

# Monitoring capabilities for solar weather nowcast and forecast

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Solar Influences Data analysis Center

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1 Dec 2004

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# Outline

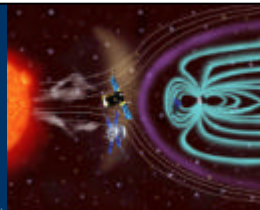
- Purposes
- Nowcasting
  - Magnetograms
  - WL images
- Forecasting
  - Solar flares
  - CMEs
- Observations needed
  - Remote sensing
  - In situ
- Function, current & future data
  - H $\alpha$  images
  - Coronal images
  - Integrated flux
  - Coronagraphic images
  - Radio
  - Other remote sensing methods
  - In situ
- Current space missions
  - Data web location
  - What is next in monitoring?
  - Future Space missions
    - STEREO
    - PROBA2
    - SDO
    - SOLAR-B
    - Timeline
- Conclusions

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# Monitoring Purposes

- **Solar Weather Nowcasting** (operational)
  - Identify geoeffective events
  - Assess severity of perturbed conditions
- **Solar Weather Forecasting**
  - Operational
    - Recognize precursors of events
      - Causality chain: Sun → Heliosphere → Earth/Mankind
      - Nowcast → Forecast
    - Quantify their forthcoming geoeffectiveness
      - CMEs: Time of arrival, dynamic pressure, Bz,...
      - EUV irradiance: F10.7
    - Assign probabilities
  - Post-event analysis
    - Gather global picture of SpW scenarios
    - Provide inputs to numerical heliospheric or solar wind models
    - Improve predictions
    - Solar variability is an input to paleo-climatology



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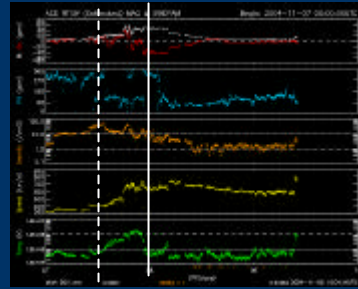
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# Nowcasting = Defining observationally the main geoeffective circumstances

Event or Circumstance	Observation type	Remote sensing	In-situ (say at L1)
Coronal Mass Ejections (filament eruptions, EIT waves, etc.)	1	New, discrete, bright, white-light feature in a coronagraph FOV with a radially outward velocity <small>Hundhausen 1984, Schwenn 1995, Robbrecht &amp; Berghmans 2004</small>	• Shock-discontinuity of all parameters • Enhanced Helium density • counter streaming e- • ambiguity with CIR possible • energetic particle events (SEPs) • faster than normal (1046) wind
	2	Metric & kilometric Type II radio bursts	
Flares (as radiative events)		Large increase of (X, UV, WL, H $\alpha$ ) photon flux monitored by radiometers & imagers	Abrupt SEPs <i>An effect of the flare</i> Ionospheric effects
Spectral Irradiance variability		All variations of (X, UV, WL) photon flux monitored by radiometers & imagers <small>Solar indexes and proxies: F10.7, F10.7</small>	N/A Ionospheric, thermospheric effects...
Coronal Holes & Corotating Interaction Regions		Dark (cooler, less dense) volumes seen in EUV images	Faster than normal (10 <sup>4</sup> K), faster wind B $\theta$ oscillations during CIRs

## CMEs

LASCO C3 (May 1998)



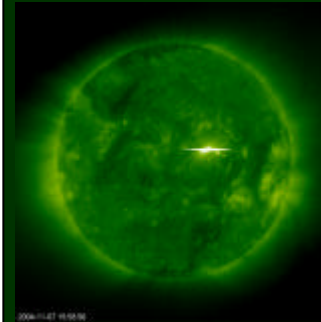
An ICME in ACE (7 Nov 2004)

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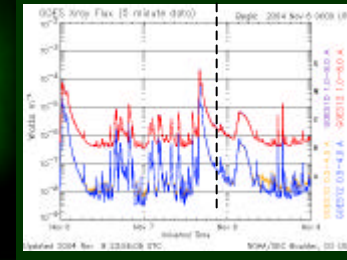
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## Flares

« October Revolution Flare »  
7 Nov 2004



EIT 195

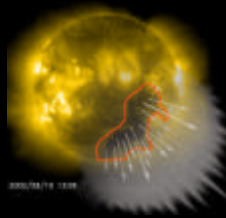


X-Ray flux

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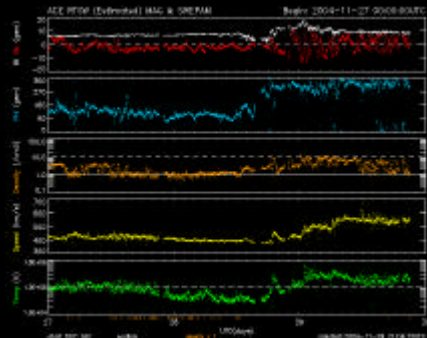
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## Coronal holes



EIT 284

ACE

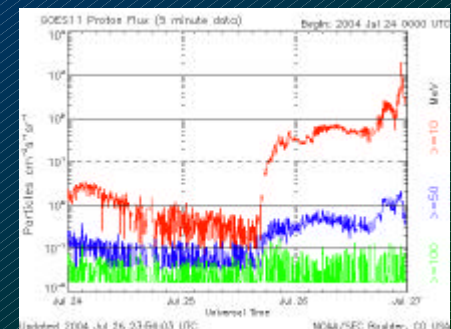


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## SEPs

Goes 11 proton flux



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## Forecasting the main geoeffective circumstances

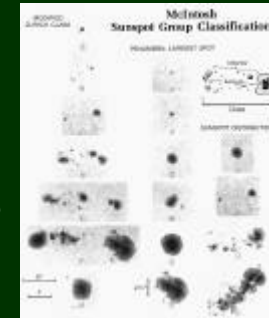
	Precursors or forecasting method	Reliability Maturity
<i>in situ</i> ICME Time of arrival, Bz...	From LASCO observations: Speed → time of arrival From EIT: Filament or not From MDI: Bz prediction (Yurchyshyn et al 2001, Martin et al 2001)	High Medium Tentative
CME In the Corona	• Cool corona & H-alpha observations • Many possible precursors: (twisted) flux emergence, Complexity, helicity buildup, filament oscillations, Relationship with flare likelihood	Weak Unreliable if specific: When, where, how much?
Flares	• Sunspot group classification (WL) • Hints in magnetograms • Modelling needed for flare forecast!	Reasonable but, Unreliable if specific: When, where, how much?
Coronal Holes & Corotating Interaction Regions	• Slow evolution • Use of previous solar rotation	Good (rather easy) but, Unreliable if specific: When, how much?

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## Solar flare predictions

- **Important** (astronauts, aircrafts...)
- **Empirical**
  - White light
    - Sunspot group **McIntosh classification**
    - Dynamics, Umbrae rotation...
    - Time-distance helioseismology
  - Magnetograms (Sammis et al 2001)
  - EUV image sequences
    - Statistics of past flares in given AR
    - Extrapolation of observed activity /dynamics
    - Temporal data mining (Nuñez et al this conf)
- **Reliability**
  - Reasonably successful globally
    - whole Sun, approximate timing
  - Unreliable if specific
    - Given AR, accurate timing

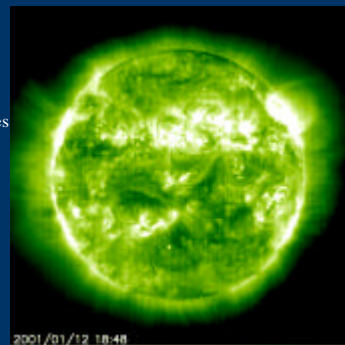


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## CME predictions from disc observations

- **Usefulness/urgency**
  - Mild for geomagnetism
    - Many hours before at Earth
  - CME shocks accelerate particles to relativistic speeds
    - SEP/ Proton events
- **Status**
  - Difficult (too many scenarii)
  - Low specific reliability
    - How, when, how much...
  - Filament twinkling
    - R. Van der Linden



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## Needed observations

1. Photospheric dopplergrams
2. Photospheric magnetograms
3. Photospheric White Light images
4. Chromospheric (H $\alpha$ ) images
5. Cool corona images
6. Hot corona images
7. Integrated flux – Spectral irradiance
8. Upper corona: « coronagraphic » images
9. Radio
10. In situ

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## Features required from SolW monitoring missions

	Nowcasting	Operational Forecasting	SpW Research
Data availability	Real Time	Real Time	Later
Data continuity	Continuous	Continuous	Continuous
Data reformatting and pre-processing	Real Time	Real Time	Later
Strawman payload	Defined	Defined	Goal-dependent
Spatial resolution	Coarse	Fine	Finest
Temporal cadence	High	Highest	Highest

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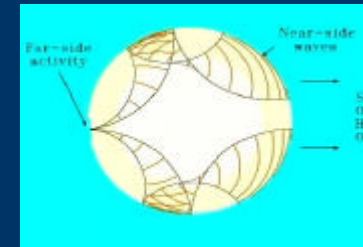
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Inspired from E Daly, Solspa 2001

## 1. Photospheric dopplergrams

- **Role**
  - Far side imaging
  - Local (time-distance) helioseismology
    - Flows in and out Active Regions (Jensen et al, this conference)

- **Current instruments**
  - Soho-MDI
- **Future instrument**
  - SDO-HMI

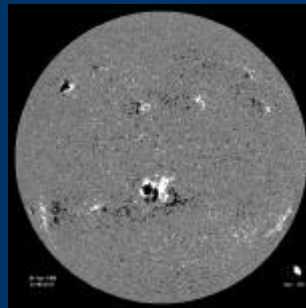


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## 2. Photospheric magnetograms

- **Role**
  - Magnetic complexity of ARs
  - Input to MHD extrapolations
    - e.g. footpoints motion or helicity evaluations
  - Input to numerical solar wind models
- **Current instruments**
  - On regular basis: LOS only
  - Space : MDI
  - Ground : Kitt peak, Mount Wilson, Wilcox solar observatory, GONG..
- **Future instrument**
  - SDO-HMI (vector magnetograph)

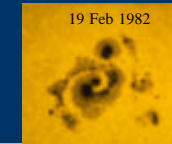
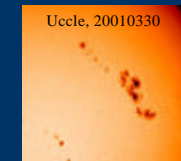


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## 3. Photospheric White Light images

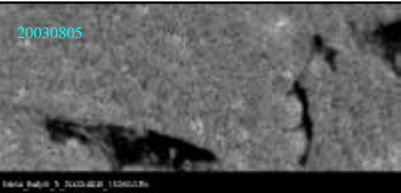
- **Role**
  - Sunspot group classification
  - WL flares
- **Current instruments**
  - Space : MDI
  - Many ground-based (such as at ROB/SIDC)
- **Future instrument**
  - SDO-HMI



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## 4. Chromospheric images in H $\alpha$



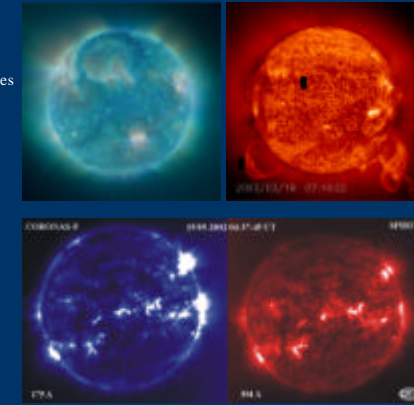
- **Role**
  - Filaments (their chirality, activity, eruption/disappearance) & flares
- **Current instruments**
  - BBSO, Yunnan NAO (China) and Kanzelhöhe are sites of the **Global High-Resolution H-alpha Network**.
  - Catania, SIDC, Hida, Meudon, Learmonth, Culgoora, Kiepenheuer-Institut für Sonnenphysik, Tenerife...
- **Future instrument**
  - Spaceborn wanted for data homogeneity & continuity

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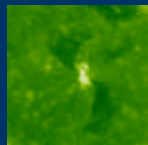
## 5. Cool corona images

- **Role**
  - **Vital**, encompassing:
    - Active Regions
    - Coronal Holes
    - filaments & prominences
    - **coronal dimmings**
    - EIT waves
    - arcades, flares...
  - Constrain MHD extrapolations
  - locate sources of UV radiation
- **Current instruments**
  - SoHO - EIT
  - Coronas F - SPIRIT
- **Future instrument**
  - Stereo - SECCHI EUVI
  - SDO - AIA
  - **Proba 2 - SWAP**

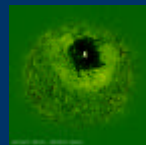


## SWAP TARGETS

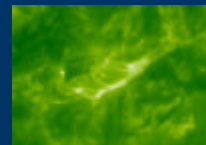
See Berghmans et al, this conference



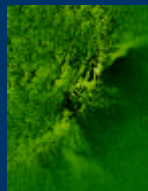
Dimmings



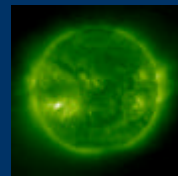
EIT wave



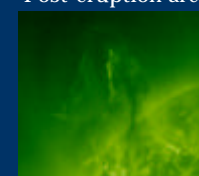
Post-eruption arcade



Loop openings  
plasmoid lifting



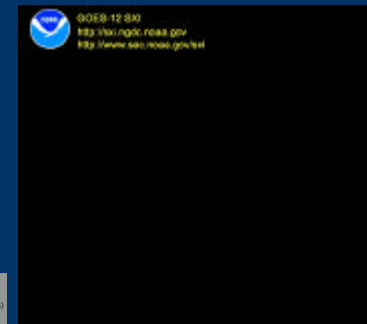
flares



Erupting prominences

## 6. Hot corona images

- **Role**
  - Flare location,
  - CH,
  - arcades
- **Current instruments**
  - GOES - SXI, Rhessi
- **Future instrument**
  - GOES series,
  - Solar B - XRT

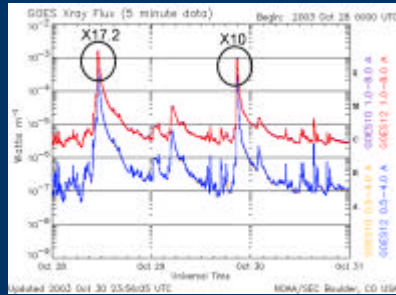


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## 7. Irradiance time series in X-ray and UV passbands

- **Role**
  - Flare monitoring
  - variability
- **Current instruments**
  - GOES – XRS series
  - SoHO – SEM
  - SNOE – SXP
  - ...
- **Future instrument**
  - GOES – XRS series
  - Proba 2 – LYRA

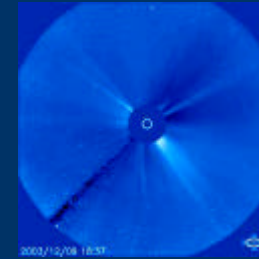


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## 8. Coronagraphic images

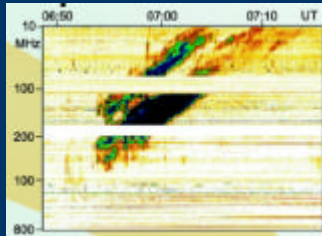
- **Role**
  - Monitor CMEs (2.2-30  $R_S$ )
    - Speed, angular span...
- **Current instruments**
  - LASCO, SMEI
- **Future instrument**
  - STEREO coronagraphs
    - COR1, COR2, HI!



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## 9. Radio data



- **Role**
  - CMEs & flares shocks
  - Identify sources of radio noise
  - See e.g. Fridman, this conference:  
« radio signatures of CME »
- **Current instruments**
  - Wind: km type II bursts
  - metric type II bursts
    - Postdam
    - Culgoora, Australia
    - Holloman, USA
    - Learmonth, Australia
    - Palahua, USA
    - Ramey, USA
    - Sagamore Hill, PA, USA
    - San Vito, Italy
  - 10cm flux
    - Cracow, Nancy, Trieste, Penicton (reference)...
- **Future instrument**
  - very large interferometer

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## Other remote sensing techniques

- **Interplanetary Scintillation**
  - See e.g. Hapgood, 1994
- **Cosmic ray (muon) anisotropy**
  - MUSTANG (Jansen, this conference)
- **Neutron monitors**
- ...

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## 10. Needed *in situ* Observations (1)

- Local magnetic field **B** (vector)
- Speed **v** (vector)
- Density **n**
- Temperature **T**
- Elemental composition
- Bidirectional electrons
- Energetic particle flux (protons, electrons, ions)

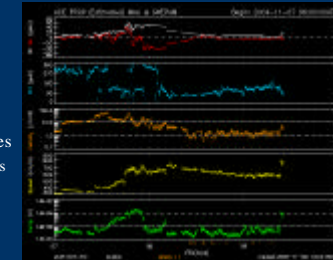
*B<sub>z</sub> and dynamic pressure  $n v^2$  are most important*

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## *In situ* (2)

- Role
  - B, v, n, T, composition...
- Current instruments
  - ACE, WIND, CELIAS, Ulysses
    - only ACE provides continuous relevant B<sub>z</sub> measurements
- Future instrument
  - SpW: None
  - Solar Orbiter, Solar Probe...

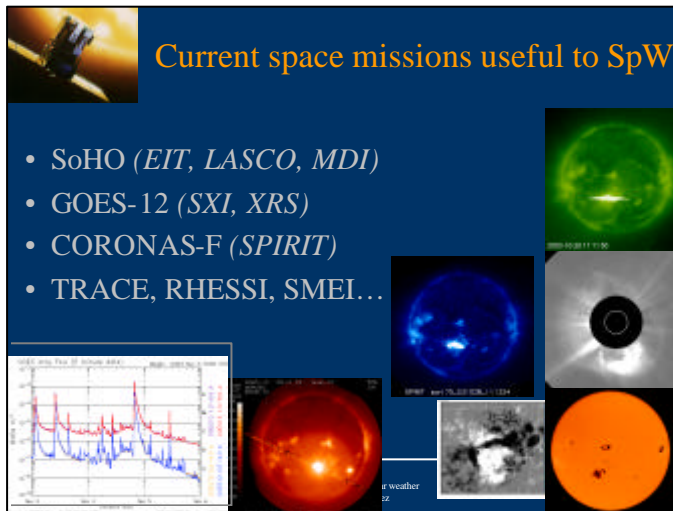


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## Current space missions useful to SpW

- SoHO (*EIT, LASCO, MDI*)
- GOES-12 (*SXI, XRS*)
- CORONAS-F (*SPIRIT*)
- TRACE, RHESSI, SMEI...



## Find & use the data

- **SEC NOAA**, Boulder, USA
  - [www.sec.noaa.gov](http://www.sec.noaa.gov)
- **SIDC RWC**, Brussels, Europe
  - [sidc.oma.be](http://sidc.oma.be) (see poster)
  - **SWB**: [sidc.oma.be/html/SWAPP/swb/swb.html](http://sidc.oma.be/html/SWAPP/swb/swb.html) (see poster)
- **Solar Soft latest events**
  - [www.lmsal.com/solarsoft/latest\\_events](http://www.lmsal.com/solarsoft/latest_events)
- **GSFC**
  - [Solarmonitor.org](http://Solarmonitor.org)
- **And actually all over the web!...**
  - Mission official web sites

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## What's next with SpW solar monitoring?

- Vector magnetographs
- Spatial/temporal resolution  
& other performance increases
- Interface with numerical models
- CME onset scenarii
- 3-D: stereo, solar sentinels
- Audience inputs ☺

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## PLANNED MISSIONS

- **STEREO** (launch: February 2006) – 2 years
- **Solar-B** (launch: summer 2006) – 3 years
- **PROBA-2** (launch: late 2006) – 2 years
- **CORONAS-Photon** (launch: 2007)
- **SDO** (launch: April 2008) – 5 years
- **Solar Orbiter** (launch: 2015?)
- **Solar Probe** (launch: 2012 – ?)
- etc...

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## STEREO (SOLAR-TERRESTRIAL RELATIONS OBSERVATORY)

- **SECCHI** (*Sun – Earth Connection Coronal and Heliospheric Investigation*): EUVI, COR1, COR2, HI
- **SWAVES** (*STEREO/WAVES*)
- **IMPACT**
- **PLASTIC**

**LAUNCH:  
February 2006**



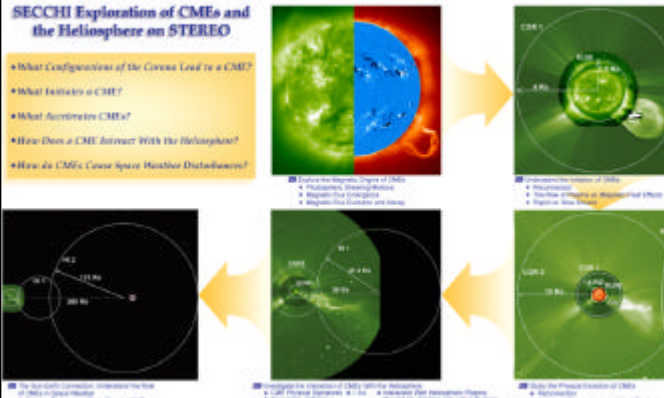
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## SECCHI SCIENCE OVERVIEW

### SECCHI Exploration of CMEs and the Heliosphere on STEREO

- What Configurations of the Corona Lead to a CME?
- What Triggers a CME?
- What Accretes to CMEs?
- How Does a CME Interact With the Heliosphere?
- How do CMEs Cause Space Weather Disturbances?



- Explore the Structure, Origin of CMEs
  - Heliospheric Structure Analysis
  - Region-Flow Correlation
  - Propagation Direction and Velocity
- Investigate the Interaction of CMEs With the Heliosphere
  - CMEs and the Heliosphere: A Case of Coronal Hole Interactions
  - Coronal Hole Interactions: A Case of CMEs and the Heliosphere
  - Coronal Hole Interactions: A Case of CMEs and the Heliosphere
- Study the Physical Structure of CMEs
  - Heliospheric Structure Analysis
  - Heliospheric Structure Analysis
  - Heliospheric Structure Analysis

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## SOLAR-B

(Solar-A = Yohkoh)



- **SOT (Solar Optical Telescope)**: photosphere, chromosphere and photospheric vector magnetic fields
- **XRT (X-Ray Telescope)**: improved spatial and temporal resolution (in comparison with Yohkoh/SXT); several filters for the DEM reconstruction
- **EIS (EUV Imaging Spectrometer)**: spatially resolved spectra of the upper chromosphere and the corona in two EUV bands

LAUNCH:  
summer 2006

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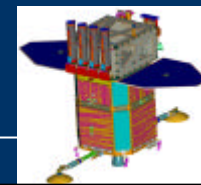
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## SDO (SOLAR DYNAMICS OBSERVATORY)



- **HMI Helioseismic and Magnetic Imager**  
dopplergrams and vector magnetograms
- **AIA Atmospheric Imaging Assembly**  
8 channels (304, 171, 193, 211, 94, 131, 335 Å, UV – atmosphere at 0.01 – 10 MK), TRACE-like resolution, 10 s cadence
- **EVE Extreme-ultraviolet Variability Experiment**  
EUV irradiance measurements

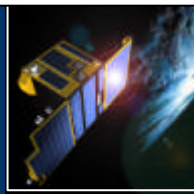
LAUNCH:  
April 2008



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## PROBA-2 (PROJECT FOR ON-BOARD AUTONOMY)



- **SWAP** Berghmans et al 2004  
– *Sun Watcher using APS detectors and image Processing*  
– 175 Å bandpass, EIT-like resolution, 1 min cadence
- **LYRA** Hochedez et al 2004  
– *LYman-alpha RAdiometer*  
– irradiance measurements in four VUV/EUV bandpasses

LAUNCH:  
2nd half 2006

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## TIMELINE

Year	2005	2006	2007	2008	2009
Magneto-grams	MDI	MDI Solar-B	MDI Solar-B	SDO Solar-B	SDO Solar-B
Disc imagers	EIT SXI	EIT SPIRIT Solar-B	EIT Solar-B PROBA-2 CORONAS- Photon	SDO Solar-B PROBA-2 CORONAS- Photon	SDO Solar-B CORONAS- Photon
Corona- graphs	LASCO	LASCO STEREO	LASCO STEREO	LASCO STEREO	LASCO

## Conclusions

- Critical instruments: LASCO, ACE
- Open data policy; a rule sometimes curbed
- Several planned (science) missions launched in 2006
- Abundant new data in 2007, 2008
- Will they suffice to feed boundary conditions of numerical models?  
Knowledge cycling anticipated:
  - Monitoring-SpW operations-SpW Science-New monitoring definition
- From monitoring to nowcast & forecast ...  
effortless one day?