TMTで紐解く惑星系の起源

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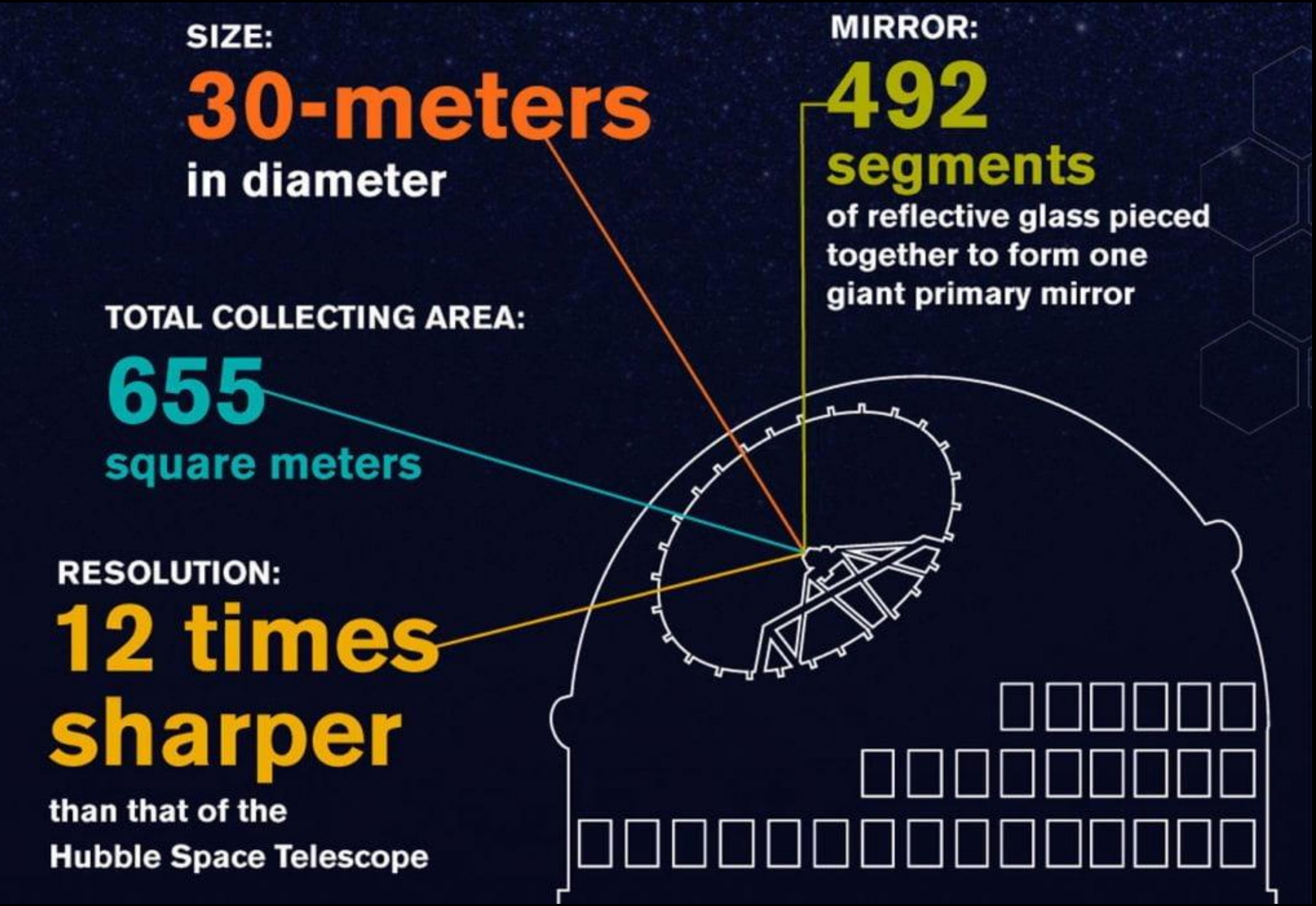
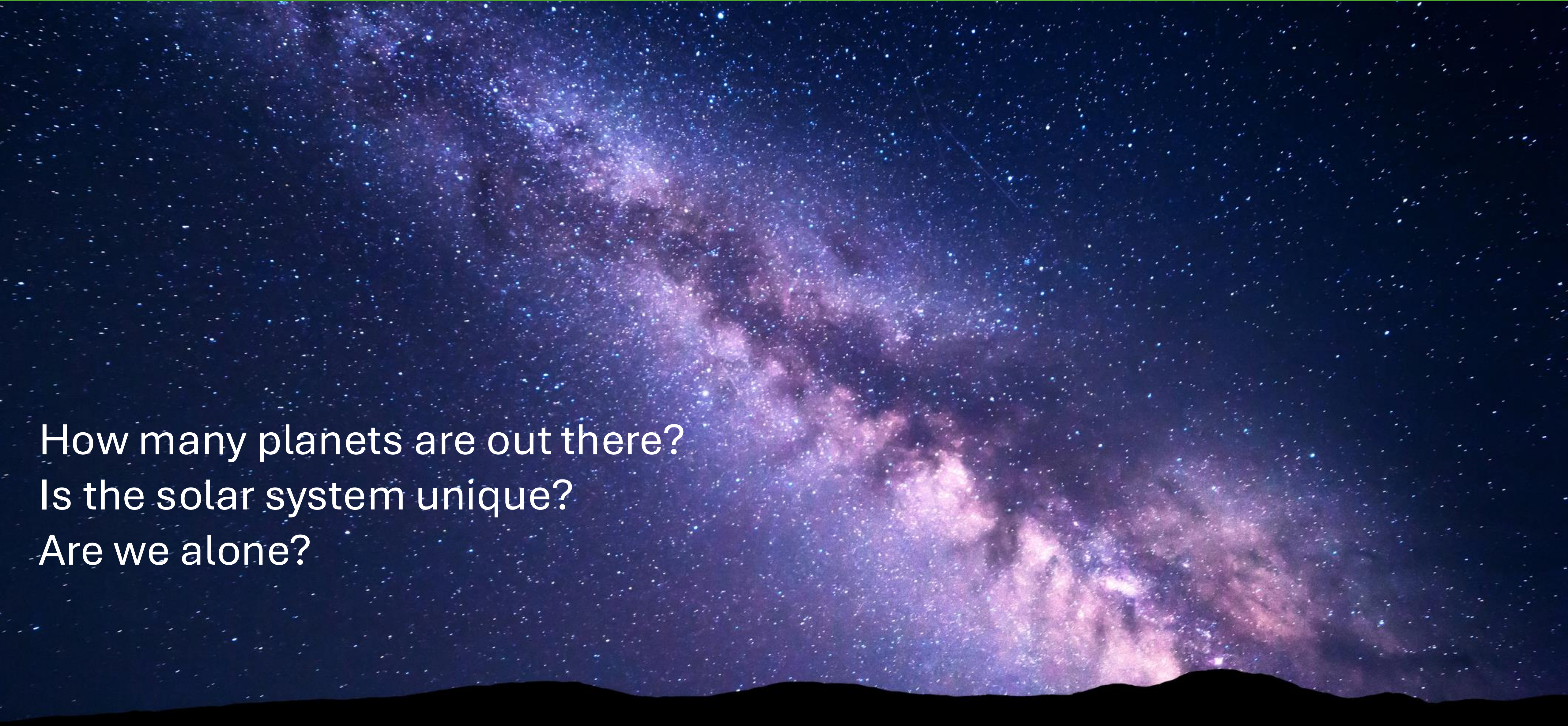


Adapted from https://www.ucobservatories.org/observatory/thirty-meter-telescope/

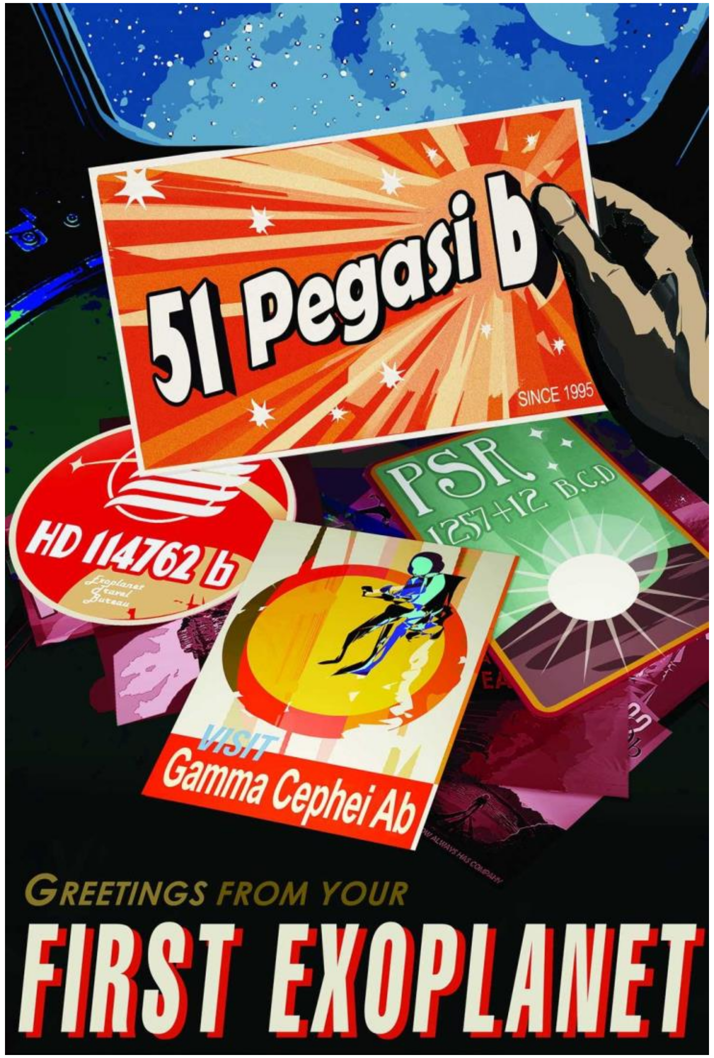
Jet Propulsion Laboratory
California Institute of Technology

Why Do We Care?



Adapted from https://advocacy.ucla.edu/10-ways-national-science-foundation-ucla-paired-progress-2017/landscape-with-milky-way-night-starry-sky-universe/

Discoveries of Extrasolar Planets (Exoplanets)



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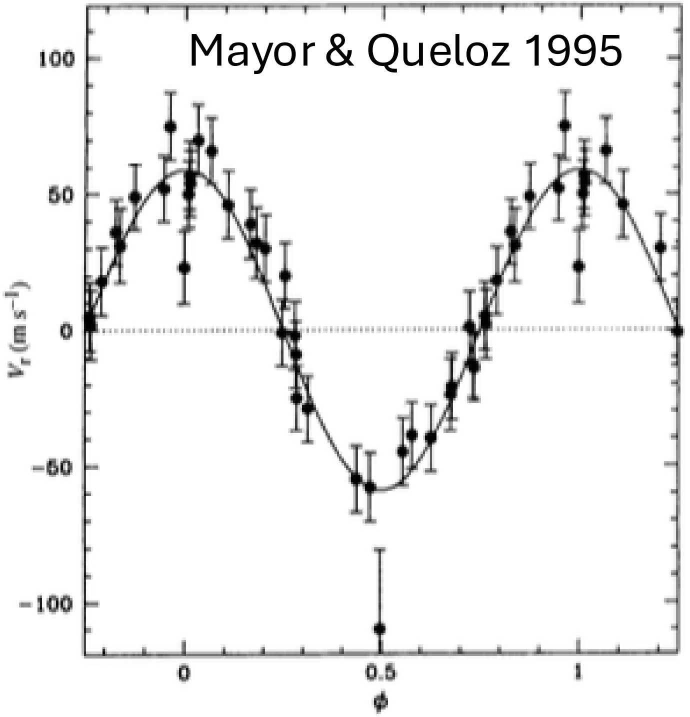
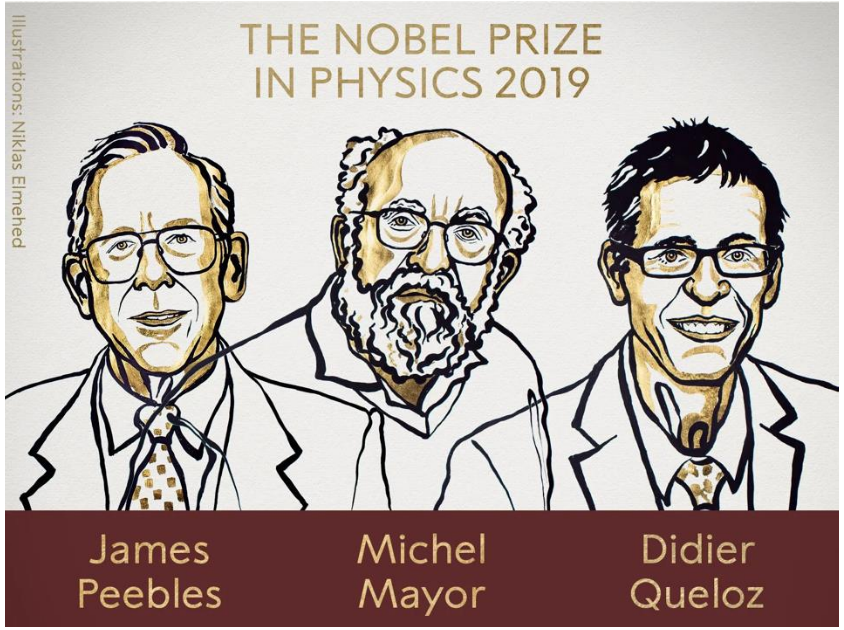




Adapted from https://www.bloomberg.com/news/articles/2019-10-08/peebles-mayor-and-queloz-share-2019-nobel-prize-in-physics

The first discovery of a gas giant planet orbiting around other Sun-like star

The radial velocity (i.e., wobble) of a star caused by a planet was observed

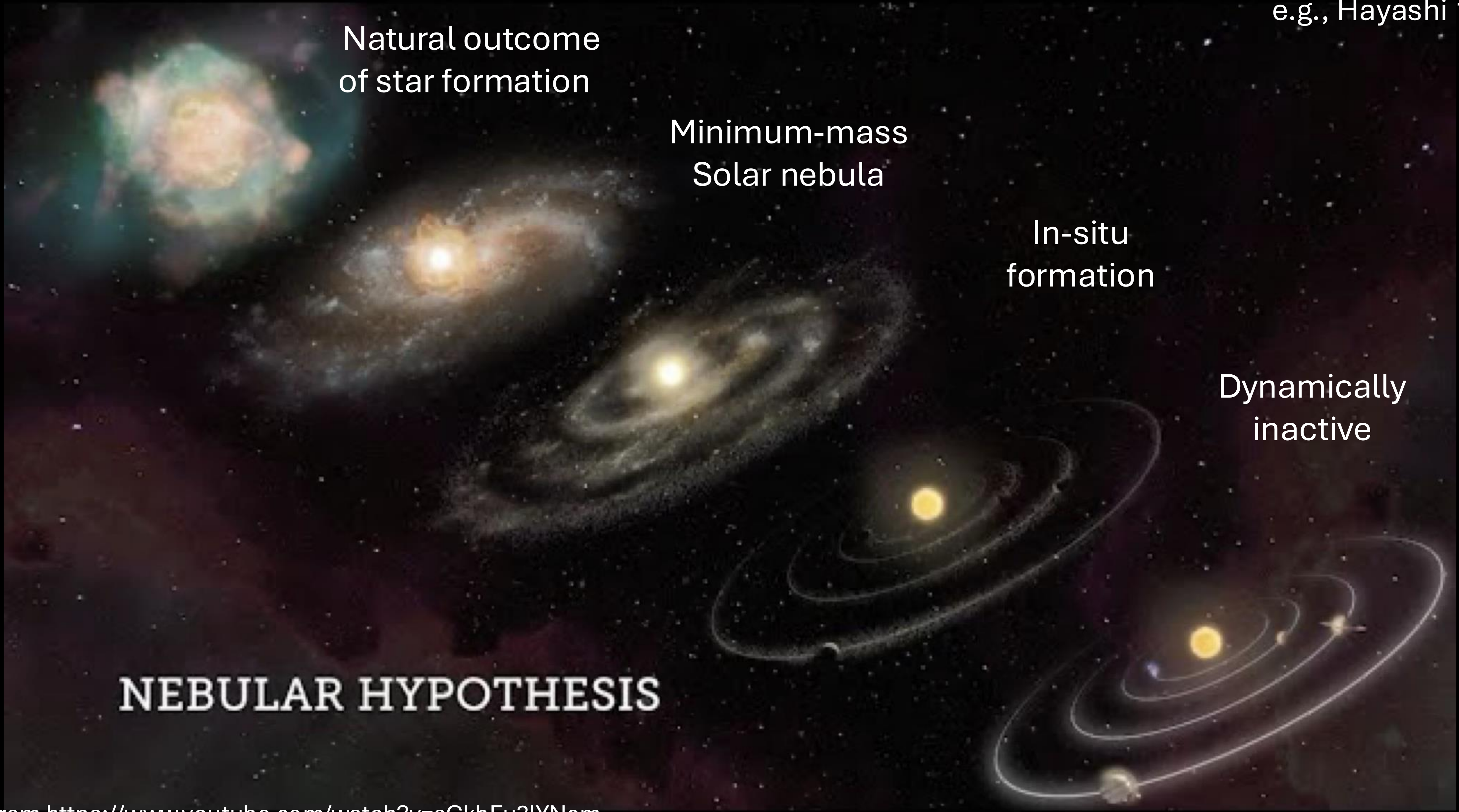
The unexpected presence of a hot Jupiter surprised the community!

Fundamental questions:

When, Where, and How Do Planets Form?

”Classical” Picture of Planet Formation

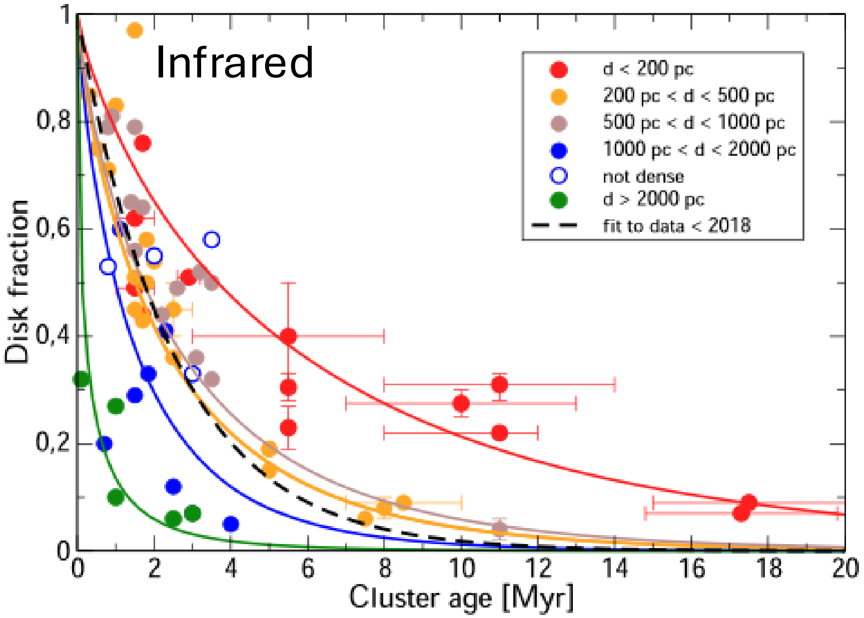
e.g., Hayashi 1981



Adapted from https://www.youtube.com/watch?v=sCkhEu3lYNcm

State-of-the Art: Disk Observations

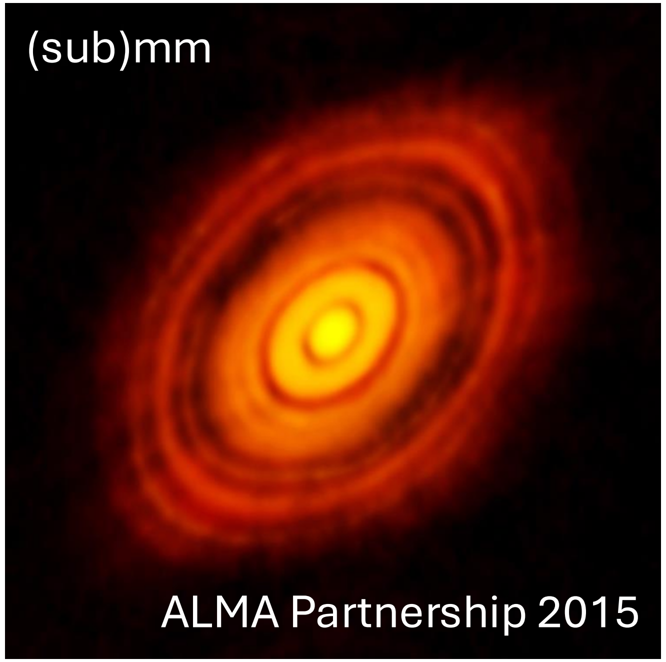
When



e.g., Pfalzner et al 2022

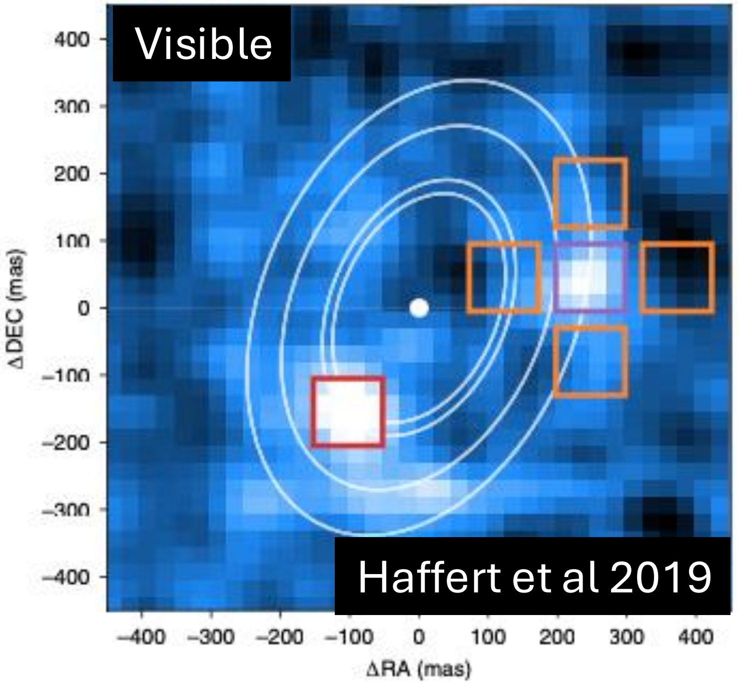
The lifetime of protoplanetary disks is typically about 1-10 Myr

Where



Gaps can be opened by embeded, forming planets

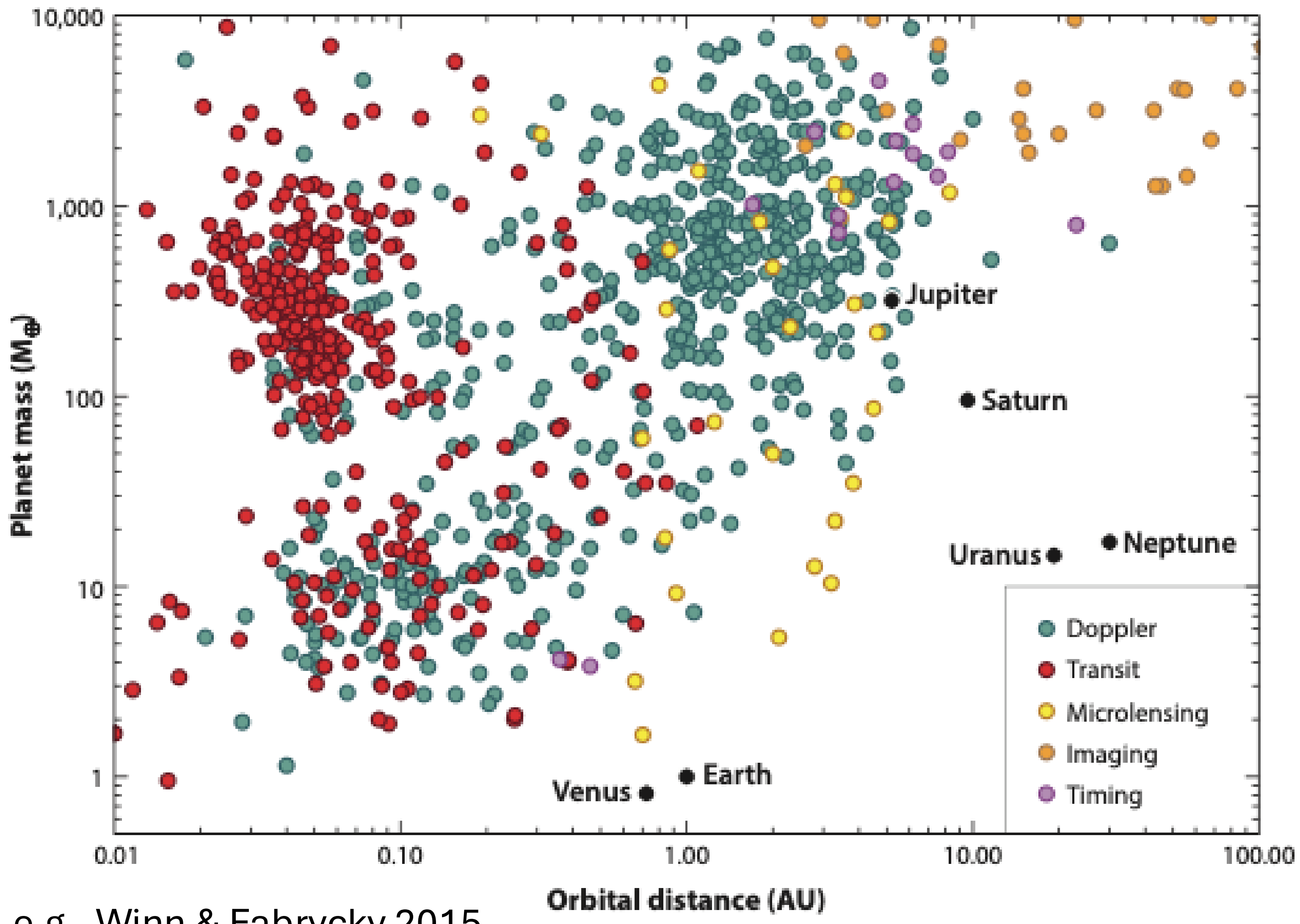
How



Halpha emission comes from accreting giant planets

State-of-the Art: Exoplanet Population

Where How



e.g., Winn & Fabrycky 2015

Exoplanets are everywhere

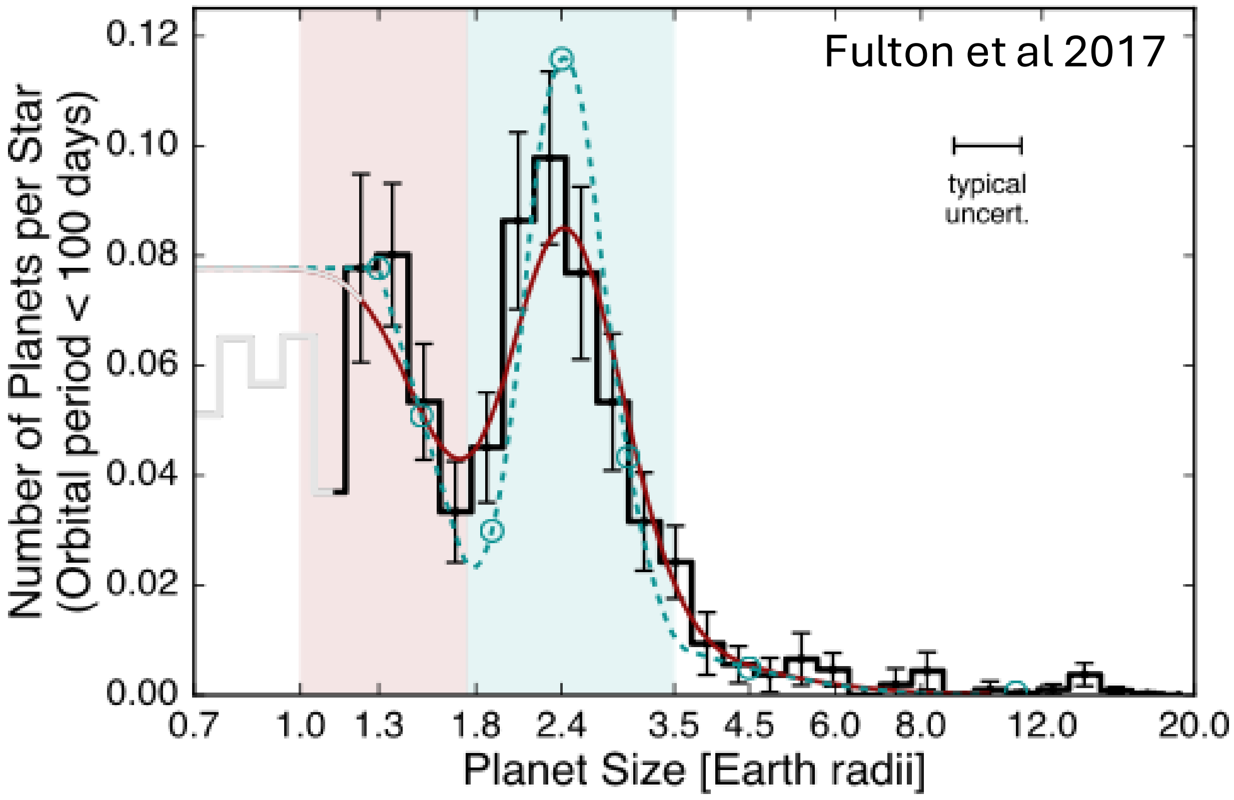
Planet formation is ubiquitous

Accretion of gas and solids leads to a wide mass range

Orbital evolution plays an important role

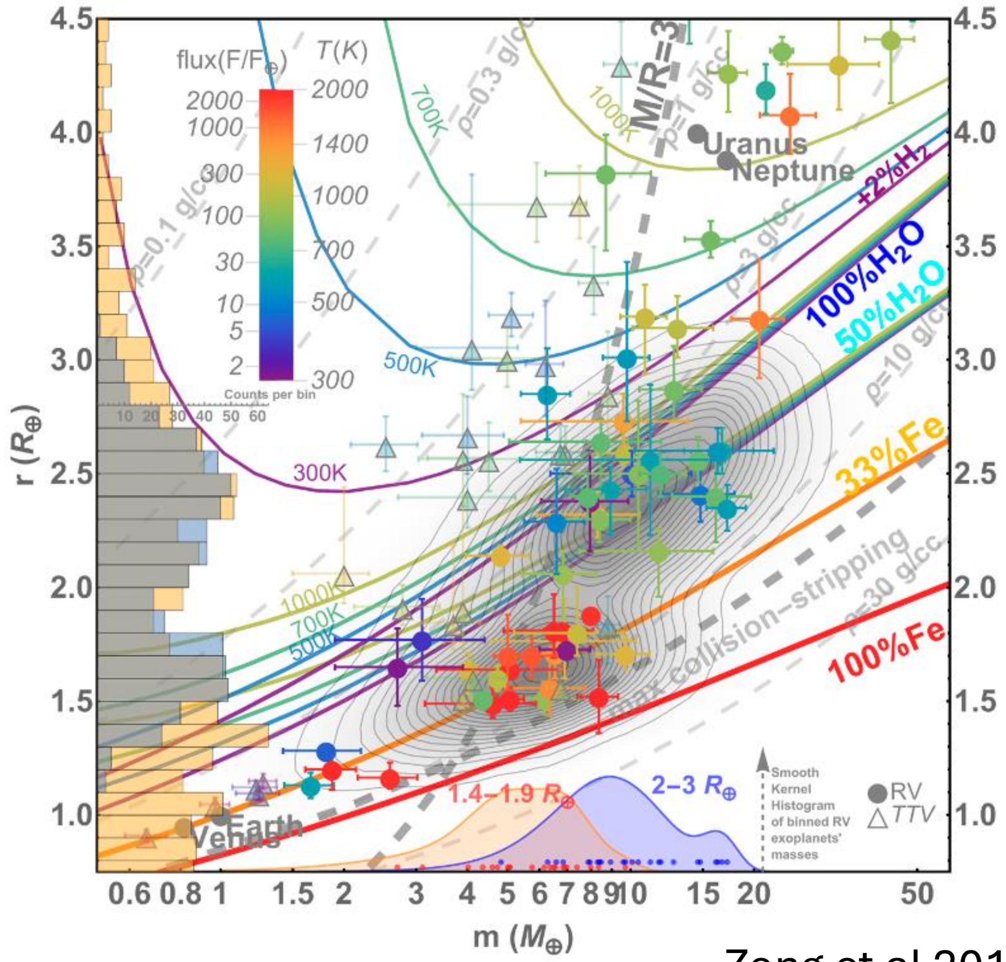
State-of-the Art: Exoplanet Composition

How



Planets with radius of < 1.8 R_Earth
are likely rocky

Where & How



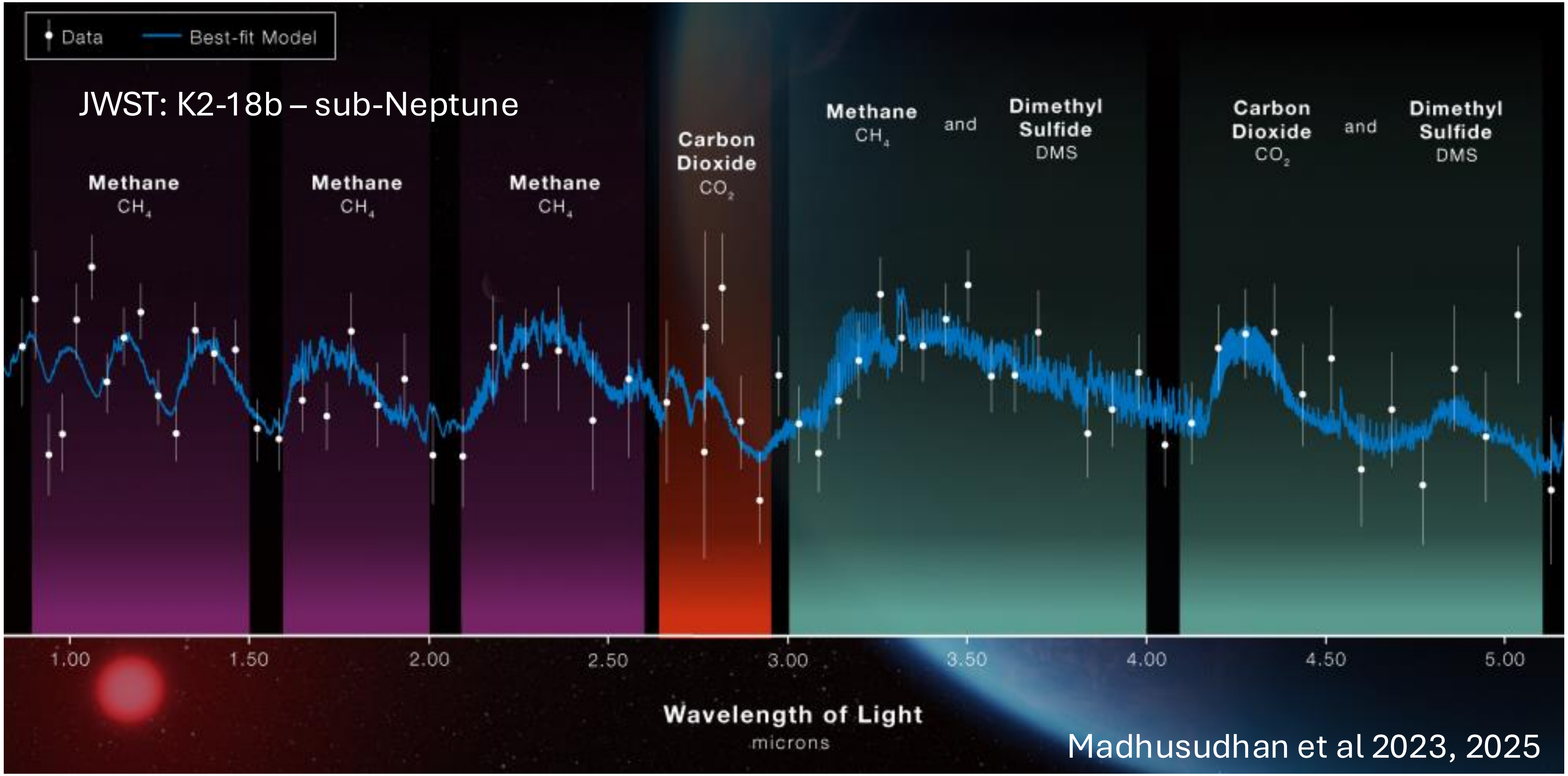
Zeng et al 2019

Some sub-Neptune planets are volatile rich

State-of-the Art: Exoplanet Climate & Habitability

How

Where



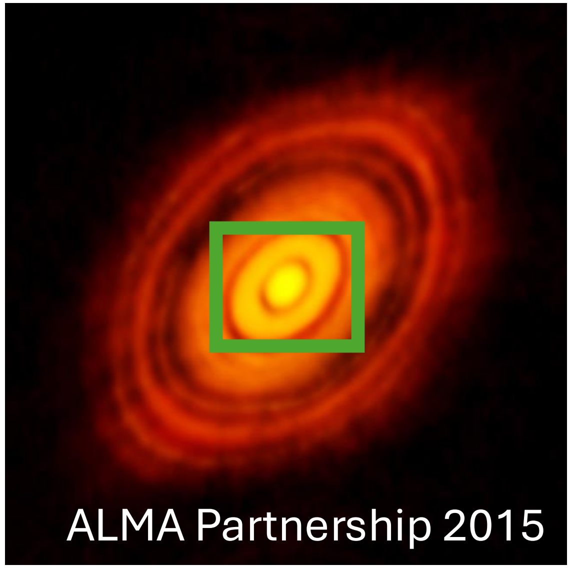
Characterization of exoplanet atmospheres can infer climate and even habitability of exoplanets

Fundamental questions:

When, Where, and How Do Planets Form?

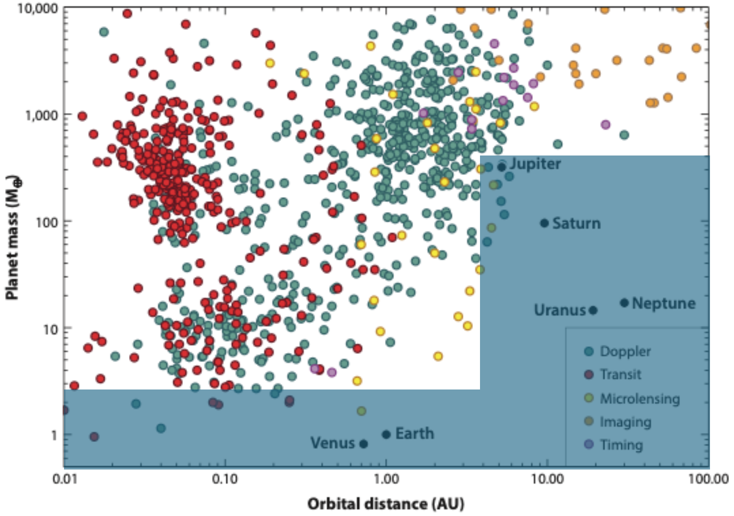
Beyond State-of-the Art: Discovery-Based

Disks



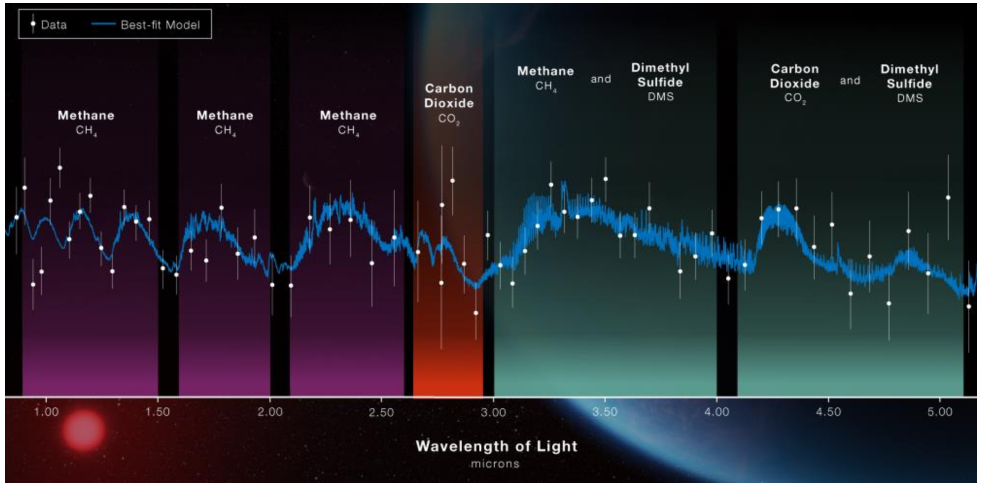
ALMA Partnership 2015

Population



e.g., Winn & Fabrycky 2015

Characterization



Madhusudhan et al 2023, 2025

Resolve inner disks

Gas kinematics

Multi-wavelength

Low-mass planets including habitable planets

Distant planets

Young planets

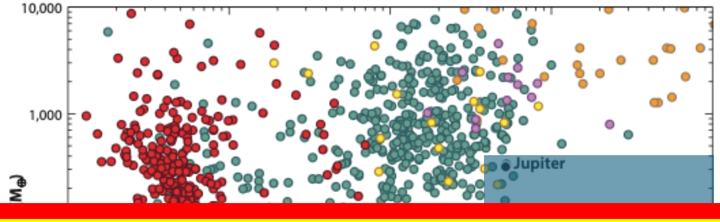
Multi-wavelength

More atoms/molecules

Beyond State-of-the Art: Discovery-Based

Disks

Population



Characterization

High sensitivity observations with high spatial and high spectral resolutions are key while setting more specific goals is preferred

Resolve inner disks

Low-mass planets including habitable planets

Gas kinematics

Distant planets

Multi-wavelength

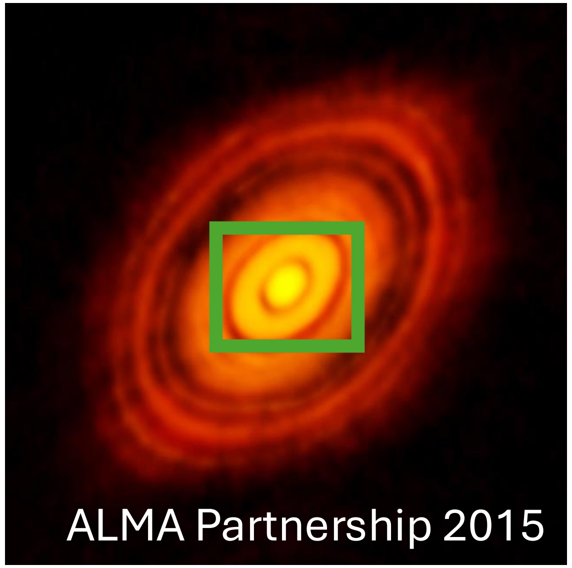
Multi-wavelength

Young planets

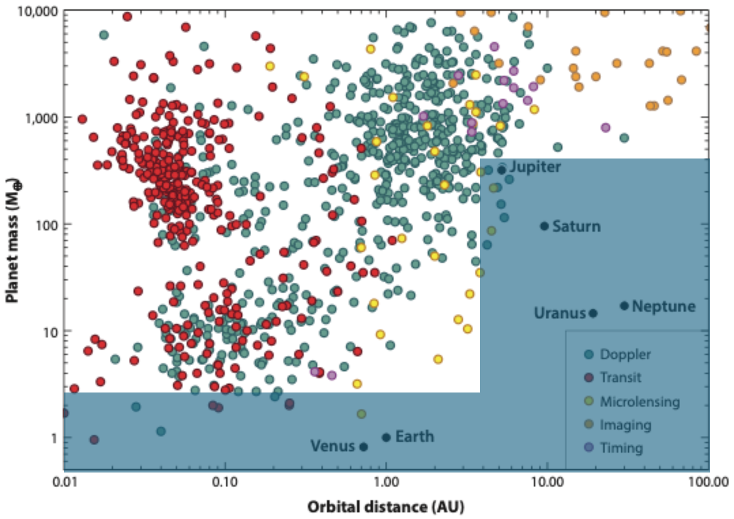
More atoms/molecules

Beyond State-of-the Art: Hypothesis-Based

Disks

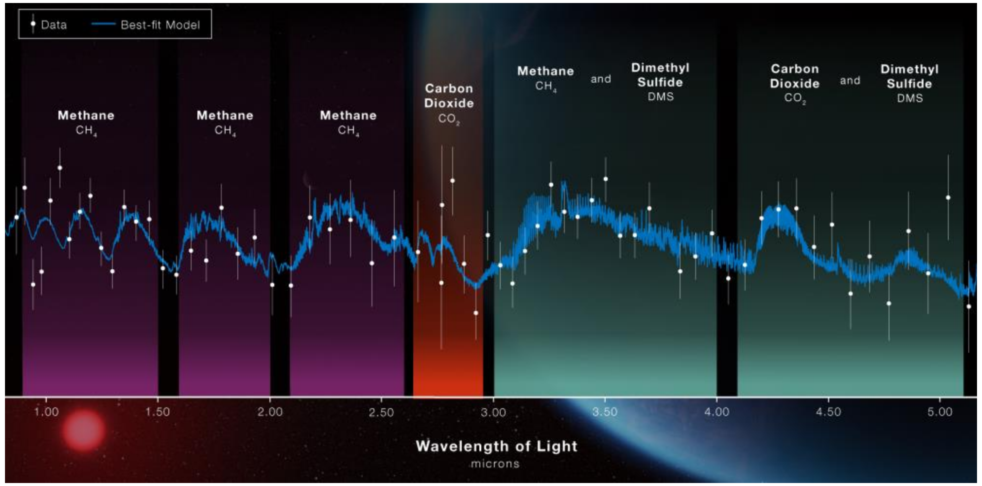


Population



e.g., Winn & Fabrycky 2015

Characterization



Madhusudhan et al 2023, 2025

Are inner disk properties set by disk winds or turbulence?

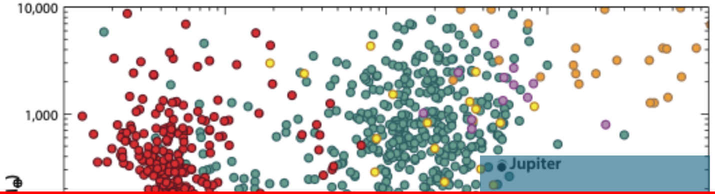
Did Low-mass planets including habitable planets form by in-situ or gas-induced migration?

Is the current properties of molecular abundance determined by equilibrium or non-equilibrium chemistry?

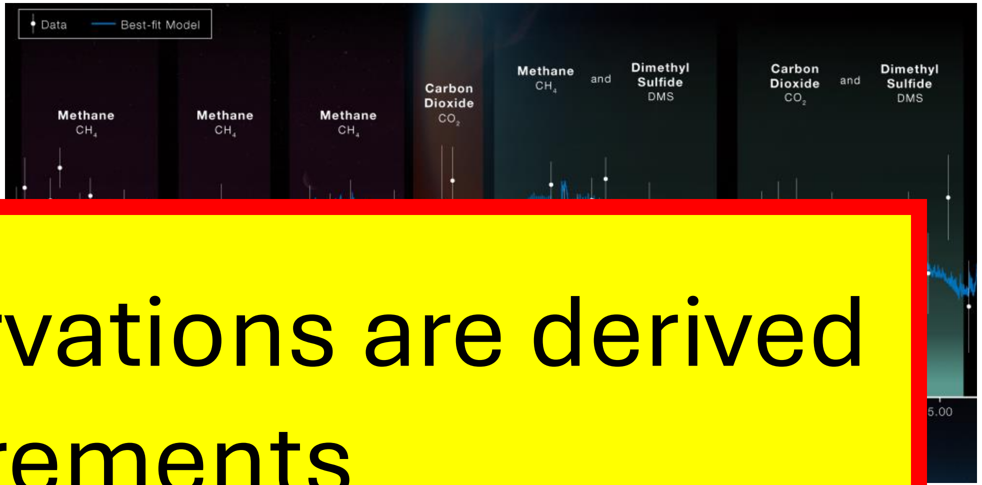
Beyond State-of-the Art: Hypothesis-Based

Disks

Population



Characterization



The specs of telescopes/observations are derived from science requirements

Are inner disk properties set by disk winds or turbulence?

Did Low-mass planets including habitable planets form by in-situ or gas-induced migration?

Is the current properties of molecular abundance determined by equilibrium or non-equilibrium chemistry?

Key Science Cases for TMT

Transit!

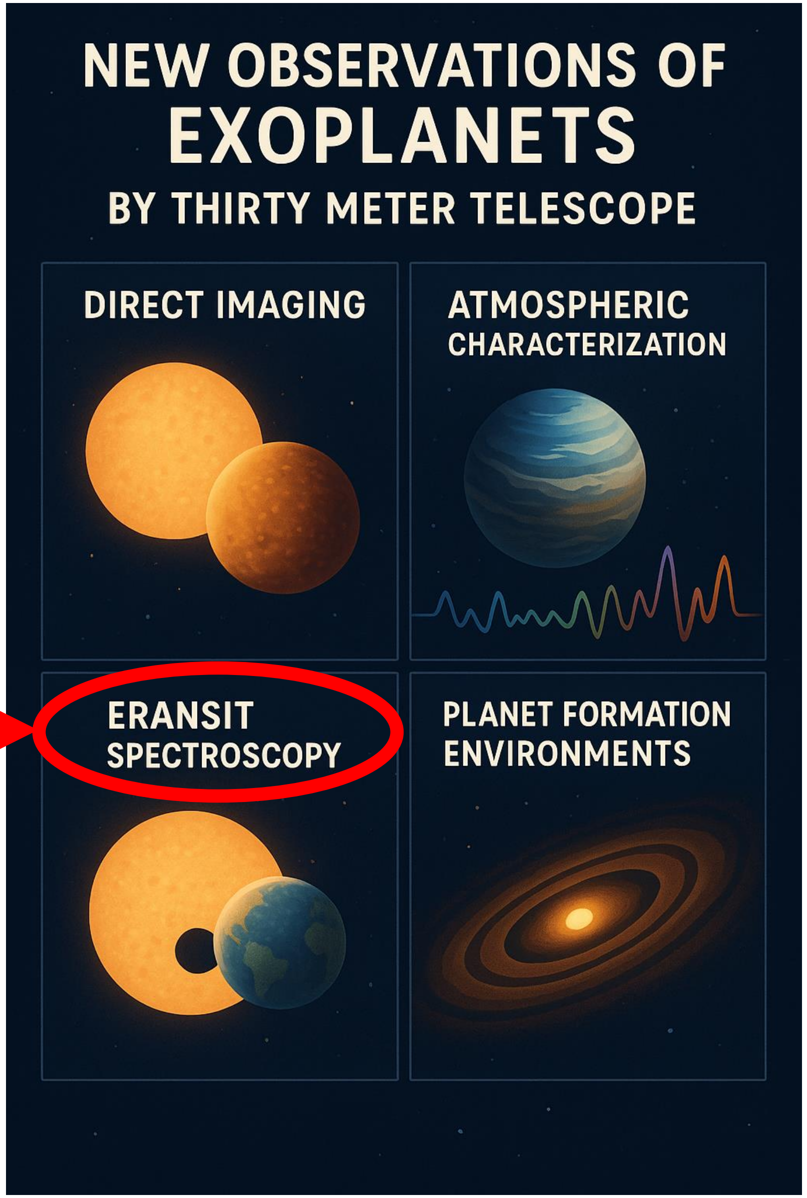
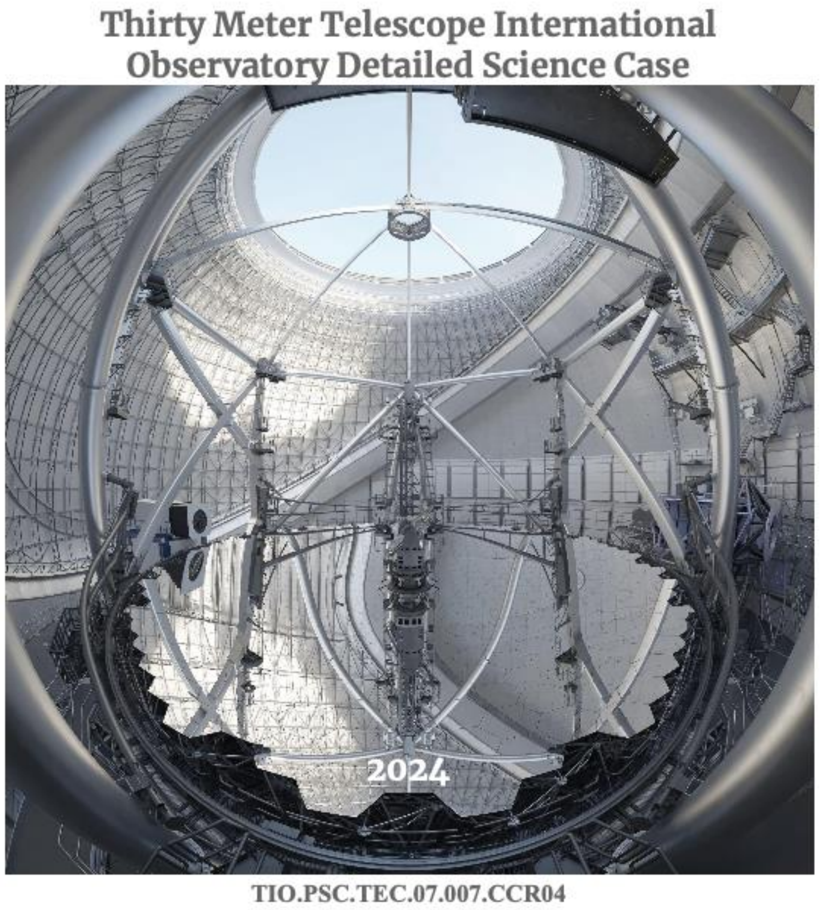


Image created by ChatGPT!

Science Requirements for TMT

Science cases from the community



https://www.tmt.org/download/Document/10/original

Planet formation & exoplanet science cases

Imaging inner (10 au) disks

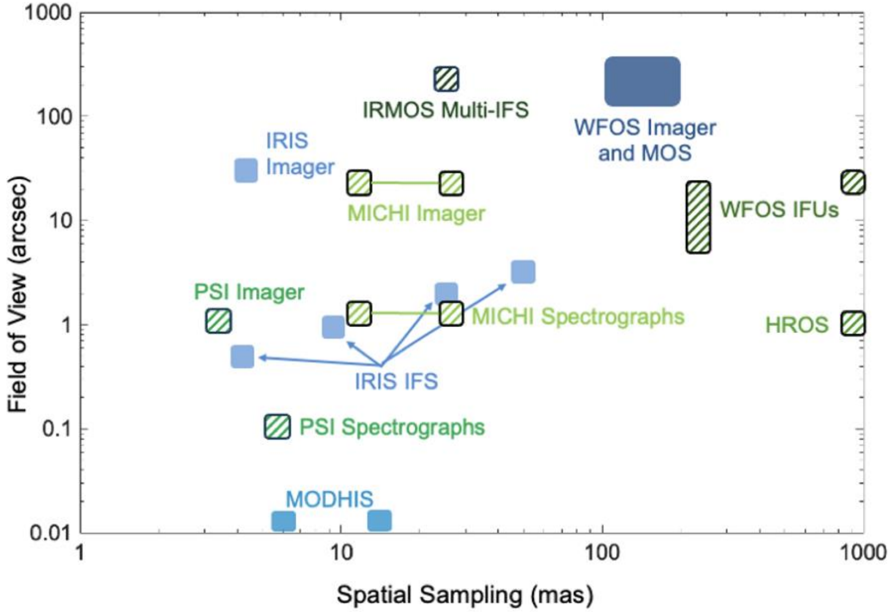
Spectroscopy of disk gas

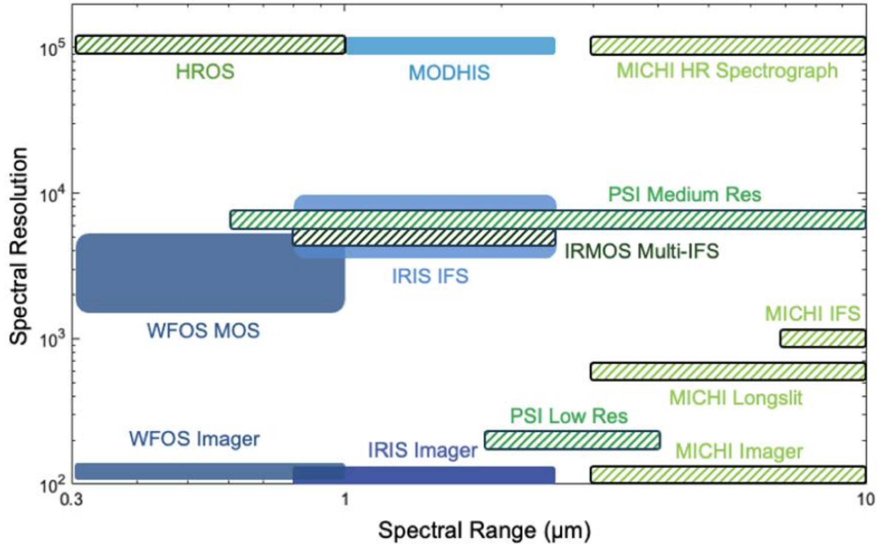
Imaging & spectroscopy of young giant planets

RV detections and transit spectroscopy of (super)Earths in habitable zones

RV detections of exomoons

Instrument specs





Some numbers...

First Light Instruments

MODHIS

10 mas @ 150 pc => 1.5 au

R ~ 10^5 => Delta v ~ 3 km/s

1 micron => 3000K

IRIS

1 as FoV @ 150 pc => 150 au

R ~ 10^4 => Delta v ~ 30 km/s

1 micron => 3000K

First Decade Instruments

PSI

5 mas @ 10 pc => 0.05 au

R < 10^5 => Delta v ~ 3 km/s

Contrast ratio ~ 10^-8-10^-9

MICHI

10 mas @ 150 pc => 1.5 au

R < 10^5 => Delta v ~ 3 km/s

10 micron => 300 K

Key physical quantities

v_Kep @ 1 au => 30 km/s   RV of 10 cm/s can be achieved by R ~ 10^5   Contrast ratio of Jupiter ~ 10^-9

Synergy with Other Telescopes

Synergy	Ch#3	Ch#4	Ch#5	Ch#6	Ch#7	Ch#8	Ch#9	Ch#10	Ch#11
	Fund. Physics and Cosmology	Early Universe	Galaxy Formation and the IGM	SMBH	MW and Nearby Galaxies	Birth & Early Lives of Stars & Planets	Time-Domain Science	Exoplanets	Our Solar System
ALMA		☑	☑ ☑	☑ ☑		☑ ☑	☑ ☑	☑ ☑	
GAIA	☑ ☑				☑ ☑	☑ ☑	☑ ☑	☑ ☑	
JWST	☑ ☑	☑ ☑	☑ ☑	☑ ☑	☑ ☑	☑ ☑	☑ ☑	☑ ☑	☑ ☑
Roman Space Telescope	☑ ☑	☑ ☑	☑	☑	☑	☑	☑ ☑	☑ ☑	
HWO	☑	☑	☑	☑	☑	☑	☑	☑ ☑	☑

https://www.tmt.org/download/Document/10/original

TMT will be very versatile and provide complementary observations

Proposing science cases unique to TMT and a next-generation of instruments can enhance the importance of TMT

TMT-ACCESS Workshop

What is the TMT-ACCESS?

新たな TMT サイエンスケースの創造 と **TMT 次世代装置の提案**
を目的とした **若手中心の TMT Workshop Series**

分野横断型	ディスカッション重視	若手中心	サイエンティスト — エンジニアの 相互理解促進

TMT-ACCESS Workshop

Former workshops

Our Activities: TMT-ACCESS

First TMT-ACCESS

日　時	2023年 9月
場　所	TIO Office (アメリカ/パサデナ)
テーマ	TMT が拓く次世代のサイエンス
講　義	TMT/ELT のサイエンス、TMT の装置、Hawaiian engagement、研究分野毎のレビュー
見　学	TMT ラボ、JPL

梅畑 豪紀 (名古屋大学)　鵜山 太智 (CSU Northridge)　衣川 智弥 (信州大学)　砂山 朋美 (ASIAA)　高橋 葵 (JAXA)　中本 崇志 (NAOJ)　長谷川 靖紘 (JPL)　百瀬 莉恵子 (Carnegie)

TMT-ACCESS 2024

日　時	2024年 6月
場　所	東北大学 (仙台)
テーマ	日本がリードする20年後の光赤外線天文学
講　義	装置開発、研究分野毎のレビュー
見　学	天文学専攻・地球物理学専攻ラボ

小野里 宏樹 (NAOJ)　木村 成生 (東北大学)　久保 真理子 (東北大学)　鈴木 竜二 (NAOJ)　田畑 陽久 (ISAS/JAXA)　富田 賢吾 (東北大学)

TMT-ACCESS Workshop

Summary

- Planet formation and exoplanets are timely in astrophysics today
- Tremendous amounts of progresses have been made
- The origins of planets – especially habitable planets – remain unclear
- High sensitive observations with high spatial and high spectral resolutions can advance the fields significantly
- TMT will be very versatile and can play such a role
- Due to complementarity of TMT observations, proposing science cases unique to TMT and a next-generation of instruments would be key
- Participation of the TMT-ACCESS workshop is a great opportunity and highly encouraged