas to 0.28 mas

On-sky Results

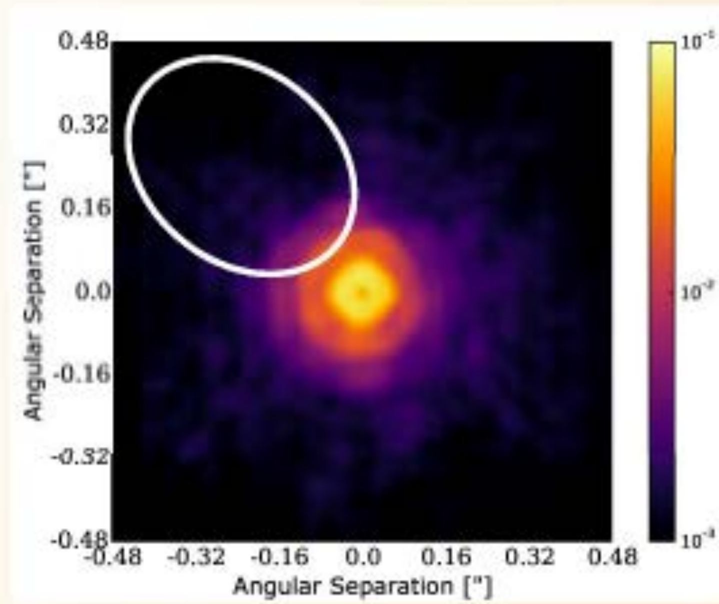
Leakage through vortex coronagraph



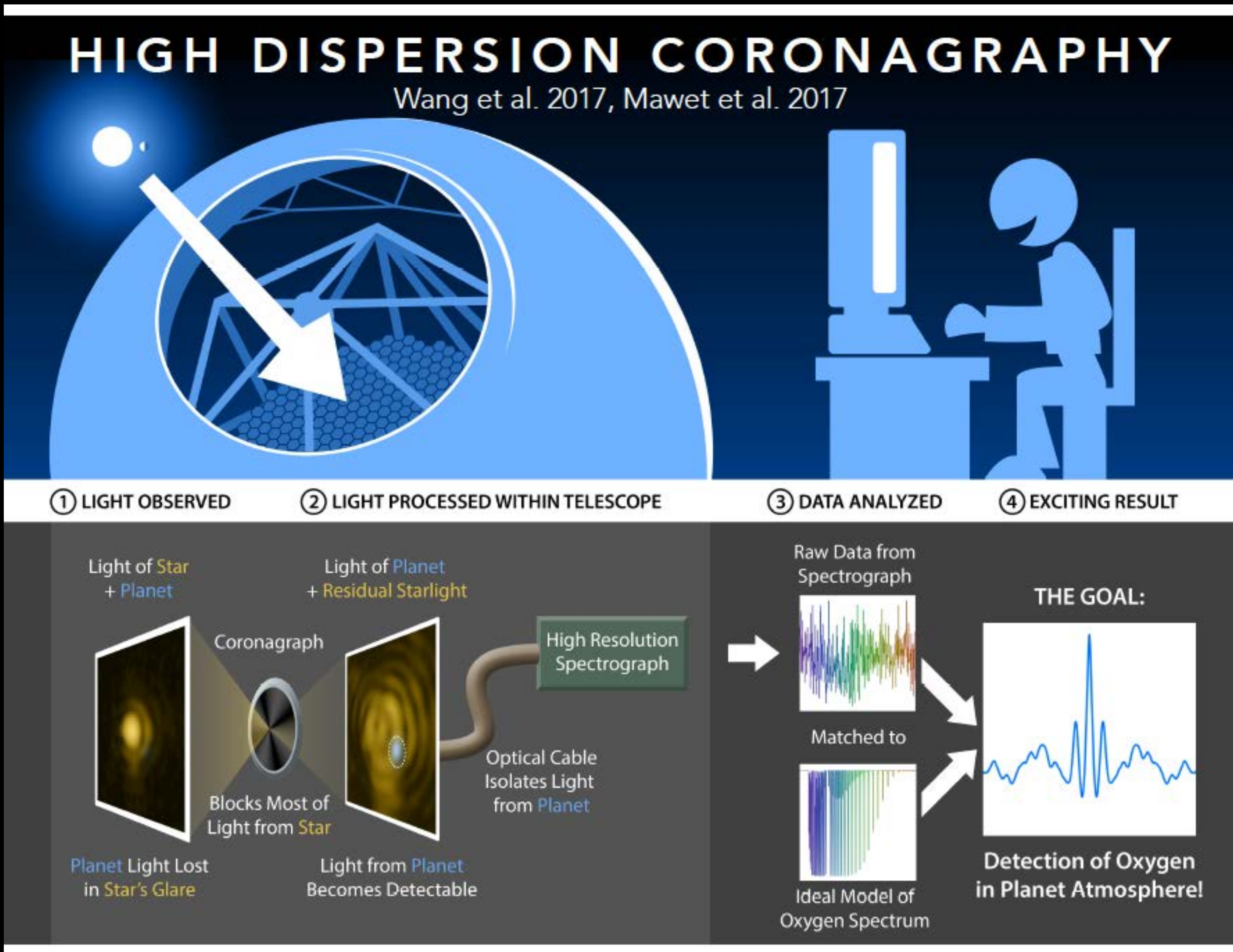
Wavefront correction using PyWFS and LLOWFS was applied



ADC correction using look-up table



Closed-loop ADC Correction

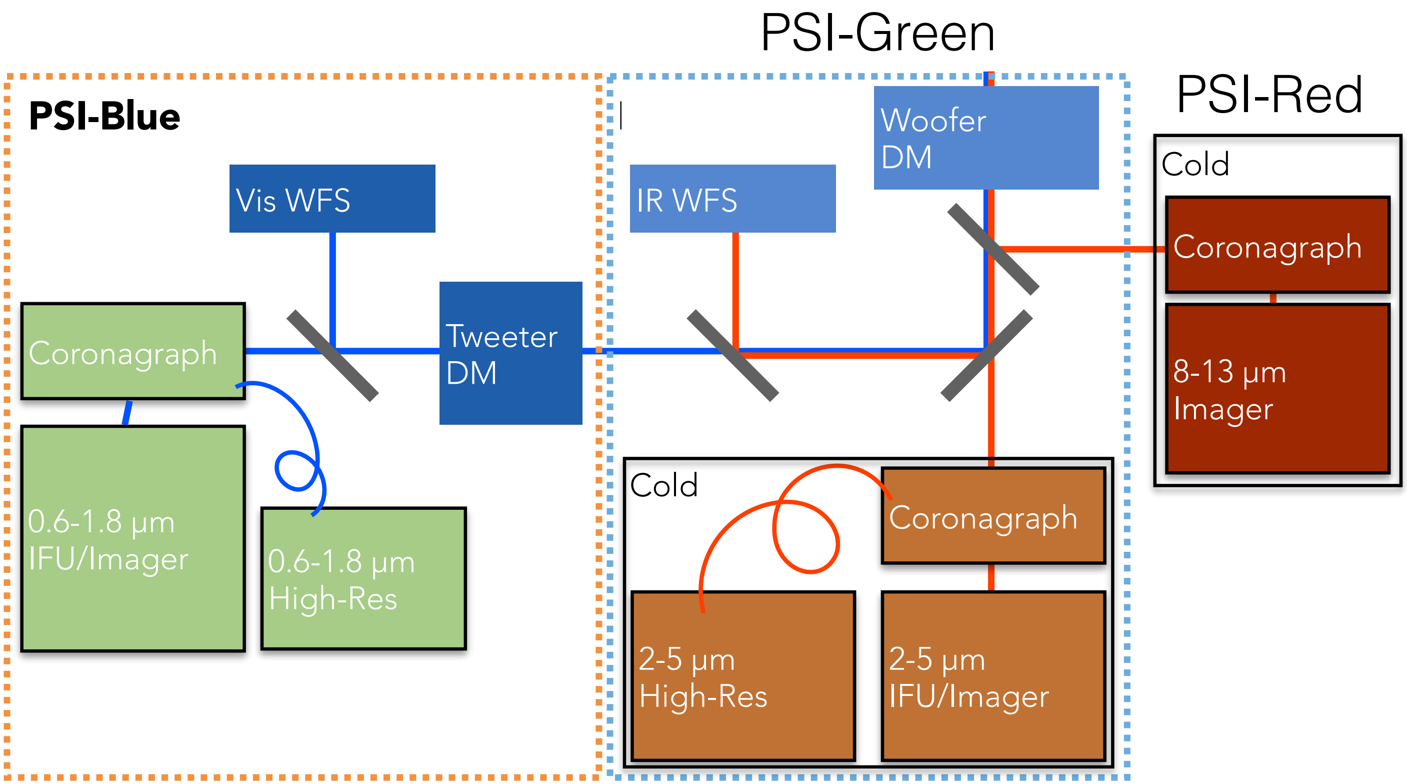

HIGH DISPERSION CORONAGRAPHY
Wang et al. 2017, Mawet et al. 2017
① LIGHT OBSERVED
② LIGHT PROCESSED WITHIN TELESCOPE
③ DATA ANALYZED
④ EXCITING RESULT
Light of Star + Planet
Coronagraph
Light of Planet + Residual Starlight
High Resolution Spectrograph
Blocks Most of Light from Star
Optical Cable Isolates Light from Planet
Planet Light Lost in Star's Glare
Light from Planet Becomes Detectable
Raw Data from Spectrograph
Matched to
Ideal Model of Oxygen Spectrum
THE GOAL:
Detection of Oxygen in Planet Atmosphere!

PSI

P~~F~~I

- Drivers: characterization of exoplanets in reflected light and thermal emission
  - Goal: Biosignatures on terrestrial planets in nearby HZs
  - Constraining composition and formation pathways
  - Circumstellar disks, solar system objects, AGB star outflows
  - General-purpose 2.5-5 um imaging, spectroscopy capabilities not in first-light instruments
- Modularity
  - Core capabilities support different science instruments
  - Upgrade paths to accommodate new technology
  - Fiber feeds allow straightforward use of instruments deployed and tested on smaller telescopes
- Relatively compact
  - Diffraction-limited, narrow field-of-view optics
- Allows for phased development and deployment

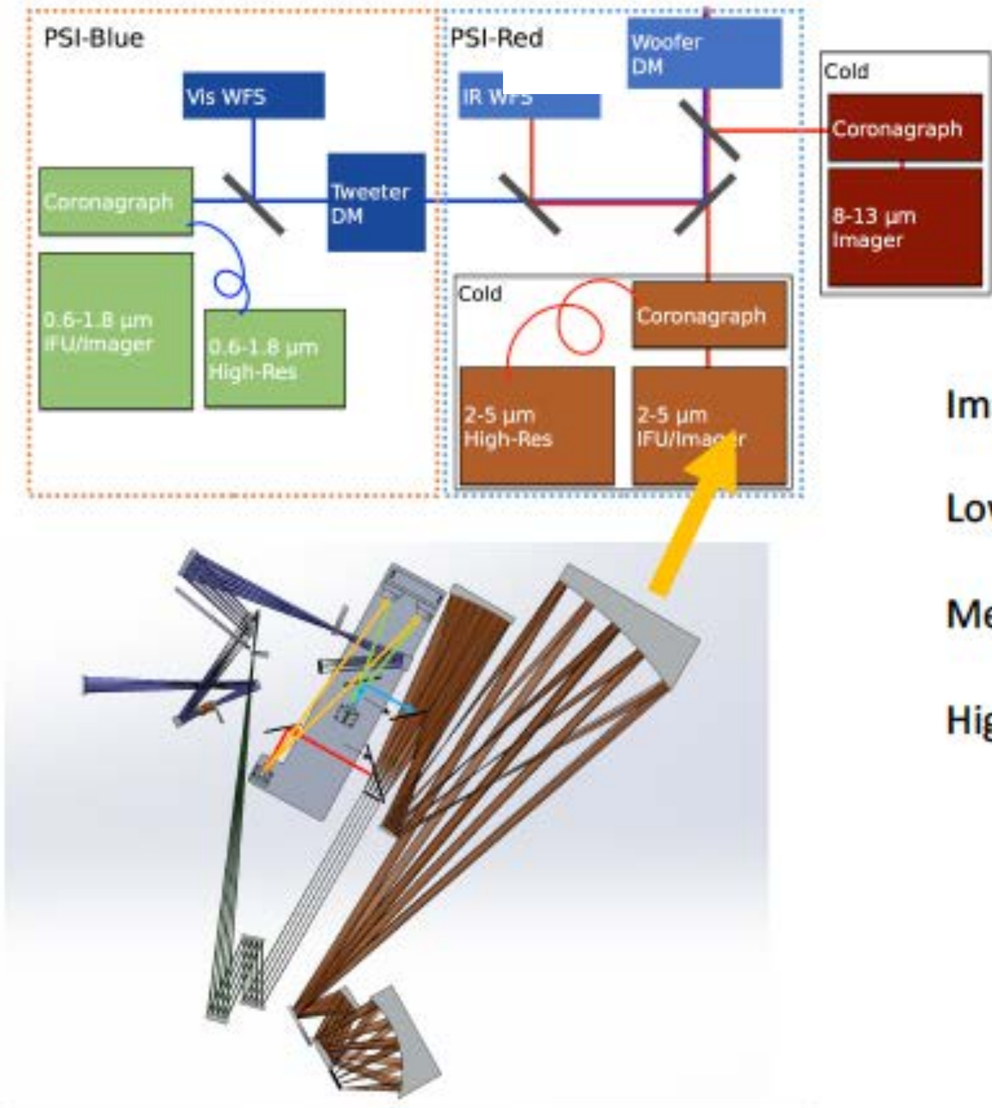
PSI concept



PSI-Green
PSI-Red
PSI-Blue
Vis WFS
Tweeter DM
Coronagraph
0.6-1.8 μm IFU/Imager
0.6-1.8 μm High-Res
IR WFS
Woofer DM
Cold
Coronagraph
2-5 μm High-Res
2-5 μm IFU/Imager
Cold
Coronagraph
8-13 μm Imager

2-5 micron Exoplanet IFS/imager

Andy Skemer



Imager: 7x7" FOV

Low-Res IFS: 1.2x1.2" FOV with R~200

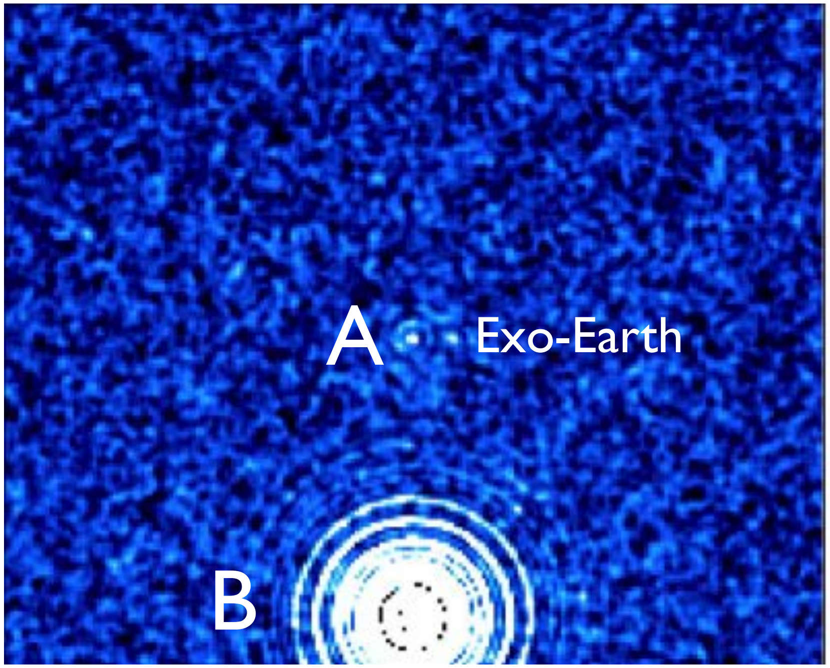
Medium-Res IFS: 0.15x0.15" with R~5000

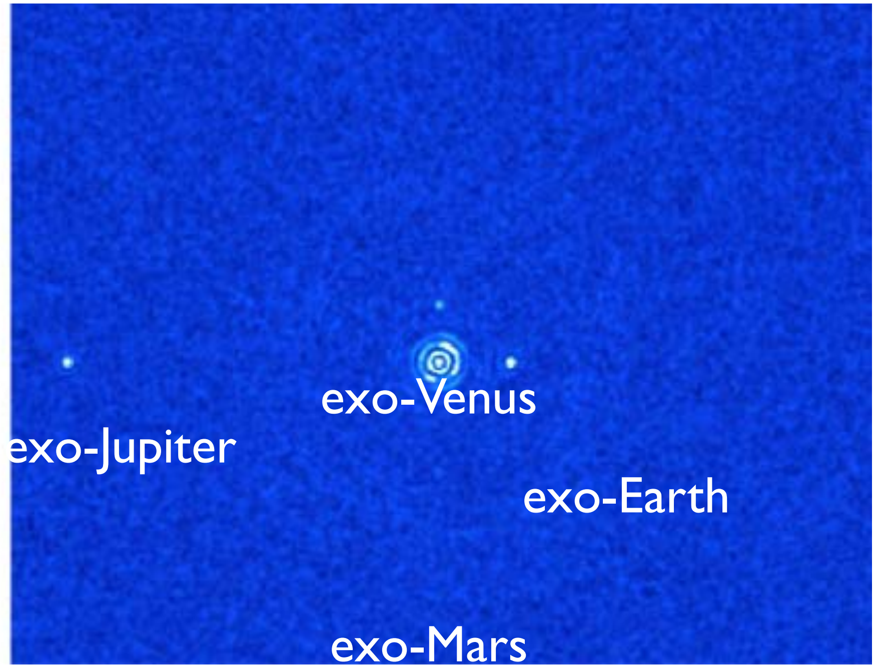
High-Res Fiber Feed: R~100,000

A. Skemer

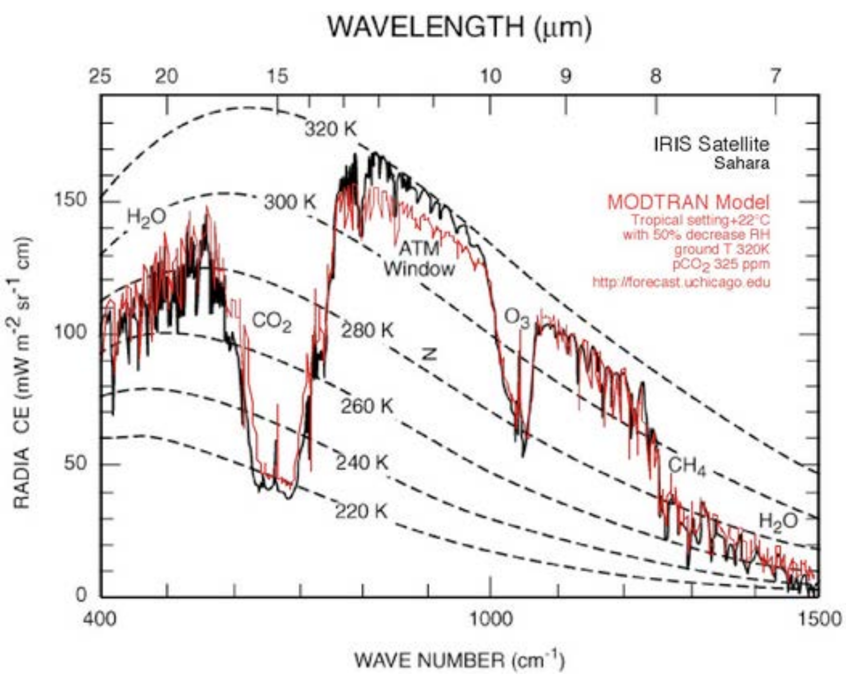
Thermal Imaging of Exoplanets with TMT

8m



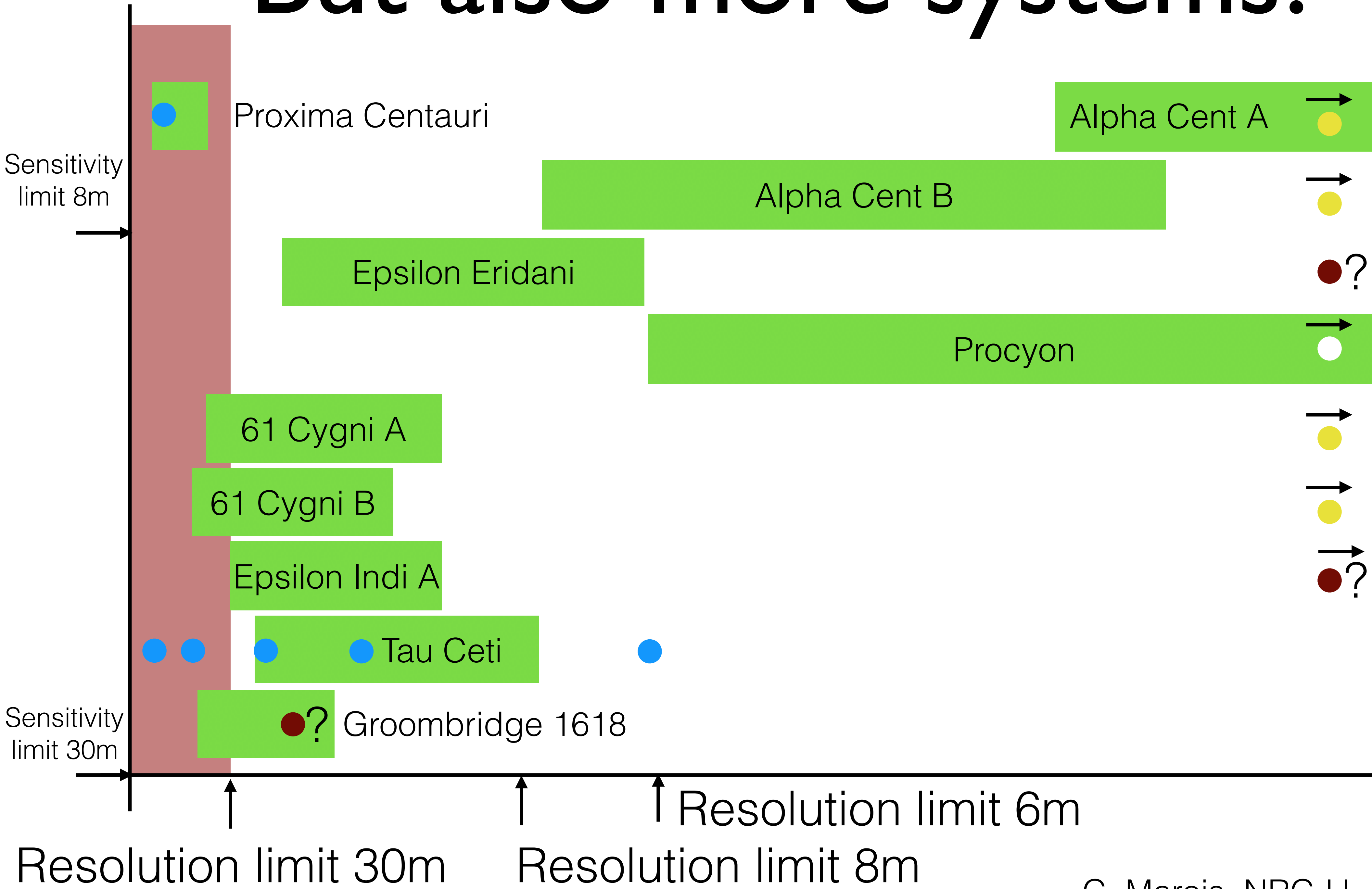


30m



C. Marois, NRC-H

But also more systems!



C. Marois, NRC-H

Summary of the "synergy of methods"

- Exoplanet underdogs
  - Astrometry
    - ~μas of nearby stars
    - TOO for microlensing astrometric counterpart (~mas)
  - Eclipse (secondary transit) mapping at very high resolution
    - >2.5μm
  - ~1 m/s or better RV
    - 4-m class telescopes for surveys (very time consuming)
    - TMT for very exciting (and faint) targets
    - Requirements similar to HR transit spectroscopy
  - All TMT instruments and most modes
    - Some exoplanets are isolated or at >1" separation
    - Comparison with self-luminous young giants
- HDC: what will we learn for CC with a line list?
  - No (?) possibility of broadband caracterisation
  - Terra incognita and interpretation of a handful of species will be hard
    - No equivalent to the HR8799 bcde comparison with field brown dwarf

E. Artigau

Discussions

- Polarization
- Synergy with MICHI (blue MICHI/“Green” PSI) & MIRAO
- ASM discussions & requirements
- Cooling AO bench for MIRAO?
- Parallel observing (blue, green, red PSI).
- Expending science team (solar system, BDs, others)?
- WP strategy