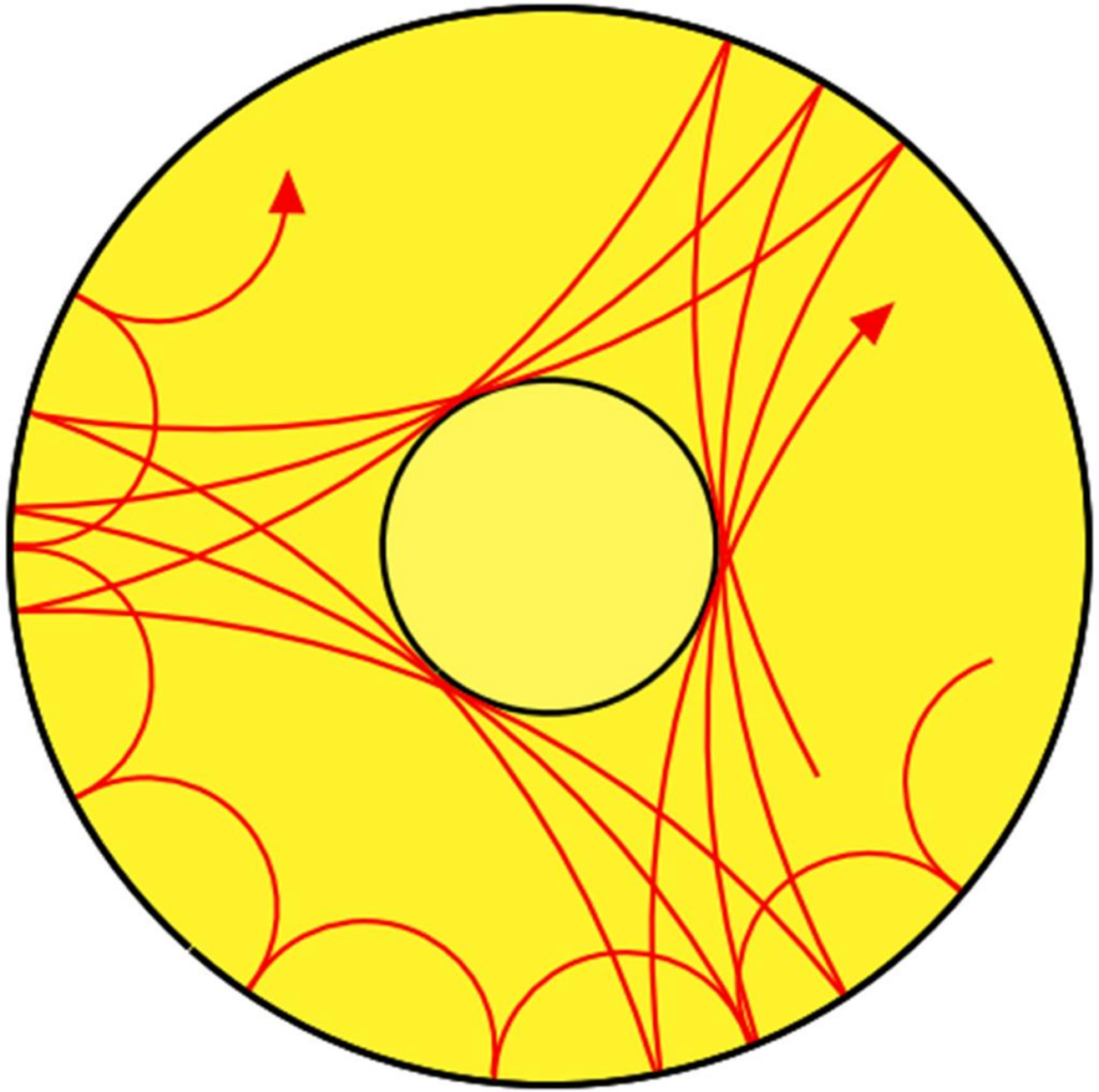
De Zon in de ziel gekeken

Martien Jacobs
20 maart 2025

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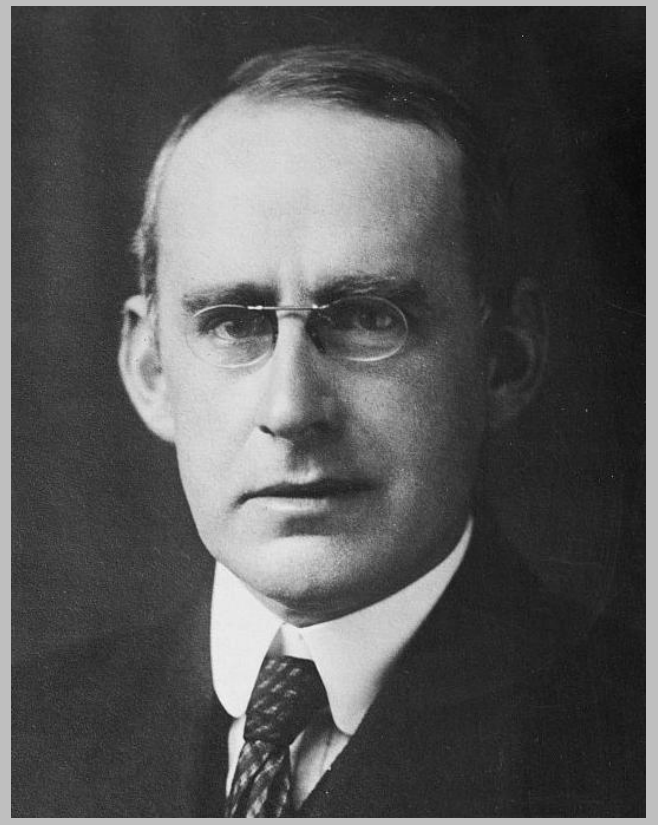
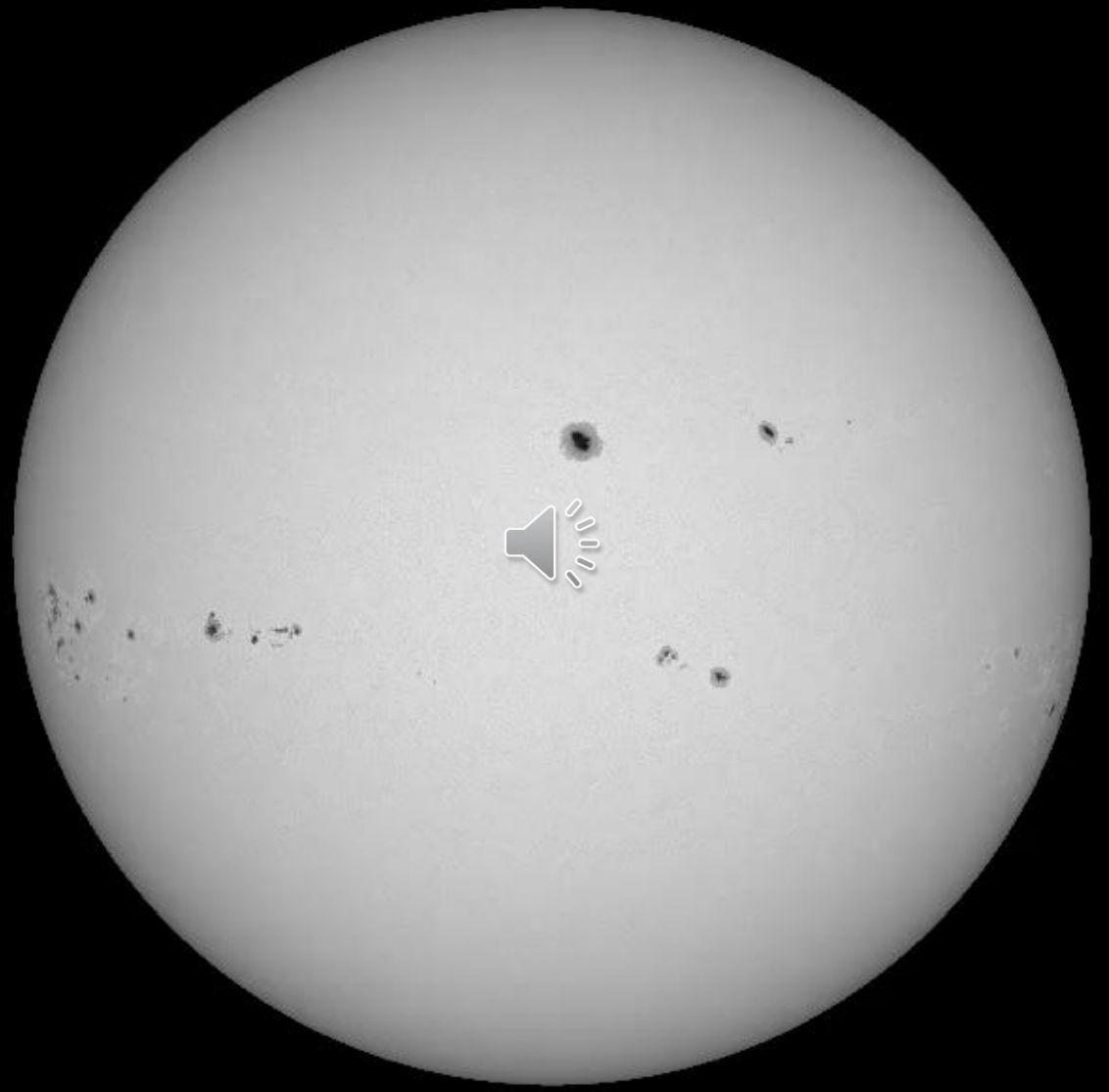
13 responses
ik doe mee
martien
test
fotonen
wim
arjen
ralf
erik
gitta
prima
hoi
bertc
henk
MJ
Menti
De zon in de ziel gekeken
Choose a slide to present

Arthur Eddington began his book “The Internal Constitution of the Stars” saying that *“At first sight it would seem that the deep interior of the sun and stars is less accessible to scientific investigation than any other region of the universe. Our telescopes may probe farther and farther into the depths of space; but how can we ever obtain certain knowledge of that which is hidden behind substantial barriers? What appliance can pierce through the outer layers of a star and test the conditions within?”* (Eddington, 1926).



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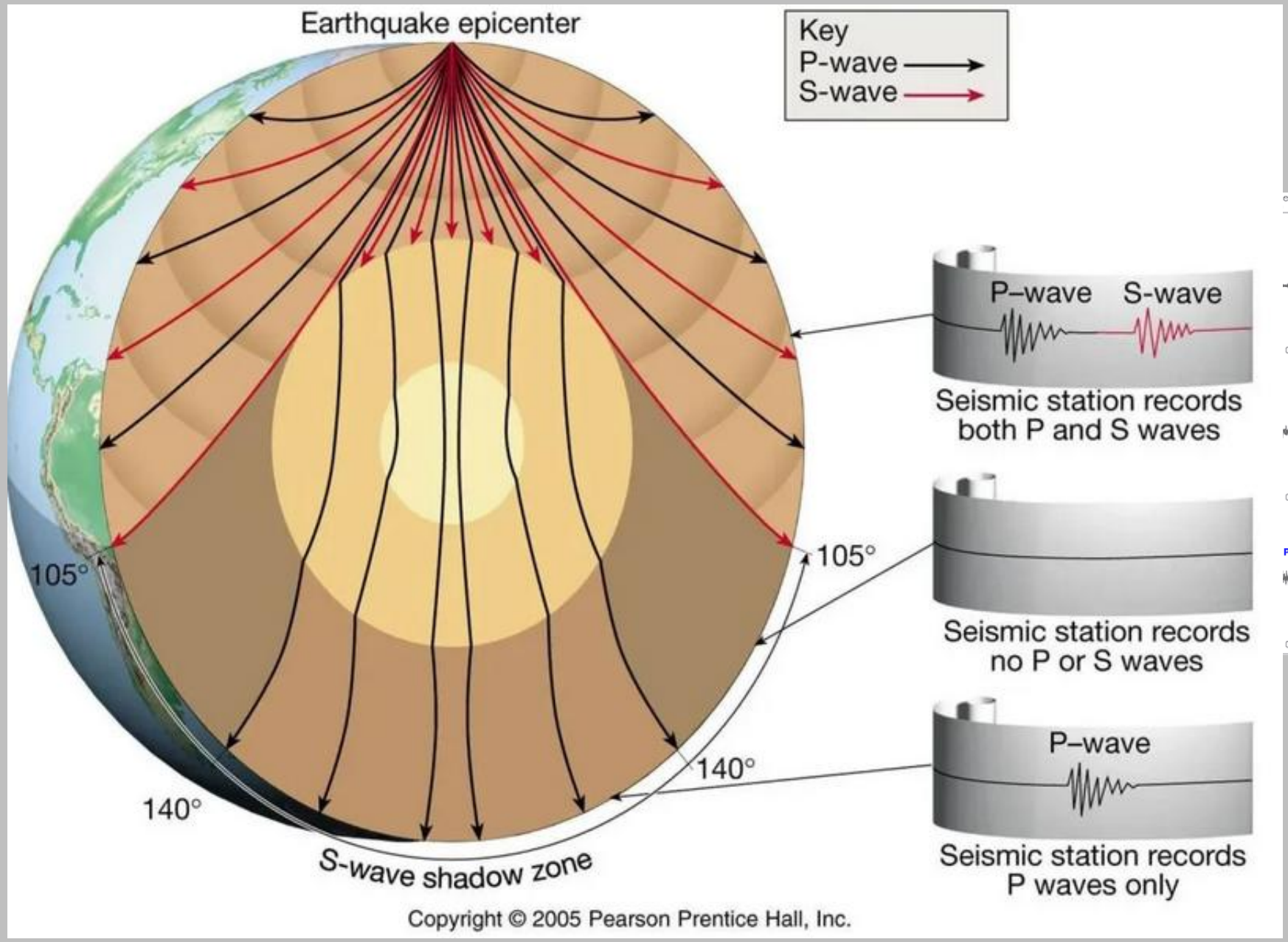
De zon in de ziel gekeken
Wat wat denk je bij het geluid van de zon?
15 responses
Choose a slide to present
aciustische conversie
trillingen oppervlak
stromingen
toetrr
trilling
stofzuiger
zoem
vibratie
misthoorn
radio signaal
slaap
brommen
beweging oppervlakte
elecyrische variaties


Earthquake epicenter
Key
P-wave
S-wave
105°
105°
140°
140°
S-wave shadow zone
P–wave
S-wave
Seismic station records
both P and S waves
Seismic station records
no P or S waves
P–wave
Seismic station records
P waves only
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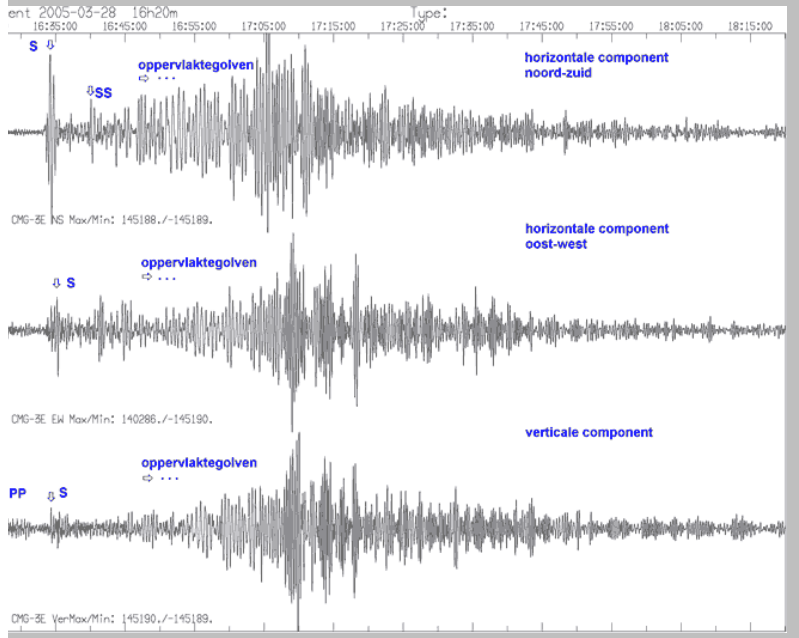
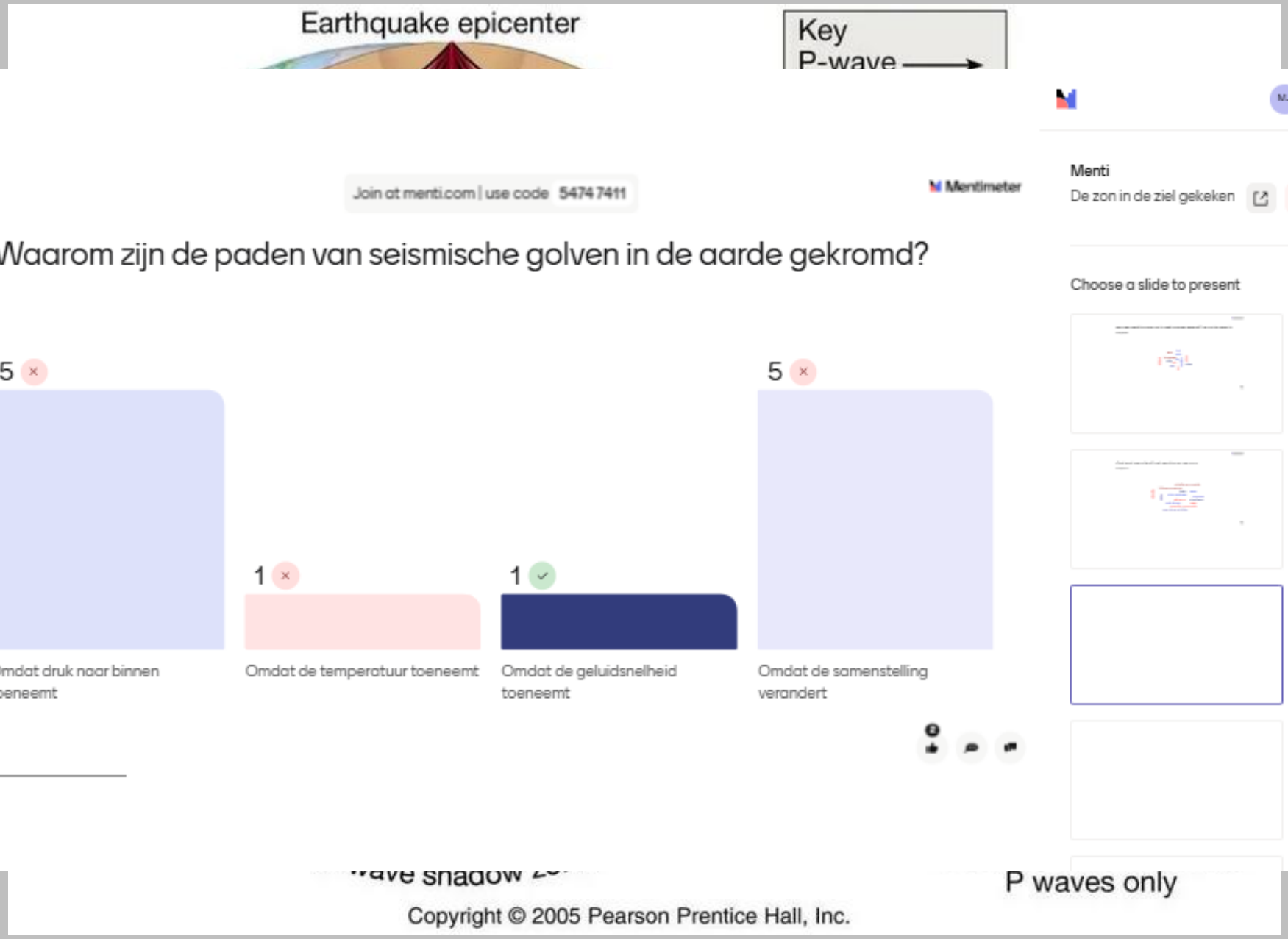

oppervlaktegolven
horizontale component
noord-zuid
oppervlaktegolven
horizontale component
oost-west
oppervlaktegolven
verticale component


Earthquake epicenter
Key
P-wave
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Mentimeter
Waarom zijn de paden van seismische golven in de aarde gekromd?
5
1
1
5
Omdat druk naar binnen toeneemt
Omdat de temperatuur toeneemt
Omdat de geluidsnelheid toeneemt
Omdat de samenstelling verandert
Menti
De zon in de ziel gekeken
Choose a slide to present
P waves only
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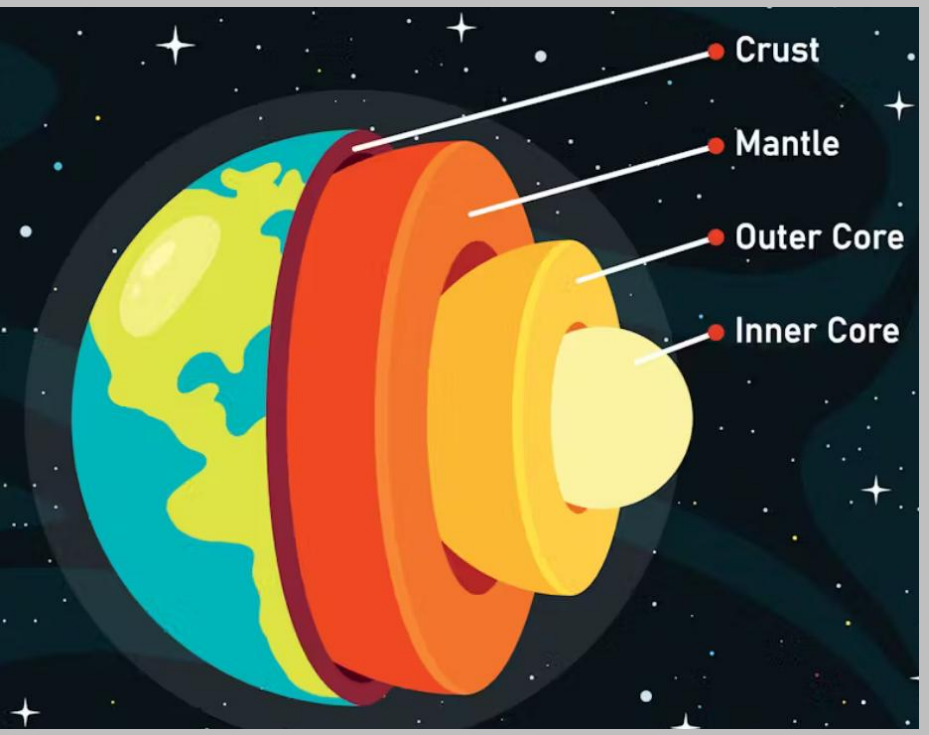
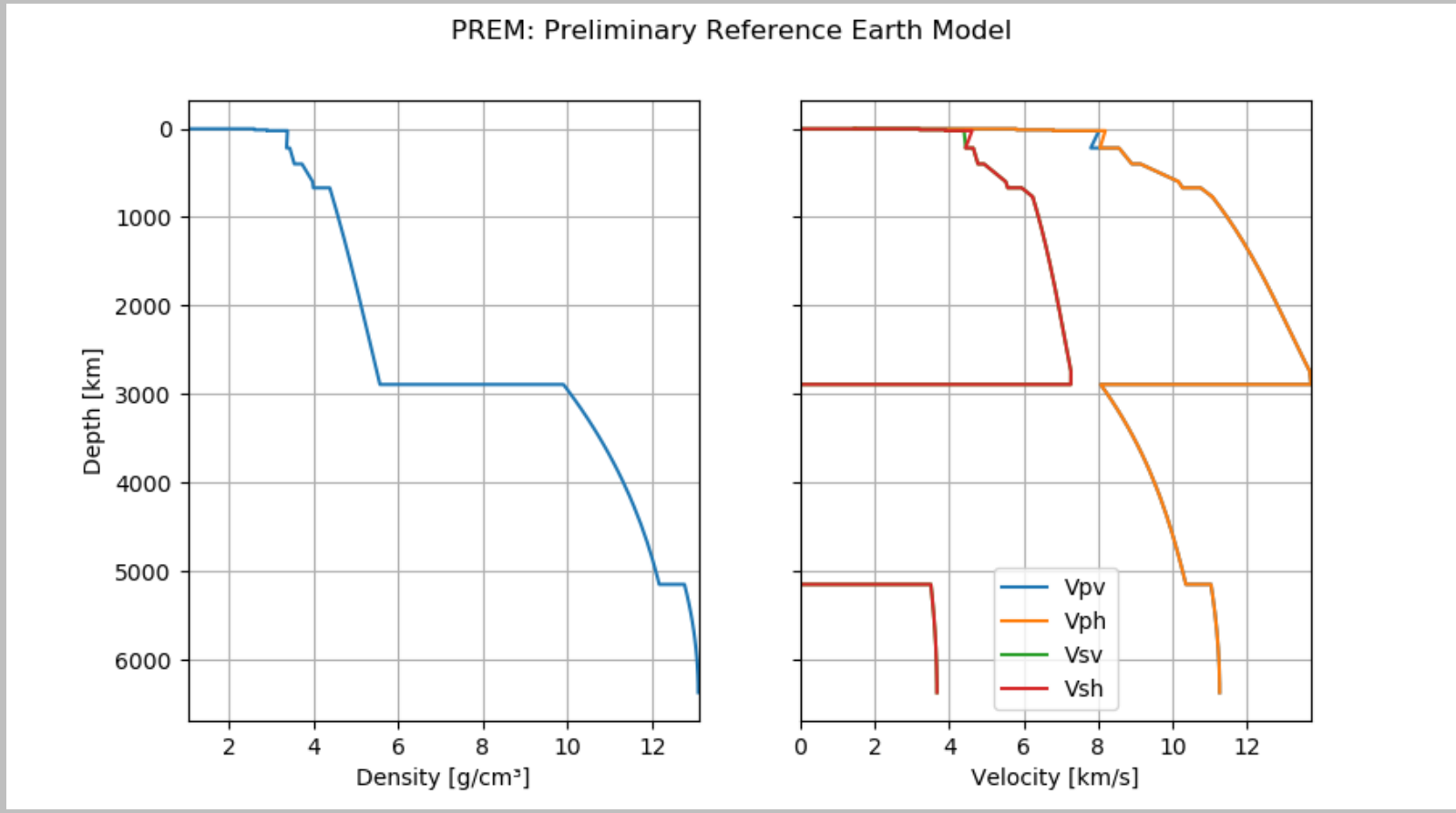
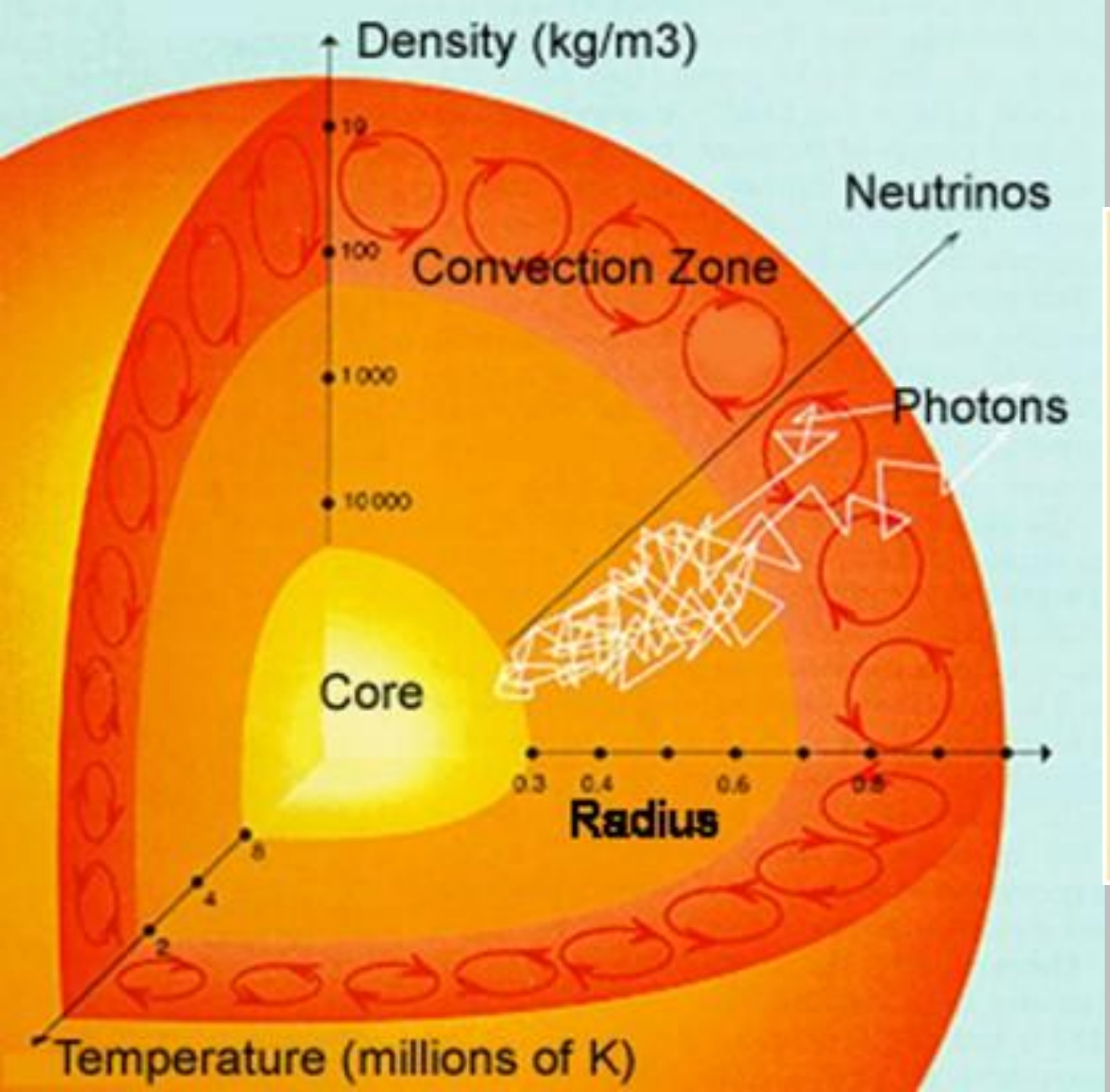
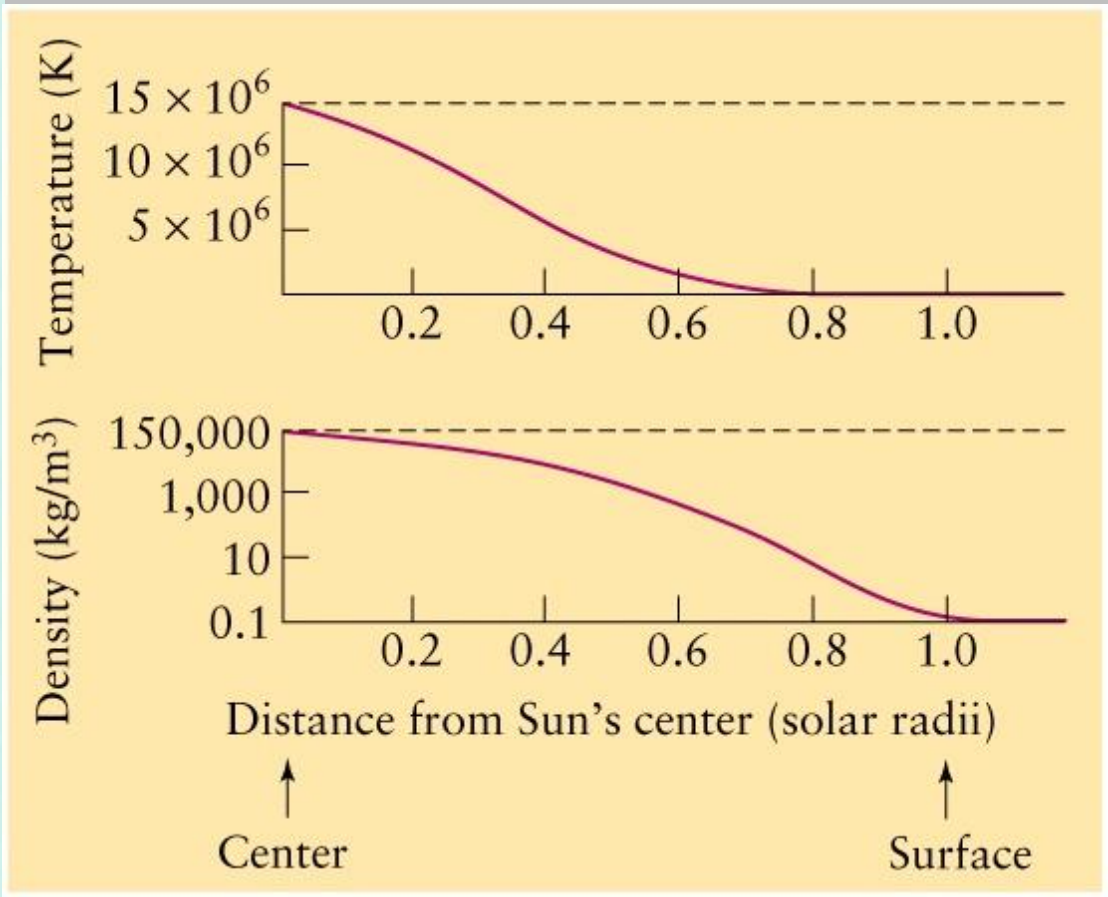
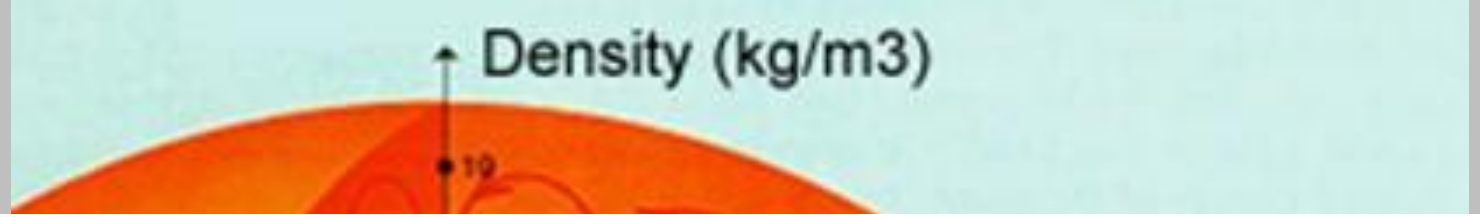

Crust
Mantle
Outer Core
Inner Core


PREM: Preliminary Reference Earth Model
Depth [km]
0
1000
2000
3000
4000
5000
6000
2
4
6
8
10
12
Density [g/cm³]
0
2
4
6
8
10
12
Velocity [km/s]
Vpv
Vph
Vsv
Vsh


Density (kg/m3)
10
100
1000
10000
Neutrinos
Convection Zone
Photons
Core
0.3
0.4
0.6
0.8
Radius
8
4
2
Temperature (millions of K)


Temperature (K)
15×10^6
10×10^6
5×10^6
0.2
0.4
0.6
0.8
1.0
Density (kg/m^3)
150,000
1,000
10
0.1
0.2
0.4
0.6
0.8
1.0
Distance from Sun's center (solar radii)
Center
Surface



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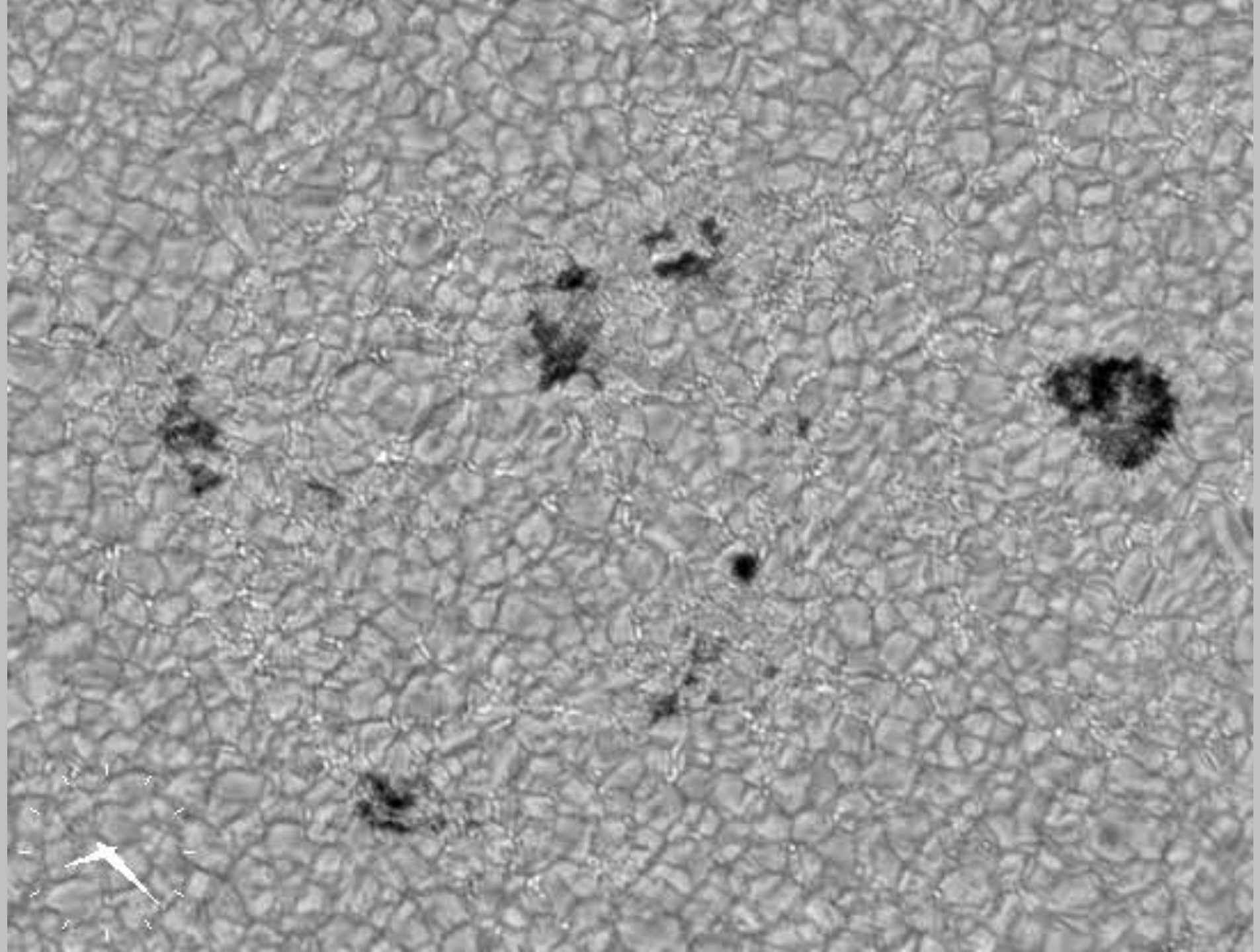
Mentimeter

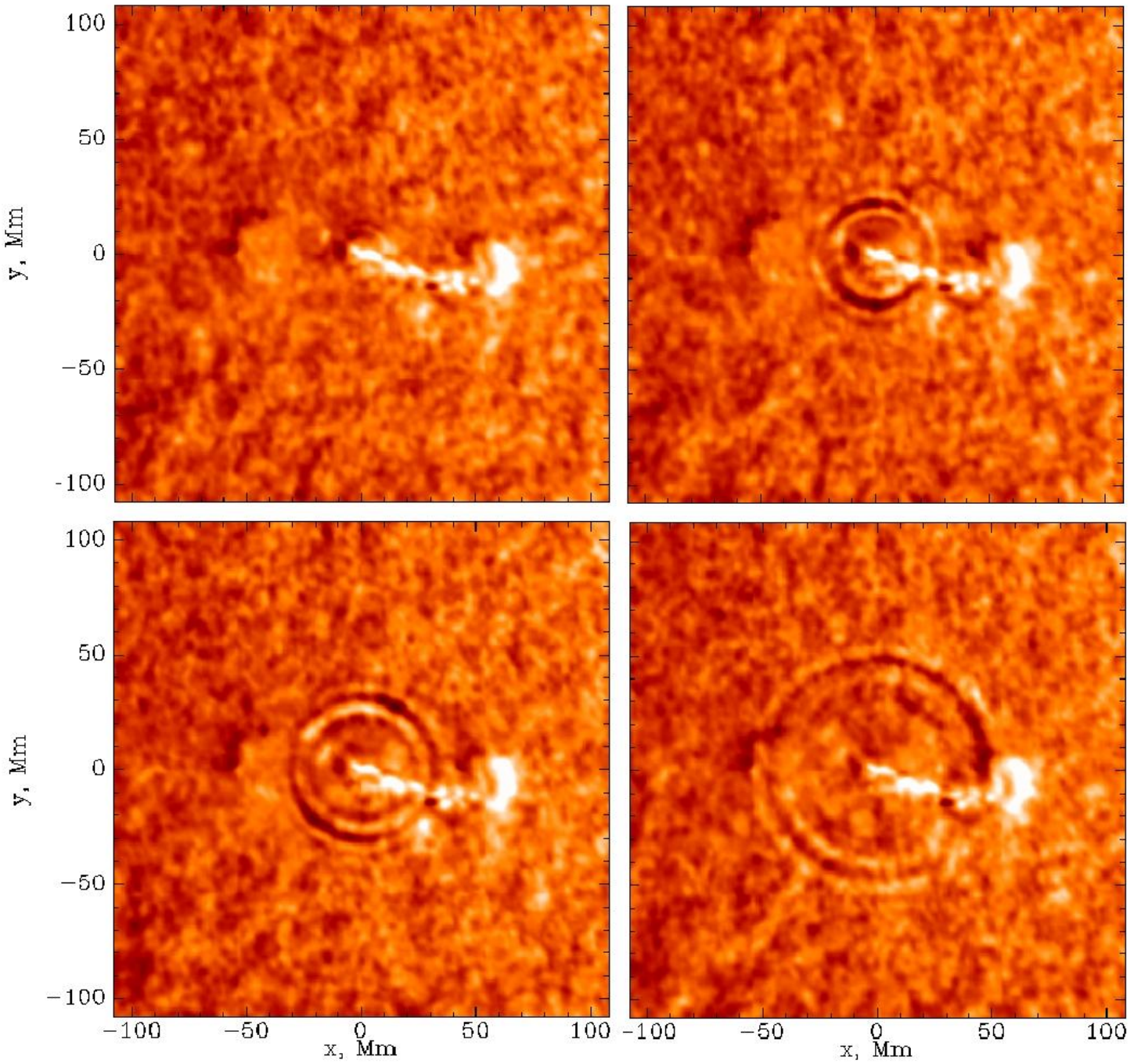
Wat veroorzaakt de trillingen van de zon?

Menti

De zon in de ziel gekeken

Choose a slide to present




100
50
0
−50
-100
y, Mm
100
50
0
−50
−100
y, Mm
−100
−50
0
50
100
x, Mm
−100
−50
0
50
100
x, Mm

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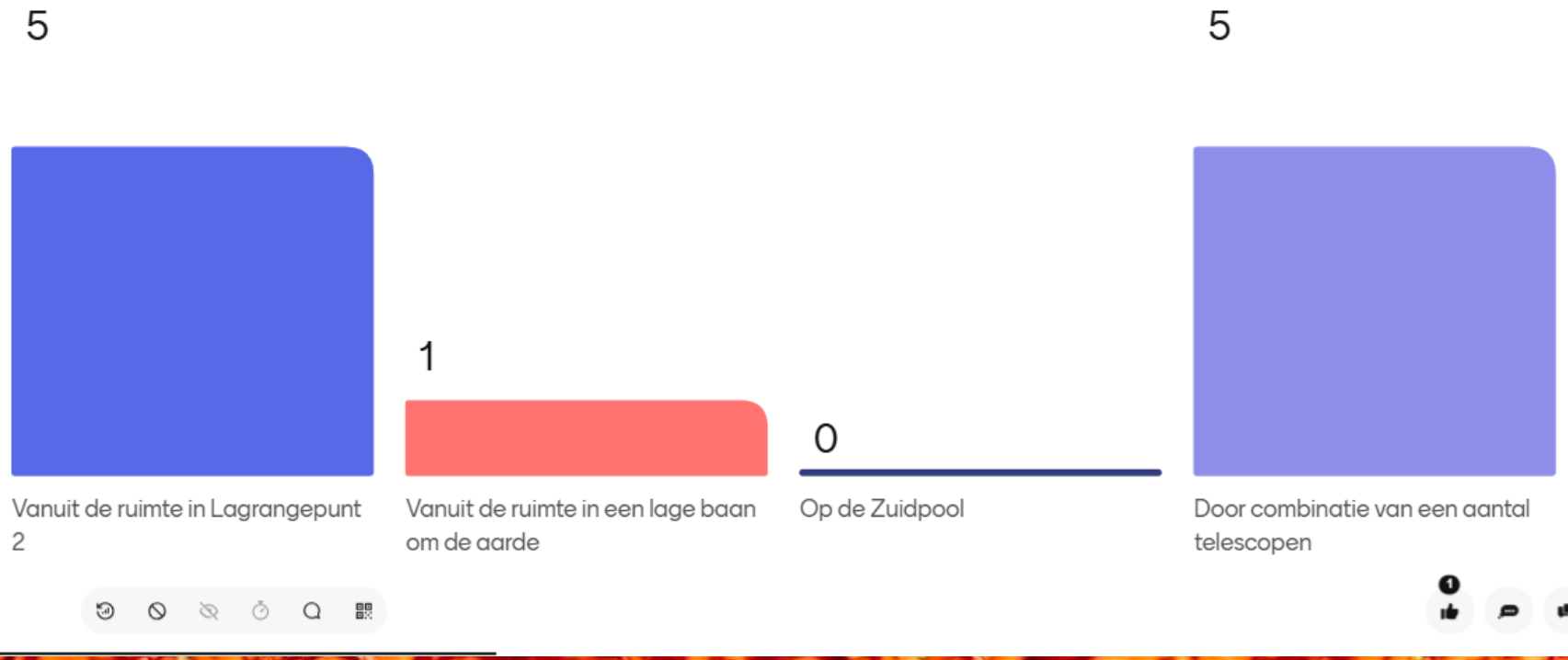
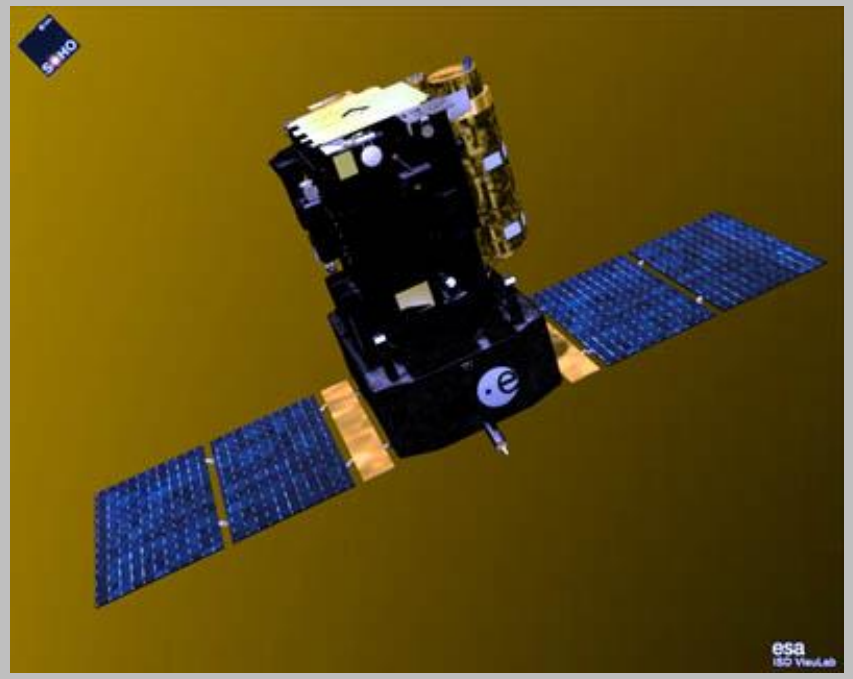
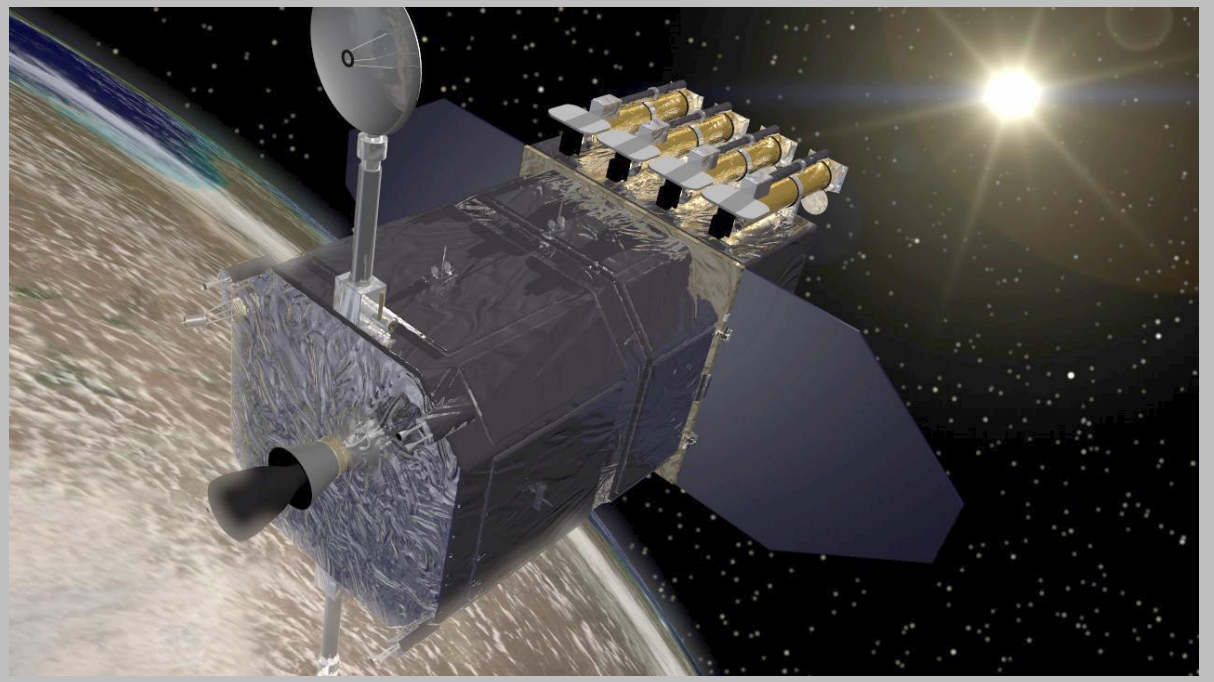
Mentimeter

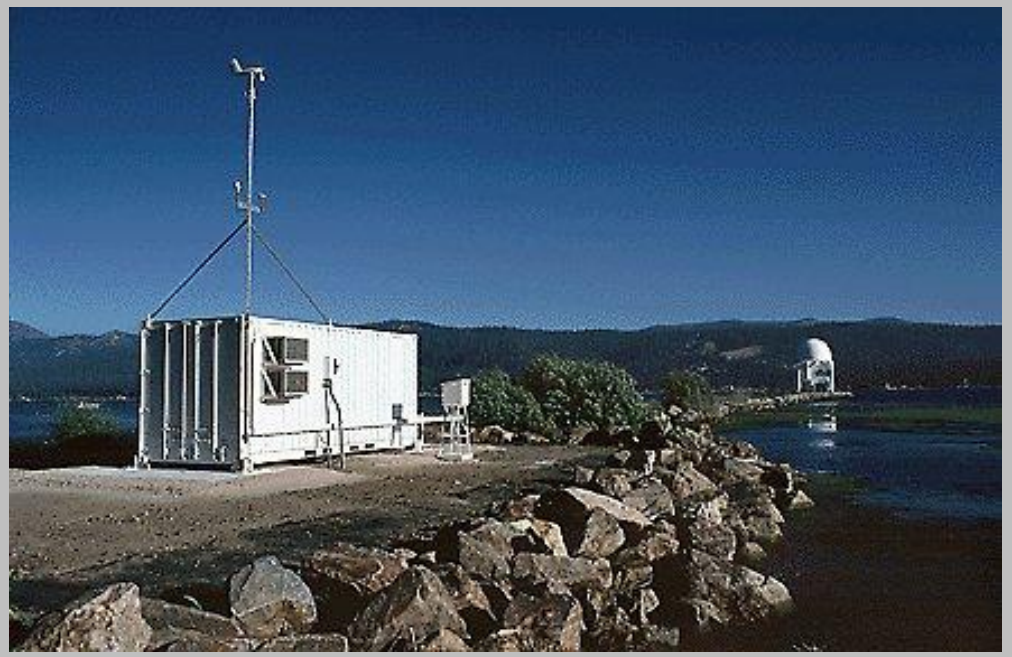
Hoe kan de zon continu waargenomen worden?



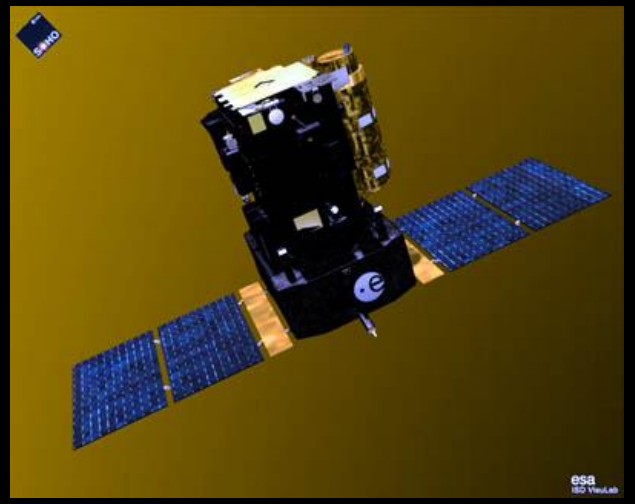
Henriques and Ainar Drews; European Solar Telescope

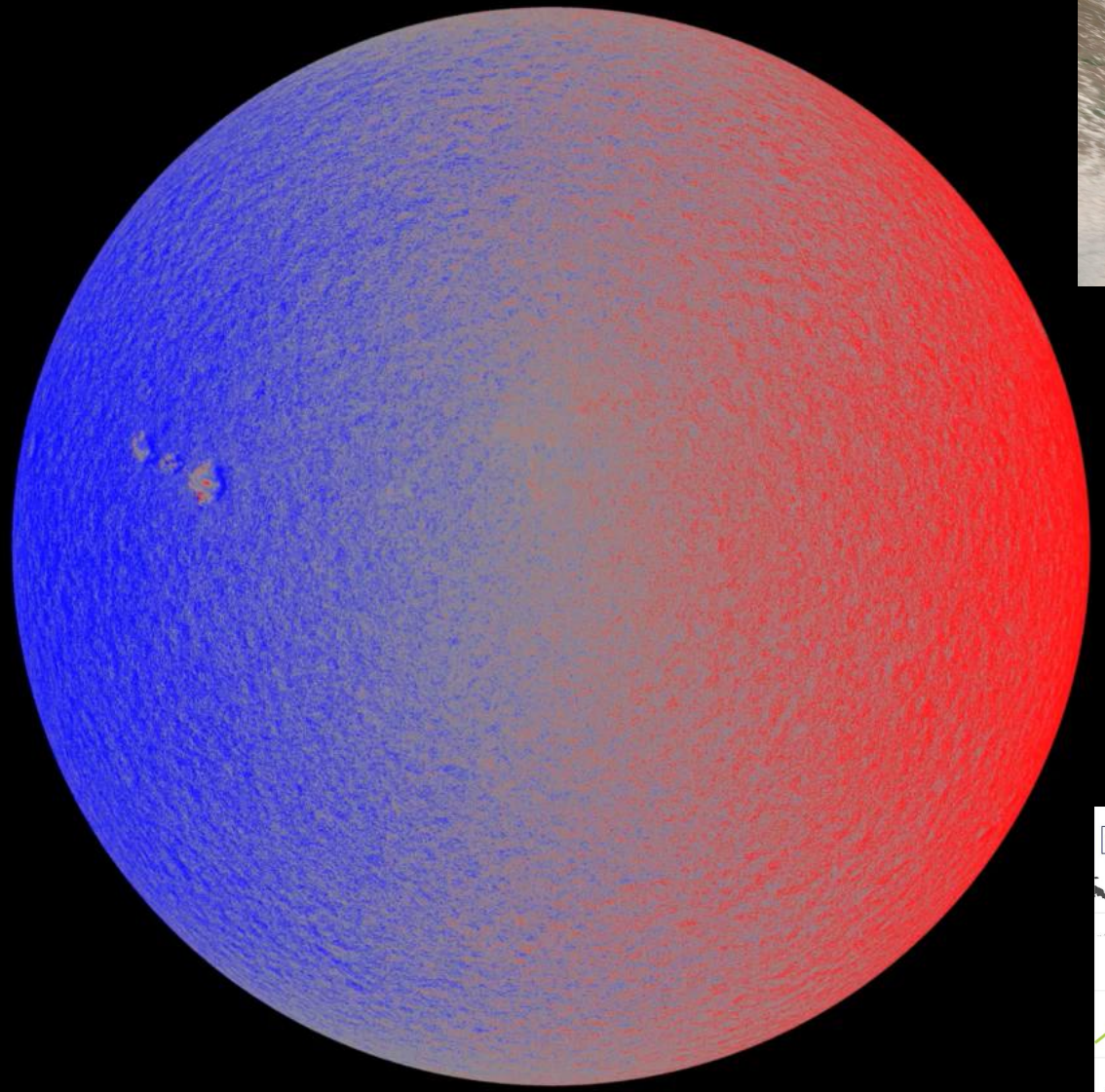

SOHO
esa
ISD ViewLab



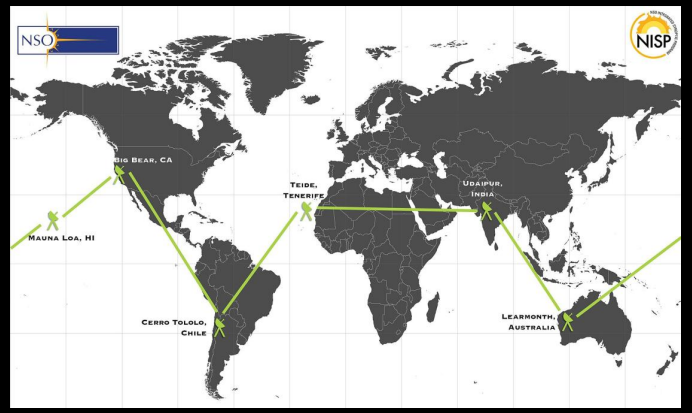



NSO
NISP
Big Bear, CA
Mauna Loa, HI
Teide, Tenerife
Udaipur, India
Cerro Tololo, Chile
Learmonth, Australia



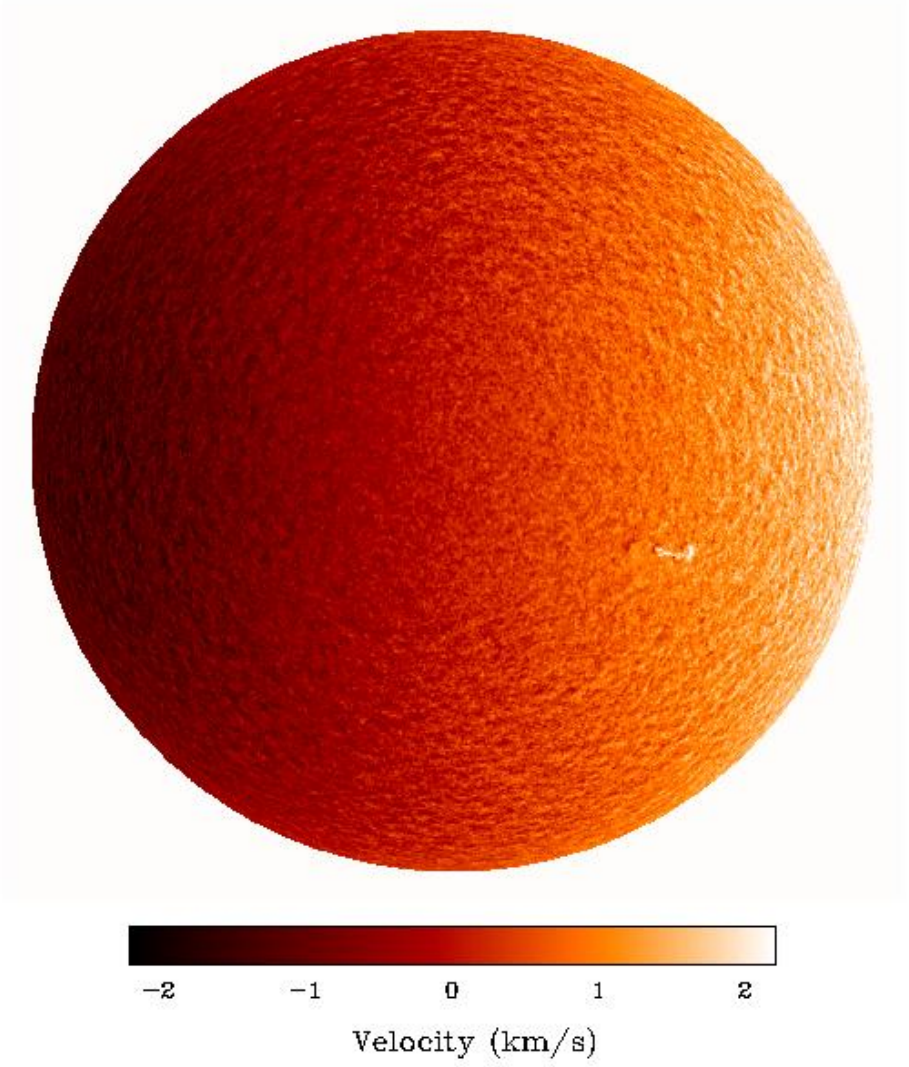


2011 Sep 25 08:00:00



Full−disk Dopplergram

9 July 1996, 9:00:00



Single Dopplergram Minus 45 Images Average

(30-MAR-96 19:54:00)

SOI / MDI

Stanford Lockheed Institute for Space Research

Lidia van Driel-Gesztelyi
ac.uk

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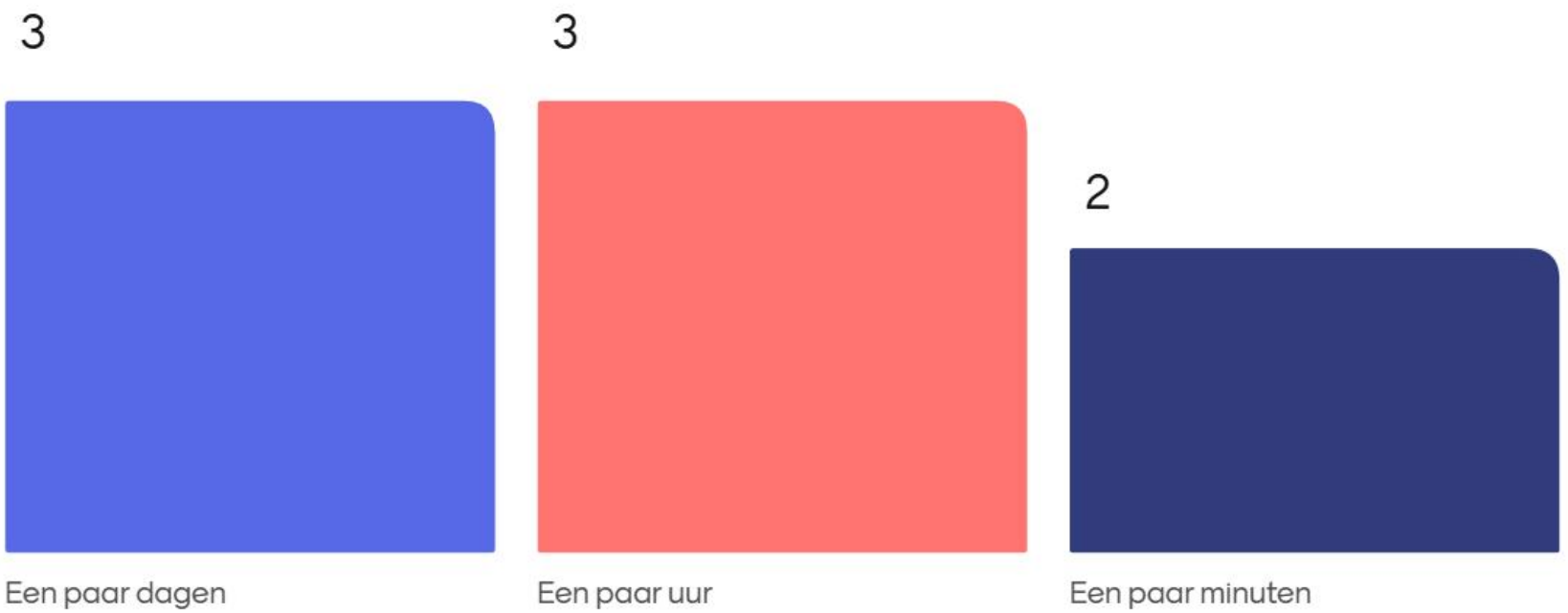
Mentimeter

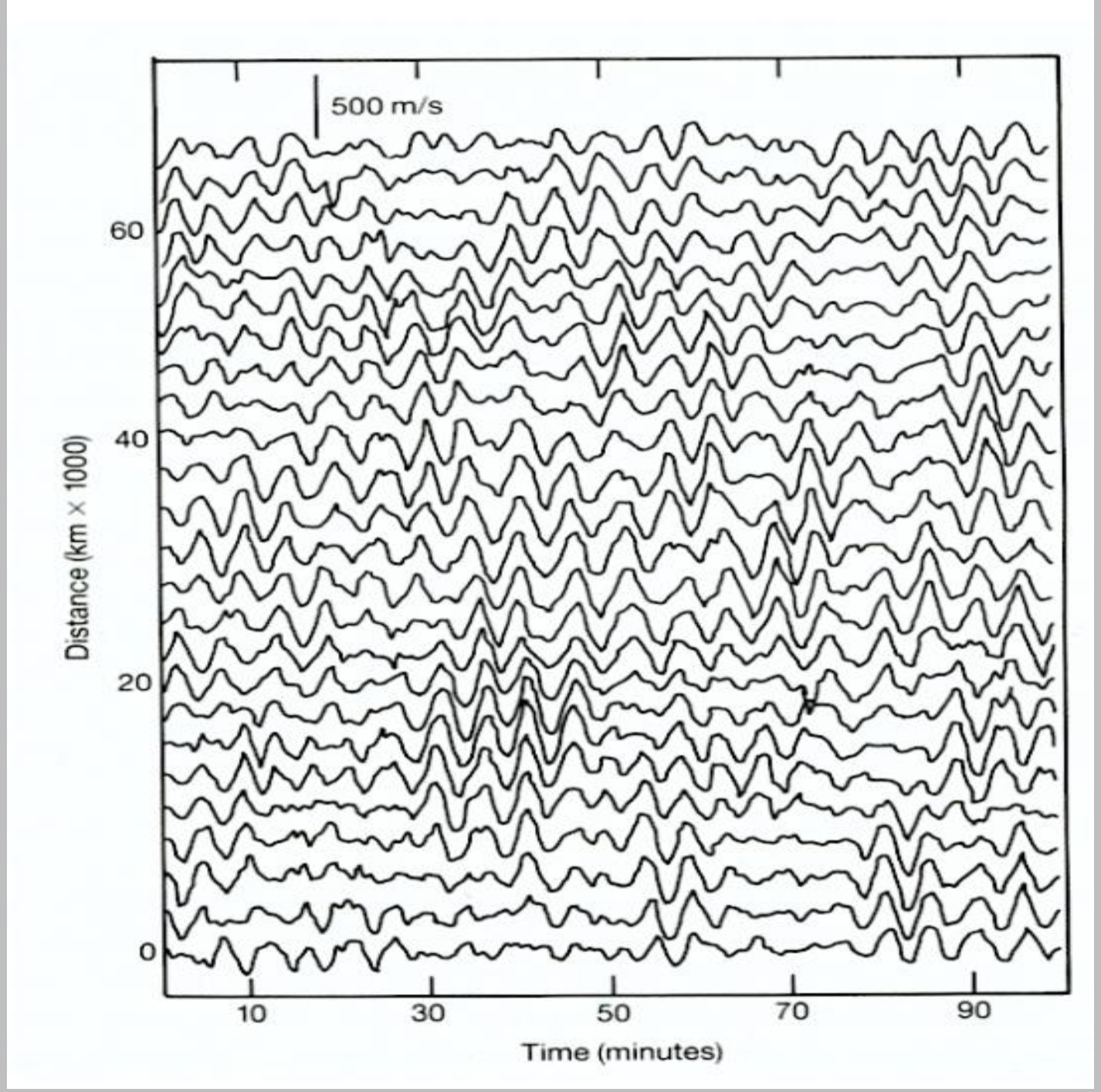
Wat is de periode van de trillingen met de hoogste intensiteit op de zon



aum &

Time (minutes)

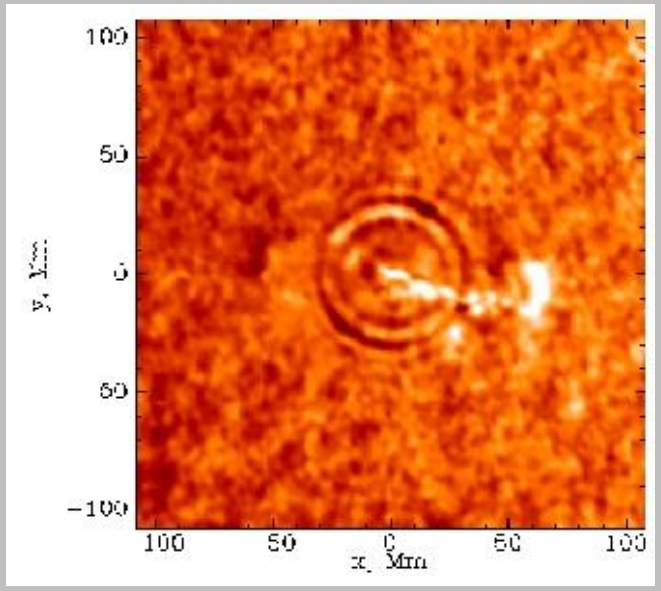
Lidia van Driel-Gesztelyi
lvdg@mssl.ucl.ac.uk

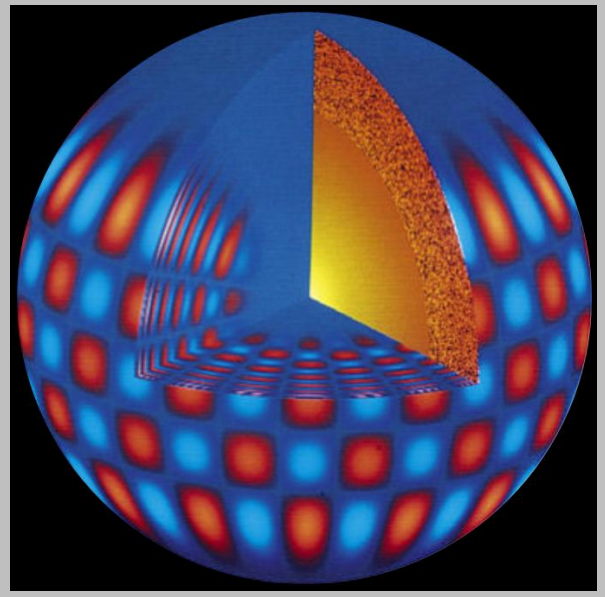


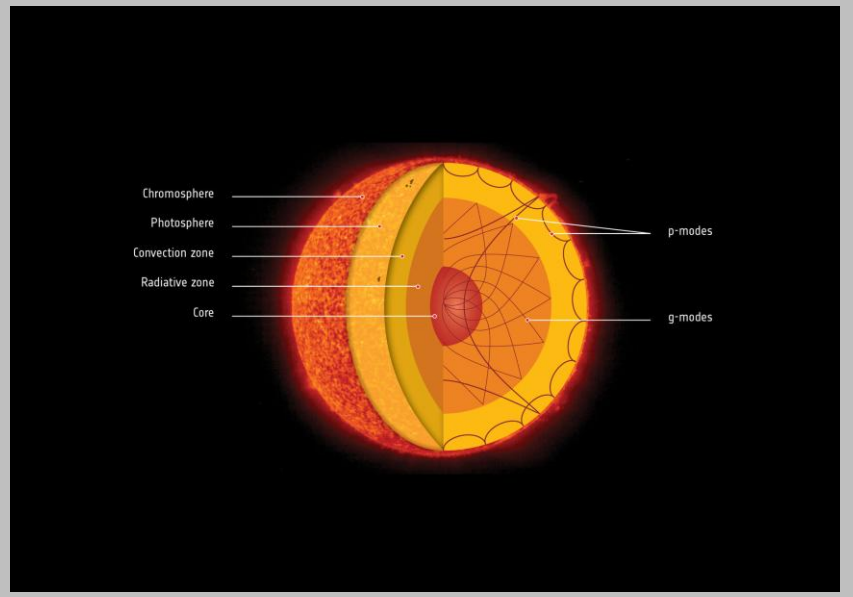
Howard, Tanenbaum & Wilcox, 1968

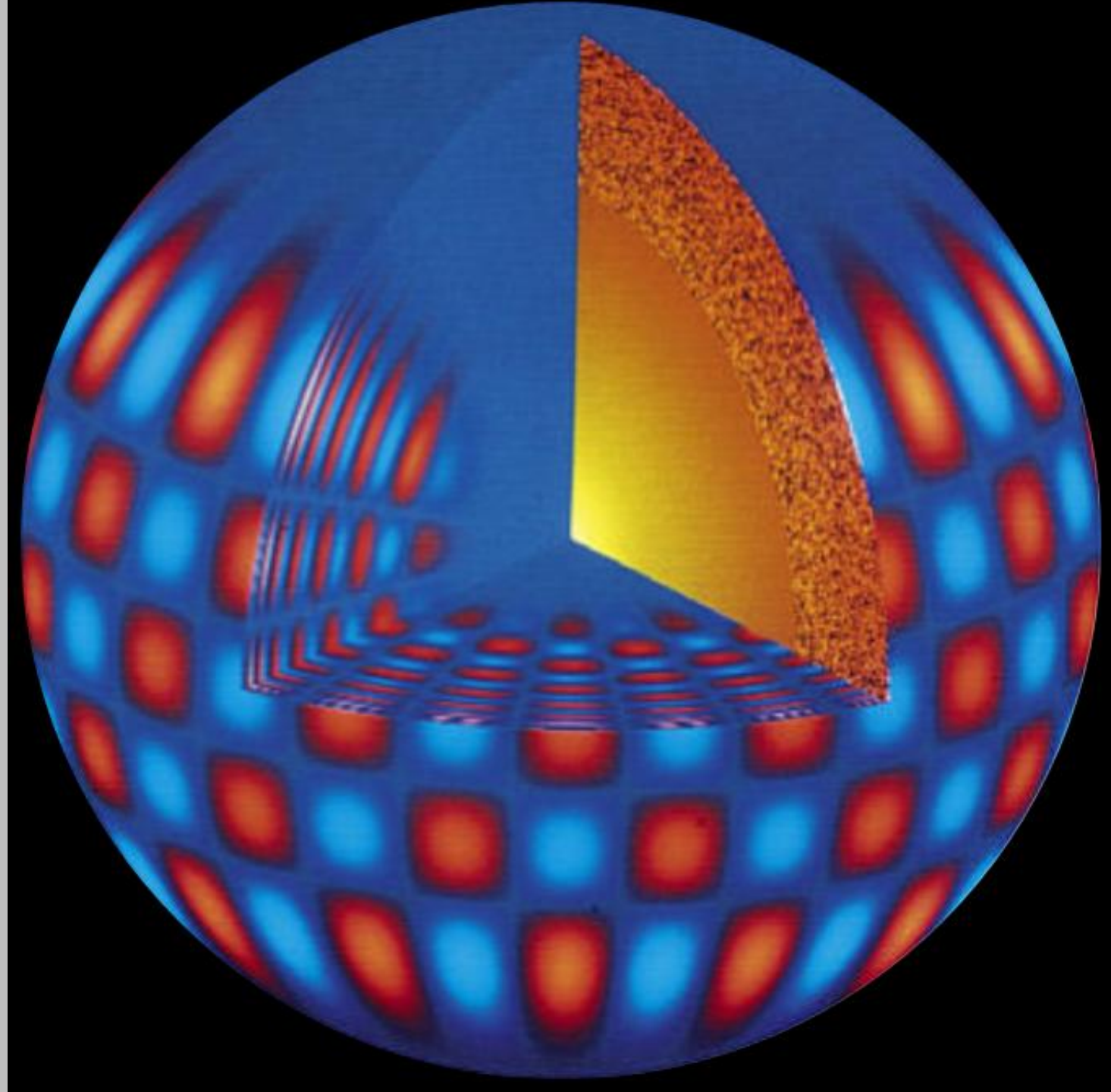
Soorten golven in de zon

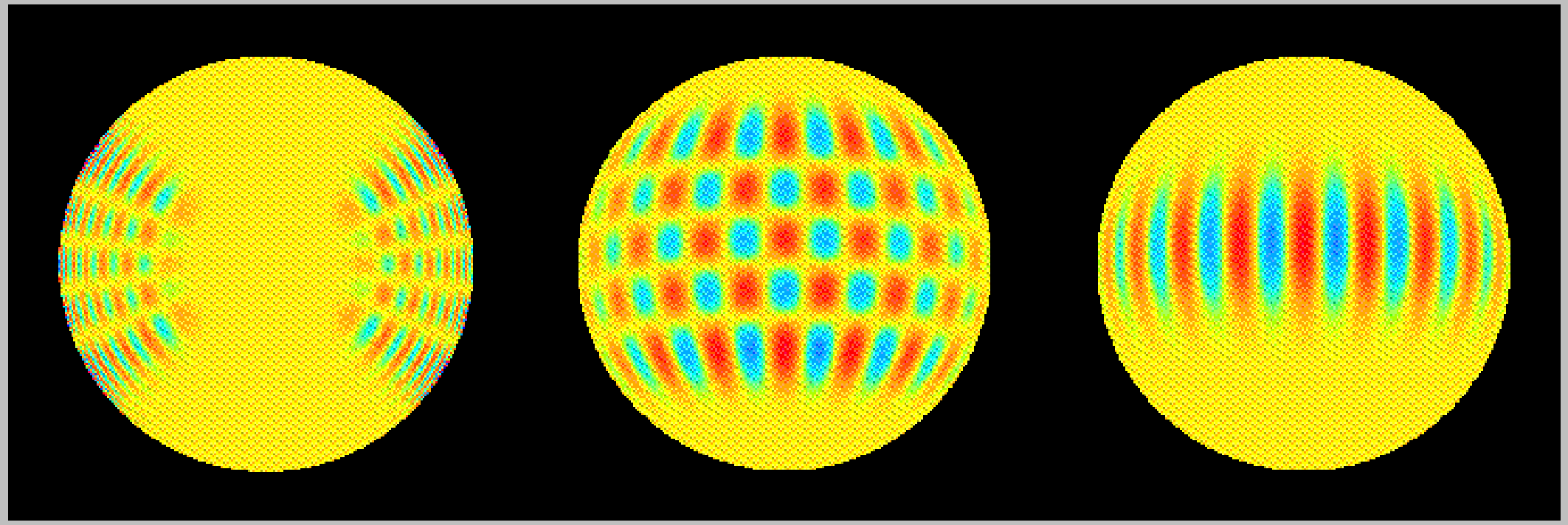
- Oppervlaktegolven, ofwel f waves
- Druk- of geluidsgolven, p waves
- Zwaartekrachtgolven; g waves



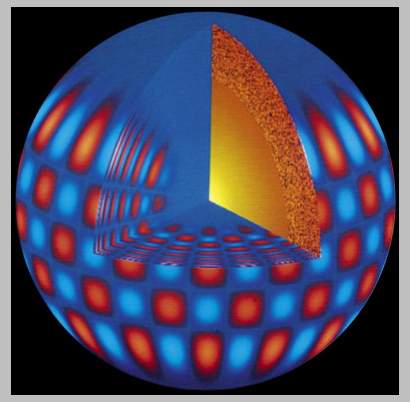


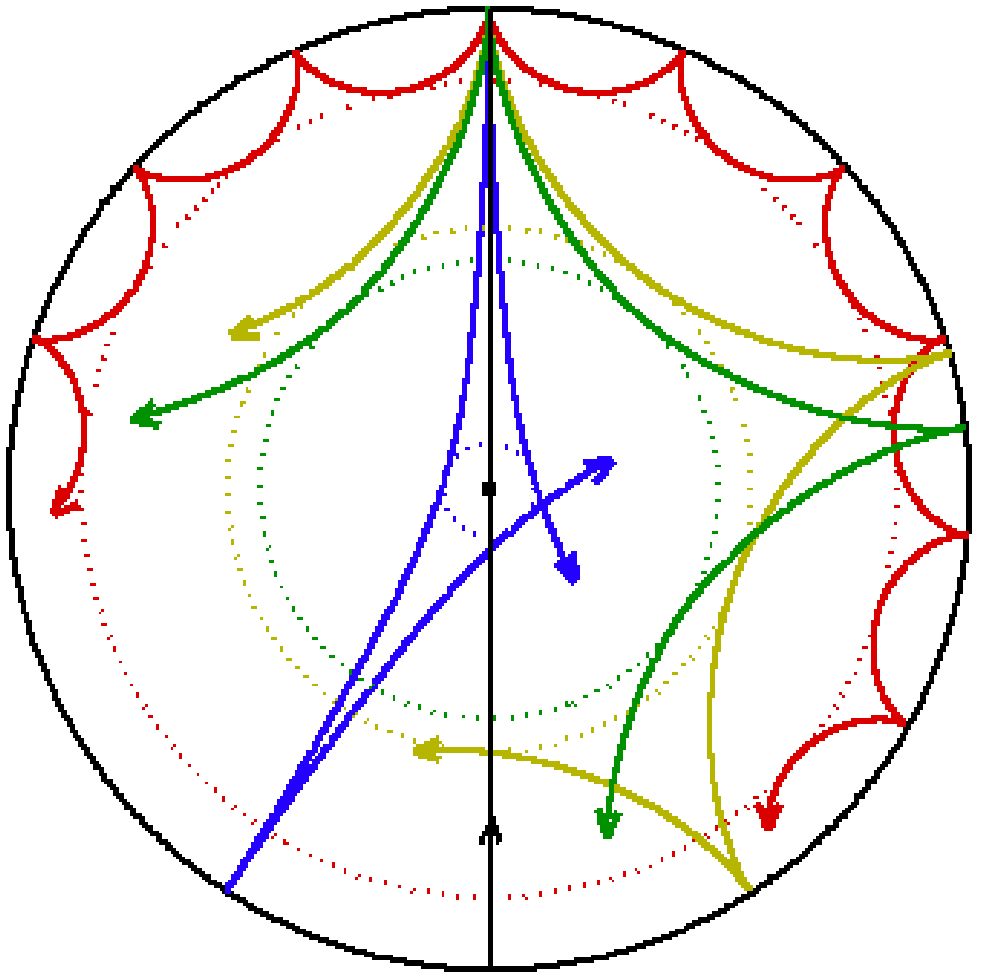






https://solarscience.msfc.nasa.gov/Helioseismology.shtml





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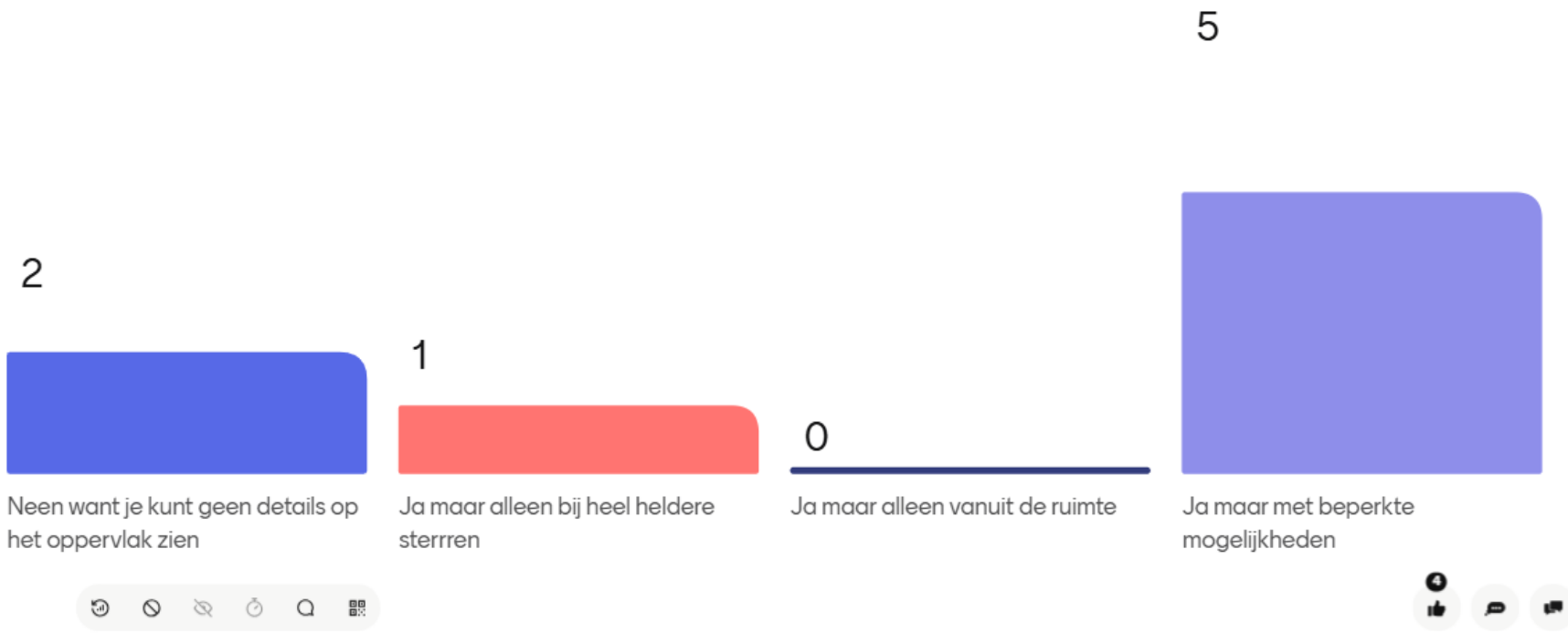
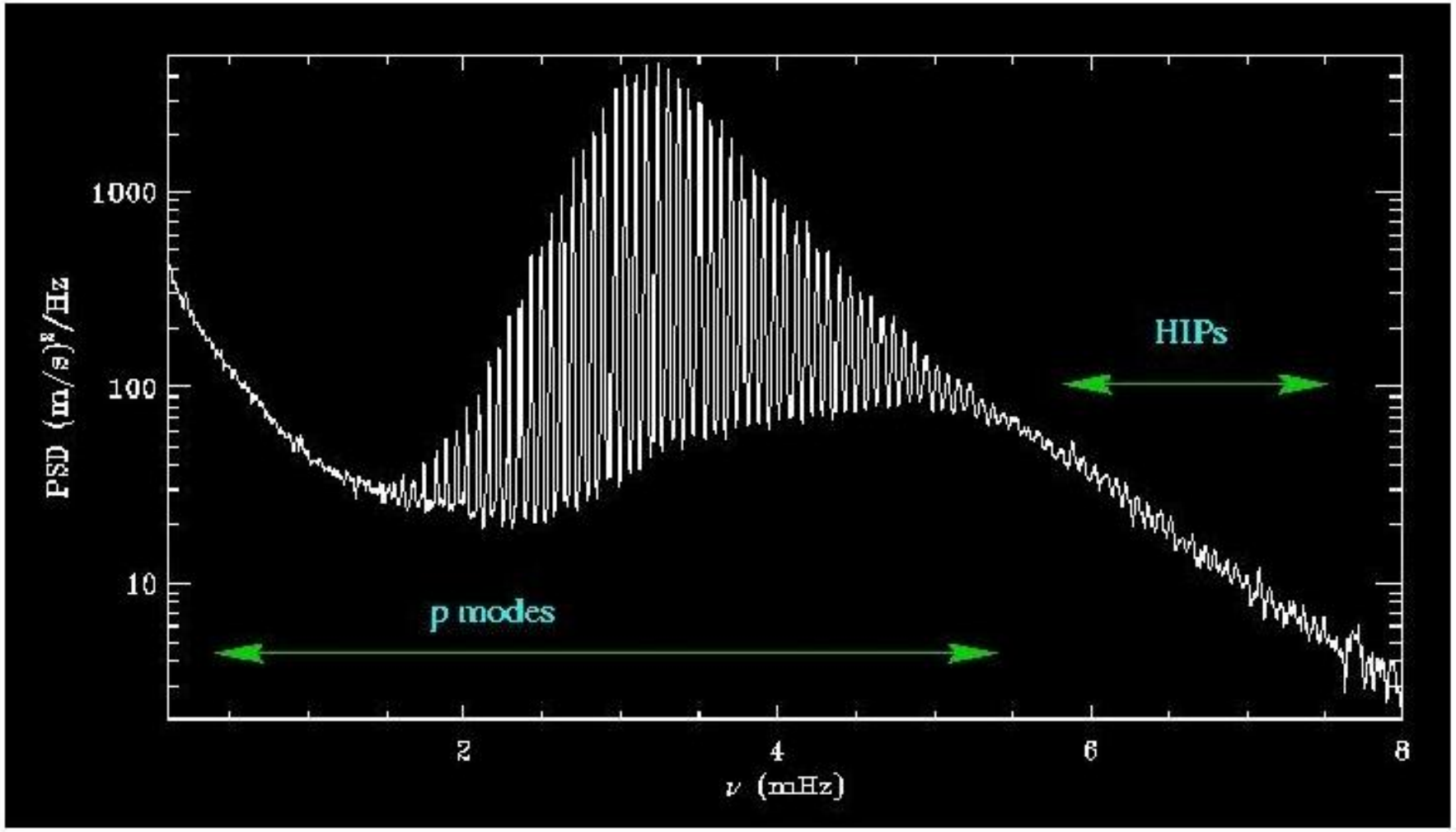
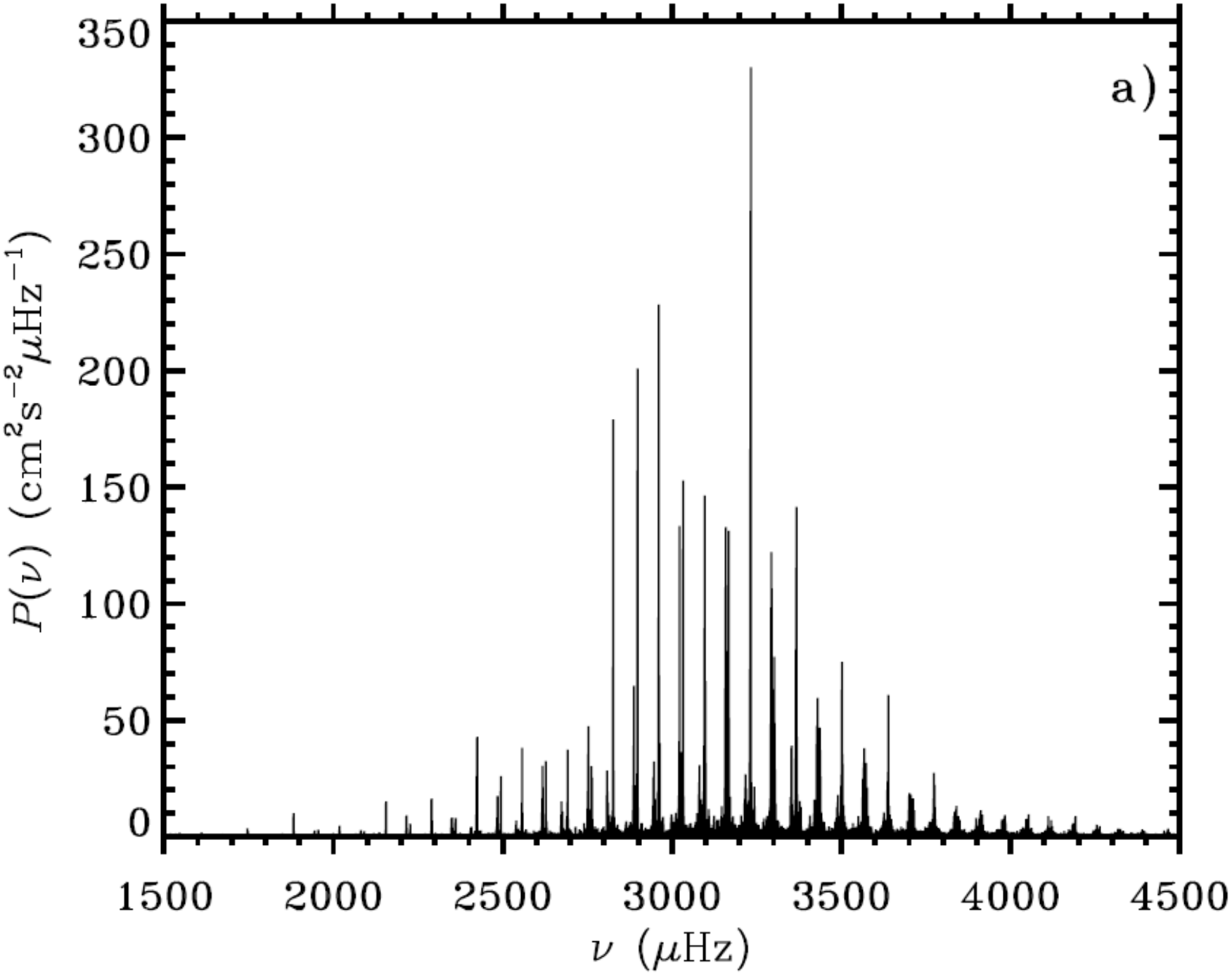
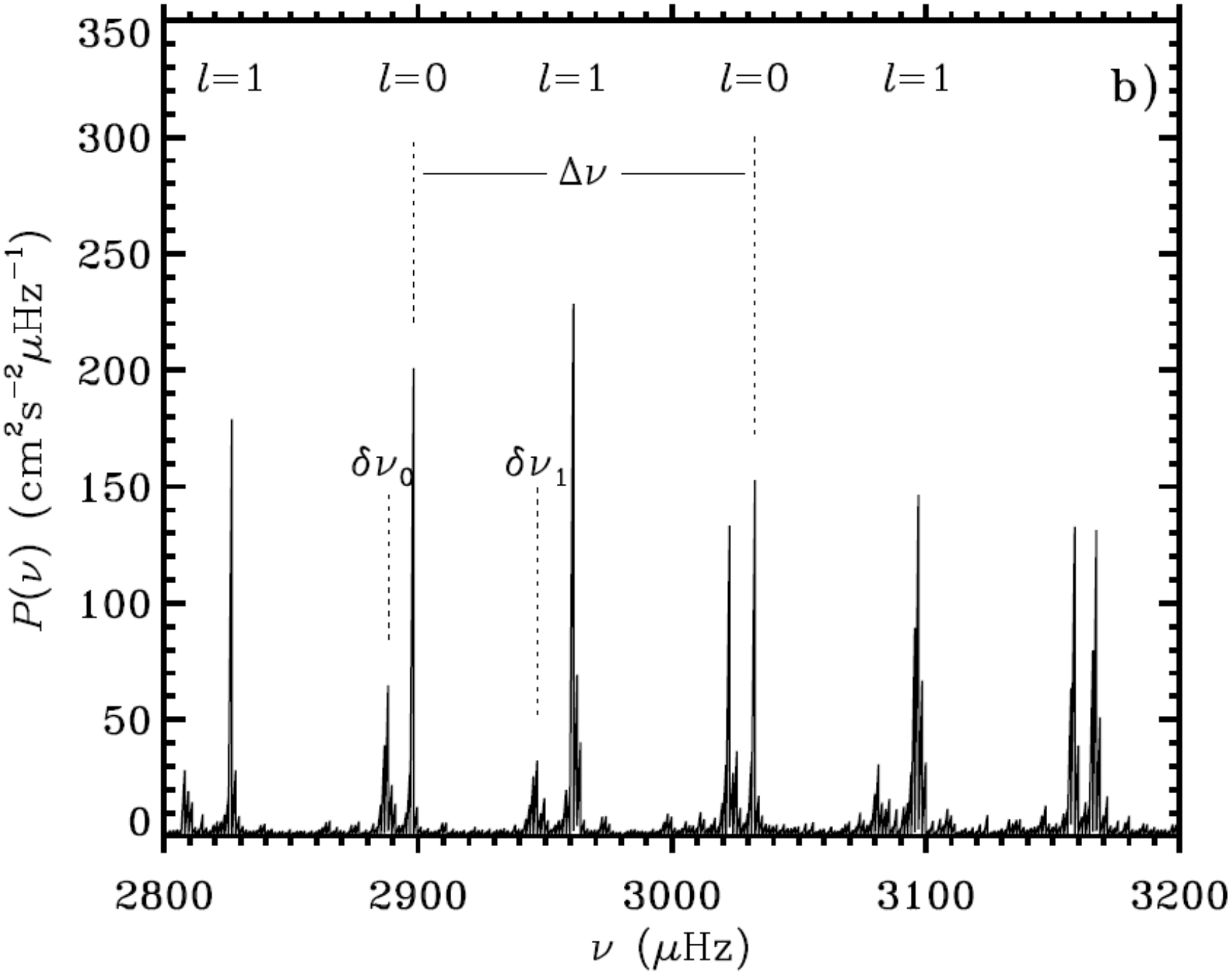
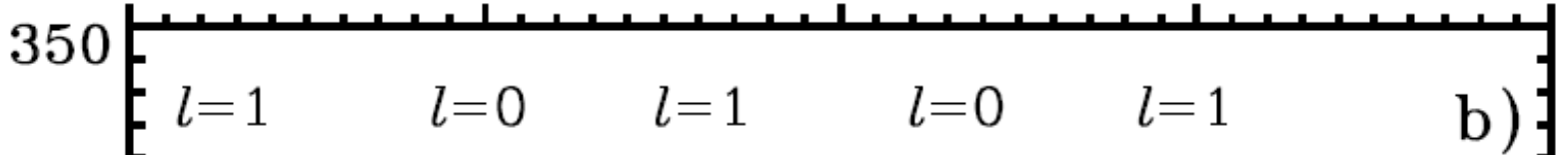
Helioseismologie is seimologie van de zon kan dat ook bij sterren?




1000
100
10
PSD (m/s)²/Hz
p modes
HIPs
2
4
6
8
ν (mHz)


a)
350
300
250
200
150
100
50
0
$P(\nu)$ (cm^{2}s$^{-2}\mu$Hz^{-1})
1500
2000
2500
3000
3500
4000
4500
ν (μHz)


l=1
l=0
l=1
l=0
l=1
b)
Δν
δν0
δν1
P(ν) (cm²s⁻²μHz⁻¹)
ν (μHz)
350
300
250
200
150
100
50
0
2800
2900
3000
3100
3200



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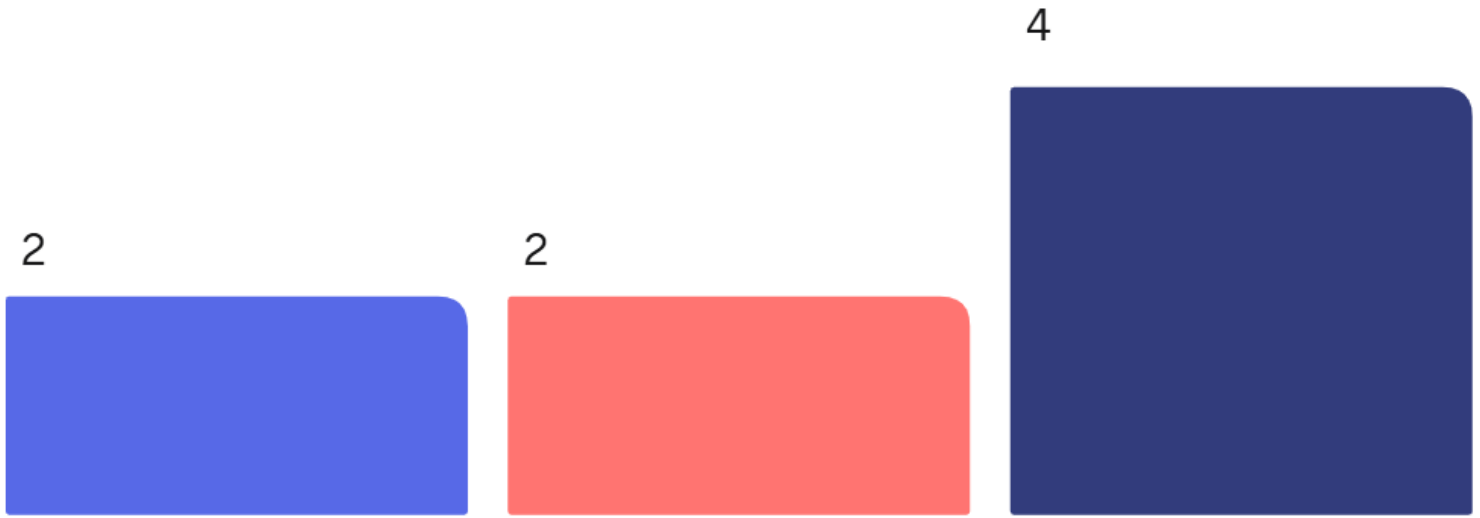
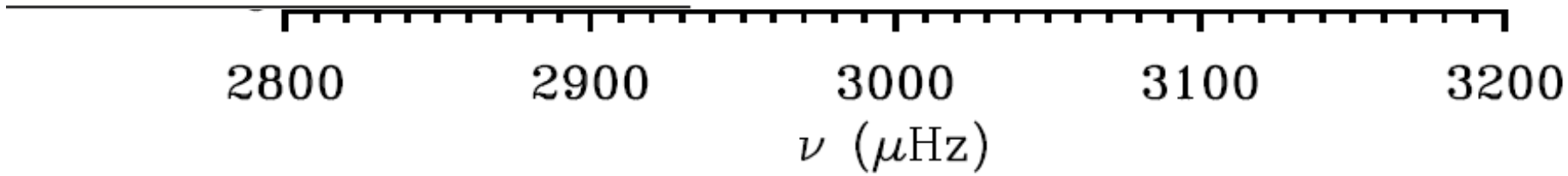
We zien een regelmatige opvolging van pieken met een constante frequentieverschuiving van 135 microHz . Wat bepaalt de afstand tussen de pieken?

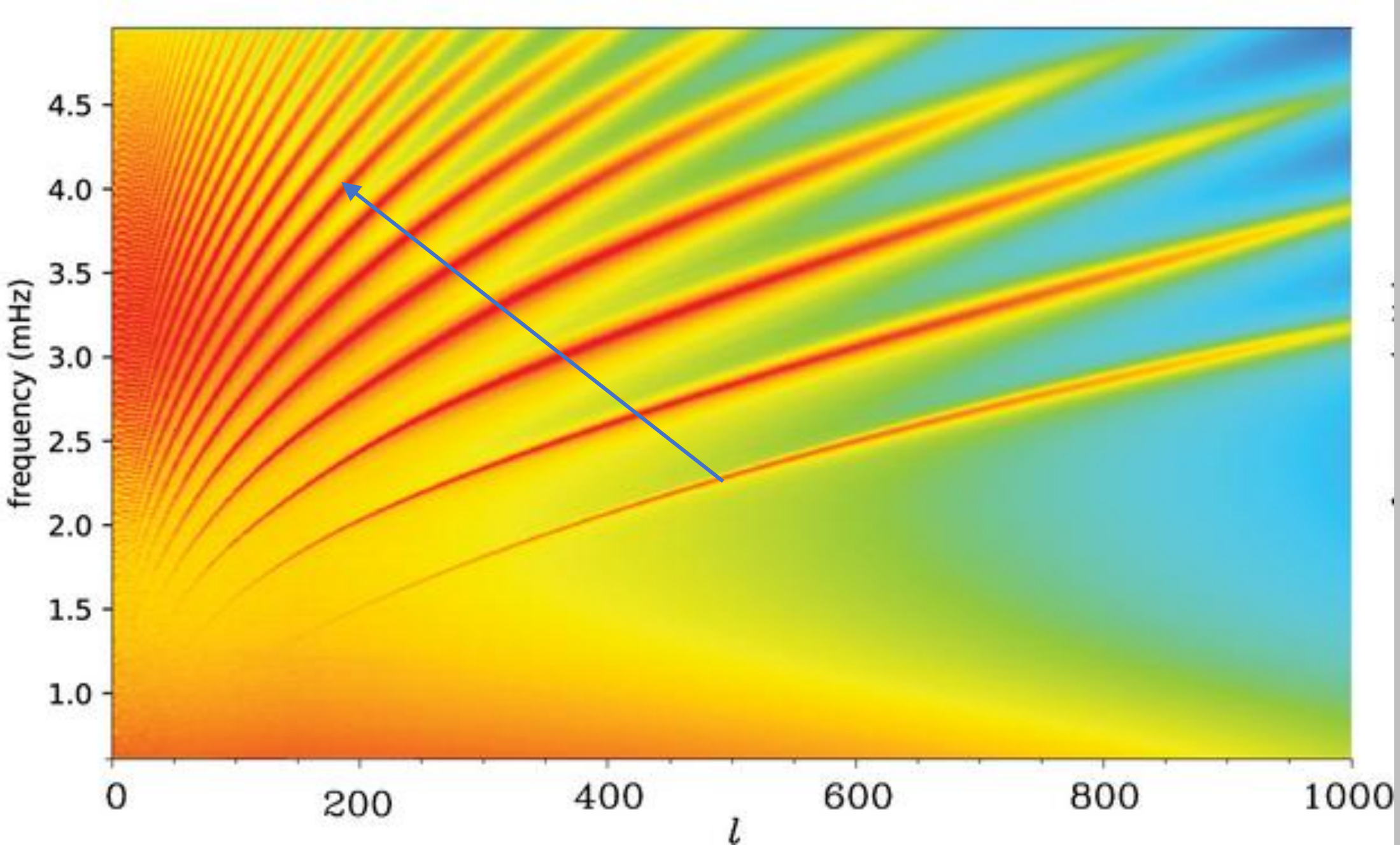


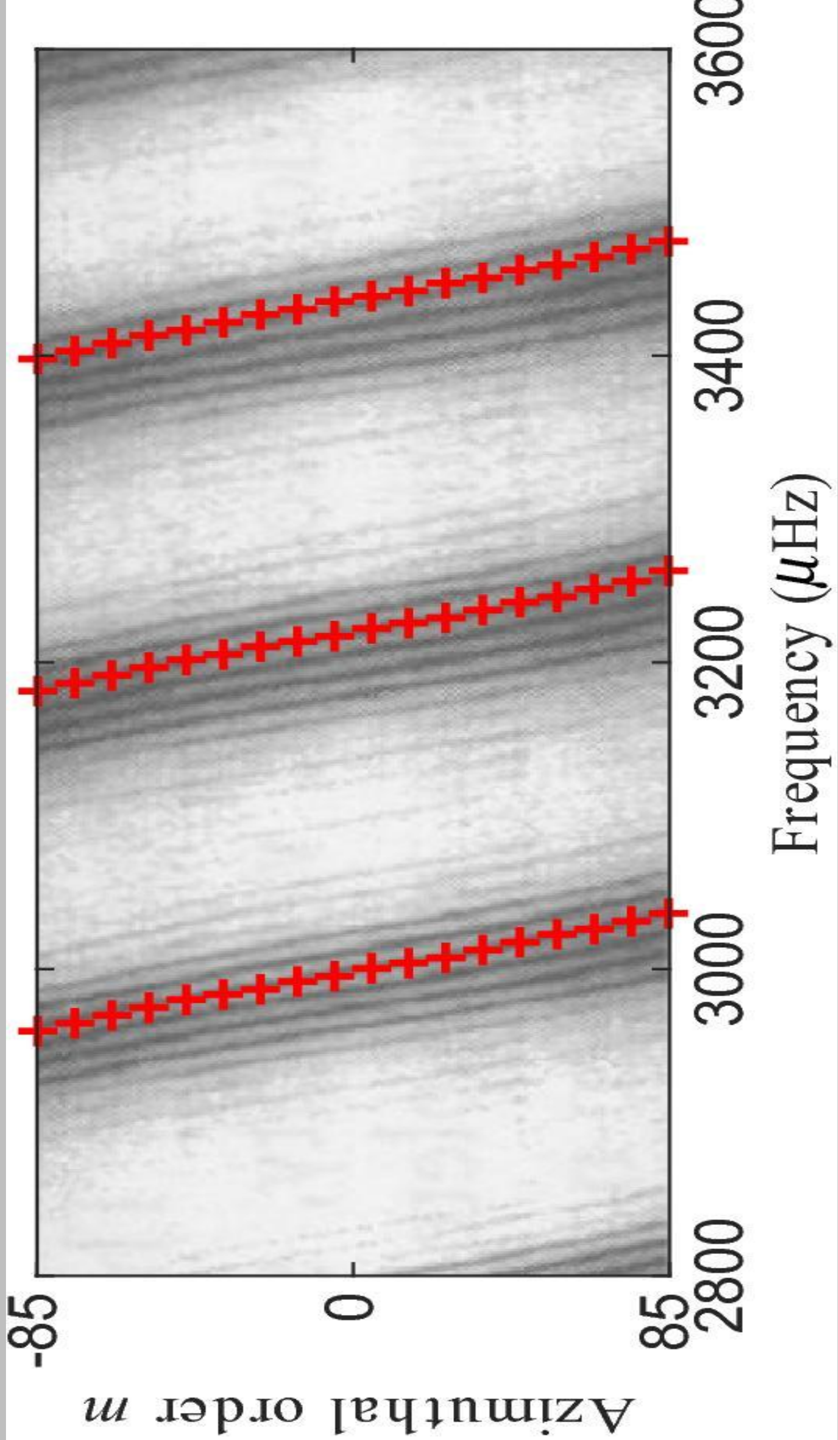


$$\nu_{nl} \simeq \Delta\nu\left(n + \frac{\ell}{2} + \alpha\right) + \epsilon_{nl},$$

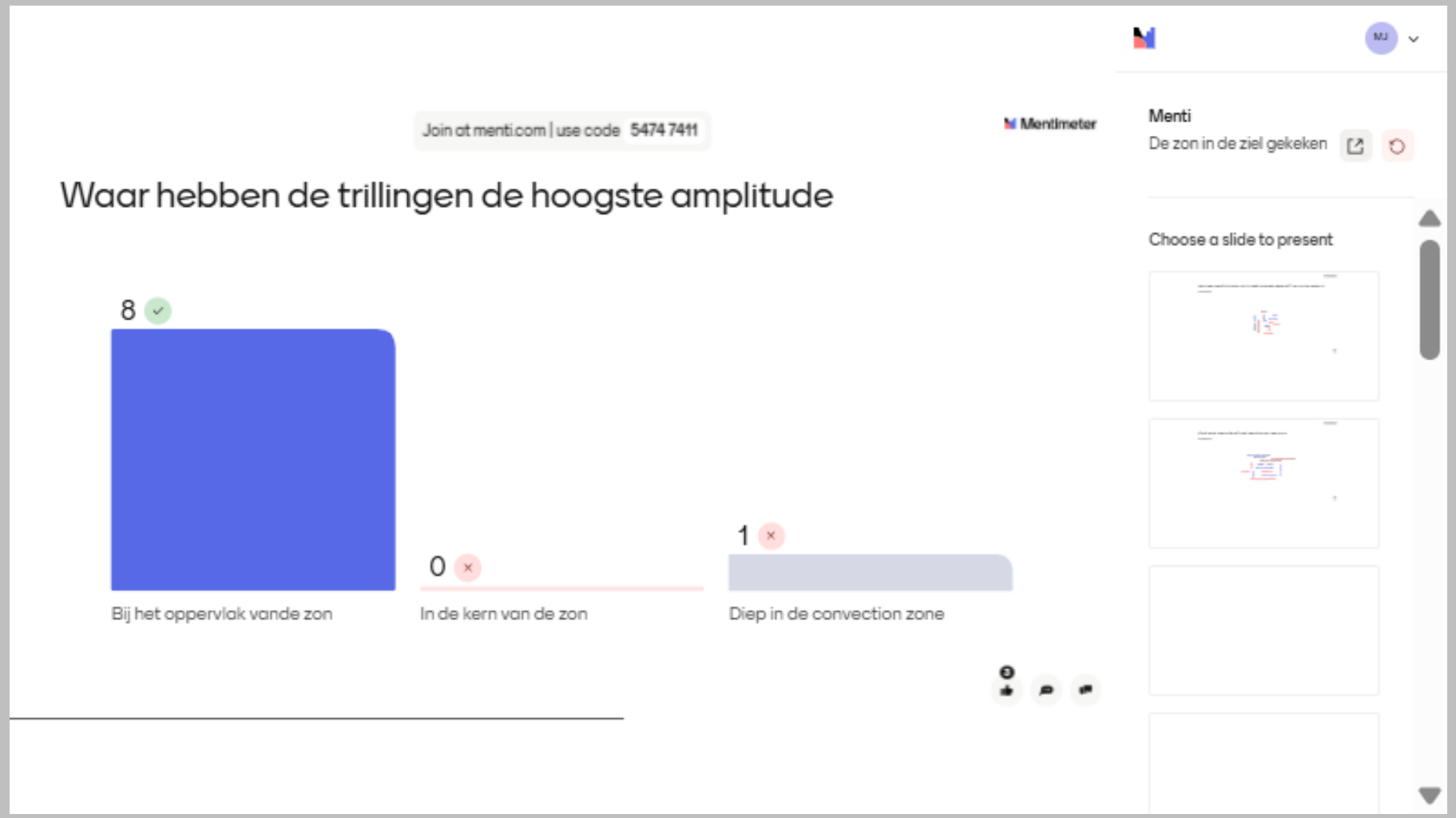
$$\Delta\nu = \left[2\int_0^R \frac{dr}{c}\right]^{-1}$$

$$\delta\nu_{nlm} = \nu_{nlm} - \langle\nu_{nl}\rangle \simeq m\,\frac{\bar{\Omega}}{2\pi},$$


frequency (mHz)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
200
400
600
800
1000
l



$$\delta\nu_{nlm} = \nu_{nlm} - \langle \nu_{nl} \rangle \simeq m \, \frac{\bar{\Omega}}{2\pi} \, ,$$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Mentimeter
Waar hebben de trillingen de hoogste amplitude
8
Bij het oppervlak vande zon
0
In de kern van de zon
1
Diep in de convection zone
MJ
Menti
De zon in de ziel gekeken
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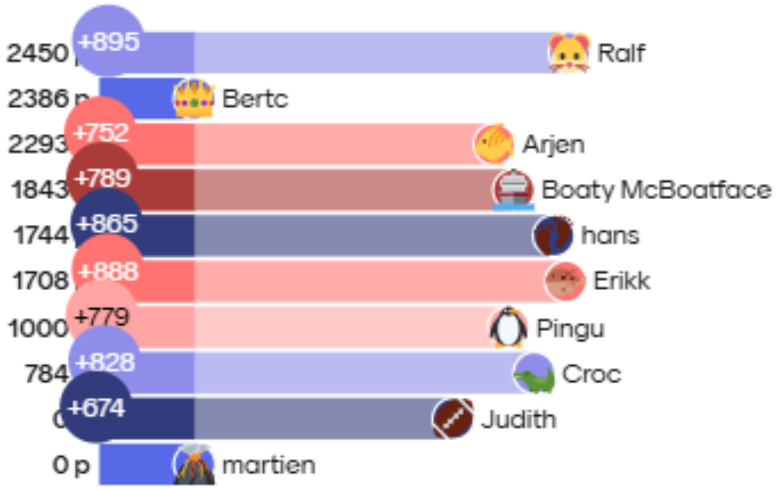
Quiz leaderboard

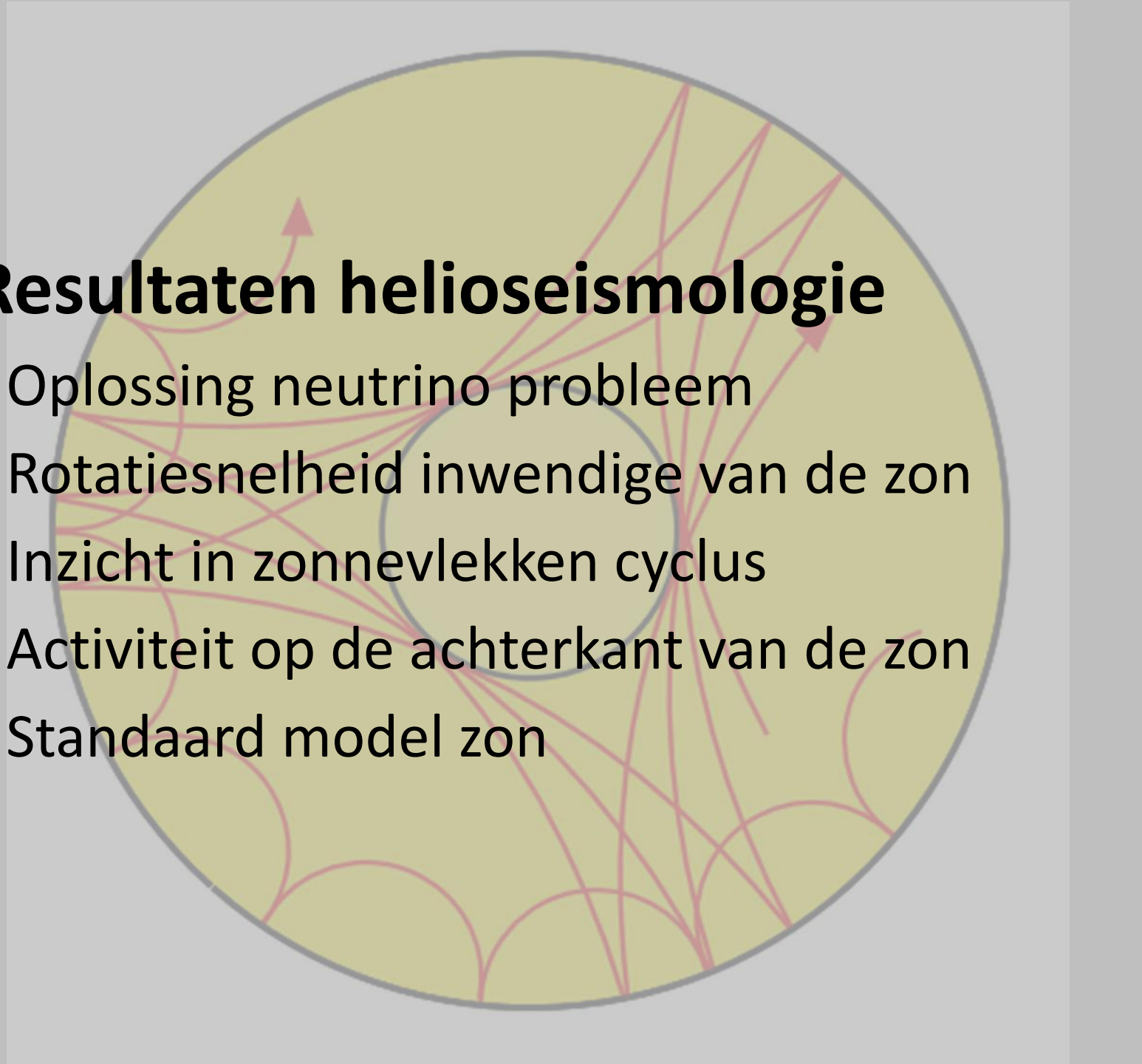


Mentimeter

Menti

De zon in de ziel gekeken

Choose a slide to present

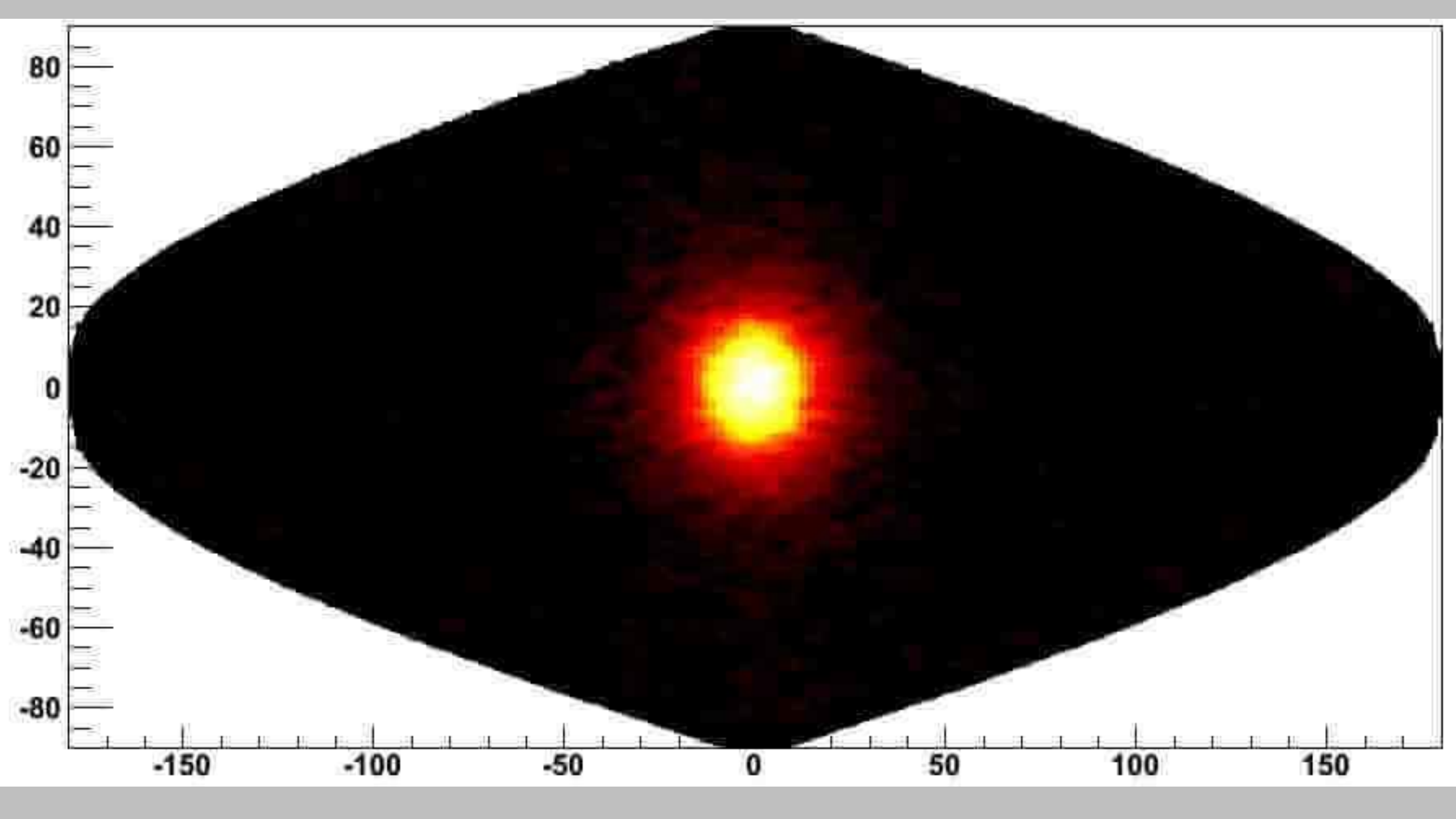


Resultaten helioseismologie

- Oplossing neutrino probleem
- Rotatiesnelheid inwendige van de zon
- Inzicht in zonnevlekken cyclus
- Activiteit op de achterkant van de zon
- Standaard model zon

Resultaten helioseismologie

- **Oplossing neutrino probleem**
- Rotatiesnelheid inwendige van de zon
- Inzicht in zonnevlekken cyclus
- Activiteit op de achterkant van de zon
- Standaard model zon


80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150

Energieopwekking in de zon door kernfusie

PP I proces 84,6%

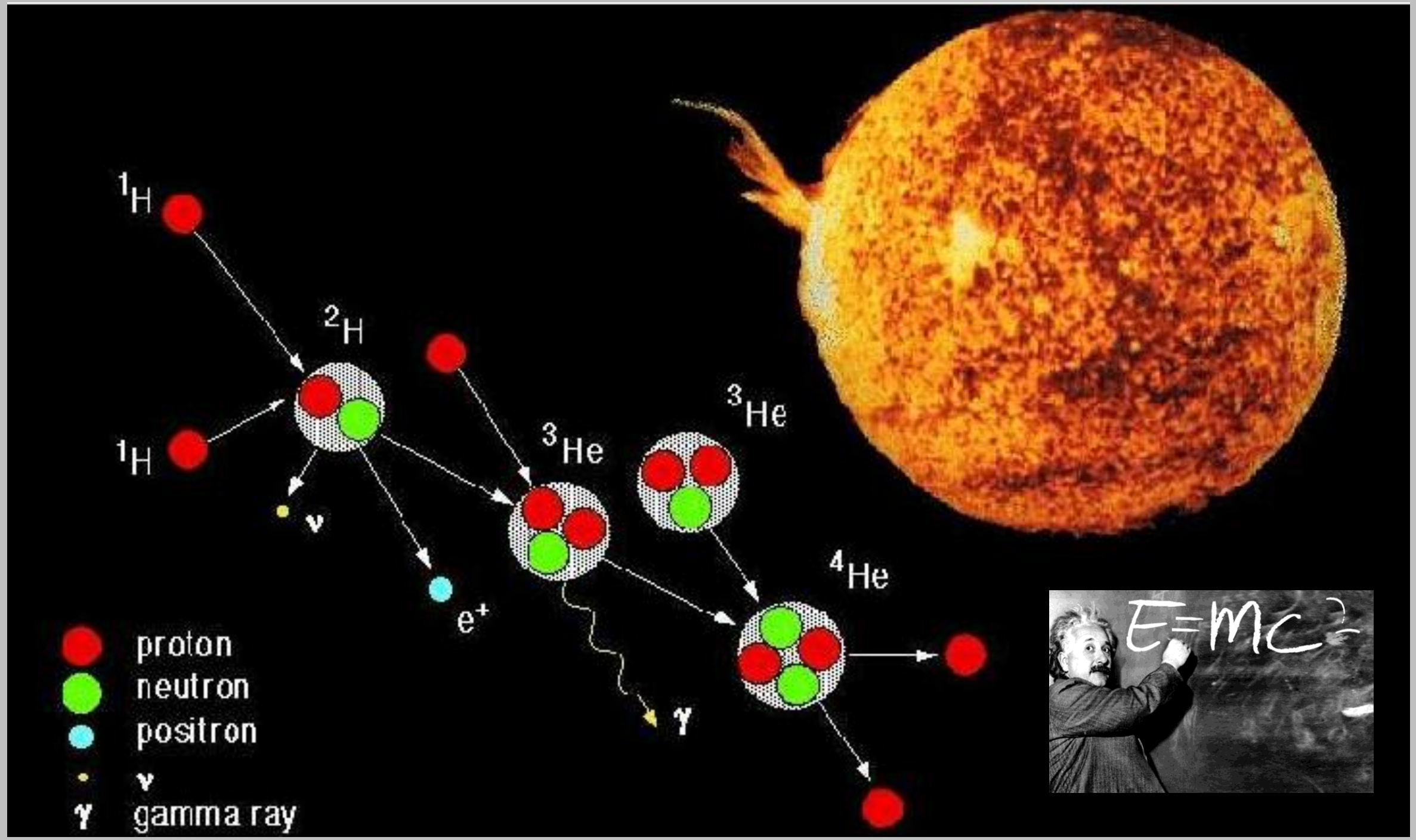
$P+P \rightarrow D$; $D+P \rightarrow {}^{3}He$; ${}^{3}He + {}^{3}He \rightarrow {}^{4}He + 2\ p$

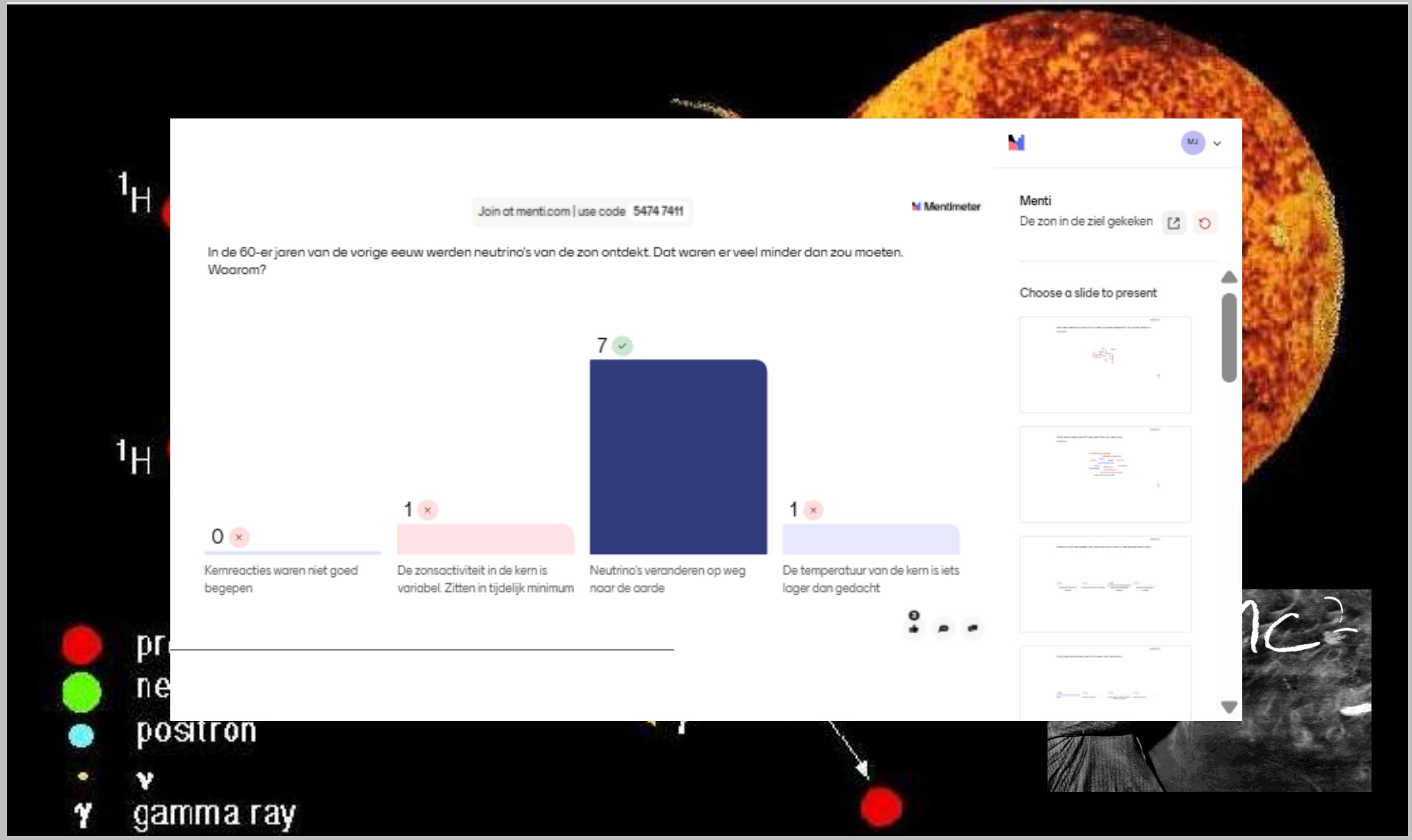
PPII proces 13,8%

${}^{3}He + {}^{4}He - {}^{7}Be$; ${}^{7}Be + P \rightarrow {}^{8}B$; ${}^{8}B \rightarrow 2\ {}^{4}He$

CNO Proces 1.6 %

${}^{12}C + P \rightarrow {}^{13}C$; ${}^{13}C + P \rightarrow {}^{14}N$; ${}^{14}N + P \rightarrow {}^{15}O + P \rightarrow {}^{12}C + {}^{4}He$


^{1}H
^{1}H
^{2}H
^{3}He
^{3}He
^{4}He
ν
e$^+$
γ
proton
neutron
positron
ν
γ gamma ray
E=mc²


1H
1H
pr
ne
positron
ν
γ gamma ray
Join at menti.com | use code 5474 7411
Mentimeter
In de 60-er jaren van de vorige eeuw werden neutrino's van de zon ontdekt. Dat waren er veel minder dan zou moeten. Waarom?
0
Kernreacties waren niet goed begepen
1
De zonsactiviteit in de kern is variabel. Zitten in tijdelijk minimum
7
Neutrino's veranderen op weg naar de aarde
1
De temperatuur van de kern is iets lager dan gedacht
MJ
Menti
De zon in de ziel gekeken
Choose a slide to present
mc²

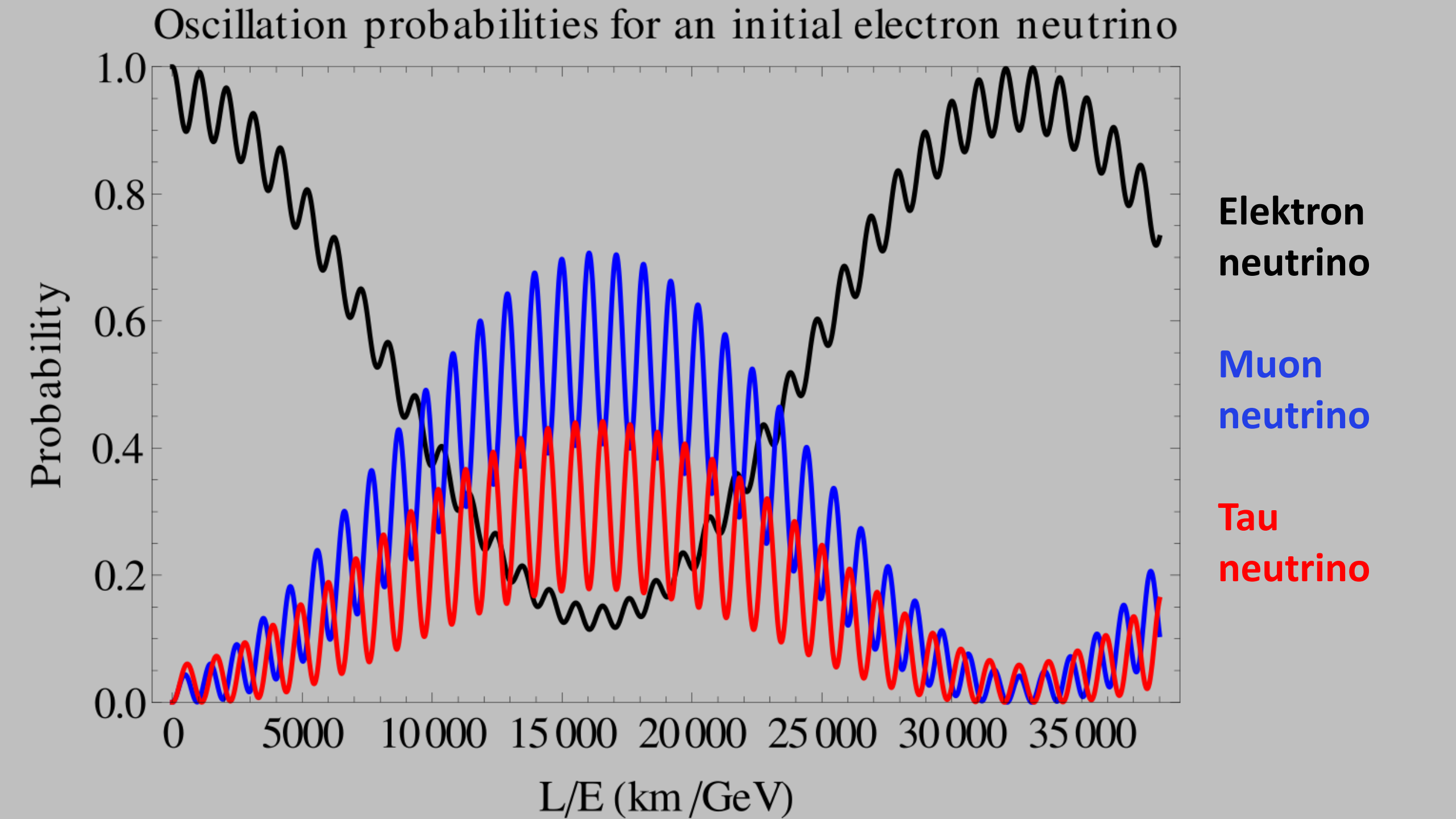
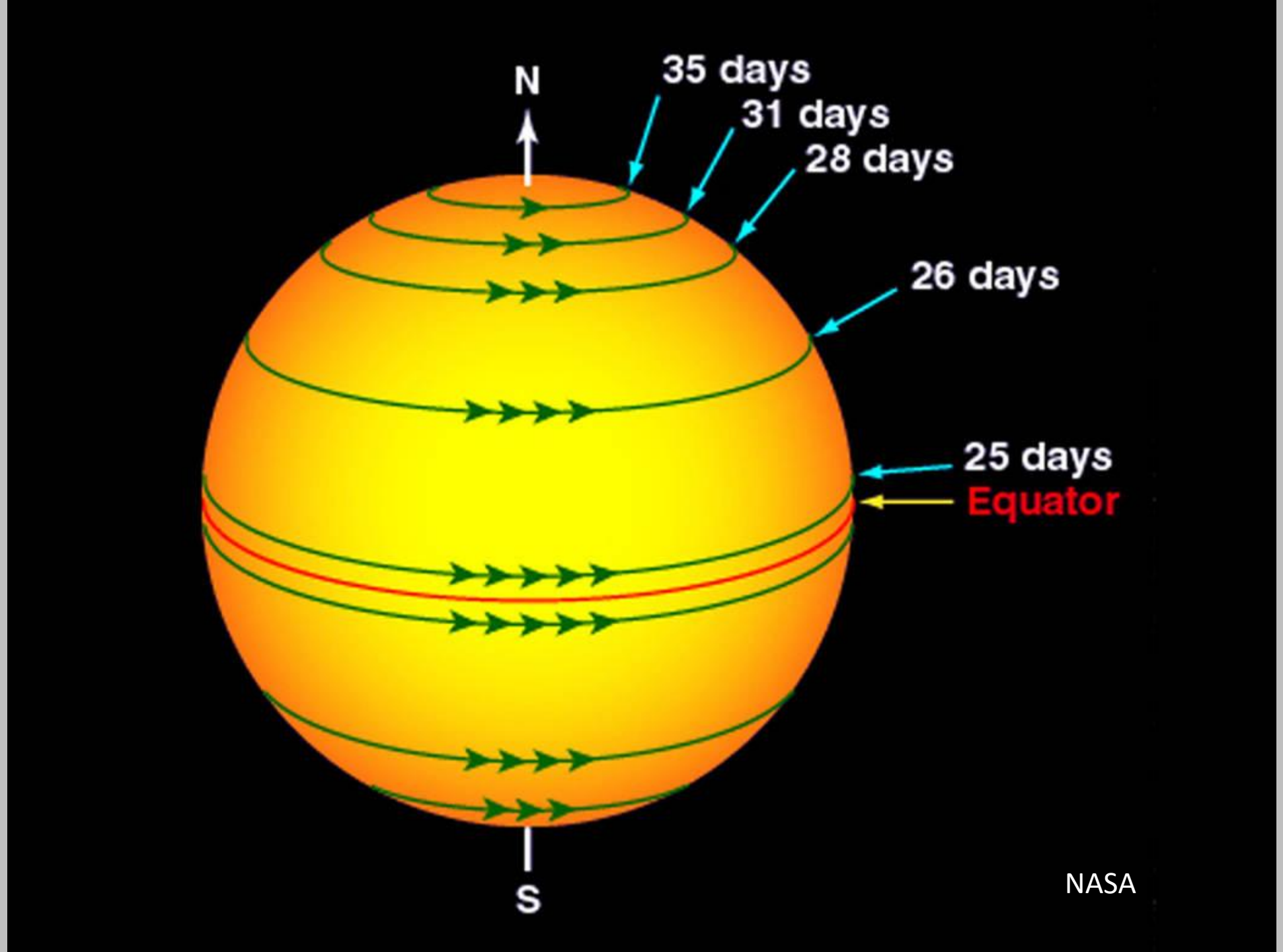

Oscillation probabilities for an initial electron neutrino
Probability
1.0
0.8
0.6
0.4
0.2
0.0
0
5000
10 000
15 000
20 000
25 000
30 000
35 000
L/E (km /GeV)
Elektron neutrino
Muon neutrino
Tau neutrino

Table 3. Neutrino predictions of the SeSM [2, 26] compared to all the neutrino experiments. The Borexino results from [25]. Same references than in Table 2.

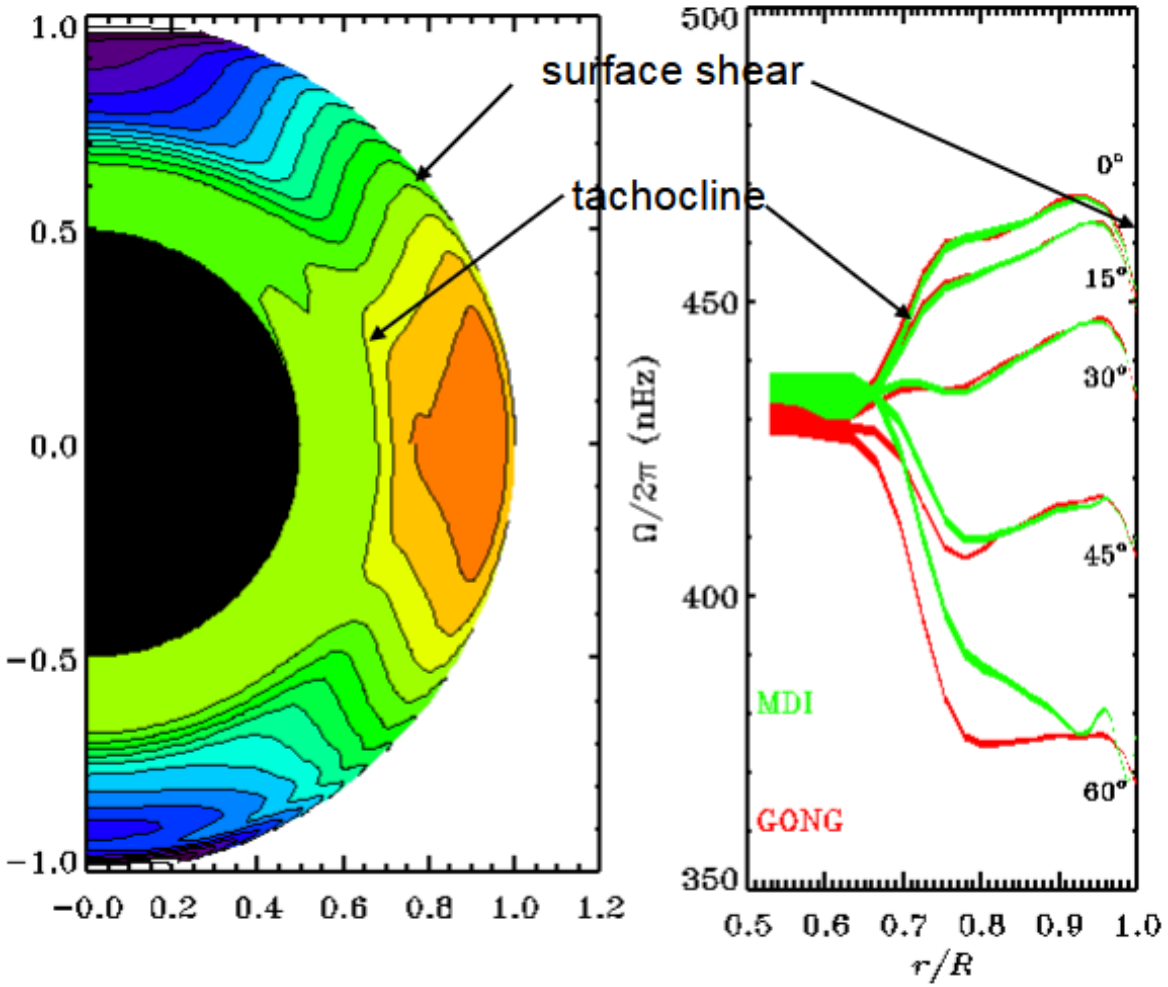
	Neutrino Predictions	Predictions including neutrino oscillation
Chlorine detector		2.56 ± 0.23 SNU
Seismic model	7.67 ± 1.1 SNU	2.76 ± 0.4 SNU
Gallium detectors	**GALLEX+GNO+SAGE**	$66.1 \pm 3.$ SNU
Seismic model	123.4 ± 8.2 SNU	67.1 ± 4.4 SNU
Borexino ^{7}Be		$3.36 \pm 0.36\ 10^9 \mathrm{cm}^{-2}\mathrm{s}^{-1}$
Seismic model	$4.72\ 10^9 \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$3.05 \pm 0.35\ \ 10^9 \mathrm{cm}^{-2}\mathrm{s}^{-1}$
Water detectors	**SNO**	**SNO + SK** in $10^6 \mathrm{cm}^{-2}\mathrm{s}^{-1}$
	5.09 ± 0.44 (stat)± 0.45 (syst)	5.27 ± 0.27 (stat)± 0.38 (syst)
Seismic model	5.31 ± 0.6	5.31 ± 0.6

Resultaten helioseismologie

- Oplossing neutrino probleem
- **Rotatiesnelheid inwendige van de zon**
- Inzicht in zonnevlekken cyclus
- Activiteit op de achterkant van de zon
- Standaard model zon


N
35 days
31 days
28 days
26 days
25 days
Equator
S
NASA

Global rotation profile



Comparison between results from GONG and MDI data (Howe, 2002)

- Differential rotation penetrates the interior. Rotation being constant on cylinders is not confirmed.
- **Tachocline:** a narrow region in the stably stratified layer just beneath the base of the convective enveloppe, where transition between differential and solid-body rotation takes place.
- The radiative core rotates slower than expected (surface-like), possibly owing to magnetic breaking in the outer envelope and its coupling with the radiative core.

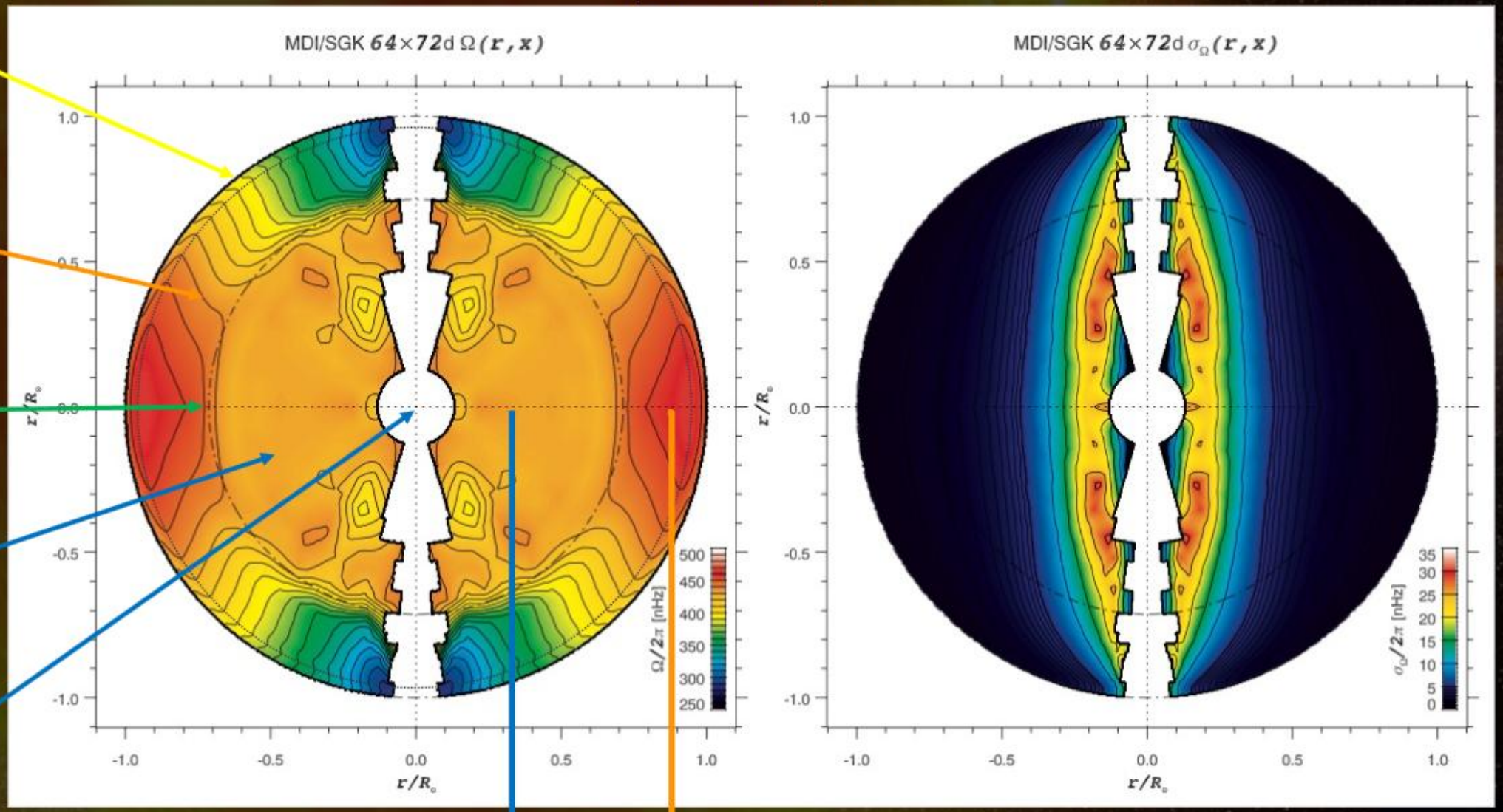
core.

(Howe, 2002)

- Medium degree modes (up to l ~200)

Cycle 23: 12.6 years

[Korzennick & Eff-Darwich 2012]

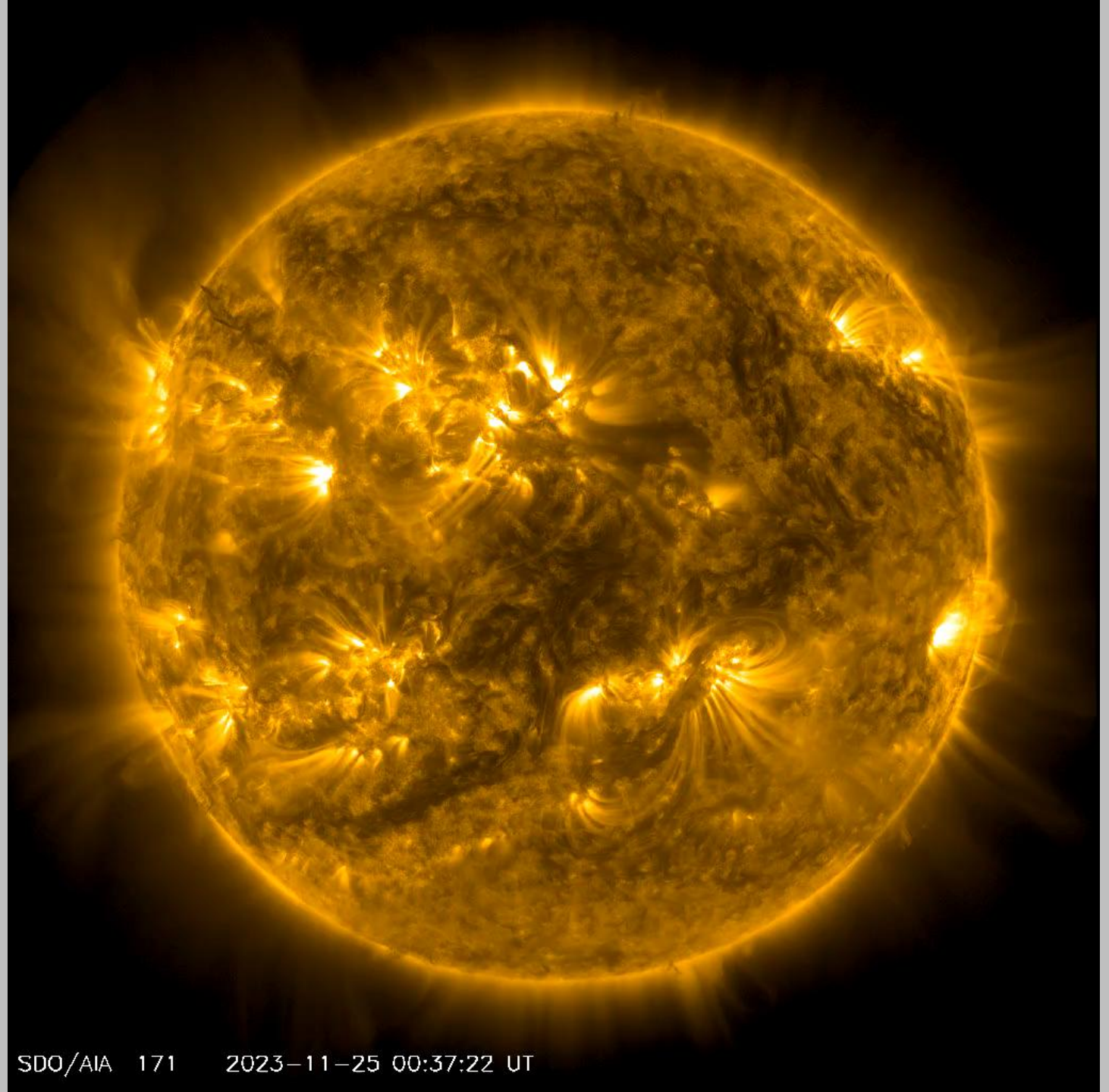


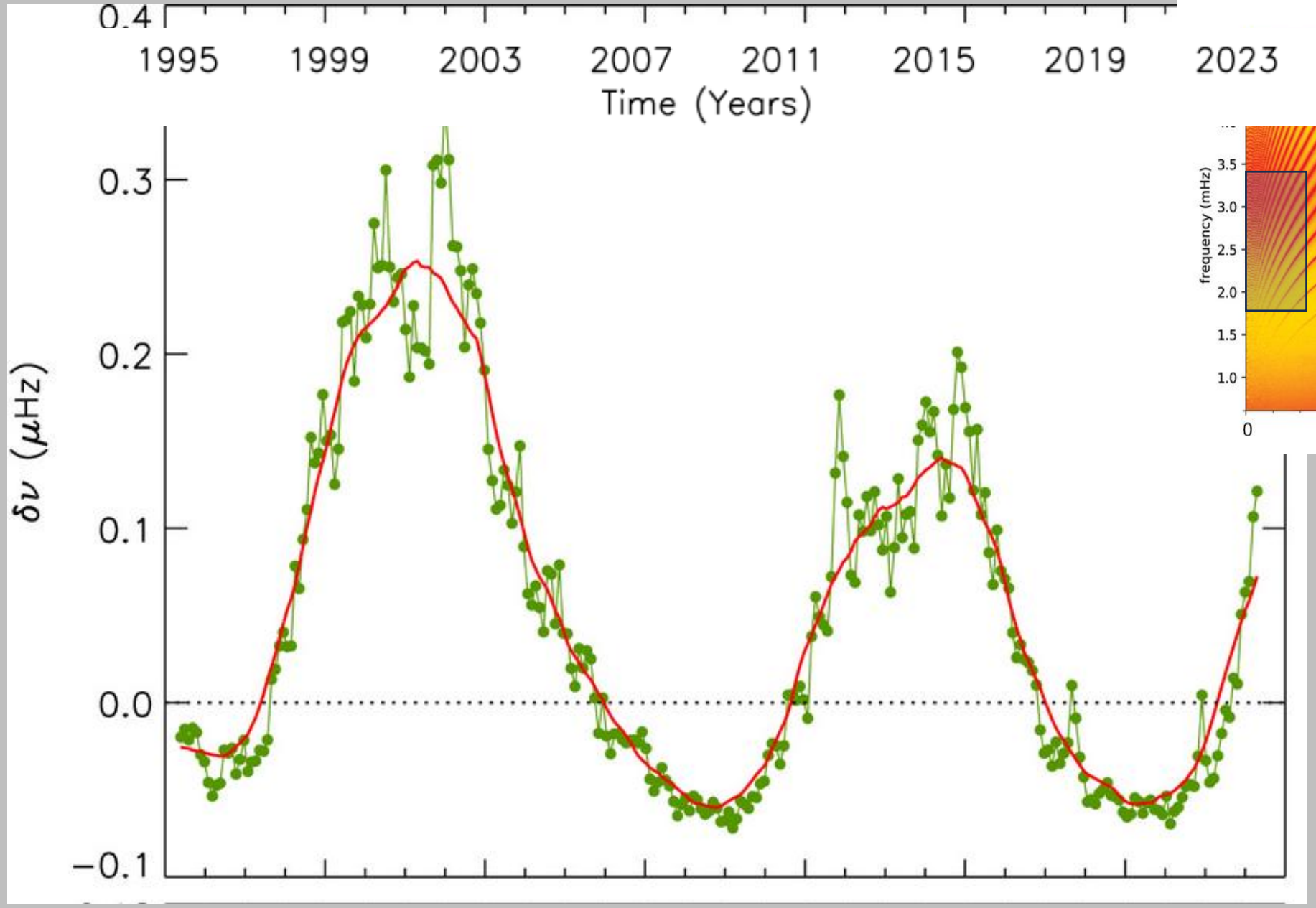
	Equator		15°		30°		45°		60°	
	MDI	GONG	MDI	GONG	MDI	GONG	MDI	GONG	MDI	GONG
Jump	19.38	18.82	15.07	14.41	-1.93	-1.06	-29.39	-30.32	-64.64	-68.92
Posi-tion	0.689	0.692	0.693	0.694	0.703	0.697	0.717	0.702	0.731	0.707
Width	0.0022 (0.006)	0.0024 (0.006)	0.0046 (0.011)	0.0040 (0.010)	0.0111 (0.028)	0.0084 (0.021)	0.0201 (0.072)	0.0144 (0.051)	0.0289 (0.089)	0.0204 (0.062)

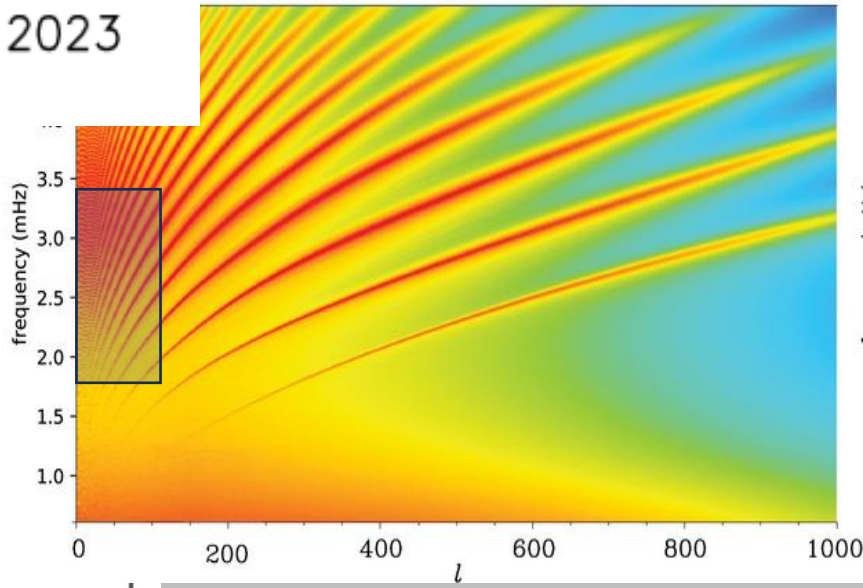
- The tachocline is prolate.
- The thickness of the tachocline is higher at higher latitudes.

Resultaten helioseismologie

- Oplossing neutrino probleem
- Rotatiesnelheid inwendige van de zon
- **Inzicht in zonnevlekken cyclus**
- Activiteit op de achterkant van de zon
- Standaard model zon


SDO/AIA 171 2023-11-25 00:37:22 UT

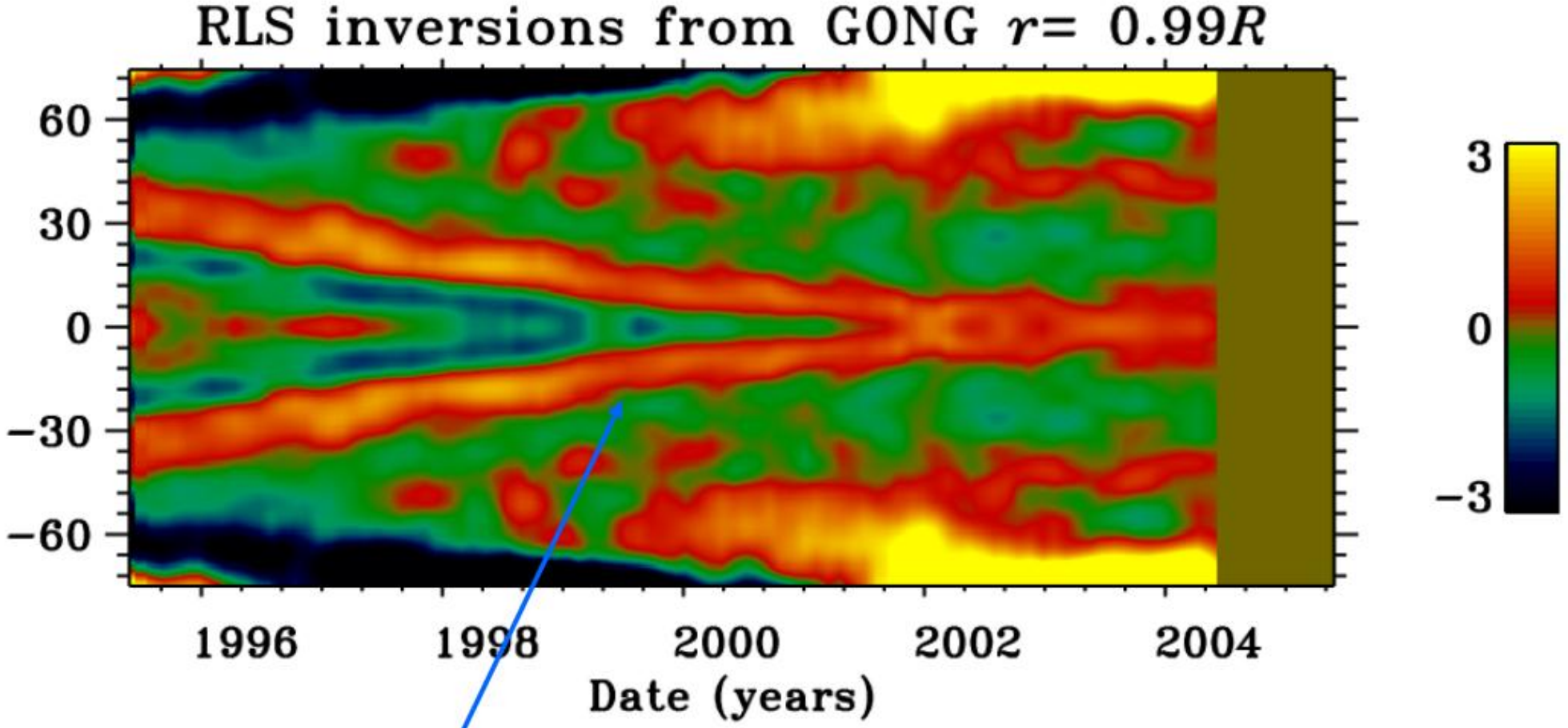




Helioseismic Investigation of Quasi-biennial Oscillation Source Regions

Kiran Jain, Partha Chowdhury, and Sushanta C. Tripathy

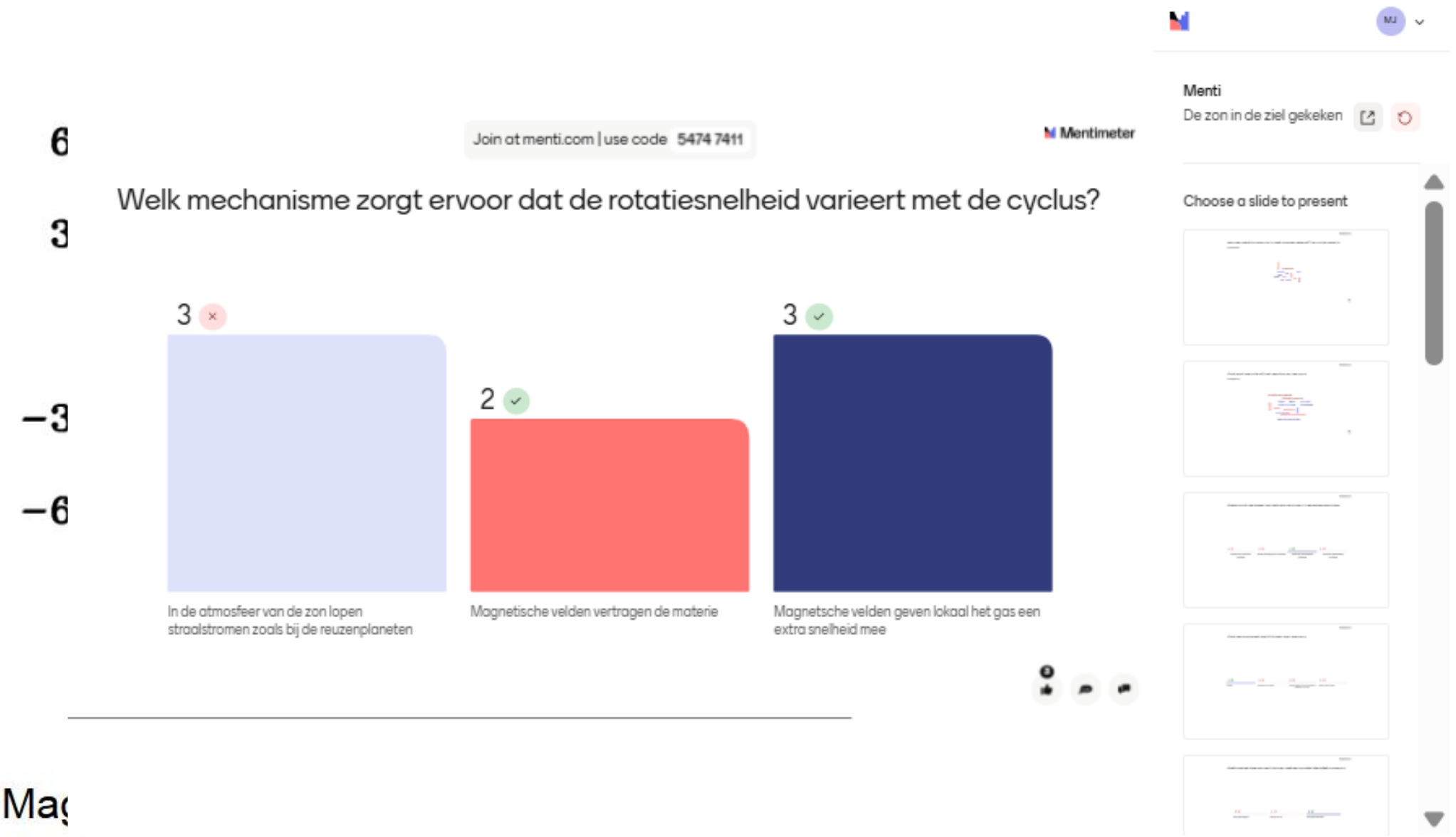
Changes of the differential rotation with the solar cycle - “torsional oscillations”
(rotation speed relative to mean speed)

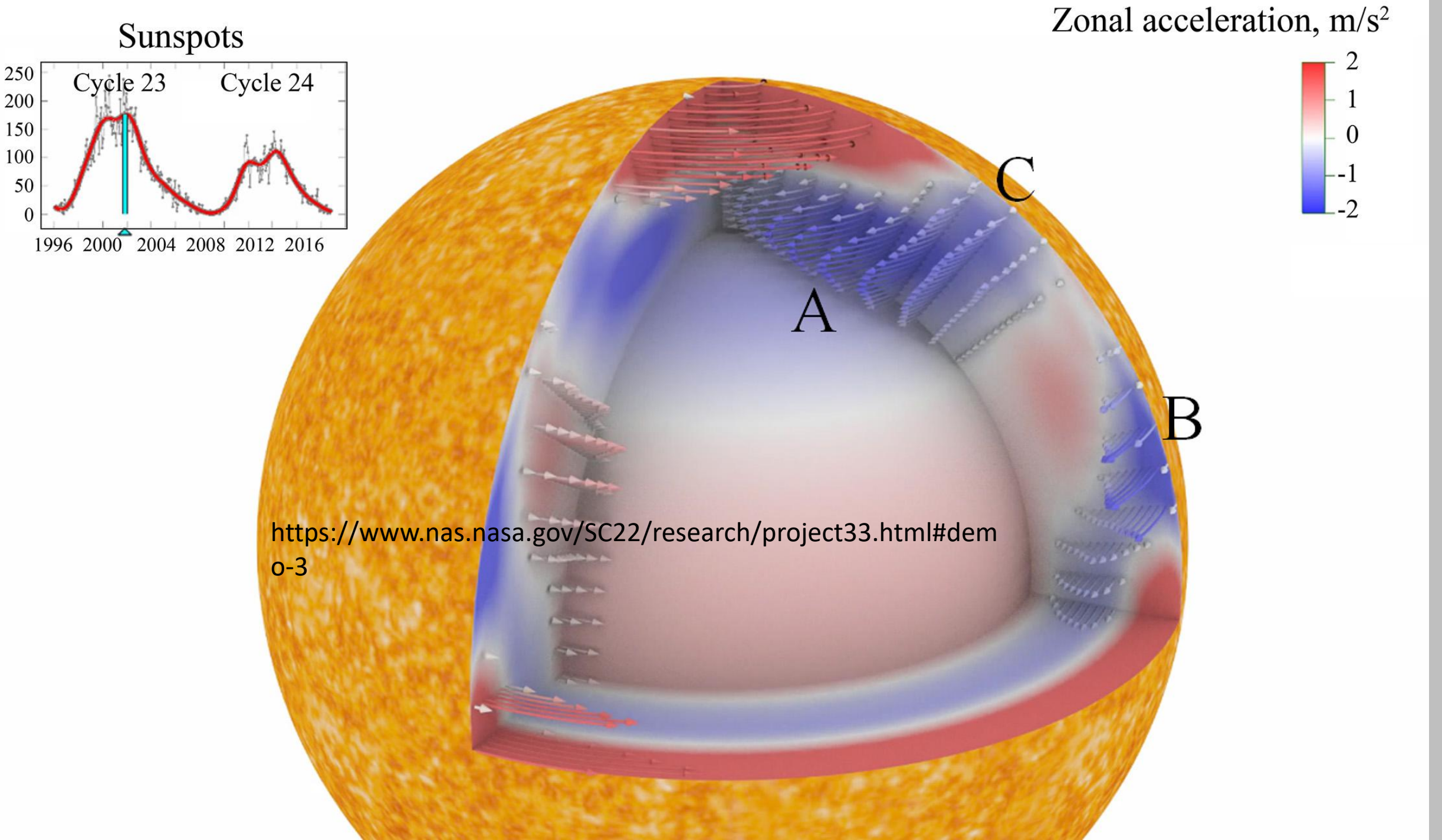


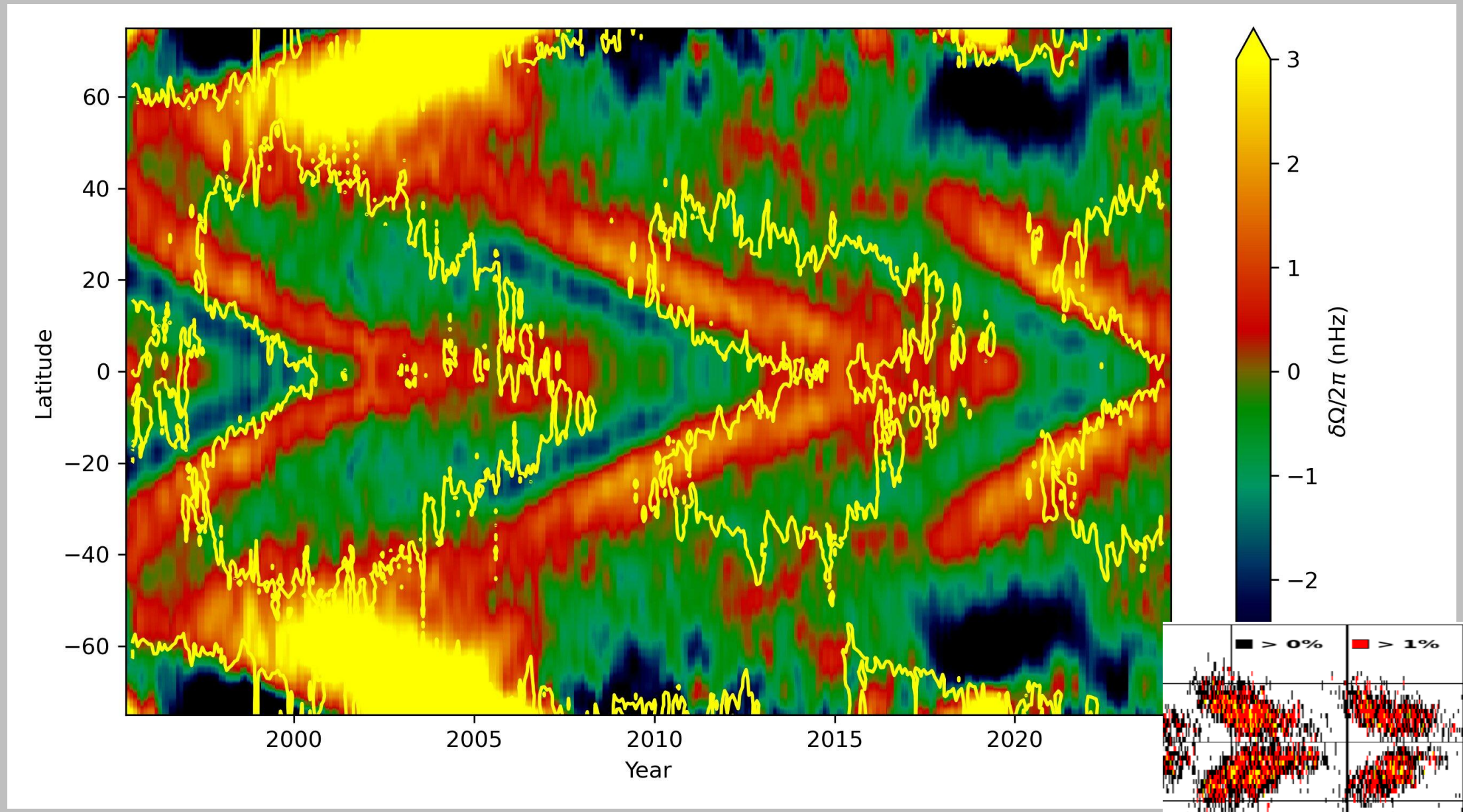
Magnetic active regions appear at boundaries between fast and slow zones

Changes of the differential rotation with the solar cycle - “torsional oscillations”

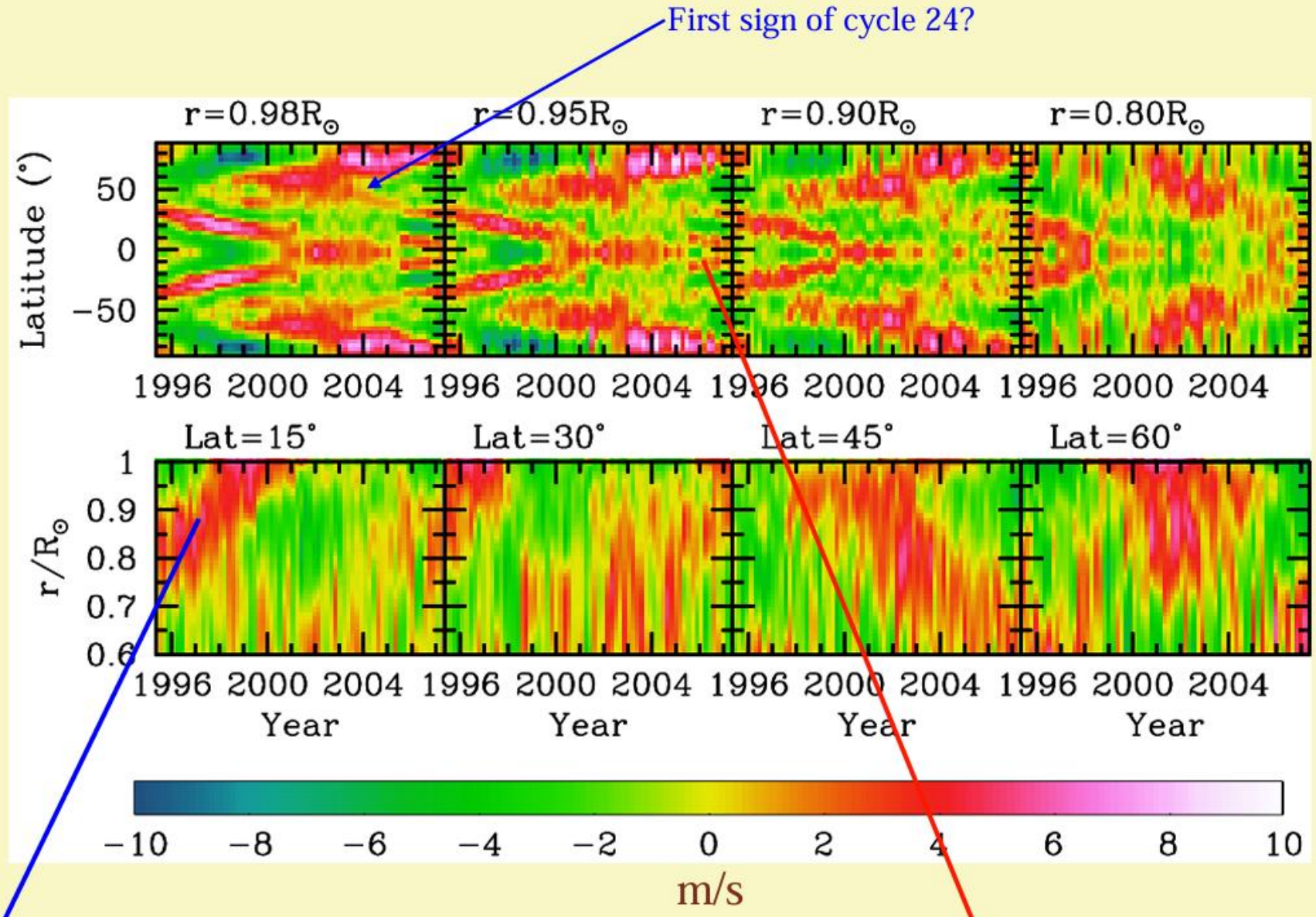
(rotation speed relative to mean speed)

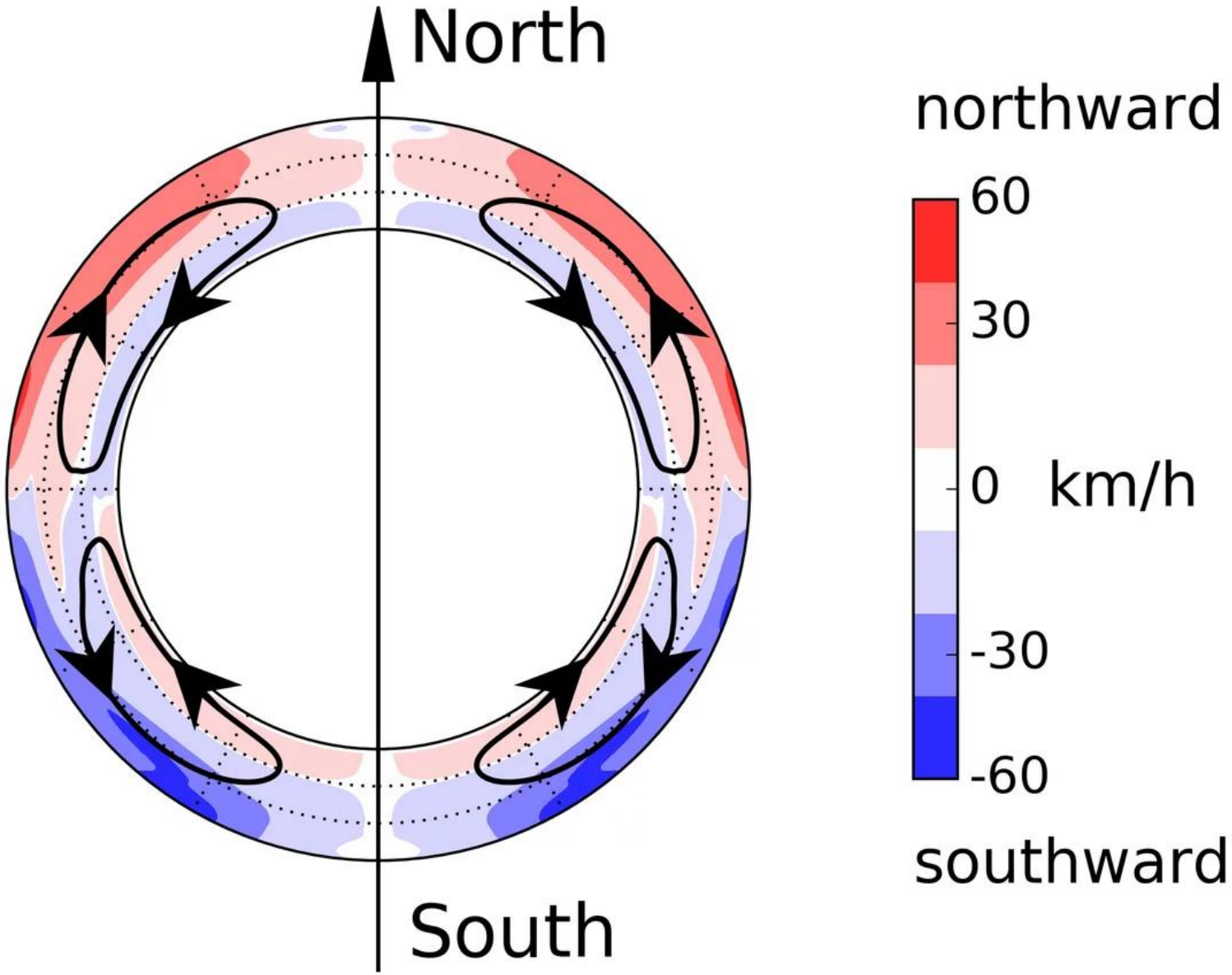


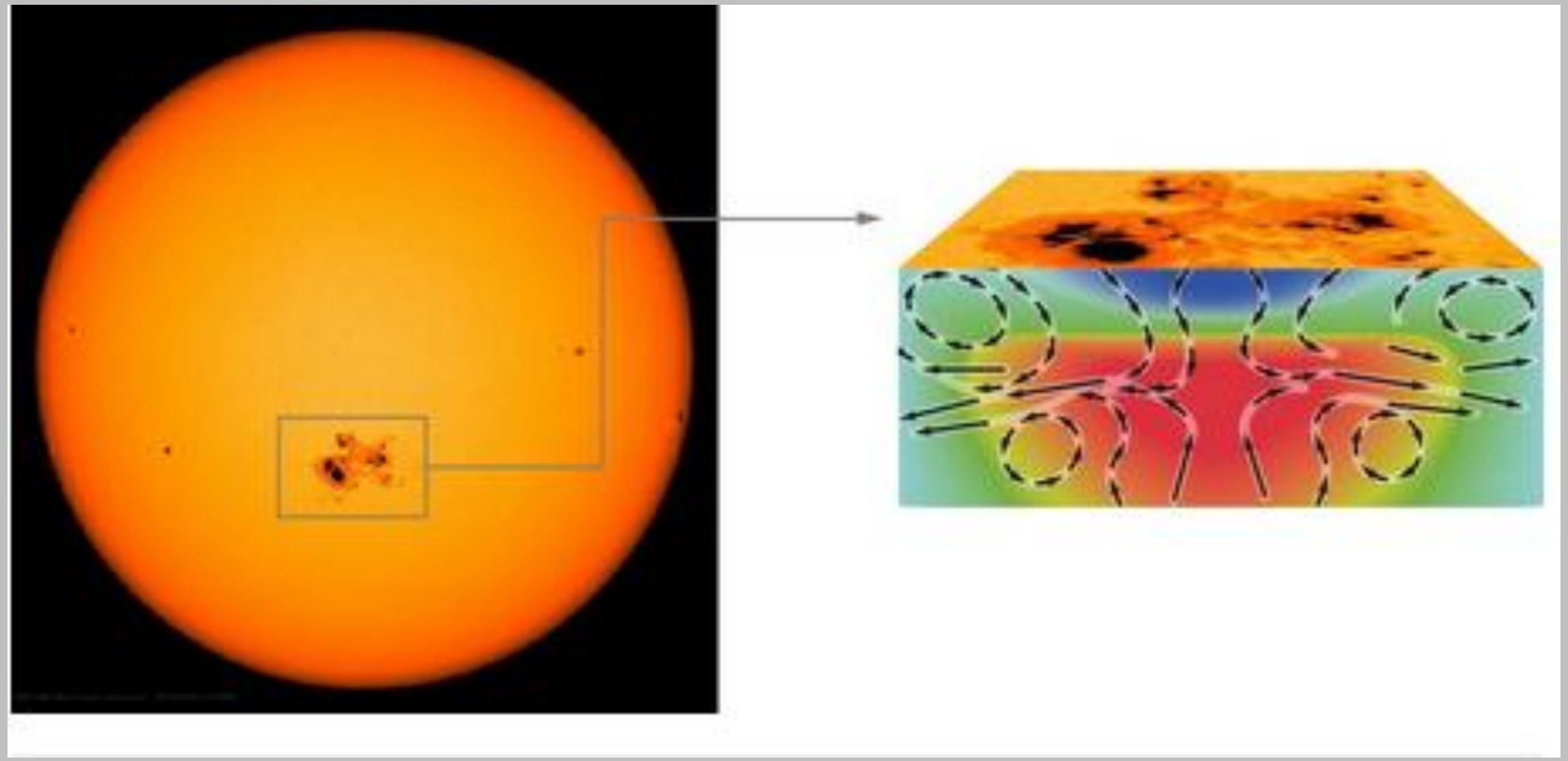

Sunspots
Cycle 23
Cycle 24
250
200
150
100
50
0
1996
2000
2004
2008
2012
2016
Zonal acceleration, m/s²
2
1
0
-1
-2
C
A
B
https://www.nas.nasa.gov/SC22/research/project33.html#demo-3


Latitude
60
40
20
0
−20
−40
−60
2000
2005
2010
2015
2020
Year
3
2
1
0
−1
−2
δΩ/2π (nHz)
> 0%
> 1%
> 10%
2000
2020

Solar zonal flows

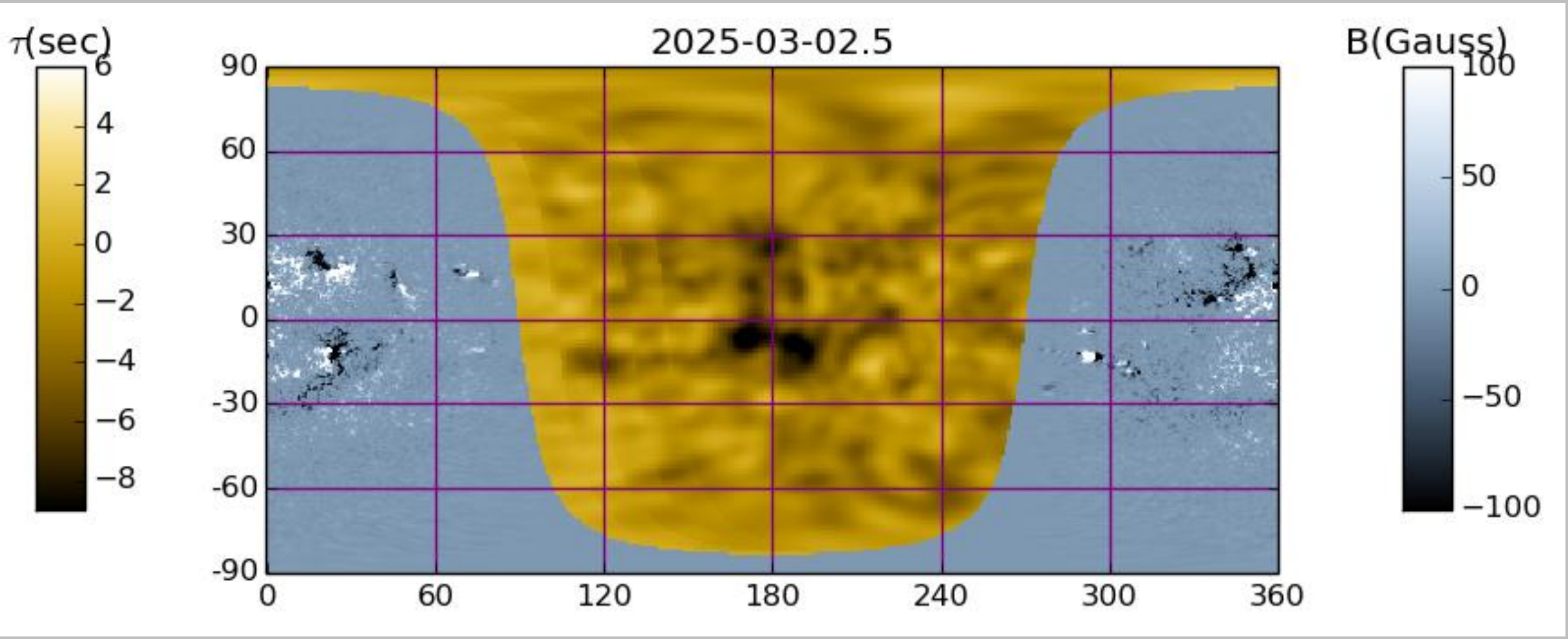


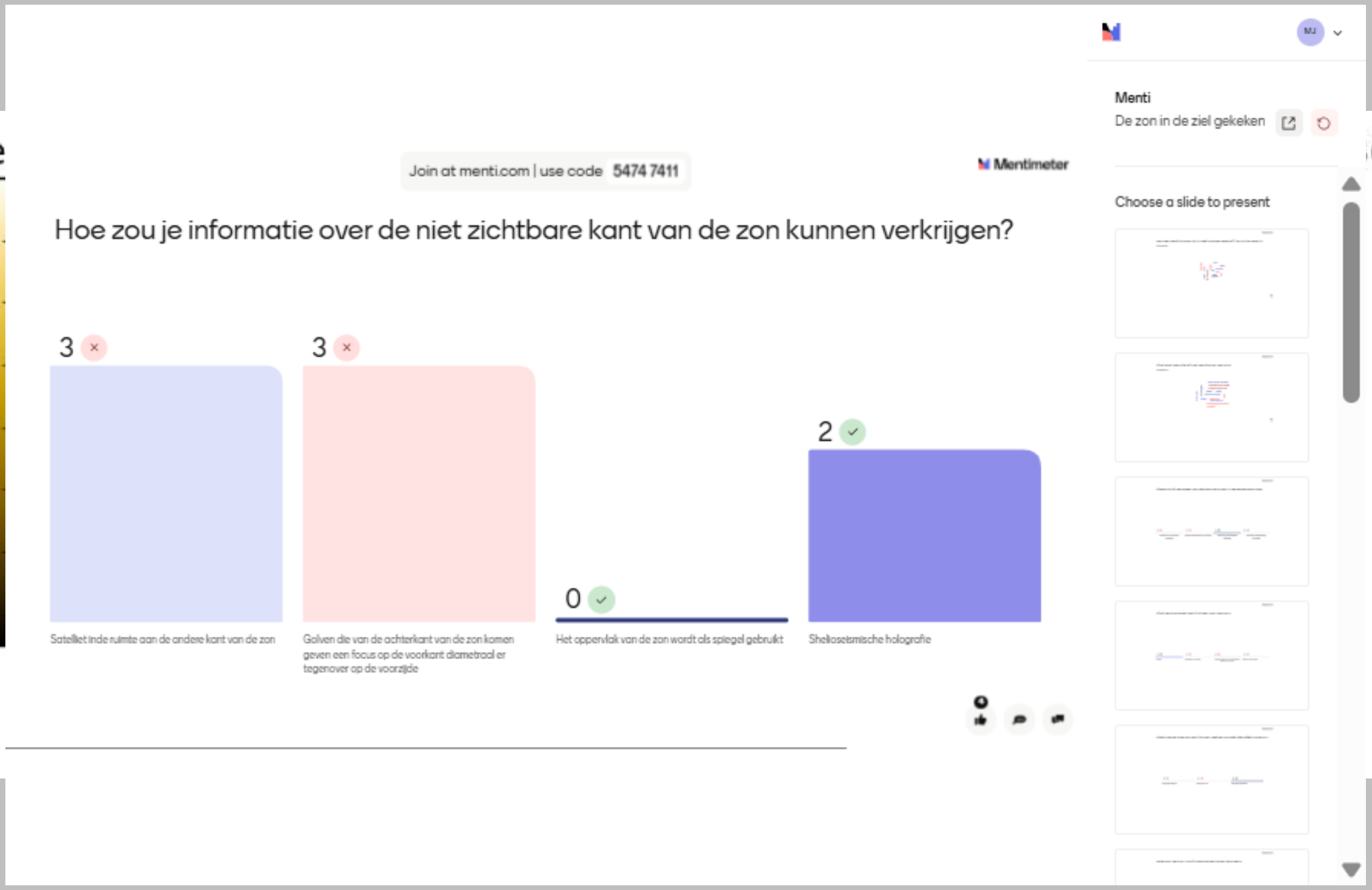

North
South
northward
60
30
0
km/h
-30
-60
southward

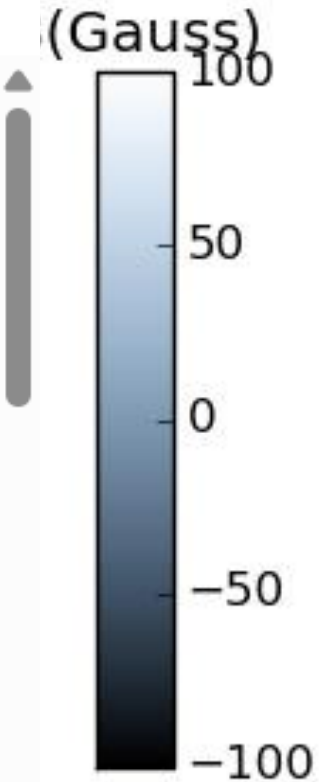


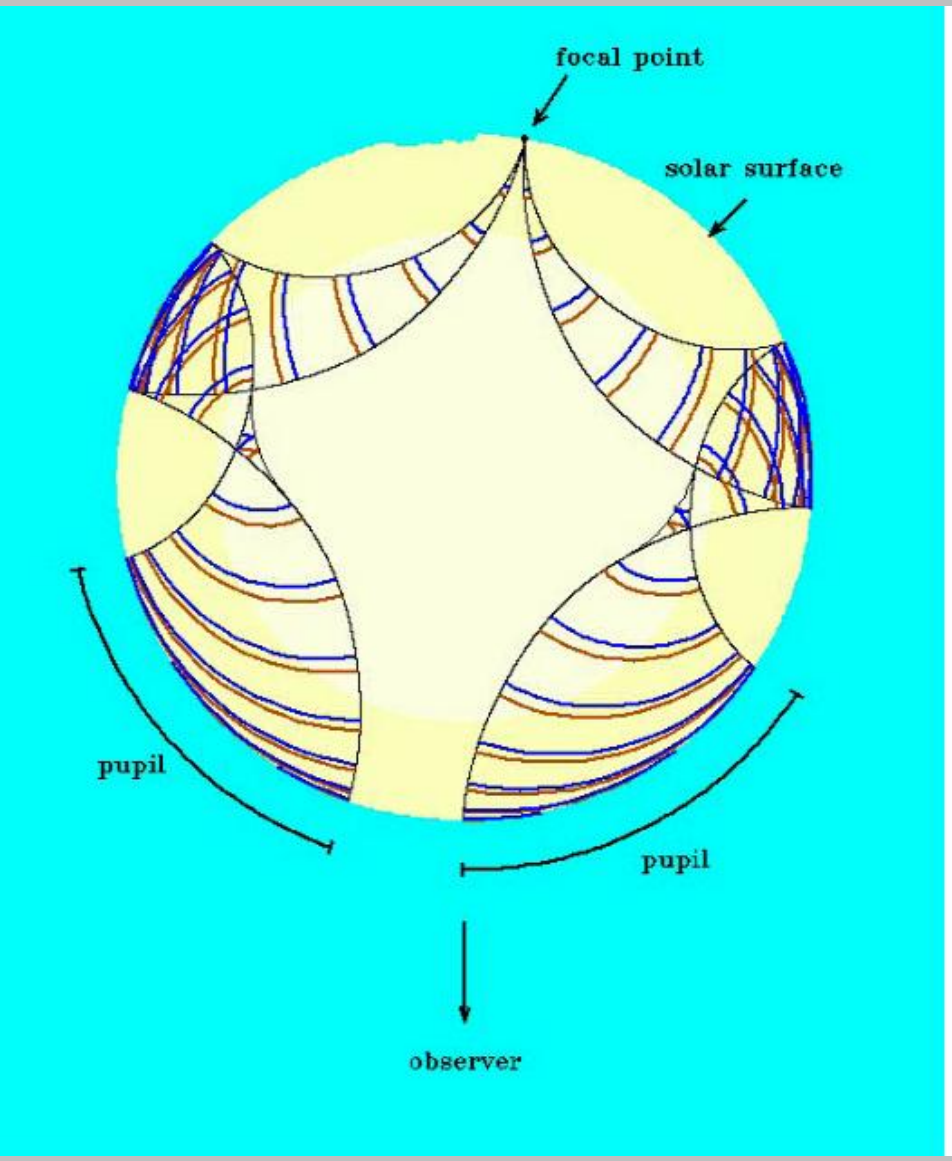
Resultaten helioseismologie

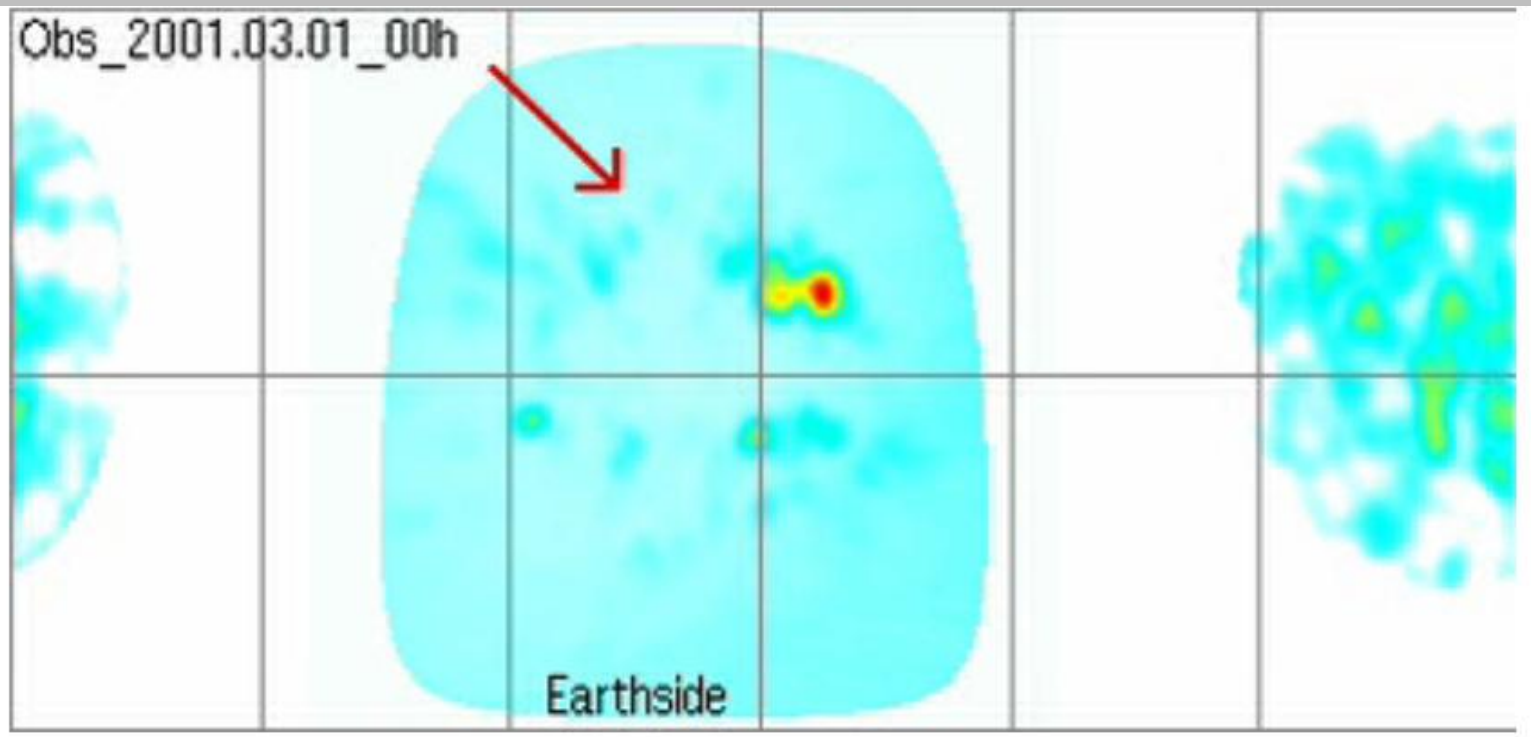
- Oplossing neutrino probleem
- Rotatiesnelheid inwendige van de zon
- Inzicht in zonnevlekken cyclus
- **Activiteit op de achterkant van de zon**
- Standaard model zon


τ(sec)
6
4
2
0
−2
−4
−6
−8
2025-03-02.5
90
60
30
0
-30
-60
-90
0
60
120
180
240
300
360
B(Gauss)
100
50
0
−50
−100


Join at menti.com | use code 5474 7411
Mentimeter
Hoe zou je informatie over de niet zichtbare kant van de zon kunnen verkrijgen?
3
3
0
2
Satelliet in de ruimte aan de andere kant van de zon
Golven die van de achterkant van de zon komen geven een focus op de voorkant diametraal er tegenover op de voorzijde
Het oppervlak van de zon wordt als spiegel gebruikt
Shellosotemische holografie
Menti
De zon in de ziel gekeken
Choose a slide to present

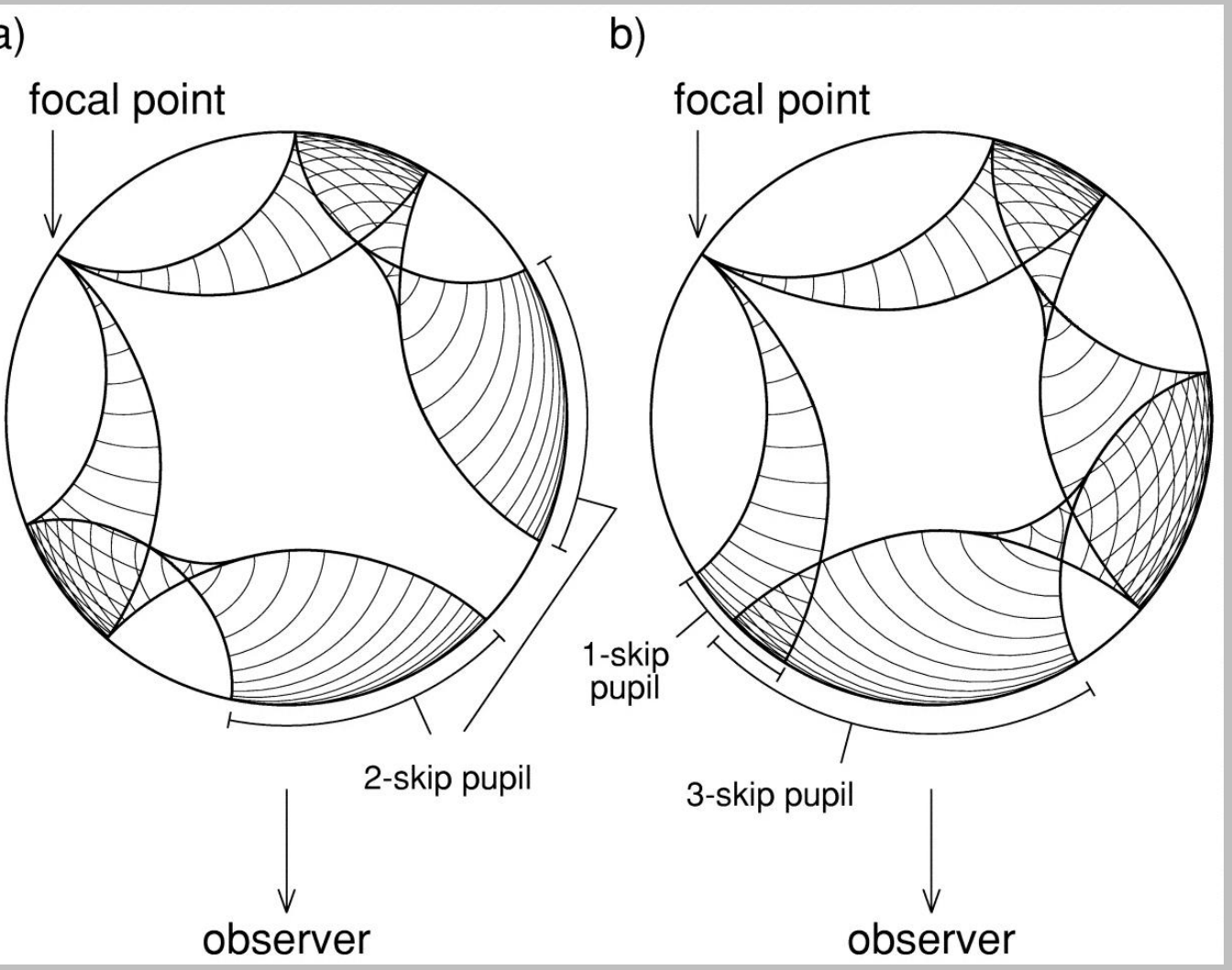

100
50
0
−50
−100





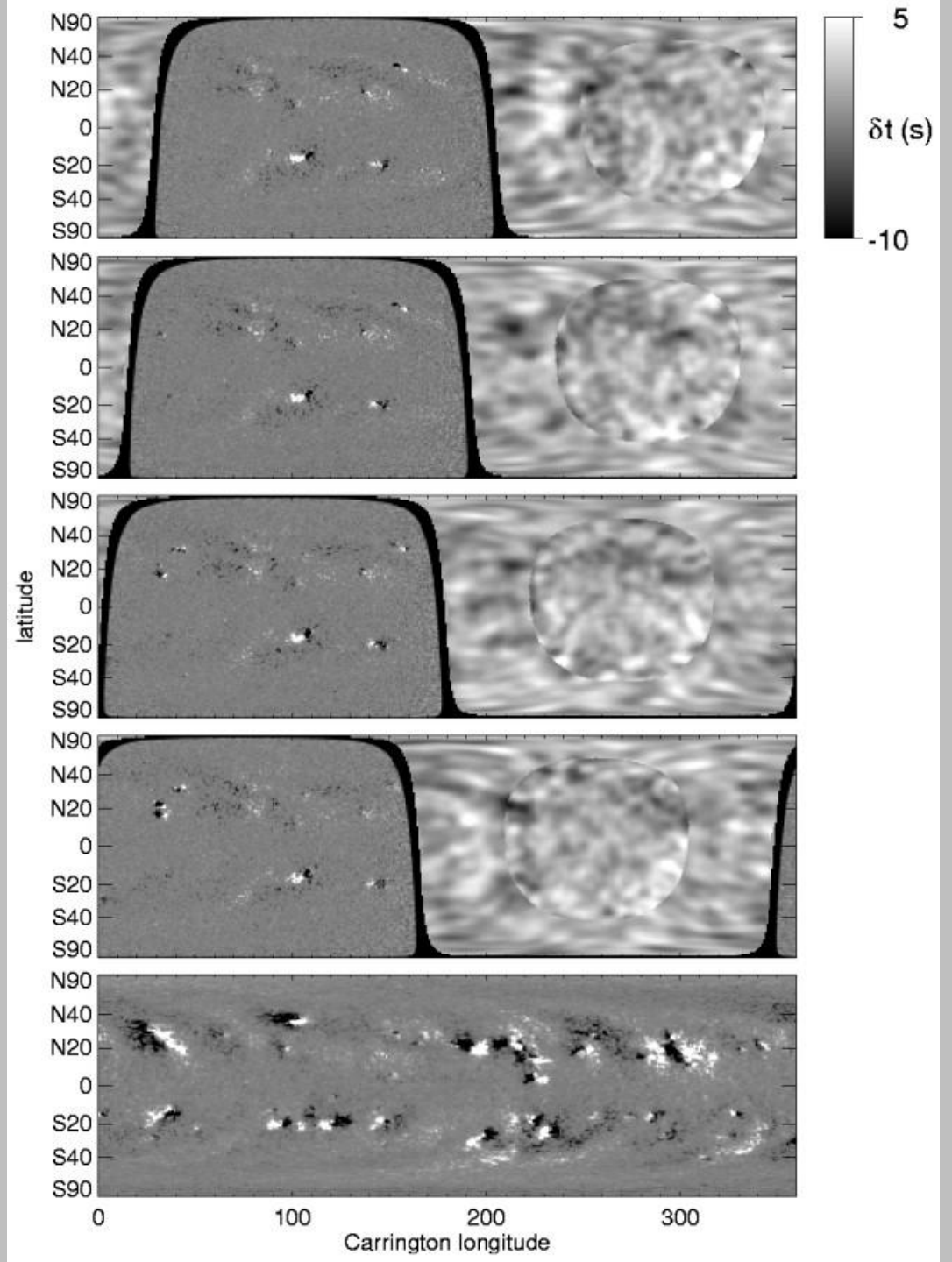
*Images of an active region on the **far side of the Sun** were derived by applying seismic holography to helioseismic observations.*

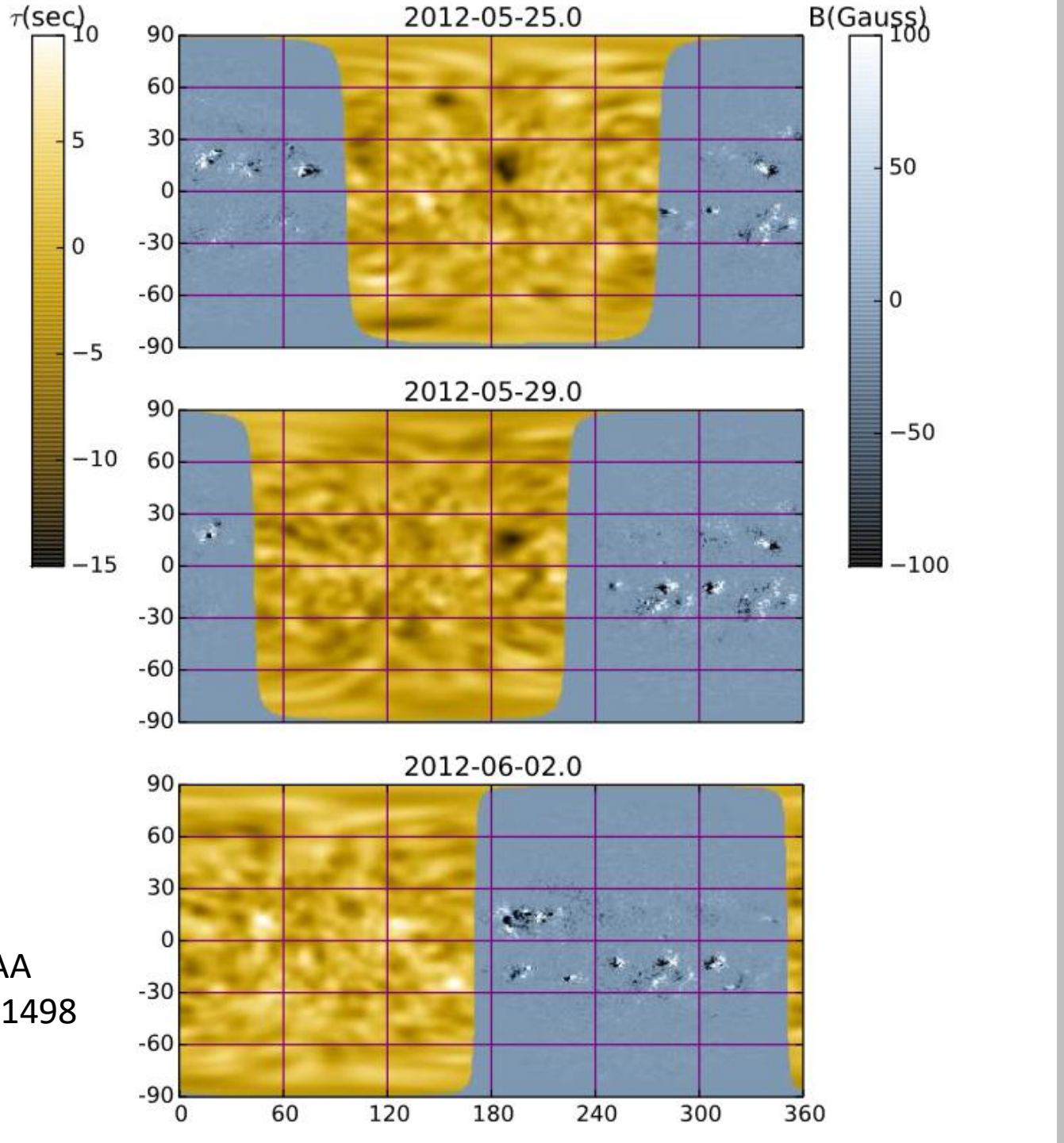
Helioseismische holografie



SEISMIC IMAGING OF THE FAR HEMISPHERE OF THE SUN

D. C. Braun





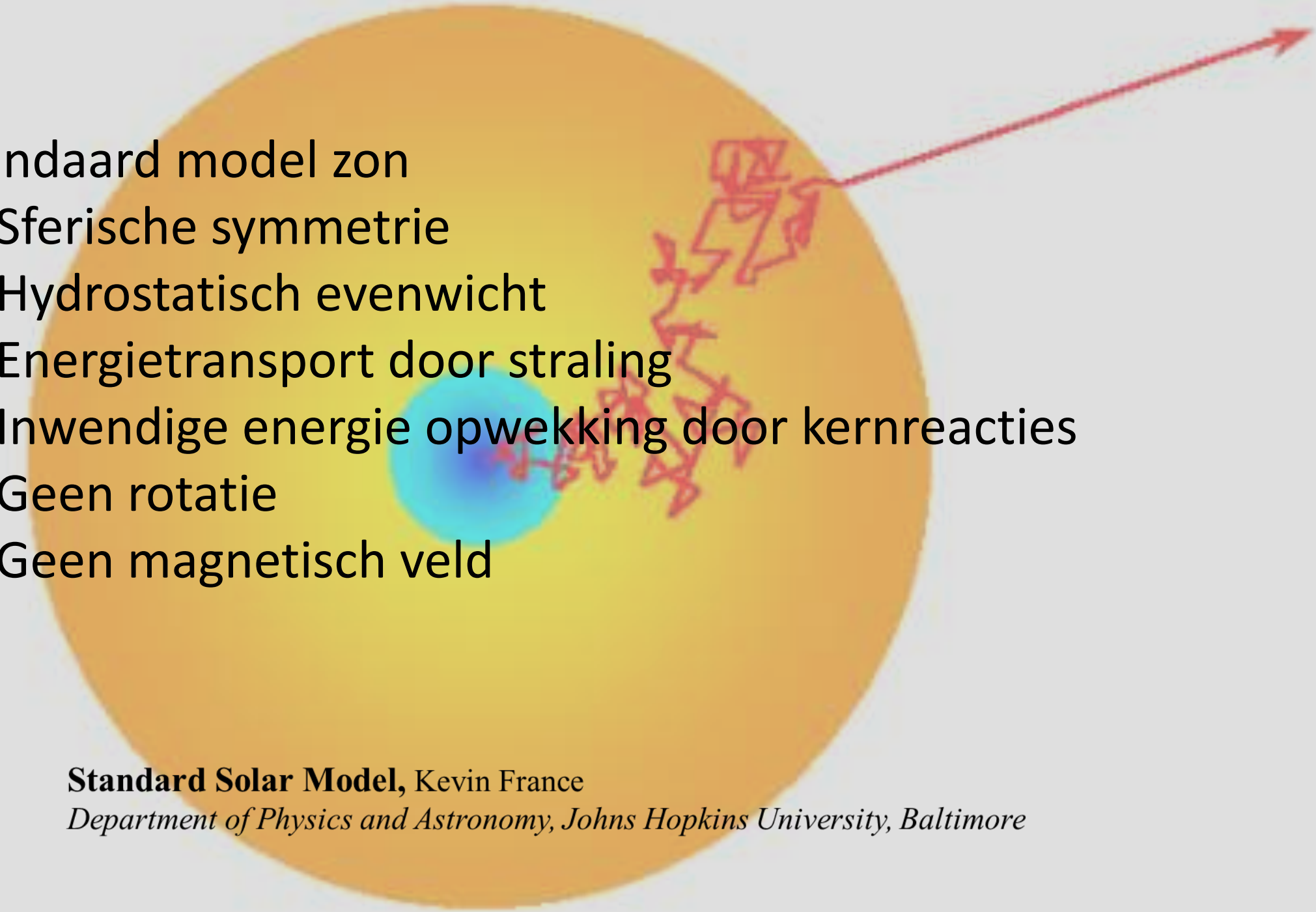
NOAA
AR11498

Resultaten helioseismologie

- Oplossing neutrino probleem
- Rotatiesnelheid inwendige van de zon
- Inzicht in zonnevlekken cyclus
- Activiteit op de achterkant van de zon
- **Standaard model zon**

Standaard model zon

- Sferische symmetrie
- Hydrostatisch evenwicht
- Energietransport door straling
- Inwendige energie opwekking door kernreacties
- Geen rotatie
- Geen magnetisch veld



Standard Solar Model, Kevin France

Department of Physics and Astronomy, Johns Hopkins University, Baltimore

1 Druk:

dP/dr = -Gmρ/r2

P = ρT R/μ (ideale gaswet)

2 Temperatuur

dT/dr = 3kρL/16πacr2T3 (straling

k = opaciteit) of

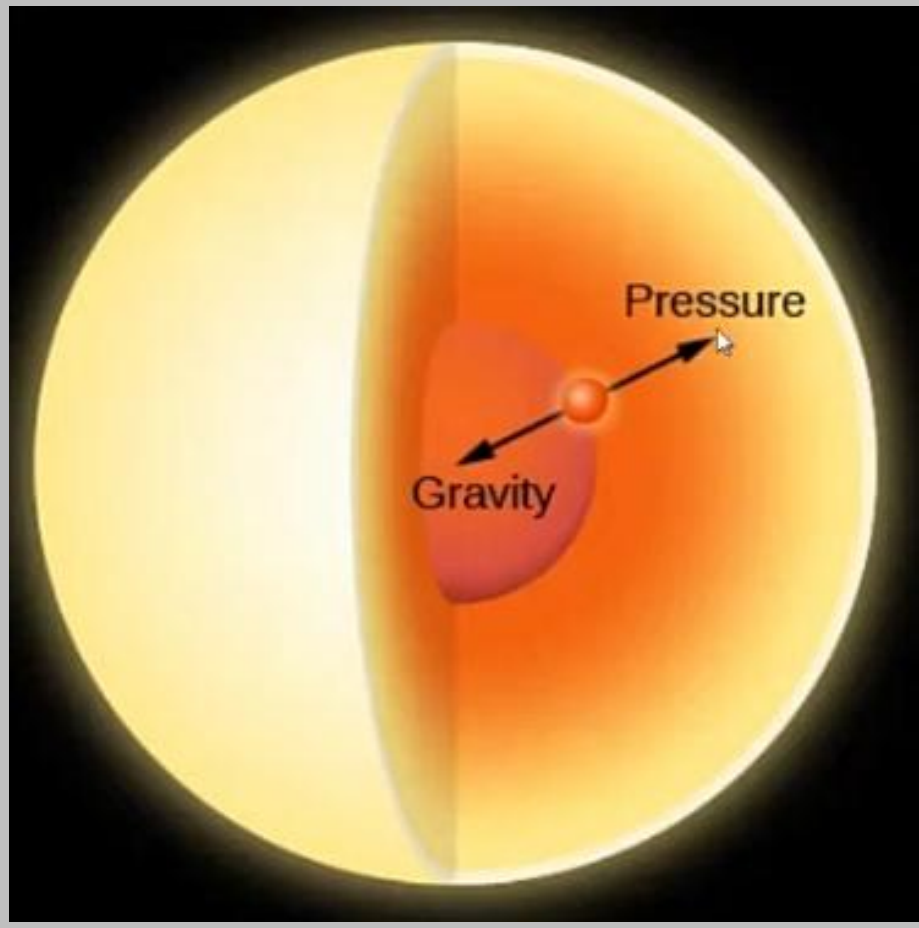
dT/dr = (1 -1/g) (T/P) dP/dr (geleiding)

3 Energieopwekking

dL/dr = $4\pi r^2 \rho \varepsilon$ (kernfusie)

4 Randvoorwaarden:

Lichtkracht, Leeftijd, Straal zon



Eisen aan een goed standaardmodel

- Diameter (1,4 miljoen km) $\pm 5*10^{-4}$ R_{zon}
- Massa: (2: 10^30 kg)
- Uitgestraalde energie (0.38 10^{27} W) $\pm 5*10^{-3}E_{zon}$
- Leeftijd (5,60 Gj) ± 0,1 Gj

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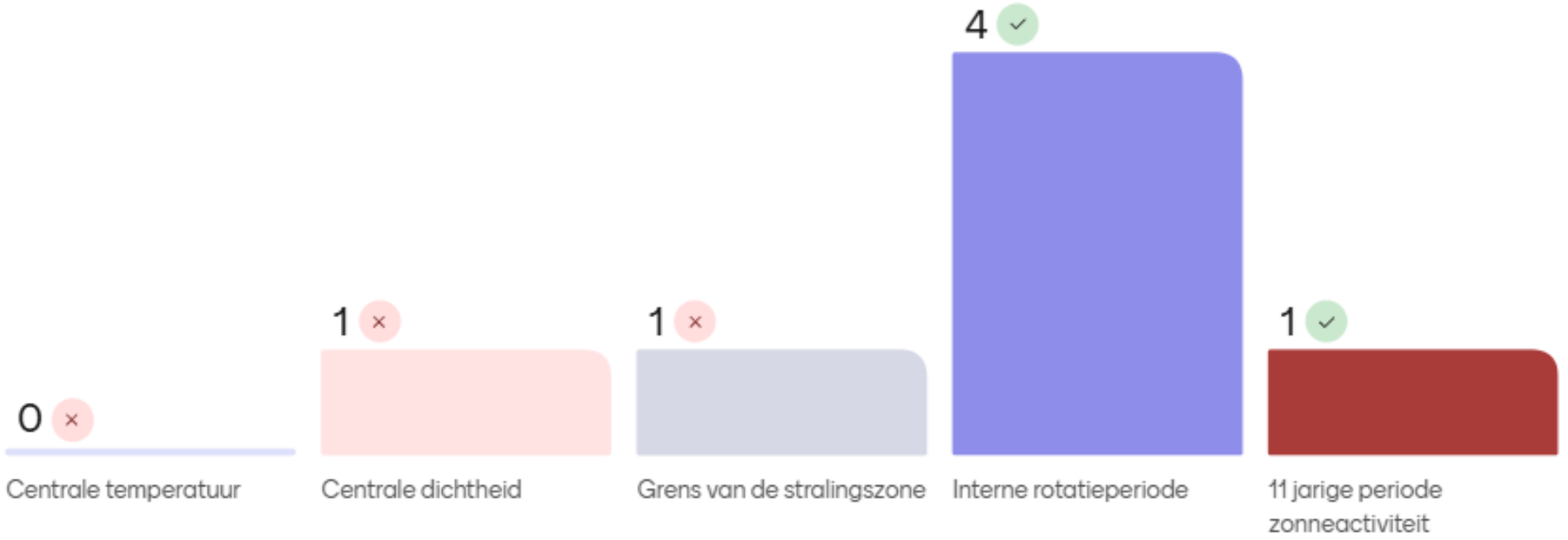
Mentimeter

Welke parameters werden door het standaard model slecht voorspeld?



2

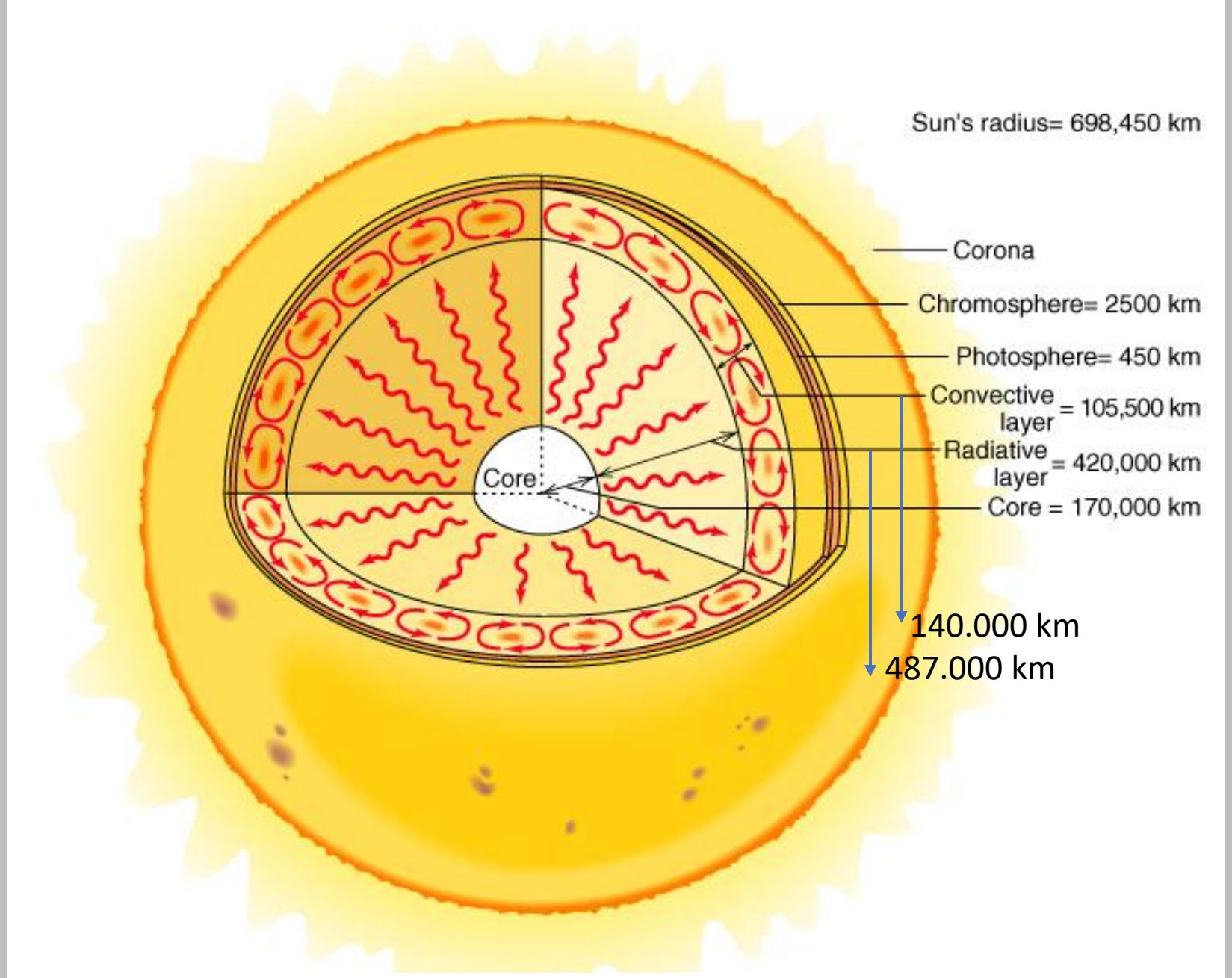
Menti

De zon in de ziel gekeken

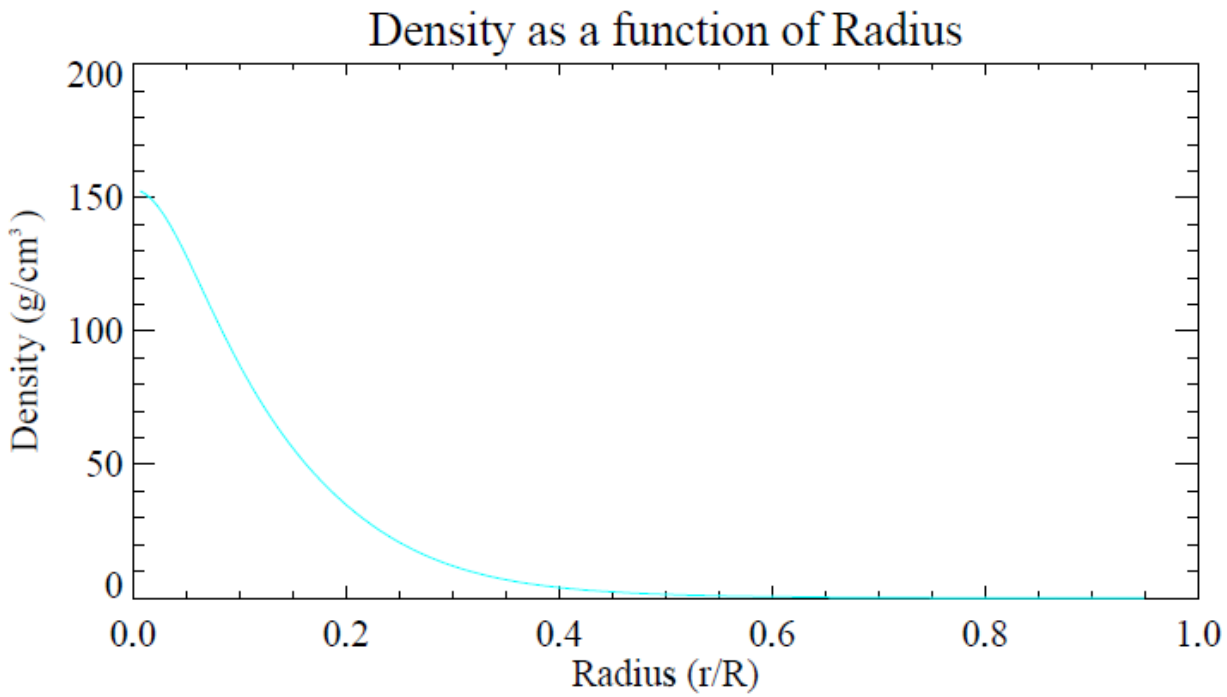
Choose a slide to present

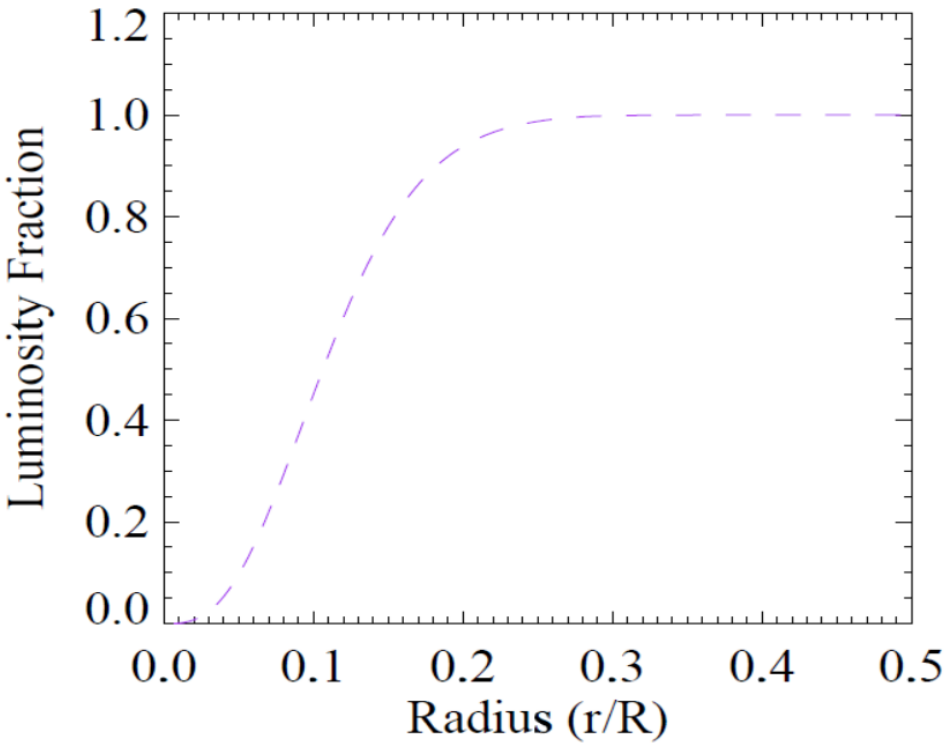
Inwendige van de zon met en zonder Helioseismologie

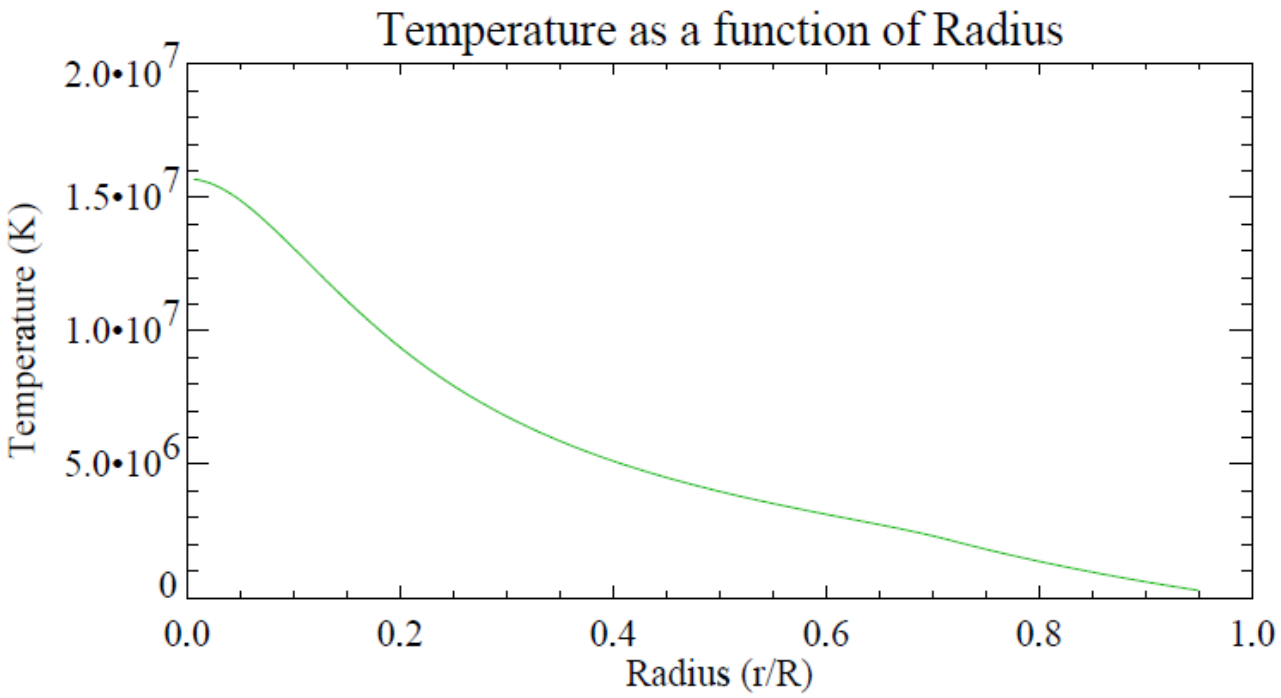
	T kern K	ρ kern g/cm^3	He/H Initieel	He/H oppervlak	Grens Convectiezone
Model SSM (niet seismisch)	15.54 10^6	150.6	0,2645	0,235	0.713 Rzon
Model SeSM (seismisch)	15.74 10^6	153.0	0,277	0.250	0,69 -0.73 Rzon

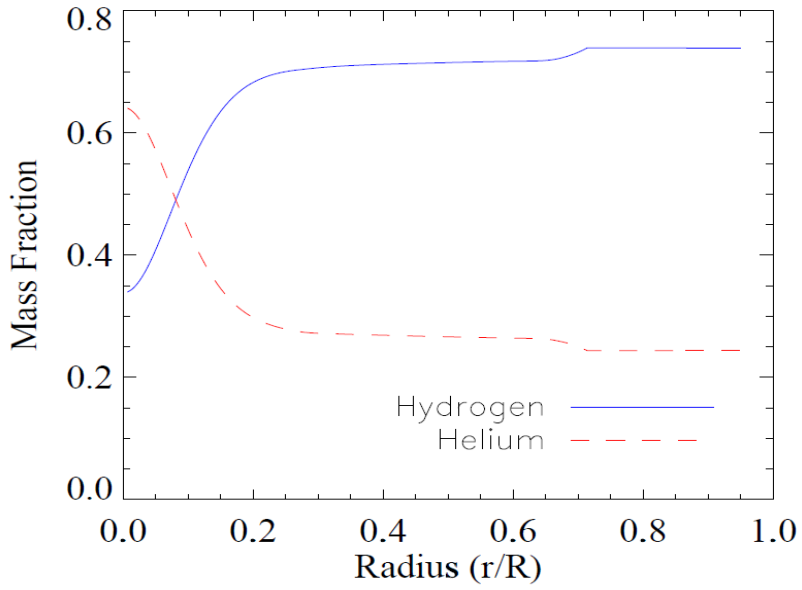


https://eso.org/public/outreach/eduoff/vt-2004/mt-2003/mt-sun.html#interior


Density as a function of Radius
Density (g/cm³)
200
150
100
50
0
0.0
0.2
0.4
0.6
0.8
1.0
Radius (r/R)

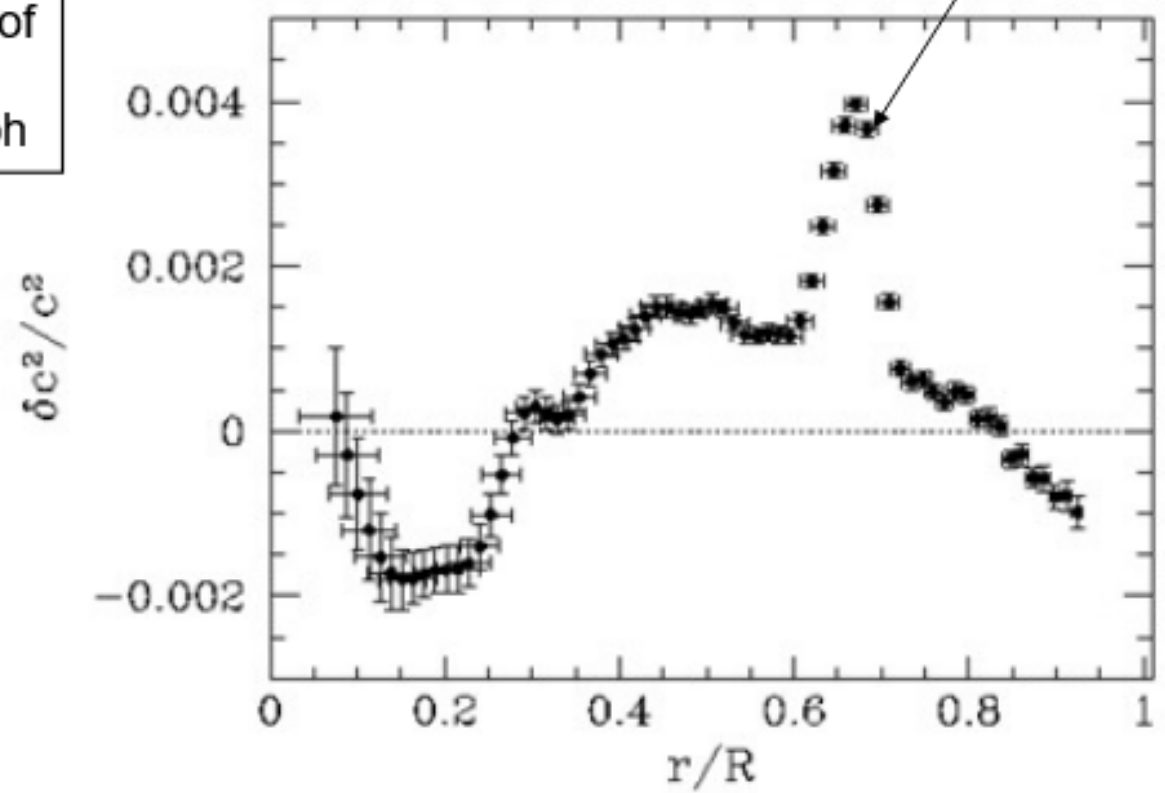

Luminosity Fraction
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
Radius (r/R)


Temperature as a function of Radius
Temperature (K)
2.0•10^7
1.5•10^7
1.0•10^7
5.0•10^6
0
0.0
0.2
0.4
0.6
0.8
1.0
Radius (r/R)


Mass Fraction
0.8
0.6
0.4
0.2
0.0
Hydrogen
Helium
0.0
0.2
0.4
0.6
0.8
1.0
Radius (r/R)

Possibly due to increased turbulence

Note change of scale from previous graph



Deviations of the observed sound speed from the model. The differences are mostly less than 0.2%

Wat leeft Helioseismologie ons gebracht

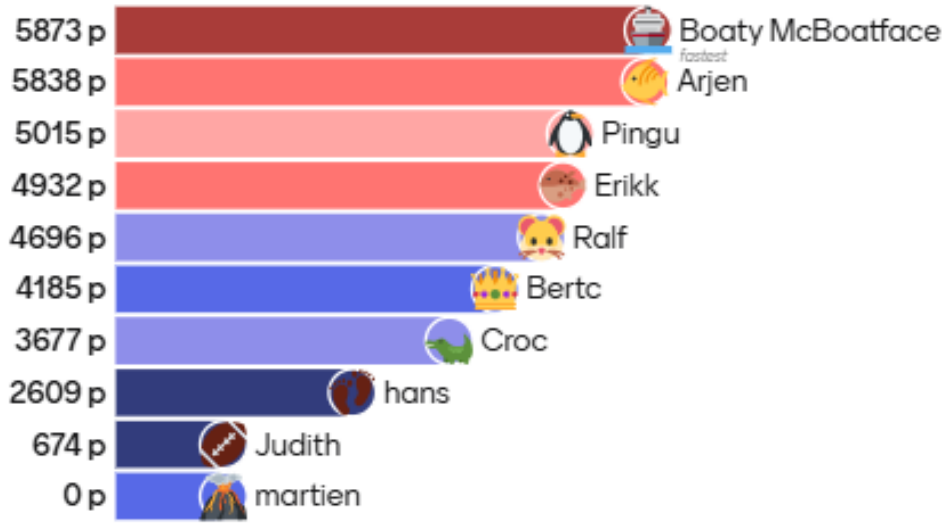
- Het neutrino probleem is een probleem van de neutrino’s
- De geluidssnelheid en de dichtheid als functie van de diepte zijn vastgesteld
- De inwendige rotatie van de zon met
- torsie oscillaties samenhangen met de activiteitsyclus van de zon.
- De chemische samenstelling in het inwendige
- Het inwendige energietransport
- Aktivieitsgebieden op acherkantkant van de zon in kaart brengen
- De structuur en stroming bij zonnevlekken.


Mentimeter
Wat onthoudt je van deze workshop?
11 responses
Heel interessant
Complex
Verrassende gevoeligheid va de dopplermetingen
Boeiend
Dat er erg slimme mensen rondlopen met briljante ideeën
Dynamische processen in de zon
Inzicht in 11 jaar's cyclus
Mooi voorbeeld van interpretatie van fourier componenten
Teveel om op te noemen
De knopen die in de zon en in mijn hoofd zitten.
Heel veel zon heel mooi
MJ
Menti
De zon in de ziel gekeken
Choose a slide to present

Mentimeter

MJ

Quiz leaderboard



Menti

De zon in de ziel gekeken

Choose a slide to present

Resultaten helioseismologie

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- Rotatiesnelheid inwendige van de zon
- Inzicht in zonnevlekken cyclus
- Activiteit op de achterkant van de zon
- Standaardmodel zon
- **Rotatieperiode kern zon 1 week?**

Table I

Frequencies and errors, in μHz, as measured by GOLF instrument. Bracketted frequencies are possible identifications with S/N < 1 (see text).

n	$\ell = 0$	$\ell = 1$	$\ell = 2$	$\ell = 3$	$\ell = 4$	$\ell = 5$
8		(1329.49±0.64)	(1393.51±0.49)			
9	(1407.77±0.32)	1472.71±0.13	(1535.95±0.13)	(1591.57±0.80)		
10	1548.40±0.04	1612.74±0.08	1674.31±0.21	(1729.68±1.80)		
11	1686.54±0.04	1749.29±0.04	1810.17±0.16	(1865.26±1.37)		
12	1822.20±0.05	1885.08±0.04	1945.73±0.09	(2001.21±0.65)	(2046.30±1.50)	
13	1957.45±0.06	2020.81±0.04	2082.06±0.07	2137.75±0.19	(2187.40±2.00)	
14	2093.51±0.04	2156.80±0.09	2217.80±0.12	2273.23±0.19	2321.94±1.00	
15	2228.69±0.07	2291.80±0.08	2352.32±0.08	2407.85±0.28	2460.10±1.00	
16	2362.69±0.08	2425.48±0.08	2485.89±0.10	2541.65±0.14	2593.70±1.00	
17	2496.04±0.06	2559.21±0.08	2619.64±0.12	2676.19±0.19	2730.00±1.00	(2778.10±0.50)
18	2629.82±0.08	2693.27±0.07	2754.43±0.08	2811.46±0.11	2864.52±0.47	2913.70±0.30
19	2764.05±0.07	2828.01±0.10	2889.64±0.08	2946.95±0.12	3000.94±0.53	3050.20±0.30
20	2898.83±0.07	2963.33±0.08	3024.65±0.09	3082.28±0.14	3137.24±0.49	(3185.77±0.30)
21	3033.68±0.06	3098.10±0.08	3159.91±0.09	3217.91±0.15	3274.01±0.77	
22	3168.53±0.06	3233.22±0.08	3295.22±0.13	3353.88±0.48	3410.00±1.50	
23	3303.22±0.09	3368.55±0.09	3430.97±0.15	3490.24±0.67	3547.60±2.00	
24	3438.72±0.12	3503.86±0.14	3566.62±0.24	3626.21±0.71	3686.70±2.00	
25	3574.50±0.16	3640.02±0.20	3703.23±0.43	3763.05±2.30		
26	3710.54±0.51	3776.46±0.25	3838.99±0.79	3901.29±2.00		
27	3846.77±0.27	3913.53±0.32	3977.19±0.86	4036.00±2.25		
28	3984.09±0.60	4049.20±0.40	4113.82±1.75	4173.55±3.05		
29	4119.95±0.91	4186.25±0.51	4250.88±2.16	4309.66±3.30		
30	4258.79±1.94	4325.00±0.66	4389.01±2.13	4450.00±3.50		
31	4395.22±2.07	4462.28±1.84	4527.00±3.00			
32	4535.00±2.62	4600.42±1.52				
33	4672.70±3.00	4736.60±2.00				
34	4808.00±3.00	4876.50±2.00				