NOAA Space Weather Update

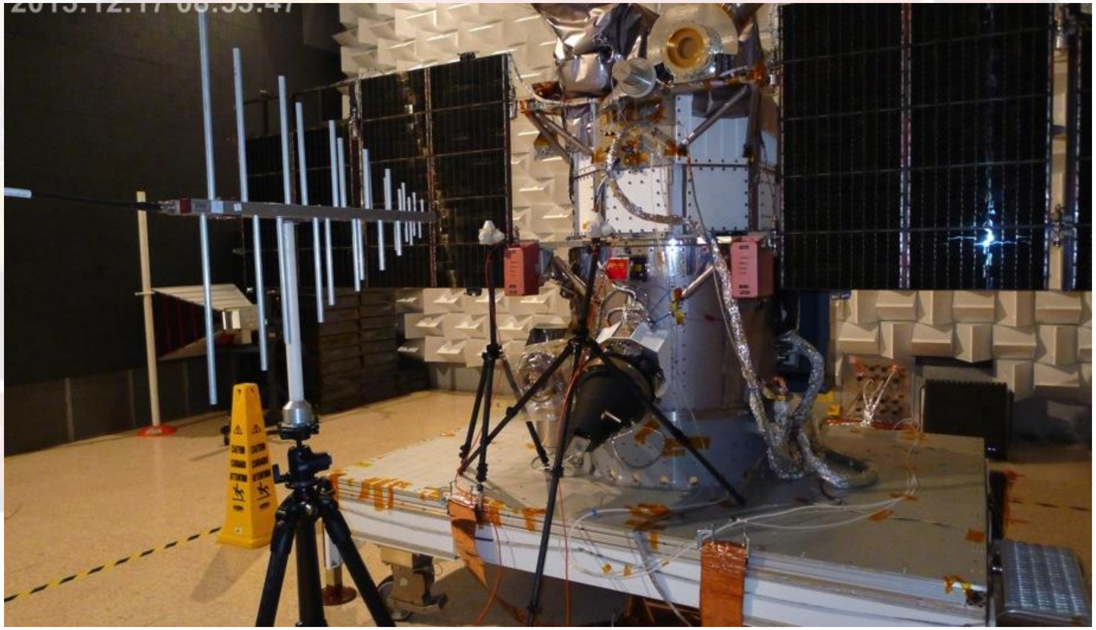
Upcoming Launches and Future Plans

Patricia Mulligan, NOAA/NESDIS/OSD

Space Weather Workshop
April 9, 2014

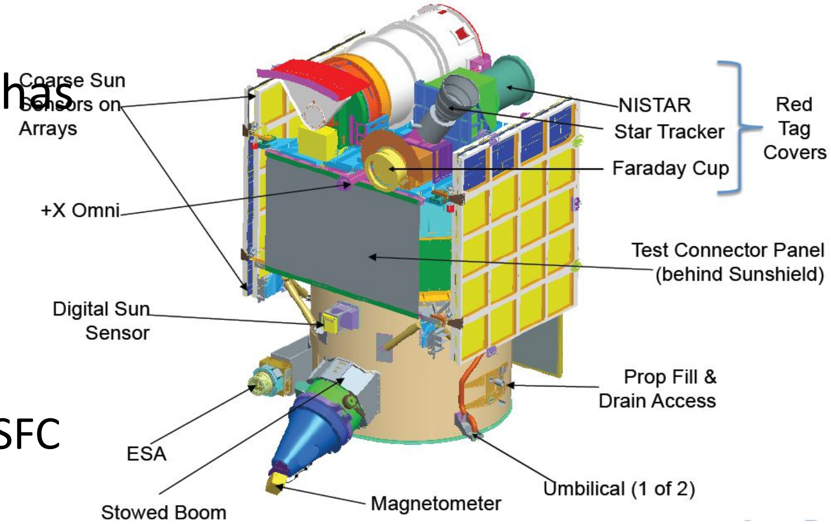
DSCOVR

- Counting down to launch
  - Refurbishment is complete
  - Thermal Vac and Thermal Balance are complete
  - Magnetometer and Faraday Cup both recalibrated and in great shape
  - Vibration testing expected to begin 4/14/2014
  - Launch Readiness Date1/13/2015



Changes since the Triana Days

- Magnetometer has been moved to the end of the boom
- The Electron Electrostatic Analyzer (ESA) has been displaced to the spacecraft bus
- The Lissajous orbit has been shrunk from being 'Wind sized' to 'ACE sized'
- Real-time data will be provided by NOAA (SWPC in real-time; NGDC archive)
  - Science data will be provided by NASA/GSFC
    - Funded by NOAA for life of mission for instrument support and calibration
- **Space Weather mission is primary**, Climate is secondary

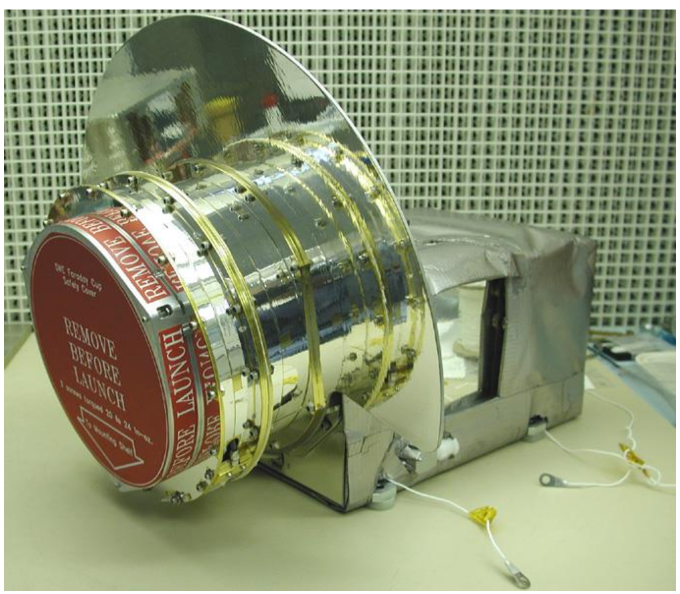


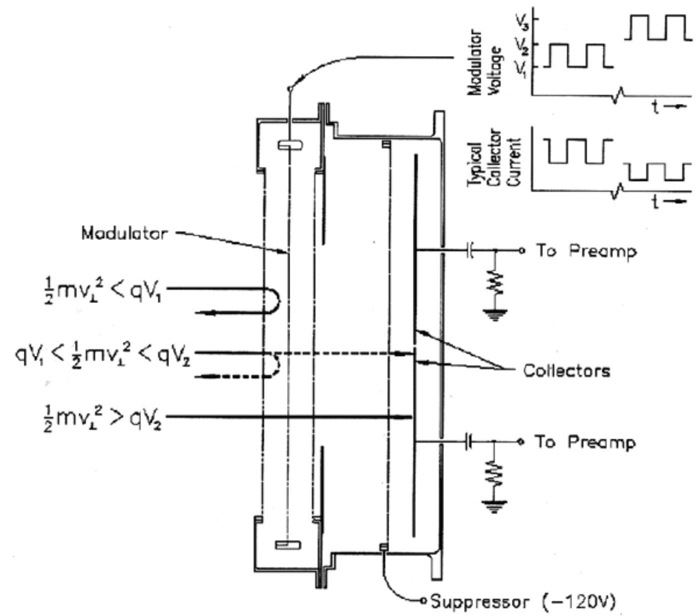
DSCOVR Faraday Cup - SAO/MIT/GSFC

The Faraday Cup is a retarding potential particle detector that provides high time resolution solar wind proton bulk properties (wind speed, density and temperature)

Robust instrument – Can operate through high energy particle storms that commonly accompany critical space weather events

Located on the spacecraft upper deck facing towards the Sun.

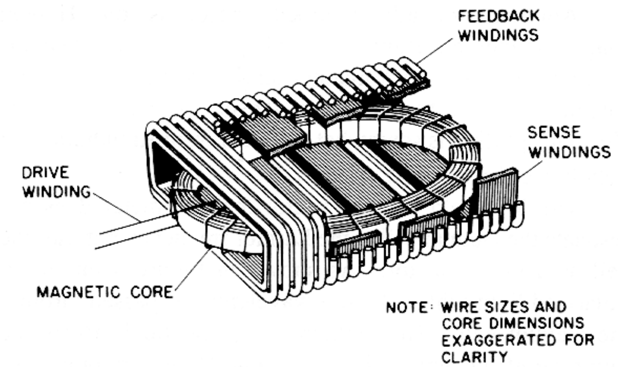




Goddard Fluxgate Magnetometer

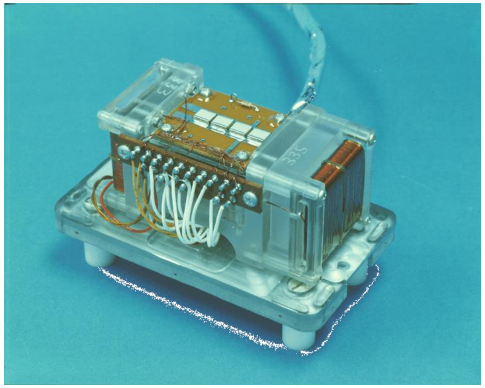
The Fluxgate Magnetometer measures the interplanetary vector magnetic field

It is located at the tip of a 4.0 m boom to minimize the effect of spacecraft fields

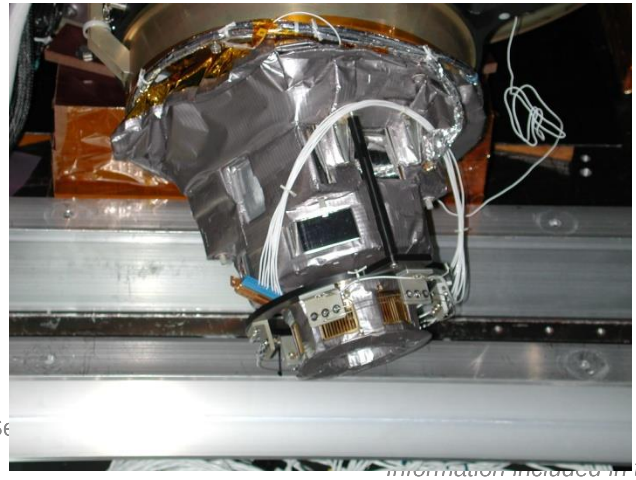


Single ring core magnetometer

Requirement	**Value**	**Method**	**Performance**
Range	0.1-100 nT	Test	0.004-65,500 nT
Accuracy	+/- 1 nT	Test	+/- (0.5-0.9) nT
Cadence	0.0167 Hz	Test	50 Hz

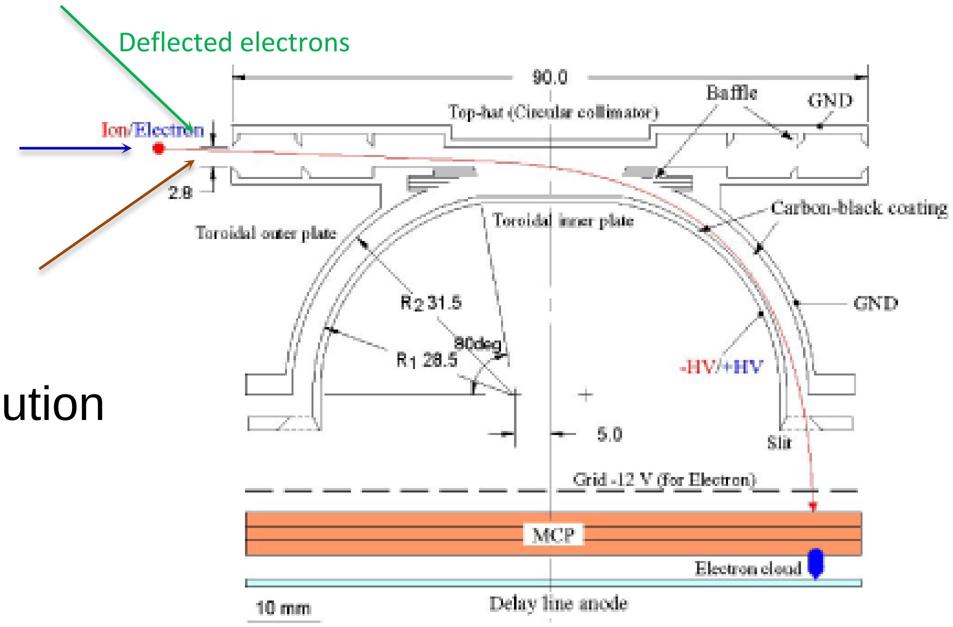


Three separate ring cores in the DSCOVR magnetometer



SWPC will provide 1s and 1m averaged FC data in real-time

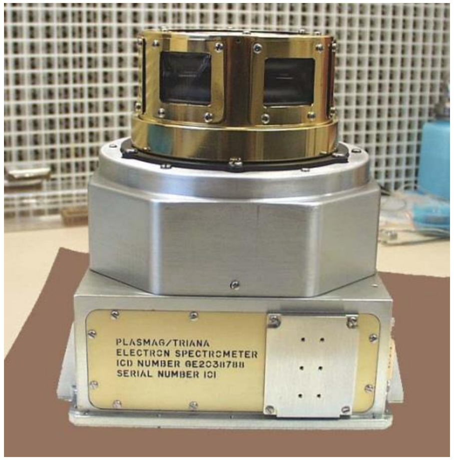
DSCOVR Electron ElectroStatic Analyzer (ESA)

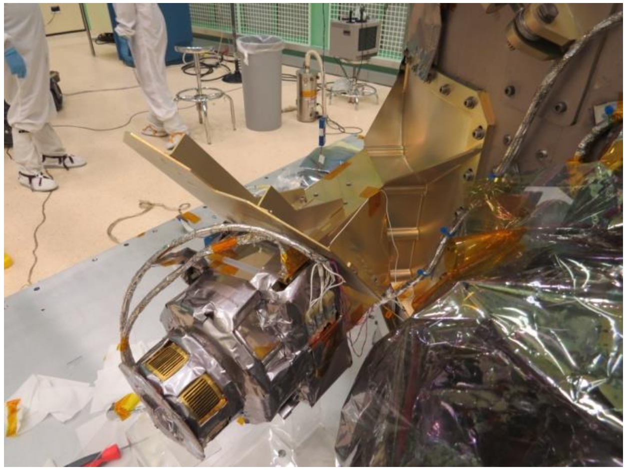


The ESA is a top hat electrostatic analyzer that measures the full distribution function of the solar wind electrons

It was relocated to a bracket on the propulsion module

The ESA is funded by the NASA Heliophysics Science Division

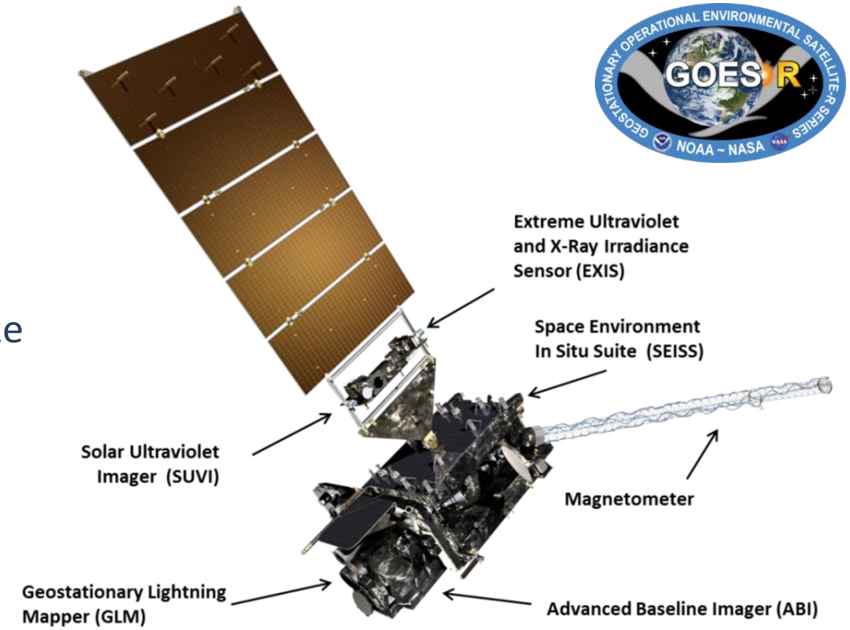




GOES-R Series Overview

Benefits

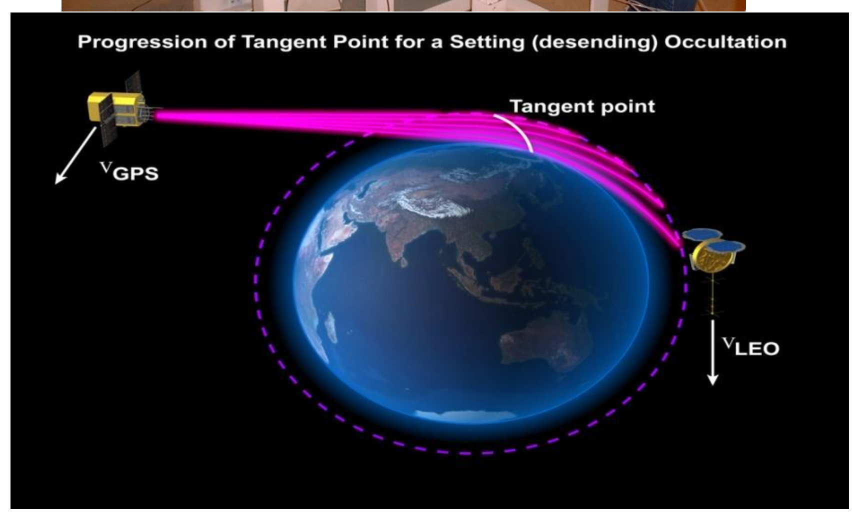
- Primarily atmospheric weather - Maintains continuity of weather observations and critical environmental data from geostationary orbit
- Provides improved warning of solar events to minimize impact to communications, navigation systems, and power grids



GOES-R Launch Readiness Date*	2QFY2016
Program Architecture	4 Satellites (GOES-R, S, T & U) 10 year operational design life for each spacecraft
Program Operational Life	FY 2017 – FY 2036
Program Life-cycle*	$10.860 billion

***Launch Readiness Date based on FY 2014 President's Budget Request**

COSMIC-1 Background



COSMIC-1

- Launched April 2006
- US/Taiwan collaboration
- US development activities managed by NSF/UCAR
- $100M project – six Orbital microsatellites
- Provided 1,800-2,500 worldwide soundings per day
- Very high accuracy temperature profiles - approaching 0.1K
- NOAA operational forecasting with the data started May 2007
- Significant positive impacts on weather forecasting
- NOAA ground station support Fairbanks, Wallops, Tromso
- End of engineering design life - 2011

COSMIC-2 Mission Overview

- Follow-on to current COSMIC-1 satellite constellation
- Design concept meets L1RD requirements
  - System will provide 8,000+ worldwide soundings per day
  - All weather, uniform coverage over oceans and land
- 12 Satellite Constellation is planned
- Planned 2 launches in different inclinations
  - 6 satellites to 24 degree orbit – carries USAF secondary payloads
  - 6 satellites to 72 degrees orbit – carries Taiwan secondary payloads
- Planned to launch on May 15, 2016 and FY18
- COSMIC-2 is now an officially NOAA funded program in FY14

Program Status and Issues

- NOAA and the USAF have made positive progress in determining a way forward for the U.S. with Taiwan
- The USAF initiated procurement of the first six Global Navigation Satellite System radio occultation (GNSS-RO) payloads for the joint COSMIC-2 mission and have identified a procurement approach for the first launch
- Taiwan's NSPO awarded a spacecraft contract to Surrey Satellite Technology Ltd (SSTL) UK, August 2012
  - Spacecraft completed Preliminary Design Review (PDR) in June 2013 and Critical Design Review (CDR) in November 2013
- USAF awarded a launch vehicle contract to SpaceX in January 2013, to launch COSMIC-2 on the STP-2 Mission Falcon 9 Heavy launch vehicle
- COSMIC-2 primary payload the TriG GNSS Radio occultation System (or TGRS) is in Integration and Test at NASA's Jet Propulsion Laboratory (JPL) and is proceeding on schedule
  - 1st IVM payload delivers to US Air Force Jan 2014; 1st RF Beacon delivers in May 2014
- NOAA continues to engage international partners to host/operate ground stations for the COSMIC-2 mission
- NOAA and U.S. partner agencies are determining if the U.S. can secure the funding to procure the remaining TGRS payloads for the second six COSMIC-2 satellites

Program Status (con't.)

- "RO is the most accurate and stable thermometer in space"…UCAR President Emeritus
- RO data ranked number 5 in positive impact of all the 24 observing systems used by the ECMWF – reducing forecast error by almost 9% even though the number of RO observations amounted to only about 3% of all observations assimilated by ECMWF
- COSMIC-2 is now an official NOAA program, which is great news for the U.S.
- COSMIC-2 is a very real program using real USAF dollars (~$120M-$130M already invested) and Taiwan has invested ~$100M US for the first 6 satellites, with a ready option for the next 6 satellites
- The COSMIC-2 data is very valuable both scientifically and operationally
- COSMIC-2 will be implemented to reduce the potential RO data gap and continue to serve the global meteorology community
- Significant efforts from U.S. and Taiwan sides have contributed to the joint mission, and the first launch of COSMIC-2 on May 15, 2016 can be expected
- The U.S. funding commitment for the second six payloads does not exist at this time, however, a solution is being actively worked within the US agencies
- NOAA is currently drafting a policy directive regarding commercial applications for data such as GNSS RO, beyond the COSMIC-2 mission timeframe

DSCOVR F/O And Coronagraph

- DSCOVR F/O continuation of solar wind measurements
- Initiation of operational CME Imaging
- Multiple planning activities underway:
  - RFI to update commercial data buy prices
  - Backup studies at APL and GSFC government satellite option
  - Resuming Compact Coronagraph studies
  - Planning to fly CCOR in an L1 orbit on DSCOVR F/O
  - Evaluating maturity of solar sail technology to allow application for forecast improvements
  - All activities are intensely coordinated with NASA Heliophysics and STMD

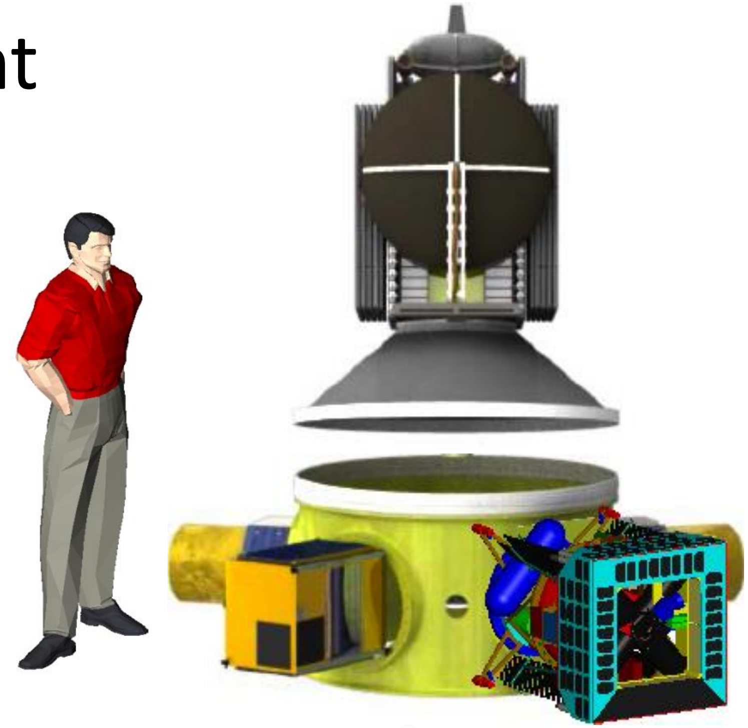
Commercial Data Purchase

- Since 2003, NOAA has been working with Commercial Service Providers on mission concepts, prices, and business plans.
  - 2003: Request for Information
  - 2005: Broad Area Announcement
    - SSHI, Lockheed, NRL, SWRI
      - Genesis of CCOR
    - Booz Allen Hamilton – assessed the commercial business case
      - Assessed the risks
      - Identified mitigation strategies (which NOAA has incorporated)
  - 2007: RFI
  - 2008-2009: RFQ
- There is substantial evidence that commercial providers could take on the risk of building, launching, and operating a mission to meet NOAA's requirements.
- NOAA continues to examine all information from commercial providers
  - In 2014 released a 'Request for Information' with due dates of March 28.
  - NOAA received proposals that have provided very valuable information

Government Concept Studies

- We have a study underway with APL for design and cost of a government satellite
  - Envisioned as one of an L1/L5 pair
- In FY14 the Goddard Space Flight Center will be funded to start design and cost studies
  - They will include a variant looking at the possible repurposing of spares from the MMS program

Sunjammer Solar Sail Flight Demonstration



- A NASA STMD Technology Demonstration Mission
  - Cubesat sensors – very much technology demo
    - **MAG**netometer from **I**mperial **C**ollege (**MAGIC**)
    - **S**olar **W**ind **AN**alyser (**SWAN**)
      - University College London/Mullard Space Science Laboratory
    - Funding from UK Space Agency
  - Demanifested from co-launch with DSCOVR; agencies are consulting on path to test flight
  - NOAA is a partner in this mission with a high interest in the flight data and the science data from MAGIC and SWAN
  - Mission is also an important indicator for the viability of commercial space missions

Sunjammer Quadrant Deployment Test 9.30.2013

Compact CORonagraph (CCOR)

- In 2010, NOAA funded NRL to perform the Compact Coronagraph (CCOR) concept study report
  - Included successful bench testing of the new optics design
- FY14 – NOAA is funding NRL to perform selected studies
  - Long lead items (mitigating schedule risk)
    - Electronics trades
    - Detector trades
  - Mid-Term report was provided to NOAA March 27
- CCOR is currently slated to fly on the DSCOVR replacement mission

CCOR compared to a Lyot coronagraph

- All coronagraphs to date follow the traditional design of Lyot – design driven by dealing with diffracted light
  - Lyot design was empirically derived
  - What if you used a modern optical model to design a coronagraph? (Q. Gong and D. Socker 2004)

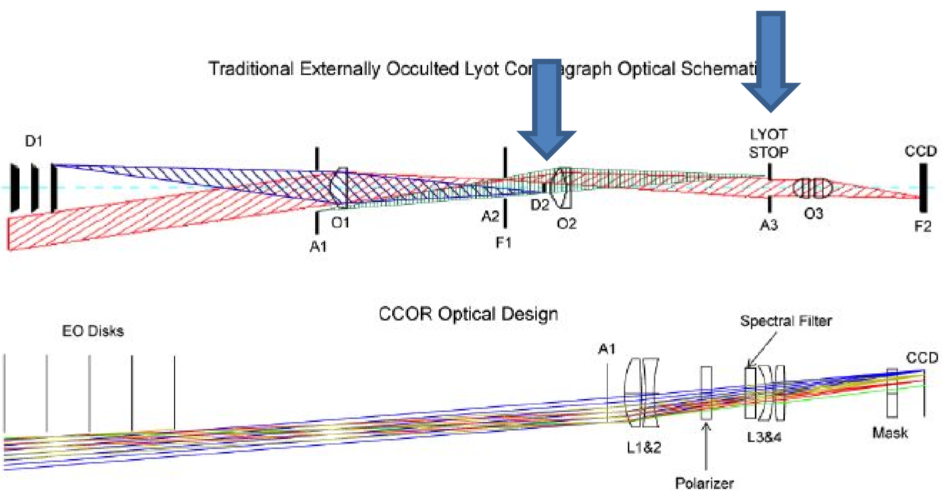


Figure 3-1. CCOR and Traditional Coronagraph Optical Design Comparison (not to scale)

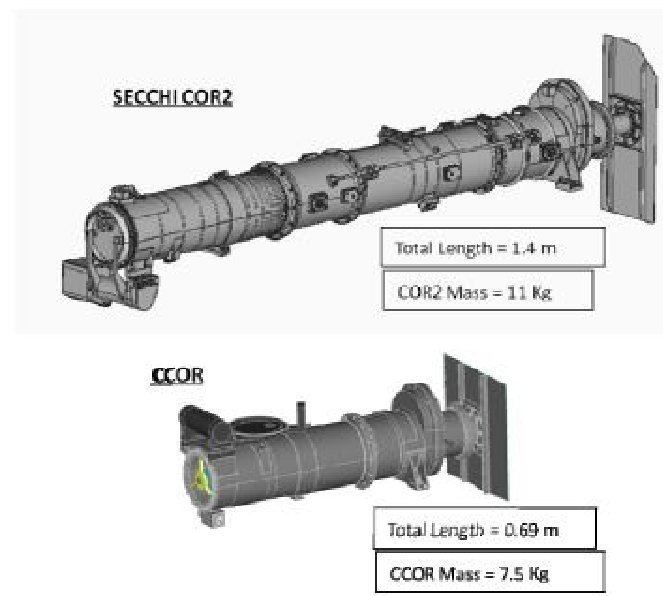


Figure 1-4. CCOR Comparison to Heritage SECCHI/COR2 Design

The Concept is Proven

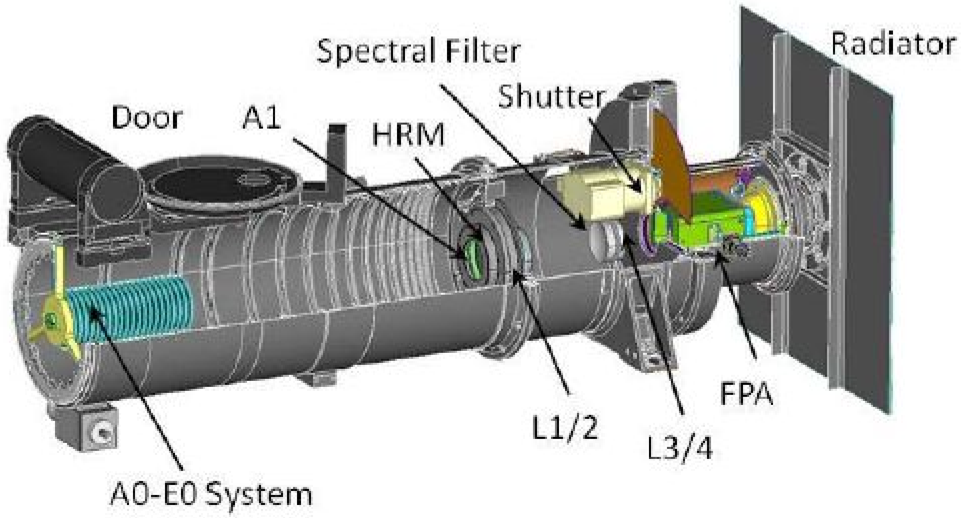
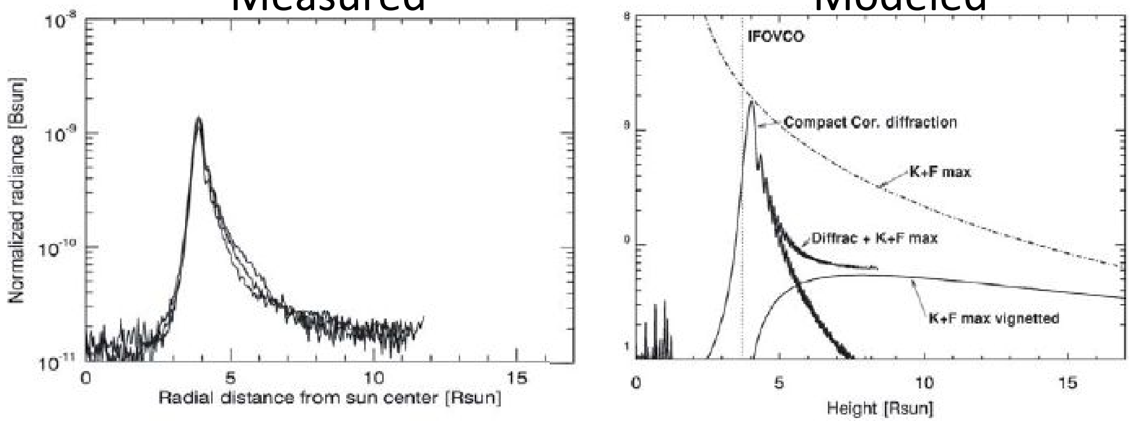


Table 2-2. Nominal CCOR Sensor Capabilities

Field of view	3.7 to 17 R⊙
Detector	E2V 42-40, 2048x2048, 13.5 μm pixels
Wavelength	650 to 750 nm (FWHM)
Plate scale	15.8 arc seconds/pixel
Stray light level	3.6 x 10^{-11} B/B⊙ at 6 R⊙
Resolution	<50 arc seconds

Measured Modeled



The left panel shows the brightness of diffracted light around the baseline CCOR occulter design (5-disk, 3.7 R⊙ IFOVCO) as a function of radial distance from Sun center in radiance units normalized to the brightness of the Sun. This is compared to the predicted brightness profile calculated by [model] shown as part of the CCOR BAA report (right panel). The brightness profile of diffracted light for the baseline CCOR occulter agrees very well with the modeled profile.

Conclusion

- We are planning for an ambitious growth of space weather operational observations
- We're encouraging the development of critical technologies
- We are engaging with the commercial space community
- We are coordinating our plans very closely NASA Heliophysics
    - -including the potential for research to operations transition collaboration

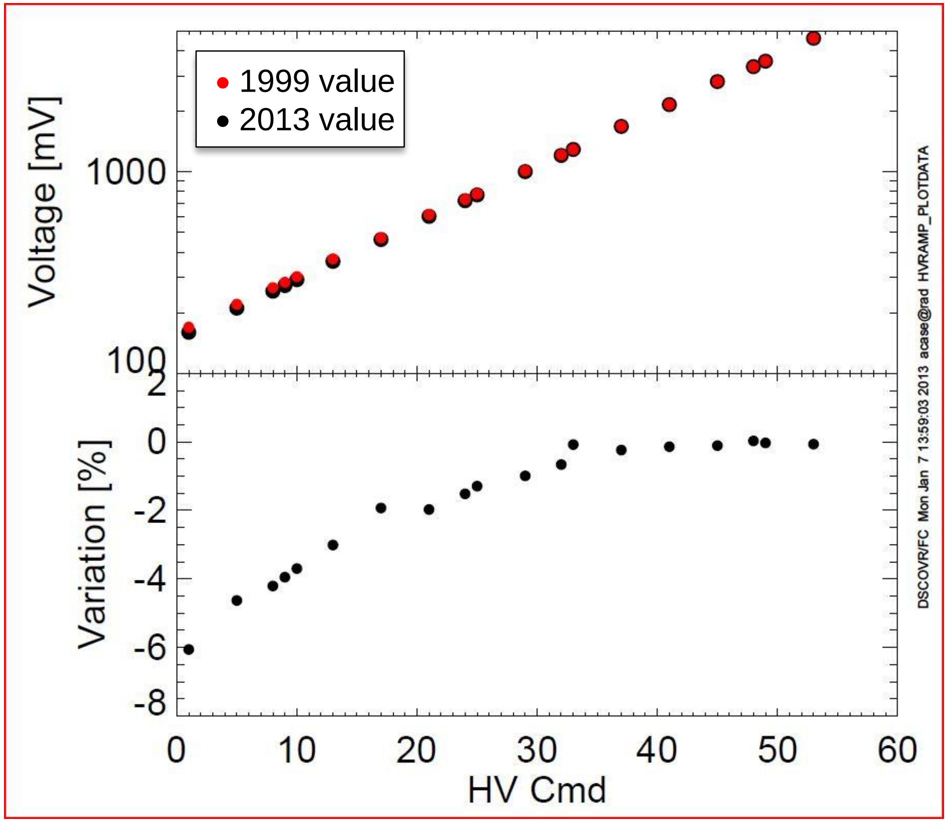
BACKUP

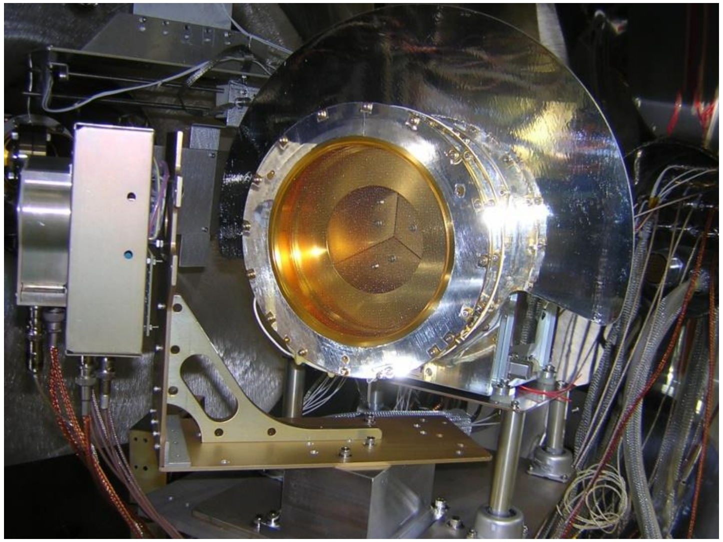
Faraday Cup Calibrations

The DSCOVR Faraday Cup was fully calibrated in the Goddard Heliophysics Ion/Electron Beam Facility in 1999

The instrument was recalibrated in the same facility in 2013

All modulator voltage steps were measured. Drifts from 1999 values were minimal





Faraday Cup Level 1 Requirement Verification

Requirement	Required Value	Method	Performance
Velocity Range	200-1250 km/s	Test	168-1340 km/s
Velocity Accuracy	20%	Test	2%
Density Range	1-100 cm^{-3}	Test	0.22-219 cm^{-3}
Density Accuracy	20%	On Orbit/Test	~1% (20% ground)
Temperature Range	$4x10^4$-$2x10^6$ K	Test	$3.9x10^4$-$7.3x10^7$ K
Temp. Accuracy	20%	Test	<8.9%
Cadence	0.0167 Hz	Test	2 Hz

The FC measurements will meet or exceed all Level 1 requirements.

SWPC will provide 3s and 1m averaged FC data in real-time

ESA Requirement Verifications

The ESA was fully calibrated in 2000 in the Goddard Ion/Electron Beam Facility

A full functional test and partial recalibration also took place in 2013 in the same facility

Requirement	Value	Method	Performance
Energy Range	5 eV – 1 keV	Test	5 eV – 1 keV
FOV	2 ster rad	Test/Analysis	2.5π ster rad
Cadence	0.0167 Hz	Test	1 Hz

SWPC, at this time, has no plans to process ESA data in real-time.

Occulter Design Trade

- Requirements are easily met with the 5-disk; inner FOV cut-off of 3.7 Rsun occulter.
- Keeping the same iFOV but adding disks gives margin
- Increasing the iFOV gives even more trade space
  - But NOAA rejected that option

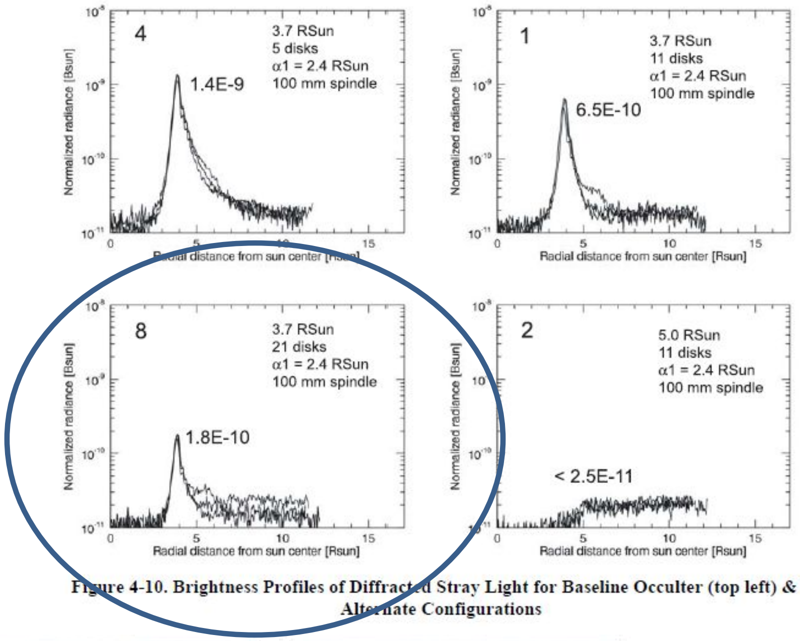
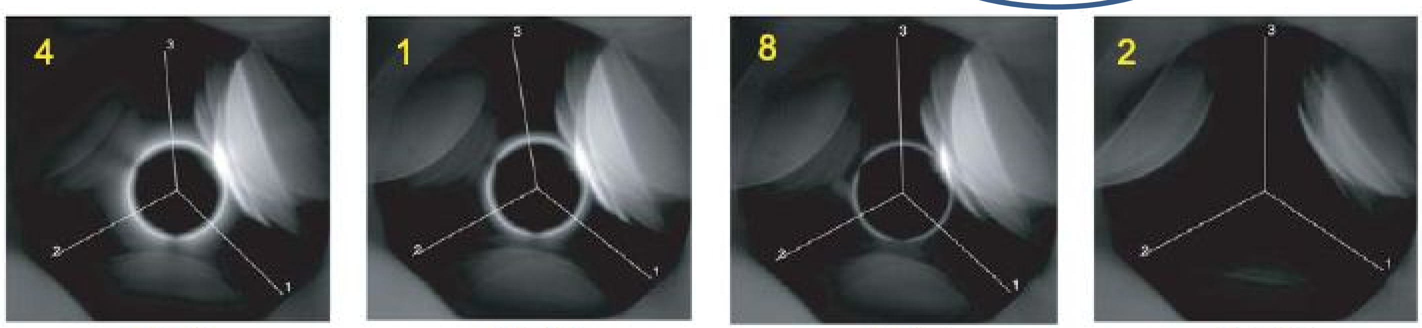


Figure 4-10. Brightness Profiles of Diffracted Stray Light for Baseline Occulter (top left) & 3 Alternate Configurations



3.7 R⊙	3.7 R⊙	3.7 R⊙	5.0 R⊙
5 disks	11 disks	21 disks	11 disks
α1=2.4 R⊙	α1=2.4 R⊙	α1=2.4 R⊙	α1=2.4 R⊙
100 mm spindle	100 mm spindle	100 mm spindle	100 mm spindle

Figure 4-9. Diffracted Stray Light Measurements Comparing Baseline to 3 Alternate Configurations

COSMIC-2 Mission Baseline

	First Launch	Second Launch
Mission Constellation	6 satellites Low-inclination angle orbit	6 satellites with one additional NSPO-built satellite [TBR] High-inclination angle orbit
Mission Orbit	Inclination 24 deg Parking altitude 720 km, Mission altitude 520~550 km Circular orbit	Inclination 72 deg (+/- 1deg), Parking altitude 520 km, Mission altitude 720~ 750 km Circular orbit
Mission Payload	TGRS (GNSS RO payload)	TGRS (GNSS RO payload)
Science Payloads	Radio Frequency Beacon scintillation instrument Ion Velocity Meter (IVM)	Taiwan-furnished payload(s)
Launcher	Falcon-9 Heavy, STP-2 Mission (rideshare)	Falcon-9, Falcon Heavy, or EELV rideshare
Launch schedule	May15, 2016	2018
Maximum Daily Average Data Latency	45 minutes	
Communication Architecture	S-FTP Multicast via VPN Internet	
Ground Station	There shall be sufficient ground stations to meet the data latency requirement	
Data Processing Centers	US-DPC (UCAR) and Taiwan-DPC (TACC)	