

Asteroseismologie: daar zit muziek in!

Prof. Dr. Conny Aerts

KU Leuven

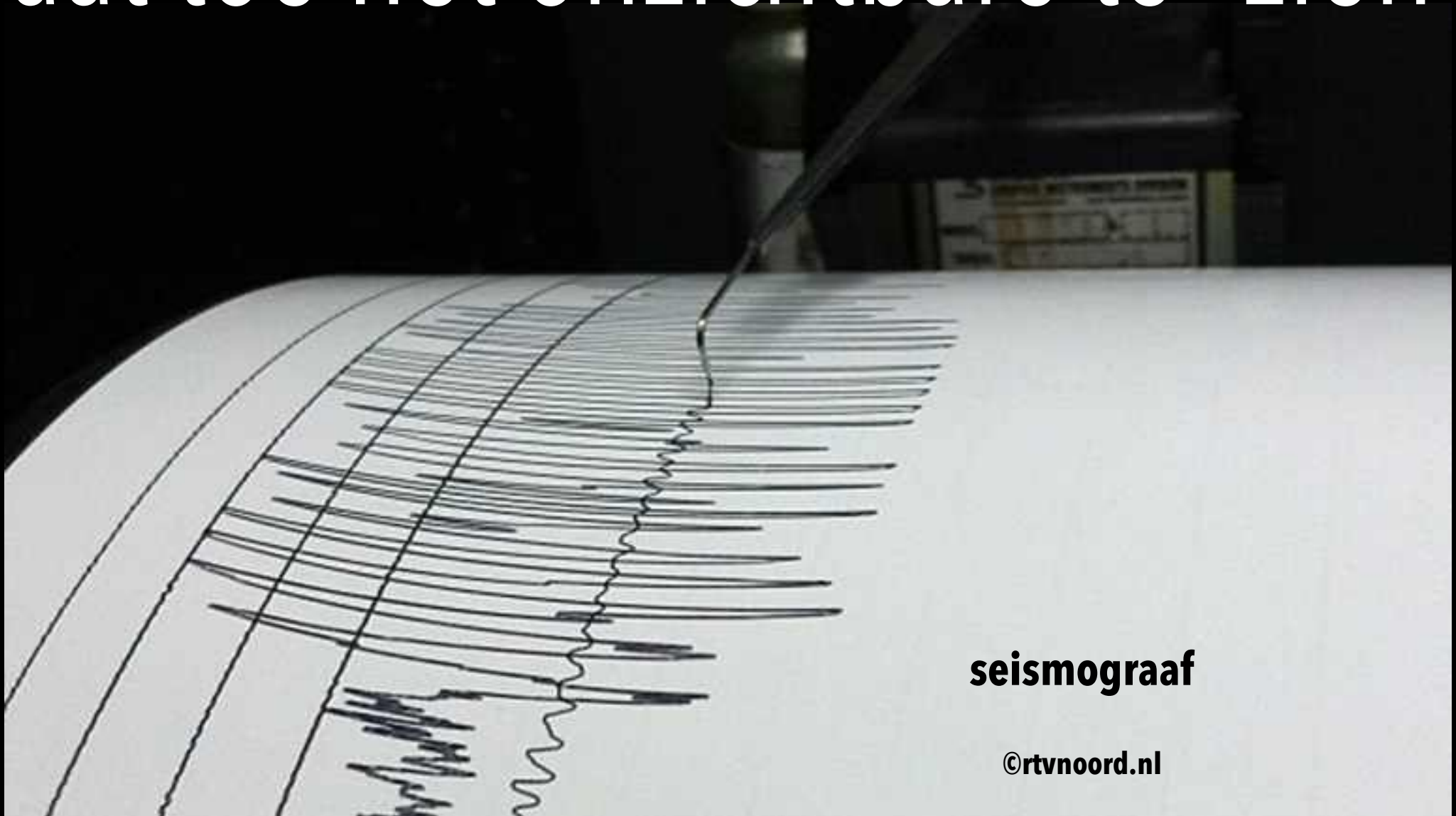
<https://fys.kuleuven.be/ster/staff/conny-aerts>

NEOS, Sint-Gillis Waas, 13 januari 2026

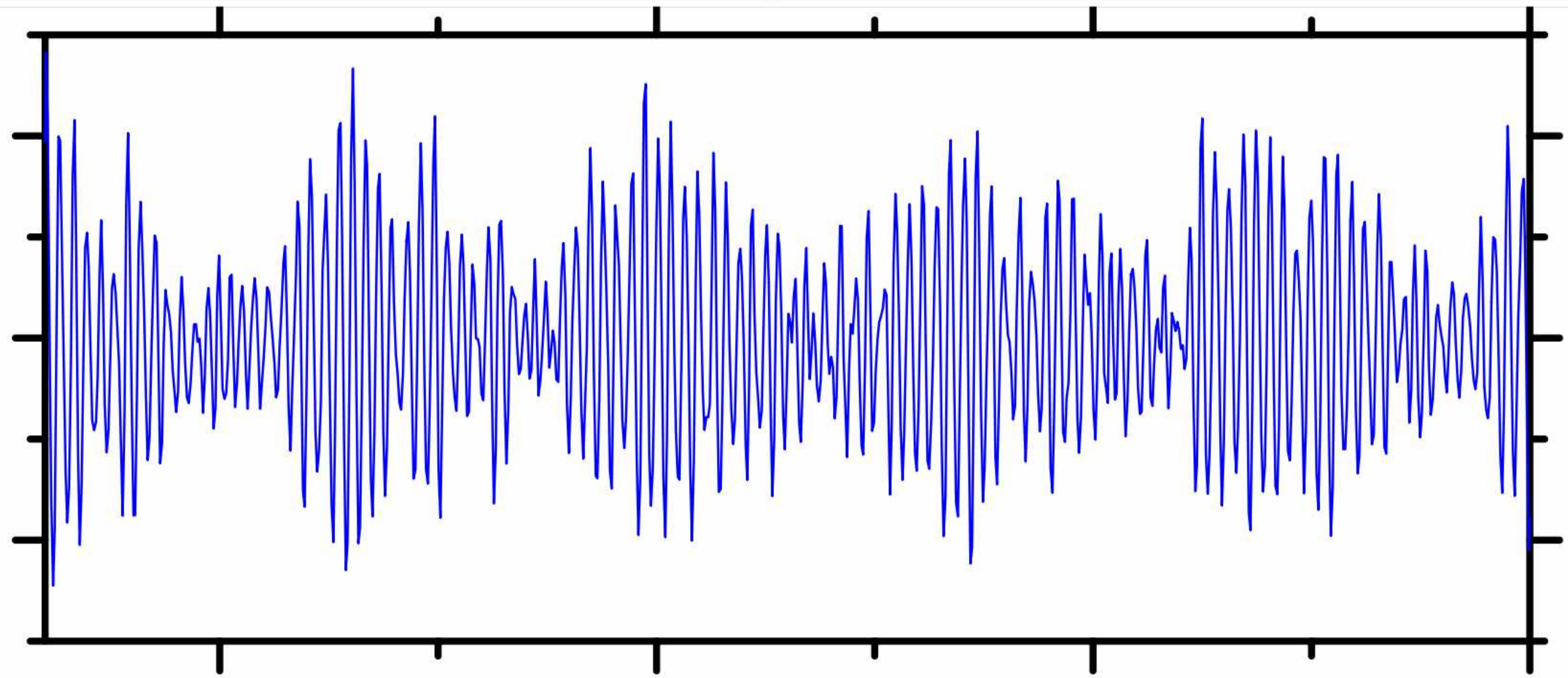
Prelude: golven
laten toe het
onzichtbare
te zien...



Lokale seismische activiteit van Aarde: laat toe het onzichtbare te "zien"



Globale seismische activiteit van ster:
laat ook toe het onzichtbare te "zien"



Deze lezing: Echografie van sterren

Sterren zijn mooi, inspireren, en zijn vitaal voor leven in het Heelal

Credit: ESO/Juan Carlos Muñoz Mateos



Sterren: hete stralende gasbollen
Planeten: gasvormig of rotsachtig,
koud, reflecteren zonlicht

$\sim 10^{\circ}$ tot $\sim 100^{\circ}$ K

zons-
oppervlak
 $\sim 5800^{\circ}$

Mercury
Venus
Earth
Mars



Jupiter



Saturn

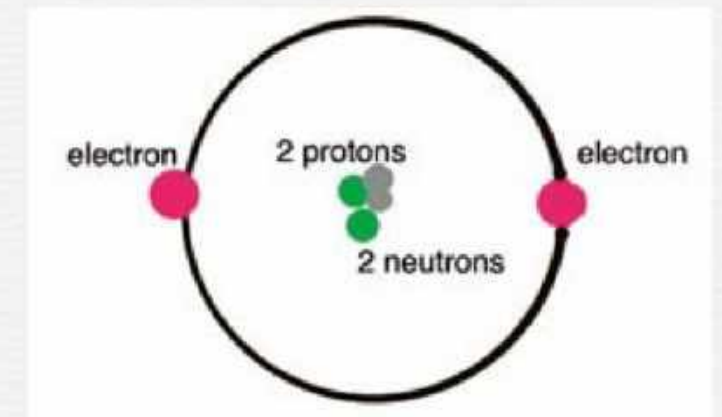
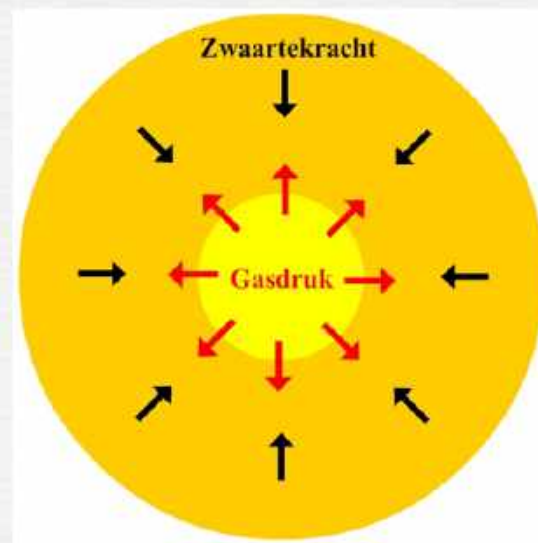
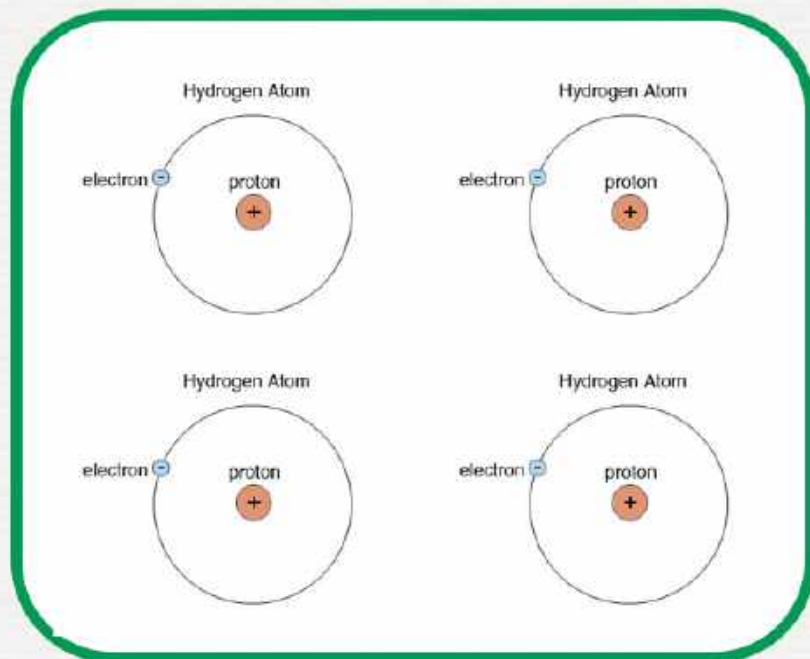
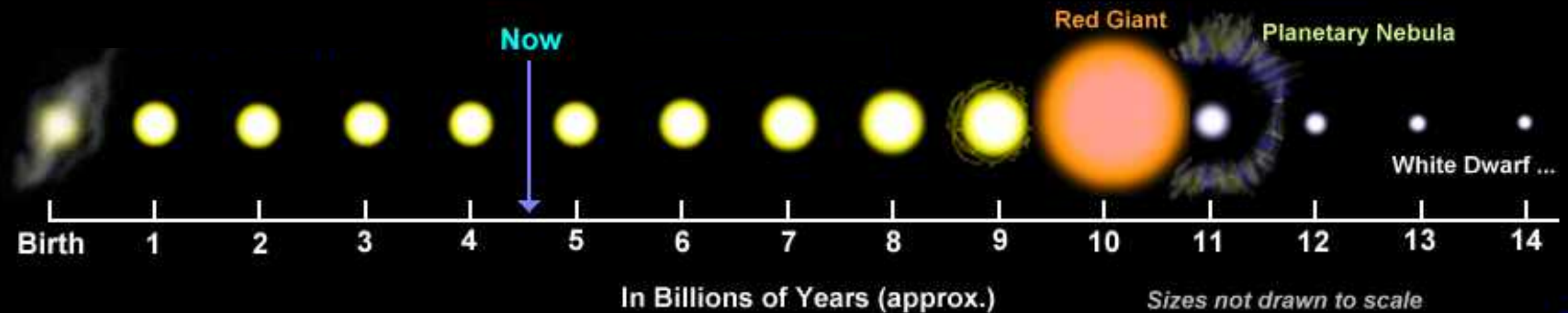


Uranus



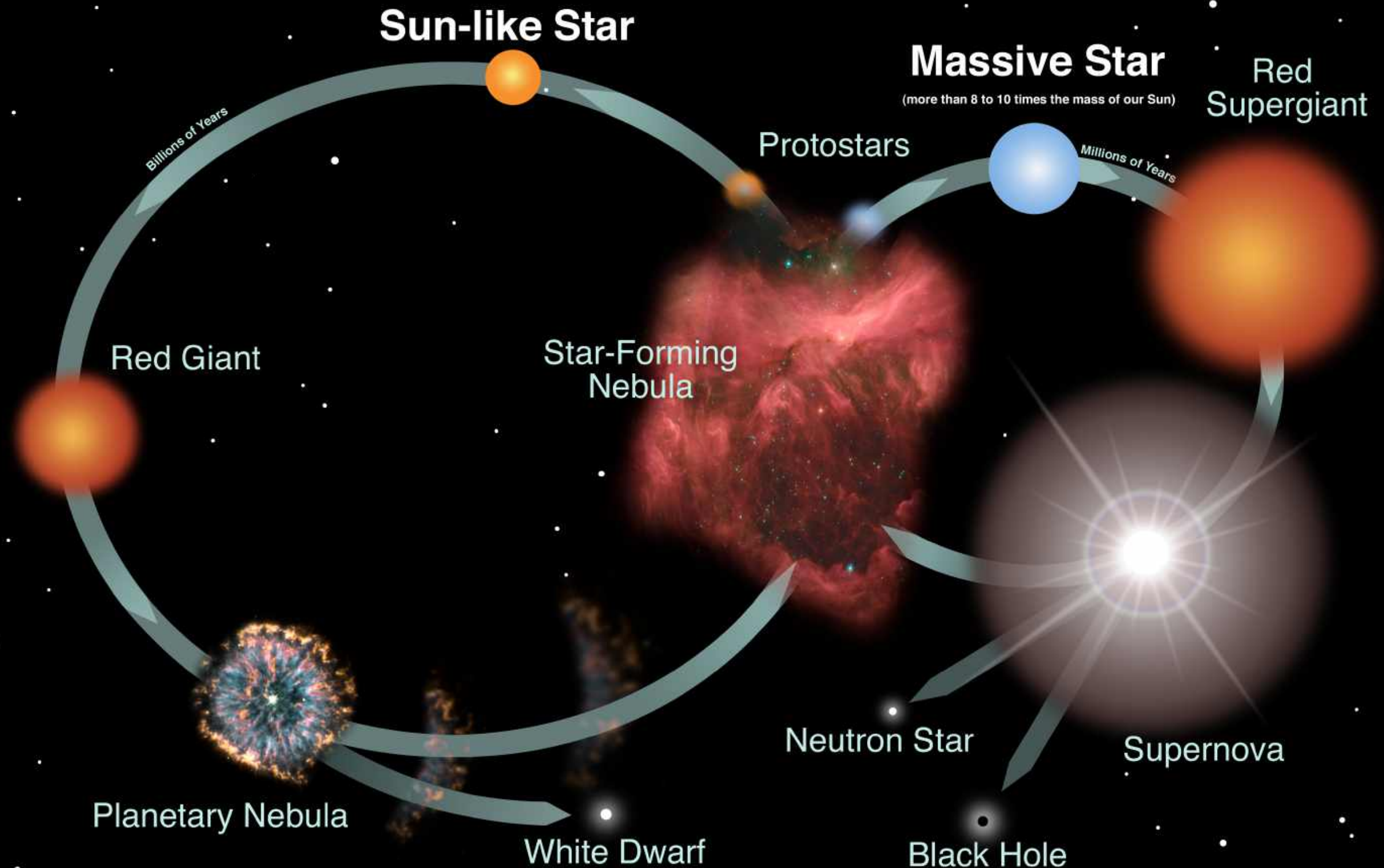
Neptune

Levenspad van de Zon: onze moederster

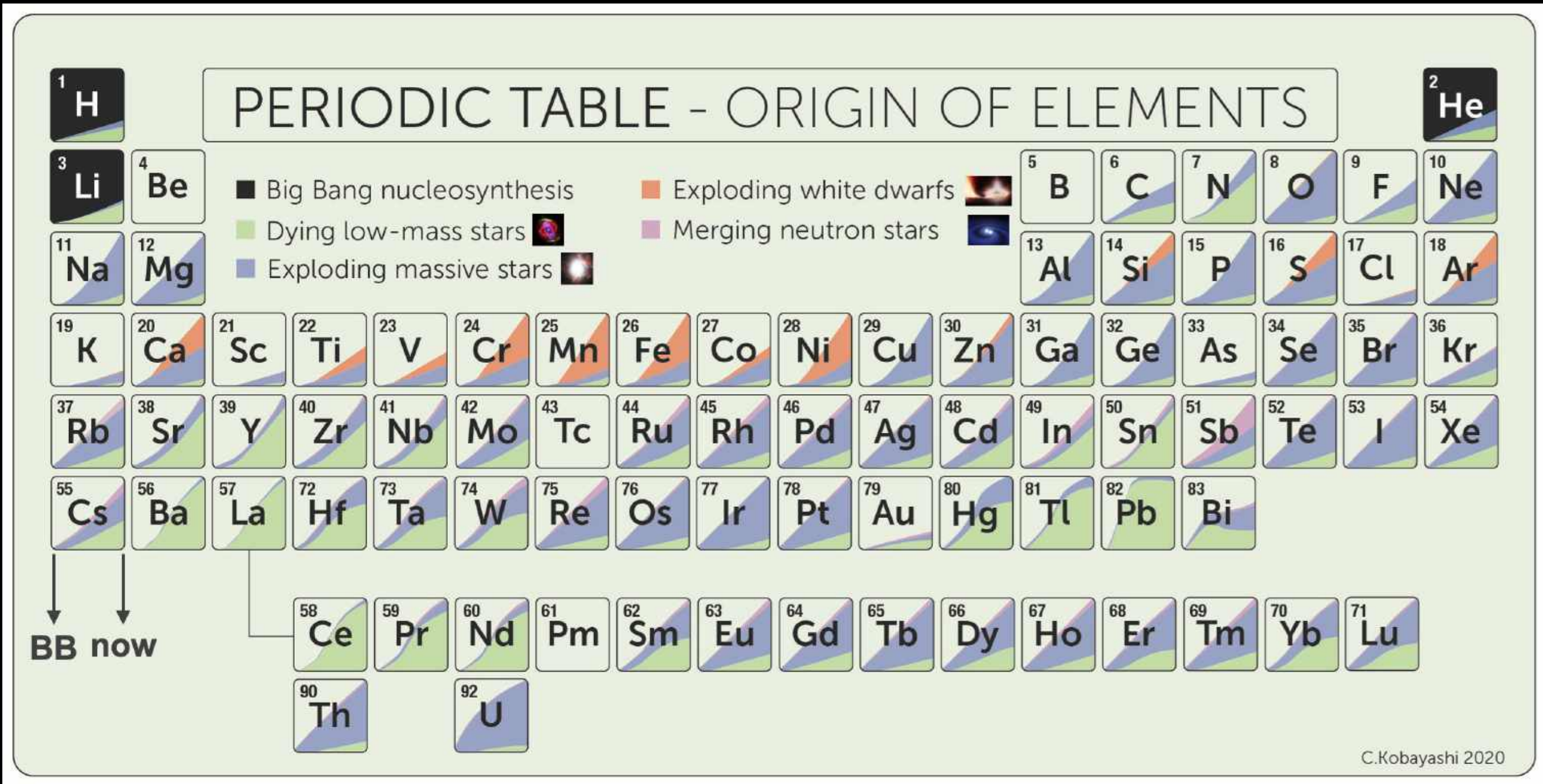


$$E=mc^2$$

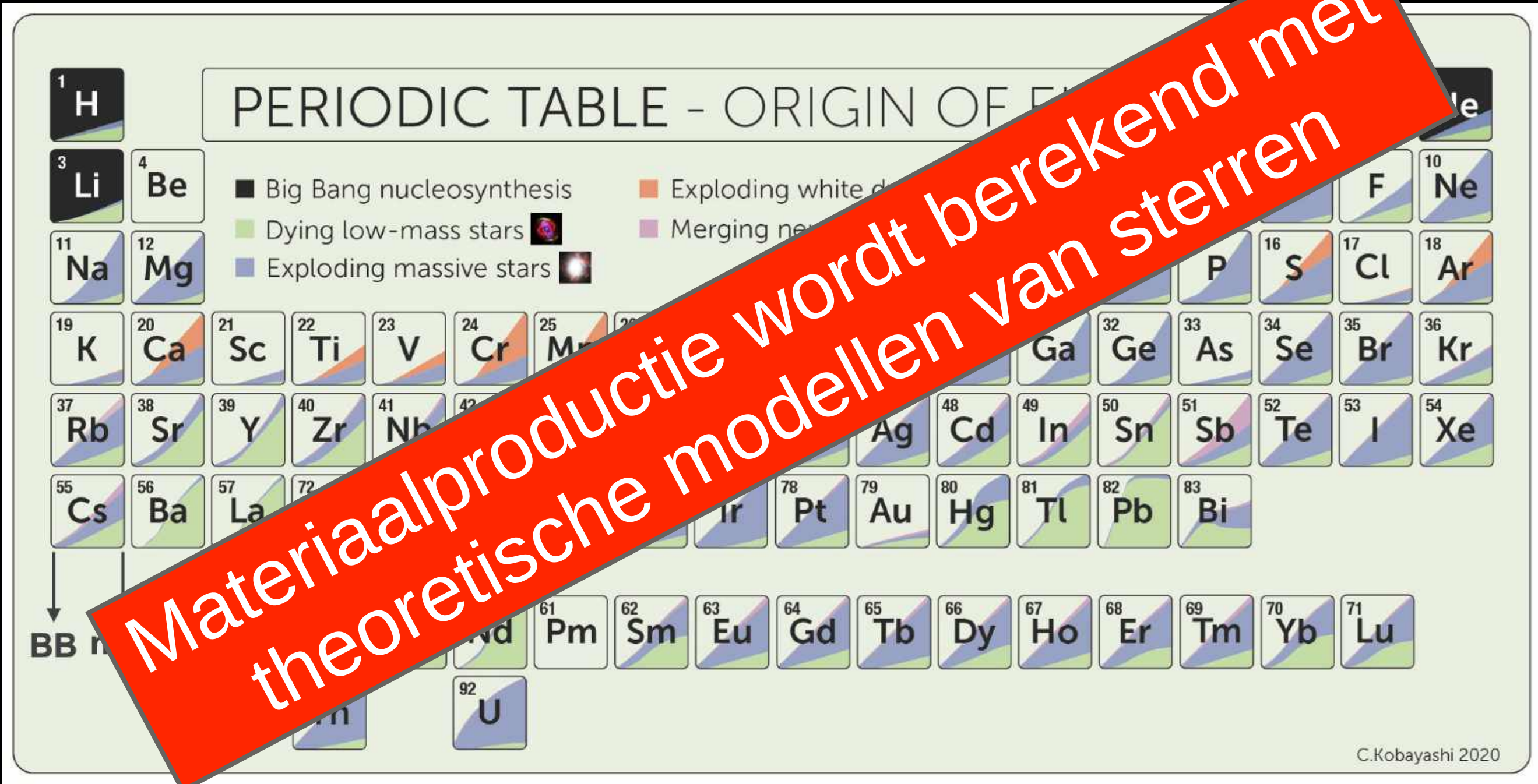
Sterleven = bepaald door stermassa



Sterren maken materialen & leiden tot leven...



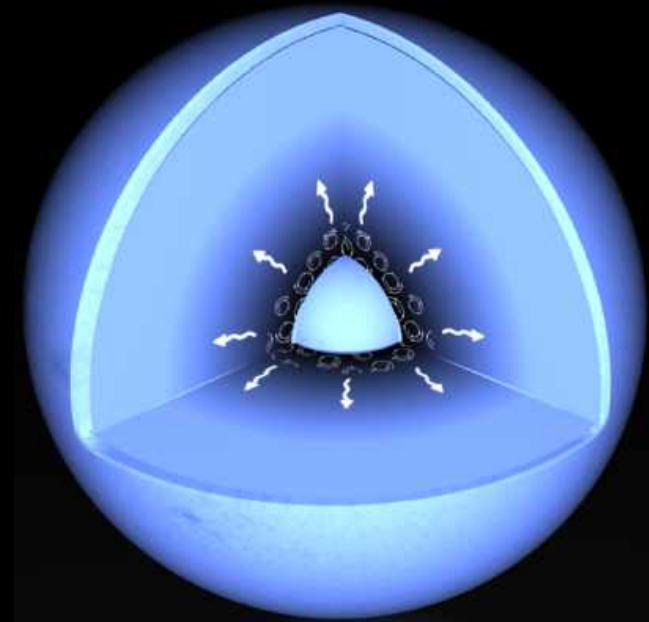
Sterren maken materialen & leiden tot leven...



Belangrijke vraag voor astrofysica



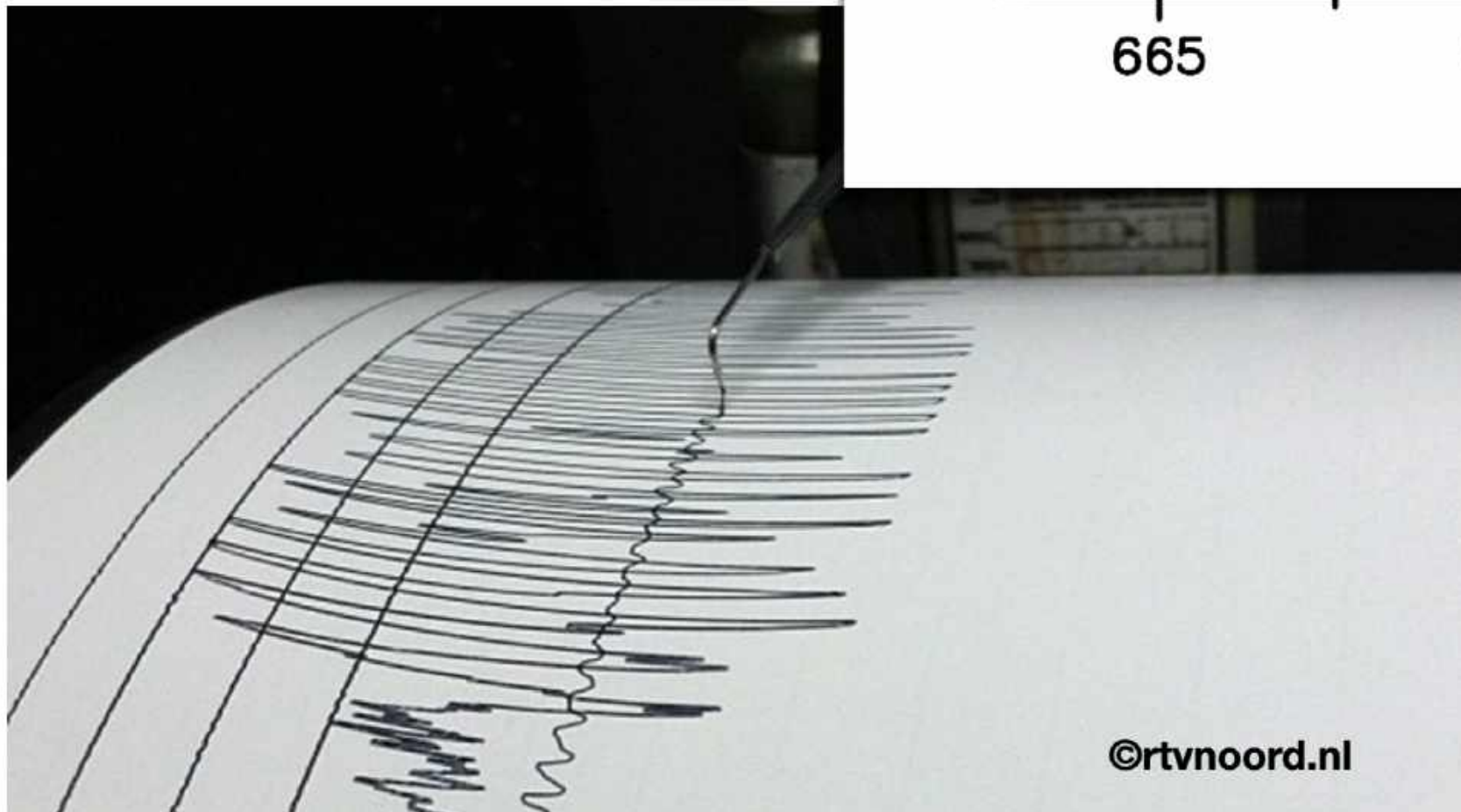
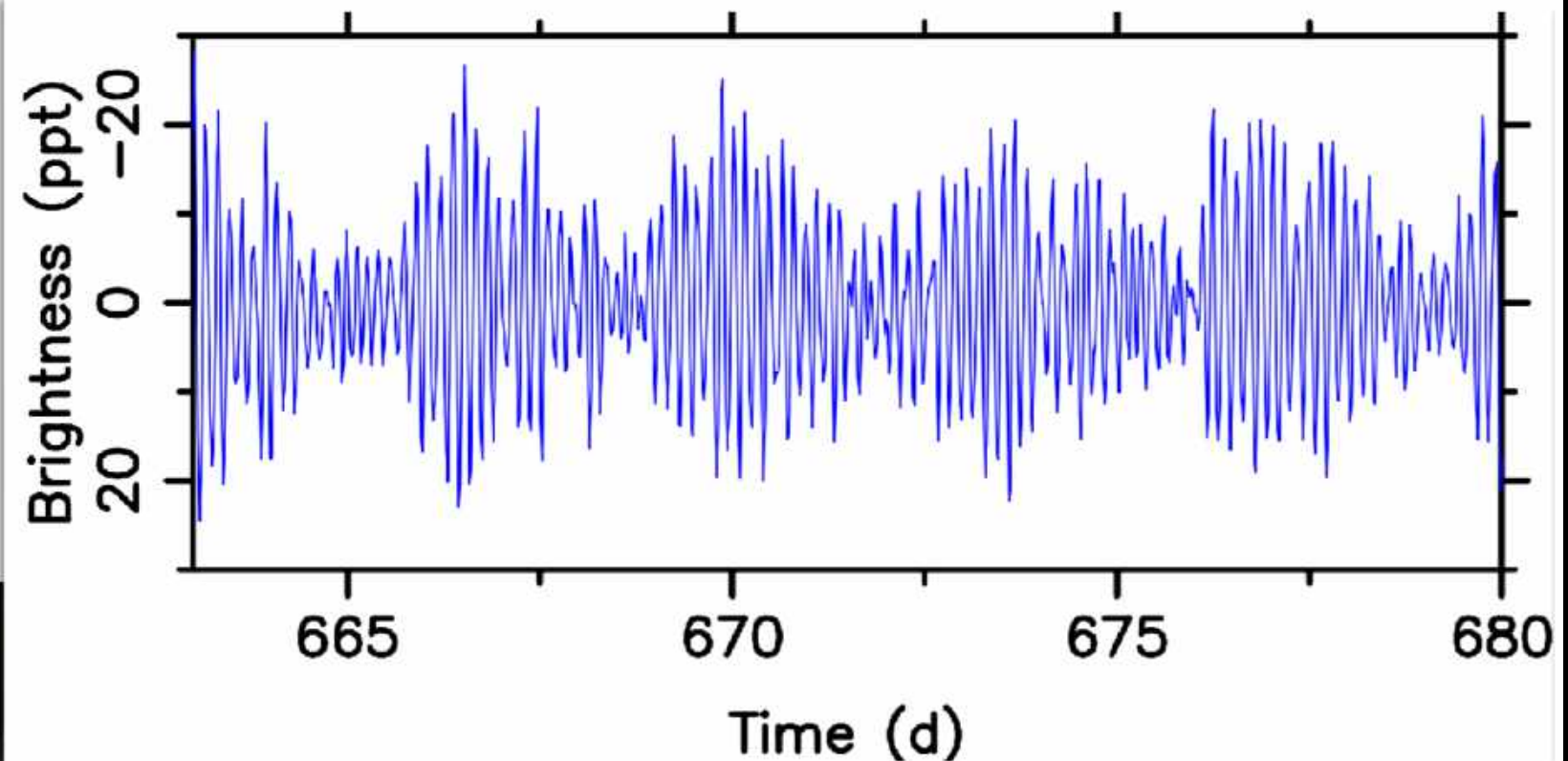
Sir Arthur Stanley Eddington, 1926
The Internal Constitution of the Stars



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

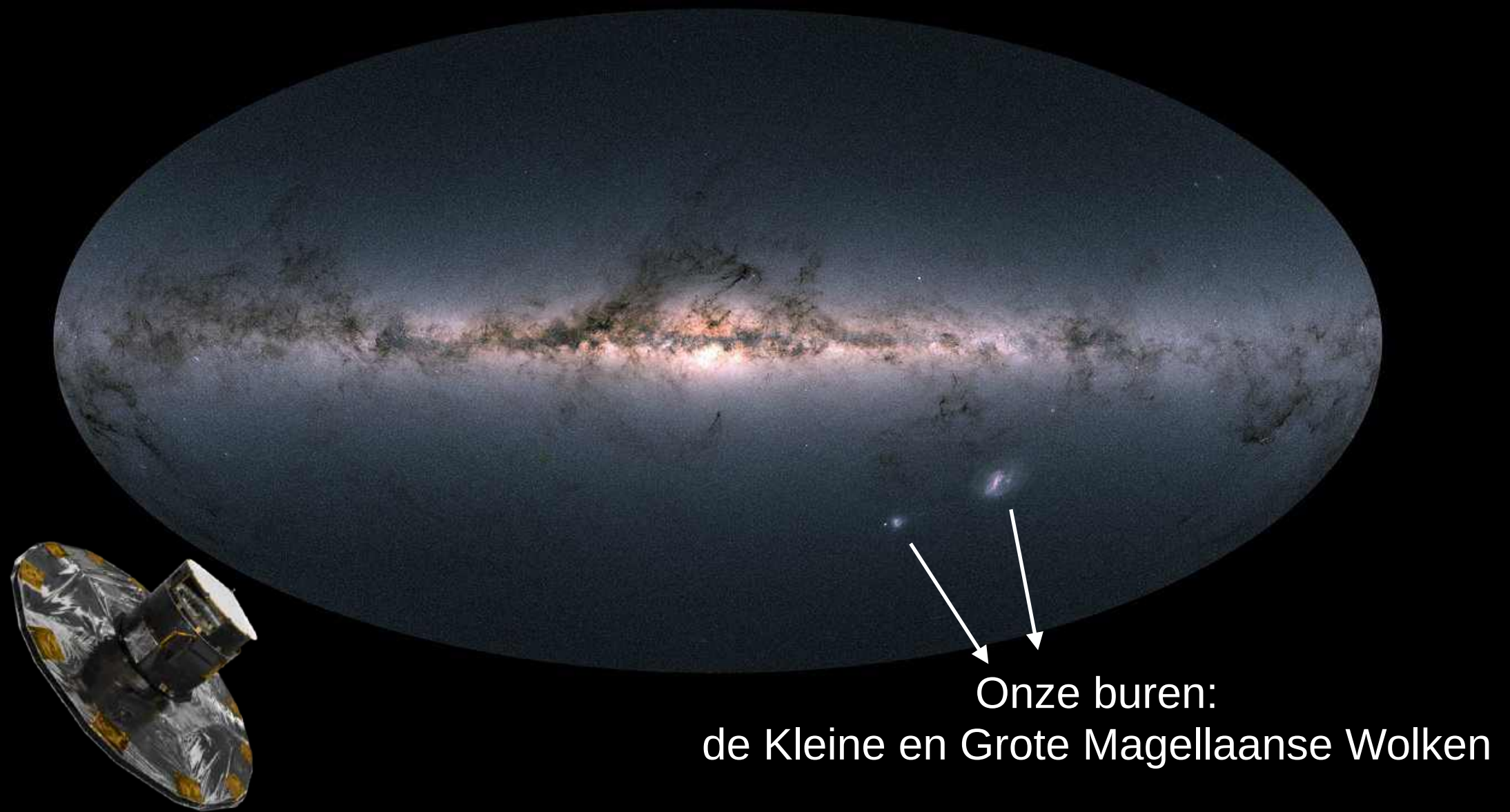
Asteroseismologie: “yes we can”!

Seismische golven:
gelokaliseerde meting
van interne fysica &
chemie + rotation

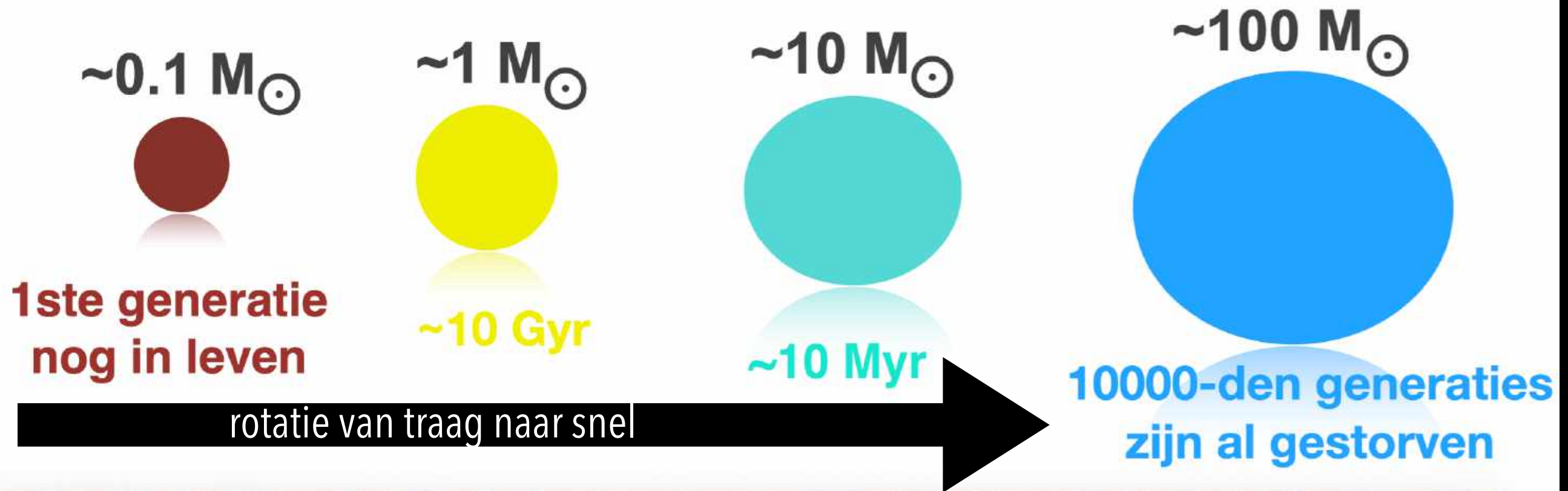


Golffrequenties:
veel precieser
dan “klassieke”
observaties:
1/miljoen!

Seismische activiteit: detecteerbaar in onze Melkweg



Maar interne stermodellen: toetsing?



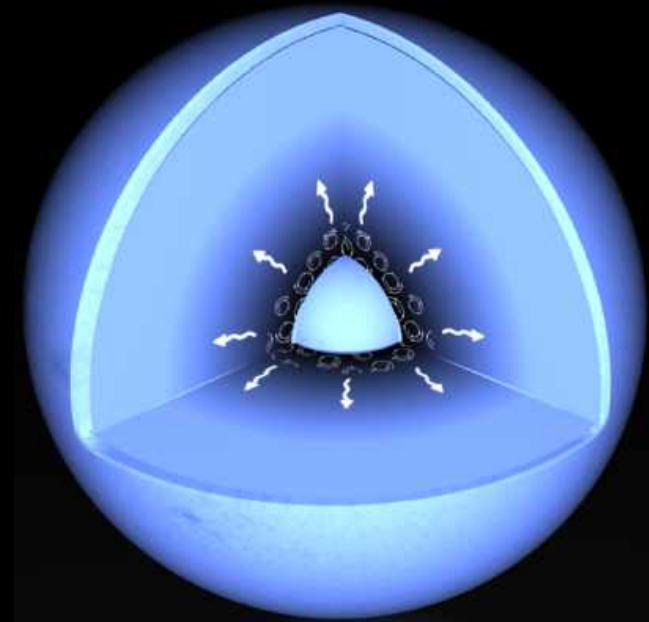
computermodellen gebruikt voor:

- bepaling van **leeftijden & energie** van objecten in Heelal, incl. supernovae, zwarte gaten, moedersterren van exoplaneten...
- afleiden van **materiaalproductie** in generaties van sterren in evoluerende melkwegstelsels: metaalgehalte van het Heelal

“Astero-seismology to the rescue”



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



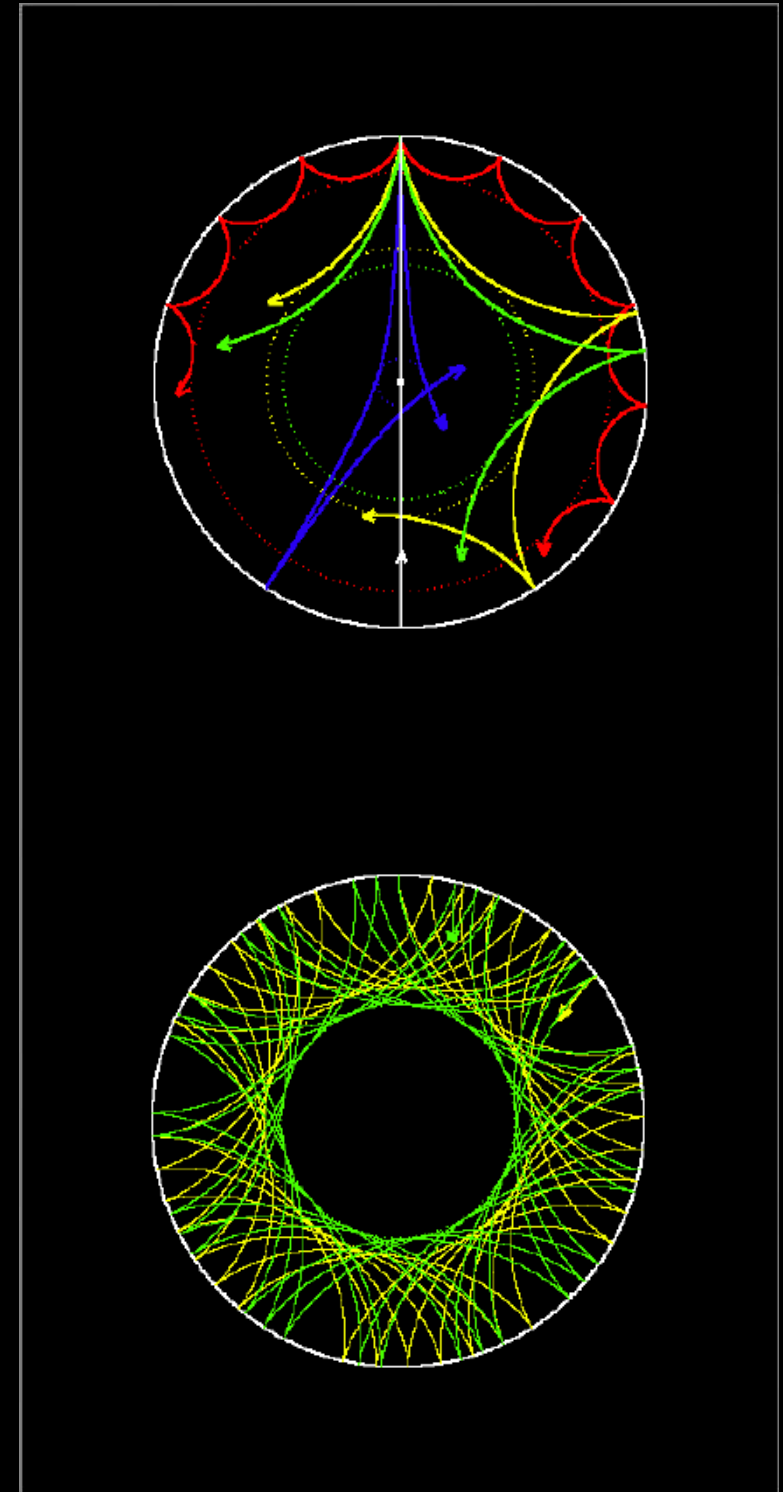
“What appliance can
pierce through the outer
layers of a star and test
the conditions within?”

Wat is het principe?

aster → star
seismos → oscillation
logos → discourse

ASTEROSEISMOLOGIE :
meten en interpreteren van
golffrequenties

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



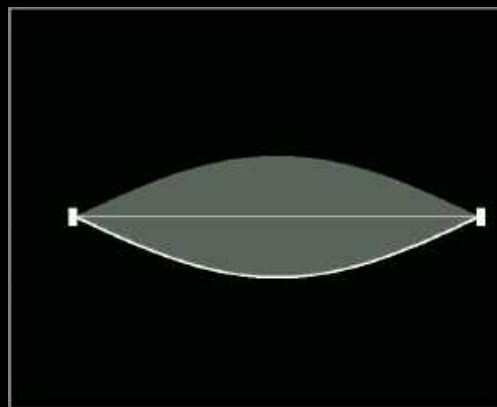
Hoe doen we de metingen?



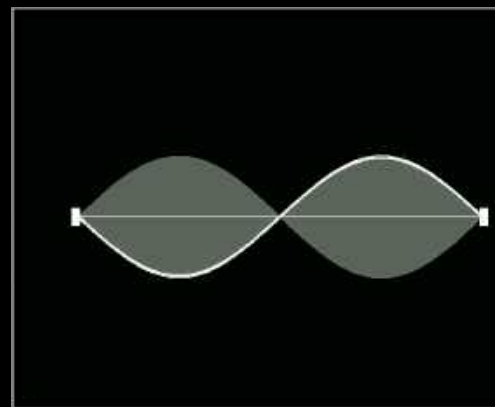
Ononderbroken langdurige helderheidsmetingen van hoge precisie (ppm!): technologische ontwikkeling is cruciaal

Geluidsgolven door bevingen 1D snaar

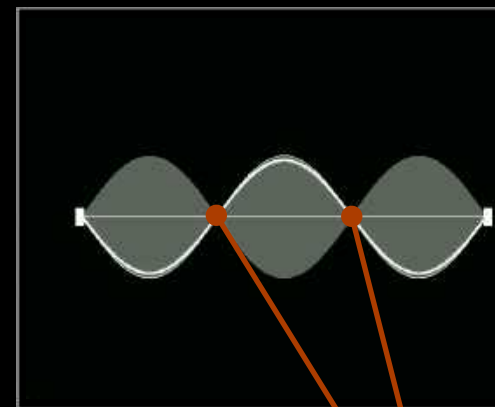
Fundamentele
modus



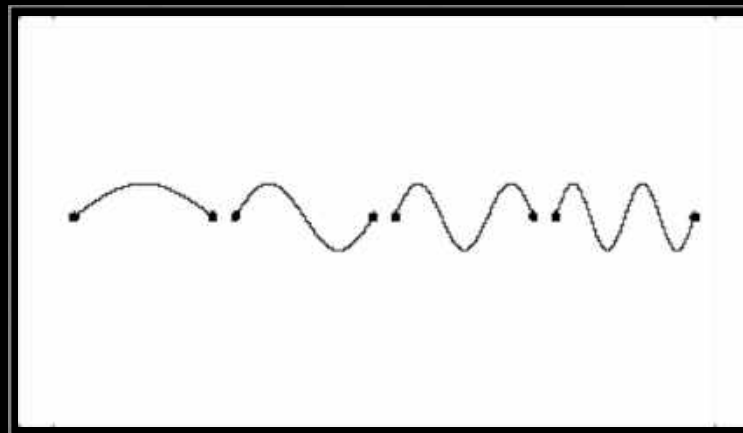
Eerste
boventoon



Tweede
boventoon

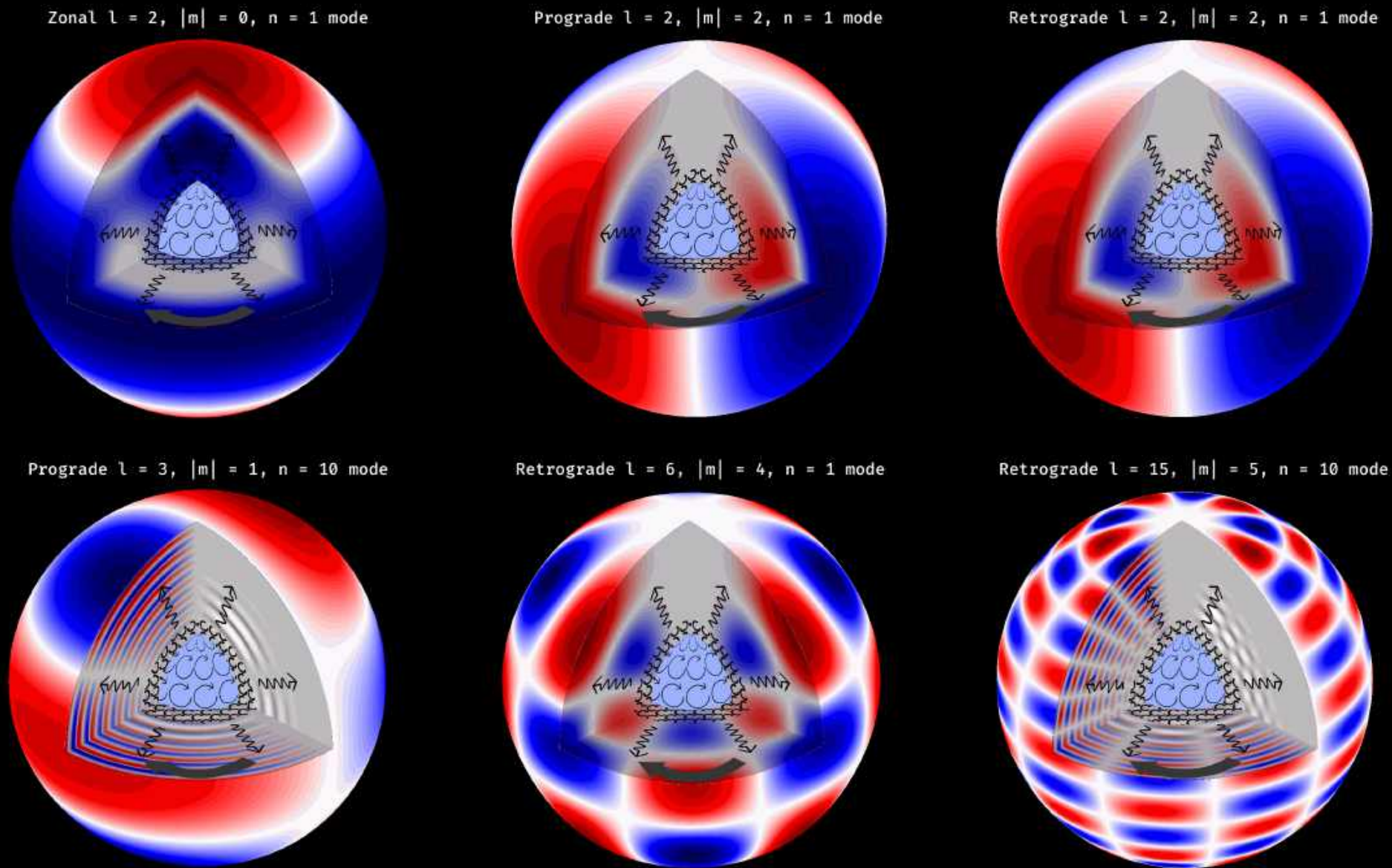


modi →



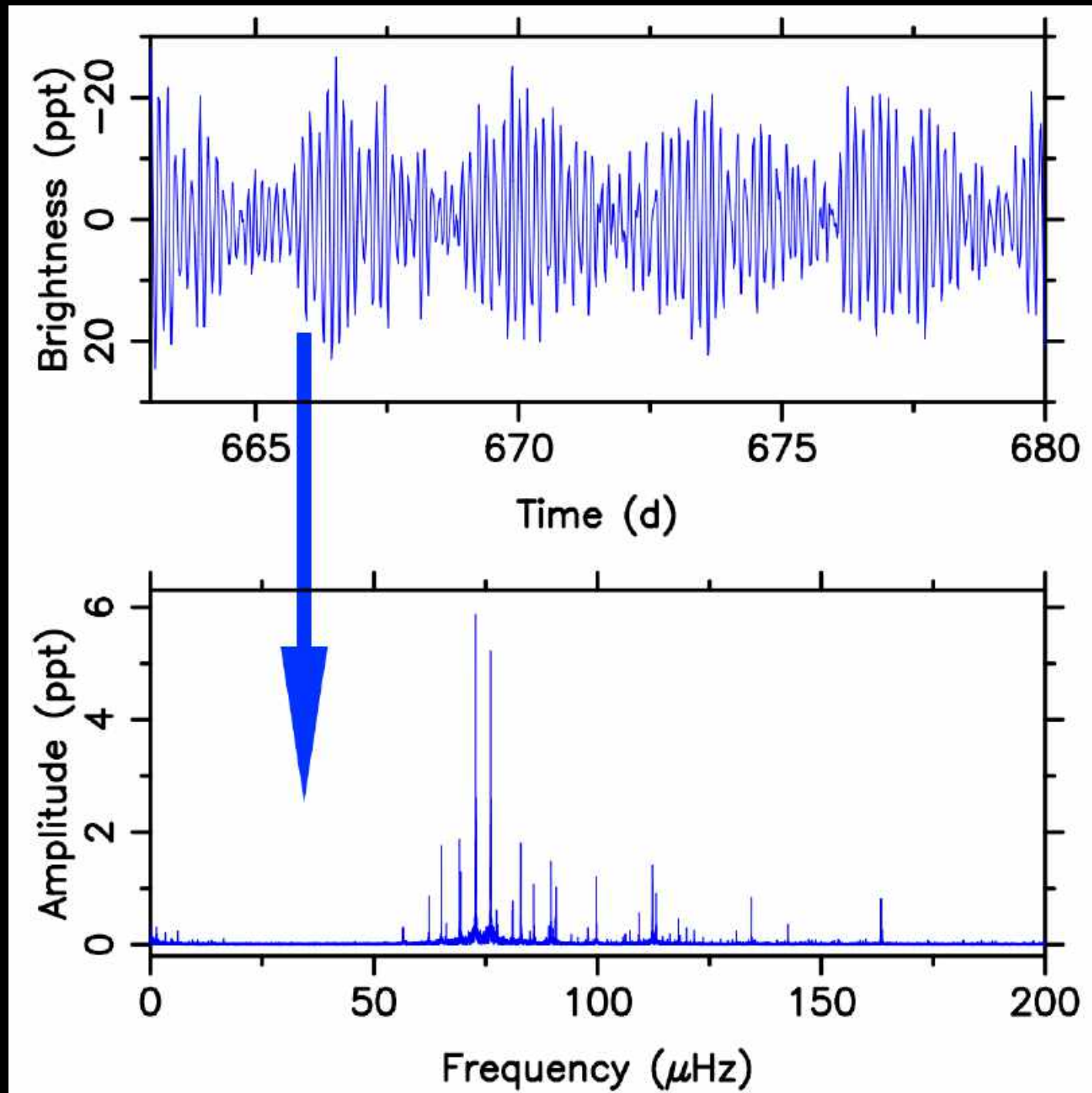
nulpunten

Sterbevingen van 3-D gasbol



Figuren & animaties: Dr. Pieter Degroote & Dr. Dries Seynaeve

Wiskunde van niet-radiale modi



Tijdsafhankelijkheid:
uitgedrukt in periodes
1 dag = 24 uur
= 86400 seconden

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

Muzikaal Intermezzo

Oscillatiesterkte

(ESA/NASA SoHO)

2000

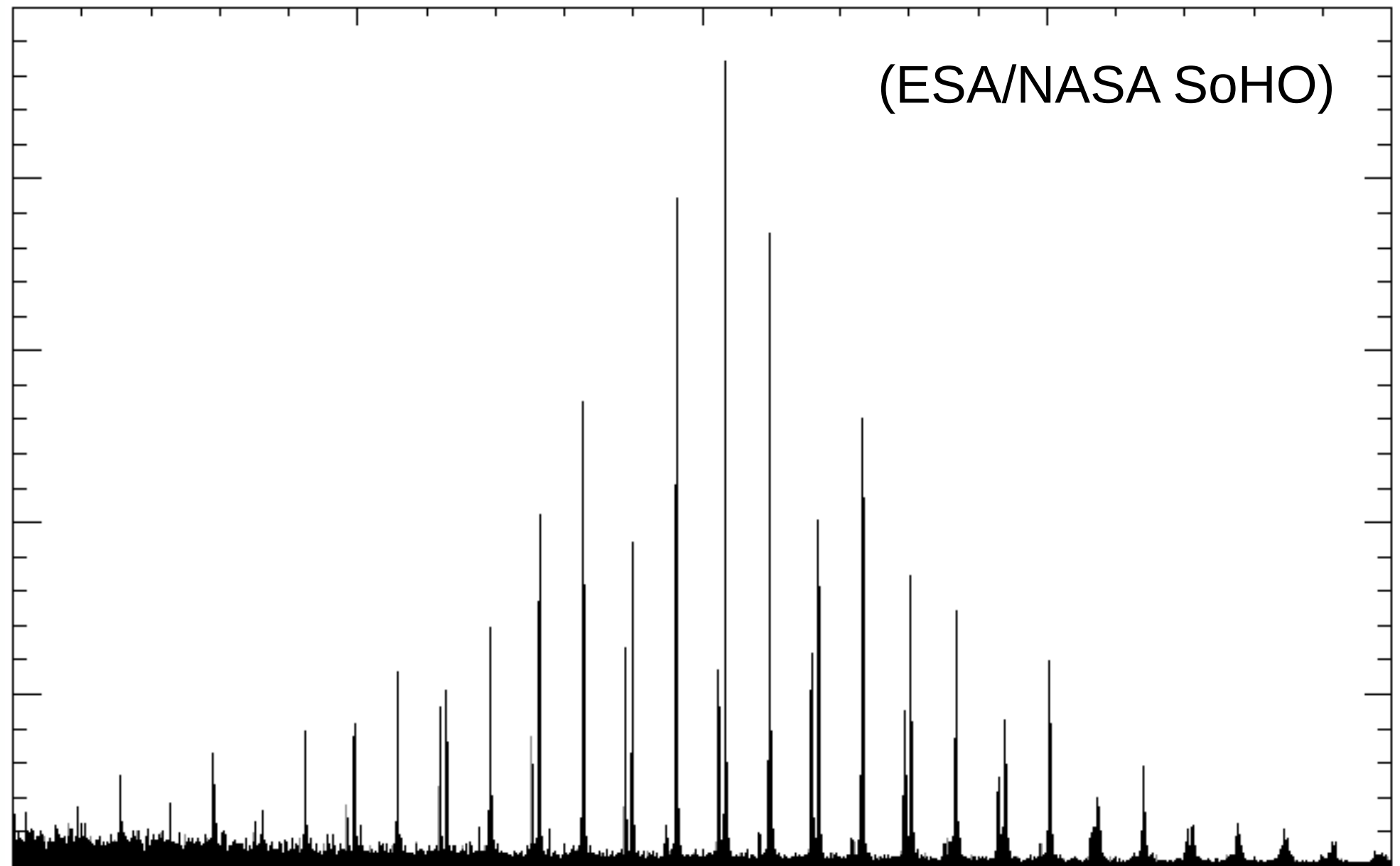
2500

3000

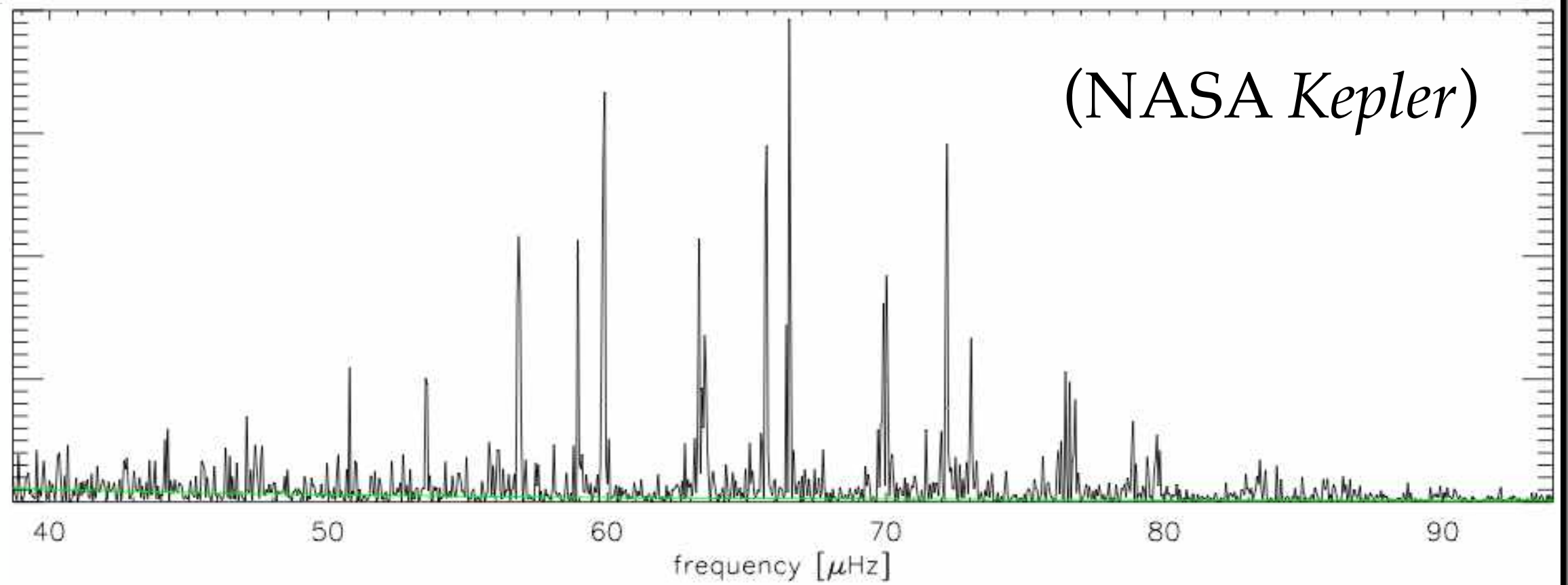
3500

4000

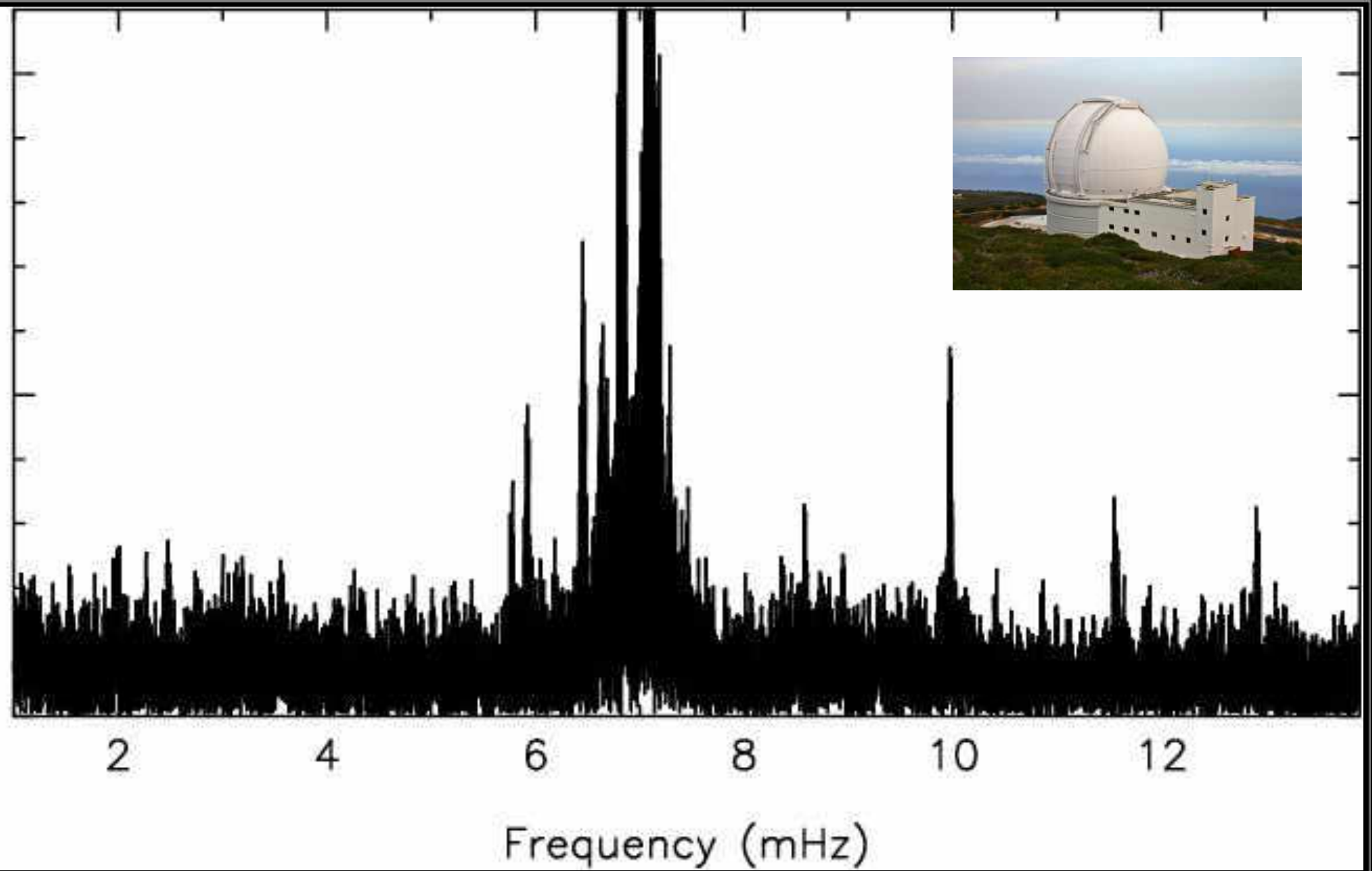
Frequency (microHz)



Oscillatiesterkte



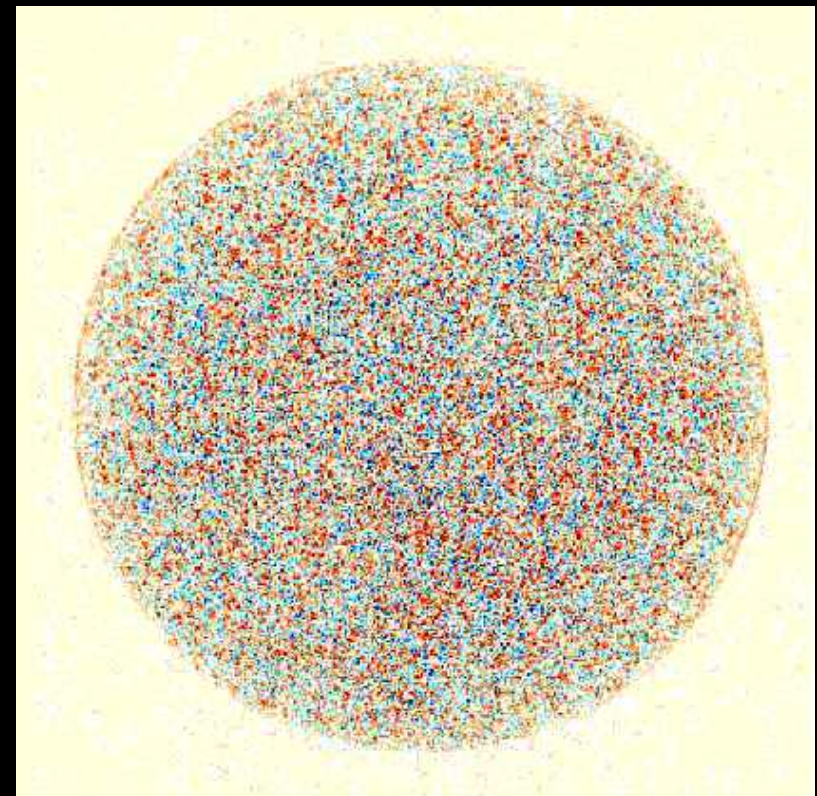
Oscillatiesterkte



Fysica van niet-radiale golven

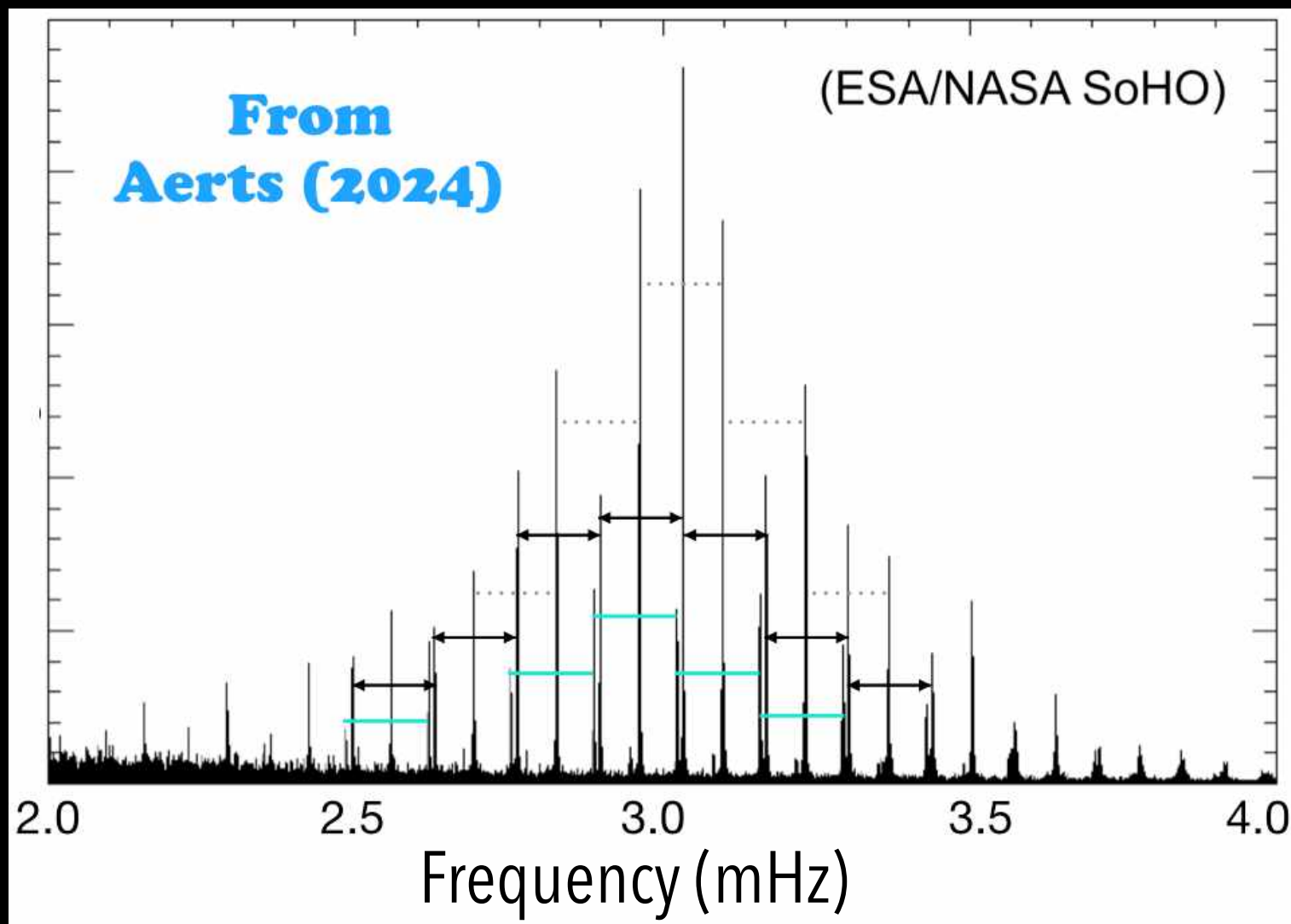
Afhankelijk van actieve dominante krachten:

1. gasdruk (geluidsgolven)
2. gravitatie (gravitatiegolven)
3. Coriolis (inertiegolven)
4. Lorentz (Alfvén golven)
5. Getijdenkracht ("gedwongen" golven)



Zon: snelle geluidsgolven (5') in trage rotator (~26d)

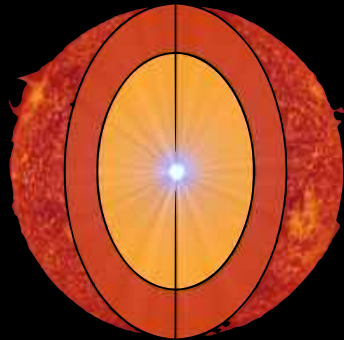
1. gasdruk (geluidsgolven)



Golffrequenties meten
straal & dichtheid:

$$= \frac{\text{Mass}}{\frac{4\pi}{3} (\text{Radius})^3}$$

Grootte van sterren: vergelijk met Zon



TIME →



KIC 11026764



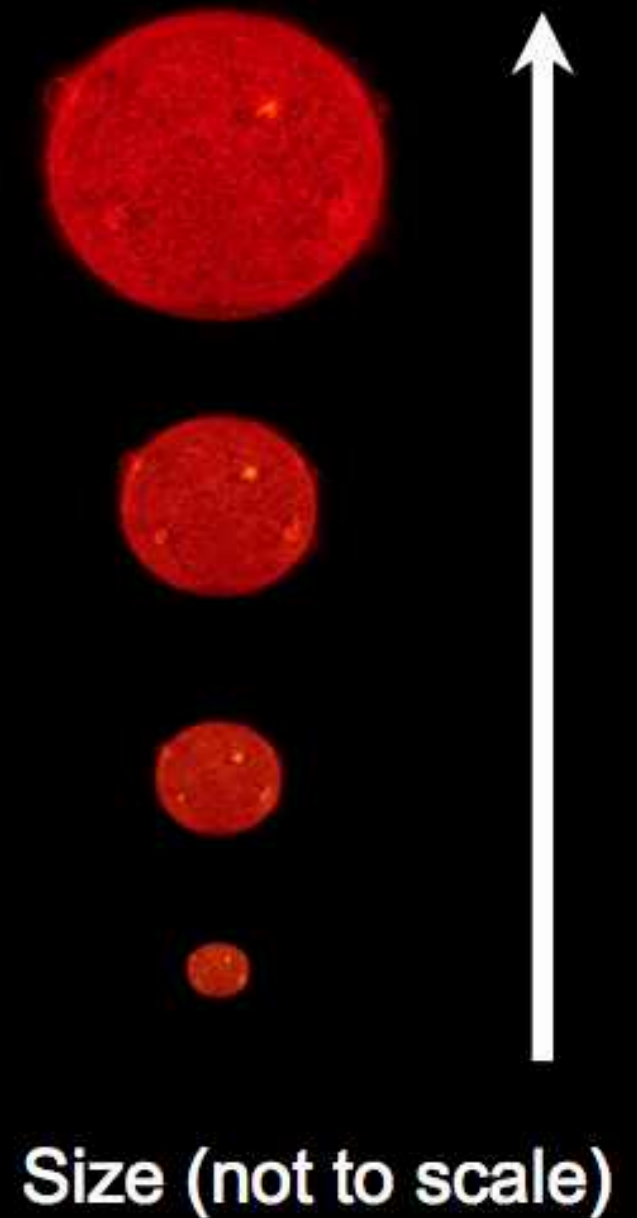
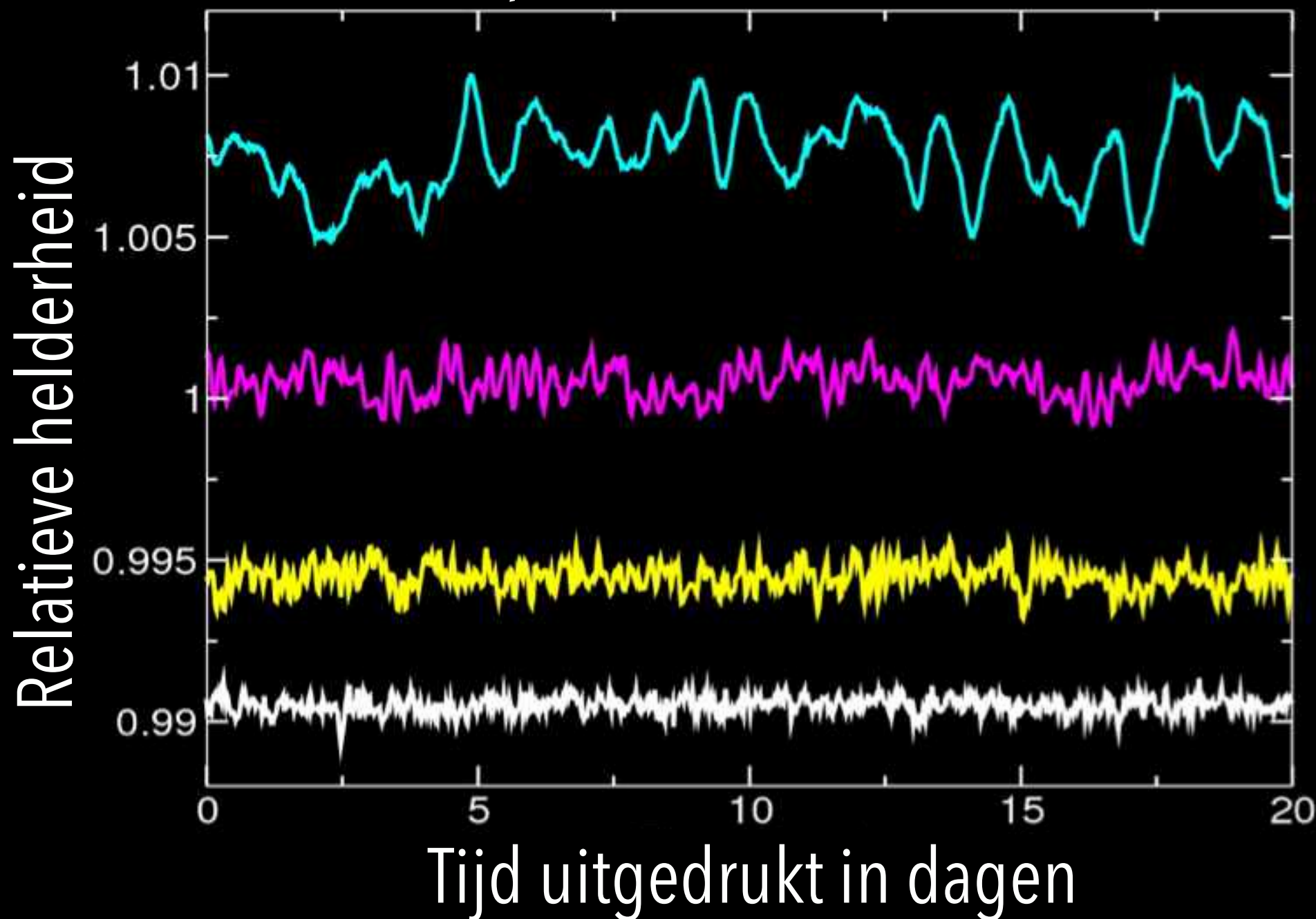
ZON



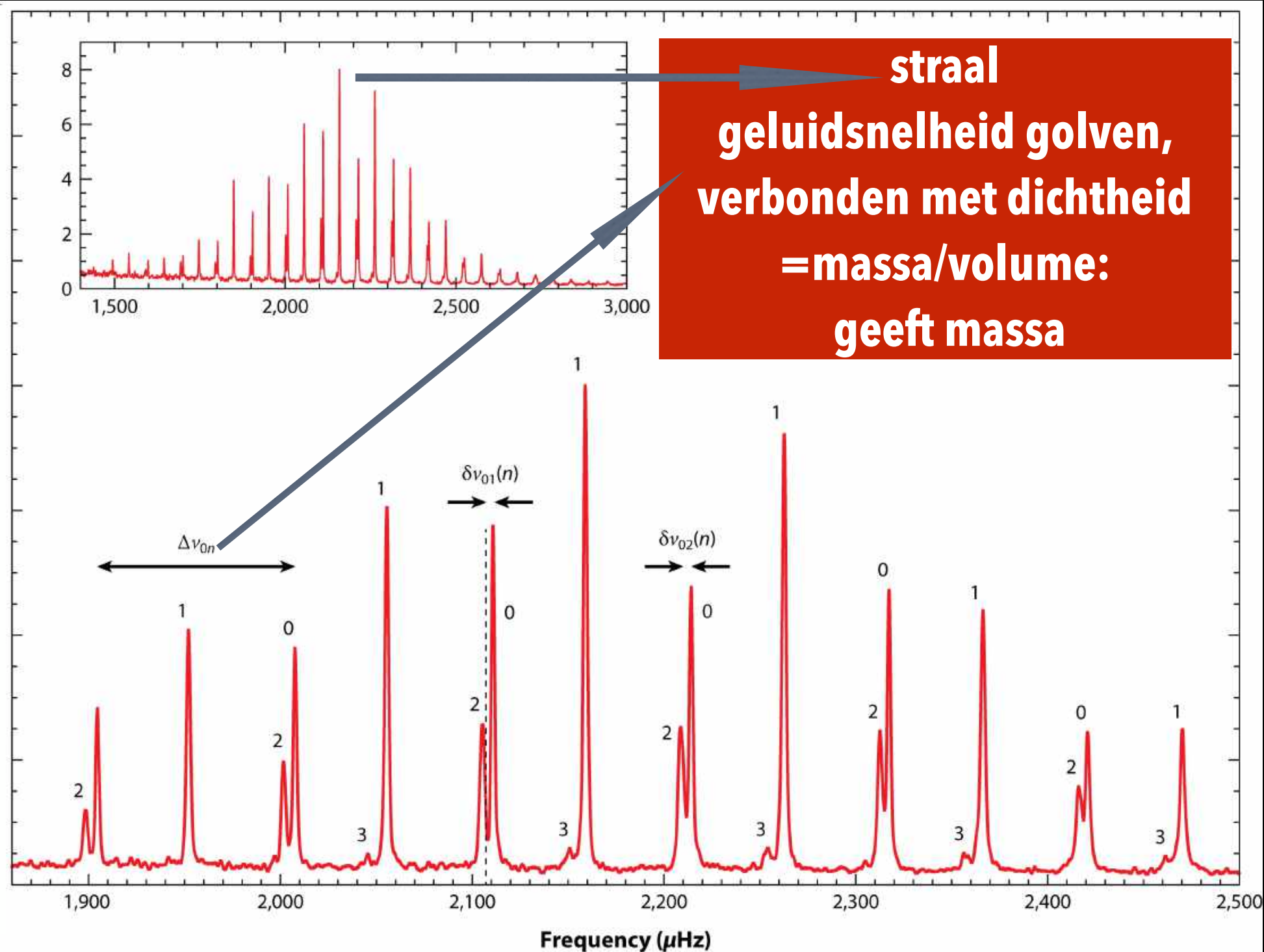
Travis Metcalfe, National Center for Atmospheric Research

Sterstralen tot op 1% nauwkeurig!

NASA *Kepler* lichtkrommen (4 jaar!)



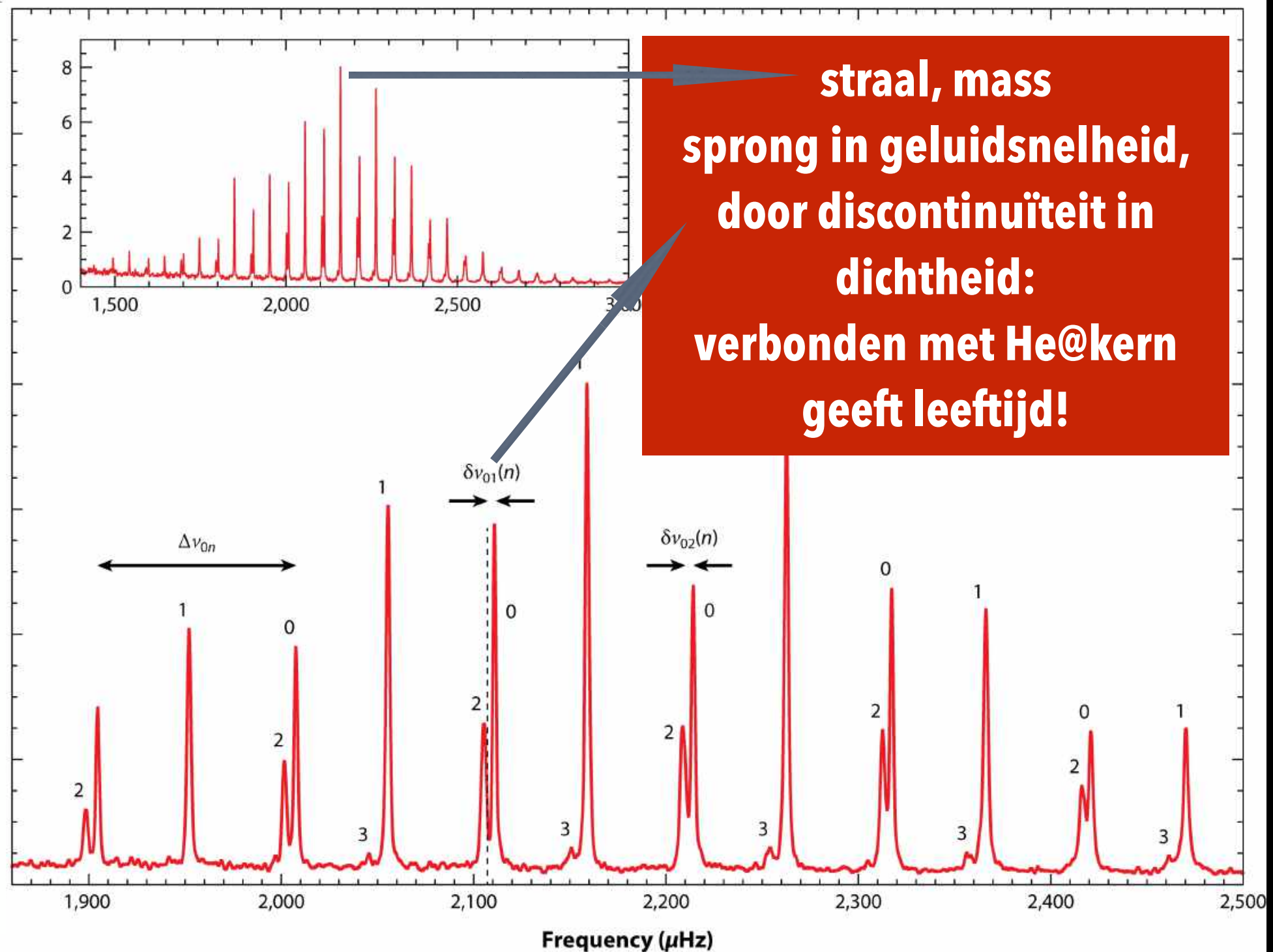
Wegen van sterren tot 2% nauwkeurigheid



Chaplin WJ, Miglio A. 2013.

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

Leeftijd van sterren tot 20% nauwkeurigheid

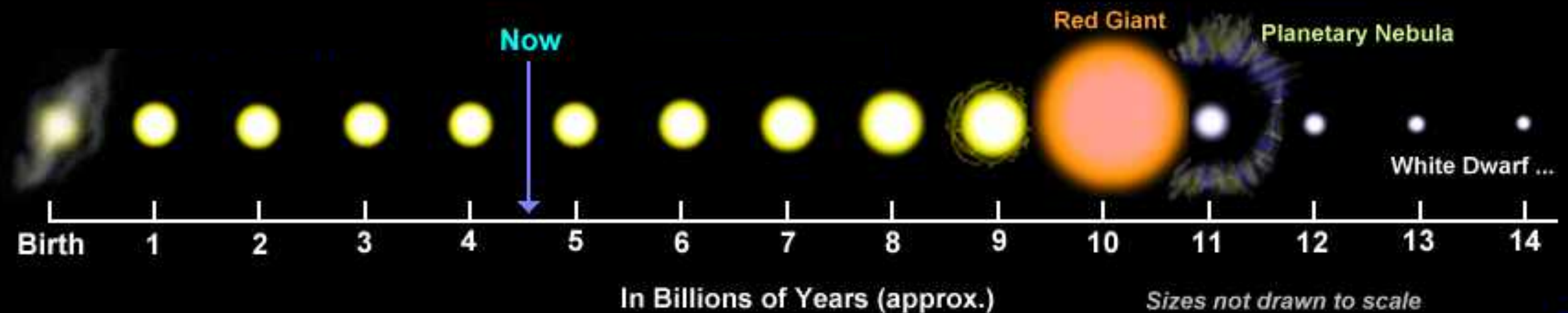


Chaplin WJ, Miglio A. 2013.

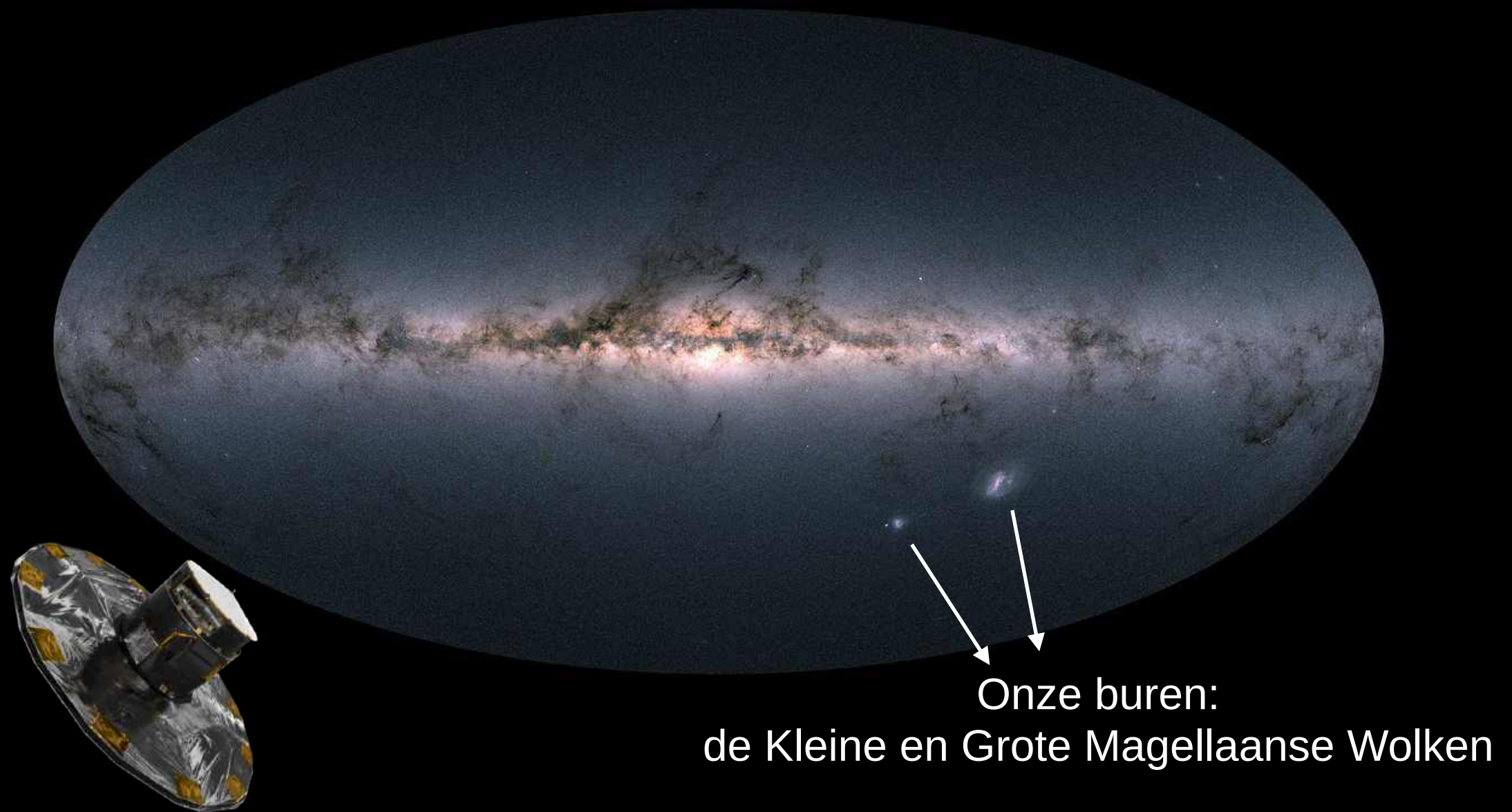
Annu. Rev. Astron. Astrophys. 51:353–92

Seismologische dateringsmethode!

Helioseismologische leeftijd: 4.57 - 4.60 miljard jaar
Leeftijd zonnestelsel via meteorieten: 4.603 miljard jaar



Datering van oude populaties: archeologie van de Melkweg



Datering van moedersterren met planeten in leefbare zones



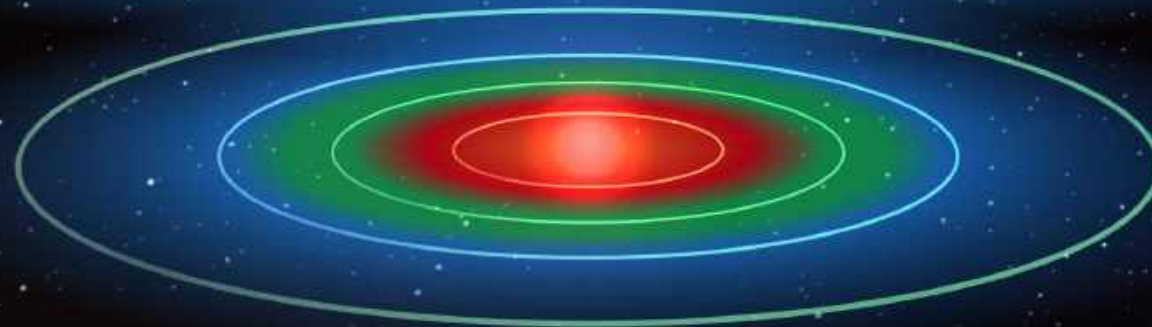
Hotter Stars



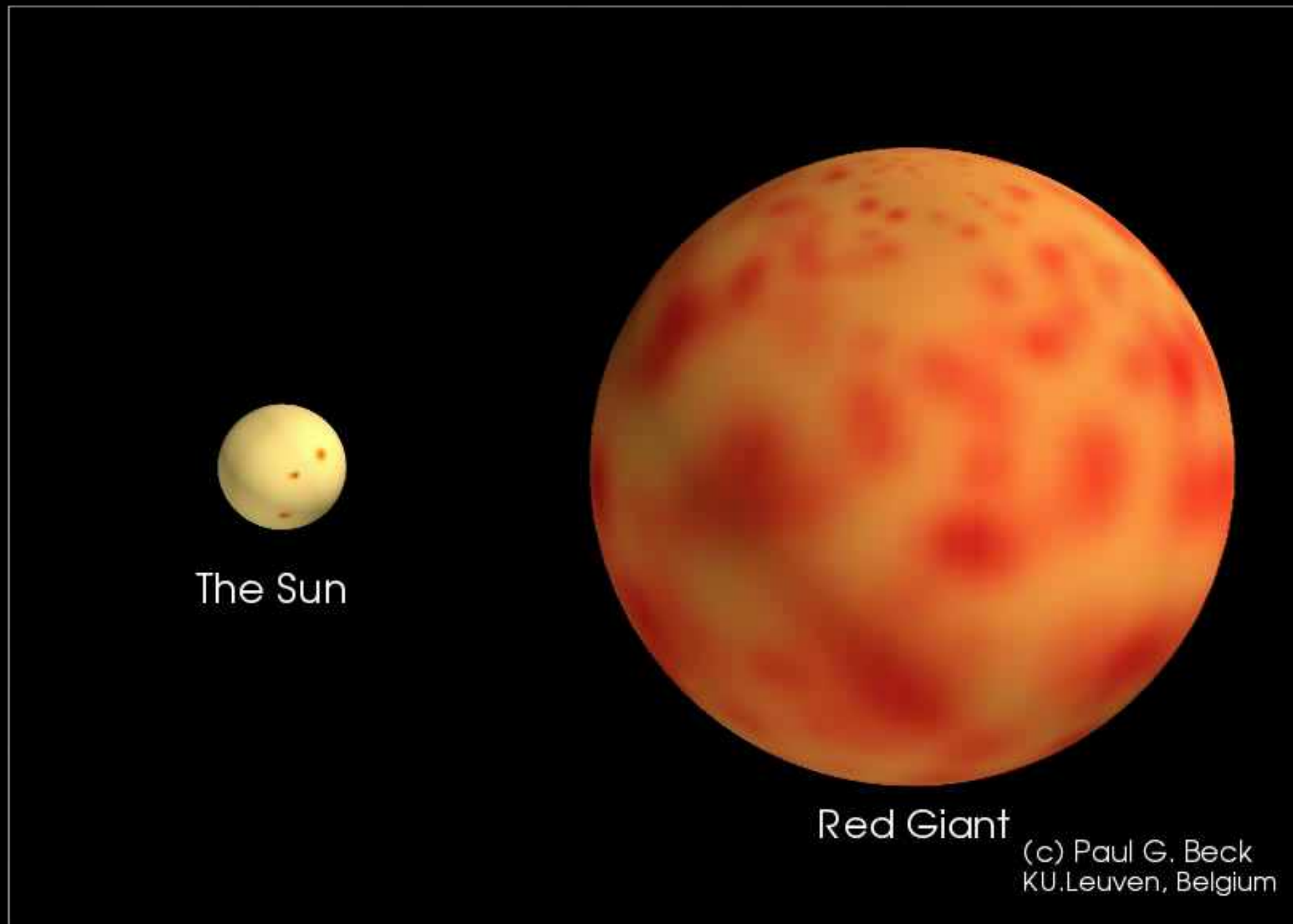
Sunlike Stars



Cooler Stars



Maar sterleven hangt fel af van rotationele
vermenging van gas: onzekerheid in modellen...

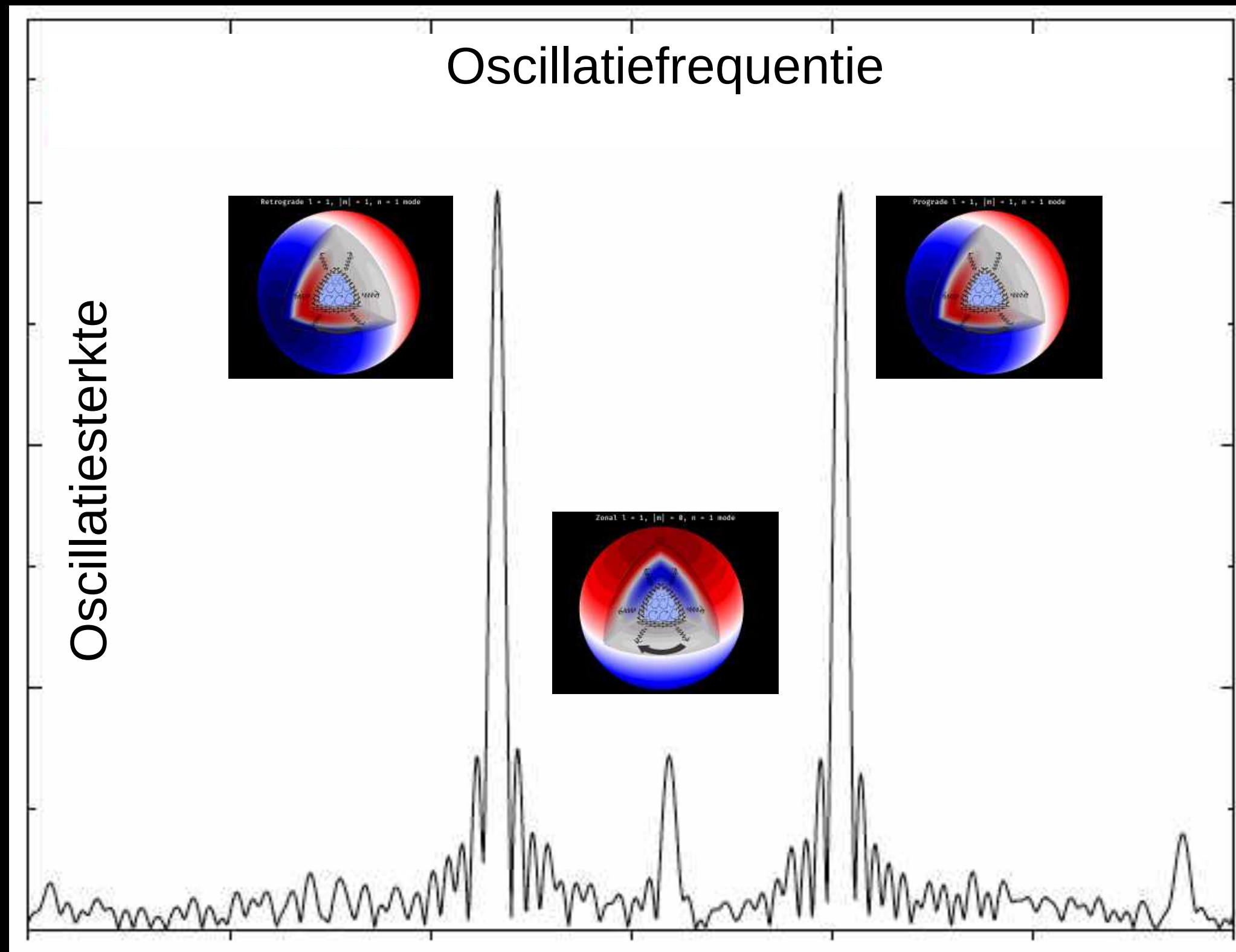


Kermis Intermezzo

Corioliskracht in actie...

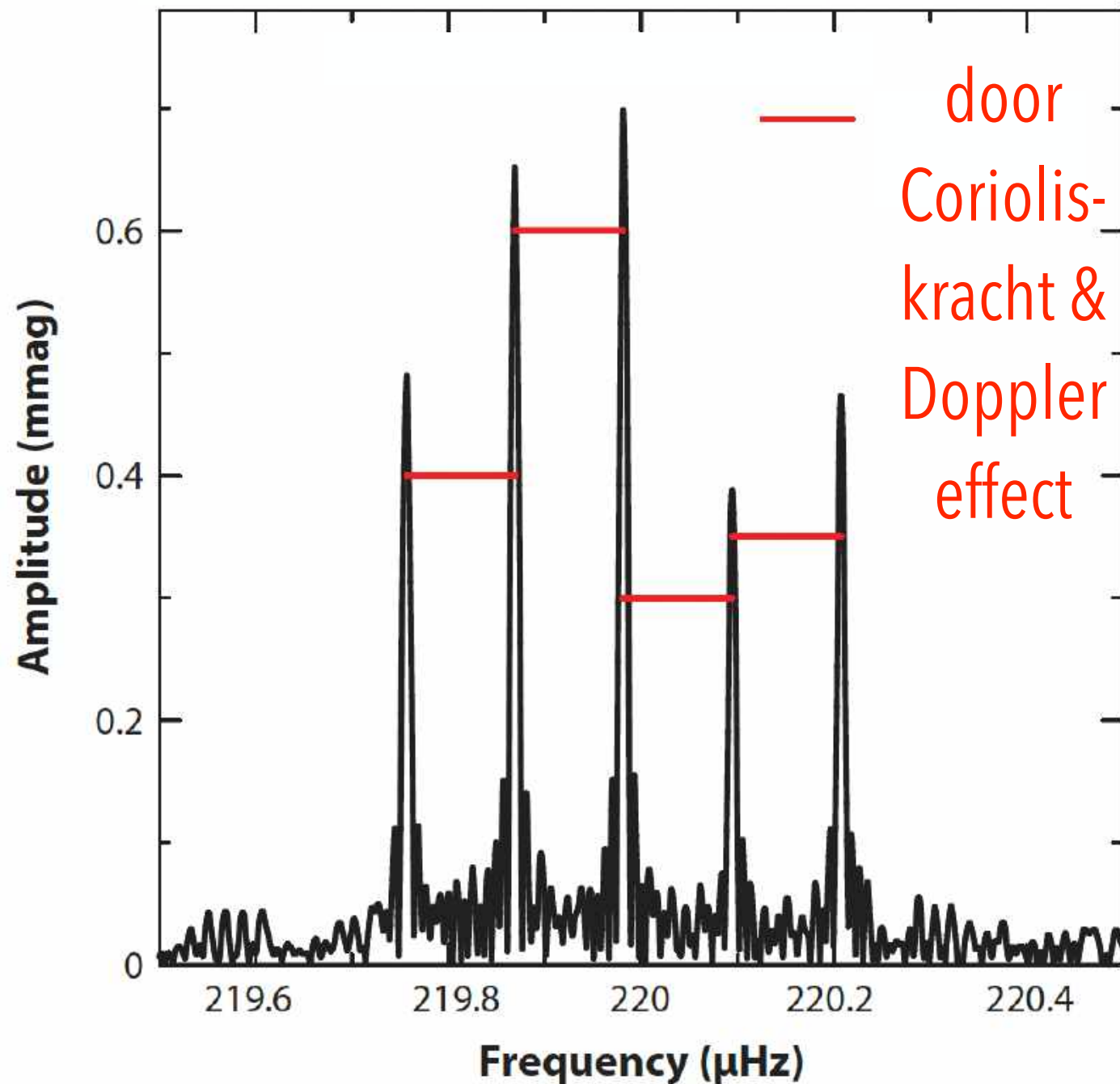


Rotatie verschuift frequenties, cf. muziek

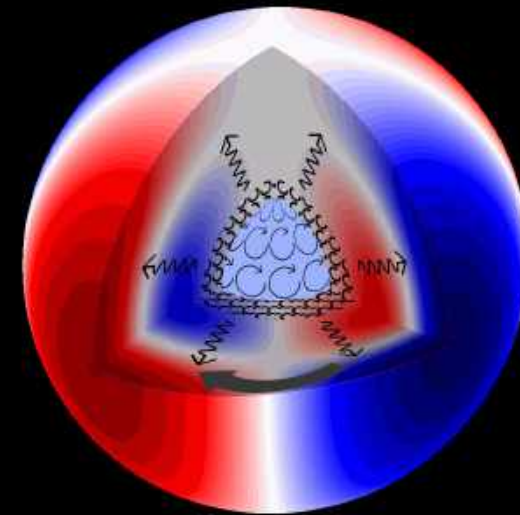


Retrograde , Zonale, Prograde dipoolmodi

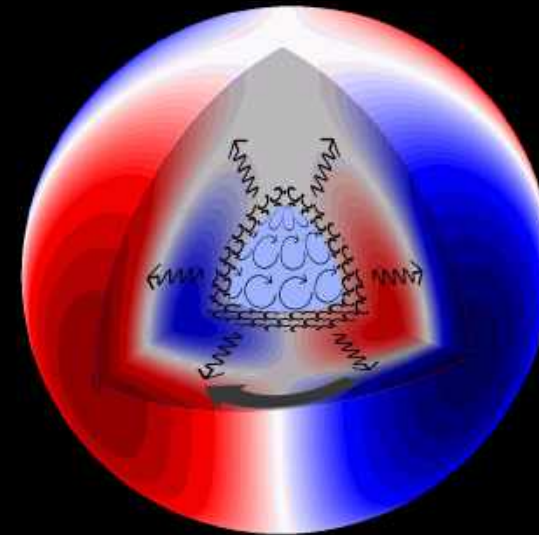
Rotatie verschuift frequenties, cf. muziek



Retrograde quadrupolemodus



Prograde quadrupolemodus



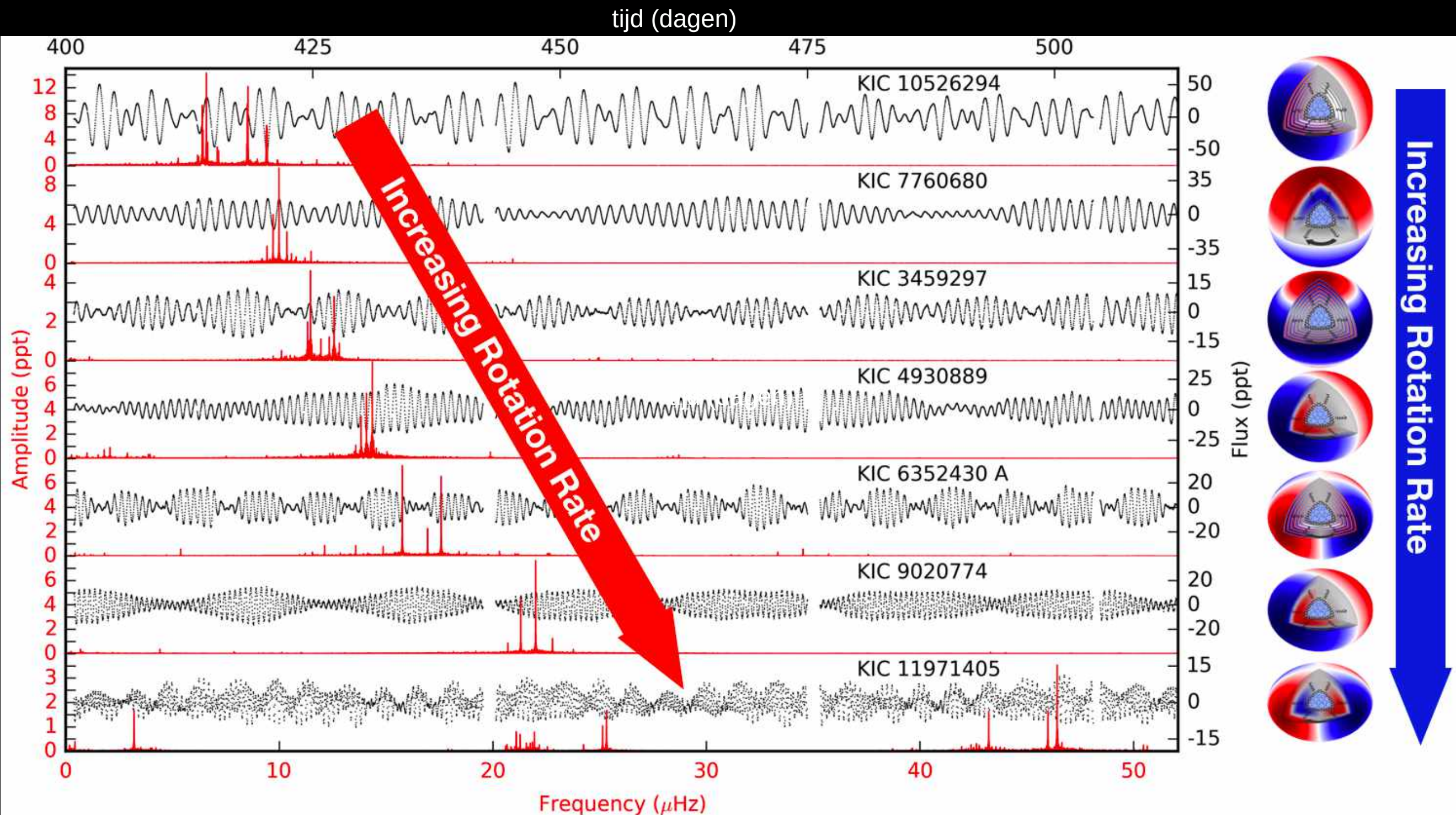
Fysica van gravito-inertiële modi

Wiskundige uitdaging: niet één dominante
kracht: rotatie & oscillaties $\sim$ perioden van dagen

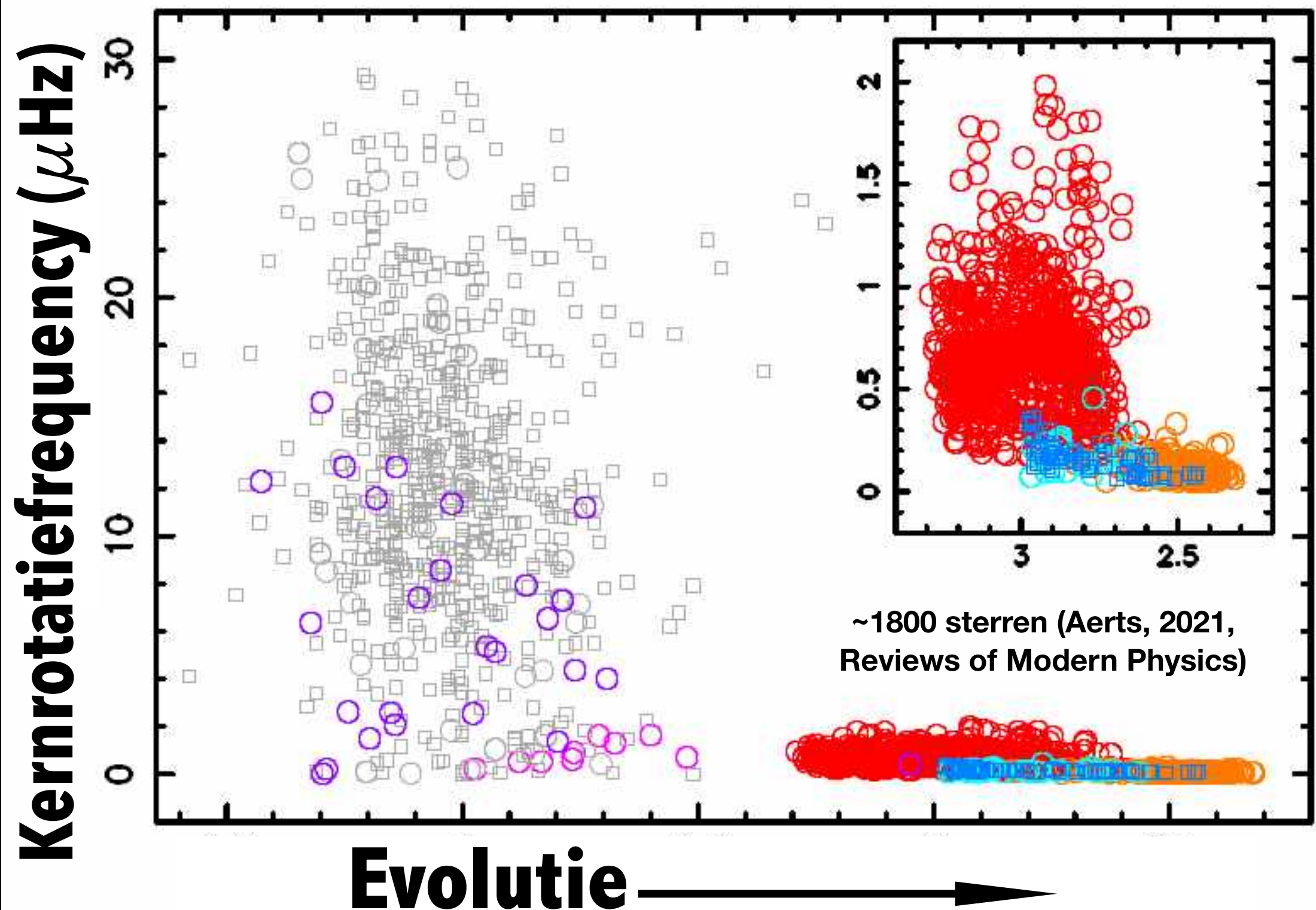
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4. Lorentz (Alfvén golven)
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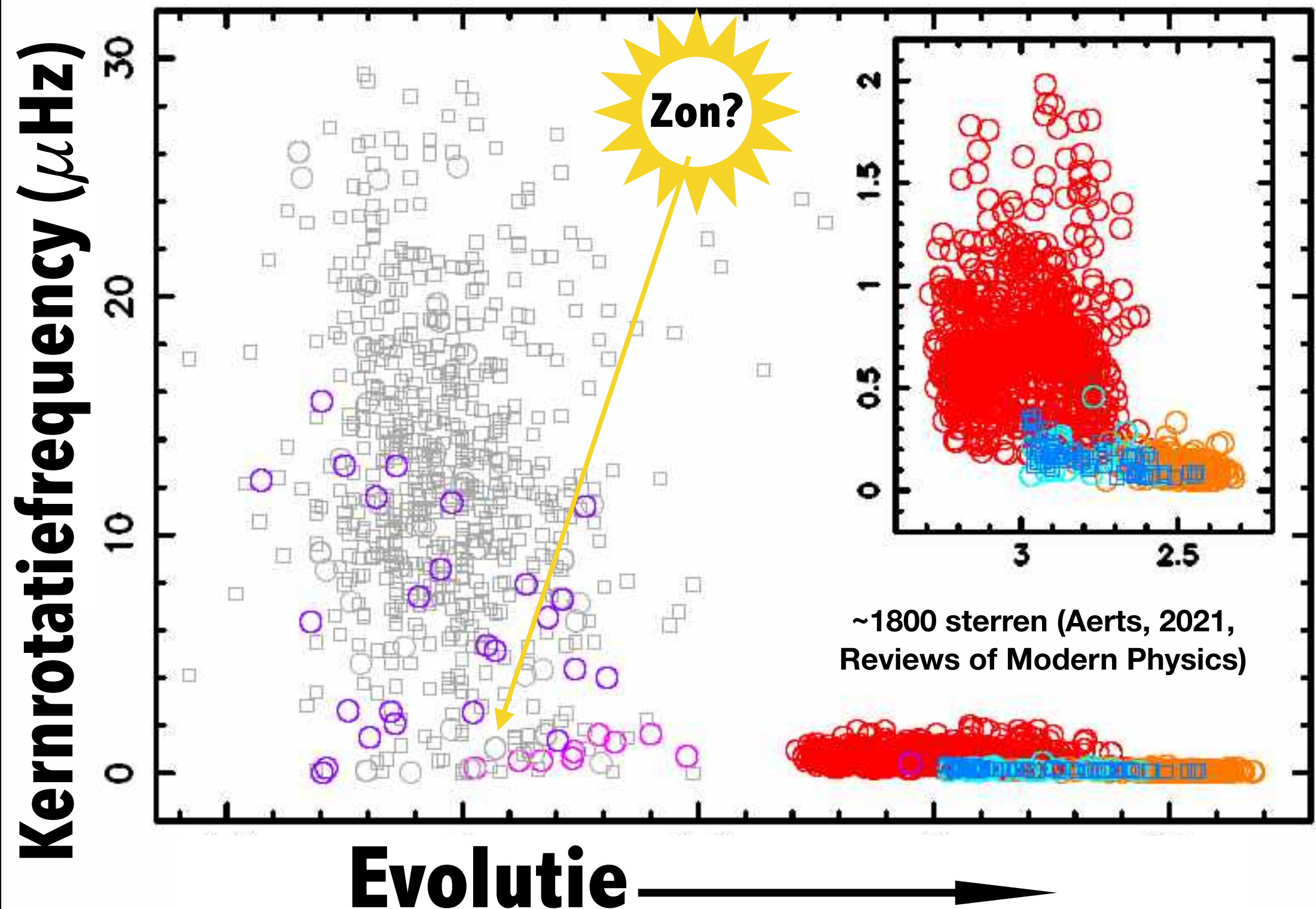
Gravito-inertiële golven begrepen (2016-2020)



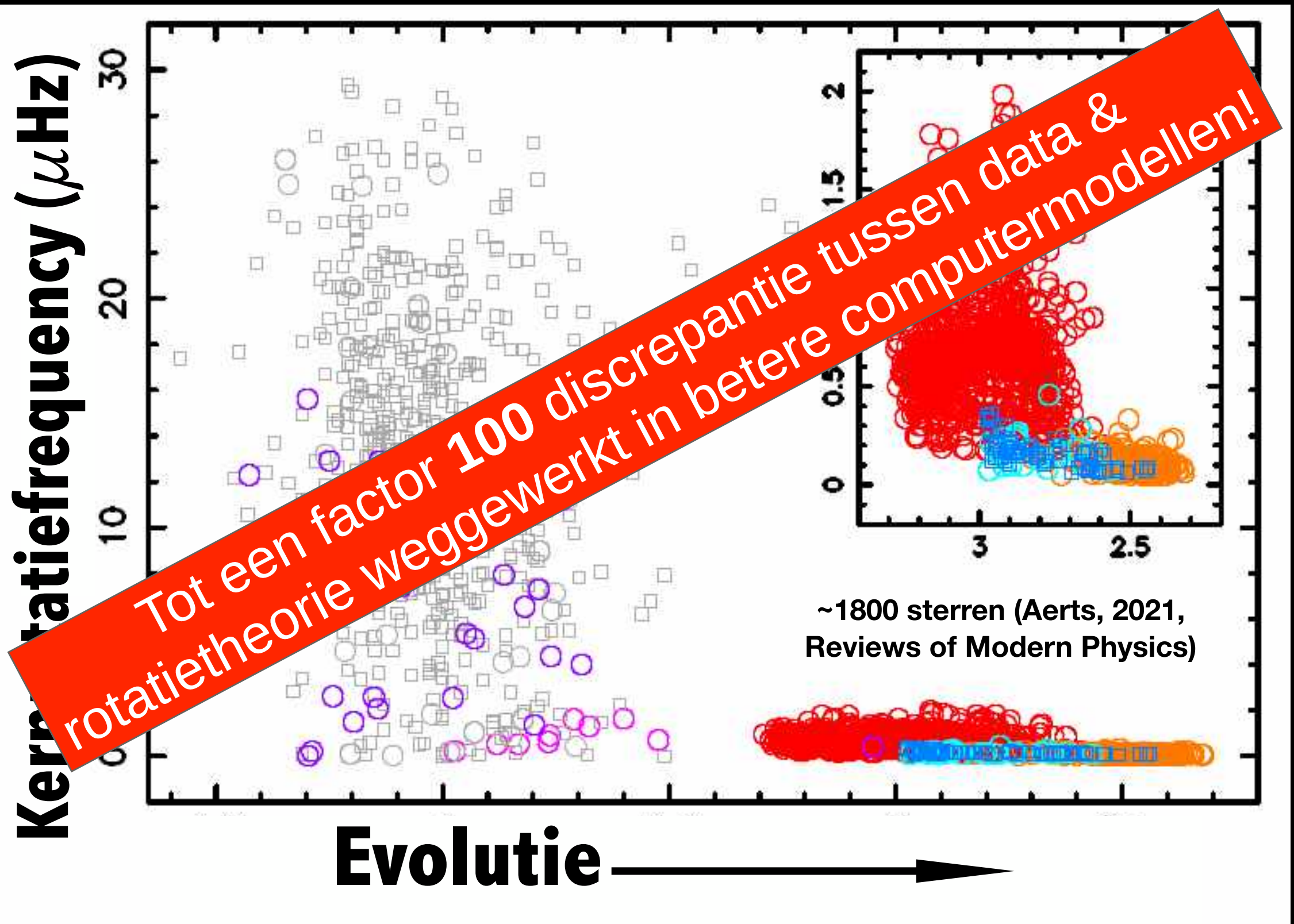
Stavaza interne sterrotatie:
15 jaar geleden was dit diagram leeg...



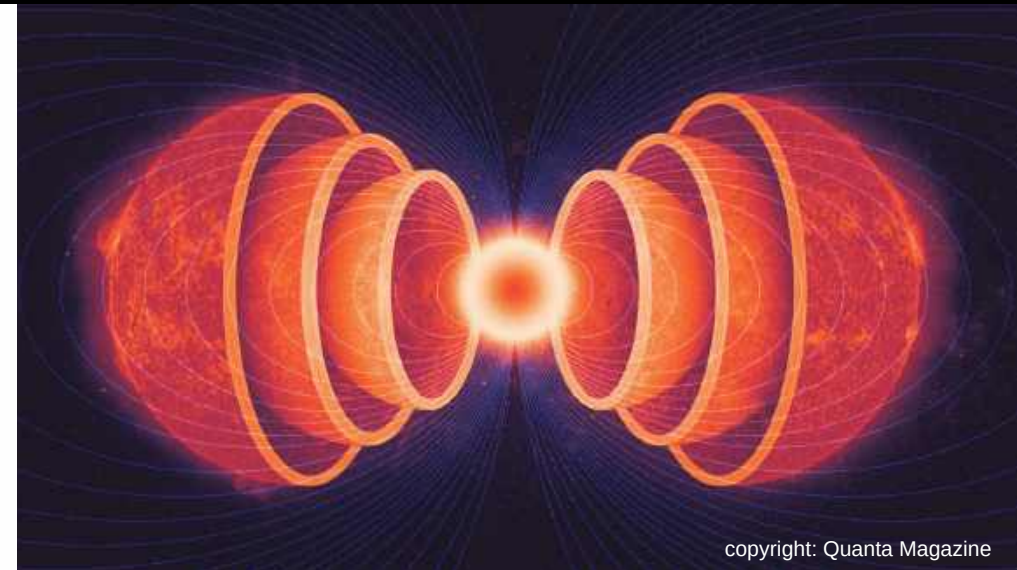
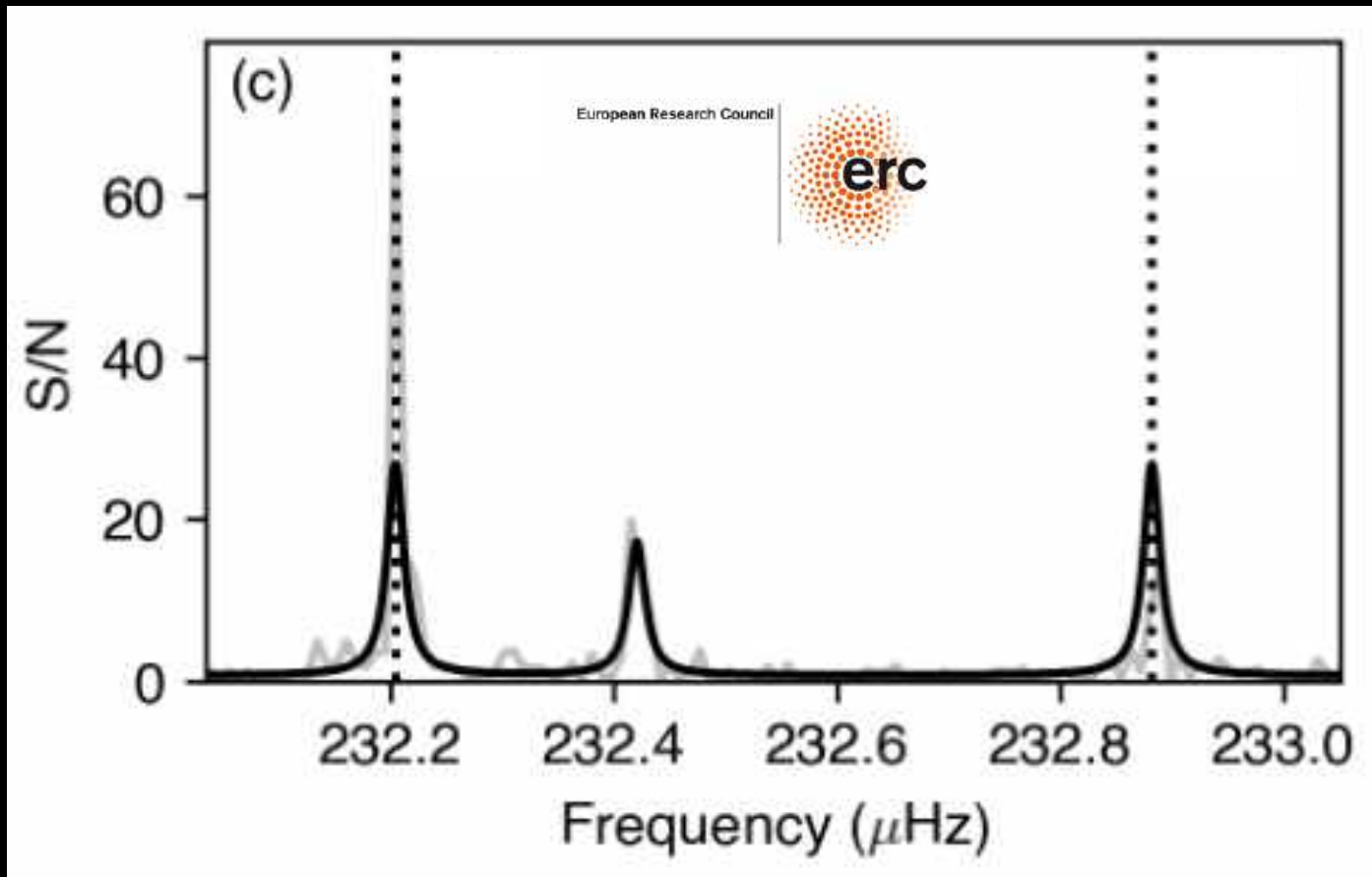
Stavaza interne sterrotatie:
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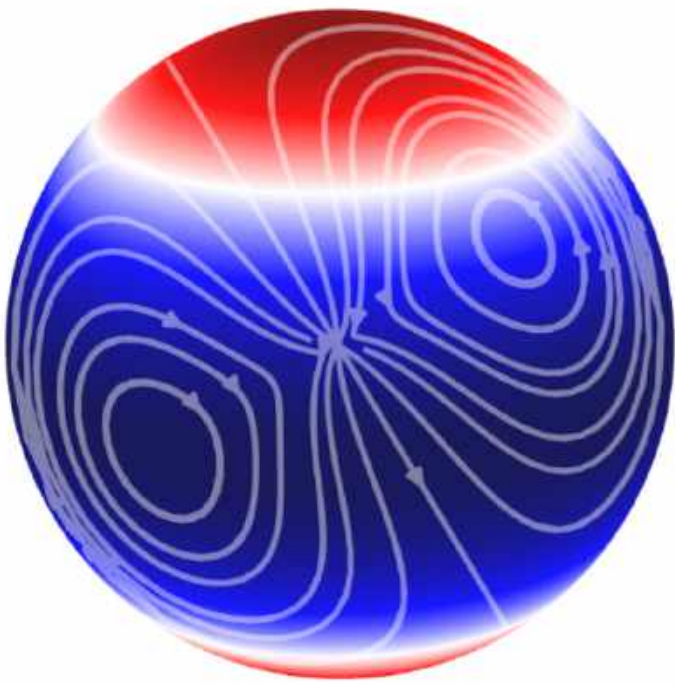
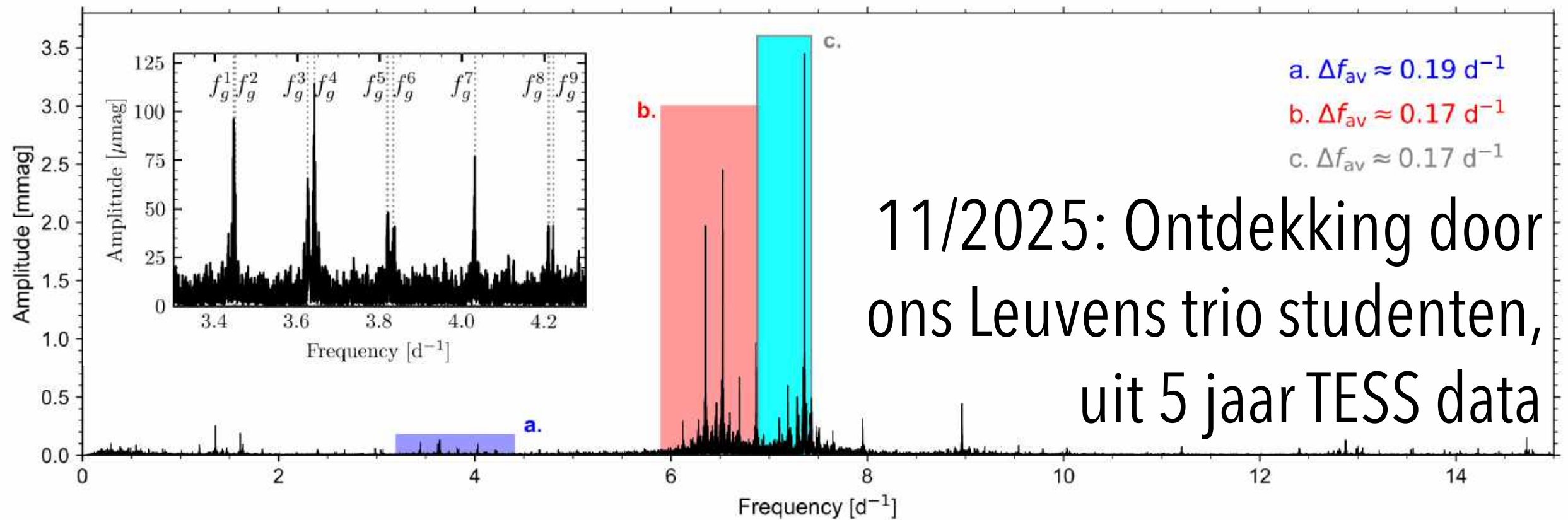
Asteroseismologie: intern magnetisme



Gang Li et al. (2022, 2024),
Deheuvels et al. (2023):

Asteroseismologische detectie van intern magneetveld
in rode reuzensterren: van ~ 20 kGauss tot ~ 150 kGauss

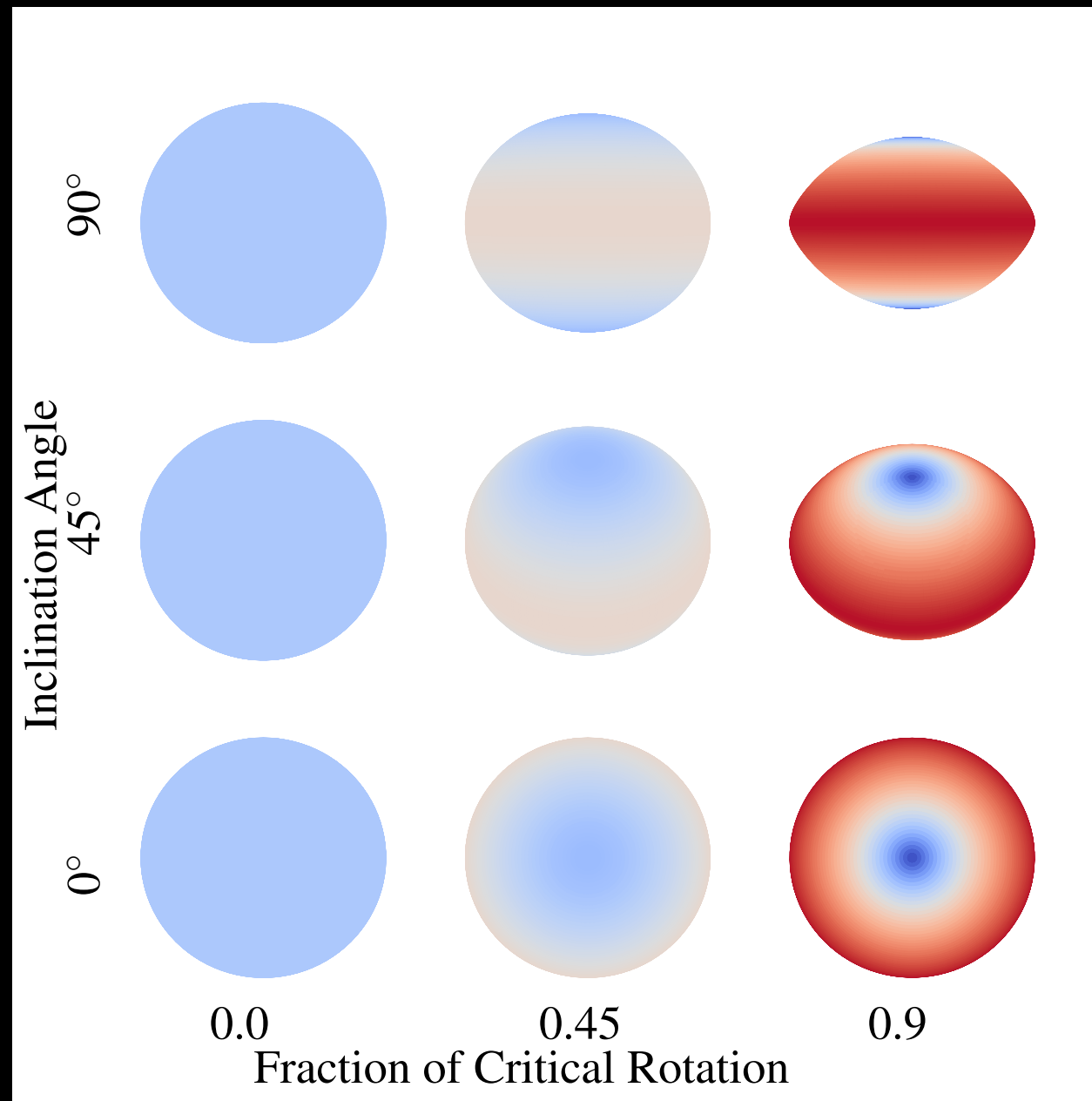
Intern magneetveld: ook in pre-SN!



Vooruitblik

En de centrifugaalkracht dan?

asteroseismologie van afgeplatte sterren



ERC SyG
(2024-2029)

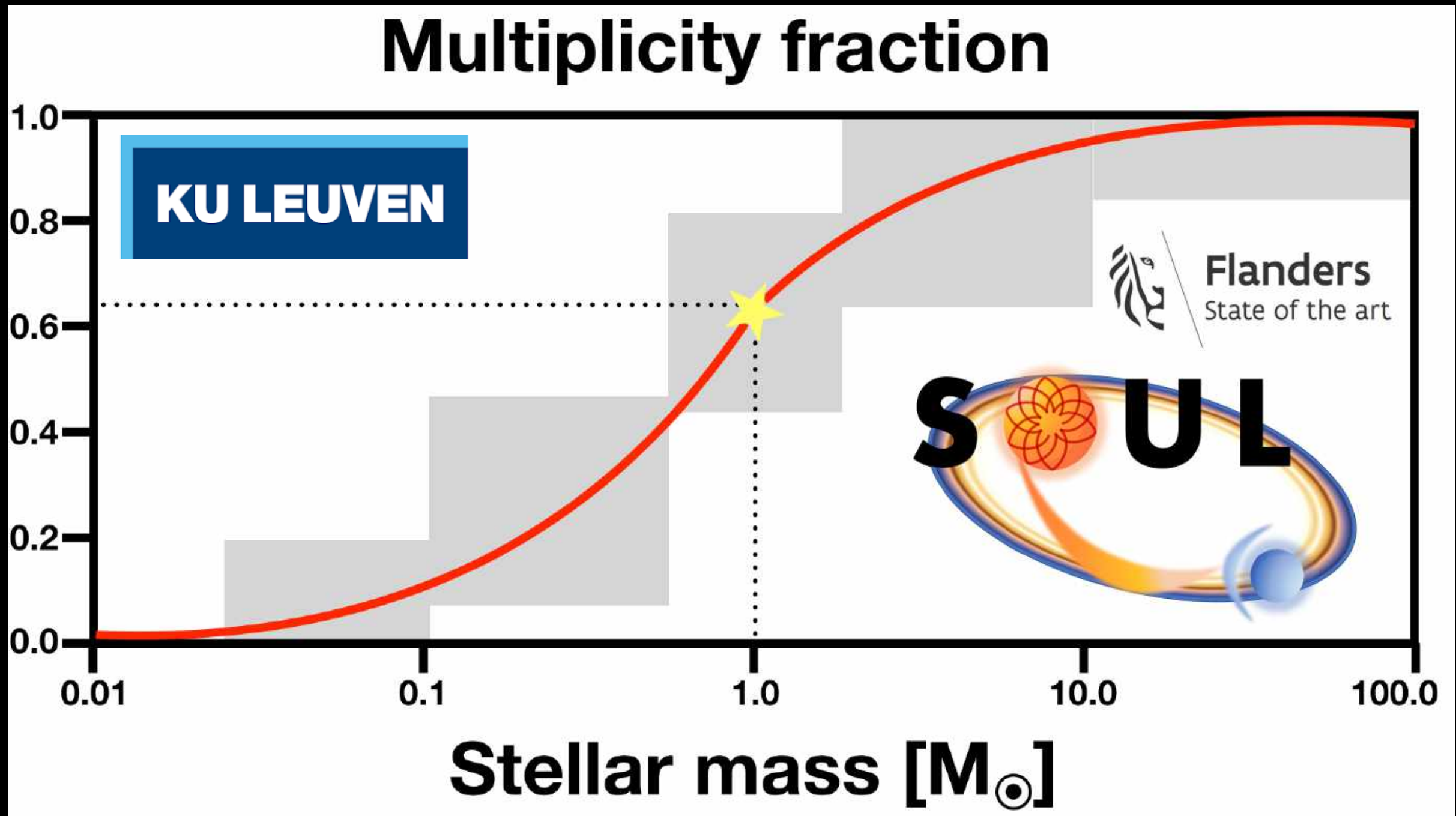


European Research Council



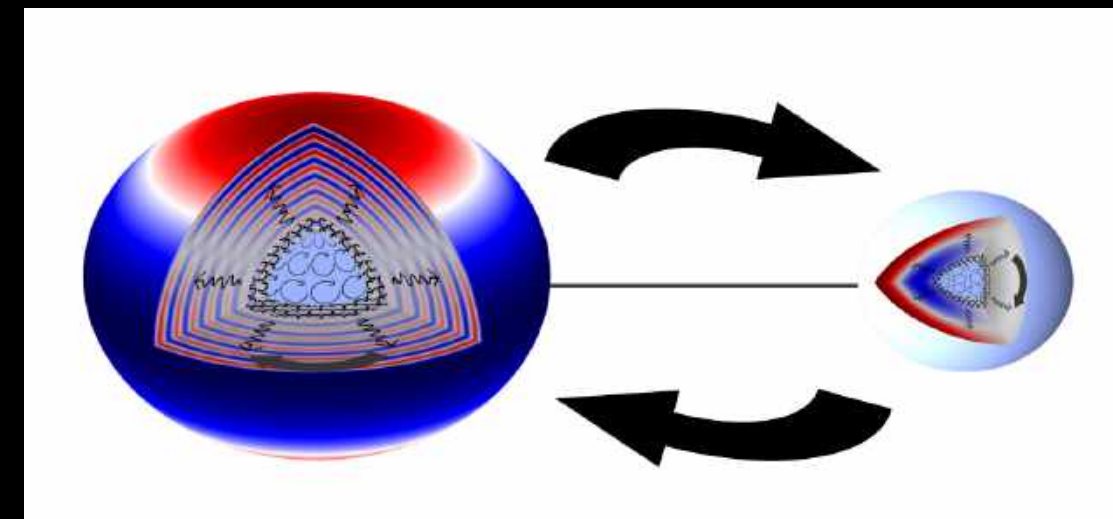
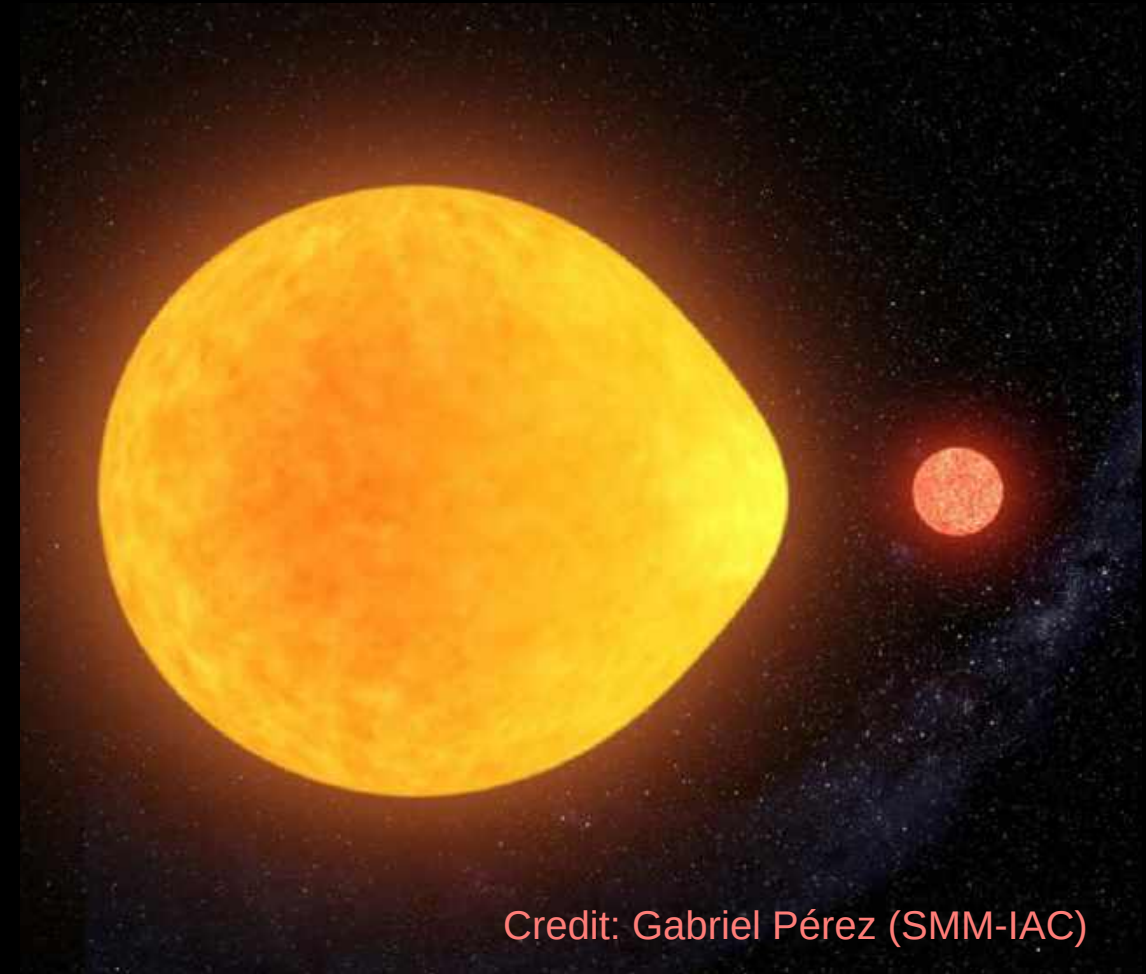
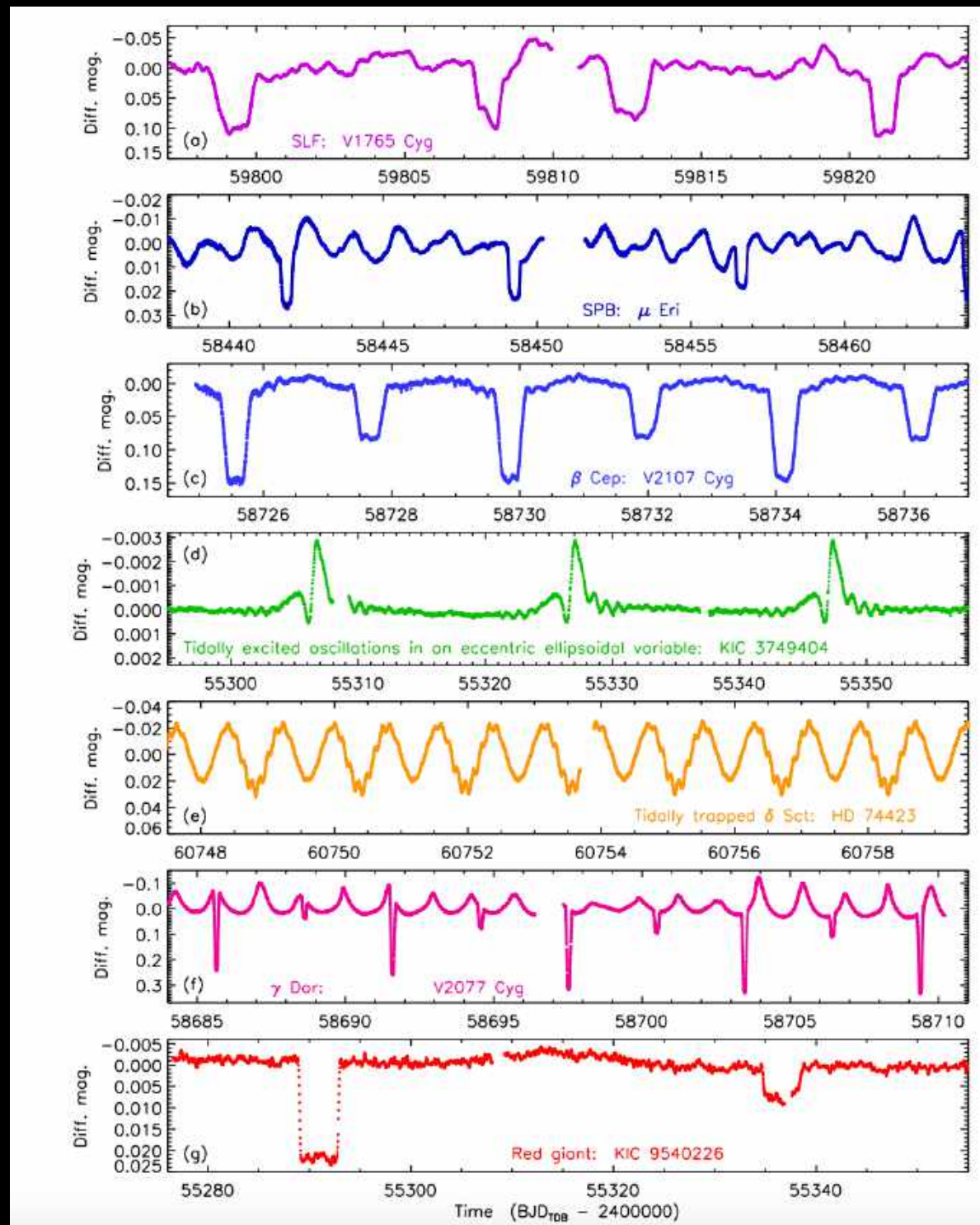
En de getijdenkracht dan?

asteroseismologie van nauwe dubbelsterren



Conny Aerts & Andrew Tkachenko (2024)

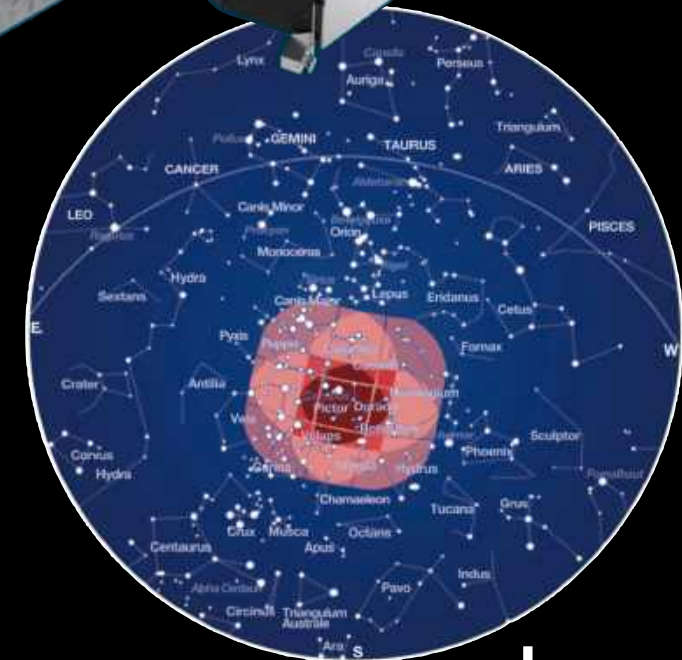
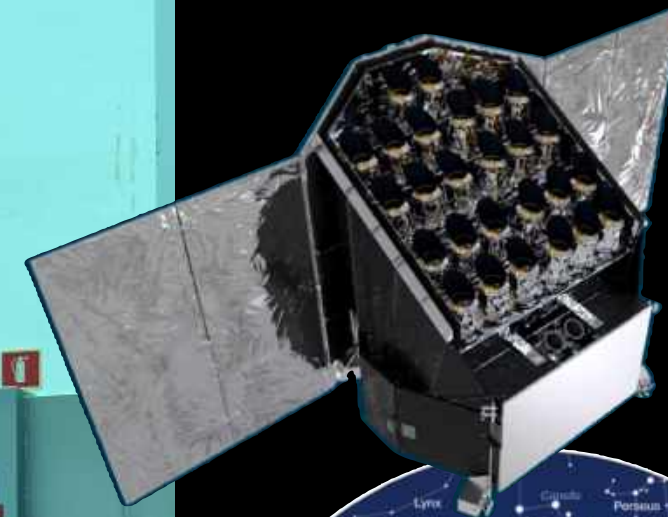
Waarnemingen van getijdenseismologie



Southworth & Bowman (2026)

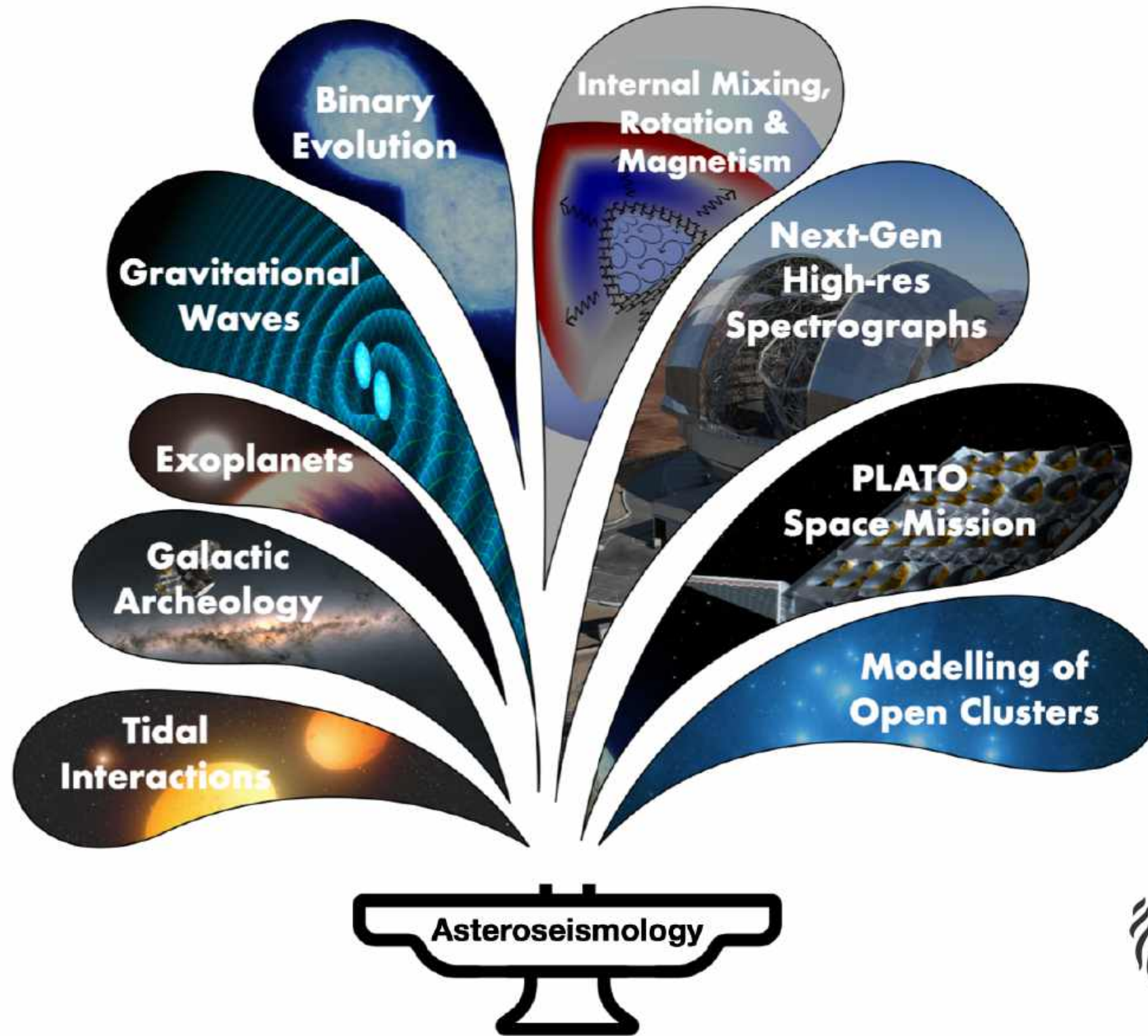
Meer langdurige data: op naar PLATO

Rauer et al.
(2025)



Lancering
Jan. 2027

Asteroseismologie: "fountain of opportunities"

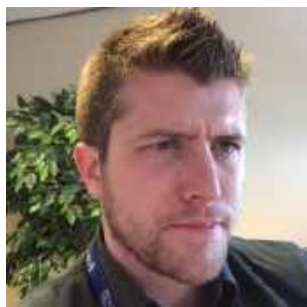


European Research Council



Flanders
State of the art

Conny Aerts & Andrew Tkachenko (2024)



Asteroseismologie: daar zit muziek in!

Prof. Dr. Conny Aerts

KU Leuven

<https://fys.kuleuven.be/ster/staff/conny-aerts>



NEOS, Sint-Gillis Waas, 13 januari 2026

