800 ANNI 1222 · 2022

UNIVERSITÀ DEGLI STUDI DI PADOVA

Optical and mechanical analysis and calibration of the EnVisS camera for the Comet Interceptor mission

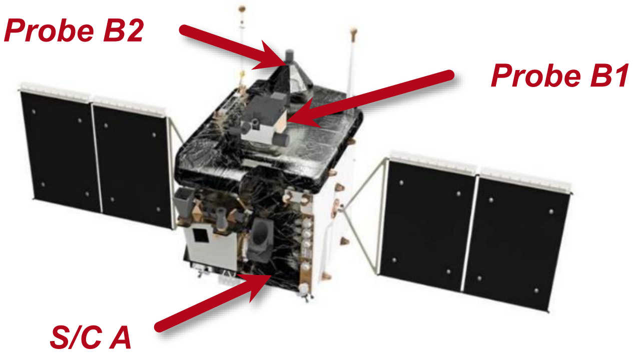
Carmen Naletto - 39th Cycle

Supervisor: Dr. Vania Da Deppo
Co-supervisor: Prof. Mirco Zaccariotto
Dr. Paola Zuppella

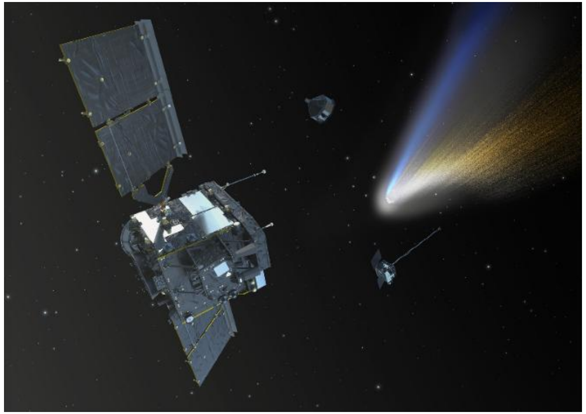
Admission to the third year - 10/09/2025

Comet Interceptor

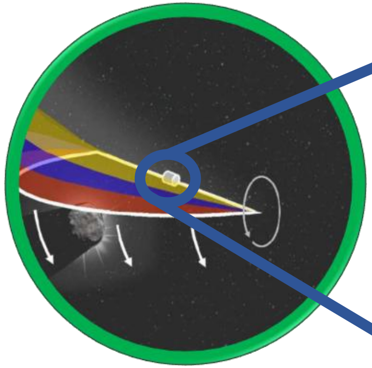
- Comet Interceptor is the first Fast mission designed by ESA, launch planned for 2029
- **Scientific task:** interception and exploration of a Dynamically New Comet to gain information about the target's morphology, composition and plasma environment.



Comet Interceptor design concept (credit ESA)

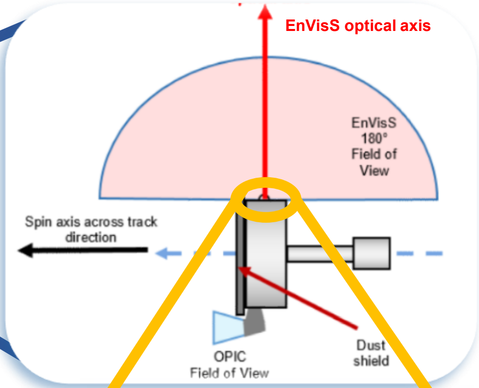


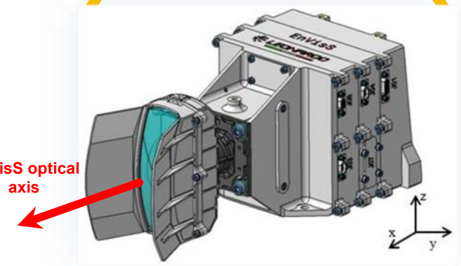
The EnVisS camera



EnVisS dynamic FoV and B2 spinning motion

EnVisS placement on B2 and its static FoV

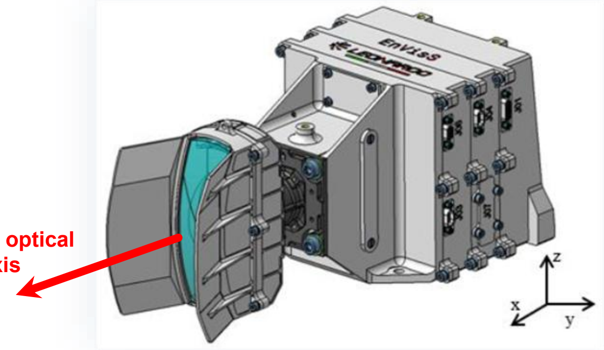




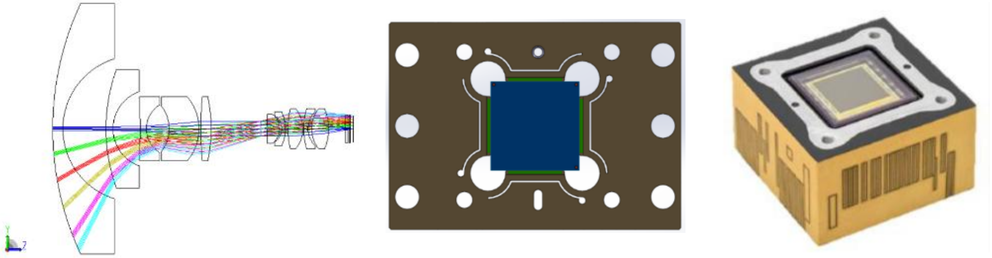
EnVisS 3D CAD model (credit LDO)

- EnVisS (**En**tire **Vis**ible **S**ky) camera mounted on Probe B2
- Remote sensing imaging
- Static FoV: **180° × 45°**
- Dynamic FoV: **180° × 360°**
- **Goal:** study the comet dust properties and distribution in the visible range (550-800 nm)

The EnVisS camera



EnVisS optical axis



EnVisS main components

- EnVisS (**En**tire **Vis**ible **S**ky) camera mounted on Probe B2
- Remote sensing imaging
- Static FoV: **180° × 45°**
- Dynamic FoV: **180° × 360°**
- **Goal:** study the comet dust properties and distribution in the visible range (550-800 nm)
- Uses push-frame technique
- Main components: optical head (OH, 10 lenses), Filter Strip Assembly (FSA), CMOS detector

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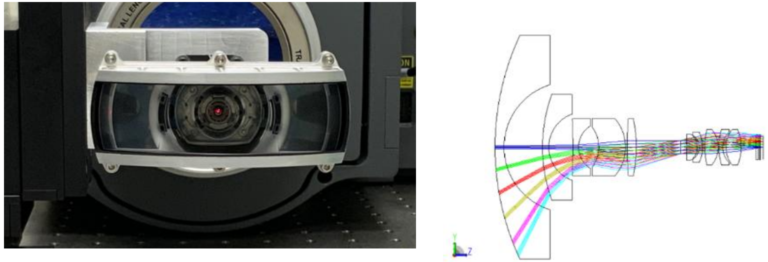
Research project - overview

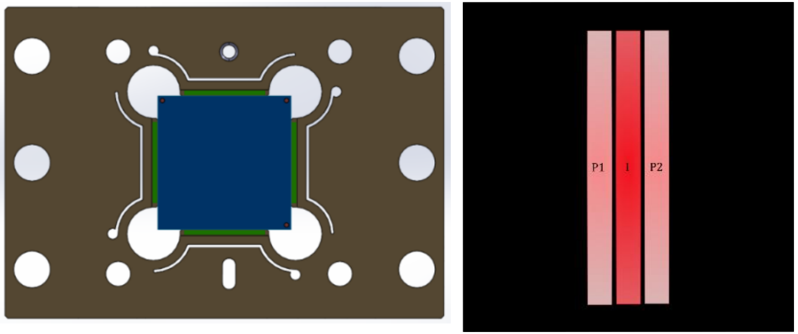
- Opto-mechanical characterization of the BreadBoard (BB) components of the EnVisS camera (collaboration with CNR-IFN)
  → Optical Head (OH)
  → Filter Strip Assembly (FSA)

- Realization of a detailed radiometric model for the EnVisS camera
  → Estimation of the Signal to Noise Ratio (SNR), collaboration with the Instituto de Astrofisica de Andalucia

- Tests and analysis on EnVisS Proto-Flight Model in collaboration with the Leonardo SpA team



Picture of the EnVisS BB OH and ray-tracing along the optical head to the sensor (credit LDO)



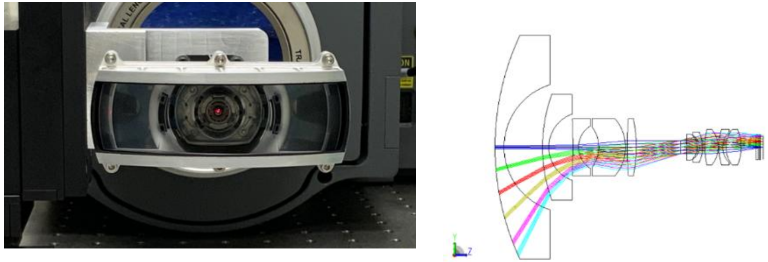
Schematic configuration of the FSA

Second year activities

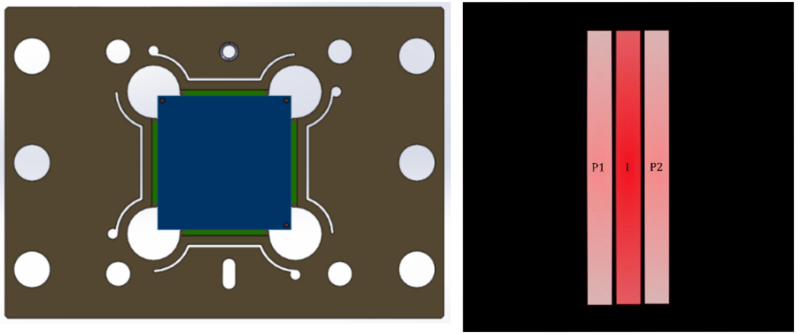
- Opto-mechanical characterization of the BreadBoard (BB) components of the EnVisS camera (collaboration with CNR-IFN)
  → Optical Head (OH)
  → Filter Strip Assembly (FSA)

- Realization of a detailed radiometric model for the EnVisS camera
  → Estimation of the Signal to Noise Ratio (SNR), collaboration with the Instituto de Astrofisica de Andalucia

- Tests and analysis on EnVisS Proto-Flight Model in collaboration with the Leonardo SpA team



Picture of the EnVisS BB OH and ray-tracing along the optical head to the sensor (credit LDO)



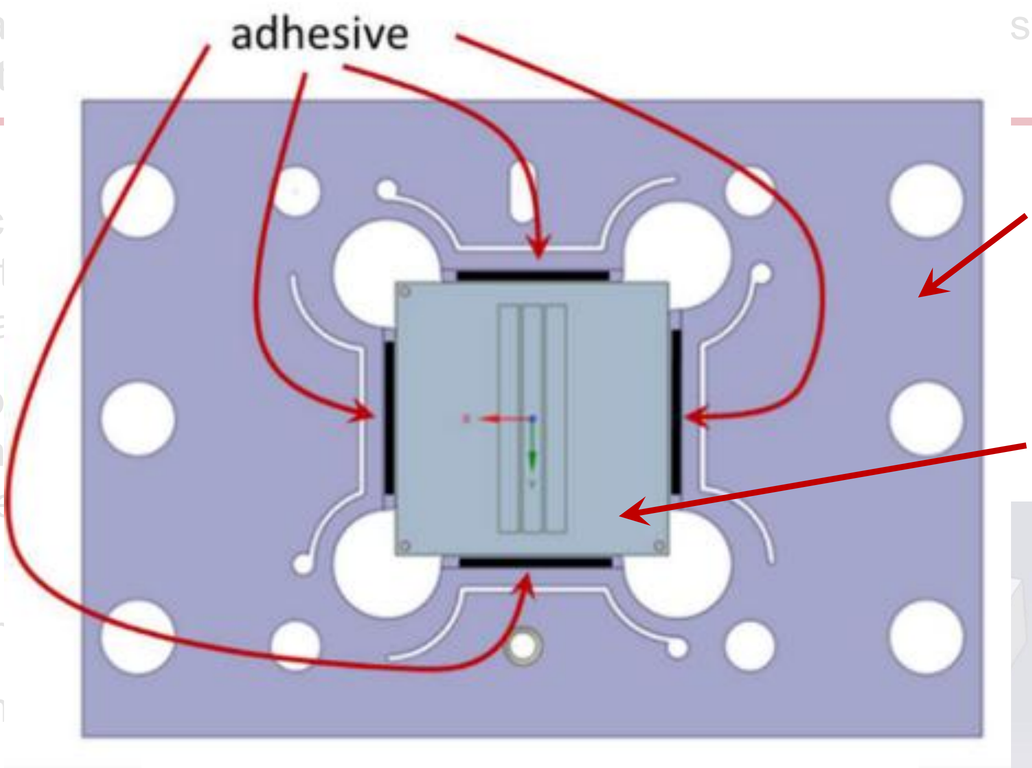
Schematic configuration of the FSA

Qualification test on the adhesive joints of the Filter Strip Assembly

Filter Strip Assembly

Goal: ensure tha ... structure withstands the loads generat

- A fused silic ... the support ... adhesive ma
- Each samp ... dedicated m ... load has bee
- When the ... displacemer
- Test perform



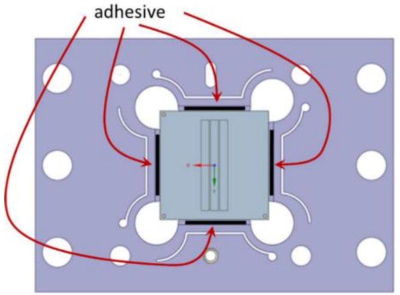
Schematic configuration of the FSA (credit LDO)

Shear test schematic configuration (credit LDO)

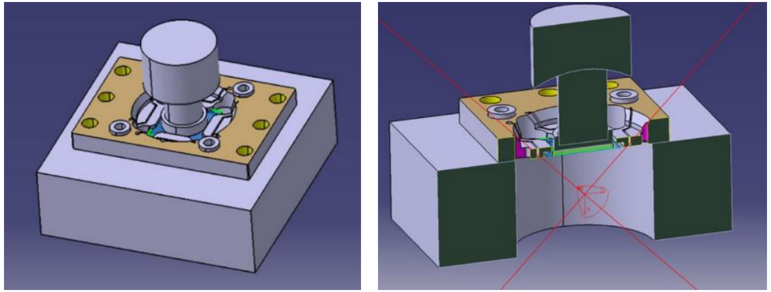
Qualification test – experimental

Goal: ensure that the adhesive between the FSA and the supporting structure withstands the loads generated during the launch

- A fused silica filter block has been glued to the supporting structure with Ec9323-2 adhesive material
- Each sample has been inserted into a dedicated mechanical holder where a shear load has been applied
- When the sample breaks, load and displacement are registered
- Test performed on 20 samples



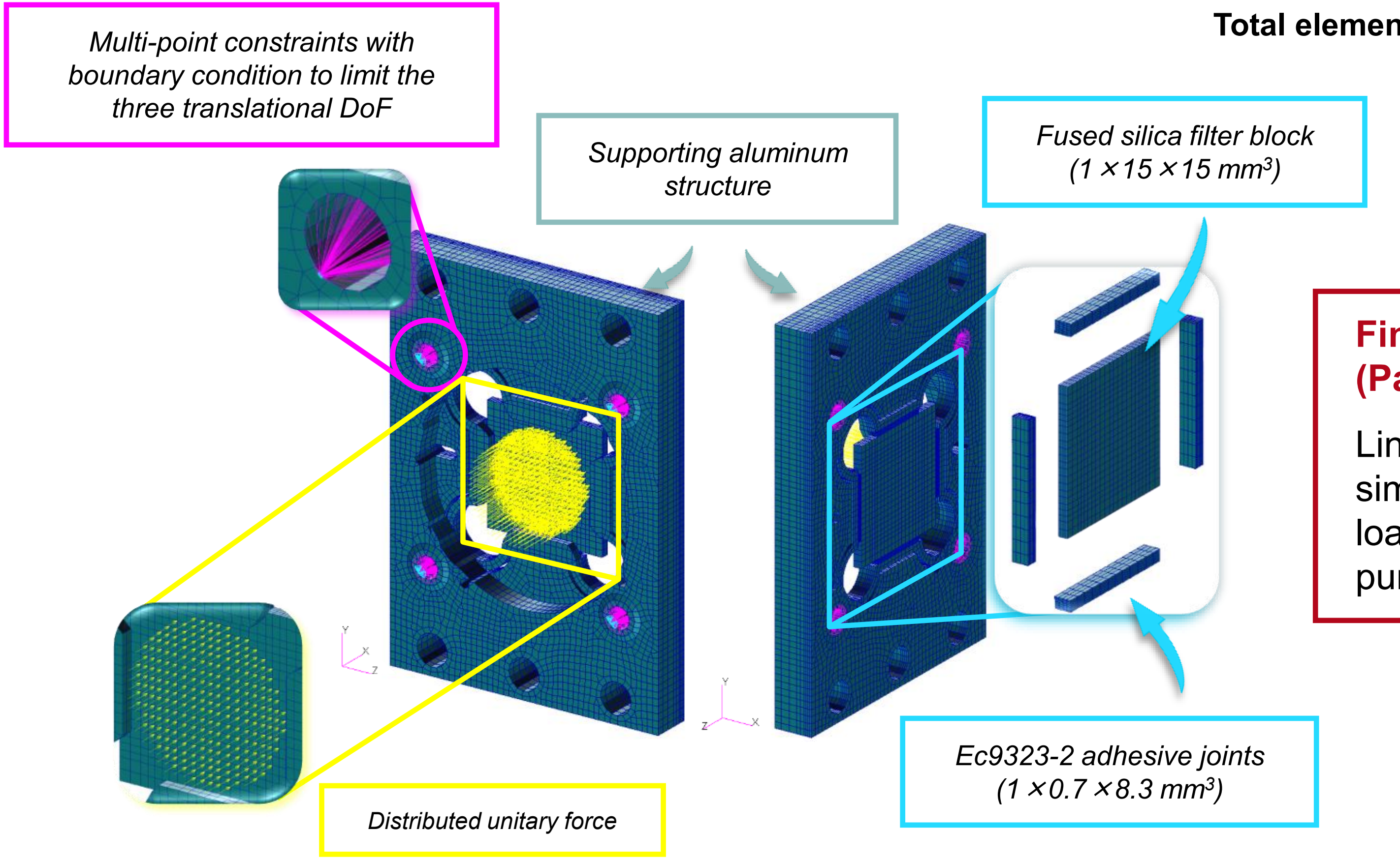
Schematic configuration of the FSA (credit LDO)



Shear test schematic configuration (credit LDO)

Qualification test – simulation

Total elements: 26337 (Penta and Hexa)
Total nodes: 32035



Finite Element Analysis (Patran-Nastran)

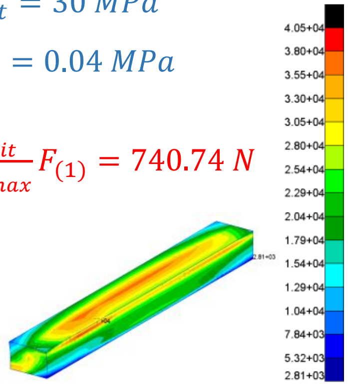
Linear static analysis to simulate the effect of the load induced by the punch on the system

Qualification test – main results

Adhesive Ec9323-2 B/A → $\tau_{limit} = 30\ MPa$

Under a $F_{(1)} = 1\ N$ → $\tau_{XY\_max} = 0.04\ MPa$

Linear Model → $F_{max} = \frac{\tau_{limit}}{\tau_{YX\_max}} F_{(1)} = 740.74\ N$

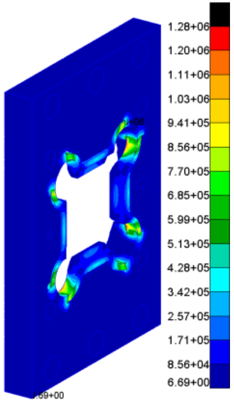


XY component of the stress tensor acting on one of the adhesive layers

Aluminum 6082 T6 → $\sigma_{yield\_limit} = 290\ MPa$

Under a $F_{(1)} = 1\ N$ → $\sigma_{VM\_max} = 1.28\ MPa$

Linear Model → $F_{max} = \frac{\sigma_{yield\_limit}}{\sigma_{VM\_max}} F_{(1)} = 226.56\ N$

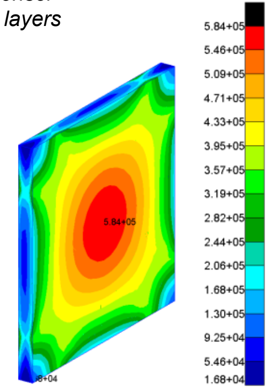


Von Mises stress distribution on the analyzed system

Fused Silica → $\sigma_{bending\_limit} = 52.4\ MPa$

Under a $F_{(1)} = 1\ N$ → $\sigma_{Z\_max} = 0.584\ MPa$

Linear Model → $F_{max} = \frac{\sigma_{bending\_limit}}{\sigma_{Z\_max}} F_{(1)} = 89.73\ N$



Normal stress in the Z direction acting on the filters

First component to **fail** is the **fused silica block** → the **system fails before the bonding zone is damaged**

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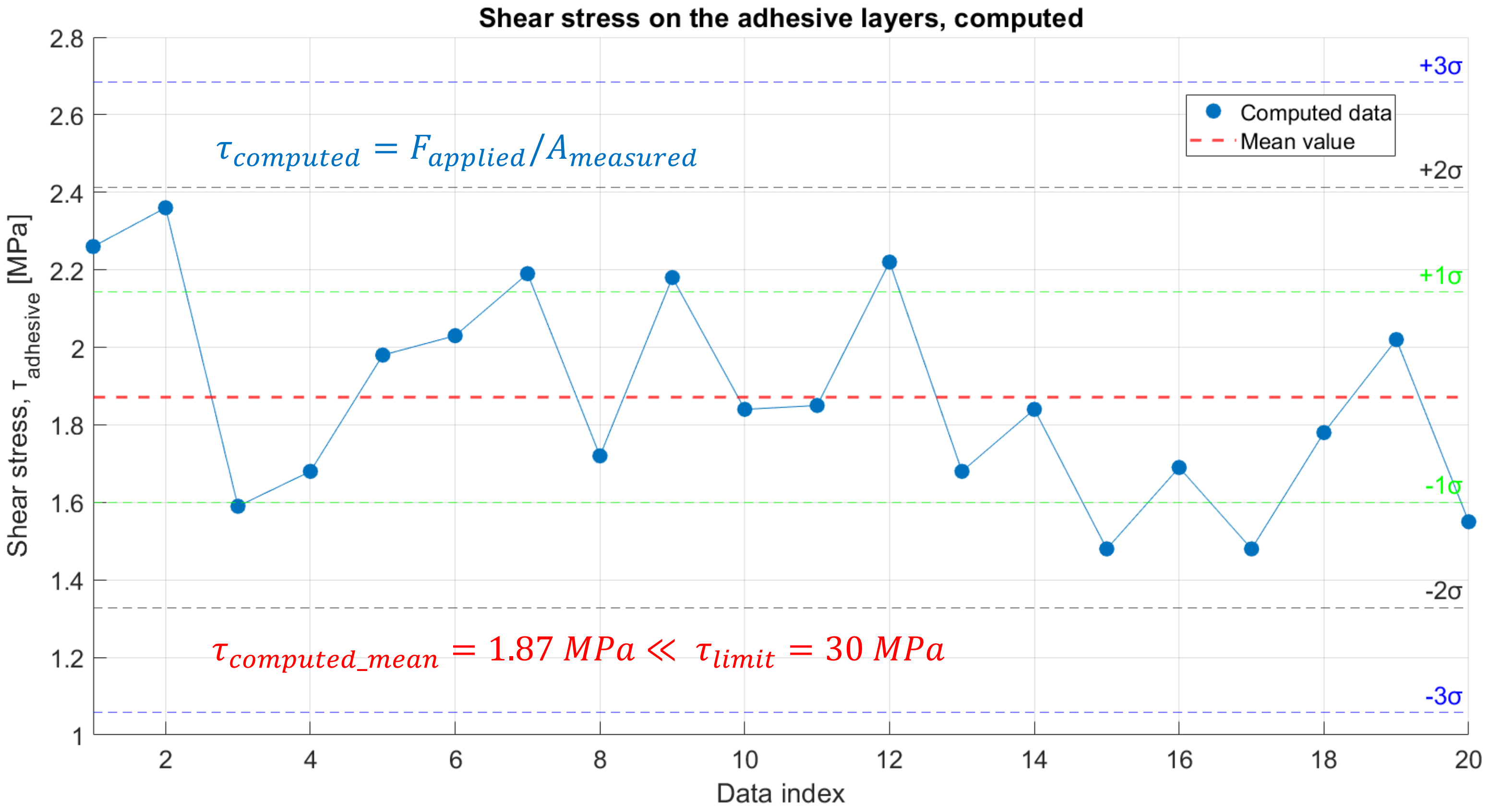
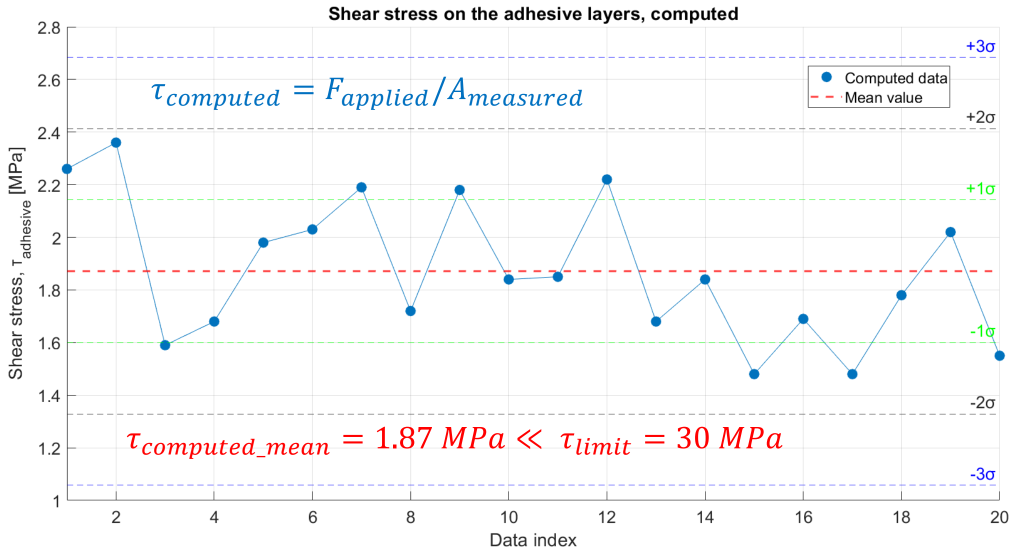
Qualification test – main results



Qualification test – main results



- The adhesive joints will be subjected to a very low shear stress with respect to the shear strength of the material → the bonding component will not fail

- All samples break because of the **fracture of the fused silica filter**

The qualification test can be considered successful!

Estimation of the Signal to Noise Ratio (SNR)

SNR Estimation

- EnVisS **best performance** is achieved when the images show the **highest usable Signal to Noise Ratio** (SNR).
- Define the most suitable **observational strategy** in terms of the **detector binning** and **exposure time** while getting closer to the target, to have the highest SNR.

Python code

→ Simulation of a comet and its coma (assumptions have been made)

→ Study of the impact of the slope of the dust size distribution, a, and the total dust production rate, Q_d, of the comet coma, for different binnings and exposure times.

→ Definition of the best observational strategy

Simulator – building blocks

INPUT PARAMETERS

- Fisheye camera
- Transmission optics/filters, q_{eff}, PSF, bits, gain
    - + distortion

- Spice kernels
    - Perturbations

- Moment (from CA), exposure time, binning, framelet, event (fps)

- COMA
    - Analytical: power law size distribution
    - Numerical density distribution.

- SCATTERING MODEL (λ_{eff})
    - Cross section
    - Mie
    - Input model

OPERATIONS

CAM MODULE

GEOM MODULE

OBS MODULE

PHASE AND SCATTERING PLANE ANGLES

REND MODULE

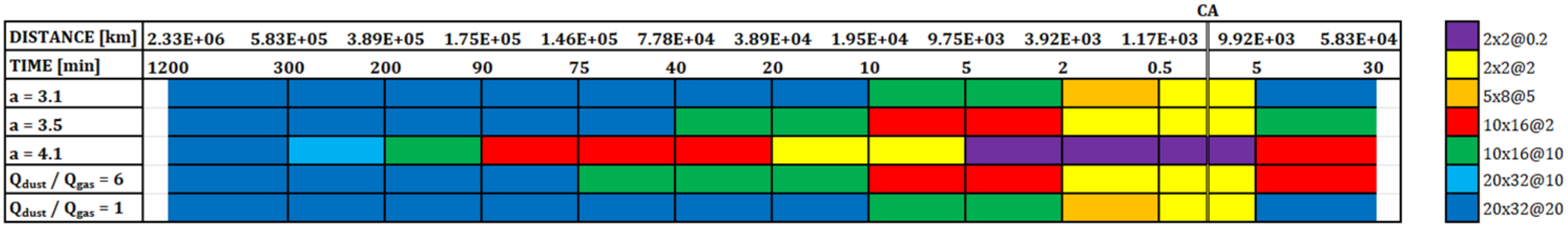
- LoS INTEGRATION

OUTPUT

SIMULATED OBSERVATION (SNR)

Best observational strategies

- The analysis has revealed that to have the maximum SNR, a combination of different binning and exposure times is necessary during the whole flyby period.
- A combination of two different images taken with different binnings or same binning but different exposure times might be a possible solution to achieve the maximum SNR possible and recreate almost the entire sky.



Summary of the binning and exposure time to obtain the best coverage of the phase function as a function of the time to close approach (or distance) for the nominal model considering the uncertainty in the slope of the dust size distribution.

Future activities

- Opto-mechanical tests of the EnVisS BreadBoard (BB) optical head and FSA in the CNR-IFN facilities and simulations with Zemax Optics Studio and COMSOL Multiphysics
- Tests and analysis on the PFM, and Alignment Integration Test and Verification (AIT/AIV) of the same (collaboration with LDO)
- Continue working on the radiometric model and implementation on the SNR simulator of the polarization component (collaboration with IAA)
- Thesis writing

CNR IFN Istituto di Fotonica e Nanotecnologie

LEONARDO

IAA INSTITUTO DE ASTROFÍSICA DE ANDALUCÍA

Publication List

- Carmen Naletto, Mirco Zaccariotto, Paola Zuppella, Vincenzo Della Corte, Lorenzo Guido Fiocco, Giuseppe Impicciché, Antonio Padelli, Miriam Zazza, Chiara Grappasonni, Giuseppe Sindoni and Vania Da Deppo; "The EnVisS camera Filter Strip Assembly Qualification test, a Finite Element Analysis"; abstract and oral presentation for the Workshop on Innovative Technologies for Space Optics (WITSO) | 13-17 October 2025 | ESA-ESTEC | The Netherlands.
- Carmen Naletto, Pedro J. Gutierrez, Luisa M. Lara, Lama Moualla, Paola Zuppella, Vincenzo Della Corte, and Vania Da Deppo; "EnVisS Signal to Noise Ratio estimates"; abstract and oral presentation for the EPSC-DPS Joint Meeting 2025, Helsinki, Finland, 7–12 Sep 2025. https://doi.org/10.5194/epsc-dps2025-1015
- Carmen Naletto, Mirco Zaccariotto, Paolo Chioetto, Paola Zuppella, Vincenzo Della Corte, Lorenzo Guido Fiocco, Giuseppe Impicciché, Antonio Padelli, Miriam Zazza, Chiara Grappasonni, Giuseppe Sindoni, and Vania Da Deppo; "Finite Element Analysis of the Filter Strip Assembly Qualification test for the EnVisS camera", Optics + Photonics, 2025 (3-7 August | San Diego, California, US), 15 pages + poster.
- Carmen Naletto, Paola Zuppella, Lara Senter, Simone Nordera, Mirco Zaccariotto, Beatrice Tofani, Riccardo Gabrieli, Lorenzo Guido Fiocco, Vincenzo Della Corte, Vania Da Deppo; "Characterization measurements for the realization of the filter strip assembly of the enviss camera"; oral presentation and paper for the ICSO 2024 (21 - 25 October | Antibes Juan-les-Pins, France) conference. https://doi.org/10.1117/12.3075213
- Carmen Naletto, Paolo Chioetto, Simone Nordera, Mirco Zaccariotto, Paola Zuppella and Vania Da Deppo; "Characterization of the polarizing filters for the EnVisS camera", Space Telescopes and Instrumentation 2024: Optical, Infrared, and Millimeter Wave, Volume 13092, 12 pages + poster, Event: SPIE Astronomical Telescopes + Instrumentation, 2024, Yokohama, Japan. https://doi.org/10.1117/12.3021121
- Da Deppo, V., Della Corte, V., Zuppella, P., Lara, L. M., Castro, J. M., and Gutierrez, P. J. and the EnVisS Team; "The Entire Visible Sky (EnVisS) camera for the ESA Comet Interceptor mission"; abstract and poster for the EPSC-DPS Joint Meeting 2025, Helsinki, Finland, 7–12 Sep 2025. https://doi.org/10.5194/epsc-dps2025-1989
- Vania Da Deppo, Lara Senter, Vincenzo Della Corte, Paola Zuppella, Luisa M. Lara, José M. Castro, Pedro J. Gutierrez, Lorenzo G. Fiocco, Alessandro Alimenti, Beatrice Tofani, Riccardo Gabrieli, Giuseppe Impicciché, Michele Dami, Leonardo Tommasi, Fulvia Verzegnassi, Ignacio Martinez-Navajas, Carmen Naletto, Paolo Chioetto, Lorenzo Cocola, Fabio Frassetto, Jaime Jimenez, Alvaro Mazuecos, Ivano Bertini, Marco Fulle, Cecilia Tubiana, Alessandra Rotundi, Juan-Carlos Gomez, Daniel Guirado, Fernando Moreno, Olga Muñoz, Stefano Bagnulo, Geraint Jones, and Jaan Praks; "THE ENVISS FISH-EYE CAMERA FOR THE COMET INTERCEPTOR ESA MISSION: DESIGN AND PERFORMANCE", submitted abstract for the ICSO 2024 (21 - 25 October | Antibes Juan-les-Pins, France) conference. https://doi.org/10.1117/12.3071592
- Vania Da Deppo, Paola Zuppella, Vincenzo Della Corte, Enrico Friso, Simone Nordera, Fabio Frassetto, Lorenzo Cocola, Paolo Chioetto, Carmen Naletto, Claudio Pernechele; "Setting up a laboratory test bench for optical verification and testing of the EnVisS camera prototype", Space Telescopes and Instrumentation 2024: Optical, Infrared, and Millimeter Wave, Volume 13092, 8 pages + poster, Event: SPIE Astronomical Telescopes + Instrumentation, 2024, Yokohama, Japan. https://doi.org/10.1117/12.3021226

Work organization

FIRST YEAR												SECOND YEAR												THIRD YEAR											
T1			T2			T3			T4			T1			T2			T3			T4			T1			T2			T3			T4		
O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S

WBS NUMBER	TASK TITLE	% OF TASK COMPLETE
1	Bibliographic research	
1.1	Study of the Comet Interceptor mission background	100%
1.1.1	Mission objectives and Instruments	100%
1.2	Study of the EnVisS camera	100%
1.2.1	Fish-eye cameras	100%
1.2.2	Optical design and performance	100%
1.3	Pristine comets' composition	100%
2	Opto-mechanical simulations	
2.1	Finite Element Analysis simulations	80%
2.2	Radiometric model	80%
2.2.1	Signal to Noise Ratio simulation	70%
2.3	Optical simulation	0%
2.3.1	Filter Strip Assembly transmissivity and reflectivity	0%
2.3.2	Wavefront distorsion	0%
2.3.3	Ghost analysis	0%
3	Optical characterization	
3.1	BreadBoard (BB)	0%
3.1.1	Optical characterization of the Filter Strip Assembly and/or representative samples	0%
3.1.2	Interferometric tests of the BB optical head	0%
3.2	Proto-Flight Model	0%
3.2.1	Alignment, Integration, Test and Verification (AIT/AIV)	0%
3.2.2	Calibration	0%
4	Data Analysis and report	
4.1	Simulations	70%
4.2	Optical characterization	0%
4.3	Pre-flight calibration data	0%
5	Educational activities	
5.1	Reports/articles writing	70%
5.2	PhD thesis writing	0%

Thanks for the attention

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Simulator assumptions

Geometrical description:

- Use of spice kernels (by ESA) for which a flyby around comet 8P
- Close approach distance of 250 km
- Probe B2 spin period of 4 s

Coma characteristics:

- Water production rate of 1e30 molec/s (or 3e4 kg/s)
- Spherical coma
- Dust size distribution from 0.1 µm to 1 mm, divided in 50 bins*
- Effective wavelength of 656 nm*
- Spherical particles, Mie scattering (n = 1.8+0.1i*)

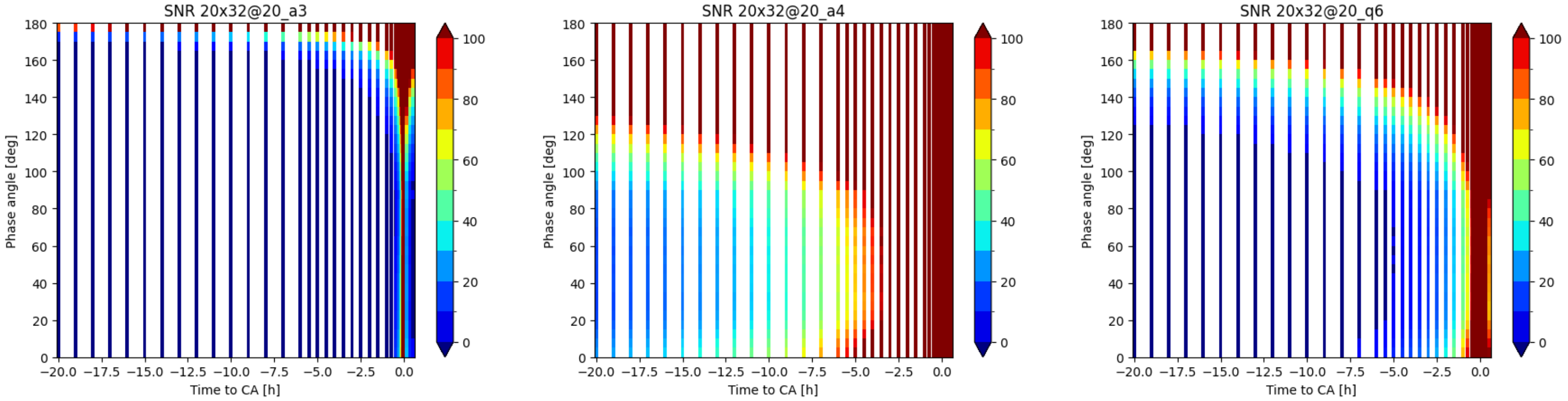
* Results obtained from previous analysis

Observational strategy – method

- Coma brightness and EnVisS observations are affected by a significant uncertainty
- The impact of the slope of the dust size distribution and the total dust production have been tested
- Three different slopes and dust-to-gas ratio have been considered:

  → a = 3.1, 3.5, 4.1

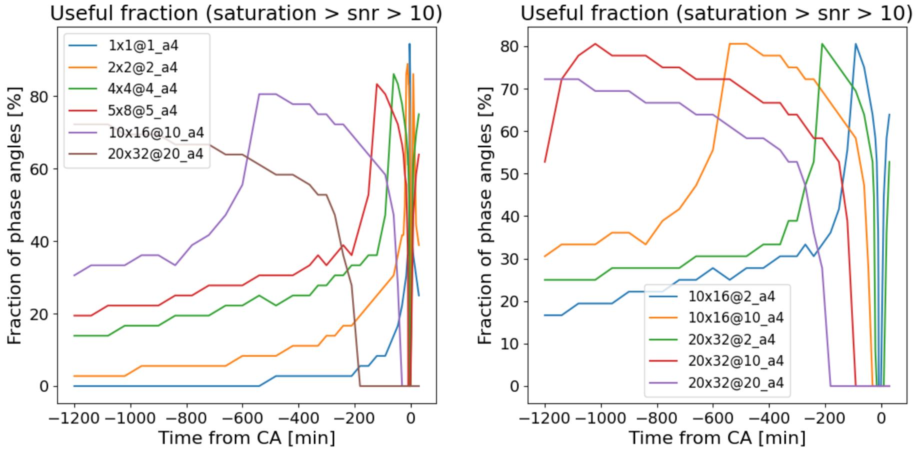
  → $Q_{dust} / Q_{gas} = 1, 3, 6$



Evolution of the SNR as Probe B2 approaches the comet with a coma characterized with a slope of the dust size distribution of -3.1 and dust to gas ratio of 3 (left), slope of the dust size distribution -4.1 and dust to gas ratio of 3 (center) and slope of the dust size distribution -3.5 and dust to gas ratio of 6 (right).

Observational strategy – method

- The previous data can be quantitatively described in terms of the saturated/useful fraction of phase curve, and how those fractions evolve with time
- To have the maximum useful fraction, a combination of different binning and exposure times is necessary during the whole period of flyby
- A combination of two different images taken with different binning or same binning but different exposure times might be a possible solution to have the maximum SNR possible and recreate almost the full sky including all phase angles



Useful fraction of the SNR as a function of time to CA when the slope of the size distribution is 4.1 and a dust to gas ratio of 3, by using different binnings and exposure times as described in the legend.