Constraining The Formation Of Directly Imaged Exoplanets by Upgrading the Gemini Planet Imager (GPI)'s Wavefront Sensor

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Talk Outline

Broad

Exoplanet detections methods & direct imaging

Planet formation theories (hot vs. cold start)

Instrument detection capabilities & formation characterization

Adaptive optics systems for exoplanet imaging

Upgrading Wavefront Sensor for better contrast

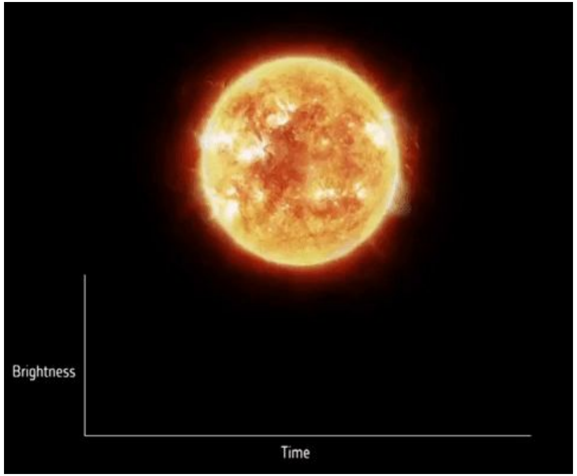
Characterizing a Detector (Camera)

My work!

Specific

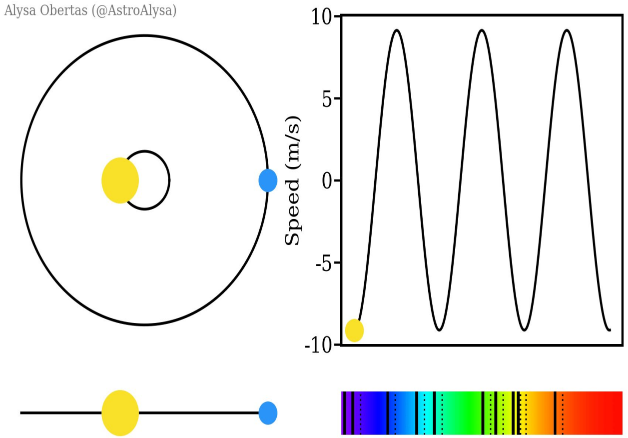
Exoplanet Detection Methods...

Transit Method



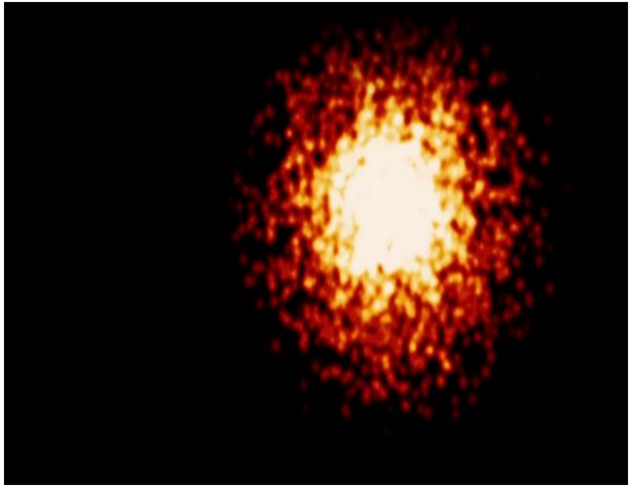
Credit: NASA

Radial Velocity Method



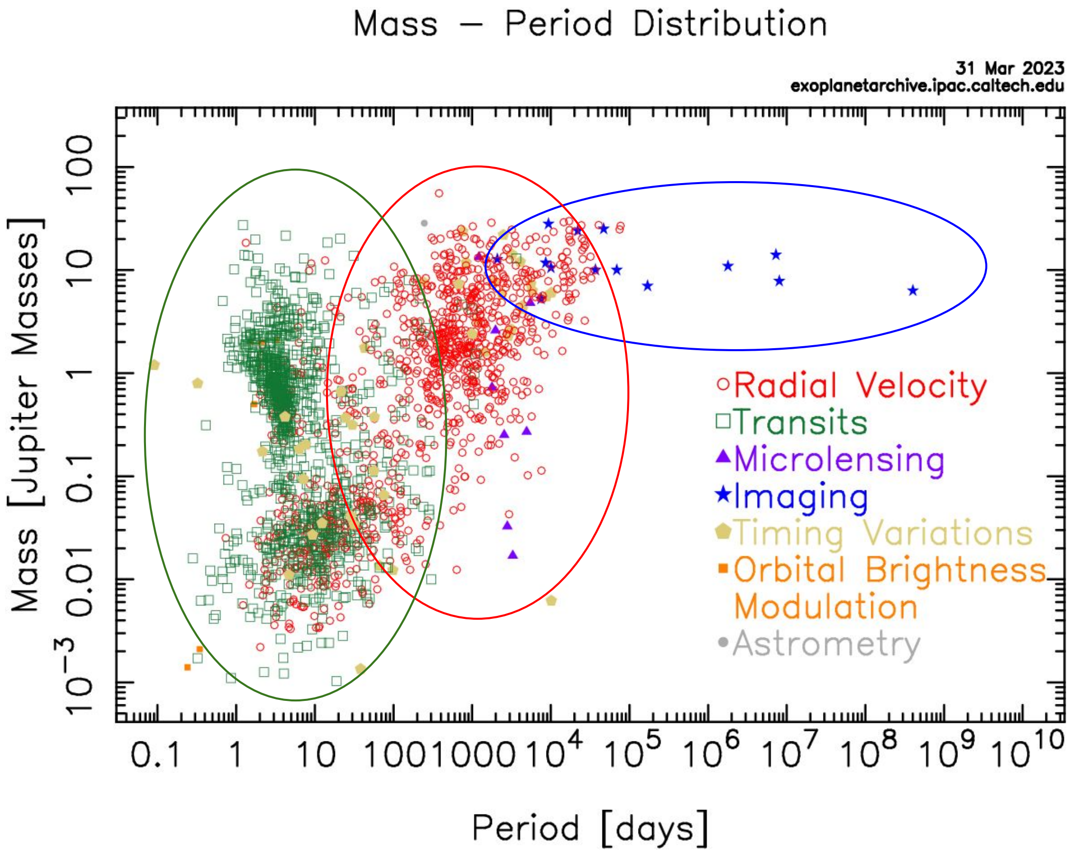
Credit: Alysa Obertas

Direct Imaging Method



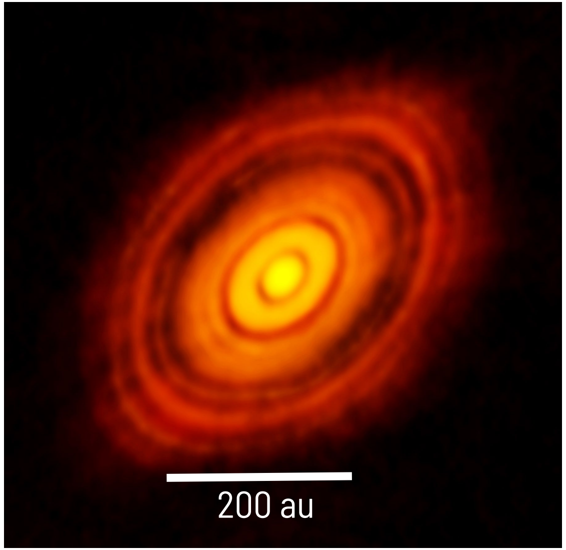
Credit: NASA

Exoplanet Discoveries So far...



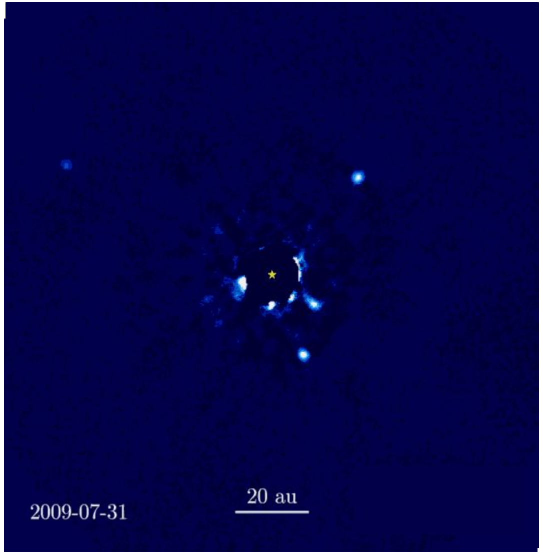
How do directly imaged exoplanet systems form?

Protoplanetary Disk **(Age ~ 100,000 years)**



Credit: ALMA, C. Brogan, B. Saxton
HL Tau System

Planetary System **(Age ~ 30 million years)**



Credit: Jason Wang (Northwestern)/William Thompson (UVic)/Christian Marois (NRC Herzberg)/Quinn Konopacky (UCSD)

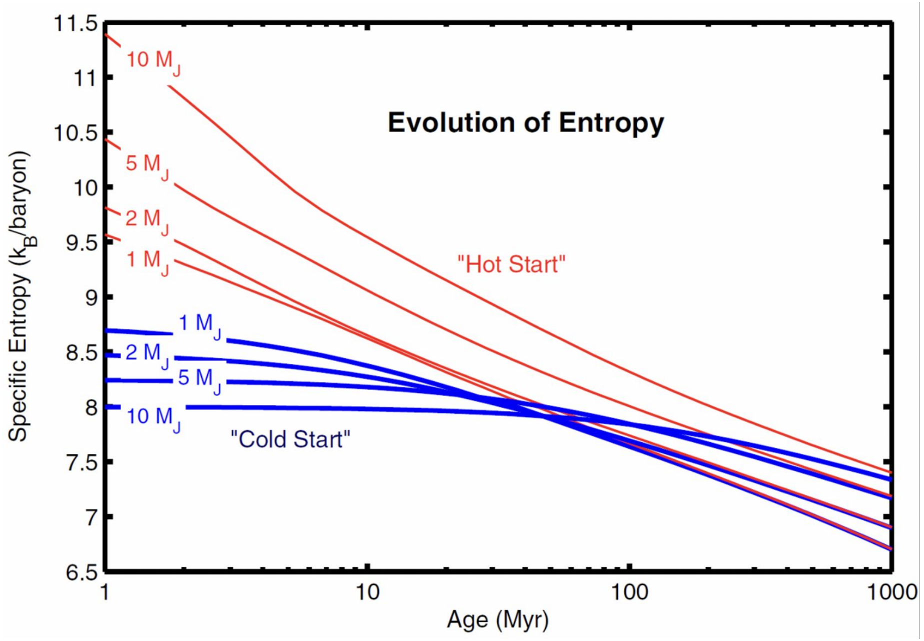
HR 8799 System

Two Main Planet Formation Theories.... Credit: NASA and A. Feild (STScI))

"Cold Start"

"Hot Start"

Formation & Entropy (Spiegel & Burrows 2012)

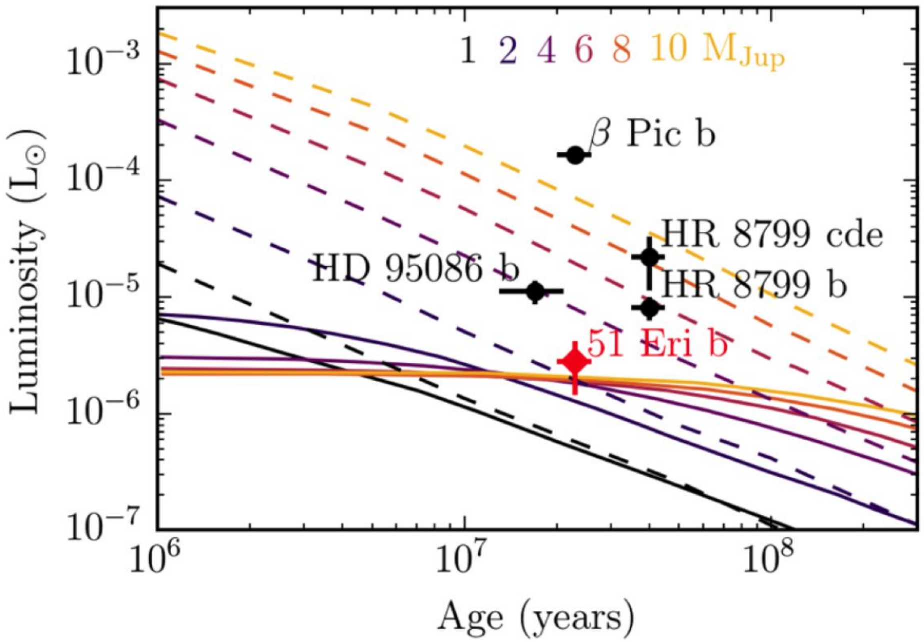


Core accretion: the solid core accretes gas through an accretion disk. This **process cools the gas**, **causing it to lose much of its initial entropy** and forms a giant planet that has low initial entropy

Gravitational Instability: the gas that collapses directly to form a giant planet retains most of it initial entropy, resulting in high initial entropy (i.e. a “hot-start”).

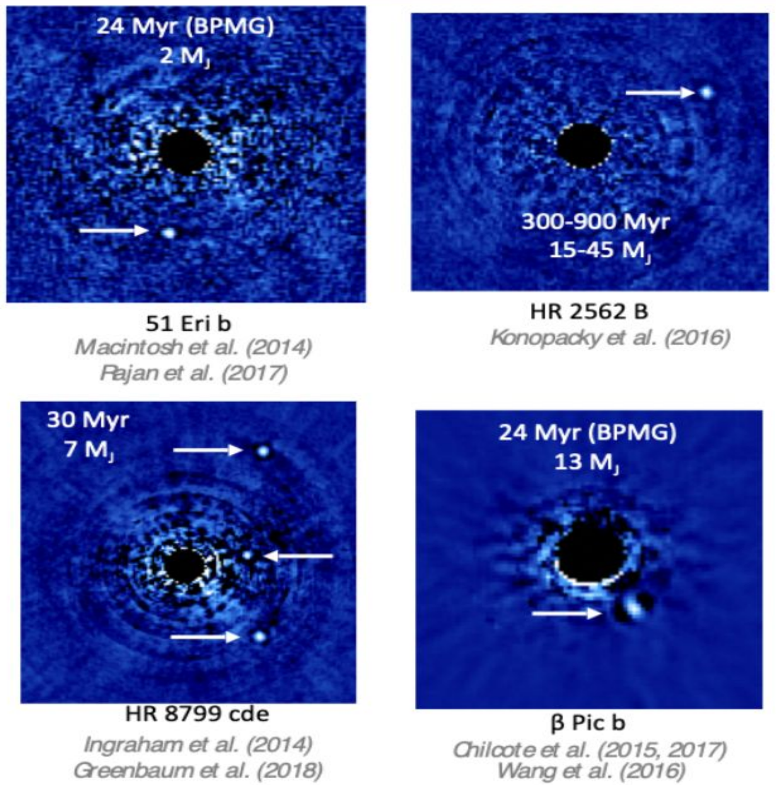
Entropy & Luminosity (Chilcote et al 2018)

In first few million years after formation, **giant planets that started hot can be ~10 to 1,000x more luminous than those that started cold** depending on the giant planet's mass and spectral band.



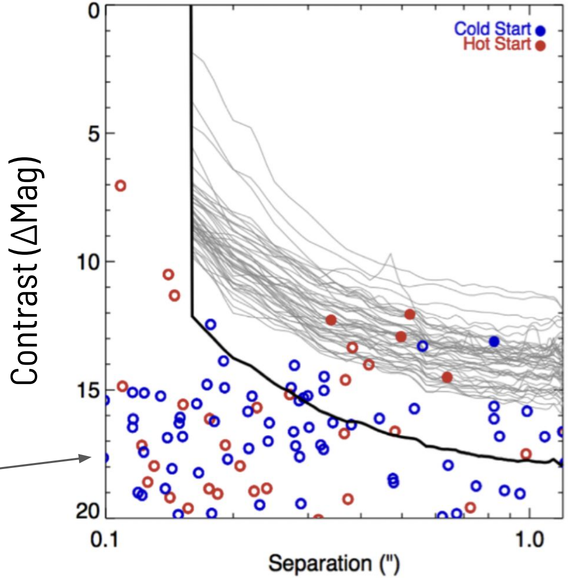
GPI 1.0

- The Gemini Planet Imager is a **high contrast imaging** instrument
- Operated for 6 years on the Gemini South Observatory
- Detects and characterizes **Jupiter-mass exoplanets in wide orbits**
- Aimed to measure the frequency of exoplanets of wide orbit gas giants
- Decommissioned in August 2020 for upgrades
- Will be moved to Gemini North



GPI 1.0 ⟶ GPI 2.0

- Science Goal: Achieve higher contrast to find Jupiter-like planets **closer to their stars** and **consistent with “cold start”** formation models



Credit: Chilcote et al. 2018

Simulated population of exoplanets!

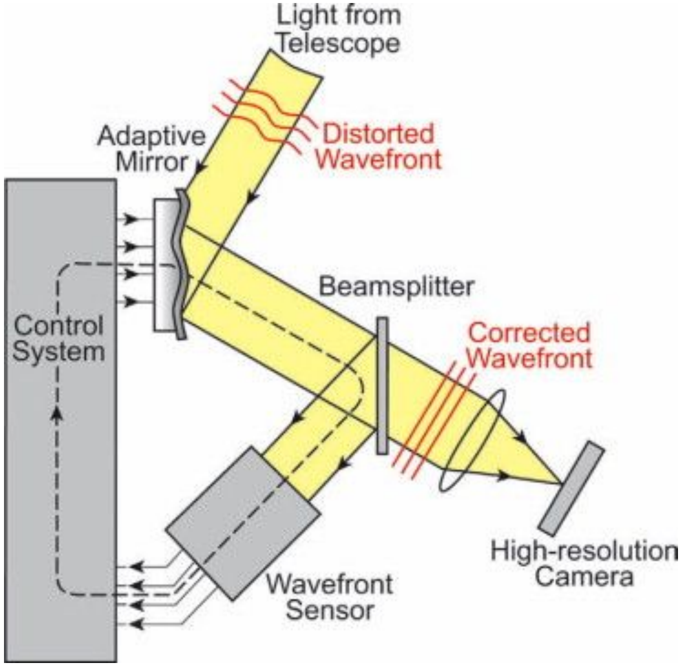
GPI 1.0 contrast limit: magnitude 9 targets

GPI 2.0 contrast limit: magnitude 14 targets

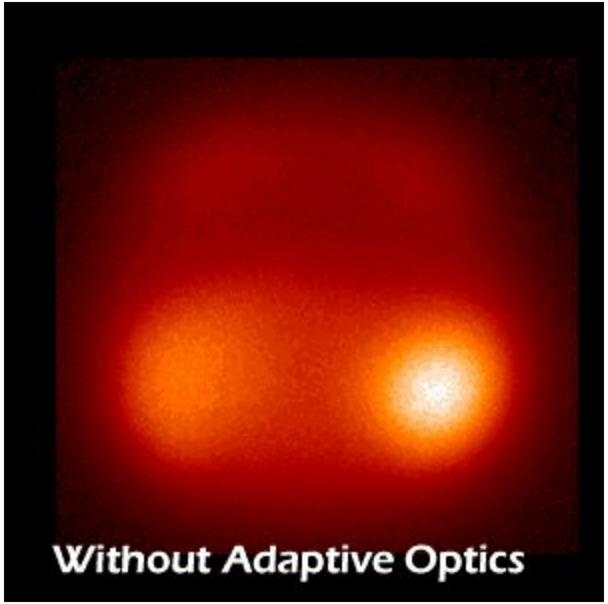
GPI 1.0 → GPI 2.0

- Upgrades to:
  - Pupil coronagraph masks
  - Top-level software
  - Calibration Unit
    - New Prisms
    - Optomechanics Upgrade
  - **Adaptive Optics**
    - **Pyramid Wavefront Sensor Upgrade**

Adaptive Optics



Credit:
ScienceDirect/Claire Max

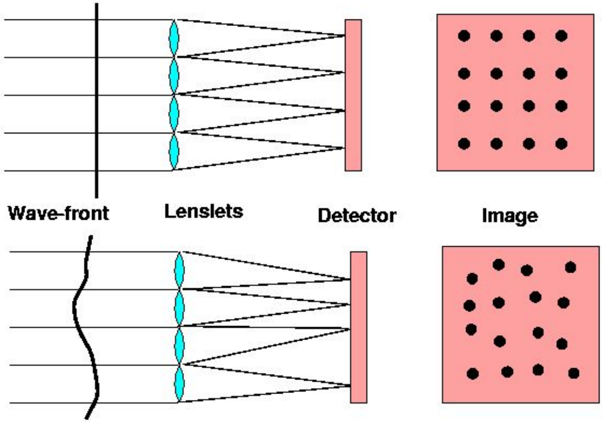


Credit: ESO

Pyramid Wavefront Sensor Upgrade

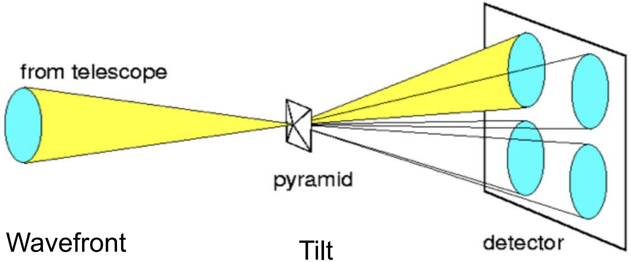
Shack-Hartmann Wavefront Sensor (GPI 1.0)

- Lenslet array receives a tilted wavefront and the spot is shifted.
- Measuring the spot displacement enables to derive the wavefront error

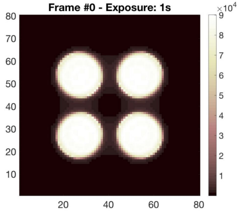


Pyramid Wavefront Sensor (GPI 2.0)

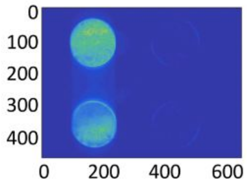
- Each face of the prism deflects the light in a different direction onto four pupil images on the detector
- Higher sensitivity to low order aberrations = **better contrast**



Perfect Wavefront

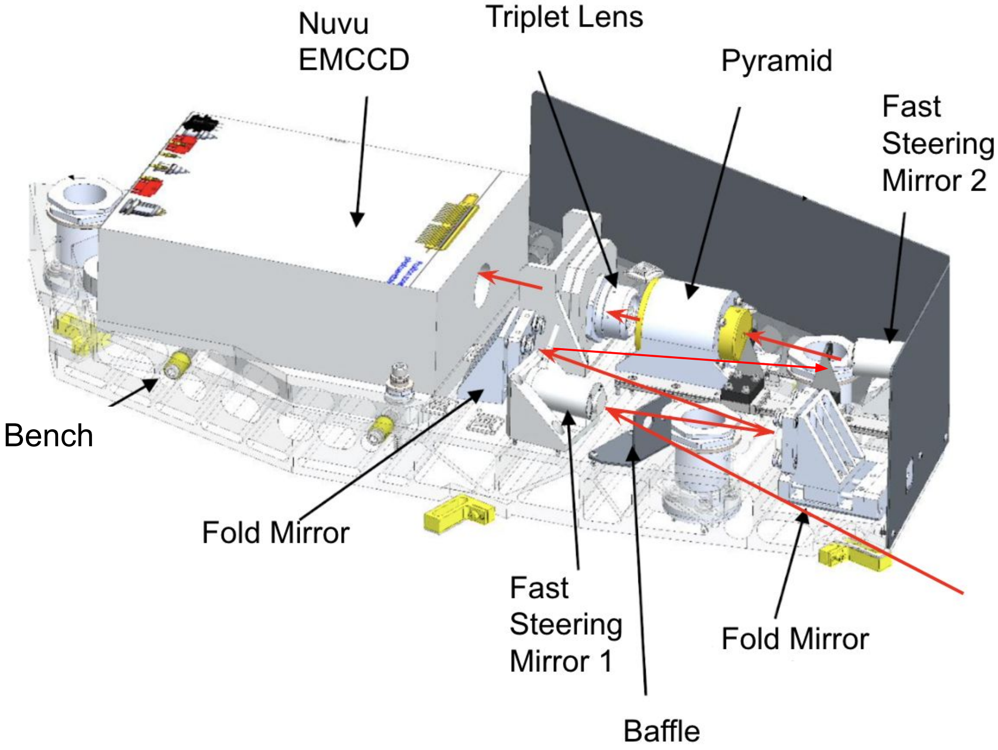


Tilt



Credit: Lauren et al. 2021; van Kooten et al. 2017

Pyramid Wavefront Sensor Upgrade (HAA)



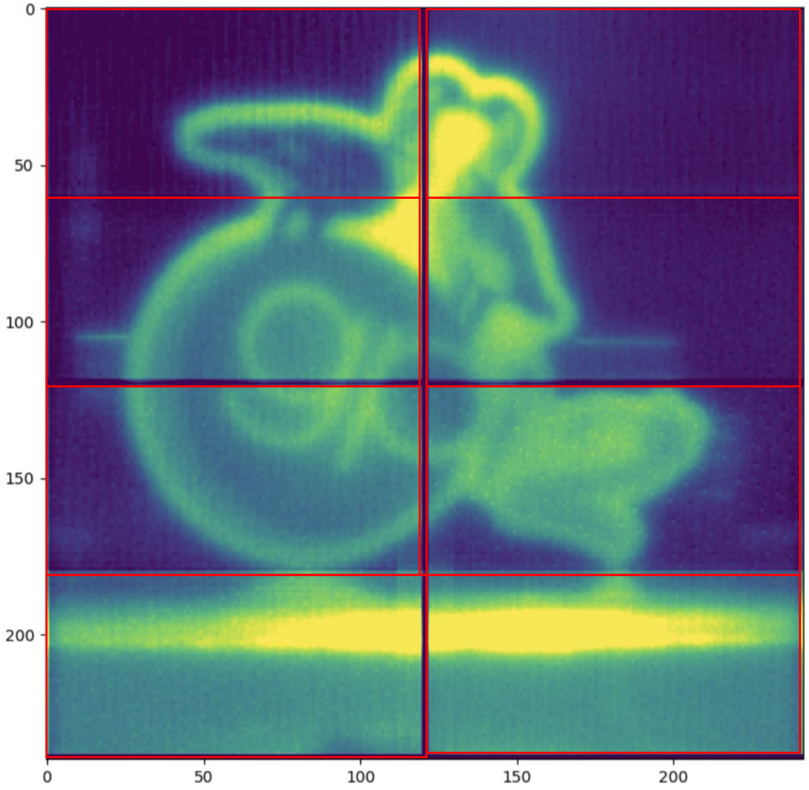
The EMCCD

The EMCCD overview:

- **Electron multiplying CCDs (EMCCDs)** are detectors capable of counting single photon events at high speed and high sensitivity.

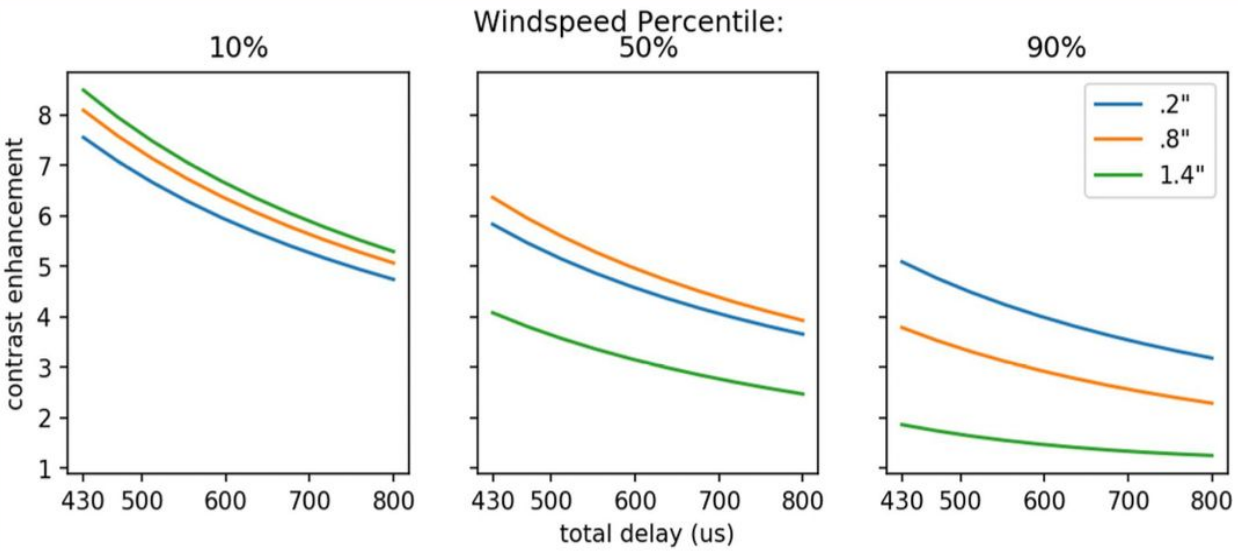
- **8 outputs**
- Operates at 2 kHz (max 3kHz)
- Operates at -45 ℃

(Do Ó et al. in prep)



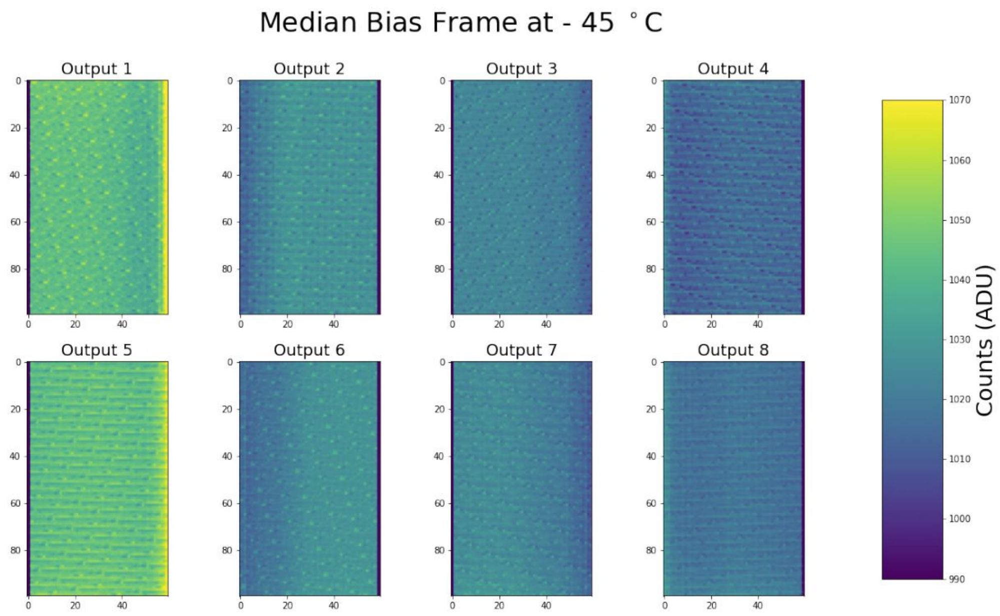
The EMCCD: Motivation

- The delay is the camera readout time + real time control (RTC).
- For GPI 2.0, the aim is to have the RTC at 100 μs, such that the camera readout dominates the delay.
- EMCCD has a fast readout time



Credit: Madurowicz et al 2020

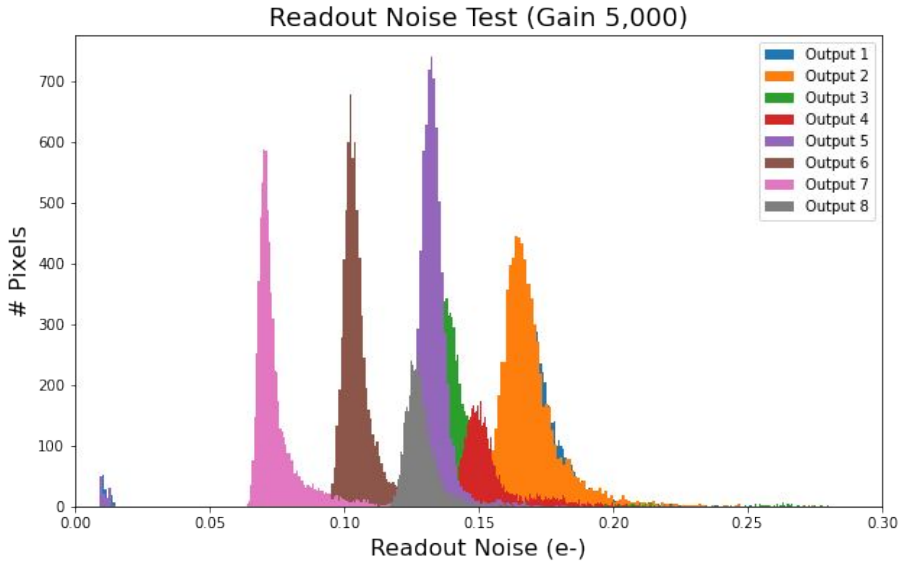
The EMCCD: Outputs



(Do Ó et al. 2023 in prep)

The EMCCD: Readout Noise

Working with fainter targets requires a low noise camera

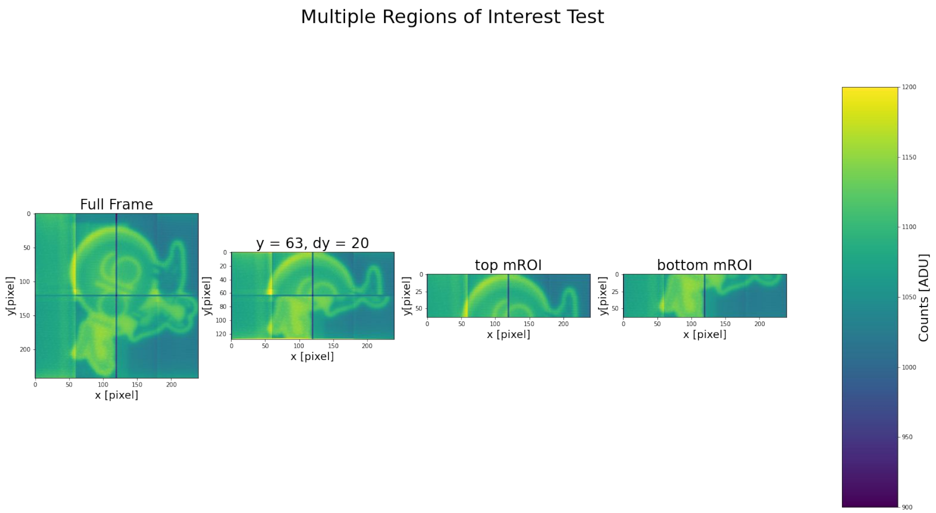


Output	Median Readout Noise (e-)
1	0.169787
2	0.167197
3	0.139553
4	0.150889
5	0.132648
6	0.103851
7	0.071985
8	0.127600

(Do Ó et al. 2023 in prep)

The EMCCD: Multiple Regions of Interest

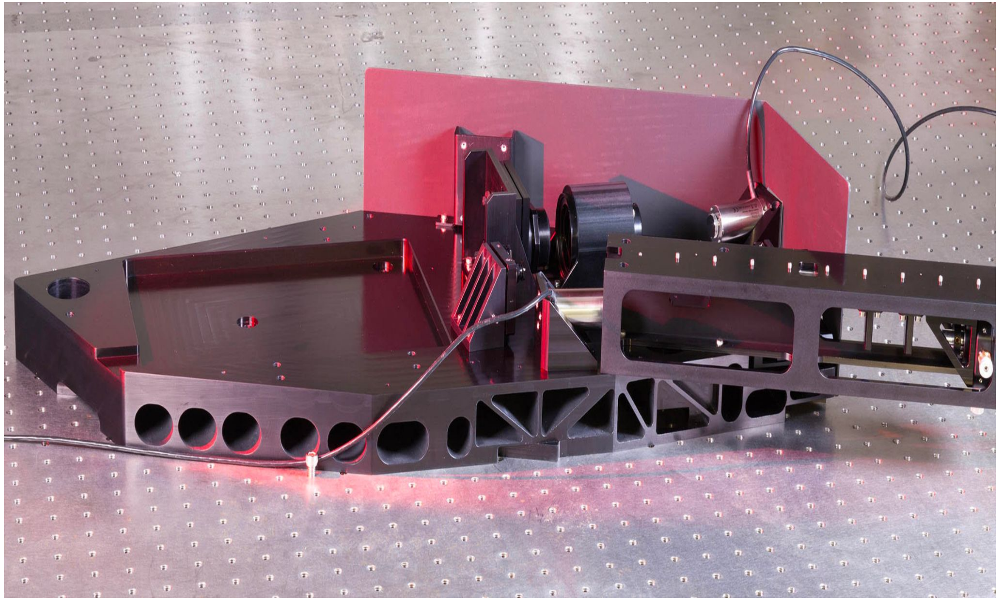
Looking at specific regions of the camera allows for faster readout

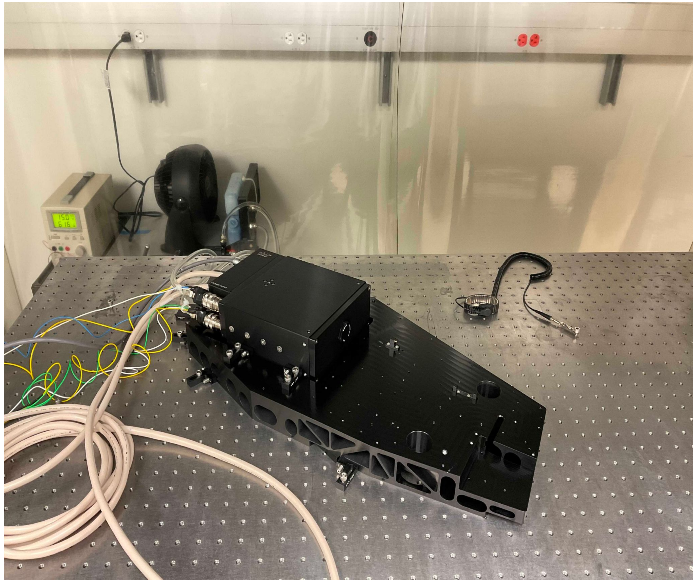


(Do Ó et al. 2023 in prep)

Wavefront Sensor Upgrade Status

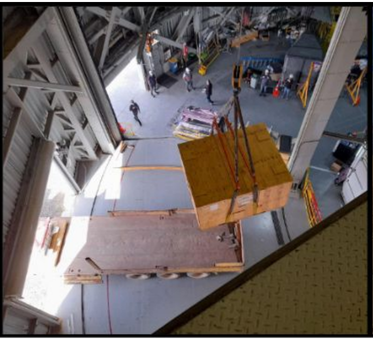
- Status: all parts now at UCSD
- EMCCD arrived last Fall!
- Currently aligning our wavefront sensor components





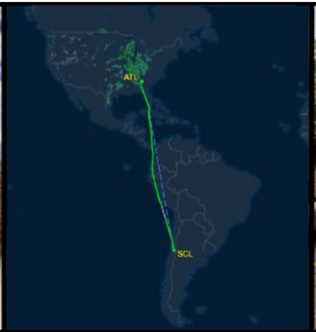
Current Instrument Status

Preparing GPI for shipping at Gemini South



Going down the mountain

In Transit



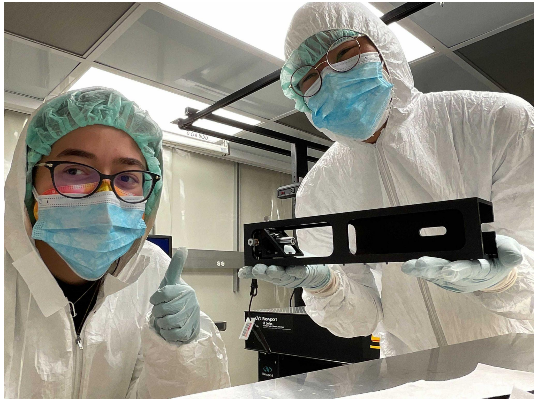
Arriving in Notre Dame

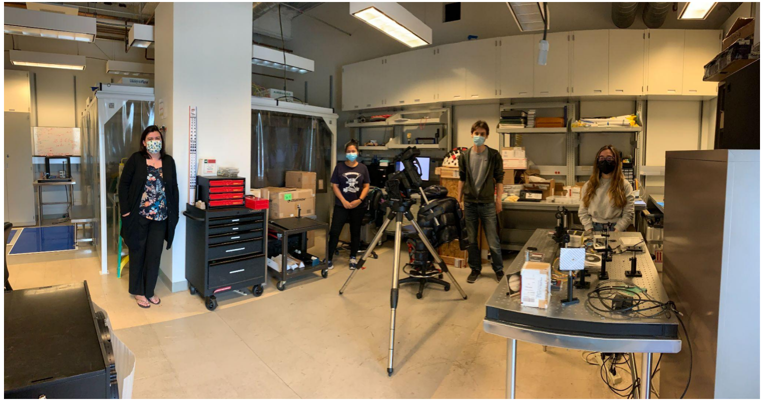
Unloaded

In the lab!

Summary

- “Cold start” planets are fainter than “hot start” planets and require more contrast to be directly imaged
- GPI 2.0 will reach fainter targets than GPI 1.0
- Upgrade has begun!
- **I am testing the EMCCD for GPI 2.0’s pyramid wavefront sensor**
- AO subsystem upgrades will allow for higher contrast
- Currently aligning our wavefront sensor components
- Commissioning in 2024A at Gemini North





Thank you! Questions?

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