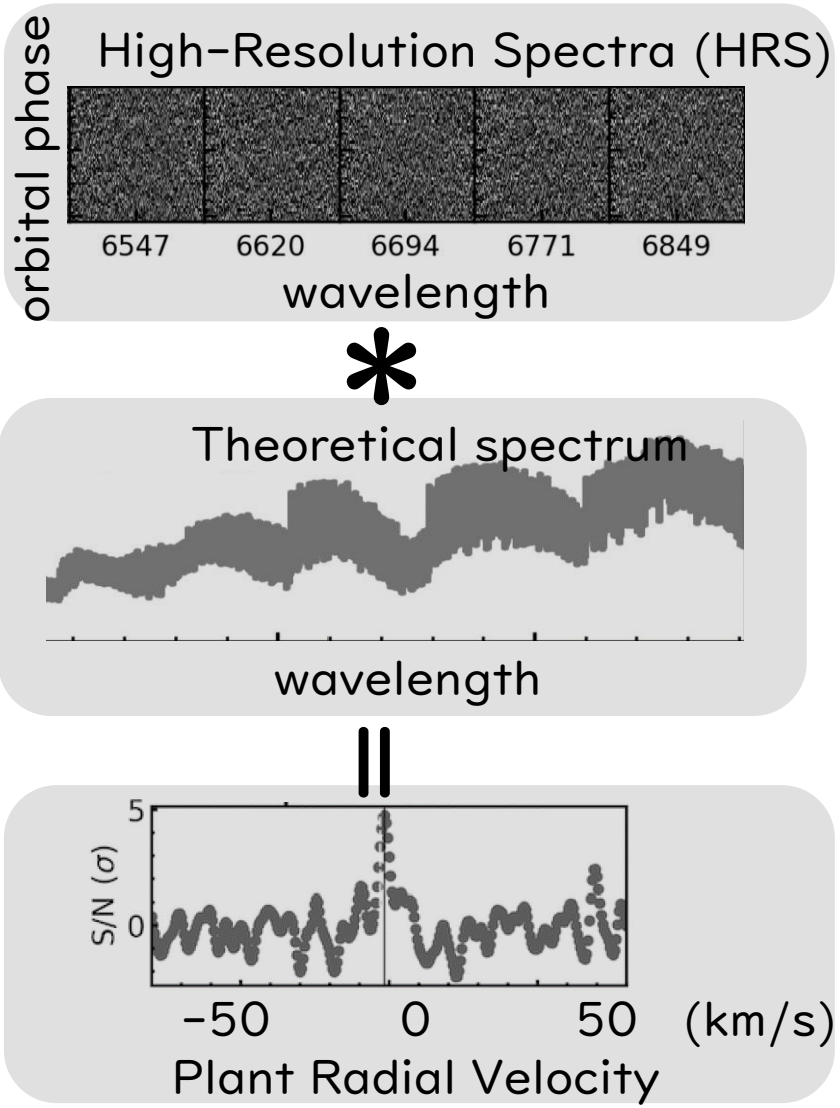
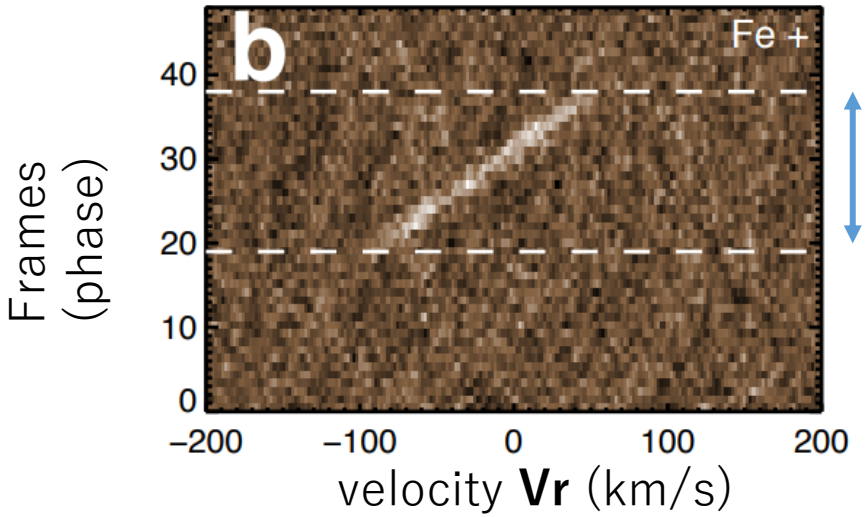
High-Dispersion Characterization of Exoplanets using REACH, IRD, and HDS on Subaru

Hajime Kawahara
Stevanus Nugroho (WASP33b) Masato Ishizuka (HD149026b), Yui Kawashima, Kento Masuda (Gl229B), Takayuki Kotani, Olivier Guyon, Julien Lozi, Sebastien Vievard, Ananya Sahoo, Vincent Deo, Nemanja Jovanovic, Motohide Tamura, Vincent Deo, Nour Skaf, Tako Ishikawa, Kenta Yoneta (REACH)
Jens Hoeijmarkers, Emily Rickman, Janis Hagelberg, Christophe Lovis,
Katy Chubb, Jonathan Tennyson, Sergey Yurchenko, Charles Bowesman (ExoMol)
Sho Shibata, Yui Kasagi, Teruyuki Hirano, Akito Tajitsu, Tomoyuki Kudo, Masayuki Kuzuhara
Neale Gibson, Ernst de Mooij, Chris Watson, and more

Detection of Atoms/Molecules in Exoplanet Atmosphere using High-Dispersion Spectroscopy

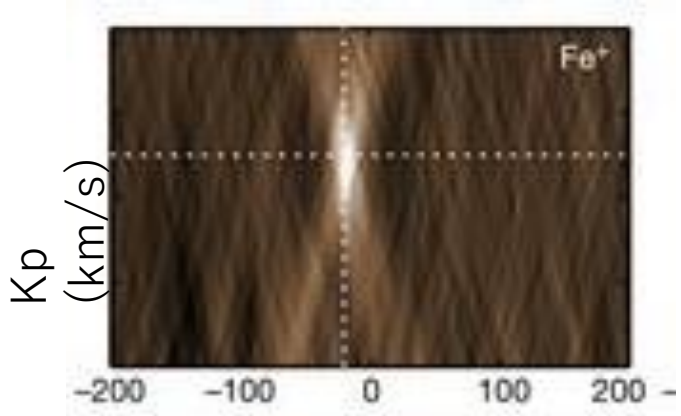


The best one so far. Hot Jupiter KELT9b

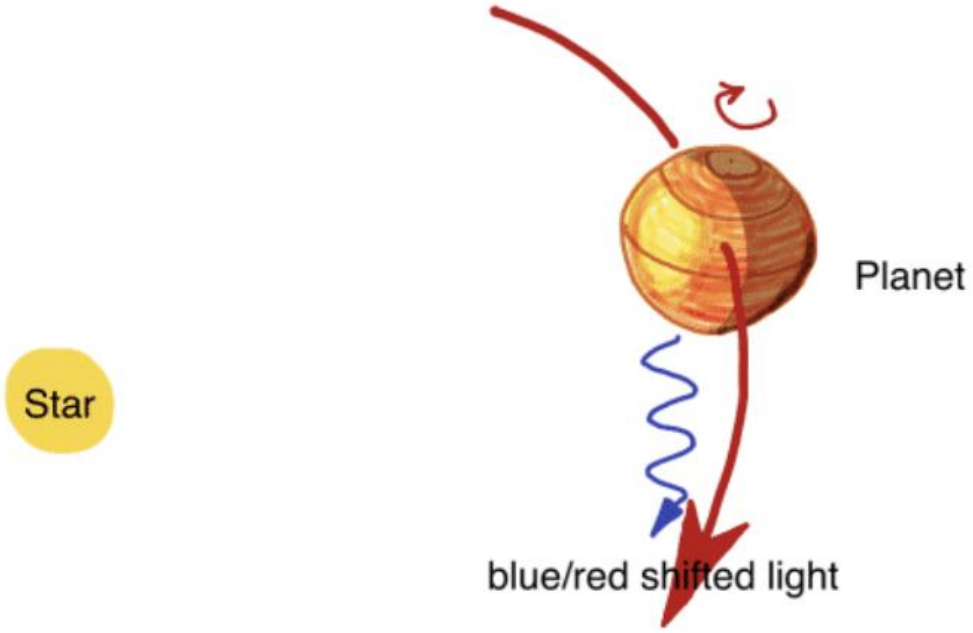


Hoeijmakers +2018

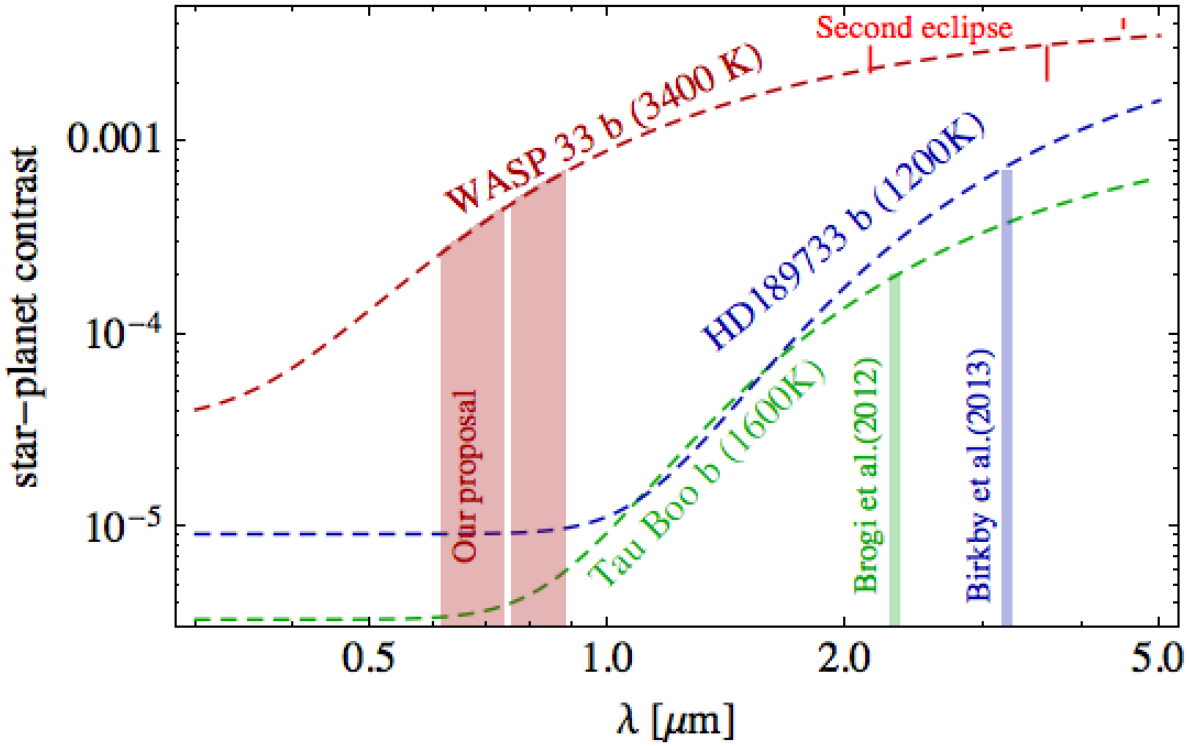
Vr = Kp cos(phase) + V0



TiO in an Ultra Hot Jupiter, WASP33b

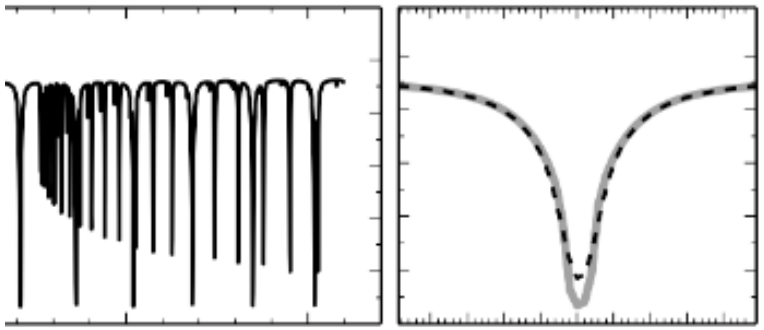


HDS **Data taken in Oct (2015)**

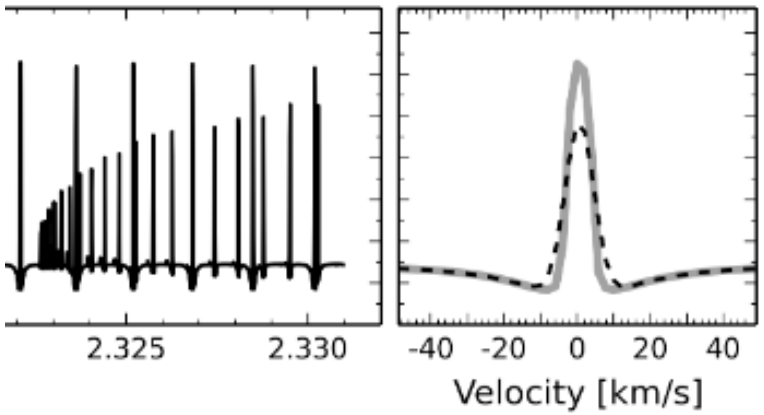


TiO in an Ultra Hot Jupiter, WASP33b

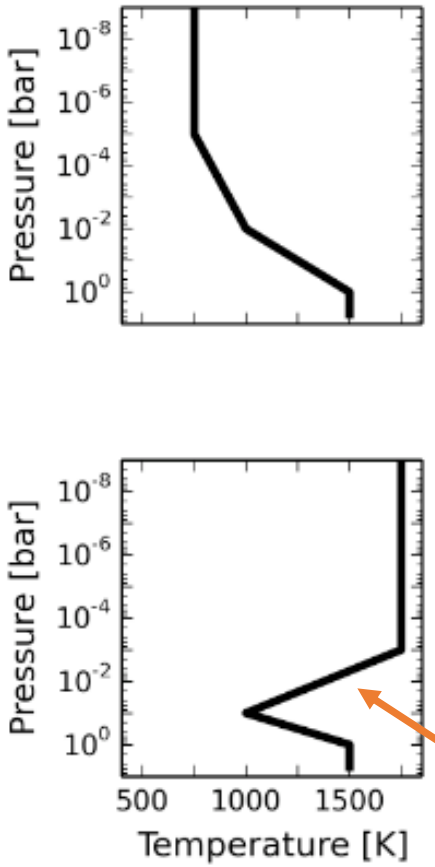
absorption-type



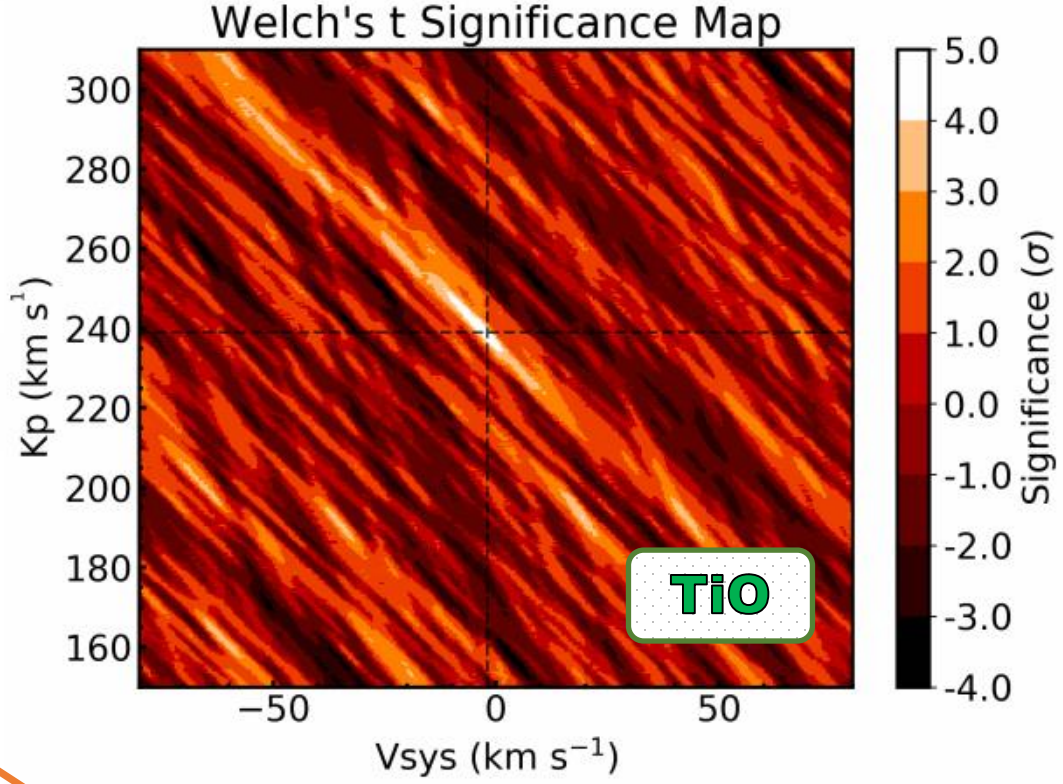
emission-type



Schwarz+2015



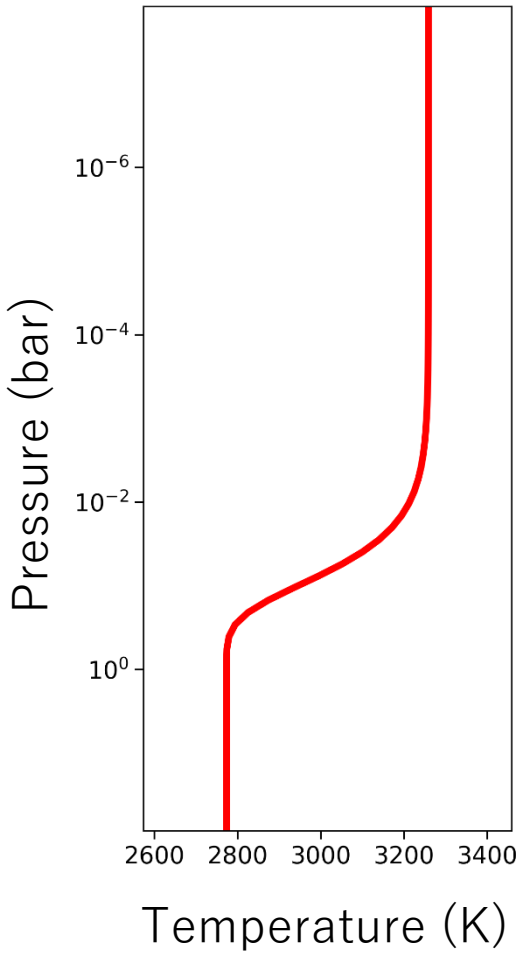
Positive for emission-type

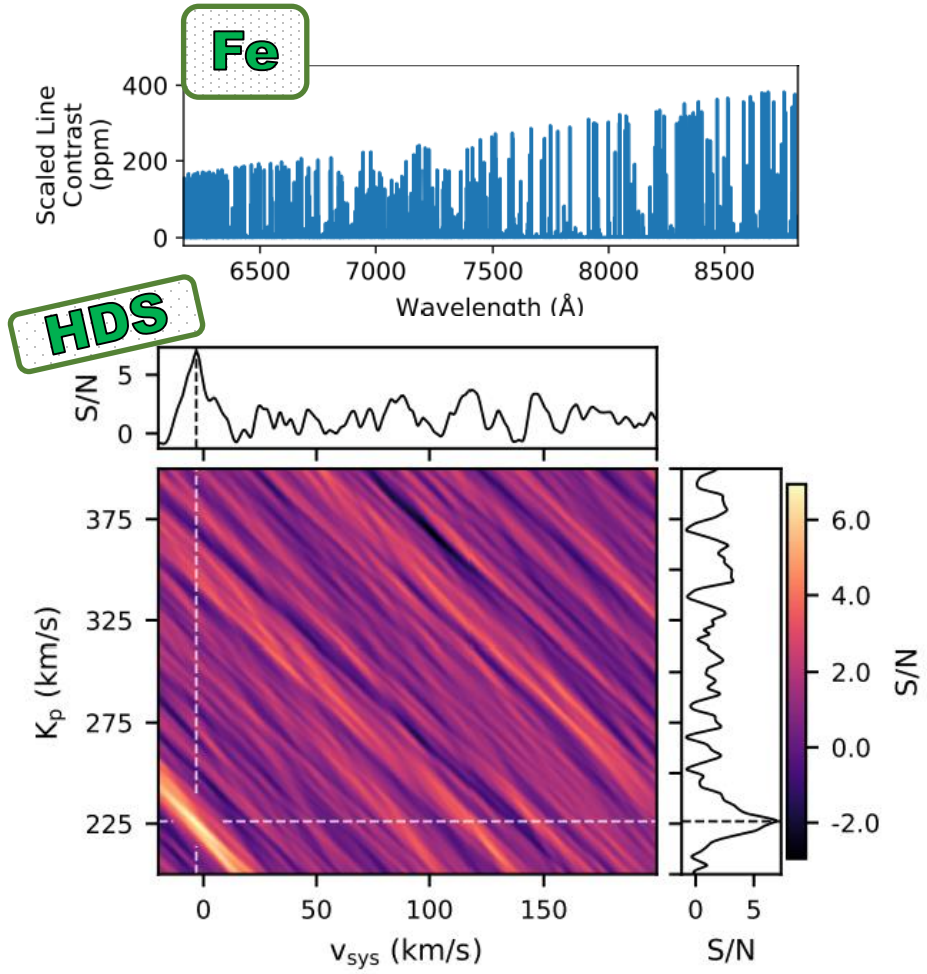


The thermal inversion layer exists!

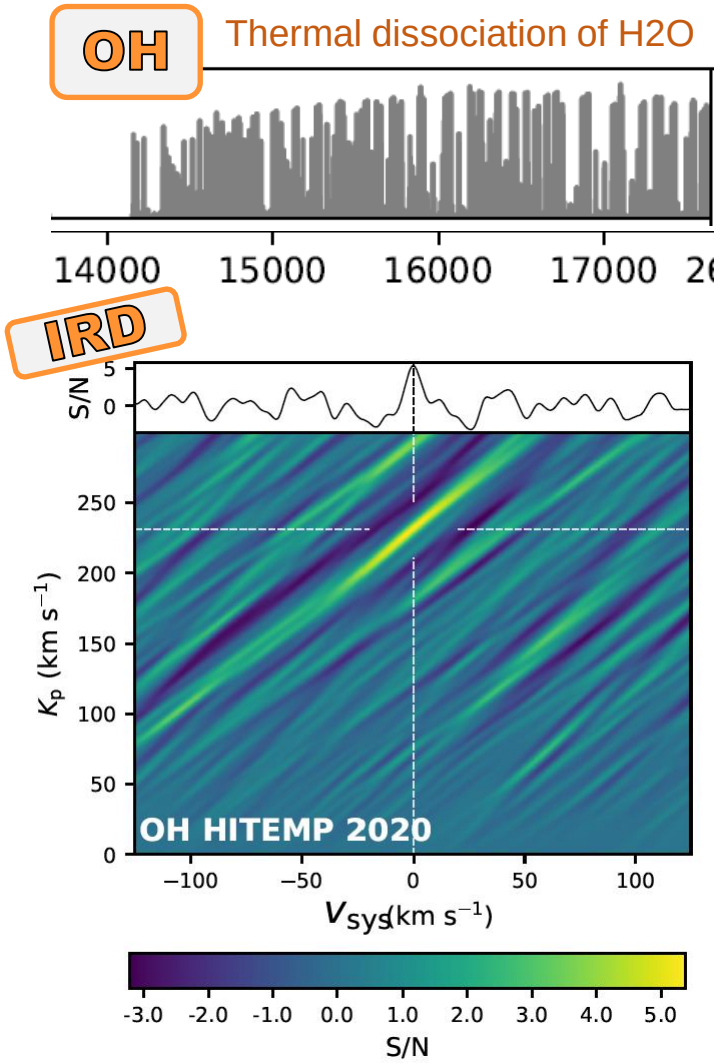
Nugroho, *HK et al. AJ (2017)*

All the molecules support the thermal inversion in WASP33b





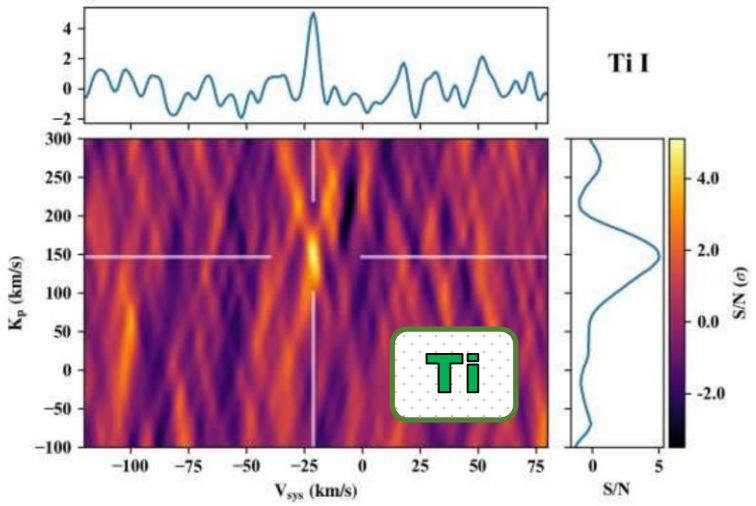
Nugroho, Gibson, *et al. AJ (2020)*

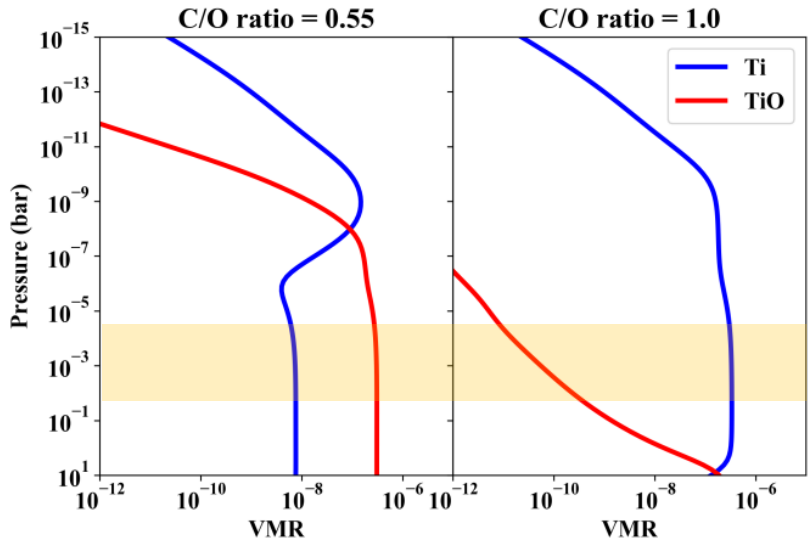


Nugroho, *HK et al. ApJL (2021)*
Accepted today's astro-ph.EP

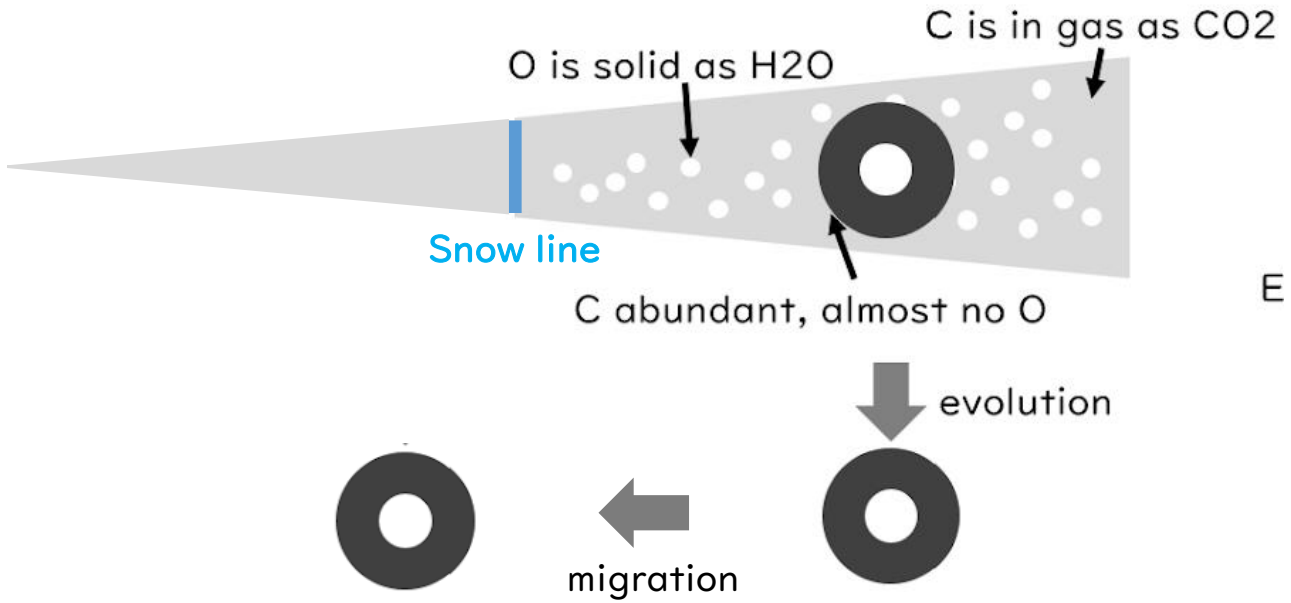
HDS

Absence of Ice at a birthplace?: Neural Ti but no TiO in HD149026b



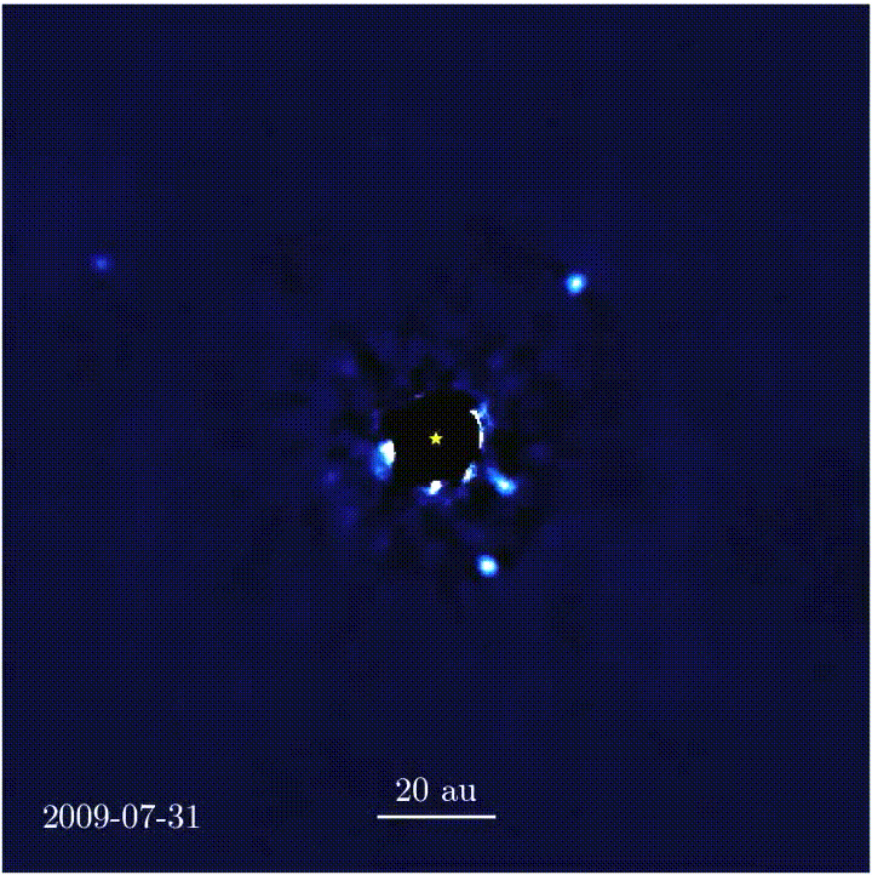


Naive interpretation of low C/O



Ishizuka, *H.K.*, et al. AJ in press arXiv:2102.00211

From close-in planets to distant exoplanets

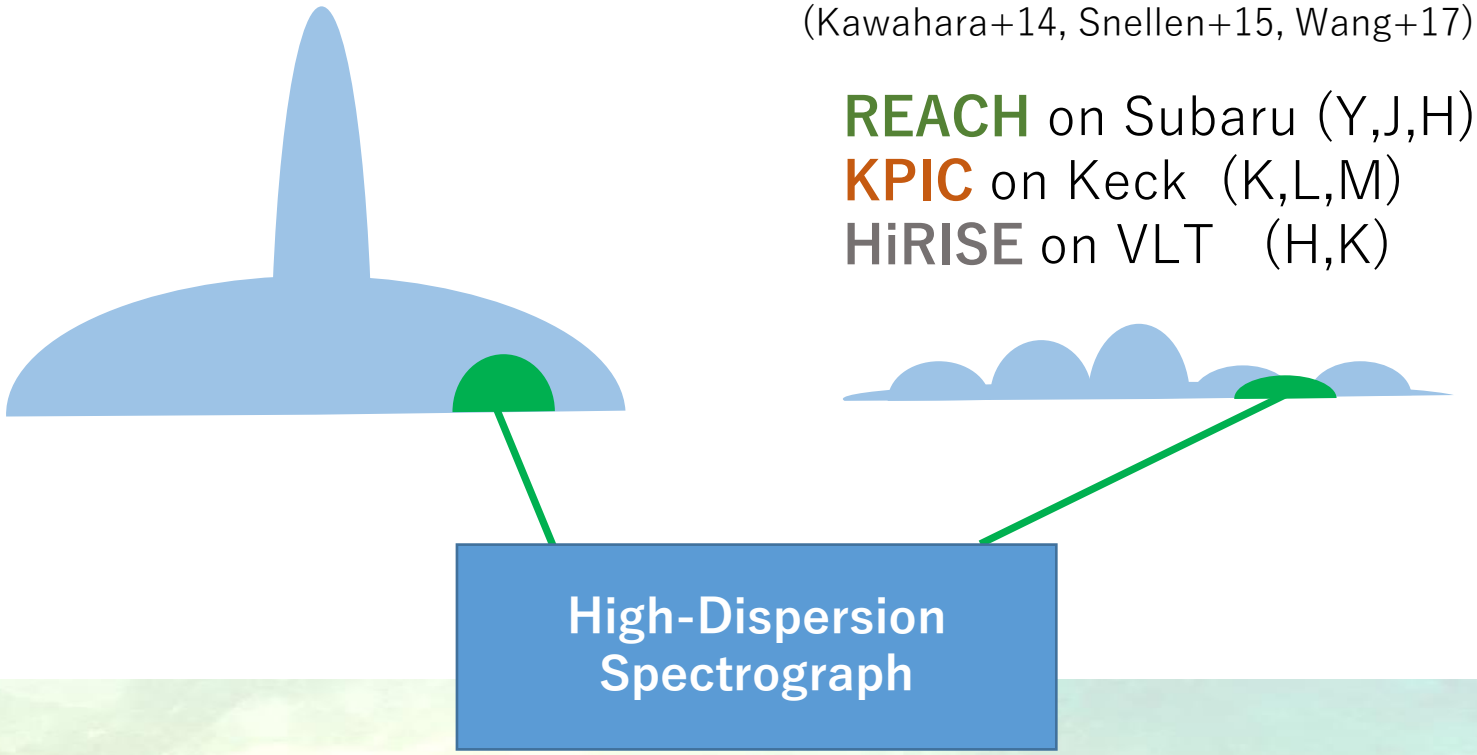


(Wang, NASA)

Classical HRS for direct imaging
(Snellen+14, Hoeijimakers+18)

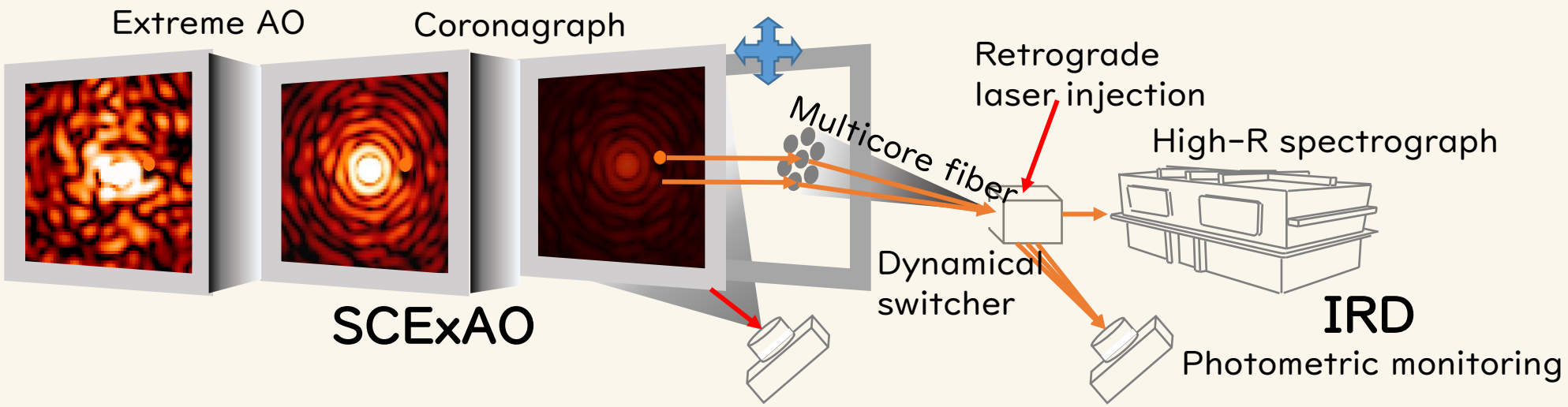
HRS + ExAO + Coronagraph
= High-Dispersion Coronagraphy
(Kawahara+14, Snellen+15, Wang+17)

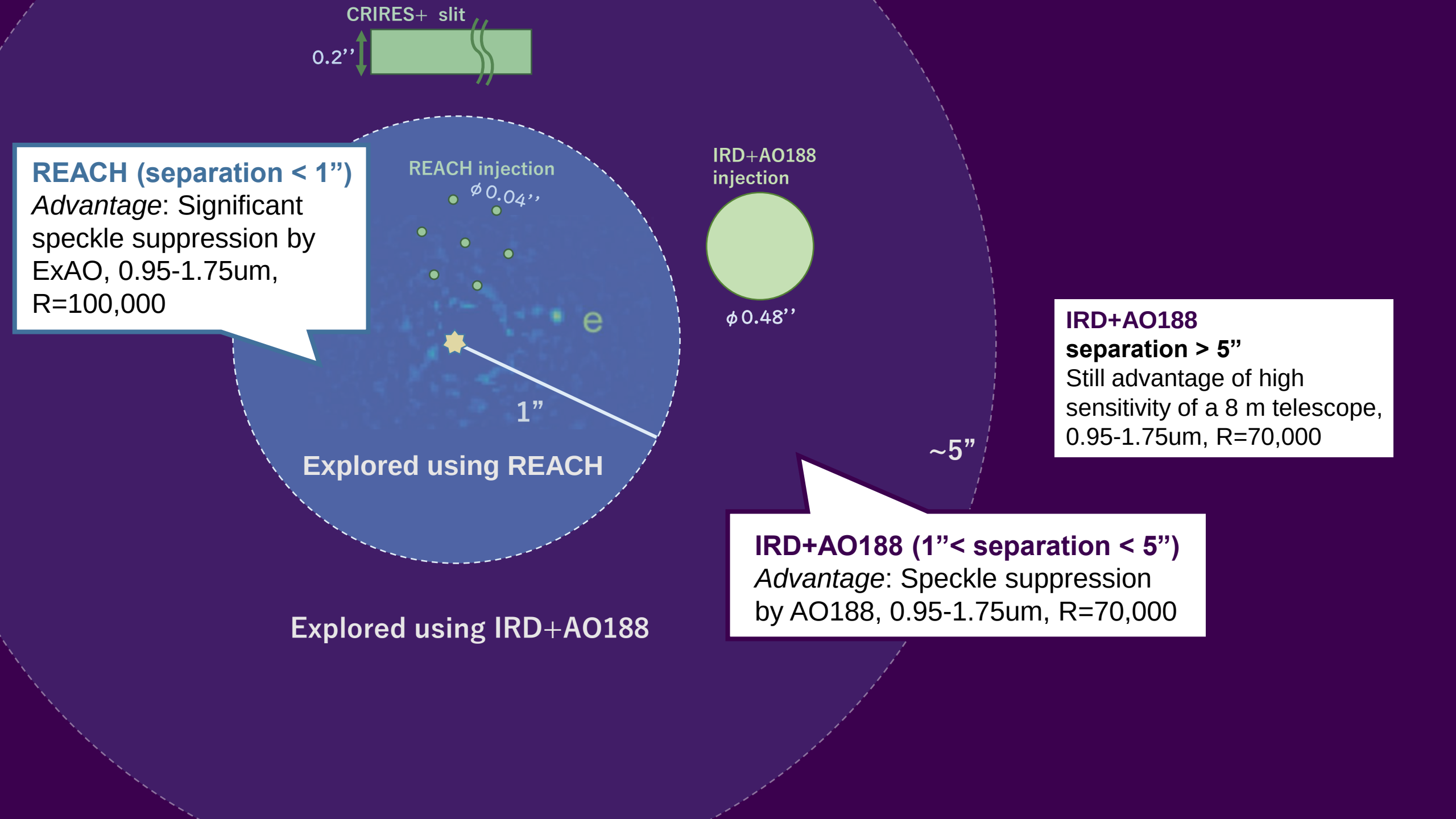
REACH on Subaru (Y,J,H)
KPIC on Keck (K,L,M)
HiRISE on VLT (H,K)



REACH

w/ Kotani
Guyon
Lozi
Vievard
Sahoo
Jovanovic
+REACH collab





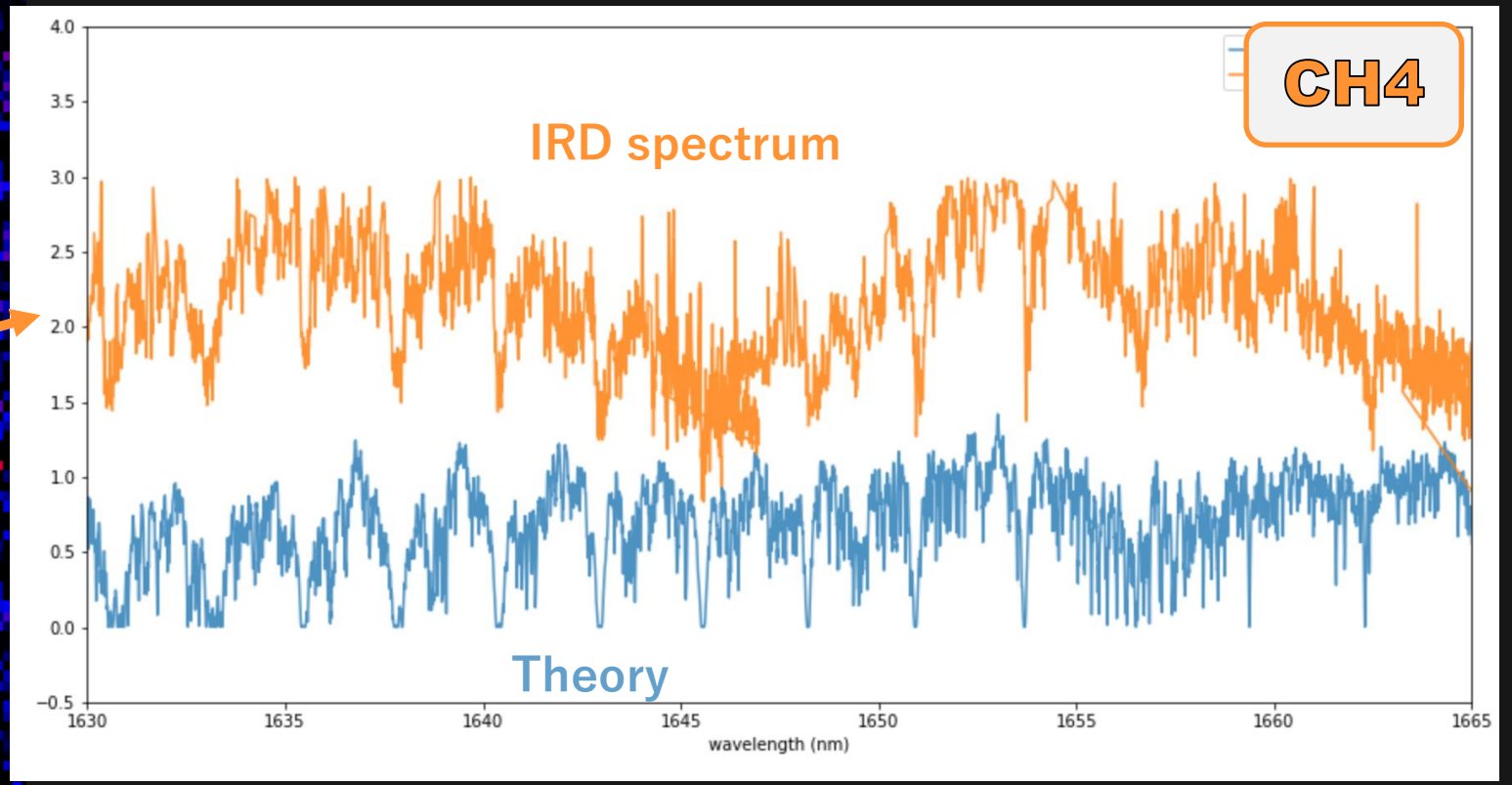
REACH (separation < 1")
Advantage: Significant speckle suppression by ExAO, 0.95-1.75um, R=100,000

IRD+AO188 separation > 5"
Still advantage of high sensitivity of a 8 m telescope, 0.95-1.75um, R=70,000

IRD+AO188 (1"< separation < 5")
Advantage: Speckle suppression by AO188, 0.95-1.75um, R=70,000

IRD+AO188

2021/1/30 GL229B

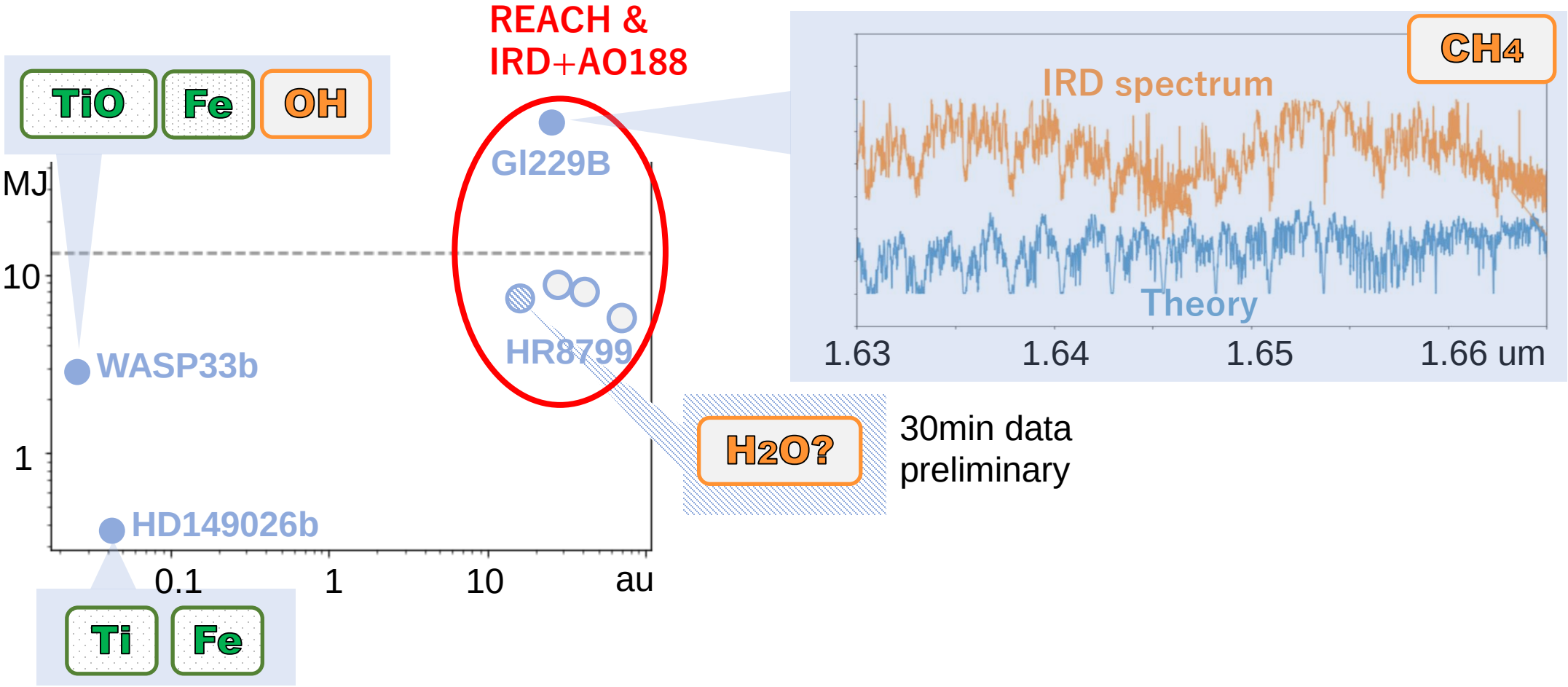


Kawashima et al. in prep

Summary: High-R Exoplanet Characterization by HDS IRD REACH

Since 2018/8

Since 2020/8



These unique capabilities on Subaru is now revealing exoplanet worlds!

International and interdiscipline team to explore exoplanet atmosphere using unique instruments on Subaru

Molecular database
Katy Chubb, Jonathan Tennyson, Sergey Yurchenko, Charles Bowesman

Experimental spectroscopy
Thomas Wall, Damien Weidmann

Instruments
Takayuki Kotani, Olivier Guyon, Julien Lozi, Sebastien Vievard, Ananya Sahoo, Vincent Deo, Nemanja Jovanovic, Motohide Tamura, Vincent Deo, Nour Skaf, Tako Ishikawa, Kenta Yoneta

Planet formation theory
Planet atmospheric chemistry
Yui Kawashima, Kento Masuda, Sho Shibata

High-Dispersion Data Analysis
Jens Hoeijmarkers, Emily Rickman, Janis Hagelberg, Christophe Lovis, Yui Kasagi, Teruyuki Hirano, Tomoyuki Kudo, Masayuki Kuzuhara