

Kosmische Evolution für Nicht-Physiker:
Wie unser Weltall wurde, was es heute ist

10. Planeten-Entstehung

Knud Jahnke, MPIA

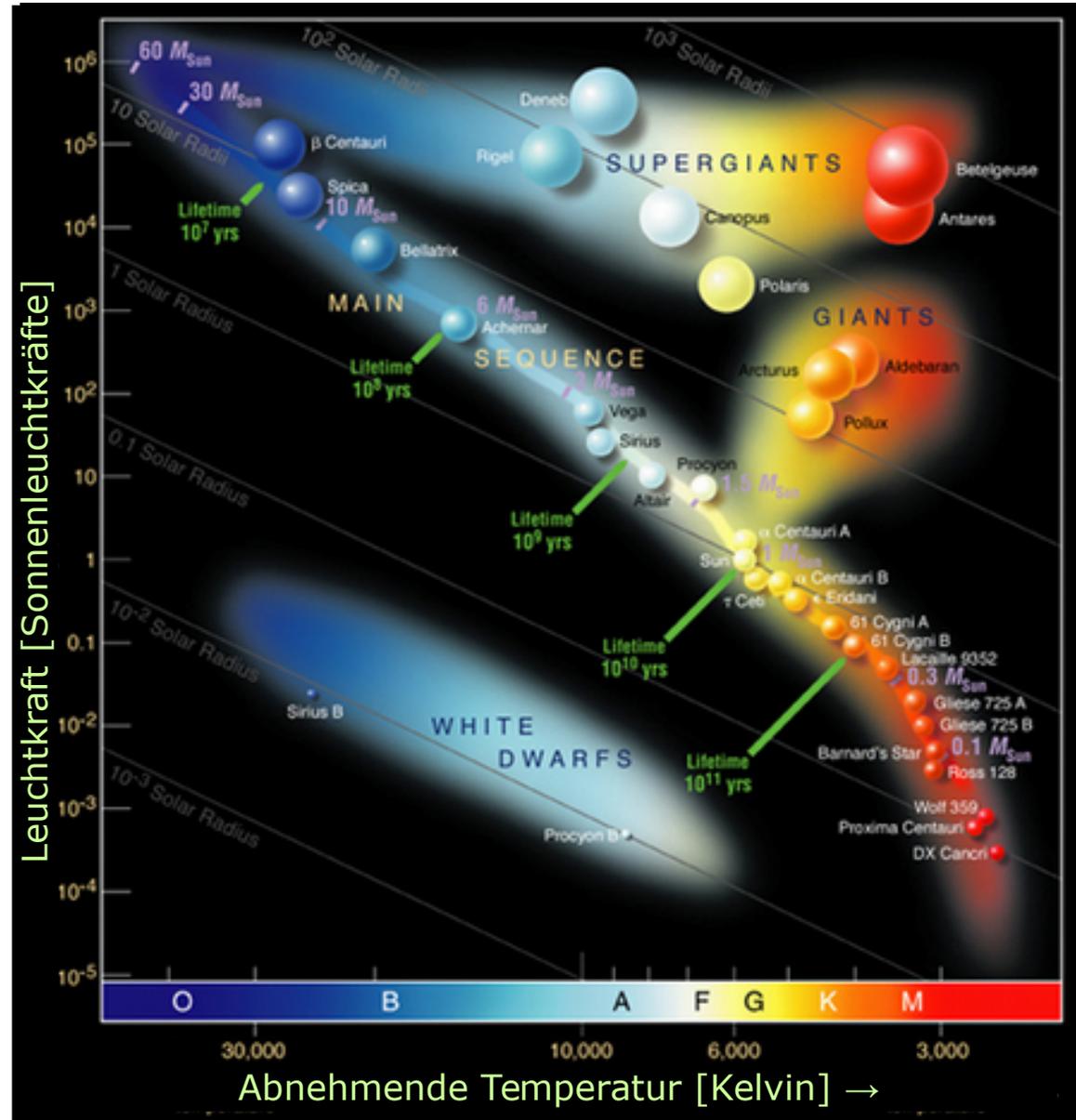
Letzte Vorlesungen:
Sterne

→ eigenes Leuchten
durch Fusion

Sterne

Letzte Vorlesungen: Sterne

→ eigenes Leuchten
durch Fusion



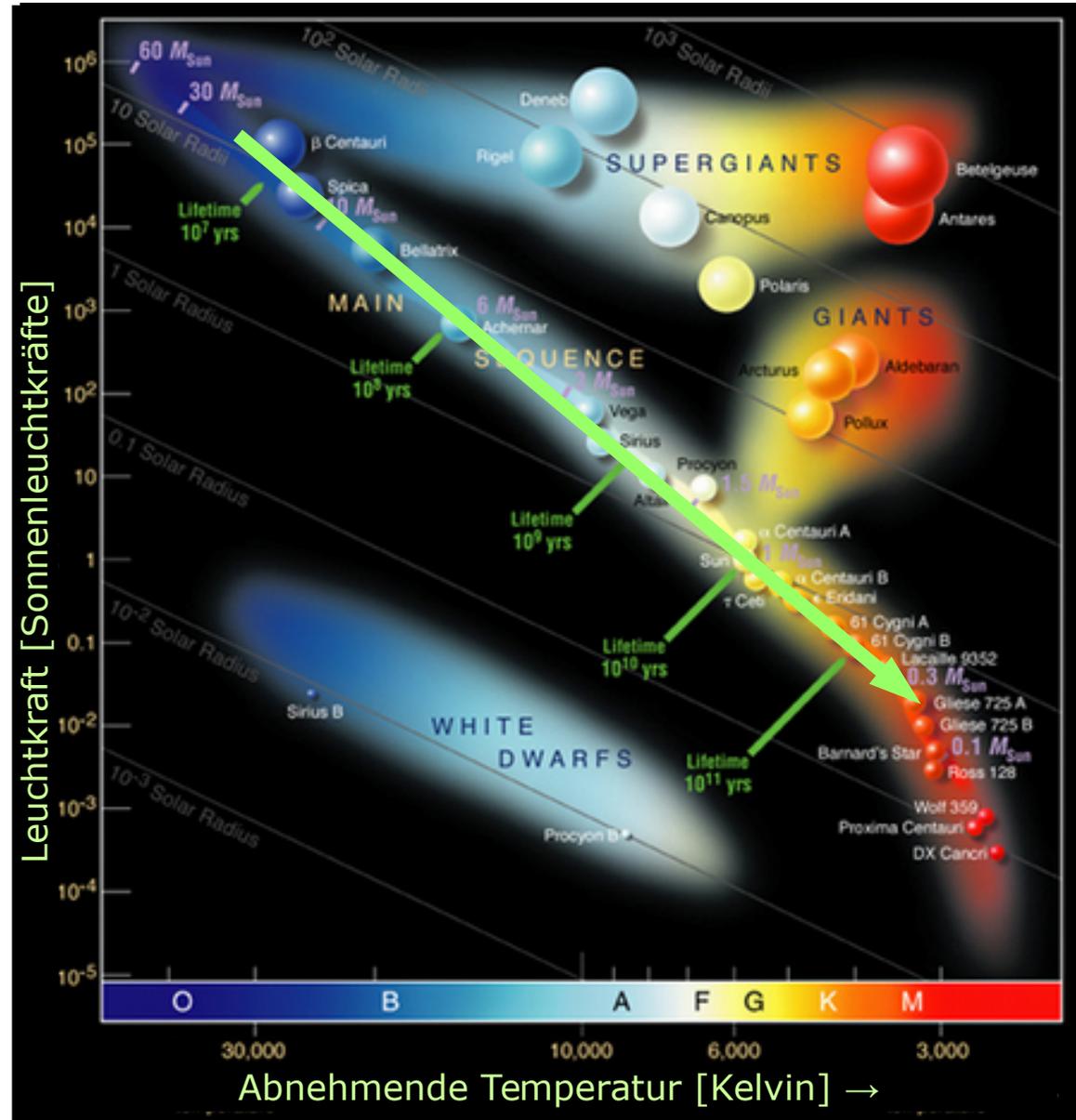
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Sterne

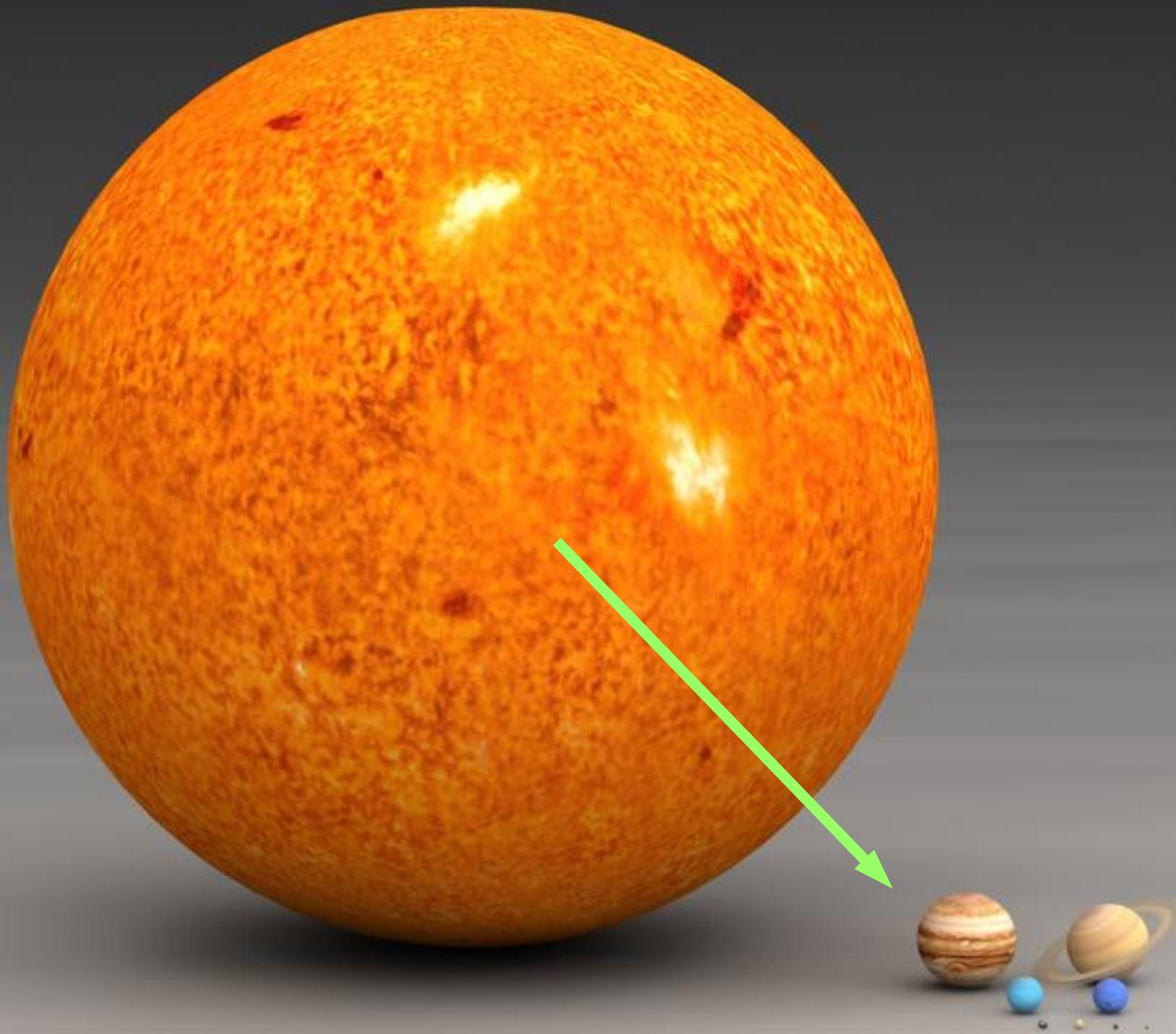
Letzte Vorlesungen:
Sterne

→ eigenes Leuchten
durch Fusion

Was passiert bei
abnehmender Masse?



ESO/Wikipedia (CC BY 4.0)



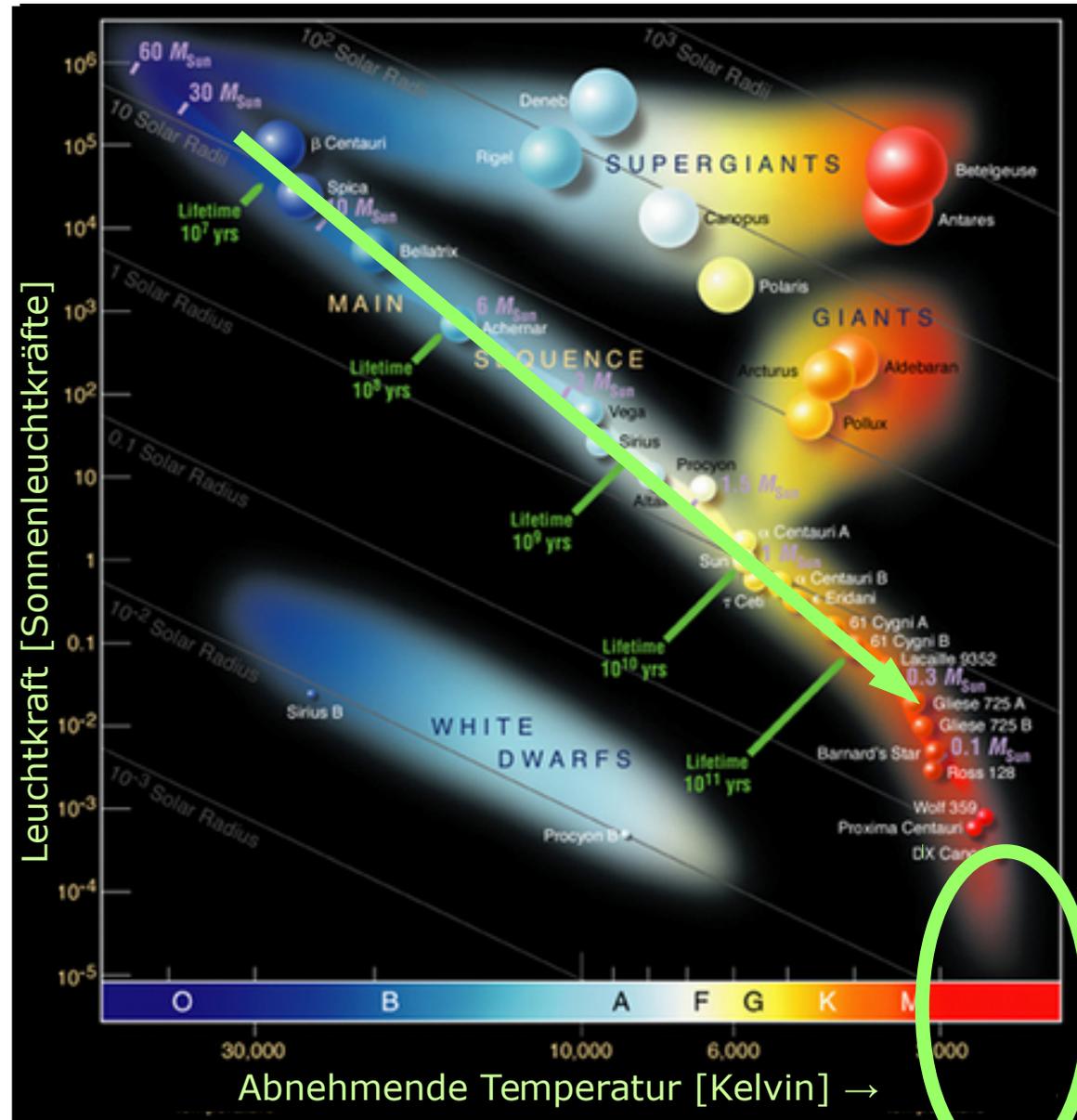
Sterne

Letzte Vorlesungen:
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Was passiert bei
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$< 0.08 M_{\text{Sonne}}$



ESO/Wikipedia (CC BY 4.0)

Sterne

Letzte Vorlesungen:
Sterne

→ eigenes Leuchten
durch Fusion

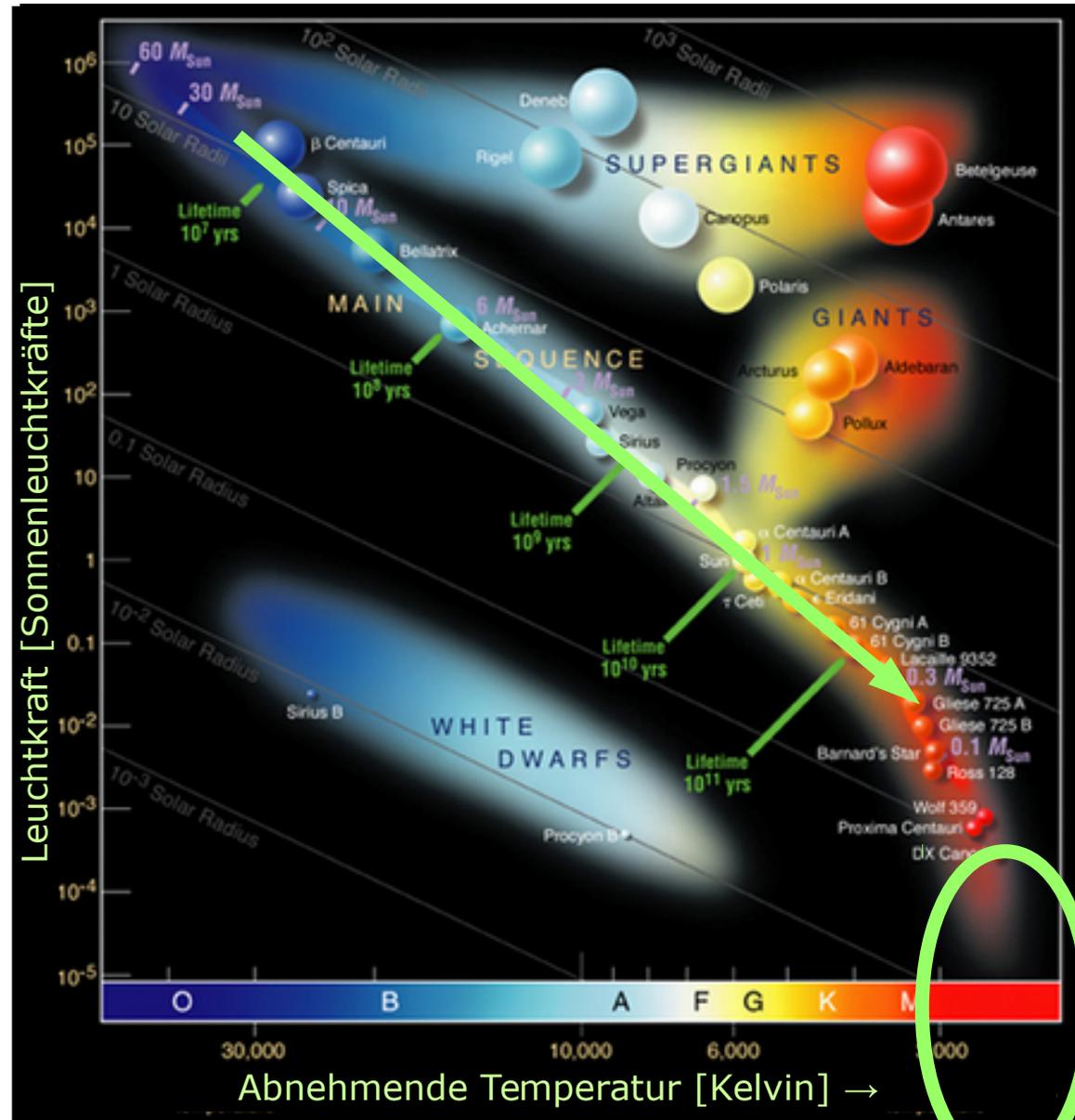
Was passiert bei
abnehmender Masse?

$< 0.08 M_{\text{Sonne}}$

$T \sim M/R$

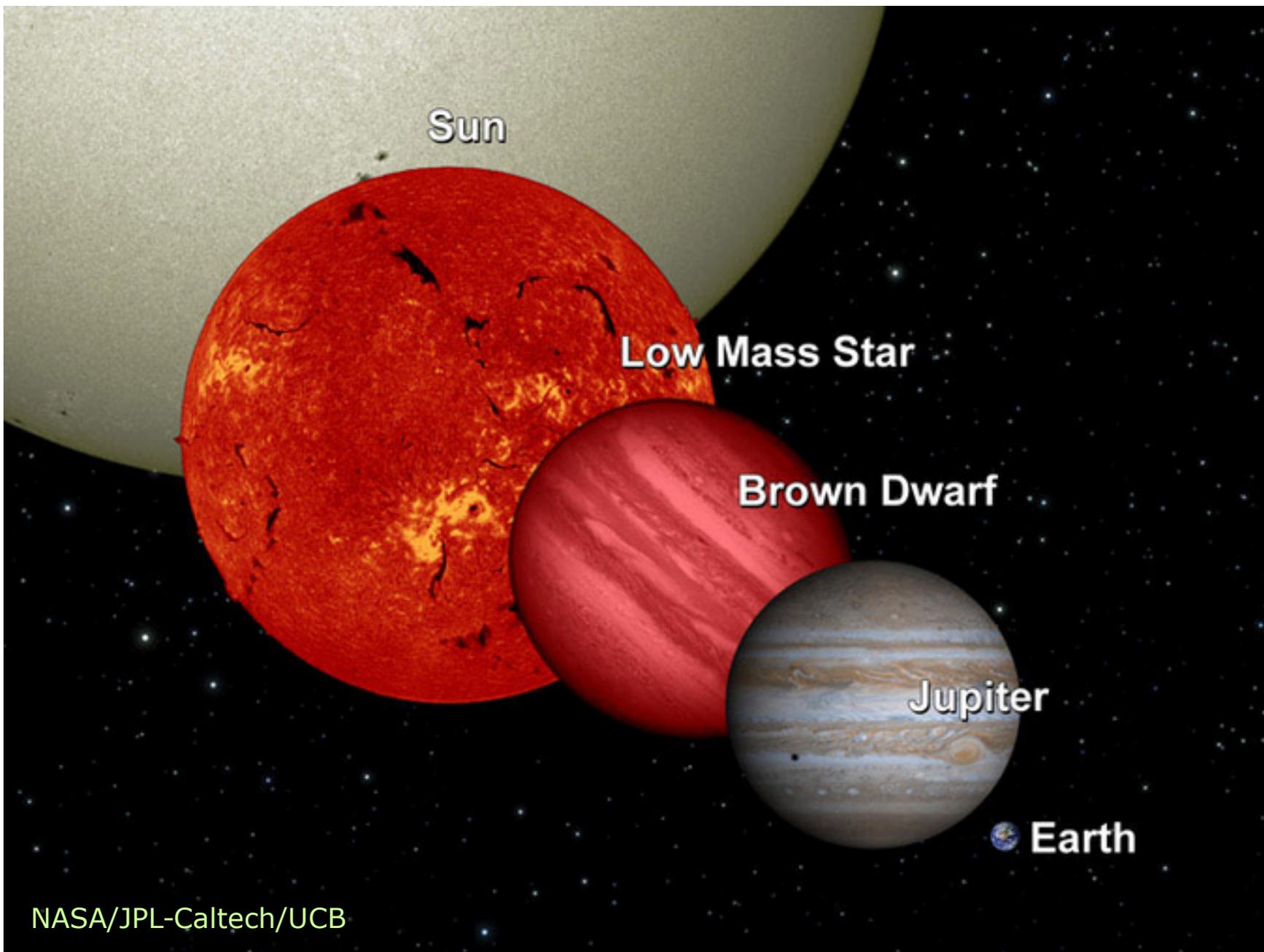
→ zu kalt für Fusion

→ Brauner Zwerg



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Braune Zwerge



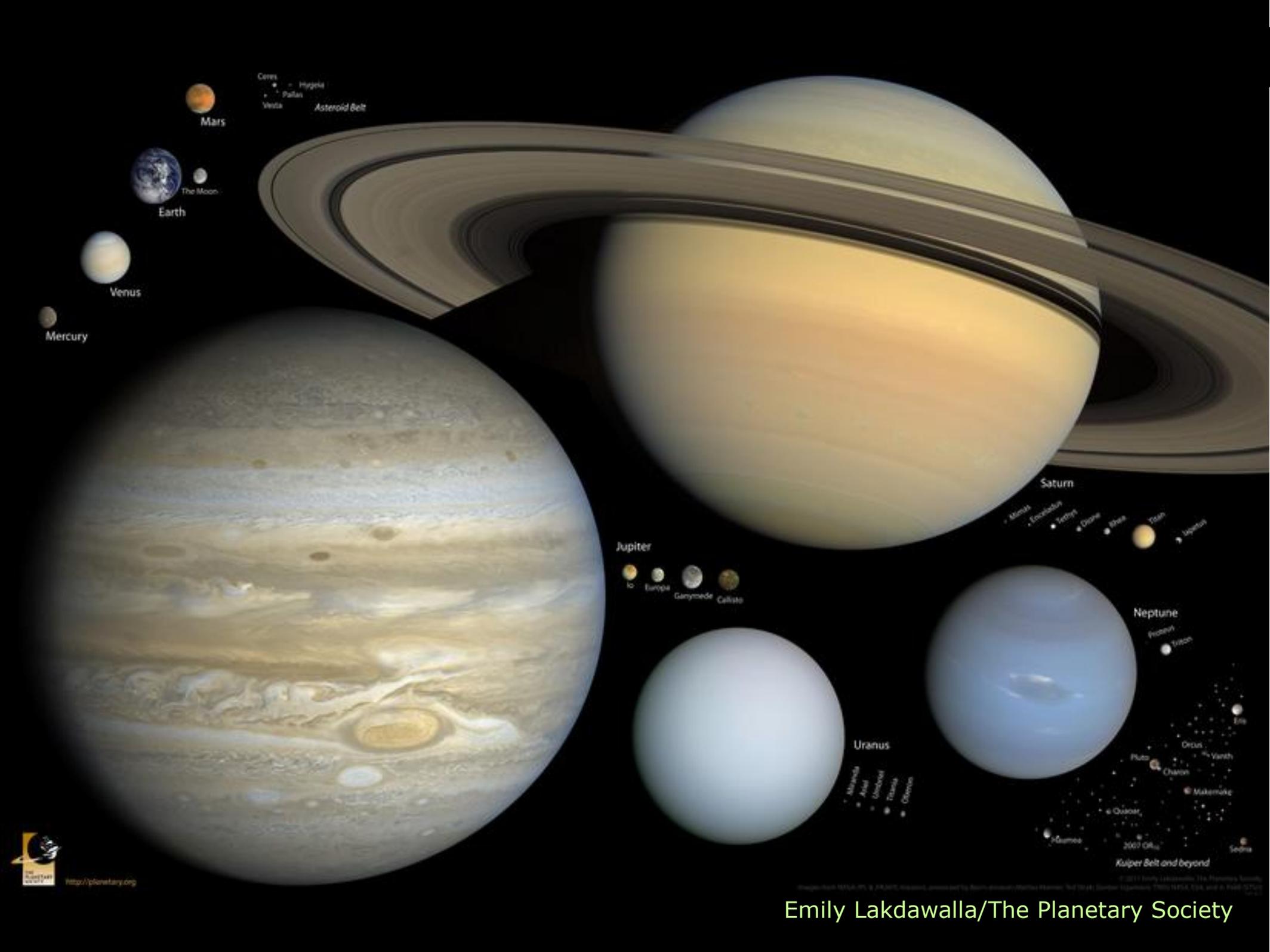
Eigenschaften Braune Zwerge

- Masse: 13–80 Jupiter-Massen
- keine Wasserstoff-Fusion
- aber Deuterium- oder Lithium-Fusion

Und bei noch weniger Masse?



K. Jahnke



<http://planetary.org>

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Emily Lakdawalla/The Planetary Society

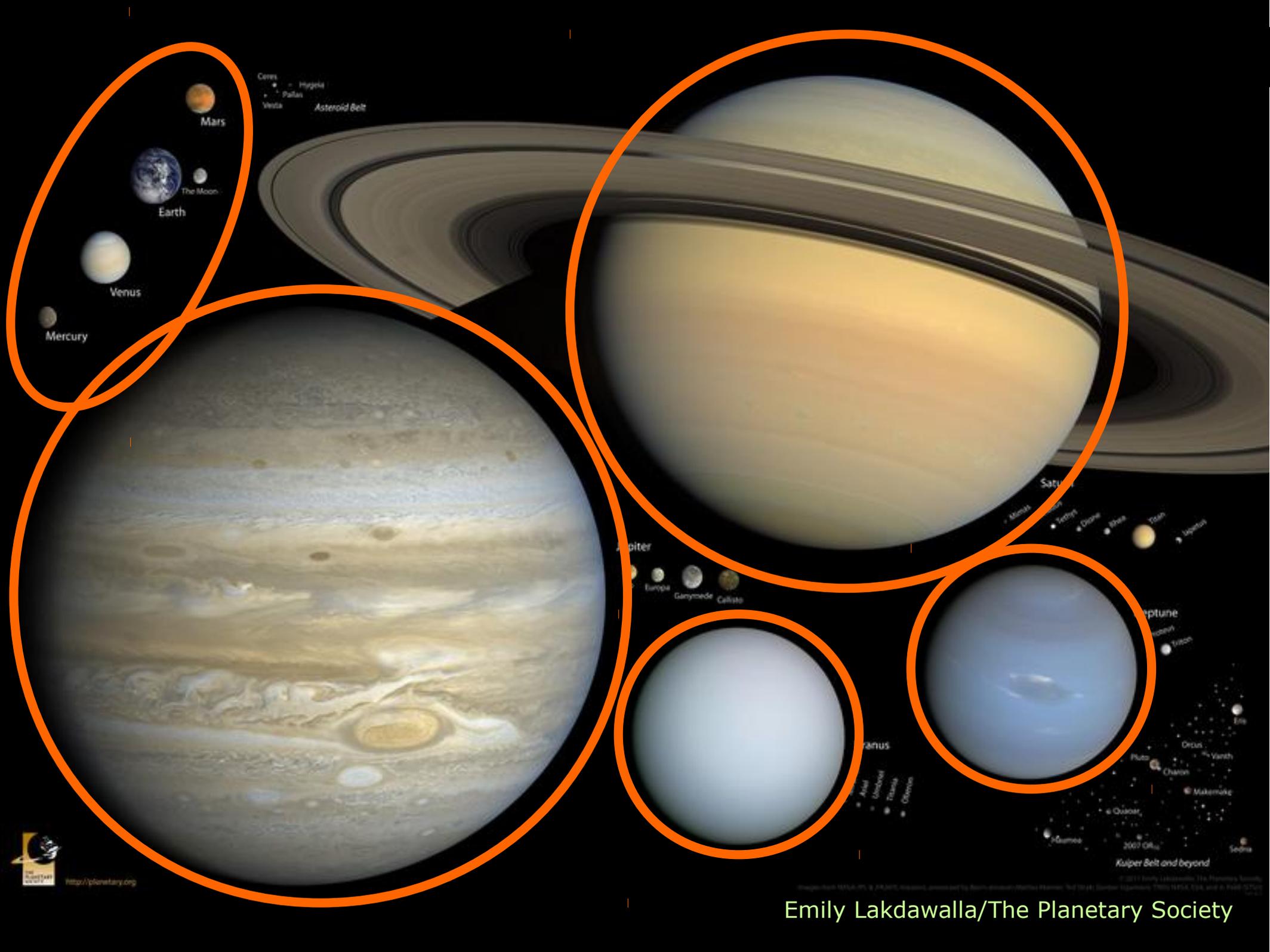
Planet (Definition IAU, 2006):

"Astronomischer Körper in Umlaufbahn um einen Stern oder Stern-Rest, der

massereich genug ist, um unter eigener Schwerkraft rund zu werden,

nicht genug Masse hat, um Fusion zu zünden und

der seine Nachbar-Region von Planetesimalen bereinigt hat."



<http://planetary.org>

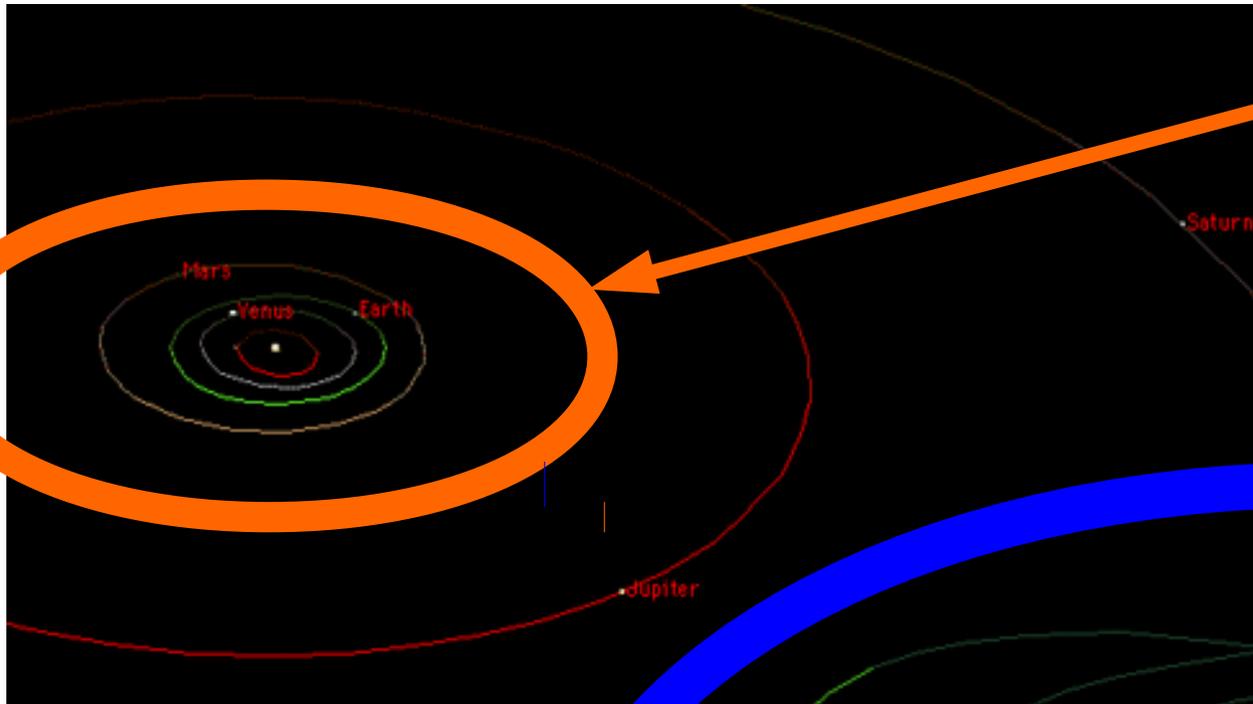
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Sonnensystem: Kleinplaneten

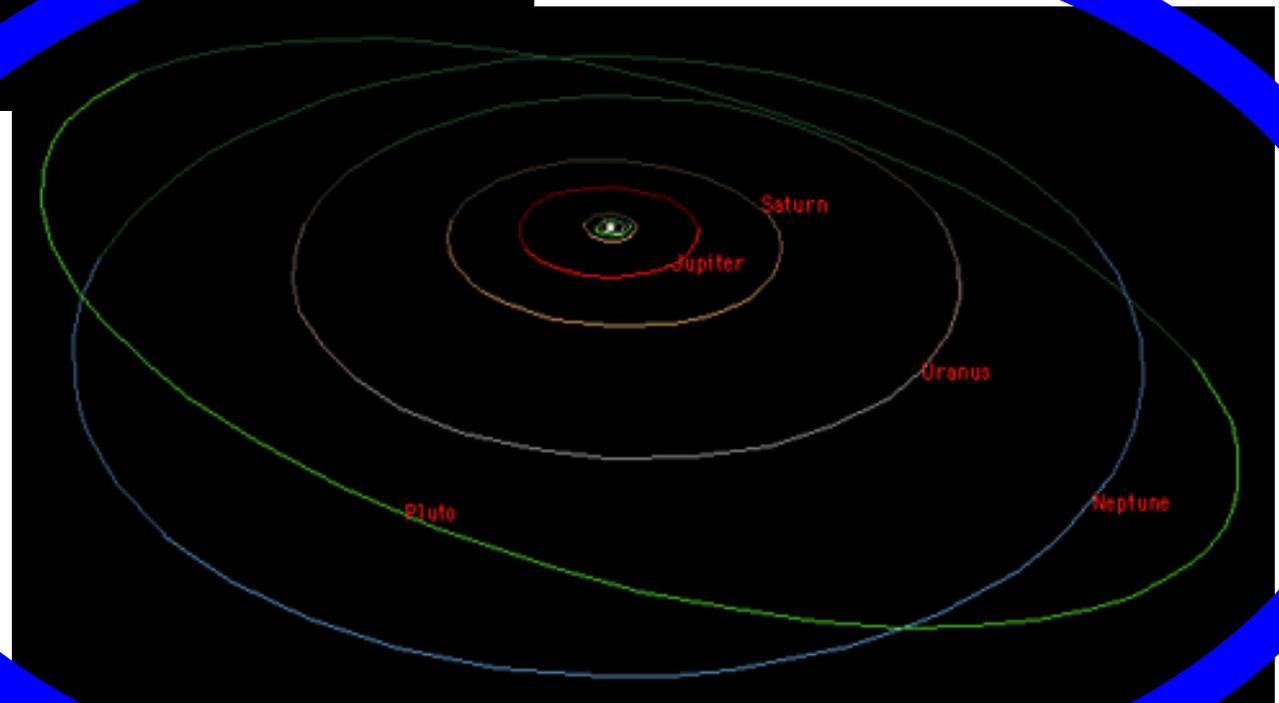


Sonnensystem: eine Ebene



Asteroiden-Gürtel

Kuiper-Gürtel



Steinplaneten + Gasriesen + Asteroiden-+Kuipergürtel

Sonnen-"System" = gemeinsame Entstehung

Protoplanetare Scheiben

— künstlerische Darstellung —

Protoplanetare Scheiben

Entstehende Stern+Planetensysteme: Blick mit HST
(sichtbares Licht)

Orion-Nebel



NASA/ESA/HST

Protoplanetare Scheiben

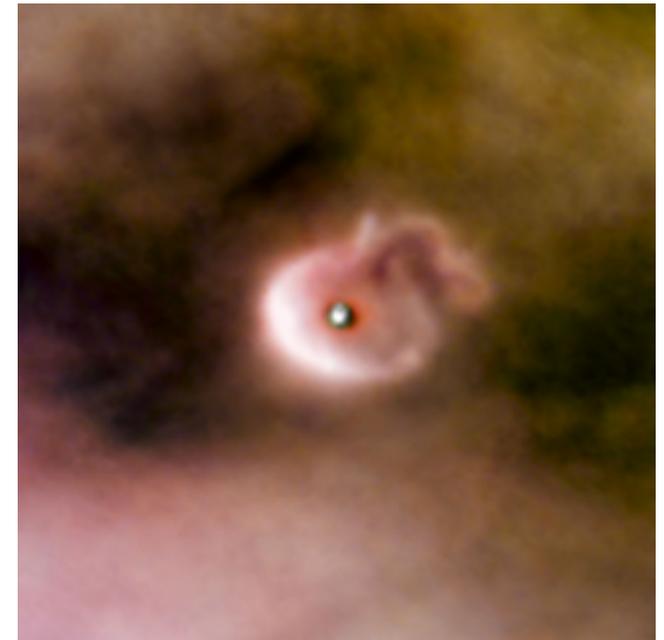
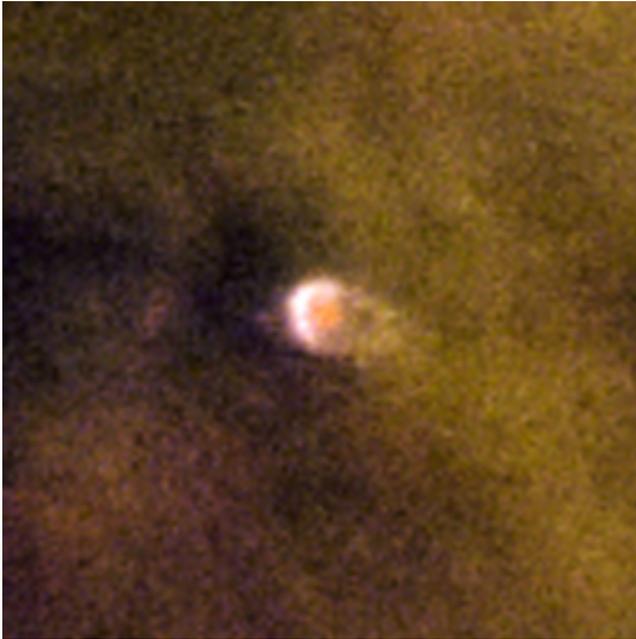
Entstehende Stern+Planetensysteme: Blick mit HST
(sichtbares Licht)



NASA/ESA/HST

Protoplanetare Scheiben

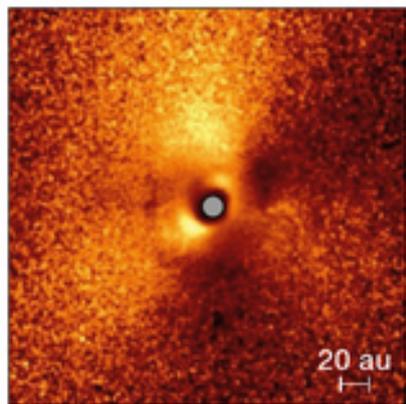
Entstehende Stern+Planetensysteme: Blick mit HST
(sichtbares Licht)



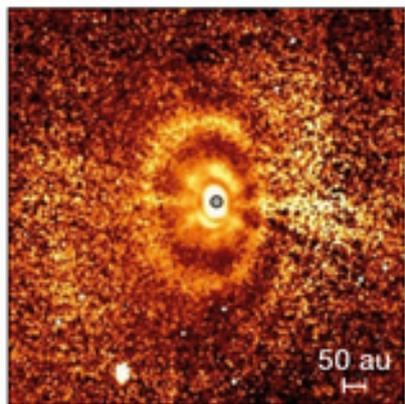
NASA/ESA/HST

Protoplanetare Scheiben

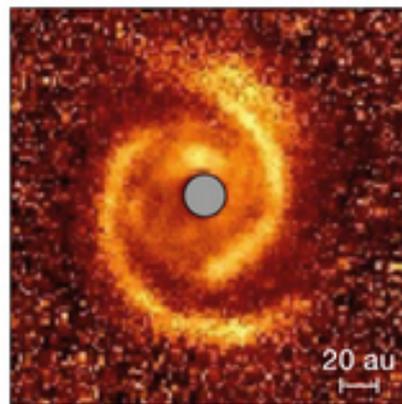
Entstehende Stern+Planetensysteme: Blick mit VLT/SPHERE
(nahes Infrarot)



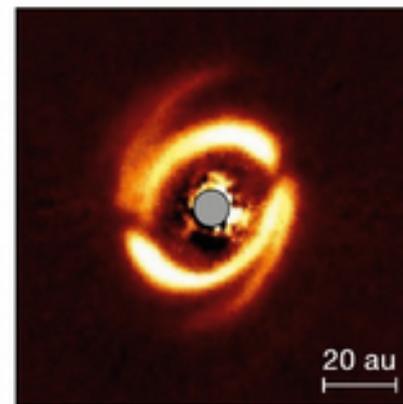
HD 100546



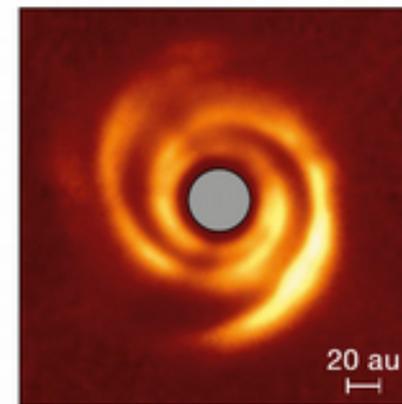
HD 97048



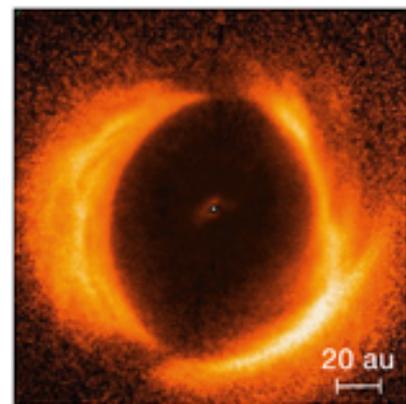
MWC 758



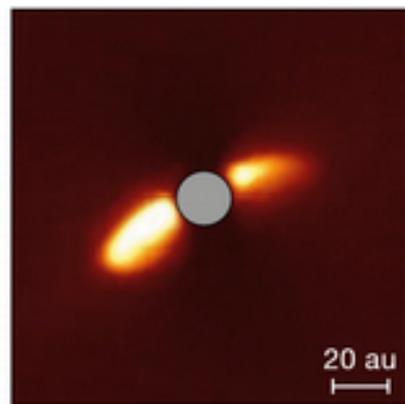
HD 100453



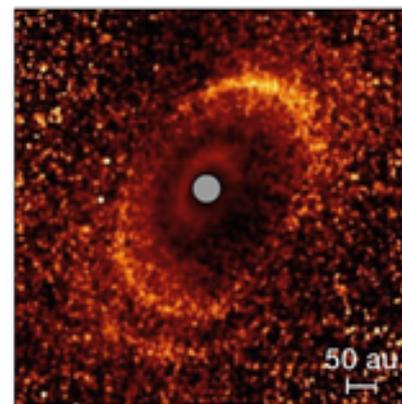
HD 135344B



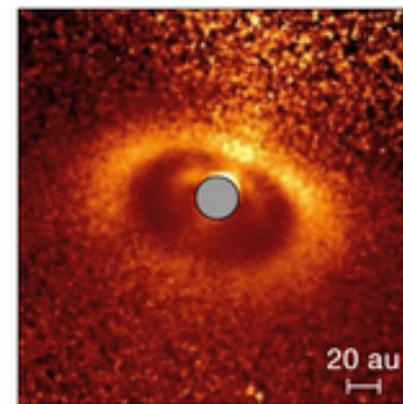
HD 142527



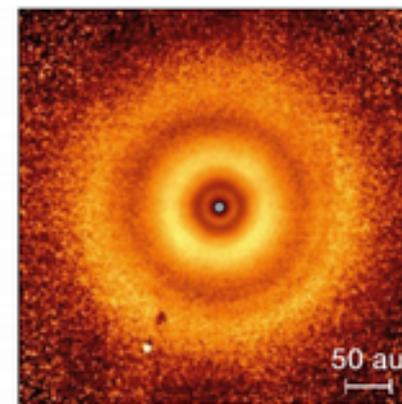
T Cha



RX J1615-3255



LkCa15



TW Hya

Erdbahnradius: 1 AU ("astronomical unit")
Uranusbahnradius: 30 AU

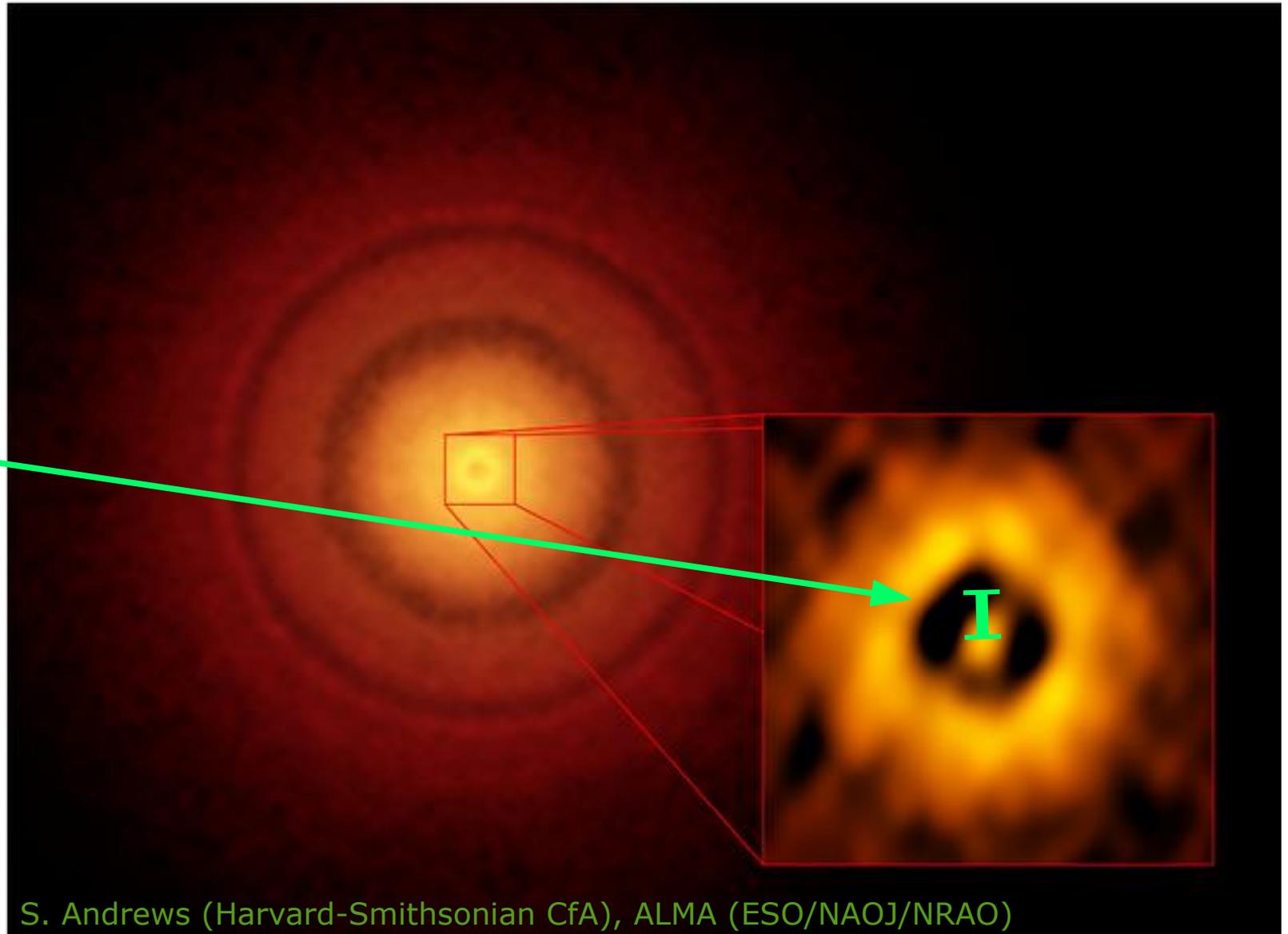
ESO Messenger #169, 12/2017

Protoplanetare Scheiben

Entstehende Stern+Planetensysteme: Blick mit ALMA
(Millimeter)

TW Hydra

1. Lücke
bei ca. 1 AU

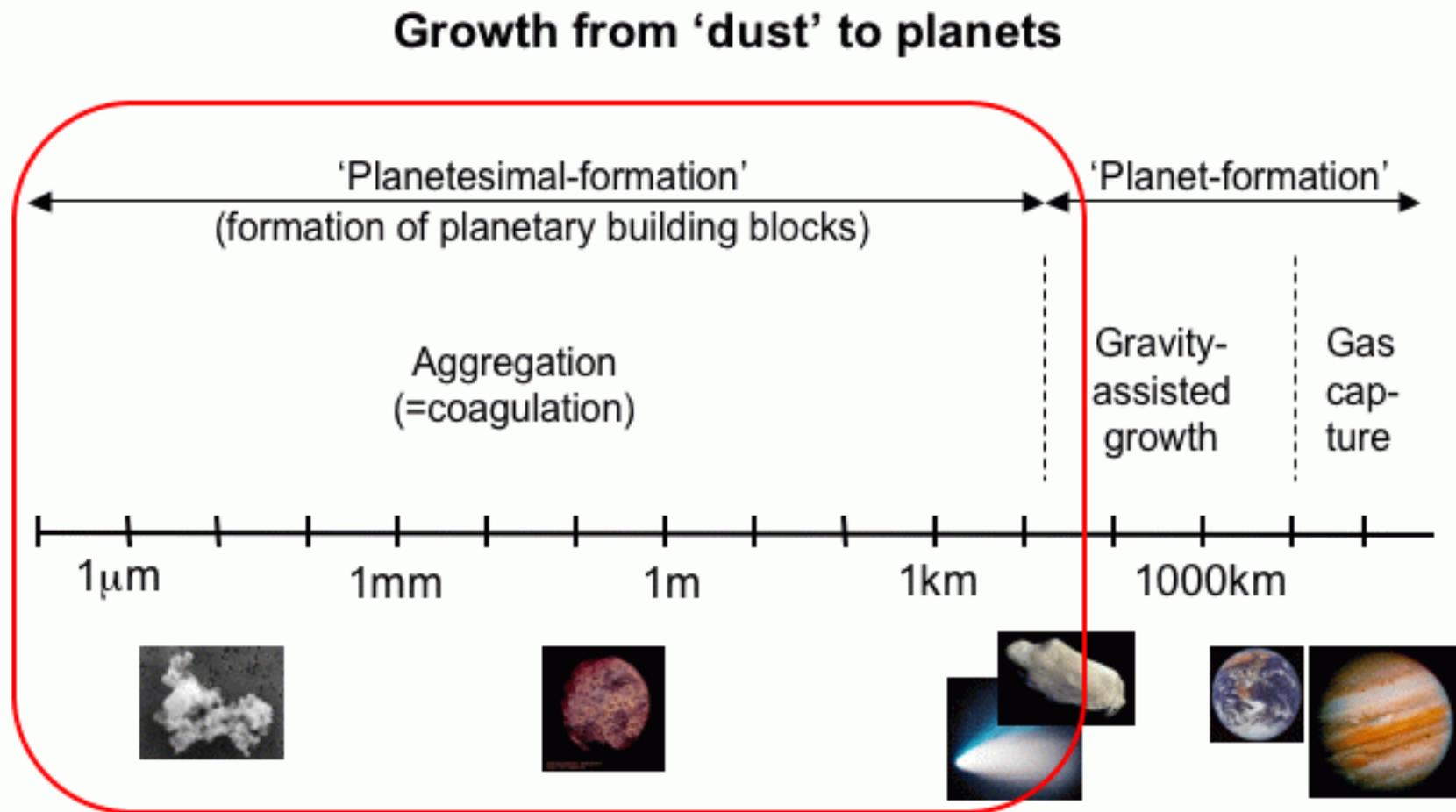


S. Andrews (Harvard-Smithsonian CfA), ALMA (ESO/NAOJ/NRAO)

Planeten

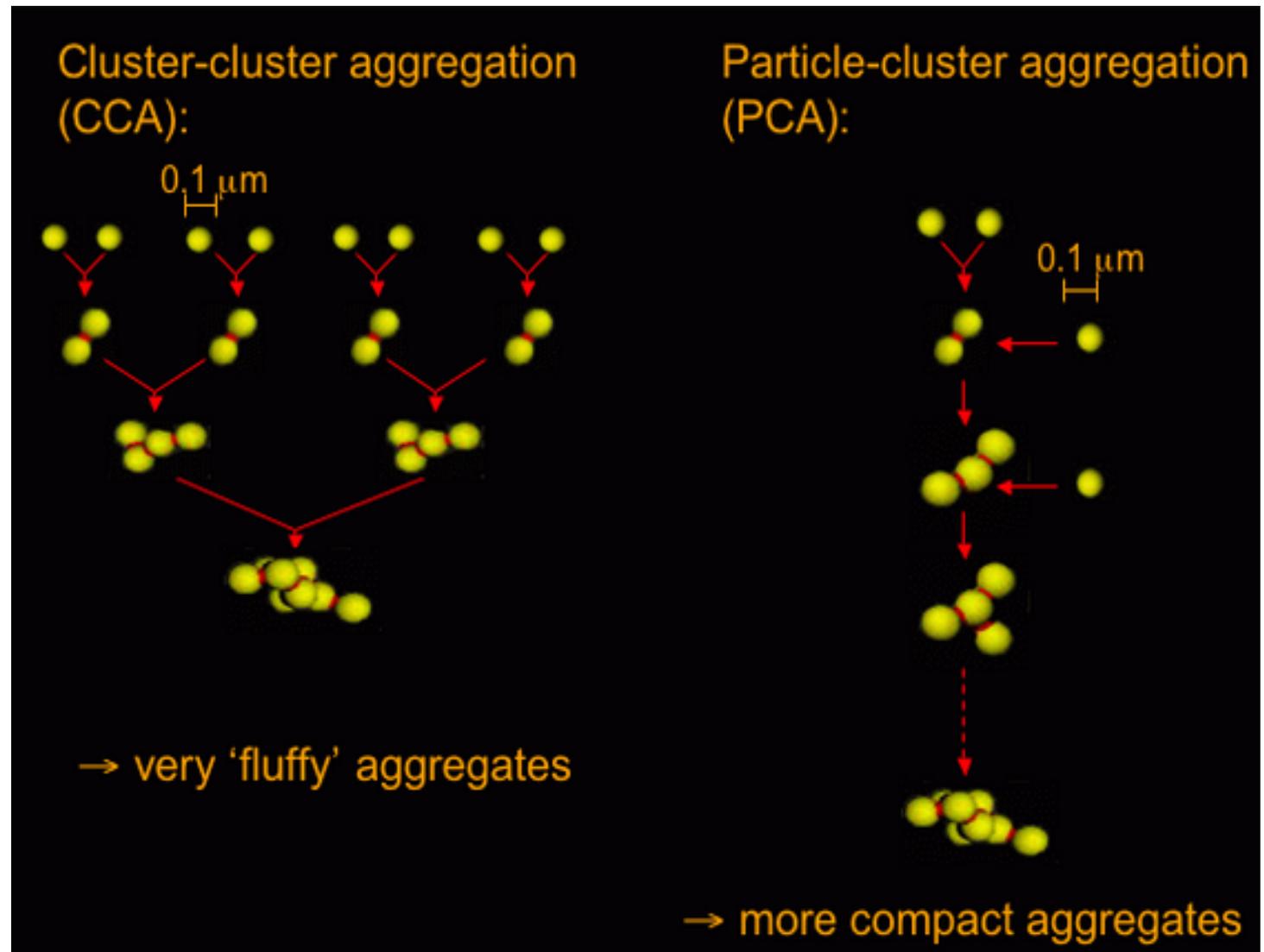
Anfang: Staub

Ende: Planet?



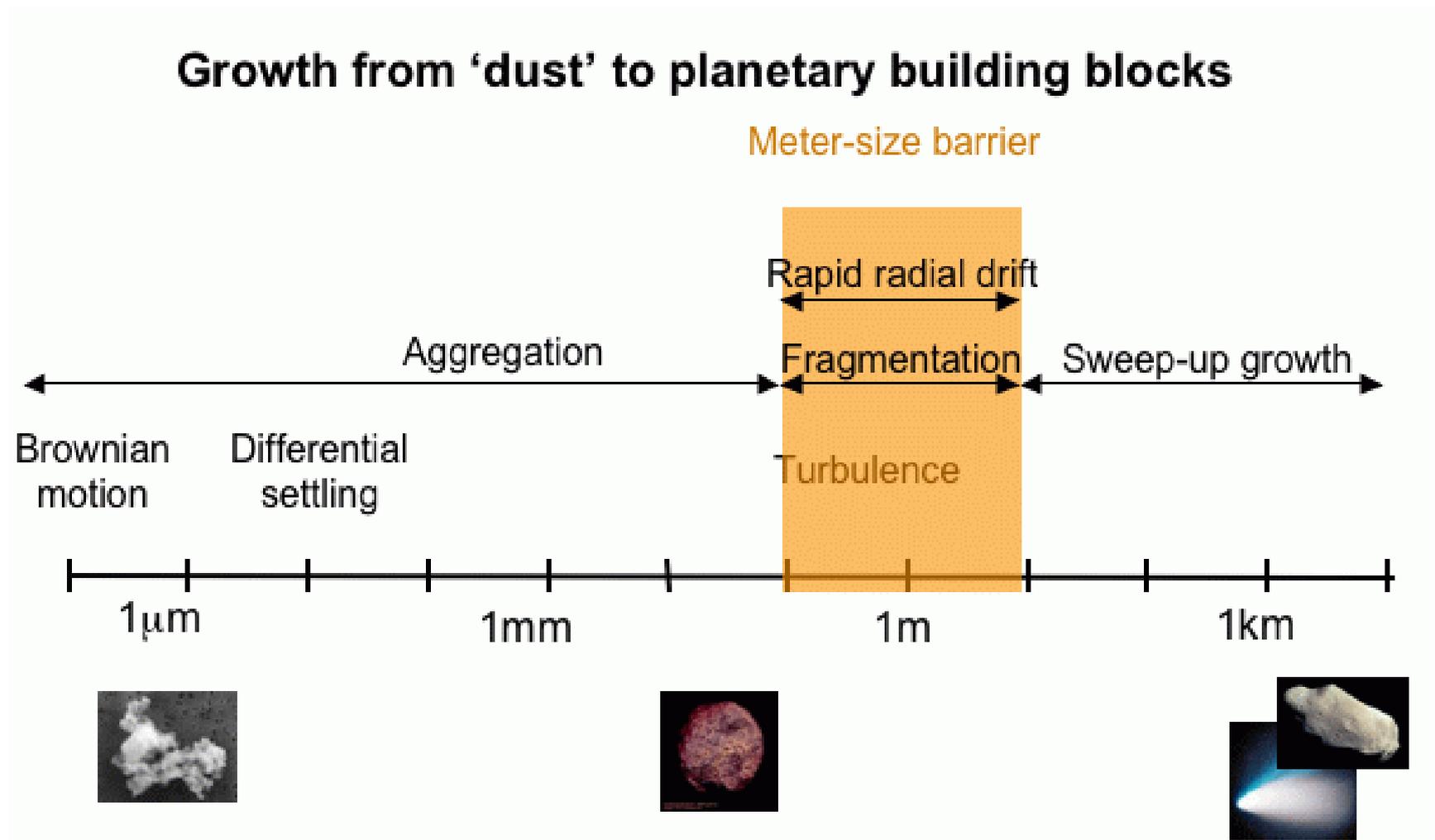
C. Dullemond (ZAH/MPIA)

“Klumpungswege”



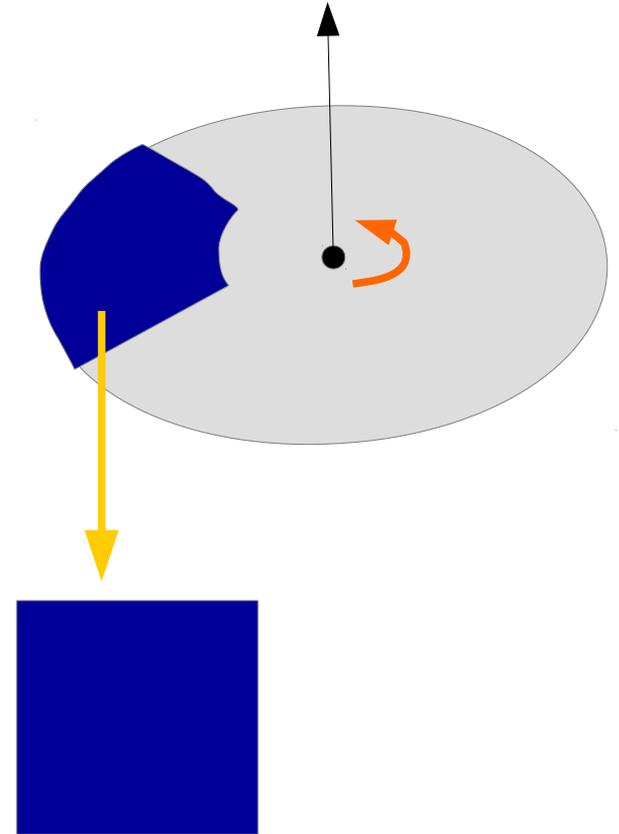
C. Dullemond (ZAH/MPIA)

Mikrometer bis Kilometer

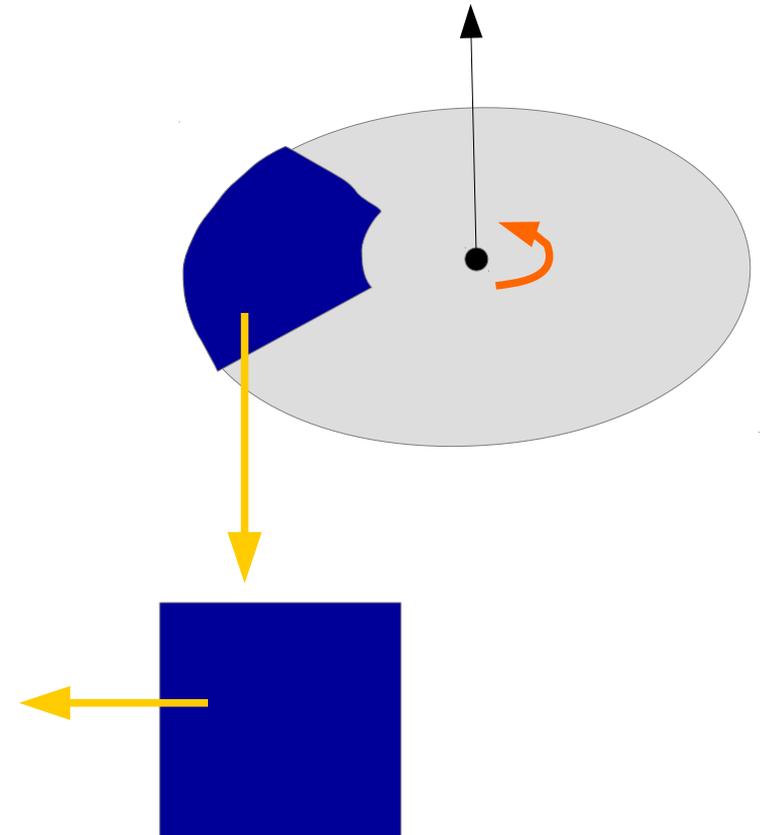
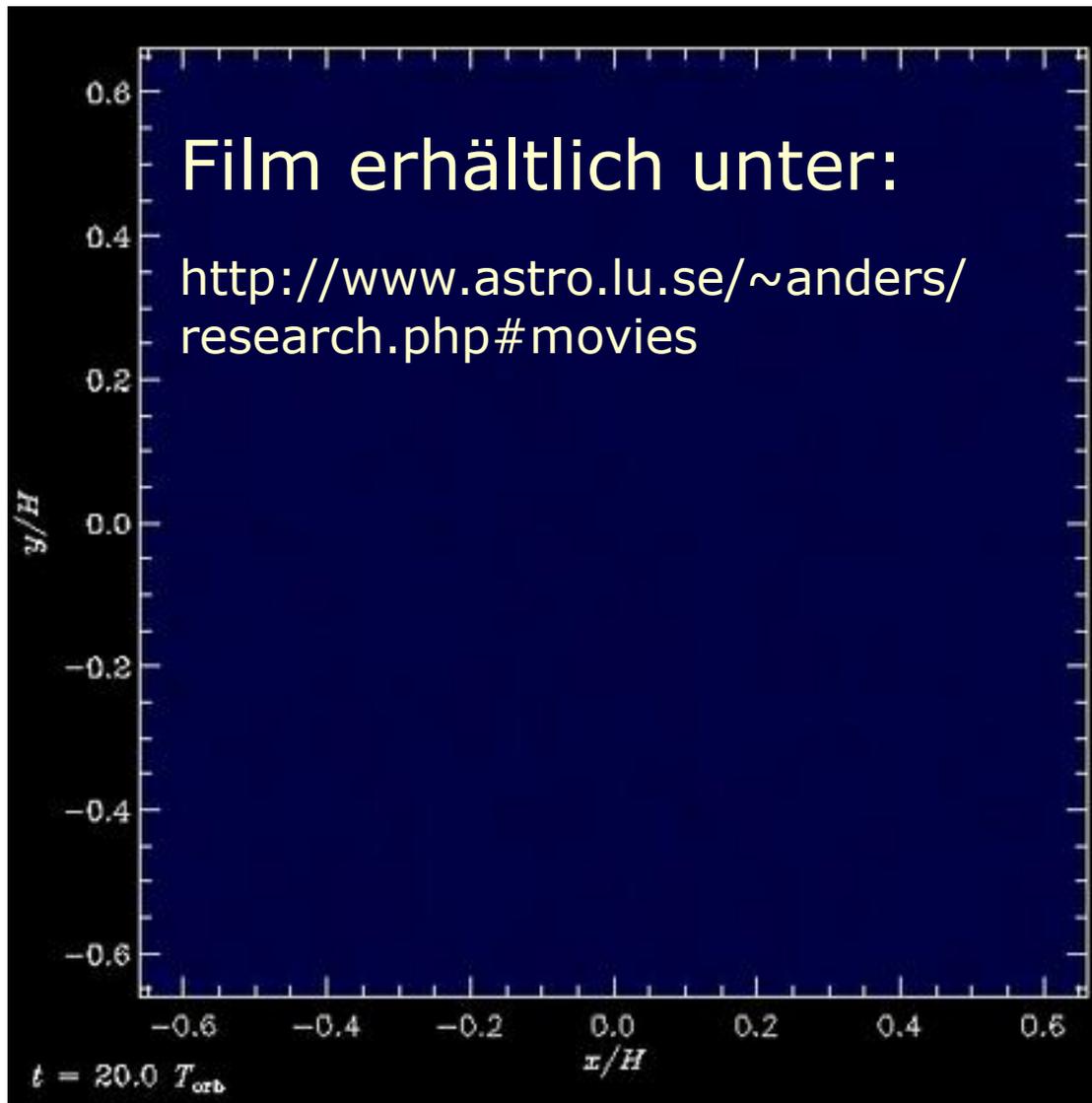


C. Dullemond (ZAH/MPIA)

Protoplanetare Scheiben

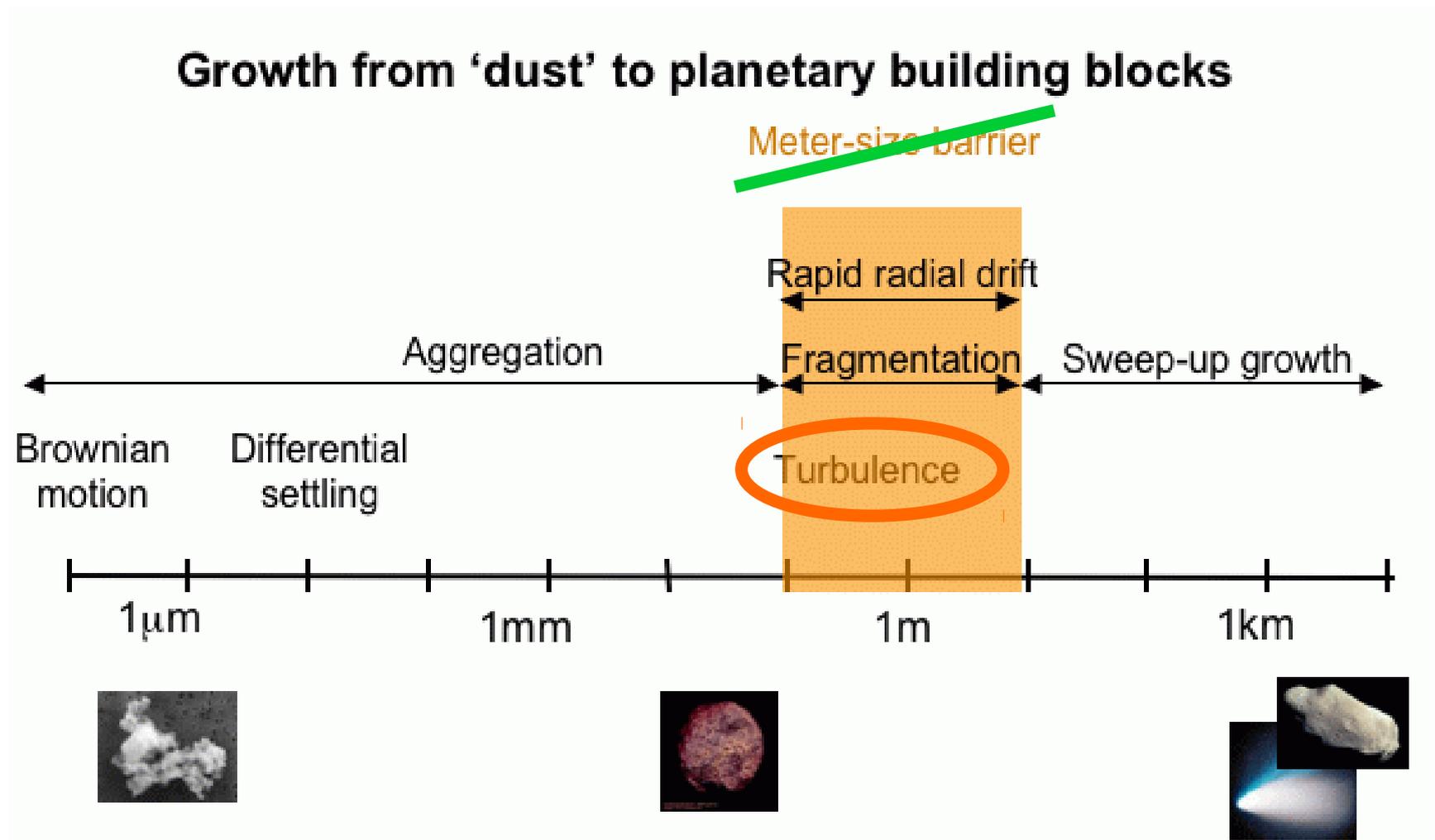


Protoplanetare Scheiben



A. Johansen (MPIA)

Mikrometer bis Kilometer



C. Dullemond (ZAH/MPIA)

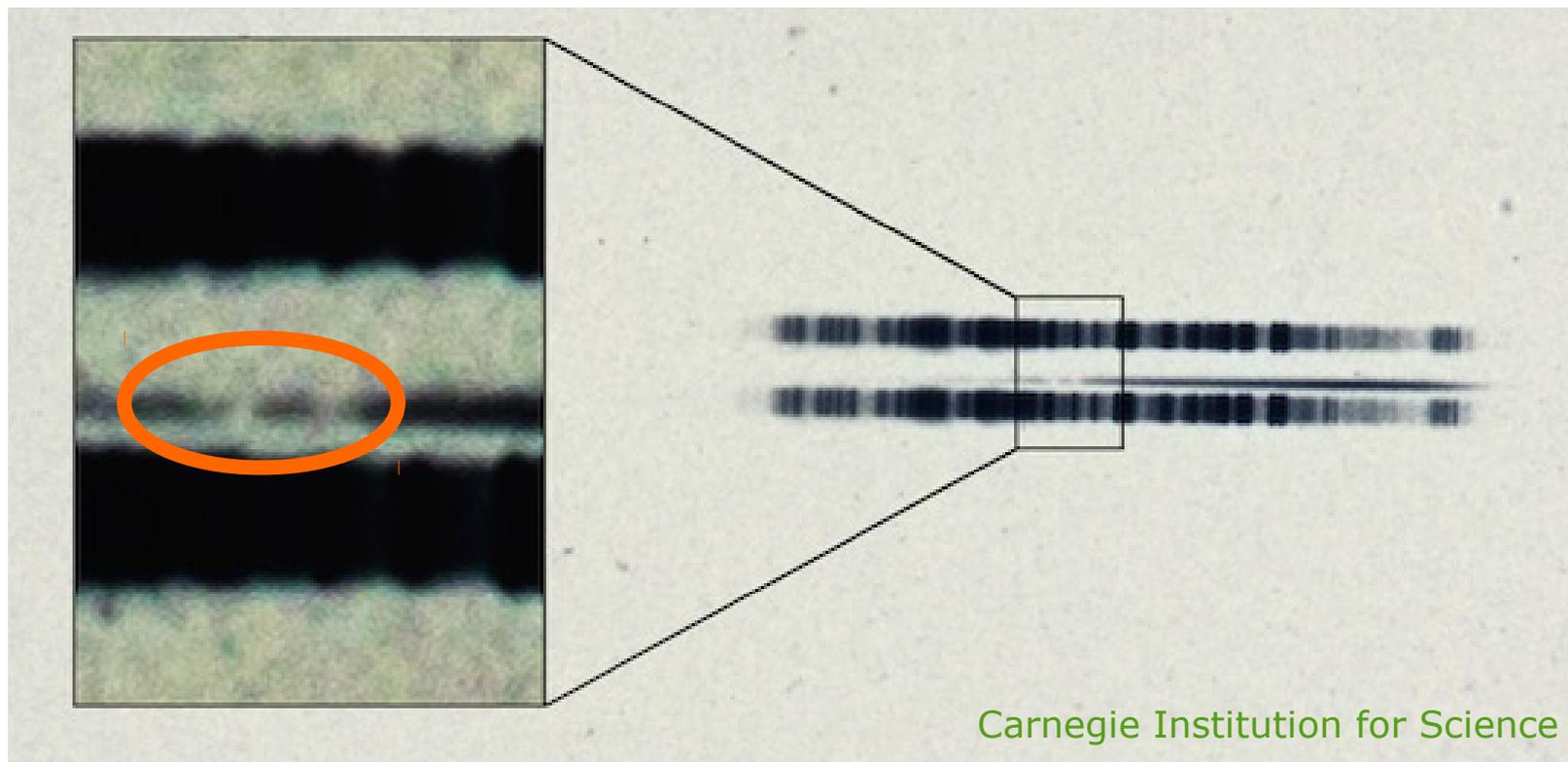
Andere Sterne, andere ... Planeten?

→ Exoplaneten

Exoplaneten

Ältester Nachweis: 24.10.1917 (erst 2016 erkannt!)

Spektrum: Absorption schwere Elemente um Weißen Zwerg → Hinweis auf einfallende Gesteinsbrocken → bewegt durch Planet



Exoplaneten

Systematische Suche: ab 1988

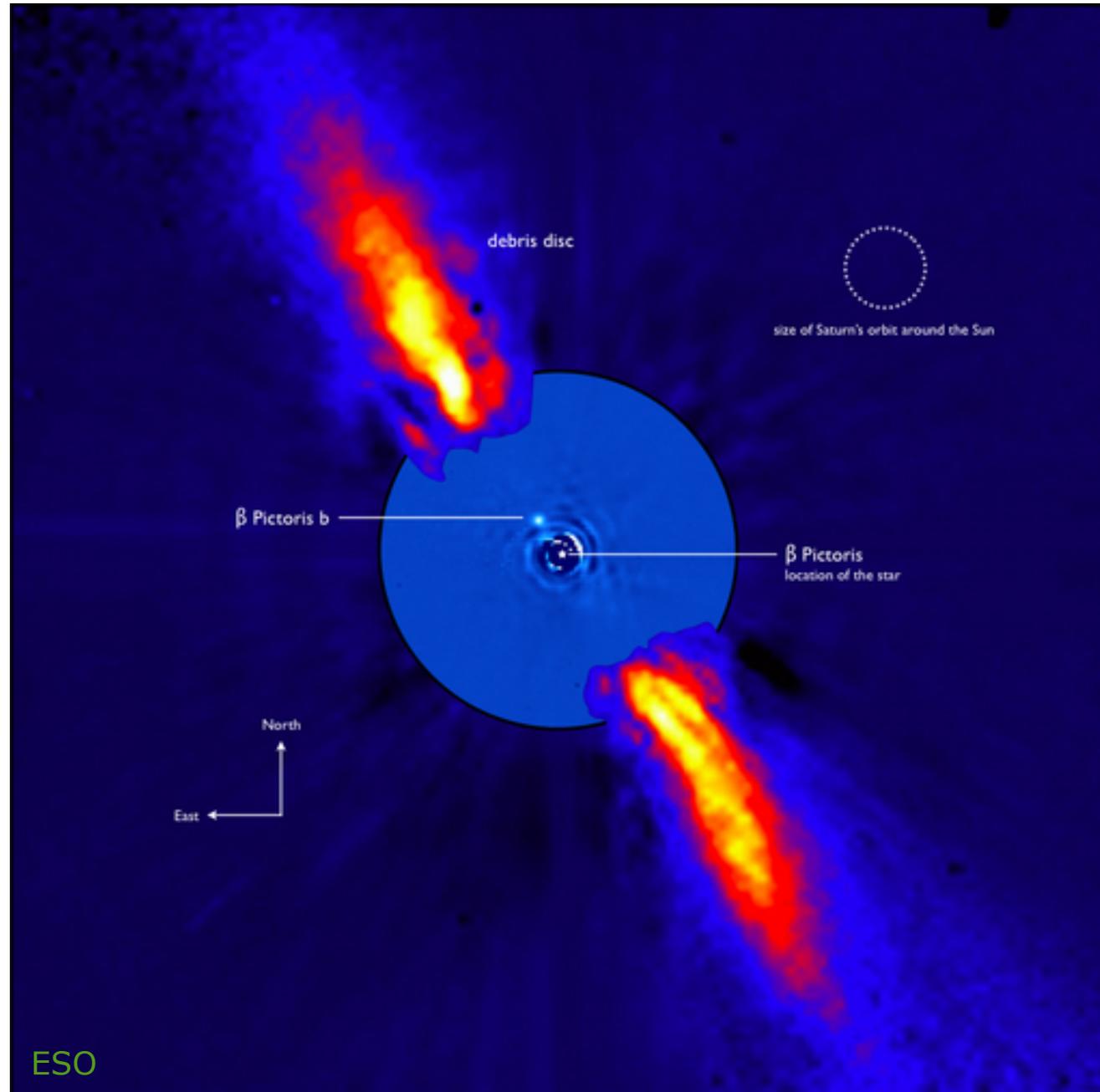
Erster Fund: 1992, Planet um Pulsar

1995, Planet um Hauptreihenstern



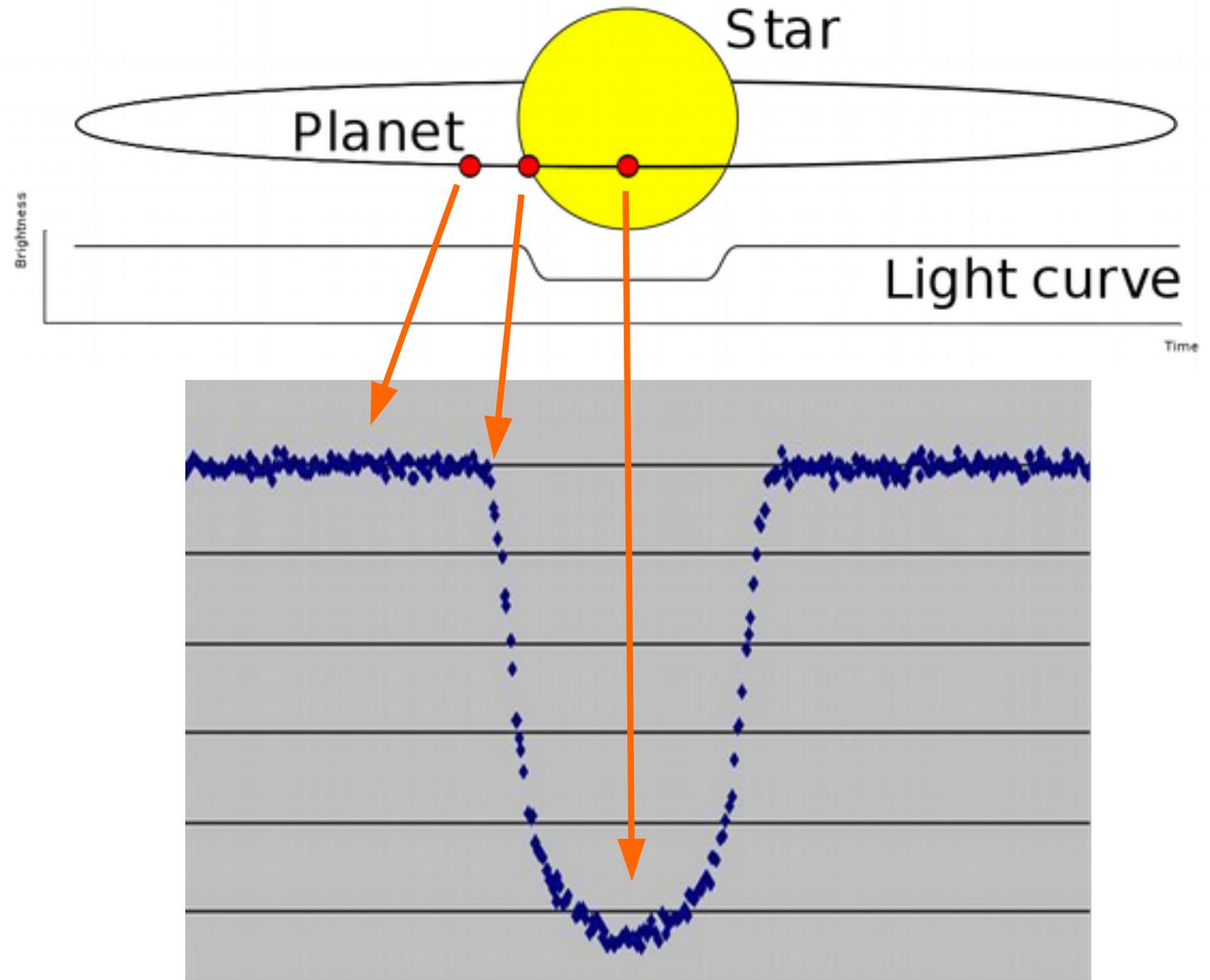
ESO/Beletsky

Direktbilder



Exoplaneten: Methoden

Bedeckung



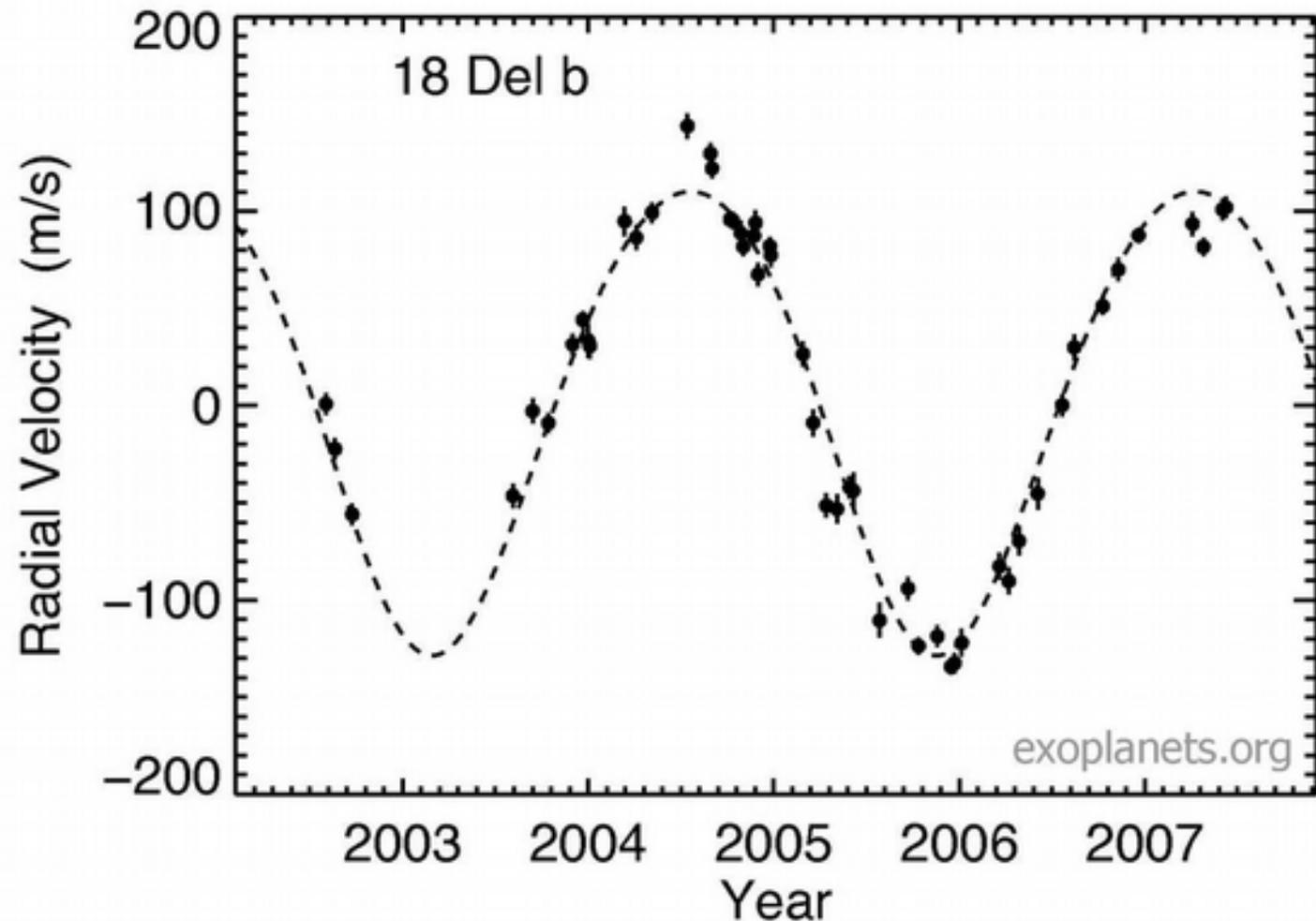
Exoplaneten: Methoden

Variationen der Radialgeschwindigkeit zu Stern

dv Sonne:

Jupiter: 13 m/s

Erde: 9 **cm/s**



Exoplaneten

Andere Sterne, andere ... Planeten?

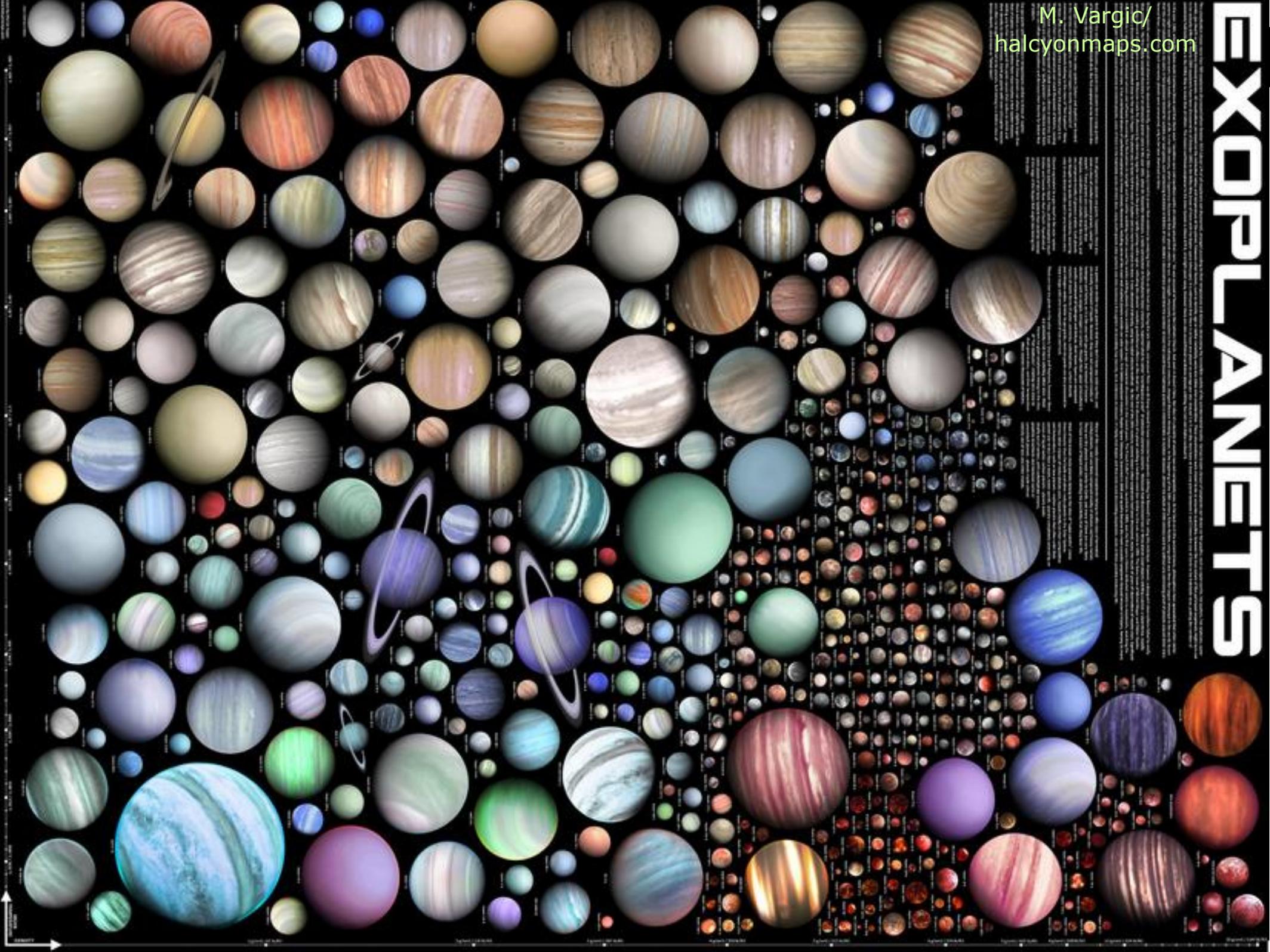
→ Exoplaneten

1988–95: erste bestätigte Nachweise

Heute:

3671 Exoplaneten in 2751 Sternsystemen
(Stand 1.10.2017)

EXOPLANETS



EXOPLANETS

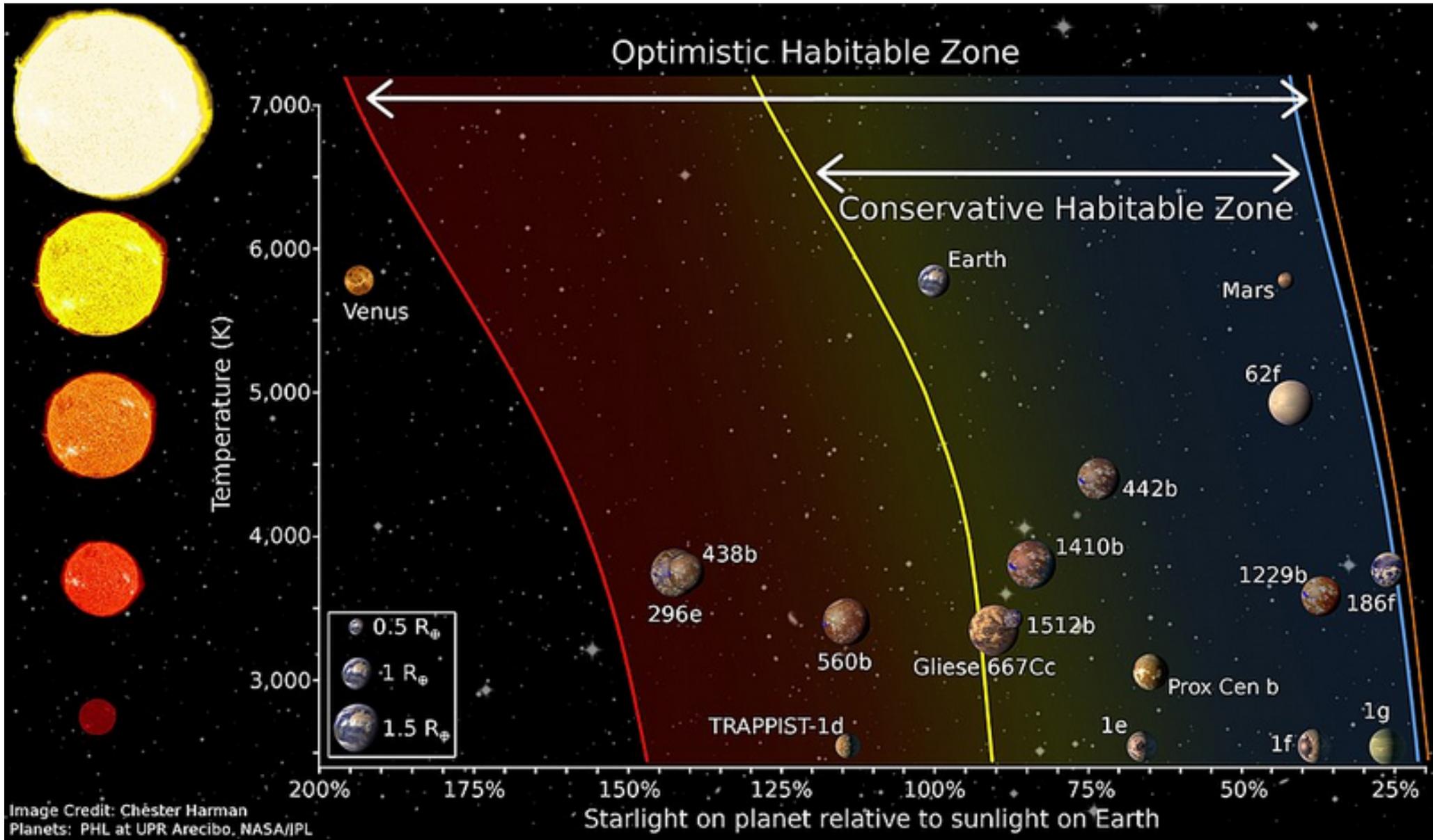
As of 2012, more than 1,000 exoplanets have been discovered. The first exoplanet was discovered in 1992, orbiting the pulsar PSR B1509-58. The first exoplanet orbiting a main-sequence star was discovered in 1995, orbiting the star 51 Pegasi. Since then, the number of discovered exoplanets has grown rapidly, and the diversity of their characteristics has increased. Exoplanets have been found in a wide range of sizes, from small rocky planets to large gas giants. They have been found in a variety of orbits, from close to their host stars to far beyond. Some exoplanets have atmospheres, and some have ring systems. The discovery of exoplanets has opened up a new field of research, and we are beginning to learn more about the diversity of planets in our galaxy.

EXOPLANETS

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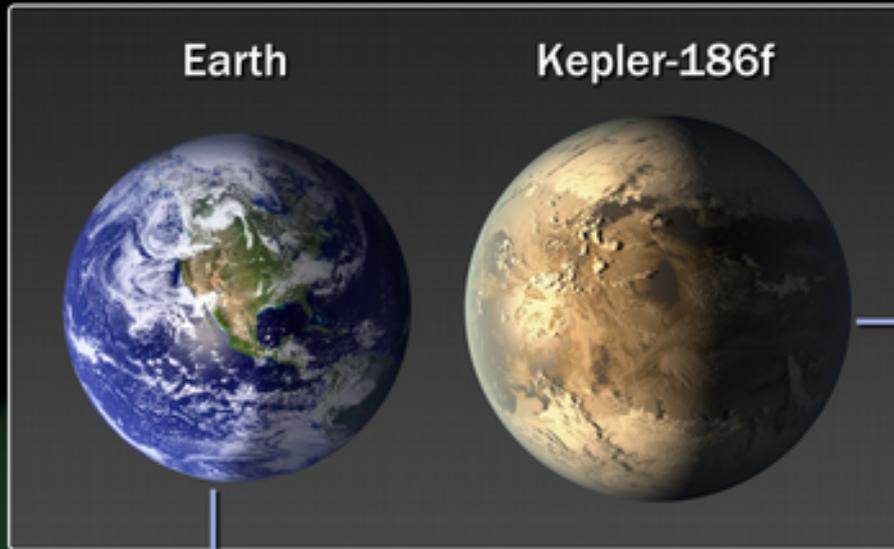
Exoplaneten: erdähnlich?

“Habitable Zone”

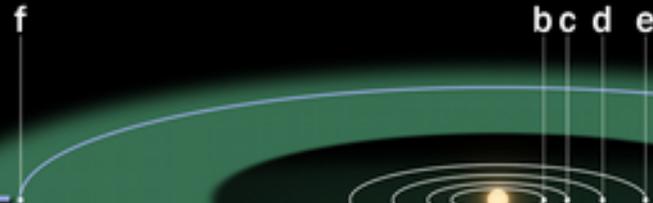


Exoplaneten: erdähnlich?

Größe + Abstand



Kepler-186 System



Solar System

Earth Venus Mercury

The diagram shows a central yellow star with three concentric elliptical orbits. The orbits are labeled 'Earth', 'Venus', and 'Mercury' from outermost to innermost. A blue line connects the 'Earth' orbit to the Earth/Kepler-186f inset.

Planets and orbits to scale

Exoplaneten: erdähnlich → bald?

Heiliger Gral: erdähnlich, muss noch gefunden werden

→ Atmosphäre?

→ Wasser?

→ Leben?

→ intelligentes Leben?

→ jemals Kontaktaufnahme?

→ jemals Besuche?

(und: schaffen wir es bis dahin...)

Zusammenfassung

- Planeten: angeleuchtet von Zentralstern, dominant auf Umlaufbahn (→ nicht Pluto)
- Entstehung aus Staub mit Klumpung, Turbulenz, Ansammlung → Planetesimale, Mikrometer bis Kilometer in protoplanetarer Scheibe
- Exoplaneten bekannt seit 1992, jetzt >3000
- Suche geht weiter; ein Ziel: "erdähnlich" + Leben