Toward a Next Generation Radioheliograph

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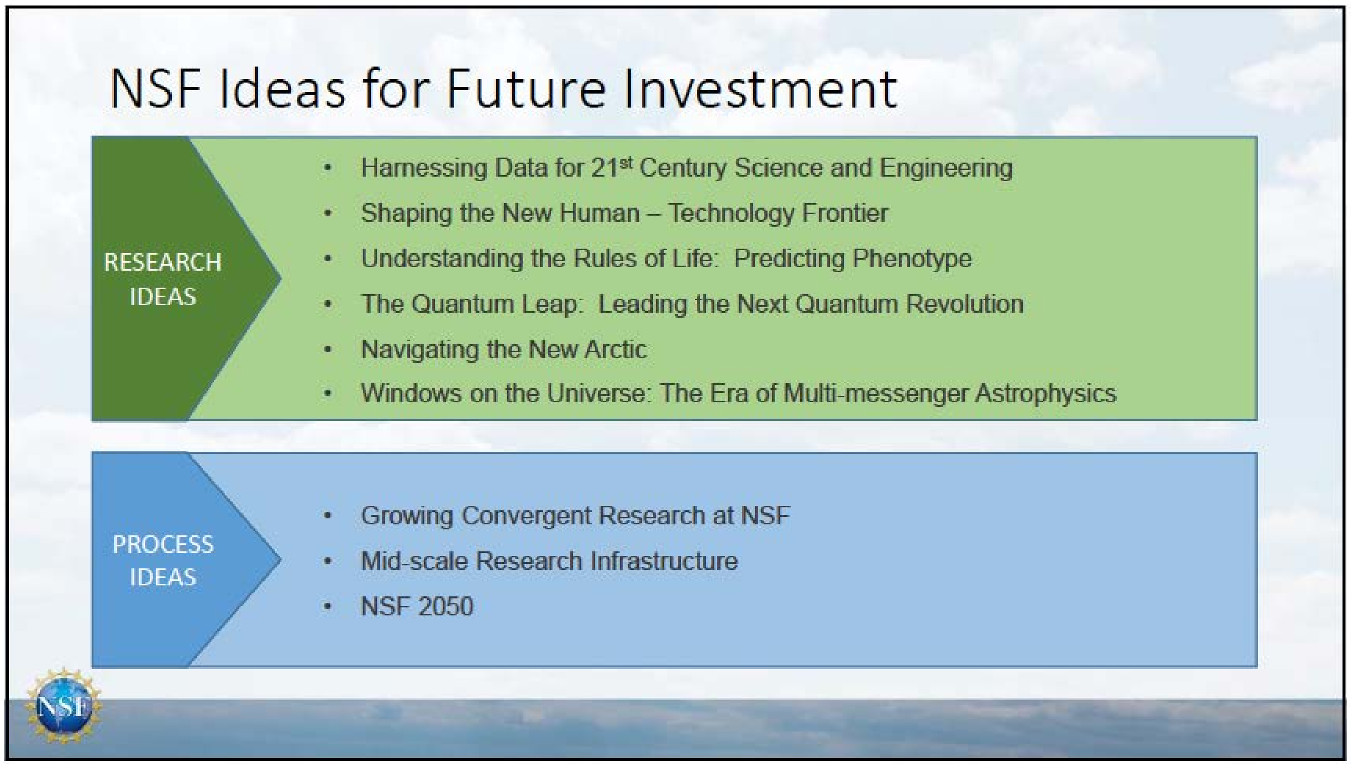
BACKGROUND

- The solar and space physics communities have tried for many years to construct a state-of-the-art radioheliograph designed to perform **ultra-broadband imaging spectroscopy** spanning 10s of MHz to 10s of GHz.
- A concept – FASR - was developed in the 2000s that was vetted by both the ***Astronomy & Astrophysics*** and the ***Solar & Space Physics*** decadal surveys. FASR was always at or near the top of the recommendations for ground based instrumentation.
- The FASR concept was sufficiently mature that it underwent a "cost and technical evaluation" (CATE) analysis. It fits in the mid-scale range and was declared "doable today" with only modest risk.
- The need for a mid-scale line is widely recognized and merited its own recommendation in both the A&A and S&SP decadals. NSF AST has opened the MSIP wedge as a result.
- Nevertheless, funding has been problematic – solar falls between NSF AST and AGS.

RECENT DEVELOPMENTS

- NSF AGS GS has conducted a portfolio review as a means of freeing up resources to develop new initiatives
- NSF Director Cordova has called out support for mid-scale infra-structure as one of 9 “big ideas” to emerge from strategic planning



RECENT DEVELOPMENTS

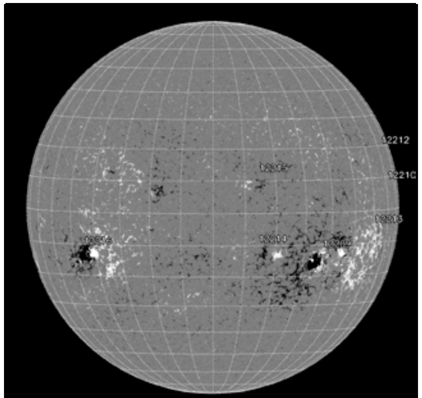
- In Oct 2015 the OSTP released the ***National Space Weather Strategy*** and the ***Space Weather Action Plan*** developed by the multiagency *Space Weather Operations, Research, and Mitigation* task force
  - Among the six strategic goals in the NSWS:
    - Improve assessment, modeling, and predictions of impacts on critical infrastructure
      - for which the SWAP includes real time observations as a goal
    - Improve space-weather services through advanced understanding and forecasting
      - for which the SWAP includes establishing and sustaining baseline observational capacities
- The *"Space Weather Research and Forecasting Act "* bill (S.2817) introduced to the Senate in April 2016. Charges NASA and NSF with providing "increased understanding of the fundamental physics of the Sun-Earth system"

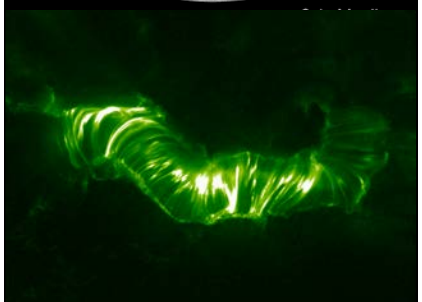
A NEXT GENERATION RADIOHELIOGRAPH

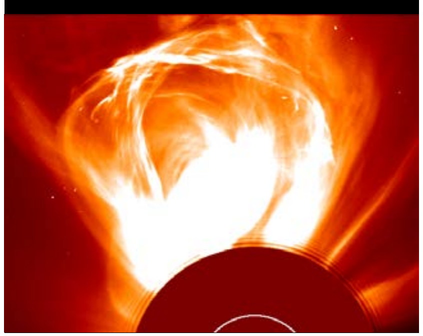
- The **scientific** need for a state-of-the-art radioheliograph remains as strong as ever. Moreover, exciting new and complementary instruments are online or soon will be:
  - Daniel K Inouye Solar Telescope (DKIST)
  - Atacama Large Millimeter/submillimeter Array (ALMA)
  - Solar Probe Plus (SPP - NASA)
  - Solar Orbiter (SO – ESA)
- In addition, such an instrument would very likely play an important **operational** role in the nation’s space weather infrastructure as a facility that provides wholly unique data products for forecasting and now-casting purposes (e.g., Earth-directed CMEs)

It is time to update the design and costs of a next generation radio-heliograph in light of recent scientific developments, possible programmatic changes at NSF, and national imperatives.

SCIENCE

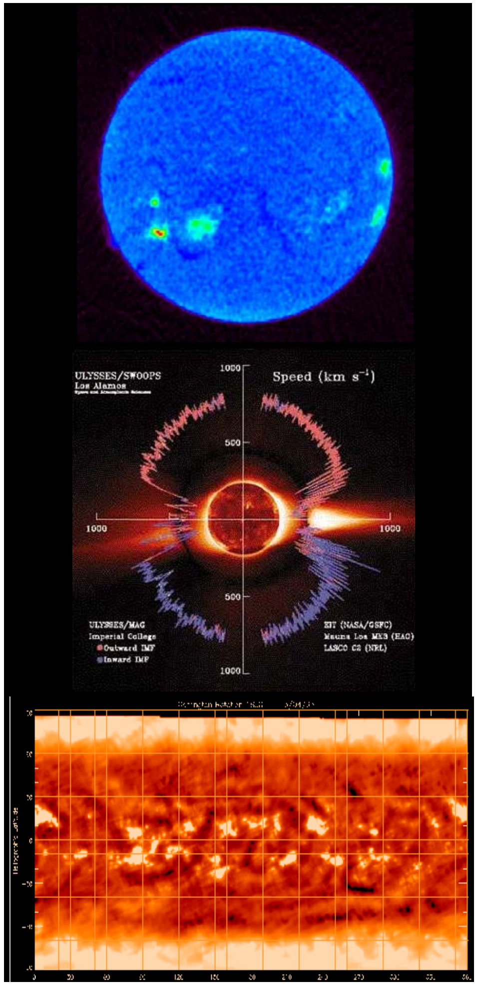






- Coronal Magnetic Fields
  - Coronal magnetography
  - Spatiotemporal evolution of fields
  - Role of electric currents in corona
  - Coronal seismology
- High energy solar physics
  - Magnetic energy release
  - Plasma heating and dynamics
  - Electron acceleration and transport
  - Origin of SEPs
- Drivers of Space Weather
  - Birth & acceleration of CMEs
  - Prominence eruptions
  - Origin of SEPs
  - Fast solar wind streams

SCIENCE



- 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

FASR SPECS

- Reference instrument
- Cost $68.5M (FY09 $)
- M&O $3M

Assume

- "monomode" observing
- Pipeline processing
- Users interact with data archive only

Design emphasized maintainability and reliability

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

TECHNICAL & SCIENTIFIC PoC

Expanded Owens Valley Solar Array

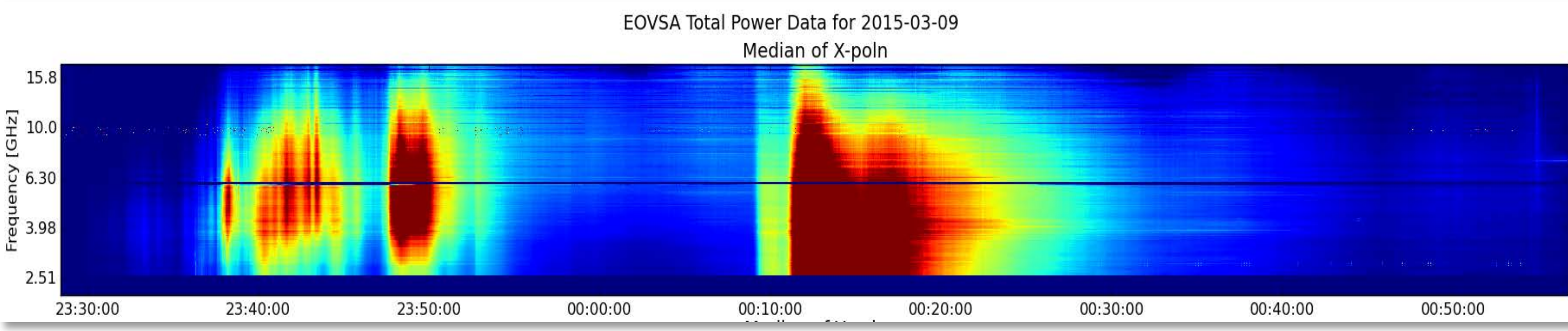
D. E. Gary (PI)

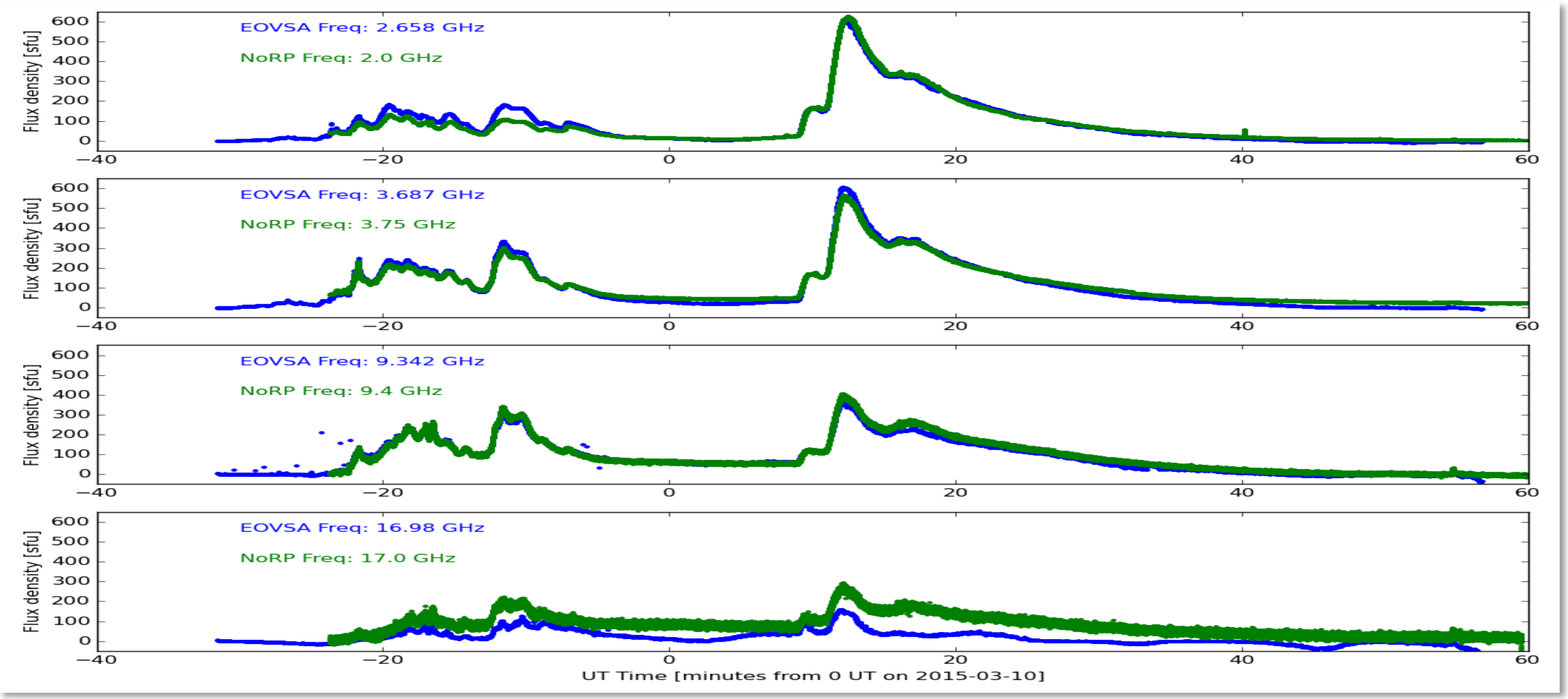
Central array dishes tracking the Sun. EOVSA has 13 such antennas, operating at 2.5-18 GHz.

OVSA Upgrade Specifications

Frequency range	2.5-18 GHz
Number of data channels	2 (dual polarization)
IF bandwidth	400 MHz per channel
Frequency resolution	Raw: 122 kHz (4096 spectral channels) Science: ~ 40 MHz
Time resolution	Sample time: 20 ms Full Sweep: 680 ms
Polarization	Full Stokes (IQUV)
Number correlator inputs per data channel	16
Number and type of antennas	Five 2-m equatorial Eight 2-m azel Two 27-m equatorial (night-time and cal. only)
Angular resolution	$57''/\nu_{GHz} \times 51''/\nu_{GHz}$
Array size	1.08 km EW x 1.22 km NS

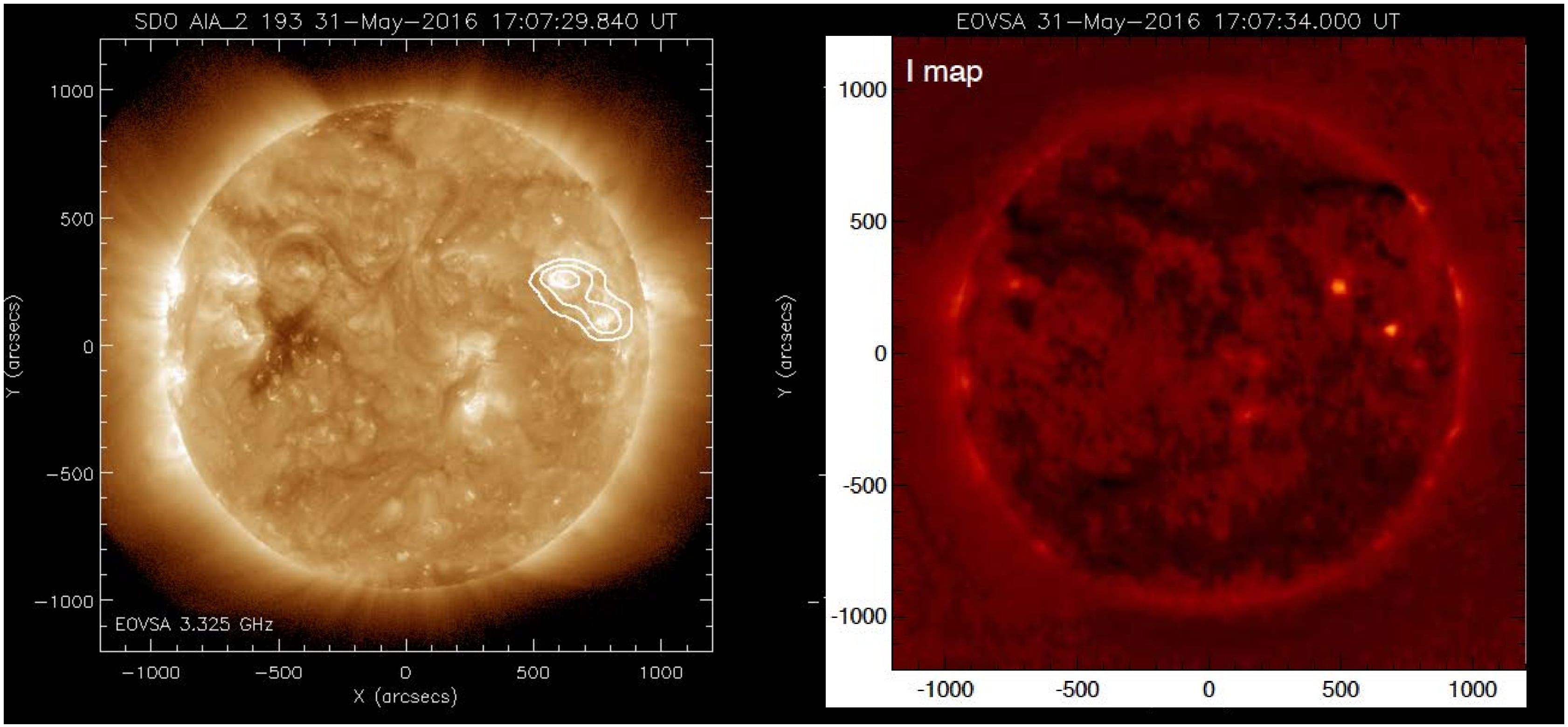
EVENT COMPARISON WITH NoRP





FIRST LIGHT MAP AT 3.325 GHZ

2016 May 31, 9 antennas



SOLAR SCIENCE WITH THE JVLA

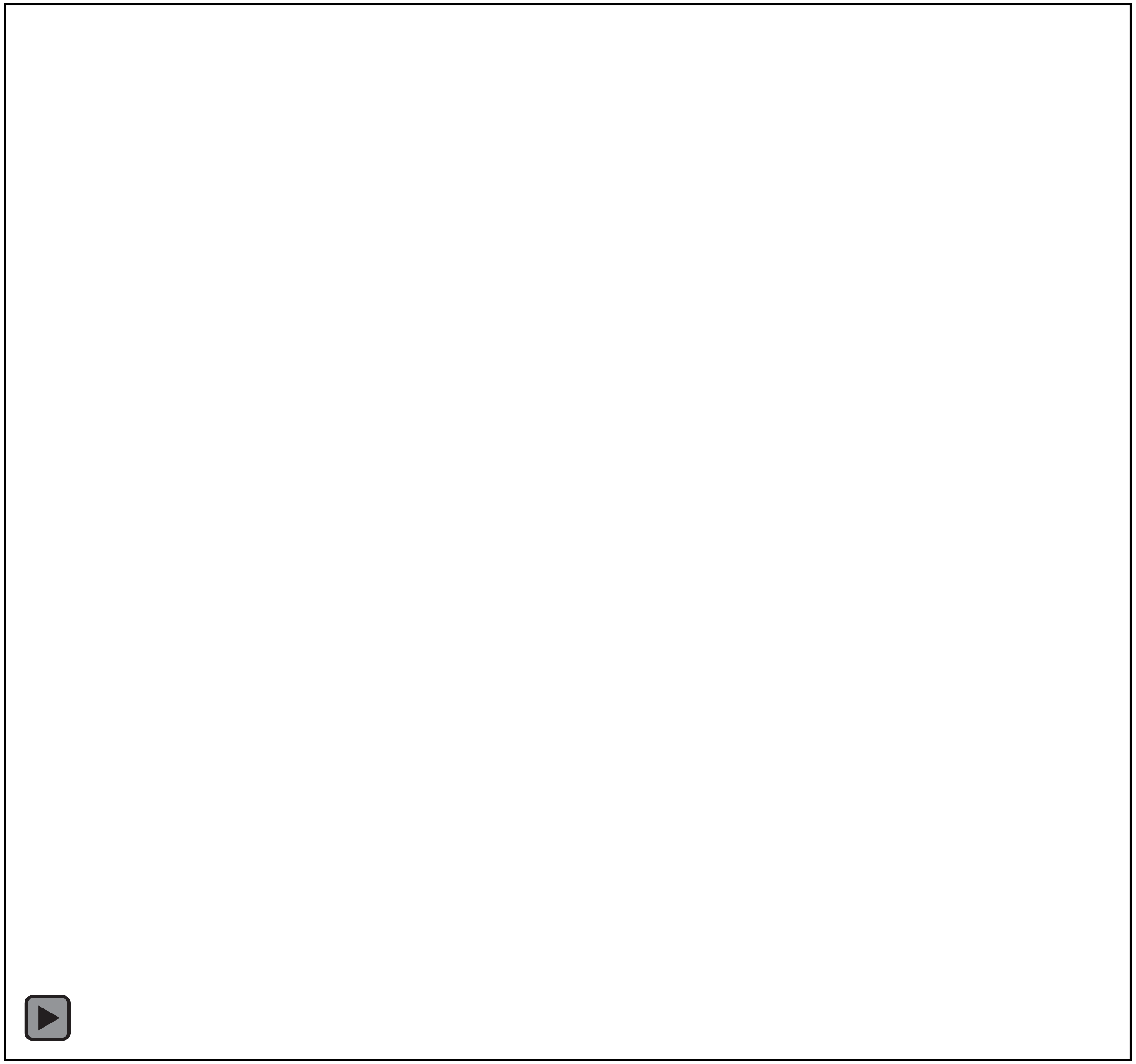
The VLA was substantially upgraded and re-dedicated. It is essentially a new instrument designed to study cosmic radio emission from 1-50 GHz.

Its capabilities include:

- New broadband receivers
  - **1-2 GHz**
  - **2-4 GHz**
  - **4-8 GHz**
  - **8-12 GHz**
  - 12-18 GHz
  - 18-26 GHz
  - 26-40 GHz
  - 40-50 GHz
- Optical fiber data transmission
- A powerful new correlator:
  - up to 2 x 64 independently tunable sub-bands
  - up to 16384 frequency channels
  - short integration times (10s of msec)
  - full Stokes polarimetry

JVLA capabilities provide an ideal testbed for certain kinds of demonstrator science.

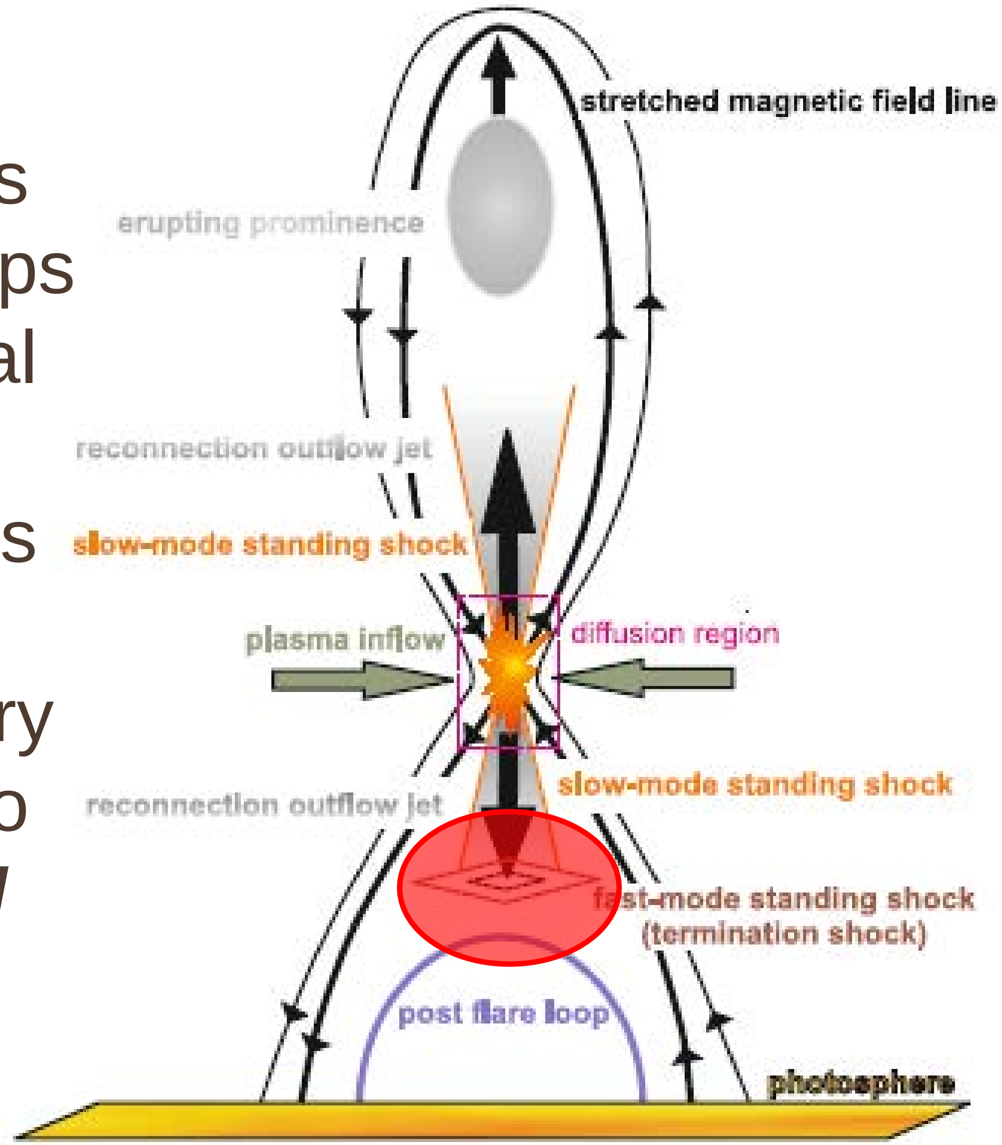
EXAMPLE: ERUPTING FLARE WITH CME



Chen + 2014

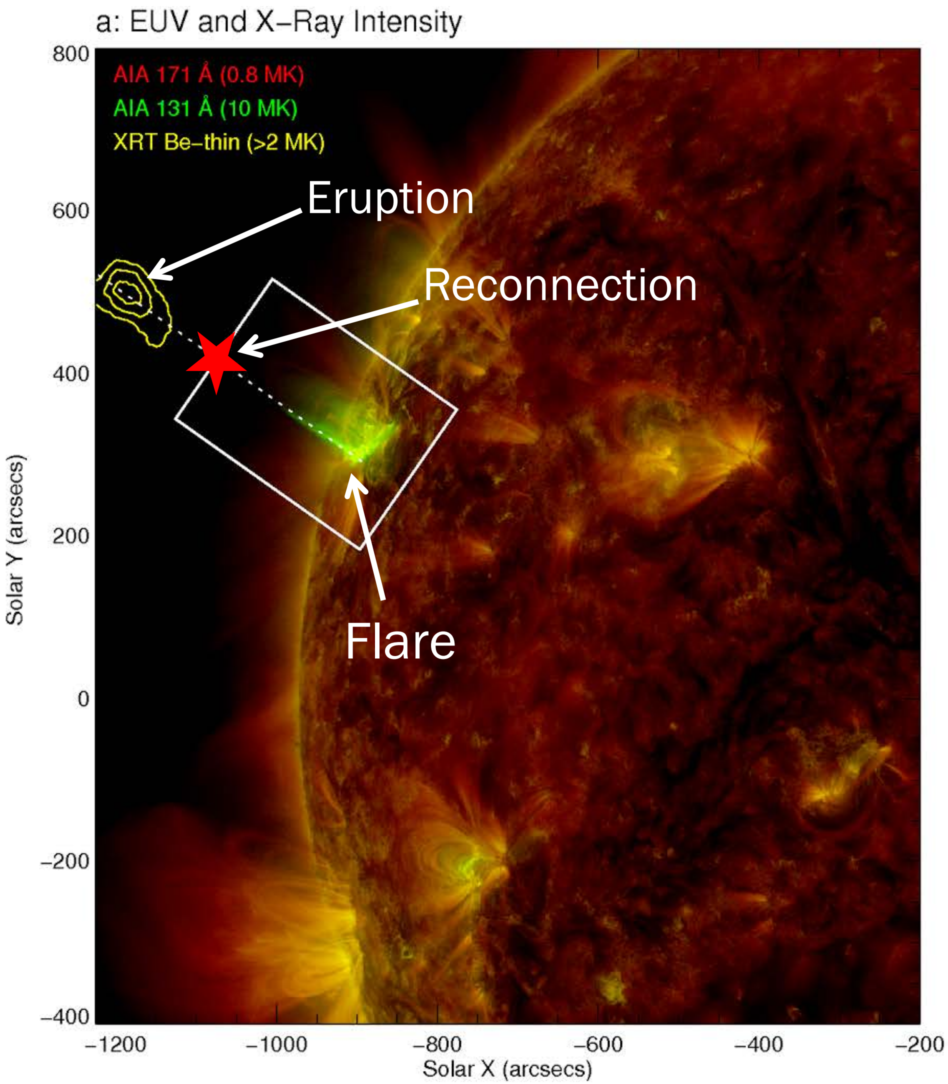
TERMINATION SHOCK IN SOLAR FLARE

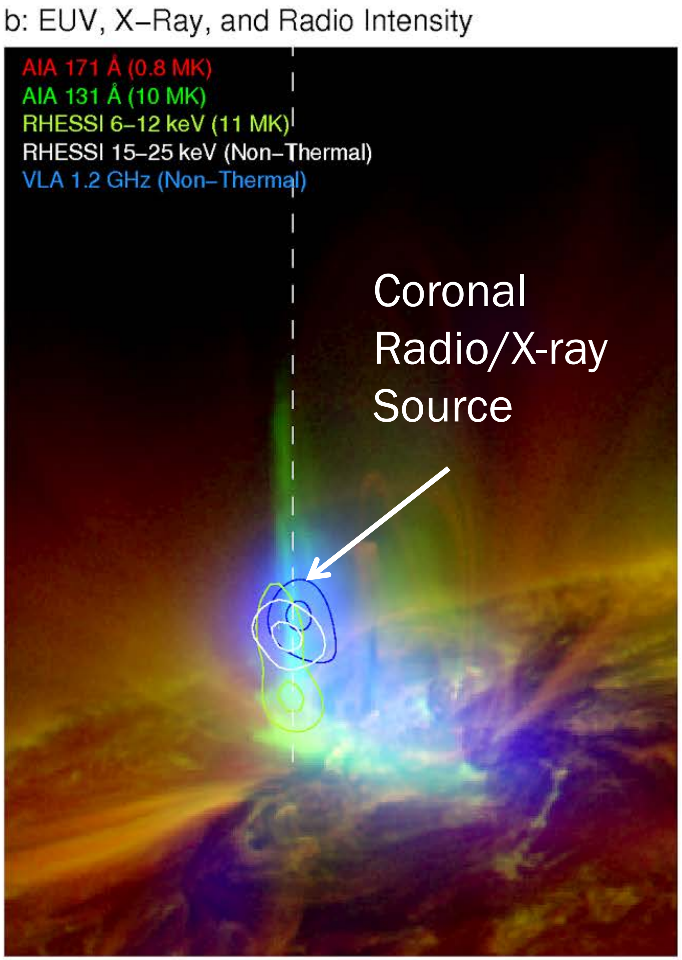
- Reconnection outflows colliding on dense loops
- Predicted by numerical simulations
- Important candidate as **particle accelerator**
- However, received very limited attention due to sparse ***observational evidence***



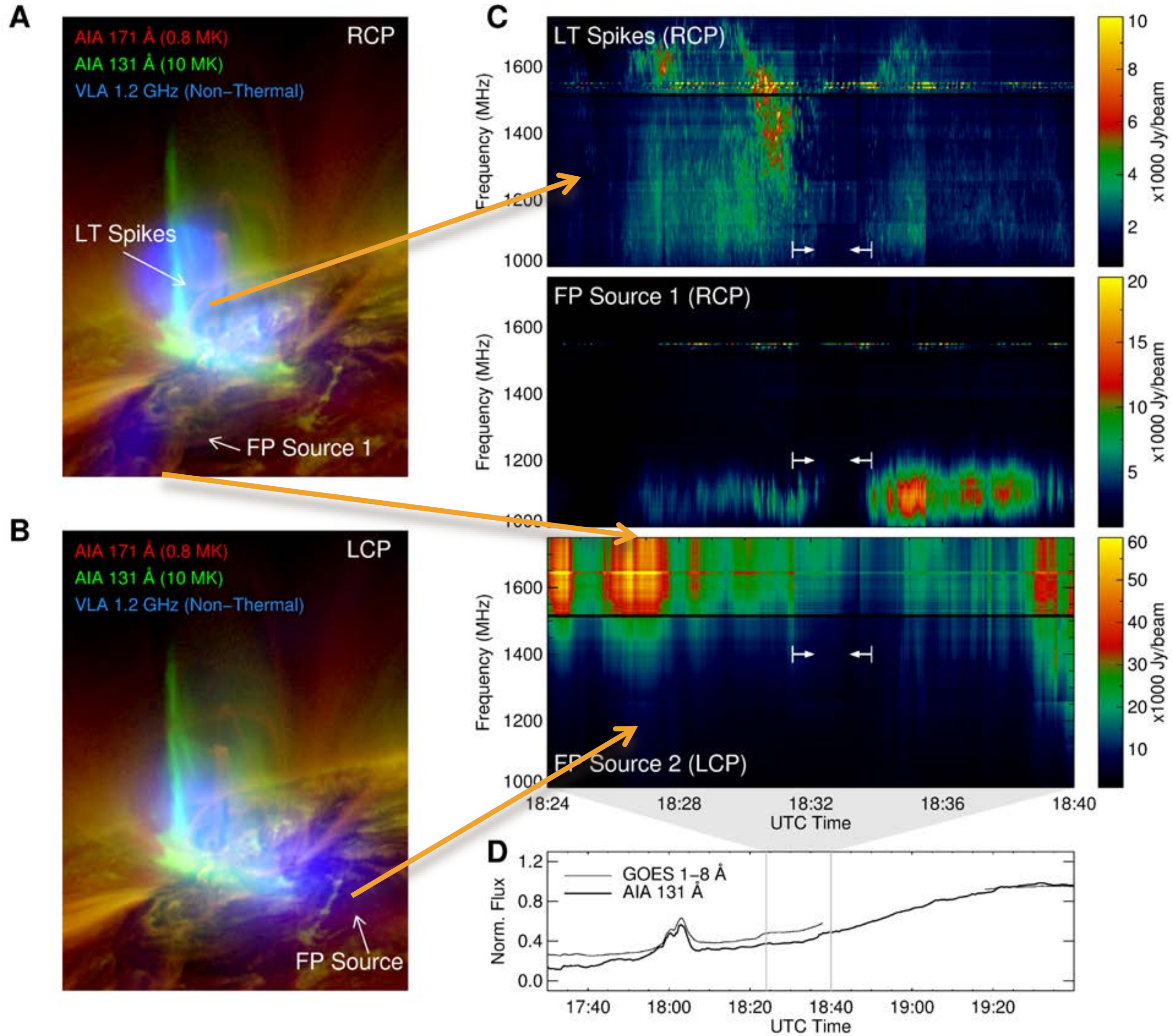
From Mann et al. 2009

CORONAL RADIO/HXR SOURCE





RADIO IMAGING SPECTROSCOPY

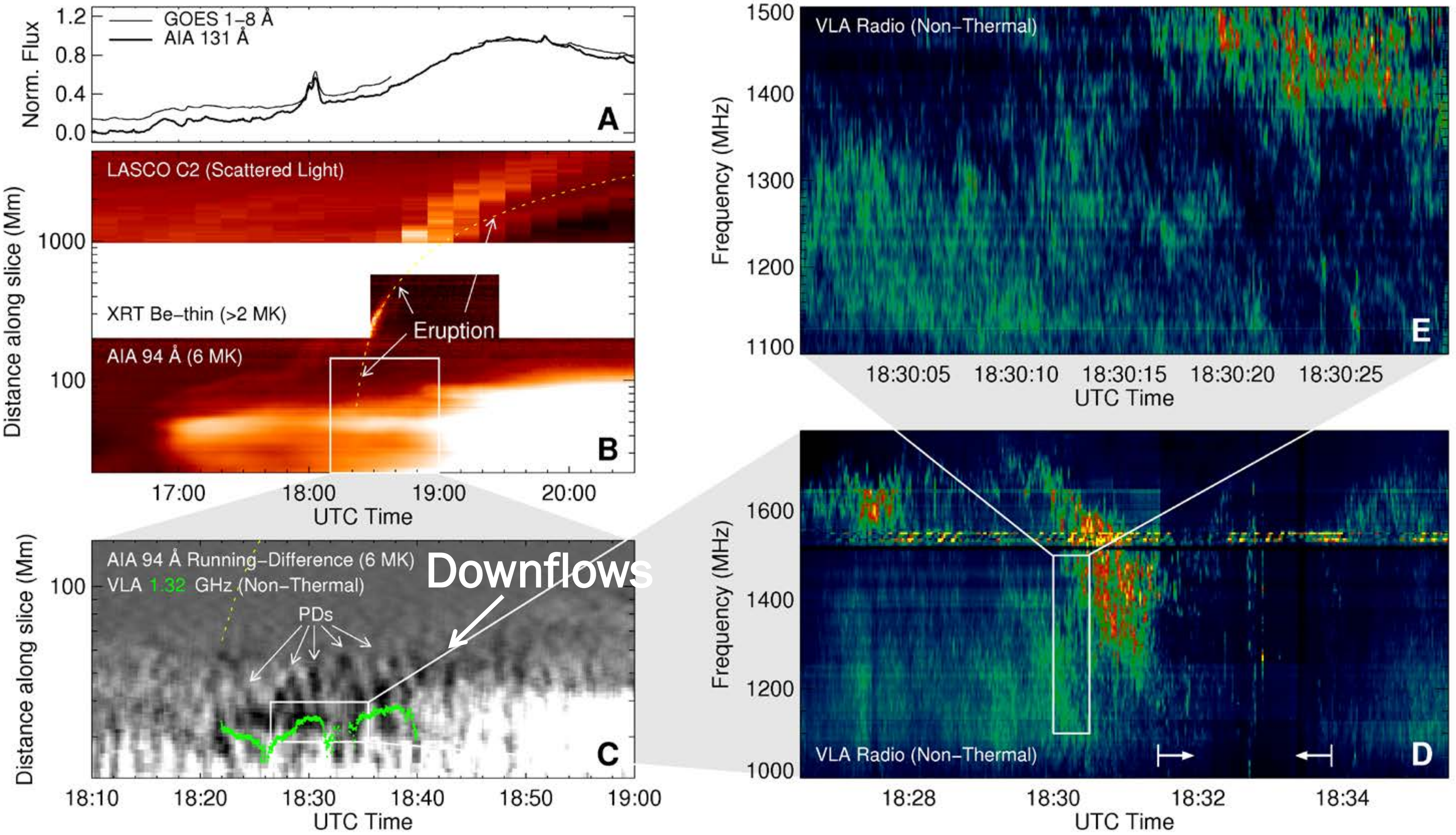


Coronal Source

S Footpoint Source

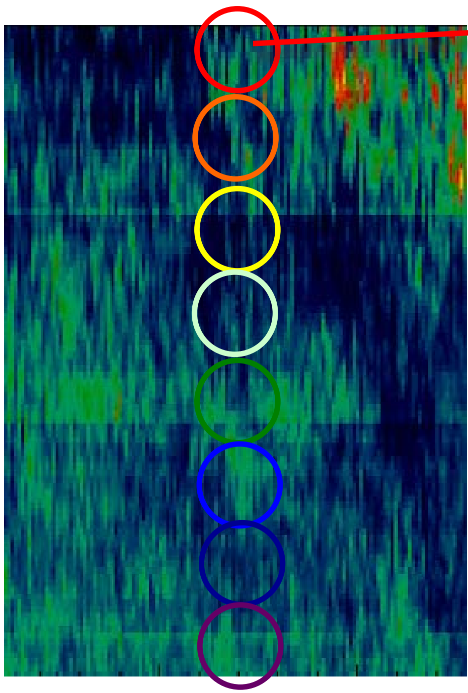
N Footpoint Source

SPIKE BURSTS & DOWNFLOWS



SHOCK FRONT DELINEATED

Dynamic Spectrum



Image

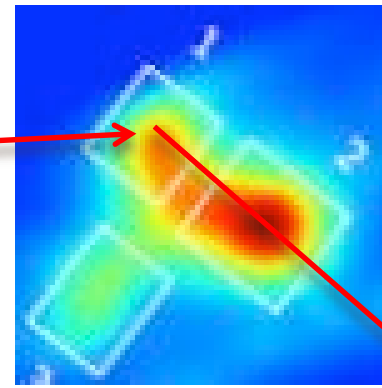
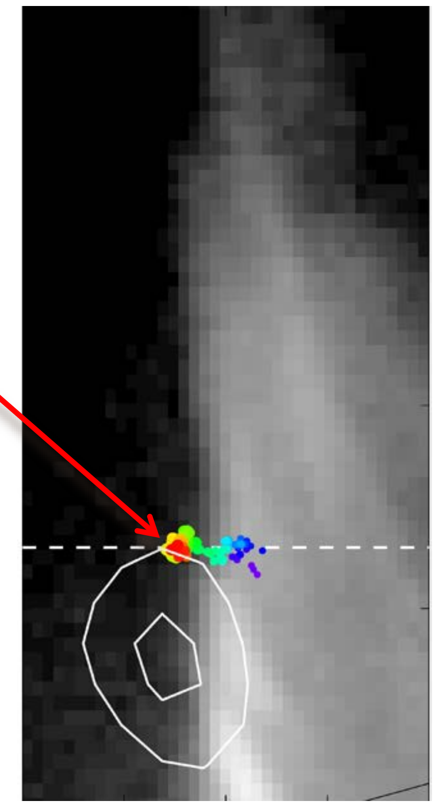
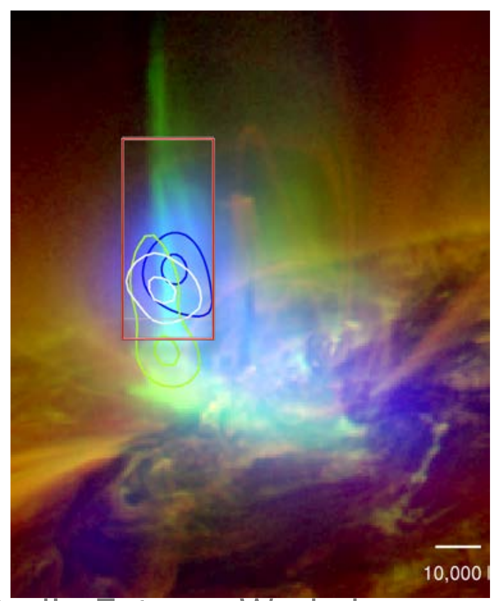
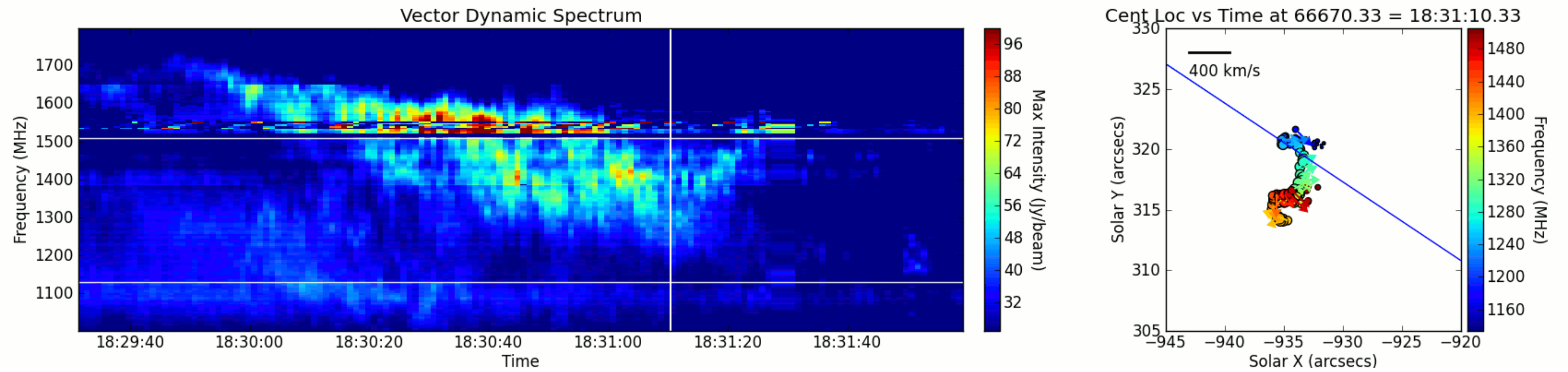


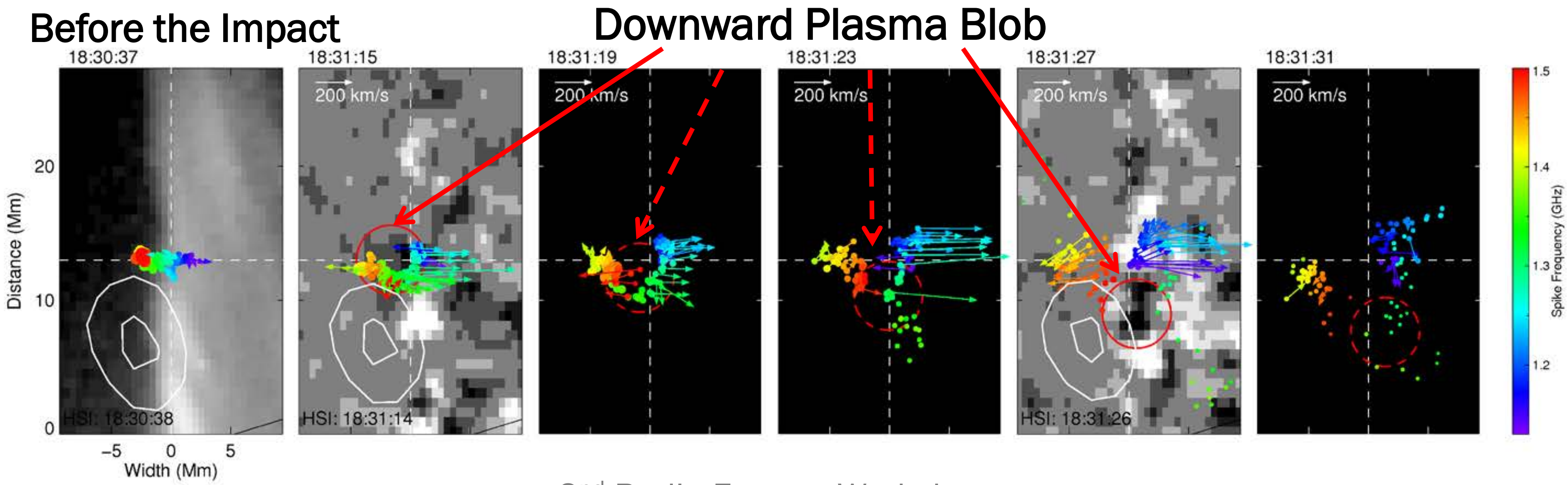
Image Centroids



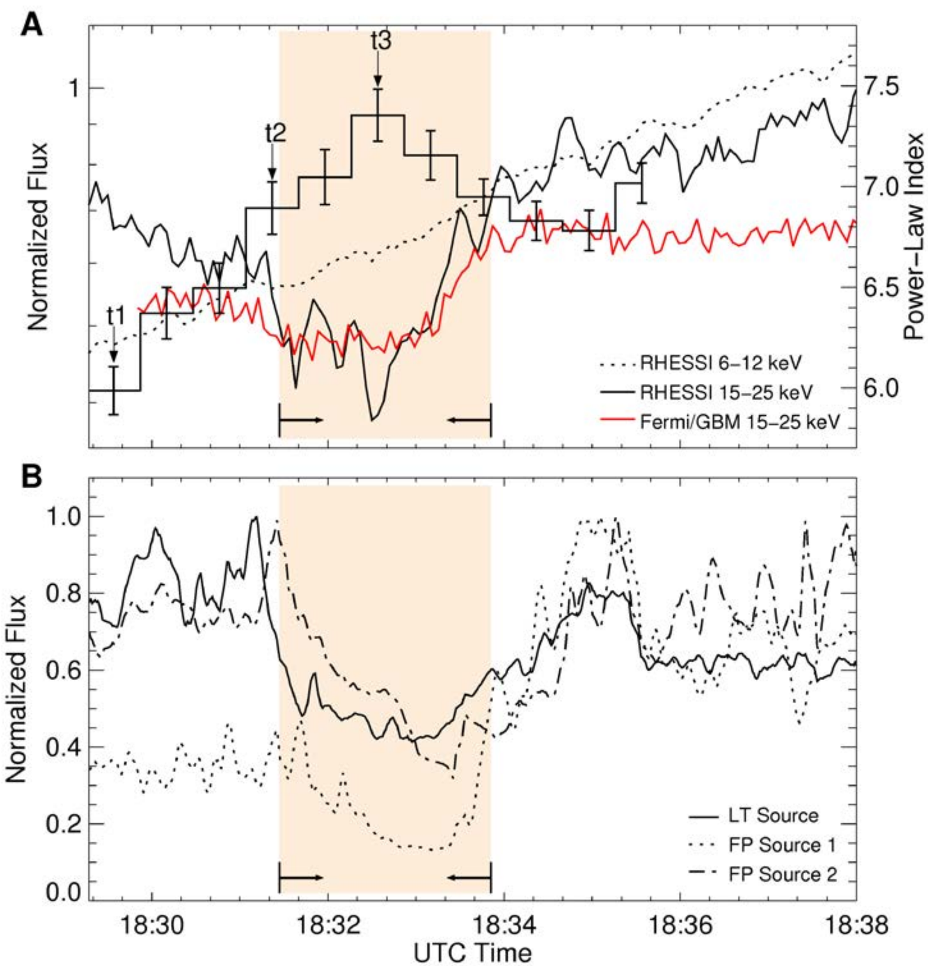


DISRUPTION OF THE SHOCK





ELECTRON ACCELERATION



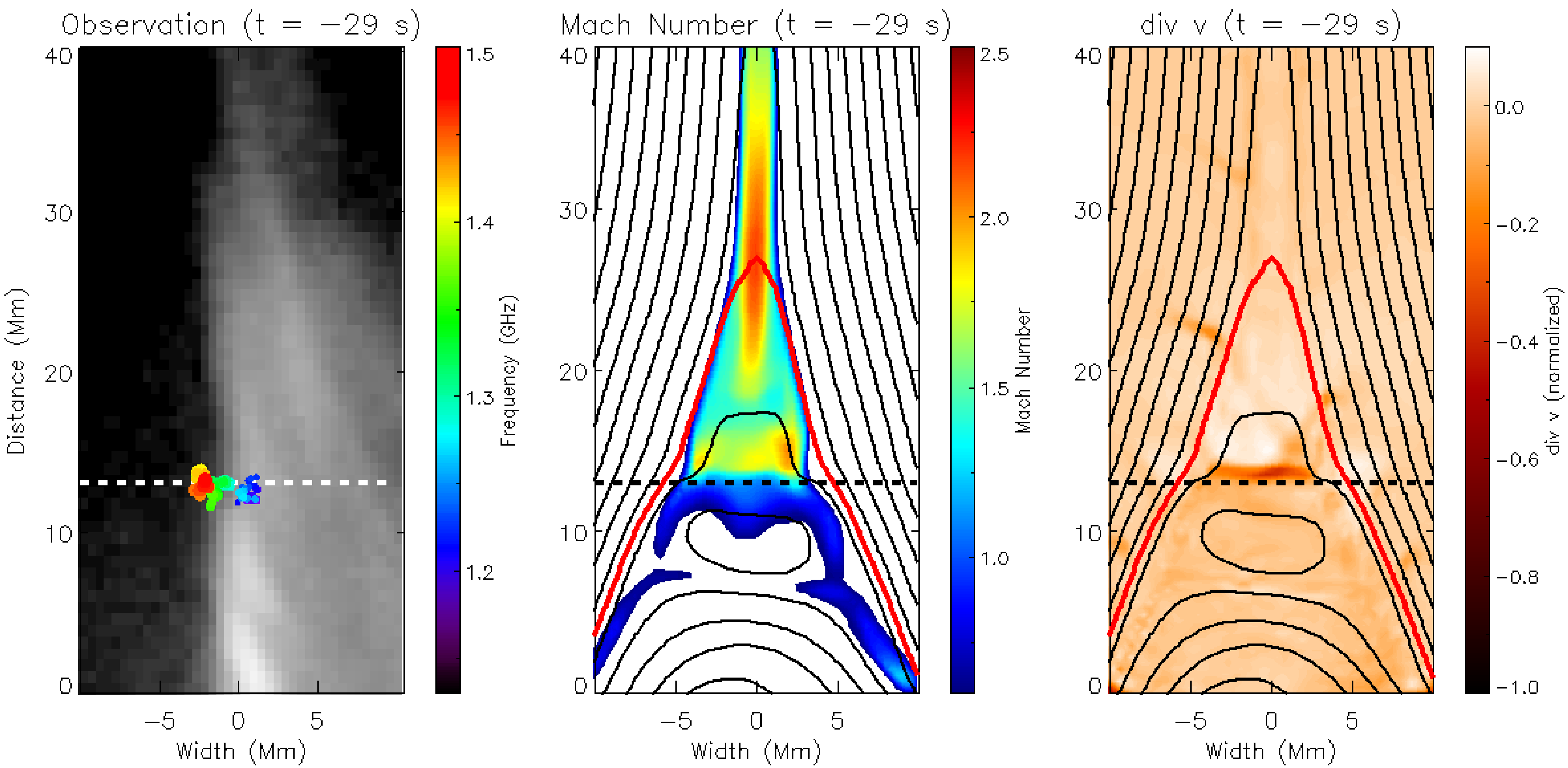
- Lower HXR and Radio flux
- Softened HXR spectrum

➡ Fewer electrons being accelerated to high energies

This termination shock may have played an important role in particle acceleration!

Chen + 2015

SIMULATIONS



LOOKING FORWARD

- New and upgraded facilities are being used to expand and enhance RMS solar opportunities
- Some of these are being leveraged to perform proof-of-concept science using ultra-wideband imaging spectroscopy (EOVSA, VLA)
- Not discussed: developing collaboration between ground based RMS and O/IR facilities with NASA
  - Support of Solar Probe Plus
  - Support of Solar Orbiter
- **Time to update the concept for ngRH informed by exciting science demonstrated by new instruments as well as new opportunities from NSWP**