CAASTRO
ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

The Dynamic Radio Sky: On the path to the SKA

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Australian Government
Australian Research Council

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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, …

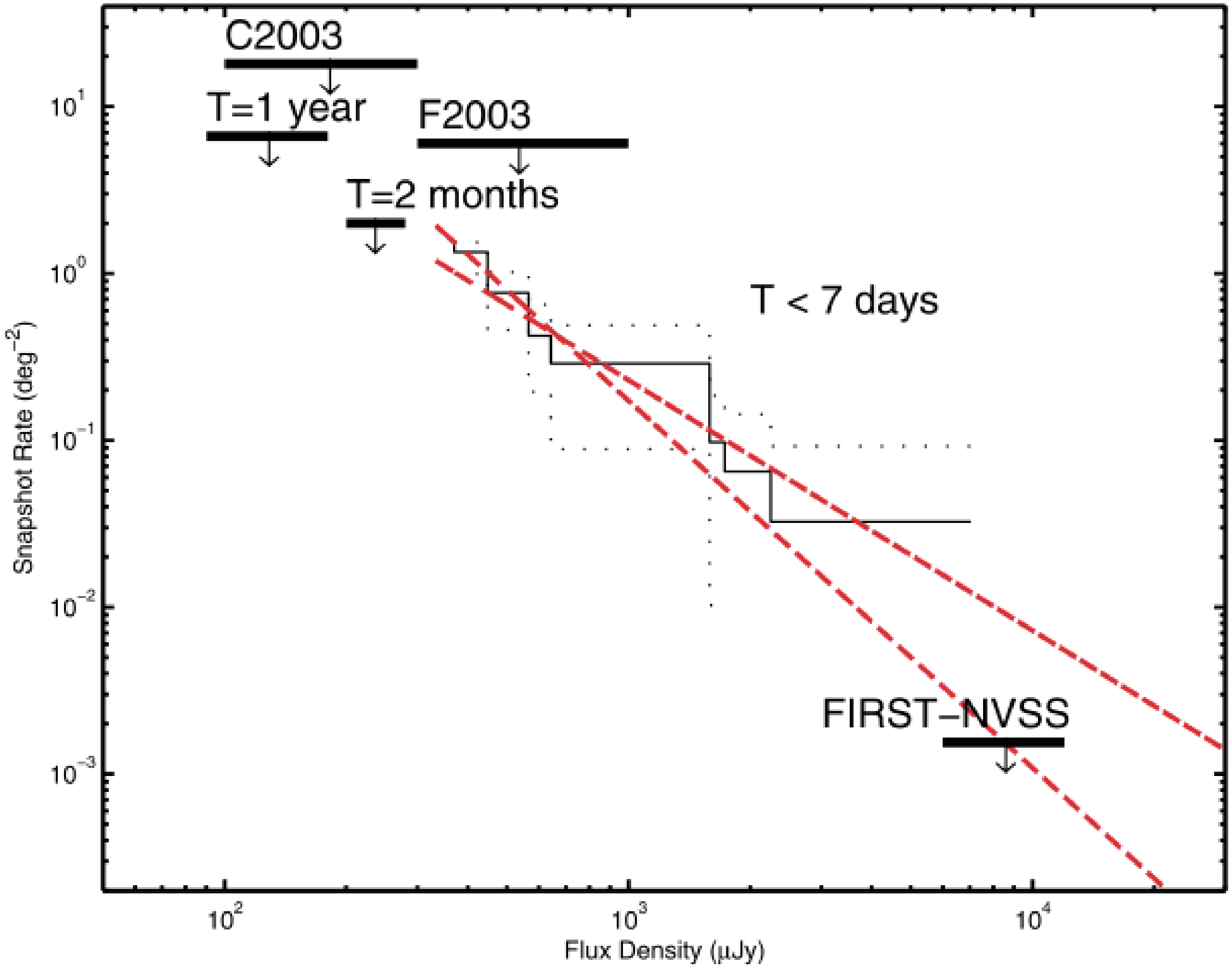
Transients with the SKA

"This working group addresses transient phenomena and the time variable unknown."

Michael Rupen	NRC	Canada	**Co-Chair** (Michael.Rupen AT nrc-cnrc.gc.ca)
Jean-Pierre Macquart	Curtin Univ.	Australia	**Co-Chair** (J.Macquart AT curtin.edu.au)
Shami Chatterjee	Cornell University	USA	Core
Stéphane Corbel	CEA	France	Core
Adam Deller	ASTRON	Netherlands	Core
Rob Fender	Univ. Oxford	UK	Core
Jason Hessels	ASTRON	Netherlands	Core
David Kaplan	University of Wisconsin Madison	USA	Core
Aris Karastergiou	Oxford Univ.	UK	Core
Casey Law	U. California at Berkeley	USA	Core
James Miller-Jones	Curtin	Australia	Core
Tara Murphy	Univ. Sydney	Australia	Core
Zsolt Paragi	JIVE	Netherlands	Core
Miguel Perez-Torres	IAA-CSIC, Granada	Spain	Core
Ben Stappers	Univ. Manchester	UK	Core
Cathryn Trott	Curtin Univ.	Australia	Core

› Many connections to other working groups: Cradle of Life, Pulsars, Solar Heliospheric & Ionospheric, Extragalactic Continuum

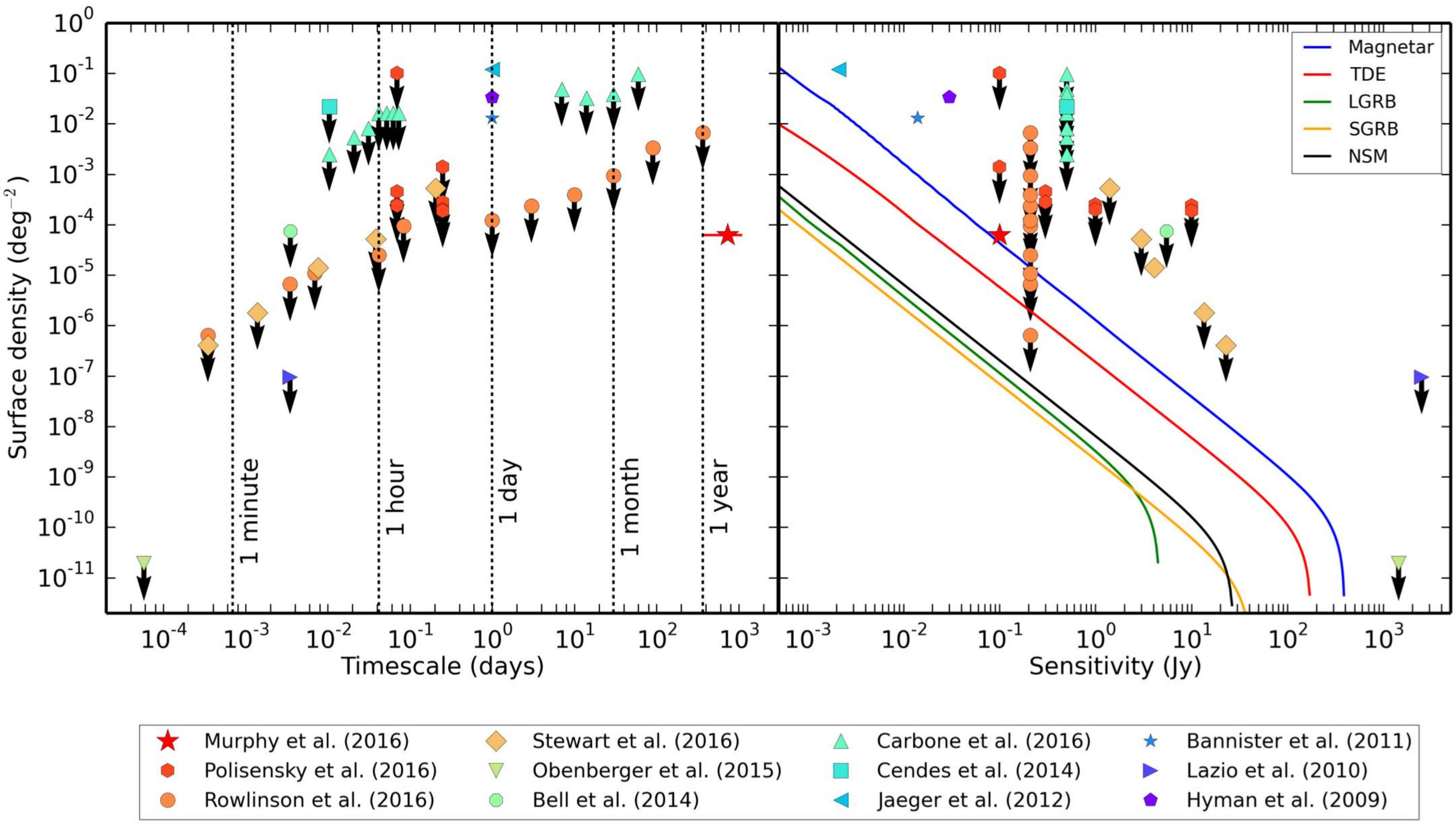
Transient snapshot rates (c. 2007)



Bower et al. 2007, ApJ, 666, 346

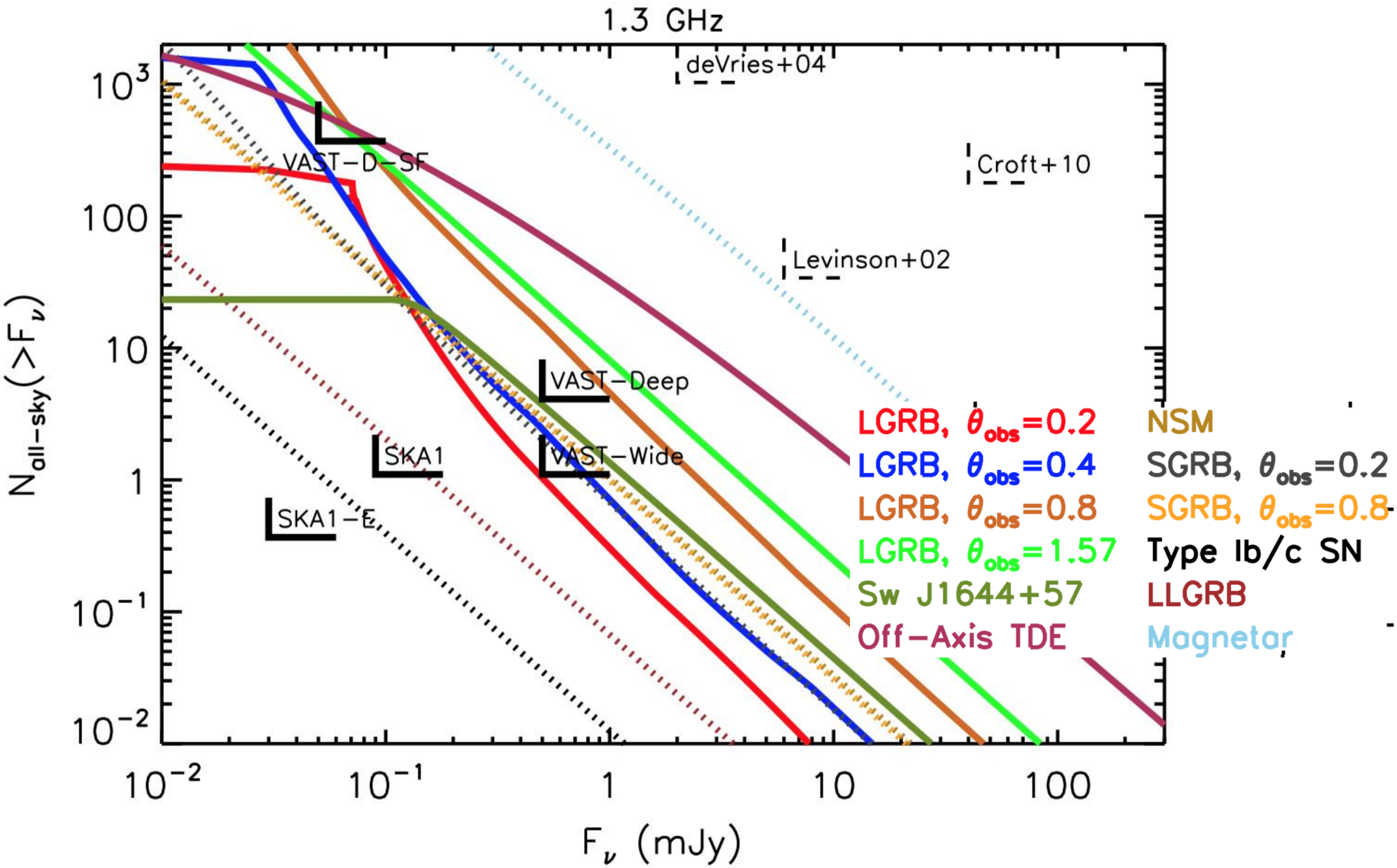
MHz snapshot rates (c. 2017)

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



Murphy et al. 2017, MNRAS, 466, 1944

GHz snapshot rates (c. 2015)



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

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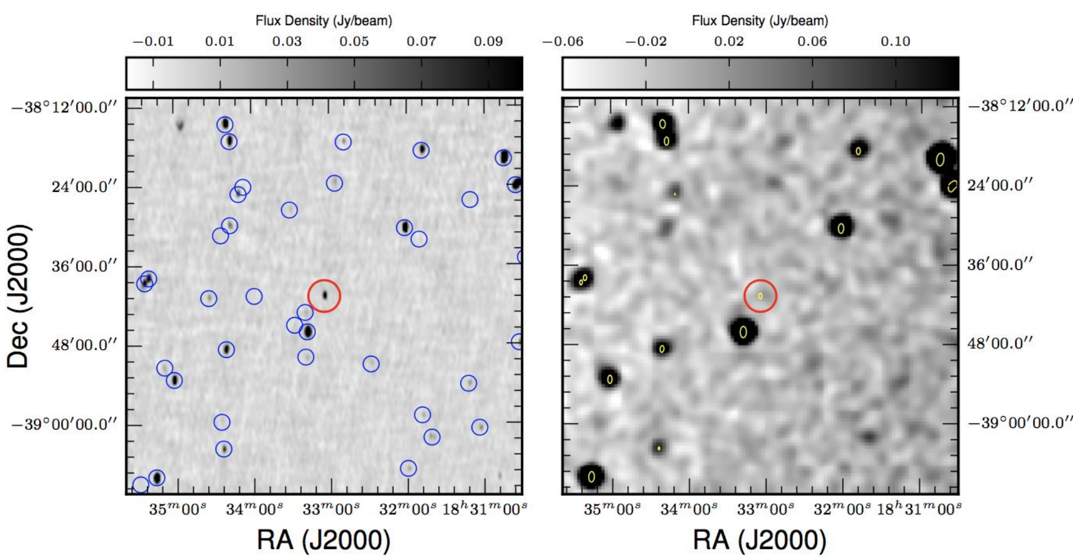
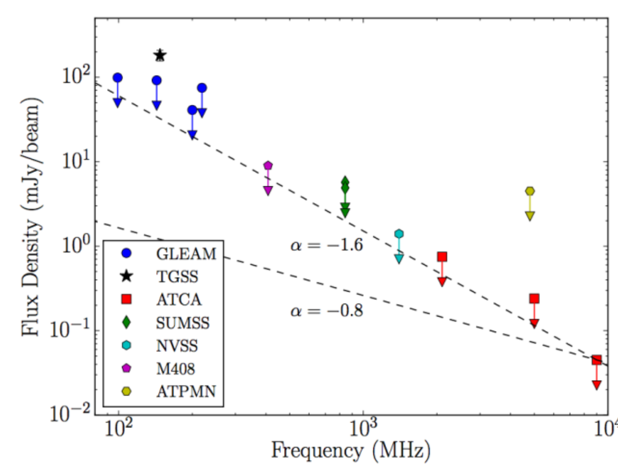
Results from blind searches

- First large scale transients search with MWA (GLEAM) and TGSS
- Highlights limitations of current radio searches:
  - Not in real time (all "archival")
  - Not consistent coverage
  - Surveys aren't designed for transient searches



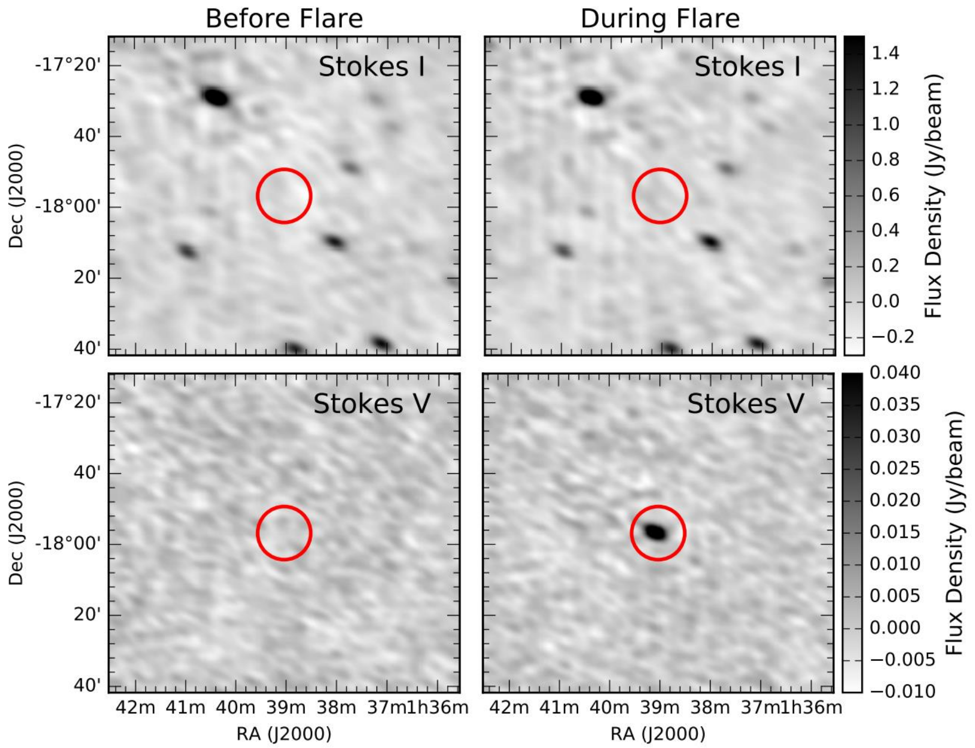


Murphy et al. 2017, MNRAS, 466, 1944

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

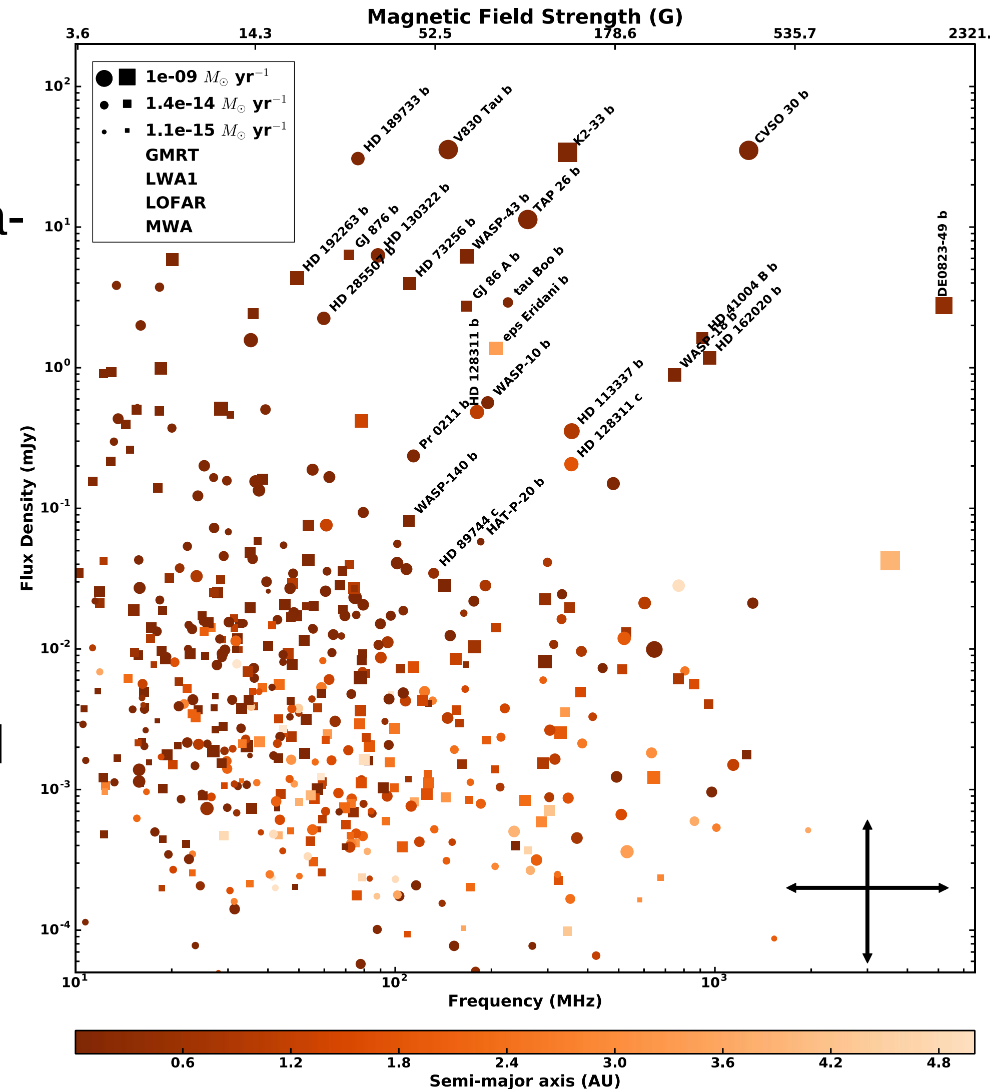
- Unique way of probing magnetic field of stars
- Implications for planetary habitability around low mass stars
- Uses innovative technique of circular polarisation search to beat confusion limit



Searching for exoplanets

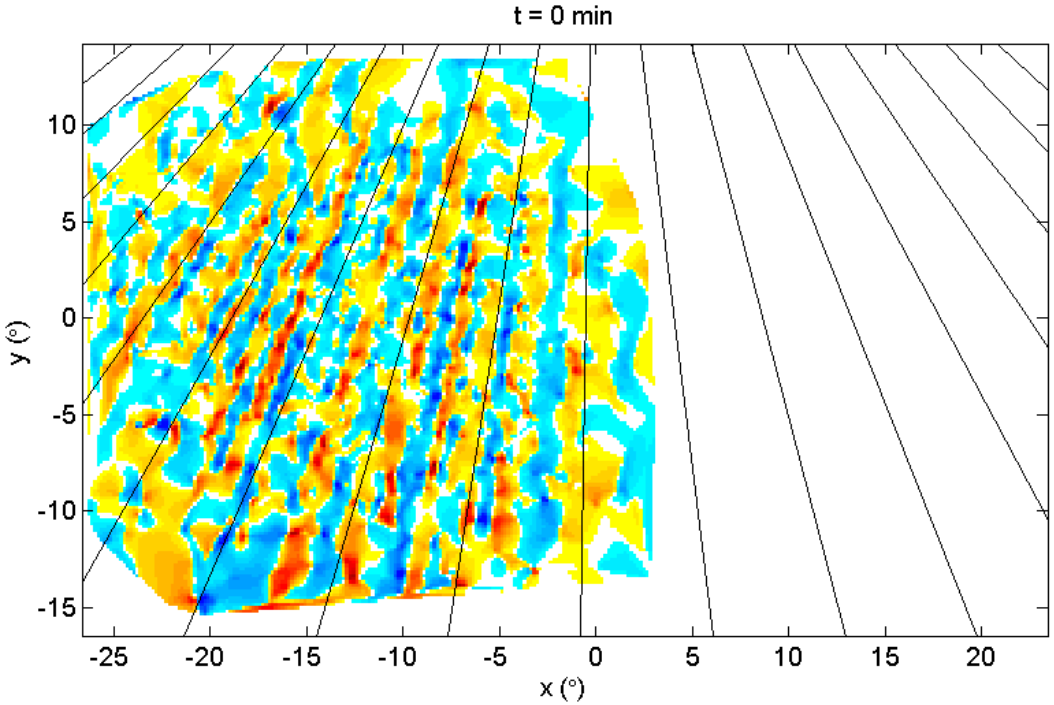
- Jupiter has strong radio emission
- Potential to make *direct* radio detection of magnetised extra-solar planets
- Hot super-Jupiters could be detected with current low frequency instruments
- Implications for planetary habitability
- Developing techniques useful for SKA

- (*Lynch et al. in prep*)



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**

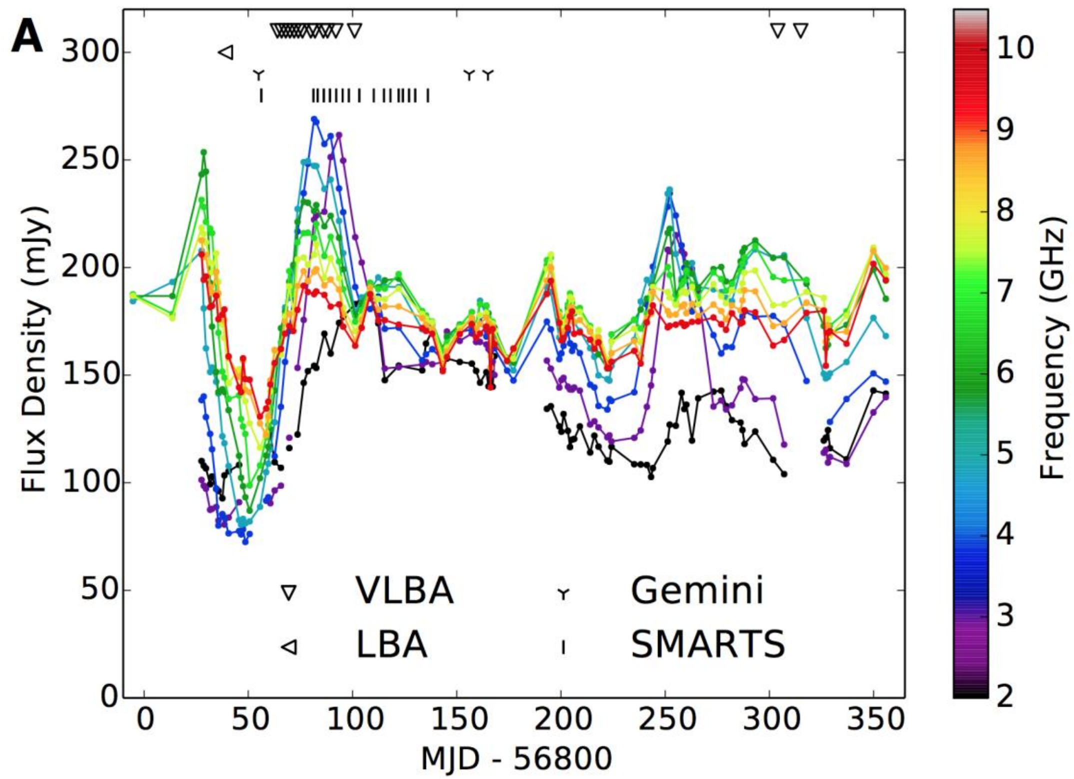


Loi et al. 2015, Geo RL, 42, 3707
Loi et al. 2015, Radio Science, 50, 574
Loi et al. 2015, MNRAS, 453, 2731
Loi et al. 2016, JGRA, 121, 1569
Loi et al. 2016, Radio Science, 51, 659

Extreme Scattering Events

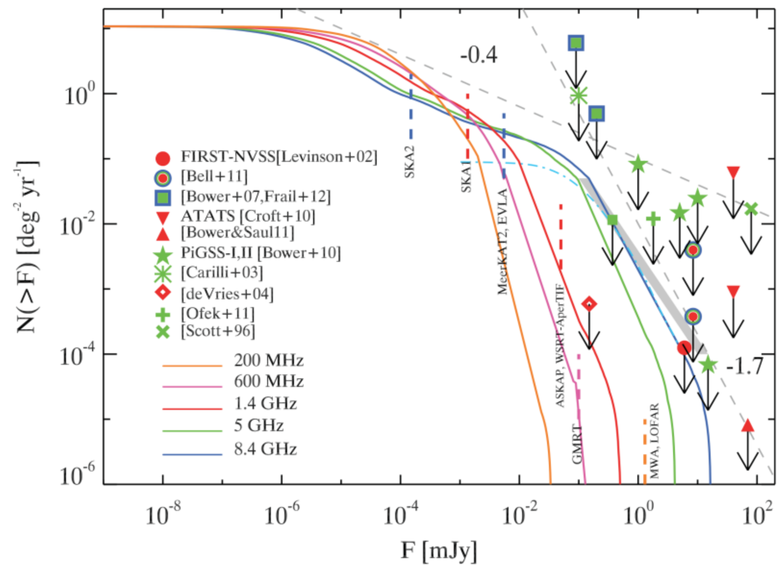
- Use Extreme Scattering Events to map neutral gas in our Galaxy
- Can account for some fraction of baryonic dark matter
- First real time detection of ESE (*Bannister et al. 2016, Science 351, 354*)

- More results to come from the ATESE survey:
- Monitoring 1000 AGN
- ATCA 4-8 GHz
- (1-12 GHz follow-up)
- Observe once per month
- 1 min/scan
- Key idea is detection in **frequency** not time
- (Bannister et al. *in prep*)

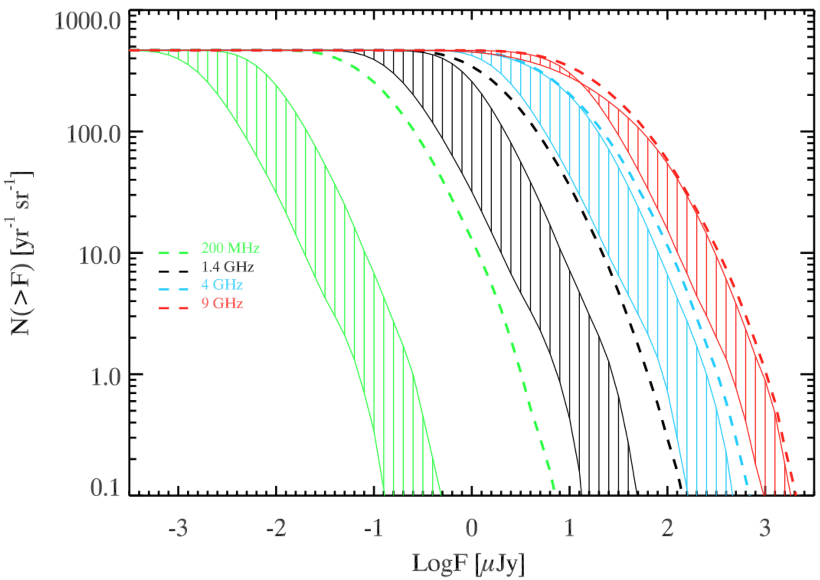


GRB (and orphan) afterglows

- Long GRBs: collapse of massive star
- Short GRBs: NS-NS/BH merger
- Trace cosmic star formation to high z
- SKA will observe large fraction of GRB afterglows



Ghirlanda et al. 2014, PASA, 31, 22

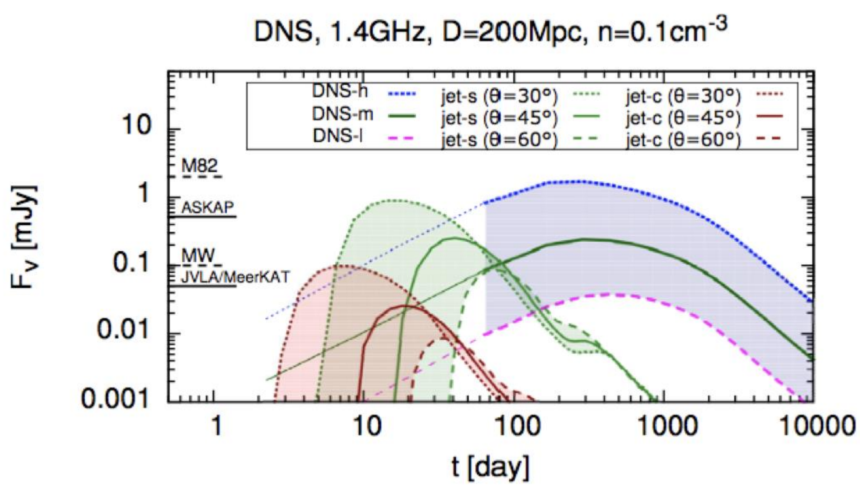


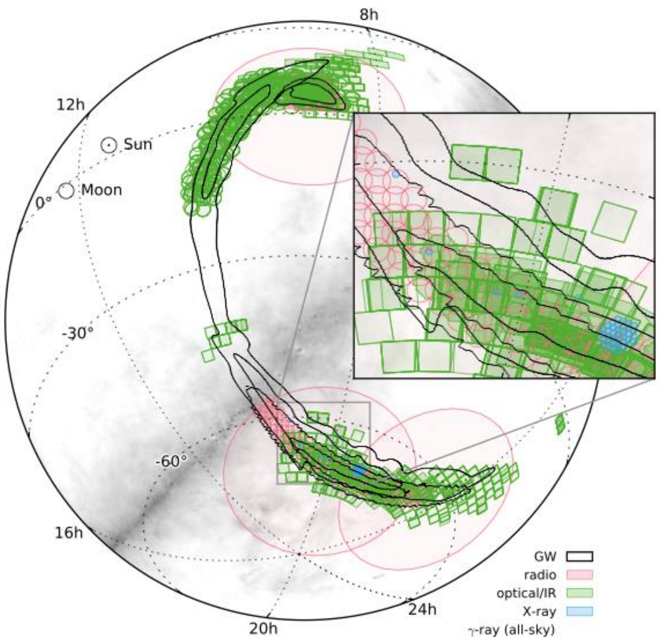
Burlon et al. 2015, PoS

- We only see a tiny fraction of GRBs where jet points towards Earth
- SKA will see orphan afterglows independent of high frequency trigger
- Possible to detect Pop III GRBs?

LIGO GW event follow-up

- 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
- Two types of emission we could detect:
  - sub-relativistic merger ejecta (years)
  - ultra-relativistic jets (weeks to months)





Other ongoing work

- LIGO O2 run and beyond
- Multi-messenger: neutrinos
- Fast radio bursts
- Triggering real-time follow-up
- Blind surveys – higher time resolution
- Time-domain and spectral properties of pulsars
- Flare stars and exoplanets
- Galactic centre monitoring
- Galactic plane survey
- Intermittent pulsar PSR J1107-5907
- Multi-epoch continuum observations with ASKAP
- Searching for pulsars using scintillation (IPS, ISS)

Lessons and challenges

- The 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