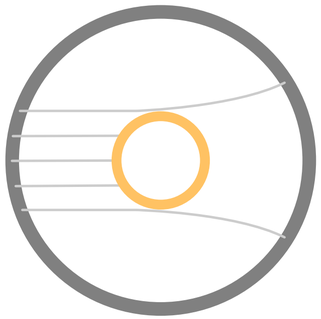
haydn



high-precision asteroseismology in dense stellar fields

Andrea Miglio, Léo Girardi & the HAYDN Consortium

Speaker: Donatella Romano (INAF-OAS Bologna)

Giornate INAF 2023, 2—5 Maggio 2023, INAF-Osservatorio Astronomico di Capodimonte

haydn

high-precision asteroseismology in dense stellar fields

recommended as one of the five candidates for the first medium-sized mission of Voyage 2050.

currently in Phase0, undergoing CDF at ESTEC

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

INAF ISTITUTO NAZIONALE DI ASTROFISICA

erc European Research Council Established by the European Commission

ASTERO CHRONOMETRY

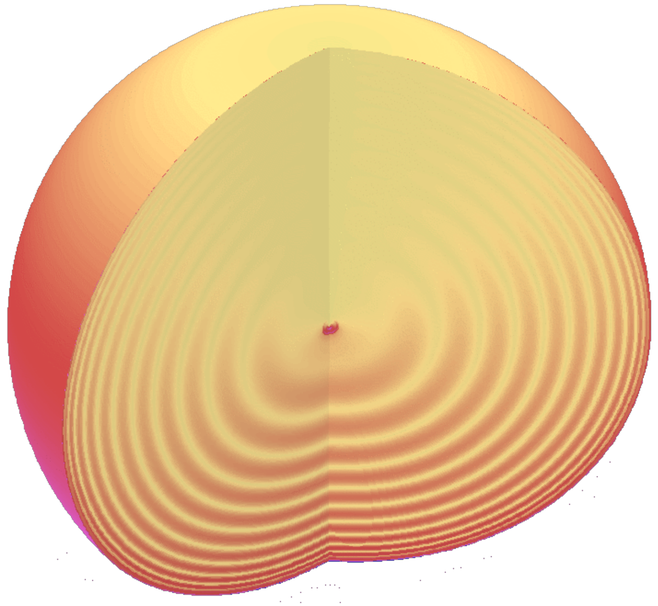
haydn: science goals

radically improve our understanding of the building blocks of cosmic structures

- Provide the most accurate benchmarks for the calibration of the cosmic distance and absolute age scale
- Enable the calibration of models of single and binary stars at low metallicity, which is key to interpret stellar populations in the early Universe,
- Provide the ultimate data for stress-testing stellar models at near-solar metallicities, including solar analogues,
- Elucidate the assembly history and chemodynamics of the Milky Way's bulge, and the origin of multiple populations in globular clusters,
- Characterise stellar binary populations, which are potential gravitational wave factories for the future missions,
- Detect exoplanetary systems in homogeneous environments and dense stellar fields.

haydn: the context

- stars are formidable physics laboratories
- our understanding of stellar structure and evolution underpins most of astrophysics



however

high-precision tests of stellar models limited, until…

the "space photometry revolution”

CoRoT, *Kepler*-K2, TESS

⇩

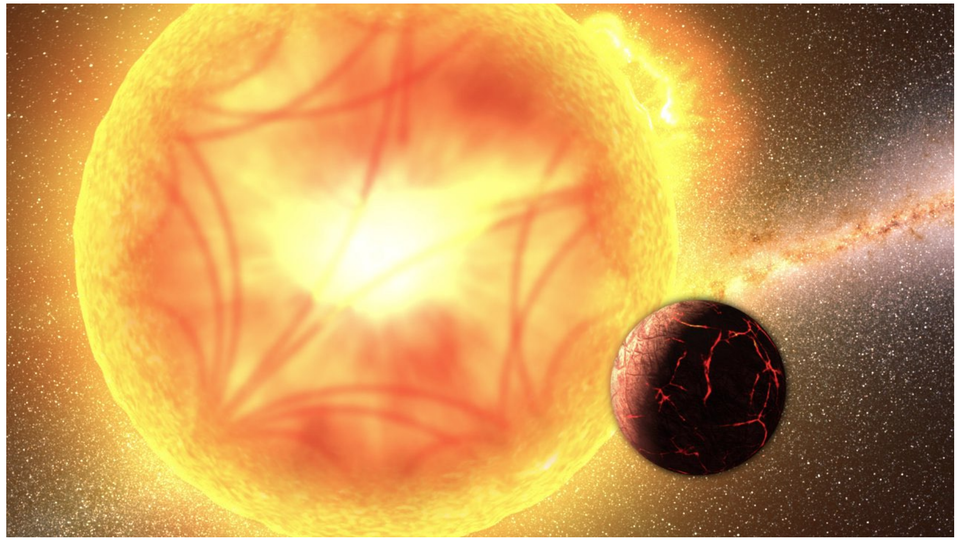
global, resonant oscillations detected in tens of thousands stars in the Milky Way

haydn: the context

the space photometry revolution: discovering the potential of asteroseismology

A. precise, accurate stellar properties (e.g. radius, mass, age)

- characterise exoplanetary systems



Credit: Gabriel Perez Diaz/Instituto de Astrofisica de Canarias

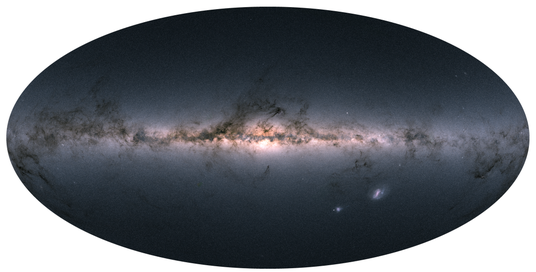
haydn: the context

the space photometry revolution: discovering the potential of asteroseismology

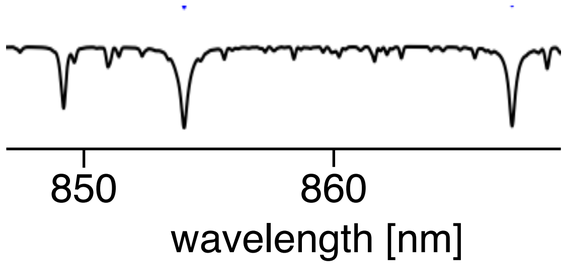
A. precise, accurate stellar properties (e.g. radius, mass, age to ~10%)

- use stars as fossils to reconstruct the assembly and chemo-dynamical history of the Galaxy

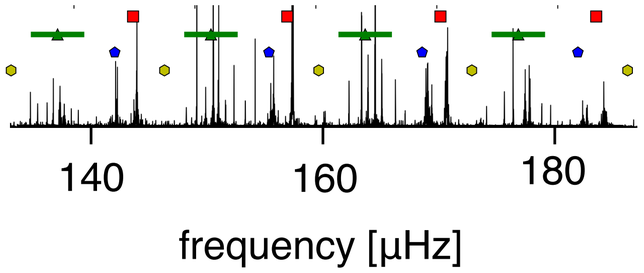
Gaia astrometry



spectroscopy



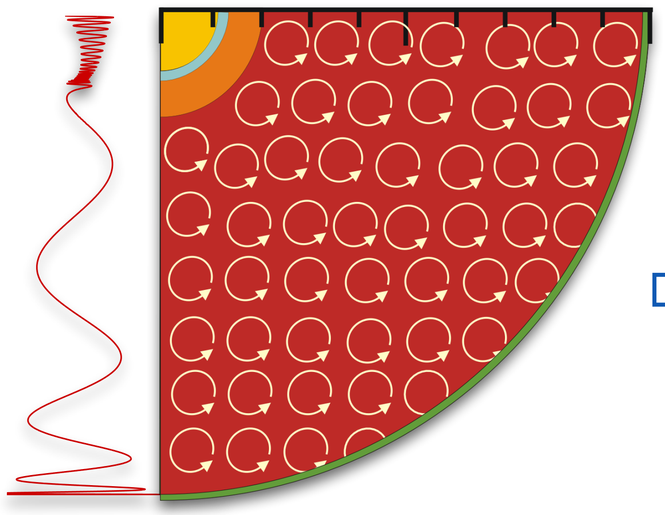
asteroseimology



haydn: the context

the space photometry revolution: discovering the potential of asteroseismology

B. high-precision stellar physics



e.g.

- chemical composition gradients
- density stratification
- internal rotational profile

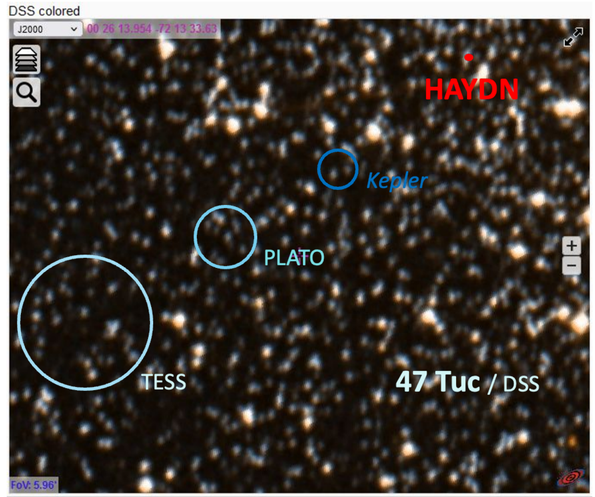
stellar interiors and their evolution accessible to our investigations

haydn

- CoRoT, *Kepler*-K2 — have demonstrated the potential of asteroseismology (in clusters)
- TESS
- PLATO

observational strategy not optimised for stellar / galactic science

designed primarily for planet searches: wide field, bright targets, large pixel sizes

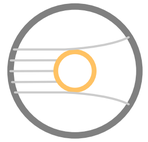


⇨ overcome these limitations i.e.

by measuring the frequencies of hundreds or thousands of stars that belong to controlled environments or key building blocks of galaxies

⇩

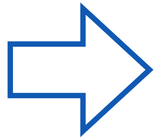
a simple mission concept strongly based on heritage from CoRoT, *Kepler*, and the knowledge being developed for



haydn: science objectives

SO1 high-precision stellar astrophysics: need to perform tests in controlled environments, i.e. stellar open and globular clusters

- Transport of chemical elements in the stellar interior
- Core rotation and transport of angular momentum
- Mass loss on the RGB
- Occurrence of mergers / products of binary evolution
- Tests of fundamental physics



high-precision tests of stellar models, especially in the metal-poor regime (early Universe)

benchmarks for the calibration of the absolute *stellar age scale* and the *cosmic distance scale*

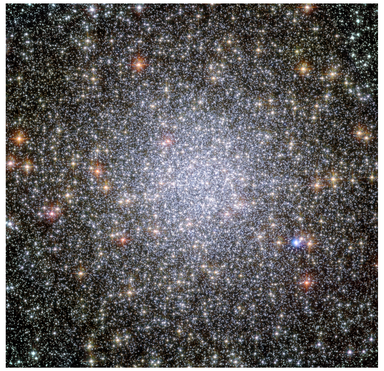
from Gaia CMDs to seeing the internal structure of hundreds of stars along isochrones

haydn: science objectives

SO2 evolution, formation and dynamics of stellar clusters

- Globular clusters formation from absolute ages
- Origin of multiple populations
- Measuring helium content in GCs with asteroseismology

47 Tuc

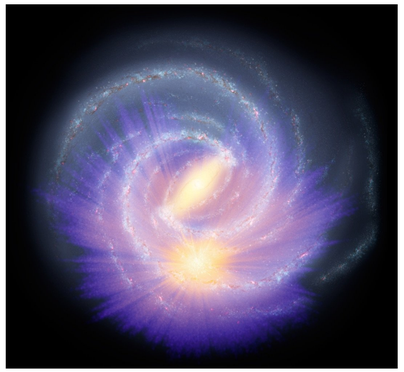


NASA, ESA, and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration
Acknowledgment: J. Mack (STScI) and G. Piotto (University of Padova, Italy)

SO3 assembly history and chemical evolution of the Milky Way's bulge and few nearby dwarf galaxies.

- key yet complex component: disentangle the composite bulge population and its formation history

Gaia-based distances for ~200 million stars (Anders et al. 2019)

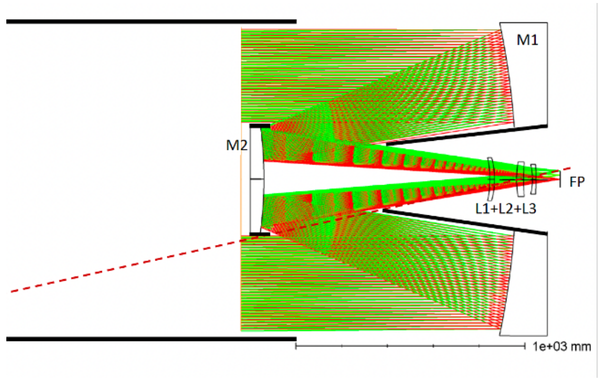


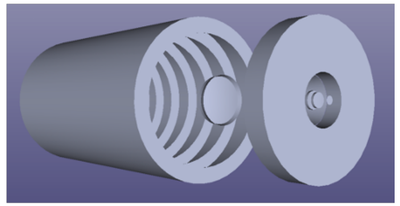
Credit:

Data: ESA/Gaia/DPAC, A. Khalatyan(AIP) & StarHorse team; Galaxy map: NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

haydn: INAF + italian contribution

- HAYDN PI: Andrea Miglio (UniBo + INAF associate)
- supported by ASI
- Key roles in:
  - Target+field selection: L. Girardi, V. Nascimbeni (OAPd), A. Bragaglia (OAS-Bo)
  - Optical design: D. Greggio, D. Magrin, R. Ragazzoni (OAPd) → likely to be followed by build-contract





haydn: INAF + italian contribution

- Ubiquitous presence in the Science Consortium:

chairs of Science Working Groups + members of science consortium

- asteroseismology
- stellar models
- cluster formation+evolutio
- spectroscopy
- exoplanets
- Galactic archeology

…

Italy – Léo Girardi, INAF - OA Padova; Santi Cassisi, INAF - OA Teramo; Elena Pancino, INAF - OA Arcetri; Giampaolo Piotto, Università di Padova; Maria Pia Di Mauro, INAF - IAPS; Giada Casali, Università di Bologna; Laura Magrini, INAF - OA Arcetri; Paola Marigo, Università di Padova; Davide Massari, INAF - OAS Bologna; Enrico Corsaro, INAF - OA Catania; Valeria Grisoni, Università di Bologna; Marco Tailo, Università di Bologna; Rita Ventura, INAF - OA Catania; Marcella Marconi, INAF - OA Capodimonte; Josefina Montalban, Università of Bologna; Scilla Degl'Innocenti, Università di Pisa; Pier Giorgio Prada Moroni, Università di Pisa; Angela Bragaglia, INAF - OAS Bologna; Domenico Nardiello, INAF - OA Padova; Donatella Romano, INAF - OAS Bologna; Valerio Nascimbeni, INAF - OA Padova; Amalie Stokholm, Università di Bologna; Mario Cadelano, Università di Bologna; Monica Rainer, INAF - OA Brera; Cristina Pallanca, Università di Bologna; Lorenzo Spina, INAF - OA Padova; Antonino Francesco Lanza, INAF - OA Catania; Michele Trabucchi, Università di Padova; Francesco Calura, INAF - OAS Bologna; Barbara Lanzoni, Università di Bologna; Paolo Ventura, INAF - OA Roma; Alessandro Bressan, SISSA - Trieste; Ennio Poretti, INAF - OA Brera; Eugenio Carretta, INAF - OAS Bologna; Nicoletta Sanna, INAF - OA Arcetri; Francesco Borsa, INAF - OA Brera; Maria Tsantaki, INAF - OA Brera; Francesca D'Antona, INAF - OA Roma; Antonino Milone, Università di Padova; Roberto Ragazzoni, INAF - OA Padova; Demetrio Magrin, INAF - OA Padova; Davide Greggio, INAF - OA Padova; Anna Fabiola Marino, INAF - OA Arcetri; Oscar Straniero, INAF - OA Teramo; Roberto Silvotti, INAF - OA Torino.

consortium structure

- consortium of 200+ contributing scientists & engineers

PI	Andrea Miglio	Italy	Università di Bologna
Co-PI / Deputy PI	Benoît Mosser	France	LESIA - Paris Observatory

- science team and national Co-Is

Consortium Science Team & National Co-Is	Daisuke Kawata	UK	MSSL UCL
	Andres Moya	Spain	University of Valencia
	Rafa Garcia	France	CEA
	Patrick Eggenberger	Switzerland	University of Geneva
	Marc Antoine Dupret	Belgium	ULiege
	Leo Girardi	Italy	INAF OAPD
	Laurent Gizon	Germany	Max-Planck-Institut für Sonnensystemforschung, Göttingen
	Robert Szabo	Hungary	Konkoly Observatory - Budapest
	Margarida Cunha	Portugal	Universidade do Porto
	Juan Carlos Suarez	Spain	University of Granada
	Cristina Chiappini	Germany	AIP

- organised in science working groups

SWG Clusters		

SWG Clusters formation, abs. ages, multiple populations		
Angela Bragaglia	IT	INAF OAS
Santi Cassisi	IT	INAF OAA

SWG Globular Clusters dynamics		
Mark Gieles	ES	ICCUB - University of Barcelona

SWG: High-precision stellar physics : models		

SWG Transport of AM and chemical species		
Patrick Eggenberger	CH	University of Geneva
Stephane Mathis	FR	CEA

SWG Tests of Fundamental physics + microphysics		
Aldo Serenelli	ES	Barcelona
Oscar Straniero	IT	INAF OAA

SWG Mergers, interacting binaries		
Rob Izzard	UK	University of Surrey
Fabian Schneider	DE	HITS

SWG Mass loss		
Michele Trabucchi	IT	Università di Padova

SWG Inferences from asteroseismology		

Solar-like oscillations in red giants		
Benoit Mosser	FR	Paris Observatory
Josefina Montalban	IT	Bologna

Solar-like oscillations in MS and subgiants		
Martin Nielsen	UK	University of Birmingham
Gael Buldgen	CH	Université de Genevę

Seismic Inference on rotation and magnetic fields		
Sebastien Deheuvels	FR	Toulouse
Angela Santos	PT	Porto

Classical Pulsators (RR Lyr, Cep field)		
Robert Szabo	HU	Konkoly Observatory - Budapest

Compact Pulsators		
Roberto Silvotti	IT	INAF OATO
Stephane Charpinet	FR	Toulouse

A-F Pulsators (including BSS)		
Juan Carlos Suarez	ES	University of Granada
Rhita Ouazzani	FR	Paris
Margarida Cunha	PT	Porto

MS B-type pulsators		
Juan Fabregat	ES	Valencia

Mode excitation and damping		
Marc Antoine Dupret	B	Université de Liège
Kévin Belkacem	F	Paris Observatory

consortium structure

- organised in science working groups

SWG Galactic Archaeology: Bulge, ω Cen, Sgr dSph		
Cristina Chiappini	DE	AIP Potsdam
Daisuke Kawata	UK	MSSL, UCL

SWG Age and distance scale		
Maurizio Salaris	UK	Liverpool
Michele Moresco	IT	Bologna

SWG Exoplanets		
Amaury Triaud	UK	University of Birmingham

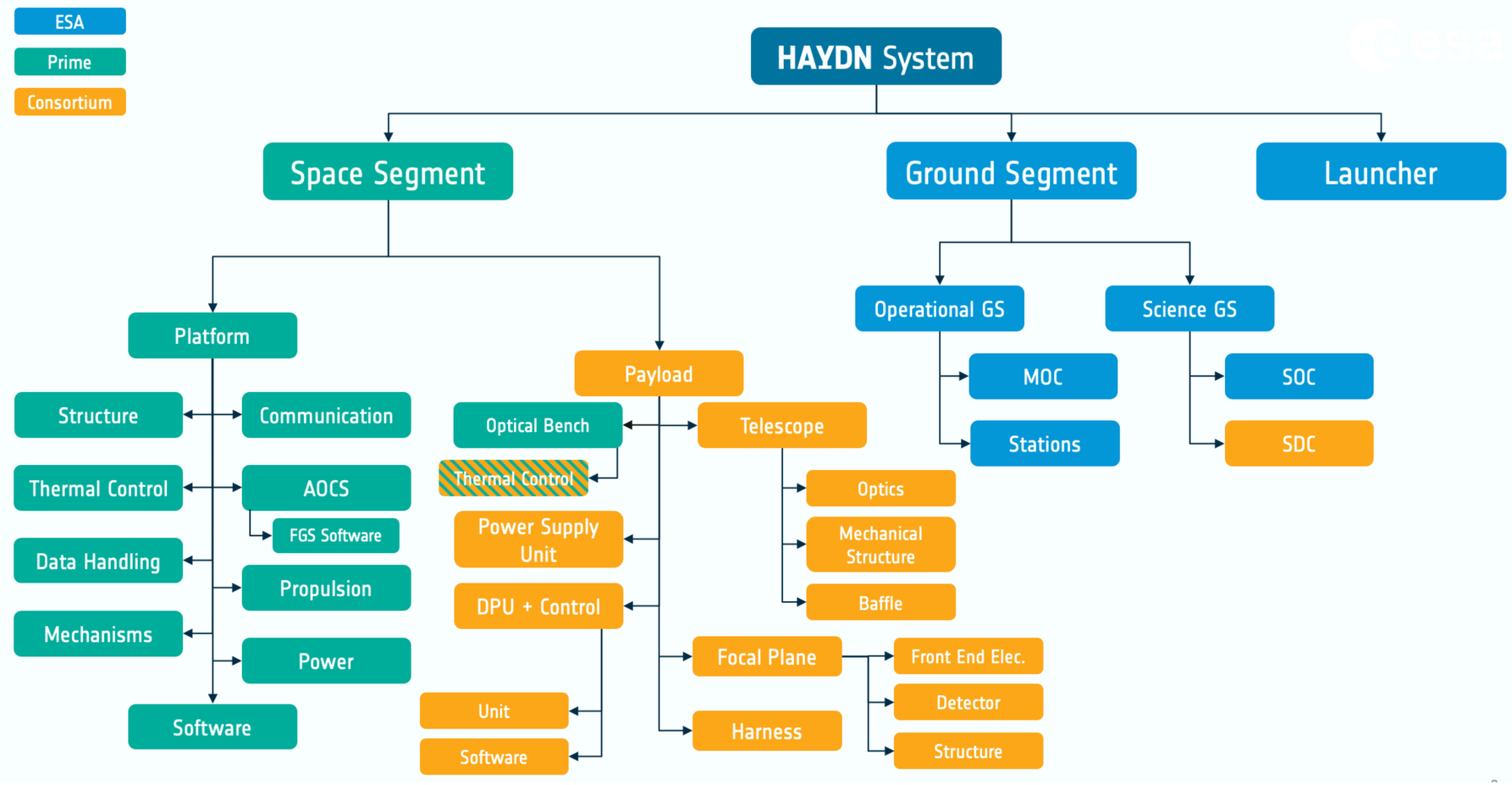
SWG Rotation, activity, granulation		
Savita Mathur	ES	Instituto de Astrof ısica de Canaria
Sydney Barnes	D	AIP Potsdam

SWG (Eclipsing) Binaries		
Karsten Brogaard	DK/IT	
John Southworth/Pierre Maxted	UK	

SWG Target selection + Simulations + LC		
Leo Girardi	IT	INAF OAPD
Valerio Nascimbeni	IT	INAF OAPD
Javier Pascual Granado	ES	IAA

ST Synergies with ground-based surveys and complementary data		
Laura Magrini	IT	INAF Arcetri

consortium responsibilities



consortium structure

- payload consortium roles

			Country	Activity	Coordinators / reference
Payload Subsystem	Telescope	Optics & Mechanical Structure	IT	Design, Build-contract	Leo Girardi leo.girardi@inaf.it Davide Greggio davide.greggio@inaf.it Demetrio Magrin demetrio.magrin@inaf.it
			IT	Design, Build-contract	
			IT	AIT/V	
		Focal Plane	GB/MSSL	Thermo-mechanics design	Daisuke Kawata d.kawata@ucl.ac.uk Berend Winter b.winter@ucl.ac.uk
			GB/MSSL	Build-contract	Daisuke Kawata d.kawata@ucl.ac.uk Berend Winter b.winter@ucl.ac.uk
			GB/MSSL	AIT/V (+GSE)	Daisuke Kawata d.kawata@ucl.ac.uk Berend Winter b.winter@ucl.ac.uk
			GB/MSSL	AIT/V Focal Plane + CCDs/CMOS + Front end electronics (+GSE)	Daisuke Kawata d.kawata@ucl.ac.uk Berend Winter b.winter@ucl.ac.uk Dave Walton d.walton@ucl.ac.uk, Mark Hailey mark.hailey@ucl.ac.uk

		Detectors CCDs/CMOS	GB/MSSL	procurement/calibration	Daisuke Kawata d.kawata@ucl.ac.uk, Dave Walton d.walton@ucl.ac.uk, Mark Hailey mark.hailey@ucl.ac.uk
			GB/MSSL	AIT/V (+GSE)	Daisuke Kawata d.kawata@ucl.ac.uk, Dave Walton d.walton@ucl.ac.uk, Mark Hailey mark.hailey@ucl.ac.uk
		Front end electronics	Fr/AIM	Design	Tony Lavanant tony.lavanant@cea.fr Jerome Martignac jerome.martignac@cea.fr Rafa Garcia rgarcia@cea.fr
			Fr/AIM	Build-contract	Eric Doumayrou eric.doumayrou@cea.fr
			Fr/AIM/IRAP	AIT/V (+GSE)	Tony Lavanant tony.lavanant@cea.fr Jerome Ballot jerome.ballot@irap.omp.eu
		Baffle	B CSL	Opto-mechanical design	Christian Kintziger ckintziger@uliege.be
			B CSL	Build-contract	Christian Kintziger ckintziger@uliege.be
			B CSL	environmental qualification of the baffle	Christian Kintziger ckintziger@uliege.be

		Additional Thermal Control	Sp/IAC	Design	Andrés Moya andres.moya-bedon@uv.es Jose Javier Díaz García. jdg@iac.es
			Sp/IAC - Hungary	Build-contract	Andrés Moya andres.moya-bedon@uv.es Jose Javier Díaz García. jdg@iac.es Robert Szabo rszabo@konkoly.hu
			Sp/IAC	AIT/V (+GSE)	Andrés Moya andres.moya-bedon@uv.es Jose Javier Díaz García. jdg@iac.es
		Power Supply Unit	Sp/UV	Spec-design	Andrés Moya andres.moya-bedon@uv.es Esteban Sanchís esteban.sanchis@uv.es Jose Luis Gasent jose.l.gasent@uv.es
			Sp/UV	Build-contract	Andrés Moya andres.moya-bedon@uv.es Esteban Sanchís esteban.sanchis@uv.es Jose Luis Gasent jose.l.gasent@uv.es
			Sp/UV	Test (+GSE)	Andrés Moya andres.moya-bedon@uv.es Esteban Sanchís esteban.sanchis@uv.es Jose Luis Gasent jose.l.gasent@uv.es

					andres.moya-bedon@uv.es Julio Rodríguez julio@iaa.es Rosario Sanz sanz@iaa.es
			Sp/IAA-CSIC	AIT/V (+GSE)	Andrés Moya andres.moya-bedon@uv.es Julio Rodríguez julio@iaa.es Rosario Sanz sanz@iaa.es
		S/W	Fr/LESIA-lead + contrib PT / Sp	Design	Réza Samadi Reza.Samadi@obspm.fr Philippe Plasson philippe.plasson@obspm.fr Margarida Cunha mcunha@astro.up.pt for PT Julio Rodríguez julio@iaa.es for Sp
			Fr/LESIA	Build-contract	
			Fr/LESIA	AIT/V (+GSE)	
	Additional Thermal Control		Sp/IAC	Design	Andrés Moya andres.moya-bedon@uv.es Jose Javier Díaz García. jdg@iac.es
			Sp/IAC - Hungary	Build-contract	Andrés Moya andres.moya-bedon@uv.es Jose Javier Díaz García. jdg@iac.es Robert Szabo rszabo@konkoly.hu
			Sp/IAC	AIT/V (+GSE)	Andrés Moya andres.moya-bedon@uv.es Jose Javier Díaz García. jdg@iac.es

Verification at the payload level

Payload	Camera / detector	B (KUL)	Ground performance verification and calibration	Bart Vandenbussche bart.vandenbussche@kuleuven.be
	Camera / detector	B (KUL)	Electrical ground support software for payload level AIV	Bart Vandenbussche bart.vandenbussche@kuleuven.be
	Camera / detector	B (KUL)	In-orbit calibration and operations	Bart Vandenbussche bart.vandenbussche@kuleuven.be
		B (KUL)	Mission Performance Analysis	Joris De Ridder joris.deridder@kuleuven.be

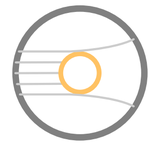
Ground segment

Ground Segment	Science Data Centre	CH	Design, System Architecture	Patrick Eggenberger Patrick.Eggenberger@unige.ch Enrico Bozzo enrico.bozzo@unige.ch
		CH	Host, engineering & operations	
		DE	Data Calibration (L1 data)	Laurent Gizon gizon@mps.mpg.de
		DE, CH	Science Data Products (L2 data)	

Table 1: Preliminary list of targets

ID	RA, Dec (in °)	age(Gyr), [Fe/H], distance(kpc)	# Stars[1]	Obs. Time (months	Priority[2]	Comments / reasons to observe
47Tuc/ NGC104	6.02, −72.08	13, −0.8, 4	7305 4350 4192	18	P0	Multiple populations (on RGB and RHB) at the same [Fe/H]. Many evolved BSS. SMC stars in the background.
M67/ NGC2682	132.85, 11.81	4, 0, 0.9	2880 469 408	9	P0	Diffusion, solar analogues, stars with small convective cores, BSS.
ωCen/ NGC5139	201.5, −47.5	12, −1.5, 5.4	21093 9047 1902	6	P0	Core of a dwarf galaxy, multiple populations with different [Fe/H], infer star formation history
Baade's Window	270.8, −30.0	3 to 11, −0.3 to +0.3, 8	52124	6	P0	Infer the bulge's complex star formation history
M4/ NGC6121	245.8, −26.5	12, −1.2, 2.2	7385 1225 431	3	P0	The closest globular cluster
M22/ NGC6656	279.0, −23.9	13, −1.5, 3.2	28698 837 388	3	P1	A scaled-down ωCen, with spread in Fe and neutron-capture elements
NGC7789	359.2, +56.7	1.5, 0.0, 2.1	15087 1550 114	3	P1	Very rich, compact intermediate-age cluster
NGC188	11.8, 85.2	7.1, 0.14, 1.7	4039 446 55	3	P1	Very old, metal-rich open cluster
NGC2243	97.39, −31.28	3.5, −0.5, 4.4	5363 98 38	3	P1	Solar age, metallicity 1/3 solar open cluster

ID	RA, Dec (in °)	age(Gyr), [Fe/H], distance(kpc)	# Stars[1]	Obs. Time (months)	Priority[2]	Comments / reasons to observe
NGC2506	120.0, −10.76	1.6, −0.2, 3.5	10423 584 69	3	P2	Open cluster with many core-He burners
NGC6752	287.5, −60.0	12, −1.5, 4.0	7096 1385 1205	7	P2	The classical, well behaved globular cluster at the peak of the GC metallicity distribution
NGC6397	265.0, −53.7	13, −2.0, 2.5	19108 1489 149	3	P2	Low-metallicity GC
M54 & Sgr dSph	283.8, −30.5	11, −1.4, 27	20244 244 77	7	P2	The closest extragalactic dwarf and its nuclear cluster
M11/ NGC6705	282.75, −6.28	0.32, 0.14, 1.7	30131 785 31	3	P2	Open cluster, outskirts of bulge in the background. With intermediate-mass core-He-burners
NGC2818	139.04, −36.6	0.83, 0.0, 3.1	11269 149 15	3	P2	Interesting age range, but few core-He-burners



Mission programmatic overview

ESA CaC
550 M€

Launcher
Ariane 6.2

Development risk
TRL6 by 2029

European
Led mission

Mission Classification
Class III