Gravitation Astrometric Measurement Experiment (GAME)

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2) ADS Int.l

3) ALTEC

4) Politecnico di Torino

GAME:

Gravitation → PPN parameters γ and β

Astrometric → Apparent star position variation

Measurement → Light deflection close to the Sun

Experiment → Space mission – **small / medium**

Approach:

build on flight inheritance from past missions

[SOHO, STEREO, Hipparcos, **Gaia**]

GAME Science goals

*** Characterisation of weak field gravity in the Solar System:**

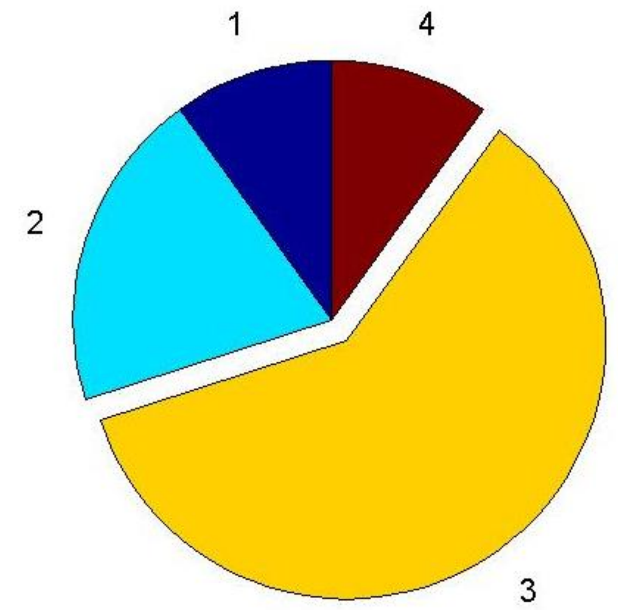
- Parametrised Post-Newtonian parameters γ, β
- Relativistic effects of oblate and moving giant planets
- High precision ephemerides of major planets

*** Science bonus:**

- Extra-solar Planetary systems
- Stellar astrophysics
- Upper limits on some Lorentz-violating SME parameters

GAME vs. ESA Cosmic Vision "Grand Themes"

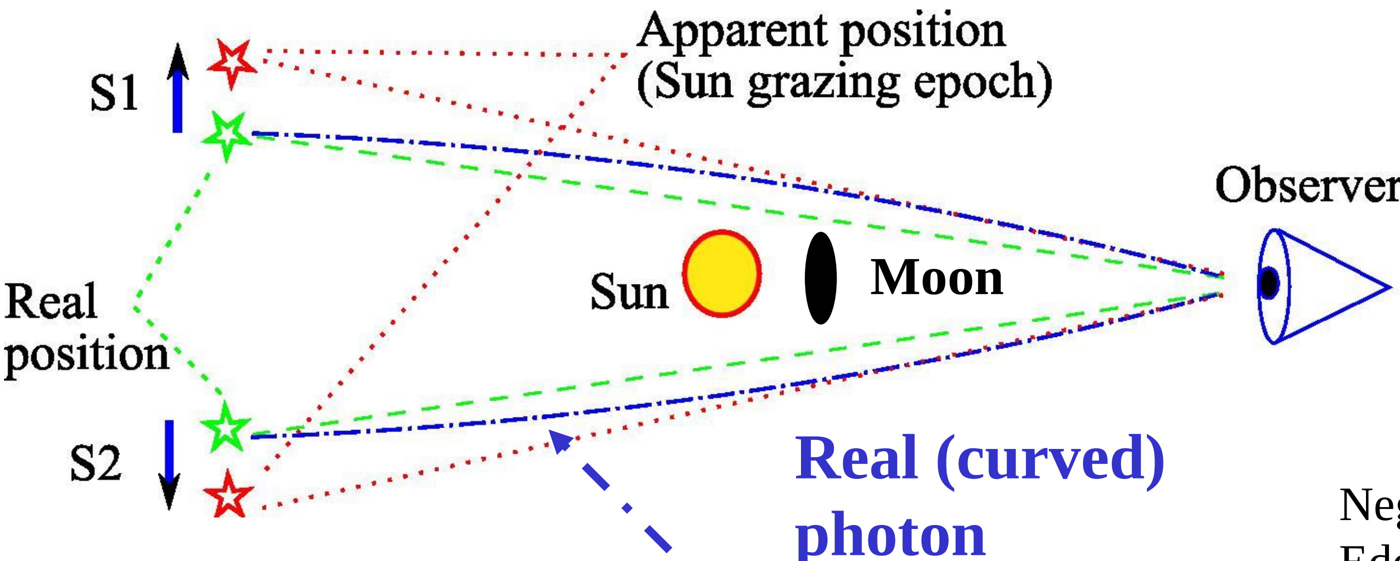
	Cosmic Vision Theme	GAME
1	What are the conditions for planet formation and the emergence of life?	10%
2	How does the Solar System work?	20%
3	**What are the fundamental physical laws of the Universe?**	**60%**
4	How did the Universe originate and what is it made of?	10%



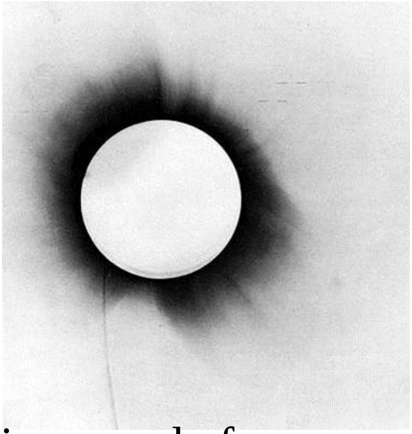
Main science case:

Astrometric tests of General Relativity in Solar system

Dyson-Eddington-Davidson experiment (1919) - I



Real (curved) photon trajectories



Negative sample from Eddington's photographs, presented in 1920 paper

First test of General Relativity by light deflection nearby the Sun

Epoch (a): unperturbed direction of stars S1, S2 (dashed lines)

Epoch (b): apparent direction as seen by observer (dotted line)

Dyson-Eddington-Davidson experiment (1919) - II

Repeated throughout XX century

Precision achieved: ~10%

[A. Vecchiato et al., MGM 11 2006]

Authors	Year	Deflection ["]
Dyson & al.	1920	1.98 ± 0.16
Dodwell & al.	1922	1.77 ± 0.40
Freundlich & al.	1929	2.24 ± 0.10
Mikhailov	1936	2.73 ± 0.31
van Biesbroeck	1947	2.01 ± 0.27
van Biesbroeck	1952	1.70 ± 0.10
Schmeidler	1959	2.17 ± 0.34
Schmeidler	1961	1.98 ± 0.46
TMET	1973	1.66 ± 0.19

Limiting factors:

- **Need for natural eclipses** → Short exposures, high background
- **Atmospheric turbulence** → Large astrometric noise
- **Portable instruments** → Limited resolution, collecting area

Why testing GR through γ (+ β)?

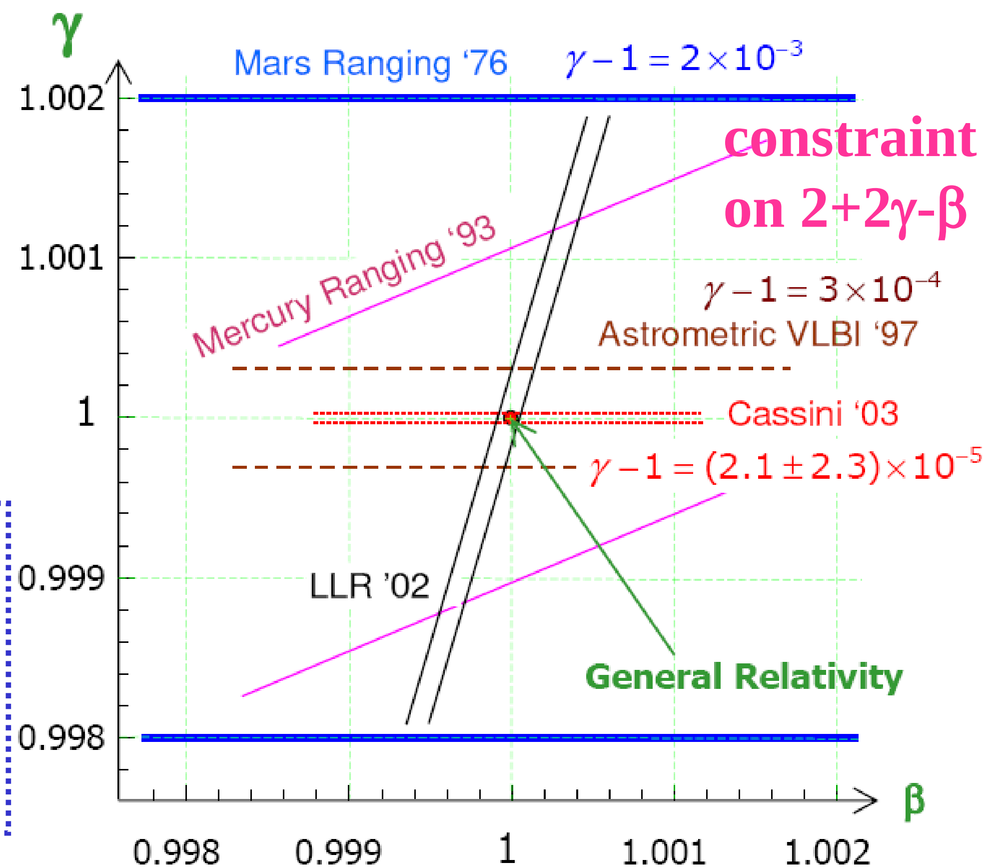
Current experimental bounds:

consistent with GR

$$|\gamma - 1| \le 2 \times 10^{-5}$$

$$|\beta - 1| \le 1 \times 10^{-4}$$

Parametrised Post-Newtonian (PPN) formulation allows comparison of competing gravitation theories



S.G. Turyshev (JPL, NASA)

***Living Reviews in Relativity*, C.F. Will (2001)**

Deviation range expected:

$$\mathbf{10^{-5} - 10^{-7}}$$

Cosmological implications

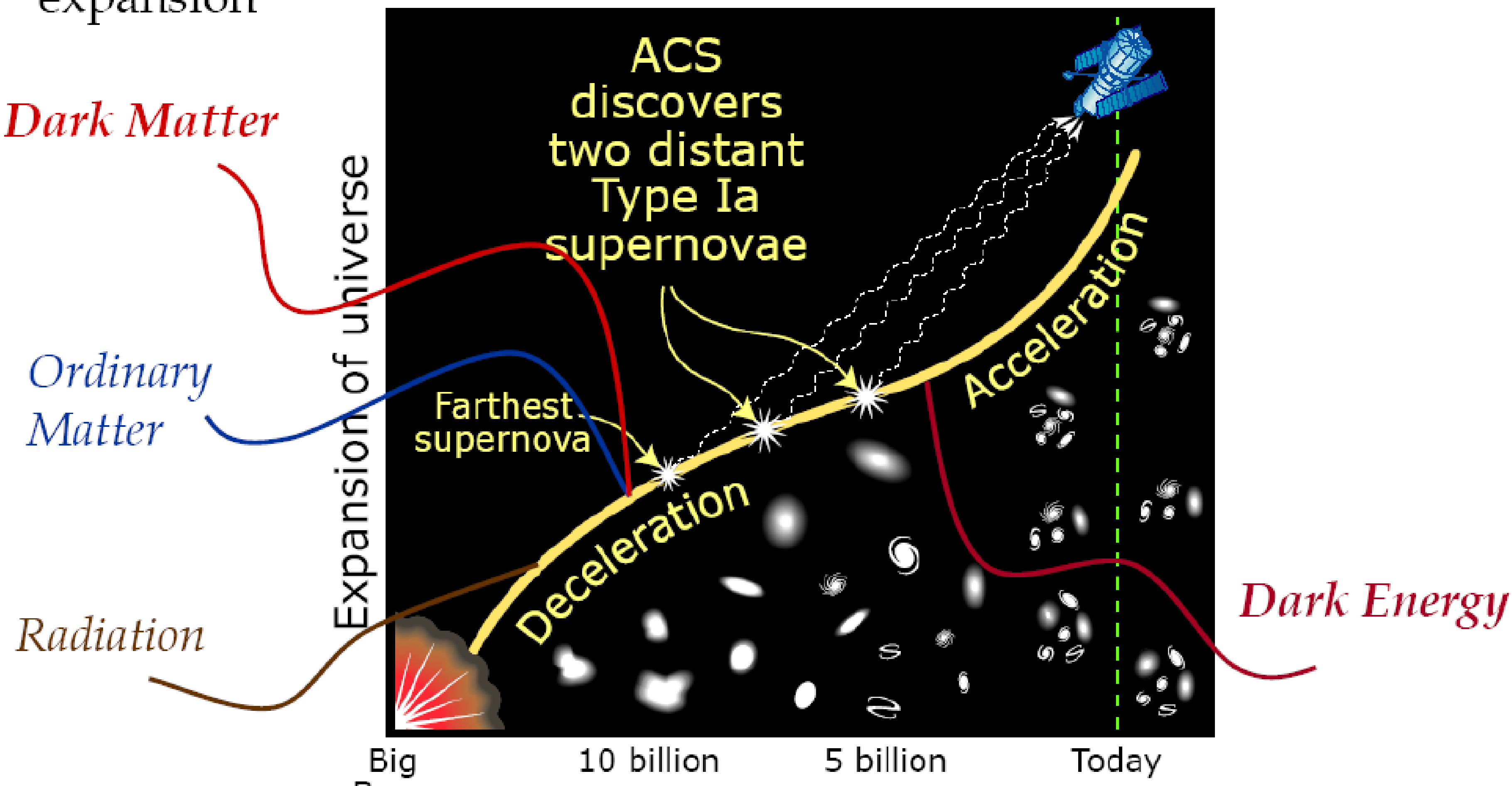
- Dark Matter and Dark Energy: explain experimental data
- Alternative explanations: modified gravity theories – e.g. *f(R)*
- Possible check: fit of gravitation theories with observations
- Check of modified gravitation theories *within Solar System*

Rationale:

replacement in Einsten's field equations of
source terms [⇔ **new particles**] on one side with
geometry terms [⇔ **intrinsic curvature**] on the other side

DE and DM from the Observations

- Universe evolution is characterized by different phases of expansion



[S. Capozziello]

Constraining the phase space of modified gravity

Taking advantage of PPN limit, e.g. for *f(R)* theories…

$$\gamma_R^{PPN}-1=\frac{-f''(R)^2}{f'(R)+2f''(R)^2},\quad \beta_R^{PPN}-1=\frac{1}{4}\left[\frac{f'(R)\cdot f''(R)}{2f'(R)+3f''(R)^2}\cdot\frac{d\gamma_R^{PPN}}{d\phi}\right]$$

[Capozziello & Troisi 2005]

Alternative formulation:

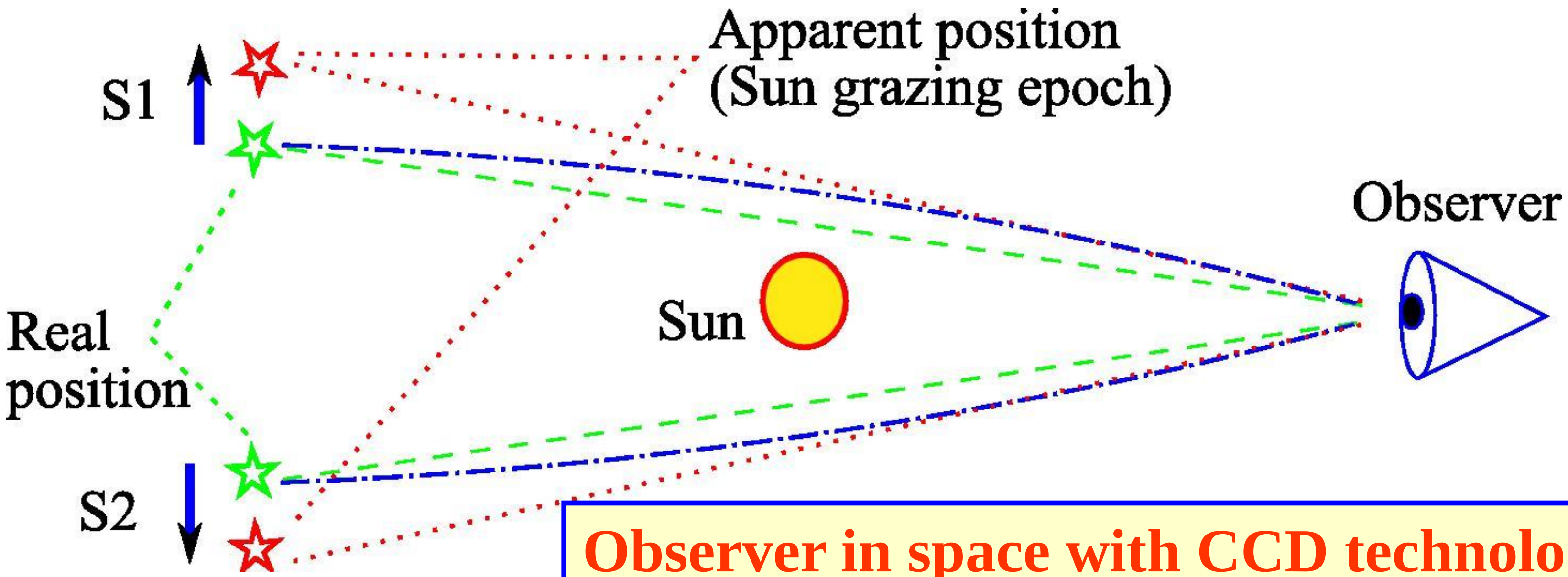
$$\gamma_R^{PPN}-1=\frac{-\left(f''\frac{dR}{d\varphi}\right)^2}{Zf'+2\left(f''\frac{dR}{d\varphi}\right)^2},\quad \beta_R^{PPN}-1=\frac{1}{4}\left[\frac{f'\cdot f''\frac{dR}{d\varphi}}{2Zf'+3\left(f''\frac{dR}{d\varphi}\right)^2}\cdot\frac{d\gamma}{dR}\cdot\frac{dR}{d\varphi}\right]$$

[Capone & Ruggiero 2010]

Check of gravitation theories within Solar System:

local measurements ⇒ cosmological constraints

The GAME concept (I)



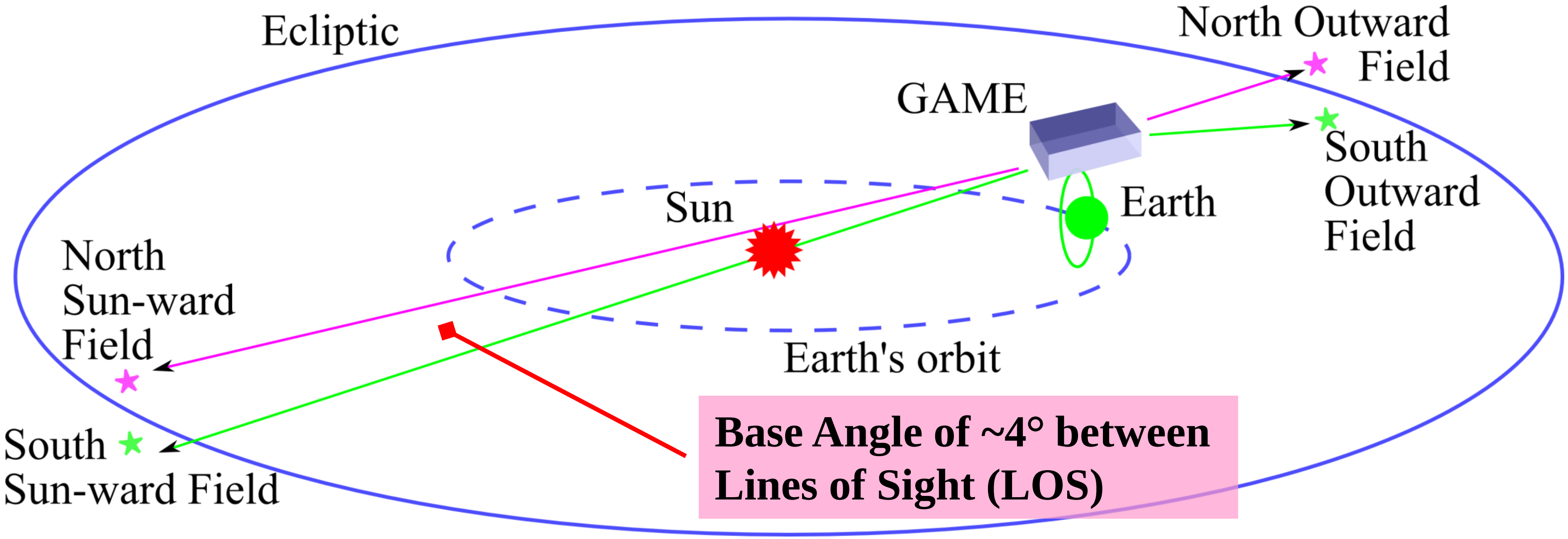
Observer in space with CCD technology

A space mission in the visible range to achieve

- long permanent artificial eclipses
- no atmospheric disturbances, low noise

Differential measurement for systematic error control

The GAME concept (II)



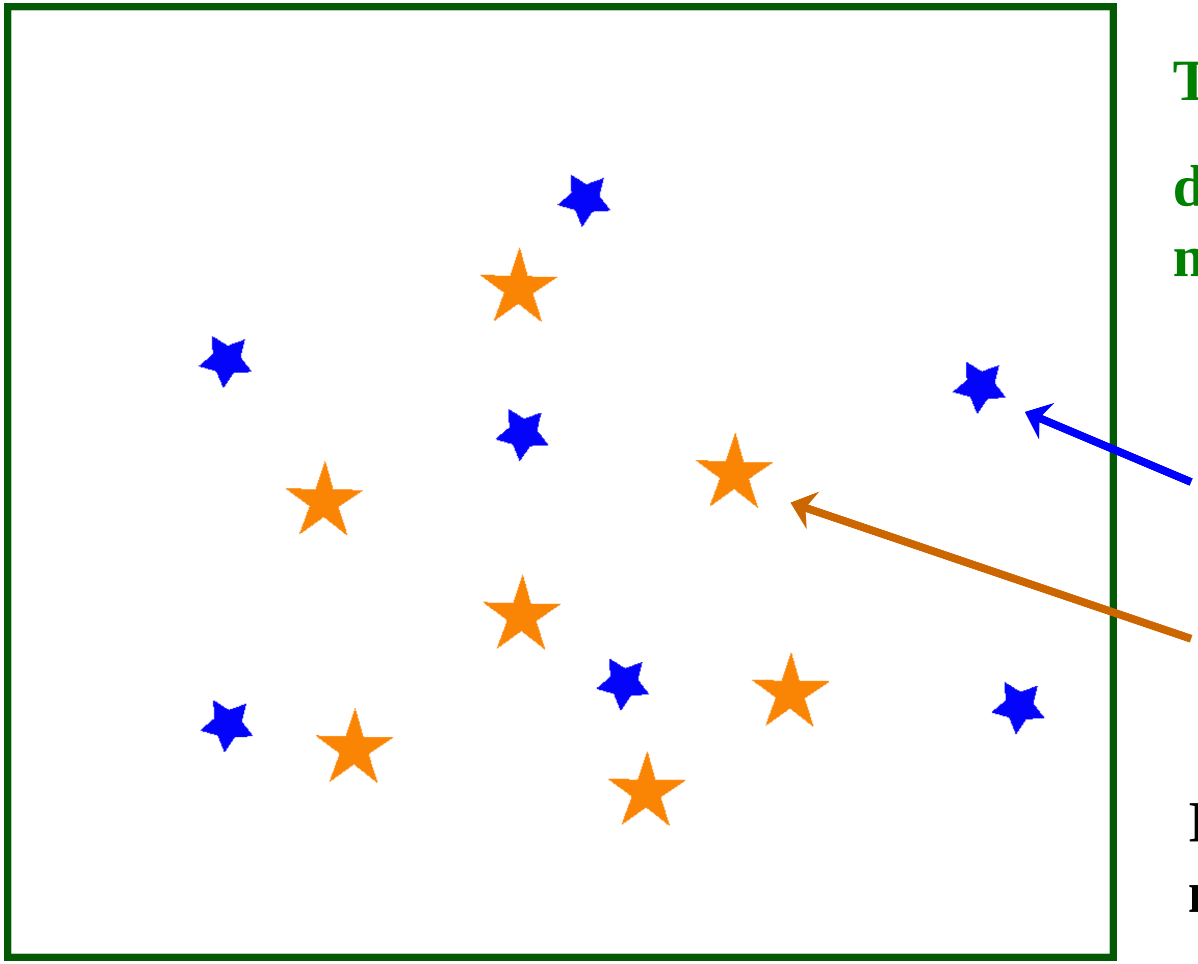
Experimental approach:

Repeated observation of fields close to the Ecliptic

Measurement of angular separation of stars between fields

2+ epochs to modulate deflection (Sun gravity "switched" on/off)

Dual field superposition + epoch modulation



Two epochs:

differential measurement of deflection

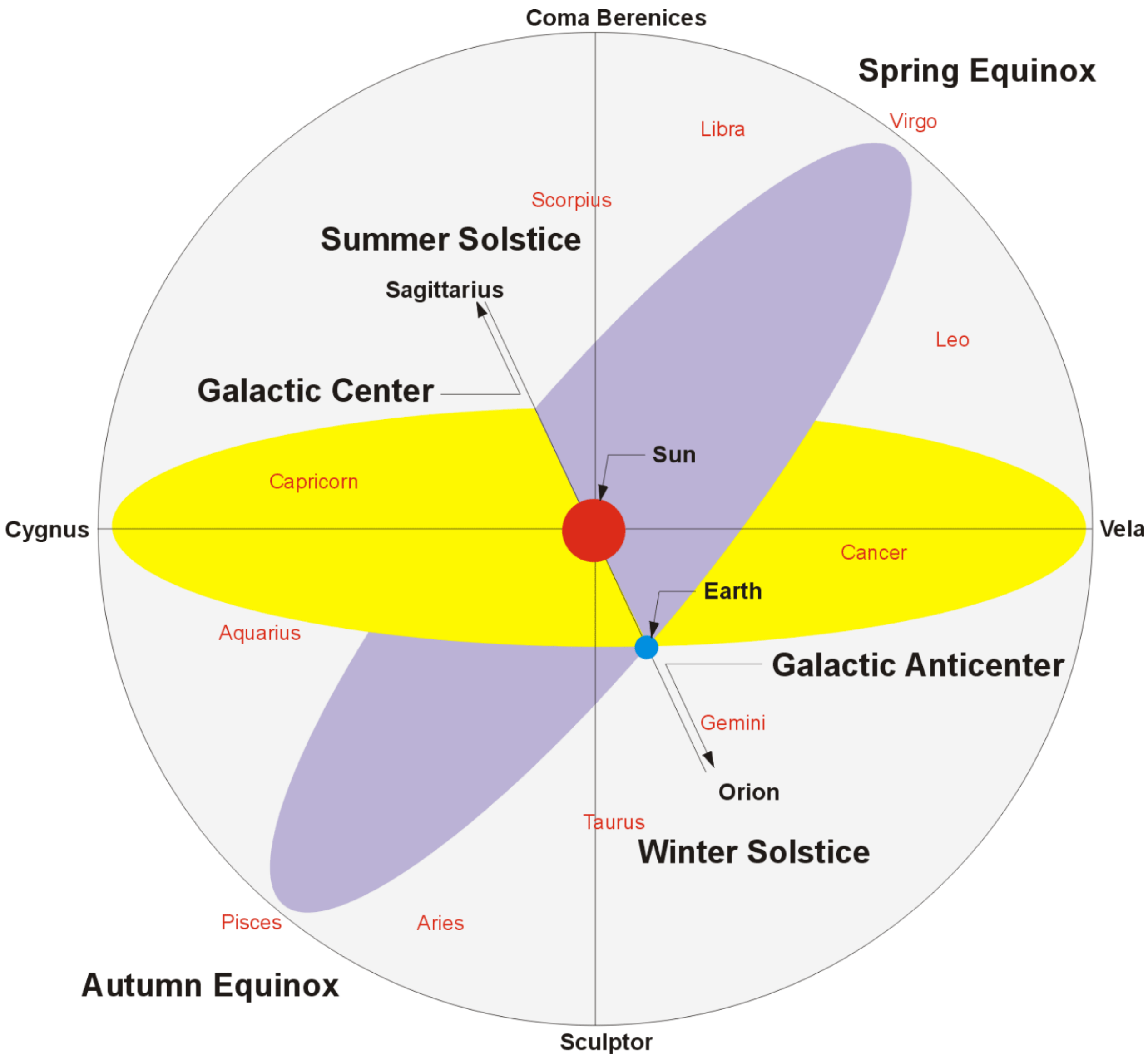
Pointing set on one field

Apparent common mode displacement of stars in other field

Instrument errors mostly common mode

Gaia catalogue: unperturbed positions, proper motions, multiplicity, colour

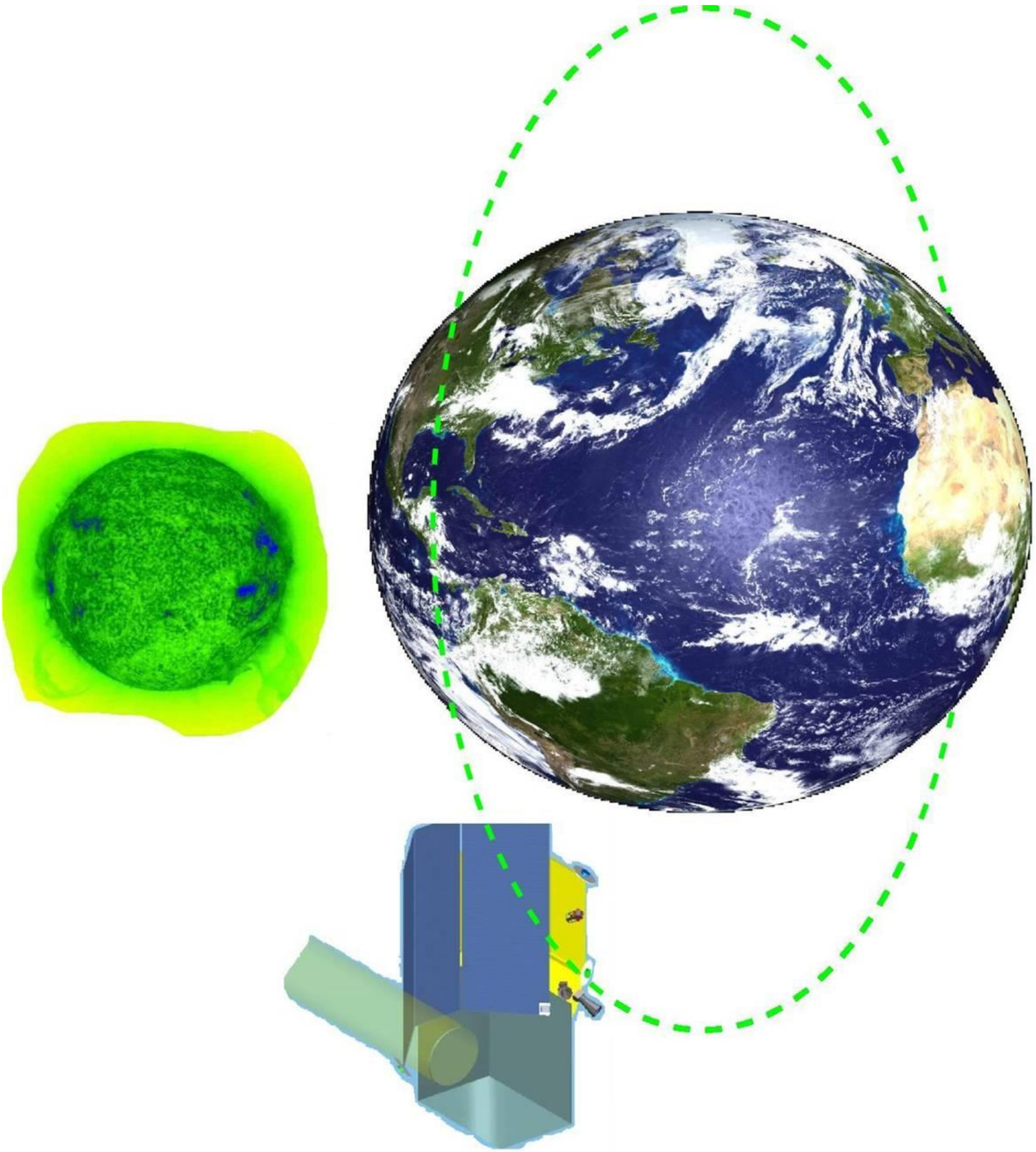
Convenient fields: Galactic ∩ Ecliptic plane



High stellar density regions:

intersection of Galactic and Ecliptic planes, toward Galactic centre / anti-centre

Mission profile

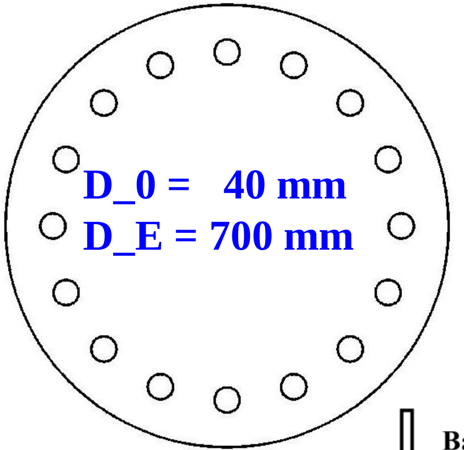


Sun-synchronous orbit, 1500 km elevation ⇒ no eclipse

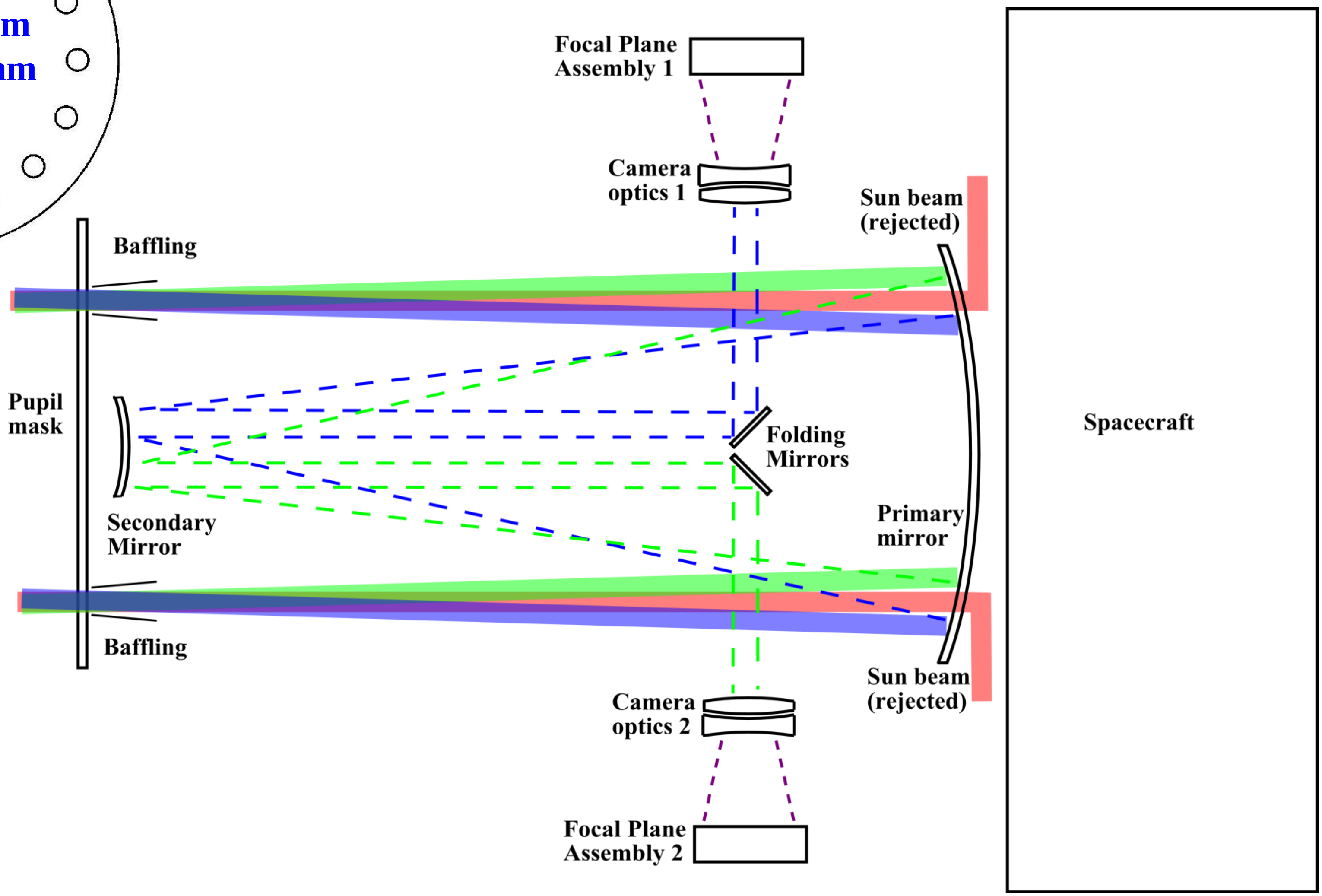
100% nominal observing time

Stable solar power supply and thermal environment ⇒ instrument structural stability

Payload concept: imaging Fizeau interferometer



Diluted aperture; Sun beam dumped to space

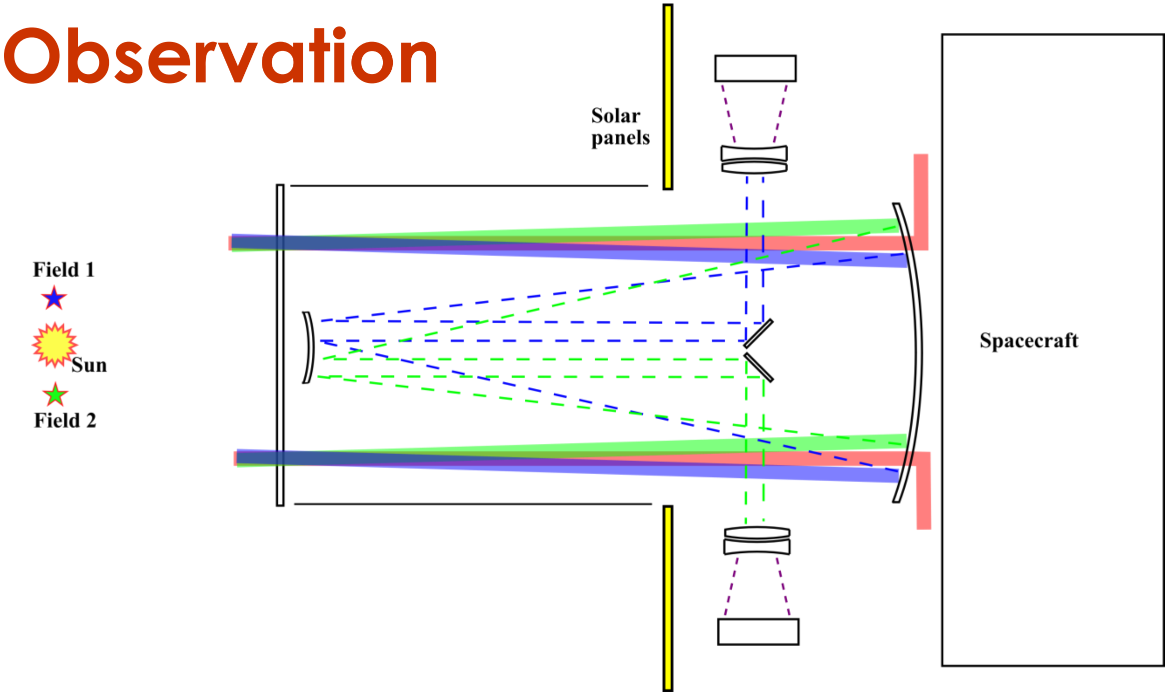


Observation

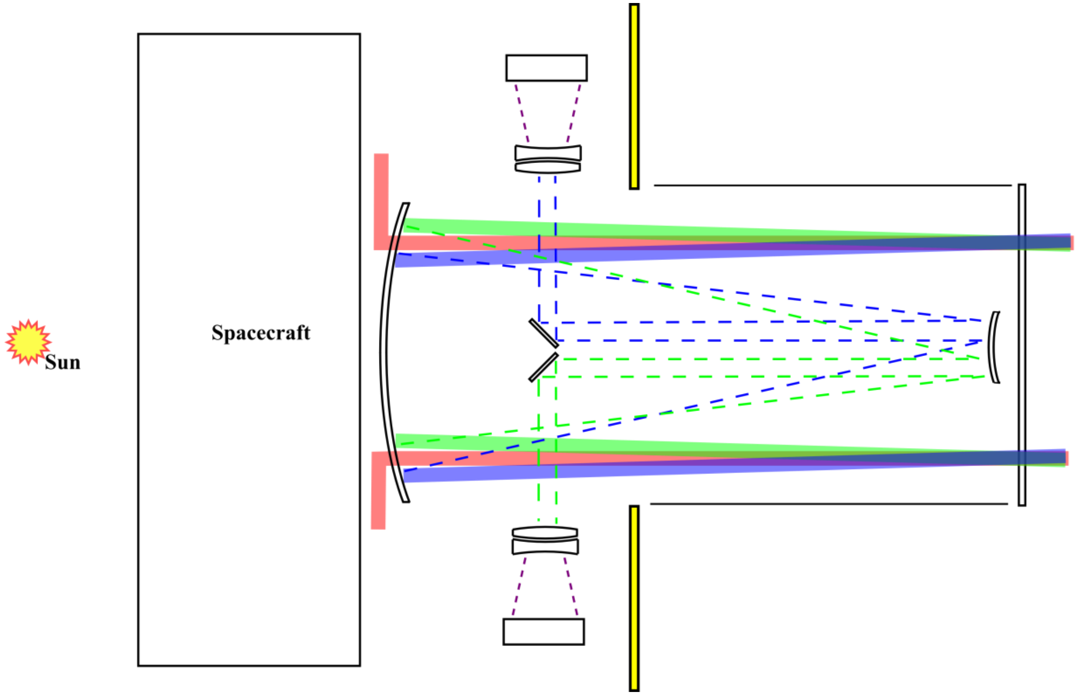
On deflected fields

Attitude options:

- Point on Sun
- Scan around Sun



Calibration



On undeflected fields

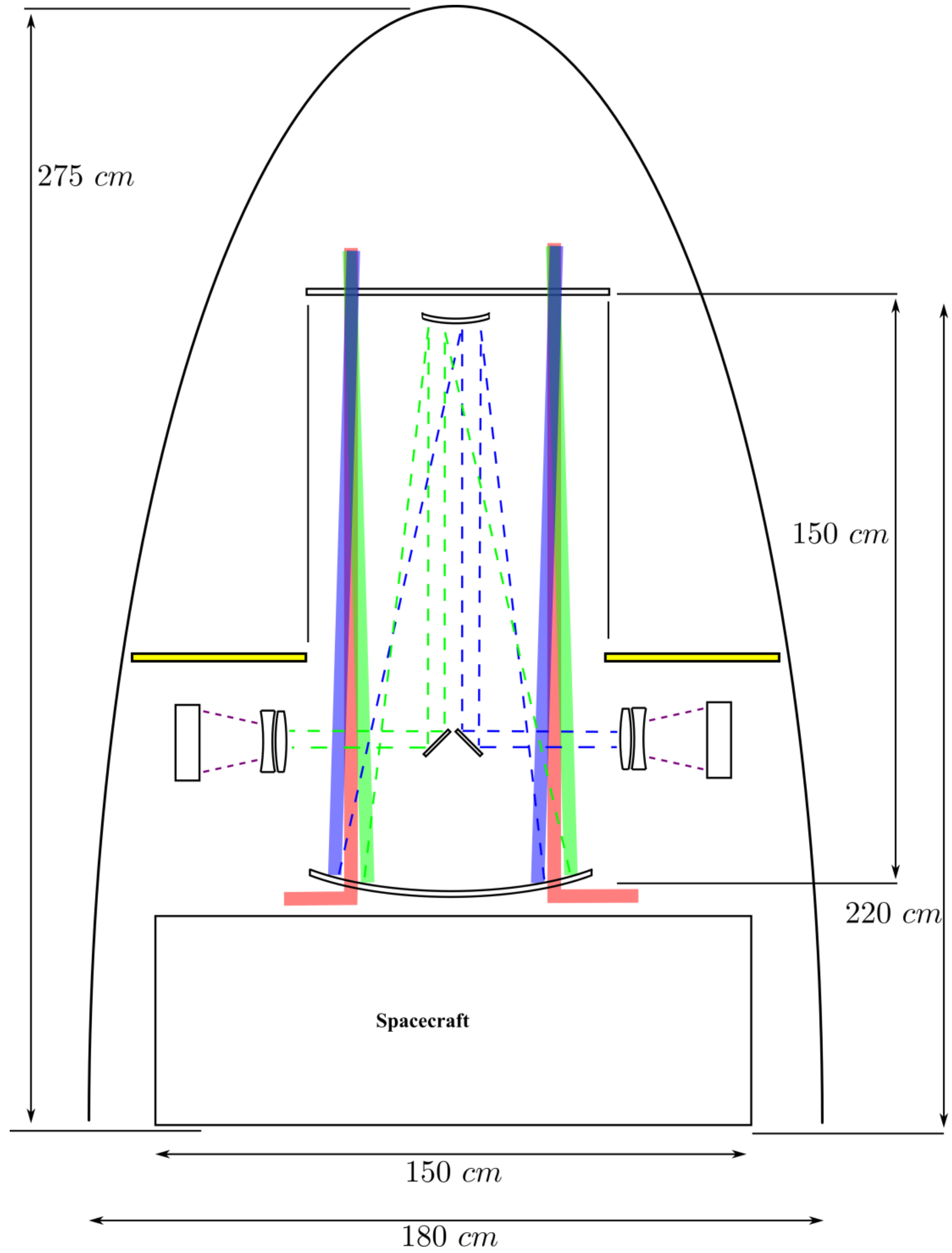
Periodic anti-Sun pointing

Fairing volume usage

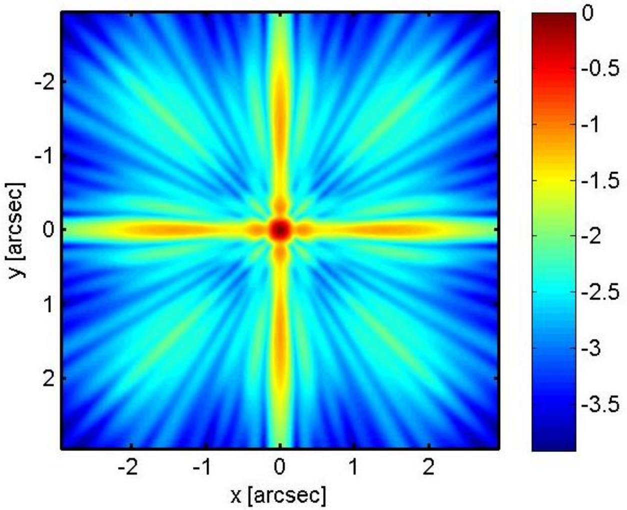
Spacecraft + payload length: 2.2 m (without interface)

No deployable subsystems

Compatible with small additional payloads



Individual imaging and location performance



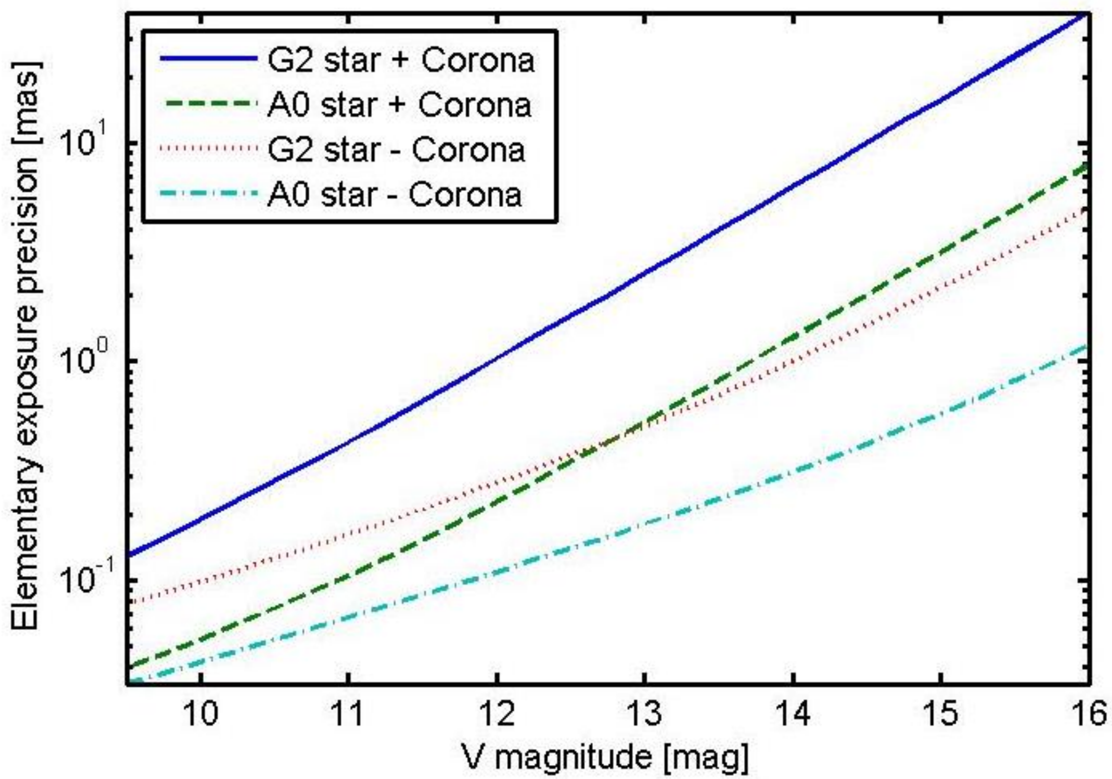
Near-solar unresolved star [log intensity]

High resolution images: ~0.2 arcsec peak

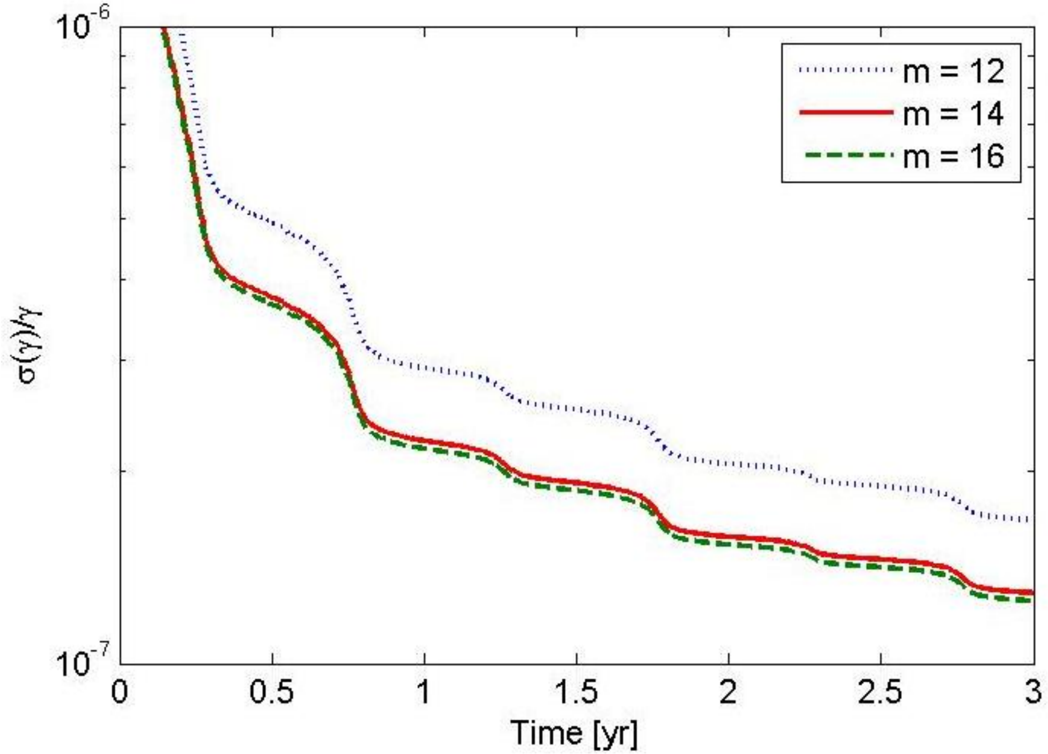
Underlying structure: spoiler detection

Photometry on side wings at <1%

Elementary precision on location in 5 min. integration



Photon limited performance – full mission



$$\frac{\sigma(\gamma)}{\gamma} < 2 \times 10^{-7}$$

$$\frac{\sigma(\beta)}{\beta} < 1 \times 10^{-5}$$

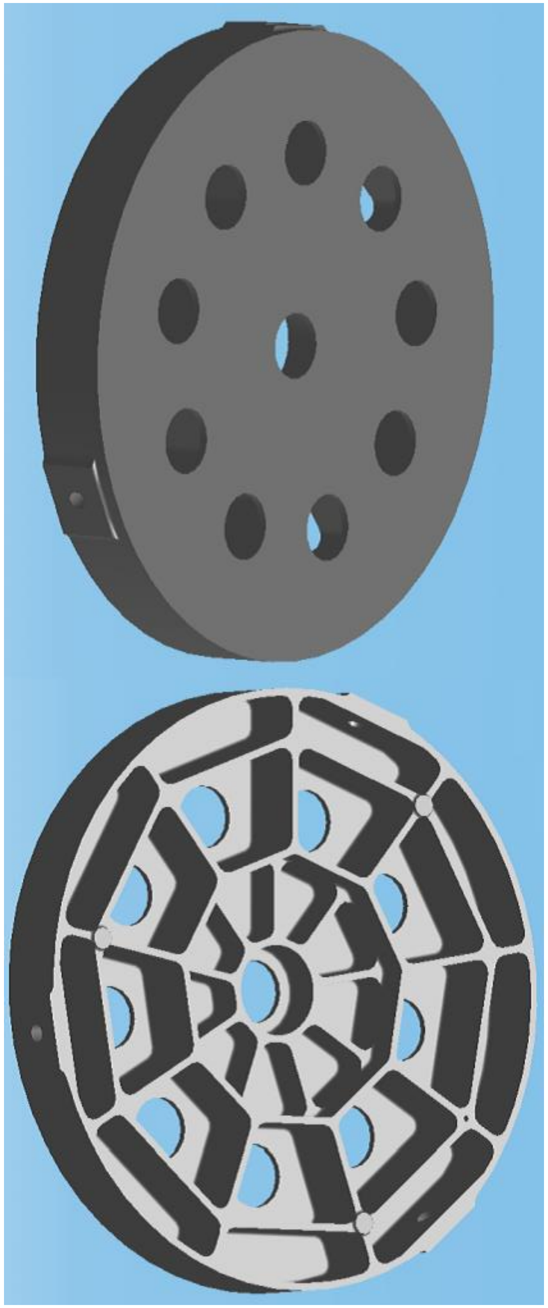
in 2 years

3 year mission extension: improve on calibration and other science topics

Medium class mission: ~10× performance improvement on γ and β

Laboratory prototype - I

Diluted SiC Mirror Demonstrator



Pupil mask [shading the telescope]

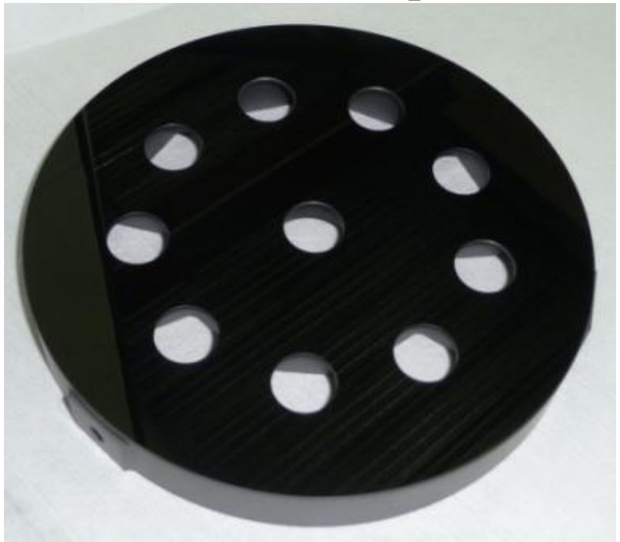
9+1 apertures, ∅ 20 mm

Outer diameter: 20 cm

Manufacturer: **Boostec** (Bazet, F)

Qualification tests at ADS Intl. (LC)

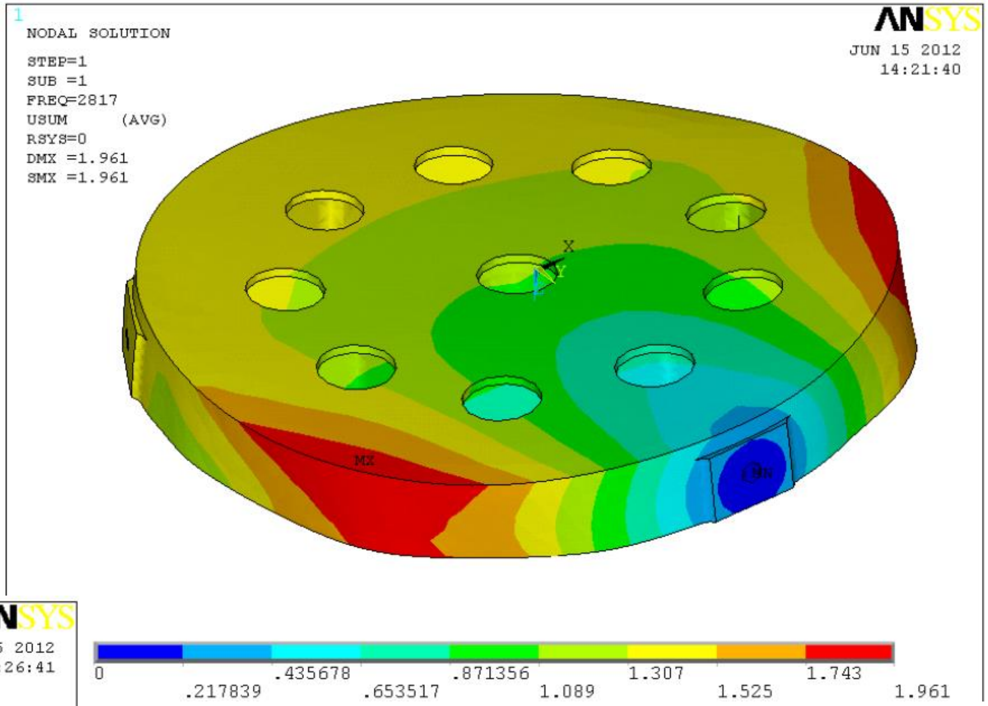
[photo]



Requirements:
Static & dynamic load compatible with e.g. Soyuz launcher

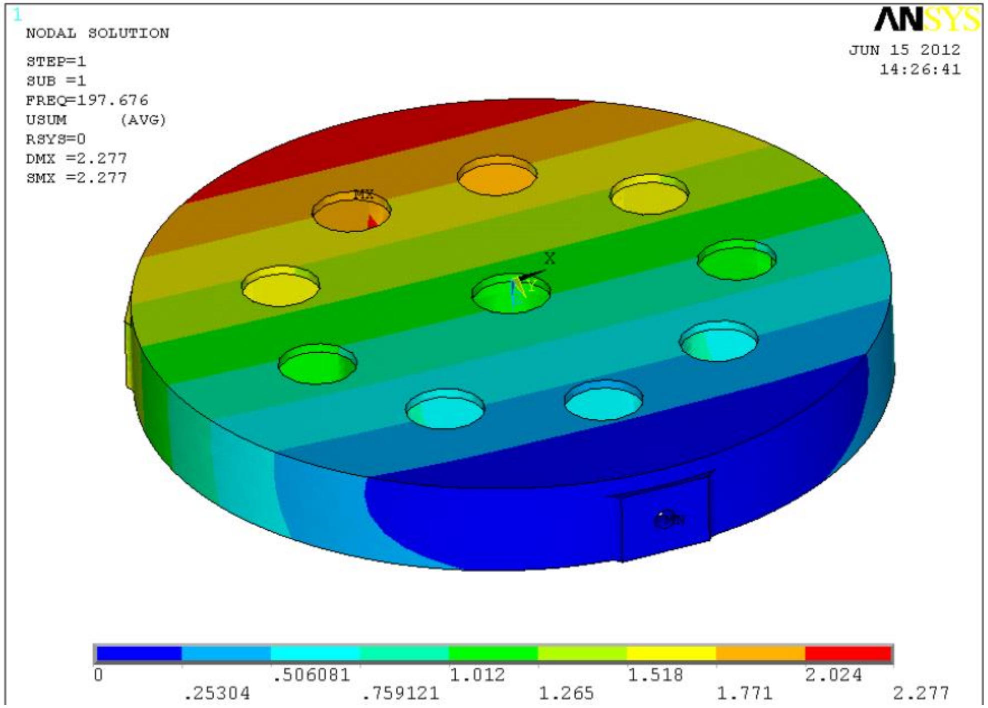
Laboratory prototype - II

Dynamic analysis (example)



3 clamping areas

First mode: 2817 Hz

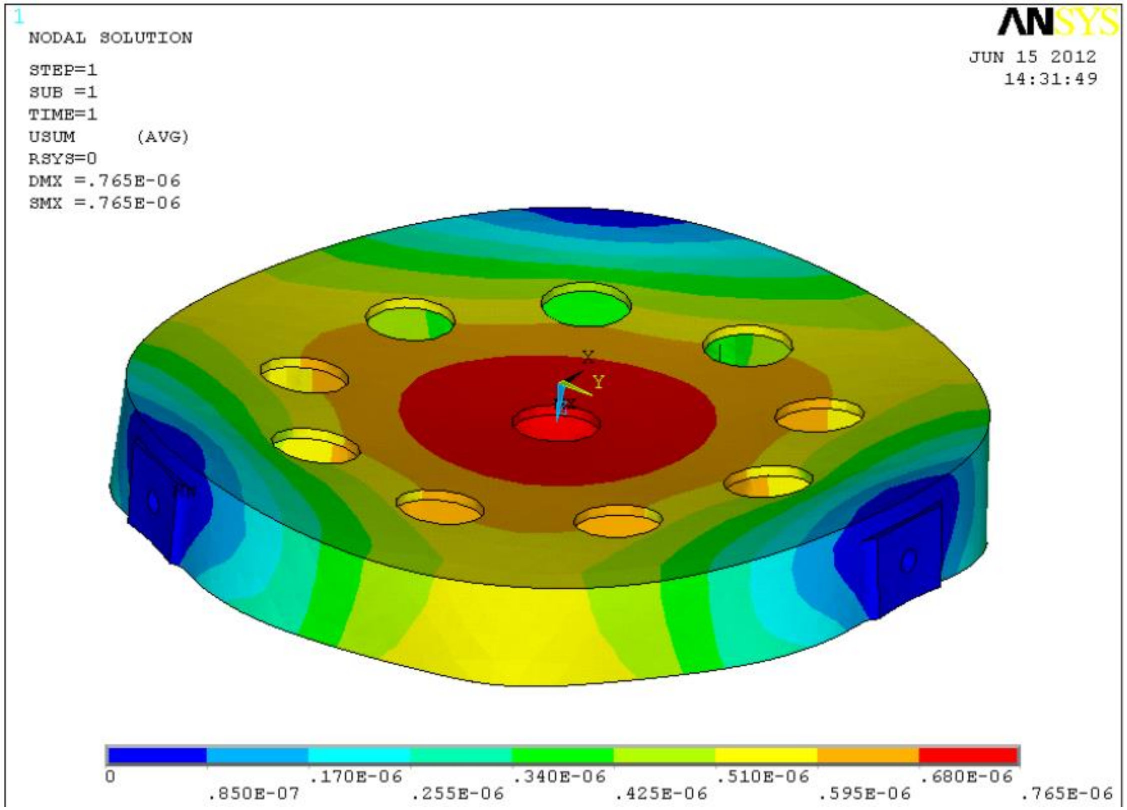


1 clamping area

First mode: 198 Hz

Tests by ADS Int.l

Laboratory prototype - III



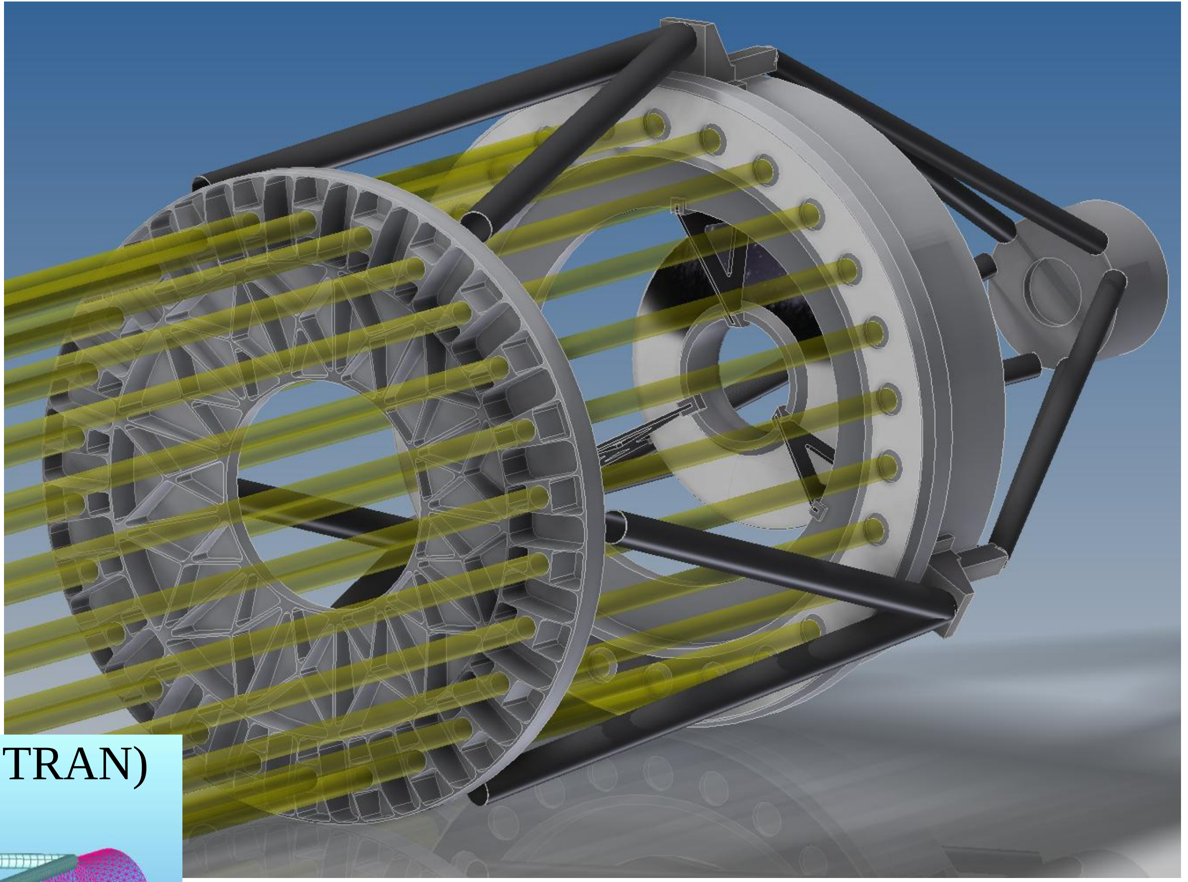
Static analysis (example)

30 g load
Deformation acceptable

Test requirements fulfilled

Design scalable to small / medium mission class

Analysis of medium mission class payload



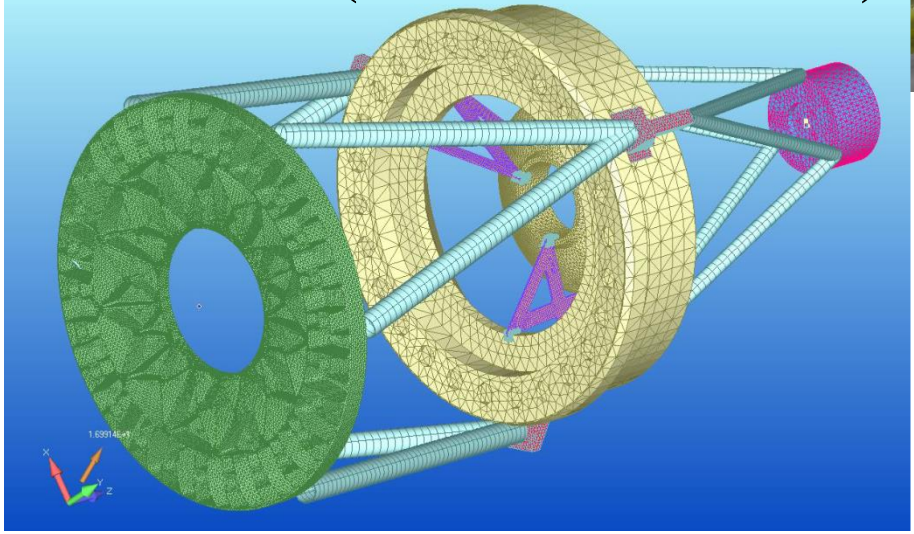
Telescope class: 1.5 m ∅

Trusses: CFRP

Optics: SiC

Invar clamps

FEM model (FEMAP / NX NASTRAN)



Preliminary mass budget: 577 kg

Scaling to small mission: 72 kg

Only pupil mask lightweighted

Additional lightweighting feasible

Roadmap: from balloon (ISAS) to satellite (GAME)

Gravitation Astrometric Measurement Experiment – GAME

Concept initially investigated for the satellite version

Main goal: Fundamental Physics (General Relativity tests);

Secondary goal: astrophysics by astrometry (solar system; exoplanets; …)

Current investigation: Precursor on stratospheric balloon

Science goal: astrometry of Solar System (major) planets

Technical goal: demonstration of main GAME concepts

Interferometric Stratospheric Astrometry for Solar system - ISAS

First technical launch:

Levaldigi airport, Dec. 9th 2013

Collaboration on stratospheric balloon experiments

INAF-OATo; ALTEC; Politecnico di Torino

Concluding remarks

- ✓ Astronomical techniques ⇒ Fundamental Physics
- ✓GAME: PPN γ to $10^{-7} – 10^{-8}$ range; PPN β to $10^{-5} – 10^{-6}$ range
- ✓ Early development phase: flexible sub-system split

Possible collaboration areas:

- ➢ Device and principle tests in lab and on sky
- ➢ Operations and data processing
- ➢ Selected sub-systems of payload and spacecraft
- ➢ Participation to data reduction and analysis consortium
- ➢ **High angular resolution Solar coronagraphy**

GAME [PRESENTATION] OVER

Thanks to CAS and ESA!