Where were you when .....the morning stars sang together.

Job 38:4,7

As·ter·o·seis·mol·o·gy

Which is the study of the internal structure of stars through the interpretation of their pulsation periods.

The word Asteroseismology is derived from the Ancient Greek.

- Astēr which means Star.
- Seismos which means Earthquake
- Logia which means body of knowledge.

Some other terms to know

Helioseismology:
which is the study of the internal structure of the Sun through the interpretation of Solar pulsation periods.

Stellar Seismology:
which is a catch all term being pushed by some to combine the terms Asteroseismology and Helioseismology as one.

For the most part this term is only used by a few, but you will run across it on the Internet.

My Preference:
For the purposes of this presentation we will use the terms Asteroseismology and Helioseismology as needed.

Limits of this Presentation

I. This is an introduction to Asteroseismology

II. Asteroseismology is a relatively new field of study.

III. Data or results change in the space of months or days.

IV. The presentation will be general in nature.

V. The main focus will be how, what, and where and to highlight recent discoveries of interest.

VI. Due to time constraints I will not elaborate on the stellar evolutionary mechanics needed to explain observations.

VII. Last but not least: keep it simple and fun and not to bore everyone.

An Unfortunate Assignment

1932

What the Sun makes Noise ?

Robert Leighton continued to work on astronomy, the old instruments on Mount Wilson had fallen into disrepair. He not only repaired them, but made improvements as well.

In 1961 he discovered the five-minute oscillation of the Sun by superposing two Doppler photographs of the same area taken in rapid succession, one a negative and one a positive of the other.

Granulation on the Sun had been known for sometime, but Leighton was the first to recognize that the patterns of granules recurred at identical spots on the surface.

He later observed the same phenomena on a much larger scale: supergranulation.

Bottom-line Leighton had discovered sound waves coursing through our Star. The Sun.

Thus Leighton's discovery of both large and small periodic patterns on the Sun marked the birth of the two subjects, Helioseismology and Asteroseismology.

So how do we study this?

We measure the waves rippling across the surface of the Sun by measuring the Doppler shift of a spectral lines in an areas across the entire Star.

We then use the wave data to study the interior of a Star. As the waves travel through the Star they are influenced by conditions inside the Star.

Two Types of Waves

First of all, acoustic waves which have pressure as their restoring force. They are generated when the Convection Zone "shakes" a Star . Their dynamics are determined by the variation of the speed of sound inside the a Star. You will see them referred to a p-mode waves in publications.

The other kind of wave are density waves which have gravity as their restoring force by buoyancy of displaced material. You will see these referred to a g-mode waves in publications.

And the beat goes on……

In 1965 Leighton's observations were confirmed.

In 1976 the Birmingham Solar Oscillations Network (BiSON) is created. Six solar observatories around the world monitoring solar oscillation modes. The BiSON network is still in operation today.

In 1979 the first Solar full-disk observations reveal that the oscillations are in fact global around the Sun revealing the convection zone of our Star.

What can we learn from Asteroseismology ?

I. Most important : Asteroseismology tests and constrains Cosmology and Stellar Models.

II. Mass

III. Radius

IV. Inclination

V. Temperature

VI. Metallicity

VII. Age

VIII. Density

IX. Internal Structures – Convection Zone and Internal Rotation

Limits to ground based Helio and Asteroseismology

Very Simple Limits but the same we face as Amateur Astronomers.

Weather: clouds, rain, and snow. All the things that are supposed to not bother the **Postman** but which we don't like.

Seeing: trying to tease out tiny Doppler shifts with poor seeing is not going to happen.

Rotation of the Earth: 24 hour period.

Day Light: less than 12 hours of night depending on time of year and location.

Space the only way to go

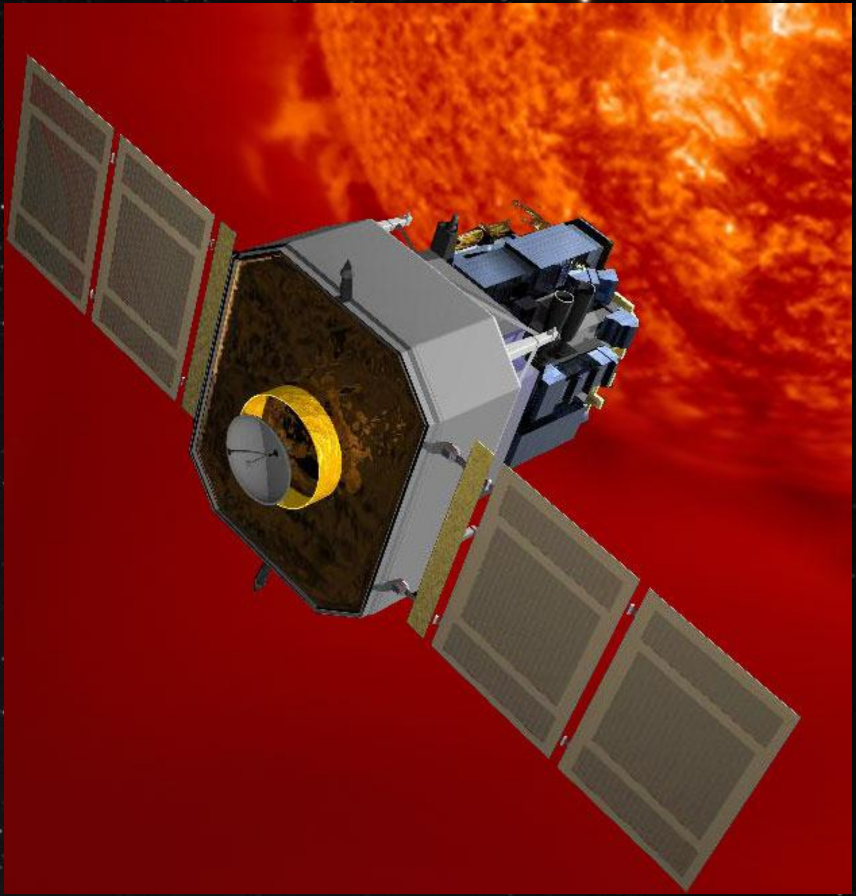
That unfortunate Assignment

Georgia State University Project

In 1996 the SOHO or Solar and Heliospheric Observatory starts operations conducting 24/7/365 observations of the Sun.

Michelson Doppler Imager:

The MDI measures the sound waves in the Sun to learn about the convection zone and the interior of the Sun. The MDI is the biggest producer of data by far on SOHO.



Case and Point: Things we learn

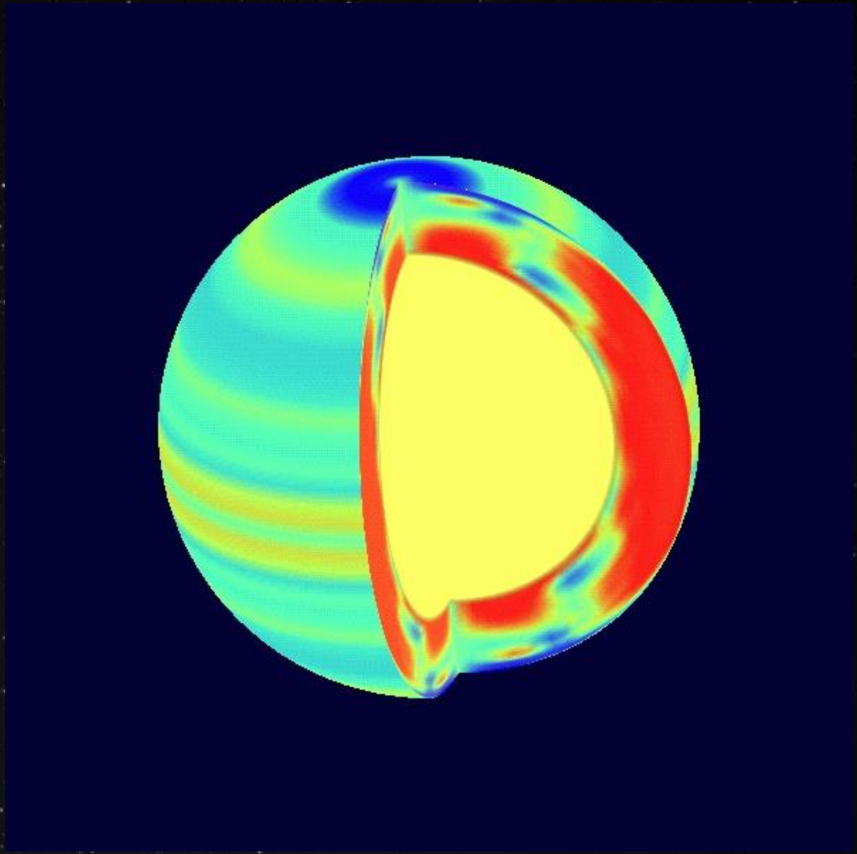
The missing Neutrino problem

In the early 1990s we had a huge problem measurements of neutrinos coming from the sun was less than a third of what should have been observed.

Many exotic models were developed for the internal structure of the core of the Sun to do away with this problem.

Astronomers using MDI on SOHO were able to prove that the Standard Model for the Sun's core was correct.

This tossed the ball back to………….. some very unhappy particle Physicists.



SDO how much more can we learn?

The age of the sun has been confirmed.

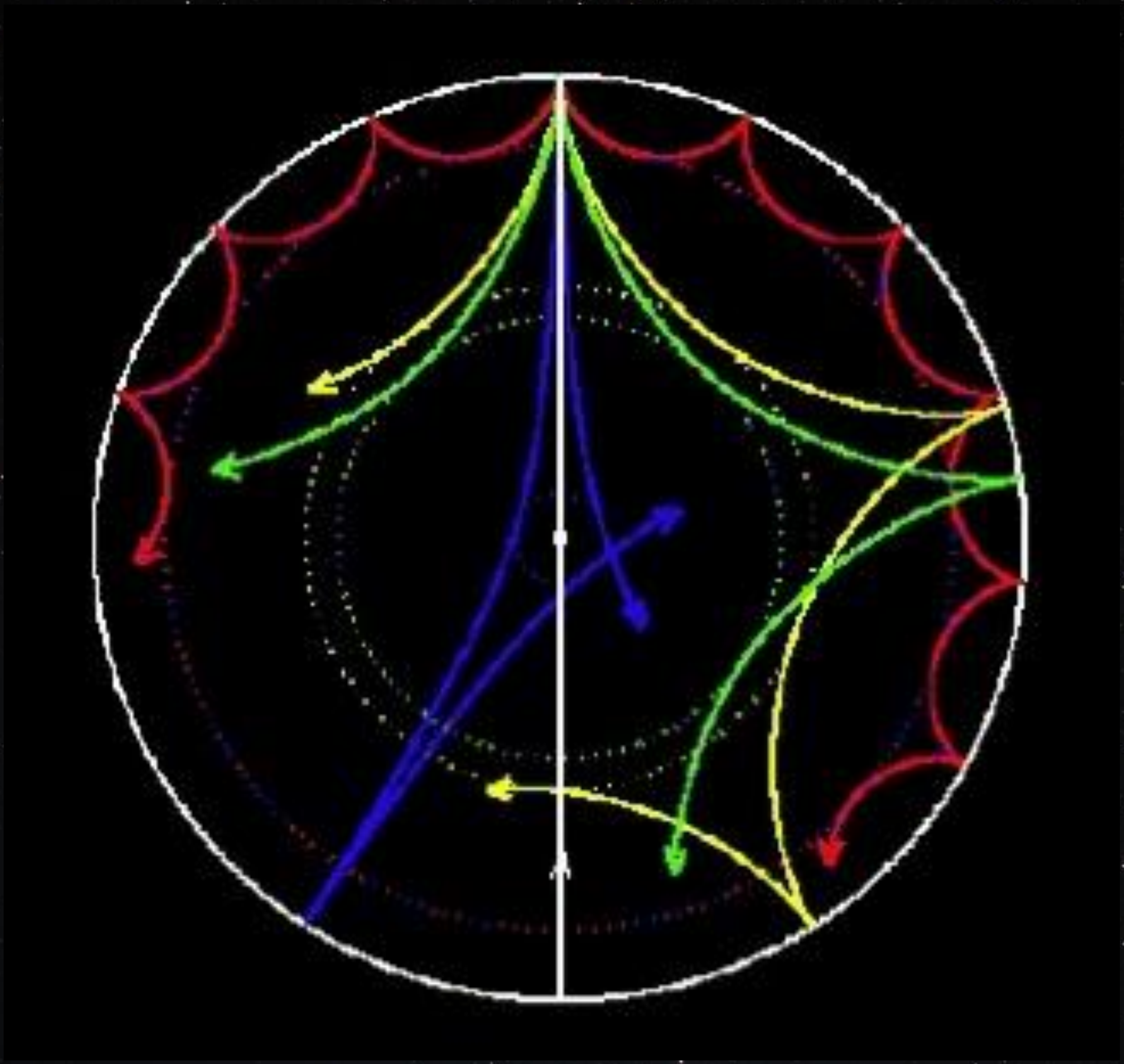
We can see the uniformly-rotating core of the and the differentially-rotating convection zone of the Sun.

We can see and track jet streams within the Sun located at the boundary of the core and convection zone.

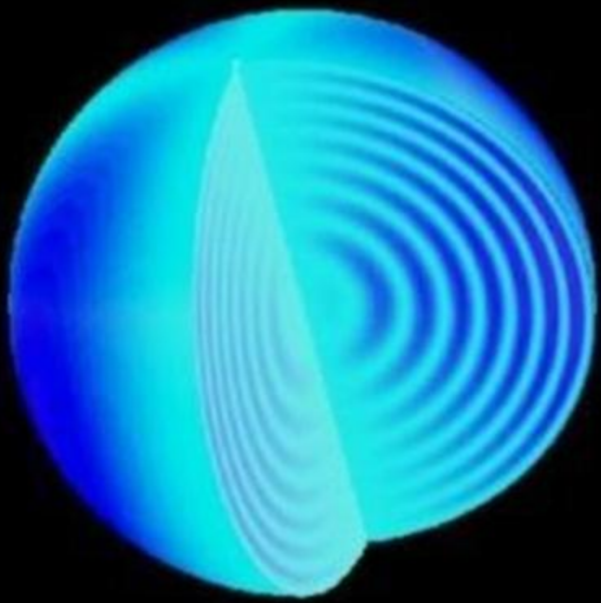
We can far-side image the Sun. Seeing sunspots before they rotate into view.

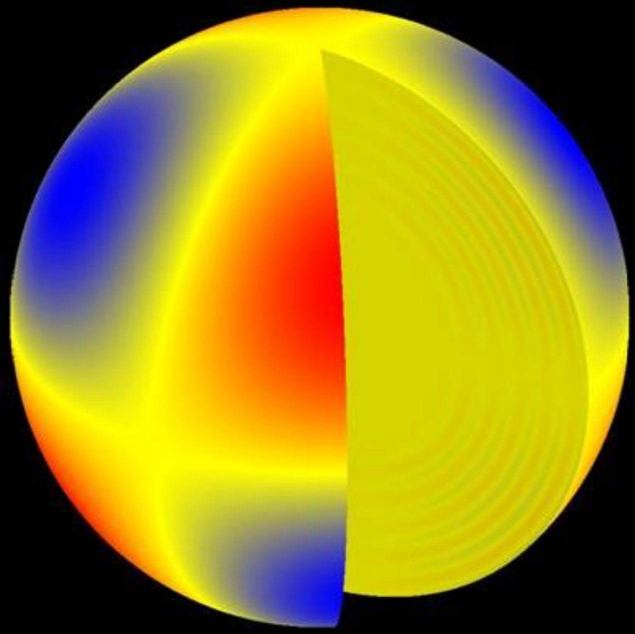
We can see sunspots form inside the Sun and we can create 3D images of them as well

The internal jet stream moving behind schedule may explain the delayed start to the solar cycle in 2009.



Stellar Vibrations





Some fun facts.

These are standing sound waves that can not escape the star.

The speed of sound increases the hotter and denser the stellar material.

The speed and angle at which the wave is generated determines how far it will penetrate into the stellar interior. The shallower the angle, the shallower the penetration, the steeper the angle, the deeper the wave will travel into the Star.

The waves are tones for all practical purposes.

The Smaller the Star the higher the tone. The larger the Star the lower the tone.

These tones are so low in some cases a Whale could not hear them.

It takes about 2 hours for sound waves to propagate through our Sun's interior.

Why?

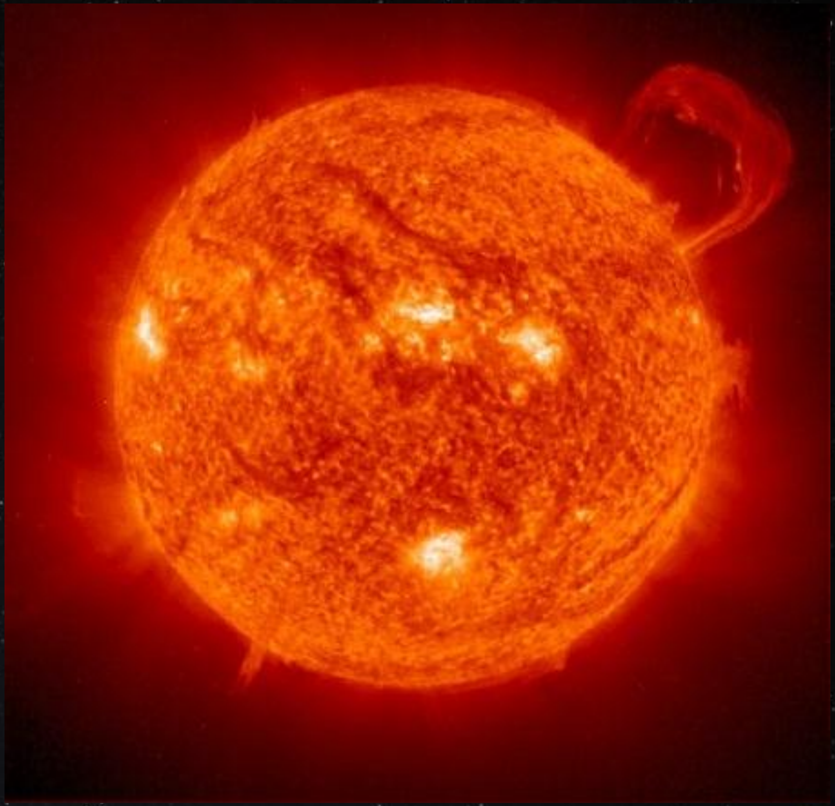
Test our understanding of Physics under and in exotic environments such as the interior of a Star.

Understand Stars in General

Learn about the Sun's past.

Learn about the Sun's future.

To Answer: Is the Sun Normal ?




Can you name that Star ?

Sun

It's our star. Non-Radial pulsations.

Alpha Centuri A

Non-Radial pulsations. 110% the mass of our Sun. 150% as luminous as the Sun
Higher metallicity than our Sun.

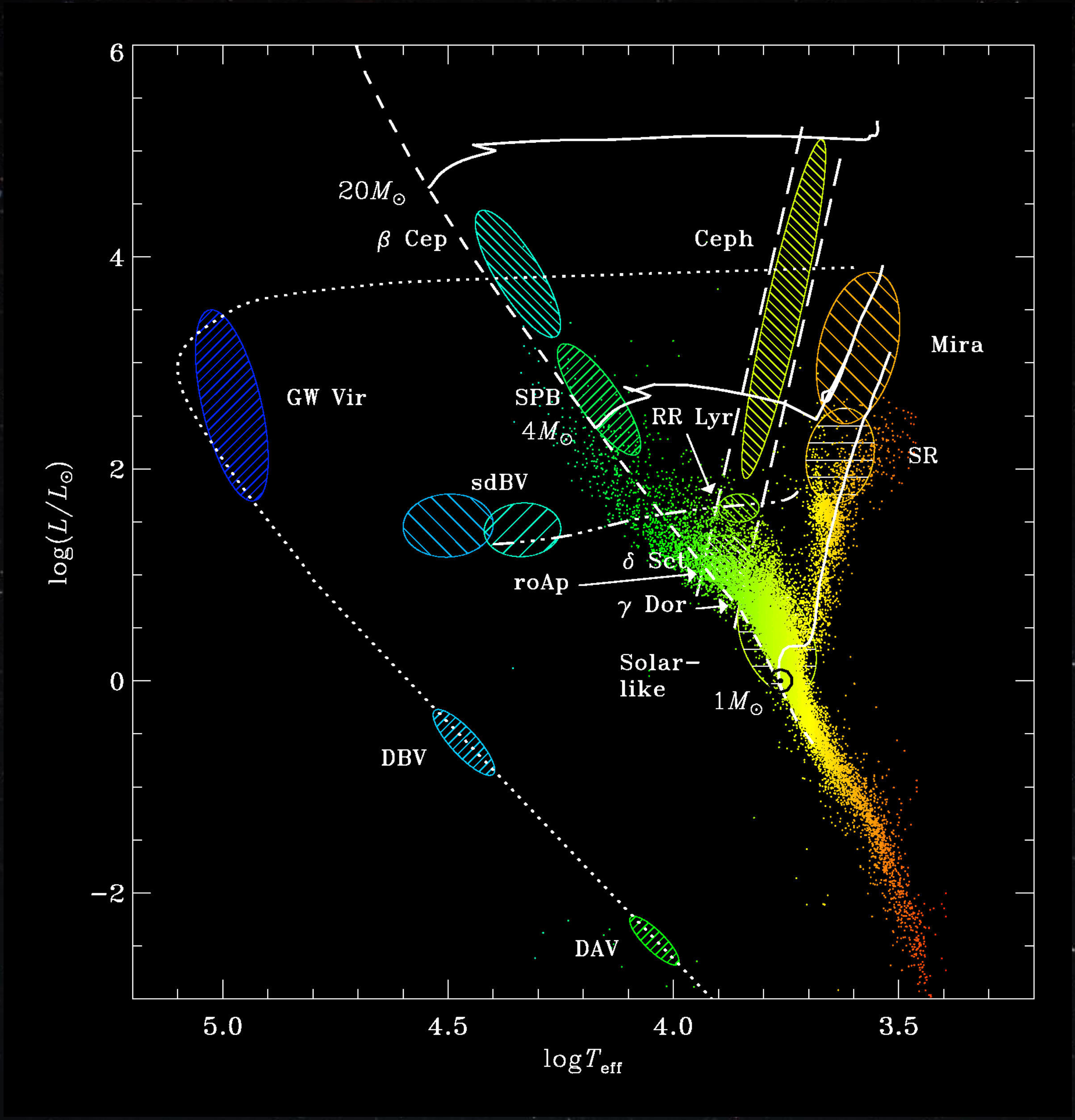
xi Hydrae

Non-Radial pulsations. Red Giant. 130 light years away. About 3 solar masses. 10 times the radius of the Sun. Pulsates every three hours. End of Life

Rapidly oscillating Ap star

Radial pulsations. Four or more Solar masses. Heavy elements play a role in pulsations. We are only just beginning to understand these stars

White Dwarf



6
4
2
0
−2
5.0
4.5
4.0
3.5
log(L/L⊙)
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

Space based Missions

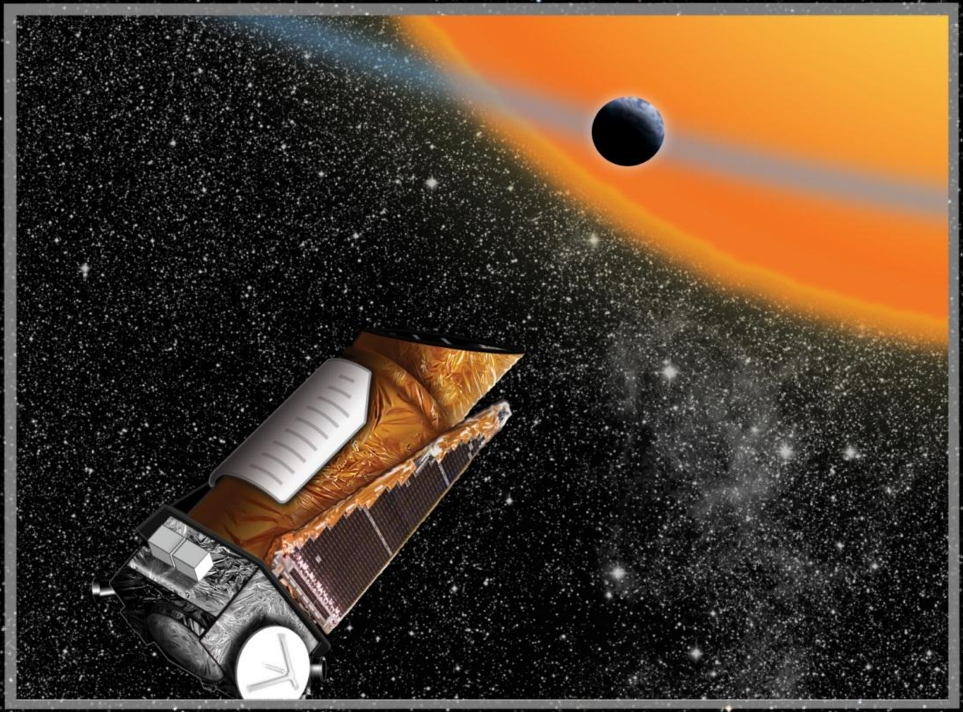
Up until 2006 most of the missions were under powered or not designed specifically for the task.

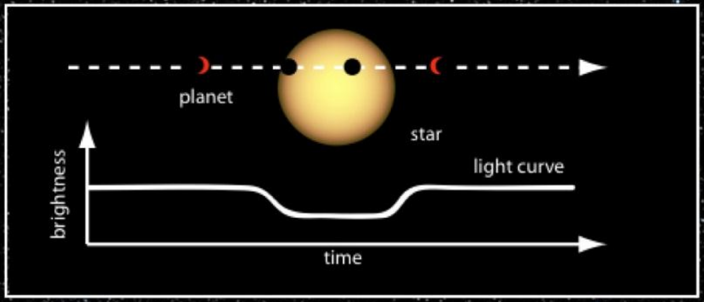
In 2006 the ESA launches CoRoT which is similar to Kepler in functionality.

In 2009 Kepler is launched by NASA with even better resolution and instruments.

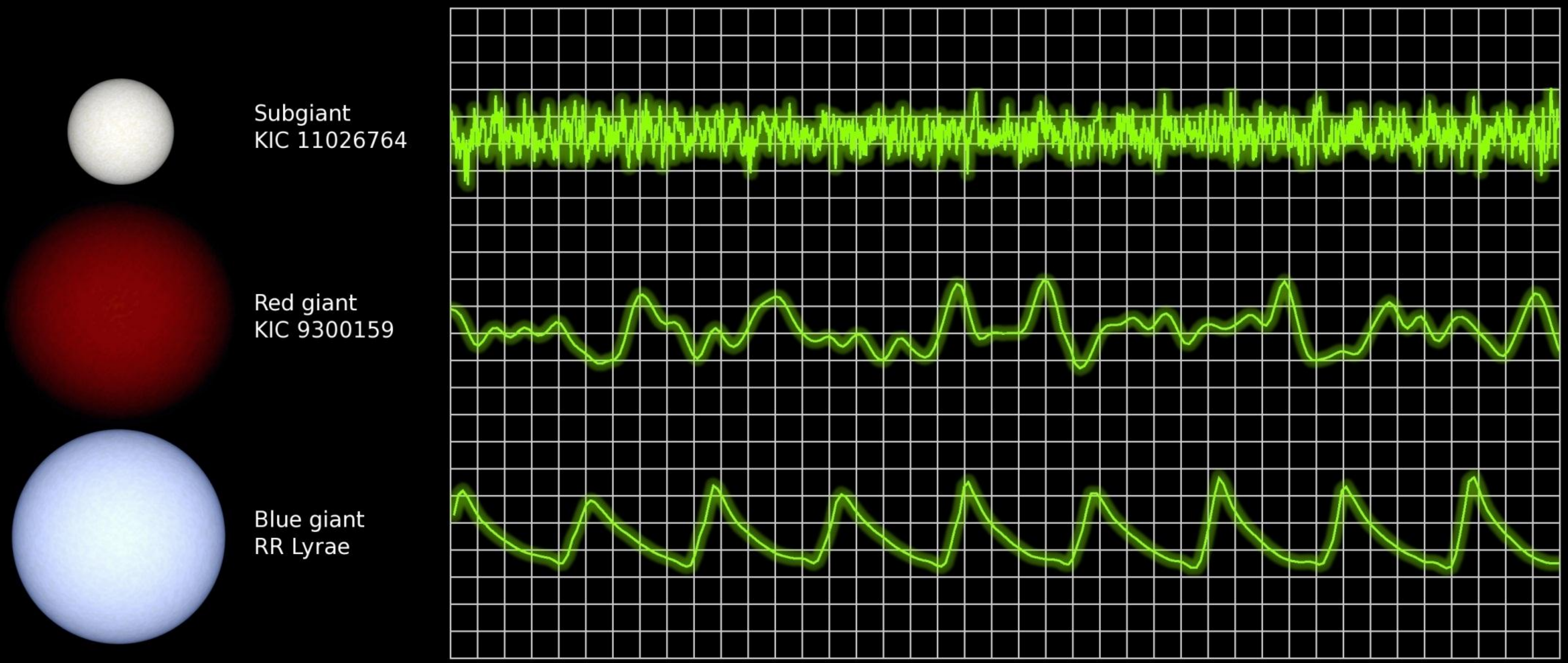
Kepler Mission

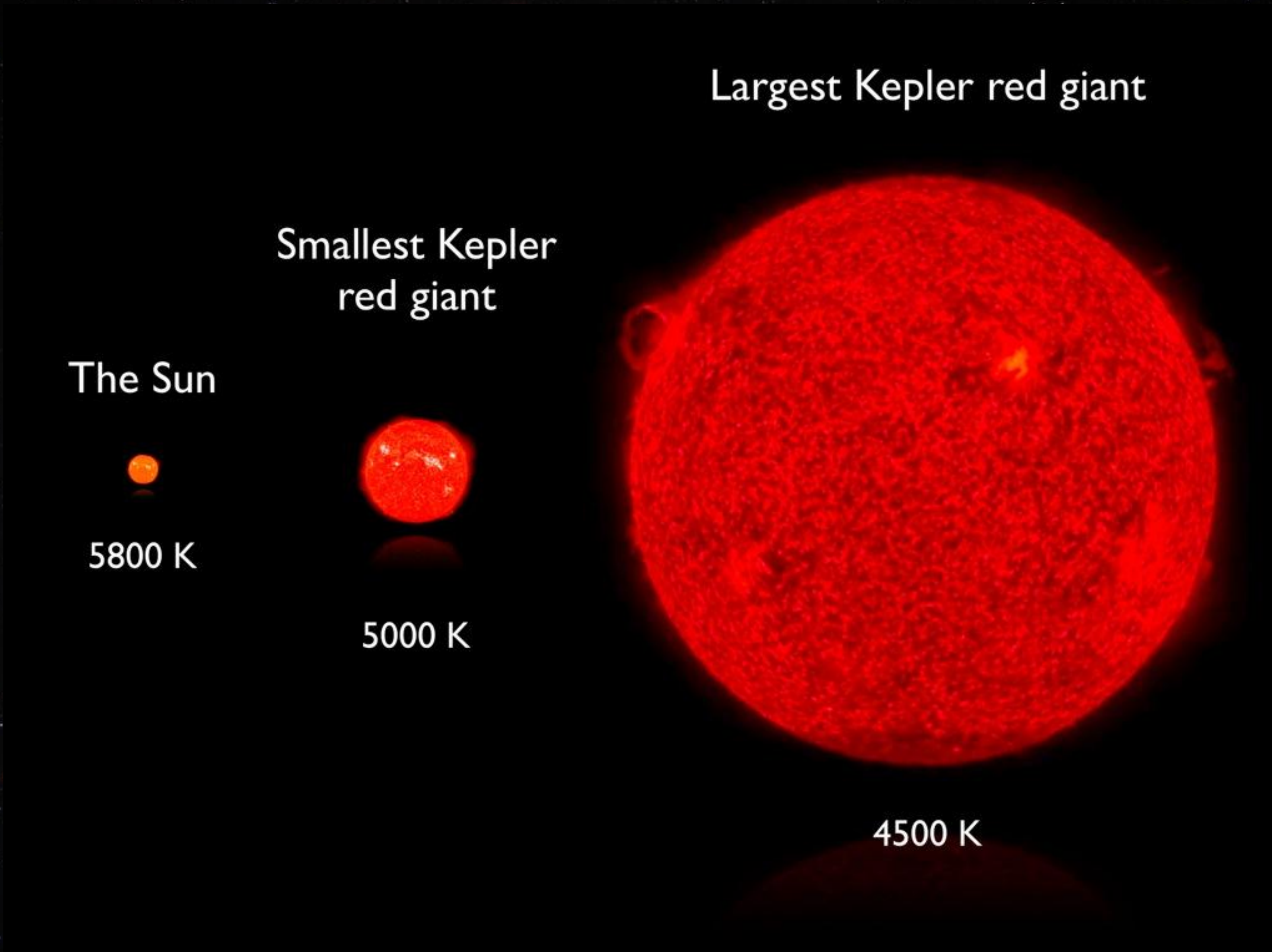
The determination of the frequency of Earth-size & larger planets in and near the habitable zone of solar-like stars



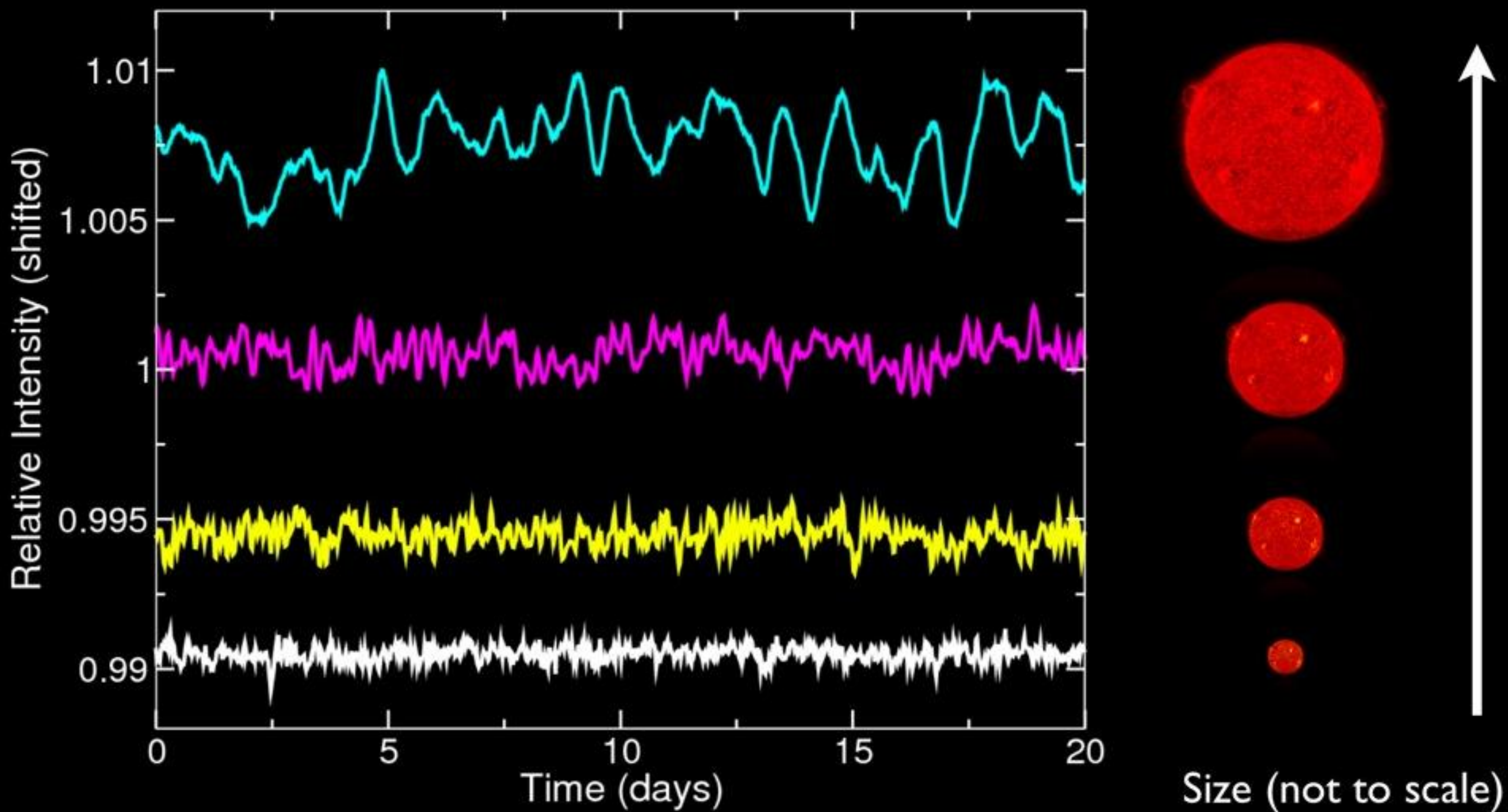


TAKING THE "PULSE" OF STARS




Largest Kepler red giant
Smallest Kepler red giant
The Sun
5800 K
5000 K
4500 K

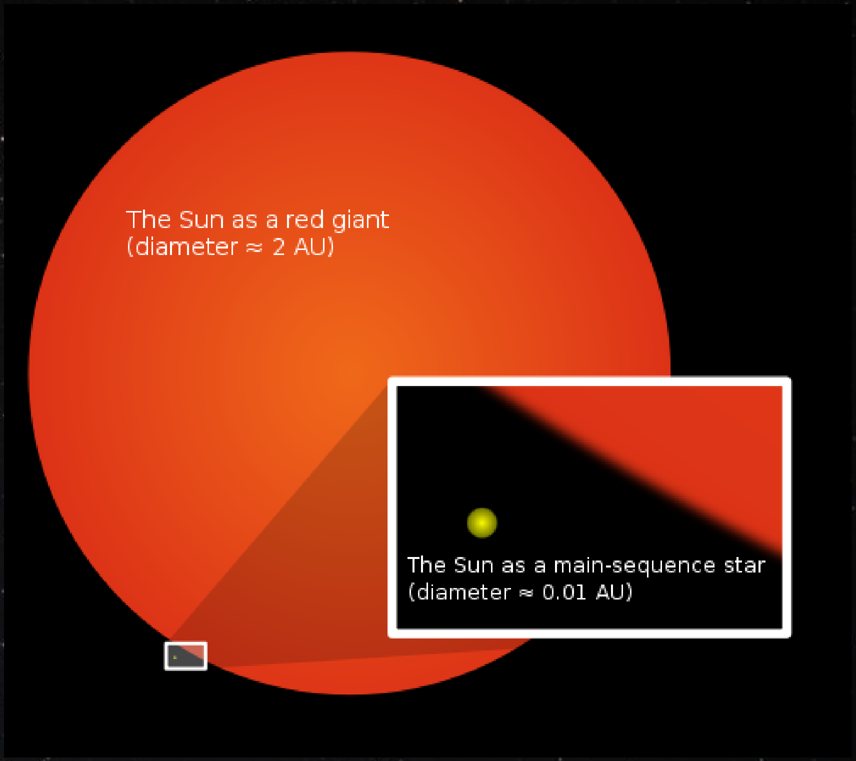
A Kepler "concert" of Red Giant Stars



Red Giants

The future of our Sun.

One of the main focuses is to study stars with similar life cycles to the Sun.



Discoveries Observed to date.

- ✓ Hydrogen Shell burning phase.
- ✓ Helium Core burning phase.
- ✓ Candidates for Helium Flash.
- ✓ Is that a Planet I see ?

Rapidly oscillating Ap star

Known Properties

These stars are located on the end of the delta Scuti instability.

They are known for their very high Metallicity. They have overabundances of metals, such as strontium, chromium and europium

Very Strong Magnetic fields.

Surface temperature is around 7,200k.

They are radial pulsating variable stars.

They have a known period range between 5 and 20 minutes.

Rapidly oscillating Ap star

Important Discoveries

They have convection zones that are only around 2,000km thick.

G-mode oscillations are dominate in these stars.

They have fixed star spots. The spots do not drift or move.

Distribution of heavy elements is not uniform in the star.

They have “Hydrogen” spots

They have two different “nodes” of pulsation

White Dwarfs

Several discoveries have been made over the years.

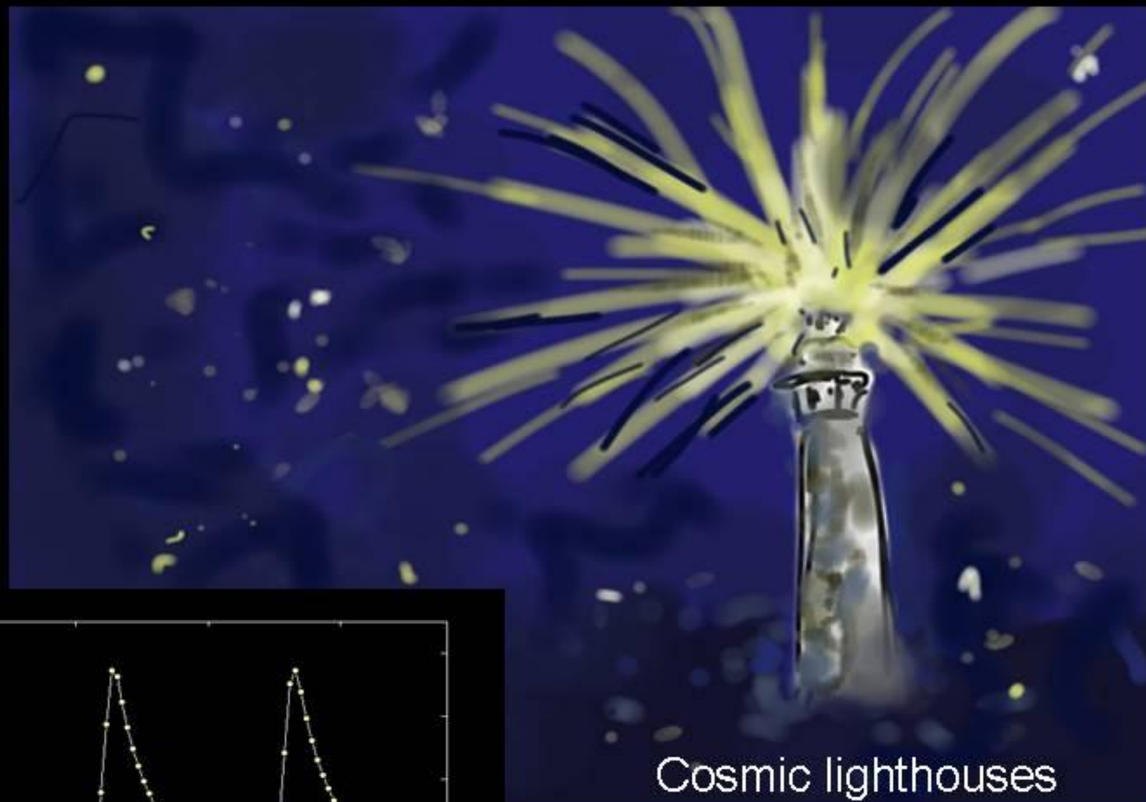
We now know that crystallization does happen in White Dwarfs.

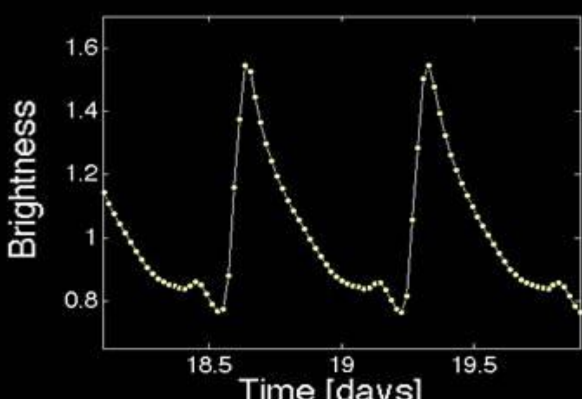
White dwarfs have been found as low as 20% the suns mass and right up to the Chandrasekhar Limit.

DA type with hydrogen atmospheres and DB type dwarfs having helium atmospheres have been found in the Kepler field, as well as dwarfs with carbon or no atmospheres.

The discovery of dwarfs with helium rich cores was believed to be confined only to clusters, but that may no longer be the case.

RR Lyrae stars





RR Lyrae before Kepler

The Blazhko effect was first observed by Sergey Nikolaevich Blazhko in 1907. Sergey managed to win two Orders of Lenin and avoid getting purged by Stalin. He also has a crater on the Moon named after him.

Blazhko effect viewed as being rare.

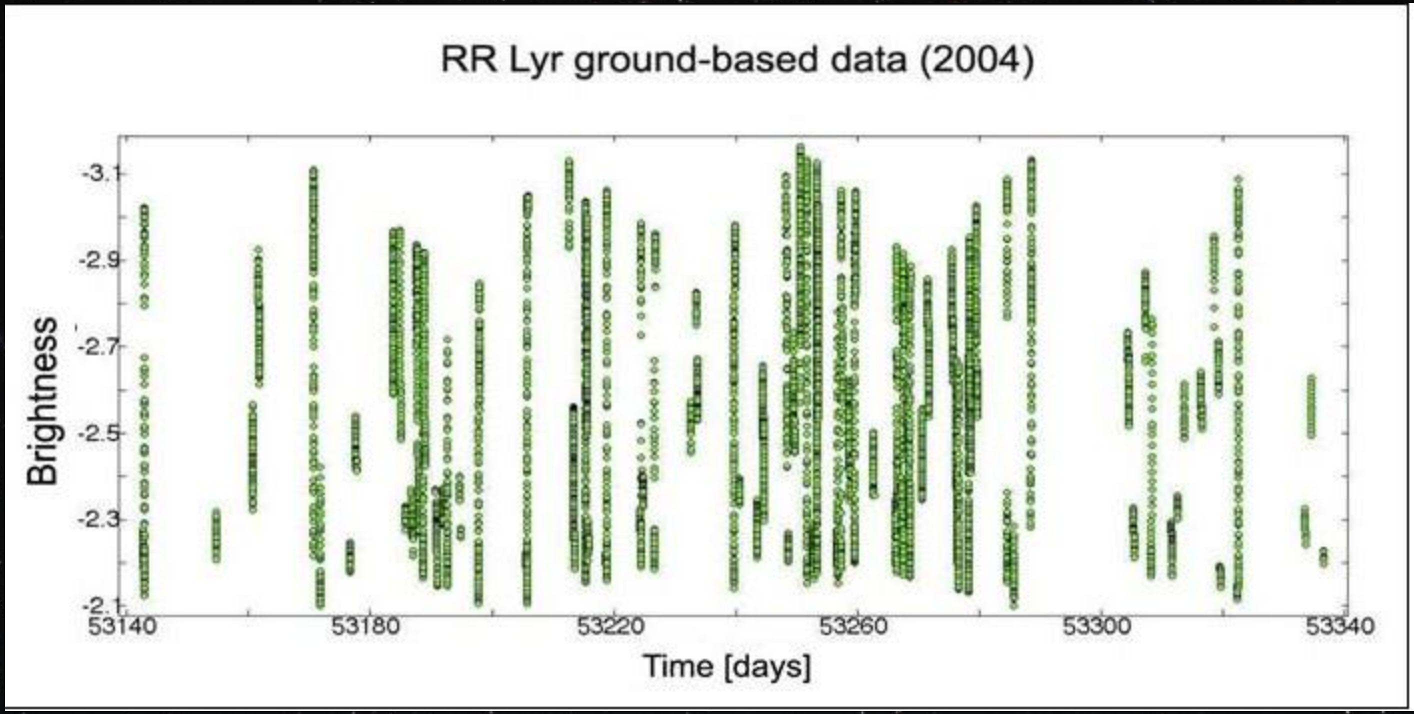
Known as radial variables.

Used as a Cosmic Lighthouses.

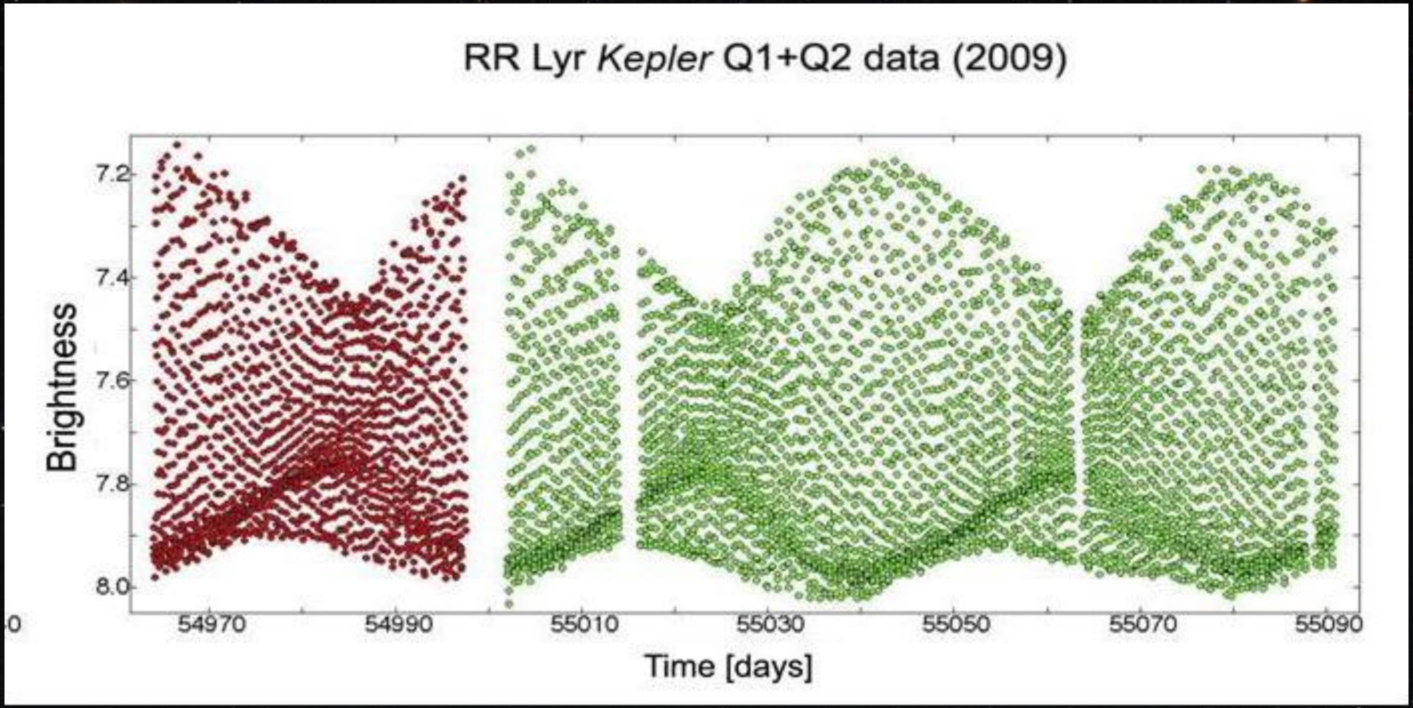
Many attempts have been made to explain the Blazhko effect. The stellar models are Resonate, Magnetic, and Convective.

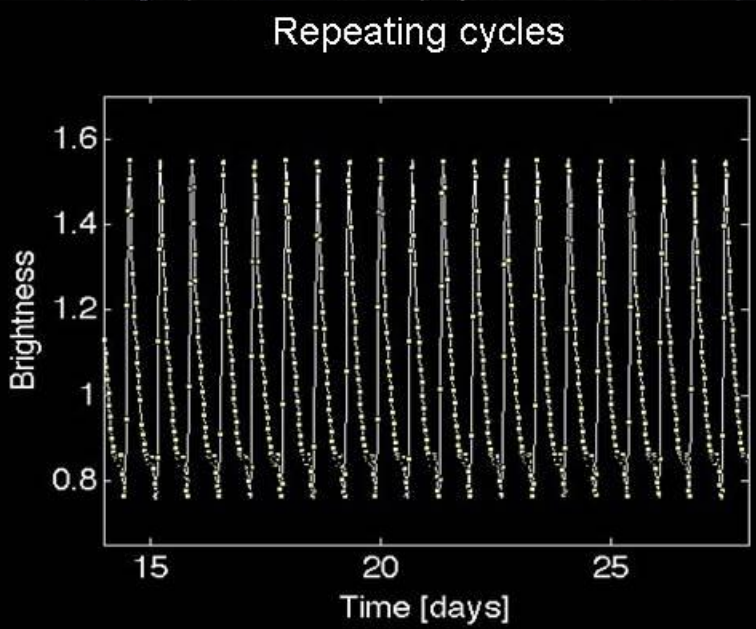
Just before Kepler two researchers abandoned observations due to alternating peaks in variability observed.

The best data that ground based observations had to offer in 2004

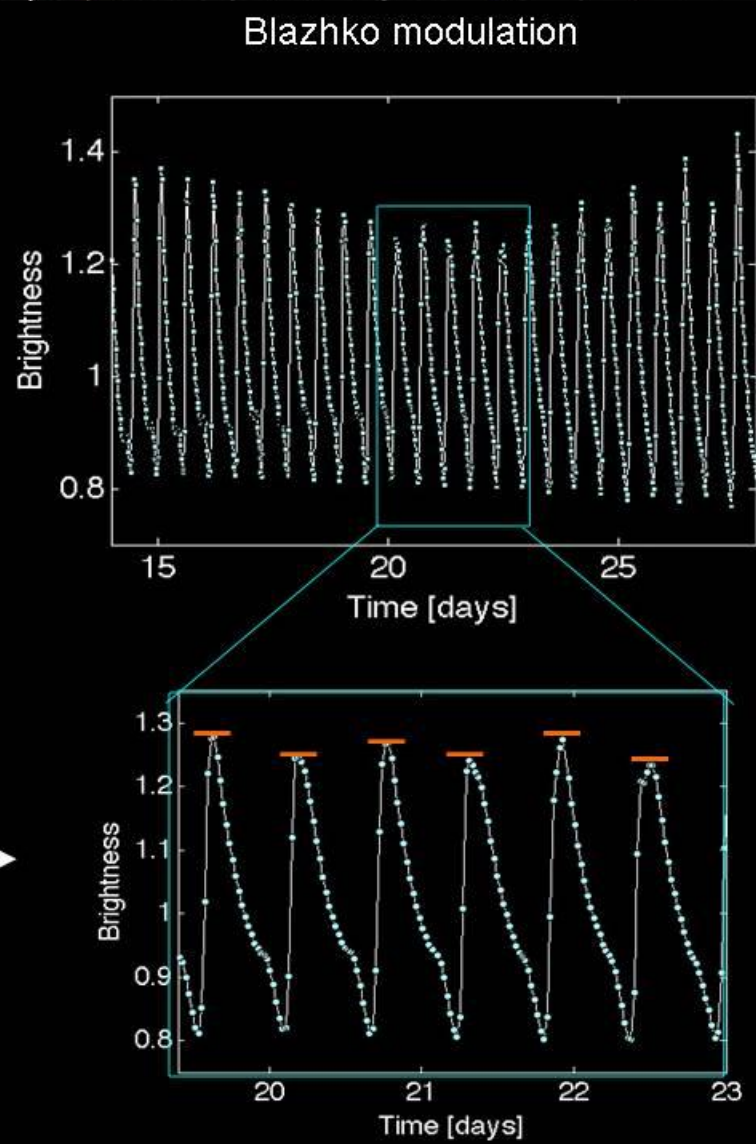


RR Lyrae after Kepler


RR Lyr *Kepler* Q1+Q2 data (2009)
Brightness
7.2
7.4
7.6
7.8
8.0
0
54970
54990
55010
55030
55050
55070
55090
Time [days]



Period Doubling →



RR Lyrae after Kepler

Over 40 stars of the RR Lyrae class are in the Kepler field of view.

50% + of RR Lyrae stars produce the Blazhko effect. So the Blazhko effect may be rule and not the exception.

The astronomers who thought that Period Doubling was a mistake lost out.

Current models to explain the Blazhko effect have been ruled out using Asteroseismology of the RR Lyrae stars by Kepler. As of now we have no idea what drives the Blazhko effect.

We now know that we are standing on the wrong planet to observe these stars. RR Lyrae stars have a 12 hour period.

The use of RR Lyrae stars as standard distance candles has been improved.

The Future

The Kepler was to complete its mission at the end of this year just in time for the ***Mayan Apocalypse***.

Kepler was granted an extension until the end of 2016 in April. So there will be no ***Mayan Apocalypse*** this year. Everyone will just have to wait.

This is very welcome news for Asteroseismology as longer period variations like our Solar cycle may be revealed.

The far future after Kepler in the 2020s

NASA/Goddard Space Flight Center are working currently on the proposed ***Stellar Imager Mission***. The goal is for a Space telescope with 200x the resolution of the HST with a 0.1 milliarcsecond resolution working in the ultraviolet/optical range. Asteroseismology will be a main mission goal.

What about other Star types ?

Is the Sun Boring ?

Places to Go

Papers at Kepler – NASA/Kepler Site
http://kepler.nasa.gov/Science/ForScientists/papersAndDocumentation/
click on ***Publications on Astrophysics***

Danish Asteroseismology Centre
http://astro.phys.au.dk/KASC/seismology/seism.html

http://asteroseismology.org/

Cornell University Library
http://arxiv.org/
Just search ***Asteroseismology*** over 500+ publications