

Exoplaneter



Hans Kjeldsen

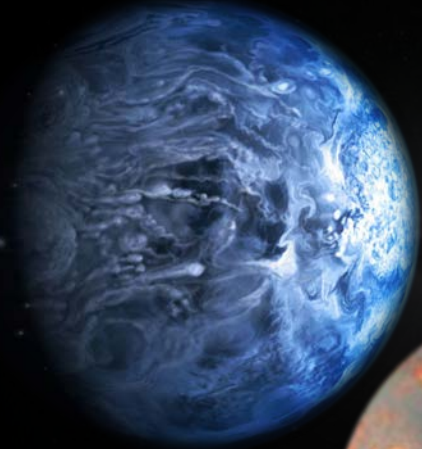
Institut for Fysik og Astronomi, Aarhus Universitet

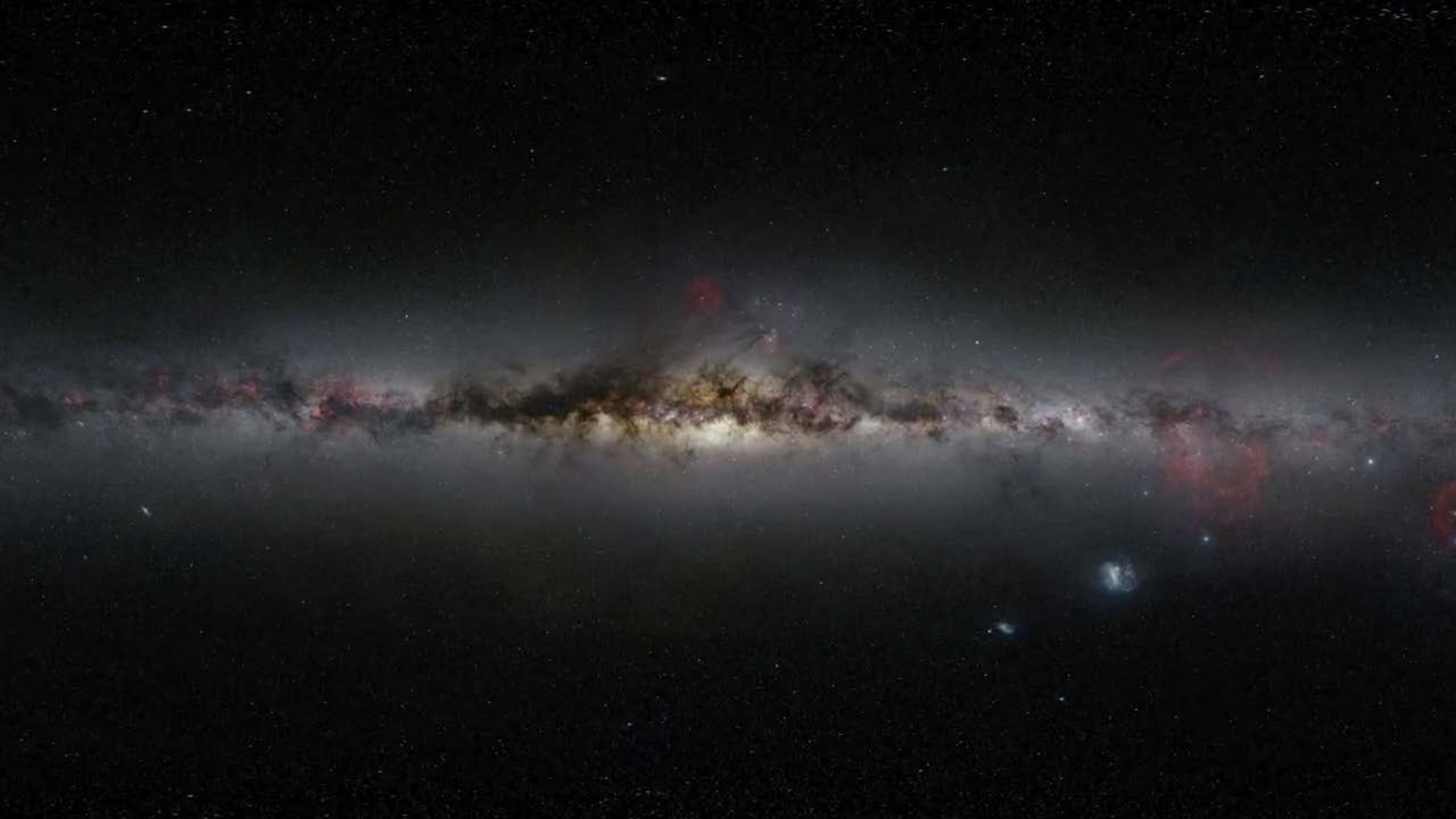


STELLAR ASTROPHYSICS CENTRE

Den første exoplanet blev fundet i 1995.

I dag kender vi flere tusinde exoplaneter
og de er meget forskellige.







Synligt





Infrarødt

M16



Optical (NOAO)

M16



Near-Infrared (Spitzer)

M16



Far-Infrared (Herschel)

M16



Optical (NOAO)

M16



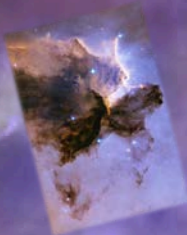
Optical (NOAO)

M16



Far-Infrared (Herschel)

M16

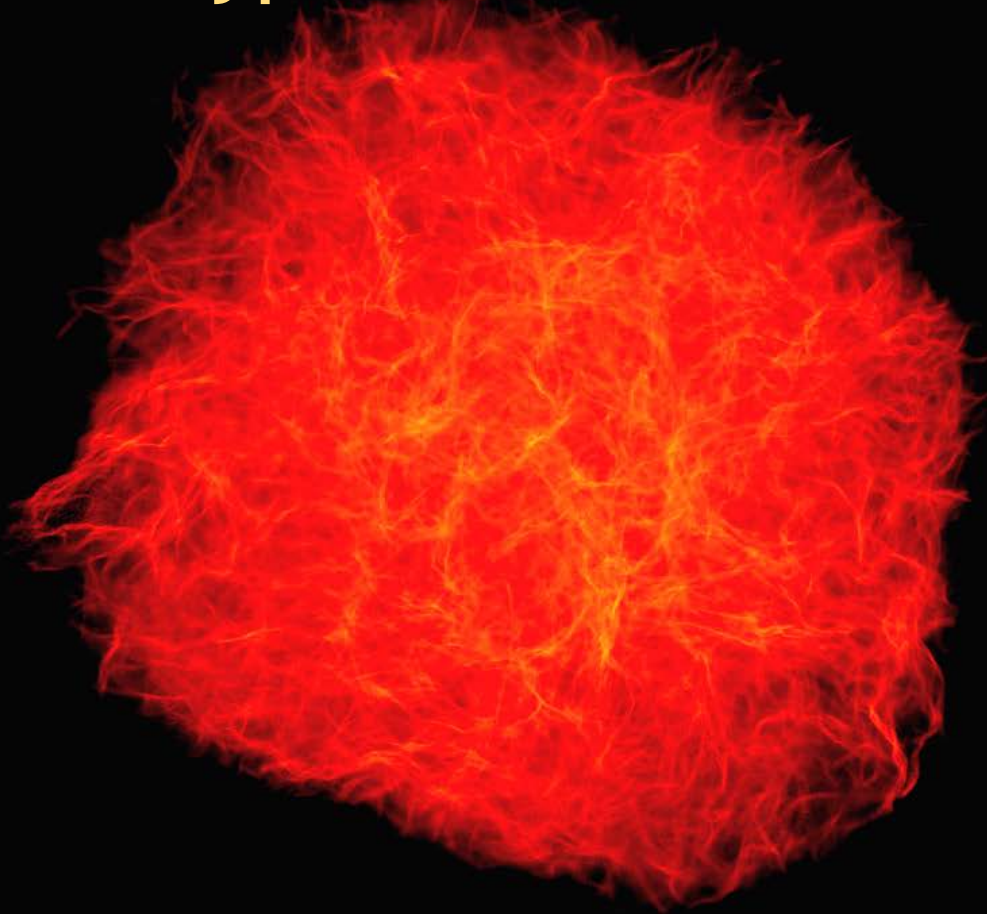


Far-Infrared (Herschel)



$$F = G \frac{m_1 m_2}{r^2}$$

Nye stjerner og planeter dannes



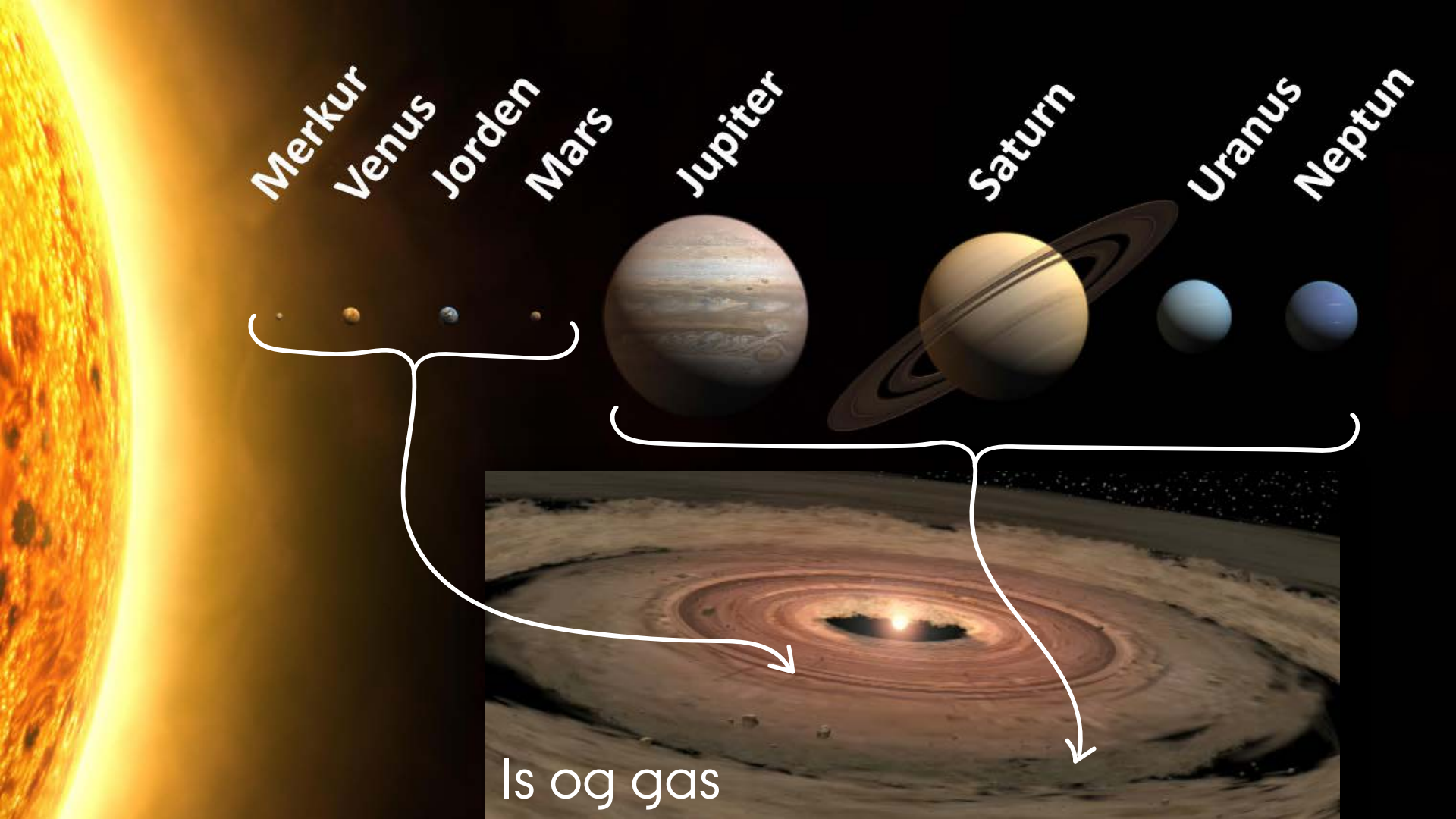
Computer-animation: 285.000 år på 1 minut

Solsystemet for 4,568 mia. år siden



Solsystemet for 4,568 mia. år siden





Merkur

Venus

Jorden

Mars

Jupiter

Saturn

Uranus

Neptun

Is og gas

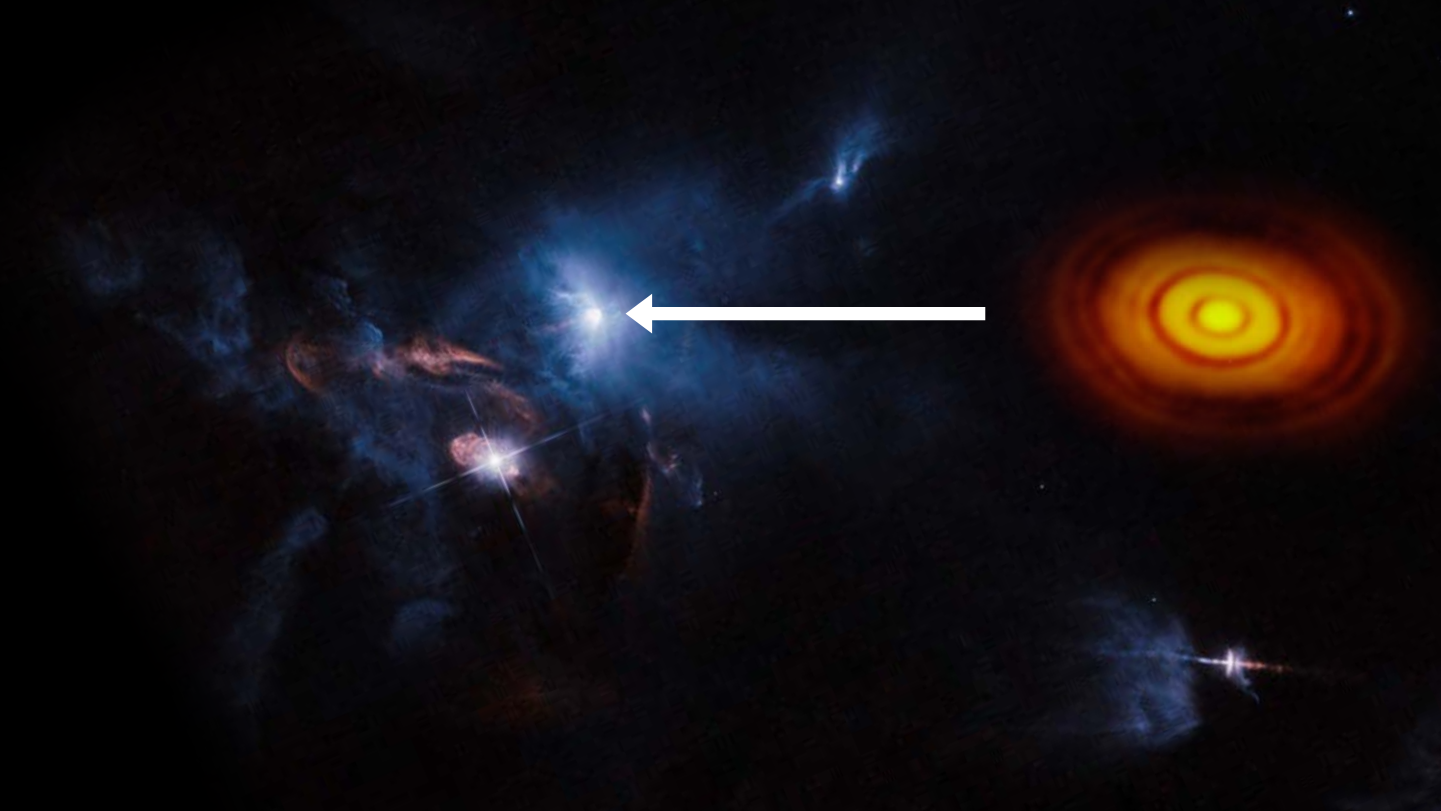
Stjernen HL Tauri

Afstand: 450 lysår

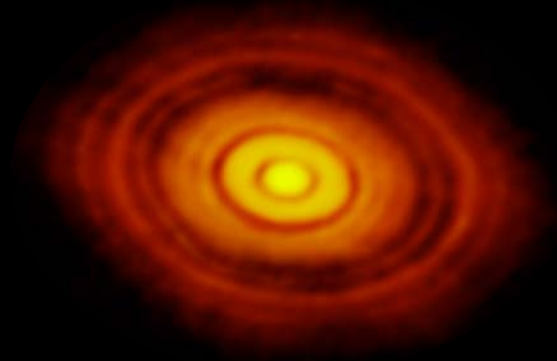
Nydannet stjerne

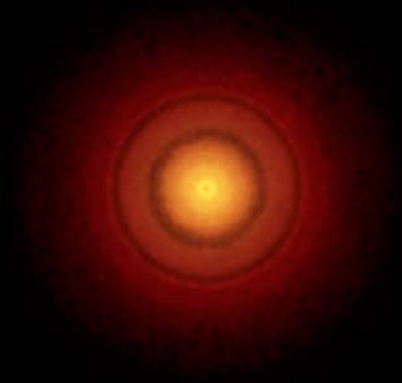


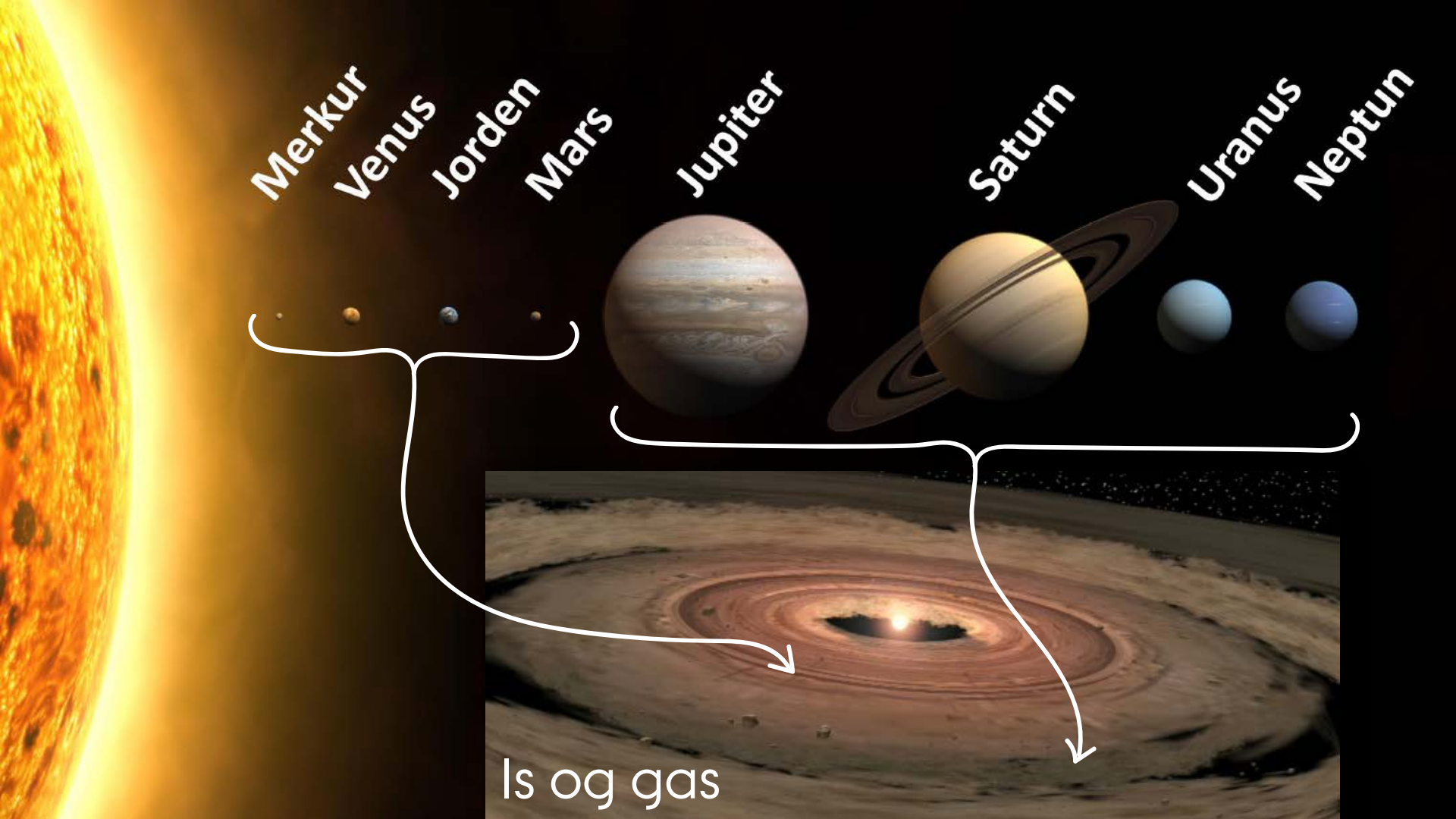
Stjernen HL Tauri: observeret med ALMA (ESO)



Stjernen HL Tauri: observeret med ALMA (ESO)







Merkur

Venus

Jorden

Mars

Jupiter

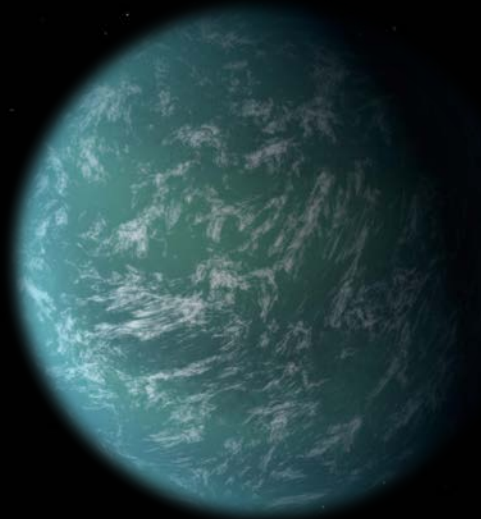
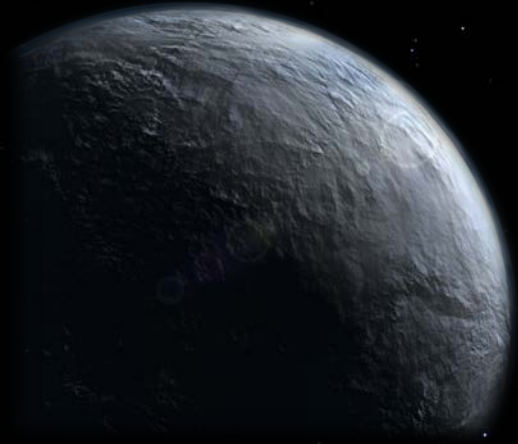
Saturn

Uranus

Neptun

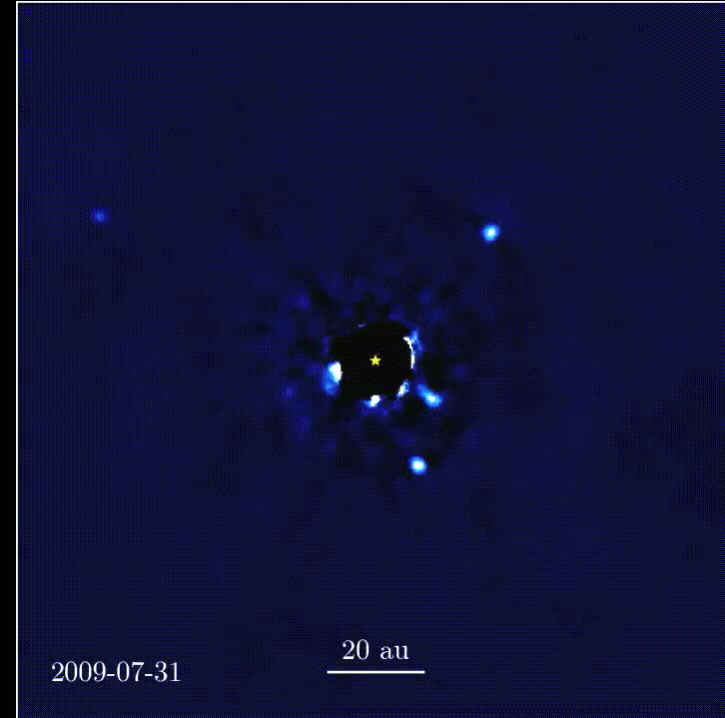
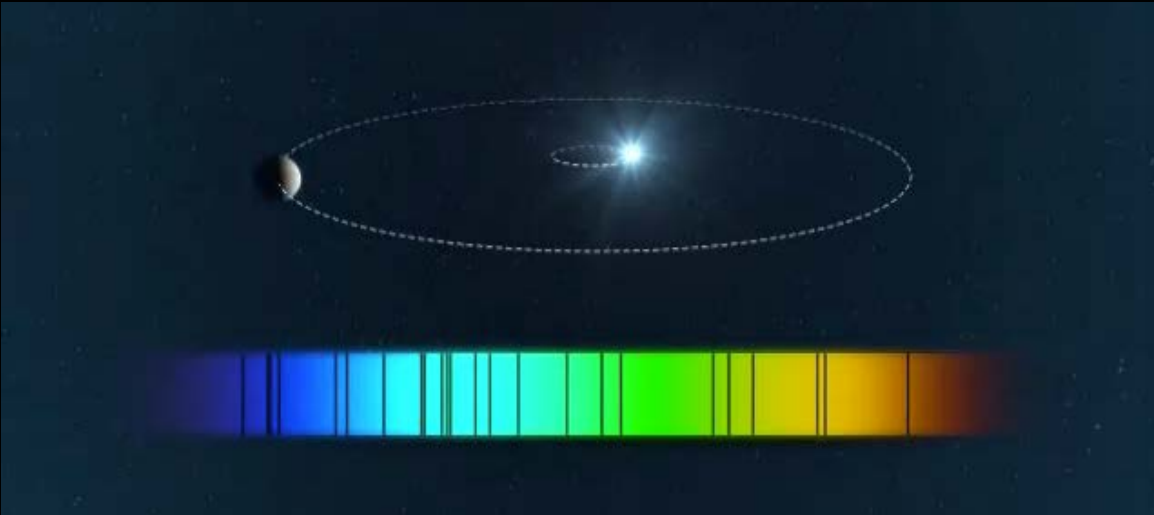
Is og gas

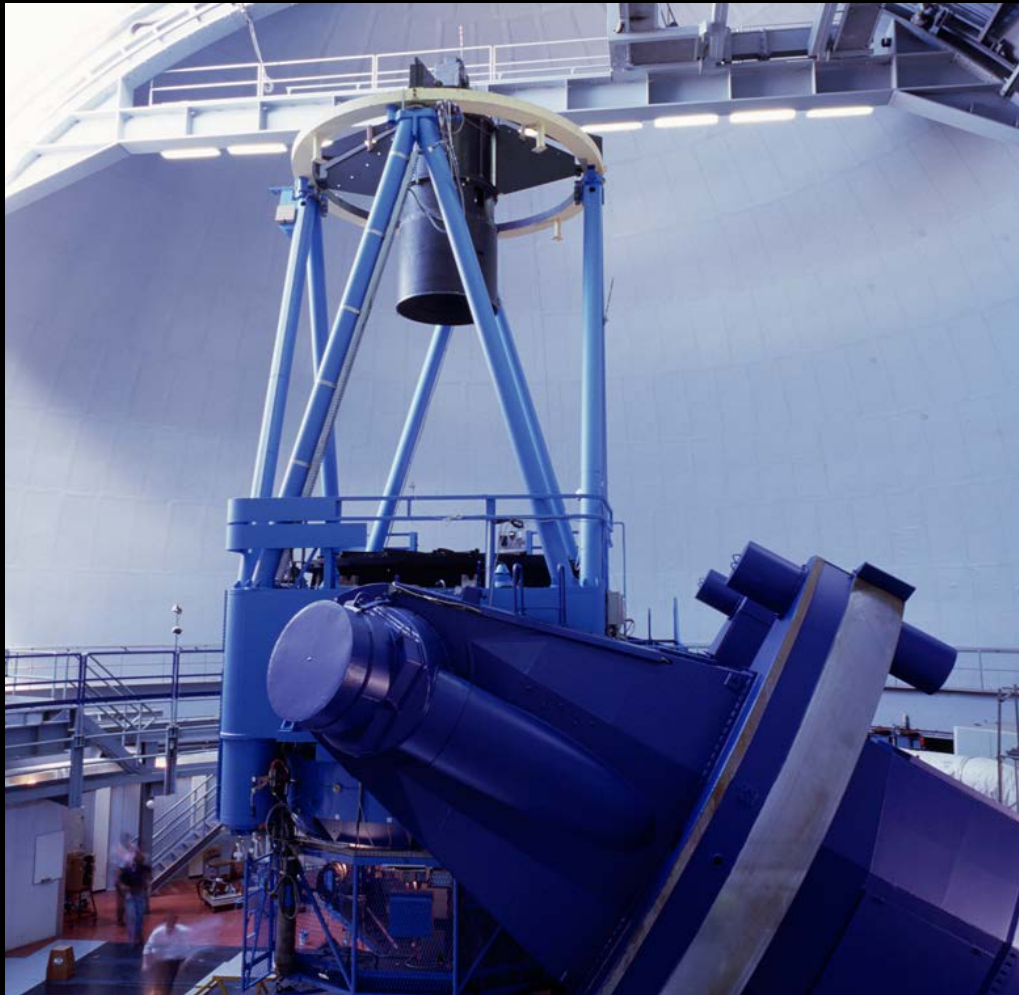
Nye typer af planeter...



Teknikker til at finde planeter

- Direkte billeder
- Tyngdekraften (radialhastigheden)
- Planetpassager (skyggen)





Måling af
radialhastigheden for en
given stjerne kan afsløre
eksistensen af en
exoplanet.

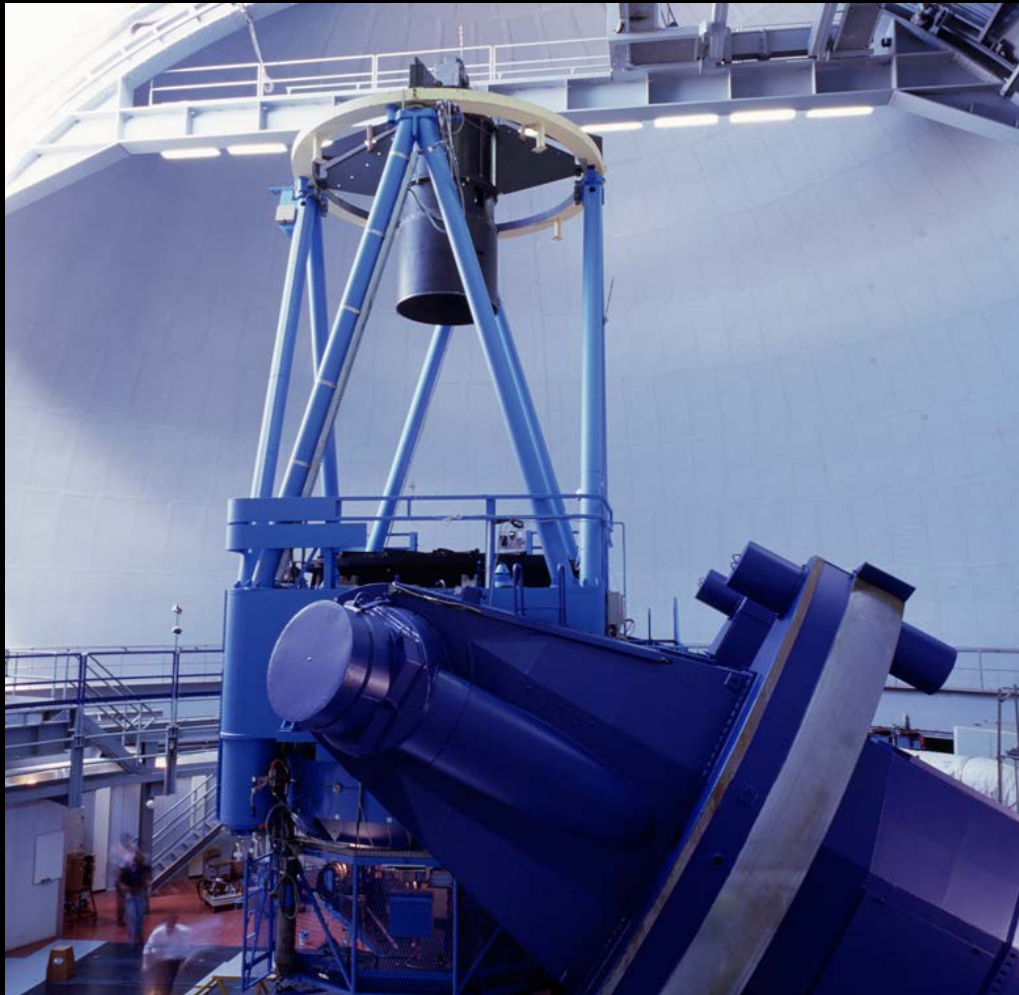
Amplituden af stjernens
bevægelse afhænger af
planetens masse.



Måleudstyr

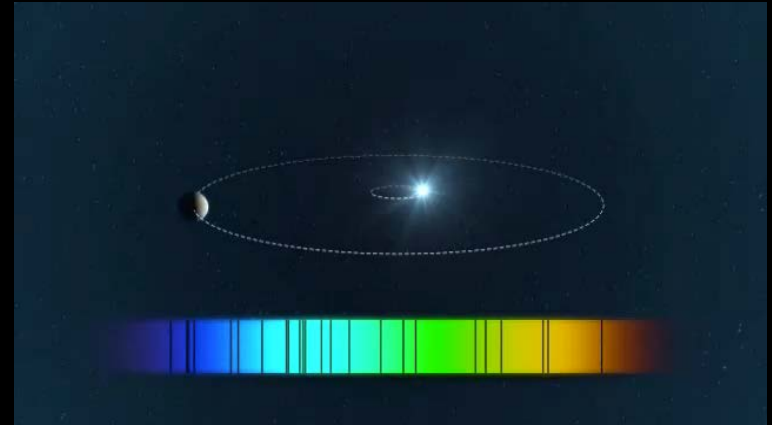
Måling af radialhastigheden for en given stjerne kan afsløre eksistensen af en exoplanet.

Amplituden af stjernens bevægelse afhænger af planetens masse.



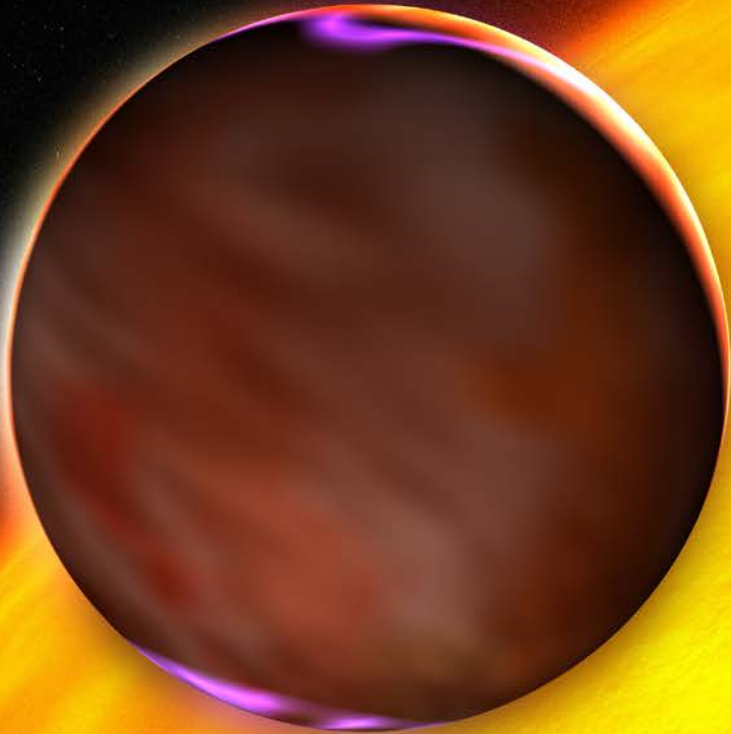
Måling af
radialhastigheden for en
given stjerne kan afsløre
eksistensen af en
exoplanet.

Amplituden af stjernens
bevægelse afhænger af
planetens masse.



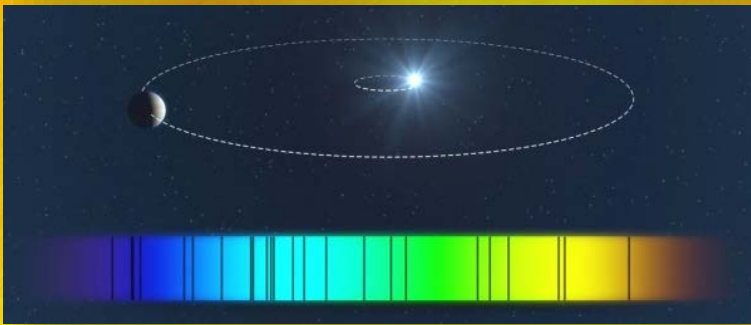
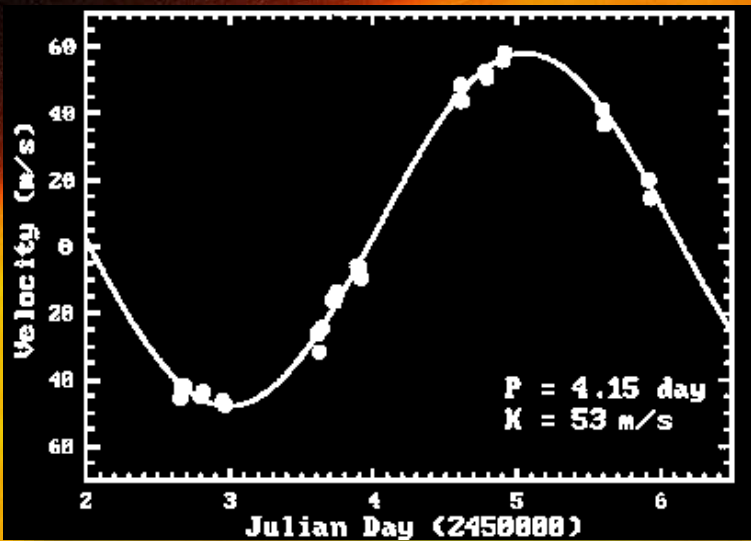
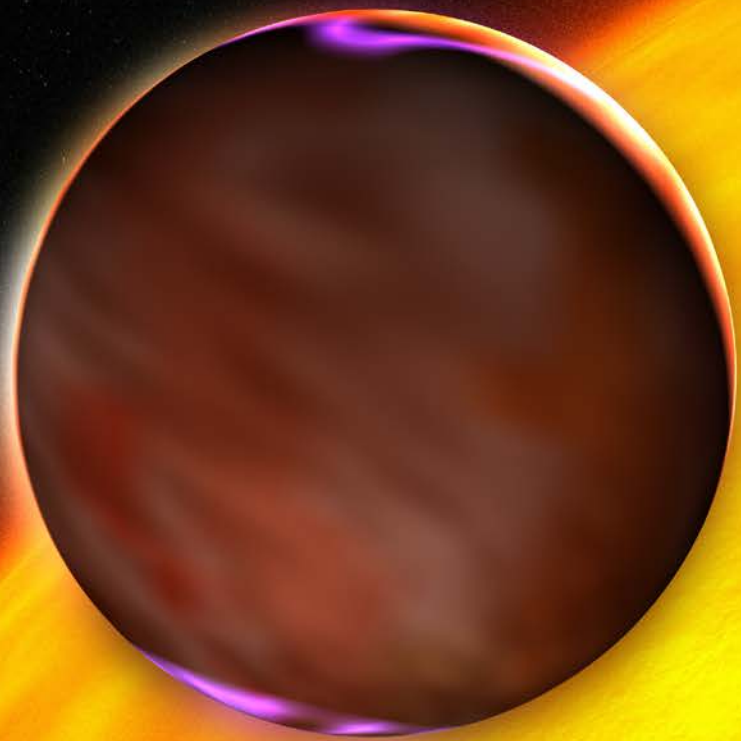
Stjernen 51 Pegasi: Opdagelsen af den første exoplanet

En stjerne af Solens type og alder



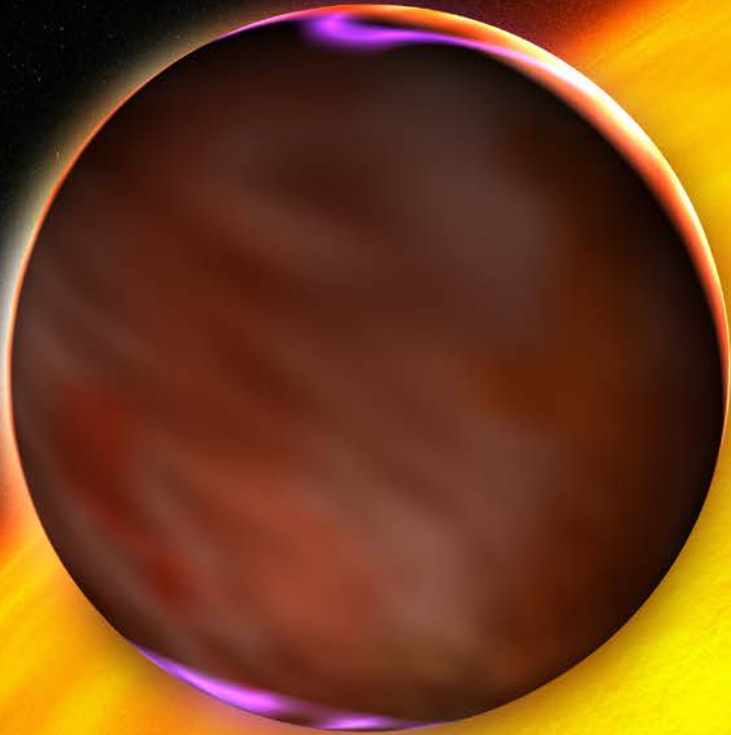
Stjernen 51 Pegasi

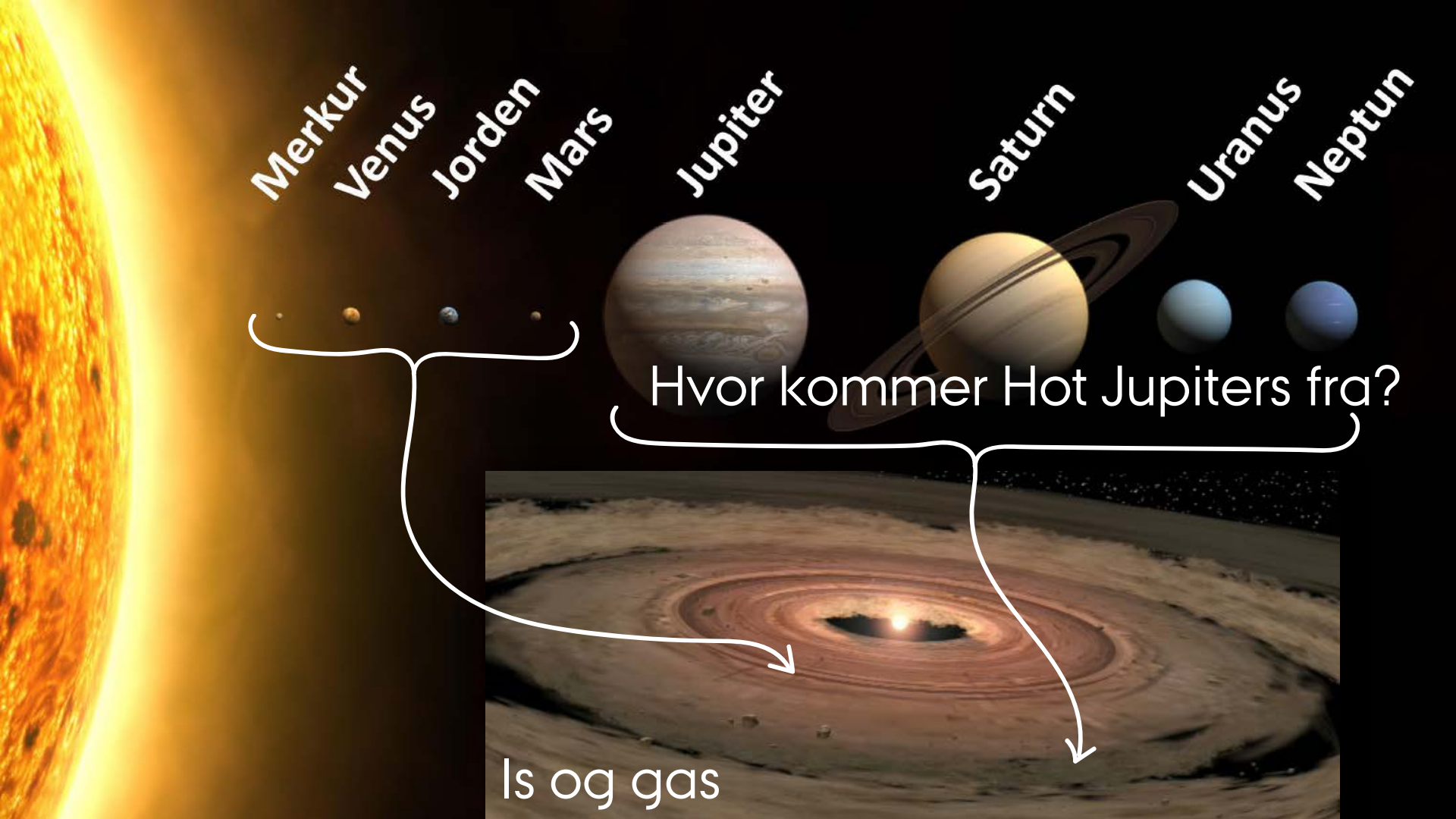
En stjerne af Solens type og alder



Planeten 51 Pegasi b (1995)

En såkaldt Hot Jupiter-planet





Merkur

Venus

Jorden

Mars

Jupiter

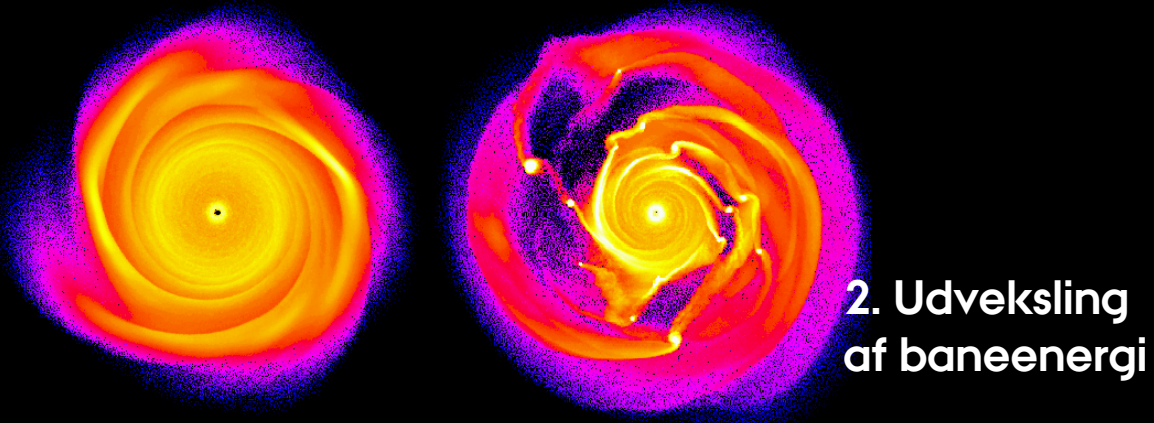
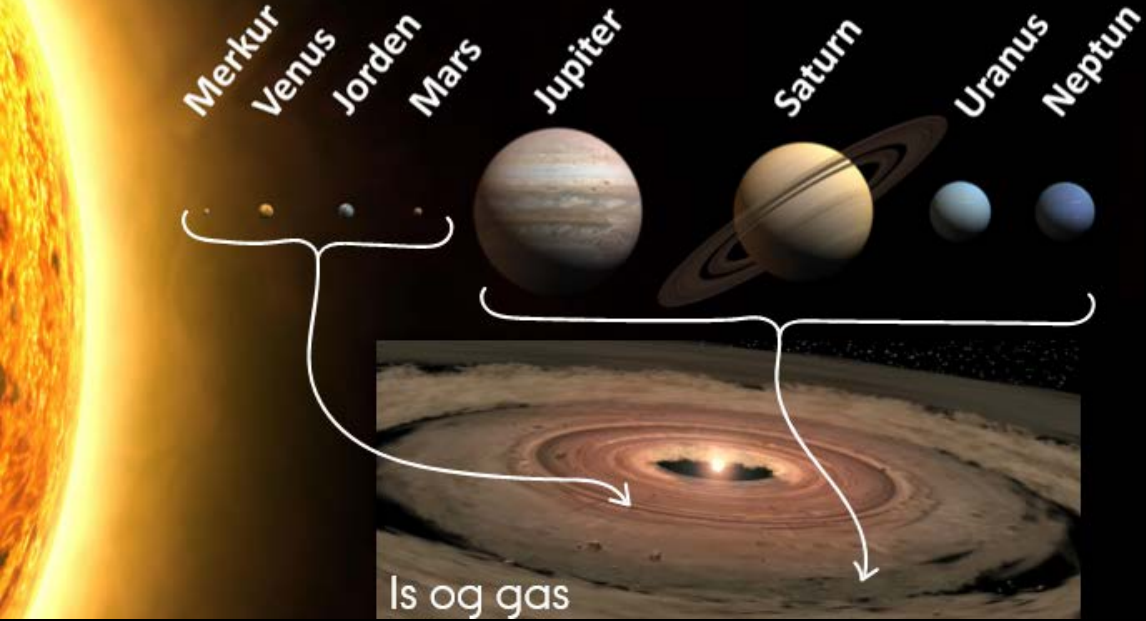
Saturn

Uranus

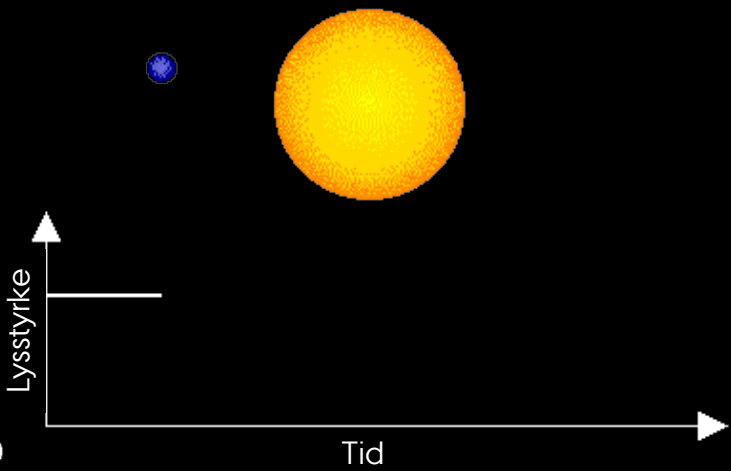
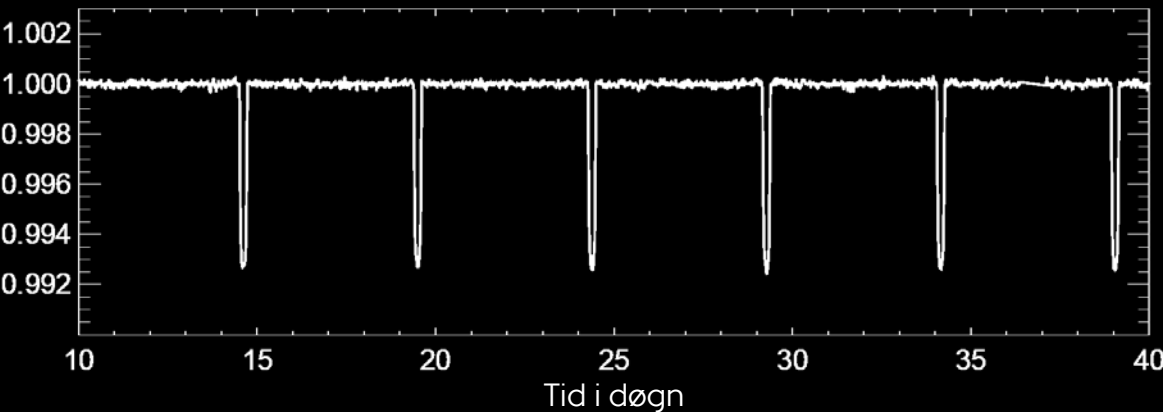
Neptun

Hvor kommer Hot Jupiters fra?

Is og gas

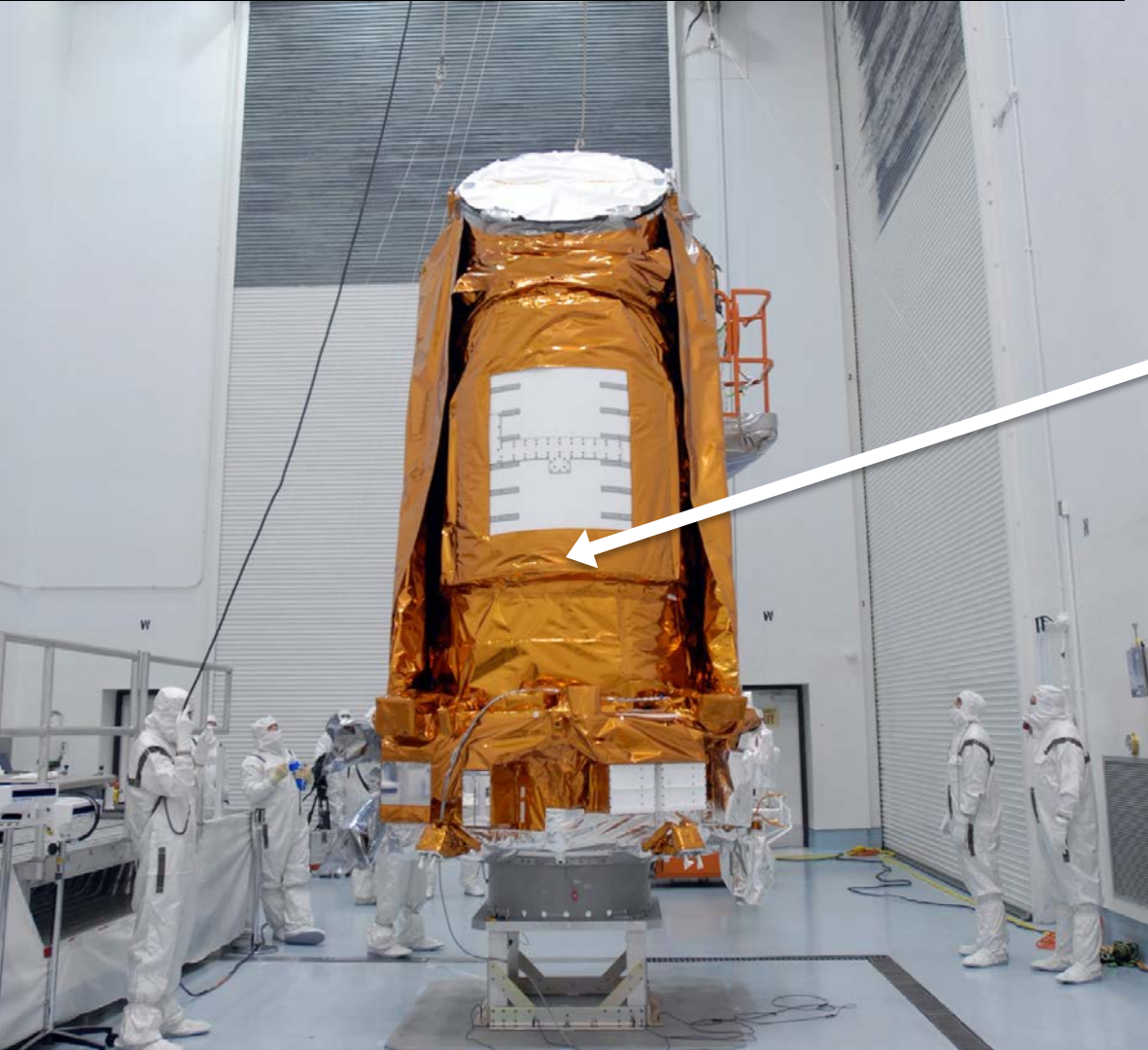


Passageteknikken



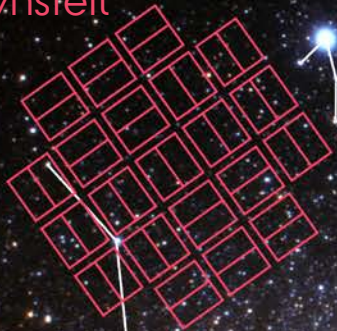


Opsendt i 2009



**Keplerteleskopets
lysfølsomme detektorer**

Keplerteleskopets
synsfelt



Vega

LYREN

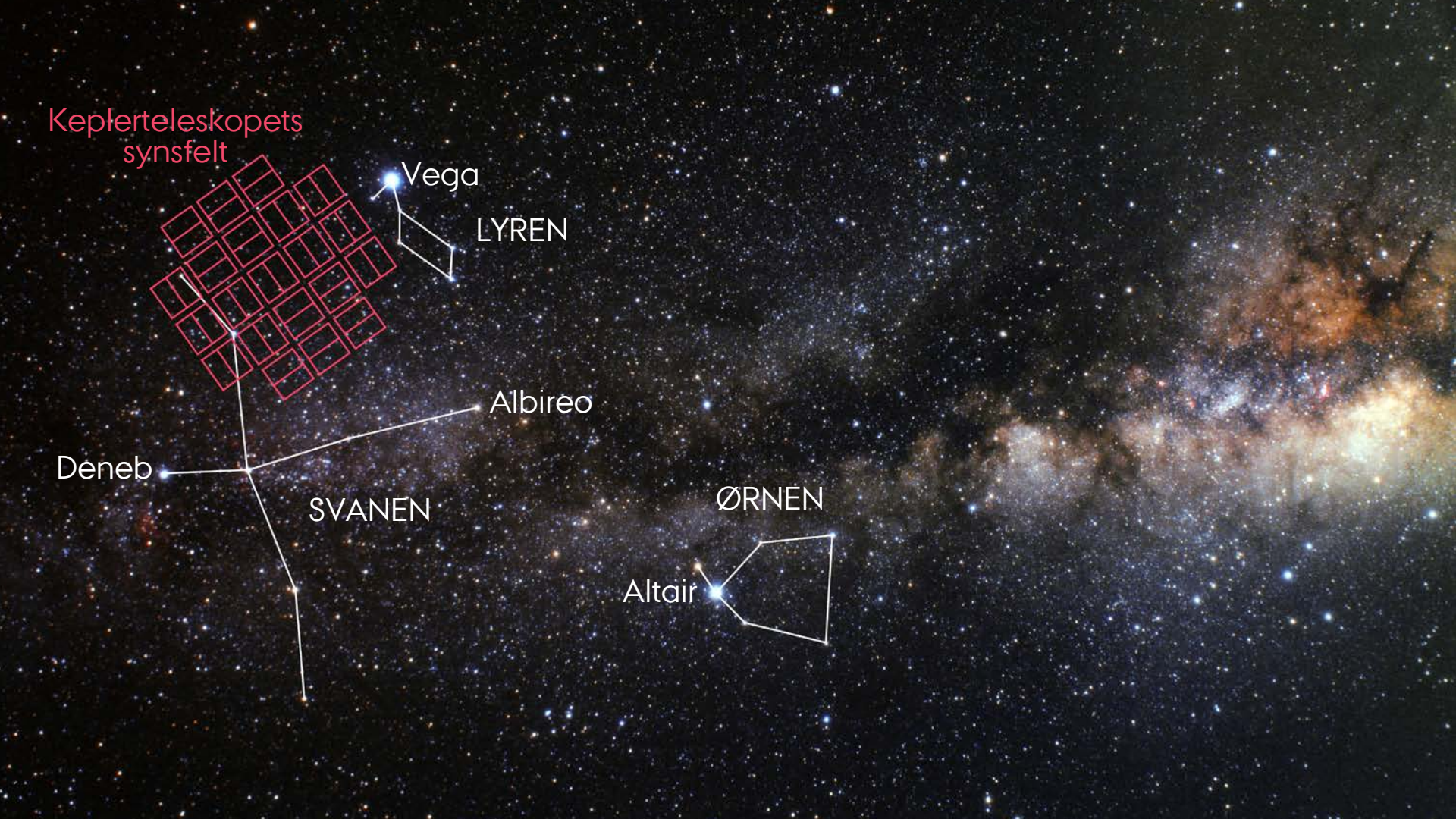
Albireo

Deneb

SVANEN

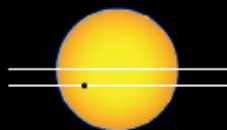
ØRNEN

Altair



Keplers første fem planetopdagelser

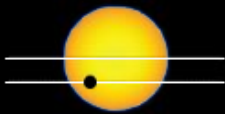
Omløbstid: 3,2 døgn



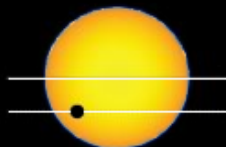
3,5 døgn



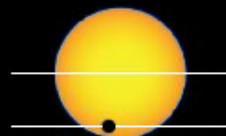
3,2 døgn



4,9 døgn

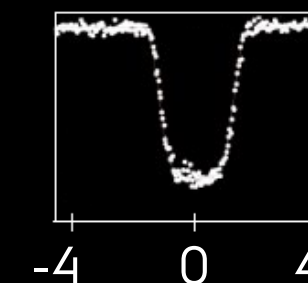
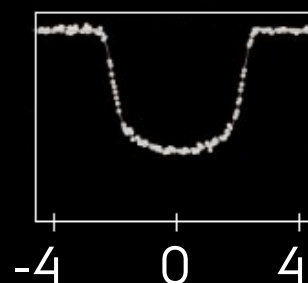
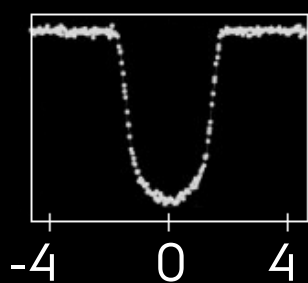
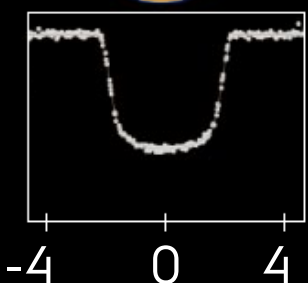
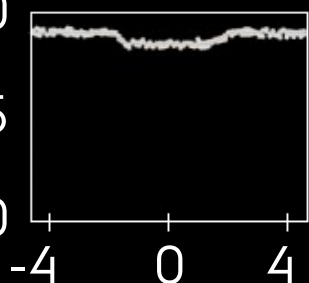


3,5 døgn



Lysstyrke

1,000
0,995
0,990

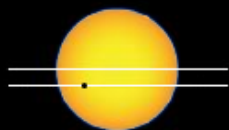


Tid (timer)



Keplers første fem planetopdagelser

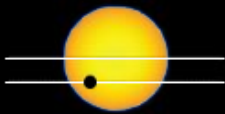
Omløbstid: 3,2 døgn



Omløbstid: 3,5 døgn



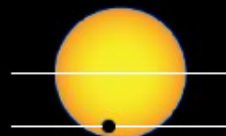
Omløbstid: 3,2 døgn



Omløbstid: 4,9 døgn



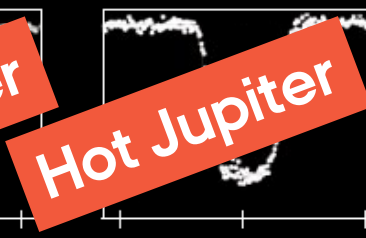
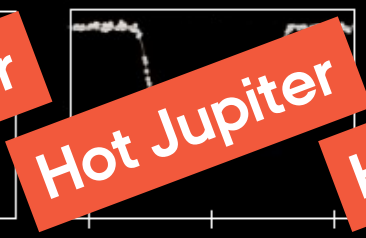
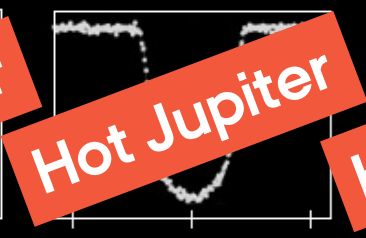
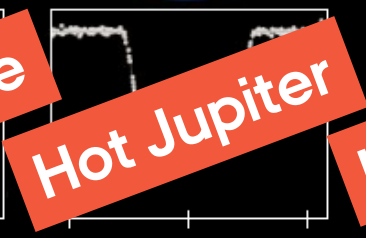
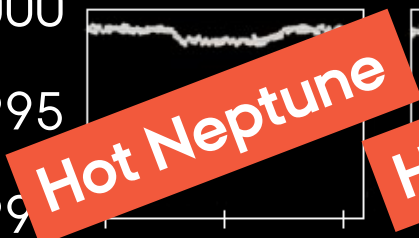
Omløbstid: 3,5 døgn



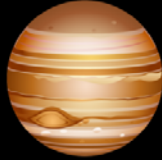
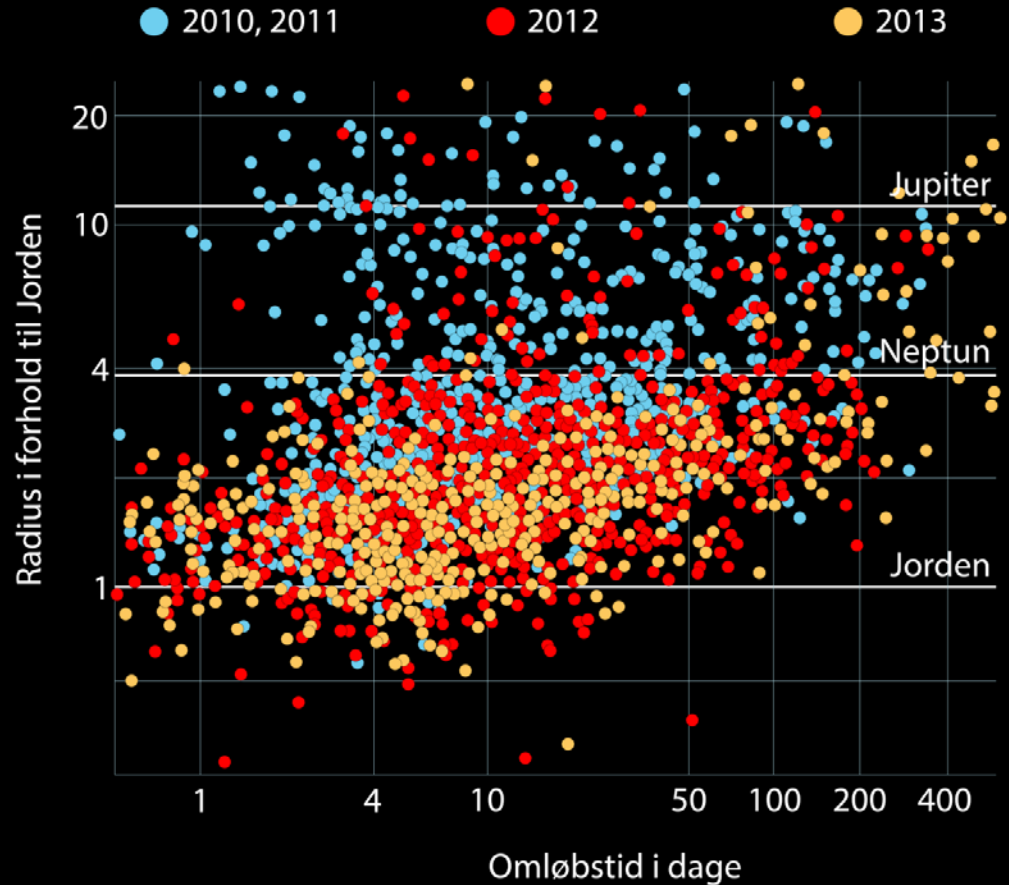
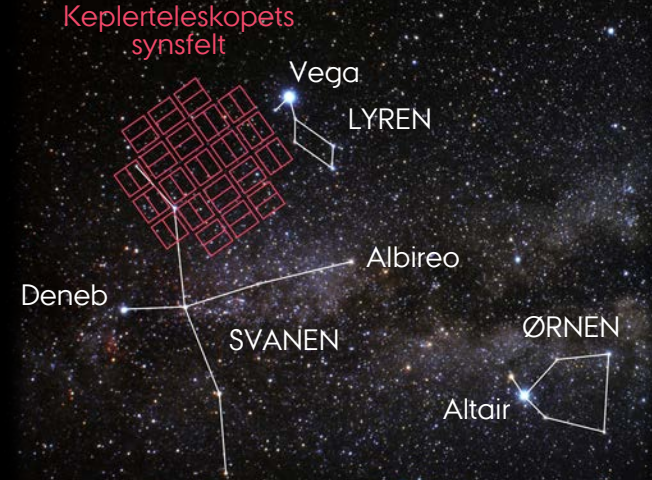
Lysstyrke

1,000
0,995
0,99

Tid (timer)

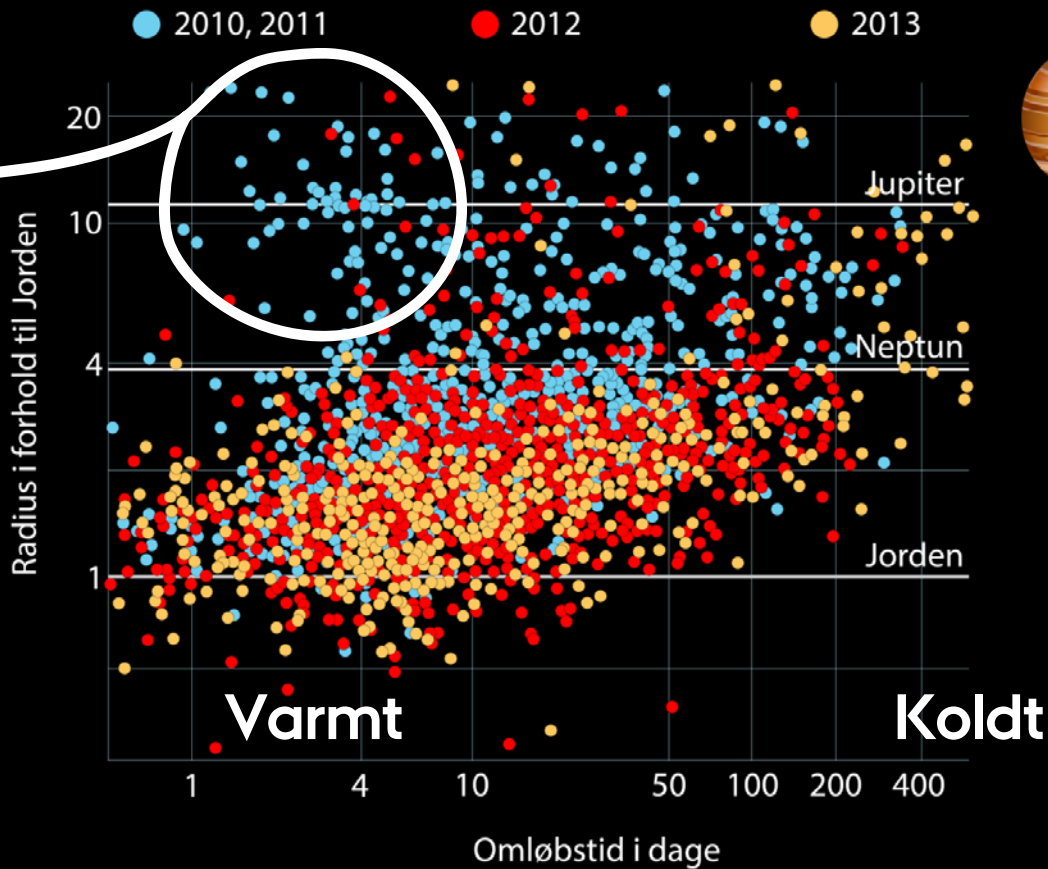


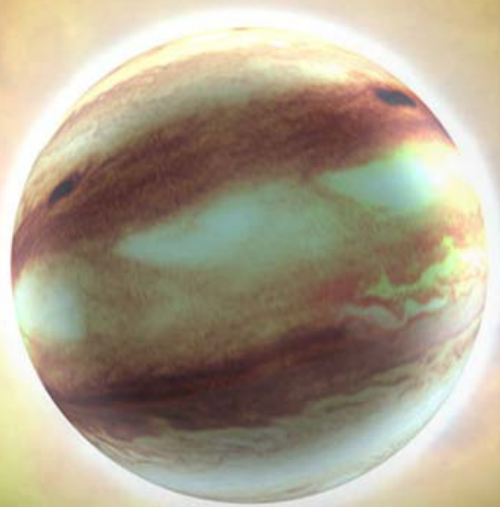
Keplers planetkandidater



Hot Jupiters

Keplers planetkandidater

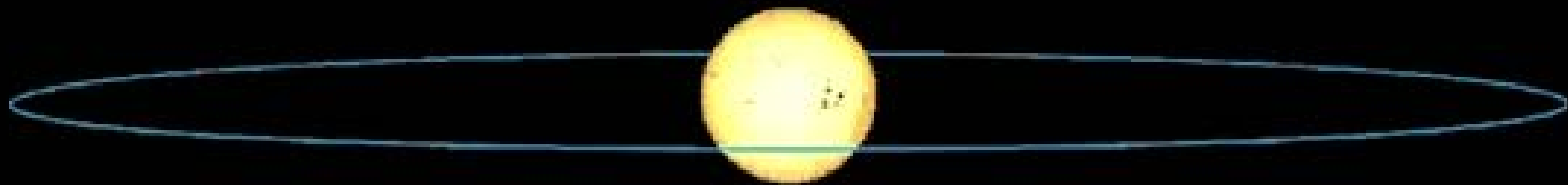


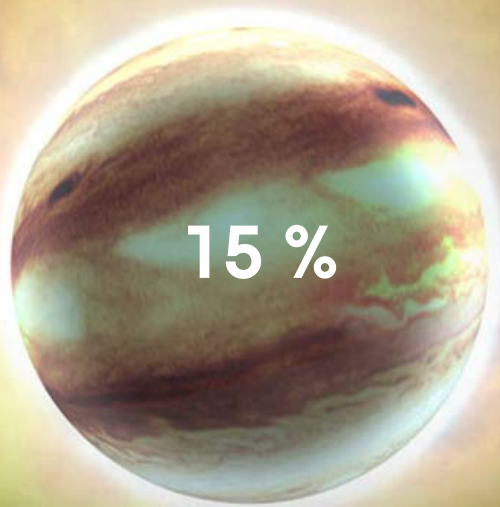


HAT-P-7b



TrES-2b

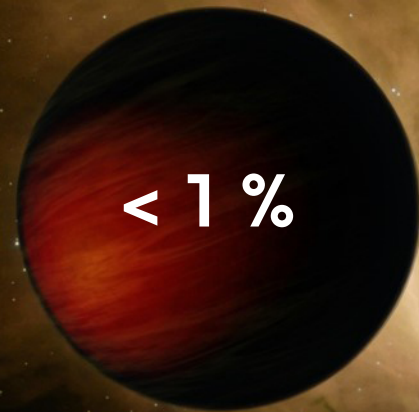




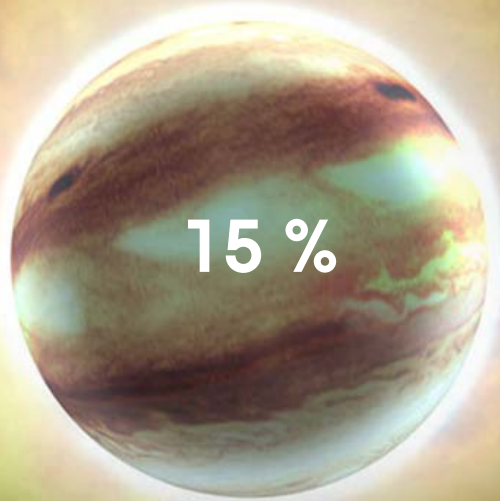
15 %

Planeten
HAT-P-7b

Planeten
TrES-2b



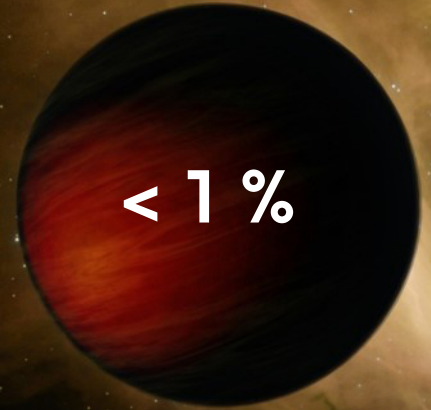
< 1 %



15 %

Planeten
HAT-P-7b

Planeten
TrES-2b



< 1 %

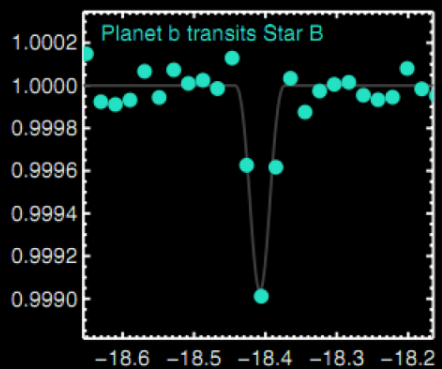
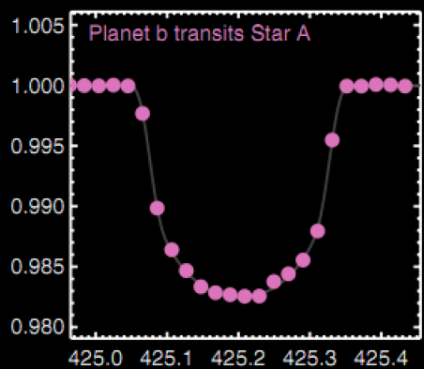
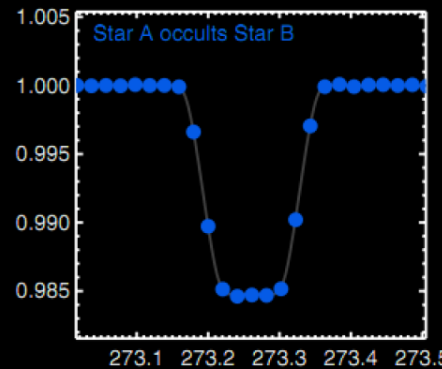
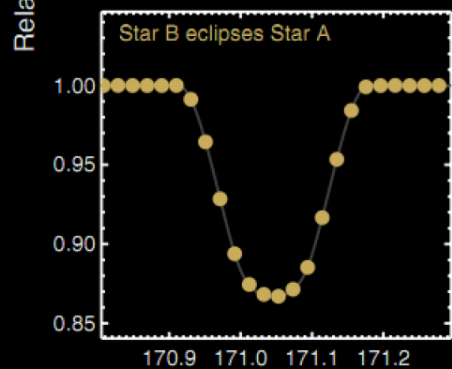
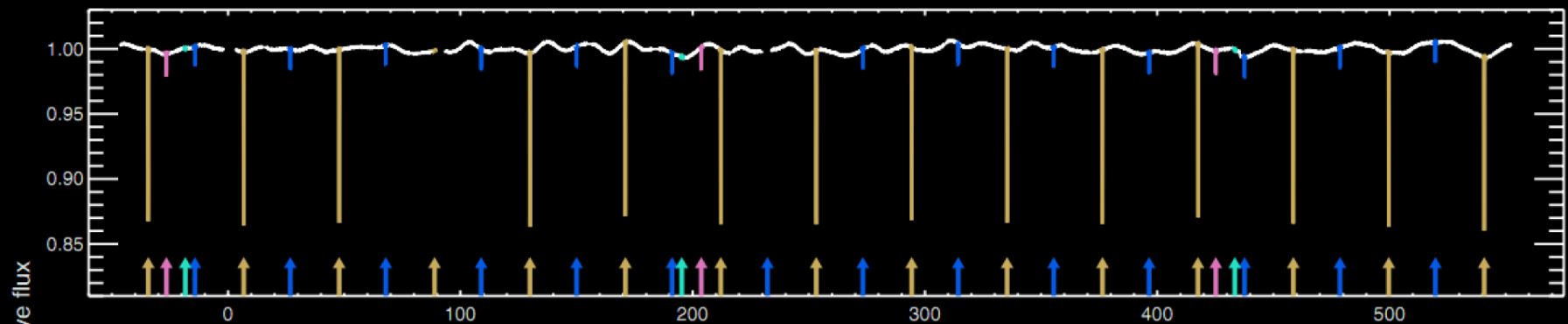
5 %





Solnedgang påTatooine
Luke Skywalker's "hjem" i Star Wars
(1977, George Lucas)

Kepler-16

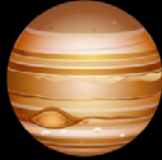
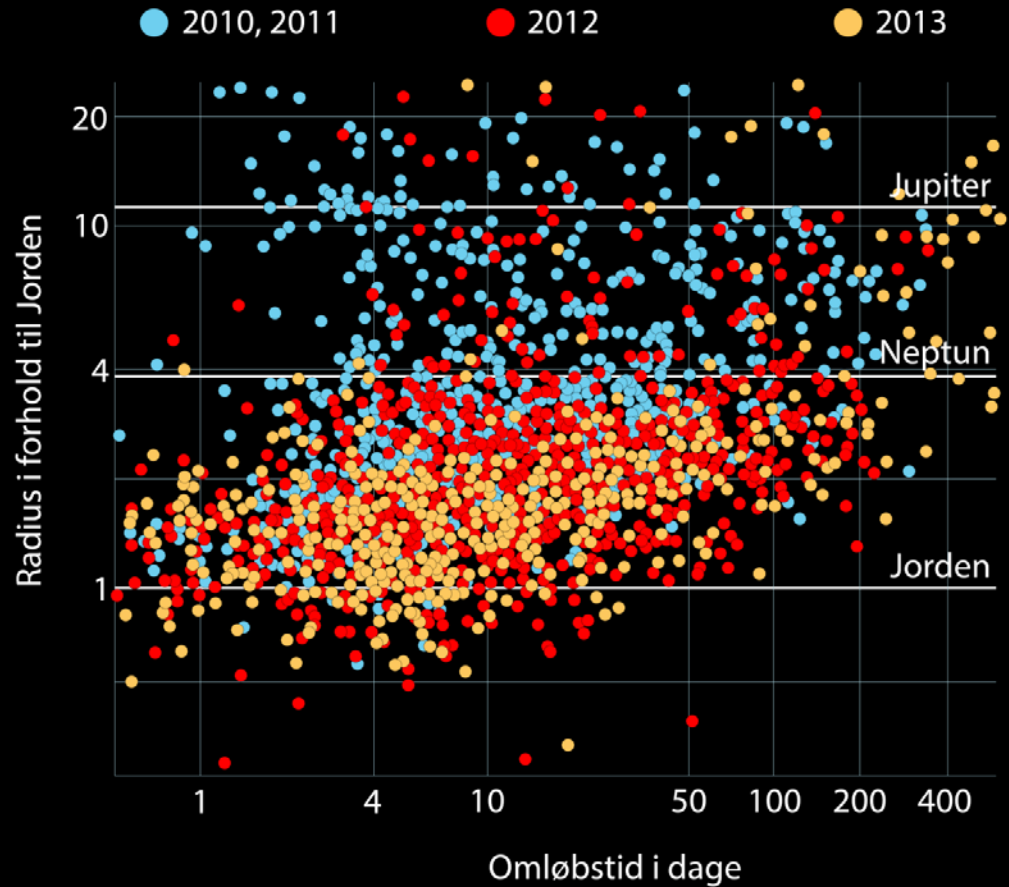


Time [BJD - 2,455,000]

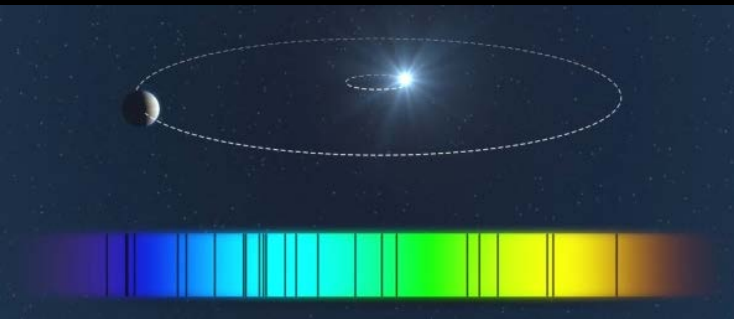
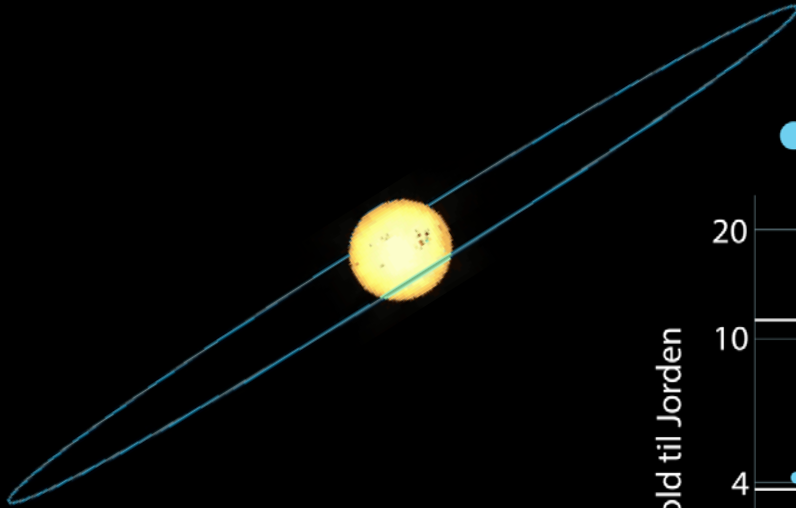
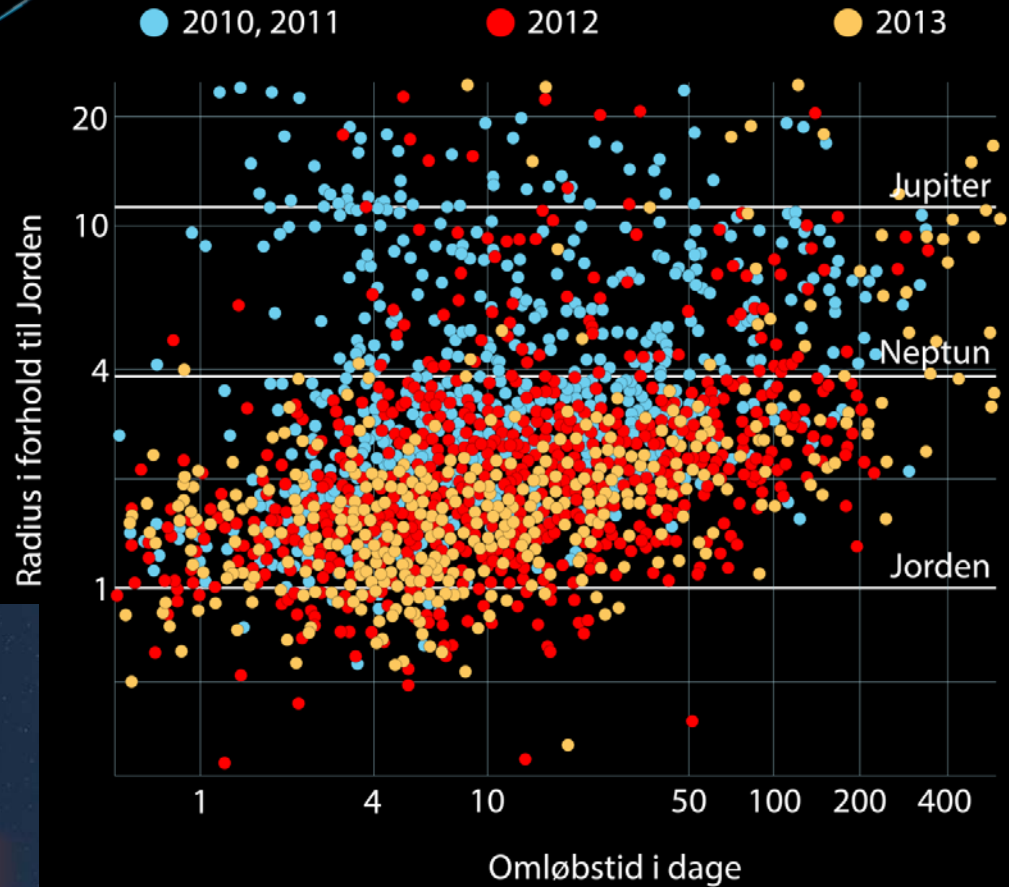


Keplers planetkandidater

Keplerteleskopets
synsfelt



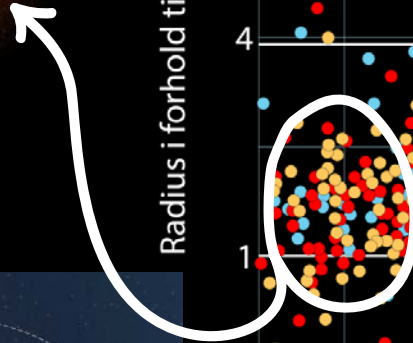
Keplers planetkandidater



Keplers planetkandidater

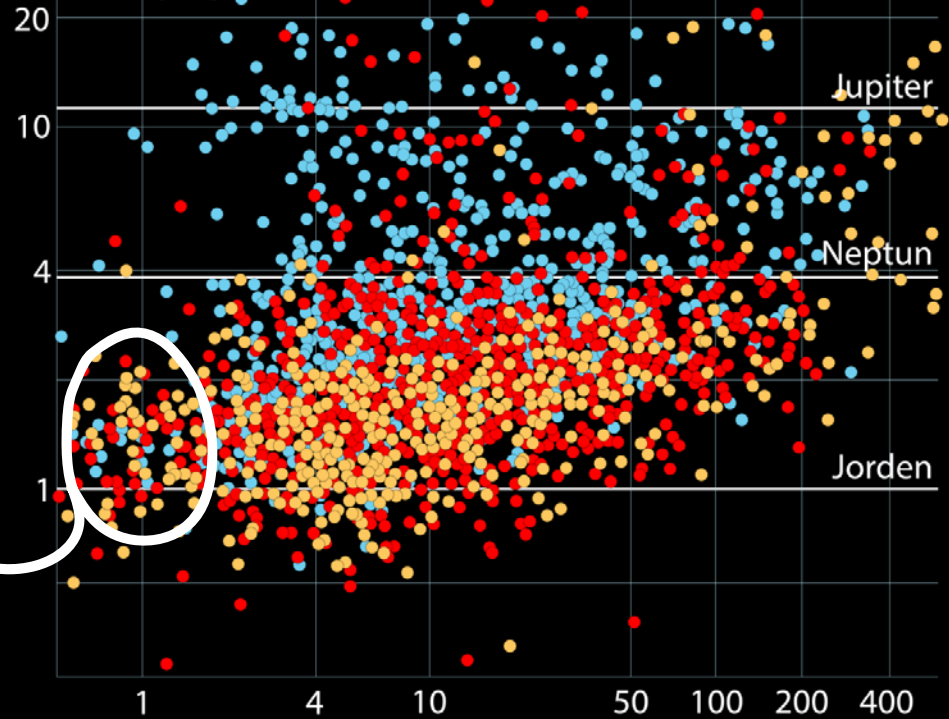


Lavaplaneter

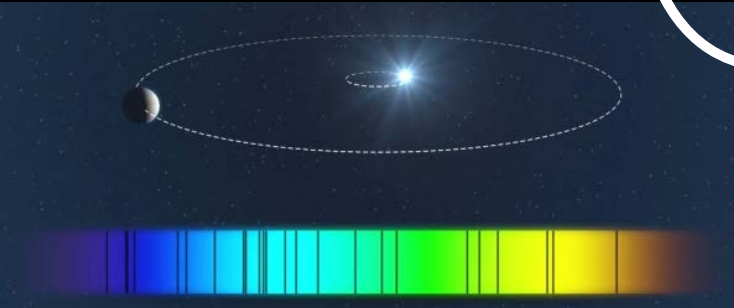


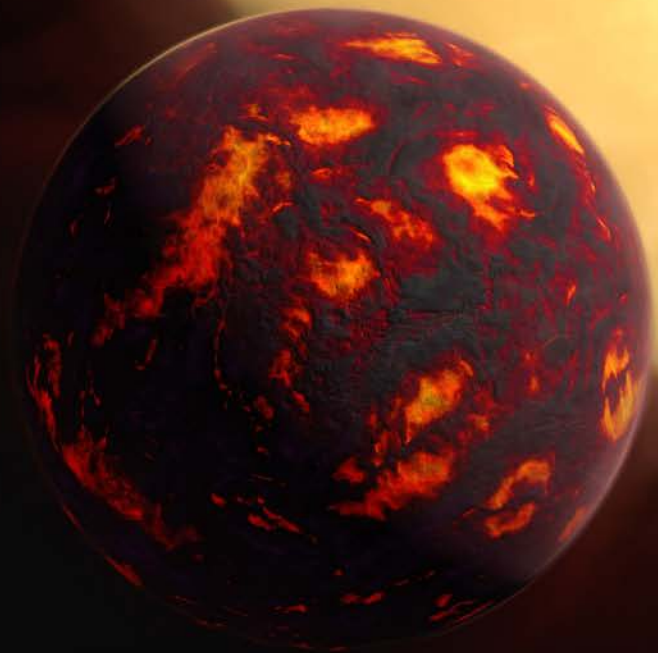
Radius i forhold til Jorden

● 2010, 2011 ● 2012 ● 2013



Omløbstid i dage

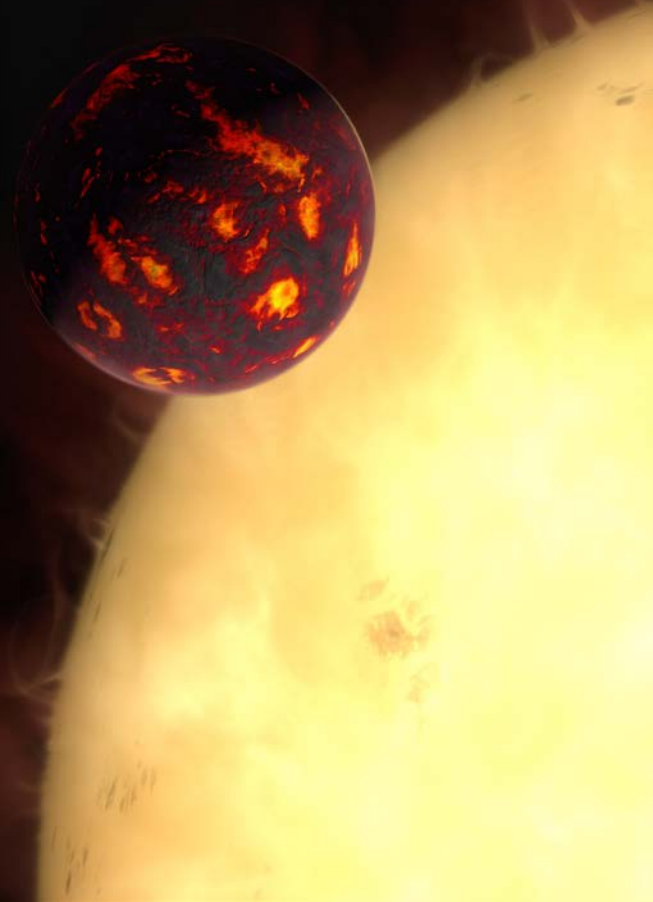
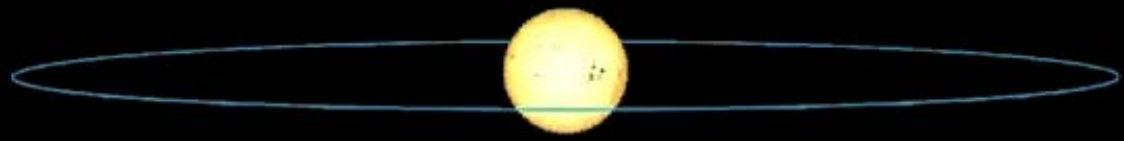
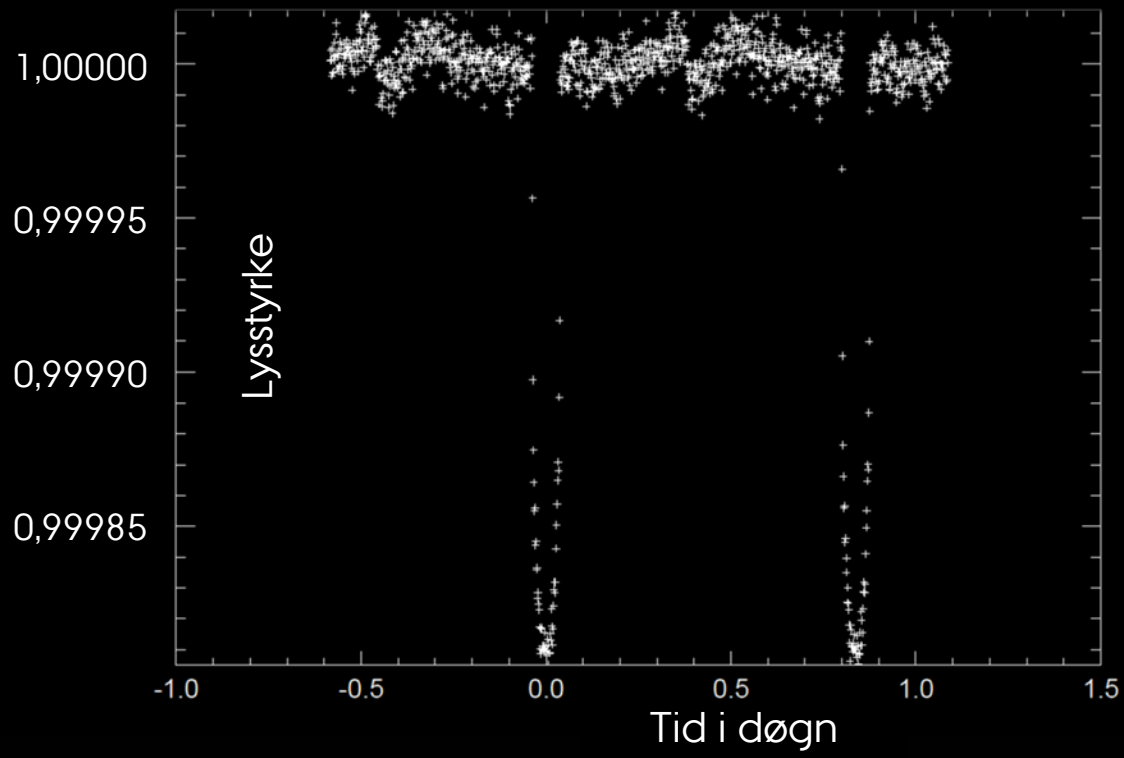




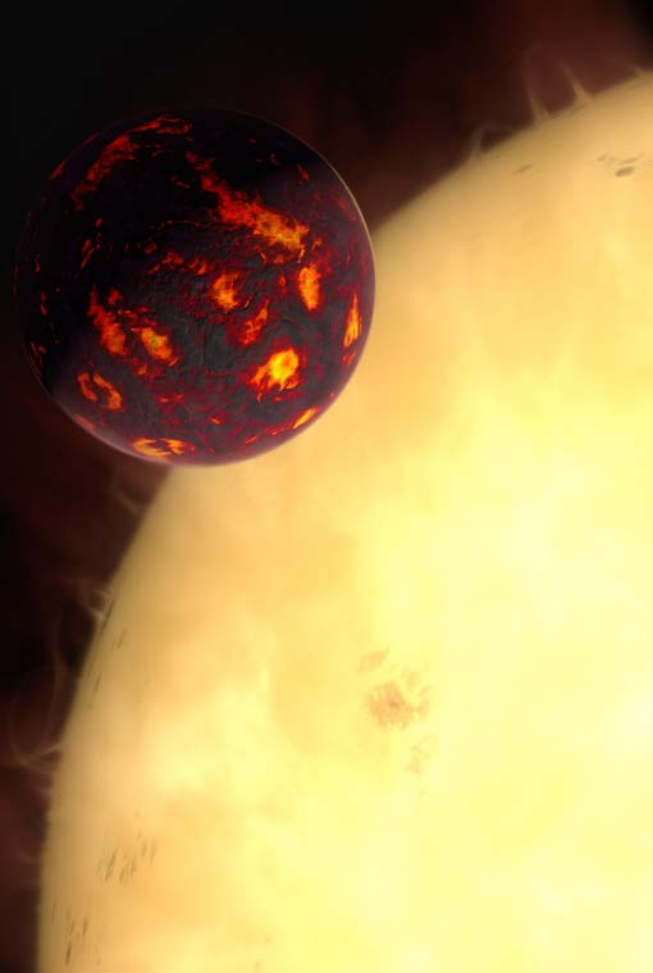
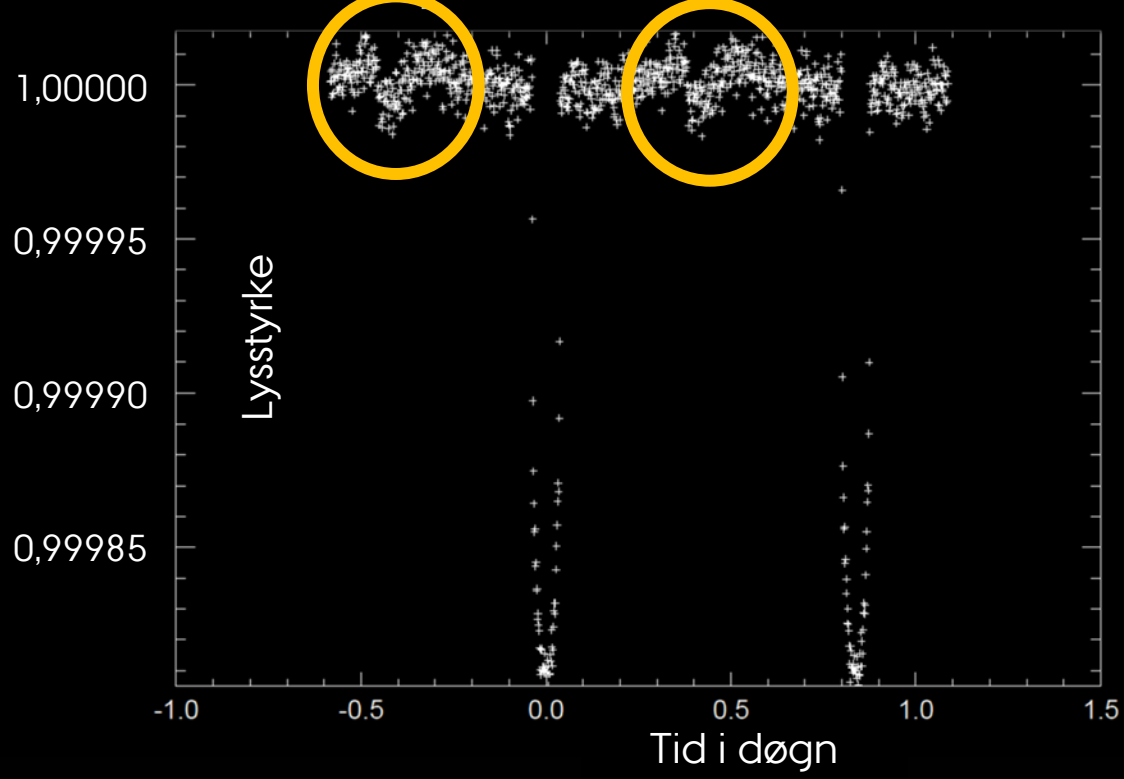
Planeten Kepler-10b



Planeten Kepler-10b



Planeten Kepler-10b



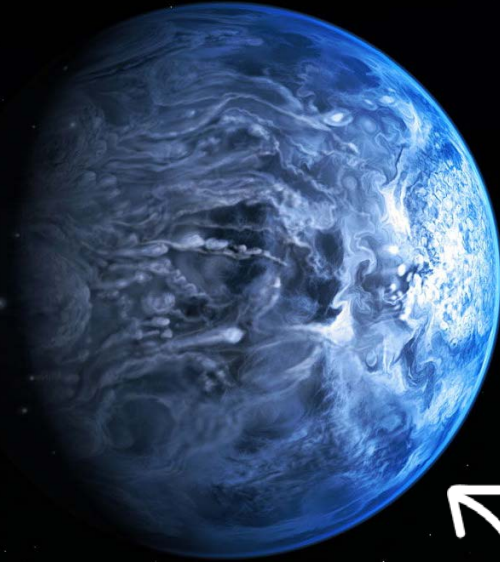
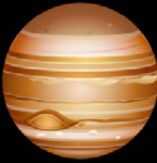
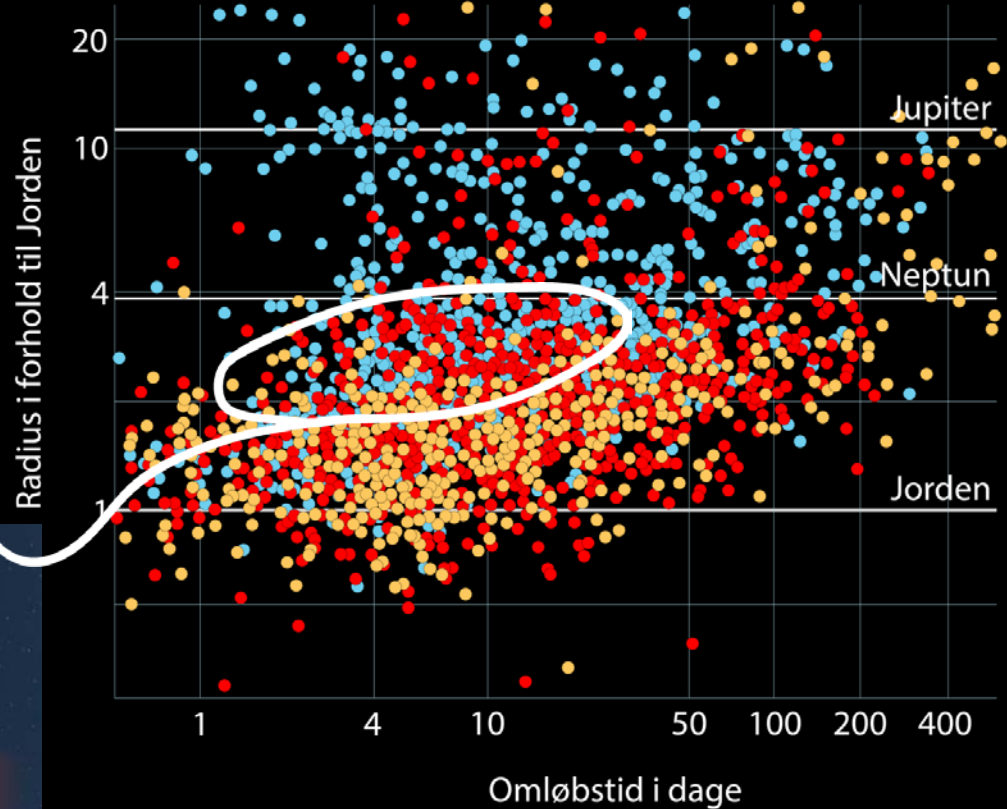


Planeten Kepler-10b



Keplers planetkandidater

● 2010, 2011 ● 2012 ● 2013

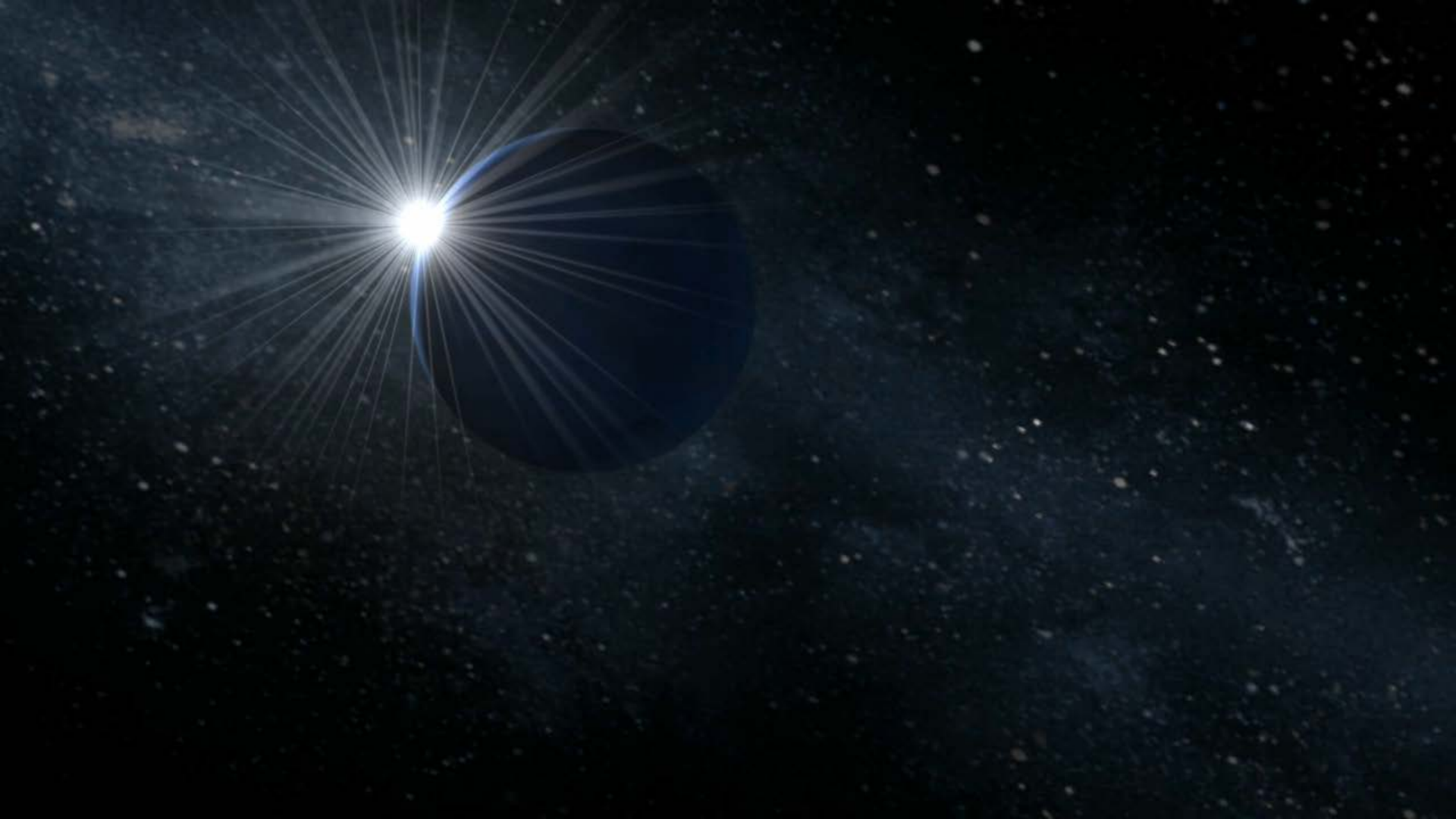


Vandplaneter

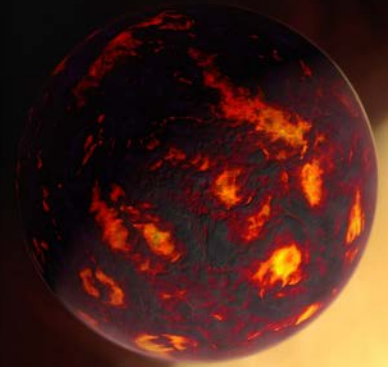


Vandplaneter: "Water Worlds"



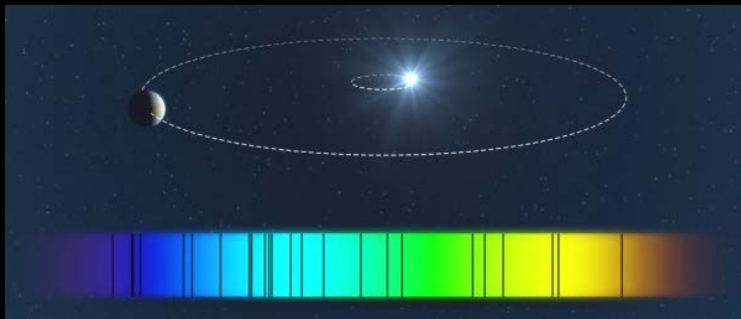
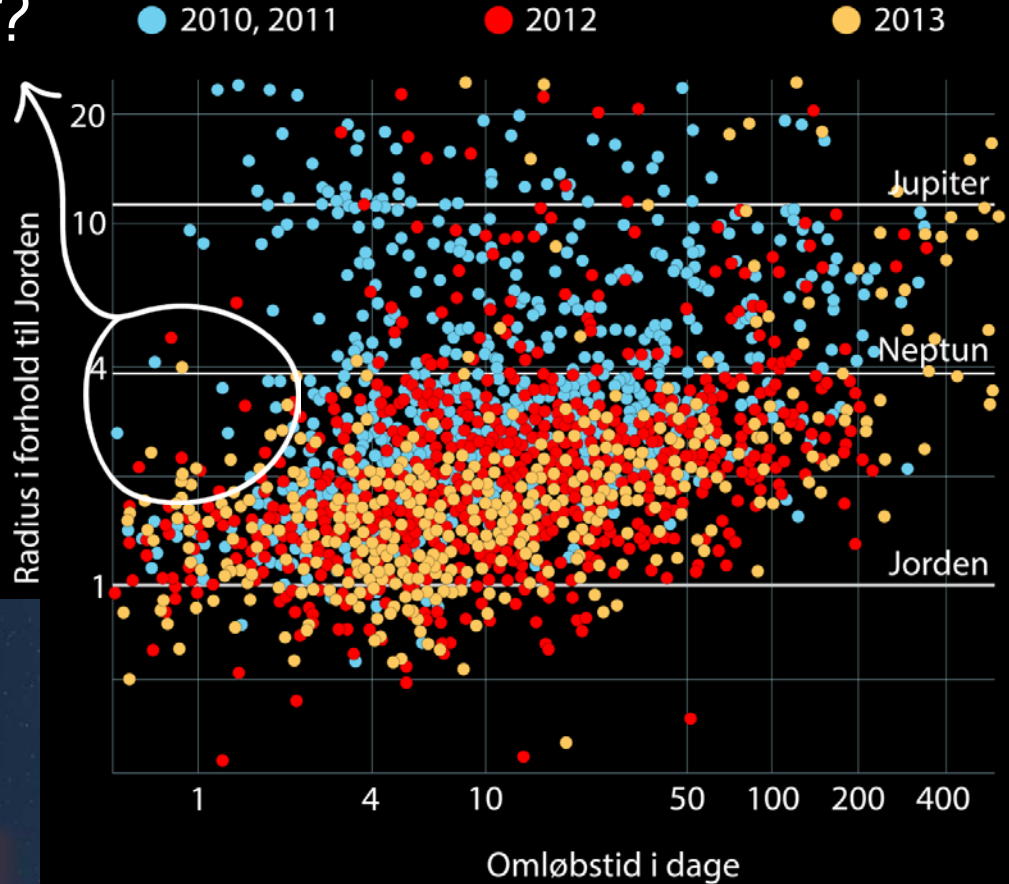


Klippe, vand, gas ?



Keplers planetkandidater

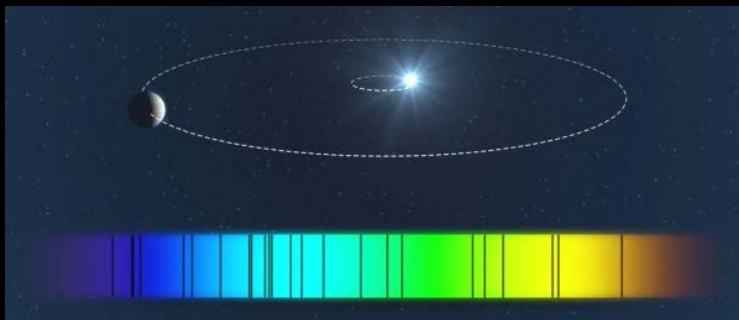
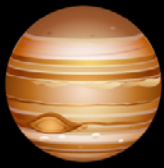
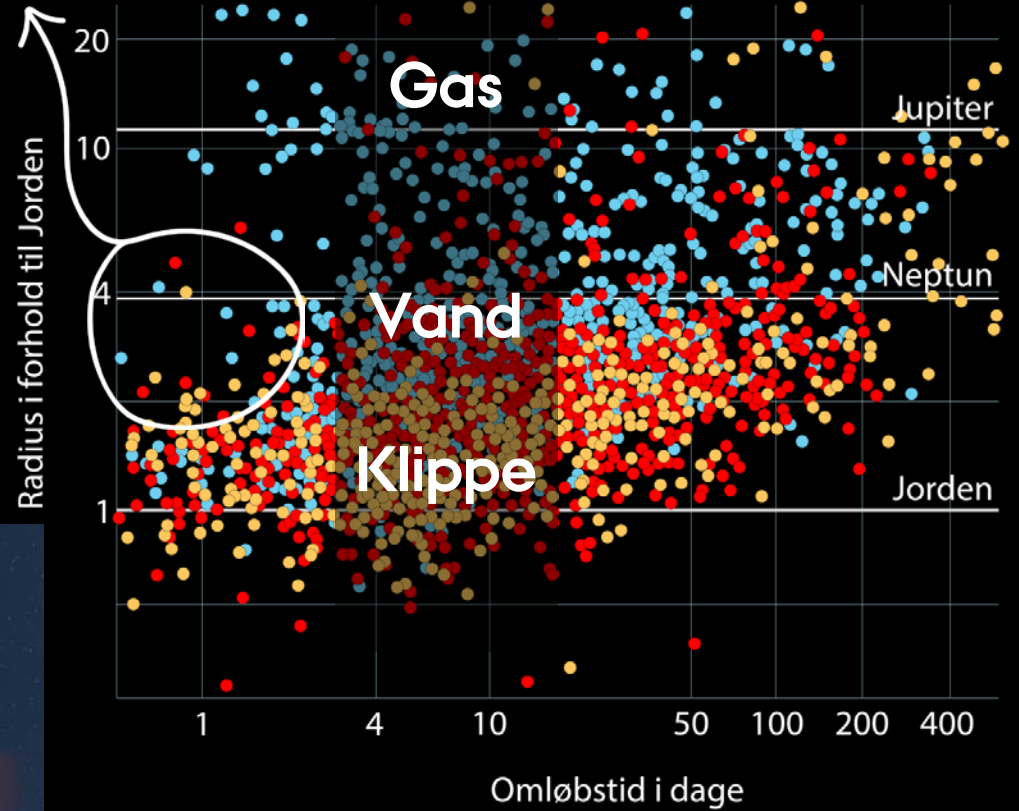
Hvorfor mangler de?



Keplers planetkandidater

Fordampende planeter

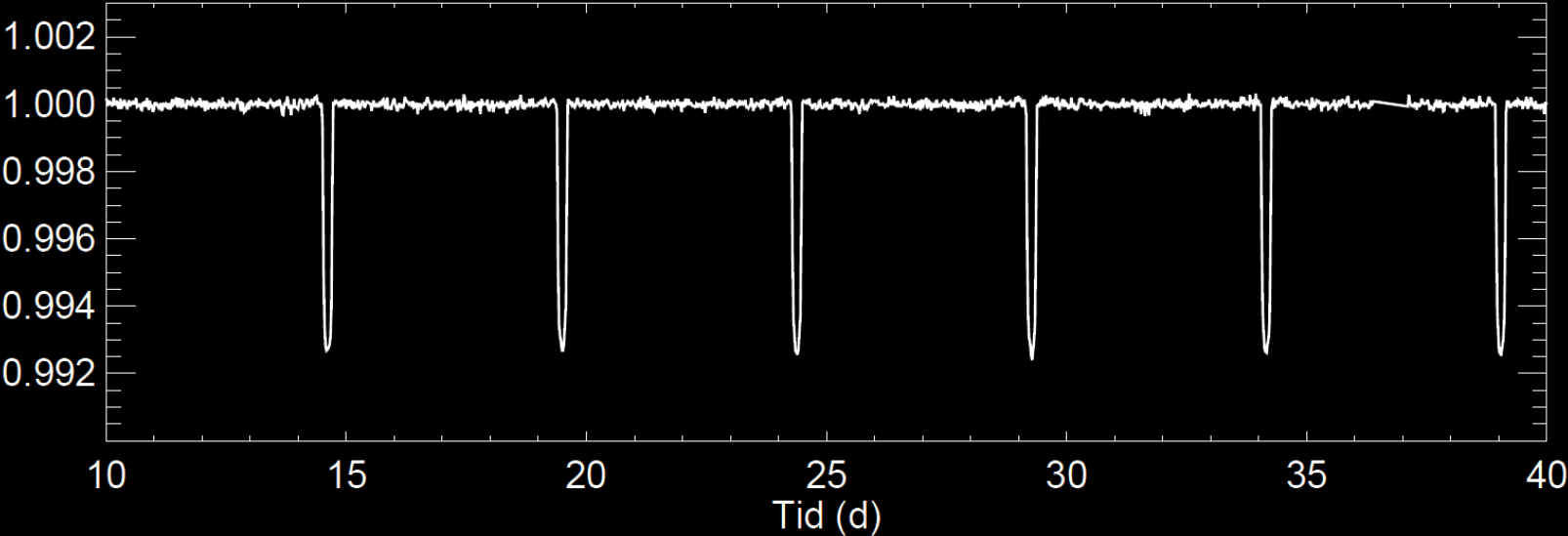
● 2010, 2011 ● 2012 ● 2013



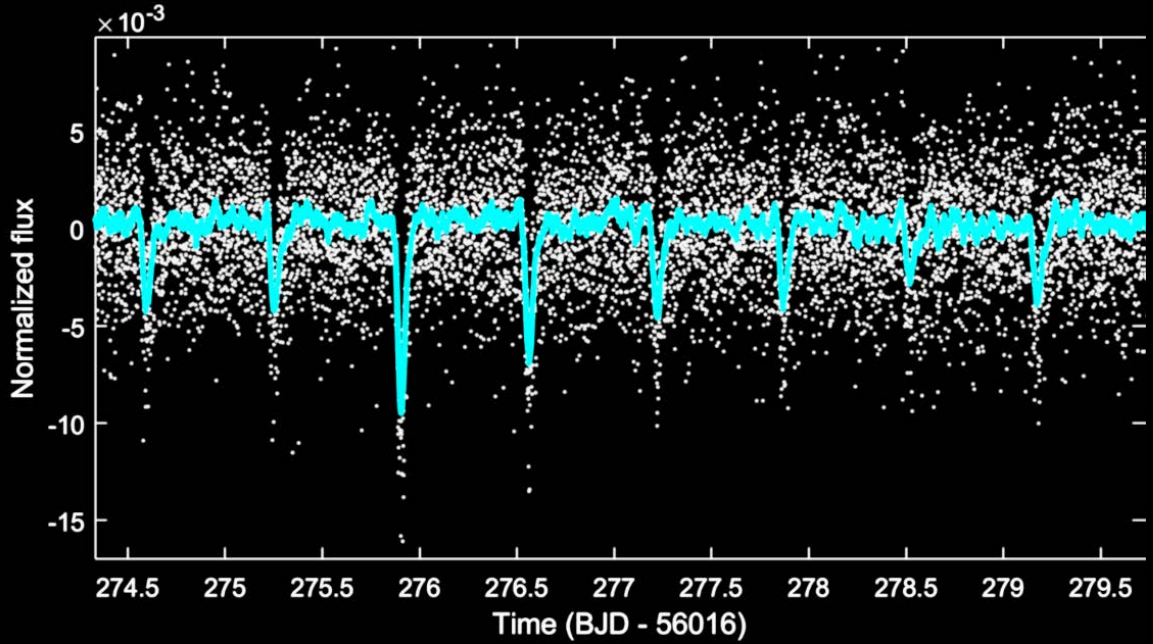
Forskning af Mia Sloth Lundkvist, Aarhus Universitet



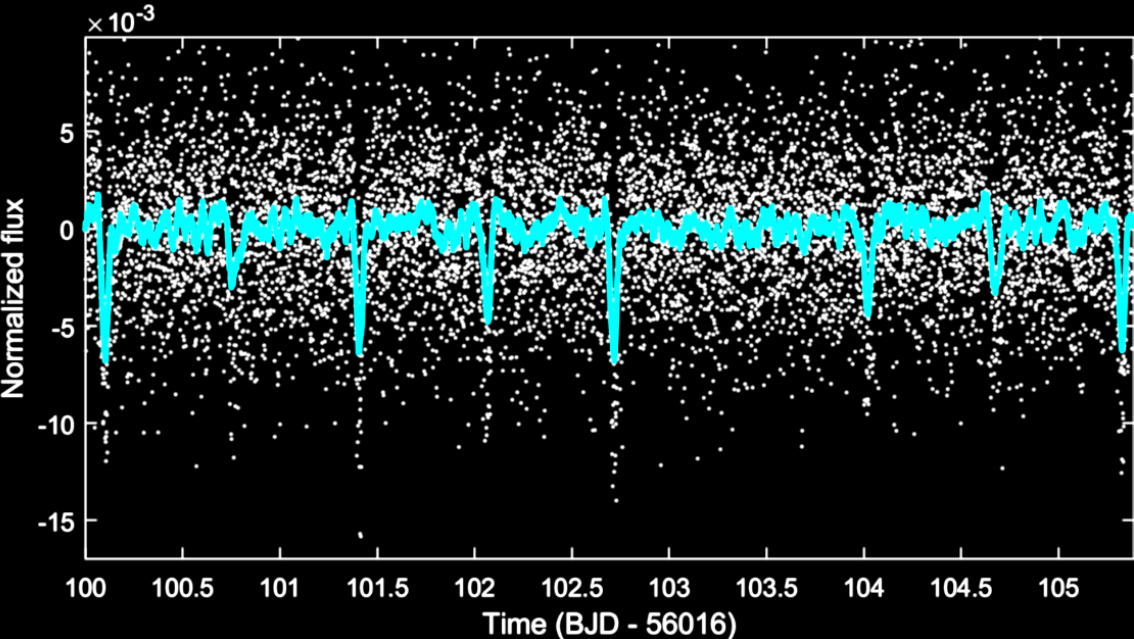
Exoplaneten Kepler-1520b



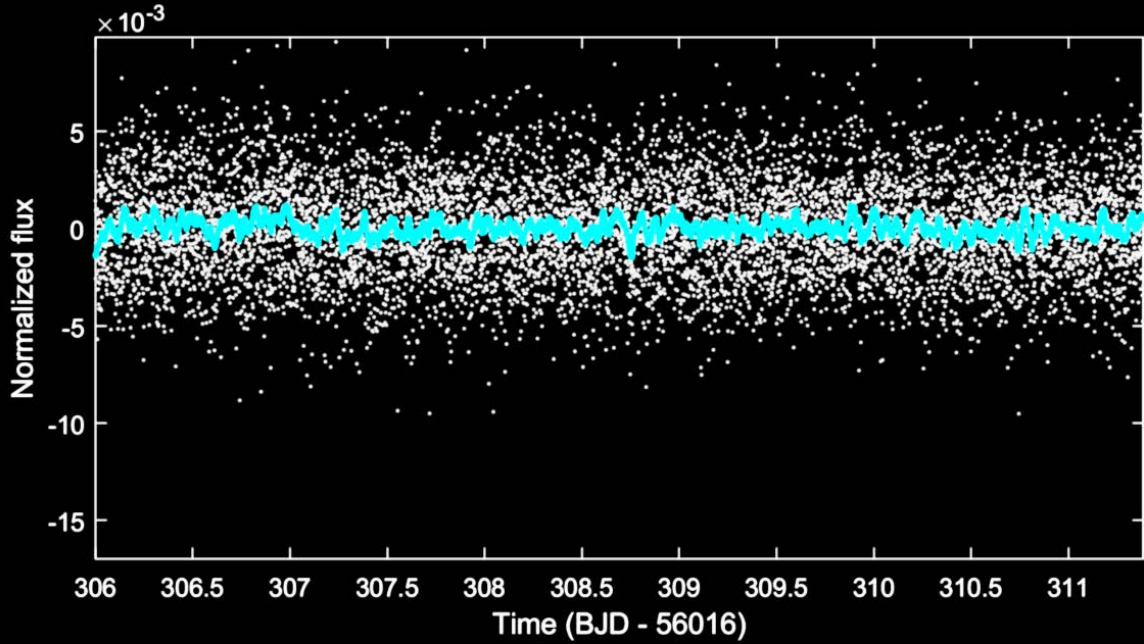
Exoplaneten Kepler-1520b



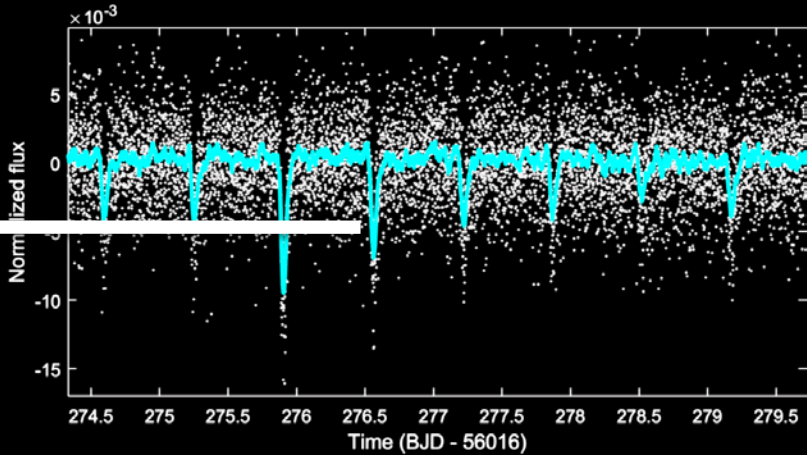
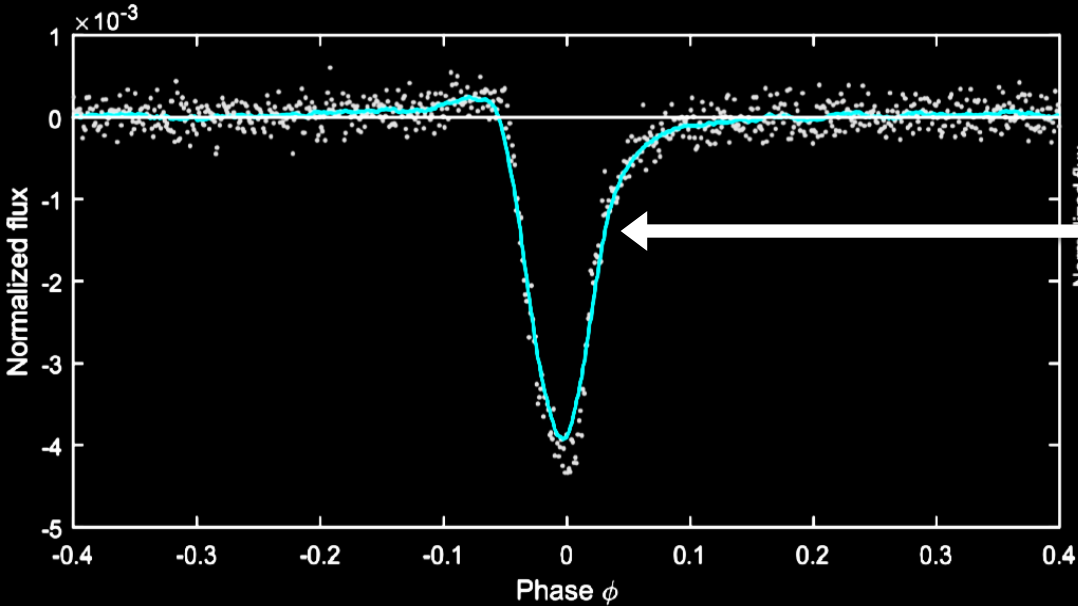
Exoplaneten Kepler-1520b



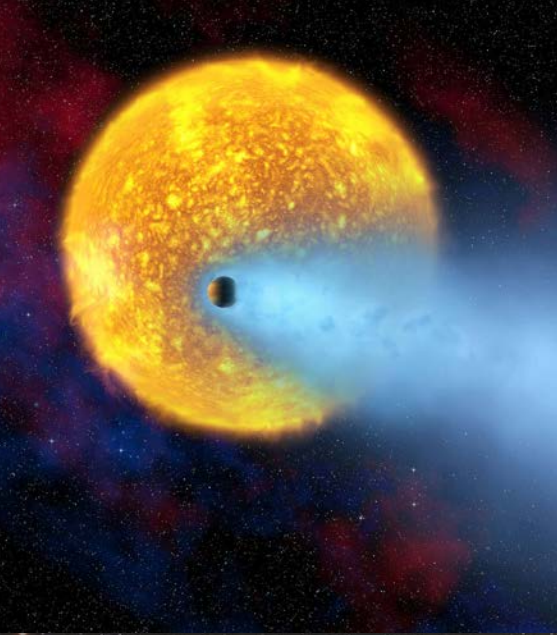
Exoplaneten Kepler-1520b



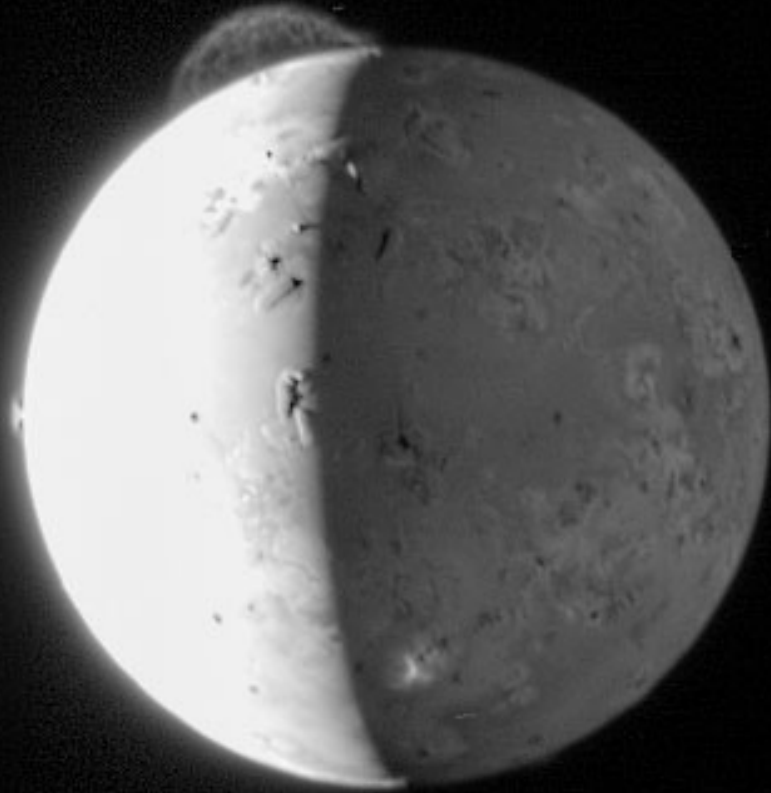
Exoplaneten Kepler-1520b



Kepler-1520b: en fordampende planet?



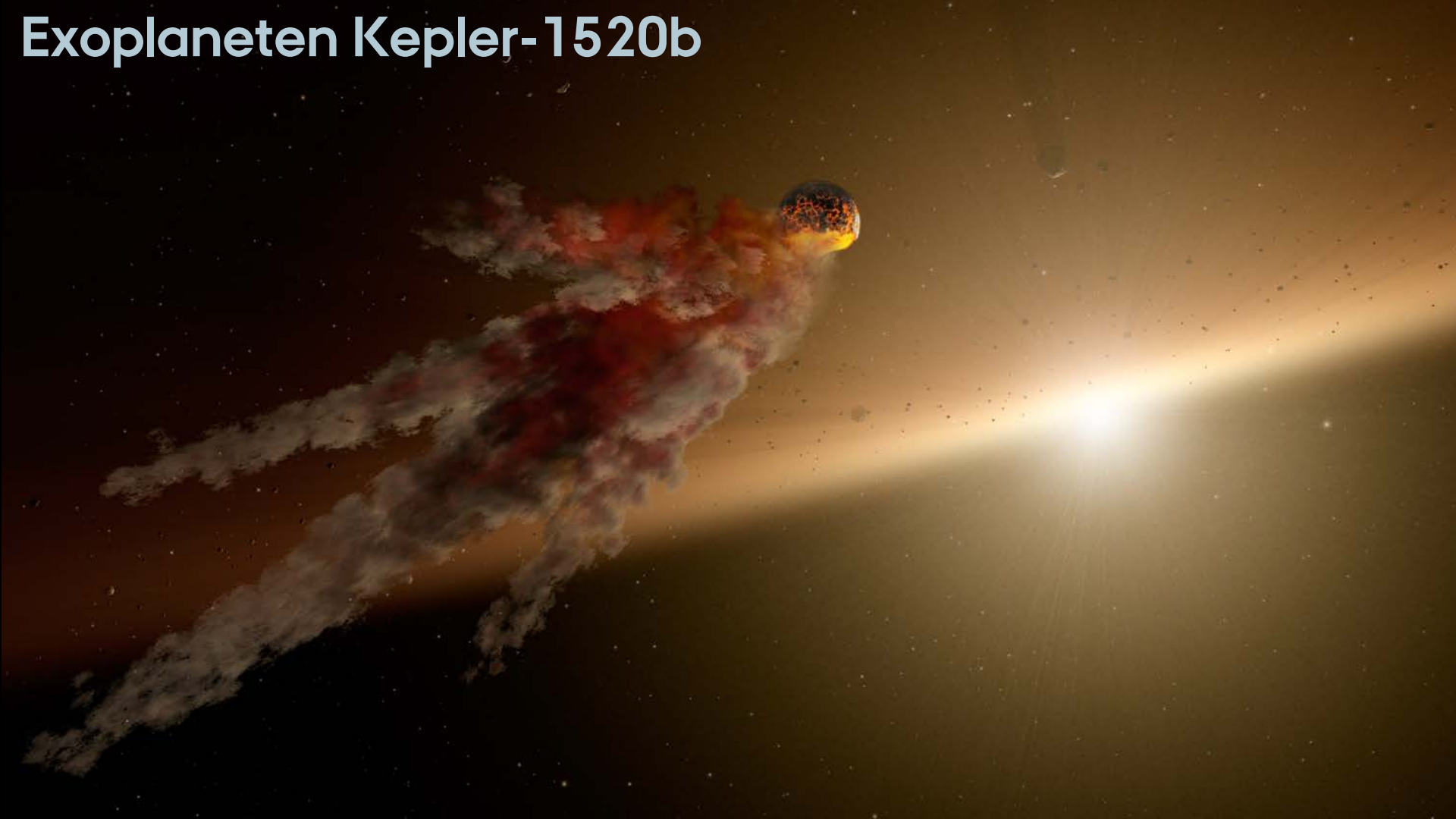
Kepler-1520b : er der store vulkaner på planeten?

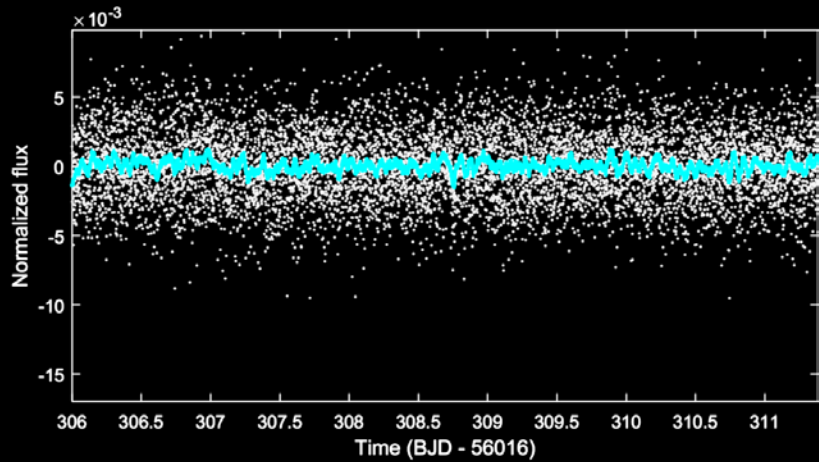
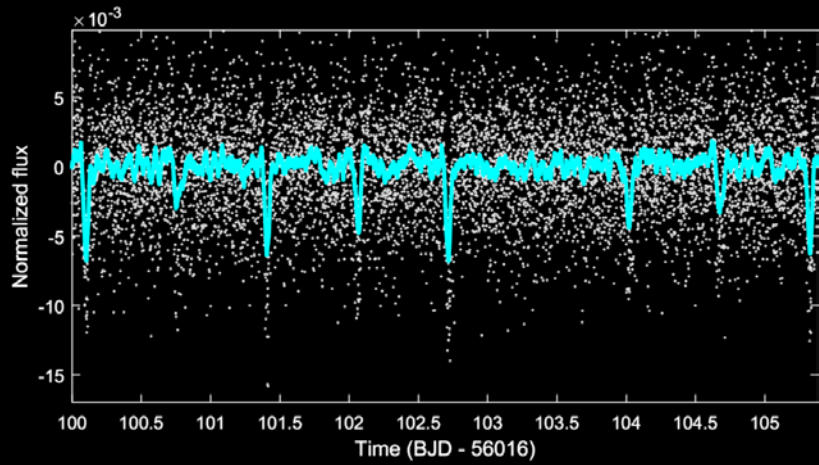


Jupiters måne, Io



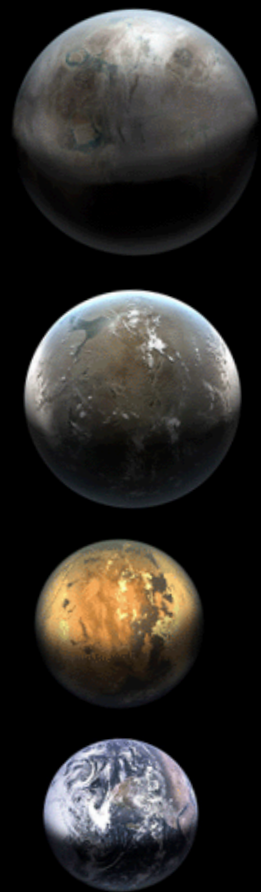
Exoplaneten Kepler-1520b





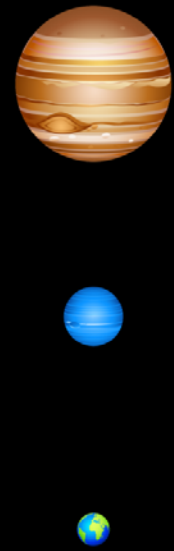
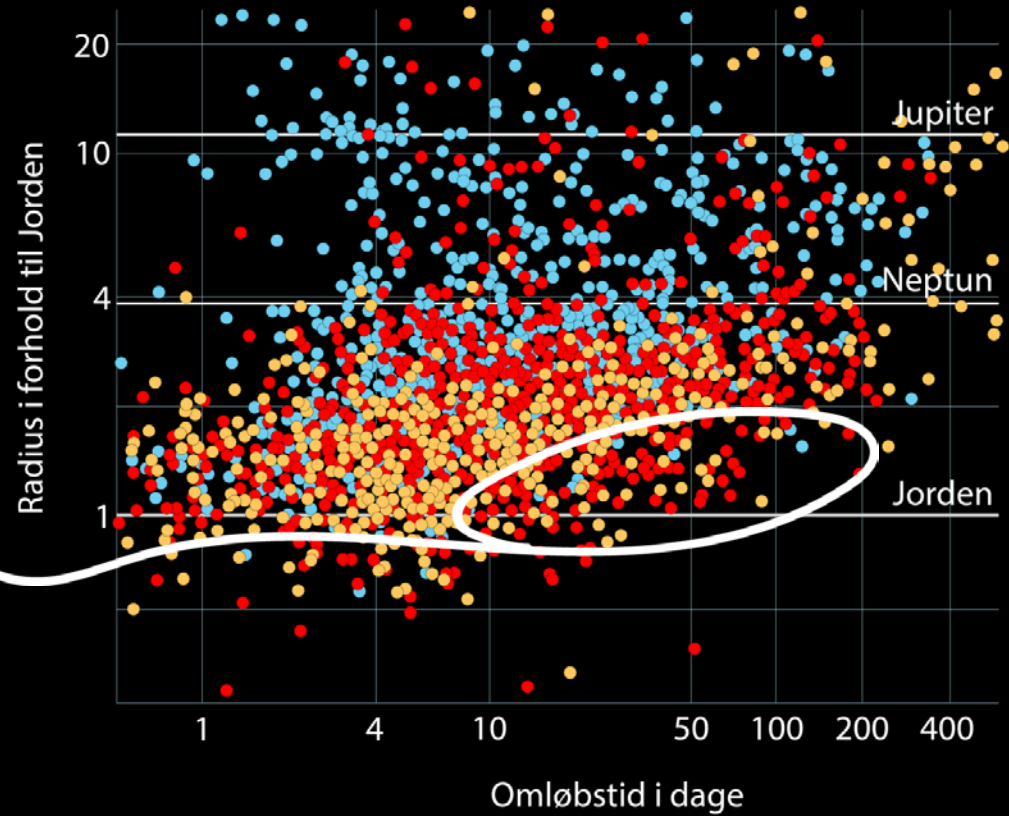
Exoplaneten Kepler-1520b

Jordlignende planeter

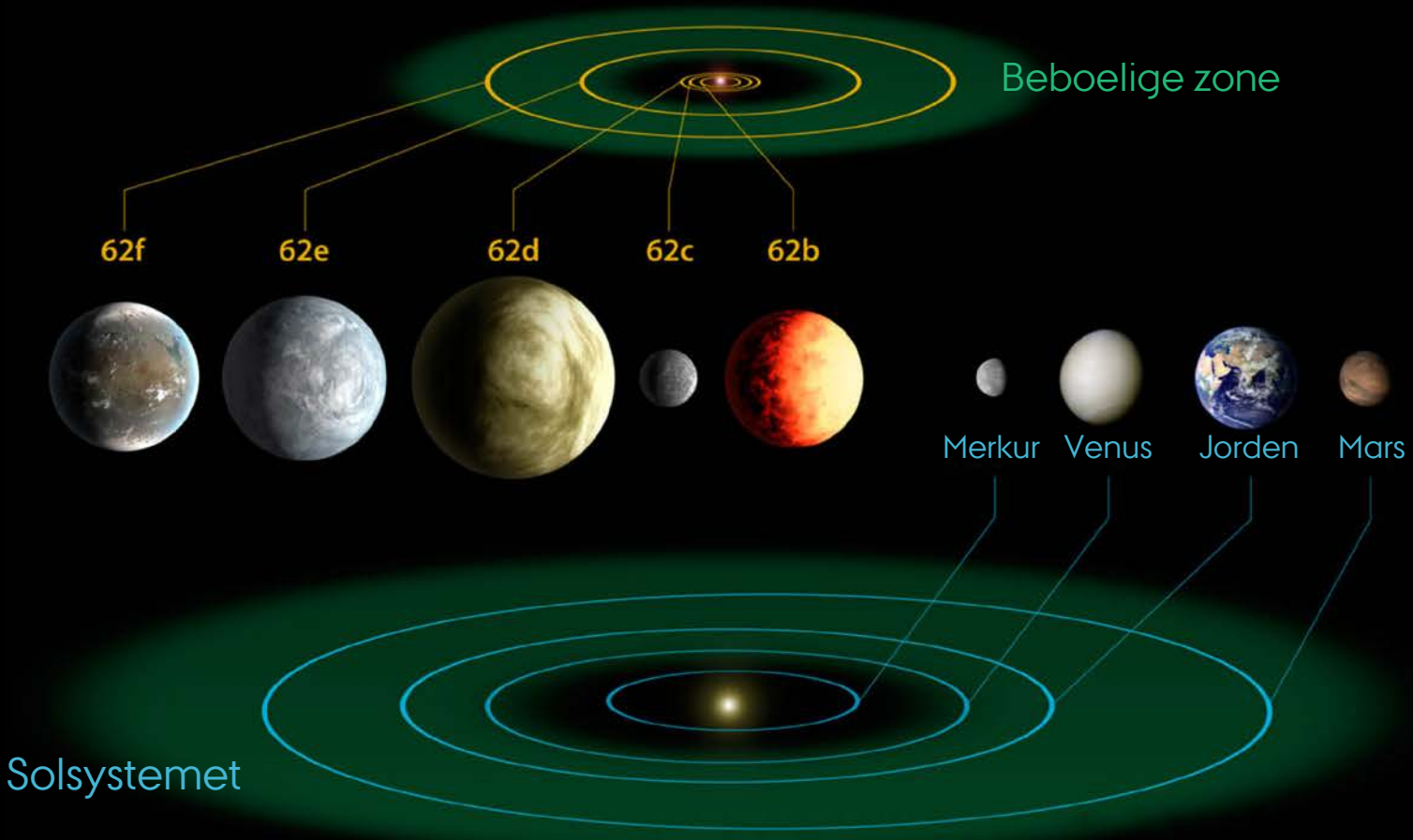


Keplers planetkandidater

● 2010, 2011 ● 2012 ● 2013



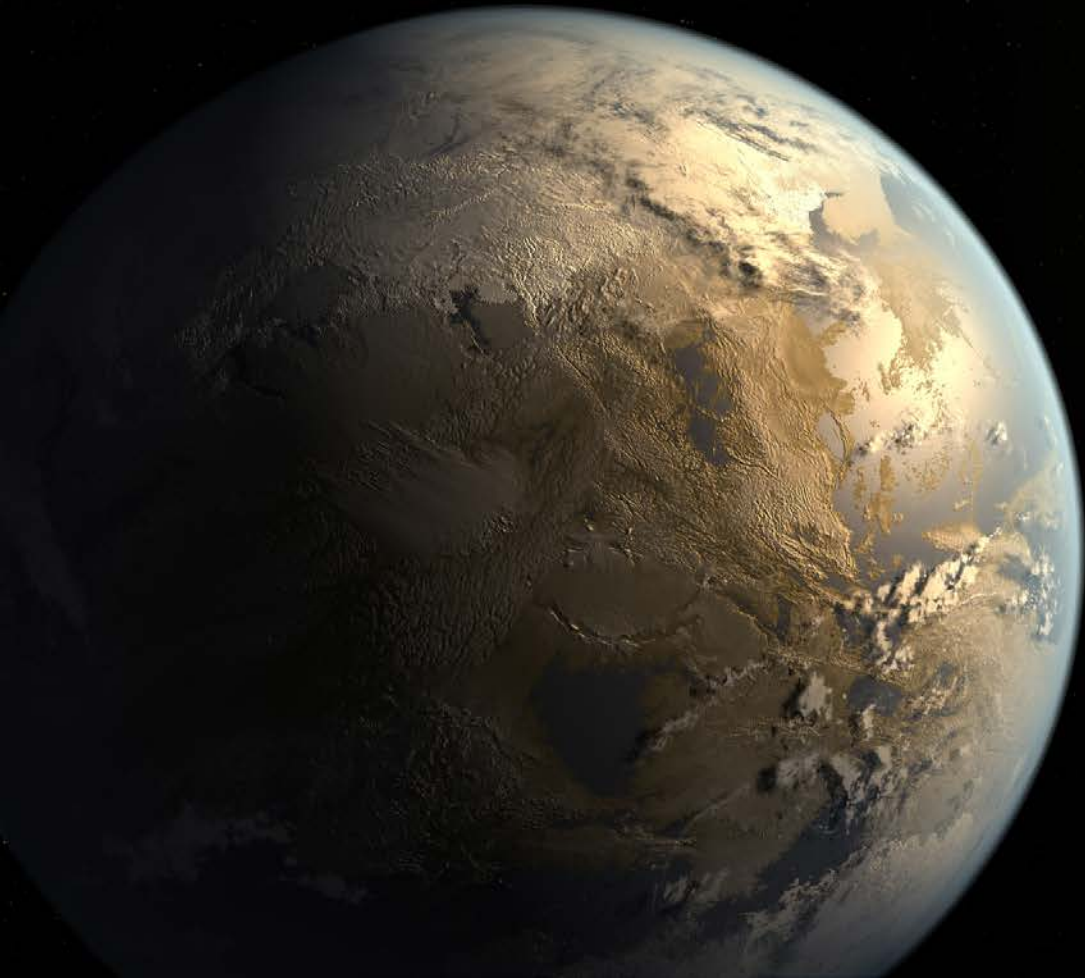
Kepler-62 System



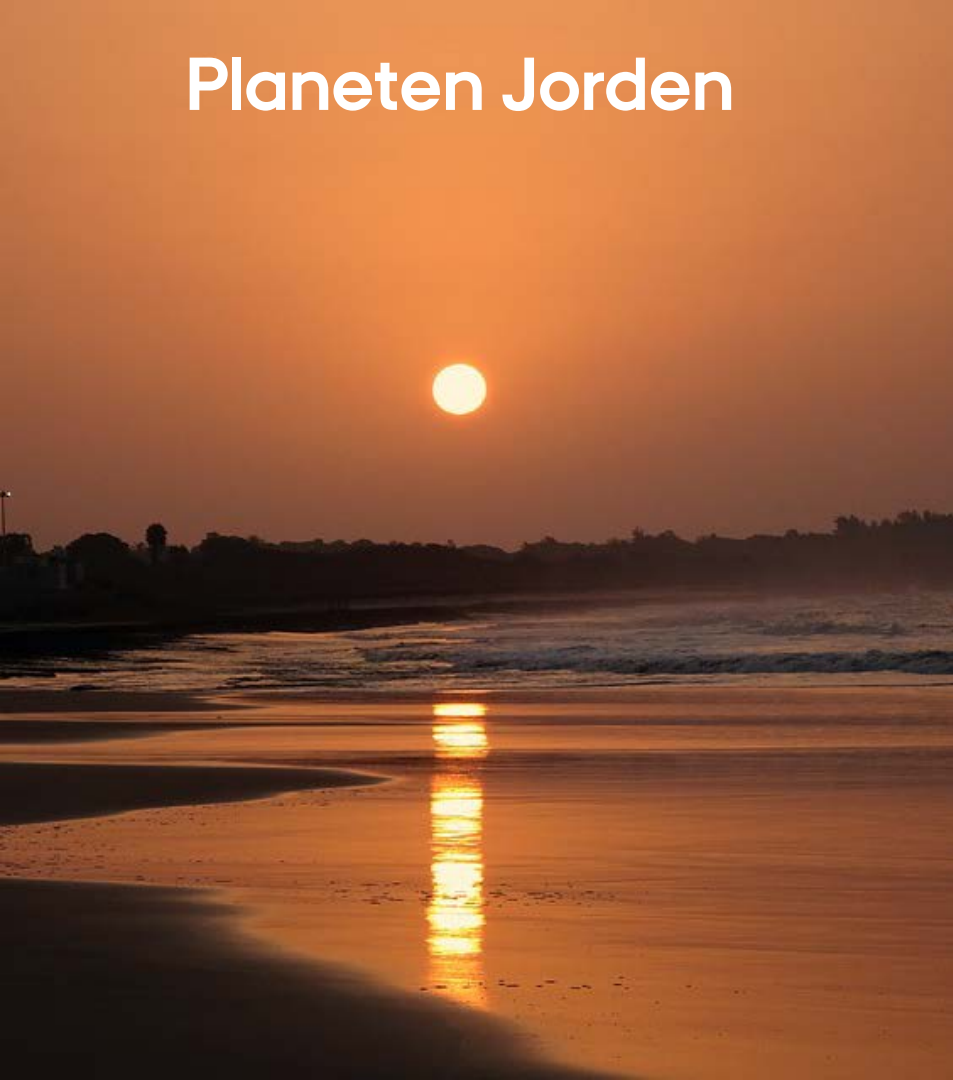
En kunstners opfattelse af Kepler-62



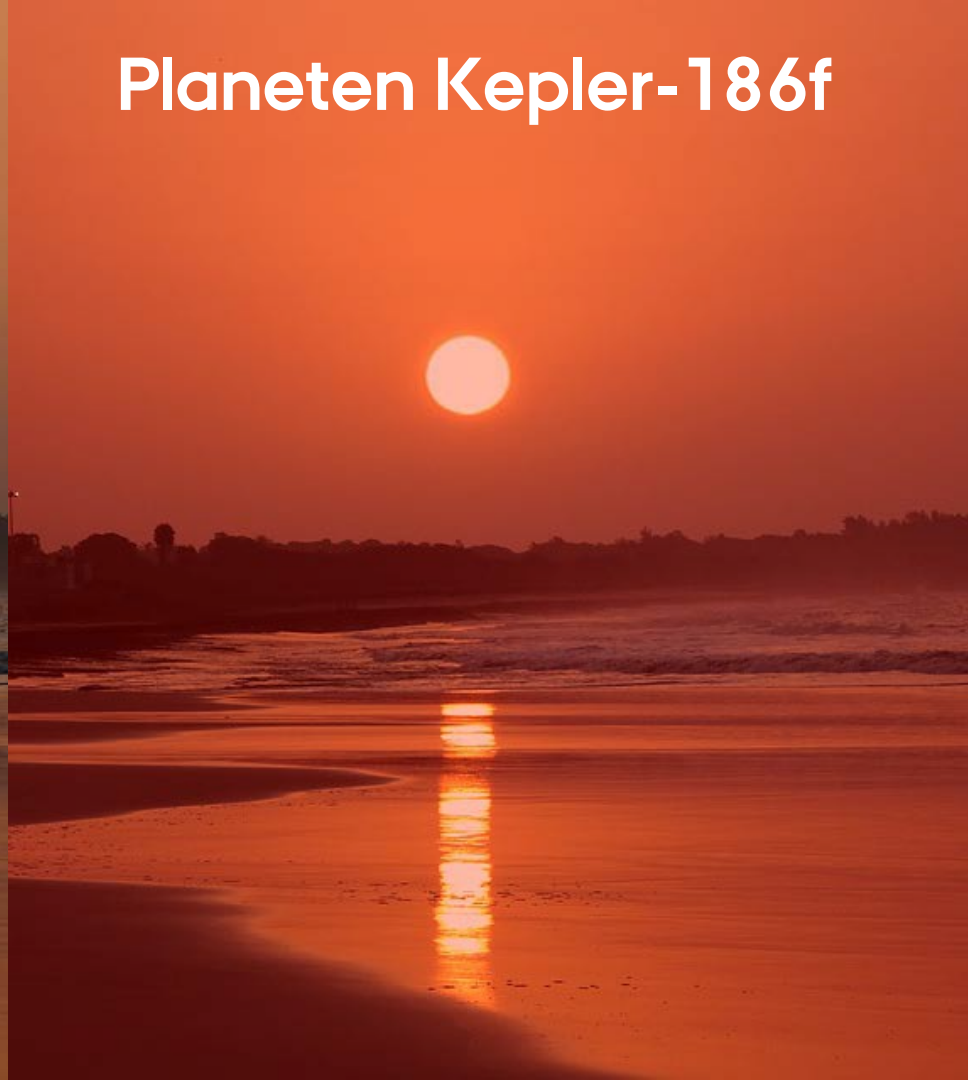
Planeten Kepler-186f



Planeten Jorden



Planeten Kepler-186f

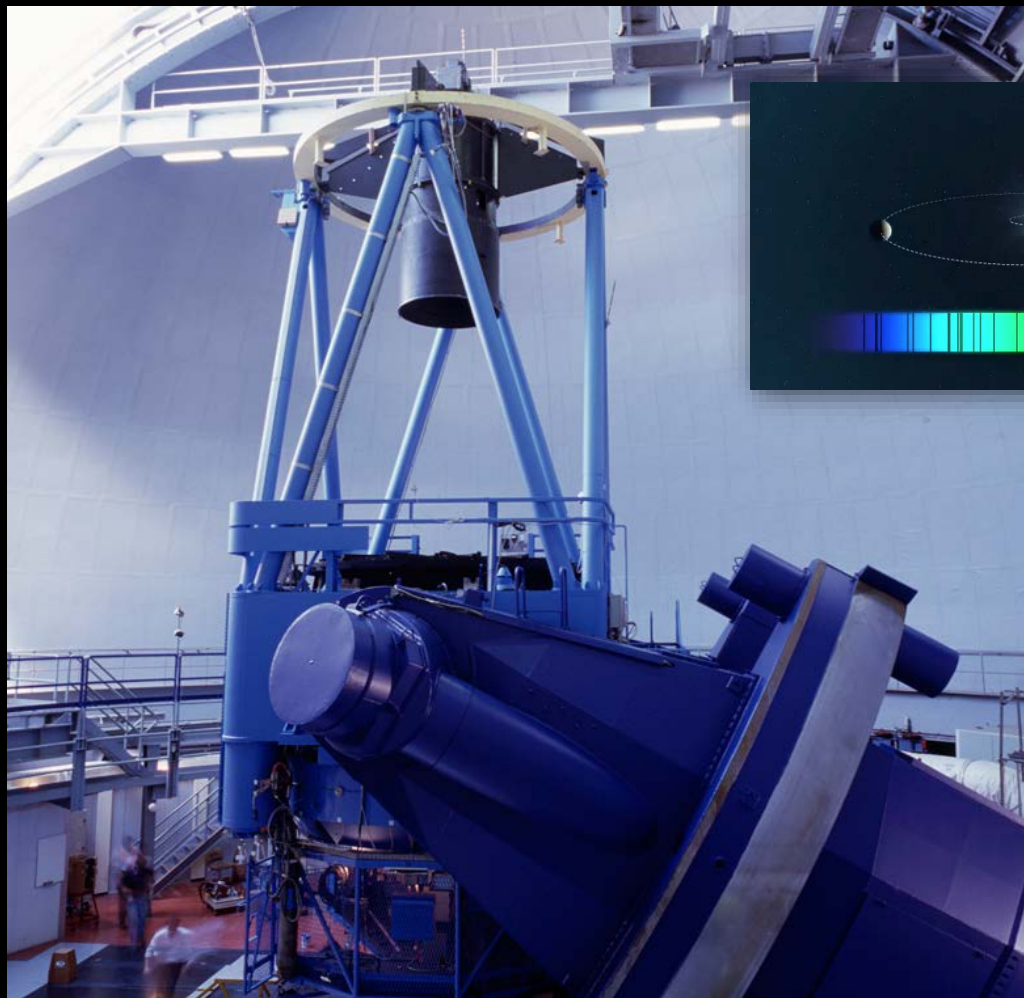


Stjernen Proxima Centauri

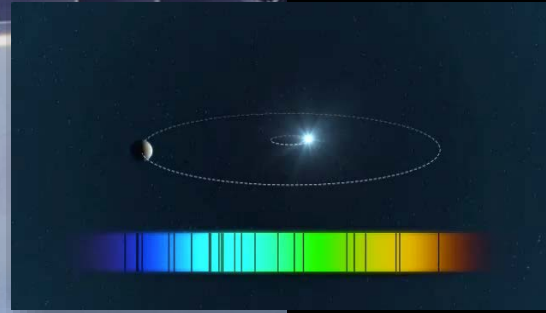


Nærmeste nabo: 4,2 lysår

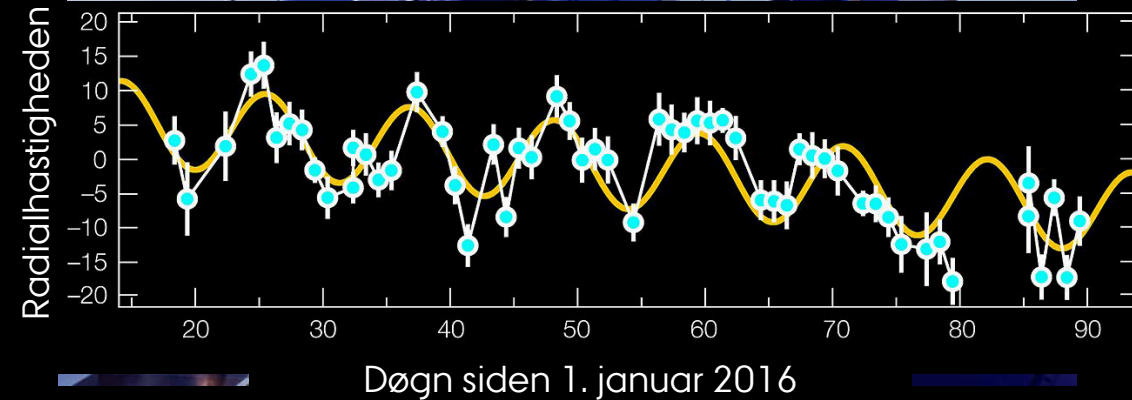




Måling af radial-
hastigheden for
stjernen Proxima
Centauri udført med
instrumentet HARPS
på 3,6m-teleskopet i
ved ESO i Chile.



Måling af radialhastigheden for stjernen Proxima Centauri udført med instrumentet HARPS på 3,6m-teleskopet i ved ESO i Chile.

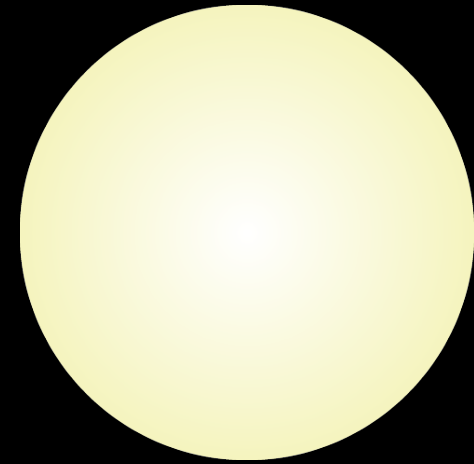


Planeten Proxima-b: 1-3 gange Jordens masse





Solen set fra
planeten
Jorden



Moderstjernen set fra
planeten Proxima-b

Rotation:

- Bunden rotation eller
- 2:3 resonans mellem rotation og omløb
(som Merkur)



Ingeniøren

Nyheder Blogs Debat Jobfinder Avisen Mere ▼ Sektioner ▼

VORES FOKUS NYE SIGNALER TIL JERNBANEN KUNSTIG INTELLIGENS 3D-PRINT DIESELSKANDALEN KAMPFL FLERE >

Her er rakterne, der kan sende os til Proxima B

Der er brug for helt ny raket teknologi, hvis vi skal kunne rejse til den nyopdagede planet Proxima B. Andreas Mogensen finder især antistofmotoren interessant.

af Thomas Djursing 3. sep 2016 kl. 14:00

Jobfinder

RELATEREDE JOB

Lands-Posten

Østjylland

BENHAVN

Nyopdagede planet giver mulighed i jagten på liv

Forskere har fundet en klippeplanet, der i størrelse ligner Jorden. Indholdet af vand og atmosfære på planeten har nemlig muligheden for at bære liv.

5 ting der gør Proxima B til den oplagte koloni

Vand og tålelige temperaturer. Solsystemets nærmeste nabo planeten Proxima B, kan være det bedste sted at bygge den første koloni udenfor Solsystemet. Læs her hvorfor.

9. maj 2017 af Rolf Haugaard Nielsen

Onsdag d. 24. aug. 2016 - kl. 14:00

Tegn på liv på planet lignende planet

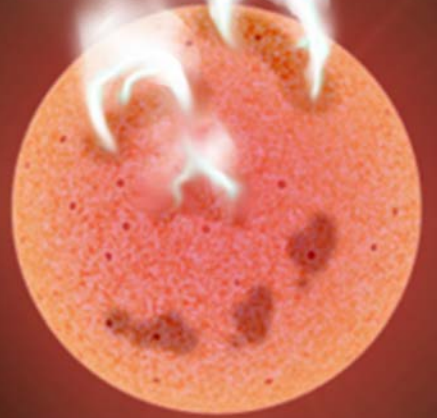
Astronomer har fundet en planet, der ligner vores egen, og som måske har vand.

Sensationel opdagelse tæt på Jorden

24. aug. 2016, 19:03 Opd. 24. aug. 2016, 21:41

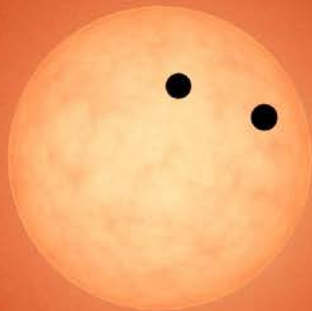
Er planeten Proxima-b beboelig?

- Moderstjernen har stærk solvind og hyppige udbrud
- Der er sandsynligvis ingen atmosfære på Proxima-b



Udbrud på Solen

Stjernen TRAPPIST-1



Stjernen TRAPPIST-1



nsdag d. 22. feb. 2017 - kl. 15:37
opdateret onsdag d. 22. feb. 2017 -

NASA afsl...

NASA har netop afsløret
her

Eksotiske øl-planeter kan rumme liv

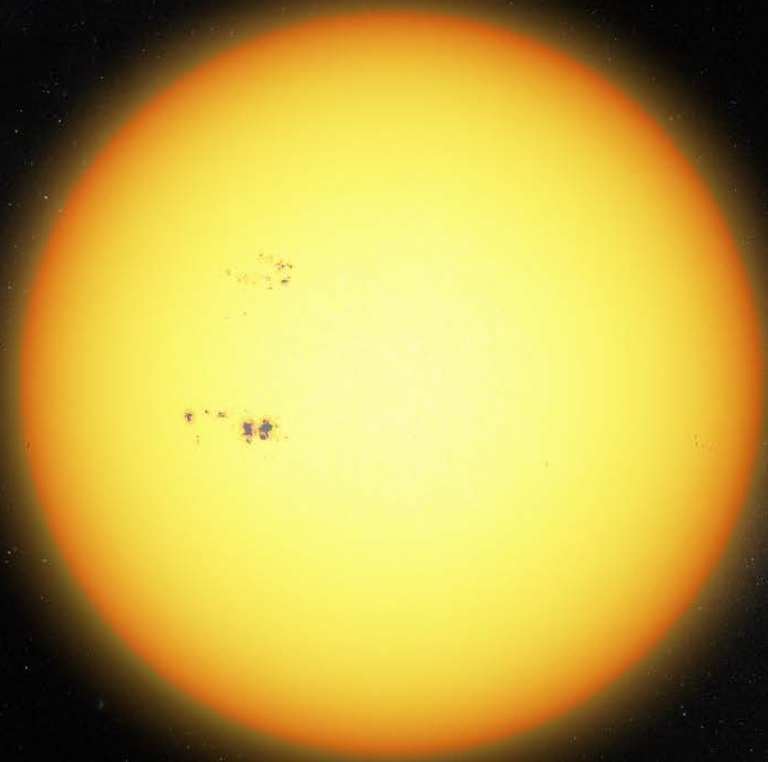
De tre lune trappist-planeter er opkaldt efter belgisk munkeøl og kan, muligvis, rumme liv under de forholdene derude er dybt mærkværdige.

TIRSDAG D. 3. MAJ 2016 KL. 18:00

Syv jordlignende planeter fundet

Forskere jager aliens: Jordlignende planeter kan have vand

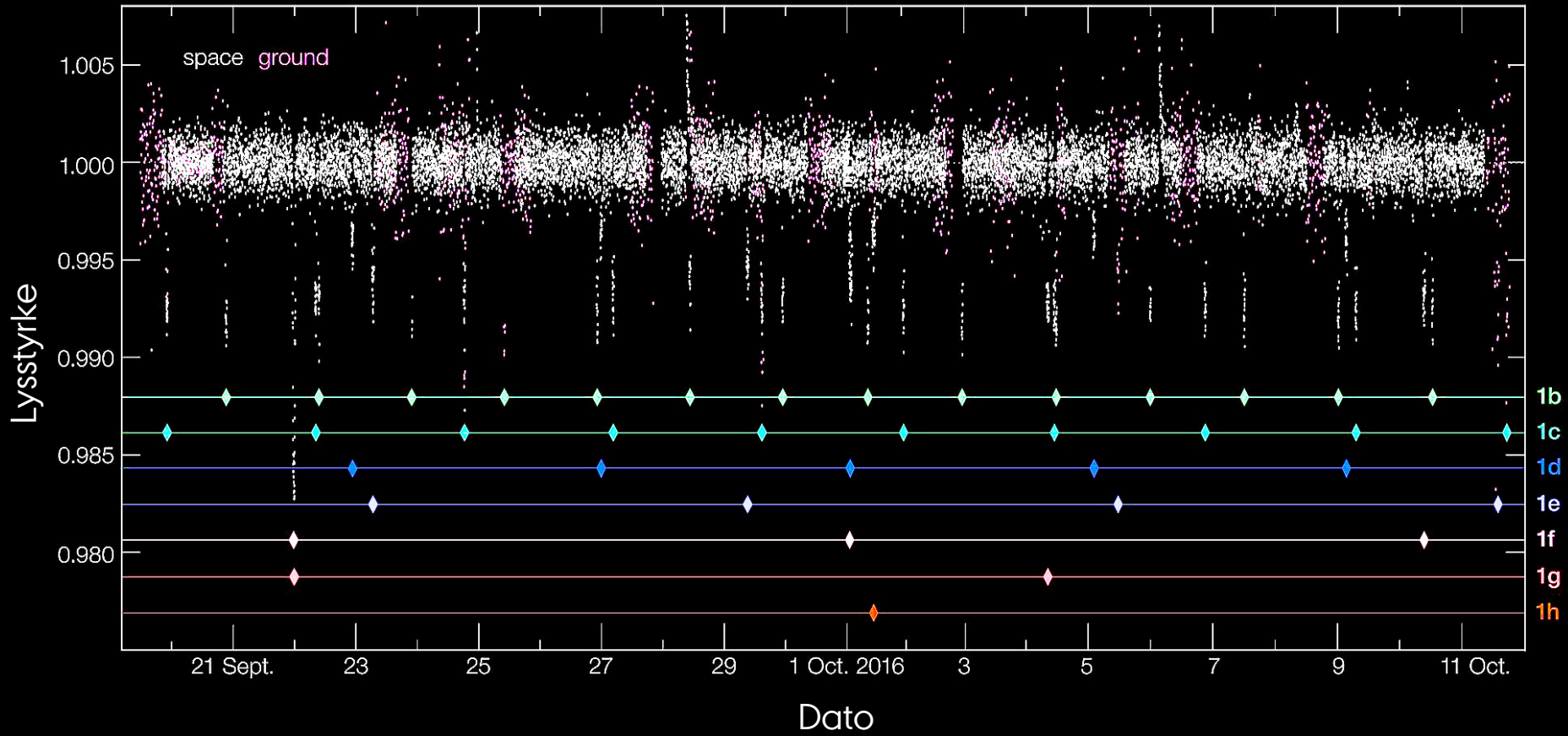
Nyt studie giver yderligere vægt til teorien om, at planeter, som kredser om den nærliggende stjerne TRAPPIST-1, kan være beboelige.



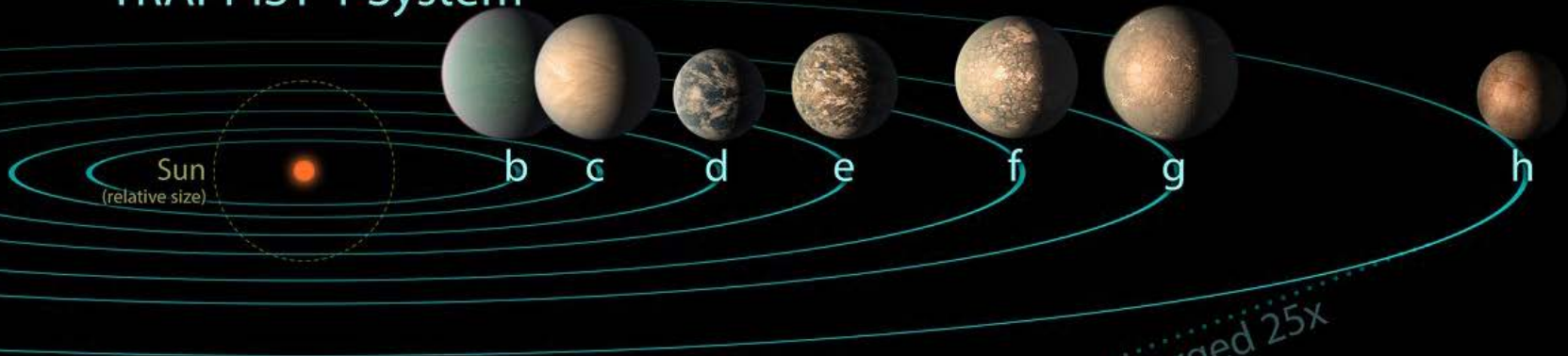
Sun



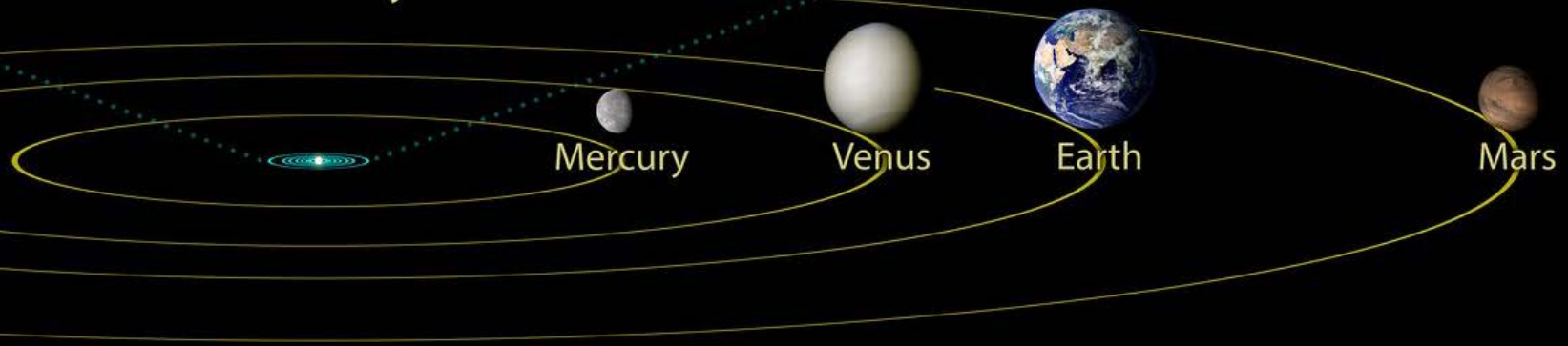
TRAPPIST-1



TRAPPIST-1 System



Inner Solar System



Orbits Enlarged 25x

TRAPPIST-1 System

Feb. 2018



b

c

d

e

f

g

h

<i>Orbital Period</i>	1.51 days	2.42 days	4.05 days	6.10 days	9.21 days	12.36 days	18.76 days
<i>Distance to Star</i>	0.0115 AU	0.0158 AU	0.0223 AU	0.0293 AU	0.0385 AU	0.0469 AU	0.0619 AU
<i>Planet Radius</i>	1.12 R_{earth}	1.10 R_{earth}	0.78 R_{earth}	0.91 R_{earth}	1.05 R_{earth}	1.15 R_{earth}	0.77 R_{earth}
<i>Planet Mass</i>	1.02 M_{earth}	1.16 M_{earth}	0.30 M_{earth}	0.77 M_{earth}	0.93 M_{earth}	1.15 M_{earth}	0.33 M_{earth}
<i>Planet Density</i>	0.73 ρ_{earth}	0.88 ρ_{earth}	0.62 ρ_{earth}	1.02 ρ_{earth}	0.82 ρ_{earth}	0.76 ρ_{earth}	0.72 ρ_{earth}
<i>Surface Gravity</i>	0.81 g	0.96 g	0.48 g	0.93 g	0.85 g	0.87 g	0.55 g

Solar System Rocky Planets



Mercury

Venus

Earth

Mars

<i>Orbital Period</i>	87.97 days	224.70 days	365.26 days	686.98 days
<i>Distance to Star</i>	0.387 AU	0.723 AU	1.000 AU	1.524 AU
<i>Planet Radius</i>	0.38 R_{earth}	0.95 R_{earth}	1.00 R_{earth}	0.53 R_{earth}
<i>Planet Mass</i>	0.06 M_{earth}	0.82 M_{earth}	1.00 M_{earth}	0.11 M_{earth}
<i>Planet Density</i>	0.98 ρ_{earth}	0.95 ρ_{earth}	1.00 ρ_{earth}	0.71 ρ_{earth}
<i>Surface Gravity</i>	0.38 g	0.90 g	1.00 g	0.38 g

TRAPPIST-1 System

Feb. 2018



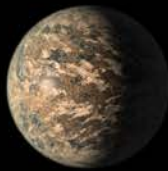
b



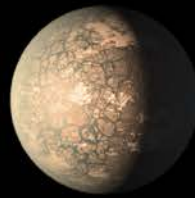
c



d



e



f



g



h

<i>Orbital Period</i>	1.51 days	2.42 days	4.05 days	6.10 days	9.21 days	12.36 days	18.76 days
<i>Distance to Star</i>	0.0115 AU	0.0158 AU	0.0223 AU	0.0293 AU	0.0385 AU	0.0469 AU	0.0619 AU
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<i>Surface Gravity</i>	0.81 g	0.96 g	0.48 g	0.93 g	0.85 g	0.87 g	0.55 g

Solar System Rocky Planets



Mercury



Venus



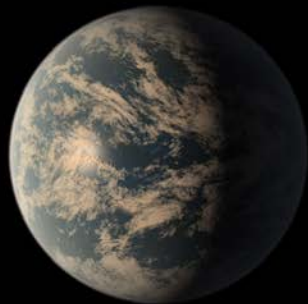
Earth



Mars

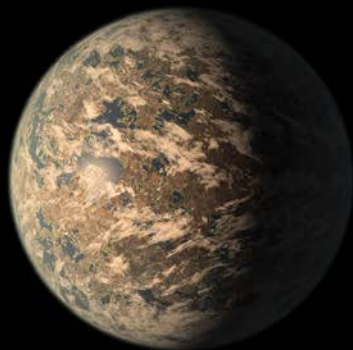
<i>Orbital Period</i>	87.97 days	224.70 days	365.26 days	686.98 days
<i>Distance to Star</i>	0.387 AU	0.723 AU	1.000 AU	1.524 AU
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<i>Planet Density</i>	0.98 ρ_{earth}	0.95 ρ_{earth}	1.00 ρ_{earth}	0.71 ρ_{earth}
<i>Surface Gravity</i>	0.38 g	0.90 g	1.00 g	0.38 g

+45° C



d

+5° C



e

-20° C



f

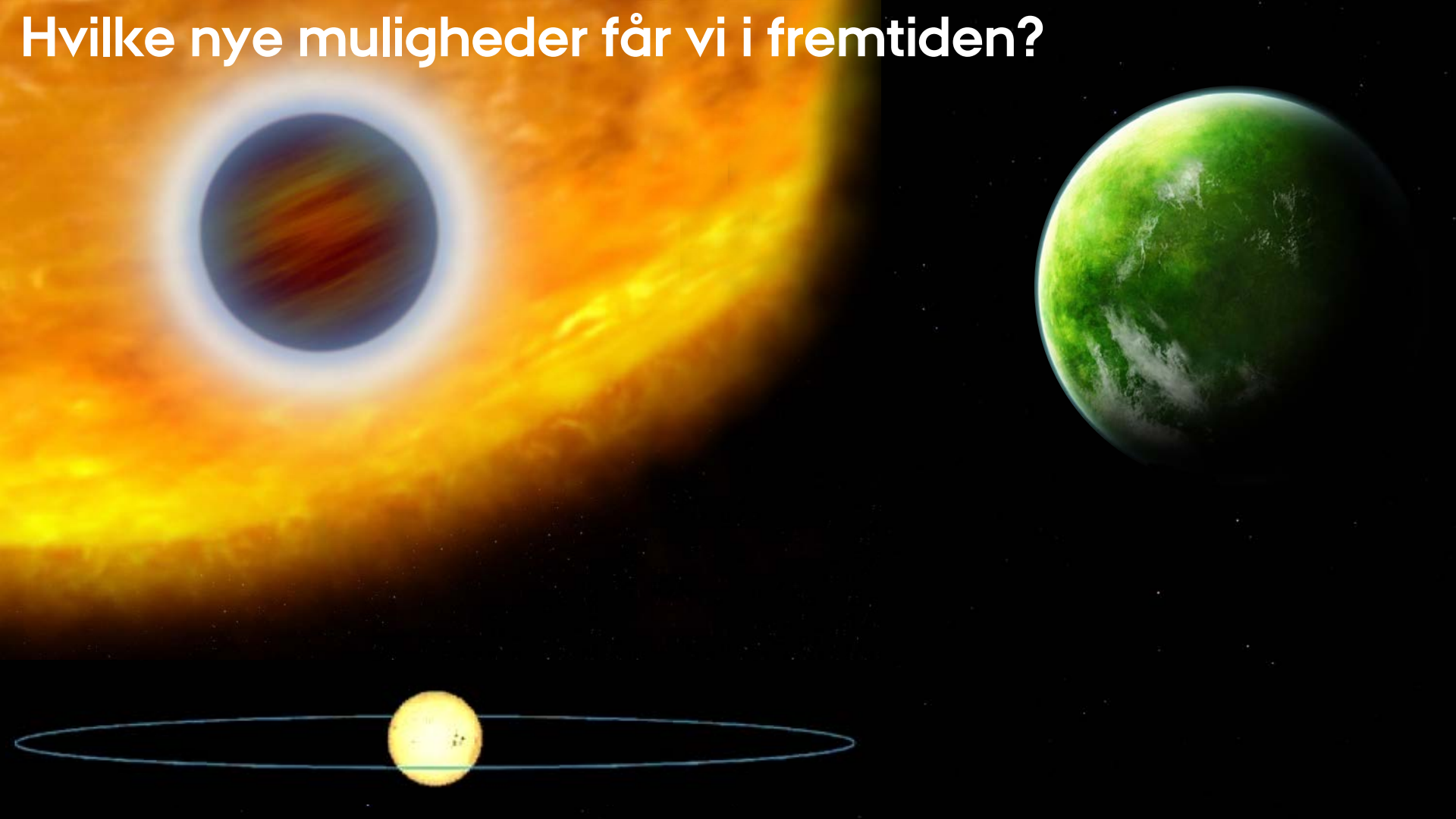
TRAPPIST-1



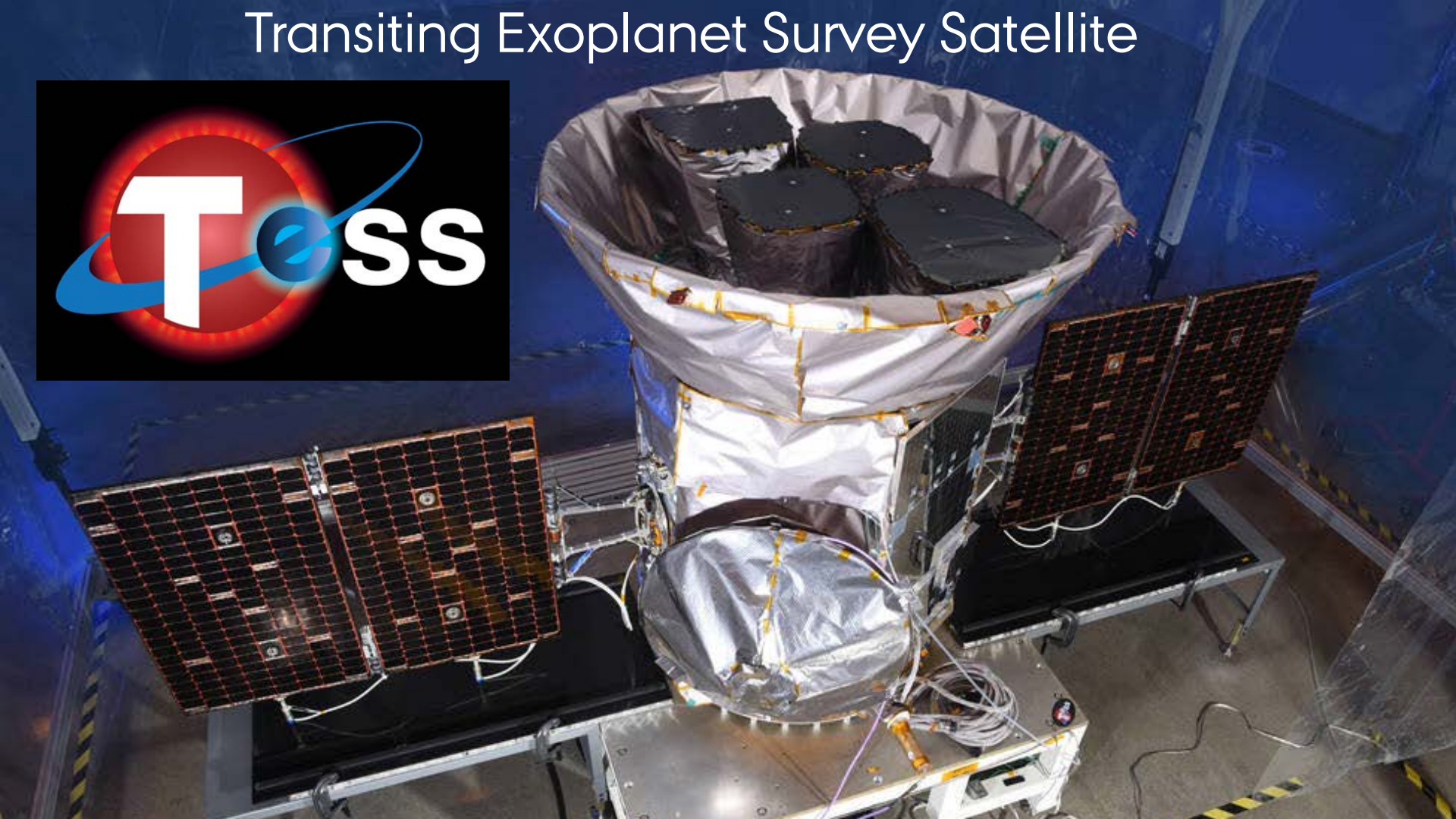
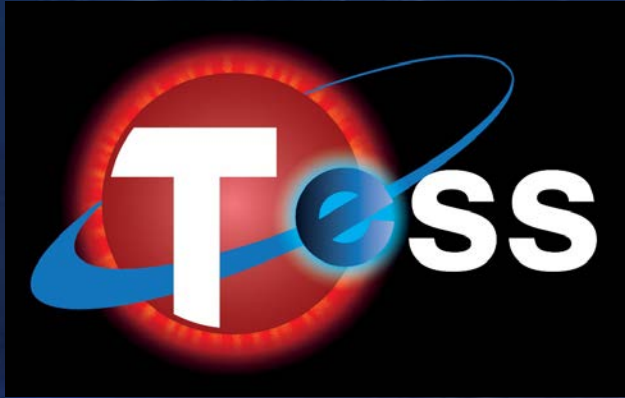
+15° C

Planeten Jorden

Hvilke nye muligheder får vi i fremtiden?



Transiting Exoplanet Survey Satellite



TESS Opsendesen KSC Florida, USA

19. april 2018

T- 00:00:25

UPCOMING LIFTOFF

STARTUP

THE FALCON 9 FLIGHT COMPUTERS
HAVE TAKEN CONTROL OF THE
COUNTDOWN

LAUNCH: TESS

STARTUP MECD ENTRY LANDING

LIFTOFF BOOSTBACK SECOND STAGE ENGINE CUTOFF

SECOND STAGE ENGINE CUTOFF

SECOND STAGE ENGINE STARTUP

DEPLOY

SPACEX

T- 00:00:25

UPCOMING LIFTOFF

STARTUP

THE FALCON 9 FLIGHT COMPUTERS
HAVE TAKEN CONTROL OF THE
COUNTDOWN

LAUNCH: TESS

STARTUP MECD ENTRY LANDING

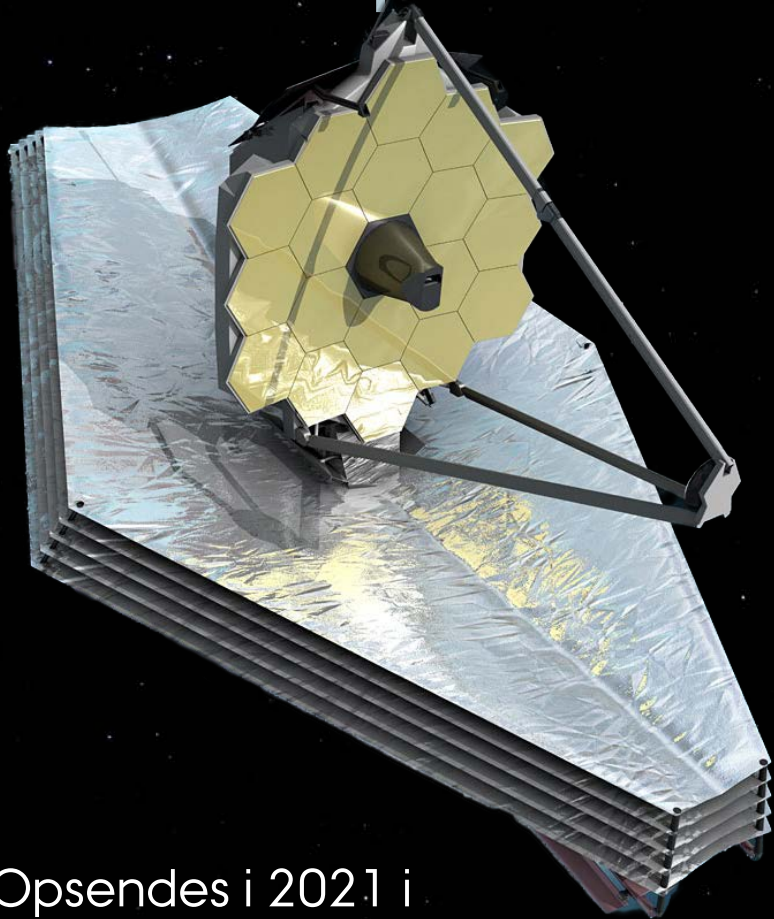


SECOND STAGE ENGINE CUTOFF

SPACEX



Rumteleskopet JWST



Opsendes i 2021 i
samarbejde mellem ESA og NASA

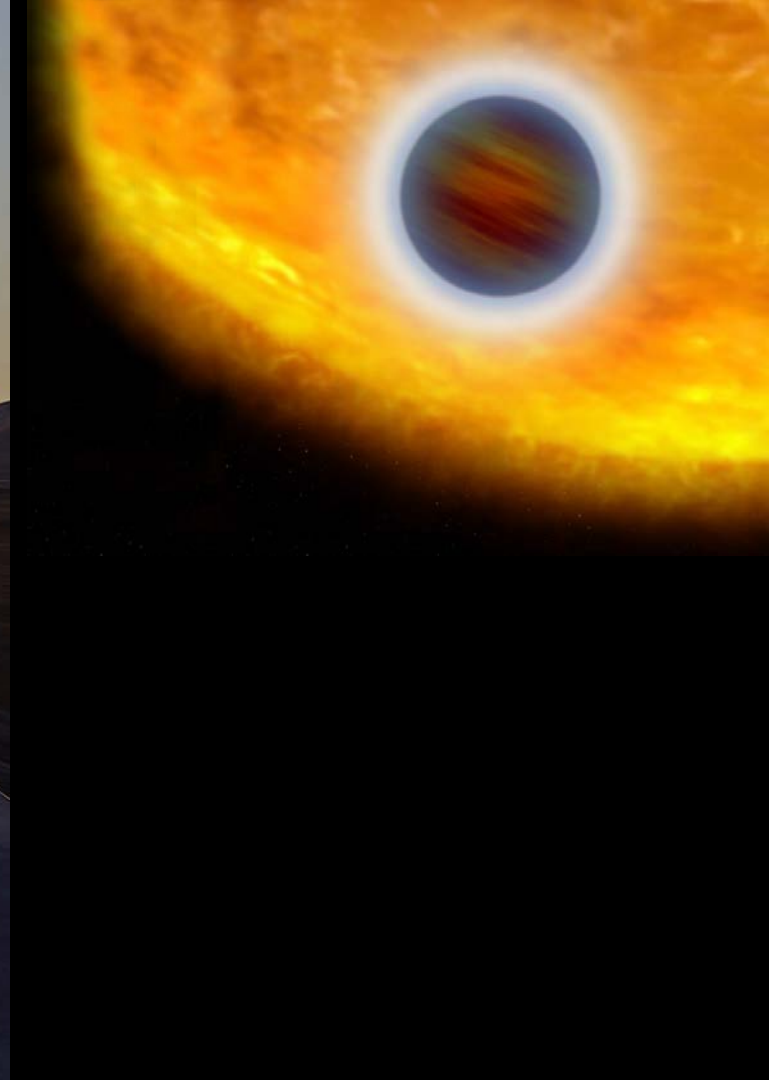


European Southern Observatory:
VLT – Very Large Telescope

**ESO's ELT:
Teleskopets diameter er 39 meter**



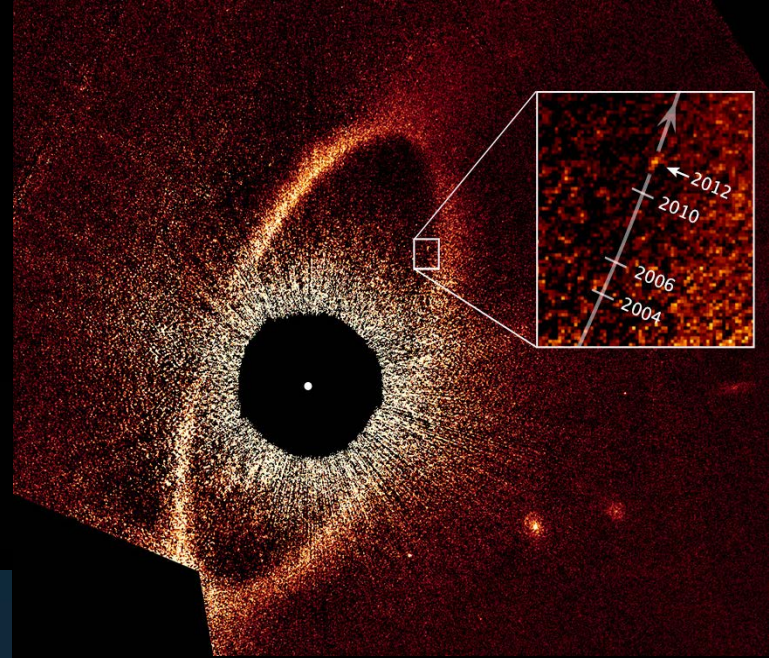
ELT står færdigt i 2026





Teknikker til at finde planeter

- Direkte billeder
- Tyngdekraften (radialhastigheden)
- Planetpassager (skyggen)



Sara Seager, Massachusetts Institute of Technology, USA



$$P(\theta) = \int P(\theta, \phi) d\phi$$
$$= \frac{\int P(\theta, \phi) d\phi}{(\pi/2)}$$

Sum of all sources and sinks

$$\frac{dI}{dt} = -kI + j$$



STELLAR ASTROPHYSICS CENTRE



Stjernerne og deres planeter ligger typisk
mere end 100.000 mia. km væk



Stjernerne og deres planeter ligger typisk
mere end 100.000 mia. km væk

Starshade
34 m i diameter

Rumteleskop med en
diameter på 1-3 meter



Stjernerne og deres planeter ligger typisk mere end 100.000 mia. km væk

Starshade
34 m i diameter

37.000 km

Rumteleskop med en diameter på 1-3 meter

Forventes bygget omkring 2030





Aarhus Universitet
Institut for Fysik og Astronomi



STELLAR ASTROPHYSICS CENTRE