

**Natuurkunde
op afstand:
sterbevingen en
exoplaneten in onze
Melkweg**

Conny Aerts, WND conferentie, 11/12/2020

The “winner” is:

The possibility of
life outside earth

“Space, life, wonder,
openness”
The most popular
for girls and boys

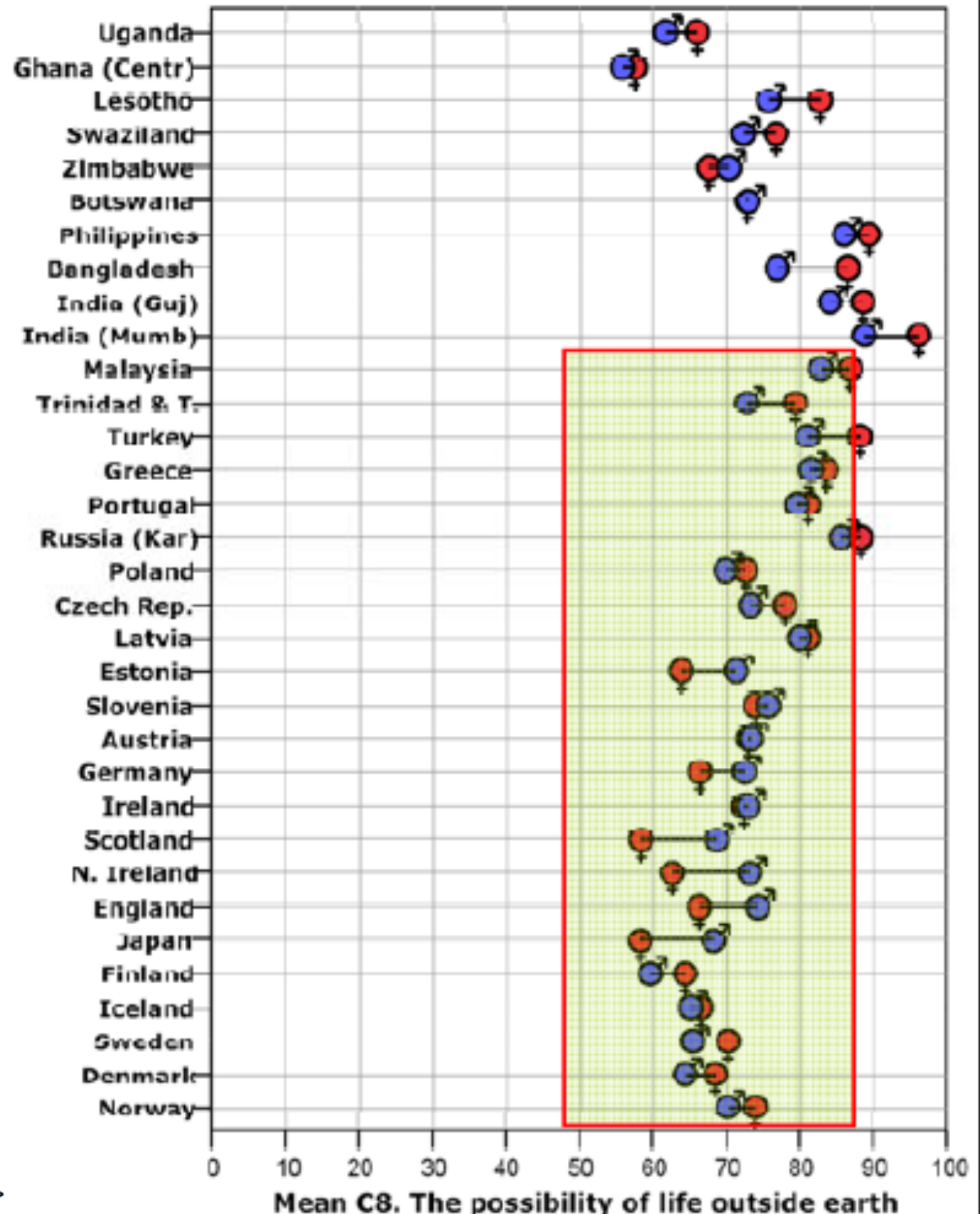
The ROSE project

An overview and key findings¹

Svein Sjøberg <svein.sjoberg@ils.uio.no>

Camilla Schreiner (Camilla Schreiner <camilla.schreiner@naturfagsenteret.no>

University of Oslo, March 2010



An extragalactic ROSE



Credit: ESA/NASA/Hubble

The ROSE project

An overview and key findings¹

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University of Oslo, March 2010

motivatie voor
(STEM) leraren:
iedereen heeft
interesse in Heelal
en bij 15-jarigen
is dit in
gender-balans!

Finland
Iceland
Sweden
Denmark
Norway

0 10 20 30 40 50 60 70 80 90 100
Mean C8. The possibility of life outside earth

STERREN: HETE GASBOLLEN DIE STRALEN

PLANETEN STRALEN NAUWELIJKS MAAR REFLECTEREN LICHT VAN HUN MOEDERSTER



Sterren:
binnenkant
miljoenen graden
buitenkant
duizenden graden



Rechtstreekse detectie
van exoplaneten is moeilijk

Sterbevingen & Exoplaneten: waar beginnen zoeken? ...

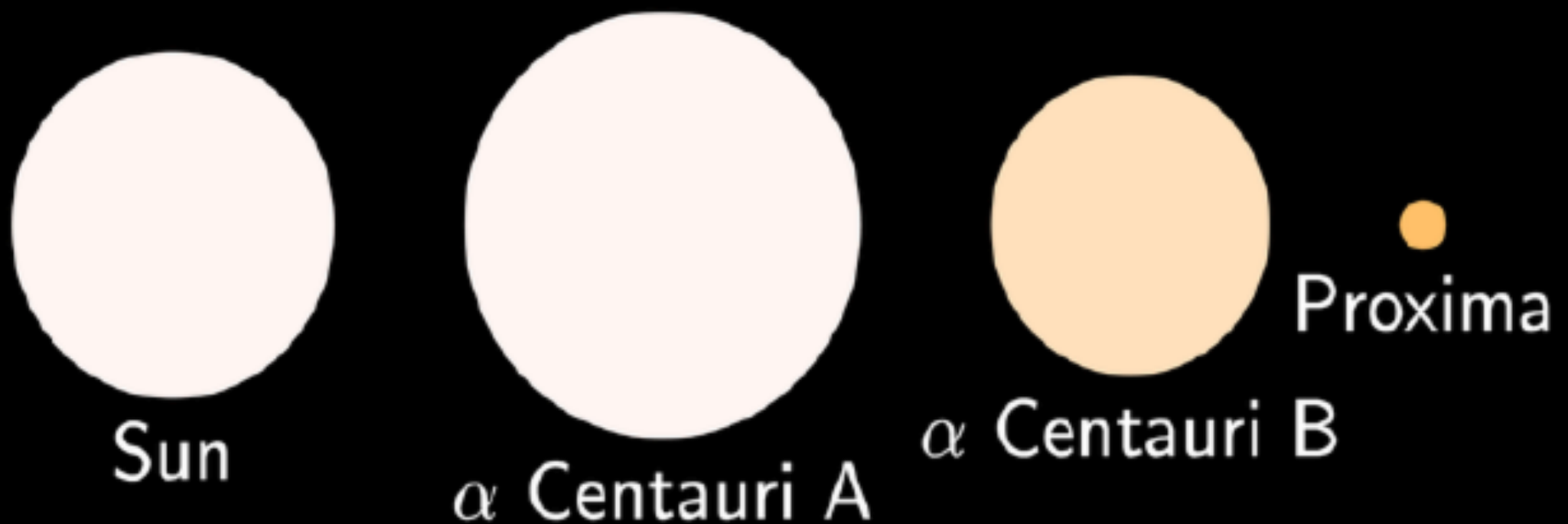
**ER ZIJN MILJARDEN
STERRENSTELSELS**

**ELK MET MILJARDEN
STERREN**

**Schalen in het Heelal
zijn immens!**

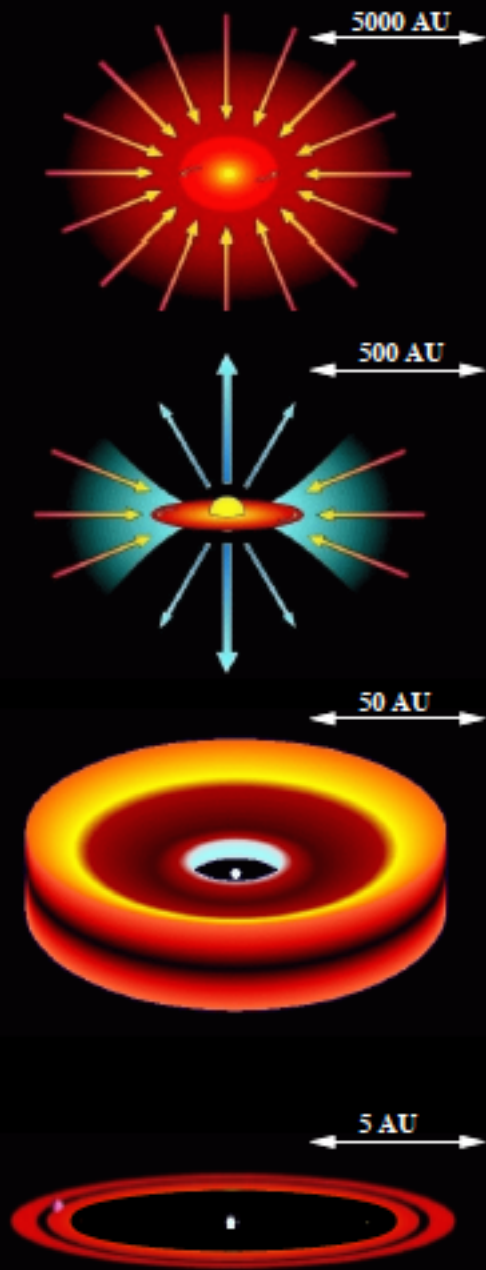
Hubble eXtreme Deep Field (XDF)
Hubble Space Telescope • ACS/WFC • WFC3/IR

LAAT ONS VLAKBIJ HUIS BEGINNEN



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

STERREN & PLANETEN WORDEN SAMEN GEBOREN

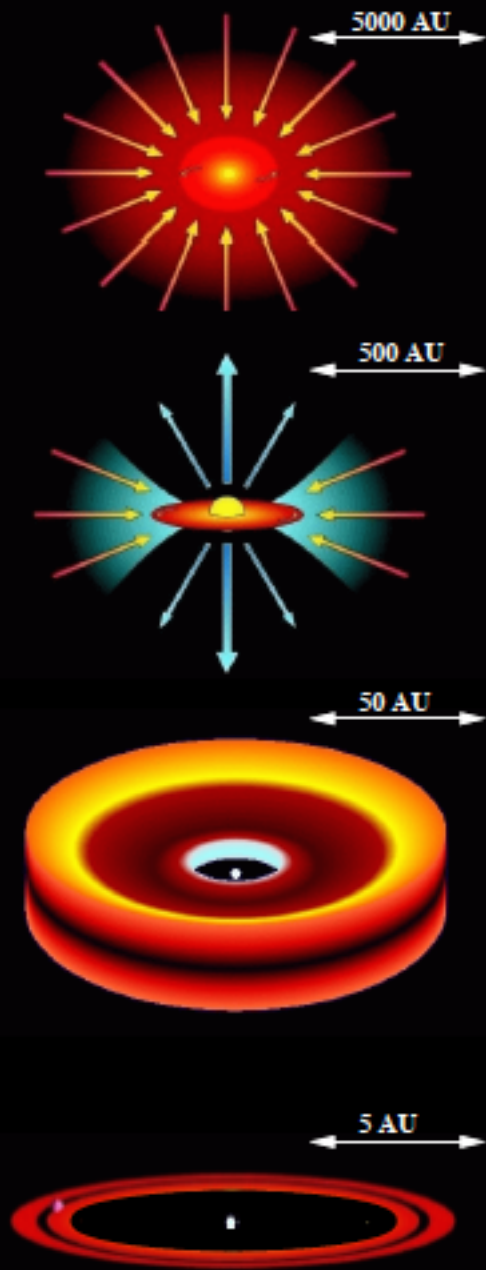


Atacama Large
Millimeter Array



STERREN & PLANETEN WORDEN SAMEN GEBOREN

LEEFTIJD
MOEDERSTER
≈
LEEFTIJD PLANEET



STERREN ZIJN KERNREACTOREN



GEEN KERNSPLIJTINGSREACTOREN



Periodiek Systeem van de Elementen


 alkalimetalen
 aardalkalimetalen
 transitimetalen
 andere metalen
 nietmetalen
 edelgassen
 lanthaniden
 actiniden

elementnaam
 atoomnummer
symbool
 atoommassa

C  Br  He  Tc  kunstmatig

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

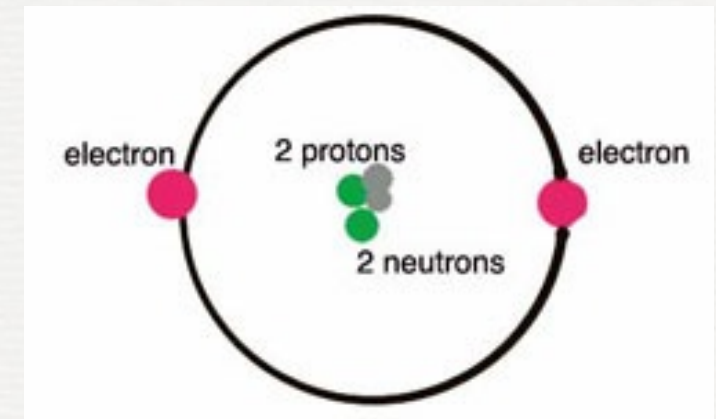
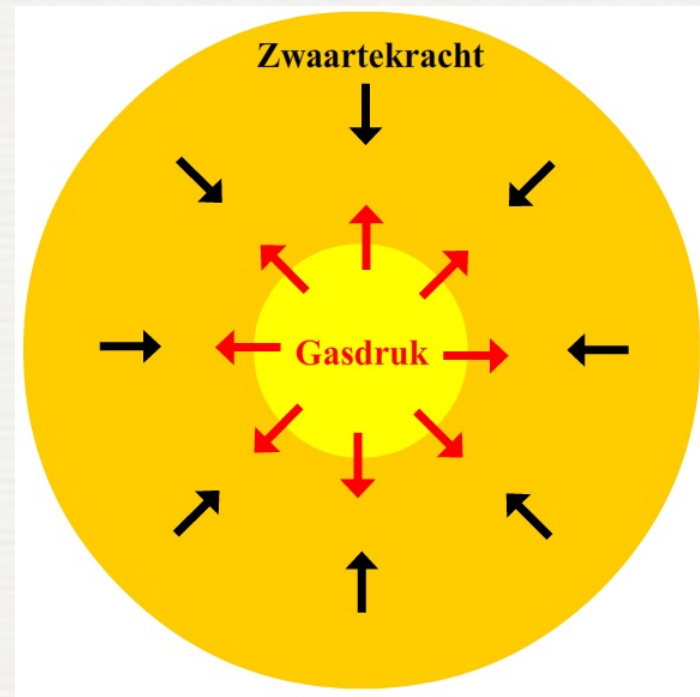
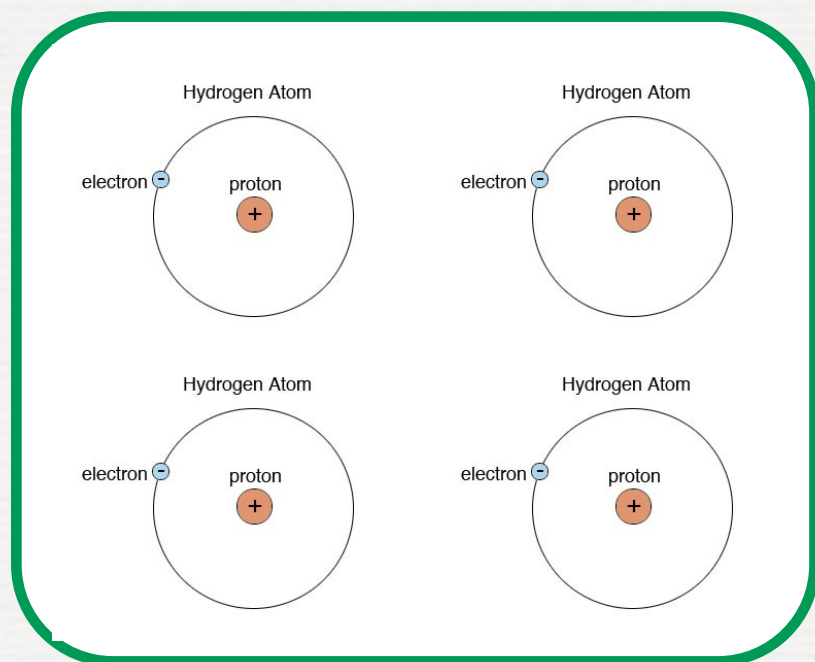
57 lanthaan 57 La 138,9	58 cerium 58 Ce 140,1	59 praseodymium 59 Pr 140,9	60 neodymium 60 Nd 144,2	61 promethium 61 Pm	62 samarium 62 Sm 150,4	63 europium 63 Eu 152,0	64 gadolinium 64 Gd 157,3	65 terbium 65 Tb 158,9	66 dysprosium 66 Dy 162,5	67 holmium 67 Ho 164,9	68 erbio 68 Er 167,3	69 thulium 69 Tm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

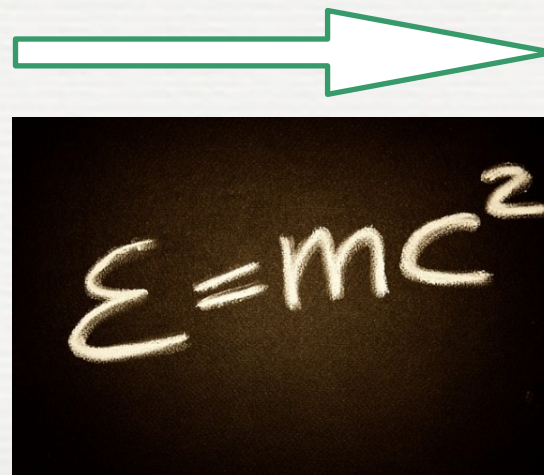
IUPAC 2009 standaard atoommassa's. De onzekerheid in het laatste cijfer is tussen ronde haken gegeven.
 Bij ontbreken van ronde haken is deze onzekerheid één. Tussen vierkante haken worden de laagste en
 hoogste grenswaarden gegeven van de standaard atoommassa. Voor elementen die geen isotopen hebben
 die in natuurlijke aardmonsters voorkomen, wordt geen waarde weergegeven.

STERREN DOEN AAN KERNFUSIE

BIJ GEBOORTE: ~71% H, ~28% HE, ~2% "AL DE REST"

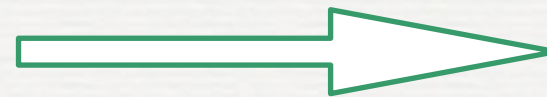
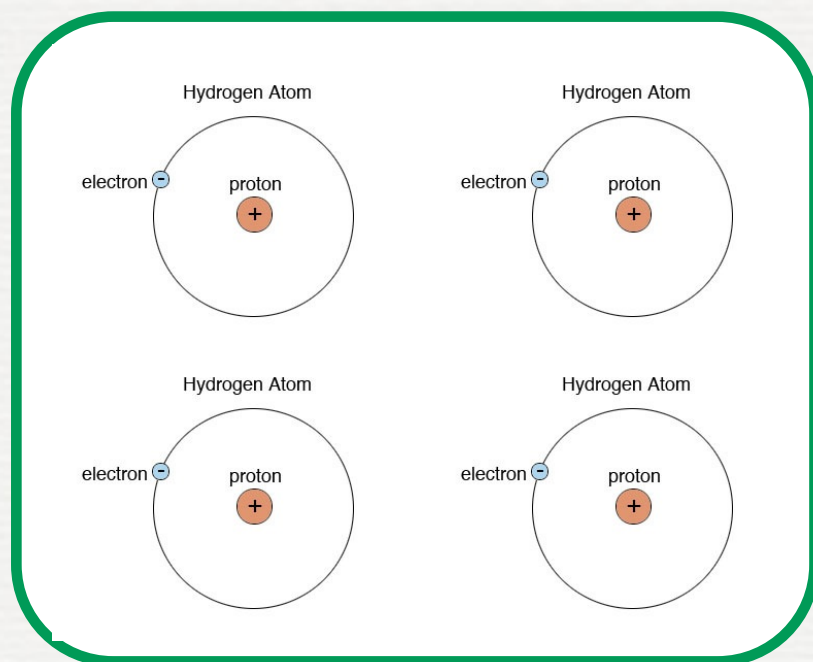
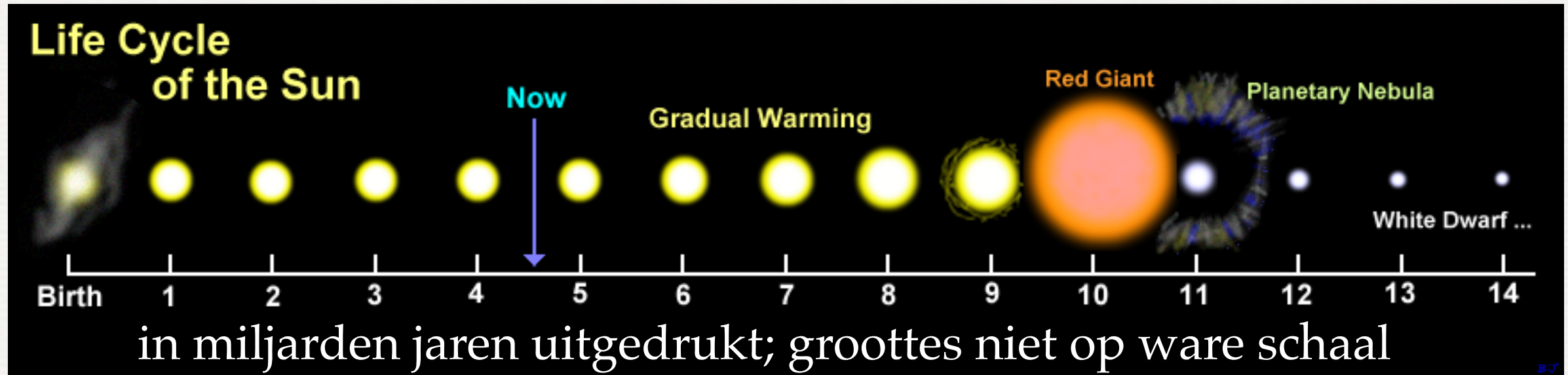
BINNENSTE STER: GAS IS MILJOENEN GRADEN
EN ER HEERST GROTE DICHTHEID EN DRUK. IN SI EENHEDEN:
 $T=15,000,000\text{ K}$; $P=20,000,000,000,000,000\text{ PASCAL}$; 150 TON/KUBIEKE METER



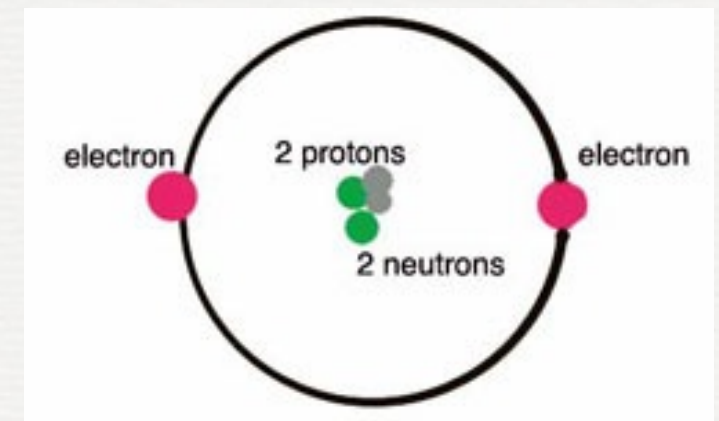


Handwritten equation $E=mc^2$ on a chalkboard, representing the equation of mass-energy equivalence.

HET LEVENSPAD VAN DE ZON

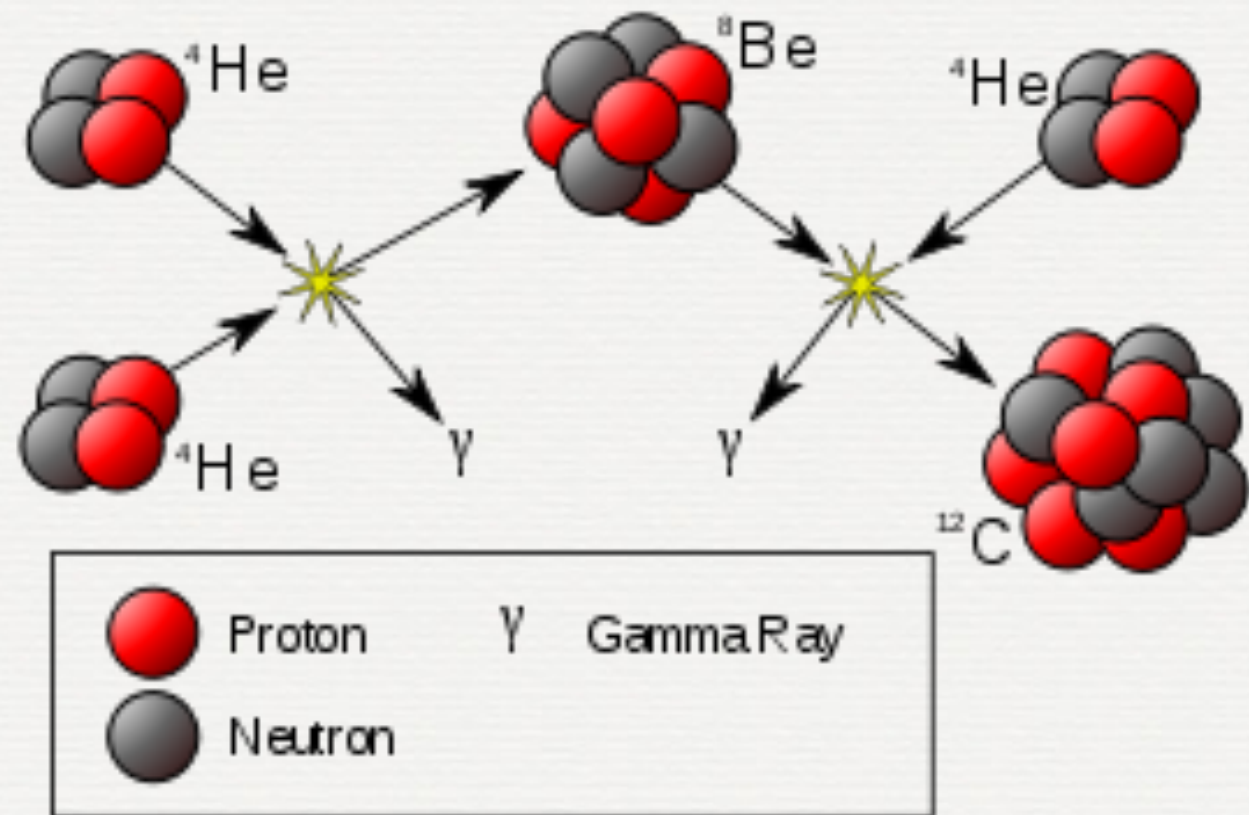
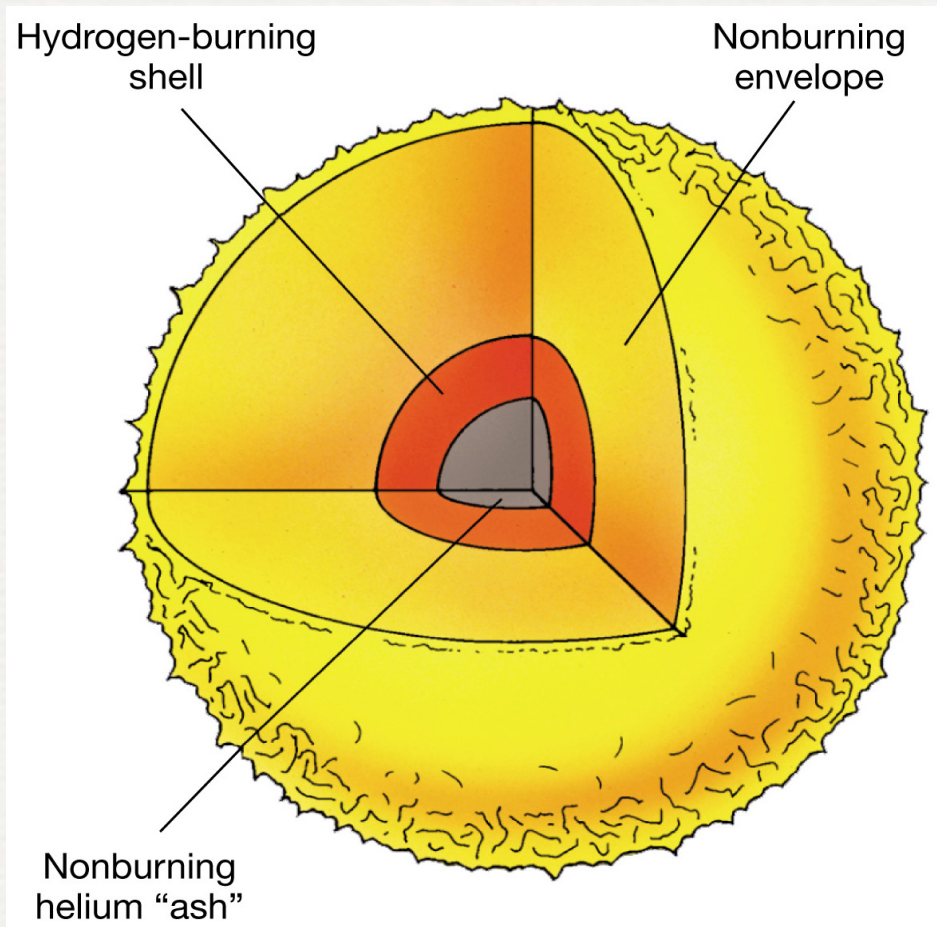


$$E=mc^2$$



Zolang de
H voorraad
strekt

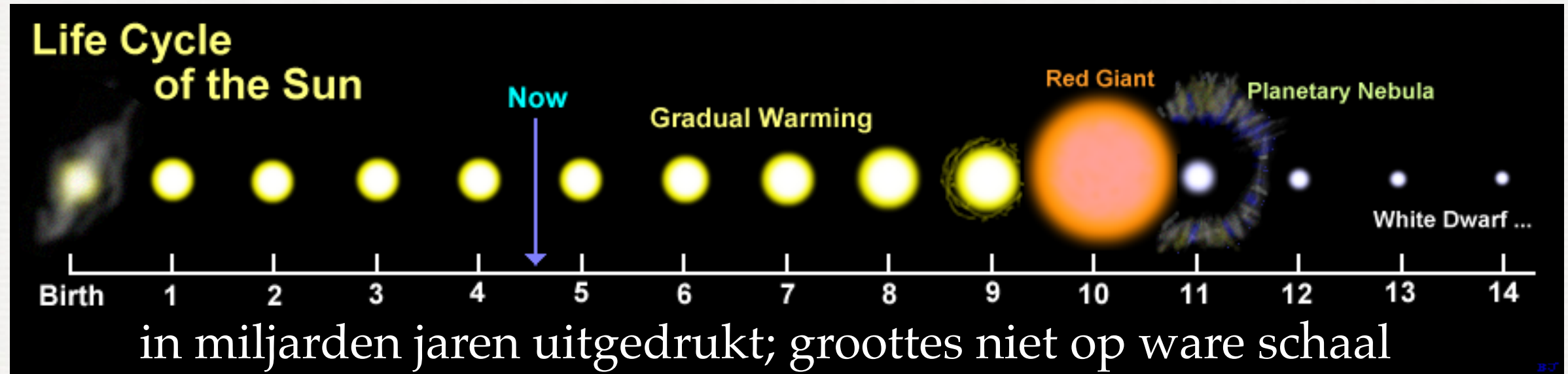
ENERGIECRISIS OP KOMST



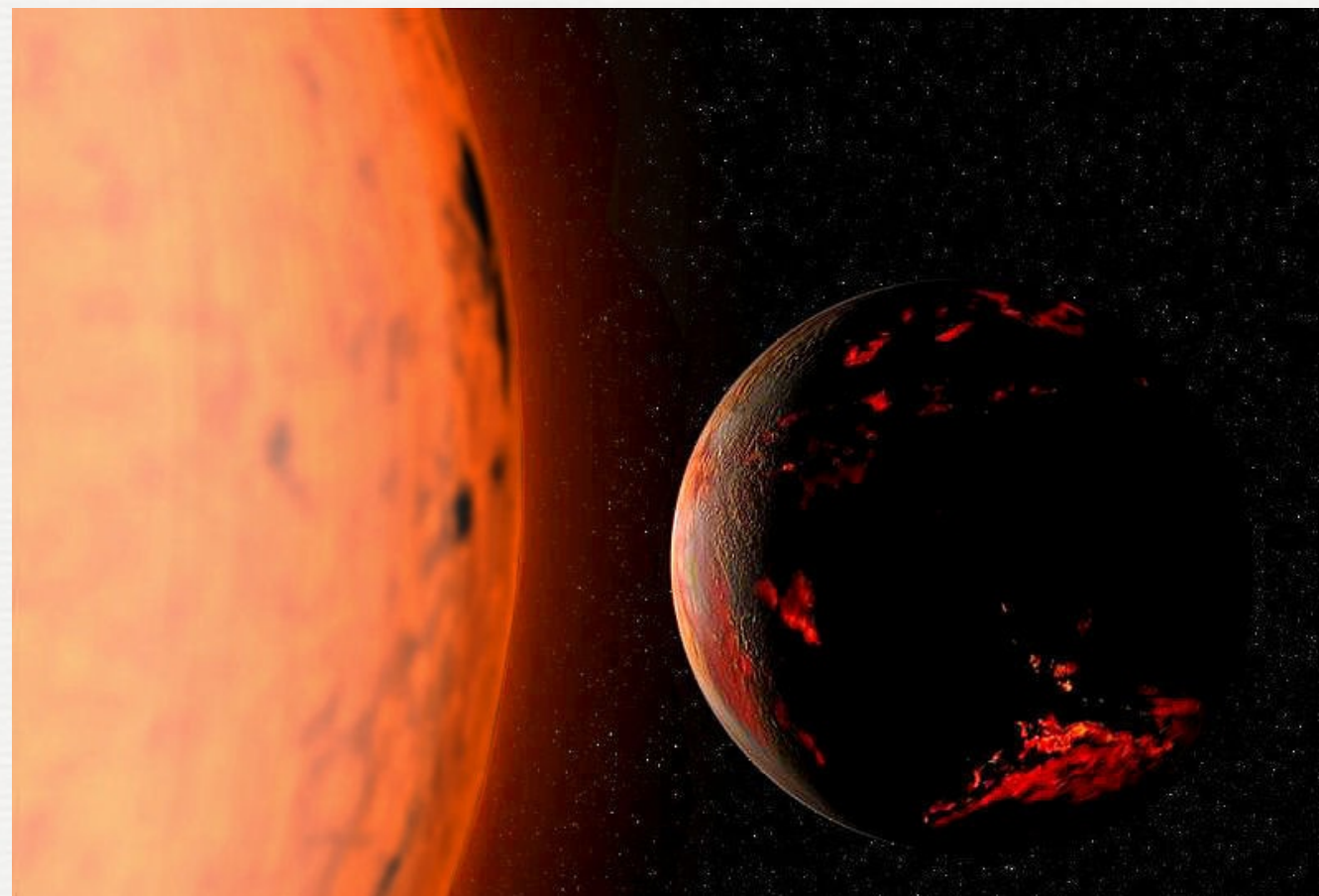
**HELIUMBAL IN BINNENSTE MOET KRIMPEN OM
10X HETER TE MAKEN, ONDERTUSSEN
WATERSTOFFUSIE IN SCHIL ROND HELIUM:**

ZON WORDT RODE REUS

HET LOT VAN ONZE AARDE...

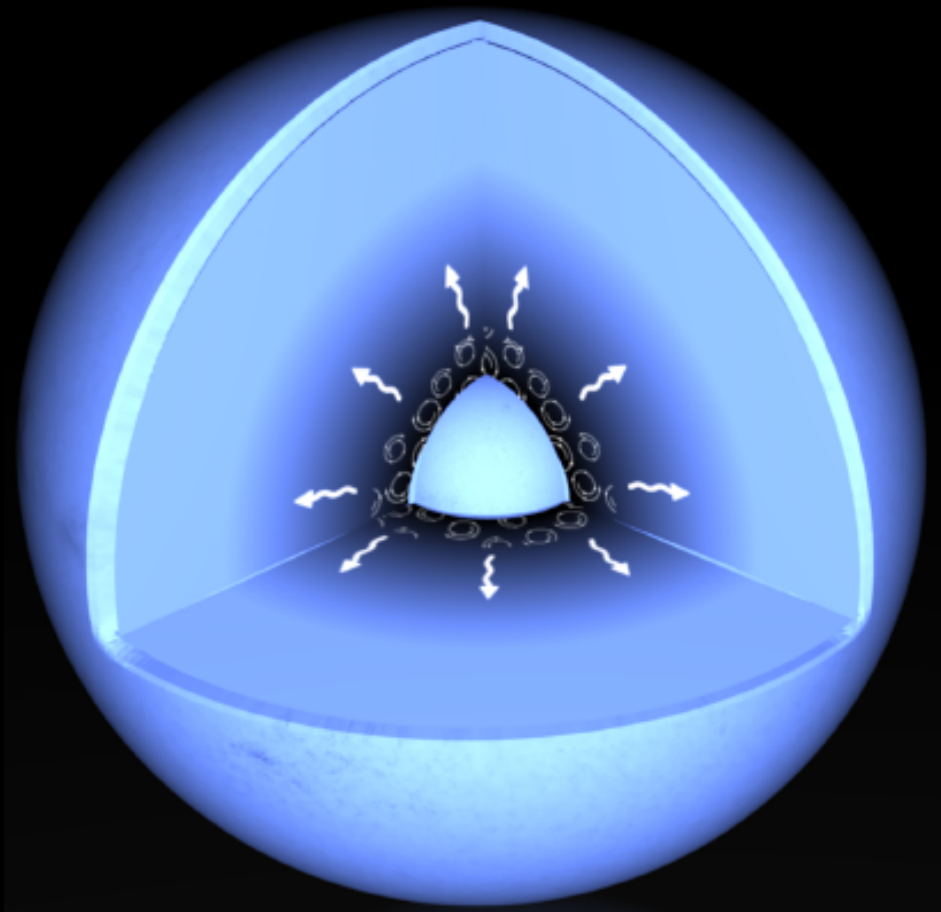


WANNEER?
(LEEFTIJD
ZON?)



HOE
DICHT?
(STRAAL
ZON?)

**Leven, grootte,
leeftijd: bepaald
door interne fysica**



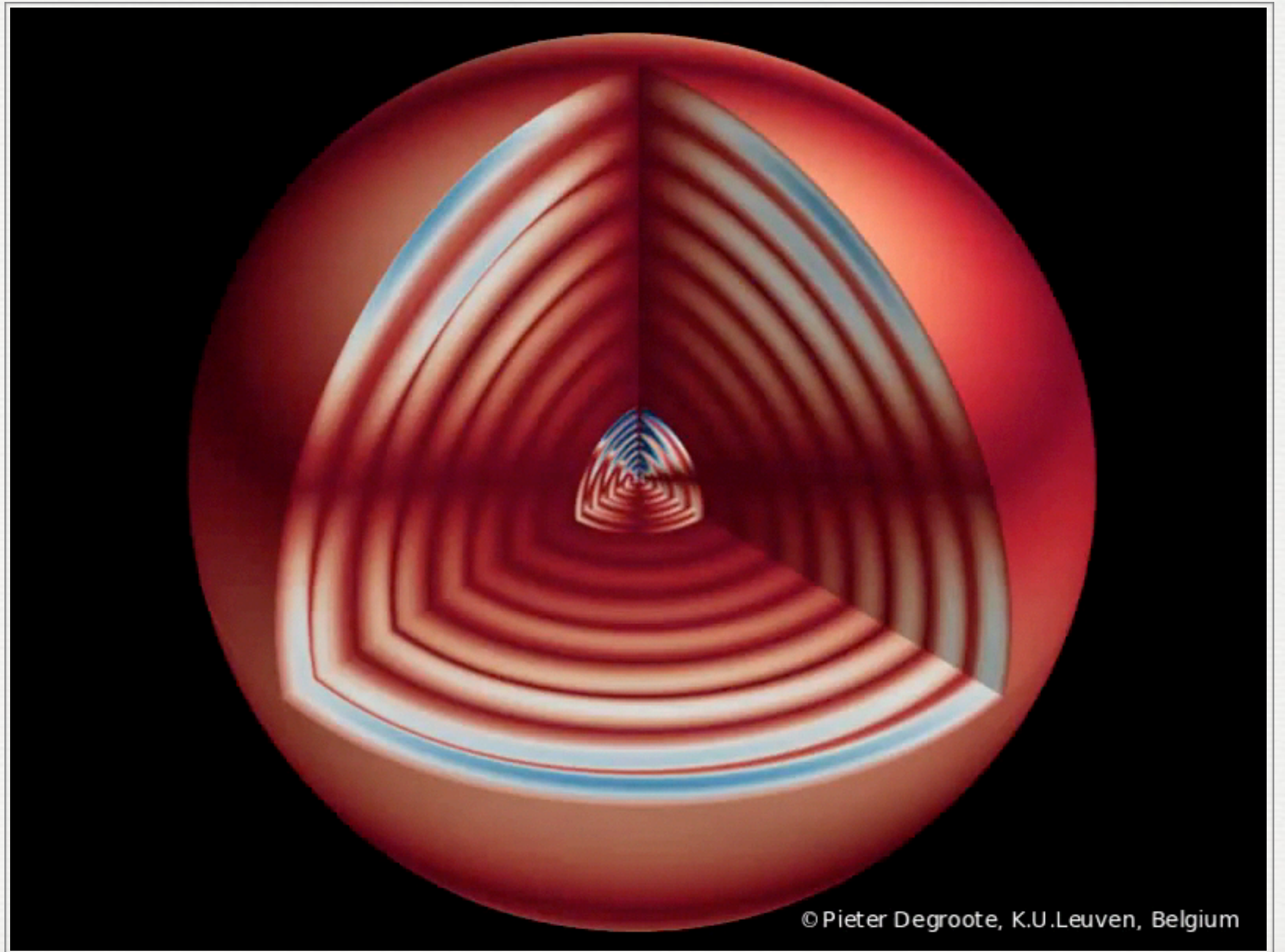
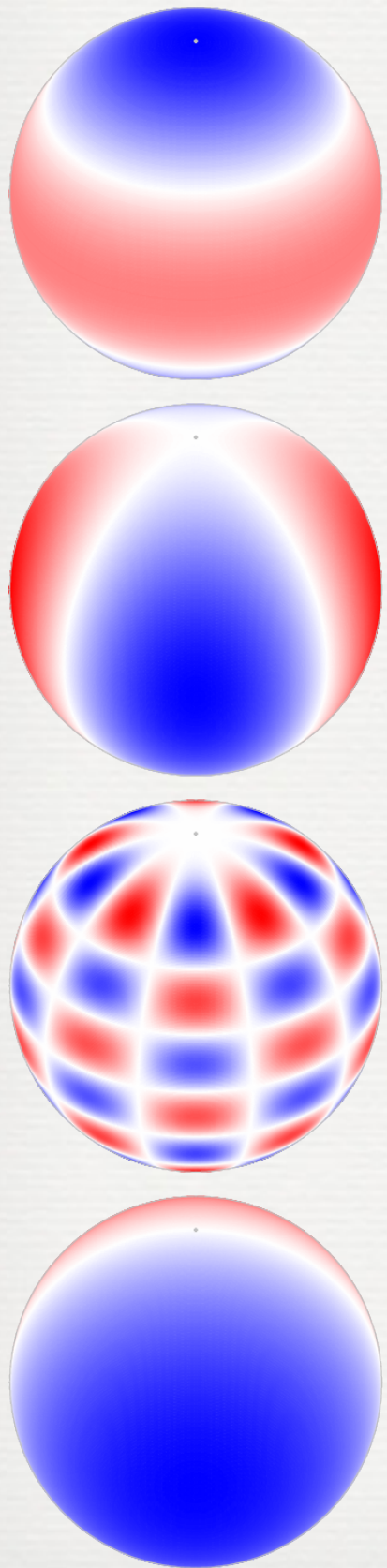
**Dé sterrenkundevraag
van vorige eeuw:**



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

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

STERBEVINGEN BRENGEN REDDING



© Pieter Degroote, K.U.Leuven, Belgium

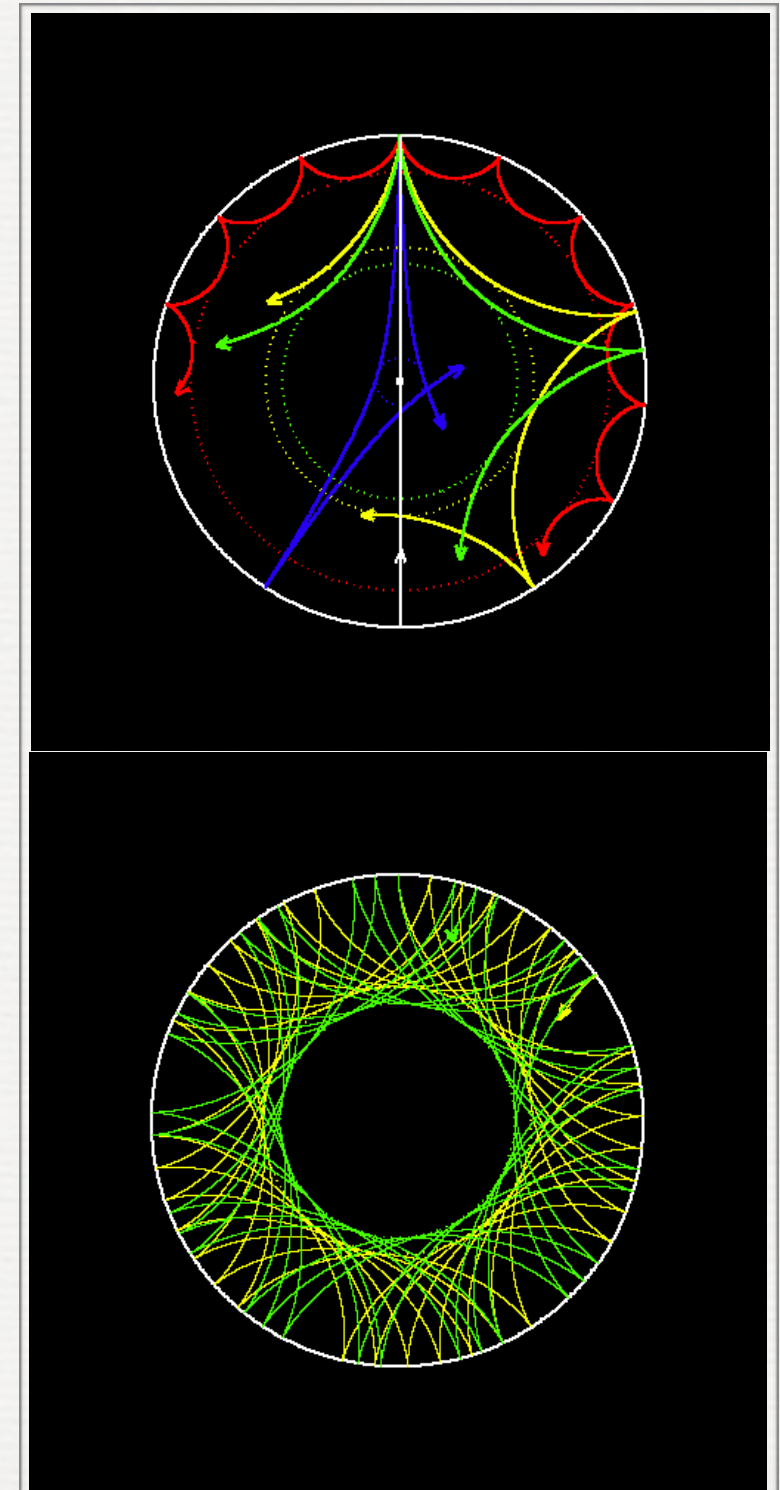
STERBEVINGEN DOORPRIEMEN STERINWENDIGEN

aster → star
seismos → oscillation
logos → discourse

ASTEROSEISMOLOGIE:

meet en interpreteer frequenties

vereist combinatie van wiskunde,
fysica, chemie, informatica en
technologie (*i* STEM !)

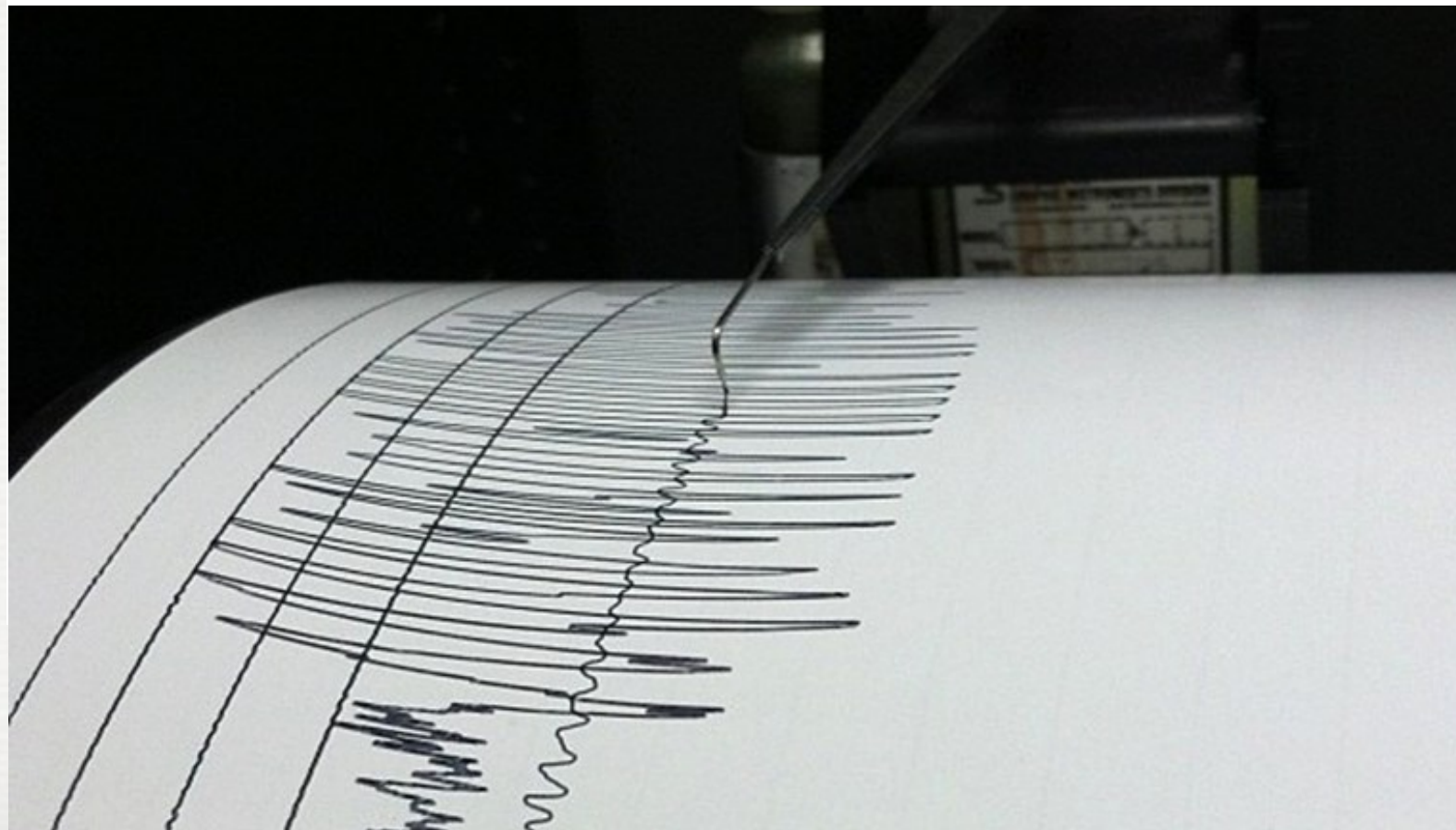
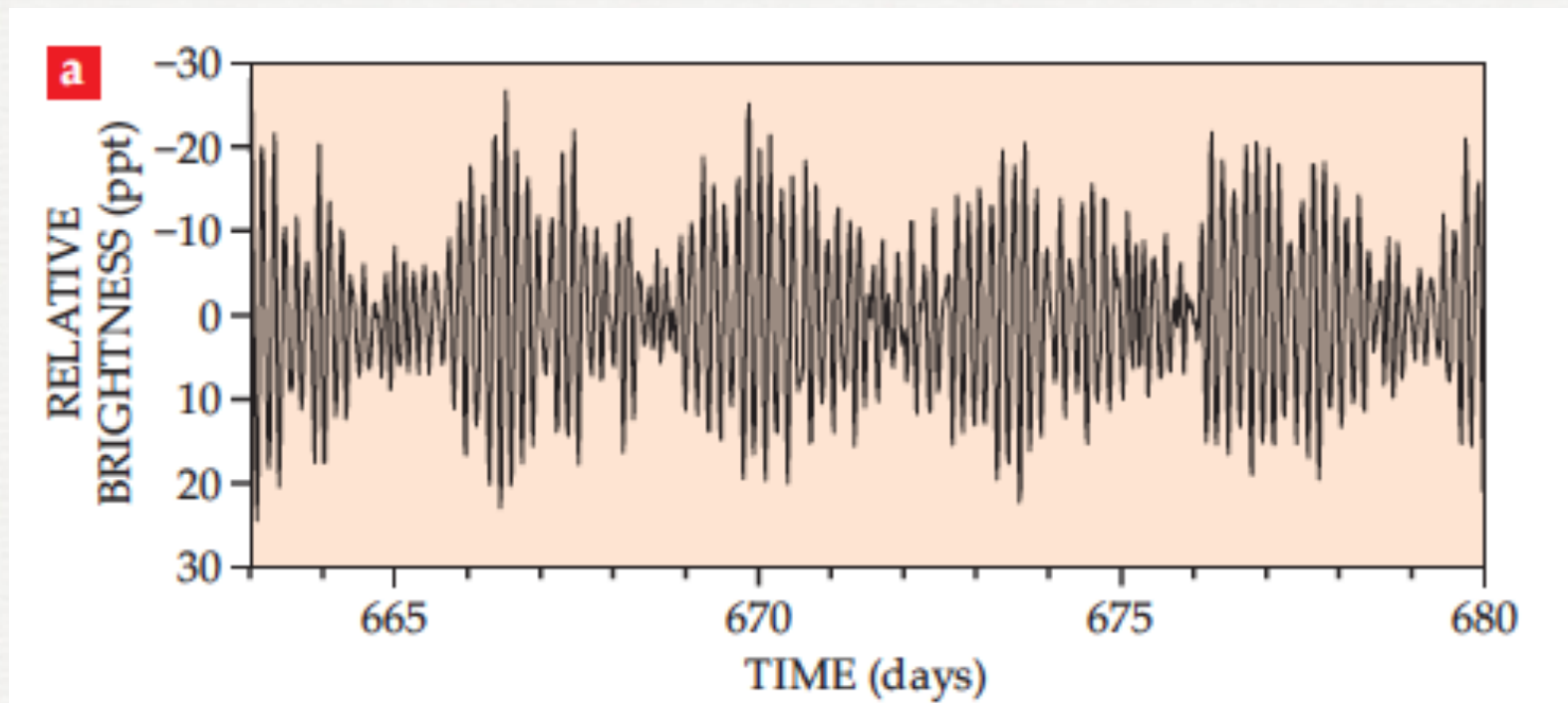


HOE WERKT HET VANDAAAG?

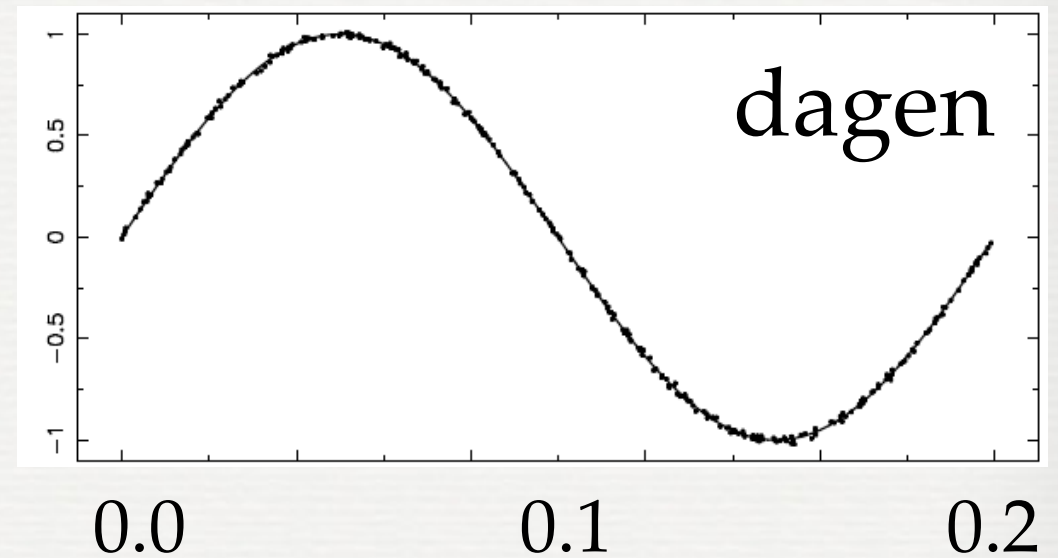


Ononderbroken langdurige helderheidsmetingen
van hoge precisie (ppm!)

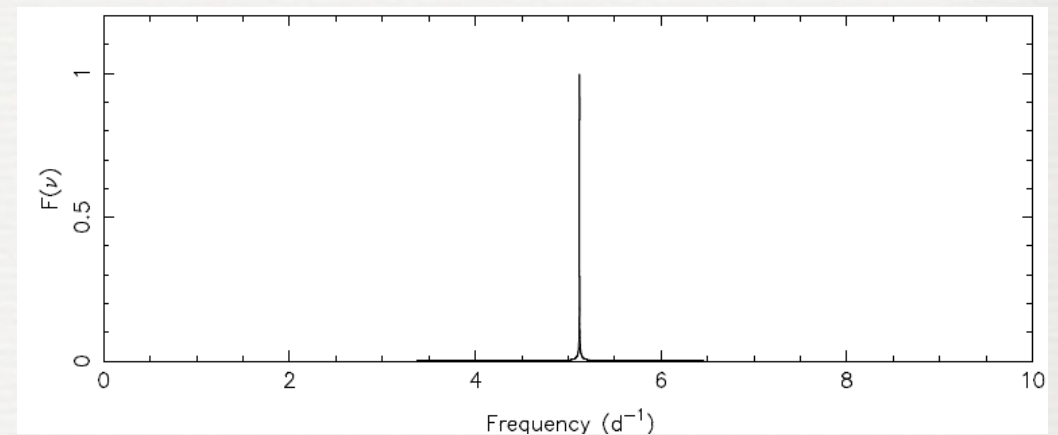
DETECTIE VAN STERBEVINGEN



ANALYSE VAN STERBEVINGEN



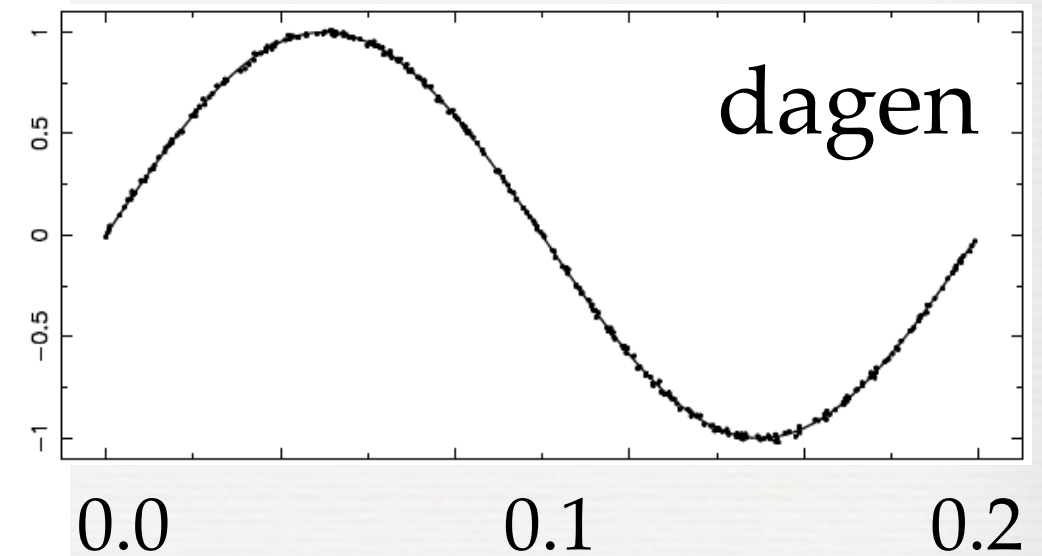
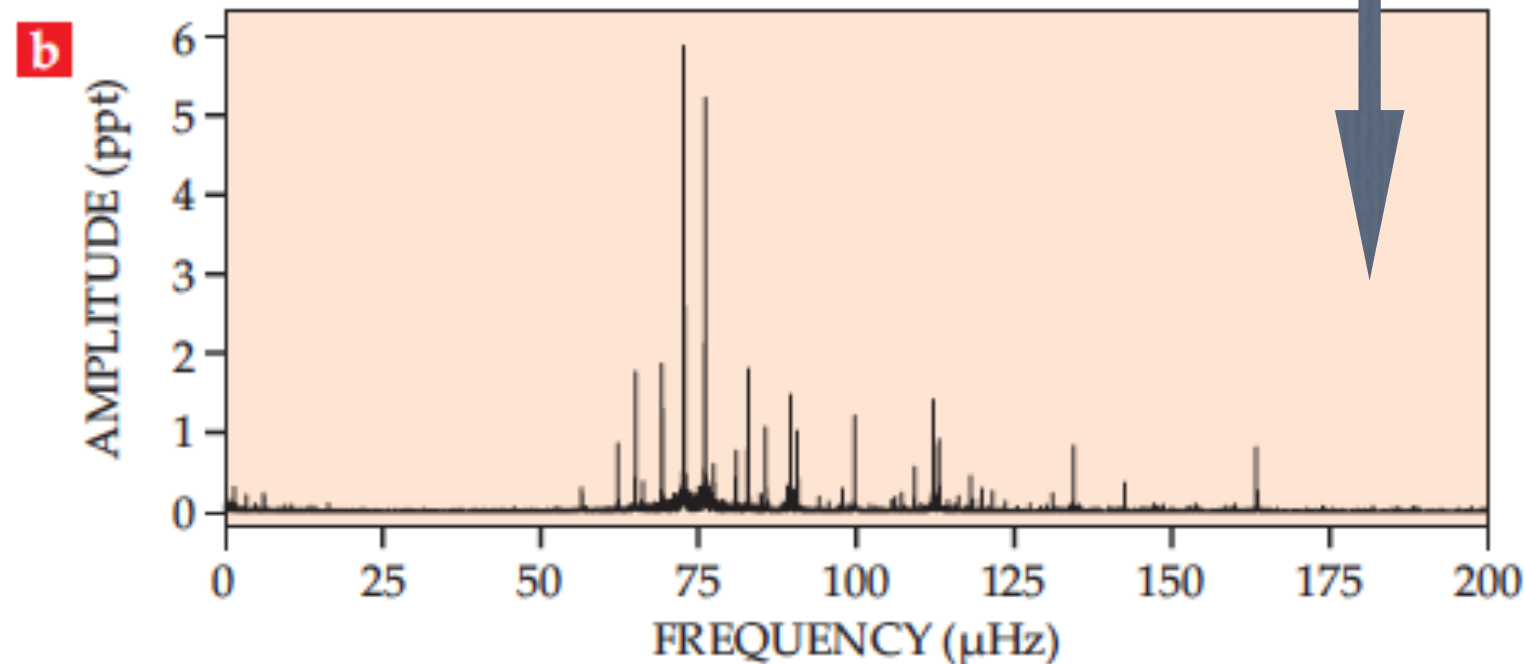
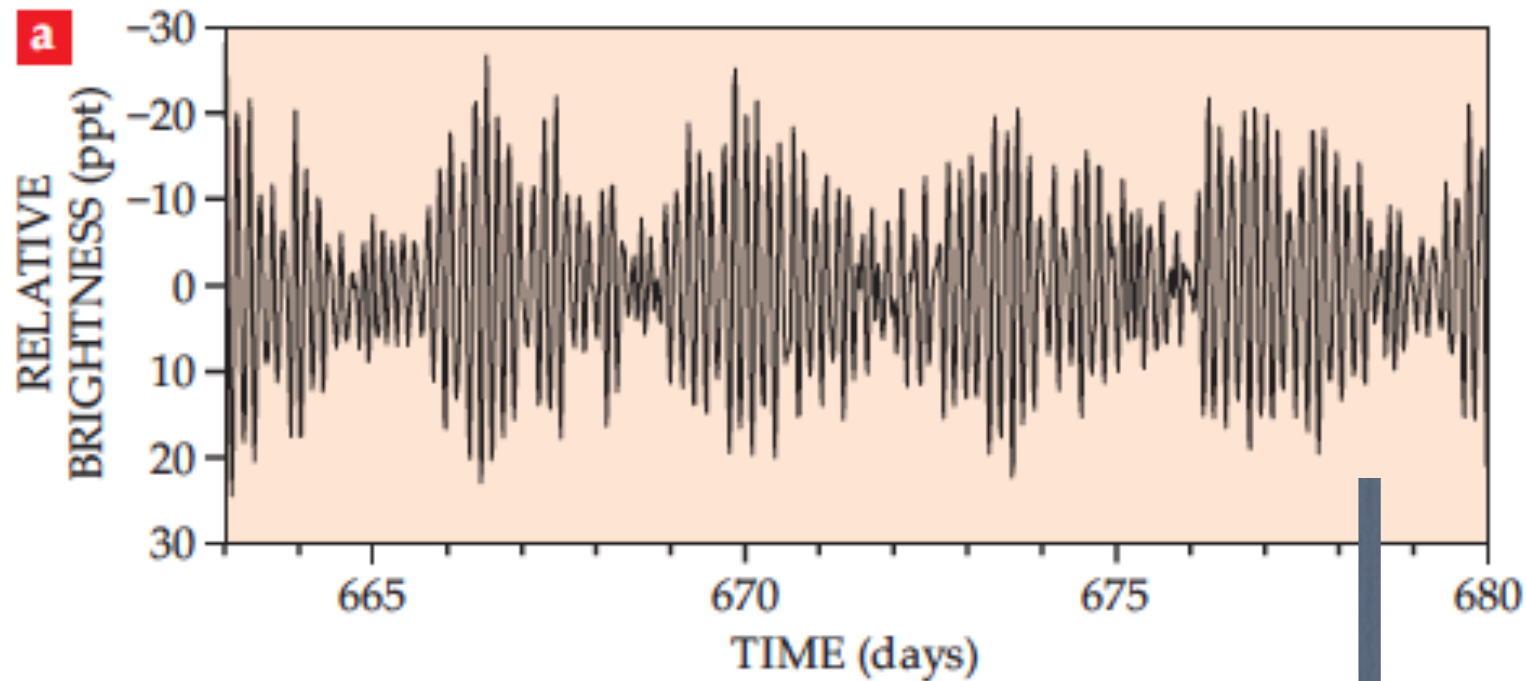
Fouriertransformatie



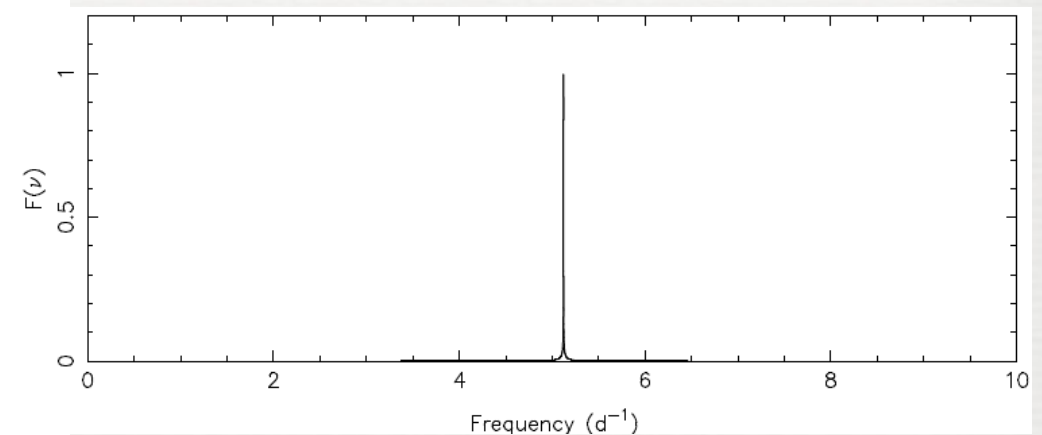
1 dag = 86400 seconden

$1/\text{dag} = 11.57 \mu\text{Hz}$

ANALYSE VAN STERBEVINGEN

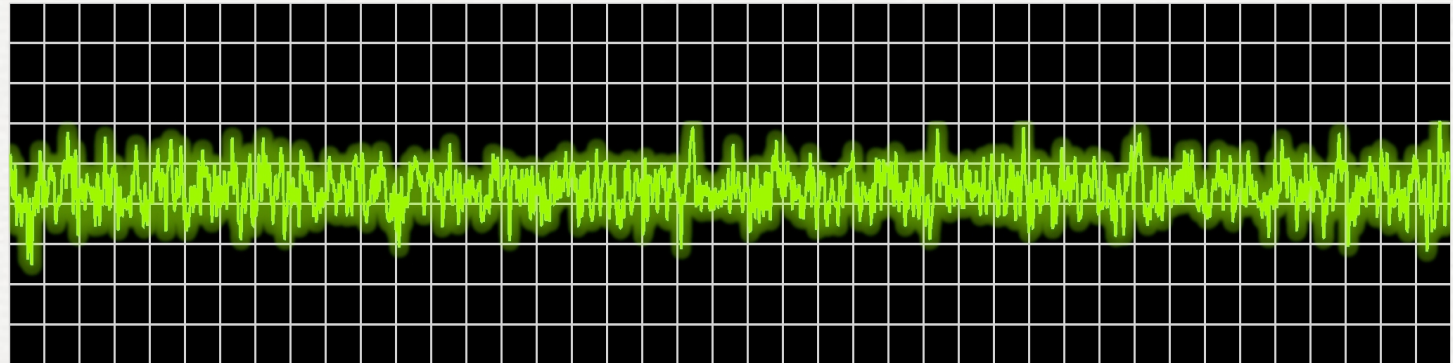
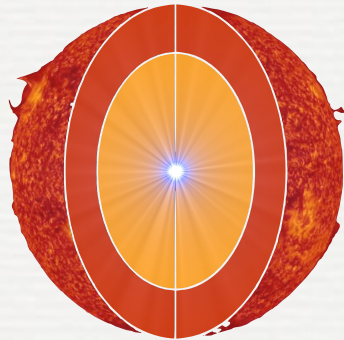


Fouriertransformatie



1 dag = 86400 seconden
 $1/\text{dag} = 11.57 \mu\text{Hz}$

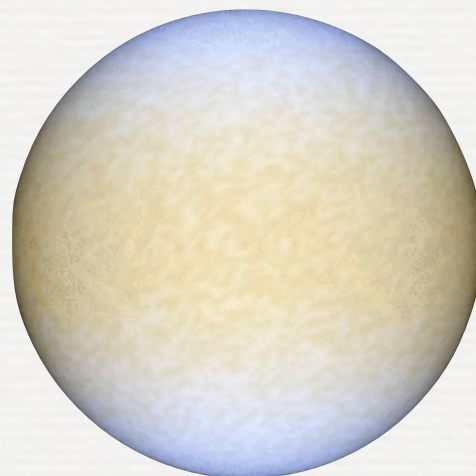
DE GROOTTE VAN STERREN METEN



TIME →



KIC 11026764



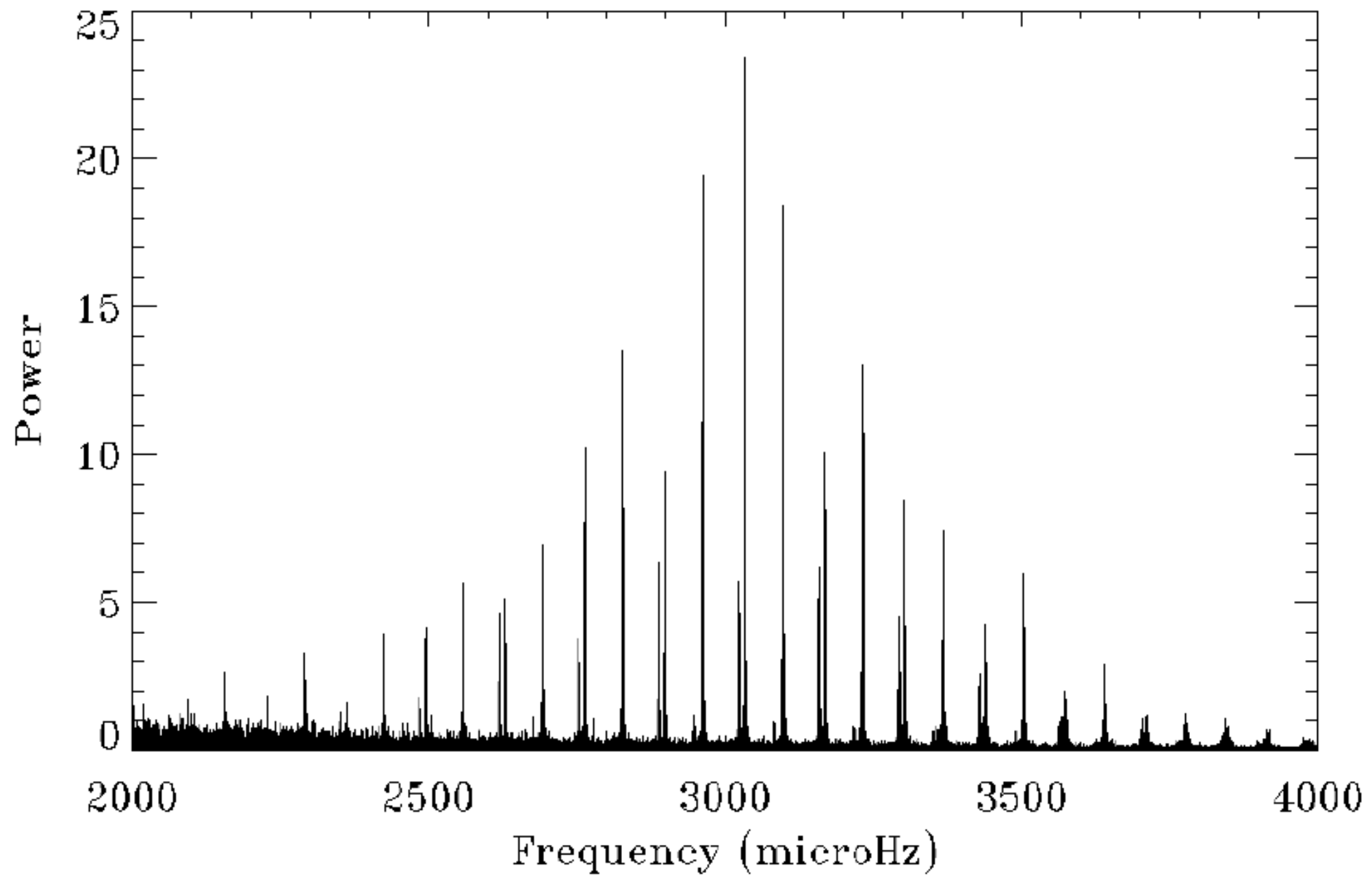
Sun



Travis Metcalfe, National Center for Atmospheric Research

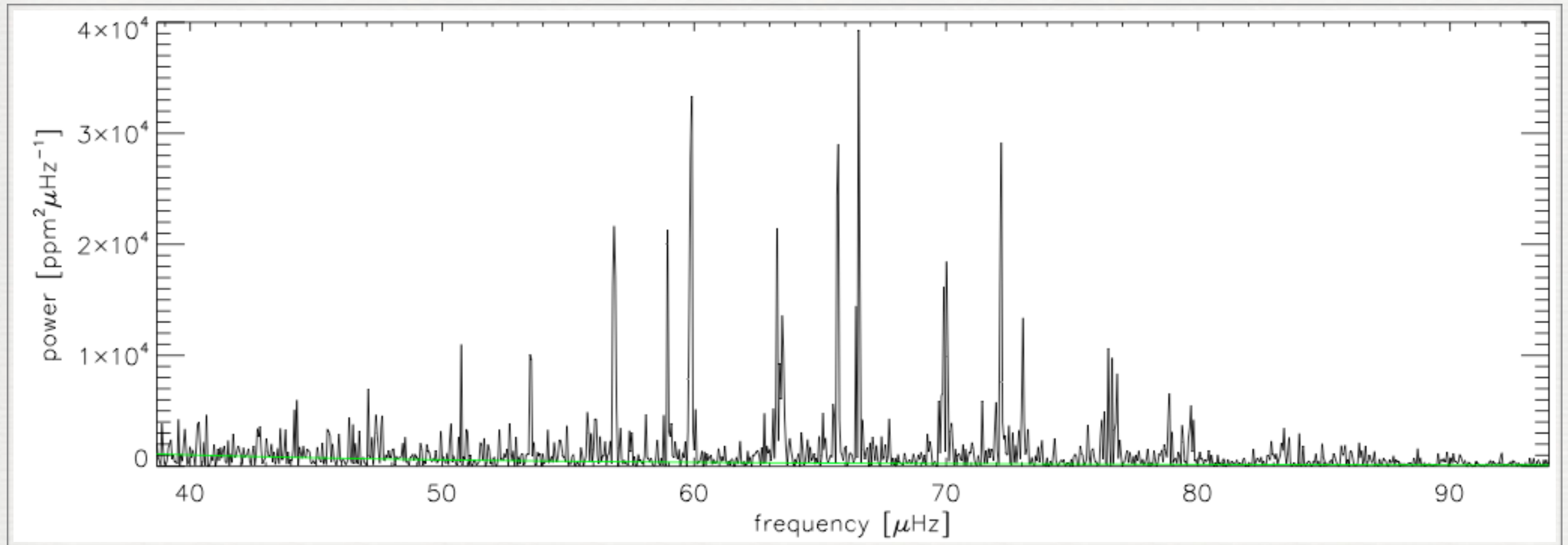
ZONNEFREQUENTIES

(ESA/NASA SoHO)



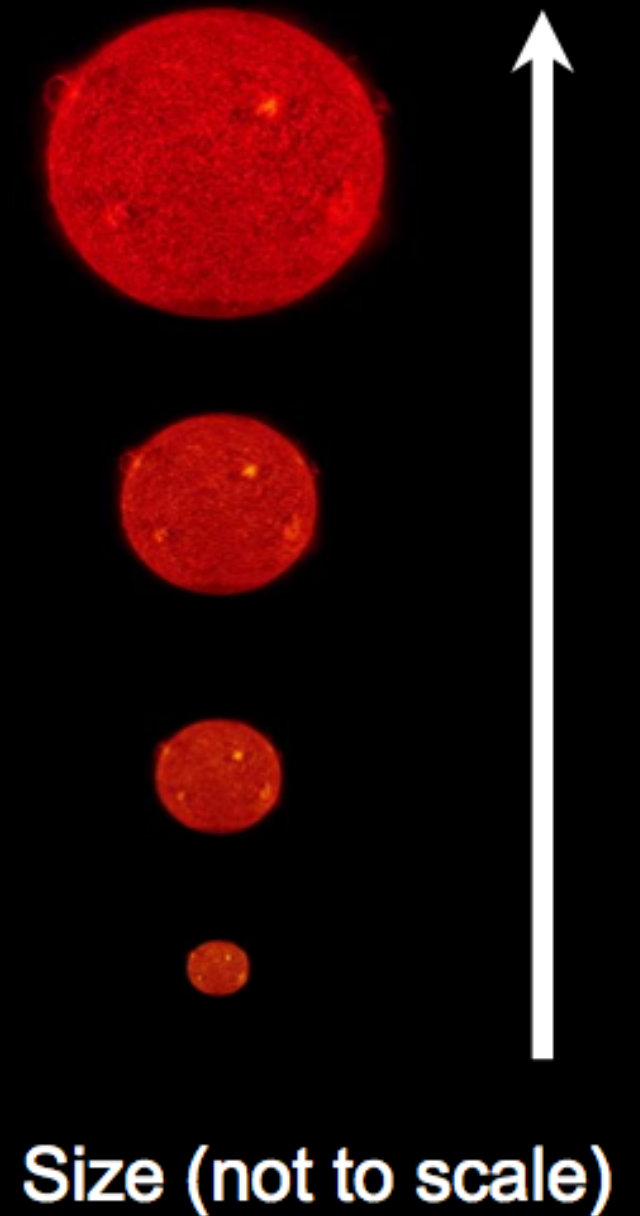
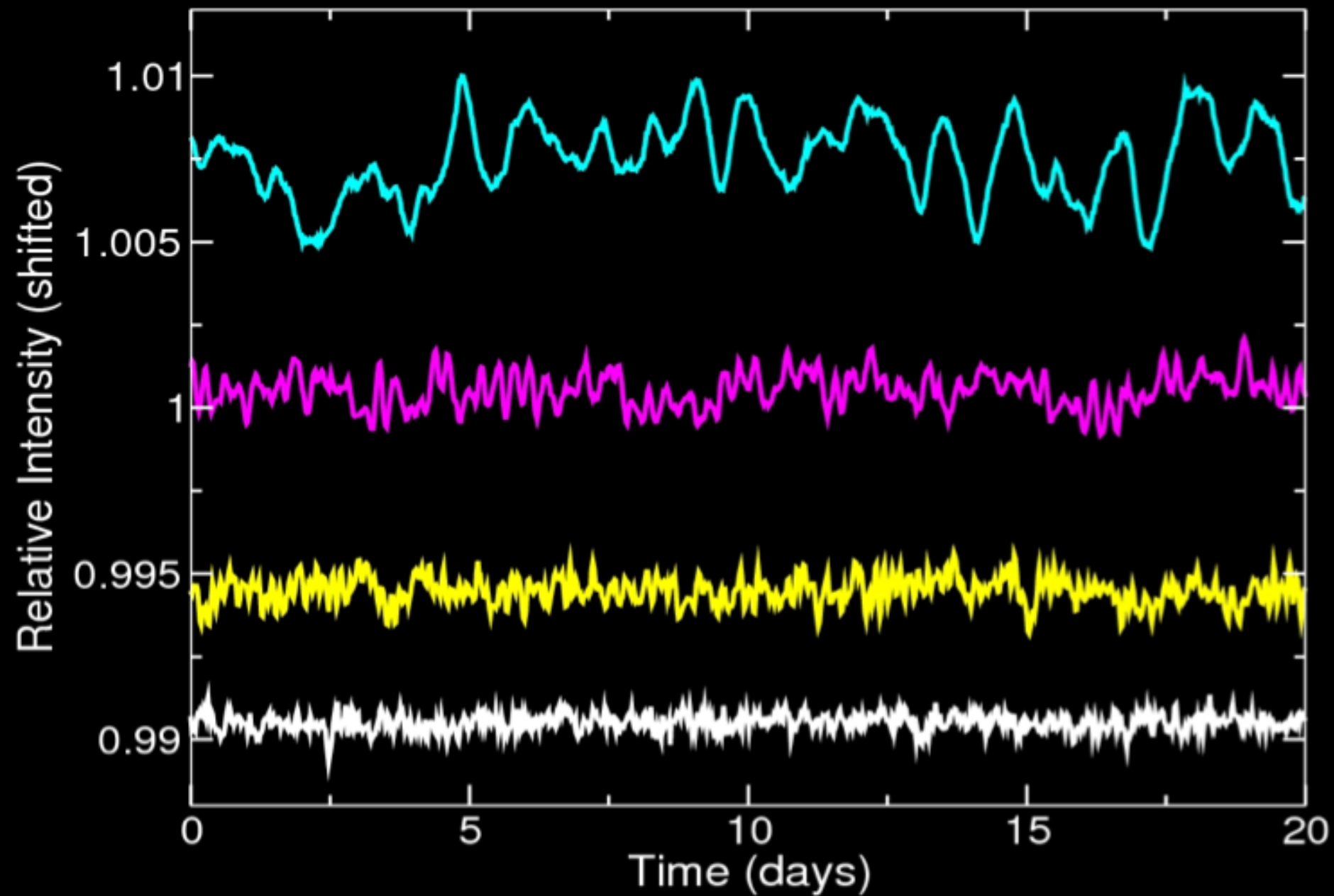
FREQUENTIES VAN EEN RODE REUS

(Kepler)

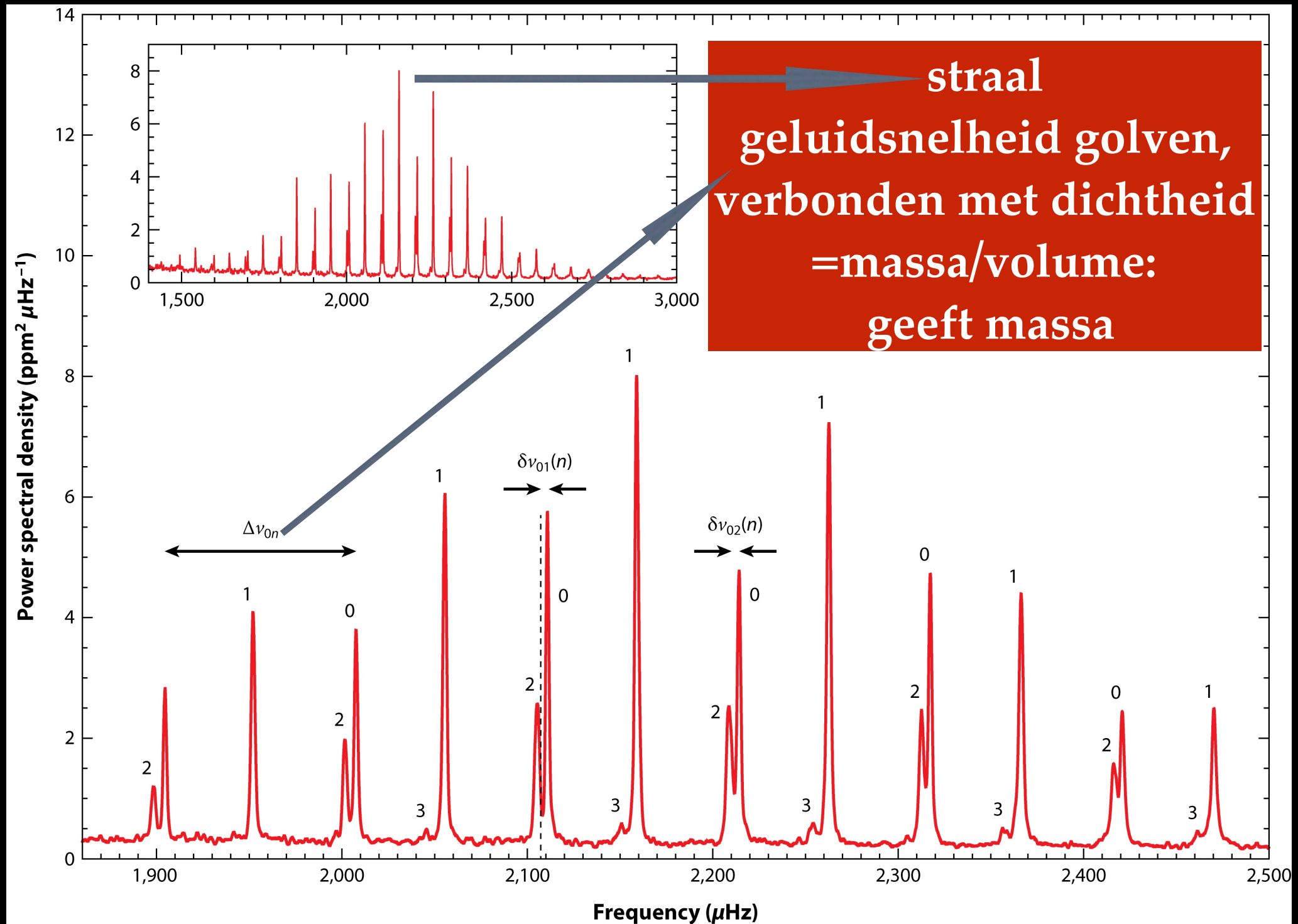


**NATUURKUNDE OP AFSTAND
IN ACTIE!**

Sterstralen tot 1% nauwkeurig



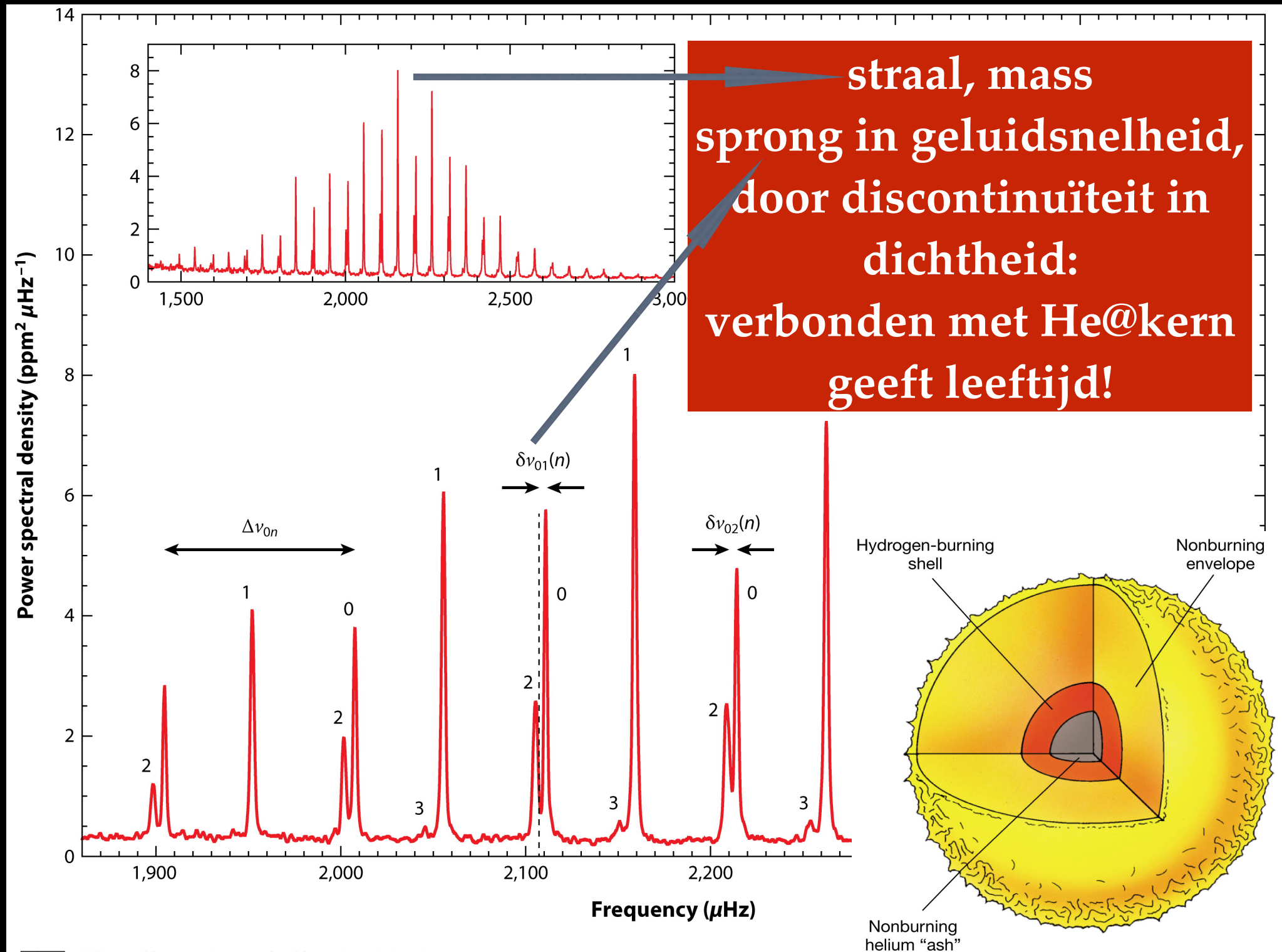
Wegen van sterren tot 2% precisie



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

16 Cygnus A, ~70 lj

Leeftijd van sterren tot 20% precisie

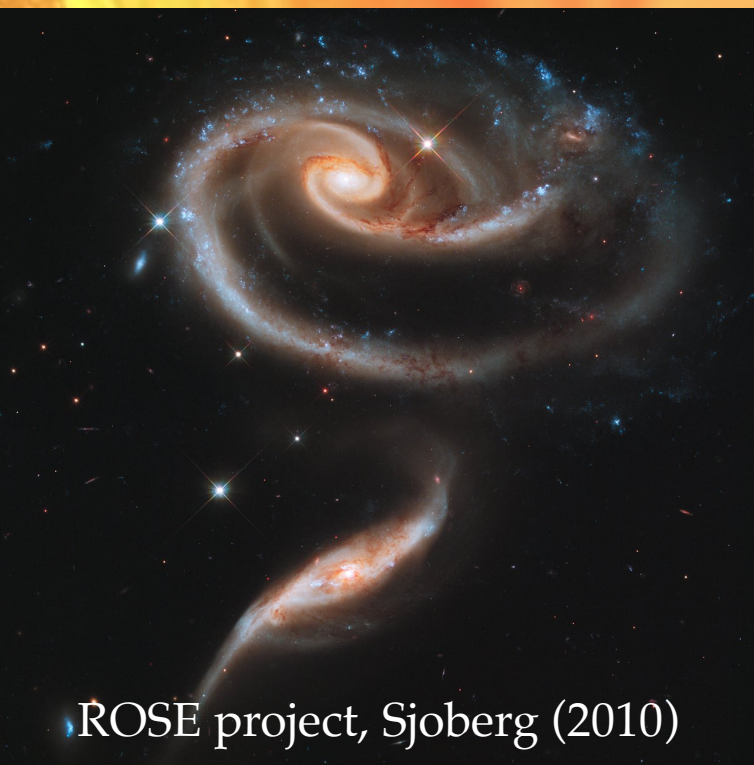


Chaplin WJ, Miglio A. 2013.

Annu. Rev. Astron. Astrophys. 51:353–92

Dé sterrenkunde-vraag van deze eeuw:

“Is er buitenaards leven?”



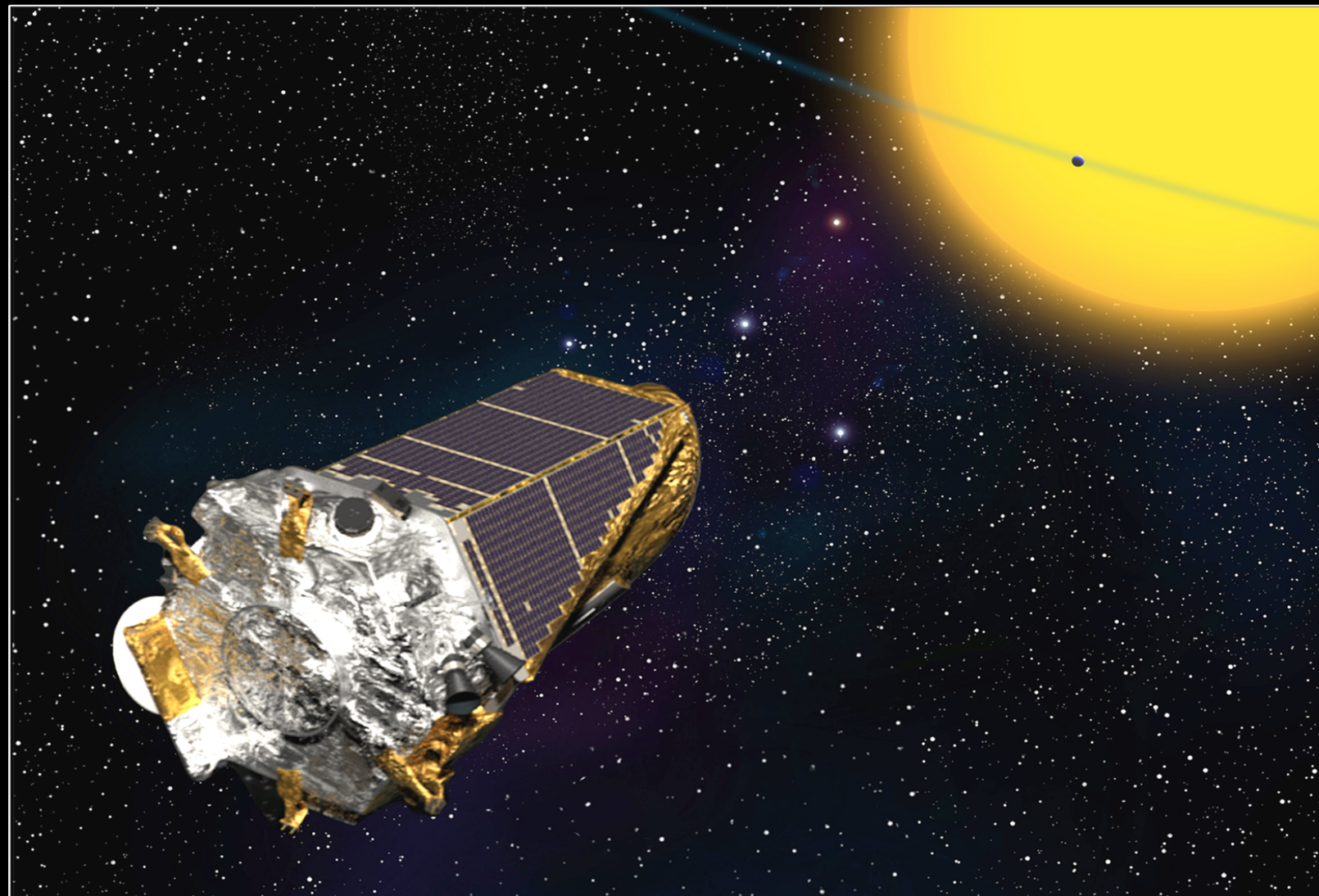
ROSE project, Sjoberg (2010)

Is er een Aarde 2.0?

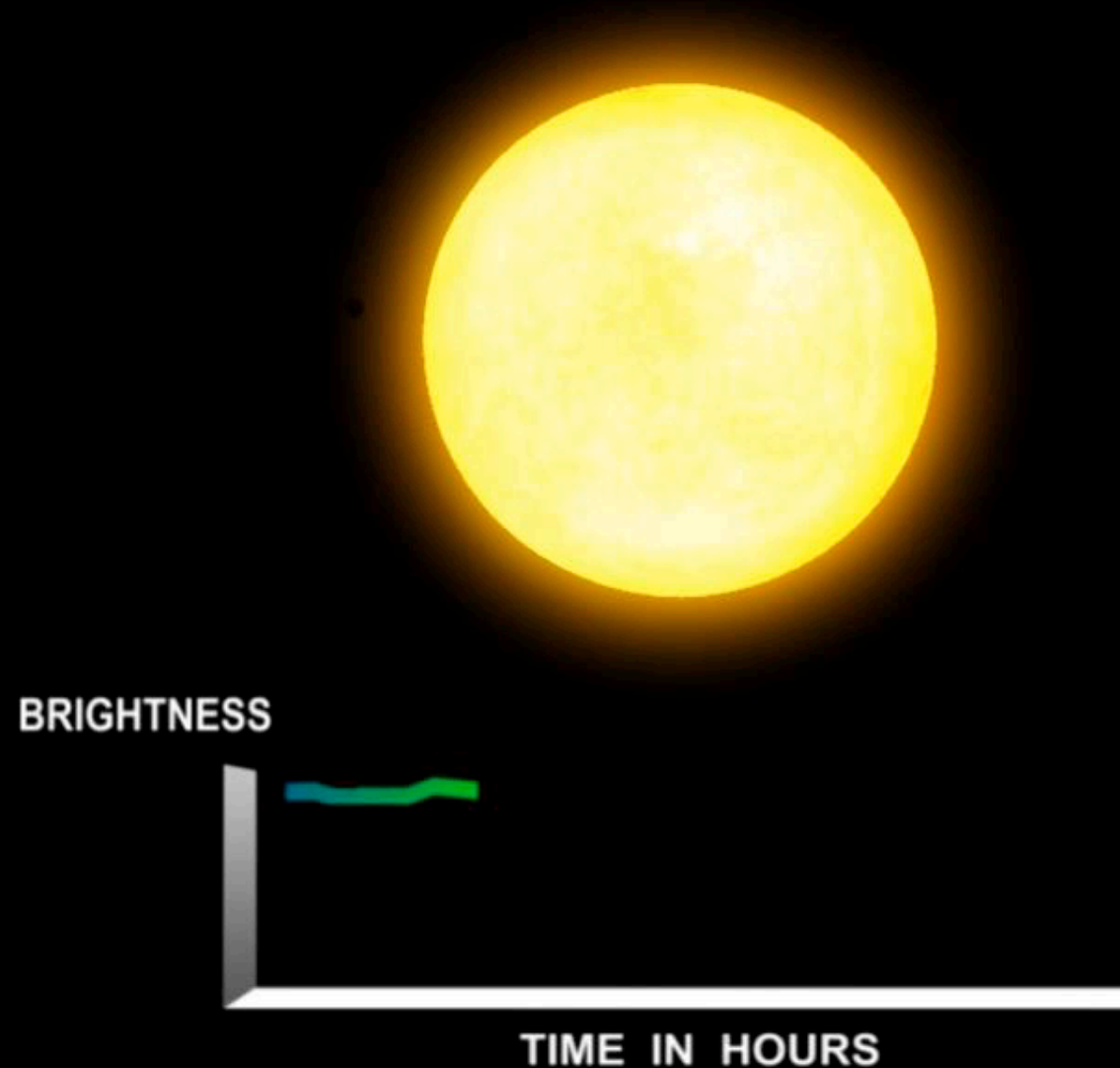


**Dé astrofysicavraag van deze eeuw:
“Hoeveel van de sterren in onze Melkweg hebben
planeten? Is er een Aarde2.0? (met levensvormen?)”**

best zoeken in grote steekproeven

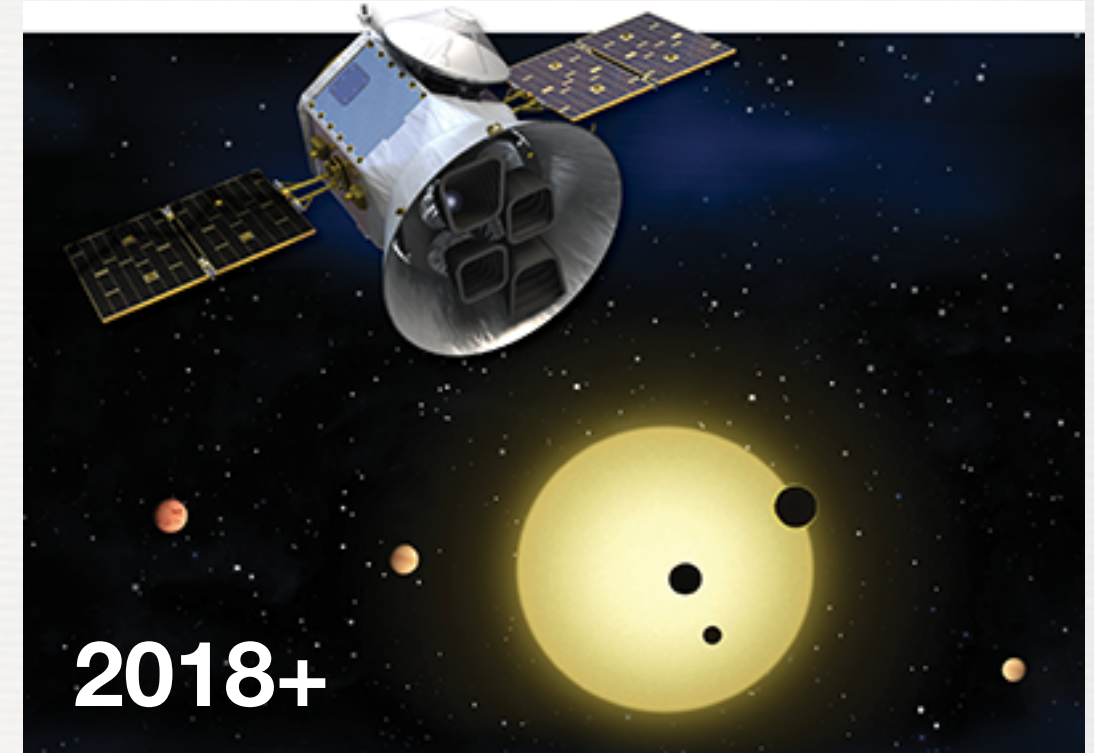
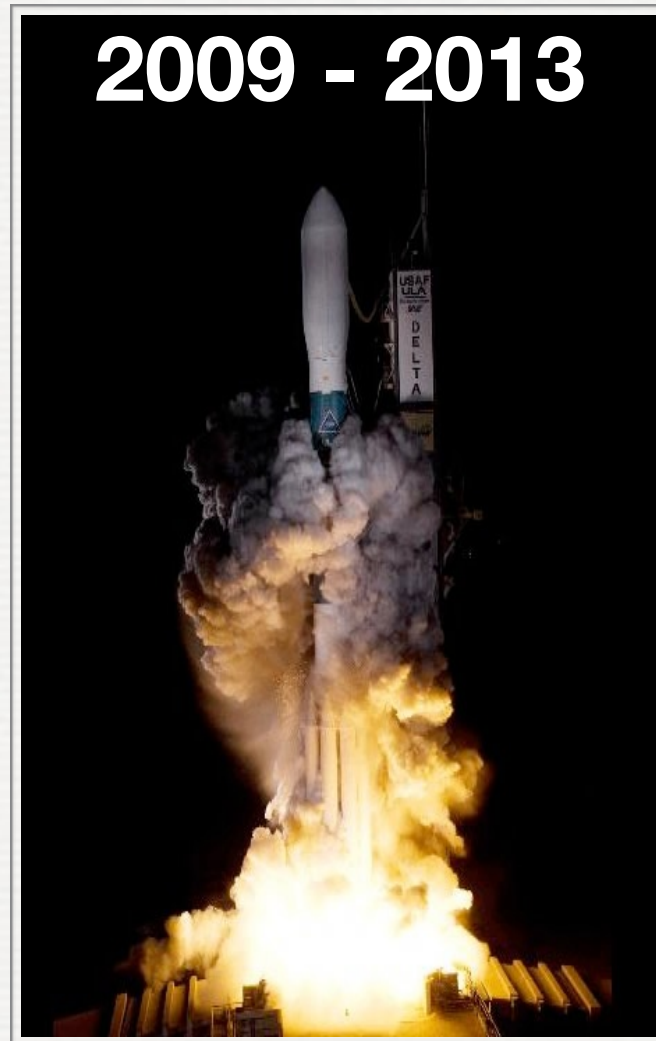


Metingen voor asteroseismologie: $<1'$ kadans;
voor detectie van exoplaneten: $<30'$ (ook ppm!)



Animation courtesy of NASA

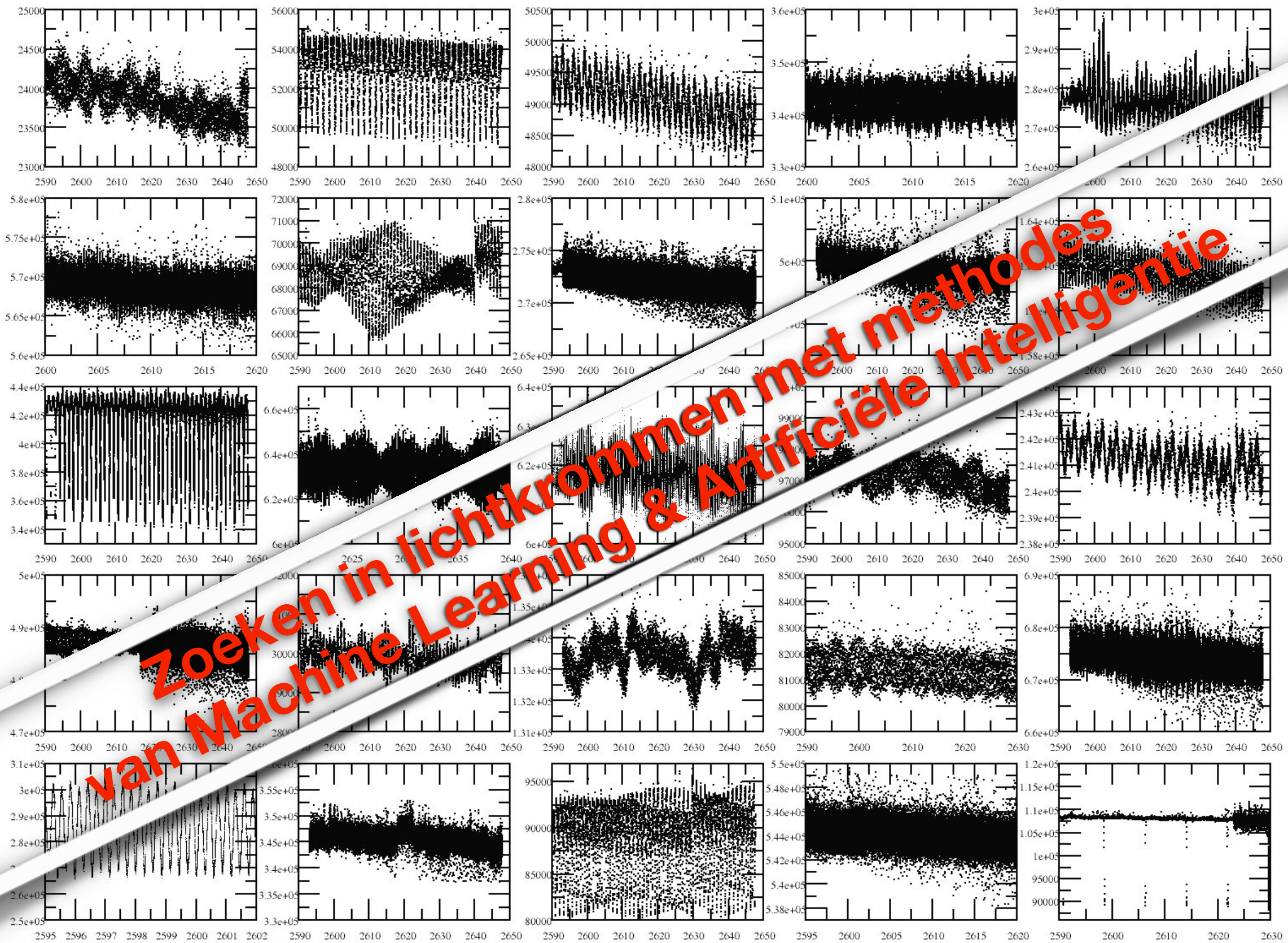
RUIMTEMISSIES NODIG OM ANTWOORD TE ZOEKEN...



Meet heldere sterren,
maar slechts 27 dagen

Tot nu toe 4379 exoplaneten in 717 meervoudige systemen
(exoplanet.eu, dd. 11/12/2020): 17 miljard rotsachtige
planeten in onze Melkweg... Waar? Hoe ver?...

Flux (counts)



Zoeken in lichtkrommen met methodes
van Machine Learning & Artificialle Intelligentie

HJD (days)

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



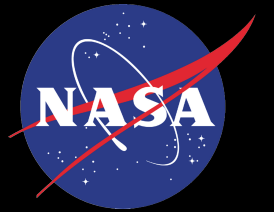
**Straal en massa
van ster nodig:
asteroseismologie**



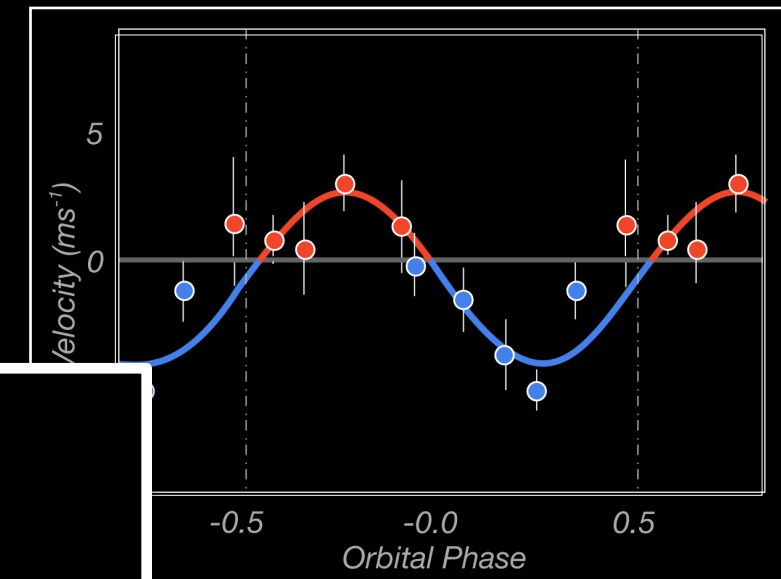
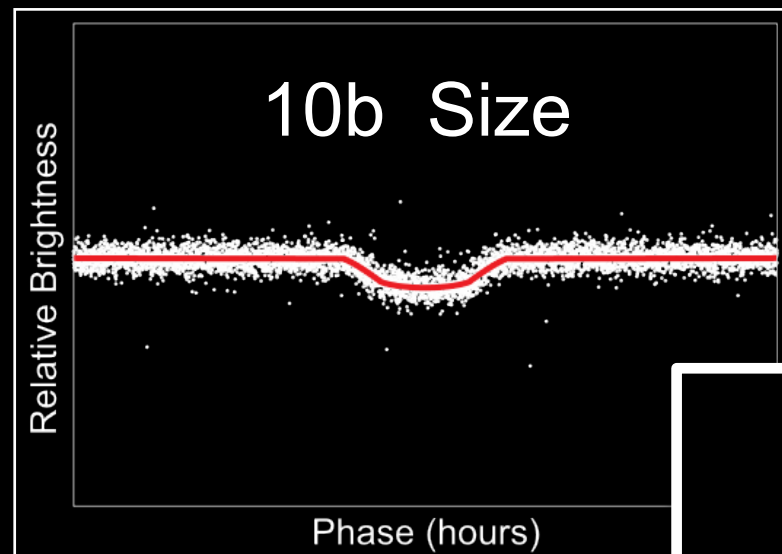
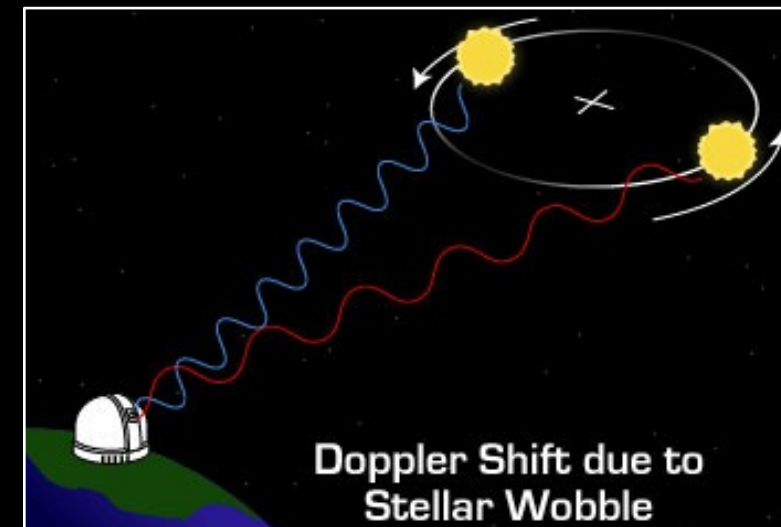
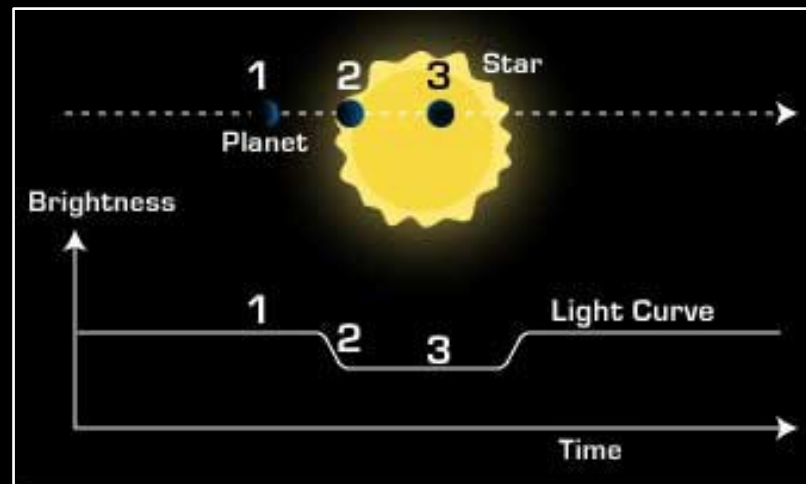
**Planeet
rotsachtig
of gasvorming?
dichtheid?
straal en massa
nodig...**



Animation courtesy of NASA



Transit en snelheid → dichtheid



dichtheid

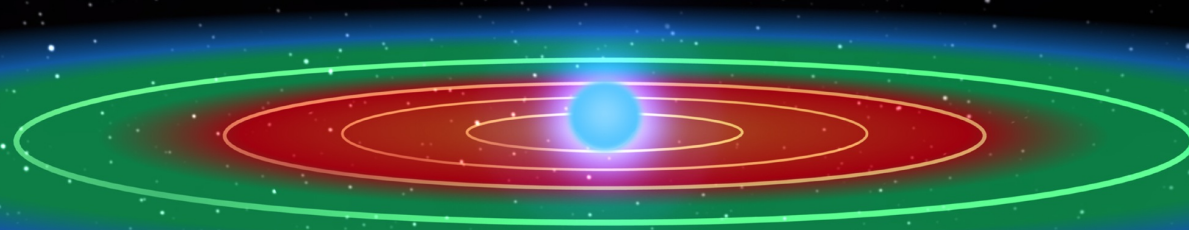
$$\frac{\text{Massa}}{\text{Volume}} = 8.8 \text{ g/cm}^3$$

Jupiter: 1,3 g/cm³
Aarde: 5,5 g/cm³

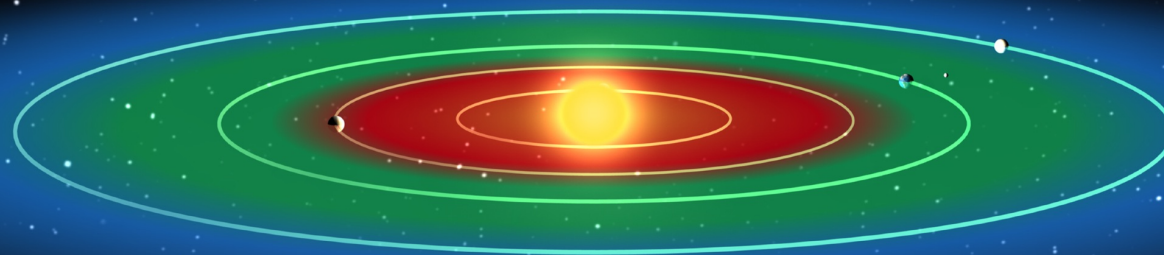
De leefbare zone



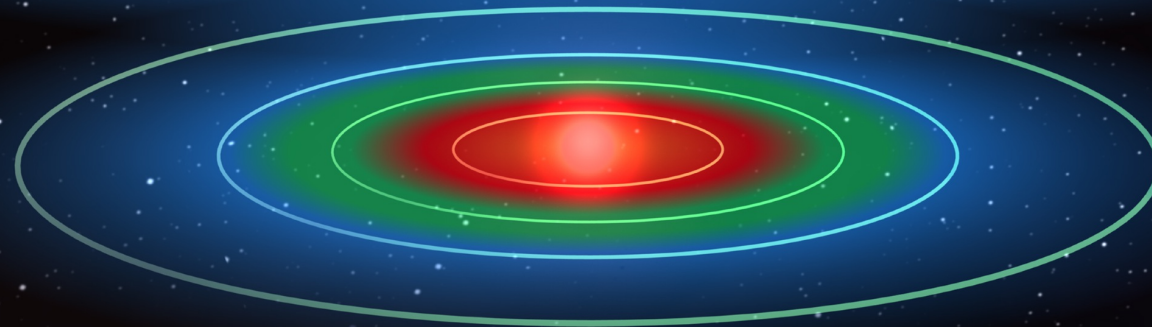
Hotter Stars



Sunlike Stars

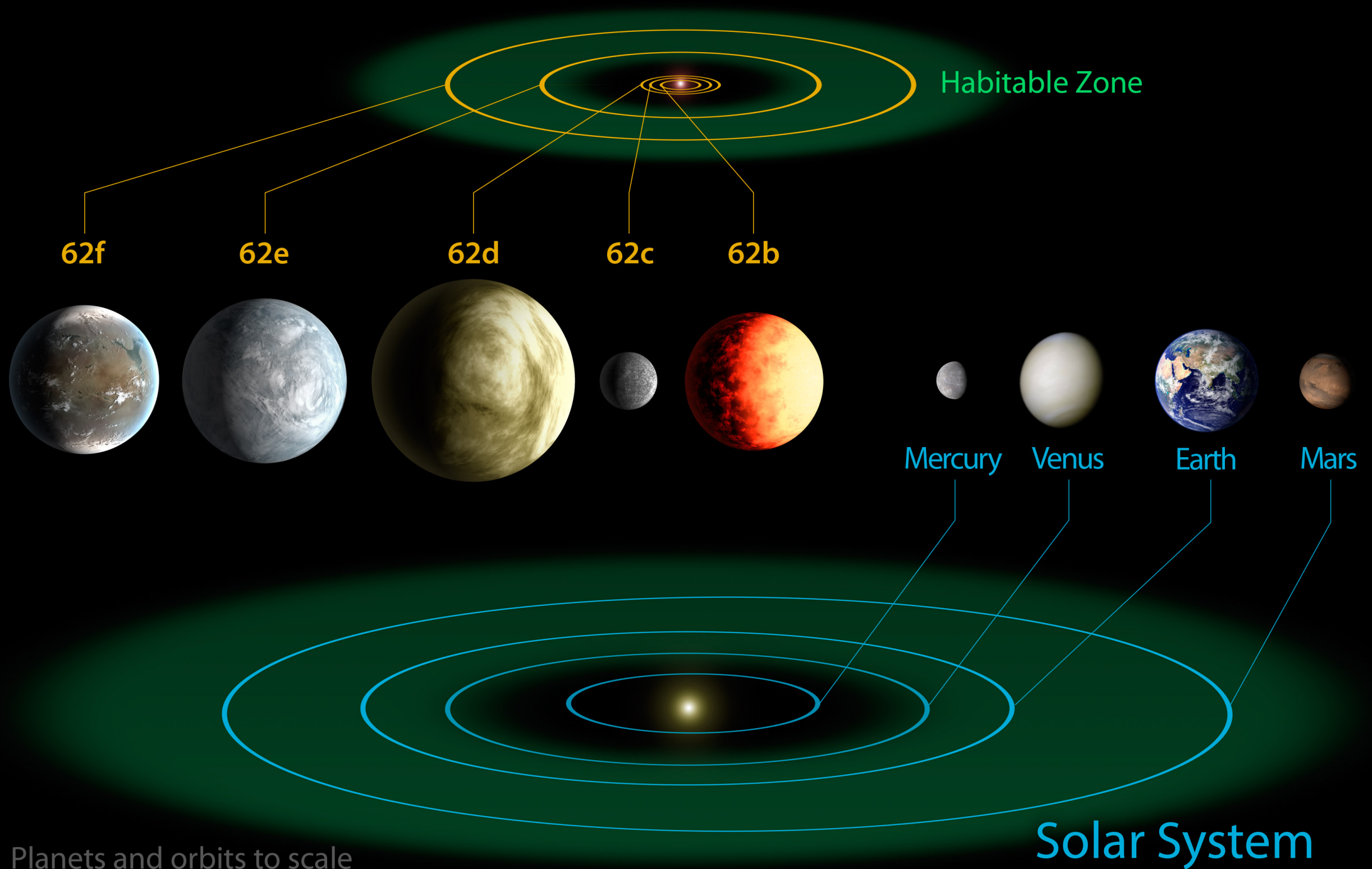


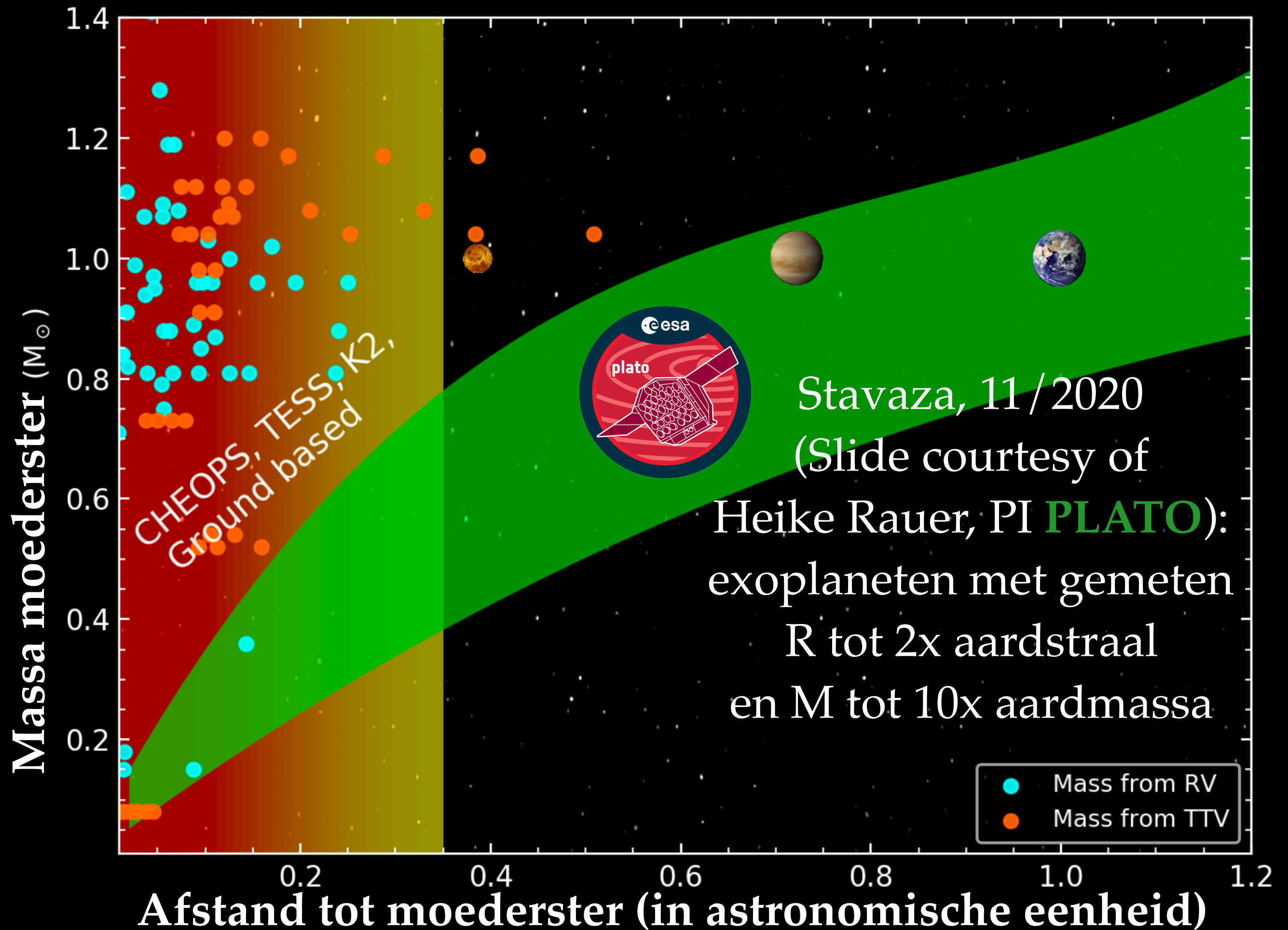
Cooler Stars



Kepler-62 System

Borucki et al. (2013, Science)





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Ruimtevaart aan de KU Leuven: missies die doen dromen

25-11-2019



Zoeken in KU Leuven nieuws

ZOEKEN

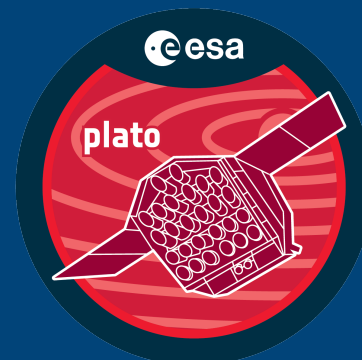
NL
doet
ook
mee!

via
SRON



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.



Sterbevingen & Exoplaneten: daar zit muziek in!

<https://www.zooniverse.org/projects/nora-dot-eisner/planet-hunters-tess>

**“Is er buitenaards leven?”
jullie leerlingen kunnen tijdens
hun studies mee
het antwoord zoeken!**

