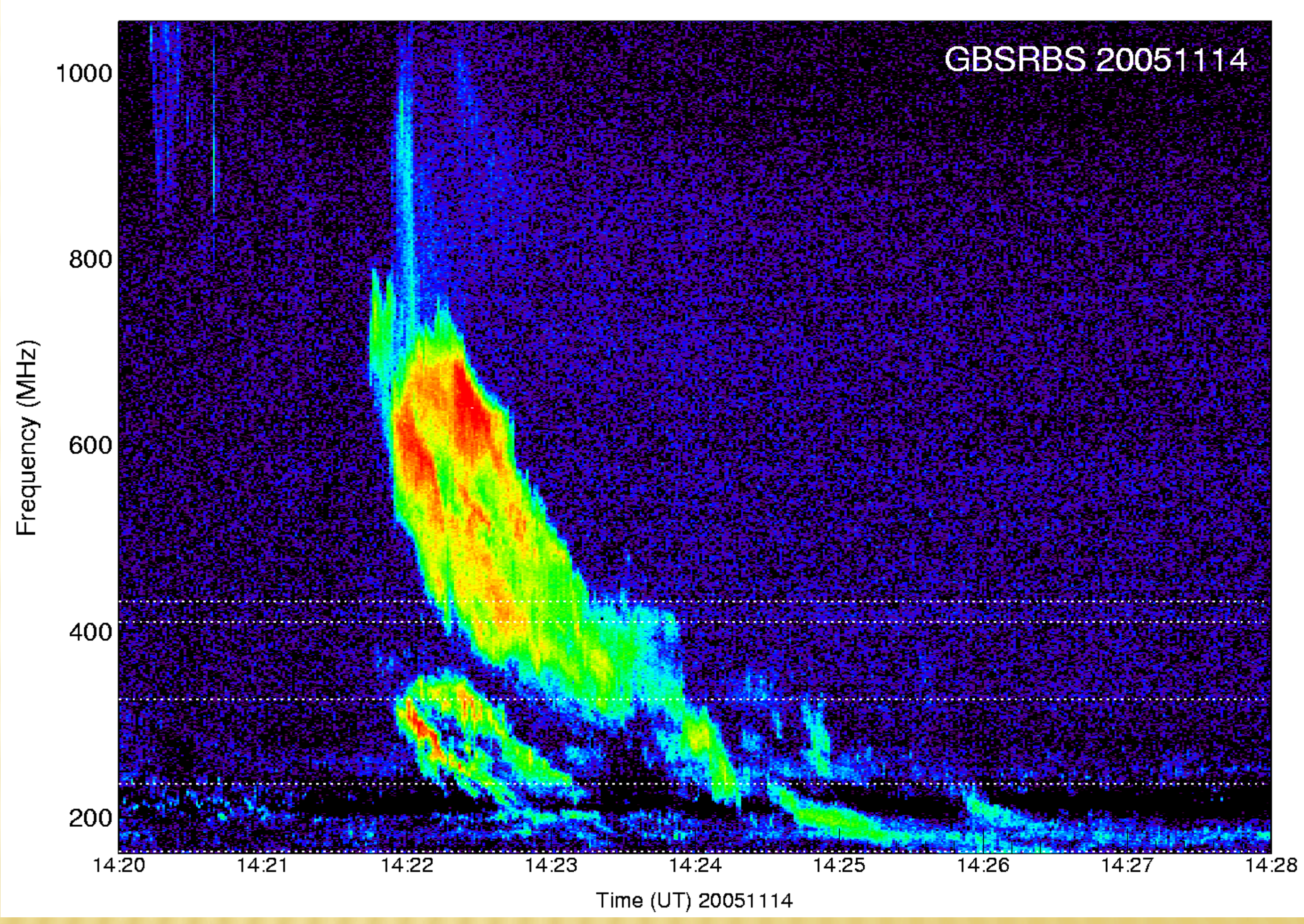
SOLAR PHYSICS WITH THE FREQUENCY AGILE SOLAR RADIOTELESCOPE

T. S. Bastian (NRAO)
and the FASR team

FASR

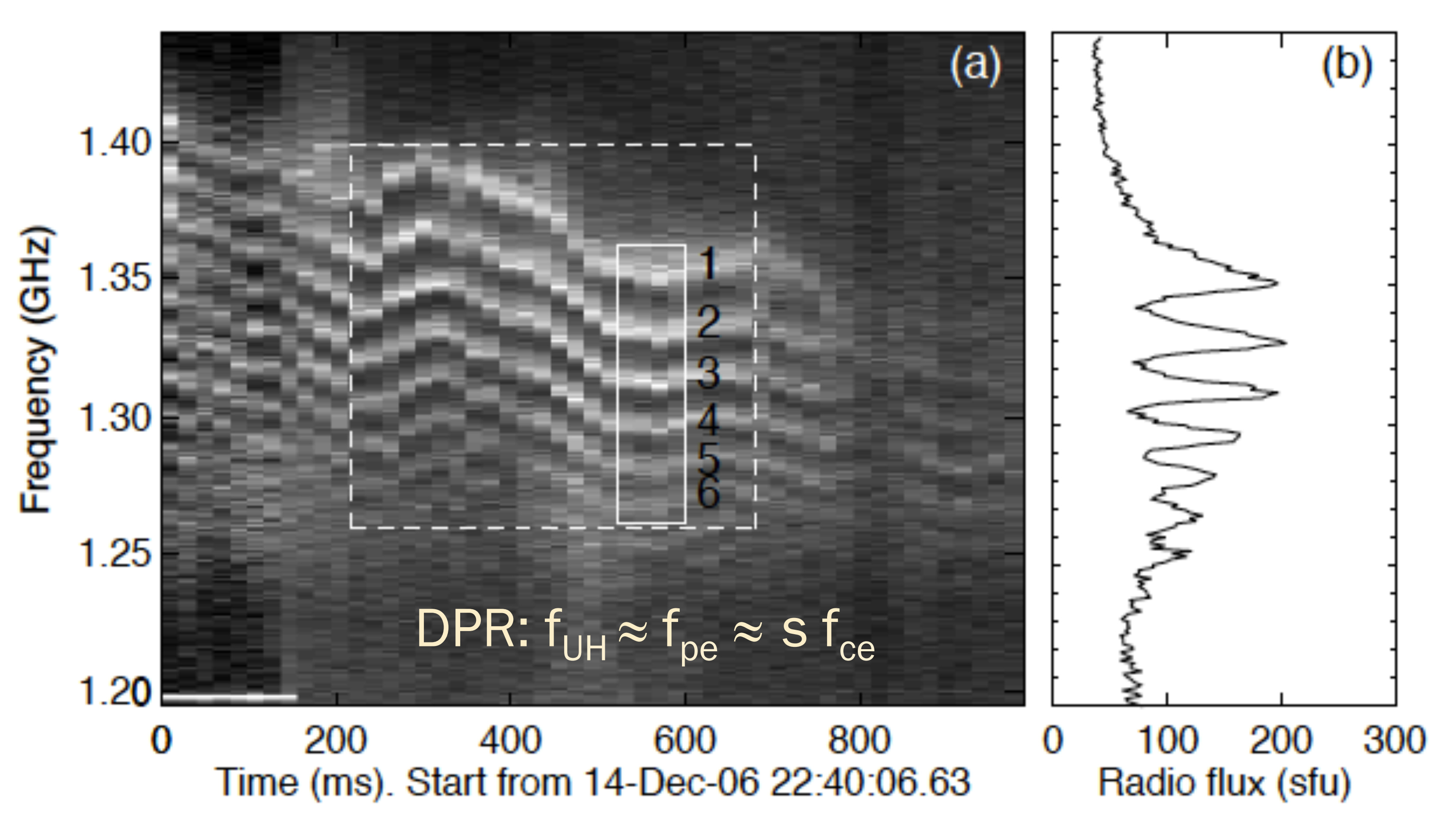
- What it is – the instrument
- What it does – the measurements
- Why do it – the science
- How – operations
- Looking forward

DYNAMIC SPECTROSCOPY FROM m-λ



Green Bank Solar Radio Burst Spectrometer White et al., in prep.

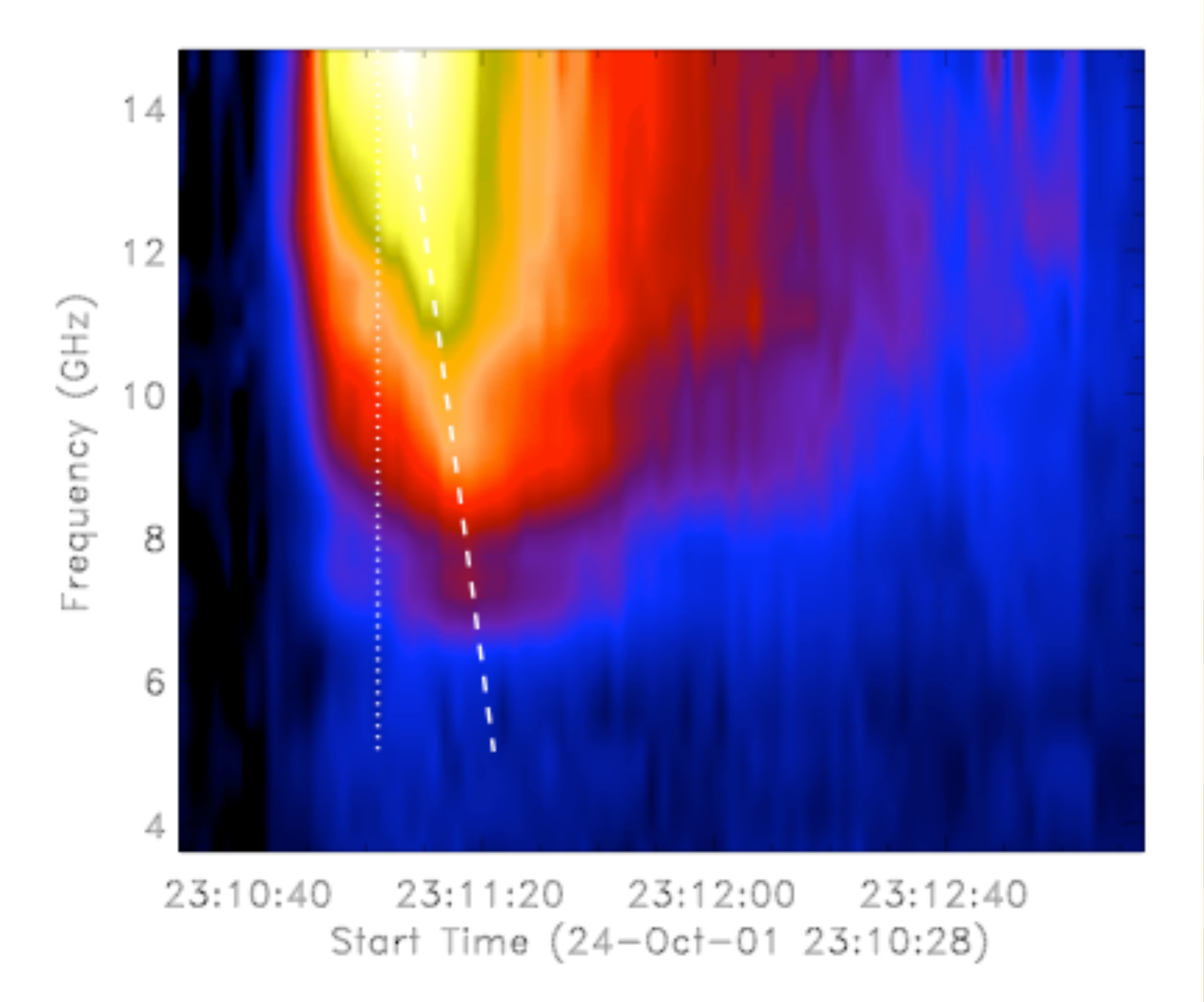
TO dm-λ



FASR Subsystems Testbed

Chen et al., submitted

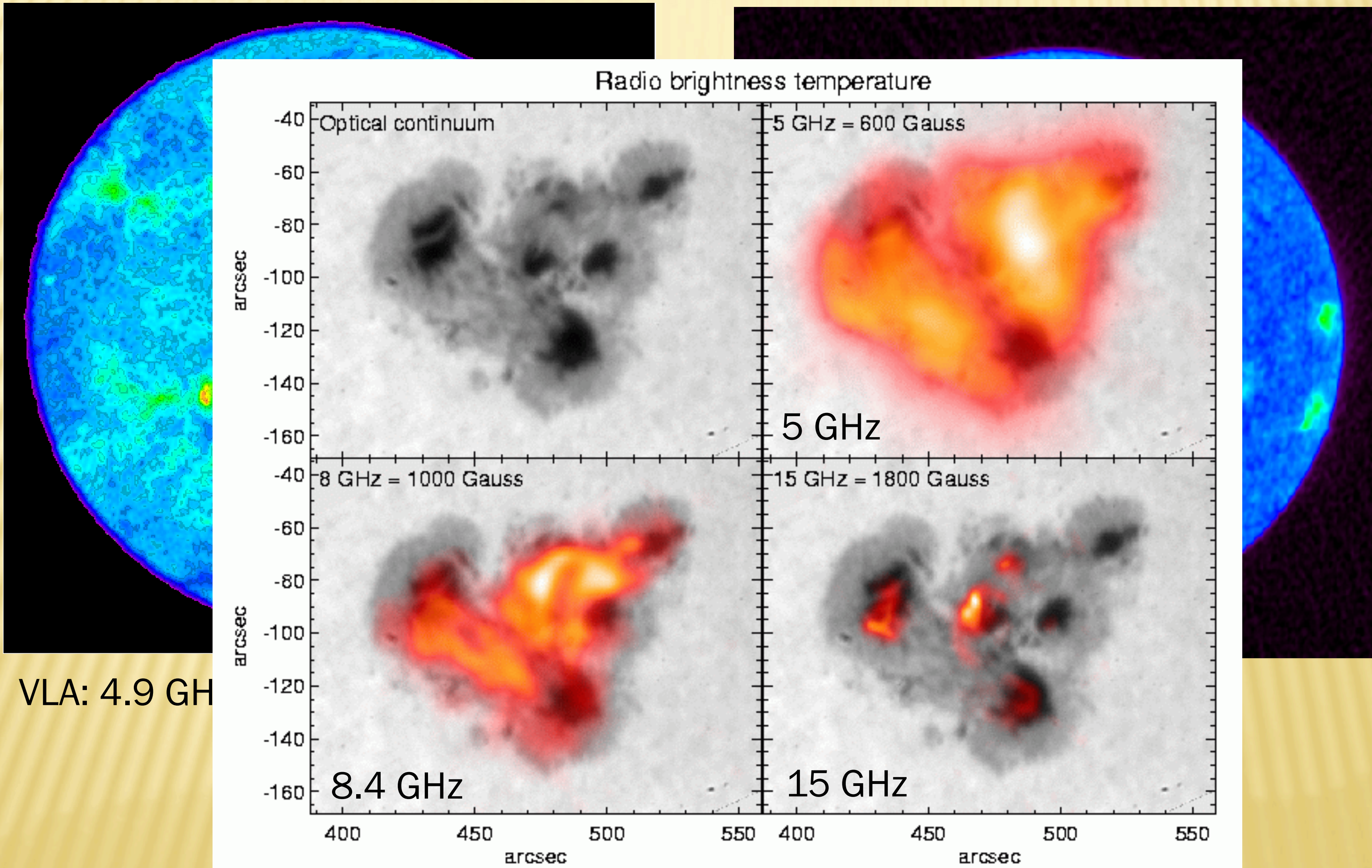
TO cm-λ



Owens Valley Solar Array

Bastian et al. 2008

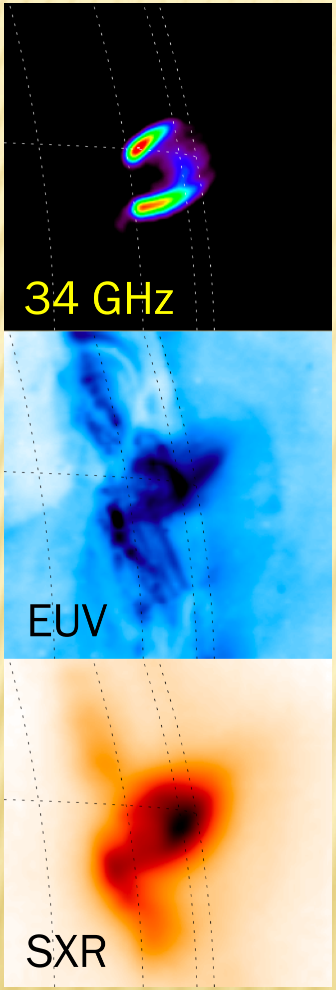
COMBINED WITH IMAGING



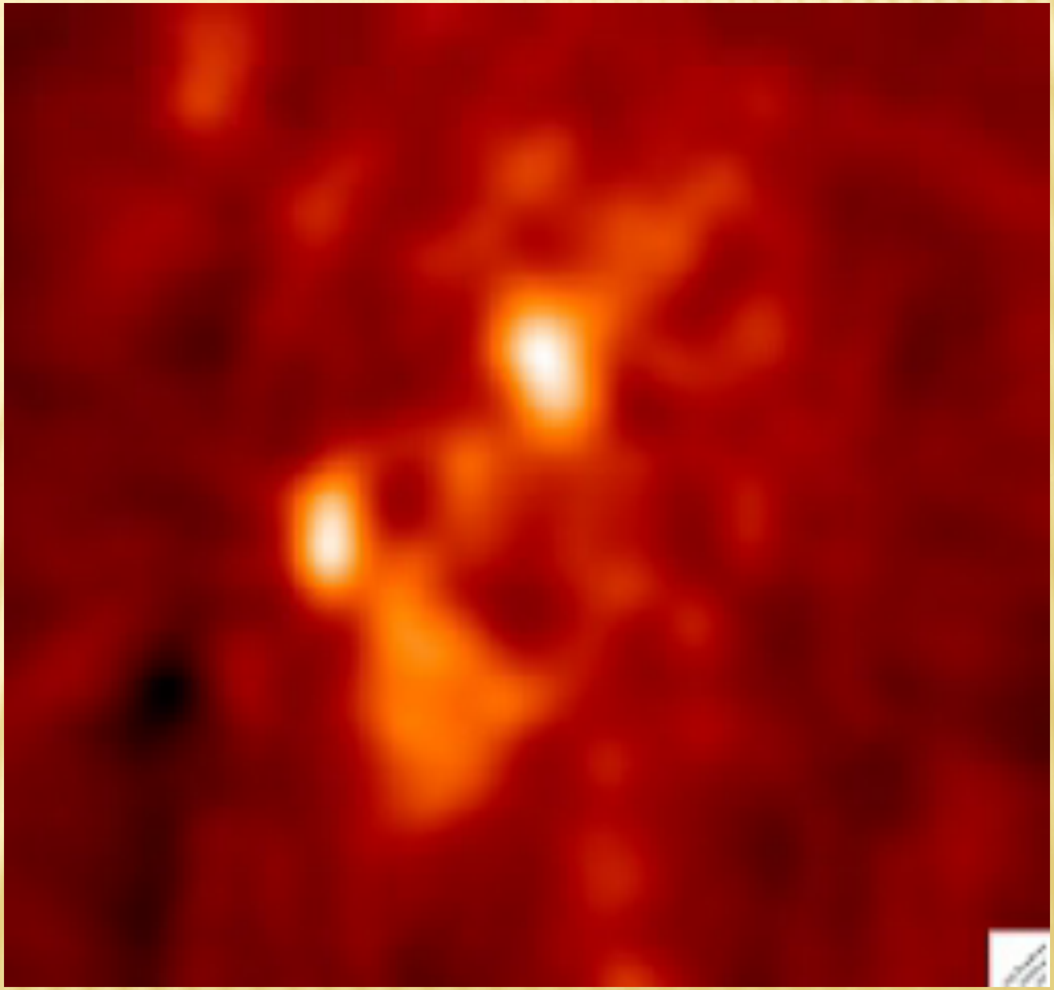
VLA: 4.9 GH

Lee et al. 1998

COMBINED WITH HIGH TIME RESOLUTION



13 July 2005 LDE: 0230-0500 UT



Nobeyama Radioheliograph 17 GHz

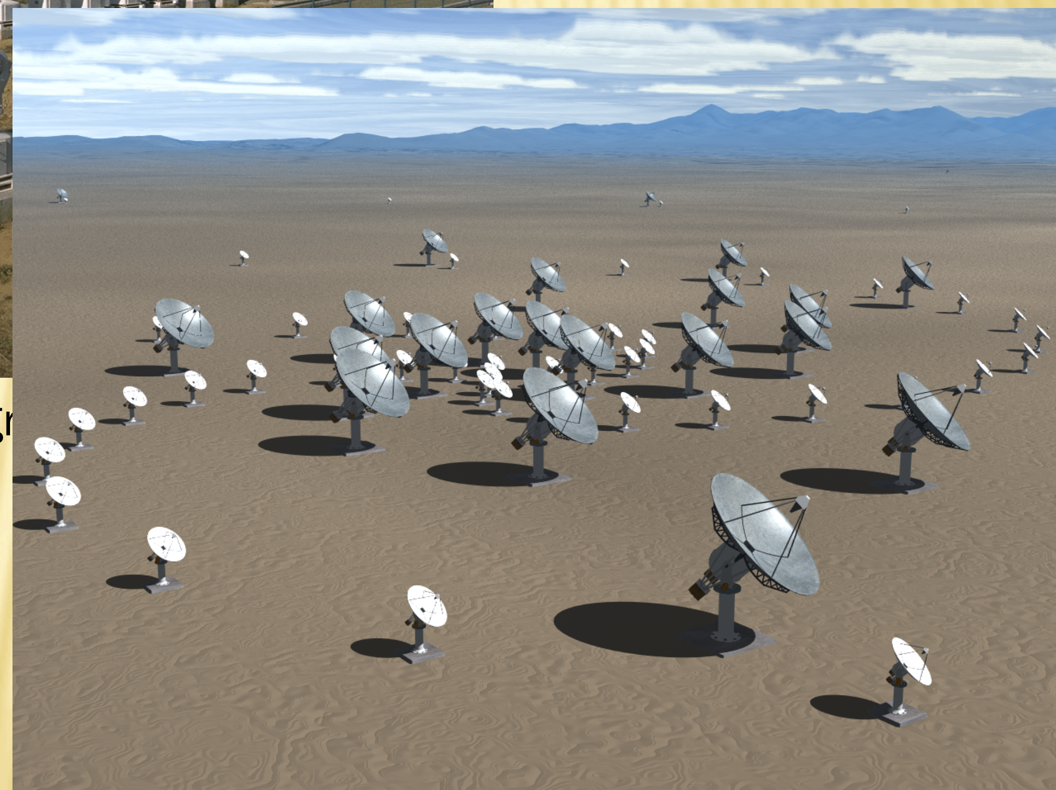
WHAT IT IS

- 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 λ=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.

FASR High Level Specifications

Angular resolution	20/ν_{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%

Nobeyama Radioheliogr



I. Gary

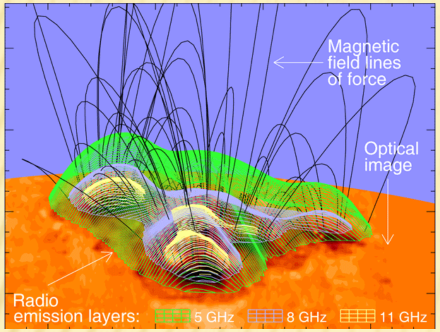
WHY DO IT

Radio waves provide unique sensitivity to magnetic fields and the electron distribution function.

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

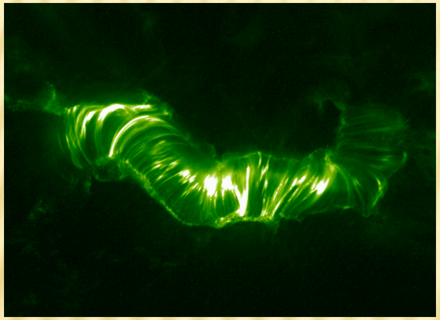
By imaging the entire solar atmosphere at once, it will provide insights into these phenomena and processes as *coupled phenomena.*

KEY SCIENCE OBJECTIVES



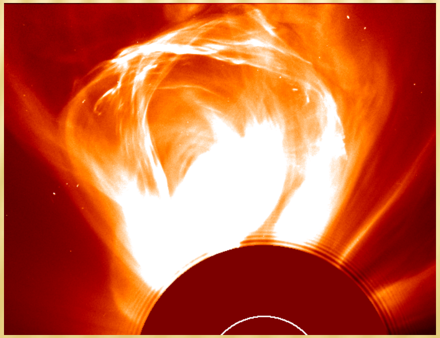
- **Nature & Evolution of Coronal Magnetic Fields**
  - Coronal magnetography
  - Temporal & spatial evolution of fields
  - Coronal seismology

  SSE – Q1/D1



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

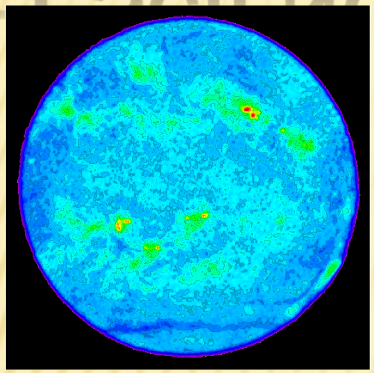
  SSE – Q1/D1

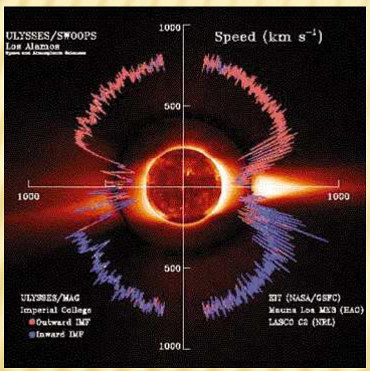


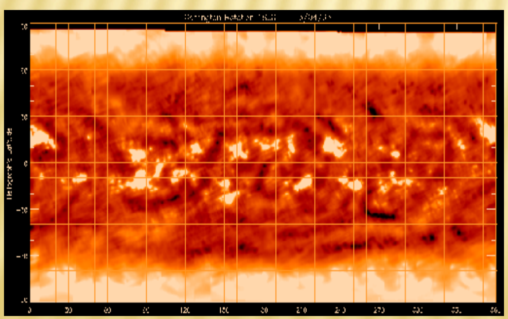
- **Drivers of Space Weather**
  - Birth & acceleration of CMEs
  - Prominence eruptions
  - Origin of SEPs

  SSE – D1

KEY SCIENCE OBJECTIVES





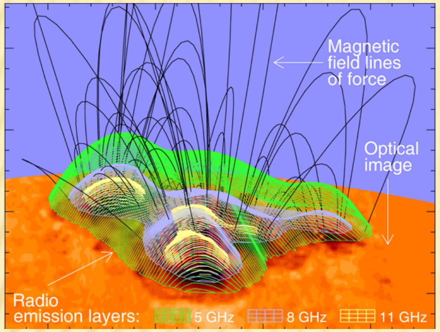


- The "thermal" solar atmosphere
  - Coronal & chromospheric heating
  - Thermal structure & dynamics
  - Formation & structure of filaments
- The Solar Wind
  - Birth in network - spicules
  - Coronal holes and fast solar wind
  - Turbulencs & waves
- Synoptic Studies
  - Radiative inputs to the upper atmosphere
  - Global magnetic field & dynamo
  - Flare statistics

CORONAL MAGNETOGRAPHY

- Non-potential fields the source of free energy for solar activity
- Radio observations provide a number of tools to measure or constrain coronal fields:
  - Thermal free-free emission – AR,QS, CH, filaments
  - Thermal gyroresonance emission – active regions
  - Nonthermal gyrosynchrotron emission – flares, CMEs
  - Coronal "seismology" – flaring magnetic loops
  - Radio bursts – outer corona
  - Propagation phenomena – topological constraints

KEY SCIENCE OBJECTIVES



- Nature & Evolution of Coronal Magnetic Fields
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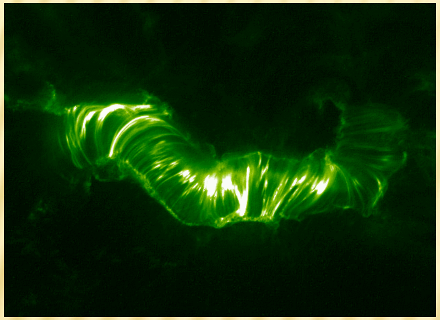
  See poster by White et al.



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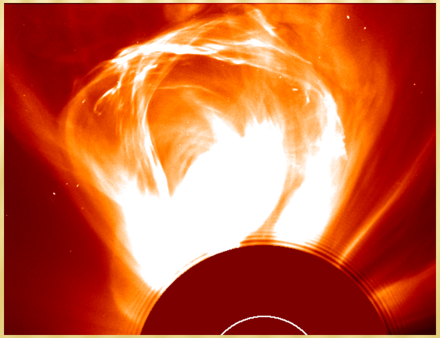

- Drivers of Space Weather
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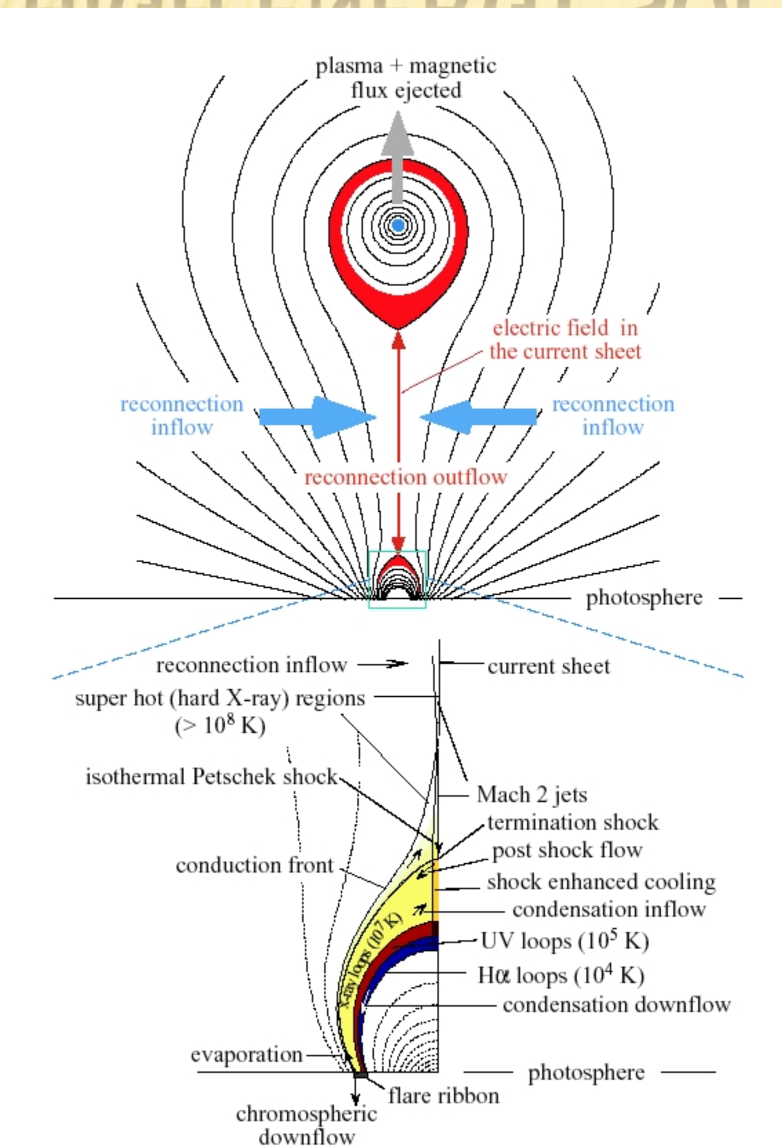
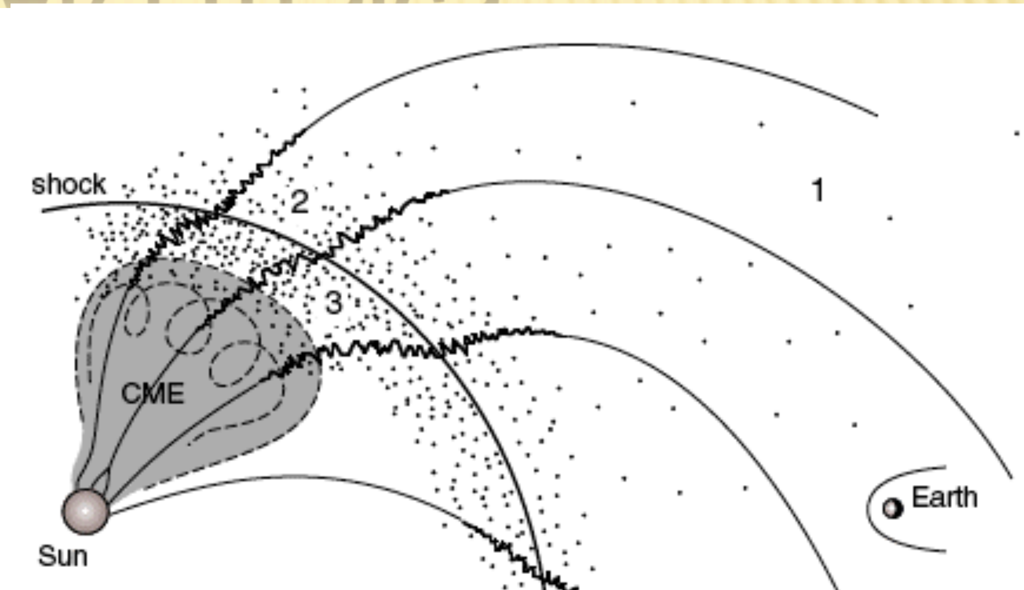
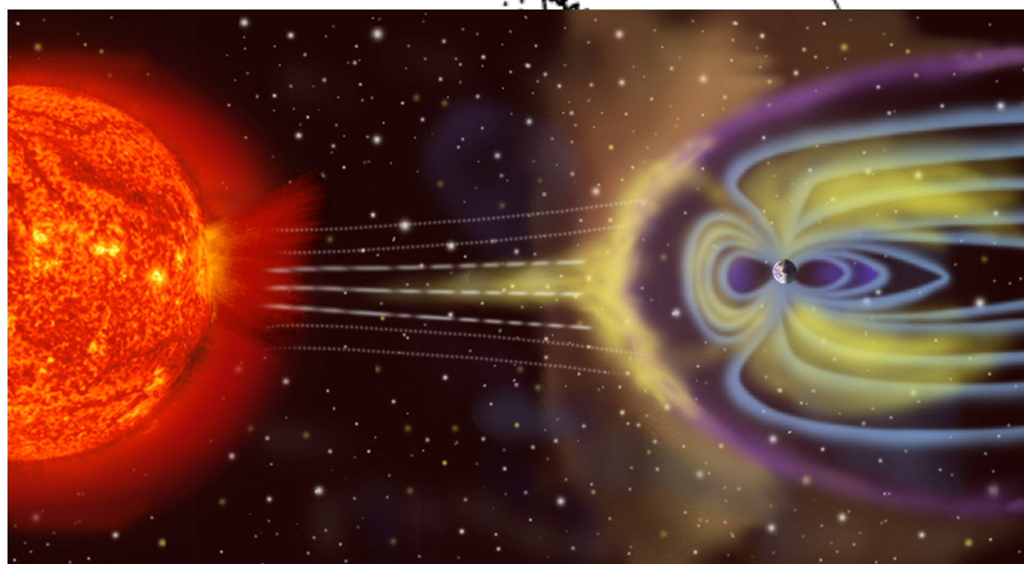
HIGH ENERGY SOLAR PHYSICS

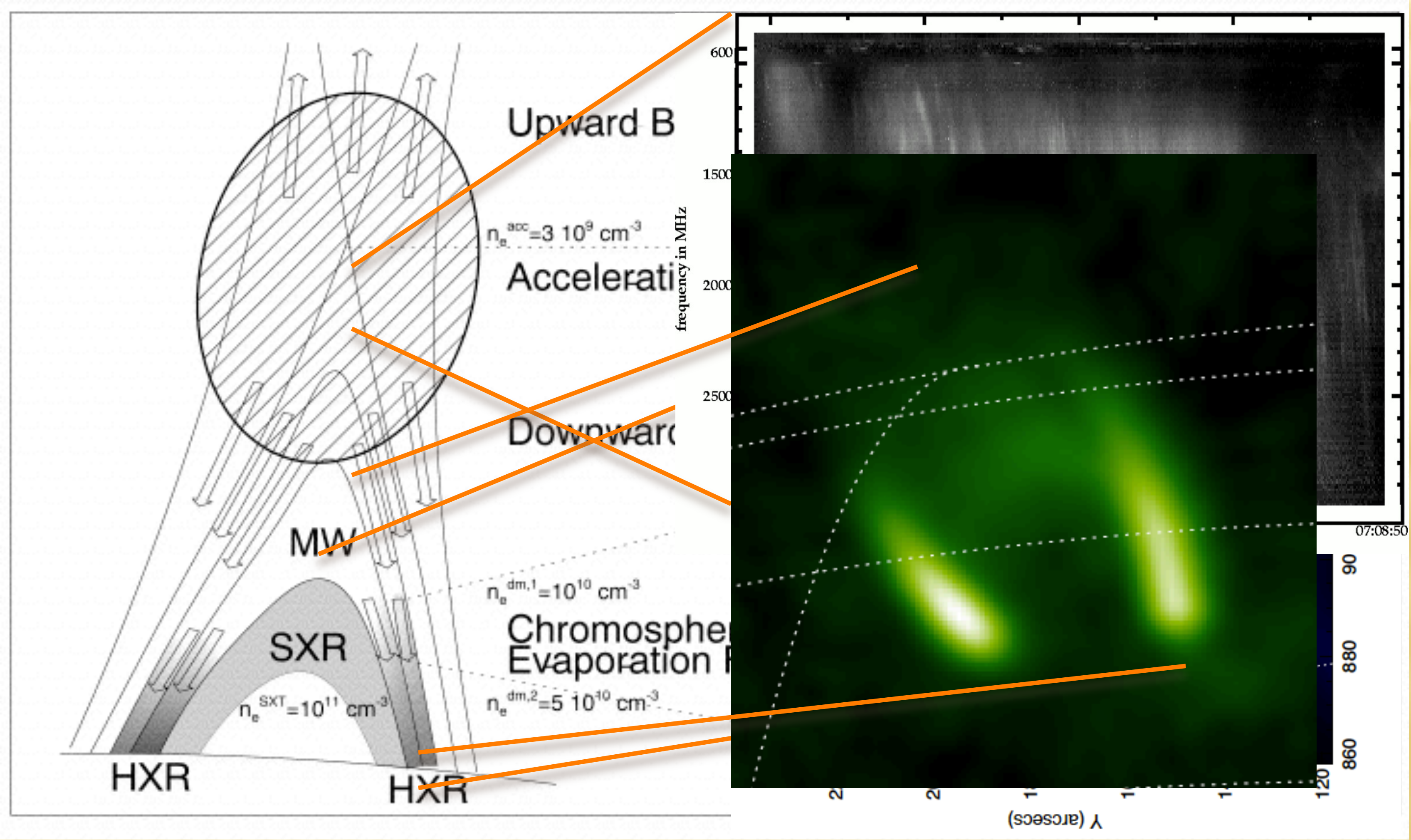
- The Sun is the most powerful particle accelerator in the solar system
  - Ions up to ~10s of Gev
  - Electrons up to ~100s of Mev
- Two types of energetic transients accelerate particles
  - Solar flares in the low corona
  - Fast coronal mass ejections
- Explosive magnetic reconnection vs destabilization and expulsion
- Both play a role in “space weather”

HIGH ENERGY SOLAR PHYSICS





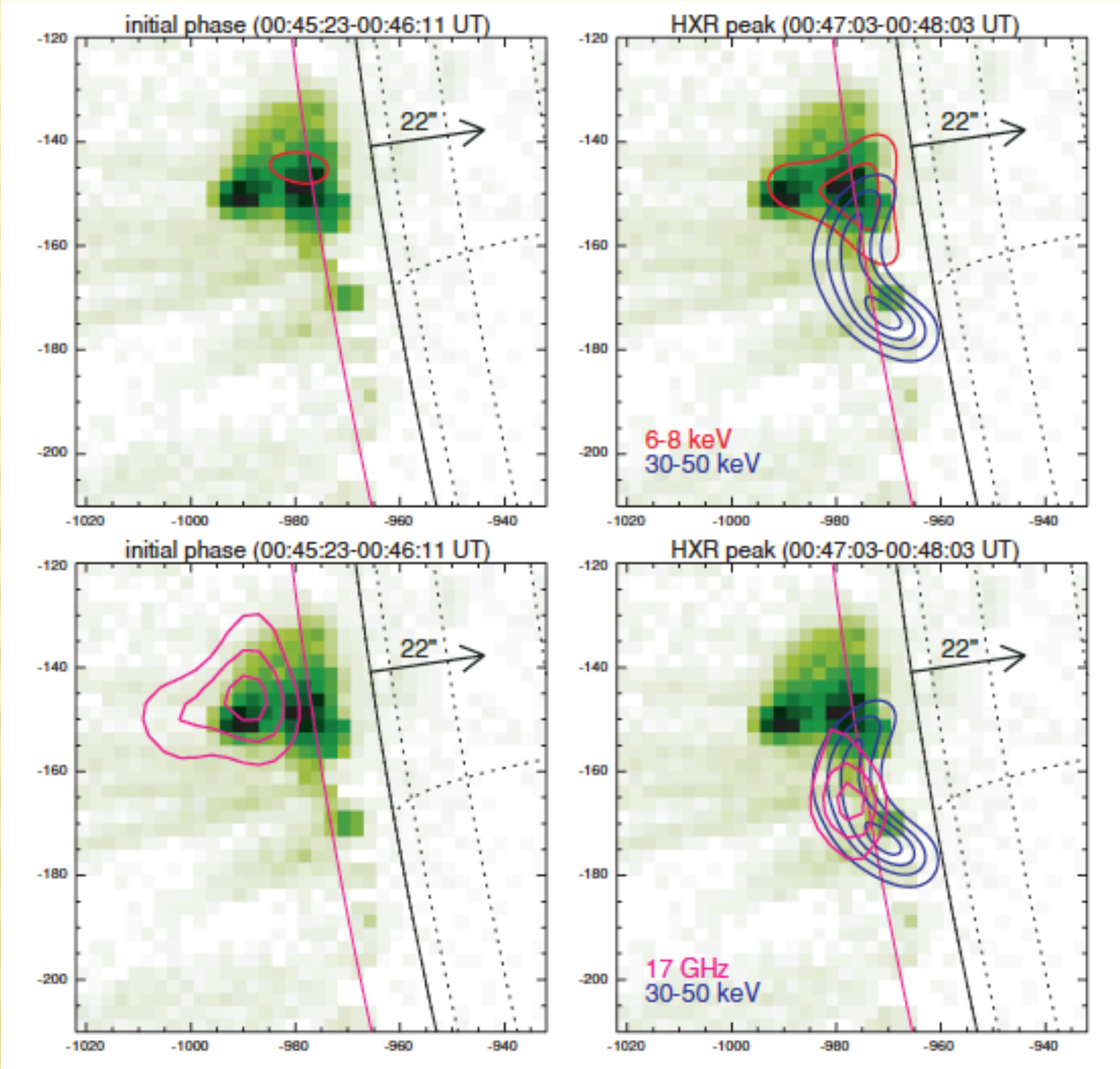


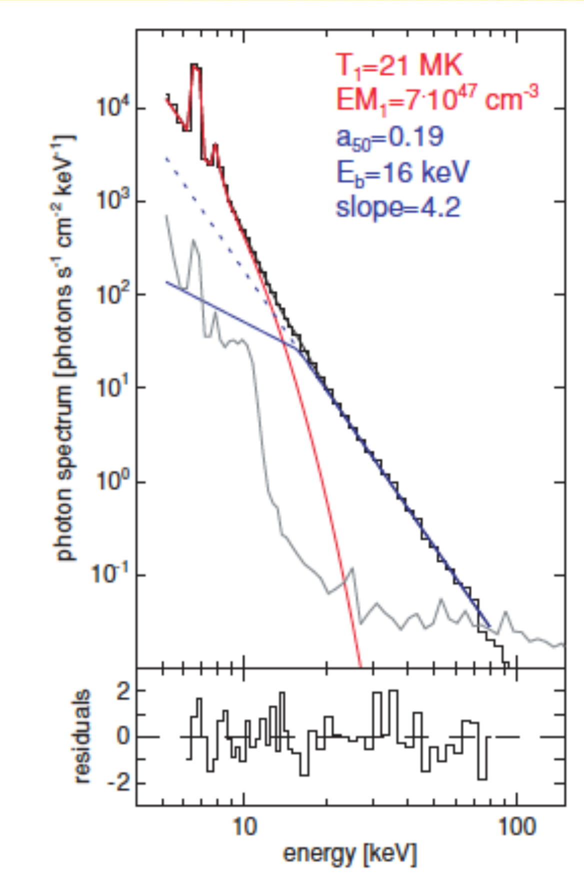


Aschwanden & Benz 1997

HIGH ENERGY SOLAR PHYSICS

- How is energy stored in magnetic fields?
- What triggers its release?
- How are particles accelerated so efficiently?
- What are the transport mechanisms?
- What processes account for abundance and charge state distributions of impulsive SEPs?
- What is the relationship of flares to CMEs?



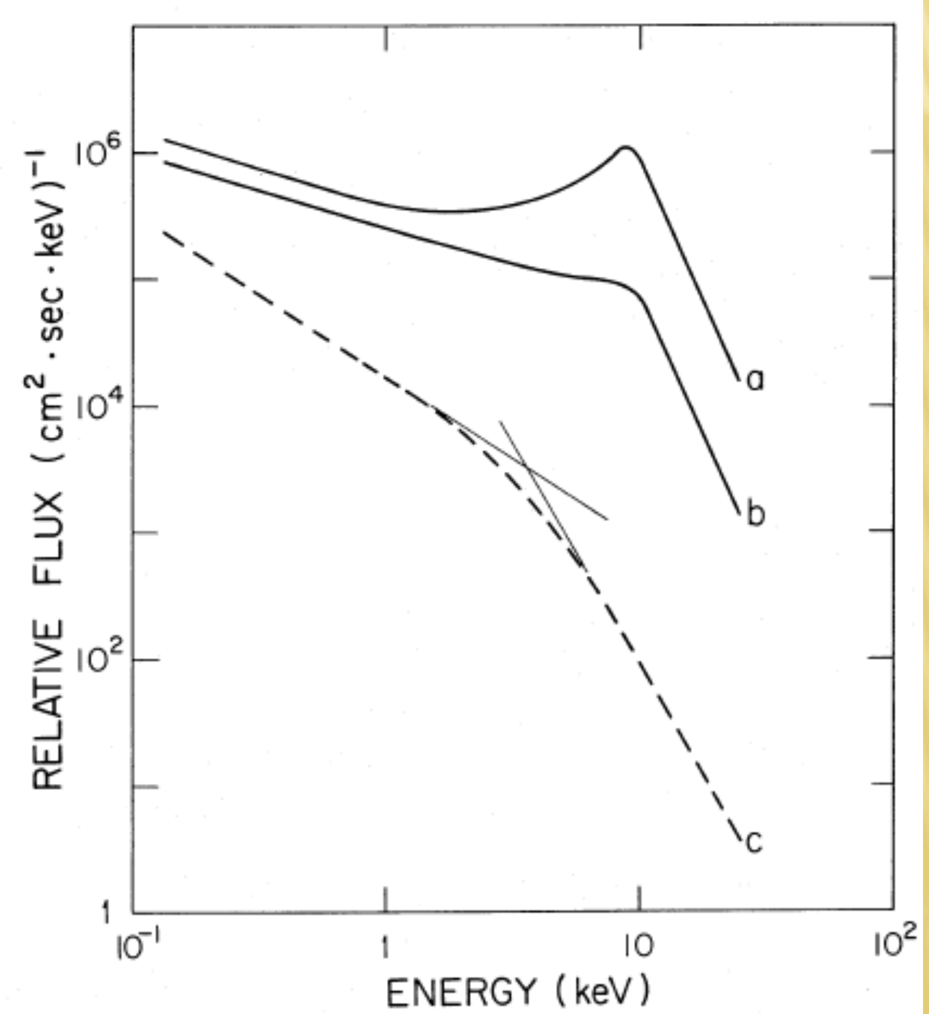


Krucker et al. 2010

It's been known for some time that a significant fraction of the flare energy is deposited in nonthermal electrons (e.g., Lin & Hudson 1974). Non-thermal HXR and microwave coronal source observed by NoRH and RHESSI. Thin target interpretation implies *all* electrons accelerated to >15 keV!

ELECTRON ACCELERATION

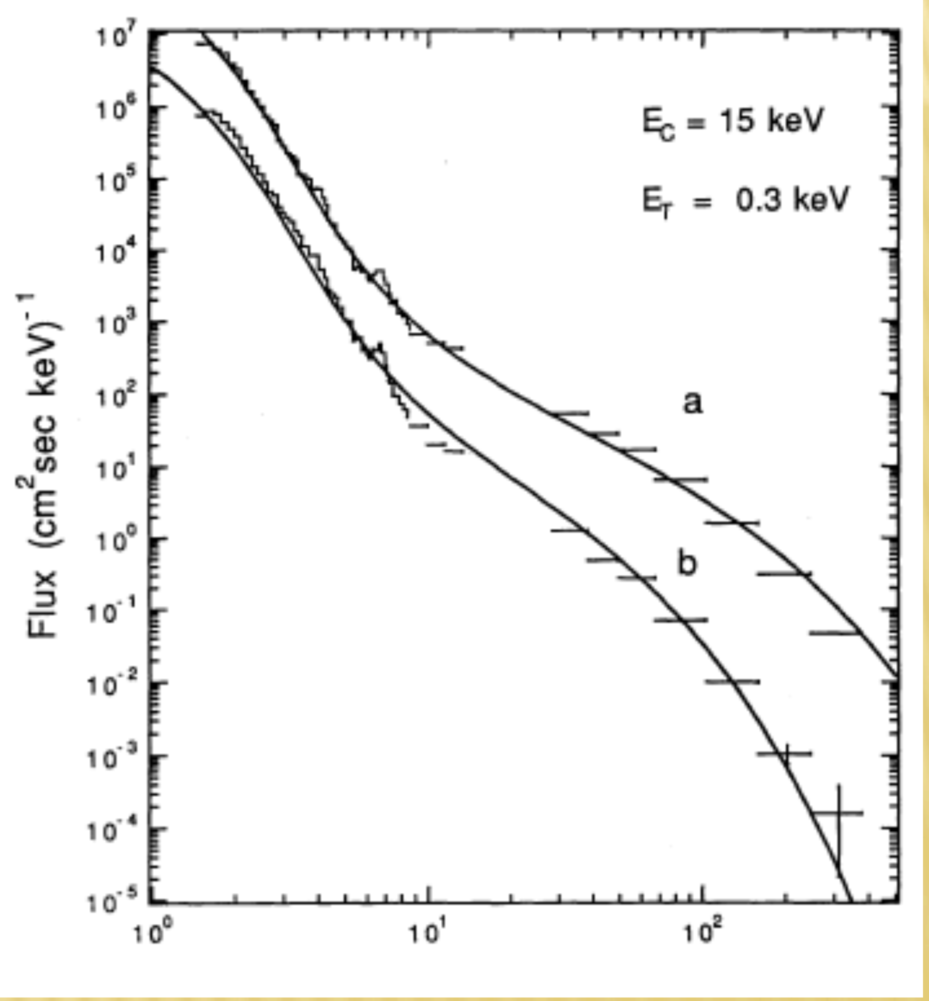
- Quasi-static electric fields? ("auroral")



Lin & Schwartz 1987

ELECTRON ACCELERATION

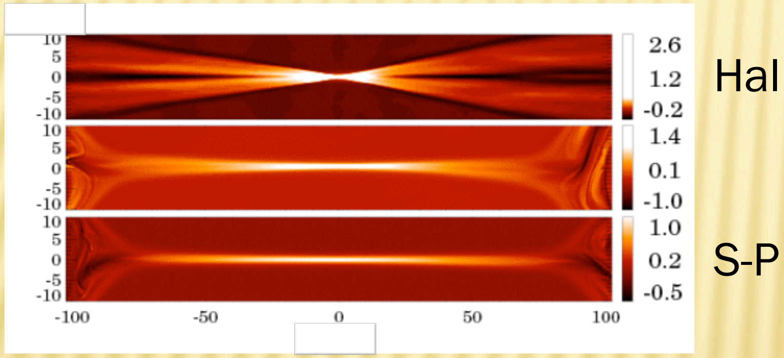
- Quasi-static electric fields? ("auroral")
- Stochastic acceleration?
- Diffusive shock acceleration?
- Double layers?



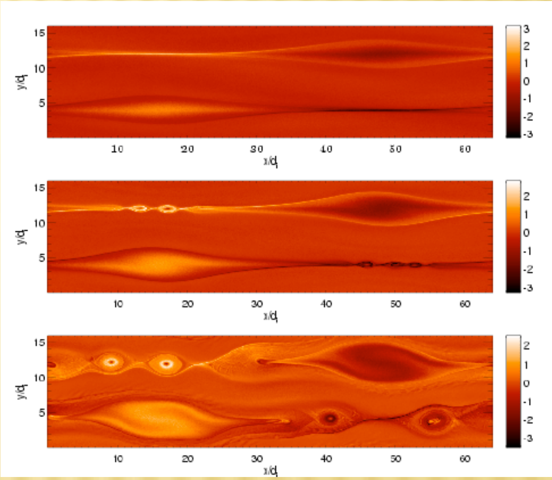
Hamilton & Petrosian 1992

HIGH ENERGY SOLAR PHYSICS

- Progress in understanding fast, collisionless (Hall) reconnection over past decade
  - Transition between Sweet-Parker (slow) and Hall reconnection (fast) – bistable



Cassak 2010



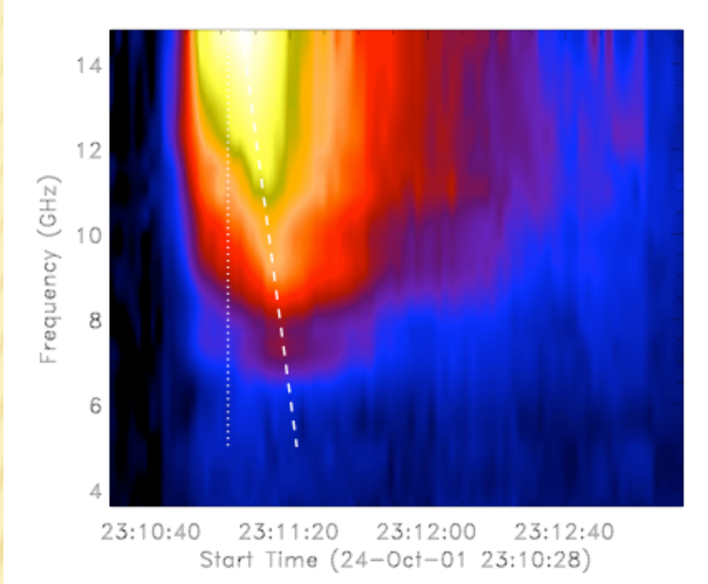
Drake et al 2006

  - Particle acceleration by secondary magnetic islands?
  - Energy distribution saturates ~$E^{-3/2}$ as $\beta \rightarrow 0$

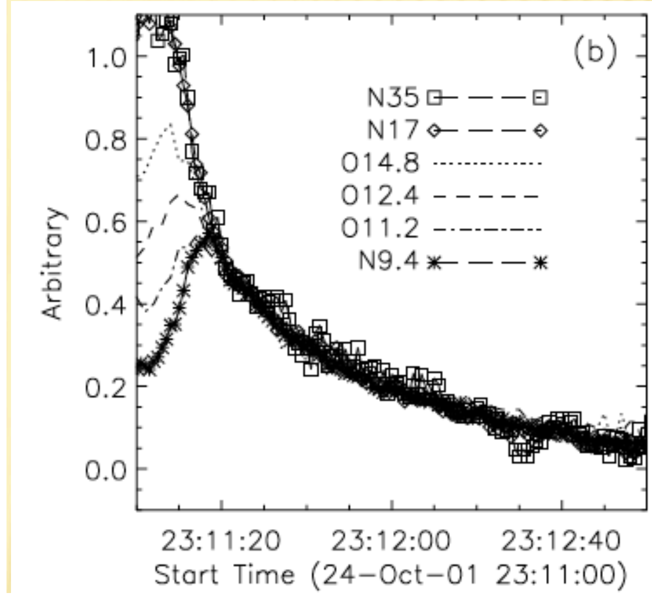
HIGH ENERGY SOLAR PHYSICS

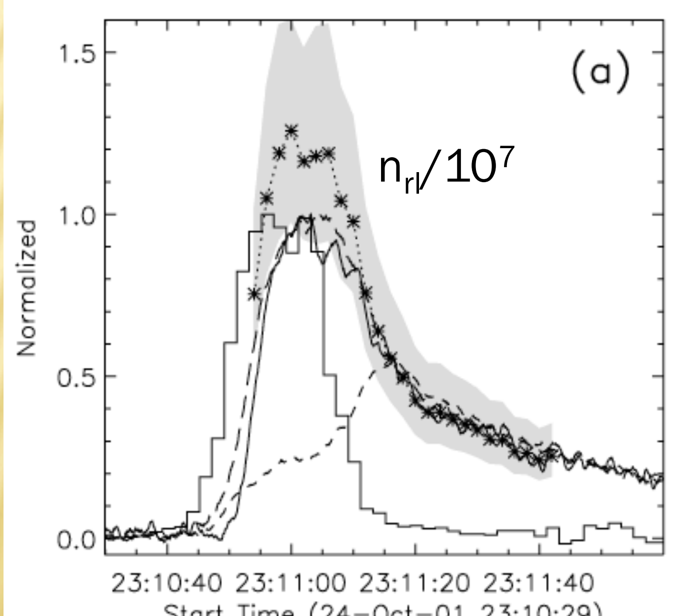
- FASR will measure the spatiotemporal evolution of the polarized brightness temperature spectrum
- Inversion of the spectrum places powerful constraints on parameters of the system
  - Electron distribution function
  - Properties of the ambient plasma
  - Magnetic field, magnetic energy release

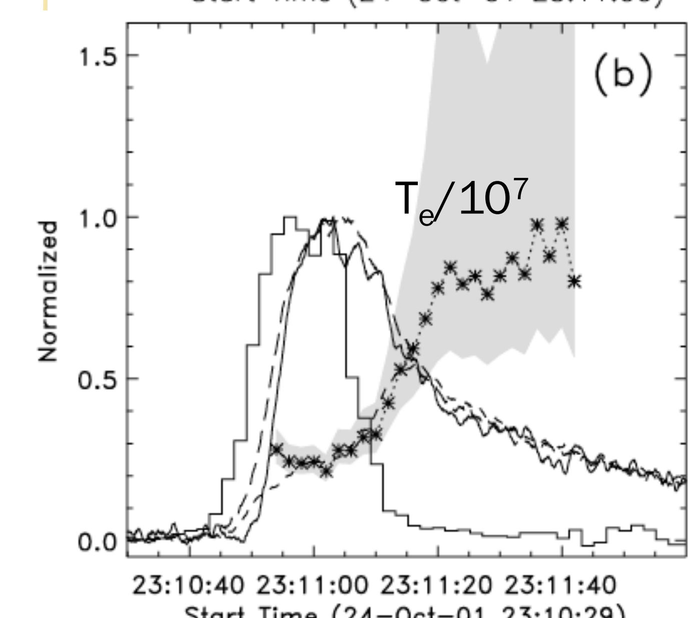
Owens Valley Solar Array



OVSA, NoRH

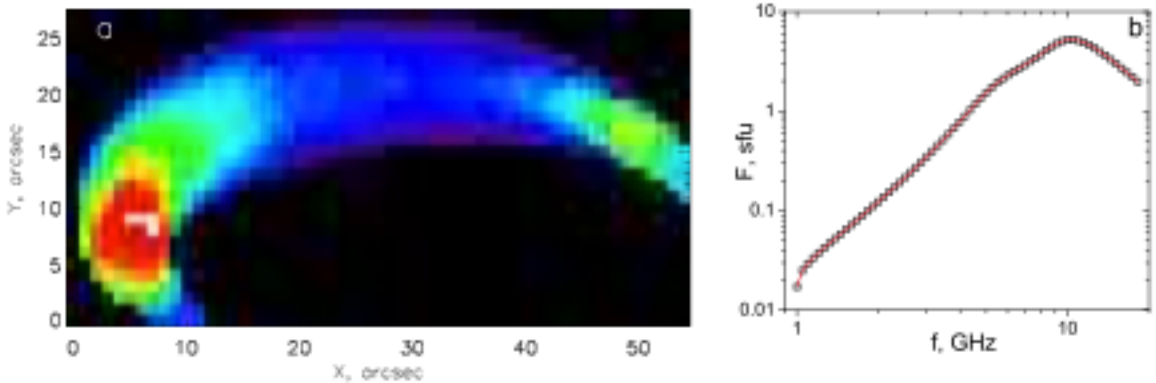


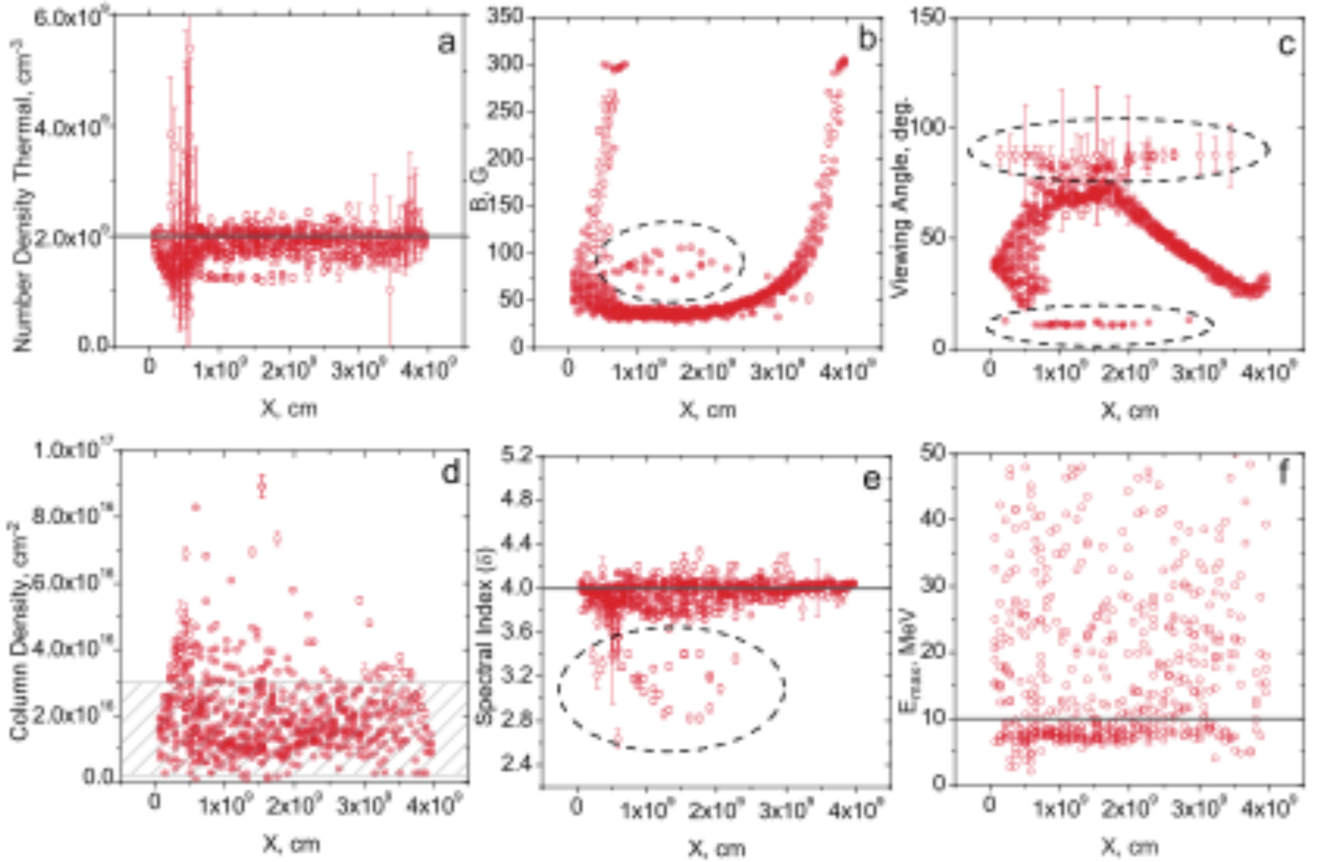




Bastian, Fleishman, & Gary 2008

Fast Spectral Inversion



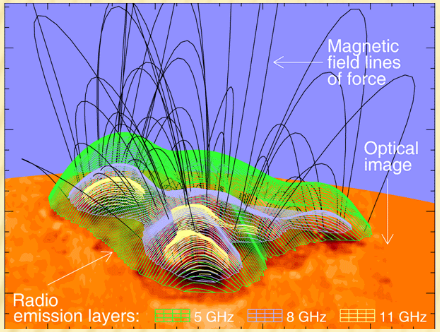


Fast gyrosynch. codes required!

Fleishman & Kuznetsov 2010

Fleishman et al. 2009

KEY SCIENCE OBJECTIVES



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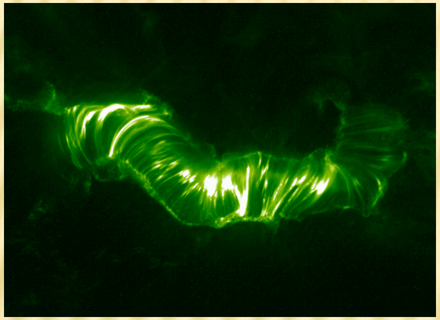

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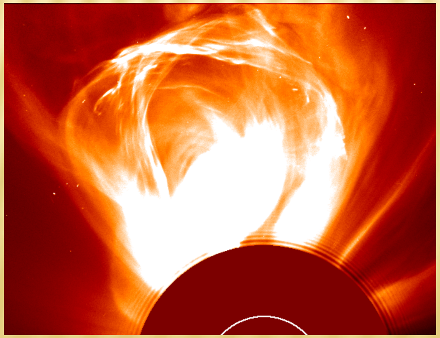

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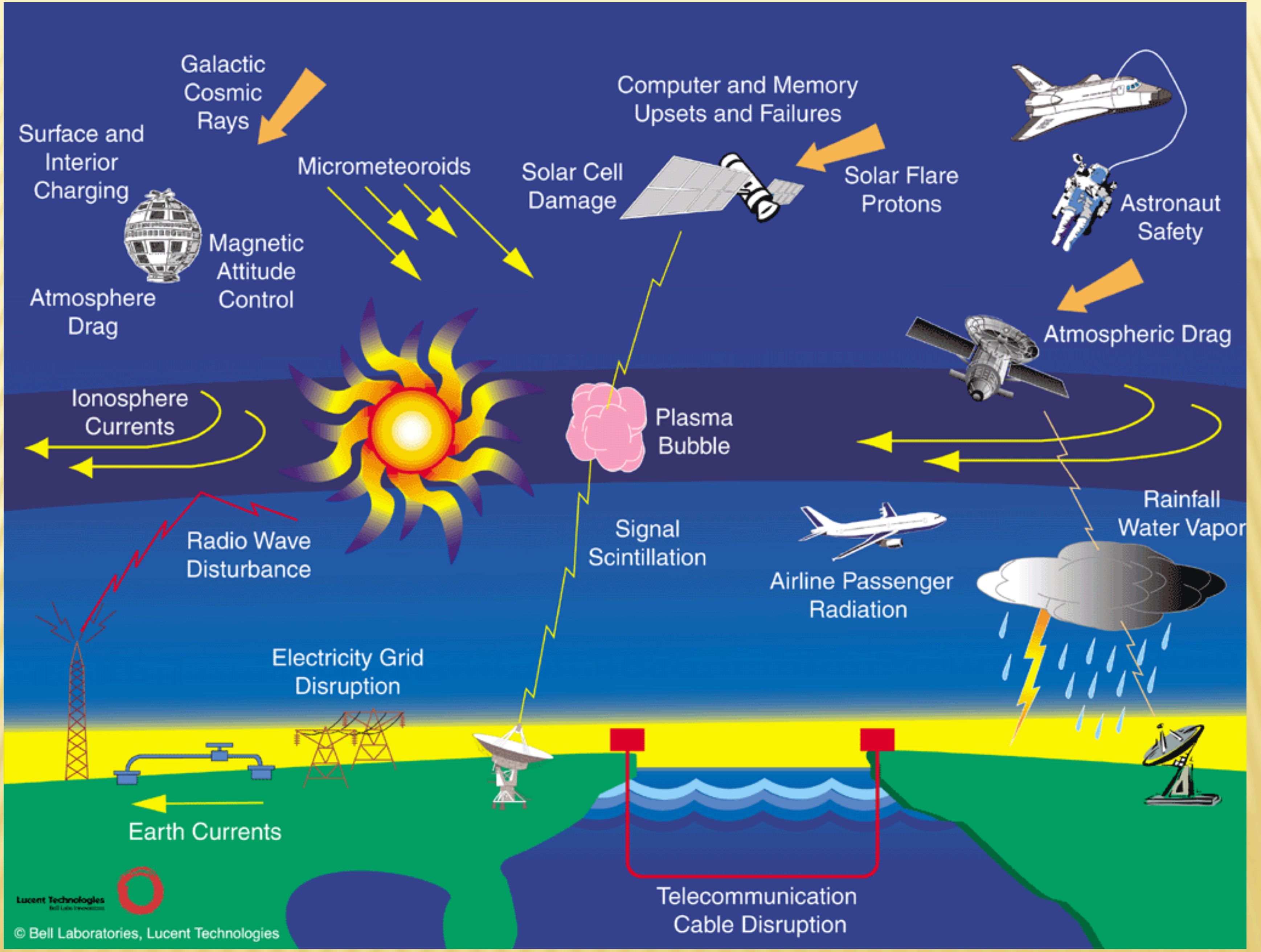
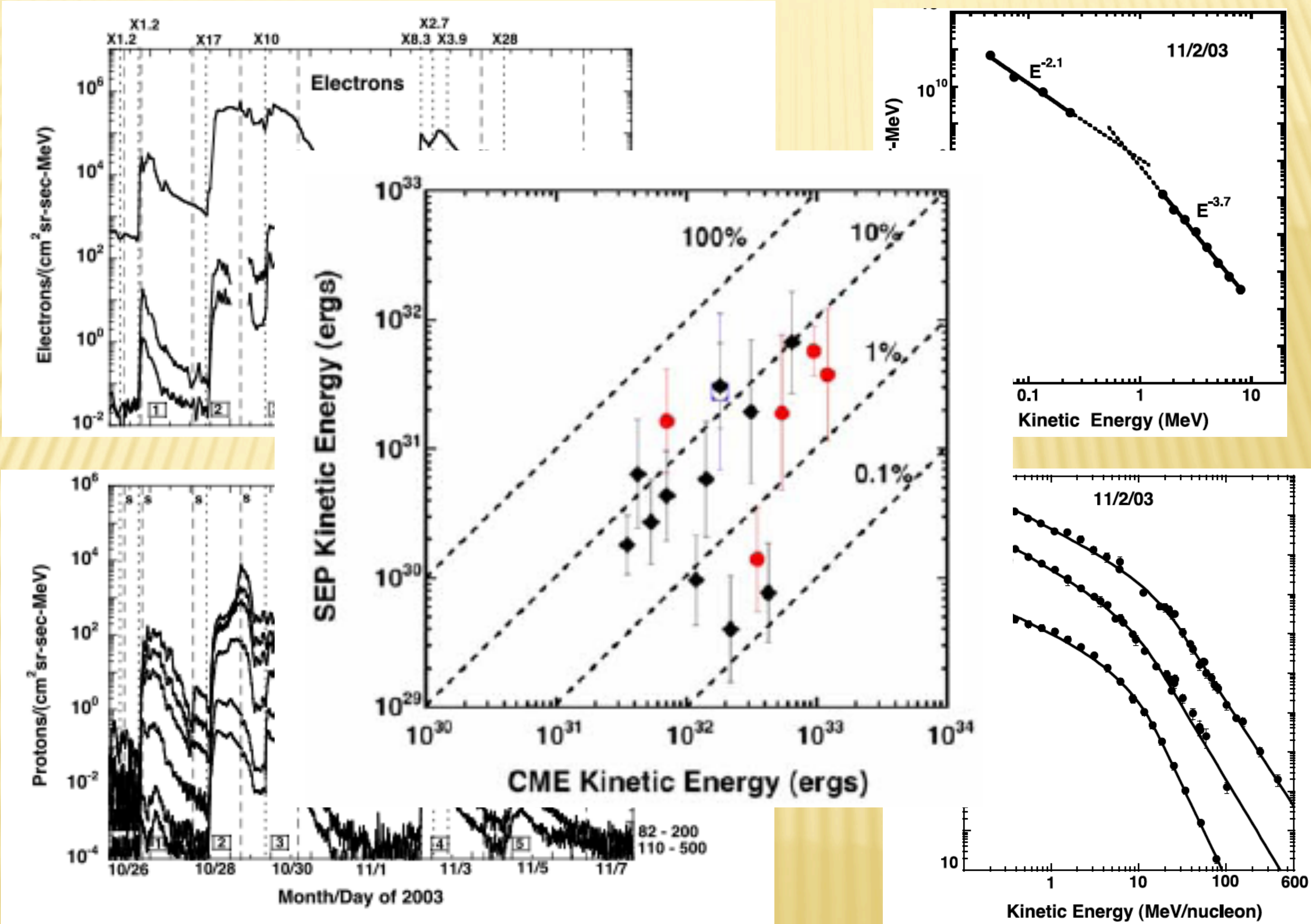


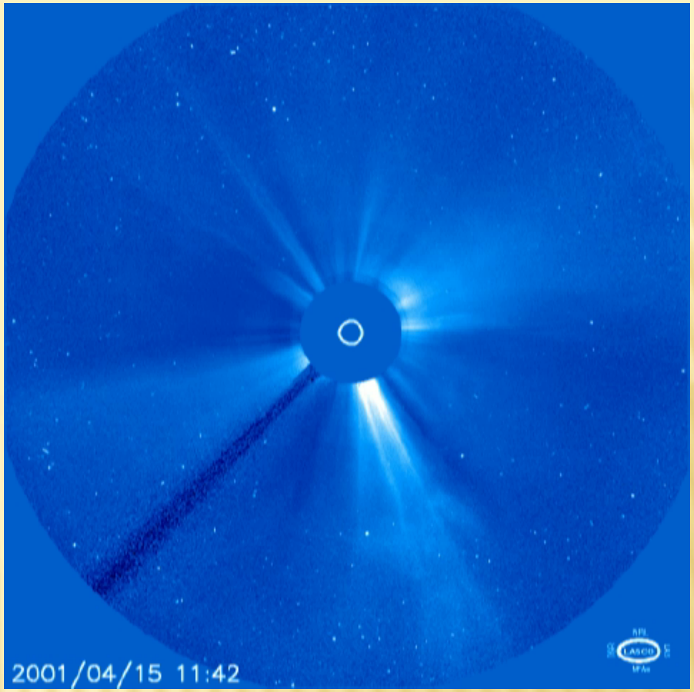
L. Lanzerotti

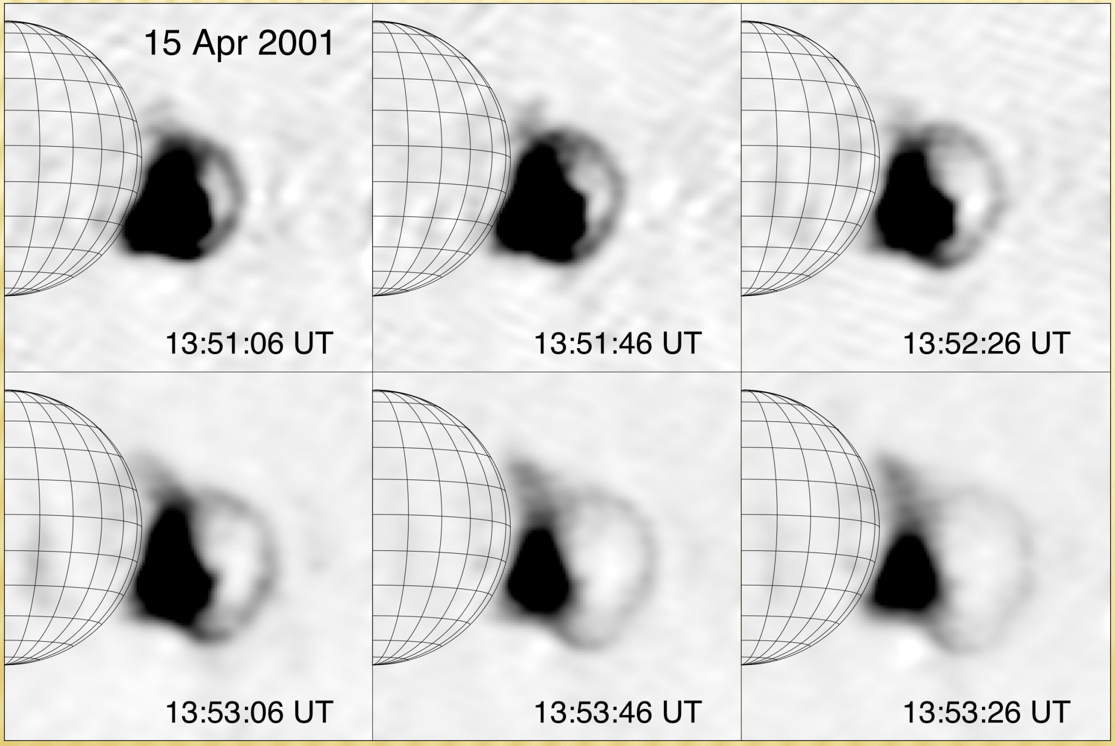


Mewaldt et al. 2005

Detection of synchrotron radiation from MeV electrons interacting with magnetic field entrained by fast CME.

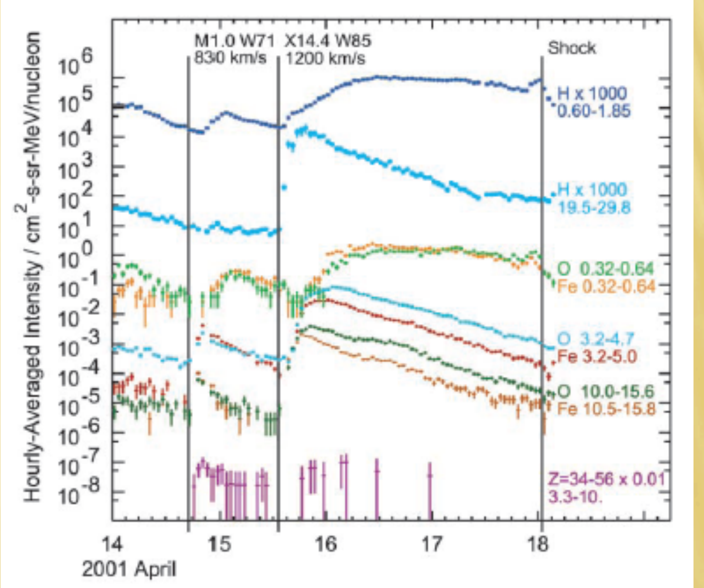
2001 April 15: X14.4 flare, partial halo CME >1200 km/s, major SEP event





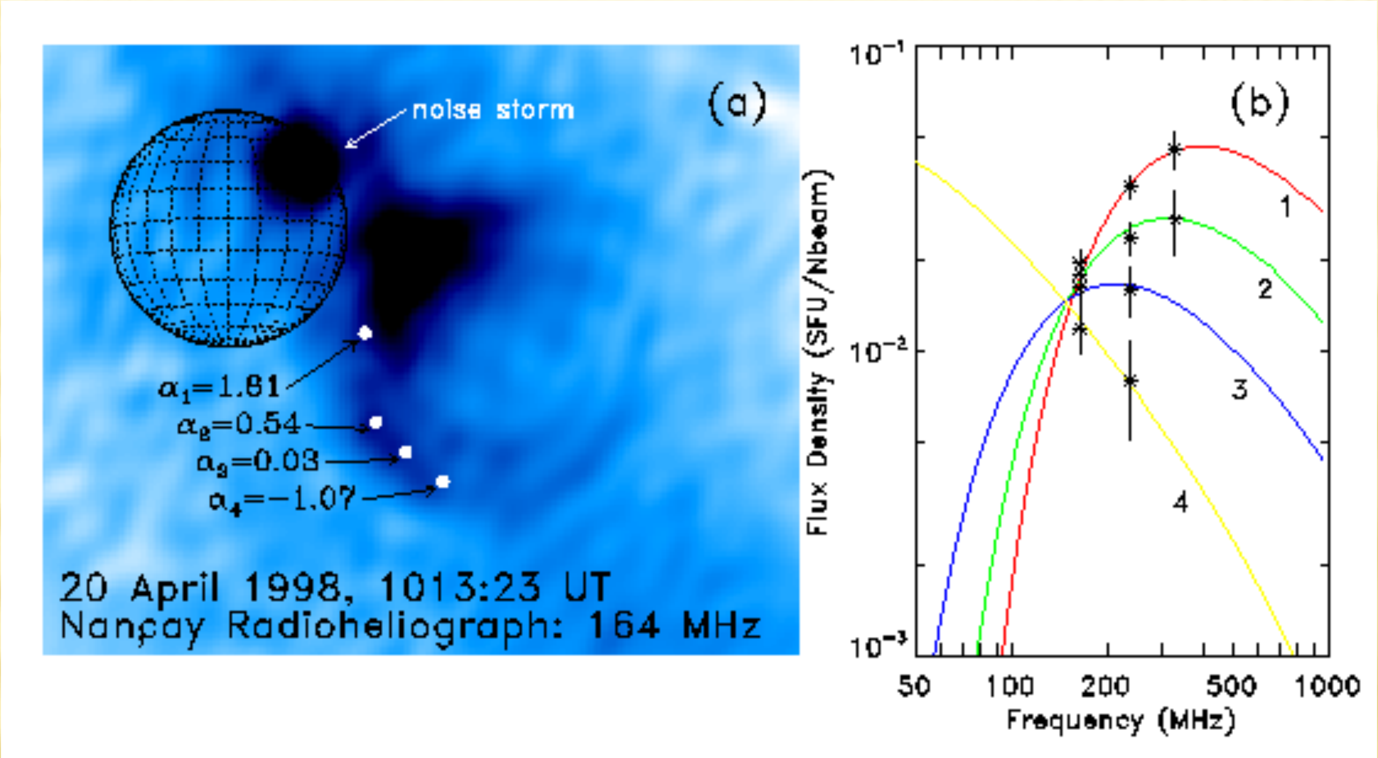
Nancay RH: 327 MHz

Maia et al. (2007)



Tylka et al. (2002)

Radio Imaging of Fast CME of 1998 April 20



LoS	α	R_{sun}	ϕ (deg)	n_e (cm^{-3})	B(G)	ν_{RT} (MHz)
1	1.81	1.45	234	2.5×10^7	1.47	330
2	0.54	2.05	218.5	1.35×10^7	1.03	265
3	0.03	2.4	219.5	6.5×10^6	0.69	190
4	-1.07	2.8	221	5×10^5	0.33	30

Determine B_z ? FR ~ $(L/\lambda)(f_{pe}^2 f_{Be})/f^3$

Bastian et al. (2001)

AN IMPORTANT ASIDE

It is worth emphasizing that since FASR observes the full disk of the Sun from 50 MHz to 21 GHz every second, it will observe the solar activity from the chromosphere into the corona as a ***coupled system:***

the flare *and* the erupting filament *and* the CME *and* the coronal shock (type II) *and* the EIT wave *and* the coronal dimming!

OPERATIONS

FASR is intended to be a solar physics instrument, not a solar radio instrument. It will not be a PI/GI instrument. Operationally, it will employ:

- “monomode” observing
- Quicklook data products
- An interim archive for offline data processing
- Pipeline processing to perform calibration, form applications data bases, & imaging; produce derived data products
- A permanent archive of applications data bases and derived data products

The primary interface between the user and the instrument will be through the data archive, supported by an extensive suite of data visualization and analysis tools, much as RHESSI is today.

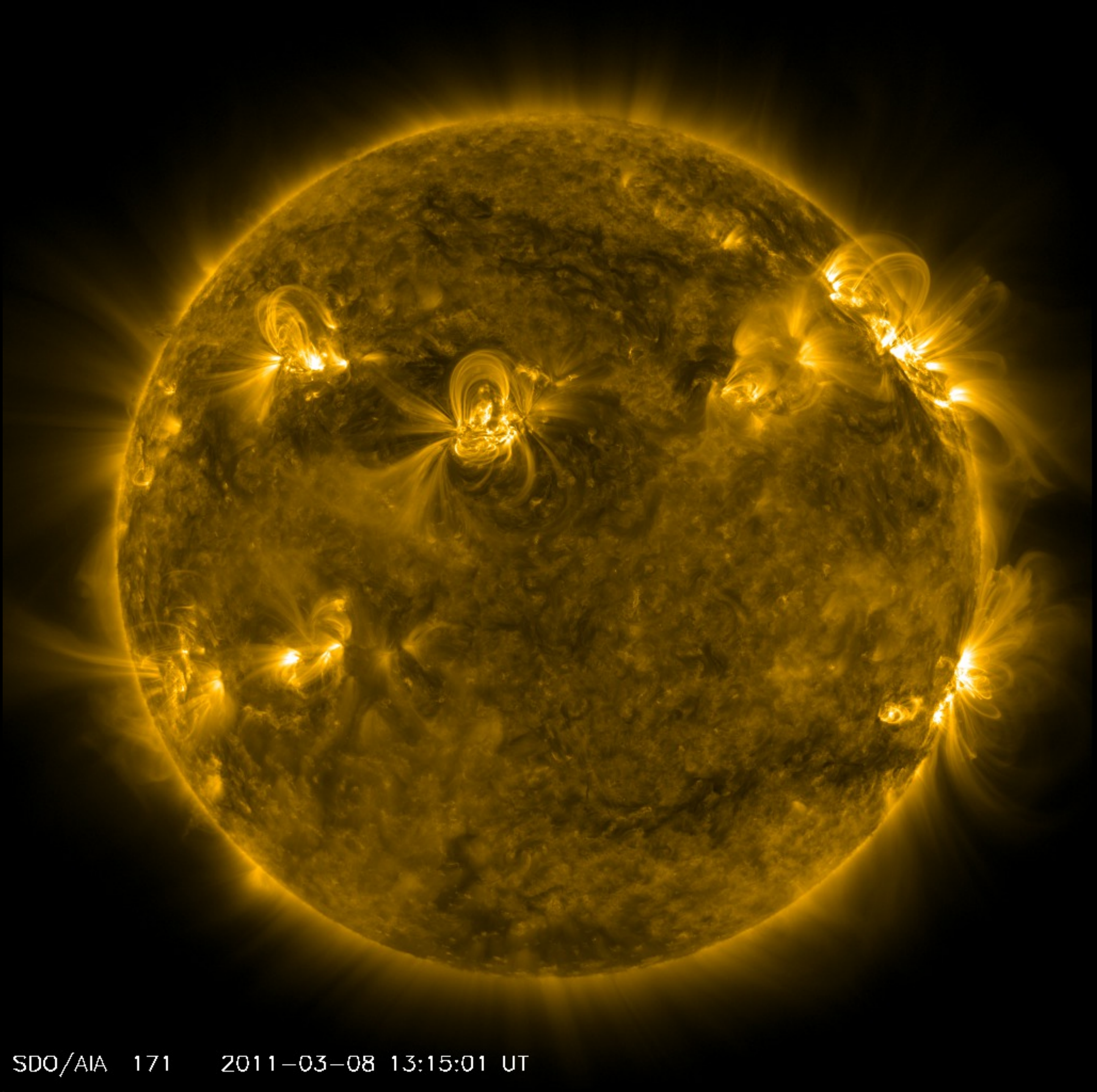
CONTEXT

FASR will be complemented by a number of new instruments:

- On the ground
  - Advanced Technology Solar Telescope (ATST)
  - Murchison Widefield Array (MWA)
  - Long Wavelength Array (LWA)
  - Expanded Very Large Array (EVLA)
  - Atacama Large Millimeter/submillimeter Array (ALMA)
- In space
  - Solar Probe Plus (NASA) – in situ/remote obs. to 9.5 $R_\odot$
  - Solar Orbiter (ESA) – in situ/remote obs to 60 $R_\odot$, 25 deg oe
  - Solar C (ISAS/JAXA) – 1 AU – EUV imaging spectroscopy
  - Several others in the planning stages

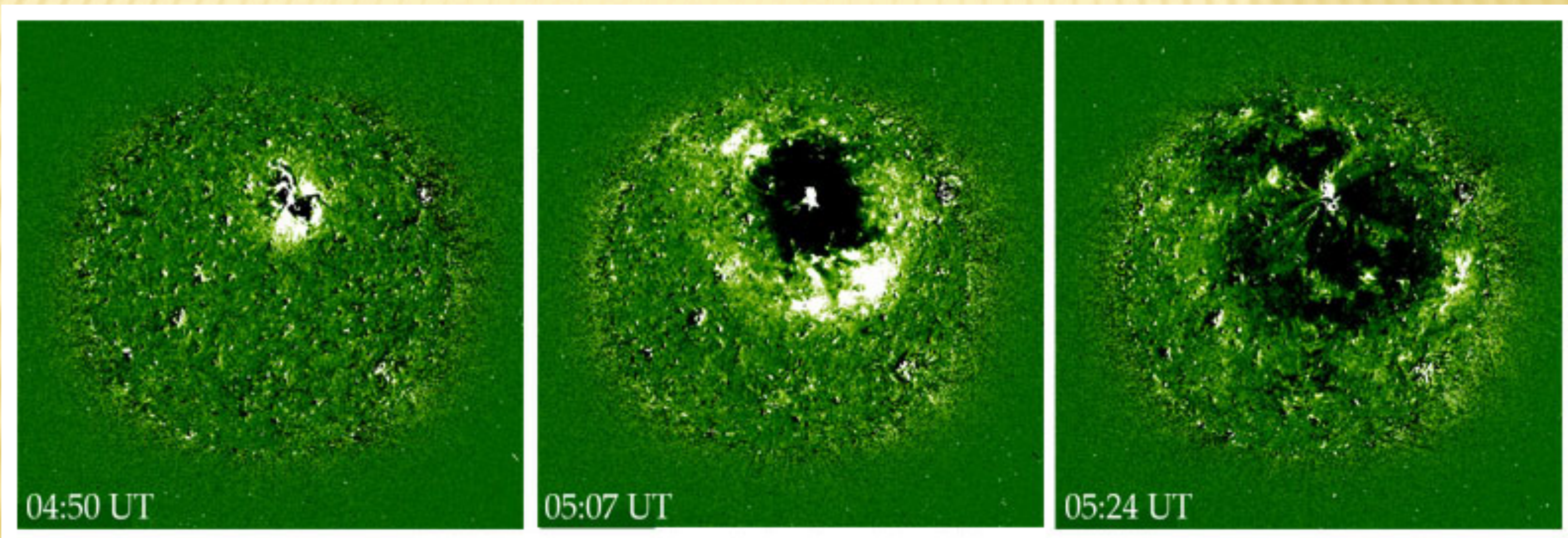
OUTLOOK

- FASR was highly rated by Astro2010 and the 2003 Solar & Space Physics Decadal Survey
- The project is well-matched to the recommended NSF Mid-scale Innovations Program
- The project is well-suited to joint funding by NSF AST and AGS
- The project is in a high state of readiness


SDO/AIA 171 2011-03-08 13:15:01 UT

SOHO EIT

12 May 1997



Thompson et al. 1998