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Ultra High Energy Cosmic Particles (UHECP) observation from space: perspectives for next-generation experiments.

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My Framework (for this talk...)

- I am not discussing science issues:
  they have been extensively discussed and I leave them to more qualified people than me.
- I restrict myself to discuss the experimental apparatus for space-based experiments for observation of UHE Cosmic Particles in the

  post Pierre Auger Observatory (PAO) era: perspectives, how-to and road-map...

- I am assuming that:
  - the present: Auger-south;
  - .... the (hopefully) near future: Auger-north
  - .... the (hopefully not too far) far future: a space-based experiment ???
- Most (but not all...) scientists are convinced that
  a space-based experiment is required after PAO,
  provided a solid enough scientific case is established.

Beyond the Pierre Auger Observatory from space ???

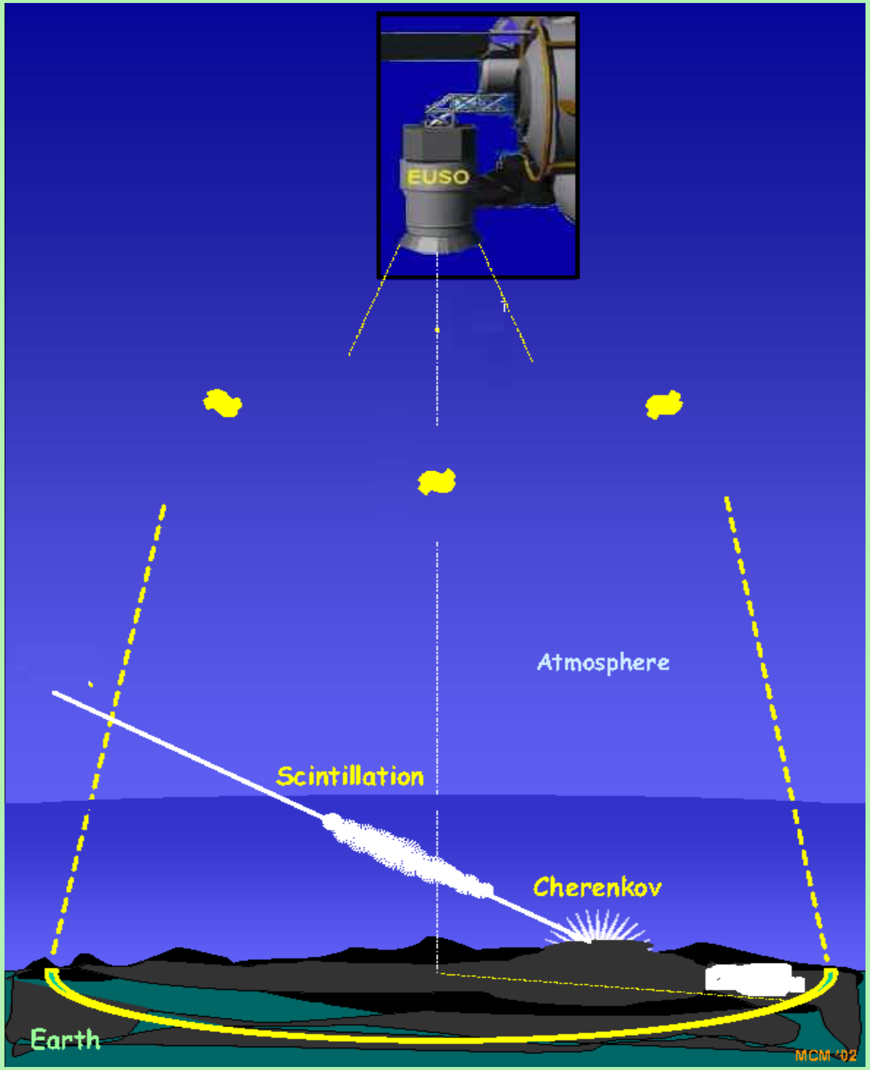
- Exceeding the PAO performance requires a huge mission/experiment, on a long time-scale, with a significant amount of preliminary R&D required.
- The challenging goal of a big space mission requires intermediate steps,
  some of which are on the way: TUS, JEM-EUSO, ...
  Other intermediate steps include some path-finder and/or technological model (see later...).
- What we will learn from PAO will help to tune the future scientific objectives:
  the Experiment-For-Everything is, most likely, impossible:
  a choice of scientific objectives will be needed,
  and trade-offs (and choices) on the performance will be, most likely, required.
- A huge mission/experiment would require the involvement
  of a large part of the UHECP physicists community, in a coordinated effort.

- Science will be, obviously, the driving force.
  However, after a careful assessment of the predictable status of science
  in some ten/fifteen years from now,
  we need to consider a realistic implementation of possible Experimental Apparata,
  to avoid dreams which will never become a reality, at least on the time-scale of a human life...

- Most new big projects have a long time duration
  and require a long time for conception, design, commissioning (plus getting funds...).
  Therefore we must start right now to think about concrete proposals
  for realistic implementations of post PAO :=(south+north) experiments,
  if the science case is compelling.

- It is not too early!
  Some ten years are certainly necessary to design and build such an apparatus...

The apparatus required for space-based UHECP observation



- The required apparatus is an Earth-watching
  large aperture, large FoV, fast and highly pixelized
  digital camera for detecting near-UV single photons from the Extensive Air Shower (EAS)
  superimposed on a huge background
  capable of five to ten years operation in space.

- It is made of:

  – a main optics, collecting photons and focusing the EAS image onto the Focal Surface (FS);
  – the Photo-Detector on the FS, registering the EAS image, which is made of:
    sensors, f/e electronics, triggering, b/e electronics and data analysis systems;
  – ancillary instrumentation: LIDAR for atmospheric monitoring, IR camera...
  – a suitable radio-detection system ???
  – system and ancillary instrumentation.

Main lines proposed to approach the problem

- Stereo vision from space: OWL. Two satellites observing the same area on the Earth.
- Telescope-like approach: TUS/KLYPVE.
- Large FoV optics with monocular view: EUSO, JEM-EUSO.

Where are we ?

Where do we start from ?

EUSO: some history

- EUSO was proposed to the European Space Agency (ESA) as a free-flyer with:
  - optics diameter: $\simeq 3.5$ m;
  - orbit height and inclination as a free parameter to be tuned;
  - mass, volume, power, telemetry and other budgets: largely unconstrained.
- ESA recommended to consider the accommodation on the ESA Columbus module on the ISS: many constraints had to be taken into account, including:
  - fixed orbit height;
  - limits on mass, volume, power, telemetry and other budgets.
  - The accommodation had to be made compatible with the ISS/Columbus resources including: mass (1.5 ton), volume ($2.5 \times 2.5 \times 4.5$ m^3), power (1 kW), telemetry (180 Mbit/orbit).
  - volume limited by the envisaged accommodation on the Shuttle, not by its capabilities...

Many constraints, mainly due to the ISS, limited the final EUSO performance

The heritage of EUSO projected into the future

- EUSO, an European-led project of the European Space Agency, underwent a detailed phase-A study.
- We have learnt a lot from the EUSO phase-A studies about space-based observation of UHECP.
- The EUSO heritage is exceedingly precious: many lessons were learnt... and we must use what we learnt from EUSO, to develop a second generation experiment.
- We can consider EUSO as our prototype exercise: we have possibly done mistakes!

One needs a safe design margin on the expected performance !

Aim (dream of ?) to an experiment with much better performance than EUSO...

From EUSO to super-EUSO ???

- EUSO: the efficiency plateau was reached at $\approx (1 \div 2) \cdot 10^{20}$ eV:
  one needs to gain a factor $(10 \div 20)$ - at least - in the energy threshold...
- More collected photons improve the energy resolution and angular resolution on the UHECP.
- Increasing the entrance pupil also increases the background rate:
  it is not enough to enlarge the entrance pupil to improve the performance;
  energy threshold: at some point the EAS will fade away in the background.
- Optics: reduce the FoV to get better optical efficacy: assume $\gamma_{\mathtt{M}} = (20^\circ \div 25^\circ)$ (half-angle).
  Aim to improve the average optical efficacy.
  Recover the instantaneous geometrical aperture by higher orbits.
- Number of channels: assume a maximum of $\approx$ one Mega (it is already very challenging).
  This implies angular granularity of 0.06 degrees (one mrad).
  One needs to account for a higher orbit, that is smaller pixels.

Optimisation of the orbital parameters

- Free-flyer: many more degrees of freedom in the choice of the orbit than from the ISS.
  One may also think to change the orbit during the mission.
  Changing the orbit height actually shifts up/down the observational energy range
  (that is the working point).
  - Tune the orbit: either elliptic orbit or orbit altitude change.
  - Baseline: elliptical orbit with perigee at $400\ \mathrm{km}$ and apogee at $1100\ \mathrm{km}$.
- Tilting is not required; if it were useful: no problem to tilt.
- Repetitive passes above specified locations at the Earth
  (calibration sources, Auger sites for cross-calibration...).

Provided suitable technologies are successfully developed ...

- Area and instantaneous geometrical aperture (depends on orbit and FoV):
  - $\approx 0.8 \cdot 10^6\ \mathrm{km}^2$ observed area (at apogee);
  - $\approx 2 \cdot 10^6\ \mathrm{km}^2 \cdot \mathrm{sr}$ instantaneous geometrical aperture (at apogee).

  Duty cycle not included! What the duty cycle is going to be? Measurements required...

- Threshold energy: depends on the optics entrance pupil and Photo-Detector Efficiency (PDE).
  - the optics aperture is the only sizeable parameter, to within the external constraints;
  - PDE can realistically improve by a factor two or so...(it is the only factor $\ll 1$);
  - a lot of other factors affect the overall efficiency (all of them ≈ 0.9).

  Guess-estimate: with $D \approx 8\ \mathrm{m}$ and PDE doubled with respect to EUSO
  one can think to reach: $E_{th} \lesssim 10^{19}\ \mathrm{eV}$ with $\Delta E/E \approx 0.1$ (statistical only).
  But background subtraction is not trivial and must be worked out !

- Can expect $\Delta\theta \approx$ (a few degrees) on the reconstructed primary particle direction: limited by the EAS visible track-length and by the affordable number of channels.

See the contributions at the Villa Mondragone workshop, June 2006.

Technological Developments

- Optics: deployable catadioptic optics.
- Sensors: use of newly developed Geiger-mode Avalanche Photo-Diode (GAPD) sensors.
- Many other developments:
  - New micro-electronics technologies:
    f/e electronics, hardware-trigger, increased on-board computing power.
- New ideas:
  - modular apparatus made of smaller complete functional units;
  - binocular apparatus for reducing the instrument noise.

All of them are interesting for many other applications.....
funding for independent R&D is possible!

Being inside a technological road-map might help to push the scientific objectives.

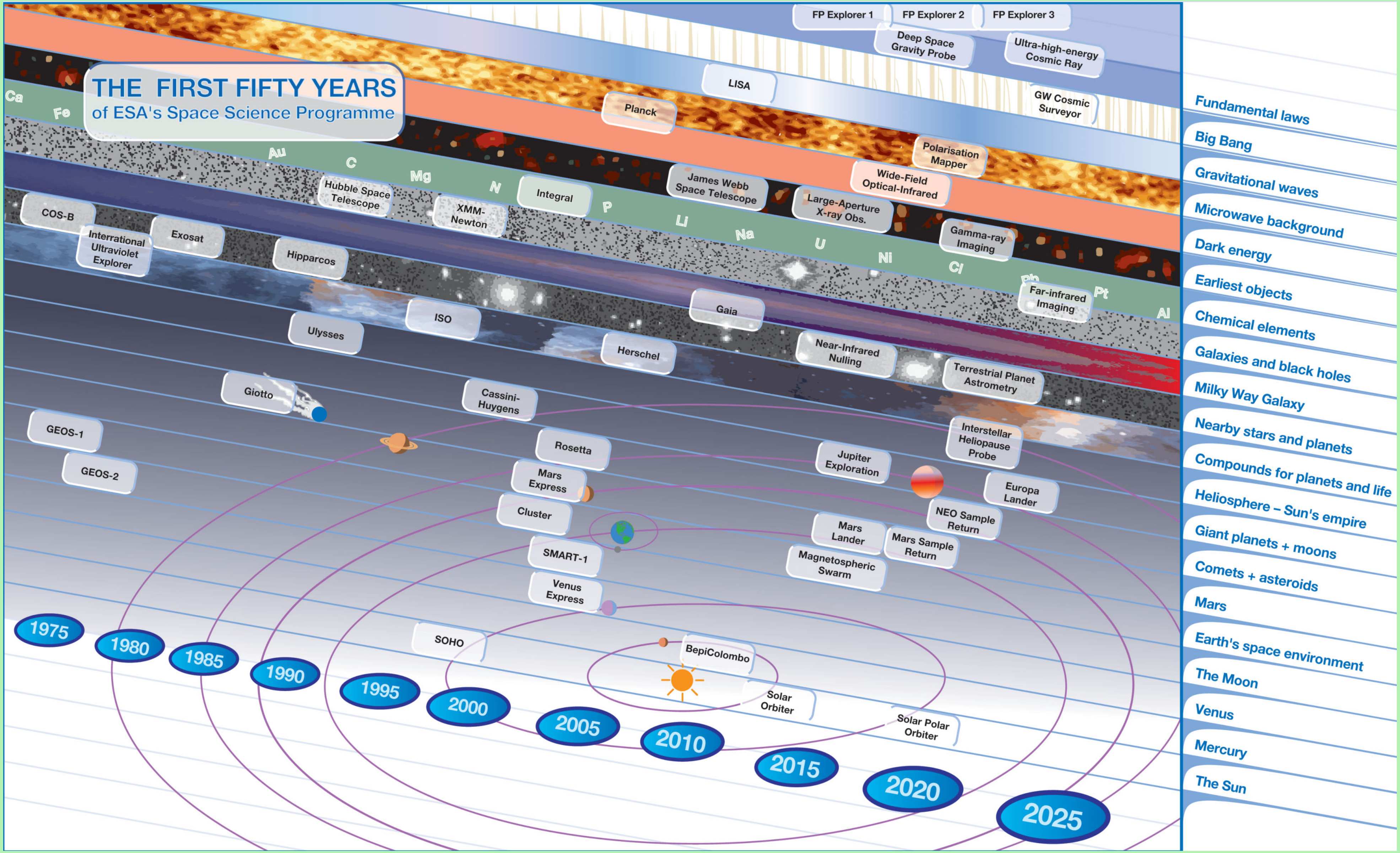
R&D is necessary.

A large mission for the ESA Cosmic Vision program (2015-2025)

- One opportunity to dream for a large future mission: ESA Cosmic Vision program (2015-2025).
- Two out of the four main themes of the ESA road-map are relevant to Particle Astrophysics:
  - What are the fundamental physical laws of the Universe?
  - How did the Universe originate and what is it made of?

  The study of UHECP from space entered the ESA road-map (so many other themes too...).
- Call for missions due for implementation in the period 2015-2018 is out
  and proposals are due for June 29.
  Within the present financial context one Class L mission is foreseen for launch in 2019.
  large missions requiring an extended preparation phase and specific technology developments.
  Implementation starts not before 2012.

An international collaboration is building up to answer the call for proposals:
any contribution/participation is welcome and invited !!!


THE FIRST FIFTY YEARS
of ESA's Space Science Programme
FP Explorer 1
FP Explorer 2
FP Explorer 3
Deep Space Gravity Probe
Ultra-high-energy Cosmic Ray
LISA
GW Cosmic Surveyor
Planck
Polarisation Mapper
Wide-Field Optical-Infrared
James Webb Space Telescope
Large-Aperture X-ray Obs.
Gamma-ray Imaging
Hubble Space Telescope
XMM-Newton
Integral
COS-B
International Ultraviolet Explorer
Exosat
Hipparcos
Far-infrared Imaging
Gaia
ISO
Ulysses
Herschel
Near-Infrared Nulling
Terrestrial Planet Astrometry
Giotto
Cassini-Huygens
Interstellar Heliopause Probe
GEOS-1
GEOS-2
Rosetta
Mars Express
Jupiter Exploration
Europa Lander
Cluster
NEO Sample Return
Mars Lander
Mars Sample Return
SMART-1
Magnetospheric Swarm
Venus Express
SOHO
BepiColombo
Solar Orbiter
Solar Polar Orbiter
1975
1980
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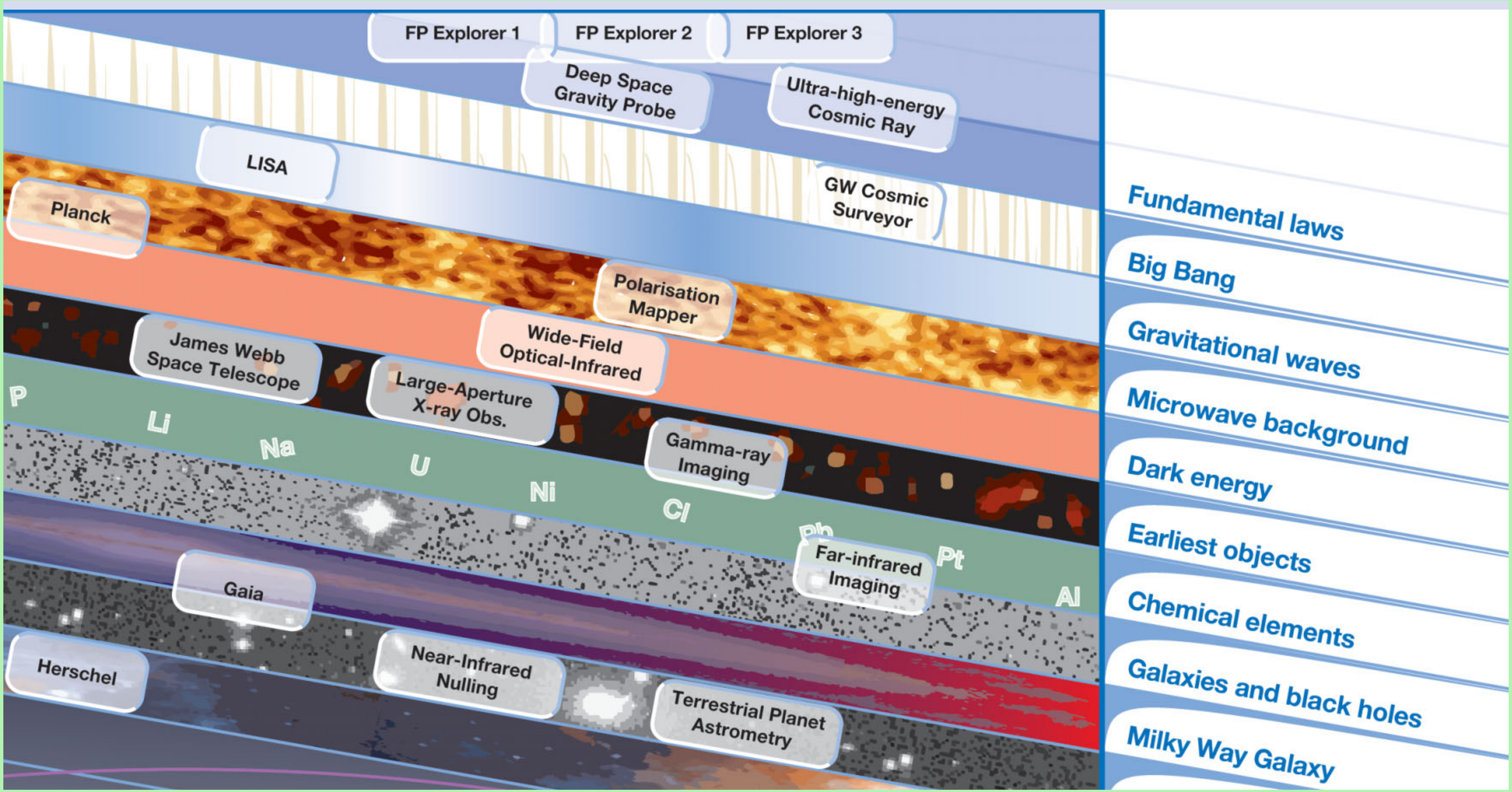
Li
Na
U
Ni
Cl
Pb
Pt
Al
Fundamental laws
Big Bang
Gravitational waves
Microwave background
Dark energy
Earliest objects
Chemical elements
Galaxies and black holes
Milky Way Galaxy
Nearby stars and planets
Compounds for planets and life
Heliosphere – Sun's empire
Giant planets + moons
Comets + asteroids
Mars
Earth's space environment
The Moon
Venus
Mercury
The Sun


FP Explorer 1
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Herschel
Near-Infrared Nulling
Terrestrial Planet Astrometry
Fundamental laws
Big Bang
Gravitational waves
Microwave background
Dark energy
Earliest objects
Chemical elements
Galaxies and black holes
Milky Way Galaxy

A few critical issues of space-base observation (same of...)

- Large distance: faint signal;
  the transverse extent of the EAS is not visible; angular resolution is not excellent.
- Non-random (night-glow) backgrounds... Total background larger than from ground.
  Huge background: online subtraction, required for triggering (HW implementation ?).
- Stray-light control with such a large FoV and sensitive apparatus.
- Orbit optimisation: man-made background, atmospheric phenomena, day-night...
- Atmospheric monitoring: critical and important item.
- The observed FoV is continuously changing...
  a continuos monitoring is needed and parameter recording is required.
- Detector calibration: one needs to calibrate $\approx$ one million channels on-orbit: a challenging task.

Demanding requirements (e.g. huge computing power) $\Longrightarrow$ impact on resources.

Careful experiment optimisation $\Longrightarrow$ collect on as much as possible information.

A well defined road-map with intermediate steps is required...

Trade-offs ???

- Stereo (better angular resolution) versus monocular (better energy threshold).
- Lower orbit (better energy threshold and angular resolution) versus higher orbit (better instantaneous geometrical aperture).

The road-map and the intermediate steps

The challenging goal of a big space mission requires intermediate steps...

- improving the current knowledge: fluorescence yield and Cherenkov albedo measurements;
- tests via stratospheric airplane flights and/or balloon flights;
- one (or a few?) small missions on a micro-satellite;
  - background characterisation;
  - test of critical technological items;
- $\Longrightarrow$ the TUS precursor;
- $\Longrightarrow$ the JEM-EUSO path-finder;
- plus the heritage of the past...

Background measurement/characterisation

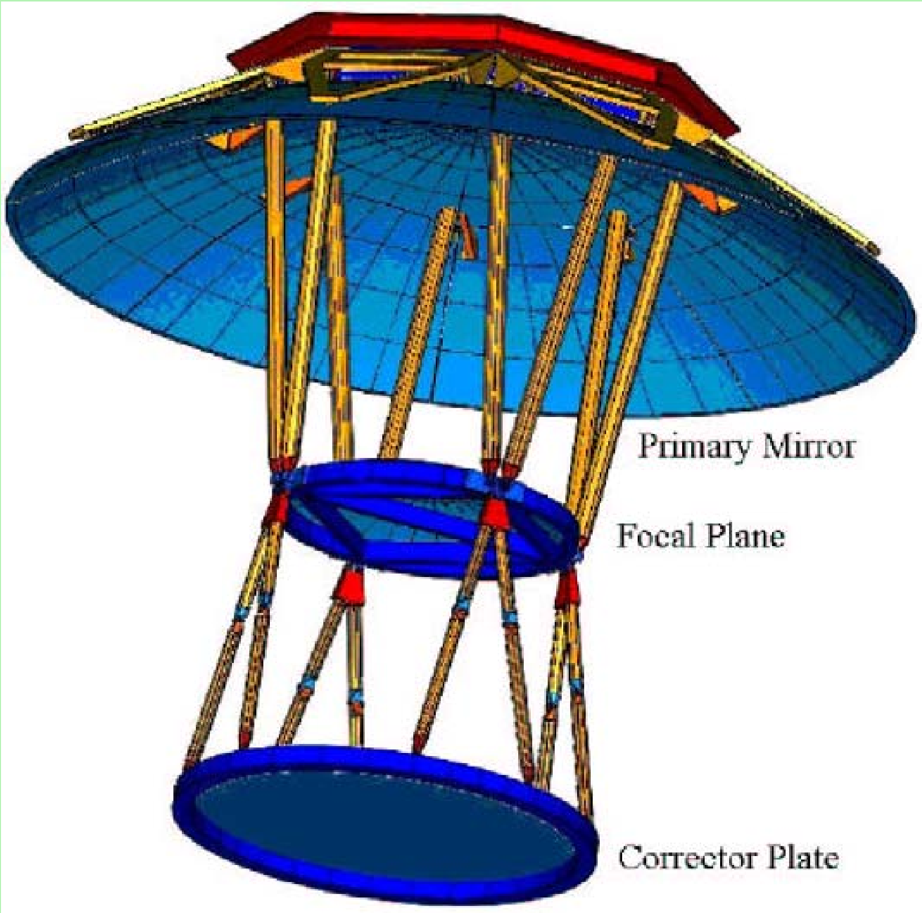
- A detailed measurement/characterisation of the background, on the space-time scales characteristics of the EAS development is required to improve our knowledge of it and possibly exploit it to improve background rejection.
  A micro-satellite to characterise the background is a fundamental step to prepare such a mission.
  Moreover: Duty cycle estimation? Stray light control? Measure far-off nadir. Test radio?
  Design tuned to mission preparation but interesting measurements for geo-physics...

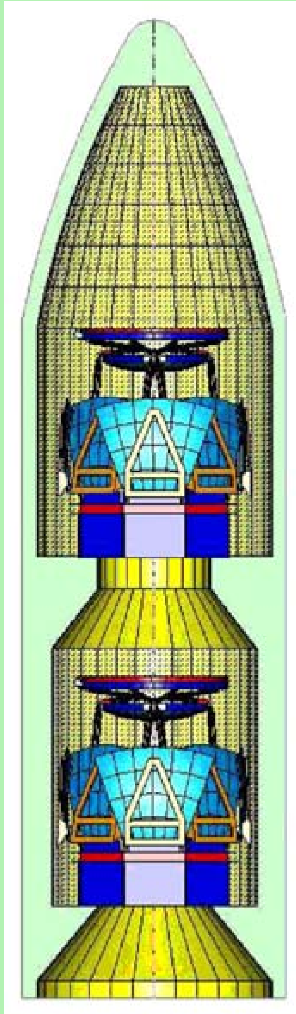
Technological model(s)

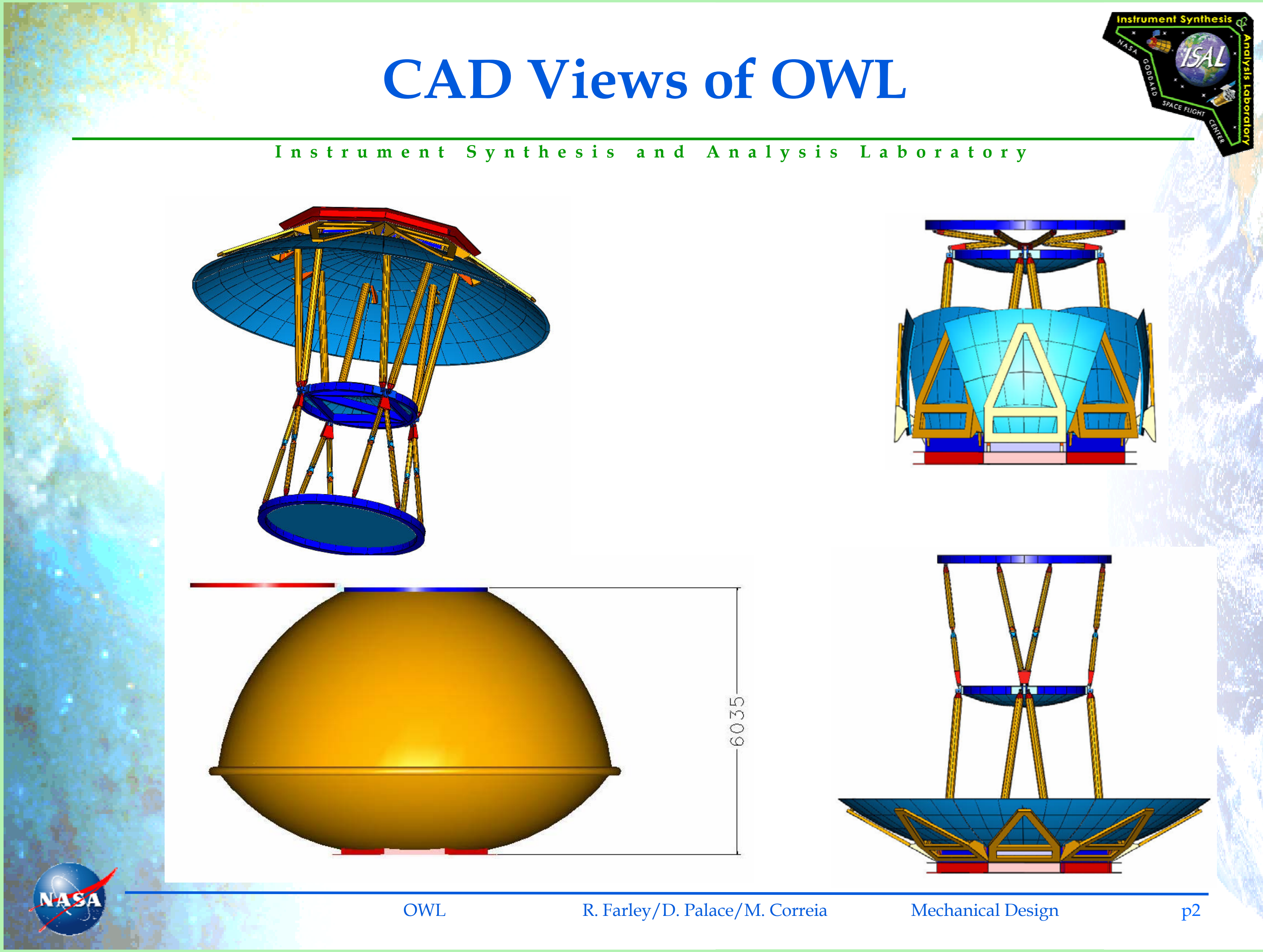
- Validation of the critical technologies, later on, by a dedicated technological small mission.
  - perform functional tests on critical parts of the apparatus (optics deployment, optics performance *in place*, atmosphere control methods);
  - qualify the observational approach (watching, for instance, laser shoots at the Earth);
  - test critical technological items.

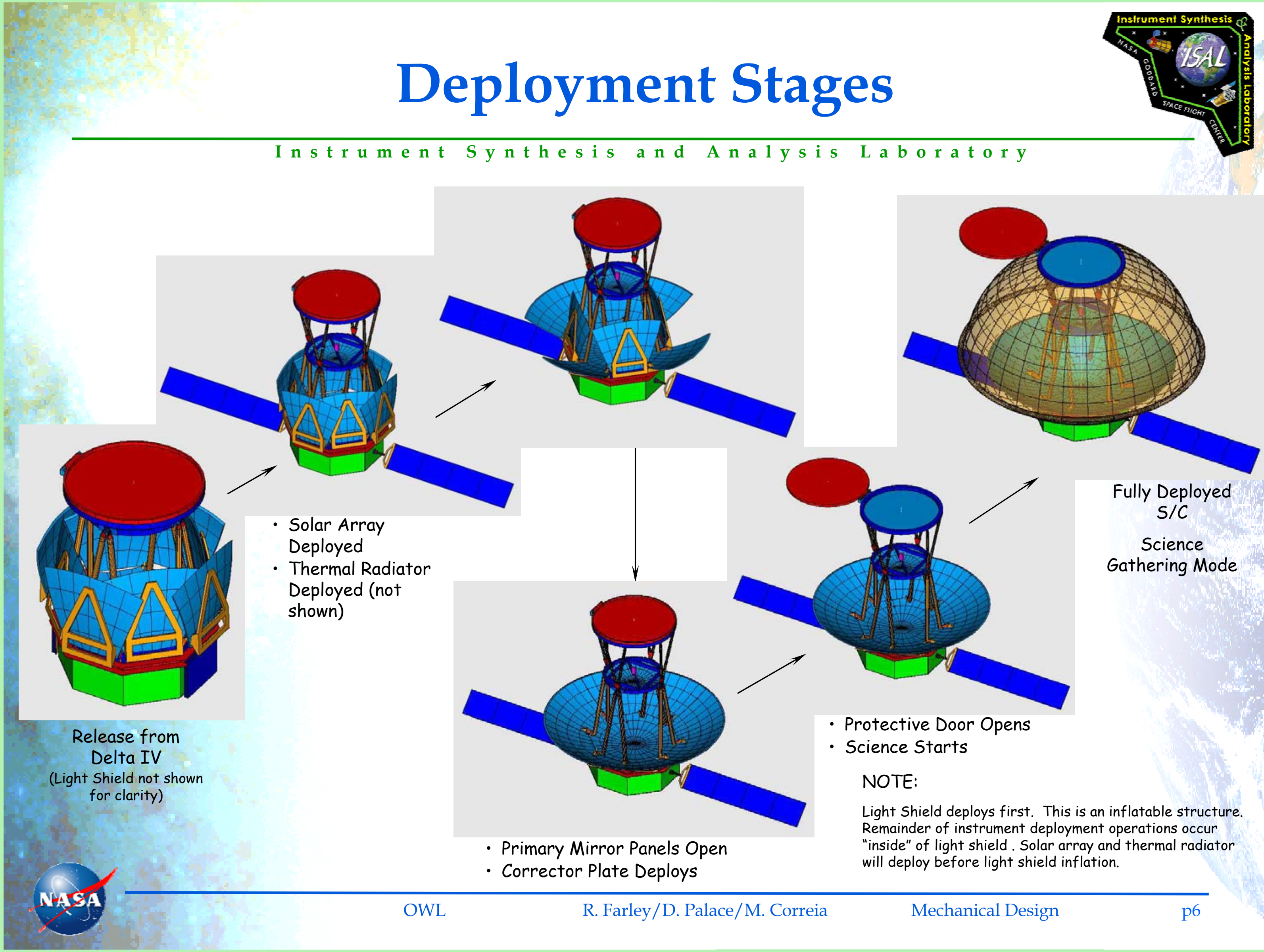
OWL: Orbiting Wide-angle Light-collectors

- A NASA mission on-hold.
- Some Mission parameters (stereo view from space).
  - Two independent telescopes with UV sensitive cameras on two satellites operating in tandem in a low inclination, medium altitude orbit to view in stereo the EAS.
  - Orbit height: 1000 km (first Phase for high-energy), 600 km (second Phase for lower energy).
- Some instrument parameters.
  - Optics: 7-meter diameter deployable Schmidt camera with $f/\# = 1$, $\gamma_{1/2} = 22.5^\circ$ half-FoV and $3.4\ \mathrm{m}^2$ entrance pupil area.
  - Pixel size: 0.17°.
  - Light detector: MAPMT, about 0.5 million pixels.
  - Ancillary instrumentation: one wavelength LIDAR.


Primary Mirror
Focal Plane
Corrector Plate




CAD Views of OWL
Instrument Synthesis and Analysis Laboratory
Instrument Synthesis Analysis Laboratory
ISAL
6035
NASA
OWL
R. Farley/D. Palace/M. Correia
Mechanical Design
p2


Deployment Stages
Instrument Synthesis and Analysis Laboratory
Instrument Synthesis
Analysis Laboratory
ISAL
NASA GODDARD SPACE FLIGHT CENTER
Release from Delta IV
(Light Shield not shown for clarity)
• Solar Array Deployed
• Thermal Radiator Deployed (not shown)
• Primary Mirror Panels Open
• Corrector Plate Deploys
• Protective Door Opens
• Science Starts
Fully Deployed S/C
Science Gathering Mode
NOTE:
Light Shield deploys first. This is an inflatable structure. Remainder of instrument deployment operations occur "inside" of light shield . Solar array and thermal radiator will deploy before light shield inflation.
NASA
OWL
R. Farley/D. Palace/M. Correia
Mechanical Design
p6

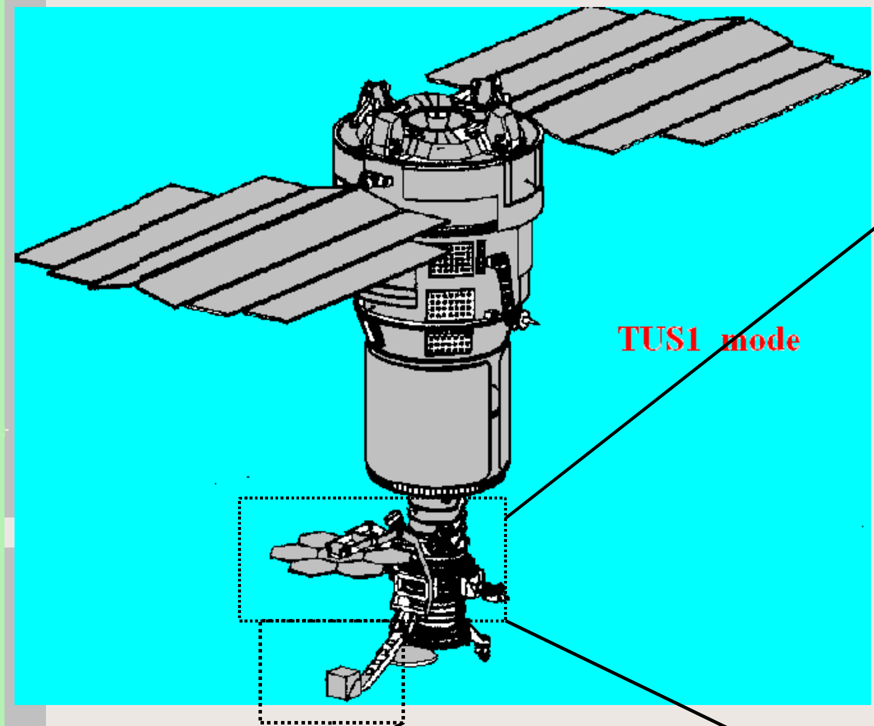
TUS: a precursor

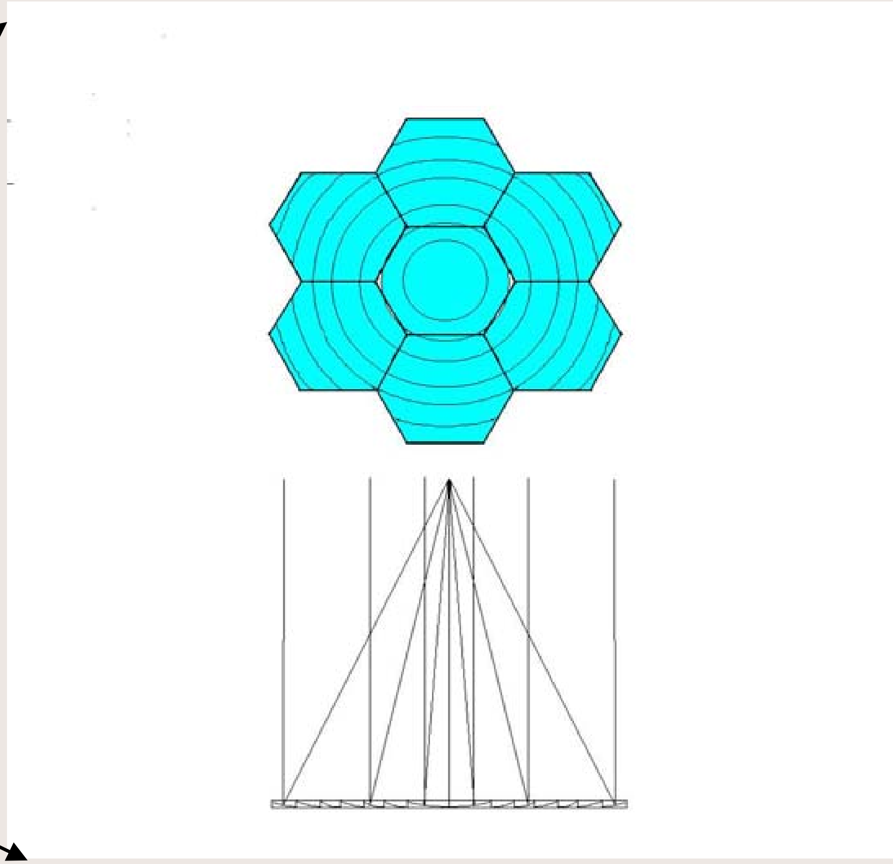
- TUS: a Russian-led project,
  planned as one step of a step-by-step progress in space instrumentation.
- First step (already achieved, TATIANA): checking the photo-receiver operation in space and getting data on the near-UV atmosphere background.
- Second step (TUS): operation in space of a pilot experiment
  with Entrance Pupil diameter $\approx 2\ \mathrm{m}^2$ and 256 pixels.
- The TUS experiment is planned to be launched in 2010 as a precursor.
- Results of the TUS experiment will help to make final design
  of the next generation of space UHECP experiments.
- It will be launched before JEM-EUSO will be constructed
  and it will test some of the JEM-EUSO technologies in space.

TUS/KLYPVE

- TUS/KLYPVE: Russia, Japan, Mexico, Corea and Czech Republic collaboration.
- Some Mission parameters.
  - TUS: prototype of the KLYPVE (ten times larger).
  - Orbit. TUS: 350 km (perigee), 600 km (apogee) elliptic orbit.
  - Orbit. KLYPVE: ≈ 430 km (on the ISS).
- Some instrument parameters.
  - Narrow FoV reflective mirror-concentrator optics.
    - TUS: 1.5-meter diameter modular Fresnel mirror, $f/\# = 1$, $\gamma_{1/2} = 4.6^\circ$ half-FoV.
    - KLYPVE: 3.5-meter diameter modular Fresnel mirror, $f/\# = 1$, $\gamma_{1/2} = 7.2^\circ$ half-FoV.
  - Pixel size: 0.57° (TUS); 0.29° (KLYPVE).
  - Light detector: MAPMT. TUS: 256 pixels; KLYPVE: 2500.
  - Ancillary instrumentation: UV-flash lamp.

The TUS Fresnel mirror operation



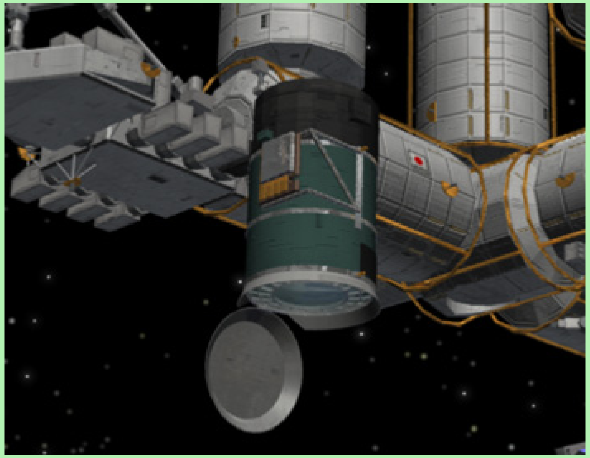
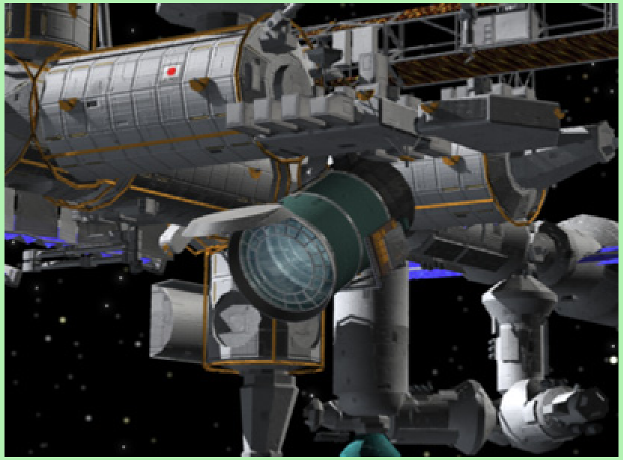


PMTs

Mirror diameter = 1.35 m

JEM-EUSO: a path-finder

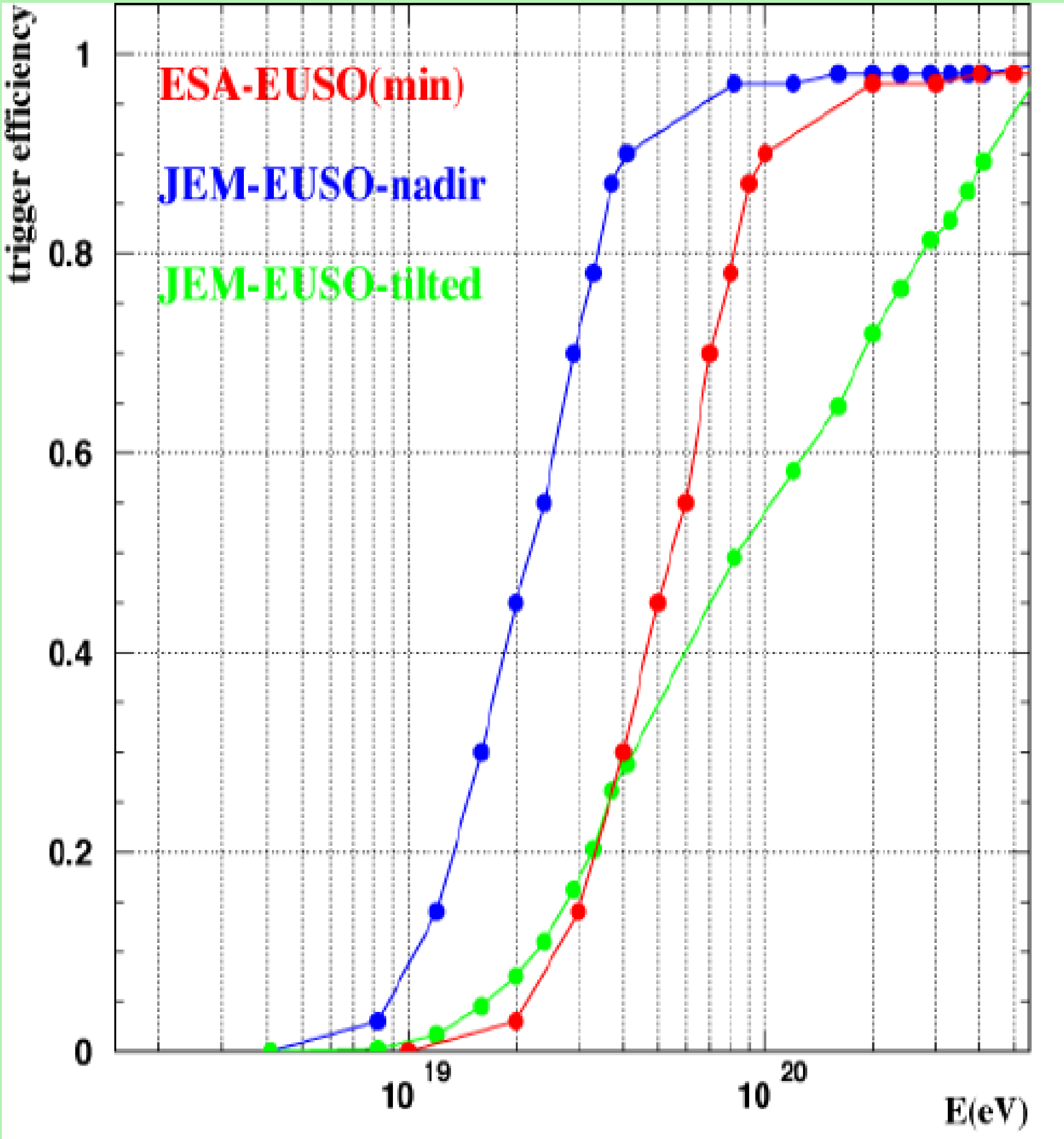
- A renewed proposal for an EUSO-like apparatus on the Japanese module of the ISS carried on by an International Collaboration under JAXA.
- In May 2007 JAXA has selected JEM-EUSO as one of the mission candidates for the second phase utilisation of JEM/EF.
- One year long phase-A study began began in June 2007 under JAXA.

JEM-EUSO: the apparatus

An improved version of EUSO...

- Improve on technological aspects with respect to EUSO:
  - improved optics (new materials giving less aberrations);
  - improved sensor quantum efficiency;
  - improved triggering scheme.


trigger efficiency
1
0.8
0.6
0.4
0.2
0
ESA-EUSO(min)
JEM-EUSO-nadir
JEM-EUSO-tilted
10^{19}
10^{20}
E(eV)

Conclusions

- A space-based apparatus is very challenging:
  technically, politically, financially...
- It is mandatory to clarify the Scientific objectives for post-PAO experiments:
  many trade-offs are required.
- Only a coordinated effort of the world-wide community of UHECP
  can hope for success.
- Planning, R&D and design should start soon,
  to cope with the long time-scale and enter the pipeline:
  volunteers are required...there is a lot of work to do...