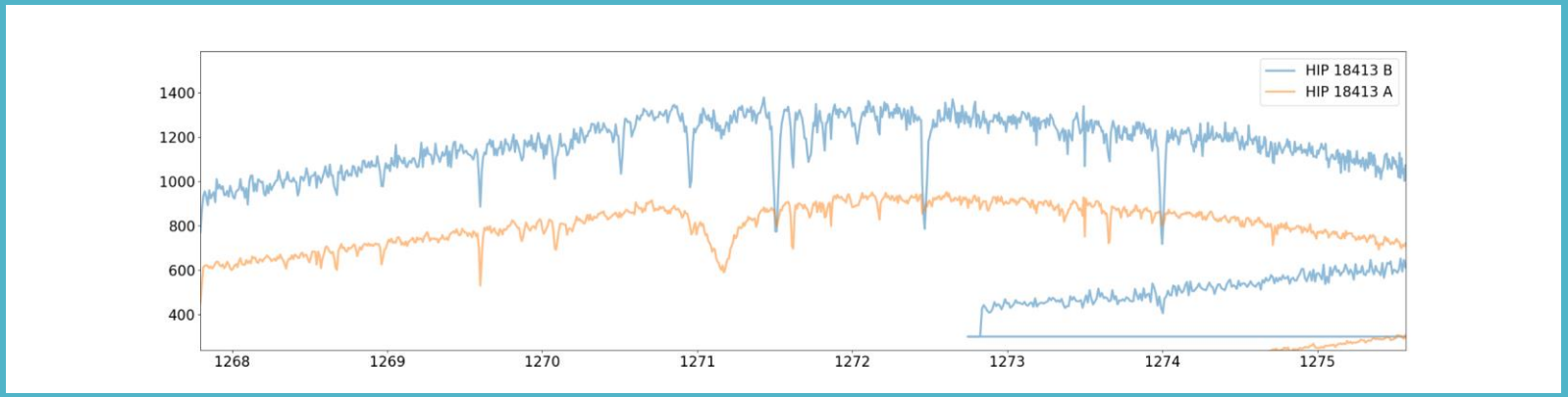
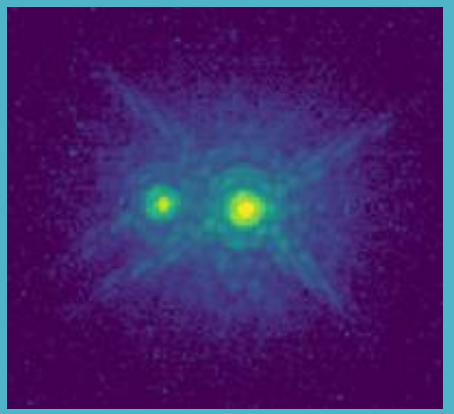


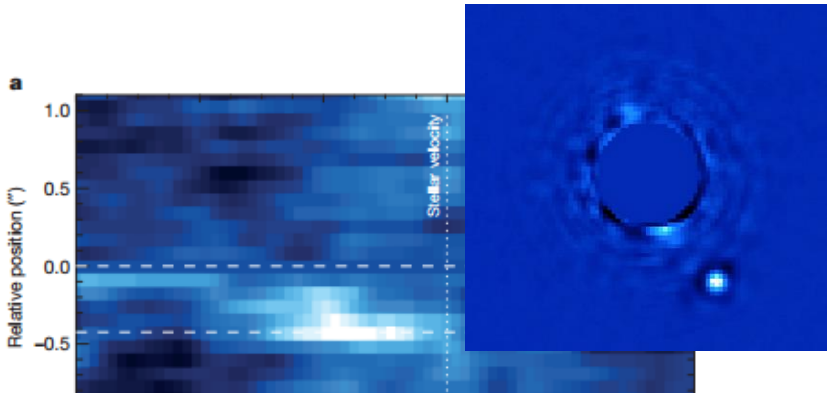
Development of the Extremely High-Contrast, High Spectral Resolution Spectrometer REACH for the Subaru Telescope

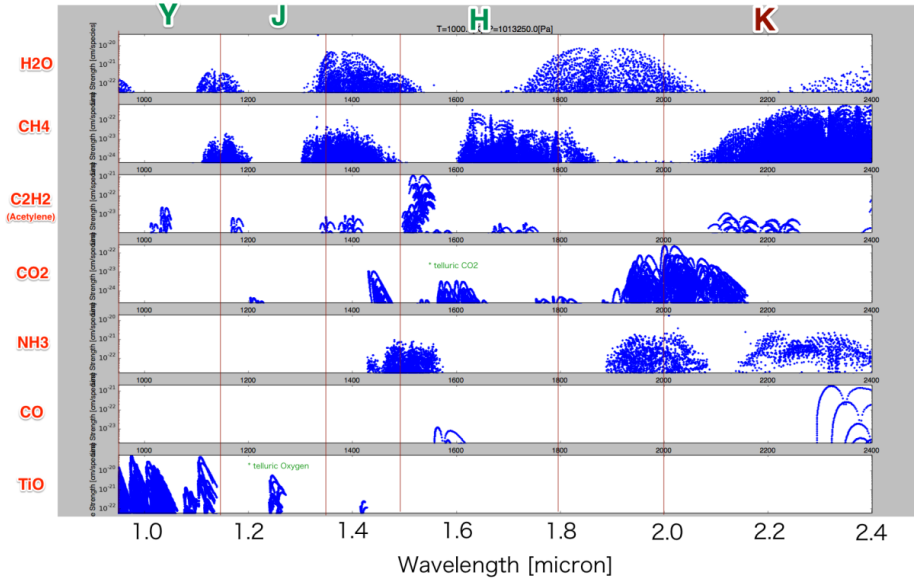


Takayuki Kotani (Astrobiology center/NAOJ),
Hajime Kawahara, Masato Ishizuka, Nemanja Jovanovic, Olivier Guyon, Sebastien Vievard, Julien Lozi, Ananya Shahoo, Motohide Tamura, REACH collaboration team

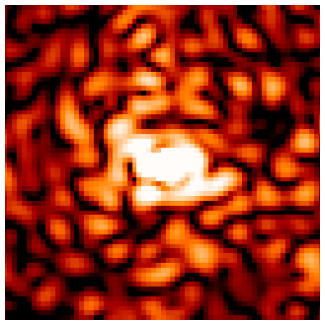
Need for EXTREMETLY High-Contrast and High-Dispersion Spectroscopy (ExHC-HDS)

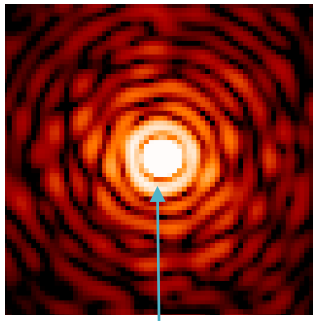
- Hight Contrast-HDS is a powerful tool for characterization of planet atmospheres and planet kinematics (radial velocity, rotation, etc)
- There is always a need for observations of fainter, closer, and colder planets
- **Solution: ExHC-HDS** = Extreme AO coronagraph + a single-mode fiber + high resolution spectrometer
- SCExAO + IRD at Subaru is an ideal instrument for ExHC-HDS
- Key technology for future biomarker detection
- See Kawahara's talk on Thursday

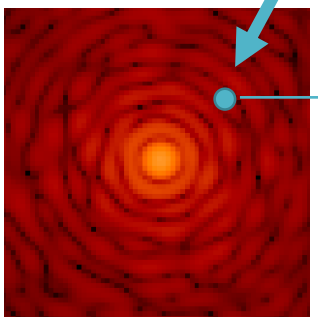




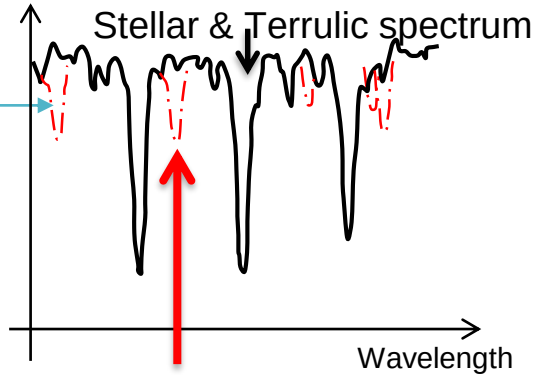
REACH (Rigorous Exoplanetary Atmosphere Characterization with High dispersion coronagraphy): Instrument concept







Single-mode fiber



Doppler shifter planet spectrum

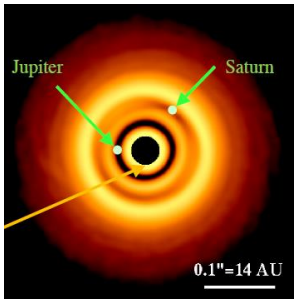
Extreme AO

Extremely precise wavefront correction

Coronagraph

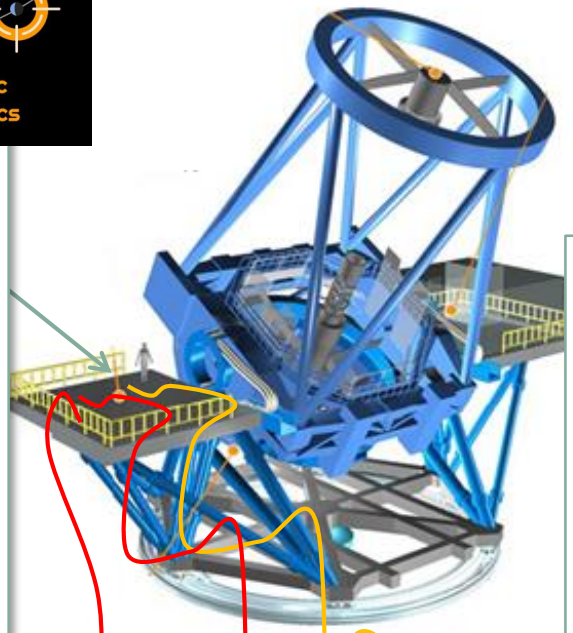
Star light suppression

simultaneous planet and speckle spectrum measurement



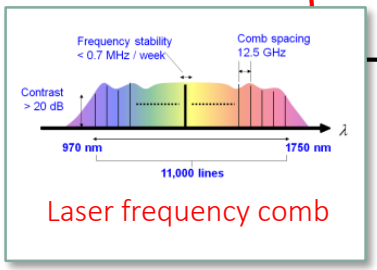
Ideal platform for High-contrast and High-dispersion spectroscopy

- Visible – y, J, H, K
- Single-mode fiber injection unit for IRD
- Various coronagraph: lyot, PIAA, Vortex, 8Octant, vAPP, shaped mask



Fiber (Comb)

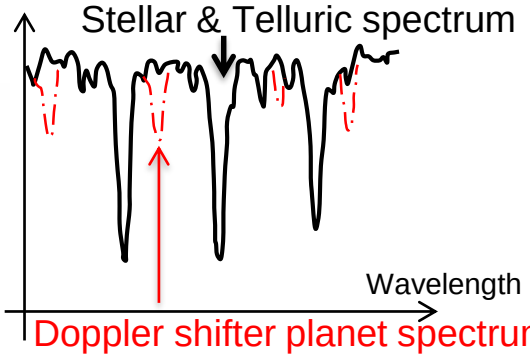
Fiber (star)



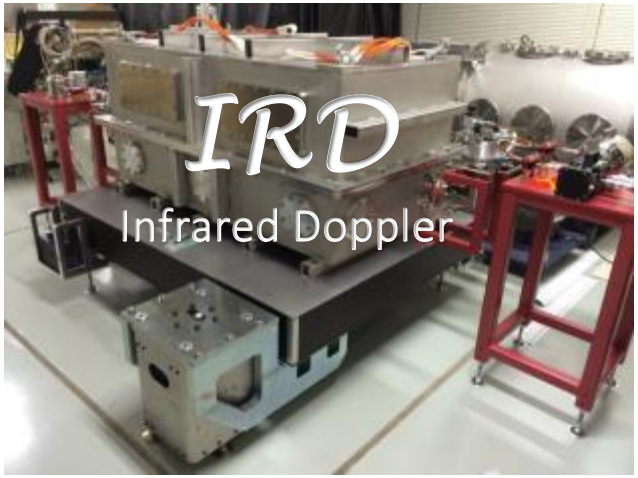
Laser frequency comb

spectrometer

Coudé Room

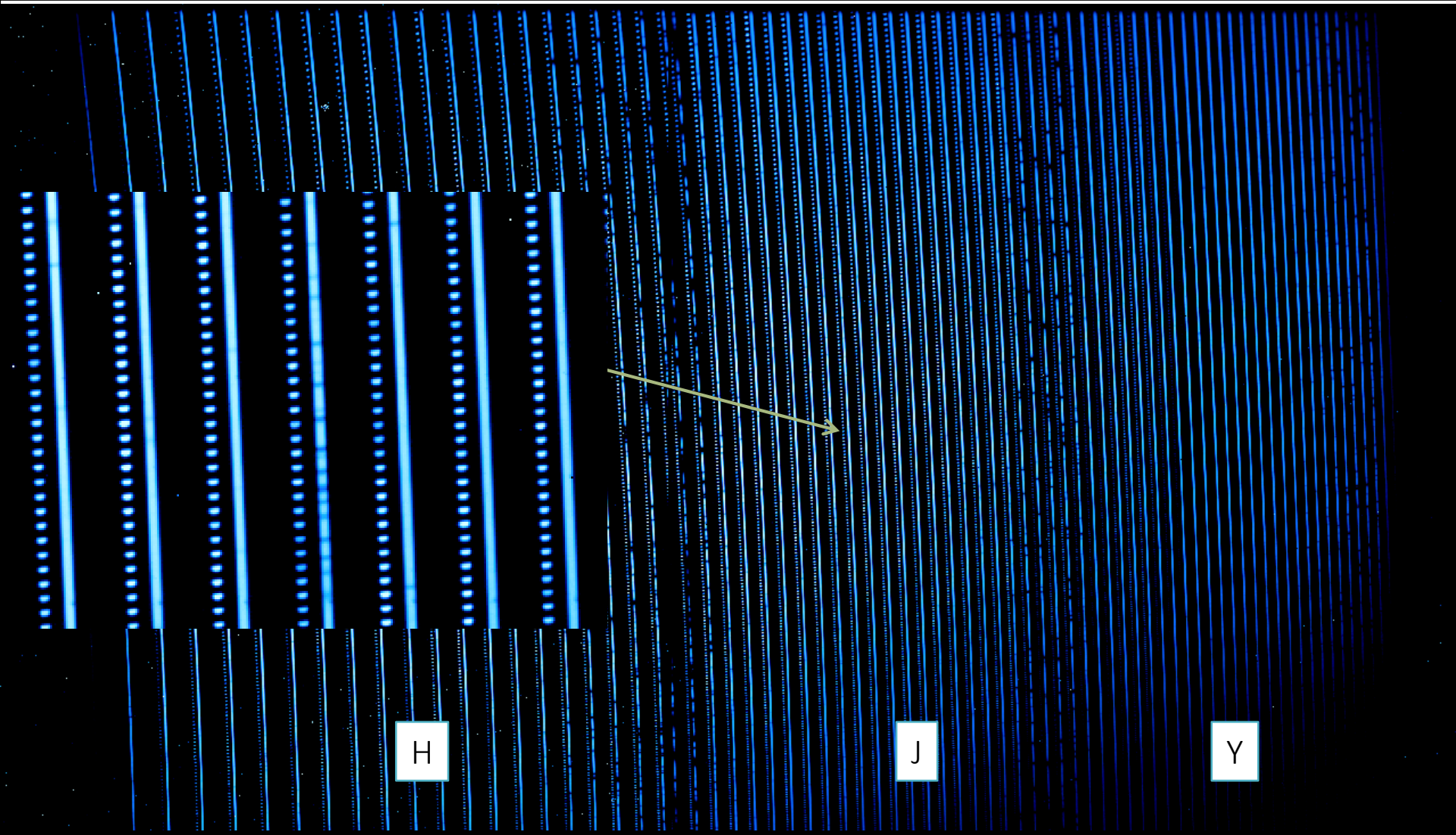


- Resolution: R=100,000 (SMF)
  70,000 (MMF)
- Wavelength: y, J, H-band
- Cryo: 60K (Camera lens), 79K (detector), 180K (optical bench)



Spectrometer system
(Coudé room)

First light with the laser comb



GJ436 YJH-band, 2018/02/03

Laser comb

SCExAO

7x Multi-core Single-mode fiber

Fiber switchyard

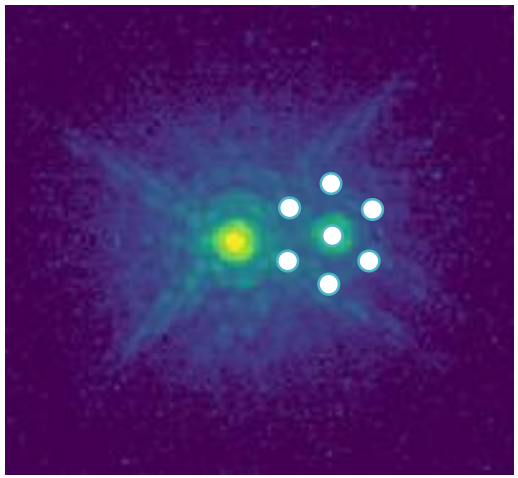
Planet light

Speckle light

IRD
R=10000
0.97-1.75um

10% light

High speed IR camera for photometric monitoring



Fiber switch-yard

tip-tilt mount

IRD SMF1

IRD SMF2

Planet/speckle characterization

Single-mode Multicore fiber bundle

90:10 BS

90:10 BS

V-groove

Camera

Imaging Optics

MMFs

fiber coupling optimization & Speckle nulling

Linear translation stages

tip-tilt mount

SCExAO

SCExAO Plate Controller for Fiber Injection

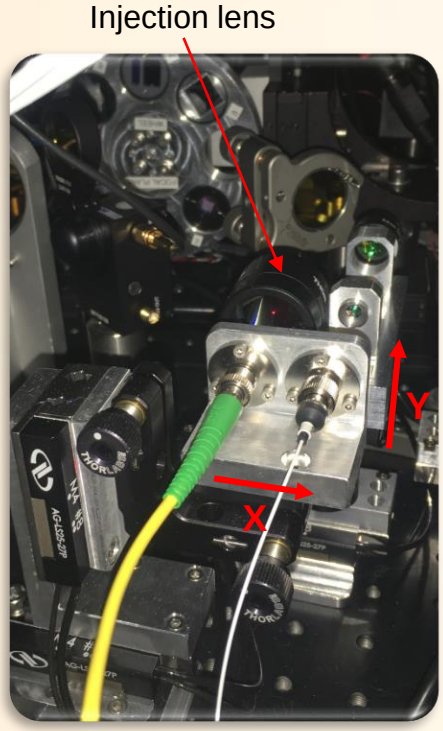
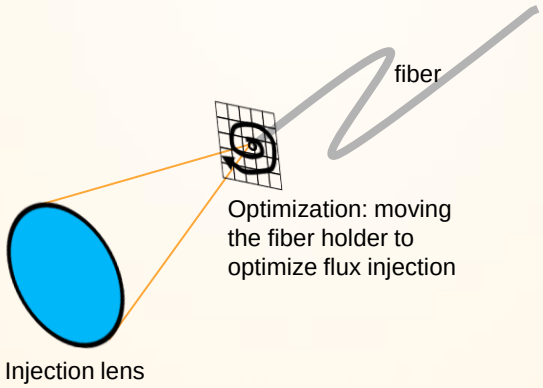
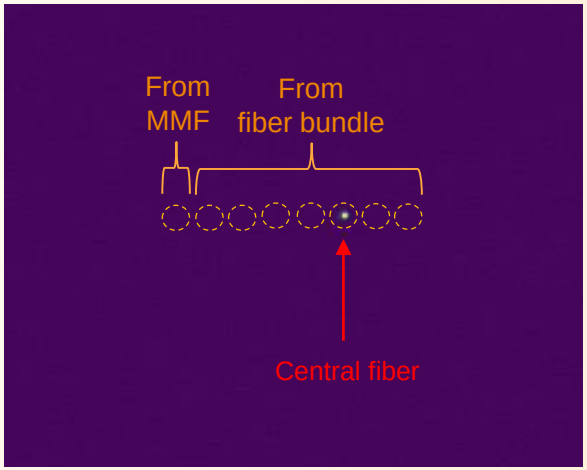


Plate for fiber injection:
- left: Multi-core fiber
- right: Multi-mode fiber

- SCExAO fiber injection module:
  - Injection in the **multi-core fiber** connected to switchyard
  - Injection in a **multi-mode fiber (MMF)** connected to the V-groove

- Optimization procedure:
  - Move the plate (XY position) and measure the flux in each circle on IRcam for each (X,Y) position. One circle = one V-groove output



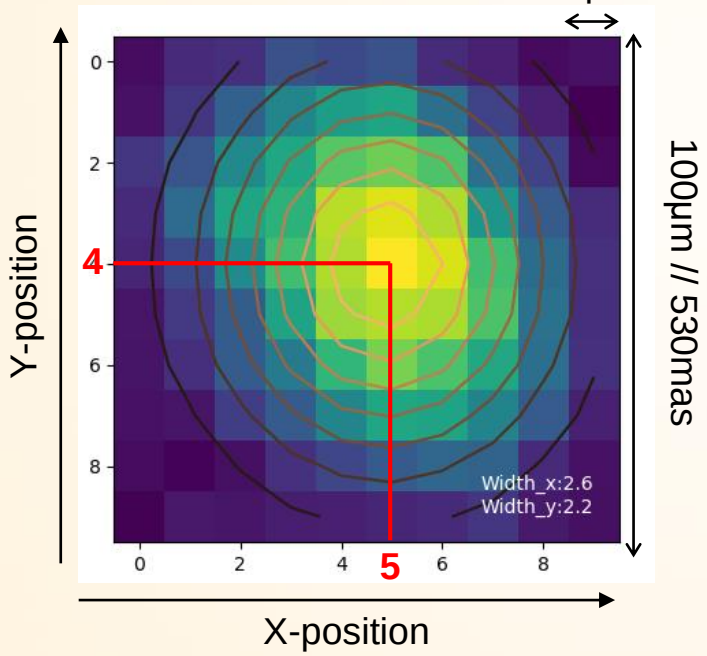


IRcam with different regions where the outputs of the V-groove are imaged – only one has flux here (on internal source)

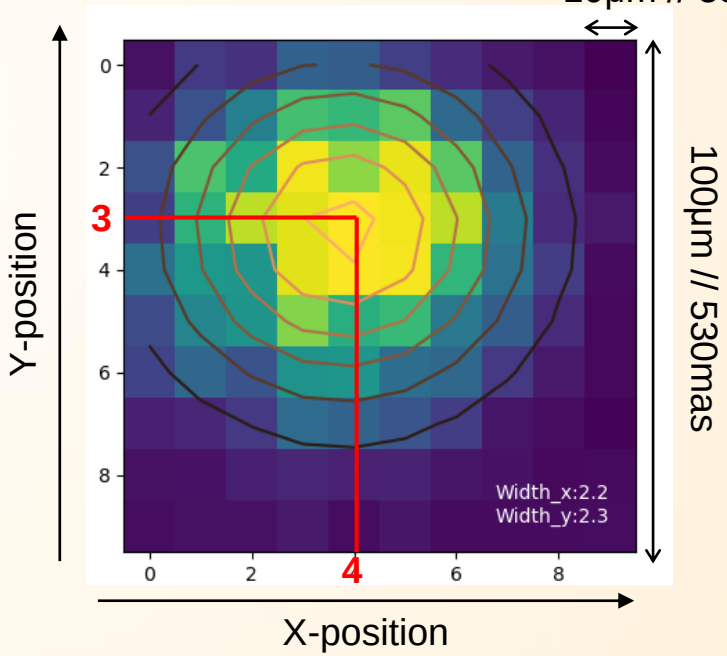
Injection optimization results: MMF in-lab/onsky (06/19)

→ Map intensities = convolution between Airy pattern of PSF after injection lens and fiber core
→ Gaussian fit contour : **similar width** in-lab and on-sky but **different optimal point**

MMF In-lab result 10µm // 53mas



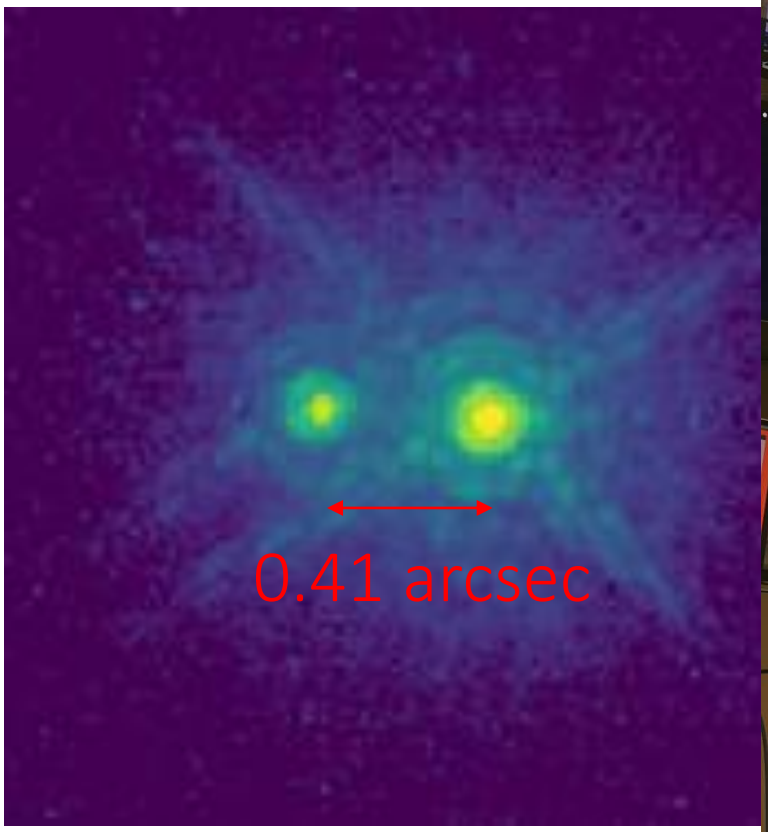
MMF onsky result 10µm // 53mas

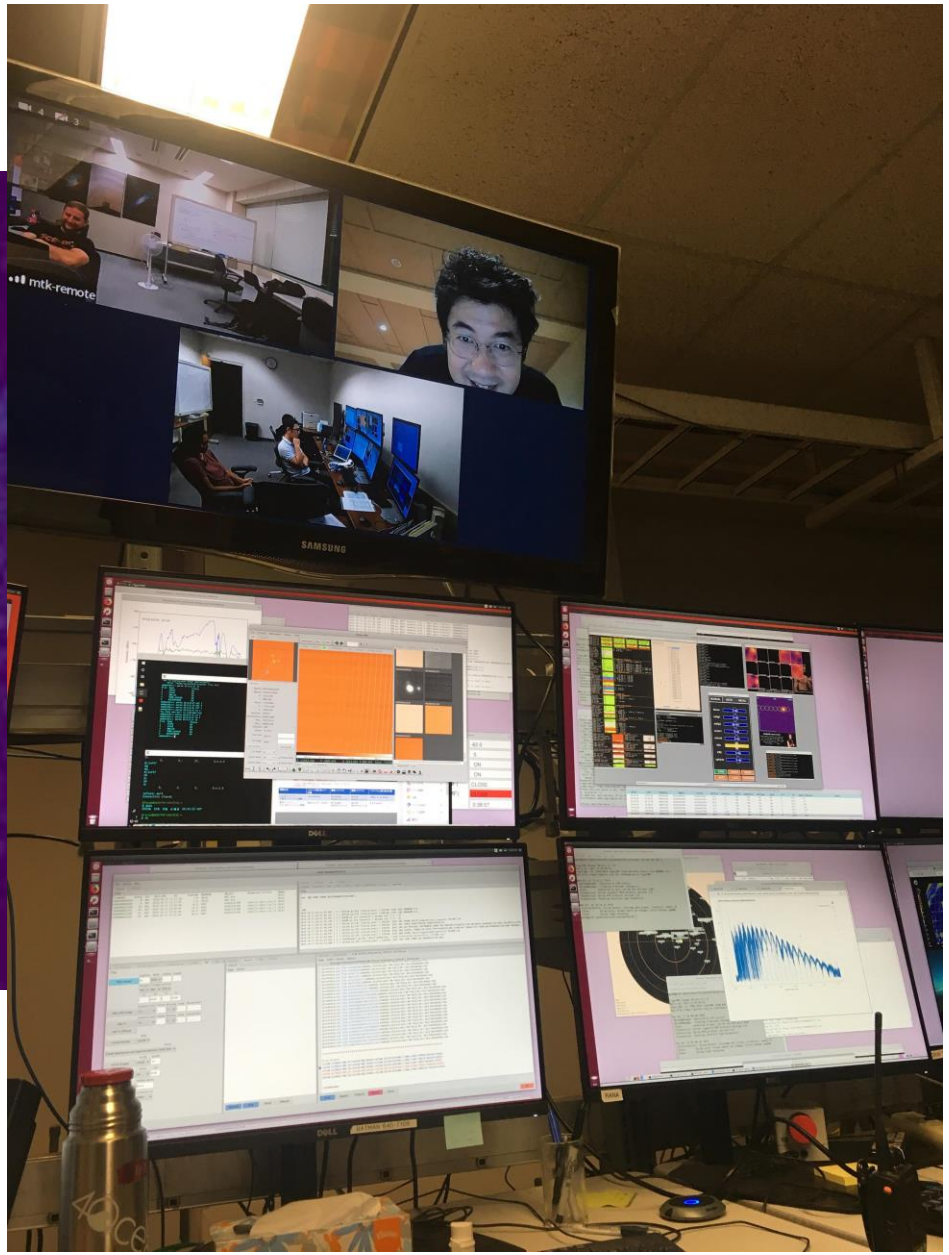


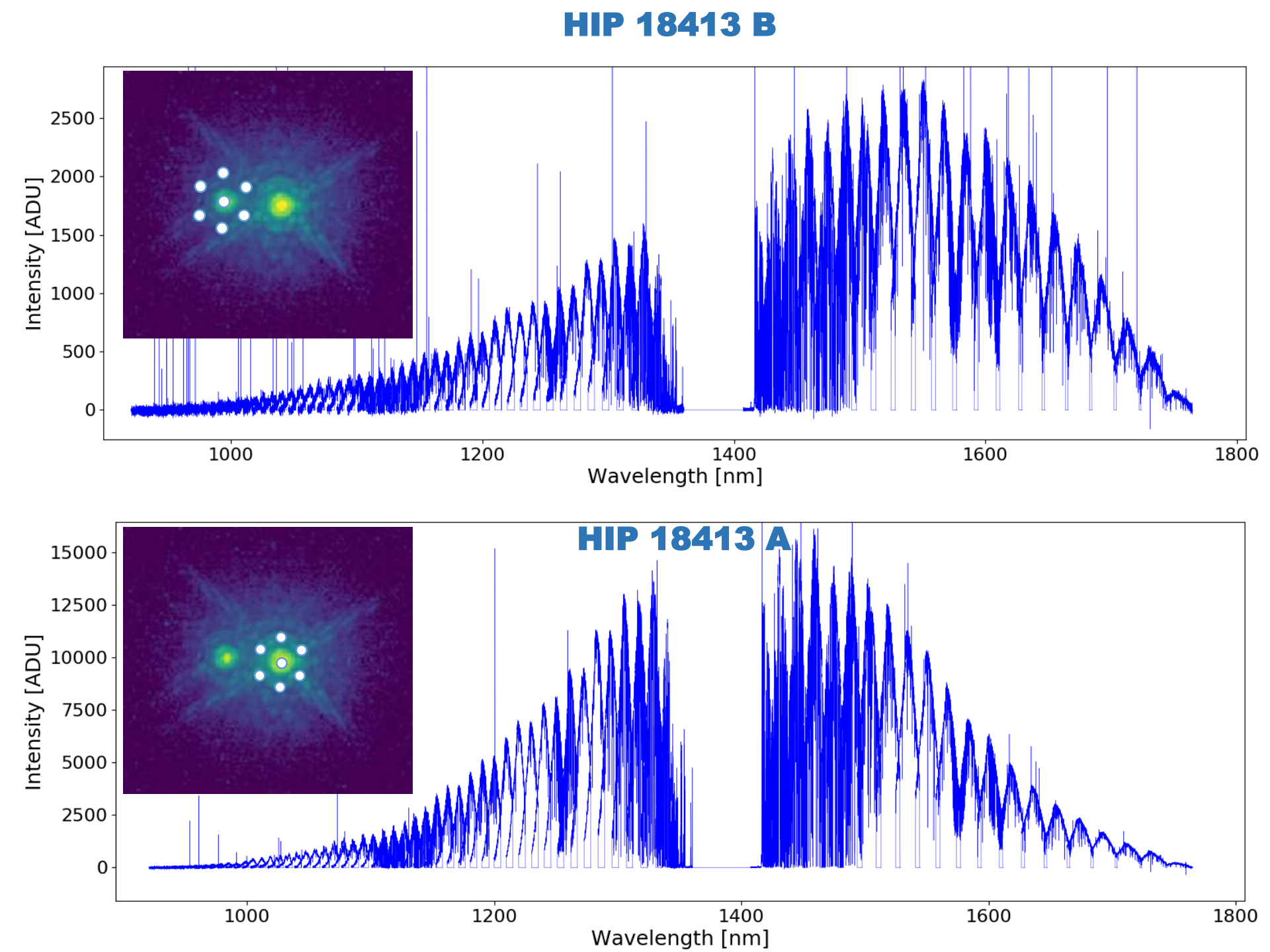
On-sky demonstration

REACH FIRST LIGHT Oct 16th (2019)

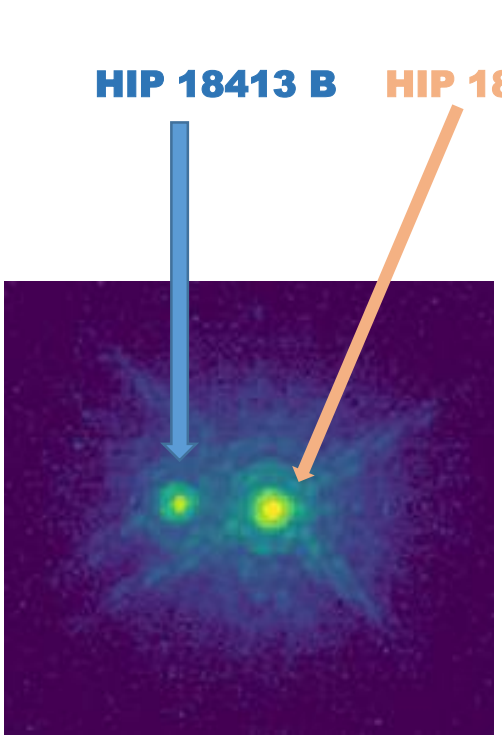
HIP 18413 A,B

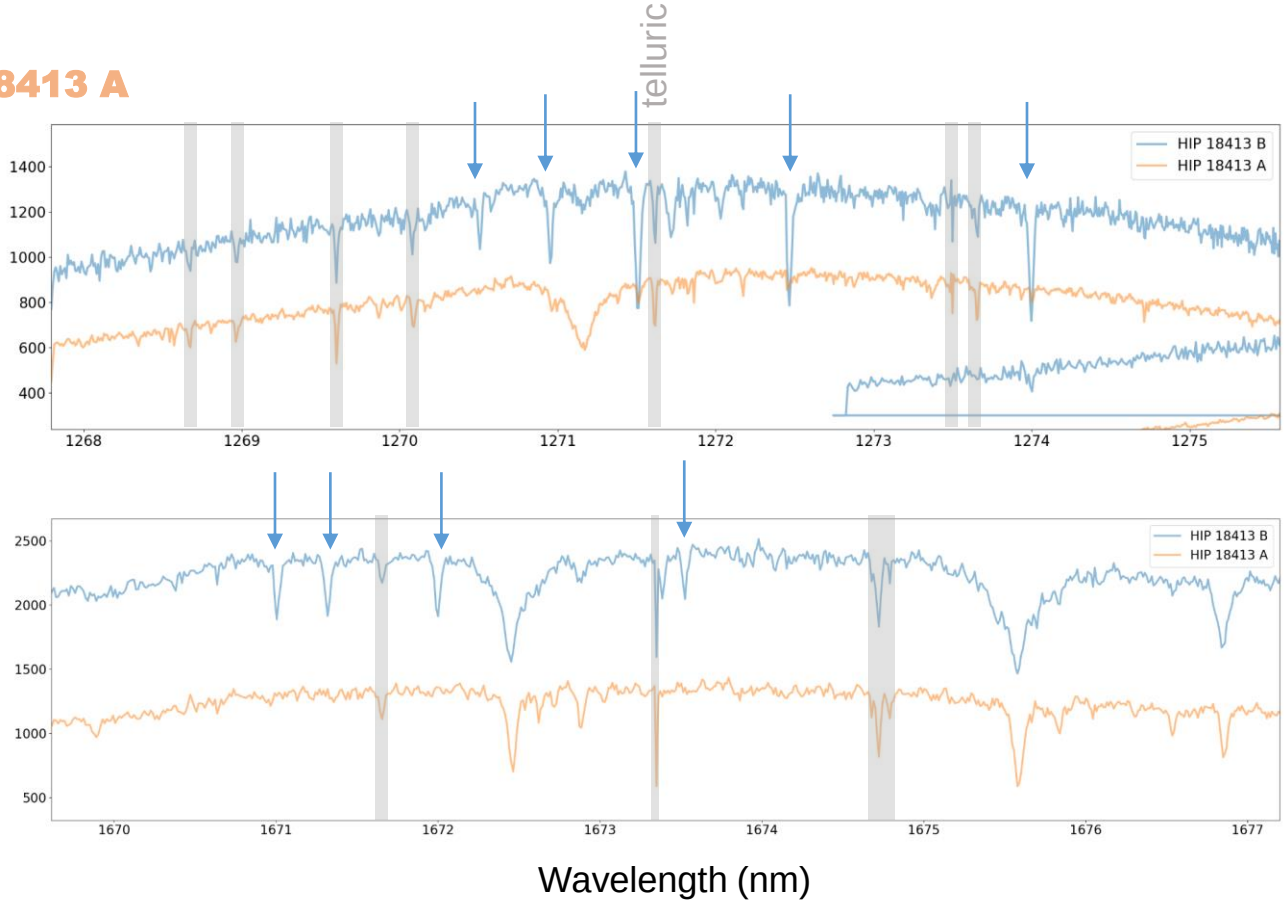




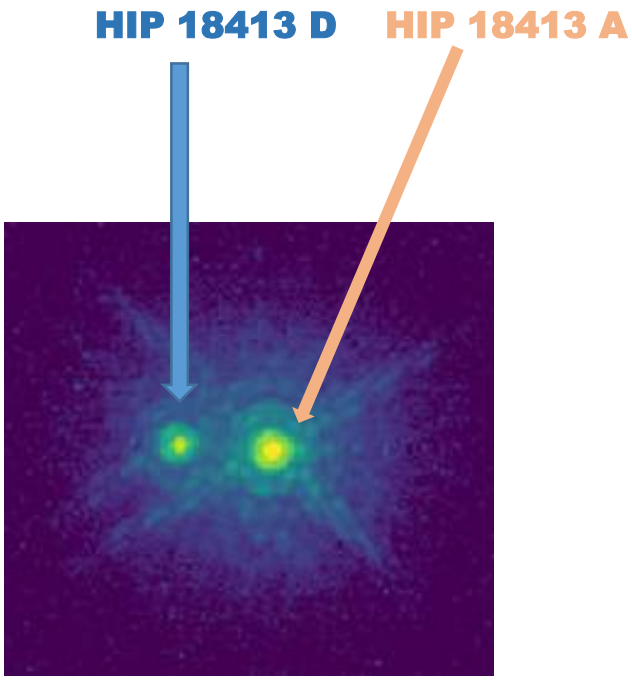

HIP 18413 B
Intensity [ADU]
2500
2000
1500
1000
500
0
1000
1200
1400
1600
1800
Wavelength [nm]
HIP 18413 A
Intensity [ADU]
15000
12500
10000
7500
5000
2500
0
1000
1200
1400
1600
1800
Wavelength [nm]

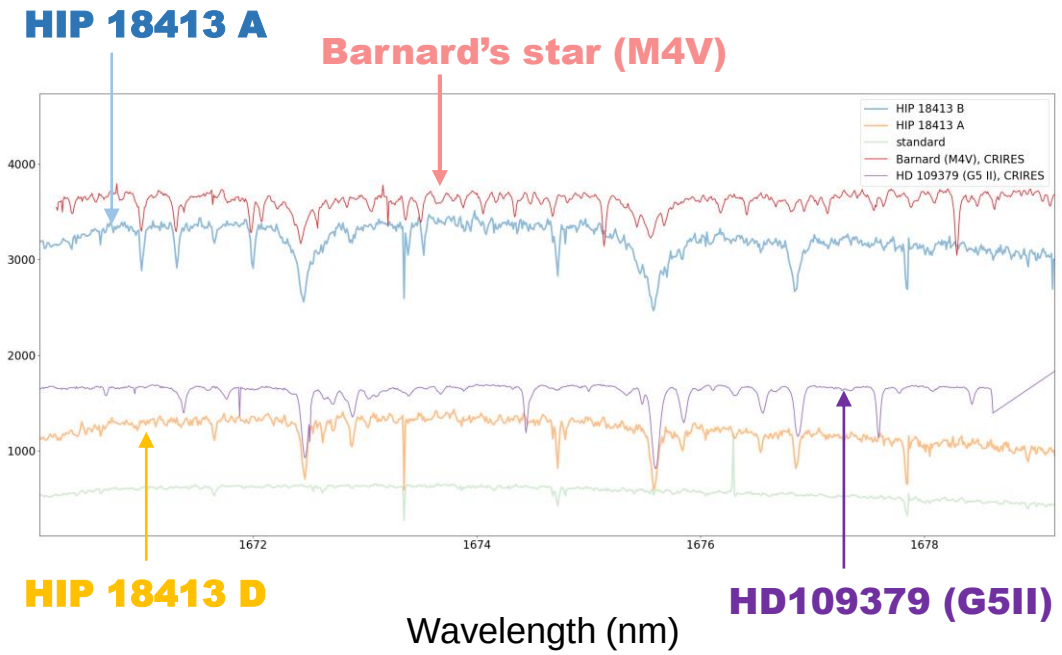
REACH Engineering Run Oct 16th (2019) Quick Look



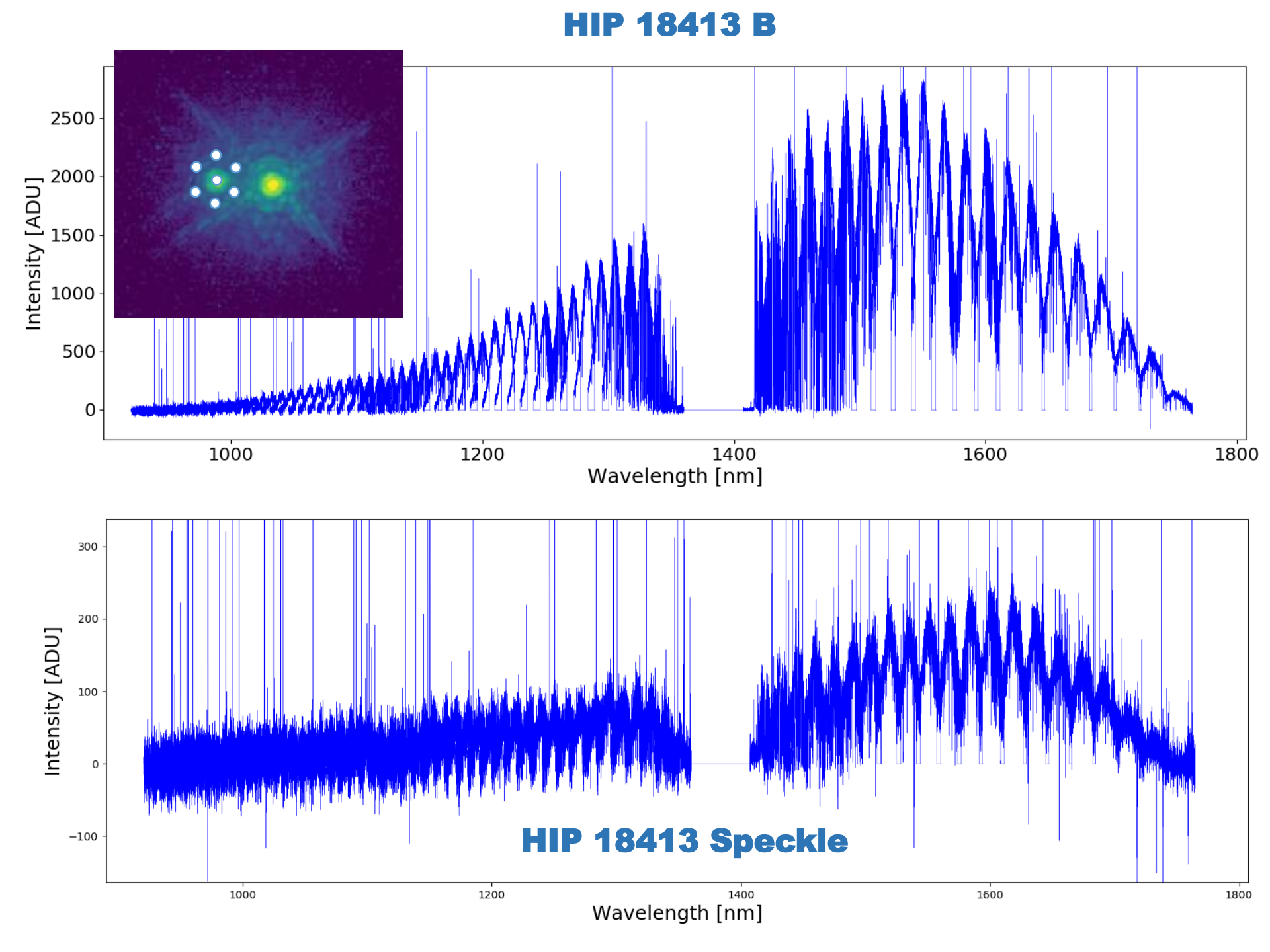


REACH Engineering Run Oct 16th (2019) Quick Look

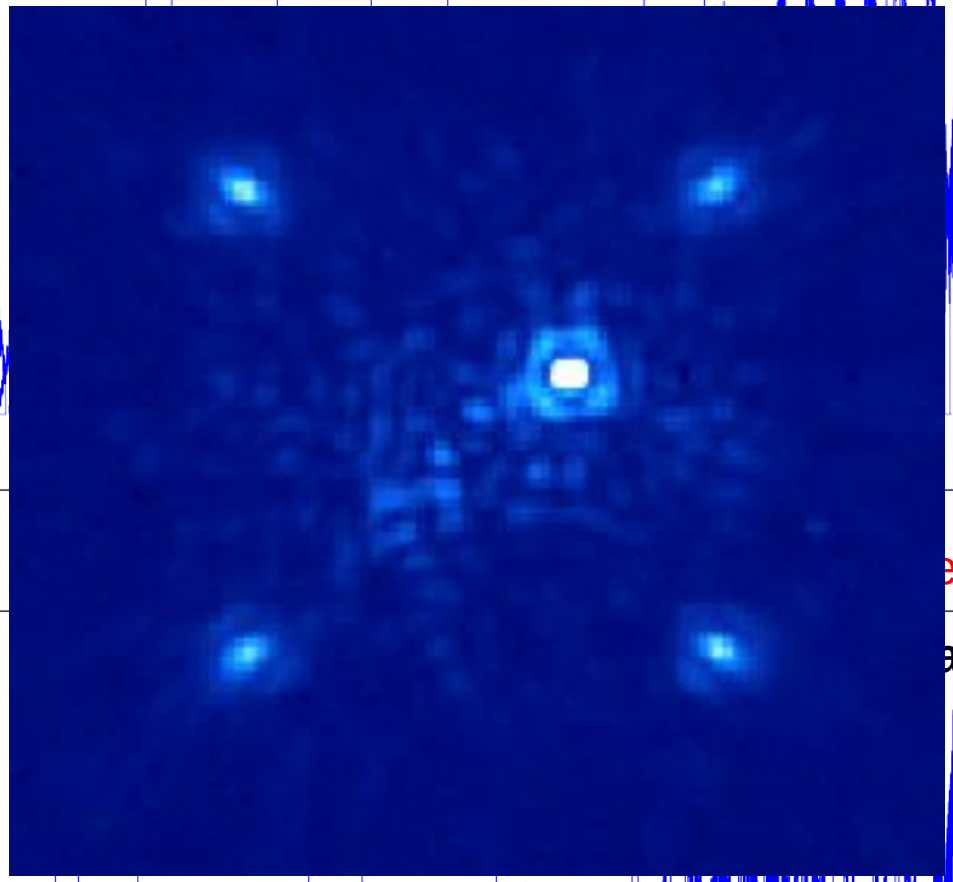


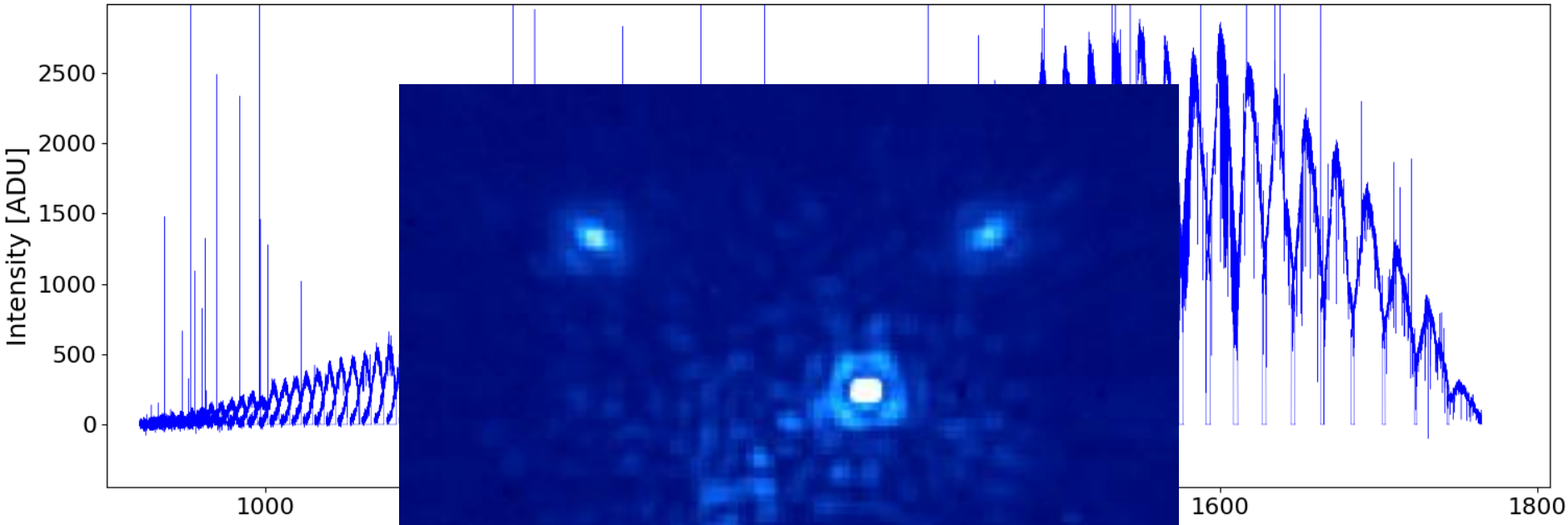


Most likely, HIP 18413 B: ~ M4V, 18413 A: ~ G5


HIP 18413 B
Intensity [ADU]
2500
2000
1500
1000
500
0
1000
1200
1400
1600
1800
Wavelength [nm]
Intensity [ADU]
300
200
100
0
−100
HIP 18413 Speckle
1000
1200
1400
1600
1800
Wavelength [nm]

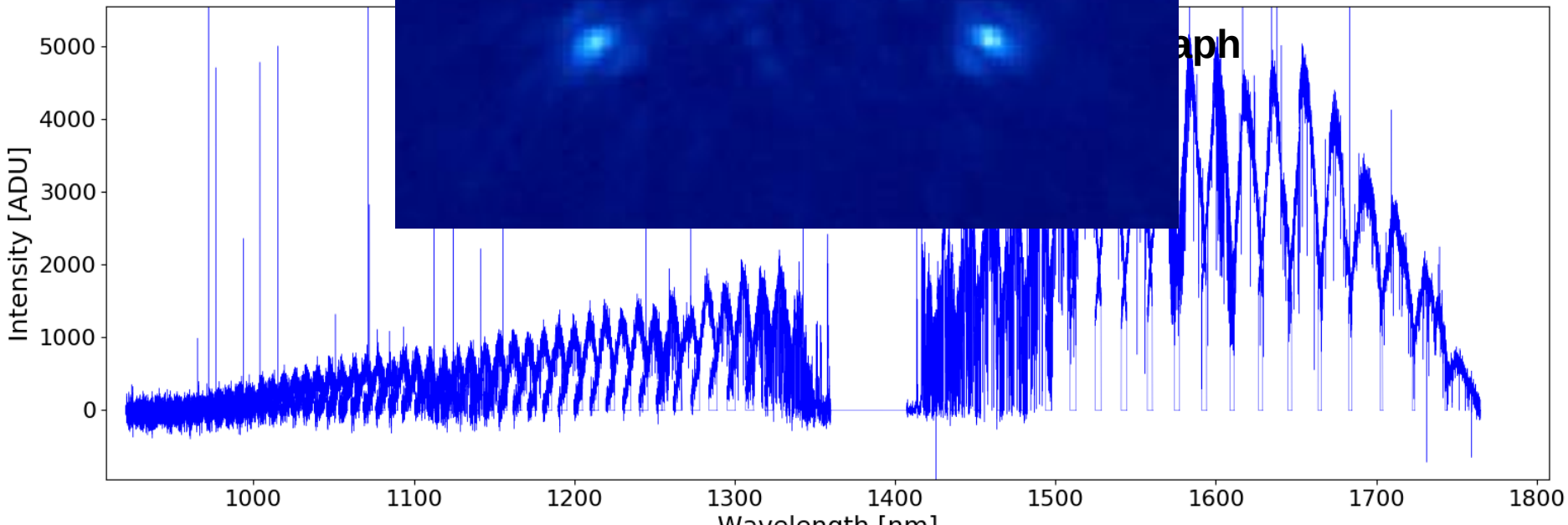
Gamma Gem WITH a lyot coronagraph



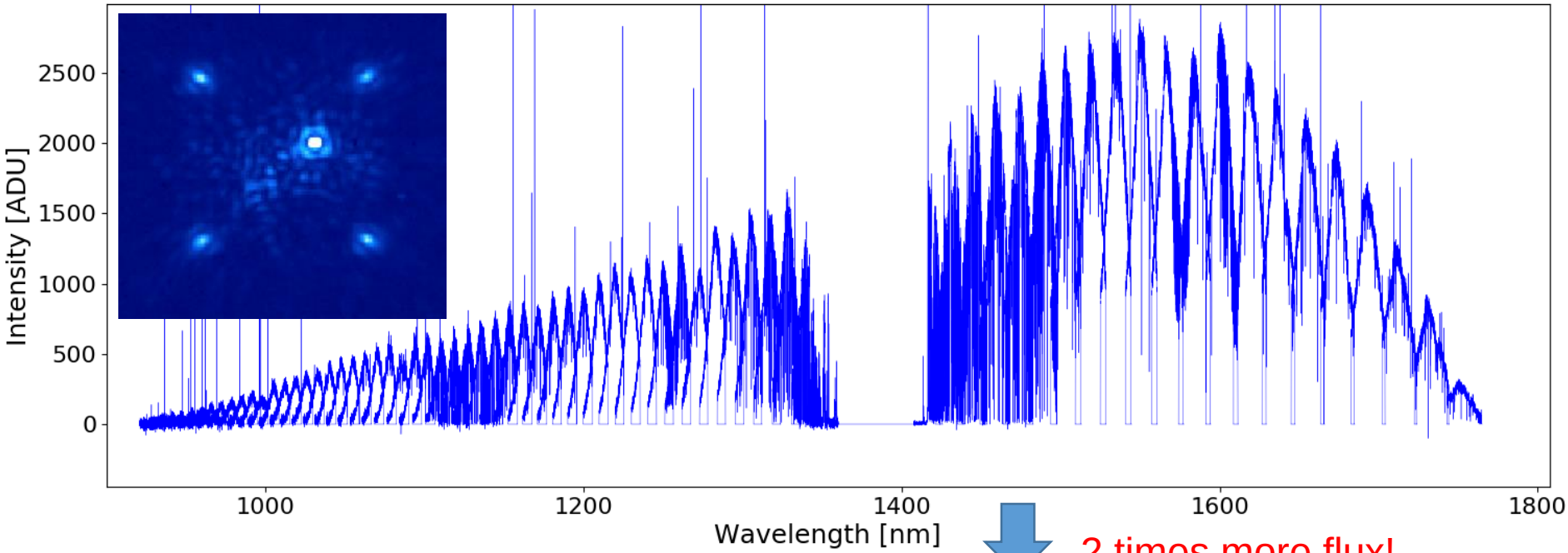


es more flux!

aph

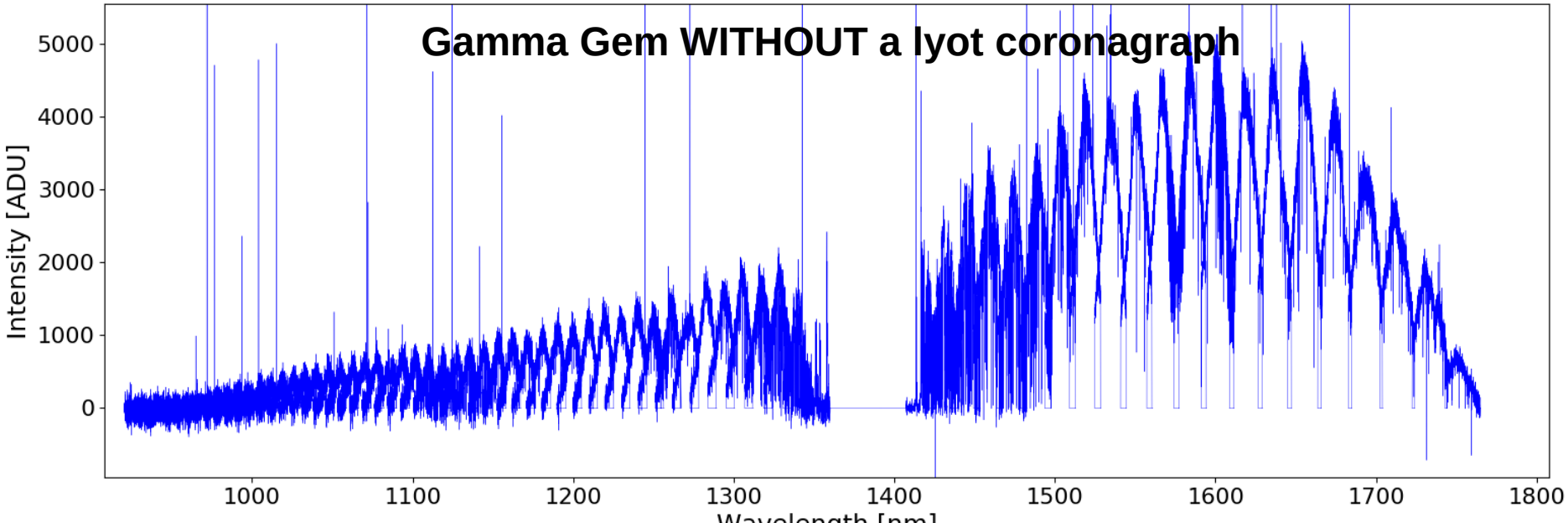


Gamma Gem WITH a lyot coronagraph

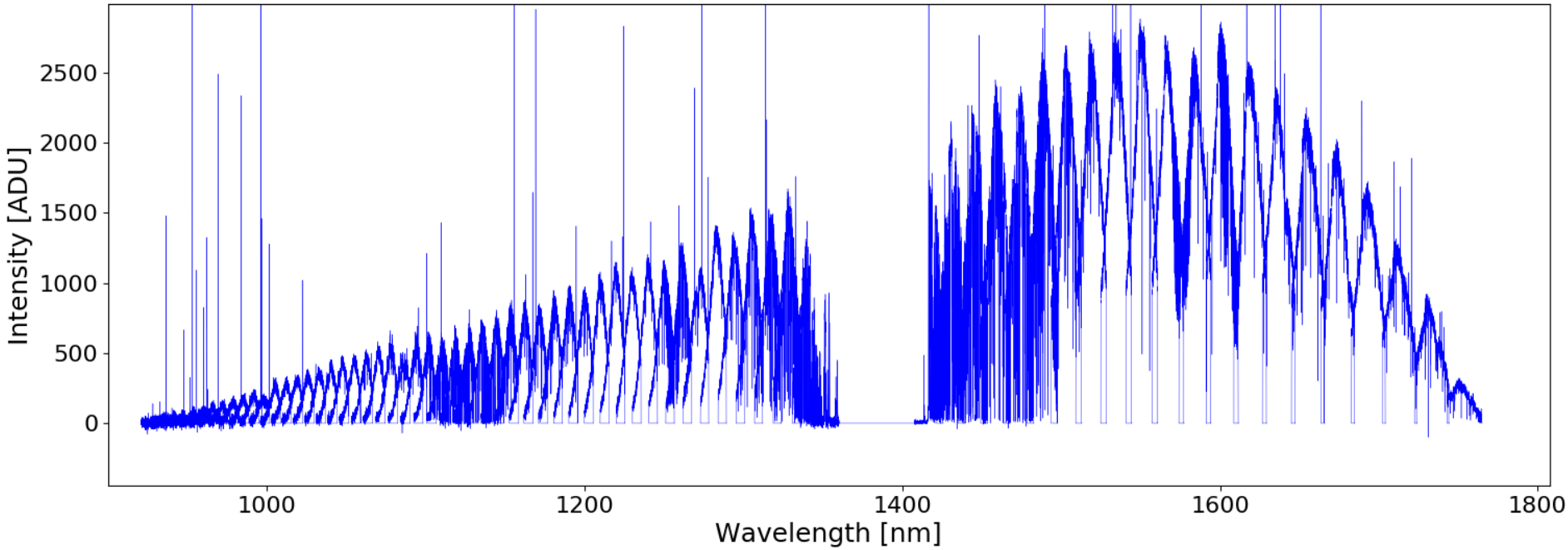


2 times more flux!

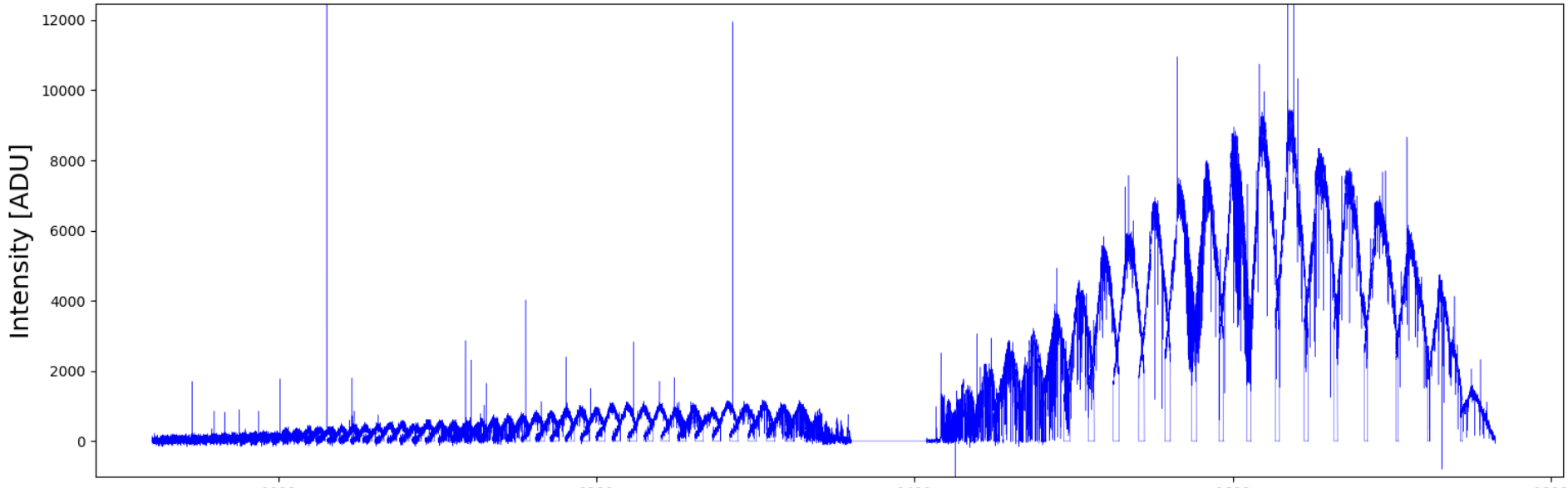
Gamma Gem WITHOUT a lyot coronagraph



Gamma Gem WITH a lyot coronagraph



Gamma Gem WITH a lyot coronagraph, but only primary star

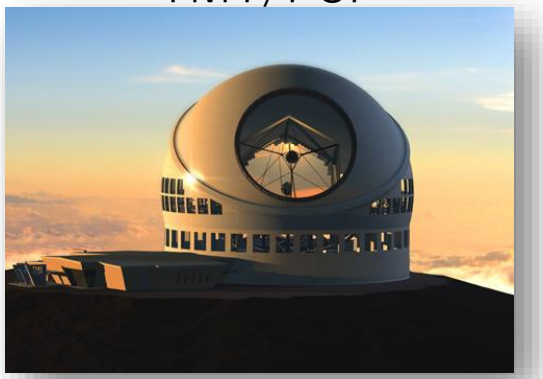


Future prospects: REACH to 30-meter class telescopes

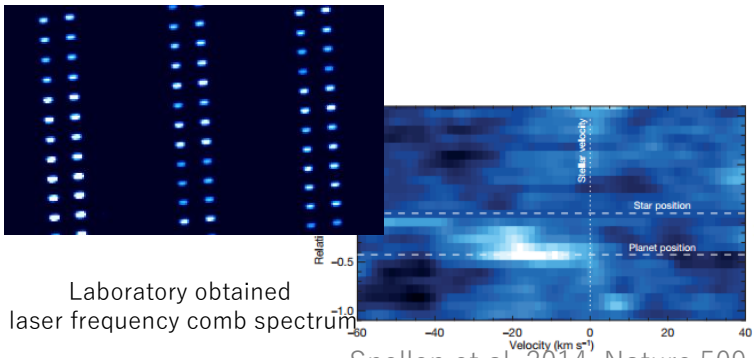
REACH/Subaru

- RV detection of Earth mass planets around M dwarfs in 2019-2024
- Characterization of Jupiter-like planet atmospheres and dynamics
- Test-bed for the future high-contrast coronagraphic spectroscopy

TMT/PSI

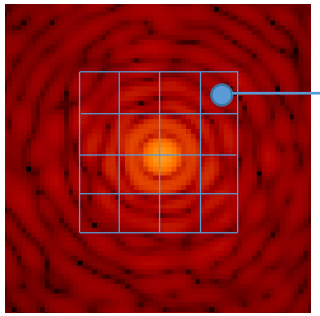


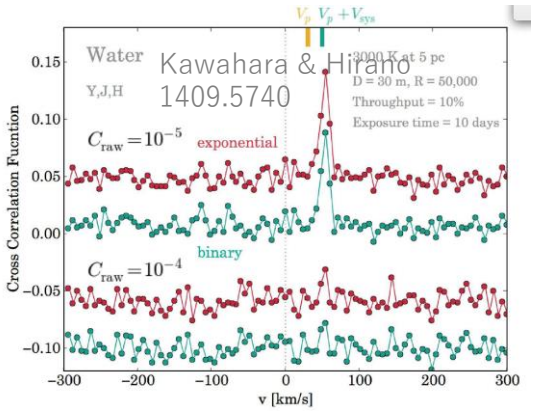
- Direct imaging and spectroscopy of Earth mass planets around late-type stars
- Characterization of Earth-mass planet, detection of biomarkers
- Fully optimized high-contrast coronagraphic spectroscopy



Laboratory obtained
laser frequency comb spectrum

Snellen et al. 2014, Nature,509, 63





Thank you for your attention!
REACH will be offered to the community from the next semester (S20B)