GPI
Gemini Planet Imager

Thanks to the full GPI team
and
the Gemini Staff

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Andrew Cardwell (SOS)
Vincent Fesquet (Laser & Optical Engineer)
Ramon Galvez (Senior Electronics Engineer)
Gaston Gausachs (Mechanical Engineer)
Kayla Hardie (Systems Technician)
Markus Hartung (AO Scientist)
Pascale Hibon (2nd IS)
Carlos Quiroz (Software)
Andrew Serio (Systems Engineer)

+ Javier, Christian, Roberto, Monica, Diego, Sofia,...

Dates

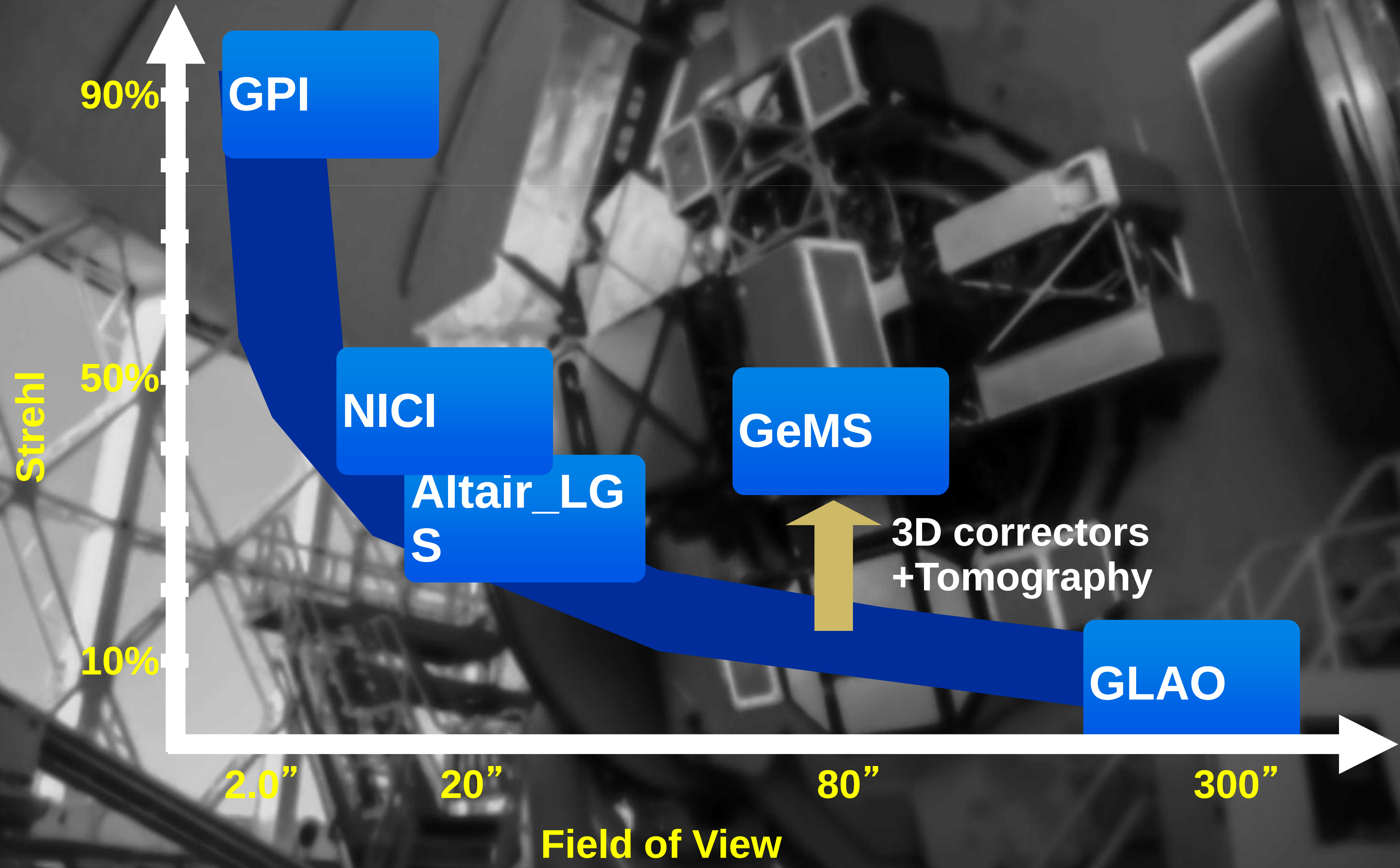
- Installation run: November 11th to 17th
  Clear conditions with median seeing or worse (up to 1.5”)

- First Commissioning Run (of 4) December 8th to 11th

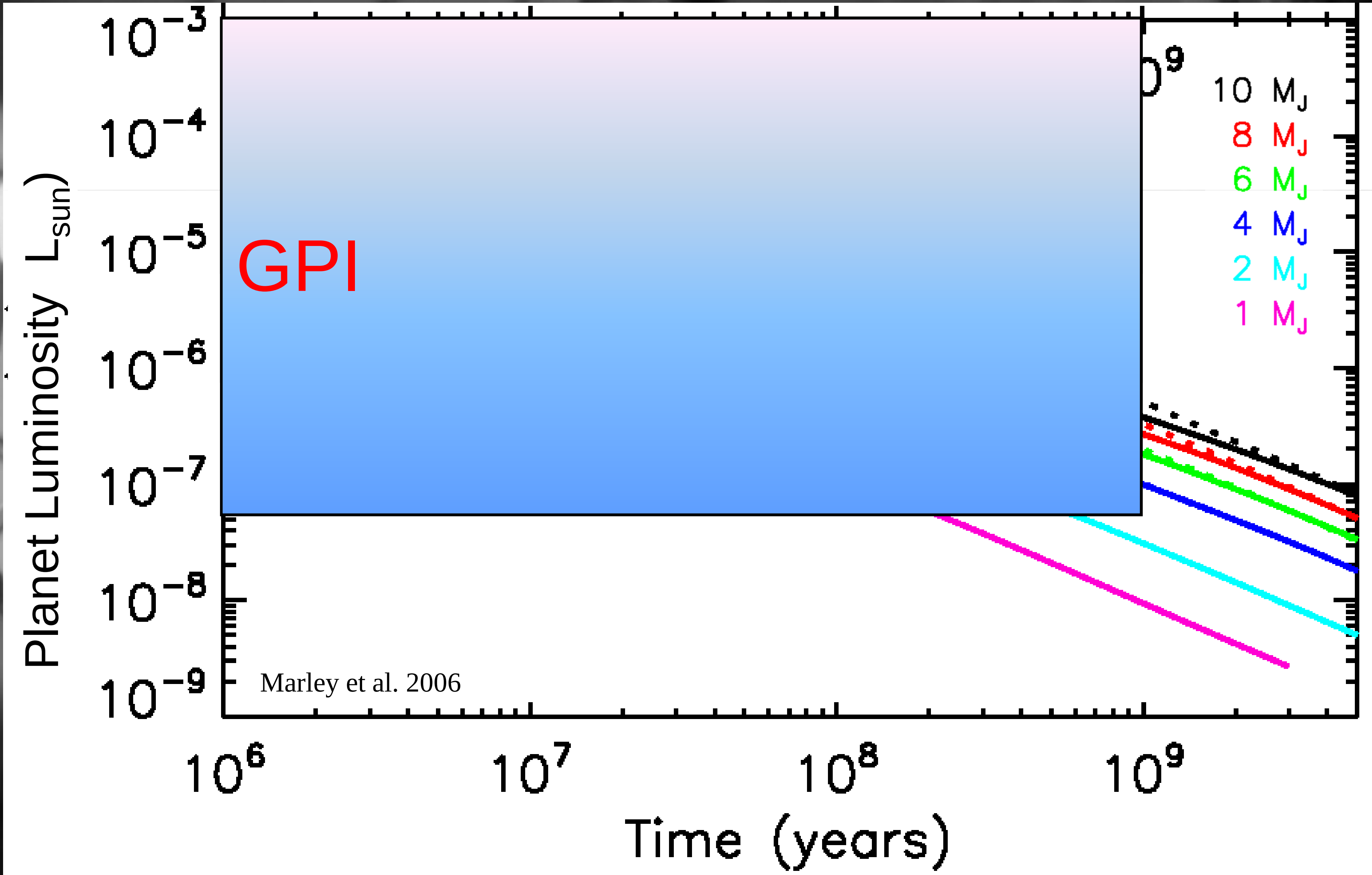
  Excellent seeing with better than median IQ

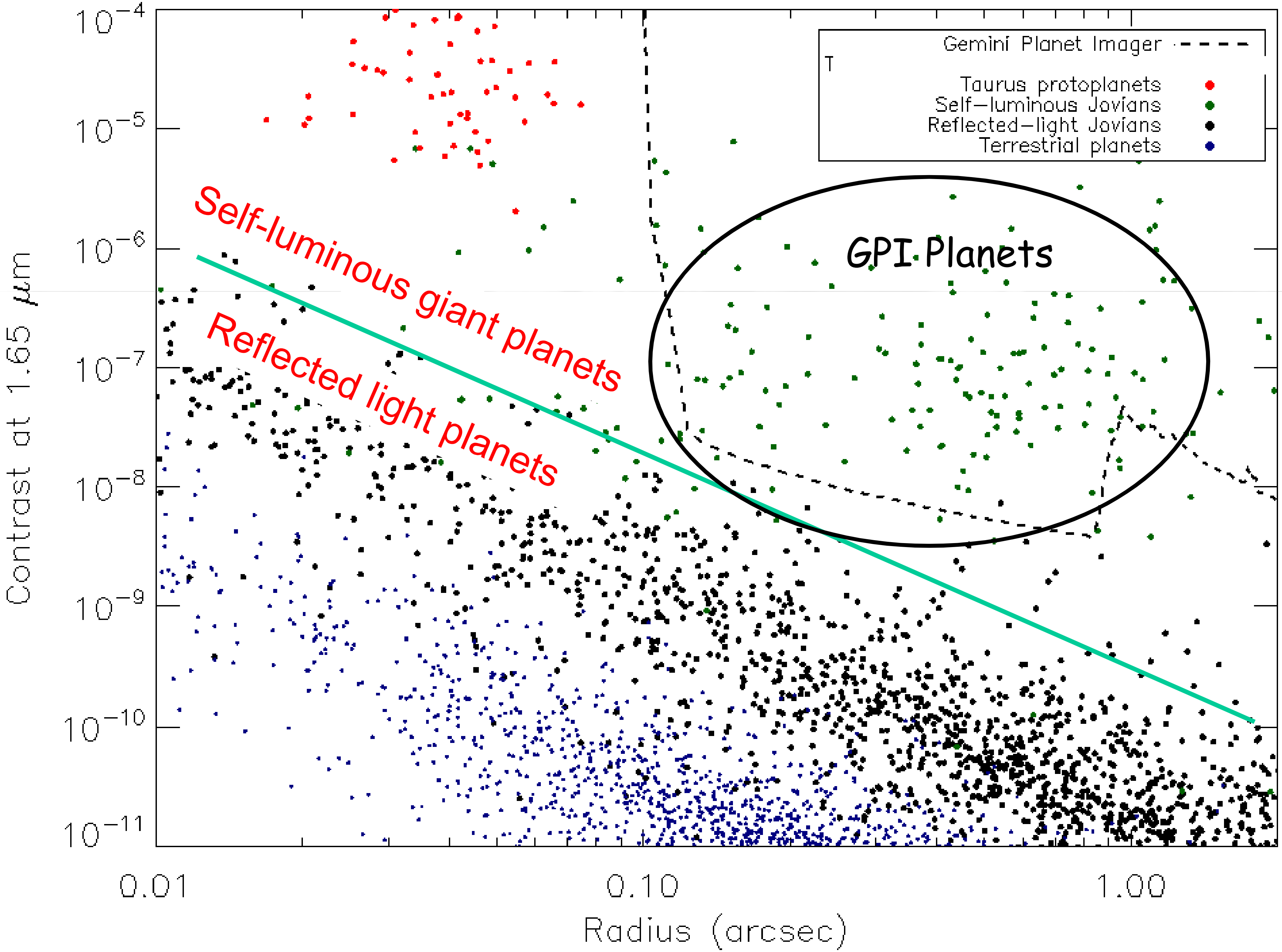
A Very Happy GPI Team

Parameter space coverage



Models of Young Planet Luminosity





Gemini Planet Imager
T
Taurus protoplanets
Self−luminous Jovians
Reflected−light Jovians
Terrestrial planets
GPI Planets
Self-luminous giant planets
Reflected light planets
Contrast at 1.65 μm
Radius (arcsec)
10−4
10−5
10−6
10−7
10−8
10−9
10−10
10−11
0.01
0.10
1.00

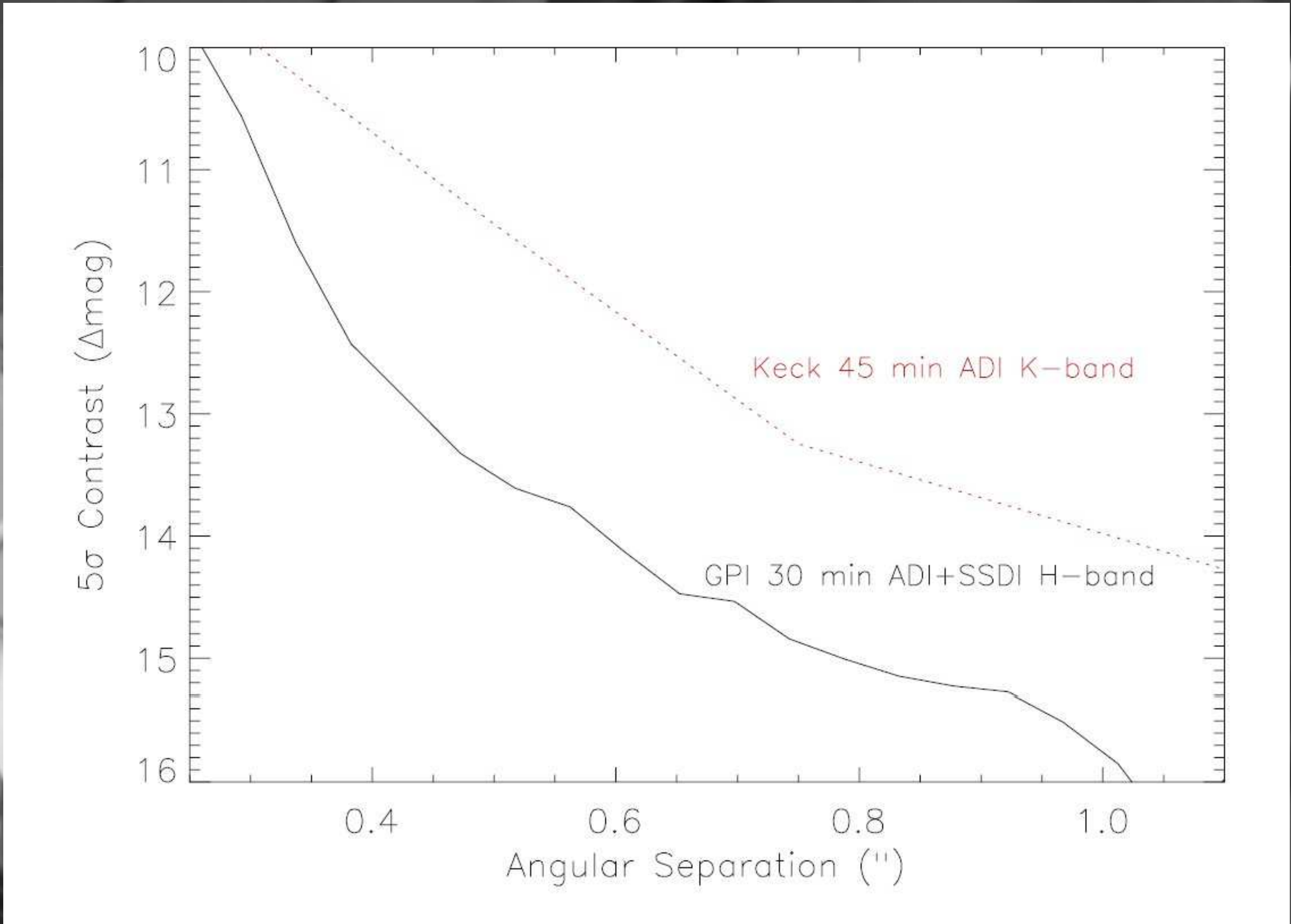
Highlights

- Smooth integration with the Gemini SW environment (OT, TCS, SeqExec).
- ADC now being used in standard observations.
- Coronograph observations in all bands (Y, J, H, K1 and K2)
- Polarization observations in H and K bands
- Non Redundant Mask (NRM) of several targets, will be offered in 15A.
- Direct images (no coro) of several solar system objects
- ~80h of GPI in 14B

Highlights II

- AO performance tweaks. Lots of data taken with various loop gain adjustments.
- GPI fully integrated and supported by the OT and SeqExec
- GPI Skeletons allowing 1-click creation of observations

Contrast



ADI – Angular Differential Imaging
SDI – Spectral Speckle Nulling

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Before proposing check this

From a Feasibility point of view GPI consists of 4 components as these are setting the constraints on feasible targets.

1. OIWFS (The Adaptive Optics, AOWFS), a high order, fast (1KHz) AO system that corrects for the atmospheric turbulence. Sets the limit on allowed brightness in I-band.

1. LOWFS (The CAL unit), low order, slow AO (0.1Hz) system that is designed to keep the object on the mask. Sets the limit on allowed brightness in H-band.

1. The IFS, Hawaii 2 NRG chip, field of view 2.4"x2.4", minimum exposure time 1.49s, maximum exposure time 999s. Sets the limit on allowed brightness in the science band and the maximum field of view.

1. Coronographic Mask or Direct. Sets the limit on Inner Working distance and brightness.

Main webpage**: http://www.gemini.edu/sciops/instruments/gpi/instrument-performance**

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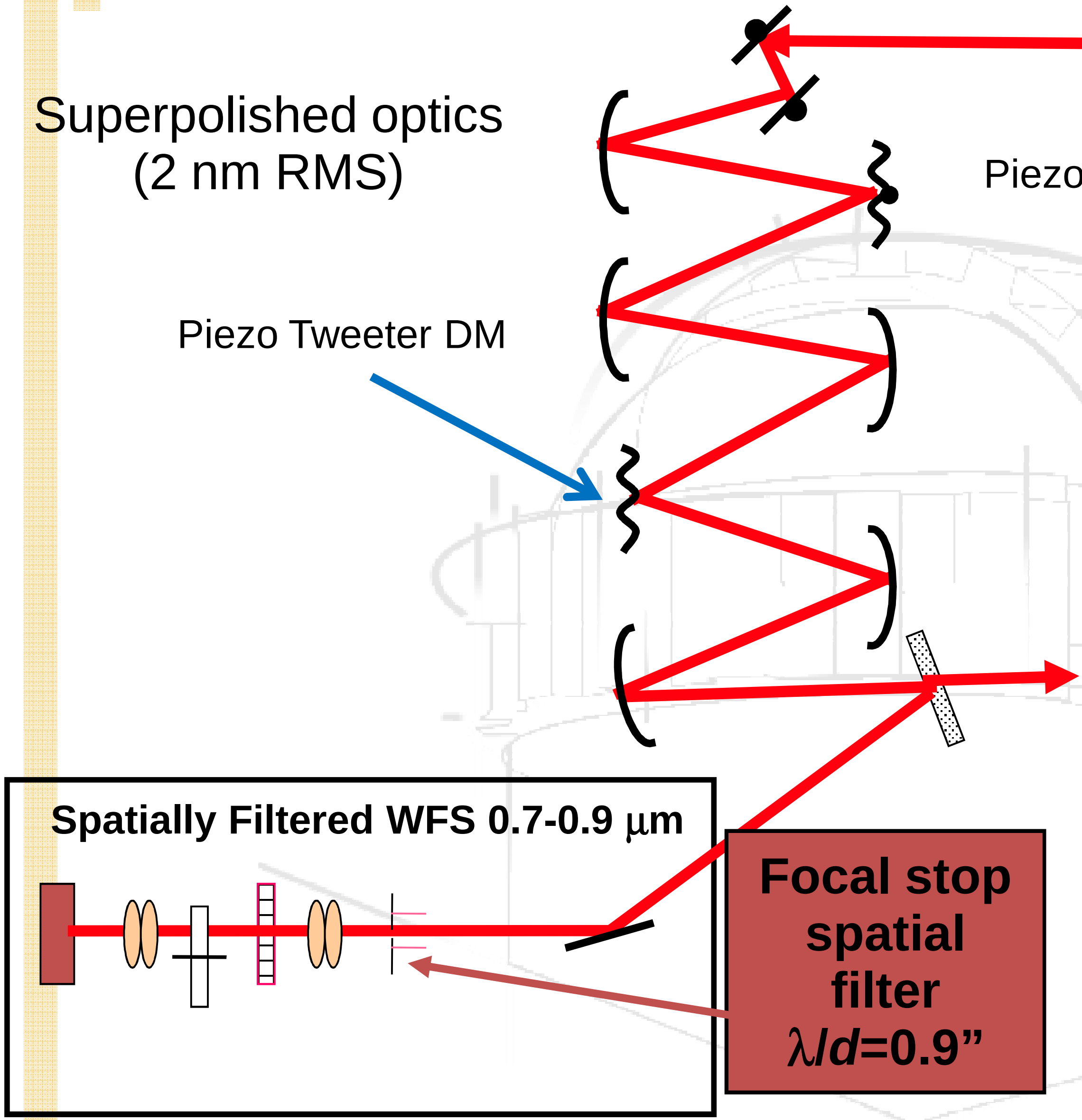
OIWFS (or AOWFS)



Deformable mirror	**4096 actuators (1809 active)**
Subaperture	**18 cm**
Control rate	**1500 Hz**
Wavefront sensor	**Spatially-filtered SH** **700-900 nm**
Strehl @ 1.65 μm	**>0.9**
Guide star mag	***I*=<9 mag.** **(V<11 aux.)**

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OIWFS and LOWFS Limits

http://www.gemini.edu/sciops/instruments/gpi/instrument-performance?q=node/12166

GPI limiting magnitudes are determined by several components, the OI WFS (I-band), the LOWFS (H-band), and the IFS (selected science filter).

In addition the observing conditions add another layer of limits. Thus the brightest of the science object is limited in **I**-band from the AOWFS, in **H**-band from the LOWFS (not a constraint in DIRECT mode as then no coronographic mask is used and no LOWFS is possible).

	Maximum brightness [mag]	**Minimum brightness [mag]**
I-band (AOWFS)	1	9.0
H-band (LOWFS)*	1	9.0

*Only valid in **Coronographic** mode, in the **Direct** mode there is no LOWFS and thus no constraint imposed by the LOWFS.

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OIWFS and LOWFS Weather Limits

http://www.gemini.edu/sciops/instruments/gpi/instrument-performance?q=node/12166

The given magnitude limits for the AOWFS and the LOWFS (if used) should be modified in the following way for worse than IQ70 CC50 conditions:

Observing conditions	Decrease of faintness limit [in magnitudes]**
IQ70 CC70	1.5
IQ85 CC50	1.5
IQ85 CC70	3

**Note that the decrease in magnitudes is ONLY applied to the faint end, it does not mean that brighter than normal targets can be observed. This is to make operations safe and avoiding locking on noise in the control loops.

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IFS Limiting Magnitudes

http://www.gemini.edu/sciops/instruments/gpi/instrument-performance?q=node/12166

The selected observing mode is strongly affecting the brightness of the target that can be observed with the IFS without saturating in the selected science wavelength by the IFS.

The principal four modes (each that can be done in all the filters Y, J, H, K1 and K2) are Coronographic Spectroscopy (the "-coro" modes), Coronographic polarization (the "-coron-pol" modes), Direct (the "-direct") observations with either spectroscopy or polarization. Note that this limit is applicable to the relevant science wavelength.

Observing Mode	Maximum brightness [mag]
[Y...K2]-coro	1
[Y...K2]-coron-pol	3
[Y...K2]-direct	8
[Y...K2]-direct-pol	11

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IFS Limiting Field of View

The GPI IFS has a field of View of 2.4”x2.4”

- Always centered on the OIWFS star
  - NO offsets allowed in the IFS

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Coronographic Mask/Mode

http://www.gemini.edu/node/11550

The tables below list the properties of the standard GPI coronagraphic configurations.
GPI will automatically select appropriate apodizer, focal plane masks, and Lyot stops for each wavelength.

Configuration	Filter	**Wavelength range (1/2 power bandpass, microns)**	Spectral resolution (per 2 pixels)	**Coronagraph focal plane mask diameter (mas)**
Y-coron/coron-pol	Y	**0.95 - 1.14**	34-36	**156**
J-coron/coron-pol	J	**1.12 - 1.35**	35-39	**184**
H-coron/coron-pol	H	**1.50 - 1.80**	44-49	**246**
K1-coron/coron-pol	K1	**1.9 - 2.19**	62-70	**306**
K2-coron/coron-pol	K2	**2.13 - 2.4**	75-83	**306**

Thus the choosen mode will set three important parameters for feasibility:

1. Inner Working Distance
2. Spectral Resolution
3. Wavelength range

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Coronographic Mask/Mode

1. Inner Working Distance
   1. Objects can NOT be seen within the inner working distance

2. Spectral Resolution
   1. Narrow lines not feasible

3. Wavelength range
   1. Can't go outside the band

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Performance

http://www.gemini.edu/sciops/instruments/gpi/instrument-performance?q=node/11552

GPI Performance has one fundamental parameter, which is the measured Contrast.

Nominally this is simple but varies with:

- I-band magnitude → Limits OIWFS
- IQ (nominal performance for IQ70, NO guarantee on performance in IQ85)
- Airmass → Nominal performance ZD=<40, allowed <=50
- Size of the object Extended objects <<2”
- Peak contrast reached ~0.3-0.4” from the object

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Performance Assessment Checks

- IQ
  - PI loosens the constraints but still uses Contrast for IQ70

- Airmass
  - PIT has “built-in” constraints but it means that Dec ~< +15 and Dec >~ 75
  - For the semester the target must be above the ZD~45 for at least 2h to be suitable.

- Size of the object
  - Contrast less for extended object, work in progress on details

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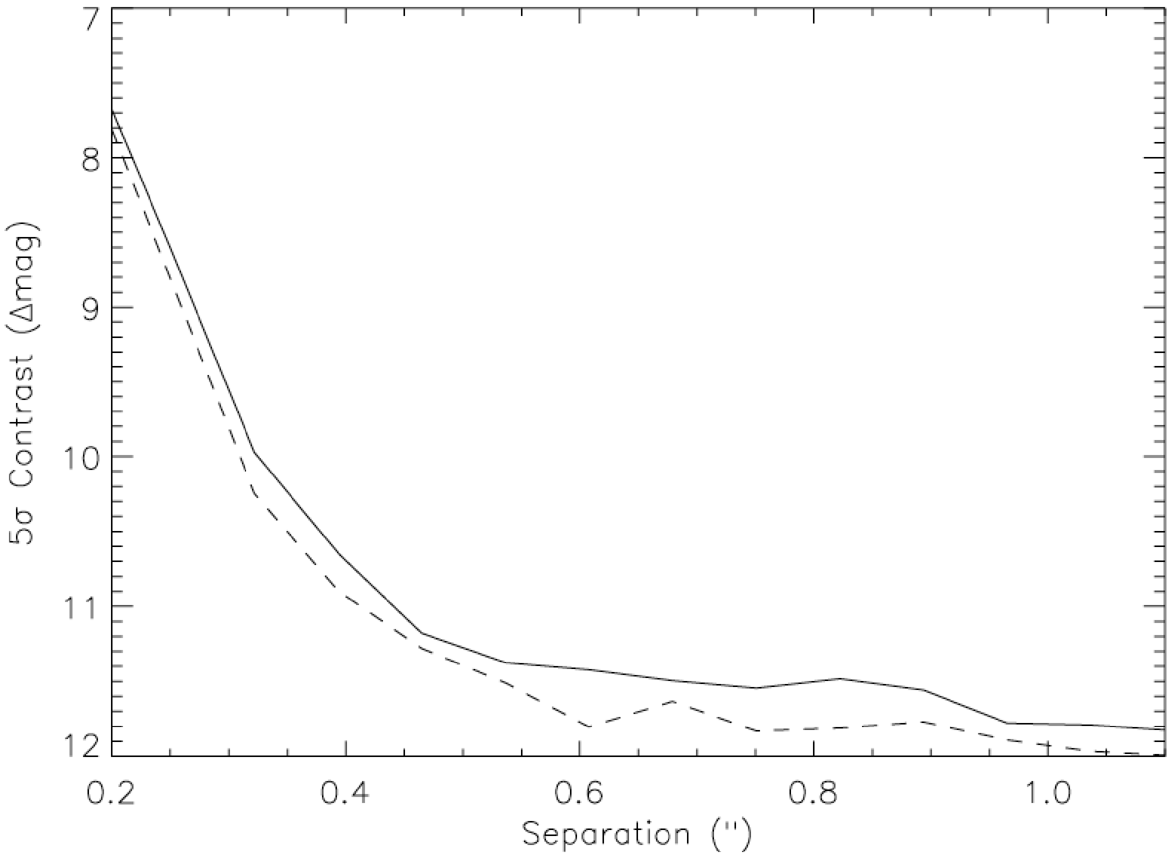
Performance Assessment Checks II

- Peak contrast reached ~0.3-0.4” from the object
  - Contrast drops sharply within this distance
  - DIRECT mode is still work in progress on contrast but expect at a minimum one order (2.5 mag) worse contrast.
  - Postprocessing works great, but not more than ~3 magnitudes



Various Items

1. Acquisition **must** be done for each requested mode (15m)

2. NO change of modes inside an observation, this includes filters.

1. Baseline calibrations includes:
    1. PSF standards
    2. Telluric cancellation standards
    3. Polarization standards
2. Close binaries are NOT allowed:
    1. Affects OIWFS
    2. May also saturate the IFS as the second is unblocked (direct)

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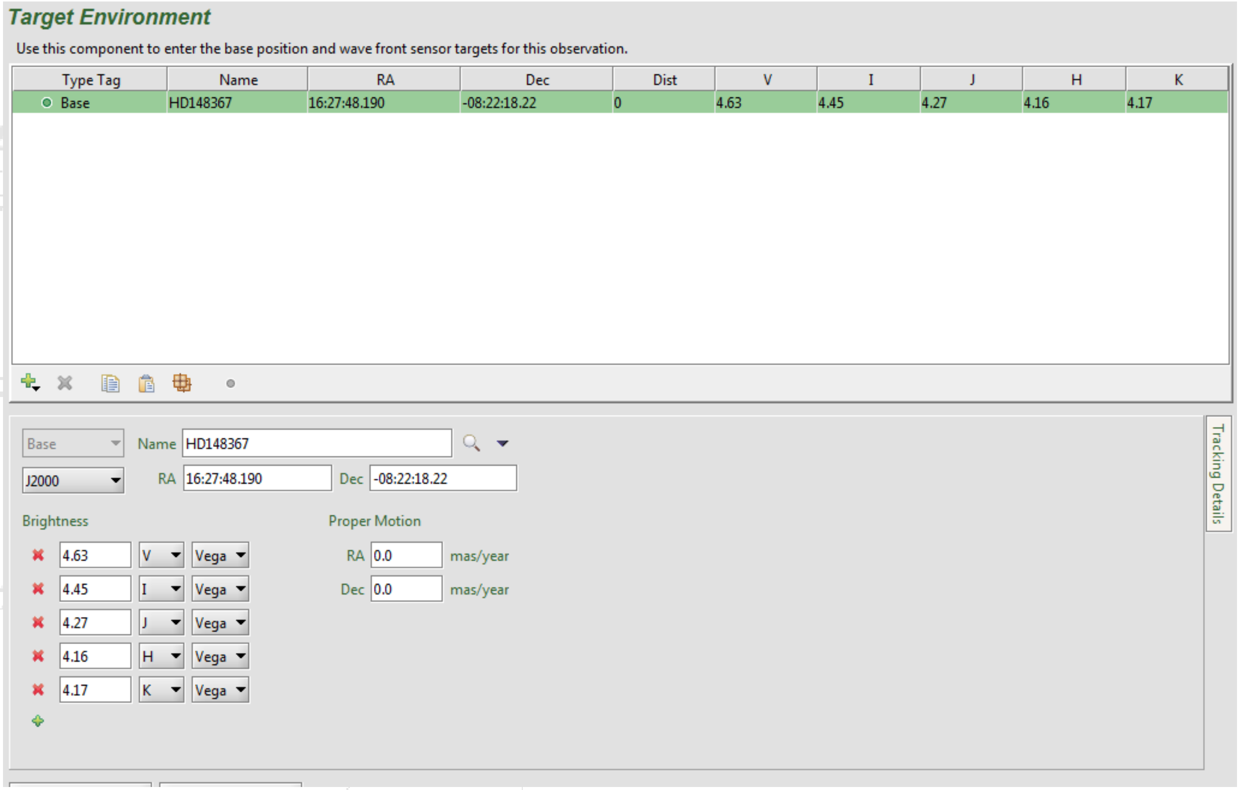
Phase II Checking

OT has a lot of built-in checks on magnitudes and modes. But sometimes issues slips through.

Common issues:

- I, Y, J, H, and K must have defined magnitudes
- Proper motions are critical, the OIWFS has a field of view of ~1" and thus wrong proper motions slows down acquisition, most stars that GPI can observe have pRA>0 and pDec>0
- For the same reason accurate source coordinates are important, use the search when possible.



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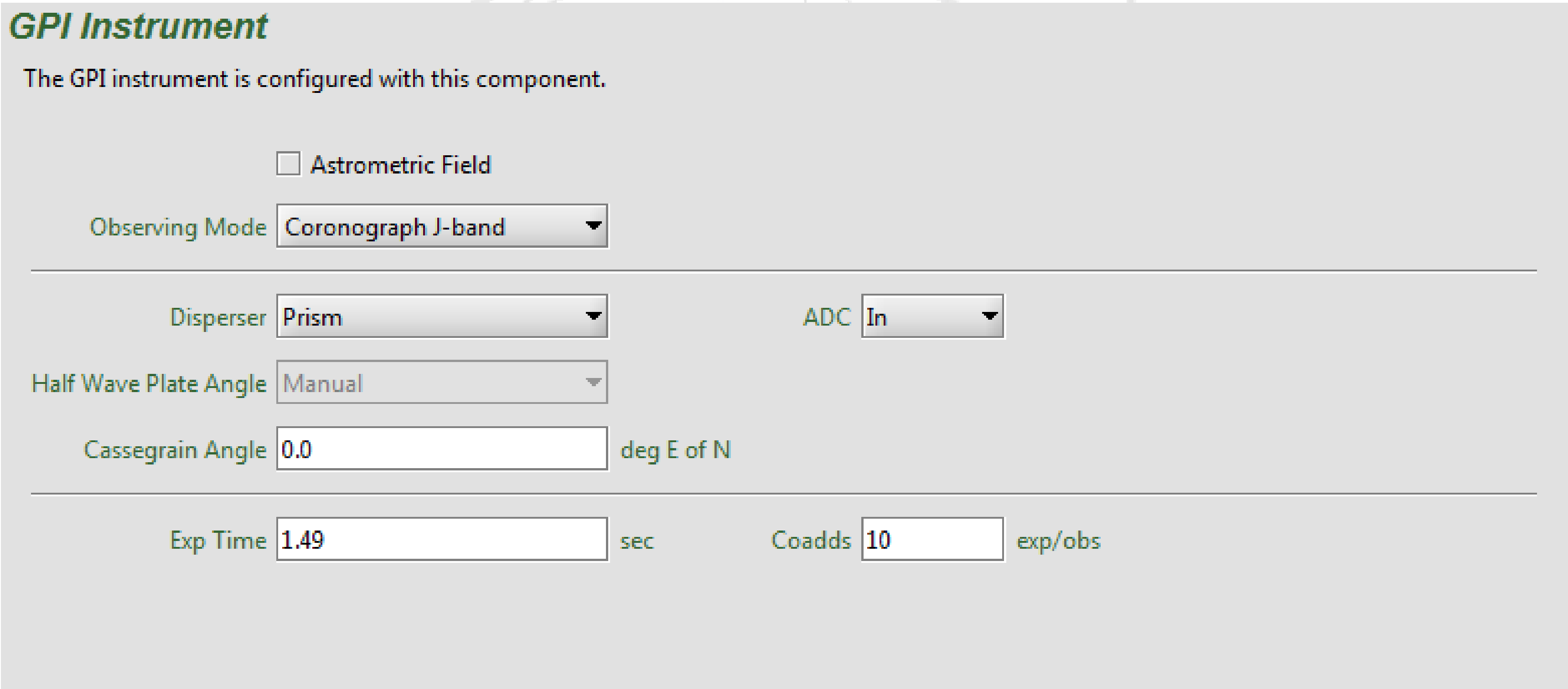
Phase II

- Cassegrain angle ONLY 0.0 (no longer visible to the end-user)
- Observing Mode **must** be selected.
- Choose Prism or Wollaston



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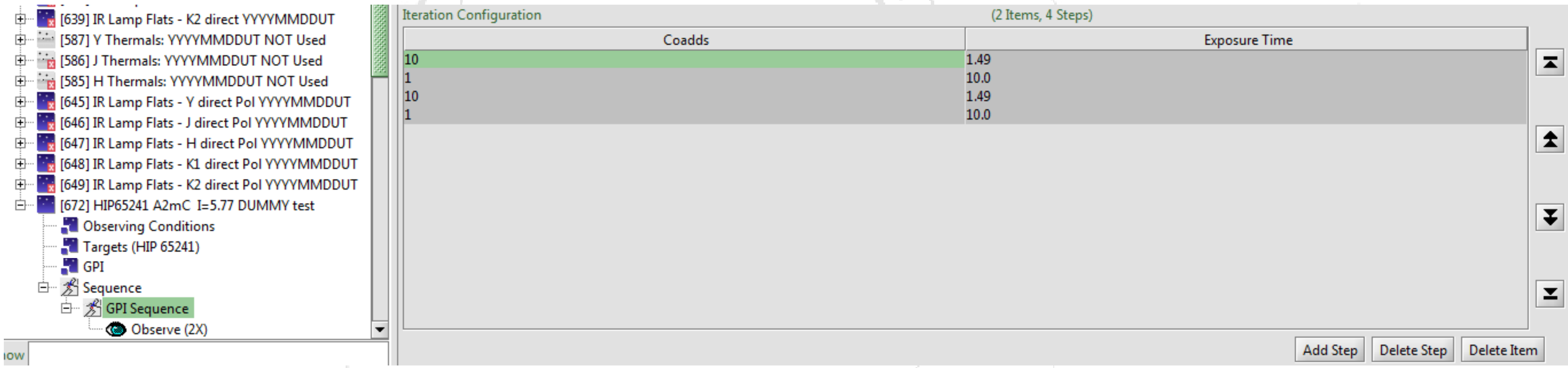
Phase II Checking

• The iterator is basically practical only for looping through exposure-times and coadds settings.

Actually we are looking at deprecating the looping in the sequencer as standard observations are not using the feature.



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Observations are organized into Observing Groups. The APPLY skeleton will automatically create these three sequences. Each group consists of three components:

1) Align and Calibration: ONLY for internal calibration purposes. Should **not** be edited by the PI.
2) ARC sequence for prism mode (no arcs for Wollaston/Polarization): Arcs being taken in the science band, though for K1 and K2 the arc is taken in H as K1 and K2 arcs would require ~0.5h instead of the 60s in H. Should **not** be edited by the PI. The arc is used by the pipeline to do a proper flexure correction.
3) Science sequence: PI should ONLY adjust the exposure time and coadds, and the number of observes to get the total desired time.

Gemini Observatory are taking arcs, flats, telluric standards, spectrophotometric standards, darks and astrometric fields as part of the standard sequence. The PIs don't need to add any calibrations, if added they are all charged to the PI allocated time.

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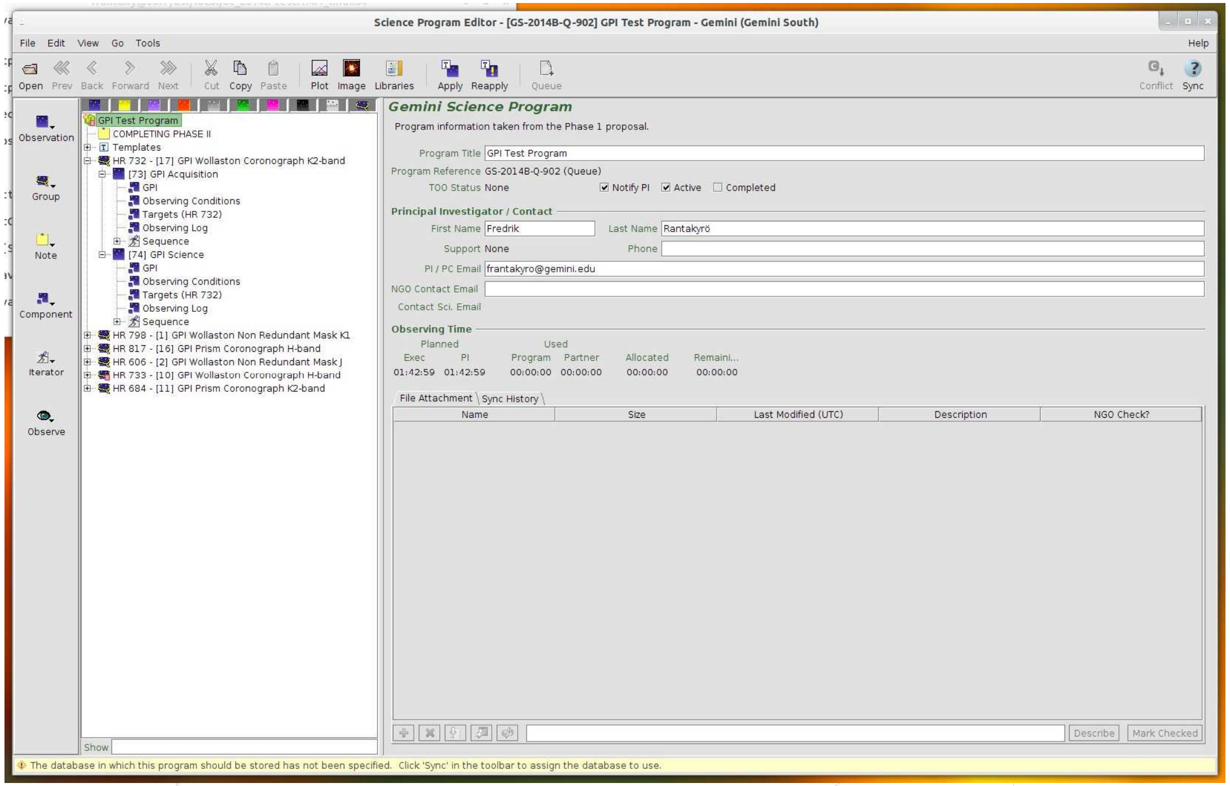
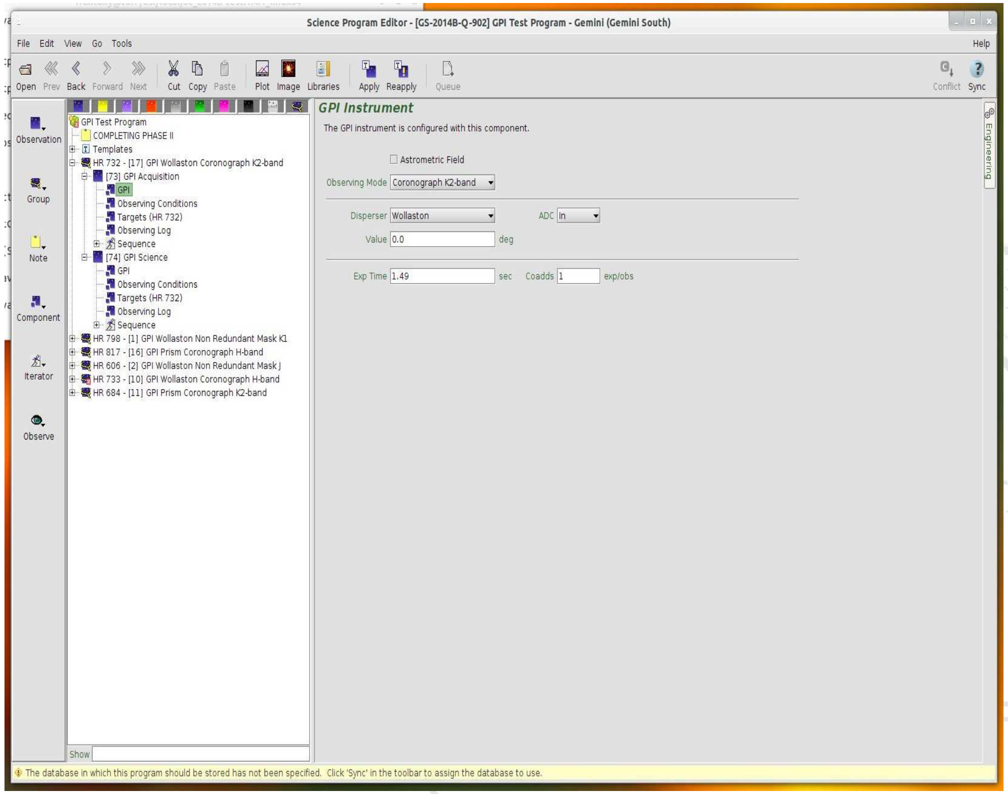
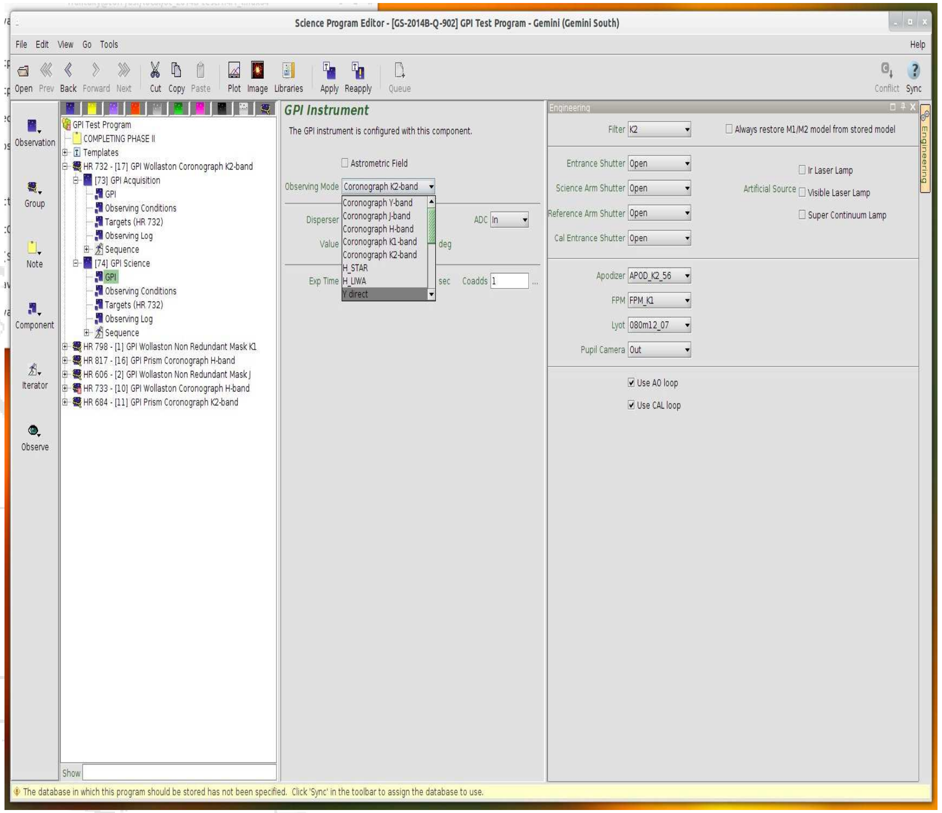


Gemini Planet Imager





Manual editing of a science component requires:

- Choose the meta-mode (right picture)
- Choose either Spectroscopy (Prism) or Polarization (Wollaston)
- Choose Exposure time and coadds based on target magnitude
- Set number of observes to suitable number

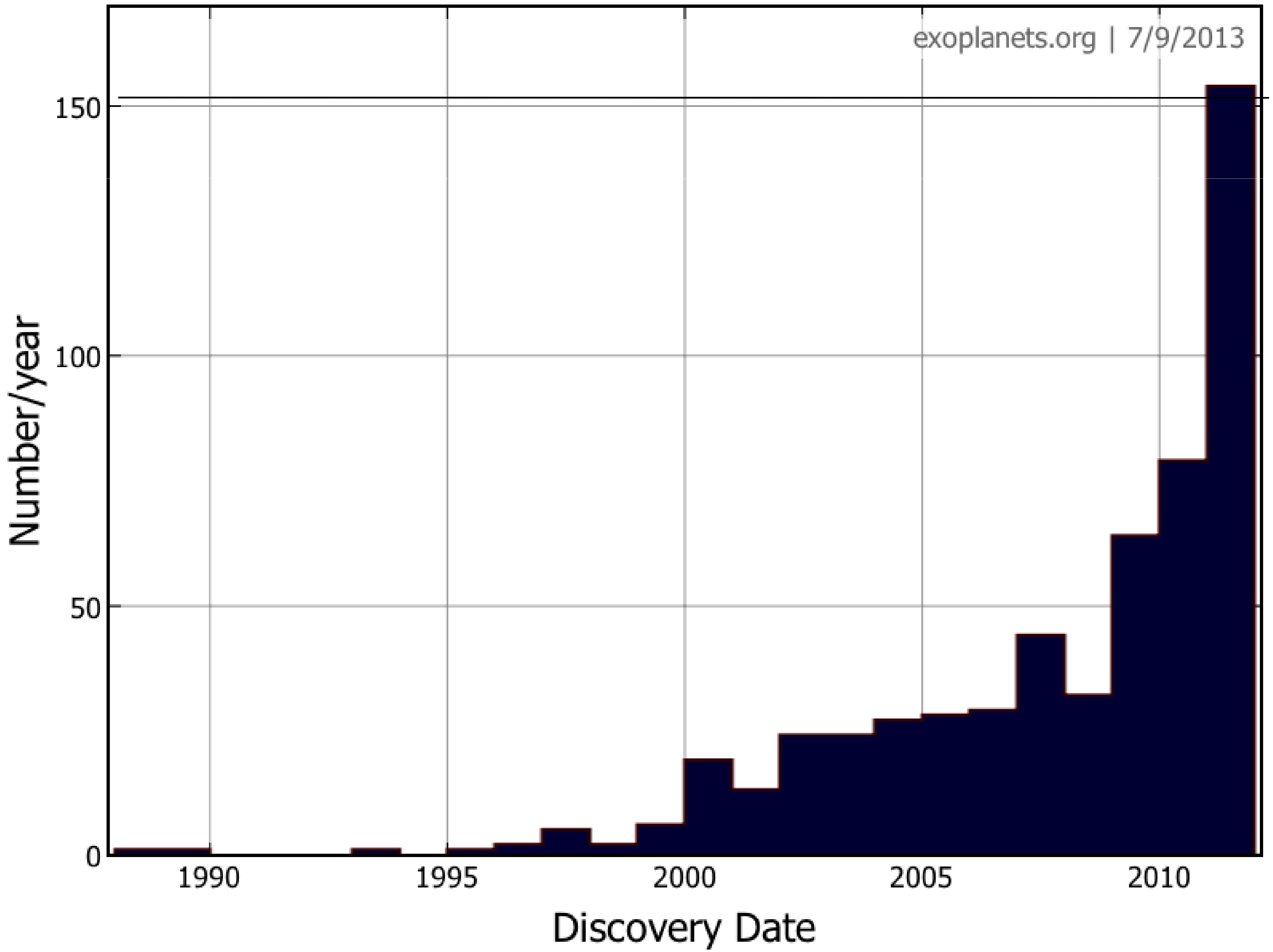
Core Science

- Direct detection of young, luminous planets
- Luminosity history & planet formation mechanisms
- Exploration of jovian planet-forming zone
- Map $5 < a/\mathrm{AU} < 30$
- Core accretion vs. gravitational instability
- Complement Doppler & astrometry
- Spectroscopy of cool planetary atmospheres

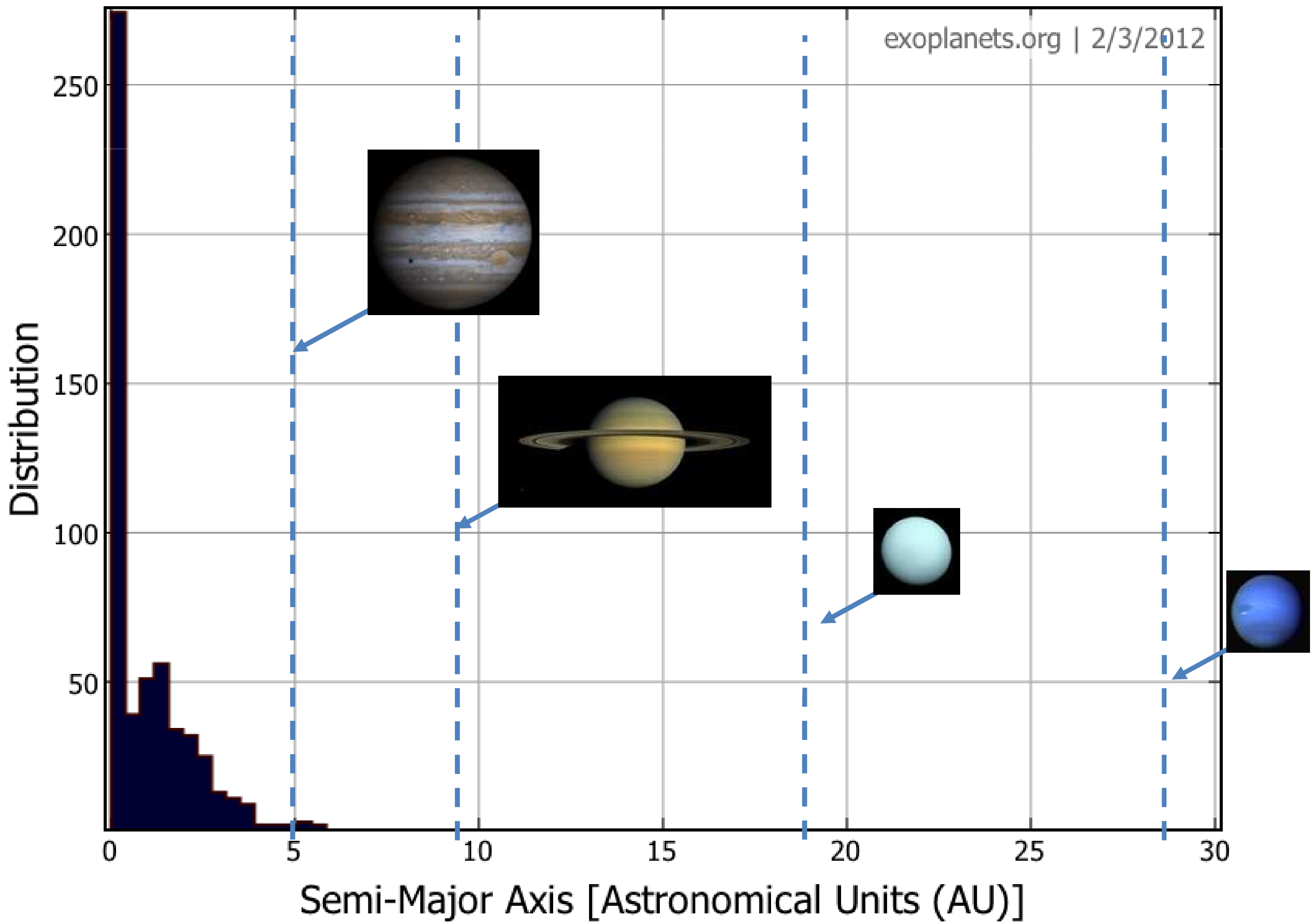
Core Science II

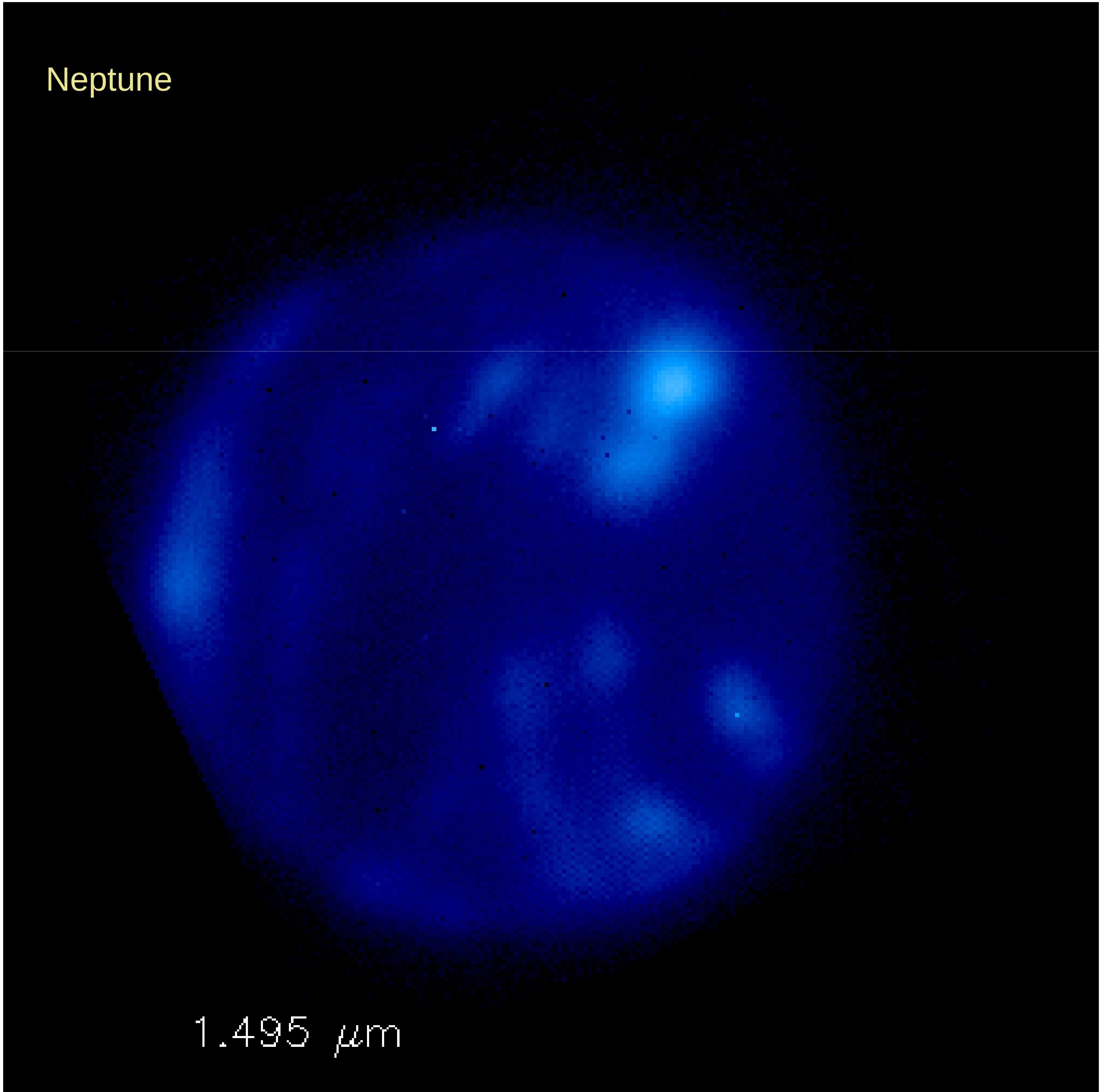
- 300 < T_{eff}/K < 500 between H_2O (water) & NH_3 (methane) condensation of debris disks
- Occurrence, morphology & composition of debris disks
- Small solar system bodies: geomorphology & volcanism of icy moons
- Asteroid moonlets

Exoplanet Discovery

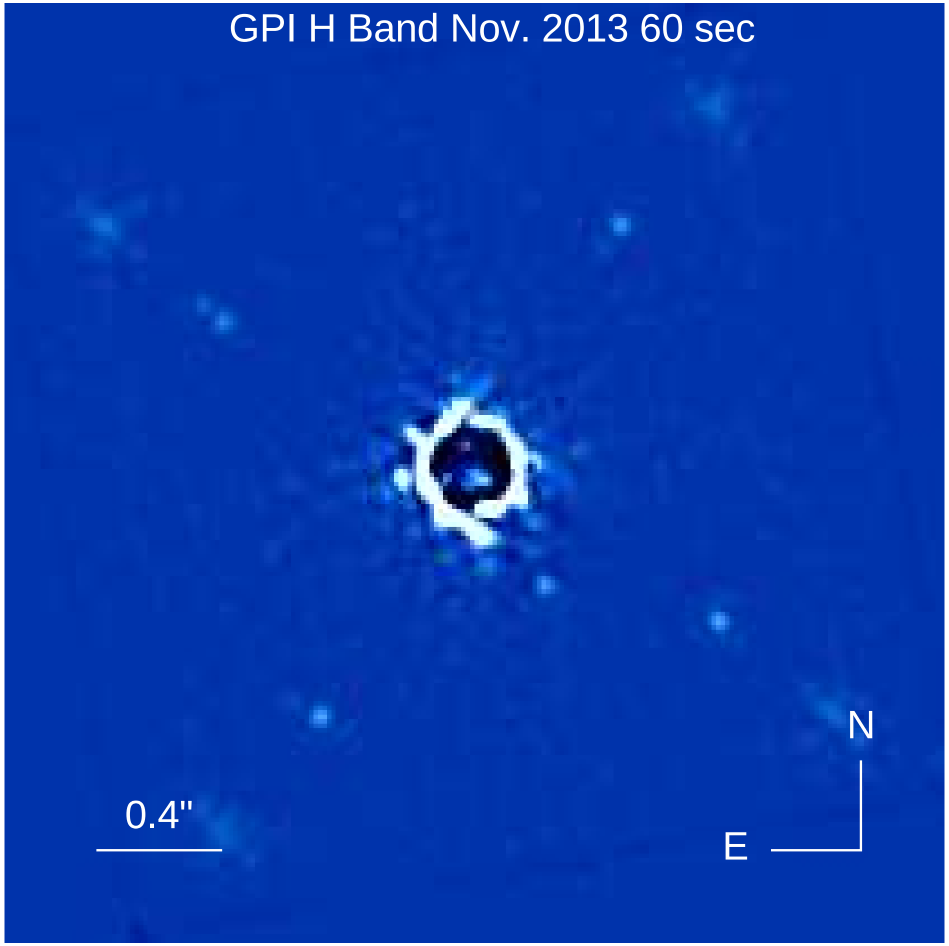


Exoplanets in Context




Neptune
1.495 μm

Beta Pictoris b



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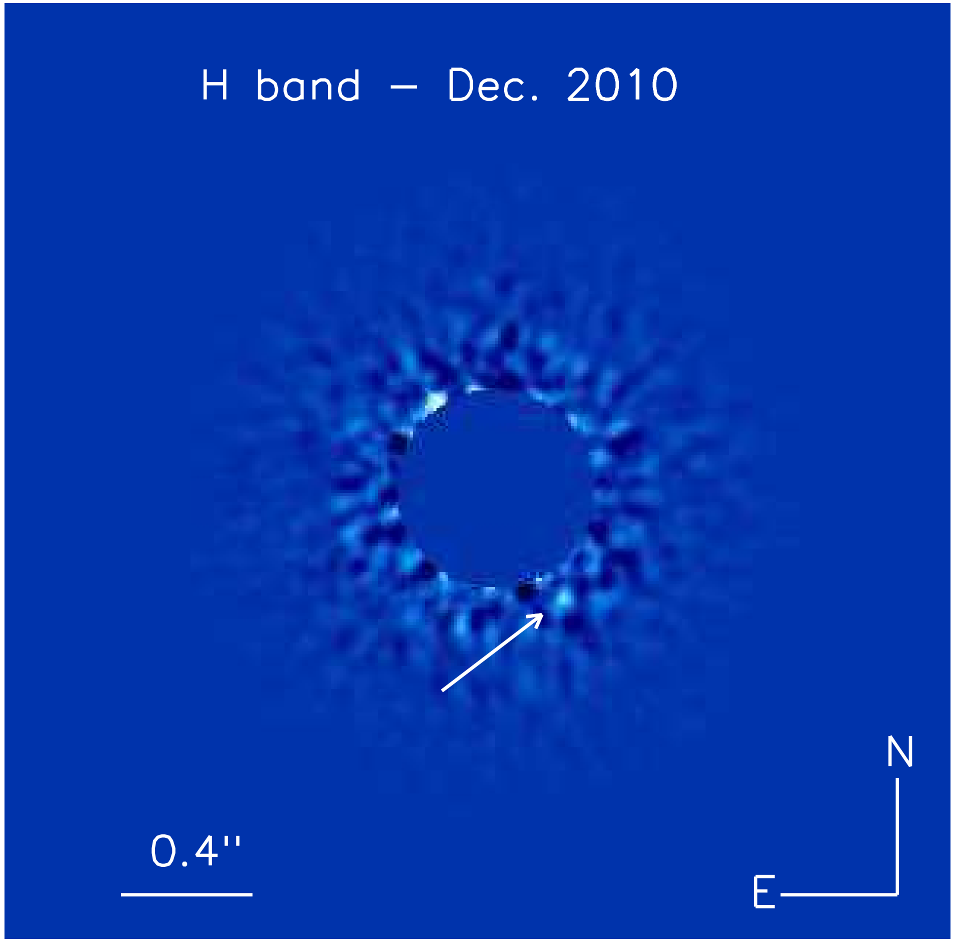
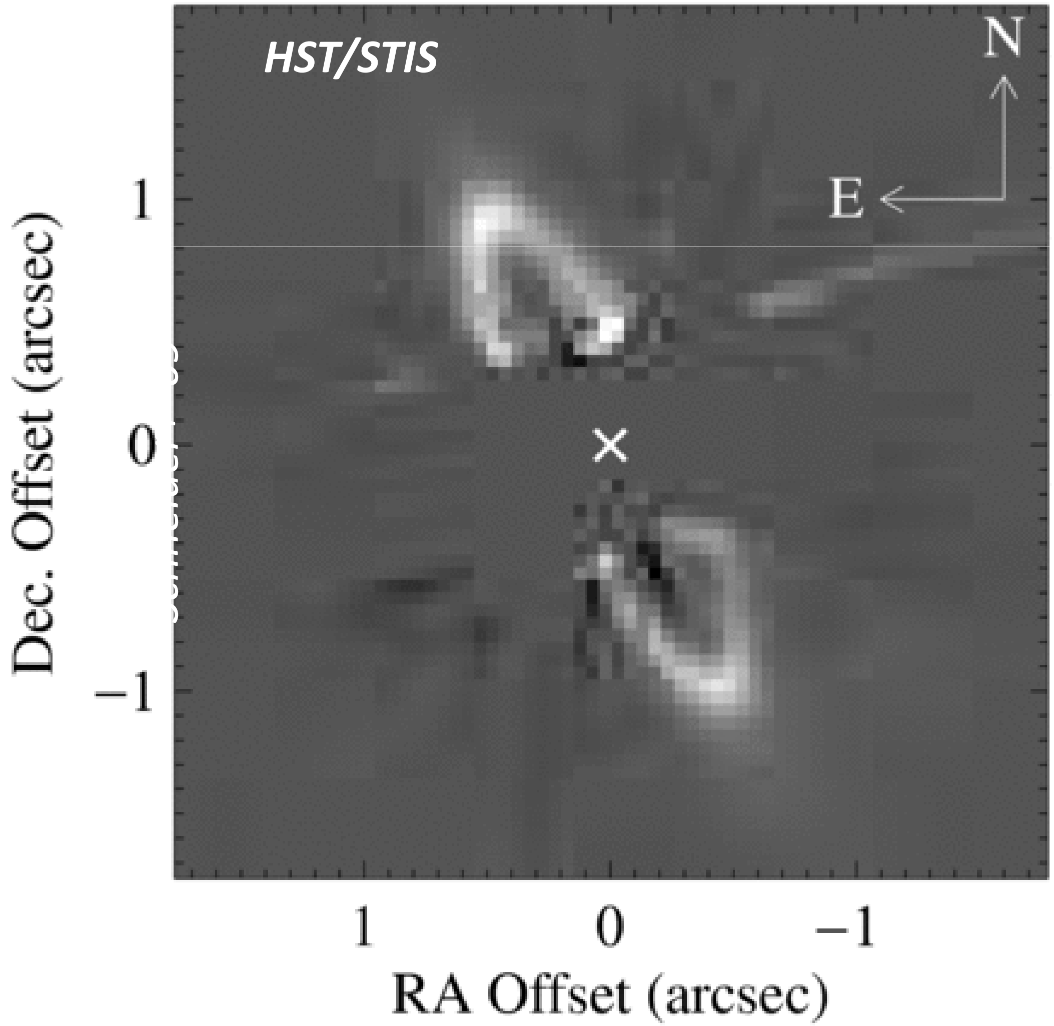
60 seconds

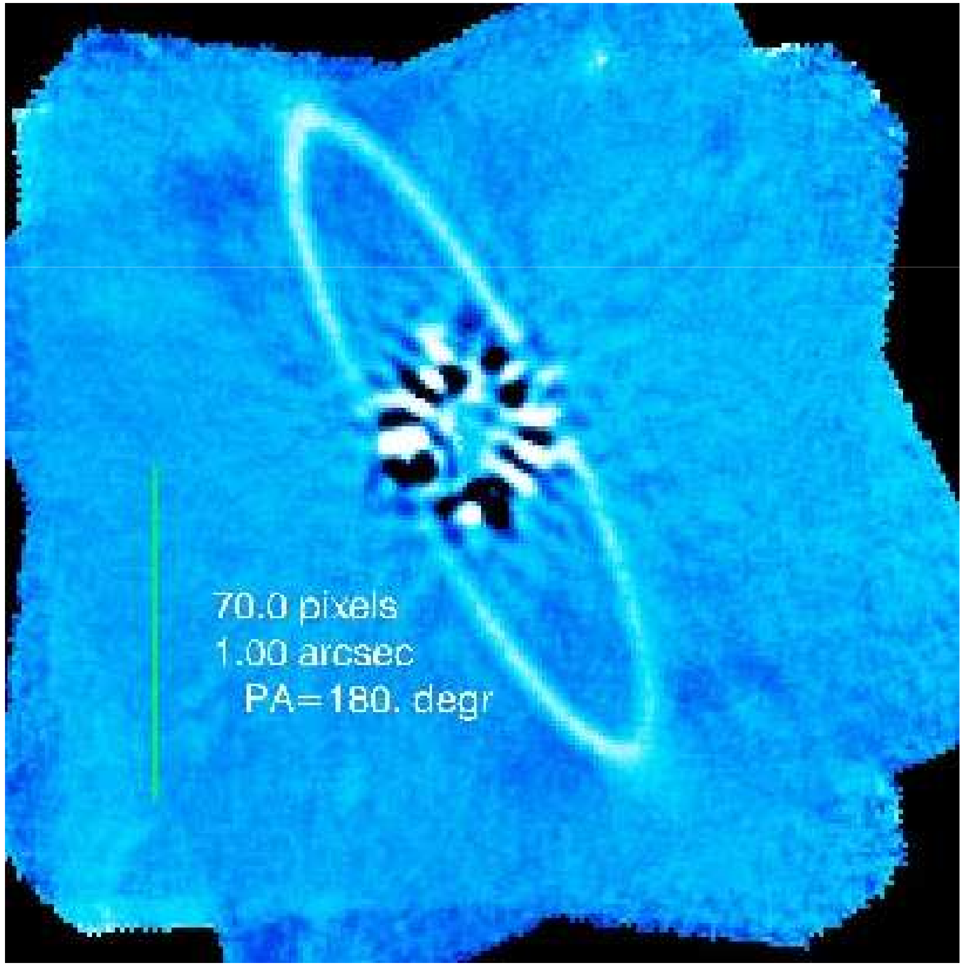


Gemini NICI

3952 seconds

HR 4796 A

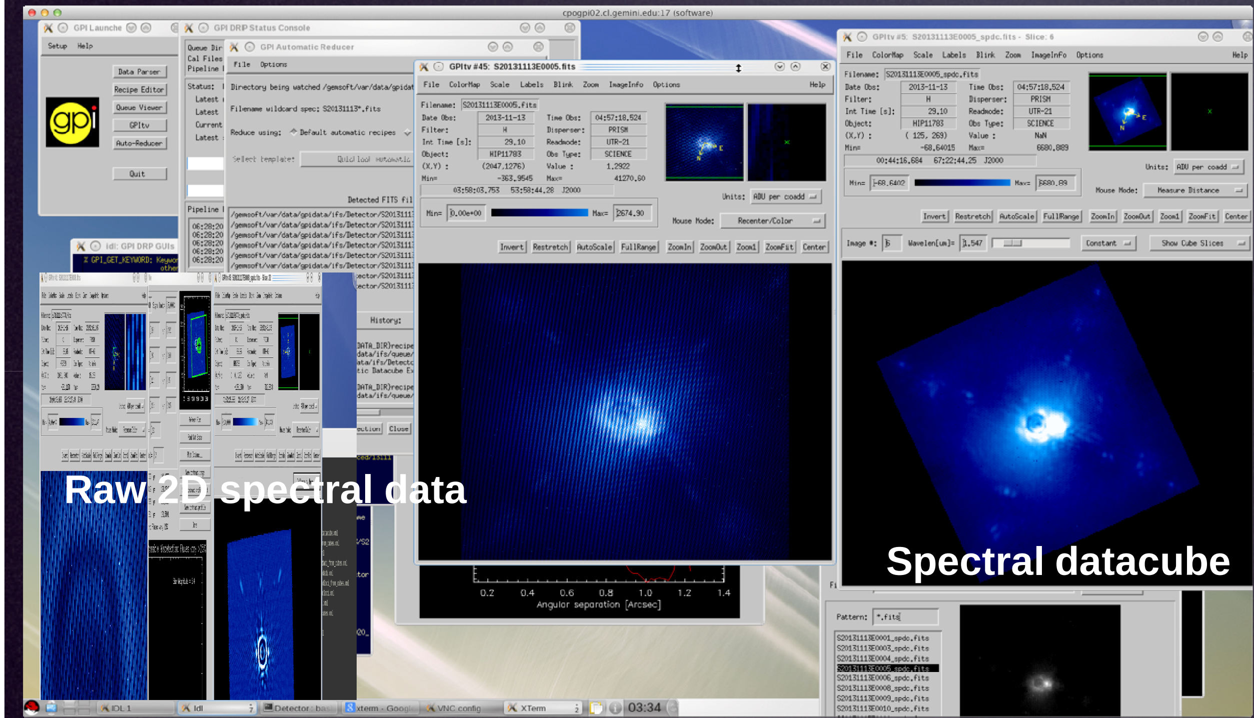




GPI

- Confirmation of basic ring geometry (*e≈0.05, i≈77°*)
- Offset of ring center w.r.t star, as previously suggested
- Narrow ring, evidence for "streamers"?
- Moderate preference for forward scattering

The GPI Data Pipeline



User-friendly reduction, calibration, & analysis for high contrast integral field spectroscopy and polarimetry.

Transforms raw data to calibrated datacubes in spectral and polarimetric modes. Runs in real-time at Gemini South providing automated quicklook data cubes for observers, and is available open source for users to perform their own publication-quality calibrated reductions.

Available from http://planetimager.org/datapipeline

Overview in Perrin et al. 2014 SPIE (in prep) + ten associated SPIE papers on calibrations and algorithms

GPI Data Analysis Team SPIE Papers

GPI observational calibrations I: Overview of the GPI data analysis pipeline. Perrin et al.

GPI observational calibrations II: Detector performance and calibration. Patrick Ingraham et al.

GPI observational calibrations III: Empirical measurement methods and applications of high resolution microlens PSFs. Patrick Ingraham et al.

GPI observational calibrations IV: Wavelength calibration and flexure correction for the integral field spectrograph. Schuyler Wolff et al.

GPI observational calibrations V: Astrometry and distortion. Quinn Konopacky et al.

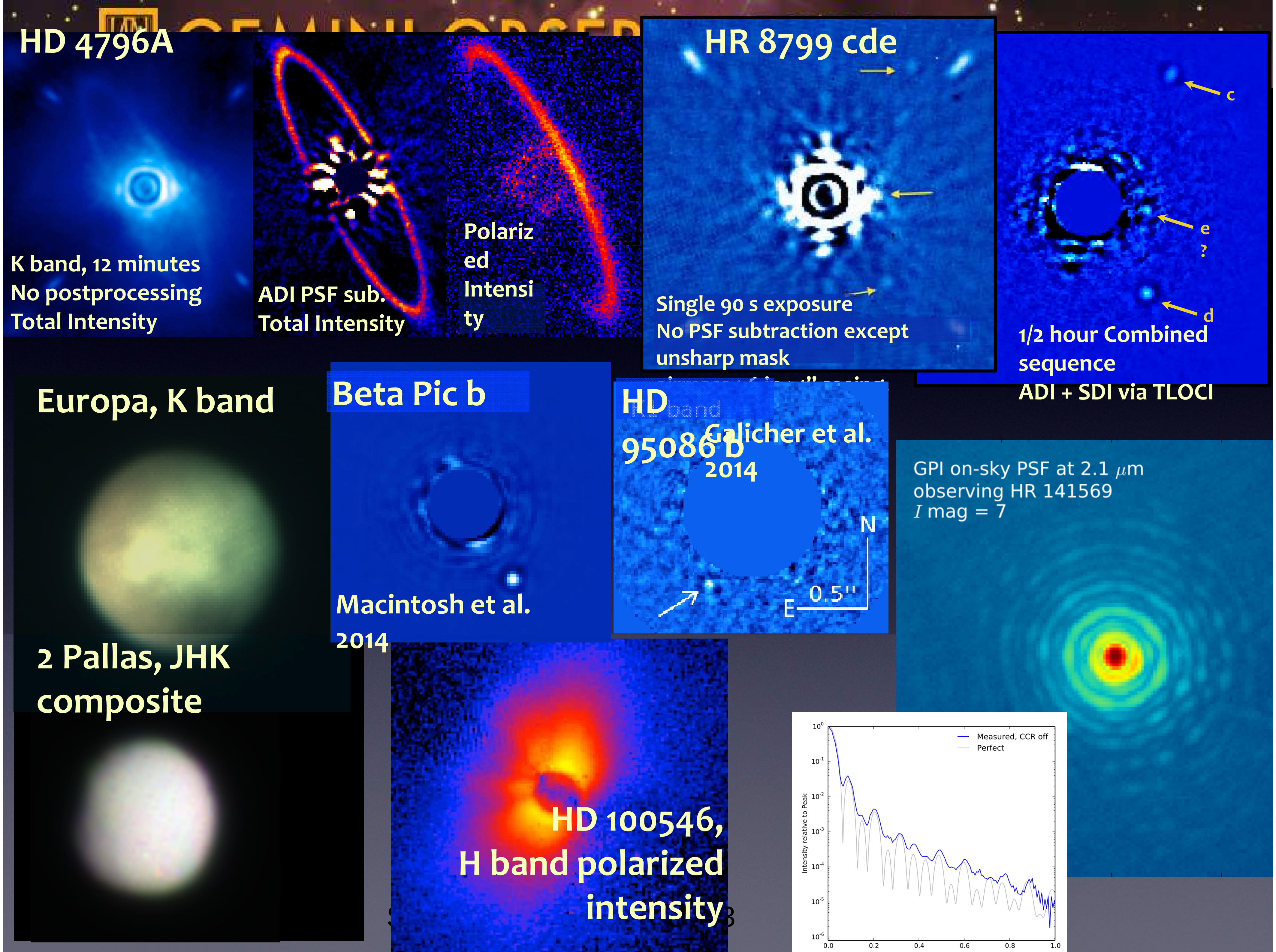
GPI observational calibrations VI: Photometric and spectroscopic calibration for the integral field spectrograph. Jerome Maire et al.

GPI observational calibrations VII: On-sky polarimetric performance. Sloane Wiktorowicz et al.

GPI observational calibrations VIII: Characterization & Calibration using satellite spots. Jason Wang et al.

GPI observational calibrations IX: Least square inversion flux extraction. Zachary Draper et al.

GPI observational calibrations X: Non-redundant masking on GPI. Alexandra Greenbaum et al.


HD 4796A
K band, 12 minutes
No postprocessing
Total Intensity
ADI PSF sub.
Total Intensity
Polariz
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Intensi
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HR 8799 cde
Single 90 s exposure
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unsharp mask
c
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d
1/2 hour Combined
sequence
ADI + SDI via TLOCI
Europa, K band
Beta Pic b
Macintosh et al.
2014
HD
95086 b
Galicher et al.
2014
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E
0.5''
GPI on-sky PSF at 2.1 μm
observing HR 141569
I mag = 7
2 Pallas, JHK
composite
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intensity
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Intensity relative to Peak
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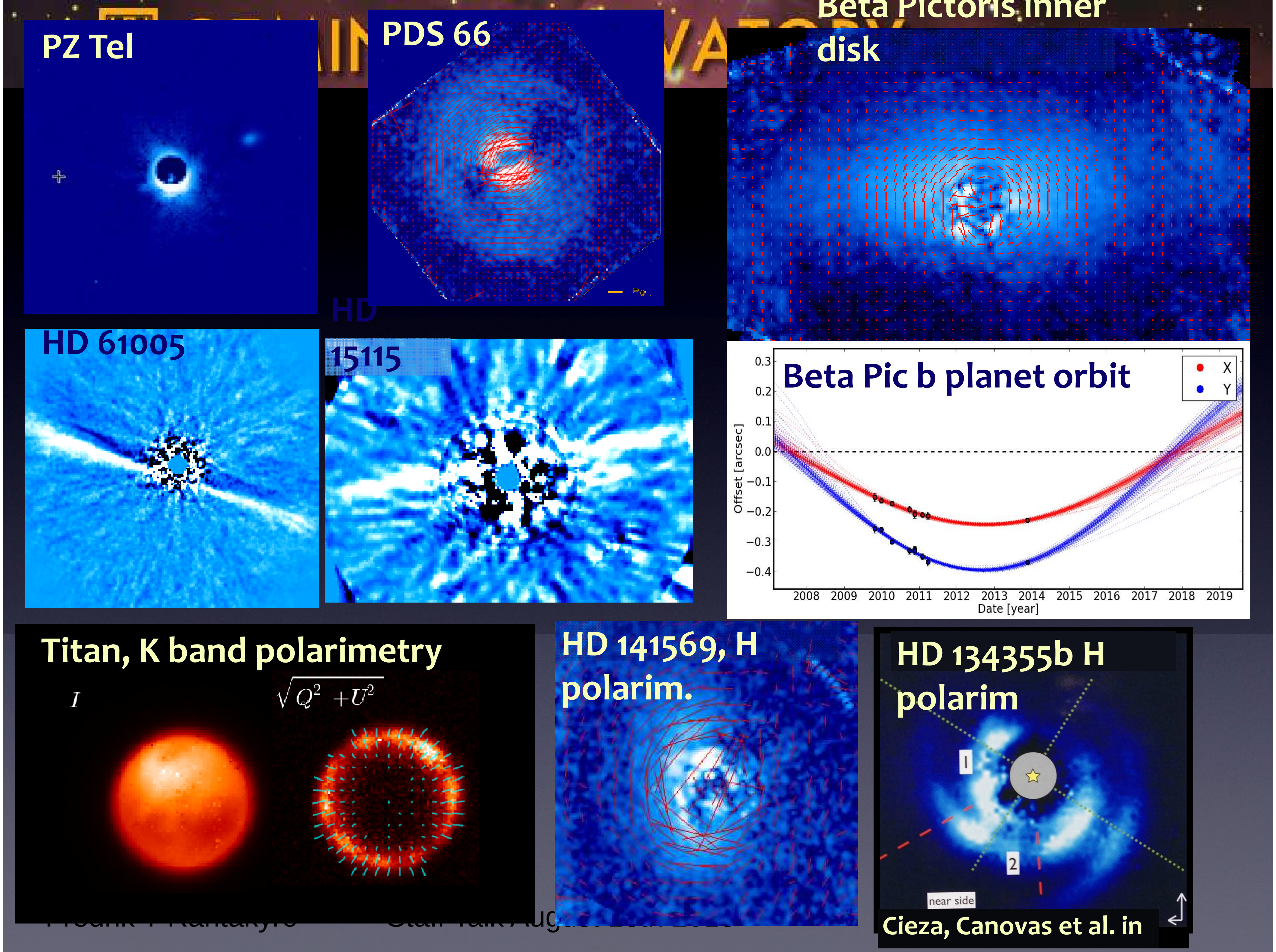
PZ Tel
PDS 66
Beta Pictoris inner disk
HD 61005
HD 15115
Beta Pic b planet orbit
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Titan, K band polarimetry
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HD 134355b H polarim
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near side
Cieza, Canovas et al. in