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ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

Exploring the Dynamic Radio Sky

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Australian Government
Australian Research Council

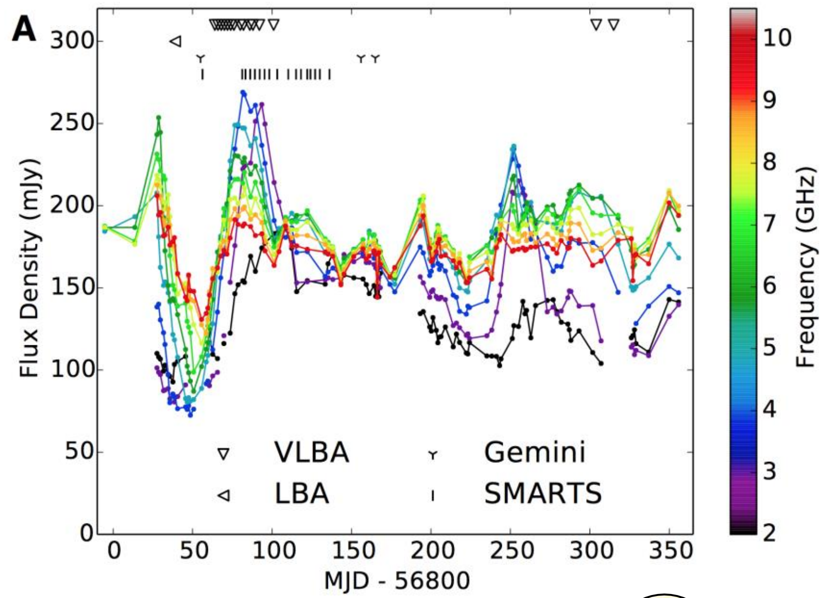
What causes radio variability?

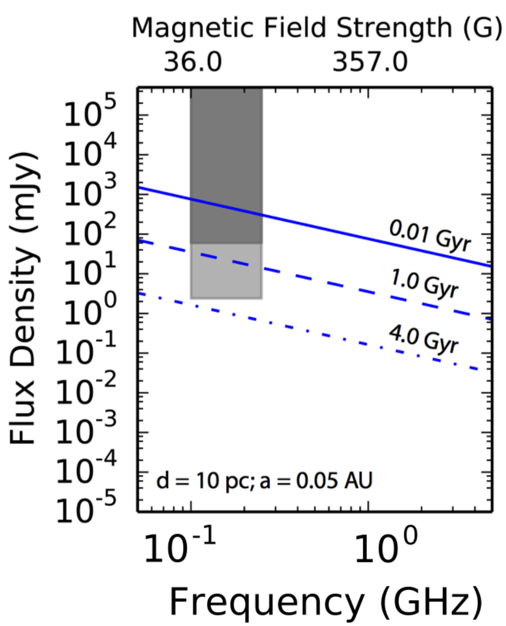
1. **Explosions**
   - e.g. supvae, gamma-ursts, orphan afterglows

2. **Propagation**
   - e.g. interstelintillation, extreme scattering events
3. **Accretion**
   - e.g. neustars, blales, qus, X-ray binaries
4. **Magnetospheric**
   - e.g. magrs, flare stars, planetariability
5. **Unknowns**
   - e.g. knownowns, unknowknowns, …

Lots of interesting questions

- Use Extreme Scattering Events to map neutral gas in our Galaxy
- Can account for some fraction of baryonic dark matter
- First real time detection of an ESE *Bannister et al. 2016, Science 351, 354*





- 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 *Lynch et al. in prep*

Exploring the unknown

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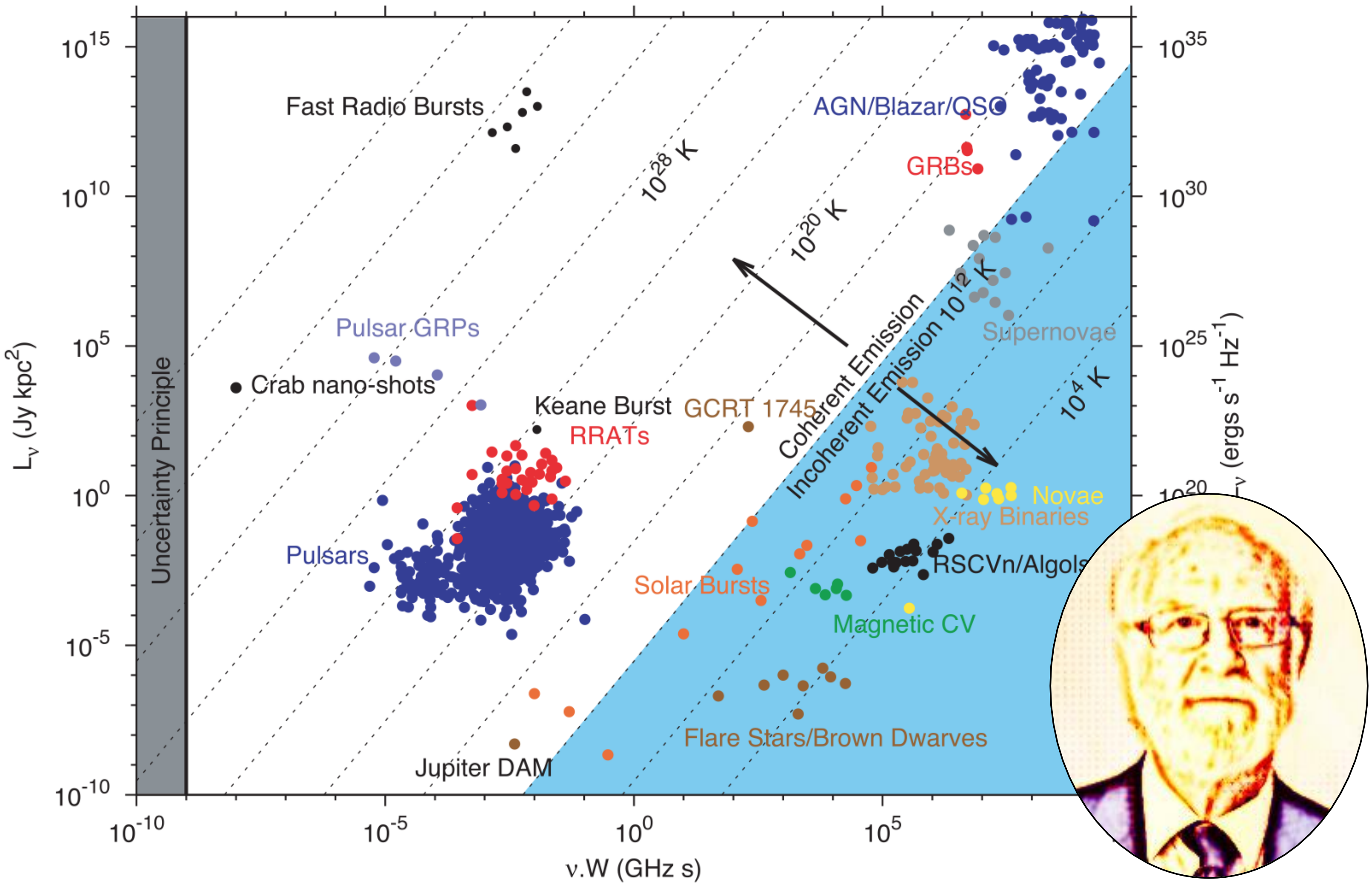


Pietka, Fender & Keane, 2015, MNRAS, 446, 3687

An ideal survey design

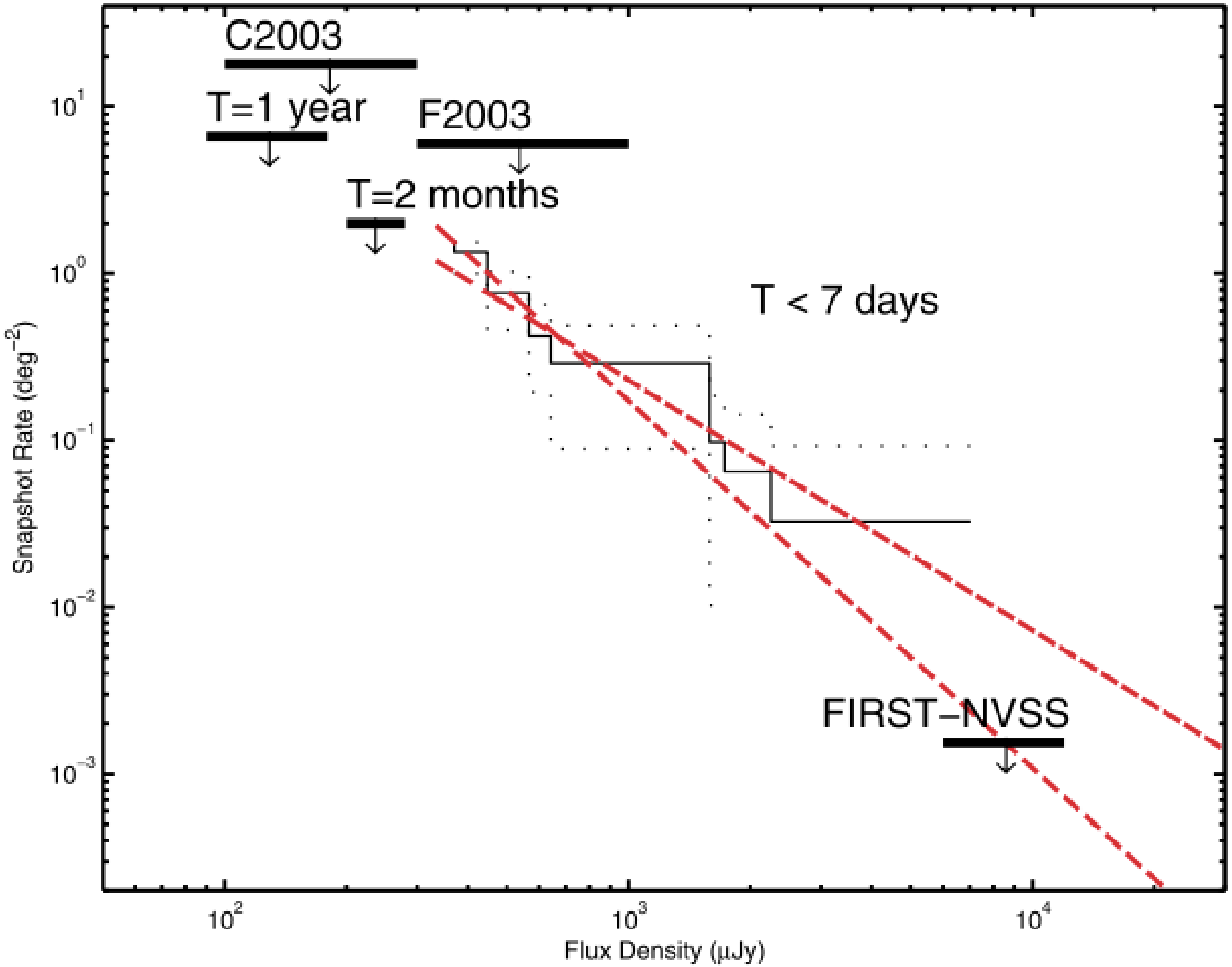
- Radio surveys have given us a largely static view of the sky
- A figure of merit for unbiased transient detection is:

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

A = collecting area
Ω = solid angle coverage
T = total duration of observations
Δt = time resolution

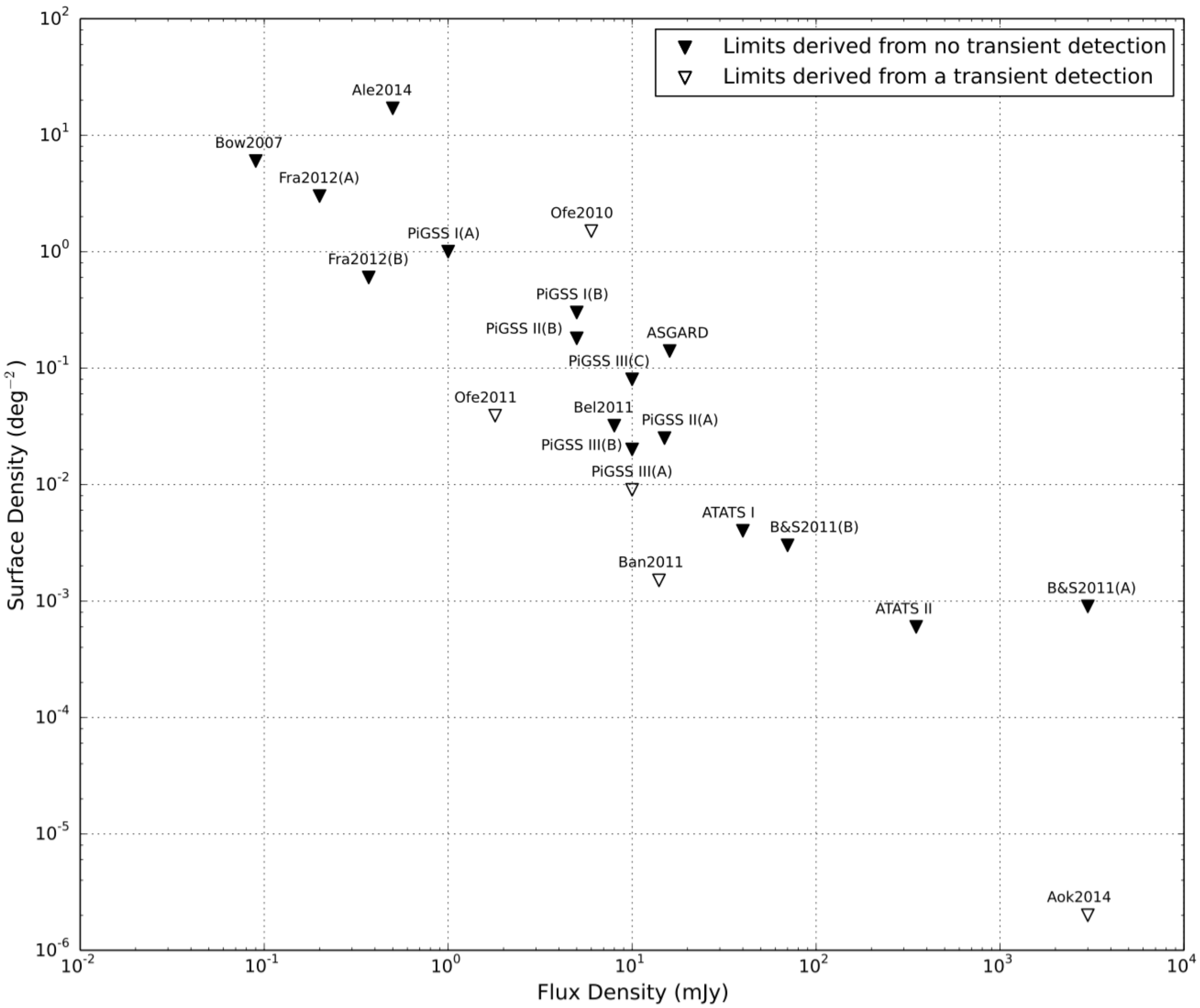
- The SKA and its pathfinders will allow us to explore transient phenomena in an unbiased way, for the first time

Transient snapshot rates (c. 2007)



Bower et al. 2007, ApJ, 666, 346

Transient snapshot rates (c. 2015)



Fender et al. 2015, Proc. of Science

Transient snapshot rates (c. 2016)

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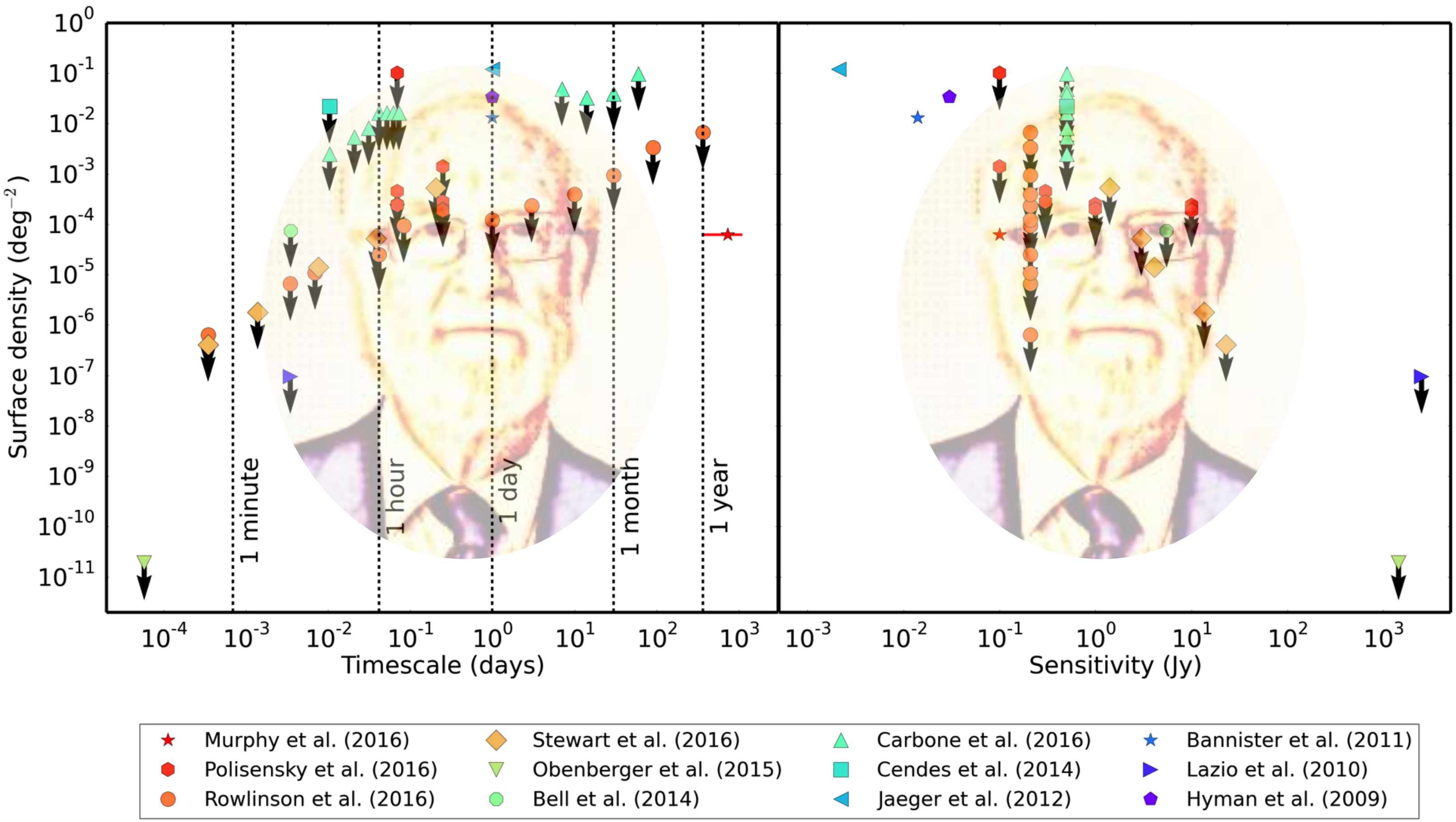
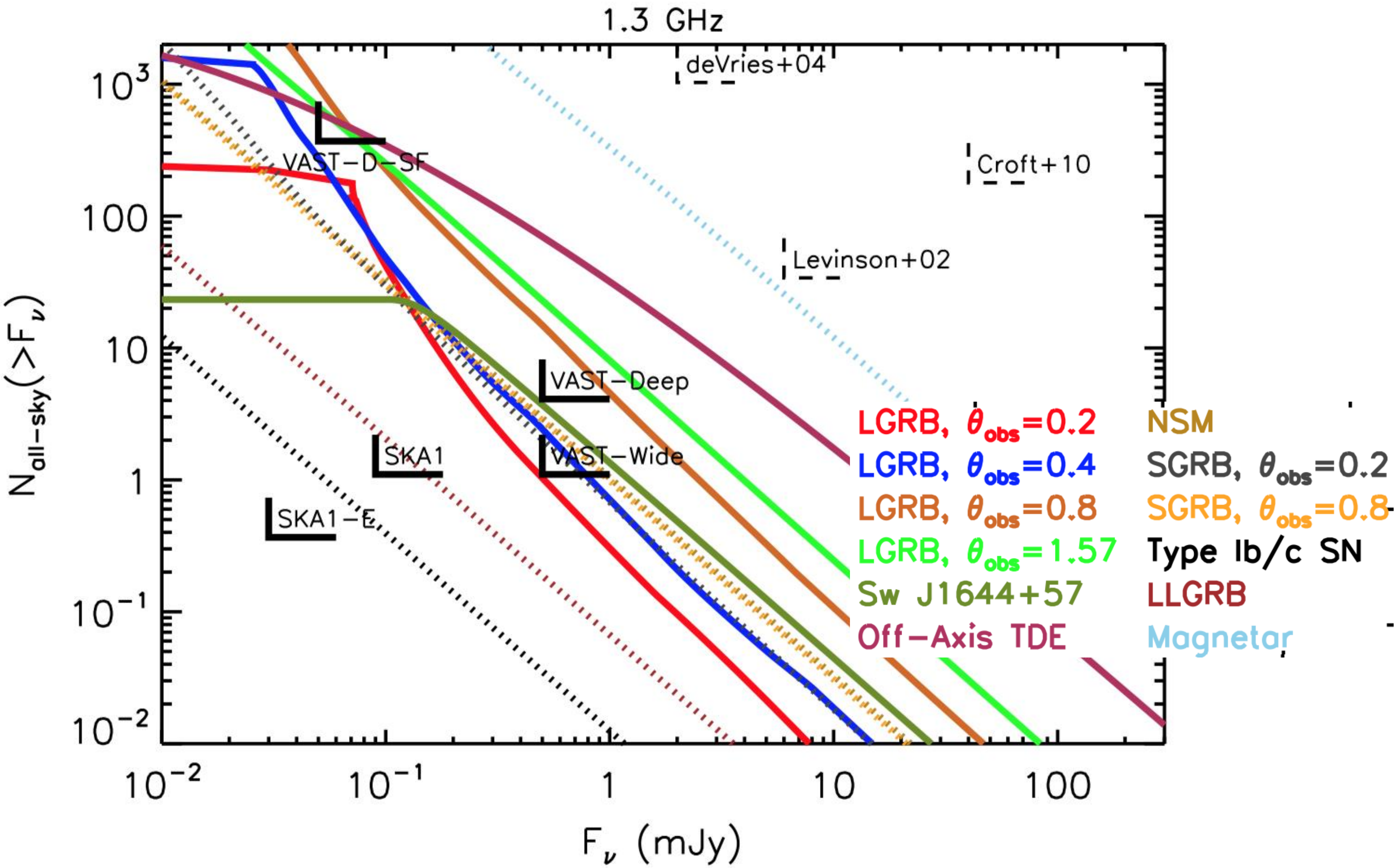
- With MWA we have set the best low-frequency limits transient rates



Murphy et al. 2016, submitted

Approaching the detection threshold



Metzger, Williams & Berger 2015, ApJ, 806, 224

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The Murchison Widefield Array

Image credit: Peter Wheeler

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The Murchison Widefield Array

- LIGO O2 run in later 2016 (Kaplan, Murphy et al.)
- Multi-messenger: neutrinos (Croft et al.)
- Fast radio bursts (Kaplan, Tingay et al.)
- Triggering real-time follow-up (Williams et al.)
- Blind surveys (Murphy, Bell, Hancock, Rowlinson et al.)
- Pulsar variability (Bell, Murphy, Kaplan et al.)
- Flare stars and exoplanets (Lynch, Murphy et al.)
- Galactic centre monitoring (Kaplan, Miller-Jones, Croft et al.
- Galactic plane survey (Kaplan, Miller-Jones, Croft et al.)

ASKAP transients

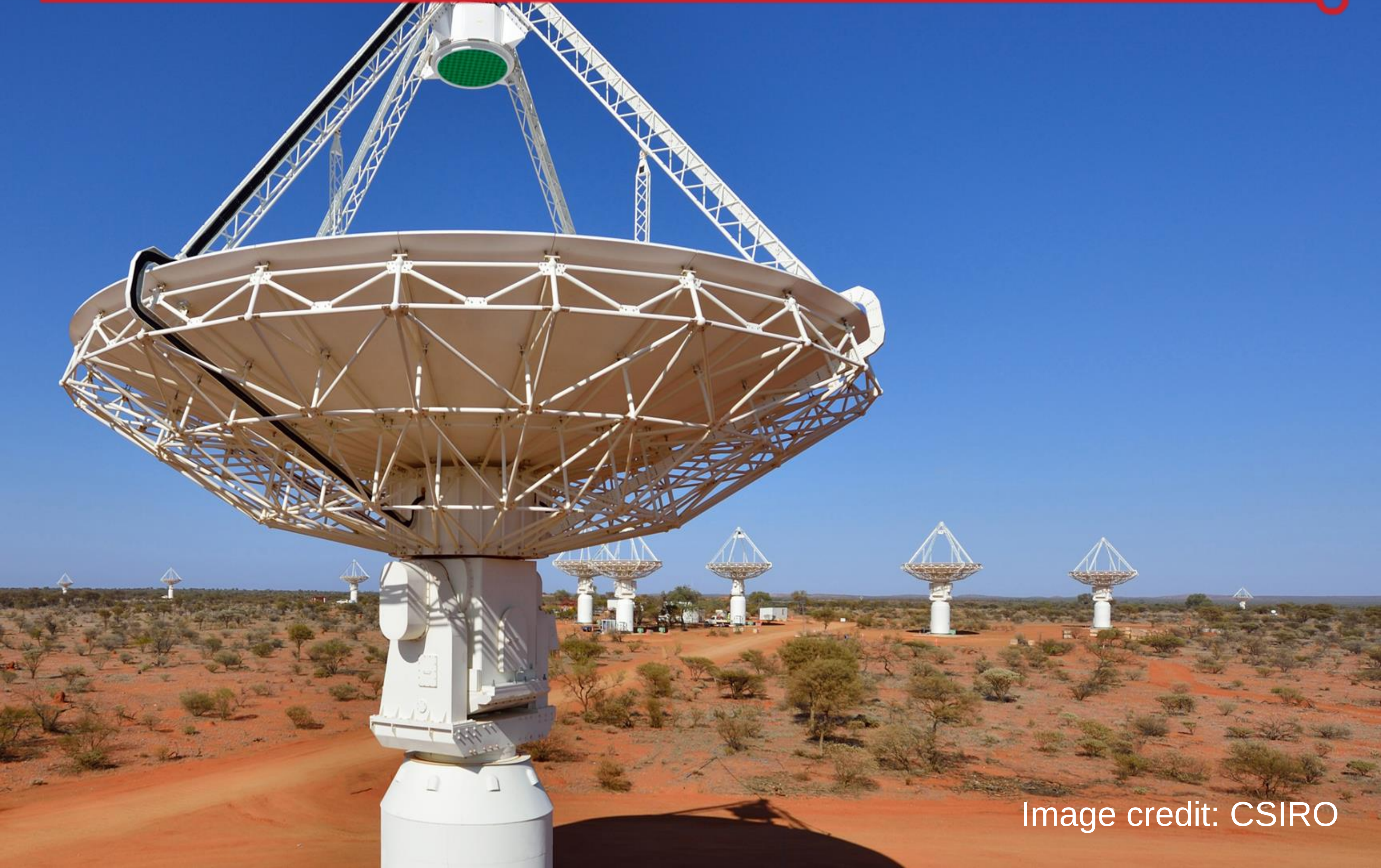


Image credit: CSIRO

ASKAP transients

- VAST: An ASKAP Survey for Variables and Slow Transients

- Intermittent pulsar PSR J1107-5907 (Hobbs et al.)
- Multi-epoch continuum survey (Heywood et al.)
- Gravitational wave event follow-up

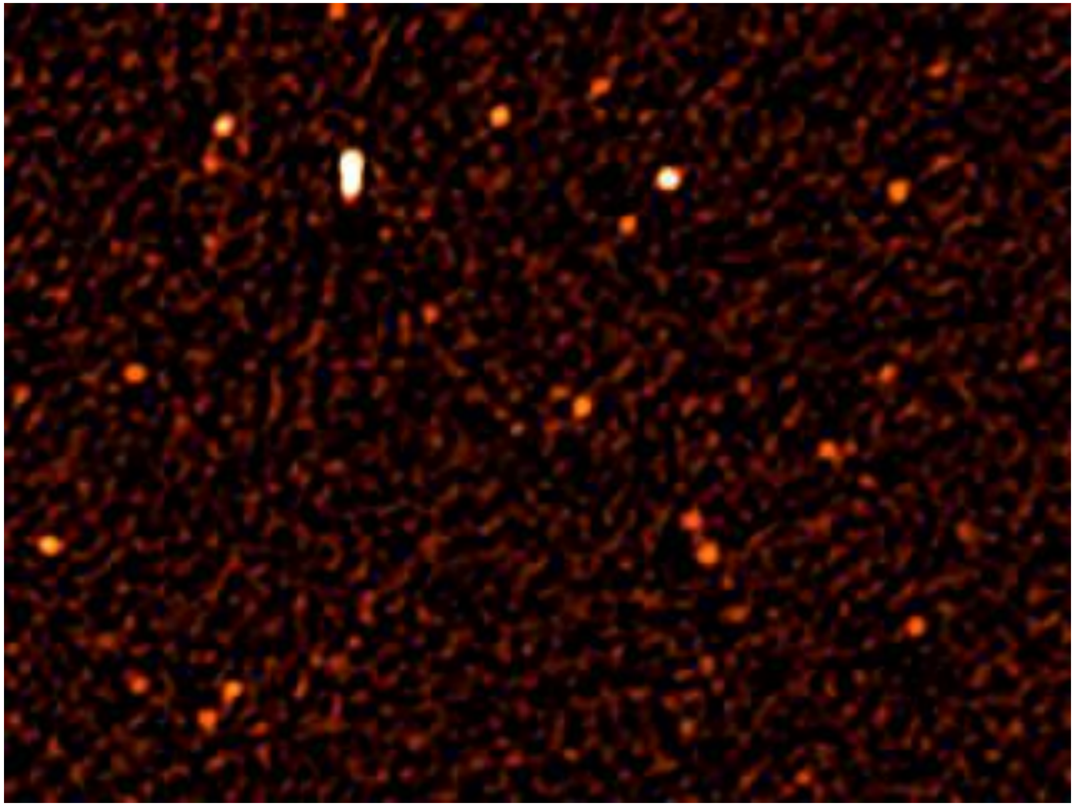
- Developing and testing transient detection pipelines

Waves in the sky:
A story of discovery

Investigating the ionosphere

› How much does the ionosphere contribute to variability?

› We knew there were bad nights, but what was typical?



Movie credit: Natasha Hurley-Walker

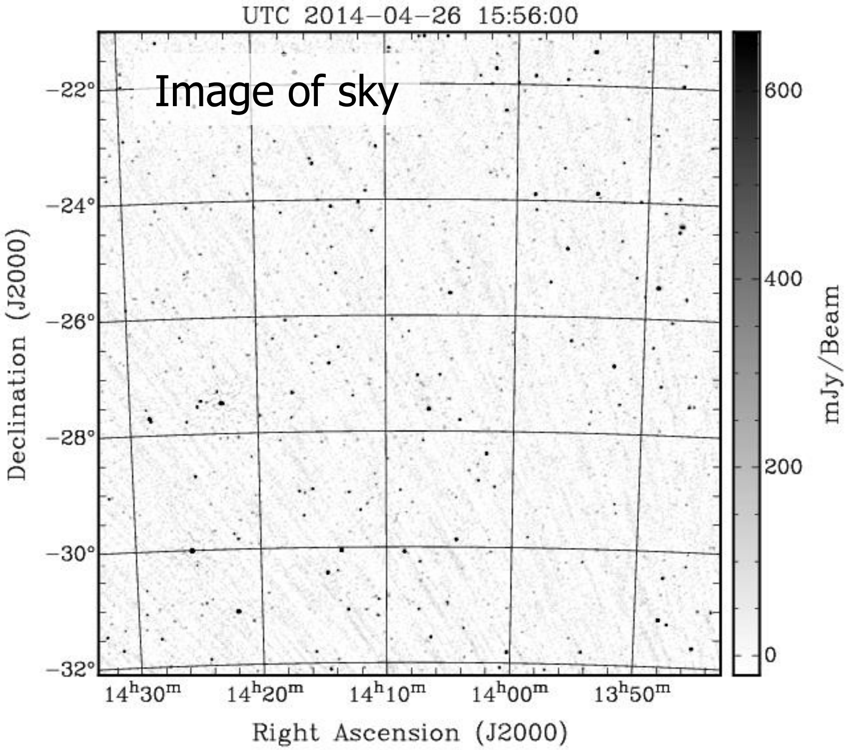
- Scintillation event @ 183 MHz on 15th Oct 2013, 1346-1517 UTC
- Mildly disturbed geomagnetic conditions
- Position shifts
- Shape distortions
- Amplitude variations

Mapping density gradients

› 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



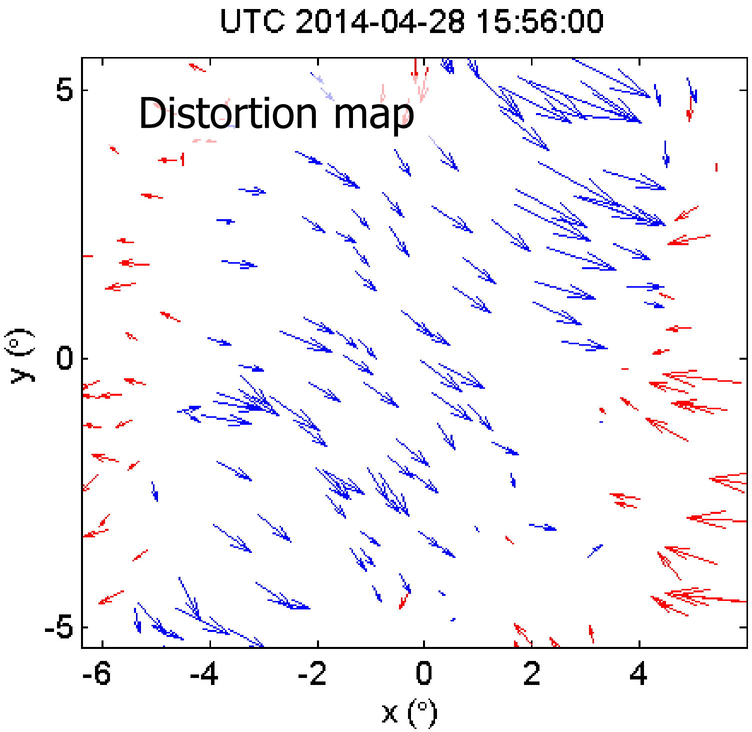


Image credit: Cleo Loi

A strange pattern in the sky

- Probably artefacts: sidelobes, gridding problems, tile position errors?
- Turns out to be **field-aligned irregularities**

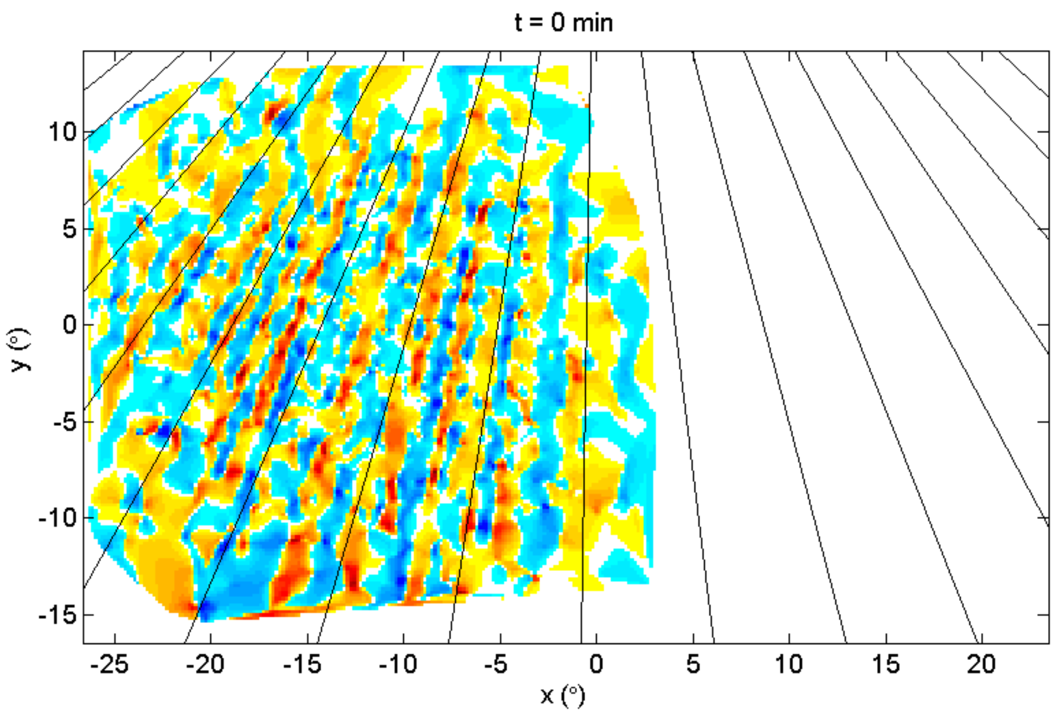
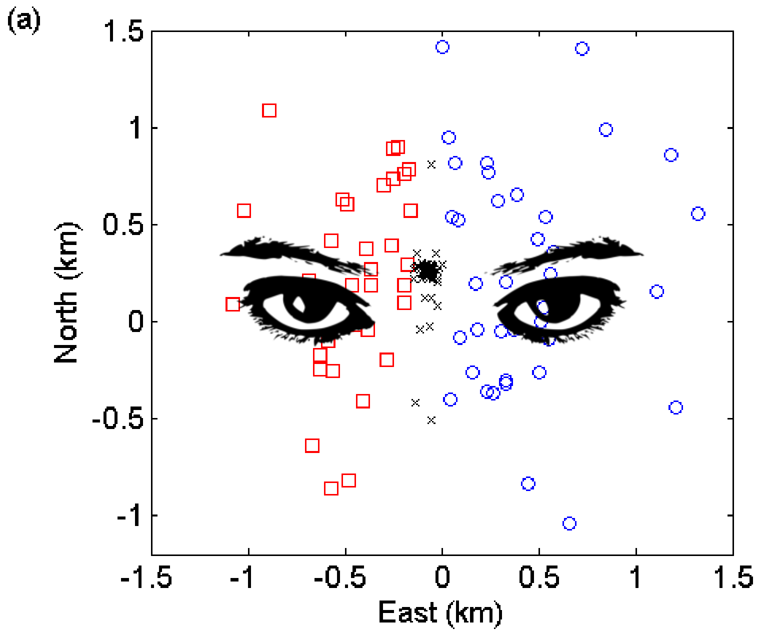
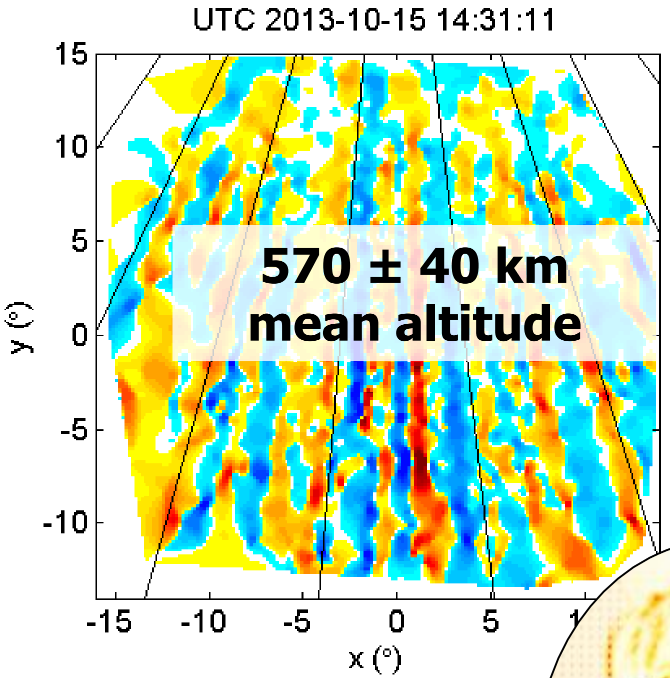


Image credit: Cleo Loi

Imaging the sky in 3D

› Could we actually place these irregularities in the ionosphere?





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

MWA is special

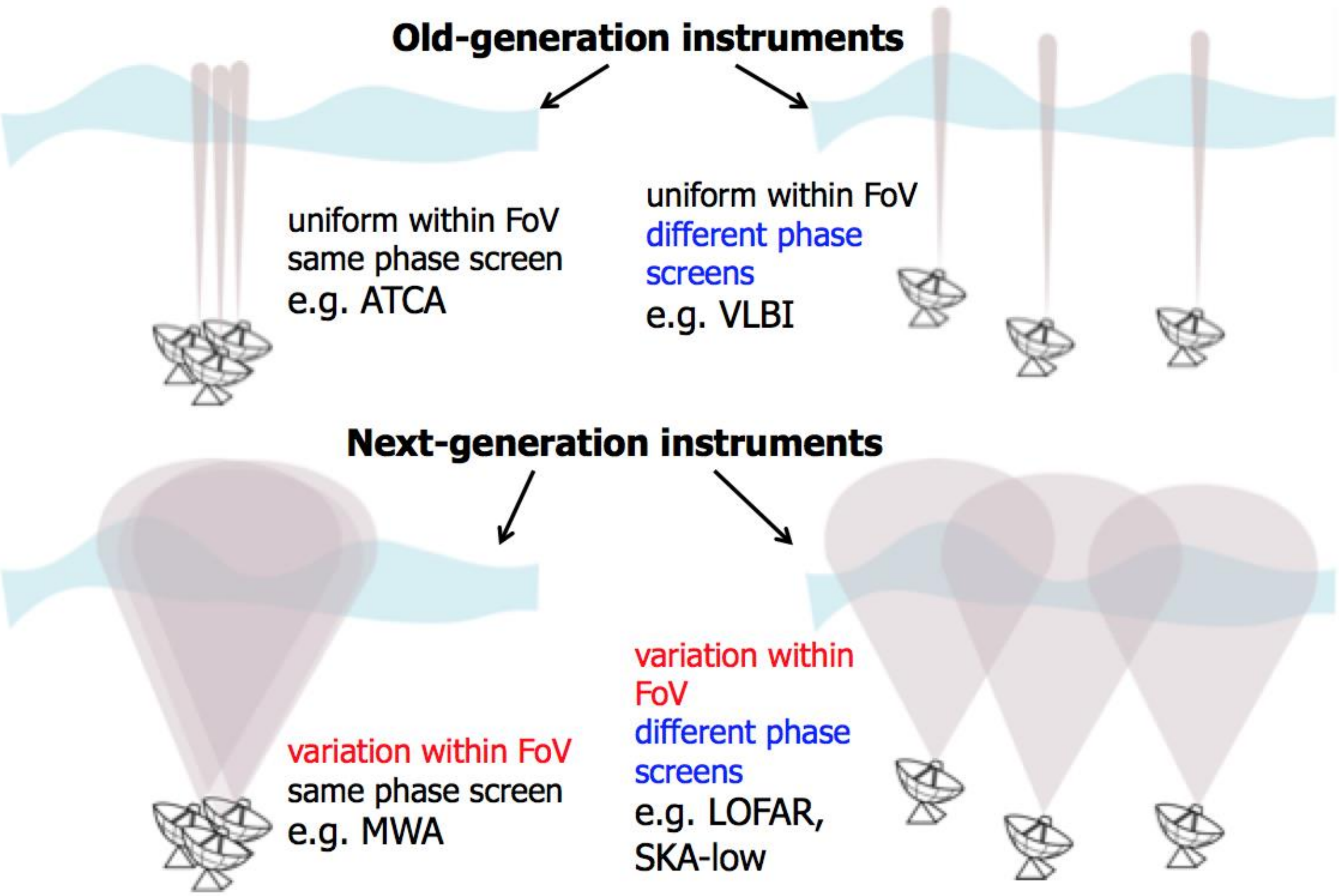


Image credit: Cleo Loi

A story of student innovation

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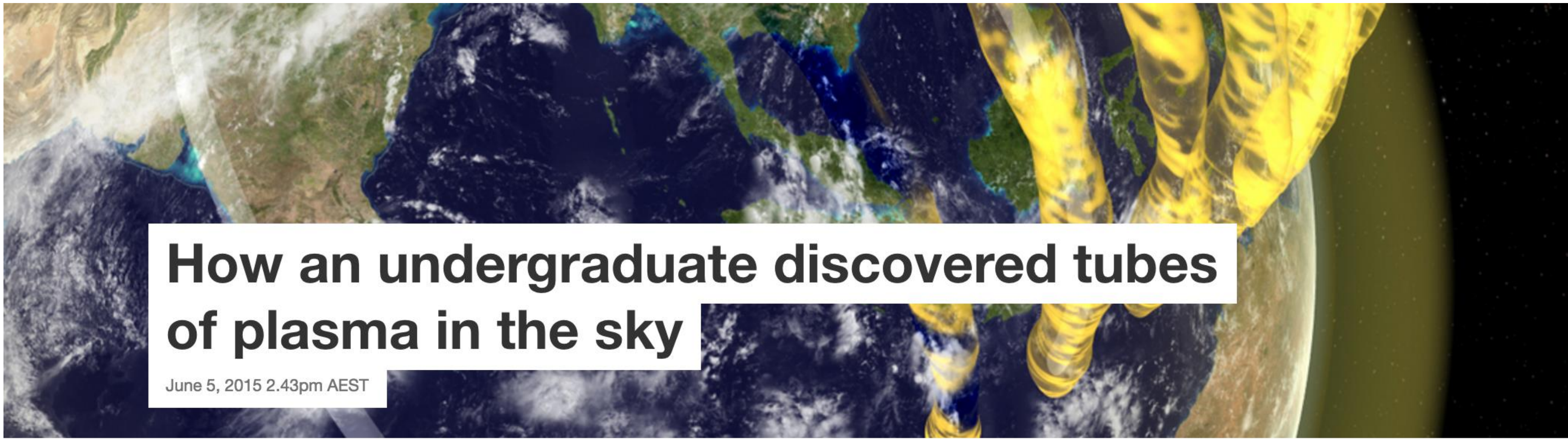

How an undergraduate discovered tubes of plasma in the sky

June 5, 2015 2.43pm AEST

A 3D visualisation of the plasma tubes conforming to the Earth's magnetic field. CAASTRO, Author provided

Email
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The discovery by an undergraduate student of tubes of plasma drifting above Earth has made headlines in the past few days. Many people have asked how the discovery was made and, in particular, how an undergraduate student was able to do it.

The answer is a combination of an amazing new telescope, a very smart student and an unexpected fusion of two areas of science.

Here is how it all happened, from my perspective as the academic who supervised the project at the Sydney Institute for Astronomy.

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Contributor

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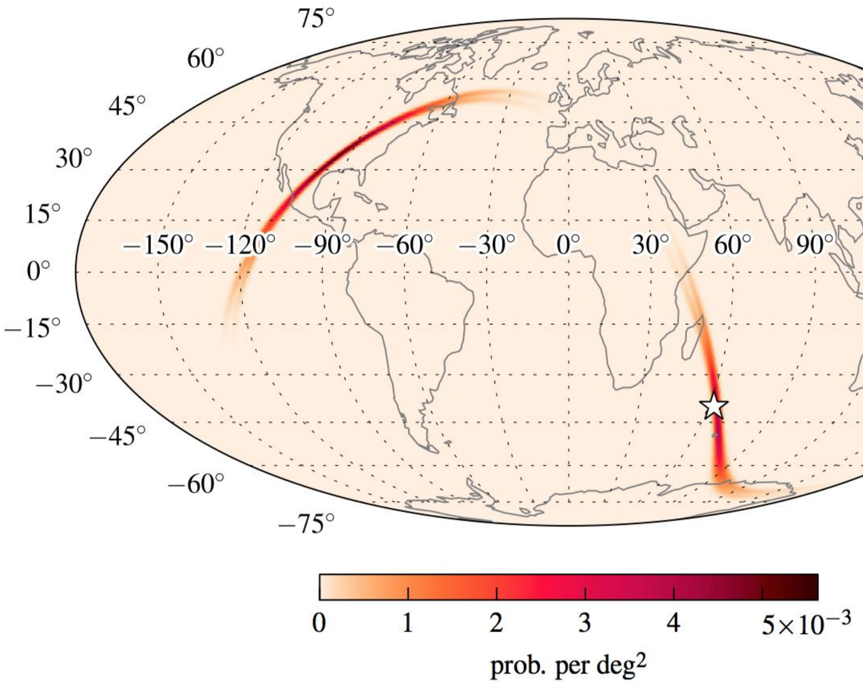
Electromagnetic follow-up of gravitational wave events

Why radio follow-up? Localisation

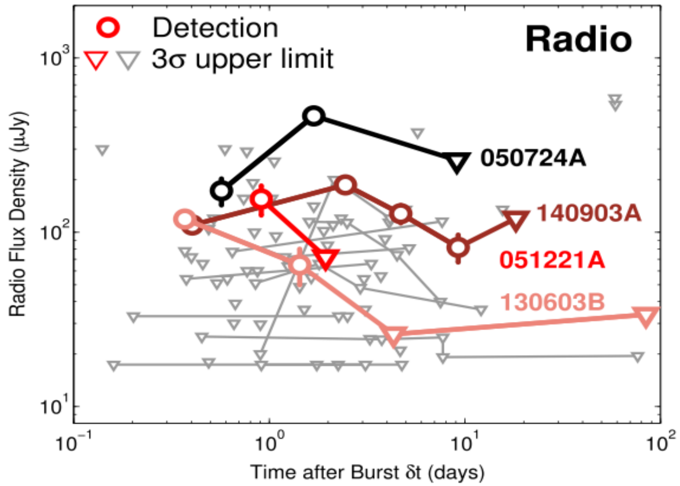
- LIGO alerts come with a probability map from one of 4 analysis pipelines
- 90% error region for GW150914 is 630 deg^2
- Number of galaxies within comoving volume of 10 Mpc is ~10^5
- Impossible to identify host without EM detection
- Virgo would improve to 10s of square degrees
- EM follow-up in O1:
  - 75 facilities with MoUs
  - 65 facilities operational
  - 25 responded to alerts



Singer et al. 2015, ApJ, 795, 105

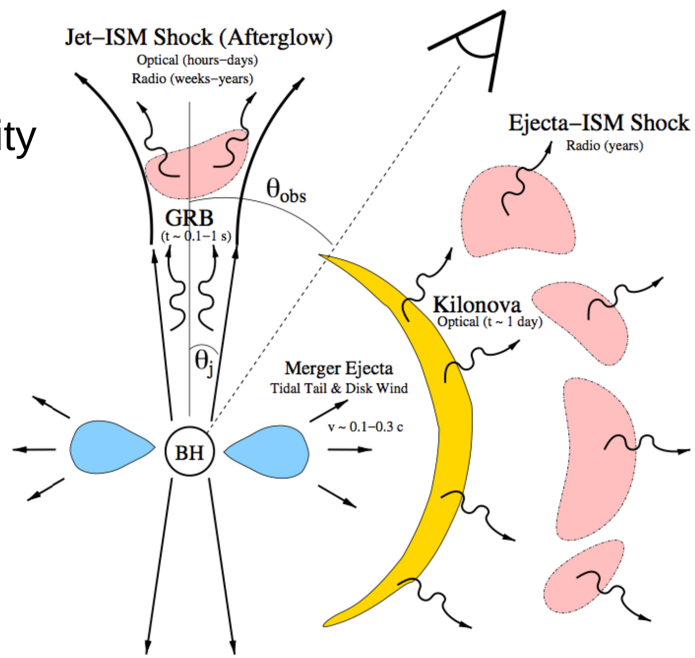
Why radio follow-up? Science

- **BH-BH mergers**: little (or no) EM radiation
- **NS-NS and NS-BH mergers:**
  - 0.4 – 400 detections a year (Abbott et al. 2016, arXiv:1304.0670)
  - Short-GRB-like emission (afterglow and remnant)
  - Detectable hours to years after event
  - Probe blast wave velocity, energy, circumburst density



Fong et al. 2015, ApJ, 815, 102

Metzger & Berger 2012, ApJ, 746, 48



- Prospects for orphan afterglow detection (Ghirlanda et al. 2014, PASA, 31, 22)

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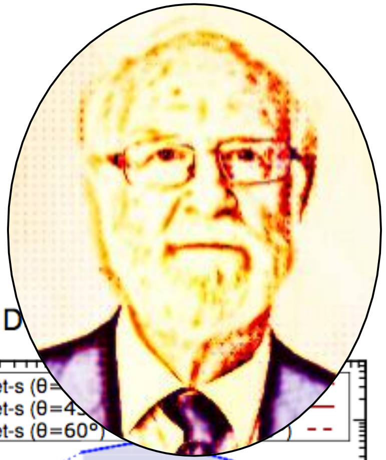
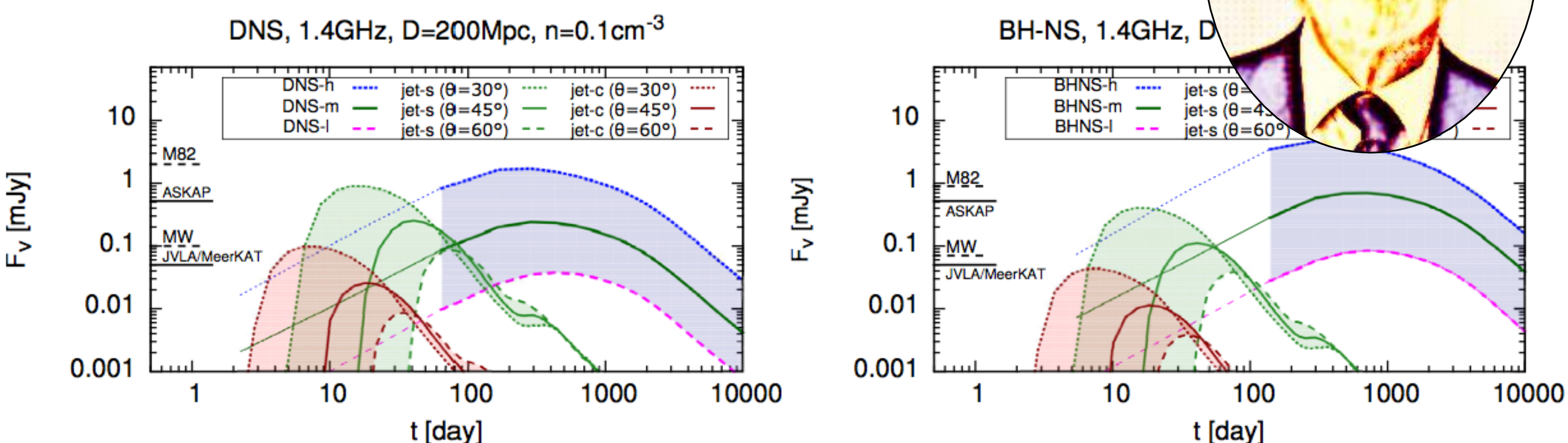
Is the radio emission detectable?

› There are two types of emission we expect to detect:

- sub-relativistic merger ejecta (years)
- ultra-relativistic jets (weeks to months)





Hotokezaka et al. 2016, submitted

› There are also more speculative possibilities:

- prompt emission from short GRBs (e.g. Kaplan et al. ApJL, 814, L25)
- Fast Radio Bursts

Radio follow-up of GW150914

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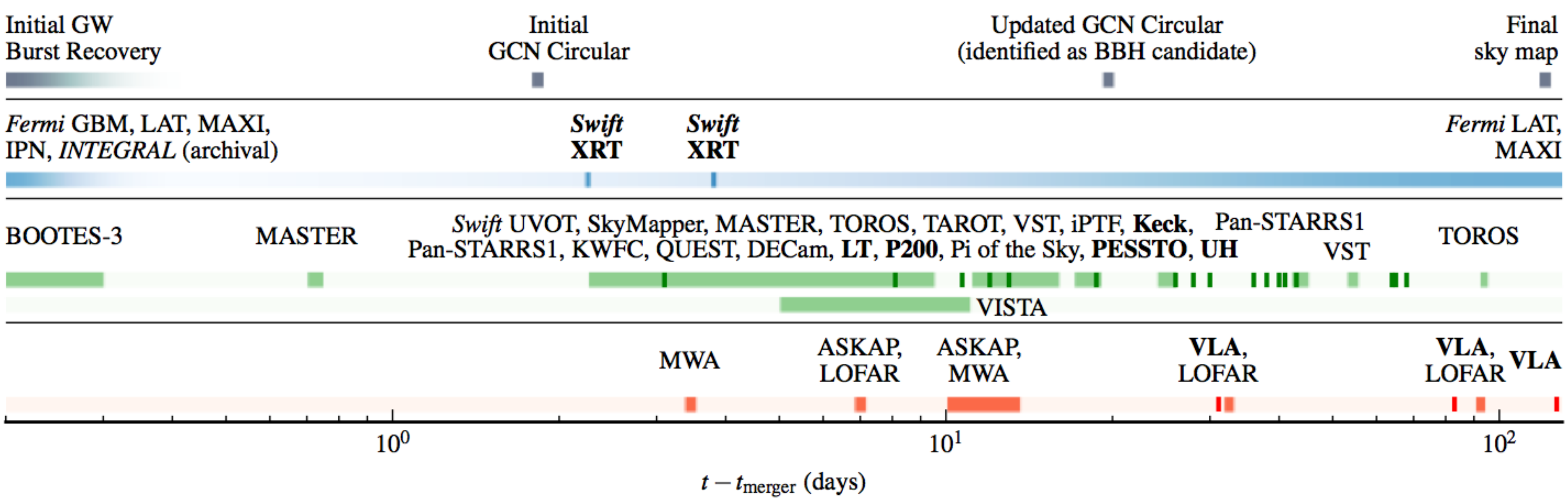
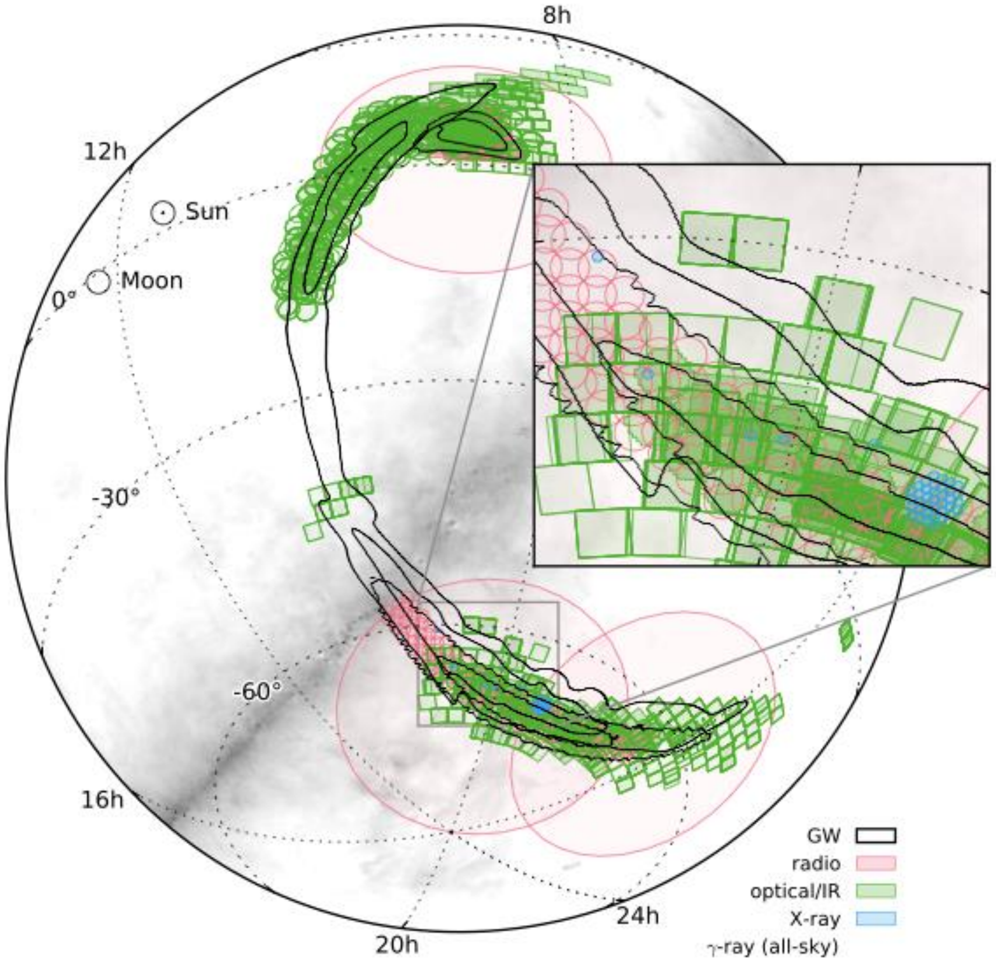
- 2015 September 12 – Calibration complete
- 2015 September 14 – **cWB reports burst candidate**
- 2015 September 16 – Email to EM follow-up teams
- 2015 September 17 – MWA obs: 97% of error region: GCN 18345
- 2015 September 21 – ASKAP obs: Northern error region: GCN 18363
- 2015 September 26 – ASKAP obs: Southern error region: GCN 18655



Overall EM sky coverage



Abbott et al. 2016, ApJL, arXiv:1602.08492

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Challenges for radio detections

› Source confusion due to (relatively) low angular resolution
  - Experimenting with smarter image subtraction
  - Planned continuum surveys will mean we have a good reference image

› False positive detections
  - We know the radio sky is relatively quiet, this works to our advantage

› Trade-off between frequency and field of view
  - Afterglow peaks at higher radio frequencies
  - Field of view means covering error circle is infeasible
  - Convolve error map with galaxy distribution in local volume

› Optimal survey strategy for prompt and long term follow-up

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Reflections

- Plan for serendipity
- Understand your data → trust your data

- Generalists play an important role in science
- Don't be limited by other people's boundaries
- Good software and software developers are important

- There's always a calm and sensible solution
- Value the diverse skills/approaches people bring
- Be optimistic and people and about science ☺