Discovery Areas with Time Domain Radio Astronomy

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May 2013

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    $\rightarrow$ High-precision measurements.

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    $\rightarrow$ Pulsar timing arrays also need radio telescopes.
  - Going from discovery to science requires follow-up.
    $\rightarrow$ High-precision measurements.
  - Radio astronomy is poised (budgets permitting) to enter an unparalleled era of discovery in the time domain.

Phase Space for Radio Transients

Rayleigh-Jeans approximation: (Adapted from Cordes, Lazio, McLaughlin 2004)

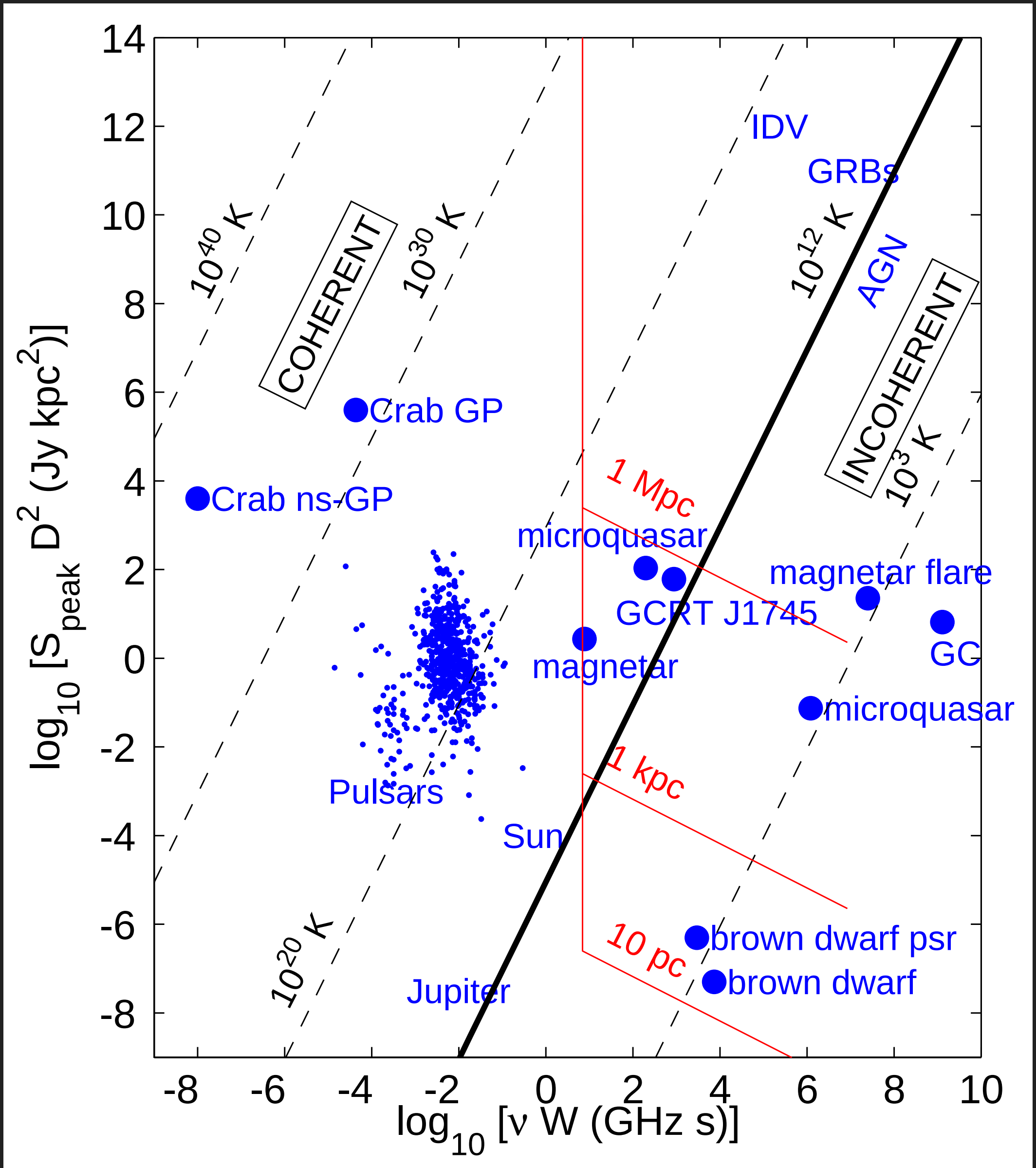
For a source brightness temperature T_B,
and a pulse width or transient duration W,

$$W^2 = \frac{1}{2\pi k_B} \frac{S_{pk} D^2}{T_B} \frac{1}{\nu^2}.$$

(SD^2 = pseudoluminosity, ν = obs freq.)

$\Rightarrow W^2 \nu^2 \propto S_{pk} D^2$, related through T_B.

Radio Transients: Phase space



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⇒ The optimist says that the plot is half-empty!

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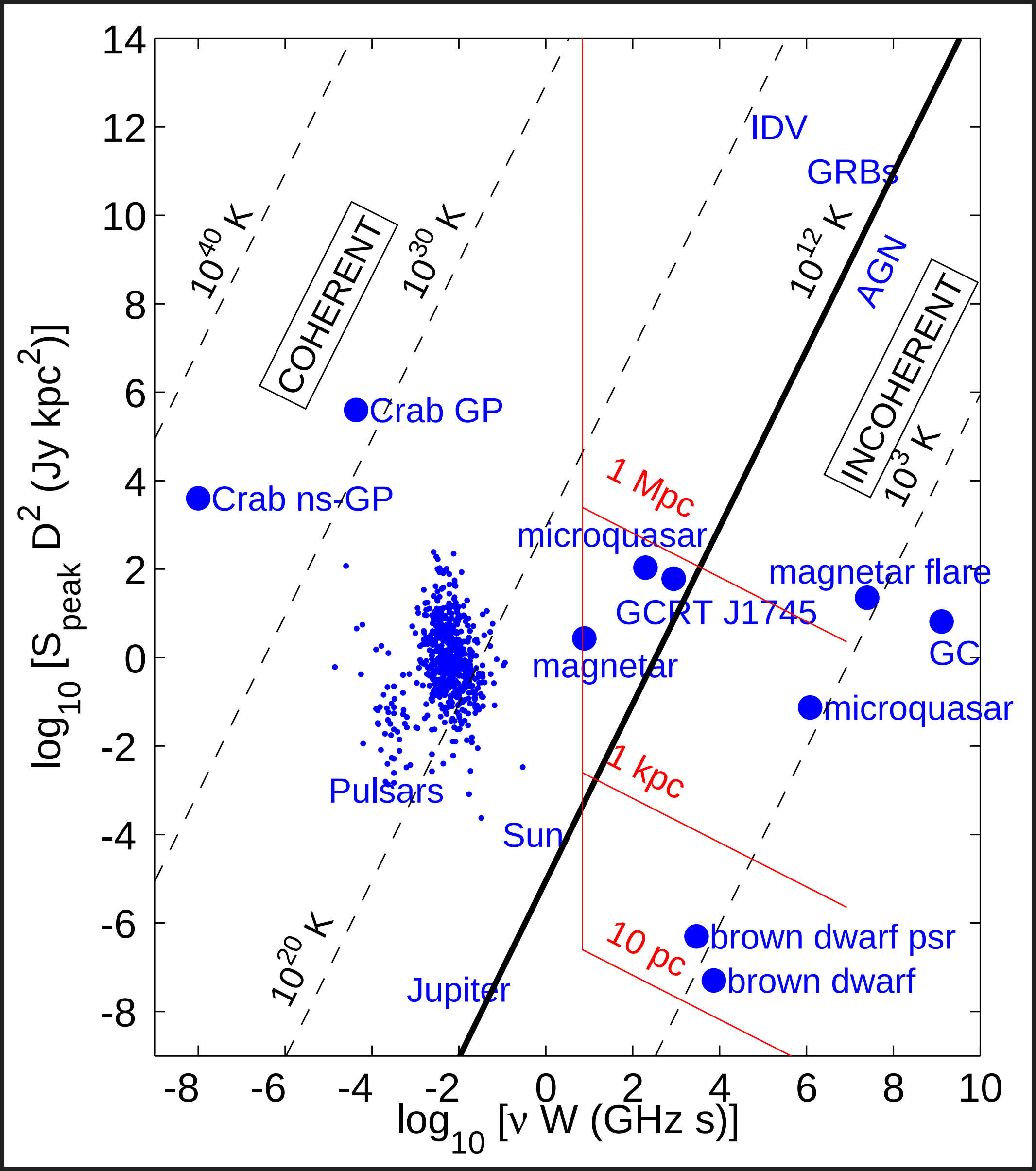

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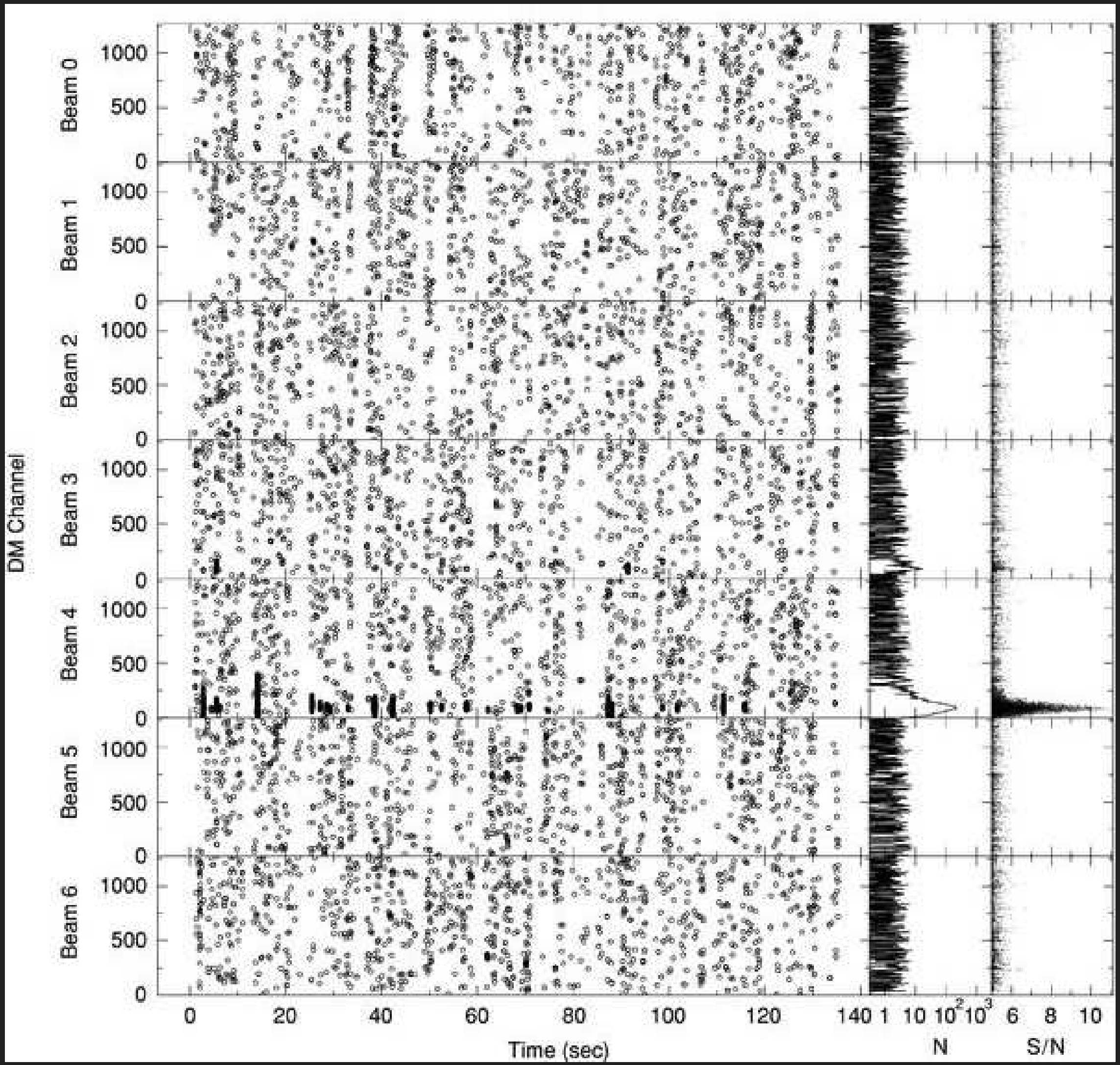
As we know,
There are known knowns.
There are things we know we know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown unknowns,
The ones we don't know
We don't know.

— US Sec Def. Donald Rumsfeld
DoD briefing, 12 Feb 2002

Discovery Area: High Time Resolution Surveys

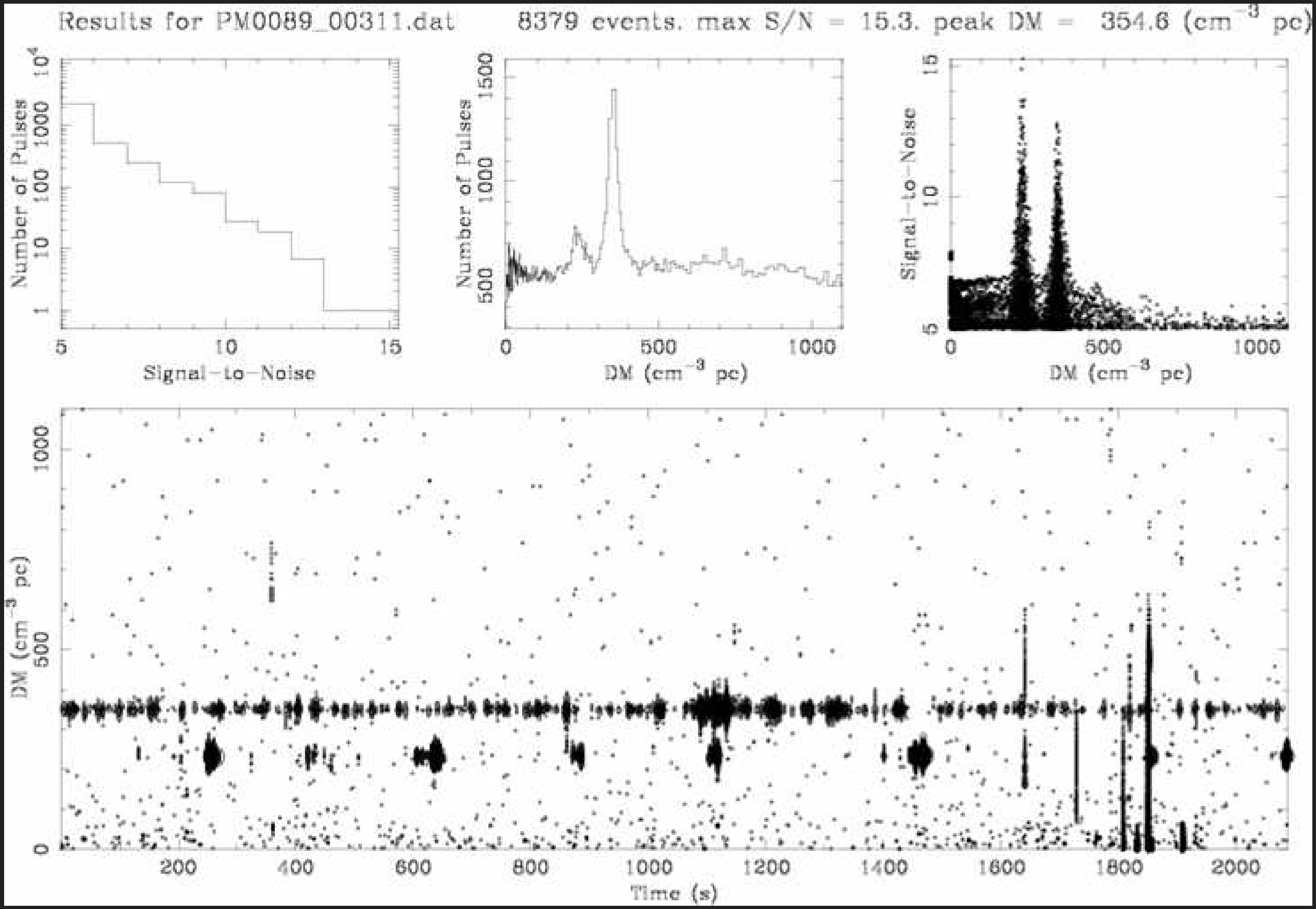
Dispersed Radio Pulses



- Pulsar ALFA survey at Arecibo.
- Multiple beams
  ⇒ Robustness to RFI.

(PSR B2020+28; Deneva et al. 2008)

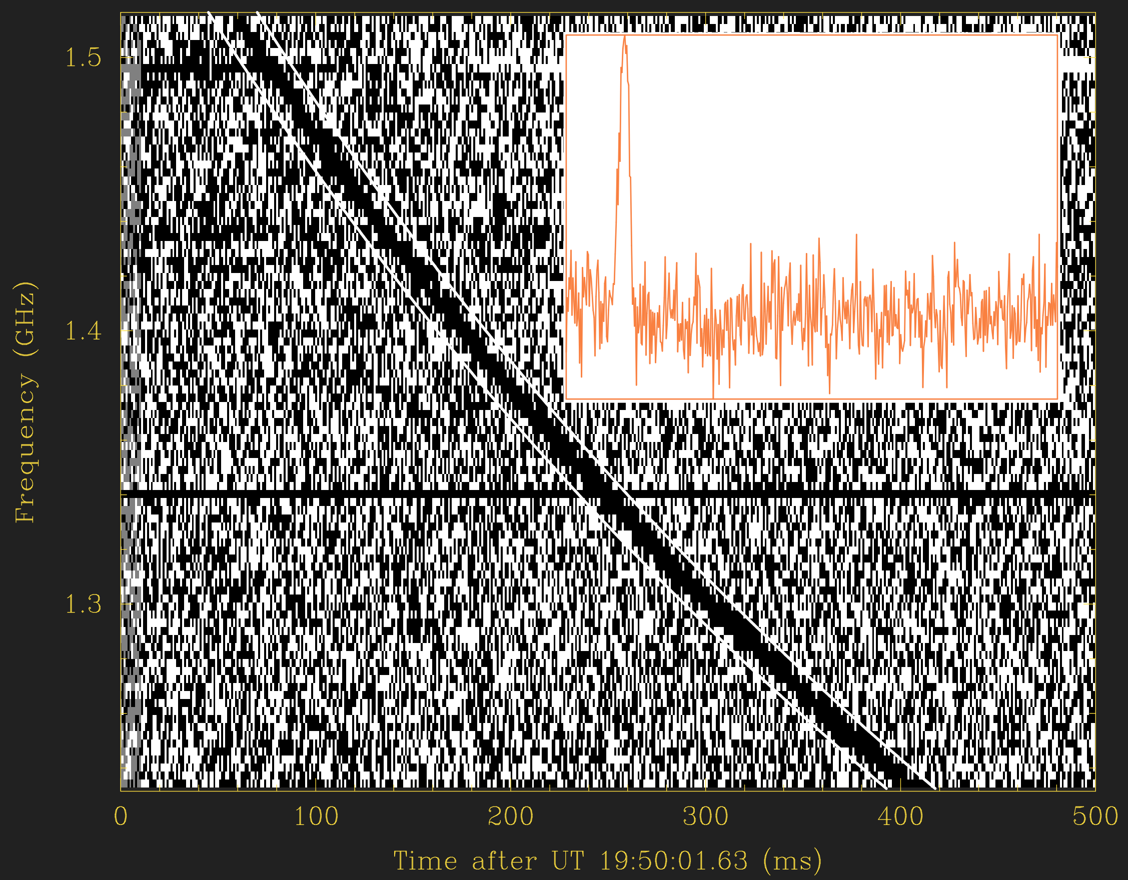
Dispersed Radio Pulses: Pulsars, RRATs, and more

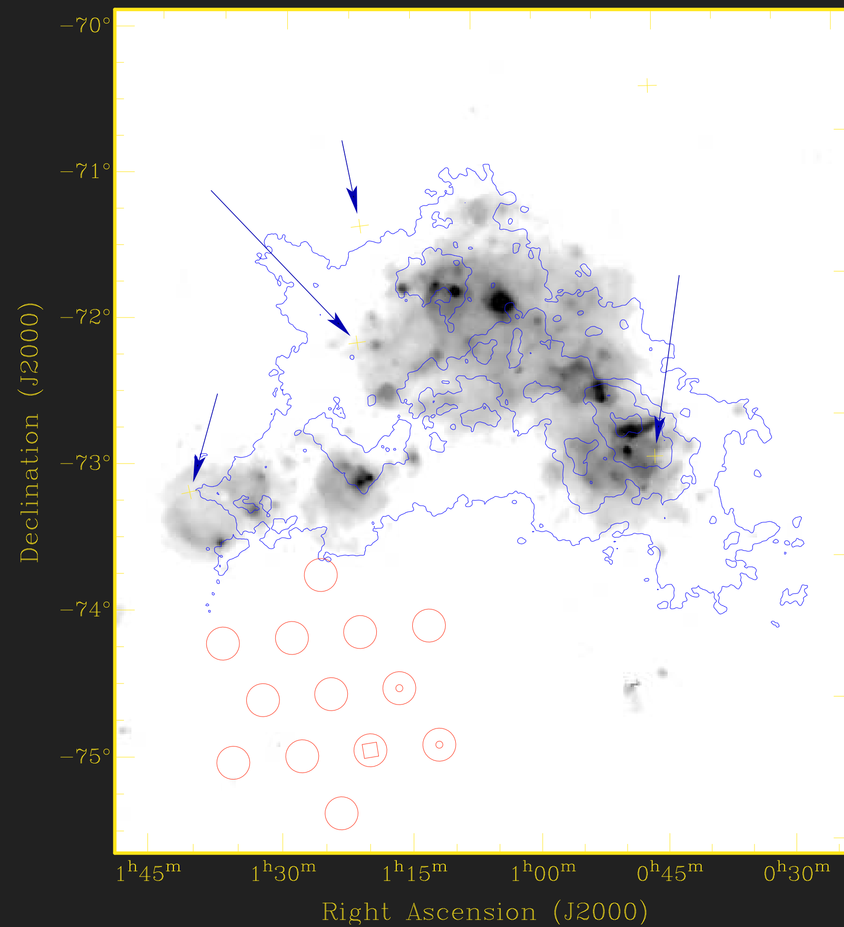


A pulsar and a nuller (RRAT?) in the same beam!

(J1840–0809, J1840–0815; McLaughlin et al.)

A Bright Extragalactic Pulse

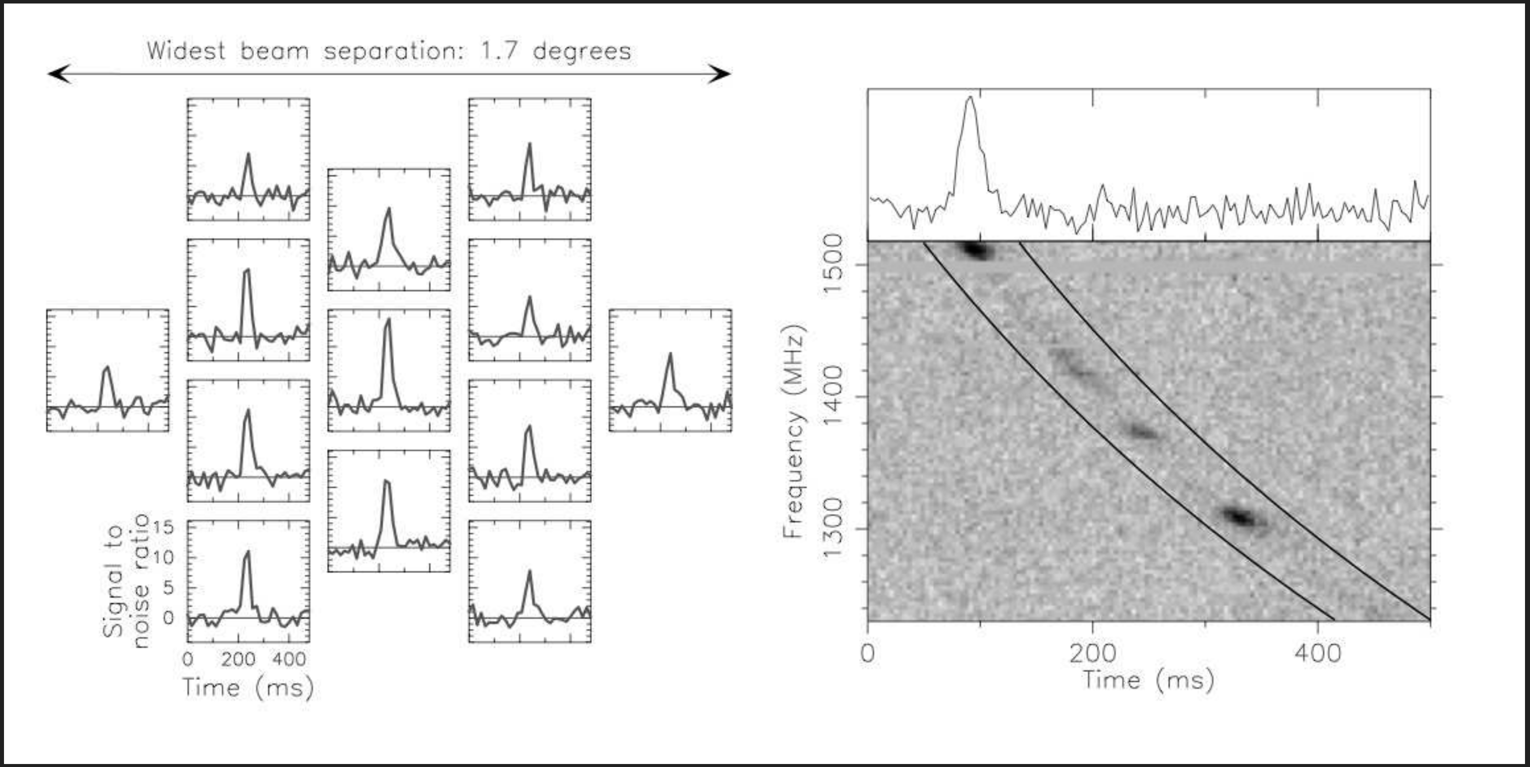




- A single dispersed pulse, $\tau < 5$ ms, 30 Jy!
- DM = 375 pc $cm^{-3} \Rightarrow$ 500 Mpc?
- Extragalactic: prompt GRB flash? Rates are puzzling.

(Lorimer et al. 2007, Science)

Bright Extragalactic Pulses?



- 16 pulses at DM similar to Lorimer et al.

(Burke-Spolaor et al. 2010)

- Detected in all beams, via sidelobes. Terrestrial?
- Not quite a ν^{-2} sweep. Atmospheric? “Perytons”.

$\rightarrow$ Compare and contrast with Lorimer burst; stay tuned.

Discovery Area: Synoptic Radio Imaging Surveys

Synoptic Imaging Surveys

- Many known source classes already:
  - → Explosive events (GRBs, SNe).
  - → Accretion-powered events (microquasars, TDEs).
  - → Magnetic field driven (cool dwarfs, magnetars).
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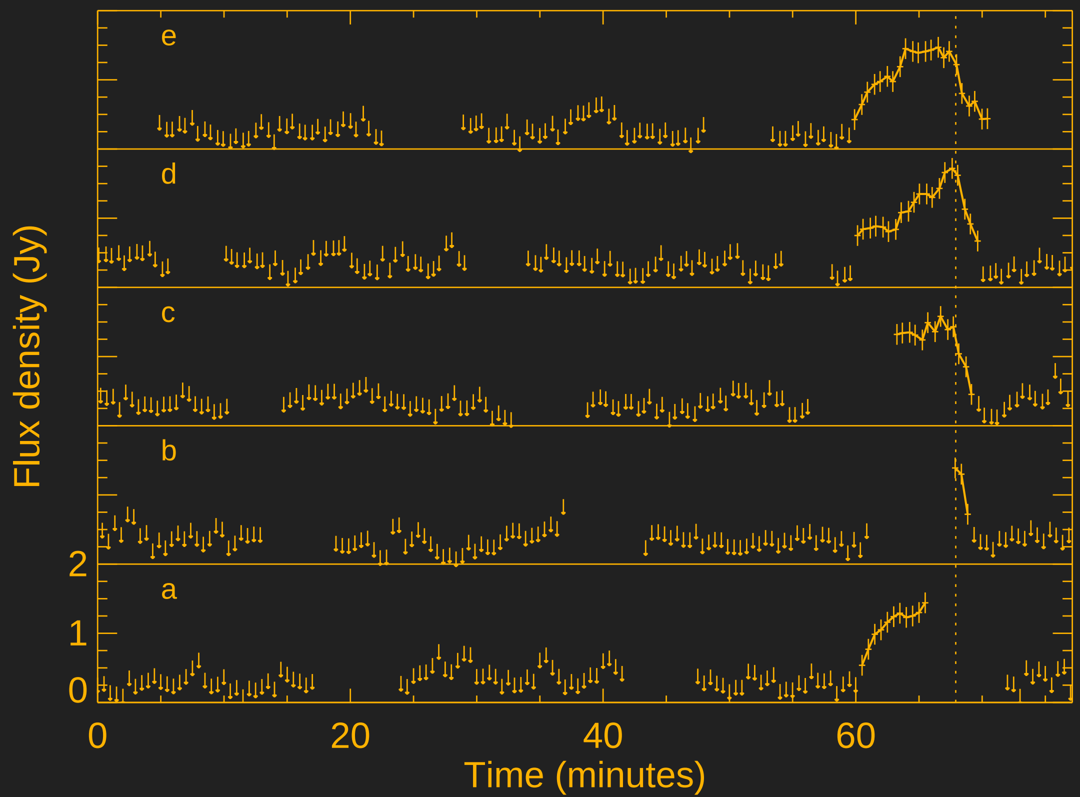
- Overall, radio sky is relatively quiet.
- Wide-field radio surveys will probe deeper into the source population.
  - e.g., VLA surveys in progress.
  - e.g., Low frequency telescopes like LOFAR, MWA, LWA.
  - Eventually, ASKAP and VAST - blurb at the end.
- Discoveries will need multi-wavelength follow-up.

Radio Transient in the Galactic Center region



- GCRT 1745–3009: Periodic 1 Jy bursts at 330 MHz.
- 77 min intervals, 10 min bursts... coherent, unexplained. (Hyman et al. 2005, Nature)
- Possibly a brown dwarf flare...?

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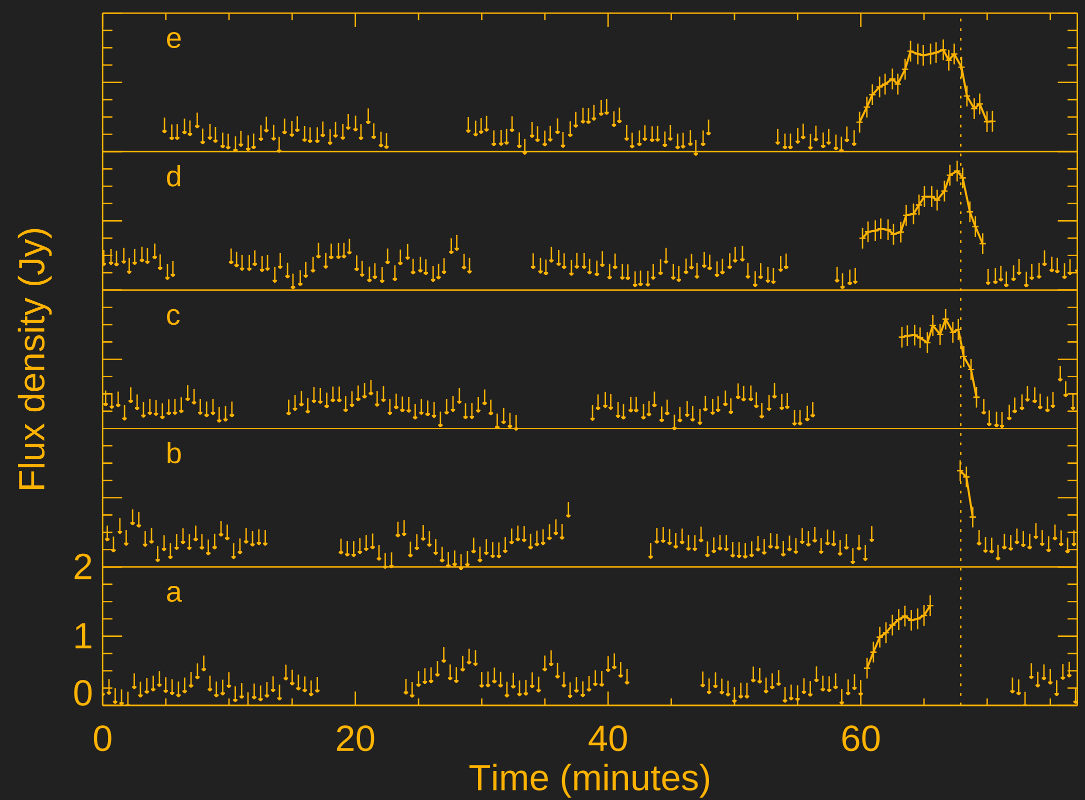

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→ Much more to be found - new magnetar, pulses in archival data, etc.

Discovery Area: Gravitational Wave Sources

Detecting Gravitational Wave Sources

- Gravitational waves from inspiral and mergers of massive objects: NS-NS, BH-NS, supermassive BH pairs, etc.
- Along with GWs, there may be prompt pulses, strong winds or bursts, flares, shock emission, afterglows. $\rightarrow$ EM counterparts. [arXiv:1305.0816]

$\Rightarrow$ Triggers from GW detectors to EM observatories. (cf. Nissanke talk)

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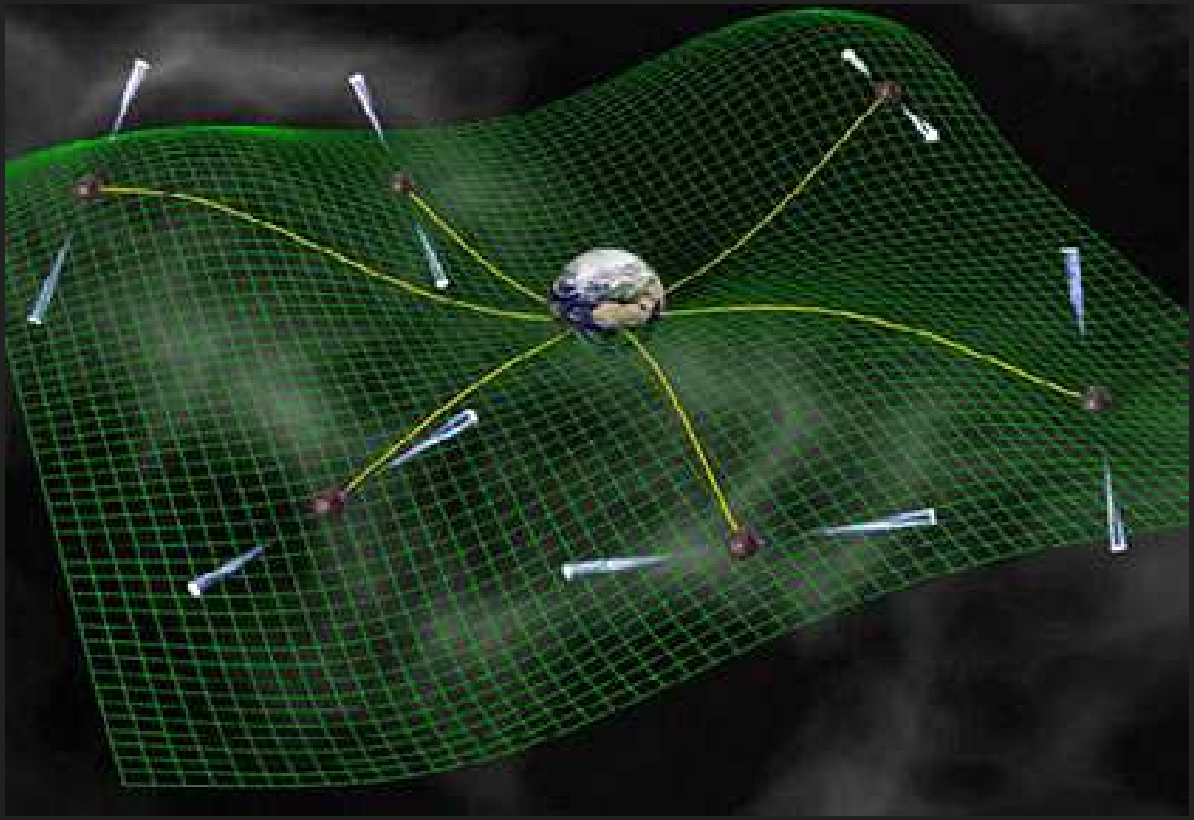
- Instead of laser metrology, we can measure lengths by placing accurate clocks at ends of arms and timing ticks.

$\Rightarrow$ Radio telescopes can detect GW sources with precise pulsar timing.

Pulsar Timing Arrays and Gravitational Waves



- Time an array of exceptionally stable pulsars.
- Correlated timing residuals $\Rightarrow$ gravitational waves.
- NanoHz frequencies $\rightarrow$ multi-year timing campaigns.
  (PPTA, EPTA, NANOGrav; IPTA)

`http://nanograv.org/`

Pulsar Timing Arrays and Gravitational Waves

- Current best NANOGrav upper limit on the strength of the nHz-frequency stochastic supermassive black hole gravitational wave background:

$$h_c(1\ \mathrm{yr}^{-1}) < 7 \times 10^{-15}\ (95\%)$$

(Demorest et al. 2013)

- Result dominated by the timing of the two best pulsars in the set, 30–50 ns timing residuals.
- Larger data set analysis underway; limits on burst sources forthcoming.
- Timing noise; ISM effects; localization may be possible.

From Discovery to Science

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  - → Multiwavelength counterparts.
  - → Spectroscopy.
  - → Distance, luminosity, energetics, physics.

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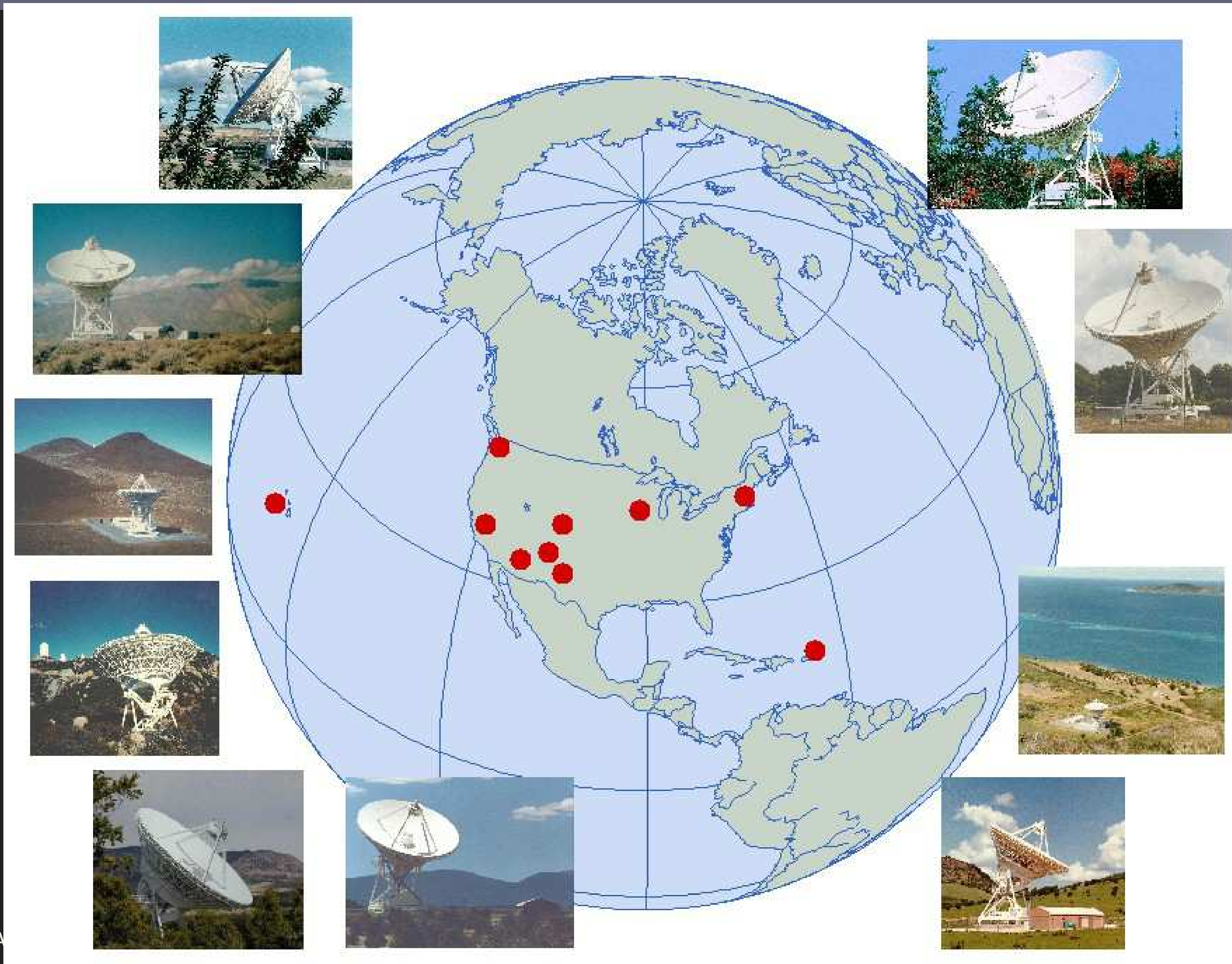
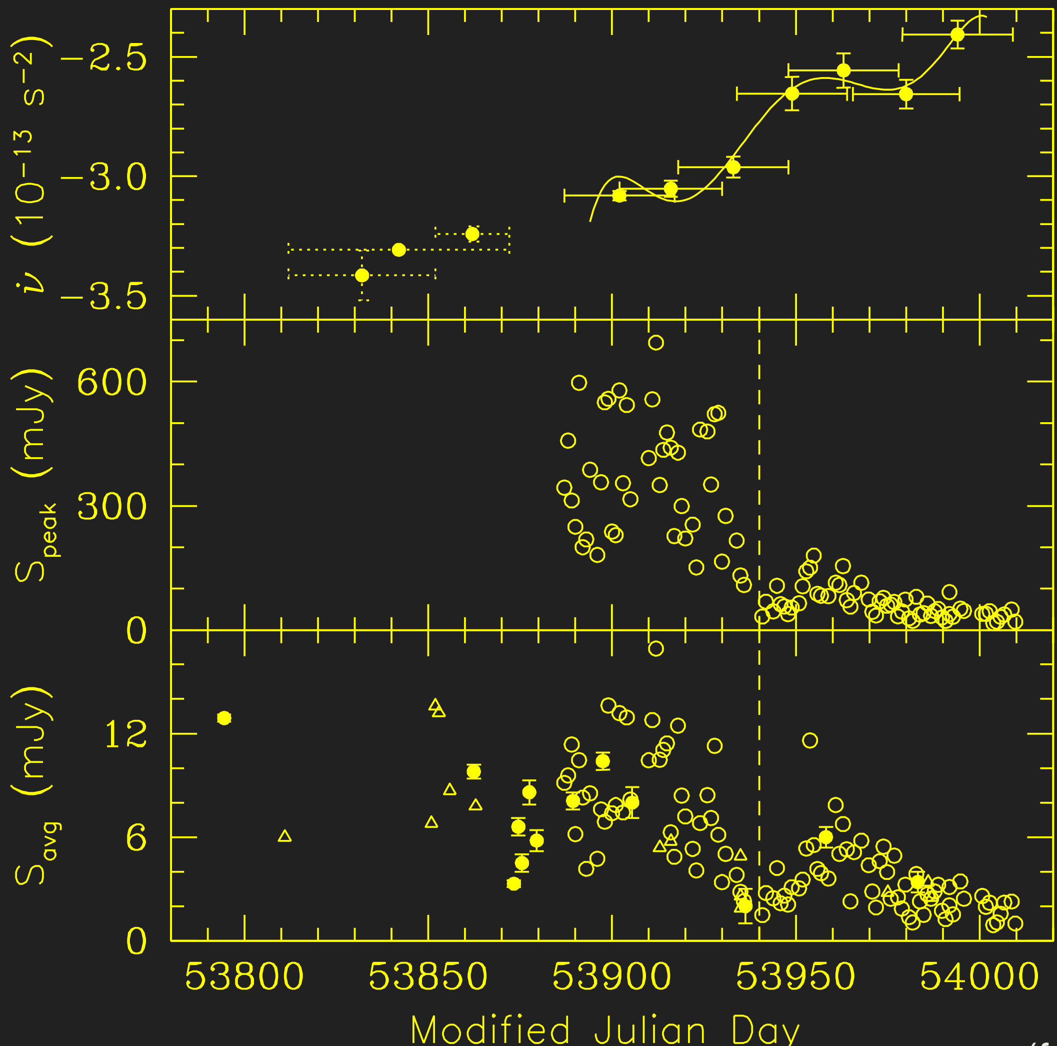
- “Après moi, lé deluge”?
  (Didn’t work out so well for Louis XV...)

The VLBA: An Astrometry Machine



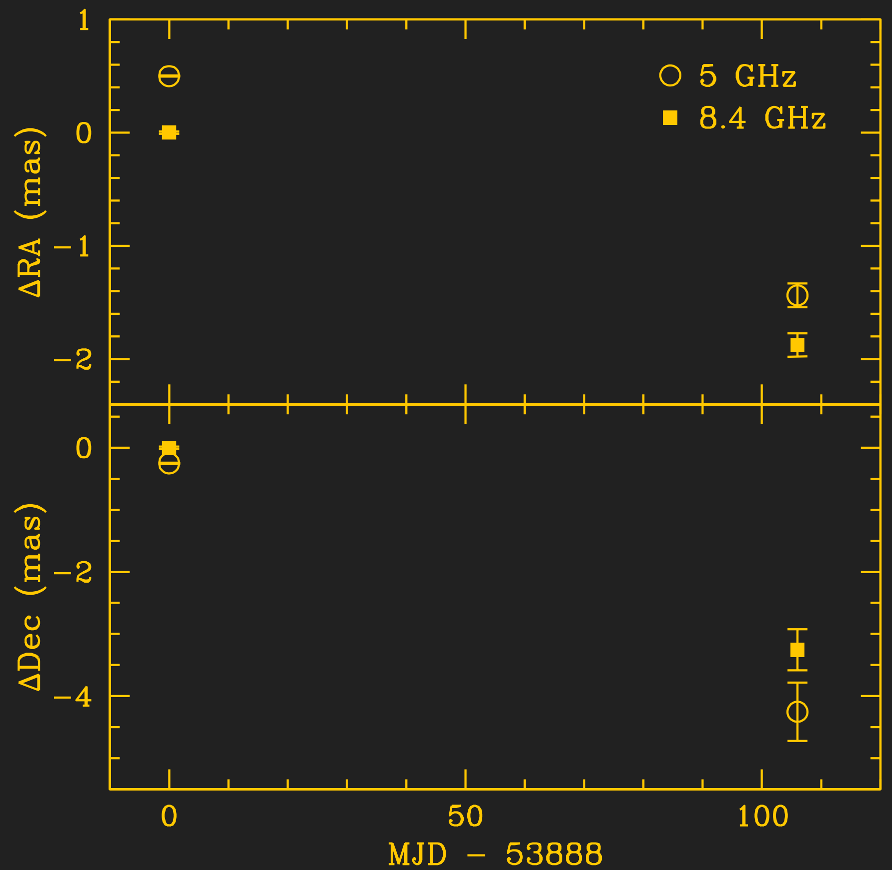
- Camilo et al. (2006): Transient pulsed radio emission.
- Rapidly fading...



(from Camilo et al. 2006)

A Magnetar Proper Motion

- Camilo et al. (2006): Transient pulsed radio emission!
- Rapidly fading: bright enough for VLBA obs at 5, 8.4 GHz over 106 days.



μ_α = -6.60 ± 0.06 mas yr^{-1}
μ_δ = -11.7 ± 1.0 mas yr^{-1}

For $D = 3.5 \pm 0.5$ kpc,
V$_\perp \sim 220$ km s^{-1}
[$180 - 270$ km s^{-1}]

(Helfand, Chatterjee, et al. 2007)

⇒ For this magnetar V$_\perp$, no exotic kick mechanisms required.

An LMXB/MSP parallax

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- Radio pulsations: MSP (Archibald et al. 2009)
  ⇒ Transition object from LMXB to recycled MSP.

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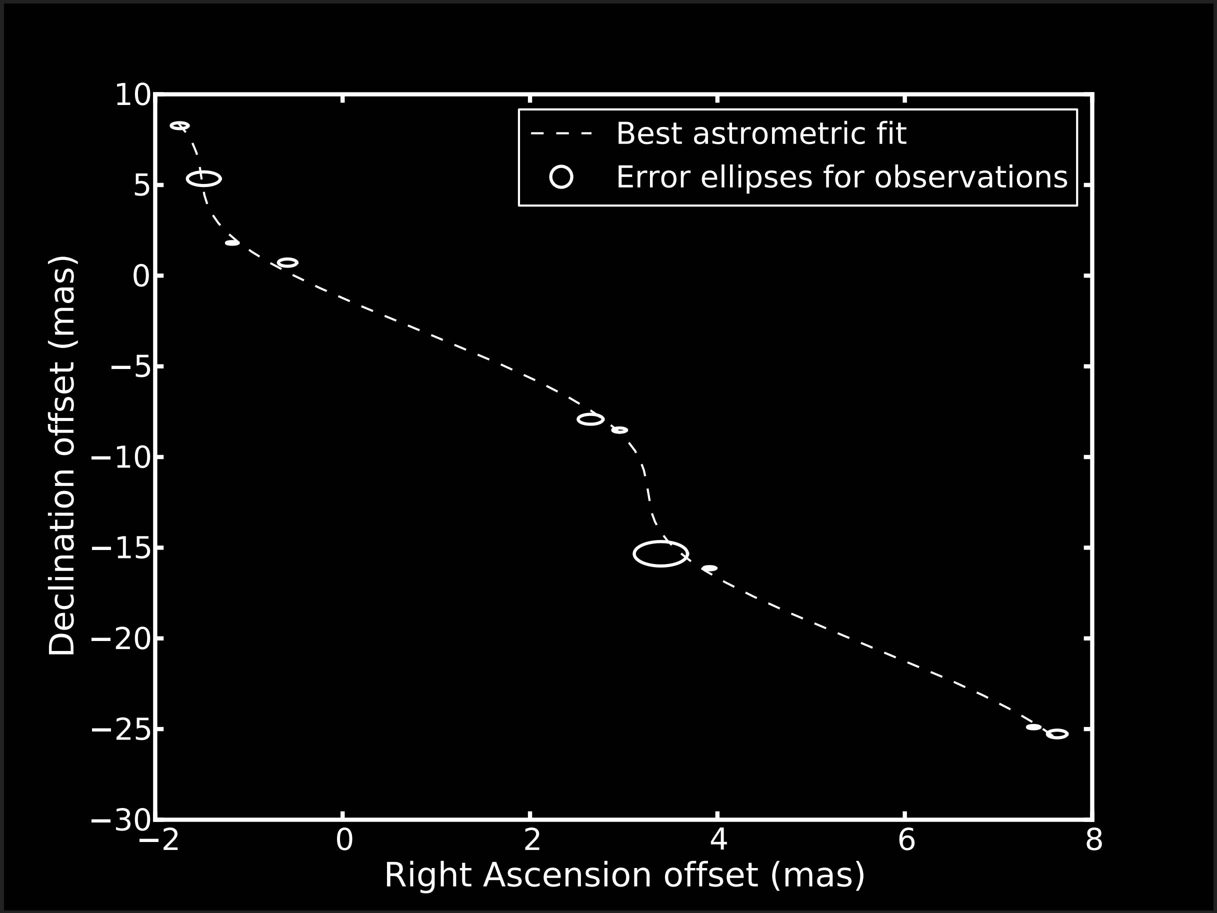

VLBA obs, 2008–2010:

- $\pi = 0.73 \pm 0.02$ mas
- D = $1368^{+0.42}_{-0.39}$ pc
- Combine with photometry and companion T ~ 5700 K:

⇒ NS Mass = $1.71 \pm 0.16\, M_{\odot}$.

VAST: An ASKAP Survey for Variables and “Slow” Transients

ASKAP: The Australian SKA Pathfinder

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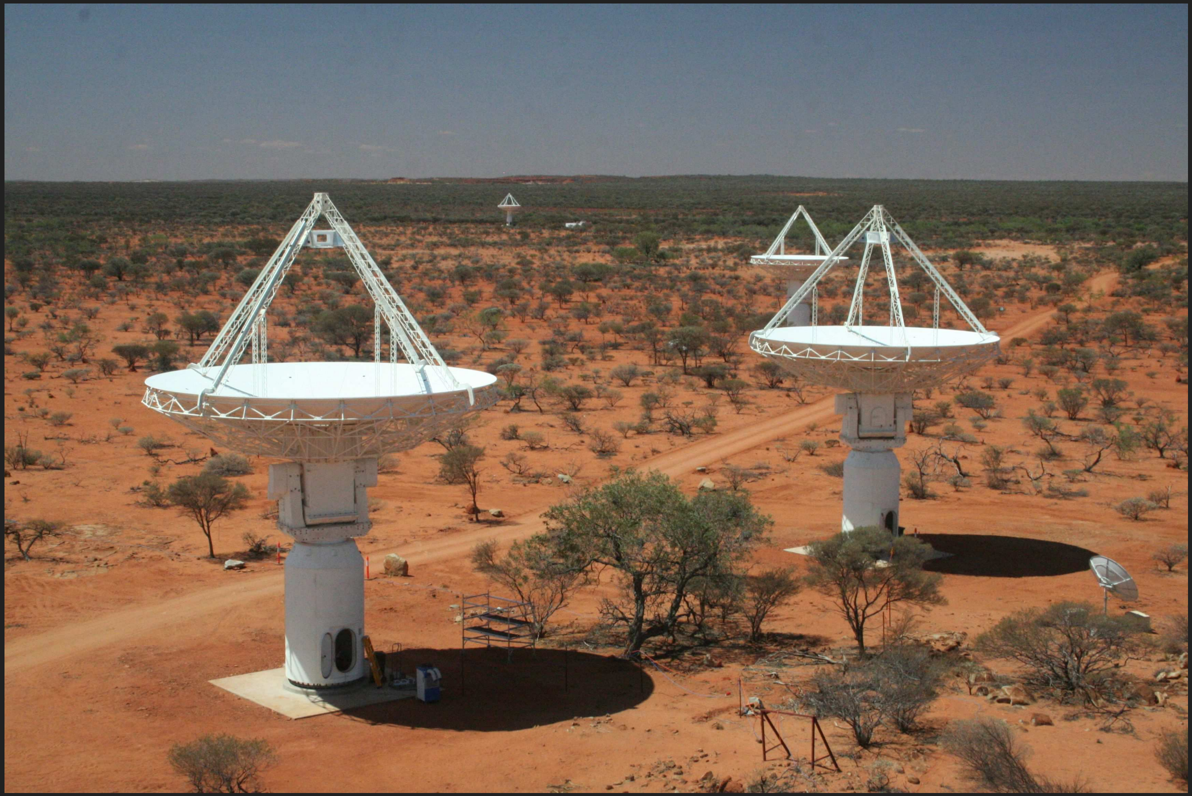
- Under construction; operations commence in 2013.
- 36 dishes, 12-m diameter, 2 km core, up to 6 km baselines.
- Operating at 0.9–1.8 GHz, with $\sim 20''$ beam.



(Oct 2010, with thanks to Ant Schinckel, CSIRO)

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Parkes testbed FPA; CSIRO July 2008

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Wide field of view ($\gtrsim$30 sq deg):
$\Rightarrow$ ASKAP is well-suited for surveys for radio transients.

ASKAP Status

Latest official update from CSIRO to Survey teams:

ASKAP Milestones from an Observers perspective

	BETA	ADE
First data files available for SST pipeline tests	Late Q2 2013	Early Q2 2014
Shared Risk Science Observing (25% time available)	April 2014	March 2015
Shared Risk Science Observing (50 +%)	November 2014	July 2015
Scheduled Observing (60+ %)		(Sept 2015)

- VAST is one of 10 approved Survey Science Proposals.
  Currently in its Design Study.
- Diverse collaboration:
  76 members, 36 institutions, 4 continents.
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- Wide range of science goals, but the same technical challenges:
  - Detection of transients and variable sources.
  - Identification and classification.
  - Triggered follow-up observations.

- Open collaboration:
  We welcome interested and active new members!

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- Discovery area: Synoptic radio imaging surveys ($\leftrightarrow$ LSST).
- Discovery area: Gravitational wave sources.
  $\rightarrow$ Pulsar timing arrays also need radio telescopes.
- Going from discovery to science requires follow-up.
  $\rightarrow$ High-precision measurements, multi-wavelength coverage.
- Data management: dealing with the flood.
- Radio astronomy is poised (budgets permitting) to enter an unparalleled era of discovery in the time domain.