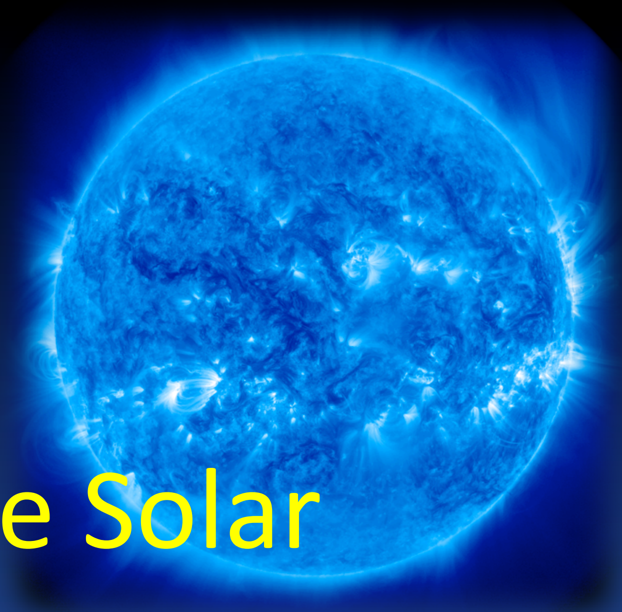


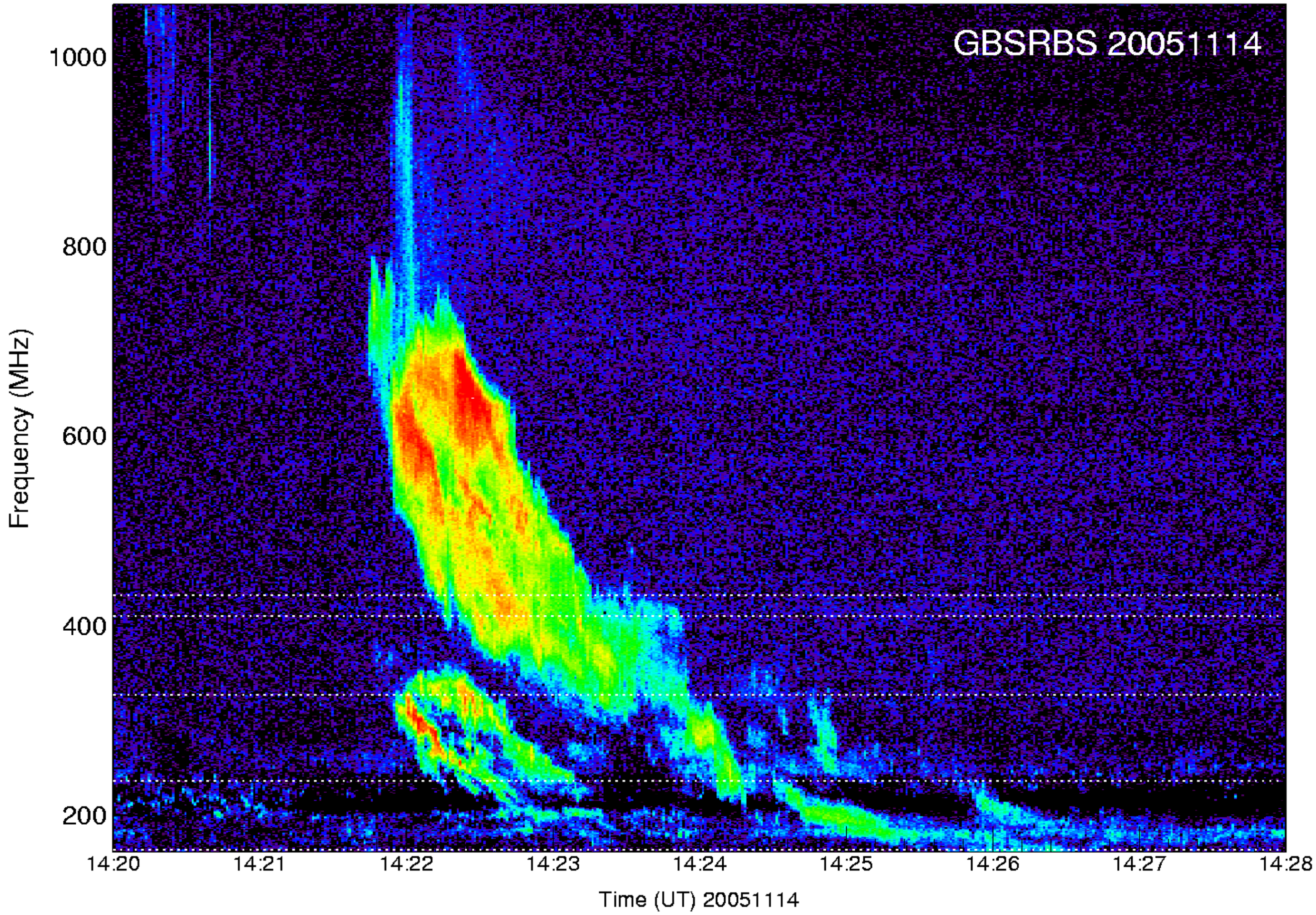
The Frequency Agile Solar Radiotelescope

T. S. Bastian (NRAO)

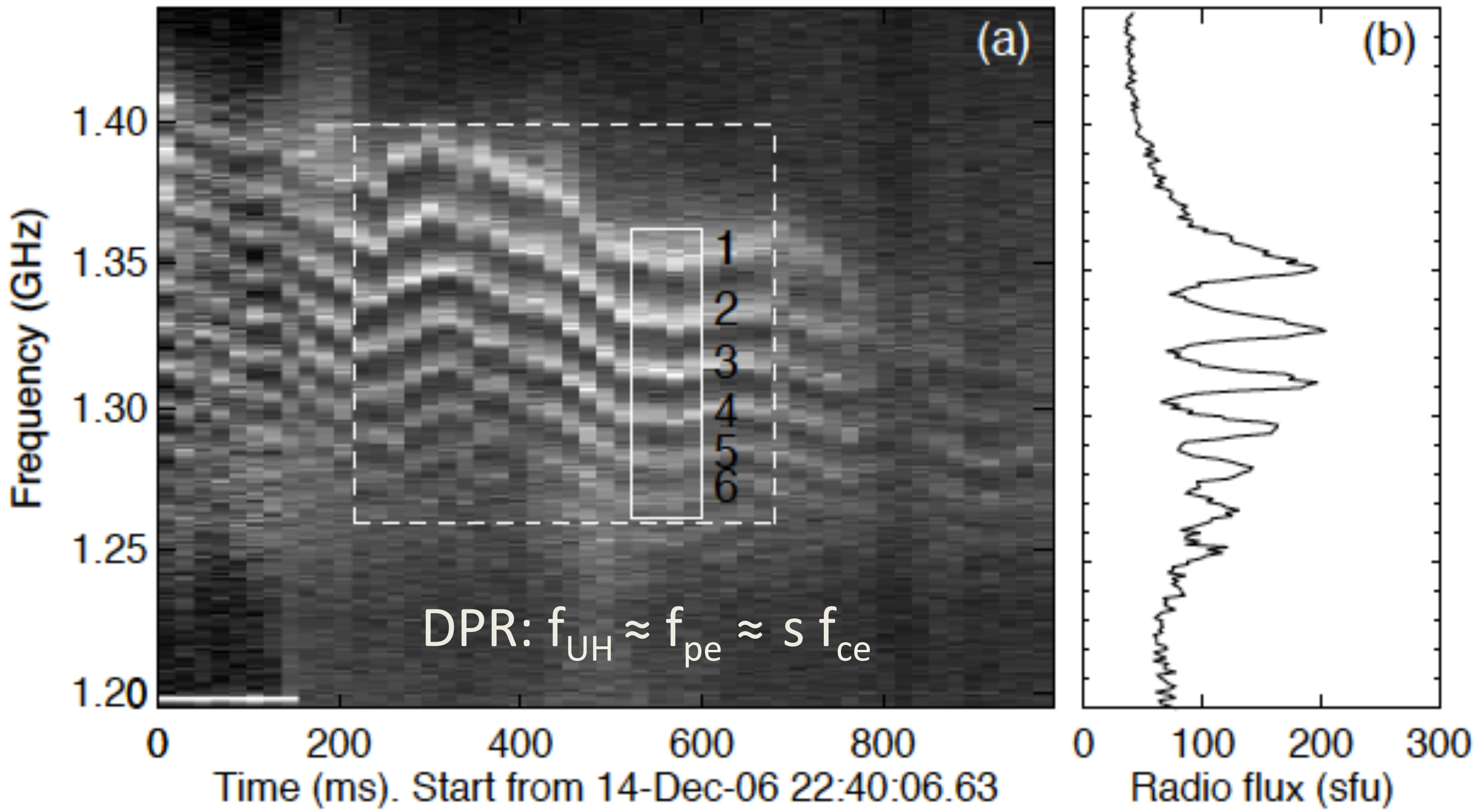
What it is

- FASR’s fundamental innovation is the ability to perform ***dynamic, broadband, imaging spectroscopy*** over an extremely large frequency bandwidth – from 50 MHz to 21 GHz (or $\lambda = 1.4$ cm to 6 m).
- FASR therefore measures the polarized brightness temperature spectrum along every line of site as a function of time.
- It was conceived as a facility for the broader solar and heliospheric physics community. It is a “general purpose” special purpose radio telescope.

Dynamic Spectroscopy from m-λ …



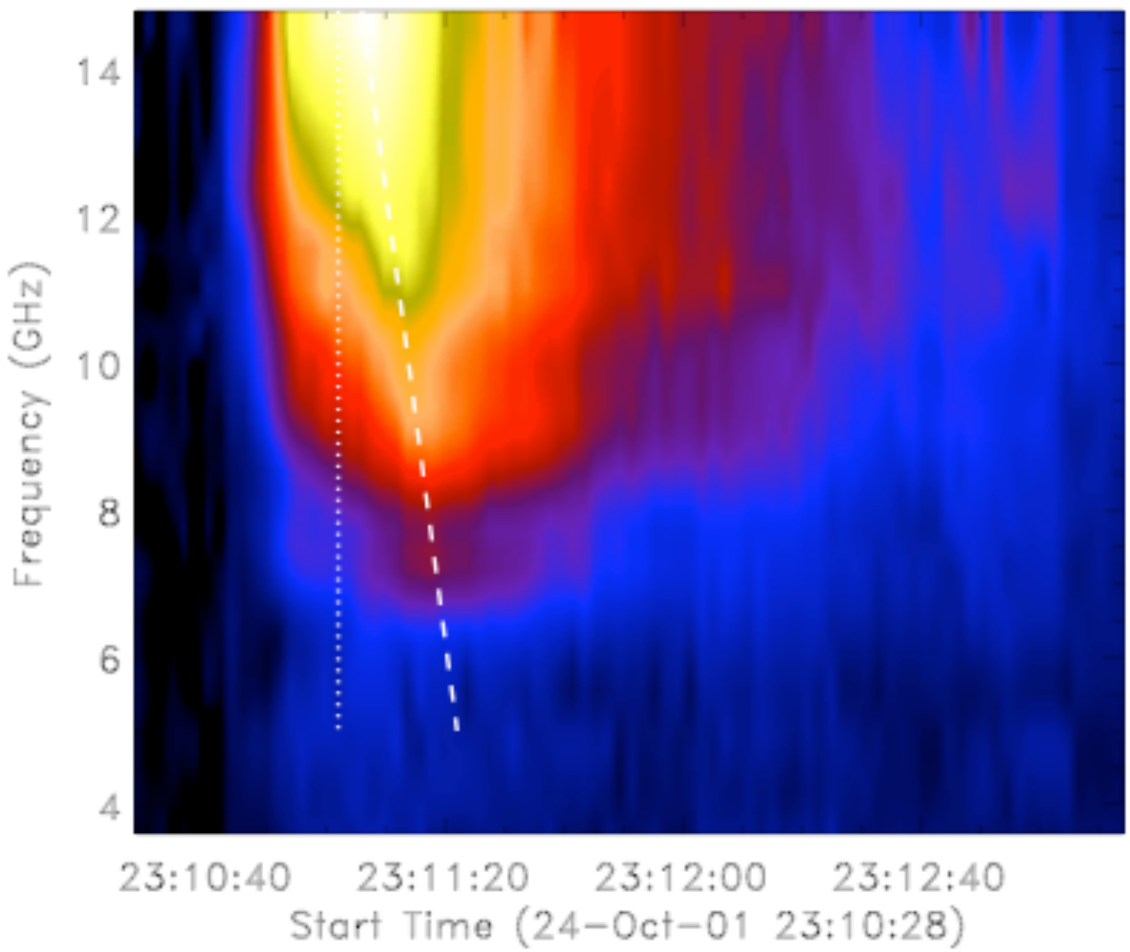
to dm-λ …



FASR Subsystems Testbed

Chen et al., 2012

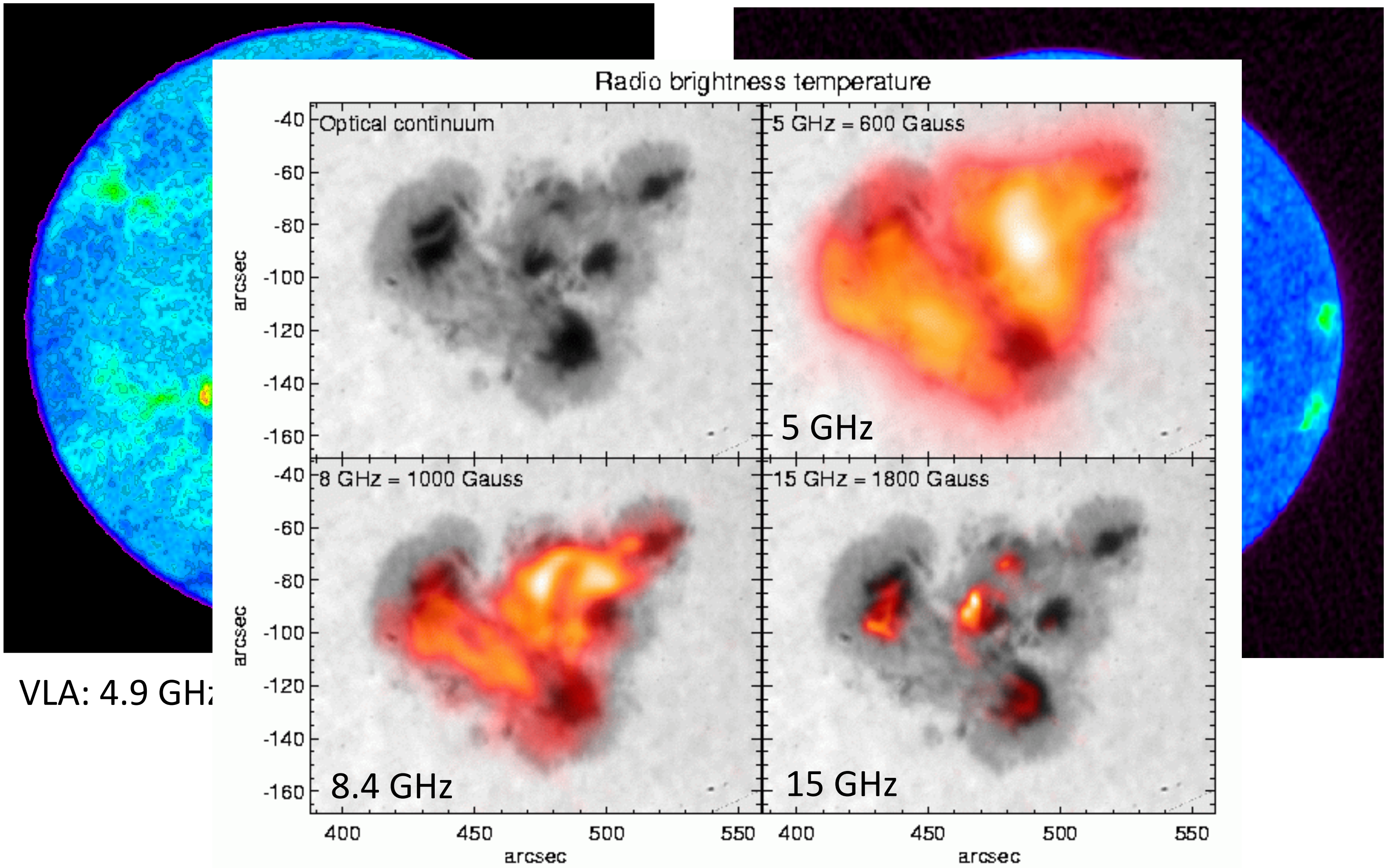
to cm-λ.



Owens Valley Solar Array

Bastian et al. 2008

combined with imaging

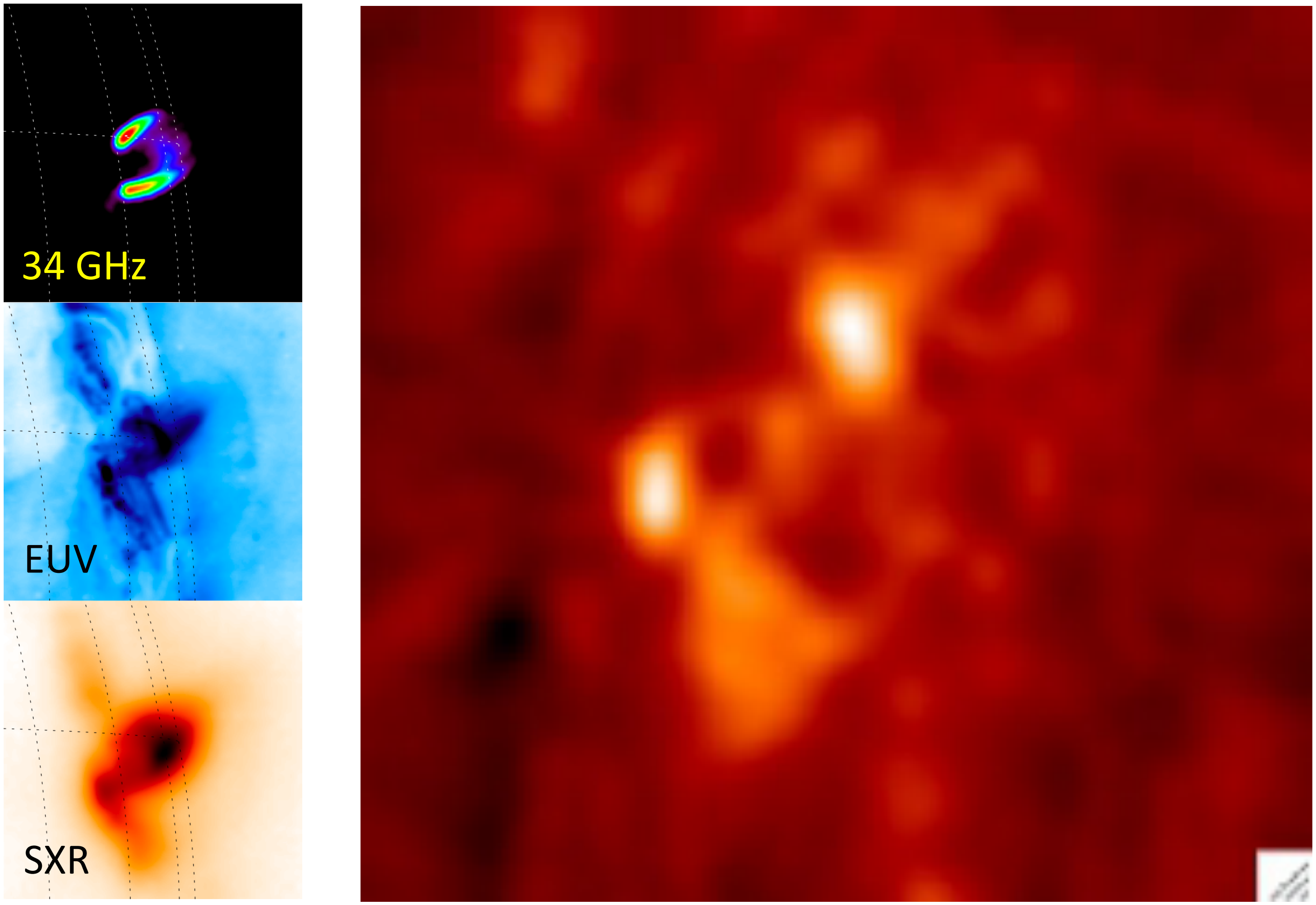


VLA: 4.9 GH

Lee et al. 1998

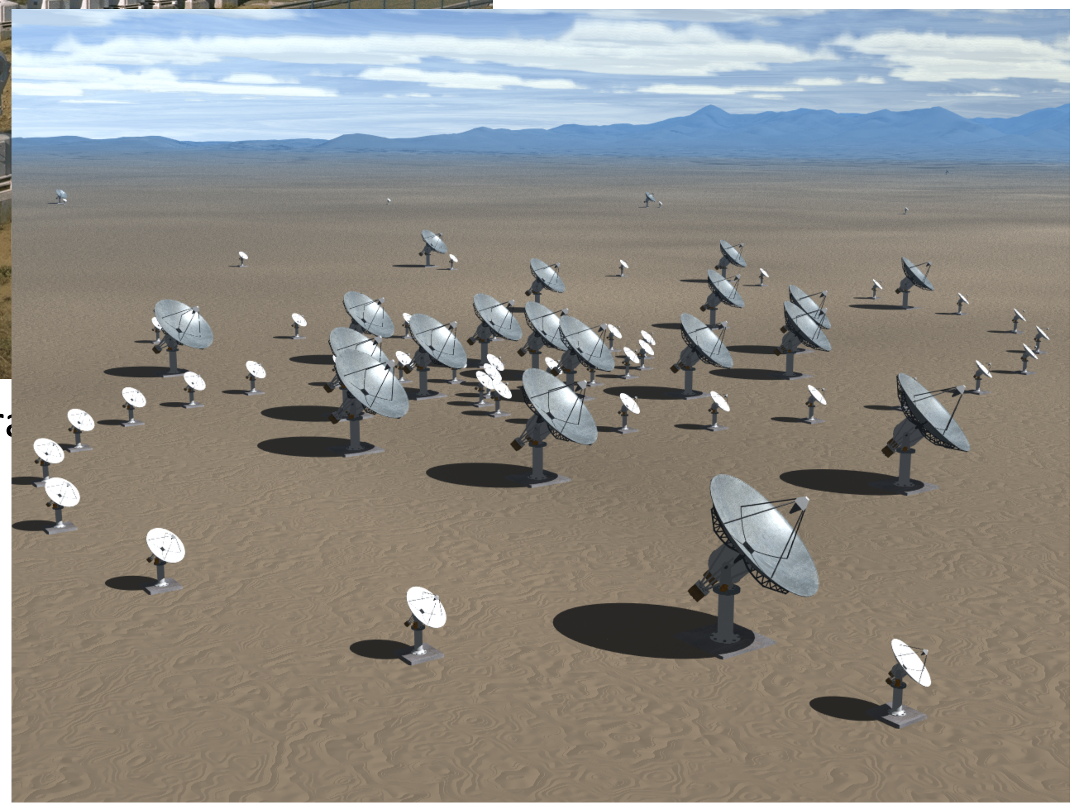
and high time resolution

13 July 2005 LDE: 0230-0500 UT



Nobeyama Radioheliograph 17 GHz

Nobeyama Radioheliogra



I. Gary

FASR High Level Specifications

Angular resolution	$20/\nu_{GHz}$ arcsec
Frequency range	50 MHz – 21 GHz
Number data channels	1-2 x 2 (dual polarization)
Frequency bandwidth	500 MHz per channel
Frequency resolution	Instrumental: 4000 channels Scientific: min(1%, 5 MHz)
Time resolution	~1 s (full spectrum sweep) 20 ms (dwell)
Polarization	Full Stokes (IQUV)
Number antennas deployed	**A** (2-21 GHz): ~100 **B** (0.3-2.5 GHz): ~70 **C** (50-350 MHz): ~50
Size antennas	**A** (2-21 GHz): 2 m **B** (0.3-2.5 GHz): 6 m **C** (50-350 MHz): LPDA
Array size	4.25 km EW x 3.75 km NS
Absolute positions	<1 arcsec
Absolute flux calibration	<10%

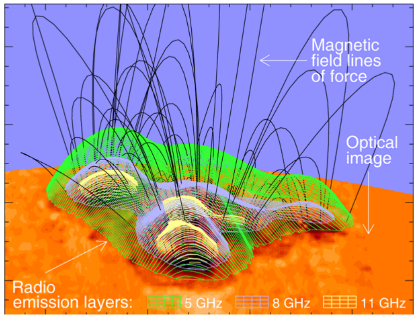
Why – The Science

Radio waves provide unique sensitivity to magnetic fields and the distribution function of energetic electrons.

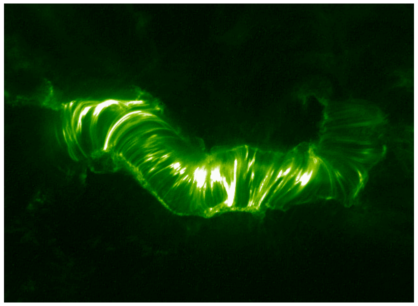
FASR will leverage observations of a number of emission mechanisms – e.g., thermal free-free emission, thermal gyroresonance emission, nonthermal gyrosynchrotron emission, & coherent plasma emission – to provide new information about fundamental phenomena and processes.

By imaging the entire solar atmosphere in 3D at once, it will provide insights into physical processes as a ***coupled system***.

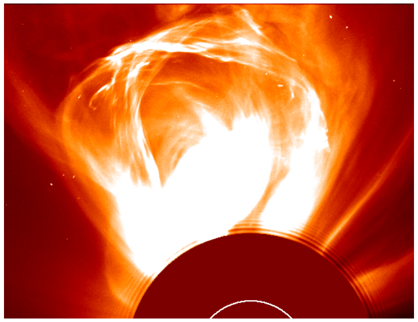
THE SCIENCE



- **Nature & Evolution of Coronal Magnetic Fields**
  - Coronal magnetography
  - Temporal & spatial evolution of fields
  - Coronal seismology

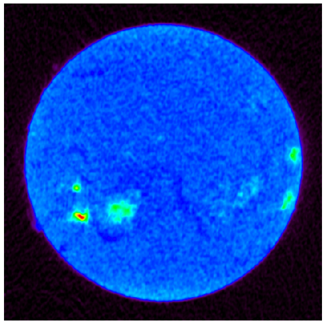


- **High energy solar physics**
  - Magnetic energy release
  - Plasma heating and dynamics
  - Electron acceleration and transport

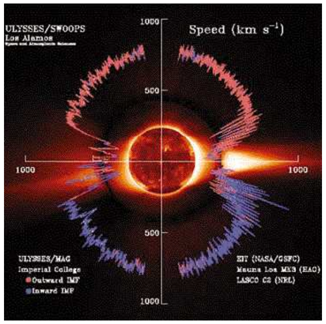


- **Drivers of Space Weather**
  - Birth & acceleration of CMEs
  - Prominence eruptions
  - Origin of SEPs

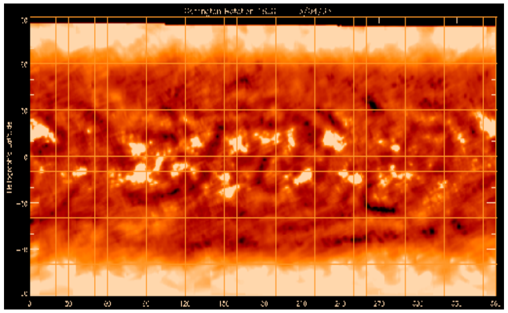
THE SCIENCE



- The "thermal" solar atmosphere
  - Coronal & chromospheric heating
  - Thermodynamic structure & dynamics
  - Formation & structure of filaments and coronal cavities



- Solar Wind
  - Birth in network
  - Coronal holes
  - Turbulence/waves



- Synoptic studies
  - Radiative inputs to upper atmosphere
  - Global magnetic field/dynamo
  - Statistical studies of energetic phenomena

Space Weather

Solar and space physics research is of direct relevance to society: specifically, understanding space weather drivers and impacts, as well as forecasting and now-casting space weather phenomena.

It has been an increasingly high profile policy concern, e.g.:

- Severe Space Weather Events – Understanding Societal and Economic Impacts (NRC SSB 2008)
- Space Weather Observing Systems: Current Capabilities and Requirements for the Next Decade (OSTP 2013)

Which has propagated into the scientific and popular press, e.g.:

- Astrophysics: Prepare for the Coming Space Weather Storm, Nature, April 2012
- When Space Weather Attacks, Washington Post Business section cover, July 2013
- Solar Storm Warning, Astronomy Magazine cover story, September 2013

How - Operations

Unlike radio telescopes designed for general science observations of sidereal sources, FASR will be solar dedicated. It will observe the full disk of the Sun all day every day.

It will not be a PI instrument. The community will interact with FASR and FASR data in a manner similar to a space mission like TRACE or RHESSI.

FASR operations will assume responsibility for calibrating and reducing the data, and producing science ready data and data products using reduction pipelines.

The user community, an inherently multi-wavelength community that is familiar with this model for many observatories and missions, will access data and data products through a user interface to the science data archive.

Community Support

FASR has received strong support from four NRC decadal surveys:

- *Astronomy & Astrophysics in the New Millenium (2001)* recommended FASR as part of an integrated suite of solar instrumentation: the SDO (launched), ATST (now DKIST - under construction), and FASR
- FASR was the number one "small" project recommended by The Sun to the Earth – and Beyond (2003) The number one "medium" project was MMS (2014 launch) and number one large project was Solar Probe (2018 launch)
- FASR was described as a "compelling" mid-scale project by *New Worlds, New Horizons* (2012), and it was ranked highly by the RMS panel.
- FASR was the top ranked ground based project *in Solar and Space Physics: a Science for a Technological Society* (2012)

How has FASR fared?

- MRI funded in 2003 for BB feed development and SRBS
- FASR DDP funded in 2005 for FASR design and development
  - Reference instrument
  - Cost model
  - Operations and maintenance plan
- FASR Subsystem Testbed (FST) funded through ATI in 2006
- FASR MSI proposal to NSF/AGS in 2008 not funded
- FASR pathfinder proposal in 2009 shelved
- EOVSA ARRA MRI2 proposal funded in 2010
- FASR MSIP proposal to NSF/AST in 2013 declined

A fundamental problem has been, and continues to be, who owns solar at the NSF? AST handles NSO and DKIST. AGS handles NCAR/HAO, SHINE, solar-terrestrial grants. A push to consolidate the two portfolios has stalled … scarce funds …

Now what?

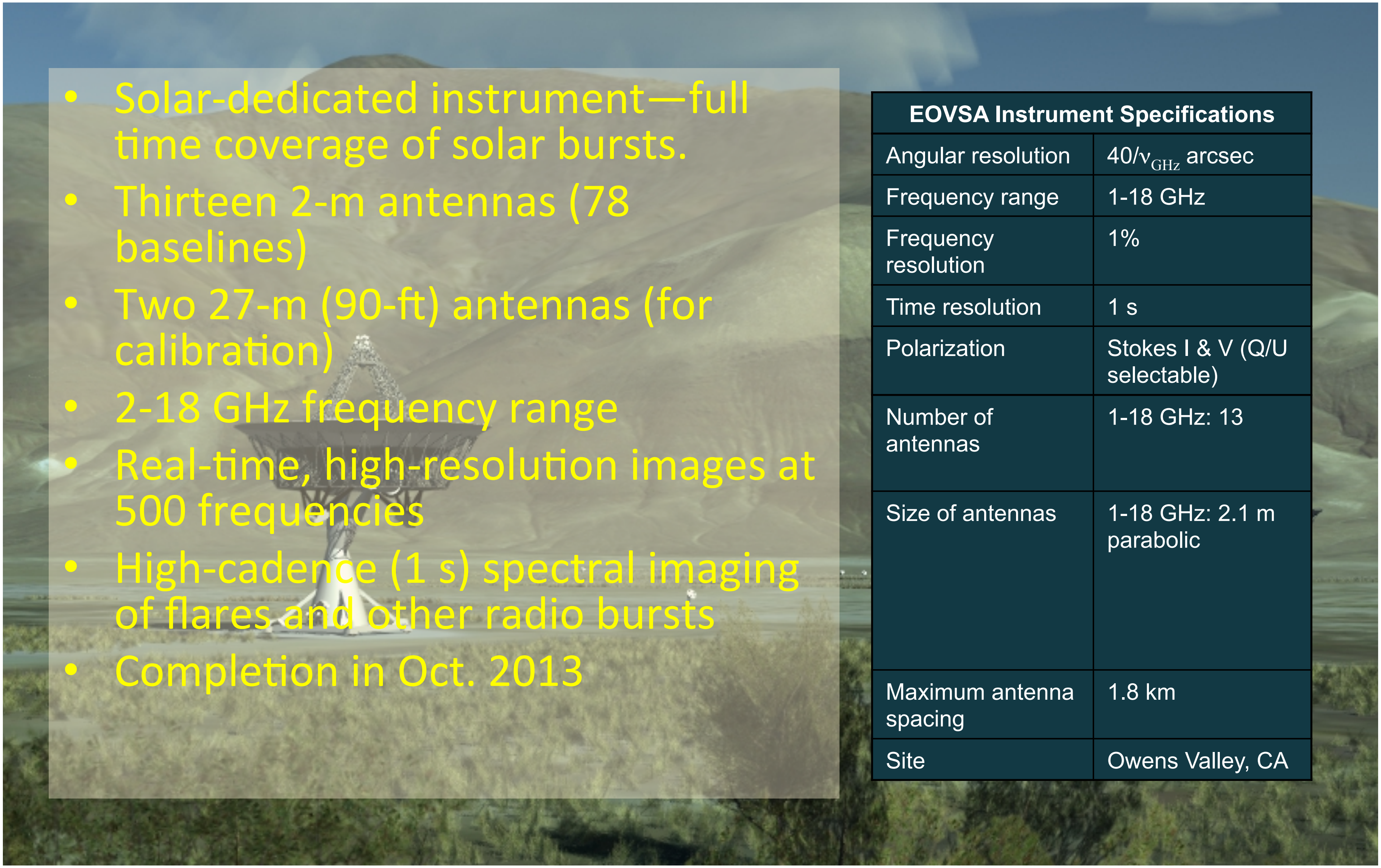
Keep calm, carry on. Continue to push NSF, NASA, and DoD sources. Continue development as opportunities arise.

Partner with international colleagues – technical, software, students, postdocs.

And, above all, continue to push hard on the relevant science with the new assets available!

- Chinese Spectral Radioheliograph (Y. Yan)
- Expanded Owens Valley Solar Array
- Very Large Array

Expanded Owens Valley Solar Array



- Solar-dedicated instrument—full time coverage of solar bursts.
- Thirteen 2-m antennas (78 baselines)
- Two 27-m (90-ft) antennas (for calibration)
- 2-18 GHz frequency range
- Real-time, high-resolution images at 500 frequencies
- High-cadence (1 s) spectral imaging of flares and other radio bursts
- Completion in Oct. 2013

EOVSA Instrument Specifications	
Angular resolution	$40/\nu_{GHz}$ arcsec
Frequency range	1-18 GHz
Frequency resolution	1%
Time resolution	1 s
Polarization	Stokes I & V (Q/U selectable)
Number of antennas	1-18 GHz: 13
Size of antennas	1-18 GHz: 2.1 m parabolic
Maximum antenna spacing	1.8 km
Site	Owens Valley, CA

Solar Observing with the Jansky VLA

- Frequency coverage from 1-18 GHz (L, S, C, X, and Ku bands)

  L, S, and C bands (1-8 GHz) available now under "shared risk" observing
  X and Ku bands (8-18 GHz) to be complete in the next 2-3 years

- All bands to include gain calibration systems

Note: the VLA does not have sufficient dynamic range to observe large solar flares from 2-18 GHz. Therefore, it will be able to observe the quiet Sun, active regions, and flares with flux densities up to a few x 100 SFU.

- However, L band will include a high dynamic range signal path that will allow it to observe even the most powerful radio bursts between 1-2 GHz. This, too, will be deployed over the next 2-3 years.

Even so, other "hard limits" remain in the use of the VLA as a solar imaging instrument:

The antennas are large (25 m) and the FOV is therefore small (1.5λ arcmin)

The number and configuration of antennas is non-optimum for solar imaging (better to have large numbers of small antennas: NoRH, SSRT, CSRH, FASR)

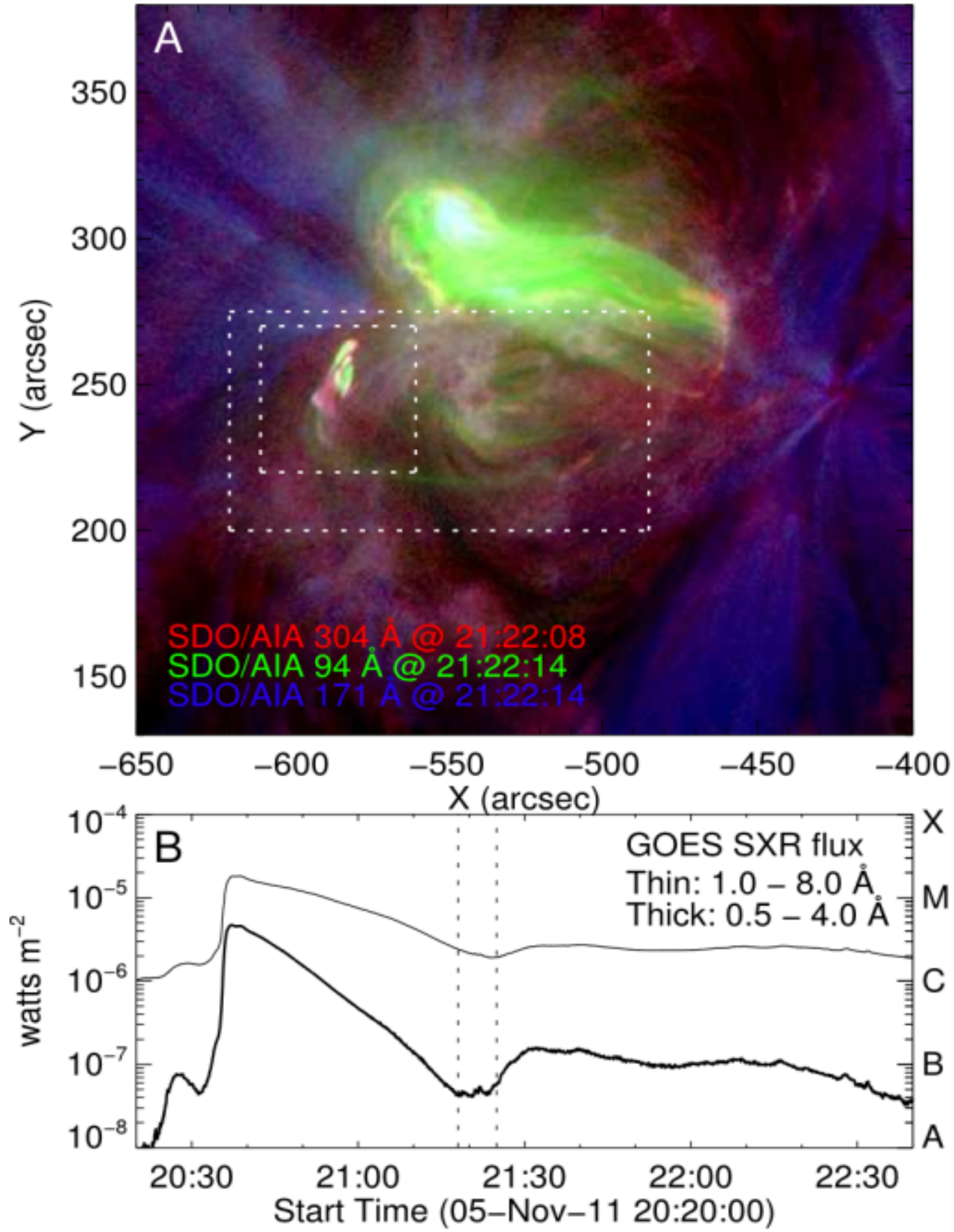
Very Large Array
5 November 2011

- D configuration
- 17 antennas
- 1-2 GHz
- 1024 channels
- Δt = 100 ms
- Dual polarization

An image is available for each integration time and frequency:

>20000 snapshots/sec !

A number of decimetric type III radio bursts were observed in association with an EUV jet observed by SDO/AIA.

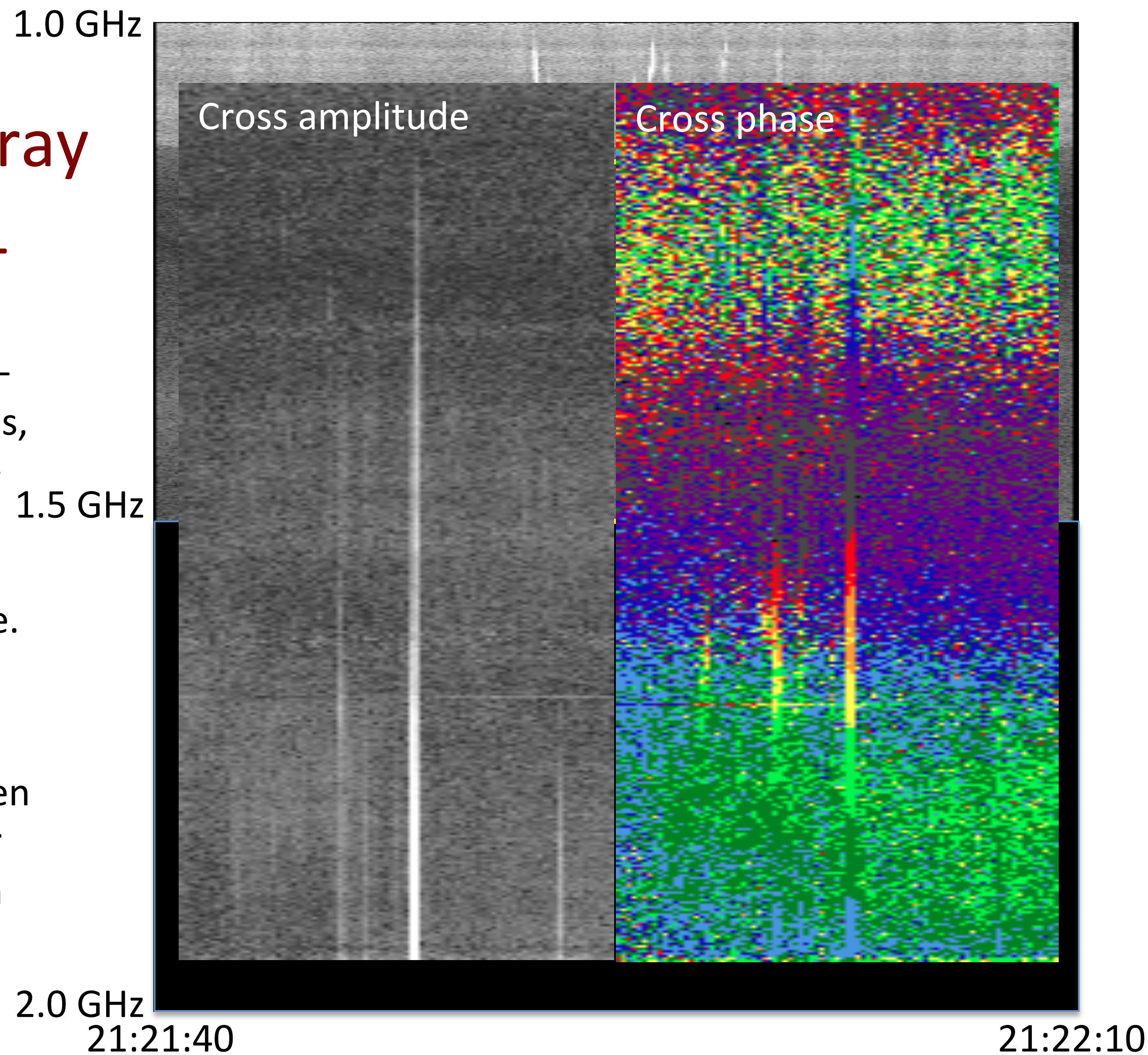


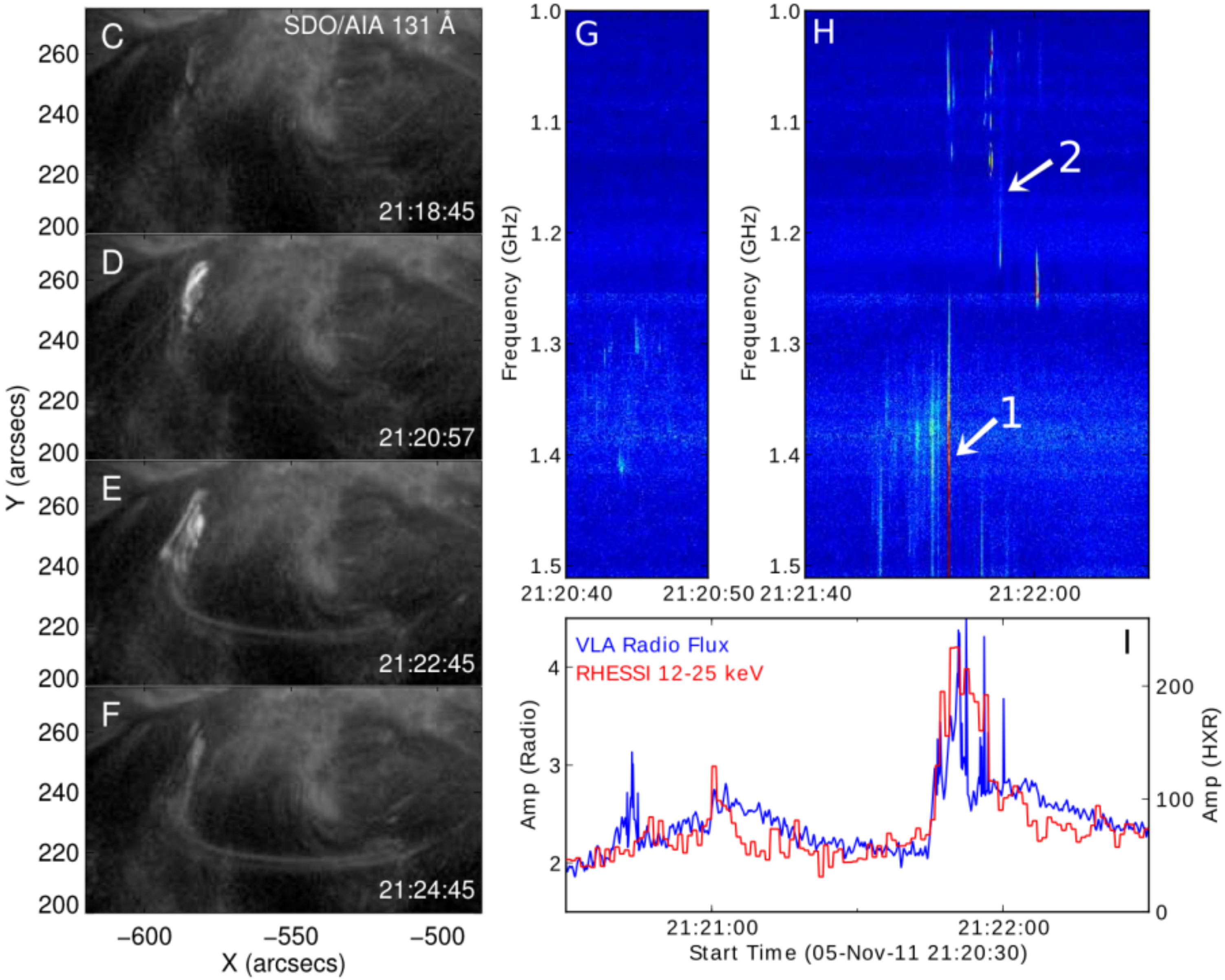
See Chen et al 2013 (ApJ 726, L21)

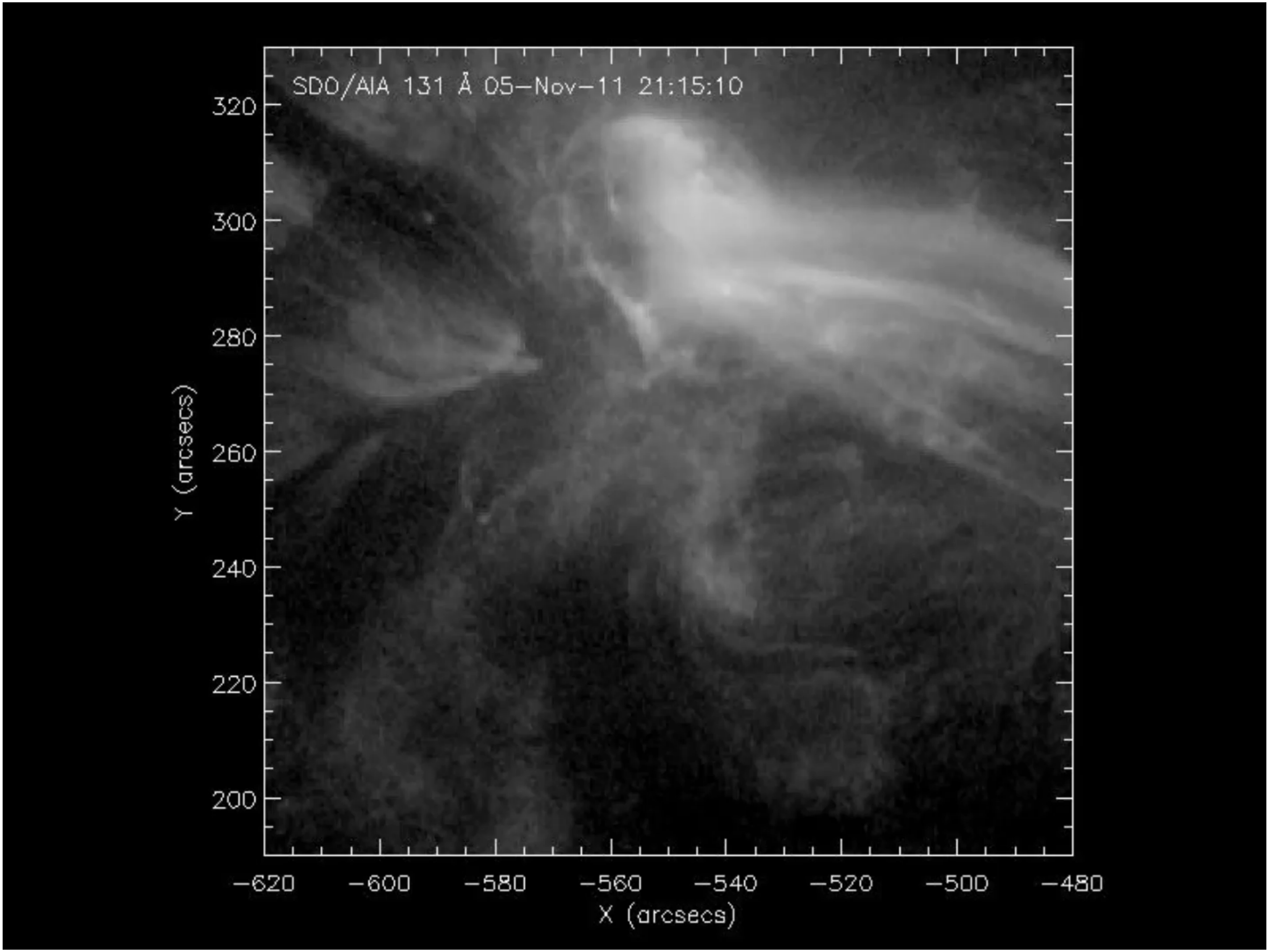
Very Large Array
5 Nov 2011

Numerous type IIIdm bursts, driven by supra-thermal electron beams, were observed in association with an EUV jet that occurred in the aftermath of an M flare.

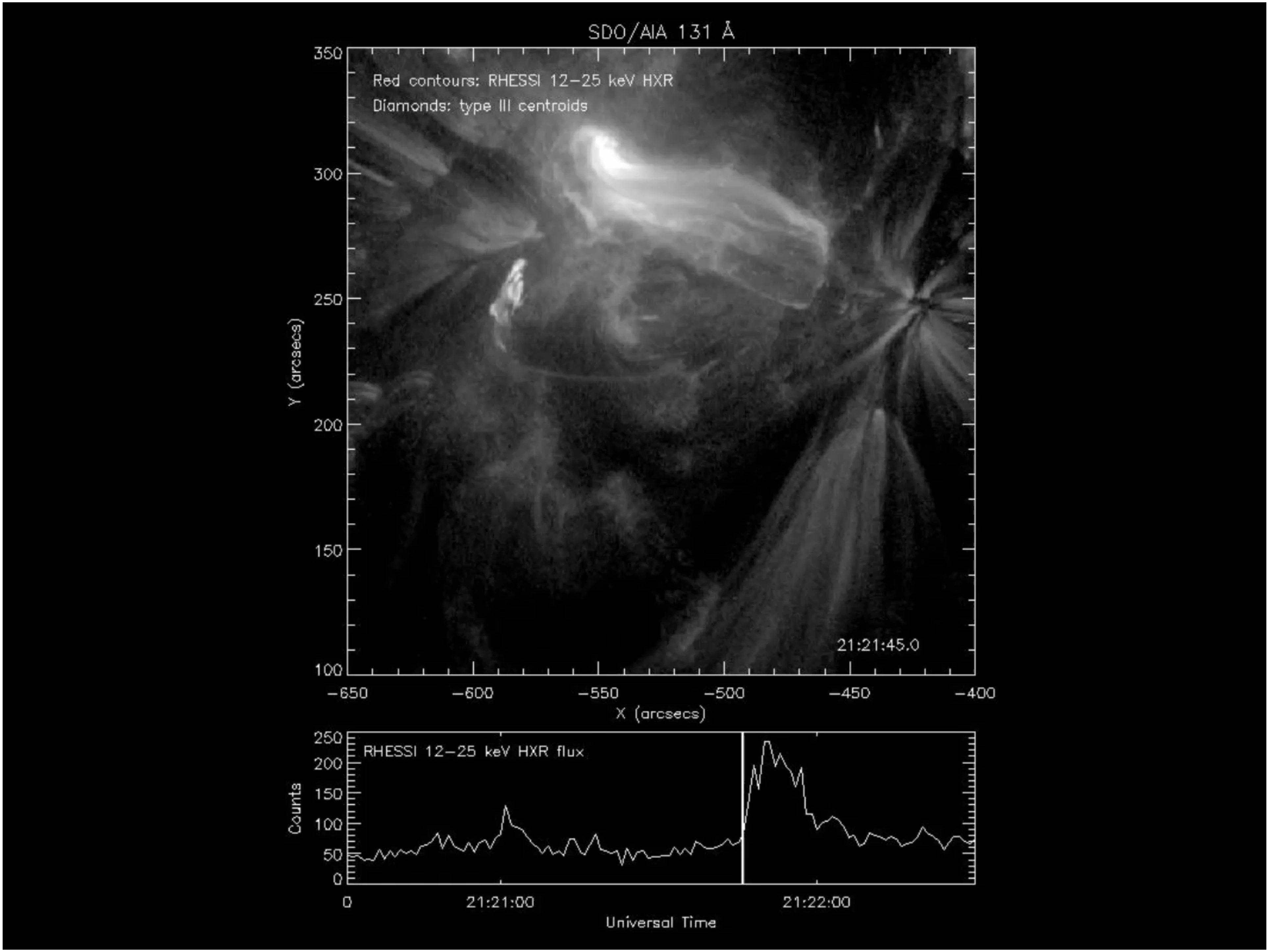
Unfortunately, a hardware fault led to the loss of data between 1.5-2.0 GHz (except for those correlations with antenna 27)

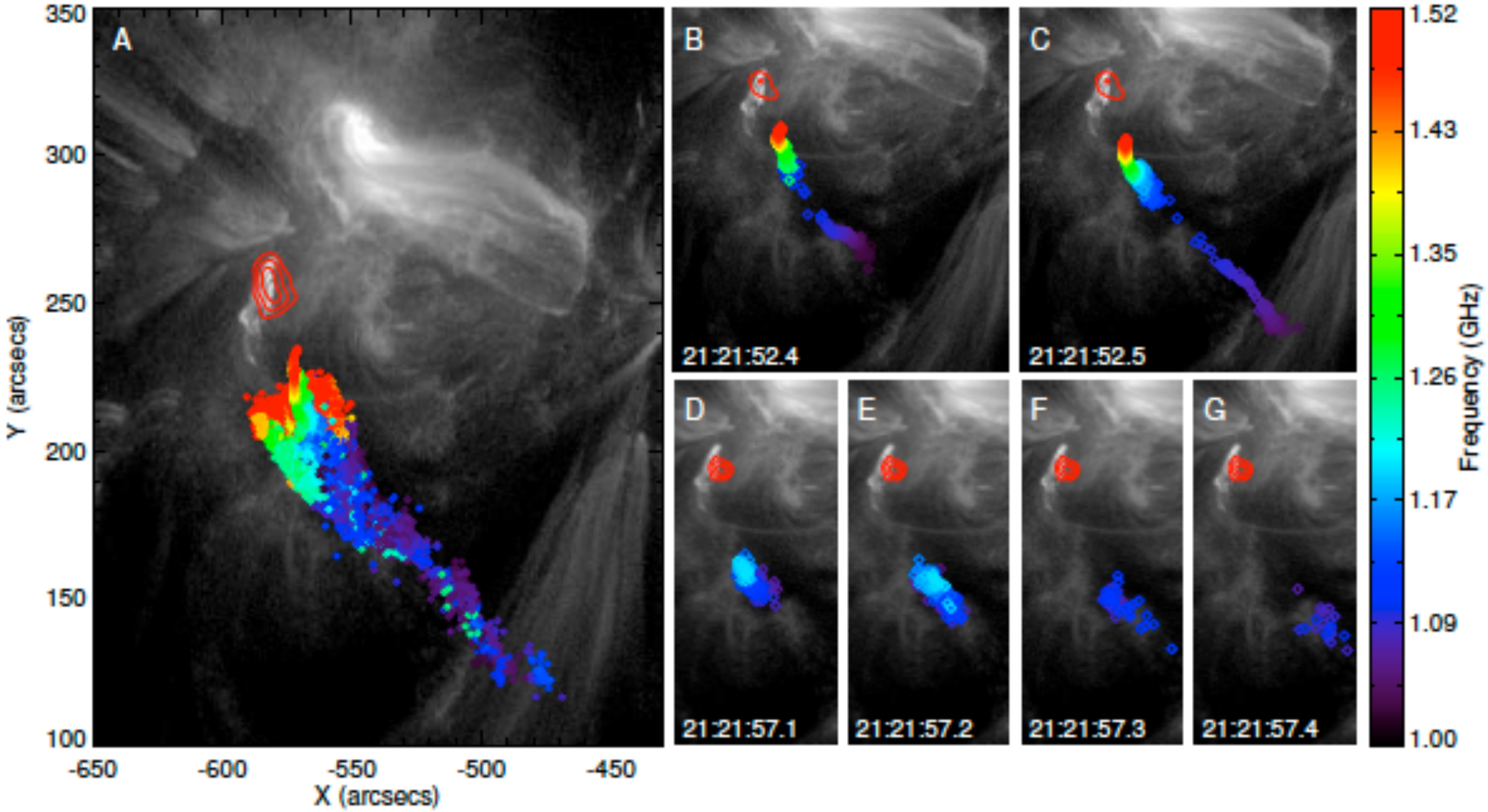



C
SDO/AIA 131 Å
21:18:45
D
21:20:57
E
21:22:45
F
21:24:45
Y (arcsecs)
X (arcsecs)
G
H
Frequency (GHz)
21:20:40
21:20:50
21:21:40
21:22:00
2
1
VLA Radio Flux
RHESSI 12-25 keV
I
Amp (Radio)
Amp (HXR)
21:21:00
21:22:00
Start Time (05-Nov-11 21:20:30)



SDO/AIA 131 Å 05-Nov-11 21:15:10
320
300
280
260
240
220
200
Y (arcsecs)
−620
−600
−580
−560
−540
−520
−500
−480
X (arcsecs)


SDO/AIA 131 Å
Red contours: RHESSI 12–25 keV HXR
Diamonds: type III centroids
21:21:45.0
Y (arcsecs)
X (arcsecs)
350
300
250
200
150
100
−650
−600
−550
−500
−450
−400
RHESSI 12–25 keV HXR flux
Counts
250
200
150
100
50
0
21:21:00
21:22:00
Universal Time



The combined radio and EIV observations allowed us to deduce the electron number density along the beam trajectories and, furthermore, to demonstrate that the corona is highly "fibrous" in nature. See Chen et al 2013 for details.

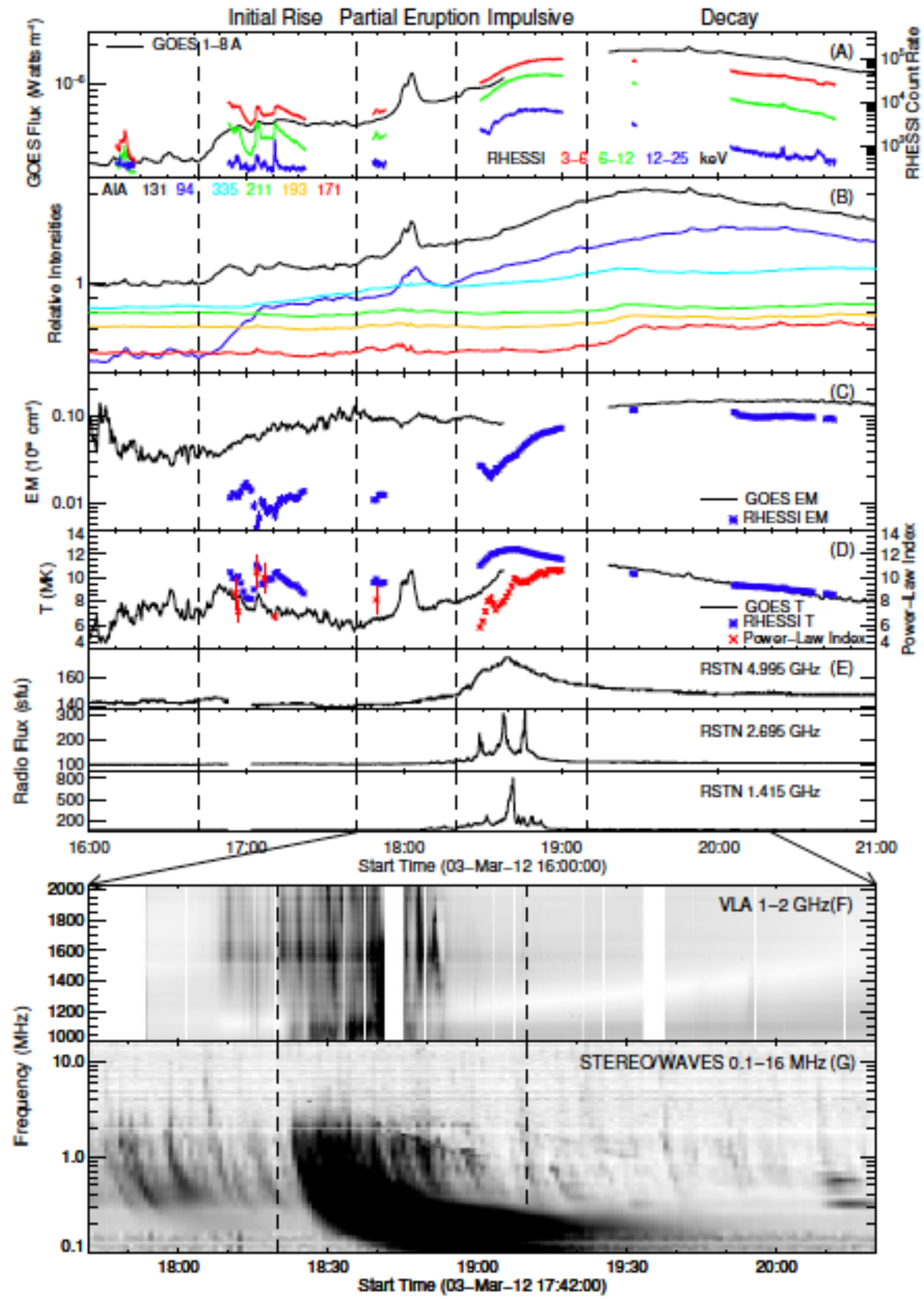
Very Large Array
3 March 2012

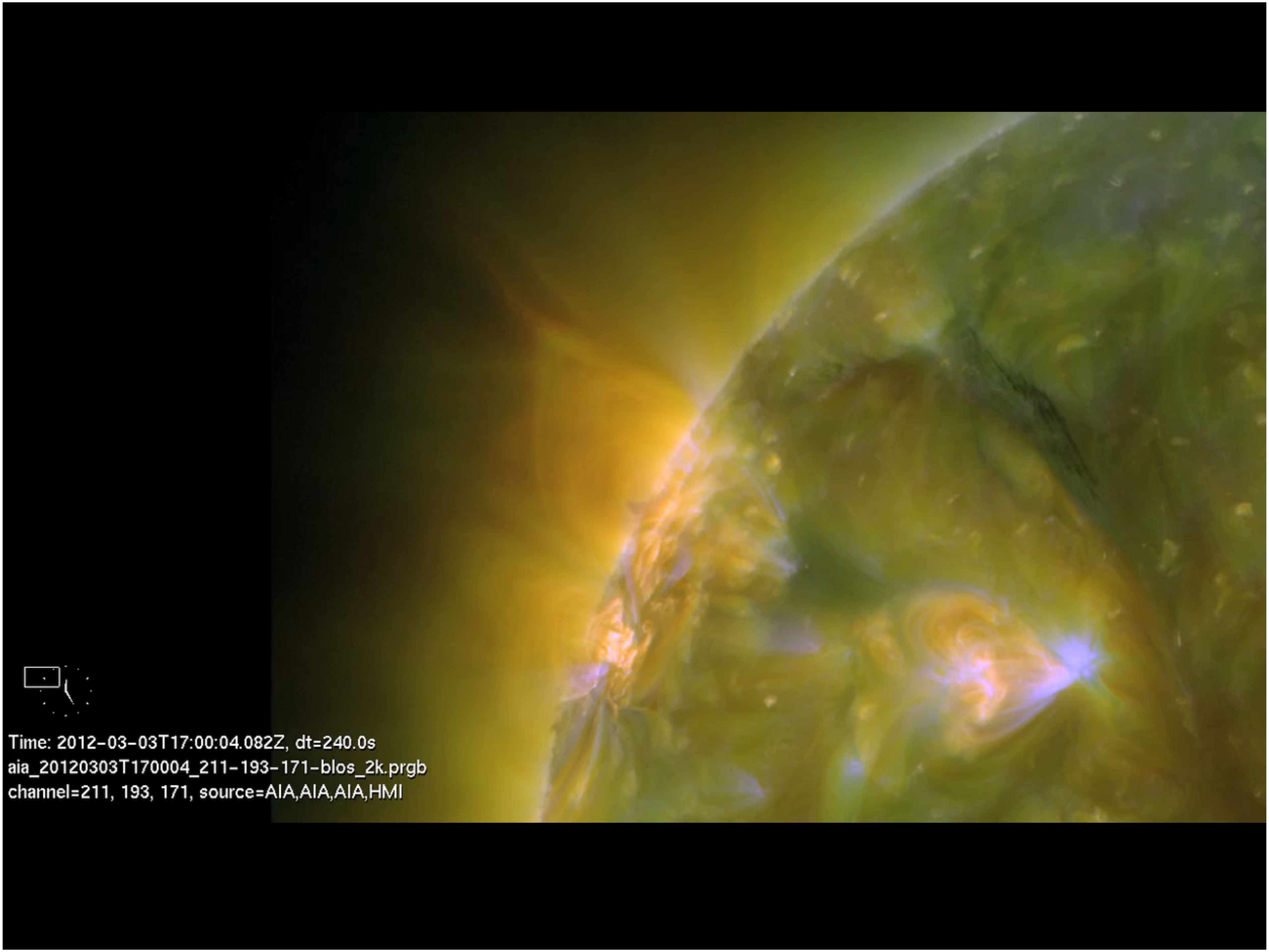
- C configuration
- 15 antennas
- 1-2 GHz
- 1024 channels
- Δt = 50 ms
- Dual polarization

40000 snapshots/sec !

A C1.9 Flare was observed at E87N18 from AR 1429. It was accompanied by a fast CME, IP type IIIs, and a *rich variety of coherent burst activity* from the time of CME launch to SXR maximum.

Chen et al 2014, in prep.

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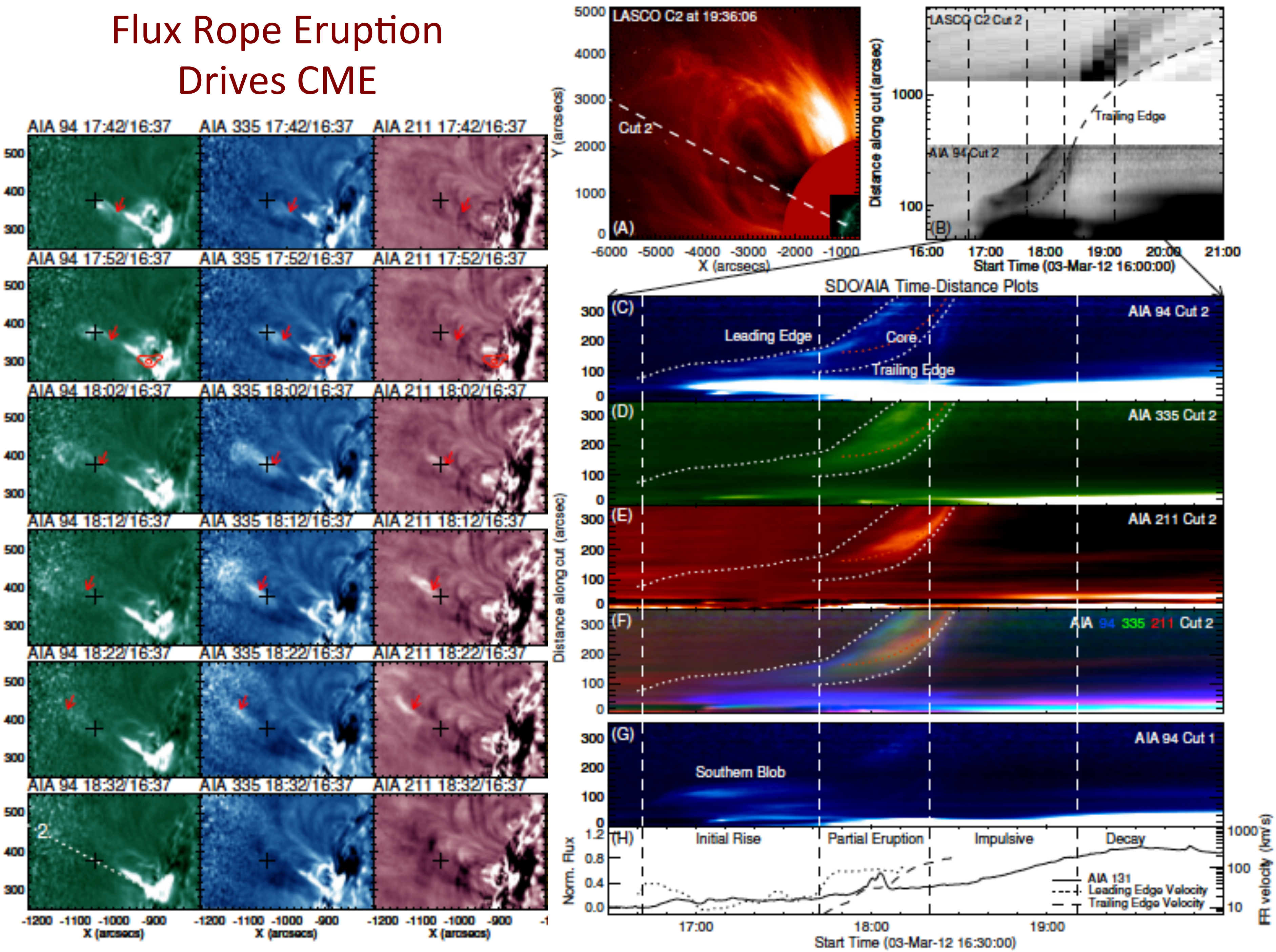
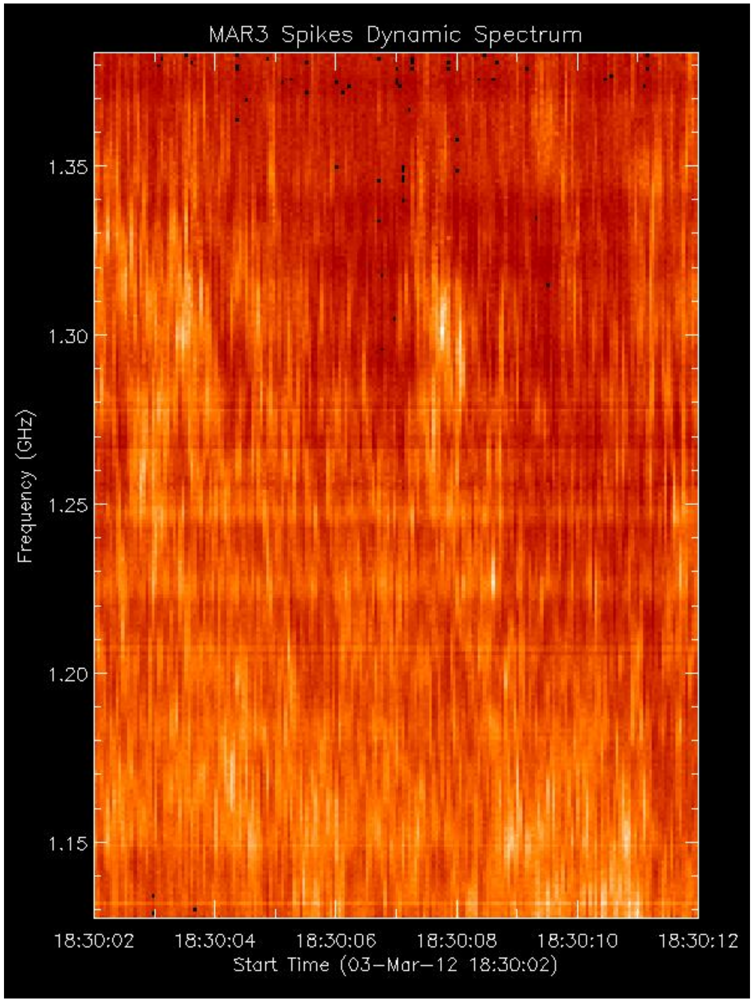
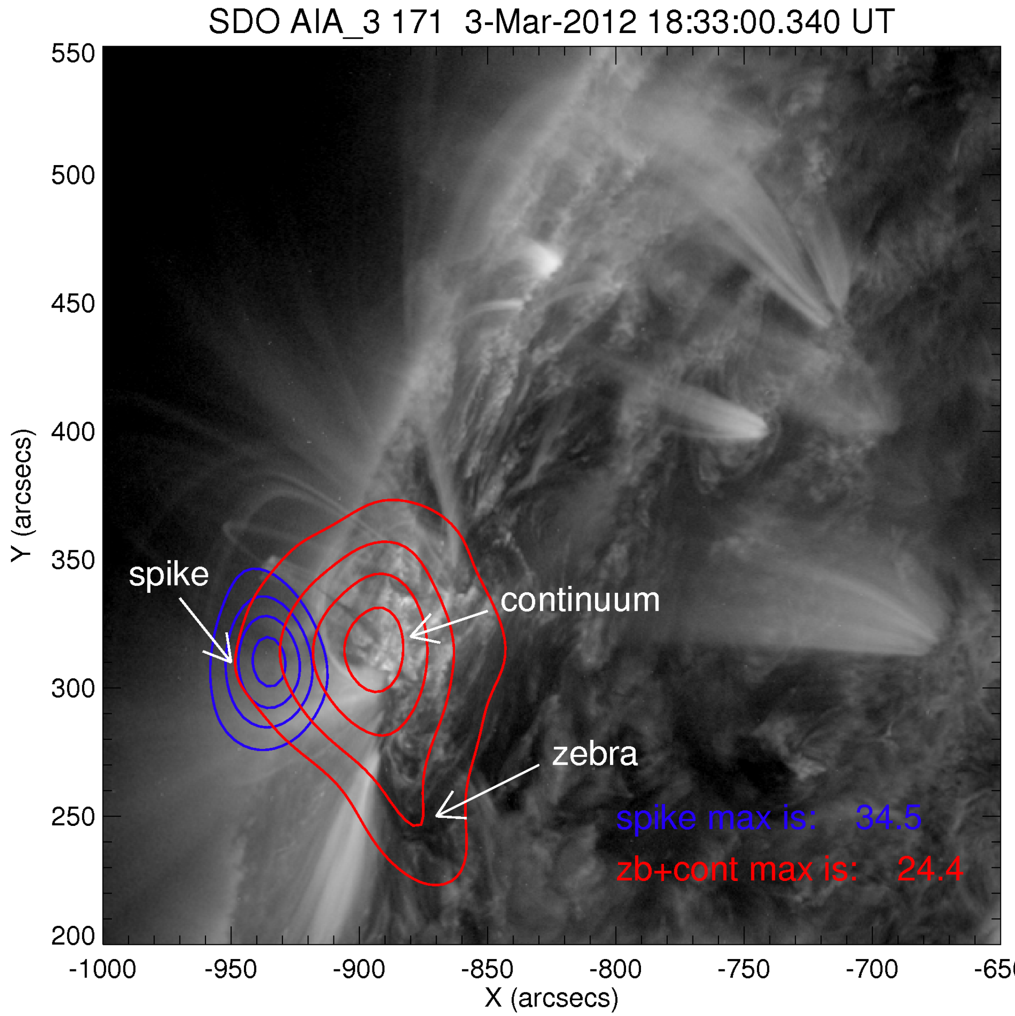
aia_20120303T170004_211-193-171-blos_2k.prgb
channel=211, 193, 171, source=AIA,AIA,AIA,HMI

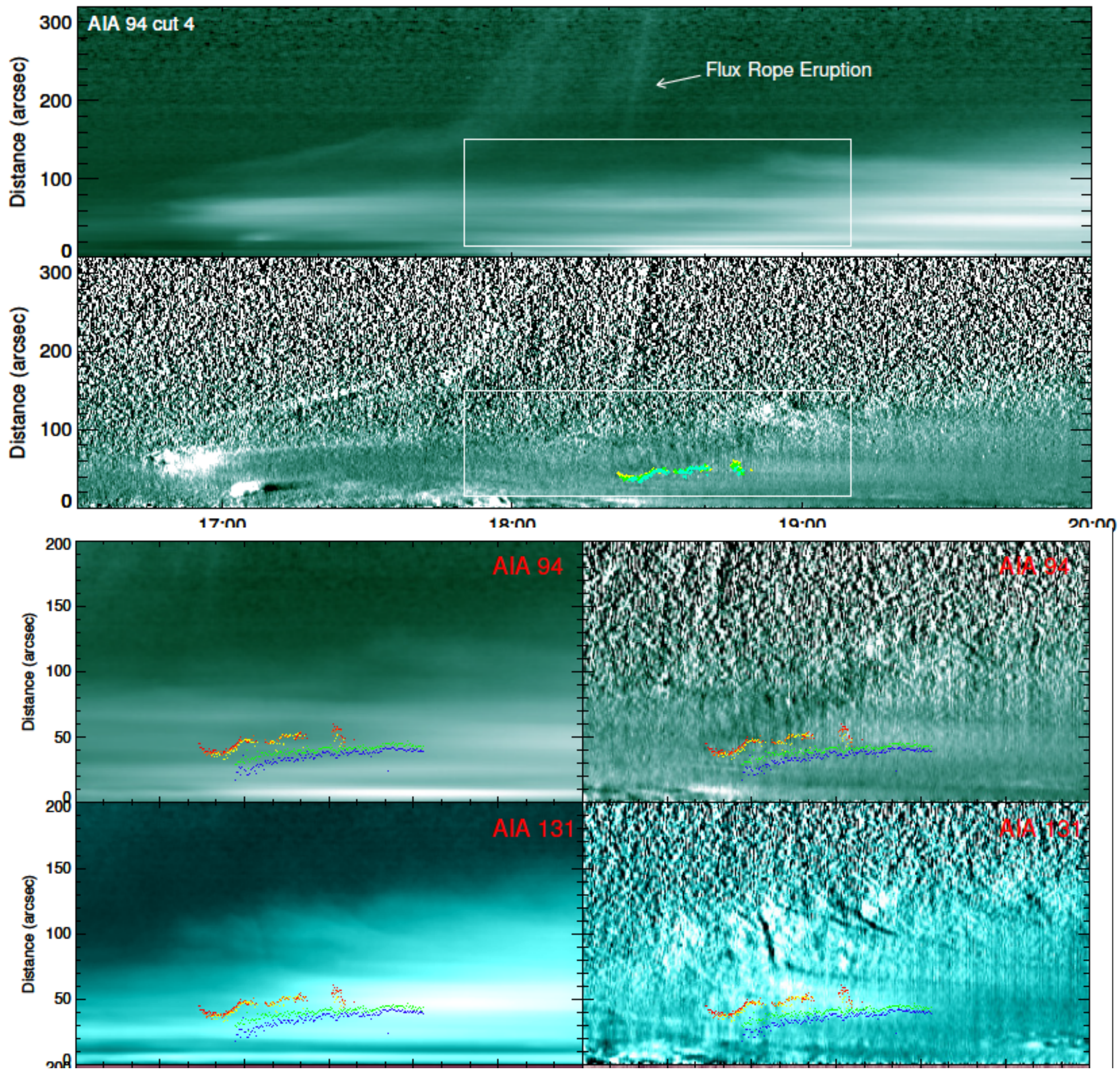
Flux Rope Eruption Drives CME





“Vector” dynamic spectrum





AIA 94 cut 4
Flux Rope Eruption
Distance (arcsec)
300
200
100
0
17:00
18:00
19:00
20:00
AIA 94
AIA 131
200
150
100
50
0