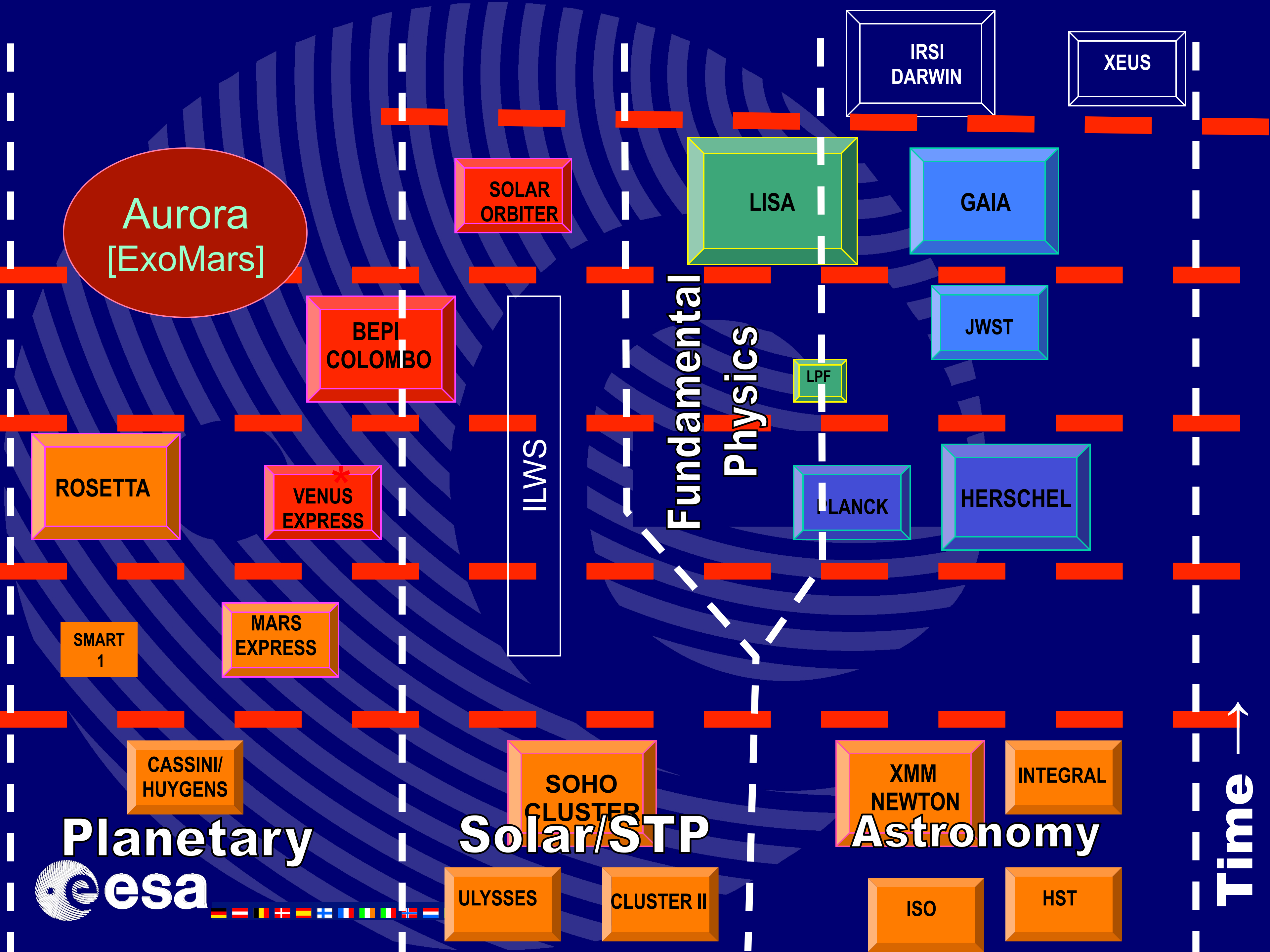
Cosmic Vision 2015 – 2025

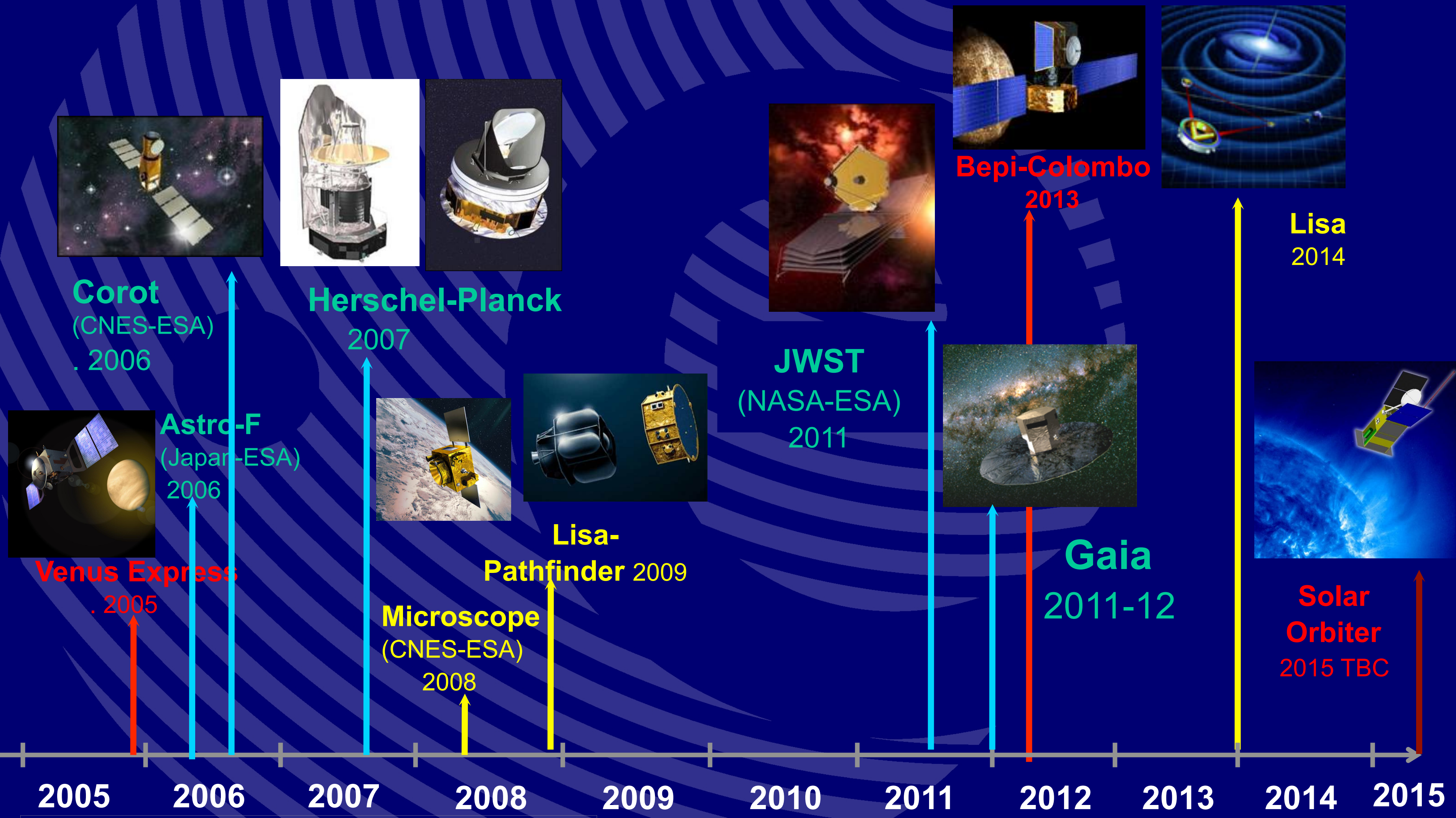
ESA's New Long Term Plan for Space Science

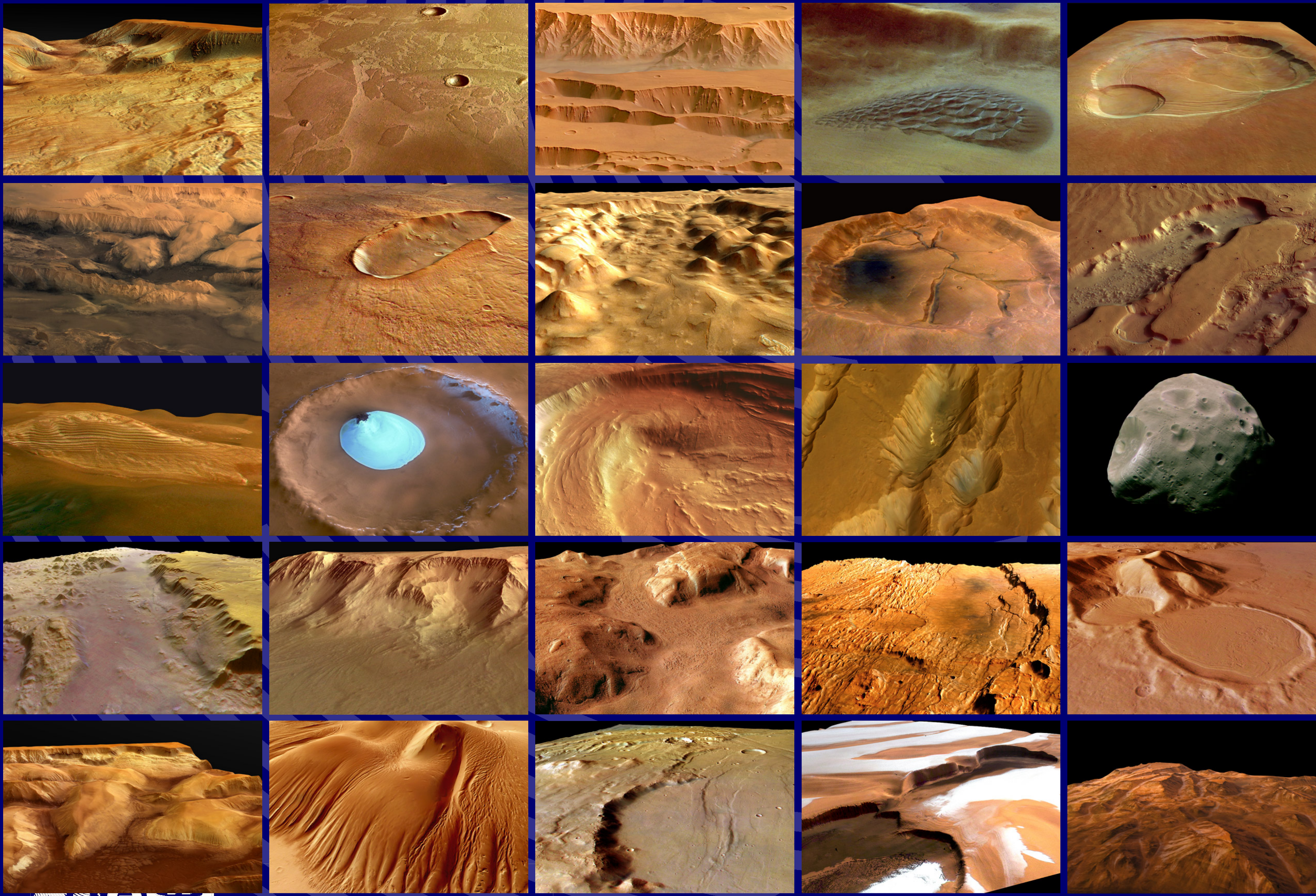
Gerhard H. Schwehm
Head of Solar System Science Operations Division
Directorate of Scientific Programme, ESA

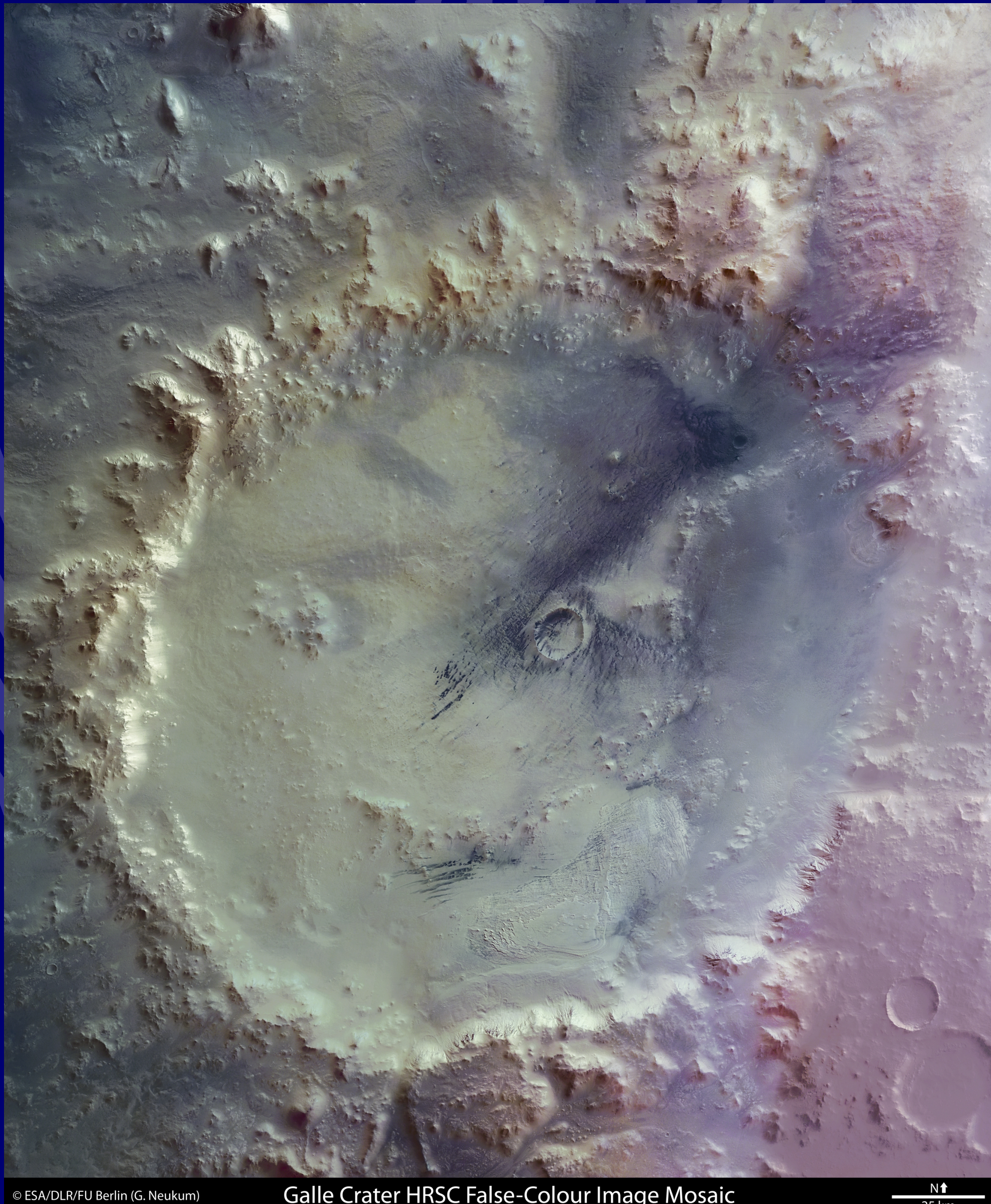
4th IPPW
Pasadena, CA, 27- 30 June 2006

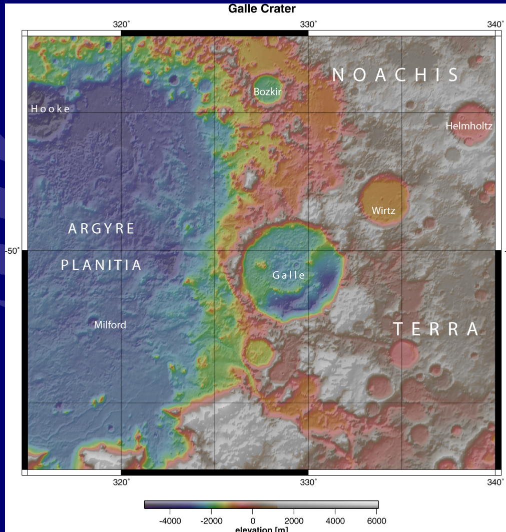

IRSI
DARWIN
XEUS
Aurora
[ExoMars]
SOLAR ORBITER
LISA
GAIA
BEPI COLOMBO
JWST
LPF
ILWS
Fundamental
Physics
ROSETTA
VENUS EXPRESS
PLANCK
HERSCHEL
SMART 1
MARS EXPRESS
CASSINI/ HUYGENS
SOHO CLUSTER
XMM NEWTON
INTEGRAL
Planetary
Solar/STP
Astronomy
ULYSSES
CLUSTER II
ISO
HST
Time →

Missions in preparation



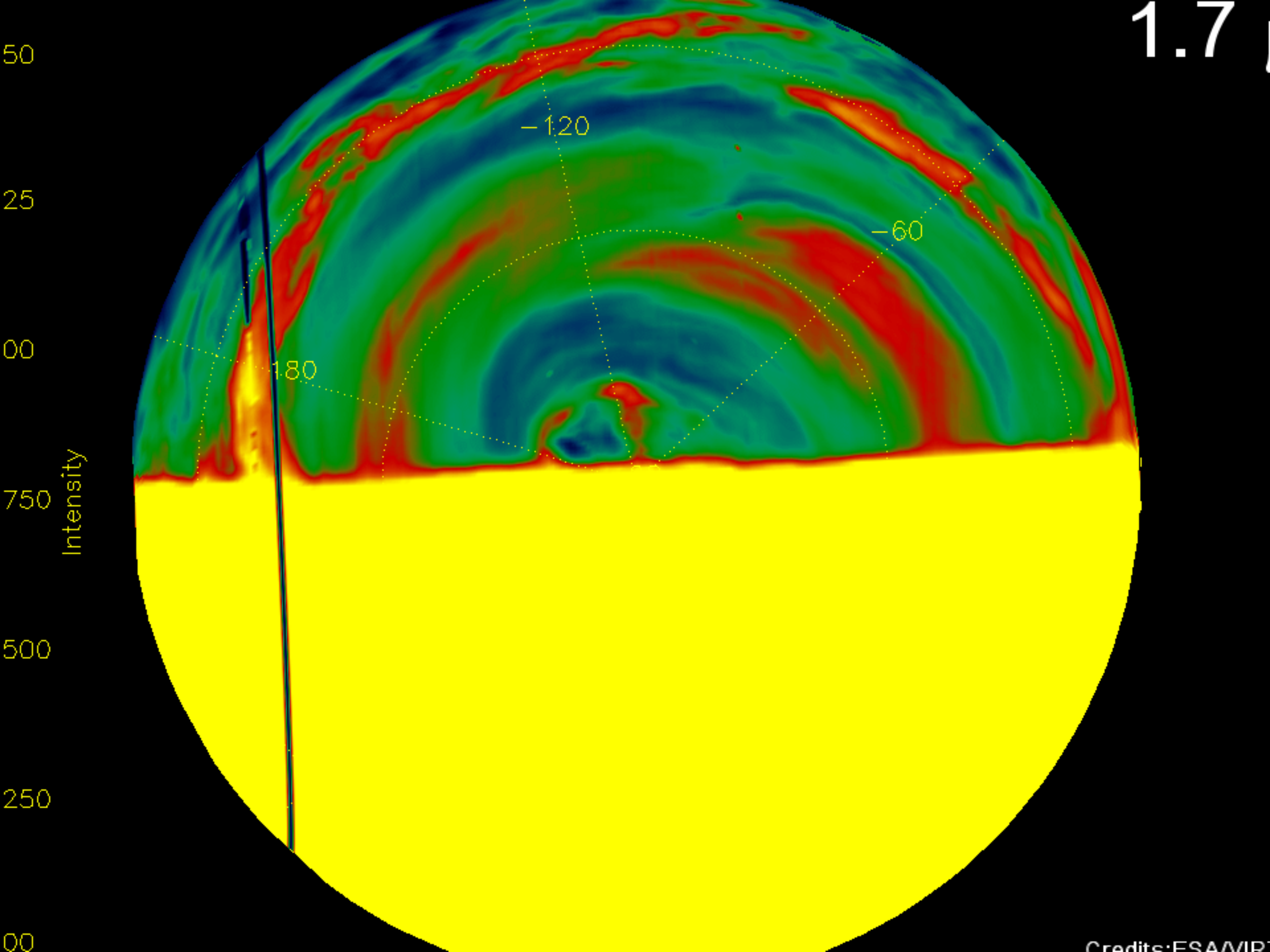






- **HRSC false color mosaic of the Galle crater**
- **(„happy face crater“):**
- **orbits 445, 2383, 2438, 2460, 2493**
- **resolution 10-20 m**
- **crater diameter 230 km**

- **Orbit 3000 on Friday 12. May**
- **19:06 CEST**


1.7
50
25
00
750
500
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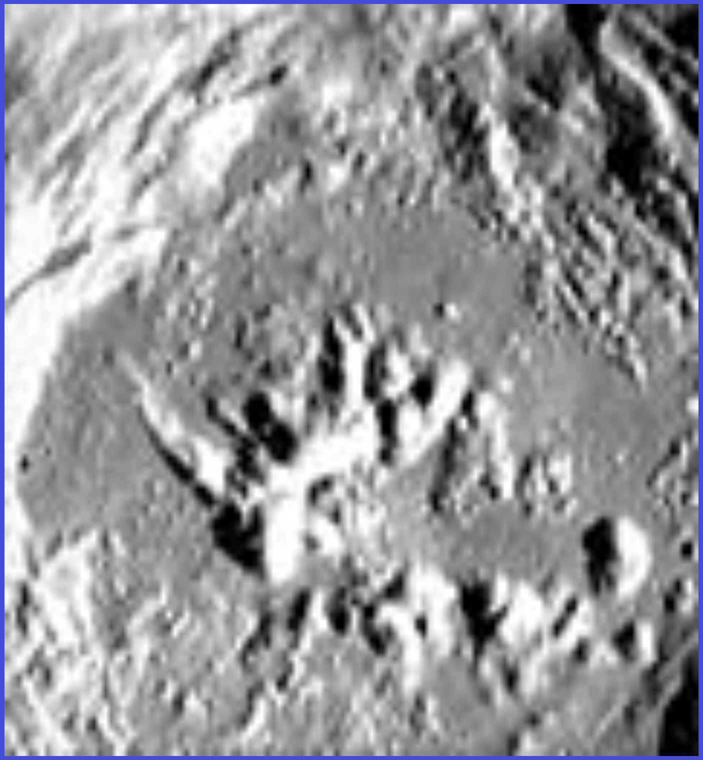
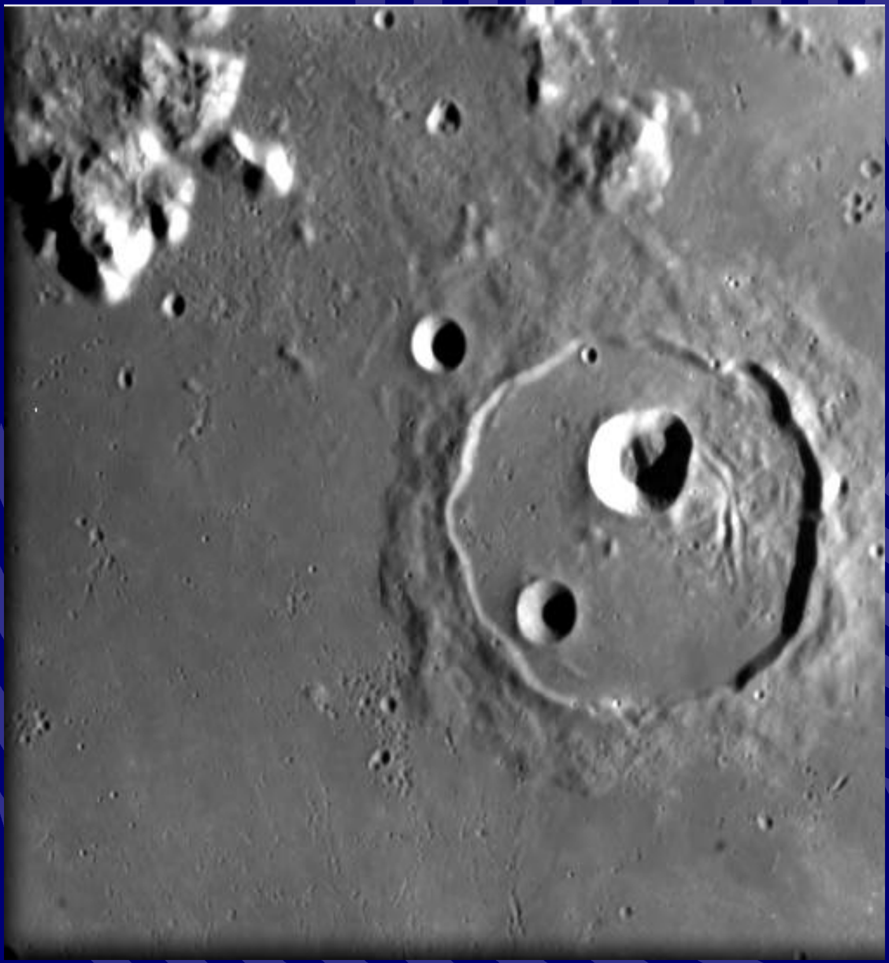
Intensity
−120
−60
180



Crater Zucchius

Crater Hopmann



Crater Cassini, 19 Jan 2005

- Vallis Alpes, 19 Jan 2005

Where are we today?

- Implementation of 'current' Cosmic Vision will be completed by 2015 (launch of BepiC in 2013 and Solar Orbiter – which is the last approved mission in the present programme in 2015/17)

- ESA has more spacecraft in orbit than ever before

- Pressure on budget has increased. Despite increase of Level of Resources at last Ministerial Conference in Dec 2005 there is not too much room to manoeuvre

- MEX and VEX are very successful! – potential mission extensions have to be covered in the Science Programme Budget

Cosmic Vision process

- Cosmic Vision 2015 –2025 process launched on 2 April 04 with call for Science themes
- 1 June 04: deadline for proposal submission
- July 04: Analysis of responses by the ESA Science advisory structure (AWG, SSWG, FPAG, SSAC)
- 15-16 September 04: Workshop in Paris (~400 participants)
- Nov 04: progress report to SPC
- Spring 05: presentation of Cosmic Vision 2015-2025 to community
- May 05: Endorsement of Cosmic Vision by SPC

Response to Cosmic Vision call

- In excess of 150 responses received !
- Horizon 2000 + consultation received less than 100 responses
- Reveals today's strong expectations of the community from the ESA Science Programme

Cosmic Vision proposal evaluation

Proposals evaluated for prime scientific objectives by ESA's working groups

- Astronomy/Astrophysics (AWG)
- Fundamental Physics (FPAG)
- Solar System Science (SSWG)

Space Science Advisory Committee (SSAC) merged working group objectives into 4 grand themes

- Building on scientific heritage from Horizons 2000 missions
- Capitalizing on synergies across disciplines

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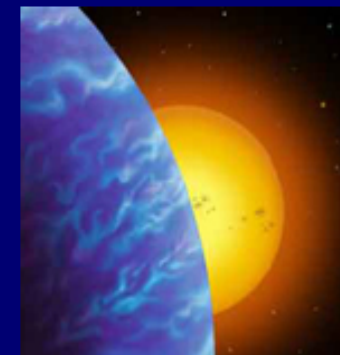
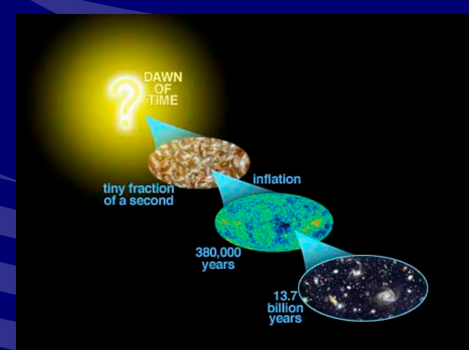
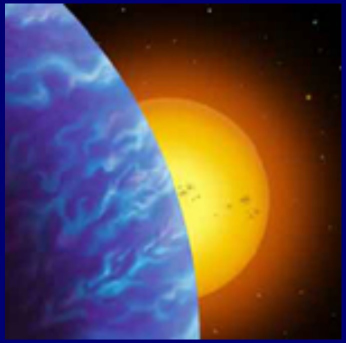
Grand themes

1. What are the conditions for life and planetary formation?
2. How does the Solar System work.
3. What are the fundamental laws of the Universe?
4. How did the Universe originate and what is it made of?



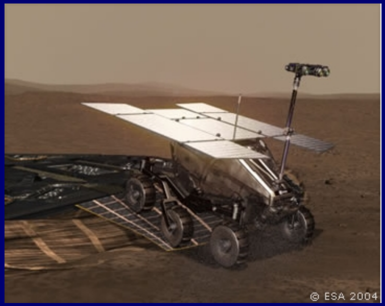


1. What are the conditions for life and planetary formation?



1.1 From gas and dust to stars and planets.

1.2 From exo-planets to bio-markers.



1.3 Life and habitability in the Solar System

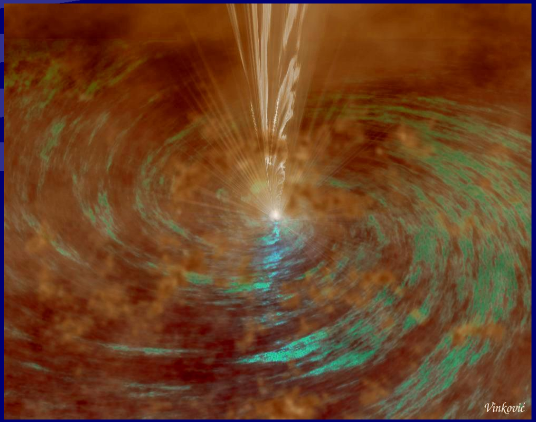
1.1 From gas and dust to stars and planets

Map the birth of stars and planets by peering into the highly obscured cocoons where they form.

Investigate conditions for star and planet formation and evolution

Are there specific characteristics in stars that host planets?

What are the different kinds of planets?



Tool: Far Infrared observatory with high spatial and low to high spectral resolution.

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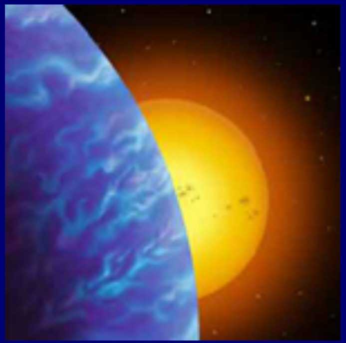
1.2 From exo-planets to bio-markers

Search for and image planets around stars other than the Sun, looking for biomarkers in their atmospheres



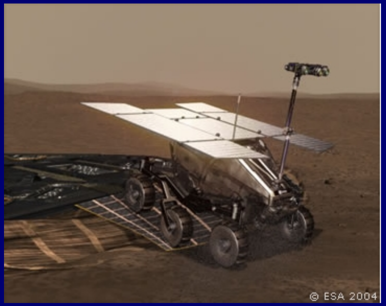
Census of exo-planets from high accuracy astrometry Detection of planets of smaller mass in the habitable zone from high accuracy photometric transits .

Direct detection of Earth-like planets. Physical and chemical characterization of their atmospheres for the identification of unique biomarkers.

Tool: Space nulling interferometer with near to mid-infrared low resolution spectroscopy capability.

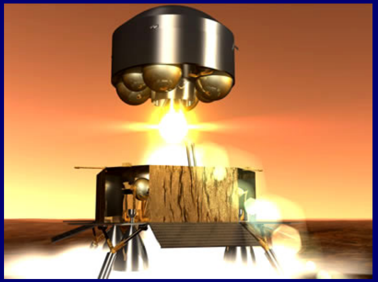
1.3 Life and habitability in the Solar System

Explore 'in situ' the surface and subsurface of the solid bodies in the Solar System more likely to host –or have hosted- life.

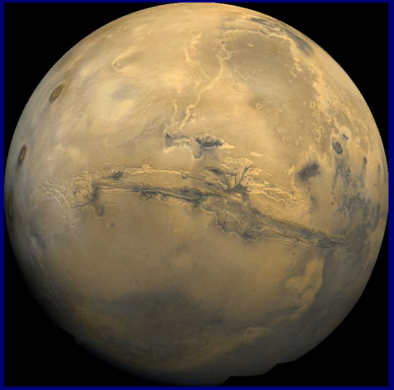


Appearance and evolution of life depends on environmental conditions (geological processes, water presence, climatic and atmospheric conditions)

Mars is ideally suited to address key scientific questions of habitability. Europa is the other priority for study of internal structure, composition of ocean and icy crust and radiation environment around Jupiter.



Tools: Mars exploration with in-situ measurements(rovers) and sample return. Dedicated Europa orbiter (lander) on Jupiter Explorer Probe (JEP).



2. How does the Solar System work ?

2.1 From the Sun to the edge of the Solar System

2.2 The building blocks of the Solar System, gaseous giants and their moons

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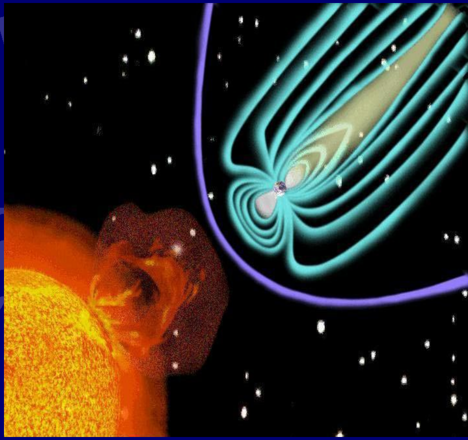
2.1 From the Sun to the edge of the Solar System

Study the plasma and magnetic field environment around the Earth, the Jovian system –as a mini Solar System-, the Solar poles and the heliopause where the Solar influence area meets the interstellar medium.

The structure of the magnetic field at the solar surface requires in particular, observations from above the poles to understand the field's origin.

The Solar System pervaded by the solar plasma and magnetic field provides a range of laboratories to study the interactions of planets (Jupiter) with the solar wind

In-situ observation of the heliopause would provide ground truth measurements of the interstellar medium .



Tools: Solar Polar Orbiter, Earth magnetospheric swarm, Jupiter Probe, Interstellar Helio-Pause Probe.

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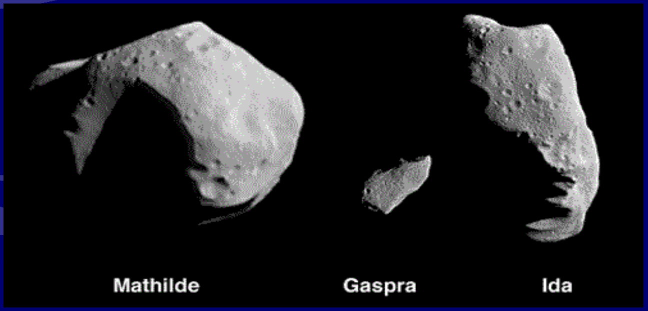
2.2 The building blocks of the Solar System, gaseous giants and their moons

Study Jupiter In-situ , its atmosphere and internal structure. Obtain direct laboratory information of the building blocks of the Solar System by analysing samples from a Near-Earth Object (NEO).

Giant planets with their rings,diverse satellites and complex environments, constitute systems which play a key role in the evolution of planetary systems.

As primitive building blocks in the solar system, small bodies give clues to the chemical mixture and initial conditions from which the planets formed in the early solar nebula



Tools: Jupiter Explorer Probe/JEP, NEO sample return

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3. What are the fundamental laws of the Universe?

3.1 Explore the limits of contemporary physics

3.2 The gravitational wave Universe

3.3 Matter under extreme conditions

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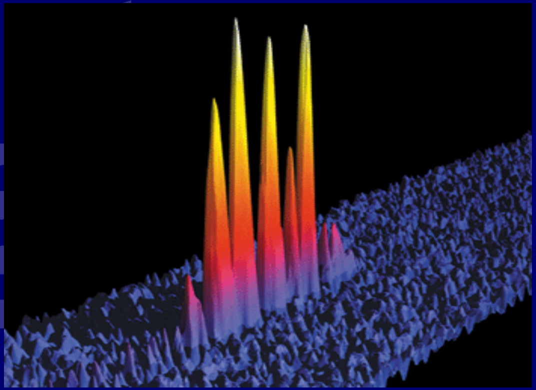
3.1 Explore the limits of contemporary physics

Probe the limits of classical GR, symmetry violations (CPT Lorentz, isotropy), fundamental constants, Short Range Forces, Quantum Physics of Bose-Einstein Condensates (BEC), Cosmic rays to look for clues to Unified Theories .

Use the stable and gravity-free environment of space to implement high precision experiments to search for tiny deviations from the standard model of fundamental interactions: Galileo's equivalence principle, gravity at very small distances, gravity on Solar System scale, time variability of fundamental constants, quantum gravity (entanglement and decoherence experiments with BEC's). Investigate dark matter from Ultra High Energy particles.



Tool: Fundamental Physics Exlorer programme

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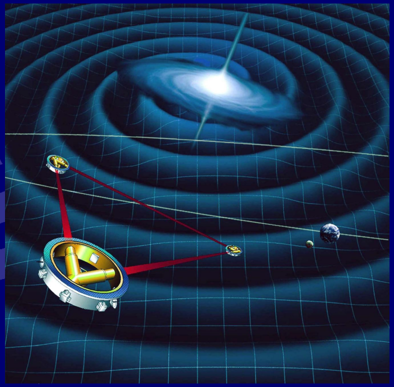
3.2 The gravitational wave Universe

Detect and study the gravitational radiation background generated at the Big Bang (BB). Probe the universe at high red shift and explore the dark universe.



Primordial gravitational waves (Cosmic Gravitational Wave Background) produced close to BB, unaffected by matter, are ideal probes of the laws of physics at the highest energies and temperatures at which physics is presently understood. They open an ideal window to probe the very early Universe and dark energy at very early times.

Tool: Gravitational Wave Cosmic Surveyor

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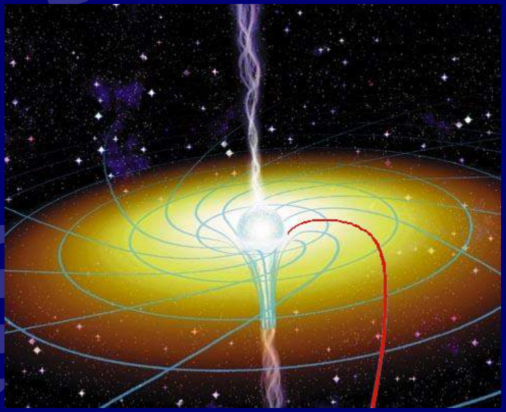
3.3 Matter under extreme conditions

Probe General Relativity in the very strong field environment of Black Holes (BH) and compact objects, as well as the equation of state of matter at supra-nuclear energies in Neutron Stars (NS).

BHs and NSs are unique laboratories where the laws of physics can be investigated under the most extreme conditions for matter in the Universe in terms of gravity and temperatures. Super- massive BHs formed very early in the centres of galaxies are believed to have powered the quasars and played a key role in the evolution of the host galaxies. The study of the spectrum and time variability of radiation from matter near BHs carry the imprint of the curvature of space-time as predicted by general relativity. This has strong implications not only for the understanding of BHs themselves but also for astrophysics and cosmology in general.

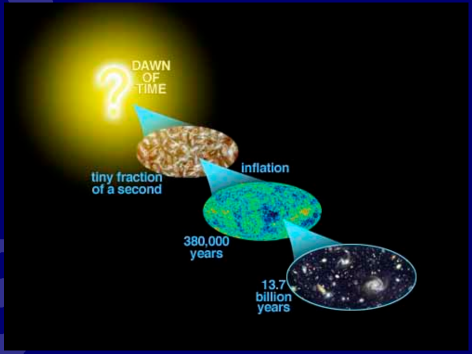


Tools: Large aperture X-ray observatory, gamma-ray observatory.

4. How did the Universe originate and what is it made of?

4.1 The early Universe

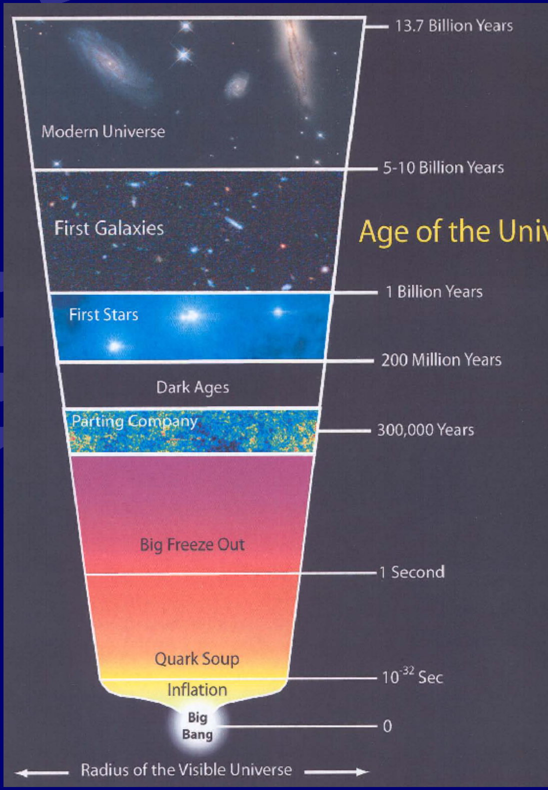
4.2 The Universe taking shape



4.3 The evolving violent Universe

4.1 The early Universe

Investigate the physical processes that lead to the inflationary phase in the early Universe during which a drastic expansion took place. Investigate the nature and origin of the Dark Energy that currently drives our Universe apart.



Imprints of inflation are related to the polarization parameters of anisotropies of the Cosmic Microwave Background (CMB) due to primordial gravitational waves from BB. Dark energy can be studied in the gravitational lensing from cosmic large scale structures and the measurement of the luminosity-redshift relation of distant Super Novae (SN) Ia.

Tools: All-sky CMB polarisation mapper, Gravitational Wave Cosmic Surveyor. wide-field optical-near IR imager.

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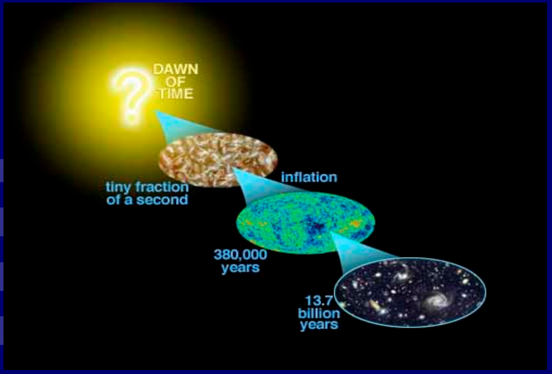
4.2 The Universe taking shape

Find the very first gravitationally bound structures assembled in the early Universe - precursors to today's galaxies, groups and clusters of galaxies- and trace their evolution to the current epoch.

The very first clusters of galaxies back to their formation epoch are keys to study their relation to AGN activity and the chemical enrichment of the Inter Galactic Medium. Also important are the studies of the joint galaxy and super-massive BH evolution, the resolution of the far IR background into discrete sources and the star-formation activity hidden by dust absorption.

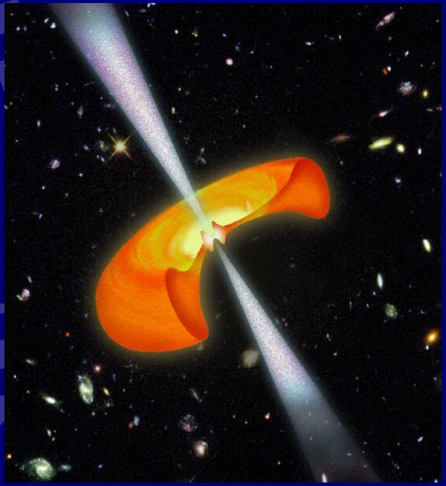


Tools: Large aperture X-ray observatory, far-infrared imaging observatory

4.3 The evolving violent Universe

Trace the formation and evolution of the super-massive black holes at galaxy centres –in relation to galaxy and star formation- and trace the life cycles of matter in the Universe along its cosmic history.

BHs are the driving engines of the birth and evolution of galaxies, the creation of heavy elements and more generally, of the transformation of matter from which stars and galaxies form. The super massive BHs at the centre of most galaxies allow to study the interplay between their formation and evolution and that of the host galaxies. Matter falling onto BHs carry the spectral and time variability imprints of the accretion process. By probing deep inside the potential well of BHs, it will be possible to study the huge amounts of gas involved in binary BH mergers and understand the processes at work in SN and Hypernova explosions which lead to Gamma Ray Bursts (GRB) and the enrichment of the interstellar and intergalactic medium in heavy elements.



Tools: Large aperture X-ray observatory, gamma-ray observatory.

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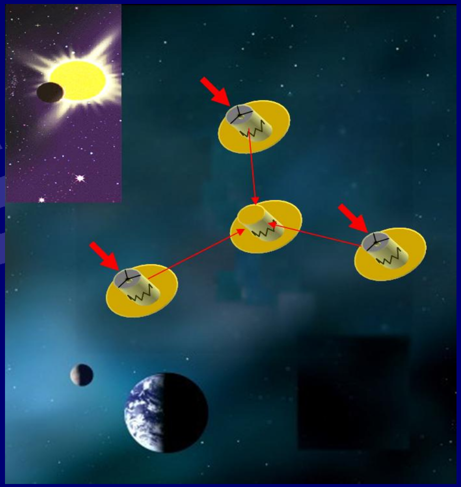
Astronomy roadmap
Observatory-type missions

2015 - 2020

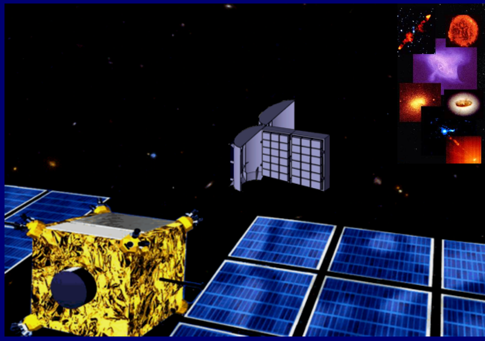


Direct detection and spectroscopy of terrestrial planets, search for biomarkers

Mid-IR NULLING INTERFEROMETER

Clusters of galaxies back to their formation epoch, warm-hot IGM, mergers of SMBH, accreting BH, Quasi-Periodic Oscillations, equation of state of neutron stars, nuclear matter vs quark matter

LARGE APERTURE X-RAY OBSEVATORY



Astronomy roadmap
Observatory-type missions

2020-2025

Star formation, imaging and spectroscopy of protostars and protoplanetary disks, resolution of far-IR background into discrete sources, star formation regions, cool molecular clouds

Far- IR OBSERVATORY

Astronomy roadmap
Focussed missions

2015-2025

Probe dark energy from high Z SNIa and weak lensing

OPTICAL-NIR WIDE FIELD IMAGER

Probe inflation from shape of the primordial fluctuations

ALL SKY CMB POLARIZATION MAPPER

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Astronomy roadmap
Further missions

Census of terrestrial planets within 100 pc,

ULTRA HIGH PRECISION ASTROMETRY

OPTICAL-UV SPECTROSCOPY

Isotope abundances, physics of SN, origin of cosmic rays, origin of antimatter

GAMMA RAY IMAGER (MeV)

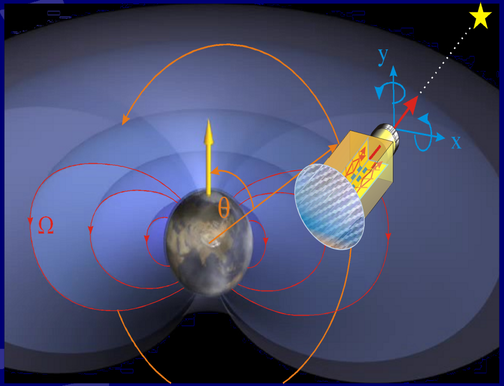
Warm/hot IGM spectroscopy, UV light-curves of SNIa as low-z templates for high-z sources

HIGH RESOLUTION UV SPECTROSCOPY

Fundamental Physics Missions

2015-2020

Probe Grand Unified Theory and gravitation i.e. measure tiny deviations from GR and SM in ultra sensitive, high precision experiments



FUNDAMENTAL PHYSICS EXPLORER

2020-2025

Probe very early Universe (close to BB) and laws of physics at highest possible energies from detection of primordial gravitational waves

GRAVITATIONAL WAVE COSMIC EXPLORER

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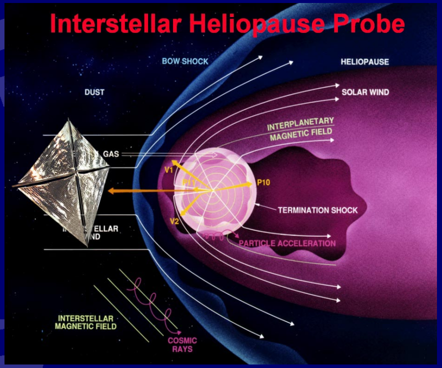
Solar System Science Missions

2015-2025

Look at Small Scales! Understand Space plasmas

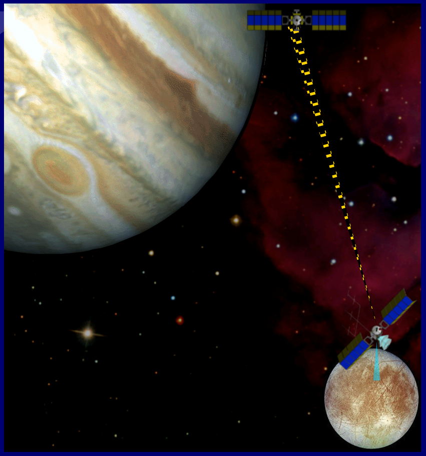
EARTH MAGNETOSPHERIC SWARM, SOLAR POLAR ORBITER, HELIOPAUSE PROBE



2020

Go Outward! Explore the outer Solar System

JUPITER & EUROPA PROBE



Solar System Science Missions

2015-2020

Look for Life! Everywhere in Solar System

Mars rovers and sample return, Europa Probe

2020-2025

Seek Ground Truth! Land on NEOs, Moons, Planets,look below surface, return samples

Jupiter and Europa Probe, NEO Sample Return

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From themes to proto-missions

How does the Solar System work ?

From the sun to the edge of the solar system
- Solar-Polar Orbiter (Solar Sailor)
- Helio-pause Probe (Solar Sailor)
- Earth Magnetospheric Swarm
- Jupiter Magnetospheric Explorer (JEP)

The Giant Planets and their environment
- Jupiter Magnetospheric Explorer (JEP)
- Jovian In-situ Planetary Observer (JEP)
- Europa Orbiting Surveyor (JEP)

Asteroids and small bodies
- Kuiper belt Explorer
- Near Earth Asteroid sample & return

What are the conditions for life & planetary formation ?

From dust and gas to stars and planets
- Far Infrared Interferometer

From exo-planets to biomarkers
- Near Infrared Terrestrial Planet Interferometer

Life & habitability in the solar system
- Europa Orbiting Surveyor (JEP)
- Mars In-situ Programme (Rovers & sub-surface)
- Mars sample and return

Looking for life beyond the solar system
- Terrestrial Planet Astrometric Surveyor
- Terrestrial-Planet Spectroscopic Observer
- Terrestrial Planet Imaging Observer

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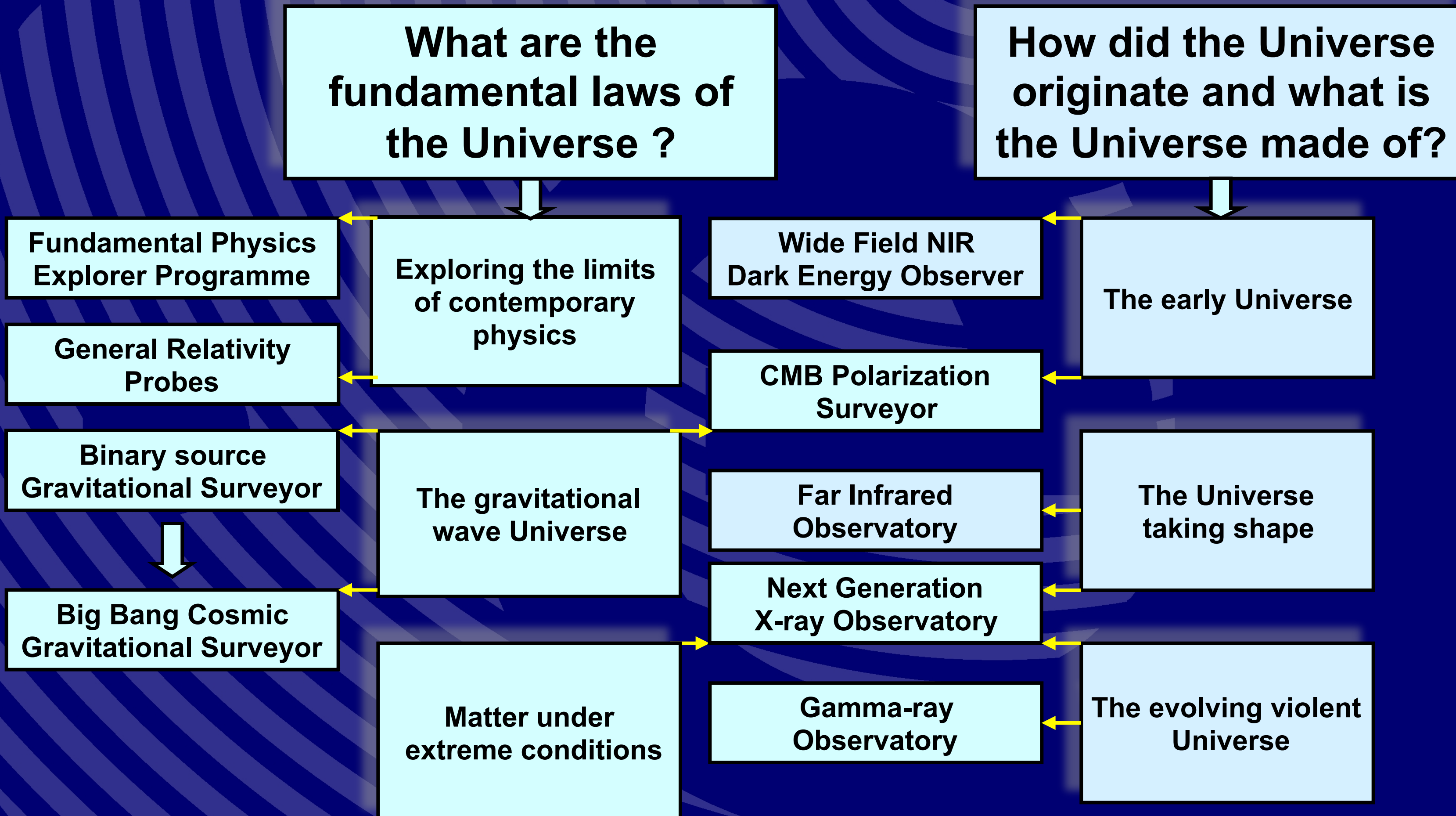
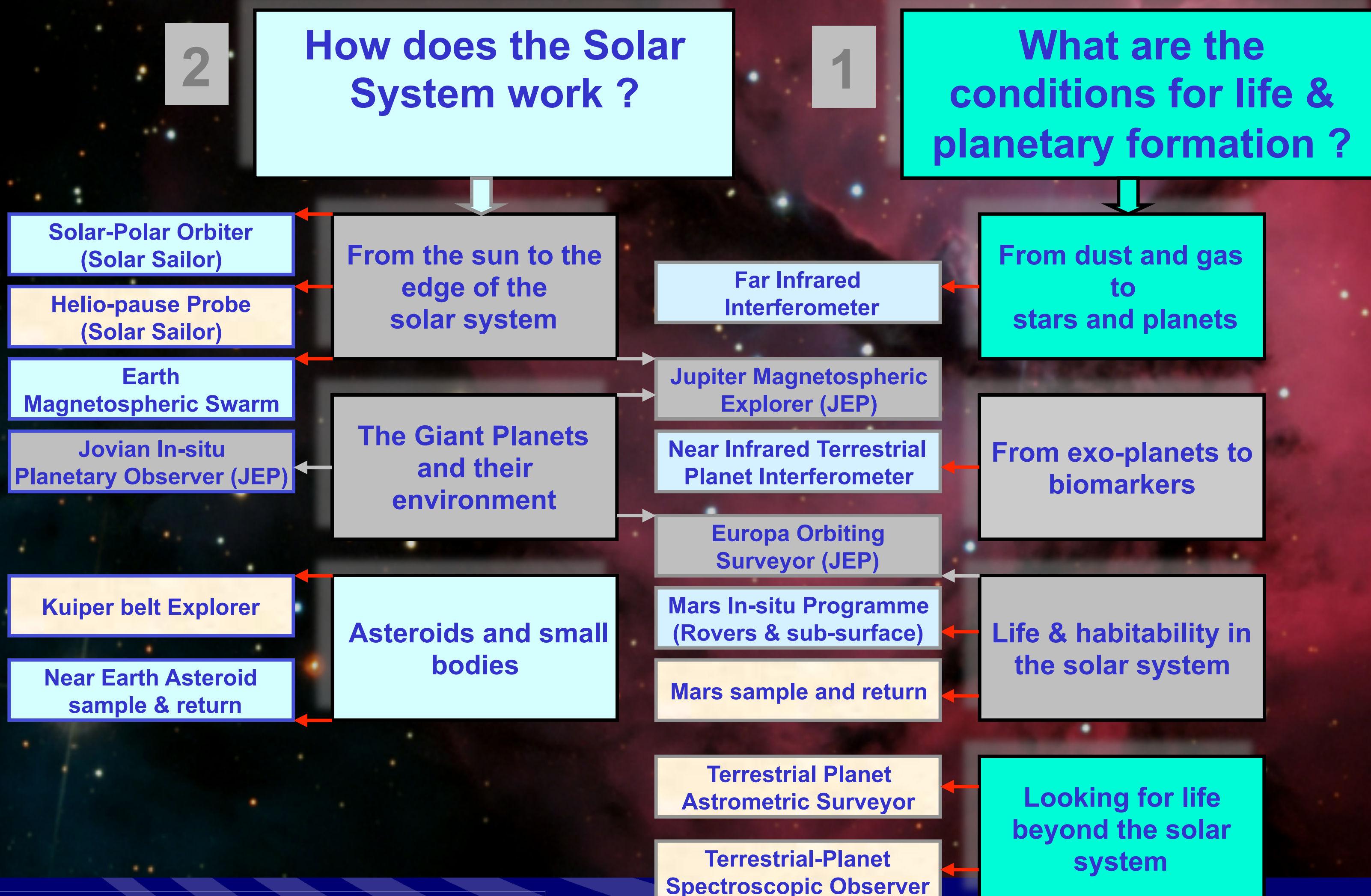
From themes to proto-missions

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How does the Solar System work ?
1
What are the conditions for life & planetary formation ?
Solar-Polar Orbiter (Solar Sailor)
Helio-pause Probe (Solar Sailor)
Earth Magnetospheric Swarm
Jovian In-situ Planetary Observer (JEP)
From the sun to the edge of the solar system
The Giant Planets and their environment
Kuiper belt Explorer
Near Earth Asteroid sample & return
Asteroids and small bodies
Far Infrared Interferometer
Jupiter Magnetospheric Explorer (JEP)
Near Infrared Terrestrial Planet Interferometer
Europa Orbiting Surveyor (JEP)
Mars In-situ Programme (Rovers & sub-surface)
Mars sample and return
Terrestrial Planet Astrometric Surveyor
Terrestrial-Planet Spectroscopic Observer
From dust and gas to stars and planets
From exo-planets to biomarkers
Life & habitability in the solar system
Looking for life beyond the solar system

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Cosmic Visions Themes 3 & 4

3 What are the fundamental laws of the Universe ?

- **Exploring the limits of contemporary physics**
  - Fundamental Physics Explorer Programme
  - General Relativity Probes
- **The gravitational wave Universe**
  - Binary source Gravitational Surveyor
  - Big Bang Cosmic Gravitational Surveyor
  - CMB Polarization Surveyor
- **Matter under extreme conditions**
  - Next Generation X-ray Observatory

4 How did the Universe originate and what is the Universe made of?

- **The early Universe**
  - Wide Field NIR Dark Energy Observer
  - CMB Polarization Surveyor
- **The Universe taking shape**
  - Far Infrared Observatory
  - Next Generation X-ray Observatory
- **The evolving violent Universe**
  - Next Generation X-ray Observatory
  - Gamma-ray Observatory

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Some Possible Embryonic Programmes

What are the conditions for the origins of life ?

Life & habitability in the solar system

The building blocks Of the solar system

From the Sun to the Edge of the solar system

Looking for life beyond the solar system

Europa Explorer- JEP

Jupiter Explorer- JEP

FIRI (extra solar)

Jupiter Magneto-Swarm

Solar-Polar Orbiter

Helio-pause Probe

NIRI

Linked outer planet MiniSat programme

Linked programme With Solar Sails

Interferometers @L2 FF & Constellation

COSMIC VISION 2015 – 2025

Potential implementation

• Potential Financial Envelope

• 10 years total ~ 3.0 B€
for Astrophysics, Fundamental Physics, Solar System Exploration

Target CaC's ref. SPC paper 2005/28

BC < 650 M€
GAIA = 550 M€
SolO = 410 M€
LISA PF = 185 M€
JWST NIRSPEC = 160 M€

Assume ~3.0 B€ / 3 slices = 1.00 B€ per slice
(ref. CV1525 Brochure BR 247 page 90)

- *Examples of simple financial combinations*
  - 1 extra large (Rosetta class ~1 B€ range)

or 1 larger and 2 smaller missions (600 M€ + 2 x ~ 300 M€)
[~ BC + LISA-PF+ SolO)
or 3 medium (3 x ~ 400M€) (~ 3 SolO)

- ⇨ First Mission ~ 300 M = Significant cost constraint !

What's ahead

A call for mission proposals will be issued in autumn 2006.

Teams have already formed to prepare proposals in response to AO

Competitive selection for study early 2007

In 2009 competitive selection of first missions in the Cosmic Vision 2015-2025 programme