STELLA

Europe's contribution to INTERSTELLAR PROBE Humanity's Journey to Interstellar Space

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Proposal submitted to ESA's call for M- and F-class mission proposals, 2022-02-14.

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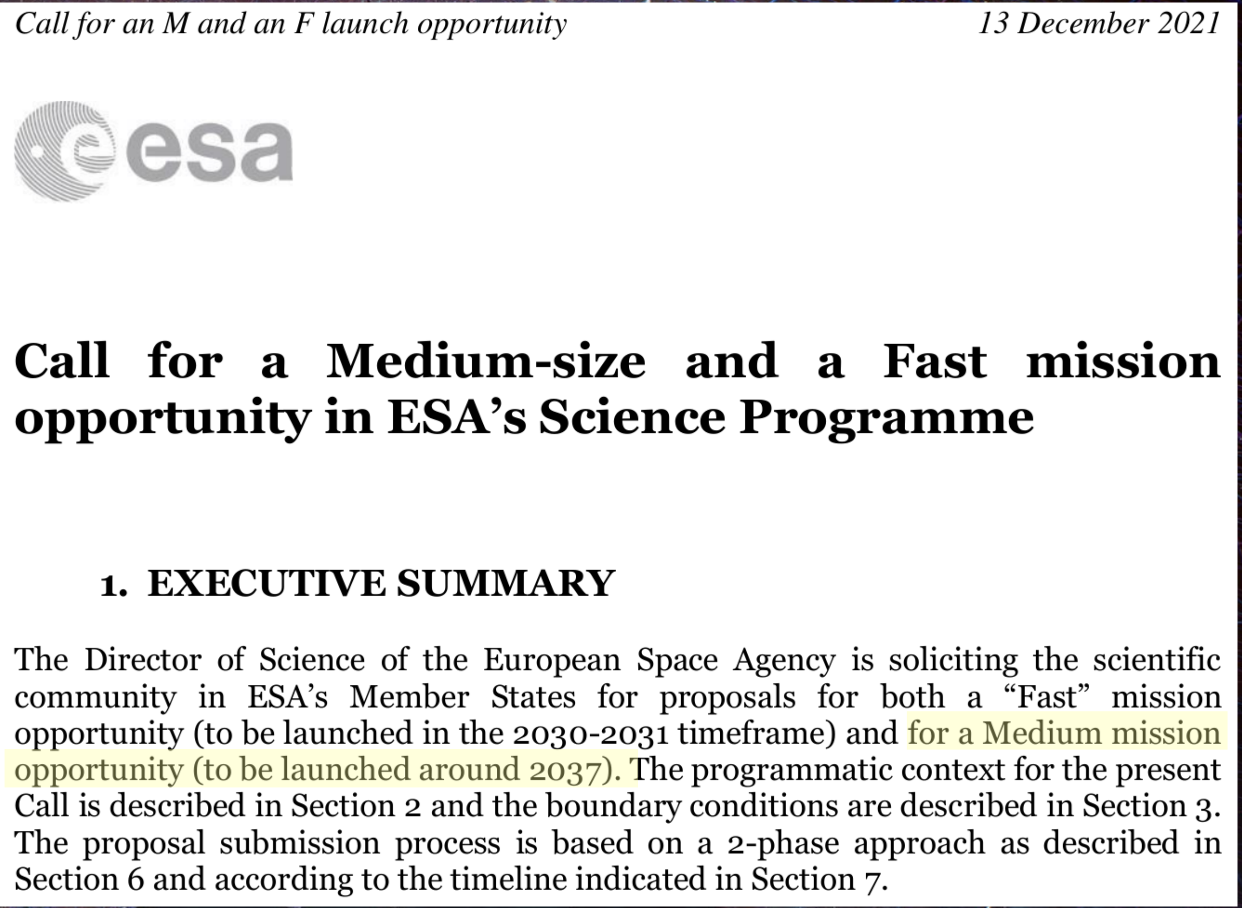
Stella – Proposal submitted to ESA's call for M & F class mission


Call for an M and an F launch opportunity *13 December 2021*

Call for a Medium-size and a Fast mission opportunity in ESA's Science Programme

1. EXECUTIVE SUMMARY

The Director of Science of the European Space Agency is soliciting the scientific community in ESA's Member States for proposals for both a "Fast" mission opportunity (to be launched in the 2030-2031 timeframe) and for a Medium mission opportunity (to be launched around 2037). The programmatic context for the present Call is described in Section 2 and the boundary conditions are described in Section 3. The proposal submission process is based on a 2-phase approach as described in Section 6 and according to the timeline indicated in Section 7.

Boundary conditions for M-class missions

ESA has 3 mission classes:
L – Large:
Cost: ~ 1500 MEUR
Next L-class missions are:
JUICE (L1, April 2023)
Athena (L2, 2034)
LISA (L3, 2037)

3.6 *International collaborations*

M-class missions are a key vehicle for pursuing collaboration opportunities between the ESA Science Programme and other space agencies. As such, any international collaboration scheme can be considered for the implementation of M-class missions: an M-class mission can be entirely European, or it can be European-led with junior participation by international partners, or (part of) the budget allocation of an M mission can be used to implement a junior European contribution to a mission led by a partner agency. All these scenarios have been implemented in the Programme's history.

M – Medium:
Decided: Solar Orbiter (M1, 2020), Euclid (M2, 2023) PLATO (M3, 2026), Ariel (M4, 2029), Envision (M5, 2031)
Next M-class launch opportunity: ~ 2037
Cost: < 550 MEUR

F – Fast/Flexi:
Comet Interceptor (joint launch w. Ariel)

Stella was proposed as M7. This call was the only option to contribute to an ISP.

In line with ISP's astronomically constrained launch window in 2036-2037.

Challenge: Different ESA-NASA time scales (Voyage 2050 - decadal)

Programmatic background

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3.2.3 Contribution to NASA Interstellar Probe concepts

The stellar-interstellar interaction remains largely unknown, even in our heliosphere, because the boundary between these regions hosts a complex interaction with highly variable and turbulent mixture of plasmas, neutrals, and dust with variable background radiation. The only missions to have probed this region *in situ* are *Voyager 1* and *Voyager 2*, currently 153 and 127 AU from the Sun respectively. The boundary has also been probed remotely in energetic neutral atoms by the *Interstellar Boundary Explorer (IBEX)* and *Cassini*.

A dedicated Interstellar Probe equipped with appropriate instruments would for the first time truly unveil the properties of the interstellar medium and the nature of its interactions with the heliosphere, which shapes our Solar System. The exploration of the interstellar medium with an Interstellar Probe travelling up to ~ 200 AU represents a very compelling science case with a unique *in situ* observatory and a high potential for discoveries to answer unsolved questions on the local interstellar medium and more generally on the formation of astrospheres.

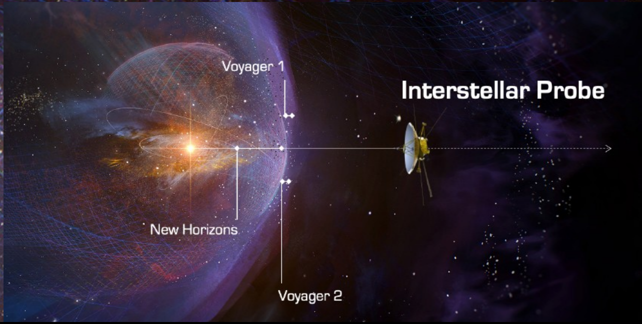
The great challenge for a mission to the interstellar medium is the requirement to reach 200 AU as fast as possible and ideally within 25-30 years. The necessary power source for this challenging mission requires ESA to cooperate with other agencies. An Interstellar Probe concept is under preparation to be proposed to the next US Solar and Space Physics Decadal Survey for consideration. If this concept is selected, a contribution from ESA bringing the European expertise in both remote and *in situ* observation is of significance for the international space plasma community, as exemplified by the successful joint ESA-NASA missions in solar and heliospheric physics: *SOHO*, *Ulysses* and *Solar Orbiter*.

Science case for Stella

Big Questions:

- What are we made of?
- Where are we going?
- Influence of ISM on solar system?
- History and future of solar system?

TQ1: How is our heliosphere upheld by the physical processes from the Sun to the VLISM?
TQ2: How do the Sun's activity as well as the interstellar medium and its possible inhomogeneity influence the dynamics and evolution of the global heliosphere?
TQ3: How do the current VLISM properties inform our understanding of the evolutionary path of the heliosphere?



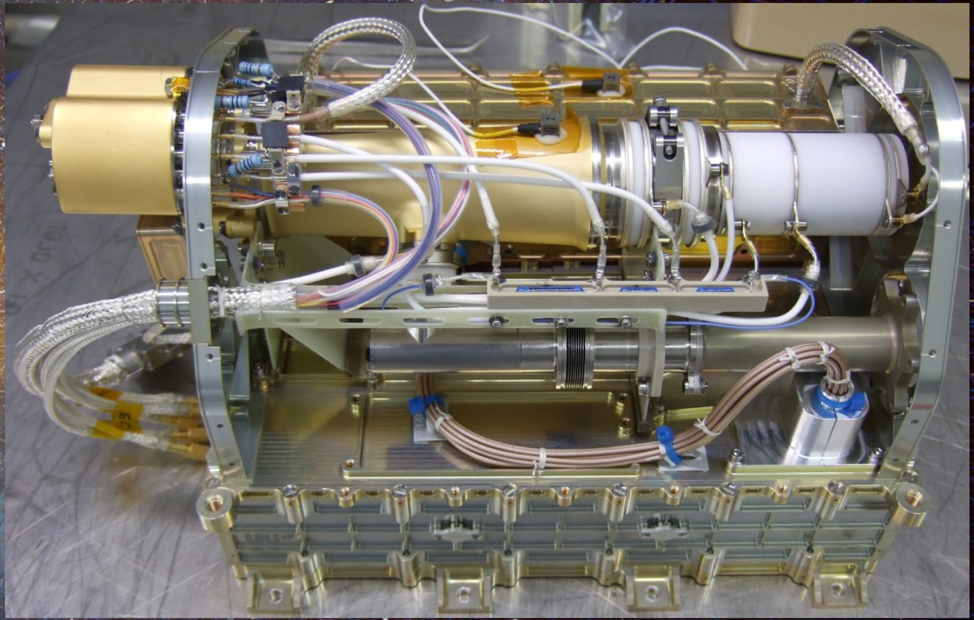
ISP's main goal is to understand our habitable astrosphere and its home in the galaxy. Stella contributes to achieving the ISP goal by answering five Stella-specific science questions:

- Q1: What is the composition of the local interstellar medium?
- Q2: How is our dynamical heliosphere upheld and how does it change from the Sun to the local interstellar medium?
- Q3: What is the origin and role of galactic cosmic rays in the solar system and beyond?
- Q4: How does the local interstellar medium become structured when it meets the heliosphere?
- Q5: Are there any deviations from the $1/r^2$ gravity law on the interstellar scale?

What is the composition of the VLISM gas?

Measure composition of VLISM gas, i.e., the neutral component:

- IBEX & IMAP measure “filtered” gas
- Pickup ions measure “filtered”^{2} particles
- ACRs are “filtered”^{3} particles
- Some species can not be measured inside heliosphere, e.g., C – key for life!
- Isotopic ratios to provide information about (galactic) evolution of matter

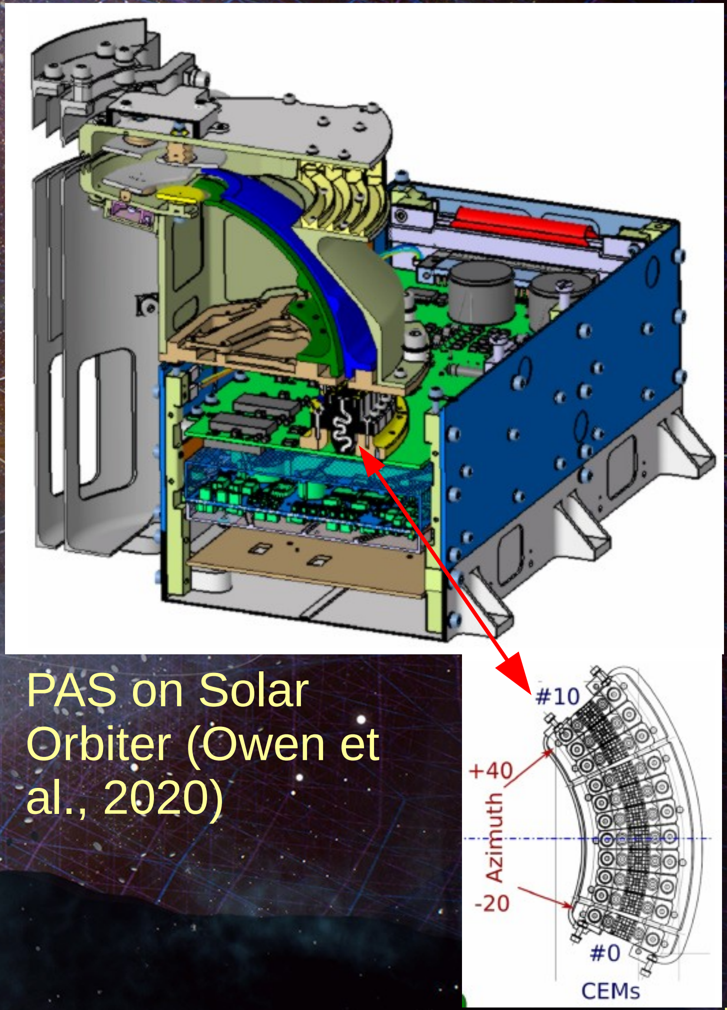


NGMS flight unit for Luna-Resurs

How is the heliosphere upheld and how does it change from Sun to VLISM?

Plasma Science System (PSS):

- Birth & evolution of interstellar & inner-source PUIs
- Acceleration processes and pressure balances in solar wind and at the heliospheric boundaries
- Establish nature and structure of heliopause, ribbon,...
- How are the heliospheric boundaries affected by solar & heliospheric activity/dynamics?
- Determine extent and impact of solar disturbances on VLISM

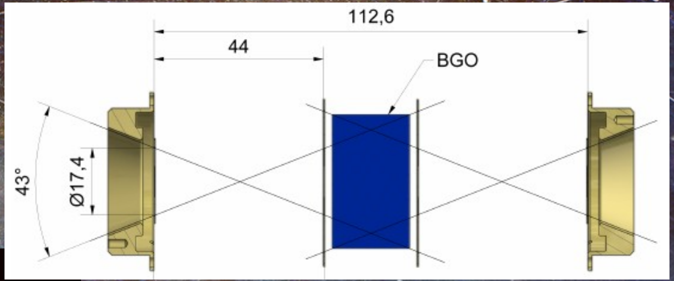


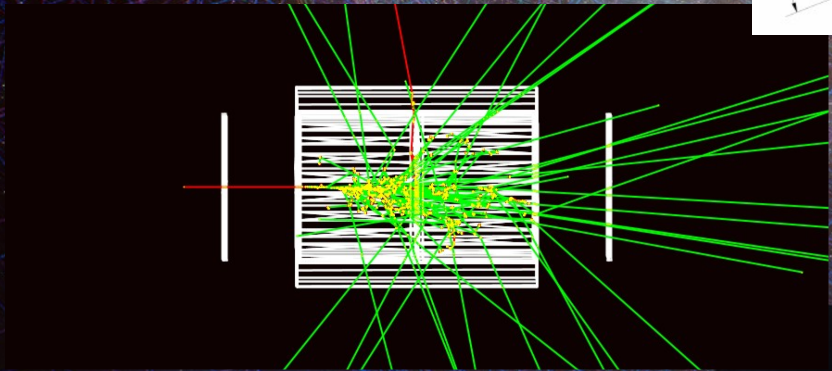
PAS on Solar Orbiter (Owen et al., 2020)

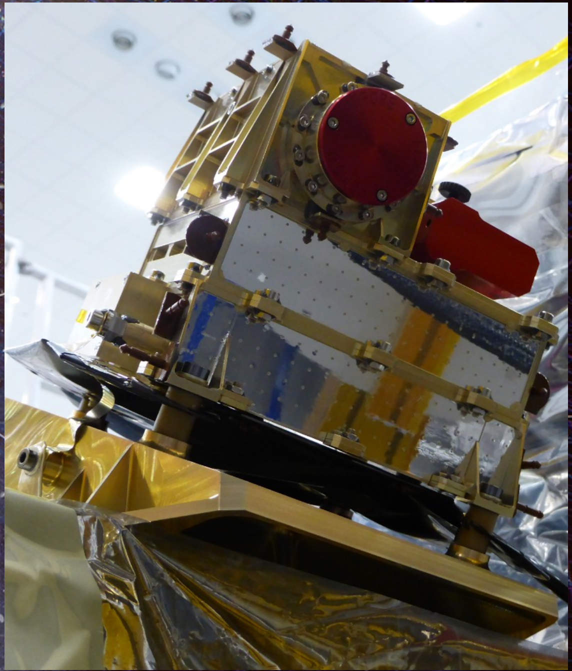
Origin and role of GCRs in solar system and beyond

Cosmic Ray Spectrometer (CRS):

- Understand nature and detailed origin of GCRs
- Establish exact nature of heliospheric shielding against GCRs
- Establish how far solar disturbances reach into the VLISM
- Composition of “Cosmic Voyagers” (i.e., GCRs)
  - - Isotopic composition of GCR
  - - Abundance of Li-Be-B
- Pitch-angle distributions
- AHEPaM as demo model







HET-EPT on Solar Orbiter (Rodriguez-Pacheco et al., 2020)

Origin and role of GCRs in solar system and beyond, cont’d

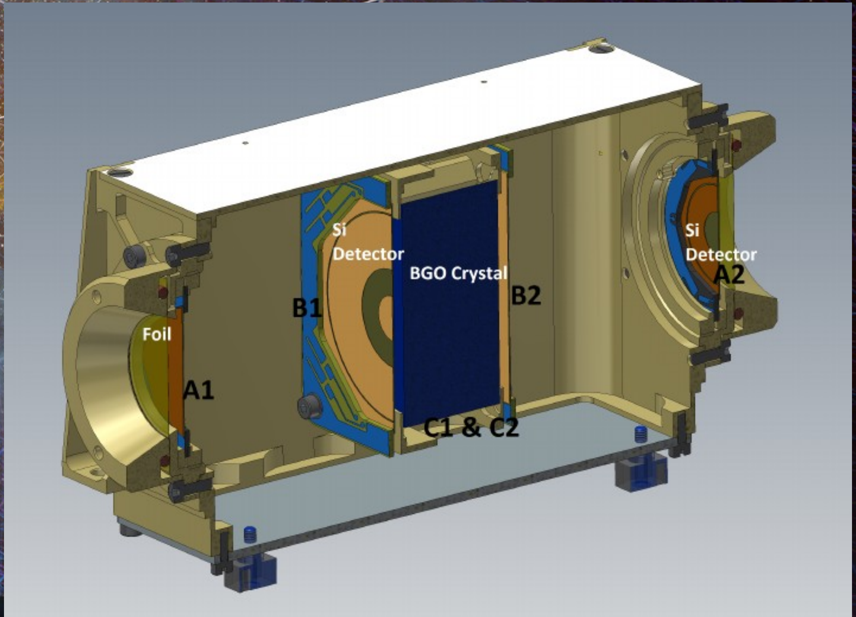
Cosmic Ray Spectrometer (CRS):

- **Geometry factor > 2 cm^2 sr**
- 7-8 kg, 7 W
- Composition H to Sn, $\Delta m/m < 10\%$ likely not sufficient to separate relevant isotopes.
- 10 MeV/nuc – 1 GeV/nuc for ions
- 1 – 10 MeV electrons
- Cadence: Weekly

But HET on Solar Orbiter does NOT resolve energy up to 1 GeV!

Solar Orbiter HET values:

Cases	Geometrical factor (mm^2 sr)
A1∧B1	27.11
A1∧B1∧C∧B2∧A2	4.43
B1∧C∧B2	79.36
A1i∧B1	1.25



Origin and role of GCRs in solar system and beyond, cont'd

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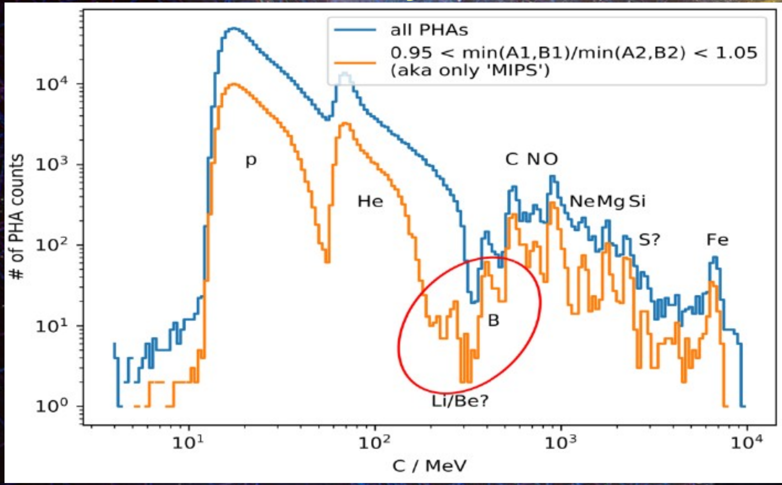

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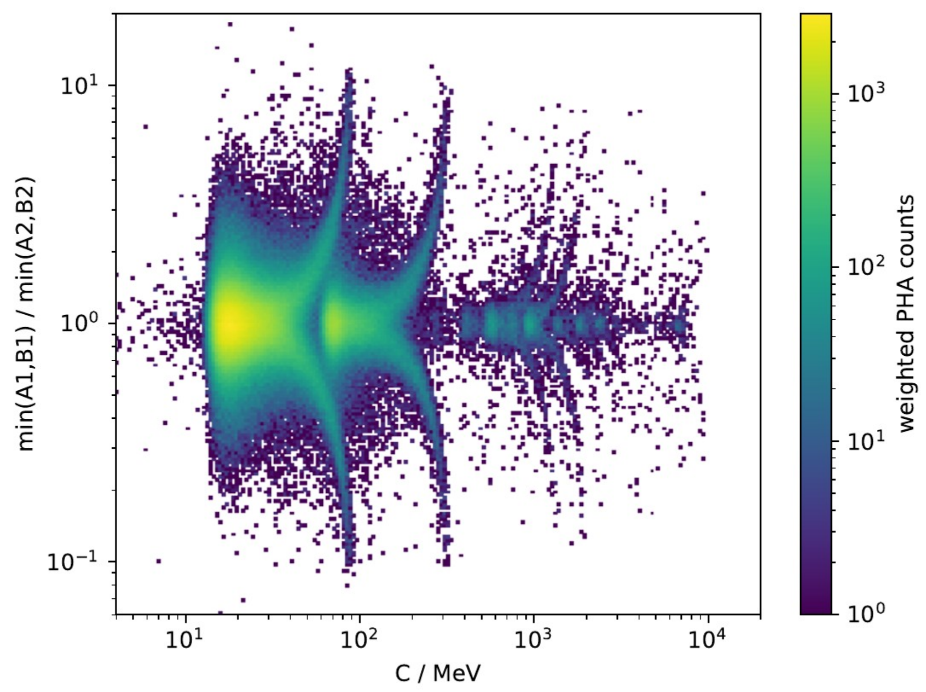
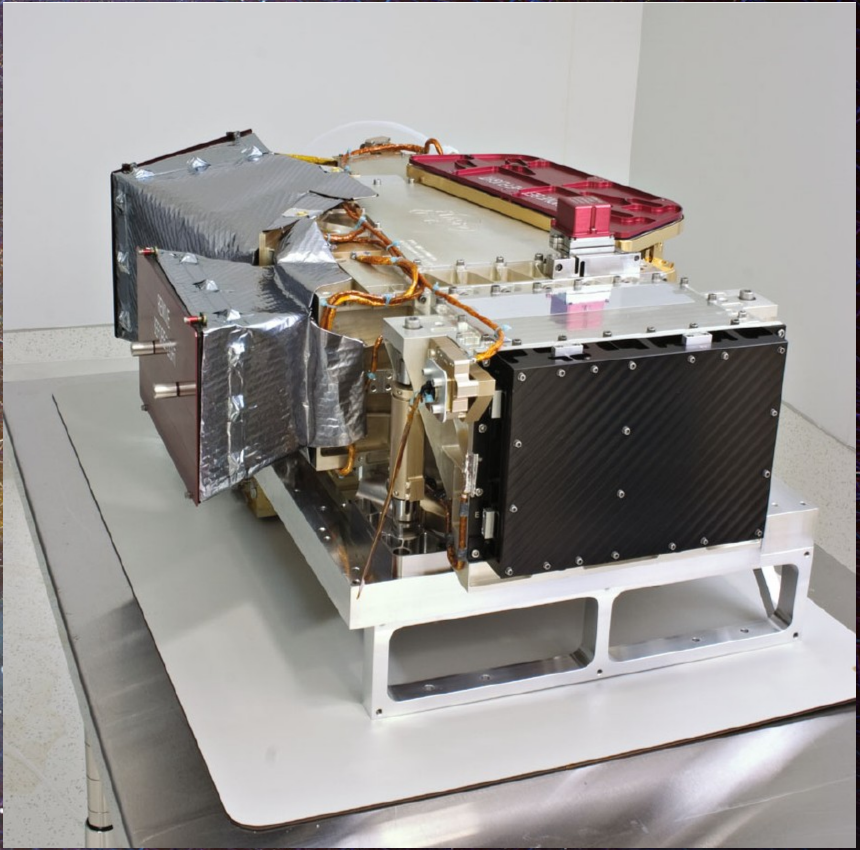


How does the local ISM become structured when it meets the heliosphere?

Lyman-α spectrometer (LyS):

- Understand filtration and hydrogen wall
- Properties of hydrogen populations
- Velocity distribution of hydrogen
- Number density, bulk velocity & temperature in VLISM



McClintock et al., Space Sci. Rev., **195**, 75-124, (2015)

Are there deviations from the gravity law on an interstellar scale?

Radio Science (RS):

- Explore gravitation at scale of solar sytem
- Are there deviations from $1/r^2$?
- Never tested beyond 50 au
- Determine acceleration of S/C
- Measure two-way range to an accuracy of 20 cm at integration times of 100s of seconds.
- Gravitational signals from TNOs?

- No HW needed, use radio signal!

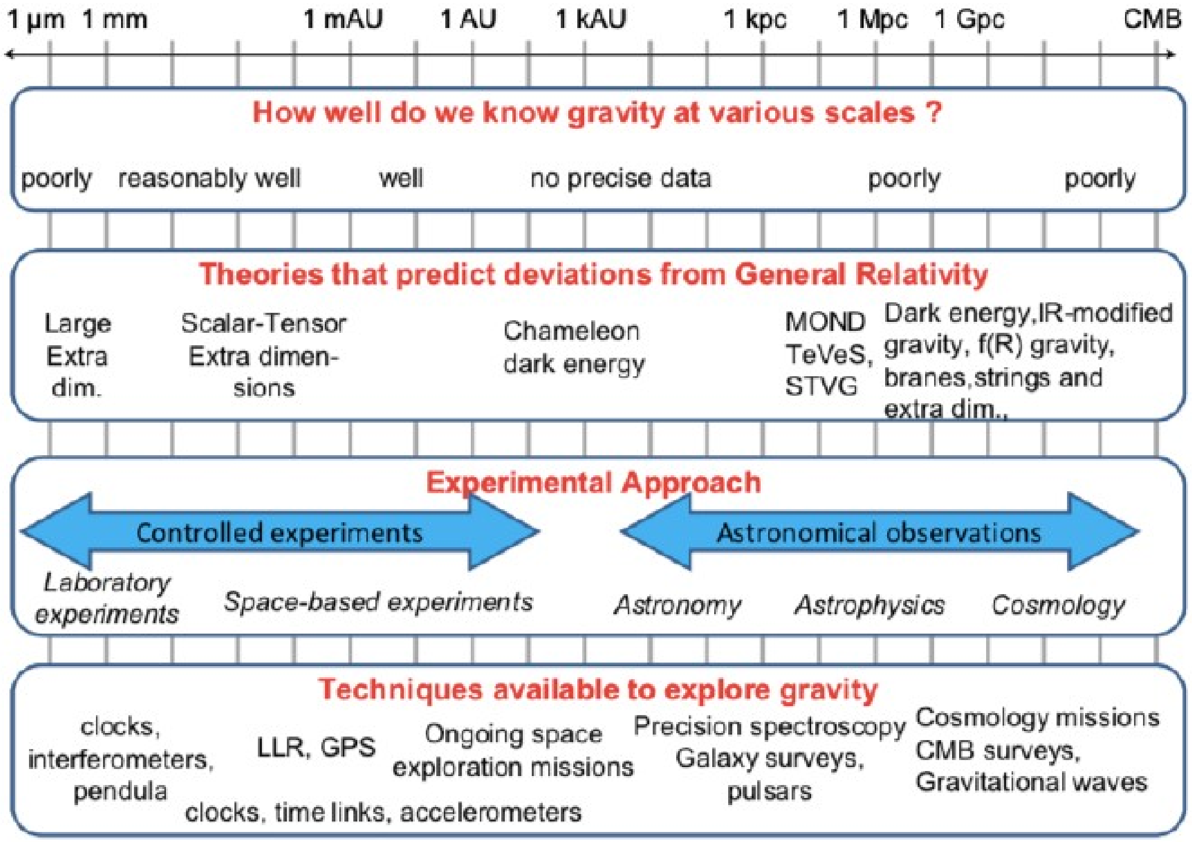


Fig. 1.7.2. Gravity at all length scales (*RFP, 2010*).

Model Stella payload (i.e., potential European payload provision)

Tab. 3.1.1. Stella science payload and the key performance

Instrument	Key Measurements	Key performance
Neutral gas mass spectrometer (NGMS)	Composition and isotope composition of the interstellar gas.	$m/\Delta m > 100$, species H – Fe
Plasma Science System (PSS)	Ion and electron 3D velocity distribution functions and plasma moments	Energy range 0.1 eV – 20 keV Dynamical range in fluxes up to 10^{11}
Cosmic Ray Spectrometer (CRS)	Composition and isotope composition of energetic particles.	Δm ~0.1 amu, H – Sn G-factor > 2 cm^2 sr
Lyman-α spectrometer (LyS)	Lyman-α line profile and hydrogen distribution	R > 15000, <20 km/s Doppler resolution (req.), 10 km/s (goal)
Radio Science (RS)	Two-way range measurements	20 cm for 100-1000 s integration time

Tab. 3.1.2. Stella instrument resource budgets

Instr.	Mass (kg) / CSR Allocation	Power (W) / CSR Allocation
NGMS	9.8 / 10.0	11 / 11
PSS-A	6.2 / n/a, partial contribution	10 /
PSS-F	3.0 / n/a, partial contribution	5 /
CRS	7.5 / 8.0	7 / 7
LyS	12.5 / 12.5	12 / 12

PSS-A: Plasma Analyzer; PSS-F: Faraday cup

Critical ESA contributions

ESA's contributions are from industrial partners. We proposed three large contributions:

- Communication system:
  - - 5m dish on ISP with radio system
- European deep space communication facility:
  - - flexible, scalable DSN augmentation
- Contribution to ISP operations:
  - - operations of European payload
  - - increase ISP science return
  - - operate radio science experiment

Tab. 3.2.1. ESA-provided ISP communication system

Parameter	**NASA ISP Value** *(CSR, 2021)*
Frequency	8.4 GHz (X-band)
Range	350 au (50-years mission)
Transmitter antenna ø	5 m
Transmit power	52 W
Min data rate	200 bps (to 4x35-m @ 350 au)

European deep space communication facility

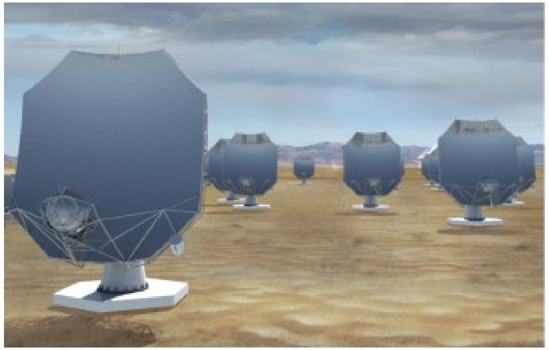
mtex antenna technology (GER) is the sole prime to develop a production-ready design and produce a prototype 18m antenna for the US National Radio Astronomy Observatory (NRAO) Very Large Array (ngVLA) facility.

Thales/Alenia (FRA/IT) and Schwartz Hautmont (ESP) are involved in the development of the new 35m DSA antenna.

Tab. 3.3.1. Options for European deep space communication facility (all numbers are preliminary, X-band)

Parameter	35-m Opt.	18-m Opt.
Antennas array	4x35-m	16x18-m
Effective aperture, m^2	3846	3629
Gain (dBi)	75.1	74.9
System noise temp (K)	49	49

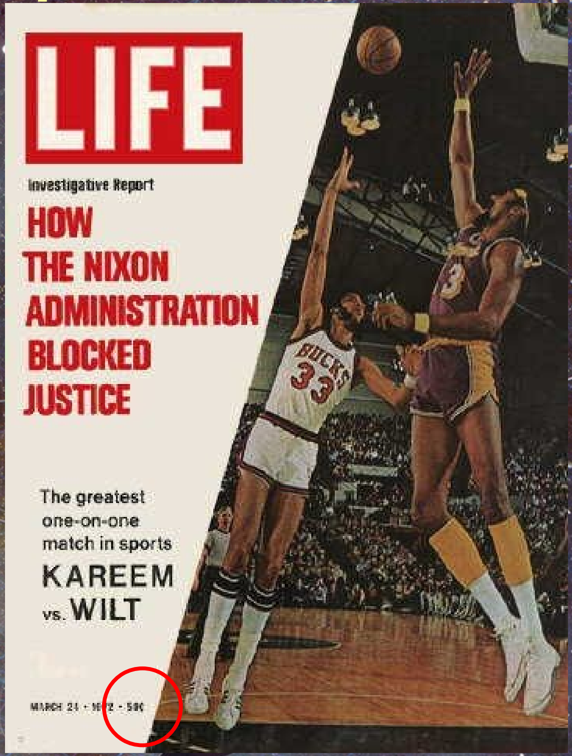
Apollo complex @ Goldstone DSCC 35m antennae



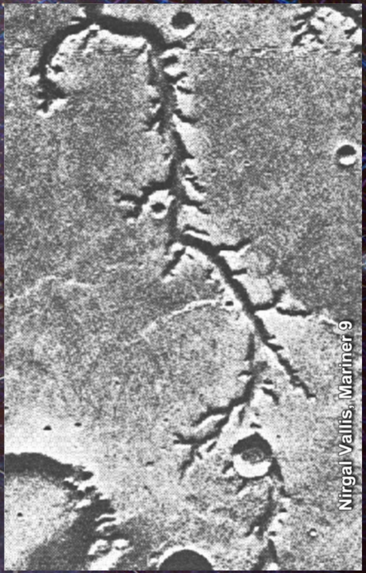
Artistic view of the NRAO ngVLA of 18m dishes
https://public.nrao.edu

Required technology tevelopments

1) **Develop qualification procedures for missions with 50-year lifetime!**
2) Studies of using integrated X/Ka band deep space transponders. Such will be flown on NASA's VERITAS mission to Venus, developed by Italian Space Agency. Already at high TRL.
3) Studies of a European deep space communication facility architecture. This would also be needed for missions to the icy giants and outer solar system



50 cts



If Stella is selected,... these studies should be kicked off in 2023/2014 to ensure completion by end of phase 0/A

Sustainability of interstellar research in Europe

Europe has demonstrated experience with long-lasting missions:
SOHO, Cluster, Ulysses, XMM-Newton, Integral, Gaia, Mars Express, etc.

Propose joint ESA/NASA science/payload reviews every 10 years

Transfer of knowledge from generation to generation by networking existing programs into a virtual Interstellar Probe Institute (IPI) following the ISSI model.

4.6 Management of knowledge transfer

The very long duration of the mission necessitates the broad involvement of young and mid-career scientists as well as encouraging scientists who were not necessarily involved in the hardware phase to join the mission. We envision that PIs will change for the different phases of the mission.

For each 10-year segment of the mission, all project and instrument teams will be requested to include three categories of their team members:

- Senior members with extensive experience. These would typically be mentors of mid-career and junior scientists and potential PIs.
- Mid-career scientists who lead smaller teams and are in charge of important subsystems or projects.
- Junior scientists who lead individual ISP science investigations.

Through the course of the mission, scientists will flow through these categories to ensure knowledge transfer and succession. ISP as the anchor will enable an entire half-century of scientists to gain mission experience.

Schedule leading up to launch is/could be realistic

	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ESA M-class Mission Schedule (*M-class mission call*)															
Phase-1 selection	Apr														
Selection of Missions for Study	Nov														
Phase 0 and A															
Mission selection					▲										
Definition phase (B1)															
Mission adoption (TRL 5-6)								▲							
Implementation phase															
Launch by 2037															▲
NASA ISP Schedule (*CSR*)															
Solar and Space Physics Decadal Kick-off		Apr													
Solar and Space Physics Decadal Completed			Dec												
PPBE *															
Phase A (SRR, MDR)															
Phase B (PDR)															
Phase C (CRD, SIR)															
Phase D (ORR, PER, PSR, MRR, LRD)															
Launch, Aug. 2036															▲

Stella near-term schedule considerations

Stella: proposal for ESA's M7:

If selected for further studies:

- More detailed proposal due 2022-07-15
- Phase 0 pre-studies would start in 2023
- M7 mission selection in 2026
- M7 mission adoption in 2028
- Stella definition phase starts 2027, well aligned with NASA's PPBE process in 2027.
- Phase A would start in 2028
- Launch in 2036/2037 (constrained by JGAM constellation)

Activity	Date
Release of Call for an M and an F mission	13 December 2021
Briefing for proposers	13 January 2022
Phase-1 proposal submission deadline	14 February 2022 – 12:00 (noon) CET
Phase-1 proposal assessment	February-April 2022
Phase-1 proposer notification	Mid-April 2022 (exact date TBD)
Workshops for Phase-2 proposers	End-April 2022 (exact date TBD)
Phase-2 proposal submission deadline	15 July 2022 – 12:00 (noon) CEST
Letters of Endorsement deadline	15 September 2022, 12:00 (noon) CEST
Proposal evaluation and scientific ranking	July – October 2022
Selection of missions for study	November 2022

Stella – summary & conclusions

- Stella is a possible European contribution to a NASA-led Interstellar Probe.
- Proposed to ESA as an M-class mission; cost cap 550 MEUR (cost to ESA)
- Two options proposed:
  - \- core: instruments & ISP communication system, incl. 5m HGA
  - \- full: Augmentation of ESA’s deep-space communication facility with 35m or 18m dishes & contribution to ISP operations
- Instrument contributions funded by member states. Proposed instrument placeholders!
- Strong role of ESA needed to ensure 50+ year flawless operation of instruments.
- Unique challenges also for science teams! Will require rethinking of how we handle successions...
- Programmatic difficulties remain, especially the critical gap between ESA & NASA schedules
- In the mean time: Stella at Cospar, IAC, AGU, etc.