THE COSMO OBSERVATORY

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All the major phenomena taking place in the solar atmosphere, such as flares and Coronal Mass Ejections (CMEs), the heating and evolution of solar atmospheric plasmas, and the acceleration of the solar wind, are powered and driven by the ubiquitous magnetic fields permeating the solar atmosphere. These phenomena control the effects that our star ultimately has on our planet’s atmosphere and on the technological infrastructure our society increasingly depends upon. In order to forecast the solar radiative and particle output, predict the occurrence of solar storms, and mitigate their adverse effects on ground and space human assets, it is necessary to continuously measure and monitor their driver, the magnetic field. However, no routine measurements of the magnetic field in the solar atmosphere are currently available.

The Coronal Solar Magnetism Observatory (COSMO) is a suite of ground-based instruments aimed to routinely measure the solar magnetic field and plasma properties from the photosphere to the extended corona, through high resolution polarimetry and spectroscopy in the visible and near IR wavelength range. COSMO consists of three instruments: the K-coronograph (K-cor), operational since 2013, the Community Synoptic Chromospheric Magnetometer (ChroMag), to be deployed in 2016, and the Large-aperture Coronograph (LC), under study.

The K-coronograph provides white light, high resolution, high cadence images in the critical 1.05-3 solar radii range, filling the strategic gap where CMEs form and accelerate and which no space instrument can currently observe. ChroMag will provide high cadence, high resolution synoptic full-disk spectro-polarimetric measurements of the magnetic field in the photosphere and chromosphere. LC will be the most important component of the COSMO suite, and will provide synoptic, high resolution spectroscopic and polarimetric observations of multiple visible and near IR lines formed in the 0.04-4 MK temperature range, from 1.05 to 2 solar radii. LC will routinely measure:

A - the solar magnetic field from the photosphere to 2 solar radii;
B - the plasma heating and evolution of accelerating CMEs close to the Sun for the first time;
C - the time evolution of the radiation and of thermodynamic properties of the solar corona; and
D - the processes responsible for the heating and the acceleration of the solar wind.

COSMO will be deployed to Hawaii at one of the world’s best sites for solar observations; its easy accessibility allows COSMO to be upgraded and maintained to last far longer than space instrumentation, at a fraction of the operational costs, thus allowing long-term studies of solar activity and evolution.

Once completely operational, COSMO will be the critical facility to understand the origin of the solar radiative and particle output and predict their evolution, to assess their effects on the Earth’s atmosphere and near-Earth interplanetary space, as well as to enable forecasting of solar storms with significant lead time.

COSMO cost: K-cor is already operational. The completion of ChroMag, already partially funded through HAO Internal funds, will require around $2M. The total cost of building LC (including telescope and lens, instruments, facility, data archive, and student participation) is estimated at $23.5M. Thus, the total cost for the whole COSMO observatory is estimated at $25.5M.
UNIQUENESS OF COSMO MEASUREMENTS

COSMO will produce long term synoptic measurements of the solar magnetic field and of the properties of the large scale solar corona.

A - COSMO will be the first facility ever built dedicated to synoptic observations of the solar magnetic field, from the photosphere to the solar corona.

By determining the magnetic field from the chromosphere (ChroMag) to the extended solar corona (LC), COSMO will allow for the first time to observe the primary agent responsible for Space Weather, solar activity, the solar cycle, coronal heating and solar wind acceleration.

B - COSMO ChroMag will provide systematic measurements of the magnetic configuration of filaments, prominences and cavities.

COSMO will enable monitoring of candidate structure for CMEs, and understand the evolution prior to the eruption of the entire prominence-cavity system, paving the way to quantitative forecasting of solar storms.

C - COSMO K-cor will fill a gap in the field of view of current space instruments at critical coronal heights.

K-cor field of view stretches 1.05 to 3 solar radii, connecting the field of view of EUV imaging and spectroscopic instruments (limited to \( \approx 0.5 \) solar radii above the limb) and visible space coronographs such as LASCO C2 (starting at around 2.5 solar radii). In this critical height range, which no current instrument can cover in its entirety, most of CME heating and acceleration takes place, the solar wind accelerates and freezes in, and coronal plasma is maintained at multimillion temperatures.

D - COSMO LC will routinely make measurements of the physical parameters of the extended solar corona simultaneously over the whole field of view.

LC combines in one design the strengths of both EUV and X-ray narrow-band imagers and high-resolution spectrometers at a fraction of their cost: while avoiding the temperature confusion of EUV narrow-band filters, LC will preserve the temperature resolution and diagnostic capabilities of EUV spectrometers, and simultaneously observe the entire corona like an EUV imager, vastly expanding the field of view of EUV spectrometers. In addition, LC will uniquely provide simultaneous measurements of 1) the coronal magnetic field, 2) the full velocity vector, and 3) the plasma thermal structure. The offset pointing mode (Fig. 1 right) will extend CME coverage up to 4 solar radii.
COSMO LC CURRENT STATUS

**LC observables:** The magnetic field measurement methodology for the COSMO LC follows from a comprehensive overview of available methods (Judge et al. 2001) that identified the Zeeman and Hanle effects observed in visible and infrared emission lines as the most promising to measure magnetic fields in the corona. The line-of-sight (LOS) strength of coronal magnetic fields can be measured directly through the Zeeman effect while the Hanle effect is used to measure the plane-of-sky (POS) direction of the magnetic field. These magnetic field measurements will be made for strengths ranging from a fraction of a Gauss to several thousand Gauss. Many coronal spectral lines are available in the visible range that can be observed to study the physics of the solar corona, the solar wind, and CMEs.

**Instrument requirements:** Observing the Zeeman effect in the solar corona is challenging, and drives the requirements for the COSMO LC. The corona is 5 to 6 orders of magnitude fainter than the solar photosphere and coronal magnetic fields are weak, of order 1 Gauss. To observe coronal fields requires a telescope with very low scattered light, a coronagraph with a large aperture to capture sufficient photons to achieve the required magnetic field sensitivity. Noise estimates show that a 1.5-m aperture coronagraph can meet the COSMO LC requirements of magnetic field sensitivity of less than 1 Gauss in 10 minutes for coronal intensity greater than 5 ppm (parts per million) with a sky background level of 5 ppm. These requirements exceed those necessary to observe coronal spectral lines for plasma diagnostic purposes.

**Instrument concept and heritage:** Scattered light analysis of reflecting and refracting coronagraph objectives shows that lenses scatter significantly less light than mirrors from the effects of both surface roughness and dust contamination. For this reason, we have selected a lens for the objective of the COSMO LC. There will be two complementary instruments at the back of the LC, a narrow-band tunable filter and a fiber-fed spectrograph. These instruments have heritage in existing prototype instruments developed at the University of Hawaii and NCAR/HAO.

**Current status:** Many engineering studies have been performed to evaluate the feasibility of constructing the Large Coronagraph including a complete optical design and preliminary designs of all major components.

**A - Finite element analysis (FEA):** We conducted a FEA of the proposed COSMO lens to determine how its figure is distorted under gravitational loading. The results of this analysis were imported into ZEMAX where the impact on image quality could be analyzed. Although gravity can cause up to 5 microns of distortion in the figure, this was found to have a negligible impact on the point spread function. The FEA analysis also considered stress-induced birefringence, and this was found to be well below acceptable levels. Blanks of fused silica of sufficient size and quality are produced regularly by Corning.

**B - Feasibility study:** The feasibility study is summarized in Nelson (2008). The engineering behind the COSMO LC continues to be developed by engineers at HAO along with partners at the University of Michigan, the University of Hawaii, the Smithsonian Astrophysical Observatory, and the Optical Institute in Nanjing, China. We have passed our conceptual design and are approaching our Preliminary Design Review in the summer of 2015. The combination of our engineering studies, recent experience with prototype instruments, and input from vendors indicates that the 1.5-m aperture COSMO Large Coronagraph is well within current technological capabilities.