What causes radio variability?

1. **Explosions**
   - e.g. supernovae, gamma-ray bursts, orphan afterglows
2. **Propagation**
   - e.g. interstellar scintillation, extreme scattering events
3. **Accretion**
   - e.g. neutron stars, black holes, quasars, X-ray binaries
4. **Magnetospheric**
   - e.g. magnetars, flare stars, planetary variability
5. **Unknowns**
   - e.g. known unknowns, unknown unknowns, …

The dynamic radio sky

- Radio surveys have given us a largely static view of the sky
- A figure of merit for transient detection is:

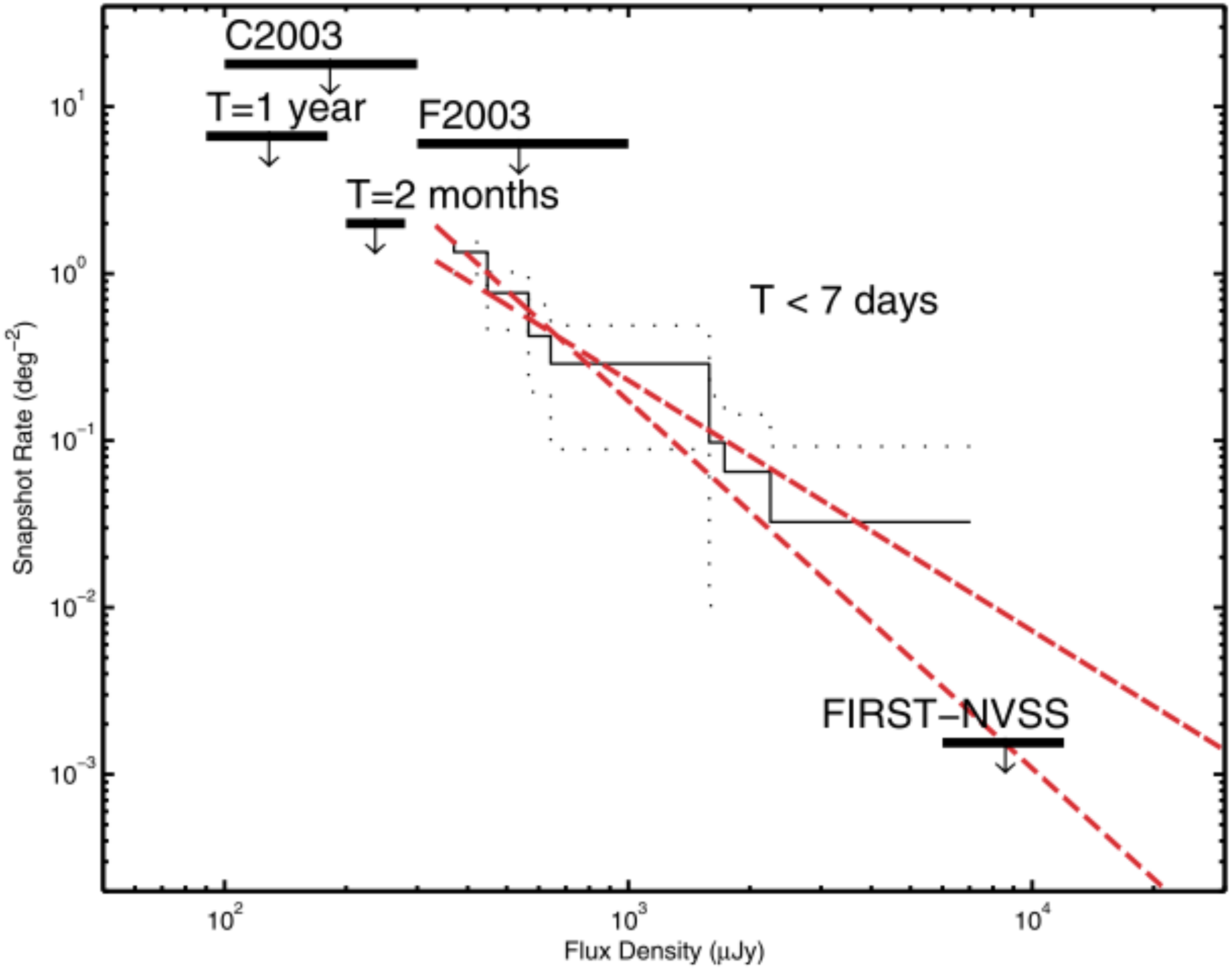
$$A\Omega\left(\frac{T}{\Delta t}\right) = \text{large}$$

$$A = \text{collecting area}$$
$$\Omega = \text{solid angle coverage}$$
$$T = \text{total duration of observations}$$
$$\Delta t = \text{time resolution}$$

Cordes, Lazio & McLaughlin (2004), New AR, 48, 1459

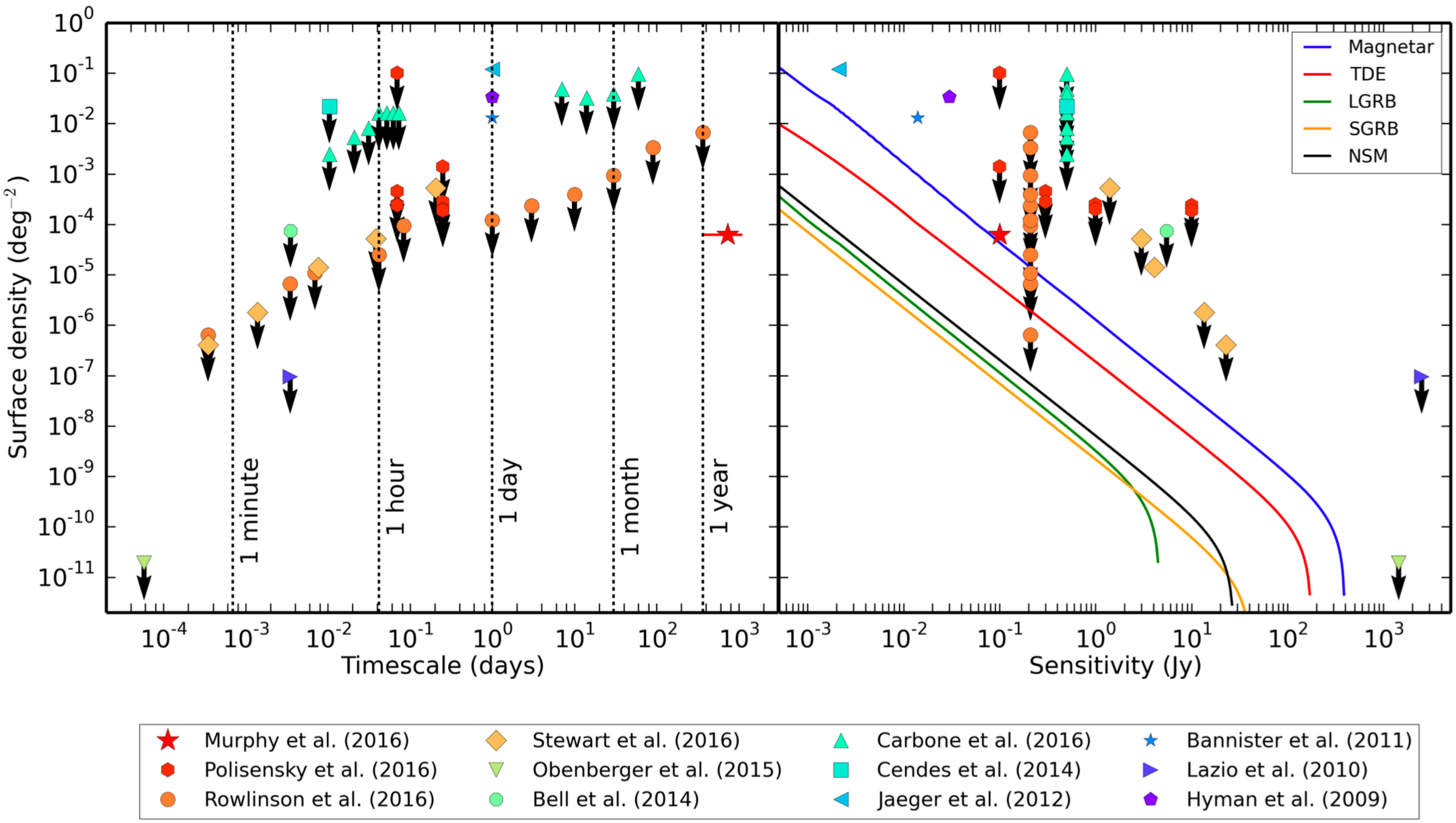
- The SKA and pathfinders will allow us to explore transient phenomena in a unbiased way for the first time

Transient snapshot rates (c. 2007)



Bower et al. 2007, ApJ, 666, 346

MHz snapshot rates (c. 2017)

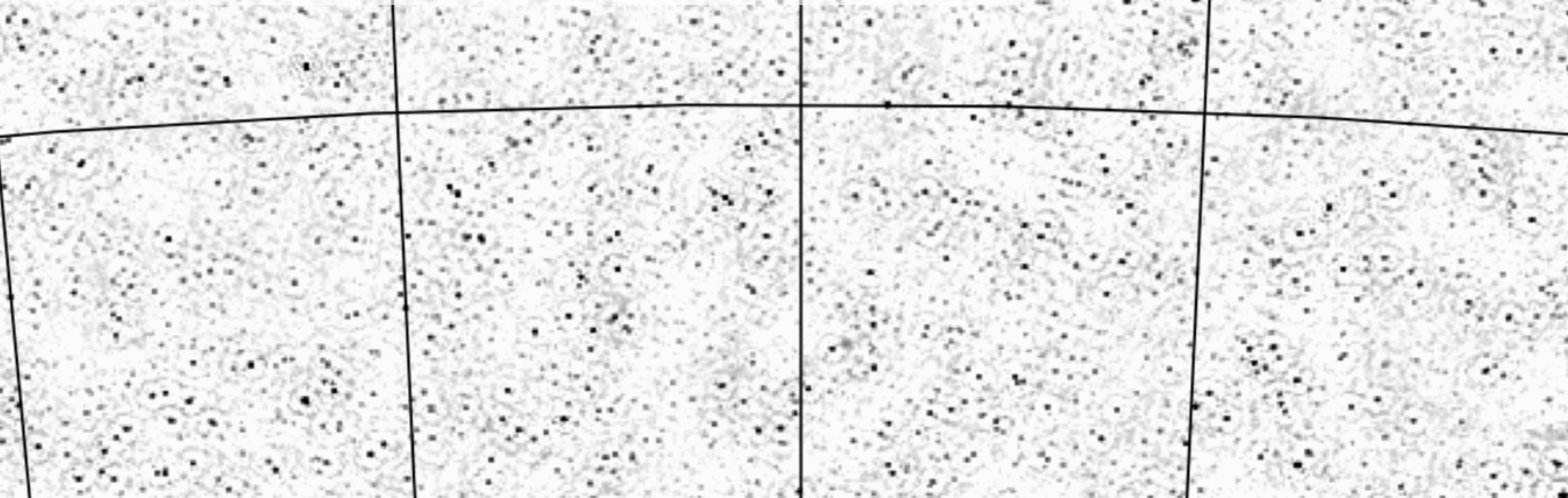


Murphy et al. 2017, MNRAS, 466, 1944

Results from blind surveys

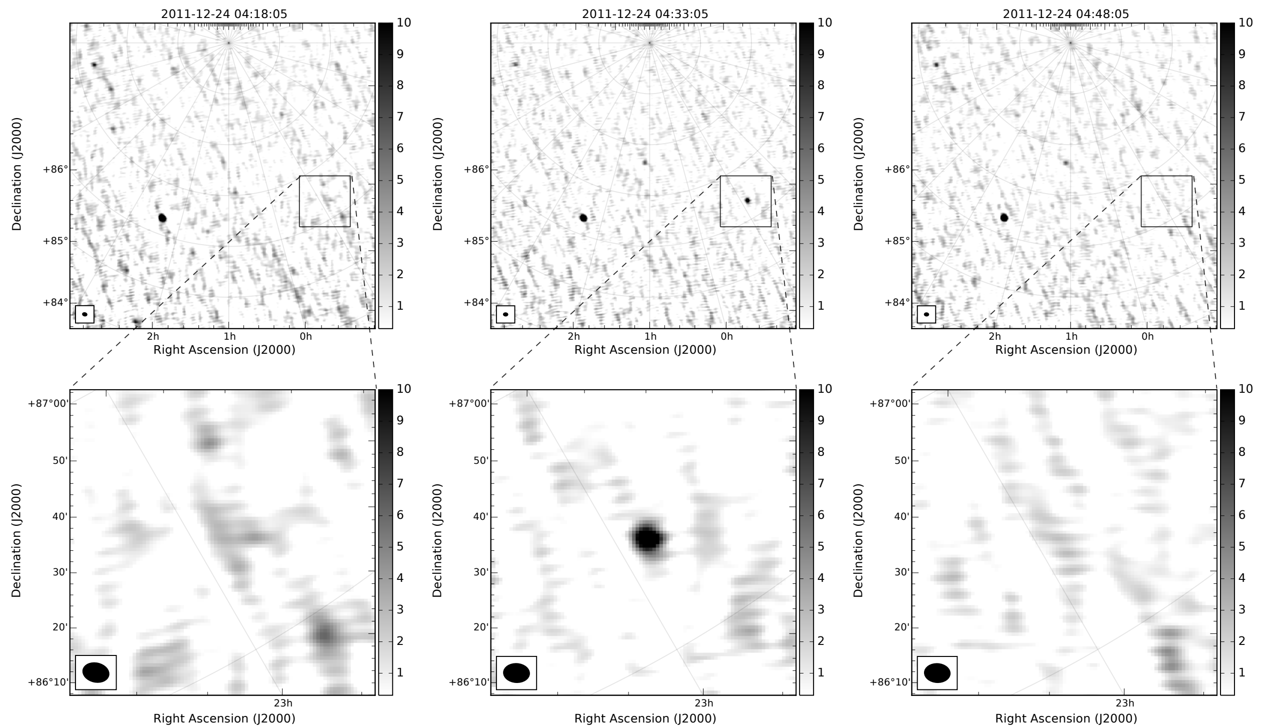
How transient is the low freq sky?

- **Rowlinson et al. (2016), MNRAS, 458, 3506**
- 10,122 images over 100 hours
- Timescales 28 s → 1 year
- Frequency 182 MHz
- Detection threshold 285 mJy
- Transient rate limit < 4.1×10^{-7} deg^{-2}



Results from blind searches

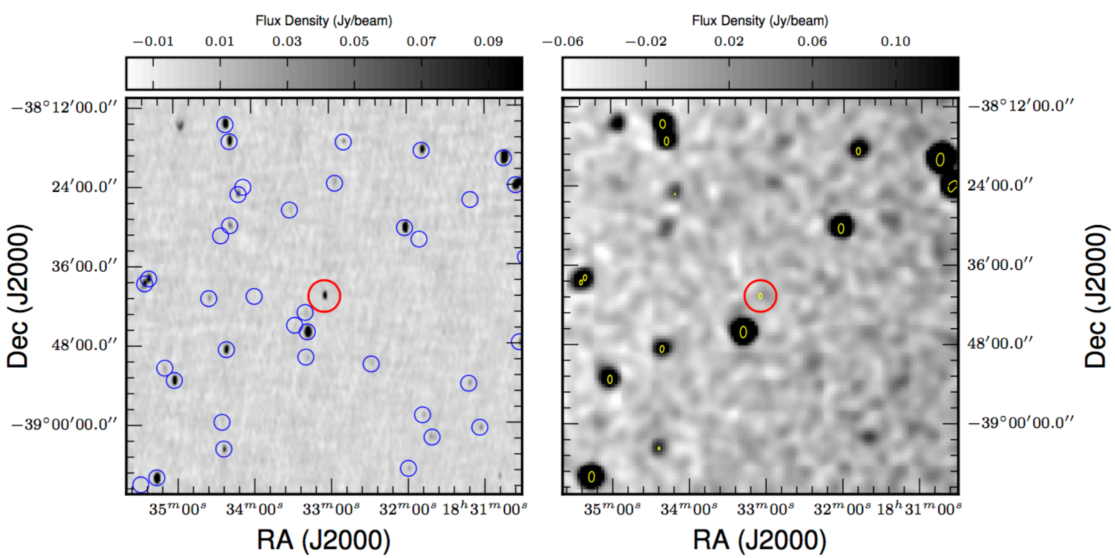
- LOFAR MSSS: 2149 x 11-min images, each covering 175 deg^2
- Frequency: 60 MHz
- Flux density 15-25 Jy

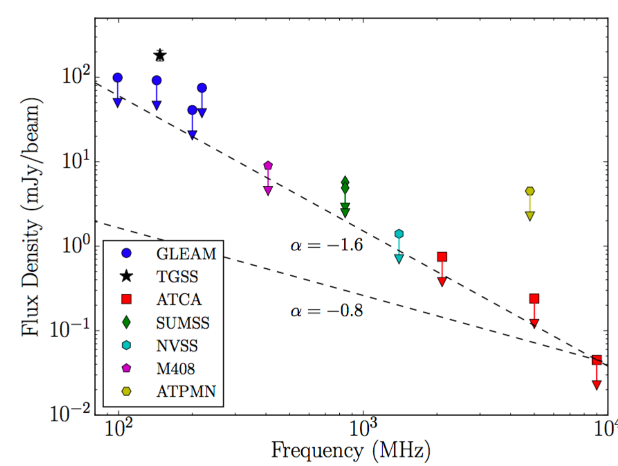


- Stewart et al. (2016), MNRAS 456, 2321
- Also blind detection of redback pulsar J2215+5135
- Broderick et al. (2016), MNRAS, 459, 2681

Results from blind searches

- First large scale transients search with MWA (GLEAM) and TGSS
- TGSS = Reprocessed GMRT 150 MHz survey (Intema et al. 2016)
- ~250,000 overlap between TGSS and GLEAM
- Selected compact sources > 100 mJy with no counterpart
- One source (182 mJy) in TGSS but not GLEAM, follow-up ongoing





Murphy et al. 2017, MNRAS, 466, 1944

How variable is the low freq sky?

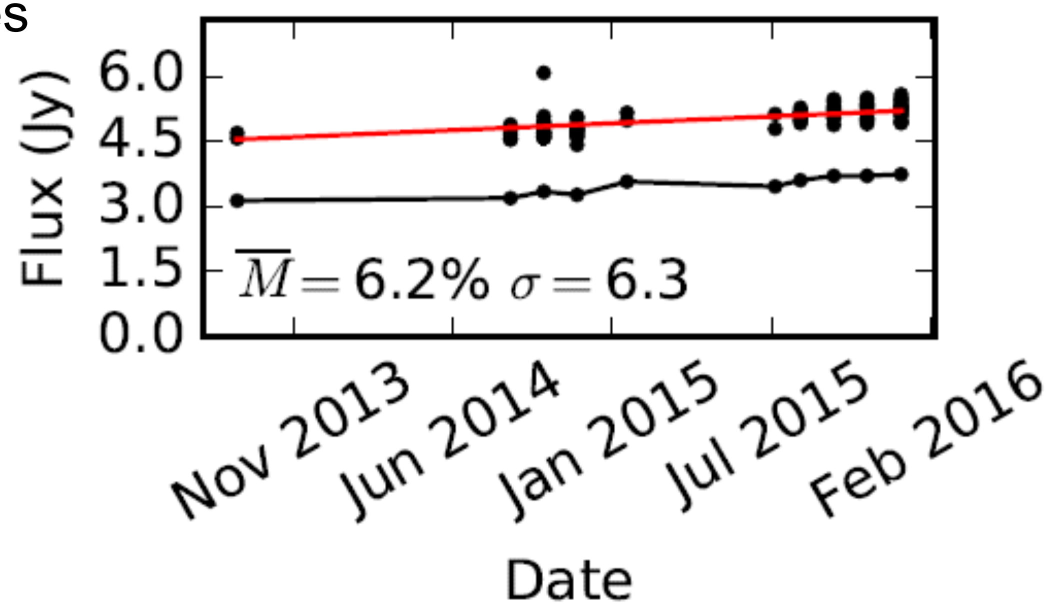
› Bell et al. (in prep) "*The Murchison Widefield Array Transients Survey*".

› Measured variability properties of 1000 **compact** and bright AGN

› 9/1000 AGN show significant variability at 5% level.

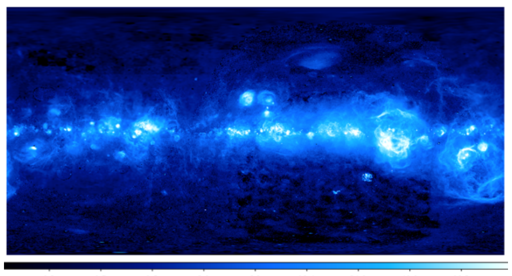
› Intrinsic AGN variability operates on timescales >100 years.

- Refractive scintillation is very rare and operates on timescales > 5-10 years and is not well sampled by this survey.
- SKA-Low will see low levels of variability on timescales < 5 yr for synchrotron emitters with angular diameter > milliarcsec.

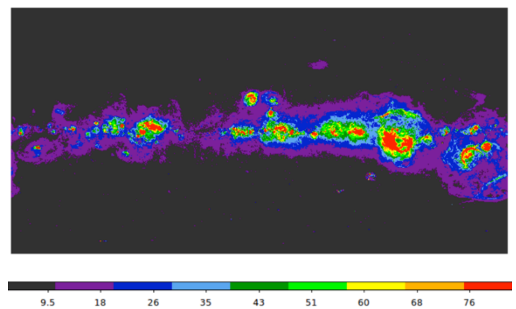


How variable is the low freq sky?

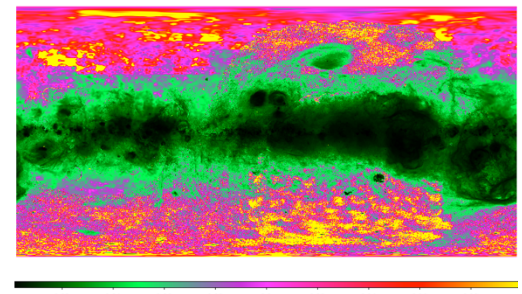
Scintillation is correlated with Hα emission



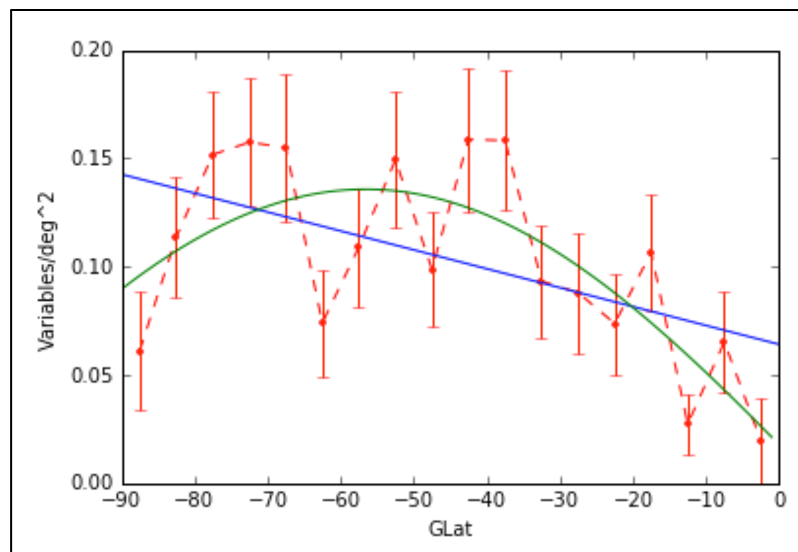
Incidence of variability is **greater** towards the plane



Degree of variability is **lower** towards the plane



Incidence and degree **compete** to give the observed distribution of variables / deg^2 vs latitude



Hancock & Macquart et al (*in prep*)

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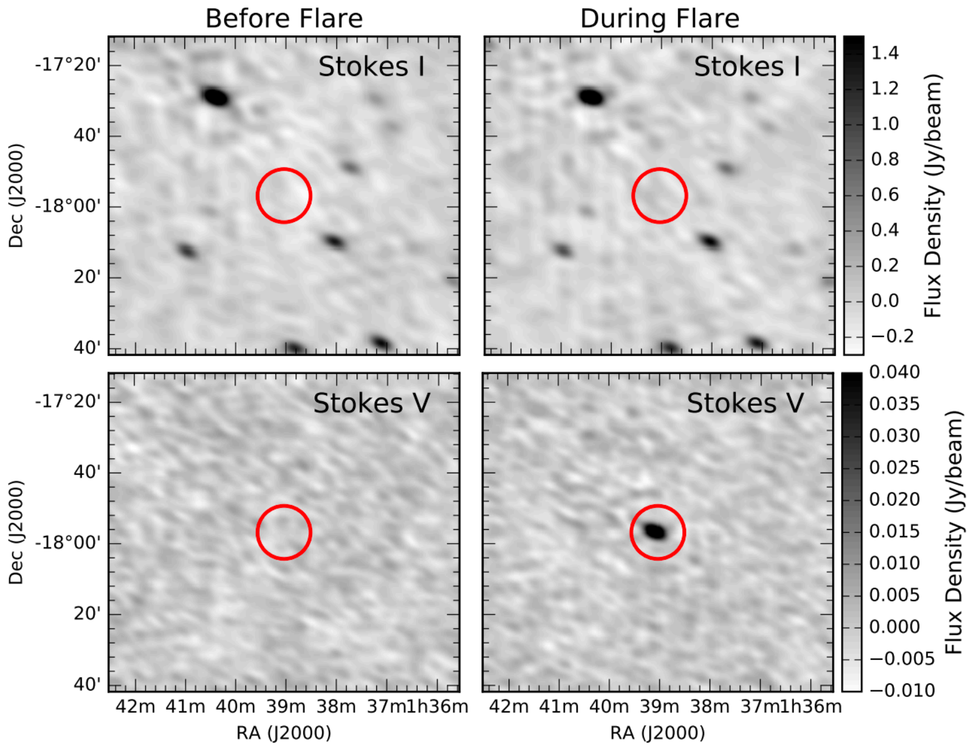
Transient sources at low frequencies

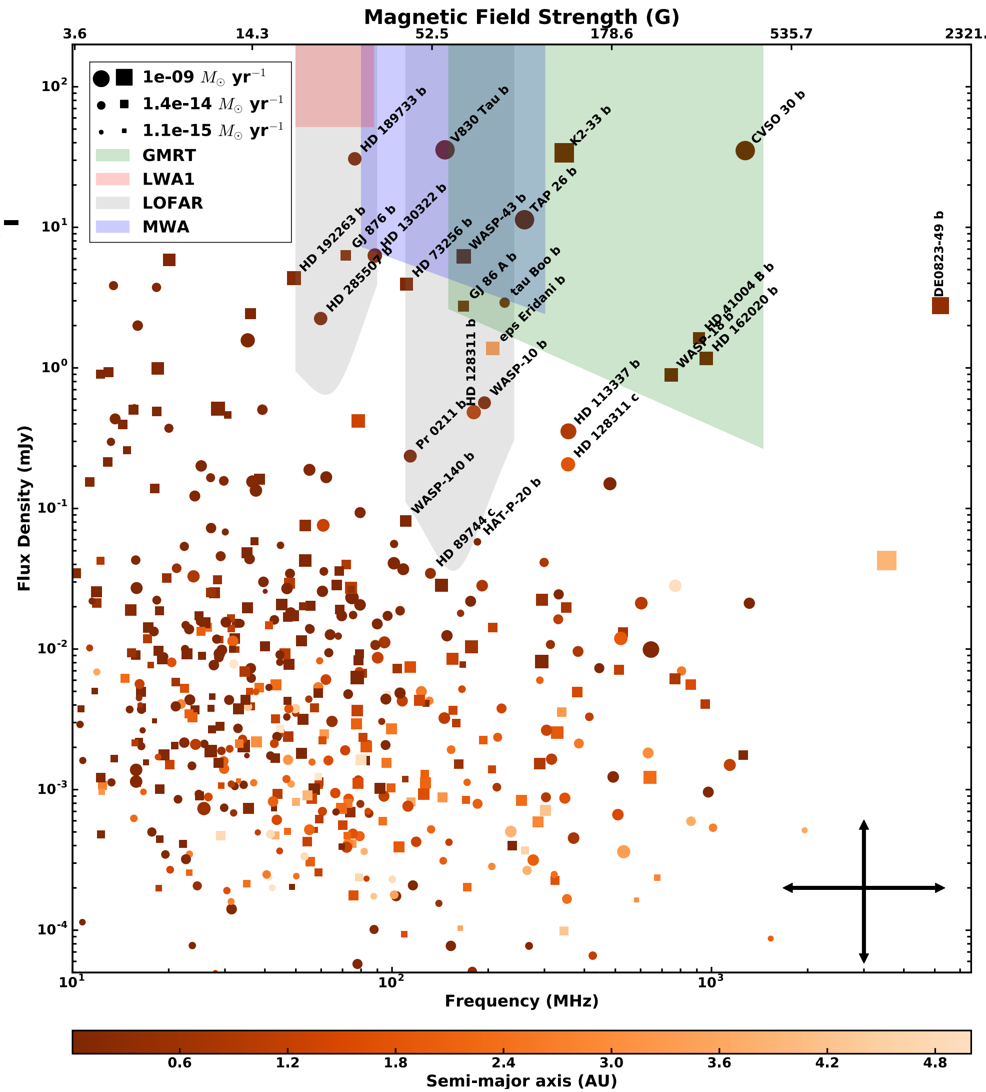
Radio emission from flare stars

- Lynch, Lenc et al. 2017, ApJ Letters, 836, 30
- *154 MHz Detection of Faint, Polarized Flares from UV Ceti*
- First result from campaign to study flare stars / low mass stars
- Unique way of probing magnetic field of stars
- Implications for planetary habitability around low mass stars
- Uses innovative technique of circular polarisation search to beat confusion limit



Searching for exoplanets

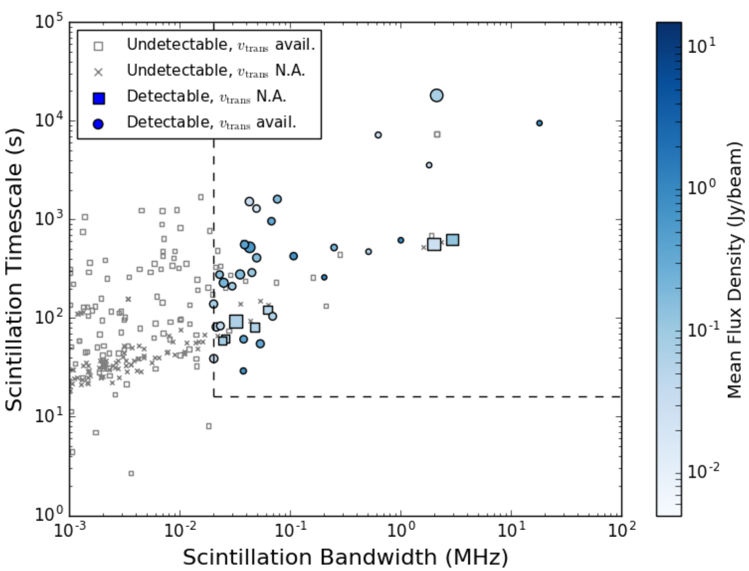
- Jupiter has strong radio emission
- Potential to make *direct* radio detection of magnetised extra-solar planets
- Hot super-Jupiters could be detected with current low frequency instruments
- Implications for planetary habitability
- Developing techniques useful for SKA



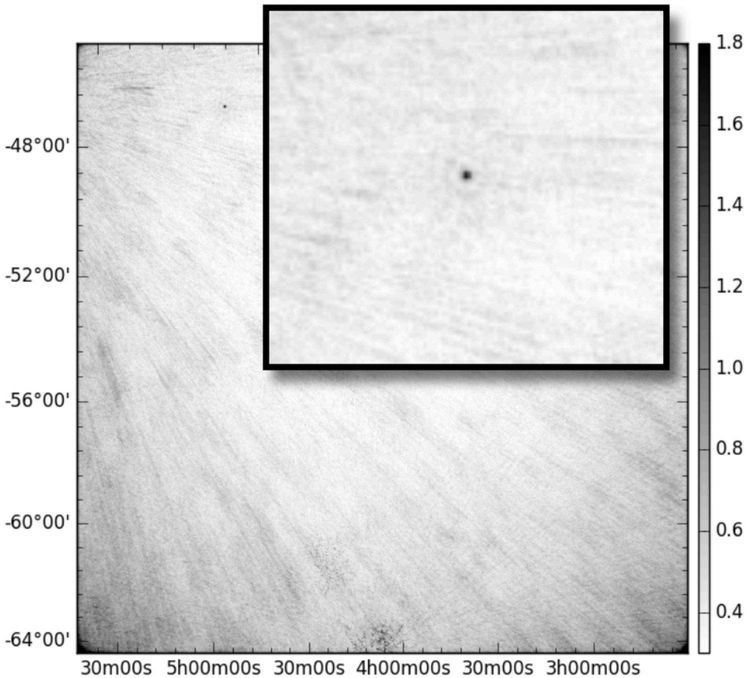
- *(Lynch et al. in prep)*

Image plane pulsars

- Use scintillation properties of pulsars to detect in image plane
- Experiment with detection metrics
  - Variance imaging (e.g. Dai et al. 2016)
  - Flux density distribution (Macquart, Ekers, Lenc)
  - Difference imaging (Lenc et al.)



Zic et al.

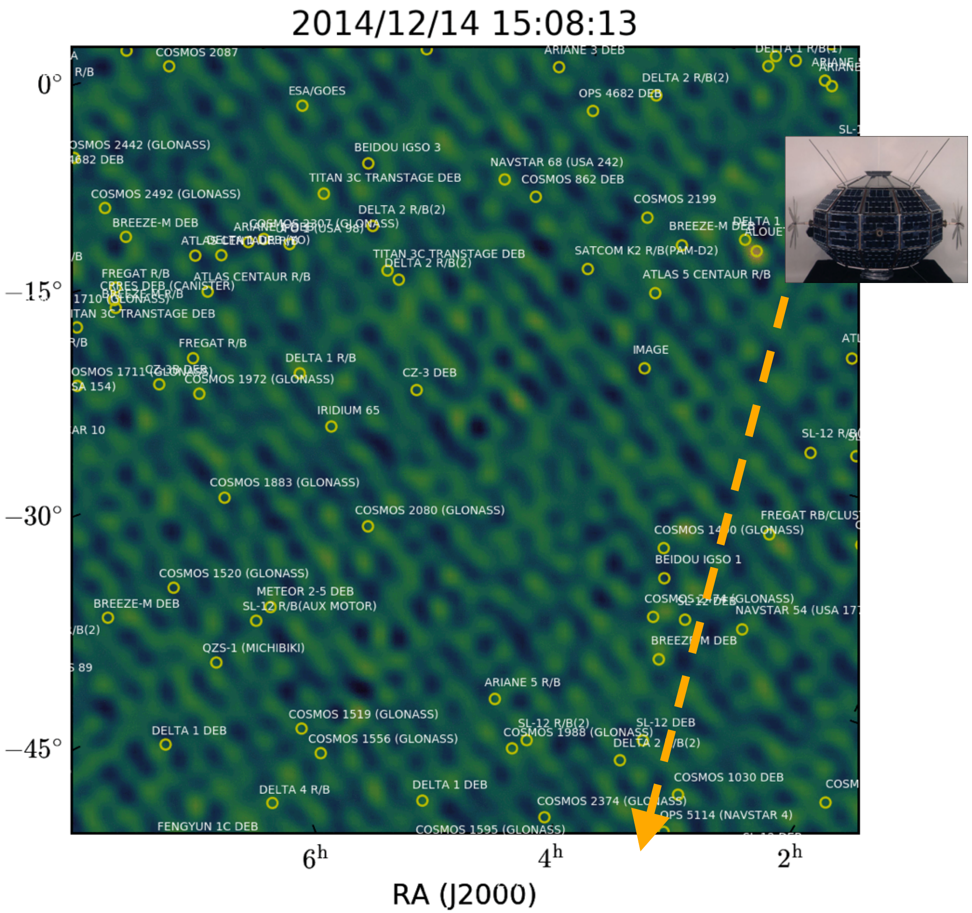


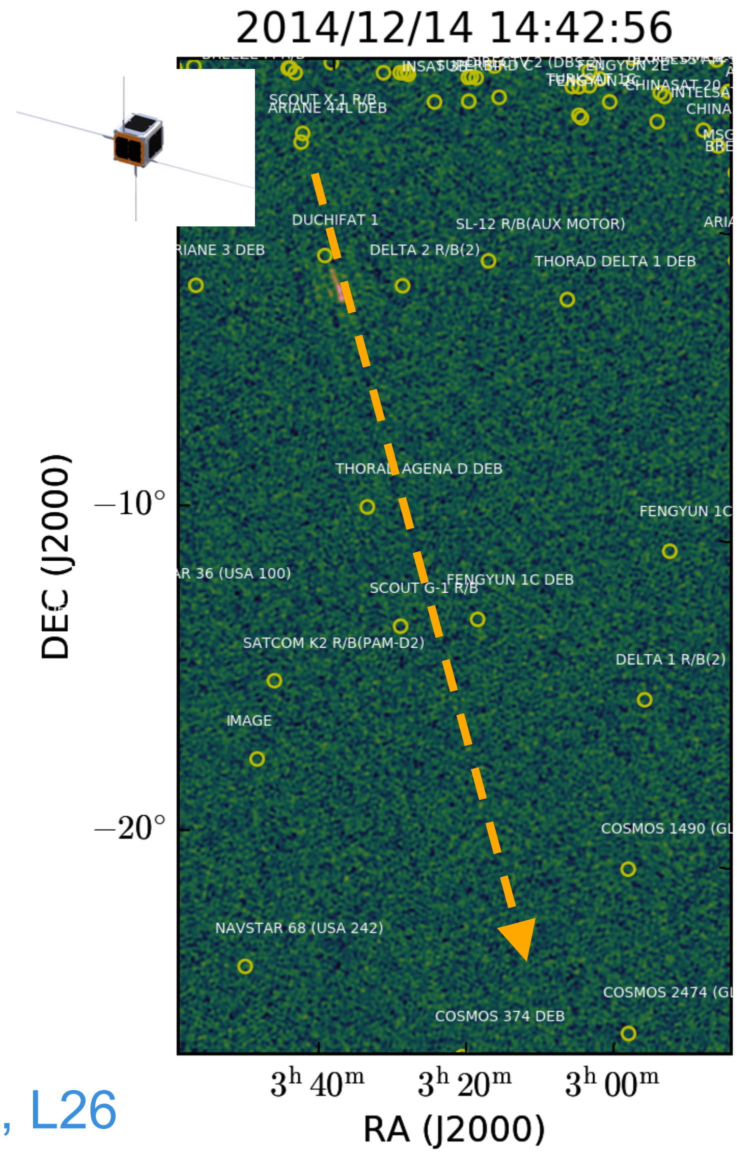
Lenc et al.

Fireballs, satellites and more

Detection of low Earth orbit satellites:
Alouette-2 (below) and Duchifat-1 (right)

Zhang, Wayth, Hancock et al.

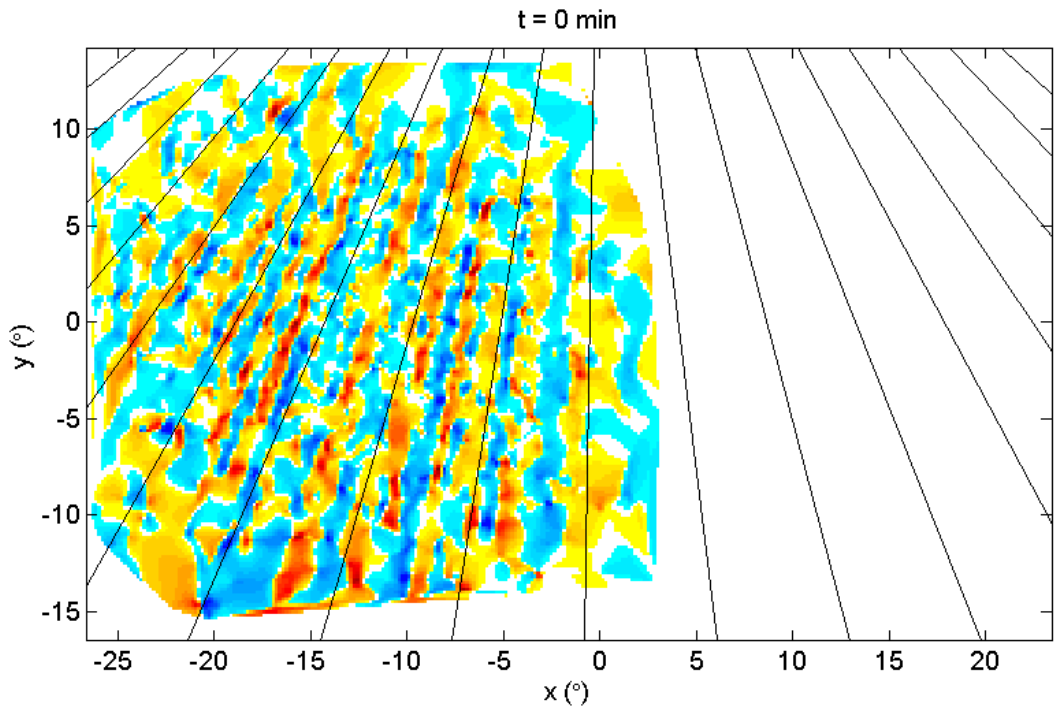




LWA Fireballs: Obenberger et al. (2015), 788, L26

Understanding the ionosphere

- MWA sees ~1000 point sources instantaneously
- Measure Total Electron Content (TEC) gradient as a function of time
- Can access spatial scales of 10-100s of kilometres
- Typical position offsets 10-12 arcsec (99% sub-pixel)
- Typical fractional flux density variation 1-3%
- Can also detect **field-aligned irregularities and travelling ionospheric disturbances**



Loi et al. 2015, Geo RL, 42, 3707
Loi et al. 2015, Radio Science, 50, 574
Loi et al. 2015, MNRAS, 453, 2731
Loi et al. 2016, JGRA, 121, 1569
Loi et al. 2016, Radio Science, 51, 659

LIGO GW event follow-up

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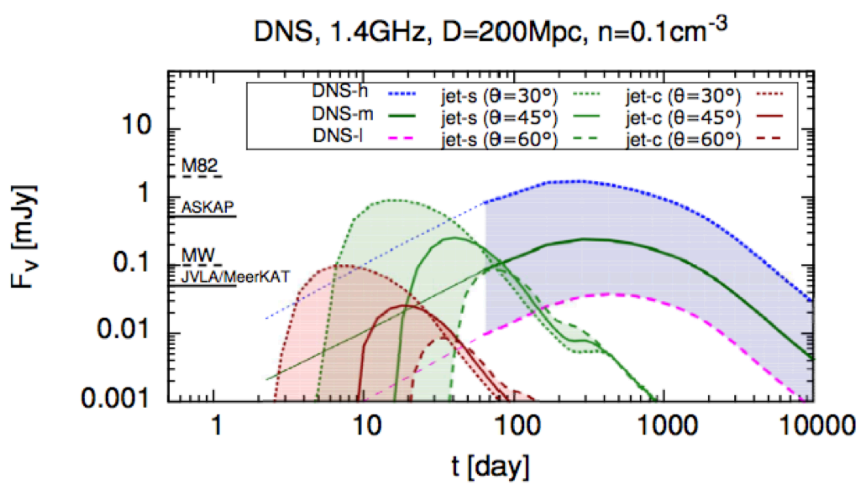
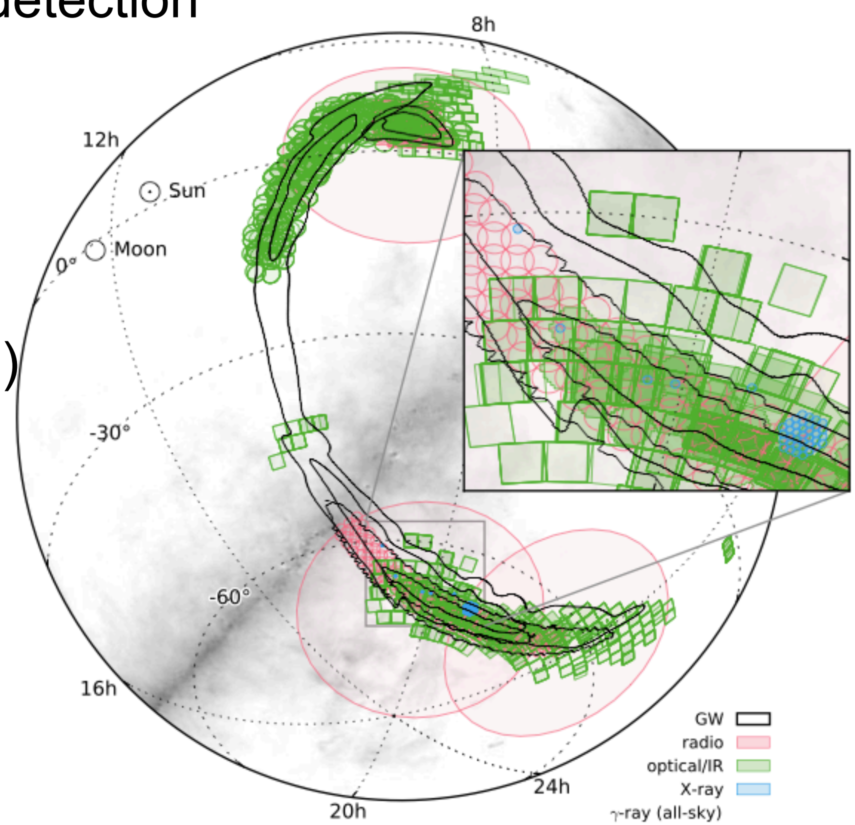
- 90% error region for GW150914 is 630 deg^2
- Number of galaxies within comoving volume of 10 Mpc is ~10^5
- Impossible to identify host without EM detection
- Types of emission we could detect:
  - prompt emission (seconds)
  - sub-relativistic merger ejecta (years)
  - ultra-relativistic jets (weeks to months)





Lessons and challenges

- The low frequency radio sky is relatively quiet…
  - at the sensitivities and time scales we have explored so far
- We are now approaching model predictions for source rates
  - starting to make first interesting detections (e.g. flare stars, ESEs)

- Survey design: is **commensal** observing enough?
- Exploring different techniques for image (LST-aligned images, image subtraction, no deconvolution)
- Need to get imaging and transient detection pipelines operating closer to real-time to maximise the science
  - **imaging speed** is a major challenge
- There is a lot to learn from MWA, LOFAR, ASKAP, experiences
  - it is critical that SKA developers are aware of this work

Radio transients postdoc

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2-year postdoctoral position in radio transients

Working on the Australian SKA Pathfinder telescope

https://jobregister.aas.org/job_view?JobID=60817

Deadline June 30th, 2017

Email: tara.murphy@sydney.edu.au

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SALF IV - Sydney

Science at Low Frequencies IV

University of Sydney, Australia

December 13th – 15th, 2017

Workshops / breakouts 12th December

Registration closes 28th July

http://www.physics.usyd.edu.au/salf_iv/