FASR FREQUENCY-AGILE SOLAR RADIOTELESCOPE

The Frequency Agile Solar Radiotelecope

T. S. Bastian

NRAO, NJIT, UMd, Berkeley, NSO, Obs. Paris

Plan of talk

- Introduction/background
- Science specifications
- Science program
- Data management issues

FASR will be a ground based solar-dedicated radio telescope designed and optimized to produce images over a broad frequency range with

- high angular, temporal, and spectral resolution
- high fidelity and high dynamic range

As such, FASR will address an extremely broad science program.

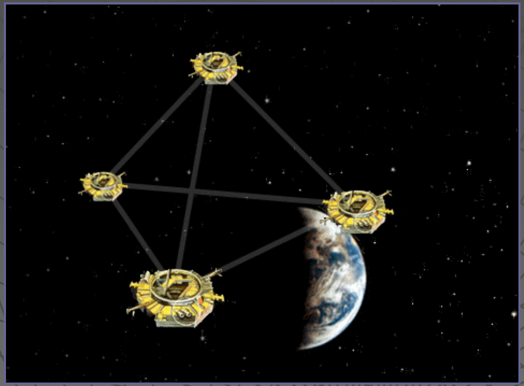
An important goal of the project is to mainstream solar radio observations by providing a number of standard data products for use by the wider solar physics community.

The decadal review of the *NAS/NRC Solar and Space Physics Survey Committee* recently considered priorities for solar, heliospheric, magnetospheric, and ionospheric physics.

>$400M (large)

Solar Probe

Solar Probe will make the first in-situ measurements inside 0.3 AU, the innermost region of the heliosphere and the birthplace of the heliosphere itself.



$250-400M (moderate)

Magnetospheric Multiscale Mission (MMS)

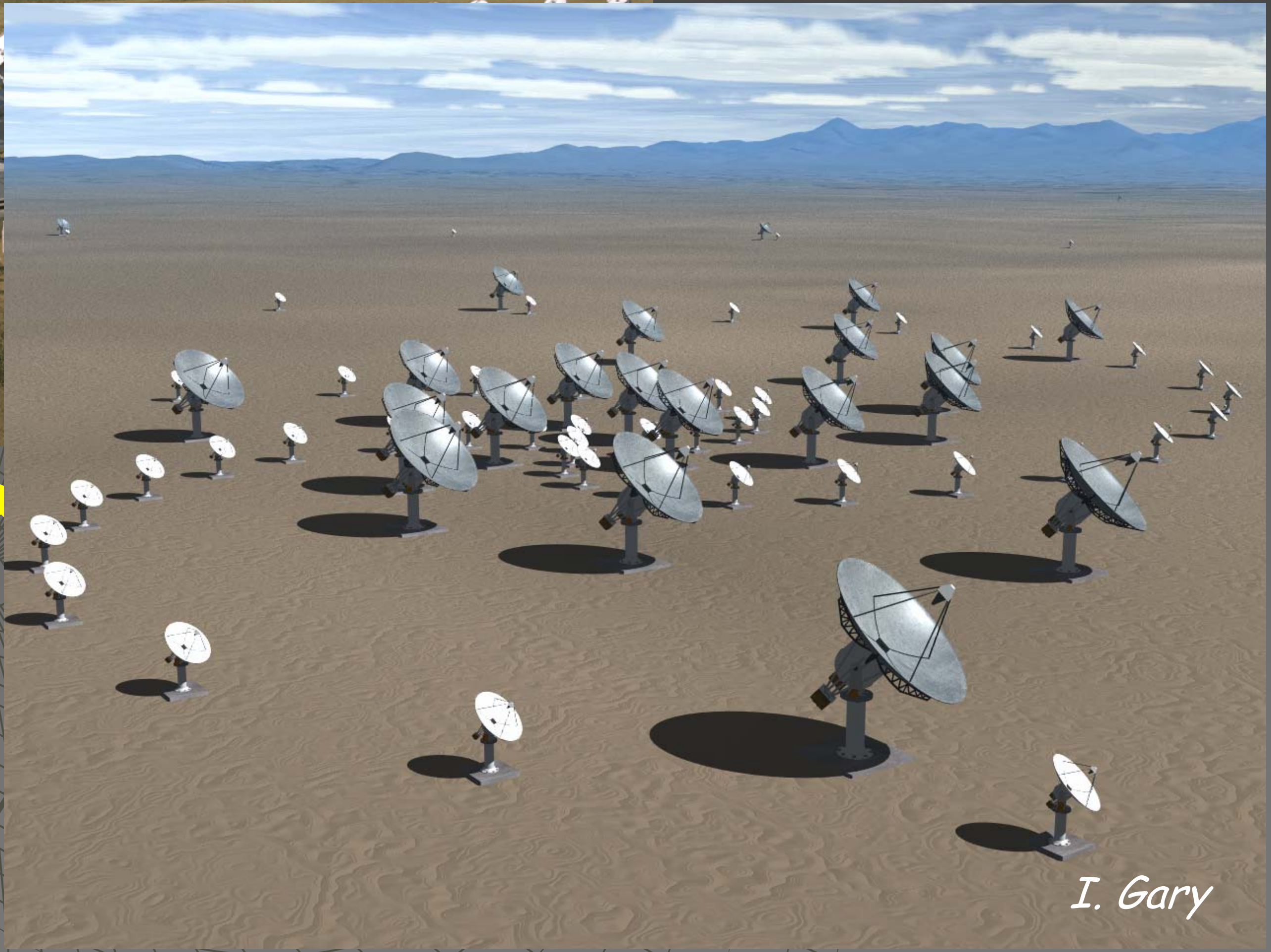
The 4 MMS spacecraft will study the fundamental physical processes that transport, accelerate, and energize plasma in the boundary layers of Earth's magnetosphere.

<$250M (small)

Frequency Agile Solar Radiotelescope (FASR)

A multi-frequency (~0.1 - 30 GHz) imaging array composed of ~100 antennas for imaging the Sun with high spectral, spatial, and temporal resolution.

Nobeyama

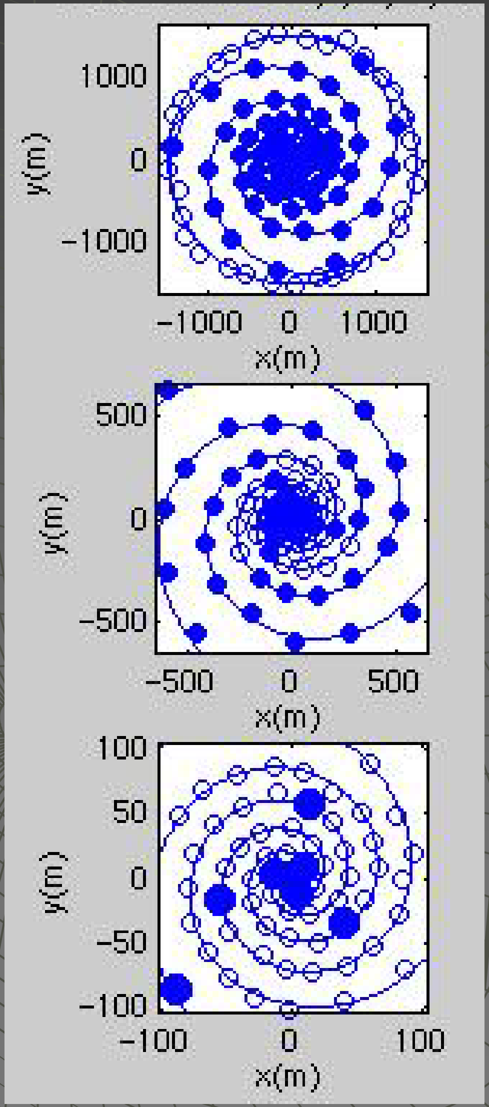


FASR Specifications

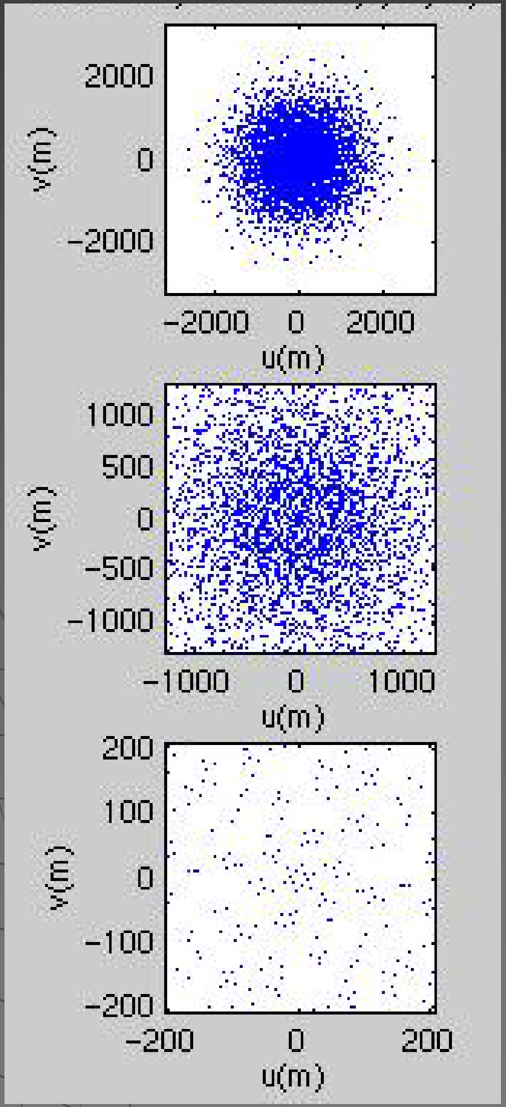
Frequency range	~0.1-30+ GHz
Frequency resolution	0.1%, 0.1 – 3 GHz 1%, 3 – 18 GHz
Time resolution	10 ms, 0.1 – 3 GHz 100 ms, 3 – 18 GHz
Number antennas	~100 (5000 baselines)
Size antennas	LPA, 6 m, 2 m
Polarization	Stokes IV(QU)
Angular resolution	$20/\nu_9$ arcsec
Footprint	~6 km
Field of View	>0.5 deg

Array configuration

"self-similar"
log spiral



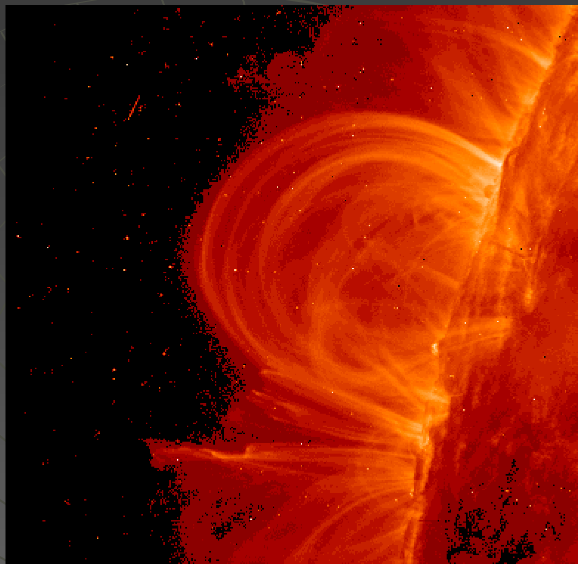
AC



Conway 2000

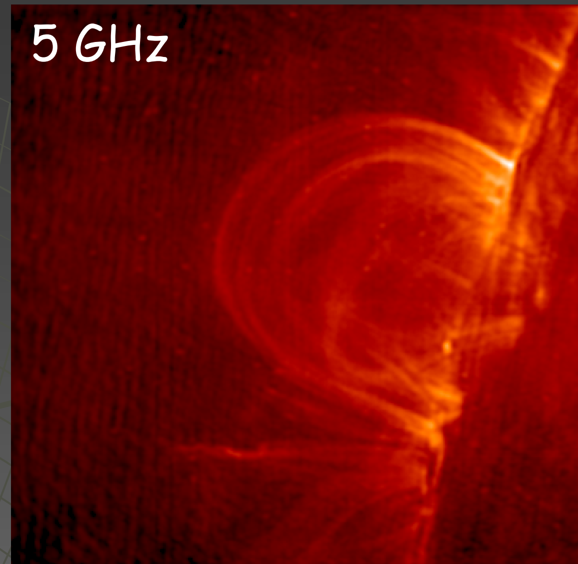
Imaging

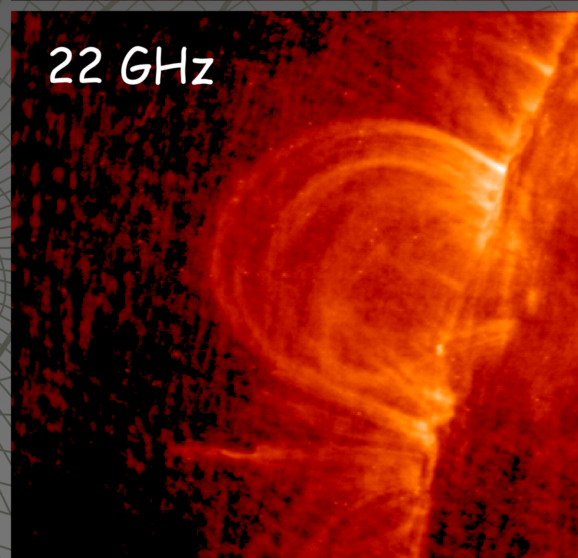
model



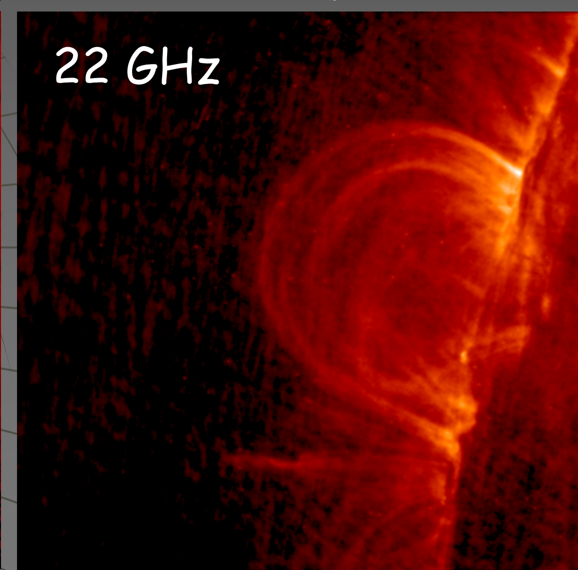
TRACE: 6 Nov 1999

snapshots





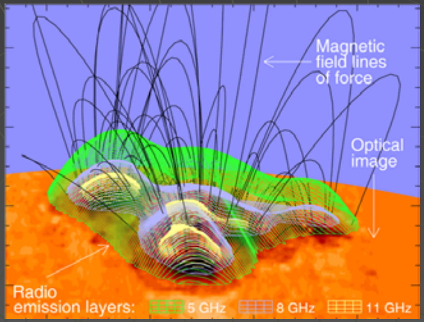
10 min synth.

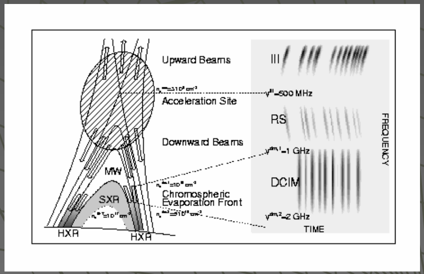


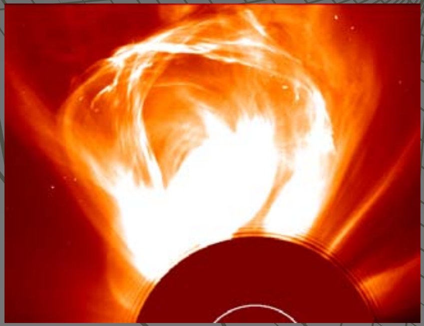
102 antenna log-spiral in three arms

(noiseless data)

FASR Key Science







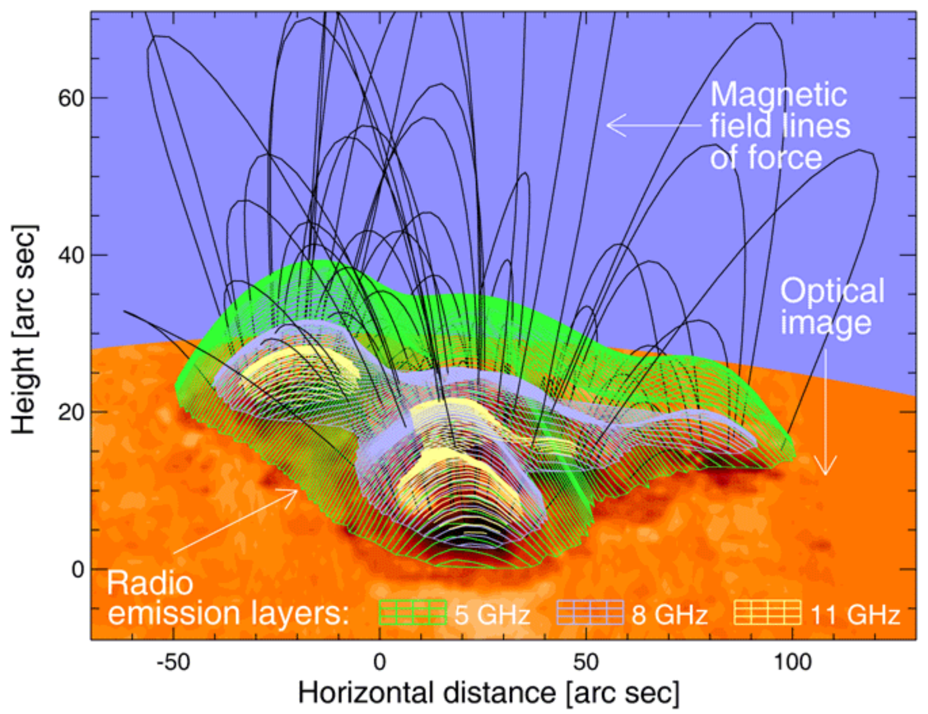
- ✓ Nature & Evolution of Coronal Magnetic Fields
  - Measurement of coronal magnetic fields
  - Temporal & spatial evolution of fields
  - Role of electric currents in corona
  - Coronal seismology

- ❑ Flares
  - Energy release
  - Plasma heating
  - Electron acceleration and transport
  - Origin of SEPs

- ❑ Drivers of Space Weather
  - Birth & acceleration of CMEs
  - Prominence eruptions
  - Origin of SEPs
  - Fast solar wind streams

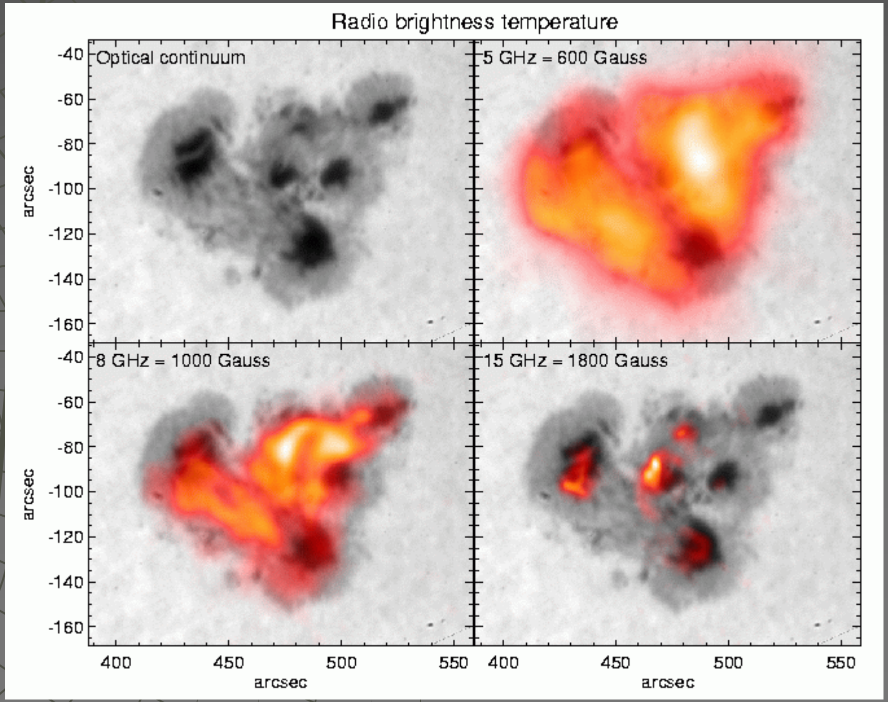
Radio observations offer an abundance of tools for measuring or constraining magnetic fields in the solar corona.

Gyroresonance emission	Free-free emission
Gyrosychrotron emission	Radio bursts
Razin suppression	Propagation



Model active region with s=3 resonance layers superposed for 5, 8, & 15 GHz.

Active region showing strong shear: radio images show high B and very high temperatures



from Lee et al (1998)

Free-Free Opacity

- Consider change of chromospheric temperature with height.
- In the absence of a magnetic field, both modes have same opacity, so reach $\tau = 1$ at same height.
- With $B > 0$, x-mode becomes optically thick slightly higher in the chromosphere and so has a higher brightness temperature.
- The o-mode becomes optically thick at slightly lower temperature.

$$\rho_C = \beta \frac{\nu_B}{\nu} \cos\theta \propto B_l \qquad \beta = \frac{d \ln T}{d \ln \nu}$$

Grebinskij et al 2000

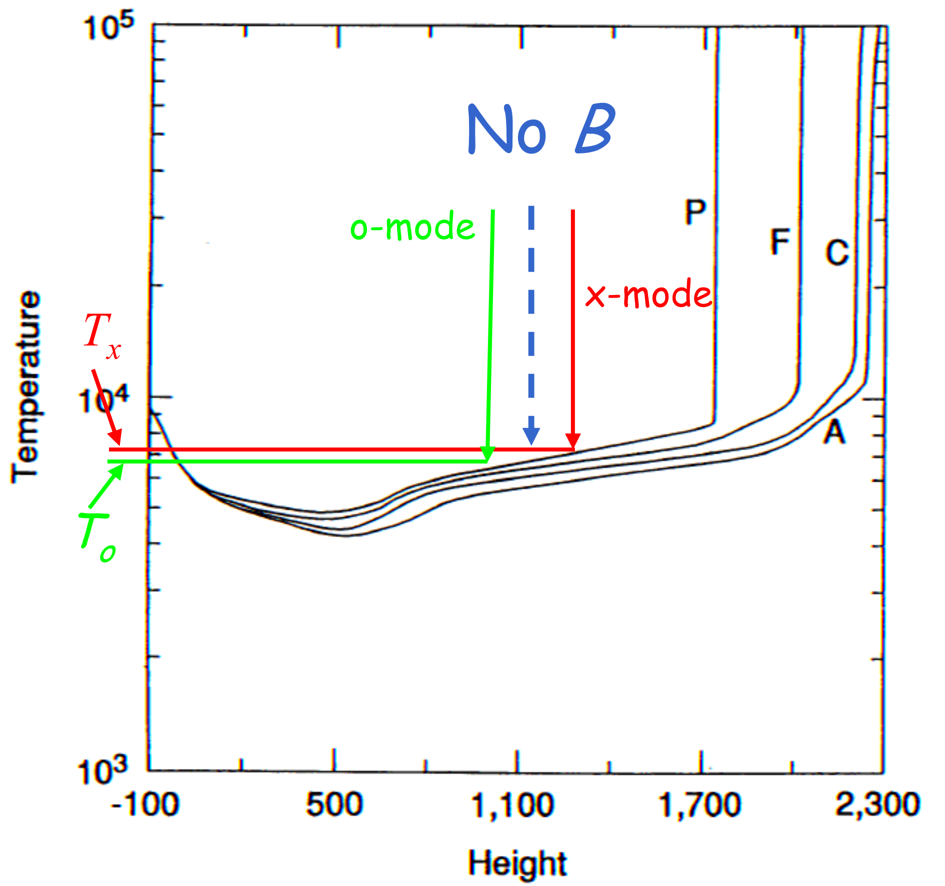
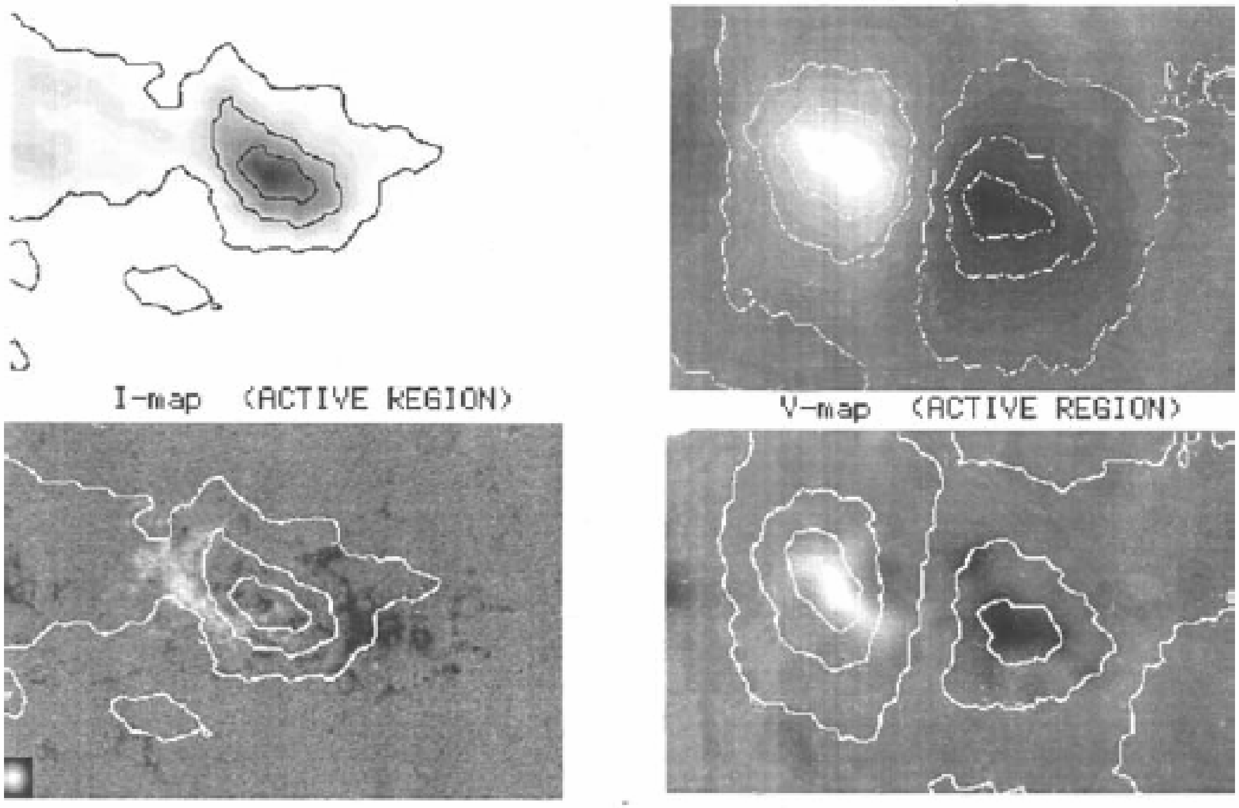


FIG. 3.—Temperature structure of our models A, C, F, and P. The height is measured in kilometers from the level; the temperature is in kelvins.

Fontenla, Avrett & Loeser (1993)

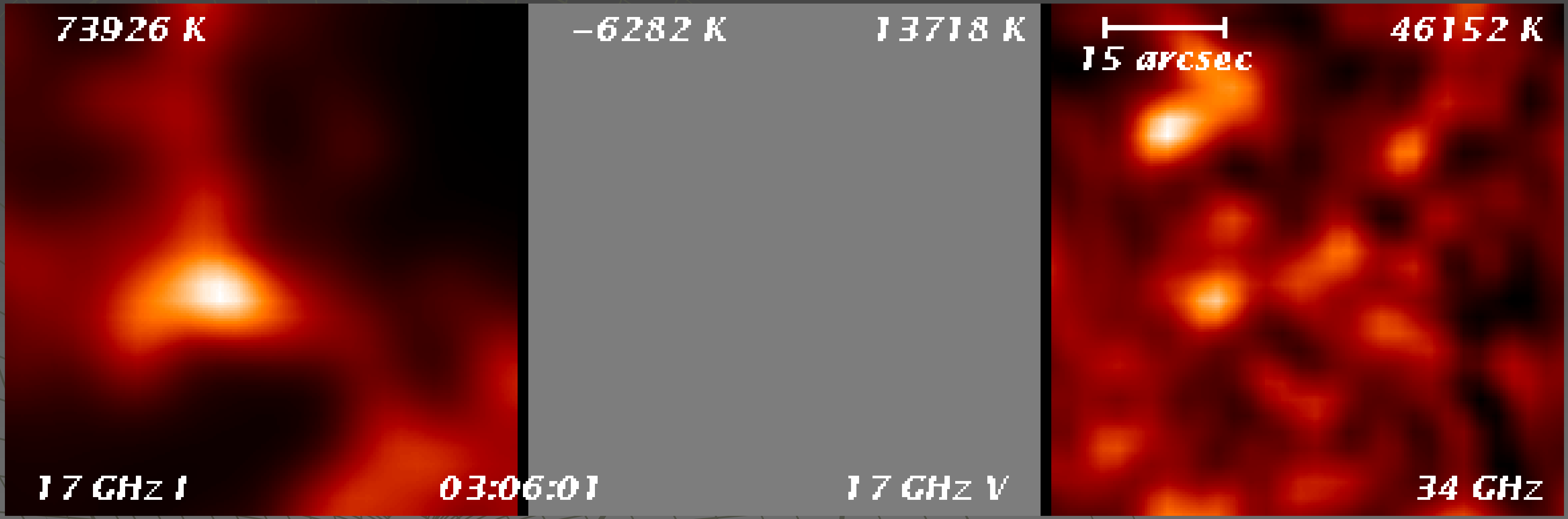


B~85 G

Figure 5.1. Radio maps of the AR observed on June 09, 1995 using Nobeyama radio heliograph at $\lambda = 1.76cm$. Contours present the brightness distribution . Maximum in I channel ($T_b = 27 \cdot 10^3 K$). Maximum in V-channel $T_b^V = 440K$. Maximum degree of polarization $P = 2.8\%$. The region maps are overlapped by gray scale magnetograms . For V-maps they are averaged by the scale of the Nobeyama radio heliograph beam (shown below on the left). The upper V-map present brightness T_b^V, the lower one - percentage $P\%$ of polarization.

Gelfreikh 2003

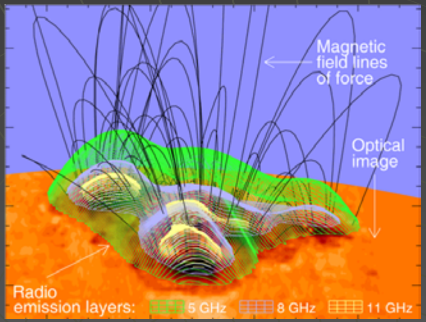
17 GHz intensity 17 GHz circ. pol. 34 GHz intensity

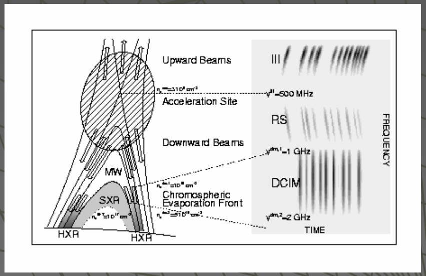


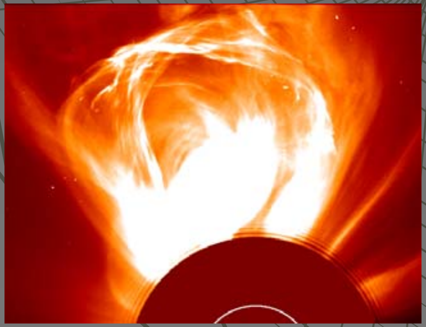
Magnetic field lines in the solar corona illuminated by gyrosynchrotron emission from nonthermal electrons.

Nobeyama RH

FASR Key Science







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  - Temporal & spatial evolution of fields
  - Role of electric currents in corona
  - Coronal seismology
- ✓ Flares
  - Energy release
  - Plasma heating
  - Electron acceleration and transport
  - Origin of SEPs
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Physics of Flares

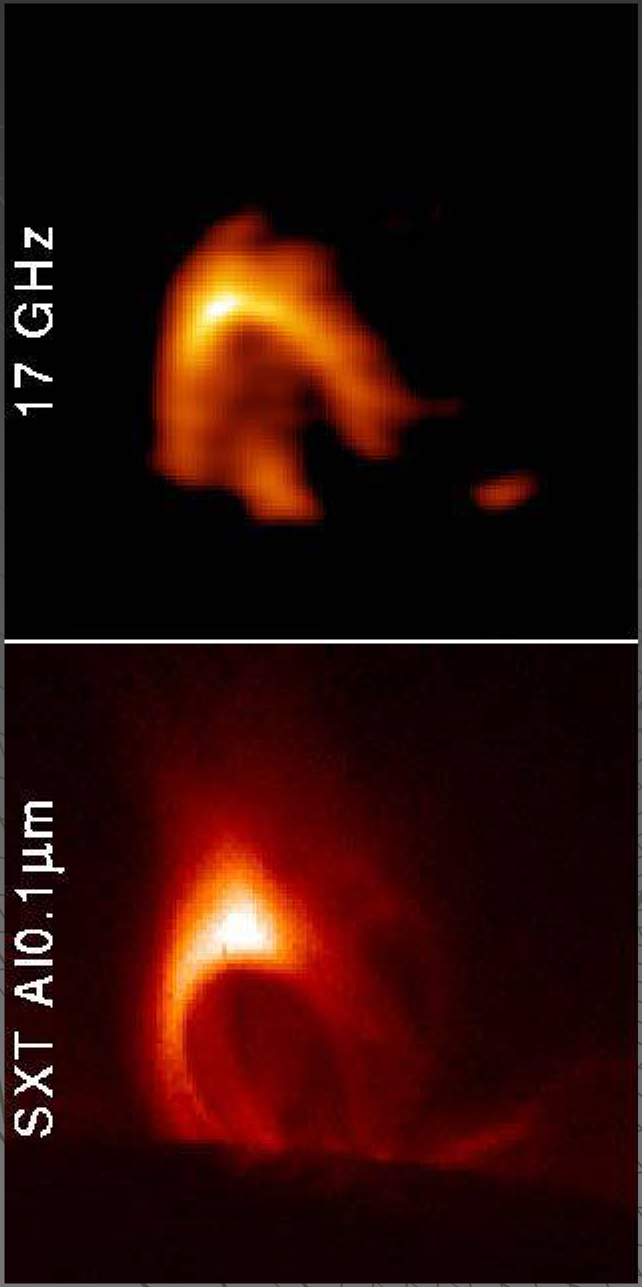
Physical conditions in energy release volume
- density diagnostics
- diagnostics of magnetic reconnection

Electron acceleration and transport
- shock/stochastic/direct acceleration
- evolution of electron distribution function
  - - electron beams
  - - trapped populations
  - - field connectivity

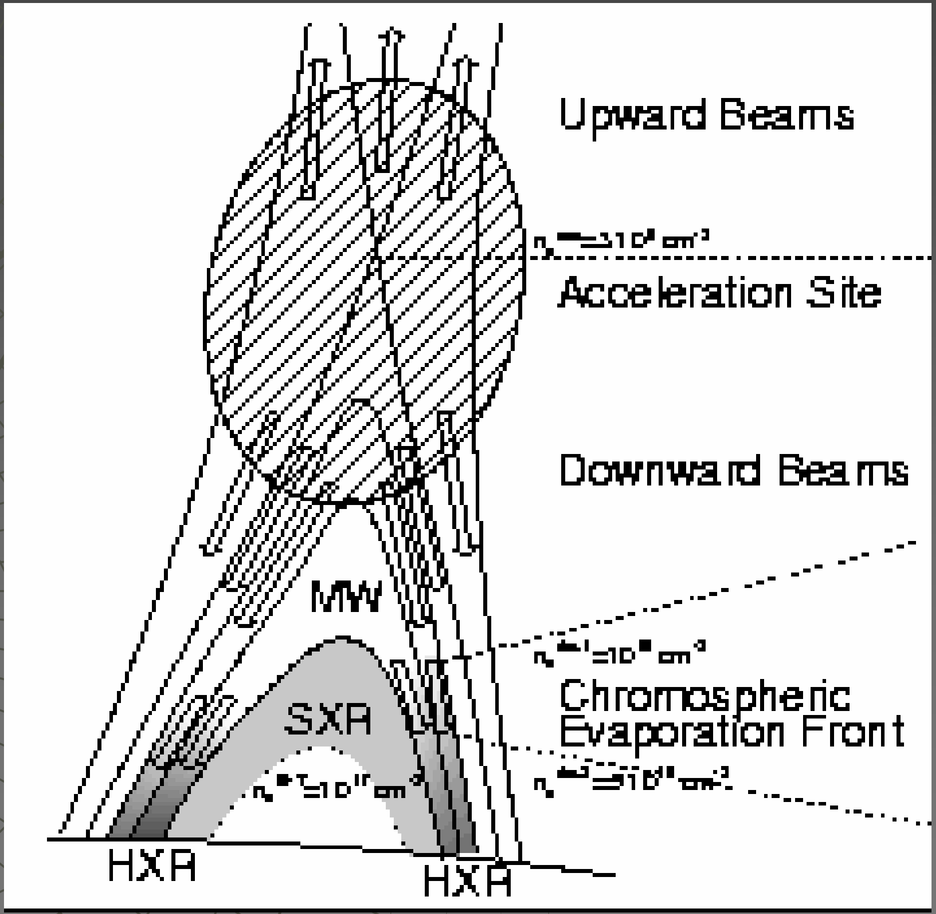
Magnetic field measurements in flaring volume

Chromospheric evaporation, origin of solar energetic particles, …

Long duration flare observed on west limb by Yohkoh and the Nobeyama radioheliograph on 16 March 1993.



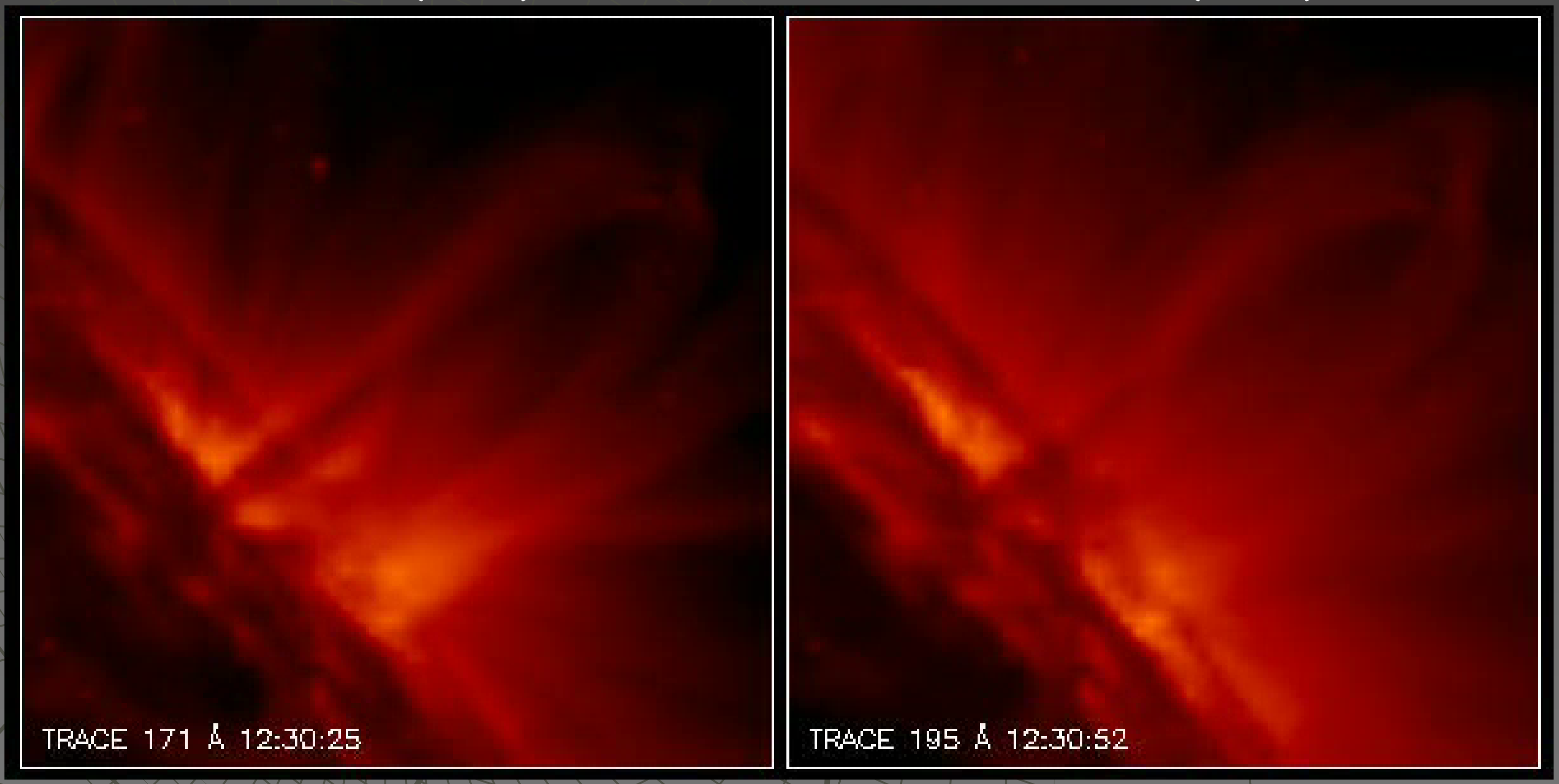
Y. Hanaoka



Aschwanden & Benz 1997

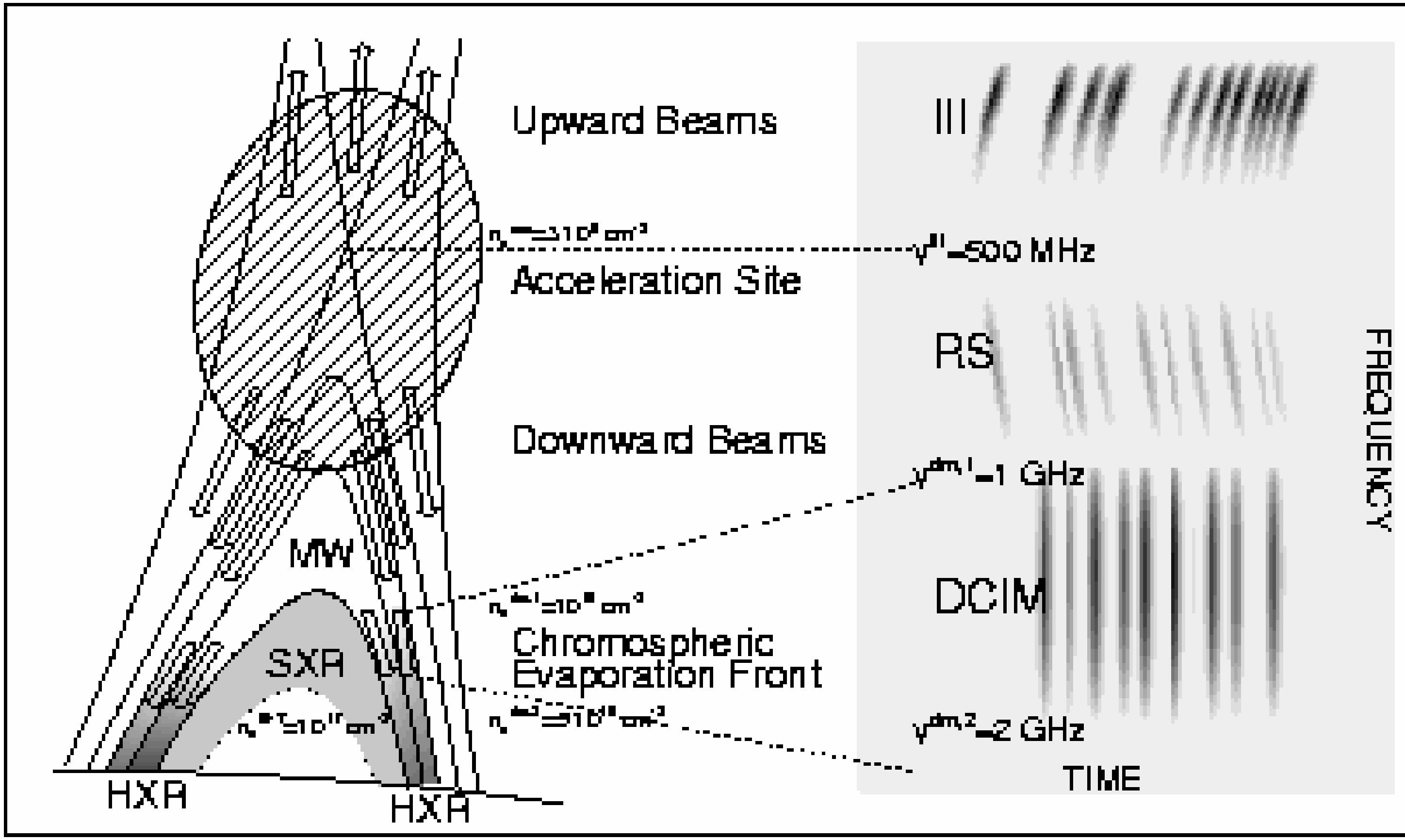
TRACE

25 July 1999



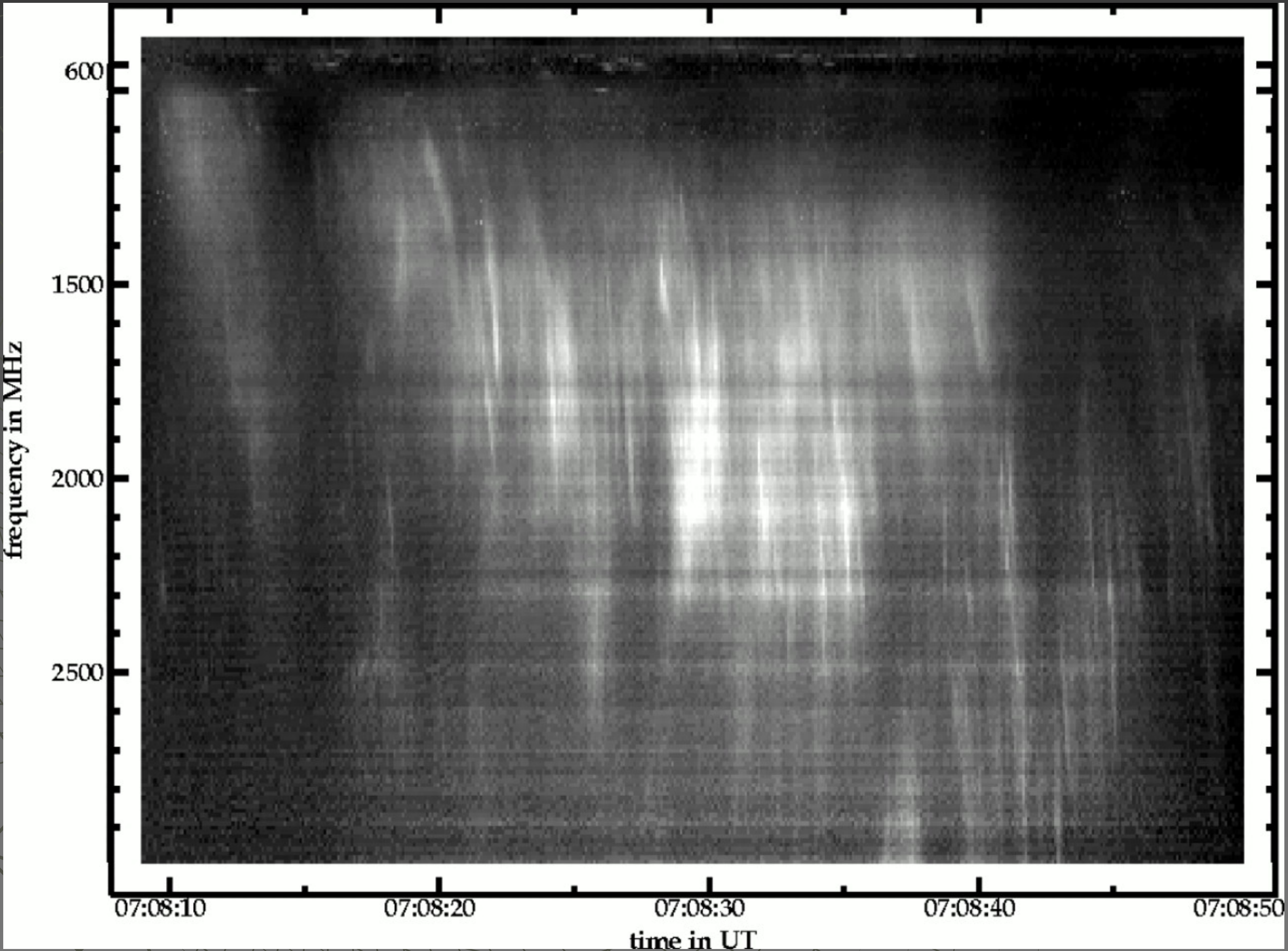
plus Fe XXIV (>10 MK)

Warren et al. 1999

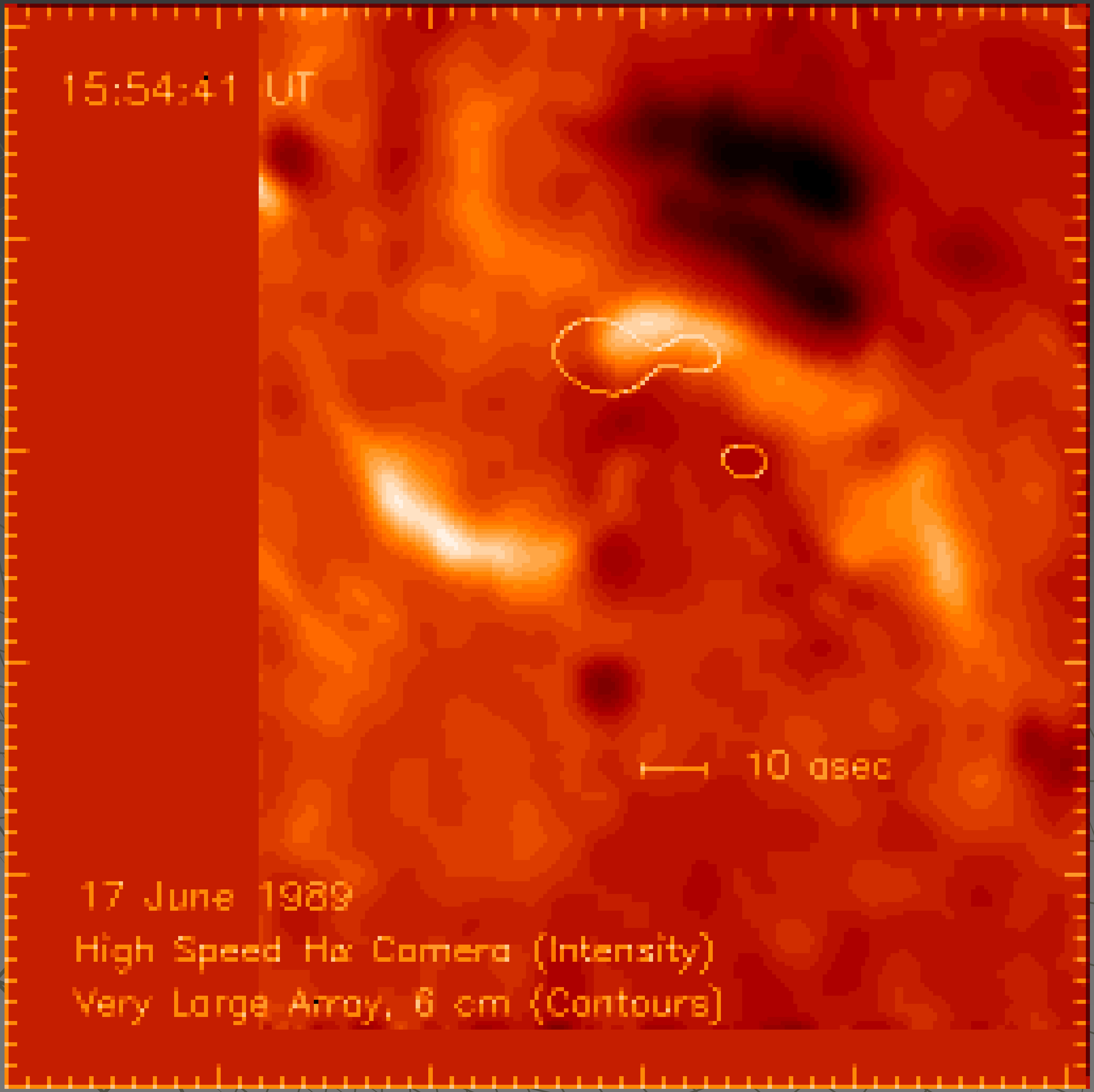


Aschwanden & Benz 1997

Reverse slope type IIIdm radio bursts



Isliker & Benz 1994



Two ribbon flare observed by the VLA on 17 Jun 89.

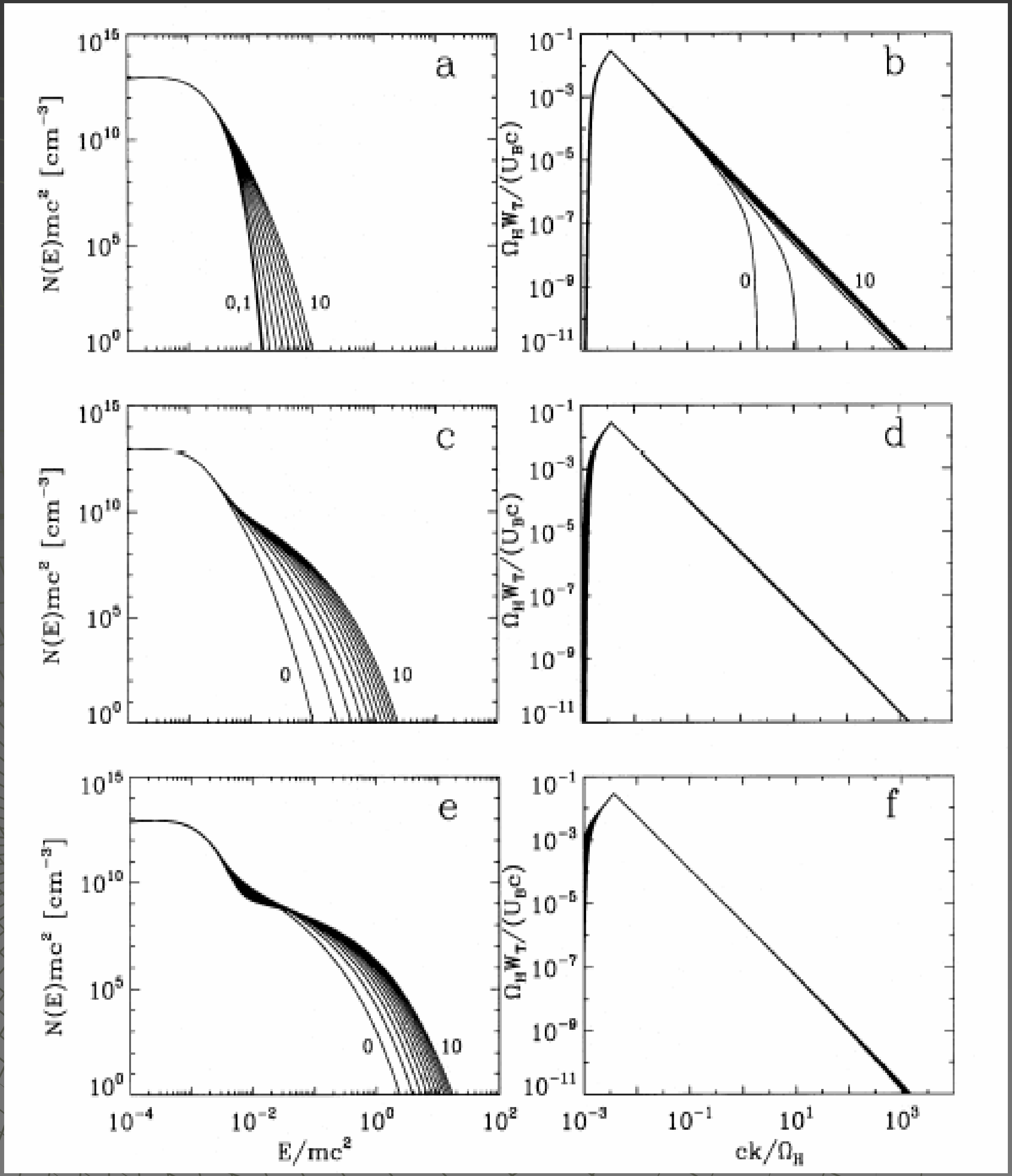
6 cm (contours)

Ha (intensity)

Bastian & Kiplinger (1991)

Electron acceleration via transit time damping

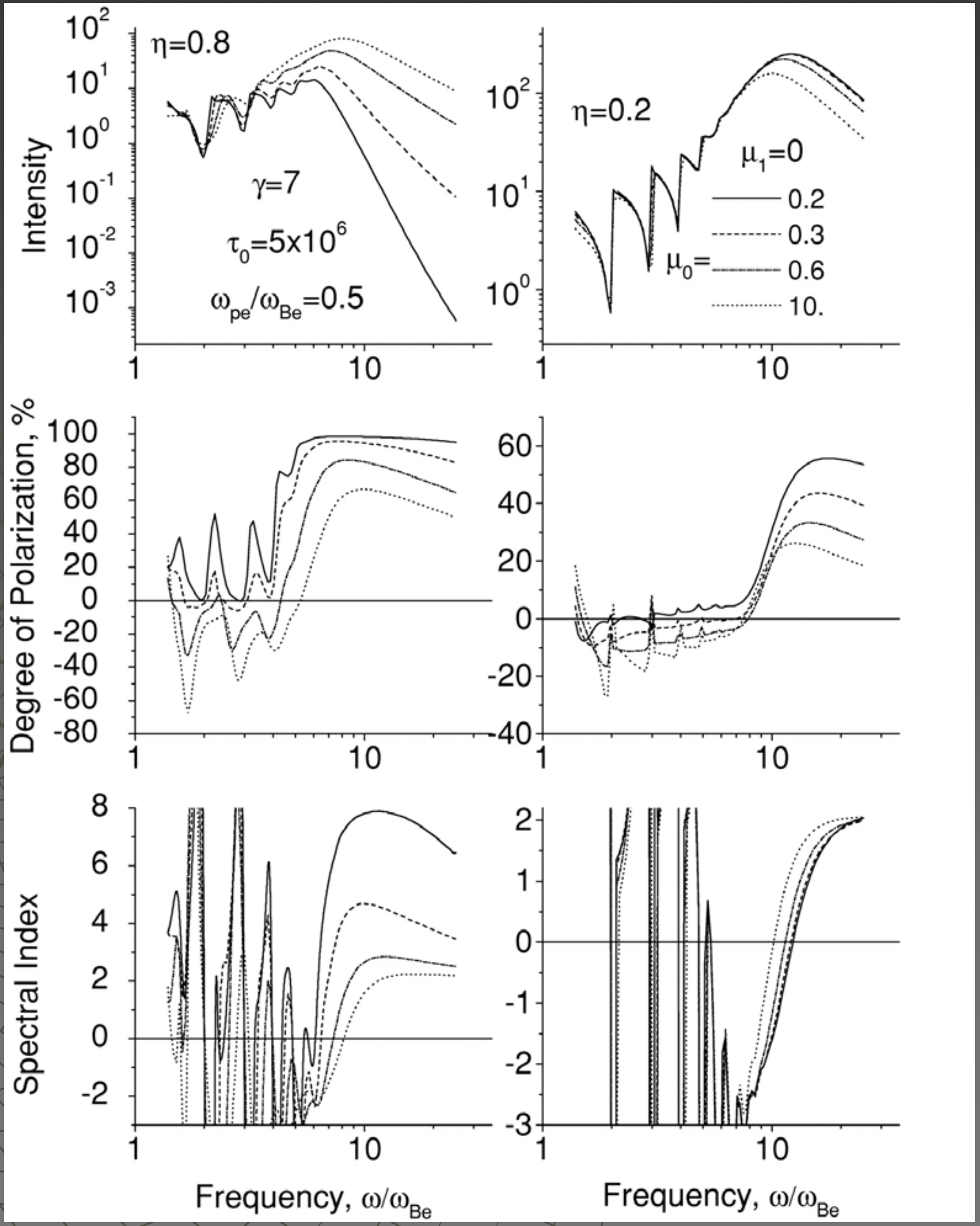
electron distributions



wave spectral density

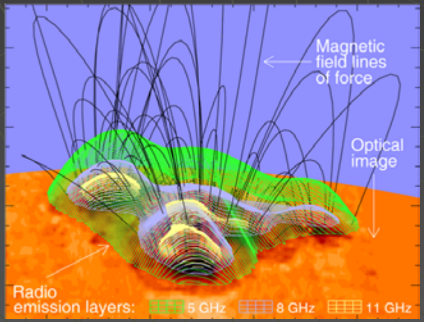
Miller et al. 1996

Consequences of anisotropic electron distribution function



Fleishman & Melnokov 2003

FASR Key Science



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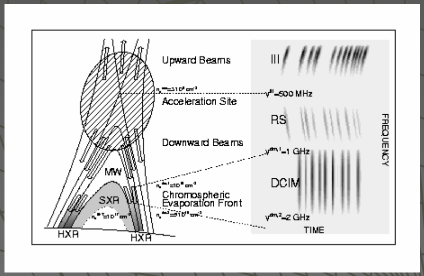

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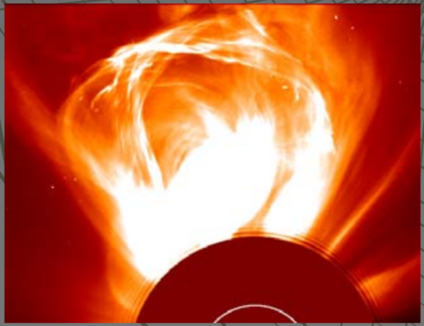

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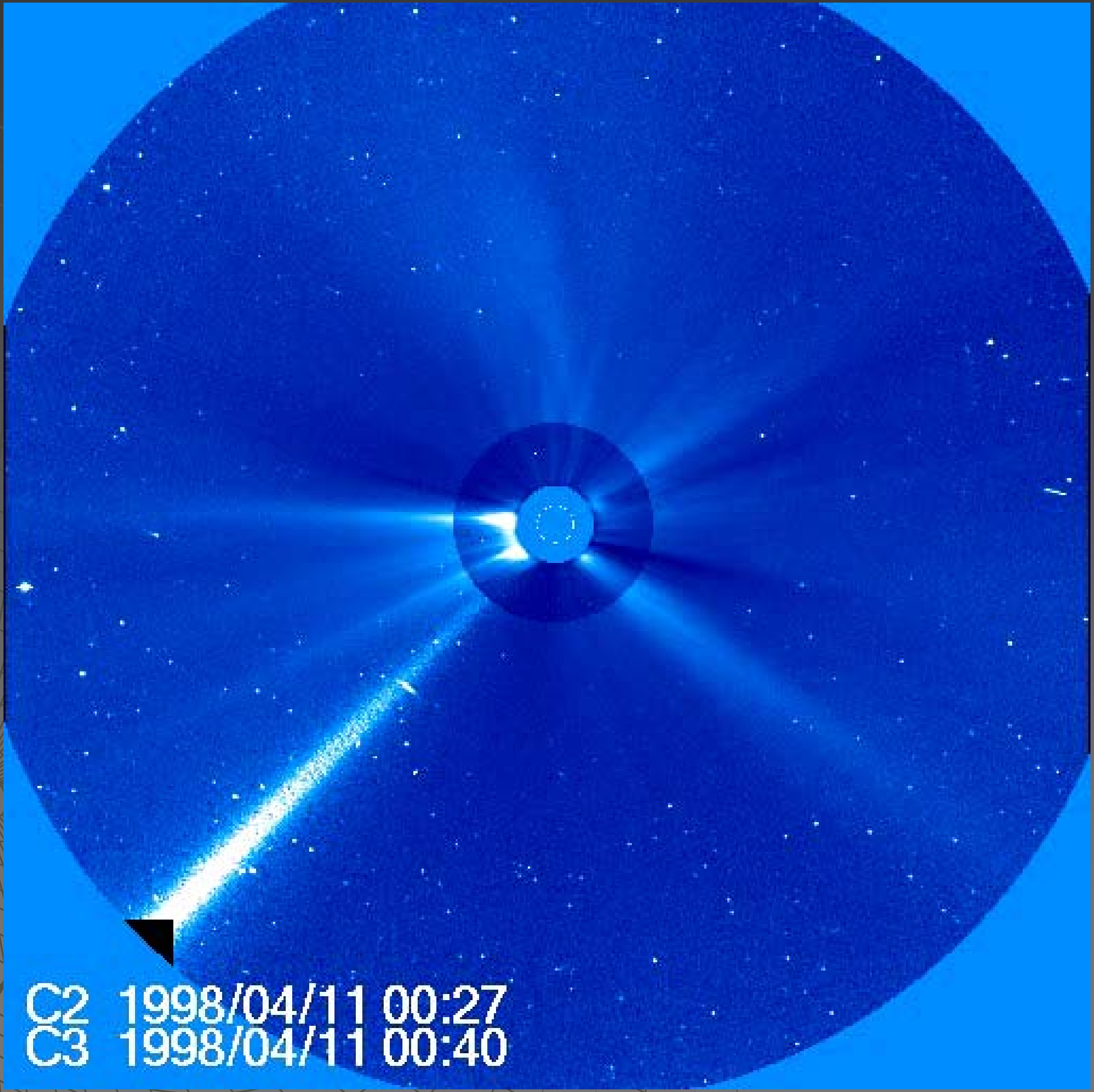
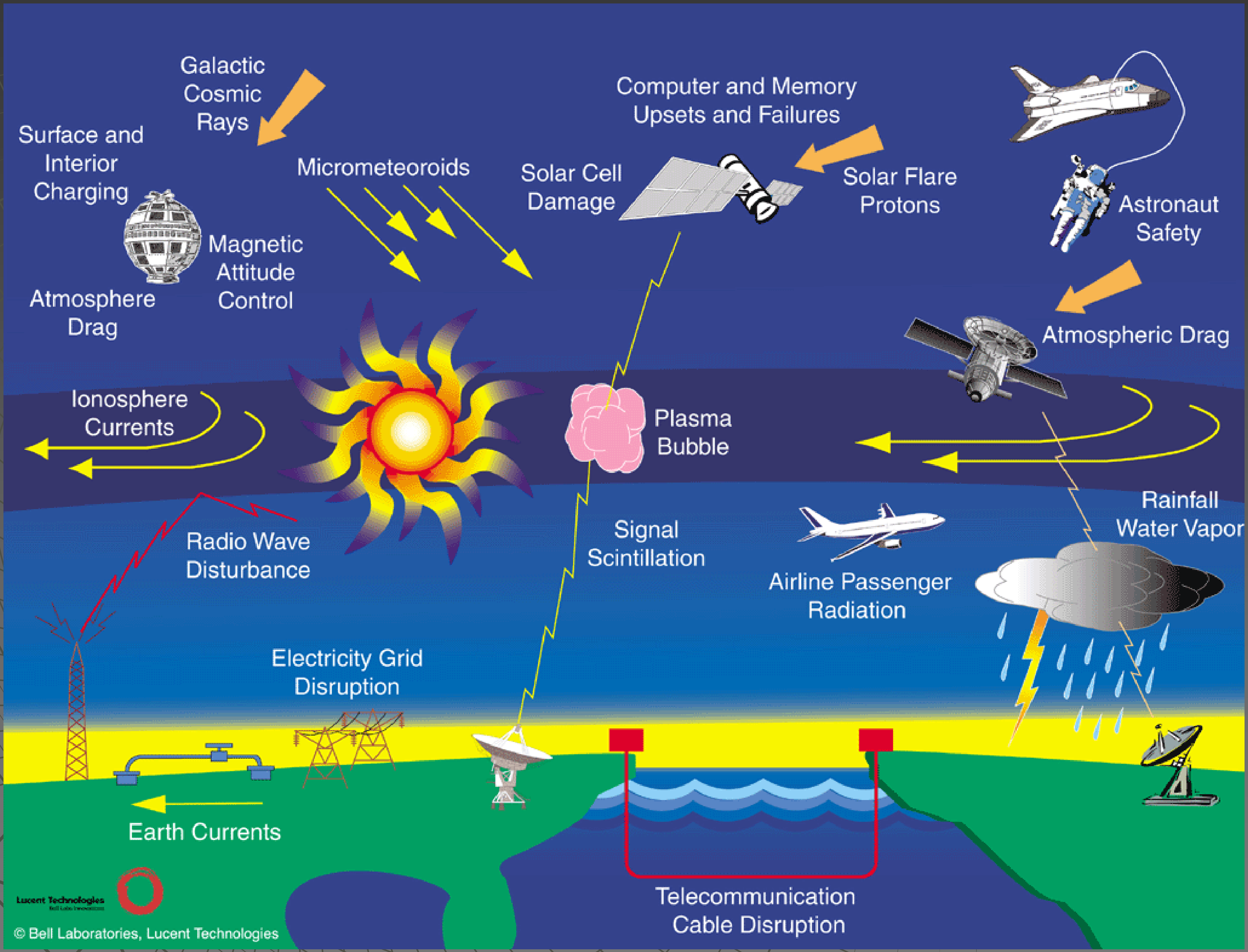
SOHO LASCO





from L. Lanzerotti

Drivers of Space Weather

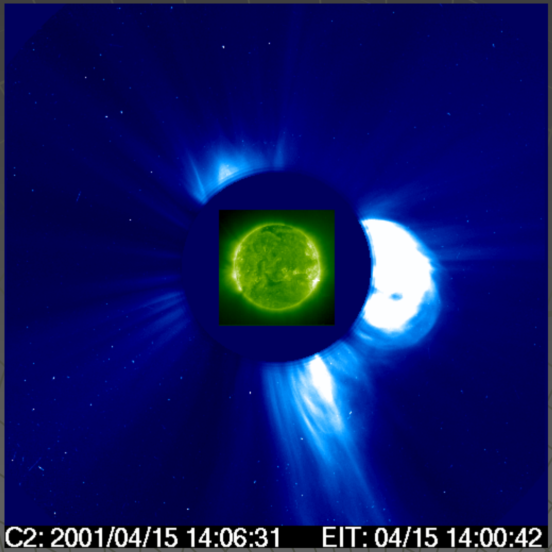
Study buildup and initiation of CMEs
- coronal field diagnostics
- diagnostics of magnetic reconnection

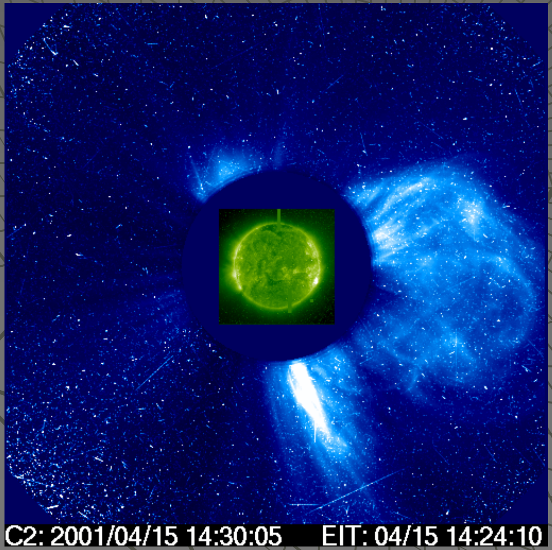
Study relation between CMEs & flares
- coronal energy release and transport
- SXT waves/EIT waves/Moreton waves

Study relation of CMEs and flares to:
- shocks (type II radio bursts)
- electron beams (type III radio bursts)
- solar energetic particles

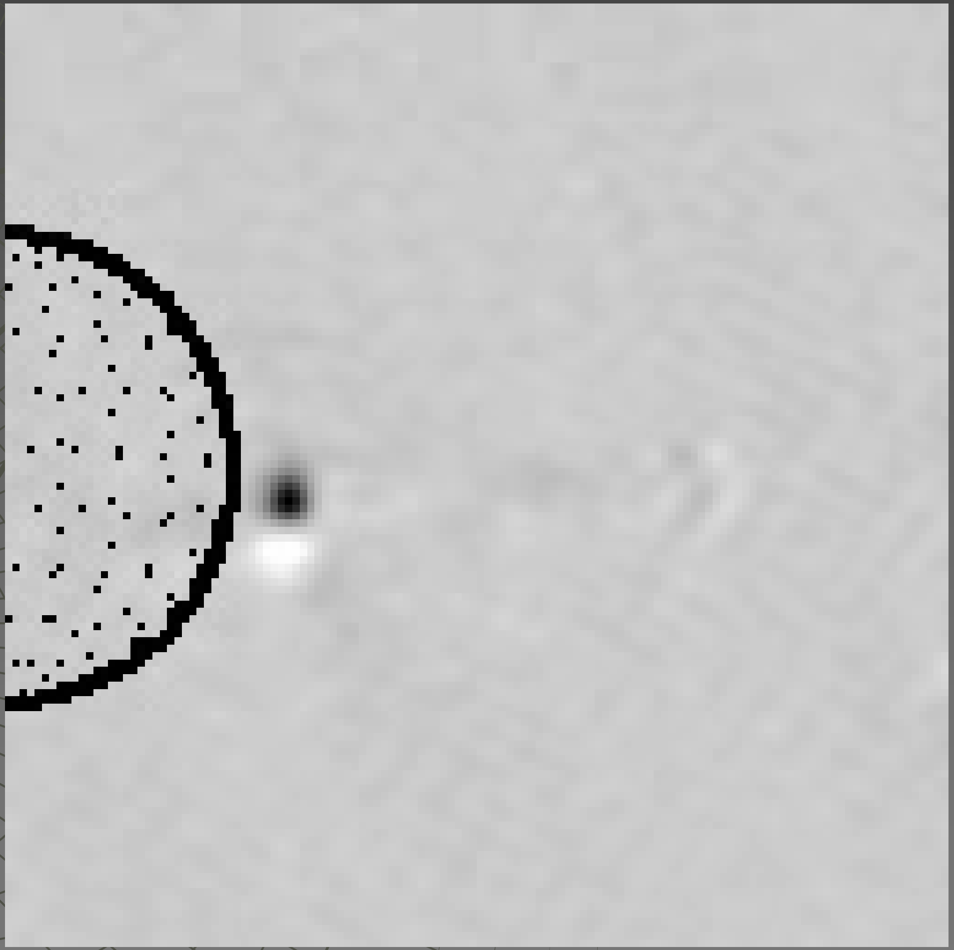
Study sources of fast solar wind

15 April 2001





Nancay Radioheliograph: 421 MHz

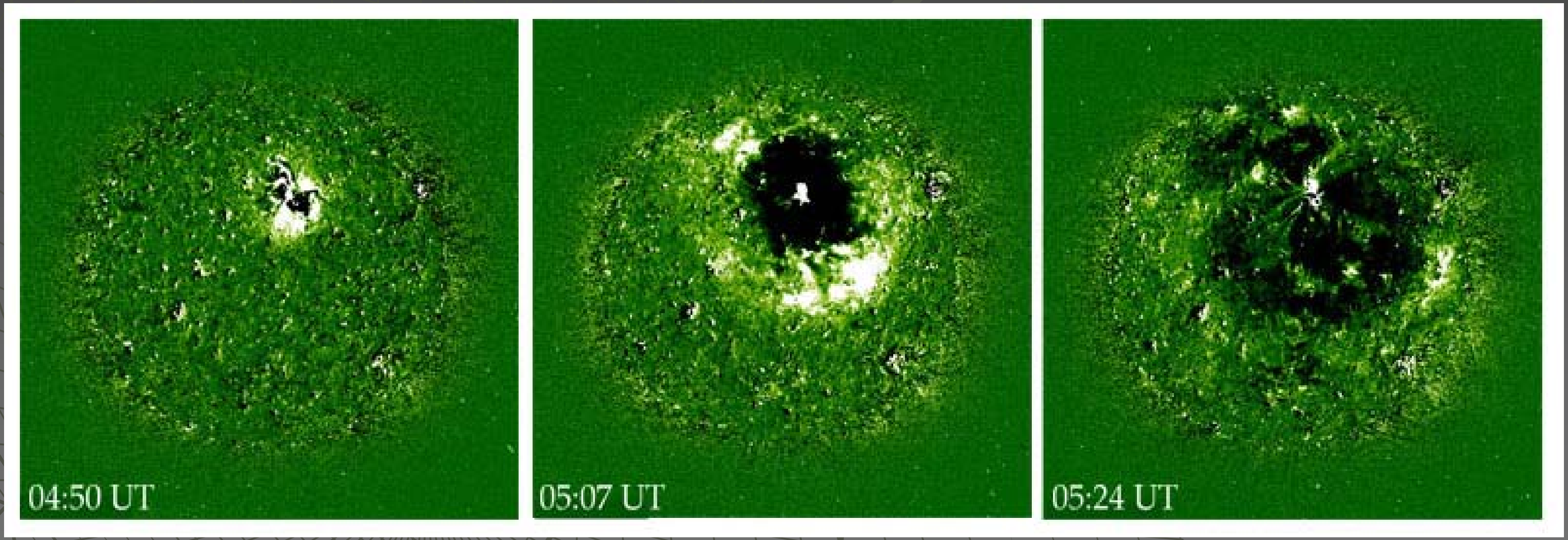


Maia et al 2003

SOHO EIT

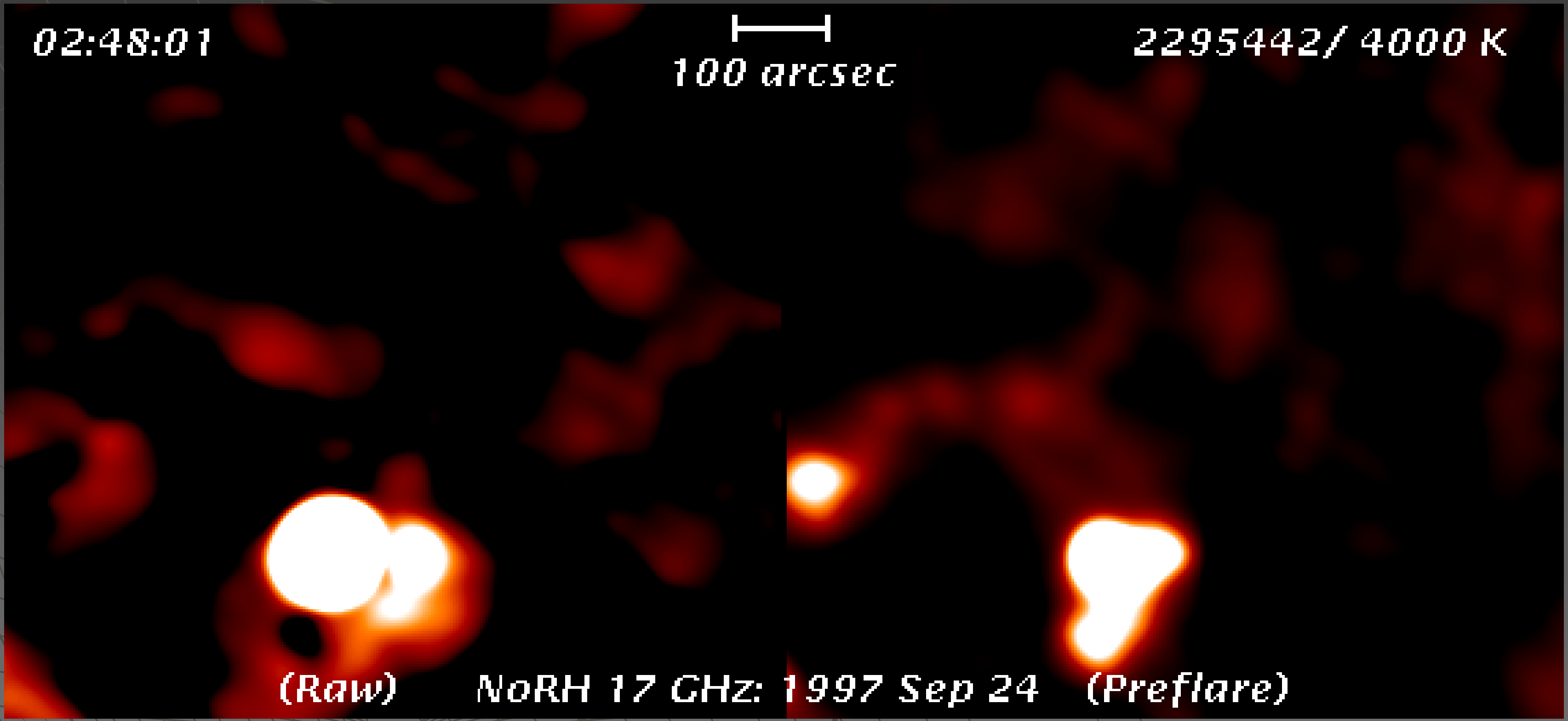
"EIT wave"

12 May 1997



V ~ 250 km/s

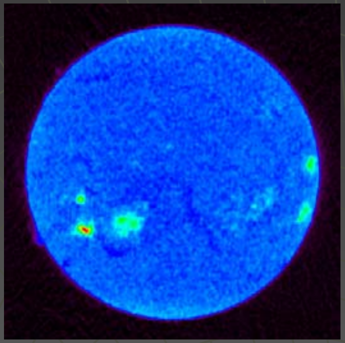
Thompson et al. 1998

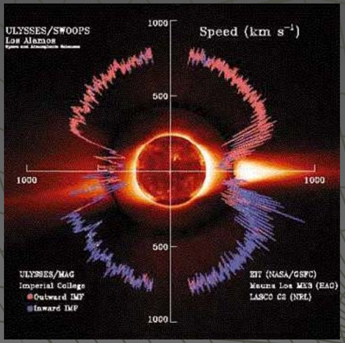


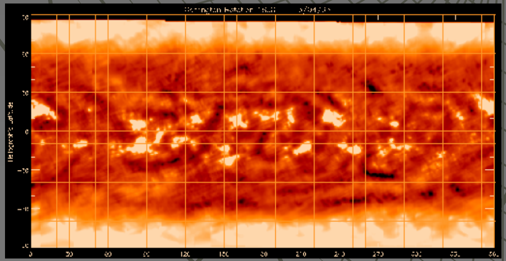
NoRH detection of an "EIT wave" at 17 GHz: possibly the signature of the expanding edge of a coronal mass ejection at the base of the corona.

White et al 2003

FASR Science (cont)

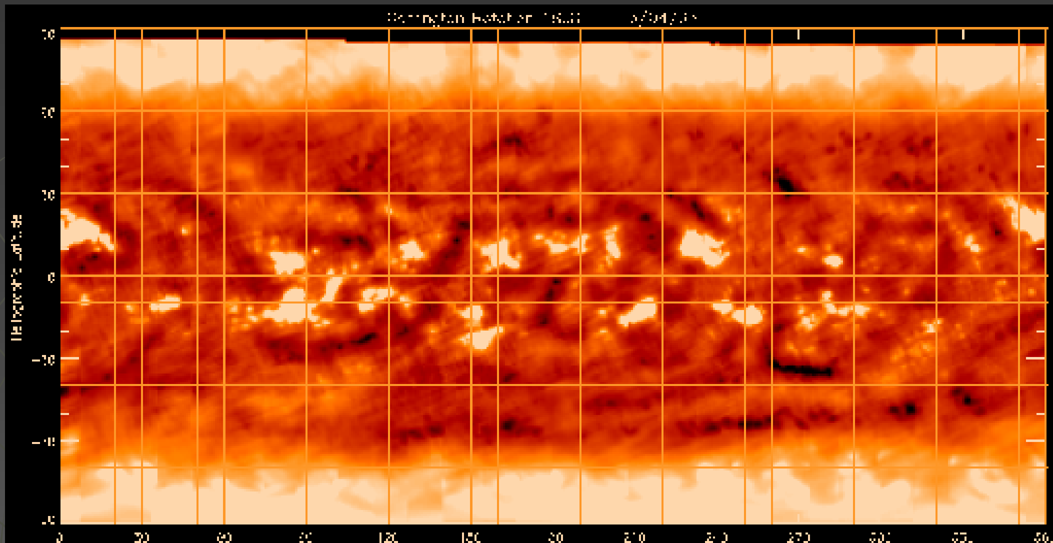




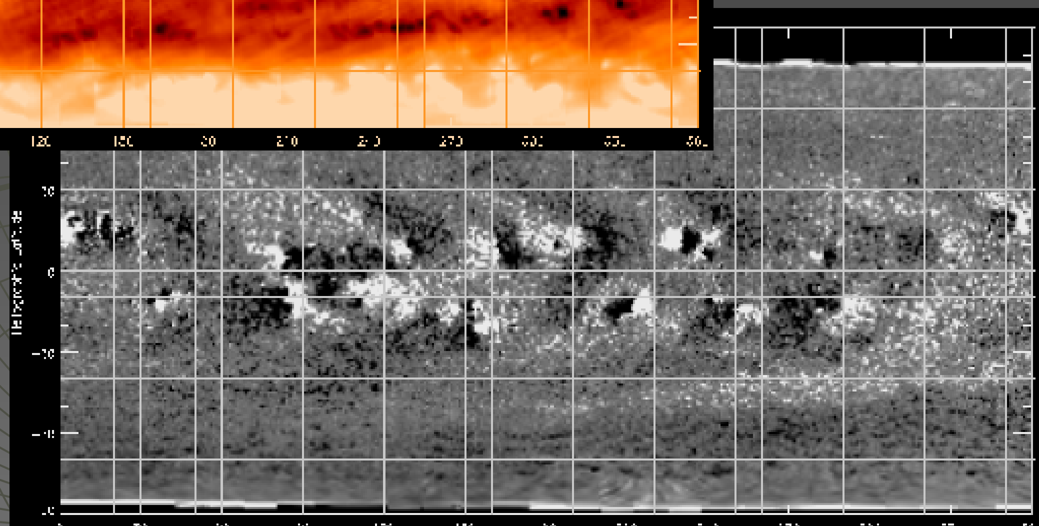


- The "thermal" solar atmosphere
  - Coronal heating - nanoflares
  - Thermodynamic structure & dynamics
  - Formation & structure of filaments
- Solar Wind
  - Birth in network
  - Coronal holes
  - Fast/slow wind streams
  - Turbulence and waves
- Synoptic studies
  - Radiative inputs to upper atmosphere
  - Global magnetic field/dynamo
  - Flare statistics

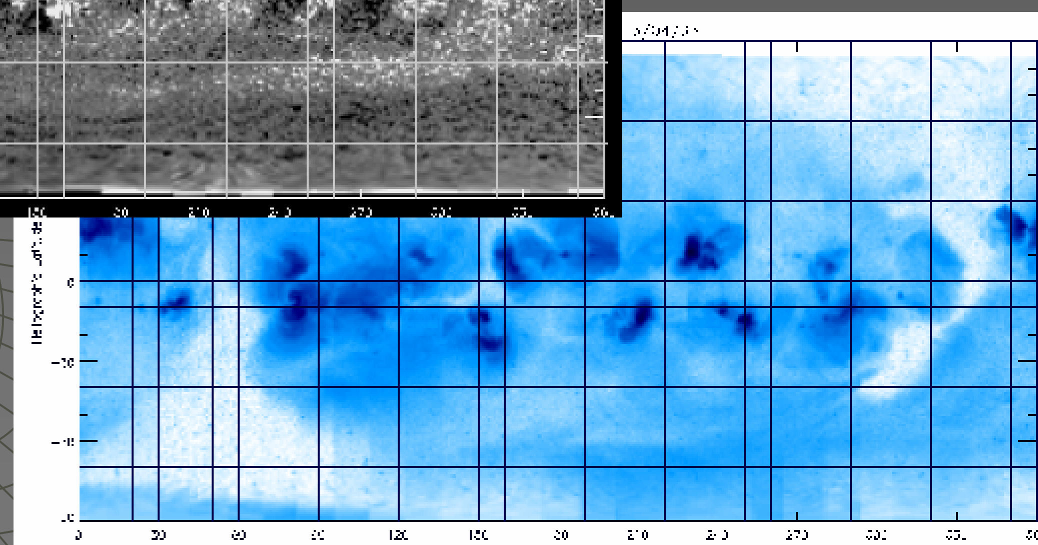
Synoptic studies



17 GHz



B gram



SXR

Data Management Issues

- Instrument monitor and control
- Data acquisition
- Data calibration
- Data selection/distillation
- Data reduction
- Data analysis
- Data dissemination
- Data archiving

Questions

Should we strive to satisfy all or most science requirements whenever observing?

Pros: simplifies operations

Cons: but will sufficient flexibility be built in to satisfy changing science requirements?

Should FASR support a GI program and support user-specified observing modes?

Pros: responsive to changing science requirements; more fully engages users

Cons: complicates operations

What about support of data analysis?

What suite of data products should be routinely produced?

For research needs?
For programmatic needs?

The data can take the form of raw visibility data to optimally deconvolved multi-dimensional data cubes: x,y,ν,t,S

Some users may wish the data to be presented in terms of maps of physical parameters: B, n_e, T

How should the data be disseminated?

Will the NVO/VSO be suitable vehicles?

Will the bandwidth be sufficient for most users?

Should alternatives be explored?

What sort of data calibration/reduction/analysis burden do we place on the user?

The idea of providing the user with calibrated image data and a suite of software tools for exploring/mining/modeling the data is appealing, but the option of going to the visibility data should always be available.

Which data must be permanently archived?

Data rates might be as much as 10 Tbytes/day, comparable with ALMA

The data could well be distilled by orders of magnitude (10-100 Gbyte) – i.e., throw away >99% of the data!

Danger: data selection criteria must be robust!