Transients at Long Wavelengths

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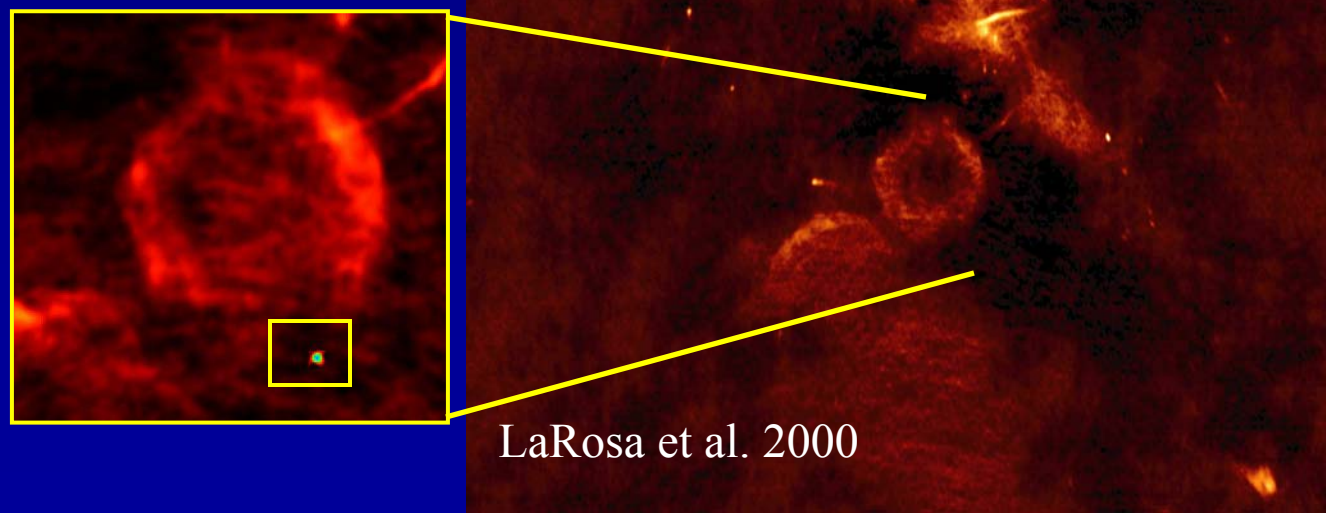
LWA
Long Wavelength Array

GCRT J1745-3009 Discovery

A monitoring campaign of the Galactic center

- $\lambda \approx 1$ meter
- Roughly 20 epochs
  more on the way
- Time samplings from ~ 1 week to 1 decade
- Observations with
  - Very Large Array (most)
  - Giant Metrewave Radio Telescope



LaRosa et al. 2000

GCRT J1745-3009 Verification

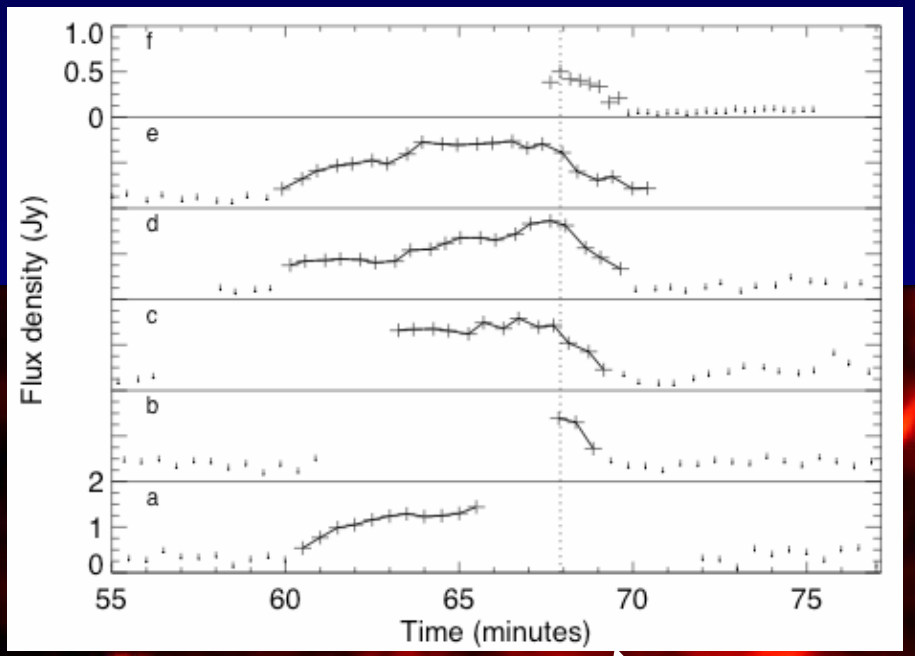
- Split data in wavelength?

  Still present

- Split data in time?

  Bursts!

  - » 5 bursts detected
  - » ~ 10 min. duration
  - » ~ 77 min. periodicity
  - » 6th burst later found in data from another epoch



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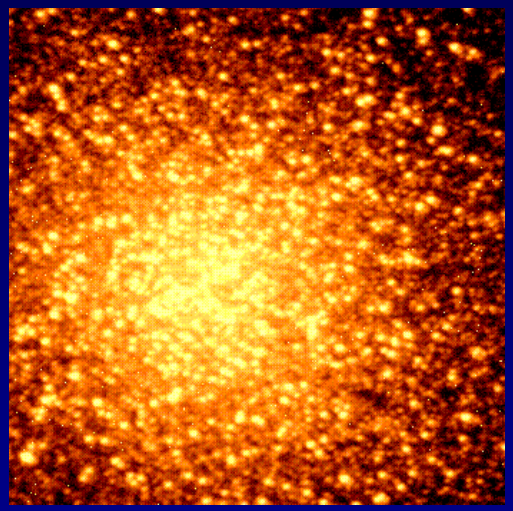
Radio Transients
Why Look?

Why look in the Galactic center?

- High stellar density
  - Globular clusters harbor many interesting pulsar systems
  - Globular cluster "on steriods"
  - High likelihood of exchange interactions, close encounters
- Concentration of X-ray transients toward Galactic center
- Hints that Galactic center may host transients
  - A1742-28
  - Galactic Center Transient (GCT)
  - *GCRT J1746-2757*
  - *XTE 1748-288*
  - *CXOGC J174540.0-290031*



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Radio Transients
Why Look?

- Transient ≡ burst, flare, pulse, etc. < 1 mon. in duration
- Transients can probe
  - Particle acceleration
  - Strong field gravity
  - Nuclear equation of state
  - Intervening media
  - Cosmological star formation history?
  - Physics beyond the Standard Model?
  - ET civilizations?
- Radio sky is poorly probed for (*radio-selected*) transients!
- Radio photons easy to make

  1 keV ~ 10^9 1-meter wavelength photons

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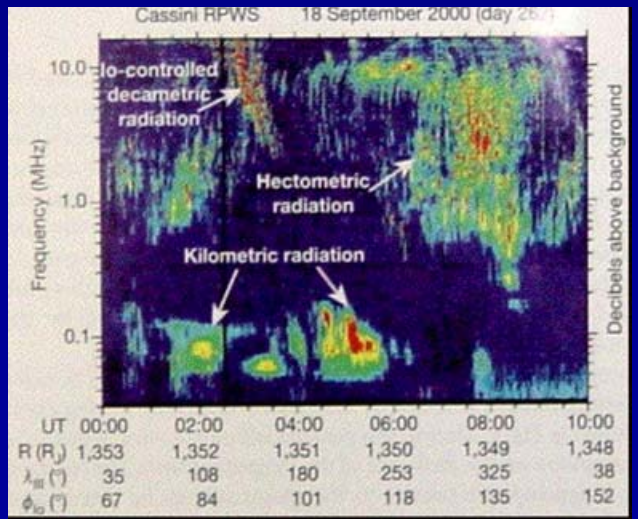
Known Classes of Radio Transients

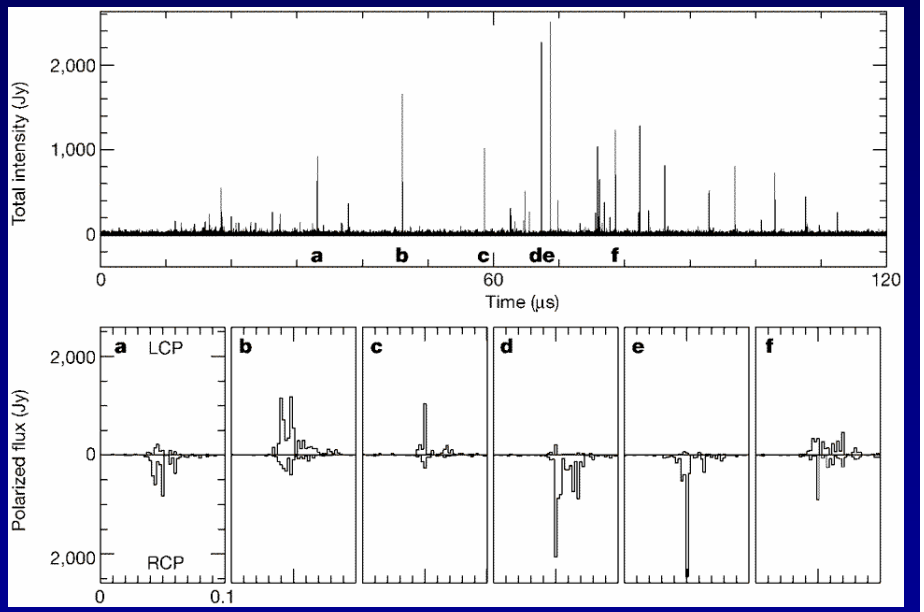
- Ultra-high energy cosmic rays
  - Radio pulses upon impact with atmosphere
  - Discovered at 44 MHz
  - Particles beyond the GZK cutoff?
  - Lunar neutrinos?
- Sun
- Planets
  - Solar system
    - Jupiter discovered at 22 MHz, one of the brightest objects below 40 MHz
  - Extrasolar?

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.



Known Classes of Radio Transients

- Brown dwarfs
- Flare (active) stars
- Neutron stars
  - "normal" pulsars
    Discovered at 80 MHz
  - "transient" pulsars
  - giant-pulse emitting pulsars
  - RRATs
  - magnetars
  - X-ray binaries
- Massive star explosions
  - Supernovae
  - γ-ray burst afterglows



←→

100 ns

Crab giant pulse (Hankins et al. 2003)

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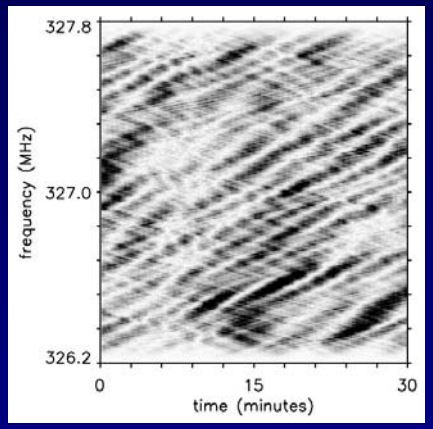
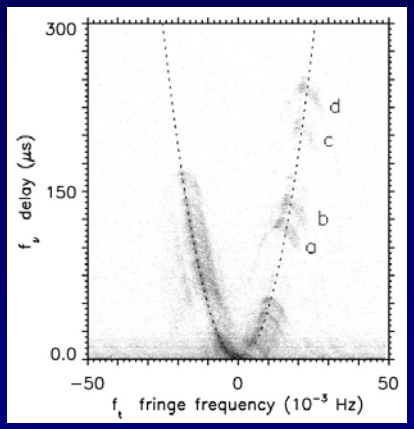
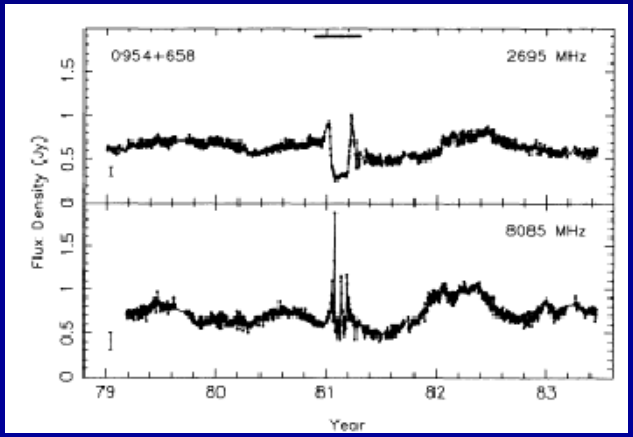
Radio Transients and Propagation Effects

- Intraday variability
  - Microarcsecond scales in AGN
- Fringing events in pulsar dynamic spectra
- Extreme scattering events





PSR B0834+06 (Hill et al.)



B0954+658 (Fiedler et al.)

Hypothesized Classes of Radio Transients

- Radio supernovae

  Coherent emission from explosion? (Colgate & Noerdlinger)

- γ-ray bursts

  Coherent emission ~ 100 MHz? (Sagiv & Waxman; Usov & Katz)

- Annihilating black holes (Rees)
- Gravitational-wave sources (EM counterparts)
- ET transmitters

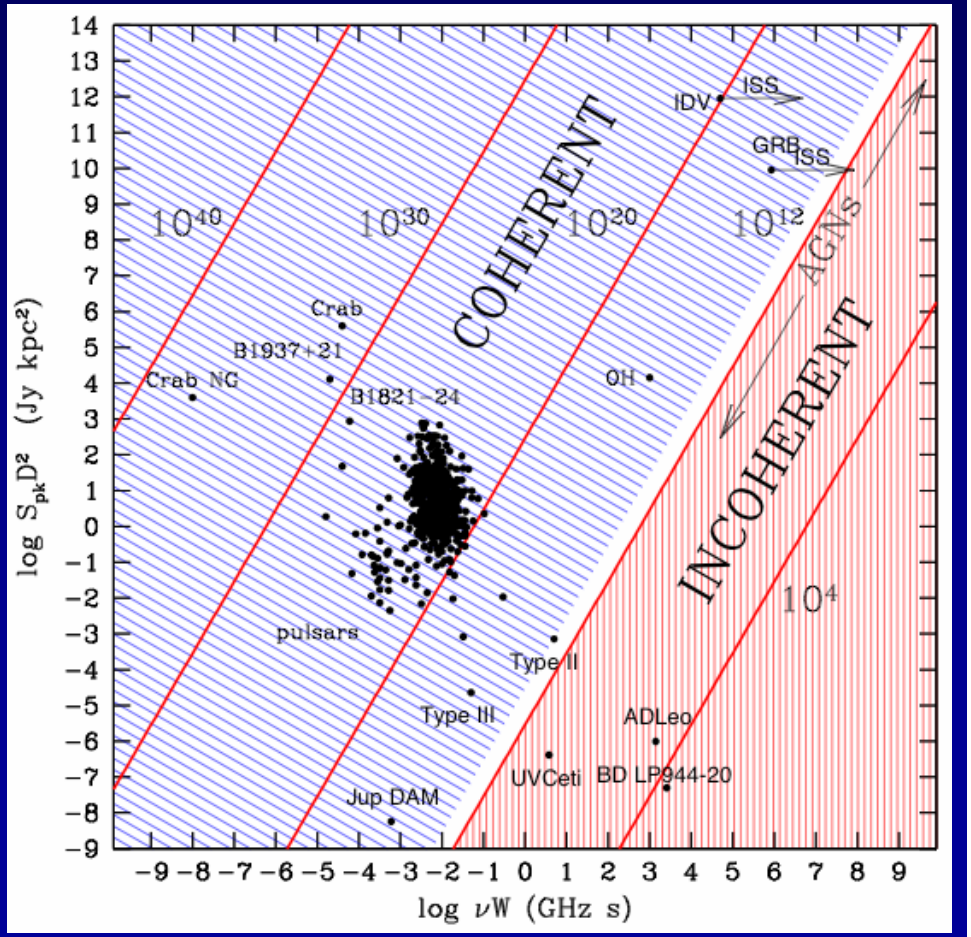
Radio Transients Phase Space

Brightness temperature of radio source

$$T \sim SD^2/(W\nu)^2$$

(Rayleigh-Jeans approximation)

- SD^2 — "pseudo-luminosity"
- $W\nu$ — uncertainty-like relation
  - S → flux density
  - D → distance
  - W → pulse width
  - ν → frequency



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Long Wavelength Array

Radio Transients
Blind Searching

$A\Omega(T/\delta t) \rightarrow$ "large"

- $A \rightarrow$ collecting area $\Rightarrow$ sensitivity
- $\Omega \rightarrow$ solid angle coverage
- $(T/\delta t) \rightarrow$ time resolution
- Similar to entendue

- Many bright radio sources are from extended regions (e.g., AGN radio lobes)
- Most radio observations
  - Image very small field of view, or
  - Don't subdivide observations in time, or
  - Don't revisit regions often (limited observing time), or
  - Single dish or small configs can be confusion limited

LWA
Long Wavelength Array

Radio vs. X-ray sky

- X-ray instruments can cover the full sky on time scales of an hour with arcminute resolution and reasonable sensitivity, e.g., RXTE ASM.
- RXTE/ASM continuously observing for more than 10 years.
- RXTE/ASM has discovered more than 200 transients!

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Finding Radio Transients: Long Wavelengths

Long Wavelength Array

$A\Omega(T/\delta t) \rightarrow$ "large"

- $A \rightarrow$ dipole $A \propto \lambda^2$
- $\Omega \rightarrow$ dipole $\Omega \sim 4\pi$
- $(T/\delta t) \rightarrow$ electronic arrays

- Emitting volume $\sim \lambda^3 \Rightarrow$ coherent emission increasingly likely
  - Cosmic ray air showers
  - Jupiter
  - Pulsars

Watch out for propagation effects!

Typically scale as λ^2 or worse

Long Wavelength Radio Transient Hunting

- Several new large, long wavelength arrays in the planning or building stages:
  - Long Wavelength Array (LWA, New Mexico)
  - Low Frequency Array (LOFAR, The Netherlands)
  - Primeval Atomic Structure Telescope (PAST, China)
  - Mileura Wide-field Array (MWA, Australia)
  - Precision Array to Probe the Epoch of Reionization (PAPER, West Virginia, Australia?)
  - Square Kilometer Array (SKA, TBD)
- Transients comprise part of the science case for most, if not all, of these telescopes.

LWA
Long Wavelength Array

LWA Overview

Far Larger than the 74 MHz VLA

One LWA Station = 256 dipoles

Full LWA: 52 stations

100 m

400 km

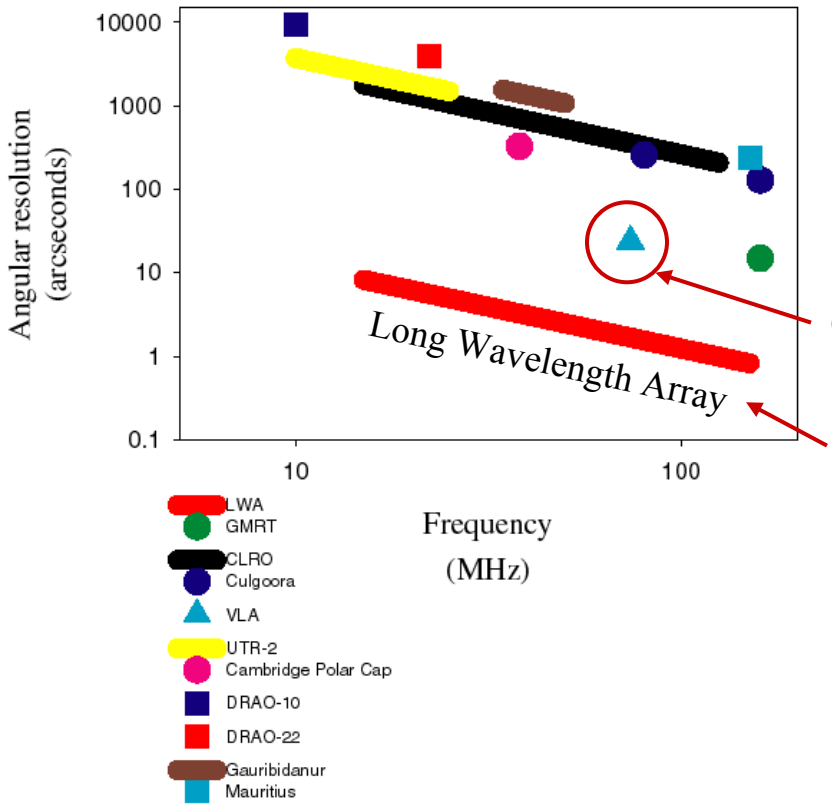
LWA
Long Wavelength Array

LWA Begins!

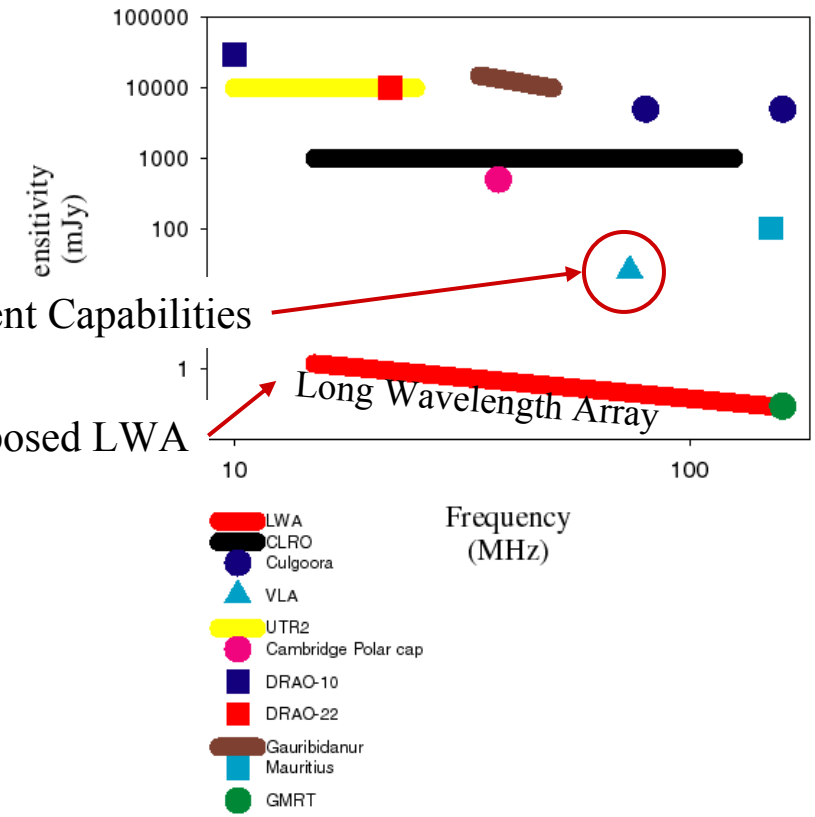
LWA
A New Window on the Universe

Long Wavelength Array

Angular Resolution vs. Frequency
for a 500 km LW Array



Sensitivity vs. Frequency
for a 500 km LW Array



Current Capabilities

Proposed LWA

LWA
Long Wavelength Array

Square Kilometer Array

- Next generation radio telescope
- ~ 100x as sensitive as the Very Large Array, Allen Telescope Array
- Frequency range: 0.1–25 GHz
- Site and design studies on-going

  (Decision points in 2006 to 2008)

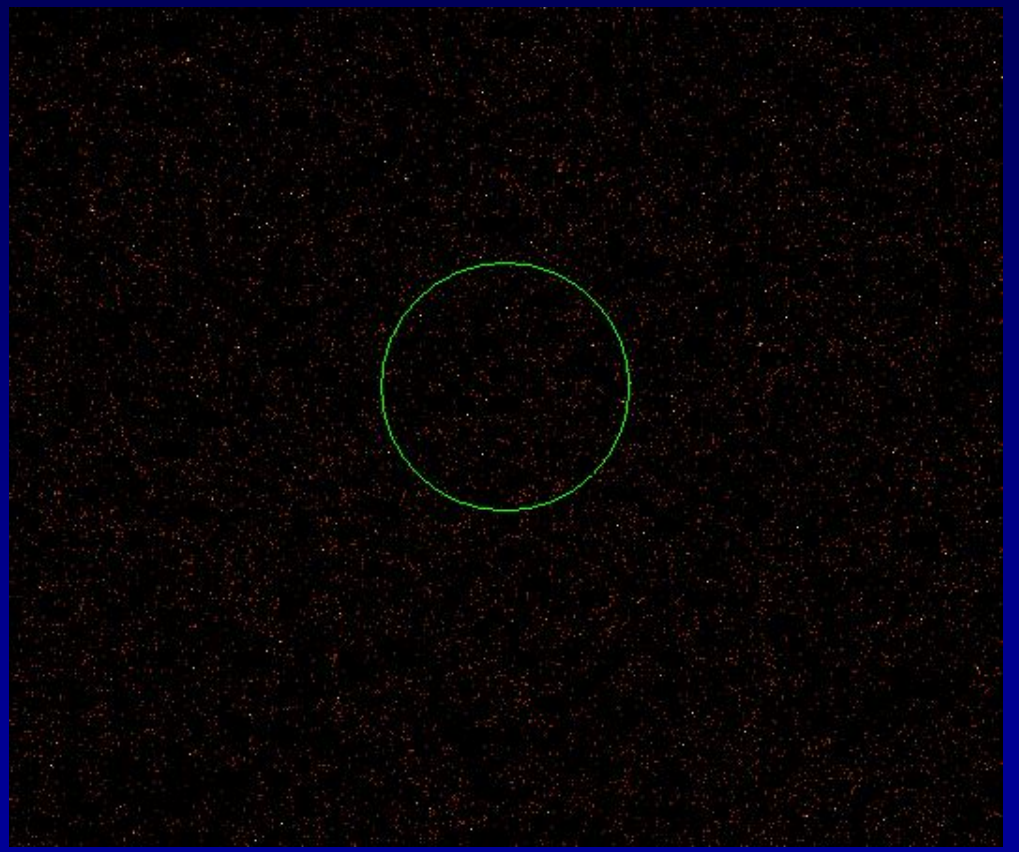
http://www.skatelescope.org/

GCRT J1745-3009 Radio Characteristics

- Five outbursts with spacing 77.1 ± 0.3 minutes
  - No interburst emission
- 1.25º from Galactic center
- No circular polarization
- Variability timescale
  - $\Delta t_{rise} \approx 10$ min
  - $\Delta t_{decay} \approx 2$ min
  - Slow rise, fast decay
  - Brightness temperature ~ 10^{12} K (D/70 pc)
- Undetected in many other observations (2002 March–August; 2003 July–December)

GCRT J1745-3009 X-ray Observations

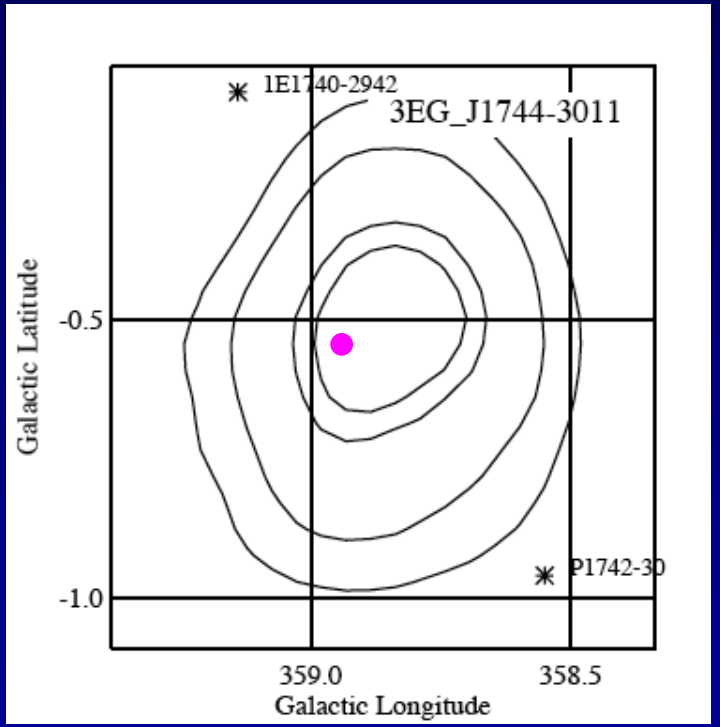
- No variability in RXTE/PCA observation between two of the radio bursts
- Nothing obvious in the PCA bulge scans (C. Markwardt)
- Nothing seen in a re-analysis of the full ASM archives (R. Remillard)
- Nothing seen in re-analysis of full BeppoSAX/WFC archive (J. in ‘t Zand)
- Nothing seen in *Chandra* DDT observation.



Upper limit: 4 x 10^{-6} ph/cm^2/s (0.3–10 keV)
= 8 x 10^{31} erg/s at 8.5 kpc

GCRT J1745-3009 Related EGRET Source?

- GCRT J1745-3009 is near the center of the error region for 3EG J1744–3011.
- The error region is large (20 arcmin), and the region is highly confused in EGRET.
  - No significant evidence of an association
- GLAST angular resolution and sensitivity will help!



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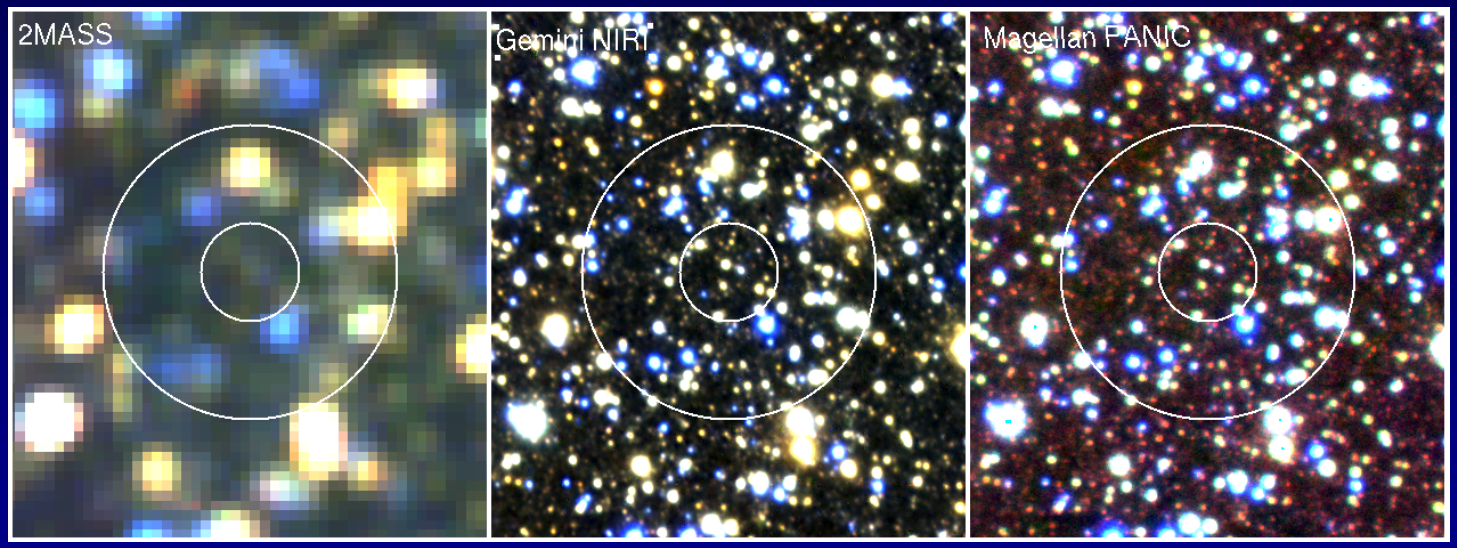
GCRT J1745-3009 Infrared



- J,H,Ks images at Magellan (PANIC) and Gemini(NIRI)
- Crowded field! (700 sources within 15" in Ks-band image

➢ Need better position!

(with D. Kaplan, D. Chakrabarty, R. Bandyopadhyay)

LWA
Long Wavelength Array

GCRT J1745-3009

What don't we know?

- Radio spectrum
  - Only detected at 1-meter wavelength
- Distance
- Counterpart at any other wavelength

- What is it?
- "Burper" (Kulkarni & Phinney)
- Microquaser
  - No bright X-ray emission?
- Nulling or transient pulsar
- Precessing pulsar (Zhu & Xu)
- Double pulsar (Turolla, Possenti, & Treves)
- White dwarf pulsar (Zhang & Gil)

LWA
Long Wavelength Array

Summary

- Radio transients offer varied and unique probes.
- Much of the radio sky may be dynamic and unexplored!
  - GCRT J1745-3009
  - RRATs
  - …
- New instruments promise to revolutionize this field
  - LWA
  - LOFAR
  - MWA
  - SKA