Scheda HELAS FINAL

Informazioni generali

1. Titolo della scheda

The modern era of asteroseismology and advancement of stellar physics

2. Acronimo

HELAS

3. Tipo di scheda

Programma

3a. Tipo di scheda - Assegnazioni secondarie

Progetto

Infrastruttura Internazionale

Missione spaziale Internazionale

4. RSN Primario

RSN2

5. RSN Secondari

RSN3

6. Attività Nuova o In Itinere

Attività: In Itinere; Data inizio: 2002; Data fine: 2033

7. Nome e indirizzo coordinatore

maria.dimauro maria.dimauro@inaf.it

8. Riassunto breve in Italiano

Recentemente, grazie alle missioni spaziali **COROT, Kepler/K2 e TESS,** dedicate alla ricerca di esopianeti e di pulsazioni stellari, l'Asterosismologia ha prodotto una straordinaria rivoluzione nel campo della astrofisica, svelando una quantità inaspettata di risultati sulle proprietà fisiche di stelle in tutto il diagramma HR e consentendo di caratterizzare sistemi planetari, la formazione della nostra Galassia e l'evoluzione chimica dell'Universo.
La comunità Italiana di Elio- e Astrosismologia (**HELAS**), che sviluppa da decenni competenze sia teoriche che di analisi dati di oscillazioni del Sole e delle stelle, è adesso pronta ad affrontare le nuove sfide della fisica stellare moderna, direttamente coinvolta nella preparazione della missione spaziale PLATO attesa per il 2026.

9. Short Abstract (in English)

Recently, thanks to the successful space missions **COROT, Kepler and TESS**, conceived for exoplanets and detection of stellar pulsations, Asteroseismology has produced an extraordinary revolution in astrophysics, unveiling a wealth of results on the physical properties of stars over a large part of the HR diagram and enabling to characterize the detected planetary systems, the formation of our galaxy and the universe’s chemical evolution.
The Italian Helio- and Asteroseismology (**HELAS)** community, with decades of expertise in theoretical modelling and analysis of data of oscillations for the Sun and stars of different spectral types, is now ready for the new challenges of the modern stellar physics, directly involved in the preparation of the future space mission **PLATO** expected in 2026**.**

12. Keywords (interne INAF)

Team Summary

15. Personale INAF coinvolto

Numero di partecipanti INAF al progetto: 12

Struttura	Nfte	N0	TI 2024	TI 2025	TI 2026	TD 2024	TD 2025	TD 2026	Nex	E
IAPS ROMA	1	0	0.60	0.60	0.60	0	0	0	0	0
O.A. CATANIA	3	0	0.60	0.50	0.70	0	0	0	0	0
O.A. CAPODIMONTE	2	0	0.30	0.40	0.40	0	0	0	0	0
O.A. ABRUZZO	1	0	0.10	0.10	0.10	0	0	0	0	0
O.A. TORINO	1	0	0.10	0.10	0.10	0	0	0	0	0
O.A. BRERA	1	0	0.10	0.10	0.10	0	0	0	0	0
O.A. PALERMO	0	0	0.00	0.00	0.00	0	0	0	1	0
O.A. PADOVA	0	0	0.00	0.00	0.00	0	0	0	0	0
Totali	9	0	**1.80**	**1.80**	**2.00**	**0.00**	**0.00**	**0.00**	1	**0**

16. Personale Associato INAF coinvolto

Numero di partecipanti Associati INAF: 9

#	Struttura	TI 2024	TI 2025	TI 2026	TD 2024	TD 2025	TD 2026	Extra
1	Universita' di Bologna	0.10	0.10	0.10	0	0	0	0.00
2	Università degi Studi di Roma Tor Vergata	0	0	0	0.00	0.00	0.00	0.20
3	Università degli Studi di Roma Tor Vergata	0	0	0	0.10	0.10	0.10	0.10
4	UniPisa	0.10	0.10	0.10	0	0	0	0.00

#	Struttura	TI 2024	TI 2025	TI 2026	TD 2024	TD 2025	TD 2026	Extra
5	INAF	0	0	0	0.50	0.50	0.50	0.00
6	Università degli Studi di Roma Tor Vergata	0.10	0.10	0.10	0	0	0	0.00
	Totali	**0.30**	**0.30**	**0.30**	**0.60**	**0.60**	**0.60**	**0.30**

Fondi a sostegno

21. Totale fondi a disposizione (dato aggregato, k€)

Certi 2024	Certi 2025	Certi 2026	Presunti 2024	Presunti 2025	Presunti 2026
25.0	25.0	0.0	0.0	0.0	0.0

Produzione scientifica e tecnologica

22. Produzione scientifica e tecnologica - Highlights

#	DOI	Descrizione	A:
1	10.3847/1538-4357/ac8f44	Titolo: On the Characterization of GJ 504: A Magnetically Active Planet-host Star Observed by the Transiting Exoplanet Survey Satellite (TESS) Autori:Maria Pia Di Mauro and Raffaele Reda and Savita Mathur and Rafael A. Garc\'\ia and Derek L. Buz .... Publisher:American Astronomical Society Rivista: The Astrophysical Journal Anno pubblicazione:2022	
2	10.3389/fspas.2022.909268	Titolo: A Synergic Strategy to Characterize the Habitability Conditions of Exoplanets Hosted by Solar-Type Stars Autori:Raffaele Reda and Maria Pia Di Mauro and Luca Giovannelli and Tommaso	

#	DOI	Descrizione	A:
		Alberti and Francesco Berrill .... Publisher:Frontiers Media SA Rivista: Frontiers in Astronomy and Space Sciences Anno pubblicazione:2022	
3	10.1093/mnras/stad440	Titolo: Cepheid metallicity in the Leavitt law (C-MetaLL) survey \textendash III. Simultaneous derivation of the $\less$i$\greater$Gaia$\less$/i$\greater$ parallax offset and period\textendashluminosity \textendashmetallicity coefficients Autori:R Molinaro and V Ripepi and M Marconi and M Romaniello and G Catanzaro and F Cusano and G De~Somma .... Publisher:Oxford University Press (OUP) Rivista: Monthly Notices of the Royal Astronomical Society Anno pubblicazione:2023	
4	10.1051/0004-6361 /202348403	Titolo: A new catalog of magnetically active solar-like oscillators Autori:Corsaro, E. and Bonanno, A. and Kayhan, C. and Di Mauro, M. P. and Reda, R. and Giovannelli, L. Publisher:EDP Sciences Rivista: EDP Sciences	
5	10.3847/1538-4357/acd118	Titolo: Magnetic Activity Evolution of Solar-like Stars. I. S ph–Age Relation Derived from Kepler Observations Autori:Mathur, Savita and Claytor, Zachary R. and Santos, Ângela R. G. and García, Rafael A. and Amard, Lou .... Publisher:American Astronomical Society Rivista: American Astronomical Society	
6	10.1093/mnras/stae450	Titolo: Classical Cepheid pulsation properties in the Rubin-LSST filters Autori:De Somma, Giulia and Marconi, Marcella and Cassisi, Santi and Molinaro, Roberto and Bhardwaj, Anupam .... Publisher:Oxford University Press (OUP)	

#	DOI	Descrizione	A
		Rivista: Oxford University Press (OUP)	
7	10.1093/mnras/stad2776	Titolo: Asteroseismological analysis of the polluted ZZ Ceti star G 29 – 38 with TESS Autori:Uzundag, Murat and De Gerónimo, Francisco C and Córsico, Alejandro H and Silvotti, Roberto and Bradl .... Publisher:Oxford University Press (OUP) Rivista: Oxford University Press (OUP)	
8	10.1093/mnras/stae734	Titolo: The Hertzsprung progression of classical Cepheids in the Gaia era Autori:Marconi, Marcella and De Somma, Giulia and Molinaro, Roberto and Bhardwaj, Anupam and Ripepi, Vincen .... Publisher:Oxford University Press (OUP) Rivista: Oxford University Press (OUP)	
9	10.1051/0004-6361/202243897	Titolo: Uncertainties in asteroseismic grid-based estimates of the ages of halo stars Autori:Moser, S. and Valle, G. and Dell'Omodarme, M. and Degl'Innocenti, S. and Prada Moroni, P. G. Publisher:EDP Sciences Rivista: EDP Sciences	
10	10.1093/mnras/stad3267	Titolo: The updated BaSTI stellar evolution models and isochrones – IV. α-Depleted calculations Autori:Pietrinferni, Adriano and Salaris, Maurizio and Cassisi, Santi and Savino, Alessandro and Mucciarell .... Publisher:Oxford University Press (OUP) Rivista: Oxford University Press (OUP)	

Informazioni Pubbliche

13. Linee di ricerca

The HELAS activity is contextualized in the scientific area of Stellar

Astronomy-> Stellar oscillations .

The main research areas (keywords and ‘schede programma INAF’) involved are:

1. Stellar Physics ->Stellar abundances; Stellar atmospheres; Stellar evolution; Stellar granulation; Stellar properties; Stellar structure; Stellar types.
2. Exoplanet astronomy -> see scheda programma “Properties of stars with exoplanets- EXO-Stars (K. Biazzo)”; Exoplanet detection methods; Exoplanets; Exoplanet dynamics -> Star-planet interactions; Planet hosting stars.
3. Solar physics->Helioseismology; Solar activity; Solar oscillations; Solar interior.
4. Galaxy physics->Milky Way Galaxy Physics->Galactic Archaeology.

Main correlated ‘schede progetto INAF’ are:

1. EXO-STARS: Properties of stars with exoplanets - Proprietà delle stelle con pianeti (PI: K. Biazzo)
2. PLATO - PLAnetary Transits and Oscillations of Stars (PLATO), the M3 ESA mission (PI: I. Pagano)
3. EXO-ARCH: Architecture and physical properties of planetary systems - Architettura e proprieta' fisiche dei sistemi planetari (PI: A. Sozzetti)
4. STEADYN-Stellar activity and dynamo theory in the era of precision astrophysics (PI: A. Bonanno)
5. Hot subdwarfs and white dwarfs: Pulsations, Binaries and Planetary Systems (P.I.: R. Silvotti)

One mini-grant proposal is related to this scheda 'HELAS':

1. Asteroseismic tools for massive data analysis: differential rotation measurements in evolved stars (P.I. Leccia S.)

17. Ruolo di Leadership di INAF

The team members are involved as PI, CoIs, and associated scientific members of Workpackages in CoRoT (CoI: E. Poretti, C. Maceroni), Kepler/K2 (PI of WP: A Miglio) and in the upcoming projects PLATO (PI of WP: A Miglio, S. Cassisi), EST (PI: F. Berrilli).

M. Marconi and M. P. Di Mauro are elected members of the IAU Commission G4 - Pulsating Stars for the period 2021-2024 and 2025-2028.

All the members are part of KASC (the Kepler Asteroseismic Science Consortium) and TASC (the Tess Asteroseismic Consortium) scientific collaborations, formed around the asteroseismic activities of Kepker/K2 and TESS missions respectively, which have guaranteed access to the asteroseismic data catalogues.

The members of our group have outstanding track records, organizers or invited contributors to several international conferences, schools and meetings and recipients of recent EU Horizon 2020 grants:

- **ERC Consolidator Grant**: "Asterochronometry: Galactic archaeology with high temporal resolution" Project ID: 772293, awarded by A. Miglio
- **Marie Sklodowska-Curie** grant 'ASTROFIT' agreement n. 664931, awarded by E. Corsaro

20. Infrastrutture coinvolte

Space missions:

- COROT-ESA;
- Kepler/K2- NASA;
- TESS-NASA;
- BRITE;
- PLATO-ESA in preparation;

Ground infrastructures:

- SONG (Stellar Observations Network Group);
- TNG-HARPSN;
- LAMOST (Large Sky Area Multi-Object Fibre Spectroscopic Telescope)
- EST (European Solar Telescope)

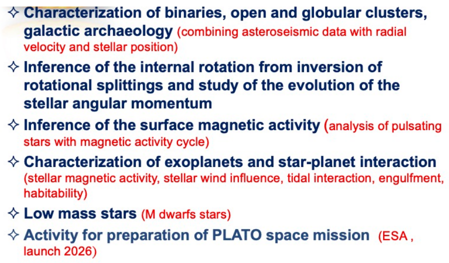
Coordinating infrastructures:

1. KASC (Kepler Asteroseismology Consortium);
2. TASC (Tess Asteroseismology Consortium);
3. BaSTI (a Bag of Stellar Tracks and Isochrones);
4. APOGEE (Apache Point Observatory Galactic Evolution Experiment);
5. GAPS (Global Architecture Planetary Systems)

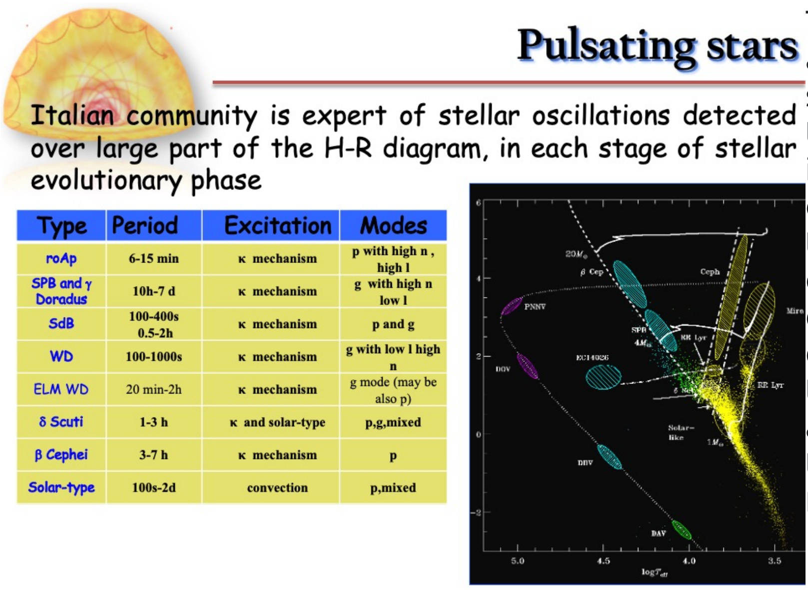
Informazioni Riservate

10. Obiettivi e Risultati

OBJECTIVES



Asteroseismology indicates the study of the internal structure and dynamics of the stars from observations of the stellar pulsations. These manifest as small motions of the visible stellar surface producing luminosity and velocity variations. A sufficiently rich spectrum of observed oscillation modes permits us to probe the internal conditions of a pulsating star and to test and revise theories of stellar structure and evolution (e.g., Di Mauro 2016). The goal of the present program is to continue to contribute to the analysis of data obtained by the photometric missions **Kepler/K2** (Borucki et al. 2010) **TESS Transiting Exoplanet Survey Satellite** (Ricker et al. 2015), and **BRITE** (BRIght-star Target Explorer) (Weiss et al. 2014), with detailed atmospheric parameters obtained from ongoing astrometric (GAIA) and spectroscopic surveys (GAIA-ESO, LAMOST, APOGEE, APOKASC etc), and complemented by the ground-based network **SONG** (Stellar Observations Network Group), which is delivering uninterrupted data of selected targets (Grundhal et al. 2008).



The team aims to strengthen the information obtained by the oscillation data and to develop, test, and apply new techniques for investigating the physics and properties of the interiors of stars in all the evolutionary stages and different spectral types from the main sequence to the white dwarf cooling sequence (see F**ig. 1**), including classical pulsators. Our investigation is applied to individual targets -also with planets- or to study similarities and differences in multiple component systems, such as binaries and clusters, which are considered well-proven benchmarks to test stellar evolution theory. The activities will be closely coordinated within the TASC and KASC consortia.

The main scientific objectives are briefly listed in **Fig. 2**. Among others, new topics for the future are represented by careful analysis of oscillations in pre-main sequence stars, searching for periodicity similar to that of solar-like stars, and the study of low-mass stars including M-dwarfs, whose completely convective structure combined with high magnetic activity can push the theory beyond the current potential and capabilities.

In addition, a community's workload is in action for preparing the ESA space mission **PLATO** (PLAnetary Transits and Oscillation of Stars, Rauer et al. 2016) planned for launch in 2026, in which some team members have important coordinating roles. To pursue the objectives of this mission, we are developing new tools for handling massive data we will receive to characterize main sequence target stars with exoplanets and subgiant and red-giant stars chosen as calibrators. The team plans to develop new inversion tools, based on old Fortran routines (Di Mauro et al. 2016), which will be made available to the entire community to produce inversion of massive data. Furthermore, attention will be devoted to refining synergic strategies to study the stellar magnetic activity, and its effect on the exoplanetary environment (Reda et al. 2022). Finally, the overall project foresees the effort to boost new collaborations with the Italian stellar modelling community, considering that stellar structure models are the fundamental requirements of any asteroseismic analysis.

RESULTS

The Asteroseismology program has been carried out in INAF since 2001 and the team has taken part in the heavy-advancement experienced in the field during the last two decades. The unprecedented high–precision and continuous photometric measurements performed by the space missions BRITE, COROT (Baglin et al. 2006), Kepler/K2, and TESS have allowed the team, to disclose the structural and dynamical properties of several thousand oscillating stars with the methods of Asteroseismology. A lively collaboration has been shaped among the members of the team by merging the theoretical and observational expertise and reaching during the last few years the results summarized below:

1. **ANALYSIS OF PHOTOMETRIC DATA BY SPACE MISSIONS AND GROUND-BASED CAMPAIGNS** The long and complex photometric time series from the satellite observations supported by ground-based observations have been analyzed by making use of fast, automated, and sophisticated codes developed within the team for different pulsating stellar types such as solar-like stars, subdwarfs and white dwarfs (Uzundag et al. 2023, 2024) and classical pulsators such as Cepheids (De Somma et al. 2024) and RRLyrae and long period variables.
   This has allowed extracting fundamental characteristics of the oscillation power spectra, useful for direct inferences of physical properties such as dependence by metallicity (Trentin et al. 2024), magnetic activity (Mathur et al. 2023, Corsaro et al. 2024) and dynamo characteristics (Bonanno & Corsaro 2022), stellar rotation and binaries (Beck et al. 2024).
2. **ASTEROSEISMIC ASSESSMENT OF STELLAR PHYSICAL PROPERTIES** The team succeeded in obtaining striking results for stars that exhibit solar-like pulsations, as in the Sun, excited

by near-surface turbulent convection, providing the opportunity to study in detail the internal structure and rotation of individual targets or clusters, and to put very stringent constraints on their fundamental parameters (e.g., Di Mauro et al. 2022). More recently we have succeeded in merging the potential of asteroseismology with planetary science for solar-like host stars (Reda et al. 2023).

The stellar parameters combined with chemical composition, position, distance, and velocity of the stars obtained by large spectroscopic surveys (GAIA-ESO) have yielded spectacular results on the formation and evolution of the Milky Way (Brogaard et al. 2023, Willett et al. 2023), applying asteroseismic tools to solar-type stars or classical pulsators such as Cepheids (Marconi et al. 2024).

Bibliography

- Baglin A.. et al. 2006, 36th Cospar Scientific Assembly. Held 16 - 23 July 2006, in Beijing, China. Meeting abstract from the CDROM, #3749
- Beck P. et al. 2024 682A, 7
- Bonanno A & Corsaro E. 2022 ApJL 939, 26
- Borucki W. et al. 2010, Science 327, 977
- Brogaard K et al. 2023 A&A 679A, 23
- Corsaro E. et al. 2024 A&A 683, 161
- De Somma G. et al. 2024 MNRAS 528, 663
- Di Mauro M. P. 2016, in Frontier Research in Astrophysics II, Mondello Workshop 2016, Palermo, May 23-28 2016, Proceeding of Science, Pos Vol. 269, id. 029, PoS(FRAPWS2016)029
- Di Mauro et al. 2016 ApJ 817,65
- Di Mauro et al. 2022 ApJ 940, 93
- Grundahl F. et al. 2008, in Journal of Physics Conference Series, Vol. 118, Journal of Physics Conference Series, 012041
- Marconi M. et al. 2024 MNRAS 529, 4210
- Mathur S. et al. 2023 ApJ 952, 131
- Pietrinferni A. et al 2024, MNRAS 527, 2065
- Rauer H. & PLATO Team. 2016, Astron. Nachrichten 337, 96
- Reda R. et al., 2022 Front. Astron. Space Sci 9, 909268
- Reda R., et al. 2023 MNRAS 519, 6088
- Ricker G. et al. 2015, JATIS 10.1117
- Salaris M., et al 2022 MNRAS 509, 519
- Silvotti R. et al. 2022 MNRAS 511, 2201
- Trentin E. et al. 2024 681, 65
- Uzundag, M. et al. 2023 MNRAS 526, 2846
- Uzundag, M. et al. 2024 A&A 684, 118
- Weiss W. W. et al. 2014, PASP, 126, 573
- Willett E. et al. 2023 MNRAS 526, 2141

Our investigations are based on stellar models produced by accurate and state-of-the-art evolutionary codes
(e.g. Salaris et al. 2022, Pietrinferni et al. 2024). Within the BaSTI collaboration (a Bag of Stellar Tracks and Isochrones), a free virtual facility to provide theoretical predictions for stars in a wide range of stellar masses and chemical compositions.

14. Organizzazione del team

The team is composed of 21 members including 3 INAF retired researchers and 6 INAF associated researchers by Universities. A lively collaboration has been shaped among the members of the team by merging theoretical and observational expertise. The table below summarizes the expertise of each component.

It's worth pointing out that the Asteroseismology group has recently found a fresh boost by disclosing its aims to new collaboration with different research groups and finding synergies with new topics, such as the characterization of exoplanetary systems, the use of Solar Physics techniques and the search of new collaborations within the stellar modelling community.

TEAM HELAS 2024

INAF institute	Personnel (21)	Expertise
IAPS Roma	Di Mauro M. P.	Asteroseismic analysis of solar-type stars,inversion of data, star-planet in
	Maceroni C.	Oscillations in binary stars
Osservatorio Astronomico d'Abruzzo	Cassisi S.	Stellar modelling, structure of M dw
Osservatorio Astrofisico di Catania	Bonanno A	Theory of stellar magnetic activity
	Corsaro E.	Analysis of oscillation data
	Ventura R.	Asteroseismic analysis of solar-type s
Osservatorio Astronomico di Brera	Poretti E.	Analysis of data for classic pulsators characterization of exoplanets
	Rainer M.	
Osservatorio Astronomico di Capodimonte (Napoli)	Leccia S.	Inversion of asteroseismic data, Gaia astrometry
	Ripepi V.	Spectroscopic analysis of stellar atm classic pulsators
	Marconi M.	Pulsational models of classic pulsato
Osservatorio Astronomico di Torino	Silvotti R.	Asteroseismic analysis of compact pu
Osservatorio Astronomico di Padova	Girardi L.	Stellar modelling
	Claudi R.	Characterization of exoplanets
Osservatorio Astronomico di Palermo	Benatti S.	Characterization of exoplanets
Università degli Studi di Roma Tor Vergata	Berrilli F.,Giovannelli L., Nigro G.,Reda R.	Space weather/climate, techniques, s planet interaction, Stellar wind effec
Dip. di Fisica,Università di Bologna	Miglio A.	Asteroseismic analysis, Galactic arch
Dip di Fisica, Università di Pisa	Degl'Innocenti S.	Stellar modelling

18. Organizzazione delle attività

The activities of the group can be summarized according to the following WPs:

WP 1: Analysis of oscillation spectra and extraction of oscillation parameters Part of the team, experts in the study of oscillation spectra, provide oscillation parameters and frequency determination from time-series analysis of photometric data obtained by space missions Kepler/K2 (Borucki et al. 2010) and TESS (Ricket et al. 2015), SONG (Groundahl et al. 2008)or other spectroscopic facilities from the ground. The analysis makes use of fast, automated, and sophisticated codes developed within the team for different pulsating stellar types such as solar-like stars (e.g., Corsaro et al. 2014, 2020), compact pulsators (e.g., Silvotti et al. 2022) and classical pulsators (Ripepi et al. 2020, 2021, 2022).

WP 2: Stellar models in accessible and documented form For obtaining a comparison between theory and observations it is necessary to use up-to-date stellar models produced by accurate and state-of-the-art evolutionary codes. The team employs structure stellar models produced by public and widely used evolutionary codes such as ASTEC (Christensen-Dalsgaard 2008) and

MESA (Paxton et al. 2018). In addition, within the BaSTI collaboration (a Bag of Stellar Tracks and Isochrones), a free suitable WEB portal has been set up from where it is possible to download both evolution and pulsational models (Salaris et al. 2022, Pietrinferni et al. 2024). The BaSTI stellar model repository id BaSTI-IAC http://basti-iac.oa-abruzzo.inaf.it.

WP 3: Asteroseismic characterization of stars Our final task is to deliver a detailed characterization of asteroseismic targets, single stars or with companions. A first estimate of global stellar parameters can be obtained starting from the main properties of the oscillation spectra, but within the team, we have members who have developed sophisticated tools enabling us to understand in detail the internal structure of the stars with different mass and evolutionary phase and to put very stringent constraints on the fundamental stellar parameters (Di Mauro et al. 2011, 2022).

- **WP 3.1 Study of the stellar-planet interaction** Some members of the team have the role of going further with the simple estimate of accurate fundamental parameters of the mother star and its orbiting planet, having the tools to study the stellar magnetic activity and the star-planet interaction. In analogy to the Sun-Earth system, we infer the stellar magnetic activity as deduced from the photometric light curves and the Ca II and K activity indexes obtained from ground-based campaigns (e.g., Mount Wilson Observatory HK Project). By using specific tools Reda et al (2022, 2023) the team is also able to find the mean stellar wind acting on the exoplanet and compute the exoplanetary magnetosphere extension.
- **WP 3.2: Internal rotation of stars by inversion of data** The observation of oscillations in stars has brought important constraints on their internal rotation rates demonstrating that an efficient transport mechanism of angular momentum (AM) is needed to explain the actual results of internal rotational profile deduced by asteroseismic analysis. Hence, to investigate the AM transport during the post-main sequence evolution we plan to develop a new modern and flexible version of the inversion code of rotational splittings built by Di Mauro et al (2016, 2018), able to study the internal rotation of pulsating stars in different stages of their evolution and with different masses.
- **WP 3.3: Galactic archaeology combining asteroseismic and spectroscopic analysis of open and globular clusters** One of the activities of the group focus on enhancing our understanding the evolutionary history of the Galaxy's disk and halo. This can be achieved by analysis of red-giant stars in well-observed open and globular clusters within the Kepler and TESS

fields by combining asteroseismic data from photometric space missions with observational parameters obtained from spectroscopic campaigns such as GALAH and Gaia-ESO (Miglio et al. 2021a, 2012b).

Bibliography

- Bonanno A & Corsaro E. 2022 ApJL 939, 26
- Borucki W. et al. 2010, Science 327, 977
- Christensen-Dalsgaard 2008 ApSS 316, 13
- Corsaro E. et al. 2024 A&A 683, 161
- Corsaro E. & De Ridder 2014 A&A 571, 35
- Corsaro E. , McKee. 2020, A&A, 640, 130
- De Somma G. et al. 2024 MNRAS 528, 663
- Di Mauro et al. 2011 MNRAS
- Di Mauro et al. 2016 ApJ 817,65
- Di Mauro M. P. et al 2018, ApJ 862, 9
- Di Mauro et al. 2022 ApJ 940, 93
- Grundahl F. et al. 2008, in Journal of Physics Conference Series, Vol. 118, Journal of Physics Conference Series, 012041
- Miglio A. et al. 2021a, Exp. Astron. DOI: 10.1007/s10686-021-09711-1
- Miglio A. et al. 2021b, A&A 645, 85
- Paxton et al 2018 ApJS 234, 34
- Pietrinferni A. et al 2024, MNRAS 527, 2065
- Reda R., et al. 2022 Front. Astron. Space Sci 9, 909268
- Reda R., et al. 2023 MNRAS 519, 6088
- Ricker G. et al. 2015, JATIS 10.1117
- Ripepi et al 2020 A&A 642, 230
- Ripepi et al. 2021 MNRAS 508, 404
- Ripepi et al. 2021b A&A 647,111
- Ripepi et al. 2022 MNRAS 512, 563
- Salaris M., et al. 2022 MNRAS 509, 519
- Silvotti R. et al. 2022 MNRAS 511, 2201

19. Evoluzione programmatica attività

Vedere produzione scientifica.

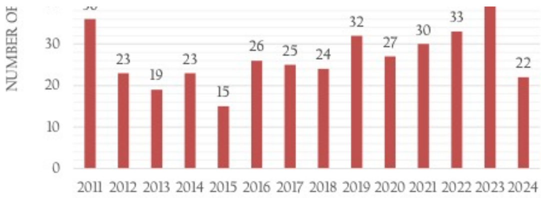
23. Produzione scientifica e tecnologica

The scientific production consists mainly in:

1. Publication of articles in main scientific journals for a total of 68 refereed articles in the period 2022-2024. See the enclosed figure to see the variation in the number of publications per year during the last 13 years.
2. Production of softwares for asteroseismic inversion to determine the internal rotation, the internal profile of density and sound speed and the global angular momentum in solar-like stars
3. Development and update of data analysis tools (e.g., DIAMOND, FAMED), stellar evolutionary codes (BaSTI), inversion codes, , etc..to exploit the huge amount of presently available and near-future expected data.

The main results are also summarized in the following web pages:

- The main page of the INAF asteroseismology group is https://asteroseismology.iaps.inaf.it
- The entire package for the DIAMONDS code to analyze oscillation data of solar-type stars is available at: https://diamonds.readthedocs.io/en/latest/
- Stellar Evolutionary Models and isochrones for asteroseismic analysis produced within the BaSTI collaboration (a Bag of Stellar Tracks and Isochrones) are collected at http://basti-iac.oa-abruzzo.inaf.it
- The results on 'Asterochronometry: Galactic archaeology with high temporal resolution' have been collected at https://www.asterochronometry.eu
- The developments of the space mission Haydn can be followed on http://www.asterochronometry.eu/haydn/



24. Competenze da acquisire e criticità

The 'Asteroseismology' program has been carried out in INAF since 2001 and the team has taken part in the heavy advancement experienced in the field during the last two decades. The INAF asteroseismic community was one of the most lively in Europe and with a full range of competencies and expertise in Asteroseimology, thanks mainly to the efforts of individual researchers, who have provided support for specific tasks in preparation or contribution to the space missions such as COROT, KEPLER/K2, BRITE and TESS, without direct official involvement of INAF management (not even ASI) in their consortia.

After the retirements of many of the researchers studying stellar pulsations, the recruitment of new staff has suffered during the last decade because of a lack of dedicated funds, and specific program guidelines. At the moment a 1-year postdoc position has been just assigned to IAPS thanks to funding received by the INAF Theory grant 2023.

The forthcoming PLATO space mission might represent a great opportunity for two communities of scientists, asteroseismologists and exoplanetary experts to work in strong synergy to fulfil the scientific objectives of the mission, which is the complete characterization of planetary systems. Given the heavy involvement of the Italian community in the PLATO mission, we are trying to strengthen the asteroseismic research by developing new collaborations with the Italian stellar physics and solar physics communities. In particular, we wish to take advantage of the Italian competencies in stellar modelling. In fact, stellar models are fundamental ingredients of any asteroseismic analysis.

Despite the plain International acknowledgement and the results obtained, financial support is still not sufficient to reinforce our team. In fact, in order to keep the competitiveness in a field which is currently extremely fast-moving, we need to consolidate the consistency of the group, which is decreasing due to the number of retirements. There is a high risk of losing the reached and recognized expertise and experience.
This will be particularly important in order to properly satisfy the computational demand for the reduction of the huge amount of presently available and near-future expected data

Concerning this point we have tried in the last 5 years to open our team to new collaborations with different science teams having found interesting synergies with groups mostly based on exoplanetary sciences and solar physics and space weather sciences.

15. Team members, Informazioni generali

Stima dell'inviluppo complessivo di FTE INAF dall'inizio a fine att

81.0

Stima delle FTE INAF a Tempo Indeterminato dall'inizio a fine att

72.0

Stima dell'inviluppo complessivo di FTE (includendo tutti i partne

100.0

15. Personale INAF coinvolto

#	Nome	E-mail	Struttura	TI	Qualifi
1	maria.dimauro	maria.dimauro@inaf.it	IAPS ROMA	Y	RICERC. ASTRON
2	rita.ventura	rita.ventura@inaf.it	O.A. CATANIA	Y	RICERC. ASTRON
3	enrico.corsaro	enrico.corsaro@inaf.it	O.A. CATANIA	Y	PRIMO RICERC.
4	marcella.marconi	marcella.marconi@inaf.it	O.A. CAPODIMONTE	Y	DIRIGEN RICERC.
5	santi.cassisi	santi.cassisi@inaf.it	O.A. ABRUZZO	Y	DIRIGEN RICERC.

#	Nome	E-mail	Struttura	TI	Qualifi
6	roberto.silvotti	roberto.silvotti@inaf.it	O.A. TORINO	Y	RICERC. ASTRON
7	alfio.bonanno	alfio.bonanno@inaf.it	O.A. CATANIA	Y	PRIMO RICERC.
8	monica.rainer	monica.rainer@inaf.it	O.A. BRERA	Y	PRIMO TECNOI
9	vincenzo.ripepi	vincenzo.ripepi@inaf.it	O.A. CAPODIMONTE	Y	PRIMO RICERC.
10	silvio.leccia	silvio.leccia@inaf.it	O.A. CAPODIMONTE	Y	RICERC.
11	serena.benatti	serena.benatti@inaf.it	O.A. PALERMO	Y	RICERC.
12	leo.girardi	leo.girardi@oapd.inaf.it	O.A. PADOVA	Y	DIRIGEN RICERC.

16. Personale Associato INAF coinvolto

#	Nome	E-mail	Struttura	TI	Qual

1	andrea.miglio	andrea.miglio@unibo.it	Universita' di Bologna	Y	Profe Ordi
2	raffaele.reda	raffaele.reda@roma2.infn.it	Università degi Studi di Roma Tor Vergata	n	Asse Post
3	luca.giovannelli	luca.giovannelli@roma2.infn.it	Università degli Studi di Roma Tor Vergata	N	Assis Profe
4	scilla.deglinnocenti	scilla.deglinnocenti@unipi.it	UniPisa	Y	profe
5	riccardo.claudi	riccardo.claudi@inaf.it	INAF	N	quies
6	ennio.poretti	ennio.poretti@inaf.it	INAF	N	quies
7	carla.maceroni	carla.maceroni@inaf.it	INAF	N	In Pens
8	giuseppina.nigro	giuseppina.nigro@roma2.infn.it	Università degli Studi di Roma Tor Vergata	N	Assis Profe
9	francesco.berrilli	francesco.berrilli@roma2.infn.it	Università degli Studi di Roma Tor Vergata	y	Profe Ordi

21. Fondi a Sostegno Iniziativa

Descrizione generale

-2006-2010: FP6- Infrastructure Coordination Action - contract n. 026138 (PI: M. P. Di Mauro, 57 keur) -2013-2017: FP7-Cooperation-SPACE-2012-1, contract n. 312844 SPACEINN (P.I. Ennio Poretti, 50keur) -2023-2025: INAF 2023 Theory grant- 'Synergic tools for characterizing solar-like stars and habitability conditions of exoplanets' (PI. Maria Pia Di Mauro 50 kEur)

Stima inviluppo complessivo intera attività (k€):

157.0

Stima inviluppo complessivo per la parte di attività INAF dall'iniz

157.0

Stima fondi acquisiti da INAF fino al 2023 (k€):

107.0

Tabella fondi:

#	Provenienza	Certi 2024 (k€)	Certi 2025 (k€)	Certi 2026 (k€)	Presun. 2024 (k€)	Presun. 2025 (k€)	Presun. 2026 (k€)	Totale Certi (k€)	T F (
1	INAF	25	25	0	0	0	0	50	0

Tabella fondi Astrofisica Fondamentale e PNRR:

#	Provenienza	Fondi 2024 (€)	Fondi 2025 (€)	Fondi 2026 (€)

Funzioni Obiettivo attualmente inserite nella scheda

F.O.	Descrizione
1.05.23.06.14	Synergic tools for characterizing solar-like stars and habitability conditions of exoplanets (ref.

F.O.	Descrizione
	Maria giuseppina Di m
1.05.23.06.07	Unveiling the magnetic side of the Stars (ref. Alfio maurizio Bonanno)
1.05.04.47.04	PLATO fase D- Accordo Attuativo n. 2022-28-HH.0 (ref. Isabella Pagano)