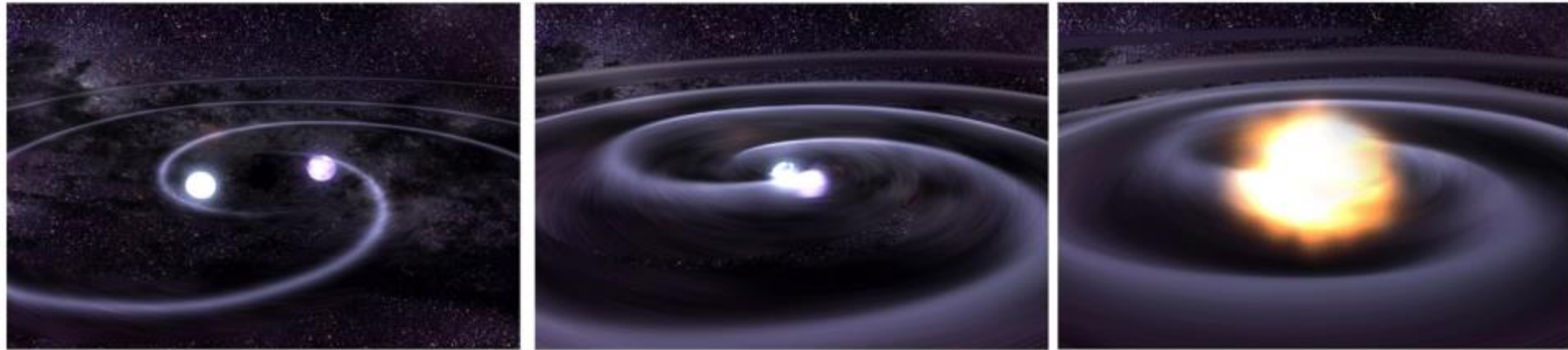


THE VERY LARGE ARRAY

THE NEXT GENERATION



Transients and Stellar Phenomena

Gregg Hallinan (Caltech)

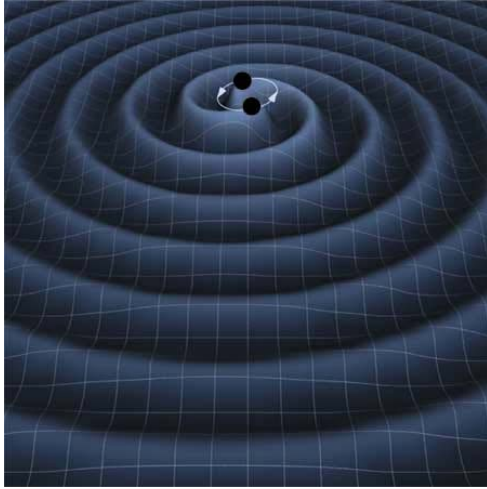
on behalf of the Time Domain, Fundamental Physics and Cosmology Working Group

Time Domain, Fundamental Physics and Cosmology Working Group

- External Chair: Geoff Bower (ASIAA)
- Internal Chair: Paul Demorest (NRAO)
- Jim Braatz
- Avery Broderick
- Sarah Burke-Spolaor
- Bryan Butler
- Tzu-Ching Chang
- Laura Chomiuk
- Jim Cordes
- Jeremy Darling
- Jean Eilek
- Dale Frail
- Gregg Hallinan
- Nissim Kanekar
- Dan Marrone
- Walter Max-Moerbeck
- Brian Metzger
- Miguel Morales
- Steve Myers
- Rachel Osten
- Frazer Owen
- Michael Rupen
- Andrew Siemion
- Ashley Zauderer

Time Domain

Radio gravitational wave counterparts
Jetted tidal disruption events



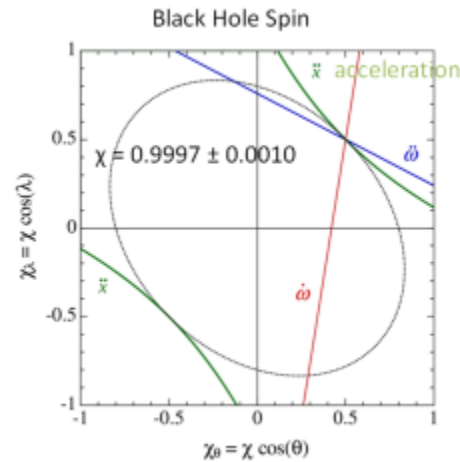
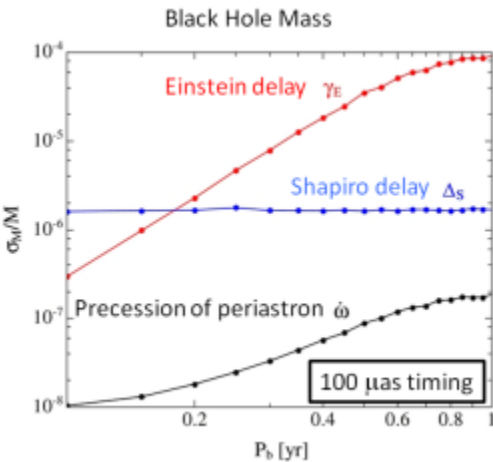
Particle Acceleration, Plasma Physics and Star-planet Interaction

Magnetic reconnection
Pulsar wind nebulae
Stellar flares and CMEs



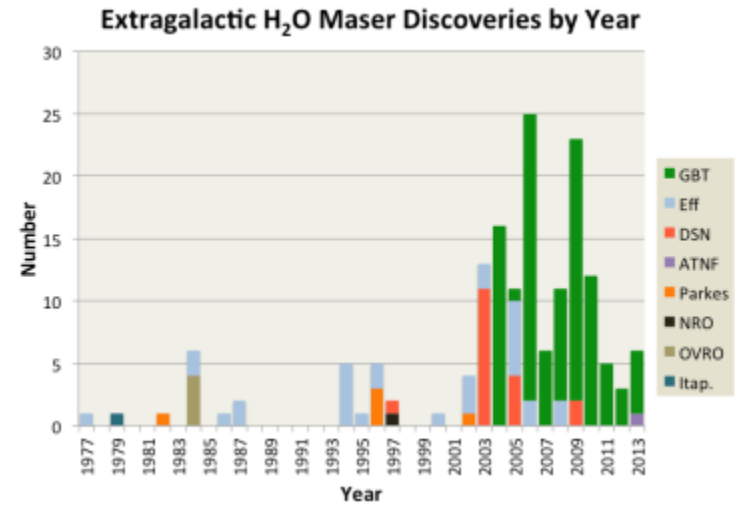
Fundamental Physics

Pulsars around Sgr A*
Fundamental constant evolution



Cosmology

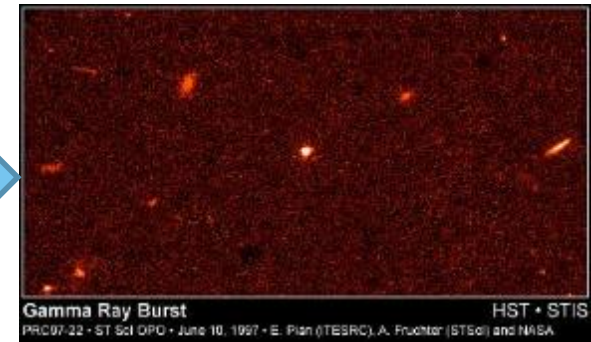
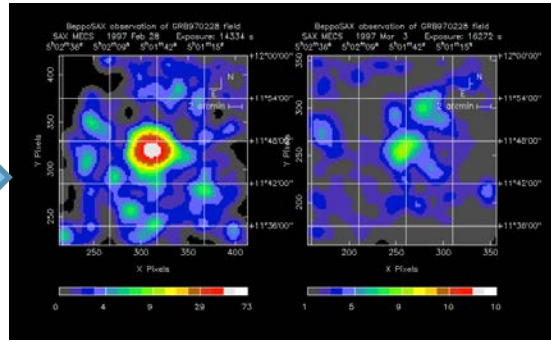
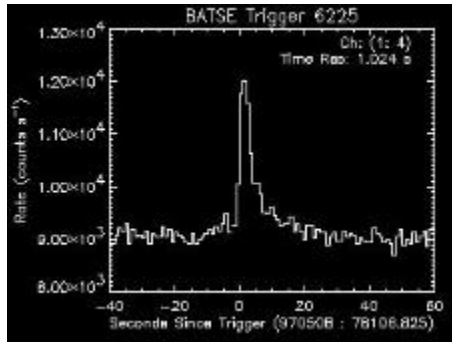
Megamasers
Intensity mapping
Astrometry



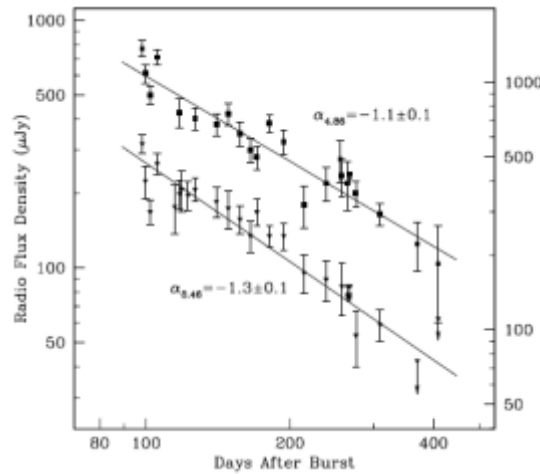
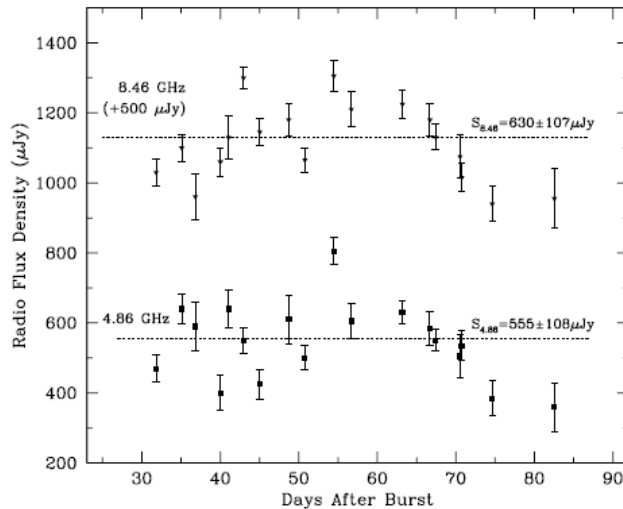
NGVLA as a follow-up instrument for time domain science

- Radio observations have played a fundamental role in the follow-up of transients

- GRB 970508



Costa et al. (1997), van Paradijs et al. (1997)



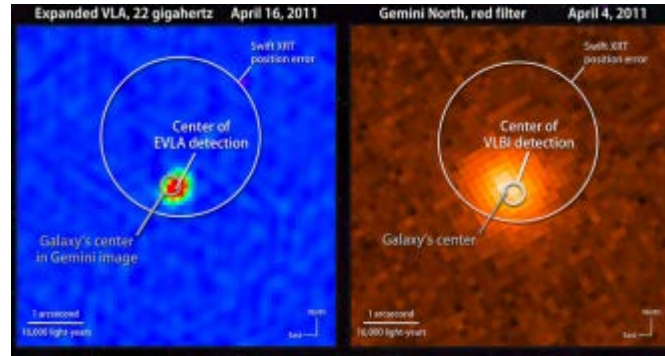
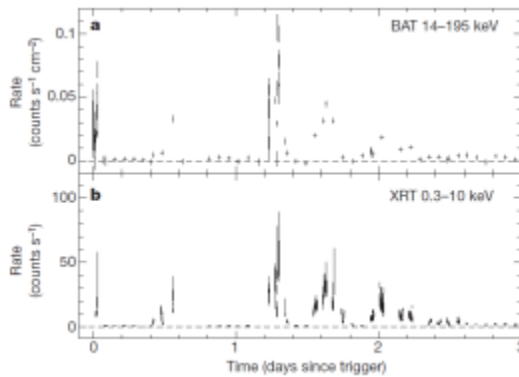
Interstellar scintillation →
angular size

Highly collimated outflow →
Only radio observations
provided reliable calorimetry
of the explosion

Frail et al. (1997), Frail, Waxman & Kulkarni (2000)

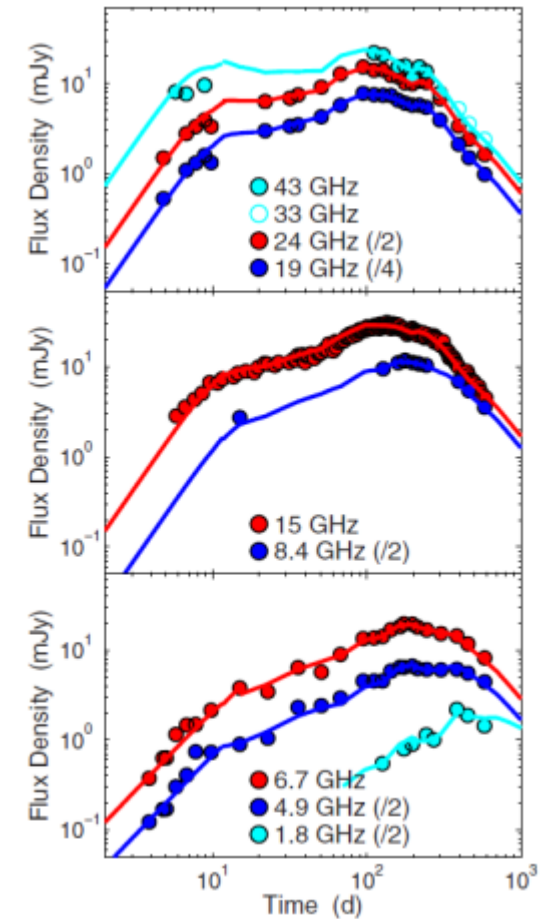
- Radio observations have played a fundamental role in the follow-up of transients

- Swift J1644+57

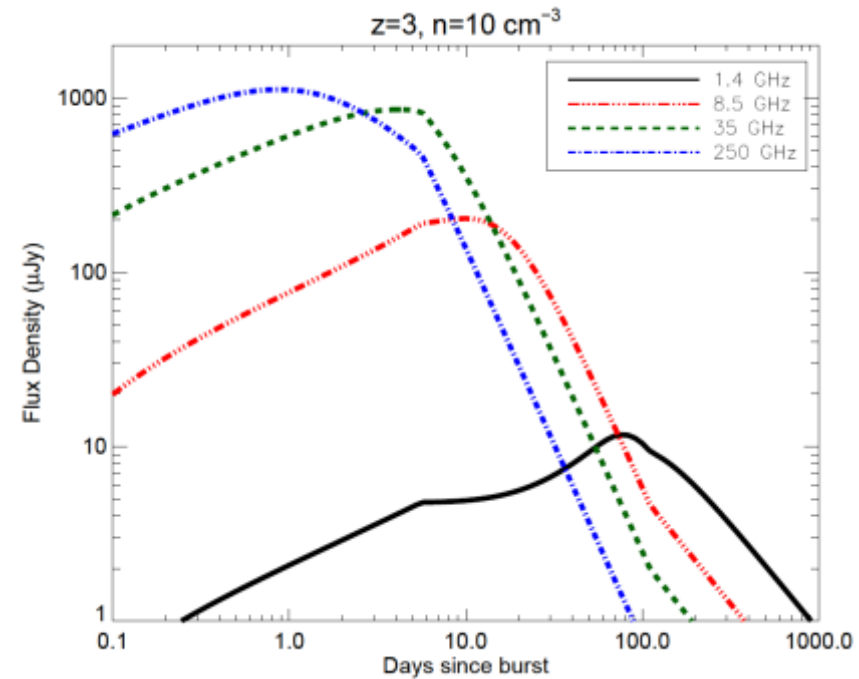
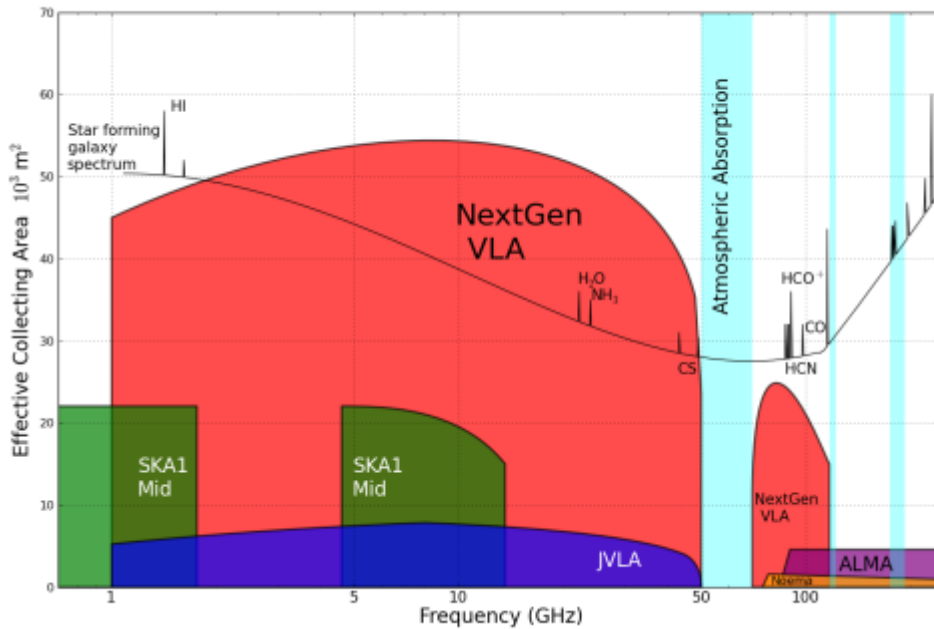


- Tidal disruption event
powering a relativistic jet

- Unique insight into the
formation and termination
of relativistic jets



Burrows et al. (2011), Zauderer et al. (2011),
Levan et al. (2011), Berger et al. (2012), Zauderer et al. (2013)

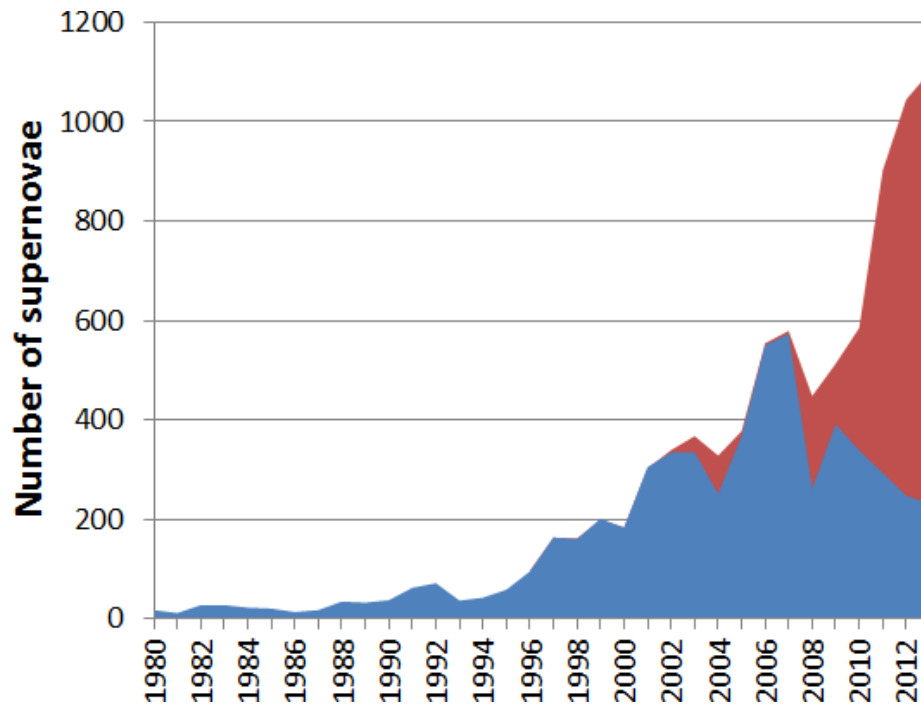


Chandra & Frail 2012

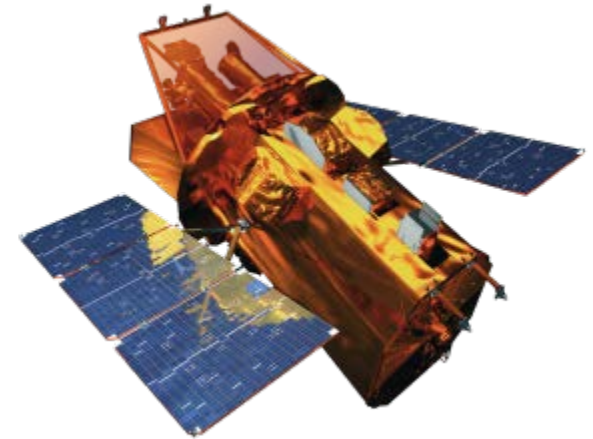
- NGVLA will be the premier follow-up instrument at radio wavelengths
- Some science uniquely accessible to NGVLA – e.g. early time reverse shock afterglows from GRBs

NGVLA as a survey instrument for time domain science

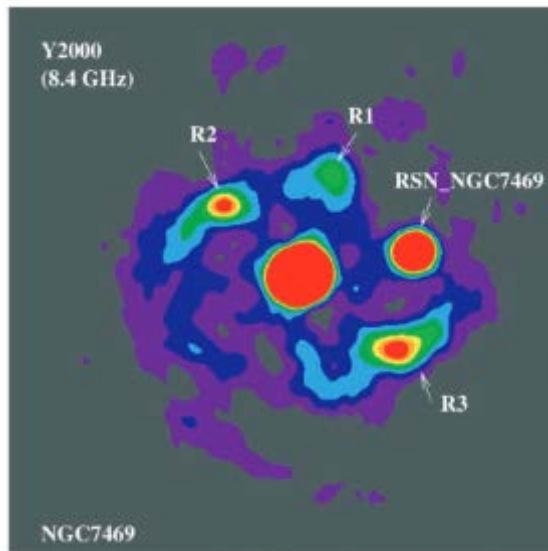
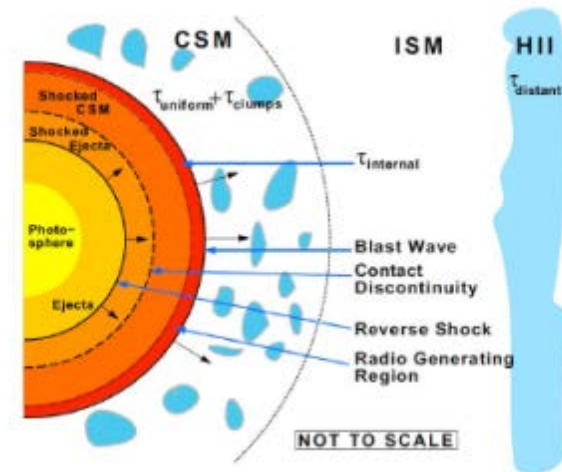
- Synoptic surveys have revolutionized transient science in optical, X-ray and γ -ray bands
- γ -ray/X-ray: BATSE, BeppoSAX, Swift, Fermi - GRBs
- Optical: PTF, Pan-STARRS, ZTF, LSST - supernovae



Synoptic radio transient surveys lag optical and higher energy surveys by at least a decade

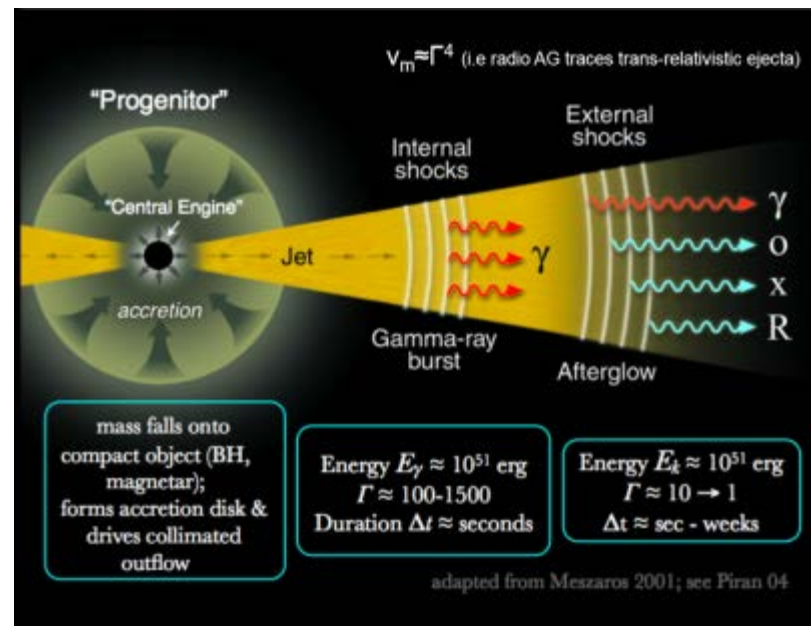


Only synoptic surveys can fully characterize the radio transient sky



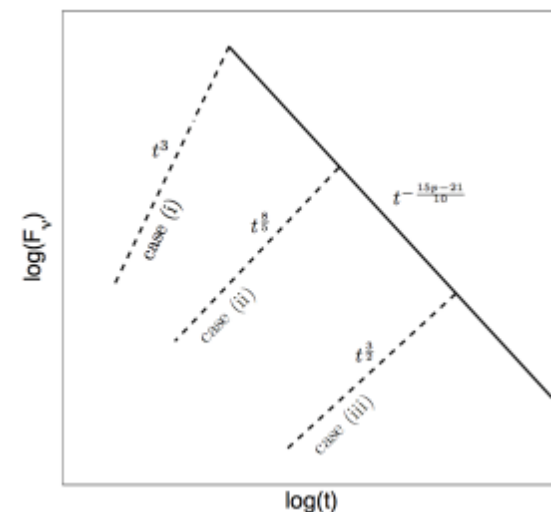
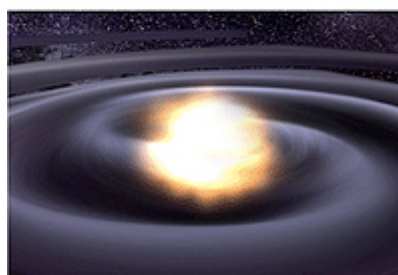
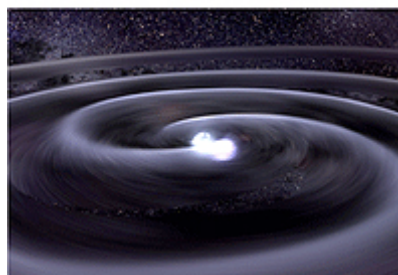
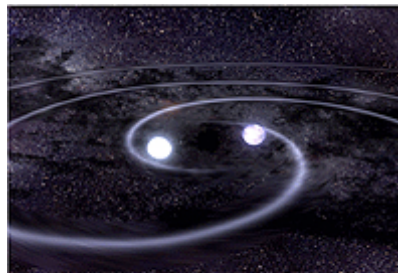
- Key questions: Radio Supernovae
- What is the true rate of supernovae in the local universe?
- As many as half of the supernovae remain undetected in the traditional optical searches, largely due to extinction via dust obscuration
- Far reaching consequences for models of stellar and galaxy evolution
- Radio observations can probe through dust for Type Ib, Ic and type II SNe

- **Key questions: Gamma-ray Bursts (GRBs)**
- Relativistic outflows associated with GRBs are highly collimated
- Only bursts collimated in the direction of Earth are detected at higher energies
- The typical opening angle of the collimated jet is poorly constrained
- Radio observations of “orphan afterglows” can provide an unbiased measure of the true rate
- E.g. Frail et al. 1997, 2012, Gal-Yam et al. 2006



The Multi-Messenger Astronomy Era

- Key questions: Neutron star mergers
- Advanced LIGO (aLIGO) and Advanced Virgo (AdV) commence in 2015
- Binary neutron star (BNS) coalescence the most likely source detected
- Associated gamma-ray burst is highly beamed - true rate poorly constrained
- Radio afterglows are isotropic – detectable with the VLA (Nakar & Piran 2011)
- NGVLA will detect binary neutron star merger afterglows out to the aLIGO and AdV horizon **for all current models**



Nakar & Piran (2011)

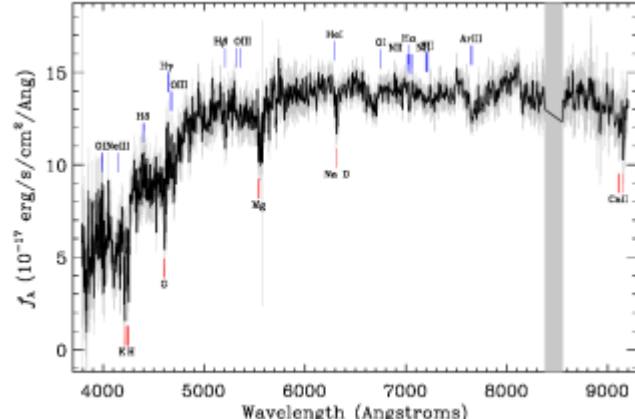
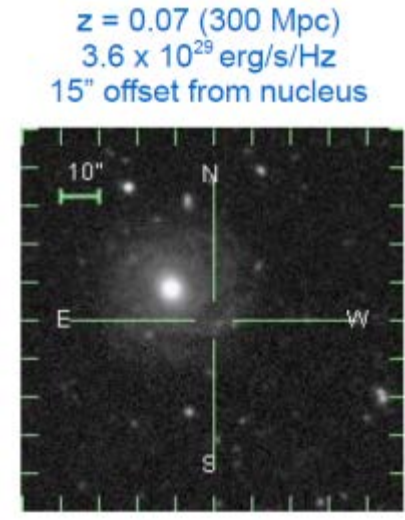
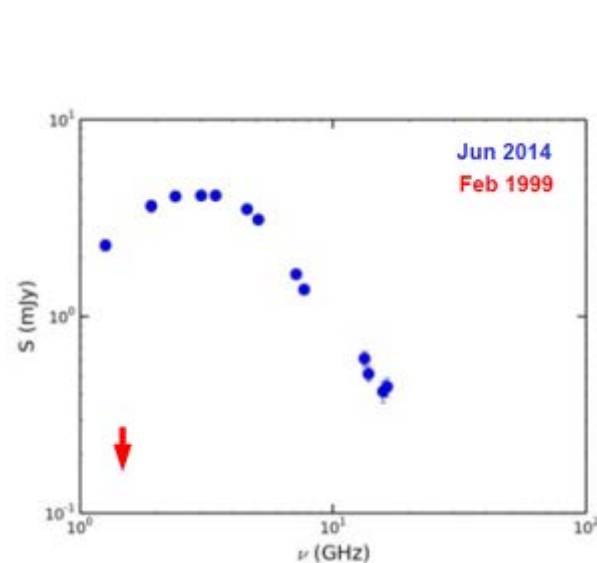
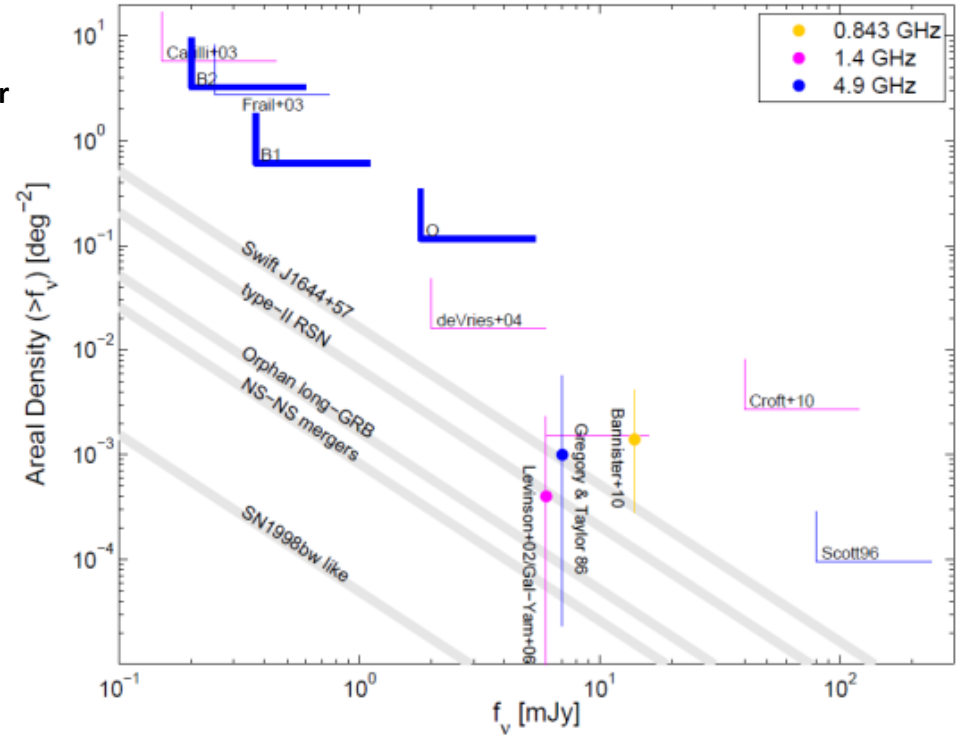
Detailed modeling underway to constrain transient rates – Nakar & Piran 2011, Ghirlanda et al. 2014, Metzger, Williams & Berger 2015

Empirical data essential!

Ongoing Caltech NRAO Stripe-82 Survey (CNSS)
 G. Hallinan, K. Mooley (thesis), S. Bourke, S.T. Myers, A. Horesh, D.A. Frail, S.R. Kulkarni, E.O. Ofek (Mooley et al. 2015 submitted)

Final combined survey – 270 sq. deg. to ~35 μ Jy (5 epochs)

Every pointing of the NGVLA will detect transients!



NGVLA probing star-planet interactions

Radio Emission from the Sun

Quiet Sun (MHz – GHz)

Free-free emission from thermal atmosphere (10^4 - 10^6 K)

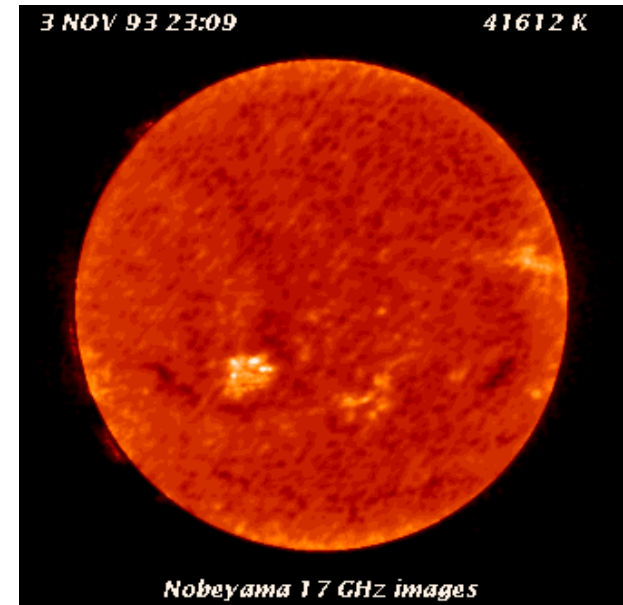
- See Villadsen et al. 2014 for first detection of quiescent radio emission from solar type stars

Flaring Sun (MHz – GHz)

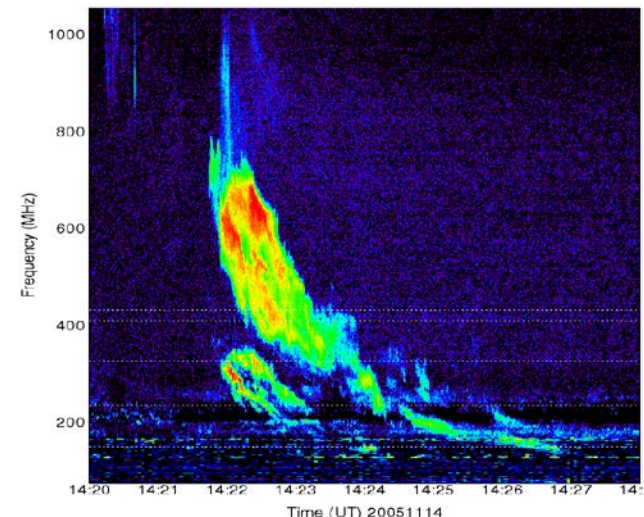
Intensely Bright Radio Emission

Gyrosynchrotron flares

Coherent bursts (Type II, Type III...)



Credit: Stephen White



VLA found the radio star...

THE ASTROPHYSICAL JOURNAL, 250:284-292, 1981 November 1

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FIRST DETECTION OF NONFLARE MICROWAVE EMISSION FROM THE CORONAE OF SINGLE LATE-TYPE DWARF STARS

DALE E. GARY

Department of Astro-Geophysics, University of Colorado

AND

JEFFREY L. LINSKY¹

Joint Institute for Laboratory Astrophysics, National Bureau of Standards and University of Colorado

Received 1981 February 27; accepted 1981 April 23

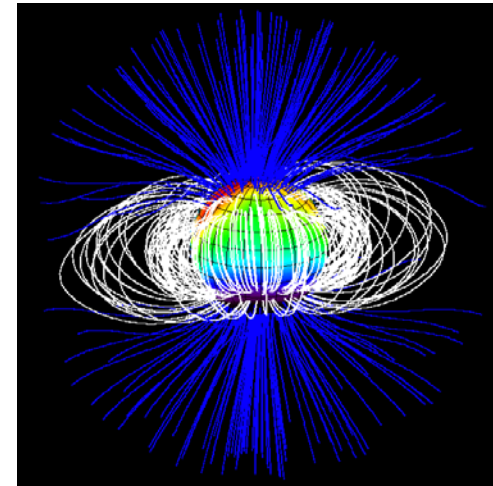
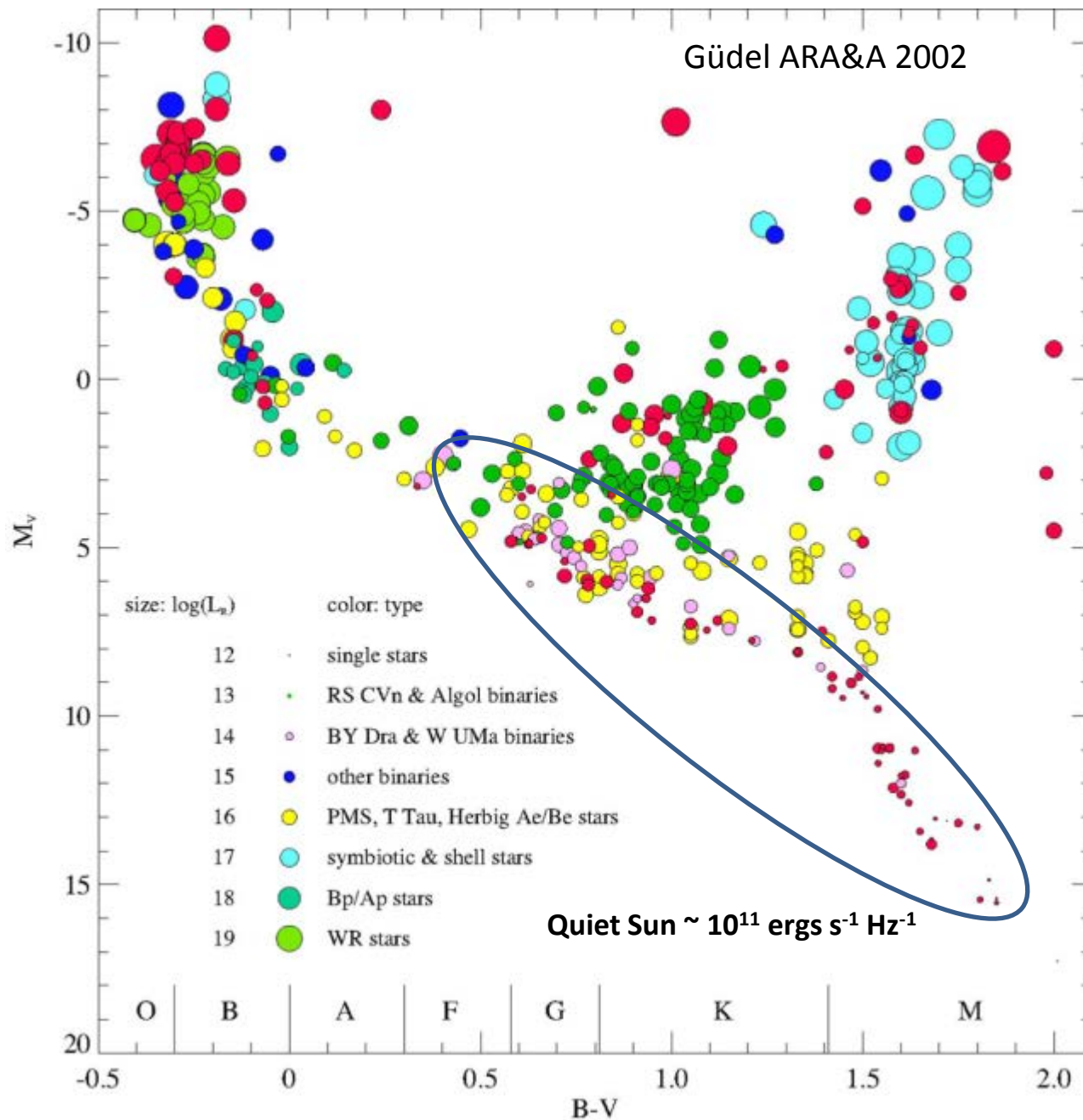
ABSTRACT

We report on an observing program with the VLA in its C configuration to detect microwave radiation from the coronae of nearby late-type dwarf stars which are not members of close binary systems and do not have large winds. Six stars, chosen on the basis of strong apparent X-ray flux, were observed during a 24 hour period, and two stars were detected. χ^1 Orionis (G0 V) was detected as a 0.6 mJy source ($S/N \approx 7$) at 6 cm, and we obtained an upper limit at 2 cm. The flare star UV Cet (dM 5.5e) was detected as a steady 1.55 mJy source ($S/N \approx 17$) at 6 cm during a 2.5 hour observation. We obtained upper limits at 6 cm for the other stars observed: π^1 UMa (G0 V), ξ Boo A (G8 V), 70 Oph A (K0 V), and ϵ Eri (K2 V). We believe that the most likely emission mechanism is gyroresonance emission, i.e., cyclotron emission from nonrelativistic Maxwellian electrons. Assuming a coronal temperature of $0.5\text{--}1.0 \times 10^7$ K consistent with the X-ray data, we find that the observed 6 cm fluxes are consistent with emission in the sixth or lower harmonics with coronal magnetic fields ≈ 300 gauss or larger covering a large fraction of the star. It is likely that χ^1 Ori, solar active regions (plages), and perhaps UV Cet, are the first detected members of a new class of radio sources.

Subject headings: stars: coronae — stars: flare — stars: late-type — stars: radio radiation —
Sun: radio radiation

Some stars have a non-thermal corona!

The Radio H-R Diagram



>1800 confirmed planets



Can we directly detect stellar flares, CMEs, stellar winds?

Can use radio observations as a powerful tool

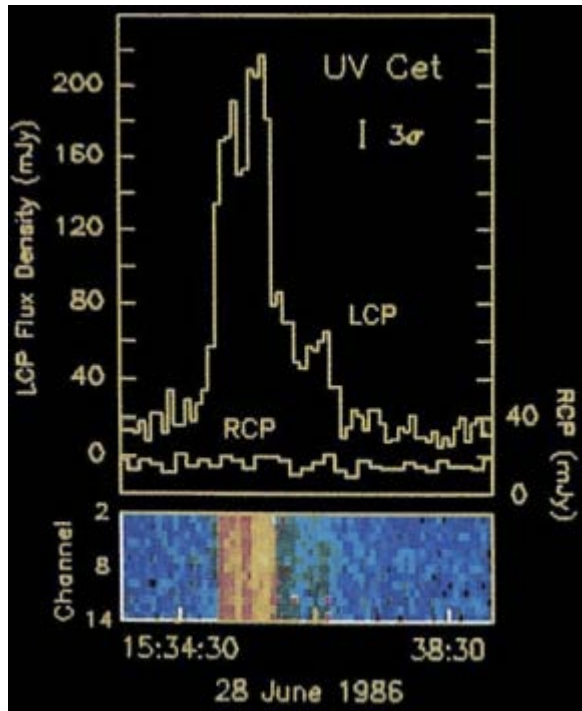
M Dwarfs – Implications of Activity

- 95% of stars that can host evolved exoplanets (age > 1 Gyr) are M dwarfs
- Kepler has shown that lower mass planets are frequent around M dwarfs (Dressing & Charbonneau 2013)
- Likely the nearest habitable planet orbits an M dwarf
- Can be much more active than the Sun and active for much longer → flares up to 10^4 times more energetic
- Flares – higher X-ray and ultraviolet radiation flux → photochemical reactions leading to significant atmospheric loss
- Coronal mass ejections (CMEs) – higher stellar wind flux → can erode atmosphere – eg. ion pick-up of a CO₂-rich atmosphere

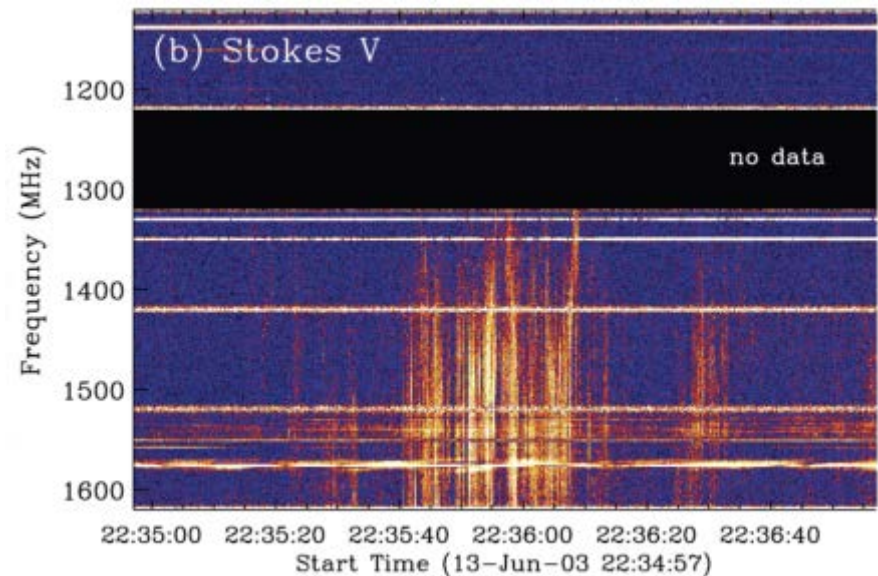




Dynamic Spectra of Radio Bursts from M dwarfs



Bastian et al. Nature (1987)

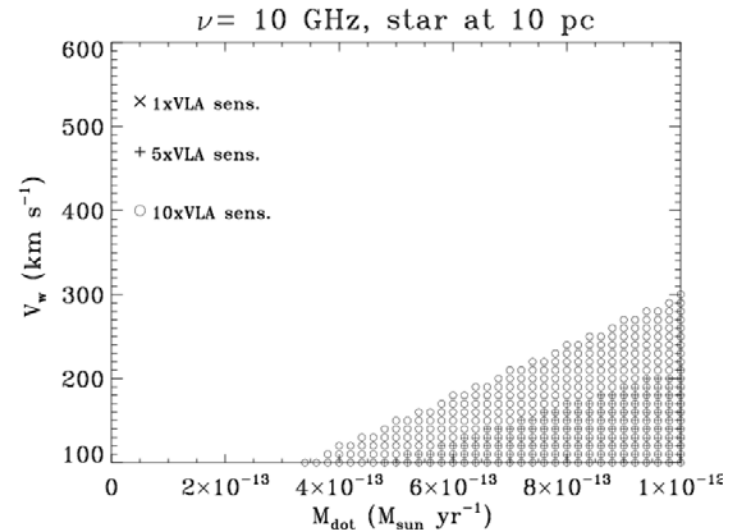
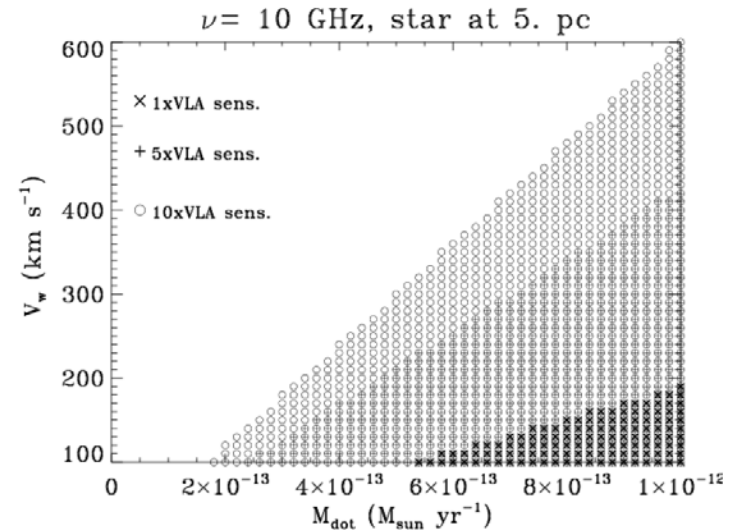


Osten & Bastian, ApJ (2006)

- First achieved in with the VLA in 1987
- Very bright bursts detected ~ 1 Jy
- NGVLA will detect radio bursts across the main sequence – tracking episodic mass loss as a function of age and mass

Detecting Stellar Winds

- Active stars, including the Sun, produce an ionized wind
- Source of free-free emission – very difficult to detect!
- NGVLA will trace continuous mass loss for young and active stars
- Current solar wind mass loss rate $\sim 10^{-14} M_{\odot}/\text{yr}$
- NGVLA will probe young solar analogs – “Faint Young Sun Paradox”



All white papers from the AAS science meeting available at:

<https://science.nrao.edu/science/meetings/2015/aas225/next-gen-vla/technical-documents>