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Journal of
Astronomical Telescopes,
Instruments, and Systems

Ultra-Doppler:

Ultra High Precision Radial Velocity Instrument for Nearby Solar Twins Search

2024.12.05 Thu 14:00–14:15 (10+5 min)

UTokyo / Astrobiology Center / NAOJ

Motohide Tamura, Cols are listed later.

*Background images are
IRD Doppler data (JATIS paper) vs.
SCExAO diffraction limit image at optical*

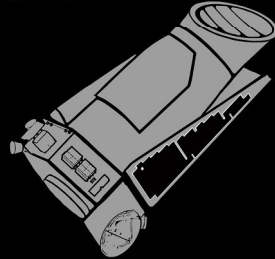
SPIE.

CONTENTS

- 1. Exoplanet science: past, now, and what will be important in 2030s-2040s**
- 2. Why radial velocity (RV)? Why not transit (like Kepler, TESS) and others?**
- 3. Science goal of Ultra-Doppler project**
- 4. What is Ultra-Doppler? How it works?**
- 5. Instrument Specifications and Cost**
- 6. WPRV concept**
- 7. Collaborators, Schedule, Why NAOJ?**
- 8. Summary**

■ BY THE NUMBERS

9.6 YEARS IN SPACE



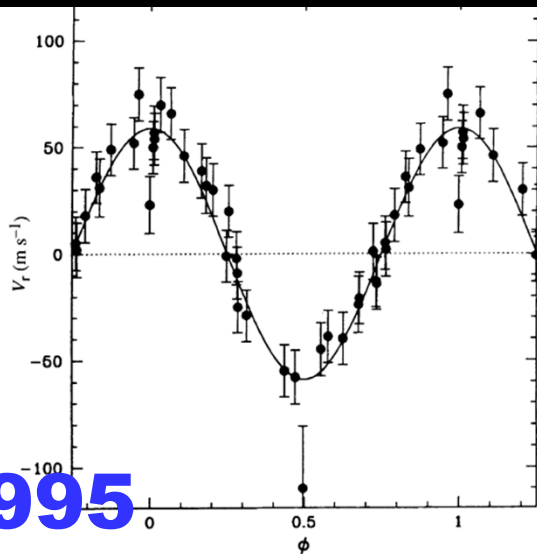
530,506
STARS OBSERVED

2,662
PLANETS CONFIRMED

61 SUPERNOVAE DOCUMENTED

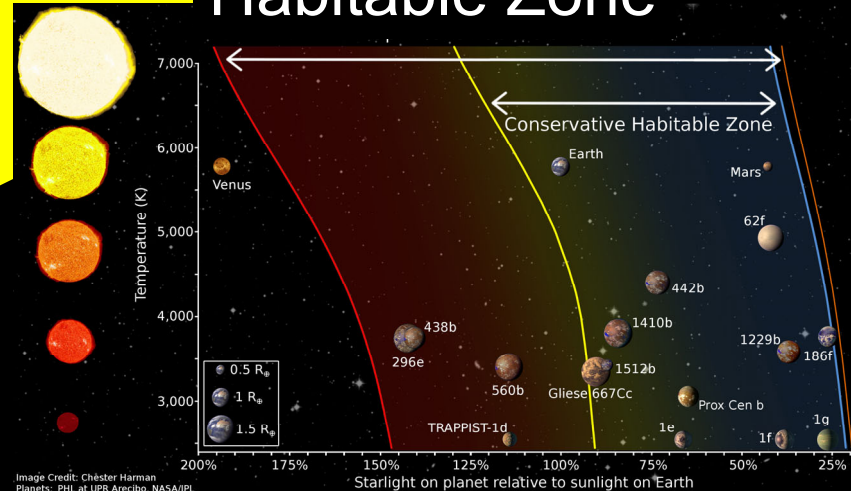
FROM EARLIEST STAGES OF EXPLOSION

51 Peg b (Hot Jupiter)



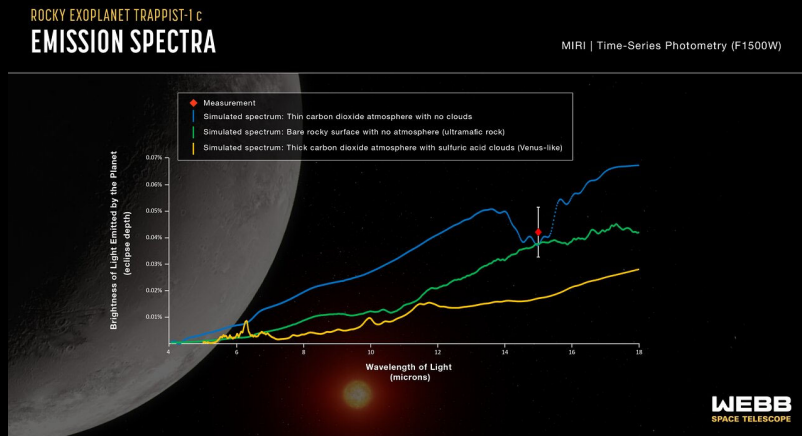
1995

Habitable Zone

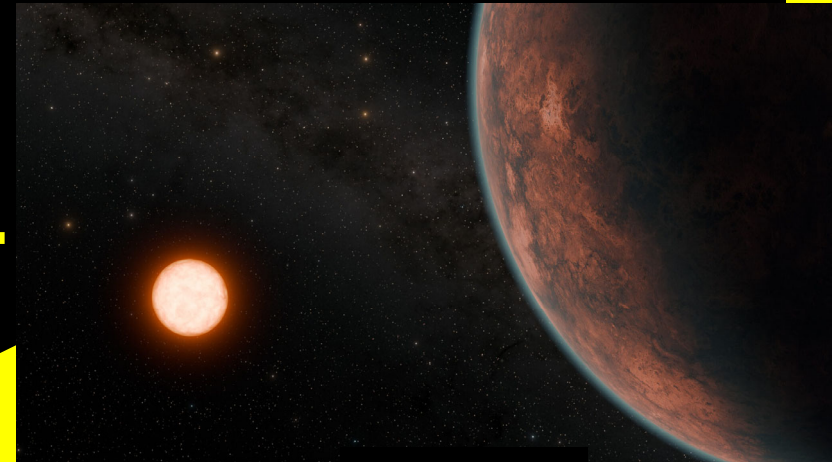


2020s: Alien Worlds

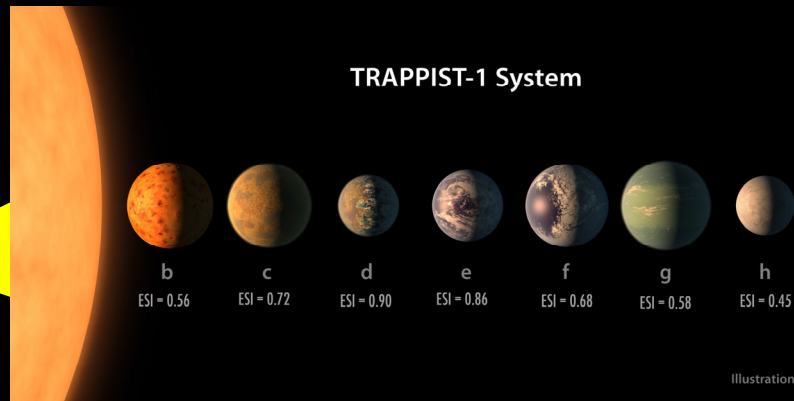
Trappist-1 c (Earth-like)
- JWST -



Gliese 12 b (Earth-like)
- Subaru discovery -



Trappist-1 system (Earth-like)



2016

TESS

BY THE NUMBERS

571
EXOPLANETS
CONFIRMED

7,351
CANDIDATES

1,500
RESEARCH
PAPERS

93 percent
of sky
OBSERVED

5 years
IN SPACE

251
TERABYTES
OF IMAGE DATA

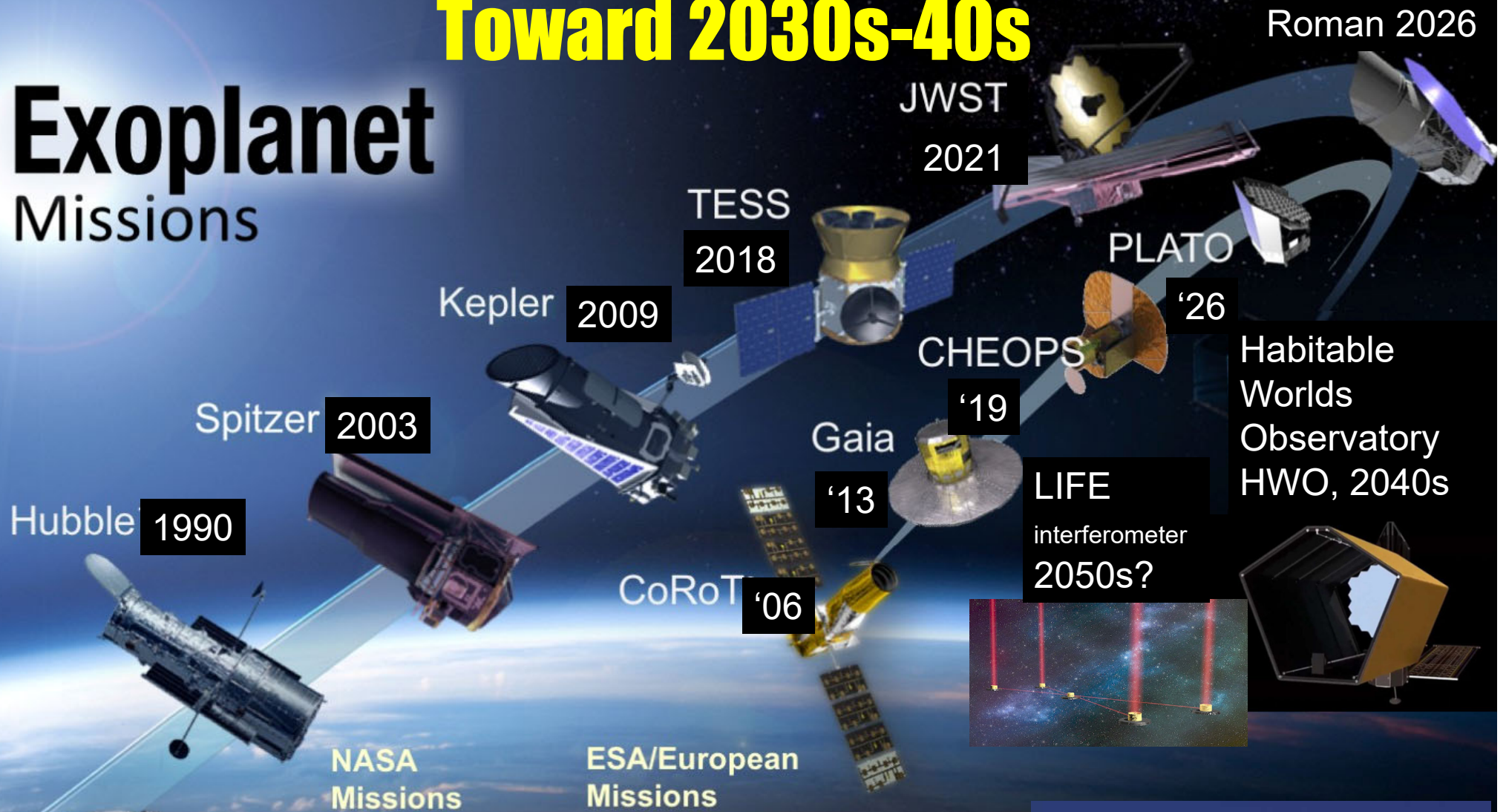
467,768
OBJECTS OBSERVED
AT HIGH PRECISION

50 nations
contributing
SCIENCE

As of April 2023

Toward 2030s-40s

Exoplanet Missions



Ground-based giant telescopes
(Keck, Subaru, etc., & TMT, ELT, GMT)



Key Science in 2030s-2040s: Our worlds

What is the limiting factor in each detection method for habitable planets?

Method	Limited by	M stars	G stars
Doppler	precision	1m/s	1cm/s
Transit	probability	Many nearby stars	No nearby stars
Micro-lensing	probability	No nearby stars	No nearby stars
Direct	contrast	10^8	10^9

- ◆ Q: Only large space telescopes such as HWO and LIFE can explore nearby G stars?
- ◆ A1: No, ultra precision RV (our proposed “Ultra-Doppler”) can explore nearby G stars even before 2040s!
- ◆ A2: Ultra-Doller can measure planet mass, orbit, and even sin(i).

Our Goal: From alien worlds to our worlds

THEME

- ◆ Next generation *multi-wavelength* Doppler instruments & Quest for habitable worlds around *both* low-temperature stars and Sun-like stars

SALESPPOINT

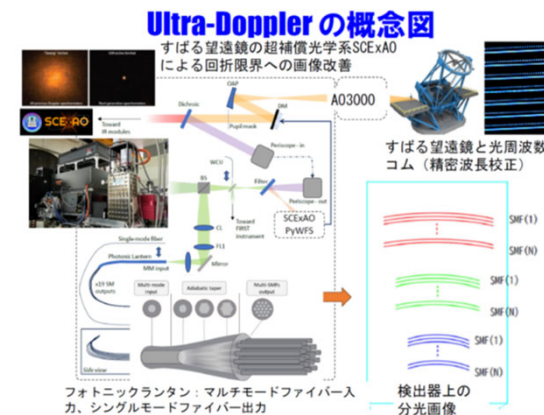
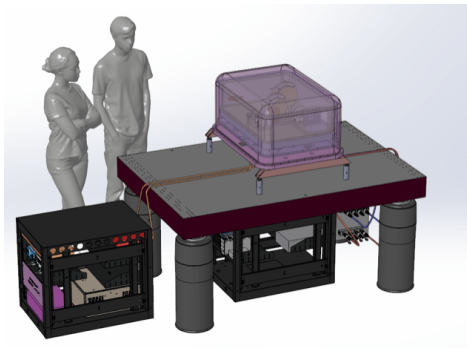
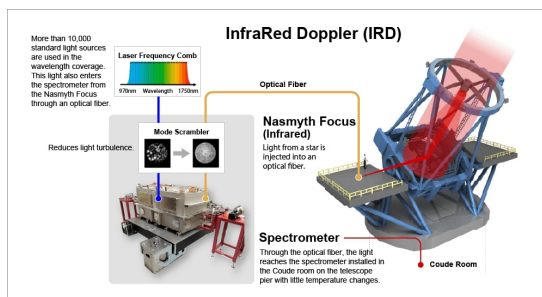
- ◆ **Wide-band & ultra-Precision Doppler (RV) method (WPRV)** for a few cm/s (best) precision RV observations of nearest stars
- ◆ IR: Subaru **IRD**、Keck **HiSPEC** ; OPT: Subaru **Ultra-Doppler**

Earth “cousin” exploration
(planets around red dwarfs and young stars)

Subaru **IRD** and Keck **HiSPEC**

Earth “twin” exploration
(planets around sun-like stars)

Subaru **Ultra-Doppler**



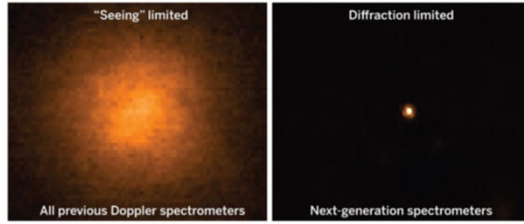
What is Ultra-Doppler (UD) ?



Our plan for the next generation astrobiology instruments

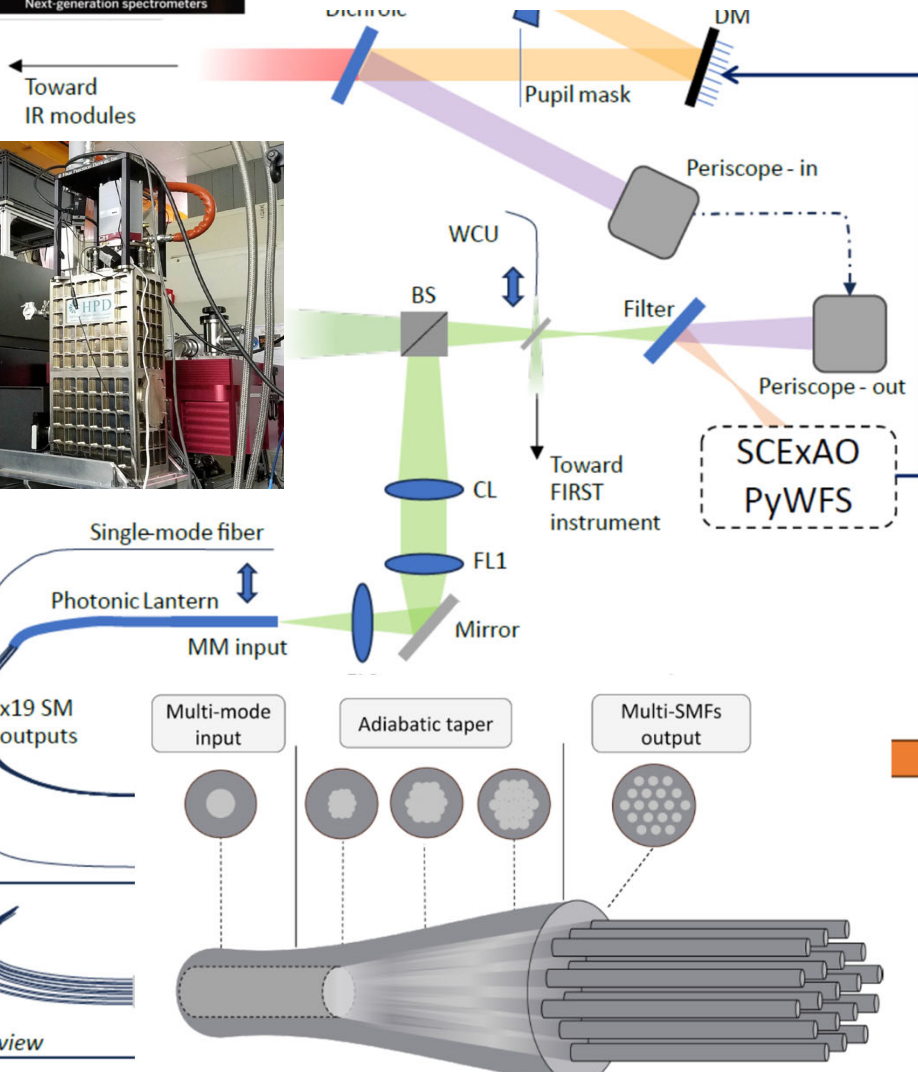
- ◆ Establish an unprecedented cm/s radial velocity measurement method (**ultra-high precision Doppler**).
- ◆ The first full-scale search for **habitable planets around nearby Sun-like stars**, to detect and determine the **frequency of Earth's twins**, i.e., terrestrial **temperate planets** that are distant from the host star.
- ◆ Other than RV, no other methods are possible for nearby stars except for future direct observations in 2040s (HWO or LIFE).
- ◆ **Mass and orbit determination** is critical for any exoplanet studies. Even **$\sin(i)$** using spectro-astrometry. Transit cannot decide planet mass unless multiple (using TTV).
- ◆ The WPRV, consisting of **visible Ultra Doppler (UD) for Subaru**, **infrared IRD for Subaru**, and **infrared HiSPEC for Keck**, will be used for the Japanese community.

How UD works ?

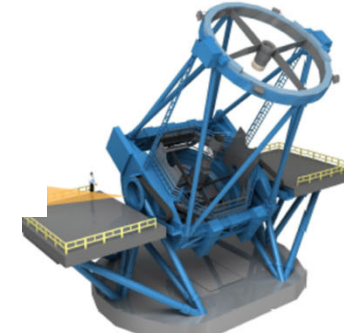


② SCExAO/AO3000

-- High-SR diffraction-limit image at optical wavelengths



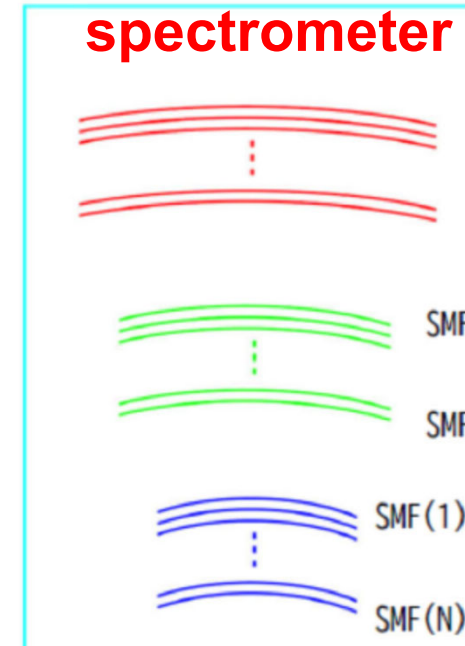
③ Single-mode fiber injection to spectrometer such as **Photonic Lantern**



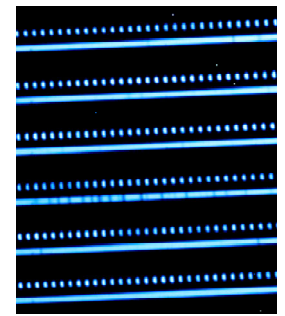
① Subaru Telescope

Large collecting area & sharp image

④ Diffraction-limit high-dispersion spectrometer



⑤ Echellogram on Detector

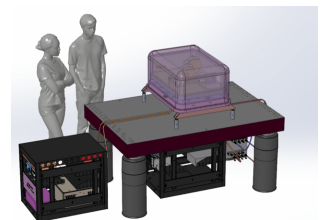


⑥ Laser Comb

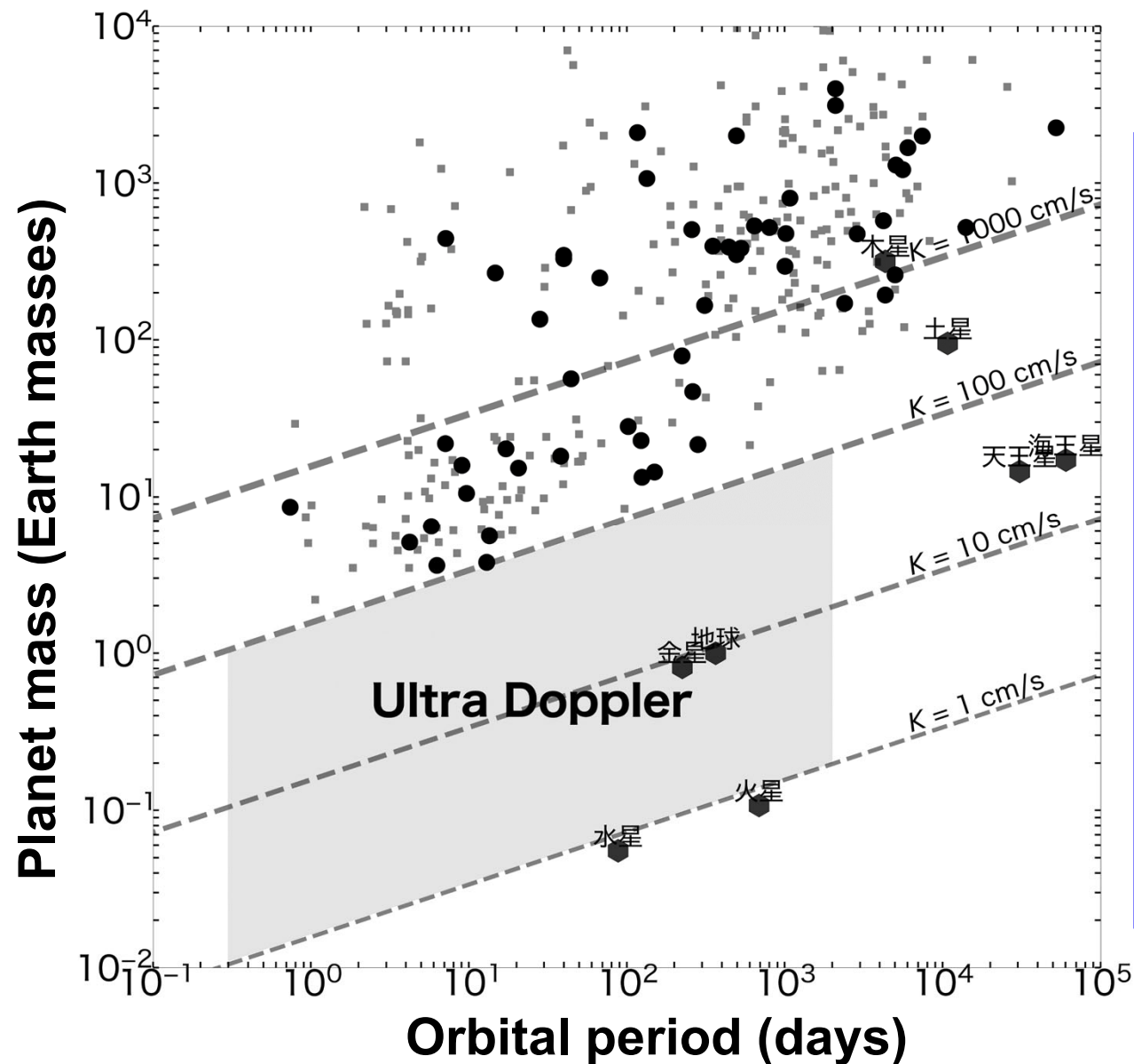
WL calibrator

⑦ Compact Size !

Stability, Cost, etc.



Parameter space for UD survey



Earth-like planets
not only in habitable
ones but also
all kinds of small
planets are
unexplored around
nearby
Sun-like stars

Needs
10 years survey

Detected planets around 0.9–1.1 Solar-mass host stars
<25pc (black circle) 、<100pc (small square), Solar system planets (hexagon)
RV accuracy (broken lines for 3, 10, 300, 1000 cm/s)

Summary

- (a) The key exoplanet target will change from nearby M stars to GK stars for Earth-like habitable planets (**Earth twins**) **Back to Arke!**
- (b) **Ultra-Doppler** or **Optical ultra high precision RV instrument** coupled with the extreme adaptive optics (**SCExAO**) is the most promising instrument to explore **Earth twins**. Essential science in **Subaru 2-3 phase**.
- (c) These can be explored **even before** the HWO/LIFE era in 2040s.
- (d) For M stars, **Infrared** RV instruments such as **IRD** and **HiSPEC**/Keck will be available.
- (e) These series of instruments will be the key to explore **astrobiology** in **2020s-40s**.

Finally published in 2024.9⇒

