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Measurement of the composition of the interstellar cloud

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A Pragmatic Interstellar Probe for Launch in the 2030's

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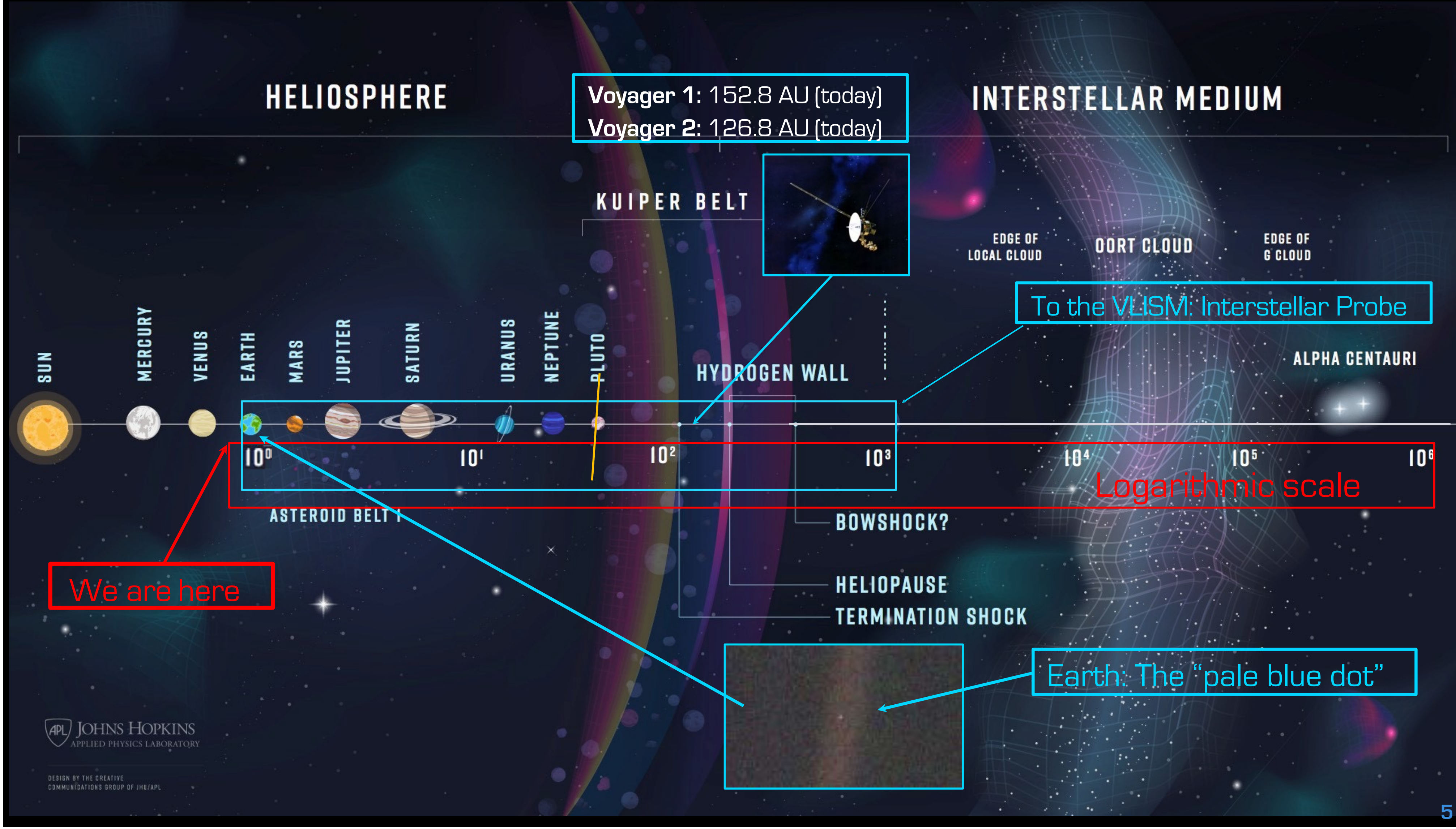

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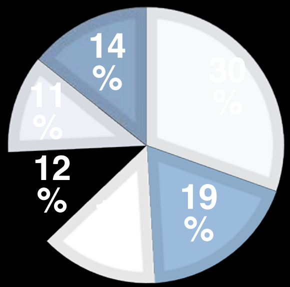
Example Model Payload for Interstellar Probe

Baseline

87.4 kg
86.7 W

- Charged Particles
- Fields and Waves
- ENA Imaging
- Dust
- Neutrals
- Ly-alpha



Instrument (Heritage)	Measurement Requirements		Mission Requirements	Science Driver
Magnetometer (MAG) (MMS/DFG)	0.01 - 100 nT; 0.01 nT (10^{-8} nT^2/Hz turb.)	≤60 s; (100 Hz)	Two FG, 10m boom	LISM (turbulence)
Plasma Waves (PWS) (Van Allen/EFW)	~1 Hz – 1 MHz; Δf/f≤4% ≤0.7 μV/m @ 3 kHz	≤60 s (≤ 4 s at TS)	4x50 m wire; spin plane	LISM n_e, T_e (QTN), turbulence
Plasma Subsystem (PLS) (PSP/SWEAP/SPAN-A)	~eV to 10's keV e, H+, He+, Li+, Be-B+, C+, N-O+	~4π; ≤60 s	Spinning	Flows, n_e, T_e, n_i, T_i Force balance
Pick-up Ions (PUI) (Ulysses/SWICS)	0.5-78 keV/q H, ^{3}He, ^{4}He, C, ^{14}N, ^{16}O, ^{20}Ne, ^{22}Ne, Mg, Si, Fe (charge states)	iFOV: 60°	Spinning	Interstellar, inner PUI Force balance
Energetic Particles (EPS) (PSP/EPI-Lo)	10's keV – 1's MeV H, ^{3}He, ^{4}He, C, O, Ne, Mg, Si, Fe	~4π; ≤60 s	Spinning	S/W, HS and ACRs Force balance
Cosmic Rays (CRS) (PSP/EPI-Hi, new development)	H to Sn; ≤1 GeV/nuc; Δm= 1 amu electrons; ≤10 MeV	≥2 directions; daily	Spinning	ACRs, GCRs LiBeB cosmic story
Interstellar Dust Analyzer (IDA) (IMAP/IDEX, new development)	1-500 amu; **m/Δm:** ≥ 200	iFOV: 90°	Ram direction Co-boresighted NMS	ISDs, galactic heavy ion composition
Neutral Mass Spectrometer (NMS) (LunaResurs/NGMS, JUICE/NMS)	H to Fe, m/Δm > 100 (1σ) 1 – 300 u/e	iFOV: 10°; weekly	Ram direction Co-boresighted IDA	LISM composition
ENA (ENA) (IMAP/Ultra, new development)	~1-100 keV; H (He, O goal)	iFOV: 170° x 90°	Spinning, 2 heads	Shape, force balance, ribbon/belt
Lyman-Alpha Spectrograph (LYA) (MAVEN/IUVS, new development)	120-130 nm; 0.004nm	iFOV: 5° 140° scan; monthly	Spinning	LISM and heliosheath H

NMS Science Questions

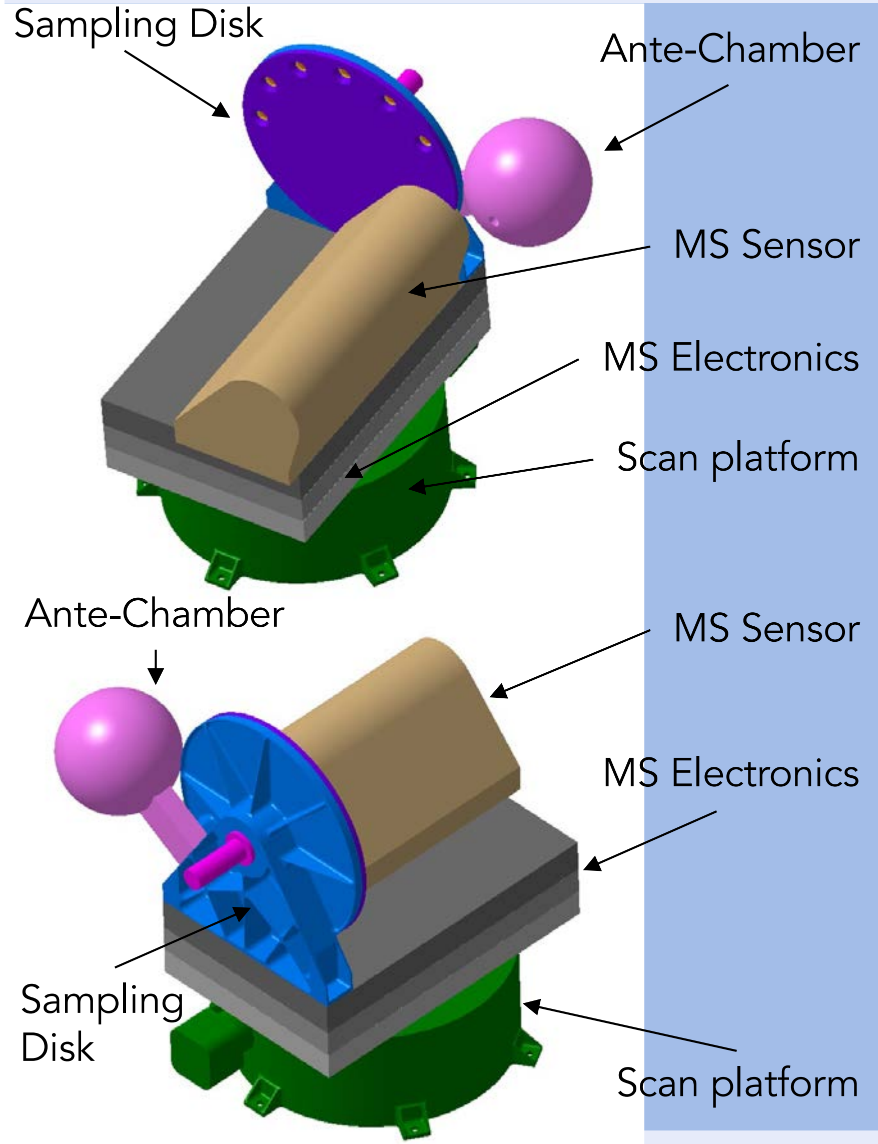
- Science Target
  - Local neutral interstellar gas (VLISM)
  - Possibly some flyby object (Quaoar, Ixion, Orcus, …)

- Science Questions
  - Chemical Composition of interstellar gas
  - Isotopic composition: D/H, $^{3}He/^{4}He$, $^{20}Ne/^{22}Ne$, $^{36}Ar/^{38}Ar$, and others
  - Density of interstellar neutral species
  - Filtration at termination shock

NMS Measurements and Instrument Concept

- Measurement approach
  - What is measured?
    - Neutral interstellar gas
  - How and where are measurements performed?
    - Mass spectrometric measurements are performed along the S/C trajectory at regular intervals
    - Direct measurements for a day every week
    - Measurements using the collection method every month
- Measurement requirements and Instrument concept
  - Mass spectrometry with specialised instrument
  - Mass range 1 – 150 u/e (regular), 1 – 300 u/e (high mass range)
  - Sensitivity better than 10^{-3} #/cm^{-3} for daily measurement
  - Sensitivity better than 10^{-6} #/cm^{-3} using the collection method
- Mission requirements for measurements
  - Trajectory in upwind direction (within 10°)
  - Pointing of instrument in ram direction (within 2° TBC)
- Data products
  - Mass spectra, density of species, isotope ratios

NMS Basic Instrument Parameters



Parameter	Current Best Estimate/Comments
Mass (kg)	10 kg, with scan platform 15 kg (if needed)
Volume (cm)	L x W x H = 30 cm x 45 cm x 45 cm
Power (W)	11 W (weekly measurement) 19 W (twice a year measurement)
Thermal Requirements	–40°C to + 60°C (Non-OP); –20°C to + 40°C (OP)
Data Volume	10 Mbyte per measurement
Current TRL	5, some sub-units 7
Duration of Experiment	Entire mission
Other	

Neutral Gas Mass Spectrometer (NGMS) for Luna-Resurs / Roskosmos

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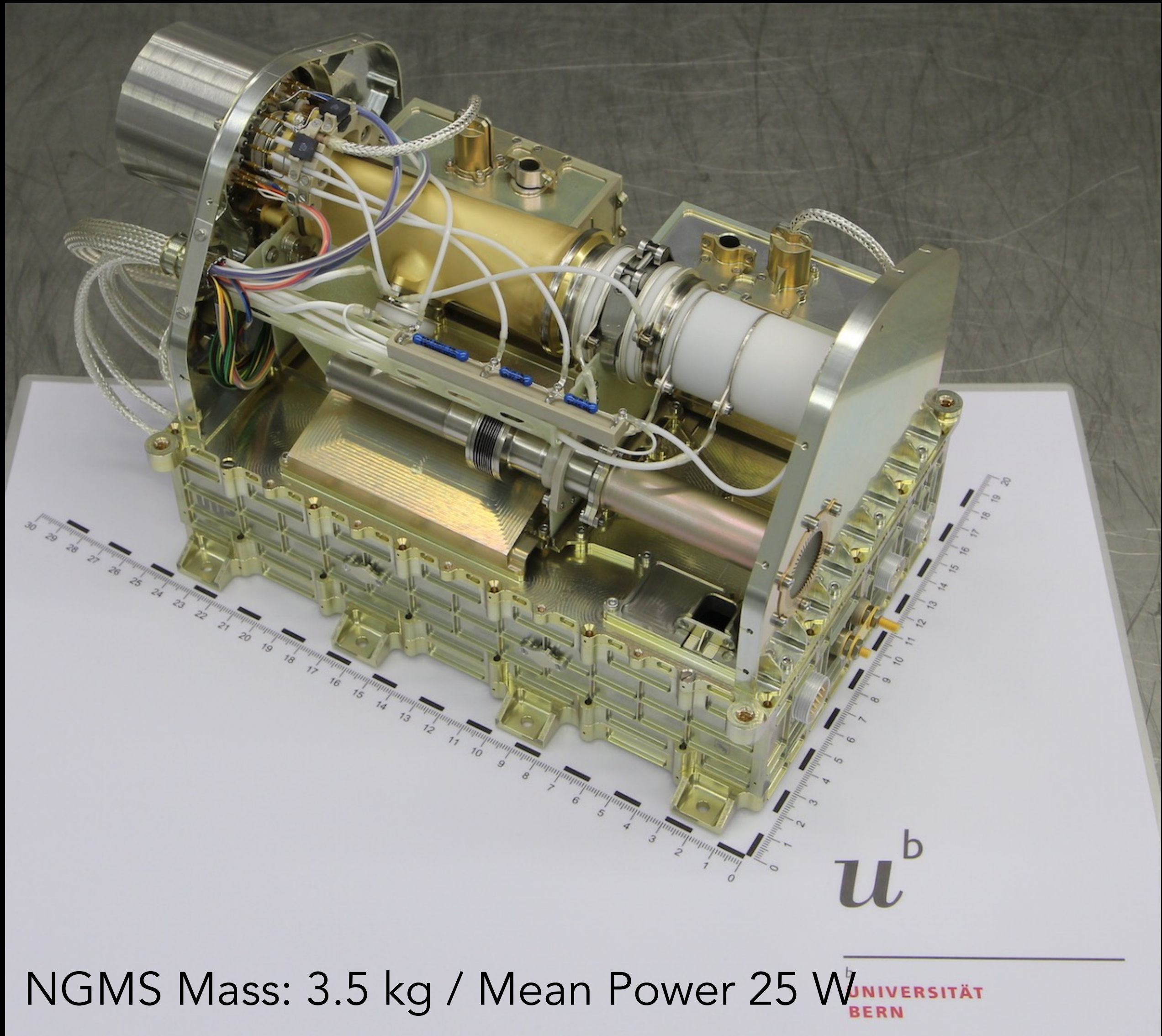
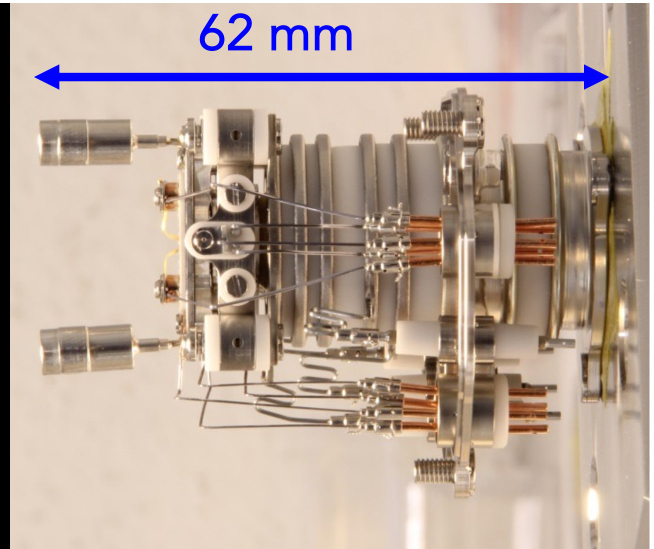
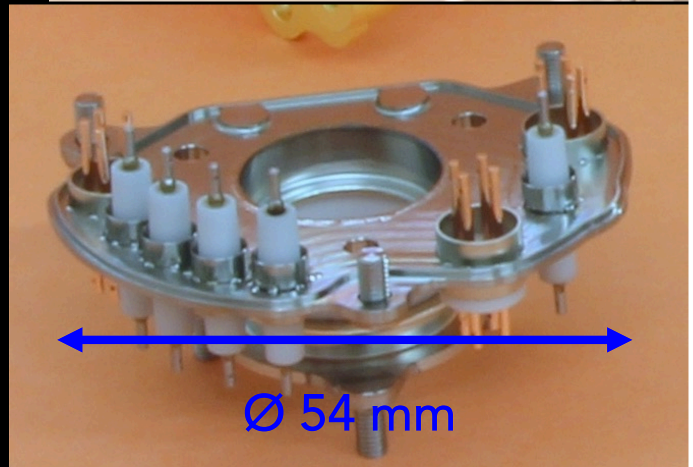
L. Hofer et al., Planet. Sp. Sci., 111 (2015) 126–133.
P. Wurz et al., Planet. Sp. Science 74 (2012) 264–269.

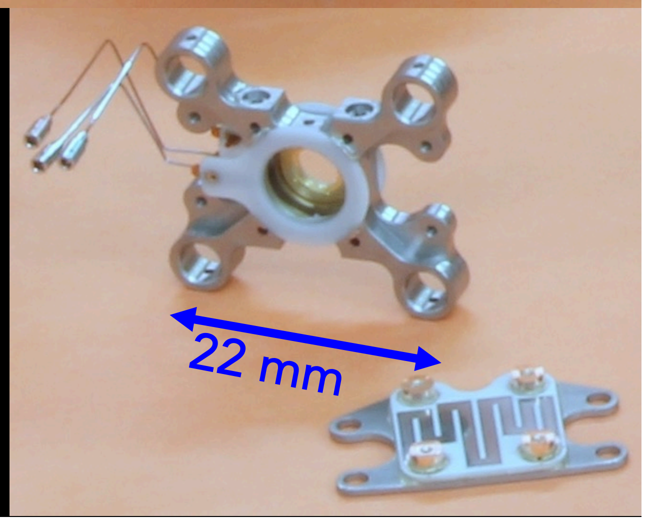
Neutral Gas Mass Spectrometer (NGMS) for the Luna-Resurs



NGMS Mass: 3.5 kg / Mean Power 25 W







L. Hofer et al., Planet. Sp. Sci., 111 (2015) 126–133.

P. Wurz et al., Planet. Sp. Science 74 (2012) 264–269.

Neutral and Ion Mass Spectrometer (NIM) of the PEP Experiment on JUICE /ESA

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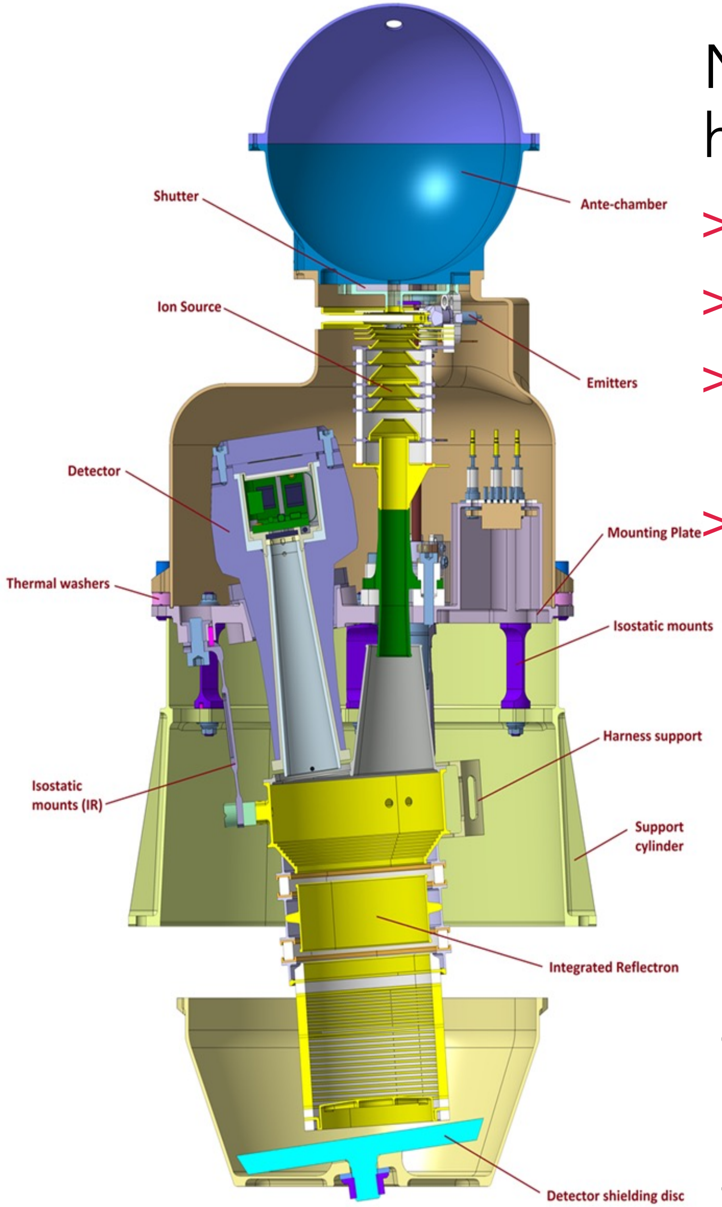
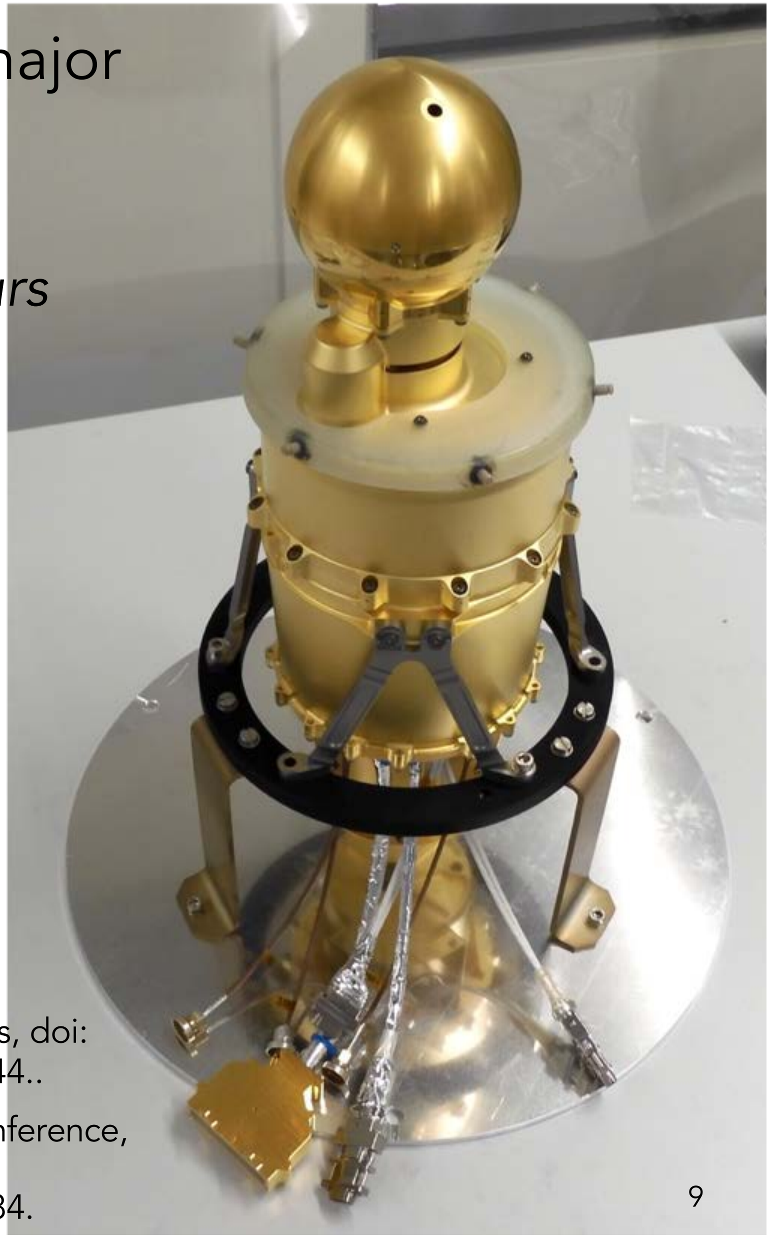


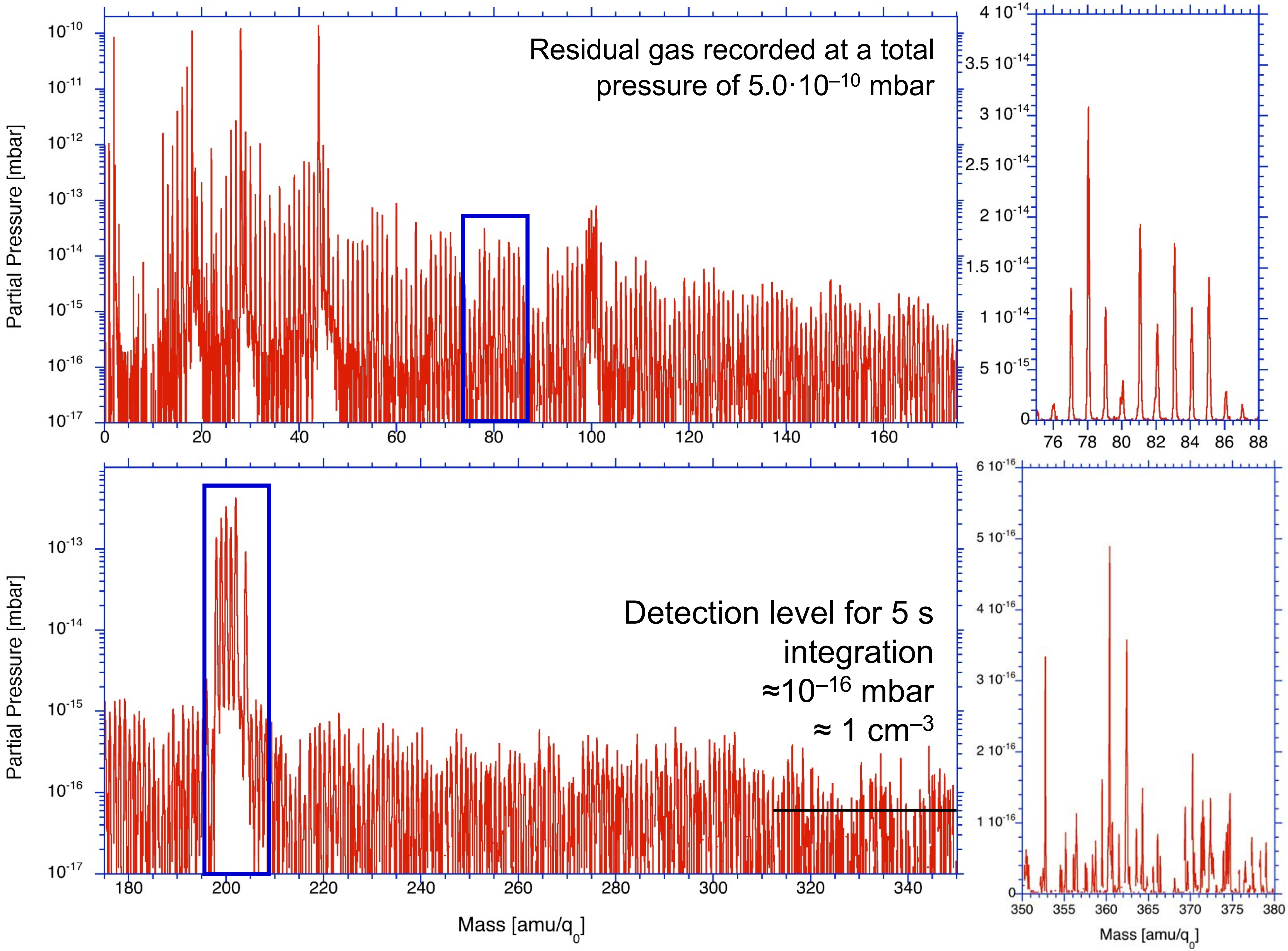
NMS builds upon major heritage from

> P-BACE/*MEAP*
> NGMS/*Luna-Resurs*
> RTOF/ROSINA/*Rosetta*
> NIM/PEP/*JUICE*



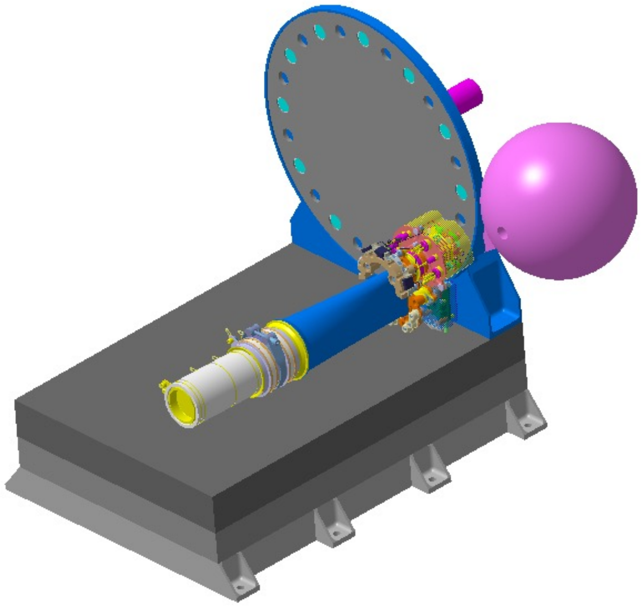
M. Föhn, et al., IEEE Aerospace Conference, 2021 50100, 14 pages, doi: 10.1109/AERO50100.2021.9438344..

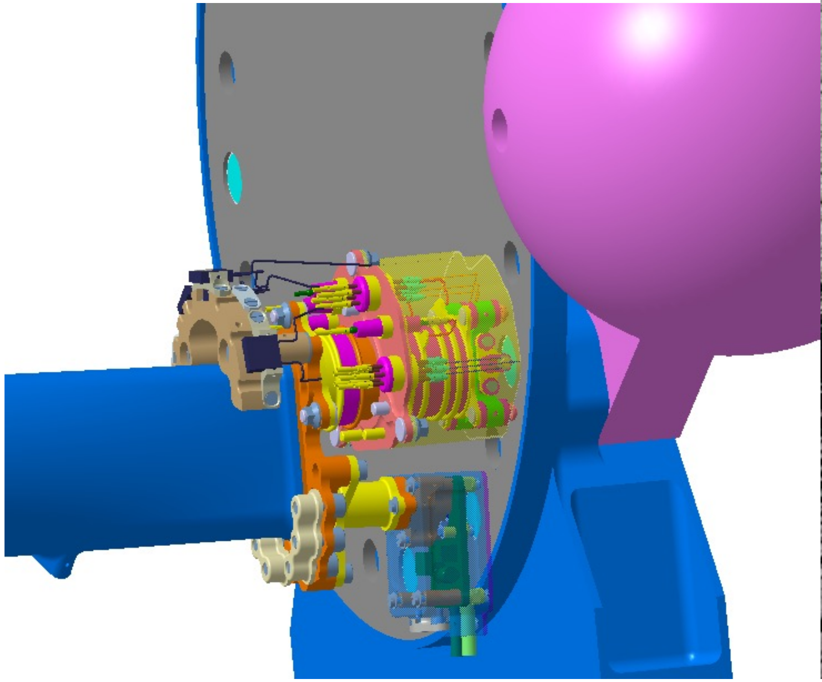
D. Lasi, et al., IEEE Aerospace Conference, 2020, 20 pages, doi: 10.1109/AERO47225.2020.9172784.

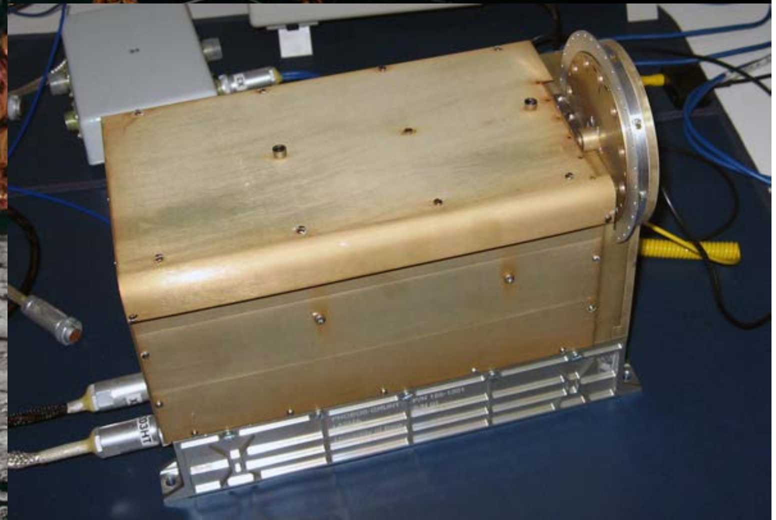


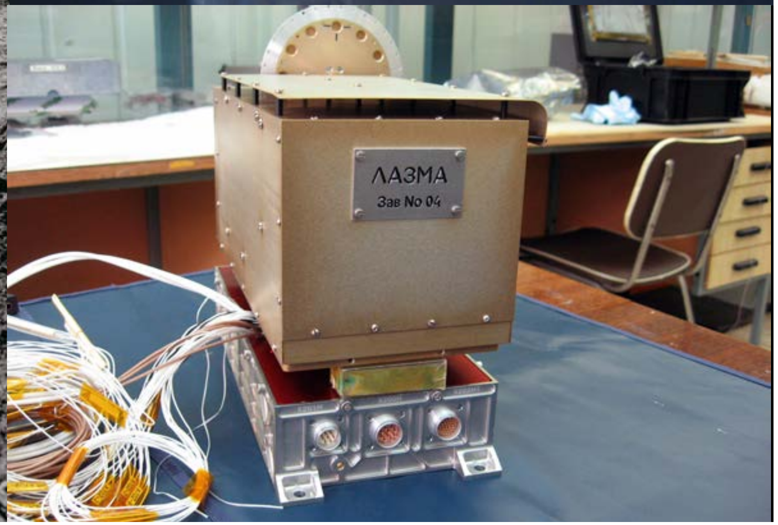
Residual gas recorded at a total pressure of 5.0·10–10 mbar
Detection level for 5 s integration
≈10–16 mbar
≈ 1 cm–3
Partial Pressure [mbar]
Mass [amu/q0]

NMS LISM Gas Sample Collection









A&A 491, 53–68 (2008)
DOI: 10.1051/0004-6361:20078101

Astronomy & Astrophysics
Special feature

The boundary conditions of the heliosphere: photoionization models constrained by interstellar and in situ data

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ABSTRACT

Context. The boundary conditions of the heliosphere are set by the ionization, de
matter.
Aims. Our aim is to constrain the properties of the Local Interstellar Cloud (LIC) at t
ionization models.
Methods. We modeled the background interstellar radiation field using observed ste
X-ray background. We also modeled the emission from the boundary between the I
that the cloud is evaporating because of thermal conduction. We created a grid of
Local Bubble properties, and used the modeled radiation field as input to radiative
the Cloudy code. Data from in situ observations of He^0, pickup ions and anomalous
absorption line measurements towards ϵ CMa were used to constrain the input paran
Results. A restricted range of assumed LIC H I column densities and Local Bubble p
all the observational constraints. The relative weakness of the constraints on N(H I) an
the H^0 and electron density in the LIC at the Sun, $n(H^0) = 0.19$–0.20 cm^{-3}and $n_e = 0$
typical of low-density gas, with sub-solar Mg, Si, and Fe, possibly subsolar O and N
Conclusions. The interstellar gas at the Sun is warm, low-density, and partially ioni
$X(H^+) \sim 0.2$, and $X(He^+) \sim 0.4$. These results appear to be robust since acceptable r
radiation fields. Our results favor low values for the reference solar abundances for tl

Table 6. Model 26 results for ionization fractions[a].

Element	PPM	I	II	III	IV
H	10^6	0.776	0.224	–	–
He	10^5	0.611	0.385	4.36(–3)	–
C	661	2.68(–4)	0.975	0.0244	0.000
N	46.8	0.720	0.280	8.52(–5)	0.000
O	331	0.814	0.186	4.71(–5)	0.000
Ne	123	0.196	0.652	0.152	2.79(–6)
Na	2.04	1.47(–3)	0.843	0.155	6.34(–6)
Mg	6.61	1.98(–3)	0.850	0.148	0.000
Al	0.0794	5.37(–5)	0.976	0.0118	0.0123
Si	8.13	4.21(–5)	0.999	8.02(–4)	3.10(–5)
P	0.219	1.35(–4)	0.977	0.0232	9.29(–5)
S	15.8	6.47(–5)	0.971	0.0288	1.95(–6)
Ar	2.82	0.263	0.500	0.238	2.83(–6)
Ca	4.07(–4)	9.21(–6)	0.0155	0.984	1.87(–4)
Fe	2.51	7.01(–5)	0.975	0.0245	5.75(–6)

[a] Numbers less than 10^{-3} are written as $x(y)$ where y is the exponent and x is the mantissa (or significand).

Signal Estimate

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	H	He	C	N	O	Ne	Na	Mg	Al	Si	P	S	Ar	Ca	Fe
n_X / n_H [*1e6]	1	0.1	661	46.8	331	123	2.04	6.61	0.0794	8.13	0.219	15.8	2.82	4.07E-04	2.51
n [cm^-3]	2.50E-01	2.50E-02	1.65E-04	1.17E-05	8.28E-05	3.08E-05	5.10E-07	1.65E-06	1.99E-08	2.03E-06	5.48E-08	3.95E-06	7.05E-07	1.02E-10	6.28E-07
n [m^-3]	250000	25000	165.25	11.7	82.75	30.75	0.51	1.6525	0.01985	2.0325	0.05475	3.95	0.705	1.02E-04	0.6275
flux [cm^-2 s]	1.28E+06	1.28E+05	842.78	59.67	422.03	156.83	2.60	8.43	0.10	10.37	0.28	20.15	3.60	0.00	3.20
Direct Entrance															
Counts [10 s-1]	12.75	1.28	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Counts [h-1]	4590.00	459.00	3.03	0.21	1.52	0.56	0.01	0.03	0.00	0.04	0.00	0.07	0.01	0.00	0.01
Ante Chamber															
Counts [10 s-1]	1.28E+04	1.28E+03	8.43	0.60	4.22	1.57	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
Counts [h-1]	4.59E+06	4.59E+05	3033.99	214.81	1519.29	564.57	0.09	0.30	0.00	0.37	0.01	0.73	12.94	0.00	0.12
Foil collection															
Counts [wk-1]	7.71E+05	7.71E+04	509.71	36.09	255.24	94.85	1.57	5.10	0.06	6.27	0.17	12.18	2.17	0.00	1.94
Counts [mo-1]	3.30E+06	3.30E+05	2.18E+03	1.55E+02	1.09E+03	4.06E+02	6.74	21.84	0.26	26.87	0.72	52.22	9.32	0.00	8.30

NMS Summary

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- Science Target
  - Local neutral interstellar gas (VLISM)
  - Possibly some flyby object (Quaoar, Ixion, Orcus, …)

- Science Questions
  - Chemical Composition of neutral interstellar gas
    - H, He, C, N, O, Ne, Na, Mg, Al, P, S, Ar, ….
  - Isotopic composition:
    - D/H, $^{3}He/^{4}He$, $^{20}Ne/^{22}Ne$, $^{36}Ar/^{38}Ar$
    - perhaps $^{13}C/^{12}C$, $^{15}N/^{14}N$,
  - Density of interstellar neutral species
  - Filtration at termination shock