Missions & Funding:

A practical guide to doing science

R. P. Lin
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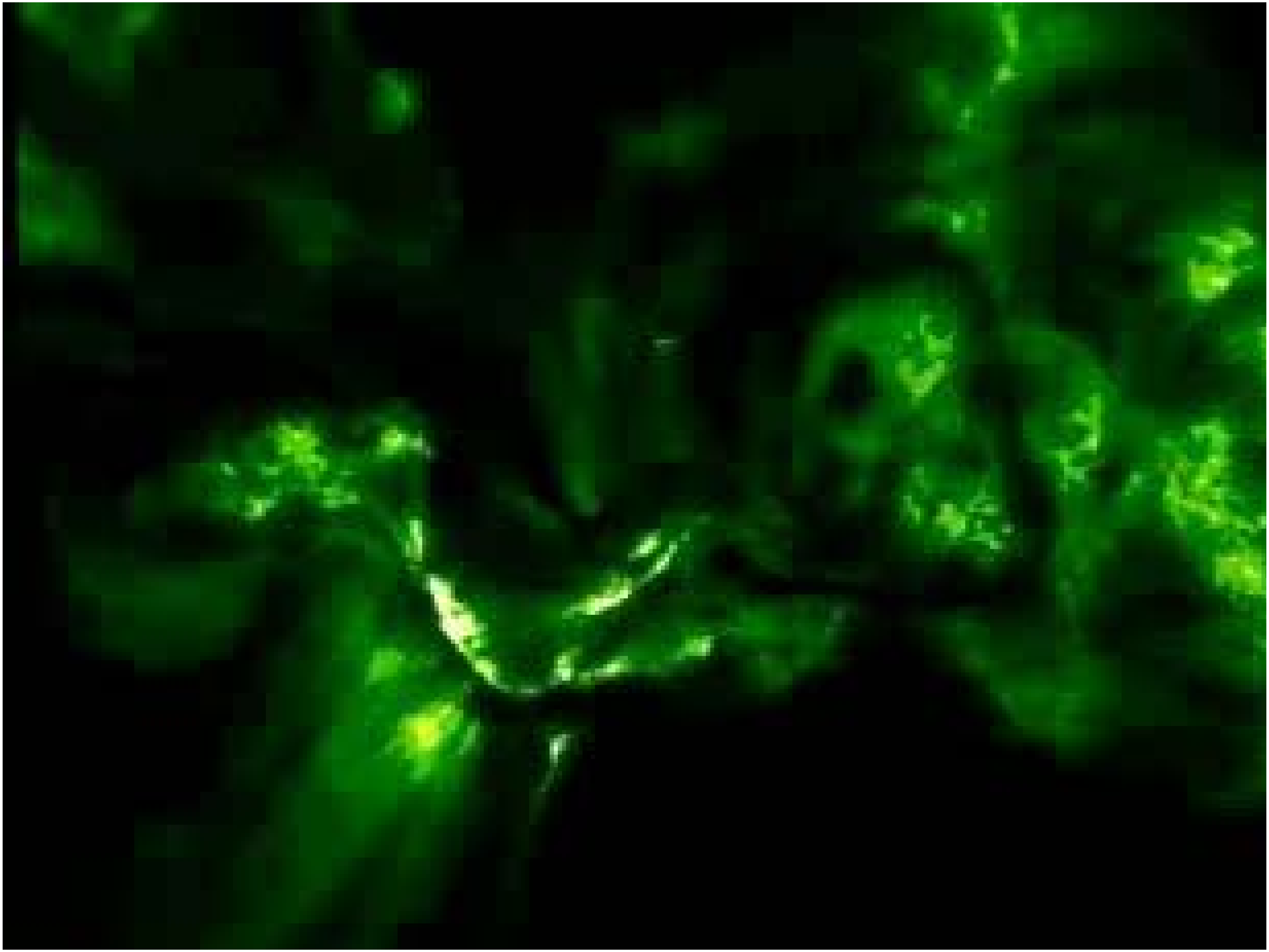
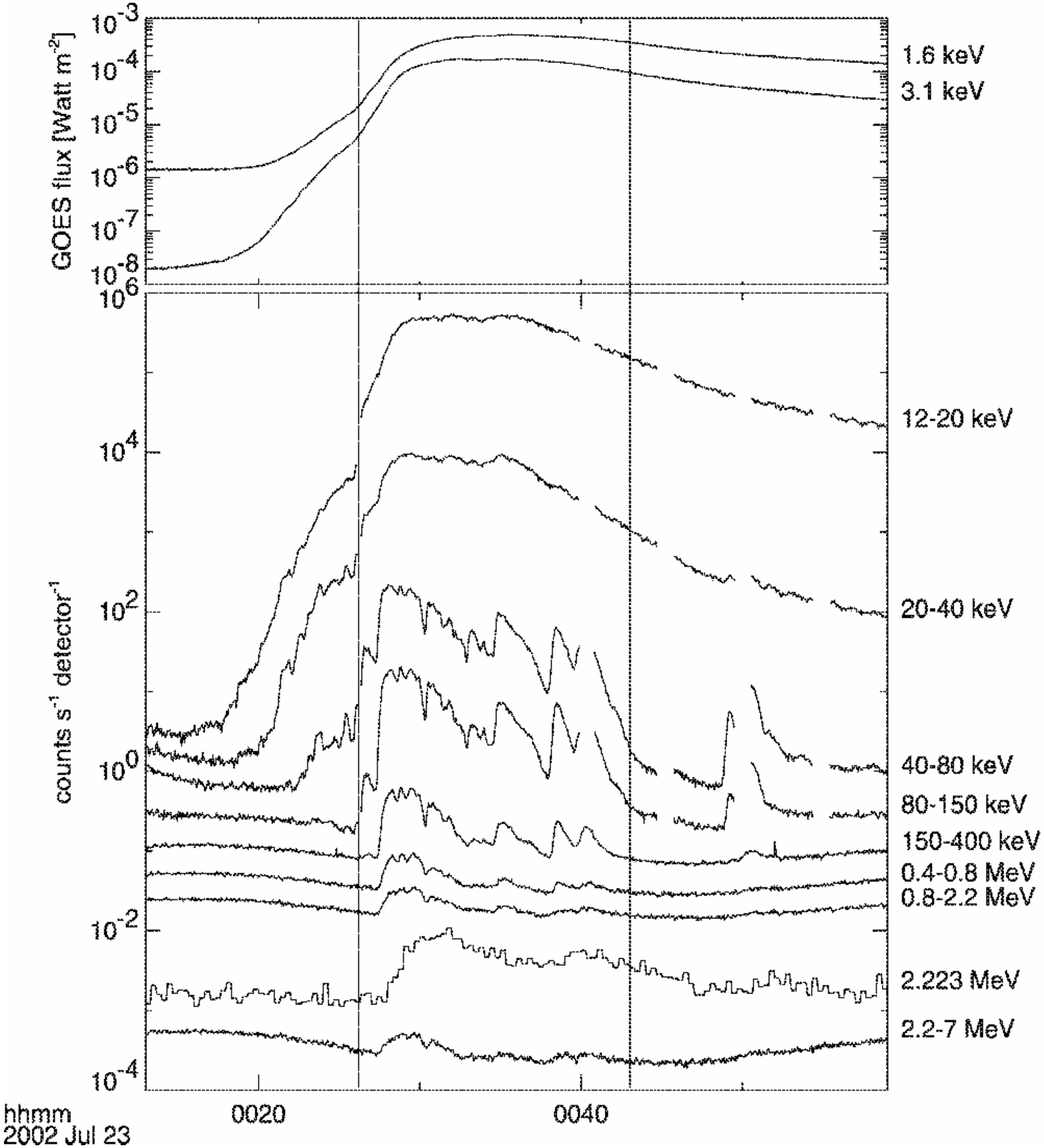
University of California, Berkeley

- Science Idea
  - Current research
  - Outstanding questions
- Measurements Required
  - New Instrument Development
  - Mission Design
- Obtaining Community Support
  - Papers & presentations
  - NASA, NSF, NAS Committees
  - Other factors
- Funding Opportunities
  - NASA (space-based)
  - NSF (ground-based)
  - Foreign





Thermal Plasma

~3x10^7 K

23 July 2002

X4.8 Flare

(Lin et al 2003)

Accelerated Electrons

~10 keV to >10s MeV

Accelerated Ions

~1 to >100s of MeV

Large solar flares are the most powerful explosions in the solar system

Up to ~ 10^{32} - 10^{33} ergs released in ~ 10 – 10^{3} s

Flare-accelerated ~20-100 keV electrons contain ~10-50% of total energy released

In large flares, >~1 MeV ions contain comparable energy

⇒ Particle acceleration is intimately related to flare energy release

The total energy released by all flares, down to microflares/nano-flares may be significant for the heating of the solar corona

The Sun is the most energetic particle accelerator in the solar system:

- Ions up to ~ 10s of GeV
- Electrons up to ~100s of MeV

Acceleration to these energies occurs in transient energy releases, in two (!) processes:

- Large Solar Flares, in the lower corona
- Fast Coronal Mass Ejections (CMEs), in the inner heliosphere, ~2-40 solar radii

Large (L)SEP events

- *tens/year at solar maximum*

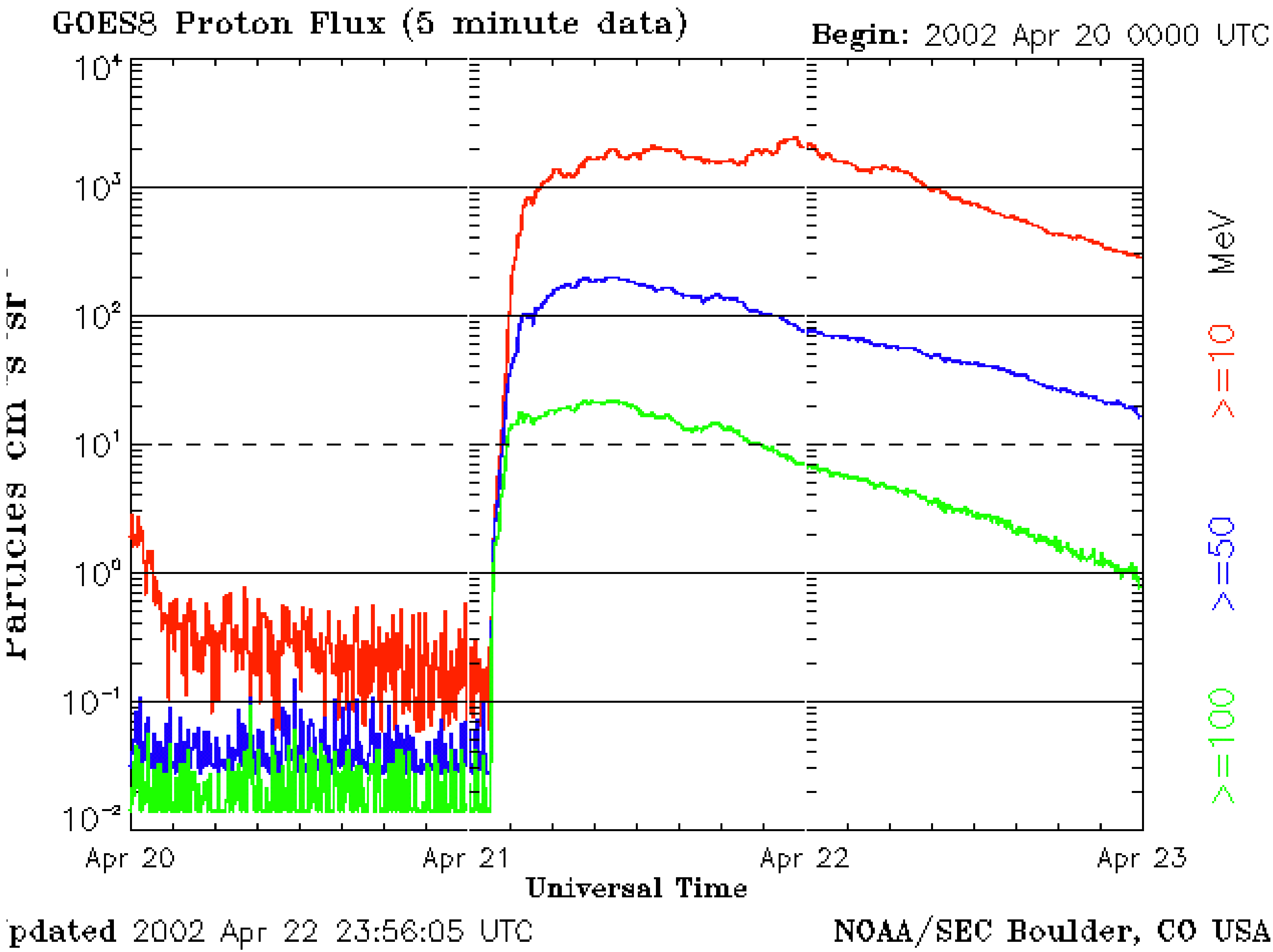
- *dominated by:* - *>10 MeV* ***protons*** *(small e/p ratio)*
  - *Normal coronal composition (?)*
  - *Normal coronal charge states (?)*

- *SEPs seen over >~100º of solar longitude*

- *associated with:* - *Fast Coronal Mass Ejections (CMEs)*
  - *Large flares (but sometimes missing)*
  - *Gradual (~hours) soft X-ray bursts*

(also called Gradual SEP events*)*

* Acceleration by fast CME driven shock wave in inner heliosphere, ~2-40 solar radii


GOES8 Proton Flux (5 minute data)
Begin: 2002 Apr 20 0000 UTC
Particles cm⁻² s⁻¹ sr⁻¹
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
Apr 20
Apr 21
Apr 22
Apr 23
Universal Time
>=10 MeV
>=50
>=100
Updated 2002 Apr 22 23:56:05 UTC
NOAA/SEC Boulder, CO USA

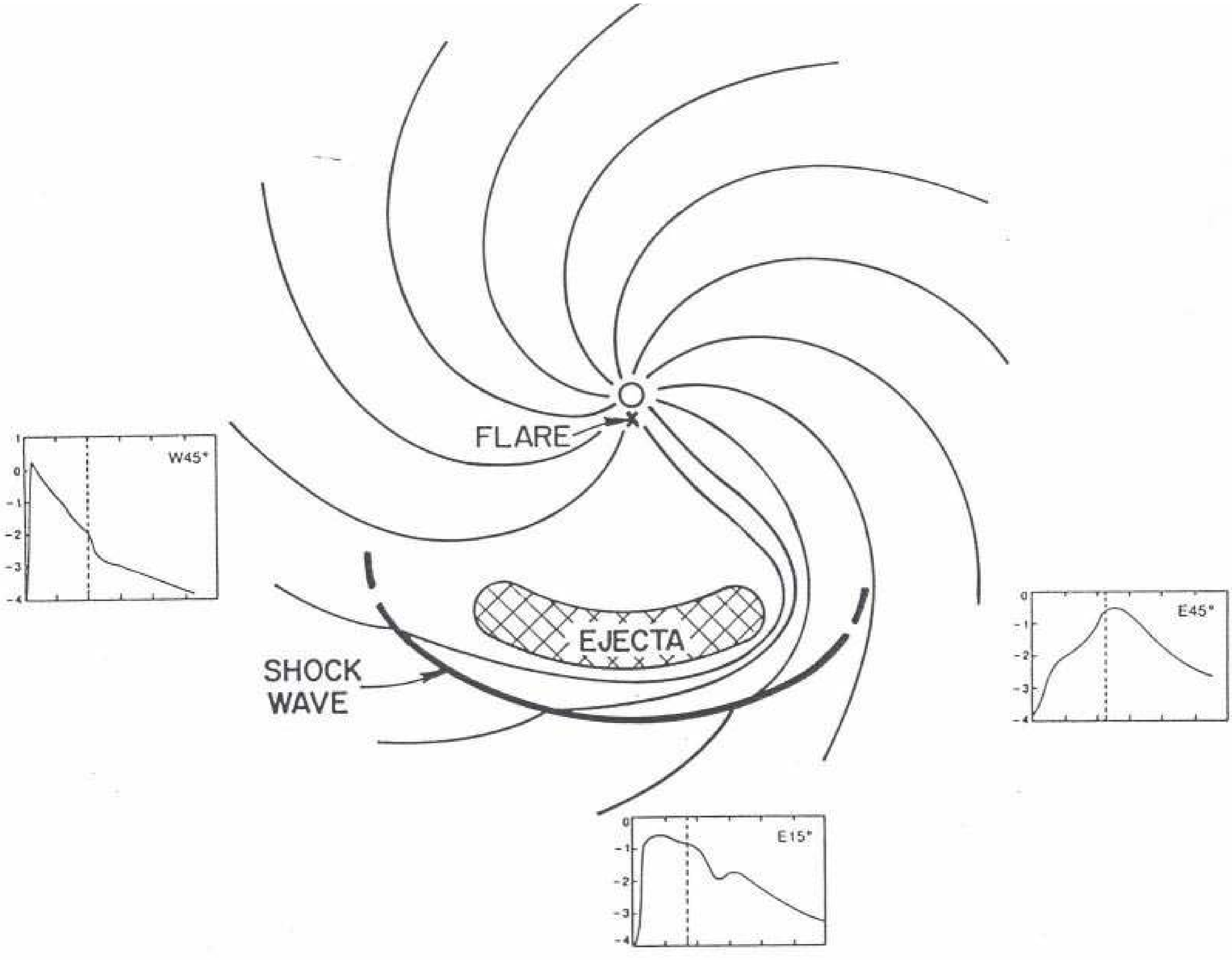
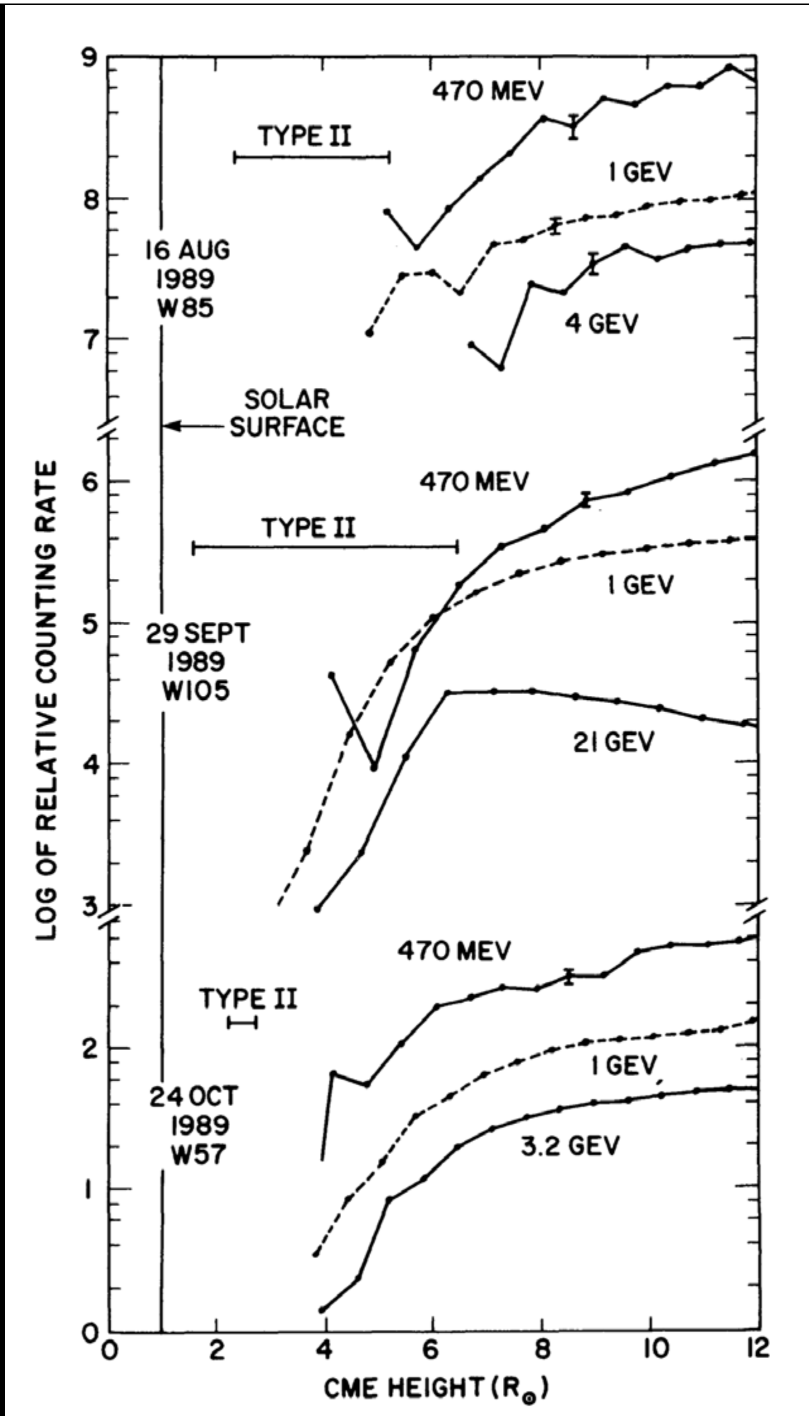


Figure 2.


Apr 17 2002 23:59:32

Ion acceleration



Kahler 1994:
Compare ion release time near Sun with CME front altitude
→CME is already several Solar radii away from the Sun

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  - Outstanding questions
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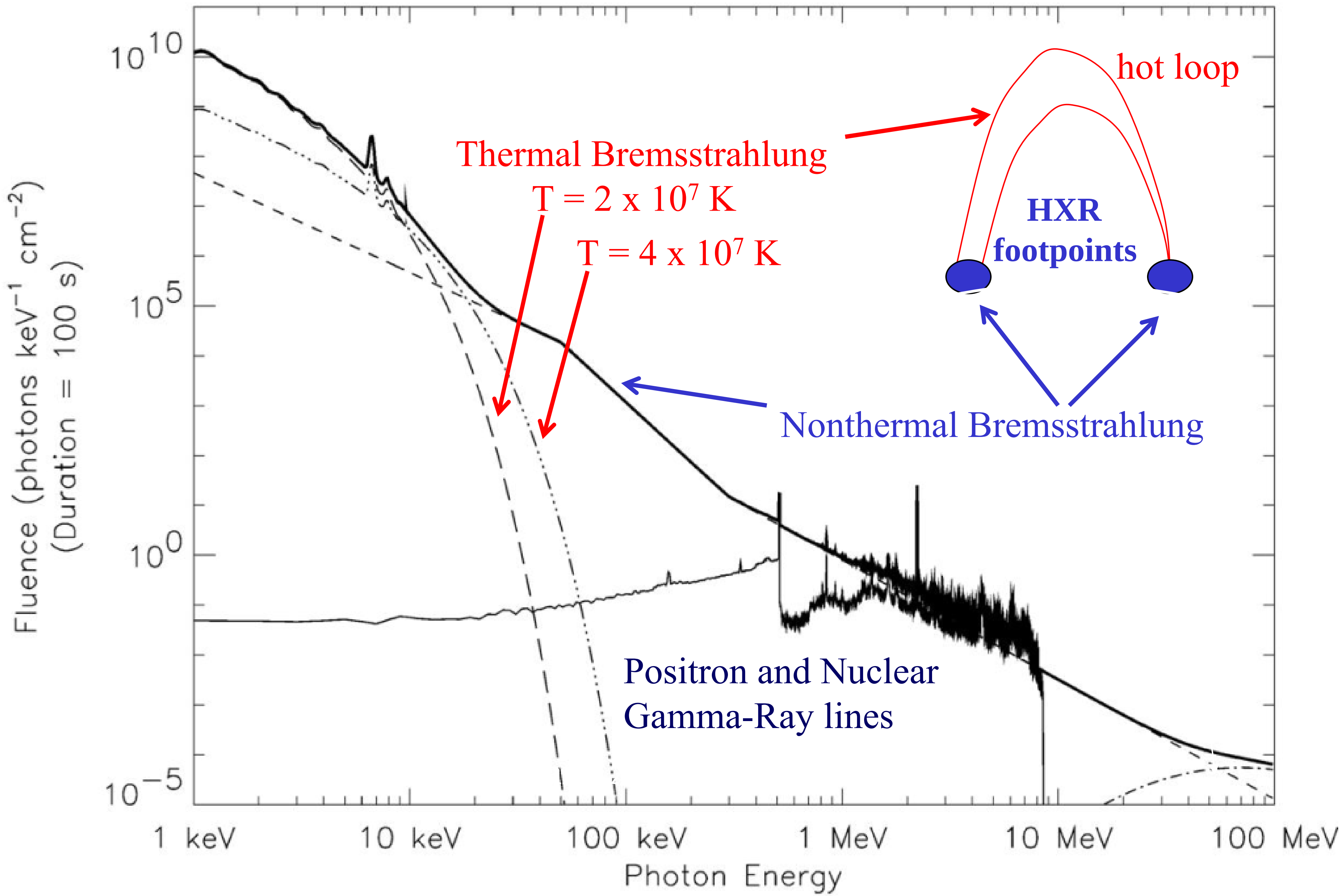
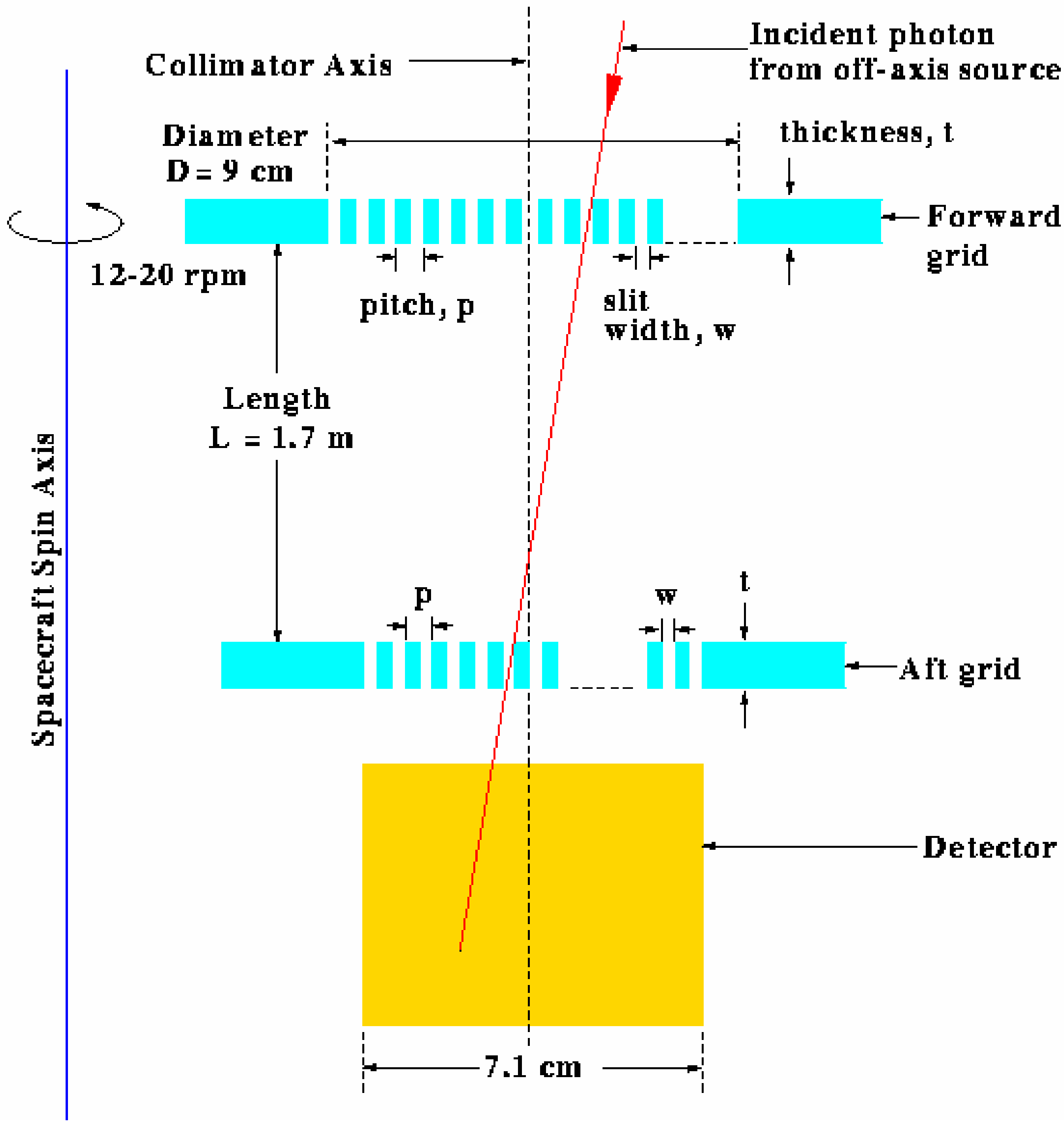
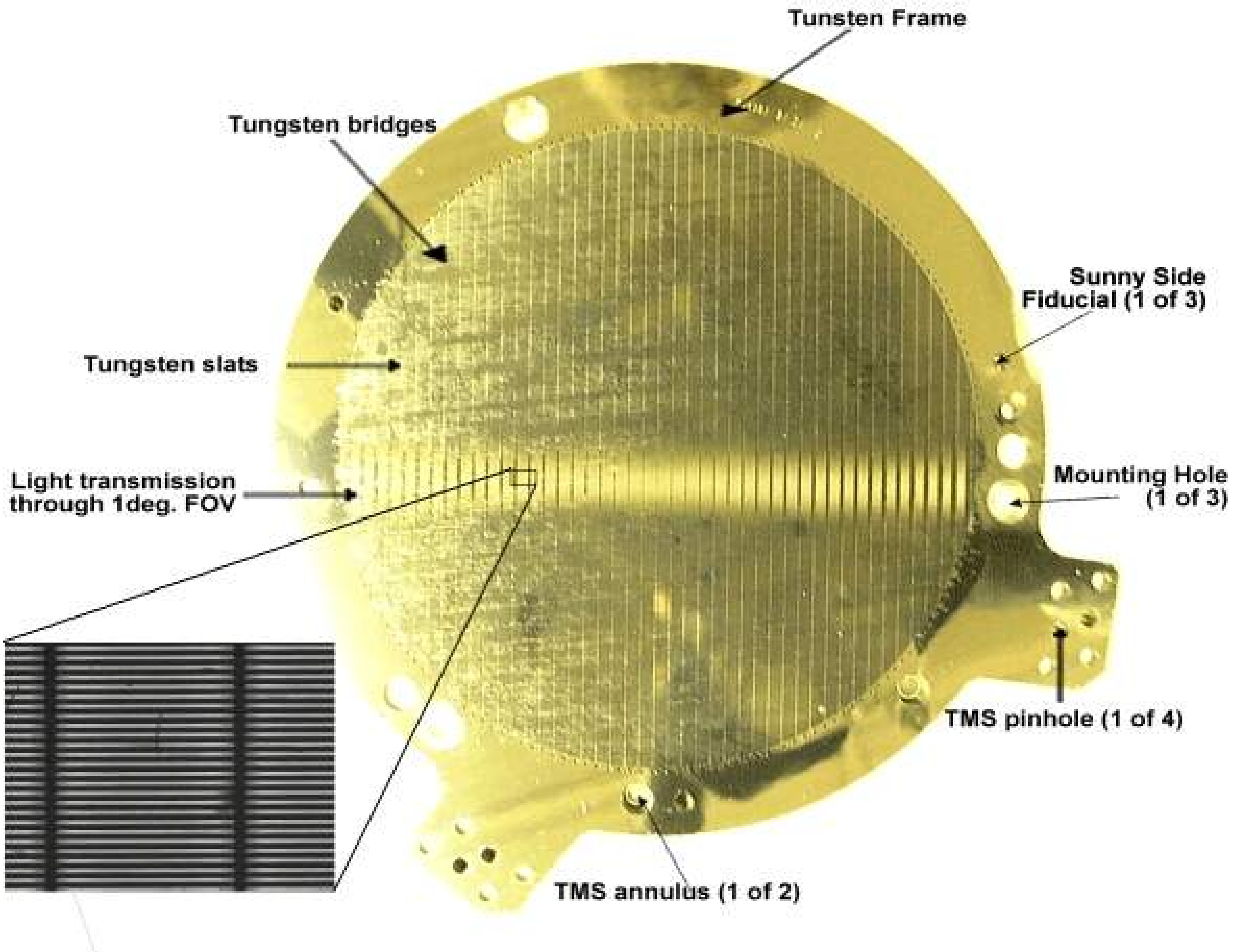


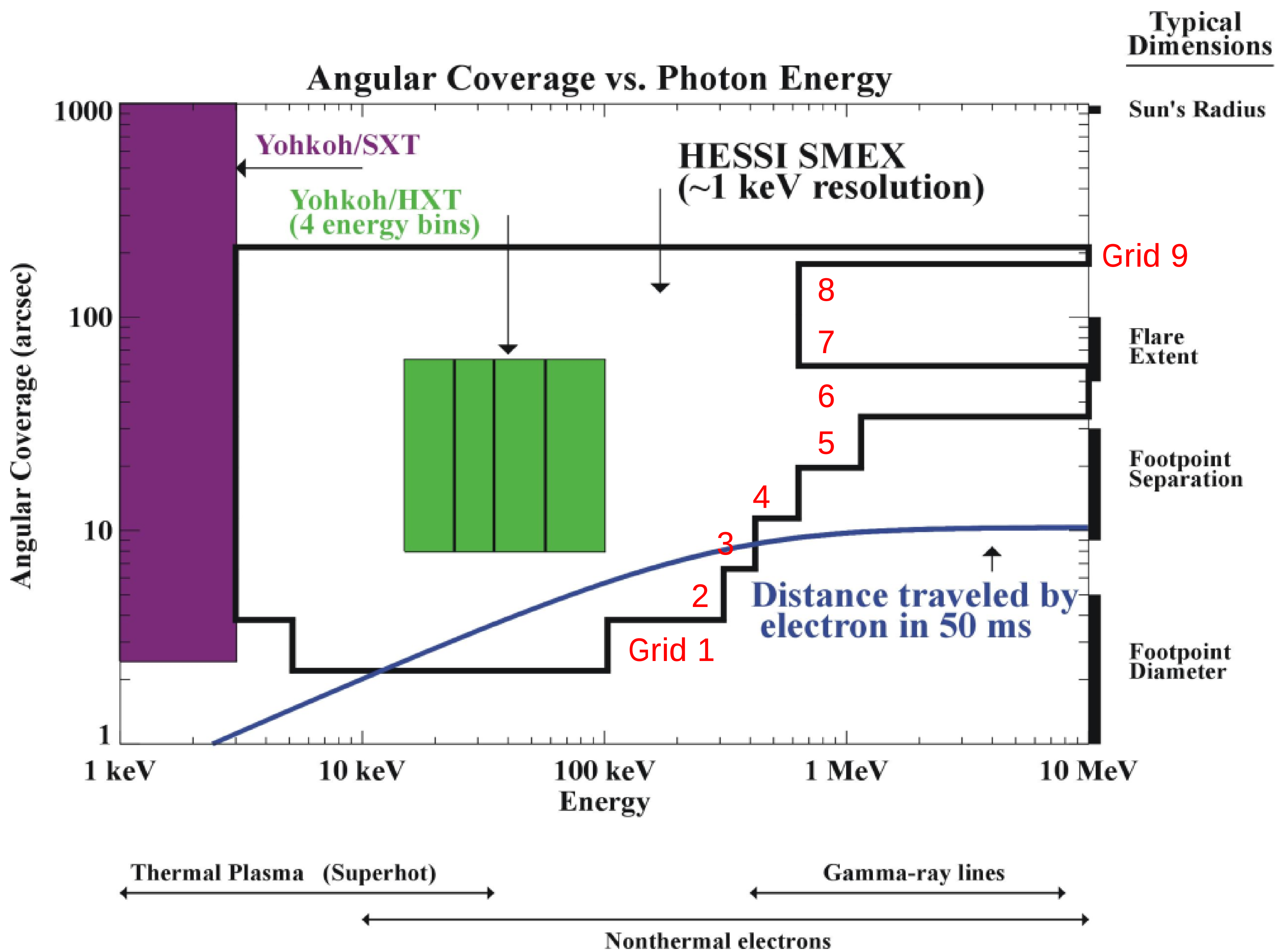
<----- RHESSI coverage ----->



Collimator Axis
Incident photon
from off-axis source
Diameter
D = 9 cm
thickness, t
Forward
grid
12-20 rpm
pitch, p
slit
width, w
Length
L = 1.7 m
Spacecraft Spin Axis
p
w
t
Aft grid
Detector
7.1 cm



Tunsten Frame
Tungsten bridges
Sunny Side
Fiducial (1 of 3)
Tungsten slats
Light transmission
through 1deg. FOV
Mounting Hole
(1 of 3)
TMS pinhole (1 of 4)
TMS annulus (1 of 2)


Typical Dimensions
Angular Coverage vs. Photon Energy
1000
100
10
1
Sun's Radius
Yohkoh/SXT
HESSI SMEX
(~1 keV resolution)
Yohkoh/HXT
(4 energy bins)
Grid 9
8
7
6
5
4
3
2
Grid 1
Flare Extent
Footpoint Separation
Footpoint Diameter
Distance traveled by electron in 50 ms
Angular Coverage (arcsec)
1 keV
10 keV
100 keV
1 MeV
10 MeV
Energy
Thermal Plasma (Superhot)
Gamma-ray lines
Nonthermal electrons

Detector Design

COLLABORATIVE EFFORT OF UCB, LBNL, ORTEC

MANUFACTURED AT ORTEC

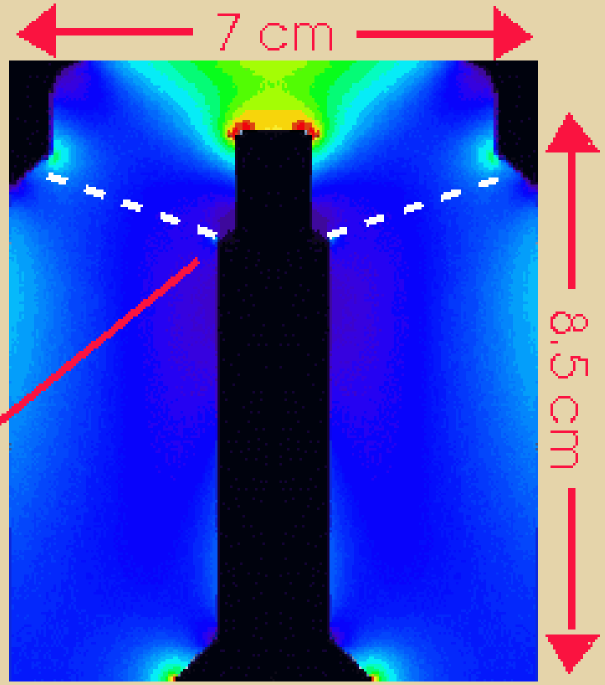
HYPERPURE Ge; SLIGHTLY N-TYPE

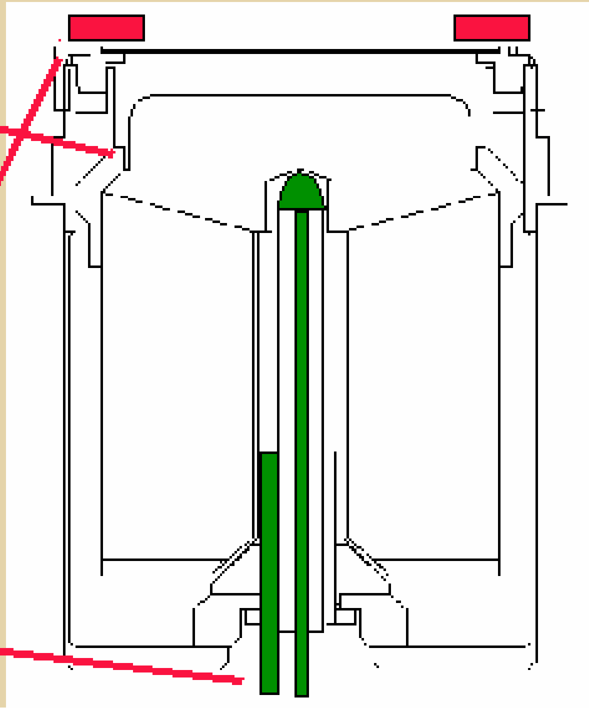
STEP AT INNER Li ELECTRODE PROVIDES TWO SEGMENTS

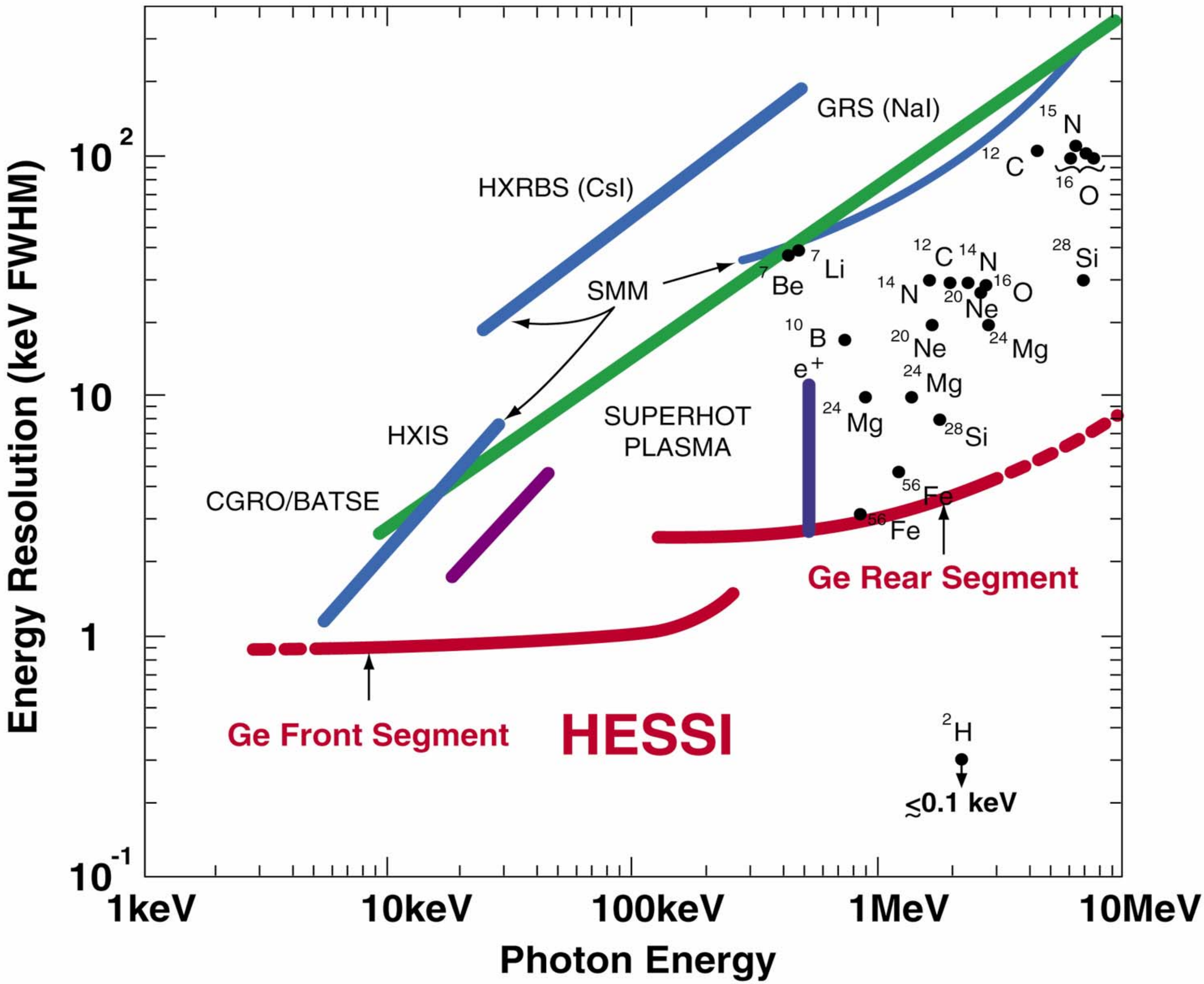
CORNER NOTCH PULLS THE "CRITICAL" FIELD LINE TO A PREDICTABLE POSITION

GRADED-Z SHIELDING PROTECTS THE REAR SEGMENT FROM SOLAR X-RAYS NOT STOPPED BY THE FRONT

FRONT AND REAR SEGMENTS READ OUT FROM THE TWO HALVES OF THE INNER CONTACT







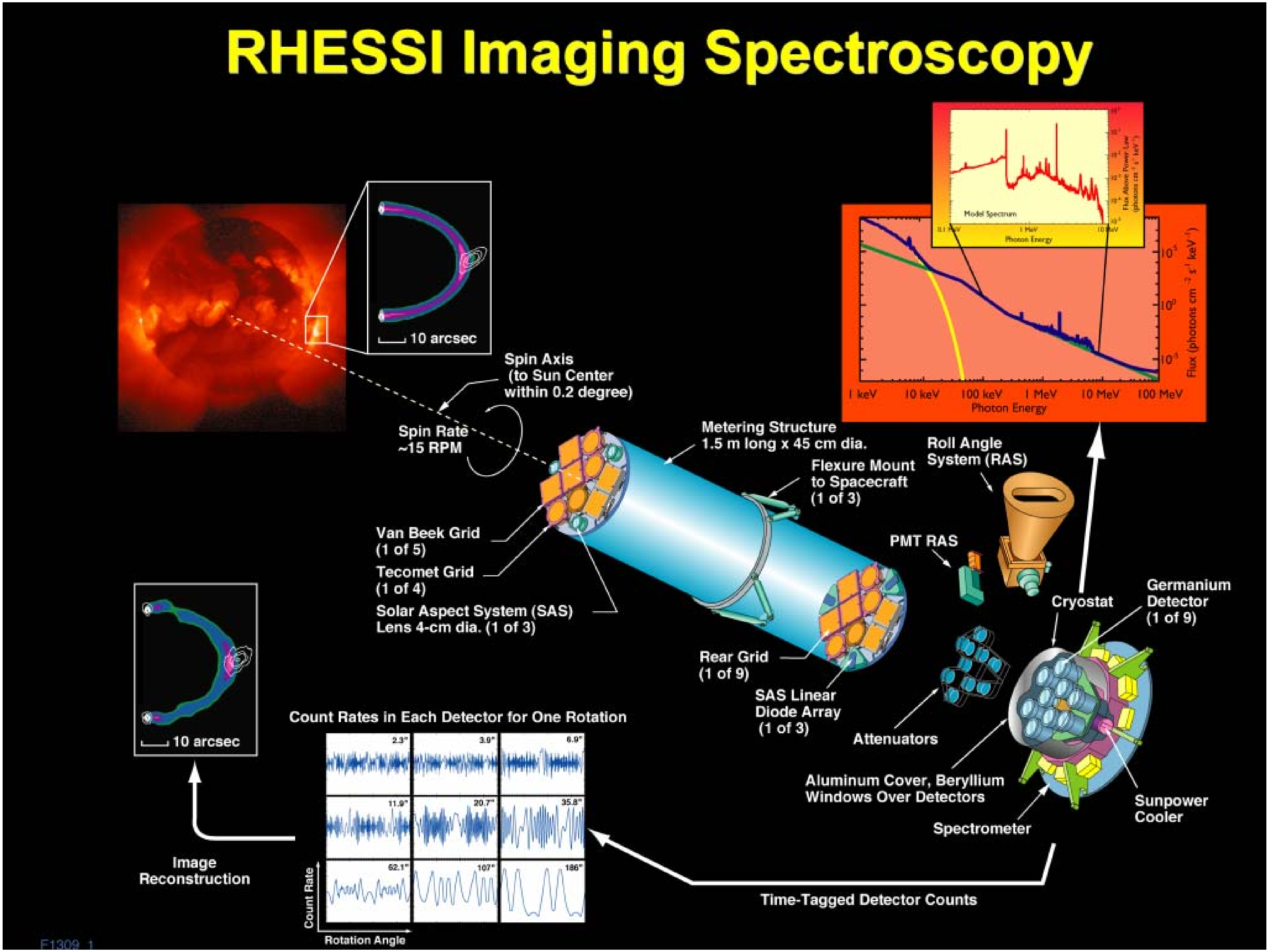
Energy Resolution (keV FWHM)
10^2
10
1
10^-1
1keV
10keV
100keV
1MeV
10MeV
Photon Energy
GRS (NaI)
HXRBS (CsI)
SMM
HXIS
CGRO/BATSE
SUPERHOT
PLASMA
e+
Ge Rear Segment
Ge Front Segment
HESSI
15 N
12 C
16 O
7 Li
7 Be
12 C
14 N
14 N
20 Ne
16 O
28 Si
10 B
20 Ne
24 Mg
24 Mg
24 Mg
28 Si
56 Fe
56 Fe
2 H
≲0.1 keV

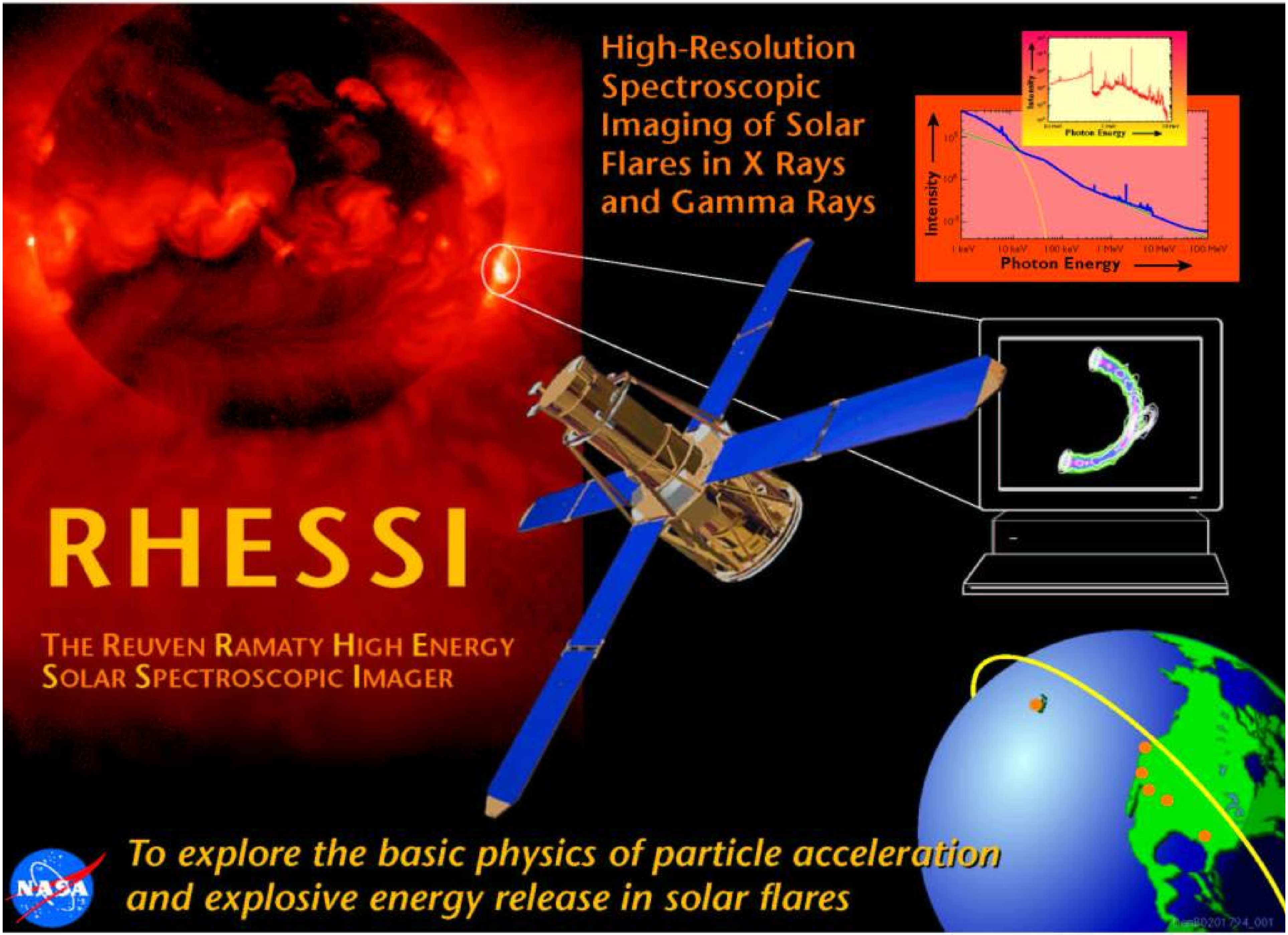
D

Instrument Development

- HIREGS (High Resolution Gamma-ray/Hard X-ray Spectrometer)
  - Long Duration Balloon Payload flown in Antarctica 1991-2

- HEIDI (High Energy Imaging Device)
  - Demonstration Balloon flight 1993


RHESSI Imaging Spectroscopy
10 arcsec
Model Spectrum
Photon Energy
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
Photon Energy
Flux (photons cm⁻² s⁻¹ keV⁻¹)
Spin Axis
(to Sun Center
within 0.2 degree)
Spin Rate
~15 RPM
Metering Structure
1.5 m long x 45 cm dia.
Roll Angle
System (RAS)
Flexure Mount
to Spacecraft
(1 of 3)
PMT RAS
Van Beek Grid
(1 of 5)
Tecomet Grid
(1 of 4)
Solar Aspect System (SAS)
Lens 4-cm dia. (1 of 3)
Cryostat
Germanium
Detector
(1 of 9)
Rear Grid
(1 of 9)
SAS Linear
Diode Array
(1 of 3)
Attenuators
10 arcsec
Count Rates in Each Detector for One Rotation
Aluminum Cover, Beryllium
Windows Over Detectors
Sunpower
Cooler
Spectrometer
Image
Reconstruction
Count Rate
Rotation Angle
Time-Tagged Detector Counts
F1309_1



High-Resolution Spectroscopic Imaging of Solar Flares in X Rays and Gamma Rays
Intensity
Photon Energy
1 keV
10 keV
100 keV
1 MeV
10 MeV
100 MeV
RHESSI
THE REUVEN RAMATY HIGH ENERGY SOLAR SPECTROSCOPIC IMAGER
To explore the basic physics of particle acceleration and explosive energy release in solar flares

- Science Idea
  - Current research
  - Outstanding questions
- Measurements Required
  - New Instrument Development
  - Mission Design
- Obtaining Community Support
  - Papers & presentations
  - NASA, NSF, NAS Committees
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- Funding Opportunities
  - NASA (space-based)
  - NSF (ground-based)
  - Foreign

Community Support

- NASA
  - Heliophysics (Sun-Earth Connections)Roadmap
- National Academy of Science
  - Committee on Solar & Space Physics (CSSP)
  - Solar & Space Physics Decadal Survey

- Studies
  - NASA –Science & Technology Definition Team
  - NSF – similar for ground-based oservatories

Other Factors

- NASA's Vision for Space Exploration
  - Humans to Moon & Mars

Funding opportunities

- Solar Terrestrial Probes ~$500M
  - STEREO, MMS, GEC
- Living with a Star (LWS) ~$500M
  - SDO, Geospace (RBSP, ITSP), Sentinels
- Explorers
  - Small Explorers (SMEX) ~$100M
  - Middle Class Explorers (MIDEX) ~$250M
- Supporting Research & Technology (SRT)
  - Low Cost Access to Space (LCAS): Rockets & Balloons
- Flagship Missions
  - Solar Probe ~$1B

Proposals

- Forming a team
  - Scientific, technical, financial, managerial
  - Maximize science
  - Minimize risk
- Instrument Design
- Mission Design
- Spacecraft
- Mission Operations & Data Analysis

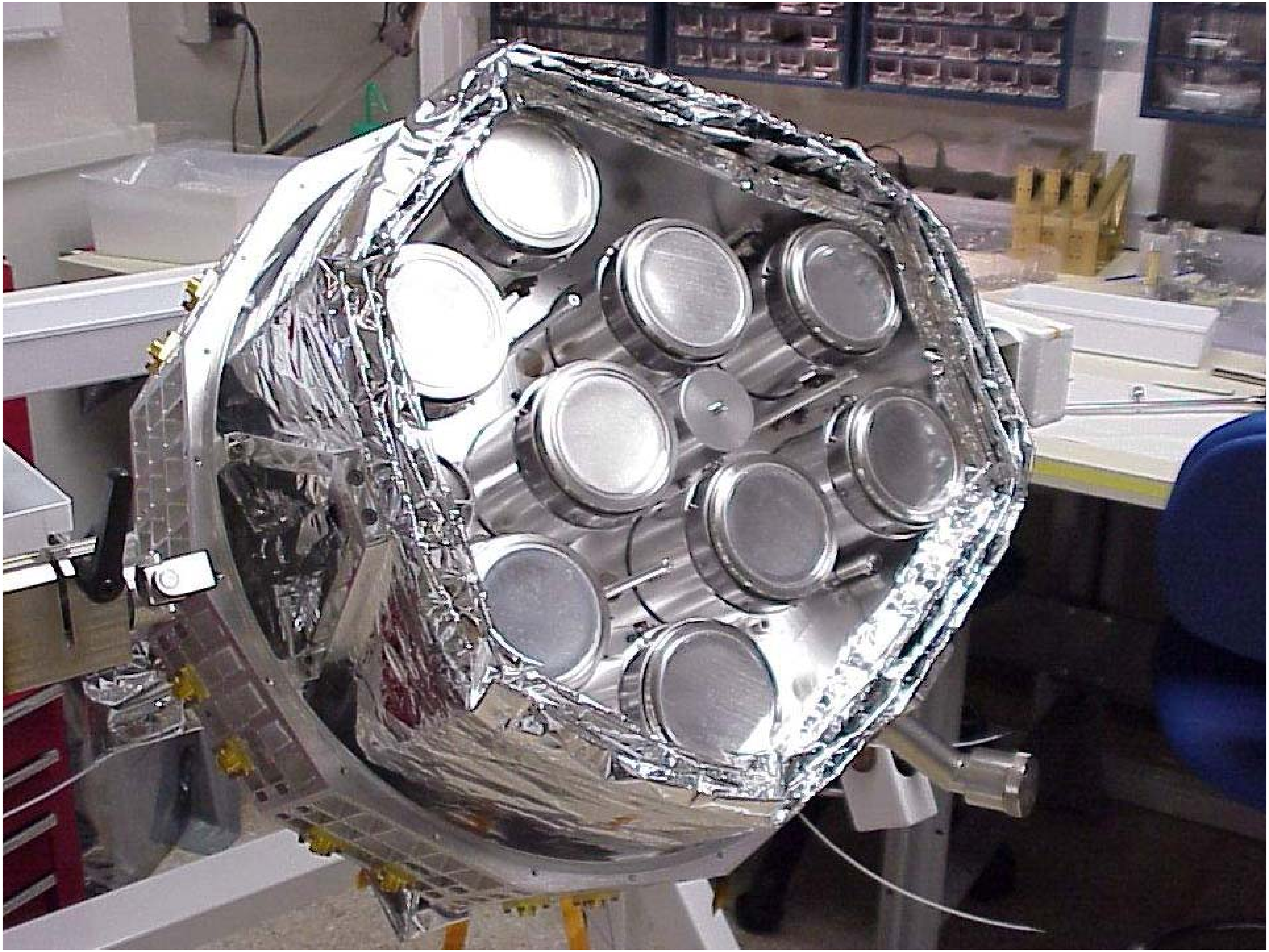
Development (Fabrication)

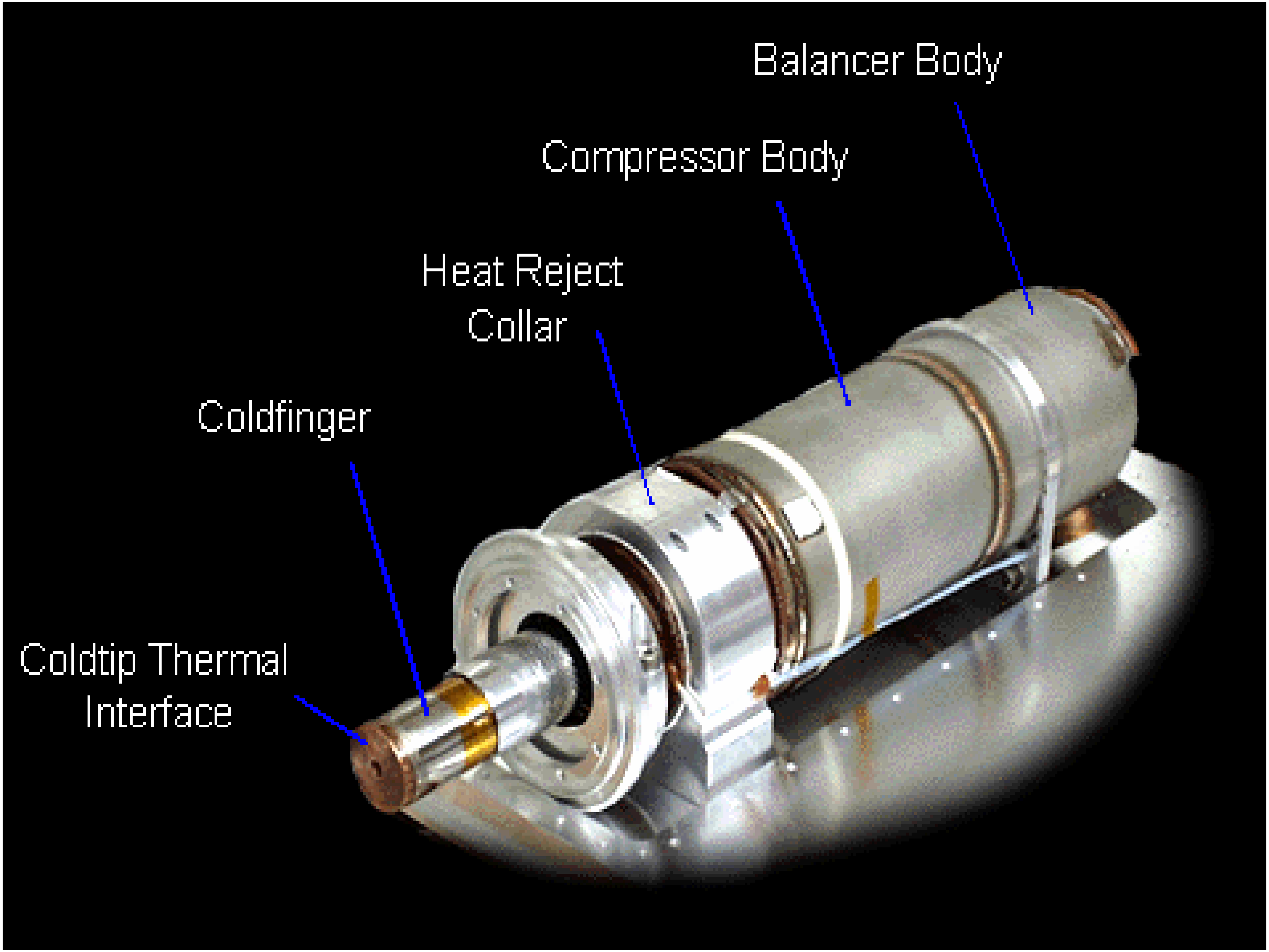
- Instrument(s)
- Spacecraft
  - Usually subcontractor
- Integration & Test
- Ground system
  - Data downlink
  - Mission Operations Center (MOC)
  - Science Operations Center (SOC)

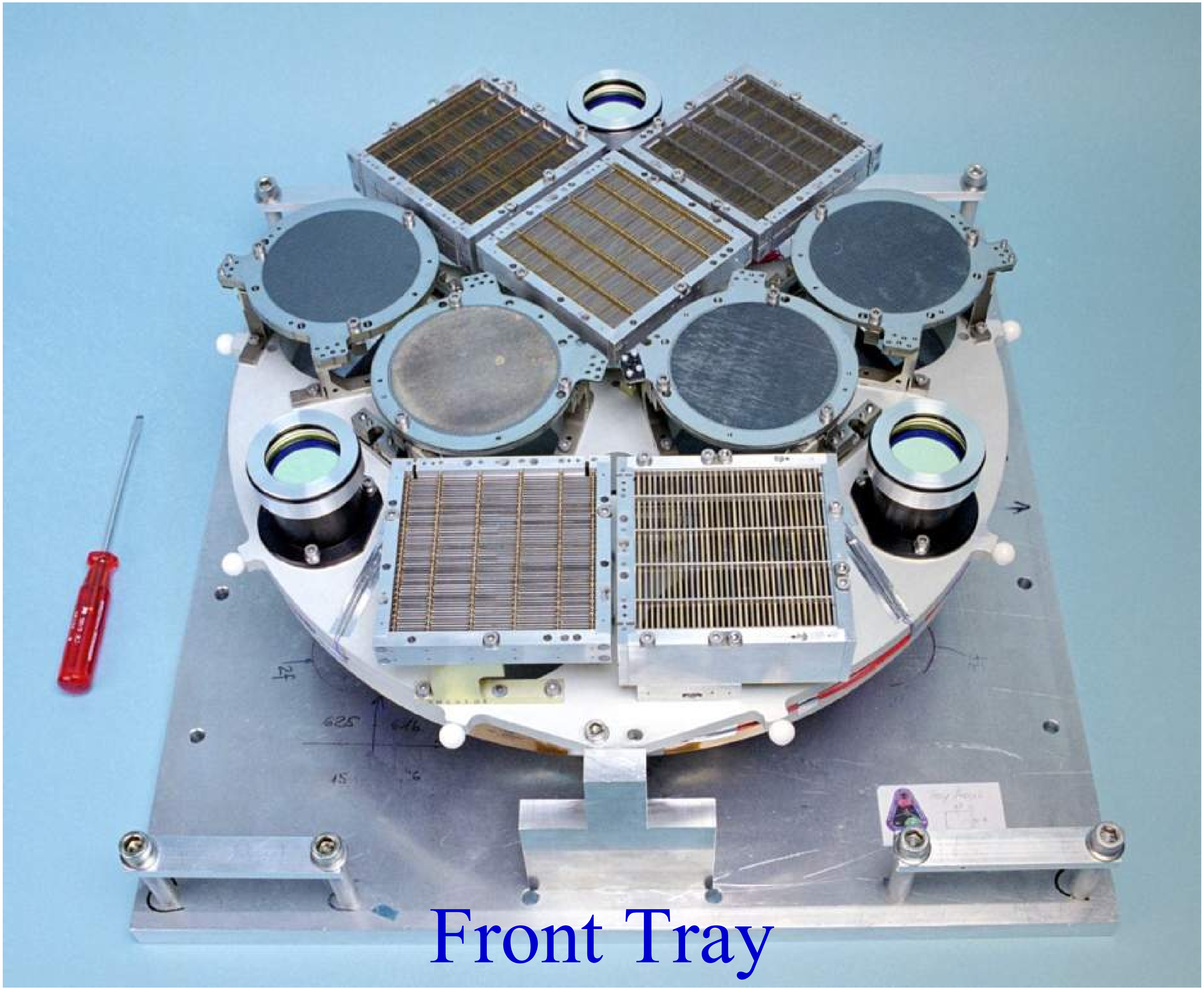
Reviews

- Competition

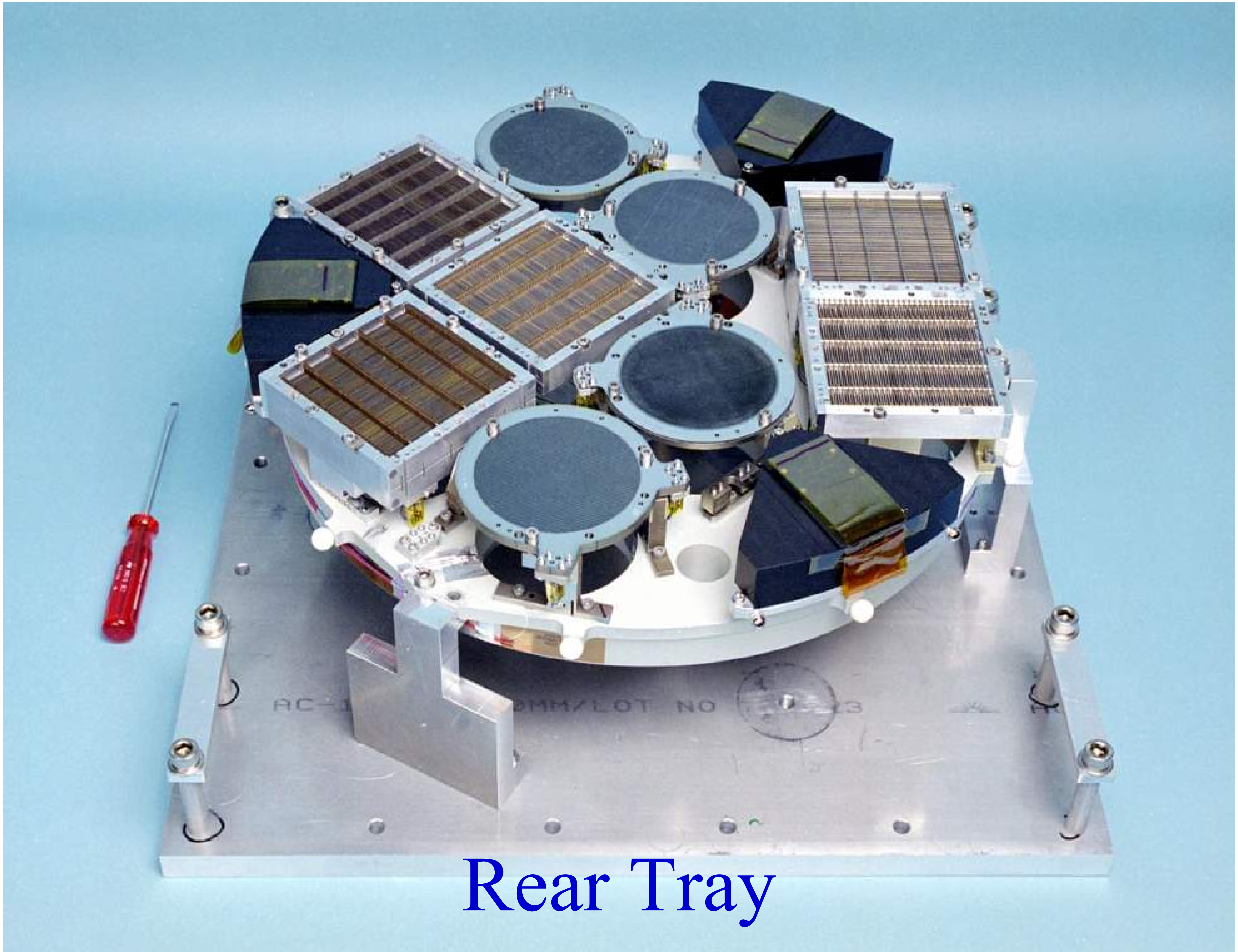
- Science ~40% - Peer review
- Implementation ~30%
- Management & cost ~30%
- TEMCO (Technical, Management, Cost) Review




Balancer Body
Compressor Body
Heat Reject
Collar
Coldfinger
Coldtip Thermal
Interface



Front Tray



Rear Tray

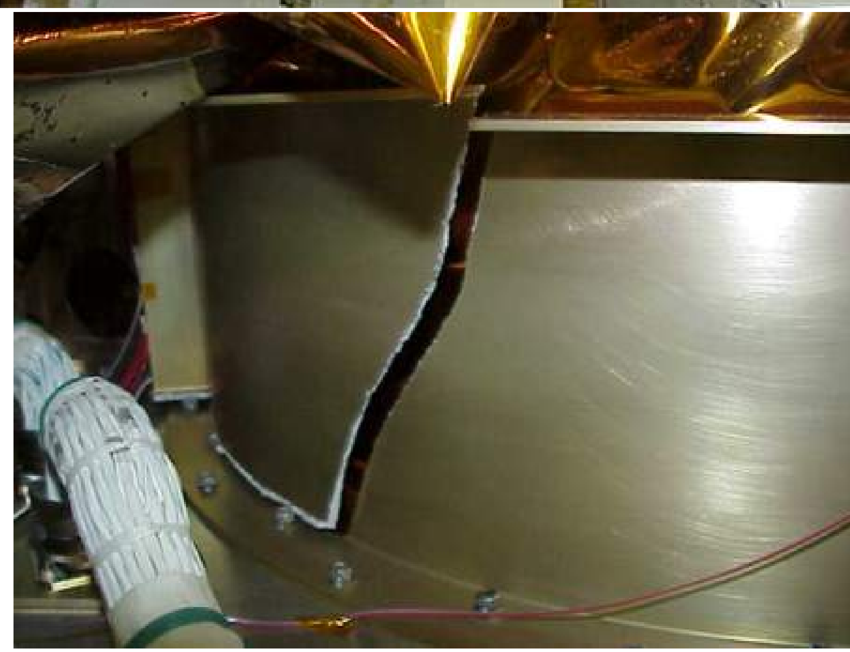
Imager – side view


CCD RAS

Paul Turin

Dave Pankow

RHESSI vibration test anomaly



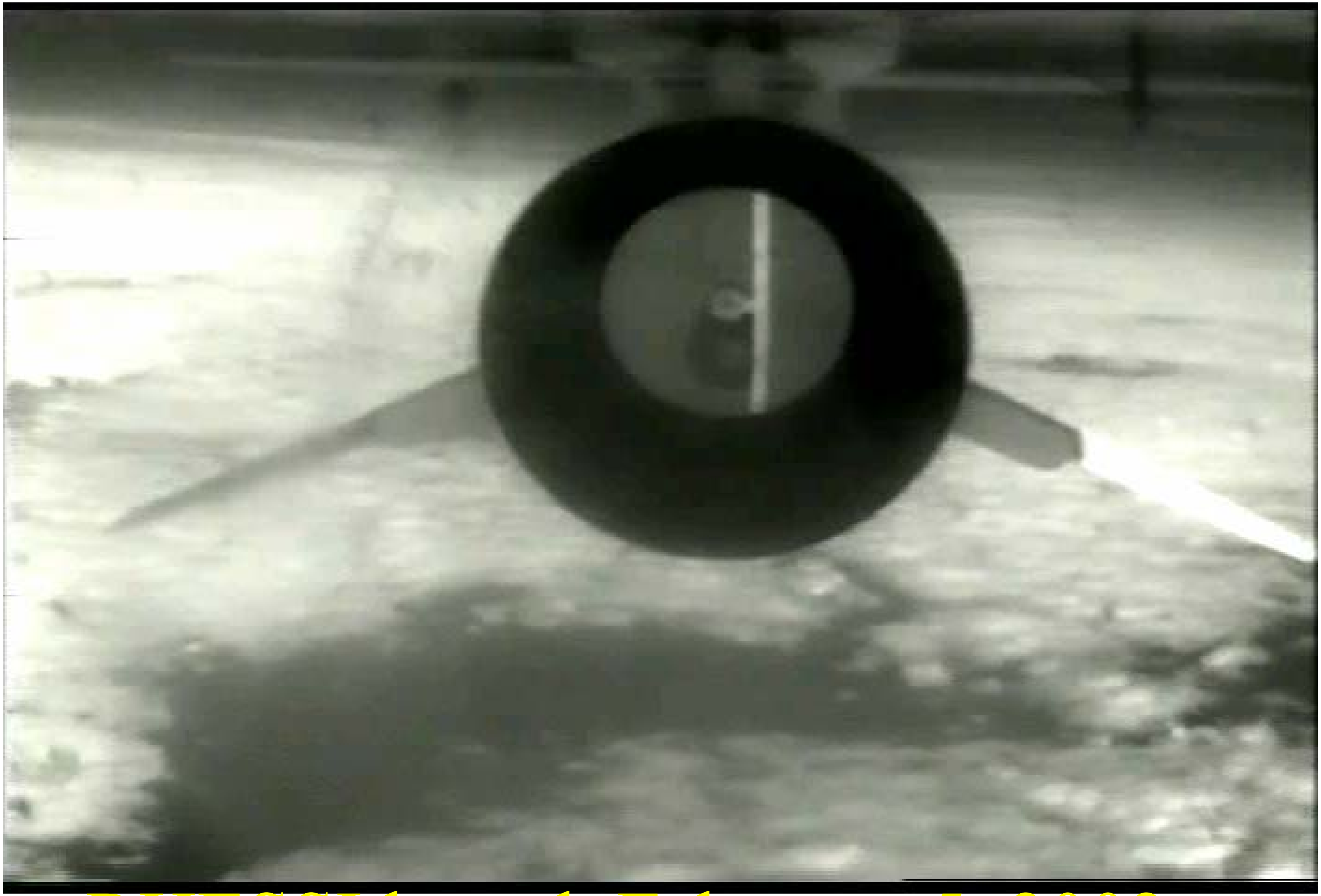
SPACEFLIGHT NOW

Posted: June 4, 2001

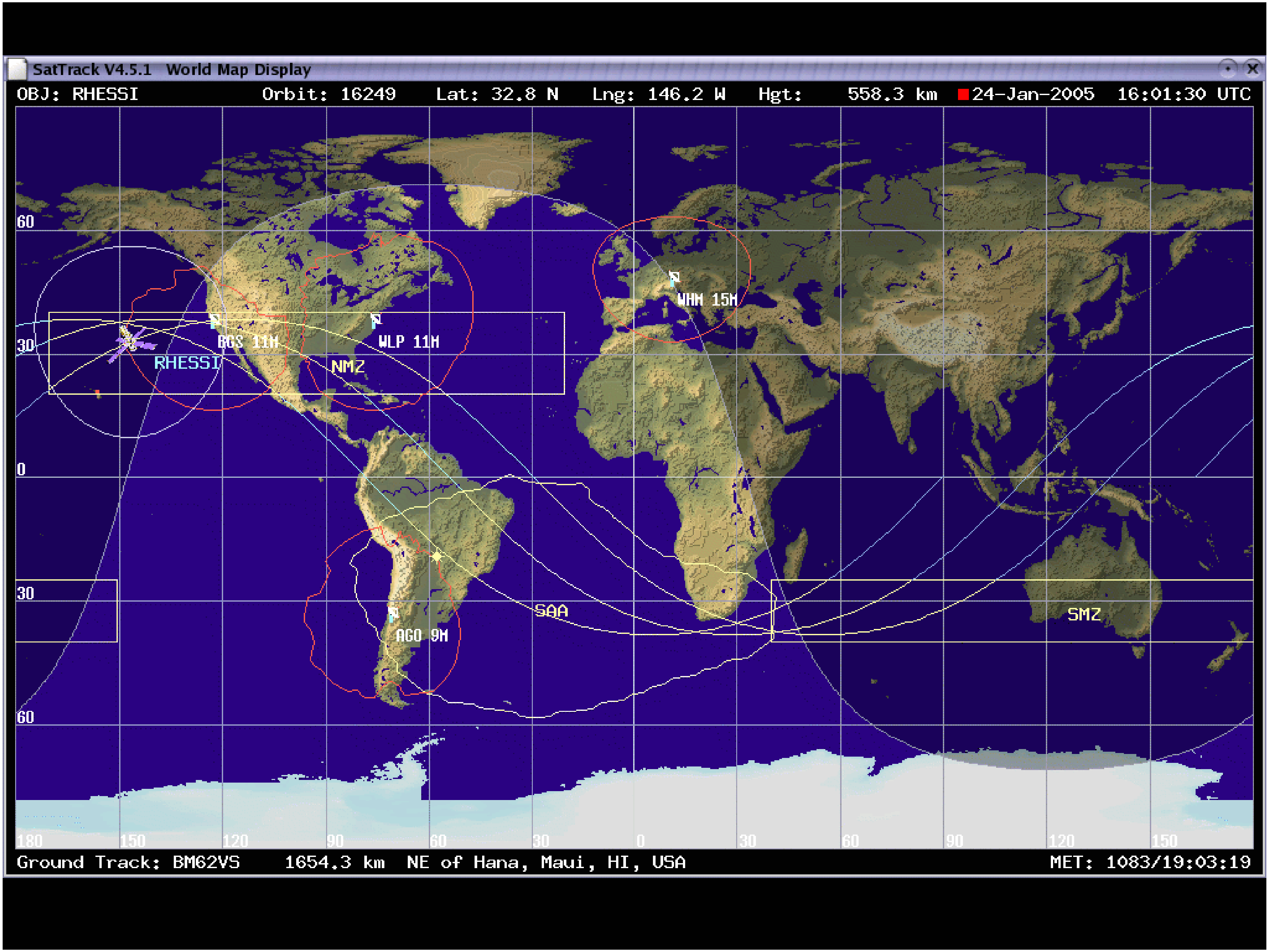
X-43A launch failure

Next Pegasus rocket launch delayed in X-43A aftermath

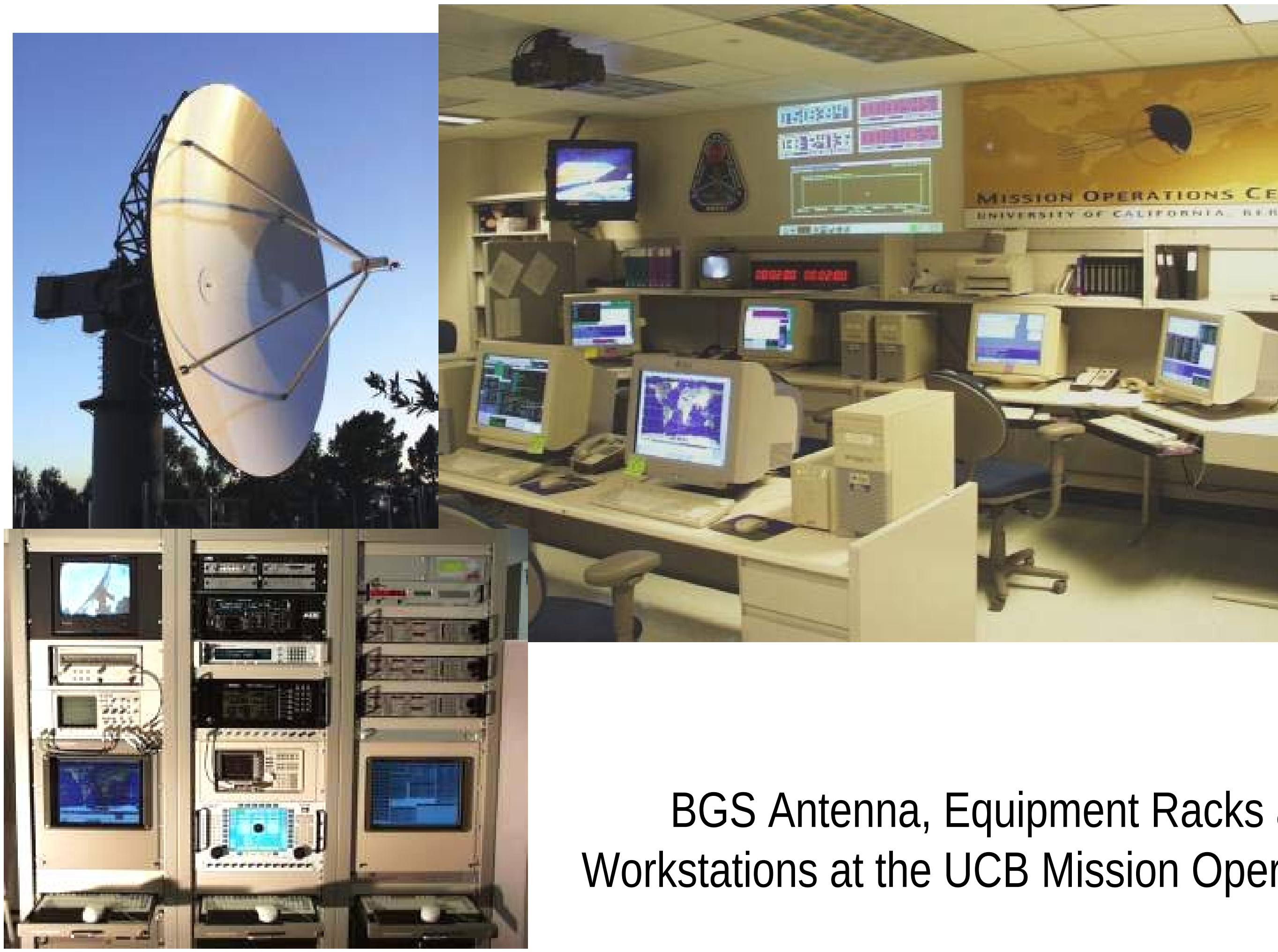
The High Energy Solar Spectroscopic Imager, or HESSI satellite, was scheduled to rocket into space on Thursday aboard an air-launched Orbital Sciences Pegasus XL booster.



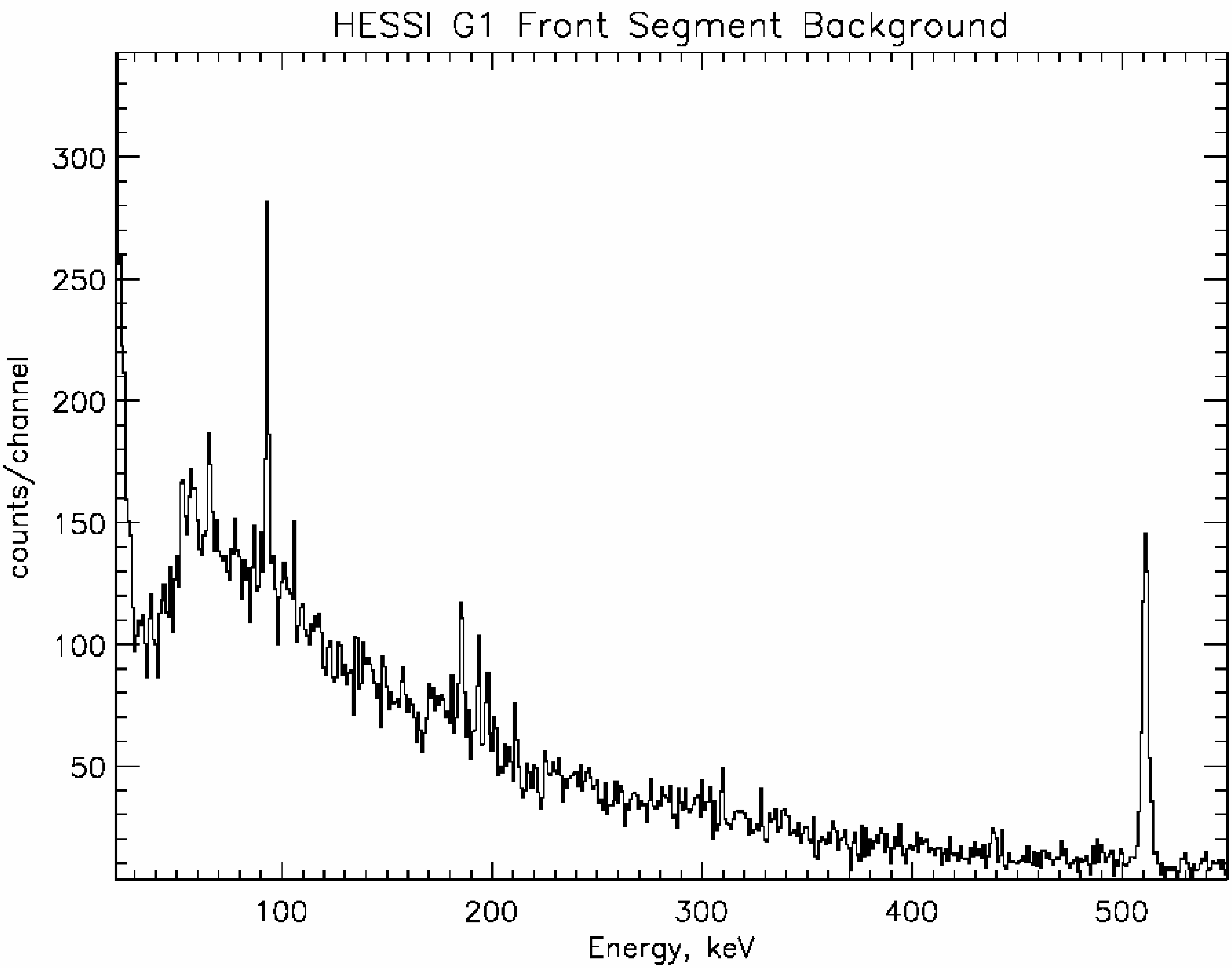
RHESSI launch February 5, 2002

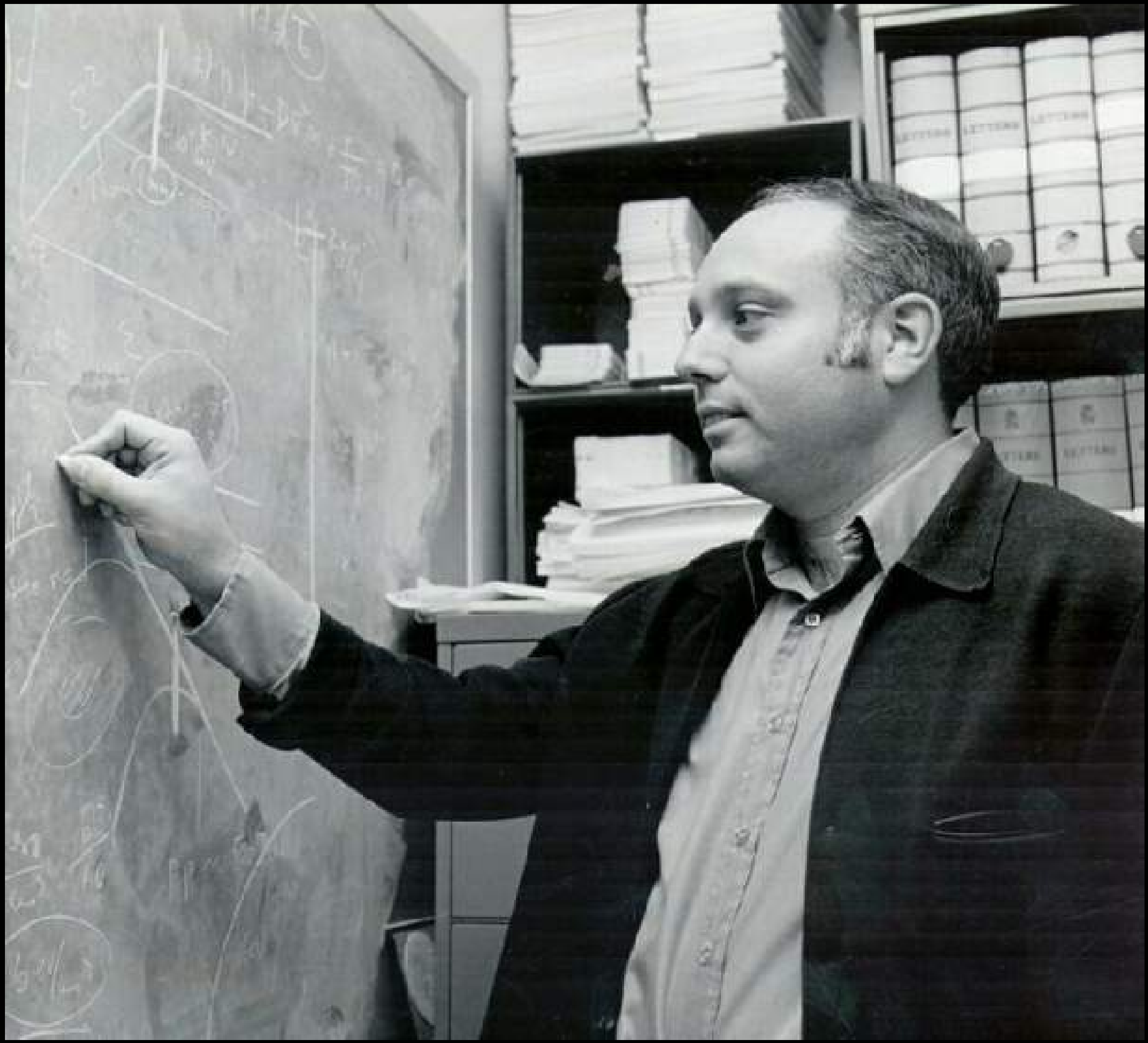

SatTrack V4.5.1 World Map Display
OBJ: RHESSI Orbit: 16249 Lat: 32.8 N Lng: 146.2 W Hgt: 558.3 km 24-Jan-2005 16:01:30 UTC
RHESSI
BGS 11M
WLP 11M
NMZ
WHM 15M
AGO 9M
SAA
SMZ
60
30
0
30
60
180 150 120 90 60 30 0 30 60 90 120 150
Ground Track: BM62VS 1654.3 km NE of Hana, Maui, HI, USA
MET: 1083/19:03:19

U.C. Berkeley Mission Operations Center



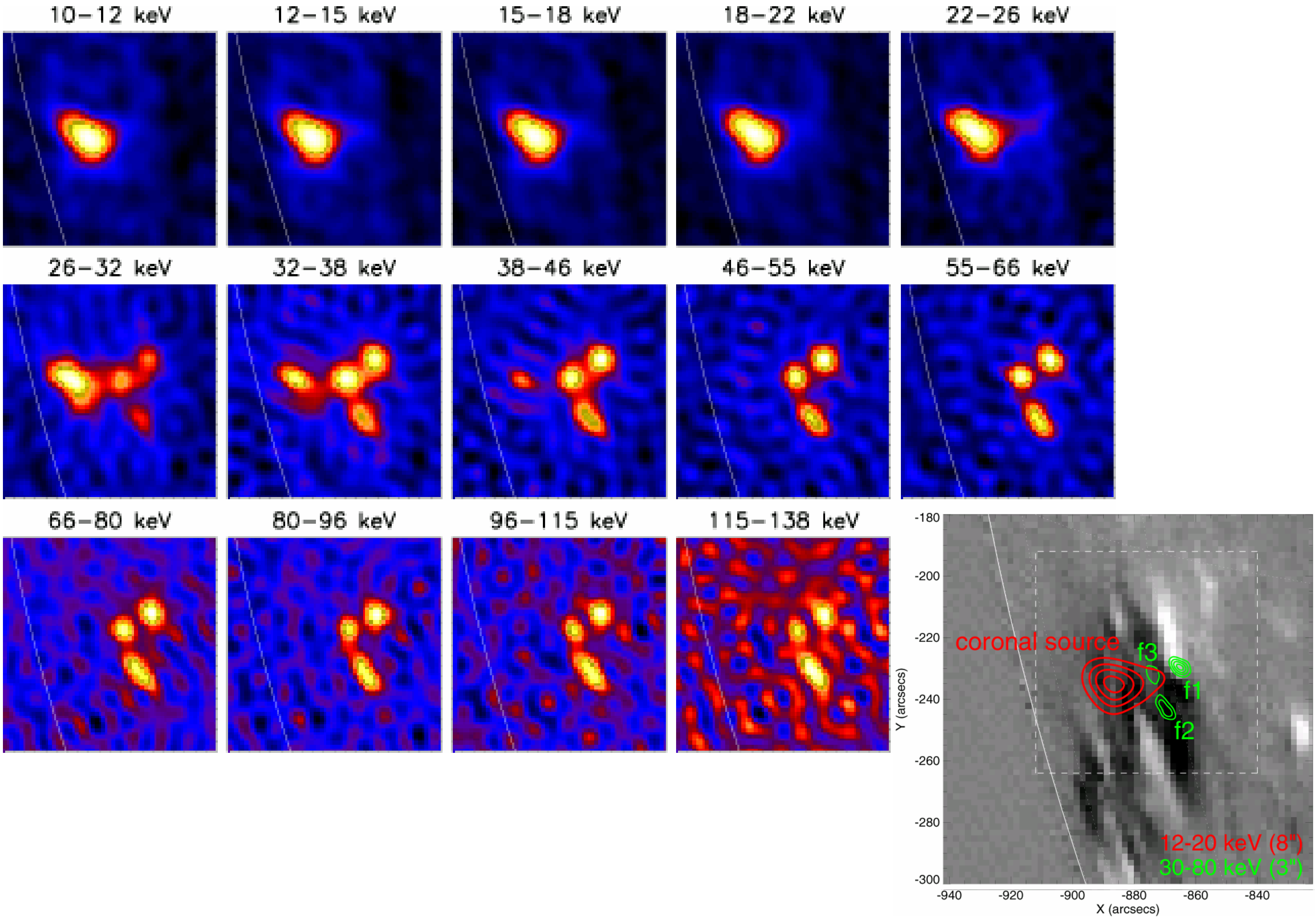
BGS Antenna, Equipment Racks and FOT Workstations at the UCB Mission Operations Center

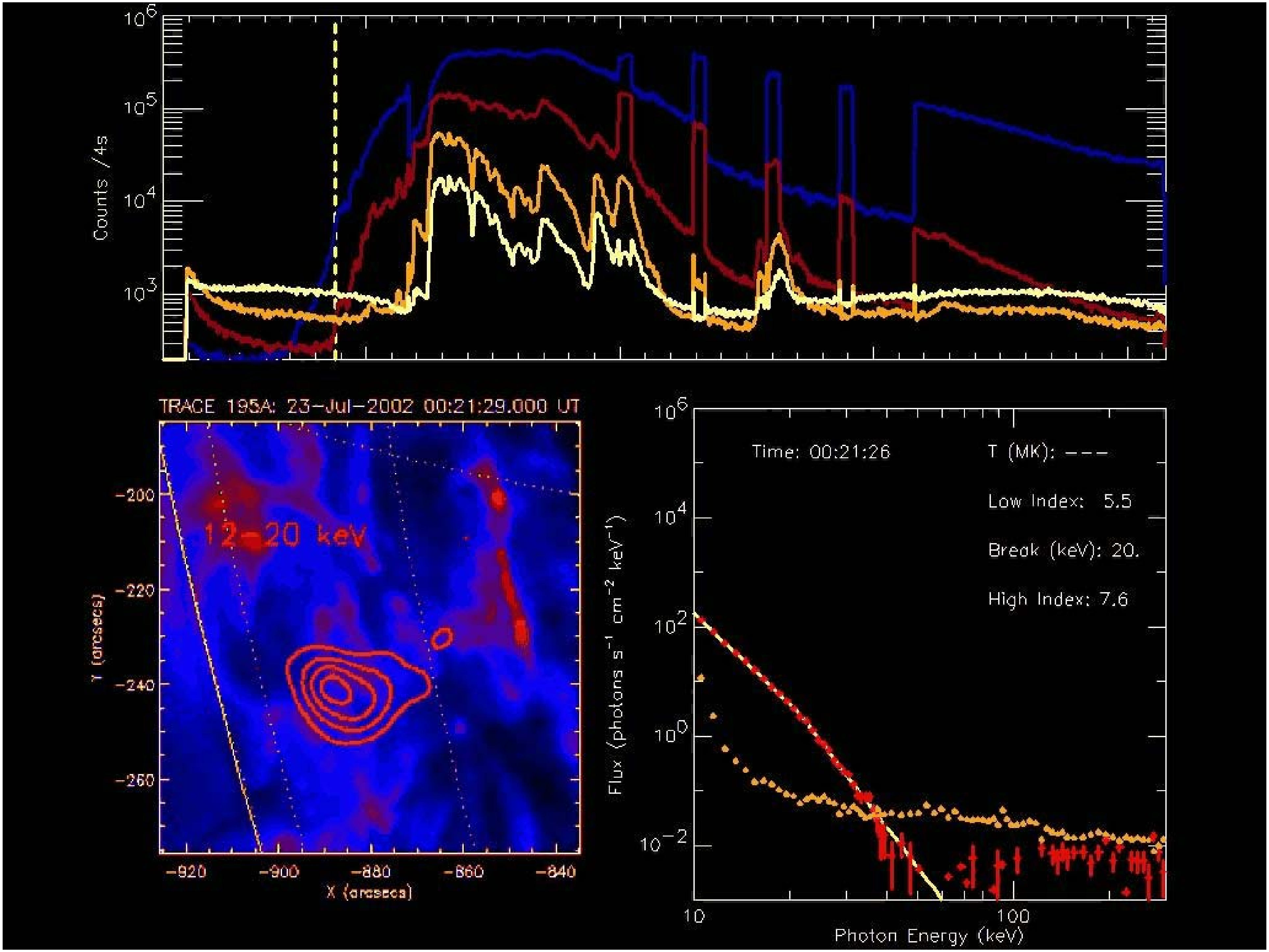

HESSI G1 Front Segment Background
counts/channel
300
250
200
150
100
50
100
200
300
400
500
Energy, keV



Reuven Ramaty (1972)
1937 – 2001

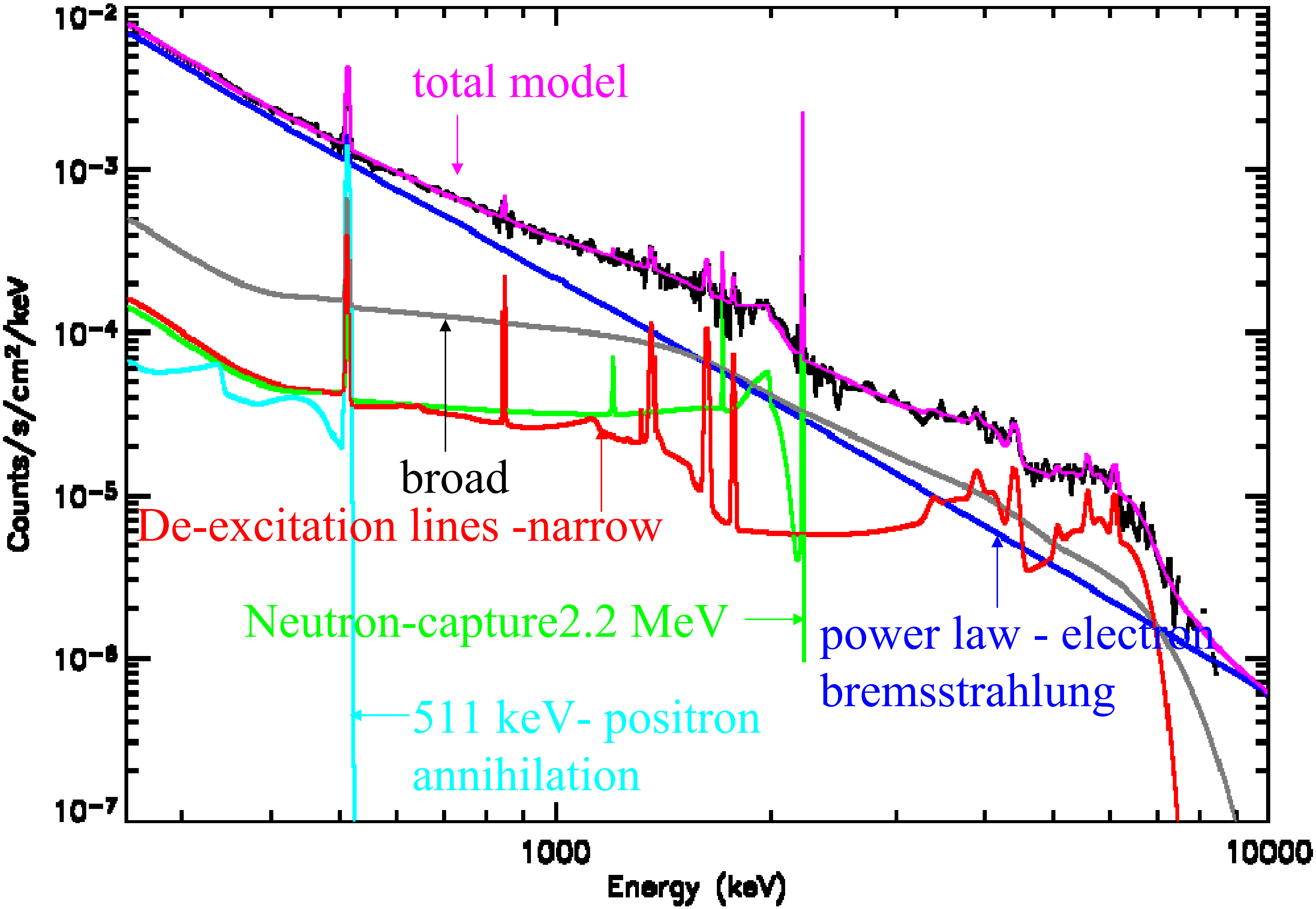
Imaging spectroscopy



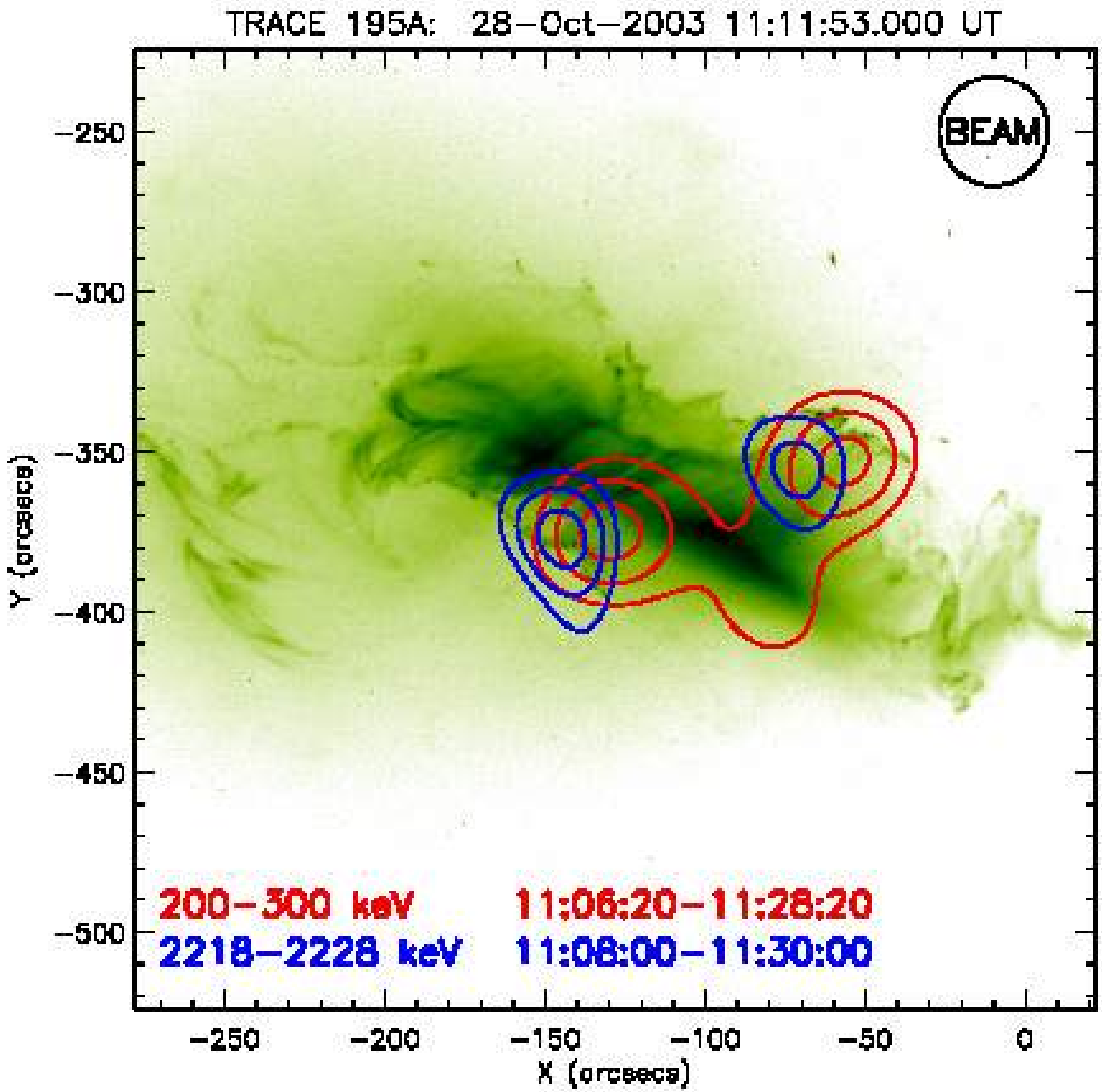


Counts /4s
TRACE 195A: 23-Jul-2002 00:21:29.000 UT
12–20 keV
Y (arcsecs)
X (arcsecs)
Time: 00:21:26
T (MK): ---
Low Index: 5.5
Break (keV): 20.
High Index: 7.6
Flux (photons s^{-1} cm^{-2} keV^{-1})
Photon Energy (keV)

Spectral Components



Electrons vs protons



200-300 keV HXR (electrons) footpoints are moving along ribbons

2.2 MeV image (protons) is averaged over 22 min, delayed by ~100 s from electrons

CONCLUSIONS:
Electrons and protons both close to ribbon, but separated by ~10^4 km

- Data Analysis
  - Workshops & Meetings
- Extended Mission
  - Senior Review

The Living With a Star (LWS) Sentinels Mission

R. P. Lin
University of California, Berkeley
A. Szabo, Study Scientist
NASA Goddard Space Flight Center
& the Sentinels STDT
(Science & Technology Definition Team)

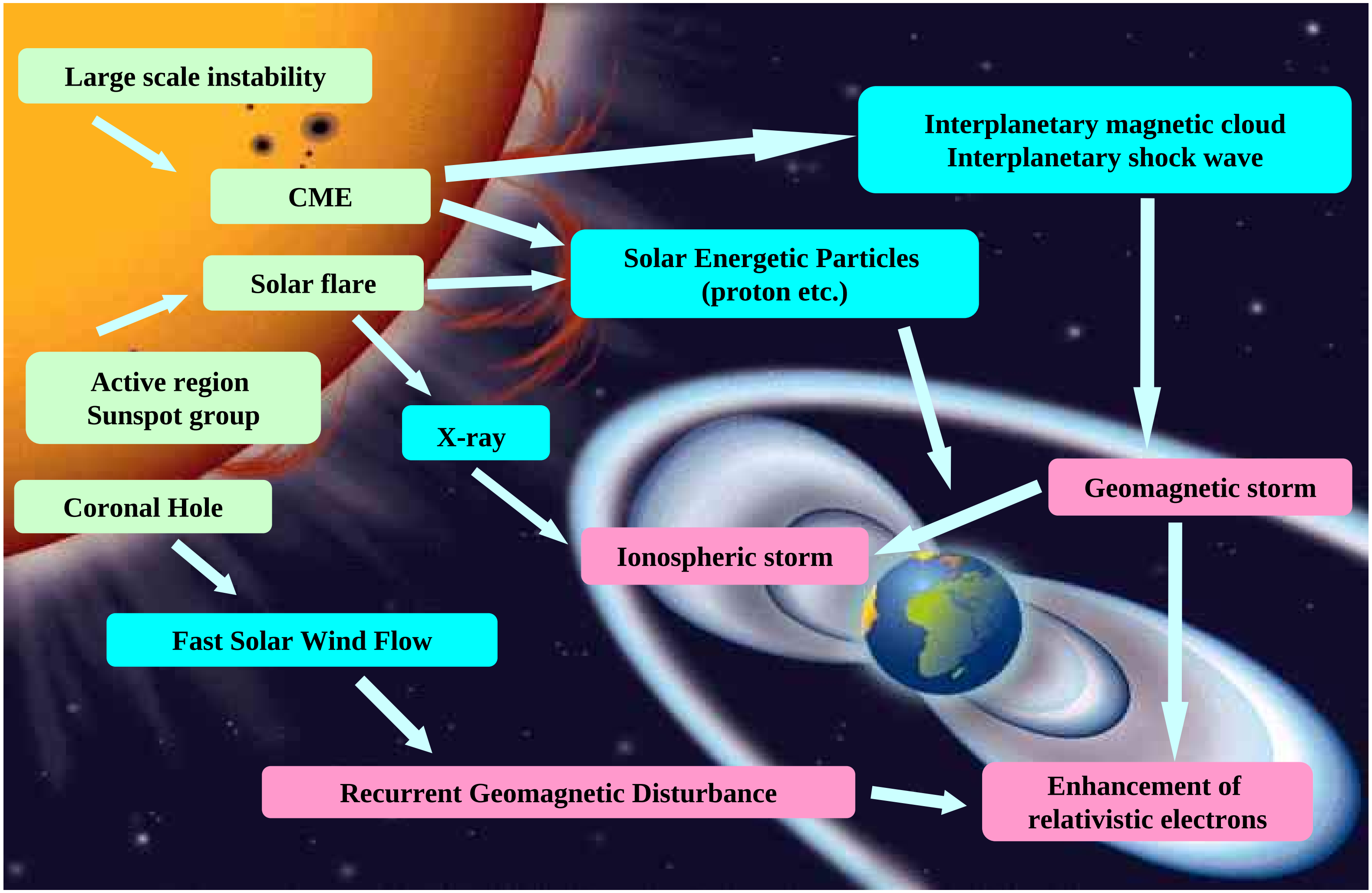
Sentinels STDT

Robert P. Lin (Chair)	UCB	Spiro K. Antiochos	NRL
Stuart D. Bale	UCB	Joseph M Davila	GSFC
Antoinette B. Galvin	UNH	Dennis K. Haggerty	APL
Stephen W. Kahler	AFRL	Joseph E. Mazur	Aerospace
Richard A. Mewaldt	Caltech	Neil Murphy	JPL
Geoff D. Reeves	LANL	Pete Riley	SAIC
James M. Ryan	UNH	Karel Schrijver	Lockheed
Rainer Schwenn	MPI Lindau	Allan J. Tylka	NRL
Thomas Zurbuchen	U Mich		
Robert F. Wimmer-Schweingruber	University of Kiel		

Ex-Officio and other non-members:

Adam Szabo	GSFC	Sentinels Study Scientist
Michael Wargo	NASA/HQ	Exploration Representative
Lika Guhathakurta	NASA/HQ	Program Scientist
Chris StCyr	GSFC	LWS Sr. Project Scientist
Haydee M. Maldonado	GSFC	Project Manager
Hermann Opgenoorth	ESA	ILWS Chair
Ronald D Zwickl	NOAA/SEC	User Community Representative

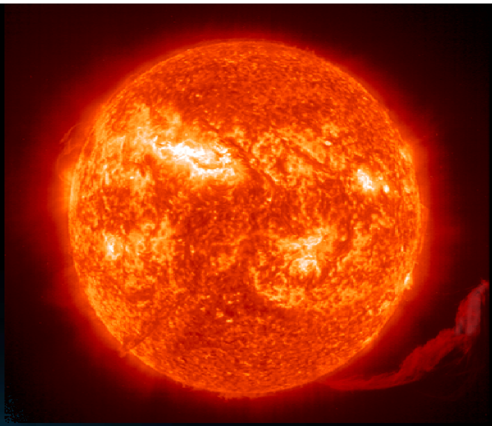
Sentinels Primary Objective



Discover, understand and model the <u>connection</u> between solar phenomena and interplanetary/geospace disturbances.

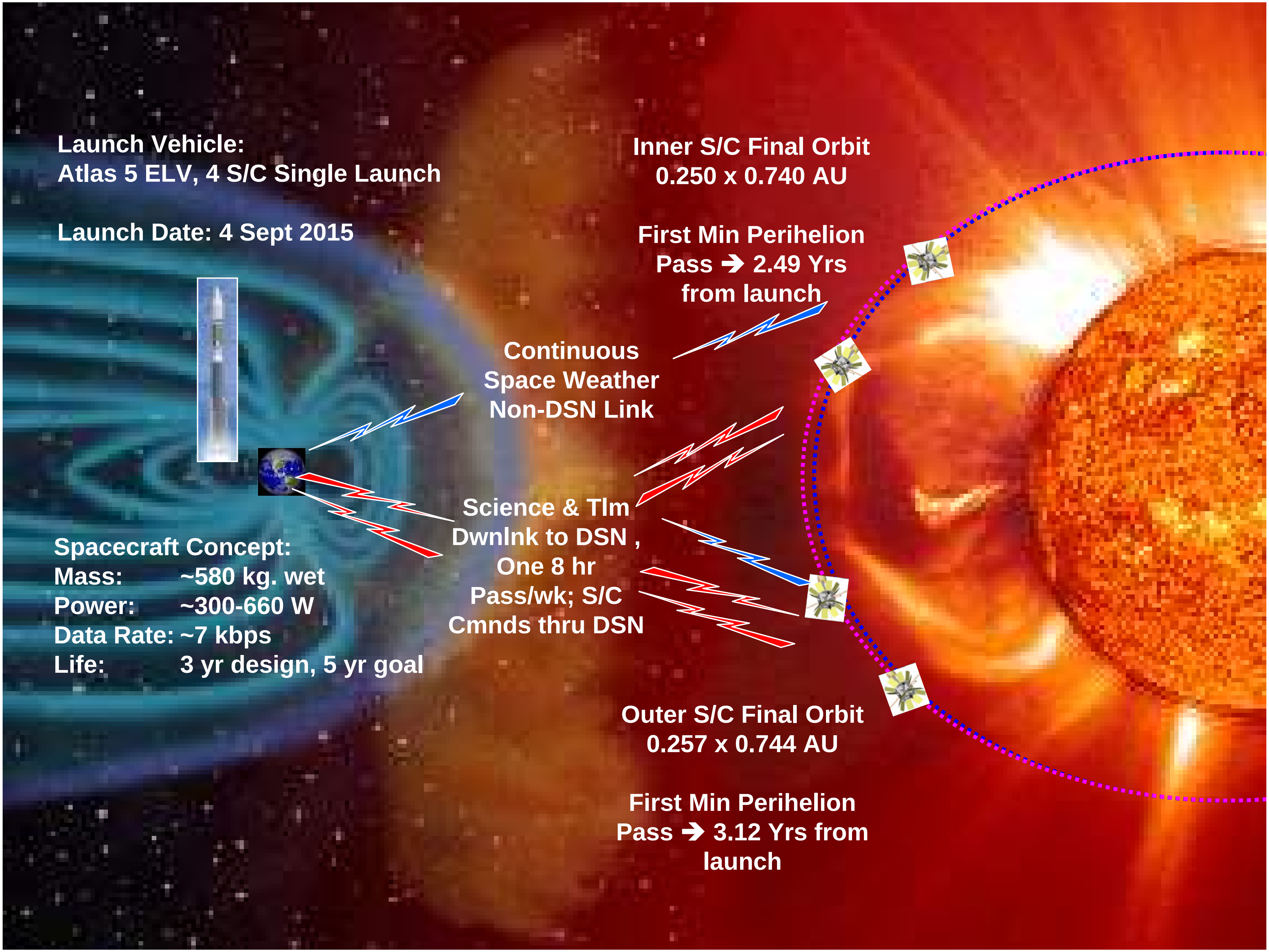
Sentinels Science Questions

SEPs	SEP Source Population	What is the origin/source of the see particles?
	SEP Acceleration	How, when and where are energetic particles accelerated?
		What is the role of CMEs and flares producing SEPs?
		How are the highest energy solar particles (>100 MeV/nuc) produced?
	SEP Propagation	How do SEPs propagate in the inner heliosphere?
		What determines the radial, longitudinal and latitudinal distribution of SEPs?
Transients	ICMEs	How are CMEs initiated? Constraints on models and mechanisms.
		What is the internal structure and solar connection of ICMEs? (Why do many CMEs become irregular ejecta?)
		How do ICMEs propagate and evolve?
	IP Shocks	What is the structure, propagation and evolution of interplanetary shocks?
Global Structure of the Inner Heliosphere		How do the heliospheric magnetic fields and plasma connect to and disconnect from the solar corona?
		How do the fast and slow streams interact to form the heliosphere?
		What is the origin of waves and turbulence and their significance for particle acceleration and dissipation?

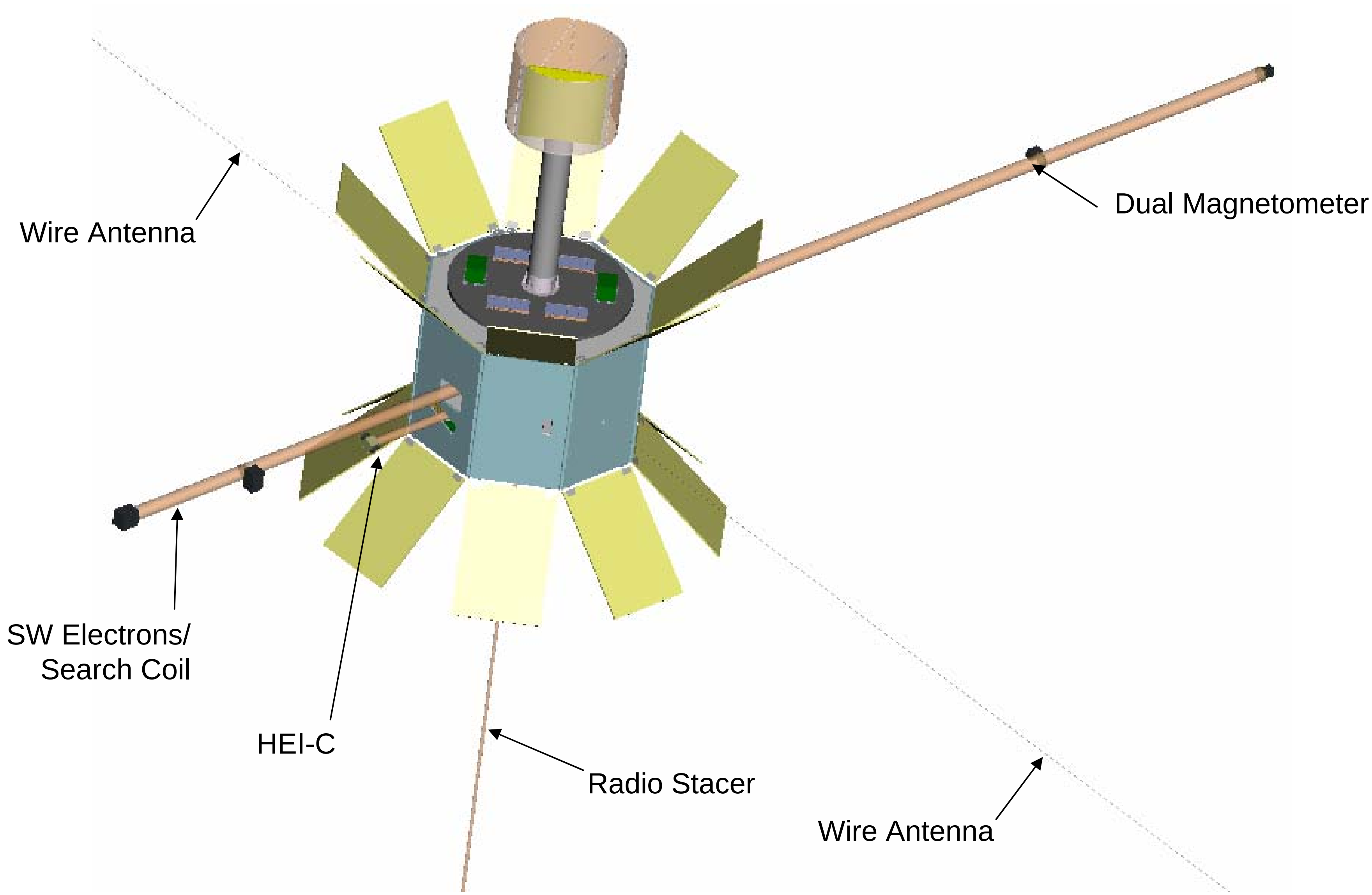


Sentinels in Exploration

- Determine where, when and how are solar energetic particles (SEPs) accelerated.
- Determine how energetic particles propagate and and are modulated.
- Characterize the interplanetary environment (worse case scenarios)
- Develop forecasting capabilities for Earth, Mars and for spacecraft in transit.


Launch Vehicle:
Atlas 5 ELV, 4 S/C Single Launch
Launch Date: 4 Sept 2015
Spacecraft Concept:
Mass: ~580 kg. wet
Power: ~300-660 W
Data Rate: ~7 kbps
Life: 3 yr design, 5 yr goal
Continuous Space Weather Non-DSN Link
Science & Tlm Dwnlnk to DSN , One 8 hr Pass/wk; S/C Cmnds thru DSN
Inner S/C Final Orbit 0.250 x 0.740 AU
First Min Perihelion Pass → 2.49 Yrs from launch
Outer S/C Final Orbit 0.257 x 0.744 AU
First Min Perihelion Pass → 3.12 Yrs from launch

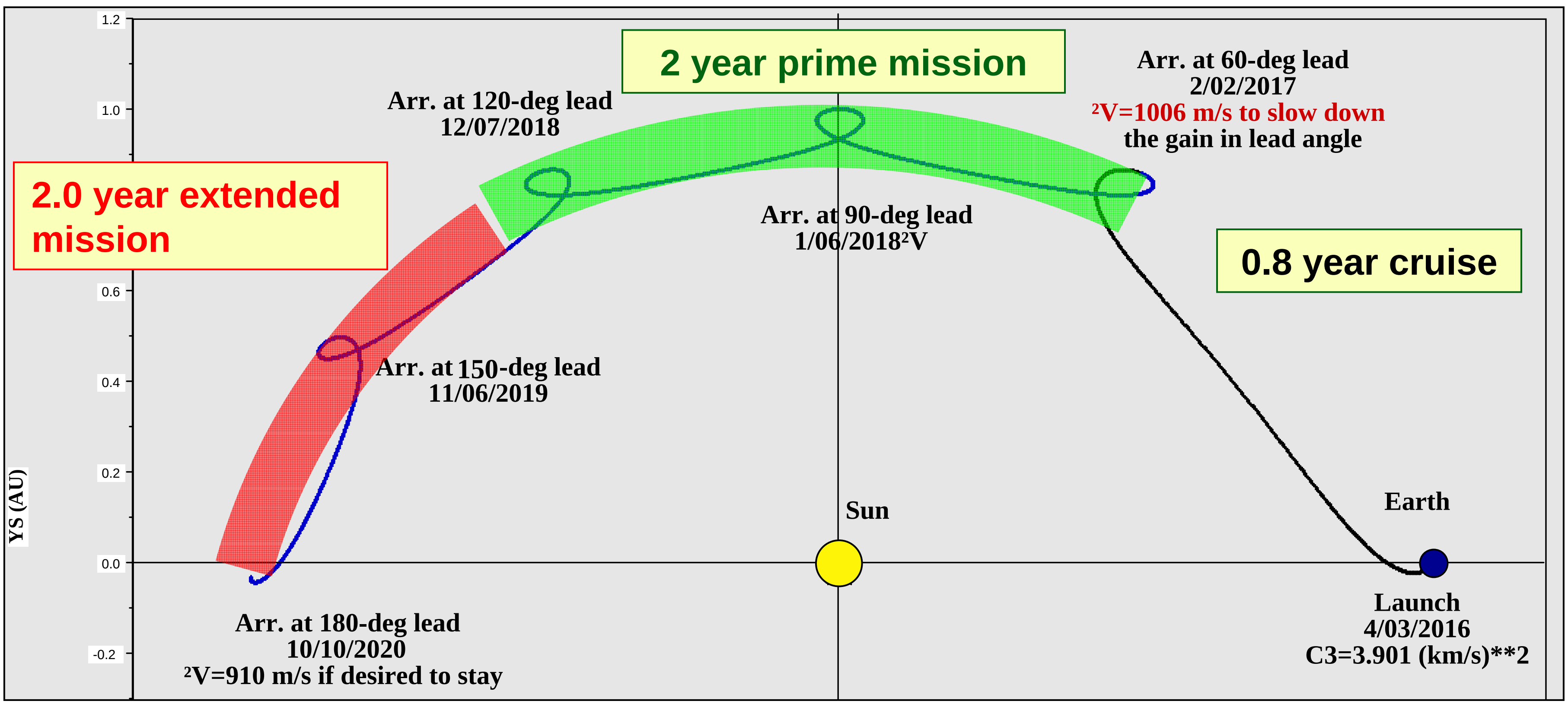
Deployed Configuration



Imaging Sentinel

Ballistic trajectory that minimizes time to 60 degrees and then drifts from 60 to 180 degrees in < 4 years

- C3 = 3.901 km2/s2
- Delta-V = 1.150 km/s (includes 144 m/s)
- Launch Vehicle: Delta II 2925H (delivers 921 kg dry mass)

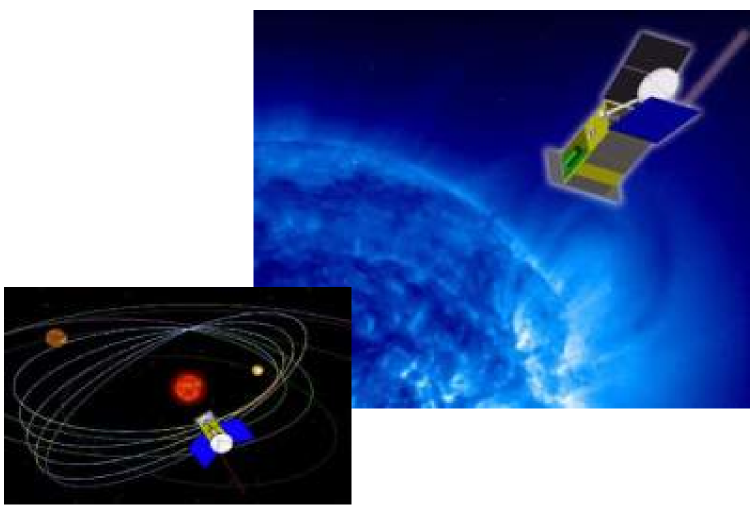


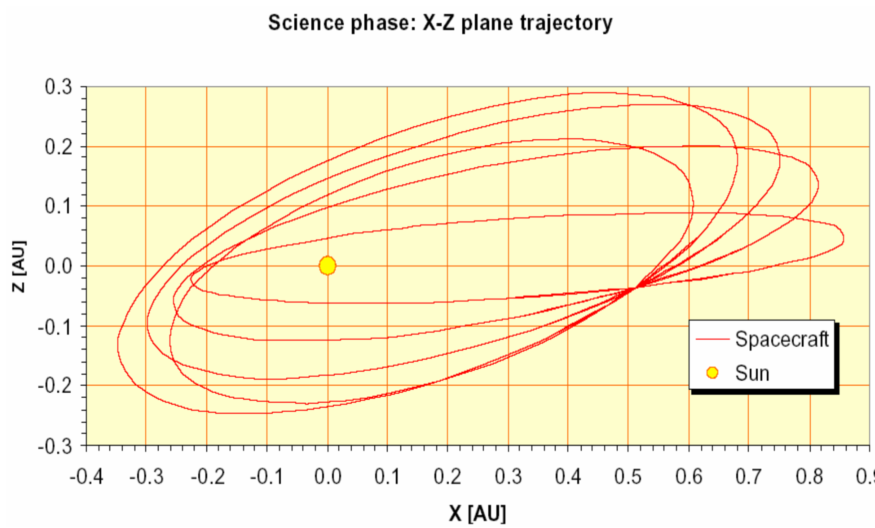
ESA Solar Orbiter and Sentinels

- Inner heliospheric (0.22 x 0.9 AU) mission in the same time frame as IHS.

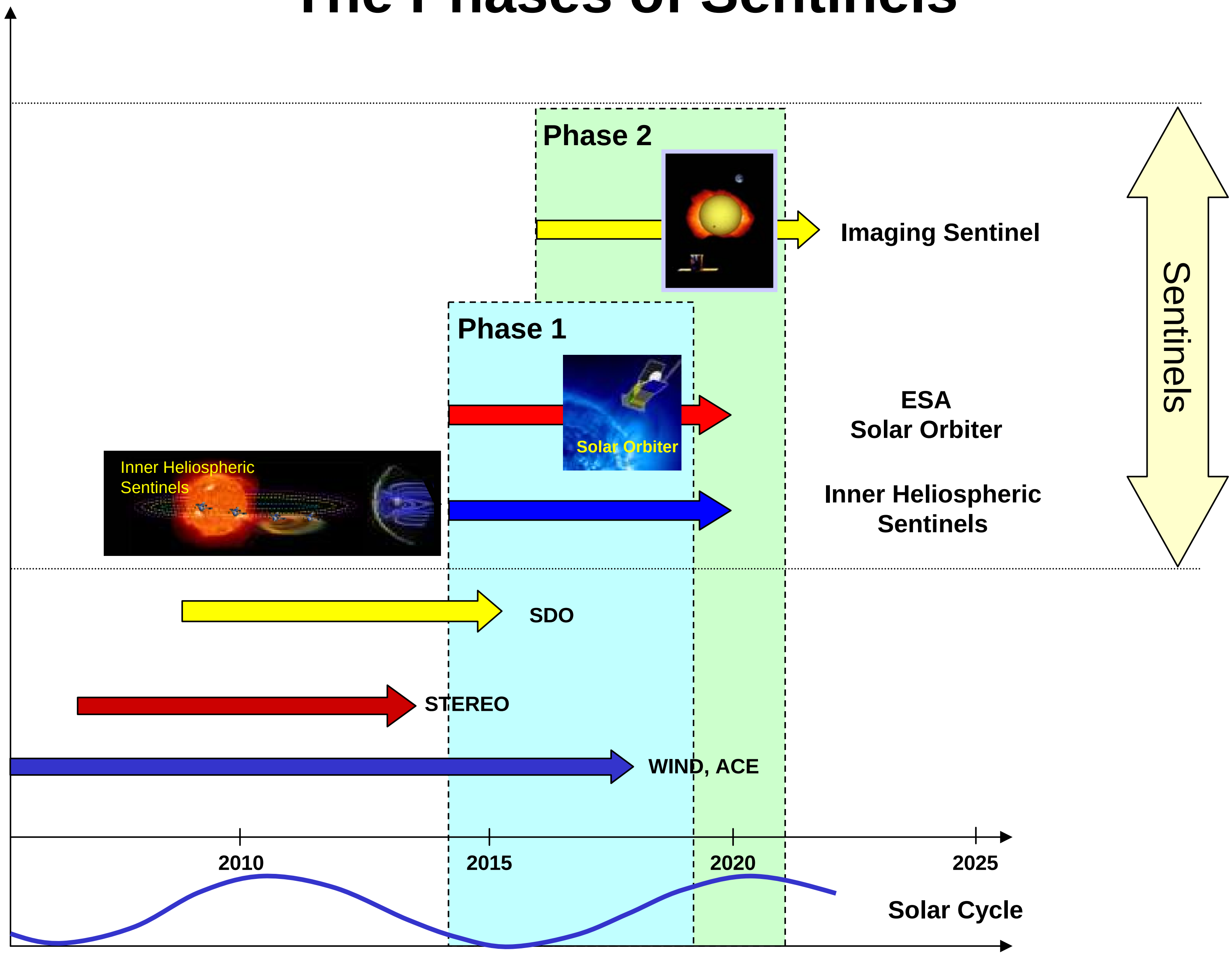
- Both in-situ and remote sensing instrumentation.

- 2nd half of mission to latitudes above 30°.





The Phases of Sentinels

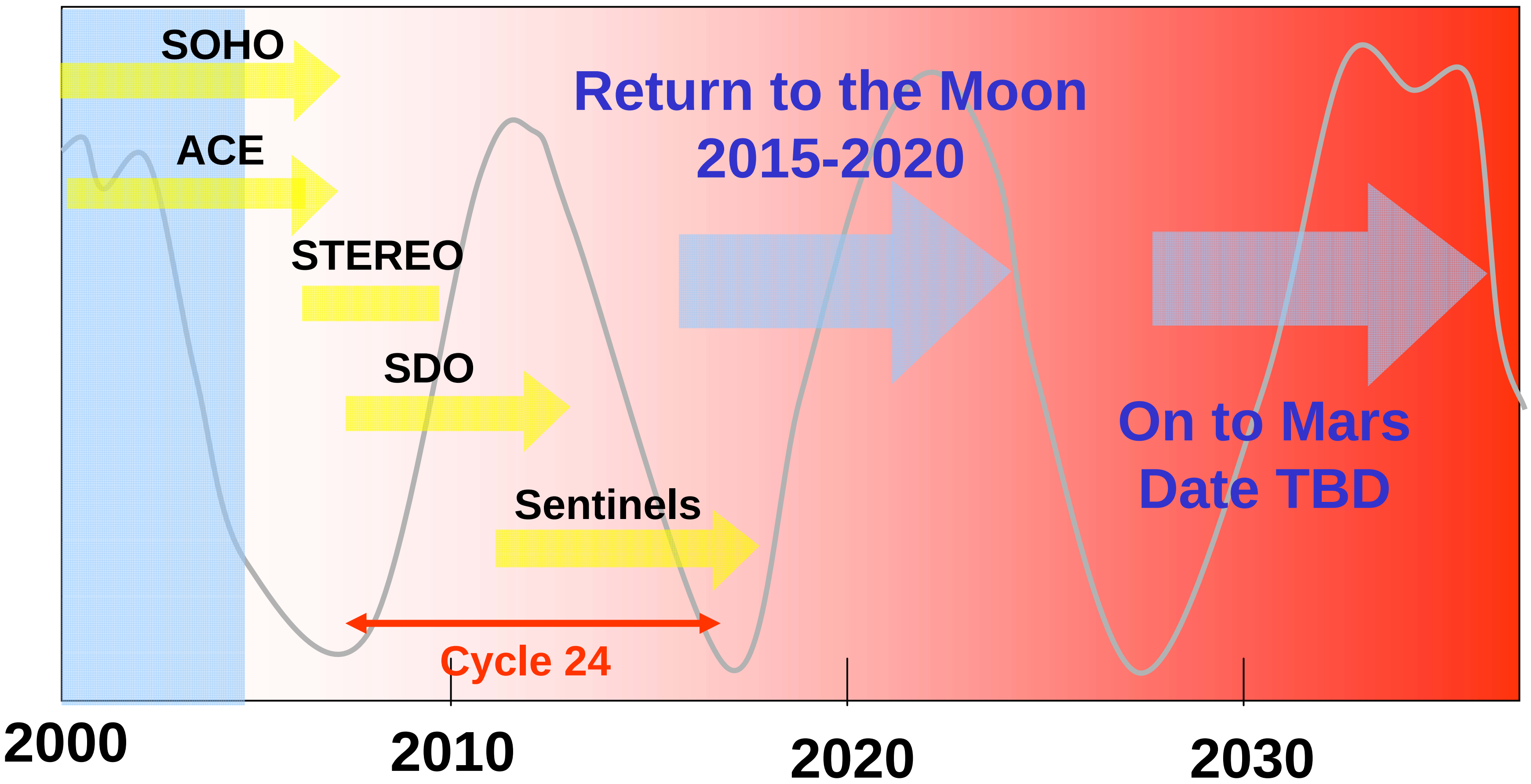


Relation to Exploration

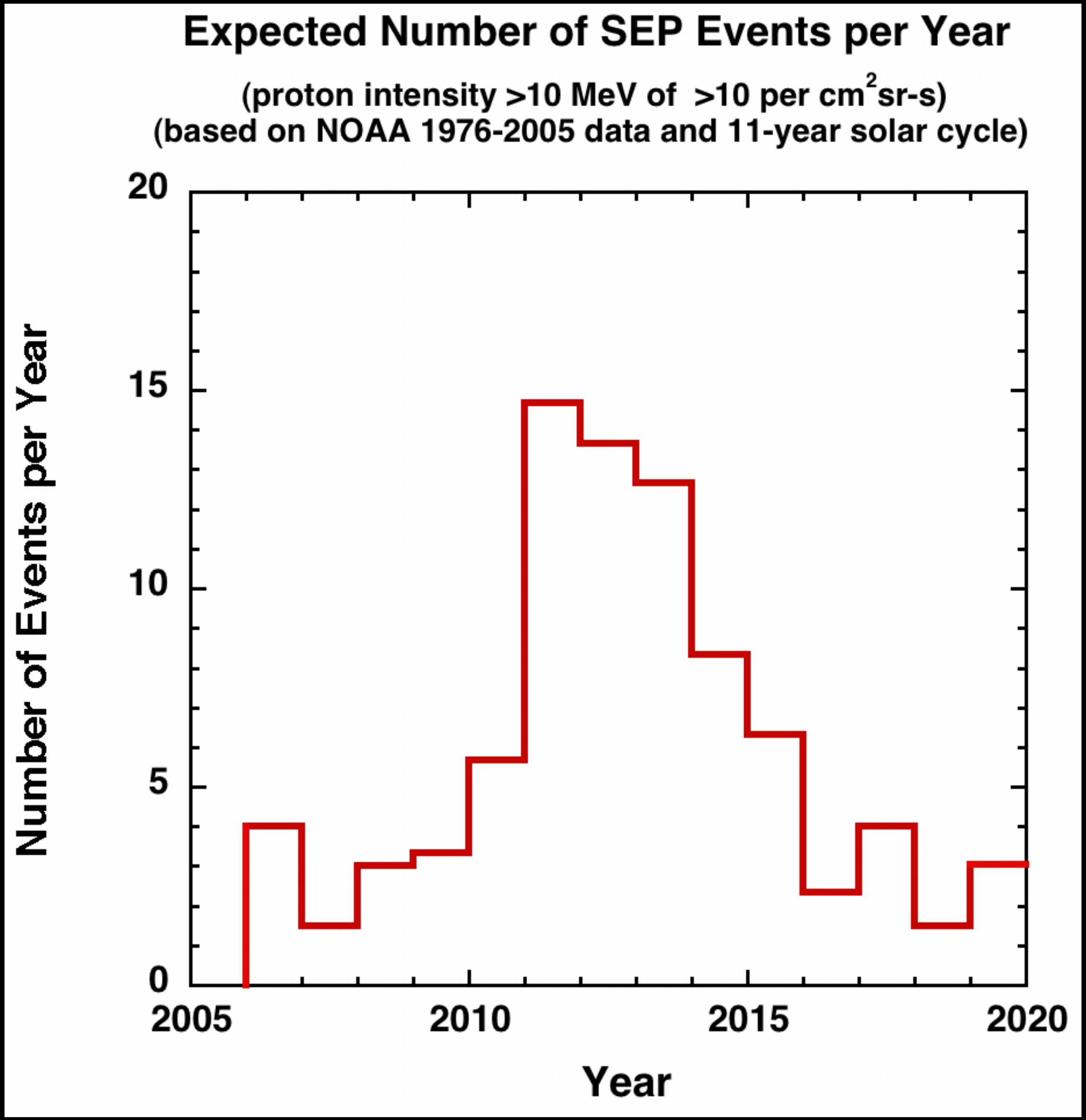
- LWS Sentinels will develop the ***physical understanding*** necessary to reliably model and predict the radiation environment for Lunar and Martian missions. Sentinels will accomplish this by discovering the physical conditions and mechanisms that govern SEP production and transport in the heliosphere.

- LWS Sentinels will develop the technical understanding necessary to implement a future heliospheric space weather warning system. Sentinels will have real-time capabilities that allow testing of space weather monitoring/forecasting functions.

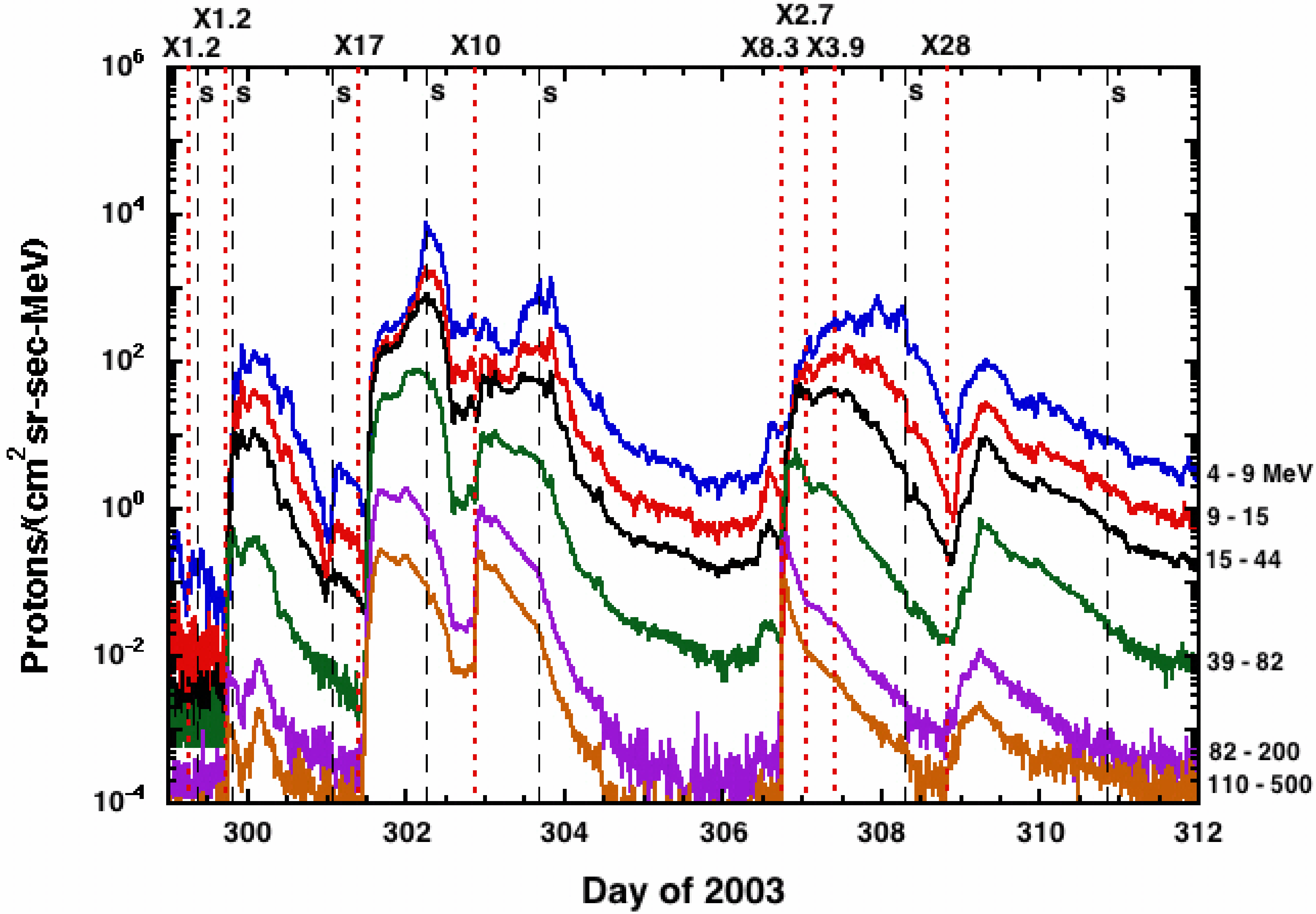
Timing of Sentinels



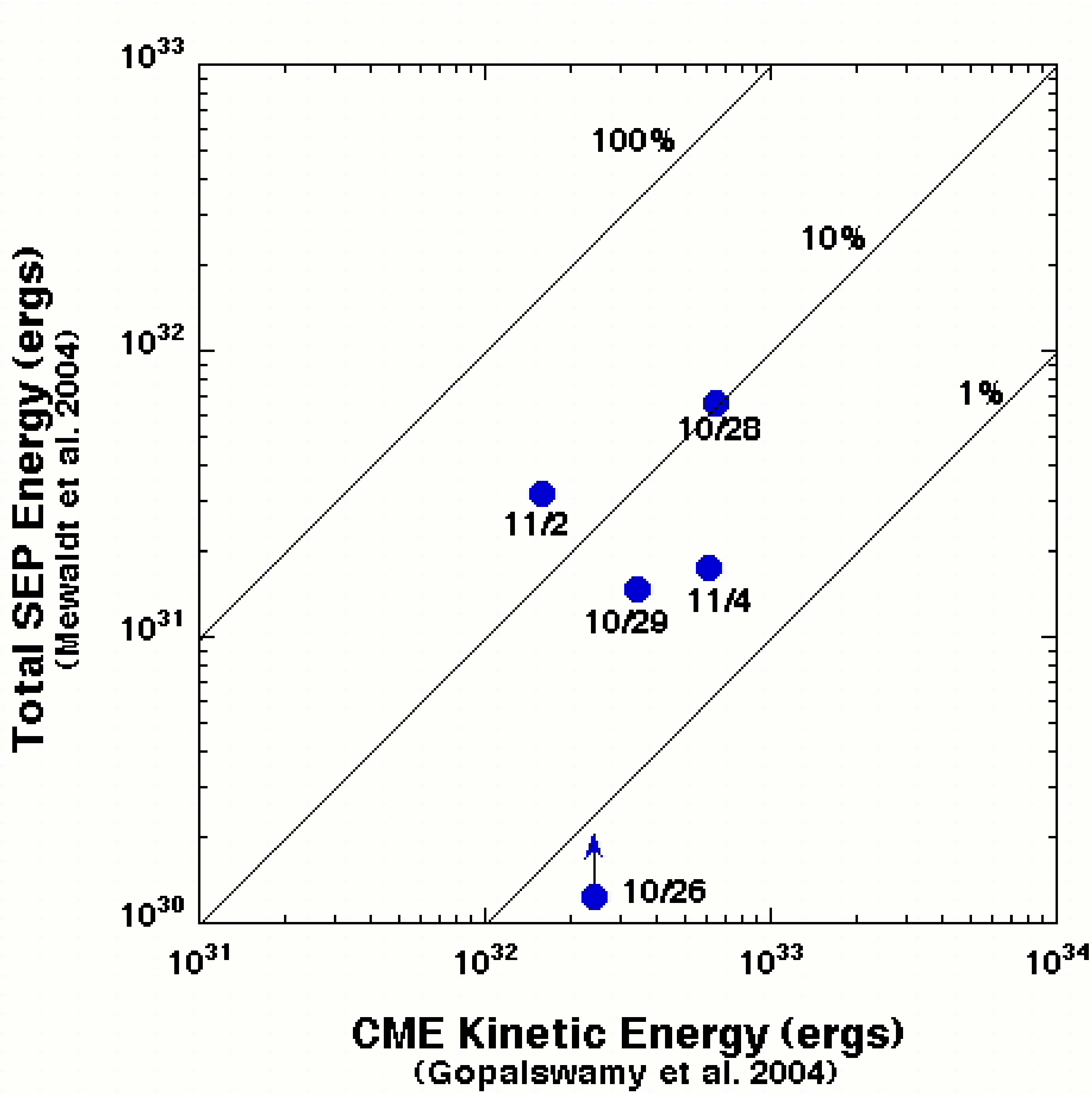
Only One More Solar Cycle Left to Learn What We Must Learn


Expected Number of SEP Events per Year
(proton intensity >10 MeV of >10 per cm2sr-s)
(based on NOAA 1976-2005 data and 11-year solar cycle)
Number of Events per Year
Year
0
5
10
15
20
2005
2010
2015
2020

[redacted]

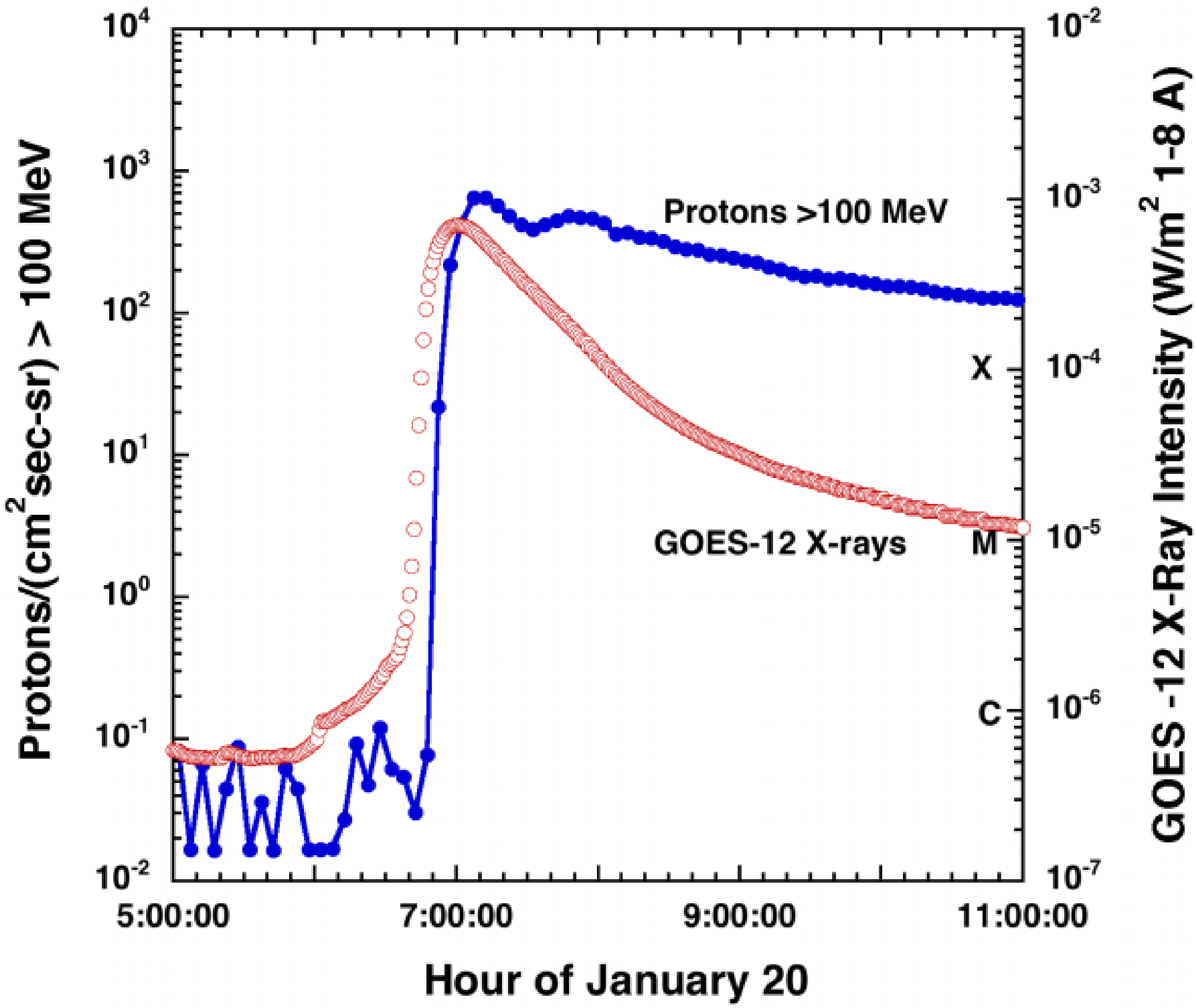


Mewaldt et al 2004

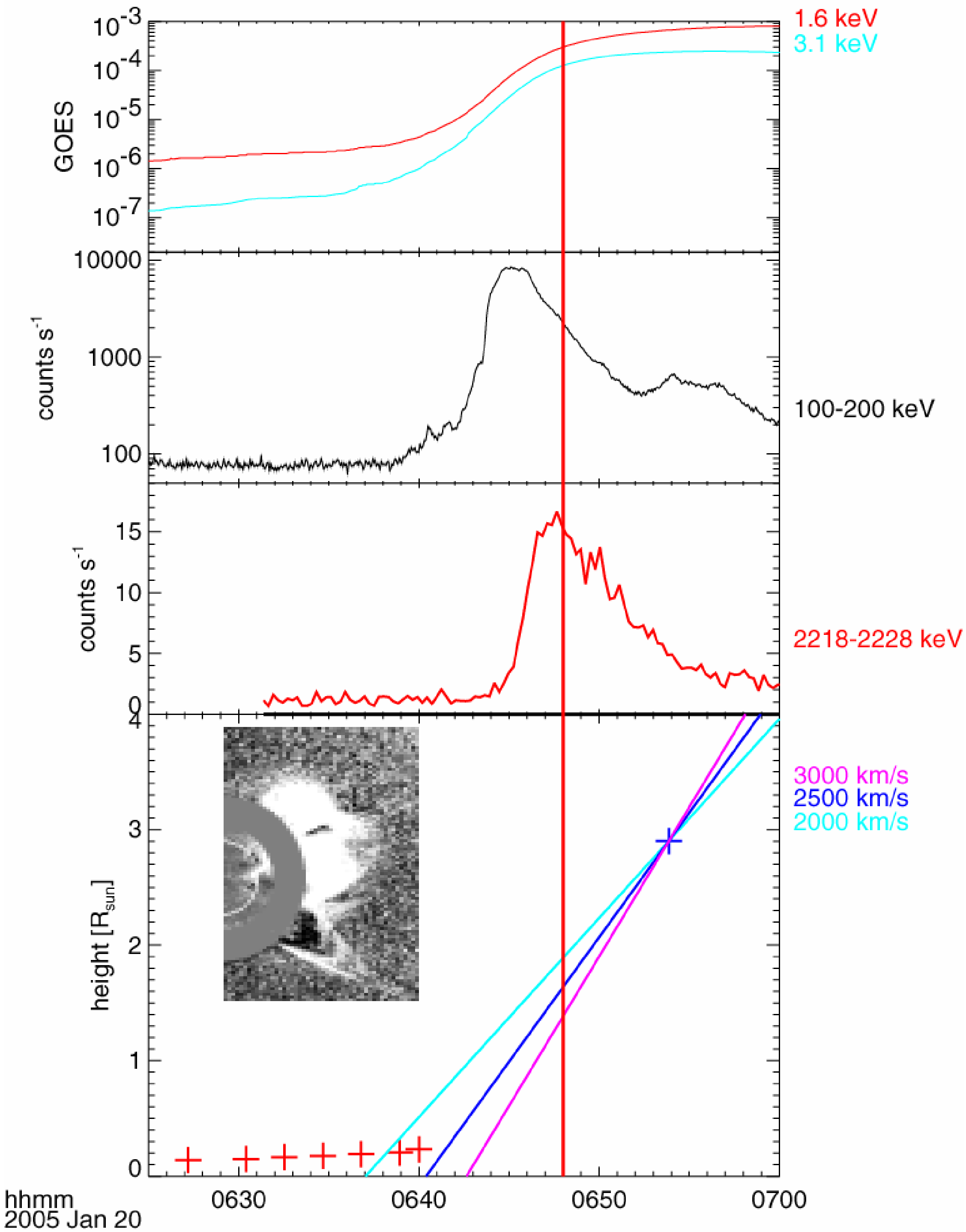


If these SEPs are accelerated by CME-driven shocks, they use a significant fraction of the shock kinetic energy (~3% to 20%)

(see also Emslie et al. 2004).



In the Jan 20 Event the high energy particle-intensities reach Earth just minutes after the x-rays from the flare (Mewaldt et al 2005)



Timing

Red vertical line (06:48UT):

Solar release time assuming first arriving particles travel at v=c along L=1.2 AU

HXRs peak at 06:45:00UT

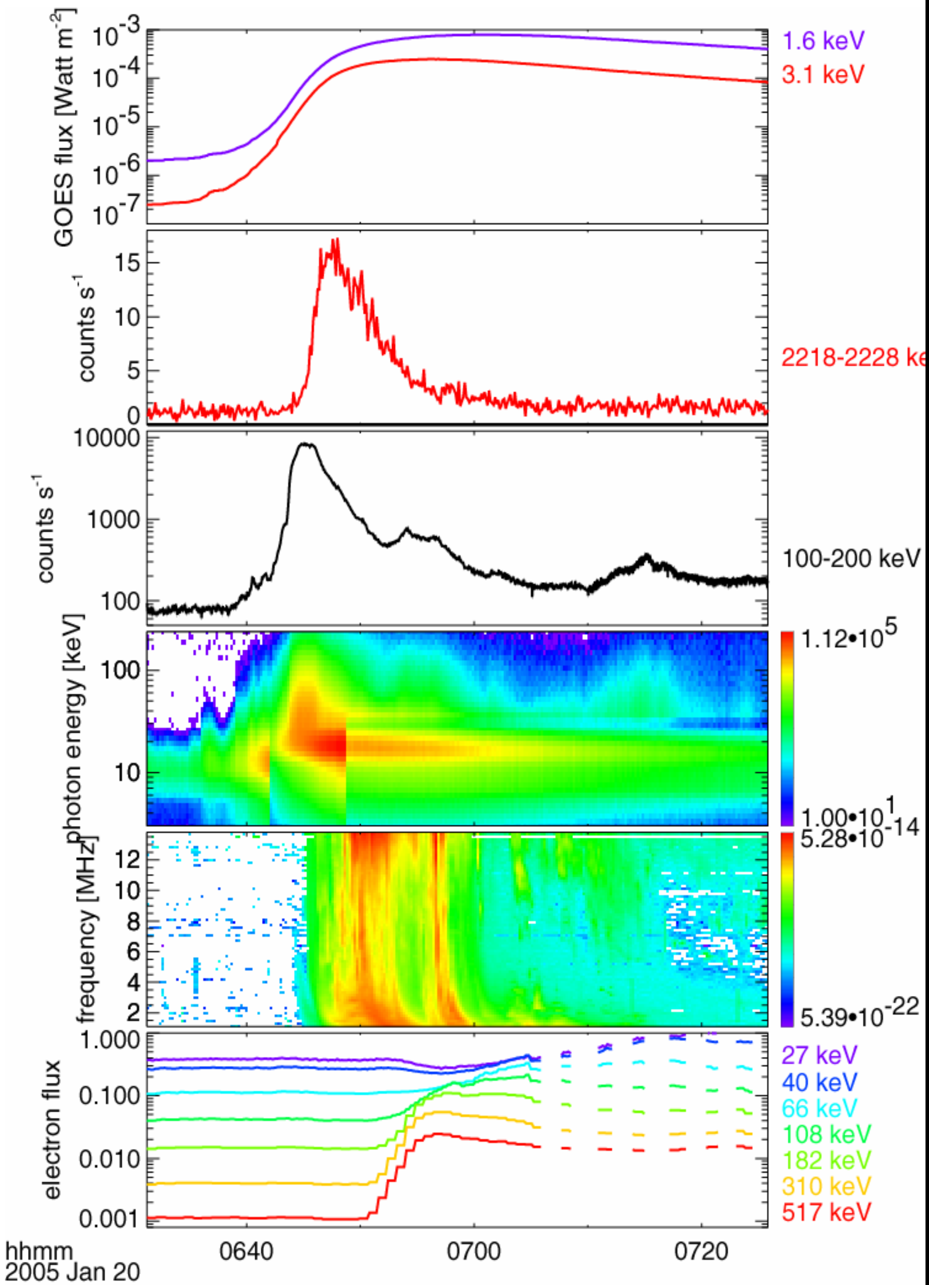
2.2 MeV peak at 0647:30UT

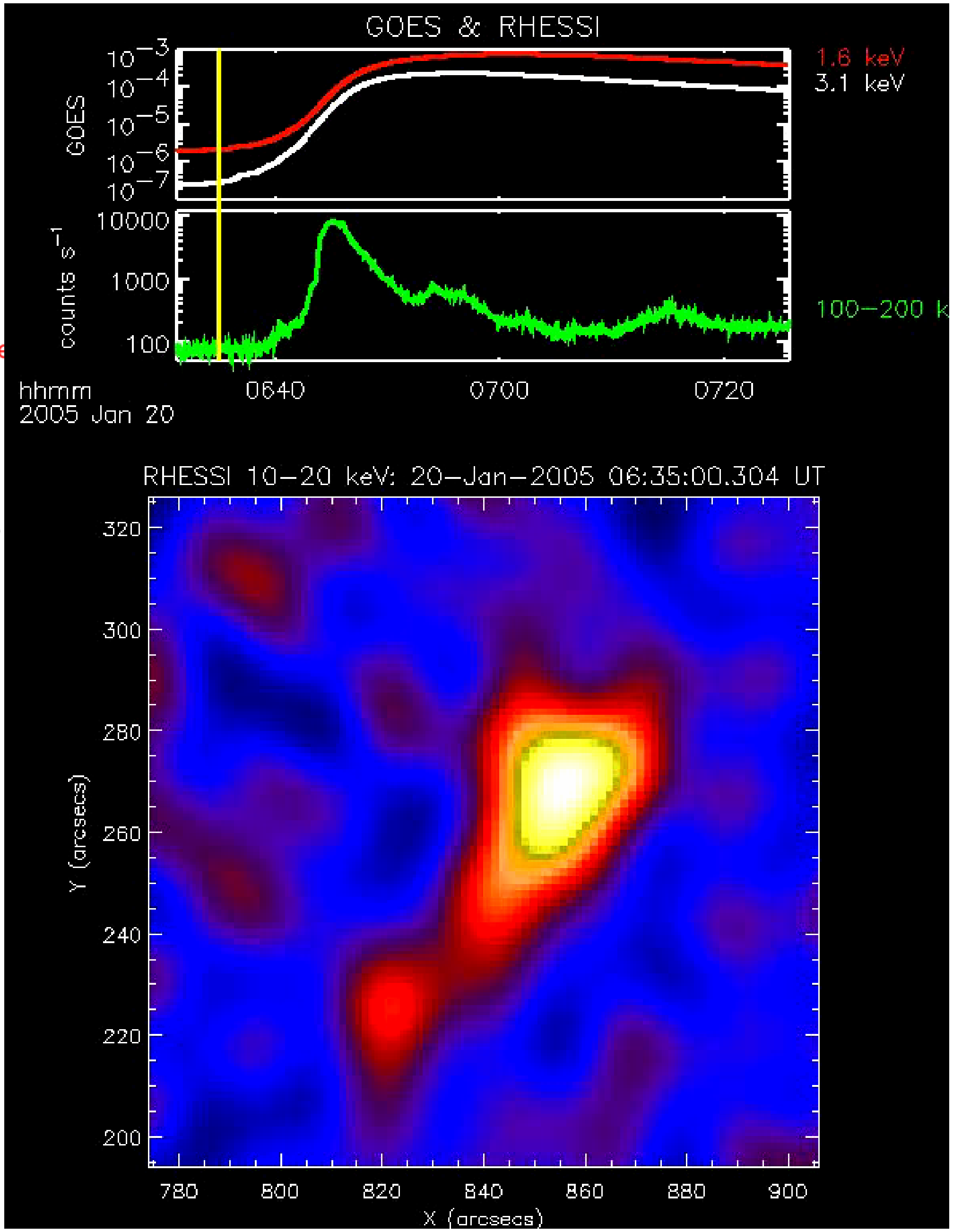
06:54UT: CME at ~3 Rsun

Line: 2500 km/s CME speed

Red crosses: Rising SXR loops

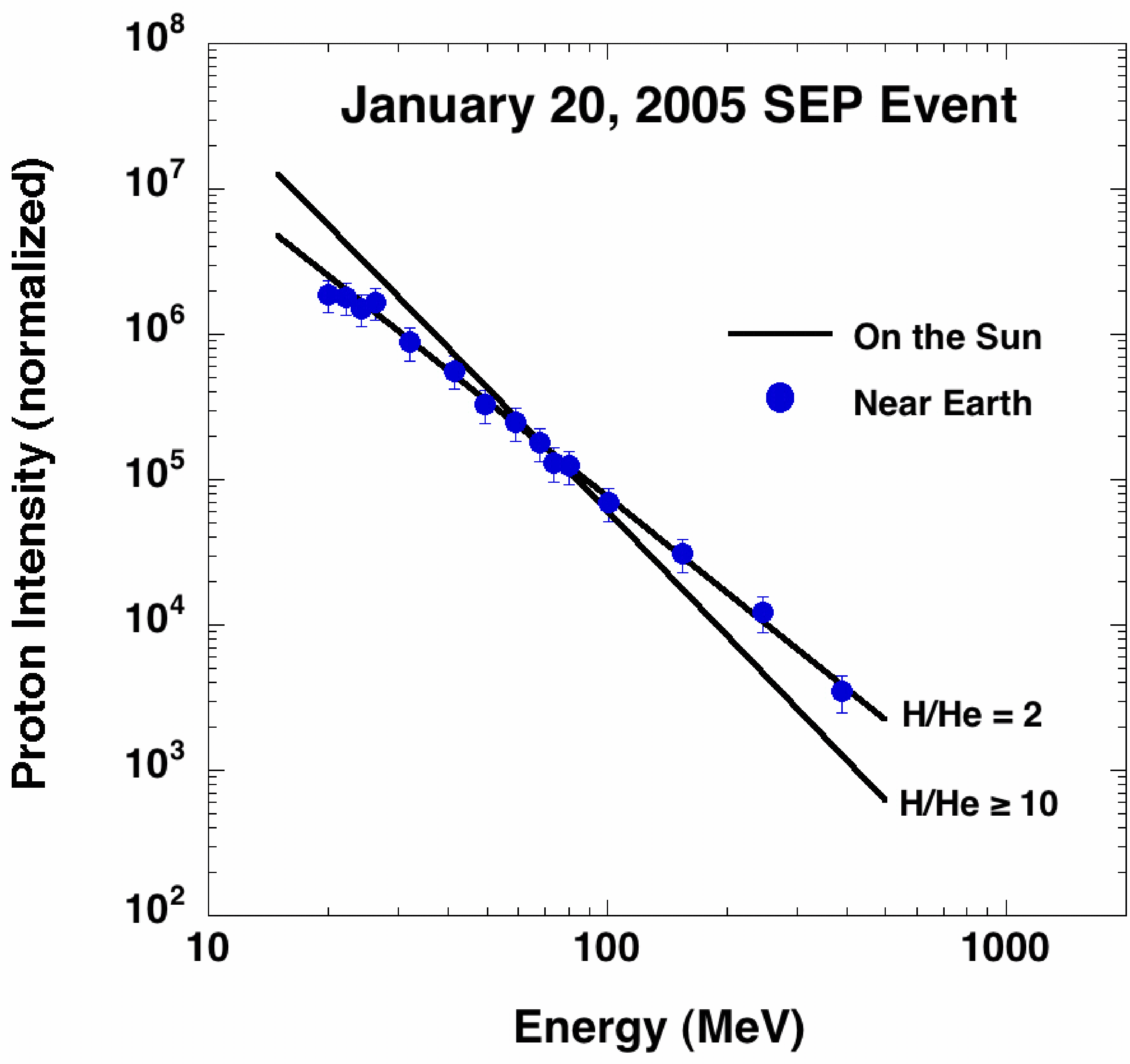
Krucker et al 2005





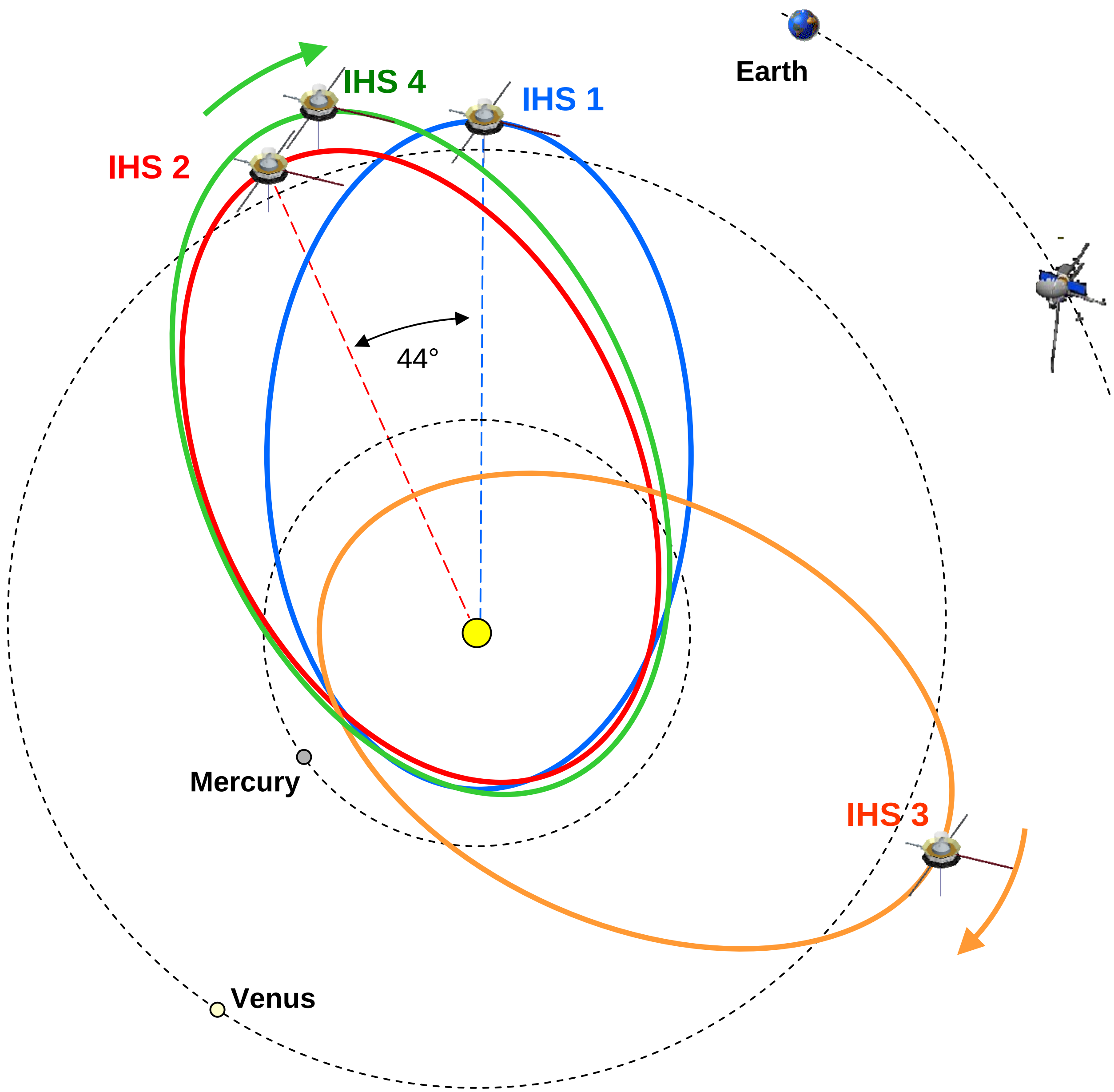
Proton spectrum:

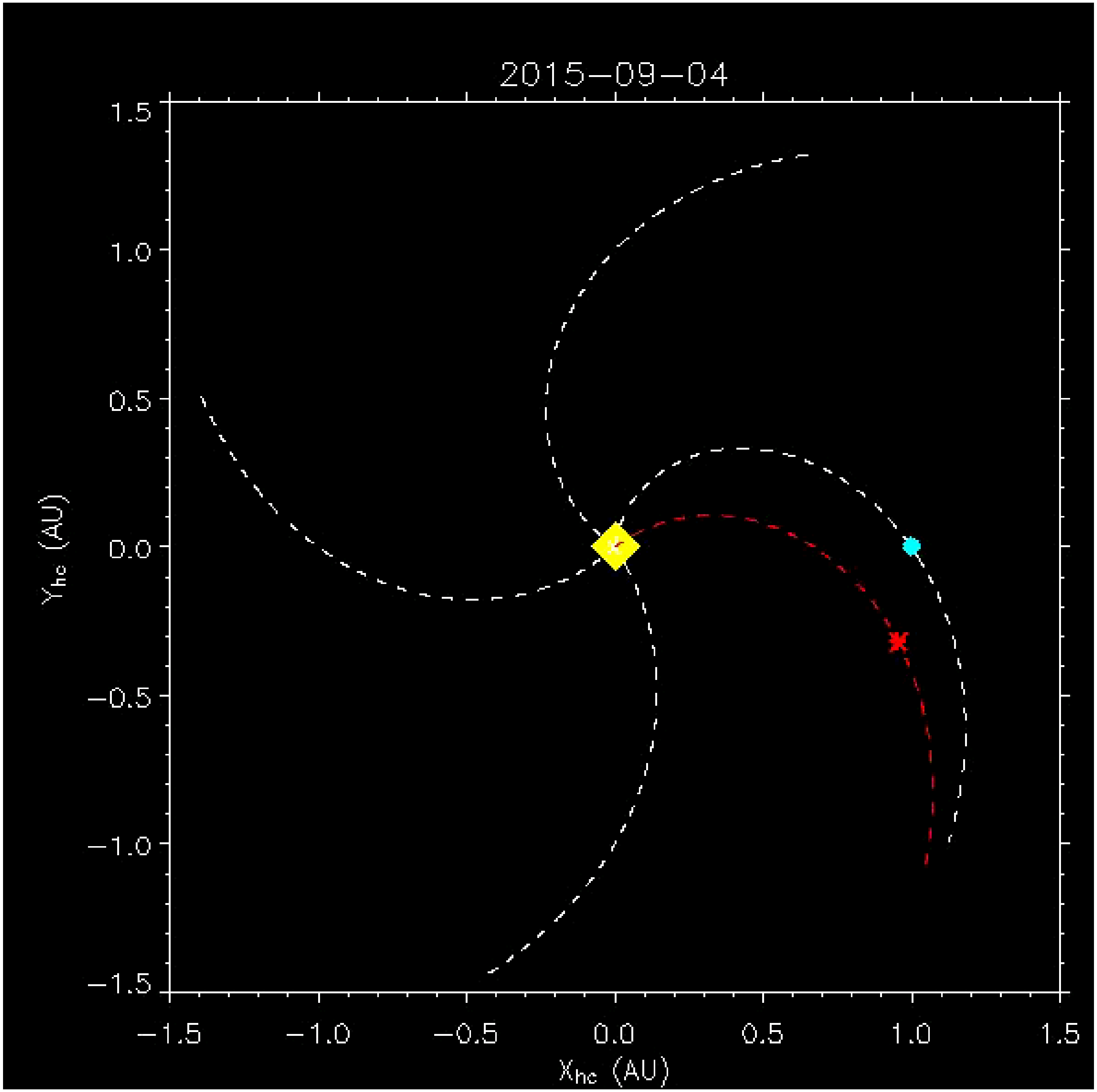
RHESSI Gamma-rays (lines) vs SEPs at 1AU (blue points)



Inner Heliospheric Orbit Design

- 3 Venus gravity assists for each spacecraft
- Final orbits: 0.25 x 0.76 AU
- Orbital periods: 127-136 days
- Cruise: 2 yr 3-11 months to final configuration, Science starts 60 days after launch
- Launch opportunities: (2012 May) 2014 Feb, 2015 Sept





2015-09-04
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Y_{hc} (AU)
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
X_{hc} (AU)