IRD, REACH, and K-REACH: Current Status and Upgrade Plans for Near-Infrared High-Dispersion Spectrometer

Takayuki Kotani, IRD and REACH team

IRD is a near-infrared high dispersion spectrometer with spectral resolution up to 70,000 in the YJH band (0.97-1.75um) and stable radial velocity measurement capability. IRD did its first light in 2017 and has been available as an open-use instrument from 2018, IRD has been used for large survey around nearby M-dwarfs by radial velocity method to search for Earth-like planets in the framework of the Subaru Strategic Program from 2019. REACH is a combination of IRD and extreme adaptive optics SCExAO, which realizes high spatial resolution, high contrast, and high spectral resolution (about 100,000) in the wavelength range of IRD. In this poster, we present the specifications and current status of IRD and REACH. In addition, we present K-band REACH, under development, which combines IRCS and SCExAO to realize high-contrast, high-resolution spectroscopy in the K-band.

IRD

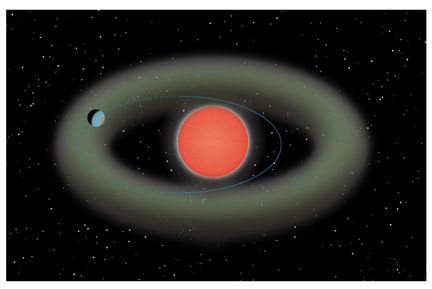
YJH-band, R=70,000 high-resolution spectrometer for highly stable radial velocity measurement

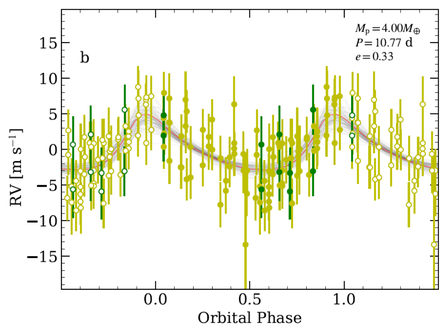
The general schematic view of the instrument is shown in the right panel and the important characteristics of IRD are summarized in the right table. The spectrometer is designed to cover wavelengths from 970-1750 nm with a 70,000 maximum spectral resolution. The instrument consists of 4 main components: a fiber injection module mounted on the adaptive optics bench at the Nasmyth platform, mode scramblers to reduce a modal noise, a spectrometer enclosed in a vacuum chamber in the Coudé room, and the laser frequency comb system as a wavelength reference. Thanks to the highly stabilized optical system in the vacuum chamber, the advanced mode scrambler, and the ultra-stable laser frequency comb, the instrumental stability better than 2 m/s can be achieved.

IRD instrument specifications

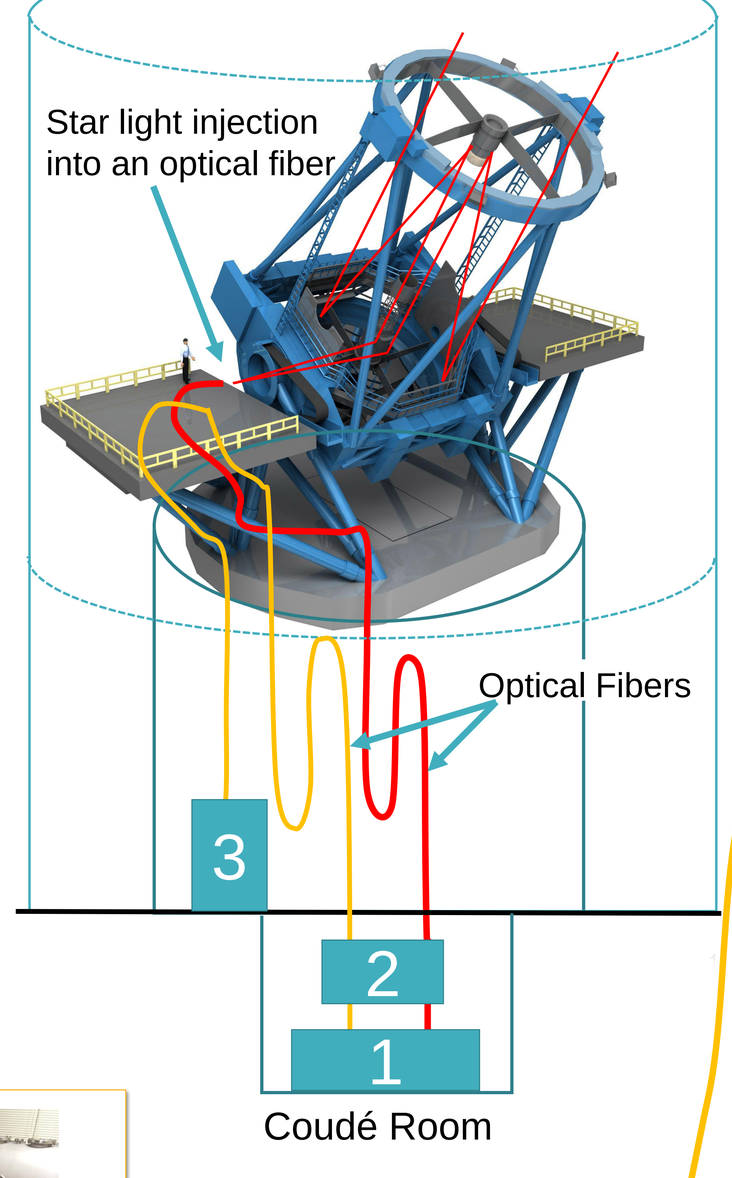
Wavelength coverage	970-1750 nm
Spectral resolution	70,000 max (Multi-mode fiber), 100,000 (Single-mode fiber)
Detector assembly	2 × HAWAII RG and Sidecar-ASIC
Fiber diameter	60 mm, 0.48 arcsec (MMF: OFS F8950), 7.5 mm MFD@1550nm (SMF: OFS BF05635-02)
Wavelength reference	Laser frequency comb, ThAr lamp
Throughput	2.3% at ~1000nm, 3.9% at ~1520 nm (Blaze peak)
Dispersive optics	High blaze angle Echelle grating (78.98-degree blaze angle) + VPH cross-disperser
Temperature	~79K (detectors), 61K (camera lens), ~ 180K (optical bench and other optics)
Radial velocity measurement stability	2 m/s instrumental stability
Adaptive optics	188-element AO188 or Extreme-AO (Subaru Coronagraphic Extreme AO)
Operation	From 2018

Kotani et al. 2018, Proc. SPIE, Vol. 10702, 1070211





4 M_{Earth} planet near the habitable zone (Harakawa et al. 2022, PASJ, 74,904)

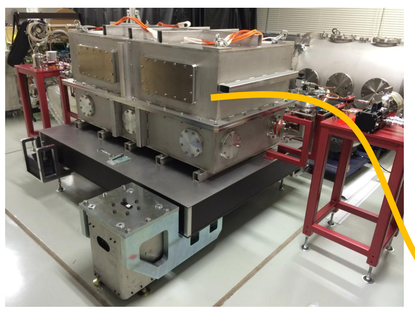


Laser comb frequency span = 12.5GHz

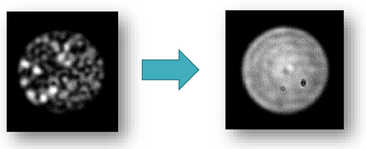
970nm 1750nm

Over 10,000 emission lines for precise wavelength reference

3: Laser frequency Comb

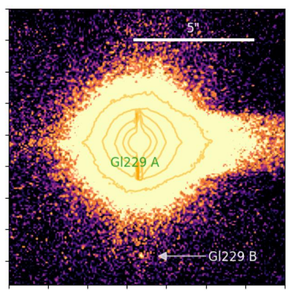


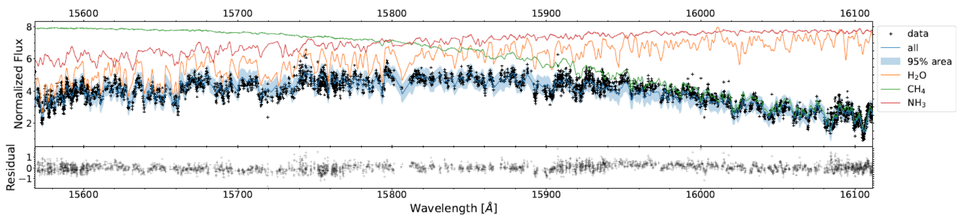
1:Spectrometer



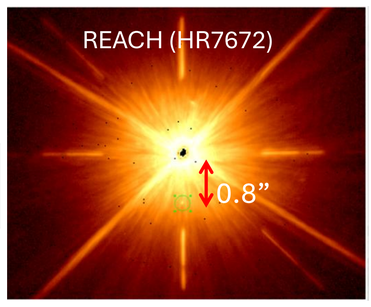
2: Mode scrambler

NIR high-resolution spectroscopy of exoplanet/brown dwarf atmosphere

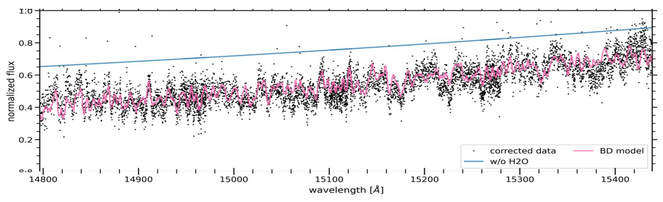




Kawashima et al. 2024, submitted, arXiv:2410.11561



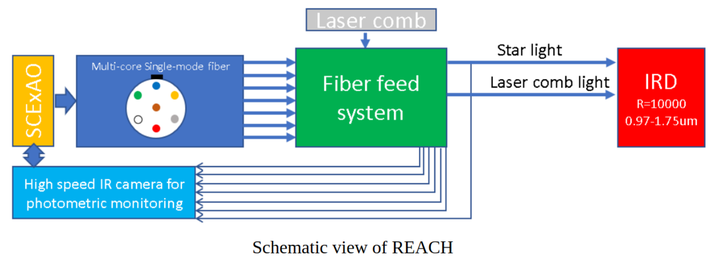
Kasagi+. in prep.



- Precise atmospheric characterization of brown dwarfs and exoplanets
- REACH can probe a region < 1 arcsec from a primary star with very high-contrast
- IRD+AO188 has an advantage to study well separated objects (<5 arcsec) with a moderate contrast

REACH

Combination of IRD and SCExAO for high-contrast and high-resolution spectroscopy



Schematic view of REACH

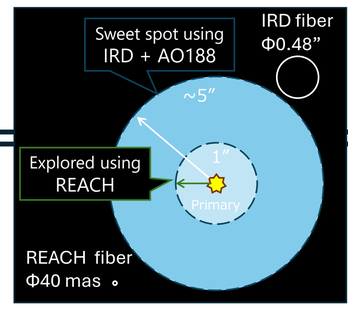
- Visible – y, J, H, K
- Single-mode fiber injection unit for IRD
- Various coronagraph: lyot, PIAA, Vortex, 8Octant, vAPP, shaped mask

REACH consists of mini-IFU like 7 single-mode Multi Core Fiber (MCF) located at a focus of SCExAO, a high-speed NIR photometric monitoring camera for the output beams from MCF, and a beam feed system from MCF to IRD's single-mode fibers (SMF). Thanks to the wavefront correction by the Extreme-AO and a mode-filtering capability of SMF, speckle light injected into a fiber will be reduced by at least 2 orders of magnitude compared to the multi-mode fiber injection of IRD with AO188. A NIR photometric monitoring module in SCExAO will be used for fiber coupling optimization and real-time speckle nulling, which can further reduce the speckle light injected into fibers. The table below shows a summary of the specification for REACH.

REACH instrument specifications

Wavelength coverage	970-1750 nm
Spectral resolution	100,000
Fiber diameter	Each fiber accepts 40 mas at 1.6um Fiber-to-fiber distance is 200 mas Fibers can be positioned at any location in the high-contrast region (2 x 2 arcsec)
Fiber	7 hexagonal packed single mode fibers (SMF) on the SCExAO focus. Light from a central fiber is fed to IRD's SM. MCF output is connected to a photometric monitoring system
Wavelength reference	Laser frequency comb, ThAr lamp
Throughput	2% at ~1520 nm at 0.6arcsec seeing condition
Operation	From 2020

Kotani et al. 2020, Proc. SPIE, Vol. 11448, 1144878



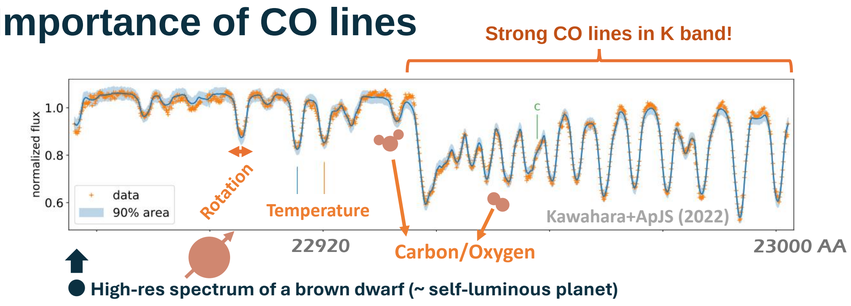
K-REACH

Combination of IRCS and SCExAO for high-contrast and high-resolution spectroscopy in the K-band (under development)

Spectral resolution	18,300 – 22,300
Spectral coverage	1.9-2.5 um
Expected throughput	0.024 (K-REACH) (0.1 IRCS+AO188)
Raw contrast	1e-3 @100 mas 1e-4 @500 mas 1e-5 @ 1000 mas
Operation	Expected from S26A or B at the earliest

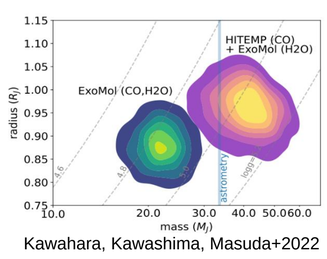
We have been developing K-REACH, which is a single-mode fiber coupling between SCExAO and IRCS, for high contrast and high spectral resolution observations in the K-band region, which is not covered by IRD/REACH. K-REACH will make it possible to observe absorption lines of important molecules such as CO in atmospheres of exoplanets with high precision. We have also started discussion of a possibility to realize a future new KL(M)-band high dispersion spectrometer with R=70,000 that will enable us to study various molecules in exoplanetary atmospheres around ~ 2030.

Importance of CO lines



CO (and H2O) lines provide
- Carbon/Oxygen ratio, the tracer where a planet was born
- Gravity (i.e. planet mass) from the spectroscopy only

Brown dwarf mass inferred from CO high-res line shape



Kawahara, Kawashima, Masuda+2022

TSHIRT

Future plan of KL(M)-band, high-resolution spectrometer and imager with the adaptive optics
Thermal infrared Spectrometer for HIResolution characTerization