The EUV Variability Experiment (EVE) for the NASA Solar Dynamics Observatory (SDO)

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EVE Science Team

- CU/LASP: Tom Woods (PI), Frank Eparvier, Gary Rottman
  - Providing MEGS instrument and EEB (electronics) subsystem
- USC: Darrell Judge, Andrew Jones, Don McMullin (NRL)
  - Providing ESP instrument
- NRL: Judith Lean, John Mariska, Harry Warren
  - NRLEUV solar irradiance model - using AIA/HMI solar images
- MIT/LL: Greg Berthiaume
  - Providing 1K x 2K CCDs and camera electronics for MEGS
- UAF/GI: Scott Bailey
  - Providing XUV calibrations
- Collaborators: Tim Fuller-Rowell, Jan Sojka, Kent Tobiska, Rodney Viereck
  - NOAA operational atmospheric and solar models

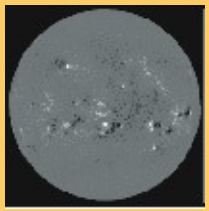
EVE Science Goal

- Specify and understand the highly variable solar extreme ultraviolet (EUV) electromagnetic radiation and its impacts on the geospace environment and the societal consequences

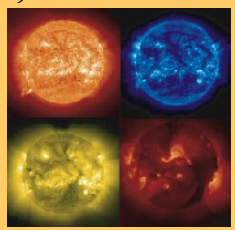
Solar Dynamics Observatory (NASA-GSFC)

Solar Images -> Flares, CMEs

HMI

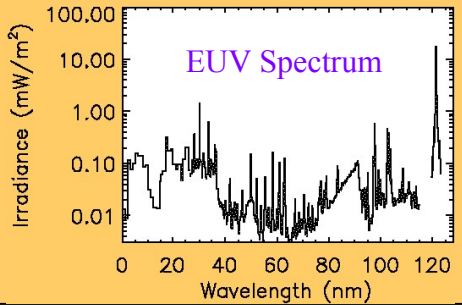


AIA



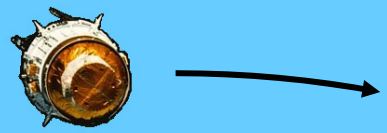
Solar Irradiance -> Energy Input

EVE

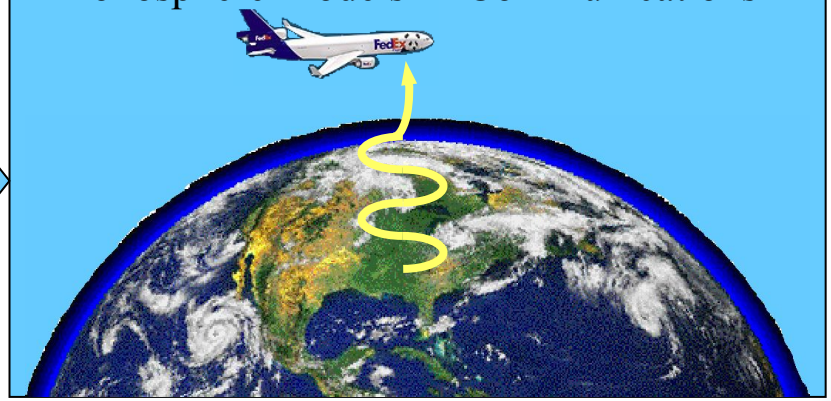


Space Weather Operations (NOAA, Air Force)

Thermosphere Models -> Satellite Tracking



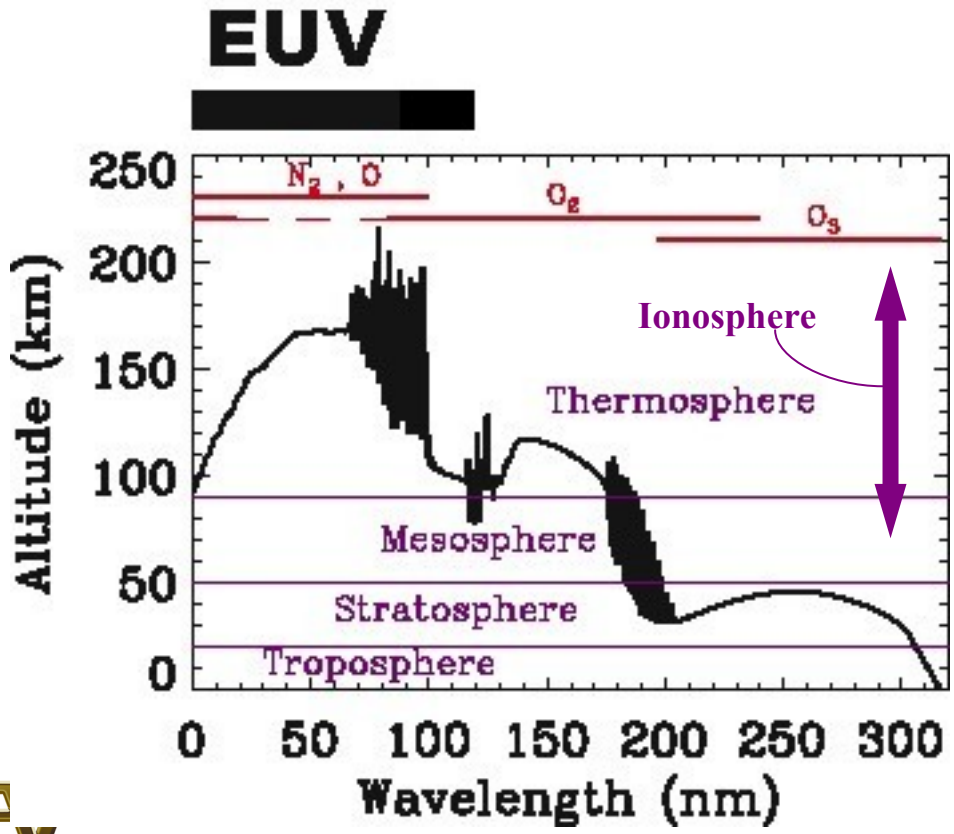
Ionosphere Models -> Communications



SDO Connects the Sun to the Earth

Why EUV measurements?

- The solar extreme ultraviolet (EUV: $\lambda < 120$ nm) radiation is the primary energy input for the thermosphere (where satellites reside) and the ionosphere (what affects communications)

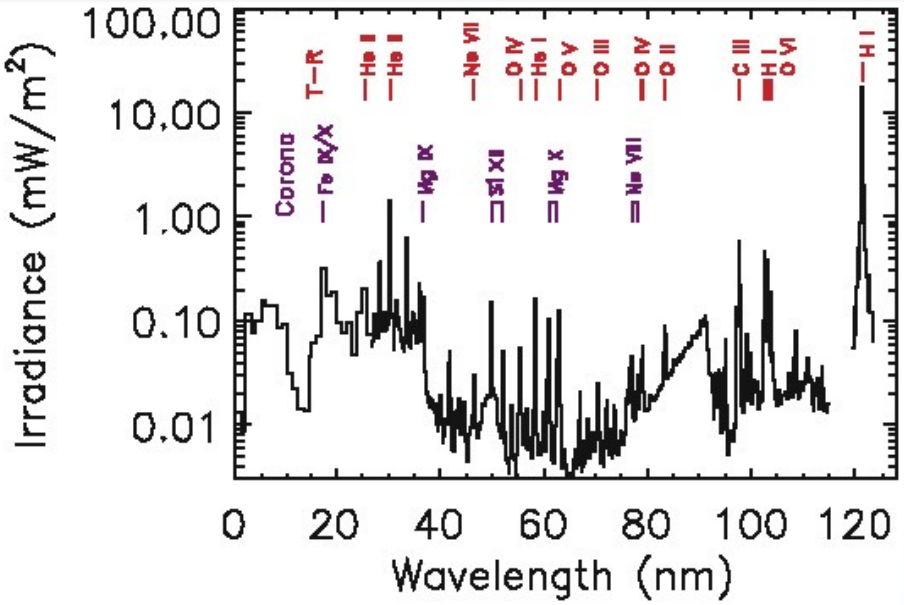


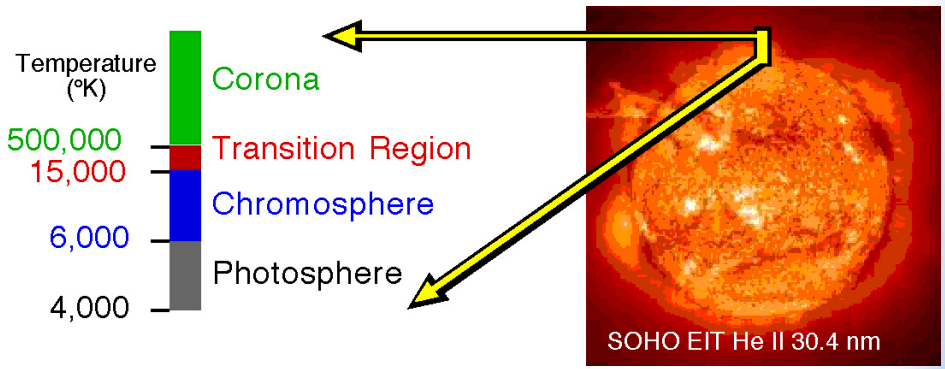
Primary atmospheric absorpers are N_2, O, O_2, and O_3

Plot shows where the solar radiation is deposited in the atmosphere

What is the solar EUV ?

- The solar EUV radiation consists of emissions from the solar chromosphere, transition region, and corona
  - EUV is < 0.01% of the total solar irradiance (TSI: >99% from photosphere)
  - But EUV variations are a factor of 2 - 100 (wavelength dependent), whereas TSI has only 0.1% variations
  - And EUV is completely absorbed in Earth's atmosphere
  - And EUV photons are energetic enough to ionize the atoms and molecules (creates the ionosphere)





EVE Science Objectives

1. Specify the solar EUV spectral irradiance and its variability on multiple time scales

   EUV: 0-105 nm (0.1 nm resolution at >10 nm) and H I Lyman-α (121.6 nm)

   Time Scales: < 20 sec cadence, continuous sequence

2. Advance current understanding of how and why the solar EUV spectral irradiance varies

   Use AIA & HMI solar images to understand the interactions of the solar magnetic fields and the evolution of the solar features (e.g., plage, active network) and how these affect the solar EUV variations

3. Improve the capability to predict the EUV spectral irradiance variability

   Develop new forecast and nowcast models of the solar EUV irradiance for use in the NOAA space weather operations

4. Understand the response of the geospace environment to variations in the solar EUV spectral irradiance and the impact on human endeavors

   Use solar EUV irradiances with thermosphere and ionosphere models to better define the solar influences on Earth's atmosphere

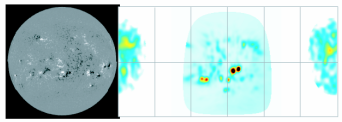
   Input EVE solar data near real-time into NOAA operational atmospheric models to improve accuracy of solar storm warnings and satellite drag calculations and to predict better communication disruptions

EVE -Understanding Solar Output

The Sun

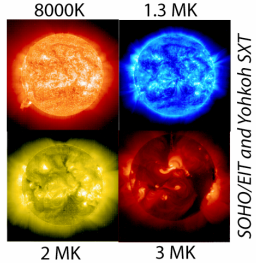
The Solar Dynamo

Magnetic Fields, Active Regions, Network, Dynamics, Rotation

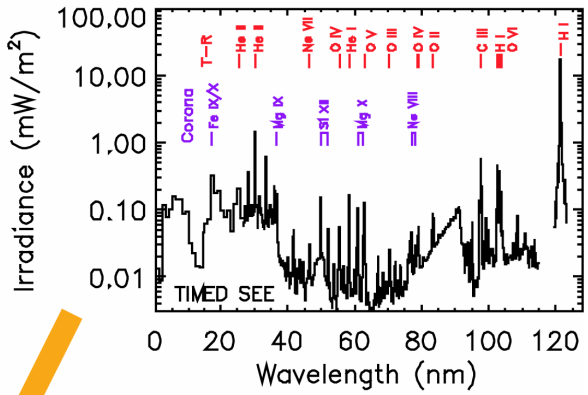


SOHO/MDI

EUV Emissions from Chromosphere, Transition Region, and Corona



Solar EUV Irradiance Spectra



HMI

AIA

EVE

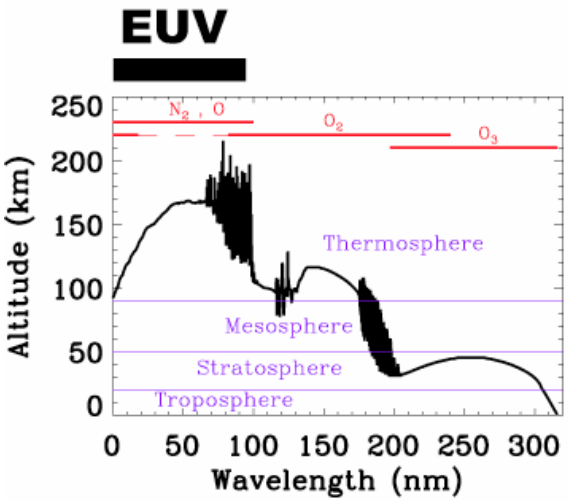
Models of the Solar EUV Irradiance

Advanced understanding of the solar variability on all time scales leads to better models, which in turn leads to better predictions

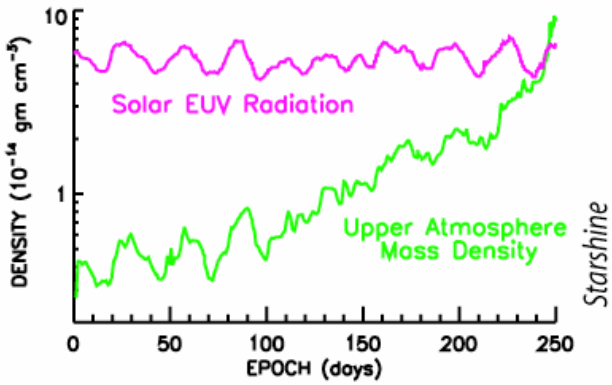
EVE-Studying Influences on Earth

Solar EUV Irradiances

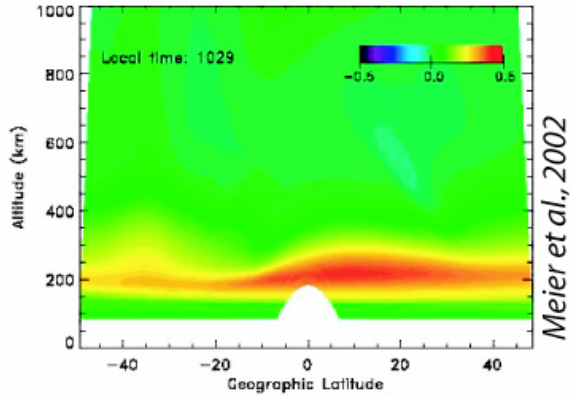
The Earth



Energy Input



Mass Density



Electron Density

Societal Impacts

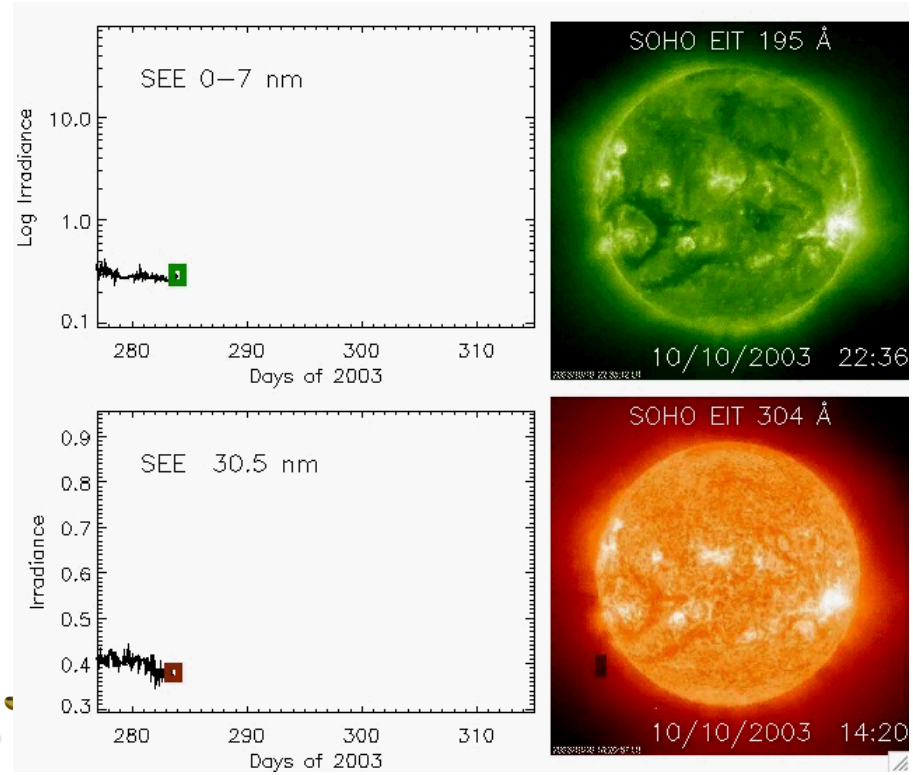
Use real-time atmospheric models to determine solar-induced atmospheric variability effects such as spacecraft drag and communication disruptions

EVE's New Science

- SNOE, SOHO, TIMED, SORCE, GOES, and SDO are providing or will provide new measurements of the solar variability over time scales of days to years and include modeling Earth's response to those changes
- New science for EVE include:
  - Flare studies with full EUV spectral coverage
  - Application of solar images at multiple temperatures from AIA and magnetic field images from HMI to study the sources of the solar irradiance
  - Providing real-time monitor of the solar EUV irradiance for NOAA space weather operations
    - Flares (communications) : 1-5 minute cadence
    - Neutral Density (satellite drag): 1 hour cadence

SDO Will Advance Flare Studies

- Improvements for flare physics research
  - EVE irradiance measurements will have full EUV spectral coverage, high time cadence, and coordination with the SDO solar imagers
- Enable flare studies of the thermosphere/ionosphere with real-time irradiance data from EVE



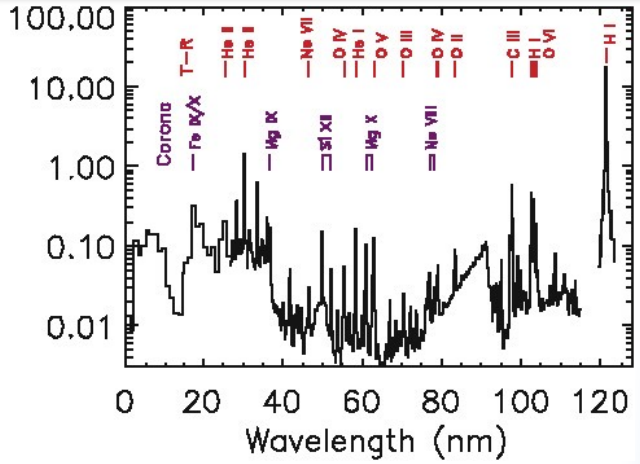
October 2003 Storm Period Movie

TIMED SEE Limitations
Broadband below 27 nm
3% duty cycle
- 3 min per 97 min orbit

SOHO EIT Limitations
One image every 12 min
4 wavelengths

EVE Data Products and Models

- Solar EUV irradiance:
  - 0.1 nm - 105 nm spectral coverage
  - 0.1 nm resolution for 5-105 nm
  - < 20 sec time cadence
  - < 25% accuracy over the 5-year mission

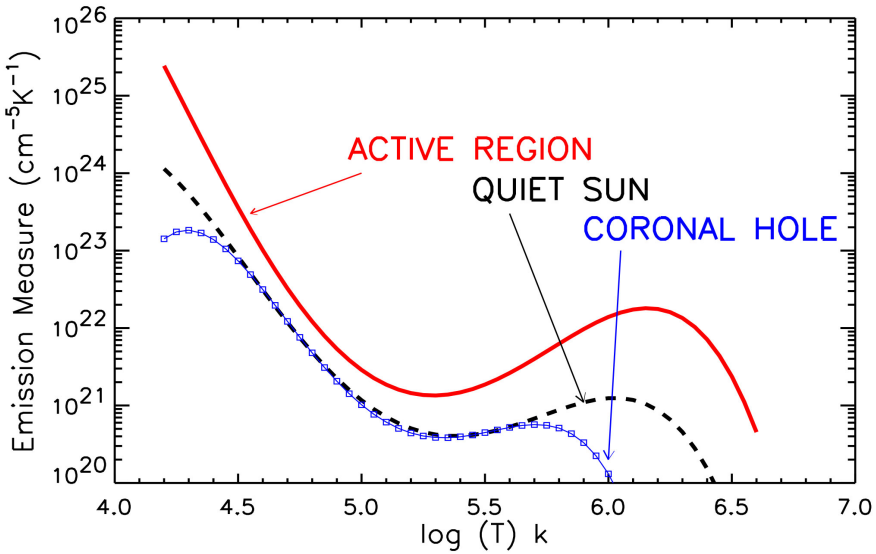


- EVE data products:
  - Real-time space weather data product of the solar EUV irradiance
    - Provided minutes after the observation to NOAA SEC for operations
  - Solar EUV irradiances on 10-sec cadence and averaged over 1-day
    - Provided on a daily basis to EVE's archive and FTP distribution center
- EVE models:
  - Solar irradiance: NRLEUV, SOLAR2000
  - Global thermosphere/ionosphere: CTIM, TDIM, GAIM

NRLEUV Model of EUV Irradiance

- Differential Emission Measures (DEMs)
  - constructed for three features from 18 optically thin Skylab emission lines
- Solar Images Analyzed
  - disk fraction of each feature vs time determined from Yohkoh SXT and BBSO CaK images, 1992-1996
- Calculate Solar Spectrum (5-120 nm)
  - CHIANTI atomic data base and solar abundances convert emission measures to radiance for 1474 optically thin emission lines, including lines not directly observed
  - 26 optically thick lines calculated directly from contrasts
- Integration over Image => Irradiance
  - integration of all disk features, with center-to-limb, is the irradiance
- Proxy Model Extension
  - fit with chromospheric Mg C/W and coronal F10.7 proxy provides estimates over longer time periods

Differential Emission Measures for three features



Warren, Mariska, Lean, JGR, 103, 12007, 1998
JGR, 103, 12091, 1998
JGR, 106, 15745, 2001

Improvements Planned for NRLEUV

- Extend spectrum below 5 nm
- Improve Differential Emission Measures (DEMs)
  - Improve accuracy using AIA and EVE results
  - Additional DEMs for other features (e.g., active network, flare)
- Improve image analysis technique
  - Will have higher spatial resolution from SDO
- Add flare component
  - Needed for nowcast predictions
- Develop magnetic field relations to the EUV irradiance
  - Is considered best approach to improve predictions

Space Weather Operations at NOAA

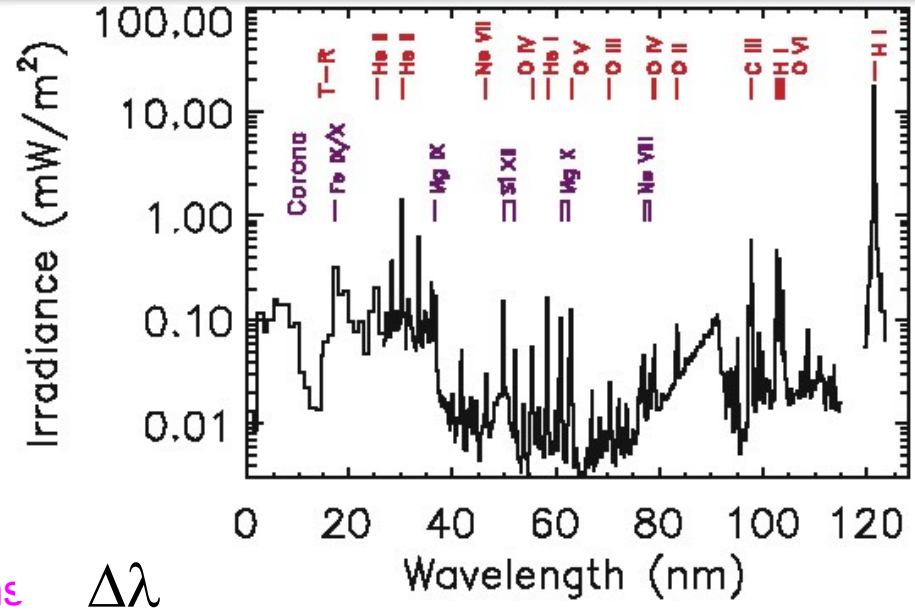
- Atmospheric Models like GAIM
  - Input solar EUV irradiances into models on 1 hour cadence
  - Global Assimilation of Ionospheric Measurements - GAIM
    - Forecast / nowcast of 3-D electron density distributions from 90 to 25,000 km
    - global distributions for the ionospheric drivers
      - neutral winds, electric fields, and particle precipitation
- High Time Resolution Solar EUV Irradiance Model
  - SOLAR2000 forecast / nowcast operated on 1 hour cadence
    - Provides 1 nm resolution and also E10.7 (better proxy for F10.7 proxy)
- Solar Flare Product - EVE “space weather” data product
  - Broadband or possibly spectrum, provided with 1-5 minute cadence
- Energetic Particle Prediction (research area)
  - Line ratios at 0.1 nm resolution, on 1-5 minute cadence
- GOES EUV Sensor Verification and Validation
  - GOES will have 5 broad wavelength bands with 5 minute cadence

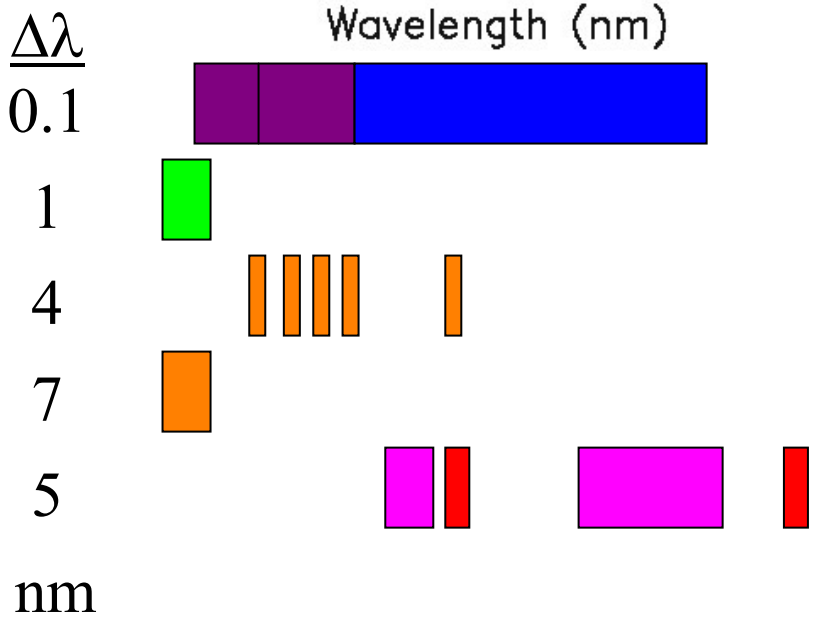
Irradiance Measurement Philosophy

- Measure simultaneously with different instrument types
  - MEGS-A,B are reflective grating spectrographs
  - ESP is transmission grating spectrograph
  - MEGS-SAM uses pulse height analysis for X-ray photons
  - MEGS-P is set of filter photometers
- Pre-flight calibrations with reliable (repeatable/accurate/precise) standards
  - Standard for EVE is NIST Synchrotron UV Radiation Facility (SURF)
- Have in-flight calibrations
  - Multiple onboard broadband channels to calibrate the MEGS higher resolution channels
  - Rocket underflight calibrations

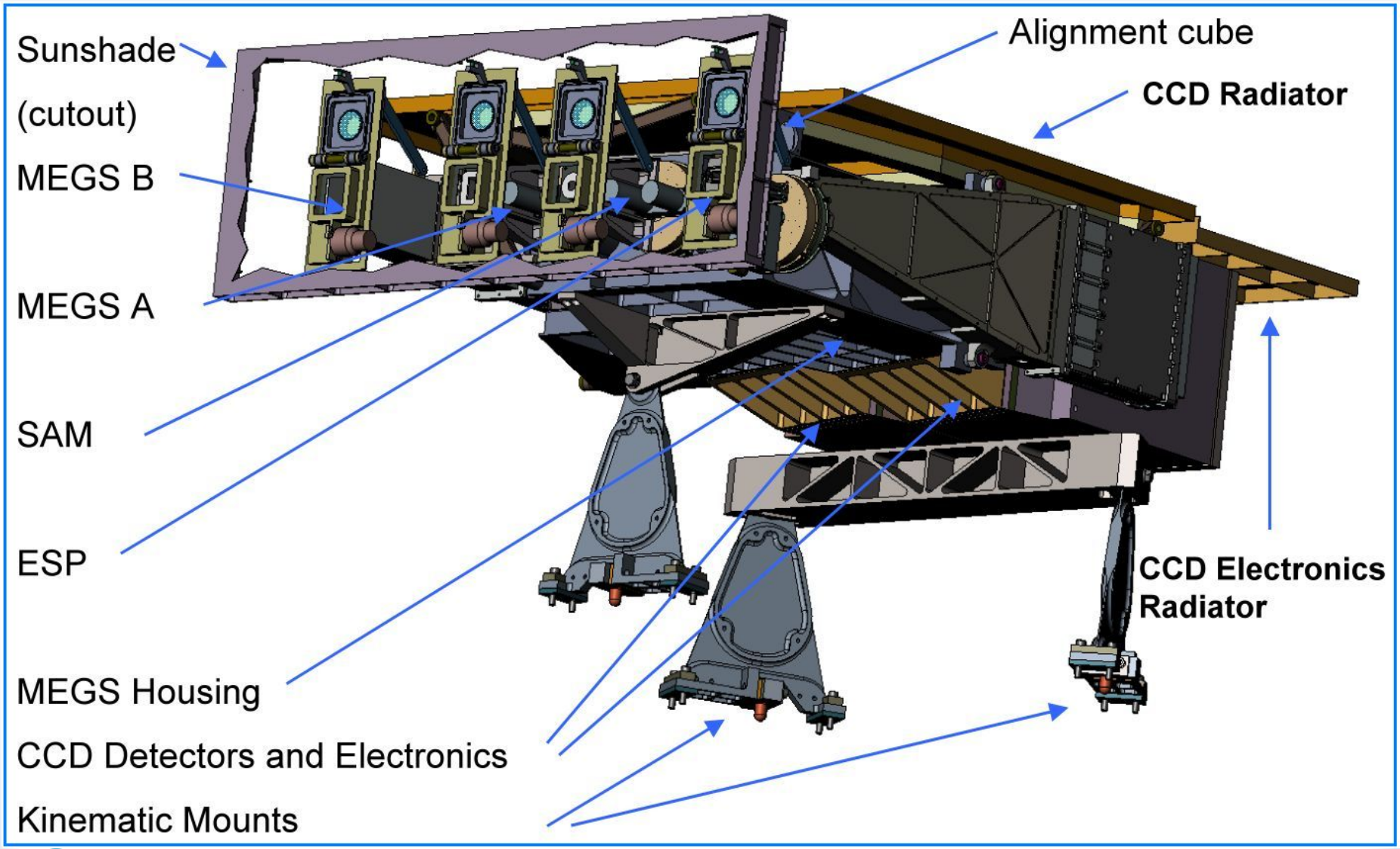
How does EVE measure the EUV?

- **Multiple EUV Grating Spectrograph (MEGS)**
  - At 0.1 nm resolution
    - MEGS-A: 5-36 nm
    - MEGS-B: 35-105 nm
  - At 1 nm resolution
    - MEGS-SAM: 0-7 nm
  - At 5 nm resolution
    - MEGS-Photometers: H I 121.6 nm and He I 58.4 nm
  - H I Ly-α Proxy for other H I emissions at 80-102 nm and He I proxy for other He I emissions at 45-54 nm
- **EUV Spectrophotometer (ESP)**
  - At 4 nm resolution
    - 17.5, 25.6, 30.4, 36, 58.4 nm
  - At 7 nm resolution
    - 0-7 nm (zeroth order)

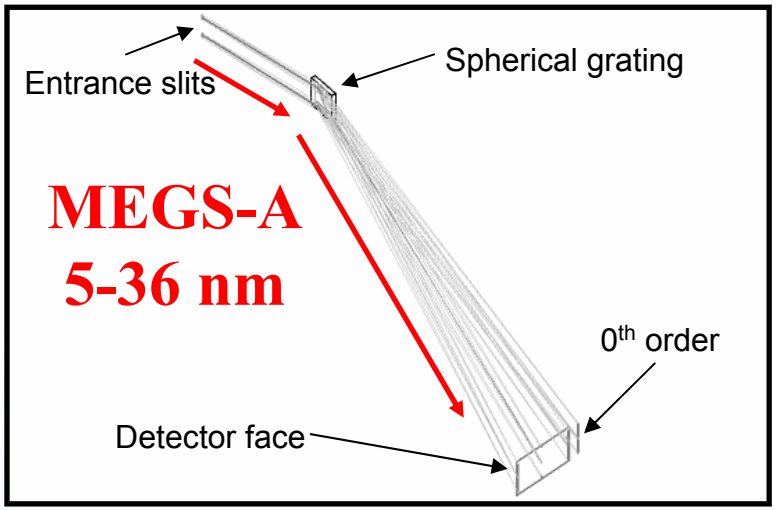


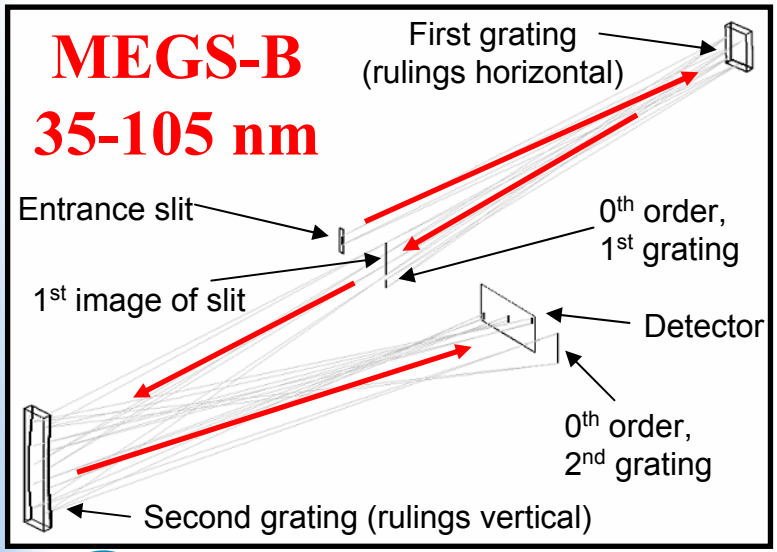


EUV Variability Experiment (EVE)



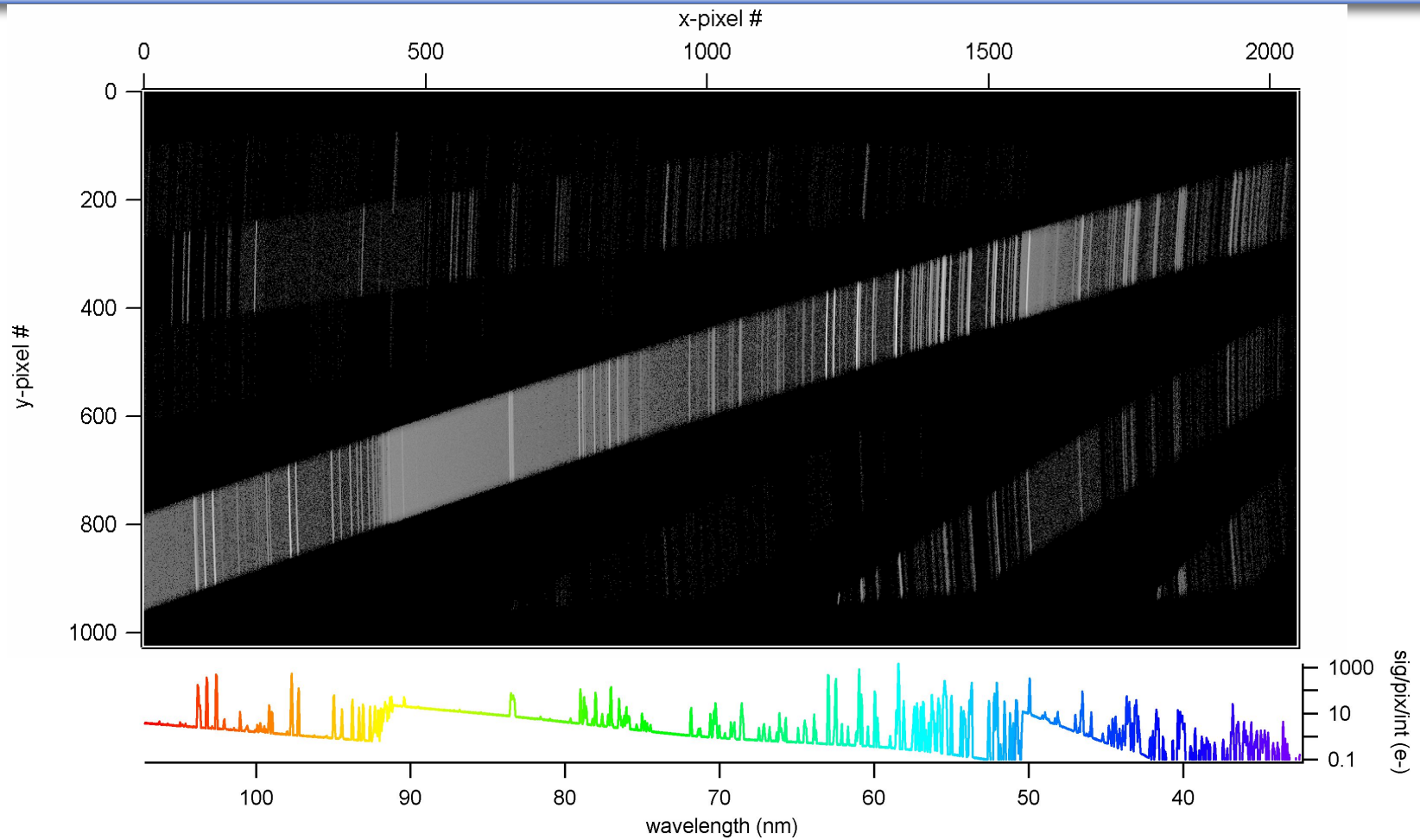
MEGS-A, B Details





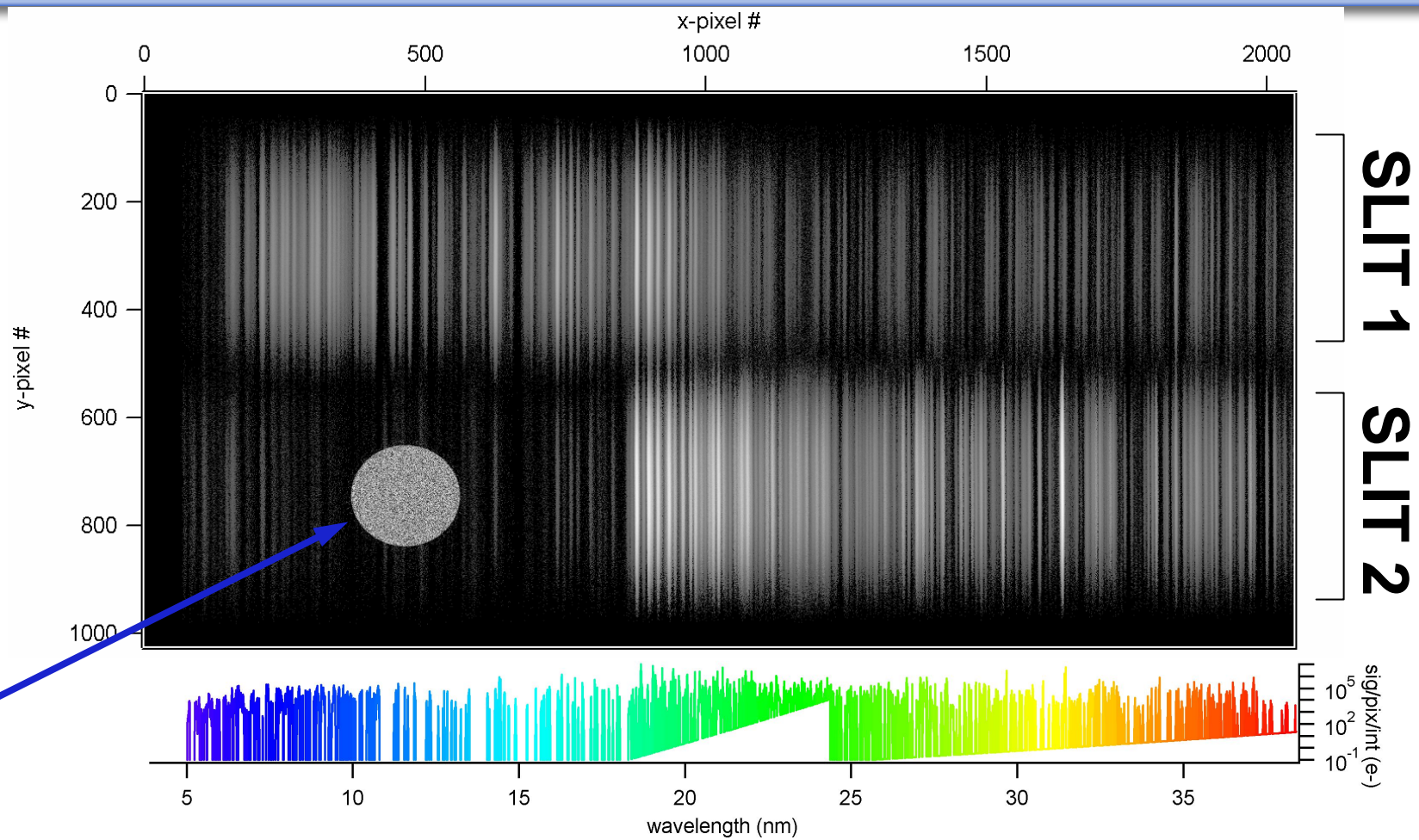
- Technique: reflection spherical gratings
- Wavelength Coverage: 5 - 105 nm
- Resolution: 0.1 nm
- Gratings:
  - MEGS-A uses single, holographic, spherical grating, used at 80° grazing incidence
  - MEGS-B uses dual, holographic, spherical grating, used near normal incidence
  - Have laminar groove profile (50% duty cycle of grooves) to suppress even orders
- CCD Detectors:
  - MIT/LL CCID-28 devices
  - 1K x 2K pixels, frame transferred,
  - back-thinned, back-illuminated
  - passively cooled to -100˚C
  - heritage on Chandra, XMM-Newton
- Slits / Filters:
  - MEGS-A has two slits and two filters:
    - Slit 1: Mo/C, 5.0 - 13.0 nm
    - Slit 2: Si, 12.0 - 36.0 nm
  - MEGS-B has one slit and no primary filter
  - Additional removable filters for higher order checks

MEGS B detector image



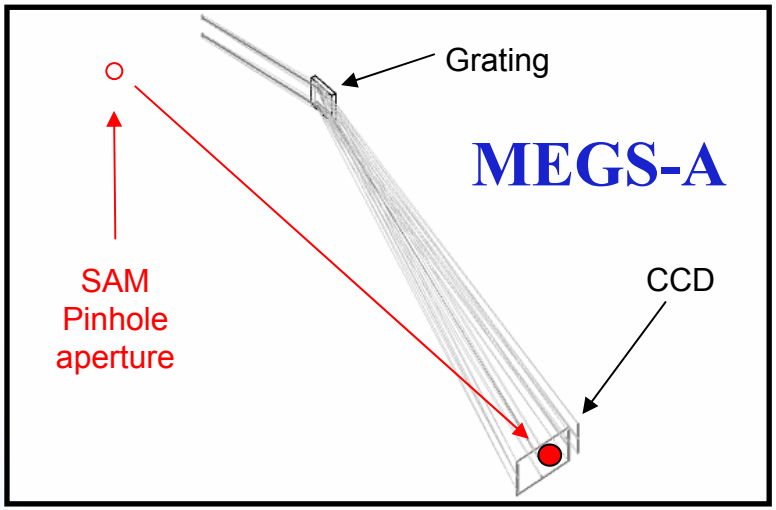
- Image shows contrast-enhanced detector signal from MEGS B
- Higher order combinations from both gratings can be seen above and below primary spectrum

MEGS A detector image



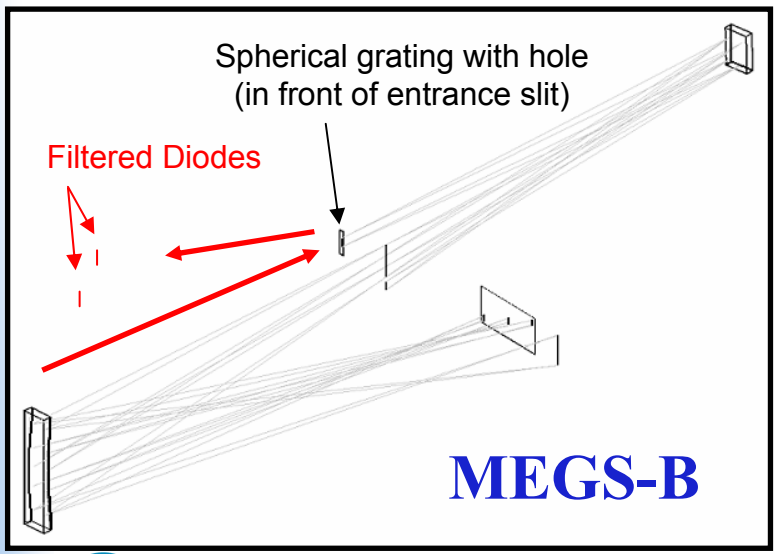
- Image shows contrast-enhanced detector signal from MEGS A
- Solar X-ray image (0-7nm) is MEGS-SAM
- Slit 1 and 2 overlap region is less than 1% of total signal

MEGS-SAM, P Details



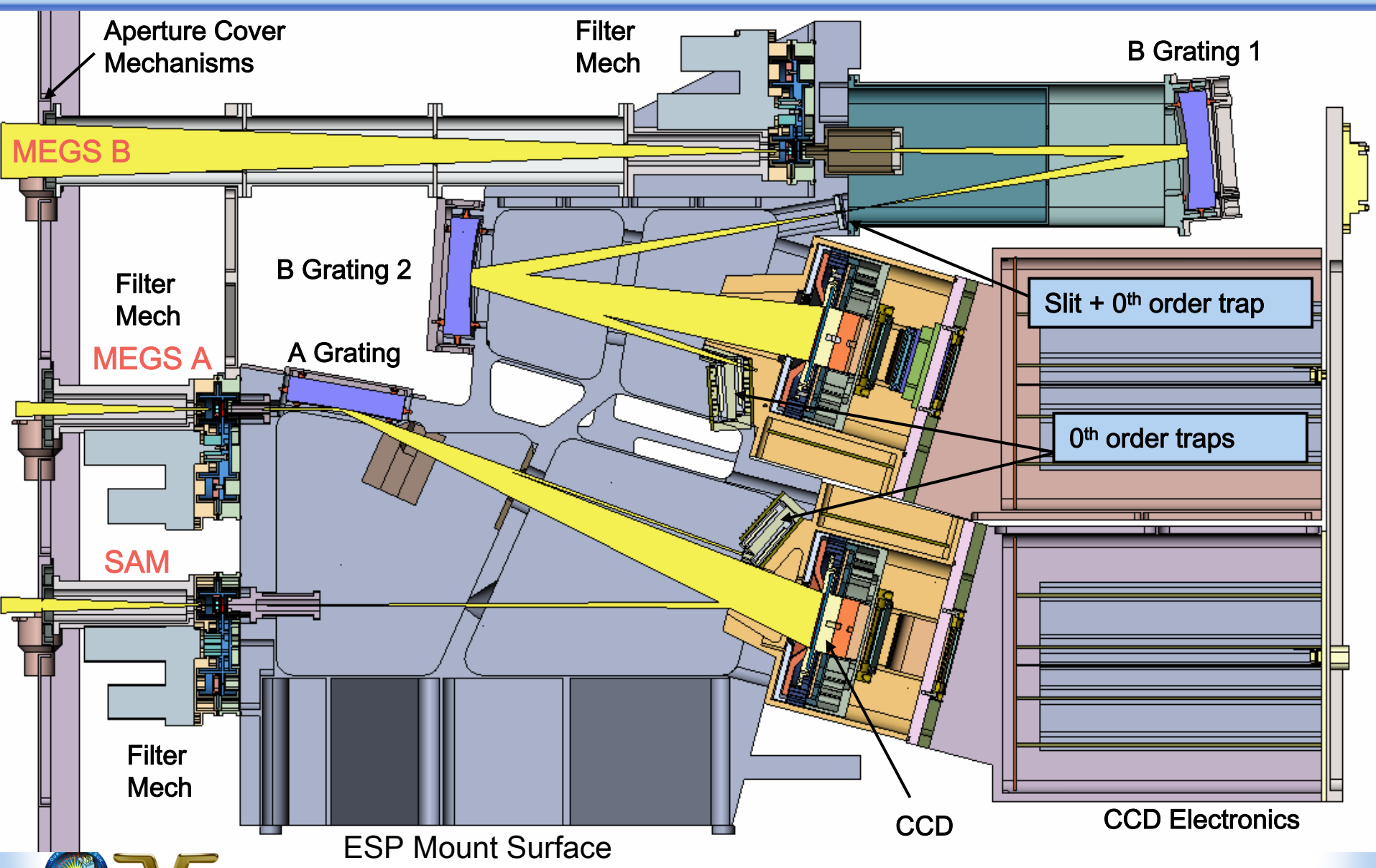
- MEGS-SAM : Solar Aspect Monitor
  - Technique: pulse height analysis of X-ray photons
  - Wavelength Coverage: 0.1 - 7 nm
  - Spectral Resolution: 0.002 - 1 nm
  - Spatial Resolution: 10 arc-sec / pixel
  - Detector: pinhole illuminates MEGS-A CCD
  - Also provides MEGS pointing information with precision of 9 arc-seconds

$$E(eV) = N_{e^-} * 3.65eV$$
$$\lambda(nm) = 1242/E$$

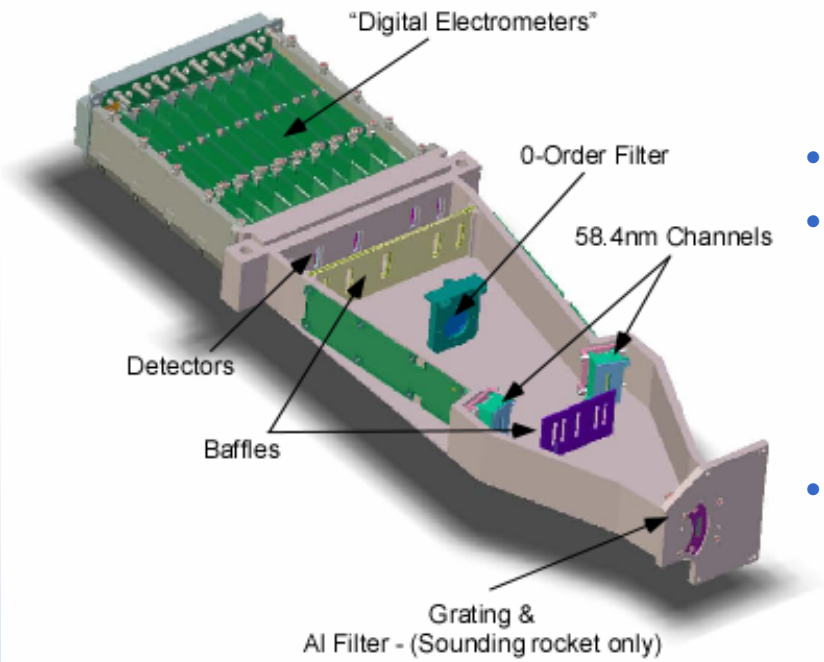


- MEGS-P : Photometer for H I 121.nm and He I 58.4 nm emissions
  - Technique: grating + filter photometer
  - Channel: H I Lyman-α 121.6 nm, He I 58.4 nm
  - Located in MEGS-B entrance baffles
  - Resolution: 5 nm
  - Detector - IRD Si photodiode
  - Filter - Acton Lyman-α filter and Al/Sn foil filter

MEGS Cross Section



ESP Details



- Technique: transmission grating used with stable Si photodiodes
- Wavelength coverage:
  - 1st order (+/-): 17-36 nm and 58.4 nm
    - Bands at 18, 25.6, 30.4, 36, and 58.4 nm
  - 0th order: 0.1-7 nm
- Spectral resolution: 4 nm
- Grating:
  - 5000 lines/mm transmission grating
  - has laminar groove profile (duty cycle of grooves chosen to suppress 3rd-order contamination of 58.4nm)
- Detectors / Filters:
  - Si photodiodes with thin film filters (IRD)
    - Al filter for 17-36 nm photodiodes (± 1st order)
    - Ti filter for 0.1-7 nm photodiode (0th order)
    - No filter for 58.4 nm photodiode
  - heritage on SOHO and TIMED
- Slit / Filter:
  - 1 mm x 10 mm slit with Al foil filter

EVE Instrument Summary

- EVE is in final design stage (Phase C)
  - EVE completed PDR in December 2003
  - SDO is planned for April 2008 launch into geosynchronous Earth orbit (GEO)
- EVE will measure the solar EUV irradiance
  - Wavelength Range: 0.1-105 nm
  - Resolution: 0.1 nm above 5 nm, 1 nm below 5 nm
  - Cadence: 10 sec
  - Accuracy: <25% over the 5-year mission
    - <10% pre-flight absolute accuracy and <2%/year long-term relative accuracy
- EVE uses multiple subsystems and technology to meet wavelength, resolution, and accuracy requirements