

Summary and Closing remarks

Steven Tingay


Meeting by the numbers

- 68 talks in three days;
- ~100 participants;
- ~20% female participants, ~80% male;
- ~35% participants > 35 yrs old, ~65% < 35 yrs old;

- Plethora of instruments and techniques, across a wide range of project team sizes, budgets, and science goals;
- About a dozen facilities/instruments represented:
 - 10 facilities commissioned/operational;
 - ~3 facilities aspirational.
- LOFAR (~8000 hrs -> 20 PB);
- MWA (~8000 hrs -> 8 PB);
- VLITE (~6000 hrs -> ??);
- OVRO-LWA (24 TB/hr);
- LWA (????);
- .
- .

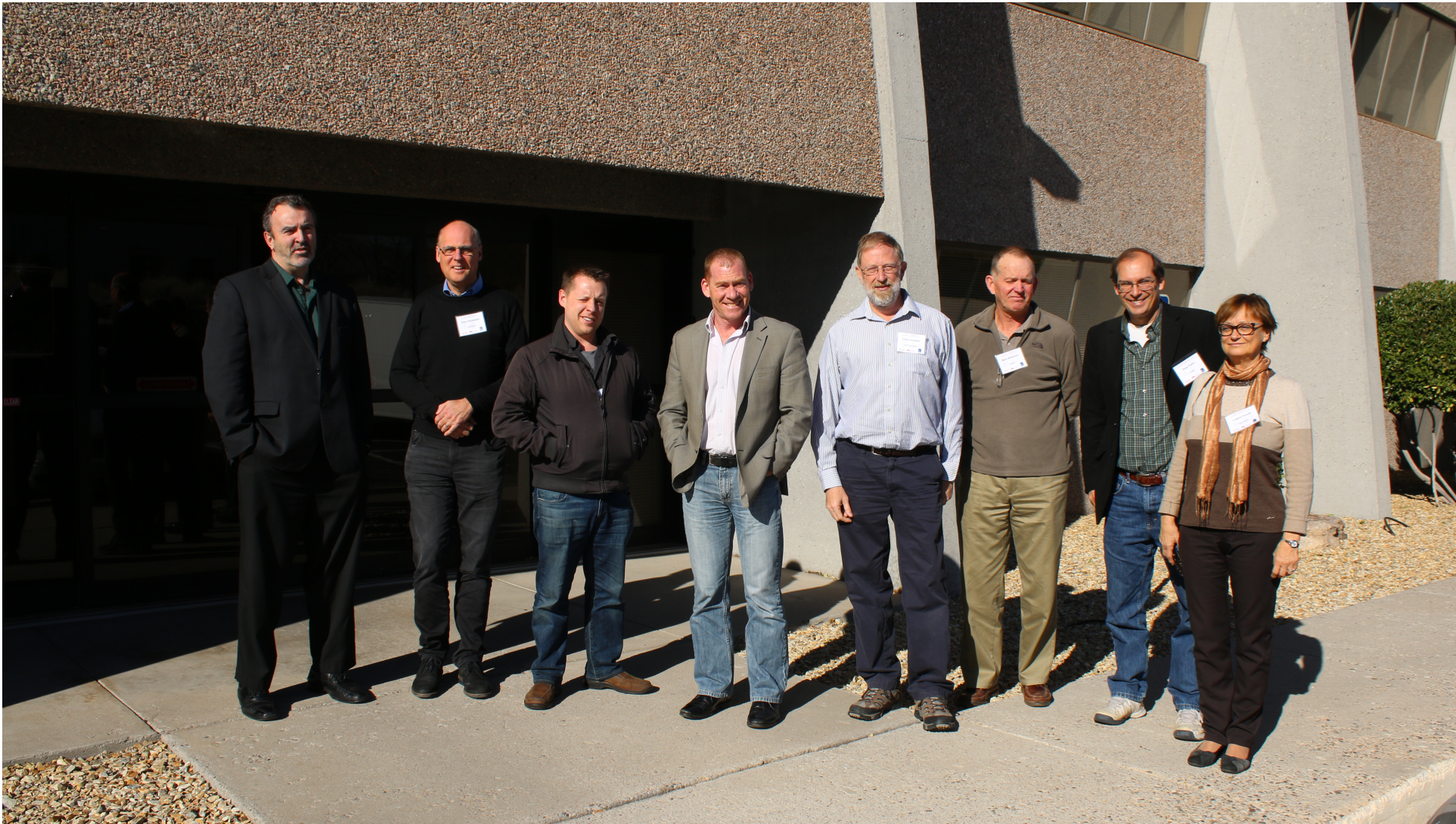
- Low frequency radio astronomy so much more than just the EoR.
- LOFAR, MWA, LWA, PAPER, GMRT in title and/or abstract in last 5 yrs (VLA too hard to separate out; apologies to other instruments):

http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?db_key=AST&db_key=PRE&qform=AST&arxiv_sel=astro-ph&arxiv_sel=cond-mat&arxiv_sel=cs&arxiv_sel=gr-qc&arxiv_sel=hep-ex&arxiv_sel=hep-lat&arxiv_sel=hep-ph&arxiv_sel=hep-th&arxiv_sel=math&arxiv_sel=math-ph&arxiv_sel=nlin&arxiv_sel=nucl-ex&arxiv_sel=nucl-th&arxiv_sel=physics&arxiv_sel=quant-ph&arxiv_sel=q-bio&sim_query=YES&ned_query=YES&adsobj_query=YES&aut_logic=OR&obj_logic=OR&author=&object=&start_mon=&start_year=2011&end_mon=&end_year=2015&ttitle_logic=OR&ttitle=LOFAR+MWA+PAPER+LWA+GMRT&txt_logic=OR&text=LOFAR+MWA+PAPER+LWA+GMRT&nr_to_return=200&start_nr=1&jou_pick=NO&ref_stems=&data_and=ALL&group_and=ALL&start_entry_day=&start_entry_mon=&start_entry_year=&end_entry_day=&end_entry_mon=&end_entry_year=&min_score=&sort=CITATIONS&data_type=SHORT&aut_syn=YES&ttitle_syn=YES&txt_syn=YES&aut_wt=1.0&obj_wt=1.0&ttitle_wt=0.3&txt_wt=3.0&aut_wgt=YES&obj_wgt=YES&ttitle_wgt=YES&txt_wgt=YES&ttitle_sco=YES&txt_sco=YES&version=1



Refereed publications: 345
Citations: 3954
Five year H-index: 31

+ve gradient is steep.....



Current publication impact:

- instrumentation;
- pulsars;
- EoR;

- Clusters;
- AGN/galaxies;
- Algorithms;

- transients (fast and slow);
- solar, heliospheric, ionospheric.

Overall impressions

- New instruments and upgrades of old instruments enabled by power, affordability, and usability of signal processing hardware, data transport (RF over fibre), computing facilities.
- Ever increasing capability of FPGAs, but increasingly HPC platforms and hybrid platforms make it "easy" to build "large-N" correlator architectures.
- New facilities and facility upgrades interact dynamically with new science (FRBs, pulsars, space weather etc etc) opportunities.
- Lessons for how to develop/build low frequency SKA??

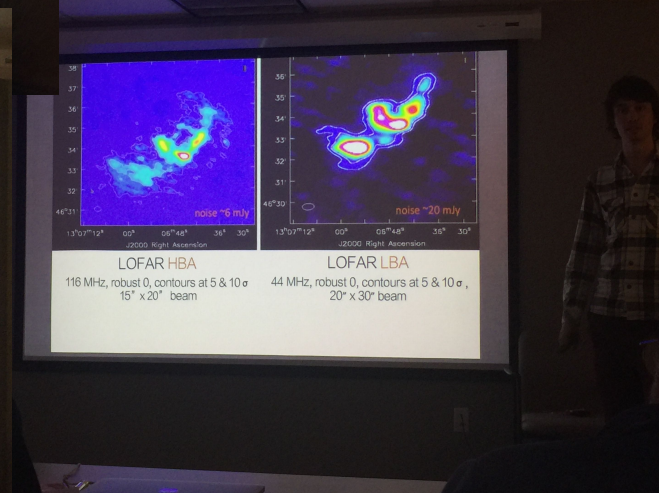
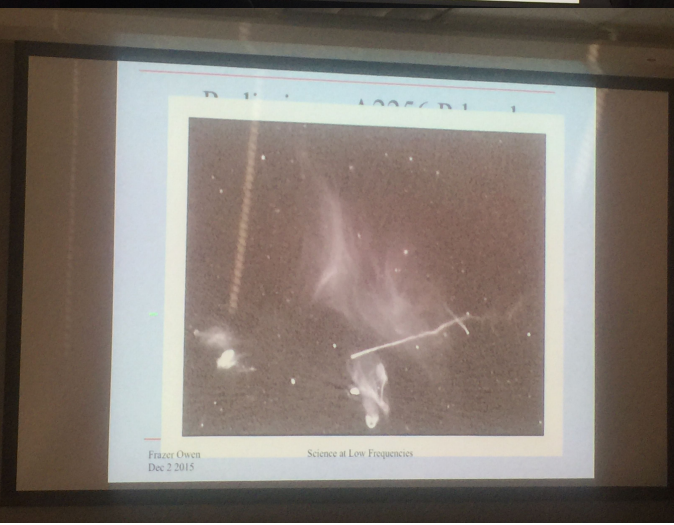
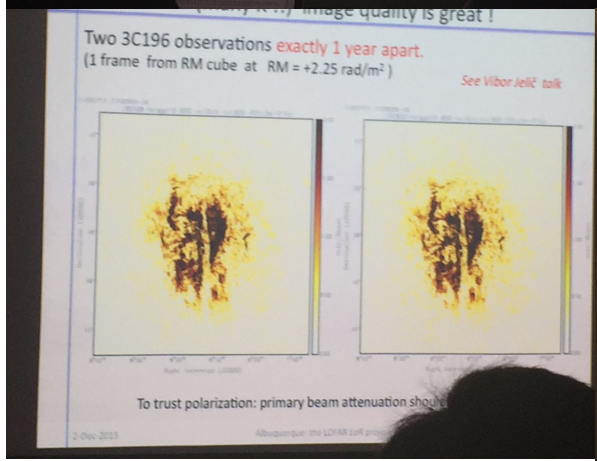
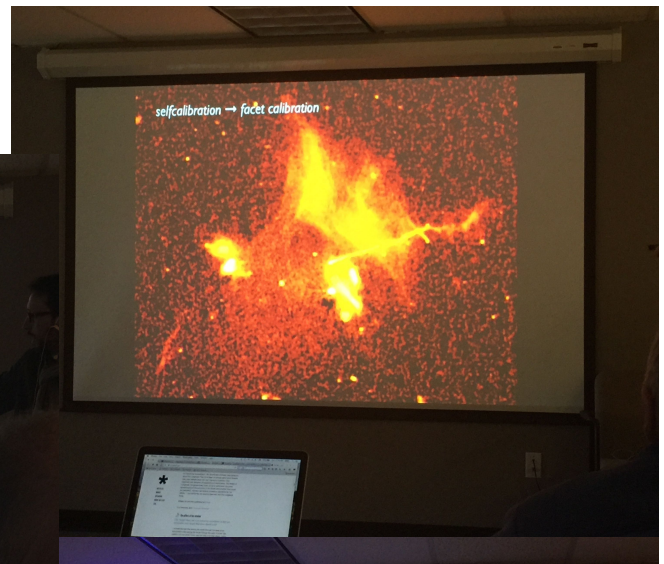
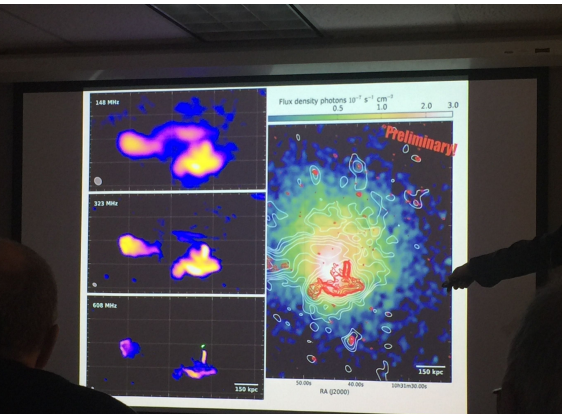
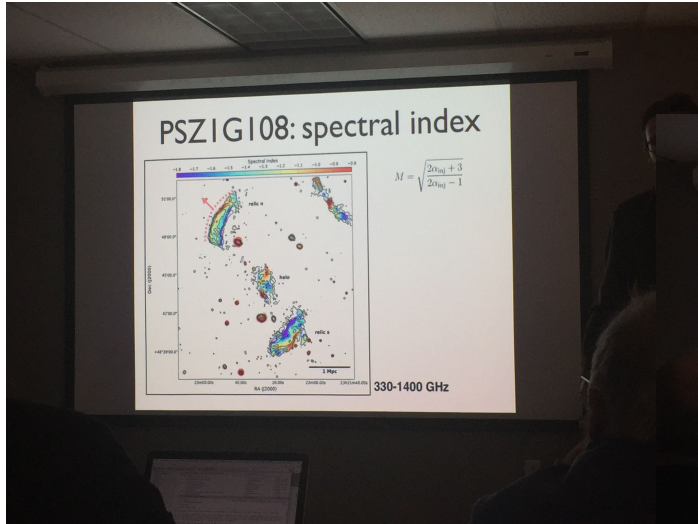
- Is this good? Overall, brilliant!
- No SKA talks on the program. Talks on telescopes that exist and people/teams dealing with real data.
- Biggest technical challenges are in generalised/optimised imaging/calibration algorithms, processing pipelines, and large-scale data handling.
- A different challenge is to harness this community to design, build, and operate at the level of SKA, while keeping the dynamism of the current community and the diversity of approaches.

Highlights

- Instruments:
 - Abundantly clear that LOFAR has really now gathered huge momentum, across lots of science areas. Leading the way in low frequency astrophysics (many speakers);
 - Shows me that multi-use LOFAR++ scales are the future (SKA-low).
 - GMRT/Ooty show what is possible in refreshing existing instruments (Gupta/Chengular);
 - VLITE/VLITE-FAST – clever and effective (Clarke/Owen/Ray);
 - 21CMA still working!! (Zheng).

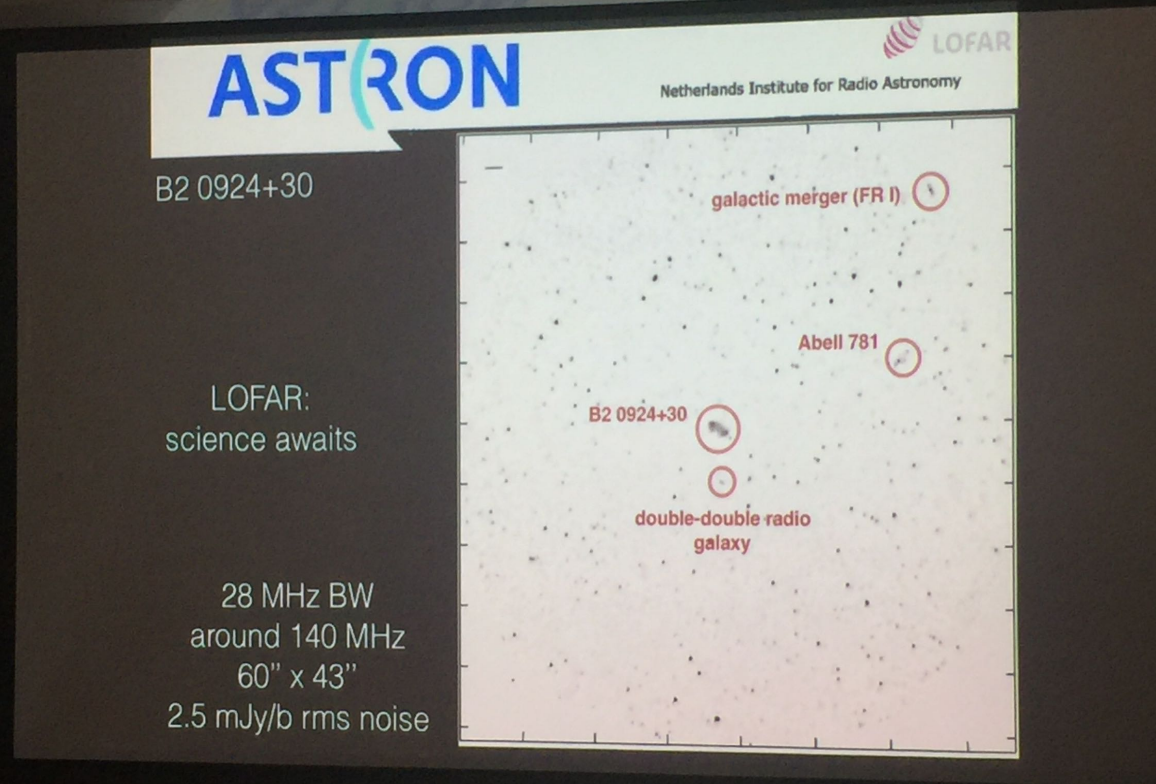
- Algorithms/software
 - WSCLEAN/AOFLAGGER being used/shared across different instruments (Offringa);
 - TraP being used/shared across different instruments.

Pure imaging quality....AKA a LOFAR-fest



Aleksandar Shulevski

“Every field contains many interesting objects!”



Experiments across global signal and power spectrum techniques, interferometers etc etc

LEDA Residuals, December 2014

Temperature [K]

Frequency [MHz]

$T_{\text{residual}} \sim 10^{-3} T_{\text{sky}}$
requirement $< 10^{-5} T_{\text{sky}}$

11-14 hrs LST, single antenna, 26-29 Dec 2014
5 order polynomial removed

Status of Analysis

- We have achieved residuals of **same order of magnitude** as expected **cosmological signal**.
- Conducting a thorough set of **validation tests**, **cross-checks**, **sensitivity analyses**.
- As **more data** are gathered, the understanding of limits **will improve**.
- In parallel, we are preparing to **rule out extreme cosmological scenarios**.
- Preparing to **rule out EoR durations** in the range $0.5 < \Delta z < 1.0$ for certain ranges of reference redshifts. Factor of **~ 10 improvement** wrt results from 2010.

Foregrounds: Major Challenge

Earth's Ionosphere (e.g., Vedantham et al. 2014, Datta et al. 2015, Rogers et al. 2015, Sokolowski et al. 2015)

Refraction, absorption, & emission

Spatial & temporal variations related to forcing action by solar UV & X-rays \Rightarrow 1/f or flicker noise acts as another systematic or bias.

Effects scale as ν^{-2} so they get much worse quickly below ~ 100 MHz.

Radio Frequency Interference (RFI)

RFI particularly problematic for FM band (88-110 MHz).

Reflection off the Moon, space debris, aircraft, & ionized meteor trails are an issue everywhere on Earth (e.g., Tingay et al. 2013, Vedantham et al. 2013).

Even in LEO (10^6 K) or lunar nearside (10^4 K), RFI brightness TB is high.

Galactic/Extragalactic

Mainly synchrotron with expected smooth spectrum (~ 3 rd order log polynomial),
 $\log T_B = \sum_{\nu} \log \left(\frac{\nu}{\nu_0} \right)$, although it is corrupted by antenna beam, e.g., Bernardi et al. 2015).

ELU&S: binned spectral structure at levels < 12 mK in foreground at 100-200 MHz.

Other Foregrounds - lunar thermal emission & reflections, Jupiter, Recombination lines.

NASA Surface Telerobotics

21 cm Fluctuations of the Cosmic Dawn with the Owens Valley LWA

Example Snapshot Image

Note: this image was made using only the core 251 antennas.

Michael Eastwood 7/17

power (arbitrary units)

frequency (MHz)

Example of the average spectra of auto- and cross-correlations over 24 hours

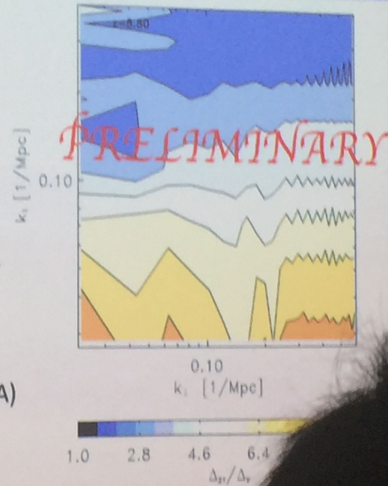
2-D power spectrum: ratio of Stokes I / V

Stokes V is close to the thermal noise level

Stokes I noise higher depending on frequency scale

Possible sources of excess noise in Stokes I:

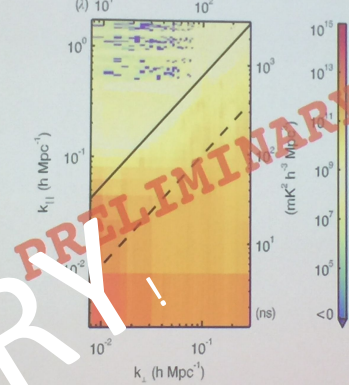
- myriad of faint sources
- imperfect subtractions
- foreground fitting (GMCA)
- ??



LOFAR

After some data cuts*

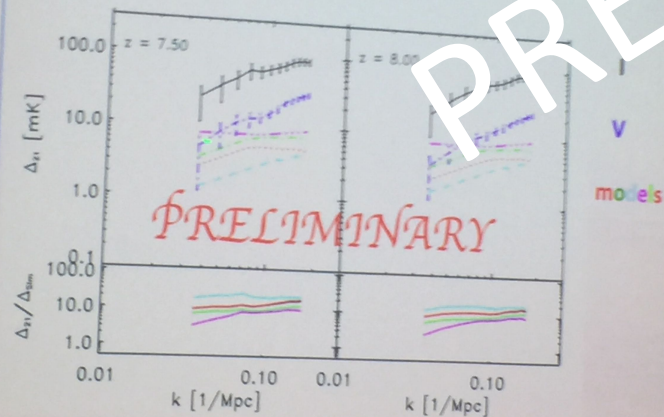
residual 32 hours of data



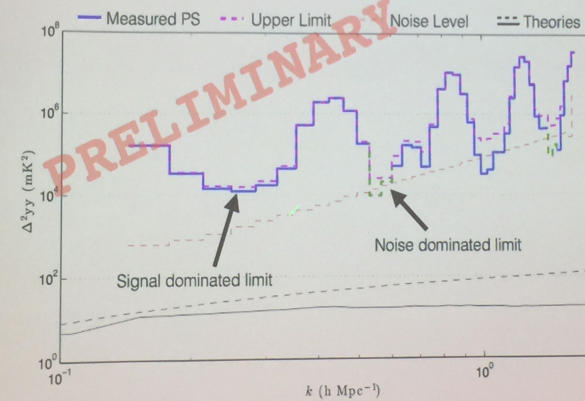
based on jackknives, delay spectra, and residual fluxes

MWA

Upper limits on the 3-D power spectrum



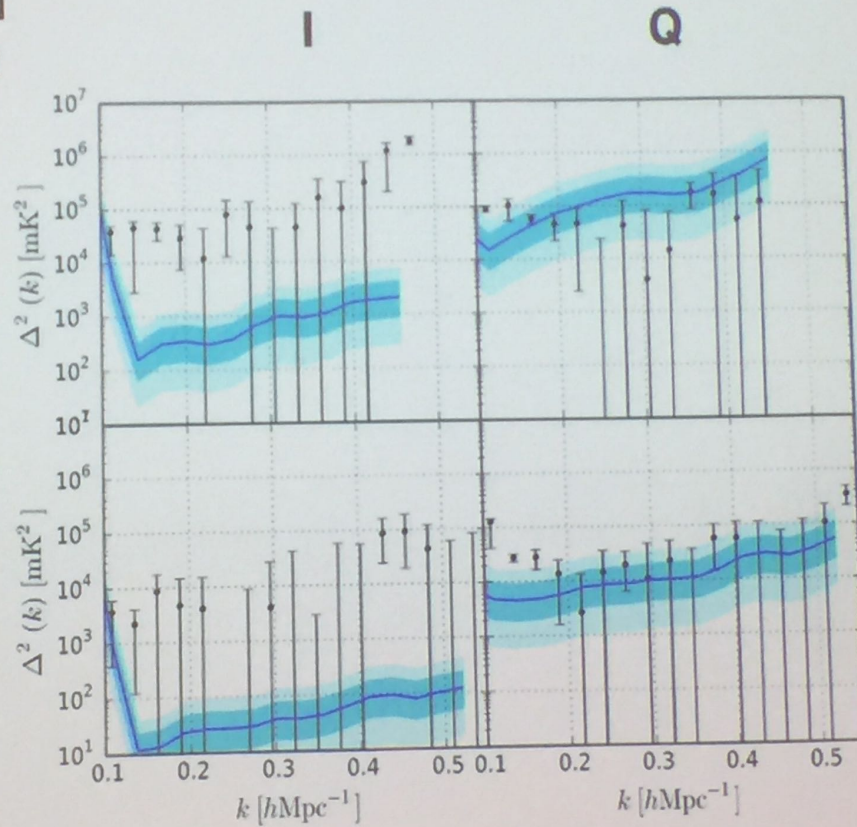
Deep 1D Power Spectrum



effective pol
frac ~ 0.002

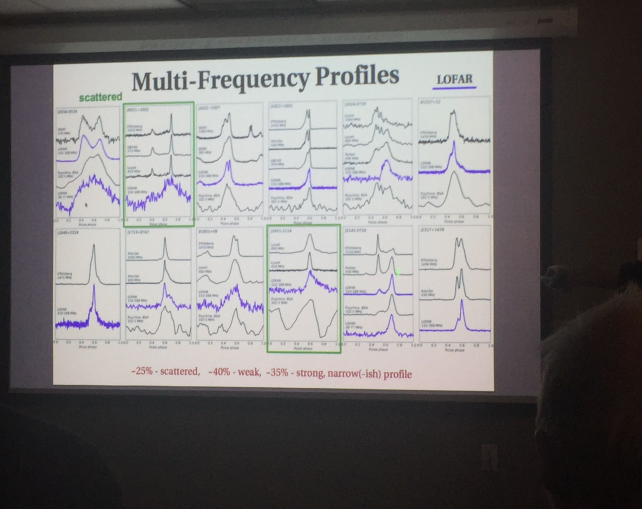
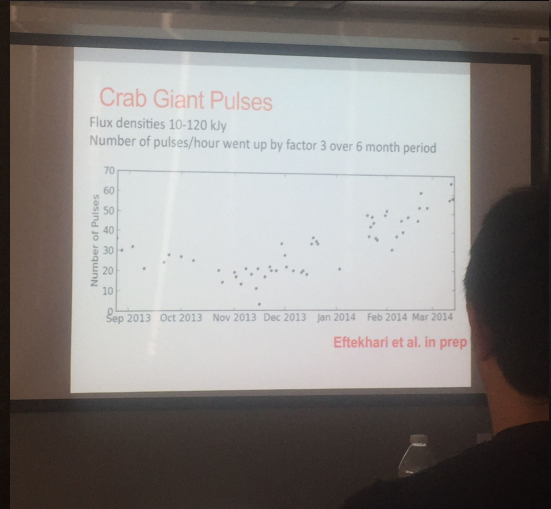
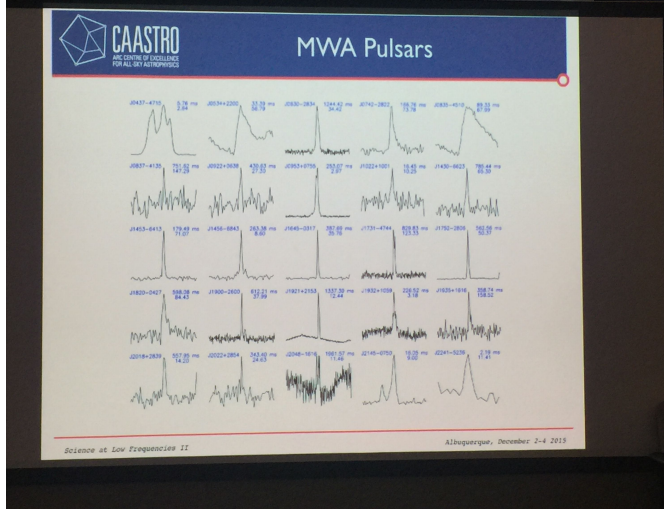
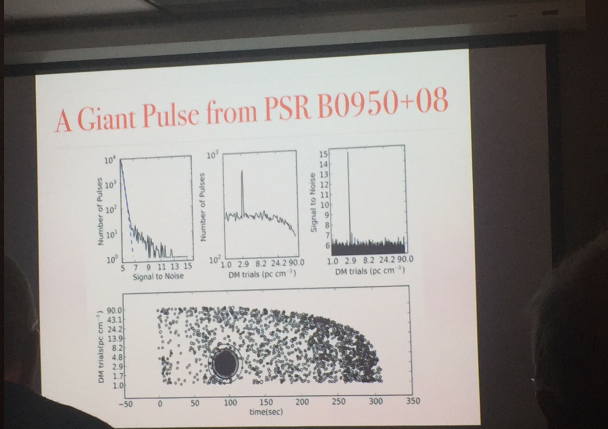
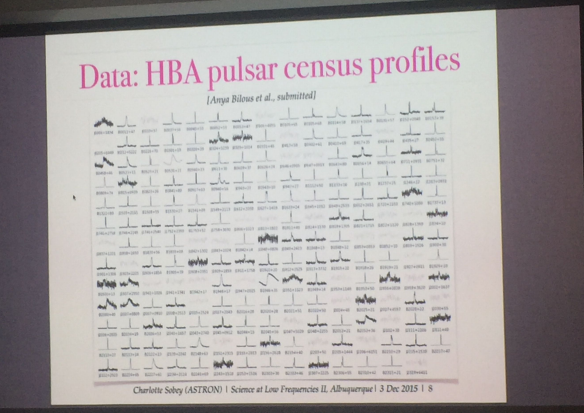
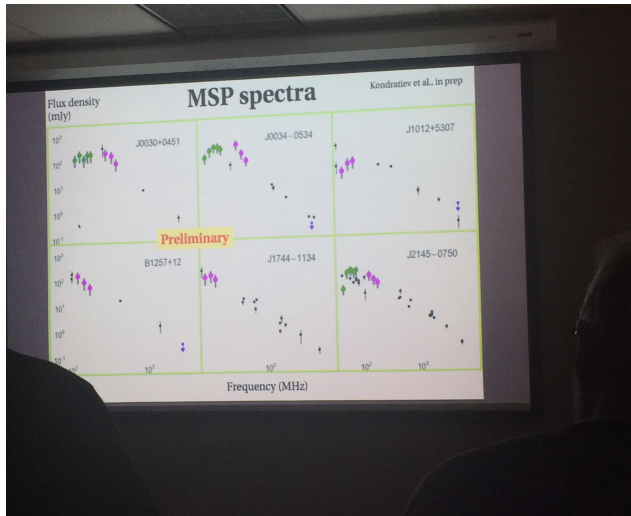
126 MHz

164 MHz



Moore et al. in prep.
Moore et al. 2013

Pulsars, pulsars, and more pulsars...

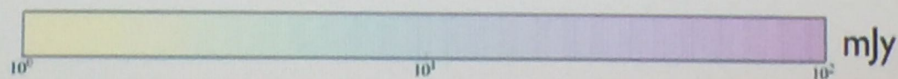
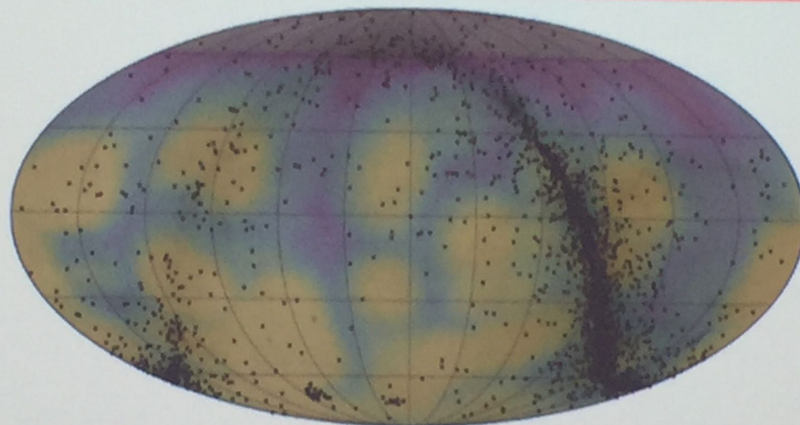


The sky on disk - forever



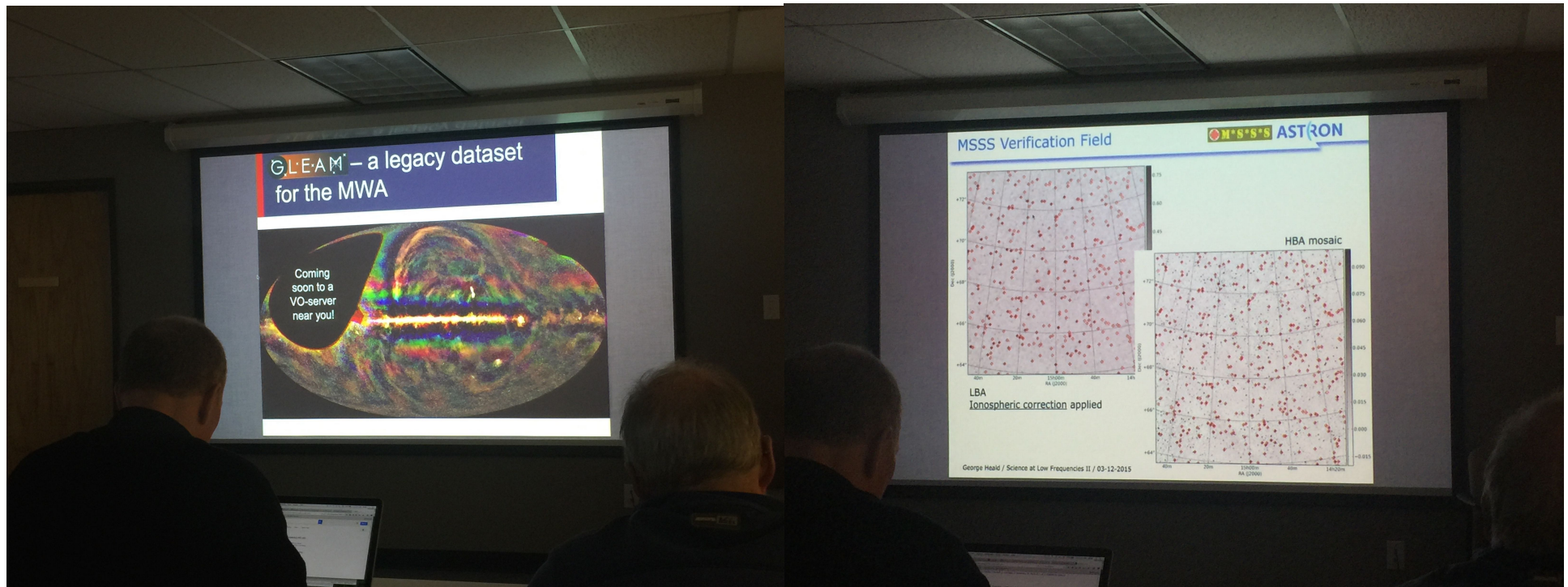
CAASTRO
ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

Archived MWA Voltages



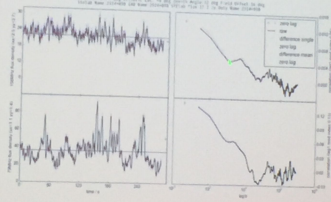
Integrated rms of archived VCS data (Oct. 9 2015)

Continuum surveys (all-sky)

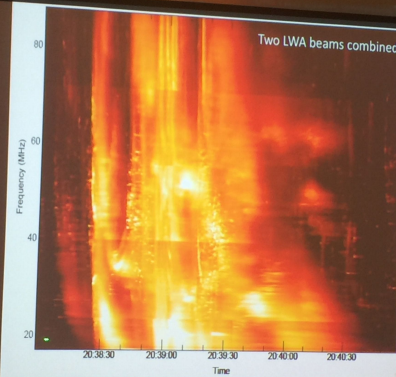


Solar and space science

Source 1



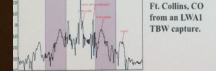
Variation on the shortest timescales: IPS



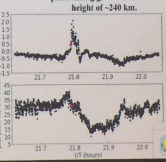
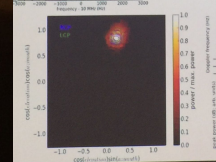
Passive Radar

❖ "All-sky" transient buffer modes allow for useful radar-based studies, esp. when paired with a "free" transmitter.

"Skywave" at 10 MHz of the WWV radio station near Ft. Collins, CO from an LWA1 TBW capture.



All-sky images of WWV 10 MHz carrier sky-waves with time series of Doppler and power before/after M-class solar flare (at 21.8 UT); pulse timing gives "reflection" height of ~240 km.

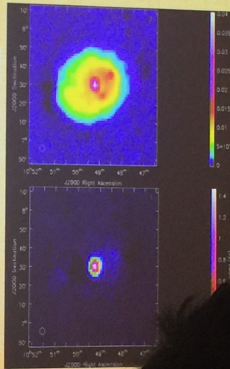
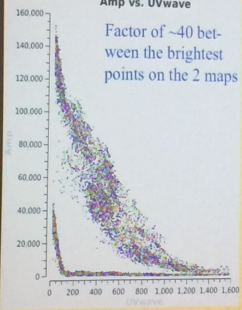


Quiet vs Active Sun

232.26 MHz

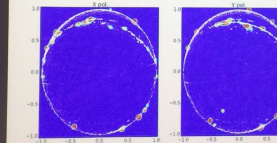
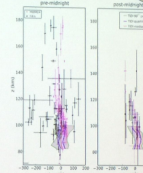
Amp vs. UVwave

Factor of ~40 between the brightest points on the 2 maps



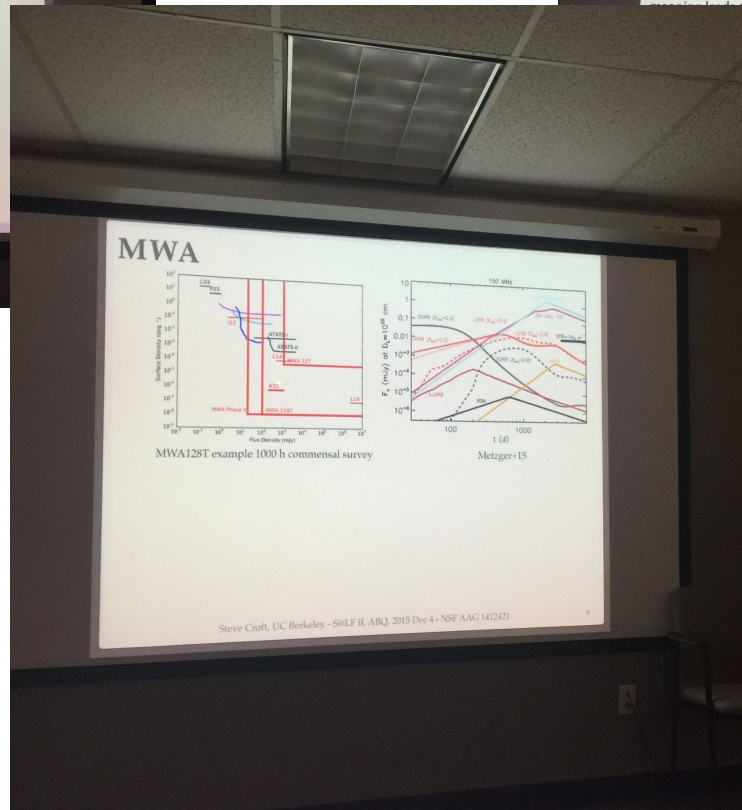
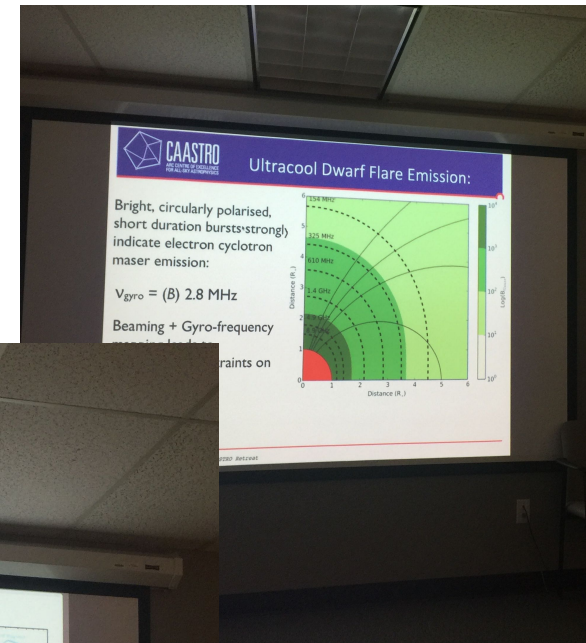
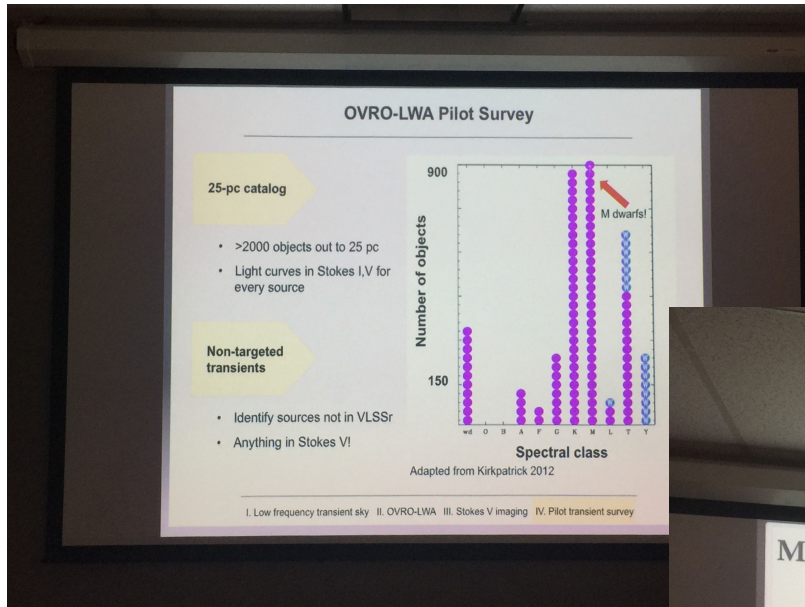
Passive Radar (cont.)

- ❖ Narrow-band video carrier of Channel 2 in Juarez (55.25 MHz) also useful; get returns from airplanes (not so useful), meteor trails, and FAIs.
- ❖ Can compute distance to FAIs with sky position, known Tx and Rx locations, and magnetic field model.
- ❖ All-sky tracking of FAIs associated with sporadic-E where ion motions largely wind driven provide new method for wind measurements up to ~150 km altitude or higher.



Left: All-sky movie from LWA1 at 55.25 MHz; FAIs along arc to the north. Above: Zonal winds from 75 different groups of FAIs found within 18 one-hour observations; compared with THD satellite measurements and HWNI4 empirical model.

Transients (mostly slow)



BLIND TRANSIENT SEARCHES

PI

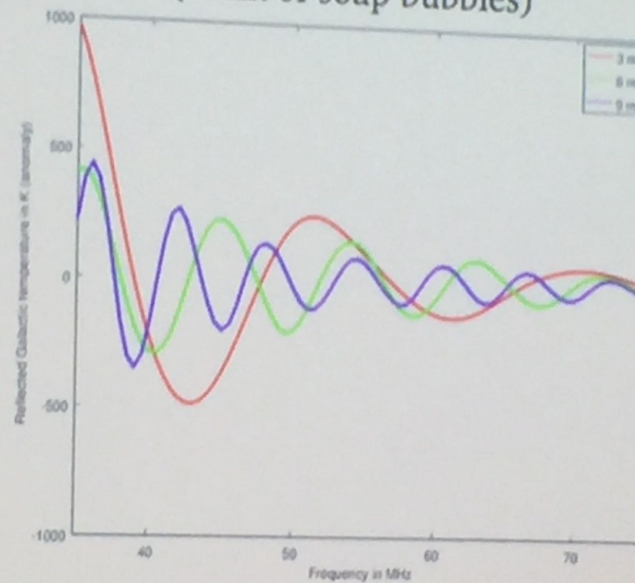
Grad
student



"In the field of observation, fortune favours the prepared mind" (Louis Pasteur, 1854)

"Know thy instrument" (Adam Beardsley, 2015)

Albedo may be frequency dependent due to thin-film interference
(think of soap bubbles)

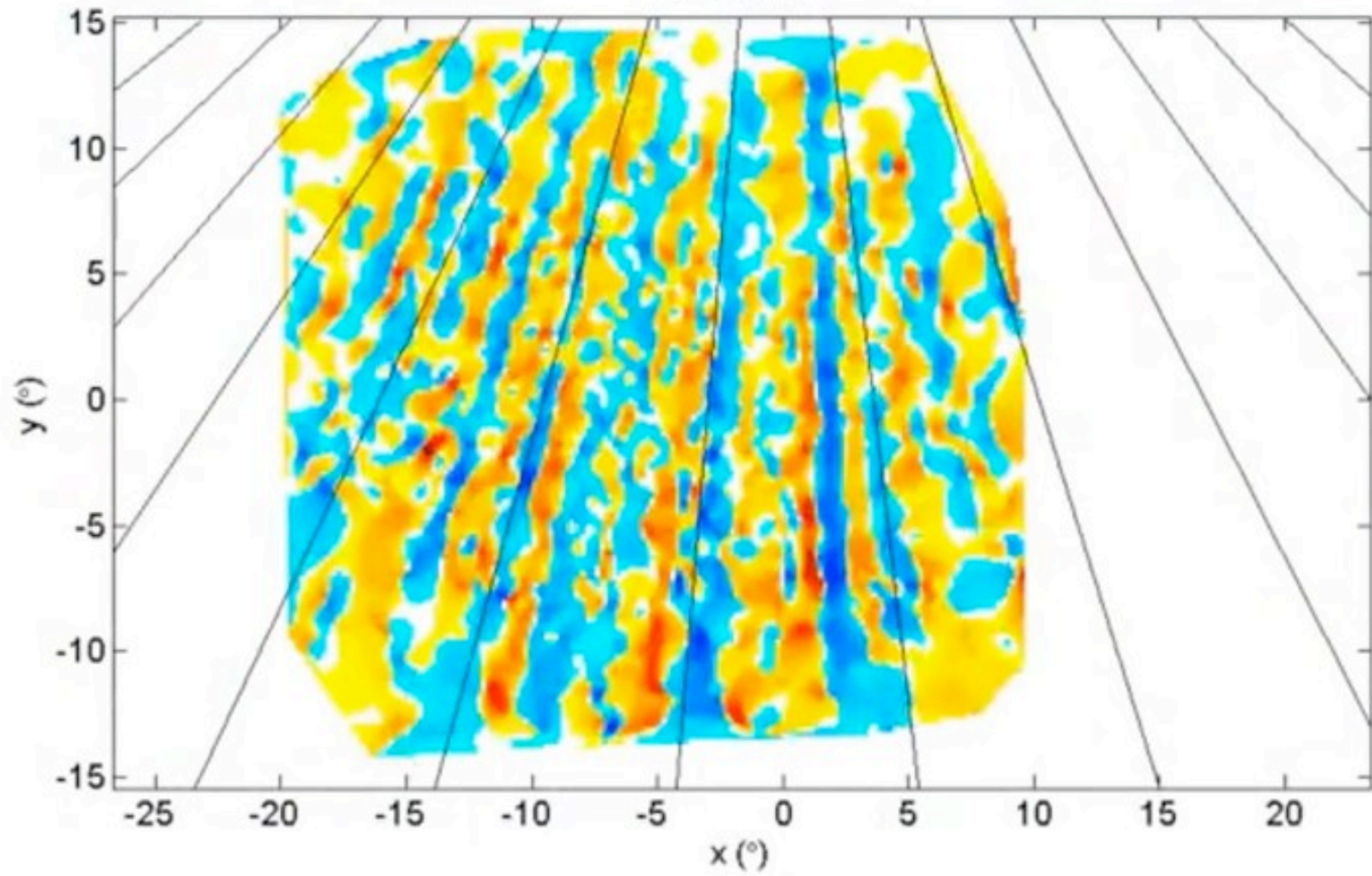


Might be a show-stopper for cosmic dawn experiment (future work)
Wealth of information on regolith vertical structure (first 10s on meters)

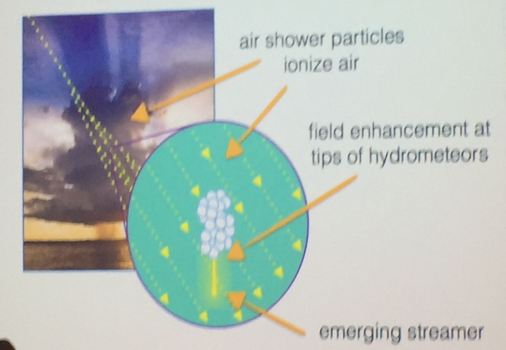
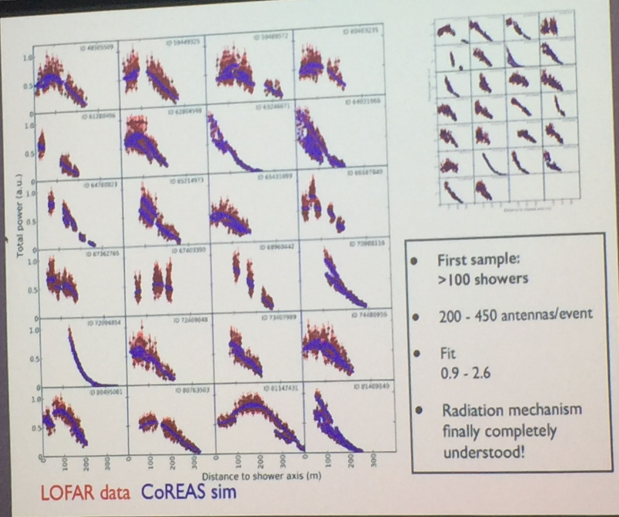
Harish Vedantham

Cleo Loi

t = 26 min



Stijn Buitink

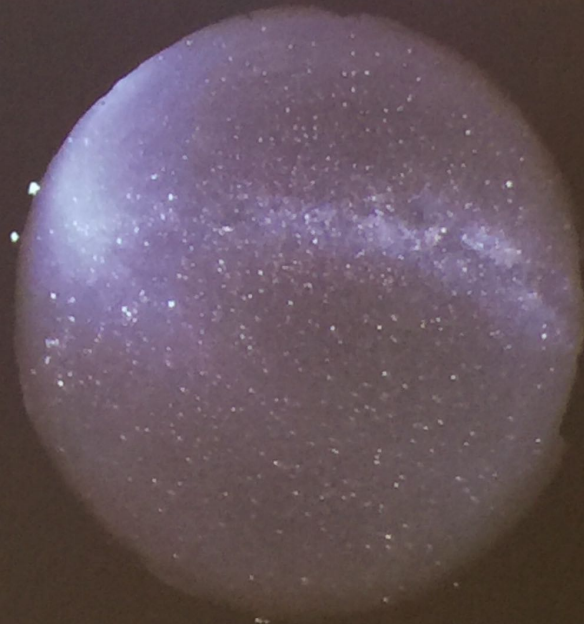


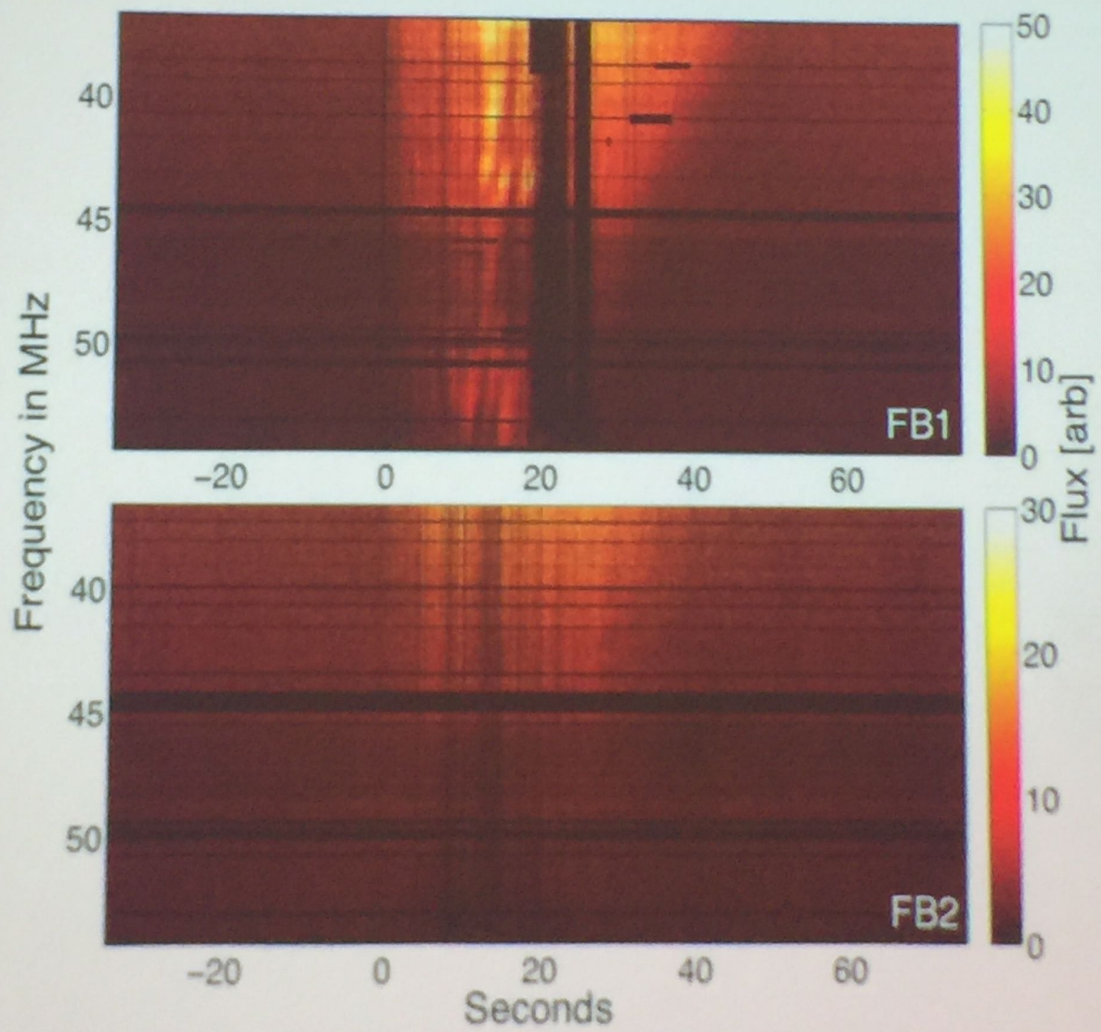
...inova, C. Rutjes, U. Ebert, S. Buitink, O. Scholten, and G. Trinh, PRL 115, 015002 (2015)

Ken Obenberger

Simultaneous Search for Radio and Optical Trains

- Goal is to see if the persistent trains are associated with the radio emission
- Run the LWA1 All-Sky imager
- Simultaneously Image the sky with two all-sky lenses attached to cooled CCDs
- take 5 s integrations every ~ 7-10 seconds
- Created a pipeline using the Hough Transform to pick out meteors
- We have detected 75 bright meteors in 13 nights, of observing during the Perseids and Leonids
- We also found 3 radio fireballs simultaneous with clear night observations







- Aside from ALMA, the most dynamic, diverse, and exciting area of radio astronomy (can't call it radio astronomy any more);
- Huge strength in instruments (diversity, flexibility, cost effectiveness);
- Huge strength in people (young, dynamic, unburdened by traditional radio astronomy);

But....

- Every instrument/facility is under-resourced to a greater or lesser degree;
- Ratio of fun things to people is too high;
- Ratio of PB to people is too high;
- Natural evolution is toward SKA-scale instruments.....change of thinking?