HAYDN

High-precision AsteroseismologY of DeNse stellar fields

BREAKING NEWS: SELECTED FOR PHASE 2

IP: Andrea Miglio, University of Bologna

Spanish contribution: UV, IAA, UGR, IAC, ICE, ICCUB

Contact person in Spain: A. Moya (UV)

Science goals

The space photometry revolution

CoRoT, *Kepler*-K2 have demonstrated the potential of asteroseismology

TESS, PLATO designed primarily for planet searches: wide field, bright targets, large pixels
observational strategy not optimised for stellar / Galactic science

→ **Voyage 2050 Senior Committee report, Sec. 3.1.8:**
A Medium mission designed to carry out pure asteroseismology

HAYDN

Asteroseismology of stellar open and globular clusters → controlled environments

Breakthroughs in stellar and Galactic science

- SG1 high-precision stellar astrophysics, especially in the metal poor regime
- SG2 evolution and formation of stellar clusters
- SG3 assembly history and chemical evolution of the Milky Way's bulge and nearby dwarf galaxies

HAYDN white paper: Miglio et al. 2021, ExpA 51.

Science goals

Benchmarks for the calibration of the absolute stellar age scale

Benchmarks for the calibration of the cosmic distance scale

Formation history and chemical evolution of key building blocks of galaxies

SG1 High-precision stellar astrophysics

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

SG2 Evolution and formation of stellar clusters

- Globular clusters formation from absolute ages
- Origin of multiple populations
- Measuring helium content in GCs with asteroseismology
- Redistribution of angular momentum from inclination of stellar spin axes

SG3 Assembly history and chemical evolution of the Milky Way's bulge and few nearby dwarf galaxies

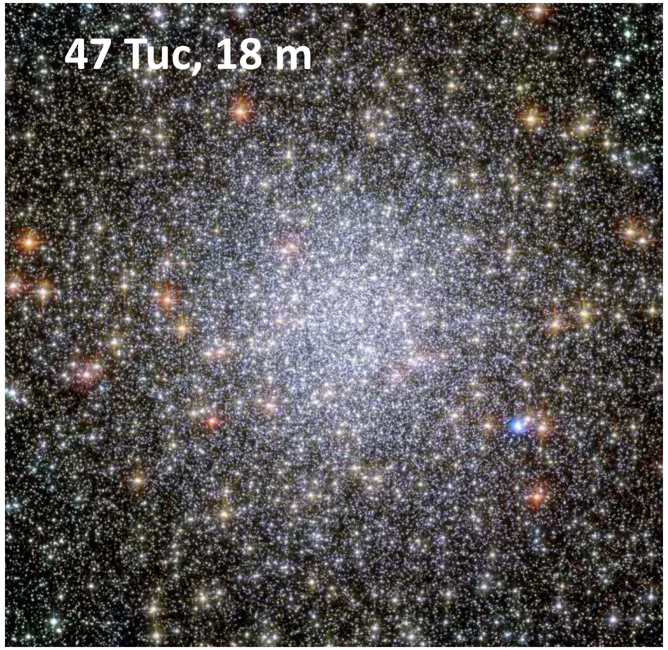
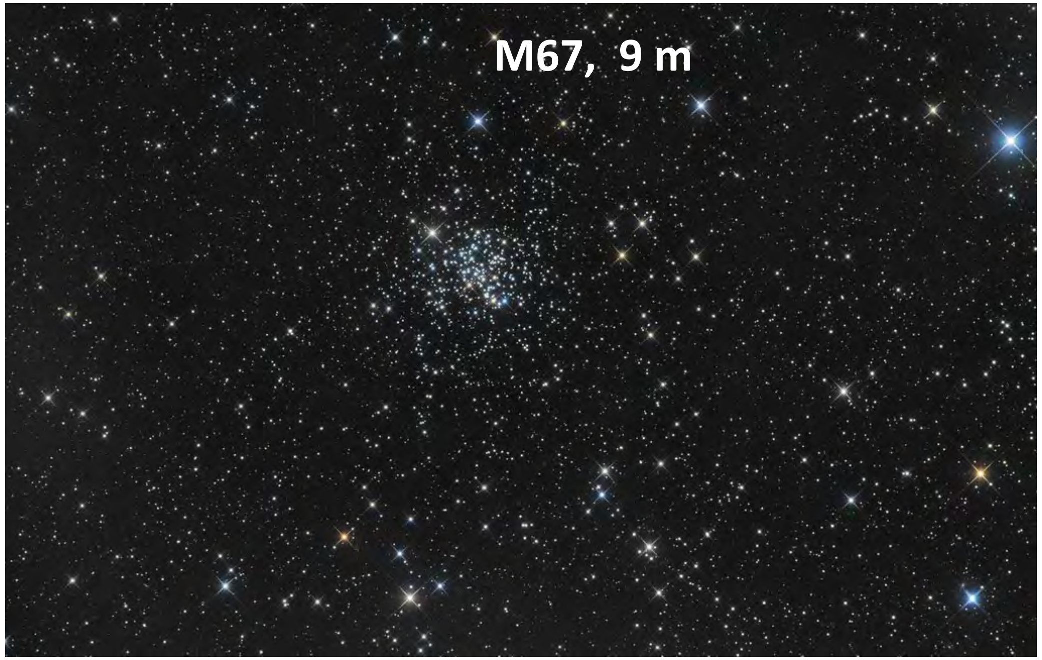
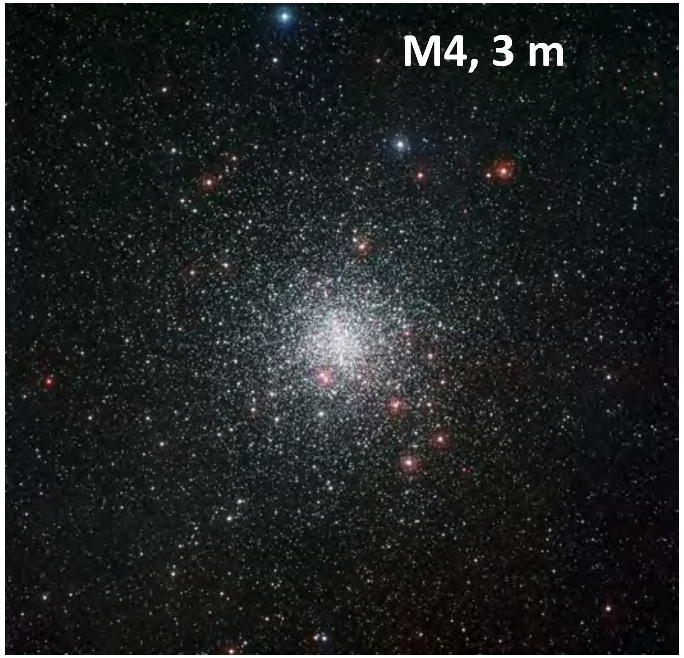
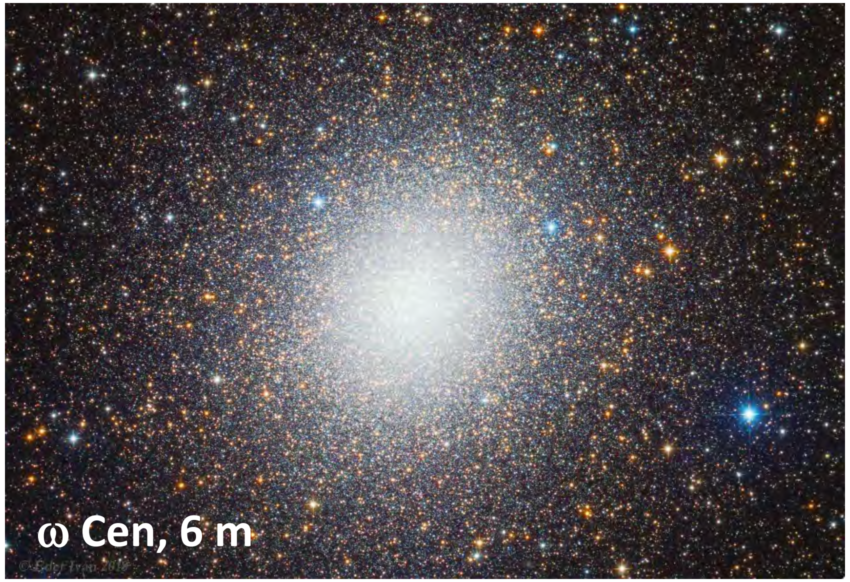
- Key yet complex component: disentangle the composite bulge population and its formation history
- Reconstruct star formation history of Sgr dSph and its interaction with the Milky Way

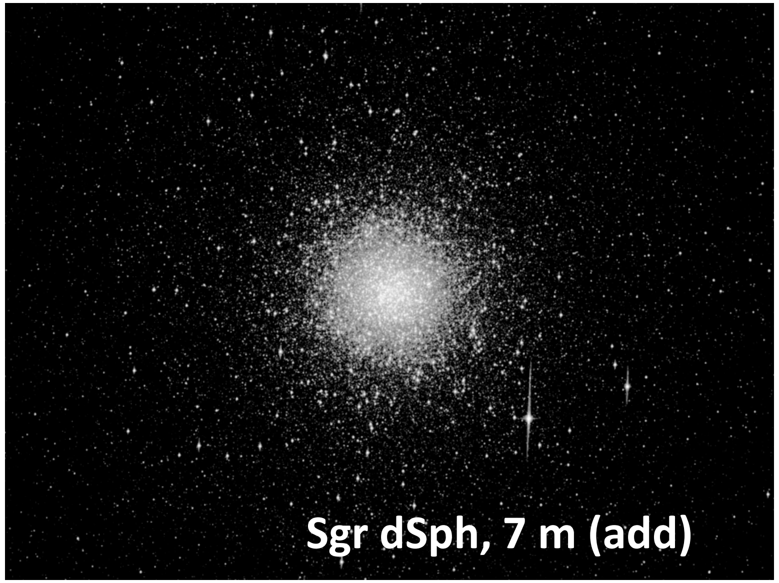
Seismic observations of stellar clusters

All previous missions intended to observe globular or open clusters
None of the previous space missions was properly designed for open clusters

Kepler	4 accessible clusters 2 old open clusters observed in acceptable conditions, with a limited number of stars NGC 6791 and 6819, e.g., Miglio et al. 2016, MNRAS 419, 2077
K2	20 accessible clusters; 2 clusters observed in sub-optimal conditions Globular cluster M4 + Open cluster M67 Miglio et al. 2016, MNRAS 461, 760, Stello et al. 2016, ApJ 832, 133;

→ Requirements and design of HAYDN adapted to dense stellar fields

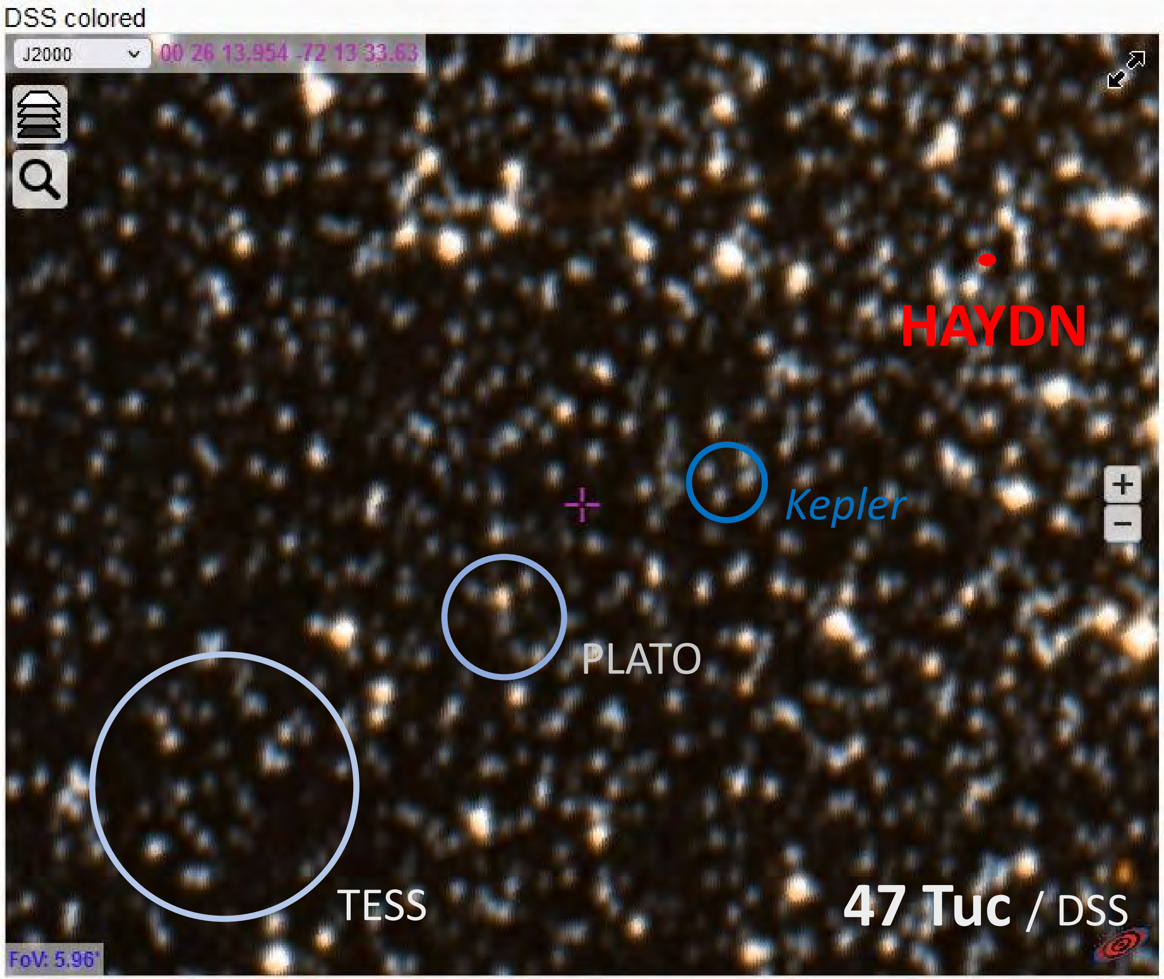

47 Tuc, 18 m

M67, 9 m

M4, 3 m

ω Cen, 6 m

Baade's window, 6 m

Sgr dSph, 7 m (add)

PSF

HAYDN benefits from the heritage of CoRoT, Eddington, PLATO, but with a PSF designed for the observation of dense stellar fields

Mission	PSF (arcsec)
CoRoT (seismo)	914
TESS	84
Kepler	21
PLATO	37
HAYDN	1.3



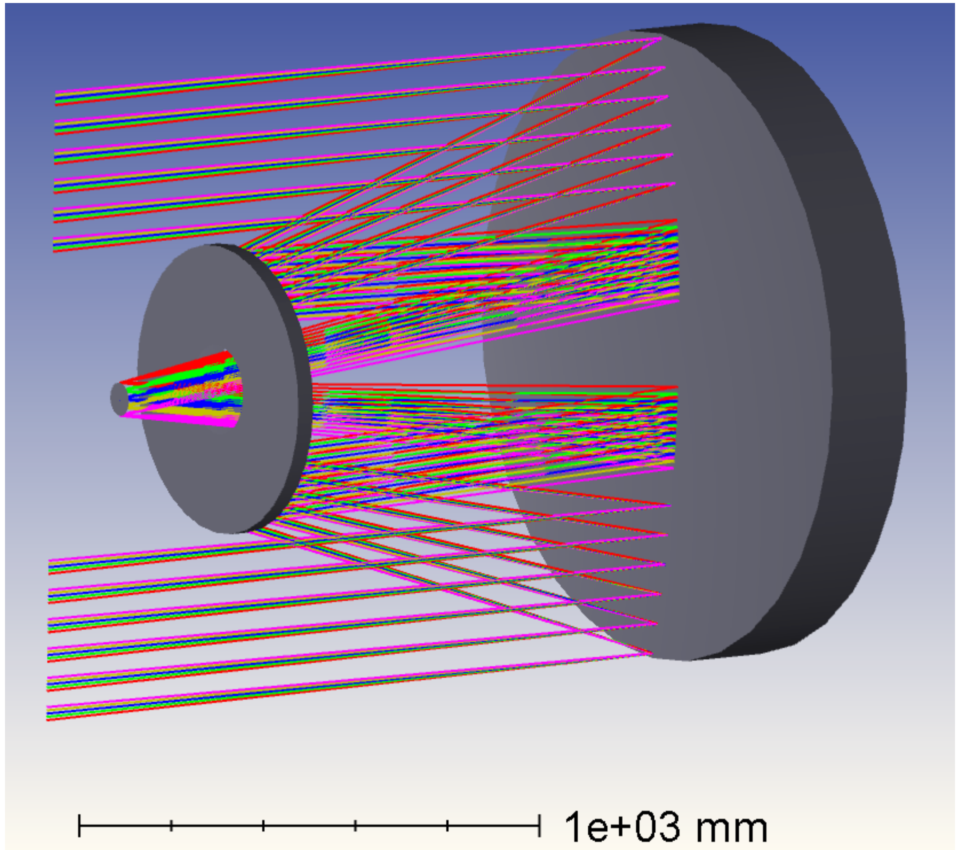
Scientific requirements

Parameter	Unit	Value	Comment(s)
Bandwidth	nm	400-1000	
Noise Level	$ppm.hr^{1/2}$	13, 300	For V = 10, 16
PSF	arcsec	1.3 or 2.6	HAYDN optical design. Diameter of the circle concentrating 90% of the PSF energy.
Sampling time	min	1 ; 8	Short and long cadence
Continuous observations	months	9	For a cluster near ecliptic
Duty cycle	-	> 92%	
Mission lifetime	years	4.5	

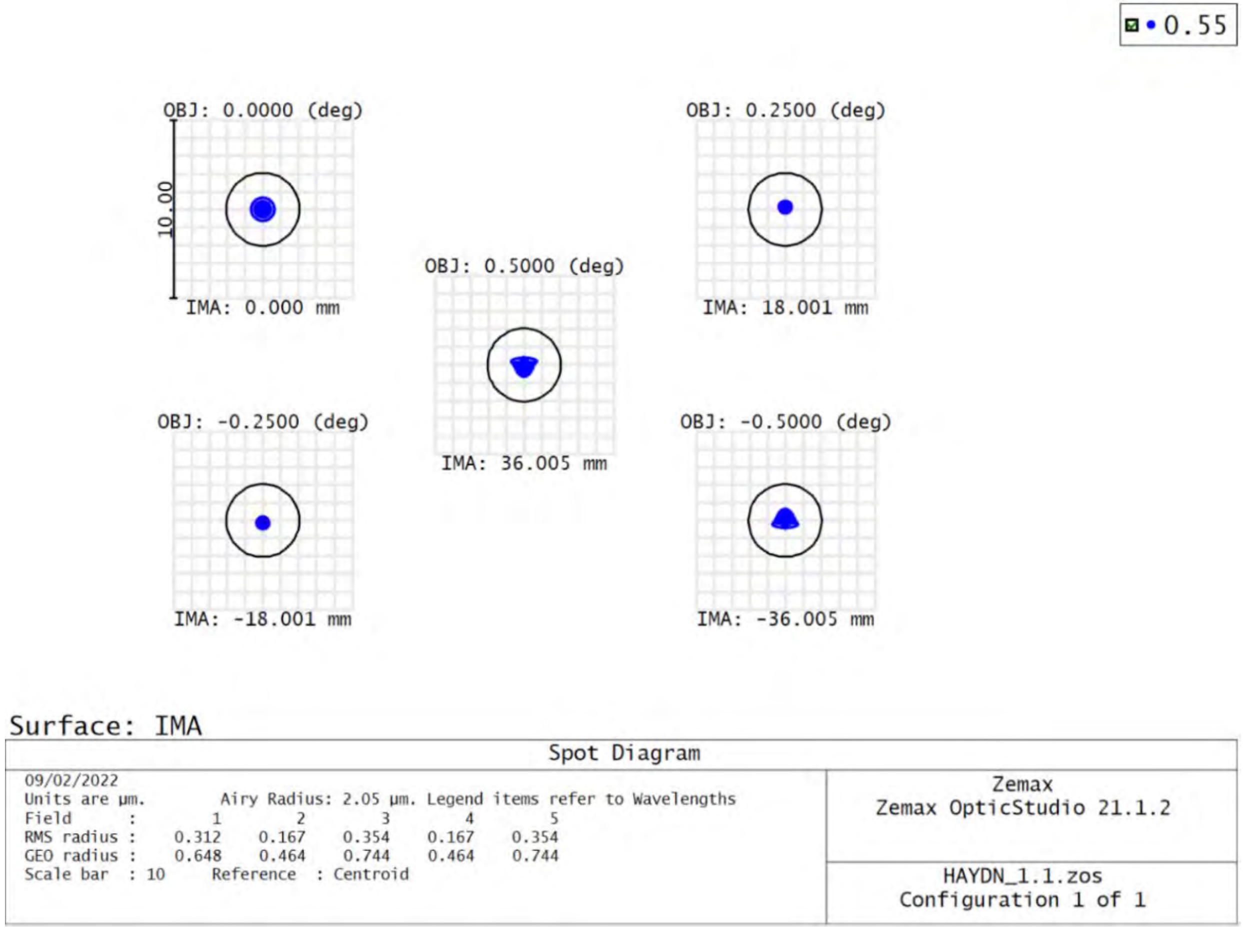
HAYDN

- Better photometric precision compared to *Kepler* and PLATO
- PSF sizing for probing dense stellar fields
- L2: no time limit for continuous observations for all objects away from ecliptic

Payload: space photometer

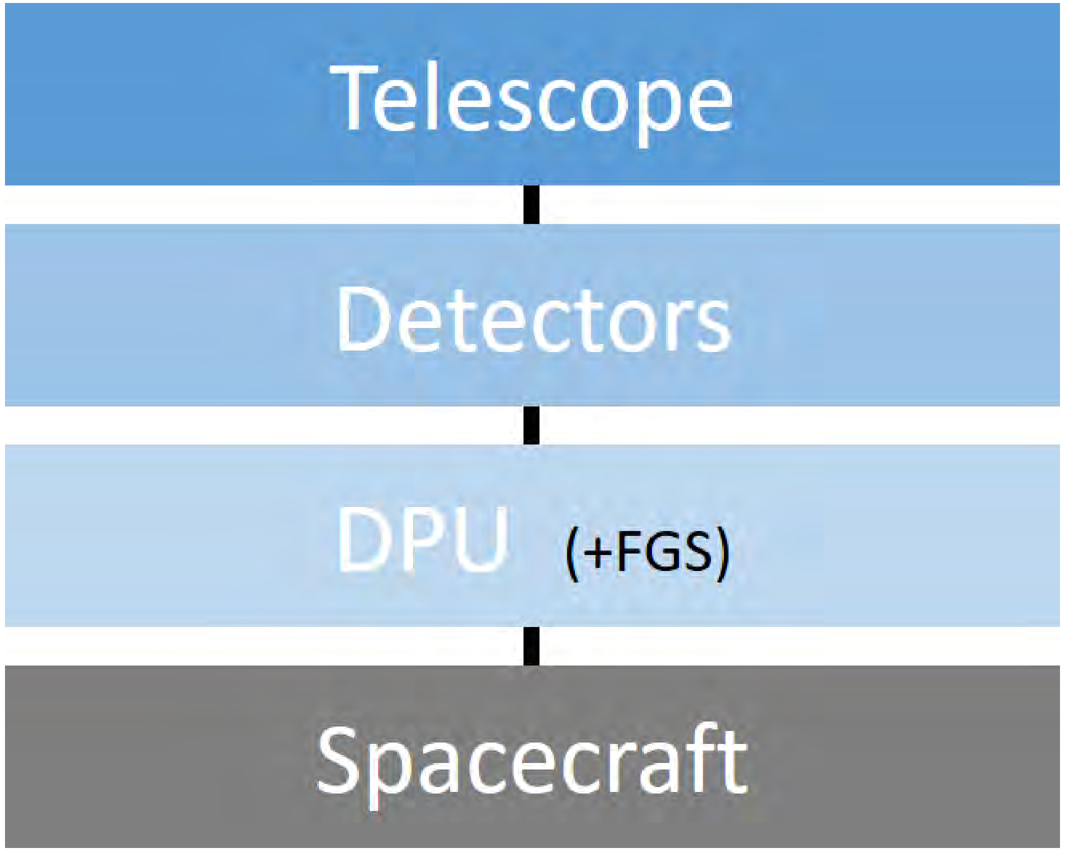


Optical design: three-reflection telescope



Spot diagrams

HAYDN block diagram



Baffle	Belgium
Telescope	Italy
Focal plane	France
Detectors	UK
Proximity electronics	France
DPU	**Spain**/Italy
On-board software	France
Power unit	**Spain**
Platform	ESA
On-ground software	France
Thermal stability	**Spain**
Data center	CH/Italy

+ Germany, contribution tbd

Organization of the HAYDN consortium

Systems/subsystems	Activity	Responsibility
Telescope (optics and mechanics + mechanical interface)	Opto-mechanical design	Italy
	Build-contract	Italy
	AIT/V (+GSE)	TBC
Baffle	Opto-mechanical design	Belgium
	Build-contract	Belgium
	AIT/V (+GSE)	TBC
Focal Plane	Thermo-mechanical design	France/AIM
	Build-contract	France/AIM
	AIT/V (+GSE)	TBC
Proximity electronics	Design	France/AIM/IRAP
	Build-contract	France/AIM/IRAP
	AIT/V (+GSE)	TBC
CCDs	Specifications and contract	GB
	AIT/V (+GSE)	TBC
AIT/V Focal Plane + CCDs + Proximity Electronics (+GSE)		France/IAS TBC
DPU + Memory	Design	Spain/Italy TBC
	Build-contract	Spain/Italy TBC
	AIT/V (+GSE)	TBC

On-board software	Design	France/LESIA-lead+consortium
	Build-contract AIT/V (+GSE)	France/LESIA France/LESIA TBC
On-ground software (SOC)	Design	France/LESIA/IRAP/IAS/OCA/AIM + consortium
	Build-contract	France/OCA/IAS
	AIT/V (+GSE)	France/OCA/IAS
Thermal stab.	Design	TBC
	Build-contract	TBC
	AIT/V (+GSE)	TBC
Power supply	Spec-design	Spain
	Build-contract	Spain
	Test (+GSE)	Spain
Data-base and data distribution	Design	CH/Italy
	Build-contract	CH/Italy
	Host	CH/Italy
	Operation	CH/Italy
Group system lead French consortium		Fr/LESIA

History & Heritage

ESA Voyage 2050 Senior Committee report

Sec. 3.1.8: → **A Medium mission designed to carry out pure asteroseismology**

Heritage of CoRoT, Eddington, PLATO:

CoRoT	first European/Spanish experience
Eddington	assessment study at ESA CDF: 1.2 m diameter three-reflection, two-mirror telescope; essentially unvignetted field of view (Eddington adopted, but stopped due to budget cut)
PLATO	4-year mission in L2, FGS; compliance with M mission constraints and budget

→ Mass, cost, telemetry budgets comply with the sizing & constraints of an M mission

→ High TRLs, no risk

Risk analysis / TRL

Heritage → high TRLs and limited risks

New analysis: CMOS detectors for ultra-precise photometry, instead of CCD

Subsystem	TRL	Heritage / remark
Baffle	≥ 7	CoRoT
Three-reflection Telescope	≥ 6	Eddington
CCD	≥ 8	*Kepler*, PLATO
CMOS	*6*	*End of phase A*
Electronics	≥ 7	CoRoT, *Kepler*, PLATO
Fine Guidance System	≥ 7	CoRoT, *Kepler*, PLATO

Heritage

Mass & Power breakdown

Eddington assessment study report
(ESA CDF study team)

Eddington	**Mass (kg)**	**Power (w)**
Payload	274	150
Service module	461	370
Launch adapter	50	
Fuel	56	
Margin	169	80
Total	*940 kg*	*600 W*

Cost & telemetry

PLATO

PLATO	**HAYDN**
26 cameras	1 telescope
26 x 4 CCD	2 CCD

HAYDN / PLATO
less demanding in terms of complexity, data transfer

Spanish consortium

The third largest community in HAYDN consortium in terms of the number of institutions and researchers

UV, IAA, UGR, IAC, ICE, ICCUB

Scientific contribution

Large expertise of the Spanish teams derived from previous projects

- Stellar physics, stellar modeling, stellar evolution, 1D, 3D modeling
- Asteroseismology, seismic data analysis
- Stellar rotation, stellar activity, magnetism
- Galactic stellar populations, cluster population simulations, Galactic archaeology

+ Instrumental contribution

Instrumental contribution derived from previous projects

- DPU, PSU, thermal stability.

Summary

1) HAYDN is a low-risk high-gain mission. It harvests one of the remaining low hanging fruits. Ultra-precise photometric time series in clusters.
2) All technology at TRL ≥ 6, except the CCD that is the only challenge.
3) High scientific return
4) Spain is the third-largest community, just after the two co-IP (Italy and France)
5) Currently under evaluation (phase 2).

HAYDN

Thank you very much

Development plan

Phasing with ESA schedule

Phase A start in 2023

Current design proposed with CCD detectors

CMOS detectors show properties that better fit with the scientific requirements than CCDs

From Teledyne-E2V:

- large area back-illuminated CMOS imager
- 9k x 9k 10-µm pixels
- 2-3 years for achieving TRL 6

Properties	CCD	CMOS
Pixel size	13 µm	10 µm
Dynamic range	x	x
Precise photometry	x	tbc

→ Phase 0-A (2023-2025): verify that CMOS detectors can achieve precise photometry

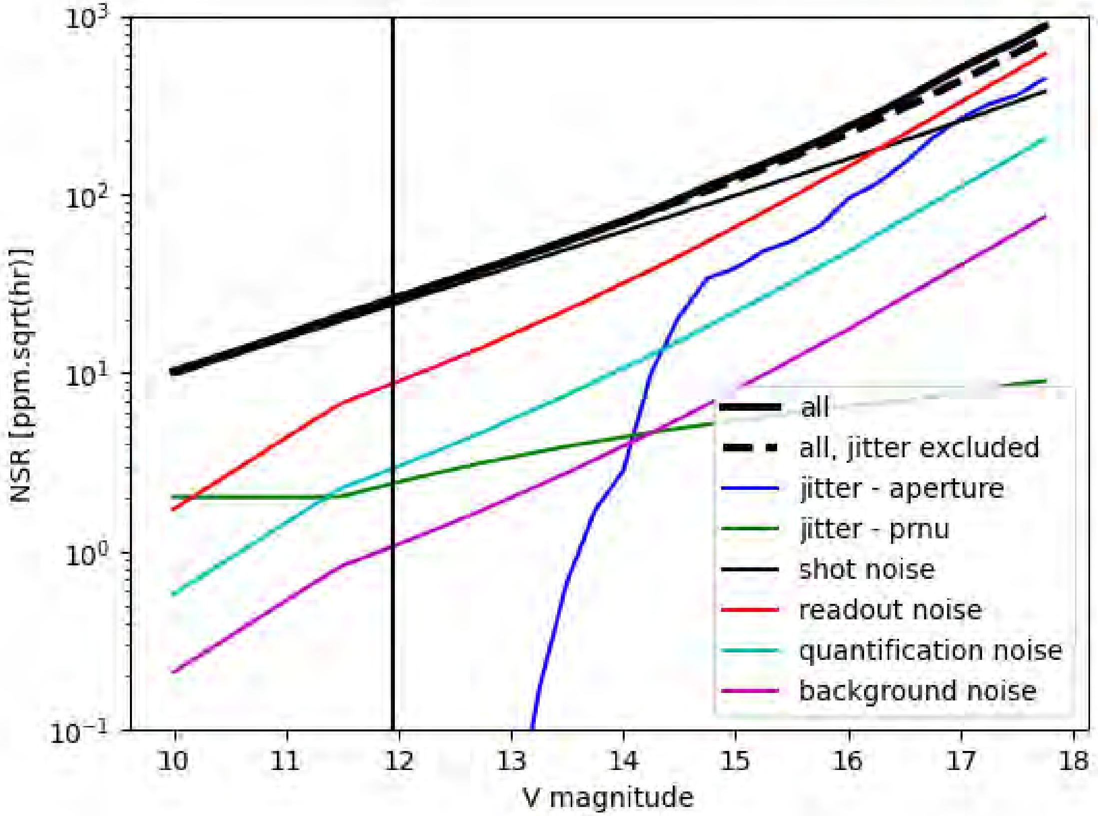
Phase 0 sizing

Parameter	Unit	Value	Comment(s) / origin
Equivalent pupil diameter	cm	120	HAYDN optical design, unobstructed pupil
Focal length	mm	4125	HAYDN optical design
PSF diameter	µm	26 or 52	HAYDN optical design. Diameter of the circle concentrating 90% of the PSF energy. Two options are explored
Integration time	s	6	*Kepler* technical characteristics
Readout time	s	0.52	*Kepler* technical characteristics
Pixel size	µm	13	HAYDN design
Pixel scale	arcsec	0.65	HAYDN design
Readout noise	e-	95 (1-σ)	*Kepler* technical characteristics
PRNU	-	1% (1-σ)	PLATO specifications (typical value: ~0.4%)
Gain	e-/ADU	110	As in *Kepler*
Full Well Capacity	ke-	1,100	PLATO specifications
Pointing error	arcsec/Hz$^{1/2}$	0.07 (1-σ)	*Kepler* technical characteristics. For each transverse axis
Reference star Teff	K	6,000	The PLATO camera bandwidth is assumed

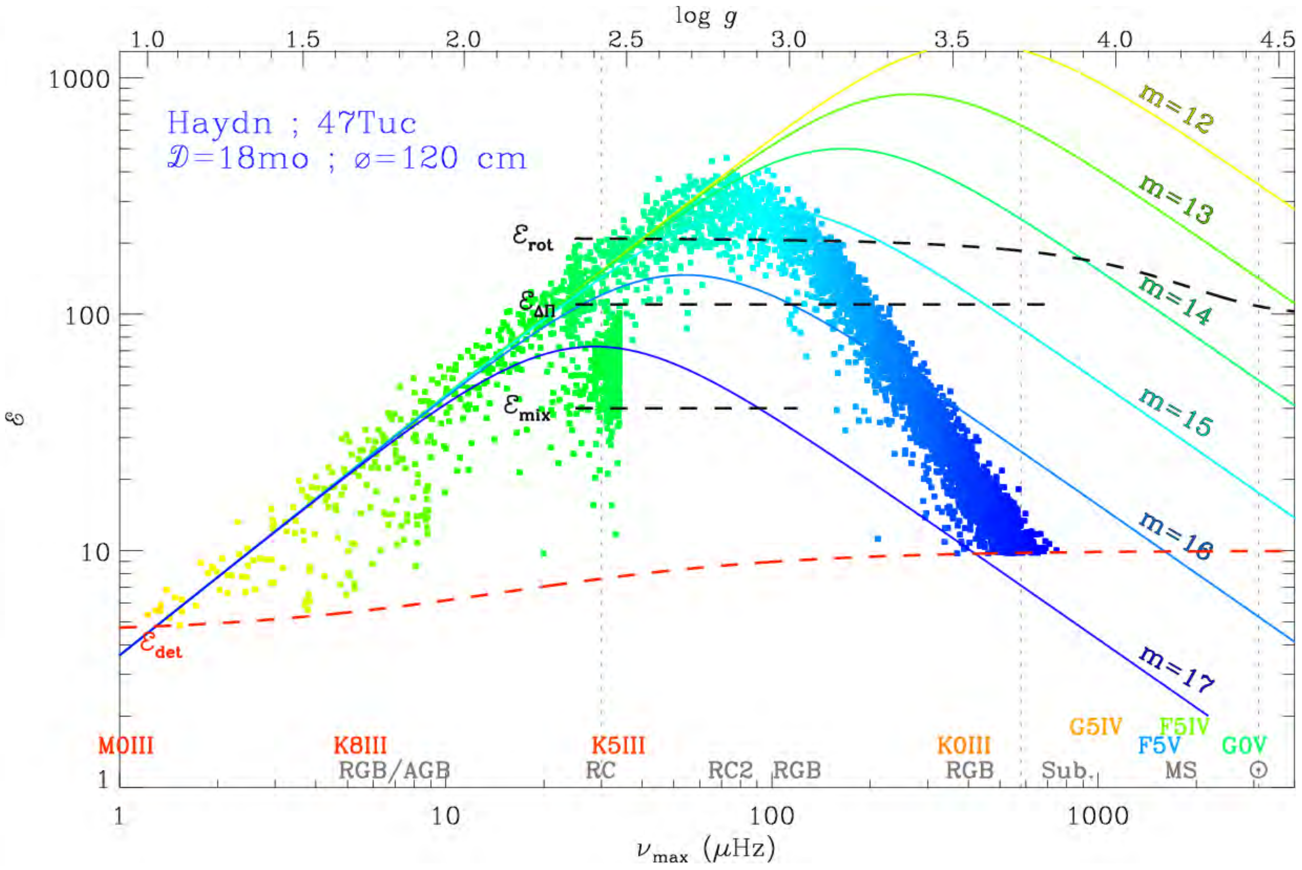
Possible targets

ID	RA, Dec (deg)	age/Gyr, [Fe/H], distance/kpc	# Stars with solar-like oscillations[1]	Time needed (months)	Mode	Comments / reasons to observe
47Tuc/ - NGC104	6.02, -72.08	13,-0.8,4	4192	18	HR	Multiple populations at the same [Fe/H]. Many evolved BSS. SMC stars in the background.
M67/ - NGC2682	132.85, 11.81	4,0,0.9	408	9	HR	Diffusion, solar analogues, stars with small convective cores, BSS.
ωCen/ NGC5139	201.5, -47.5	12,-1.5,5.4	1902	6	LR	Core of a dwarf galaxy, multiple populations ,different [Fe/H], infer star formation history
Baade's Window	270.8, -30.0	10,-0.3 to+0.3, 8	52124	6	LR	Infer the bulge's complex star formation history
M4/NGC6121	245.8, -26.5	12,-1.2,2.2	431	3	LR	The closest globular cluster
M22/NGC6656	279.0, -23.9	13,-1.5,3.2	388	3	LR	A scaled-down ωCen, with spread in Fe and neutron-capture elements
NGC7789	359.2, +56.7	1.5,0.0,2.1	114	3	LR	Very rich, compact intermediate-age cluster
NGC188	11.8, 85.2	7.1,0.14,1.7	55	3	LR	Very old, metal-rich open cluster
NGC2243	97.39, -31.28	3.5,-0.5,4.4	38	3	LR	Solar age, metallicity ⅓ solar open cluster
NGC2506	120.0, -10.76	1.6,-0.2,3.5	69	3	AD	Open cluster with many core-He burners
NGC6752	287.5, -60.0	12,-1.5,4.0	1205	7	AD	The classical, well behaved globular cluster at the peak of the GC metallicity distribution
NGC6397	265.0, -53.7	13,-2.0,2.5	149	3	AD	Low-metallicity GC
M54 & Sgr dSph	283.8, -30.5	11,-1.4 ,27	77	7	AD	The closest extragalactic dwarf and its nuclear cluster
M11 - NGC6705	282.75, -6.28	0.32,0.14,1.7	31	3	AD	Open cluster, outskirts of bulge in the background,with intermediate-mass core-He-burners
NGC2818	139.04, -36.6	0.0,0.0,3.1	15	3	AD	Interesting age range, but few core-He-burners

Noise model & seismic performance



Noise model: Marchiori et al. 2019, A&A 627, A71



Seismic performance: Mosser et al. 2019, A&A 622, A76