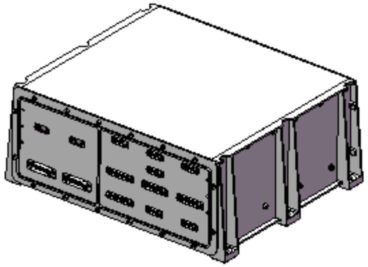
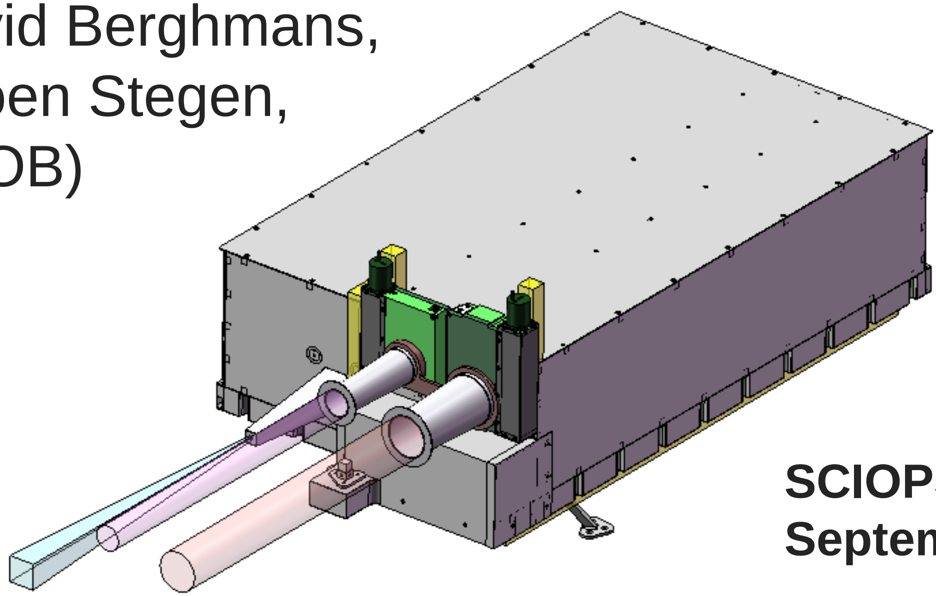
Design exercise: the EUI Data Centre at the Royal Observatory of Belgium

Cis Verbeeck, David Berghmans, Samuel Gissot, Koen Stegen, Bogdan Nicula (ROB)





SCIOPS 2013, ESAC, September 13, 2013

Presentation Summary

- The variable Sun
- Solar Orbiter mission
- EUI onboard Solar Orbiter
- The EUI Data Centre (EDC)
- Challenges for EDC
- FITS generating pipeline
- Conclusions

The variable Sun

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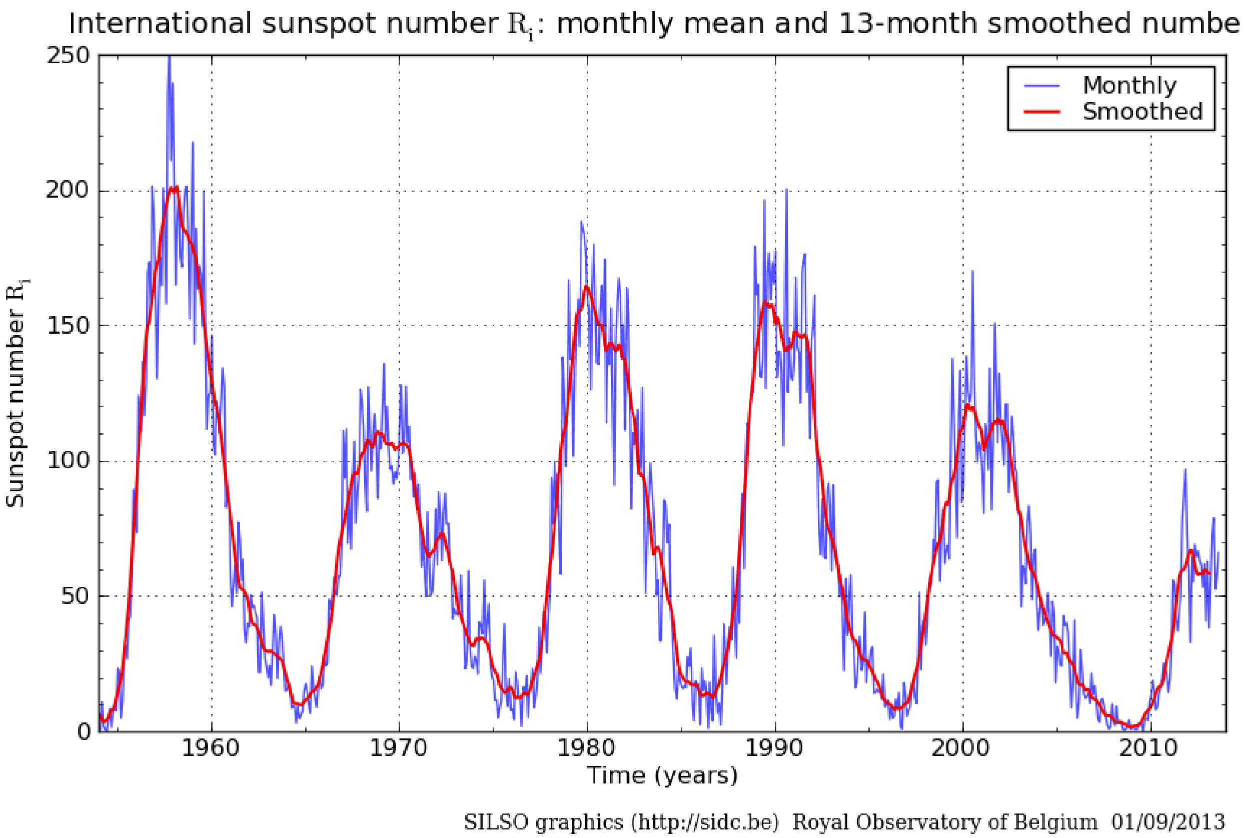
The variable Sun

- **Solar cycle** of 11 years: max in 2012-2013, near min in 2020
- **Solar** (differential) **rotation** ~ 27 days
- **Variability of solar features** in a matter of hours and days



Solar Orbiter mission

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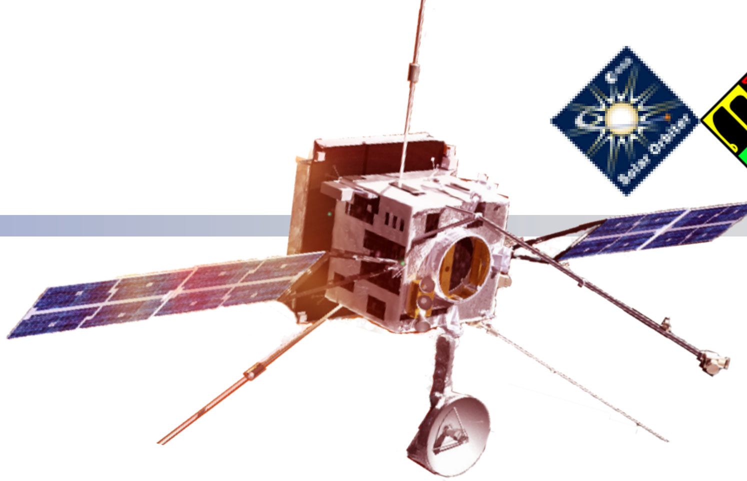
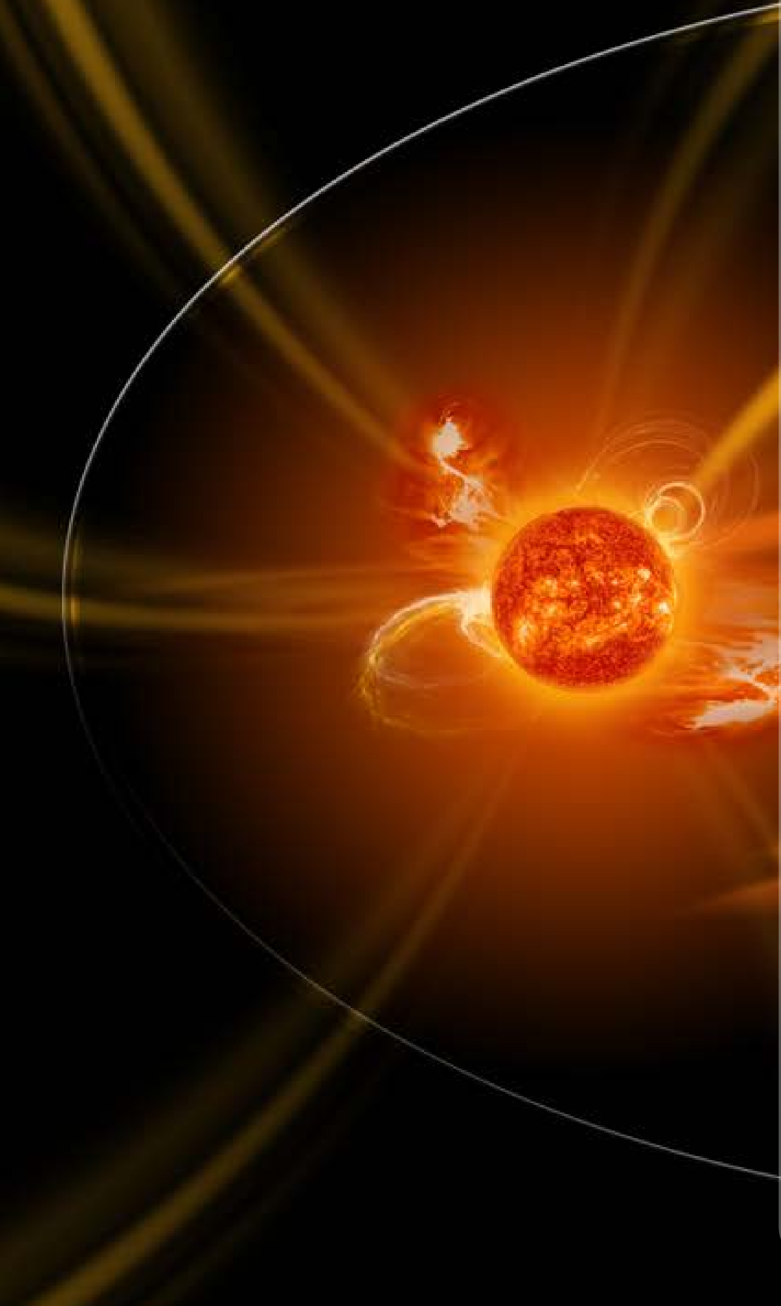
What is required



- Close to the Sun
- Out of the ecliptic
- Long duration observations of the same region
- Remote measurements of the Sun and corona
- In situ measurements of fields and particles

- It is this unique combination provided by Solar Orbiter that makes it possible to address the question of how the Sun creates and controls the heliosphere http://www.solarorbiter.org/



Solar Orbiter

Carefully optimised payload of ten remote sensing and in situ instruments

Launch: January 2017

Cruise Phase: 3 years

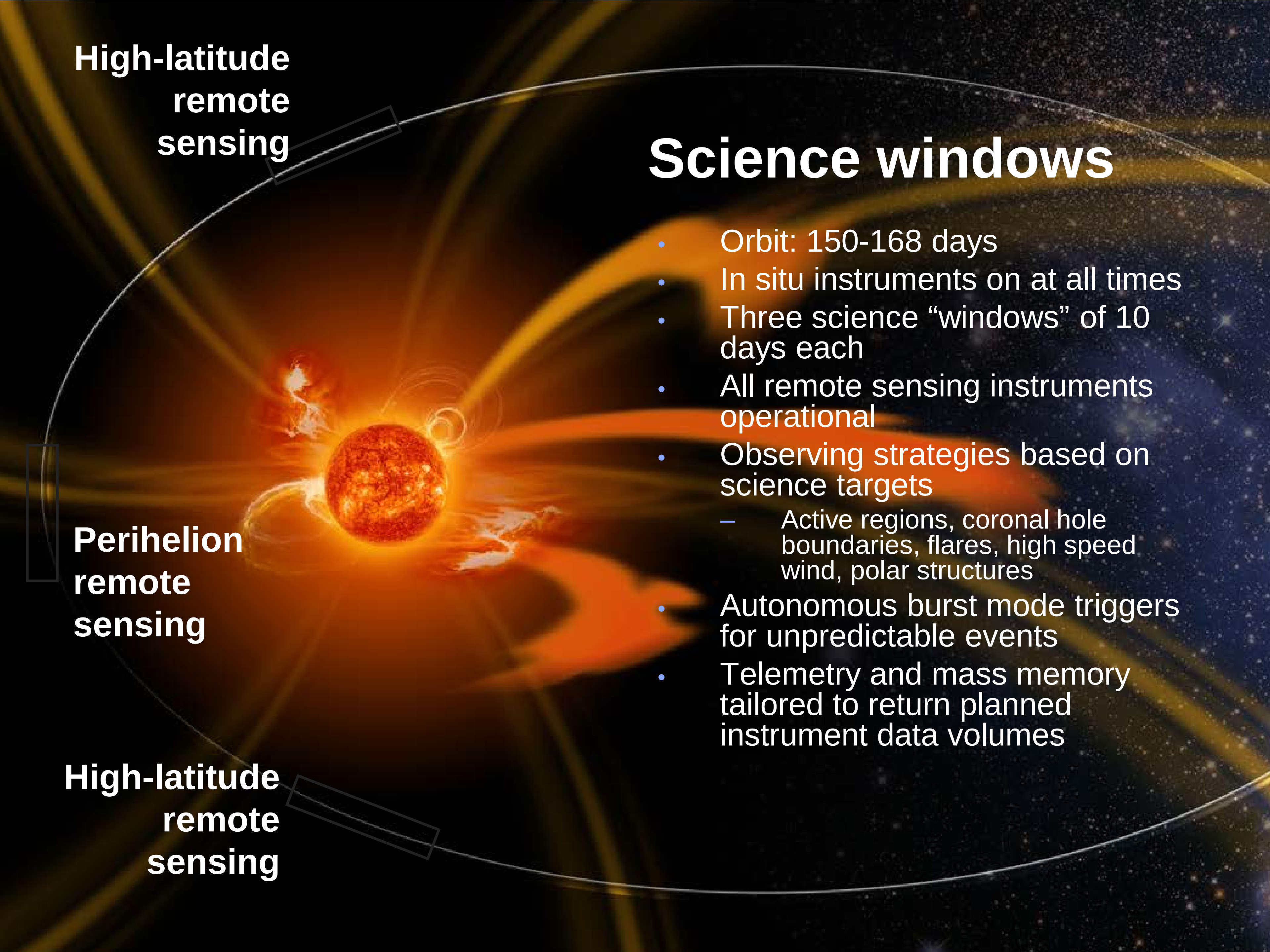
Nominal Mission: 3.5 years

Extended Mission: 2.5 years

Perihelion: 0.28 – 0.3 AU

Fast perihelion motion: solar features visible for almost complete rotation

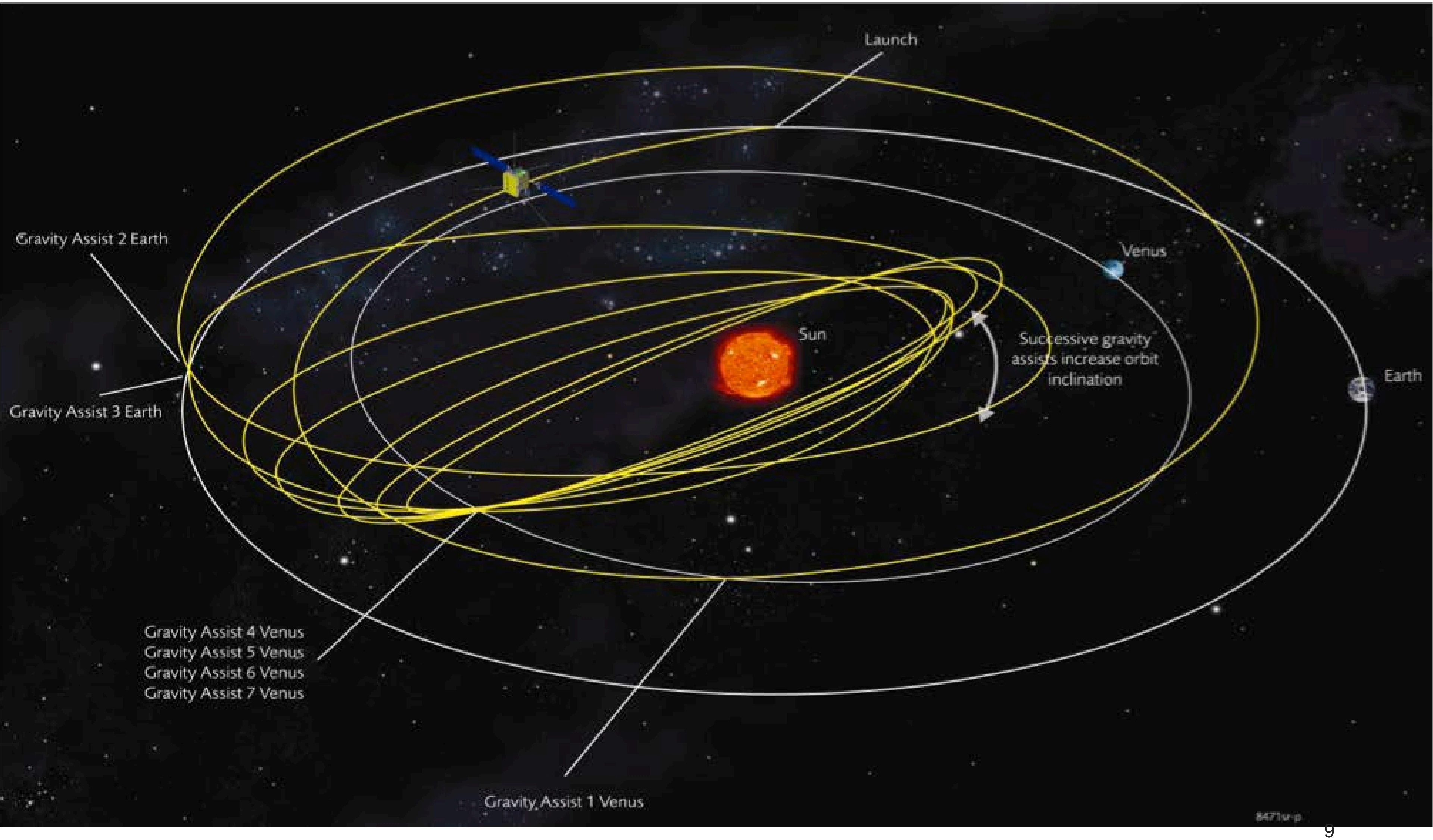
Out of ecliptic: first good view of solar poles



Science windows

- Orbit: 150-168 days
- In situ instruments on at all times
- Three science “windows” of 10 days each
- All remote sensing instruments operational
- Observing strategies based on science targets
  - Active regions, coronal hole boundaries, flares, high speed wind, polar structures
- Autonomous burst mode triggers for unpredictable events
- Telemetry and mass memory tailored to return planned instrument data volumes

Solar Orbiter mission profile



EUI onboard Solar Orbiter

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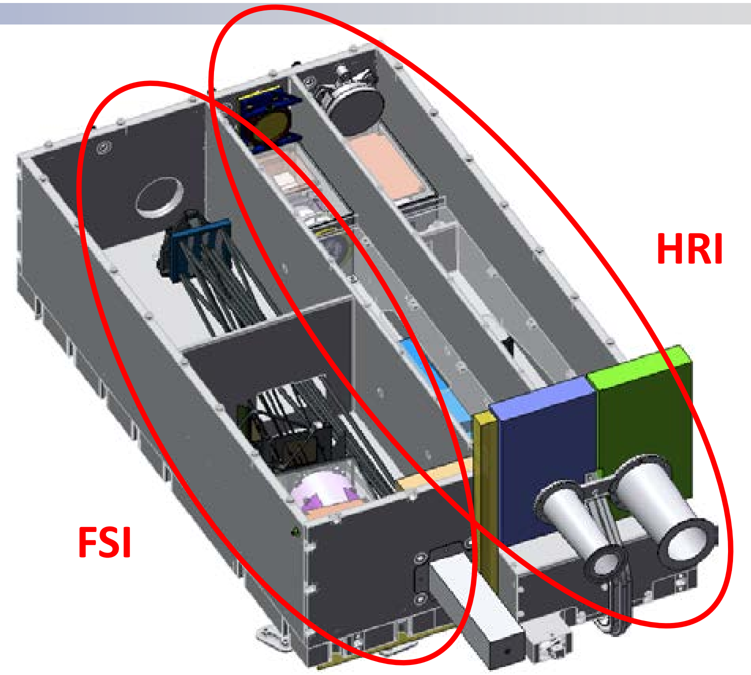
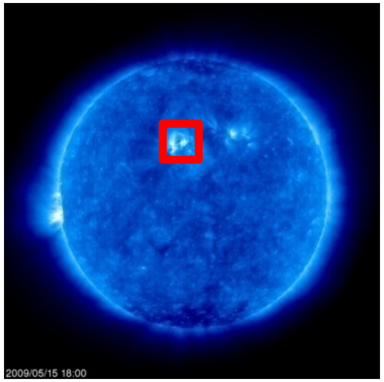
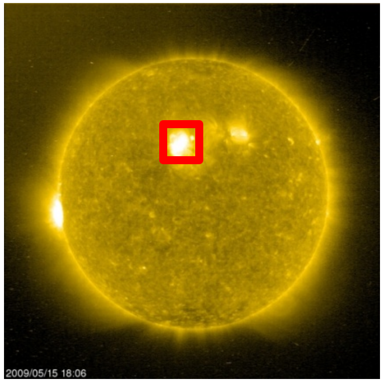
EUI (Extreme Ultraviolet Imagers) onboard Solar Orbiter

Channel	Parameter	Values
	Dimensions	
	- Optical bench	- 550x175x785mm
	- Electronic box	- 120x300x250mm
	Mass (incl. margins)	18.20 kg
	Nominal power	28 W
	Telemetry	20 kb/s
FSI dual EUV	Wavebands	174 Å et 304 Å
	Field of View	5.2 arcdeg × 5.2 arcdeg
	Resolution (2 px)	9 arcsec
	Cadence	600 s
HRI	Wavebands	174 Å
	Field of View	1000 arc sec square
	Resolution (2 px)	1 arcsec
	Cadence	2 s
HRI Lyman-α	Wavebands	1216 Å
	Field of View	1000 arcsec square
	Resolution (2 px)	1 arcsec
	Cadence	< 1s







http://eui.sidc.be/

The EUI Data Centre (EDC)

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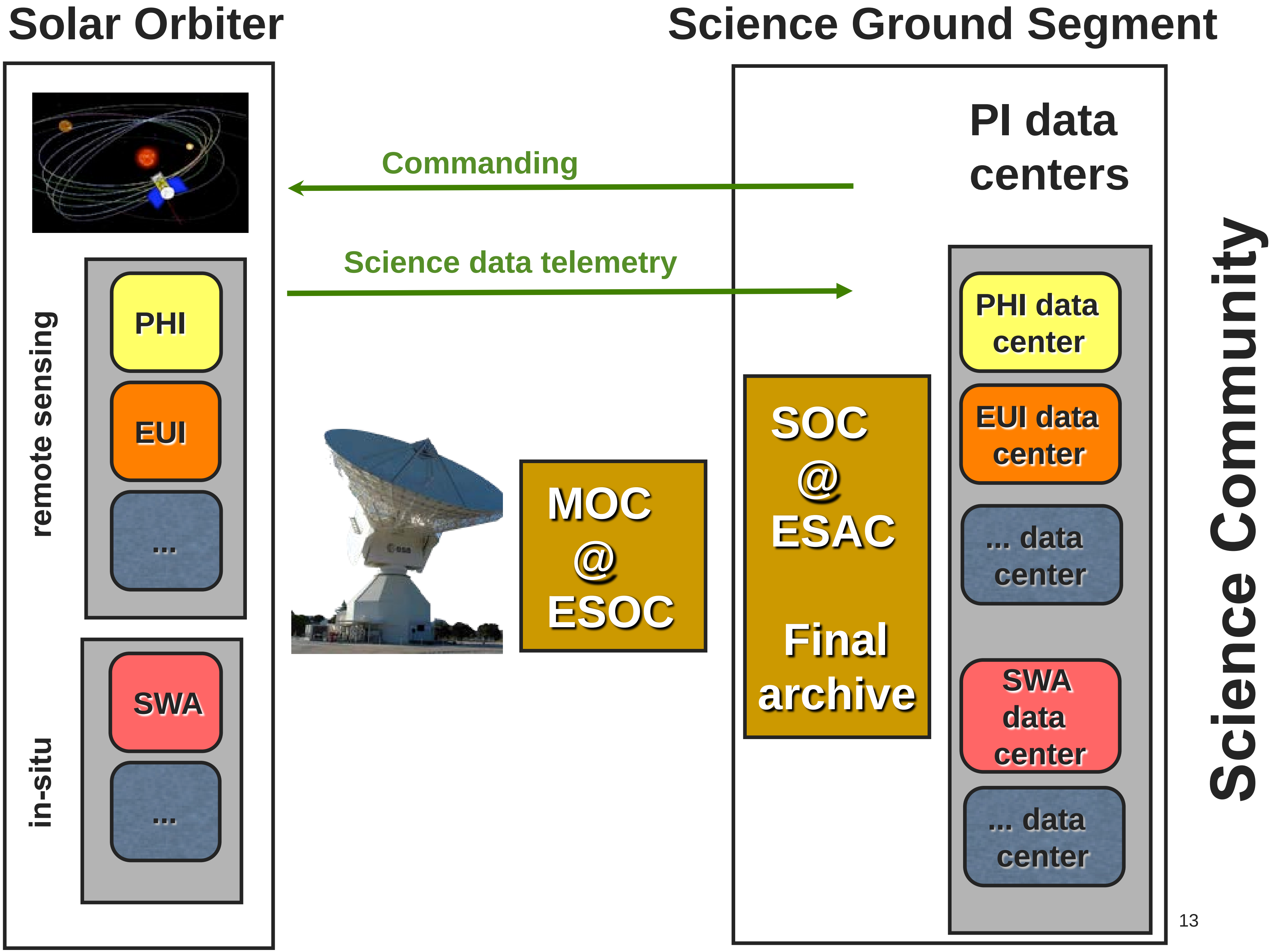
Solar Orbiter
Science Ground Segment
Commanding
Science data telemetry
remote sensing
PHI
EUI
...
in-situ
SWA
...
MOC
@
ESOC
SOC
@
ESAC
Final
archive
PI data
centers
PHI data
center
EUI data
center
... data
center
SWA
data
center
... data
center
Science Community

Challenges for EDC

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Challenges for EDC

Challenges of science operations (deep space mission):

- **Lack of real-time contact**
- **Lack of telemetry:** 19 orbits over 7 yrs (extended mission) ~ **120 GB** ~ **340 000 images** (20x compression)

Operations ideas under study:

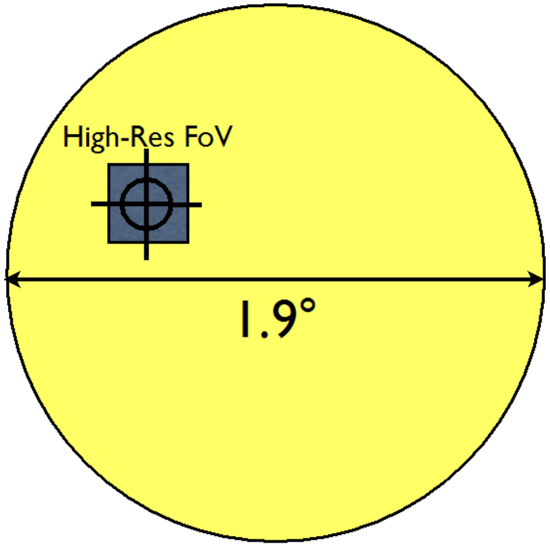
- **Improved planning**
- **Data selection by onboard intelligence**
- **Data selection a posteriori** from the ground

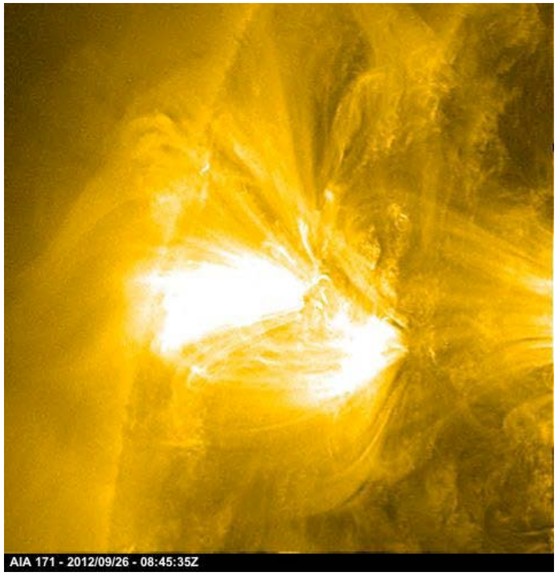
Challenge for EDC: Compression

- Most EUI data need to be **extremely compressed**

Challenge for EDC: Selecting targets

- **Lack of real-time contact**
- **Solution:** perform **precursor observations** before start of most remote-sensing windows to enable SOC to choose a fine-pointing profile for the spacecraft that is commensurate with the science goals defined by the SWT for a particular orbit.
- **Downlink low latency data during the next ground station pass** to make a quick assessment of promising offpointing targets.





Left: FOV (1000” x 1000”) of EUI’s high-resolution imager HRI at perihelion (0.28 AU). This corresponds to a square of about (200 Mm)^2 of solar surface at disk center, i.e., less than 3% of the solar disk. *Right*: same area on SDO/AIA image.

Challenge for EDC: Observing flares

- Slim prospects for observing solar eruptions

- HRI covers 1/40th of the solar disk
- telemetry limit: only 2 hours of high cadence per orbit (duty cycle = 1/720)
- over 30 days we expect 10 eruptions

operations:
random pointing
random time frame

the probability per orbit to observe an eruption =
~ 10/ (720.*40) ~ 1 / 3000

Challenge for EDC: Observing flares

- **Solution**: dedicated **flare trigger** for EUI
- Human decision based on flare trigger

Ex: EUI leads a major eruption campaign

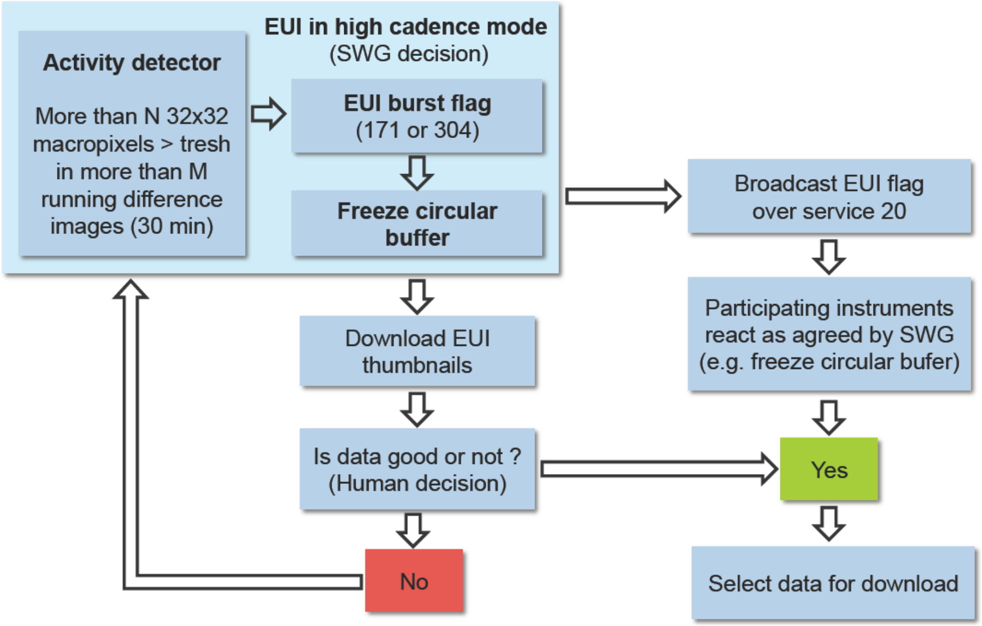
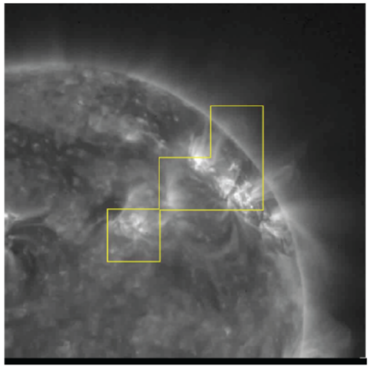


Table 3. SWAP flare detection characteristics for one particular event that occurred during 7 March 2011. Parameters (a) to (e) are explained in Table 2.

Event nr.	(a) Start	(b) End	(c) Location	(d) Size	(e) Significance
14	19:35 UT	22:22 UT		3	50%



GOES: M3.7 20:01

FITS generating pipeline

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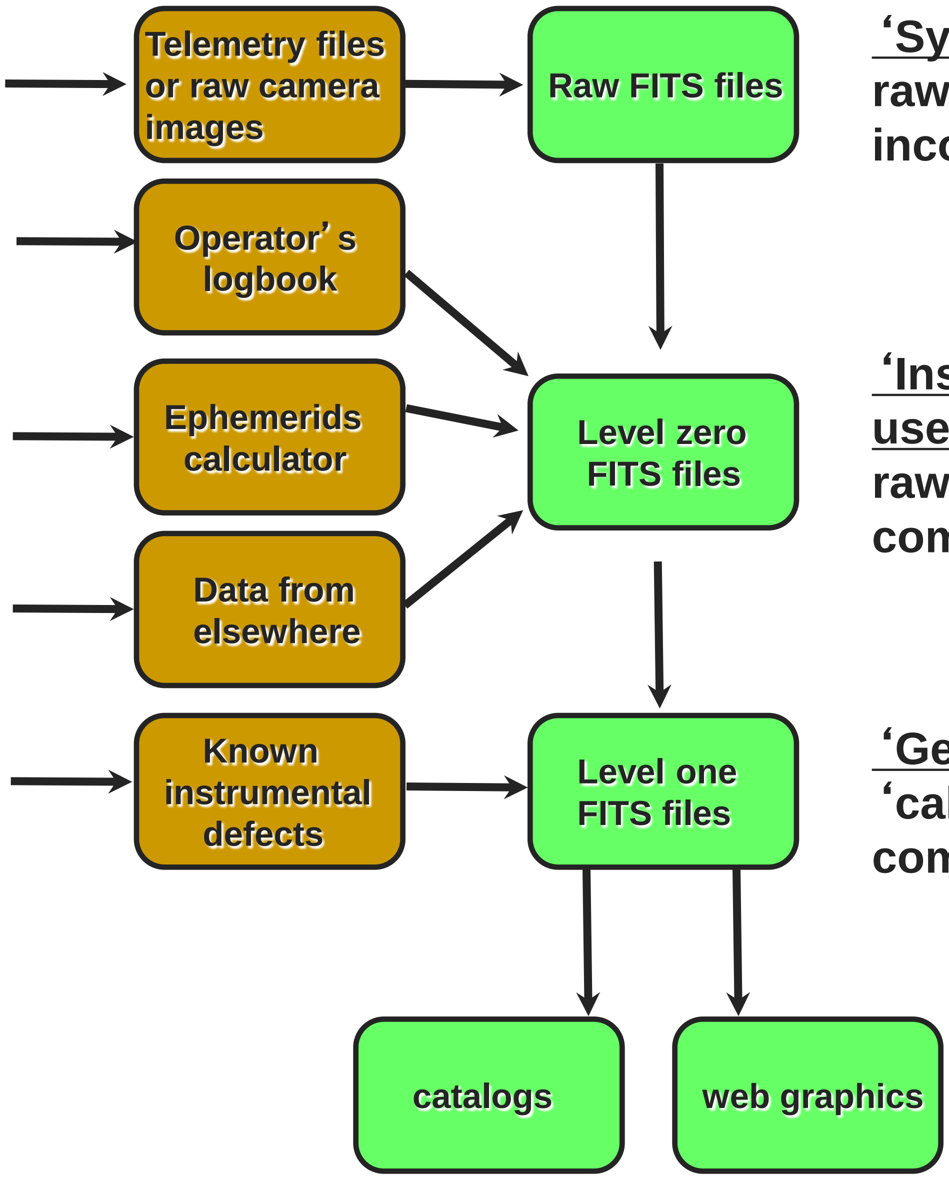
FITS generating pipeline



<u>‘System use’: only for operators or processes</u>
raw data
incomplete metadata

<u>‘Instrument engineering use’: public, use at own risk</u>
raw data
complete metadata

<u>‘Generic science use’: public, fully supported</u>
‘calibrated’ data
complete metadata

www, easy viewing, virtual observatories, advanced queries

Conclusions

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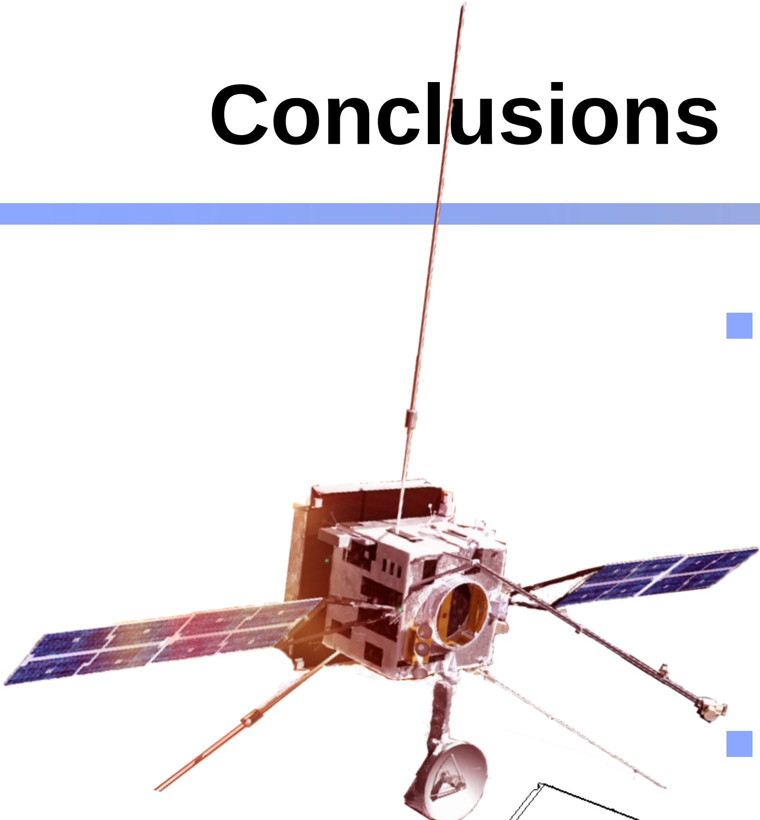
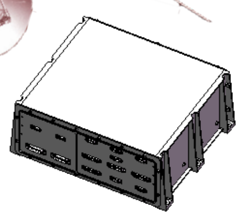
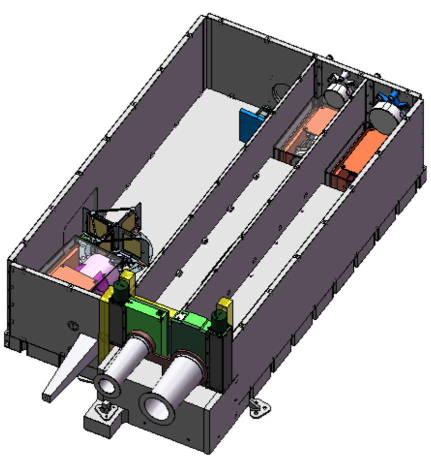
Conclusions







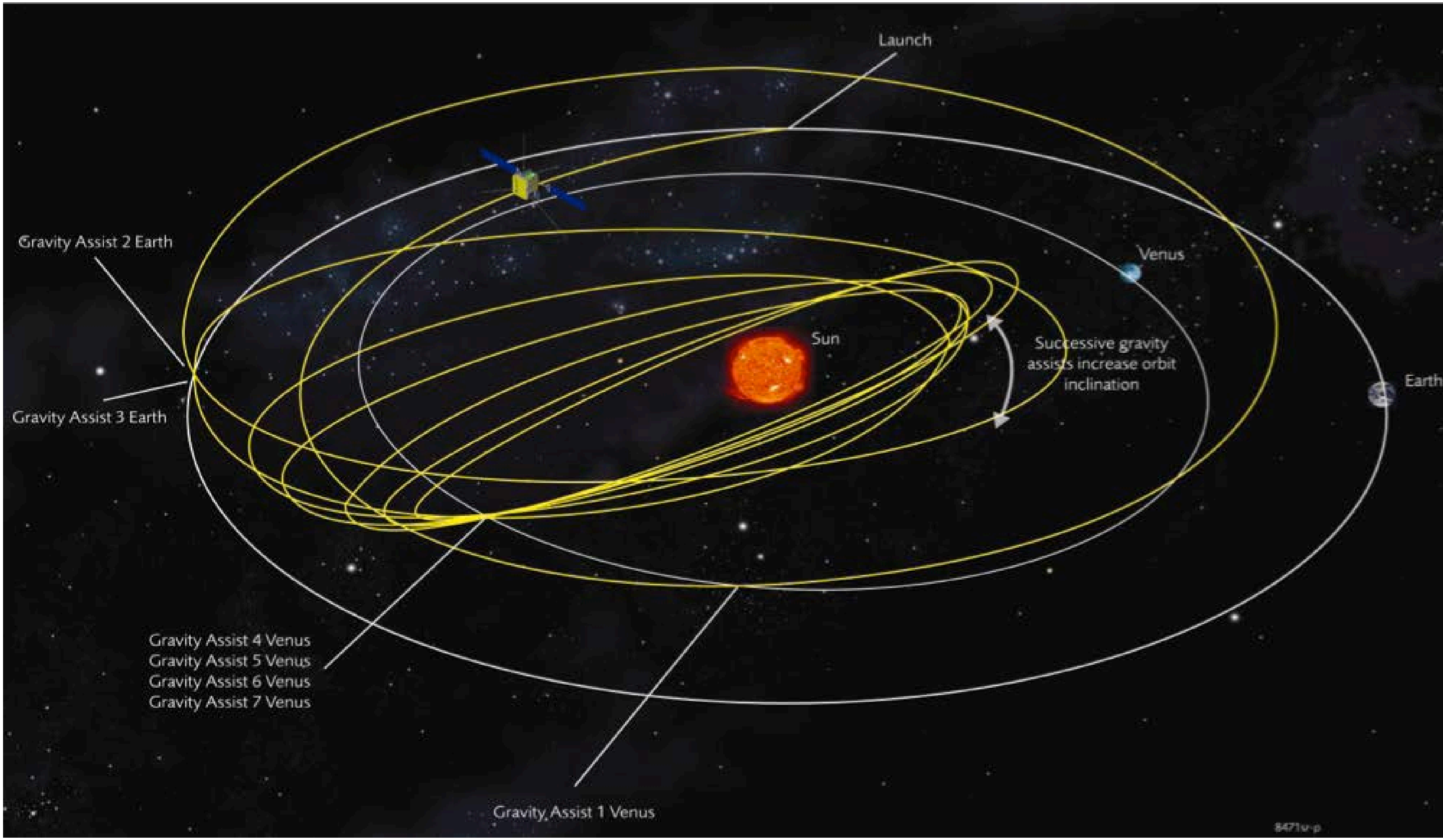
- Solar Orbiter
  - Launch: January 2017
  - Cruise Phase: 2017-2020
  - Nominal Mission: 2020-2024
  - Extended Mission: 2024-2026
- EUI instrument onboard Solar Orbiter
  - High res EUV images of solar features
  - Linking solar & heliospheric phenomena
  - Better view on solar poles
- EUI Data Centre at ROB
  - EDC requirements: 2013
  - Start EDC development: 2014

Extra slides

Why study the Sun-space connection?

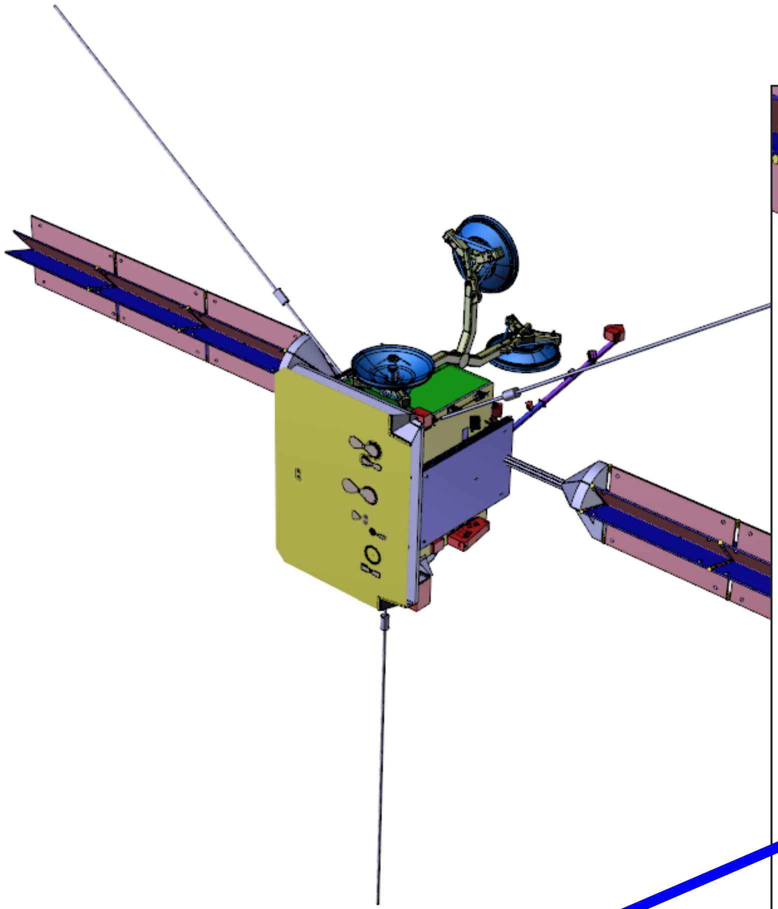
- Addresses ESA's Cosmic Vision question "How does the solar system work?"
- Study plasma phenomena which occur throughout the Universe
  - Shocks, particle acceleration, magnetic reconnection, turbulence, etc.
  - Also addresses Cosmic Vision question "What are the fundamental physical laws of the Universe?"
- Solar wind and energetic particles directly affect life on Earth
  - Impact on space and ground-based assets
- Builds on European heritage: Ulysses and SoHO

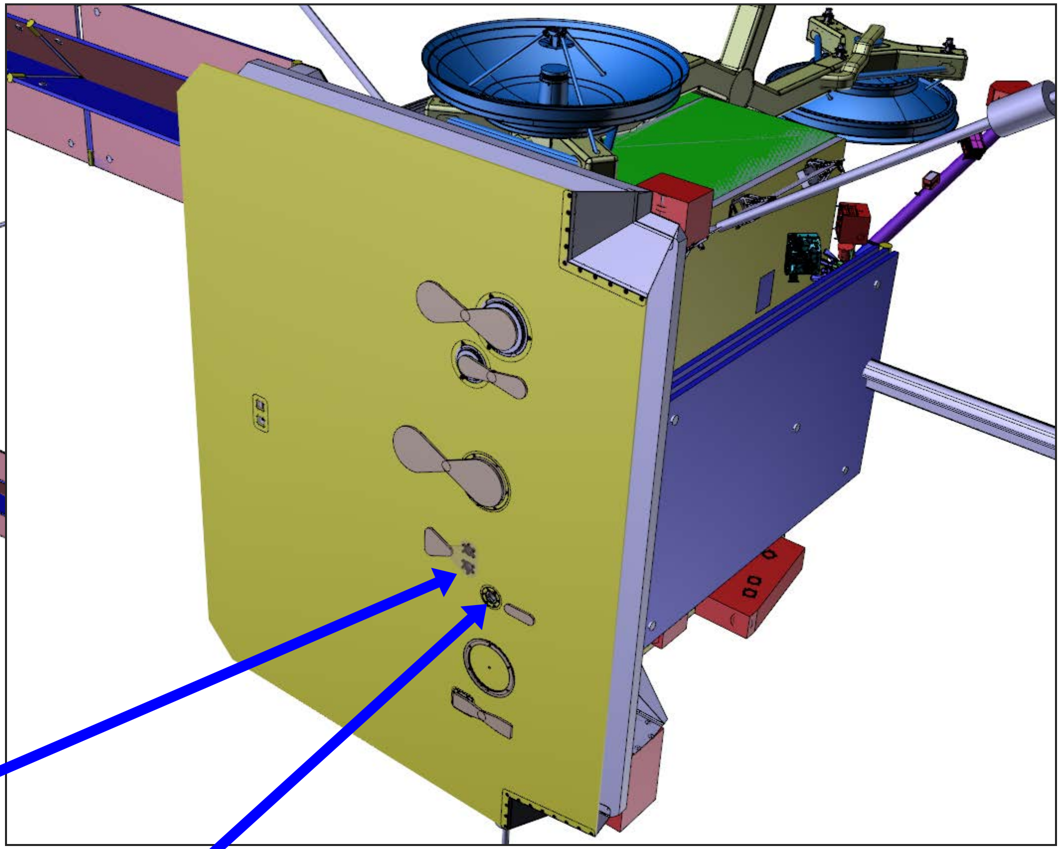
Mission profile



In situ instruments			
SWA	Solar wind analyser	Chris Owen, UK	Sampling protons, electrons and heavy ions in the solar wind
EPD	Energetic particle detector	Javier Rodriguez-Pacheco, Spain	Measuring timing and distribution functions of accelerated energetic particles
MAG	Magnetometer	Tim Horbury, UK	High-precision measurements of the heliospheric magnetic field
RPW	Radio and plasma wave analyser	Milan Maksimovic, France	Studying local electromagnetic and electrostatic waves and solar radio bursts
Remote sensing instruments			
PHI	Polarimetric and heliospheric imager	Sami Solanki, Germany	Full-disc and high-resolution visible light imaging of the Sun
EUI	Extreme ultraviolet imager	Pierre Rochus, Belgium	Studying fine-scale processes and large-scale eruptions
STIX	Spectrometer/telescope for imaging X-rays	Arnold Benz, Switzerland	Studying hot plasmas and accelerated electrons
METIS	Multi-element telescope for imaging and spectroscopy	Ester Antonucci, Italy	High-resolution UV and extreme UV coronagraphy
SoloHI	Solar Orbiter heliospheric imager	Russ Howard, US	Observing light scattered by the solar wind over a wide field of view
SPICE	Spectral imaging of the coronal environment	Facility instrument, ESA provided	Spectroscopy on the solar disc and corona

Design overview (1/30)





HRI entrance apertures

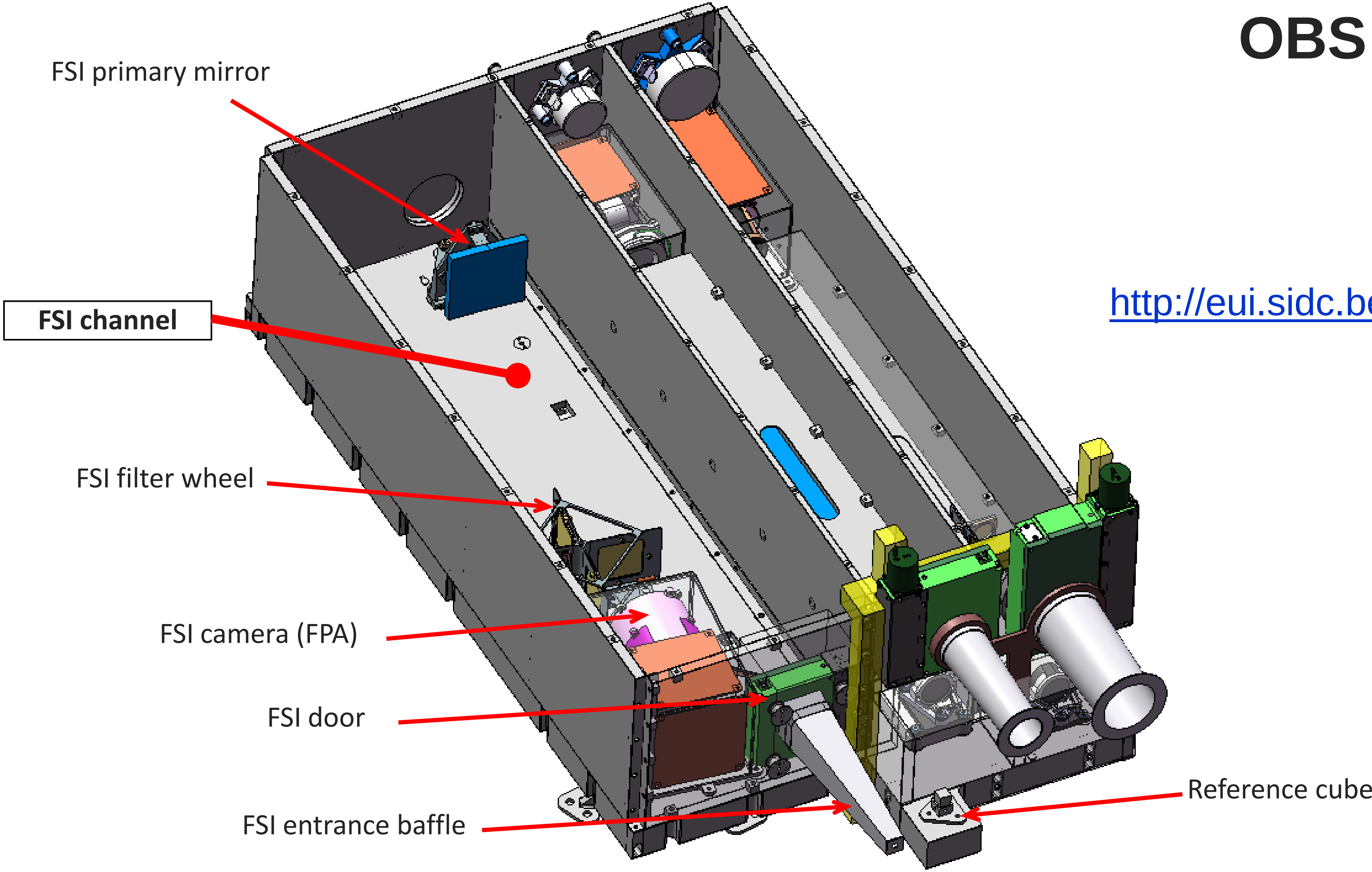
FSI entrance aperture

Design overview (2/30)

- Heritage
  - PROBA2-SWAP → HRI optical design, detector & filters
  - HERSCHEL Rocket → FSI optical design
  - SOHO-EIT, STEREO-EUVI → EUV multilayers mirror coatings
- Passive thermo-mechanical design
  - No active control, passive detector cooling
  - Low CTE optical bench
  - Heat rejection entrance baffles
- Compact
  - Small entrance apertures
  - Three channels on a single optical bench
  - Decoupling of optical and electrical units
- Low telemetry
  - Compression and on-board data processing/selection

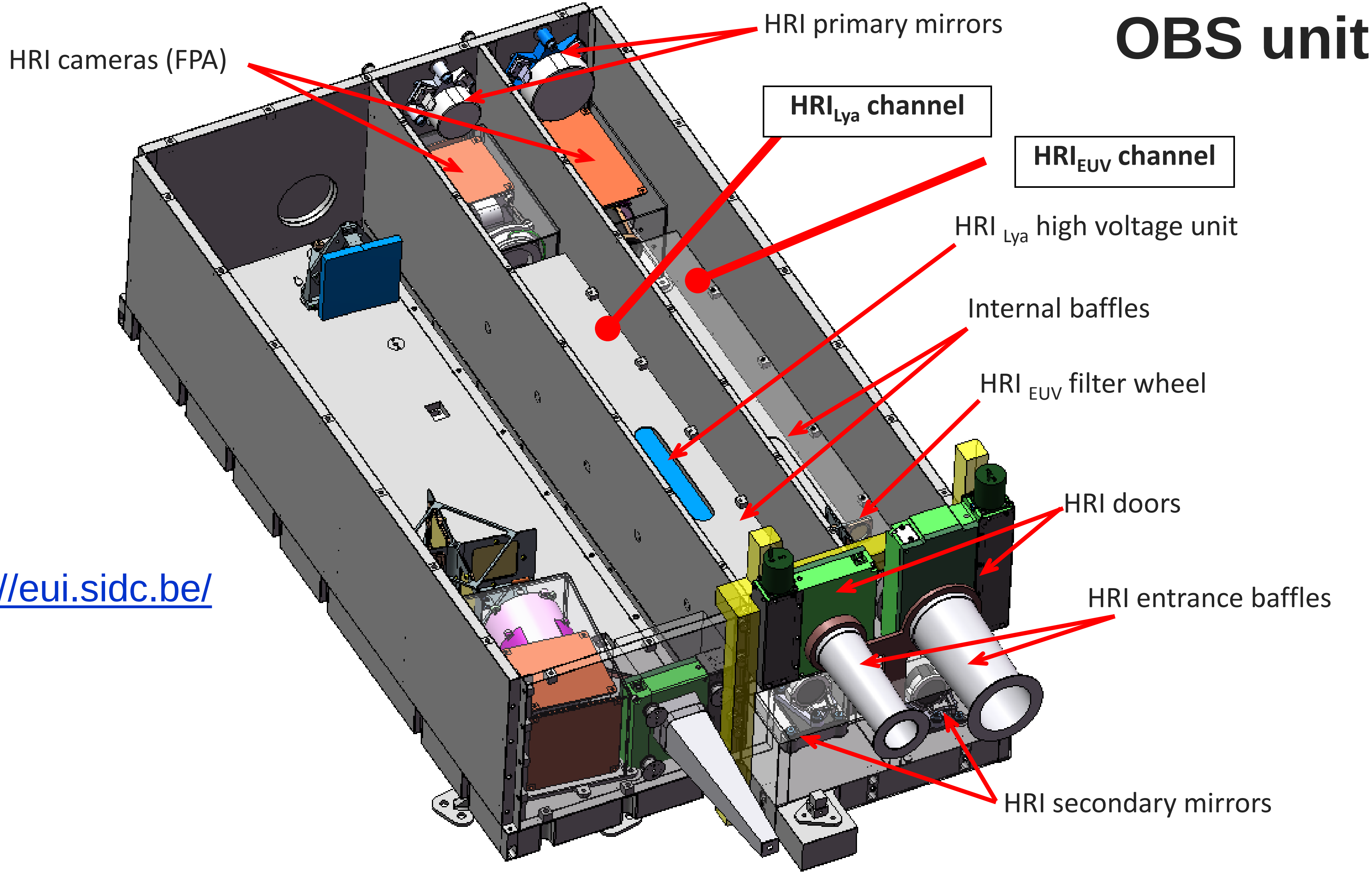
EUI: Extreme Ultraviolet Imagers

OBS unit



http://eui.sidc.be/

EUI: Extreme Ultraviolet Imagers



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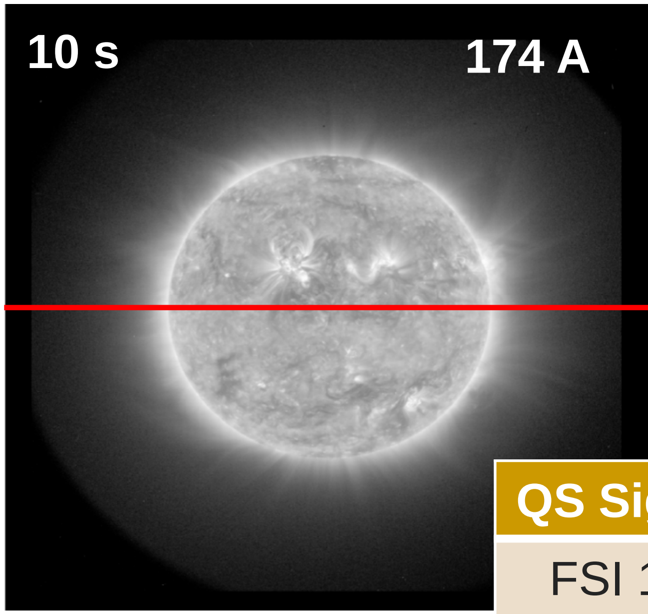
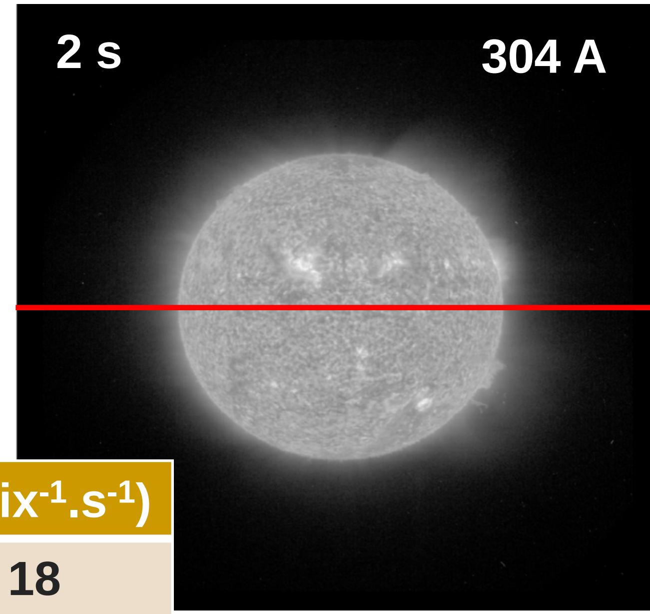
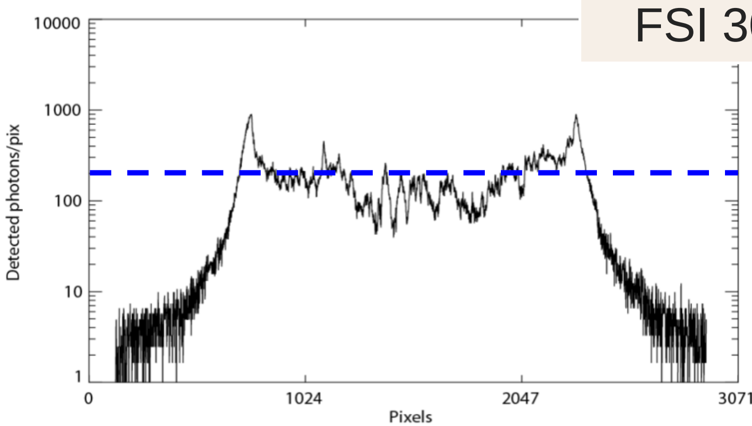
Scientific performances (2/3)

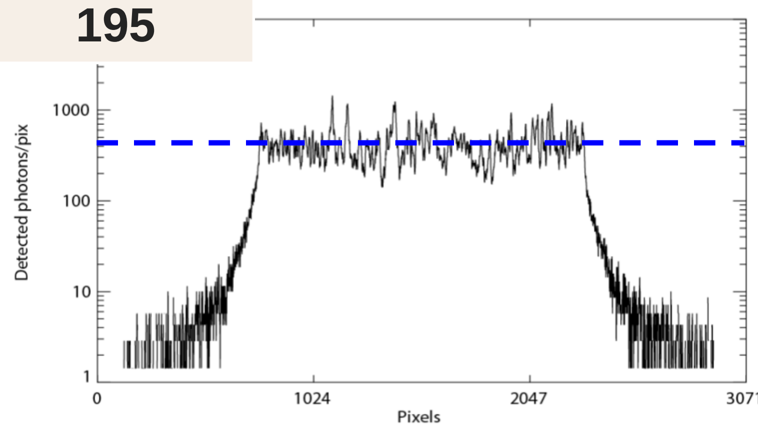
- FSI photometry





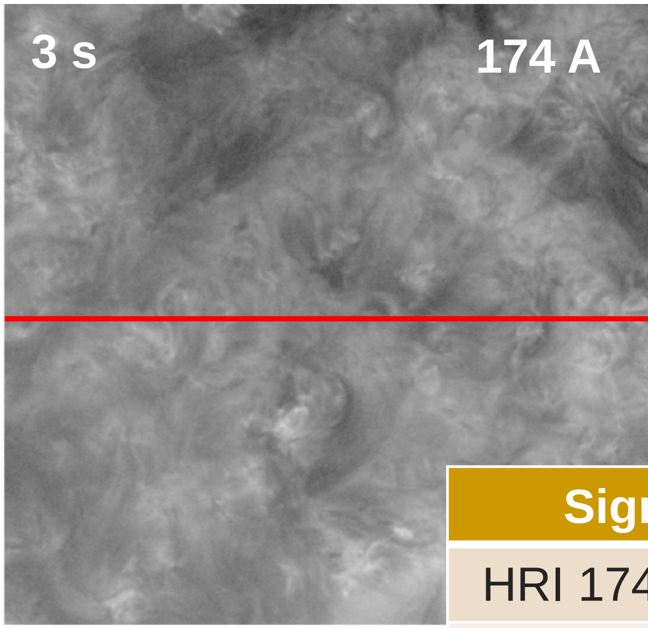
QS Signal (ph.pix^{-1}.s^{-1})	
FSI 174	**18**
FSI 304	**195**

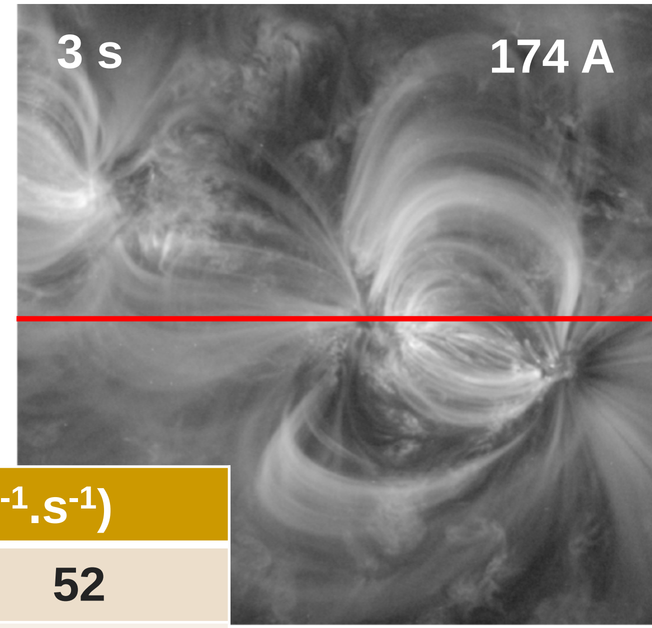




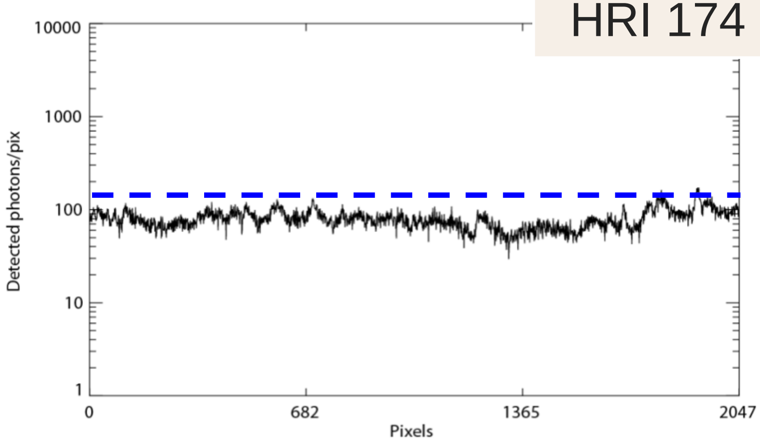
Scientific performances (2/3)

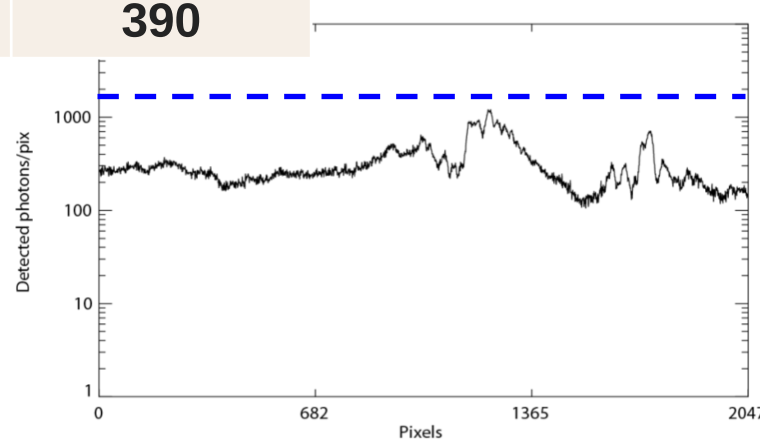
- HRI_{EUV} photometry





Signal ($ph.pix^{-1}.s^{-1}$)	
HRI 174 (QS)	**52**
HRI 174 (AR)	**390**





EUI observing programs

Science program	Science Data Reqt	Channel	Cadence (sec)	Compression	TM (Gbits / h)
(S) Synoptic	4 x 4 R_{sun} window centered on disc centre	FSI_{174} FSI_{304}	600	50	0.0075
(R) Reference Synoptic	4 x 4 R_{sun} window centered on disc centre	FSI_{174} FSI_{304}	1day	4	0.0025
(G) Global eruptive event	Full FOV centered on event.	FSI_{174} or FSI_{304}	10	10	4.43
(C) Coronal Hole	Full FOV centered on CH with its boundary and/or plumes. High latitude, perihelion, possibly near co-rotation.	HRI_{174} $HRI_{Ly\alpha}$	30 30	5 15	1.75
(Q) Quiet Sun	Full FOV centered on QS. Perihelion/encounter, near co-rotation	HRI_{174} $HRI_{Ly\alpha}$	8 1	7 15	16.6
(A) Active region	Full FOV centered on AR. Perihelion/encounter, near co-rotation	HRI_{174} $HRI_{Ly\alpha}$	2 1	15 15	19.7
Eruptive event (E)	Perihelion/encounter, near co-rotation Full FOV	HRI $_{174}$ HRI $_{Ly\alpha}$	1 1	15 15	26.1
Discovery (D)	*High cadence dynamics* Perihelion/encounter, near co-rotation, 645 x 645 FOV for Lyα	HRI $_{174}$ HRI $_{Ly\alpha}$	1 0.1	15 15	26.1

Scientific objectives (2/4)

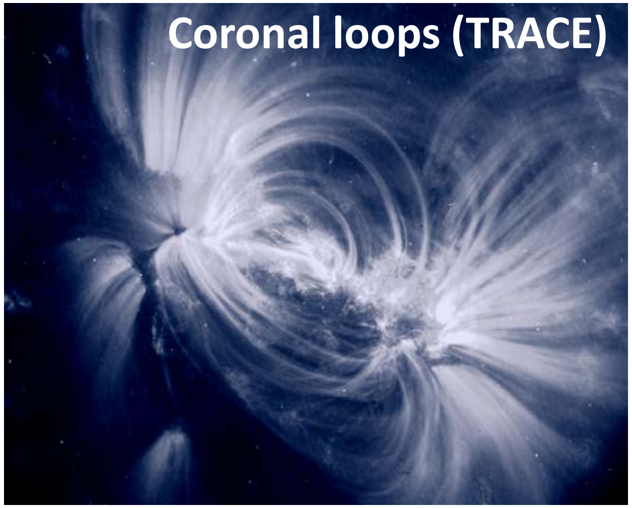
- Selected open question:

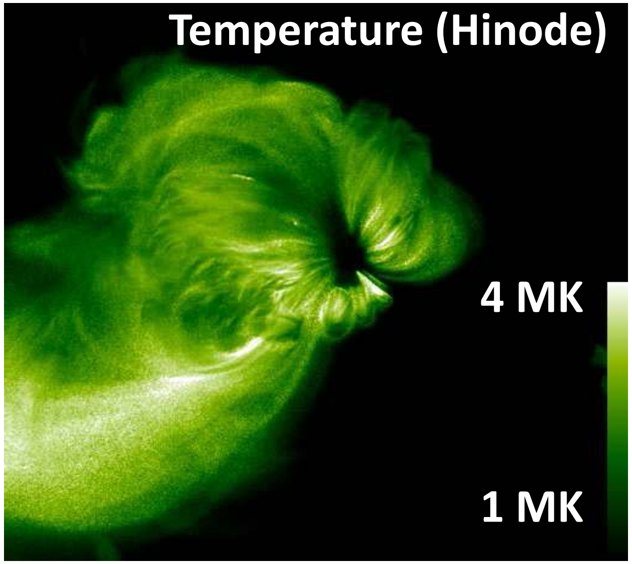
YB O2.1. How and where do the solar wind plasma and magnetic field originate in the corona?

- The fine structuring of the corona is the key for understanding the fundamental dissipation processes at play
  - Minimal observed width of loops (~900 km) equal to resolution of instruments

    Aschwanden 2005, ApJ
  - Fine thermal structure at the limit of Hinode resolution: 1000 km

    Reale, Parenti et al. 2007, Science





EUI flexibility and constraints

Telemetry for the orbit : 49.4 Gb

- **Science target: dynamics/discovery**

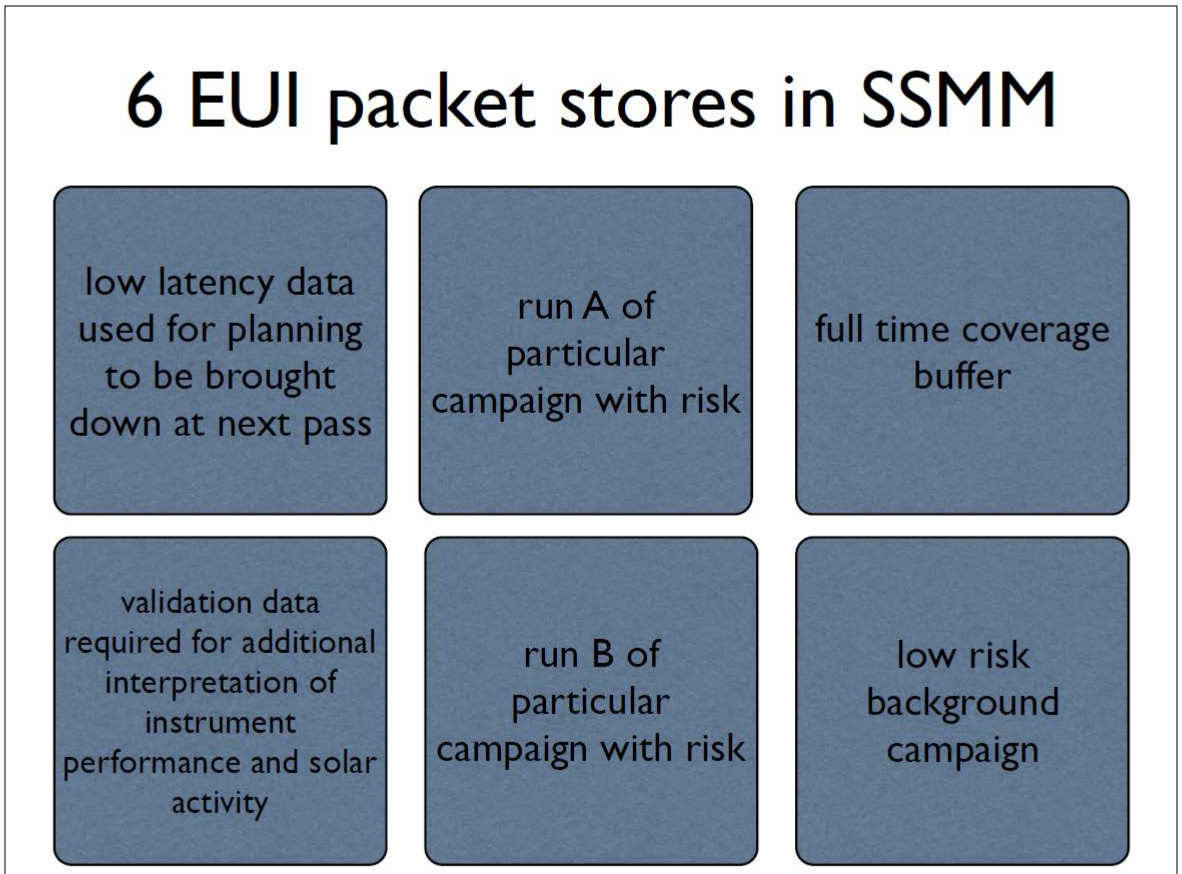
Channel	FOV	Cad. (s)	Exp. (s)	Compression	Duration (min)	Telemetry (Gbits)	Total TM
F174	$4x4R_S$	600	10	50	10	0.0025	22.0987
F304	$4x4R_S$	600	10	50		0.0025	
H174	Full	10	3	15		0.2188	
HLya	645^2	0.1	0.1	15		21.8750	

- **Science target: plumes tomography**

F174	$4x4R_S$	28800	100	4	10	6.4600	18.6621
F304	$4x4R_S$	28800	100	4		6.4600	
H174	Full	28800	100	4		2.8711	
HLya	Full	28800	10	4		2.8711	

Challenge for EDC: data prioritization

- Since only a fraction of the acquired images can be sent to the ground, proper prioritization of images is essential.
- **Solution**: Six packet stores based on campaign type and image quality.

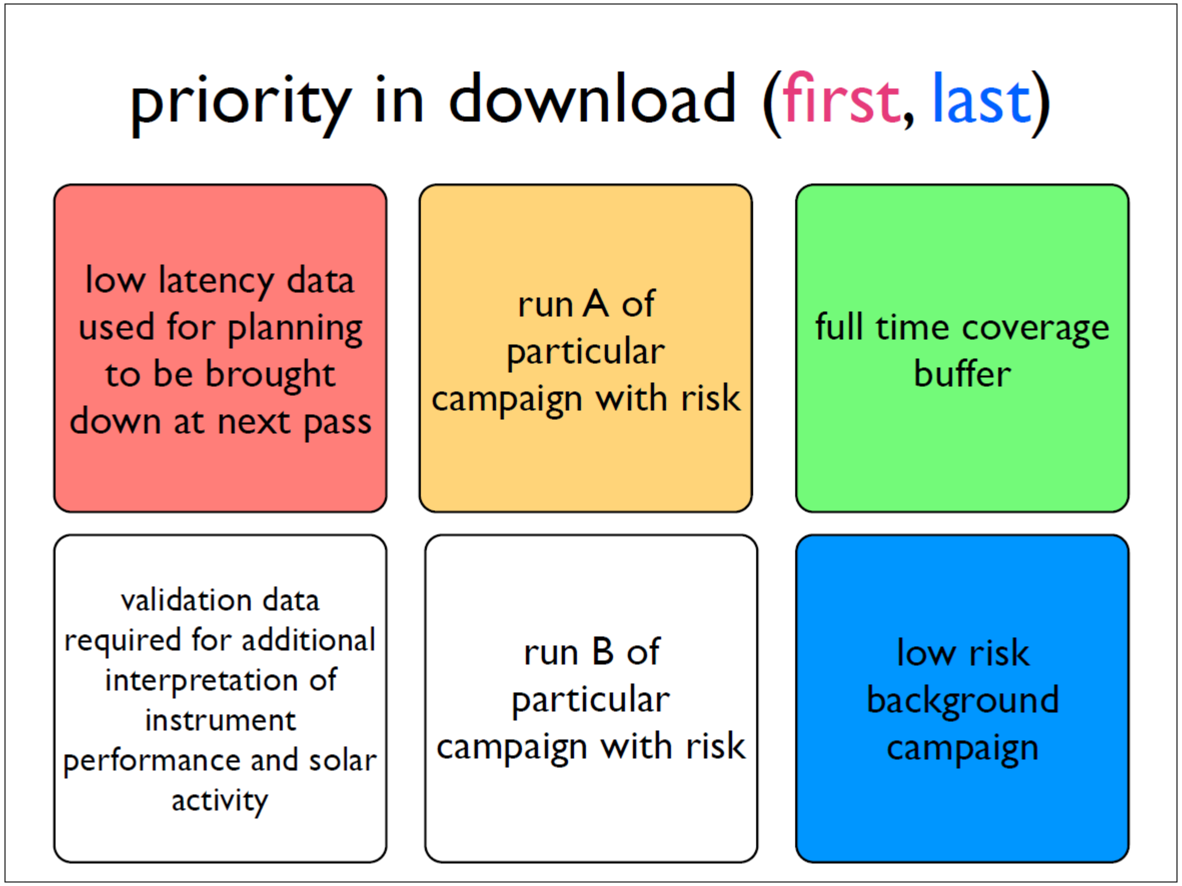


Challenge for EDC: data prioritization

fractions of EUI telemetry (~50 %, <10%)

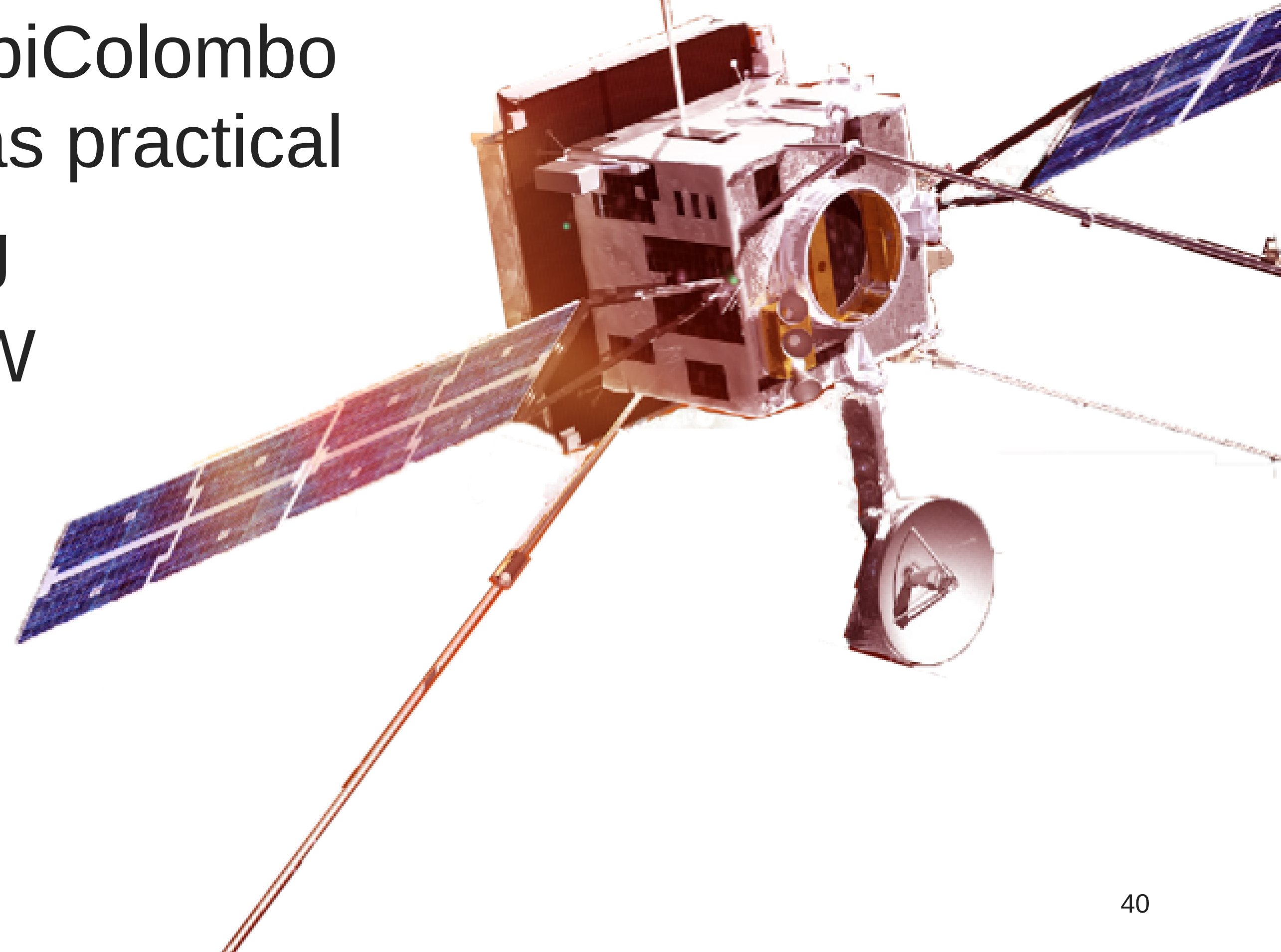
low latency data used for planning to be brought down at next pass	run A of particular campaign with risk	full time coverage buffer
validation data required for additional interpretation of instrument performance and solar activity	run B of particular campaign with risk	low risk background campaign

Challenge for EDC: data prioritization

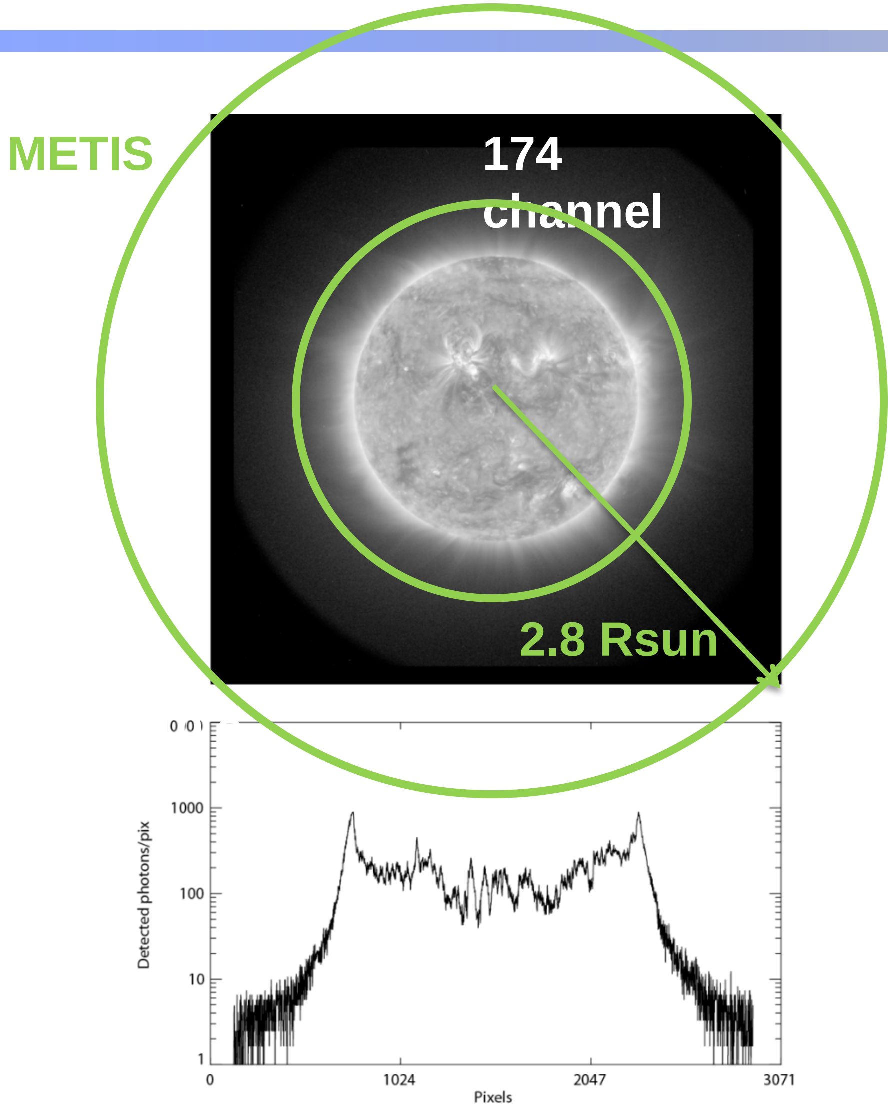


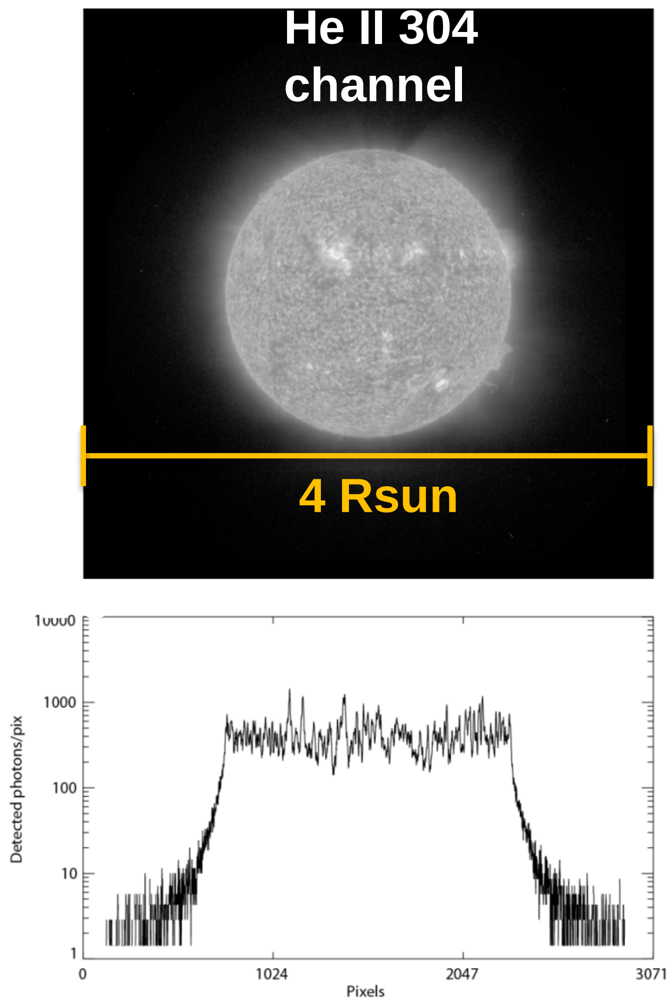
Solar Orbiter spacecraft

- Three-axis stabilised, Sun pointing
- Heatshield at front
- Re-use of BepiColombo unit designs as practical
- Mass: 1750kg
- Power: 1100W
- Launch: ELV



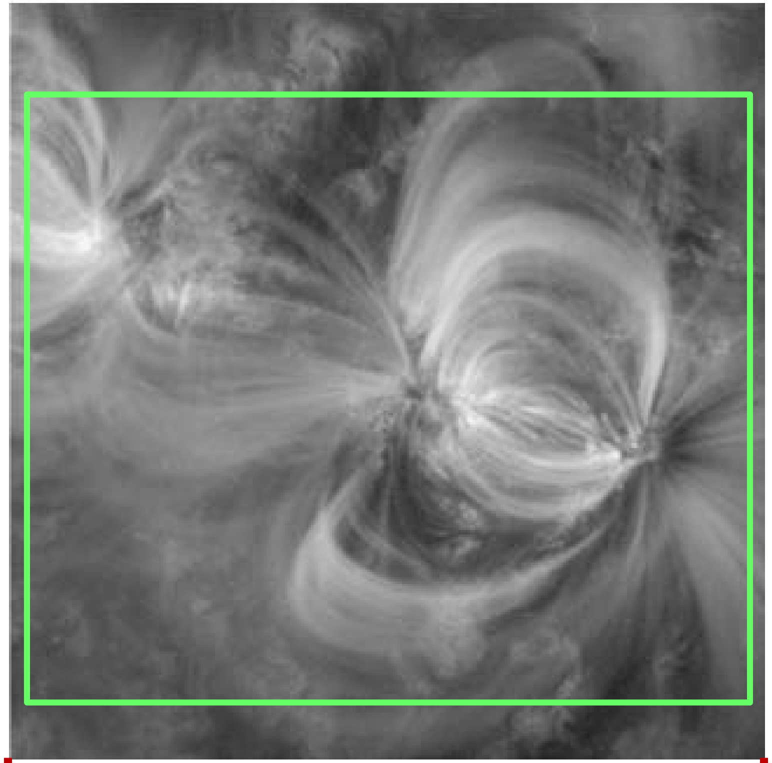
EUI Full Sun Imager (FSI)





EUI High Resolution Imager (HRI)

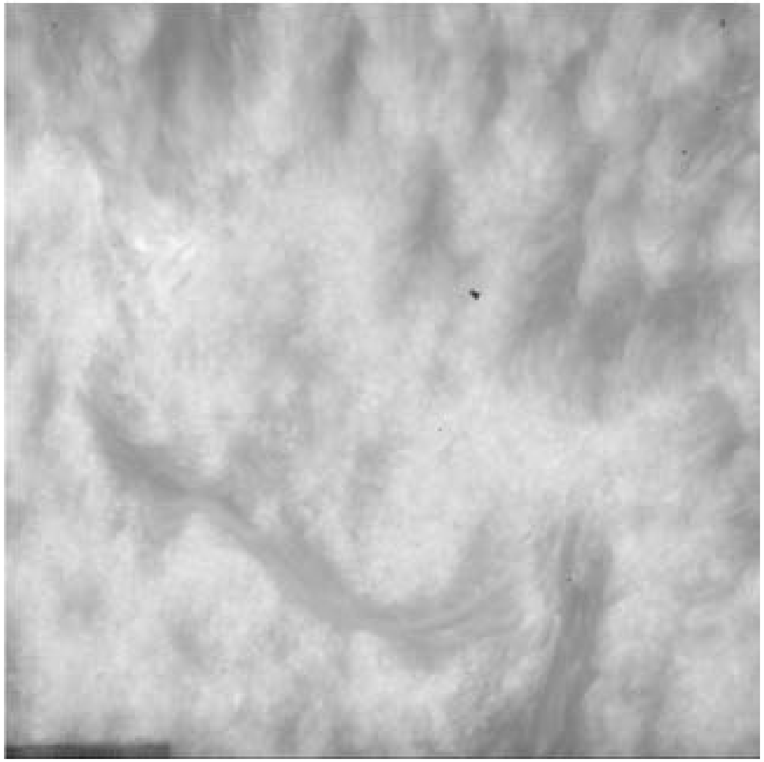
Fe IX/X 174



17’

SPICE FOV: 16’ x 13’

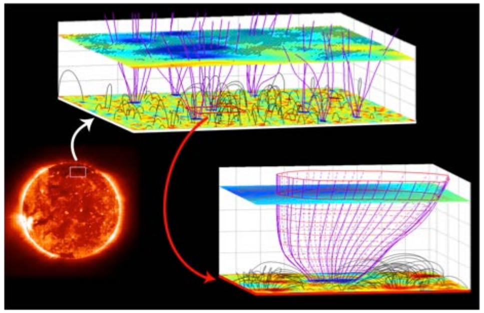
H Ly α



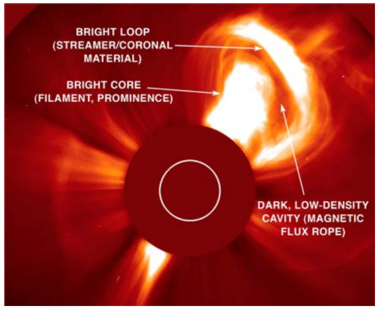
1 pixel: ~100 km @ 0.3AU

Four basic science questions

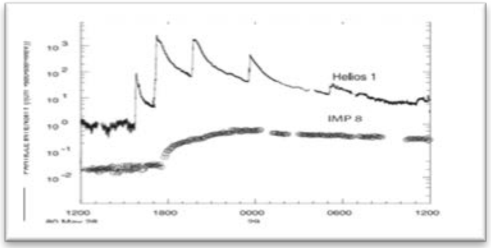
1) How and where do the solar wind plasma and magnetic field originate in the corona?



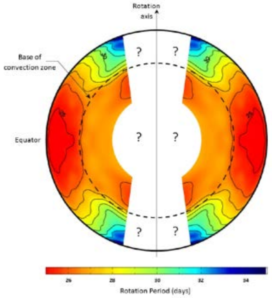
2) How do solar transients drive heliospheric variability?



3) How do solar eruptions produce energetic particle radiation?



4) How does the solar dynamo work?



EUI Consortium

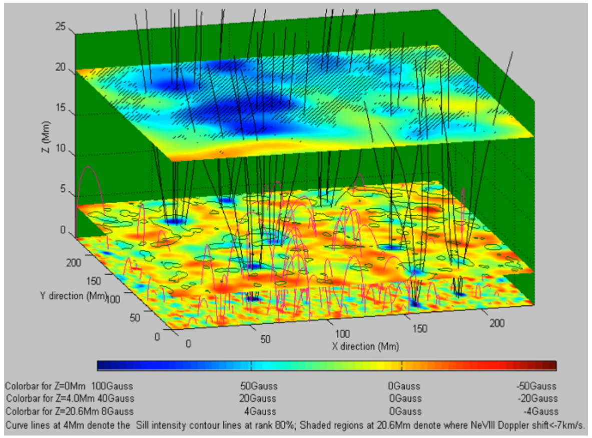
- PI-ship, Project Office, PA management, System Engineering, FEE's, covers, instrument AIV
- Detector characterisation and calibration, on-board data processing algorithms, operations
- FSI lead, filter wheels, optics and mounts
- Optics and coatings
- Common electronic box, on-board software, EGSE
- $HRI_{Ly\text{-}\alpha}$ lead, contamination control plan, ground calibr.
- Optical bench, structural elements…

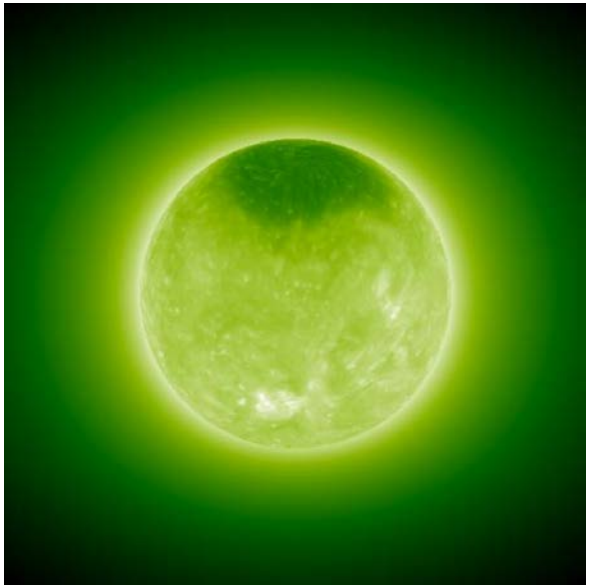
EUI contribution to science question 1

1) How and where do the solar wind plasma and magnetic field originate in the corona?

- Connect the chromosphere, corona and inner heliosphere:
  - Structure and dynamics of network cells, possible sources of fast wind.
    Tu et al. (2005)
- Determine the global structure of polar coronal holes (e. g. plumes)

  Barbey et al. 2008, Gabriel et al. 2005





EUI contribution to science questions 2 & 3

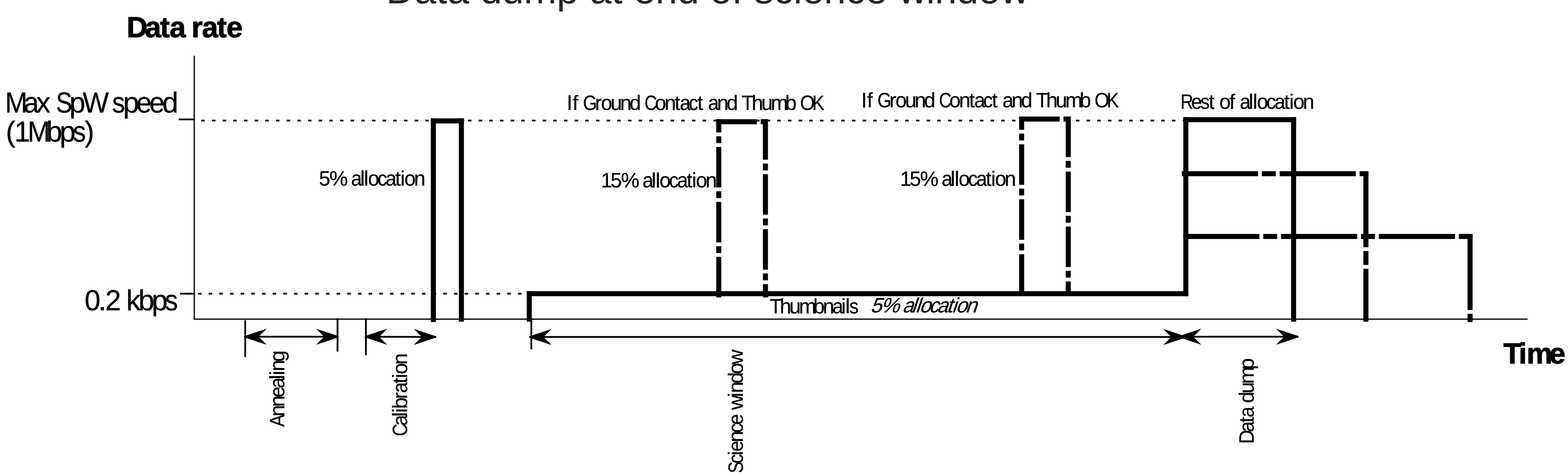
"How do solar transients drive heliospheric variability?"

"How do solar eruptions produce energetic particle radiation that fills the heliosphere?"

Remote instruments should be able to return observations of the source regions of eruptions that have an effect measured by the in-situ instruments.

Challenge for EDC: Limited telemetry

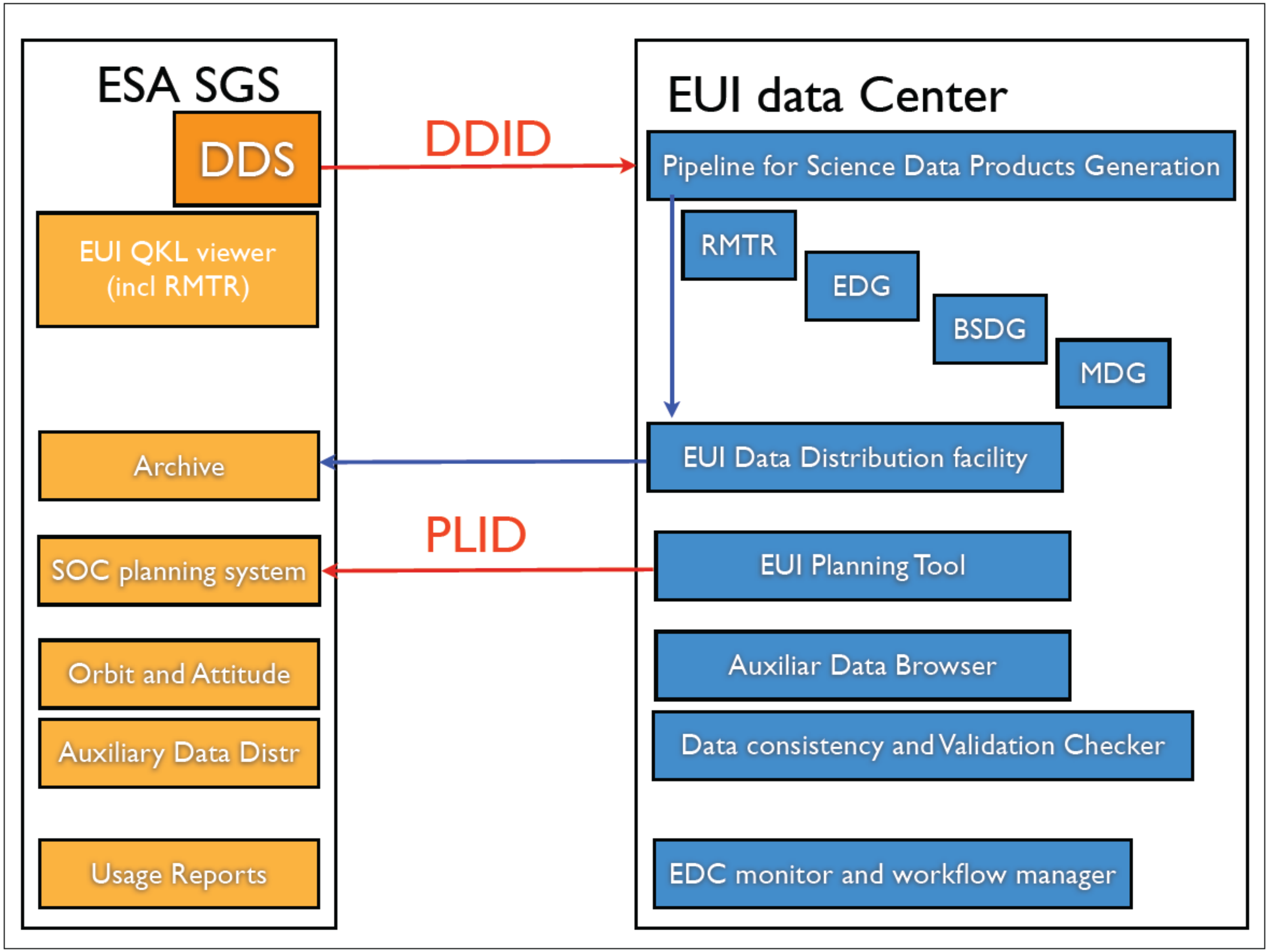
- Telemetry limited to 20 kbps, 30 days per orbit
- 19 orbits over 7 yrs (extended mission) ~ **120 GB ~ 340 000 images** (20x compression)
- Adaptive data transfer
  - 5% of TM for calibration images
  - 5% of TM allocation for thumbnails
  - Part of TM used if ground contact
  - Data dump at end of science window



EDC schedule

#	Date	Document	Risk
D4.1	2014 Q1	EDC Requirements & Specifications Document	No significant risk
D4.2	2014 Q3	EDC Design document	Timely availability of SO ground segment Baseline Design doc.
D4.3	2016 Q1	Functional version of EDC software (SVT time)	Timely availability of ICDs (interface documents)
D4.4	2016 Q4	Online user manual	No significant risk

Sketch of EDC design



Sketch of EDC design

Level 0b telemetry files as we get them from MOC

RMTR: EUI reformatter: depacketizer, decompression

Level 1b uncalibrated, raw FITS. Containing only information coming from Level 0b files. Suitable for EUI quicklook viewer.

Pipeline for Science Data Products Generation

Sketch of EDC design

Level 0b telemetry files as we get them from MOC

RMTR: EUI reformatter: depacketizer, decompression

Level 1b uncalibrated, raw FITS. Containing only information coming from Level 0b files. Suitable for EUI quicklook viewer.

EDG: EUI engineering data generator: combination with all relevant metadata (from auxiliary data archive, pointing, attitude, etc)

Level X uncalibrated, raw FITS containing all metadata. Base data product.

Pipeline for Science Data Products Generation

Sketch of EDC design

Level 0b telemetry files as we get them from MOC

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SDG: EUI science data generator (=IDL eui_prep.pro). Calibration. Regular updates

Level 2 calibrated science data FITS

Pipeline for Science Data Products Generation

Sketch of EDC design

Level 0b telemetry files as we get them from MOC

↓ RMTR: EUI reformatter: depacketizer, decompression

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↓ EDG: EUI engineering data generator: combination with all relevant metadata (from auxiliary data archive, pointing, attitude, etc)

Level X uncalibrated, raw FITS containing all metadata. Base data product.

↓ SDG: EUI science data generator (=IDL eui_prep.pro). Calibration. Regular updates

Level 2 calibrated science data FITS

↓ EUI media data generator

Level 3 pngs, movies, Helioviewer

Pipeline for Science Data Products Generation

The EUI Data Centre (EDC)