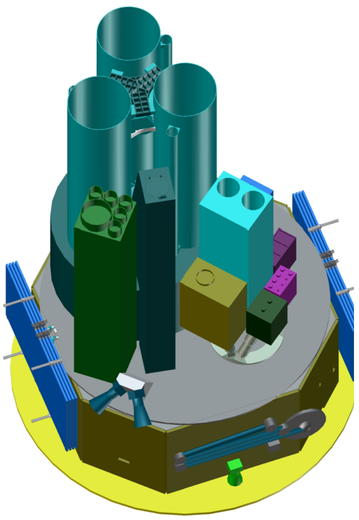
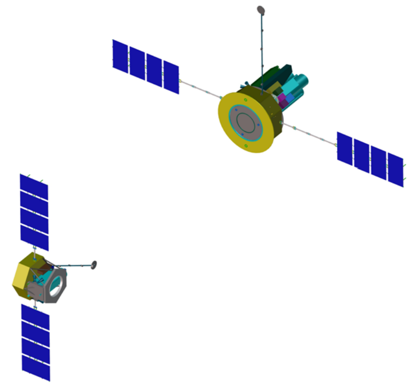
HiRISE/NEOCE

High Resolution Imaging and Spectroscopy Explorer/ New External Occulting Coronagraph Experiment



A new generation, ultrahigh resolution, interferometric and coronagraphic, Solar Physics mission



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Guyancourt, September 16, 2014

HiRISE/NEOCE ESA/M4 Letter of Intent

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Science Objectives

Recent solar physics missions have shown the definite role of waves and magnetic field deep in the inner corona, at the chromosphere-corona interface, where dramatic and physically dominant changes occur. The scientific rationale of HiRISE (*High Resolution Imaging and Spectroscopy Explorer*), the ultimate new-generation ultrahigh resolution, interferometric and coronagraphic, solar physics mission is to address these issues and provide the best-ever and most complete *solar observatory*, capable of observations of the solar atmosphere, from the photosphere to the corona, and provides new insights of the solar interior from the core to the photosphere. It is a truly major revolution in solar physics.

Despite excellent progress in recent years in understanding the link of the solar atmosphere to coronal dynamics and coronal heating there remain major crucial questions that are still unanswered. Limitations in the observations are one important reason. Both theoretical and observational considerations point to the importance of small spatial scales of impulsive energy release, dominant dynamics and extreme plasma non-uniformity. Consequently, high spatial resolution, broad temperature coverage with high temperature fidelity and sensitivity to velocities and densities, are all critical observational parameters. Current instruments lack one or more of these much-needed properties for major leaps. Recent novel ideas about coronal heating and diagnostics emphasize that high spatial resolution observations, especially combining spectroscopic and imaging observations, are absolutely necessary to make major progress on this fundamental problem of modern astrophysics. In particular, the critical region between the chromosphere and corona, the transition zone, needs to be addressed as well as measuring the nature and connectivity of magnetic fields from the photosphere to the corona, directly.

The global understanding of the solar environment through the magnetic field emergence and dissipation, and its influence on Earth, is at the centre of the four major thematics addressed by HiRISE/NEOCE. They are interlinked and also complementary: the internal structure of the Sun determines the surface activity and dynamics that trigger magnetic field structuring which evolution, variation and dissipation will, in turn, explain the coronal heating onset and the major energy releases that feed the influence of the Sun on Earth. The major themes of HiRISE/NEOCE are:

1. to reveal and understand the detailed structure and evolution of the solar atmosphere. HiRISE/NEOCE's high-resolution imaging and spectroscopy will trace the Sun's magnetic field structure and evolution from the deep photosphere to corona. It will reveal the links between the building layers of the Sun's atmosphere. It will track the complete evolution of magnetically-driven processes from the smallest scales to the largest, address magnetic emergence, evolution and reconnection, the development and regression of active regions, the development and nature of transient events in the magnetised atmosphere, the onset and fine-structure of flares from the smallest (e.g. nanoflare scales) to the largest (white light flares), and the propagation of magnetic activity through the different regimes of the solar atmosphere.
2. to answer longstanding and fundamental solar physics questions: how is the corona heated? How does magnetic energy build upon the corona? What is the role of fine structure (strands)? Of convective motions? Waves, wave and/or ion-cyclotron, shock acceleration, dissipation and energisation? How and where are the different components of the solar wind, slow and fast, accelerated? How are Coronal Mass Ejections accelerated? What is the strength of the coronal magnetic field? What is the magnetic building block of the corona? Its topology, connectivity and coupling role? HiRISE/NEOCE, with its unique set of coronagraphs, externally occulted for inner corona access, and ultraviolet for direct magnetic field measurement in the corona, has the privilege to directly address these questions.
3. to evidence the internal, sub-photospheric structure of the Sun, the transfer from the radiative to the convection zone, the role of the tachocline, the links between internal flows and the magnetic cycle. Magnetic activity and its variations are the consequences of the internal regimes of convection. *g*-modes and long-period *p*-modes are the only known modes capable to penetrate deeply enough to constrain the solar dynamics of the core. These modes will be looked for at the limb and in the UV, where their amplitude is expected to be 4-5 times greater than with full-disc measurements, and, with multi-points velocity measurements of increased sensitivity. In addition, second-generation observations of local magnetically

influenced oscillations guarantee the correct understanding of the transition from inside to outside the Sun, from sub-surface to surface flows and manifestations.

4. to measure and understand the profound influence of the Sun on Earth and the consequences for human life through the predictions of long-term climatic changes. For this, HiRISE/NEOCE carries a new-generation of solar shape, solar constant, stratospheric UV and IR flux inputs, Lyman-alpha imaging and *in-situ* measurements of the solar wind at L1. They are necessary to measure and follow in great details the solar inputs received on Earth and their local and global variations with high precision.

HiRISE/NEOCE, at the L1 Lagrangian point, provides meter class FUV imaging and spectro-imaging, EUV and XUV imaging and spectroscopy, magnetic fields measurements, and ultimate coronagraphy by a remote external occulter (2 satellites in formation flying 375 m apart: coronagraph on chaser satellite). This major and state-of-the-art payload will allow to characterize temperature, densities and velocities in the solar upper chromosphere, transition zone and inner corona with, in particular, 2D very high resolution multi-spectral imaging-spectroscopy, *direct* coronal magnetic field measurement: a unique set of tools to understand the structure and onset of coronal heating. HiRISE's objectives are natural complements to the Solar-Probe-type missions lacking duty cycle, high resolution, spatial, spectral and temporal multi-temperature diagnostics and full coronal magnetometry. HiRISE will address:

- fine structure of the chromosphere-corona interface by 2D spectroscopy in FUV at very high resolution;
- coronal heating roots in inner corona by ultimate externally-occulted coronagraphy;
- resolved and global helioseismology thanks to continuity and stability of observing at L1 Lagrange point;
- solar variability and space climate with a global comprehensive view of UV variability as well.

<u>Fine structure of the chromosphere-corona interface</u>. The most interesting and novel observations will be made by a cophased interferometer of 1.4 meter baseline coupled to a UV double monochromator and Imaging Fourier Transform Interferometer to join high spatial, temporal and spectral resolutions, and to a visible 8 channels Vector Magnetograph. By using interferometry in the UV with a spectral-imaging mode, HiRISE will allow remote sensing of the solar surface and atmosphere with an unprecedented spatial resolution of 20 km on the Sun that Solar Probes or Orbiters, despite their closer distance to the Sun, will never be able to achieve! High resolution EUV and X-ray imagers and spectrometer complete the view with both high resolution context views and detailed (to the tenth of an arcsec) in depth imaging.

<u>Coronal Heating</u>. This problem has been around for many decades and initial progress has been made. It is now known that the origin of this once mysterious heating is most probably magnetic in nature. However, one still needs to probe the magnetic field further with high spatial, spectral, temporal and velocity resolution in order to distinguish between, for example, magnetic wave heating, small scale reconnection events or convective leakage. Further, the nature of the magnetic field needs to be accurately understood in order to construct the magnetic building blocks of the solar atmosphere. Connectivity is a key ingredient that is poorly understood at present. Different phenomena such as active regions, “quiet Sun” and coronal holes are all likely to have different heating mechanism(s). HiRISE will provide us with the revolutionary opportunity to determine this with very high resolution in the transition zone and with its giant externally occulted coronagraph (formation flying) in the visible, IR and UV, with direct measurement of the coronal magnetic field very near the limb (1.01 solar radii).

<u>Ultimate Magneto-Helioseismology</u>. HiRISE's novelty is also its permanent Sun viewing orbit which, alike SOHO or SDO, allows resolved and global magneto-helioseismology. This is the third breakthrough of HiRISE, with its unique package of instruments for limb oscillations in the UV (predicted highest *g*-modes sensitivity), intensity, global and resolved observations, and high-resolution full and resolved Sun velocity oscillations (with the Magneto Optical Filter and GOLF-NG multi-points velocity measurements).

<u>Solar Variability and Space Climate</u>. The fourth breakthrough is the thorough set of diagnostics to study solar variability. A complete new set of solar constant, global and spectrally resolved irradiance monitors, are implemented and coupled to enhanced Lyman α imaging and a unique solar limb shape (and solar differential rotation) monitor. To this third set, the VM and MOF bring the magnetic field information, and the coronagraphs, the coronal extension of the field. This will directly address the nature of UV variability and its climate consequences. EUV, X-ray imagers and X-rays and gamma-rays spectrometers complete the variability survey as well as i*n-situ* measurements of the solar wind at L1 (particles and magnetic field) that allow to monitor the development of interplanetary perturbations and study the geoeffectiveness.

Technical and Programmatic Aspects (Mission Profile, Model Payload)

Mission Profile Summary. HiRISE/NEOCE will achieve its impressive aims with a major mission scenario involving two satellites in formation flying 375 m apart at the L1 Lagrangian point. The main spacecraft uses a modified Herschel platform and the chaser spacecraft, forming a giant externally occulted coronagraph, a Herschel-like platform. Novelty is also in state-of-the-art, new instruments, allowing kilometric resolution and reasonable mass and volume, like the SOLARNET interferometer. The numerous high technologies and new features of HiRISE/NEOCE will lead to novel insights into how the Sun works from the interior to the outer corona and to the Earth. With orders of magnitude in spatial resolution but also in sensitivity (UV spectro-imaging, diameter oscillations, and more), HiRISE/NEOCE has the potential to resolve major open questions in modern solar physics and to bring in important discoveries. For the first time a mission will address directly the key component in understanding the Sun: the magnetic field structuring. We will resolve it in much smaller features to analyze thoroughly the Sun's magnetic activity on multiple scale: time variability, evolution and fine-scale structure of the dynamic chromosphere, transition region and corona, origin, confinement, acceleration and release of energy, heating of the chromosphere and corona. HiRISE/NEOCE will complement the *in situ* observations of the Solar Probe Plus (SPP) and fly-by of Solar Orbiter and build upon HINODE and SDO moderate spatial resolution observations.

The payload, platforms and mission scenario were studied with Thalès Alenia Space in 2007 and 2010 (ESA/M3). The mission is international with participation of China and Russian Federation. The cost conscious approach of re-using Herschel and Heschel-like platforms allows a mission at the Lagrange point L1 with extreme coronagraphy thanks to formation flying. Telemetry in Ka band with the Cebreros antenna allows an impressive average downlink superior to 13.6 Mbits/s (41 Mbits/s 8h/day) while HiRISE/NEOCE requires about 12 Mbits/s. The expected volume and format of the data coming from the various instruments will be larger than any previous solar physics spacecraft but small compared to current Earth observation missions. No particular difficulties are foreseen to handle, process and archive data in an operation facility.

MISSION SUMMARY TABLE	
Launch vehicle	Soyuz-Fregat with 2 satellites in "stacked composite" configuration (< 1700 kg)
Orbit	Halo orbit around the Lagrange L1 point
Formation Flying	2 satellites 375 m apart controlled to 4-6 arcsec alignment
Spacecrafts	main satellite: Herschel platform re-use chaser satellite: Herschel-like platform (smaller: functional chains)
Mission duration	3 years nominal (extended: 6 to 12 years) – launch in 2025 (solar cycle 25)
Data handling	~ 12 Mb/s downlink using Ka-band high rate modulation, a 40 cm antenna and the 35 m Cebreros antenna – or New Norcia if upgraded (< 90% capacity)

Scientific Payload Concept. The dynamics of the chromosphere and corona is controlled by the emerging ubiquitous magnetic field. The plasma dynamics in each magnetic thread is believed to be linked to the formation of filaments, each one being dynamic on its own, in a non-equilibrium state. Mechanisms sustaining these dynamics, their manifestation in oscillations or waves (Alfvén or magneto-acoustic), require both very high-cadence, multi-spectral observations, and high resolution. HiRISE/NEOCE is combining ultrahigh resolution and coronagraphy to achieve:

- resolution (0.02”) chromosphere-corona interface characterization with a 1.4 m UV-FUV telescope equivalent (3 x 500 mm telescopes, independent or combined) and 3D imaging spectro-polarimetry;
- eclipse-like extreme coronagraphy of inner corona (up to 1.01 R_s) in vis., UV, NIR by Formation Flying between 2 satellites 375 m apart: Fe XIV, He I D3 & 1083, Fe XIII 1075 & 79, Lyman series & O VI;
- continuity, waves and oscillations, global and local magnetoseismology, EUV & XUV complementary imagers and spectrometers, TSI and photometers, and particles and magnetic fields experiments.

The HIRISE/NEOCE payload is distributed on two satellites 375 m apart with respective payloads (instruments) of 605 and 150 kg. The major payload includes the 3 telescopes of SOLARNET and 11 instruments (3 in the I2P, the Interferometer Instrument Package), in a volume of Ø2.8 m by 3 meters high:

- SOLARNET Interferometer (3 x 50 cm telescopes, 1.4 m baseline, actively cophased and pointed). 120 kg
- I2P: UV Imaging Spectrometer (UVIS) — subtractive double monochromator and IFTS ....70 kg
- I2P: high resolution Vector Magnetograph (VM) ....70 kg
- I2P: Chromospheric Imaging Camera (CIC)...40 kg
- EUV Diagnostic Spectrometer (EUDS) ....55 kg
- EUV and X-rays Imagers (EUXI) ....70 kg
- High Energy Burst Spectrometers (HEBS) hard X-rays and gamma-rays, 10 keV to 600 MeV...........20 kg
- Dual Magneto Optical Filter (DMOF) for full Sun magnetograph and oscillations ....60 kg

- SLIM, solar limb oscillations and solar shape changes (full Sun 220 and 160 nm imaging) .... 35 kg
- GOLF-NG multi-points global velocity oscillations .... 40 kg
- STIP (Spectral and Total Irradiance Package)... 14 kg
- PREMOS II (TSI and Photometers with EUV, FUV, NUV channels and fast sampling rates) .... 11 kg

On the Chaser satellite, NEOCE, in formation flying at 375 m (on a Herschel-like platform), we have:
- SuperASPIICS Green, IR (1074.7 nm) and UV giant externally occulted coronagraph .... 120 kg
- HLI, Heliospheric Large FOV (20°) Imager .... 20 kg
- SWIP *in-situ* Solar Wind Instrument Package (magnetic field, shocks, thermal plasma) .... 10 kg

The payload is a unique set of instruments to truly follow the magnetic field from its generation in the convective zone by local helioseismology, to its development and structuration in the chromosphere and transition zone, and energy release through waves, flux tubes motions, tangled magnetic field strands or the combination of these processes in the corona. The very complete UV to Near-IR externally occulted coronagraph allows imaging and spectroscopy (polarization) very near the limb in the inner corona. Direct magnetic field measurements are carried from the photosphere to the corona (Hanlé effect polarization of Lyman series).

HiRISE/NEOCE will serve a large community of more than 70 Co-Is in 15 countries around the world. In addition, with the very significant participation of Chinese institutes in this proposal (the interferometer and 3 major instruments), the payload can be extremely ambitious gaining orders of magnitude on previous recent missions (HINODE, STEREO or SDO) or on the ones to come (SPP or Solar Orbiter). Colleagues from the Lebedev Institute (Moscow) also contribute to an instrument. Resulting charge for the European countries is, therefore, limited to a reasonable 185 M€ (more than 30%, 80 M€ China and 25 M€ Russia, are external).

HiRISE/NEOCE proposal at L1 Lagrange point is highly complementary to the NASA Solar Probe+ mission to which it brings coronagraphy, coronal magnetometry and very high resolution in the upper-chromosphere, transition zone and inner corona where most of the coronal heating physics is thought to happen through flux tubes convective motions, waves or magnetic reconnection of tangled magnetic field strands. HIRISE/NEOCE builds upon our European competencies in EUV/XUV imaging and spectroscopy, enhances global and local helioseismology measurements, uses the revolution in high resolution made possible by interferometry, and adds the breakthrough of formation flying to achieve close limb coronagraphic observations. Furthermore, continuity of observation at the L1 Lagrangian point allows unprecedented new limb and velocity oscillations search for g-modes, to understand the magnetic origin of the solar activity leading, hopefully, to predictions for coming decades.

I.3 Readiness and Risk Issues

The "Stacked Composite" approach, proposed and studied by Thalès Alenia Space for the launch of the two HiRISE/NEOCE satellites, is providing a comfortable margin (~17 %: 350 kg). Telemetry is evaluated to 12 Mbits/s, what is indeed high but in the cope of the Cebreros antenna Ka-band high rate modulator 41 Mbits/s (i.e. 13.6 on 8h/day). Costs have been thoroughly evaluated by Thalès Alenia Space in 2007 (HiRISE Cosmic Vision proposal: €340M) and revised accounting a 20% increase resulting in €411M to ESA (with 16 % contingency). This is the result of the consequent heritage of the mission (Herschel platform).

There is no scientific revolution without a technological one. Both formation flying – allowing ultimate coronagraphy near the limb – and interferometry on extended objects in the Far UV – allowing to evidence the energy release at the chromosphere-corona interface, are building on this. The risk taken, reasonable in respect of the precursors and technological developments, is worth the unique results anticipated, that none of the current or planned missions will bring. Though, we are conscious that the gain in high-resolution comes for part from the FUV access of our spectro-imaging approach and from the interferometer that makes the last factor 3, from 60 to 20 km: a major step to disentangle coronal heating theories but, also, a major cost and risk issue. Accordingly, and to minimize risk, the payload is using interferometry ultrahigh resolution as a plus, as an extra. The 3 x 50 cm telescopes can, indeed, be combined together towards the 2D UVIS spectrograph but they can also be used *independently* and *simultaneously* for multi-spectral multi-temperature sensing by the 3 instruments in the I2P since to each telescope is directly linked one major instrument: the FUV 2D spectrograph (UVIS), the Vector Magnetic Field Instrument (VM) and the Chromospheric Imaging Camera (CIC). This way, risk is minimized and innovation preserved with access to interferometry, a major key to discoveries.

Concerning spacecrafts' readiness since of the ambitious Formation Flying (FF) configuration of HiRISE/NEOCE with a control to arcsec of the 375 m between the satellites, ESA can directly evaluate the risk since demonstrators, PRISMA and soon ASPIICS/PROBA-3 (2017), will pave the way.