

Characterizing Long-Period Interacting Planetary Systems with EXTRASTEP and PLATO

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Presentation Outline

- I. Interacting Planetary Systems and why they're Interesting**
- II. Antarctica: the Perfect Location for Observing Long-Period Targets**
- III. Introducing the EXTRASTEP Program**
- IV. Characterisation of Long-Period Interacting Systems**

I. Interacting Planetary Systems and why They're Interesting

Mutual planet-planet perturbations → shifts in transit timings →

System Architecture

What can interactions give us?

Transit depth → Radius

TTVs / chopping → Mass

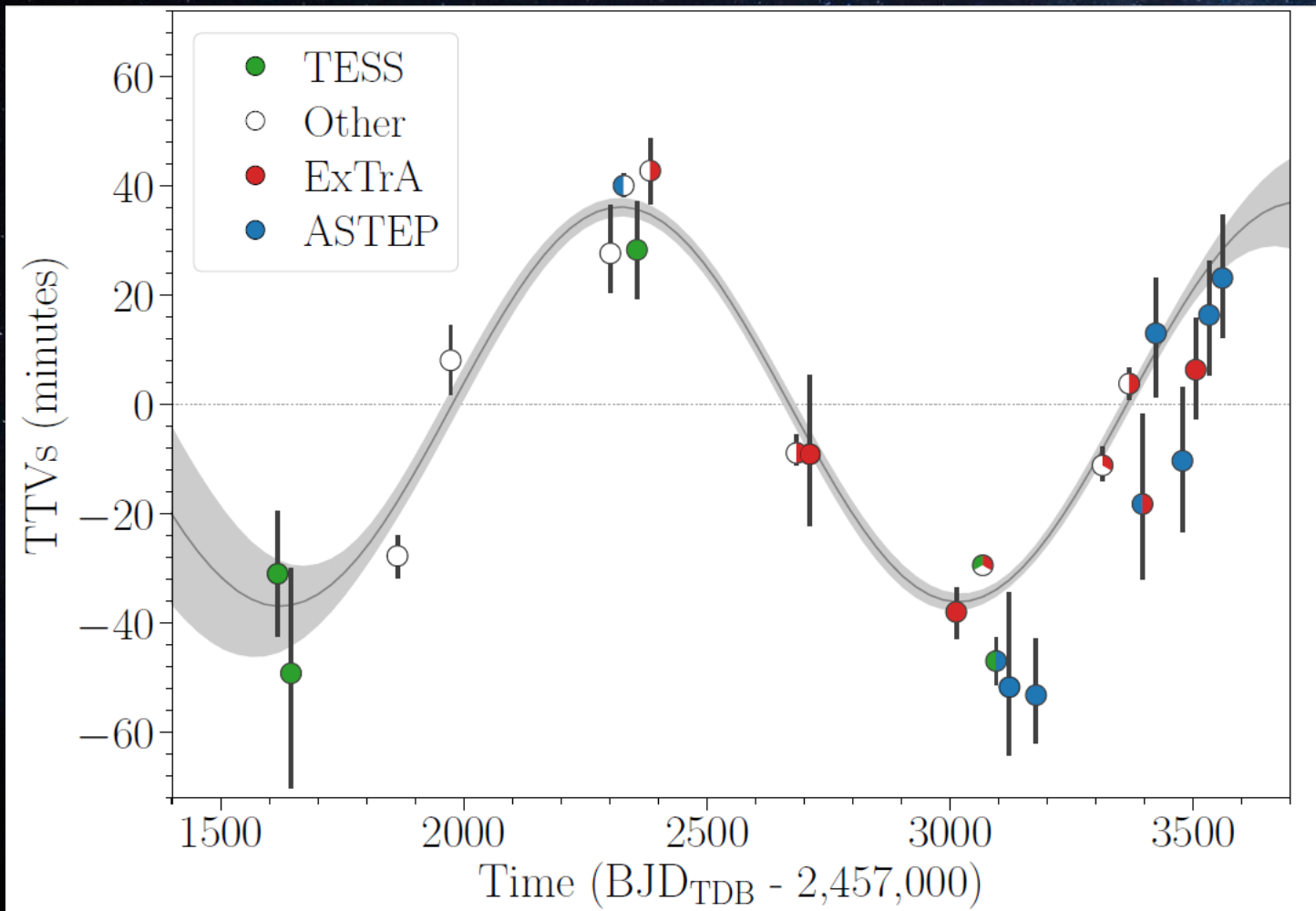
Mass + radius → Density

Timing pattern → Dynamics Formation

Why focus on long-period temperate targets?

- ✓ **A sparsely sampled space:** few targets with well constrained parameters
- ✓ **Bridge for population studies:** different compositions + less irradiation → more information on primordial structure?
- ✓ Temperate Planets with TTVs → Large TTVs mean direct constraints on planetary masses → **Super-Puffs?**

I. Interacting Planetary Systems and why They're Interesting



Courtesy of Jose Manuel Almenara, Geneva Observatory

Evidence for transit-timing variations of the 11 Myr exoplanet TOI-1227b

Almenara et al. (2024)

$T_{\text{eq}} \approx 244\text{K}$

Transit duration $\approx 4\text{h } 50\text{ mins}$

Planet Info

Radius: $0.854 R_{\text{Jup}}$

Mass: $0.209 M_{\text{Jup}}$

Period: 27.4 d

Star Info

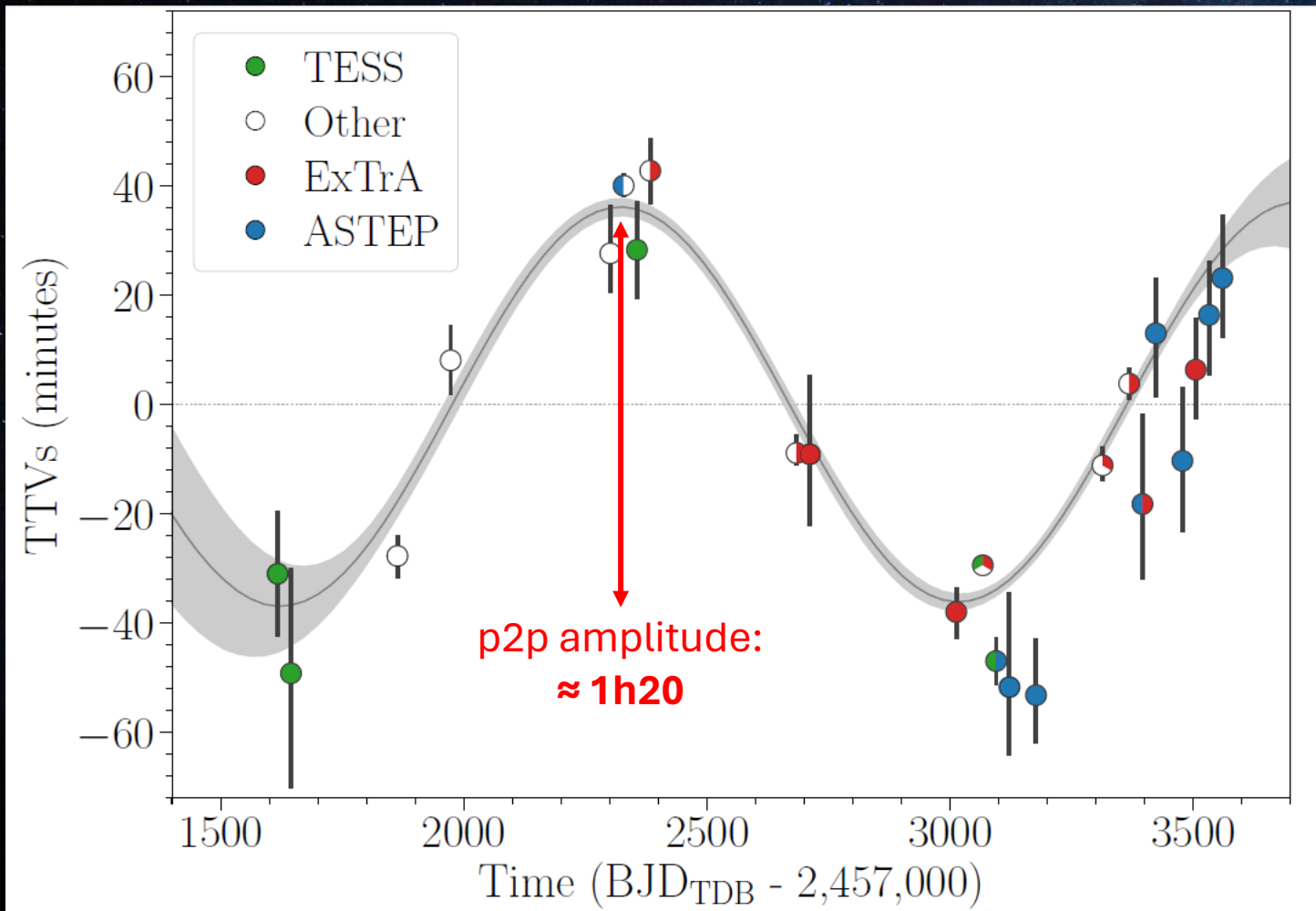
Radius: $0.56 R_{\text{Sun}}$

Mass: $0.17 M_{\text{Sun}}$

Mag (V): 17 ± 1.113

- Orbits around a faint PMS M-dwarf
- TTVs not due to stellar activity
- Possible second non-transiting planet?

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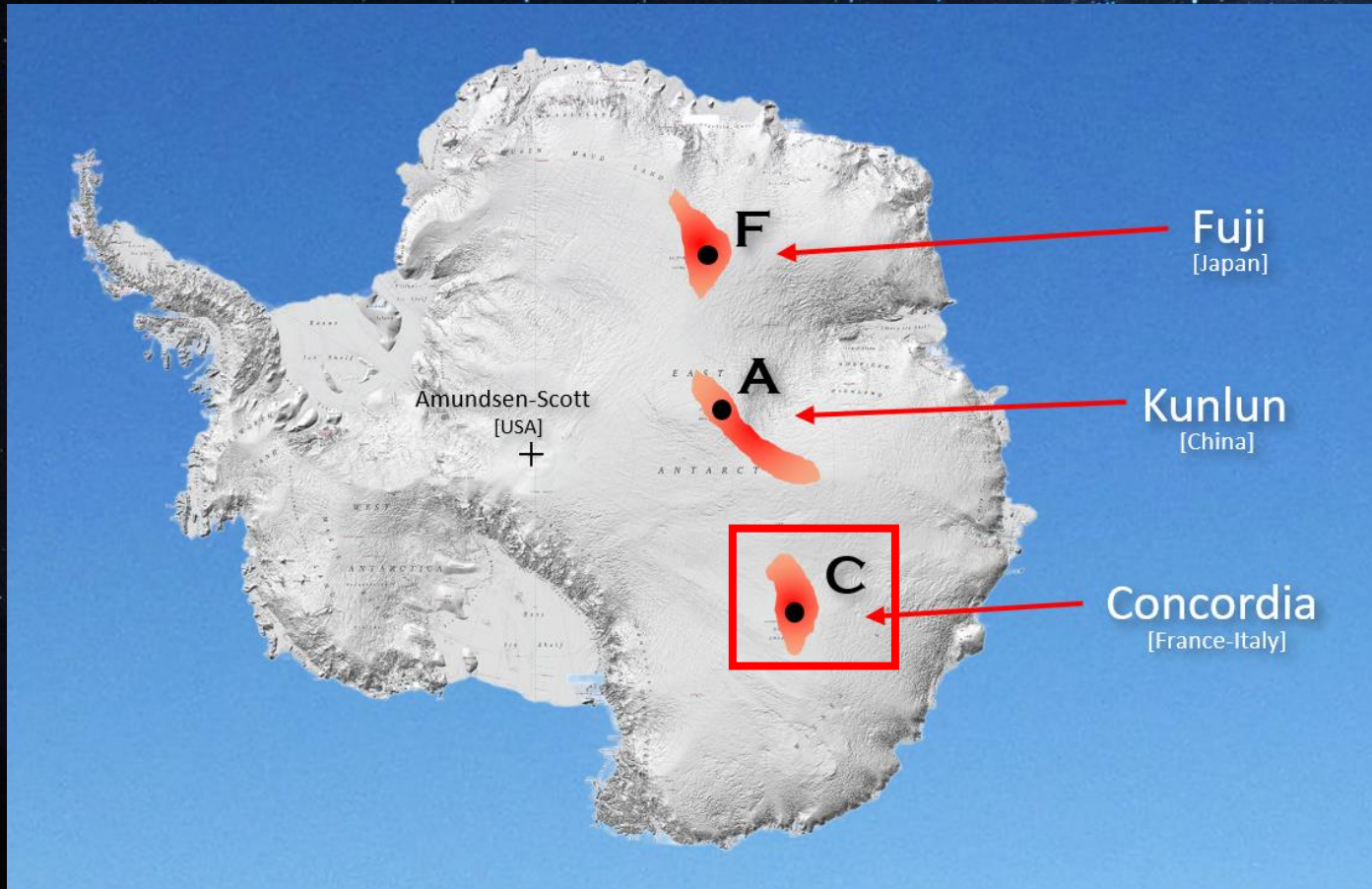
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II. Antarctica: the Perfect Location for Long-Period Observations



- Long, near-continuous polar night
- Very low precipitable water
- Stable, often photometric weather
- Low wind and good seeing
- Cold background for infrared observations

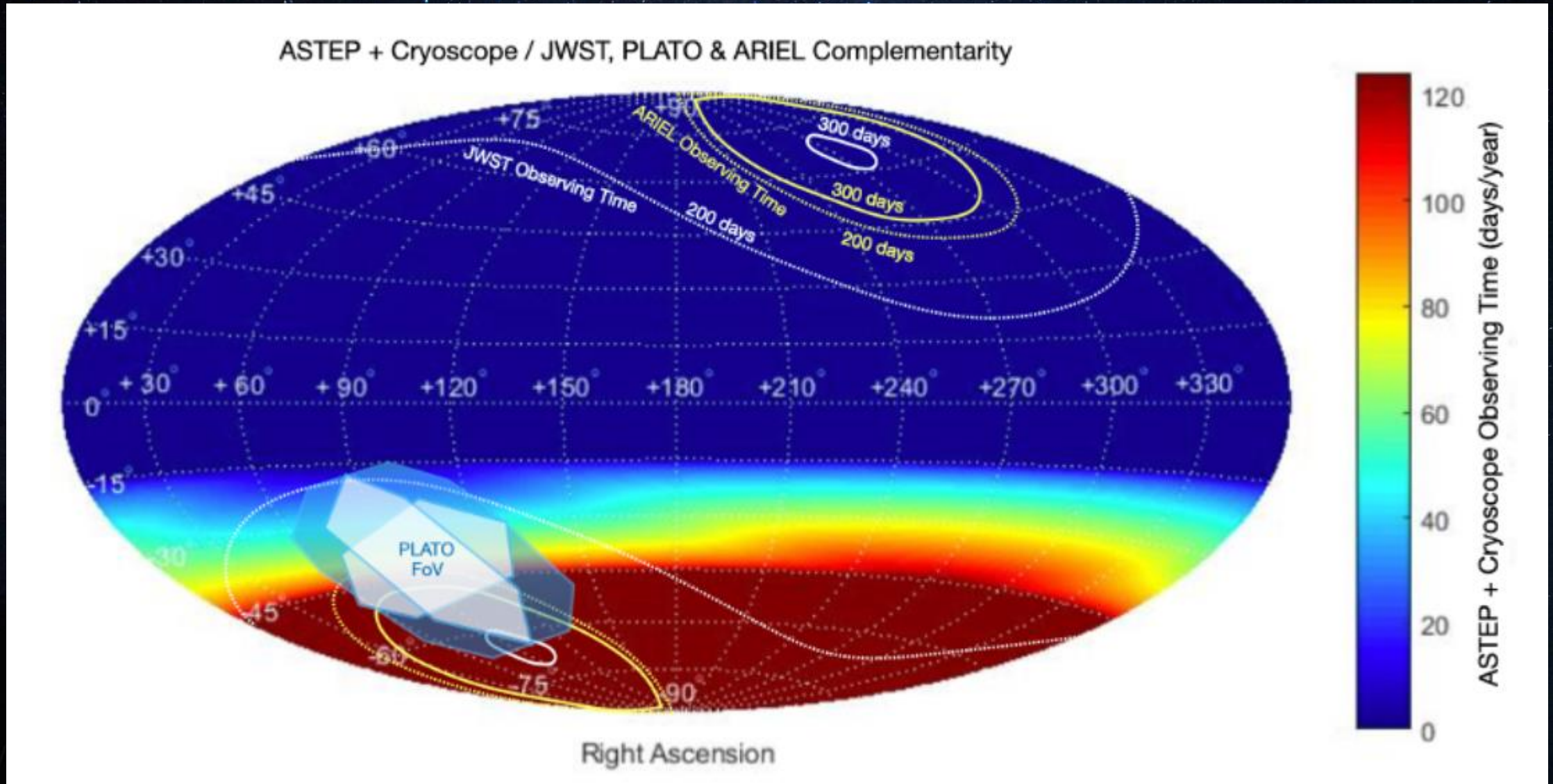
Concordia Station

Coordinates: 75°05'59"S 123°19'56"E
Elevation: 3,233 m

Concordia Station is the only station inhabited year-round



II. Antarctica: the Perfect Location for Long-Period Observations



III. Introducing the EXTRASTEP Program

a. **ASTEP** – Antarctic Search for Transiting ExoPlanets

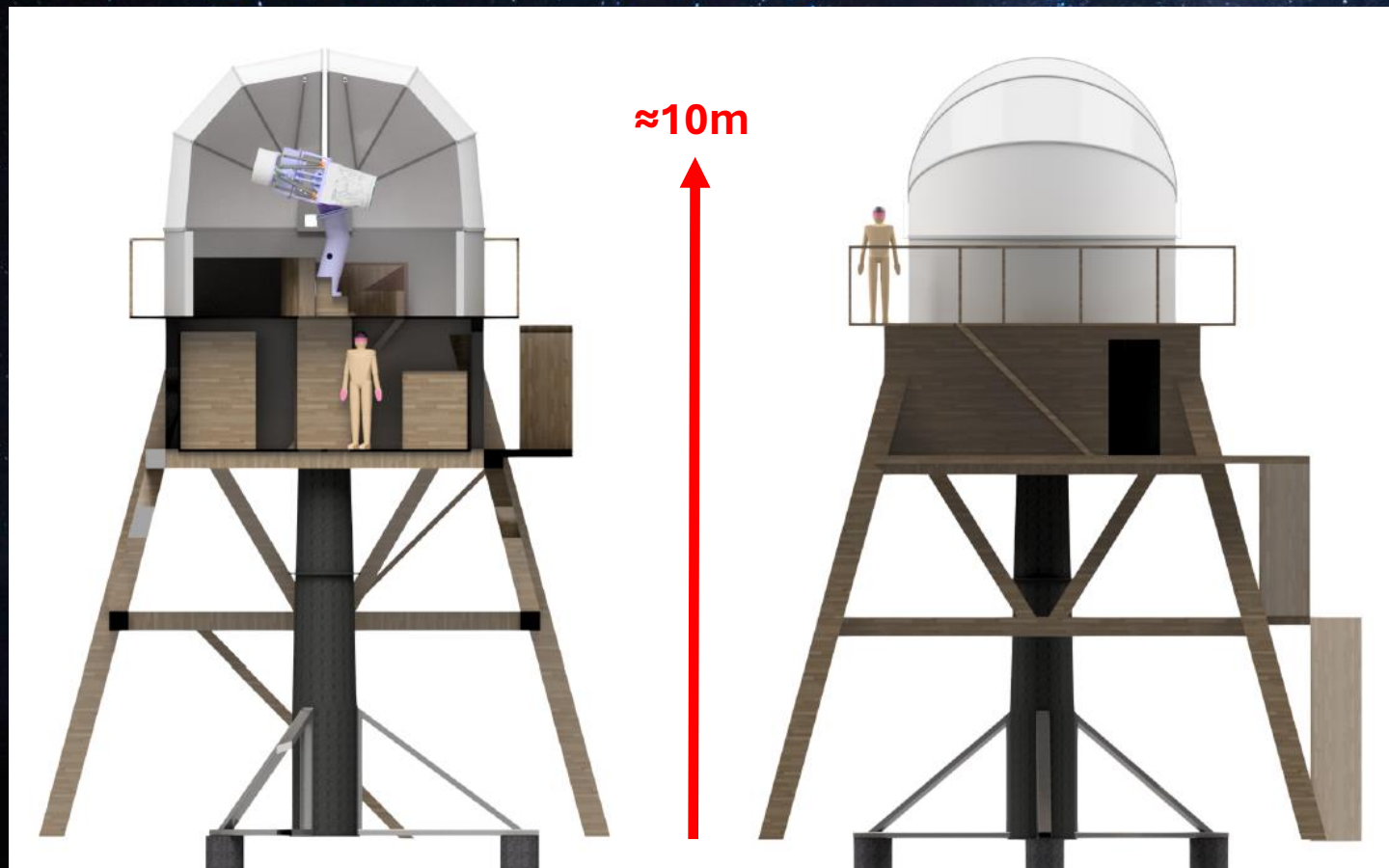


- A 40cm telescope observing in 2 bands
- Exceptional time coverage from the Antarctic polar night
- New dome and tower → improved observations
- Direct drive mount operational since 2024

References: Crouzet et al. (2010), Guillot et al. (2015), Mékarnia et al. (2016), Schmider et al. (2023)

59 Scientific Articles Published Using ASTEP Data

II. Antarctica: the Perfect Location for Long-Period Observations



New Tower and Dome

Even higher elevation



No more flying ice, lower turbulence

A fully retractable dome allows for the observation of more targets

Courtesy of Maël Boussange, Observatoire Midi-Pyrénées

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III. Introducing the EXTRASTEP Program

b. ExTrA – Exoplanets in Transit and their Atmospheres

- 3 × 60 cm telescopes + one shared near-IR spectrograph (0.9-1.55 μ m)
- Optimized for precise transit follow-up of M dwarfs
- Spectral information helps correct atmospheric systematics
- Also useful for checking whether a signal is achromatic and planetary

References: Bonfils et al. (2015), ESO ExTrA webpage, <https://extra.cnrs.fr>

58 Papers and ~30 TESS Planet Validations With ExTrA



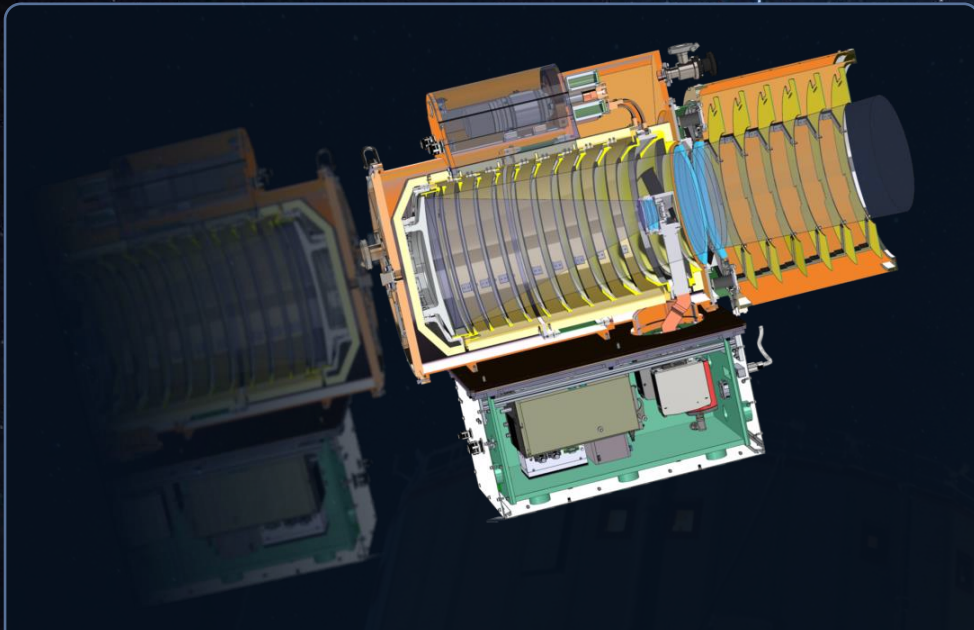
Differential spectro-photometry

not just broadband photometry

Telescopes based in La Silla Observatory, Chile

III. Introducing the EXTRASTEP Program

c. Cryoscope - A Cryogenic Infrared Survey Telescope in Antarctica



Pathfinder concept and geometry, which will be installed at Dome C.

Kdark (2.2–2.5 μm): the darkest practical ground-based IR window

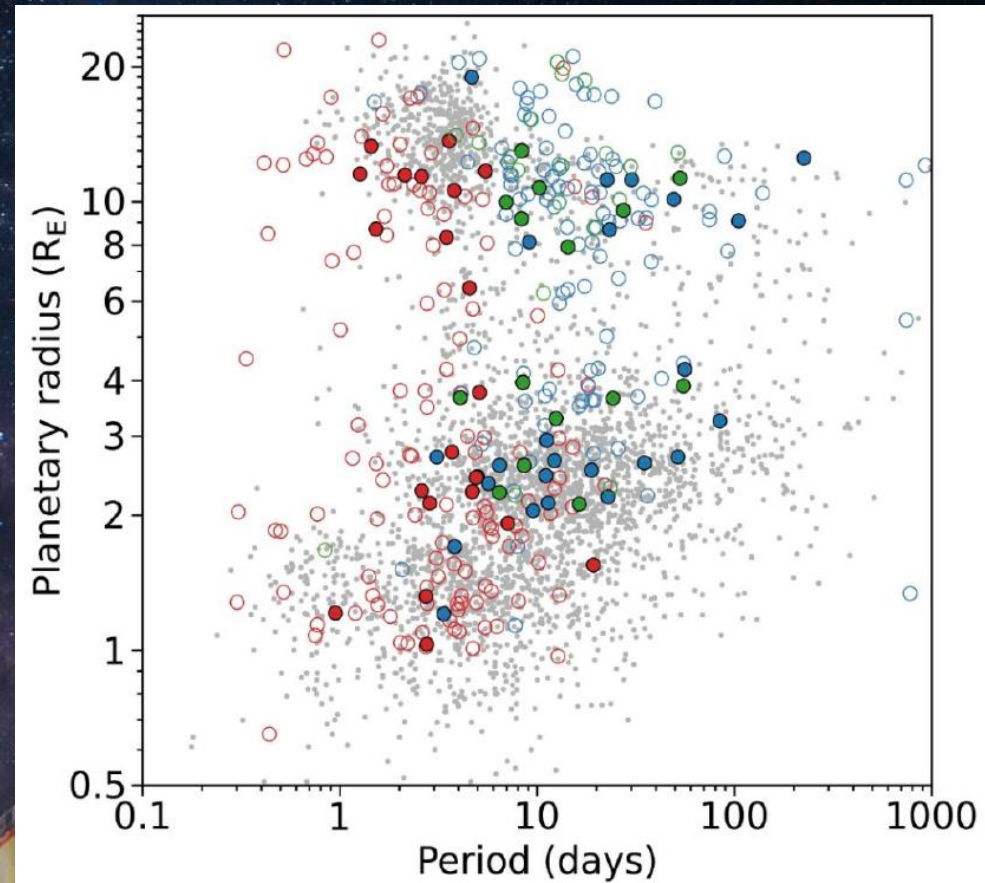
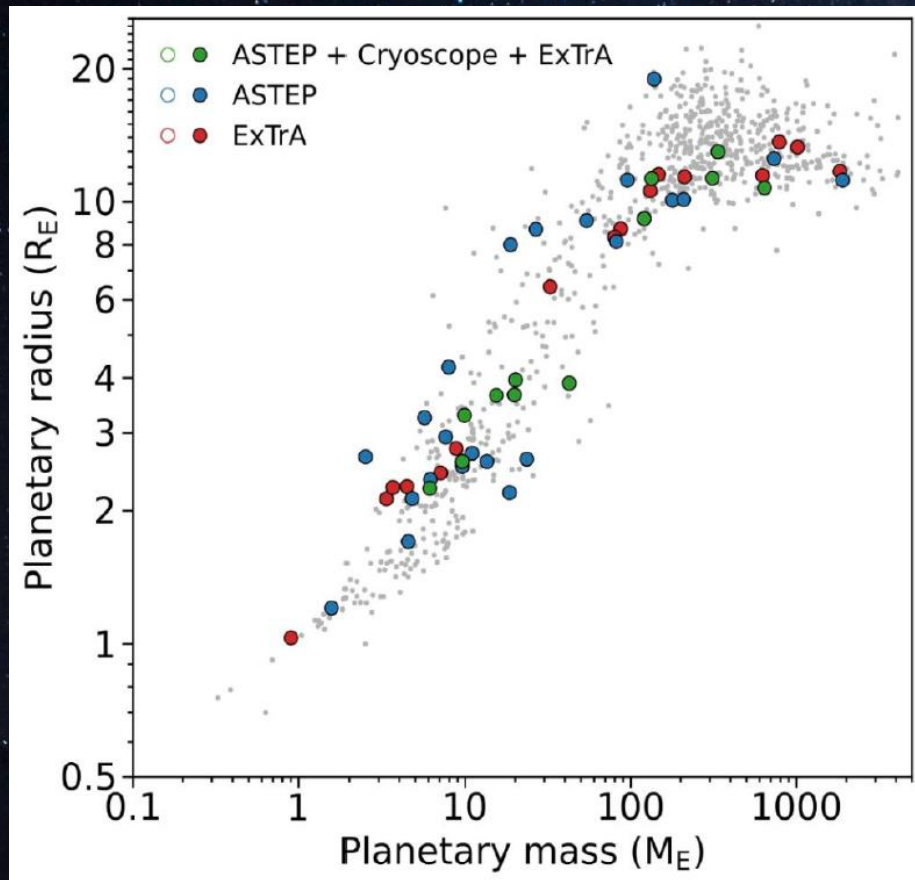
- 26 cm Pathfinder and 1.2 m full cryogenic infrared telescope
- Cooling suppresses thermal background in the near-IR
- Designed to take advantage of the very dark Antarctic infrared sky (*K dark window*)
- Expands EXTRASTEP follow-up for cool stars and long-period planets

References: Early et al. (2024), de Ugarte Postigo et al. (2024), Kasliwal et al. (2025)

installation on Dome C scheduled

End of 2026 (Pathfinder)
2030+ (Cryoscope)

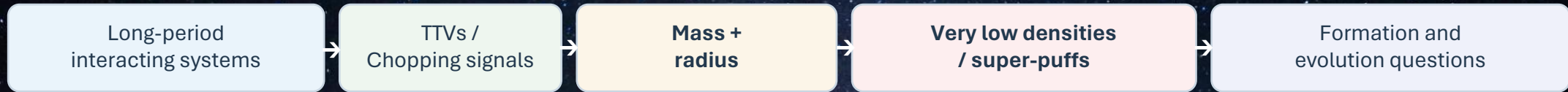
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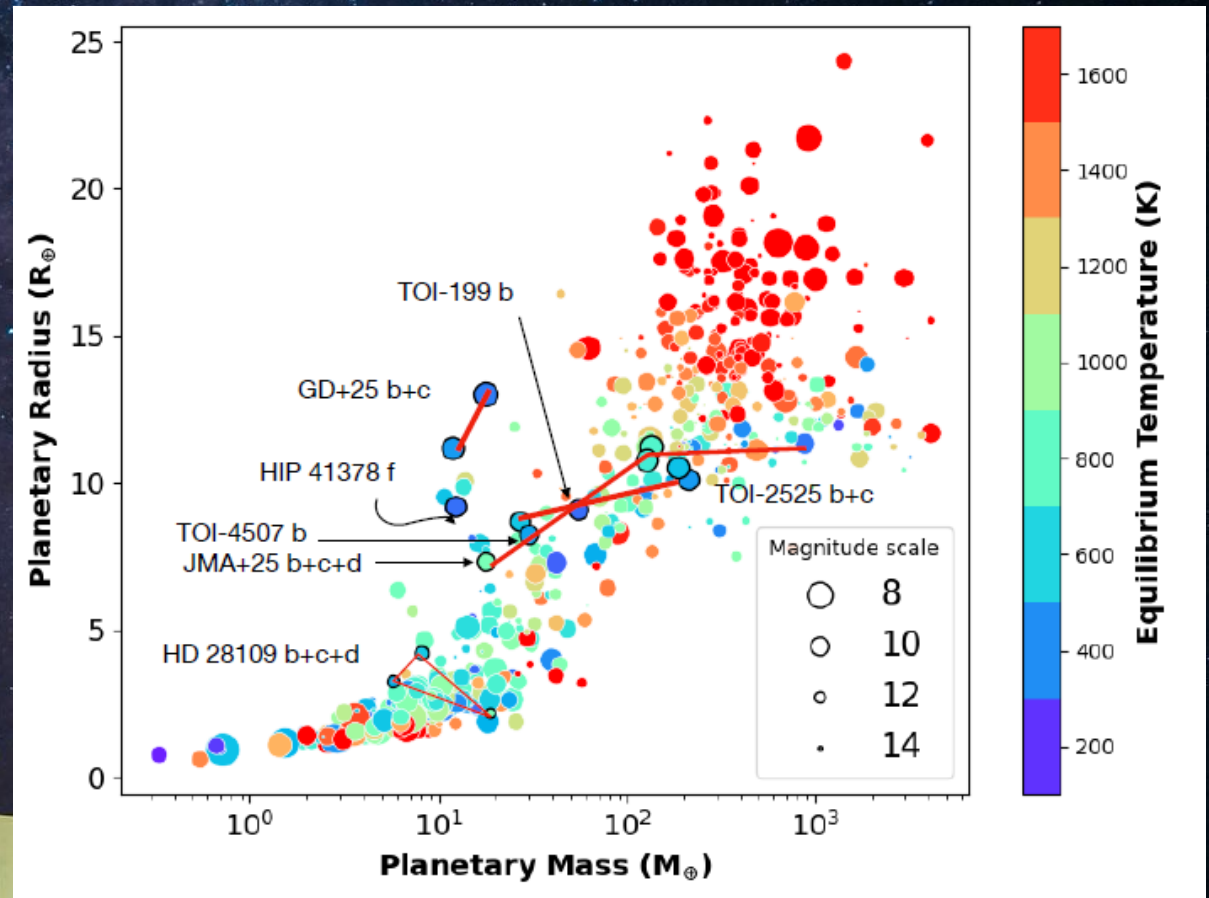
EXTRASTEP: Discovery and characterisation of...

Temperate exoplanets, giant planets around M-dwarfs, interacting planetary systems with TTVs, etc.

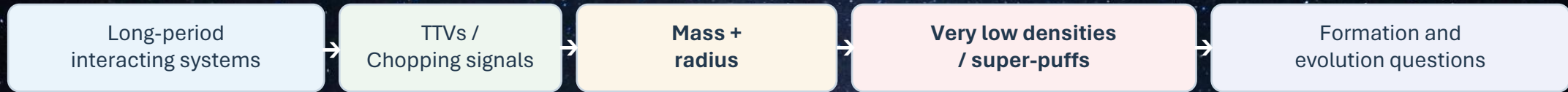
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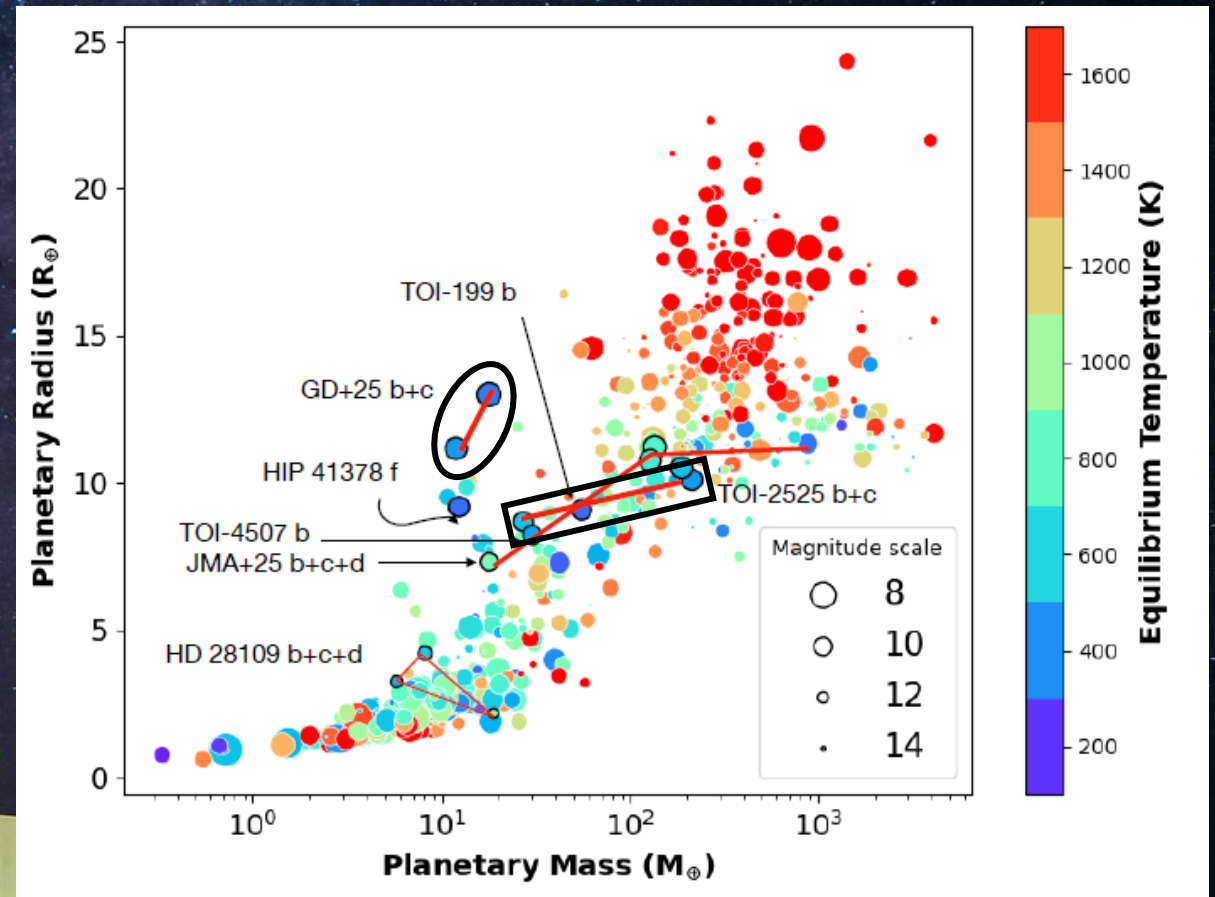
- ✓ TTVs provide masses for long-period systems
- ✓ Temperate planets probe less irradiation-processed structures
- ✓ Mass–radius measurements constrain envelope content and bulk composition
- ✓ Evolution/interior models help test possible formation paths



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IV. Characterisation of Long-Period Interacting Systems

Precise measurements on observable parameters



Strong constraints for planetary modelling



CESAM2k20 provides the initial PLATO stellar grid

Stellar Observables

- Photometry
- Spectroscopy
- Asteroseismology

CESAM's

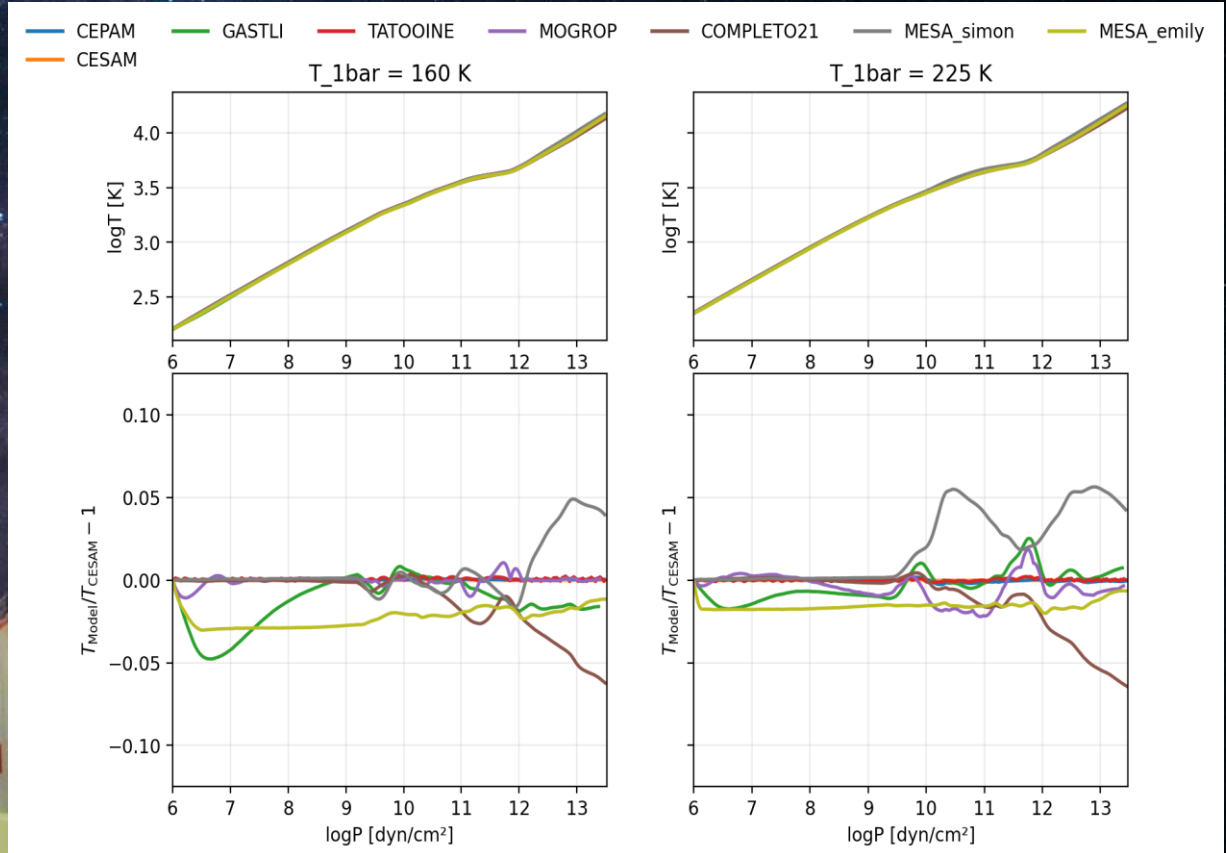
grid

Stellar Parameters

- Mass
- Radius
- Age
- Composition



Part of PLATO WP116100 – Composition & Formation of Gas & Ice Giants



Conclusion

- ✓ Long-period TTV systems probe dynamics, masses, and densities
- ✓ Antarctica enables exceptional long-transit follow-ups
- ✓ EXTRASTEP provides complementary optical and IR characterisation
- ✓ PLATO + modelling will connect observations to formation and evolution

Conclusion

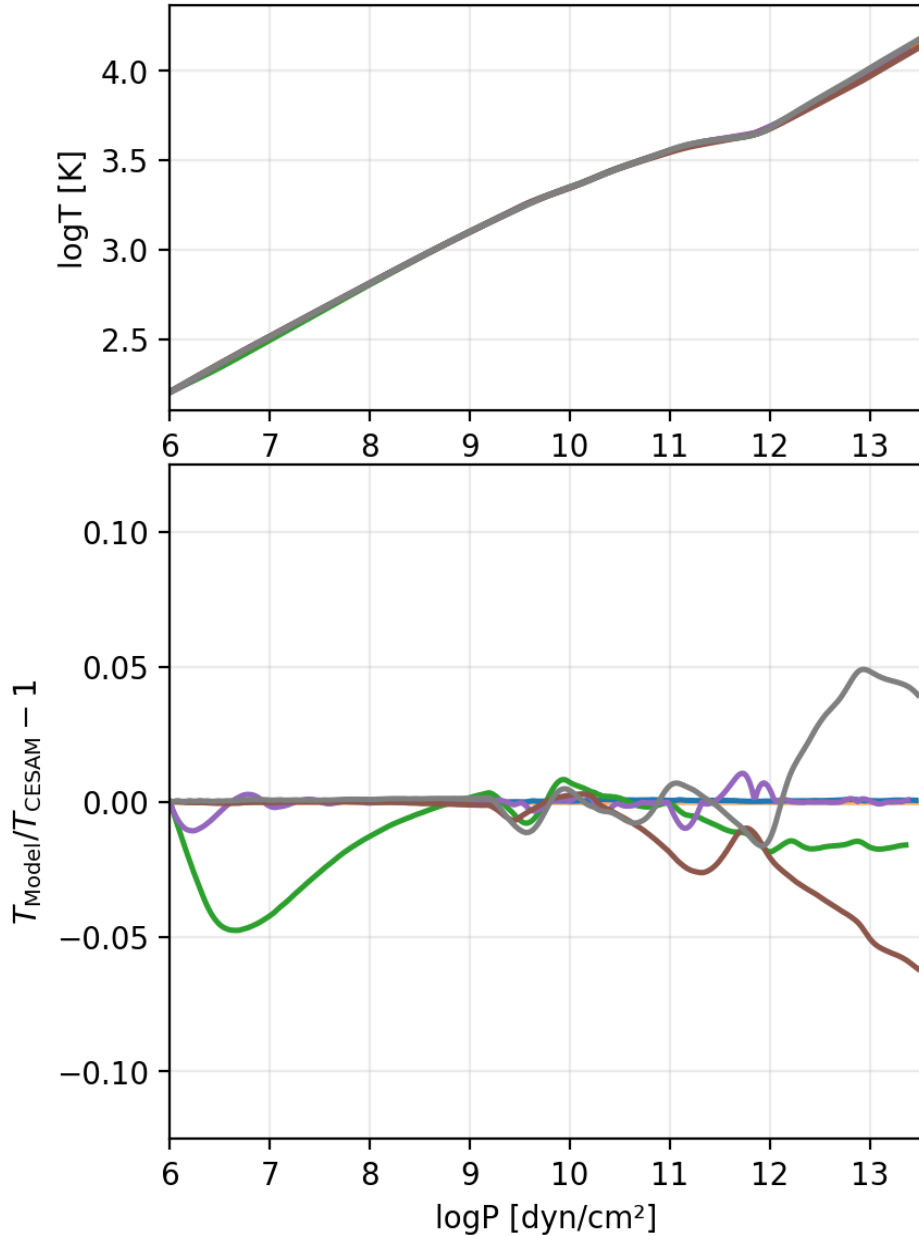
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**Precise Ephemerides and Follow-Up Opportunities with
ASTEP and ExTrA are Available!!**

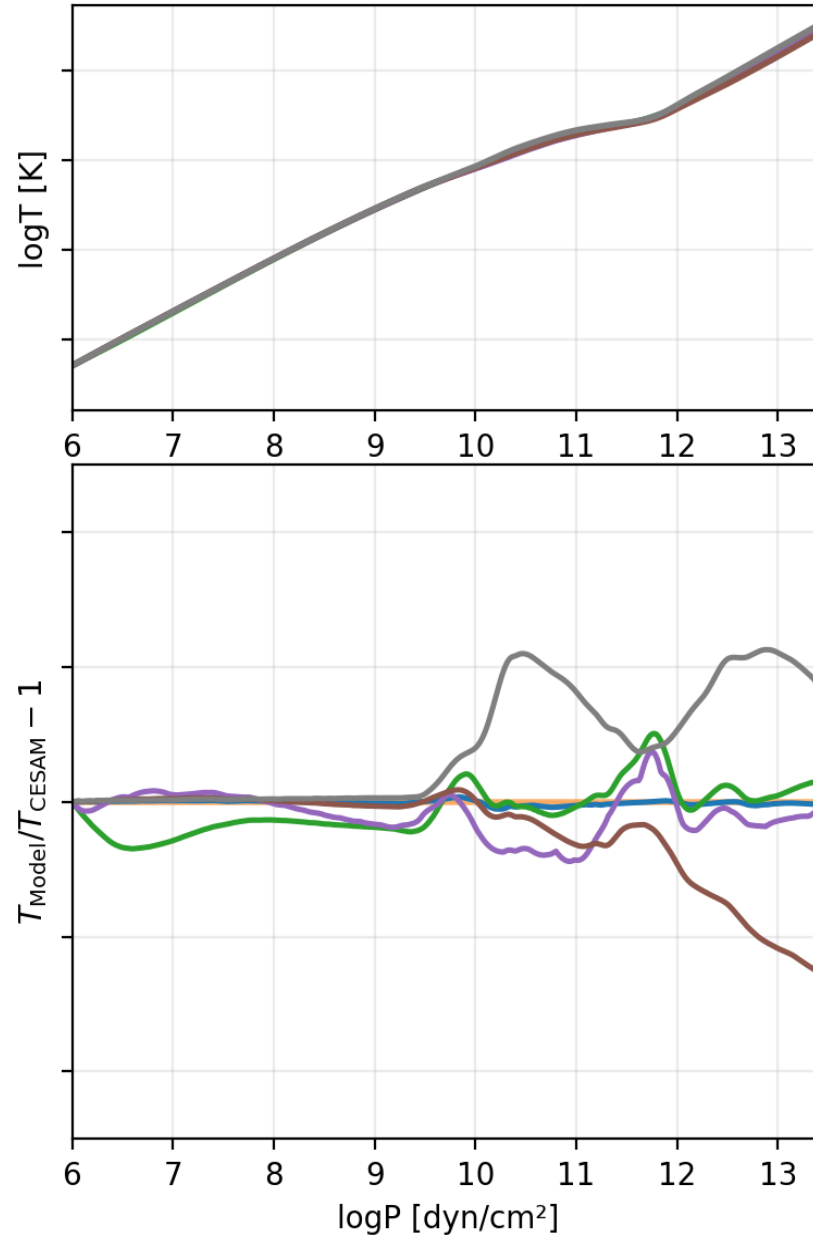
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— CEPAM
 — CESAM
 — GASTLI
 — MOGROP
 — COMPLETEO21
 — MESA

$T_{1bar} = 160 \text{ K}$



$T_{1bar} = 225 \text{ K}$



b **CESAM**: uses the **entropy derived adiabatic gradient** from CD21

- **TATOINE**: structure files are for an older model, not included in these structure comparisons

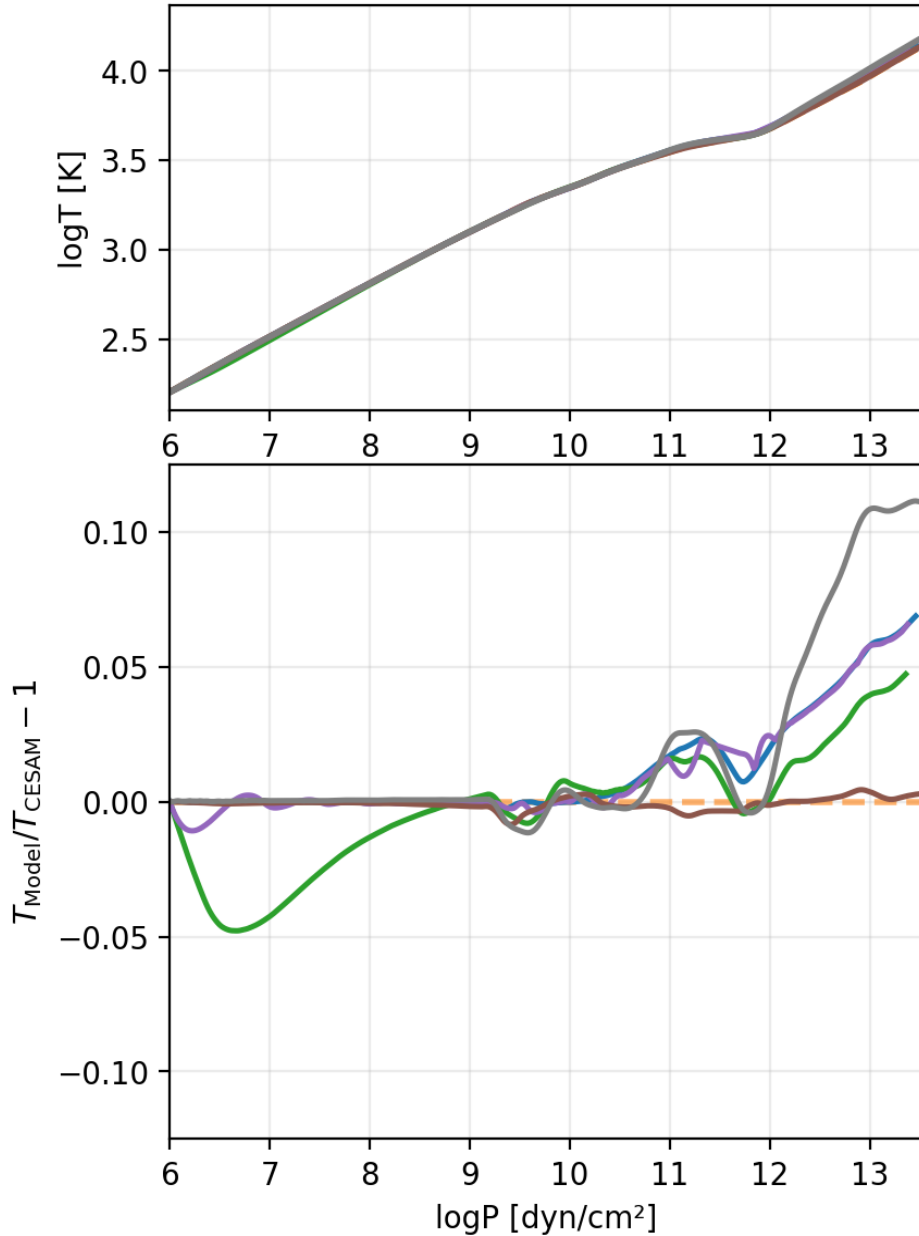
Interpolation Process

Using PCHIP
Piecewise Cubic Hermite
Interpolating Polynomial

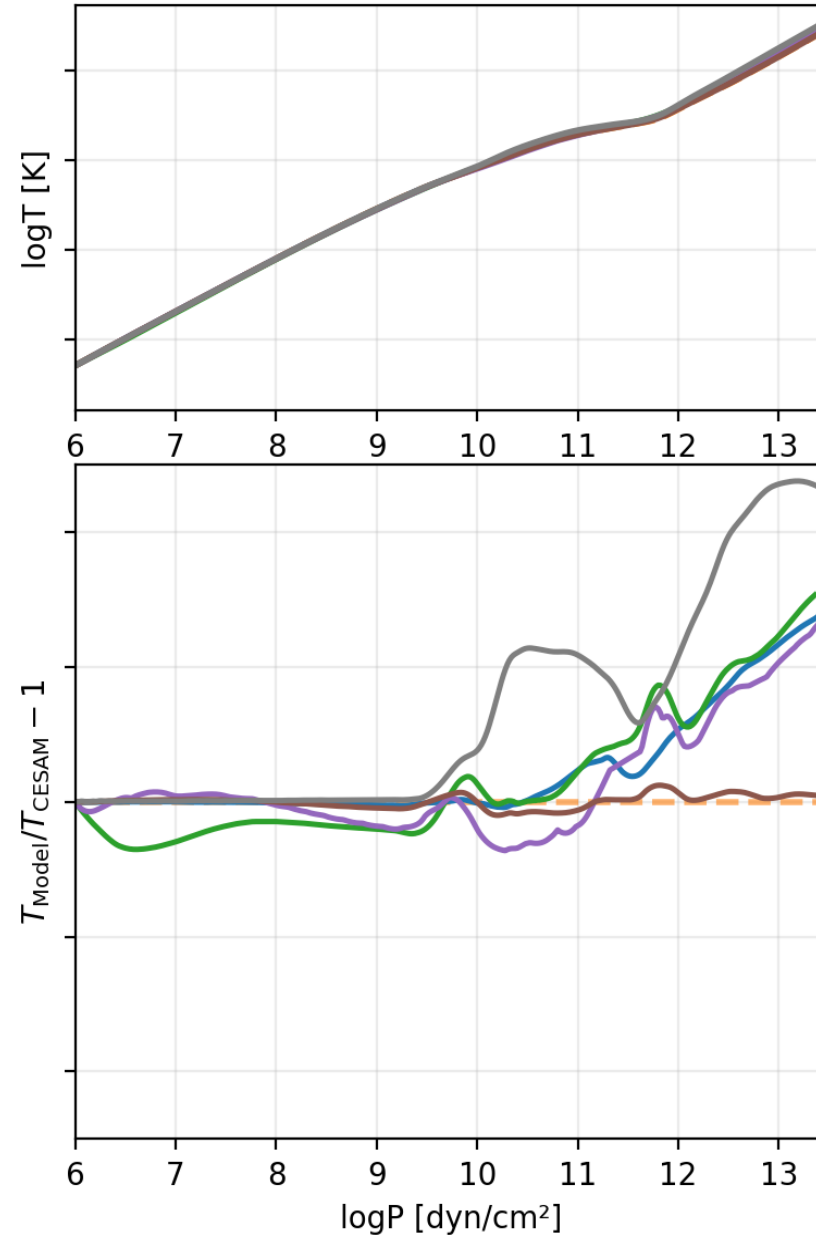
- Interpolate onto a common $\log(P)$ grid
- Interpolate between 2 T_{int} T_{1bar} profiles

— CEPAM
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CESAM:

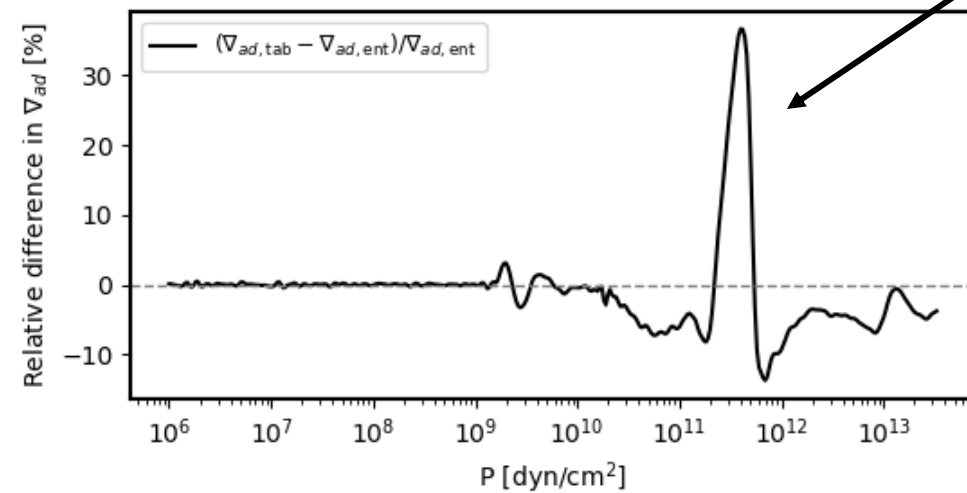
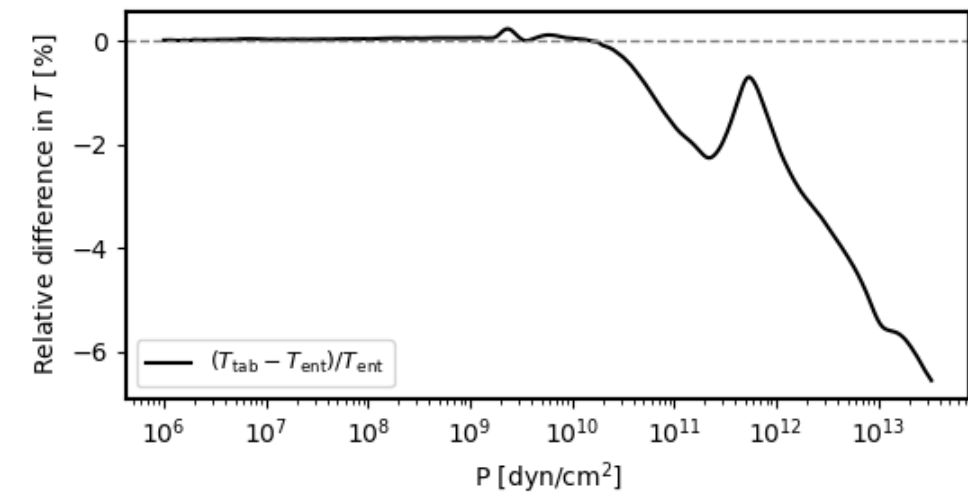
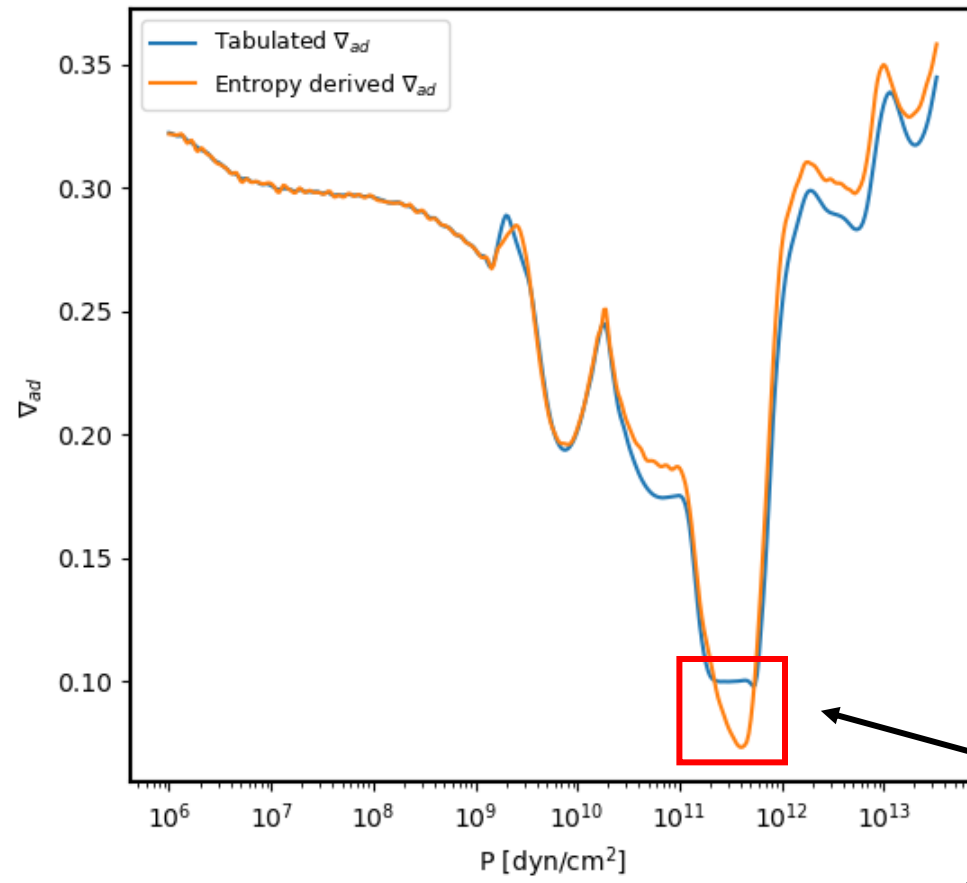
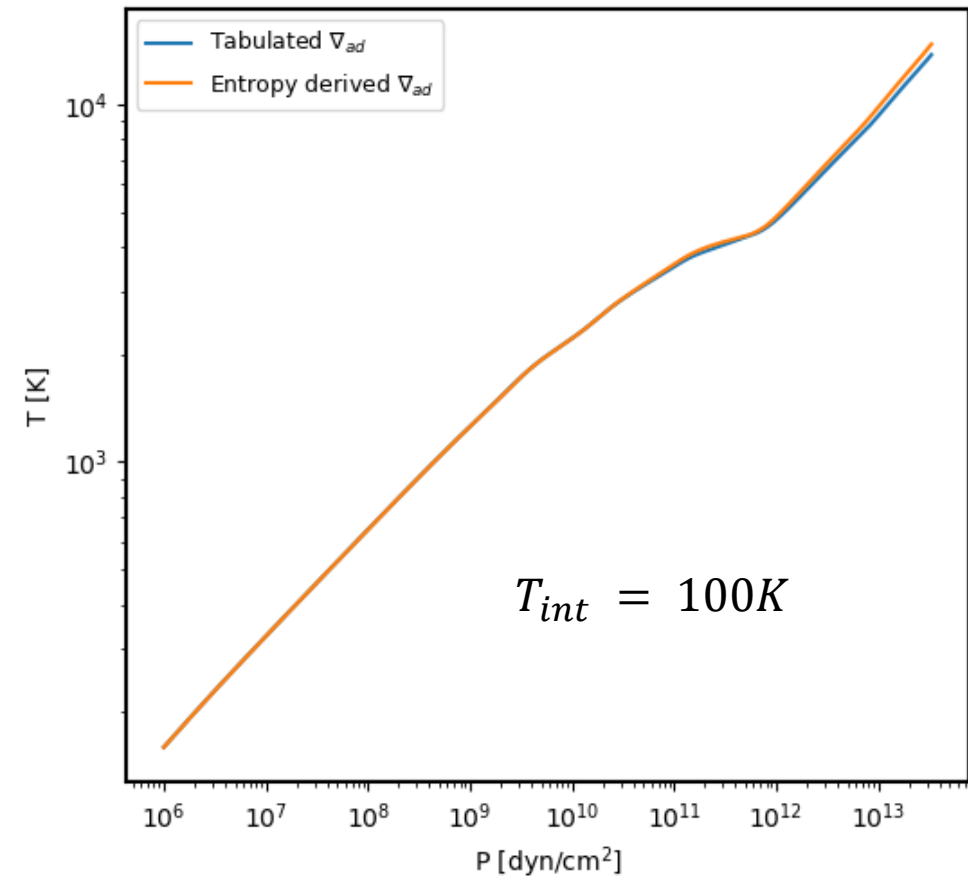
uses the **precomputed adiabatic gradient** from CD21

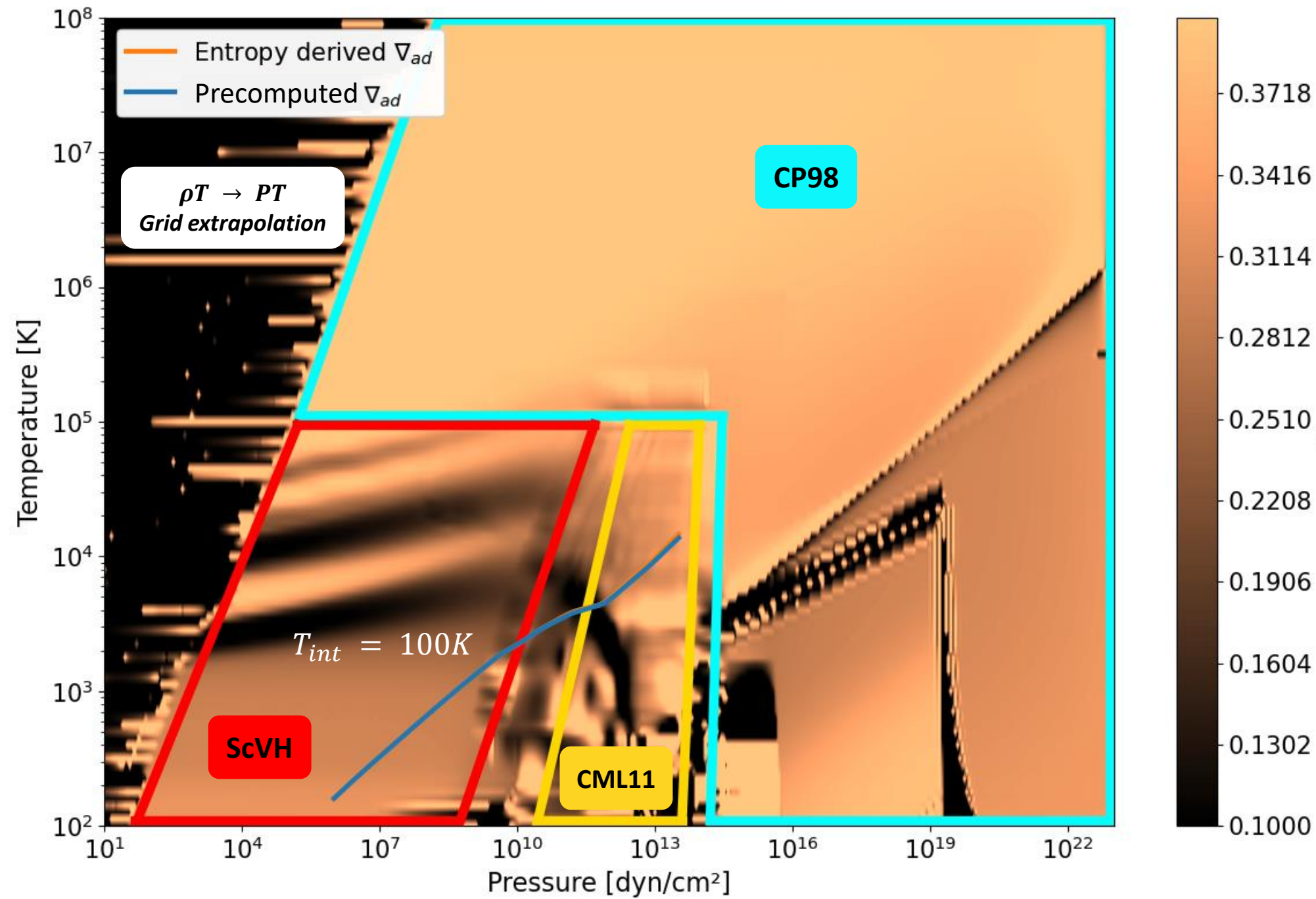
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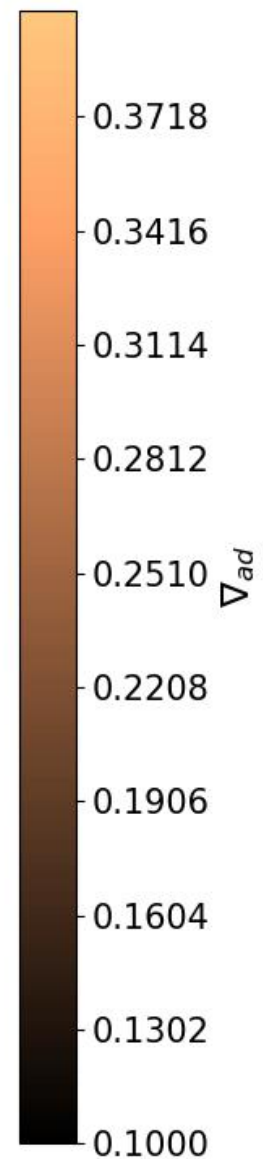
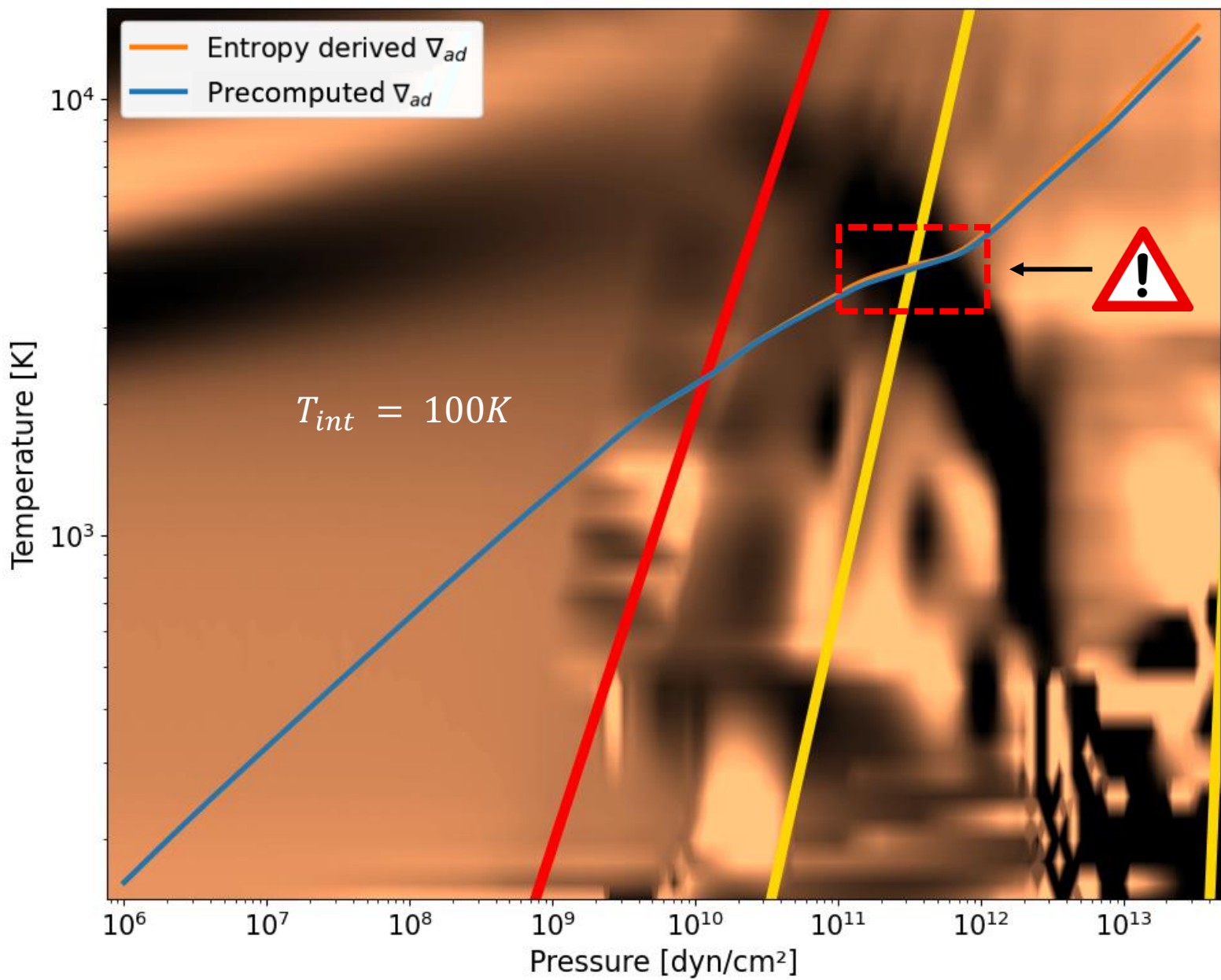
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1. Interpolate onto a common $\log(P)$ grid
2. Interpolate between 2 T_{int} T_{1bar} profiles







Precomputed
adiabatic gradient

- Differences come from ab-initio transition?
- Minimal ∇_{ad} value set at 0.1?