really Fast Radio Transients

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KITP Talk

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Fast Radio Transients

- Seconds or less
  - Source size ≤ 10^6 km
  - e.g. Lorimer et al burst < 5 ms
- Typically expected to be coherent
- Typically dispersed/scattered by interstellar and intergalactic medium (ISM/IGM)
- Possible sources
  - Pulsar giant pulses
  - Rotating Radio Transients (RRATs)
  - Gamma-ray bursts?
  - AGN?

Two Primary References

- *Searches for Fast Radio Transients*, Cordes and McLaughlin, ApJ, **596**, 1142 (2003)
  – Nuts and bolts of fast radio transient searches
  – Dedispersion, scintillation, pulse broadening, etc
- *A bright millisecond radio burst of extragalactic origin*, Lorimer et al., astro-ph/0709.4301 (2007)
  – Detection of a fast radio transient
- Other references
  – *The Dynamic Radio* Sky, Cordes, Lazio, & McLaughlin, astro-ph/0410045 (2004). Future transient searches with the Square Kilometer Array.
  – *On the Detectability of Prompt Coherent Gamma-Ray Burst Radio Emission,* Macquart, ApJL*,* **658**, L1 (2007)

Preliminaries - Brightness Temperature

Plank Law:

$$B(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1}$$

(Watt / m^2 rad Hz)

Rayleigh-Jeans:

$$B_{R-J}(\nu,T) = \frac{2\nu^2}{c^2}kT$$

$$h\nu << kT$$

$$\nu(GHz) << 20.8\ T(K)$$

Relates temperature
to radiation flux

Brightness Temperature: $$T_B(\nu) \equiv \frac{c^2 B(\nu)}{2k\nu^2}$$

Preliminaries: Giant pulses and RRATs

- Giant pulses
  - Extremely large pulses from normal pulsar (e.g. Crab, typical once per hr pulse is 10^5 Jy)
  - Up to 1000 x’s larger than mean pulse intensity
  - Power law distribution of pulse intensities
  - Could be detected in nearby external galaxies
- RRATs
  - 2-30 ms in duration
  - Pulse intensities: 0.1-5 Jy
  - Time between bursts: minutes - hours
  - Roation periods: 0.4-7 s
  - Power law distribution of pulse intensities

Fast Radio Transient Surveys

- **Parkes pulsar survey**
  - Magellanic Clouds (0.2^o beam @ 1.4 GHz w/ 64m dish)
  - Archival single pulse search
  - 9 sq deg x 2.3 hours = 21 sq deg hr
  - Lorimer et al., astro-ph:0709.4301
- **GBT350**
  - Northern Galactic Plane (0.6^o beam @ 350 MHz w/ 100m dish)
  - Includes single pulse search
  - 100 sq deg x 120s = 3.3 sq deg hr
  - Hessels et al., astro-ph:0710.1745
- **STARE**
  - Northern hemisphere
  - 3 geographically separated antennas (125 ms resolution) - 27 kJy threshold
  - Katz et al., PSAP, 115, 675 (2003).

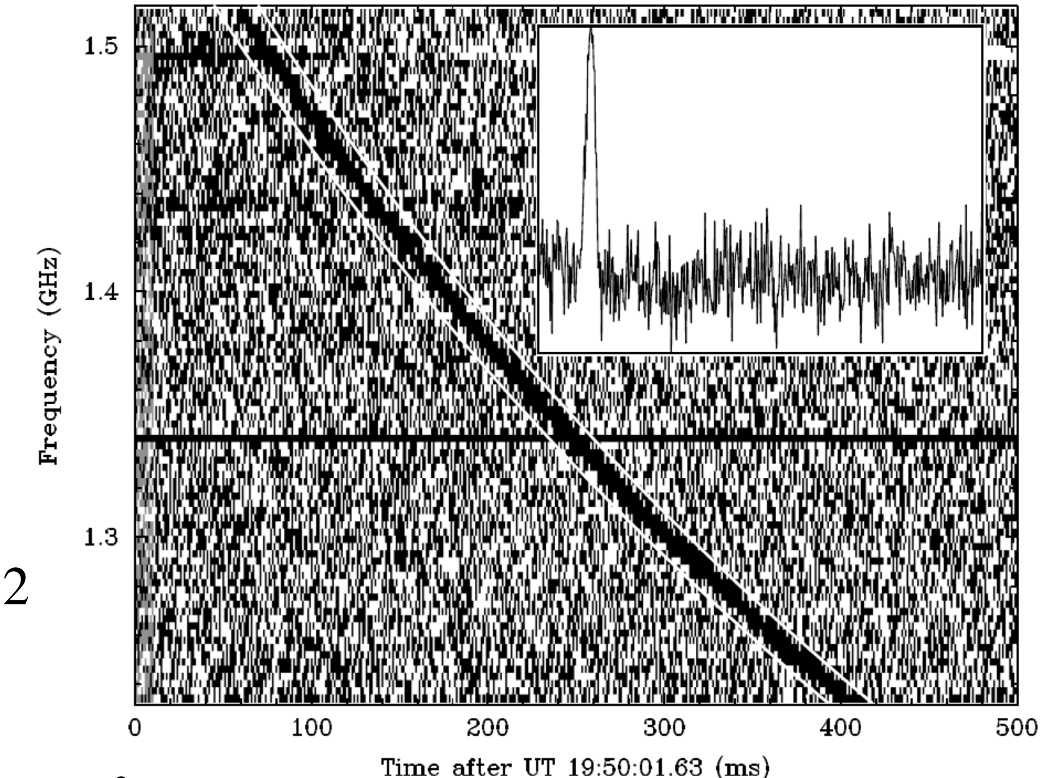
For reference - Lorimer et al. burst

- Obs. Frequency: 1.4 GHz
- Flux: 30 Jy
- Pulse width: 5 msec
- Burst DM: 375 pc cm^{-3}

Effects of the ISM/IGM

- Pulse broadening (Δt) [Eq 2,A4]
  - Dispersion broadening (Δt_{DM}) [Eq 3]
  - Scatter broadening (Δt_{scat} [= τ_d]) [Eq 6]
- Scintillation
  - Bandwidth ($\Delta \upsilon_d$) [Sec 4.3]
  - Timescale ($\Delta \tau_d$) [Eq 20]
- Angular Broadening (θ_d) [Sec 4.2, Eq A3]

Pulse Broadening



Lorimer et al. (2007)

$$\Delta t = (\Delta t_{DM}{}^{2} + \Delta t_{scat}{}^{2})^{1/2}$$

$$\Delta t_{DM} = 8.3\mu s \left(\frac{DM}{pc\ cm^{-3}}\right)\left(\frac{\Delta\nu}{MHz}\right)\left(\frac{\nu}{GHz}\right)^{-3}$$

$$\log \Delta t_{scat}(\mu s) = -3.72 + 0.411 \log DM + 0.937(\log DM)^2 - 4.4 \log\left(\frac{\nu}{GHz}\right)$$

Scintillation

- Much theoretical analysis of this effect
- Cordes and McLaughlin only a summary
- Predict and observe characteristic scintillation time and bandwidth
  - Bandwidth is inversely proportional to $\Delta t_{scat}[= \tau_d]$

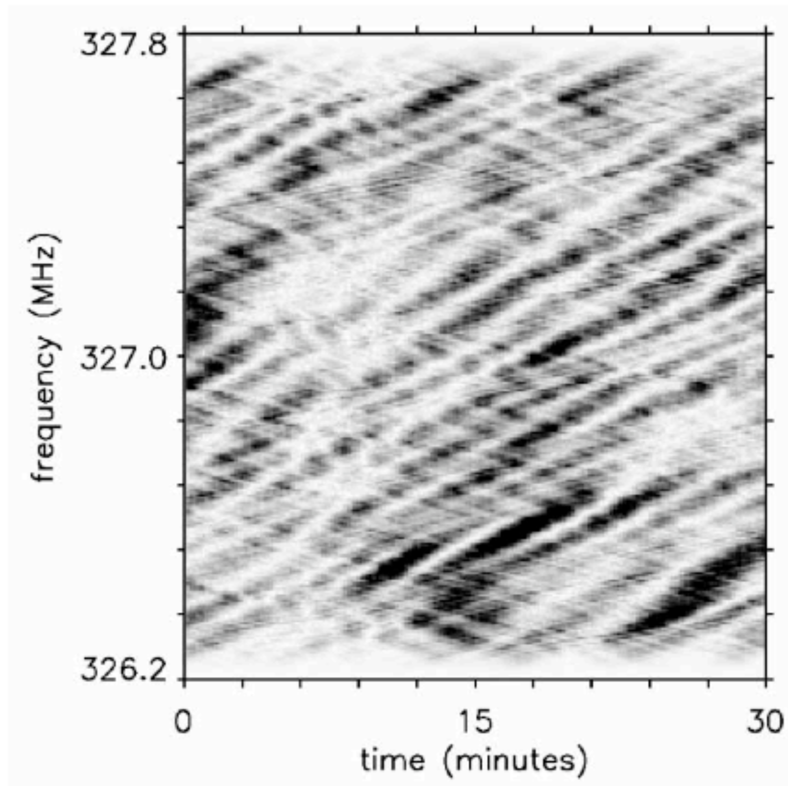
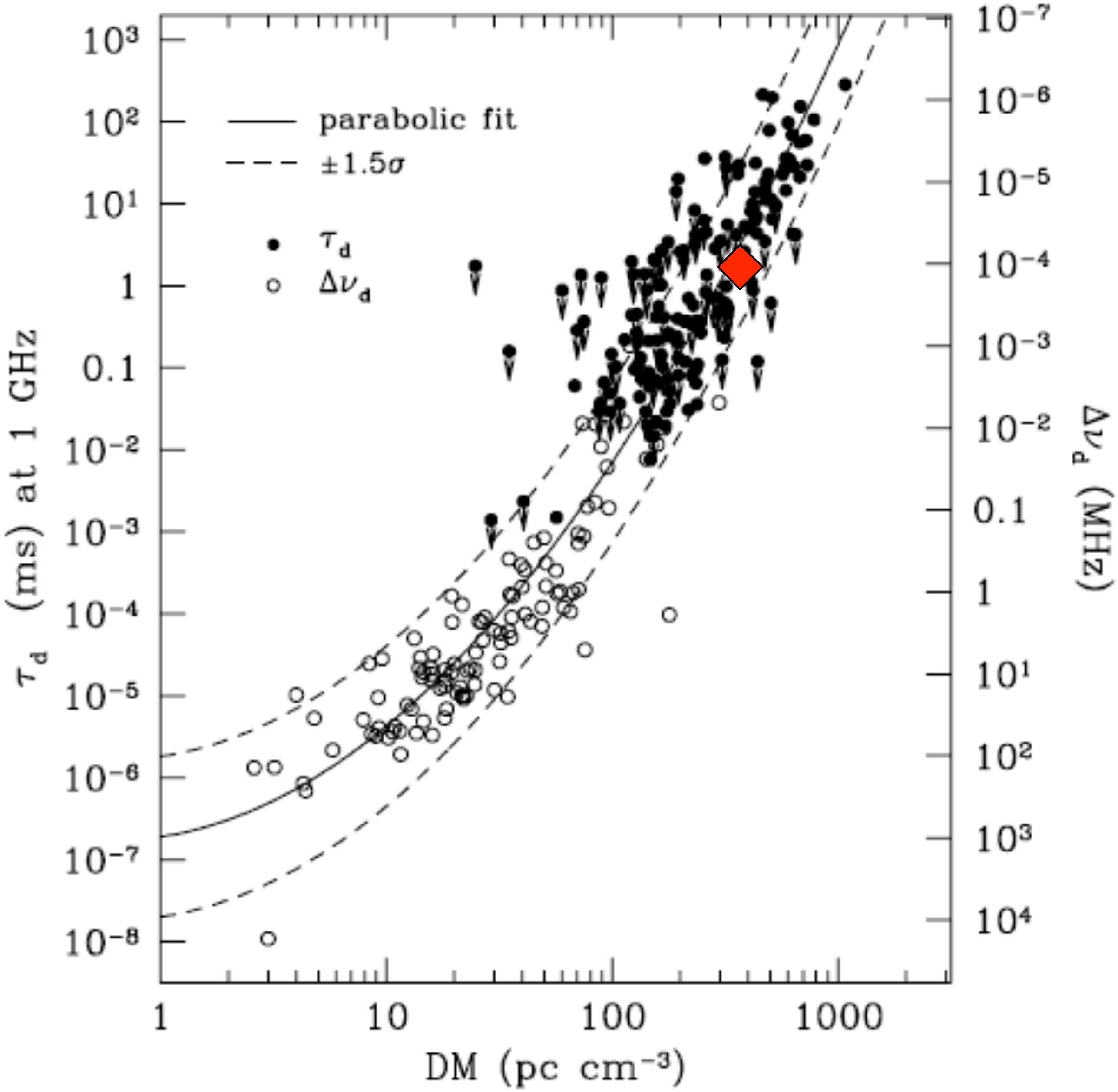
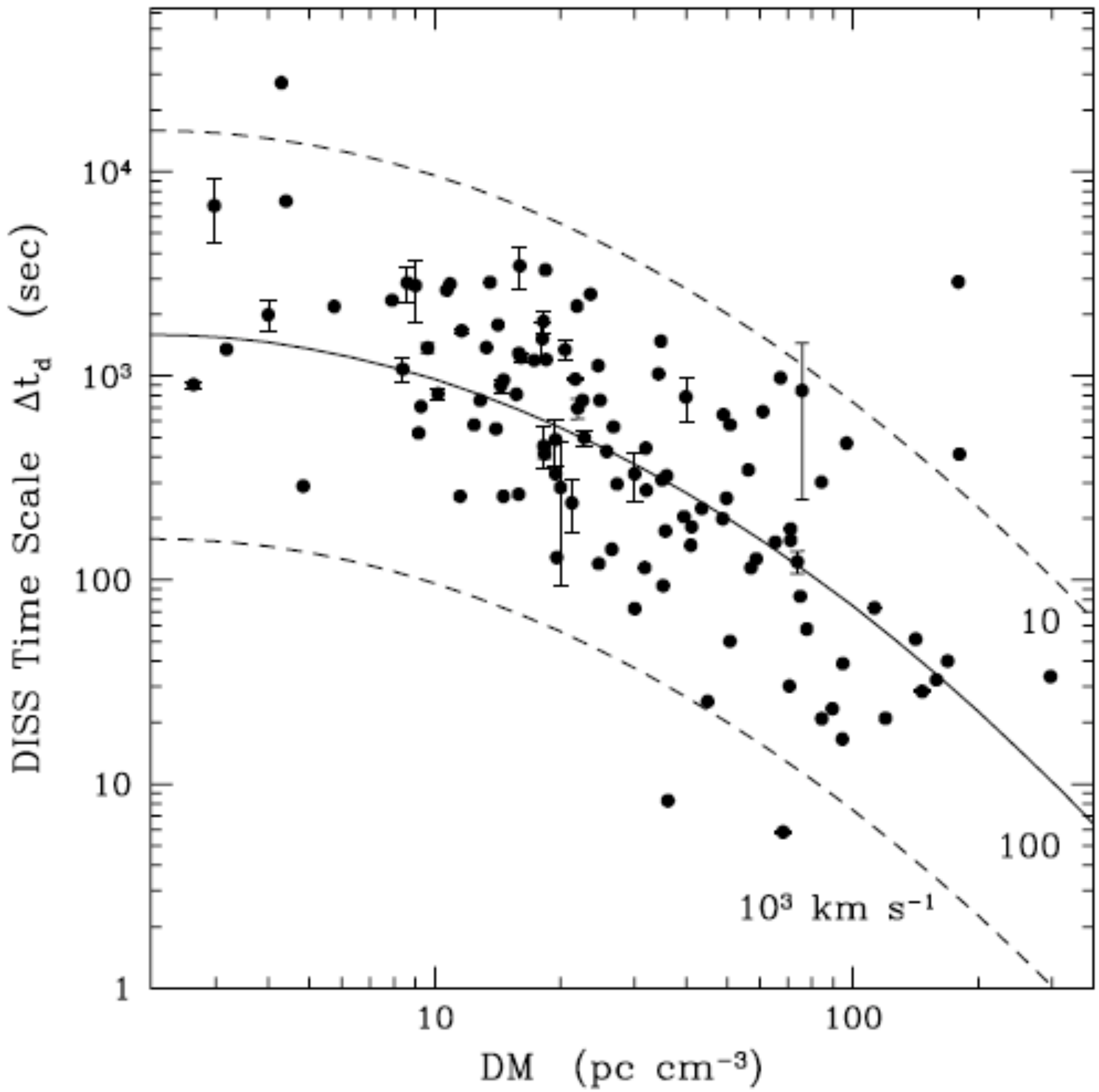


FIG. 1.—Dynamic spectrum of PSR B0834+06 observed on 2003 December 31. The flux density as a function of frequency and time is shown using a gray scale that is linear in power, with dark regions indicating high power. The criss-cross pattern is due to radio waves reaching the observer from a variety of angles (~10 mas away from the pulsar position), as detailed in the text.

Scintillation Bandwidth and Scatter Broadening Time



Scintillation Time Scale

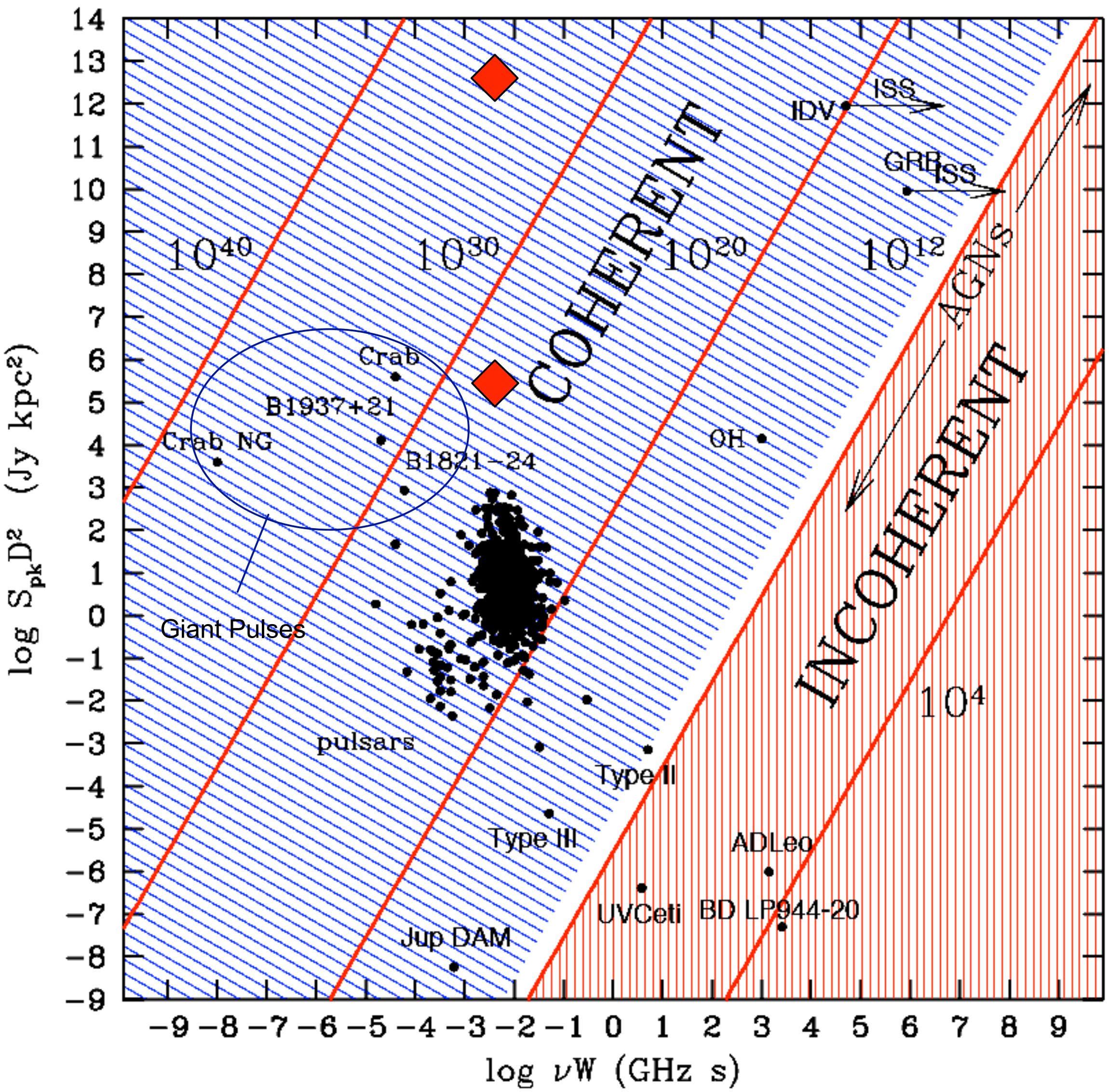


Brightness Temperature & Energetics

$$\left(\frac{T_B}{K}\right) \approx 10^{14.8}\left(\frac{S}{\text{mJy}}\right)\left(\frac{D}{\text{kpc}}\right)^2\left(\frac{\nu}{\text{GHz}}\right)^{-2}\left(\frac{\Delta t}{\text{sec}}\right)^{-2}$$

- Brightness Temperature
  - Lorimer et al.
    - 10^{34} K (at 500 Mpc)
  - Cordes & McLaughlin
    - 2 x 10^{34} K / Γ^2 at 500 Mpc
    - 4 x 10^{26} K / Γ^2 at 61 kpc (SMC)
- Energetics
  - 10^{40} erg (at 500 Mpc)
  - 2 x 10^{32} erg (at 61 kpc)

Pseudo-Flux and Time-Frequency

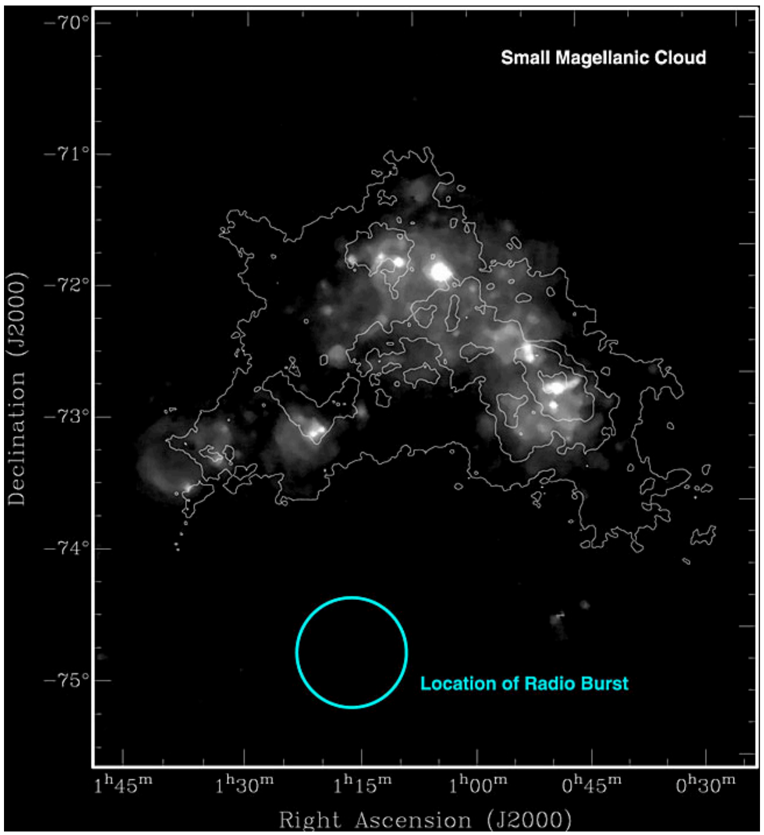


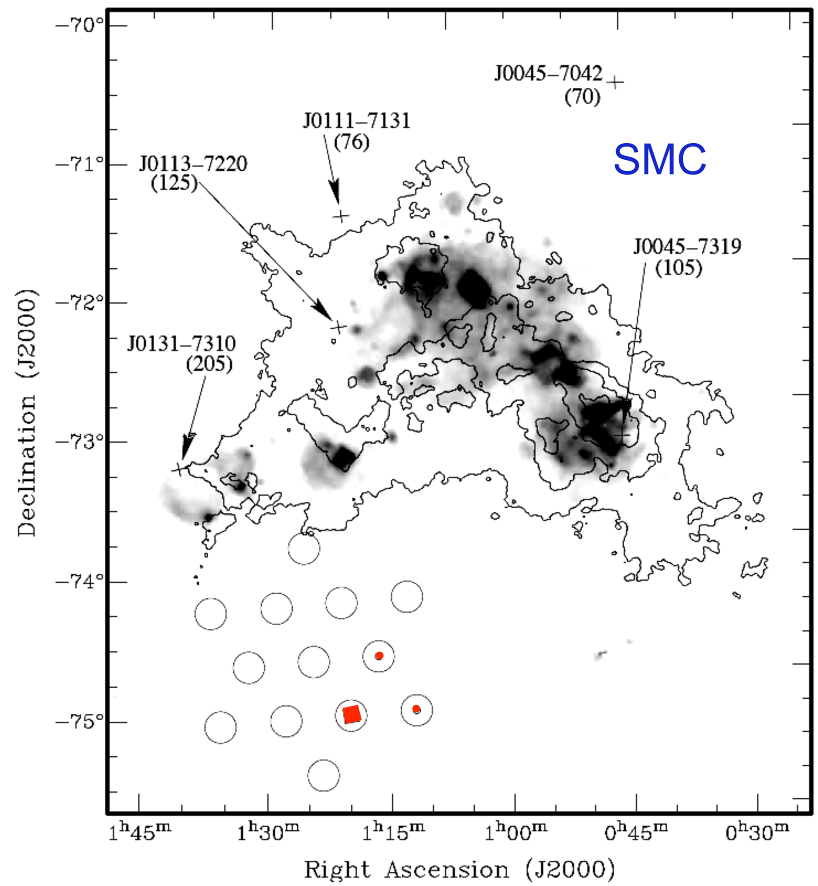
Is the Lorimer et al burst extragalactic?

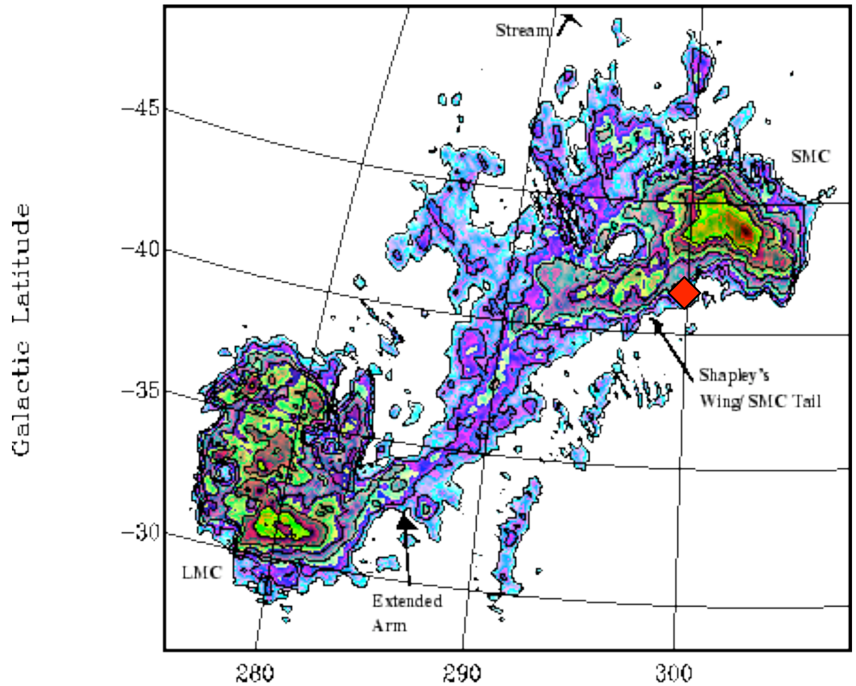
- Indications of extragalactic origin
  - Large DM, no known high-column density in vicinity
  - No other bursts detected in follow-up observations as might be expected for a giant pulse source or a RRAT
- Issues with interpretation as extragalactic
  - Requires new source type
  - Flux is more than 100 times detection threshold; deeper searches have not yielded additional detections

(extragalactic => D>1 Mpc)

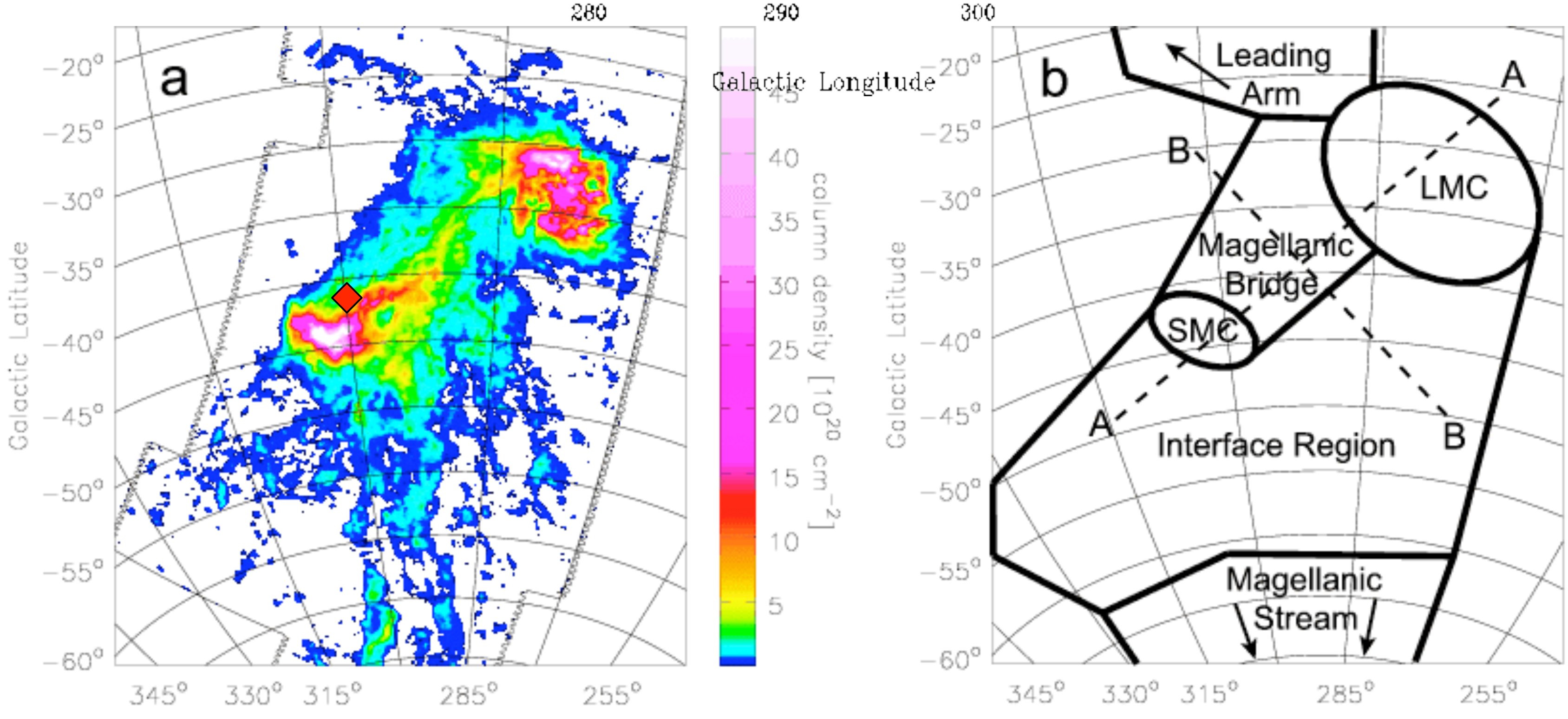
Position of Burst







Neutral Hydrogen (HI)
Column Density Map



Future Surveys

- **Allen Telescope Array (ATA)**
  - 42 antennas (~10^3 m^2); eventually 350 (~10^4 m^2)
  - 5 sq deg FOV at 1.4 GHz
- **Low Frequency Array (LOFAR)**
  - 10-250 MHz (better for slow transients)
  - 7700 antennas: 7 x 10^4 m^2
  - ? sq deg FOV
- **Mileura Wide-Field Array (MWA)**
  - 500 antennas (each w/ 16 dipoles)
  - ~16 m^2 each (80-300 MHz)
  - 25 deg steerable FOV for each antenna (150 MHz)
- **Square Kilometer Array (SKA)**
  - 1 sq deg FOV at 1 GHz
  - 5 x 105 m2 collecting area