Overview of HMI Coronal Observations

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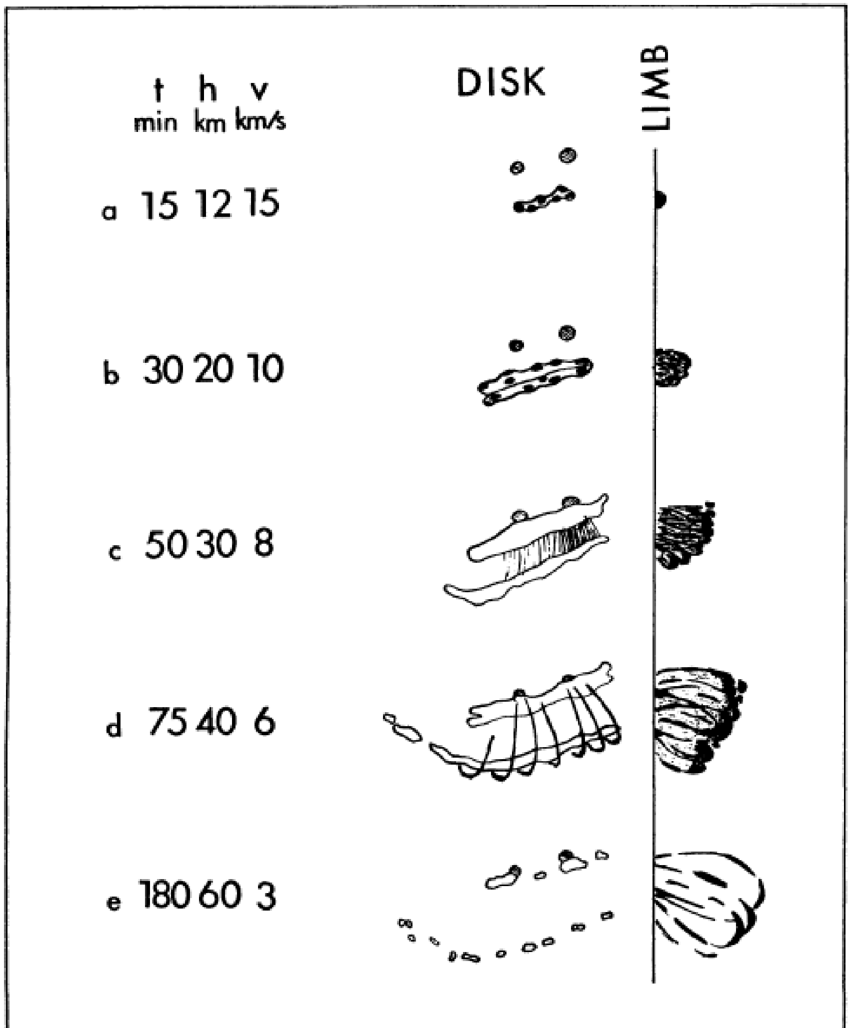
We have a brand-new way to look at the lower corona via HMI:

- *Martinez Oliveros et al., ApJL 780, 28 (2014)*
- *Saint-Hilaire et al., ApJL 786, 19 (2014)*
- *This presentation, a mini-survey for 2011*

Solar flare mass cycle

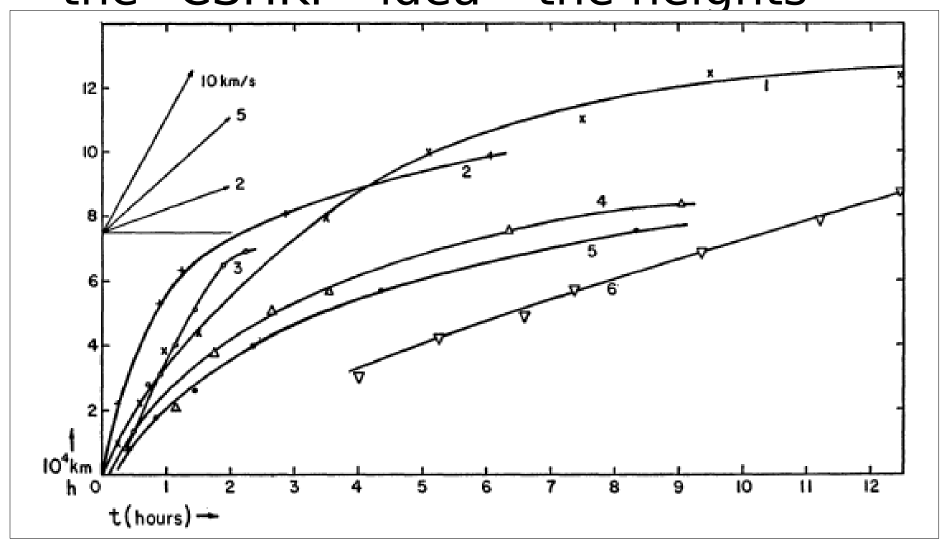
1. “Free energy” accumulates slowly in the empty solar corona at very low beta, in the form of magnetic stress.
2. Some of this energy converts suddenly to particle kinetic energy, and the gas pressure increases.
3. The pressure increase requires hydrostatic readjustment; new mass heats and flows up into the corona (“evaporation”; the Neupert effect).
4. The mass cools and drains slowly back into its reservoir (the Serio phase).
5. The final stage of this process involves Field’s thermal instability; “coronal rain”.

Loop Prominences in Hα



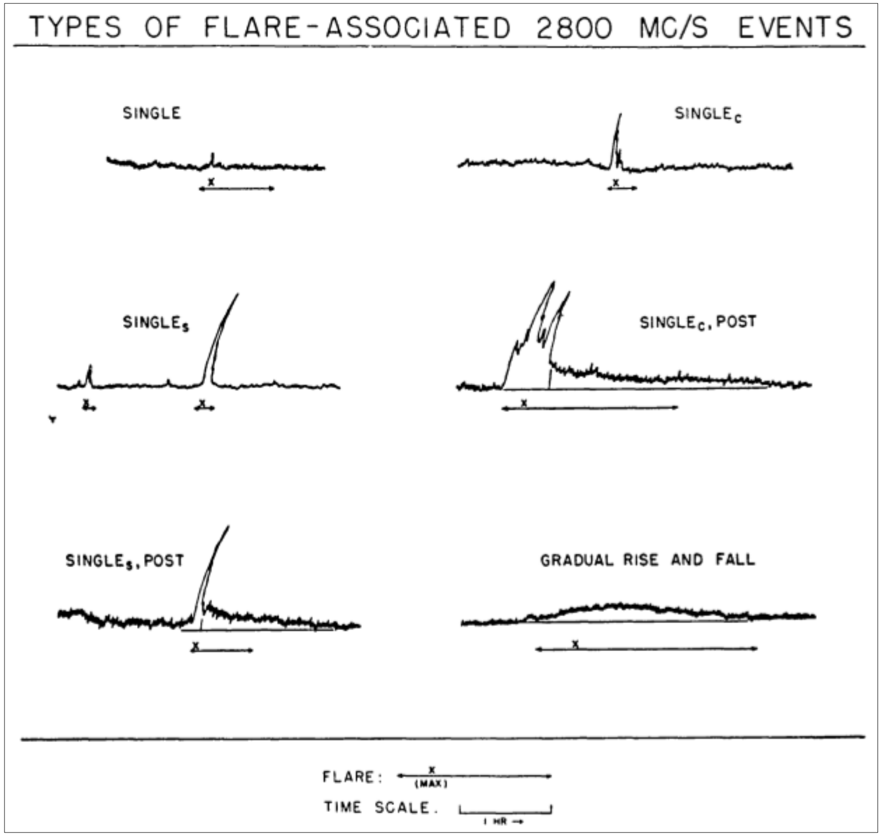
Iconic sketches from Bruzek (1964):

- These are Hα loops
- We know them today as “arcades”
- From such observations sprang the “CSHKP” idea – the heights



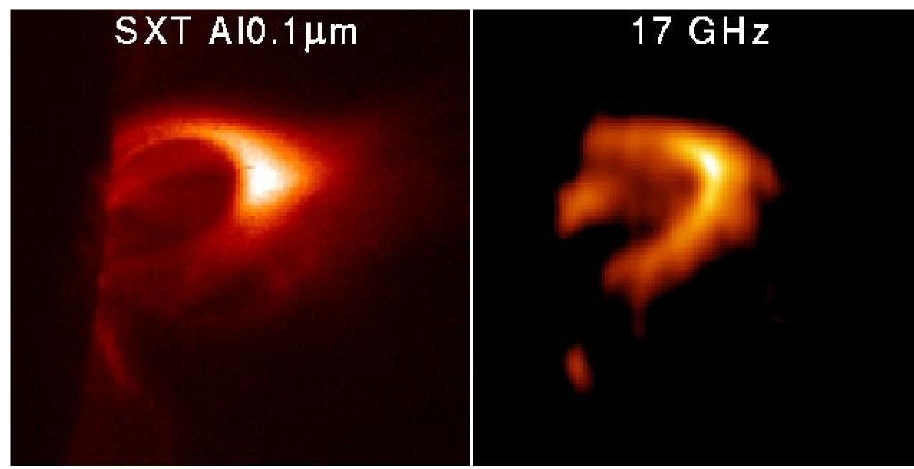
Height-vs-time plots for loop systems

Post-burst Increase



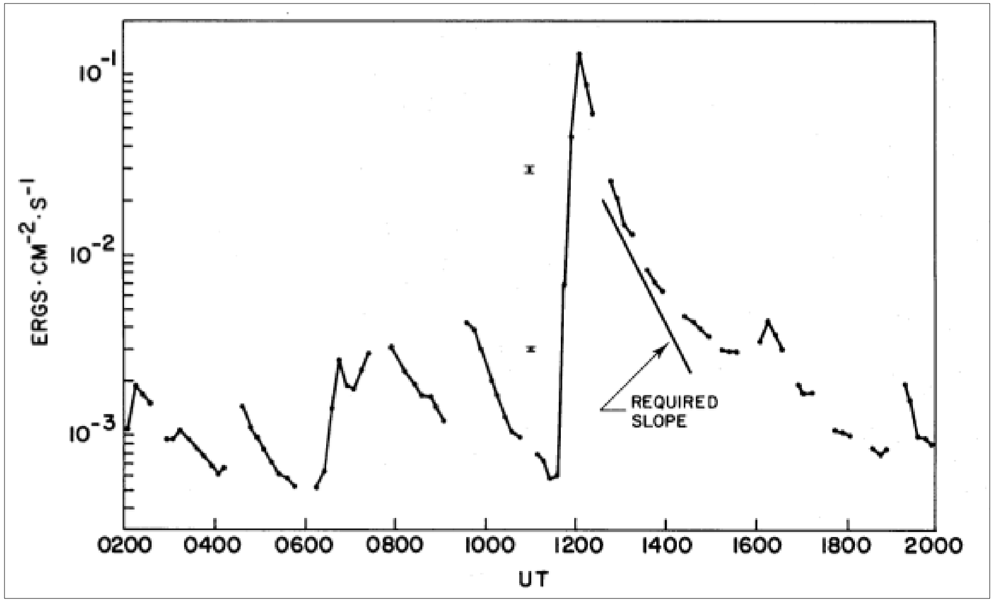
10 cm records from Dodson et al. (1954):

- Gradual increases can follow impulsive bursts (PBI) or just happen (GRF)
- Elwert (1956) bremsstrahlung theory
- Consistent with the coronal-line observations

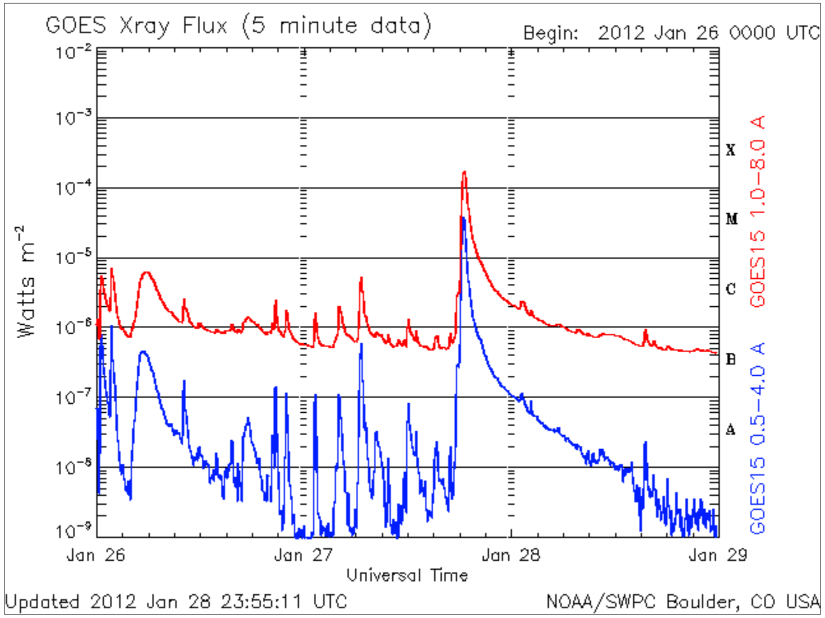


Hanaoka et al., 1994

Long-Decay Event



Kahler, 1977 (SOLRAD)

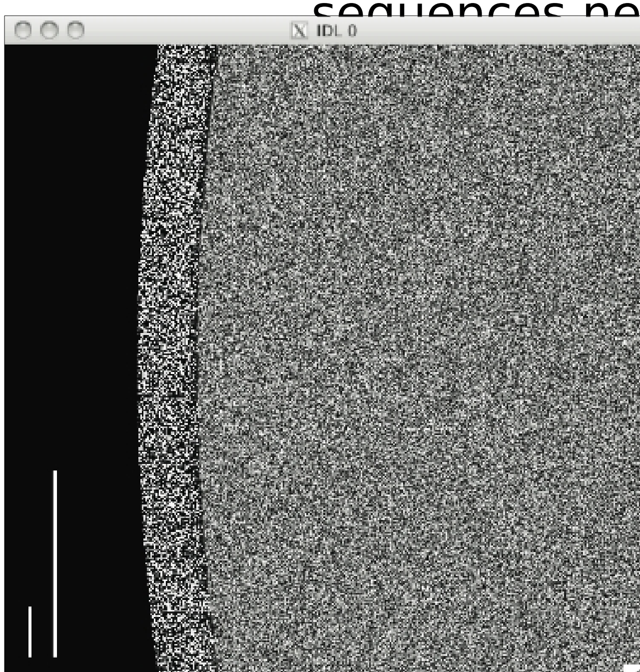


Recent (GOES)

The long-decay or long-duration soft X-ray events (Kahler, 1977; Sheeley et al., 1983) are the soft X-ray counterparts of the loop-prominence phenomenon, but of course all flares have coronal loops.

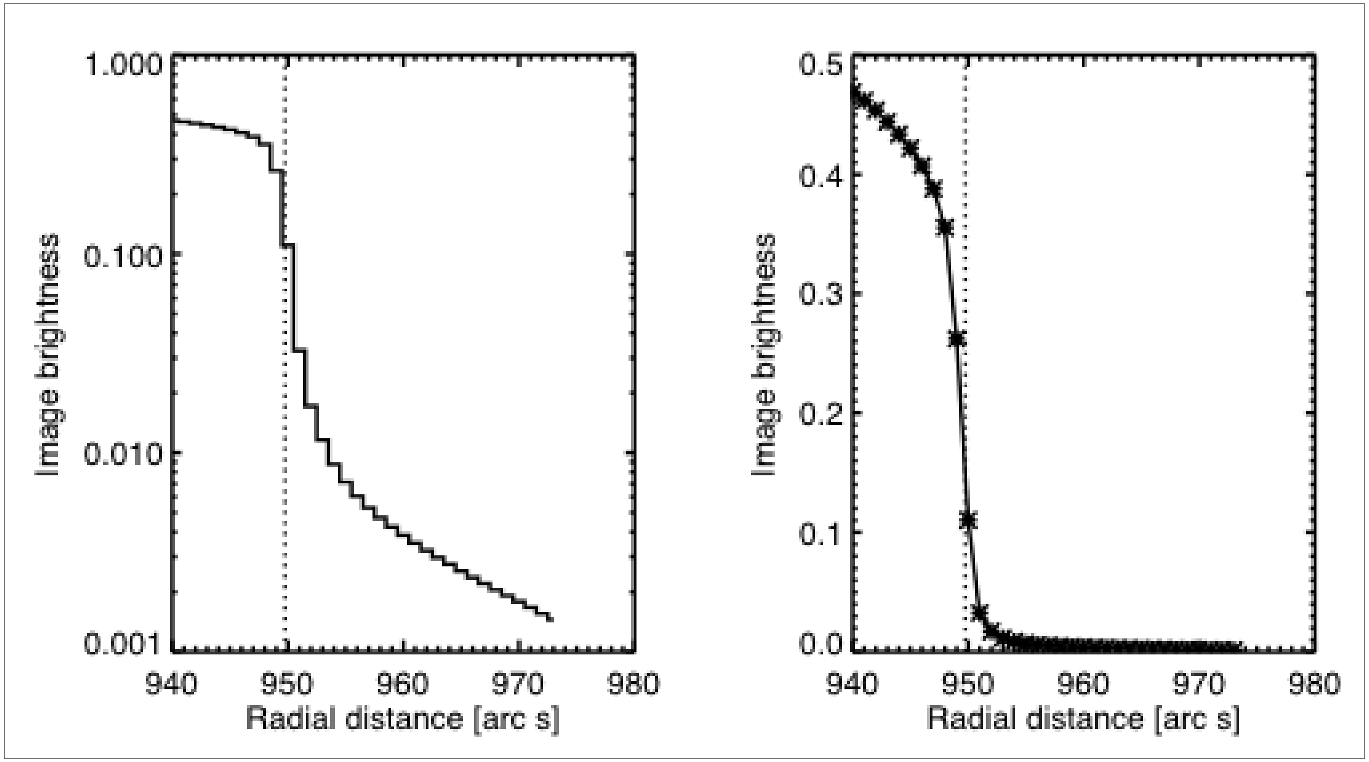
The HMI cameras on SDO

- Narrow-band spectroscopy at 6173Å as designed for helioseismology and for magnetography on the disk, full Stokes
- Image cadence 1.88 s, but 135 s sequences needed for full



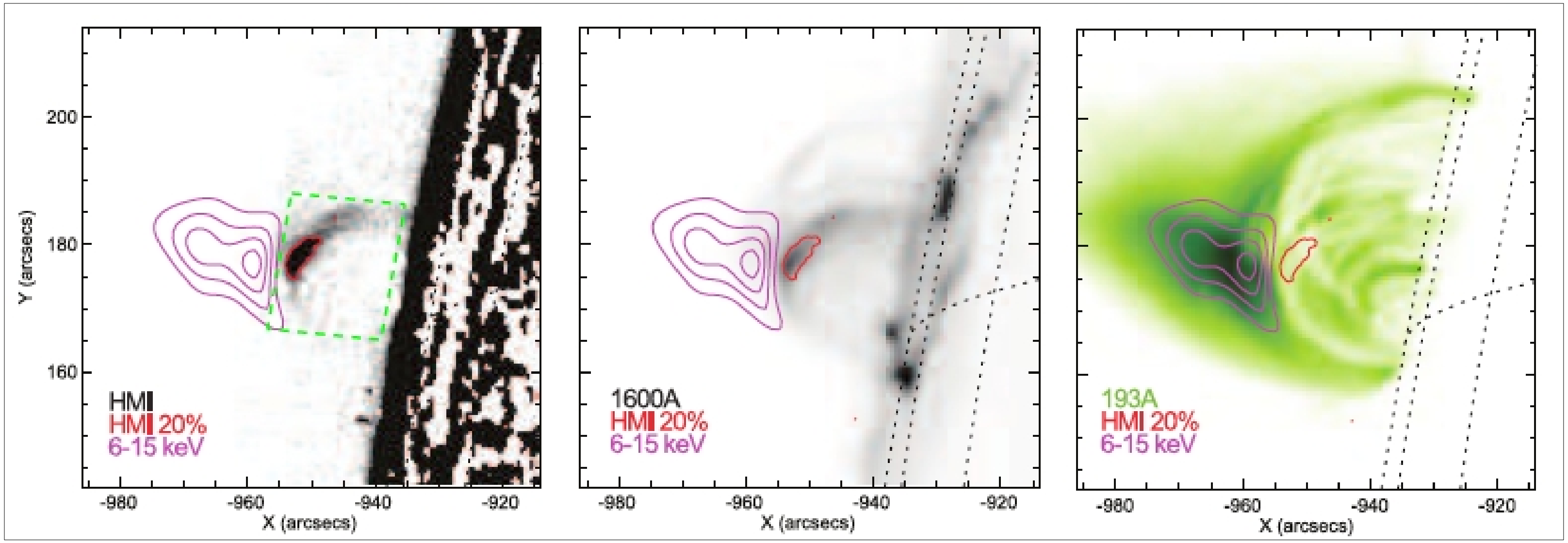
- A normal coronagraph views only above an occulting edge
- HMI has sufficient sensitivity and stability that difference images show features in the low corona directly, in spite of the glare

The HMI cameras on SDO



- HMI (vs. a coronagraph) has 0.1-1 I scattered light, not coronagraphic ppm levels
- But, the I_c noise level in difference images is ~200 ppm

The May 2013 Flares



HMI, AIA, and RHESSI view of SOL2013-05-13T16

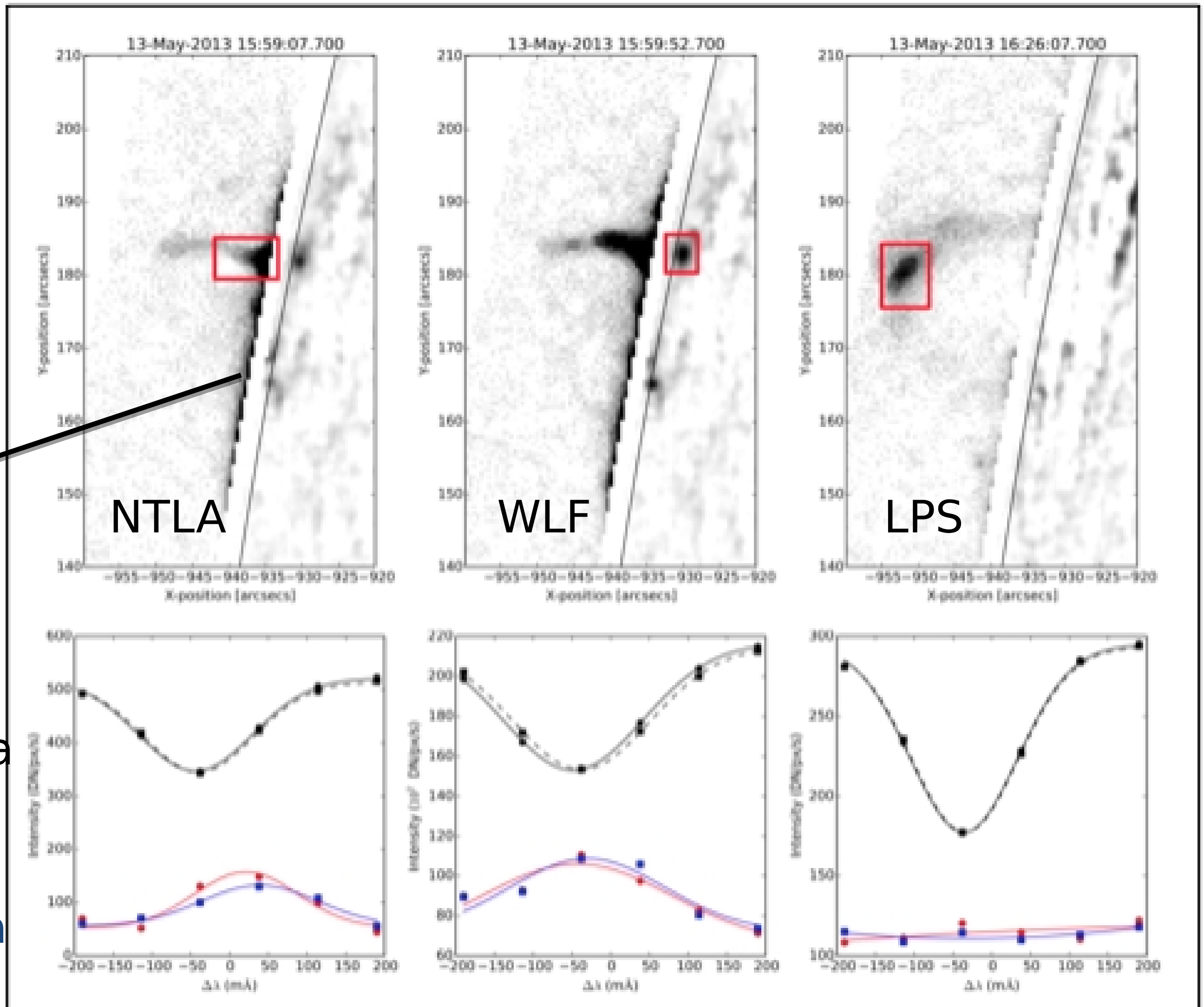
SOL2011-05-13T16

Difference images

80x

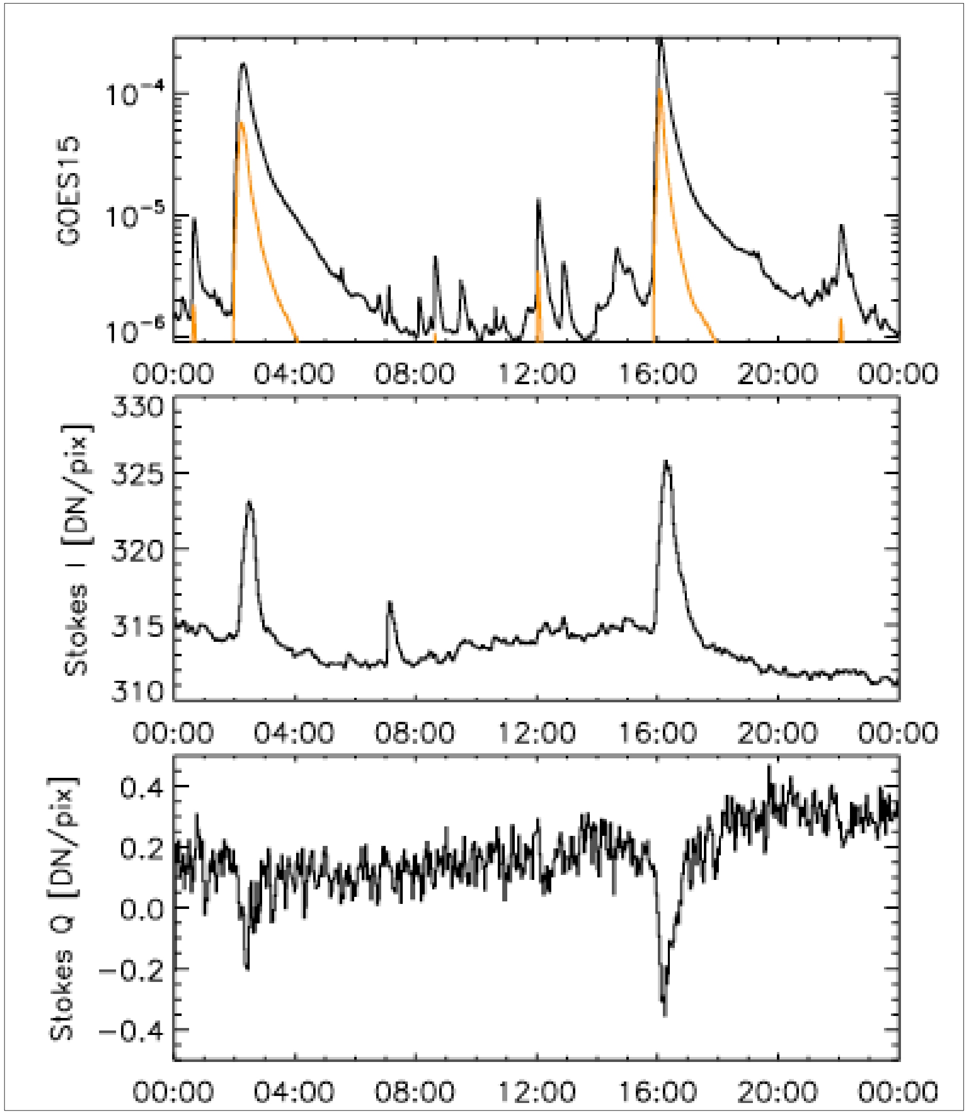
Background spectra

Difference spectra



Martinez-Oliveros et al., 2014

Polarization



Saint-Hilaire et al., 2014)

- HMI capability allows us to determine the linear polarization due to Thomson scattering
- It is detectable, and we can therefore infer the magnitude of the free-free contribution
- Both components seem reasonable in this example, but there may also be emission

The new HMI observations match the loop-prominence scenario

- Linear polarization has been detected by Pascal Saint-Hilaire, permitting a direct mass estimate from Thomson scattering
  - HMI signal includes free-free and possibly emission

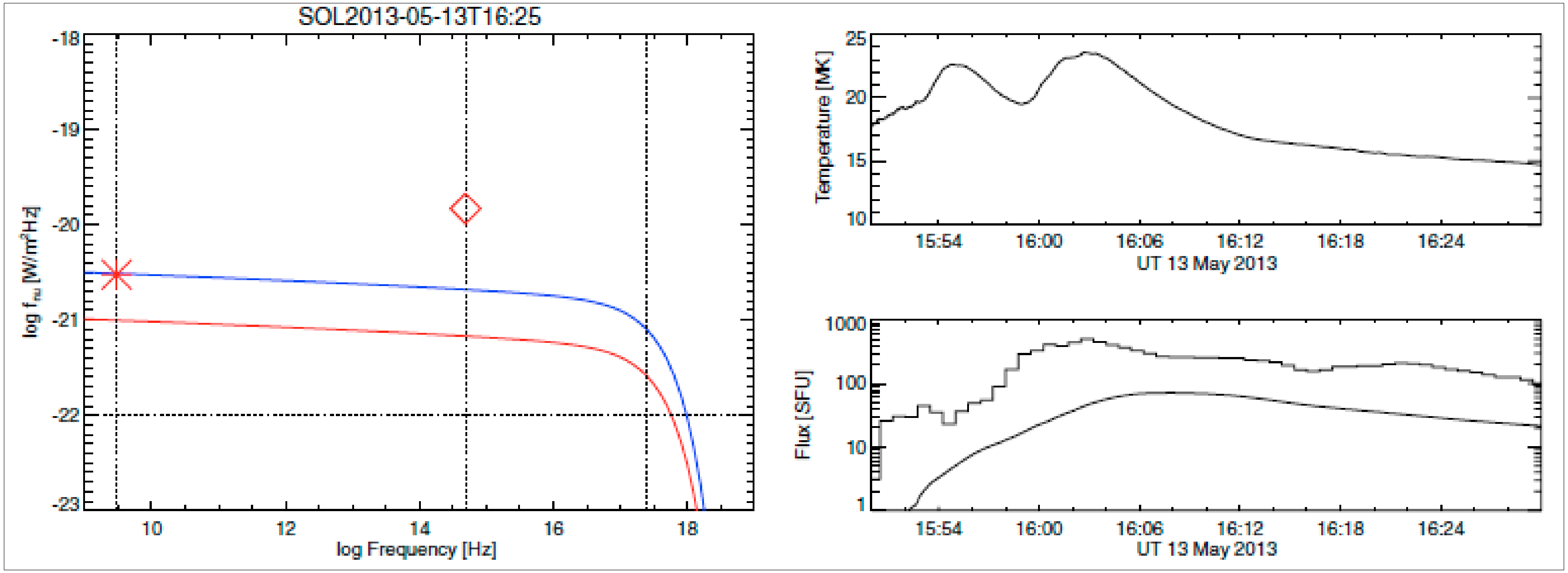
- Late-phase motions seen strongly suggest "coronal rain," via sub-Alfvenic downward flows

- The spectral flux density interpolates well between microwaves and soft X-rays (e.g. Hudson & Ohki, 1972)

The broad free-free spectrum

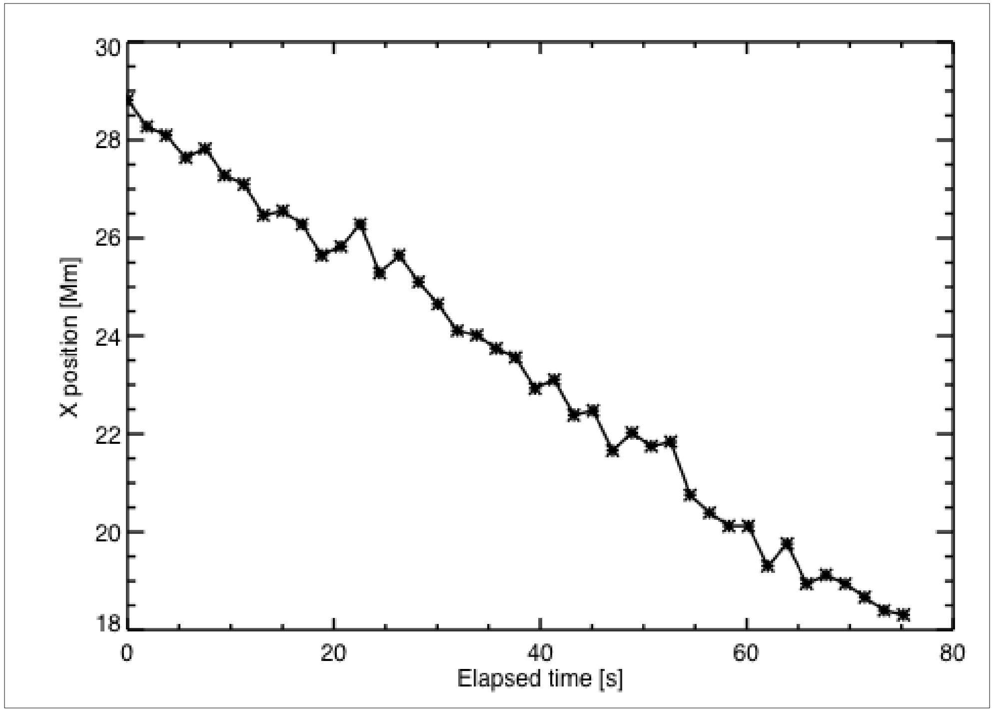
- Free-free continuum underpins flare spectra across the range 10 GHz – 1 EHz (10 cm – 1 Å): $f_\nu \sim g \exp(-h\nu/kT)$

- The HMI loop sources require some excess above this level



Martínez-Oliveros et al. 2014

Coronal Rain



- Individual exposures from the two HMI cameras are interleaved, giving high time resolution
- The plot shows height vs time for highest point in the HMI early source for SOL2013-05-13T16
- The slope is 134 +- 8 km/s, with negligible acceleration
- This view of rain is a true measure of mass motion

Mini-survey

Of the 21 near-limb M- and X-class flares in 2011 for which RHESSI had observations, HMI saw 9

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 1 SOL2011-01-28T01:03 M1.3 N17W119
Yes
 2 SOL2011-02-24T07:35 M3.5 N28E 90
Yes
 3 SOL2011-03-07T21:50 M1.5 S20W 85   No
 4 SOL2011-03-08T02:29 M1.3 S18W 79   No
 5 SOL2011-03-08T03:37 M1.5 S19E 68   No
 6 SOL2011-03-08T18:28 M4.4 S20W 91
Yes
 7 SOL2011-03-10T22:41 M1.1 S20W122
Yes
 8 SOL2011-05-28T21:30 M1.1 S20E 71   No
 9 SOL2011-06-14T21:47 M1.3 N15E 77
Yes
10 SOL2011-09-05T04:28 M1.6 N20W 89
Yes
11 SOL2011-09-05T07:58 M1.2 N20W 87   No
12 SOL2011-09-22T11:01 X1.4 N15E 83
Yes
13 SOL2011-09-24T09:19 -
14 SOL2011-09-24T23:54 M1.0 S29W 68   No
15 SOL2011-09-25T09:35 M1.5 S27W 73   No
16 SOL2011-10-20T03:25 M1.6 N20W124
Yes
17 SOL2011-10-21T13:00 M1.3 N07W 56   No
18 SOL2011-10-31T14:00 M1.1 N22E 87   No
19 SOL2011-10-31T18:08 M1.4 N22E 87
Yes
20 SOL2011-11-15T09:07 M1.2 N20W 74   No
21 SOL2011-12-29T13:50 M1.9 S27E 72   No
22 SOL2011-12-29T21:51 M2.0 S27E 65   No
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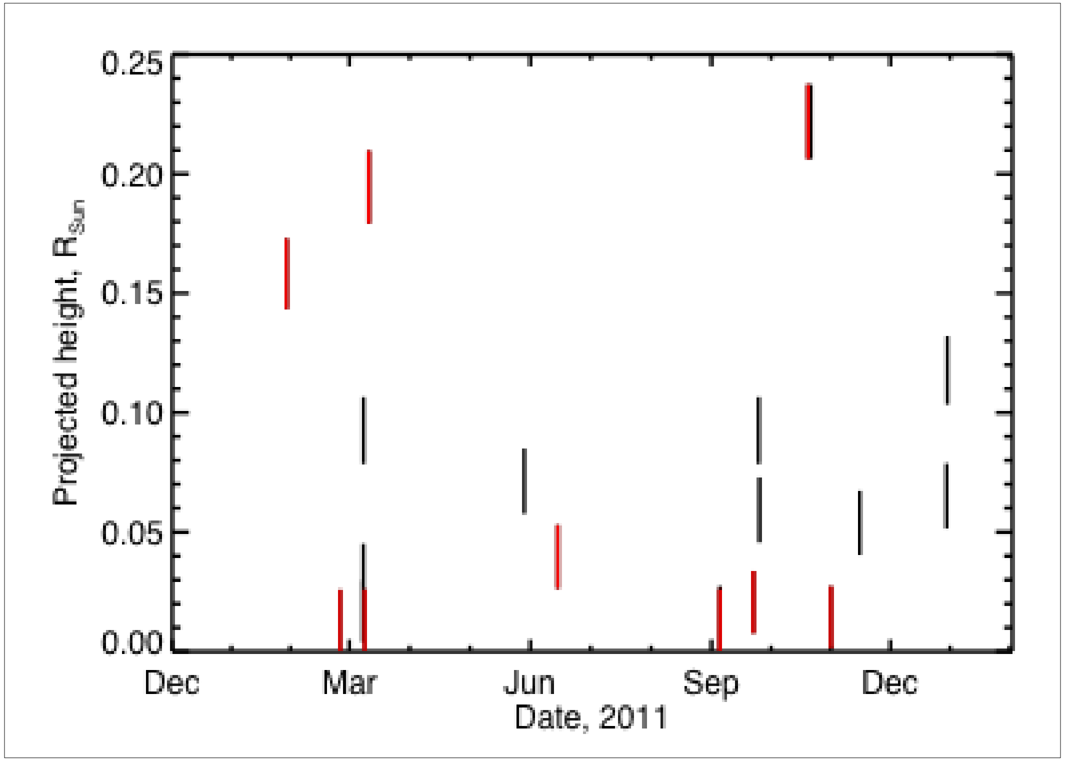
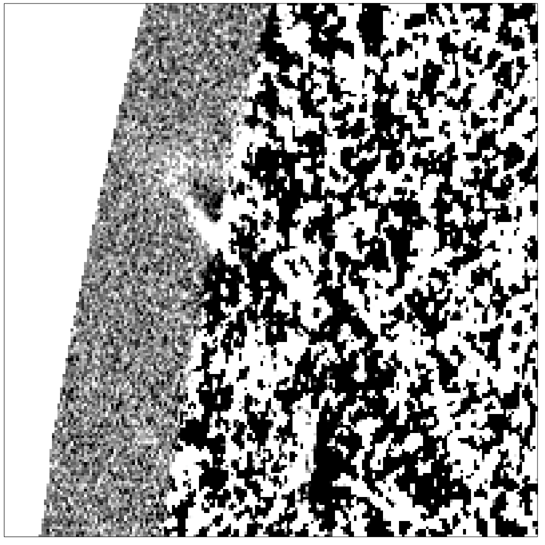
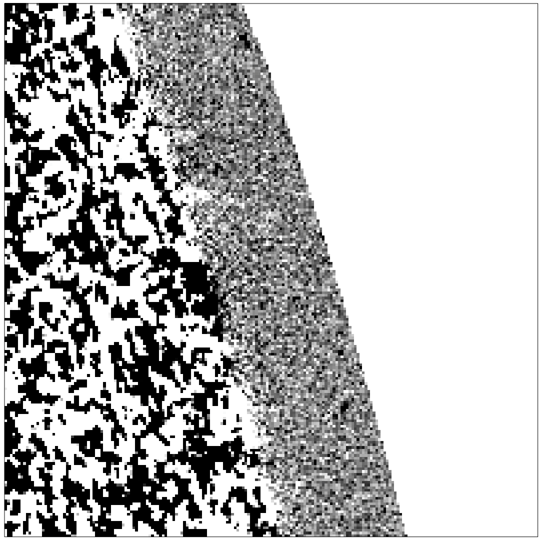


Projected heights of HMI annulus

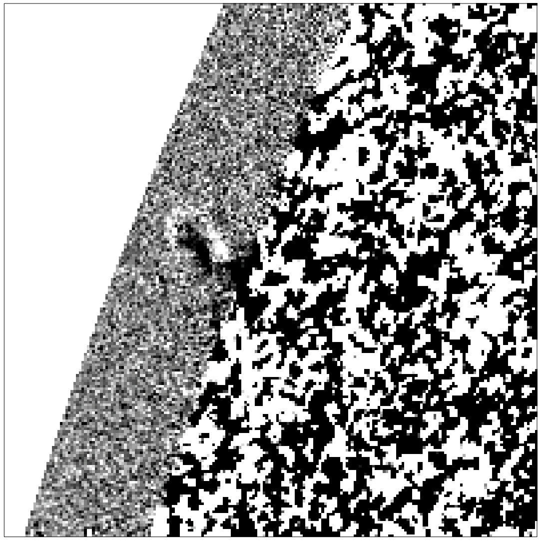
Mini-survey I



SOL2011-09-22



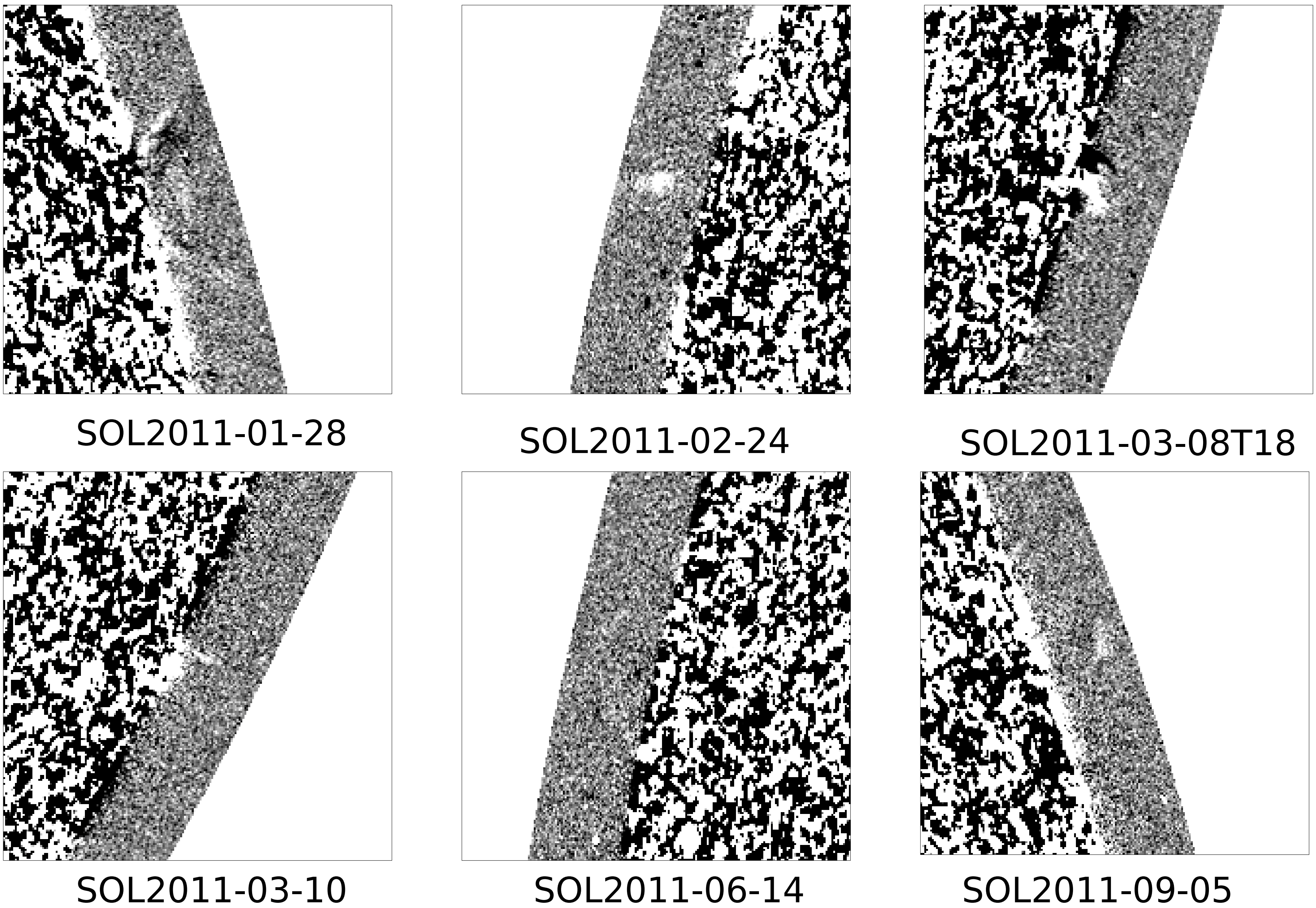
SOL2011-10-20



SOL2011-10-31T17

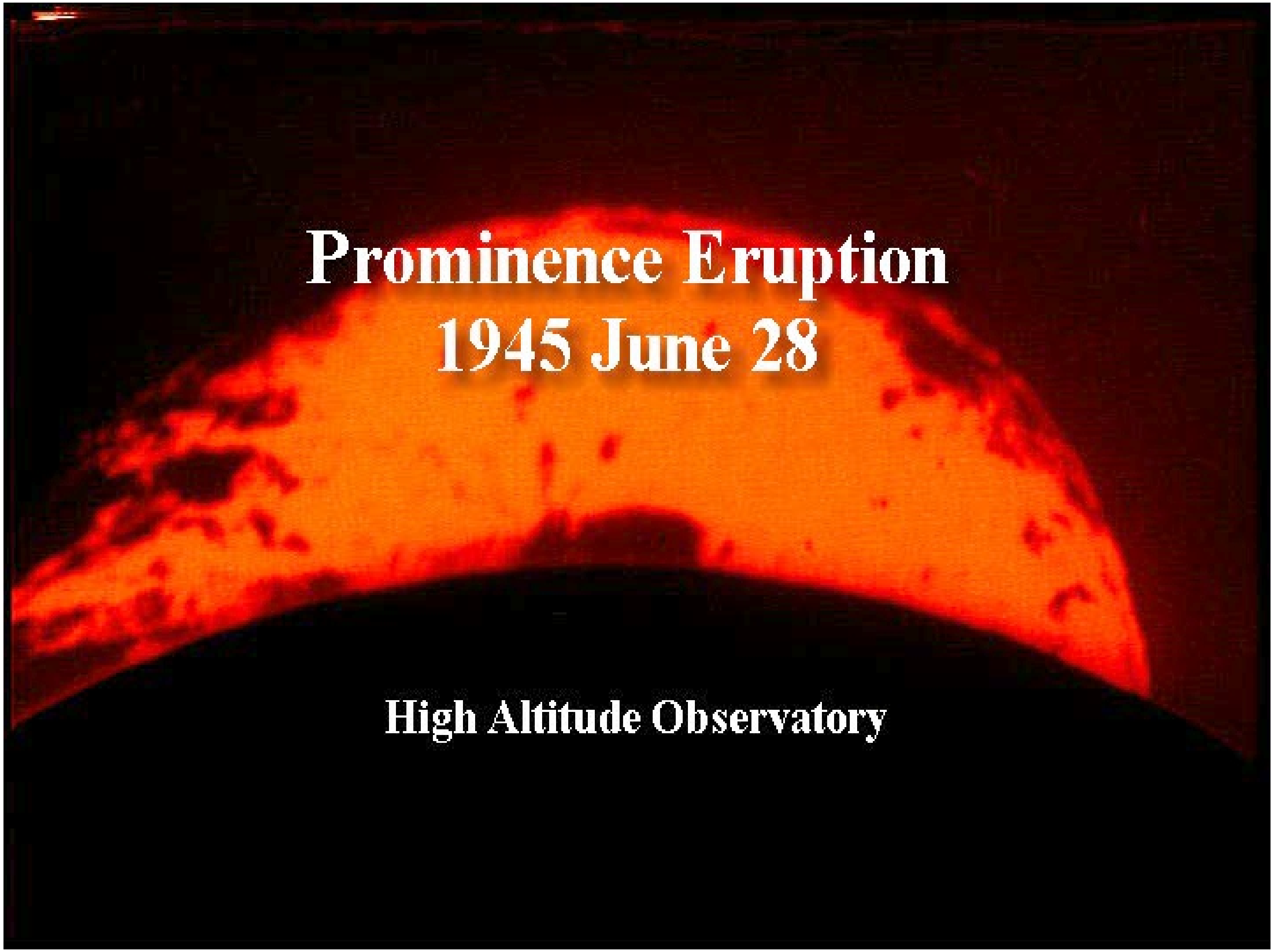
- The snapshots show HMI difference images, on a scale +-20 DN having a full range of about 10^{-4} of disk-center brightness
- HMI sees 8/21 M- and X-class events
  - near limb
  - with RHESSI

Mini-survey II

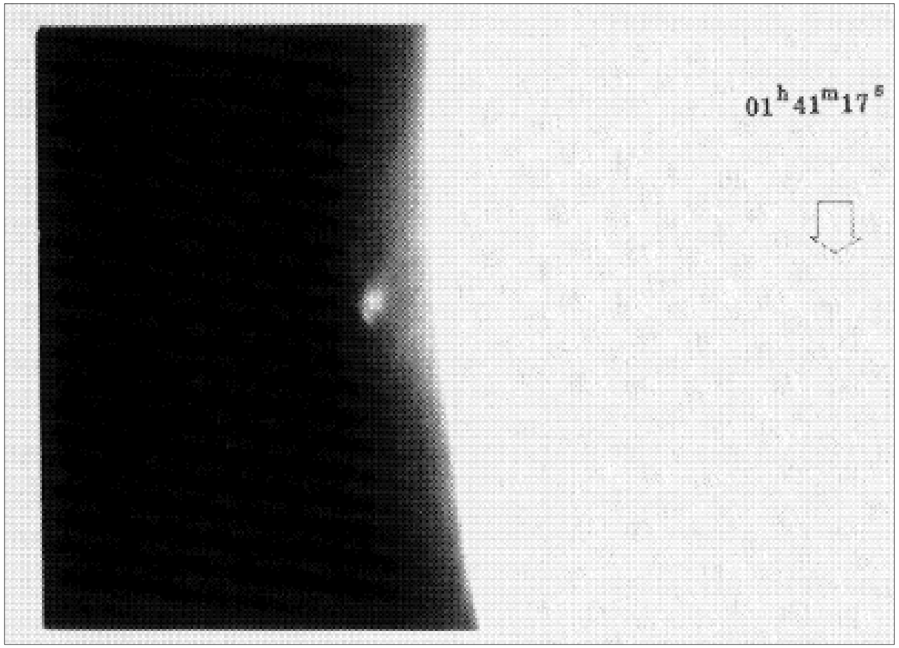


Conclusions

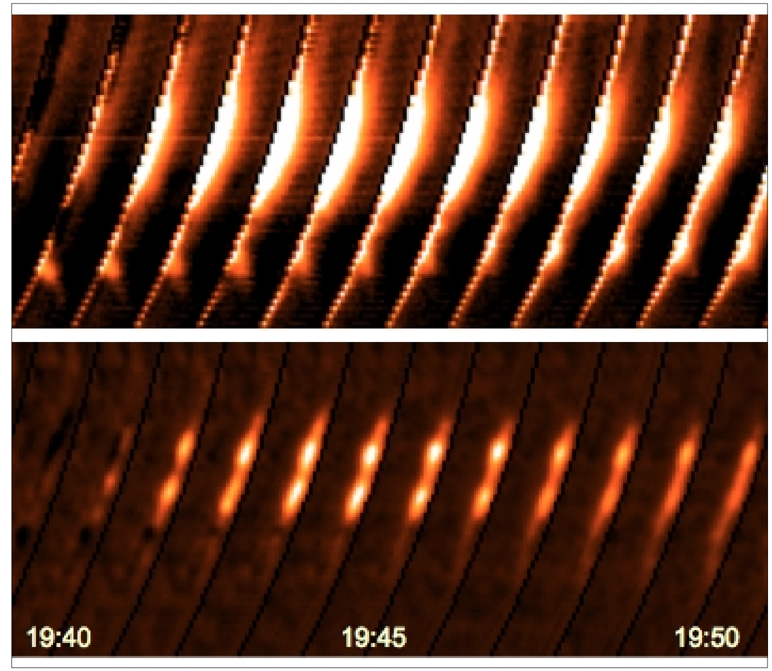
- HMI readily detects sources above the solar disk
- We identify SOL2013-05-13 as a loop prominence system
  - Linear polarization => Thomson scattering
  - Free-free component linking SXR and microwaves
  - Fe I?
  - Coronal rain
- Other flares have other morphologies


Prominence Eruption
1945 June 28
High Altitude Observatory

Prior related observations



SOL1989-08-16 (~X20): Hiei et al., 1992

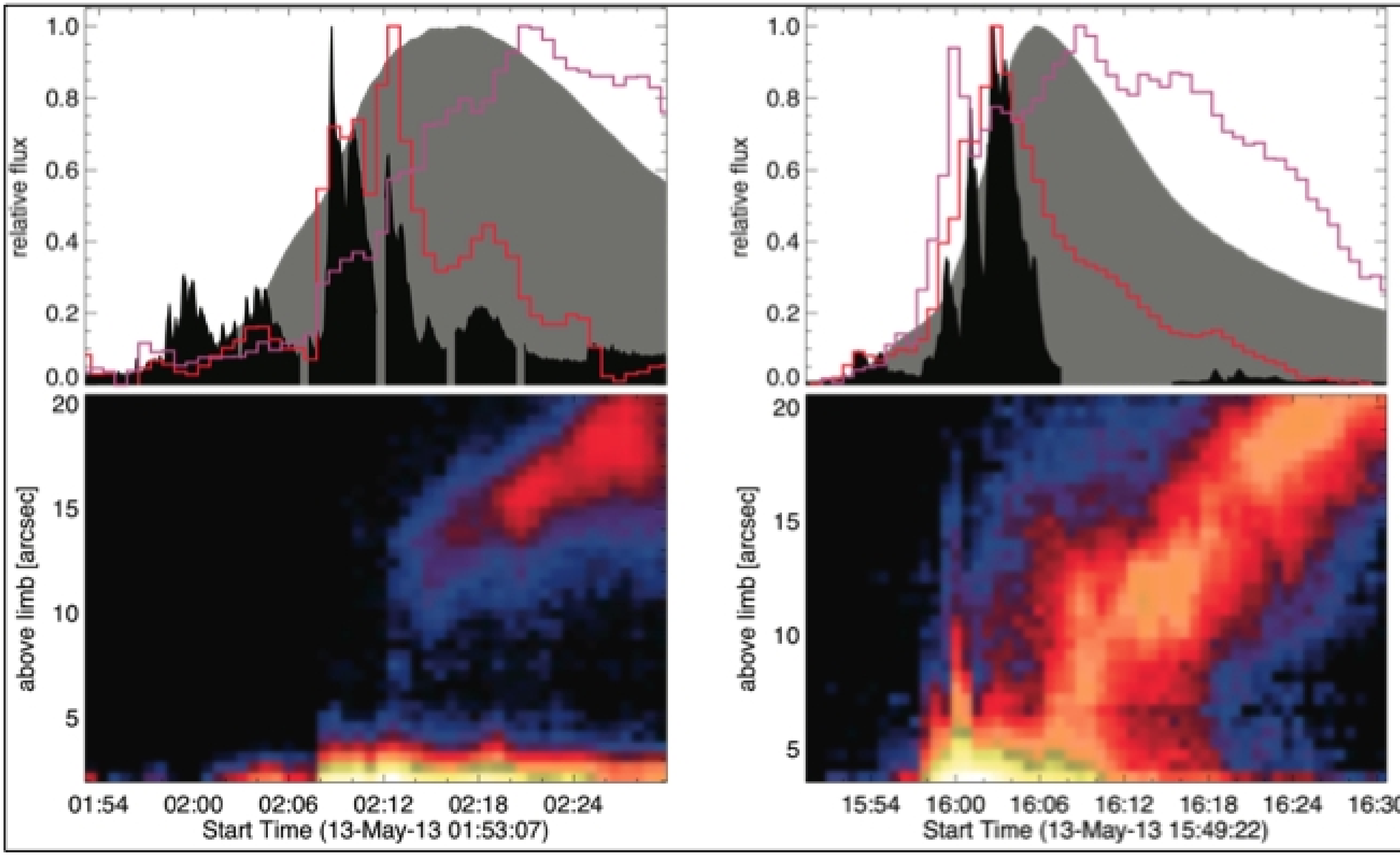


SOL2003-11-04 (~X20): Leibacher et al., 2004

- Otherwise, "white light prominences" have mainly been reported visually and anecdotally.

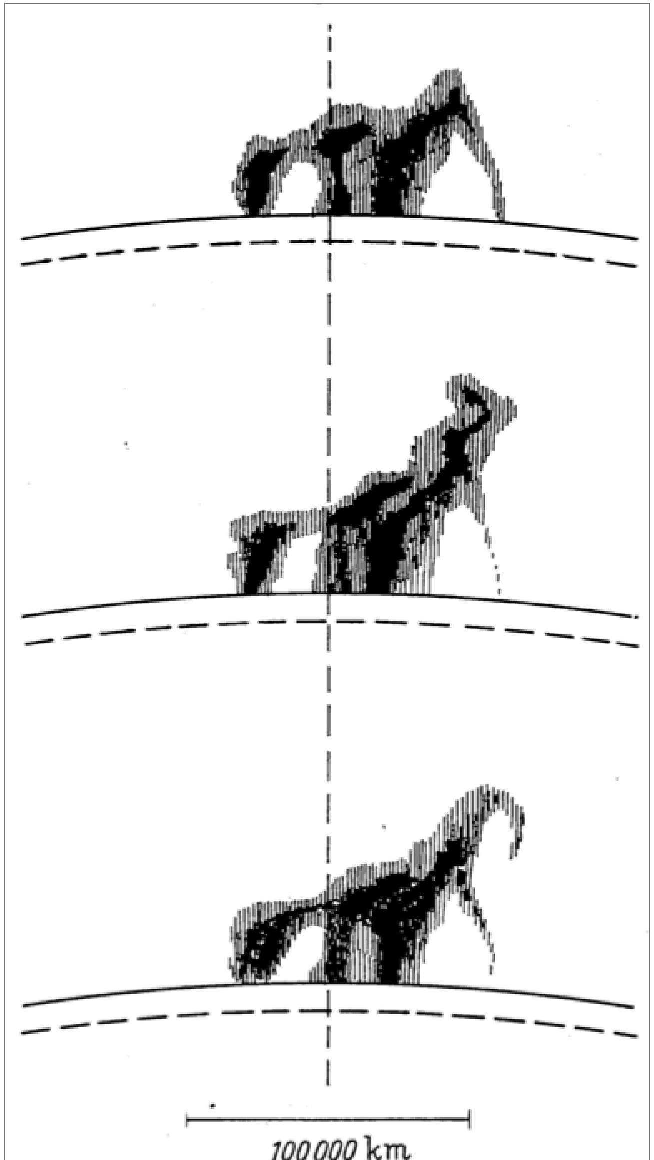
- Note the meaning of "white light" in this

Two flares in May 2013:
RHESSI, GOES, Inner HMI, Loops



Courtesy Säm Krucker

Sporadische koronale Kondensation



Sketches from Waldmeier (1956):

- Loops in Fe XIV 5303
- We know them today as "arcades"
- From such observations sprang the "CSHKP" idea – these looked like hotter versions of the Hα loops

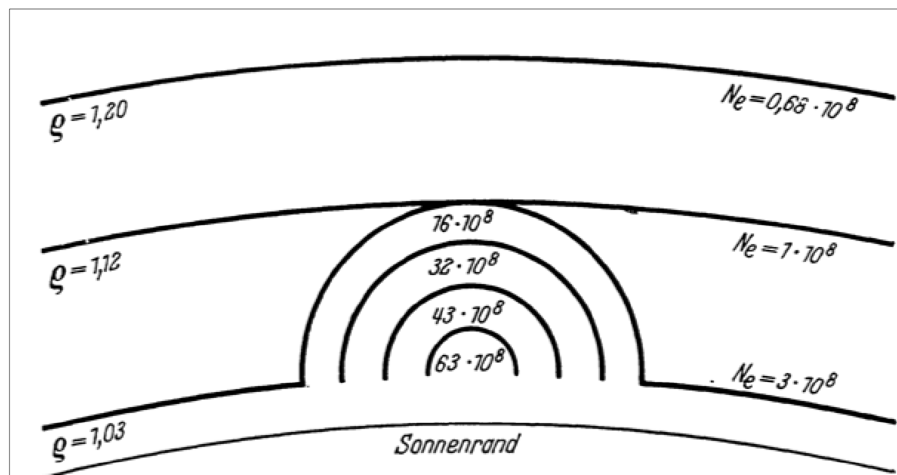


Abb. 3. Modell einer koronalen Kondensation.

Waldmeier-Muller 1950