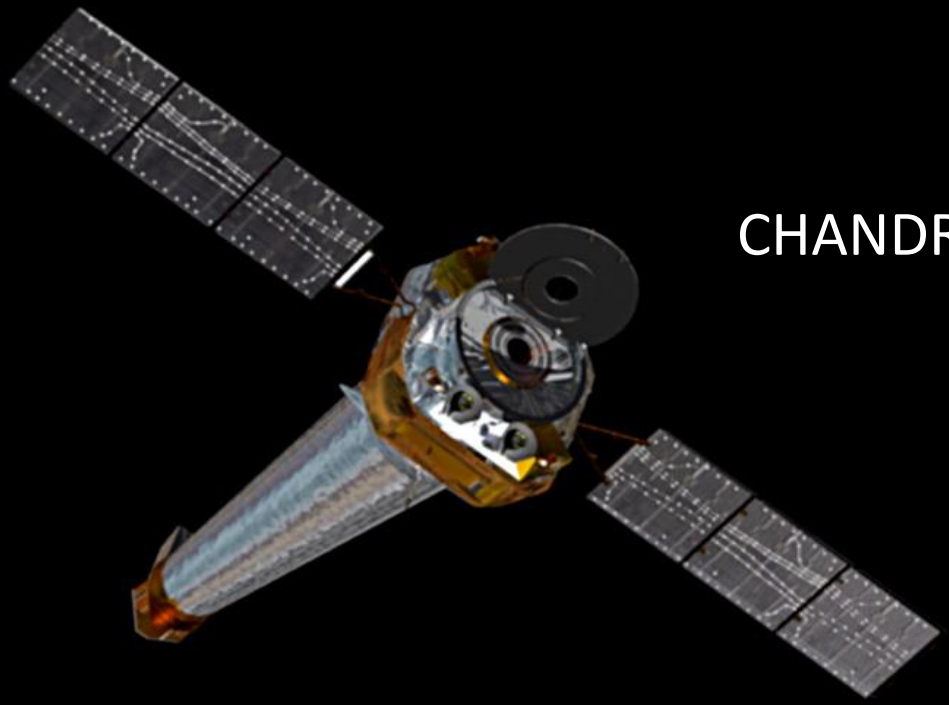

CHANDRA Space Weather Vulnerabilities and Needs Update

Joseph Minow
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NASA Space Exploration & Space Weather Workshop
27 – 28 September 2016
Goddard Space Flight Center, Greenbelt, MD
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Outline

- Chandra X-Ray Observatory radiation sensitivity and radiation mitigation strategy
- Update on radiation interruptions of science operations
- Status on ACE RTSW data
- ACE Browse Data

Chandra Radiation Team

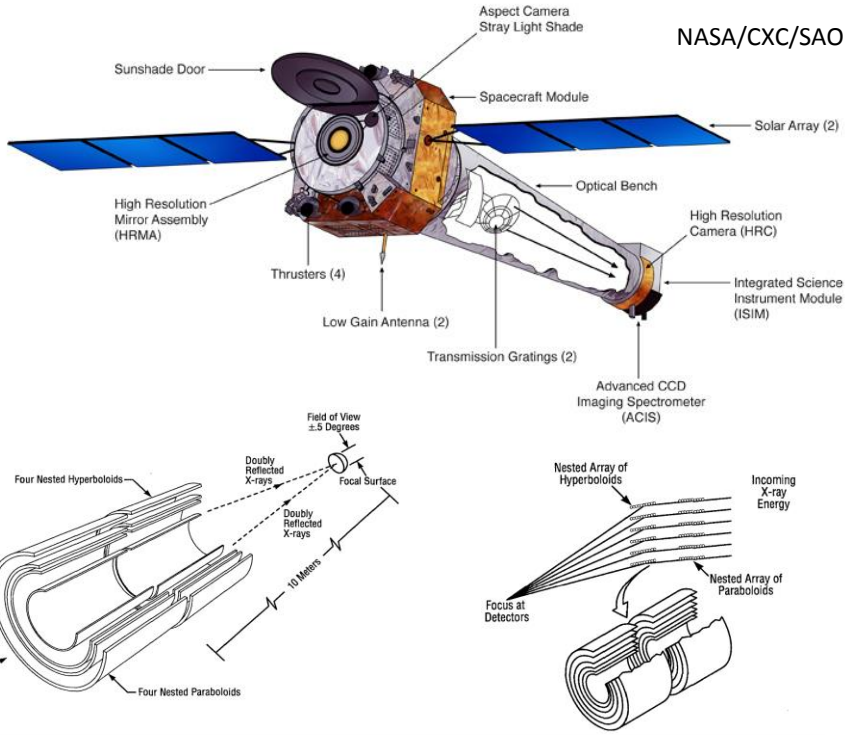
- Steve O'Dell/MSFC
- Greg Wright/MSFC
- Linda Parker/MSFC/USRA
- Scott Wolk/SAO
- Brad Spitzbart/SAO
- Joe Minow/LARC

Chandra X-Ray Observatory (CXO)

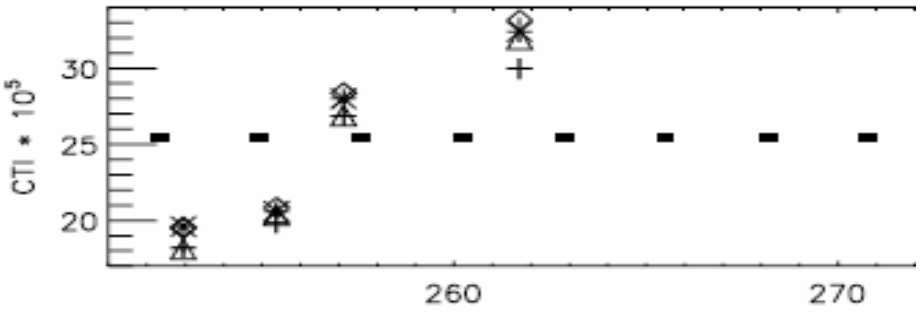
- Launched 23 July 1999 by STS-93
- Current orbit (Sep 2016, geocentric): ~2.8 R_E x 21.5 R_E x 75.4°, ~63.4 hour period
- Mission
  - 5-year primary science mission
  - Currently in 3rd 5-year extension
  - Planning for 4th to 2024

- Advanced CCD Imaging Spectrometer (ACIS) is CXO's premier science most often requested in observatory proposals
  - Degradation of the 8 front illuminated ACIS CCD detectors was observed to be much worse than expected soon after launch, 2 back illuminated CCD's immune to damage
  - ~5 years worth of degradation in a single perigee passage
  - Damage mechanism identified as soft protons (~100 to 200 keV) depositing energy in CCD substrate

- ACIS can't be operated in high flux, soft proton environment within the magnetosphere and solar particle events



http://chandra.harvard.edu/about/top_ten.html

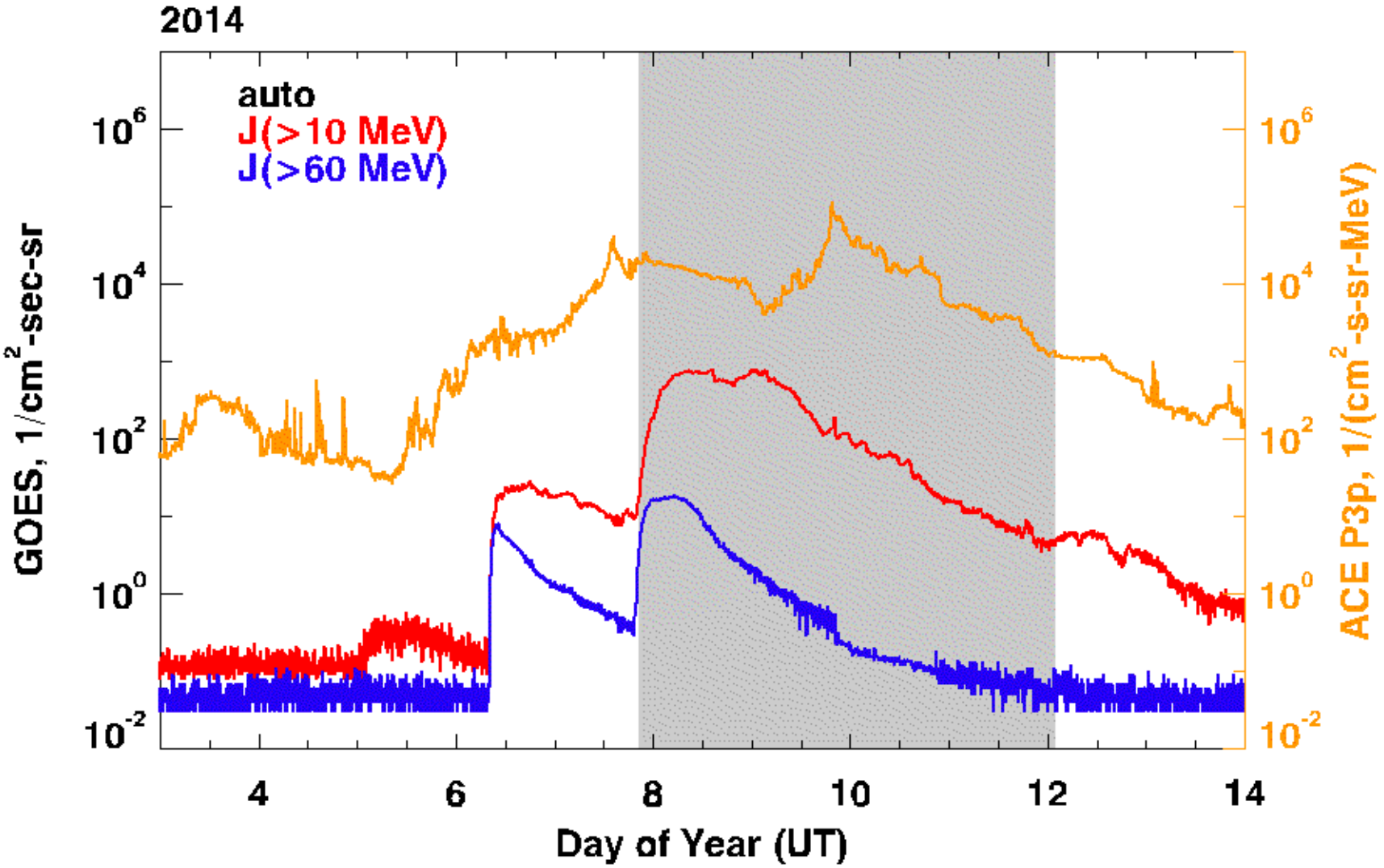


CXO Radiation Mitigation Strategy

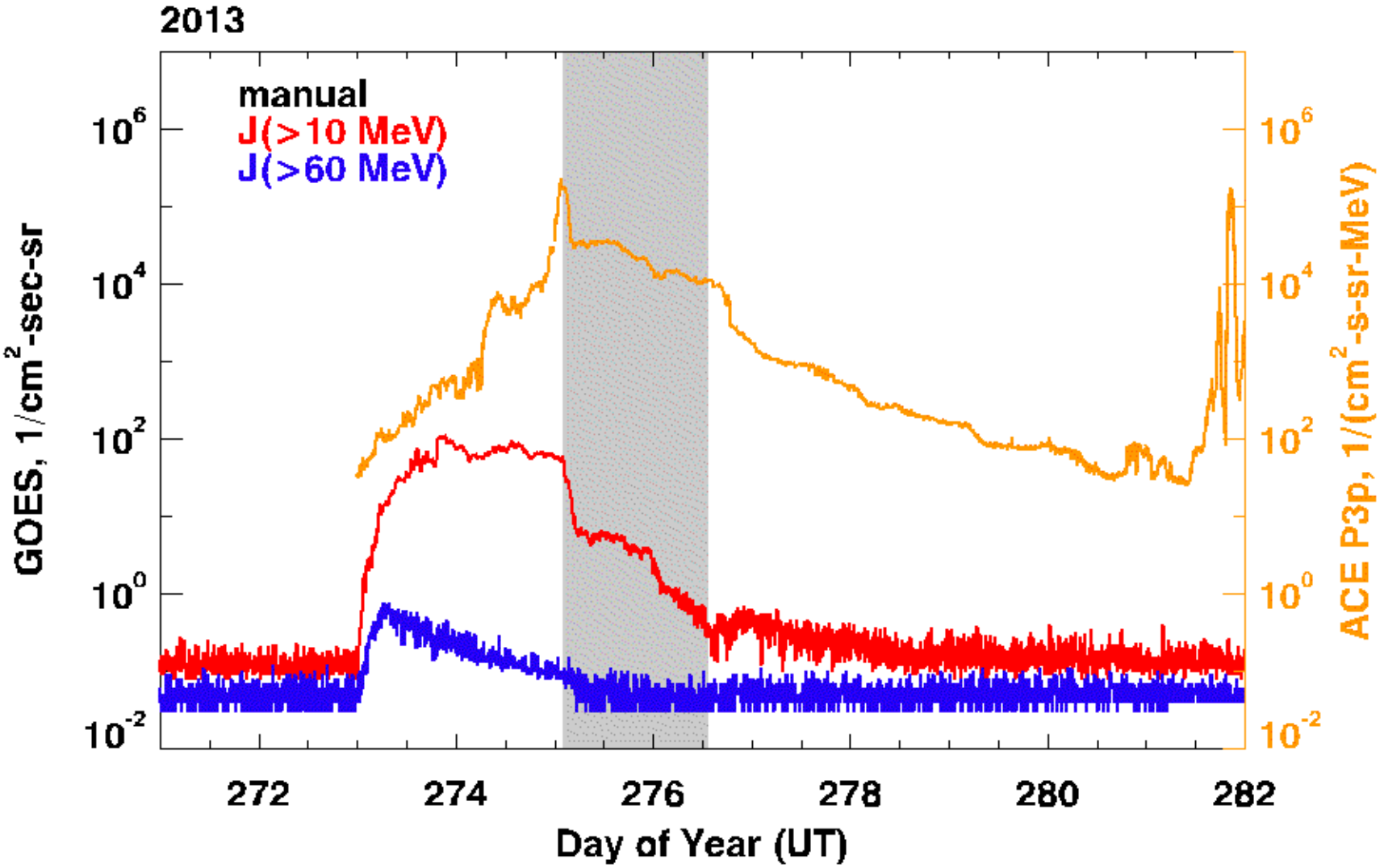
- Schedule science operations to avoid high soft proton flux in the Earth's ring currents using Chandra Radiation Model, AP-8/AE-8
- Real time radiation monitoring using in-situ (autonomous) and other data sources (manual), move ACIS to protected position during periods of high particle flux
- CXO Monitoring and Trends Analysis (MTA) Team utilizes data from a variety of sources for real-time monitoring of CXO radiation environment:

Satellite	Instrument	Species	Energy	Notes
CXO (NASA)	EPHIN rates	H^+, e^-	H^+ 25 – 41 MeV e^- 2.6 – 6.2 MeV	In-situ, autonomous ACIS safing
	HRC rates	H^+	>10's MeV	In-situ, autonomous ACIS safing
	ACIS rates	H^+	>10's MeV	In-situ, autonomous ACIS safing
GOES (NOAA)	EPS P2 (P4GM proxy)	H^+	4 – 8 MeV	NOAA real time (5 min), manual
	EPS P5 (P41GM proxy)	H^+	38-80 MeV	NOAA real time (5 min), manual
	EPS E	e^-	>2 MeV	NOAA real time (5 min), manual
ACE (NASA)	P3'	H^+	115 – 195 keV	NOAA real time (5 min), manual
XMM (ESA)	Radiation Monitor	H^+, e^-	H^+ >1 MeV e^- > 130 keV	ESA real time (2 to 60 minutes), manual

Auto


2014
auto
J(>10 MeV)
J(>60 MeV)
GOES, 1/cm²-sec-sr
ACE P3p, 1/(cm²-s-sr-MeV)
Day of Year (UT)
10⁶
10⁴
10²
10⁰
10⁻²
4
6
8
10
12
14

Manual ACE P3’



Solar Cycle 24 Radiation Interventions

Event	Start	End	Lost Science time	Auto/Manual	Cause
3 *(+1)*	**2011**		**406 ks (113 hr)**	**2/1**	
1**	Jun 7 15:23 UT	Jun 8 12:50 UT	74.9 (20.8)	Auto	HRC (hard)
2	Aug 4 07:03	Aug 7 10:25	270.4 (75.1)	Auto	HRC (hard)
3	Oct 24 18:27	Oct 25 22:35	61.1 (17.0)	Manual	ACE P3' (soft)
4	*Oct 26 11:40*	*Oct 28 12:33*	*154 (42.8)*	Auto	*Command Telemetry Unit (SEU)*
10	**2012**		**1,246 ks (346 hr)**	**7/3**	
5	Jan 23 06:00	Jan 26 08:27	192.1 (53.4)	Auto	HRC (hard)
6	Jan 27 19:39	Jan 30 02:20	163.4 (45.4)	Auto	HRC (hard)
7	Feb 27 03:24	Feb 27 20:23	61 (16.9)	Manual	ACE P3' (soft)
8	Mar 7 05:30	Mar 13 05:14	440 (122.2)	Auto	HRC (hard)
9	Mar 13 22:41	Mar 14 13:57	53.3 (14.8)	Auto	HRC (hard)
10	May 17 02:18	May 18 04:52	93.8 (26.1)	Auto	E1300 (hard)
11	Jul 12 19:59	Jul 14 00:09	61.7 (17.1)	Auto	E1300 (hard)
12	Jul 14 21:08	Jul 16 05:16	80.1 (22.3)	Manual	ACE P3' (soft)
13	Jul 19 11:44	Jul 20 04:09	56.5 (15.7)	Auto	HRC (hard)
14	Sep 3 12:57	Sep 4 12:41	44.5 (12.4)	Manual	ACE P3' (soft)

* First radiation interruption since 2006 December 13 **First ACIS trigger event

Source: Chandra Radiation Central http://asc.harvard.edu/mta/RADIATION/

Solar Cycle 24 Radiation Interventions

Event	Start	End	Lost Science time	Auto/Manual	Cause
3	**2013**		**367 ks (102 hr)**	**1/3**	
15	Mar 17 12:32	Mar 19 05:58	105.7 (29.4)	Manual	ACE P3' (soft)
16	May 22 14:49	May 24 12:22	123.6 (34.3)	Auto	ACIS (hard)**
17	May 24 20:41	May 25 11:56	54.0 (15.0)	Manual	ACE P3' (soft)
18	Oct 02 02:04	Oct 03 13:27	83.3 (23.1)	Manual	ACE P3' (soft)
3	**2014**		**545 ks (151 hr)**	**2/2**	
19	Jan 07 20:39	Jan 12 01:54	364.5 (101.3)	Auto	SCS-107
20	Sep 12 11:51	Sep 13 12:48	89.0 (24.7)	Manual	SCS 107
21	Dec 22 04:52	Dec 22 23:26	65.1 (18.1)	Manual	ACE P3' (soft)
22	Dec 23 11:33	Dec 23 18:59	26.0 (7.2)	Manual	ACE P3' (soft)
3	**2015 (through Q3)**		**132 ks (37 hr)**	**0/2**	
23	Mar 17 04:34	Mar 19 08:04	131.8 (36.6)	Manual	ACE P3' (soft)
24	Jun 22 22:40	Jun 23 21:40	82.0 (22.8)	Manual	ACE P3' (soft)
25					

* First radiation interruption since 2006 December 13 **First ACIS trigger event

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Solar Cycle 24 Radiation Interventions

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25					

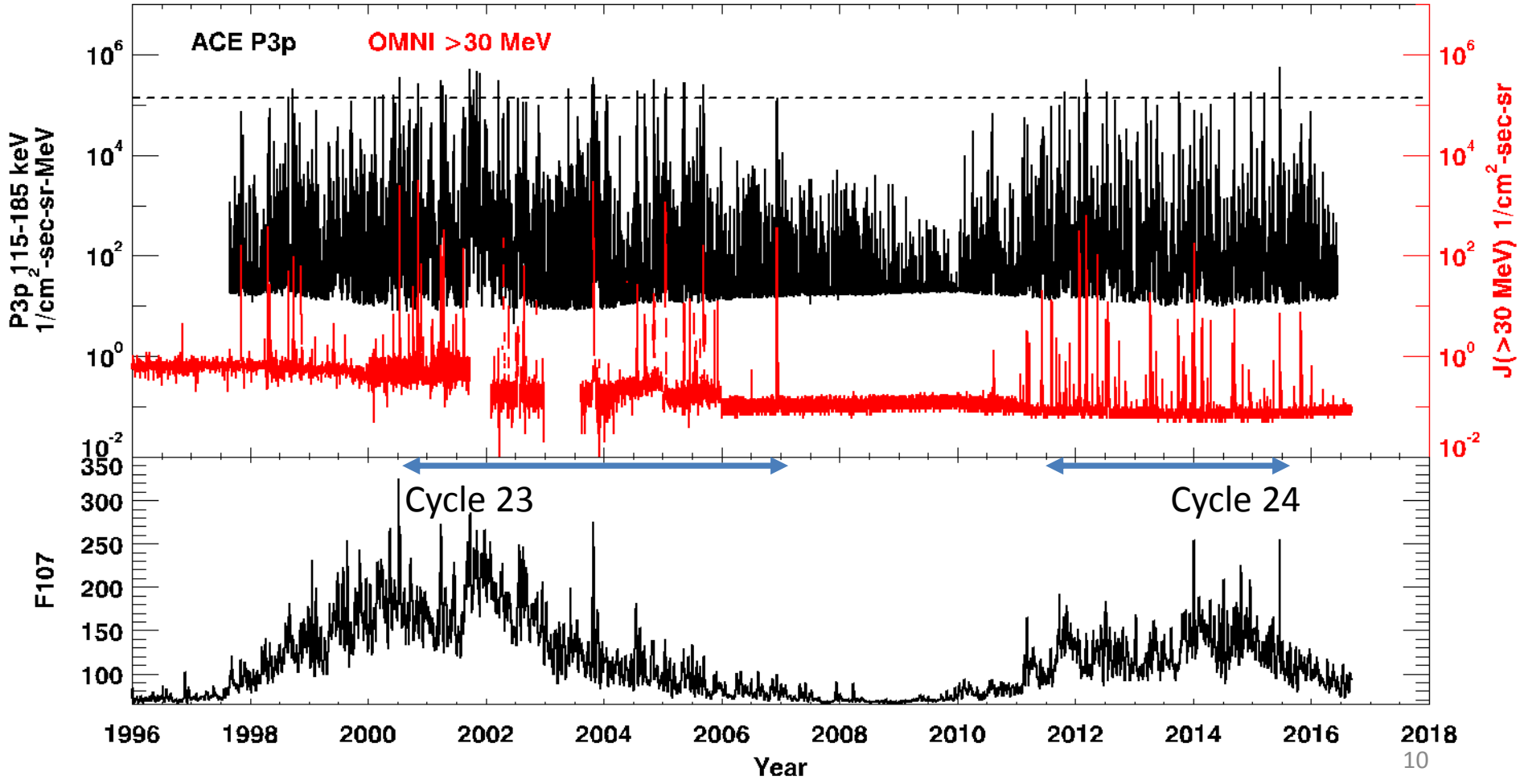
Last radiation interruption was in June of 2015!

* First radiation interruption since 2006 December 13 **First ACIS trigger event

Source: Chandra Radiation Central http://asc.harvard.edu/mta/RADIATION/

Radiation Intervention Summary

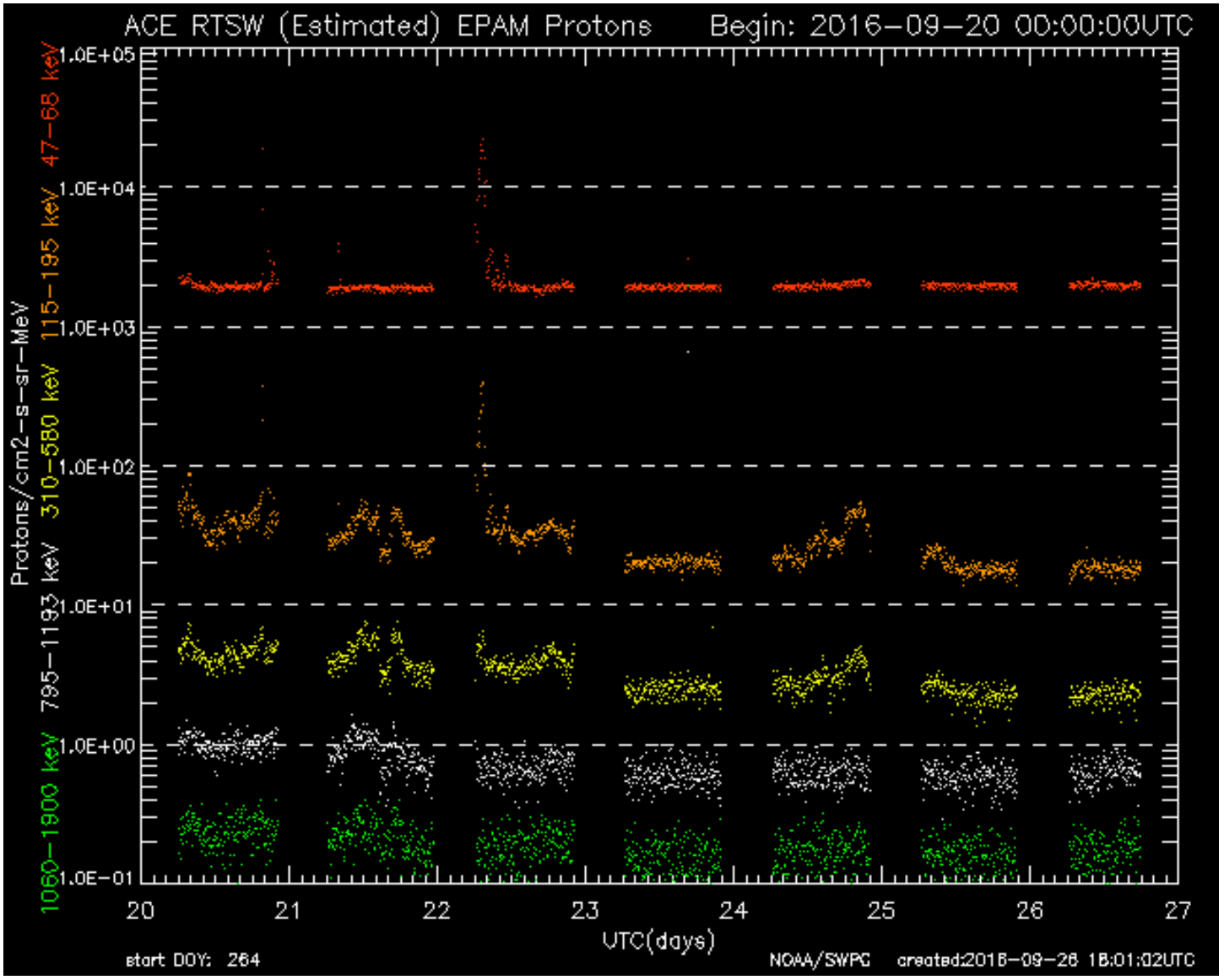
- Total of 89 interrupted science runs to date due to radiation
  - Solar Cycle 23 manual: 45 auto: 20 total: 65
  - Solar Cycle 24 manual: 12 auto: 12 total: 24



ACE Real Time Solar Wind (RTSW) Data

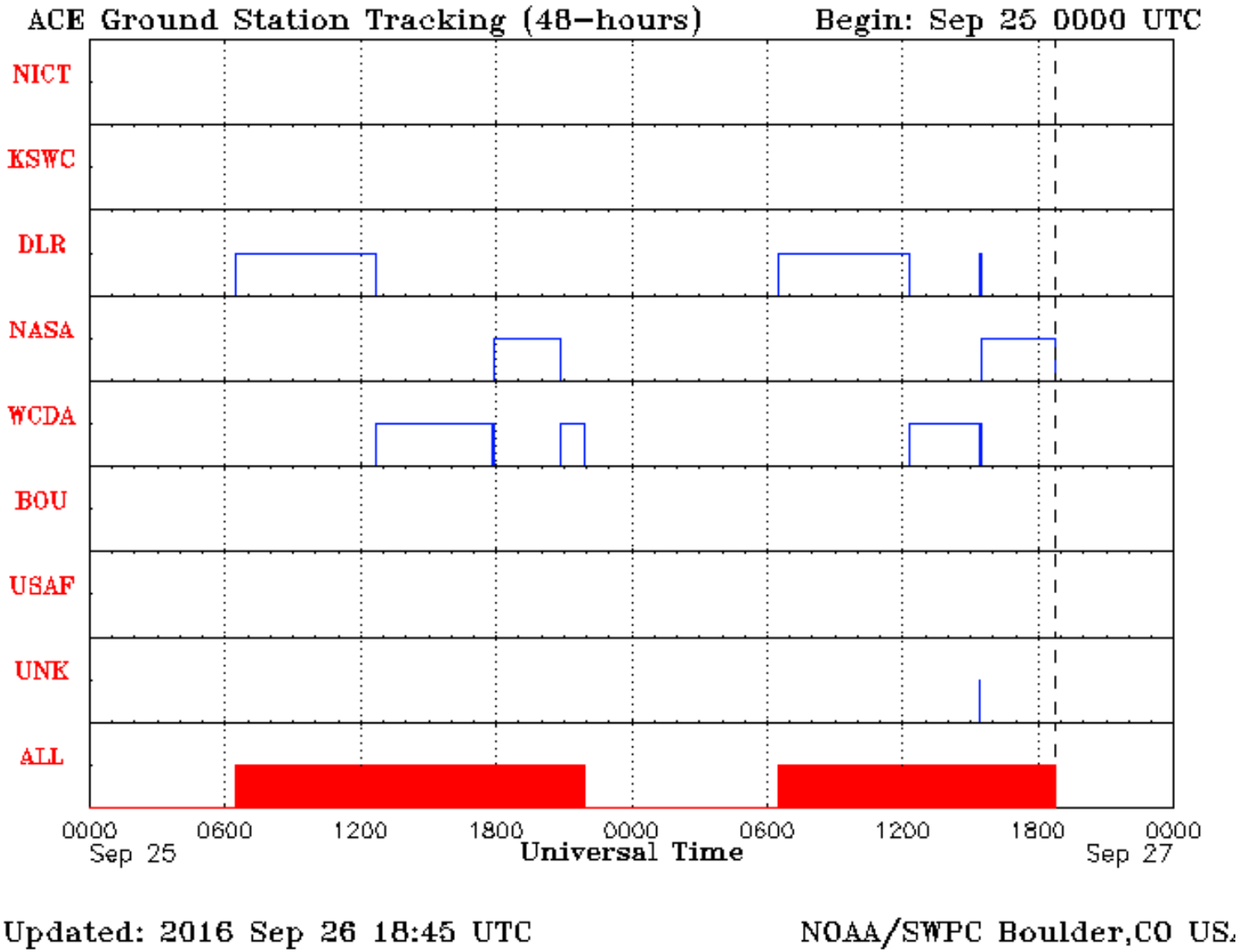
- ACE EPAM LEMS120 P3' (115-185 keV) RTSW record used to monitor interplanetary ~100-200 keV protons that damage ACIS front illuminated CCD's
  - Automated warning sent to operations team for high P3' fluence
  - Manual intervention used to protect ACIS if necessary
- Deep Space Climate Observatory (DSCOVR) replaced ACE on 27 July 2016 as NOAA's primary L1 real-time space weather data source
  - DSCOVR does not include an EPAM replacement instrument
- CXO strategy DSCOVR-era operations is to
  - Develop contingency plans to operate without ACE RTSW data
  - Work with NOAA SWPC to identify options for continuing ACE RTSW data
- NOAA agreed to a NASA request (CXO through SMD) to continue processing and distributing ACE RTSW data if NASA can provide the data to NOAA
  - NOAA SWPC's tracking station network is insufficient to support both ACE and DSCOVR
  - NASA, with NOAA SWPC support, is working on identifying additional tracking stations for ACE

ACE RTSW EPAM Protons



http://services.swpc.noaa.gov/images/ace-epam-p-7-day.gif

ACE Ground Stating Tracking Summary



http://services.swpc.noaa.gov/images/ace-tracking-48-hour.gif

ACE RTSW Tracking Station Status

Current ACE RTSW availability remains at >66% coverage:

- NASA Deep Space Network (DSN) at Goldstone and White Sands will continue to provide ~3.5 hr/day RTSW signal during science downlink [*confirmed*]
- NOAA Wallops Command and Data Acquisition Station (WCDA) continues to provide ~7 hr/day [*TBD*]
- DLR continues to provide ~6 hr/day [*TBD*]

RTSW available ~16 to 17 hr/day with ~7 to 8 hr/day gap, minimally acceptable for CXO needs (CXO satellite contacts are once every ~8 hr, prefer ACE data every 4 to 6 hr)

In work:

- Confirm future plans for WCDA and DLR for continued ACE RTSW support
- John Hopkins University/ Applied Physics Laboratory has a demonstrated capability to acquire ACE RTSW data, agreed to support ACE RTSW effort (0.5 to 1.5 hours/day)
- Investigating ability of DSN to acquire ACE RTSW during Madrid, Canberra contacts (~1 to 1.5 hours about every other day)
- Additional efforts to establish capability for acquiring ACE RTSW underway:
  - Roenne, Germany has acquired signal, working technical issues
  - RBC Signals using antenna in Fairbanks, Alaska working to acquire signal

Questions?