Solar Flares @RNO-G

Imposter: dzb

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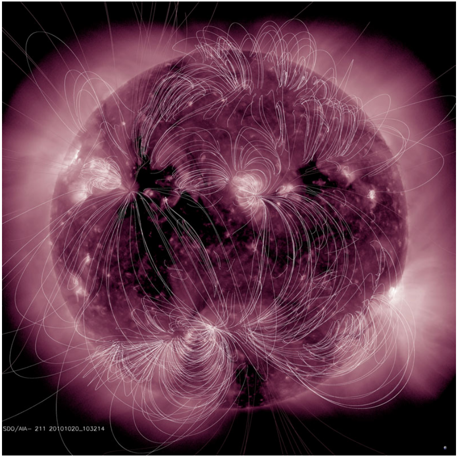
Outline

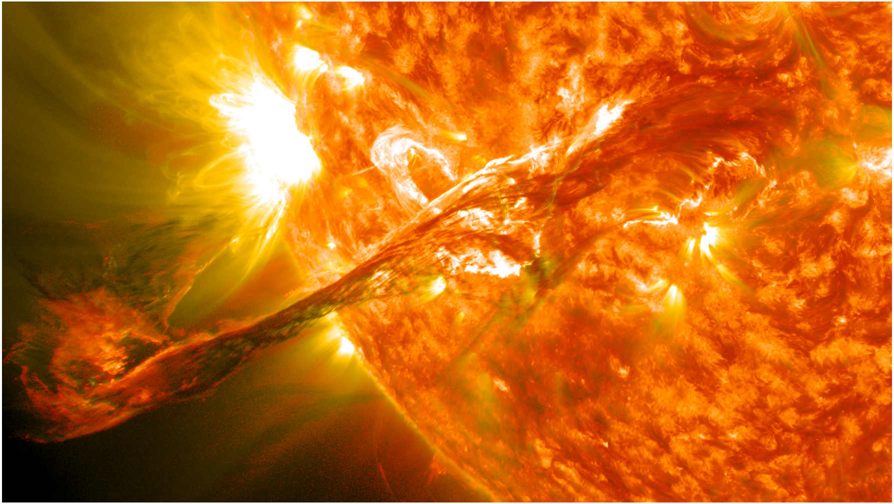
- Solar Flares, overview
  - Solar Maximum, now!
- Observation in RNO-G
- Use as a calibration tool
- Current Status and Future work
- Flares, Summit vs. South Pole

Better Col Sol (sdo.gsfc.nasa.gov)

Flares/CME$\leftrightarrow$ $\vec{B}$ re-alignment around sunspots

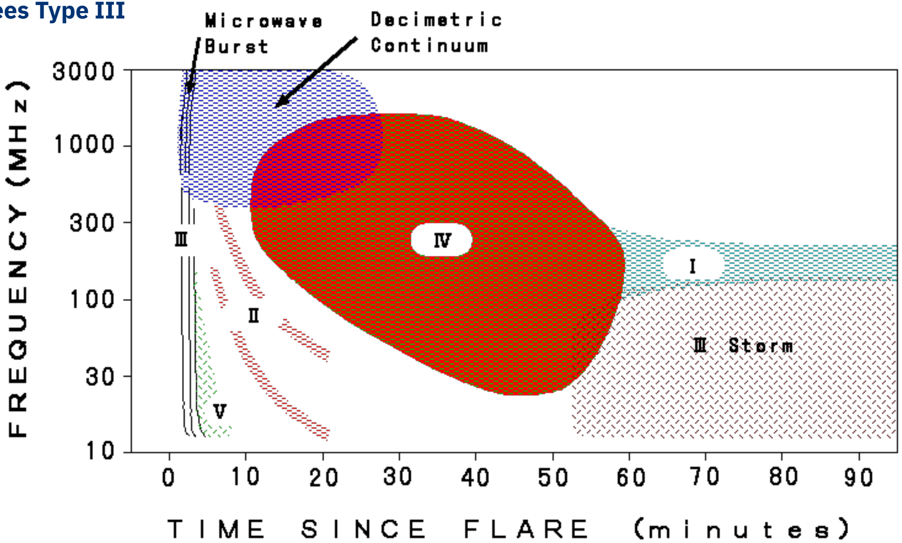


Close-up image of CME along B-lines



Taxonomy (NJIT Solar Group)

RNO-G sees Type III



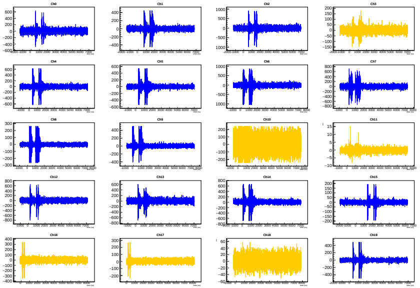
An ideal Solar Flare observatory would:

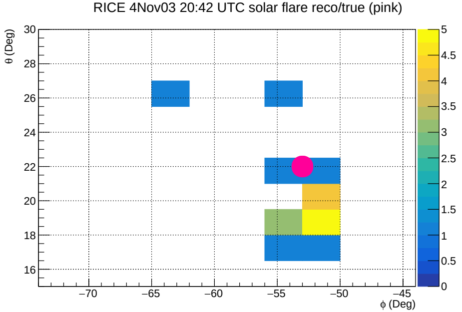
1) Measure emissions @GSa/s (RNO-G: 3.2 GSa/s)
2) Reconstruct source location on sun with arc-minute precision (RNO-G: 30’ precision)
3) Reconstruct full 3-d polarization, over frequency range from X-ray down to decameter radio (RNO:G VPol/HPol, from 100-400 MHz)
4) Large amplitude dynamic range (RNO-G: 1 μV/m$\rightarrow$1 mV/m at antenna input)
5) Ability to unfold and correct for ionospheric dispersive effects in real-time (generally below RNO-G bandpass)

Not perfect, but combines unique capabilities!

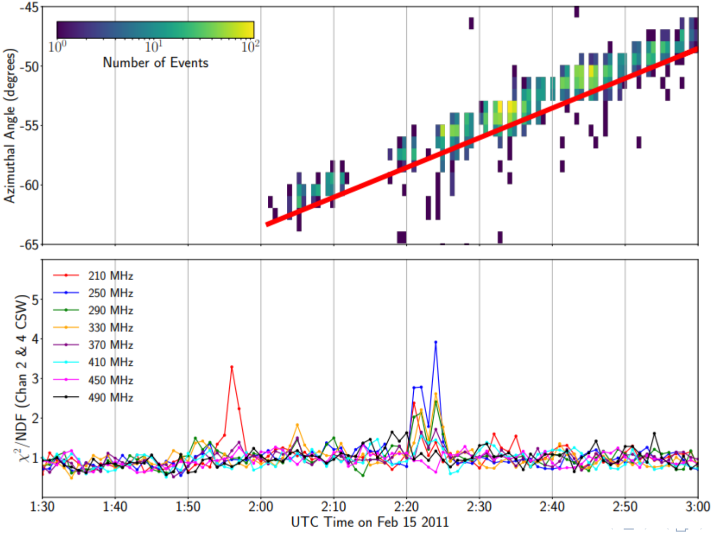
Previous reported observations by UHEN observatories

2 Solar Max ago: RICE 20:42:54 3Nov2003; 20-ch wf and ϕ/θ reco; $\sigma_\phi \sim 5°$; $\sigma_\theta \sim 2°$



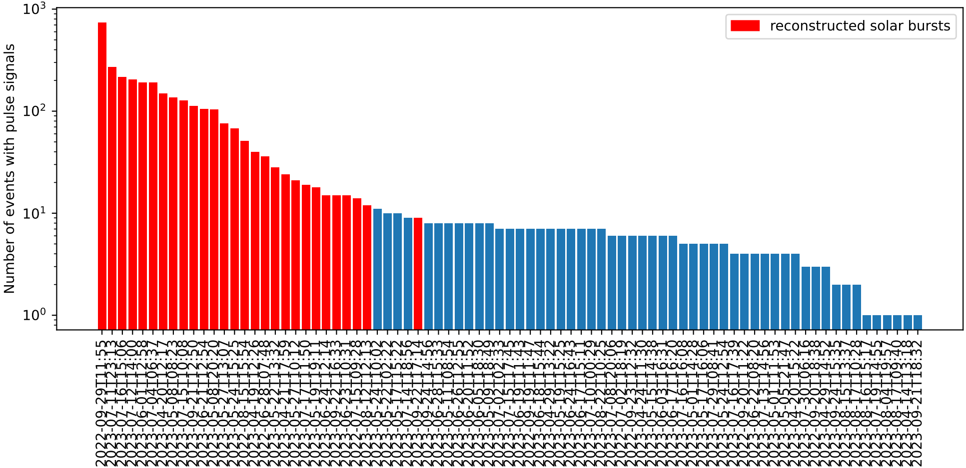


ARA Testbed: 15Feb2011 - track azimuth over full hour!



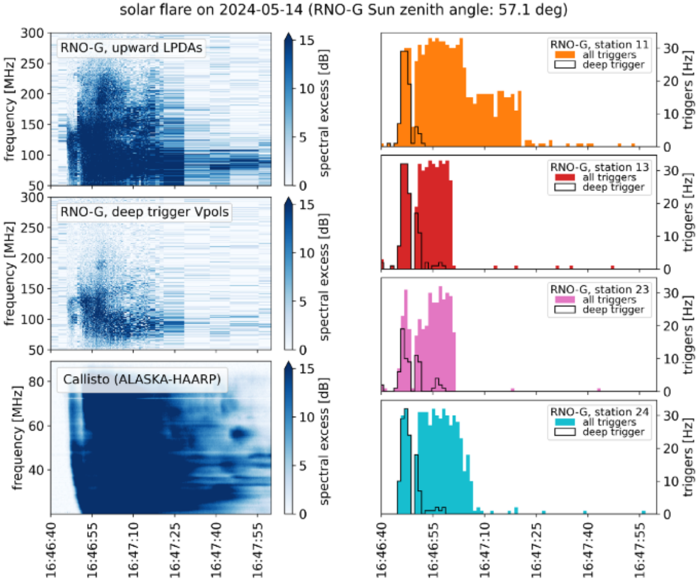
∼70 RNO-G solar flares, 2022-23

Elevated triggers coincident with dedicated solar observatories

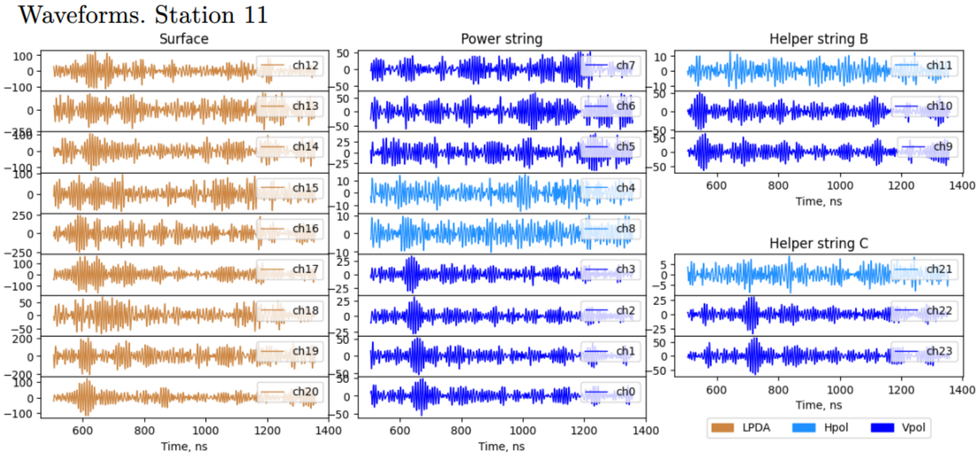


General Features of RNO-G Solar Flares

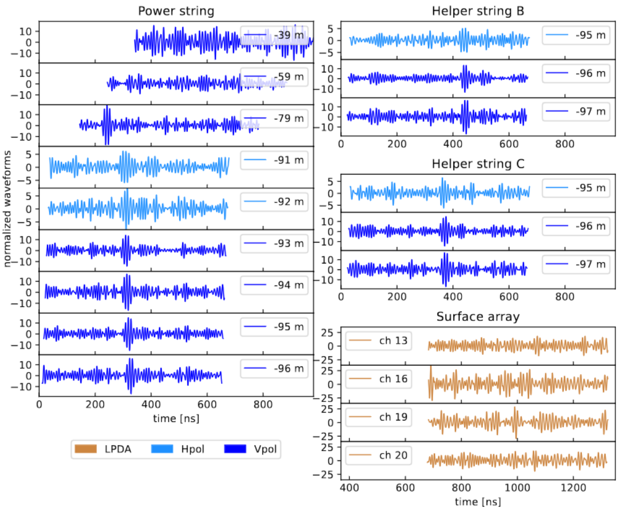
- 10–300 second period of saturated triggers
- ‘Continuous’ illumination of all channels in all stations:
  Since trigger rates are saturated, SF observations cannot be used to calibrate inter-station clocks.
- Impulses sweeping downwards through array, superimposed on ‘mash’ of extended, less-distinctive enhancement
- Power spectrum shifting to lower frequencies with time


solar flare on 2024-05-14 (RNO-G Sun zenith angle: 57.1 deg)
RNO-G, upward LPDAs
RNO-G, deep trigger Vpols
Callisto (ALASKA-HAARP)
frequency [MHz]
spectral excess [dB]
RNO-G, station 11
RNO-G, station 13
RNO-G, station 23
RNO-G, station 24
all triggers
deep trigger
triggers [Hz]
16:46:40
16:46:55
16:47:10
16:47:25
16:47:40
16:47:55

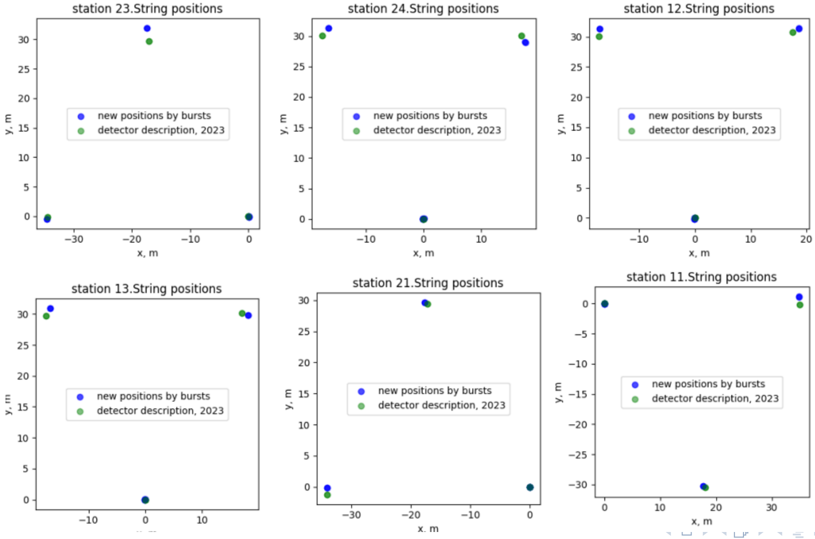
Solar Flare sweeping through array; V(t) by channel



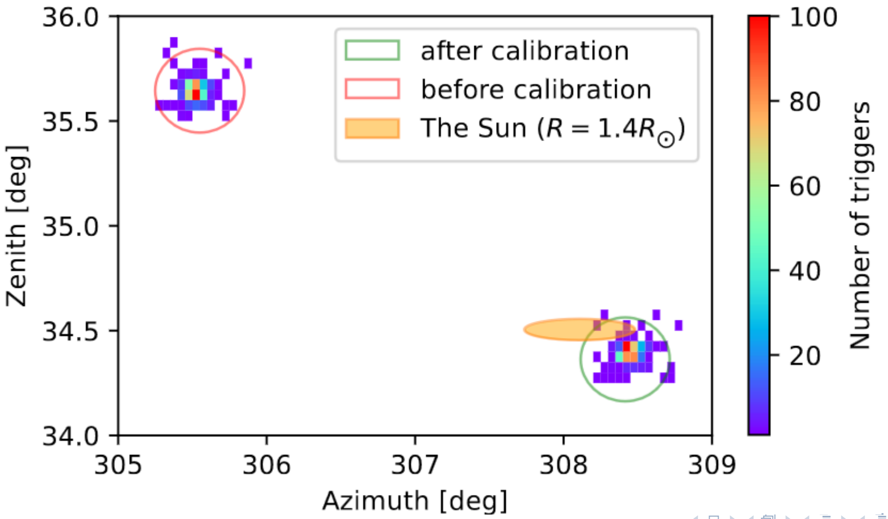
29Sep22

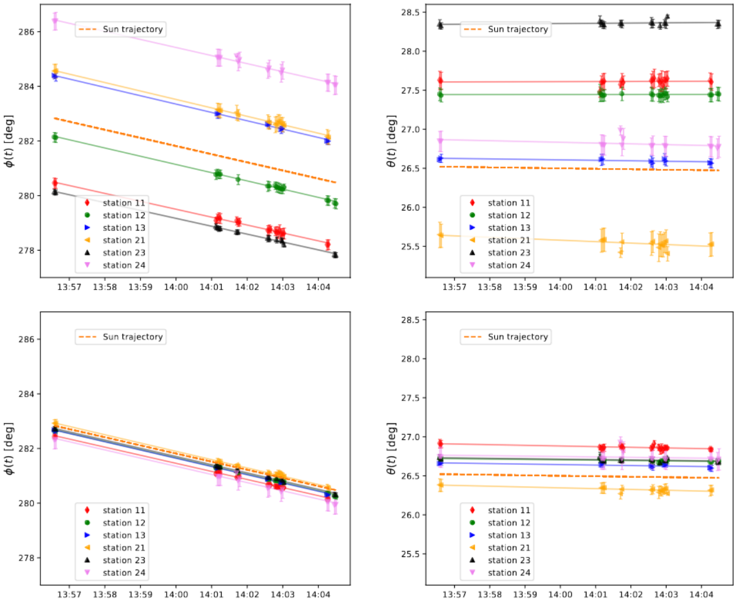

Power string
Helper string B
Helper string C
Surface array
-39 m
-59 m
-79 m
-91 m
-92 m
-93 m
-94 m
-95 m
-96 m
-97 m
ch 13
ch 16
ch 19
ch 20
normalized waveforms
time [ns]
LPDA
Hpol
Vpol

Optimize 3-d geometry, constrain by known $(\Theta_\odot, \Phi_\odot)$



Calibrated Antenna Locations ($\delta \sim$10–15 cm)




Sun trajectory
station 11
station 12
station 13
station 21
station 23
station 24
$\phi(t)$ [deg]
$\theta(t)$ [deg]
13:57
13:58
13:59
14:00
14:01
14:02
14:03
14:04

Checks

1) Solar reconstruction on independent (non-calibration) sample: reconstruction improves by $\sim$2 degrees for 14May24 flare
2) Sensitivity to ice refractive index: Toggle n(z) by +/-1%$\Rightarrow$change calibrated antenna locations by $<$15%.
3) Divide calibration sample into two sub-samples - calibration constants agree to $\sim$10%
4) xy-shifts of antennas in same hole (generally) coherent

Ongoing Work:

1) Develop a solar flare simulation to meld to **`nuradiomc`**
2) Calibrate surface antenna response and reconstruction (useful for reconstruction of radio emissions from UHECR!)
3) Incorporate SF alerts into online station monitoring/shifting
4) Deep Rx signals, combined with measured radio fluence from other observatories, as f(solar zenith) to estimate $n_{surface}$.
5) Deep Rx signals $\Rightarrow$ extract in-ice beam pattern
6) $A_{surface\ Rx}/A_{in-ice-Rx}$(time) to extract effect of snow accumulation on response of surface LPDA antennas
7) ‘Stack’ events, adjusting for motion of sun through sky to see ‘ambient’ sun

Conclusions and Summary

1) Owing to excellent planning. RNO-G deployed and commissioned around solar maximum!
2) SF observations provide powerful constraints on geometry
3) Much more (polarization, surface antenna calibration, etc) TBD!