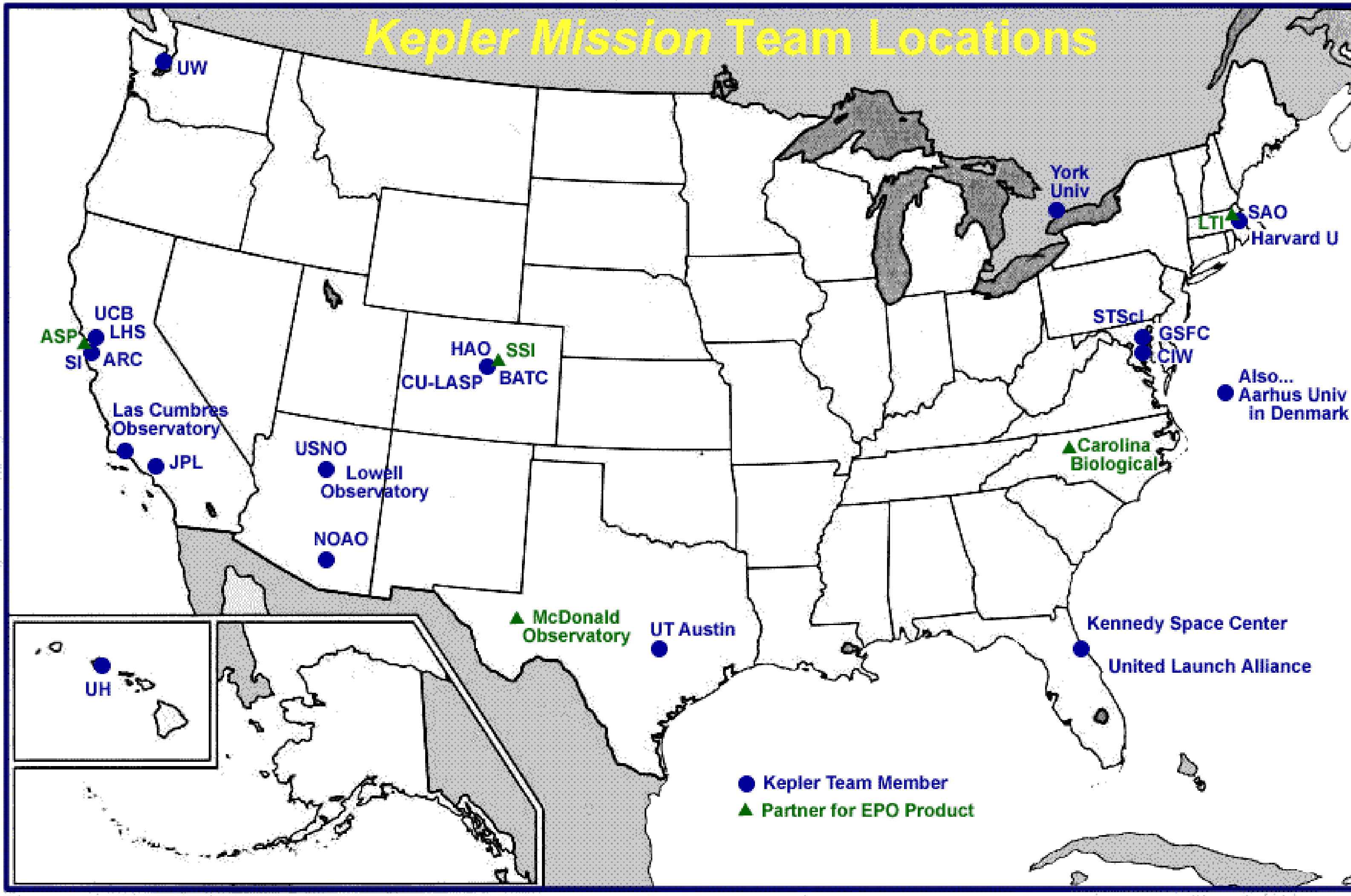
Kepler satellitten

Exoplaneter og Asteroseismologi

Rasmus Handberg
rasmush@phys.au.dk

Astronomidag
19. marts 2010



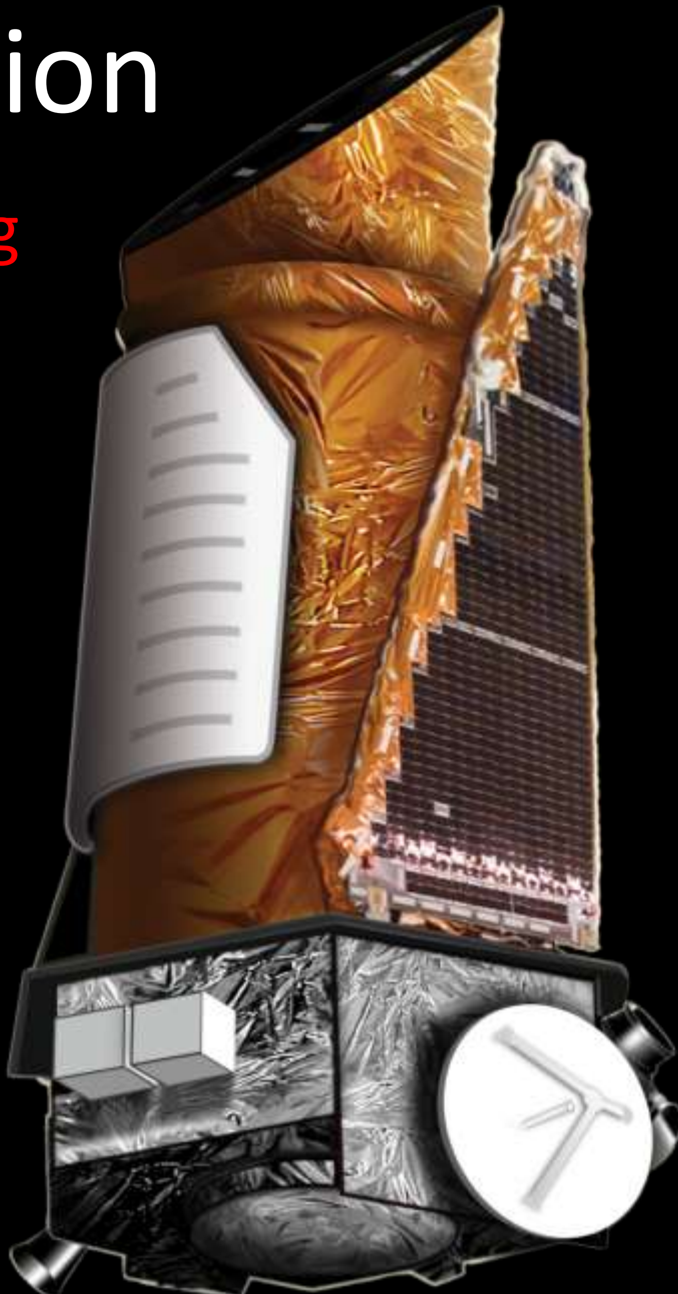
Abbreviations

ARC-NASA Ames Research Center
Arhus University, Denmark
ASP-Astronomical Society of the Pacific
BATC-Ball Aerospace & Technology Corp
CIW-Carnegie Institution of Washington
Carolina Biological
CU-LASP-University of Colorado-
Laboratory for Atmospheric & Space Physics
GSFC-NASA Goddard Space Flight Center
HAO-High Altitude Observatory
Harvard University
JPL-Jet Propulsion Laboratory
Kennedy Space Center
LTI-Learning Technologies, Inc
LHS-Lawrence Hall of Science
Lowell Observatory
MacDonald Observatory
NOAO-National Optical Astronomy Observatory
(WIYN Observatory)
SI-SETI Institute
SAO-Smithsonian Astrophysical Observatory
SSI-Space Science Institute
STScI-Space Telescope Science Institute
USNO-US Naval Observatory
UH-University of Hawaii
UW-University of Washington
UCB-University of Califonia, Berkeley
United Launch Alliance
UT-University of Texas, Austin
York University

kepler.nasa.gov

Kepler's mission

At finde Jordens tvilling



Er planeter som Jorden almindelige?

Er der mulighed for liv andre steder?

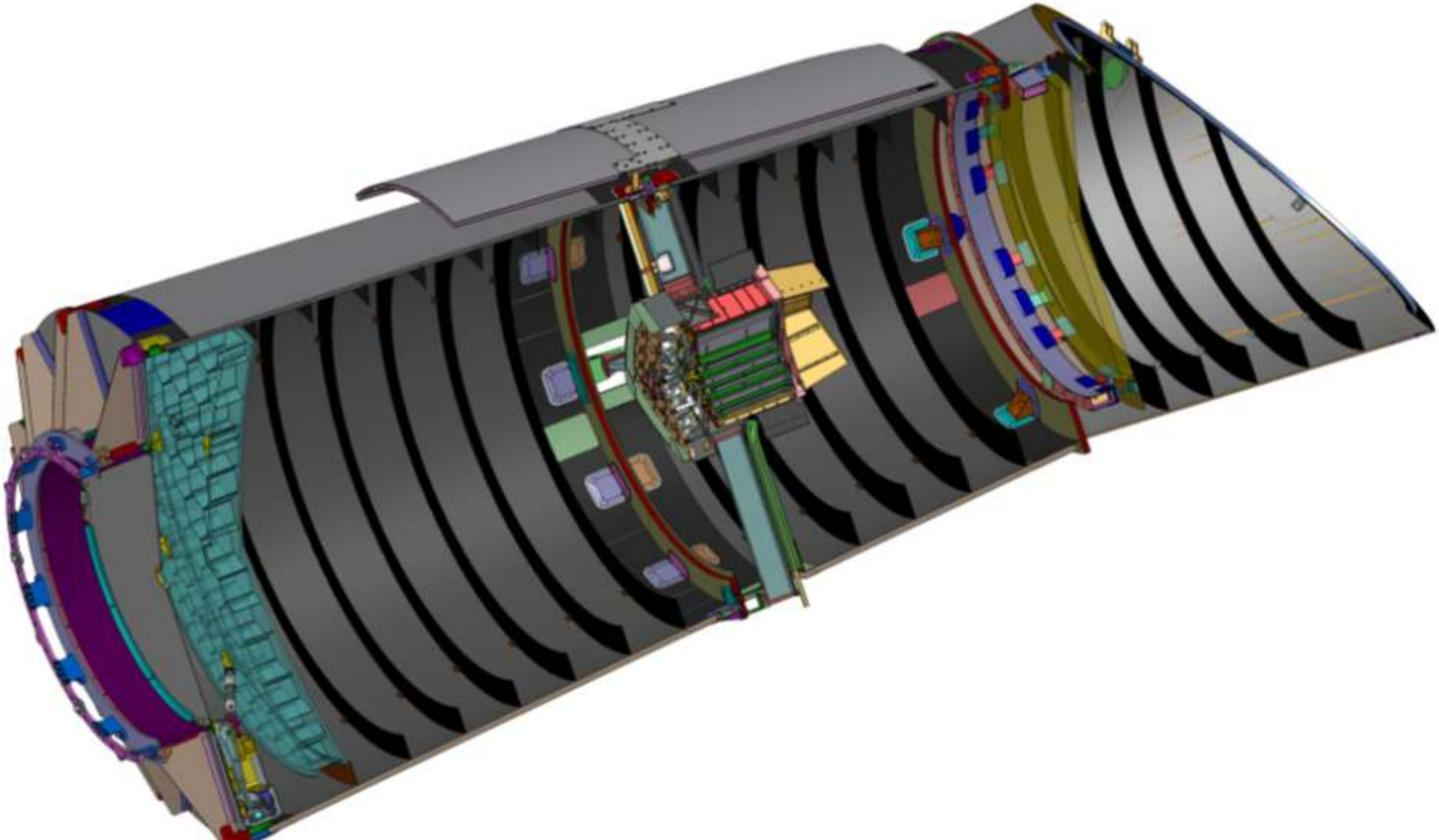
Ligner andre solsystemer vores?

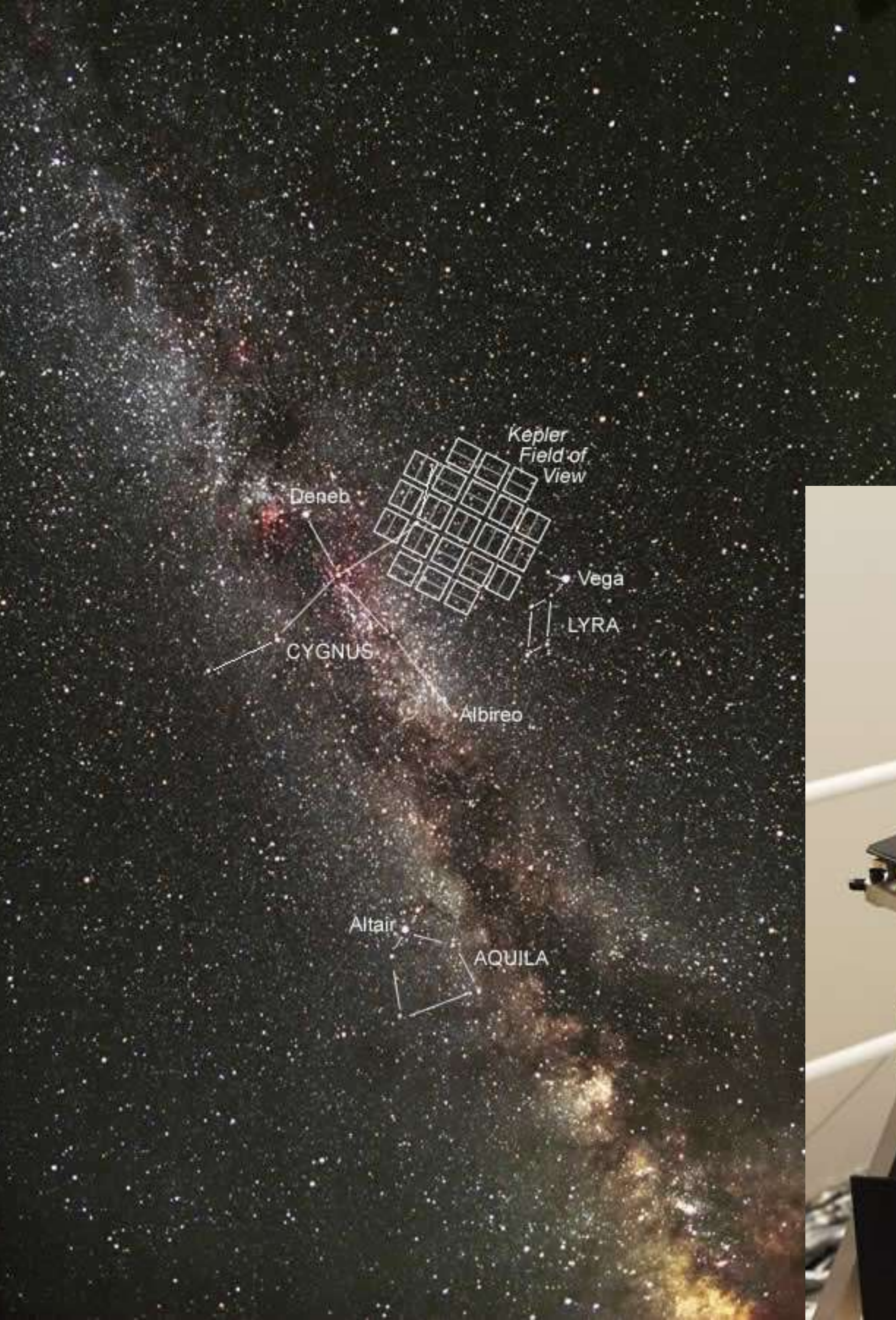
Planet + stjernedannelse

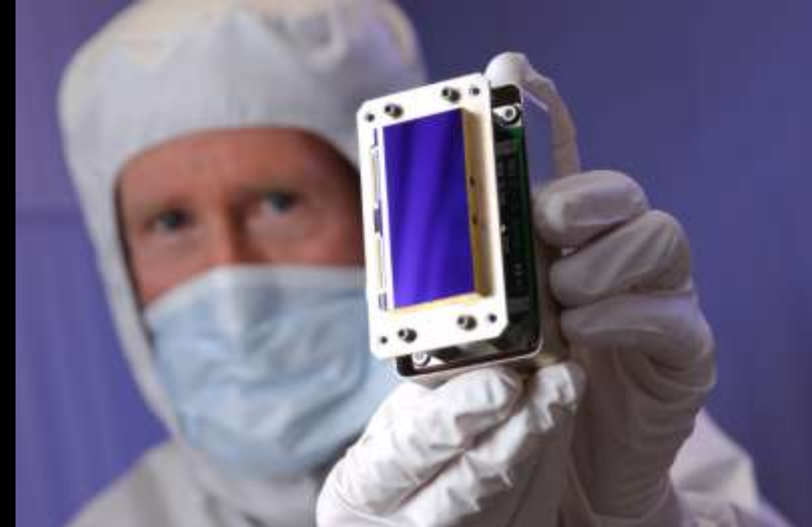
Hvordan?

Skal holde nøje øje med 170.000 stjerner

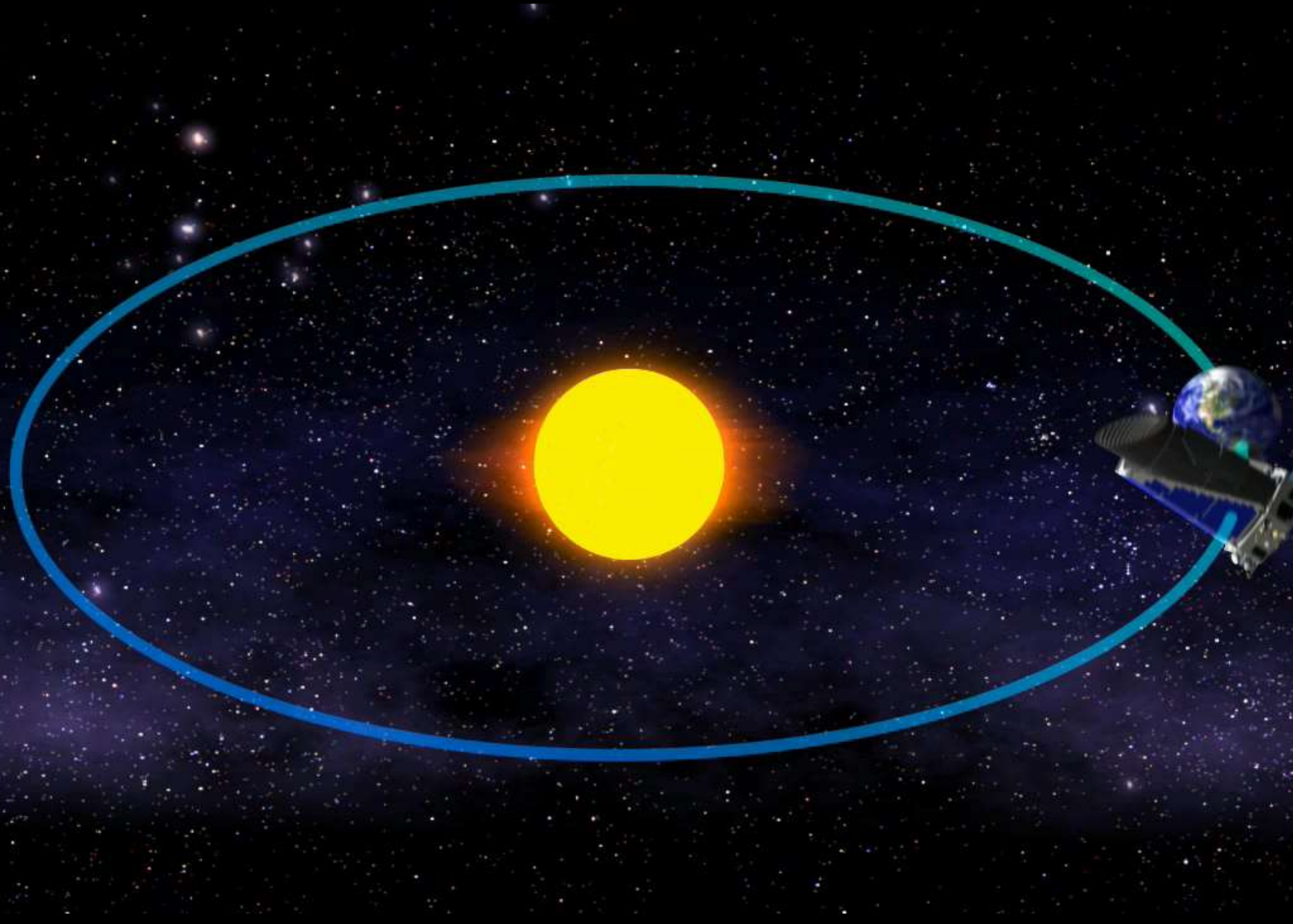
I over 3½ år – Non-stop!

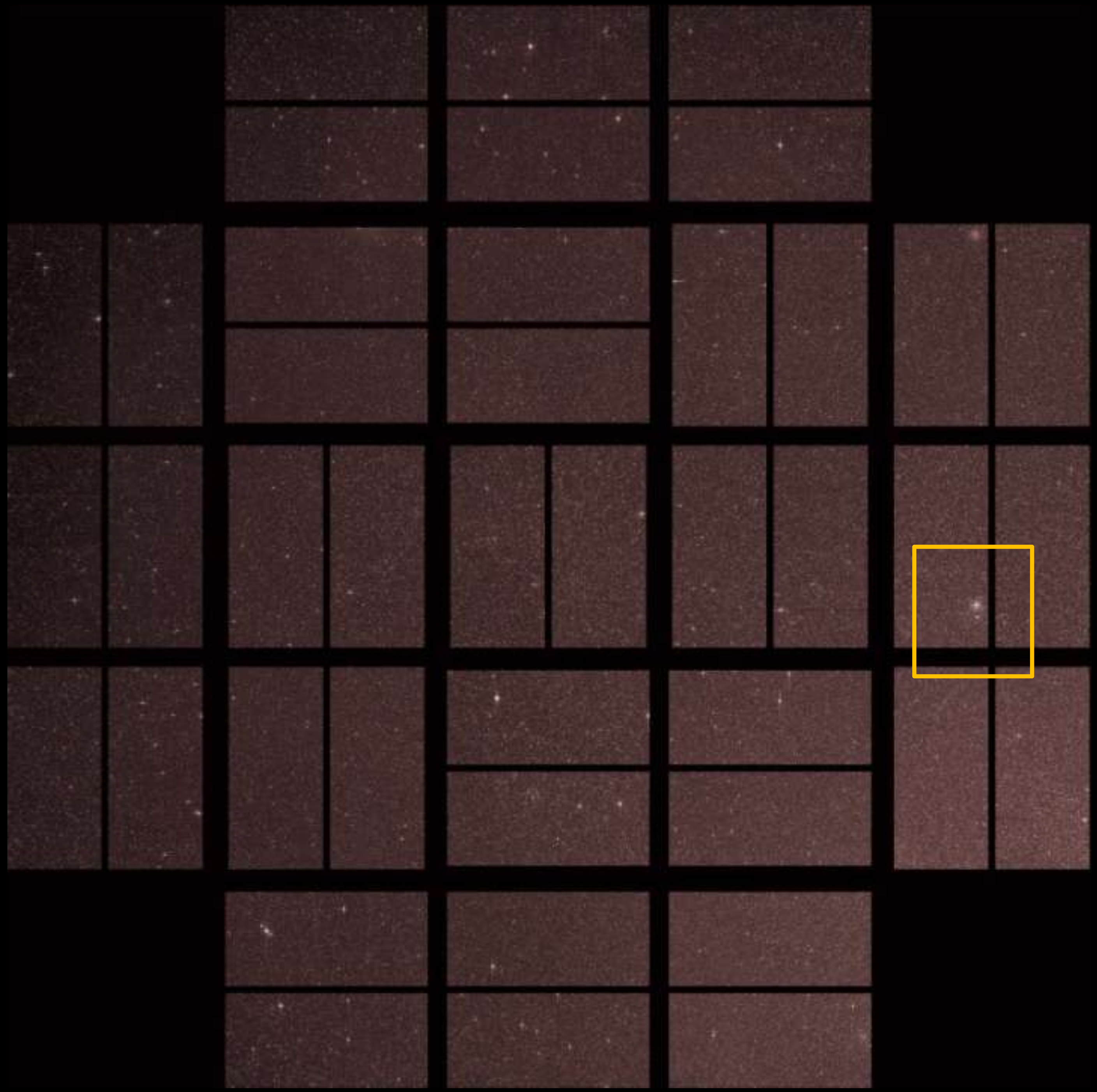


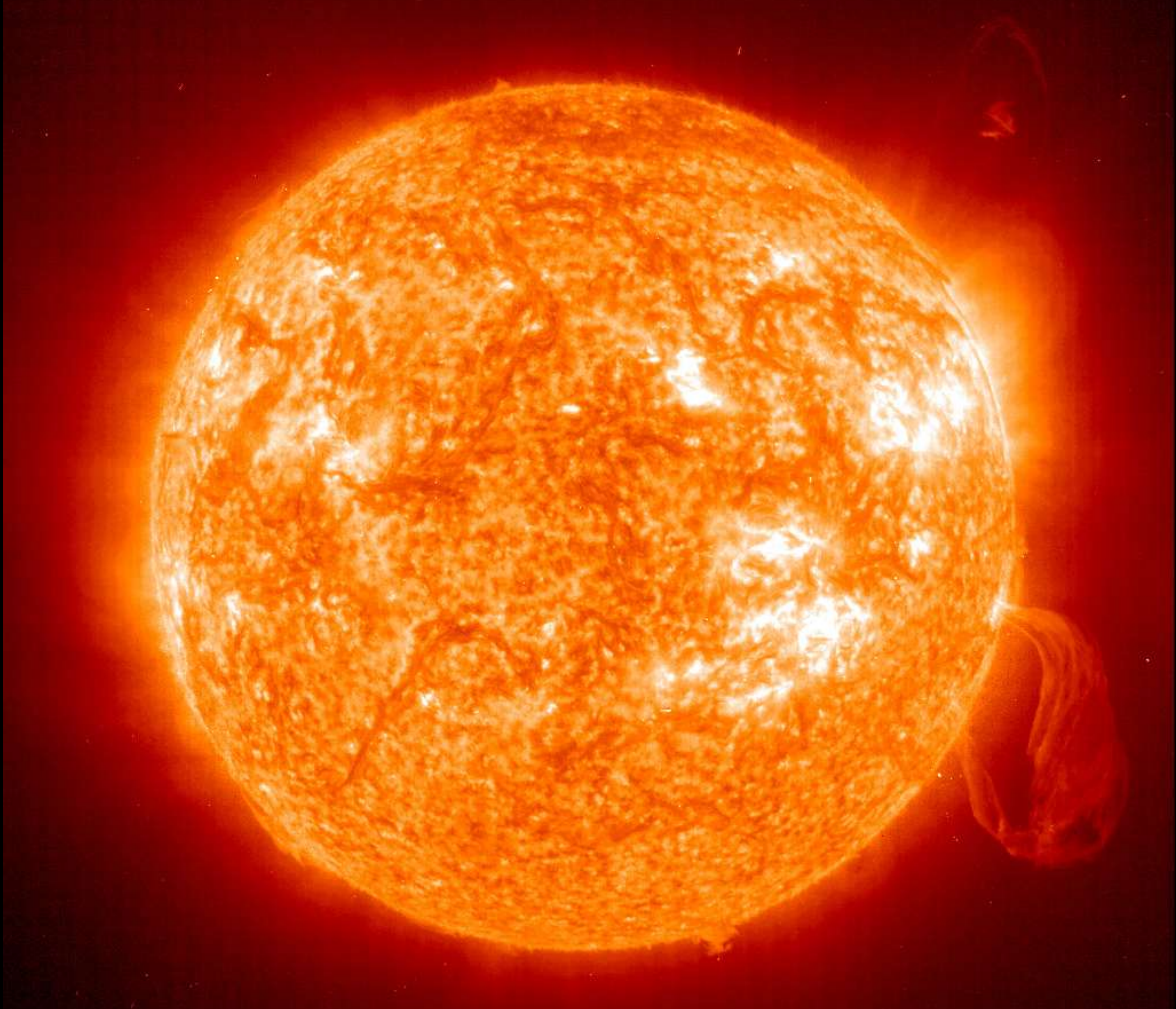

Kepler
Field of
View
Deneb
Vega
LYRA
CYGNUS
Albireo
Altair
AQUILA

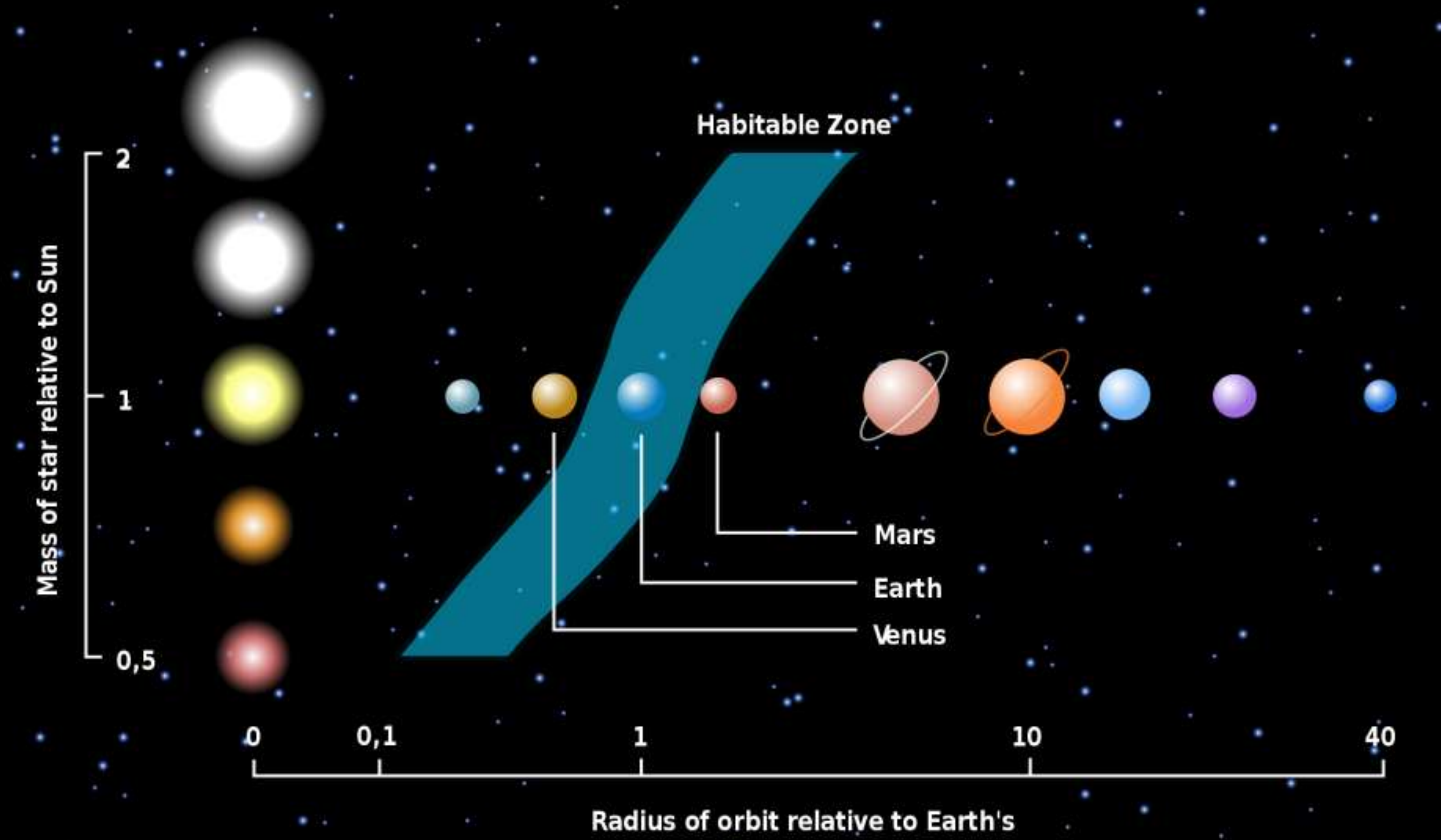


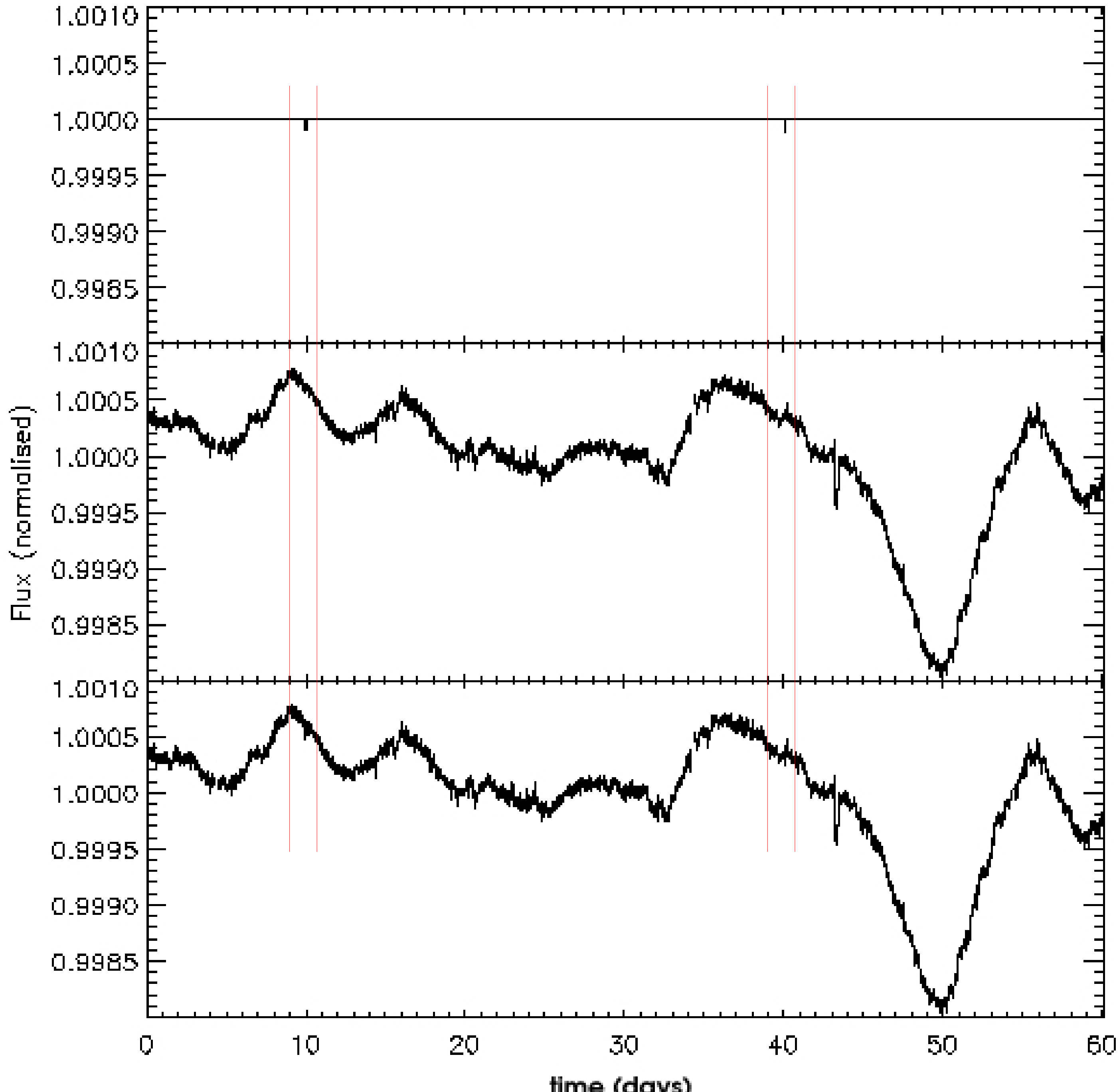

7. marts 2009 03:49:57 UTC





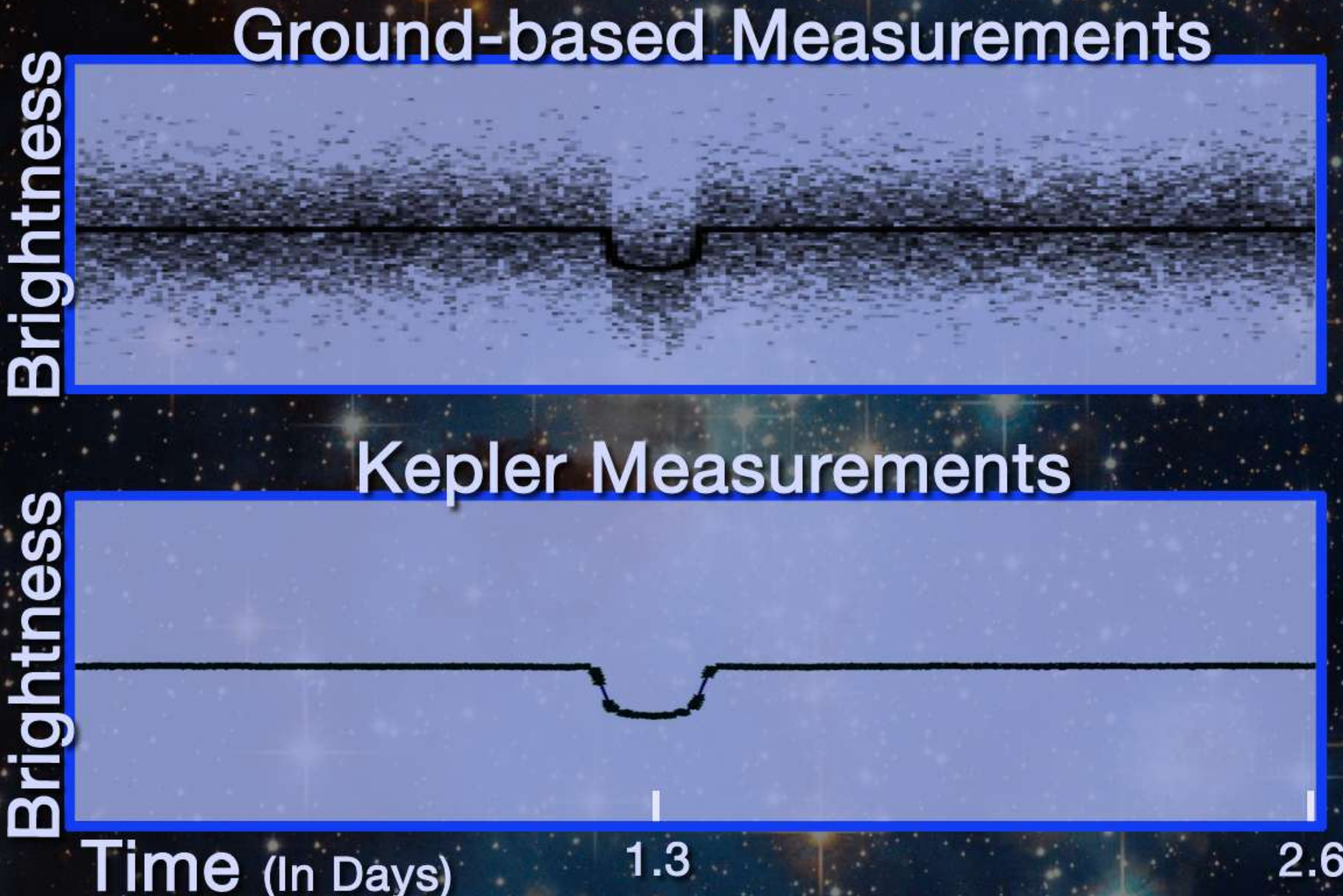



Habitable Zone
Mass of star relative to Sun
2
1
0,5
Mars
Earth
Venus
0
0,1
1
10
40
Radius of orbit relative to Earth's

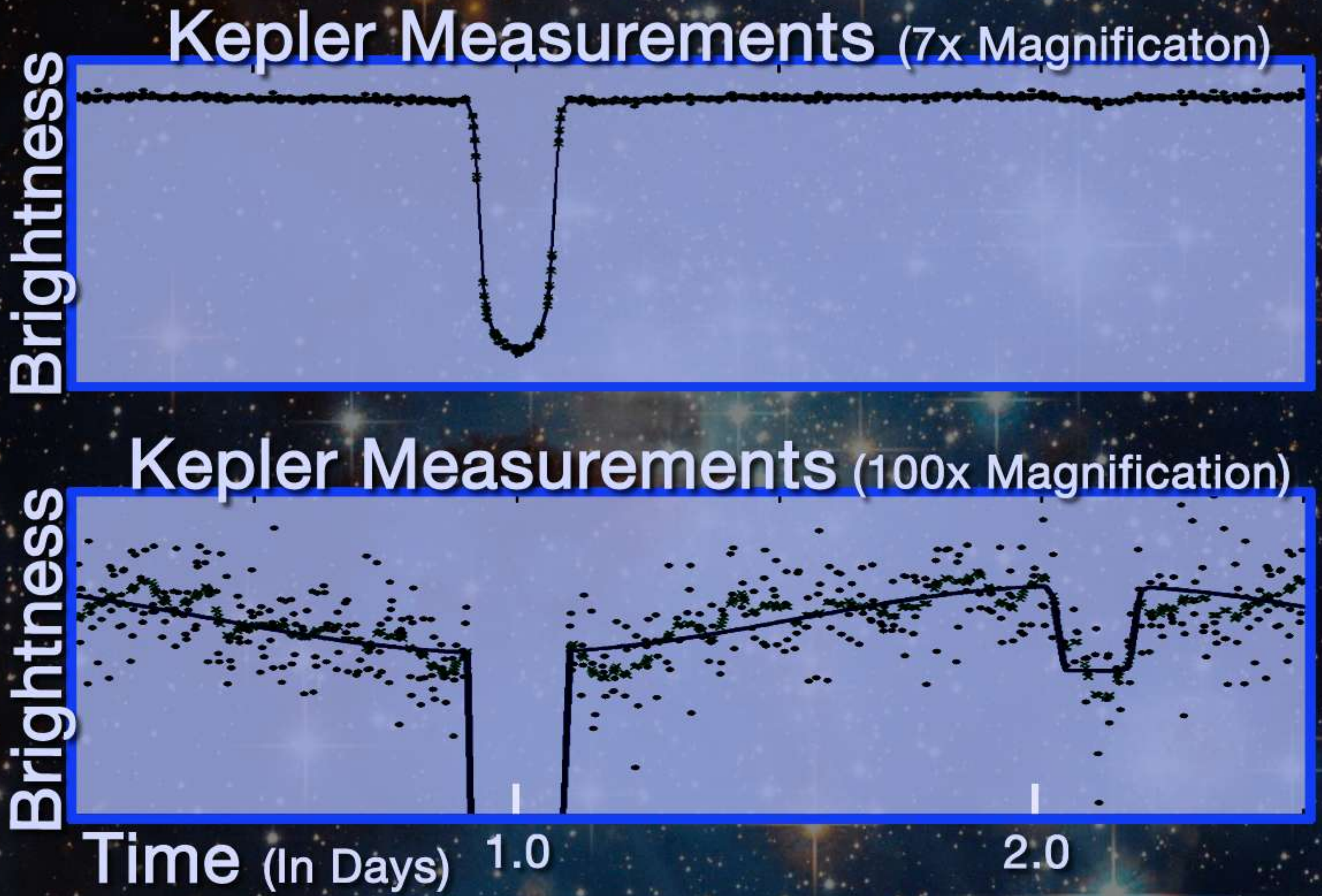


Flux (normalised)
time (days)
1.0010
1.0005
1.0000
0.9995
0.9990
0.9985
0
10
20
30
40
50
60

HAT-P-7 Light Curves

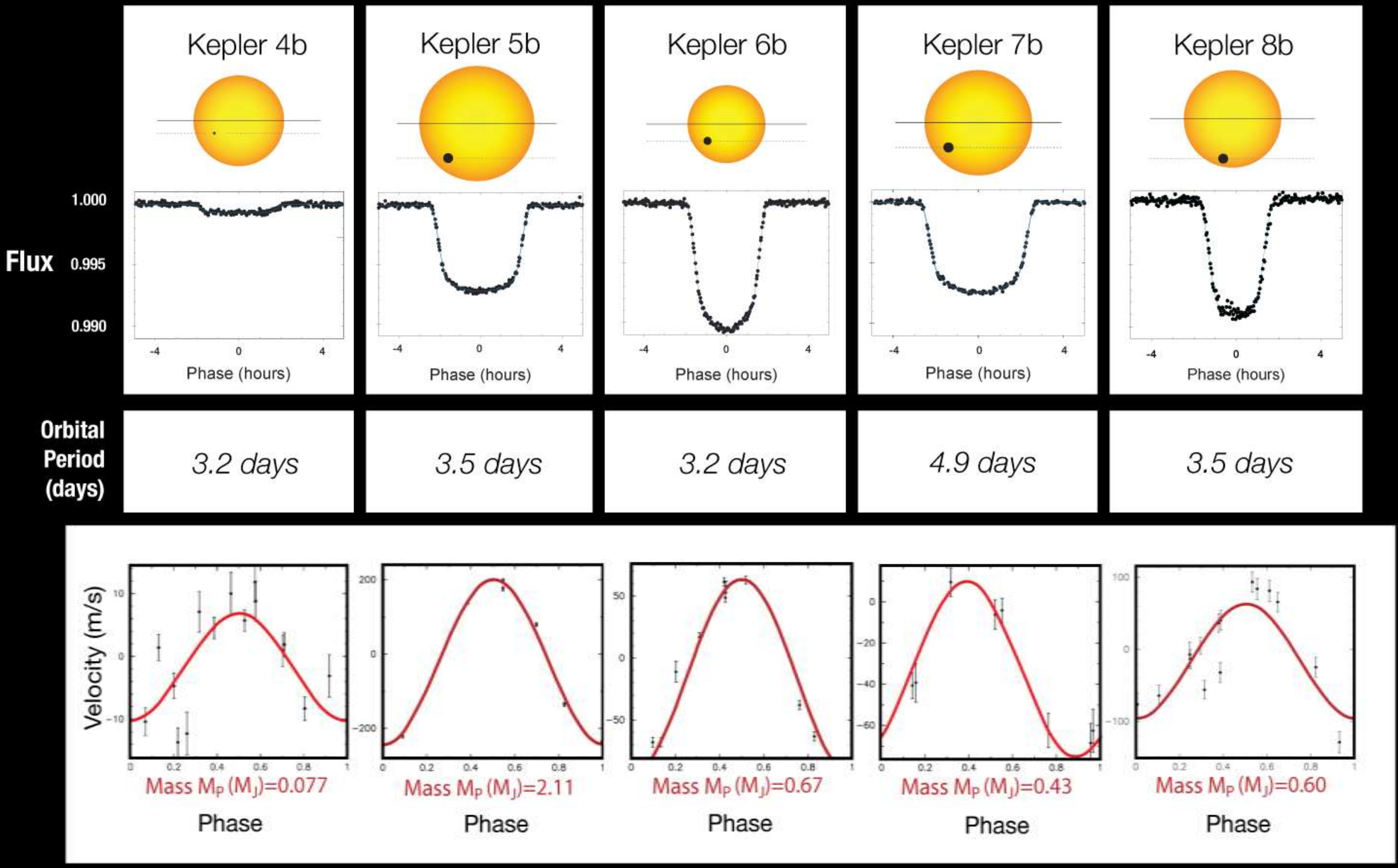


HAT-P-7 Light Curves

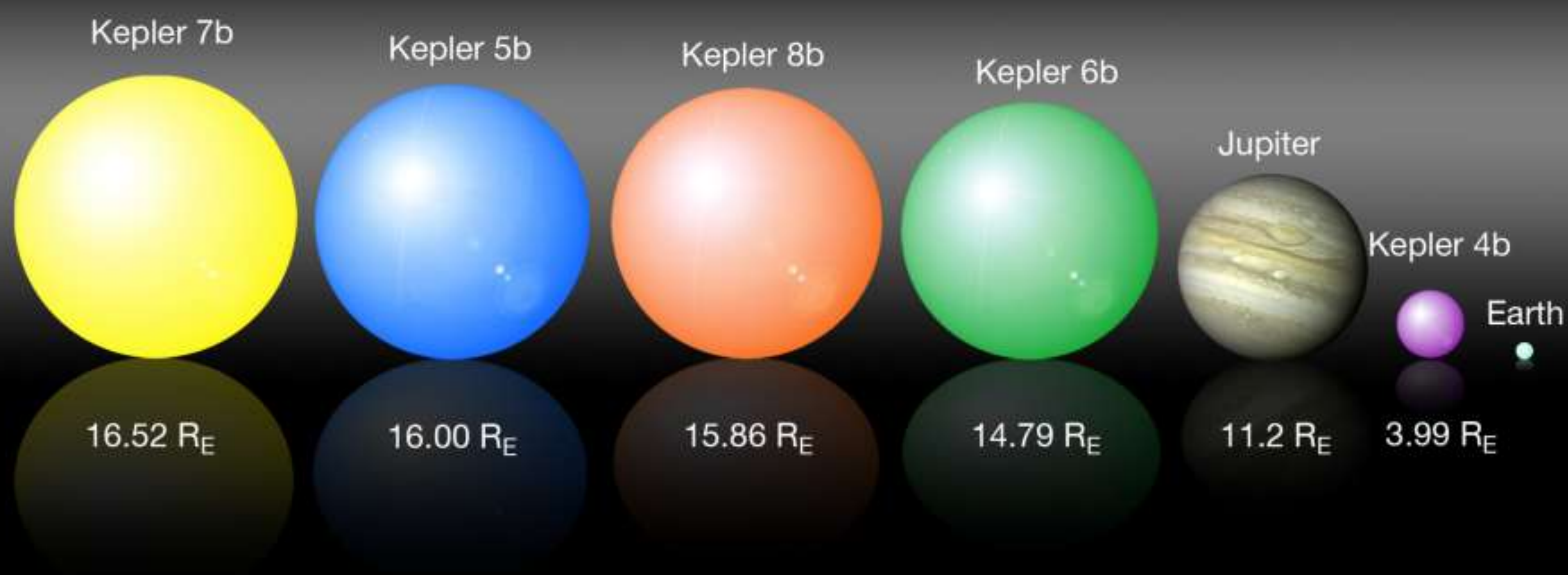


Nye Kepler Planeter

Borucki et.al 2010

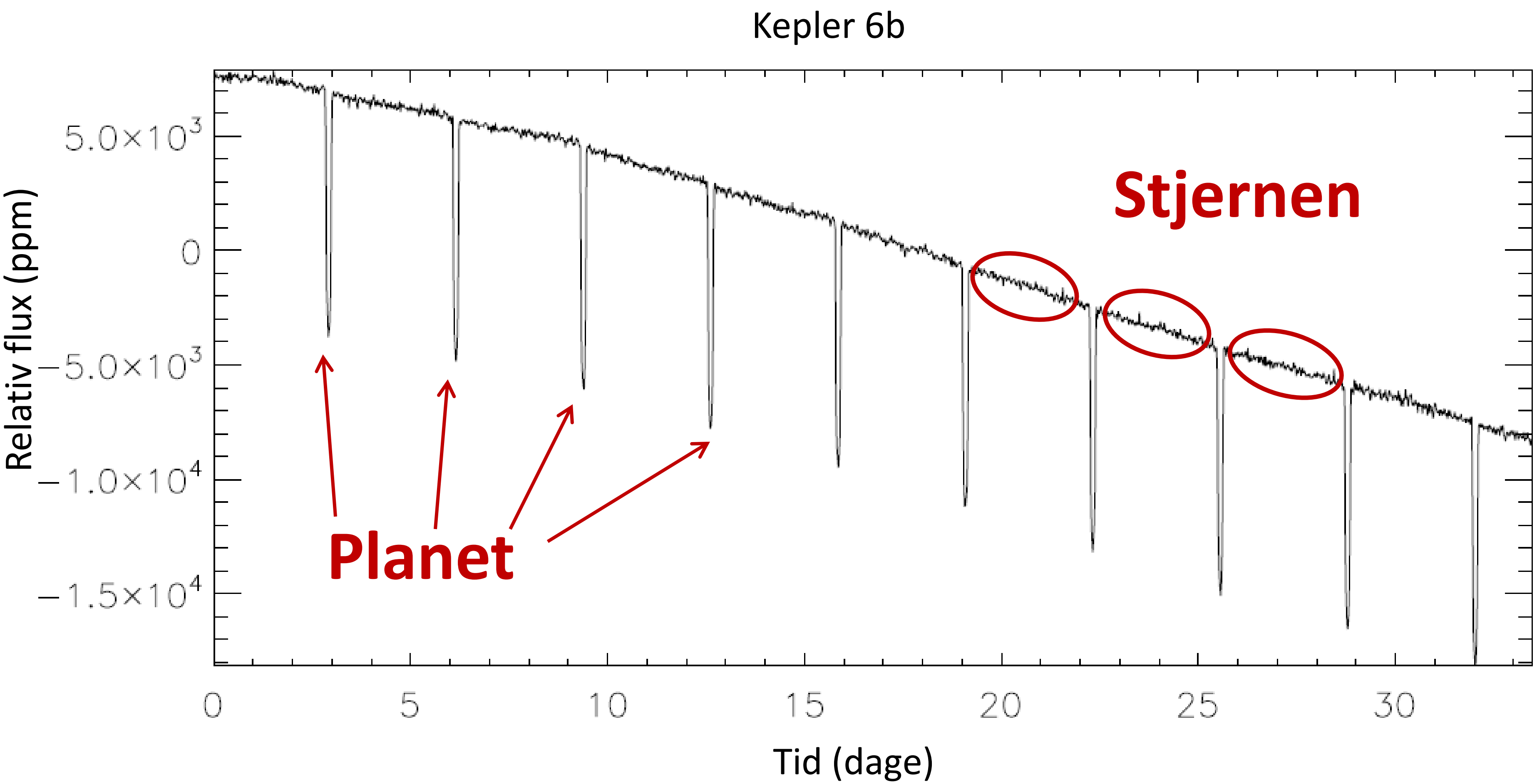


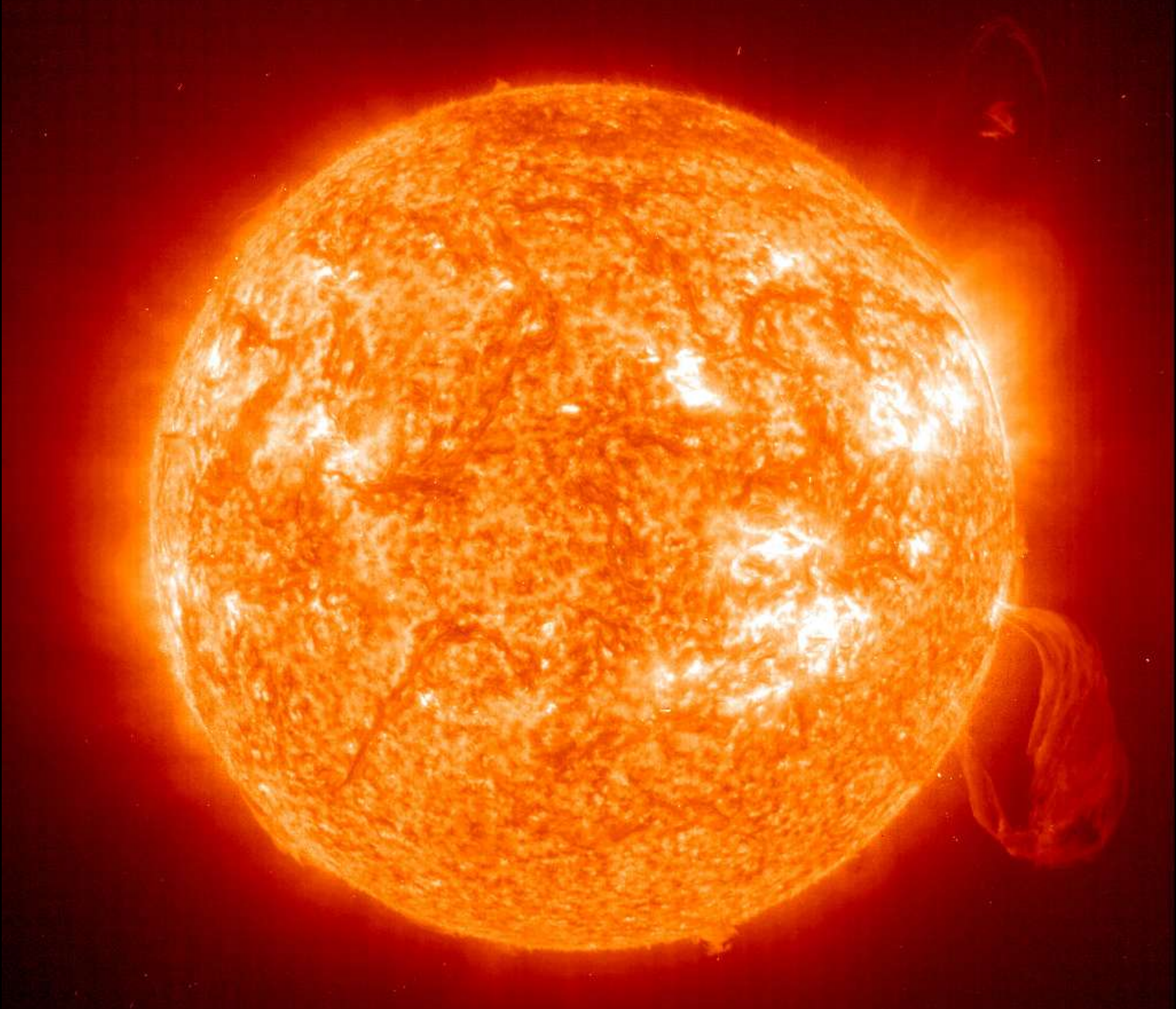
Nye Kepler Planeter

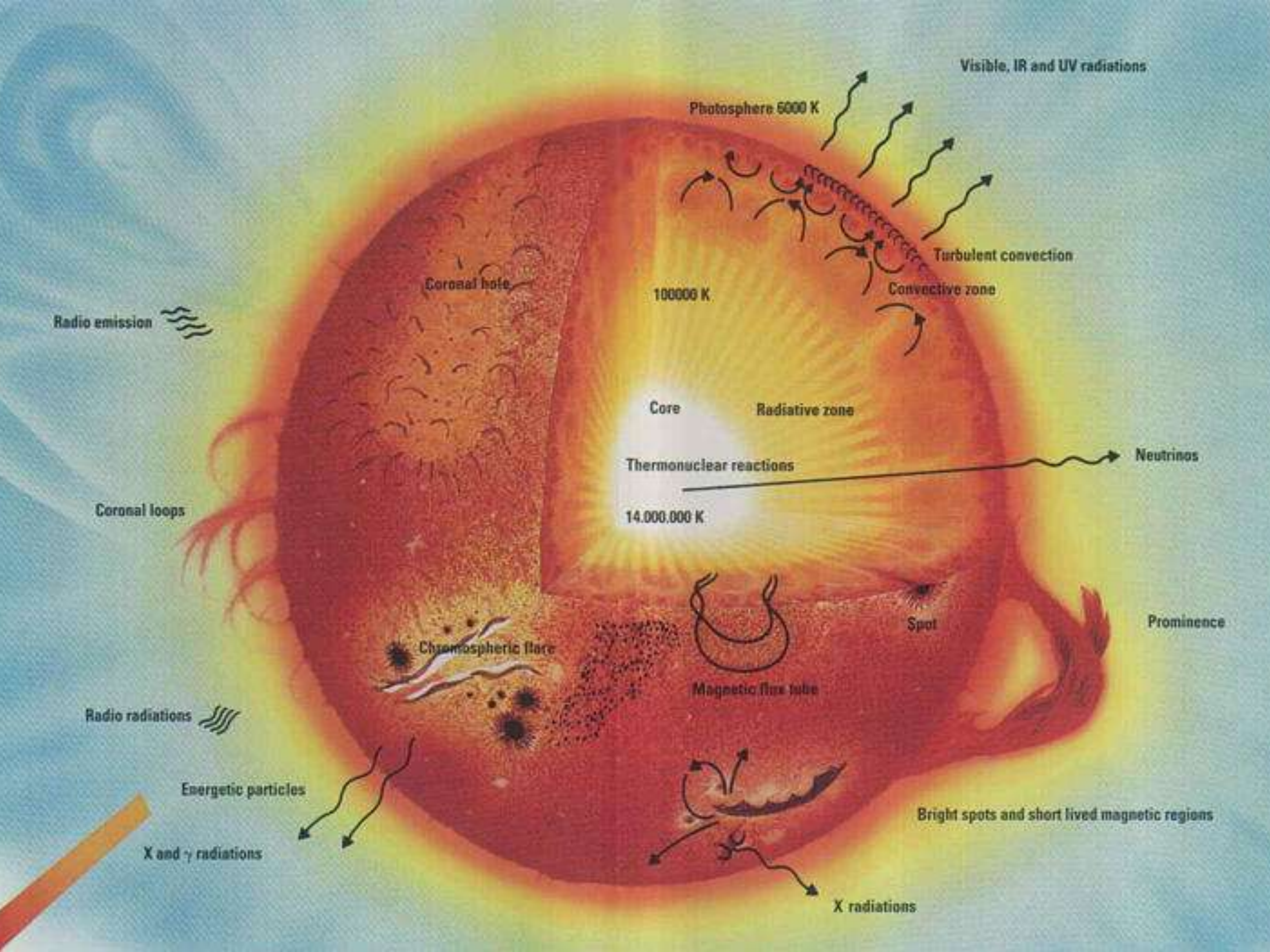


Borucki et.al 2010

Hvad Kepler måler

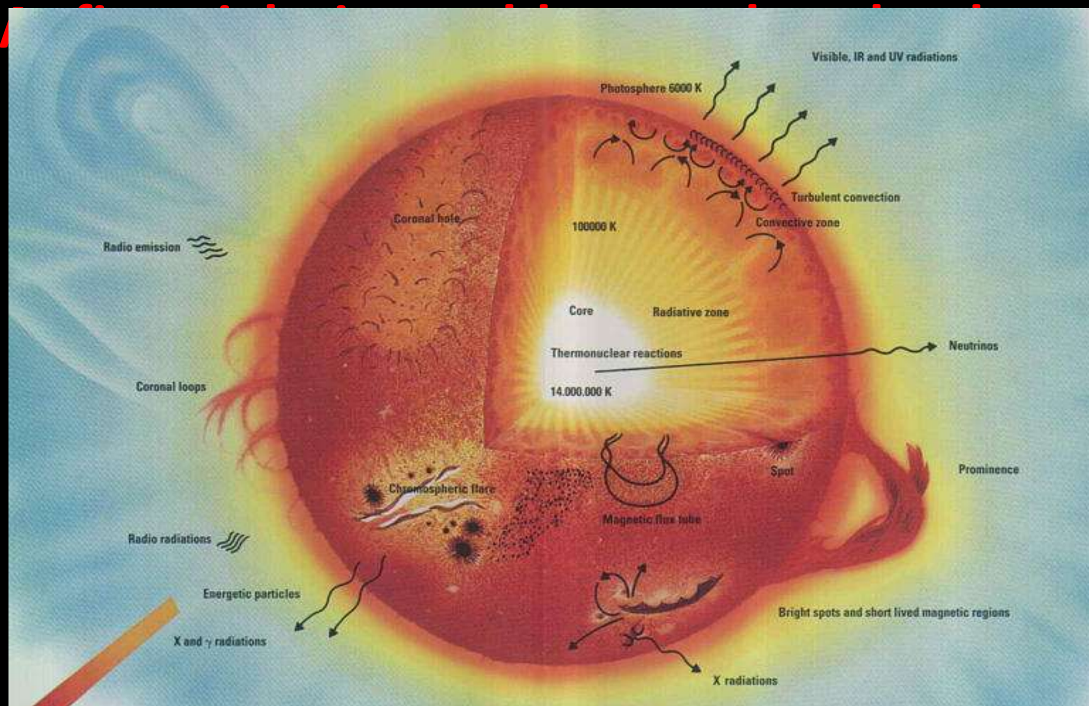






Visible, IR and UV radiations
Photosphere 6000 K
Turbulent convection
Coronal hole
100000 K
Convective zone
Radio emission
Core
Radiative zone
Thermonuclear reactions
Neutrinos
Coronal loops
14.000.000 K
Spot
Prominence
Chromospheric flare
Magnetic flux tube
Radio radiations
Energetic particles
Bright spots and short lived magnetic regions
X and γ radiations
X radiations

Hvordan ved vi hvordan Solen og stjernerne ser ud indeni?

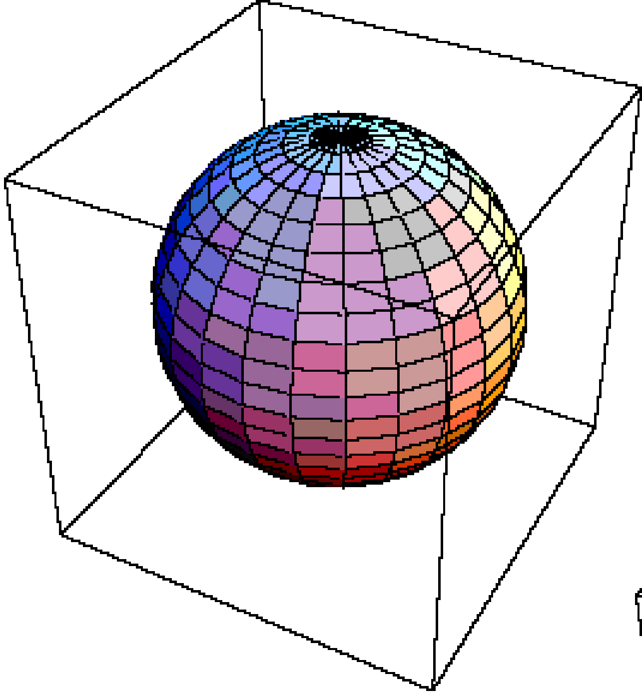


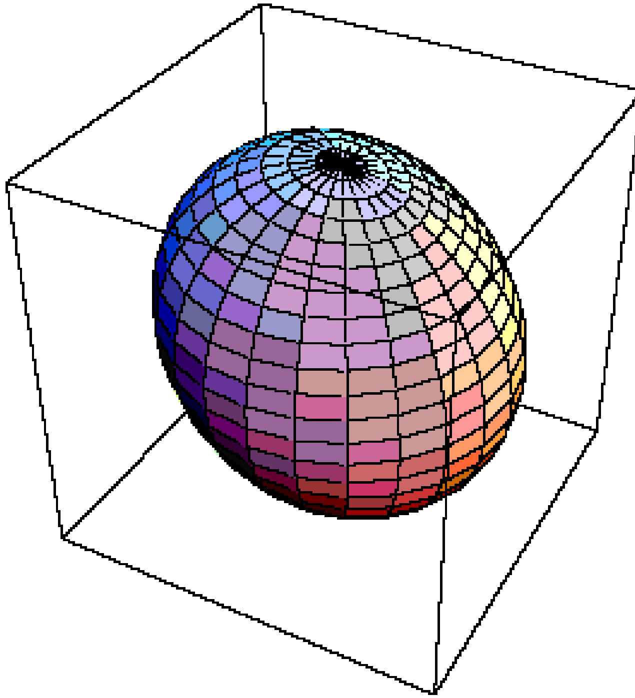
and test the conditions within?

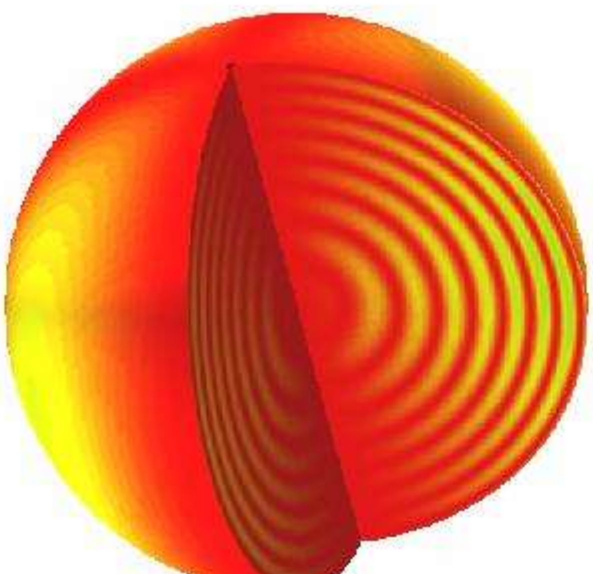
Sir Athur Eddington

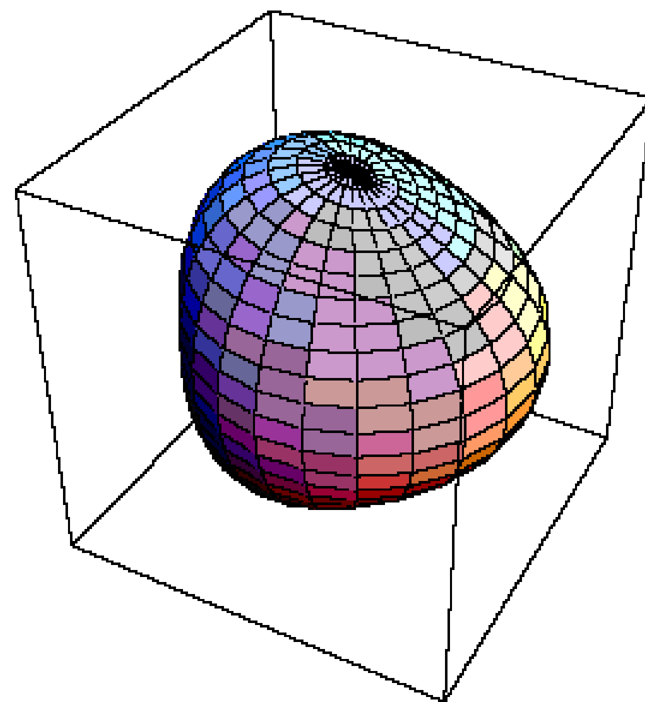
The Internal Constitution of the Stars, 1926

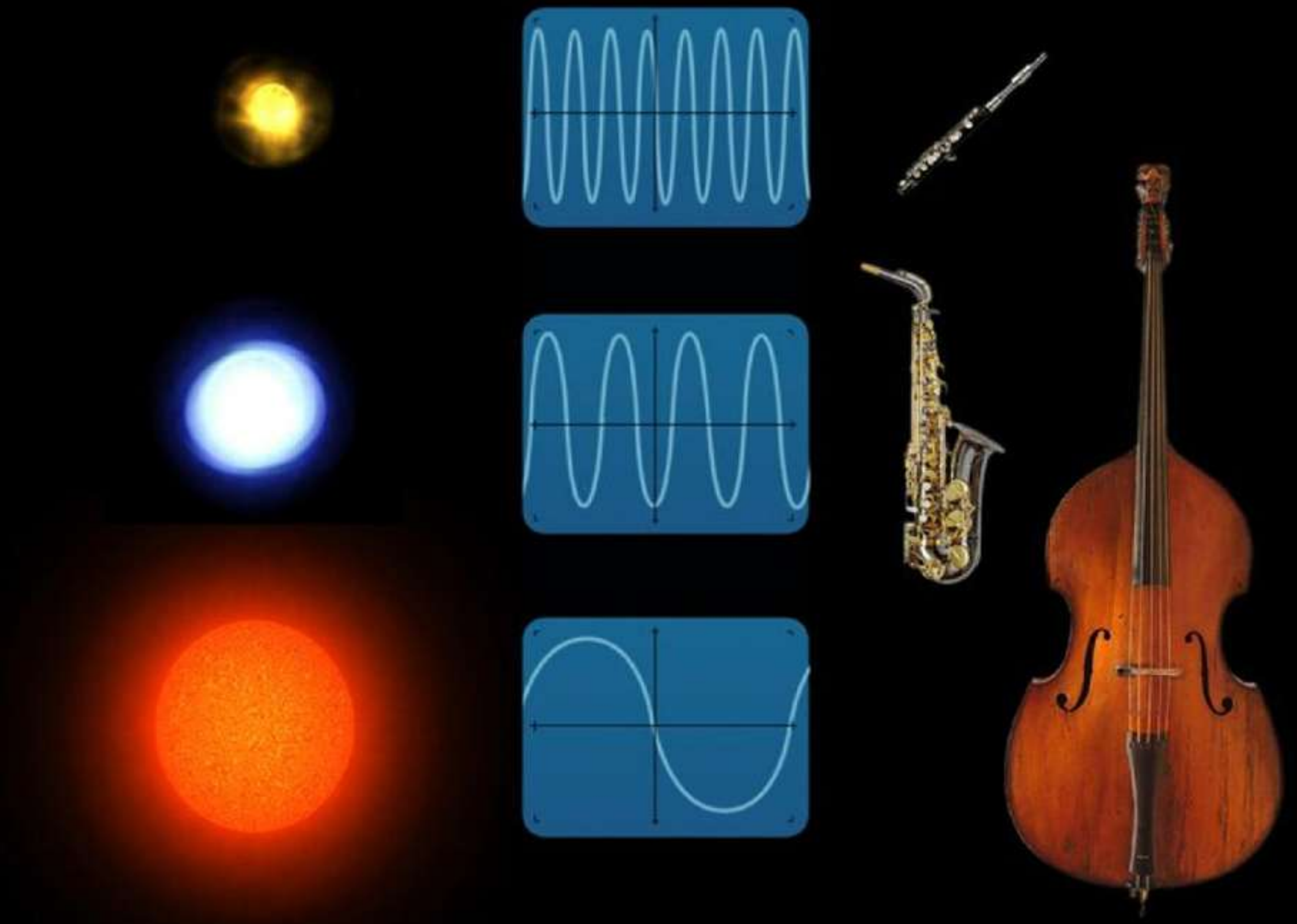
Stjerne-svingninger (Asteroseismologi)









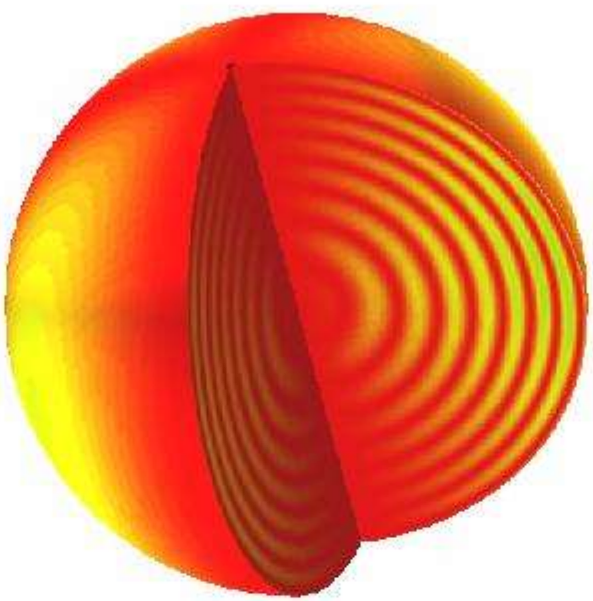


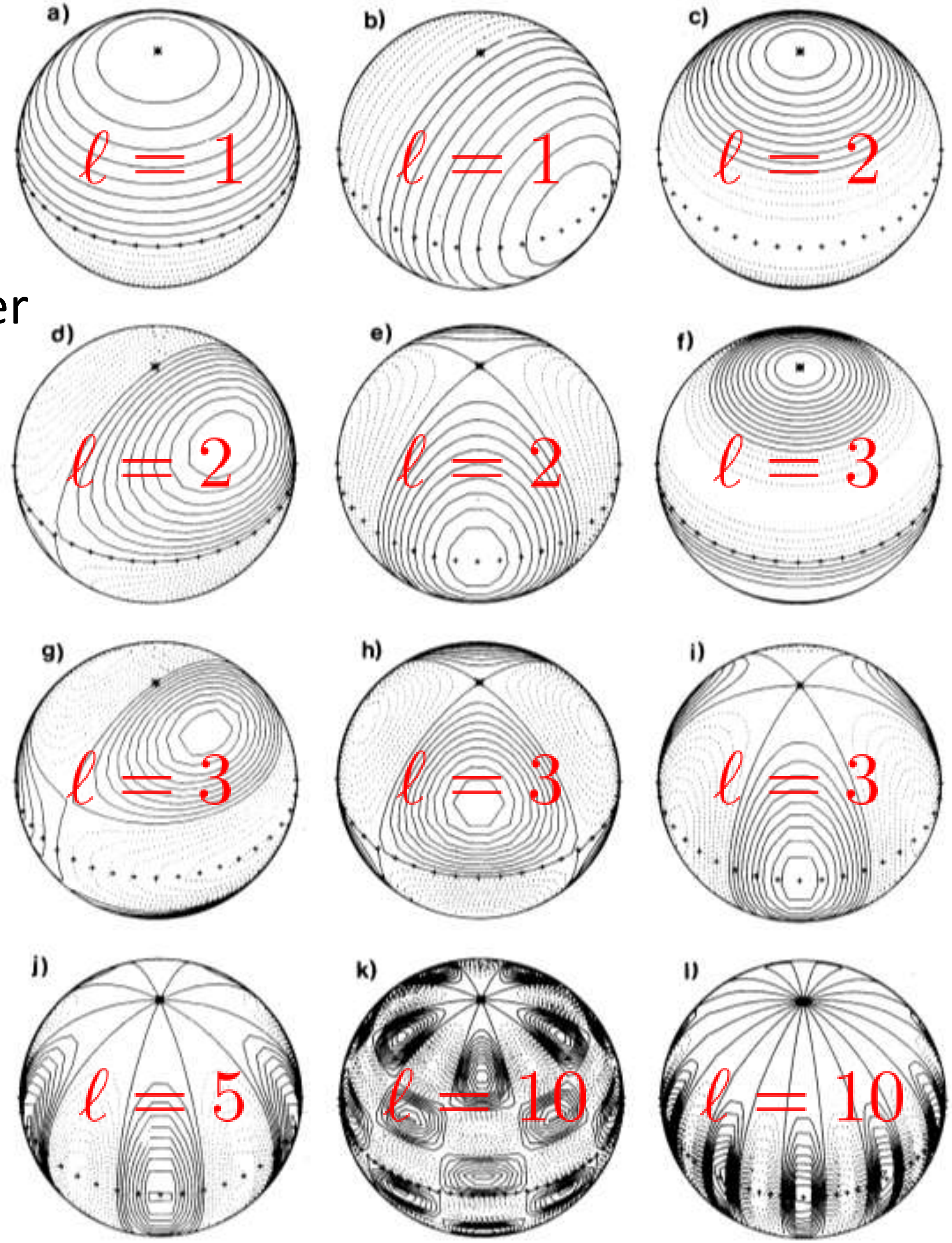
Sfærisk harmoniske funktioner

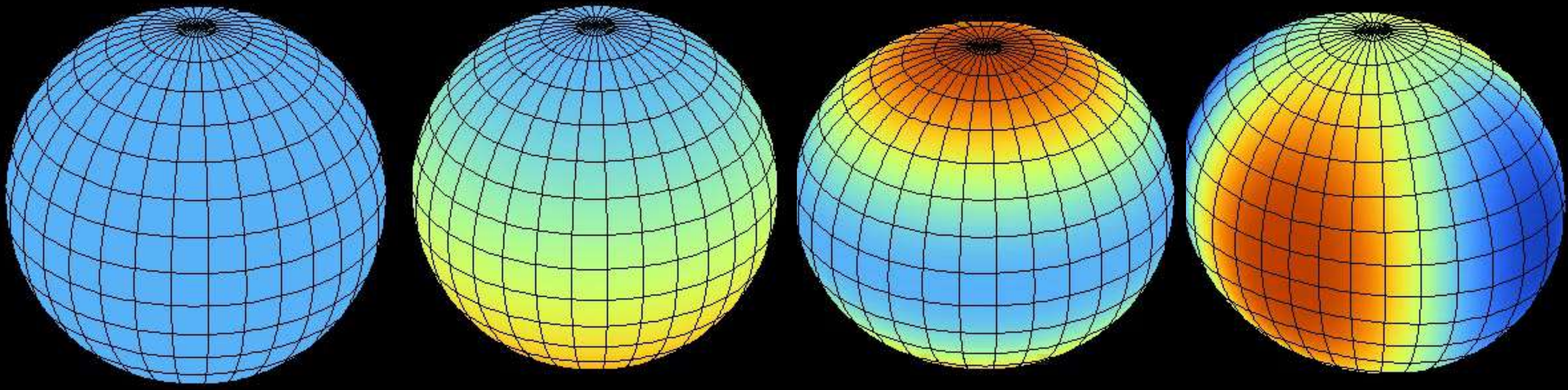
”Kvantetal”

$$(n, \ell, m)$$

Overtoner



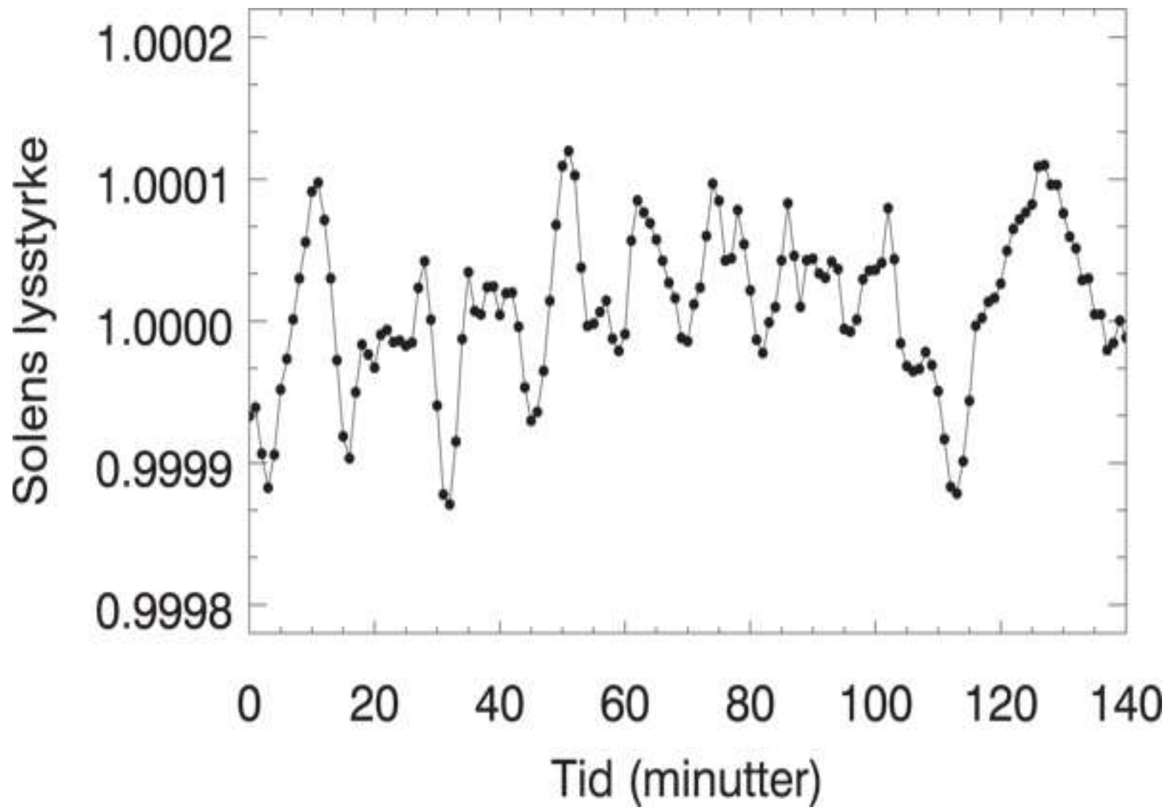




Svingningerne er *lydbølger*

Mange svingninger tilsammen får overfladen og lysstyrken til hele tiden at ændre sig på en meget kompliceret måde

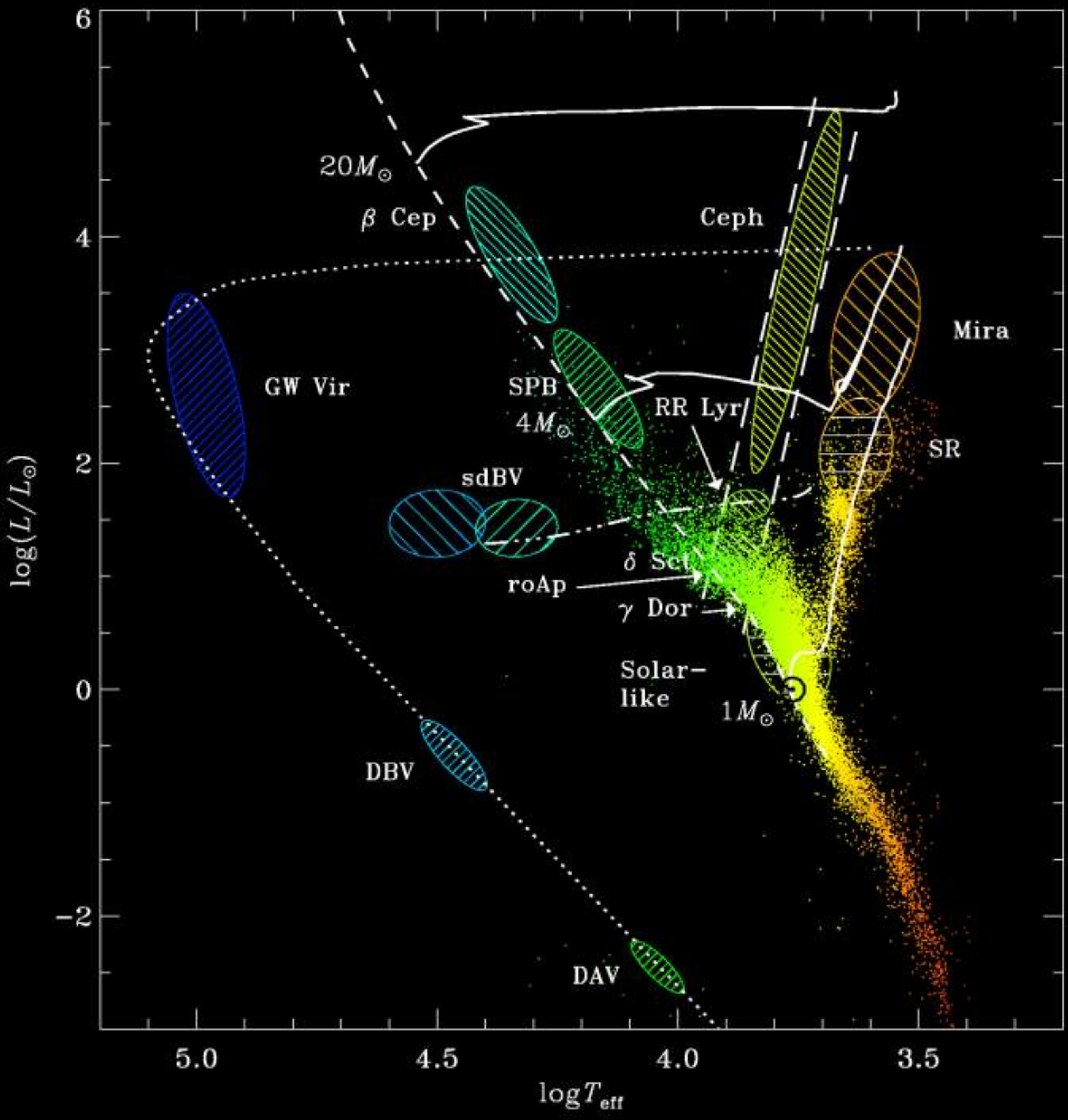
Ændring i størrelse = Ændring i lysstyrke



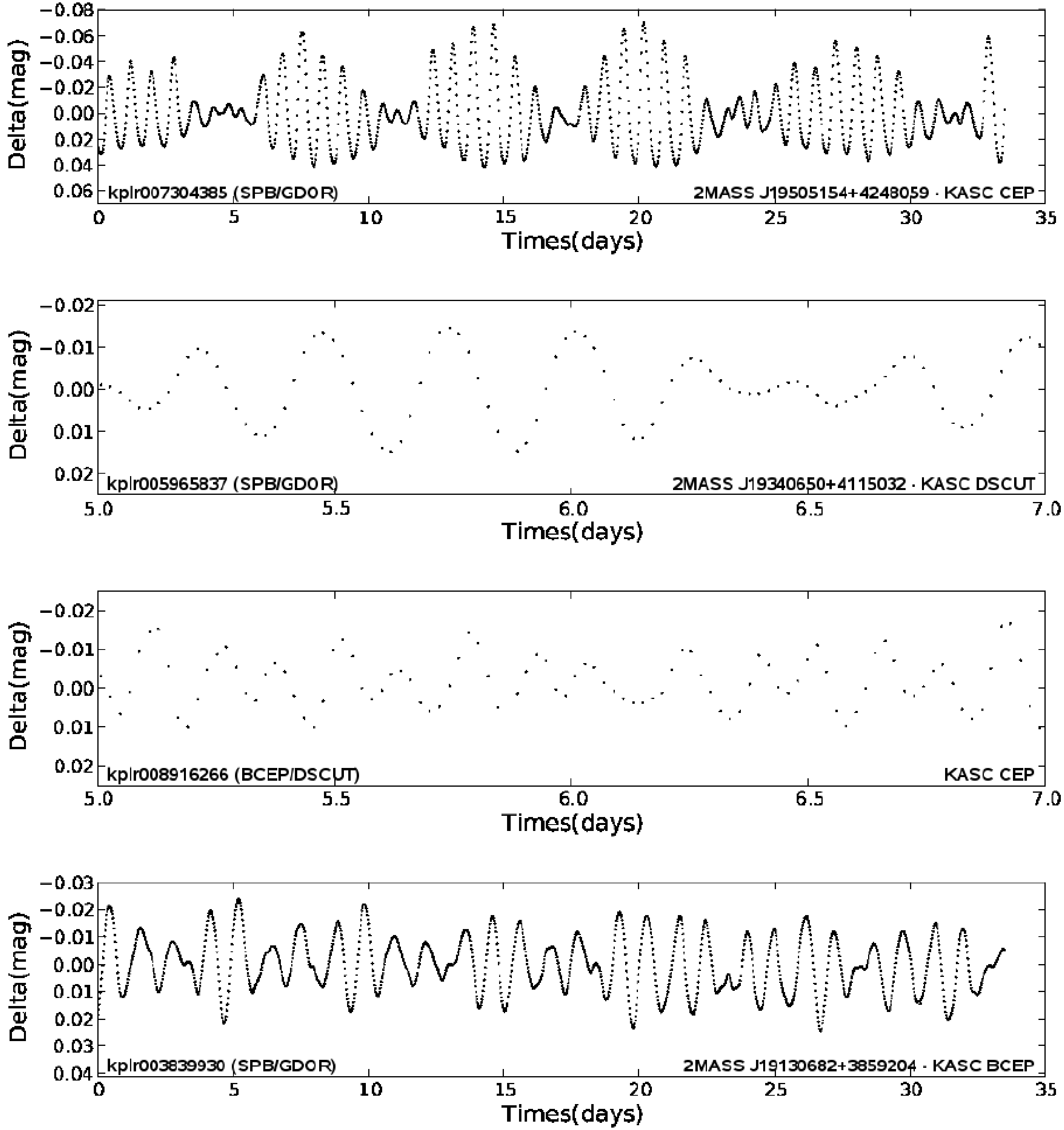
Kræver meget præcise målinger af lysstyrken!

Kan ikke gøres fra Jorden's overflade

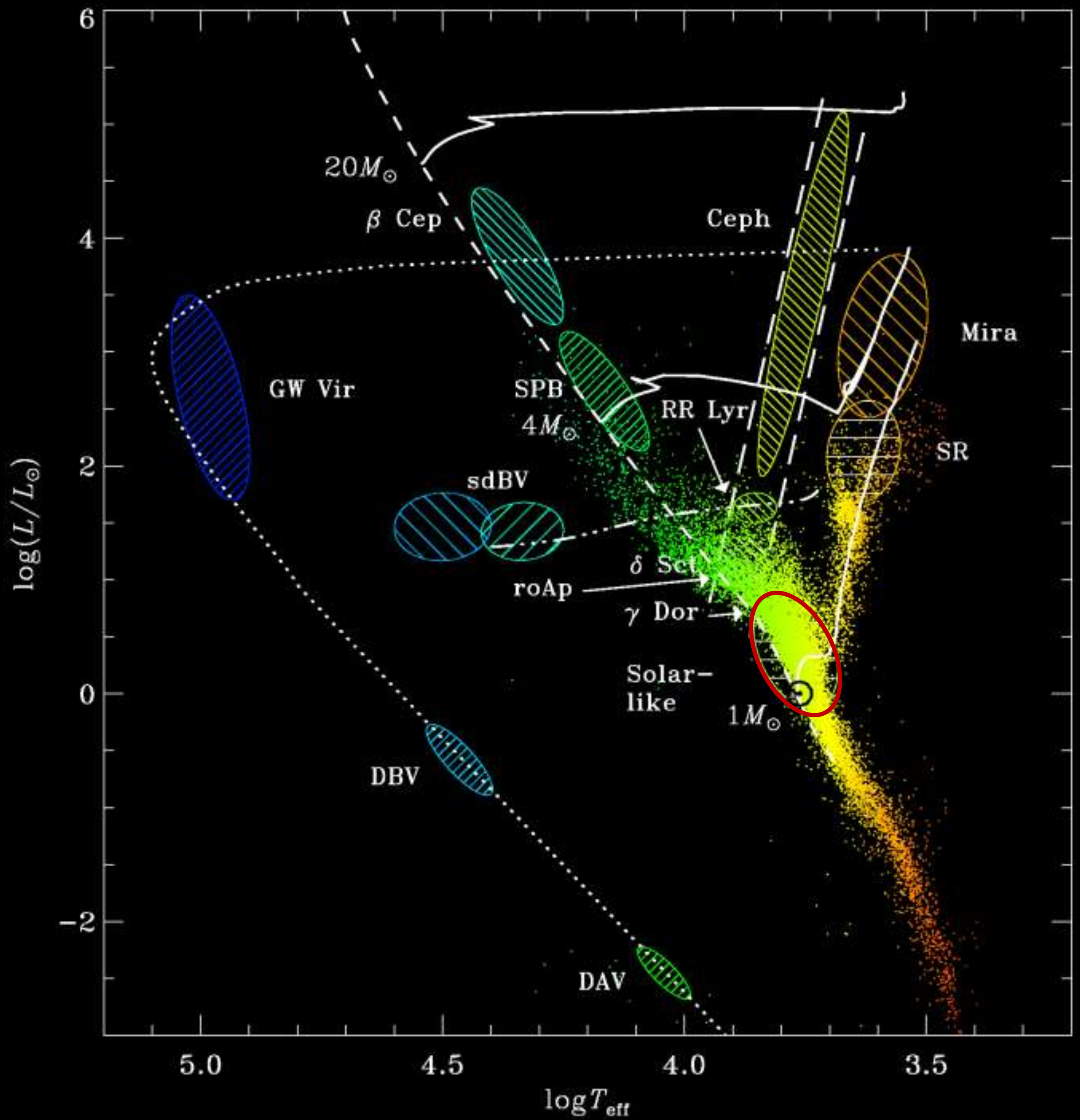
Atmosfæren er “i vejen”

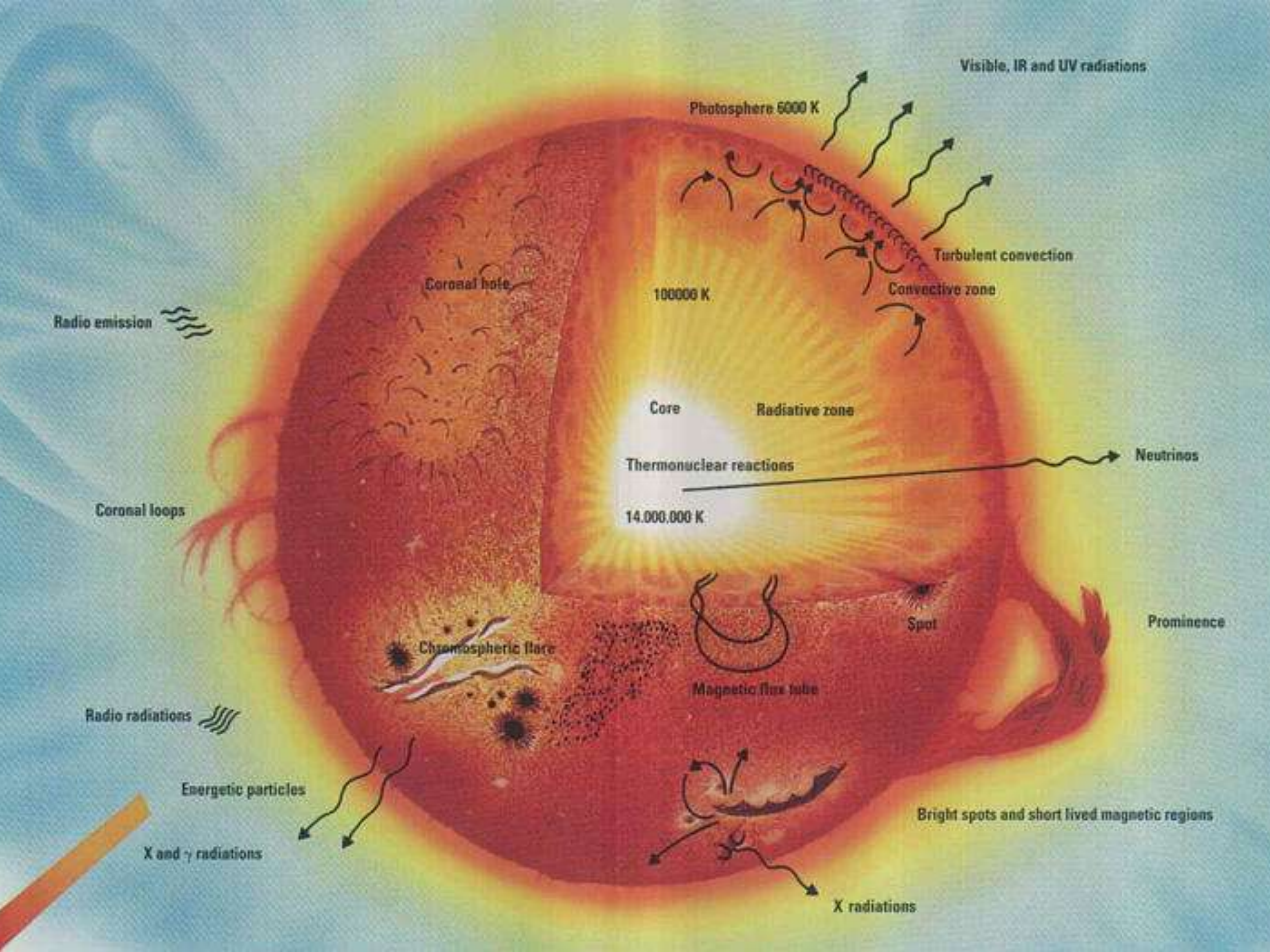


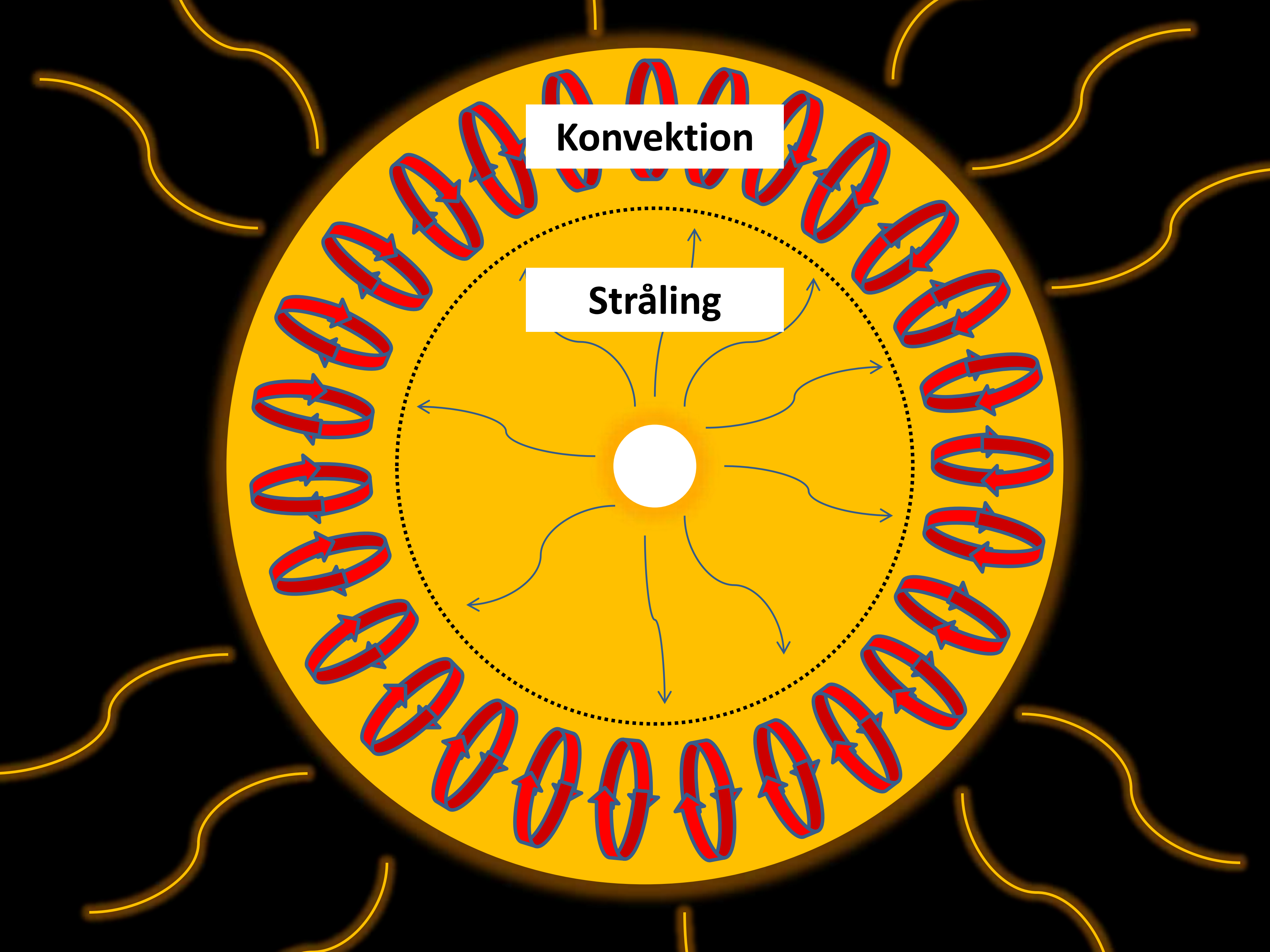
20$M_\odot$
β Cep
Ceph
Mira
GW Vir
SPB
4$M_\odot$
RR Lyr
SR
sdBV
δ Sct
roAp
γ Dor
Solar-like
1$M_\odot$
DBV
DAV
log($L/L_\odot$)
logT_{eff}
6
4
2
0
−2
5.0
4.5
4.0
3.5

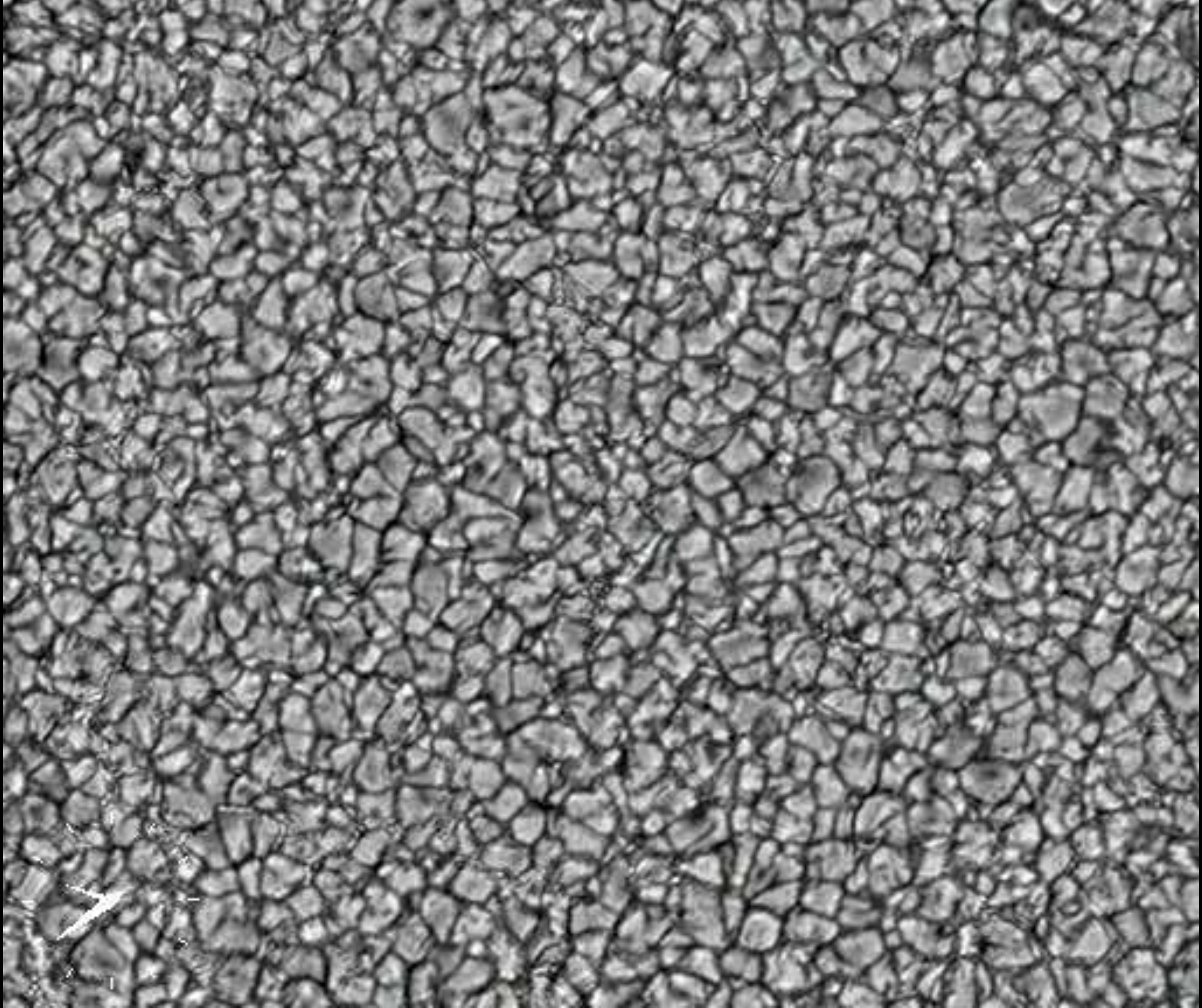


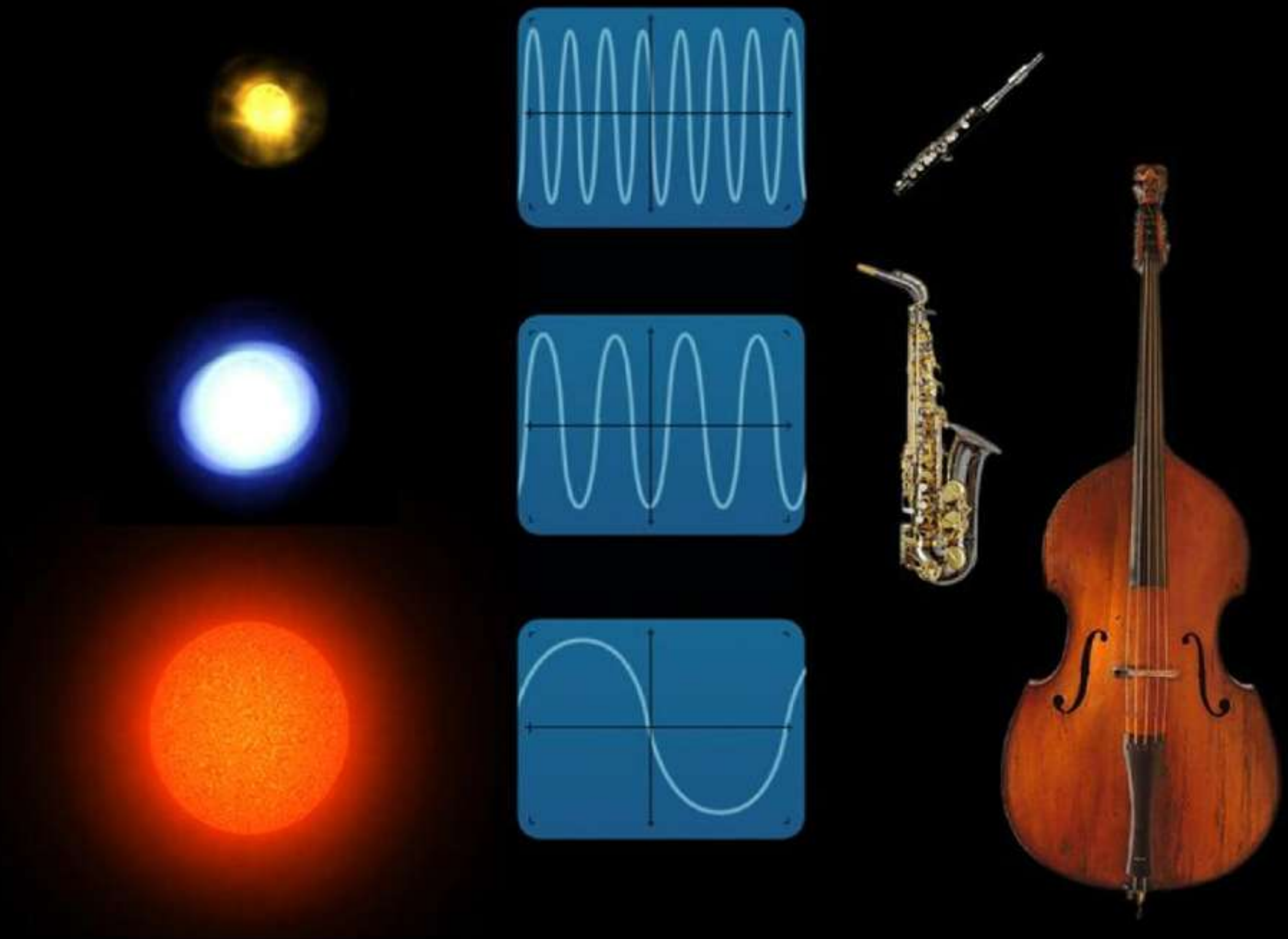
Delta(mag)
Times(days)
kplr007304385 (SPB/GDOR)
2MASS J19505154+4248059 · KASC CEP
kplr005965837 (SPB/GDOR)
2MASS J19340650+4115032 · KASC DSCUT
kplr008916266 (BCEP/DSCUT)
KASC CEP
kplr003839930 (SPB/GDOR)
2MASS J19130682+3859204 · KASC BCEP


6
4
2
0
−2
log(L/L_⊙)
5.0
4.5
4.0
3.5
log T_eff
20M_⊙
β Cep
Ceph
Mira
GW Vir
SPB
4M_⊙
RR Lyr
SR
sdBV
δ Sct
roAp
γ Dor
Solar-
like
1M_⊙
DBV
DAV


Visible, IR and UV radiations
Photosphere 6000 K
Turbulent convection
Coronal hole
100000 K
Convective zone
Radio emission
Core
Radiative zone
Thermonuclear reactions
Neutrinos
Coronal loops
14.000.000 K
Spot
Prominence
Chromospheric flare
Magnetic flux tube
Radio radiations
Energetic particles
Bright spots and short lived magnetic regions
X and γ radiations
X radiations

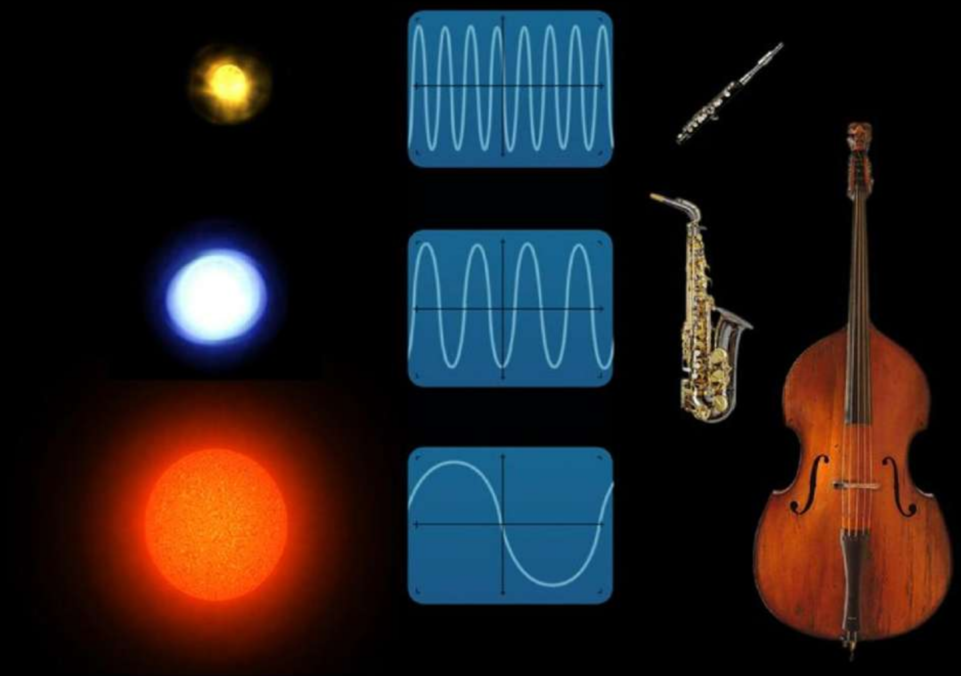

Konvektion
Stråling

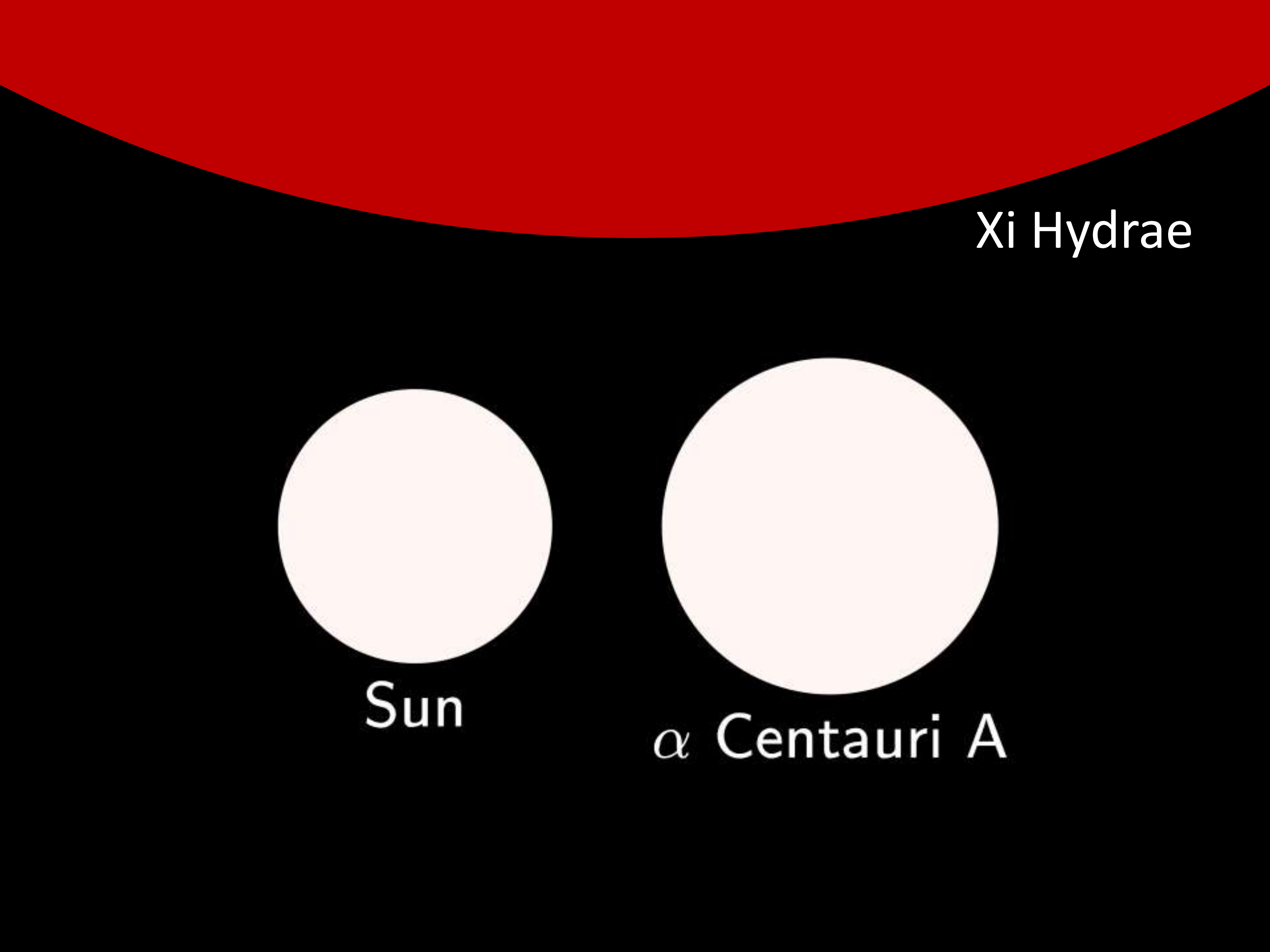


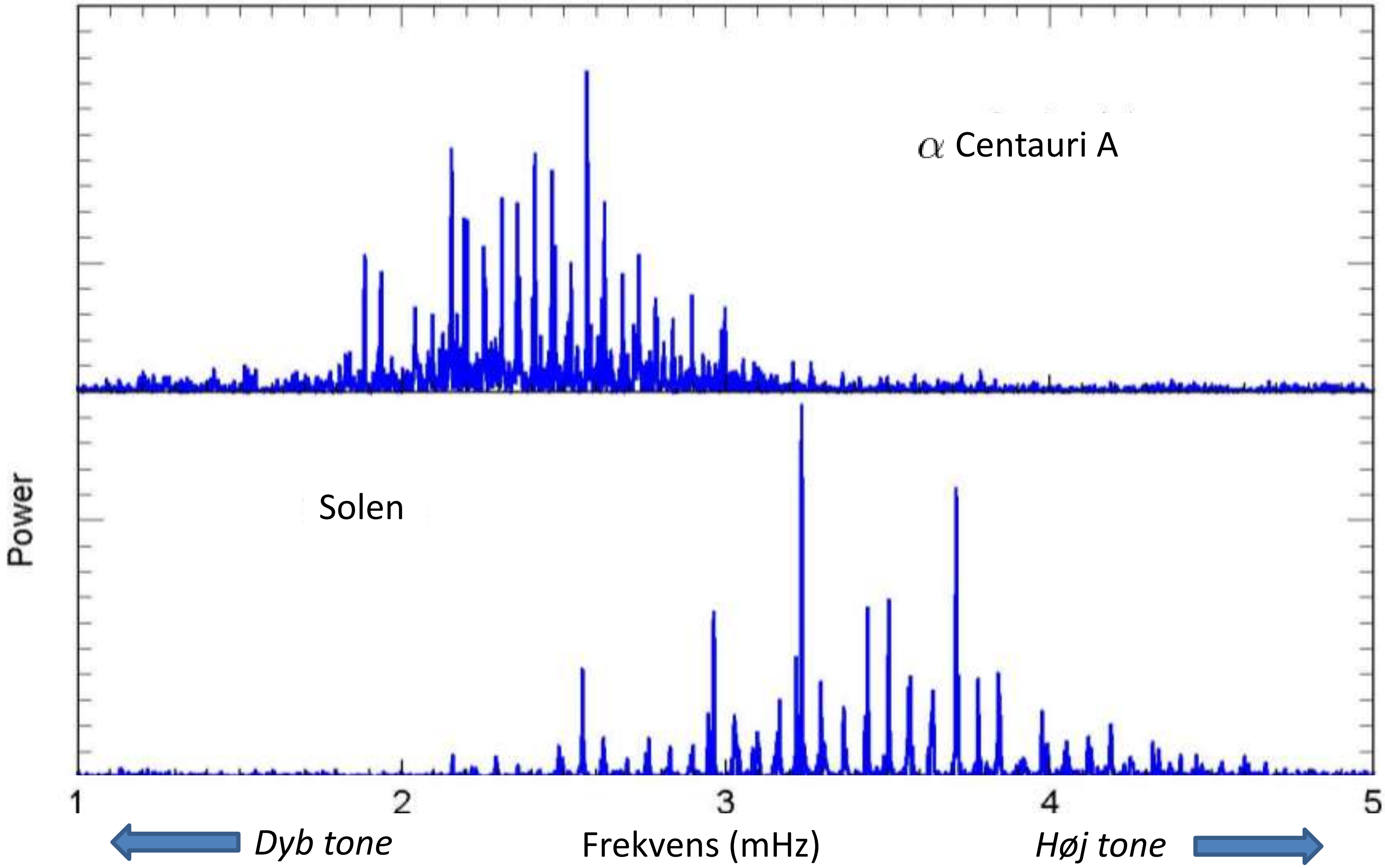


Lytte-øvelse

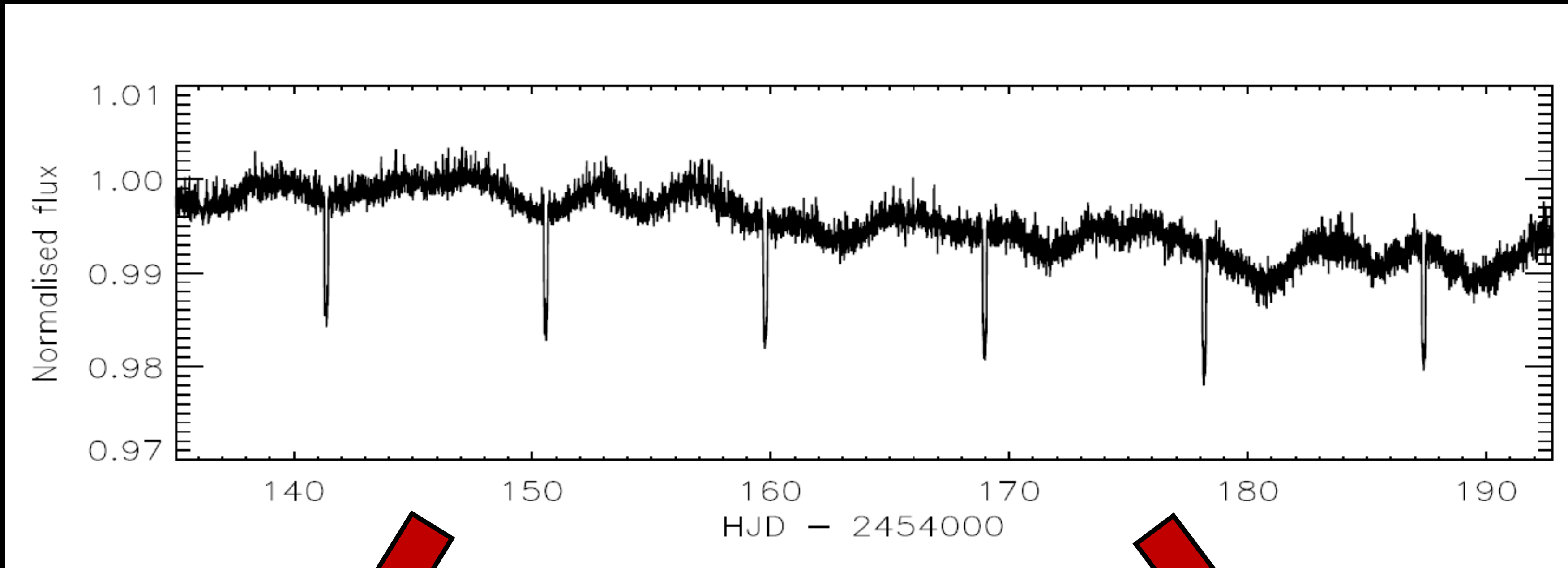
- α Centauri A
- Xi Hydrae

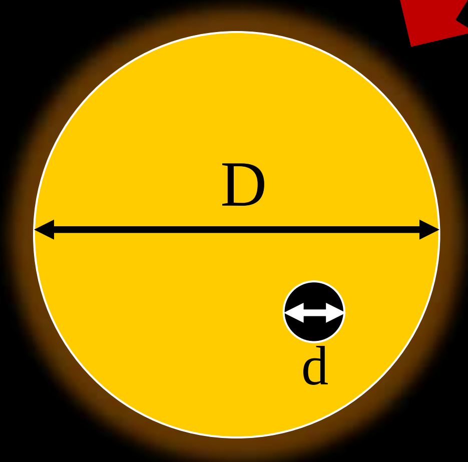


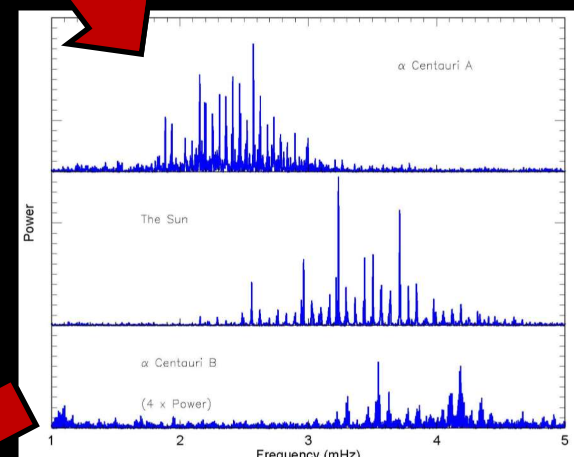

Xi Hydrae
Sun
α Centauri A



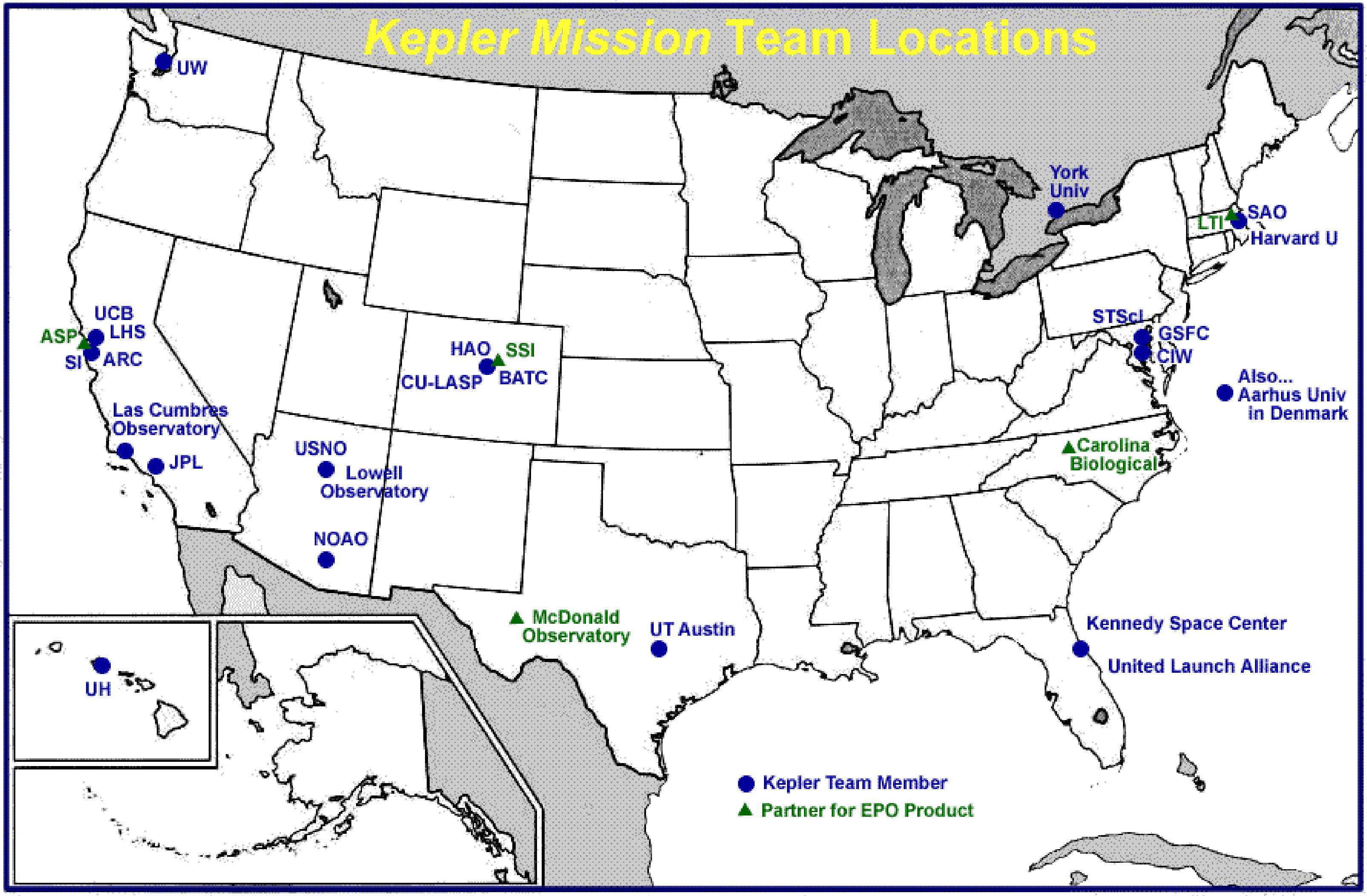
α Centauri A
Solen
Power
1
2
3
4
5
Dyb tone
Frekvens (mHz)
Høj tone







$$\Delta F \propto \frac{\frac{1}{4}\pi d^2}{\frac{1}{4}\pi D^2} = \left(\frac{d}{D}\right)^2$$



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Laboratory for Atmospheric & Space Physics
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HAO-High Altitude Observatory
Harvard University
JPL-Jet Propulsion Laboratory
Kennedy Space Center
LTI-Learning Technologies, Inc
LHS-Lawrence Hall of Science
Lowell Observatory
MacDonald Observatory
NOAO-National Optical Astronomy Observatory
(WIYN Observatory)
SI-SETI Institute
SAO-Smithsonian Astrophysical Observatory
SSI-Space Science Institute
STScI-Space Telescope Science Institute
USNO-US Naval Observatory
UH-University of Hawaii
UW-University of Washington
UCB-University of Califonia, Berkeley
United Launch Alliance
UT-University of Texas, Austin
York University

kepler.nasa.gov

Århus Universitet i centrum!

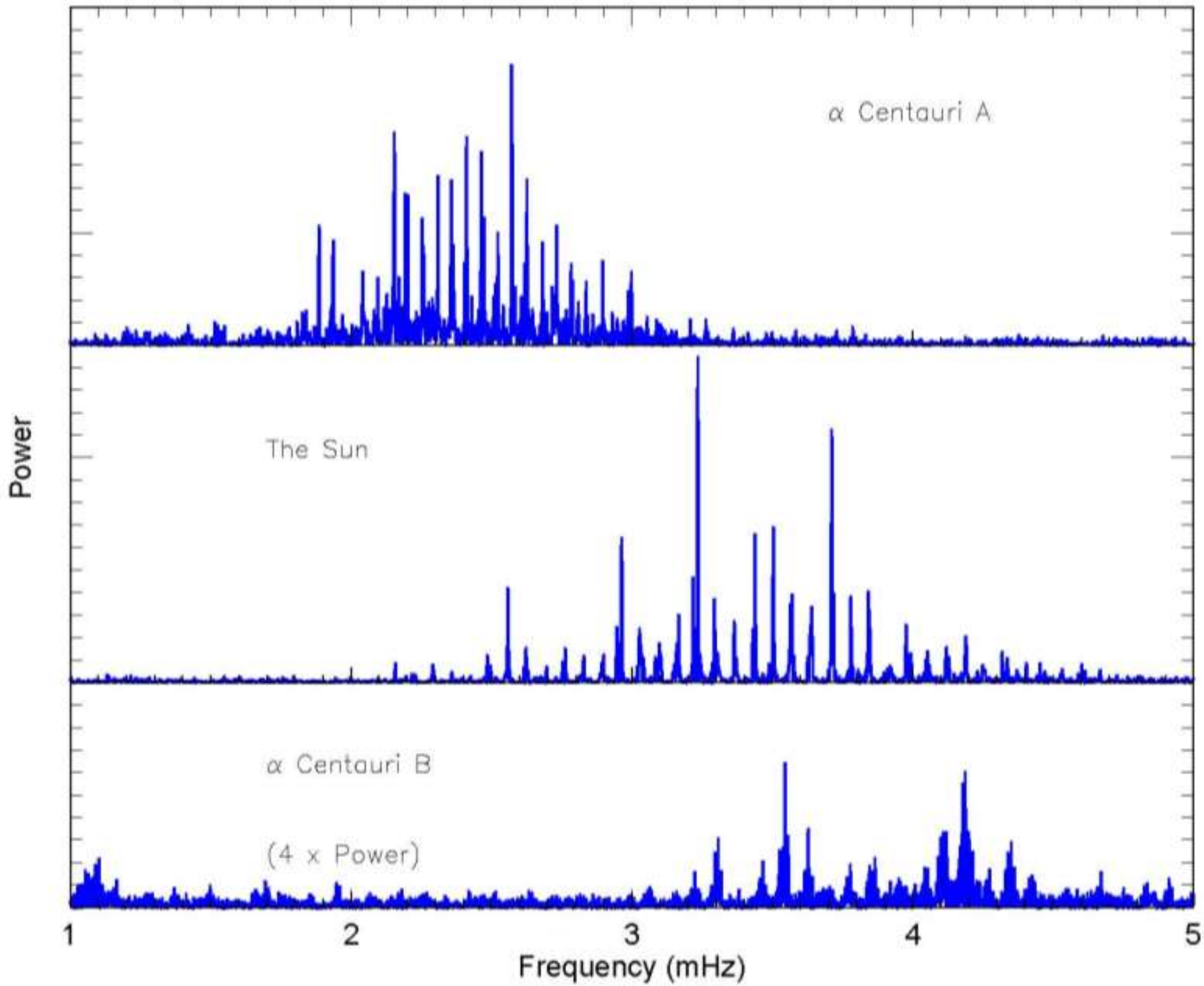
Stjerne-diametre fra *Asteroseismologi*
Præcis bestemmelse af planet-diametre

Forskning i stjernernes opbygning og udvikling

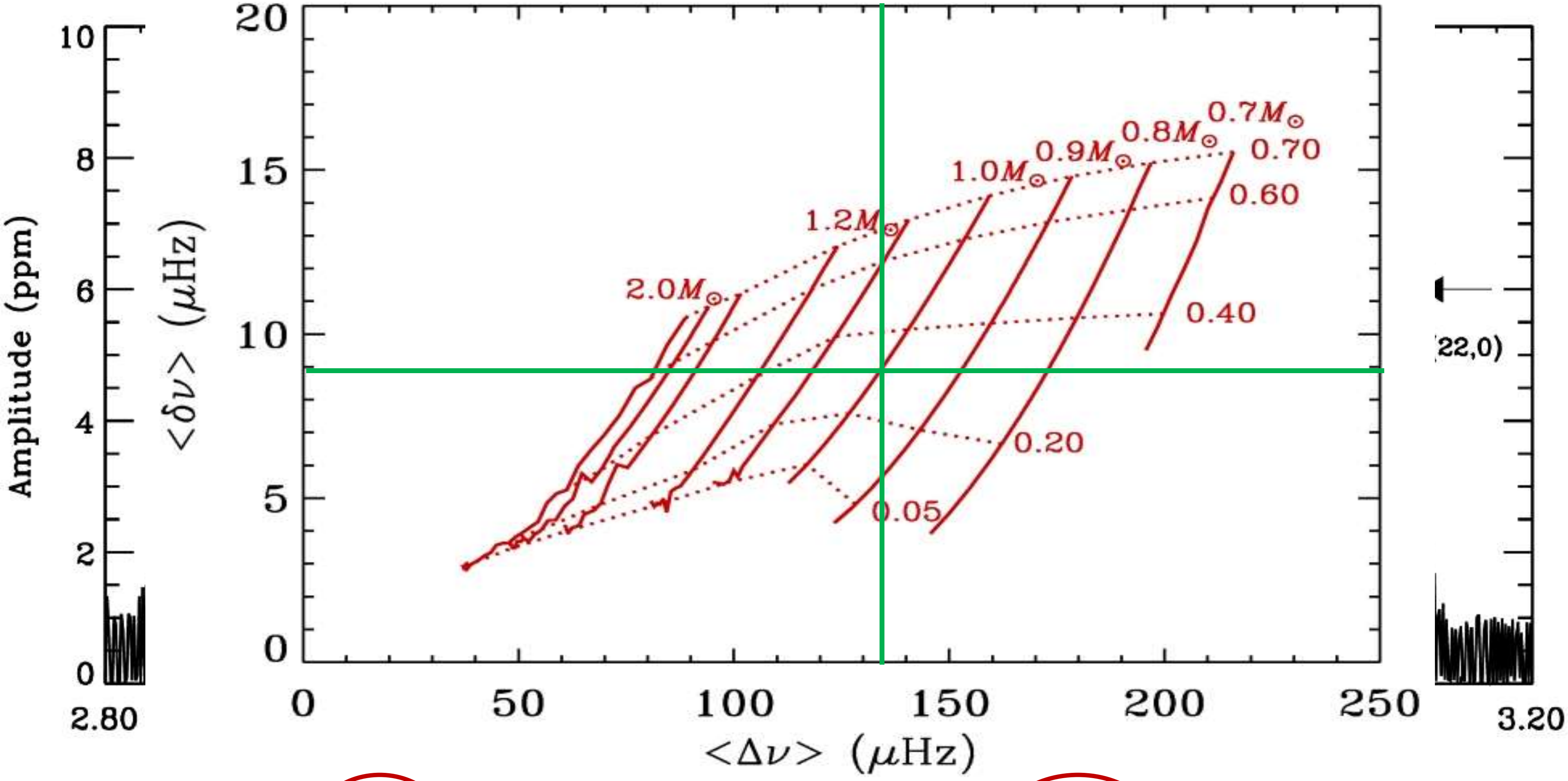
KAI organiseres fra KASOC på IFA

Kepler Asteroseismic Investigation
Kepler Asteroseismic Science Operations Center

Tættere kig på powerspektret

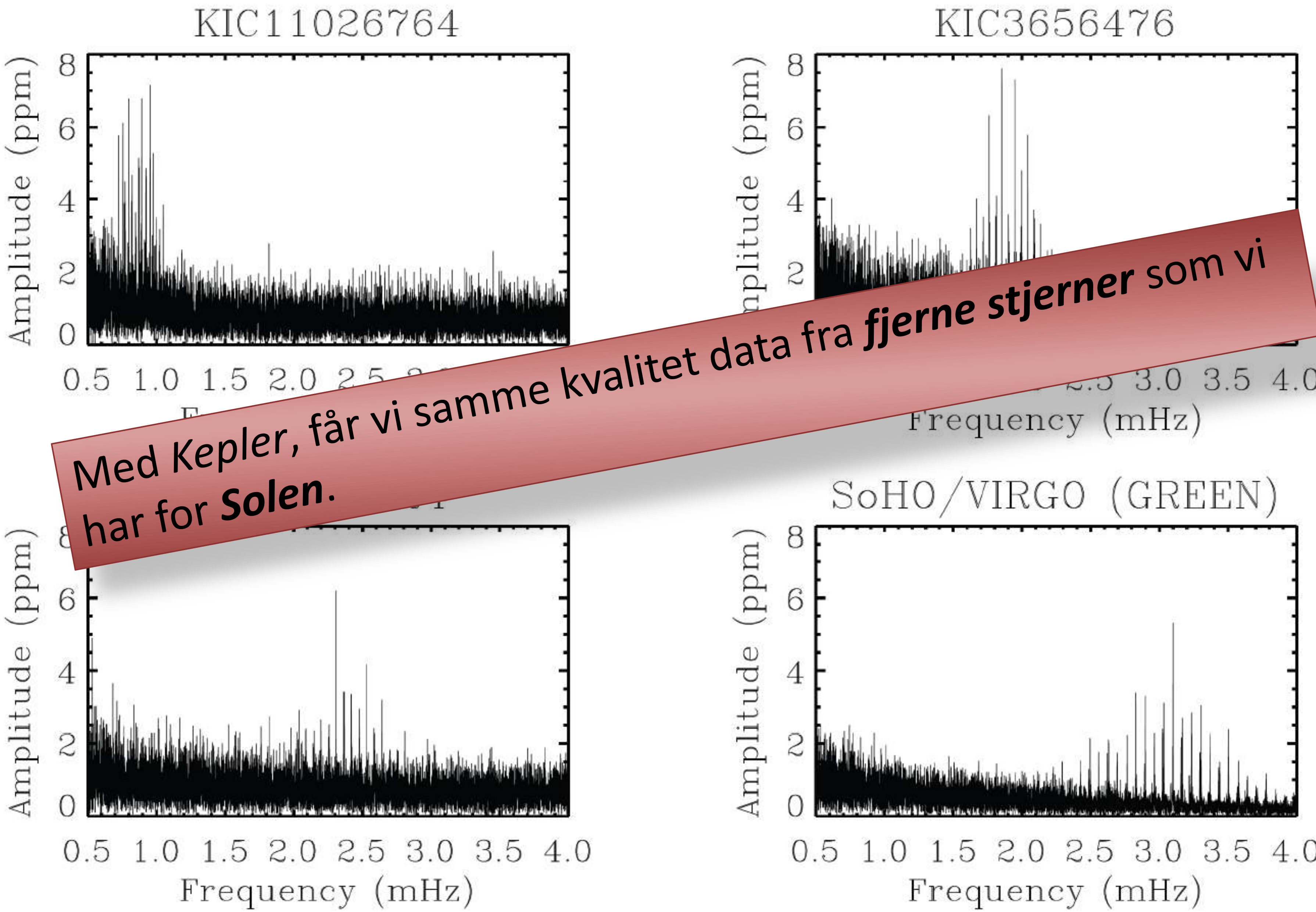


Oscillations Spektre



$$\nu_{n\ell} = \Delta\nu(n + \ell/2 + \epsilon) + \delta\nu_{02}\,\ell(\ell+1)/6$$

Kepler: Første kig på dataene



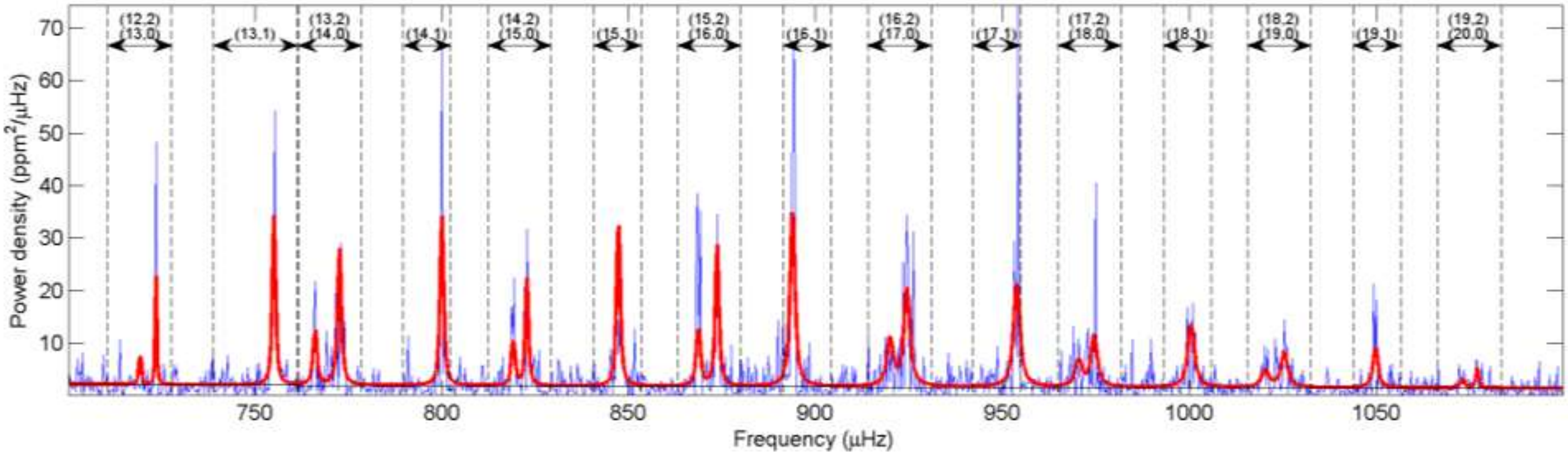
Med *Kepler*, får vi samme kvalitet data fra ***fjerne stjerner*** som vi har for ***Solen***.

Detaljeret fit af powerspektret

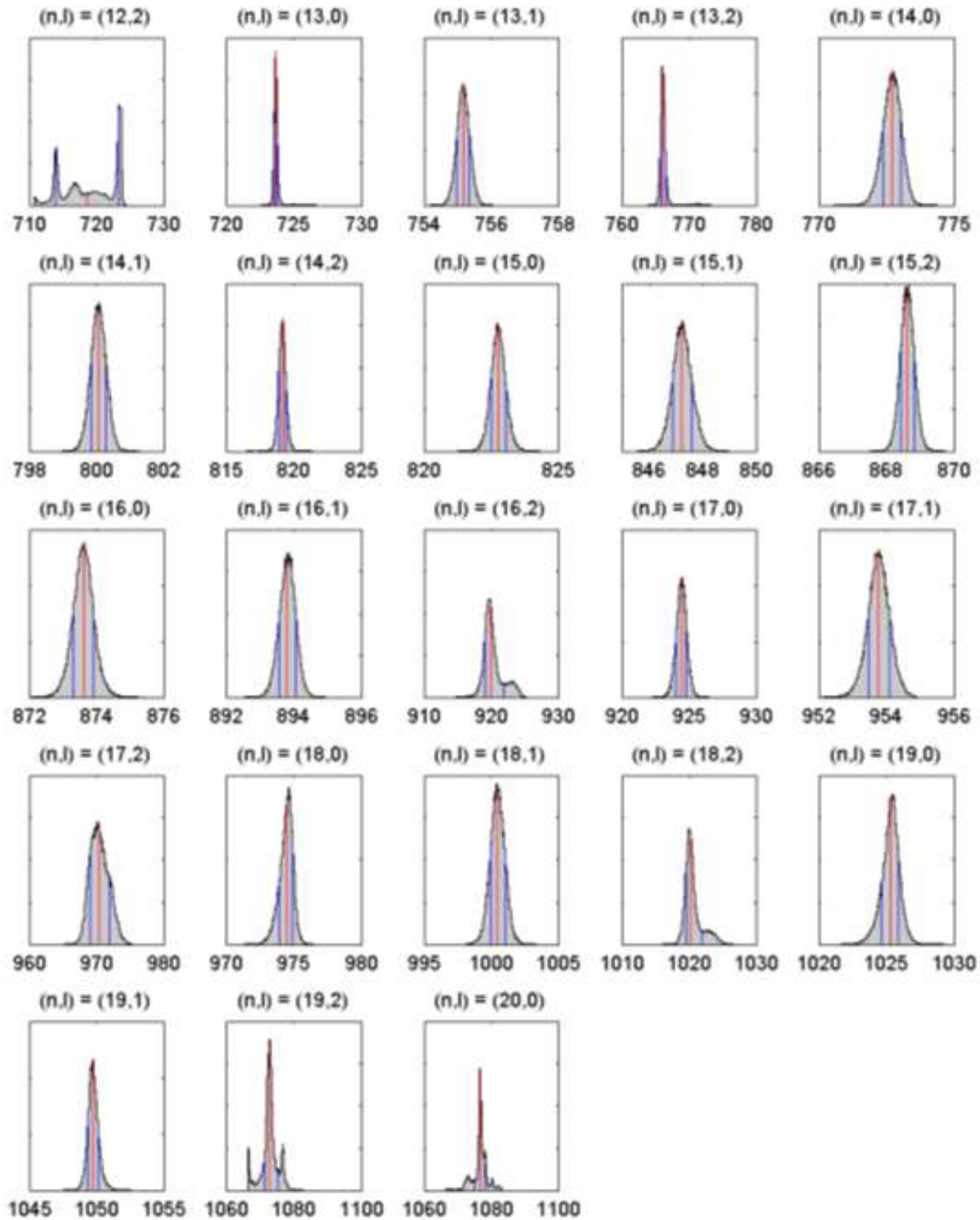
"Automated Parallel Tempering Markov Chain Monte Carlo"
= Avanceret fitte-program.

Fitter detaljerne i powerspektret med en model der indeholder frekvenser, højder, bredder, baggrund, inklinations vinkel, rotation...

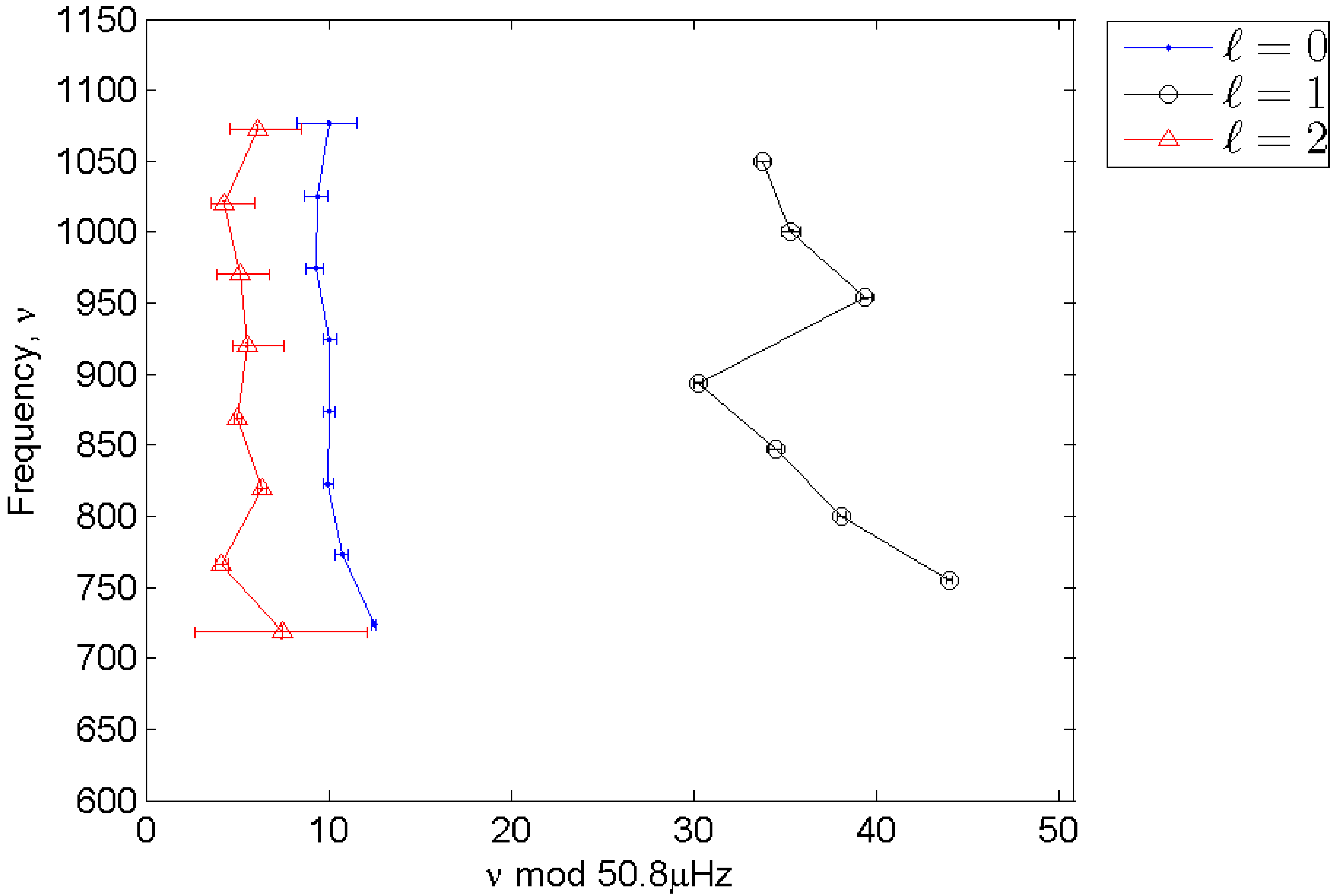
Kepler target "Gemma"



Resultaterne er Sandsynligheds-fordelinger



Kepler target "Gemma"

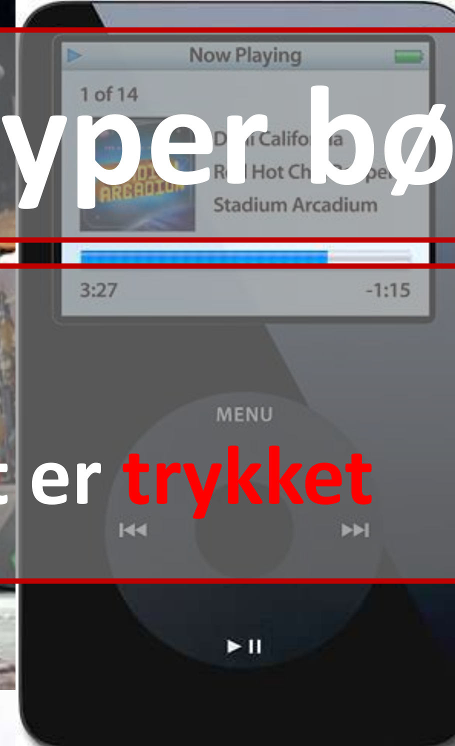


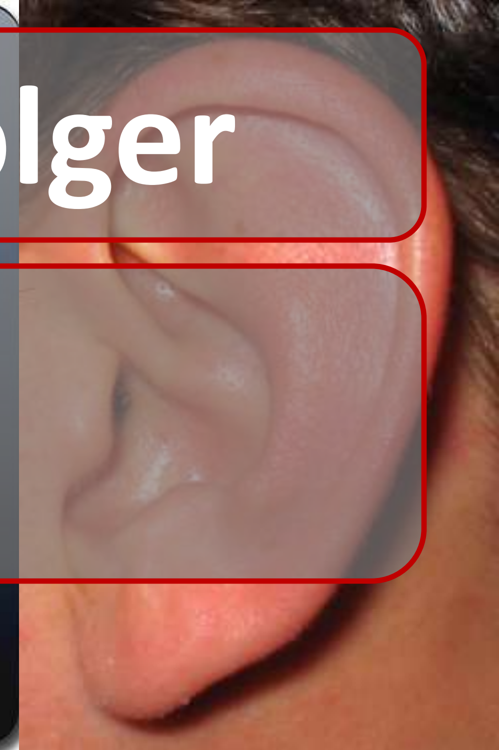
$$\nu_{n\ell} = \Delta\nu(n + \ell/2 + \epsilon) + \delta\nu_{02}\,\ell(\ell+1)/6$$

Forskellige typer bølger

Lydbølger = P-modes

Den genoprettende kraft er **trykket**





”Tyngdebølger” = G-modes

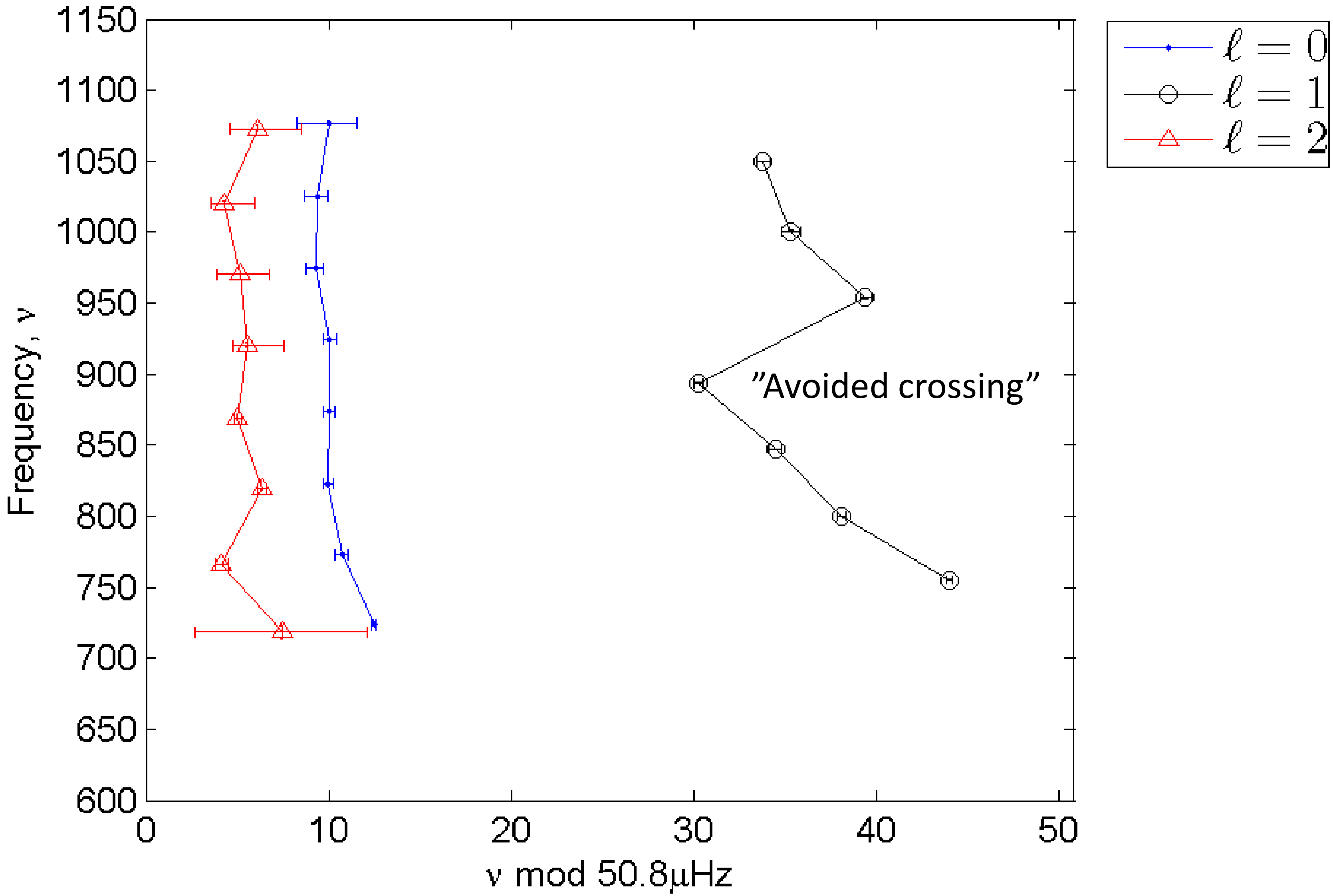
Den genoprettende kraft er **tyngdekraften**

Forskellige typer bølger

Lydbølger = P-modes
Den genoprettende kraft er **trykket**

"Tyngdebølger" = G-modes
Den genoprettende kraft er **tyngdekraften**

Kepler target "Gemma"



$$\nu_{n\ell} = \Delta\nu(n + \ell/2 + \epsilon) + \delta\nu_{02}\,\ell(\ell+1)/6$$

Hvad har vi lært om Gemma?

$$\Delta\nu = 50.8 \pm 0.3\,\mu\mathrm{Hz}$$

$$\delta\nu_{02} = 4.3 \pm 0.5\,\mu\mathrm{Hz}$$

Alder mellem 6 og 7 Gyr.

Udviklet væk fra hovedserien.

$$R = 2.10 \pm 0.10\,R_\odot$$

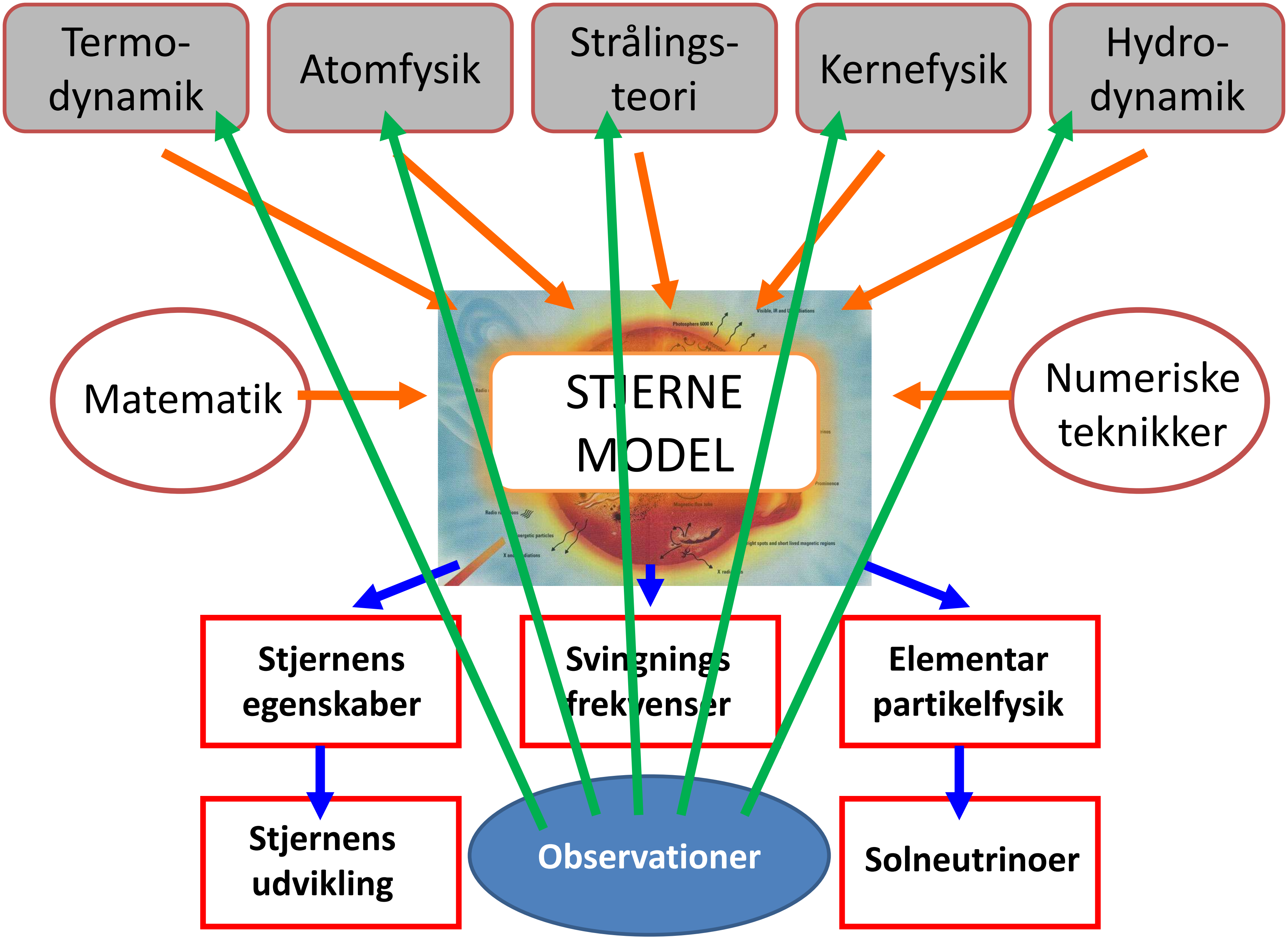
$$M = 1.10 \pm 0.12\,M_\odot$$

Modes har bredder på omkring 1μHz, med en stigende trend.

Roterer langsomt.

Har ”avoided crossing” hvor p- og g-modes blander.

Work in progress…



Termo-dynamik
Atomfysik
Strålings-teori
Kernefysik
Hydro-dynamik
Matematik
STJERNE MODEL
Numeriske teknikker
Stjernens egenskaber
Svingnings frekvenser
Elementar partikelfysik
Stjernens udvikling
Observationer
Solneutrinoer

Konklusioner

Asteroseismologi er *nødvendig* for at kunne finde Jordens tvilling.

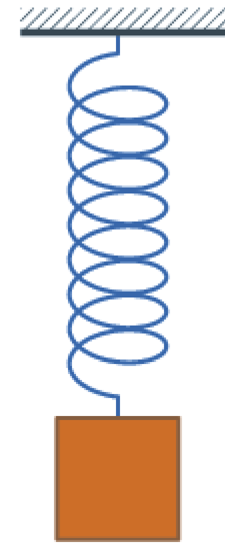
Det vælter ind med Kepler-data,
af fantastisk kvalitet.

”Helioseismologi på stjernerne”


Tak for opmærksomheden

Harmonisk Oscillator

$$\frac{1}{\omega_0^2}\frac{d^2x}{dt^2} + x = 0$$



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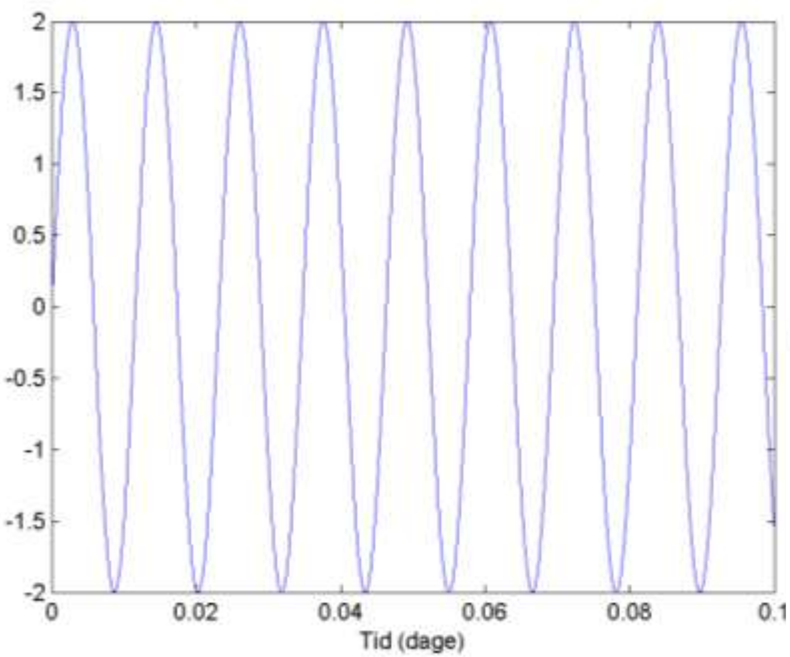

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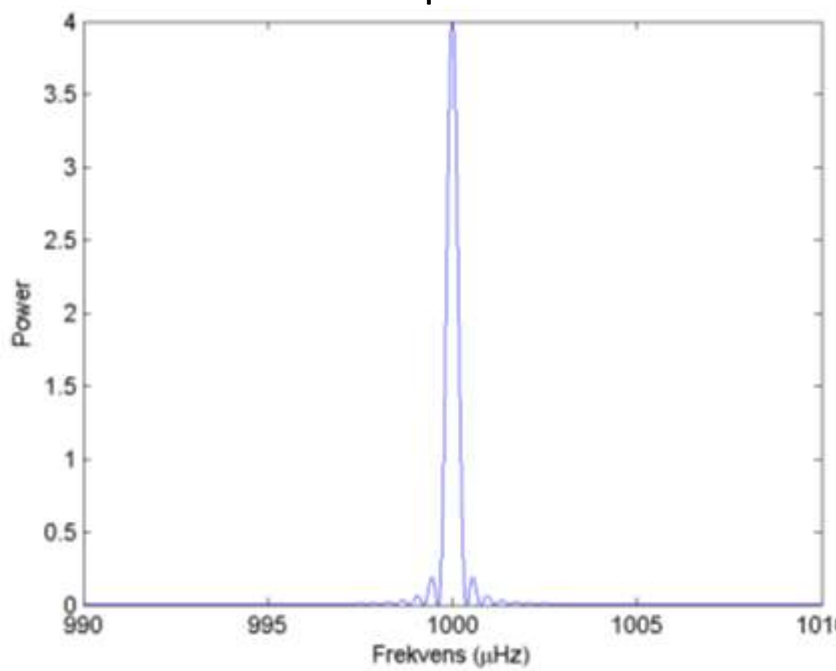
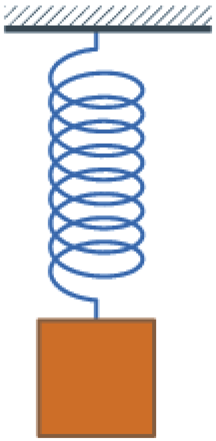


Dæmpet Harmonisk Oscillator

$$\frac{1}{\omega_0^2}\frac{d^2x}{dt^2} + \frac{1}{\omega_0 Q}\frac{dx}{dt} + x = 0$$



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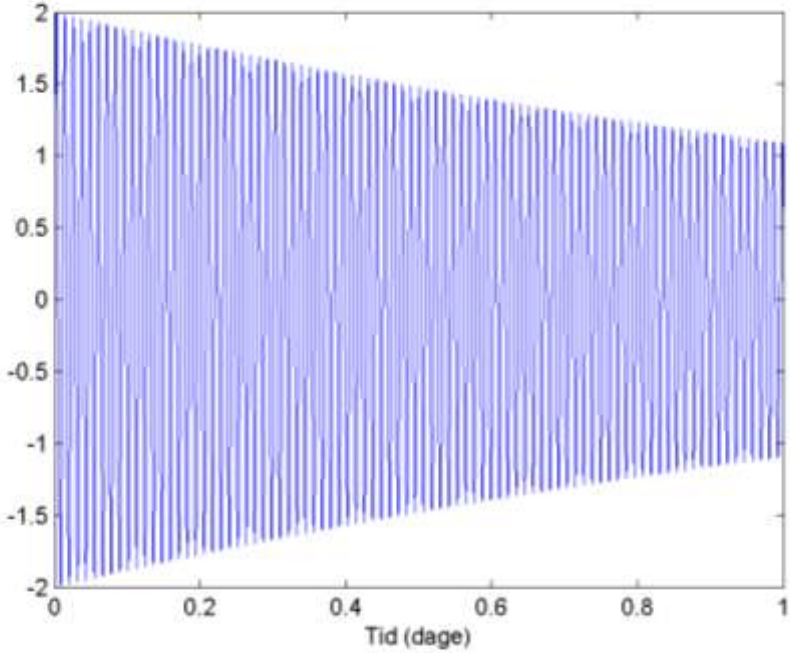

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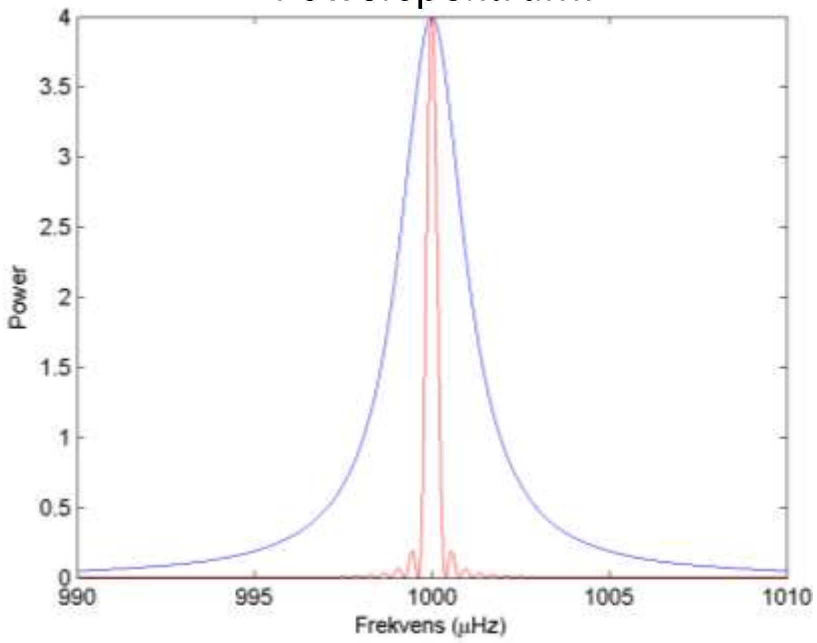
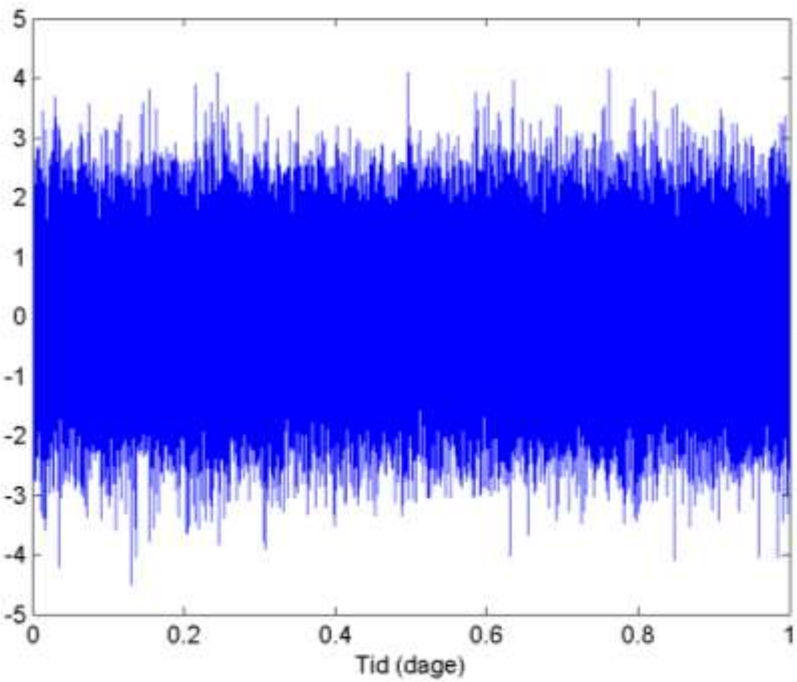


Drevet Dæmpet Harmonisk Oscillator

$$\frac{1}{\omega_0^2}\frac{d^2x}{dt^2} + \frac{1}{\omega_0 Q}\frac{dx}{dt} + x = f(t)$$

Tilfældig variabel
"Stokastisk exiteret"

Tidsserie:



Powerspektrum: