THE NEAR-INFRARED CHROMOSPHERE OBSERVATORY

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ABSTRACT

The Near-Infrared Chromosphere Observatory (NICO) is a proposed balloon-borne observatory aiming to investigate the magnetic structure and the sources of heating in the solar chromosphere. NICO will be based on the successful Flare Genesis Experiment (FGE), a pioneer in applying novel technologies for the study of the Sun. NICO will map magnetic fields, velocity fields, and heating events in the chromosphere with unprecedented quality.

Key words: Chromosphere; Corona; Magnetic fields; Photosphere.

1. INTRODUCTION

The solar chromosphere is a prodigious, yet unexplored, environment. The discovery of the million-degree corona, half a century ago, has shifted interest into this vast part of the outer solar atmosphere, overlooking the vital role of relatively narrow layers, such as the chromosphere. Recent missions, such as *Yohkoh*/SXT, SOHO/EIT, and TRACE, have focused in explaining coronal heating. It has been recently acknowledged, however, that a hot corona is inconceivable without a well-sustained chromosphere (Brown et al. 2000). The energy flux required to sustain the quiet chromosphere is $\sim 10^{6.4} erg\ cm^{-2} s^{-1}$, almost an order of magnitude larger than the flux required to sustain the quiet corona ($\sim 10^{5.5} erg\ cm^{-2} s^{-1}$). Moreover, for corona to be filled with plasma, one has to loft mass into the chromosphere first. It is becoming clear to theorists and observers that there is little hope in understanding coronal heating before chromospheric heating and mass distribution are fully understood.

Understanding chromospheric heating and dynamics are the principal objectives of NICO. The primary science objectives and their implementation are addressed in §2. In §3 we describe the future NICO mission. In §4 we discuss the NICO instrumentation. In §5 we outline our conclusions.

2. SCIENCE OBJECTIVES AND IMPLEMENTATION

NICO will address the following key questions:

(1) How is the chromosphere heated ?

(2) What is the structure of chromospheric magnetic fields ?

(3) Which processes control the mass distribution in the chromosphere ?

NICO will obtain simultaneous observations in a series of spectral lines (Table 1). The selected lines cover an array of heights above the photosphere, in order to map the evolution in the atmosphere as a function of the altitude. Table 2 provides the required observing sequences.

Chromospheric heating is an outstanding problem, thought to be achieved either by - MHD or acoustic - waves (Lites, Rutten & Kalkofen 1993; Kupke, LaBonte & Mickey 2000), or by magnetic reconnection events (Aschwanden, Schrijver & Alexander 2001). An interrelation between low-altitude reconnection and MHD waves, or Alfvén waves, cannot be ruled out (Takeuchi & Shibata 2001). NICO will detect both waves and low-altitude reconnection events, and will determine which activity precedes the other. Signatures of chromospheric reconnection will be detected using observing sequences #1 + #2, and #5 (Table 2). To determine the relative significance of waves vs. reconnection events, a cadence better than 30 s is required. This cadence is achievable by NICO. Observing sequences #5, and #6, will

Filter Number	1	2	3	4	5	6	7
Spectral line (Å).....	$H\alpha$ 6563	HeI 10830	CaII 8498	CaII 8542	CaII 8662	FeI 8688	KI 7699
Bandpass (Å).....	20	30	20	20	30	10	10
Landé g_{eff}.....	1.05	–	1.07	1.1	–	1.66	1.33
Height above $\tau_{5000} = 1$ (km).....	2000 ± 500	2000 ± 500	1100 ± 400	1000 ± 500	–	500 ± 100	450

Table 1. List of interchangeable broadband filters and relative spectral lines used by NICO

Seq. ID	Measurement	Spectral Line	Spectral states	Polarimeter states	Time used (sec)	Cadence (sec)	Notes
#0.....	Structure	$H\alpha$, continuum	1	1	2	30	Runs continuously during mission
#1.....	Fast u_{chr}	$H\alpha$, Ca, or He	5	1	5	20-30	
#2.....	Fast B_{chr}	$H\alpha$, Ca, or He	8	4	32	40-80	
#3.....	B vs height	$H\alpha$, Ca, He Fe I, and K I	20	4	400		Line order changed on command to alter time intervals
#4.....	Fast u_{phot}	Fe I or K I	5	1	5	15-20	
#5.....	$B_{phot} + B_{chr}$	$H\alpha$, Ca, or He plus Fe I or K I	20	4	160	180-240	Line pair changed on command to sample all combinations
#6.....	Structure	$H\alpha$ wing, Ca ctr, He ctr, Fe ctr	1	1	4		

Table 2. NICO observing sequences

be used to determine the energy input from emerging magnetic flux.

To understand the evolving solar atmosphere, knowledge of the chromospheric magnetic fields is crucial. However, our knowledge of the magnetic field vector is restricted on the photospheric plane. In view of profound difficulties in coronal magnetography (Lin, Penn & Tomczyk 2000), the use of mathematical extrapolations of the magnetic field in the corona is inevitable. Extrapolations can only be force-free, either linear (Alissandrakis 1981), or non-linear (Low 1982), and use the photospheric fields as boundary conditions. While magnetic fields in the upper chromosphere and the corona are force-free (Metcalf et al. 1995), the photospheric magnetic fields are not (Georgoulis, Rust & Bernasconi 2002). This compromises the results of the extrapolations. Between the photosphere and the upper chromosphere, therefore, there must exist a *magnetic transition region* (MTR) at which magnetic fields become force-free. NICO will identify the MTR by means of high-resolution vector magnetograms, taken simultaneously at various heights. This will reveal the variation of the magnetic field with height, in the low chromosphere, and it will be achieved using observing sequence #3. Sequences #5, and #6, will be used to determine the spectrum of the current helicity and the current density in the photosphere/chromosphere. The expected magnetogram resolution, already achieved by FGE, will be $\sim 0.5''$, or higher.

Mass can be injected in the chromosphere either by filaments, or by intermittent, discrete injection events. With the gravitational energy of the cool filament material exceeding its thermal energy, the interpretation of cold plasma suspended in the atmosphere for days, or weeks, is troublesome. Magnetic twist, as well as shear, are thought to be key processes in sustaining the mass (Karpen et al. 2001). Filament magnetic fields and miniature eruptive events are, therefore, important parts of the puzzle. Measurement of the filament magnetic fields can be achieved in the He I line, at 10830 Å (Lin, Penn & Kuhn 1998), whereas the study of small-scale eruptive events is very similar to the study of chromospheric heating (LaBonte 1979), already addressed above. NICO will obtain high-resolution filament magnetograms in He I. Physical processes of the filament structures will be studied using sequence #3, while mass injection in fibrils will be studied using sequences #1+#2, and #5. Chromospheric velocities, continuum intensities, and vector magnetic fields will be obtained at a cadence better than 1 *min*, via spectral sampling of the Stokes profiles, while context data will be available every 5 *min*.

3. MISSION IMPLEMENTATION

NICO mission relies on experience gained from two successful FGE flights in Antarctica. The instrument will reach an altitude ~ 37 km. The anticipated flight duration is $10 - 20$ d. The mission and payload characteristics are described in Table 3. Flying in Antarctica is advantageous, because *(i)* un-interrupted, $24 - h$ view of the solar disk is guaranteed, *(ii)* the thermal design of the gondola is greatly simplified, *(iii)* only modest battery energy is required, and *(iv)* the vortical Antarctic winds allow a predictable, circumpolar, flight trajectory.

Mission Information	
Vehicle.....	LDB zero-pressure balloon
Launch location.....	Williams Field, Antarctica; 77.9^o S; 167.1^o E; sea level
Baseline launch date.....	December 15, 2005 - January 15, 2006; 1 month launch window
Launch date flexibility.....	Every Antarctic summer from December to January
Mission duration.....	$10 - 20$ days
Flight trajectory.....	Circumpolar, at $73^o - 82^o$ S latitude
Flight altitude.....	37 $km \pm 2km$; 30 km minimum
Telemetry.....	**Primary:** TDRSS satellite relay; continuous 4 $kb\ s^{-1}$ up- & downlink **Backup:** INMARSAT-C satellite relay; packets of max 256 bits per 50 min up- & downlink
Ground station.....	**Primary:** Williams Field, Antarctica **Secondary:** NSBF operation control center, Palestine, Texas
Payload characteristics	
Mass.....	1600 kg
Dimensions.....	$5.6 \times 1.5 \times 5.5\ m^3$ $(W \times D \times H)$
Attitude.....	Gravity-gradient; reference system Sun; $\pm 10''$ RMS pointing accuracy
Power.....	Solar cells; max power production 1300 $Watt$
Instrument.....	80 cm-diameter Cassegrain telescope; alt-azimuth mount
Data storage.....	On board; 20×160 $Gbytes$ hard drives; 3.2 $Tbytes$ total

Table 3. NICO mission summary and payload characteristics

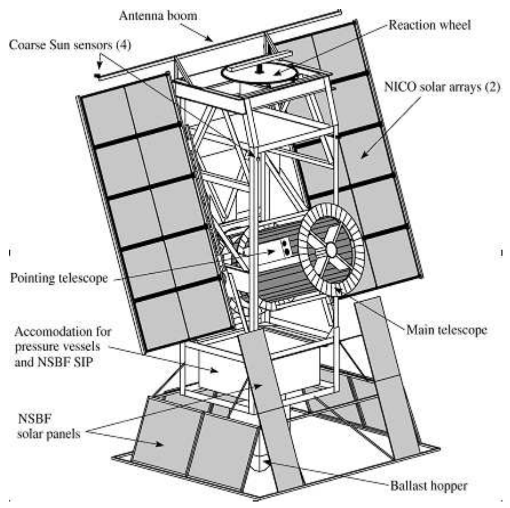

Figure 1. Schematic of the NICO payload configuration.

Both FGE flights were successfully recovered, following mission termination. The same is expected for NICO.

The NICO payload is schematically given in Figure 1. The gondola is directly derived from FGE and is suspended by a helium-filled balloon provided by the NASA Ballooning Facility. The gondola is stable enough to allow a very stable telescope pointing. The pointing system is an azimuth-elevation, gravity-gradient system, successfully used in FGE. Pointing errors are corrected by means of a momentum-transfer unit (MTU), which *(i)* minimizes disturbances introduced through the balloon suspension cable, and *(ii)* shifts accumulated momentum from the azimuth reaction wheel to the balloon. The power system will be the same as in FGE, consisting of four elements: the solar panels, the charge control unit, the voltage regulators, and the battery stacks. Communication, command, and control of the instrument will be possible through the TDRSS satellite link. Another link to INMARSAT-C will be available as a backup, low-rate, data storage. The main data storage will be done on-board, with a total capacity of 3.2 $Tbytes$, or ~ 270 $Gbytes\ d^{-1}$.

4. INSTRUMENTATION

The characteristics of NICO instrument are summarized in Table 4. The telescope is an $80 - cm$ Cassegrain design, with a graphite-epoxy structure for lightweight, temperature-insensitive support. The primary and the secondary surfaces are coated with silver to reflect more than 97% of the incident solar energy. The secondary is made of single-crystal silicon, to provide excellent thermal conduction from surface-to-mount with minimal thermal distortion, while a third mirror acts as a heat dump. It passes the light from a $15 - mm$ diameter aperture in its center, recording a $322''$-diameter section of the solar disk. The remaining solar radiation is reflected back out of the front of the telescope. The selected segment of the solar image is retrieved through a sophisticated analysis package that includes *(i)* a polarization analyzer unit, *(ii)* an image-motion compensator based on a fast CCD and a cross-correlator, *(iii)* two Fabry-Pérot lithium-niobate etalon filters with 0.08 Å tunable passband, *(iv)* a $2K \times 2K$ science camera, and *(v)* a wavefront analyzer that uses 3 fast CCDs.

The NICO Stokes polarimeter will record all four components of the Stokes vector: I (total intensity); Q (linear polarization at $0^o/90^o$); U (linear polarization at $45^o/135^o$); and V (left/right circular polarization) as a function of space, time, and wavelength.

Major System	Optical Parameters	
Cassegrain telescope	**Primary:**	$80-cm$ diameter; F/1.5; ULE
	Secondary:	$10-cm$ diameter; silicon
	Primary focus:	$322''$ diameter field stop; F1/2
	Focal plane:	F/37; $200'' \times 200''$ FOV; $0.097''$ per pixel
	Diffraction limit:	$\lambda(nm)$... 656.3 850 1100 Resolution... $0.21''$ $0.27''$ $0.35''$
Spectral filter	8 positions filter wheel with 7 prefilter blockers with $10-30$ Å bandpass	
	Dual Fabry-Pérot etalon	
	WL range:	650 nm-1100 nm
	FSR:	26.4-74.1 Å
	Bandpass:	0.08-0.224 Å
Polarimeter	2 liquid crystal variable retarders + 1 linear polarizer	
	2 calibration filter wheels with polarizers and $\lambda/4$ retarders	
	Records Stokes I, Q, V, U in 4 s with 4 consecutive exposures	
Science camera	Thomson Camelia $4M$	
	$2K \times 2K$ pixels; 12 bit; 14 μm square pixels; 4.2 images s^{-1}	
IMC	**Algorithm:**	Correlation tracking
	Optics:	Secondary mirror on hexapod act. with 6 deg. of freedom 90/10 beam splitter; refocusing lenses
	Detector:	$256'' \times 256''$ pix camera; $0.2''$/pix; 100 frames s^{-1}
Autonomous telescope alignment	**Algorithm:**	Curvature wavefront sensing
	Optics:	Secondary mirror on hexapod act. with 6 deg. of freedom Movable beam folding mirror & 2 beam splitters (66/33, 50/50)
	Detectors:	3 cameras; $256'' \times 256''$ pix; $0.2''$/pix Simultaneously record 3 images at 3 focus positions: in focus, focus+5 mm, focus-5 mm

Table 4. Instrument characteristics

It consists of a polarization modulator and a calibration section. The former consists of two linear retarders and a linear polarizer at 0^o. Polarization calibration will be made by liquid crystal retarders (proven in FGE), as well as by a series of pre-flight calibrations and environmental performance tests.

NICO is expected to acquire 2 images s^{-1} in wavelength range 650 nm $-$ 8600 nm, with a signal-to-shot noise of 600 per $0.1''$-pixel. In 1000 nm $-$ 1100 nm, NICO will obtain 1 image s^{-1} with a signal-to-shot noise of 250 per $0.1''$-pixel. The signal-to-noise ratio can be improved by a 2×2-pixel binning, to provide images with pixel size $\sim 0.194''$. The expected velocity uncertainties are $5-10$ m s^{-1}, per 5 s of observation. For longitudinal magnetograms, the uncertainties will be $5-10$ G in the chromosphere, and $3-5$ times better on the photosphere. For transverse magnetograms, uncertainties will be $5-10$ times larger. During the flight, parallel observations will be performed by the Imaging Vector Magnetograph (IVM), in the Mees Solar Observatory, for comparison with the acquired data.

5. CONCLUSIONS

NICO complements future missions, such as NASA's Solar-B. Like the FGE, NICO will also be a test bed for innovative technologies. Missions envisaged under the Living With a Star initiative will need innovative filters and magnetograms. NICO will advance the required knowledge and technology.

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