Status updates of IRD-SSP

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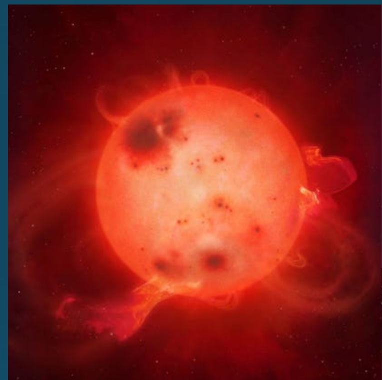
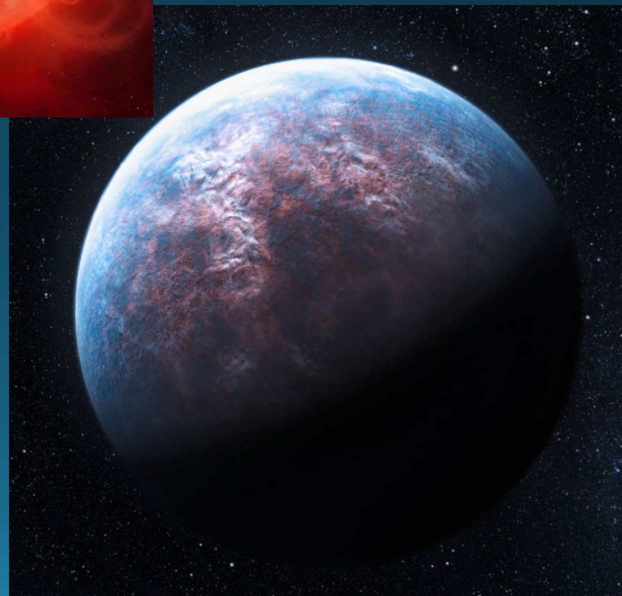
on behalf of the IRD-SSP team

Redefinition of science goals in 2022

- Minimum Success
  - **Detection of >1 terrestrial planets (m sini = 1 -10 M_{Earth})**
  - Limit on the distribution of giant planets (> a few 10 MEarth), located up to ~0.1 a.u. for >40 stars that can be compared to the result of gravitational microlensing planet.
  - Provide an upper limit on the frequency of HZ planets, >3 MEarth
- Full Success:
  - **Discover at least one HZ planet with m sini = 1-10 M_{Earth}**
  - Limit the distribution of short-period (orbital period < 10 days), planets >3 M_{Earth}
  - Limit the frequency of existence of low-mass planets (>3 MEarth), including HZ planets
- Extra Success:
  - **Discovery of one or more HZ planets of about Earth mass (m sini= 1-3 M_{Earth})**
  - Obtain frequency of existence for terrestrial planets (>1 MEarth), including Earth-mass HZ planets
  - Discover Earth-like planets that can be followed up (transit photometry) to understand the atmospheres and internal compositions (e.g. mass-radius relationship)





Observation progress in S24A&S24B

- A total of 175 nights allocated for S19A~S23B period
- 25.5 nights lost due to troubles (telescope, detector, COVID-19). The nights are compensated in S24A-S25A.
- 169 nights were used for IRD-SSP by January 2025.
- Success rate was particularly not good in July and December in 2024.

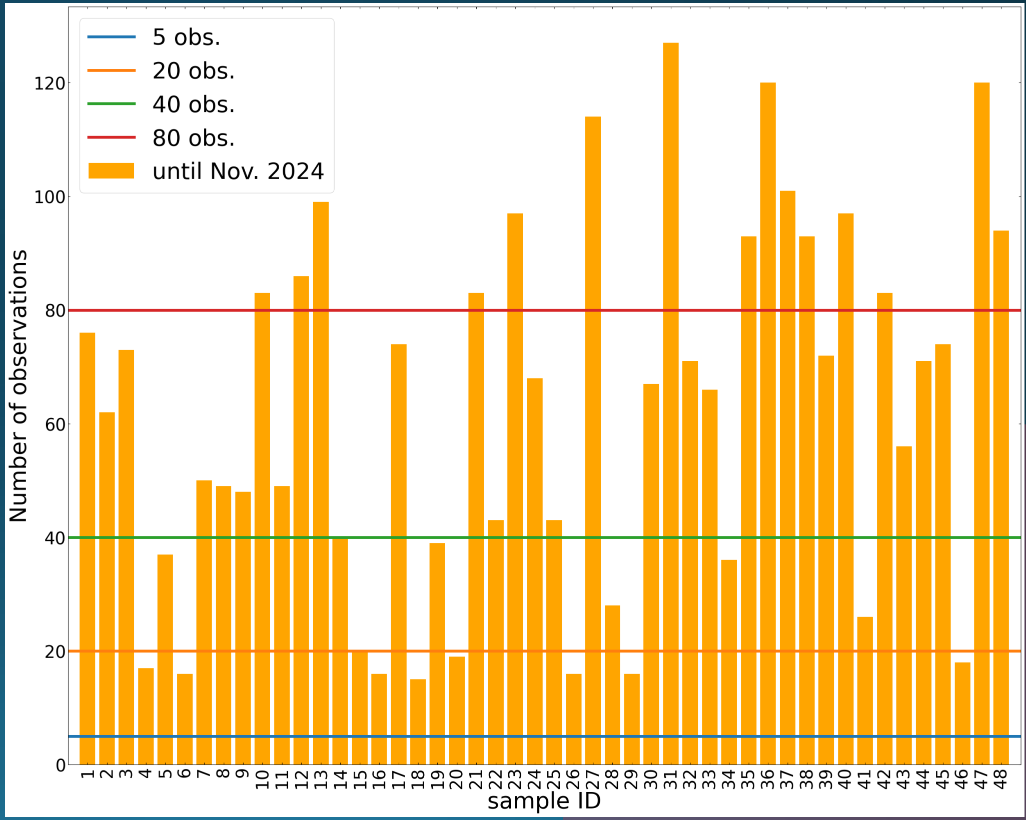
S24A	Allocated (nights)	Observed (nights)	Success rate (%)
February	0	0	
March	2	1.1	53
April	1.5	1.1	71
May	0	0	
June	2	1.8	91
July	1.5	0.6	40
Total (S24A)	**7**	**4.5**	**64.8**

S24B	Allocated (nights)	Observed (nights)	Success rate (%)
August	3	2.0	68
September	3	1.5	50
October	3	2.2	74
November	1.5	1.2	83
December	2	0.7	35
January	0	0	
Total (S24B)	**12.5**	**7.7**	**61.5**

Number of observations for each target

- Monitoring observations were carried out according to several criteria with levels of priority (screening, variability check, monitor, intensive follow-up).
- The numbers of observations for monitoring stars are shown on the right figure.
- The numbers of key stars are listed in the table below.

Number of observations	Number of stars
≥ 5	83
≥ 20	40
≥ 40	34
≥ 80	15



Publications

1. "A Super-Earth Orbiting Near the Inner Edge of the Habitable Zone around the M4.5-dwarf Ross 508", Harakawa et al. 2022, PASJ, 74, 904
2. "Elemental Abundances of nearby M Dwarfs Based on High-resolution Near-infrared Spectra Obtained by the Subaru/IRD Survey: Proof of Concept", Ishikawa et al. 2022, AJ, 163, 72
3. "An Earth-sized Planet around an M5 Dwarf Star at 22 pc", Hirano et al. 2023, AJ, 165, 131
4. "Direct Imaging Explorations for Companions around Mid-Late M Stars from the Subaru/IRD Strategic Program", Uyama et al. 2023, AJ, 165, 162
5. "Planetary companions orbiting the M dwarfs GJ 724 and GJ 3988: A CARMENES and IRD collaboration", Gorrini et al. 2023, A&A, 680, 28
6. "Gliese 12 b: A Temperate Earth-sized Planet at 12 pc Ideal for Atmospheric Transmission Spectroscopy", Kuzuhara et al. 2024, ApJ, 967, id.L21

Several more papers are in preparation.

Property of Gliese 12 System

Gliese 12 b is receiving an insolation comparable to a temperate planet

Orbital Period (days)	12.76
Planet Radius (R_E)	0.96 ± 0.05
Mass (M_E)	< 3.9 (3σ)
Semi-major axis (au)	0.067 ± 0.002
Equilibrium Temperature (K) (albedo = 0)	288 (+6, -5)
Insolation (S_E)	1.6 ± 0.1

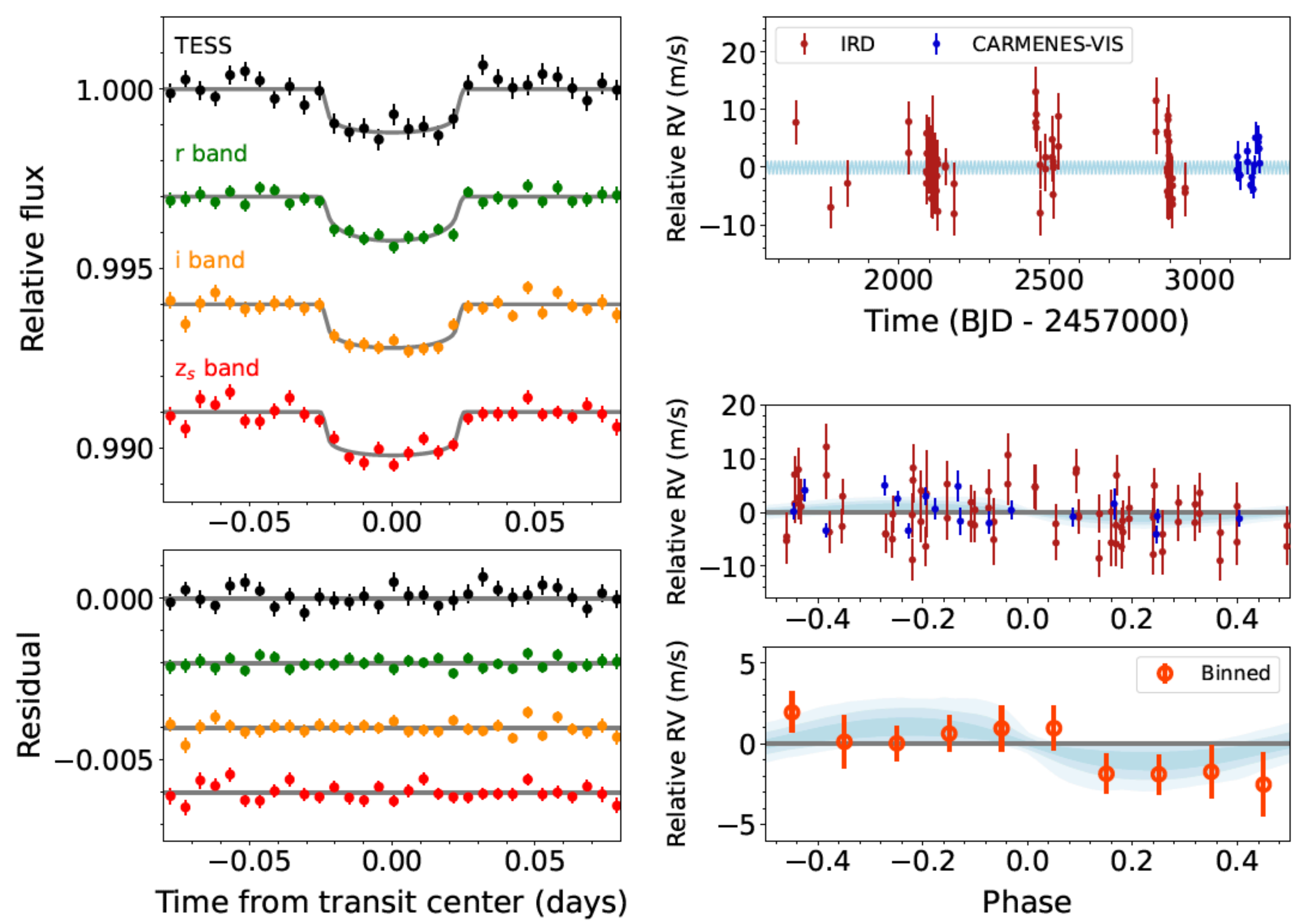
Insolation of Venus = 1.9 S_E

T_{eff} (K)	3296 (+48, -36)
M (M_{sun})	0.241 ± 0.006
R (R_{sun})	0.262 (+0.006, -0.007)
[Fe/H]	−0.32 ± 0.06
Distance (pc)	12.166 ± 0.005

Kuzuhara-san's talk this afternoon

Artist's concept

Image Credit: NASA/JPL-Caltech/R. Hurt (Caltech-IPAC)

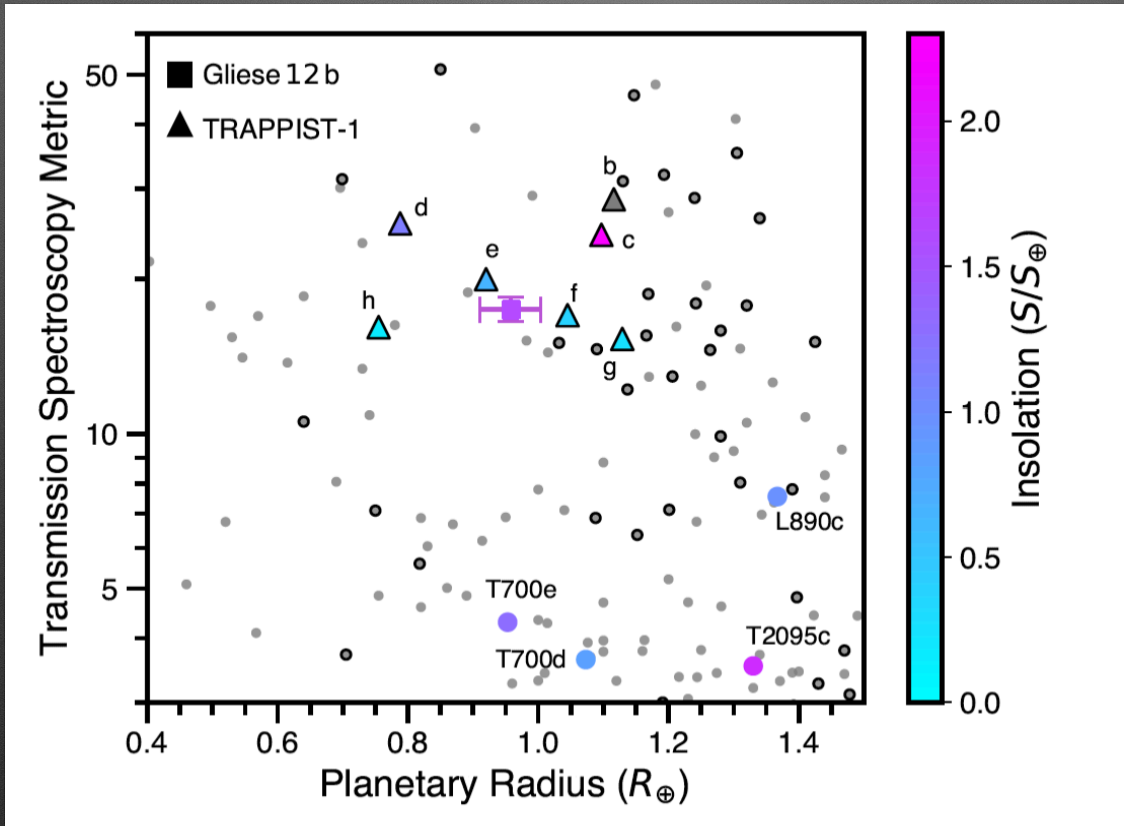


RV+ Transit Joint Fit

IRD, CARMENES, TESS, MuSCAT 2&3

How easily transmission can be done

How the planet is suitable for transmisssion: TSM



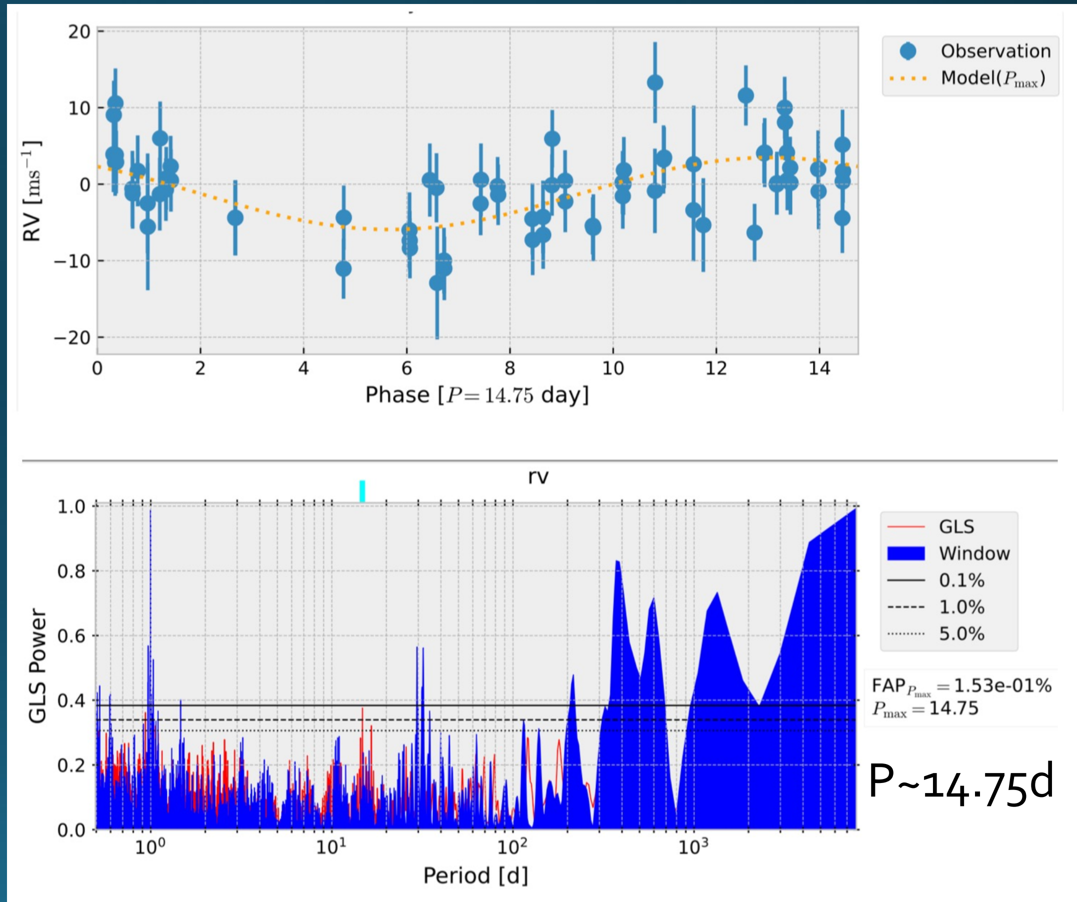
Challe nging

Definition of TSM:
Atmosphere areas through lights from star pass is propotional to scale height.
Larger TSM = Larger scale height x Greater SNR (=brightness)
(Kempton+2019)

Among planets receiving insolations smaller than that on Venus, only Gliese 12 b and TRAPPIST-1 are realistic

Other planet candidates

We have 3 more planet candidates (FAP<1%), but we need more observations (> 10-20 RVs) to confirm them.

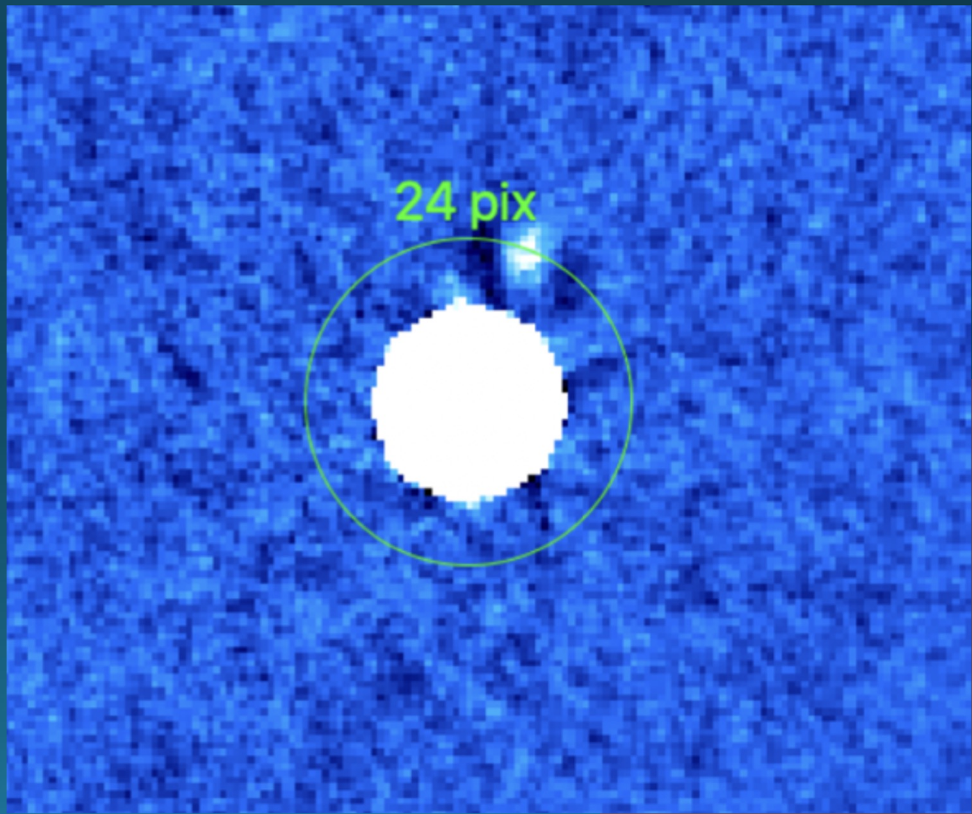


Collaboration with CARMENES

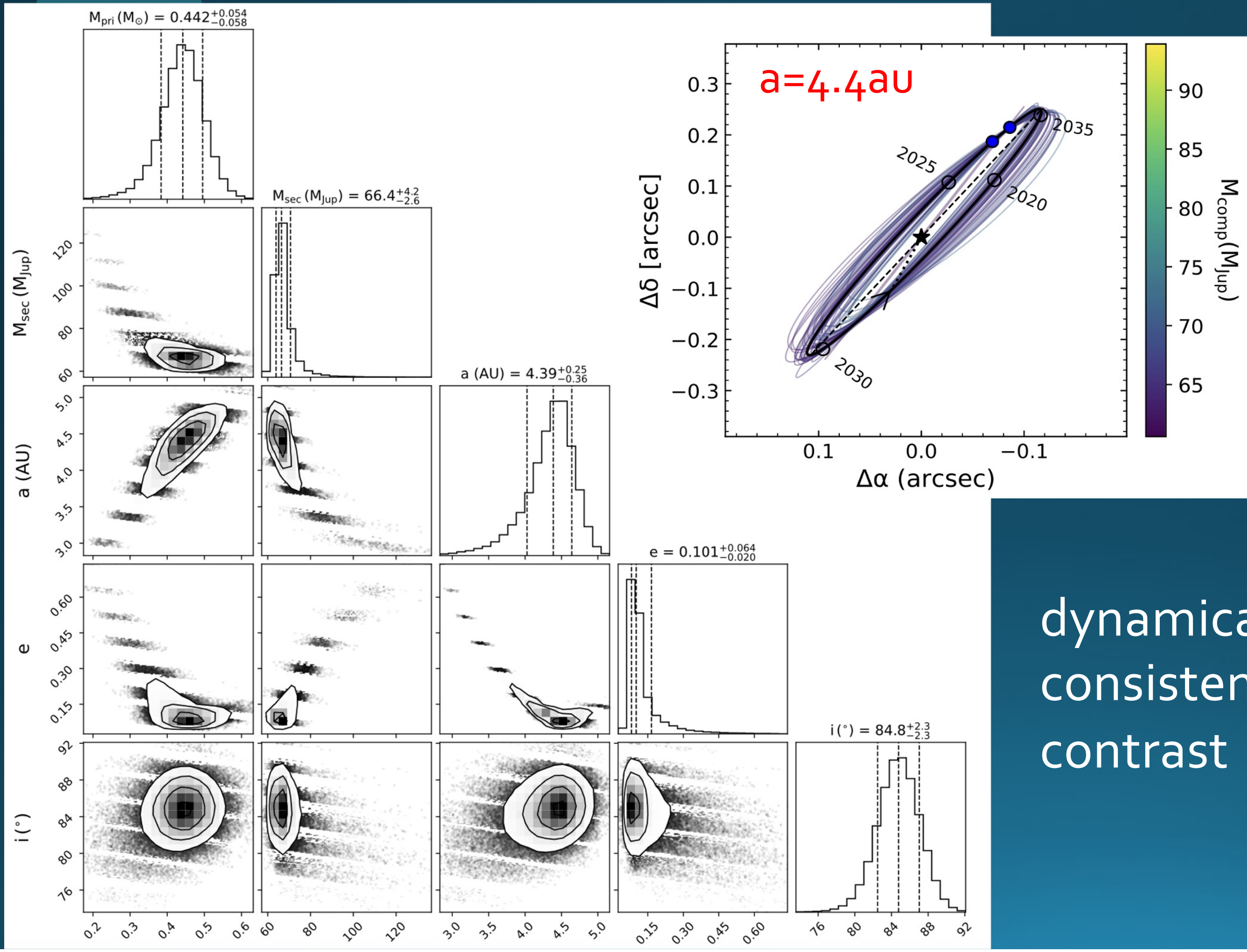
- New collaboration with the CARMENES team from 2022/09 to maximize science output of IRD-SSP
  - CARMENES project: visible & NIR RV survey of M-dwarfs started in 2016 (750-night exoplanet survey targeting ~300 M dwarfs)
  - Sharing a target list and RV data, coordinated observations, data reduction, activity analysis, etc.

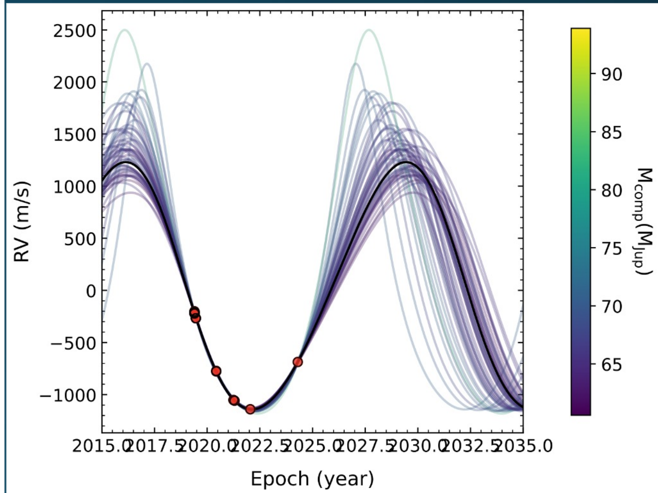
Direct imaging explorations for companions around Mid-Late M stars

- Binarity study of IRD-SSP sample by Keck/NIRC2 and IRD/FIM
- “Deprioritized” IRD-SSP targets that have signatures of long-term RV trends and/or large RUWE values from the Gaia catalog suggesting unresolved systems
- Detected 7, including 4 new, companions at projected separations between ~ 2 – 20 au from the target stars (Uyama+ 2023)
- Detected more companions including a brown dwarf from 2023-2024 campaign (right fig.)



Orbital fitting of the new brown-dwarf





dynamical mass of 66 Mjup, consistent with a ~10 Gyr contrast

Uyama et al. in prep.

Papers in planning

- Input catalog (target parameters, stellar activity, Hα intensity etc.)
- Spectral library (1D spectra of IRD-SSP targets)
- Binary study (orbital motion, dynamical mass, etc.) using FIM and RV data
- Magnetic activity of M dwarfs (activity indicator, line-profile analysis etc.)
- Atmospheric parameters and abundance analysis for IRD-SSP targets
- RV data release paper (DR1, DR2)
- Follow-up works on known planet-host stars
- Statistical analysis (occurrence rate, distribution of planets etc.) for IRD-SSP targets
- Development of calibration method for telluric lines using rapidly rotating stars taken with IRD
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