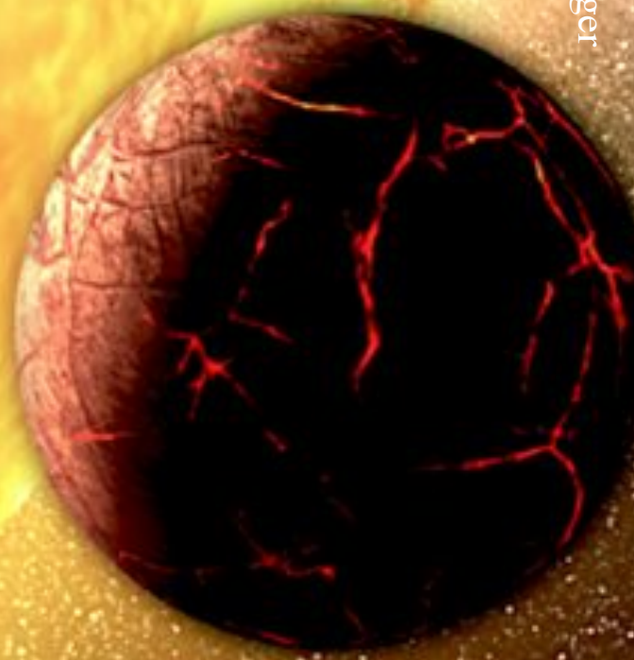
Sterbevingen, exoplaneten, en buitenaards leven?

door Conny Aerts



9/3/2020, Het Turnhouts Wetenschapscafé

Image credit: NASA's Goddard Space Flight Center/S. Wiessinger

STERREN: HETE GASBOLLEN DIE STRALEN

PLANETEN STRALEN NIET ZELF MAAR REFLECTEREN LICHT VAN HUN MOEDERSTER

Zon:
binnenkant
miljoenen graden
buitenkant
5500 graden

Rechtstreekse detectie
van exoplaneten is moeilijk

Sterbevingen & exoplaneten: waar beginnen zoeken? …

ER ZIJN MILJARDEN STERRENSTELSELS

ELK MET MILJARDEN STERREN

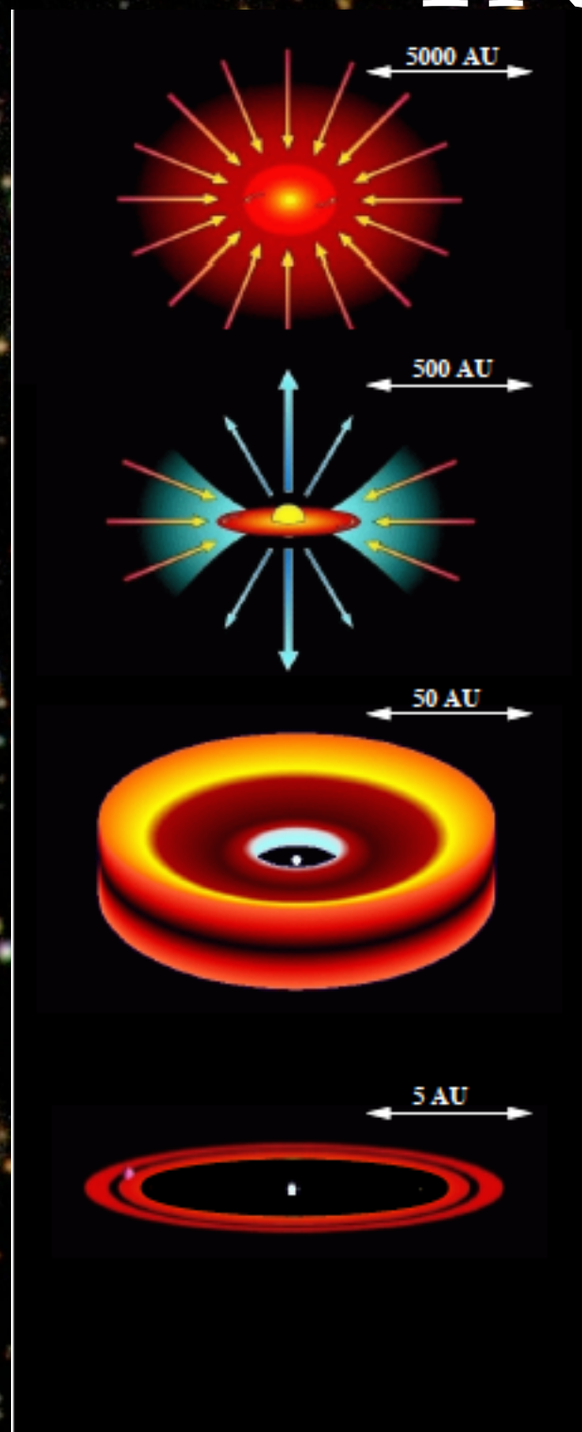
Hubble eXtreme Deep Field (XDF)

Hubble Space Telescope • ACS/WFC • WFC3/IR

LAAT ONS VLAK BIJ HUIS BEGINNEN

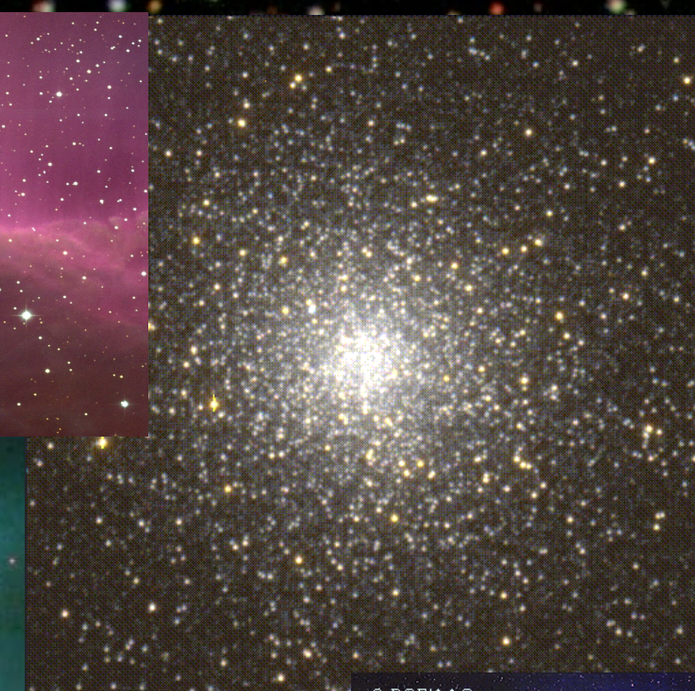
OP AFSTAND VAN
40,000,000,000,000,000 M
(OFTE 4,2 LICHTJAREN)

STERREN & PLANETEN WORDEN SAMEN GEBOREN IN STERRENHOPEN

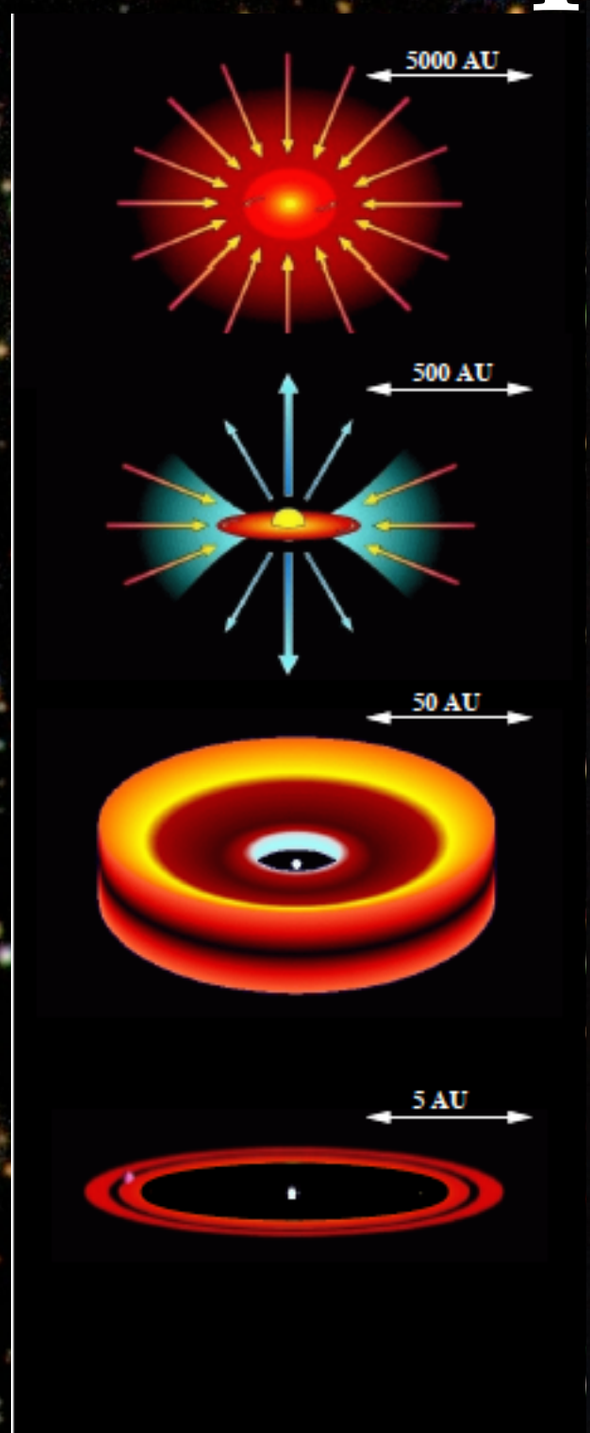


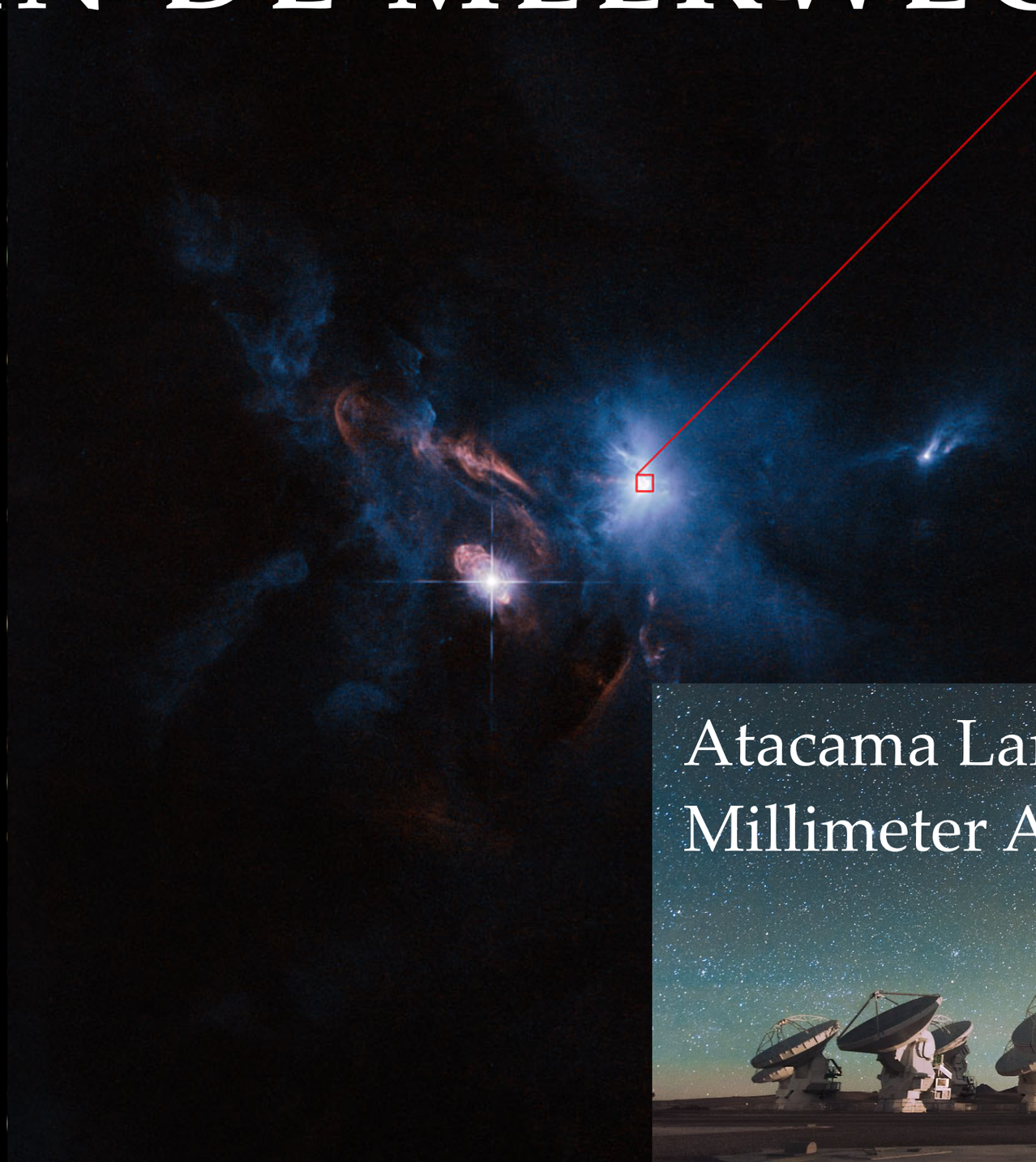
Gaseous Pillars · M16 HST · WFPC2

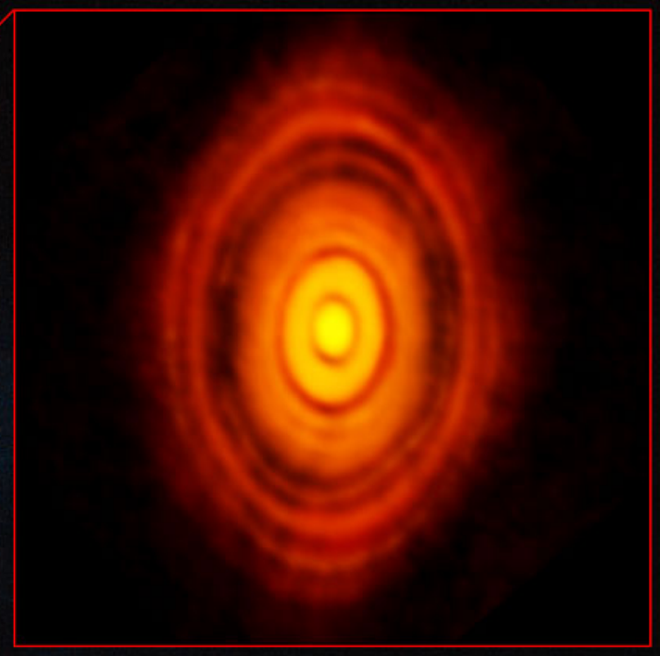
PRC95-44a · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

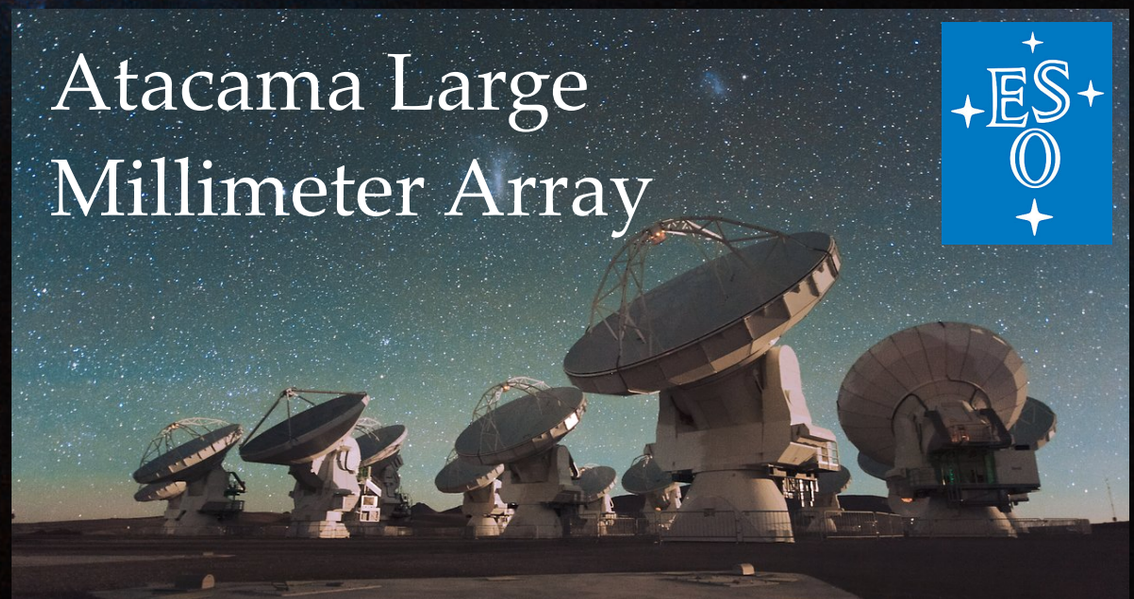


STERREN & HUN PLANETEN GERAKEN DAN GEÏSOLEERD IN DE MELKWEG

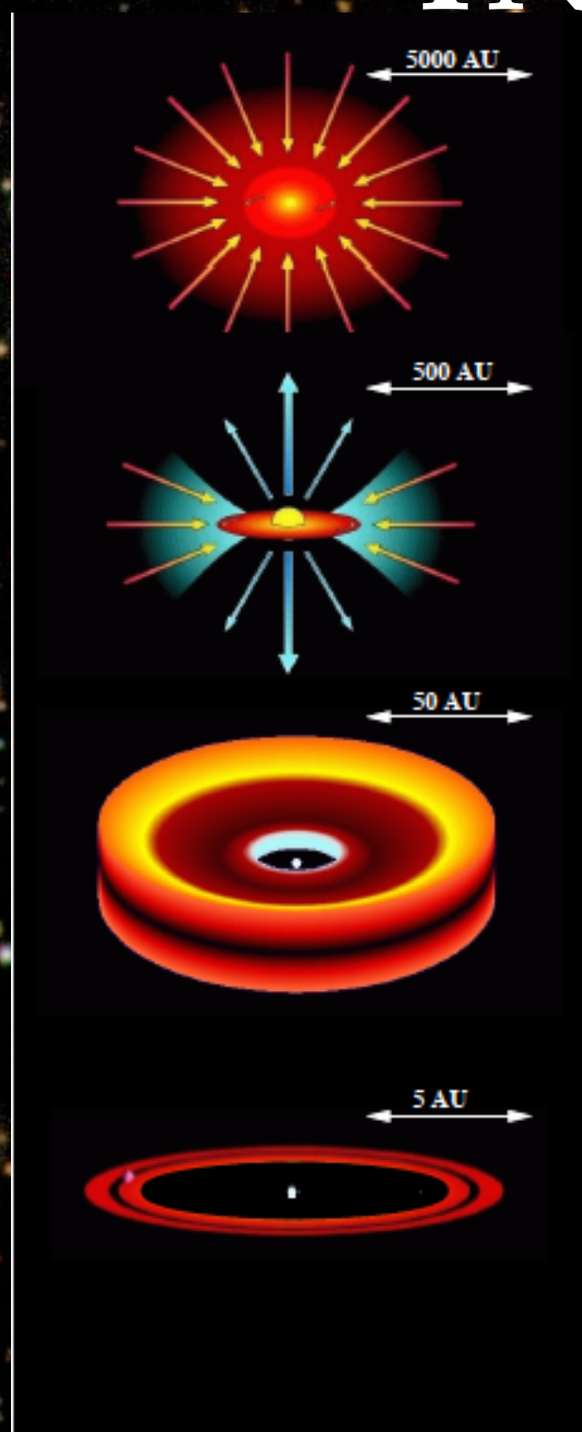








STERREN & PLANETEN WORDEN SAMEN GEBOREN IN STERRENHOPEN



LEEFTIJD MOEDERSTER

≈

LEEFTIJD PLANEET

STERREN ZIJN KERNREACTOREN

GEEN KERNSPLIJTINGSREACTOREN

Periodiek Systeem van de Elementen

- alkalimetalen
- aardalkalimetalen
- transitiemetalen
- andere metalen
- nietmetalen
- edelgassen
- lanthaniden
- actiniden

C — Br — He — Tc kunst-matig

elementnaam
atoomnummer
symbool
atoommassa

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
waterstof 1 **H** [1,007; 1,009]																	helium 2 **He** 4,003
lithium 3 **Li** [6,938; 6,997]	beryllium 4 **Be** 9,012											boor 5 **B** [10,80; 10,83]	koolstof 6 **C** [12,00; 12,02]	stikstof 7 **N** [14,00; 14,01]	zuurstof 8 **O** [15,99; 16,00]	fluor 9 **F** 19,00	neon 10 **Ne** 20,18
natrium 11 **Na** 22,99	magnesium 12 **Mg** 24,31											aluminium 13 **Al** 26,98	silicium 14 **Si** [28,08; 28,09]	fosfor 15 **P** 30,97	zwavel 16 **S** [32,0; 32,08]	chloor 17 **Cl** [35,44; 35,46]	argon 18 **Ar** 39,95
kalium 19 **K** 39,10	calcium 20 **Ca** 40,08	scandium 21 **Sc** 44,96	titaan 22 **Ti** 47,87	vanadium 23 **V** 50,94	chroom 24 **Cr** 52,00	mangaan 25 **Mn** 54,94	ijzer 26 **Fe** 55,85	kobalt 27 **Co** 58,93	nikkel 28 **Ni** 58,69	koper 29 **Cu** 63,55	zink 30 **Zn** 65,38(2)	gallium 31 **Ga** 69,72	germanium 32 **Ge** 72,63	arseen 33 **As** 74,92	seleen 34 **Se** 78,96(3)	broom 35 **Br** 79,90	krypton 36 **Kr** 83,80
rubidium 37 **Rb** 85,47	strontium 38 **Sr** 87,62	yttrium 39 **Y** 88,91	zirkonium 40 **Zr** 91,22	niobium 41 **Nb** 92,91	molybdeen 42 **Mo** 95,96(2)	technetium 43 **Tc**	ruthenium 44 **Ru** 101,1	rhodium 45 **Rh** 102,9	palladium 46 **Pd** 106,4	zilver 47 **Ag** 107,9	cadmium 48 **Cd** 112,4	indium 49 **In** 114,8	tin 50 **Sn** 118,7	antimoon 51 **Sb** 121,8	telluur 52 **Te** 127,6	jood 53 **I** 126,9	xenon 54 **Xe** 131,3
cesium 55 **Cs** 132,9	barium 56 **Ba** 137,3	57-71 lanthaniden	hafnium 72 **Hf** 178,5	tantaal 73 **Ta** 180,9	wolfraam 74 **W** 183,8	renium 75 **Re** 186,2	osmium 76 **Os** 190,2	iridium 77 **Ir** 192,2	platina 78 **Pt** 195,1	goud 79 **Au** 197,0	kwik 80 **Hg** 200,6	thallium 81 **Tl** [204,3; 204,4]	lood 82 **Pb** 207,2	bismut 83 **Bi** 209,0	polonium 84 **Po**	astaat 85 **At**	radon 86 **Rn**
francium 87 **Fr**	radium 88 **Ra**	89-103 actiniden	rutherfordium 104 **Rf**	dubnium 105 **Db**	seaborgium 106 **Sg**	bohrium 107 **Bh**	hassium 108 **Hs**	meitnerium 109 **Mt**	darmstadtium 110 **Ds**	roentgenium 111 **Rg**	copernicium 112 **Cn**	nihonium 113 **Nh**	flerovium 114 **Fl**	moscovium 115 **Mc**	livermorium 116 **Lv**	tennessine 117 **Ts**	oganesson 118 **Og**

lanthaan 57 **La** 138,9	cerium 58 **Ce** 140,1	praseodymium 59 **Pr** 140,9	neodymium 60 **Nd** 144,2	promethium 61 **Pm**	samarium 62 **Sm** 150,4	europium 63 **Eu** 152,0	gadolinium 64 **Gd** 157,3	terbium 65 **Tb** 158,9	dysprosium 66 **Dy** 162,5	holmium 67 **Ho** 164,9	erbium 68 **Er** 167,3	thulium 69 **Tm** 168,9	ytterbium 70 **Yb** 173,1	lutetium 71 **Lu** 175,0
actinium 89 **Ac**	thorium 90 **Th** 232,0	protactinium 91 **Pa** 231,0	uranium 92 **U** 238,0	neptunium 93 **Np**	plutonium 94 **Pu**	americium 95 **Am**	curium 96 **Cm**	berkelium 97 **Bk**	californium 98 **Cf**	einsteinium 99 **Es**	fermium 100 **Fm**	mendelevium 101 **Md**	nobelium 102 **No**	lawrencium 103 **Lr**

Chemie
Biochemie

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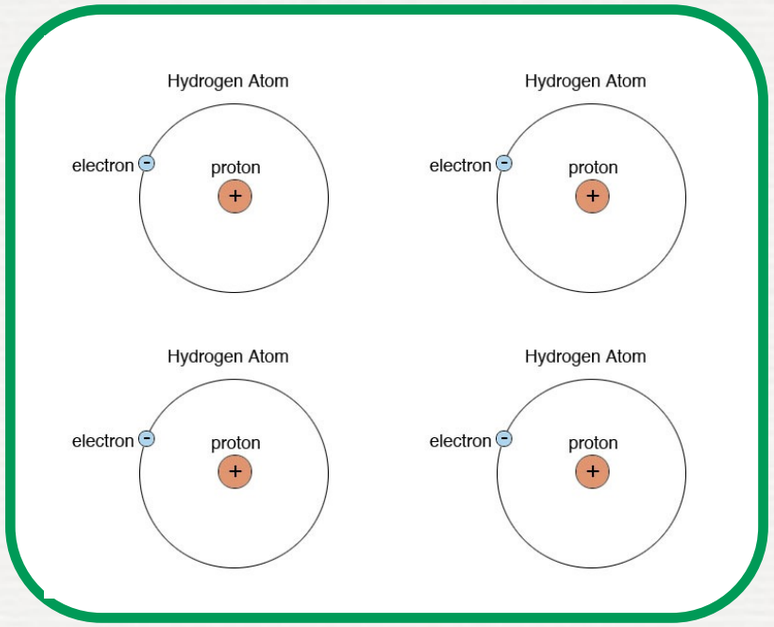
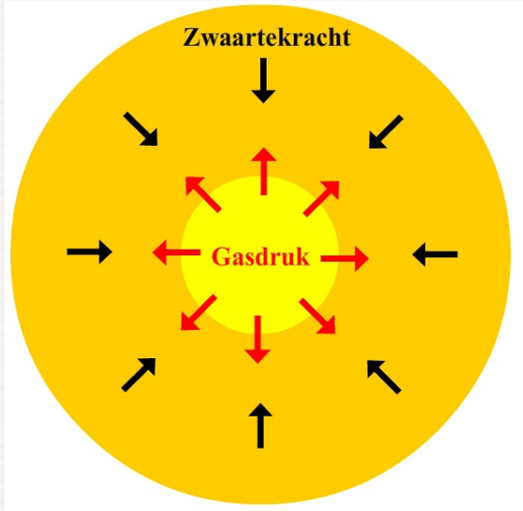
KU LEUVEN

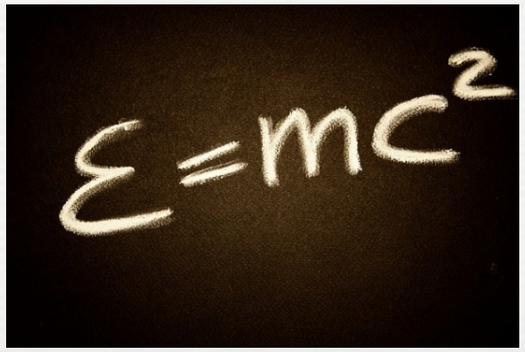
STERREN DOEN AAN KERNFUSIE

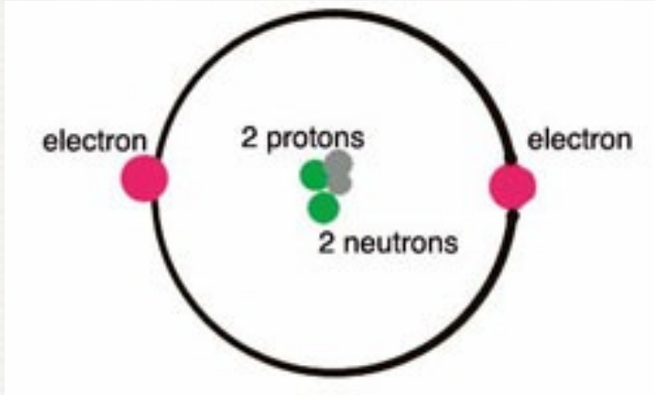
BIG BANG: 75% H, 25% HE, KLEIN BEETJE LI

BINNENIN STERREN: GAS IS MILJOENEN GRADEN HEET EN ER HEERST GROTE DICHTHEID EN DRUK

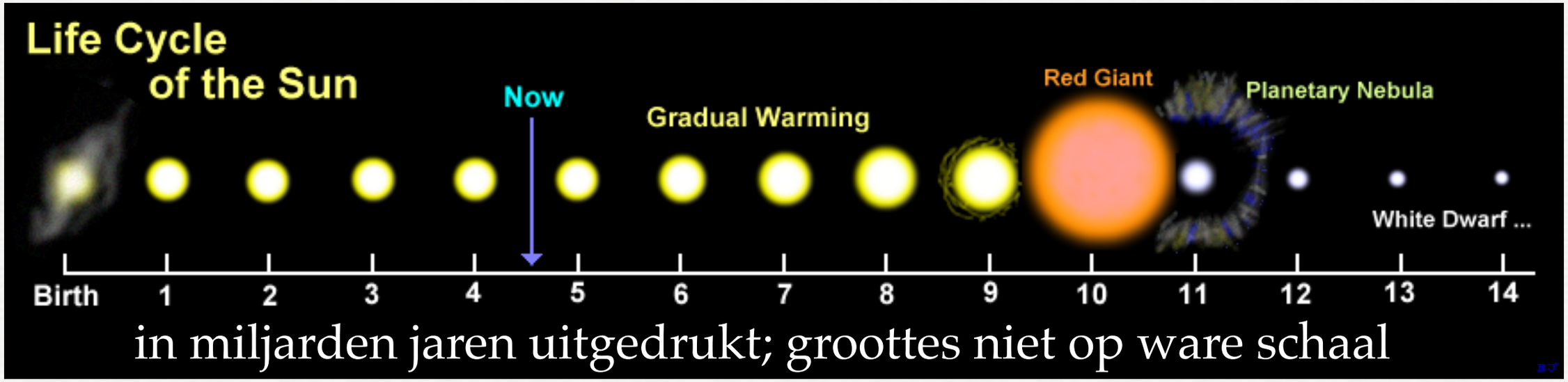


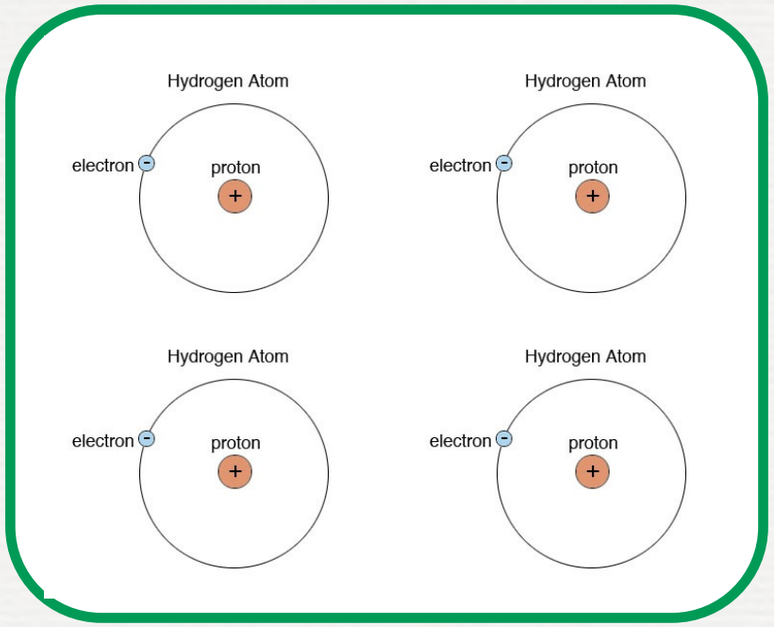


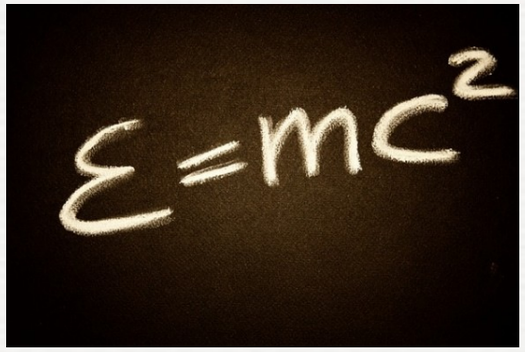


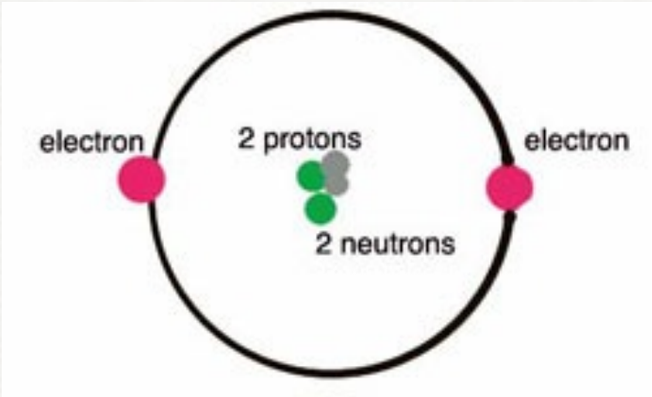


HET LEVENSPAD VAN DE ZON





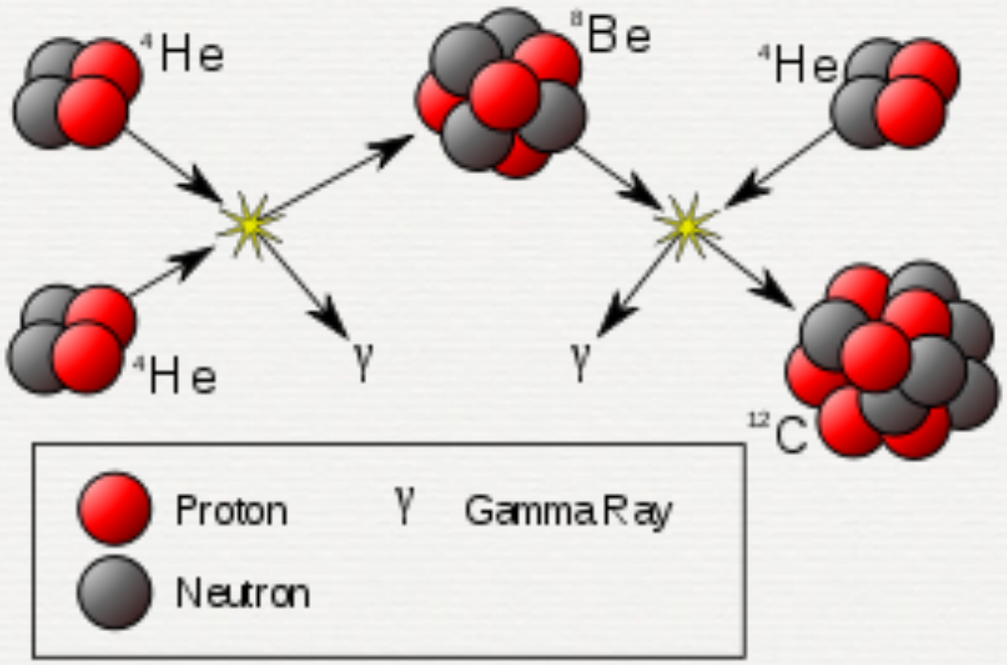




Zolang de H voorraad strekt

ENERGIECRISIS OP KOMST

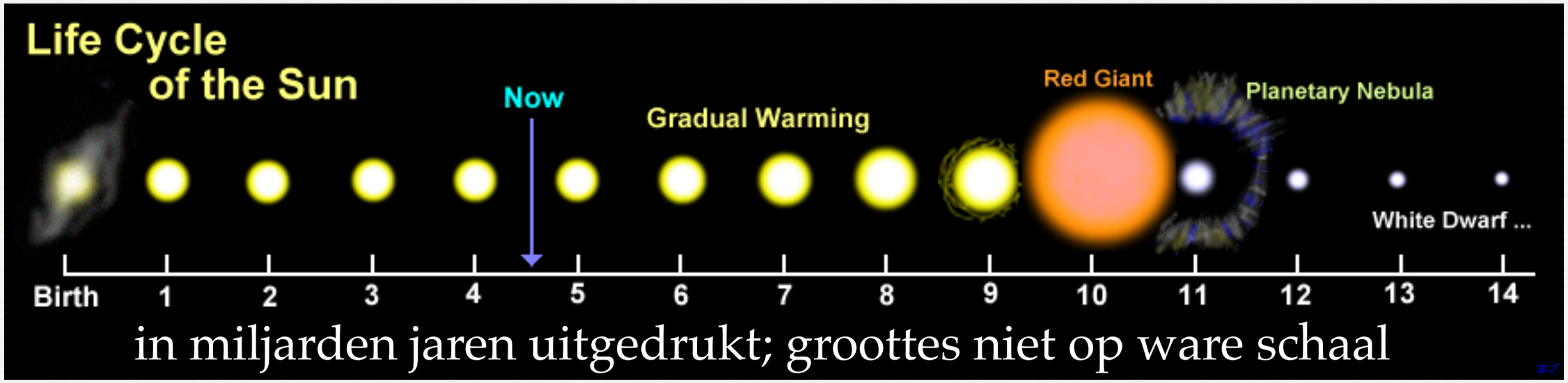
Om koolstof te maken: He nodig & 10x heter



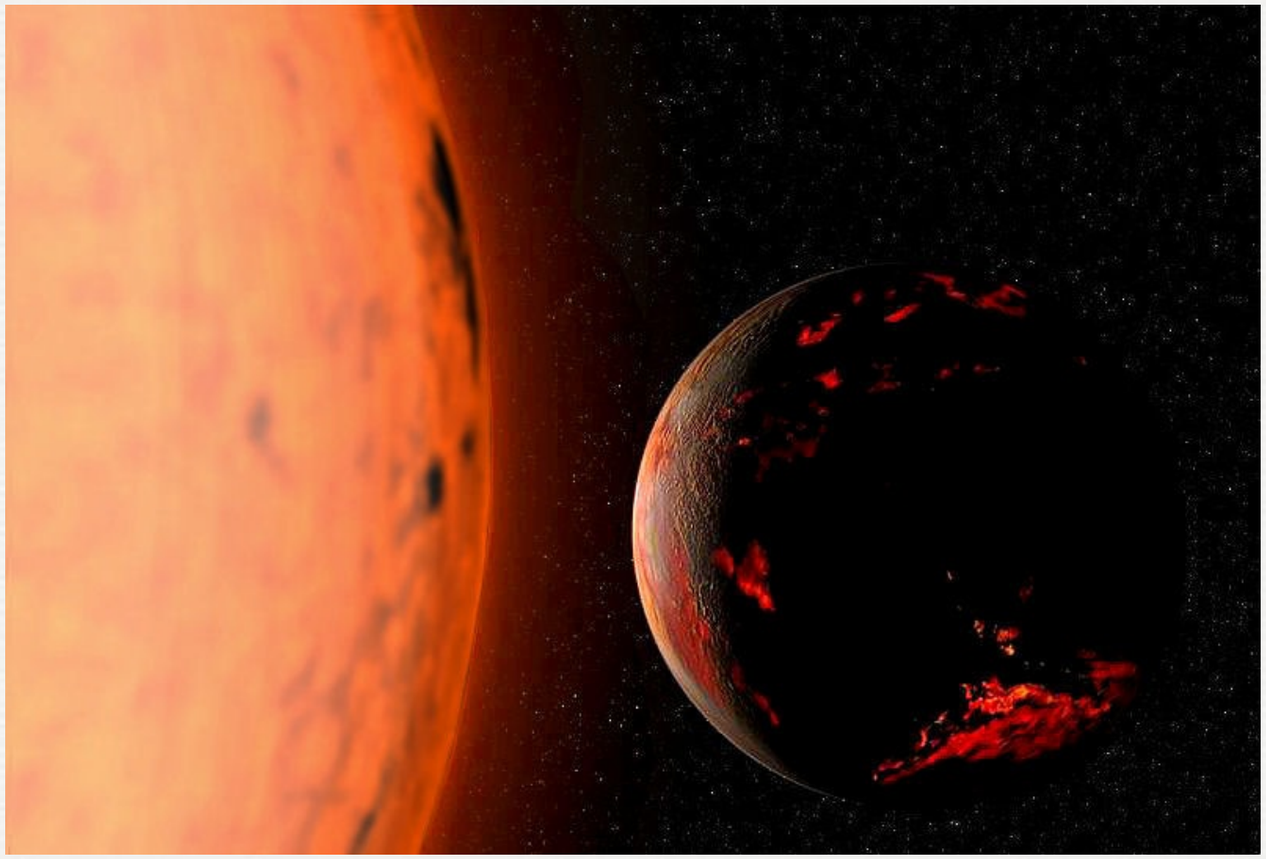
HELIUMBAL IN ZON MOET KRIMPEN OM 10X HETER TE MAKEN:

ZON WORDT RODE REUS

HET LOT VAN ONZE AARDE...

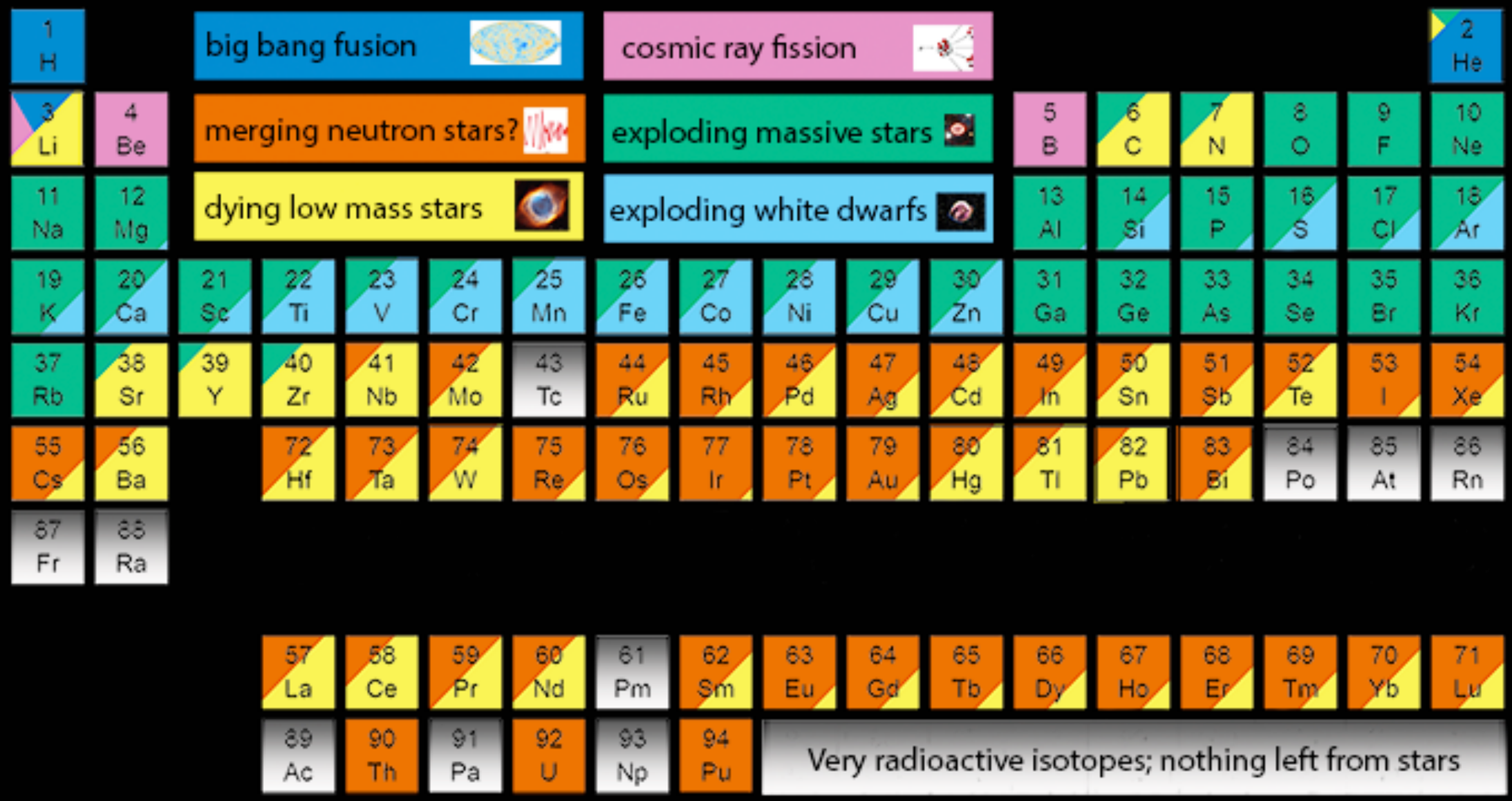


WANNEER? (LEEFTIJD ZON?)



HOE DICHT? (STRAAL ZON?)

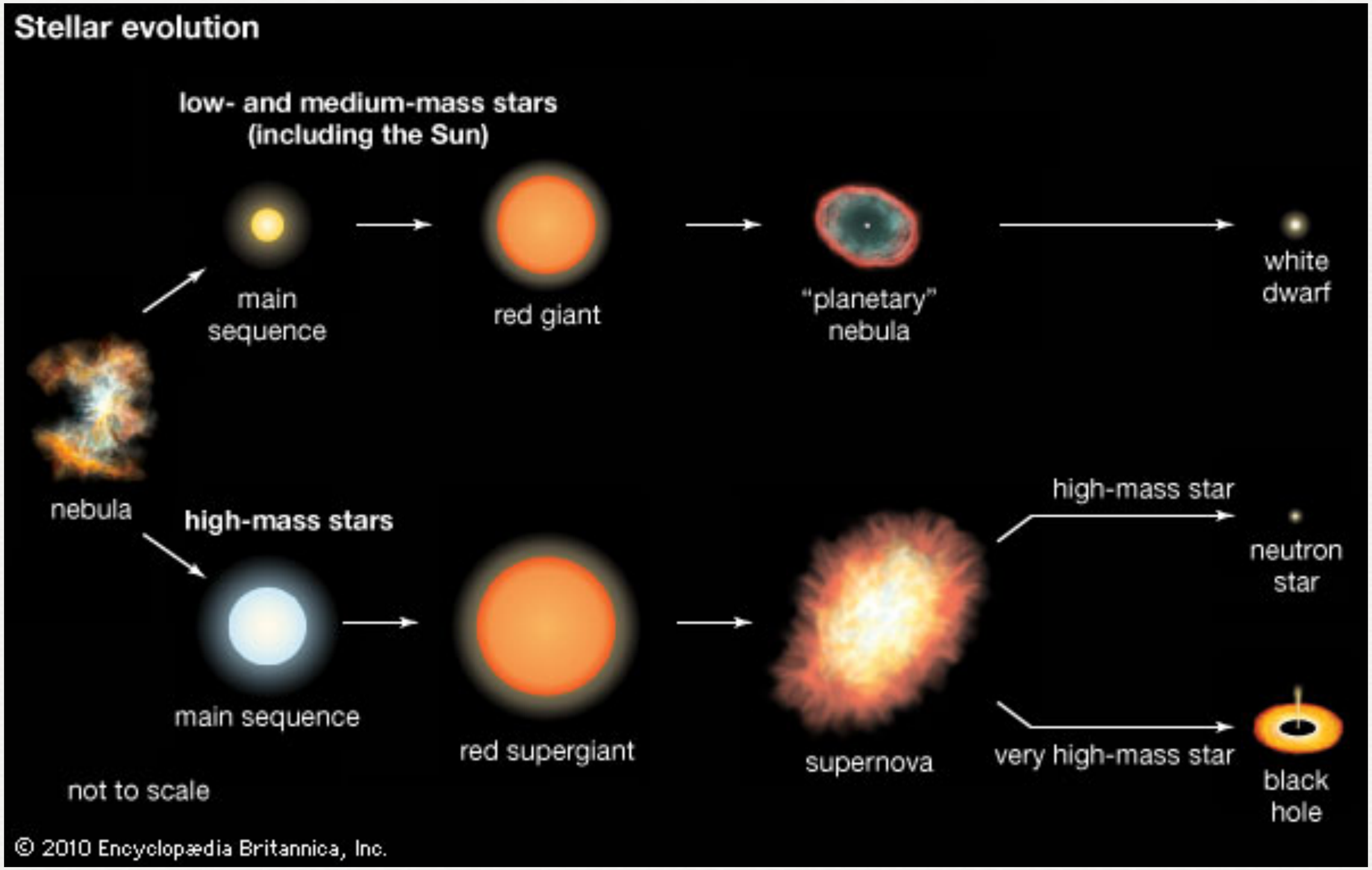
The Origin of the Solar System Elements



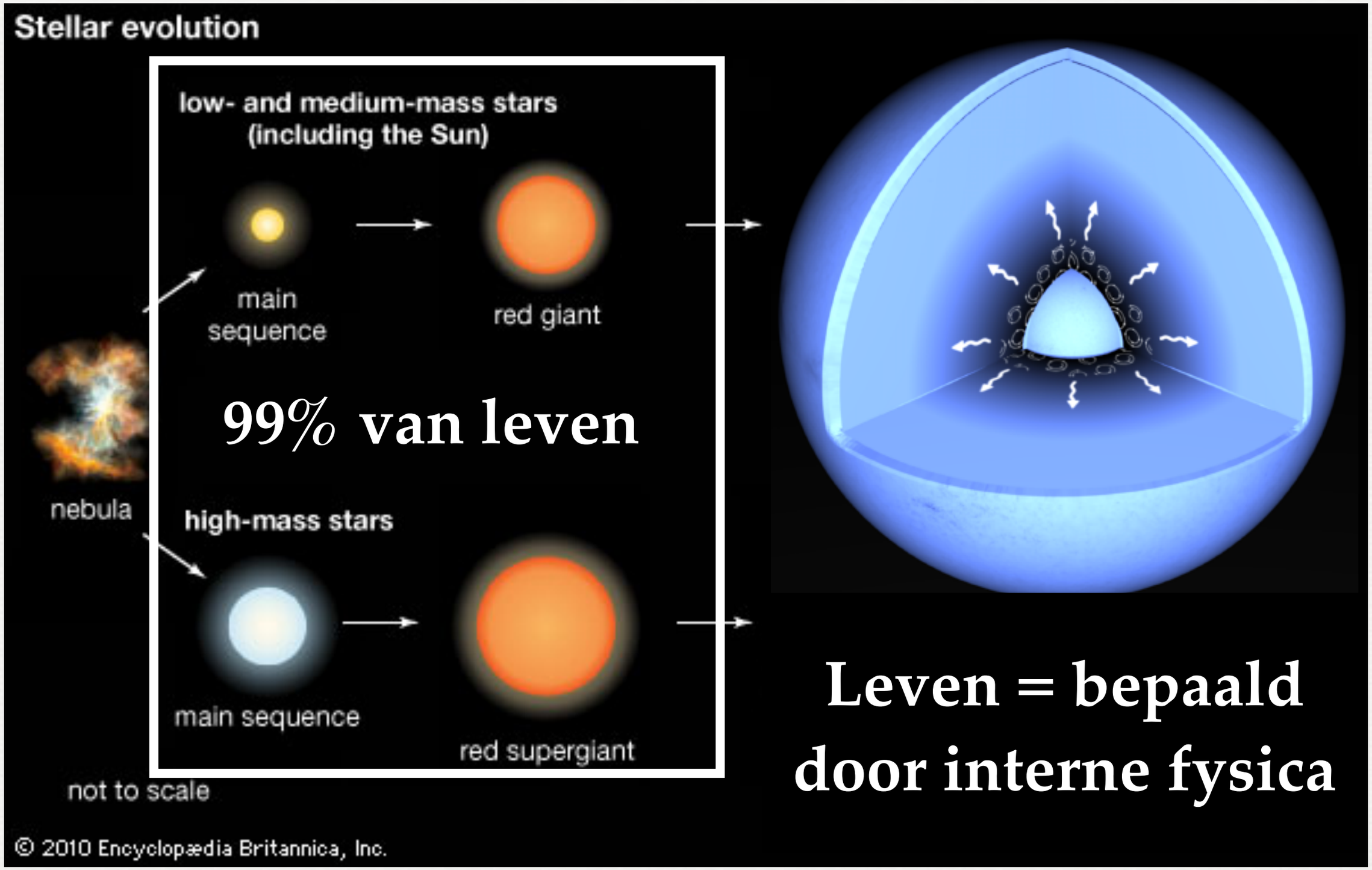
Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
ESA/NASA/AASNova

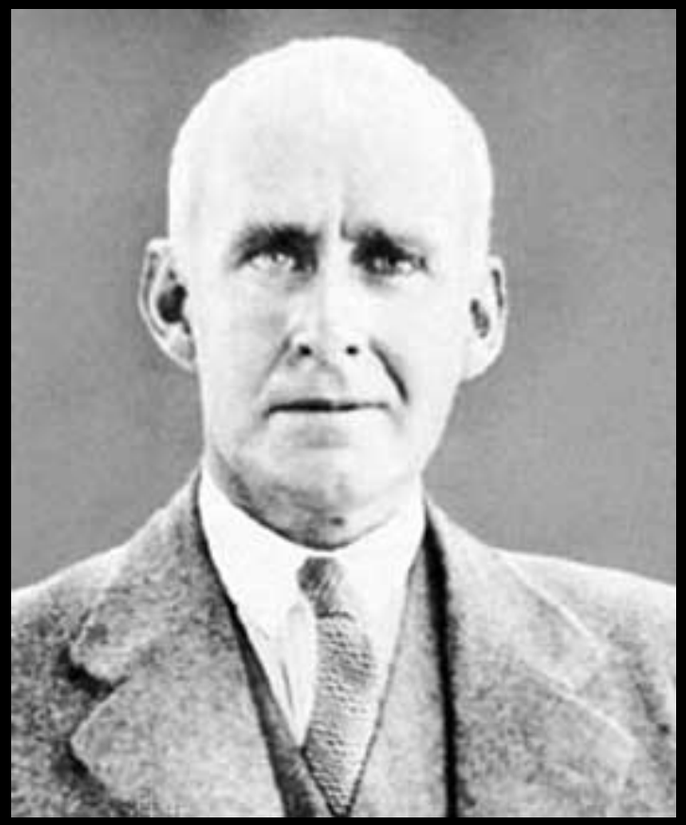
HOGERE GEBOORTEMASSA = KORTER LEVEN



HOGERE GEBOORTEMASSA = KORTER LEVEN



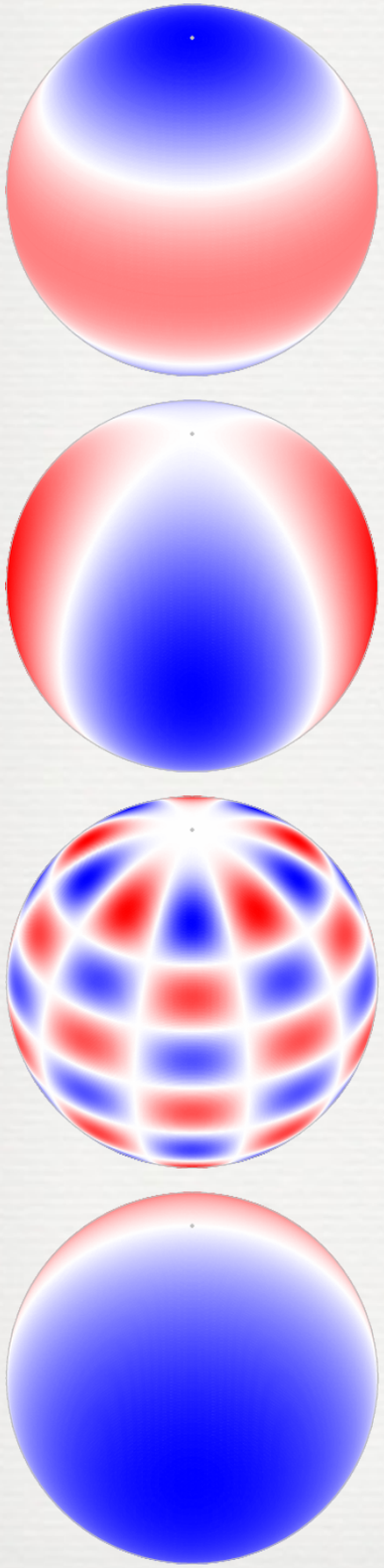
Dé sterrenkundevraag van vorige eeuw:

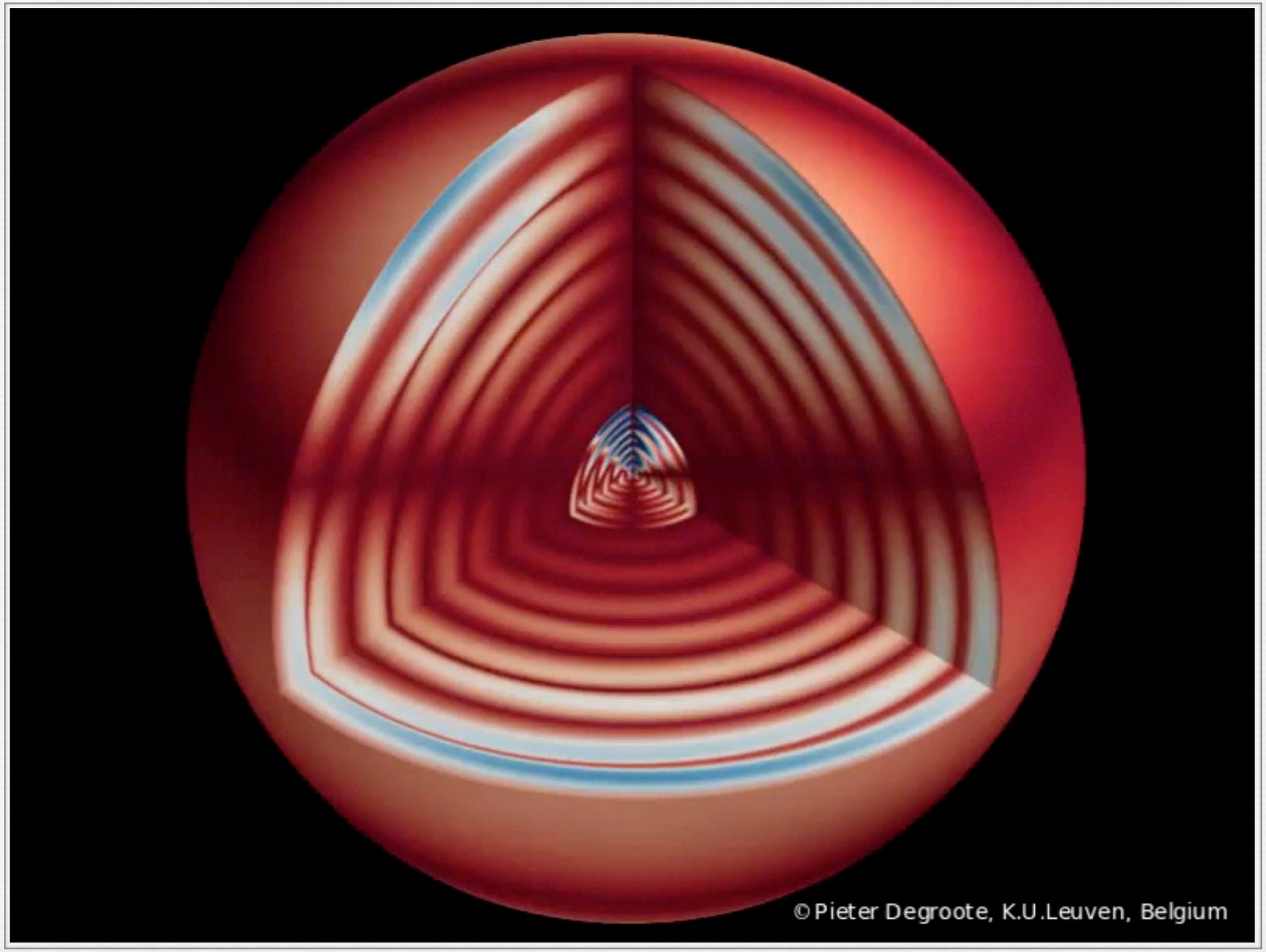


Sir Arthur Stanley Eddington
***The Internal Constitution of the Stars* 1926**

“What appliance can pierce through the outer layers of a star and test the conditions within?”

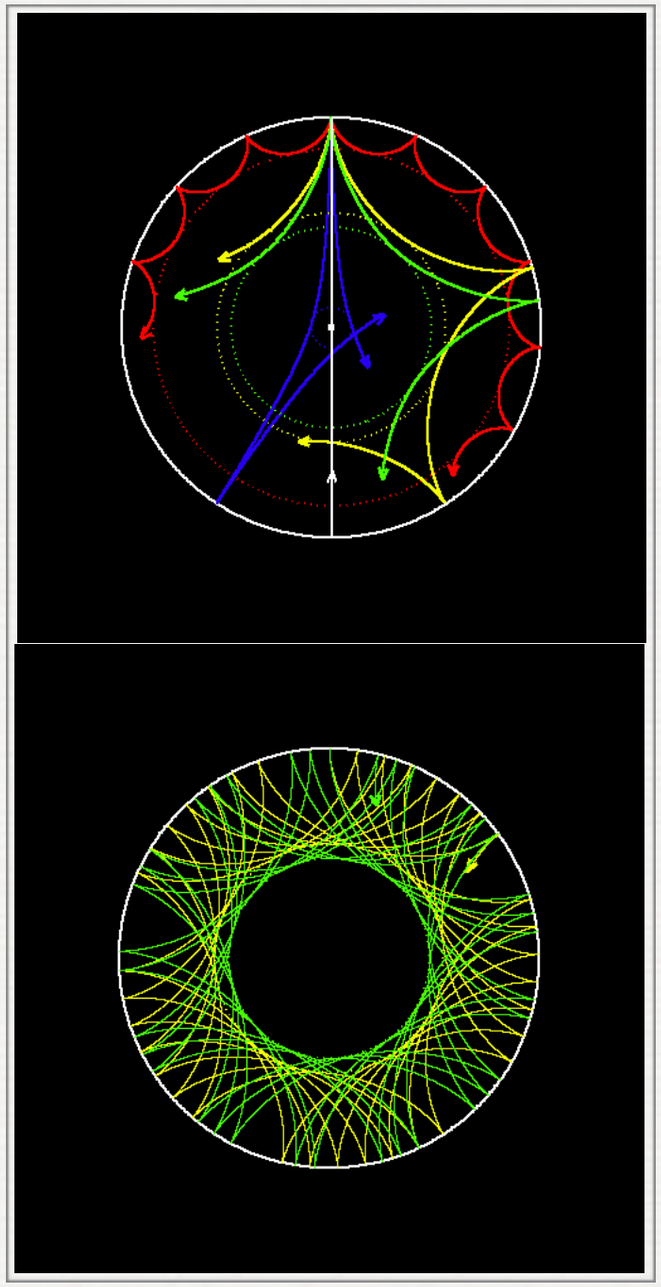
STERBEVINGEN BRENGEN REDDING





STERBEVINGEN DOORPRIEMEN STERINWENDIGEN

Sterbevingen veroorzaken golven die zich voortplanten doorheen het stergas; de fysische eigenschappen van de gaslagen waarin de beving het sterkst is, zit gecodeerd in haar frequentie

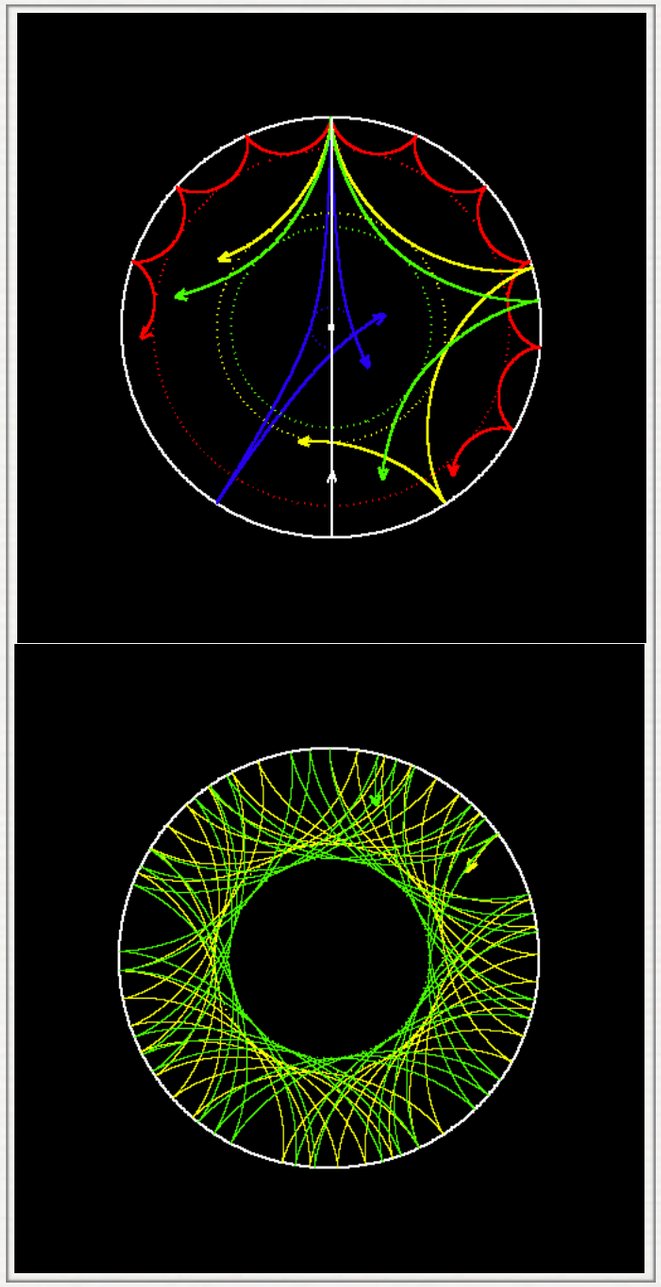


STERBEVINGEN DOORPRIEMEN STERINWENDIGEN

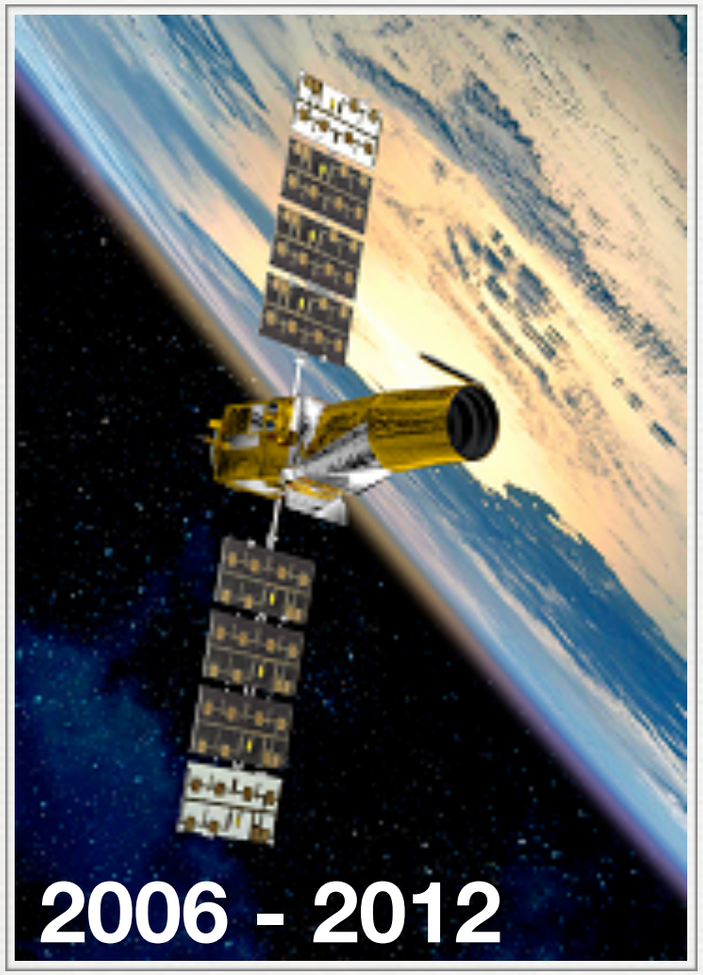
aster ⟶ star
seismos ⟶ oscillation
logos ⟶ discourse

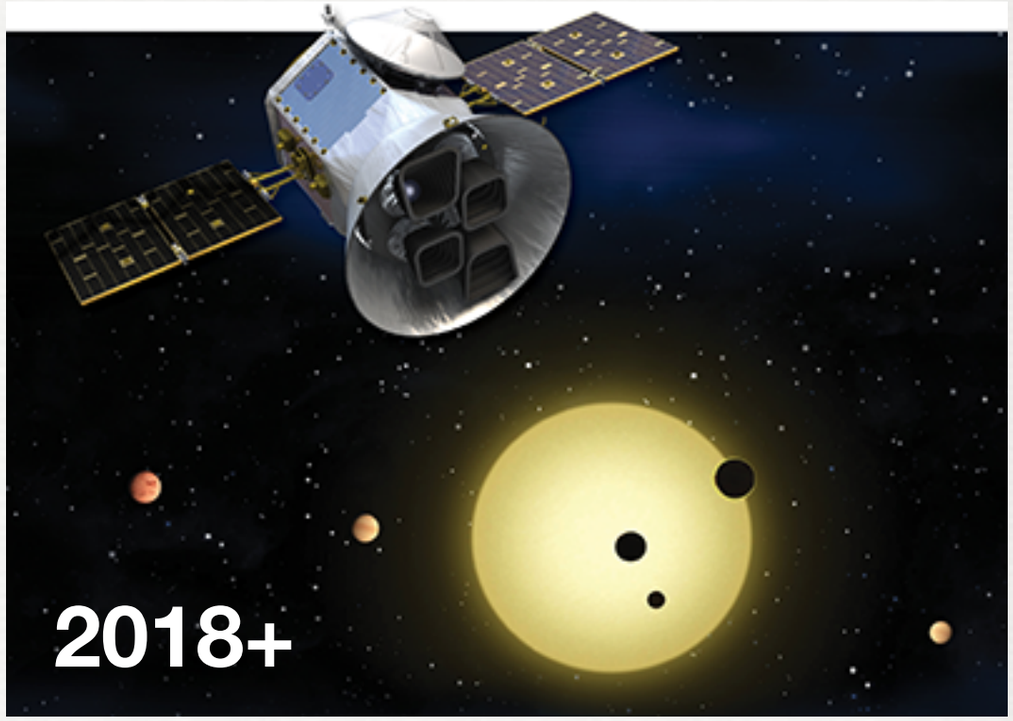
ASTEROSEISMOLOGIE:

vereist combinatie van wiskunde, fysica, chemie, informatica en ingenieurswetenschappen (STEM!)



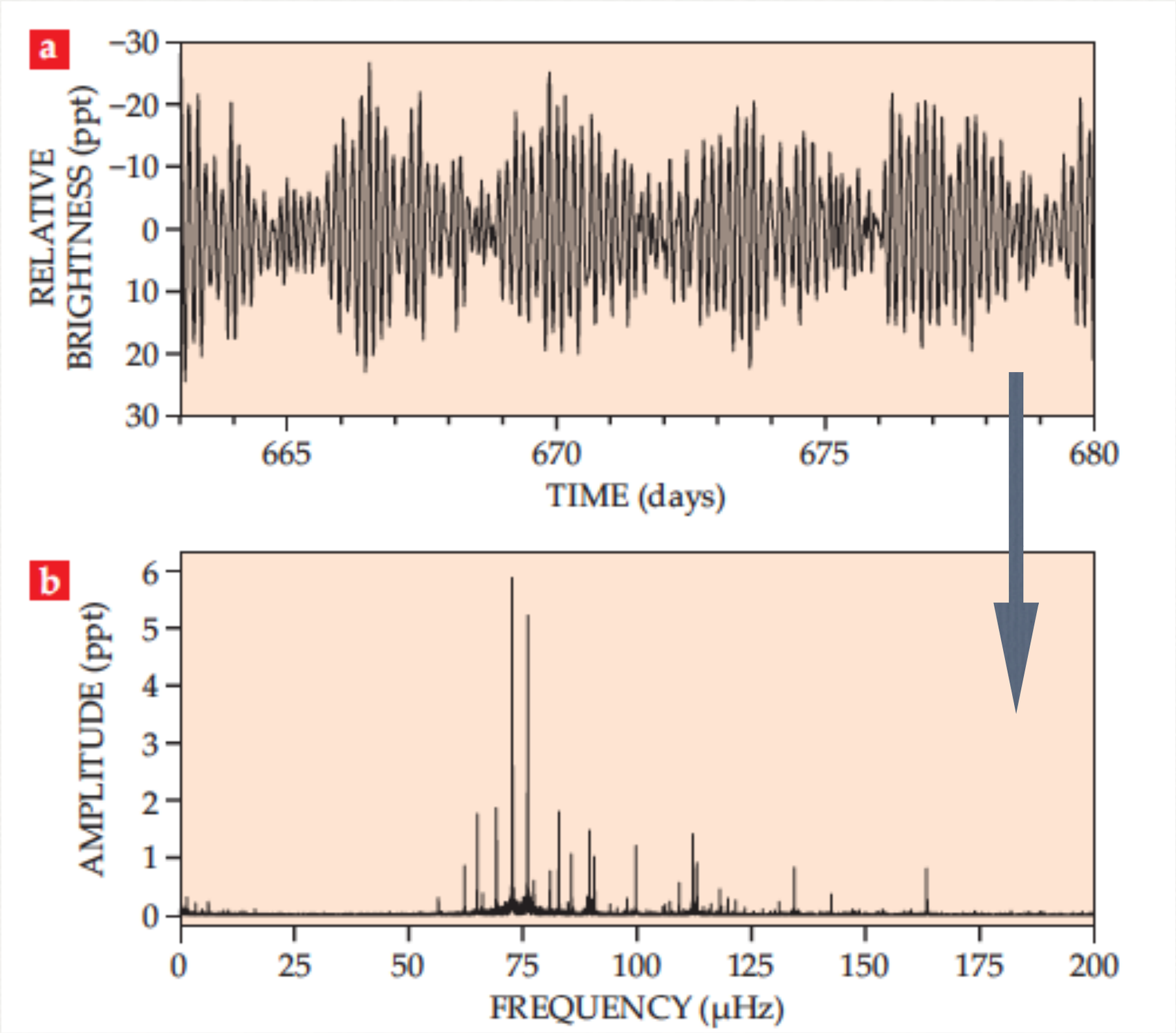
HOE WERKT HET VANDAAG?



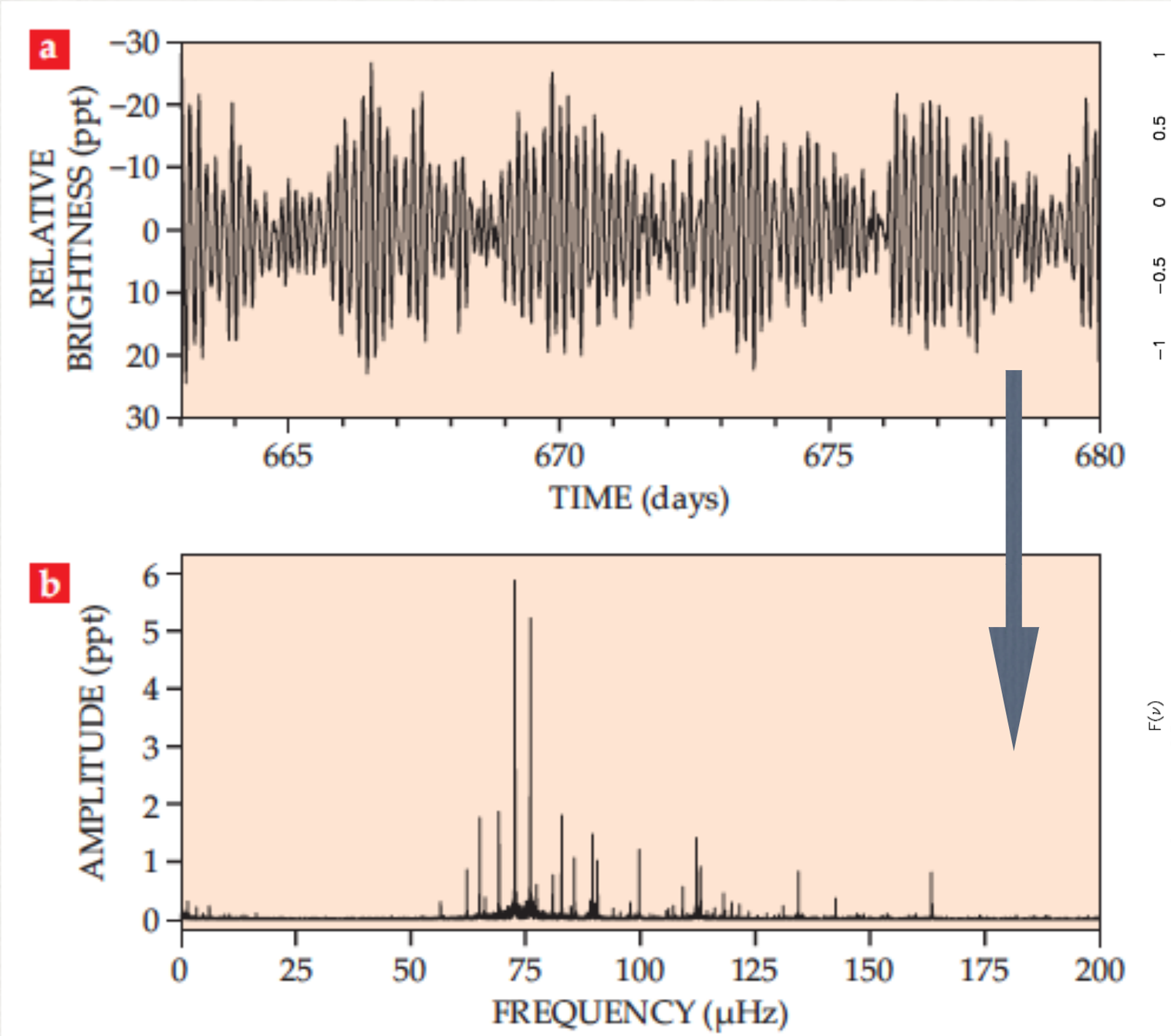


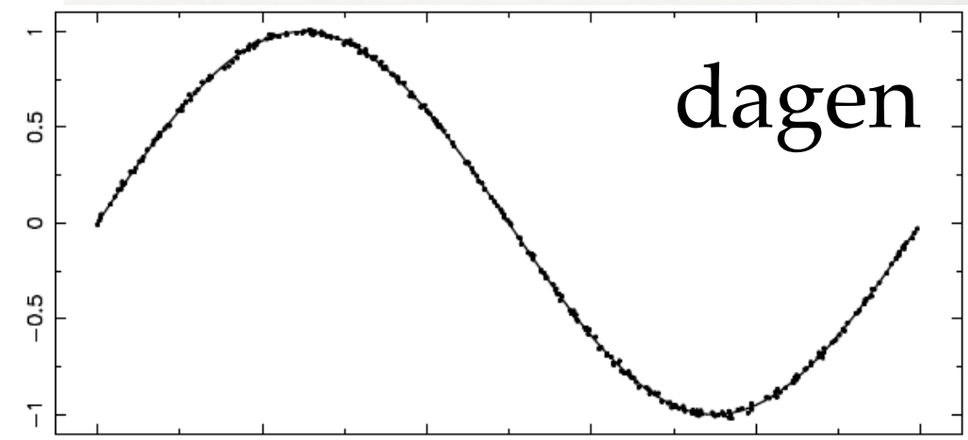
Ononderbroken langdurige helderheidsmetingen
van hoge precisie (ppm!)

DETECTIE VAN STERBEVINGEN



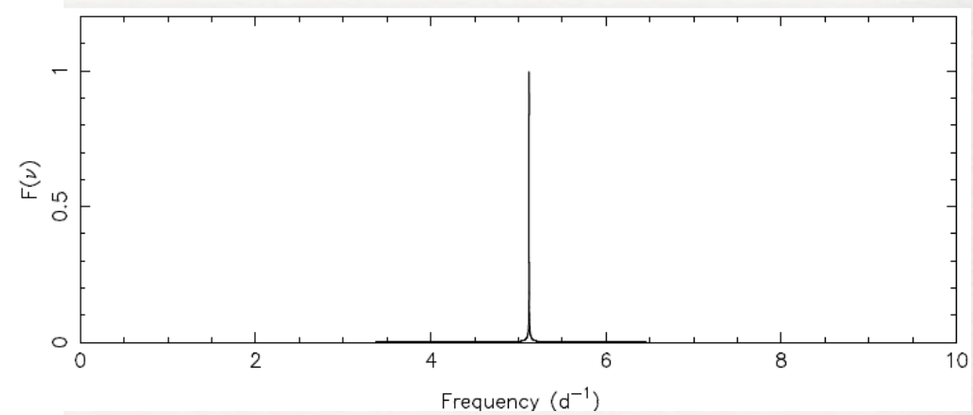
ANALYSE VAN STERBEVINGEN





0.0 0.1 0.2

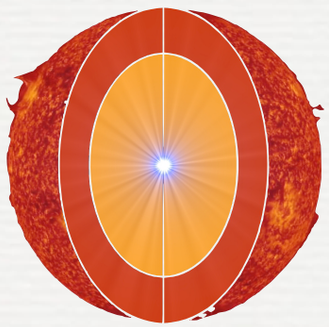
Fouriertransformatie

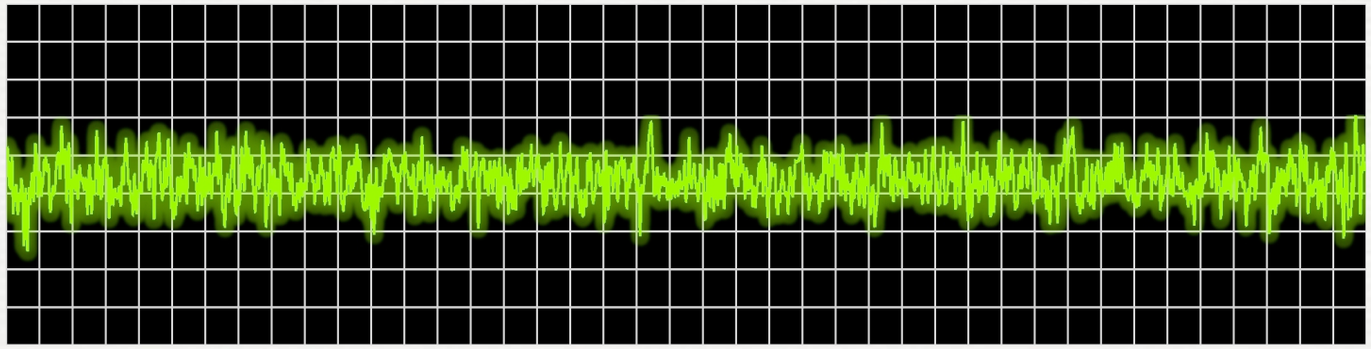


1 dag = 86400 seconden

1/dag = 11.57 μHz

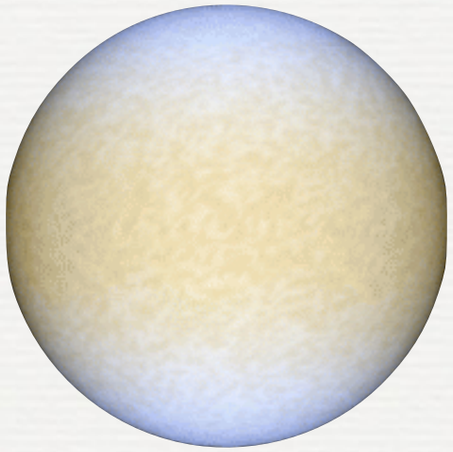
DE GROOTTE VAN STERREN METEN





TIME →

KIC 11026764



Sun

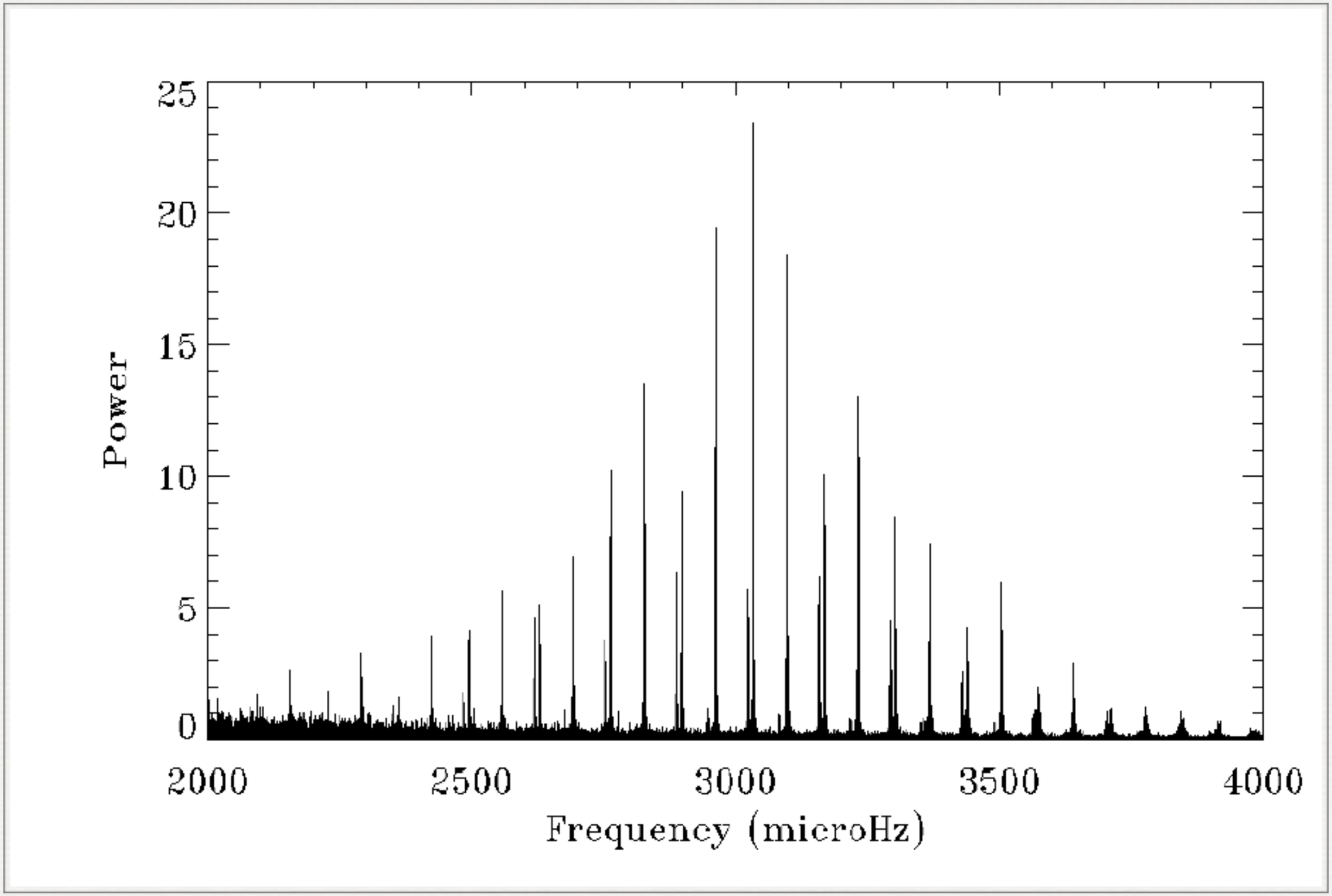
Travis Metcalfe, National Center for Atmospheric Research

KOSMISCHE SYMFONIEËN

We begeven ons naar de sterkern
en helpen onze oren een beetje…
(frequenties x 100,000)

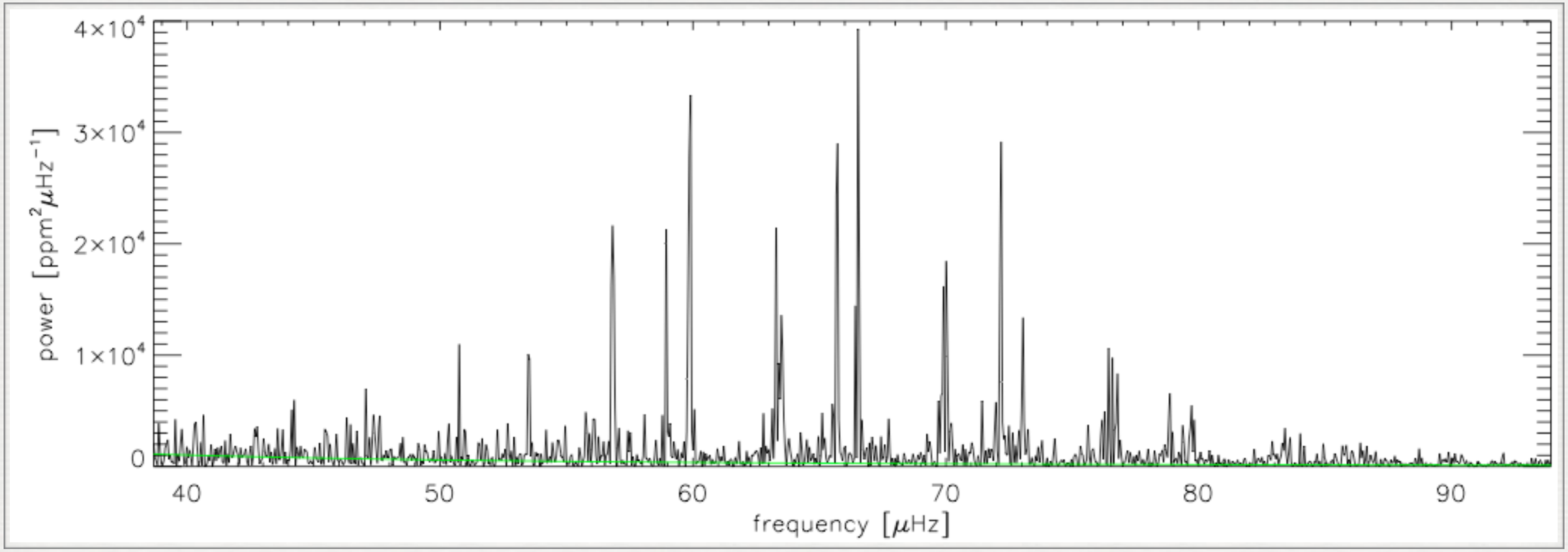
ZONNEFREQUENTIES

(ESA/NASA SoHO)

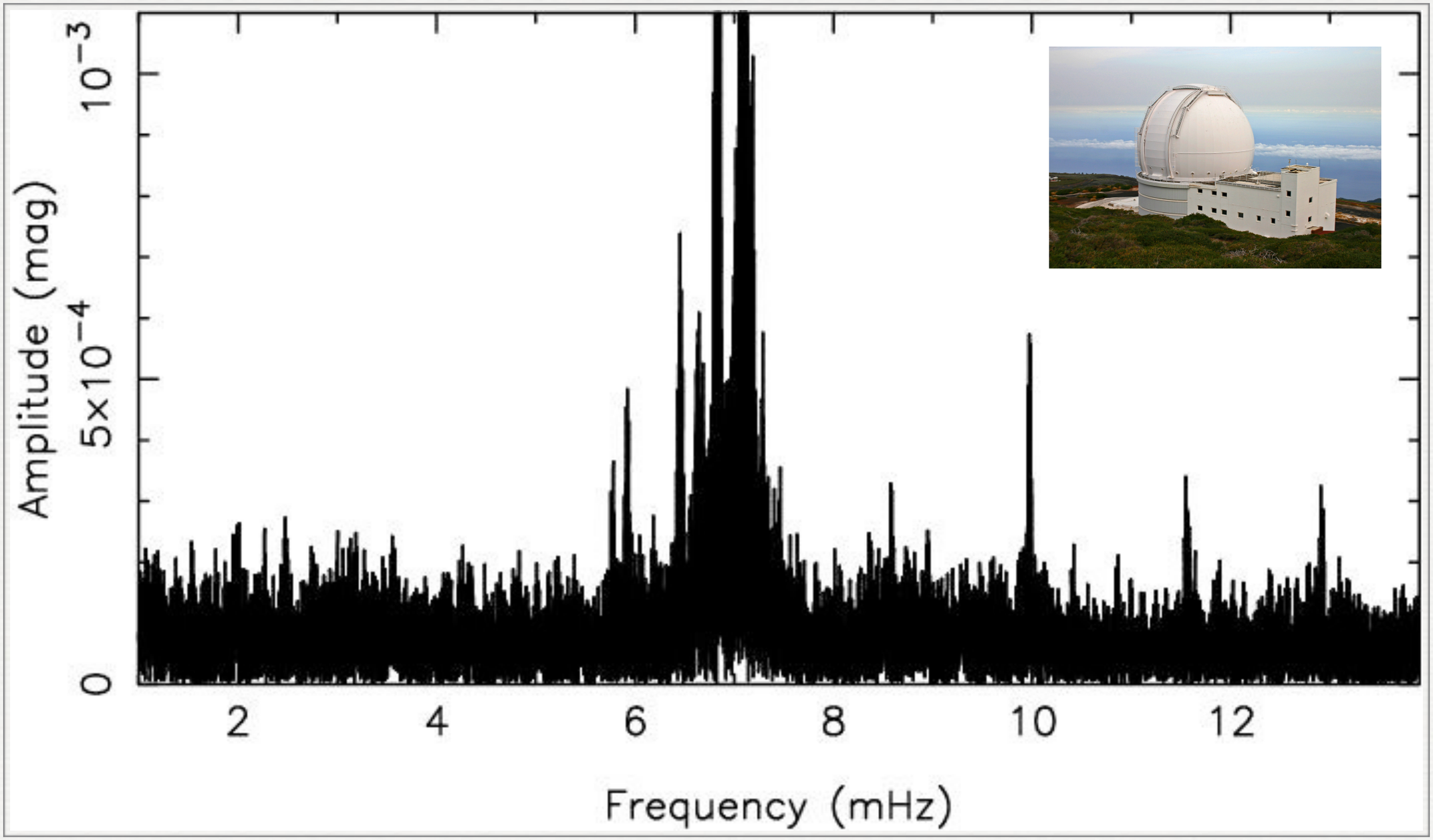


FREQUENTIES VAN EEN RODE REUS

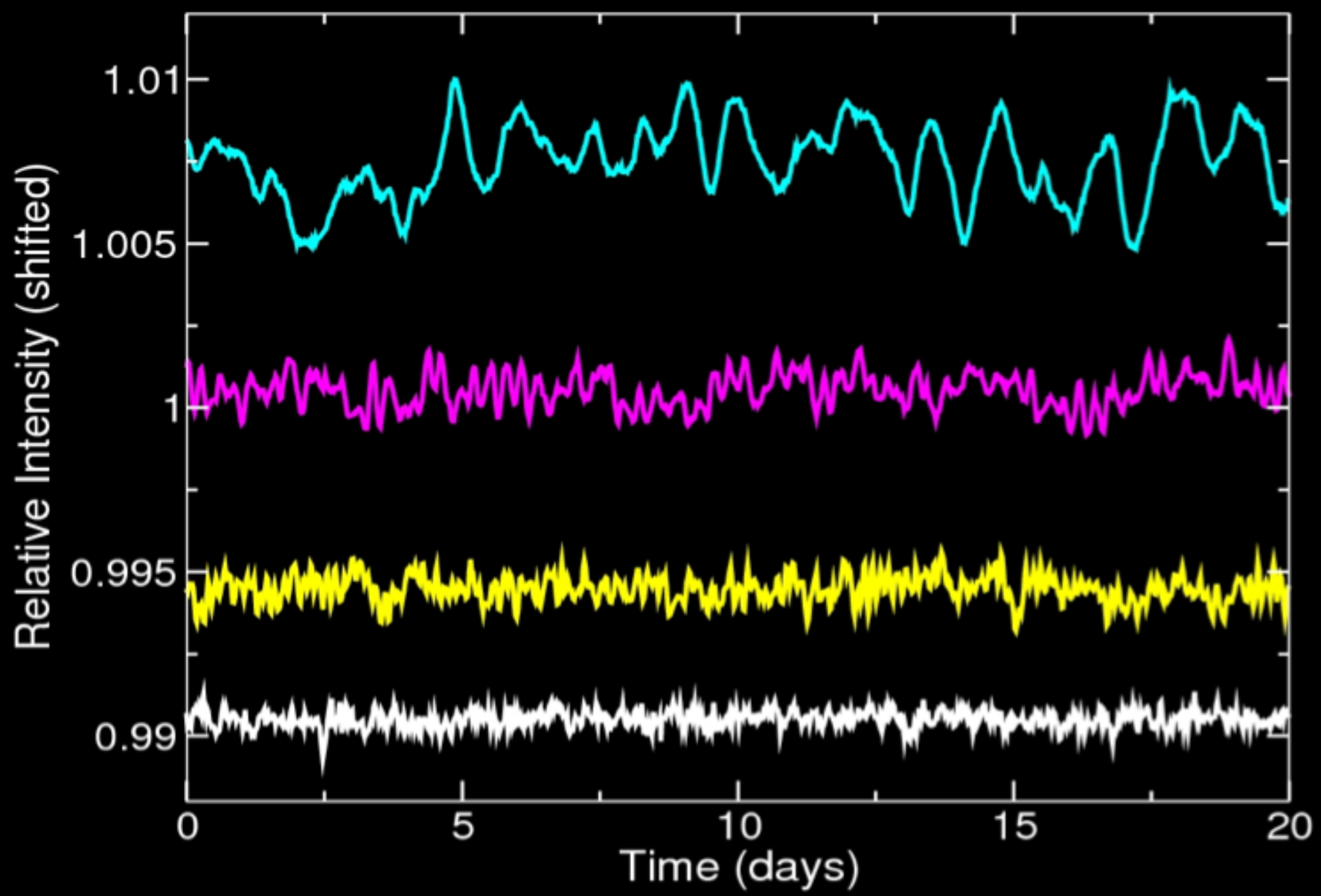
(Kepler)

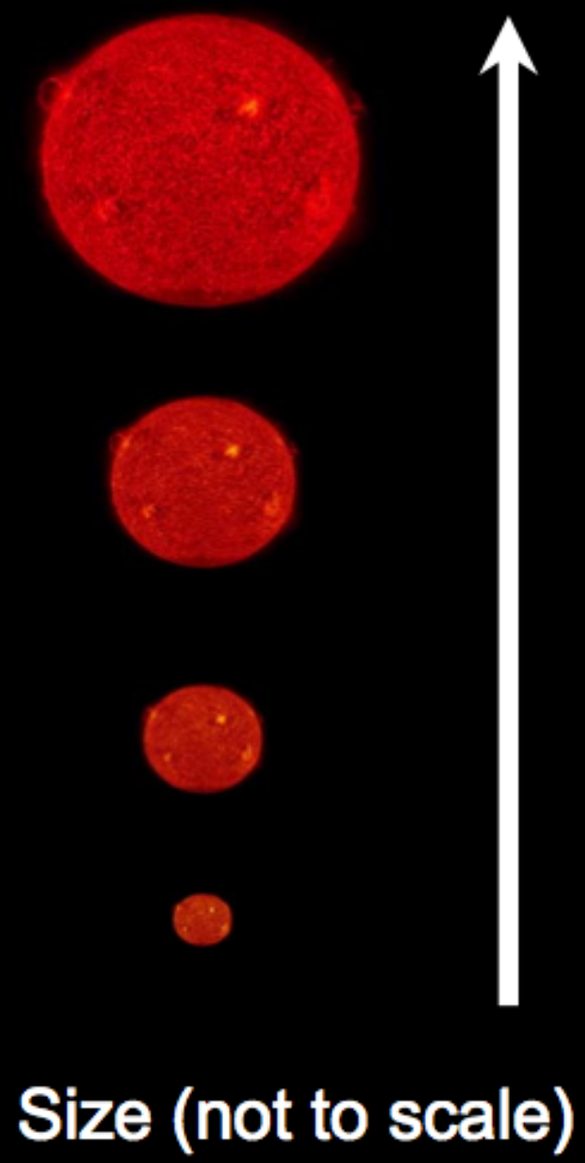


FREQUENTIES VAN EEN DWERGSTER



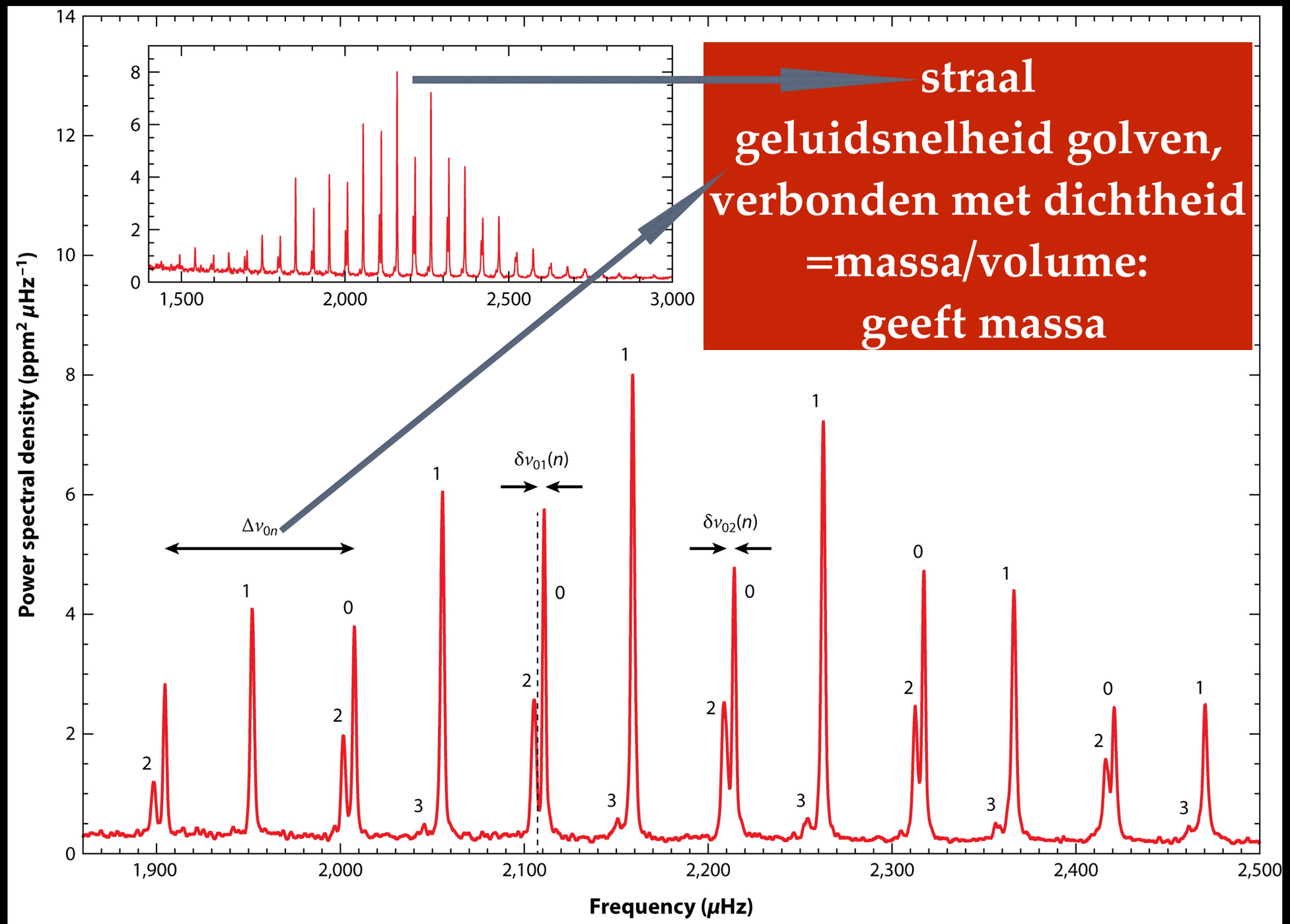
Sterstralen tot 1% nauwkeurig





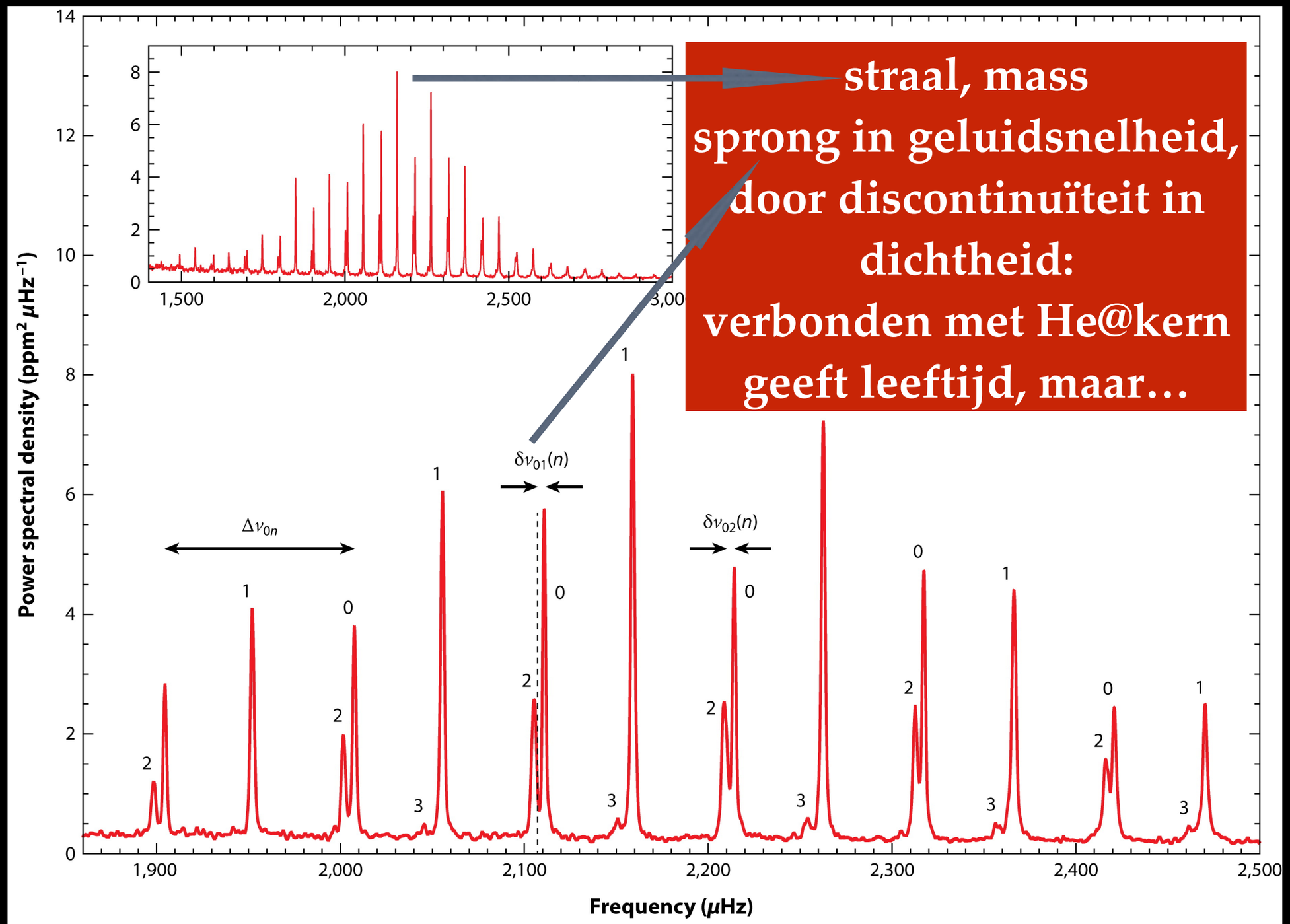
Slide courtesy of Daniel Huber

Wegen van sterren tot 2% precisie



Chaplin WJ, Miglio A. 2013.
Annu. Rev. Astron. Astrophys. 51:353–92

Leeftijd van sterren tot 20% precisie



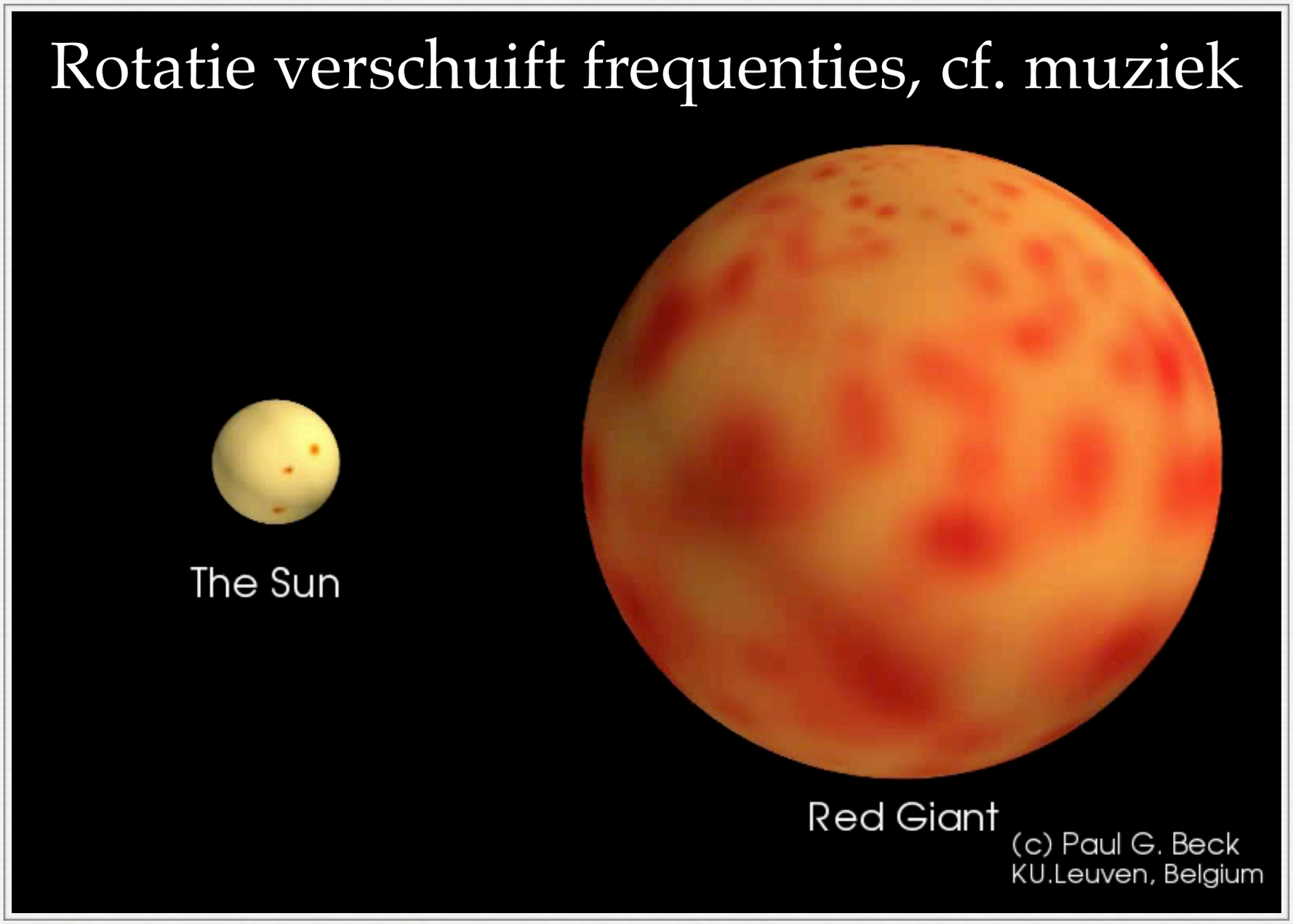
Chaplin WJ, Miglio A. 2013.
Annu. Rev. Astron. Astrophys. 51:353–92

KOSMISCHE SYMFONIEËN

worden verstoord als muzikanten op
een draaiend podium zouden spelen:
kunnen we meten via de frequenties!

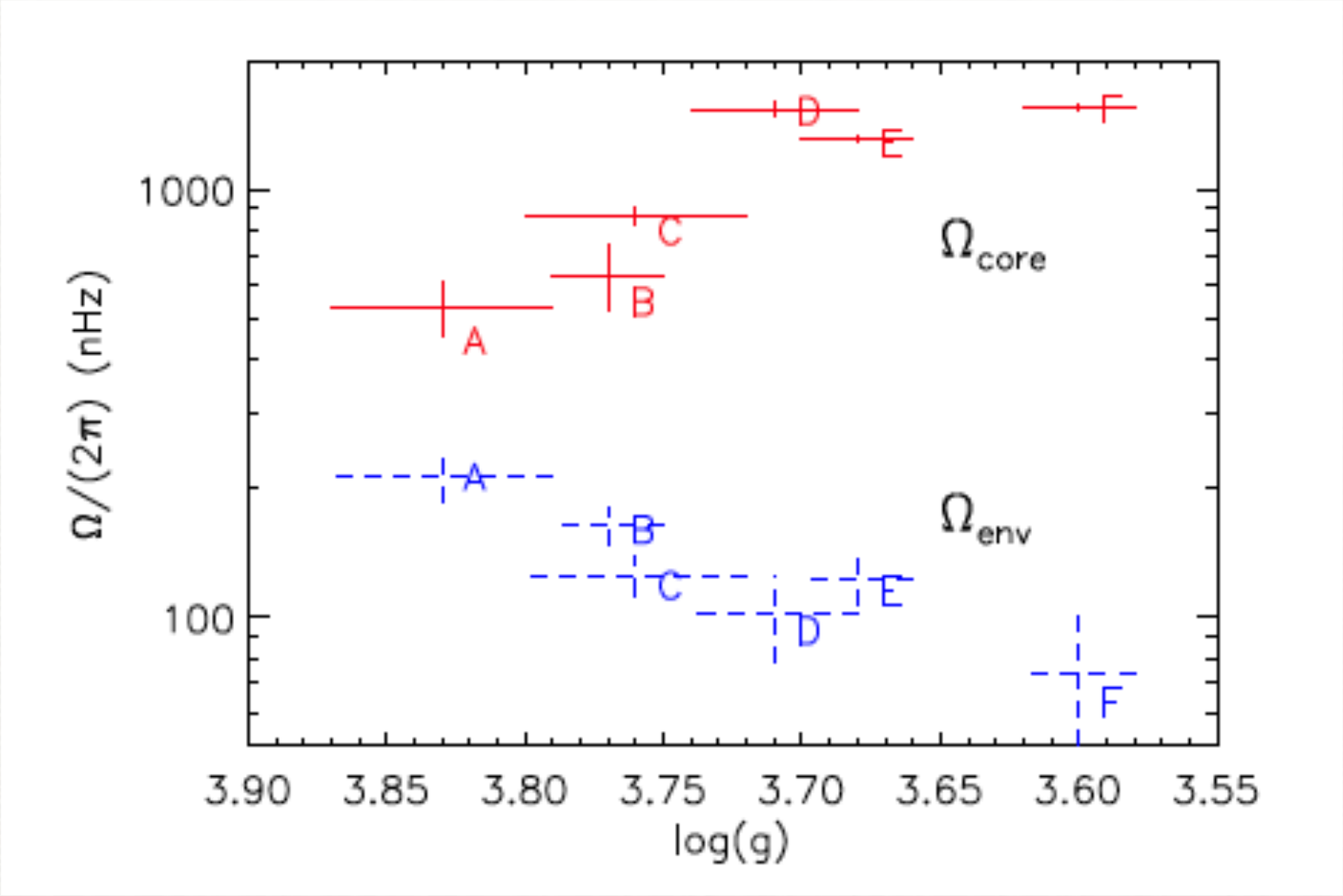
rotatie geeft vermenging van materiaal
cf. koffie met melk…

HELIUM IN KERN HANGT AF VAN
VERMENGING VAN GAS NABIJ REACTOR



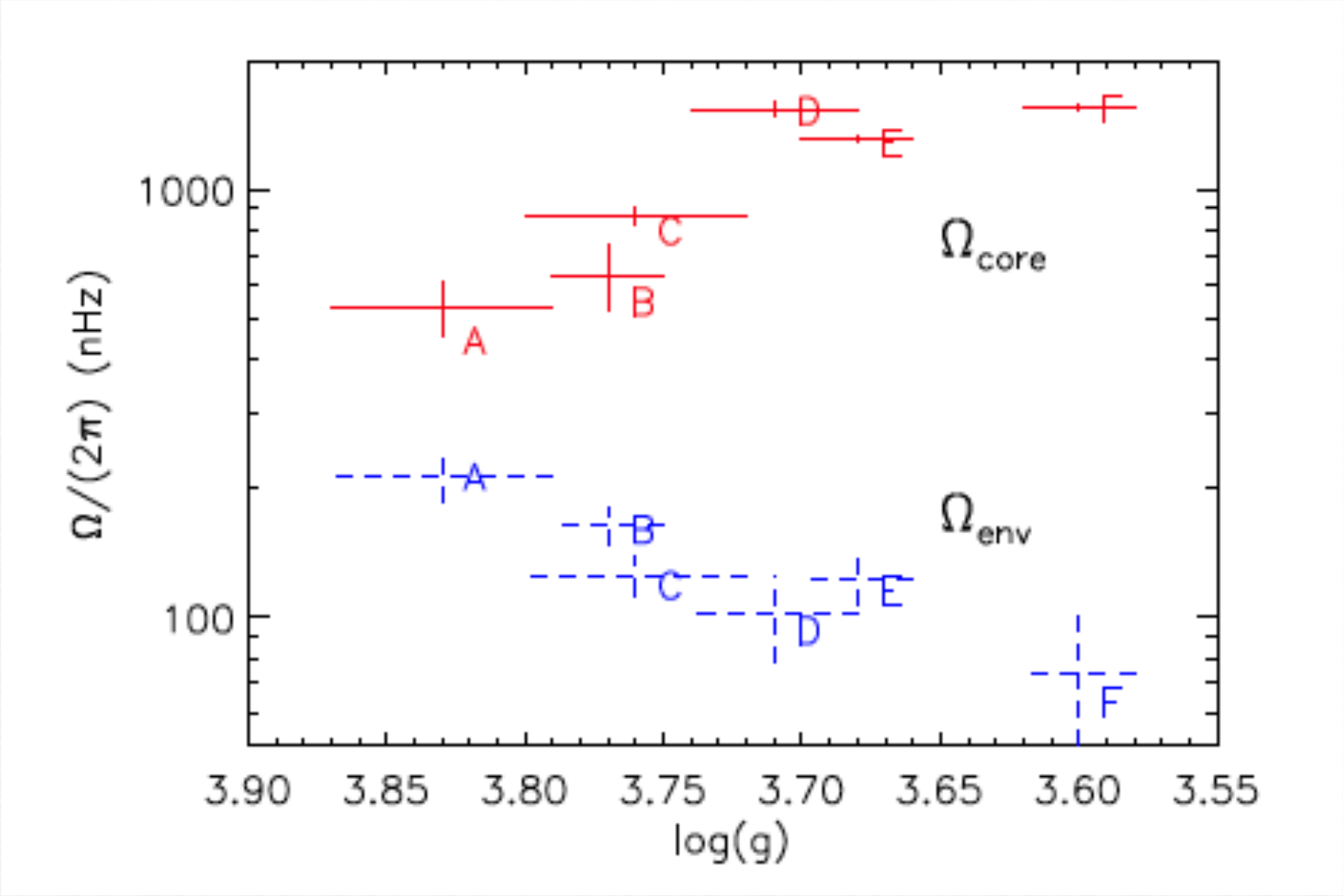
Verschuivingen miniem: pas meetbaar na 2 jaar data (Beck et al., 2012, Nature)

"ZIE" STERREN OUD WORDEN



Rechtstreekse meeting van rotatie nabij sterkern (Deheuvels et al., 2014): kunnen we niet voor de zon want heeft geen geschikte bevingen…

"ZIE" STERREN OUD WORDEN: THEORIE VAN STERROTATIE FAALT…



Onzekerheid in leeftijd door gebrek aan kennis rond rotationele vermenging: kern 10x trager dan gedacht… moeten we "fixen" in theorie

Dé sterrenkunde-vraag van deze eeuw:

“Is there life beyond Earth?”

(veruit interessantste vraag volgens 15-jarige scholieren wereldwijd, zowel arm en rijk, zowel meisjes als jongens!)

ROSE project, Sjoberg (2010)

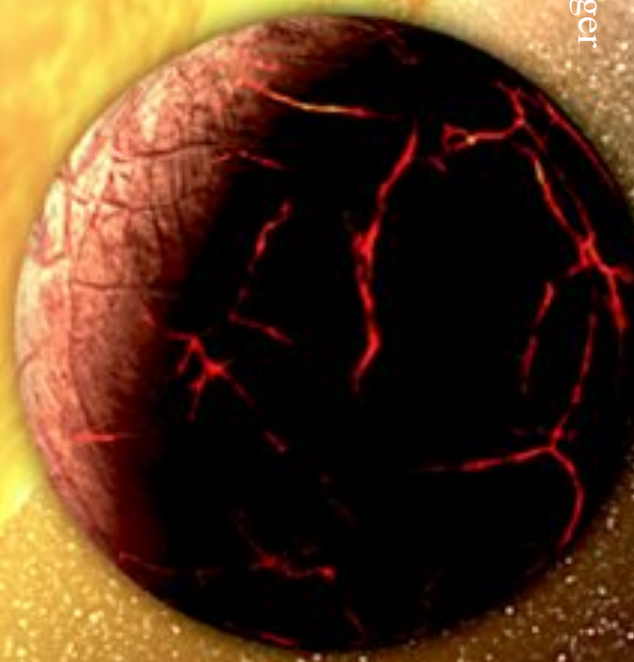
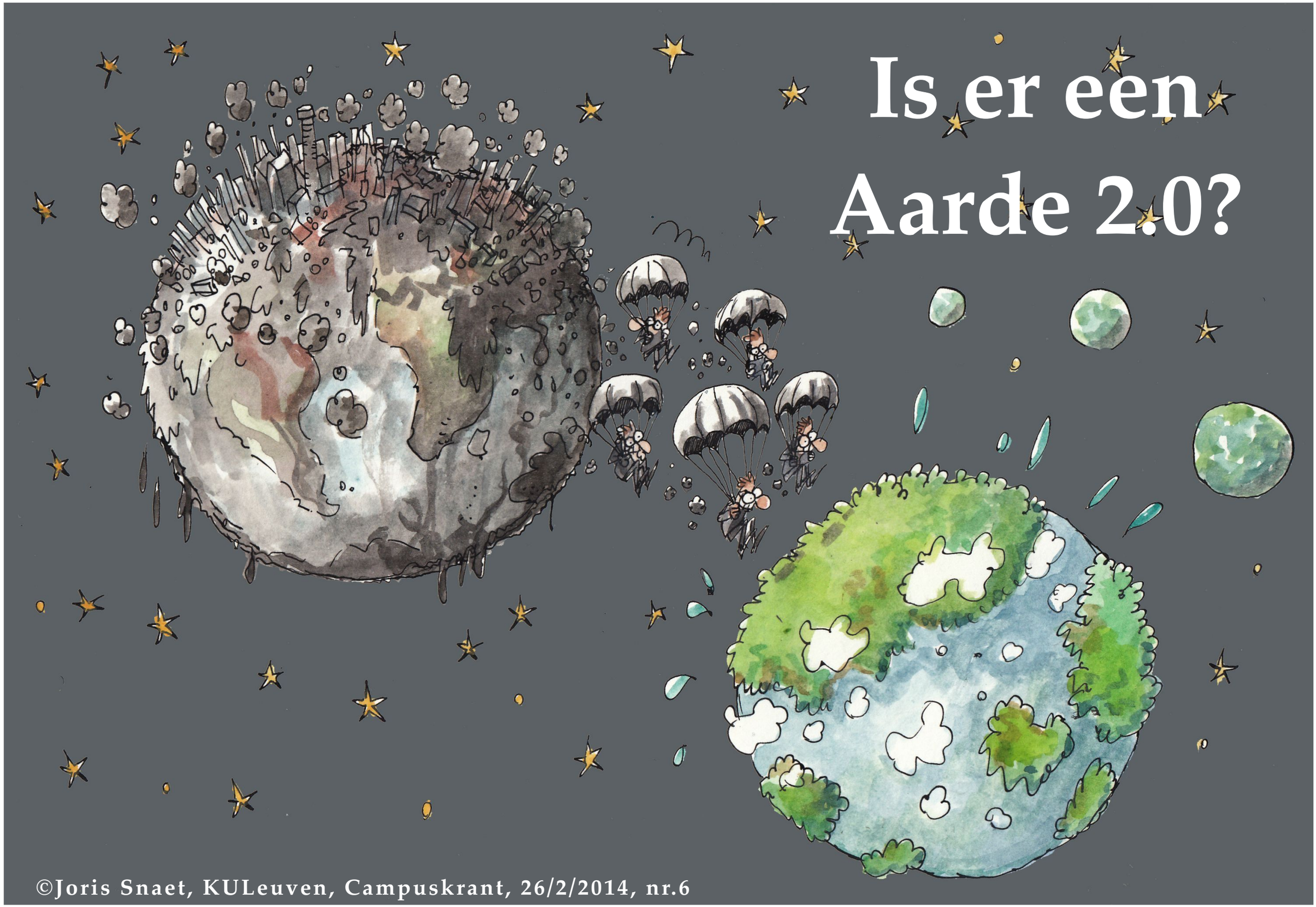
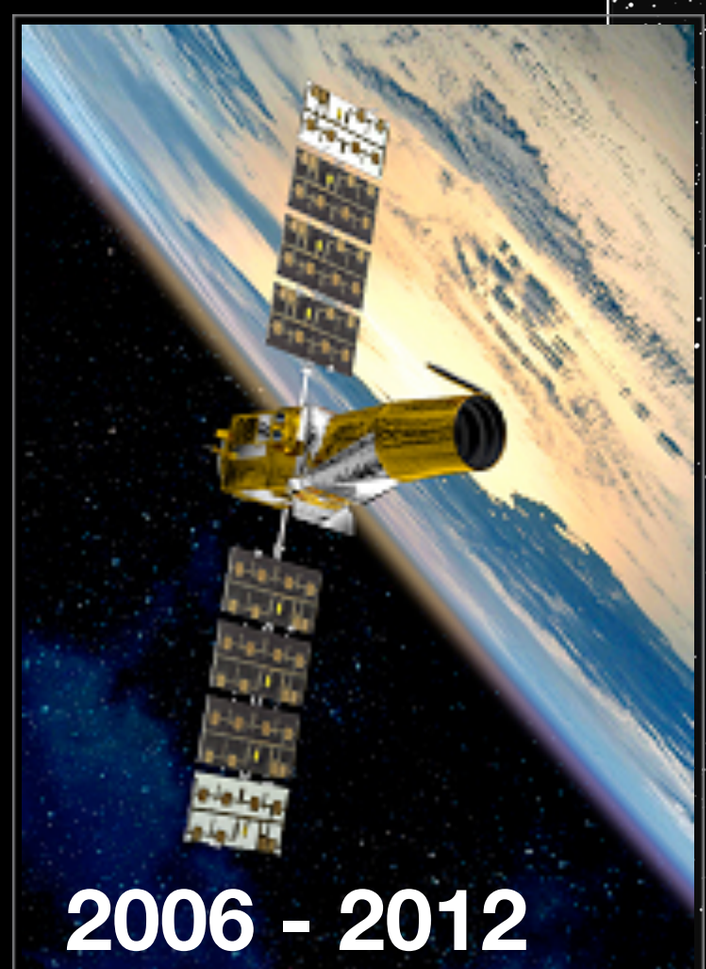


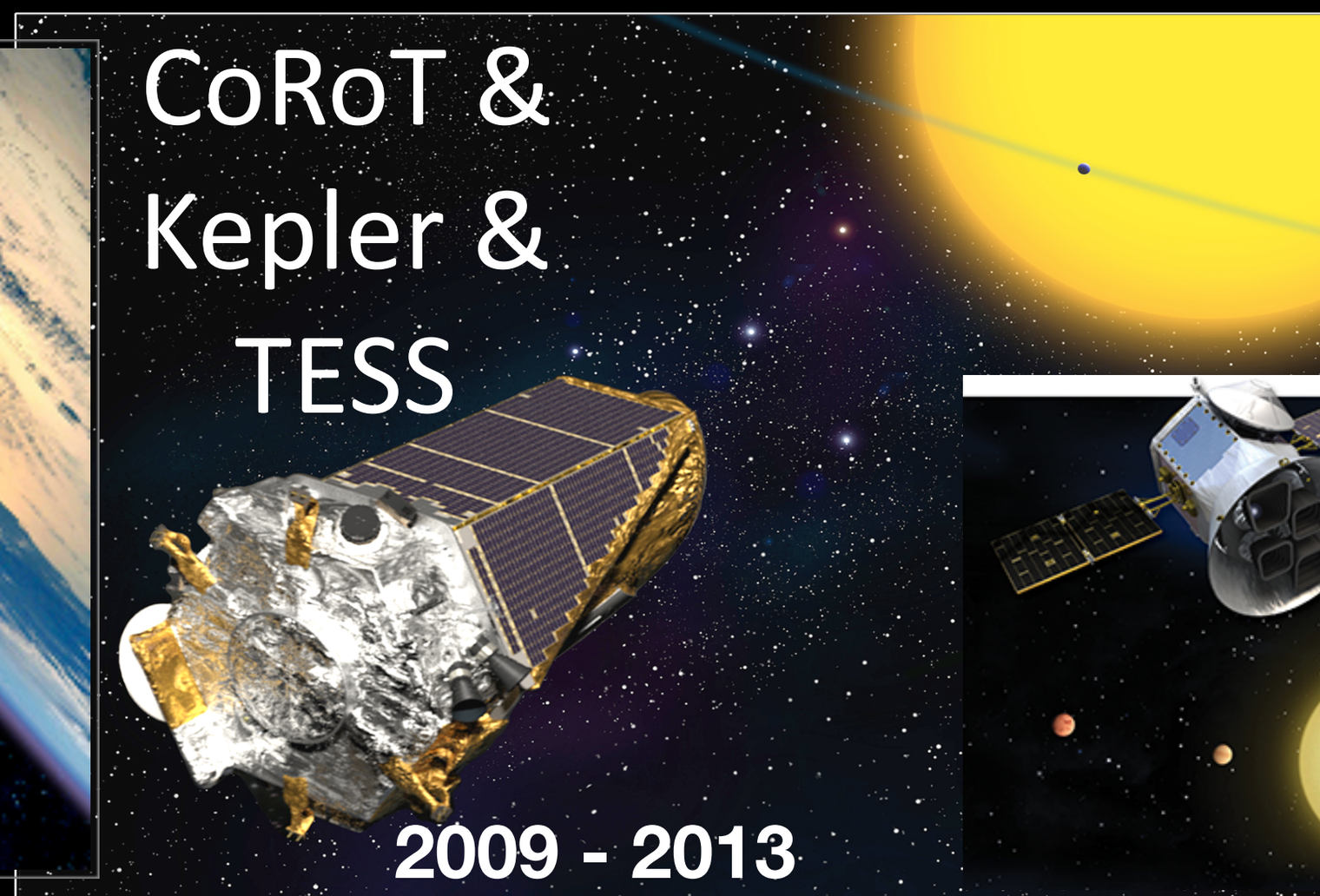
Image credit: NASA's Goddard Space Flight Center/S. Wiessinger

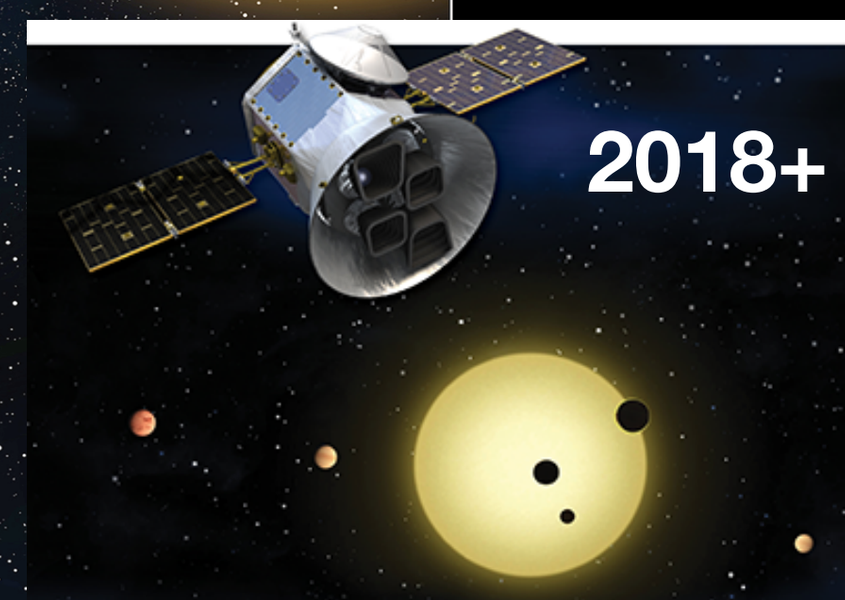

Is er een
Aarde 2.0?
©Joris Snaet, KULeuven, Campuskrant, 26/2/2014, nr.6

Dé sterrenkunde-vragen van deze eeuw:
“Hoeveel van de sterren in onze Melkweg hebben planeten? Is er een Aarde2.0? (met levensvormen?)”

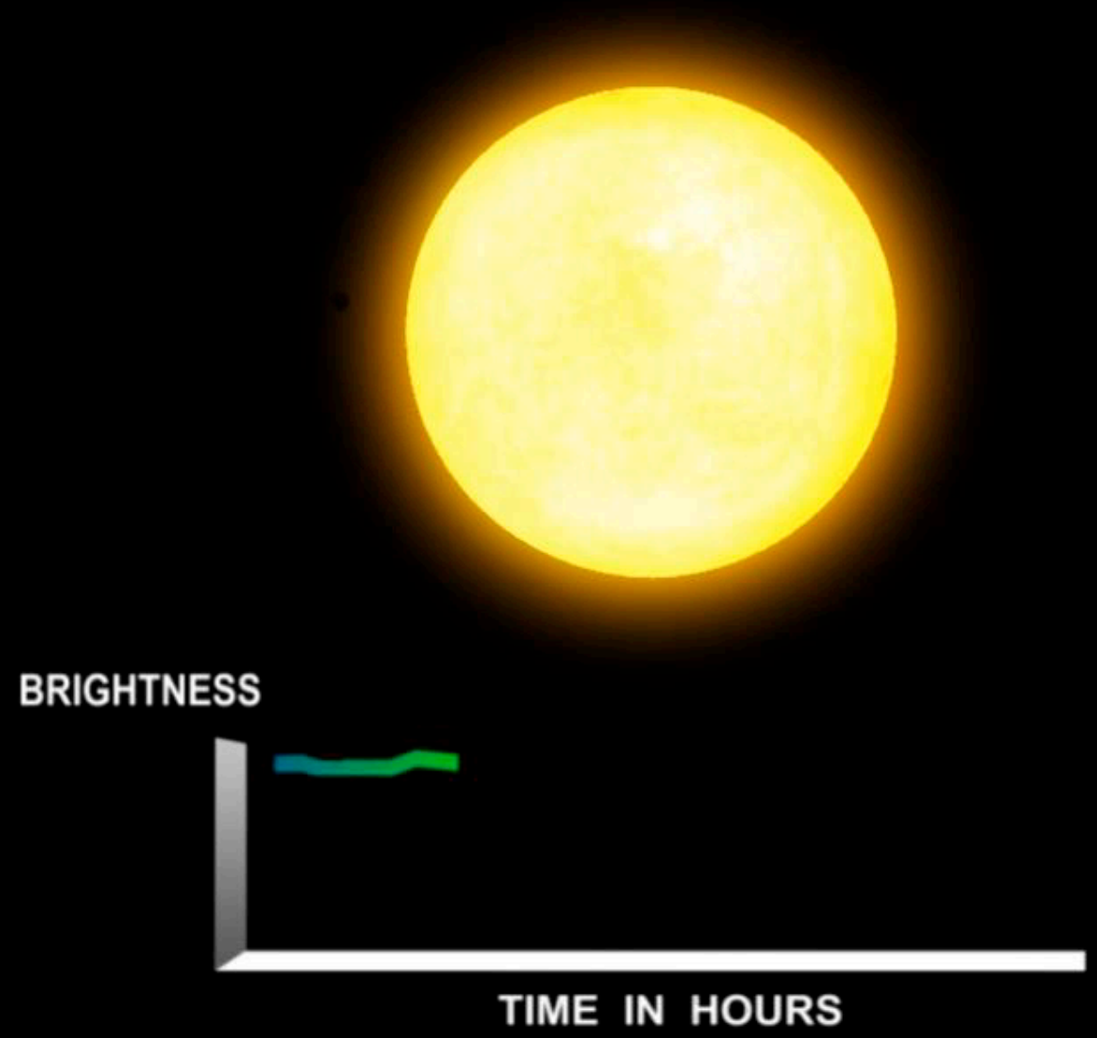
zoeken op 2 wijzen: grote steekproeven en detailspeurtocht “vlakbij”







Metingen voor asteroseismologie: 1’ kadans; voor detectie van exoplaneten: 30’ is OK (ook ppm!)



Animation courtesy of NASA

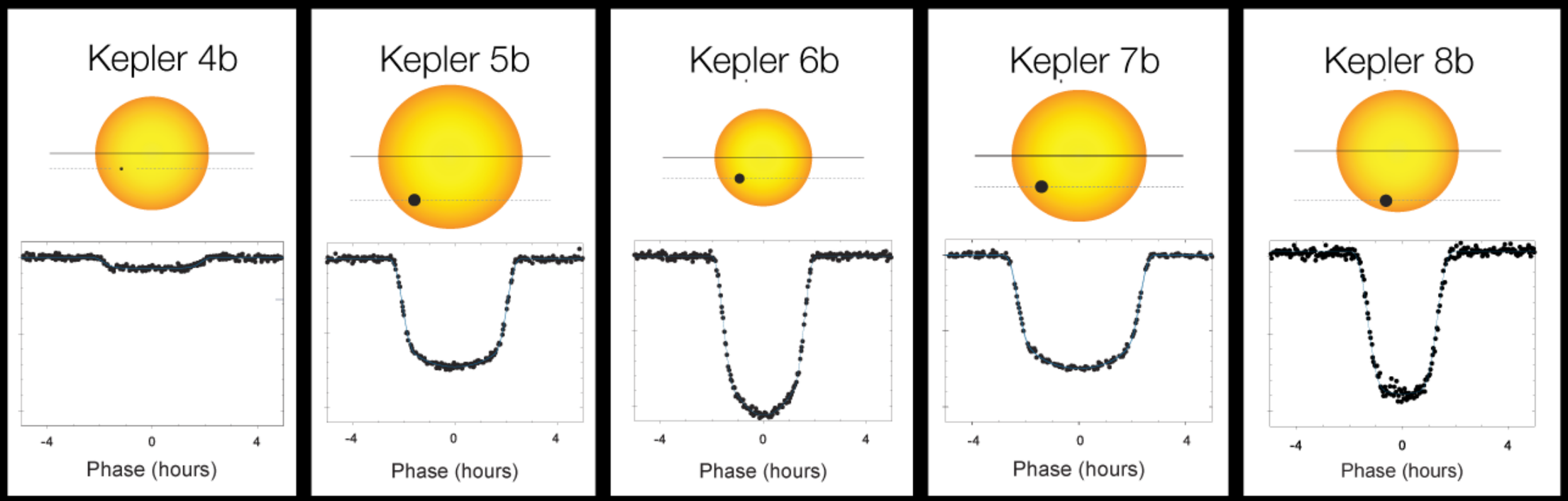
Metingen voor asteroseismologie: 1’ kadans; voor detectie van exoplaneten: 30’ is OK (ook ppm!)

Planeet rotsachtig of gasvorming? dichtheid ? straal en massa nodig…

Straal en massa van ster nodig: asteroseismologie

Animation courtesy of NASA

Transit Light Curves

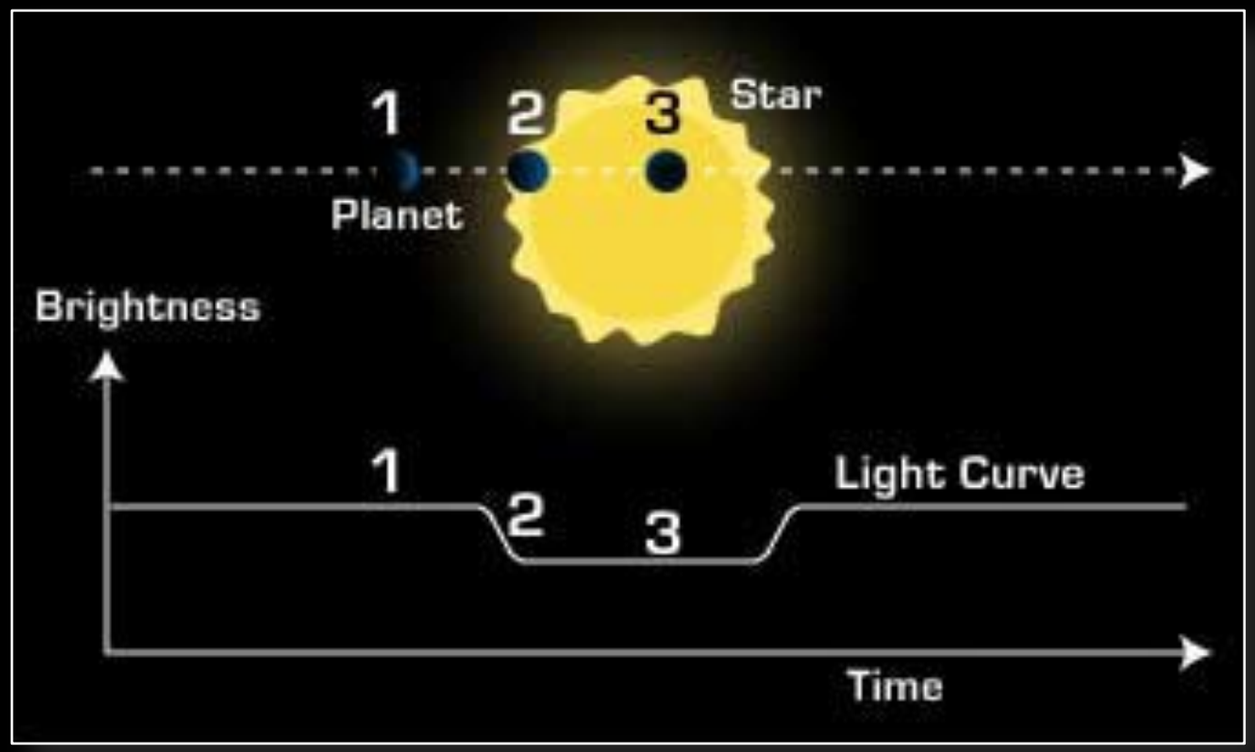


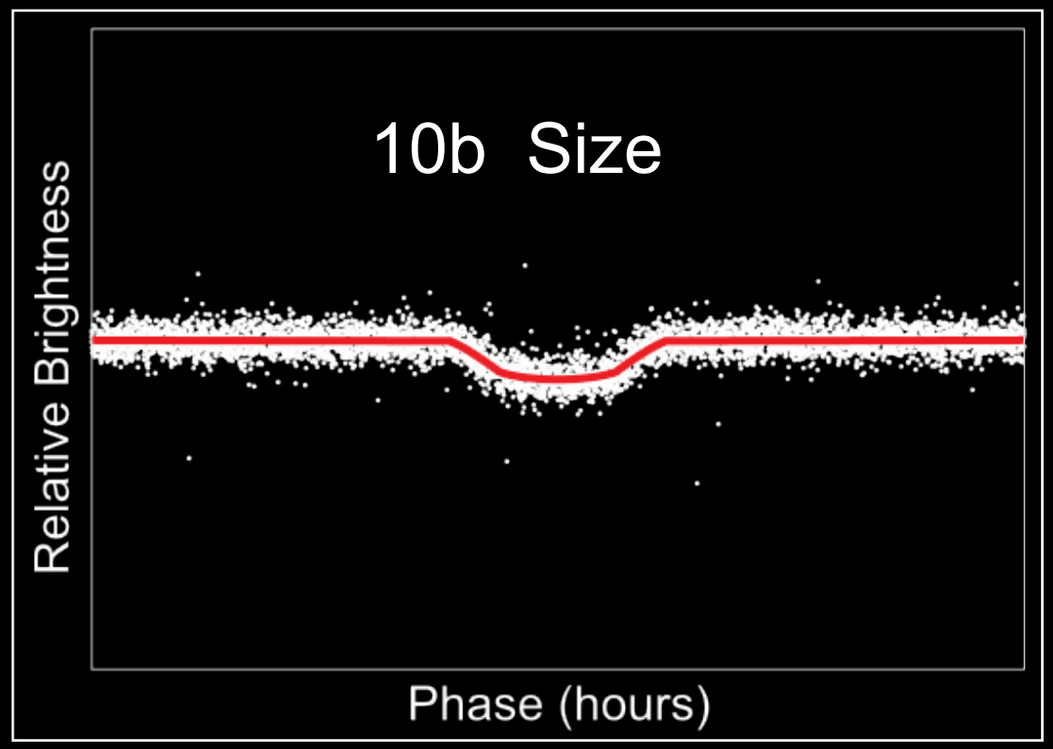
	Kepler 4b	Kepler 5b	Kepler 6b	Kepler 7b	Kepler 8b
Orbital Period (days)	*3.2 days*	*3.5 days*	*3.2 days*	*4.9 days*	*3.5 days*
Size (R_E)	*4.31*	*18.8*	*15.0*	*16.9*	*18.3*

→straal en massa van ster nodig!

Slide courtesy of W. Borucki, NASA

Transit geeft grootte op VW dat je de straal van de ster kent met grote precisie…

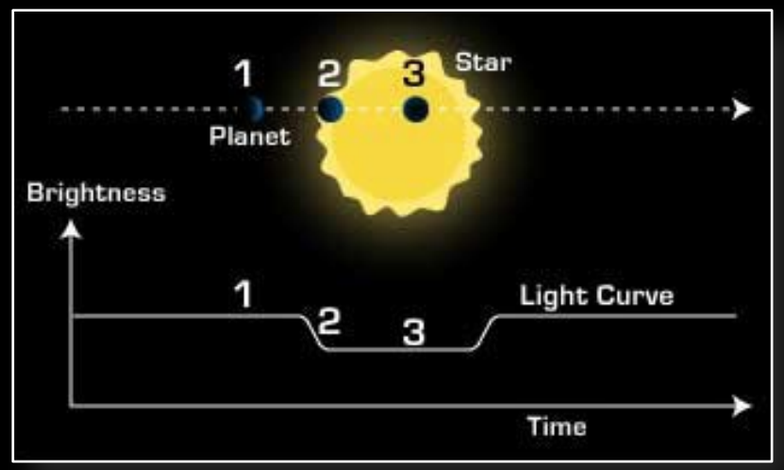




Kepler 10b: straal = 1.4 $R_{\oplus}$

Slide courtesy of N. Batalha, NASA

Transit en snelheid → dichtheid



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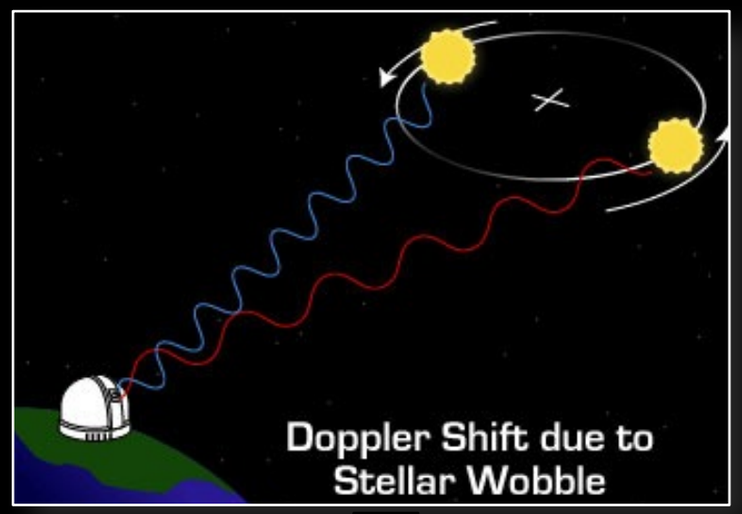
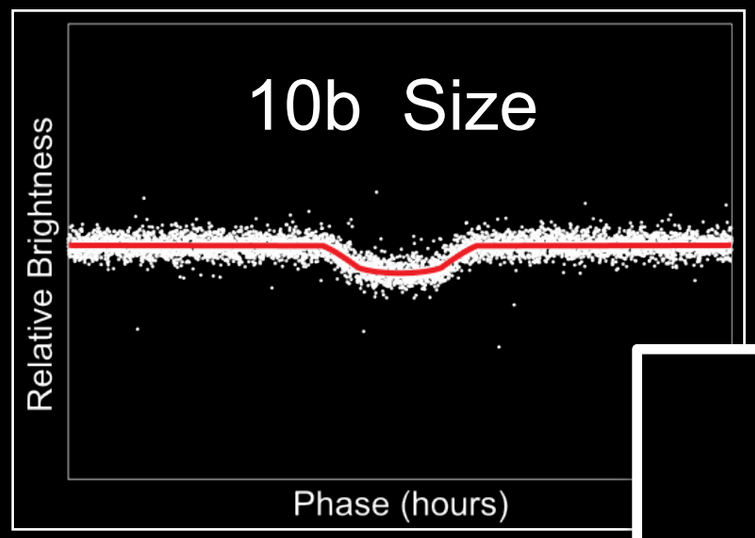
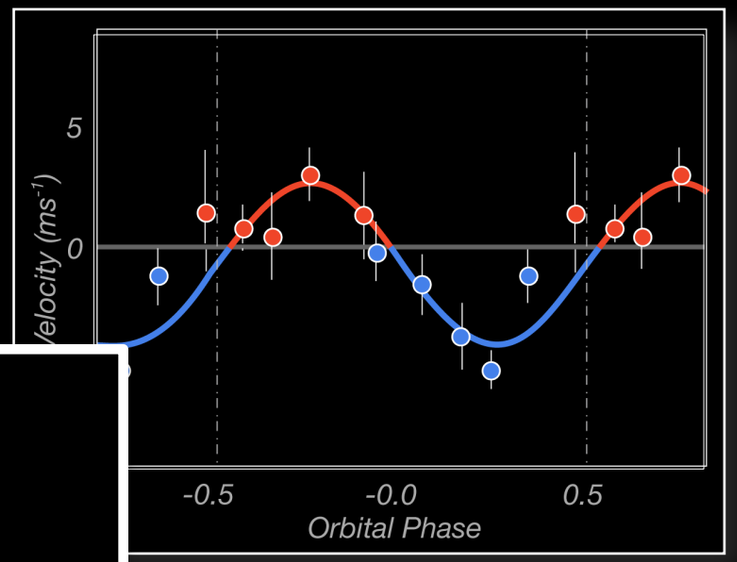


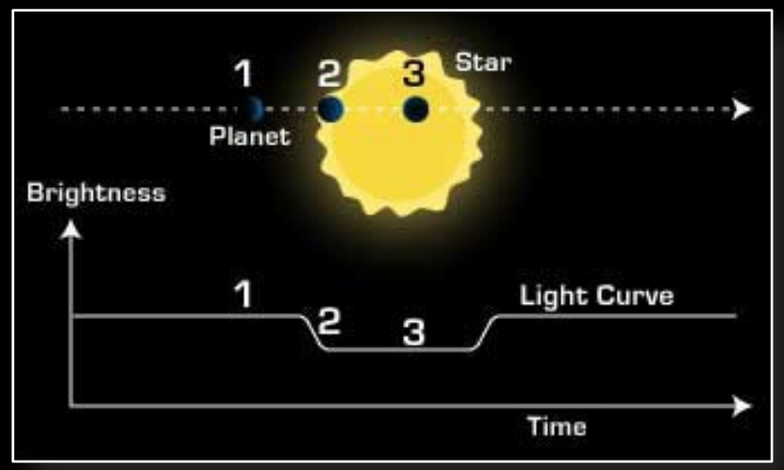




dichtheid

$$\frac{\text{Massa}}{\text{Volume}} = 8.8\ \text{g/cm}^3$$

Transit en snelheid → dichtheid



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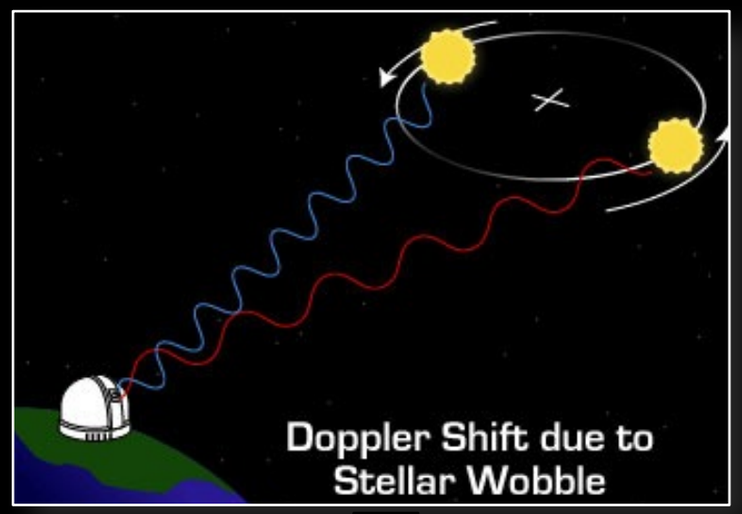
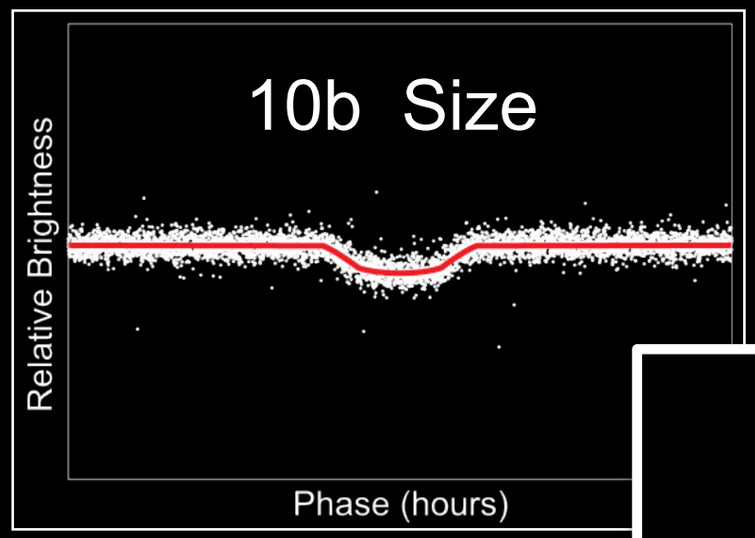
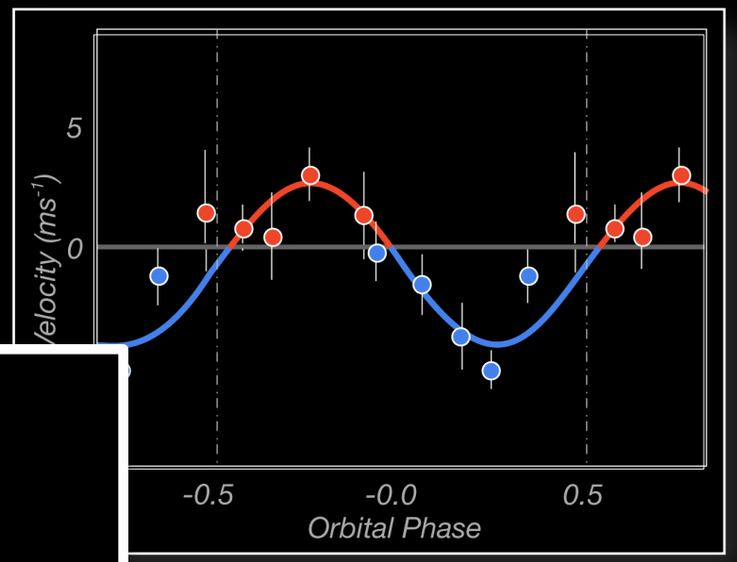




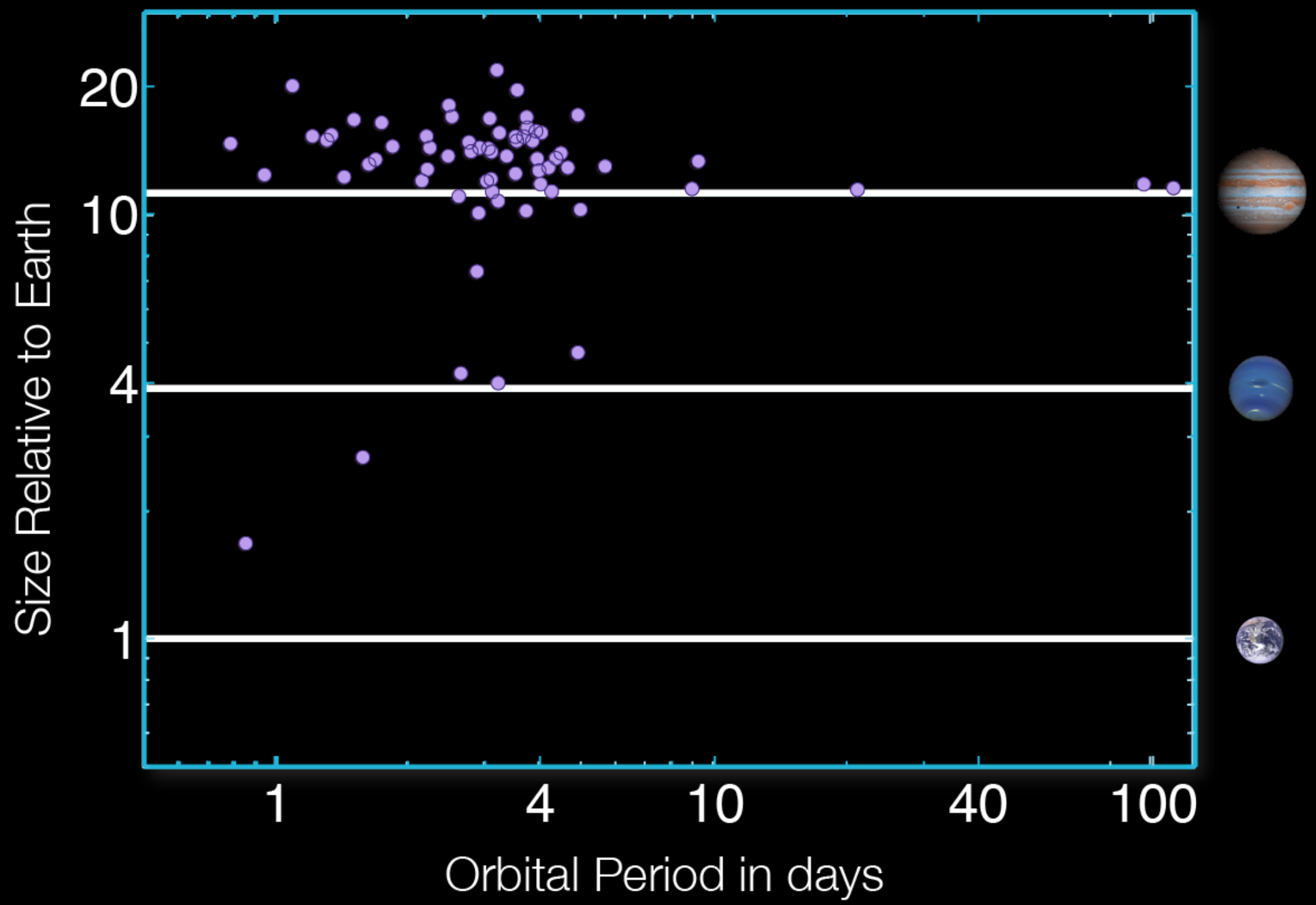


dichtheid

$$\frac{\text{Massa}}{\text{Volume}} = 8.8\ \text{g/cm}^3$$

Jupiter: 1,3 g/cm³
Aarde: 5,5 g/cm³

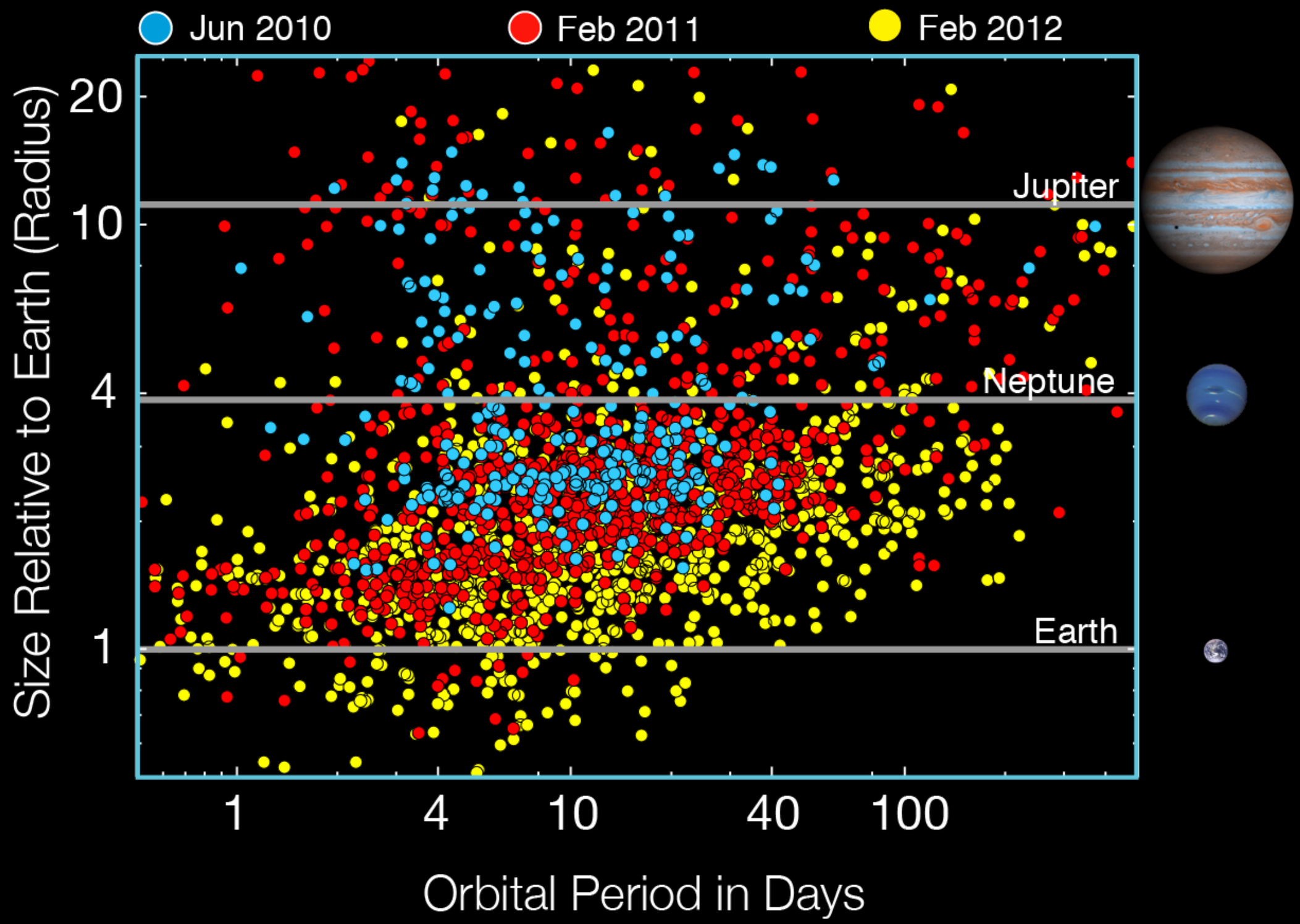
Pre-Kepler Transiting Planets - 2009



Slide courtesy of W. Borucki, NASA, February 2011

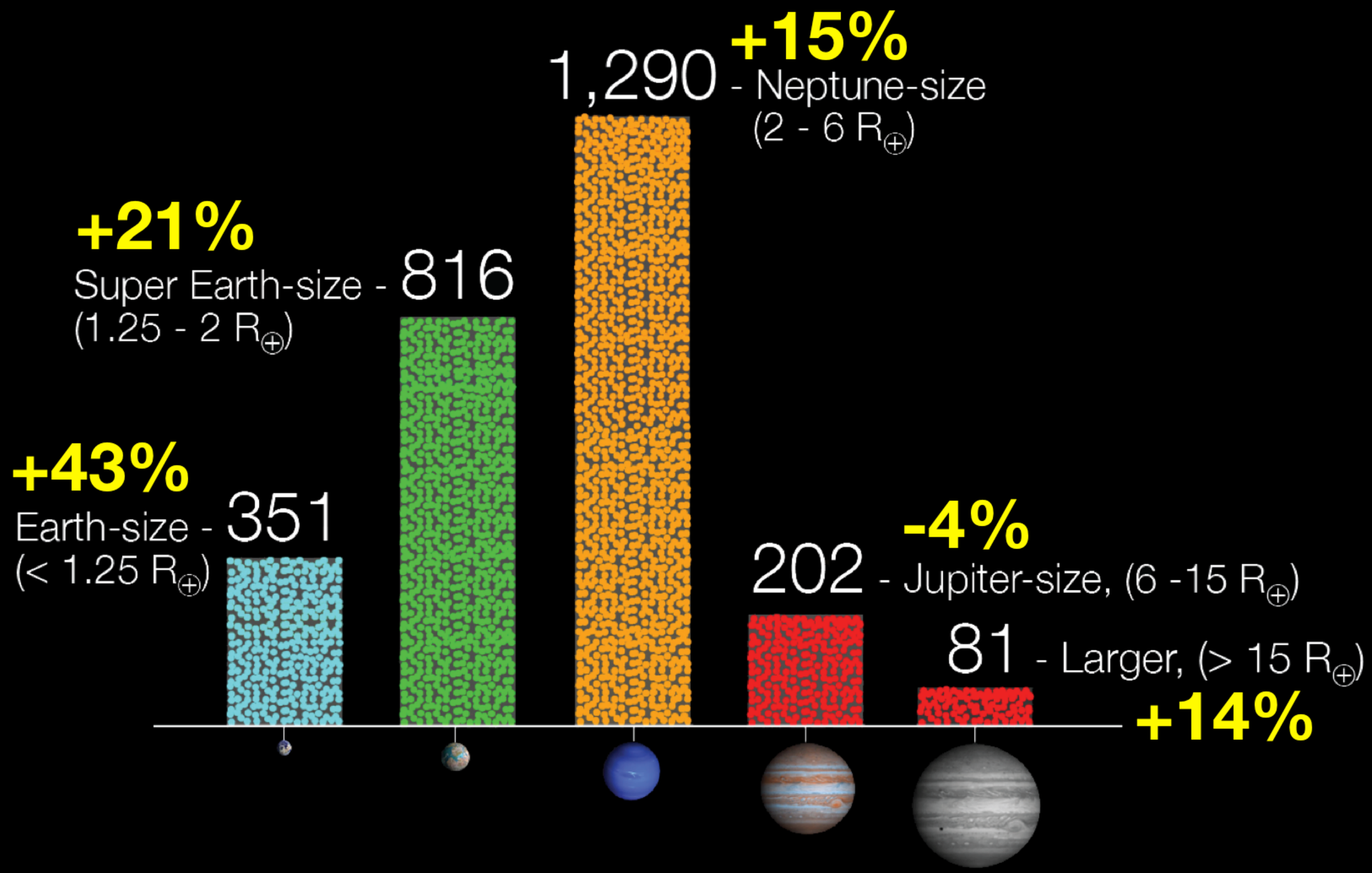
Planet Candidates

As of February 27, 2012

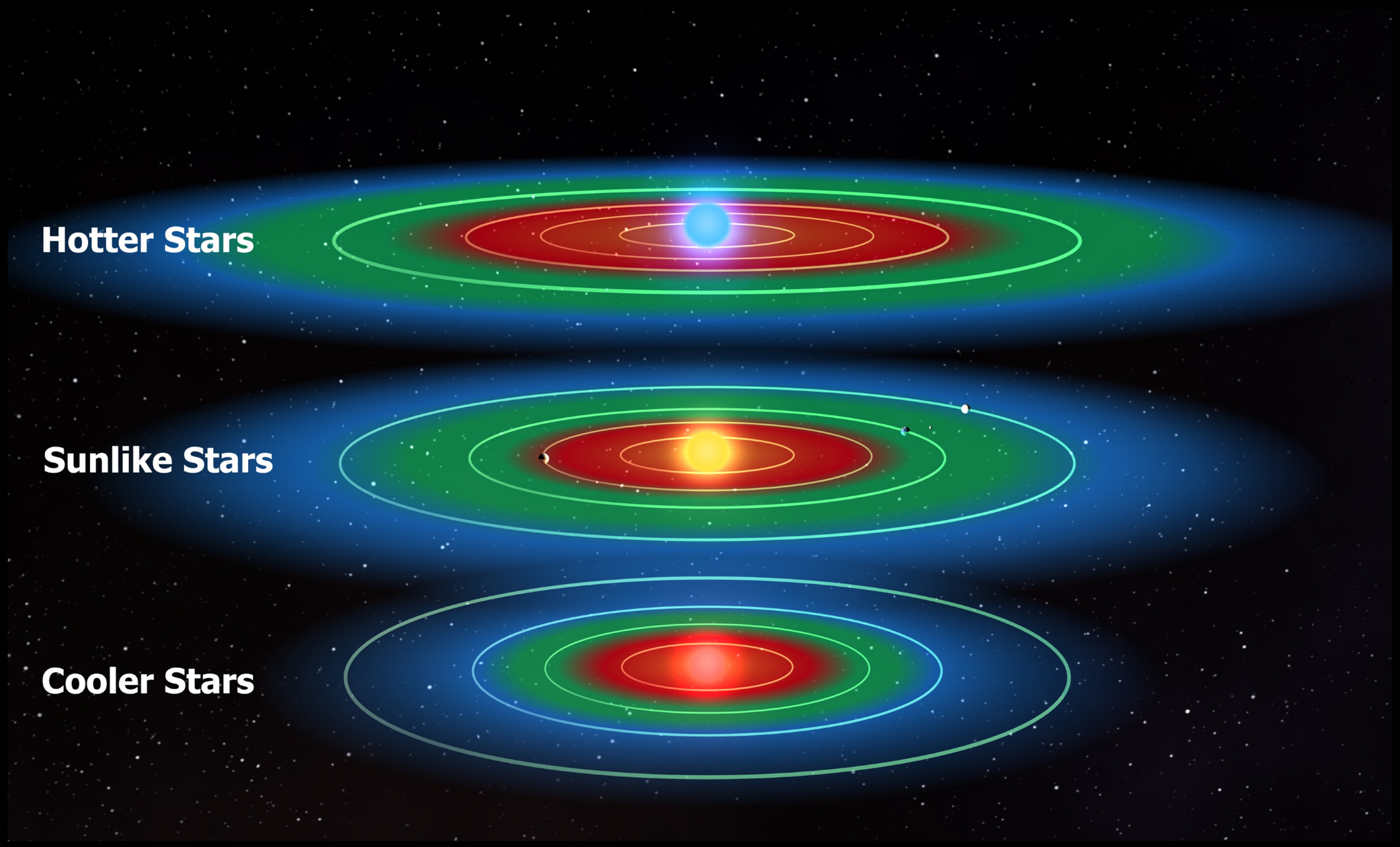


Sizes of Planet Candidates

As of January 7, 2013

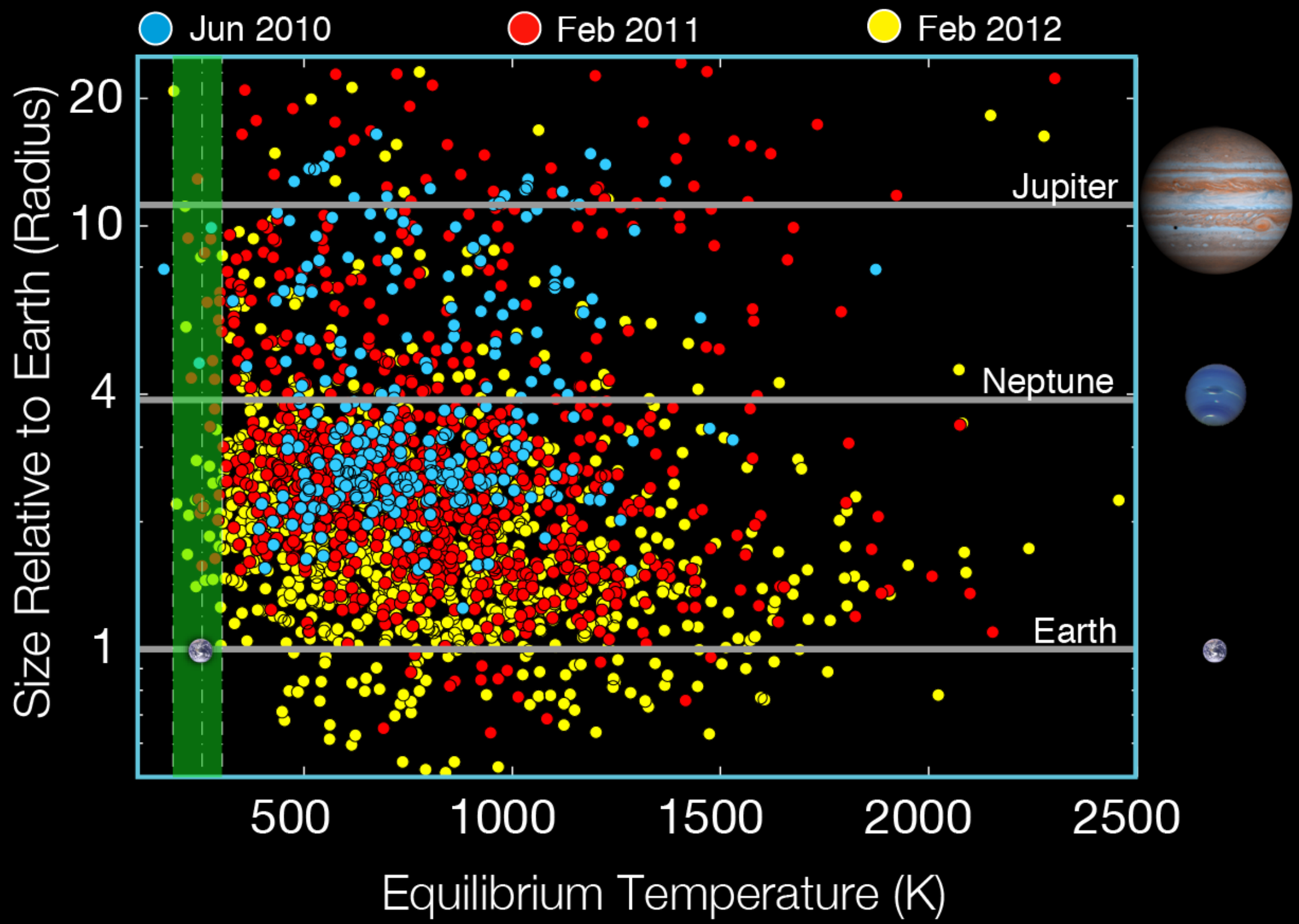


De leefbare zone

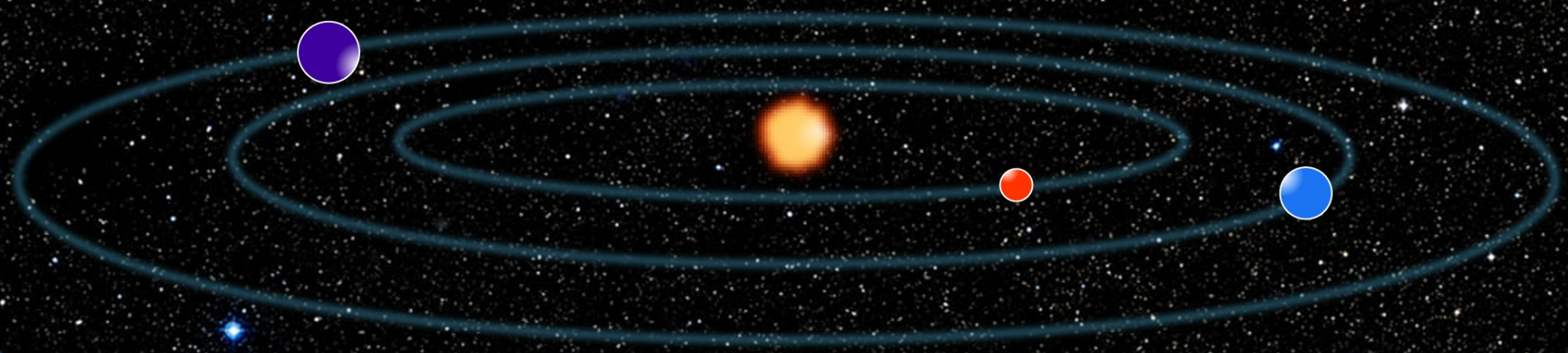


Candidates in the Habitable Zone

As of February 27, 2012

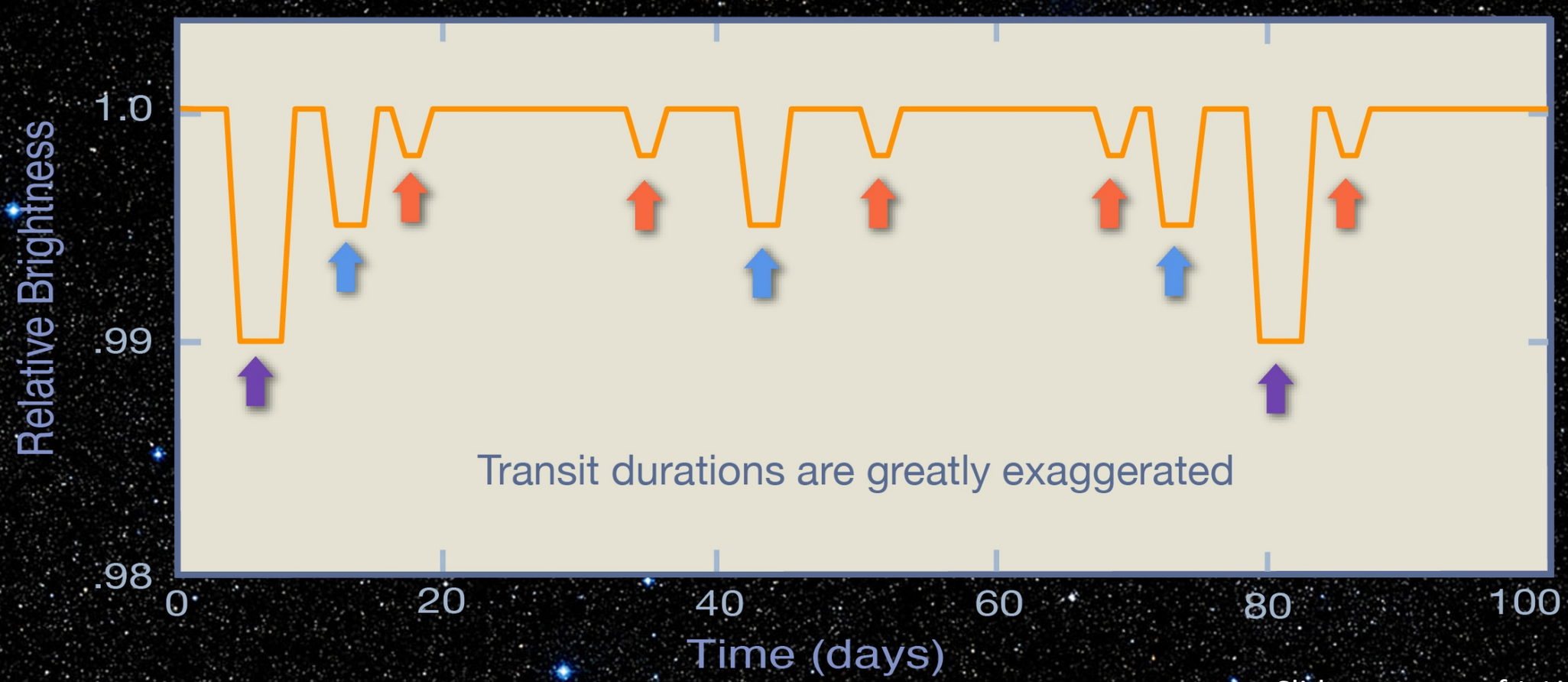


Transit Signature of a Multiple-Planet System



Planets can be distinguished by:

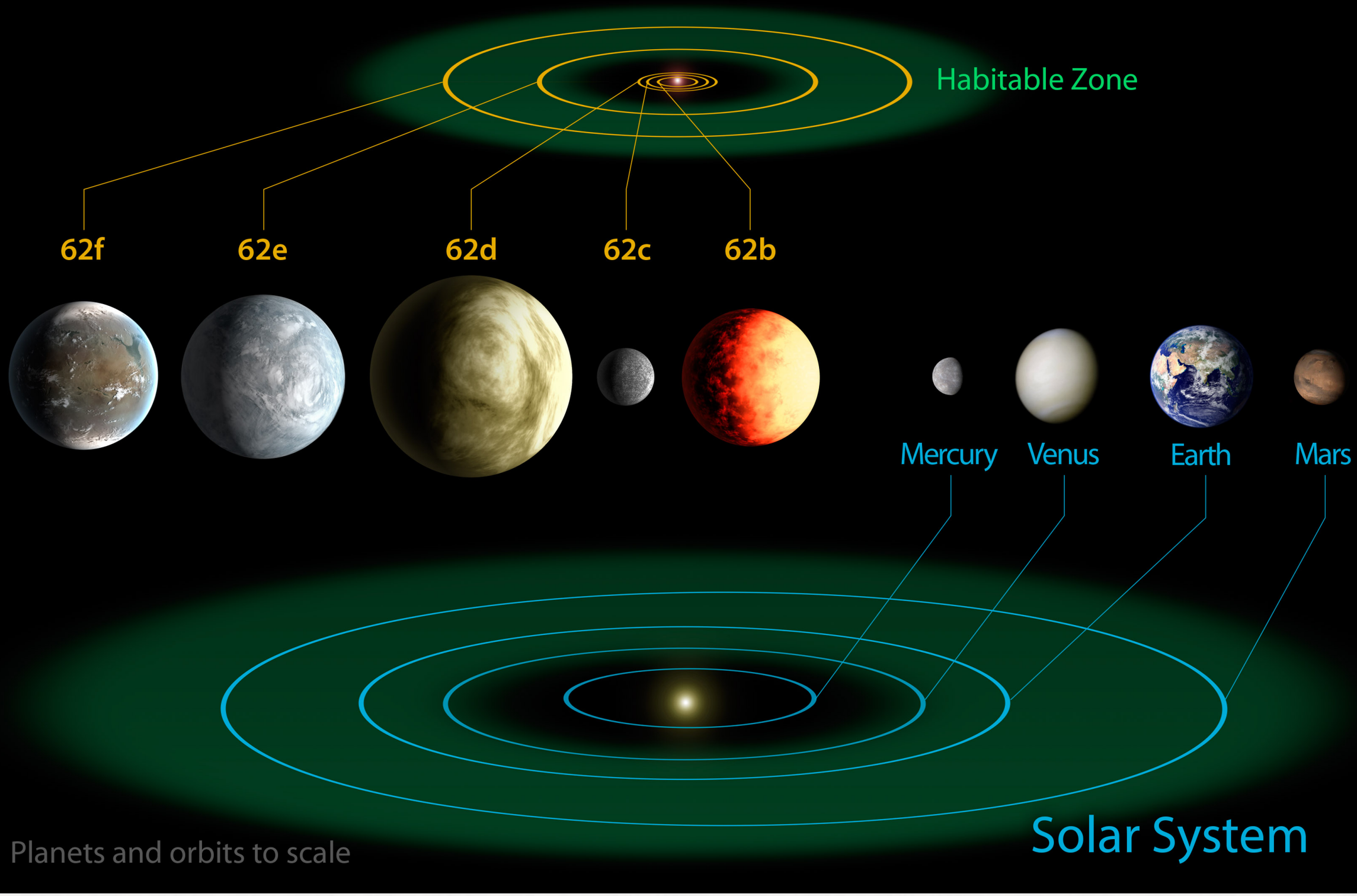
- Different periods
- Different depths
- Different durations



Slide courtesy of J. Lissauer, NASA

Kepler-62 System

Borucki et al. (2013, Science)



Huidige stand van zaken

- 9/3/2020: 4197 exoplaneten/683 meervoudige systemen gekend + nog eens zoveel kandidaten **http://exoplanet.eu**

- Enkele zeer goede kandidaat aardachtige planeten in leefbare zone bij zon-achtige sterren, oa. Kepler 62,…

- **Schattingen voor aantal bestaande exoplaneten: 400 miljard exoplaneten in Melkweg**
- Gemiddeld één planeet per ster
- 17 miljard aardachtige planeten in Melkweg

Speciale Categorie: exoplaneten rond koude rode sterren… zoektocht ster-per-ster

Pale Blue Dot - Carl Sagan

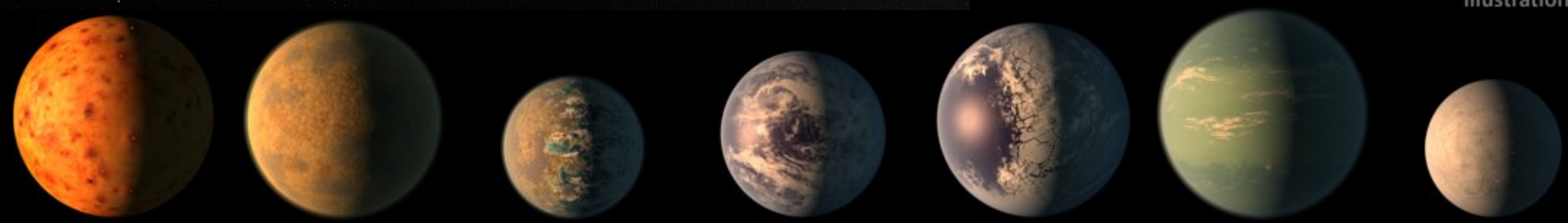
PALE RED DOT

Staat op 4,2 lichtjaren

https://www.eso.org/public/news/eso1629/

Trappist-1: 0,08 keer massa Zon
Jupiter: 0,001 keer massa Zon

Illustrations



TRAPPIST-1 System	b	c	d	e	f	g	h
Orbital Period *days*	1.51 *days*	2.42 *days*	4.05 *days*	6.10 *days*	9.21 *days*	12.35 *days*	~20 *days*
Distance to Star *Astronomical Units (AU)*	0.011 *AU*	0.015 *AU*	0.021 *AU*	0.028 *AU*	0.037 *AU*	0.045 *AU*	~0.06 *AU*
Planet Radius *relative to Earth*	1.09 R_{earth}	1.06 R_{earth}	0.77 R_{earth}	0.92 R_{earth}	1.04 R_{earth}	1.13 R_{earth}	0.76 R_{earth}
Planet Mass *relative to Earth*	0.85 M_{earth}	1.38 M_{earth}	0.41 M_{earth}	0.62 M_{earth}	0.68 M_{earth}	1.34 $_{earth}$	–

Bewoonbare exoplaneten: ver weg…

- Dichtstbijzijnde gekende exoplaneet cirkelt rond Proxima Centauri in 11.2 dagen; op ongeveer 40,000,000,000,000 km;
- Trappist-1op 400,000,000,000,000 km;
- Barnard's ster op 57,000,000,000,000 km;
- Kepler 62 op 11,400,000,000,000,000 km;

- Mars op 100,000,000 km; heeft geen leven (meer) op oppervlak
- Met huidige technologie bereiken "wij" de dichtsbijzijnde exoplaneet Proxima Centauri b na ≈100,000 jaren… nieuwe tech met laser parachuutjes (1/5 lichtsnelheid) duurt ≈20 jaar

Ruimtevaart aan de KU Leuven: missies die doen dromen

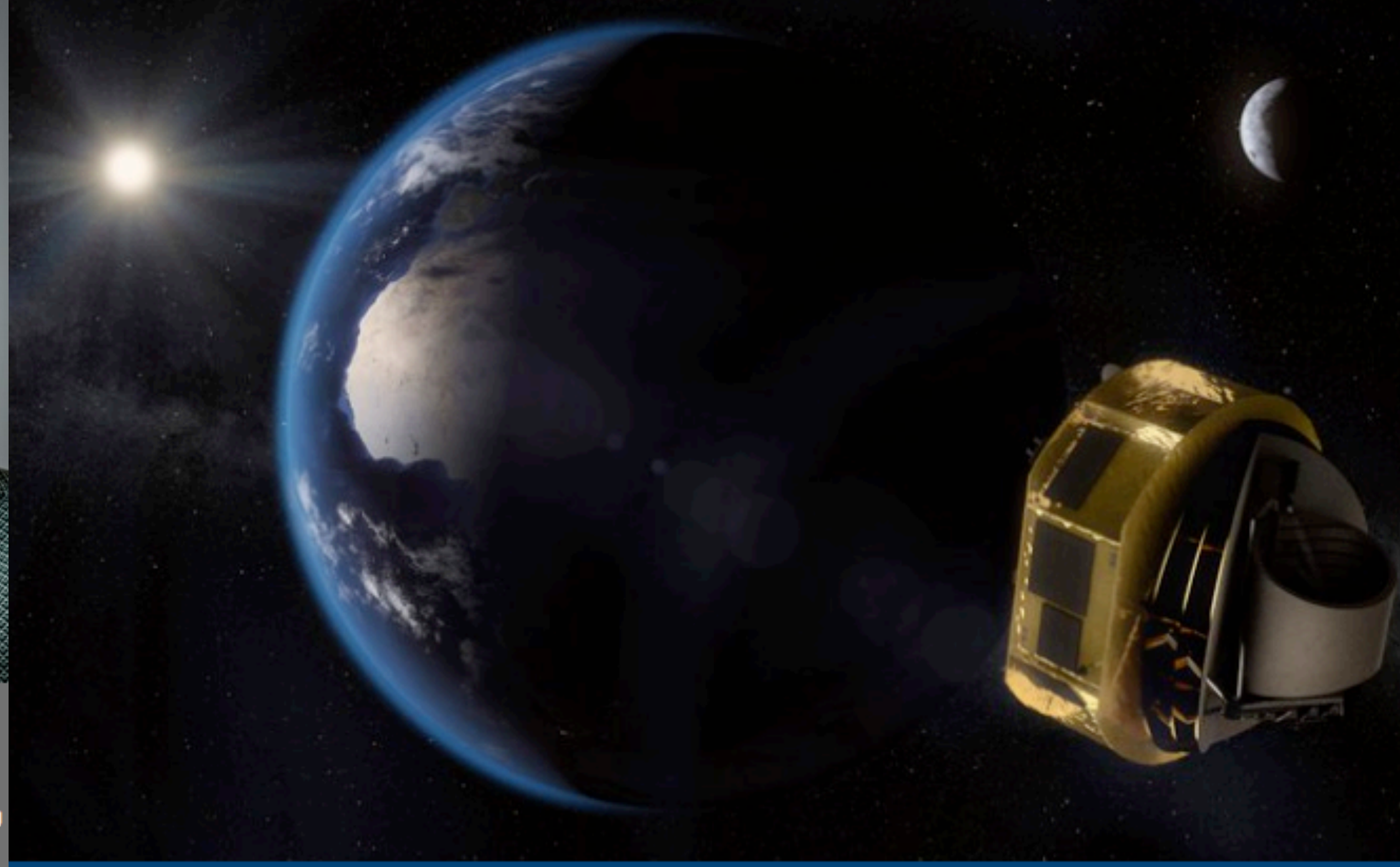
25-11-2019

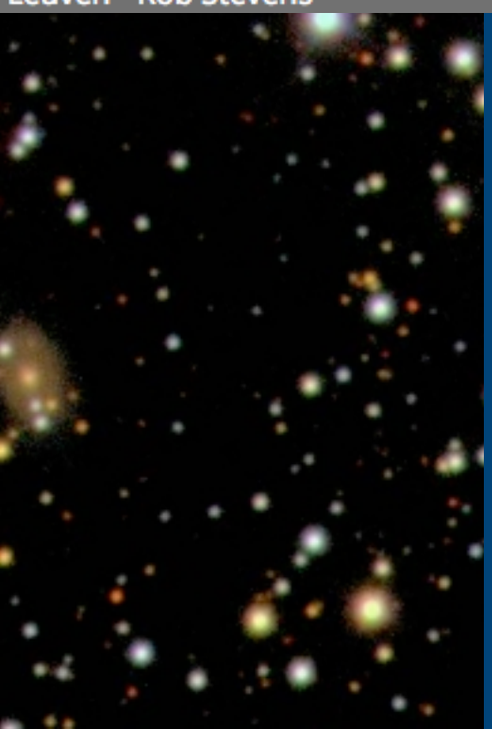
Professor Conny Aerts: ""We willen met PLATO exoplaneten vinden – planeten buiten ons zonnestelsel – die voldoende op onze aarde gelijken om leven mogelijk te maken." | © KU Leuven - Rob Stevens

PLATO: Op zoek naar Planeet B

- *Planetary Transits and Oscillations of Stars*
- Brengt mogelijk leefbare exoplaneten en hun moedersterren in kaart
- Lancering in 2026
- Budget: 500 miljoen euro
- Conny Aerts is medebedenker en Belgisch hoofdonderzoeker. De KU Leuven is onder meer verantwoordelijk voor de simulator en voor de assemblage en het testen van de 26 camera's.

Bart Vandenbussche: "Reizen naar bewoonbare planeten? Nee, je geraakt er nooit in een mensenleven. We doen dit puur om onze kennis te vergroten." | © KU Leuven - Rob Stevens





ARIEL: Allen daarheen?

- *Atmospheric Remote-sensing Infrared Exoplanet Large-survey*
- Zoekt in de atmosfeer van exoplaneten naar moleculen die leven mogelijk maken
- Lancering in 2028
- Budget: 450 miljoen euro
- Bart Vandenbussche is Belgisch hoofdonderzoeker. De KU Leuven is onder meer verantwoordelijk voor het coördineren van de ontwikkeling en bouw van de telescoop.

Sterbevingen, exoplaneten, en buitenaards leven?

Als er een vorm van buitenaards leven is dichtbij ons, zullen we deze vinden in de "nabije" toekomst…

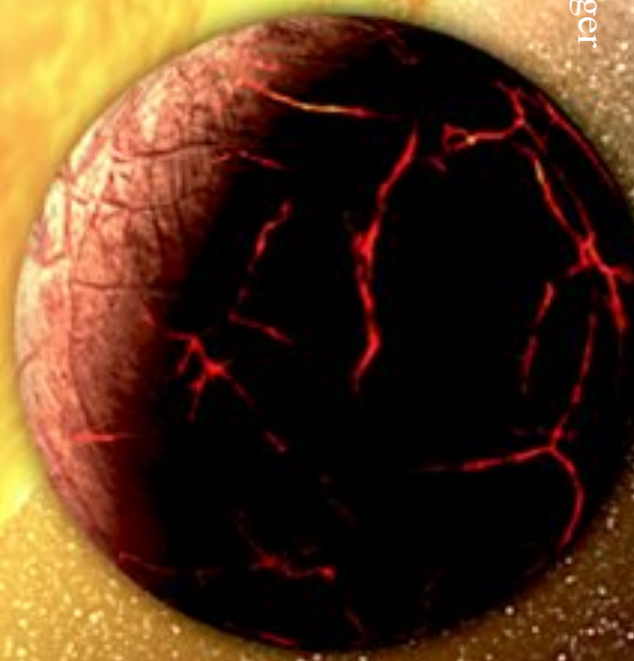


Image credit: NASA's Goddard Space Flight Center/S. Wiessinger

9/3/2020, Het Turnhouts Wetenschapscafé