CROMIS – The case for an orbital Hα solar telescope

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***Abstract*—Monitoring of the Sun and space weather is becoming increasingly important, with applications ranging from satellite and astronaut safety to GNSS reliability and power grid operations. The chromosphere, a complex and dynamic layer of the Sun's atmosphere best visible in the Hα spectral line, holds significant information for resolving open questions like coronal heating and improving space weather forecasting. Ground-based telescopes are severely limited by weather, geographical distribution, schedule, or insufficient spatial or temporal resolution. At the same time, existing space observatories often lack high cadence or full-disk coverage of the chromosphere. The CROMIS (ChROmosphere Monitoring InStrument) project, funded by ESA and optimized for a SmallSat platform, addresses this critical data gap by providing near 24/7 full-disk monitoring of the Sun in Hα. The core technical challenges and focus areas of CROMIS include instrument design to achieve high-resolution, high-cadence imaging within a compact form factor; robust systems design and integration to embed a sensitive, high-data-rate instrument into a cost-effective small satellite bus; and the development of mission operations and ground architecture for constant monitoring and rapid data access. We present the CROMIS mission concept, highlighting architectural decisions made to balance demanding scientific performance requirements with the constraints of a SmallSat platform. As the first Croatian astrophysical space science instrument, this initiative also serves as a capacity-building project and a valuable case study in designing a space science mission within the collaborative framework of the broader SmallSat community.**

Keywords—missions, research, scientific payloads, Sun, Hα, chromosphere

I. Introduction

The Sun influences Earth's climate, human activity, and technology both on the ground and in orbit, and it is the main driver of space weather. Eruptive phenomena like flares, coronal mass ejections (CMEs), and solar energetic particles (SEPs) can cause geomagnetic storms, radio blackouts, or even power grid failures [1, 2]. Satellites are also vulnerable to high-energy particle bombardment from severe solar storms, even during the launch and deployment phase. Space weather effects in orbit are more persistent as the damage is cumulative, degrading the performance of satellite subsystems and even the health of astronauts. Moreover, solar storms cause increased atmospheric drag in Low Earth Orbit (LEO), affecting orbits and decreasing the lifetime of satellites. The persistent threat posed by eruptive solar phenomena necessitates continuous surveillance of solar activity from both terrestrial and space-based platforms to forecast upcoming storms and implement mitigation strategies. In response, international space agencies have established initiatives like the European Space Agency's (ESA) Space Situational Awareness program to advance the research and creation of sophisticated space weather prediction systems [2].

The Sun can be described as a sphere of hot plasma composed mainly of hydrogen and helium, and powered by nuclear fusion at its core. Decades of research have provided insight into solar structure and many mechanisms responsible for the Sun's observed properties [3]. One of the crucial open questions in solar physics is understanding the processes that heat the corona, the outermost layer of the solar atmosphere with a temperature of more than a million degrees, compared to the lower photosphere, where the temperature is 5800 K. The energy responsible for coronal heating is transported from the solar interior and photosphere through the chromosphere, a complex and dynamic layer extending from ~400 km to at least 2000 km above the photosphere [3].

The chromosphere is not visible directly in the optical continuum light, where radiation from the photosphere dominates. Traditionally, it has been observed in narrow spectral lines of hydrogen (Hα) in the red part of the spectrum and calcium (K line) in the violet, using special narrow-band filters or spectrographs [4, 5]. In recent decades, the solar chromosphere has been observed with high spatial and temporal resolution in the ultraviolet and extreme ultraviolet (UV/EUV) part of the spectrum (using several satellites and space missions) and in the optical and mm/sub-mm wavelength range (using ground-based telescopes and interferometers). The problem with many of these telescopes is that they provide high resolution and cadence, usually with a very small field of view covering only a part of the Sun. Other telescopes offer a full disk view of the chromosphere, but with lower resolution and cadence.

Understanding the Sun and its processes requires a multiwavelength approach - combining measurements over a wide range of wavelengths, which requires coordinating different observatories to observe the same feature at the same time, which can be difficult. Unfortunately, very often there are no simultaneous other wavelength and Hα solar observations. The main reasons for this are: (i) different time zones of the ground-based solar observatories, (ii) bad weather conditions, and (iii) a small field of view with telescopes possibly observing different features.

The primary scientific driver for an orbital Hα mission is to facilitate near-continuous full-disk monitoring of the solar chromosphere with high spatial and temporal resolution. The ChROmosphere Monitoring InStrument (CROMIS) project addresses this data gap by developing a dedicated Hα solar imager optimized for a SmallSat platform. Designed to operate in Low Earth Orbit (LEO) at altitudes of 600–800 km, CROMIS aims to provide near 24/7 full-disk imaging.

II. Filter Selection

The Hα line serves as a vital diagnostic for probing the solar chromosphere. It is formed by emission from hydrogen atoms in the deep red part of the visible spectrum, and has a wavelength of 656.28 nm in air and 656.46 nm in vacuum. With a formation height spanning 1200 to 1700 km above the photosphere, the line core samples the upper chromosphere, partially coinciding with the origin of millimeter radiation. Conversely, the Hα line wings originate at lower altitudes beneath the temperature minimum, providing data from just a few hundred kilometers above the photosphere [4, 6]. This vertical sensitivity allows for a sophisticated multi-layered investigation of solar atmospheric physics.

The solar Hα spectral line is visible as an absorption line with the ~20% light intensity dip in the solar continuum, and the Full Width at Half Maximum (FWHM) of ~0.1 nm (Fig. 1). The Hα filter bandwidth has to be narrower than this to prevent photospheric continuum light leakage into the imaging system and lower the contrast of the chromosphere. Thus, a minimum FWHM of the Hα filter should be <0.07 nm, taking into account manufacturing deviations from the ideal filter. Such a narrowband filter cannot be produced by standard methods like ion beam sputtering, meaning that a special filter is needed. There are several options to choose from: a) Fabry-Perot (F-P) etalon, b) Lyot filter, c) spectroheliograph.

An F-P etalon is a resonator or optical cavity filter, basically an interferometer consisting of two parallel, partially reflective mirrors that form a resonant cavity.

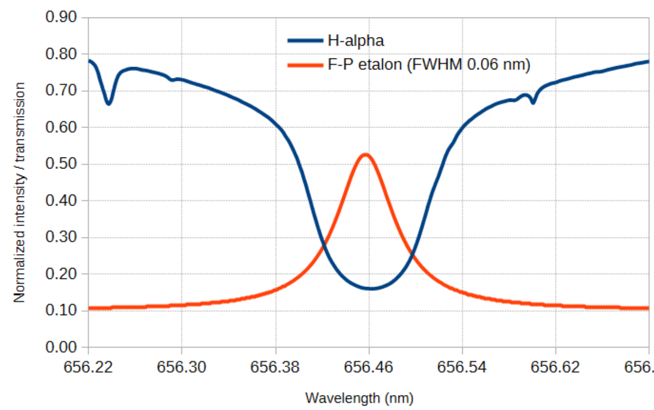

Fig. 1. Transmission curve of the Fabry-Perot etalon (red) compared with the profile of the solar Hα line (blue). Solar spectrum data derived from the BASS2000 - Observatoire de Paris/Meudon - LEISA

Light waves interfere constructively at specific wavelengths within this cavity, resulting in a very narrow passband that can be tuned to isolate the Hα line. Tuning is achieved by adjusting the mirror spacing with piezo actuators, tilting the etalon, or controlling the temperature or pressure. The cavity can be empty (vacuum/air) or made from a material like mica or fused silica. Since F-P etalon produces a "comb" spectrum with evenly spaced resonant peaks, additional filters are needed to isolate a single peak. An example of the solar image taken with a 0.07 nm F-P etalon is shown in Fig. 2.

A Lyot filter is a different type of narrowband filter consisting of a series of birefringent waveplates and polarizers. These waveplates create phase differences that lead to interference, allowing the filter to select a narrow wavelength band. The design often involves multiple stages, where each thicker waveplate doubles the effect of the previous one, narrowing the FWHM to the target range. Fine-tuning is possible by rotating the waveplates. While the Lyot filter has some advantages over F-P etalons, it has a high cost and temperature sensitivity.

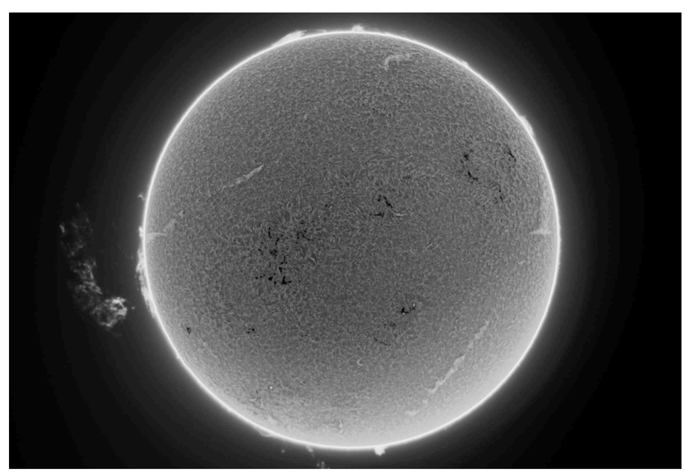

Fig. 2. Sun photographed on 20 August 2025 in the Hα line with the 0.07 nm F-P filter. The disk intensity has been inverted to enhance various surface features (chromospheric network, filaments), while the intensity of the limb was increased to better show prominences (Astronomical Society "Anonymus", Valpovo, Croatia).

Spectroheliograph works by focusing incoming light on a narrow slit, after which the light is collimated and passed onto the diffraction grating that disperses it into spectral components. The dispersed light is refocused onto the detector. Sometimes, another slit is used before the detector to select only a single spectral line. Since the resulting light comes from only a thin slit across the solar disk, the instrument (or a part of the instrument like the grating) has to be moved to scan the whole Sun, which limits the temporal cadence. This design was used for the Chinese H-alpha Solar Explorer (CHASE), which provides raster scan full disk spectral images at 655.97 - 656.59 nm and 656.78 - 657.06 nm with 1 arcsec spatial resolution, 1 minute temporal resolution, and 0.0072 nm spectral resolution [7, 8].

From the available filter types, the F-P etalon seems like a reasonable choice due to the price and simplicity. Though it needs additional filters like an energy rejection filter to remove the heat load from other parts of the spectrum, and a blocking filter to isolate the resonant peak of interest, it provides an instant full disk image in the Hα spectral line (Fig. 3). Since the central wavelength depends on the incidence angle, tilting the etalon makes tuning possible but at the cost of bandwidth. To avoid the so-called "sweet spot" effect, where the central wavelength shifts gradually when moving from the center of the field, a telecentric lens system is needed. In this case, an f-ratio of >25-30 is preferred [9]. Also, the resonant cavity is sensitive to temperature, and a precise thermoregulator to keep the filter temperature within ±0.5°C of the nominal would be needed to keep the filter tuned.

III. Resolution and Bandwidth

The main CROMIS mission parameters are the required spatial and temporal resolution. These two are interconnected, as the temporal scale, i.e., the scale of dynamic events in the chromosphere, depends on the spatial scale under observation. Almost all dynamic phenomena in the solar chromosphere are influenced by the shear Alfven waves. The phase velocity of these waves is called the Alfven velocity, c_A, and is given by (in cm/s) (see, e.g., [10]):

$$c_A = \frac{2.03\times10^{11} B}{\sqrt{n_e}}, \quad (1)$$

where B is the magnetic field in gauss (G), and n_e is the electron density in cm^{-3}. For the magnetic field in the chromosphere, we can use a value of 100 G. Earlier, it was mentioned that the Hα line is formed at a height in the range 1200 - 1700 km. From the recent model of the solar atmosphere, the Avrett-Tian-Landi-Curdt-Wülser (ATLCW) model [6], we take the quiet Sun electron density at approximately the middle formation height of the Hα line: for h = 1465 km, $n_e = 1.8 \times 10^{11}$ cm^{-3}. When these values are put in the equation for Alfven velocity, we get c_A = 480 km/s, from which we can estimate the temporal resolution as a function of the given spatial resolution: $\Delta t \approx \Delta x / c_A$. For example, if we want to achieve a spatial resolution of 1 arcsec (near the center of the solar disc, which approximately corresponds to 700 km), we get the optimal temporal resolution of 1.46 s.

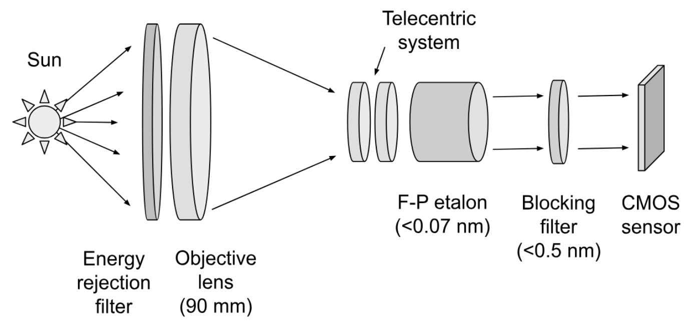

Fig. 3. Schematic diagram of the optics system.

System design is about balancing the mission requirements with the physical constraints and the available budget. On Earth, spatial resolution is limited by the atmospheric turbulence (seeing) with a typical value of ~1-2 arcsec. Adaptive optics is used in some observatories to go well below this limit. Ideally, CROMIS would need to achieve a resolution of better than 1 arcsec. However, there are several constraints. The first is related to the size of the imaging sensor and the requirement to image the full solar disk. When viewed from Earth, the solar angular diameter in perihelion (when it is largest) is 0.55 deg. We would also like to capture the prominences, at least some of them, so the minimum field of view (FoV) would be 0.6 deg, ideally 0.7 deg. With a Nyquist criterion to sample at least twice the required resolution, we get that the sensor should be more than 18 Mpix in size. We can use the Rayleigh criterion to estimate the size of the objective lens (D) for the given FoV (θ, in radians) and central wavelength (λ):

$$\theta \approx 1.22\frac{\lambda}{D} \quad (2)$$

With the FoV of 0.7 deg at Hα wavelength, the size of the objective lens would have to be 166 mm. Now, if we opt for 2 arcsec resolution, the minimum objective lens is ~90 mm. This nicely fits into a 1U cube. The minimum sensor size is now also smaller at 7 Mpix. The F-P etalon needs an f-ratio of at least f/25 for a relatively uniform response across the FoV. This directly translates into an objective focal length of ~2300 mm, giving an image size of the FoV of 24.1 mm at the focus, meaning that a full-frame (36x24 mm) sensor is needed. The focal length of 2.3 m indicates that a folded optics path is required within a microsat platform. That can be realized by flat mirrors or prisms.

The 2 arcsec resolution also affects the optimal temporal resolution, which in this case is 3 seconds. With a 7 Mpix 16-bit sensor and an assumed lossless image compression factor of 2, that is ~200 GB of data per day. While this seems manageable, it would be reasonable to lower the cadence or enable two modes of operation: a) patrol mode, where there are no dynamic events on the Sun and the cadence is slower, and b) fast event triggered mode, which is enabled when an eruptive event is detected, and the cadence is faster. For this, onboard processing of the solar images is needed to detect the changes.

IV. Mission Concept

We turn to the question of the CROMIS orbit. The goal is to observe the Sun as much as possible, so the Sun-synchronous (SSO) LEO orbit along the terminator seems like an optimal choice. That way, the Sun would be almost constantly in view, with occasional seasonal shadowing amounting to ~20-30% per year. This orbit also has one nice feature: the relative velocity towards/away from the Sun is small, since the orbital plane is perpendicular to the Earth-Sun direction (Fig. 4). That means that there is almost no Doppler effect changing the central wavelength of the filter.

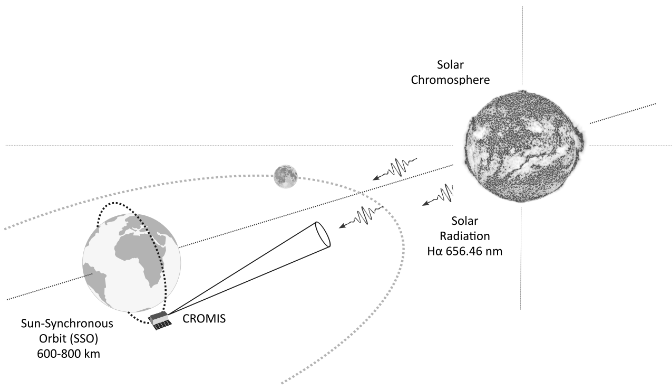

Fig. 4. Concept of operations for the CROMIS mission.

For a ground station at mid-latitudes (45 deg), 4-6 passes daily are expected, 2-3 around sunrise and around sunset. The revisit time would be ~100 minutes for consecutive orbits and ~12 hours on longer gaps. A pass would last 6-8 minutes on average, totaling to a ~40 minutes access time per day. Taking all that into account and the previously calculated daily storage needs, we reach ~1 Gbps, which is available only through Ka-band or optical link. Thus, the cadence has to be decreased. Using two (patrol and fast) cadence modes would considerably decrease the required data rate into the X-band limits.

The power budget can be estimated as follows. The thermal control of the F-P etalon would be 5-15 W, full frame imaging sensors use another ~5 W, with onboard processing using Field Programmable Gate Arrays (FPGAs) adding another 5-10 W. Adding a healthy margin, the total instrument budget would be ~40 W, fitting nicely on a microsat platform.

The mass of the instrument depends mainly on the optics system and structure. Let us assume that the lenses, mirrors and the F-P etalon contribute 5-8 kg. Structure could add another 2-3 kg, while detector and electronics would be < 2 kg. Adding to that thermal control block and some margin leads to ~15-20 kg for the whole instrument, again comfortably within the limits of the microsat platform.

Total integrated dose (TID) of radiation in LEO orbit over five years is typically around 20 krad. The impact on the optics is ~5% loss in transmission, mostly in the blue part of the spectrum, which is of almost no effect at the Hα wavelength. Impact on the imaging sensor would be an increase of hot and dead pixels, as well as dark current. The first problem is just cosmetic and can be corrected in software and mapping the hot/dead pixels using dark and flat frames. Dark current, on the other hand, is negligible in case of solar imaging as there is plenty of signal there, providing high SNR. Shielding the electronics with 2-3 mm of aluminium and using radiation tolerant components should provide enough protection for a 3-5 year mission. The derived mission requirements are listed in Table 1.

TABLE I. CROMIS Requirements

Parameter	Requirement
Central wavelength (vacuum)	656.46 nm
Bandpass (FWHM)	0.05-0.07 nm
Field of View	0.6° - 0.7°
Spatial resolution	1.5 - 2 arcsec
Typical cadence	1 min
Maximum cadence	1 - 3 sec
Mission lifetime	3–5 years
Orbit	LEO, SSO (terminator)
Platform	Microsat
Mass	~20 kg
Power	~40 W

The microsat hosted platform for the CROMIS instrument should provide the sub-arcminute pointing accuracy with a stability/jitter no larger than 1 arcsec. However, with clever onboard processing using multiple exposure stacking, jitter can be used to improve the spatial resolution, since the single frame exposures would be in the range of 1-20 ms. The X-band communication module needed is also within the microsat margins. The block diagram of the instrument and the connections with the host platform is shown in Fig. 5.

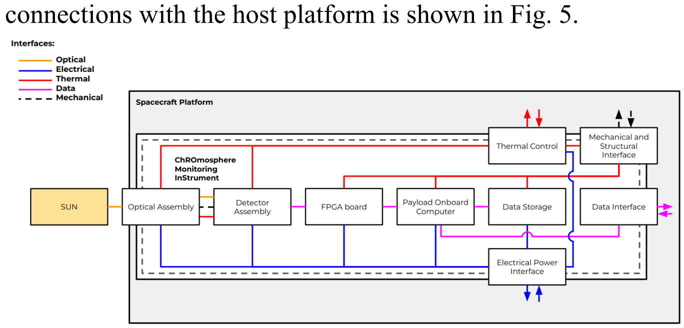

Fig. 5. CROMIS architecture block diagram.

The most significant risks of the CROMIS mission are related to the F-P etalon and its thermal control. A critical single-point failure would be loss of thermal control which would lead to filter detuning and imaging of the solar photosphere in continuum rather than chromosphere in the Hα line. It could be mitigated with a redundant heater. Another risk is the temperature sensor drift, which can be easily mitigated by triple sensor configuration. Another critical point is the failure of the data storage and data corruption. Using several modules of Error correction code (ECC) memory could provide some protection.

V. Conclusion

The CROMIS mission is a project designed to provide near-continuous, full-disk monitoring of the solar chromosphere in the Hα spectral line. Currently, it is a feasibility study with a goal to derive technical requirements, provide an initial optical design and test it on a breadboard model. By optimizing the instrument for a cost-effective SmallSat platform, the project balances scientific requirements with the physical constraints of a compact satellite bus. Key architectural decisions, including the selection of a Fabry-Perot etalon as an Hα filter, a full-frame monochrome sensor, a singlet objective lens, and the utilization of a Sun-synchronous terminator orbit, ensure optimal data collection at the required resolution and cadence. Inclusion of onboard processing to help mitigate some constraints was considered. Beyond its scientific objectives, CROMIS serves as a landmark capacity-building initiative for the Croatian space community, demonstrating the feasibility of designing sophisticated astrophysical instruments within the collaborative framework.

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