The Frequency Agile Solar Radiotelescope

FASR

...an overview by Kevin Urban...

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Black Belt Radio Astronomy ~~for lazy white belt astronomers~~ **for Everyone!**

First things first…

- Wow.
- An excellent example of how trailblazing can be done.
- JWST: > 8 [G$]

What is FASR?

- The straight talk: FASR is a solar-dedicated "broadband spectroscopic imager"
- Legend has it that FASR was born in 1995, but…
- …at least 3 strong Letters of Rec:
  - Decadal Survey of Astronomy + Astrophysics (2002)
  - Solar and Space Physics Survey Committee (2003)
  - New Worlds, New Horizons in Astronomy and Astrophysics (2010)

…and most recently:
- Kevin Urban's Radio Astronomy Final Project (2012)

FASR's Future Feats

- Major advances:
  - ultra-wide frequency coverage
  - high spectral resolution
  - outstanding image quality

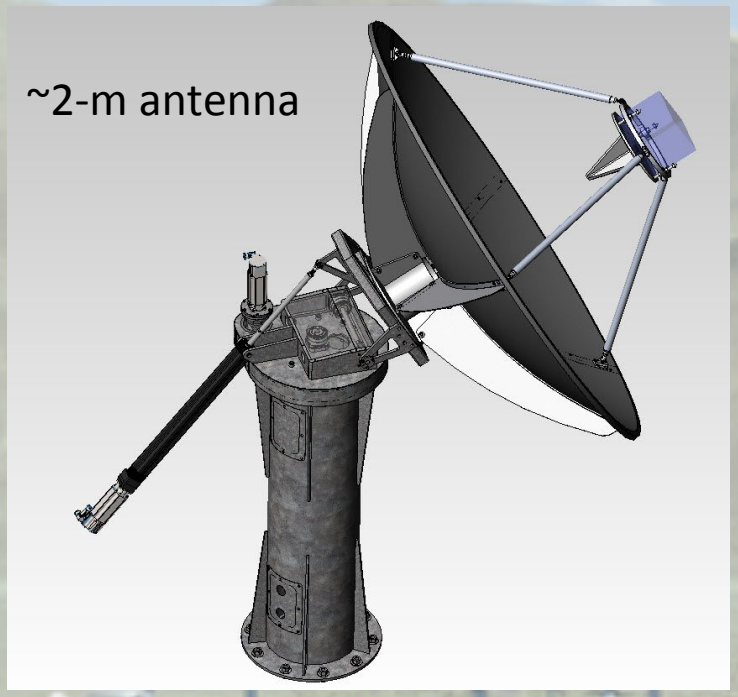
FASR measures the polarized BT spectrum (from 0.05-21[GHz]) along every line-of-sight to the sun --- and it only takes a second! (or as little as 20[ms])

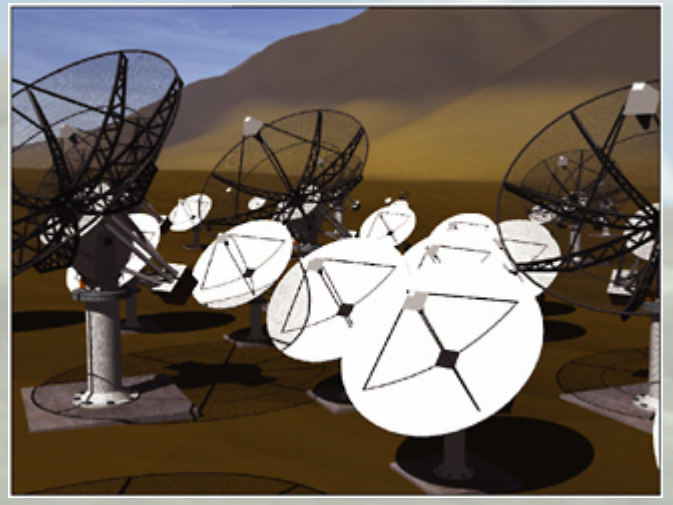
Probes middle chromosphere to outer reaches of Corona.

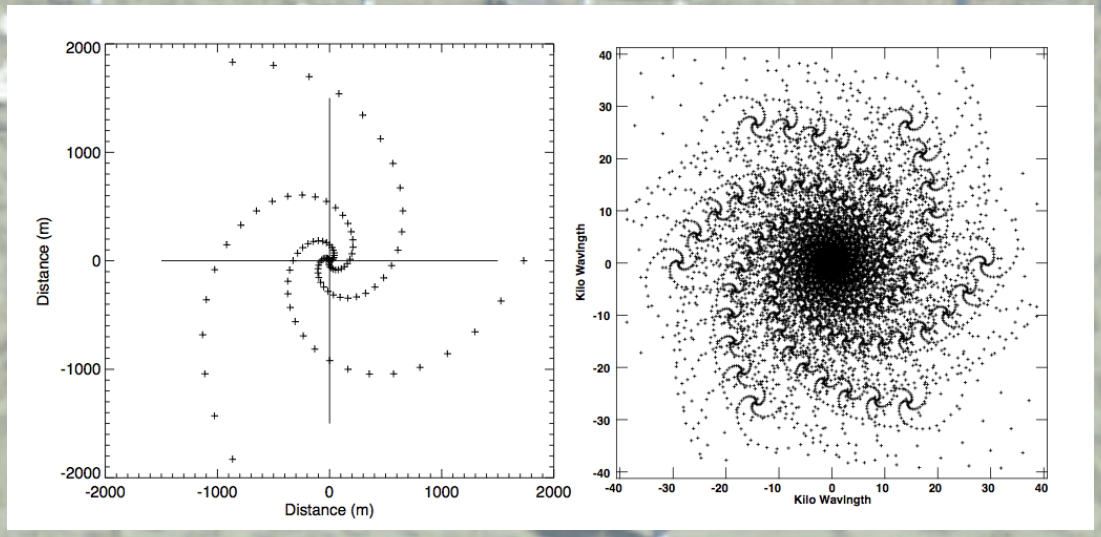
Panoramic view!

Angular resolution	$20/\nu_{GHz}$ arcsec
Frequency range	50 MHz – 21 GHz
Number data channels	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
Astrometry	1 arcsec
Flux calibration	<10% absolute 1% relative

~2-m antenna






2000
1000
0
-1000
-2000
Distance (m)
-2000
-1000
0
1000
2000
Distance (m)
40
30
20
10
0
-10
-20
-30
-40
Kilo Wavlngth
-40
-30
-20
-10
0
10
20
30
40
Kilo Wavlngth

Baselines and Beam sizes

- FASR-A (2-21[GHz]): ~100 antennas
  → Sum(1:99) = 4950 baselines
- FASR-B (0.3-2.5[GHz]): ~70 antennas
  → Sum(1:69) = 2415 baselines
- FASR-C (50 – 350 [MHz]): ~50 LPDA's
  → Sum(1:49) = 1225

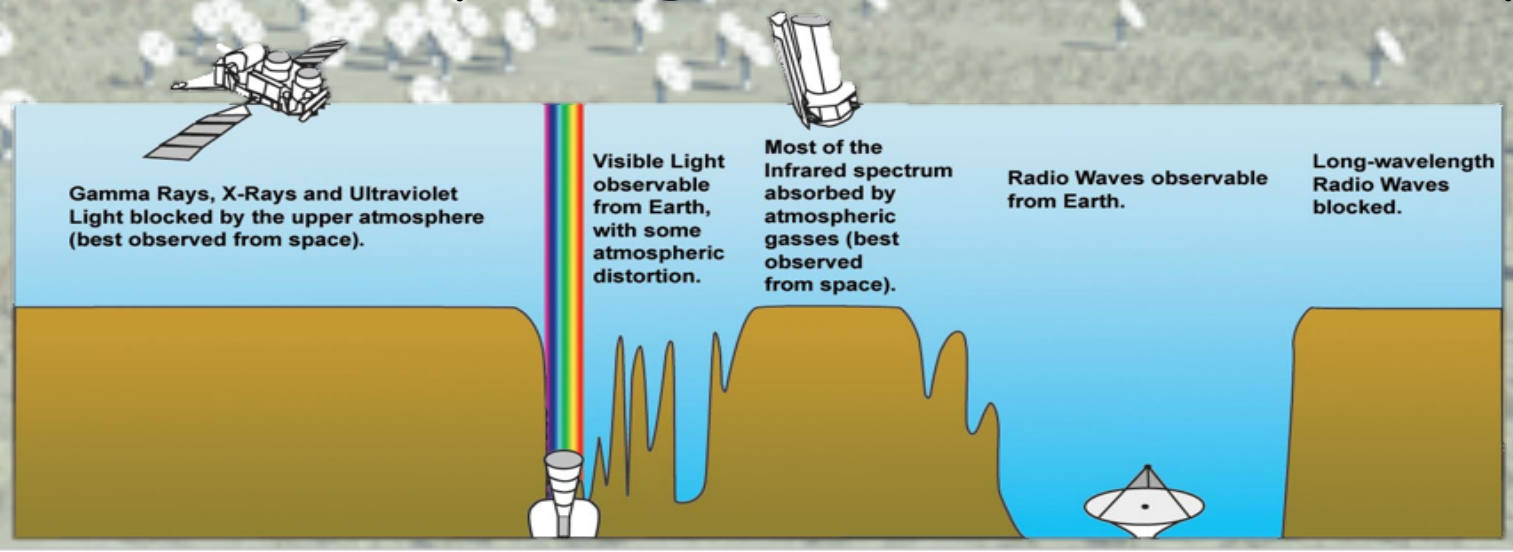
That is g.e. 8590 baselines

Setting the Scene

Why Radio Astronomy?

--because we can!

--Added plus: radio emissions encode quantitative physical info about conditions at the source (temp, mag fld, electron density, etc)

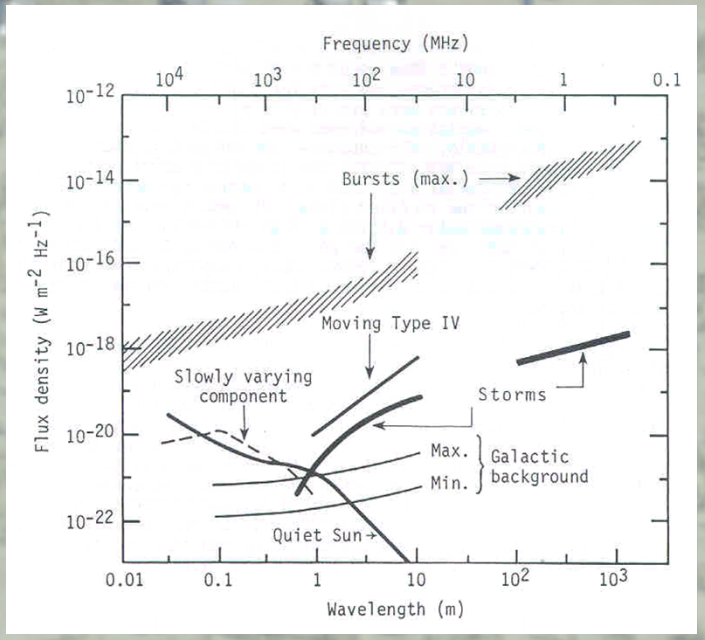


Radio-observing the Sun

- Quick evolution and impulsive events
- Large dynamic range
- The sun dominates the system temp
- No need for large telescopes:
  - » SAVINGS $$$!!!

$$P_{tot} = P_a + P_{sys} => T_{tot} = T_a + T_{sys}$$

$$T_{sys} = T_{bg} + T_{sky} + T_{spill} + T_{loss} + T_{cal} + T_{rx}$$

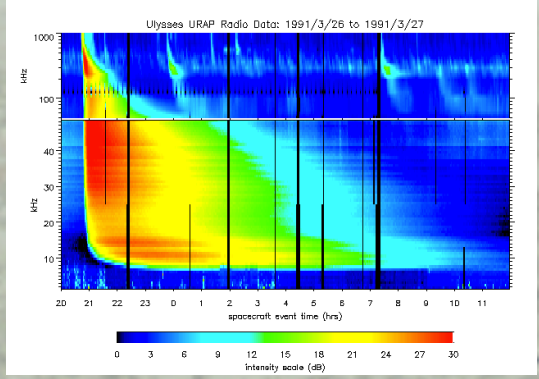


A world without FASR…

- 1940s – Radio Astronomy says, "Hello World." (kinetic temp. of solar corona is measured)
- Two plot lines developed and became estranged: (i) Spectroscopic Observations
  (ii) Imaging Observations

Radio Spectroscopy

- Traditionally pursued at decimeter, meter, and decameter λ's (recently cm λ's have joined the club)
- Radio bursts galore!
- Advantages
- Disadvantages

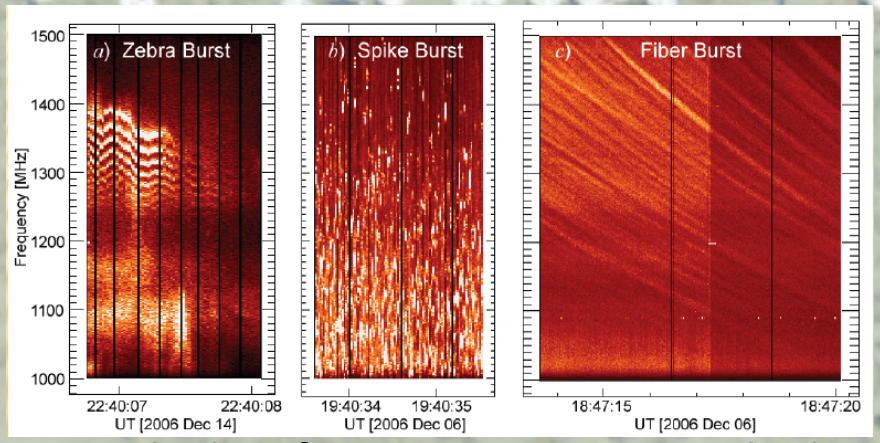


Current State of the Art: Owens Valley Solar Array

Five 2-m antennas
Two 27-m antennas

Expansion:
Move the 2-m antennas
Upgrade the 27-m antennas
Add 8 more antennas

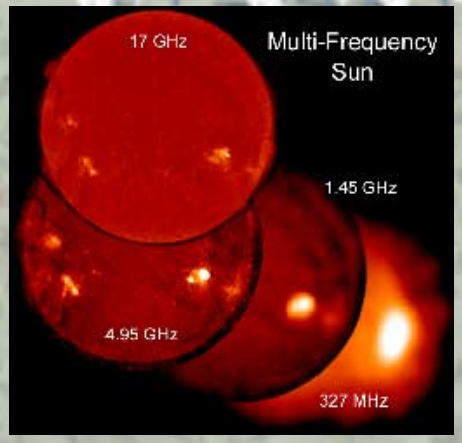
Owens Valley Solar Array Expansion is ~10% of the full FASR project (in size and cost)



Sample data from FASR-System Testbed

Radio Imaging

- Prevailing technique: Fourier Synthesis
- Advantages
- Disadvantages
- Blackbelt Radio astronomers



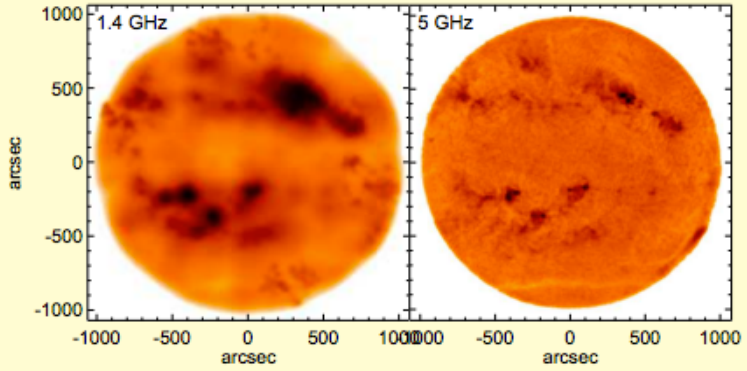
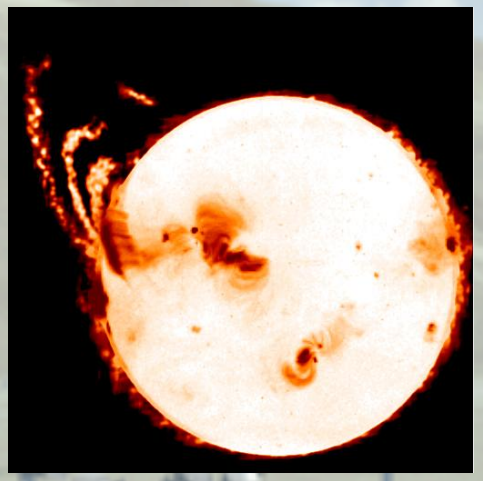
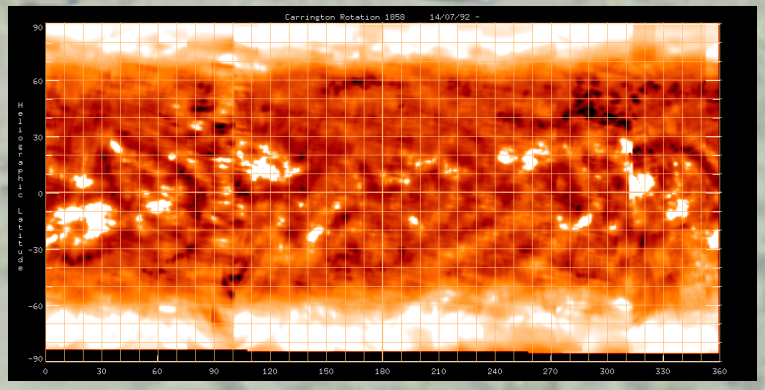


Fig. 1: VLA images of the Sun. 12-hour full disk radio images of the Sun at (left) 1.4 GHz and (right) 4.6 GHz made with the Very Large Array. The 4.6 GHz image is a 26-□eld mosaic. These are essentially the best microwave images of the Sun that can be made at present: *it will take FASR a few seconds to make snapshot images with vastly better resolution and image quality than these all-day maps.*

Current State of the Art: Nobeyama Radioheliograph



- **84** parabolic antennas with 80-cm diameter
  Array: 490 m EW, 220 m NS
- Frequency: (1) 17 [GHz] (Right and left circular polarization),
  (2) 34 [GHz] (only intensity)
- Field of view: Solar full disk
- Spatial resolution: 10 arcsec (17GHz), 5 arcsec (34GHz)
- Temporal resolution: 0.1 [s] (Event), 1 sec (Steady)



Fourier Synthesis and the Technical "black belt" stuff!

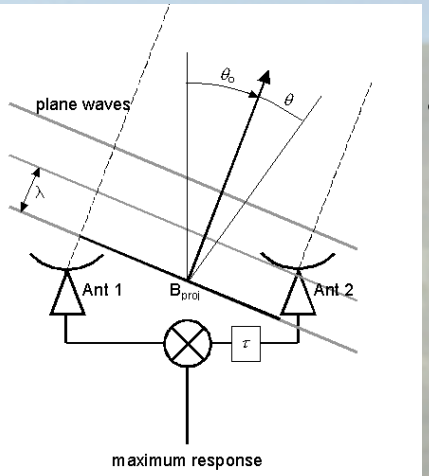


Figure 3: Geometry of an interferometer baseline where a delay t is inserted in one antenna, in order to steer the phase center to a direction q_o from the vertical I.

CORRELATION

INTERFEROMETRY

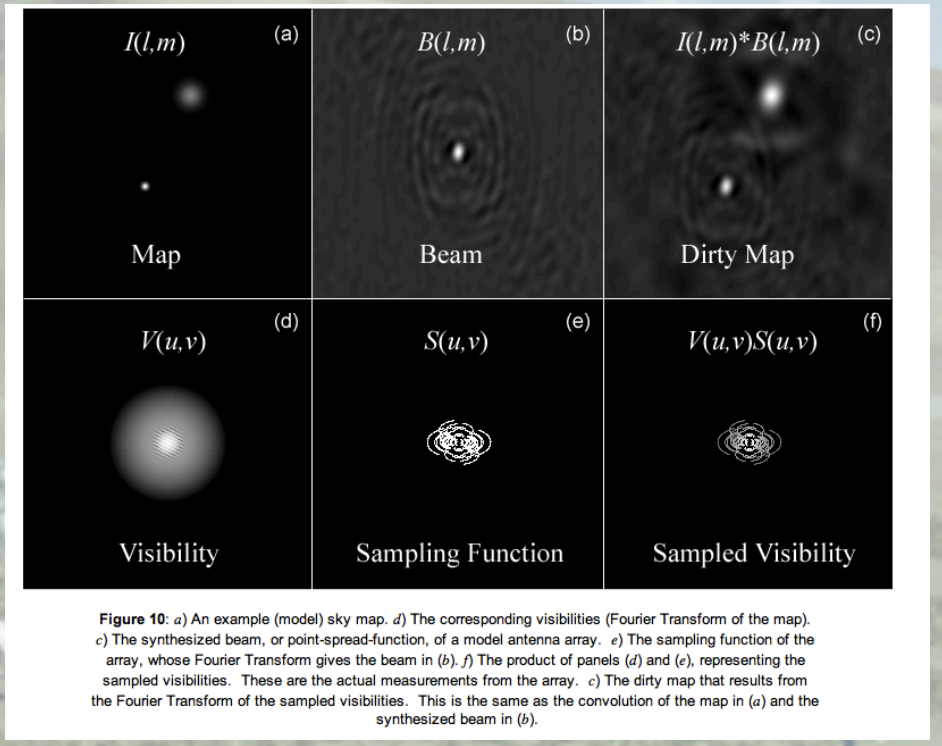


Figure 10: *a*) An example (model) sky map. *d*) The corresponding visibilities (Fourier Transform of the map). *c*) The synthesized beam, or point-spread-function, of a model antenna array. *e*) The sampling function of the array, whose Fourier Transform gives the beam in (*b*). *f*) The product of panels (*d*) and (*e*), representing the sampled visibilities. These are the actual measurements from the array. *c*) The dirty map that results from the Fourier Transform of the sampled visibilities. This is the same as the convolution of the map in (*a*) and the synthesized beam in (*b*).

CLEAN

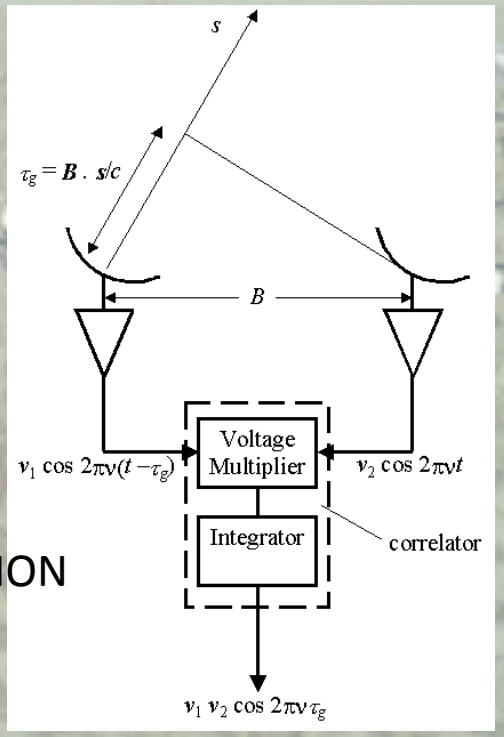


IMAGE RESTORATION

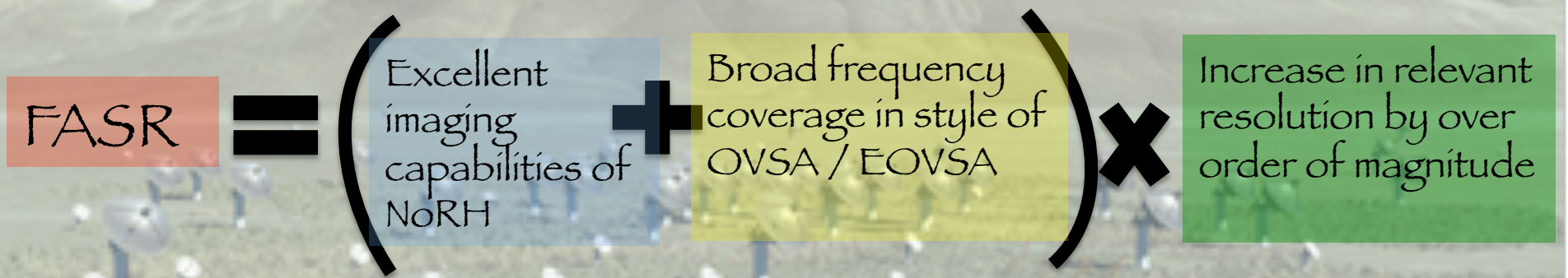
MEM

EARTH ROTATION SYNTHESIS

DECONVOLUTION

Why not both? And why not for everyone?

- FASR is that awesome twist at the end of the movie where the plotlines converge:



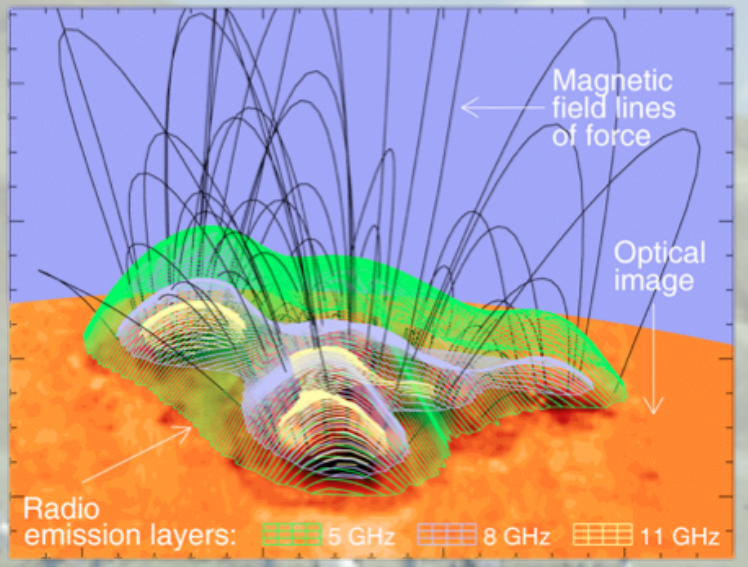
- Dojo master, dark lord, triple-black-belt radio astronomer powers – not just for Dojo master, dark-lord, triple-black-belt radio astronomers anymore!

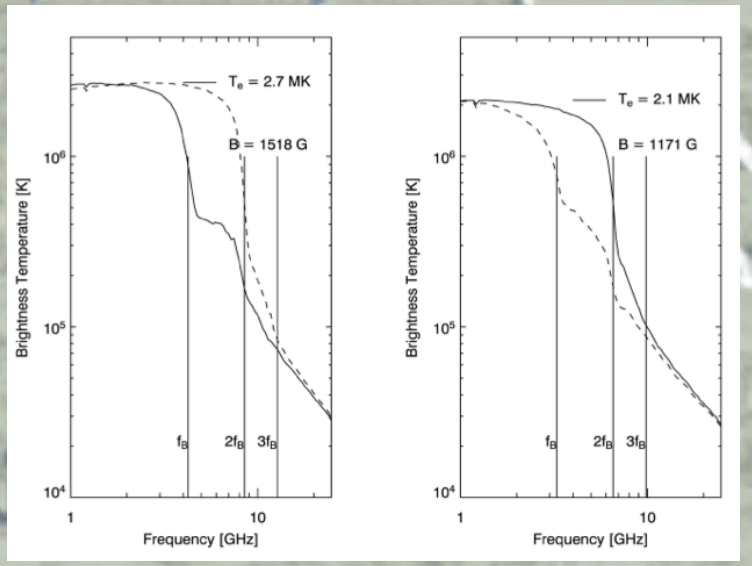
FASR Science

- Nature + evolution of coronal Bflds
- Physics of Solar Flares
- Drivers of Space Weather
- The Quiet Sun
- Synoptic Studies

Coronal Magnetic Fields

- Need: quantitative knowledge
- Why: active regions, impulsive energy release, particle accelerations, heating, ….
- Best available: radio observations – the "gyroresonance method"
  - effective from ~120-2000 [G]
  - $\nu = s\nu_B = 2.8 \times 10^6 sB$, [Hz]
  - CAT-scan-like view of nested isogauss surfaces





Other techniques for coronal fields

- Polarization measurements of free-free emission (B_L of quiet corona)
- Radio bursts at meter/decimeter λ's (middle corona)
- Gyrosynchrotron emission (flaring loops, CME's)
- Mode-coupling (further constrain on coronal field)

- -

FASR will provide the spatial, temporal, and spectral resolution necessary to tap the true power of these techniques.

Flare Physics

- Outstanding problems:
  - Magnetic energy release (How?)
  - Particle acceleration (How?)
  - Particle injection (Where?)
  - Particle transport (Where? How?)
  - 3D Magnetic Reconnection

Relevant diagnostic: Gyrosynchrton emission

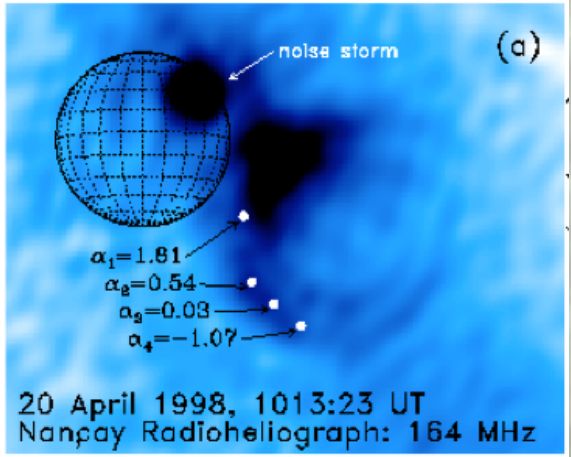
- Illuminates magnetic coronal loops which energetic e's have access to

FASR's Contribution

- Will image entire Sun at high temporal resolution
- Quantitative measurements of magnetic fields in flaring source
- Will probe location, topology, and evolution of 3D magnetic reconection
- Electron distribution
- Rule out or validate competing flare theories and heating theories

Space Weather

…because satellites are expensive and "space weather" is a great buzz word.

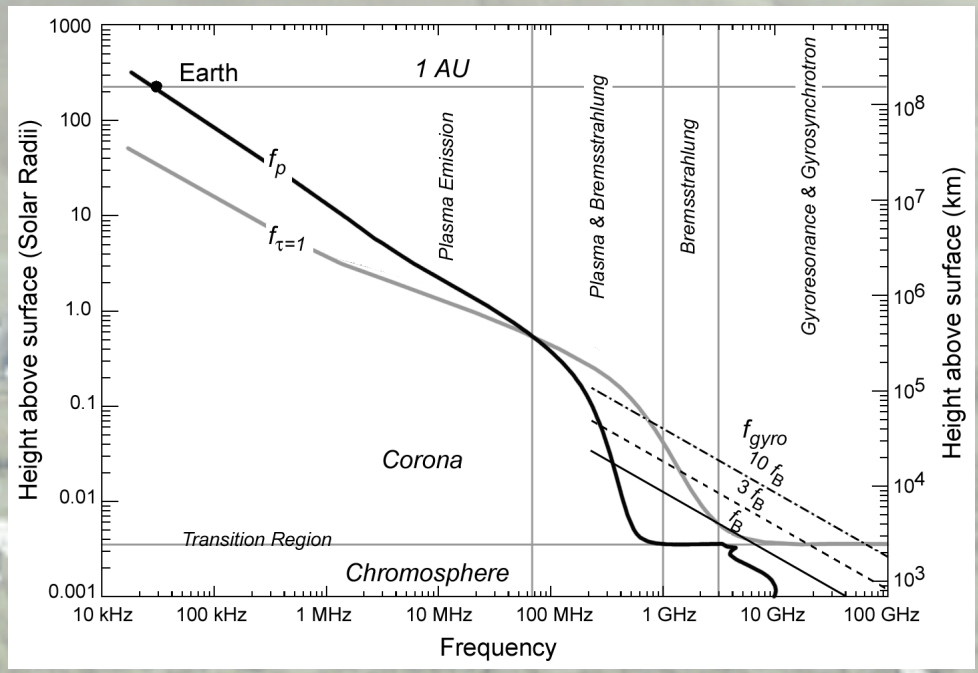


Seriously though: CME's

Important new insights on mysterious connections

The Quiet Sun

- "Quiet" kind of means "not near active region" – still fairly dynamic itself though
- Diagnostic tool: free-free diagnostics



$$\nu_p = 9(n_e)^{1/2}, \quad [\text{kHz}]$$

FASR's Contribution

- Multifreq imaging → more CAT-Scans
- Connection: chromosphere + solar wind
- Quiet sun dynamics in unprecedented detail
- Refutation and validation of various coronal heating models/ideas

Summary

- Mature, recommended, well-developed
- Radio diagnostic tools have been developed have been limited in their application
- FASR is ready to go!

References

- The Frequency Agile Solar Radiotelescope: A white paper for "A Decadal Strategy in Solar and Space Physics." D. E. Gary, T. S. Bastian, G. J. Hurford, S. M. White.

- Solar and Space Weather Radiophysics:
  Ch3: The Frequency Agile Solar Radiotelescope. T. S. Bastian
  Ch4: Radio Spectral Diagnostics. D. E. Gary.

- New Frontiers in Solar Physics: Broadband Imaging Spectroscopy with the Frequency Agile Solar Radiotelescope.
  T. S. Bastian, D. E. Gary, S. M. White, G. J. Hurford

- Report of the Panel on Radio, Millimeter, and Submillimeter Astronomy from the Ground (2010)

- Nobeyama: http://solar.nro.nao.ac.jp/norh/
- RA Course: http://web.njit.edu/~gary/728/
- FASR: www.fasr.org
- OVSA: www.ovsa.njit.edu