



# Exploitation of Space Data for Innovative Helio- and Asteroseismology



## *Results and Impact*

Markus Roth & SpacelInn Board  
Kiepenheuer-Institut für Sonnenphysik

SpacelInn / HELAS VIII / KASC / TASC Terceira

July 11, 2016



# SpaceInn

## Collaborative Project

by the European research groups active in helio- & asteroseismology

*initiated by HELAS (European Helio- and Asteroseismology Network)*

## Objectives:

to make full use of data collected in space and on ground for the physics of solar and stellar interiors



## Reviewer:

Anne Thoul, University of Liège, Belgium

## Scientific Coordinator:

Markus Roth, Kiepenheuer-Institut für Sonnenphysik, Freiburg

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for the period January 1, 2015 - December 31, 2016





# Spaceln Work

- Organization of large and increasing volume of space- and ground-based data
- Provision of tools to efficiently make use of those data

## Service for the Research Community to enable

- In-depth studies of the interiors of the Sun and the stars
- Strengthening the cooperation in Europe
- Greatly improve understanding of solar and stellar structure, evolution and activity

***This conference:***

*Present the results of Spaceln  
and discuss the scientific progress*



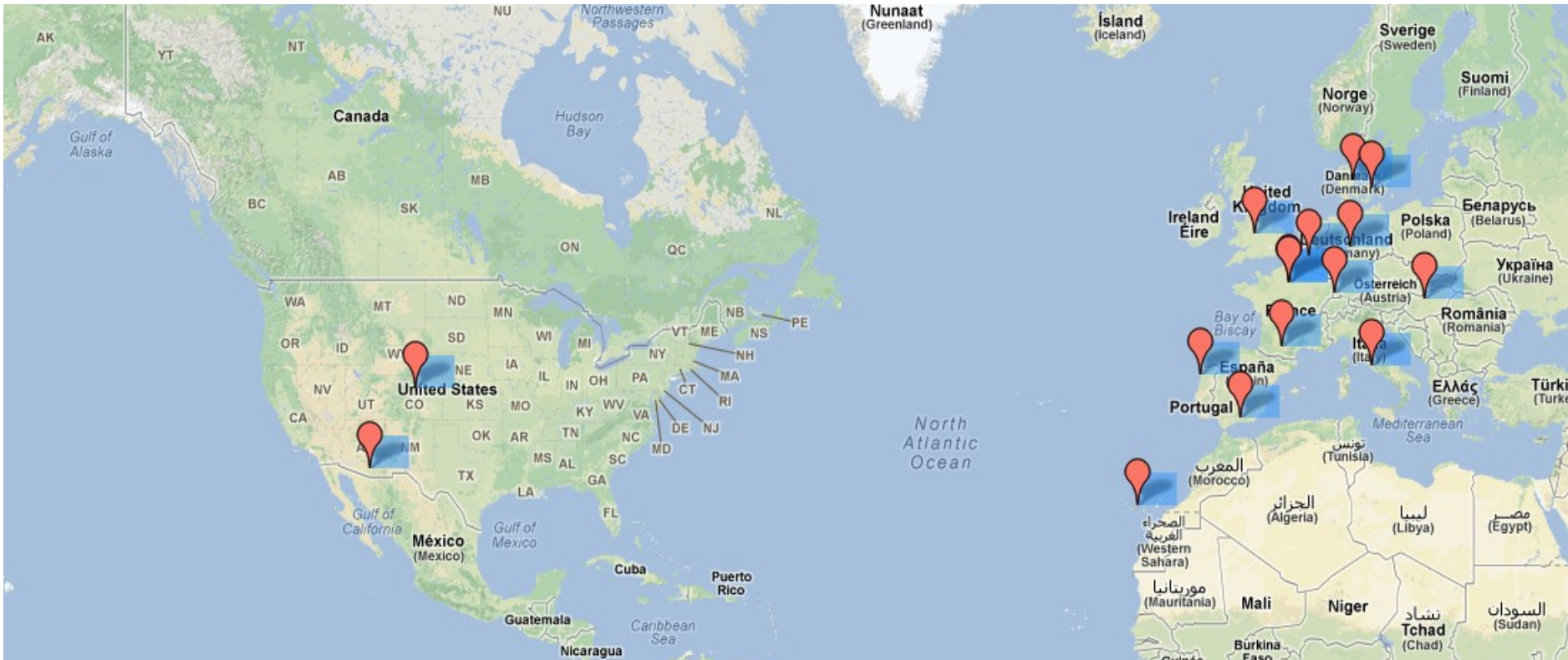


# The SpaceInn Consortium

- 1 Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany KIS
- 2 Instituto de Astrofísica de Canarias, La Laguna, Spain IAC
- 3 Commissariat à l'Énergie Atomique et aux Énergies Alternatives, Saclay, France CEA
- 4 Max-Planck Institute for Solar System Research, K.- Lindau, Germany MPG
- 5 Istituto Nazionale di Astrofisica, Rome, Italy INAF
- 6 Katholieke Universiteit Leuven, Instituut voor Sterrenkunde, Belgium KUL
- 7 Observatoire de Paris, Meudon, France OBSPARIS
- 8 Universidade do Porto, Centro de Astrofísica, Porto, Portugal CAUP
- 9 University of Birmingham, United Kingdom UOB
- 10 Århus Universitet, Institut for Fysik og Astronomi, Århus, Denmark AU
- 11 Institute Astrophysique Spatial, Orsay, France UPS
- 12 Université Paul Sabatier (Toulouse III), France UPST
- 13 *Instituto de Astrofísica de Andalucía, Granada, Spain CSIC*
- 14 Royal Library Copenhagen, Denmark KB
- 15 National Solar Observatory, Tucson, USA AURA
- 16 High Altitude Observatory, Boulder, USA UCAR
- 17 Konkoly Observatory of the Hungarian Academy of Sciences, Hungary MTA-CSFK



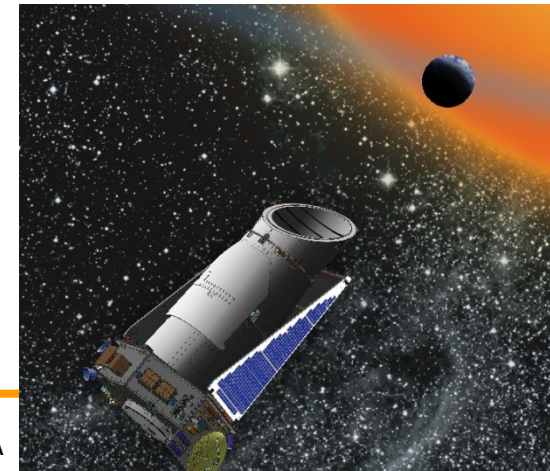
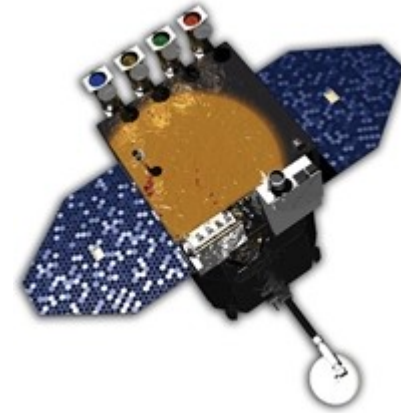
# The Spacelnn Consortium





# Data Bases in Europe

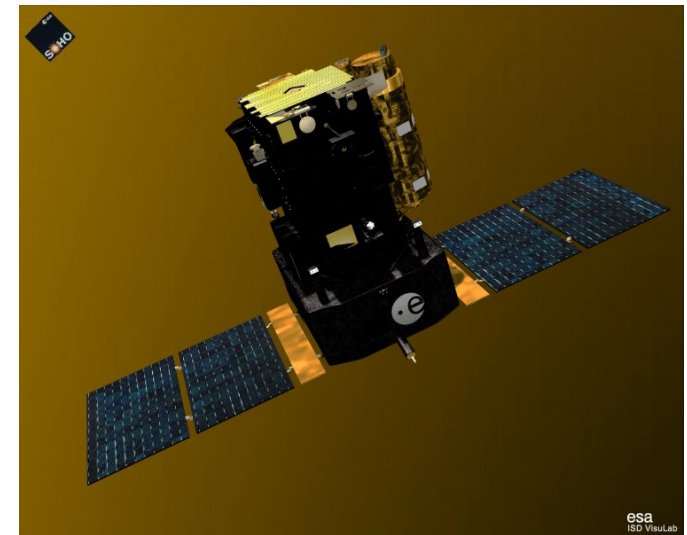
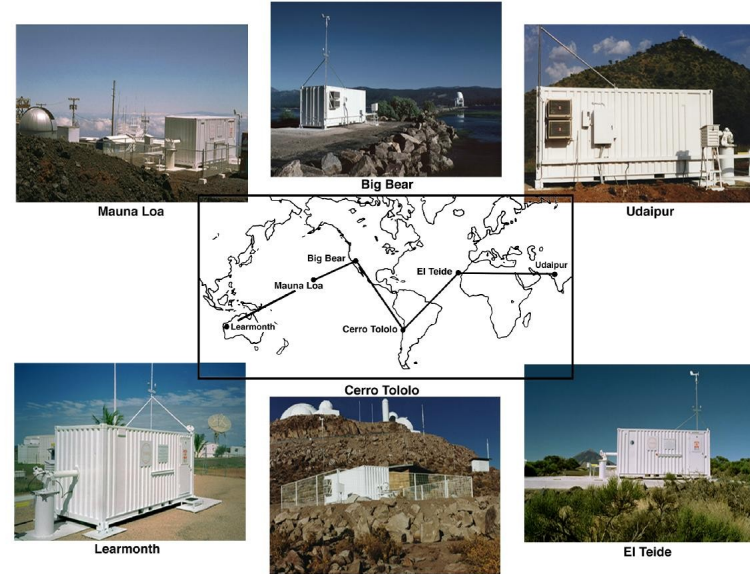
- BISON
  - Birmingham Solar Oscillation Network
- CoRoT
  - Data processing: Paris Observatory and Laboratoire d'Astrophysique de Marseille.
  - Scientific data is made available through the project archive located at IAS (Space Astrophysics Institute), Orsay, France
- SDO
  - Centre for the distribution and analysis of data at the Max-Planck Institute for Solar-system Research, Germany.
- KEPLER
  - Use of asteroseismic data is led by Aarhus University, Denmark, through the establishment of the Kepler Asteroseismic Science Operations Centre (KASOC) and the leadership of the Kepler Asteroseismic Science Consortium (KASC)





# Data Bases in USA

- GONG
  - Freely available helioseismic data recorded from the GONG instruments hosted by the National Solar Observatory in Tucson, USA
- SOHO
  - Freely available helioseismic data recorded by the the instruments aboard SOHO are available through the data bases at Stanford University, USA

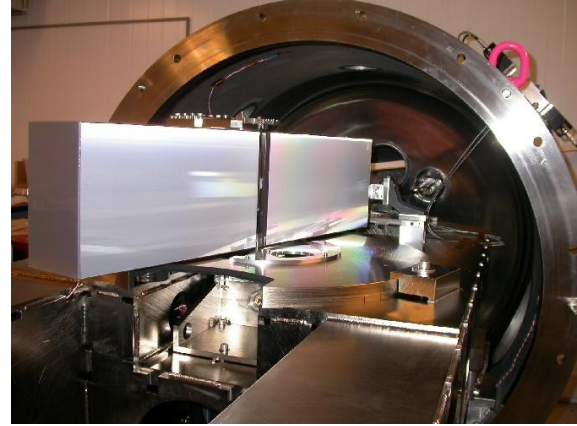




# European Investments on Ground

Europe has made large investments in ultra-precise modern instrumentation suitable for asteroseismology:

- **UVES** spectrograph at the Very Large Telescope
- **HARPS** spectrograph at the 3.6m Telescope of the European Southern Observatory
- Danish-led asteroseismic **SONG** network



+ many more observations were made from ground

These are important complementary data sets

- *Important for follow-up studies of space-based observations*

**SpaceInn ensures:**

Availability and efficient exploitation of these asteroseismology data by

- Spreading the data
- Combining data from ground and s







# SPACEINN.EU

Exploitation of Space Data for Innovative Helio- and Asteroseismology

## TESS

The Transiting Exoplanet Survey Satellite will identify Earth-sized planets that orbit nearby stars by using the light of distant stars. The satellite is scheduled for launch in 2017 and will observe the sky in a systematic way, scanning for transiting planets in the most sensitive 200-degree band by 2020.

## CoRoT

CoRoT was the first space mission devoted to the study of transiting exoplanets. It was launched in 2006 and operated for 3 years and 9 months. During its mission, the satellite observed 120 stars, including 10 transiting exoplanets. The mission was a joint effort between ESA and CNRS.

## SOHO

SOHO has revolutionized our understanding of the Sun. It has provided us with a wealth of information about the Sun's interior, atmosphere, and surface. The mission was a joint effort between ESA and NASA.

## Solar Orbiter

Solar Orbiter is the first mission to orbit the Sun at a distance closer to the Sun than any other spacecraft. It will provide us with a wealth of information about the Sun's atmosphere and surface.

## SDO

The Solar Dynamics Observatory provides us with a wealth of information about the Sun's atmosphere and surface. It is the first mission to observe the Sun in the extreme ultraviolet (EUV) range.

## Kepler

The Kepler mission has discovered thousands of exoplanets. It is the first mission to observe the sky in a systematic way, scanning for transiting planets in the most sensitive 105-degree band by 2012.

## GONG

The Global Oscillation Network Group (GONG) is a network of seven helioseismology observatories. It provides us with a wealth of information about the Sun's interior.

## BISON

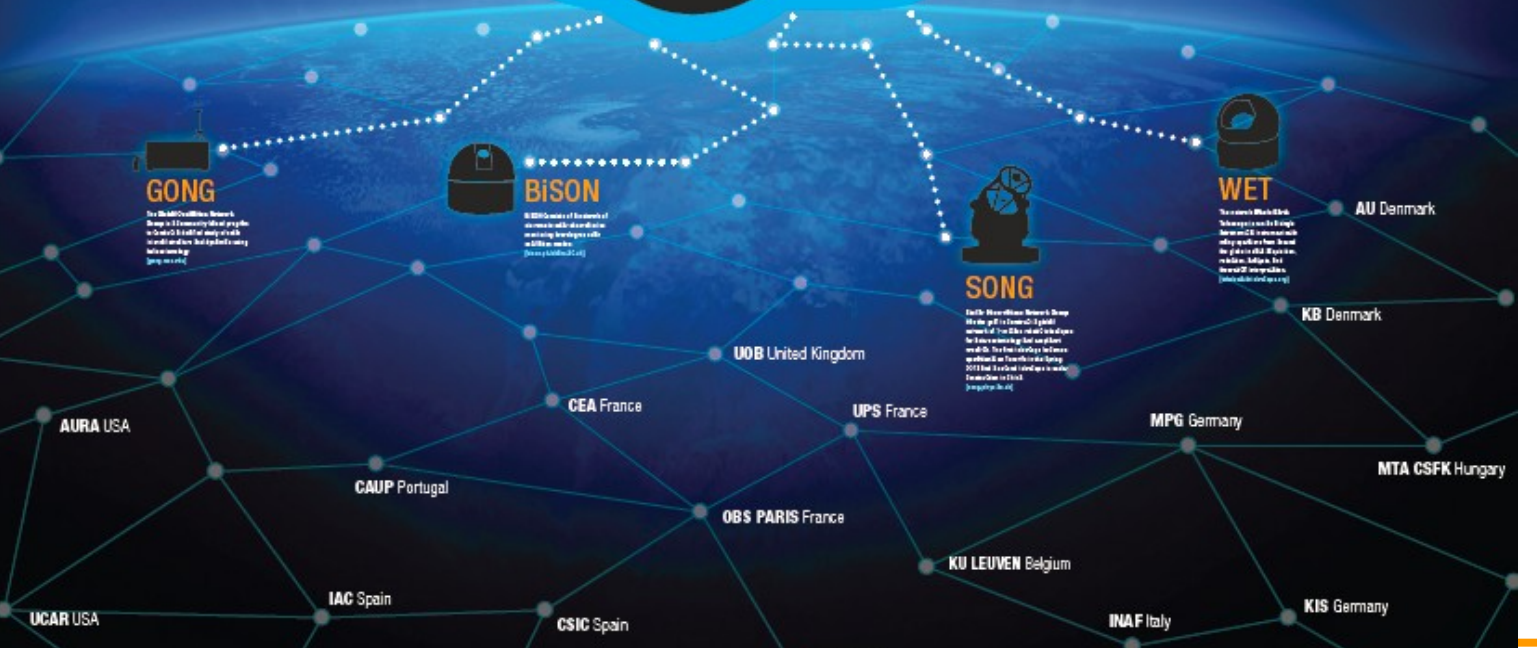
BISON is a network of helioseismology observatories. It provides us with a wealth of information about the Sun's interior.

## SONG

The Solar Oscillation Network Group (SONG) is a network of helioseismology observatories. It provides us with a wealth of information about the Sun's interior.

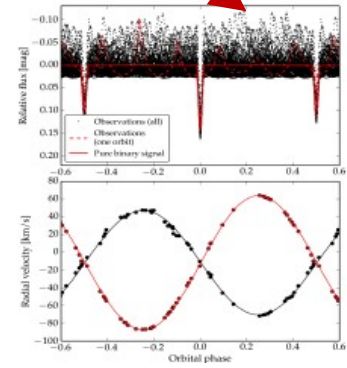
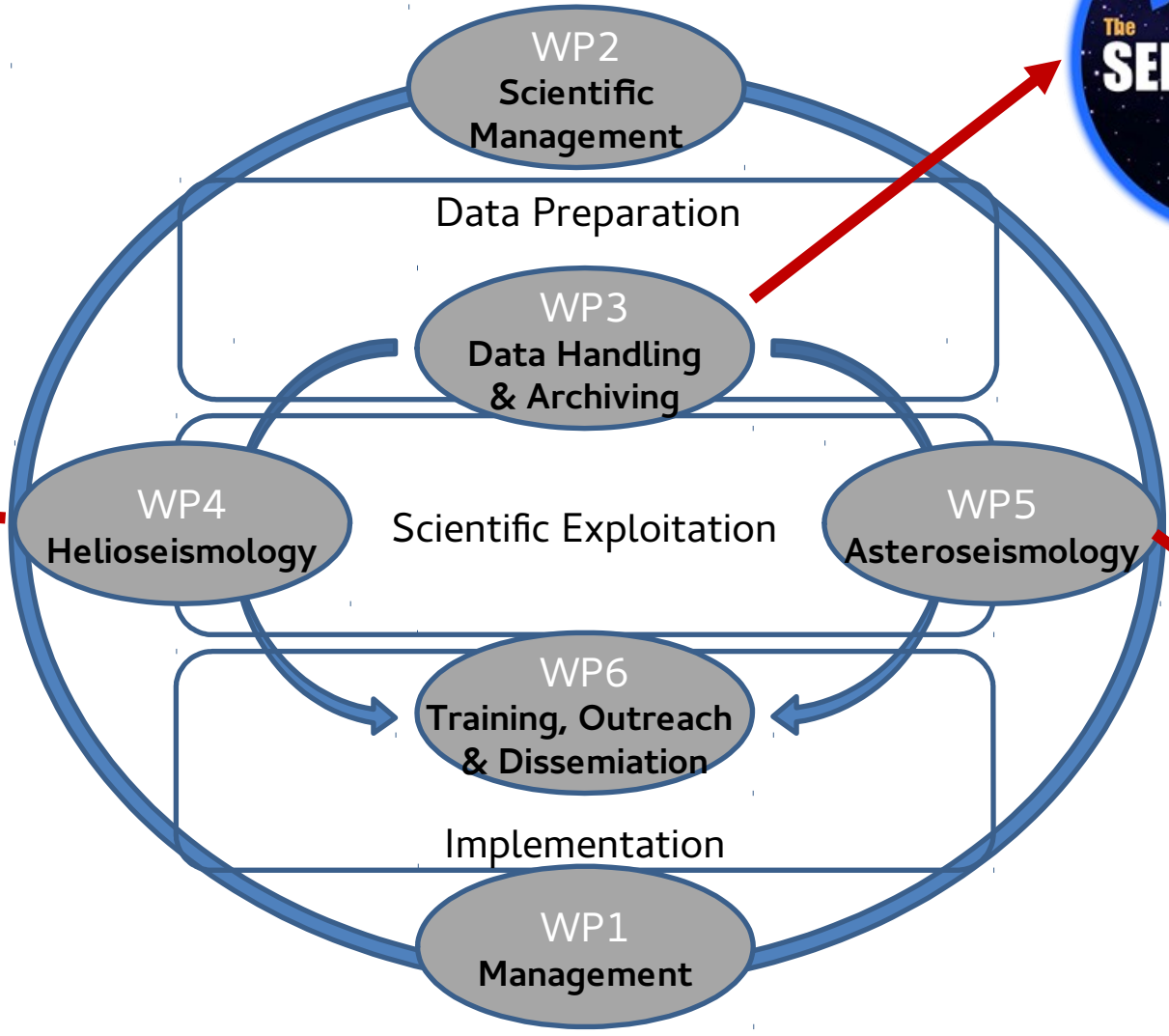
## WET

The Western European Time-series of Helioseismicity (WET) is a network of helioseismology observatories. It provides us with a wealth of information about the Sun's interior.





# Project Overview





# Seismic Plus Portal

- CoRoT archive (UPS, France)
- KASOC, Kepler archive (AU, Denmark)
- HMI/SDO European data centre (MPG, Germany)
- BASS2000/TBL legacy (archive of the spectropolarimetric data from Narval, UPST, France)



The screenshot shows the homepage of the Seismic Plus Portal. At the top, there is a navigation bar with links for Home, Data sources description, Data query, User guide, and About/Contact. The main content area features a welcome message and several key points about the portal's purpose and data sources. On the right side, there is a circular logo for 'The Seismic Plus Portal' and a row of logos for partner organizations: GONG, ISOC SDO, and MPS. The footer contains a disclaimer about the project's funding and logos for SpaceInn, Observatoire de Paris, LESIA, and P. Duran.

**Welcome to the Seismic Plus Portal**

An astero- and helioseismic Portal to promote the awareness and the use of existing seismic data within the stellar physics community and beyond.

**Why and for whom?**

**The growing amount of seismic data available** from space missions (SOHO, CoRoT, Kepler, SDO,...), and also from ground-based observations (GONG, Bison, Song, ground-based large programmes...), is boosting solar and stellar structure and evolution studies. While it is now possible to have new insights into stellar structure and evolution, the Sun remains more than ever a crucial reference and a precious guideline for numerous stellar studies.

**New scientific perspectives emerge for a broad scientific community**, e.g. to characterize stellar populations in our Galaxy or to characterize planetary systems by giving model-independent estimates of global properties of stars such as mass, radius, and surface gravity within several percent accuracy, as well as to constrain the age.

**Seismic data become a 'plus' to be used in conjunction with data of various types and from various sources**, e.g. space seismic archives and ground-based spectroscopic surveys, or solar seismic data to be analyzed 'as a star' and used as a reference in stellar studies.

**The intention of the Seismic+ portal is to bridge over various data types and over different scientific communities.**

**How?**

**What does it contain?**

This project is currently being developed in the framework of the SPACEInn project (Exploitation of Space Data for Innovative Helio- and Asteroseismology), initiated by the European Helio- and Asteroseismology Network (HELAS) and financed by the European Union under the Seventh Framework Programme (FP7 project n° 312844).

Logos at the bottom: GONG, SpaceInn, Observatoire de Paris, LESIA, P. Duran.



# Seismic Plus Portal


Additional sources:

- Ground-based CoRoT complementary archive (INAF, Italy)
- Stellar/Solar Models: (CSIC, Spain/CAUP, Portugal)
- Seismic Indices data base (OBSPARIS, France)
- "Mark-I" solar spectrophotometer data base (IAC, Spain)

**PA.S4.18 – Activities in the SpaceInn project: the HARPS archive of the CoRoT mission**

**PA.S4.20 – The Stellar Seismic Indices (SSI) data base**

**SpaceInn** Ground-based spectroscopy



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Monica Rainer – The CoRoT ground-based complementary archive – 21 October 2013





# Activities for Helioseismology

## 4.1 Global Helioseismology

*(R. Garcia, CEA, talk tomorrow)*

- Study the changing Sun as it evolves in many different time scales (new magnetic activity index)
- New techniques to extract low-amplitude signals (p and g) modes by combining information provided by all the instruments.
- Tools to combine Sun-as-a-star observations (e.g. GOLF, BISON and VIRGO) with the imaged ones (e.g. GONG, MDI or HMI)
- Improve the realism of solar 3D models in which the convective envelope is non-linearly coupled to the deep solar radiative interior



# Activities for Helioseismology

## 4.2 Local Helioseismology

*(L. Gizon, MPG, talk tomorrow)*

- Explore systematic effects present in the analysis of space observations
- Make available and exploit numerical simulations of seismic waves and their interactions with internal heterogeneities and magnetic regions.
- Preparation of the Solar Orbiter mission to be launched in 2017
- Implement Fourier-Hankel/Legendre analysis (FH) to study structures like sunspots
- Develop fast, automated data processing by implementing efficient workflows to process historical data sets (MDI and GONG) and for the continued analysis of SDO-HMI data



# Activities for Asteroseismology

## *Two major components:*

- WP5-1: Solar-like oscillators (*W. Chaplin, UoB*)
- WP5-2: Heat-driven oscillators (*C. Aerts, KULeuven*)

## *Objectives:*

- Reduce uncertainties in our understanding of stellar interiors physics
- Improvements to stellar properties estimation
- Leverage high-quality data from space missions, ground-based observations
- Linkages/synergies:
  - evolution & characterisation of stellar systems (incl. stellar activity)
  - stellar populations studies

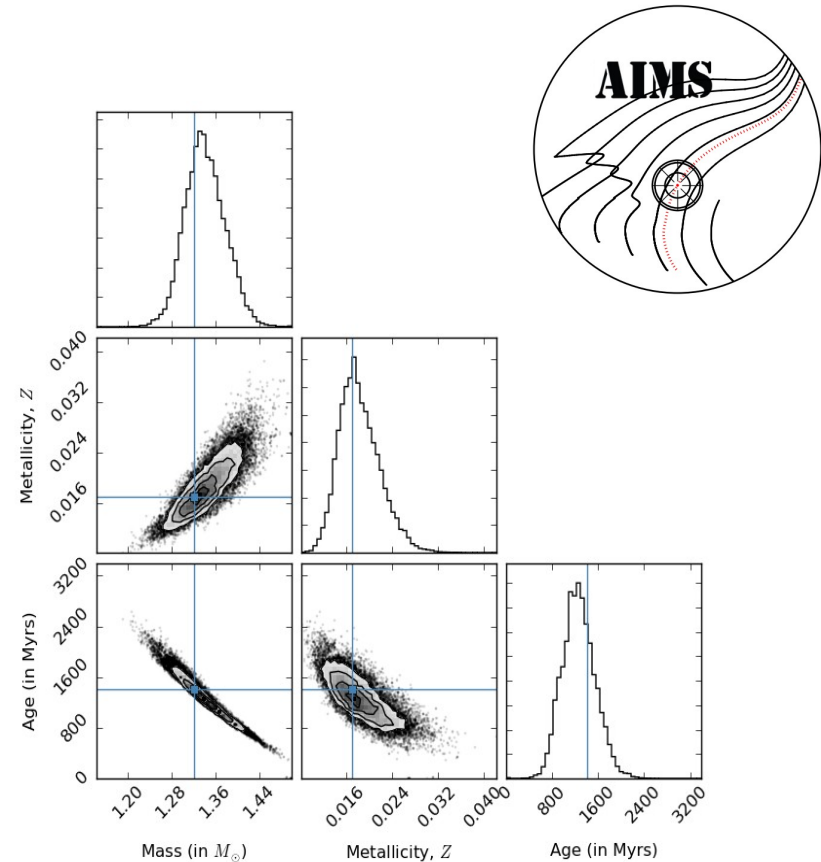


# Analysis tools for solar-like oscillators



- The Asteroseismic Inference on a Massive Scale (AIMS) code
  - Fully documented, automated Bayesian sampling tool for stellar properties estimation
- Inversion tools
  - Inversion Kit & Inversion Pipeline
- Catalogues
  - Stellar properties for 500+ stars combining Kepler and ground-based data
  - Activity proxies for 2750 stars

See Poster by Miglio et al.:  
**PB.S11.69 – AIMS – Asteroseismic Inference on a Massive Scale**

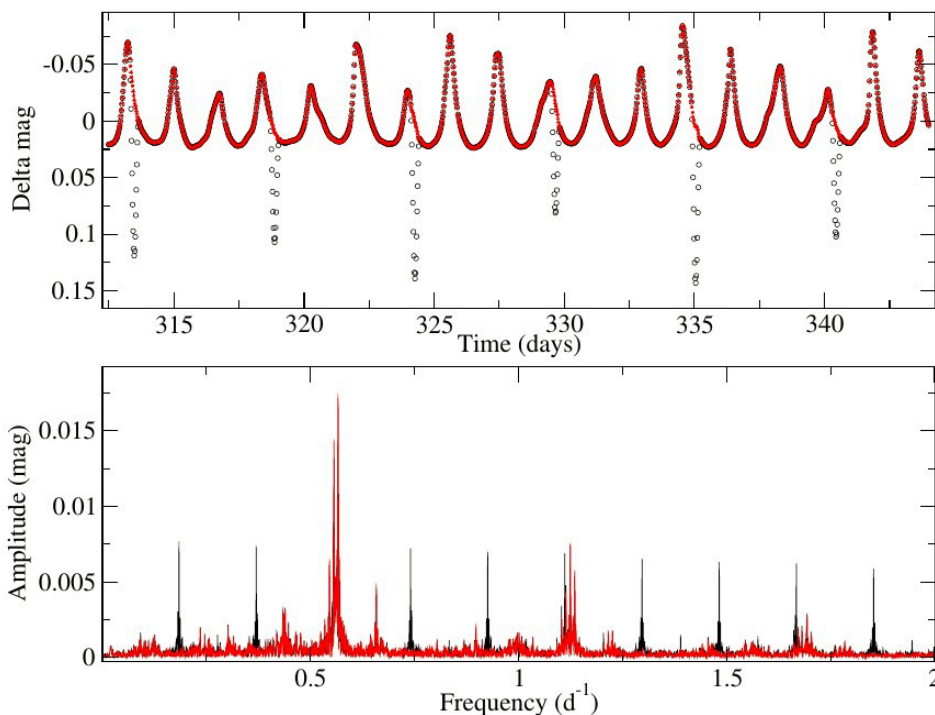






# Analysis tools for heat-driven pulsators

- PHOEBE 2 code (Python package)
  - Simulate and fit **photometric and spectroscopic** time series of single and multiple stars systems
  - Inclusion of pulsations: simultaneous modelling of variability due to binary effects and pulsations of one or more components.
- Grid Search in Stellar Parameters (GSSP) package
- Seismic Grid of Models of Massive Stars with Mixing



# Workshops & Tutorials

- Dynamics of solar-like stars: current theoretical and observational challenges
- Peak-Bagging Techniques, Data Inversion and Modelling
- Frequency Analysis of Pulsating Stars in Eclipsing Binaries
- Massive Asteroseismic Data Analysis in the XXIth century
- Exploiting Seismic Data of Fast Rotating Stars
- *Photometric and Spectroscopic Mode Identification*



**All material available via the  
SpaceInn website:  
[www.spaceinn.eu](http://www.spaceinn.eu)**





# Announcement of Last Workshop

“Mode Identification from Photometry &  
Spectroscopy of Heat-Driven Pulsators”

8 - 10 November 2016, Leuven, Belgium

See SpaceInn Website or

[https://](https://fys.kuleuven.be/ster/meetings/spaceinn-ws-2016)

[fys.kuleuven.be/ster/meetings/spaceinn-ws-  
2016](https://fys.kuleuven.be/ster/meetings/spaceinn-ws-2016)



# Ten Years of "HELAS"



- **EU FP6 Capacities, *Coordination Action***  
**"European Helio- and Asteroseismology Network"**  
*04/2006 – 03/2010*
  - Co-ordinate activities among European institutions and organizations in helio- and asteroseismology
  - Enable transfer of knowledge, data, and data analysis techniques
- **ESF *Research Conference 05/2012***
- **EU FP7 Cooperation Theme 9: Space**  
***Collaborative Project SPACEINN***  
***since 01/2013***
- EU FP7 Capacities  
Collaborative Project & Support Action  
*Solarnet -> **SPRING, Conferences, Mobility Program, and Schools***  
*since 04/2013*



# What is next?

- HELAS will continue its coordination activities
- SpaceInn has created a unique research infrastructure with the Seismic Plus portal
  - Continue operating this portal
  - Extend its capabilities
- **Plans:**
  - Include sophisticated stellar models
  - Enable access to data and observing facilities
  - Train the next generation

**Stay tuned!**



# Thank you very much

- All staff scientists, postdocs, PhD students for their hard work for SpaceInn
- All WP Leaders
- All partners in the project
- EU for the funding of the project
- Our reviewer and advisor Anne Thoul
- The SpaceInnAdvisory Board

