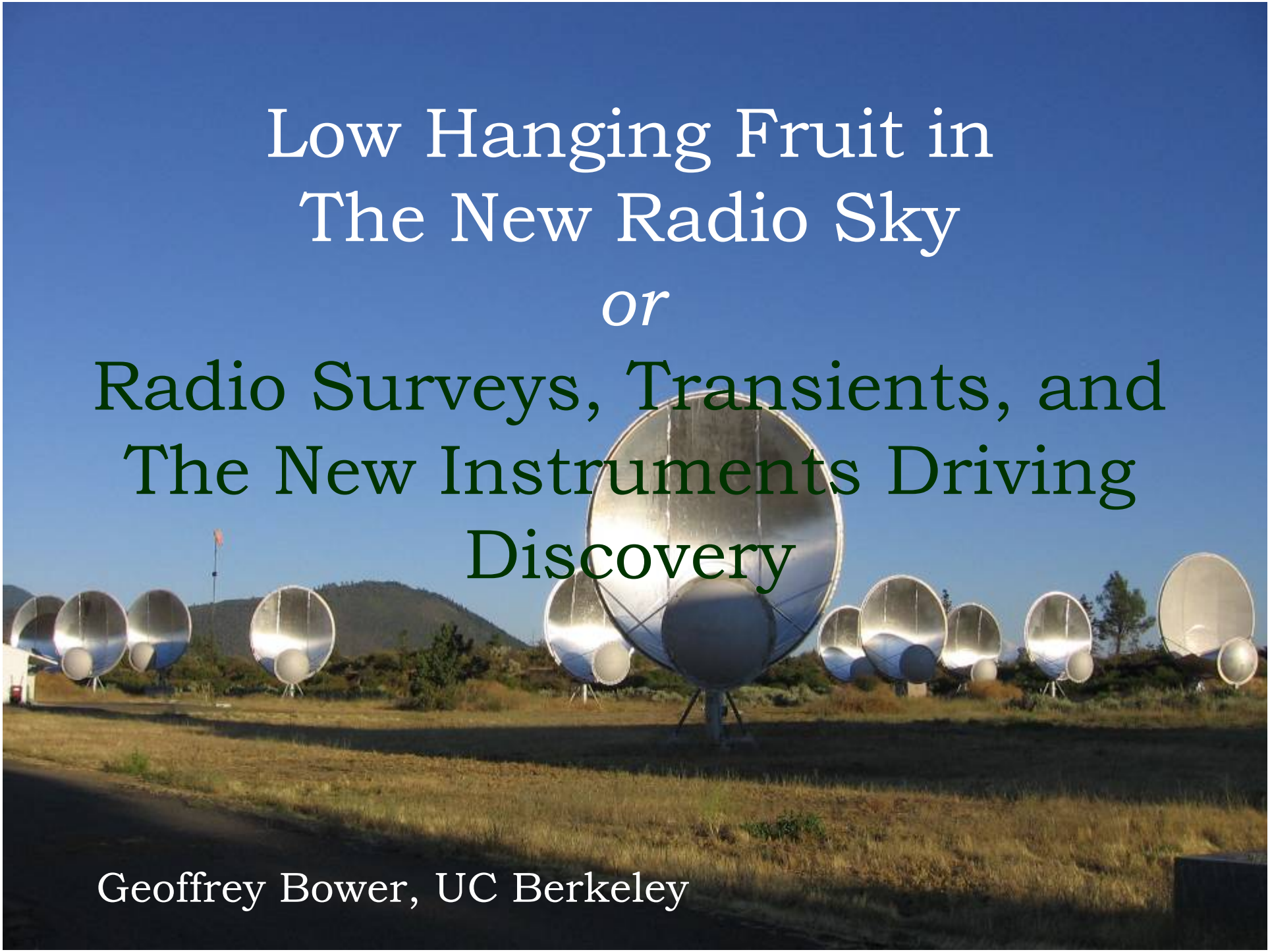


Low Hanging Fruit in The New Radio Sky

or

Radio Surveys, Transients, and The New Instruments Driving Discovery

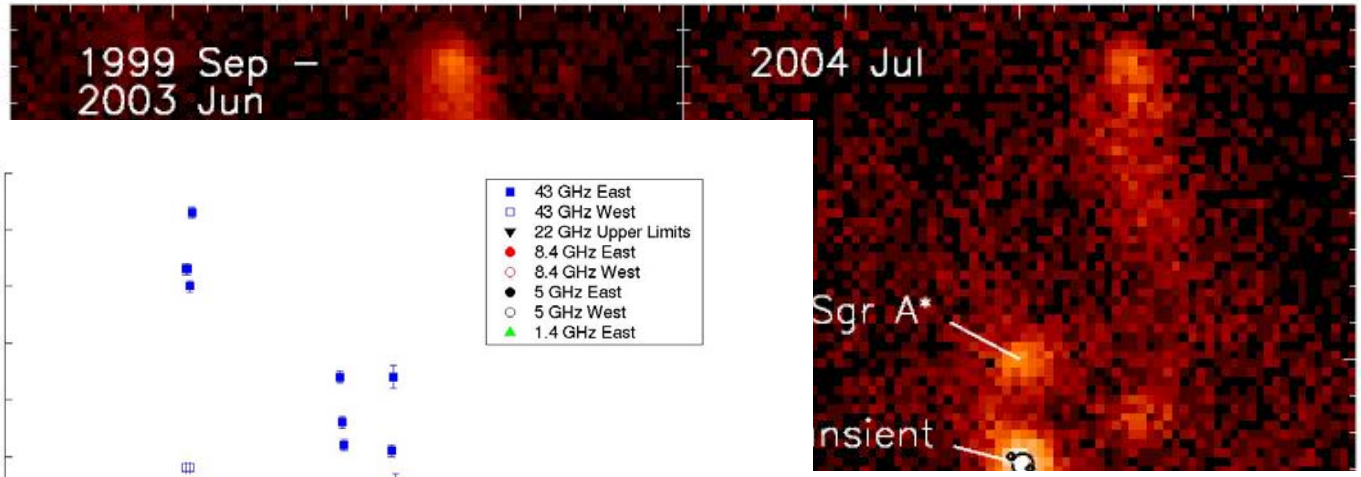
Geoffrey Bower, UC Berkeley

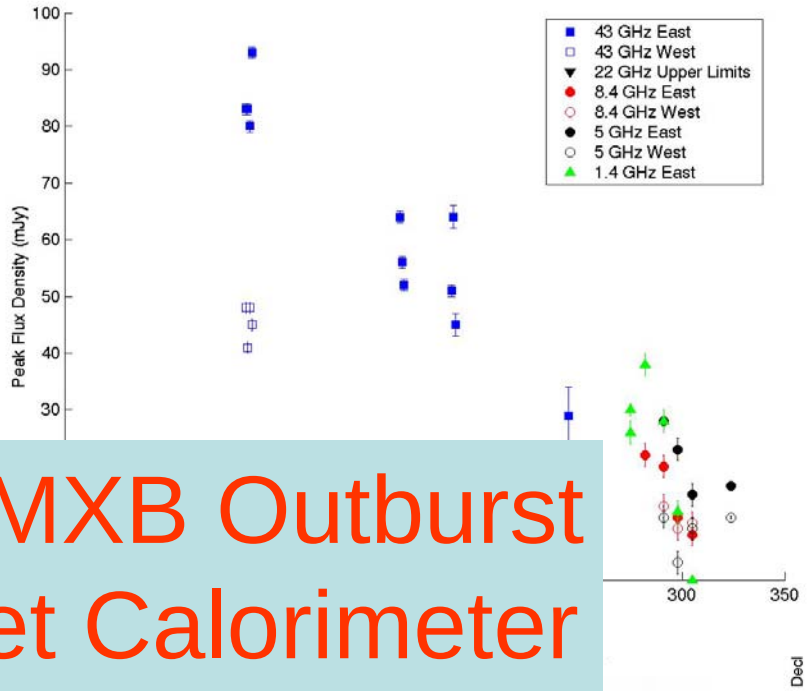
Collaborators

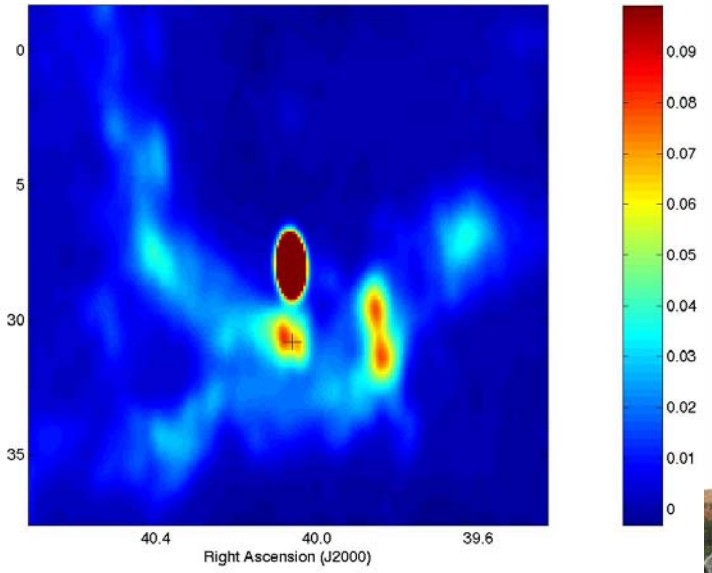
- ATA team
  - UCB: Welch, Blitz, Wright, Bock, Bower …
  - SETI Inst: Tarter, DeBoer, Dreher, Davis …
- Douglas Bock
- Alberto Bolatto
- Eliot Quataert
- Many others
  - Backer, Baganoff, Bloom, Falcke, Goss, Macquart, Muno, Plambeck, Wright, et al.

Allen Telescope Array

Galactic Center Radio Transient







LMXB Outburst Jet Calorimeter

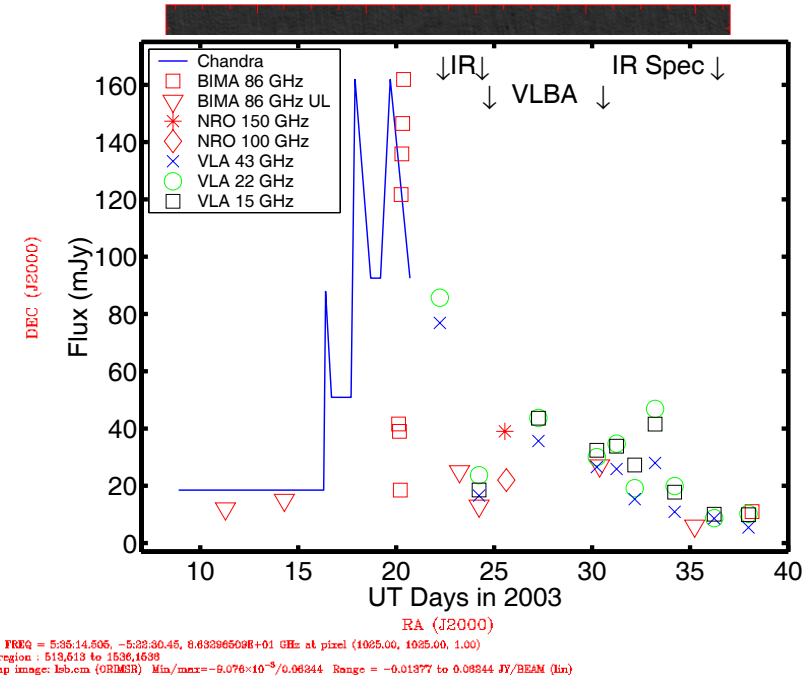
$L_{jet} \sim L_x$

Bower et al 2005, Muno et al 2005

Allen Telescope Array

SETI INSTITUTE

MM Wavelength T Tauri Outburst in Orion

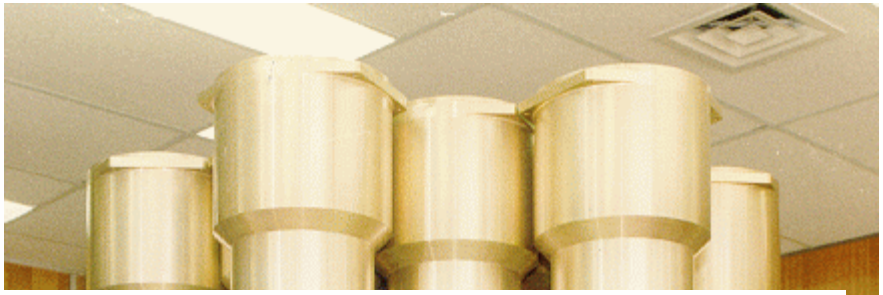


- 2nd most luminous stellar radio outburst
- Briefly, brightest object in nebula
- Required long baselines for detection
- Magnetized T Tauri outburst
- Contemporaneous with X-ray outburst
- Many such objects likely to be found by CARMA & ALMA

BIMA A configuration images

(Bower, Plambeck, Bolatto, Graham, de Pater, McCrady, Baganoff 2004)

RRATs

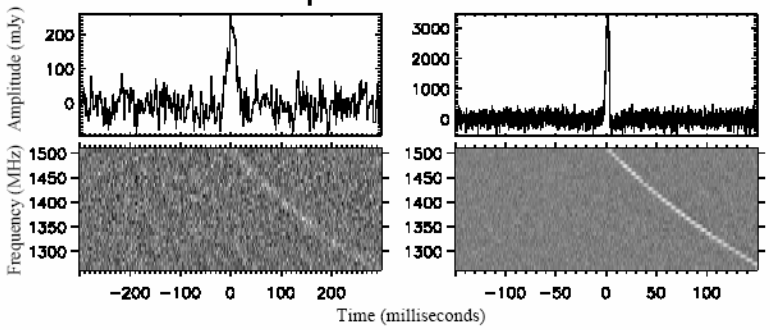


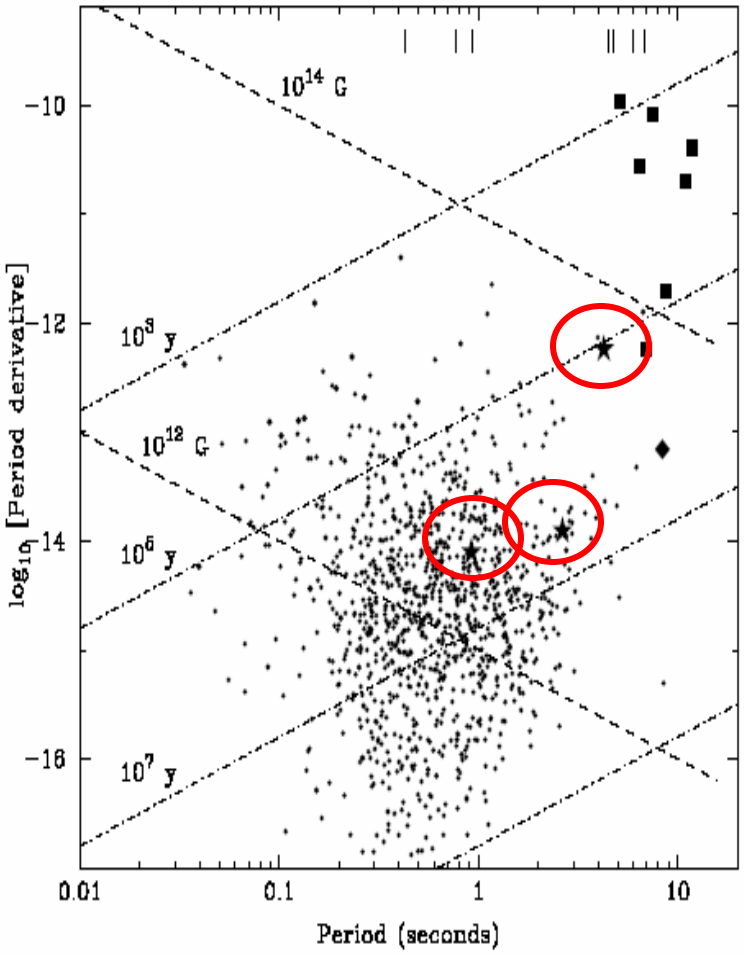
Single burst detections

Duty cycle < 10^{-5}

Rotating radio transients (McLaughlin et al 2005)

$N_{RRAT} > N_{psr}$





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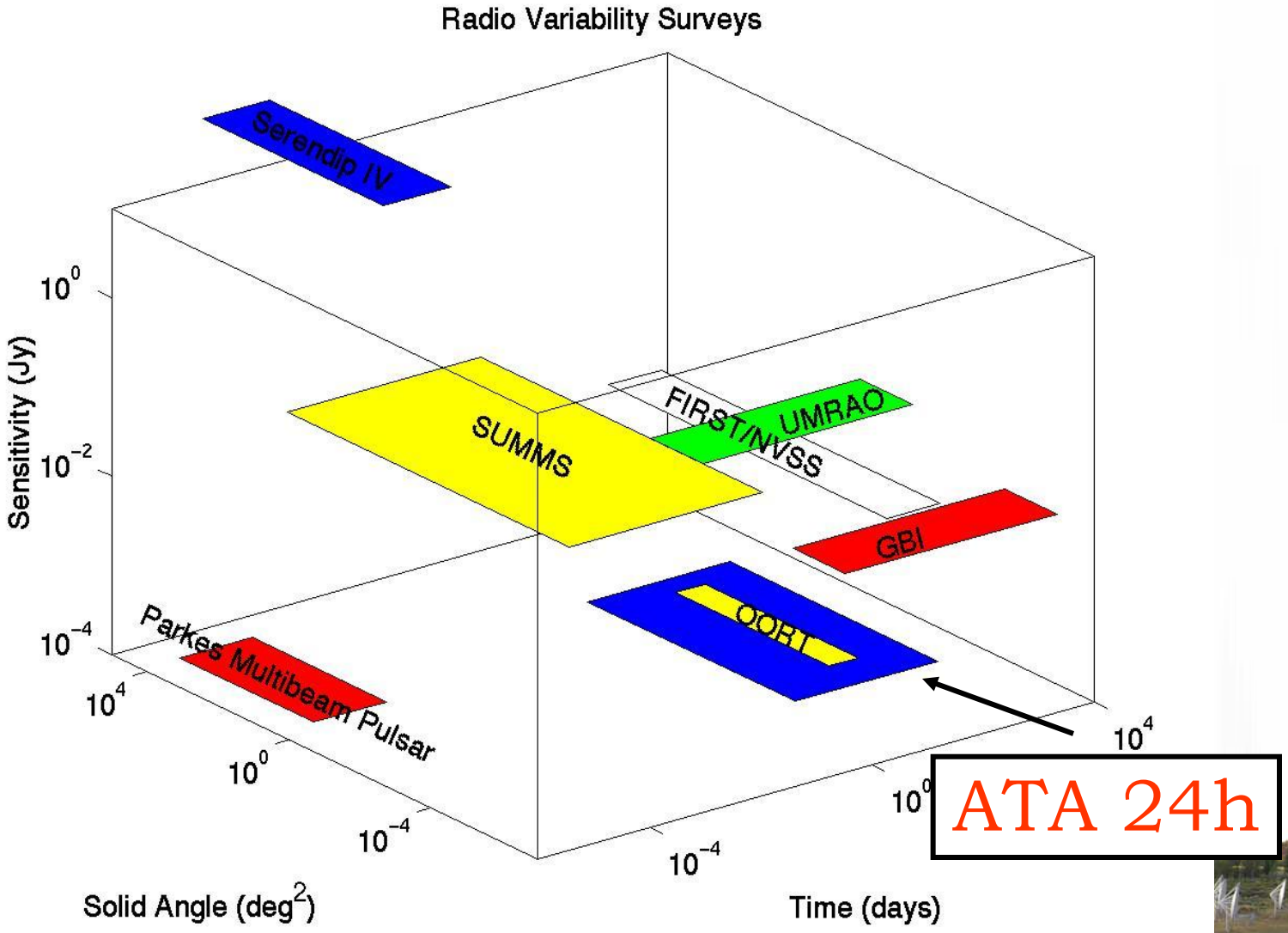
Radio Transient Discovery

- Wide range of properties
  - Frequency: 330 MHz → 90 GHz
  - Timescales: milliseconds → days → years
  - Bright: Tip of the iceberg
  - Coherent and incoherent phenomena
  - Galactic and extragalactic
- Modes of Transient Discovery
  - Serendipity
    - GCRT, GMRA
  - High Energy Follow-up
    - GRBs
  - Dedicated searches
    - Burper, RRATs
  - New instrumentation
    - RRATS, GMRA

Transient Discovery!

Allen Telescope Array

Transient Parameter Space is Wide Open



Allen Telescope Array

Allen Telescope Array

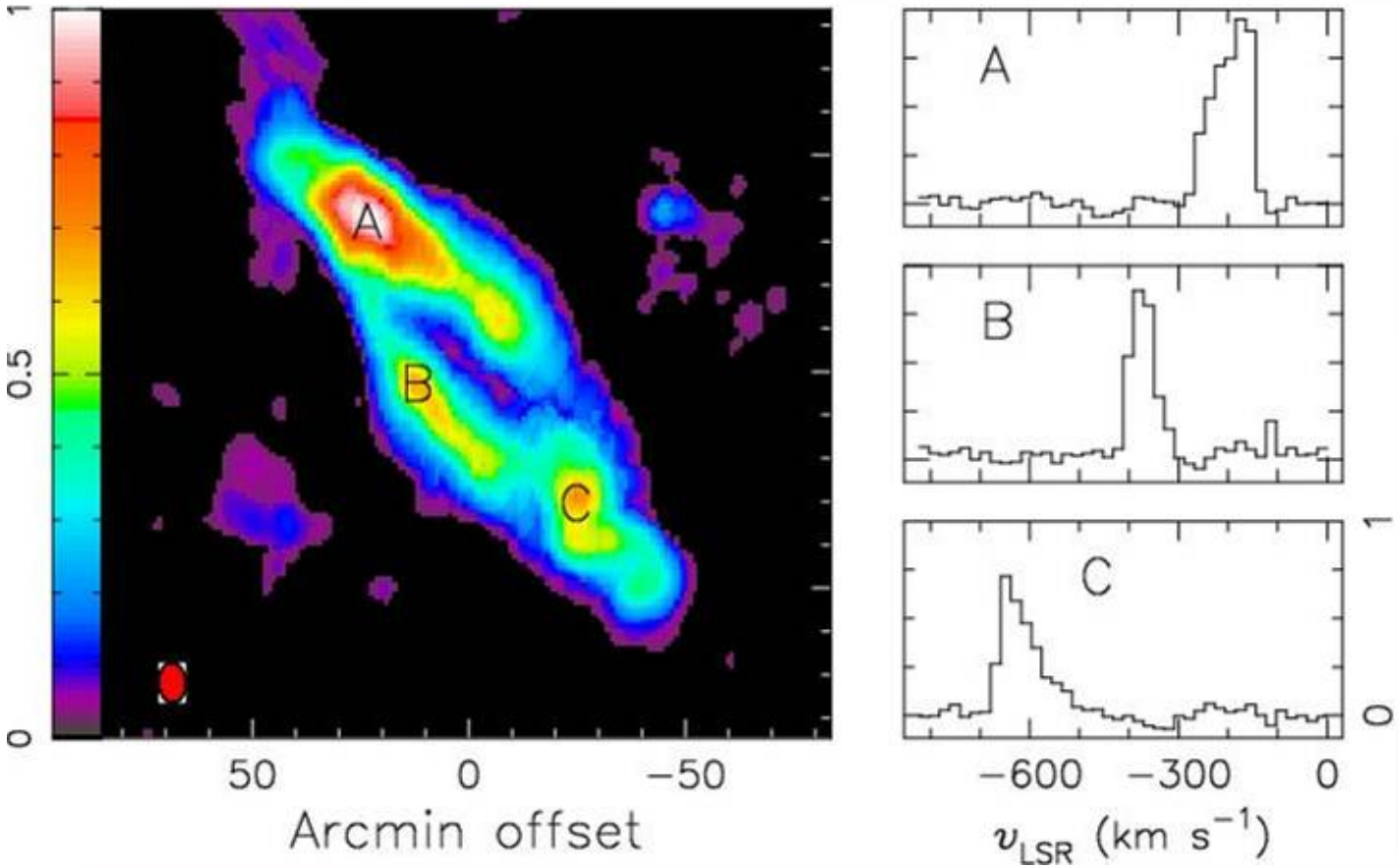
- Large N design
  - 350 x 6.1m antennas
  - Sensitivity of the VLA
  - Unprecedented imaging capabilities
- Continuous frequency coverage
  - 0.5 to 11.2 GHz
- Wide field of view
  - 3 degrees at 1 GHz
  - Excellent survey instrument: 17x FOV of VLA
- Compact Configuration
  - 1 arcmin at 1.4 GHz (350), 1 arcmin at 5 GHz (42)
- Simultaneous observing with multiple backends
  - Correlator: 2 x 100 MHz x full Stokes x 1024 channels
  - Phased array beams: 32 indepent at 4 frequencies

- Joint project of UC Berkeley/SETI Inst.
- Privately funded construction
  - NSF support for correlator & operations
- Prototype for US SKA proposal & pioneer of LNSD

ATA-42 Operational This Spring

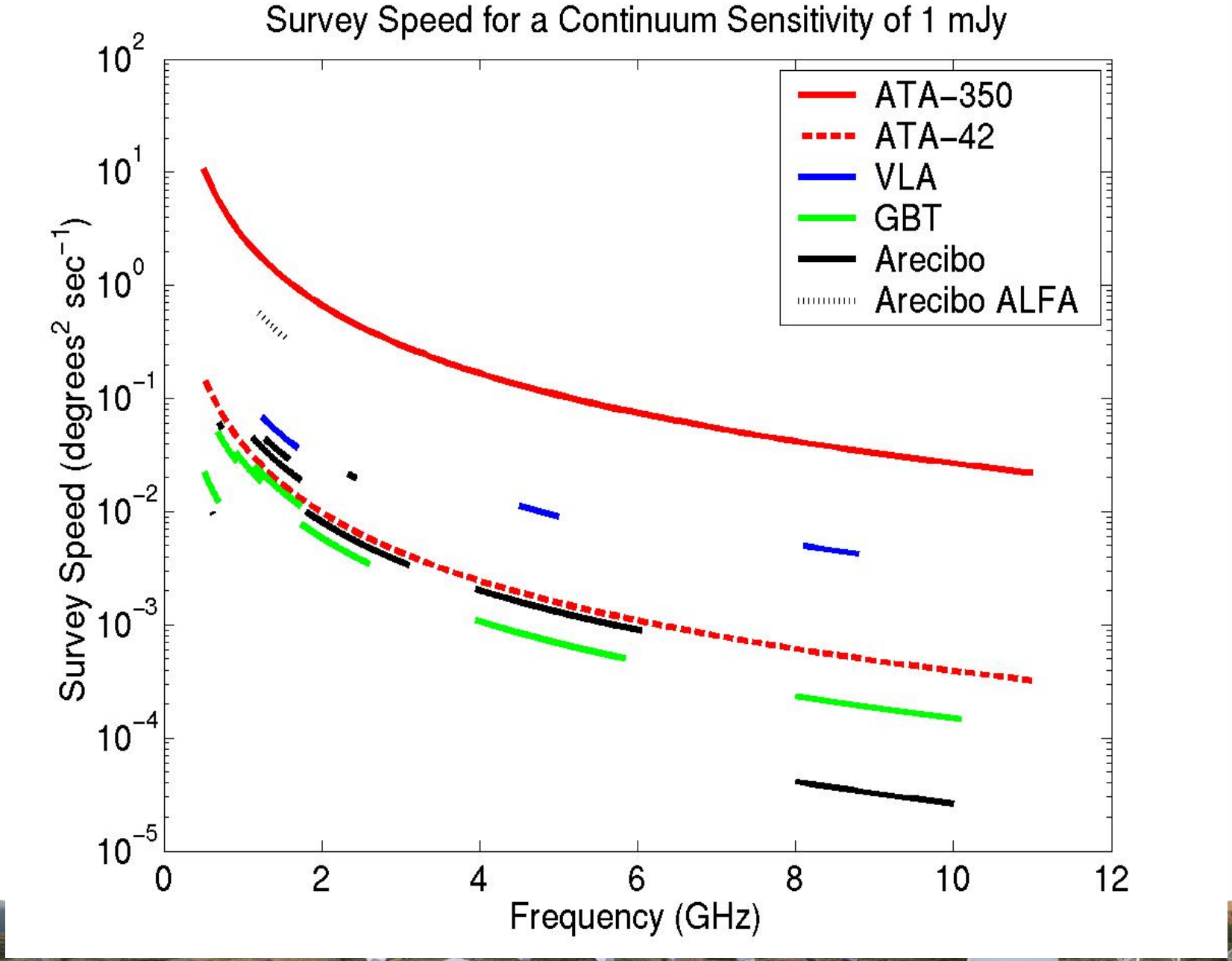
Allen Telescope Array

M31 in a Single Pointing



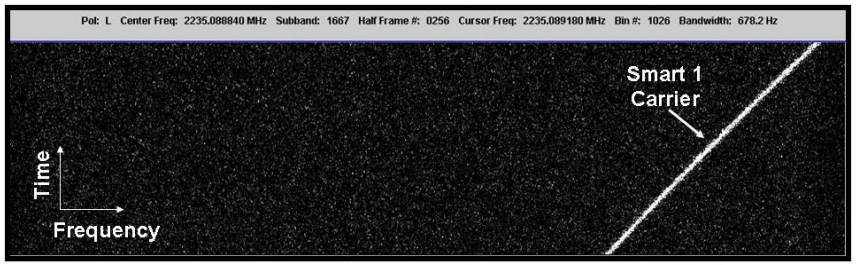
Allen Telescope Array

Allen Telescope Array



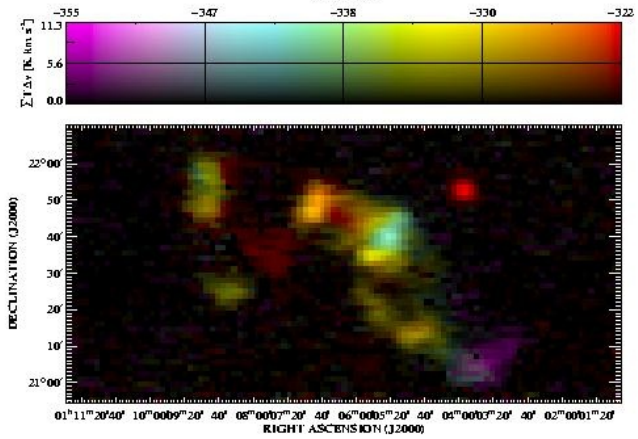
ATA Science

- SETI
  - GC survey: 20 sq. deg, 1.4-1.7 GHz, 6 months
  - 10^6 stars over 1-10 GHz
    - Arecibo radar detectable at 300 pc
  - Simultaneous with correlator



- Extragalactic HI survey
  - Neutral gas SDSS equivalent
  - L* at z=0.1 over the entire sky
- Galactic magnetic fields, HI, long-chain molecules
- Pulsars
- Radio continuum science

Robishaw, Simon & Blitz 2002



Allen Telescope Array

LGS 3

Transient Science with the ATA

- Targeted Monitoring
  - Exploits multiple beams
  - Can be done simultaneously with other science
  - Pulsars
  - Gamma-ray burst afterglows
  - Black holes
  - Supernovae
  - Intraday variability
  - *Your Favorite Object Here*
- Blind Surveys
  - Exploit survey speed
  - Orphan GRB afterglows
  - New Radio Supernovae
  - Tidally disrupted stars around Massive BHs
  - Stellar radio emission
  - The "Twinkling" Radio Sky
  - *Something New!*

Allen Telescope Array

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ATA Transient Surveys

- FiGSS: Five GHz Sky Survey (ATA-42)
  - 5 GHz
  - 1 mJy rms
  - 10^4 square degrees/6 months
- Deep Survey (ATA-350)
  - 5 GHz
  - 50 microJy rms
  - 20 square degrees/day
- All Sky Low Frequency Survey (ATA-350)
  - 700 MHz
  - 250 microJy rms
  - 10^4 square degrees/day
- Long Period Pulsar/Transient Survey (ATA-42)
  - Any frequency
  - 0.01 – 10000 sec
  - Targeted: Galactic Center, Globular Cluster, Andromeda

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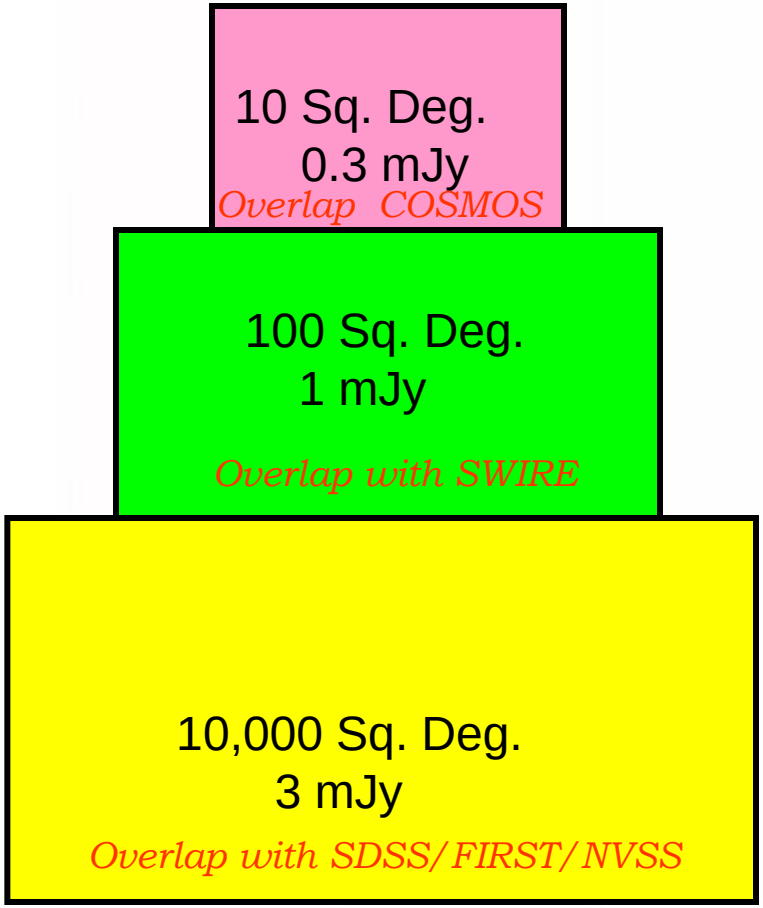
ATA FiGSS
Five GHz Sky Survey

- 5 GHz Counterpart to Sloan Digital Sky Survey
  - Overlap with NVSS, FIRST & SDSS
  - 10^4 Square degrees
  - Arcminute resolution
- Highest Frequency Deep, Large Radio Survey
  - 0.6 mJy rms
  - Factor of ~10 more sensitive than GB6
  - 2 Smaller, deeper fields
  - >1000 dynamic range
- 6 calendar months to complete with ATA-42
- Extendable in area and sensitivity

Allen Telescope Array

FiGSS Layer Cake



Daily

Every 10 Days

Every 100 Days

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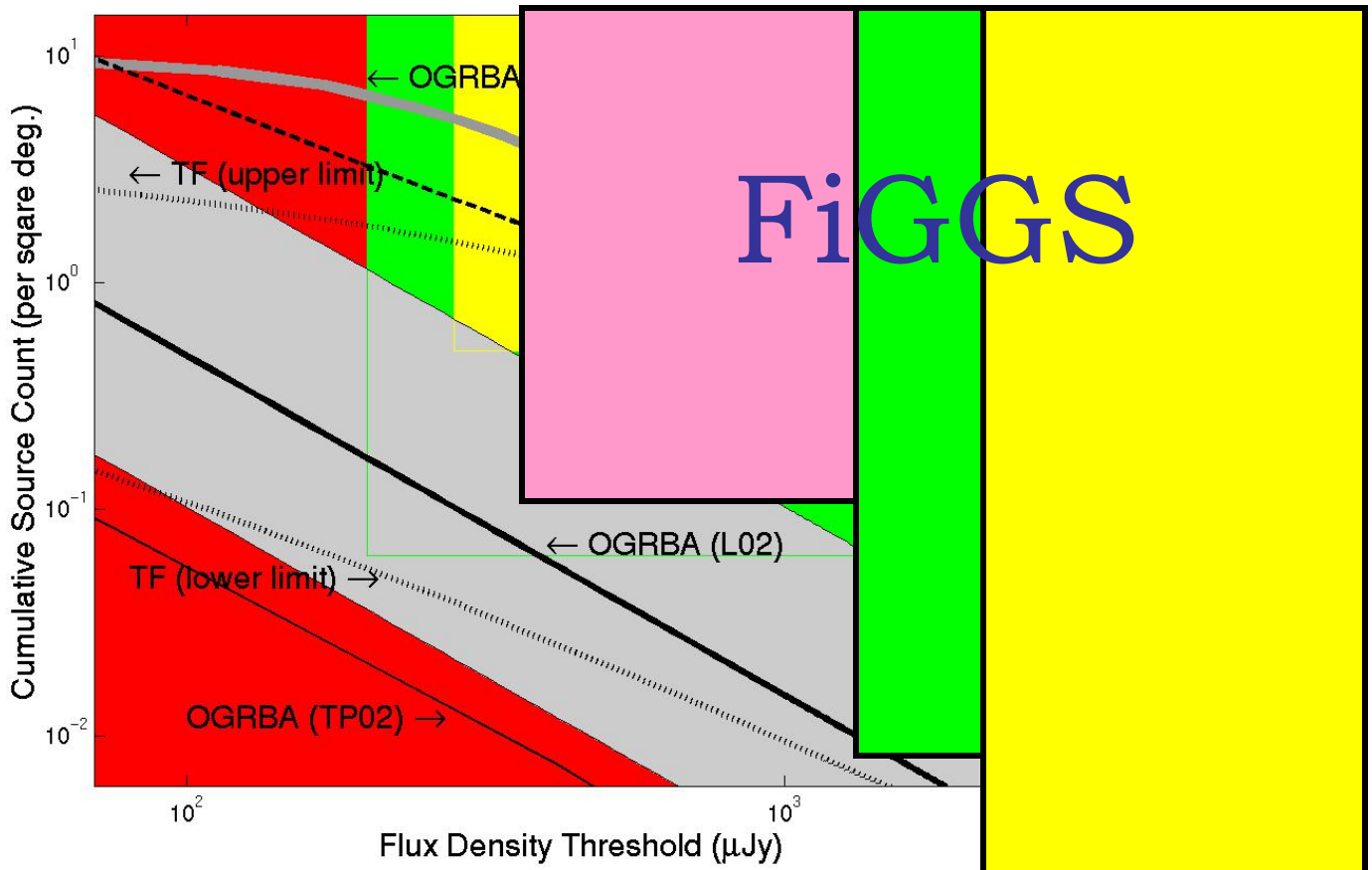
Radio Transient Source Counts



FiGGS

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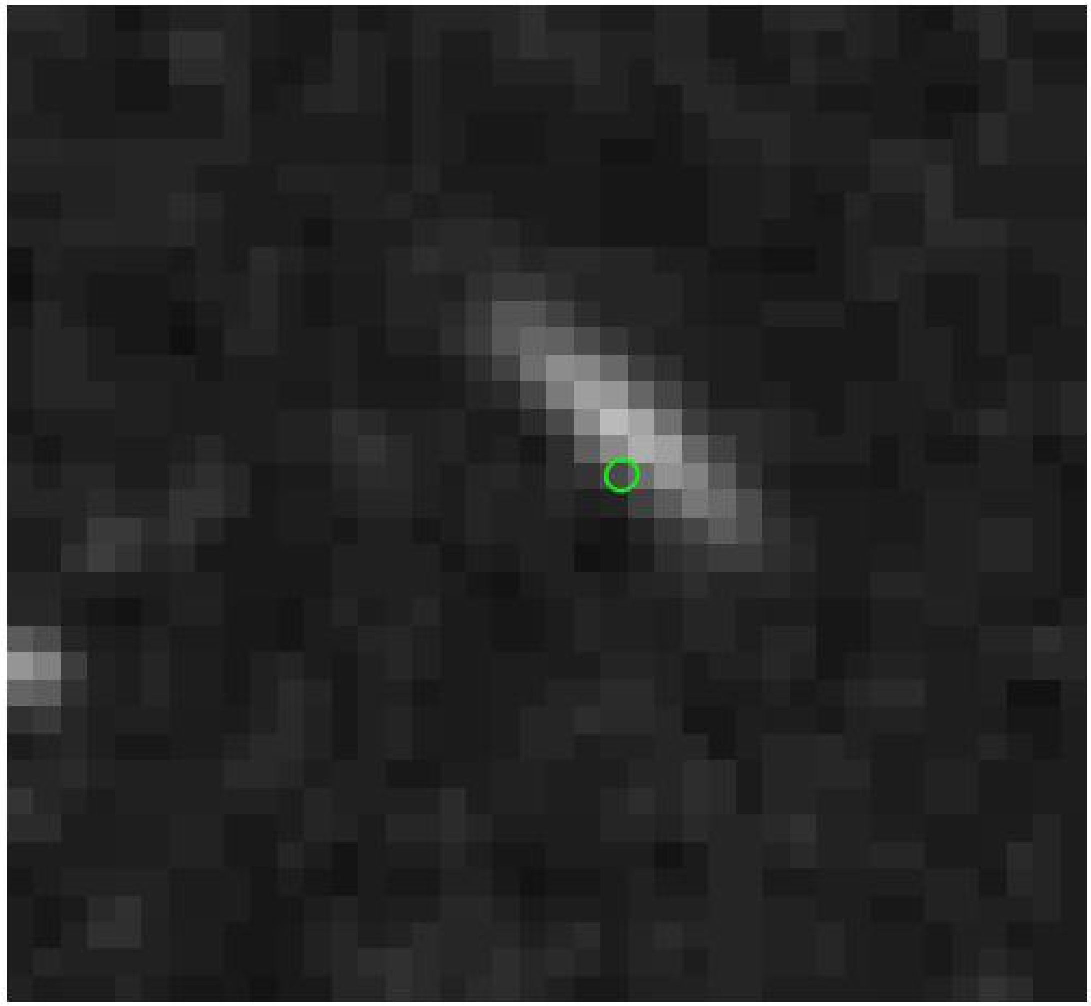
Archival Discovery of Extragalactic Transients

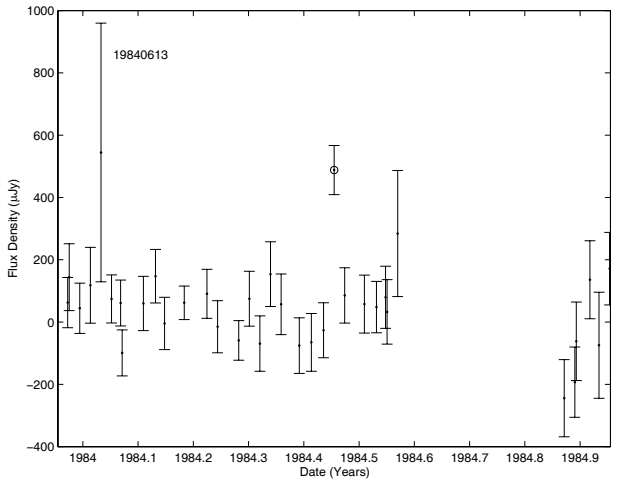
- VLA calibration check observations
- 1983-1999
- 600 epochs/every 7 days
- 5 GHz
- 40 microJy rms/epoch
- Effective surveyed area at 600 microJy ~10 square degrees
- *Work in progress*

Allen Telescope Array



Transient Light curve

- Peak flux ~ 566 +- 81 uJy
- Not detected in individual epochs (<300 uJy)
- Not detected in annual averages (<20-30 uJy)
- Consistent with t^{-1} evolution

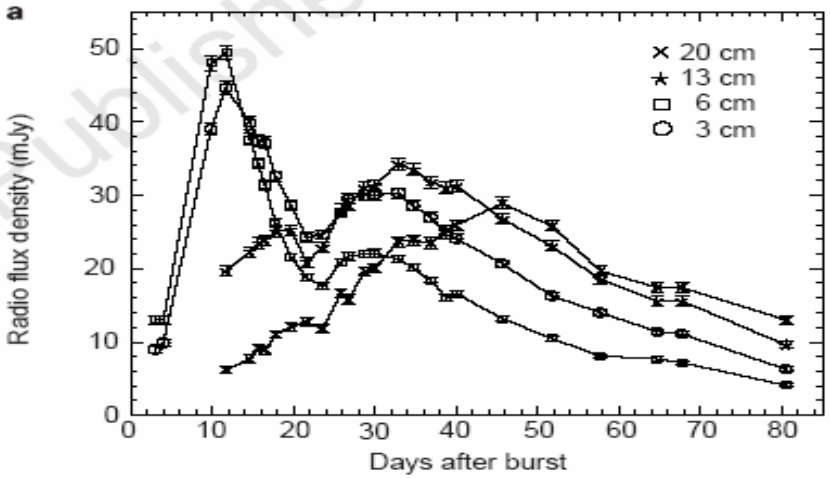


Allen Telescope Array

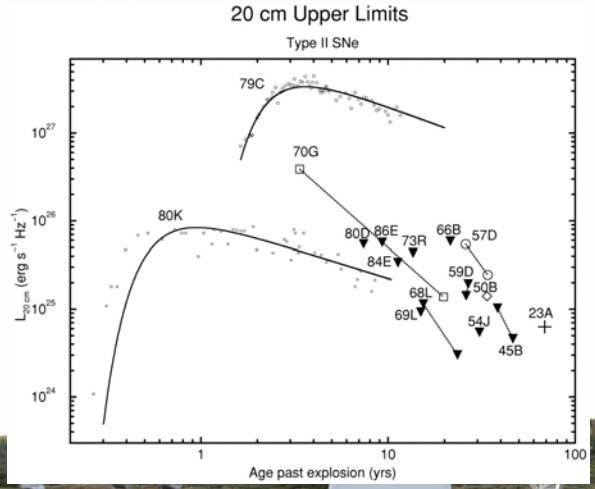
A Type Ib/c RSN?

- Z=0.04, D=170 Mpc
  - Keck spectrum (Filippenko & Foley)
- 3” off nucleus (3 kpc)
- $L_\nu \sim 2 \times 10^{21}$ WHz^{-1} → $L \sim 2 \times 10^{38}$ erg s^{-1}
- Peak duration <7 d
- Fast decline: > t^{-1}
- Alternatives?
  - Short-duration GRB
  - Galactic source

SN1998BW/GRB980425



Kulkarni et al 1998



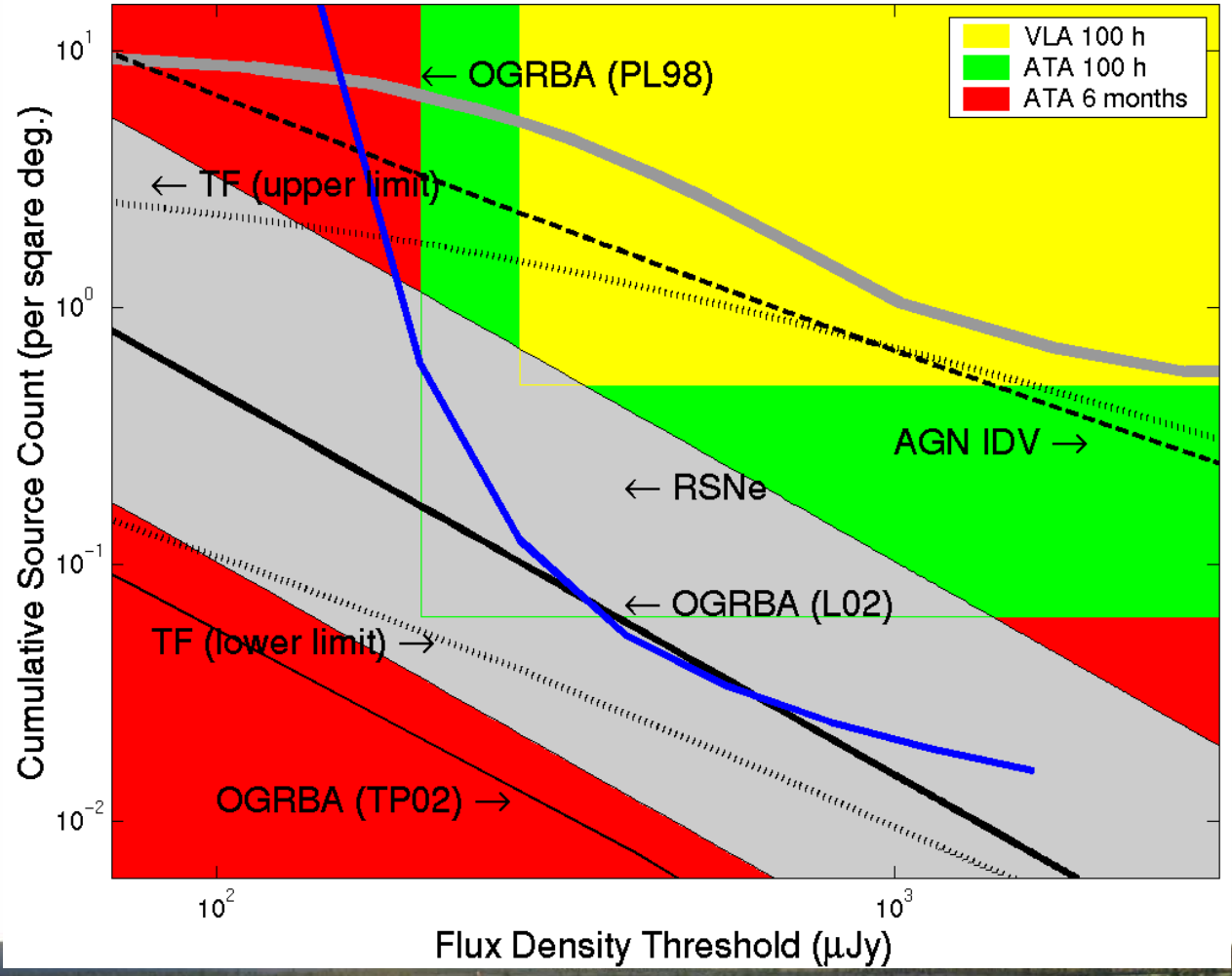
Eck, Cowan & Branch 2002

Transient Summary

Number	Radio Host	Optical Host	
1	+	+	Ib/c SN?
2	+	-	AGN
2	-	+	???
5	-	-	???

False detection rate < 1 source for entire survey

Allen Telescope Array



Transient Event Rates

- Ib/c SNe rate
  - V~200 Mpc^3
  - $R_{Ib/c}$ = 3 +/- 3 x 10^5 Gpc^{-3} y^{-1}
  - Optically determined rate ~ 5 x 10^4 Gpc^{-3} y^{-1} (Berger et al. 2003)
- Total transient rate
  - 10 events between 370 – 6000 microJy
  - 0.05 < R < 50 deg^{-2} y^{-1}
    - Dependent on T_{char}

Allen Telescope Array

The Radio Revolution

Array

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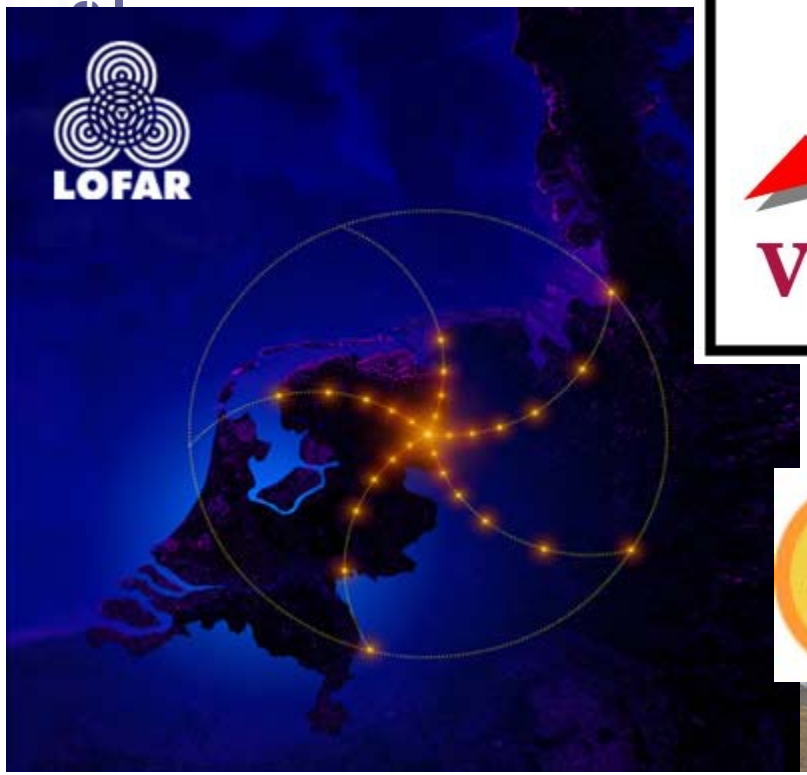
MWA
XNTD
PAPER
FAST
PAST
LAR
LWA

SKA
SQUARE KILOMETRE ARRAY

CARMA
Combined Array for Research in Millimeter-Wave Astronomy

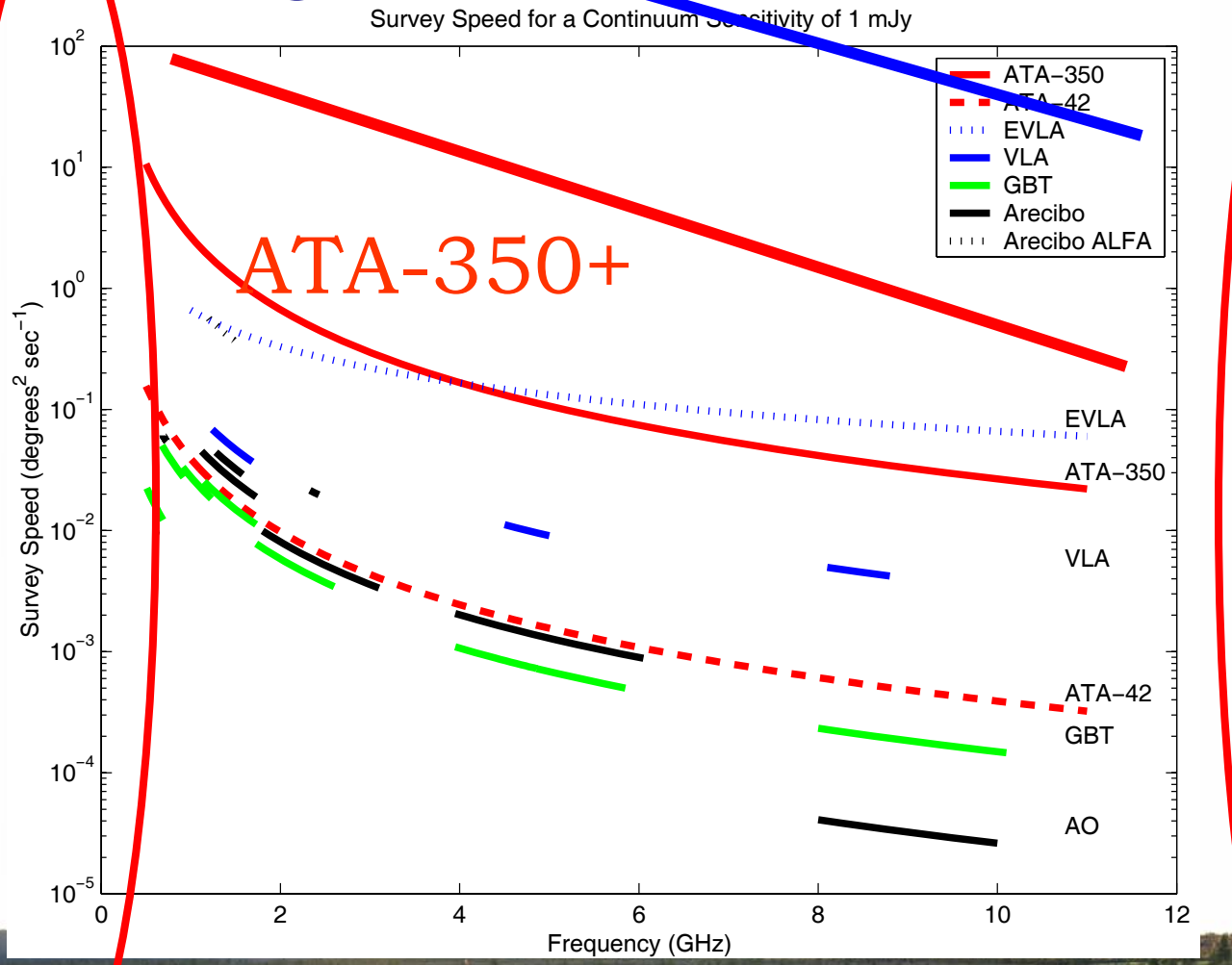


Expanded
Very Large Array

LWA

Future Surveys

SKA



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Conclusions

- Radio transient survey parameter space is wide open
- New discoveries indicate there is much to be found
- ATA and other next generation telescopes will become *transient discovery machines*
- Multiwavelength coordination critical for source identification

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