STARQUAKES & EXOPLANETS
IN OUR MILKY WAY

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Stars shine
planets reflect starlight
STARS ARE NUCLEAR REACTORS

Special thanks to massive stars: all chemical elements heavier than hydrogen and helium was made by such stars

90% of your body is stardust!
STARS HAVE A LIFE & DEATH

The more massive they are, the shorter their life
BUT...INCREASINGLY MORE SHORTCOMINGS IN THE THEORY
Exoplanets surrounding post-Red-Giant stars (Silvotti et al. 2007; Charpinet et al. 2011)

How did these exoplanets survive the red-giant phase?

Internal angular momentum and its evolution?
An important astrophysics question in the previous century:

“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

tough, tough, tough, …
Starquakes enable to study the stellar interior because different waves penetrate to different depths inside the star.
1-DIMENSIONAL OSCILLATIONS

Fundamental

First overtone

Second overtone

modes → nodes
1-DIMENSIONAL OSCILLATIONS

Fundamental

First overtone

Second overtone

modes

nodes
3-DIMENSIONAL OSCILLATIONS

$(l,m) = (3,0)$
- Zonal

$(l,m) = (3,2)$
- Tesseral
  - Blue: Moving towards Observer
  - Red: Moving away from Observer

$(l,m) = (3,3)$
- Sectoral
3-DIMENSIONAL OSCILLATIONS

$(l,m)=(3,0)$

zonal

$(l,m)=(3,2)$

tesseral

Blue: Moving towards Observer
Red: Moving away from Observer

$(l,m)=(3,3)$

sectoral
MUSICAL INTERMEZZO
Stars as musical instrument
THE SIZE OF THE STARS

KIC 11026764

Sun

TIME ➔

Travis Metcalfe, National Center for Atmospheric Research
COSMIC SYMPHONIES
COSMIC SYMPHONIES

We move towards the stellar core
SOLAR FREQUENCIES

(ESA/NASA, SoHO)
FREQUENCIES OF A RED GIANT

(NASA/Kepler)
FREQUENCIES OF A RED GIANT

(NASA/Kepler)
FREQUENCIES OF A SUB-DWARF STAR

(ultracam/WHT)
FREQUENCIES OF A SUB-DWARF STAR
(ultracam/WHT)
HOW DOES IT ACTUALLY WORK NOWADAYS?

Unmanned spacecrafts with scientific instruments onboard
A Kepler concert of Red Giant Stars

Relative Intensity (shifted)

Time (days)

Size (not to scale)

Slide courtesy of Daniel Huber
DISCOVERY OF MIXED MODES IN RED GIANTS REVEALS NUCLEAR REACTOR

Beck et al. (2011, Science); Bedding et al. (2011, Nature)
DISCOVERY OF MIXED MODES IN RED GIANTS REVEALS NUCLEAR REACTOR

Beck et al. (2011, Science); Bedding et al. (2011, Nature)
INTERNAL ROTATION OF THE SUN

Rotational motion slightly shifts the frequencies, cf. music for the Sun, we can only detect modes that probe its outer envelope: no information about the core rotation of our star…
DISCOVERY OF CORE ROTATION IN RED GIANTS FROM MIXED MODES
DISCOVERY OF CORE ROTATION IN RED GIANTS FROM MIXED MODES
WATCHING STARS GROW OLD

Mixed modes reveal if red giant has H-shell or core-He burning

Classical data cannot make this distinction

Frequency shifts after 4 years of Kepler data reveal core-to-envelope rotation
Beck et al. (2012, Nature), Deheuvels et al. (2014)
ECHOGRAPHY OF BABY-STARS

Zwintz et al. (2014, Science)
ECHOGRAPHY OF BABY-STARS

Zwintz et al. (2014, Science)
An important astrophysics question in the current century:

“Are there exoplanets with forms of life in our Milky Way?”
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Transit Light Curves
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Transit Light Curves

<table>
<thead>
<tr>
<th></th>
<th>Kepler 4b</th>
<th>Kepler 5b</th>
<th>Kepler 6b</th>
<th>Kepler 7b</th>
<th>Kepler 8b</th>
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<tbody>
<tr>
<td>Phase</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3.2 days</td>
<td>3.5 days</td>
<td>3.2 days</td>
<td>4.9 days</td>
<td>3.5 days</td>
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<td>Flux</td>
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<tr>
<td>Size (R_J)</td>
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<td>18.8</td>
<td>15.0</td>
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<td>18.3</td>
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<tr>
<td>Time in hours</td>
<td></td>
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</tbody>
</table>
Transit & velocity $\rightarrow$ density

\[ \text{density} = \frac{\text{Mass}}{\text{Volume}} = 8.8 \text{ g/cm}^3 \]
Candidates in the Habitable Zone
As of February 27, 2012
New Planet Candidates
As of January 2015

Total = 4,175
TOWARDS SEISMOLOGY OF STARS WITH PLANETS IN THE HABITABLE ZONE
Kepler-62 System

Borucki et al. (2013, Science)

Planets and orbits to scale

Solar System
Is there an Earth2.0?
PLENTY OF EXOPLANETS...

- But where are the closest habitable ones?...
- Current closest exoplanet around star Alpha Centauri B; at a distance of 40,000,000,000,000 km (13 zeros…); this exoplanet is NOT habitable
- Kepler 62 is at 11,360,000,000,000 km
- Neptune in our solar system is at “only” 4,500,000,000 km: Voyager 2 reached it after 12 years…
- 12/11/14: Philae landing on Comet 67P/Churyumov–Gerasimenko at only 5,000,000 km, after 10 years of travel by ESA spacecraft…
- With current technology we reach closest exoplanet Alpha Centauri Bb after 142,000 years…
ESA M3 mission PLATO: searching for new worlds close by (launch 2024)
So more than enough reason to take good care of our planet Earth...
STARQUAKES & EXOPLANETS IN OUR MILKY WAY

The End

With gratitude to the Kavli Institute of Theoretical Physics @ UCSB for its hospitality!