High contrast imaging with the JWST-NIRSpec Integral Field Unit

Marie Ygouf (IPAC/Caltech), Charles Beichman (IPAC/Caltech), Klaus Hodapp (University of Hawaii), Tom Roellig (NASA Ames Research Center)

Abstract

With its integral field unit, the near-infrared spectrograph NIRSpec[1] on JWST[2] will allow to measure high-resolution spectra into the 3-5 µm range with an increased sensitivity over ground-based systems. This capability will considerably extend our knowledge of brown dwarfs and bright exoplanets at large separations from their host star. But because there is not any coronagraph on NIRSpec, the performance in term of contrast at close separation will be extremely limited. In this communication, we explore possibilities to further push this limitation by comparing different observing strategies and associated post-processing (PP) techniques.

1. Direct Imaging of Exoplanet and Brown Dwarfs in the NIRCam GTO Program*

***PI: Marcia Rieke**

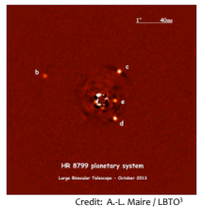
Spectroscopy of Young, Widely Separated Planets (Klaus Hodapp)

- *Goal*: understanding the spectra of self-luminous, fairly young objects below the deuterium burning limit throughout their contraction and cooling.

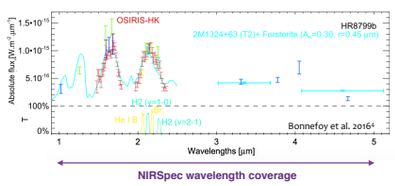
Y Dwarf Observations with JWST (Tom Roellig)

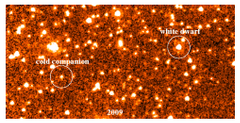
- *Goal*: understanding the nature of the coolest brown dwarfs - their formation, their atmospheres, including their composition, temperature, pressure structures, and the nature of any clouds that may be present.

- *Methodology*: Obtain NIRSpec IFU R=2700 spectra to allow direct imaging and spectroscopy. Use of NIRSpec will extend the measurements into the 3–5 µm range with a substantial sensitivity advantage over competing ground-based systems.



Credit: A.-L. Maire / LBTO[3]





A substellar object with six to nine Jupiter masses has been found to share the same proper motion as the white dwarf WD 0806-661. Luhman et al. 2011[5]

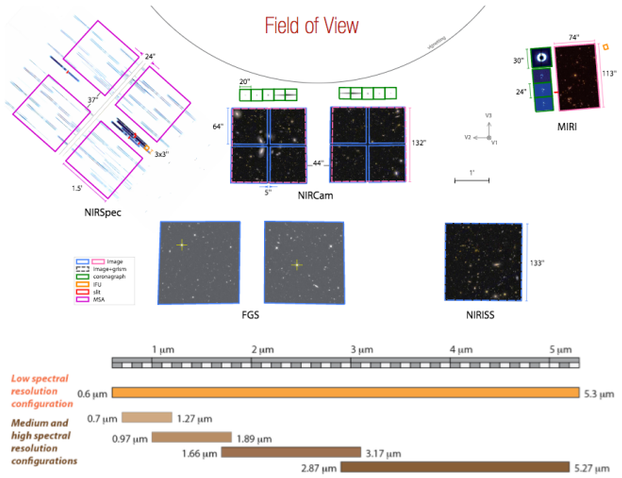
2. The JWST-NIRSpec Integral Field Unit (IFU)

Moderate contrast but high-resolution imaging with NIRSpec

- Coronagraphs on NIRCam and MIRI will not provide the high spectral resolution needed to get spectra of exoplanets and certain brown dwarfs
- NIRSpec provides this high spectral resolution but provides only a moderate contrast

NIRSpec is not optimized for high-contrast imaging

- Need to carefully optimize the observing strategy
- Need for exquisite techniques of post-processing to subtract the starlight while preserving the flux from the planet

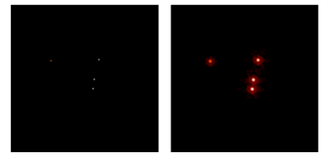


https://jwst-docs.stsci.edu

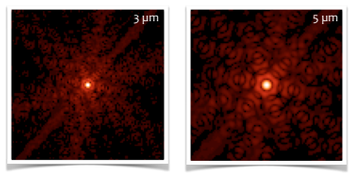
3. Simulations

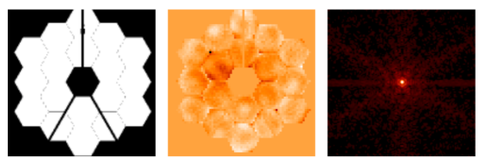
Using the WebbPSF software[6] to simulate NIRSpec images

- 30 slices multispectral data cube [3-5µm]
- Temporal drift between target and reference stars of 20nm (pretty conservative)
- Ref star of same spectral type
- Flat spectrum for planets
- 400 sec exposure time
- Photon noise included



(a) Object map with the four HR 8799 planets (b) Image of the object map in the focal plane



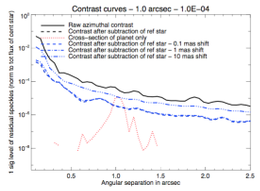


(c) JWST pupil (d) Aberration map (e) Image of the NIRSPEC PSF

4. Comparing different observing strategies and associated PP techniques

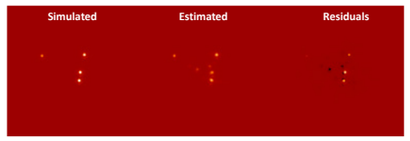
Reference star differential imaging (RDI)

- Uses a reference star (without planet) for starlight calibration
- Tested post-processing technique: Classical PSF subtraction
- The gain on contrast after post-processing is of about 10 matching the typical results that we should expect from post-processing.
- A registration error up to 1 mas has a negligible impact on the contrast curves

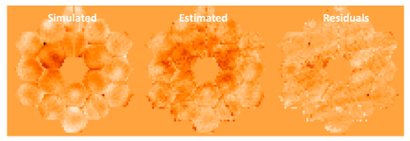


Spectral Differential Imaging (SDI)

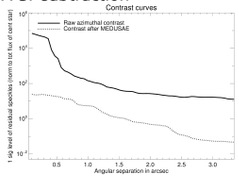
- Uses redundant information from images at different wavelengths for starlight calibration
- Tested post-processing technique: Medusae (Multispectral Exoplanet Detection Using Simultaneous Aberration Estimation)[7]
- Higher gains are achieved from 2 to 10 times better than classical PSF subtraction
- Estimation of the OPD map is possible with this technique

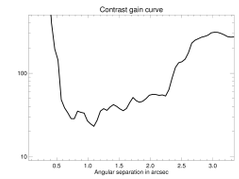


(a) Object estimation



(b) OPD estimation





References

[1] Ferruit et al., "The JWST near-infrared spectrograph NIRSpec: status", 2012, Proc. SPIE. 8442
[2] Gardner et al., "The James Webb Space Telescope", 2006, Space Science Reviews, Volume 123
[3] Maire et al. "The LEECH Exoplanet Imaging Survey. Further constraints on the planet architecture of the HR 8799 system", 2015, A&A 576, A133
[4] Bonnefoy et al., "First light of the VLT planet finder SPHERE IV. Physical and chemical properties of the planets around HR8799", 2016, A&A, 587, 58
[5] Luhman et al 2011, "Discovery of a Candidate for the Coolest Known Brown Dwarf", 2011, The Astrophysical Journal Letters, Volume 730
[6] Perrin et al., "Updated point spread function simulations for JWST with WebbPSF", 2014 , Proc. SPIE. 9143
[7] Ygouf et al., "Simultaneous exoplanet detection and instrument aberration retrieval in multispectral coronagraphic imaging", 2013,