Quasi-Periodic Pulsations 14 May 2013

Brian Dennis

RHESSI Workshop

Graz, Austria

27 – 30 July, 2016

Long-lived X-ray Quasi-Periodic Pulsations in the X-class Solar Flare on 2013 May 14

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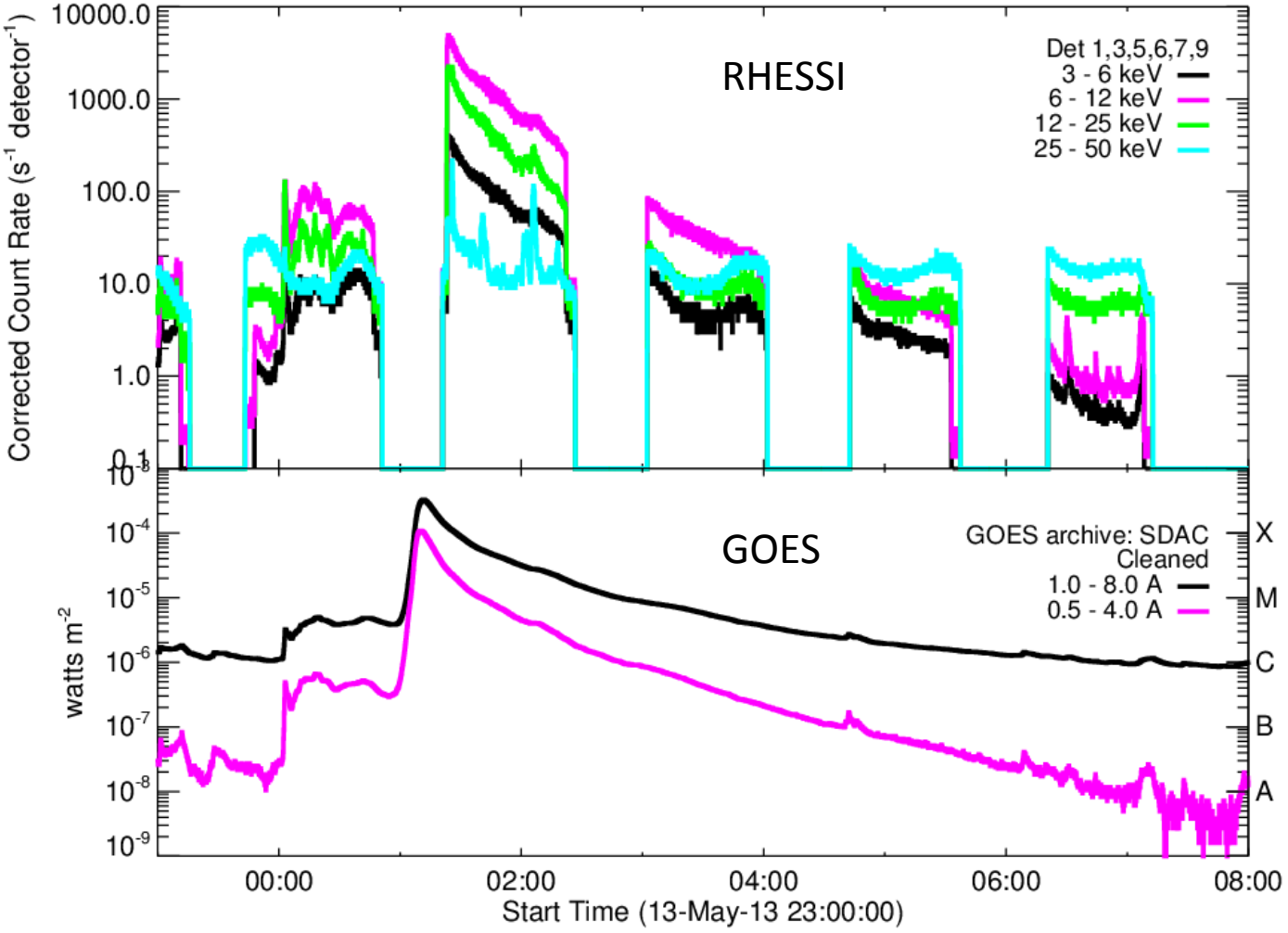
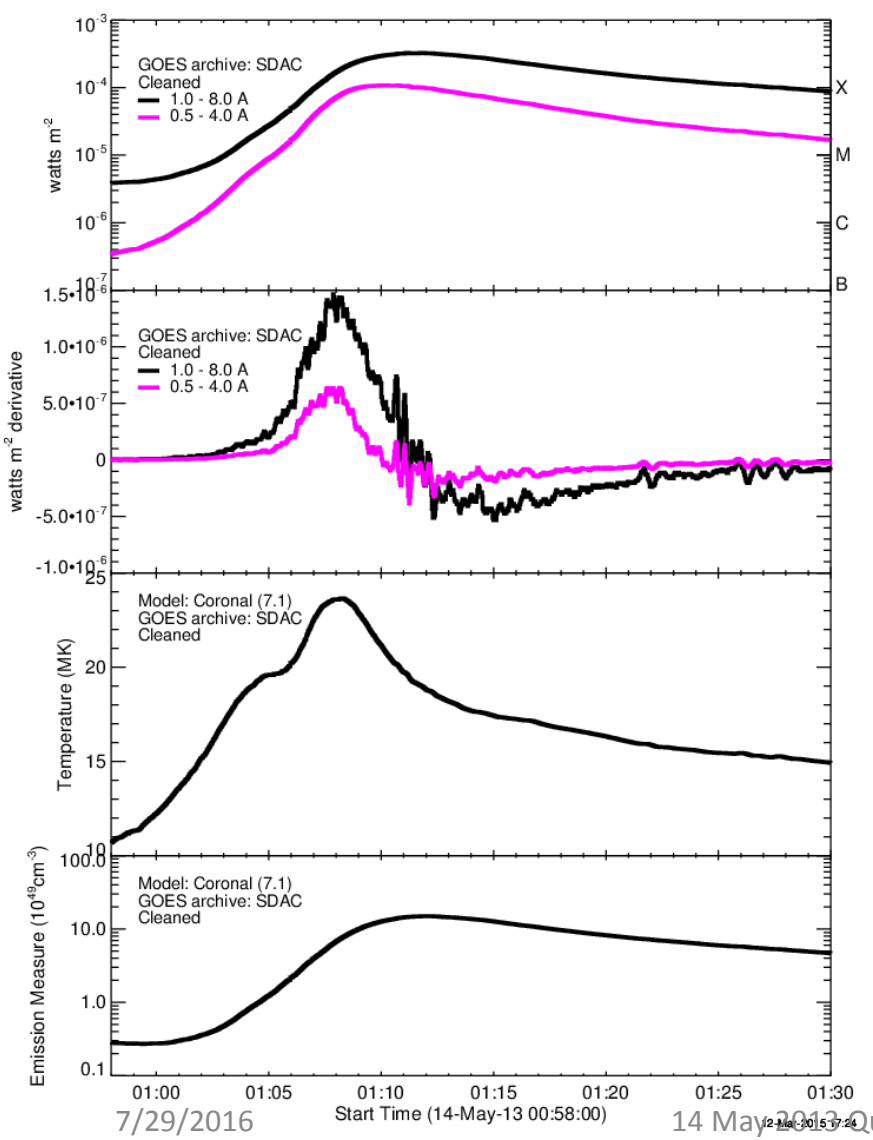
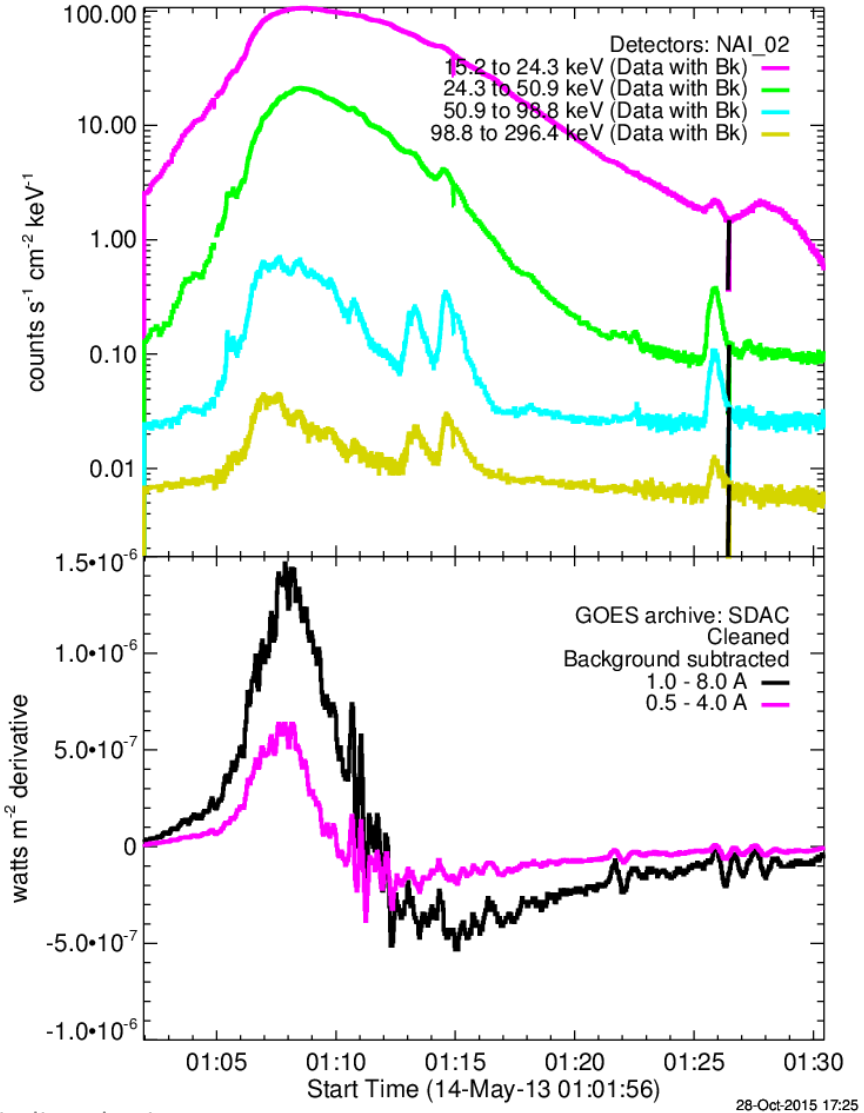
14 May 2013, RHESSI & GOES



14 May 2013, GOES & Fermi



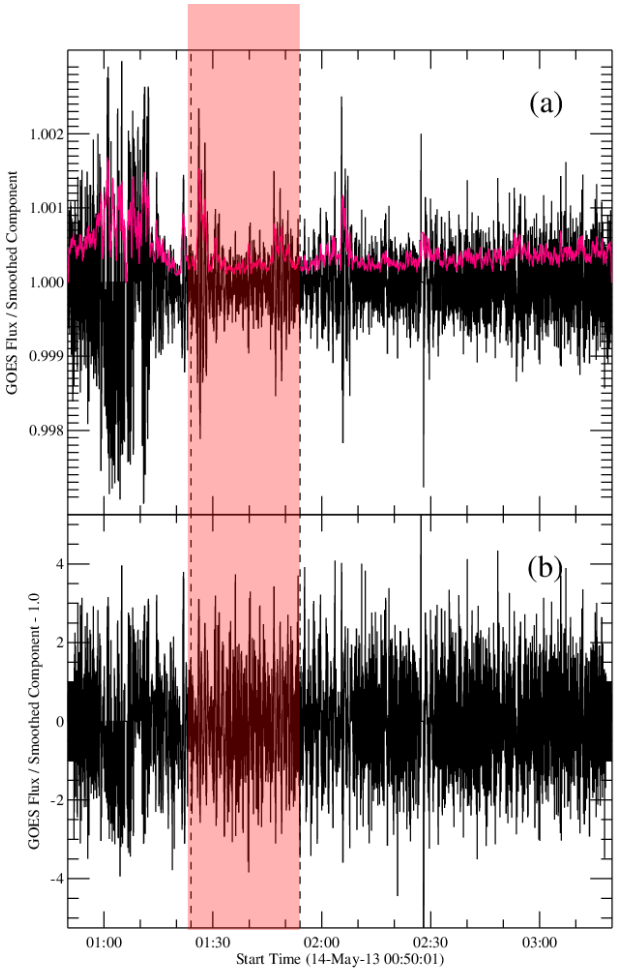


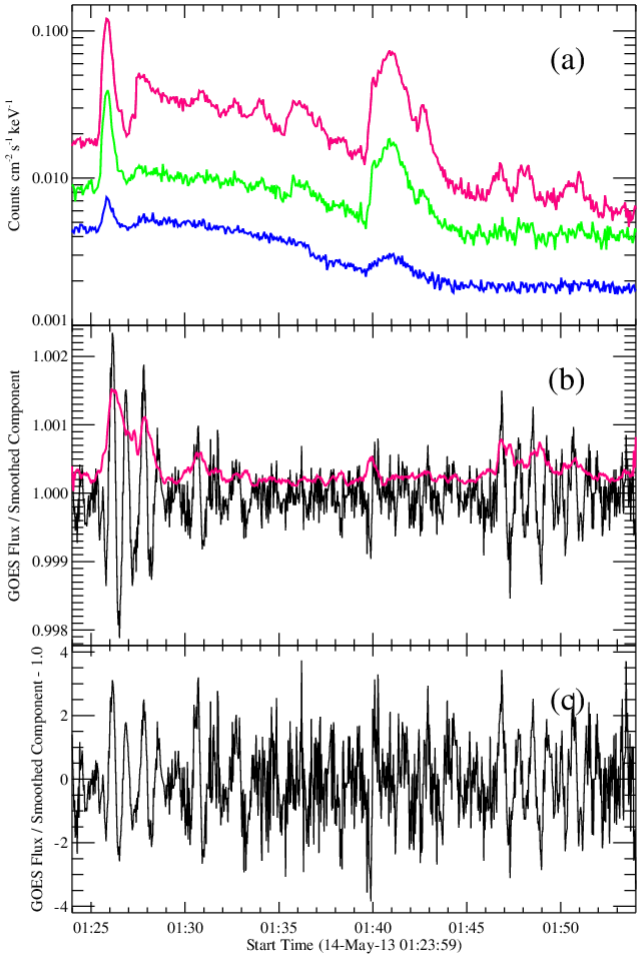
14 May 2013
Flux Normalization

GOES
1 – 8 Å

$\text{flux}/\overline{\text{flux}}$

$$\frac{\text{flux} - \overline{\text{flux}}}{\overline{\text{flux}}}$$





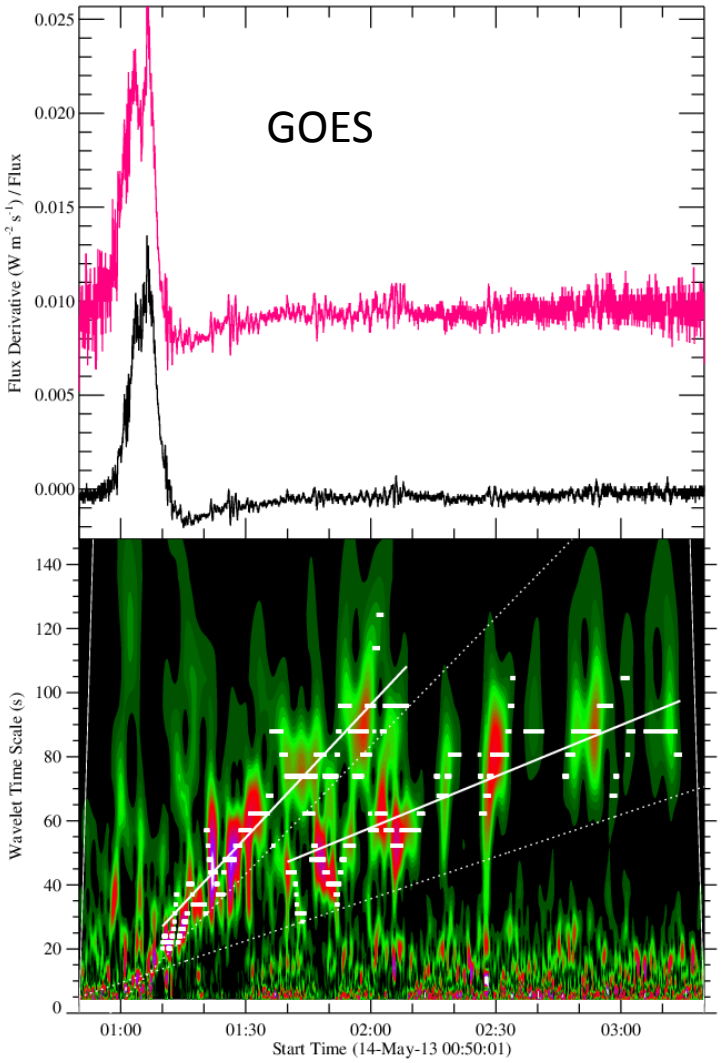
RHESSI
6 – 12 keV
12 – 25 keV
25 – 50 keV

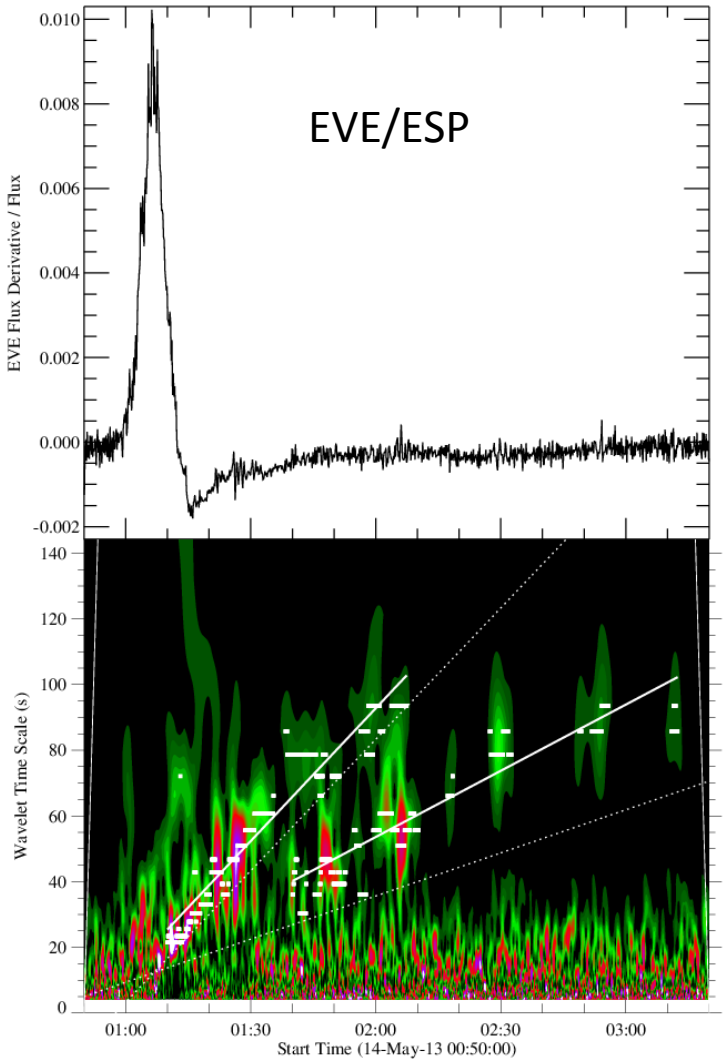
GOES
1 – 8 Å

$\text{flux}/\overline{\text{flux}}$

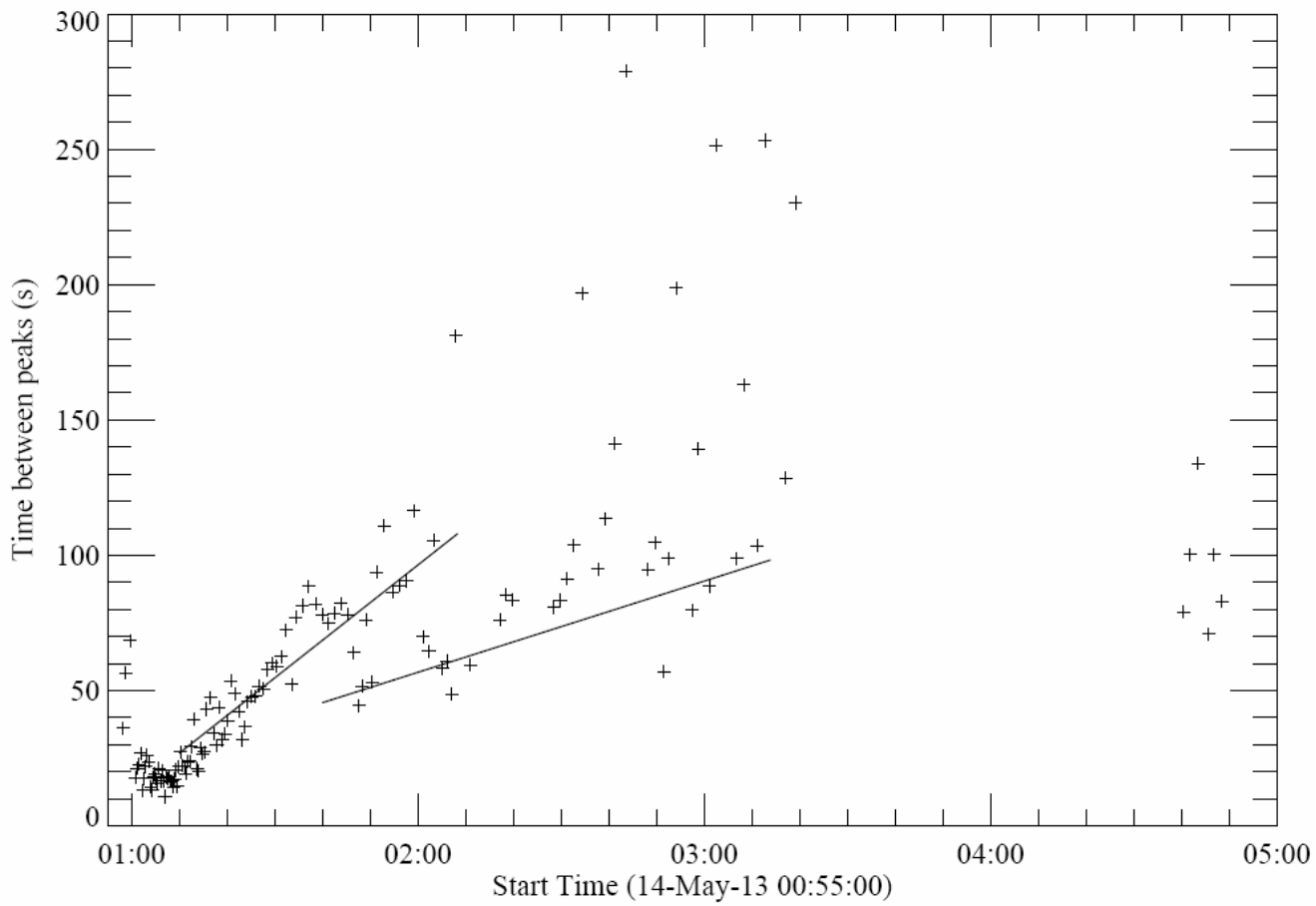
$$\frac{\text{flux} - \overline{\text{flux}}}{\overline{\text{flux}}}$$

14 May 2013 – Wavelet Analysis





14 May 2013
Time between peaks

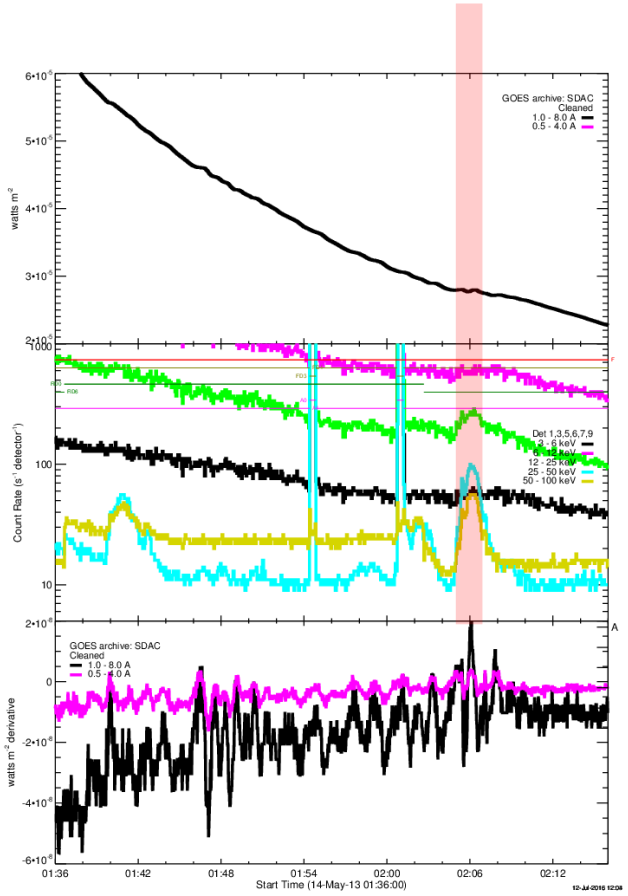


14 May 2013
AIA & RHESSI Images

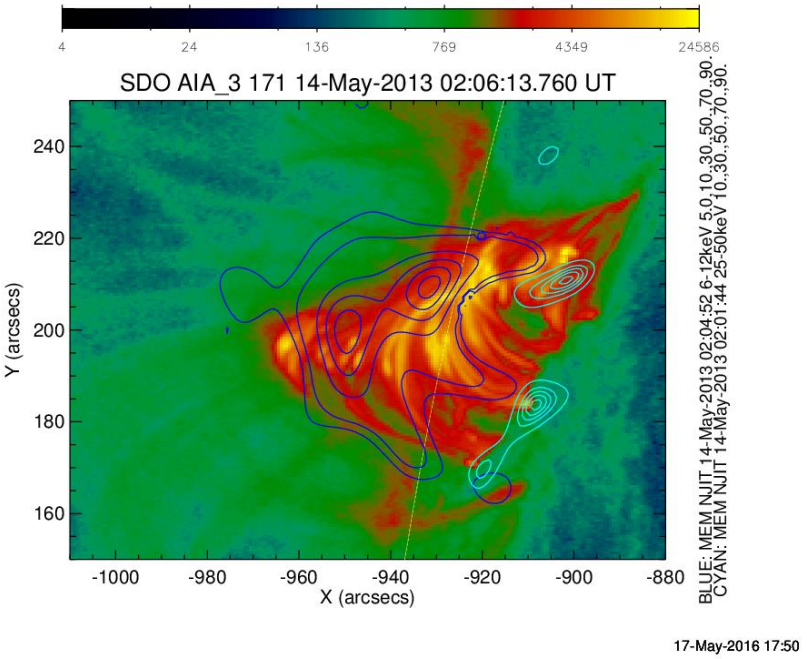
GOES Flux

RHESSI Flux

GOES Derivative



AR 1748



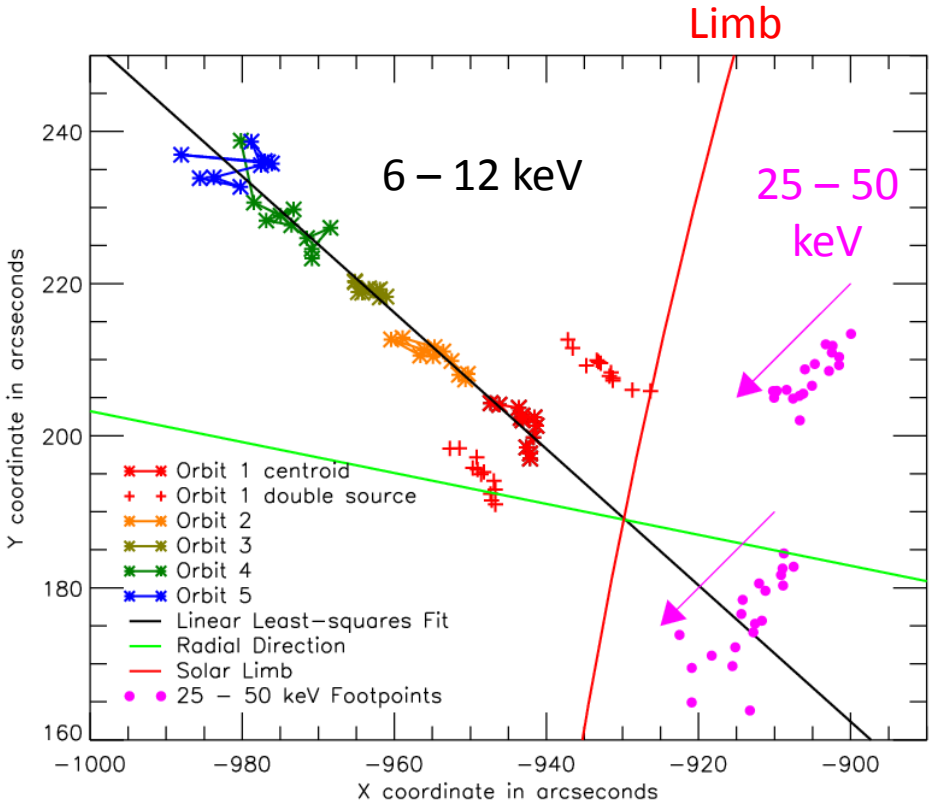
Color: AIA 171 Å

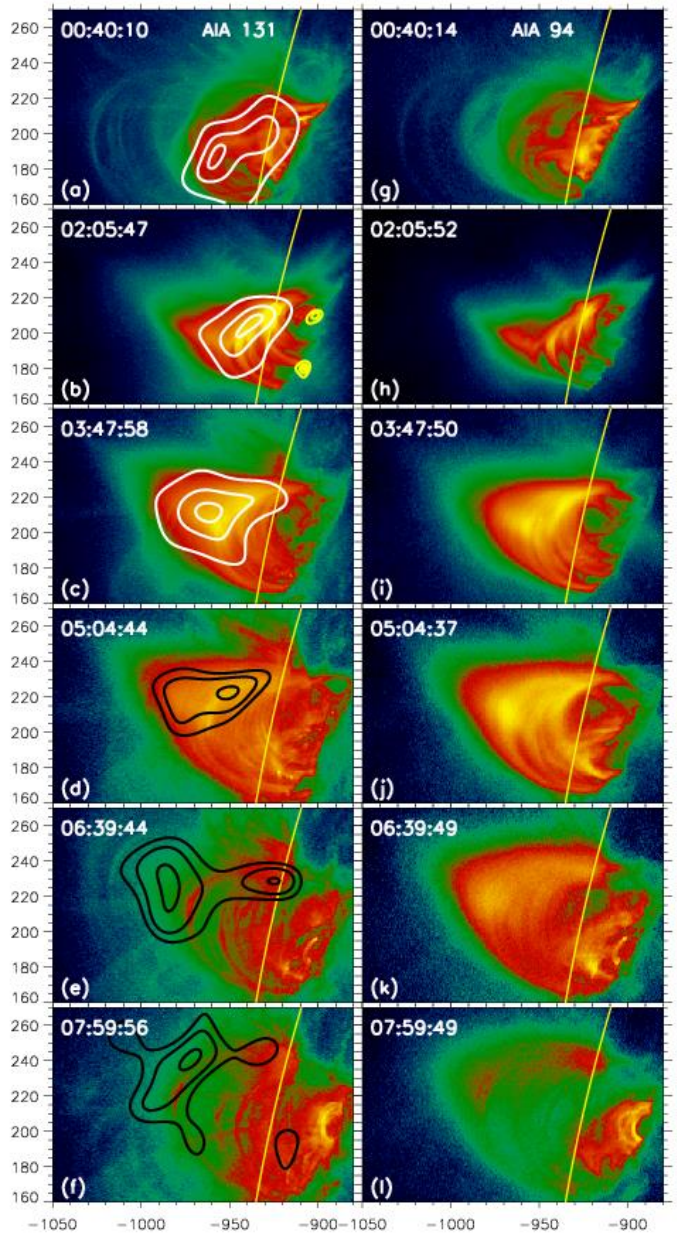
Contours: RHESSI

Blue 6 – 12 keV

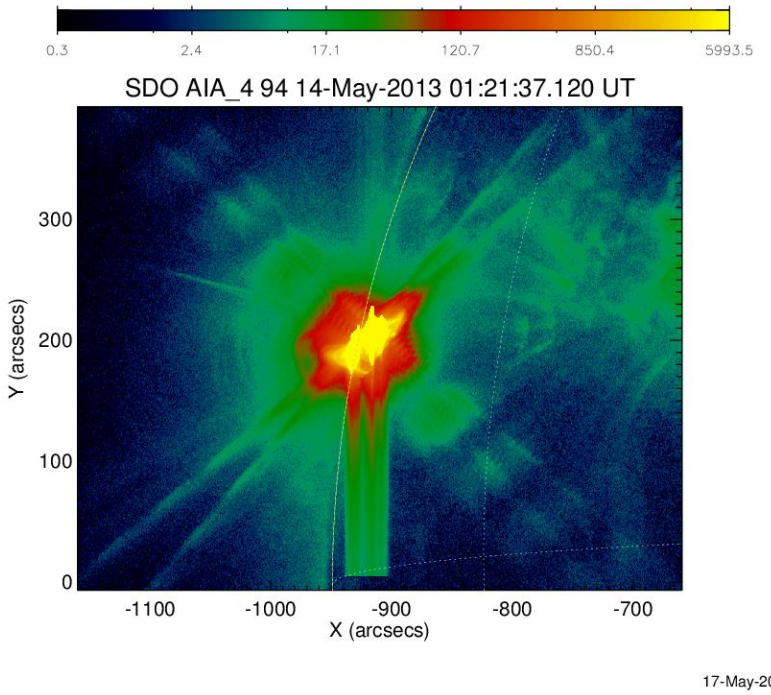
Cyan 25 – 50 keV

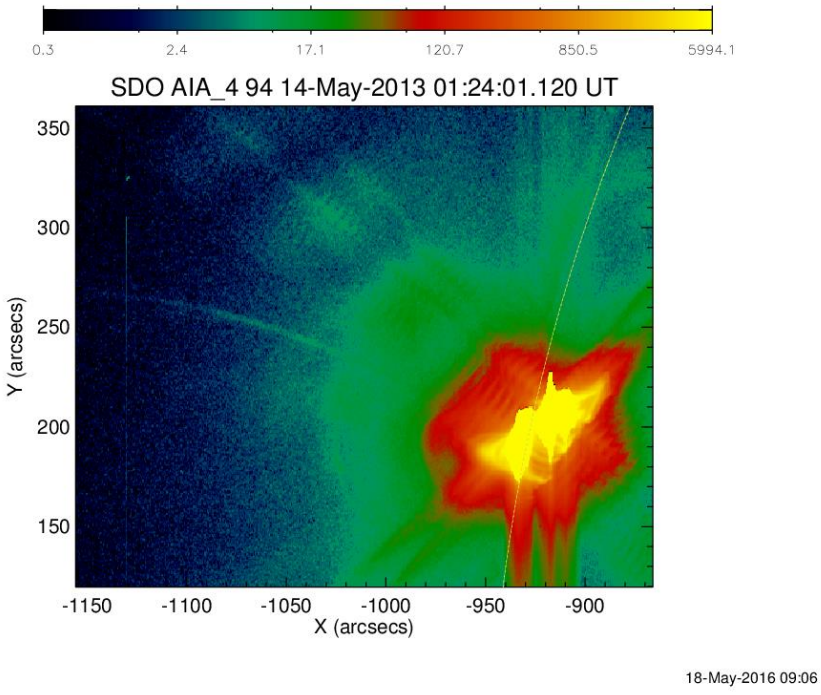
14 May 2013 RHESSI Imaging





14 May 2013
AIA 94 Å Current Sheet

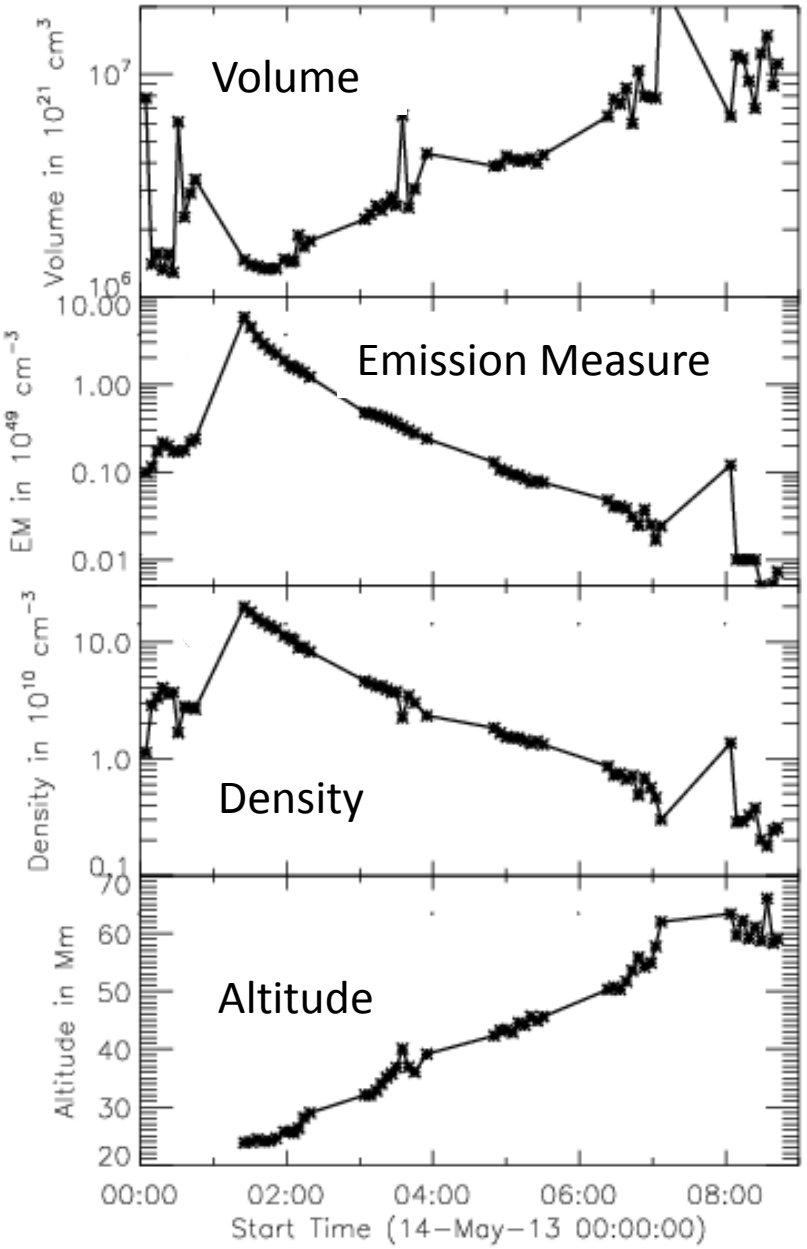




14 May 2013

RHESSI

3 – 6 and 6 – 12 keV



Coronal Magnetic Field Estimate

Assume QPP are consistent with **vertical kink mode oscillations** in the newly formed magnetic loops resulting from reconnection in the current sheet stretching up to the base of the CME.

Kink-mode period, $P_k = 2\sqrt{2}\, L/v_A$

$L = \pi\, h/2\ cm$ - loop half length with height, h, obtained from RHESSI images,

$v_A = D\, B/\sqrt{n}\ cm\ s^{-1}$ - Alfven speed,

$D = 1.93 \times 1011$, B is the magnetic field in gauss.

$n = \sqrt{\frac{EM}{f\, V}}$ - plasma density in loop, assumed large compared to outside loop

EM is emission measure from GOES fluxes, f - filling factor assumed = 1.

$V = \pi\, \sigma_x\, \sigma_y\, (\sigma_x + \sigma_y)/2$ is the source volume estimated from RHESSI 6 – 12 keV images.

$\sigma_{x,y}$ - second moments of RHESSI source.

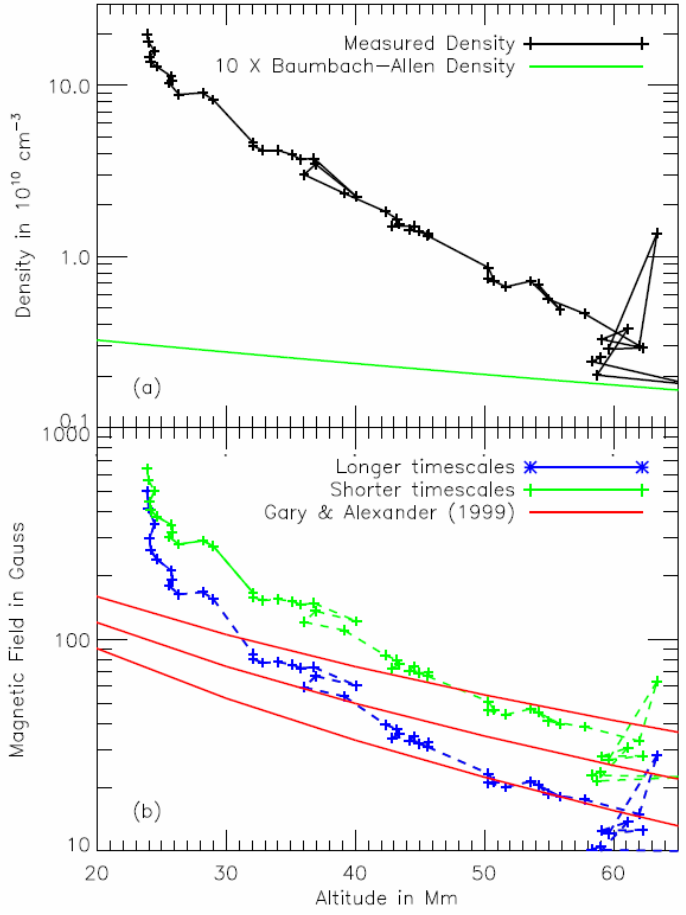
Let $Pk(t) = \tau(t) -$ time scale at peak wavelet power at time, t < 03:20 UT.

Linearly extrapolate the trend lines for t >03:30 UT.

Then,

$$B = \pi\sqrt{2n}\, h\, /(D\, \tau)$$

14 May 2013
Density & Magnetic Field vs. Altitude



Conclusions

- GOES X3.2 flare on 14 May 2013
- QPP seen for >2 hours – 163 peaks.
- Time scale increases from ~25 to ~100 s in ~1 hour.
- Consistent with vertical kink mode oscillations with

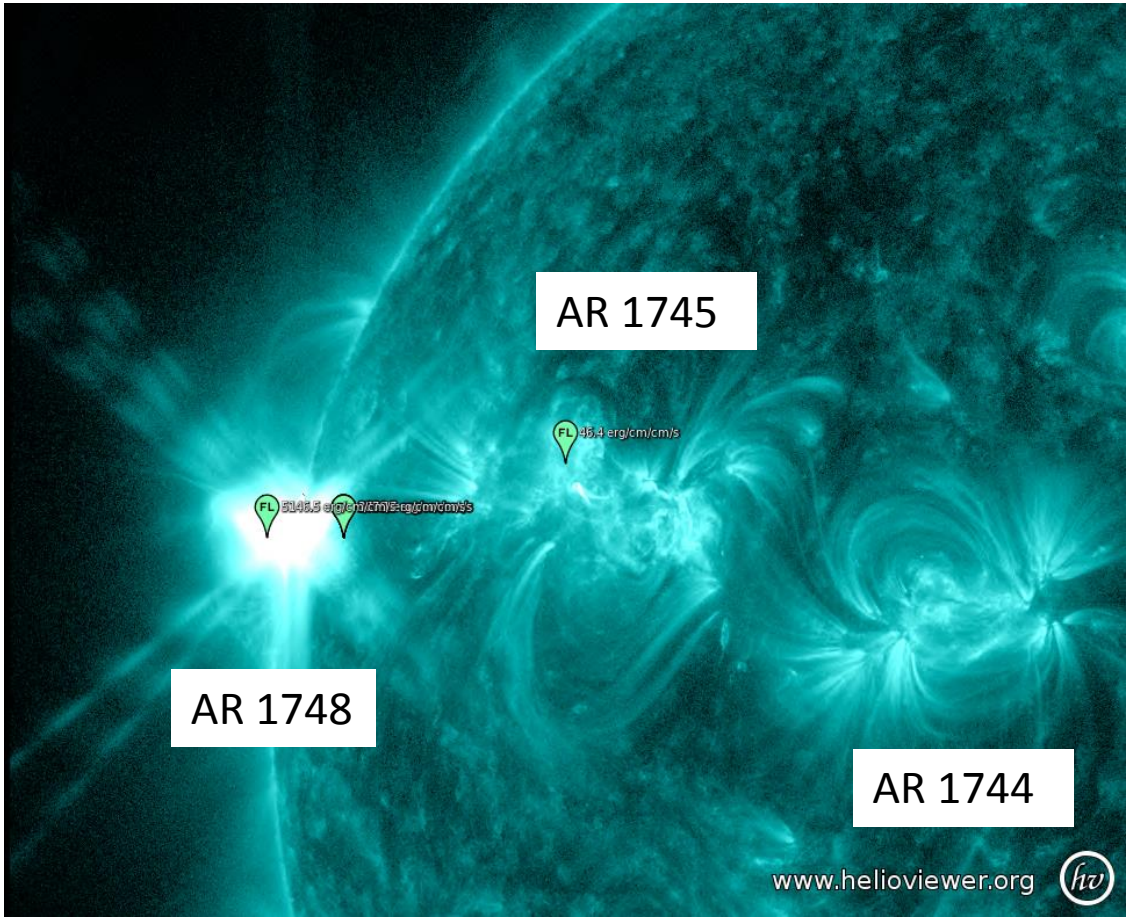
$$P_k = 2\sqrt{2}\, L/v_A$$

B = 500 G at 24 Mm

→ 10 - 40 G at 60 Mm

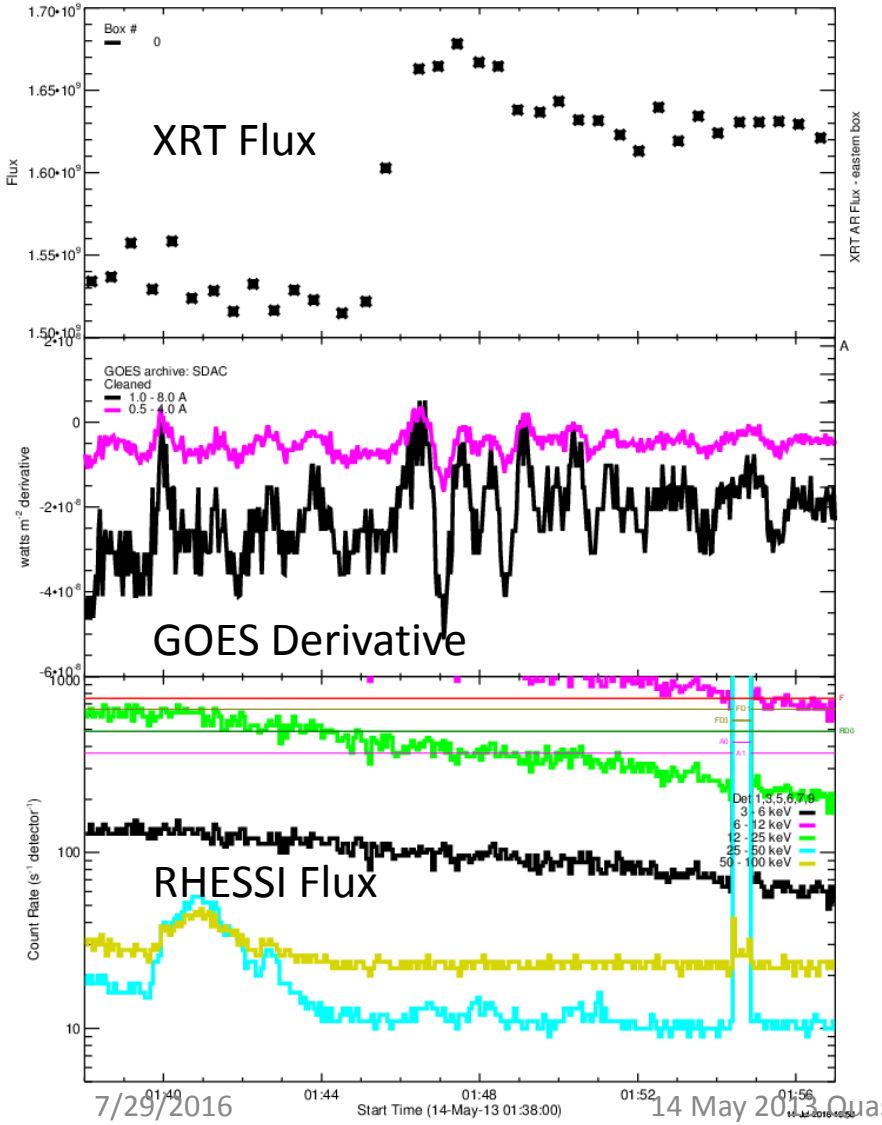
- Density = 2×10^{11} cm^{-3} at 24 Mm
  2×10^{10} cm^{-3} at 60 Mm

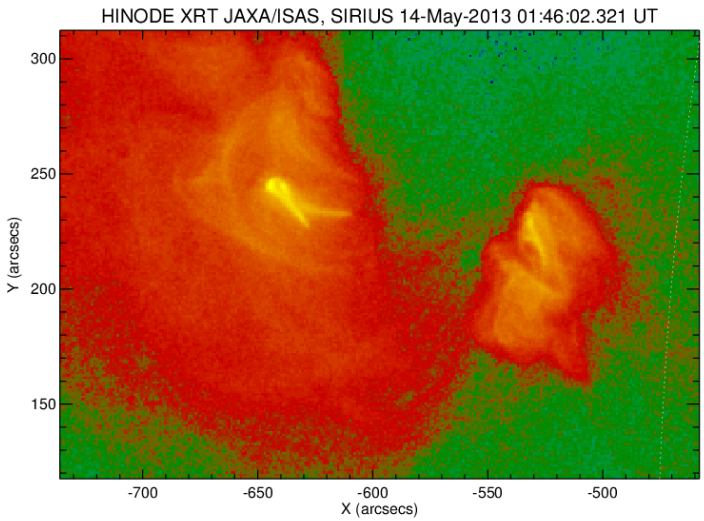
14 May 2013 01:45 UT
AIA 131 Å

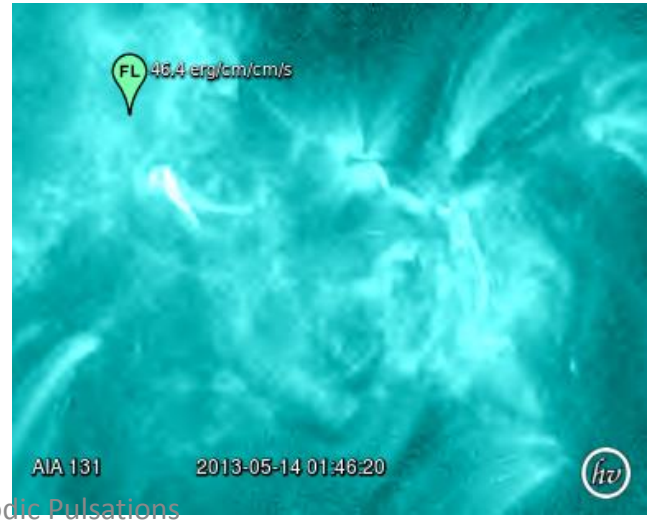


14 May 2013

XRT & AIA 131Å
Flare from different location
AR 1745



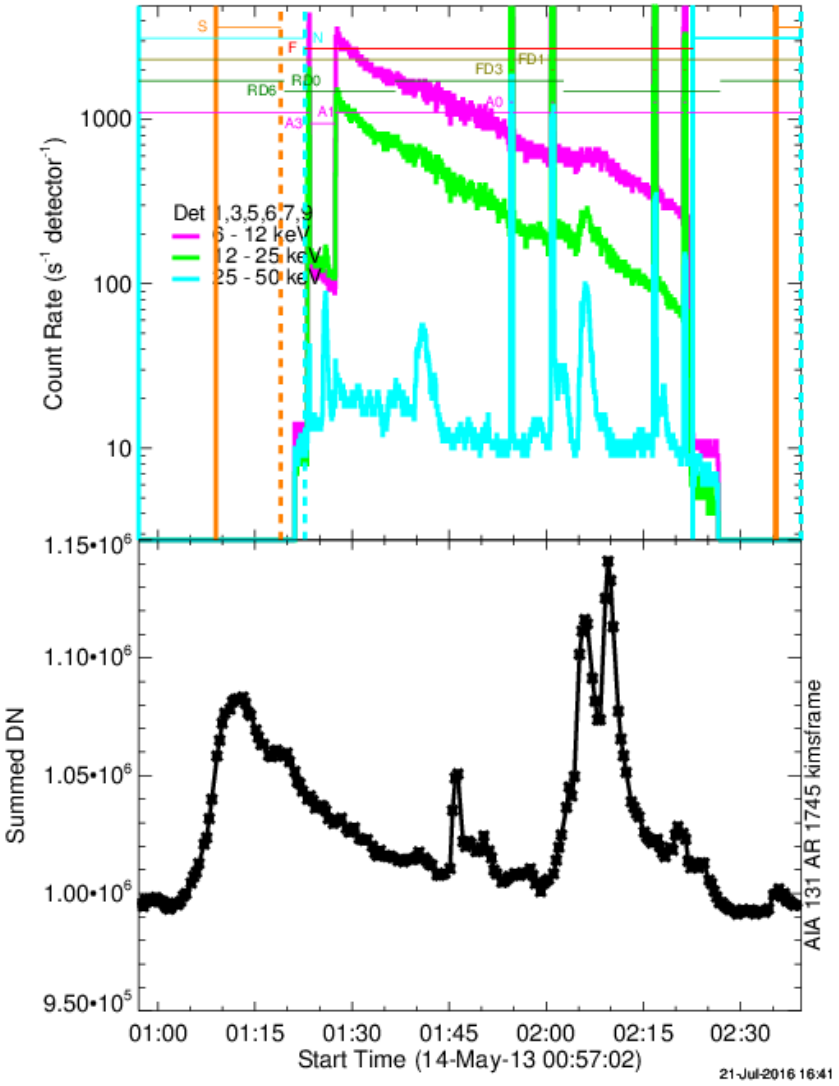




14 May 2013

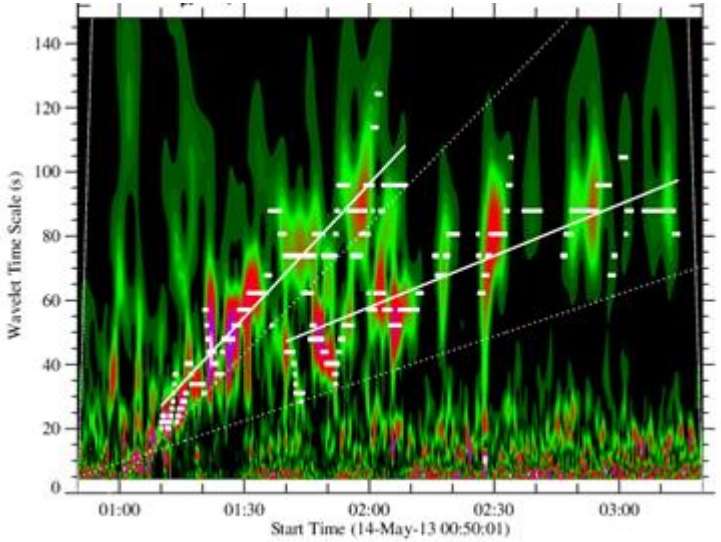
RHESSI
6 – 50 keV

AIA 131 Å
Flux from
AR1745

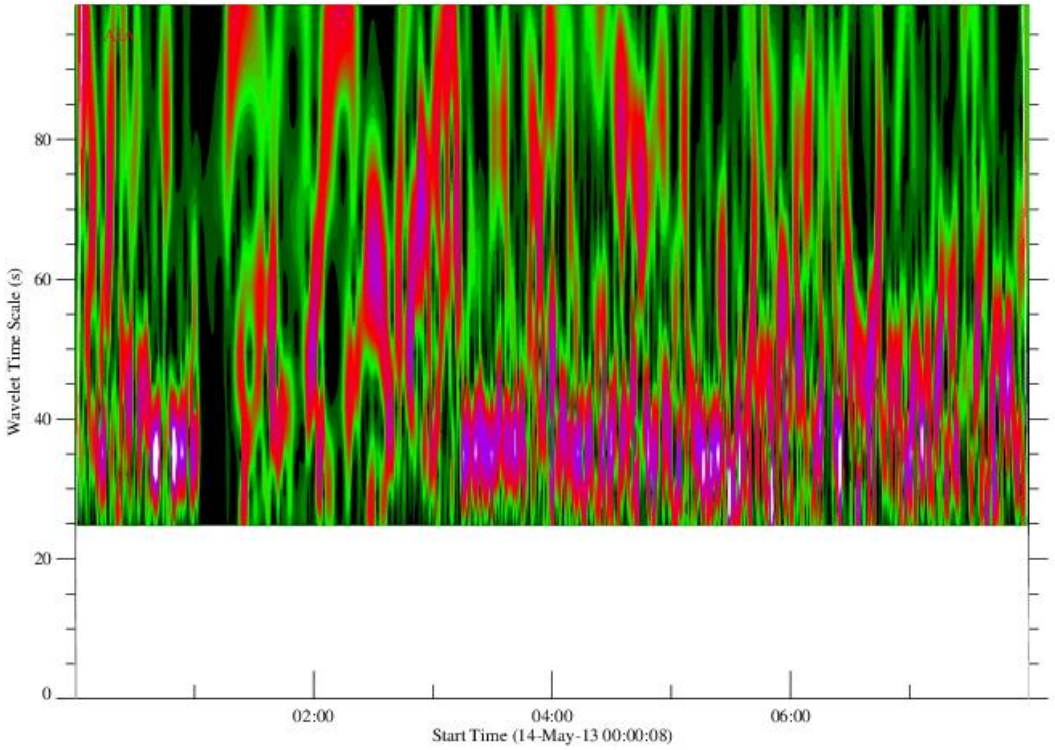


14 May 2013
Wavelet Power

GOES



AIA 131 Å, AR1458 fullframe



New Conclusions

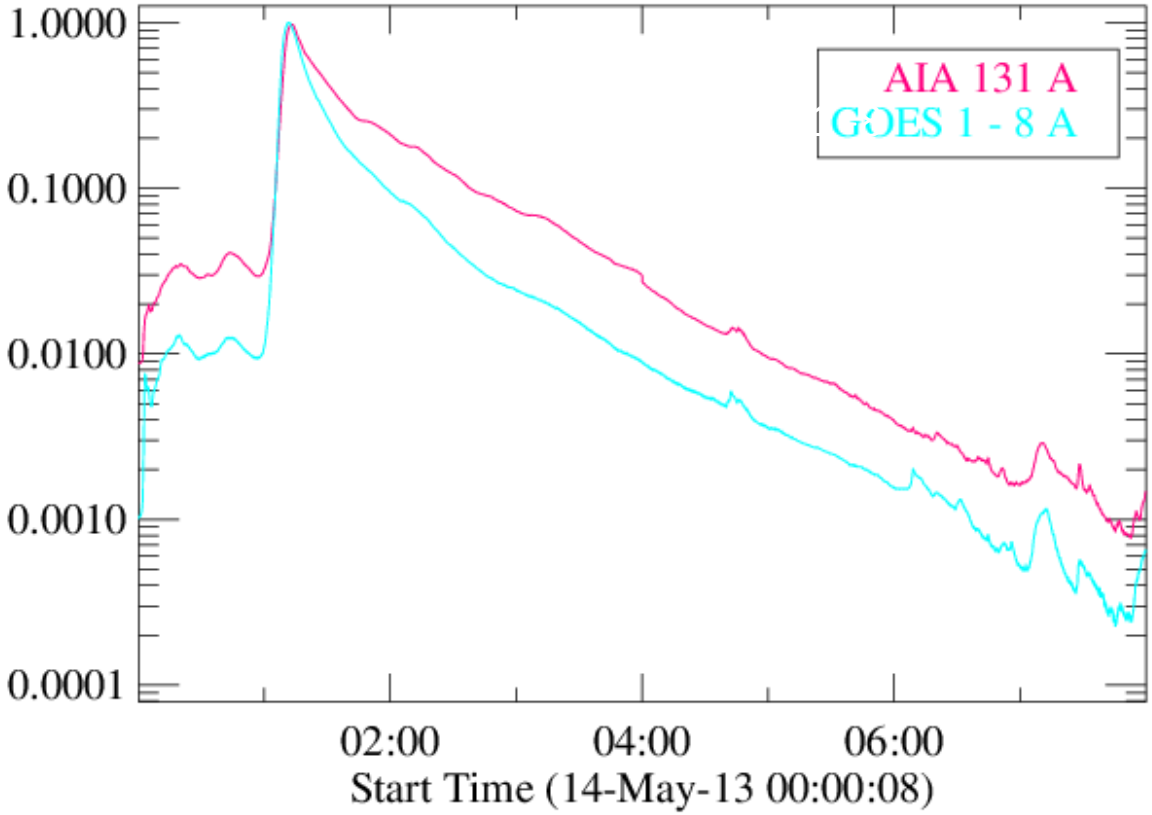
- GOES X3.2 flare on 14 May 2013
- QPP seen for >~~21~~ hours – fewer than 163 peaks.
- Time scale increases from ~25 to ~100 s in ~1 hour.
- Consistent with vertical kink mode oscillations with

$$P_k = 2\sqrt{2}\, L/v_A$$

→ B = 500 G at 24 Mm
10 - 40 G at 60 Mm

- Density = 2×10^{11} cm^{-3} at 24 Mm
2×10^{10} cm^{-3} at 60 Mm

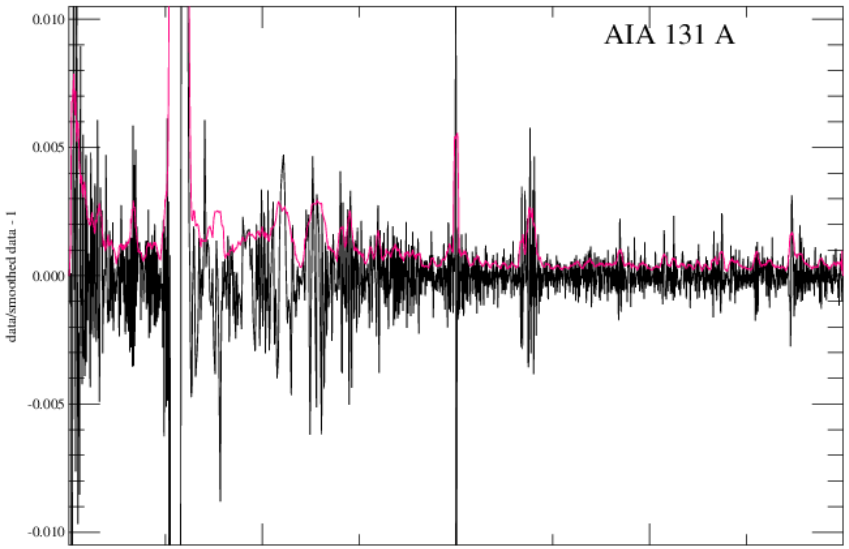
14 May 2013 AIA 131 Å AR1748 Fullframe Light Curve

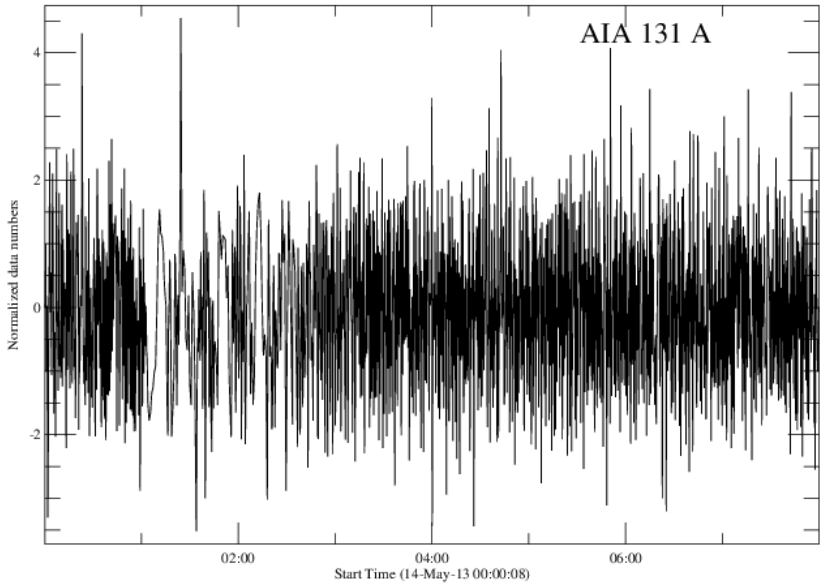


14 May 2013

AIA 131 Å

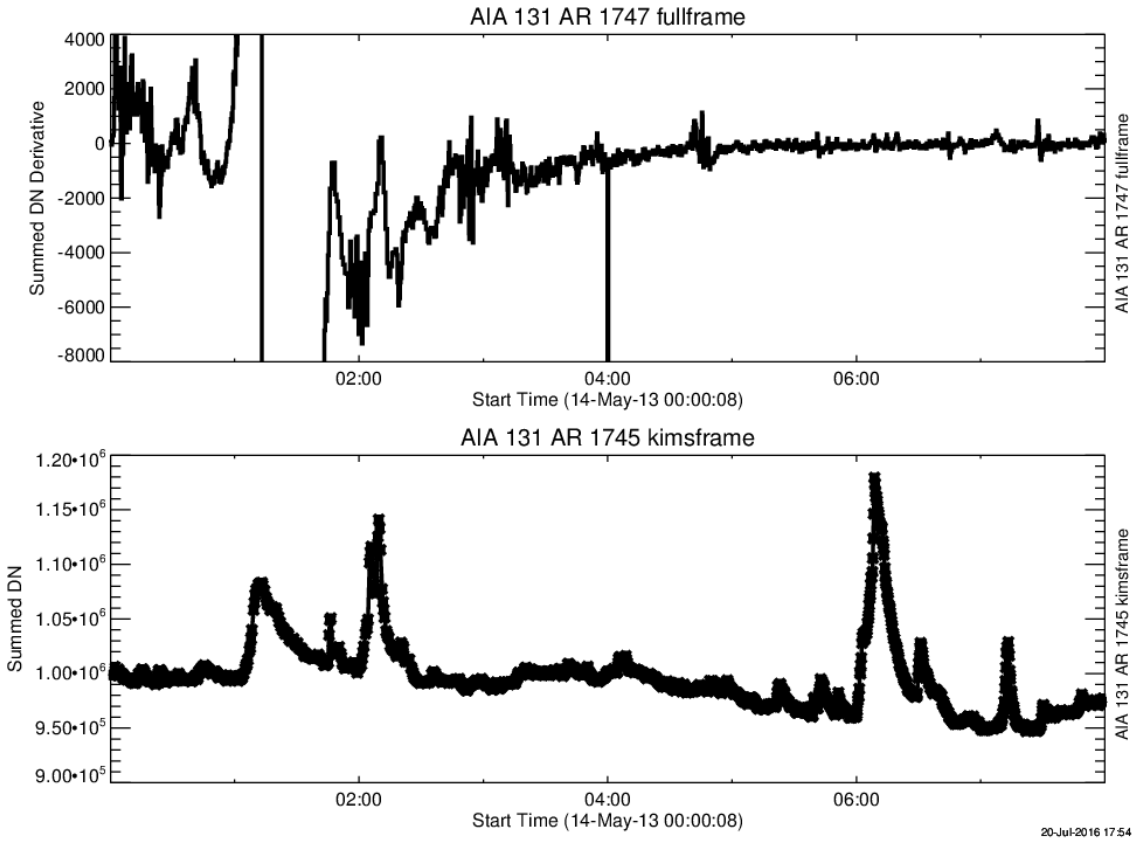
AR 1458



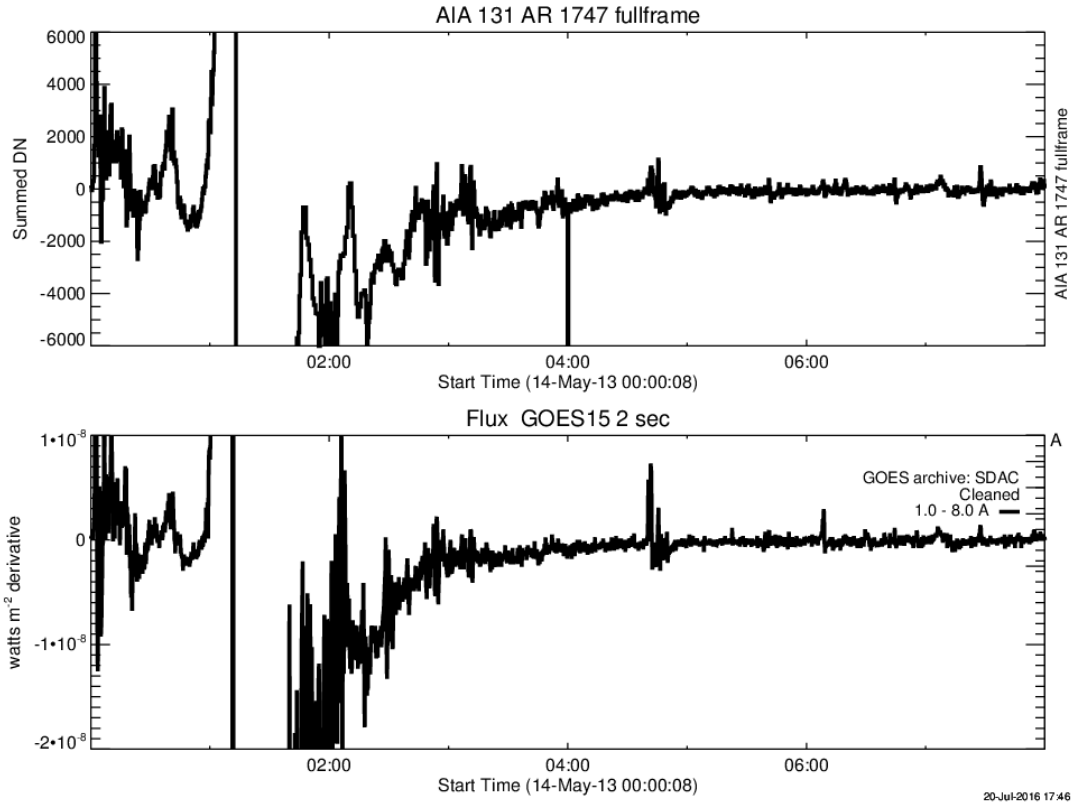


New Conclusions

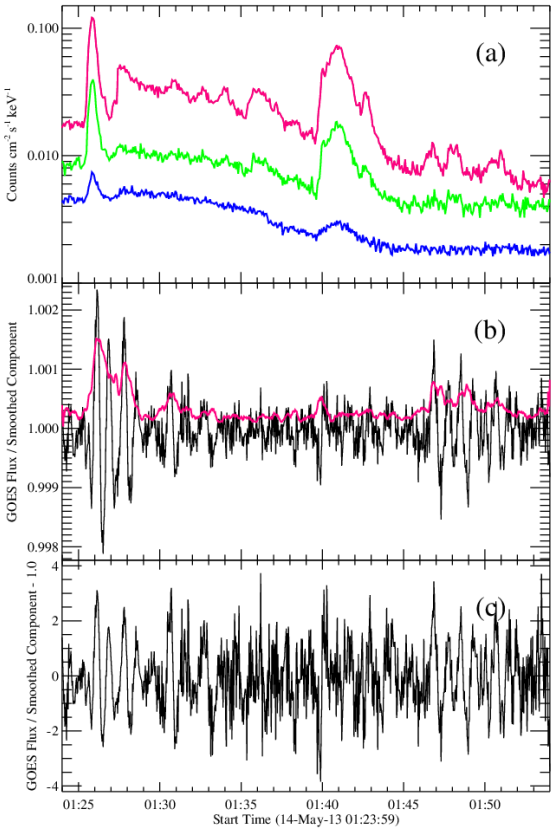
14 May 2013
AIA 131 Å lightcurves
AR 1745 & 1747

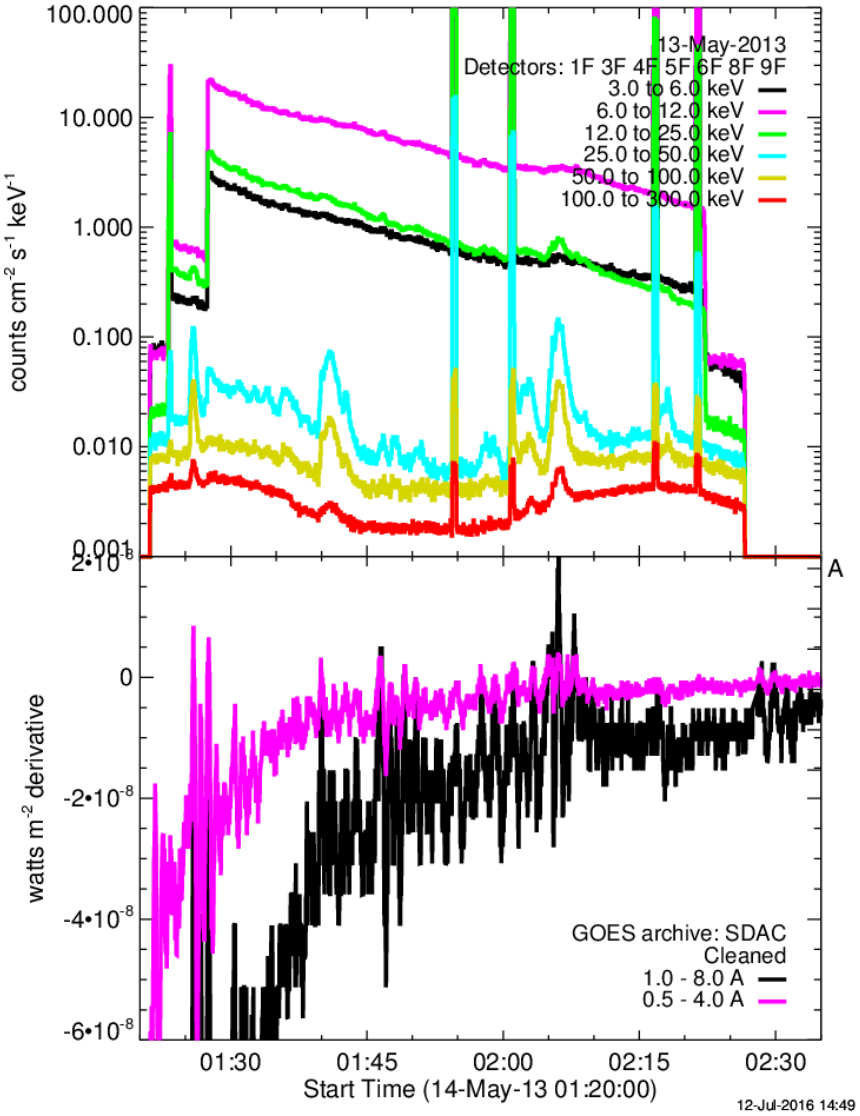


14 May 2013
AIA 131 Å & GOES Time Derivatives

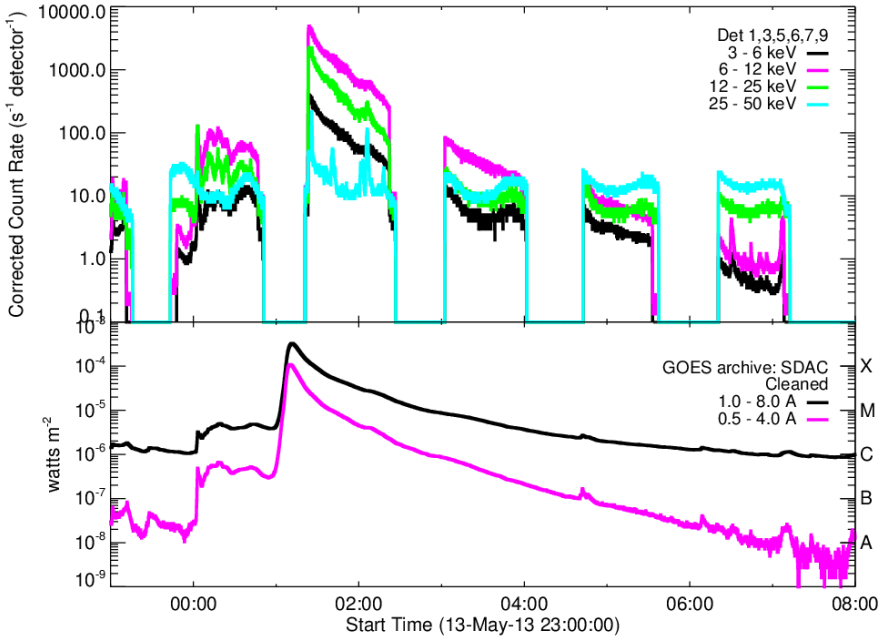


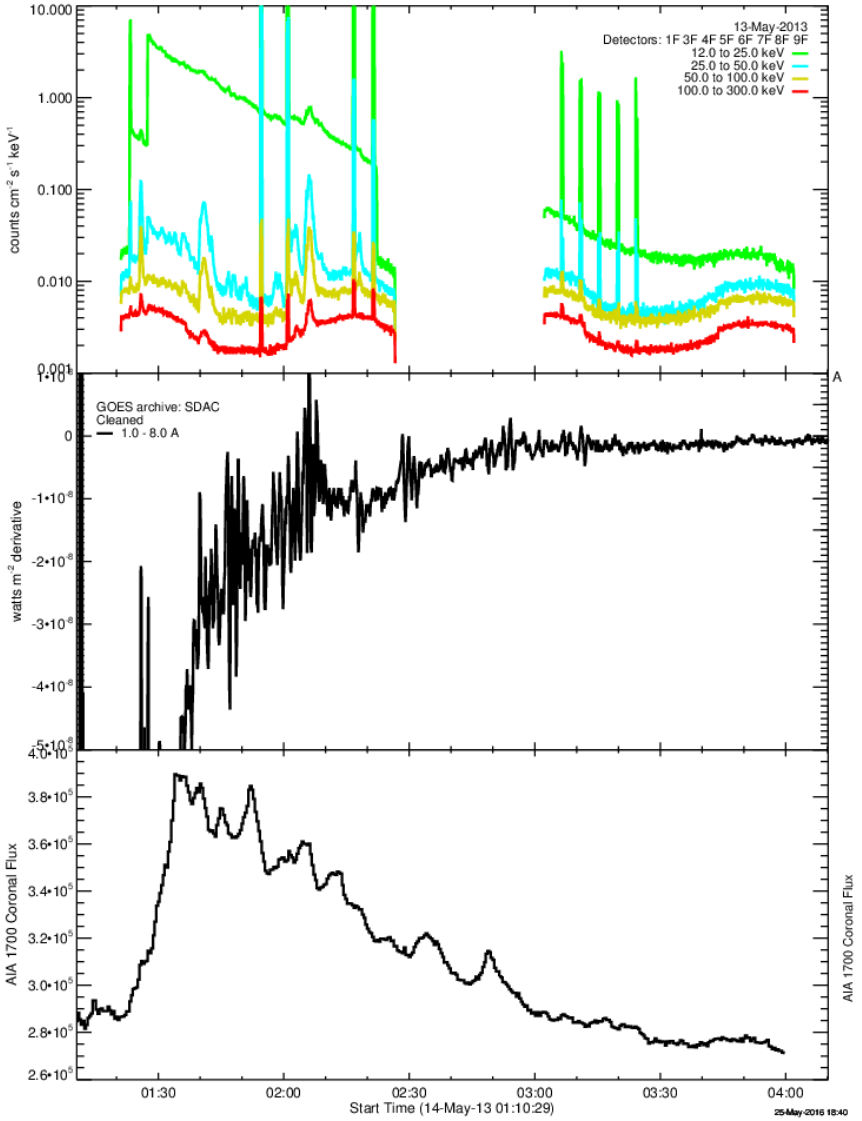
14 May 2013

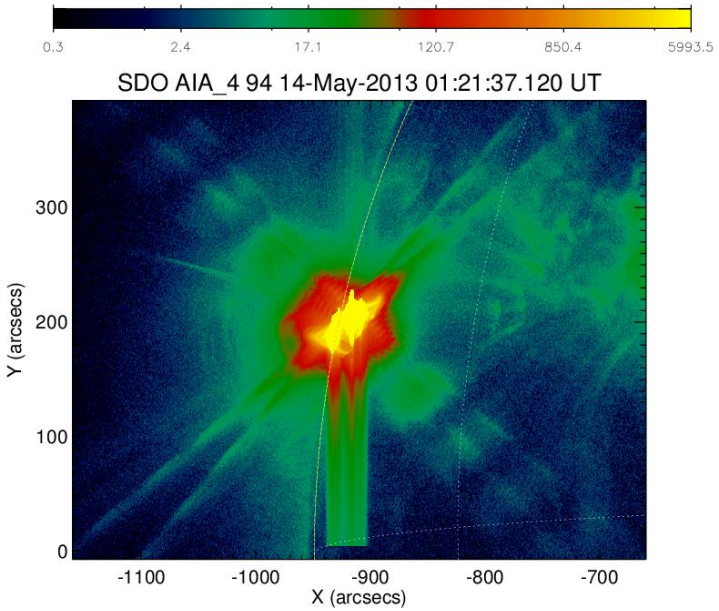

(a)
(b)
(c)
Counts cm^{-2} s^{-1} keV^{-1}
GOES Flux / Smoothed Component
GOES Flux / Smoothed Component - 1.0
0.100
0.010
0.001
1.002
1.001
1.000
0.999
0.998
4
2
0
-2
-4
01:25
01:30
01:35
01:40
01:45
01:50
Start Time (14-May-13 01:23:59)

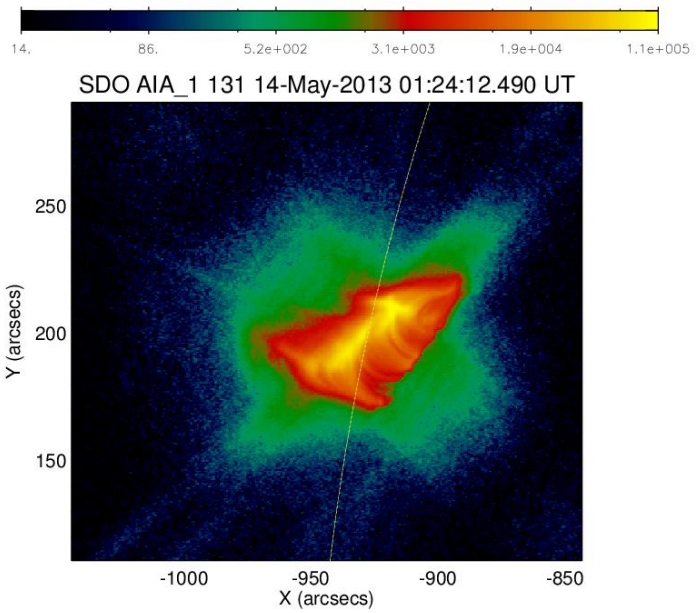

13-May-2013
Detectors: 1F 3F 4F 5F 6F 8F 9F
3.0 to 6.0 keV
6.0 to 12.0 keV
12.0 to 25.0 keV
25.0 to 50.0 keV
50.0 to 100.0 keV
100.0 to 300.0 keV
counts cm^{-2} s^{-1} keV^{-1}
100.000
10.000
1.000
0.100
0.010
0.001
watts m^{-2} derivative
2•10^{-8}
0
-2•10^{-8}
-4•10^{-8}
-6•10^{-8}
A
GOES archive: SDAC
Cleaned
1.0 - 8.0 A
0.5 - 4.0 A
01:30
01:45
02:00
02:15
02:30
Start Time (14-May-13 01:20:00)
12-Jul-2016 14:49

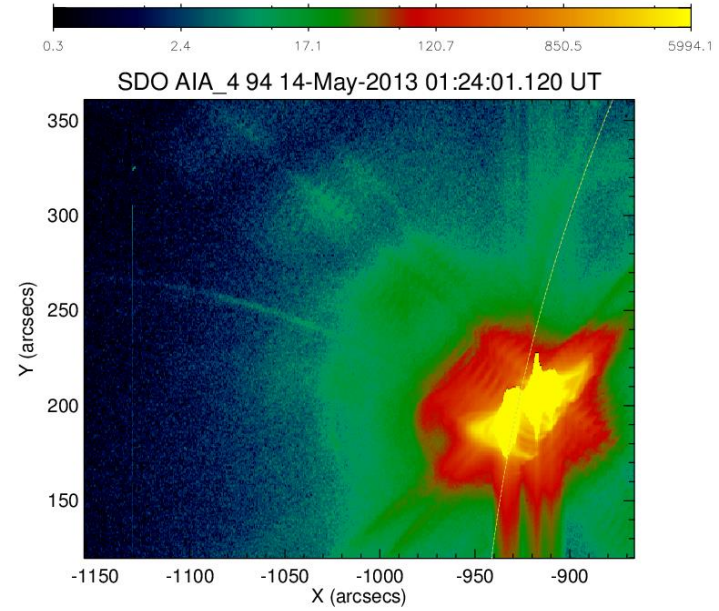
14 May 2013
AIA 1700 Å

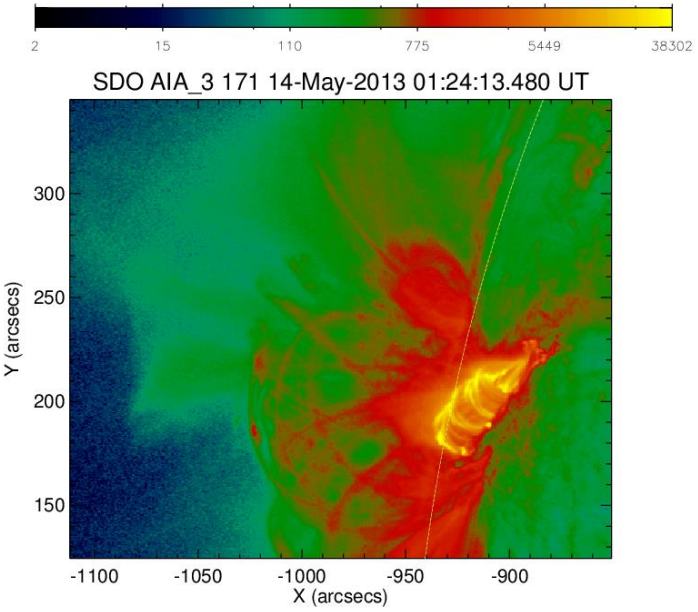


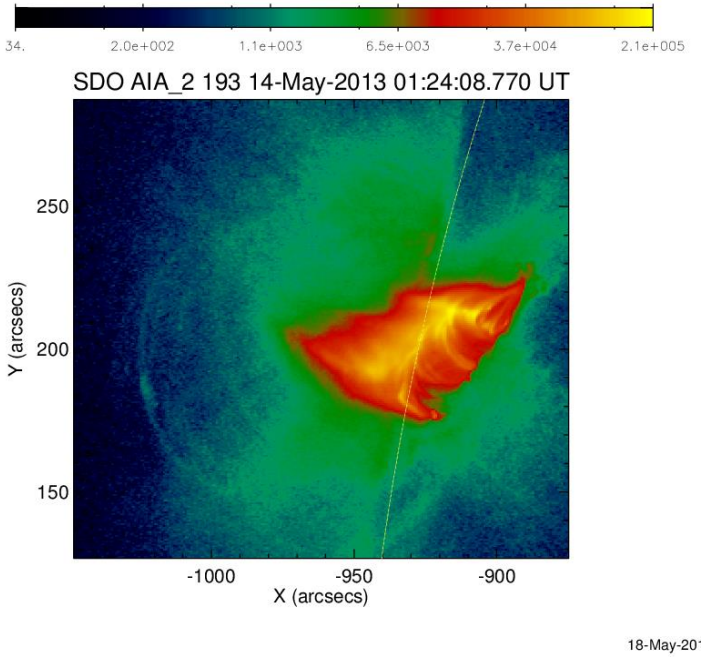


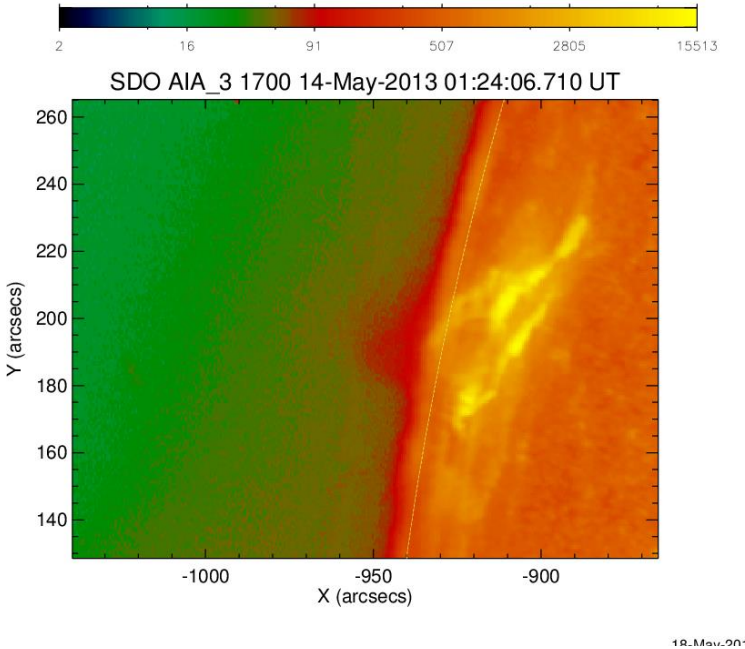

0.3
2.4
17.1
120.7
850.4
5993.5
SDO AIA_4 94 14-May-2013 01:21:37.120 UT
Y (arcsecs)
X (arcsecs)

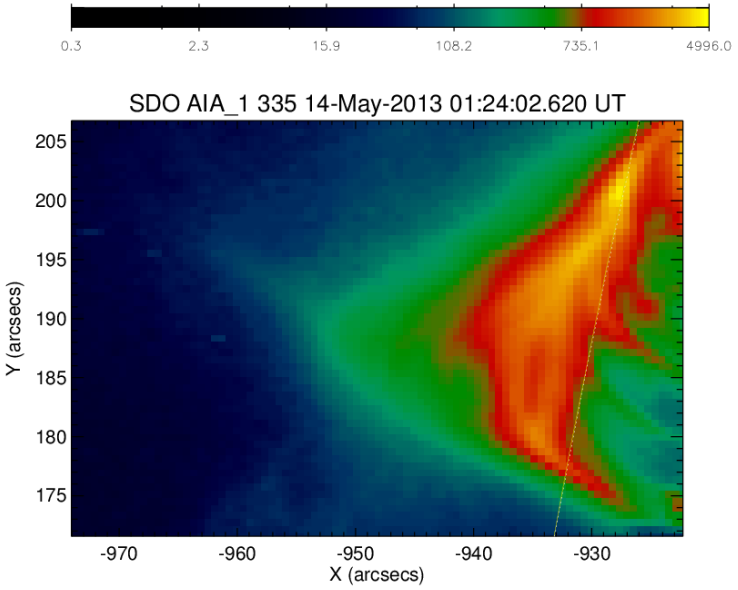

14.
86.
5.2e+002
3.1e+003
1.9e+004
1.1e+005
SDO AIA_1 131 14-May-2013 01:24:12.490 UT
Y (arcsecs)
X (arcsecs)

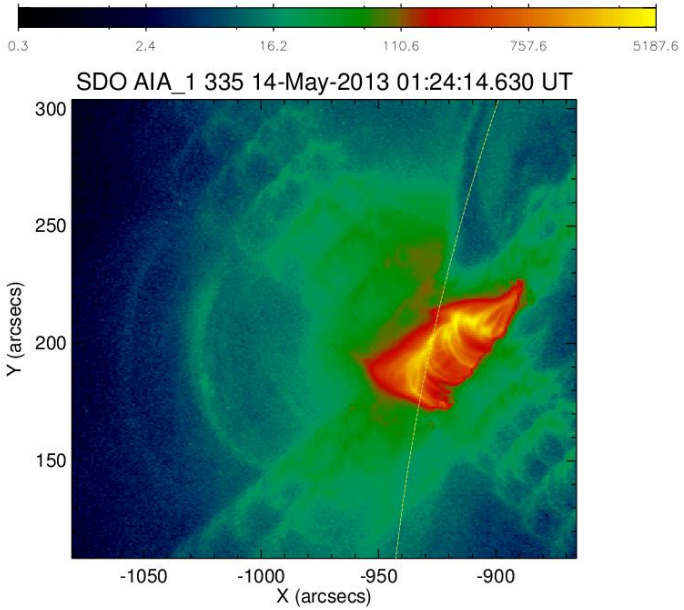

0.3
2.4
17.1
120.7
850.5
5994.1
SDO AIA_4 94 14-May-2013 01:24:01.120 UT
Y (arcsecs)
X (arcsecs)

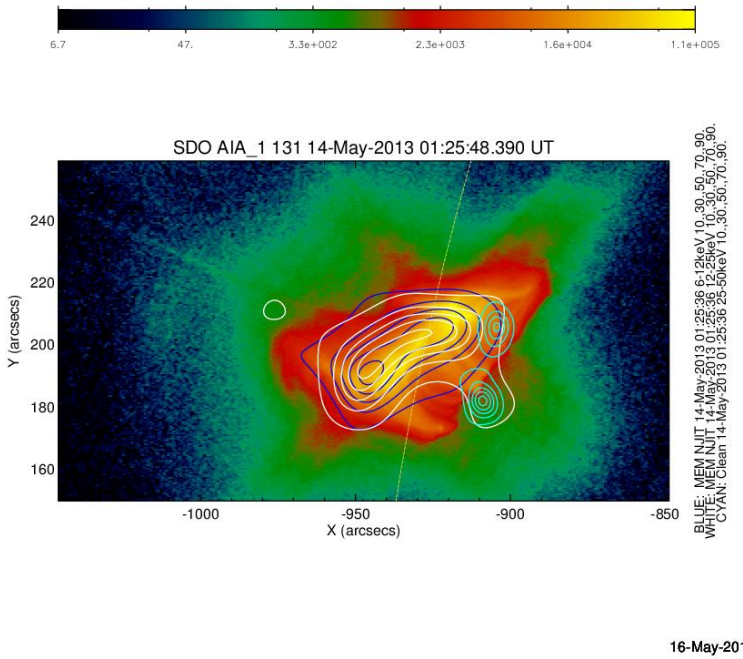

2
15
110
775
5449
38302
SDO AIA_3 171 14-May-2013 01:24:13.480 UT
Y (arcsecs)
X (arcsecs)

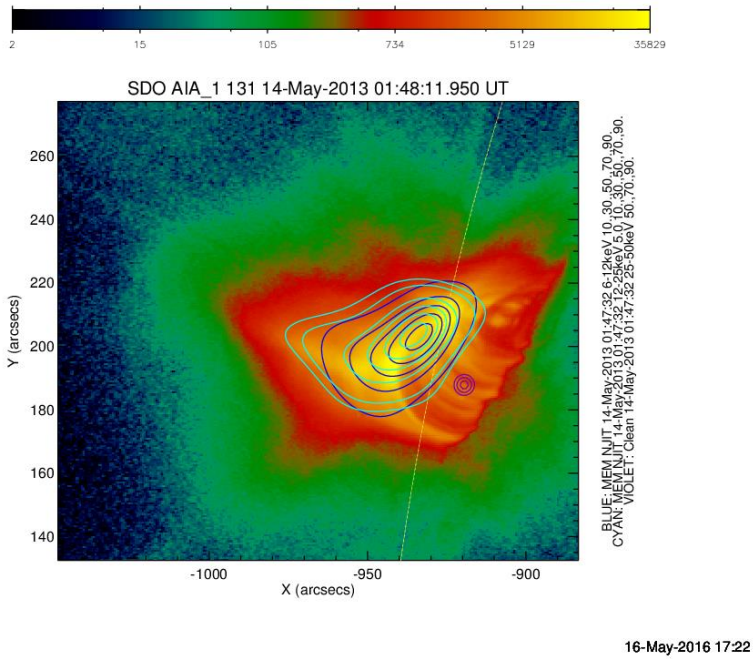

34.
2.0e+002
1.1e+003
6.5e+003
3.7e+004
2.1e+005
SDO AIA_2 193 14-May-2013 01:24:08.770 UT
Y (arcsecs)
X (arcsecs)
18-May-2016 09:15

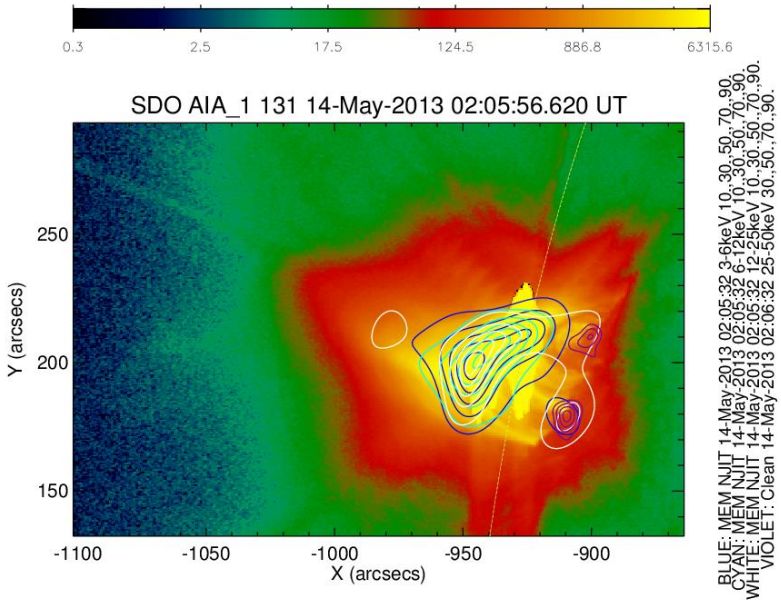

2
16
91
507
2805
15513
SDO AIA_3 1700 14-May-2013 01:24:06.710 UT
Y (arcsecs)
X (arcsecs)

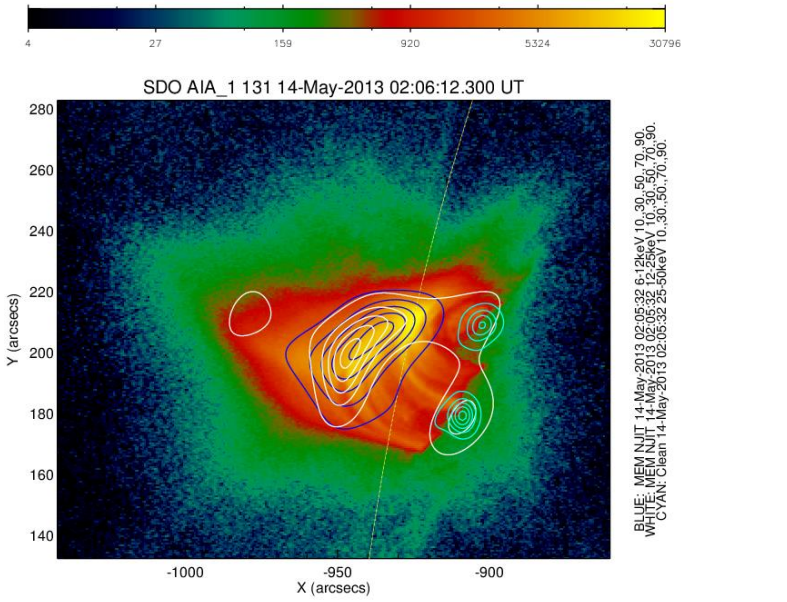

0.3
2.3
15.9
108.2
735.1
4996.0
SDO AIA_1 335 14-May-2013 01:24:02.620 UT
Y (arcsecs)
X (arcsecs)
18-May-2016 09:10

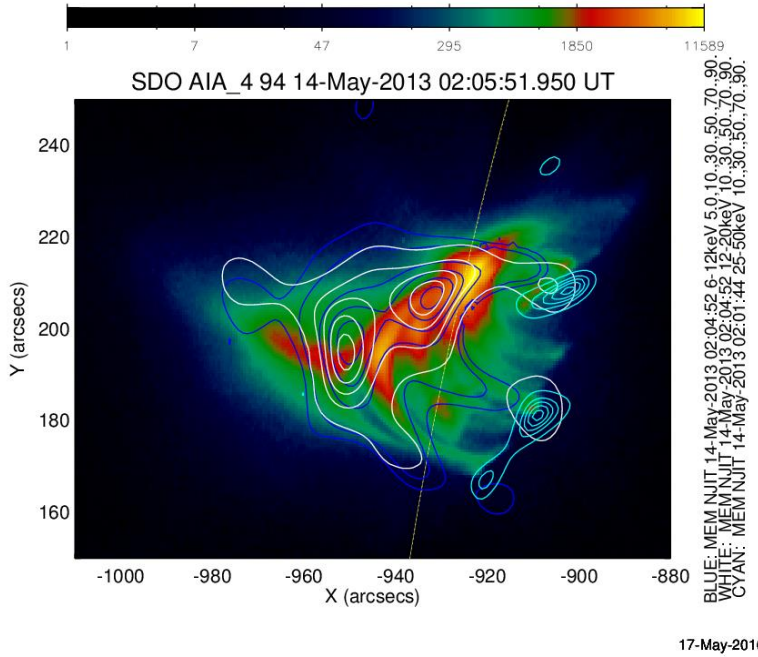

0.3
2.4
16.2
110.6
757.6
5187.6
SDO AIA_1 335 14-May-2013 01:24:14.630 UT
Y (arcsecs)
X (arcsecs)
18-May-2016 09:24

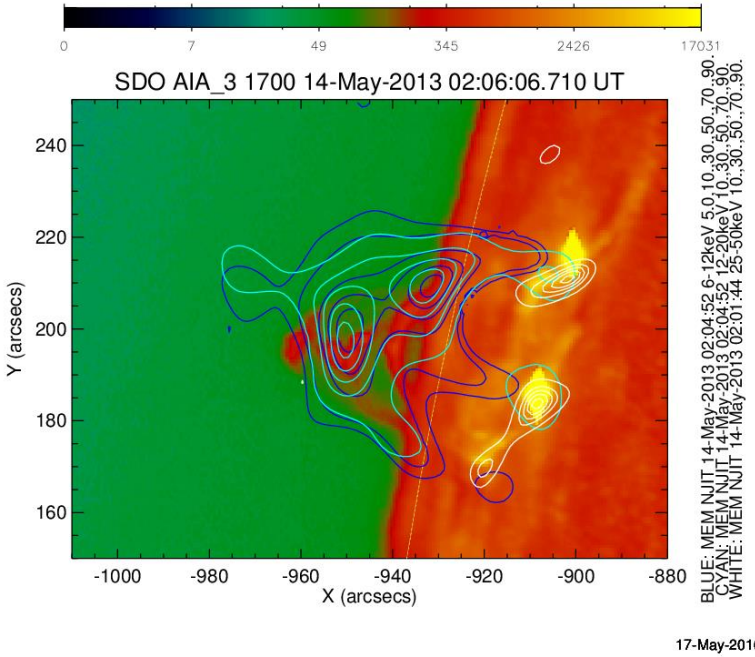

6.7
47.
3.3e+002
2.3e+003
1.6e+004
1.1e+005
SDO AIA_1 131 14-May-2013 01:25:48.390 UT
Y (arcsecs)
X (arcsecs)
BLUE: MEM NJIT 14-May-2013 01:25:36 6-12keV 10.,30.,50.,70.,90.
WHITE: MEM NJIT 14-May-2013 01:25:36 12.25keV 10.,30.,50.,70.,90.
CYAN: Clean 14-May-2013 01:25:36 25-50keV 10.,30.,50.,70.,90.
16-May-2016 17:36

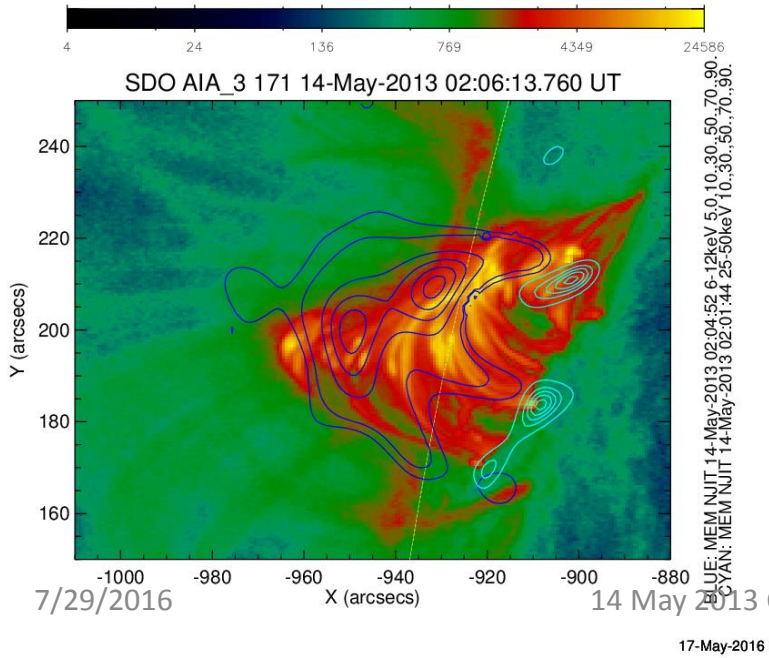

2
15
105
734
5129
35829
SDO AIA_1 131 14-May-2013 01:48:11.950 UT
Y (arcsecs)
X (arcsecs)
BLUE: MEM NJIT 14-May-2013 01:47:32 6-12keV 10.,30.,50.,70.,90.
CYAN: MEM NJIT 14-May-2013 01:47:32 12.25keV 5.0,10.,30.,50.,70.,90.
VIOLET: Clean 14-May-2013 01:47:32 25-50keV 50.,70.,90.
16-May-2016 17:22

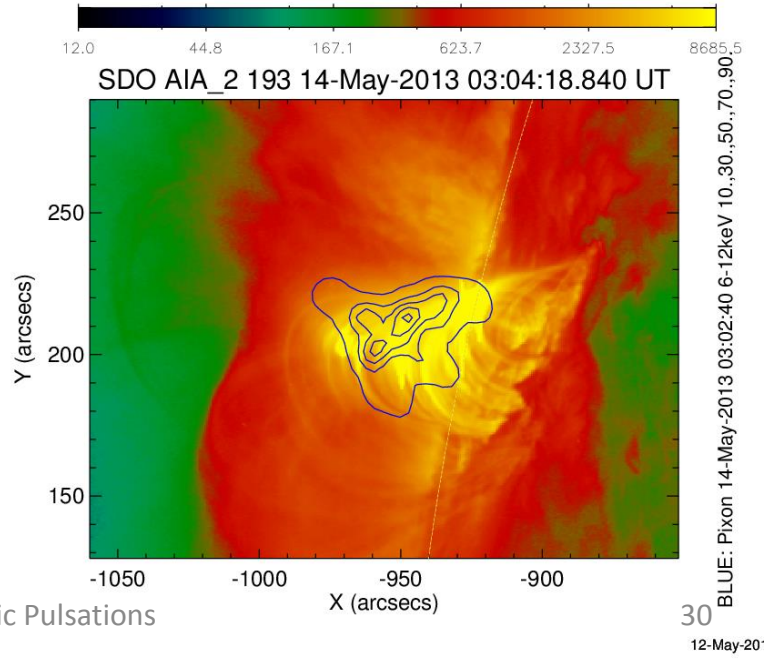

0.3
2.5
17.5
124.5
886.8
6315.6
SDO AIA_1 131 14-May-2013 02:05:56.620 UT
Y (arcsecs)
X (arcsecs)
BLUE: MEM NJIT 14-May-2013 02:05:32 3-6keV 10.,30.,50.,70.,90.
CYAN: MEM NJIT 14-May-2013 02:05:32 6-12keV 10.,30.,50.,70.,90.
WHITE: MEM NJIT 14-May-2013 02:05:32 12.25keV 10.,30.,50.,70.,90.
VIOLET: Clean 14-May-2013 02:06:32 25-50keV 30.,50.,70.,90.
16-May-2016 15:31


4
27
159
920
5324
30796
SDO AIA_1 131 14-May-2013 02:06:12.300 UT
Y (arcsecs)
X (arcsecs)
BLUE: MEM NJIT 14-May-2013 02:05:32 6-12keV 10.,30.,50.,70.,90.
WHITE: MEM NJIT 14-May-2013 02:05:32 12.25keV 10.,30.,50.,70.,90.
CYAN: Clean 14-May-2013 02:05:32 25-50keV 10.,30.,50.,70.,90.
16-May-2016 16:37

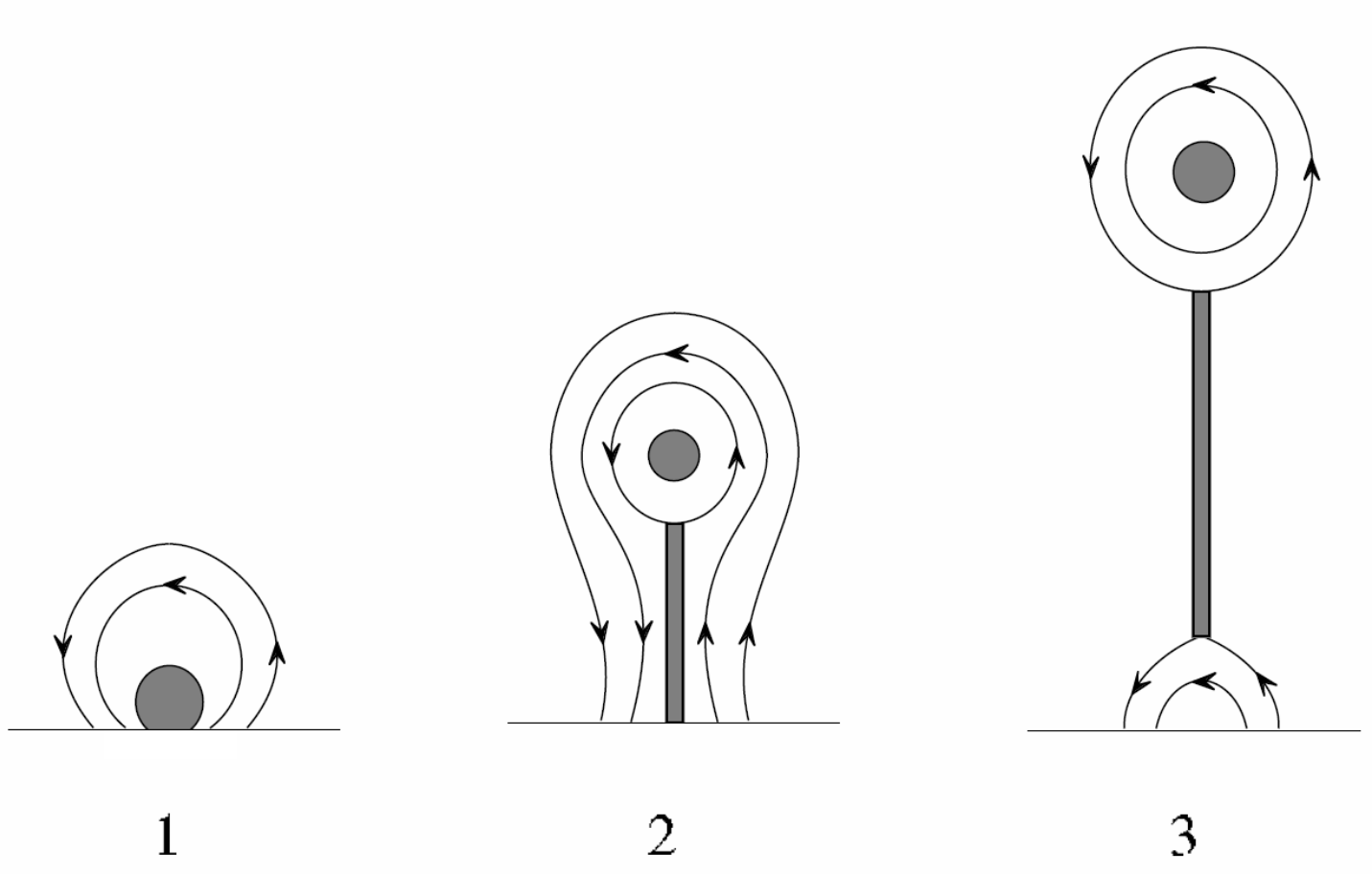

1 7 47 295 1850 11589
SDO AIA_4 94 14-May-2013 02:05:51.950 UT
Y (arcsecs)
X (arcsecs)
BLUE: MEM NJIT 14-May-2013 02:04:52 6-12keV 5.0,10.,30.,50.,70.,90.
WHITE: MEM NJIT 14-May-2013 02:04:52 12-20keV 10.,30.,50.,70.,90.
CYAN: MEM NJIT 14-May-2013 02:01:44 25-50keV 10.,30.,50.,70.,90.
17-May-2016 18:25


0 7 49 345 2426 17031
SDO AIA_3 1700 14-May-2013 02:06:06.710 UT
Y (arcsecs)
X (arcsecs)
BLUE: MEM NJIT 14-May-2013 02:04:52 6-12keV 5.0,10.,30.,50.,70.,90.
CYAN: MEM NJIT 14-May-2013 02:04:52 12-20keV 10.,30.,50.,70.,90.
WHITE: MEM NJIT 14-May-2013 02:01:44 25-50keV 10.,30.,50.,70.,90.
17-May-2016 18:09

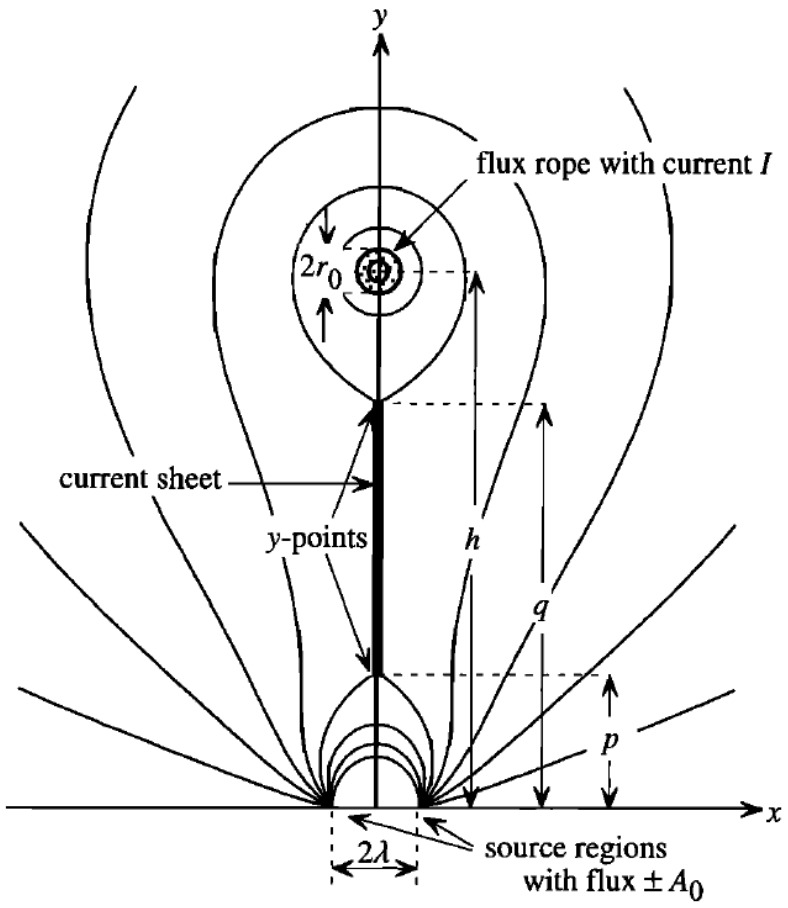

4 24 136 769 4349 24586
SDO AIA_3 171 14-May-2013 02:06:13.760 UT
Y (arcsecs)
X (arcsecs)
BLUE: MEM NJIT 14-May-2013 02:04:52 6-12keV 5.0,10.,30.,50.,70.,90.
CYAN: MEM NJIT 14-May-2013 02:01:44 25-50keV 10.,30.,50.,70.,90.
17-May-2016 17:50


12.0 44.8 167.1 623.7 2327.5 8685.5
SDO AIA_2 193 14-May-2013 03:04:18.840 UT
Y (arcsecs)
X (arcsecs)
BLUE: Pixon 14-May-2013 03:02:40 6-12keV 10.,30.,50.,70.,90.
12-May-2016 17:09

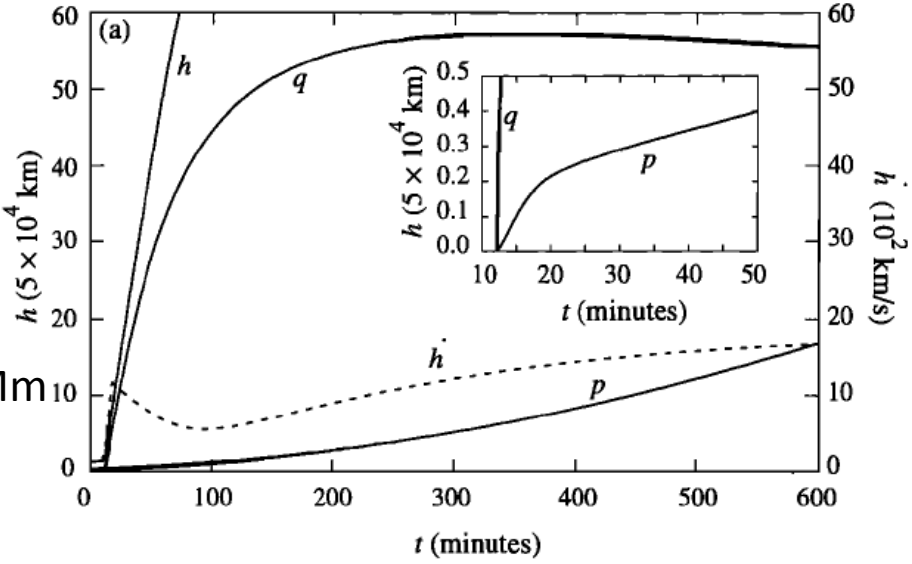
Priest & Forbes (2002)



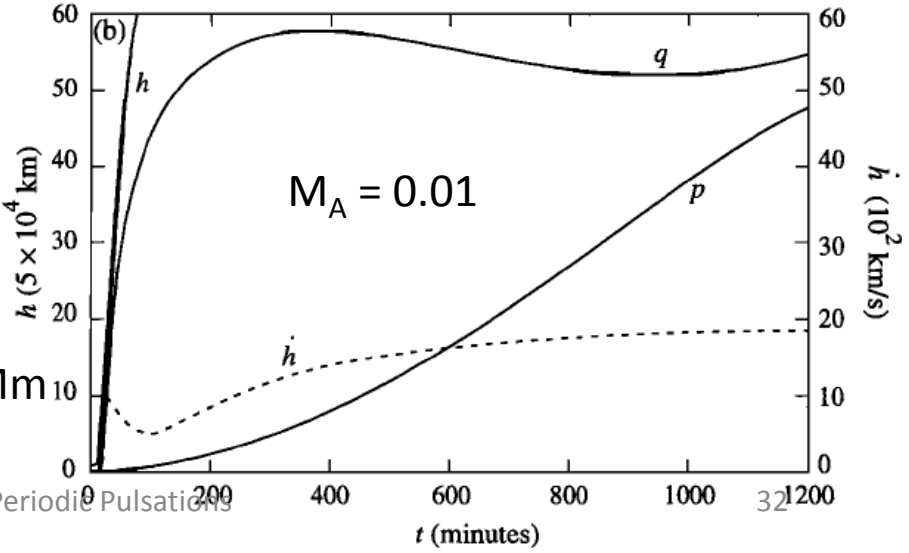
Lin & Forbes, JGR, 105, 2375 (2000)



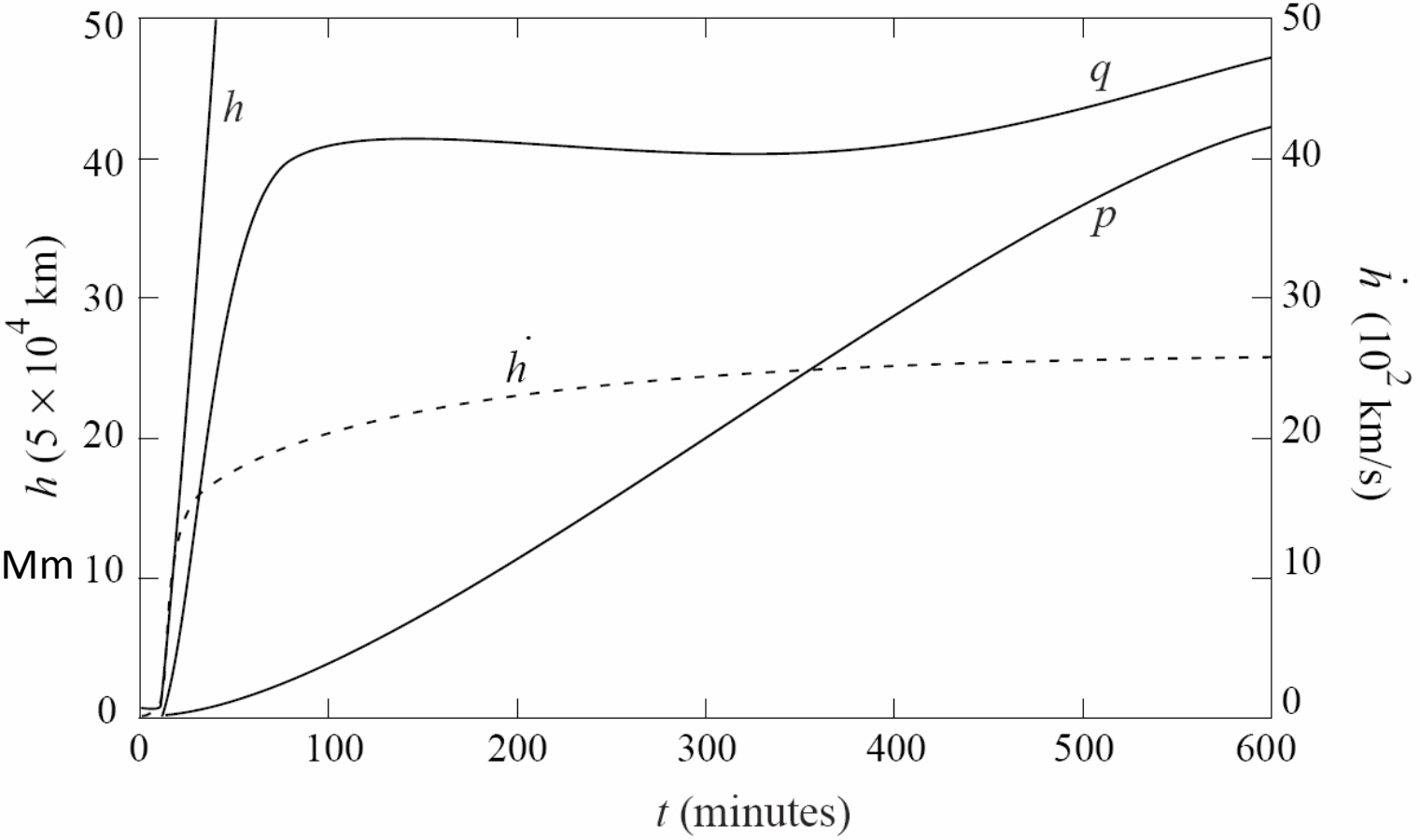
500 Mm



500 Mm



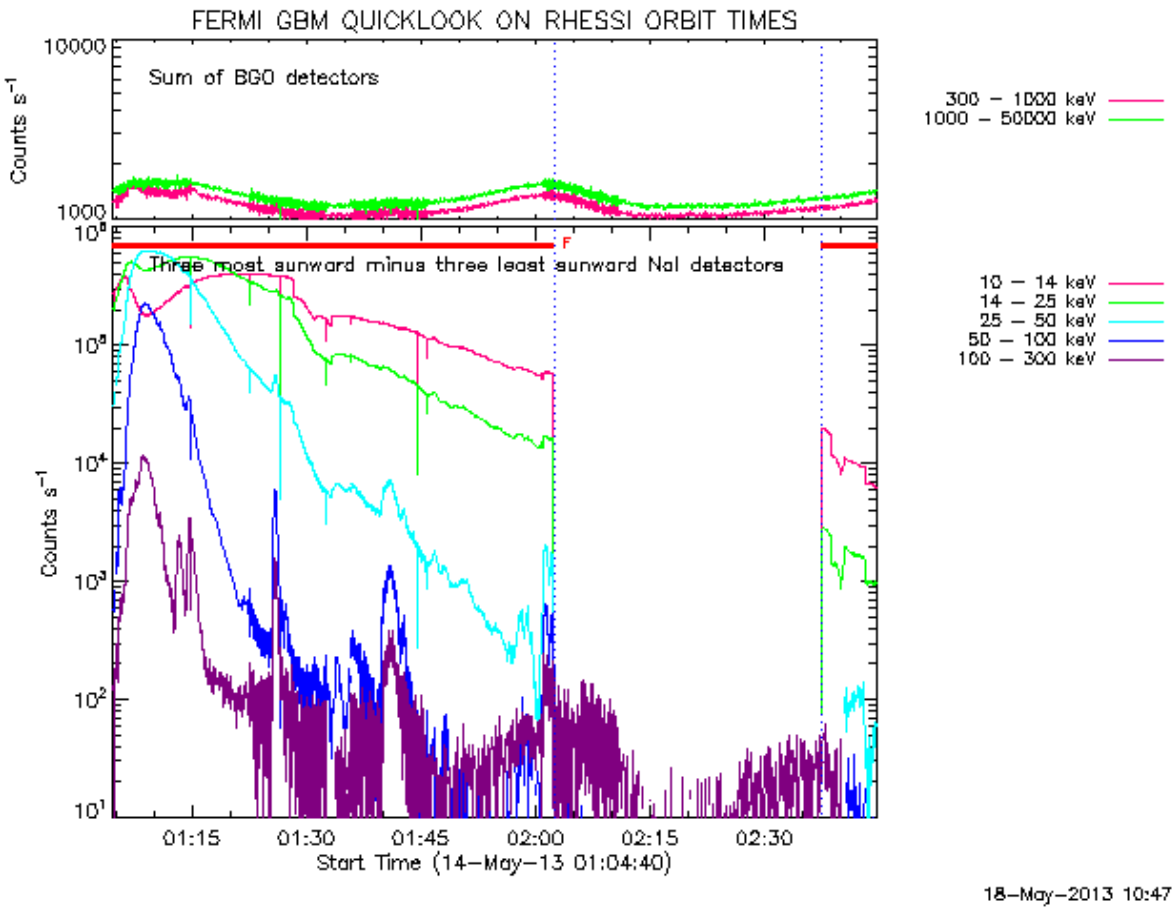
Priest & Forbes (2002)



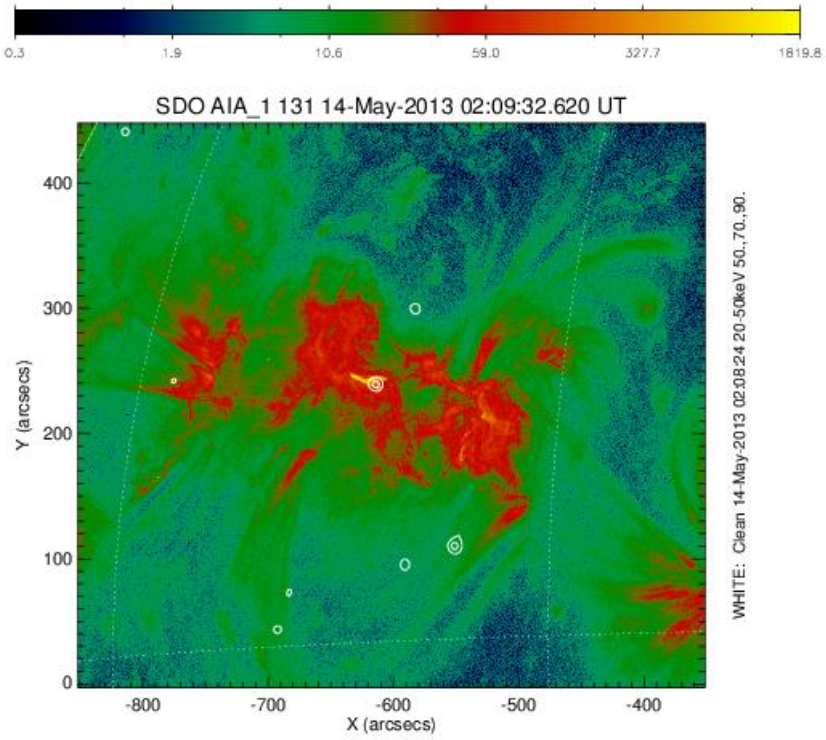
500 Mm

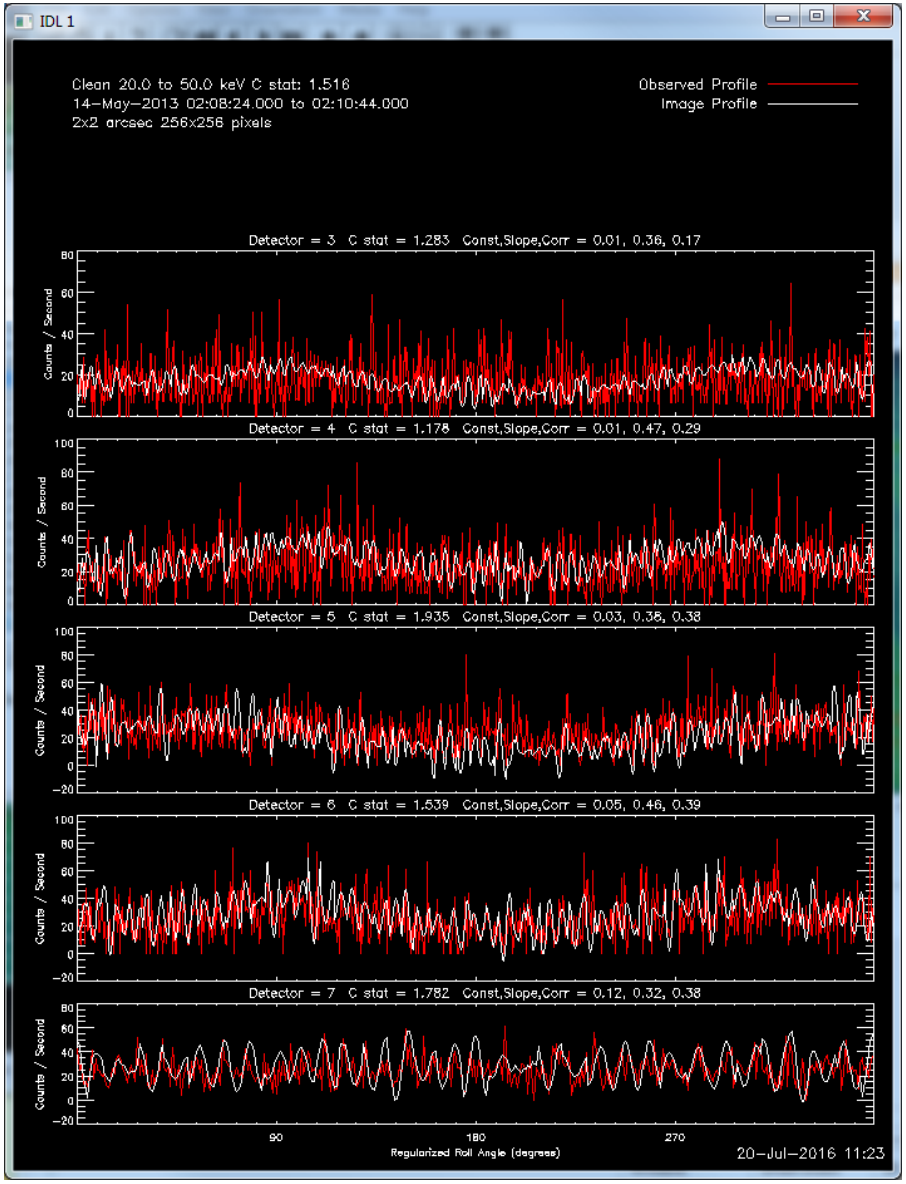
Trajectories for flux rope (*h*), and upper (*q*) and lower (*p*) tips of the current sheet.
Dashed line shows flux rope speed (*hdot*).
Inflow Alfv´en Mach number = 0.1 at centre of current sheet.

14 May 2013
Fermi GBM 10 – 300 keV

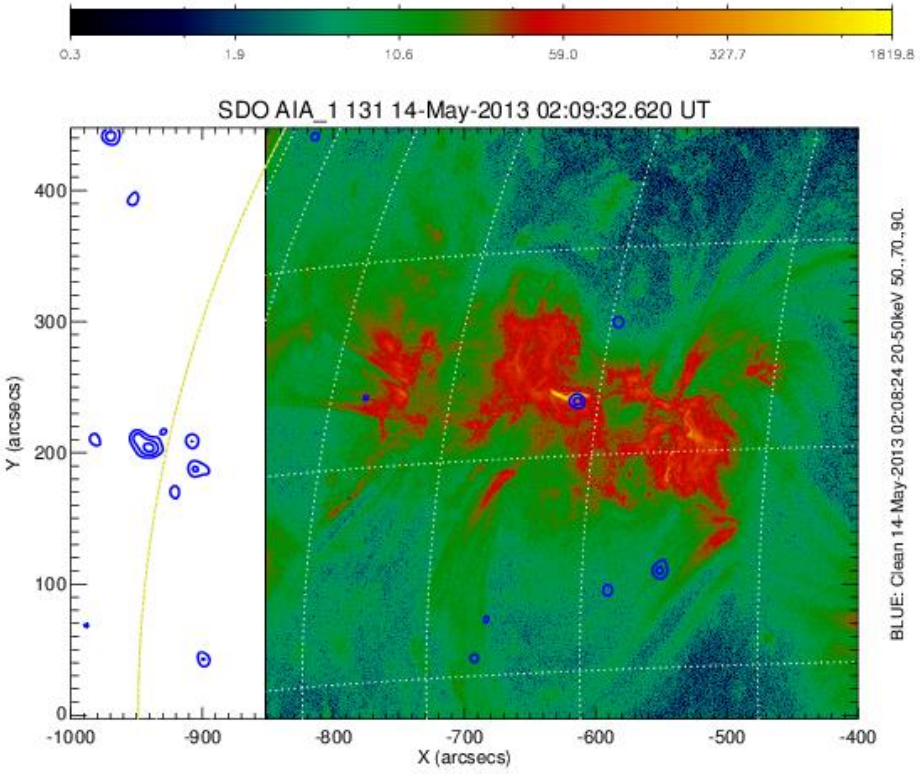


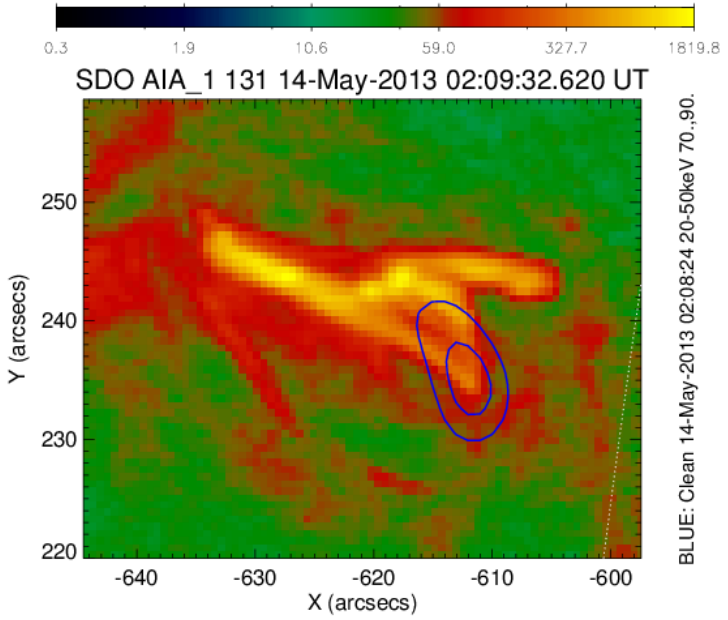
14 May 2013
AR 1745

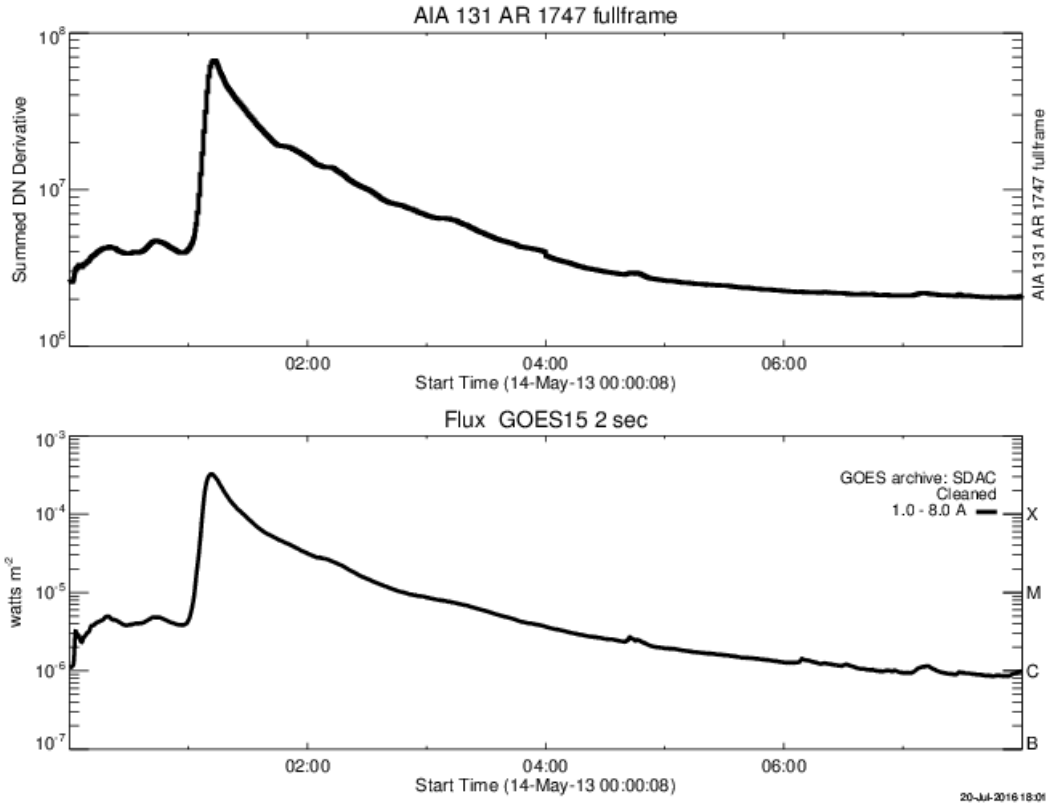




14 May 2013
20-50 keV flux from AR 1745 & 1747?






AIA 131 AR 1747 fullframe
Summed DN Derivative
AIA 131 AR 1747 fullframe
02:00
04:00
06:00
Start Time (14-May-13 00:00:08)
Flux GOES15 2 sec
watts m-2
GOES archive: SDAC
Cleaned
1.0 - 8.0 A
X
M
C
B
02:00
04:00
06:00
Start Time (14-May-13 00:00:08)

HEK Flare

- concept: Flare
- eventtype: 9
- event_c1error: 2
- event_c2error: 2
- event_coord1: -652.8
- event_coord2: 268.8
- event_coordsys: UTC-HPC-TOPO
- event_coordunit: arcseconds
- Event End Time: 2013-05-14T01:53:10
- Event Peak Time: 2013-05-14T01:46:22
- event_score: 0.00606790242831606753
- Event Start Time: 2013-05-14T01:45:10
- event_testflag: false
- Type of Event: FL
- fl_peakflux: 46.4379
- fl_peakfluxunit: erg/cm/cm/s
- kb_archivdate: 2013-05-14T02:10:21
- kb_archivid: ivo://helio-informatics.org/FL_FlareDetective-TriggerModule_20130514_020419_2013-05-14T01:45:10.070_1
- kb_archivist: flare_detective
- obs_channelid: 131
- obs_instrument: AIA
- obs_meanwavel: 0.00000131
- obs_observatory: SDO
- obs_wavelunit: cm
- frm_contact: Paolo C. Grigis - pgrigis@cfa.harvard.edu
- frm_daterun: 2013-05-13T19:02:30
- frm_humanflag: false
- frm_identifier: Feature Finding Team
- frm_institute: SAO
- frm_name: Flare Detective - Trigger Module
- frm_paramset: DerivativeThreshold= 8.00000e-02 EndFraction= 2.50000e-01
- frm_url: http://www.cfa.harvard.edu
- frm_versionnumber: 0.51