The CubeSat Heliospheric Imaging Experiment – CHIME

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What is the Heliosphere?

- Wikipedia:
  - The heliosphere is a bubble in space "blown" into the **interstellar medium** (the hydrogen and helium gas that permeates the galaxy) by the solar wind.
  - Virtually all of the material in the heliosphere emanates from the Sun itself.
  - Consists of particles, ionized atoms from the solar corona, and fields, in particular magnetic fields.

- Contains Interplanetary Coronal Mass Ejections (ICMEs)
  - ICMEs are large, fast-moving clouds of solar plasma that have been ejected into interplanetary space from the Sun.
  - They are the largest eruptions of matter and energy from the Sun.
Geomagnetic storms result from the impact of ICMEs on the Earth’s Magnetosphere.

Geomagnetic storms:
- Energize the van Allen belts
- Cause aurora
- Shift the magnetopause
- Give rise to energetic particle showers

They have been associated with:
- Power station failure
- Spacecraft damage and destruction
- Increased radiation dosage for airline passengers and astronauts
- Disruption of radio communications

Power system events due to the March 13, 1989, geomagnetic storm.

B: Blackout, D: Equipment Damage, T: Tripping Equipment

IMAGE SOURCE: Electric Power Research Institute, Inc.

2003 “Halloween” Storms

An X17 flare observed during the 2003 “Halloween” storms with SOHO’s Extreme-ultraviolet Imaging Telescope (EIT) (left) and a difference image showing the associated halo CME (right). SOHO is stationed 1.5 million kilometers upstream from Earth, at the Lagrangian point 1.

Right is a coronograph Image

Space weather and satellite anomalies/failures.

CAPTION: Most events/failures are not attributed to space weather, but 46 of 70 [events/failures] in 2003 occurred during Halloween storms.

Coronagraph observations are limited in the info about CMEs they provide.

This is because coronagraph images are two-dimensional and so can only provide a projected view of the CME (and corona).

This projection is into the sky plane, so CMEs of most importance for space weather (Earth-directed ones) are also those that suffer the most projection.

The result is that there is no way to extract 3-D information on CMEs and we are stuck with projected measurements.
What is it?
- Heliospheric imagers are white light cameras that have a wide field of view, so they observe at very large distances from the Sun.

How Do They Solve the 3-D Problem?
- Projection effects imposed on coronagraph images are mathematical consequences of the geometry and Thomson scattering that allow us to observe CMEs.
- This leads to a linearity that allows both the analysis of coronagraph CMEs to be simplified, but at the cost of loss of 3-D information.
- At large distances from the Sun this linearity breaks down, so while the analysis is more complex the 3-D information is retained.

With careful analysis of heliospheric imagers, we can extract 3-D information on CMEs not available in coronagraphs.
**Existing Heliospheric Imagers**

**Coriolis SMEI (launched Jan 2003)**
- Sun-synchronous polar orbit
- Scanning
- Cadence 102 minutes
- Whole sky imager beyond 20°
- 7 year dataset

**STEREO HI-2 (launched Oct 2006)**
- Solar orbit
- Staring
- Cadence 120 minutes
- Observes from ~20-90°
- Limited FOV to ecliptic plane
- 3 year dataset (Solar minimum)
SMEI continues to operate and has detected well over 300 ICMEs during its 7 year lifespan
- SMEI is nearing end-of-life and no replacement is currently underway
  - The innermost camera of SMEI (Camera 3) has been running hot since launch. This results in an accumulation of hot pixels on the field of view which obscures real parts of the image. This has been fixed over the last 7 years by doing an anneal at regular intervals, but the problem has been slowly getting worse. Camera 3 is the camera of most use because it is the one that observed CMEs closest to the Sun when they are brightest.

STEREO HI's have further demonstrated the utility of heliospheric imaging
- A combination of limited field-of-view and exotic solar orbits will eliminate their ability to observe Earth-directed events by mid 2011

Both STEREO-HI and SMEI will thus become unusable for terrestrial space weather monitoring, just as the solar cycle enters its rapid rise phase and ICME effects at Earth become important.

CHIME is also a significant enhancement to SMEI
- 3D field provides better noise resistance
Space Weather Forecasting

Current Techniques
- Data amalgamation from
  - CME Coronographs at L1
  - Solar Flare location
  - ICME-related radio bursts
- Warning time: 1 day
- Predication Capability: none
- Difficulty: ICMEs do not move linearly through space or at a consistent speed

Proposed Technique
- TH Prediction Model (AICMED code)
  - Leading edge determinations from time series heliospheric images
- Warning time: >1 day
- Predication Capability: +/-2 hour precision
- Accuracy improves as ICME approaches Earth
The TH Model

The TH model produces an estimation of ICME geometry and kinematics by comparing leading edges measured in heliospheric image data with those from simulated ICMEs.

First, a basic structure is chosen:

A spherical arc, solar centered (shell).

Then independent combinations of:
- Speed
- Distance
- Central Latitude
- Central Longitude
- Latitude Width
- Longitude Width
- Distortion Parameter

Are combined to produce ICME simulated images from which leading edges are produced relative to a fixed observer.

[Tappin & Howard, 2009]
TH Results

TH Model Distances Extrapolated from Elongation Angle from Image.

[Howard & Tappin, 2009b]
TH Model 3-D ICME Reconstruction from STEREO data
TH Model Results (from AI CMED)
CHIME Spacecraft

- CHIME is a complete Heliospheric Imaging Platform in a 3U CubeSat Package built primarily from COTS components.

- **Spacecraft Systems:**
  - Instrument
    - CCD Camera
    - Baffle
  - 3-axis stabilized ADACS
  - S-Band Radio (developed by SwRI)
    - Patch Antenna
  - C&DH Computer
  - Power
    - Solar Panels
    - Controller
    - Batteries
  - Thermal Control
Instrument

- Imager consists of COTS CCD Camera
  - 7-10 arcmin resolution
  - 60° Field of View
  - 1300x1000 pixel resolution
  - 16-bit photometric capable
  - 300 seconds per exposure

- Baffle system
  - Shields camera from sunlight
  - Stray light rejection ratio of $10^{-13}$ towards sun, $10^{-9}$ anti-sun
Subsystems

- Attitude Determination and Control System (ADACS)
  - Intellitech IMI-100 with supplemental sun sensor
  - 1-3 arcsecond pointing accuracy
  - GPS Receiver for location determination

- SwRI S-Band Radio
  - S-Band reconfigurable transceiver radio
  - In development on IR funding
  - Ground station with United Space Network
  - Link margin of 10dB with 1Mbps bandwidth
  - Baseline five 5-minute passes per day

- Command and Data Handling
  - Gumstix Single Board Computer
  - I/O board provides S/C-wide control
  - Watchdog reset provides radiation tolerance
Subsystems (cont.)

- Power
  - 3 deployable solar cell strings (ClydeSpace)
  - 17 W, 30% margin, 22W CBE
  - Power Controller (ClydeSpace)
  - Batteries

- Thermal Control
  - Temperature maintained ~30°C
  - Thermocouples
  - Heaters
  - Baffle thermally isolated
    - Maintains 0°C near camera
  - Spacecraft Pointing

- Actuators
  - Launch Rails
  - Camera Safety Shutter
**Conclusions**

- ICMEs are critical Solar Electromagnetic storms that play a key role in space weather effects on Earth.
- Heliospheric Imaging is an excellent way to detect and forecast the motion of ICME events.
- All current Heliospheric Imagers will be inoperable within the next few years.
- To fill the need for Heliospheric Imaging in Space Weather Forecasting in a cost effective manner, a constellation of CHIME spacecraft is the best solution.
- **CHIME is more than a replacement for SMEI** -- it enables lower noise, quantitative measurement of ICMEs that are not currently possible from near Earth.
Far-ultraviolet images of the pre-shock (left) and post-shock (right) aurora obtained with the auroral imager on NASA’s IMAGE satellite during the July 14-15, 2000, “Bastille Day” event. Courtesy NASA/IMAGE FUV team.
“The red light was so vivid that the roofs of the houses and the leaves of the trees appeared as if covered with blood” (report of the aurora seen in San Salvador, September 2, 1859; see note 2 at the end of this chapter). Low-latitude red auroras, such as those widely reported to have been observed during the Carrington event, are a characteristic feature of major geomagnetic storms. The aurora shown here was photographed over Napa Valley, California, during the magnetic storm of November 5, 2001. Reprinted with permission from D. Obudzinski (www.borealis2000.com). © Dirk Obudzinski 2001.

Locations of reported auroral observations during the first ~1.5 hours of the September 2, 1859, magnetic storm (orange dots). Courtesy J.L. Green, NASA