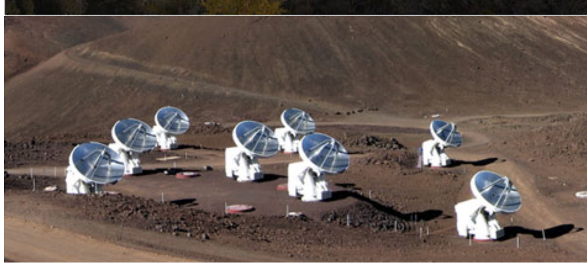
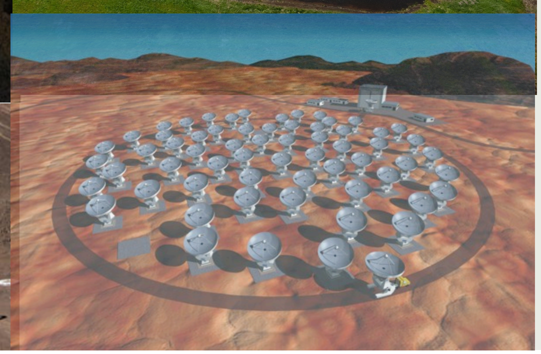
Radio Astronomy in the LSST Era:

Radio Followup of MultiWavelength Transients





Ashley Zauderer

Harvard University

Charlottesville, VA

May 6 – 8, 2013

Conclusions

Special thanks to contributions from:
Laura Chomiuk, Steve Meyers, Edo Berger, Dale Frail, Brad Cenko, Alicia Soderberg, Kartik Sheth, Stuart Vogel, Peter Williams

- Deep all-sky radio survey
  - Several wavelengths (C/X with Jansky VLA, ?)
  - Focus on sky overlap with ALMA/LSST (-40 to +10)
- Pay attention to lessons learned from LSST "pathfinders"
  - Trigger mode: PTF/PanSTARRs
  - Catalog/reference mode: SDSS
- Continue doing what is working
  - Emphasize importance/utility of radio observations
    - Multi-wavelength synergy
    - Unique contribution from radio observations
  - Rapid response / pipeline reductions / computing
    - Sample size will increase
    - Quality of supplementary data will increase

Triggers

Radio Transients traditionally not discovered in the radio

- Optical/NIR/uv (e.g. GALEX, ground-based telescopes)
- High energy (e.g. Fermi, Swift)
  - X-rays
  - Gamma-rays
- Non-electromagnetic (e.g. LIGO)

pan-starrs.ifa.hawaii.edu

ptf.caltech.edu

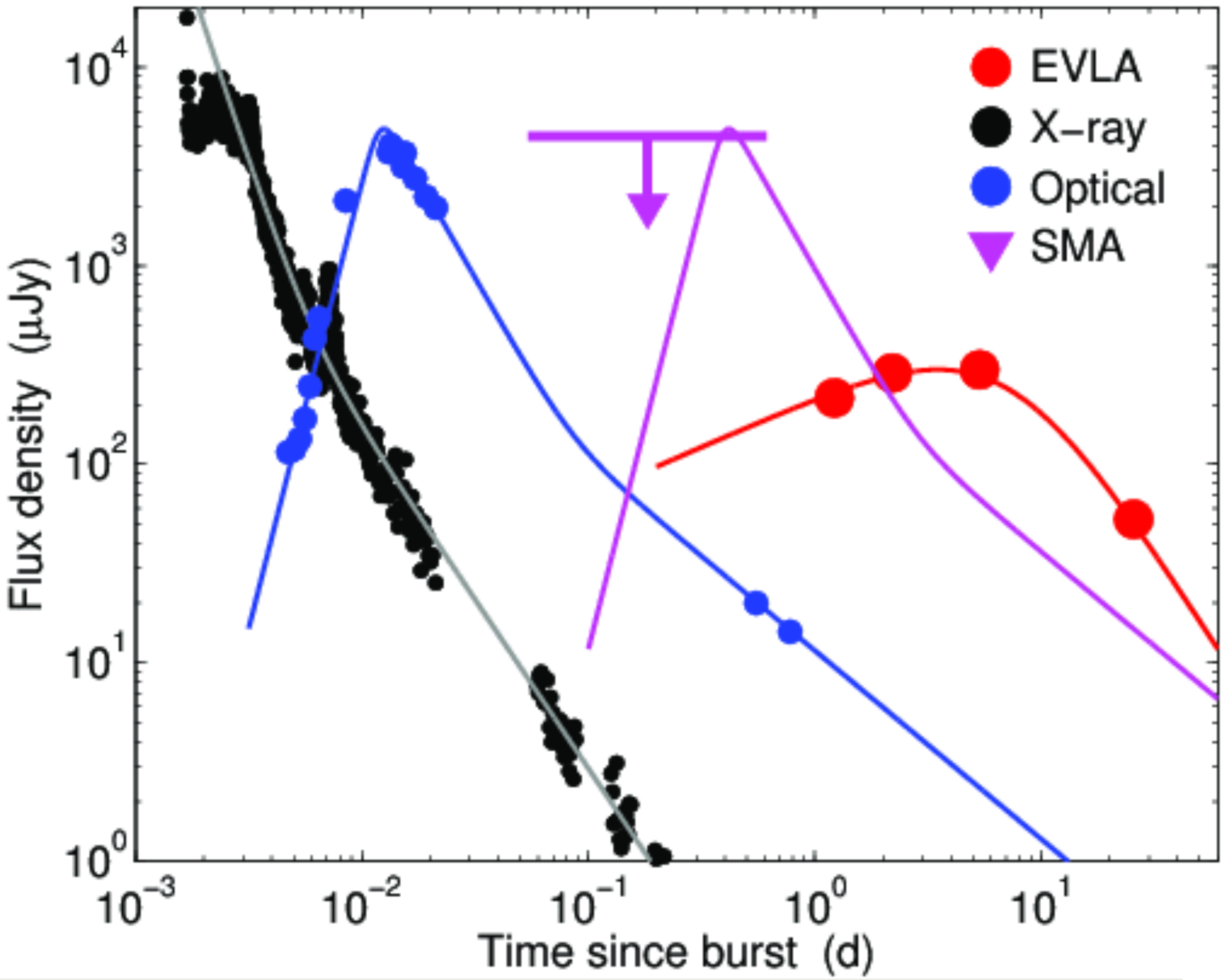
PALOMAR TRANSIENT FACTORY

spacetoday.org
nasa.gov/swift

ligo.caltech.edu

Timing is an important consideration

Evidence for RS
From optical
Zheng et al.
(2011)



Laskar et al. (2013, in prep)

What do we know about the radio transient sky?

Three kinds of radio emission:

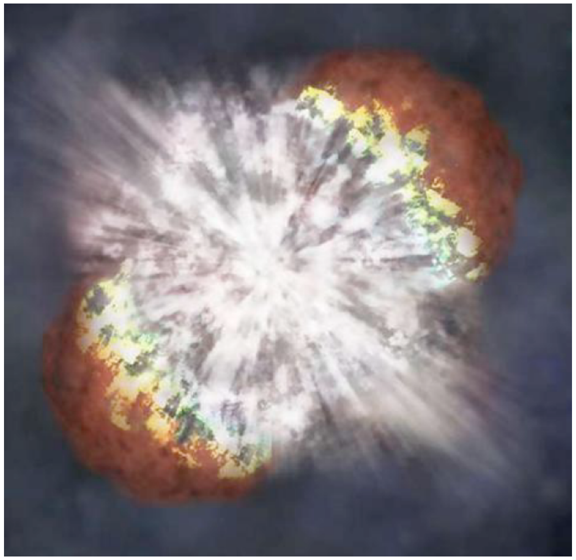
Synchrotron

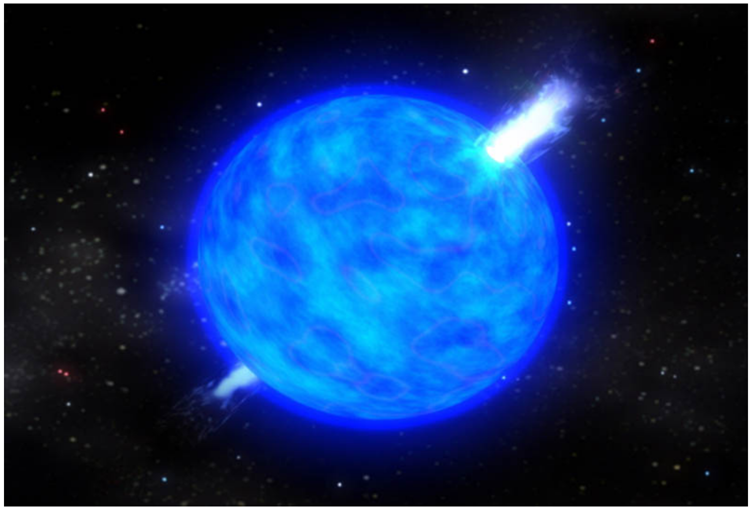
Non-thermal coherent

Thermal

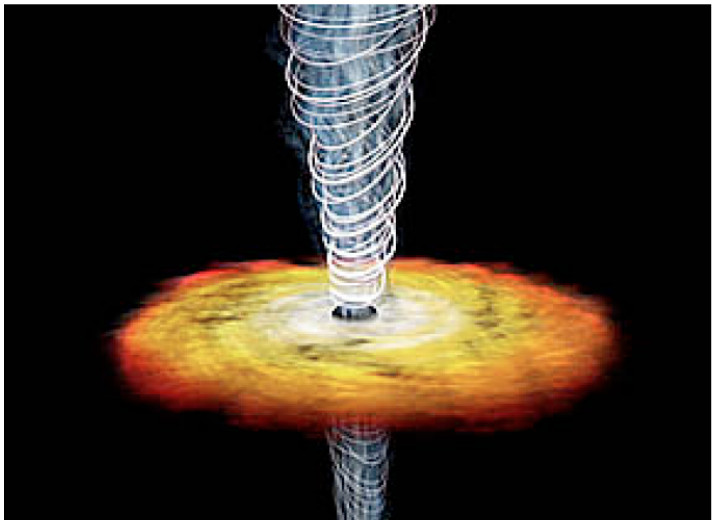
Slide courtesy of Laura Chomiuk

Synchrotron emission traces shocks and jets





- Supernovae
- Gamma-ray bursts
- (Jetted) tidal disruption events
- Flare stars, X-ray binaries



-the majority of 'slow' radio transients

Three kinds of radio emission:

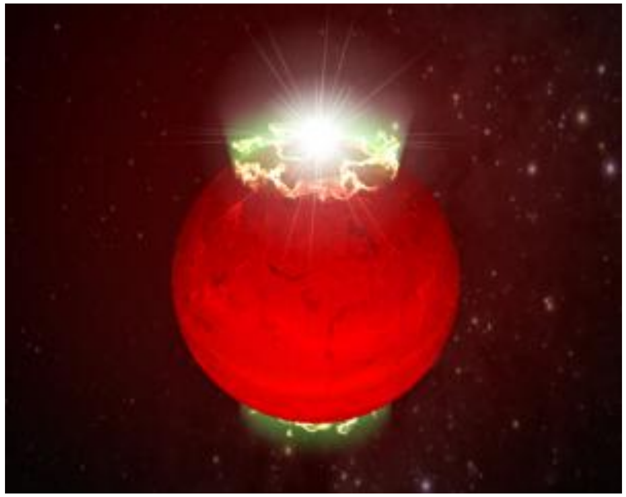
Synchrotron

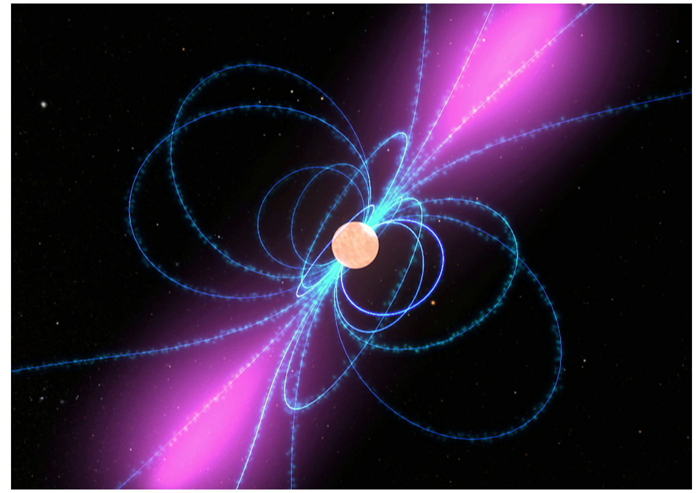
Non-thermal coherent

Thermal

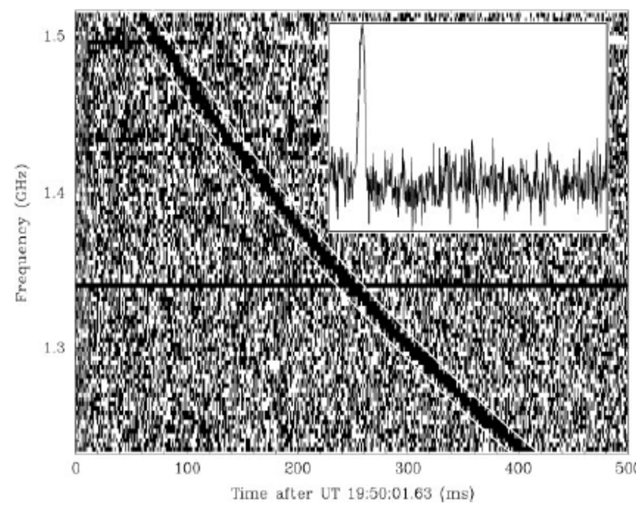
Slide courtesy of Laura Chomiuk

‘Fast’ radio transients (~< 1 second duration)





- Pulsars
- Flare stars
- Lorimer bursts ?



Lorimer et al. 2007

Different strategies to study these but can be complementary with searches for ‘slow’ transients

Three kinds of radio emission:

Synchrotron

Non-thermal coherent

Thermal

Slide courtesy of Laura Chomiuk

Expanding HII regions

- Novae
- Symbiotic stars

Synchrotron

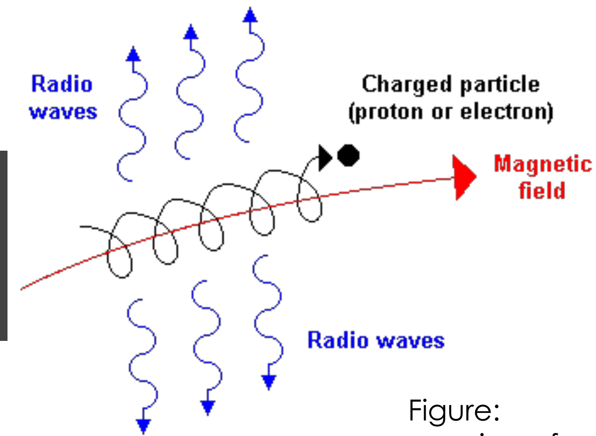
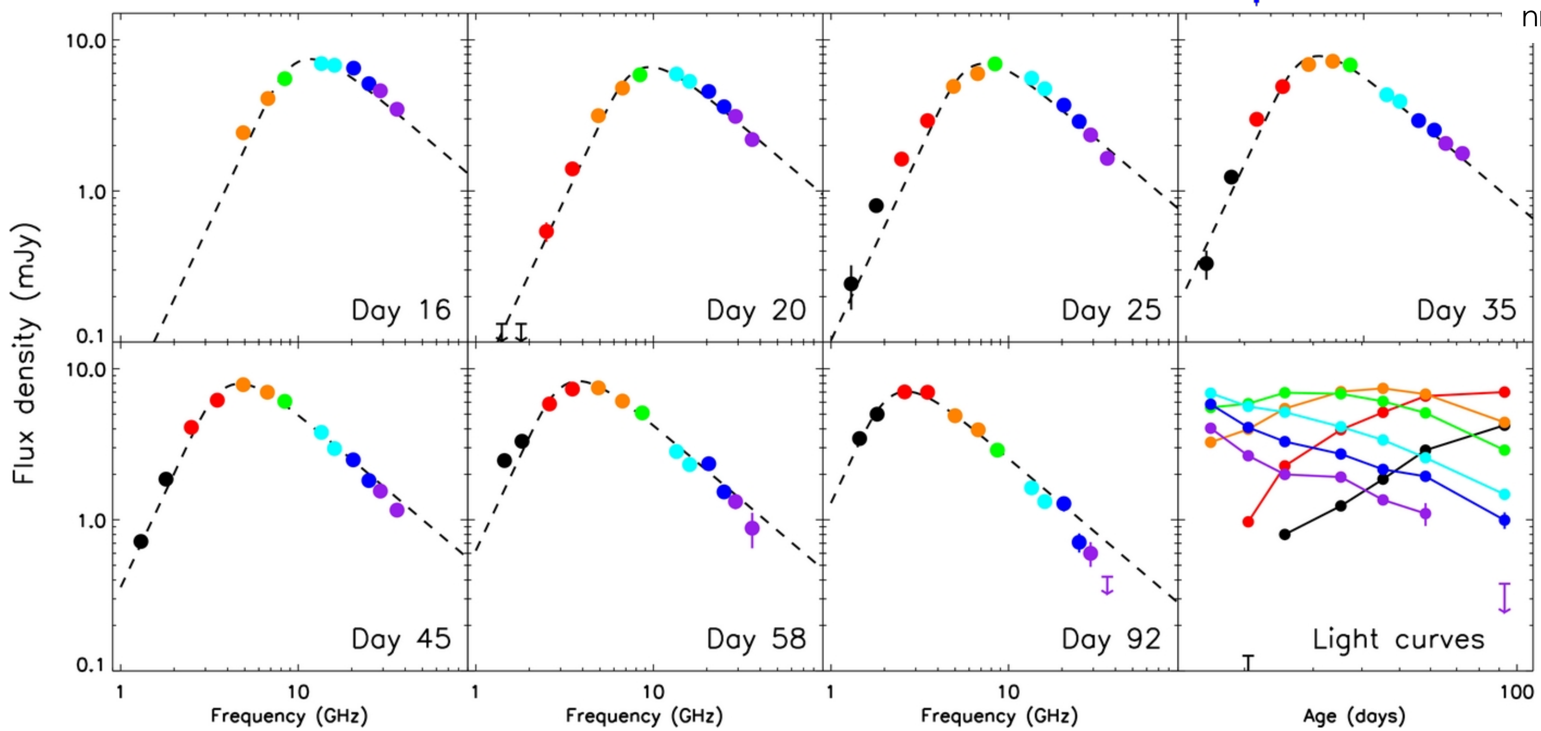


Figure: nrumiano.free.fr



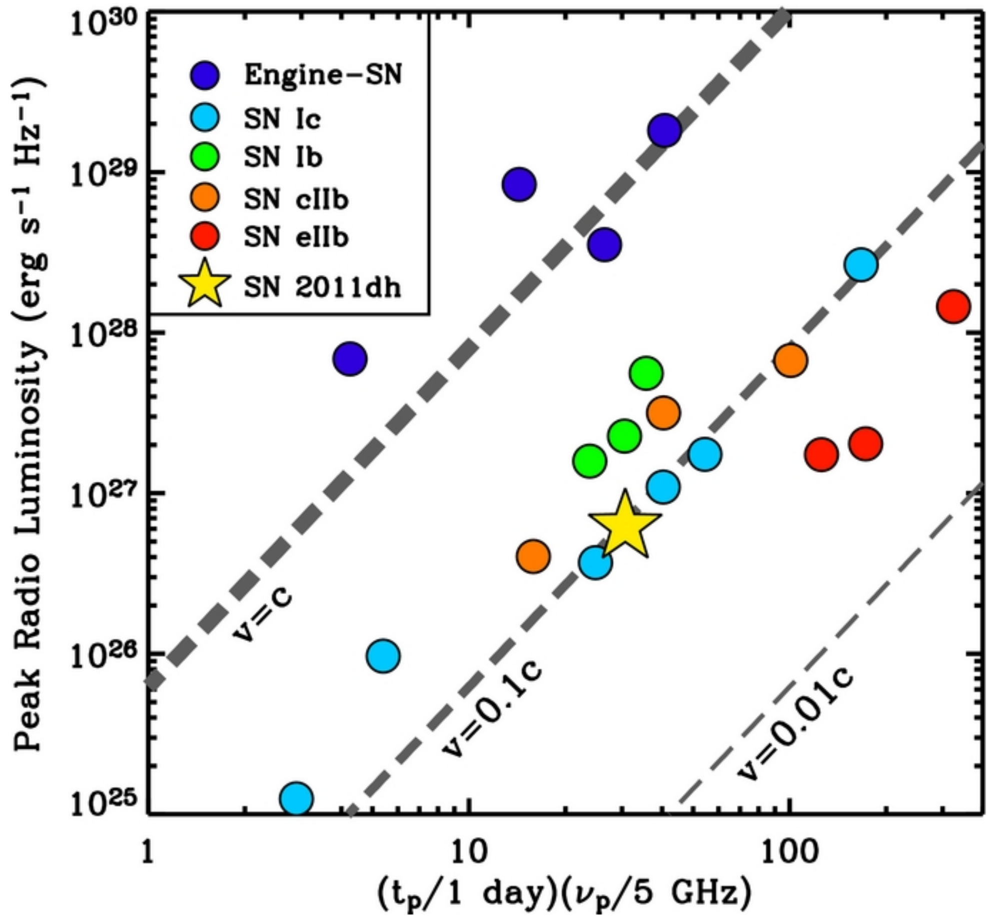
SN 2011dh – Type IIb

Krauss et al. 2012
ApJ, 750, 40

Unique Information from Radio

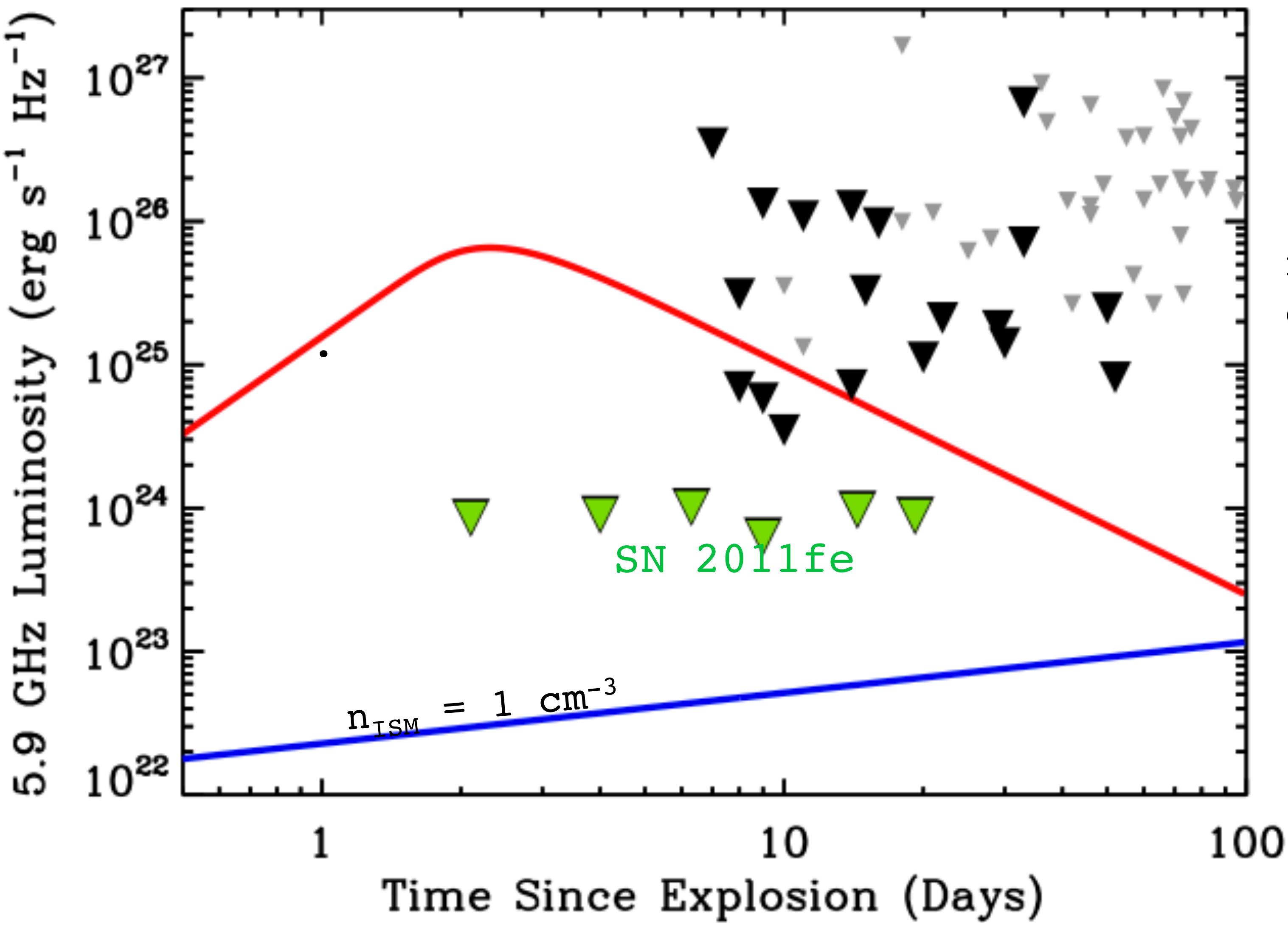
- Localization
- Energy / blastwave velocity
  - Beaming
  - Size and size evolution
- Circumburst density
- Polarization

e.g. Chevalier et al. (SNe; ApJ, 1998, 499, 810) Granot & Sari (GRBs; ApJ, 2002, 568, 820)



Soderberg et al. 2012 ApJ, 752, 78

Strong limits on environment of SN2011fe from Jansky VLA



no radio emission from SNe Ia

(Chomiuk et al. 2012, Horesh et al. 2011)

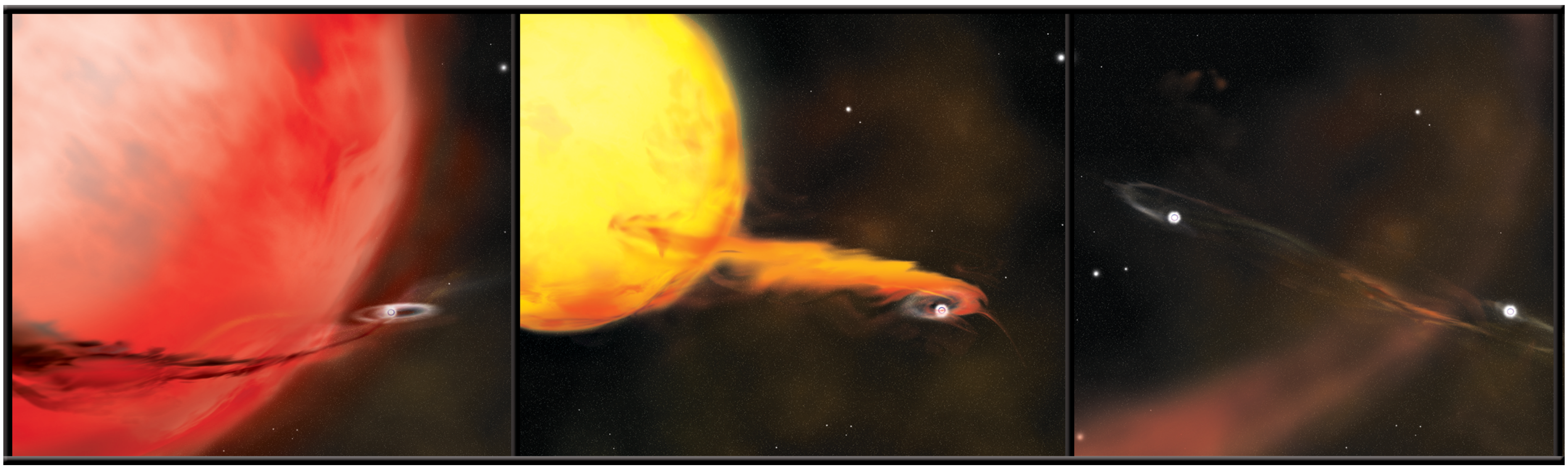
assumes v_w = 50 km/s

Type IA progenitor?

WD + Giant

WD + Sub-giant or Main Sequence

WD + WD

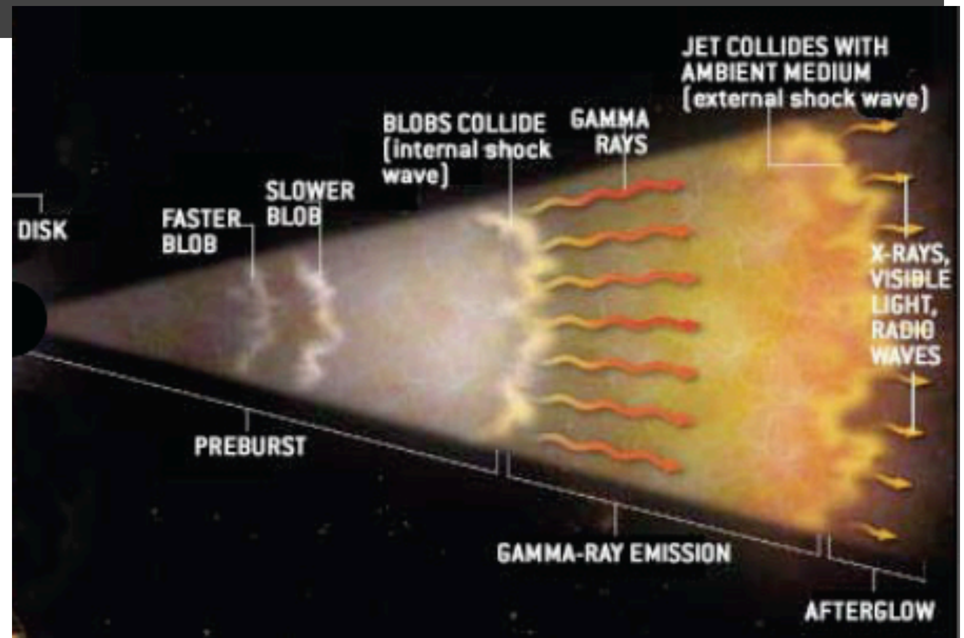


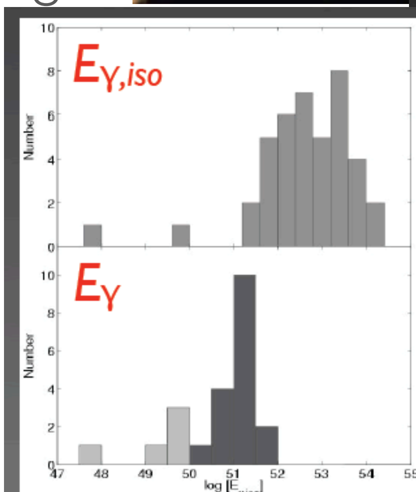
(NASA/Swift/ Aurore Simonnet, Sonoma State Univ.)

Slide courtesy of Laura Chomiuk

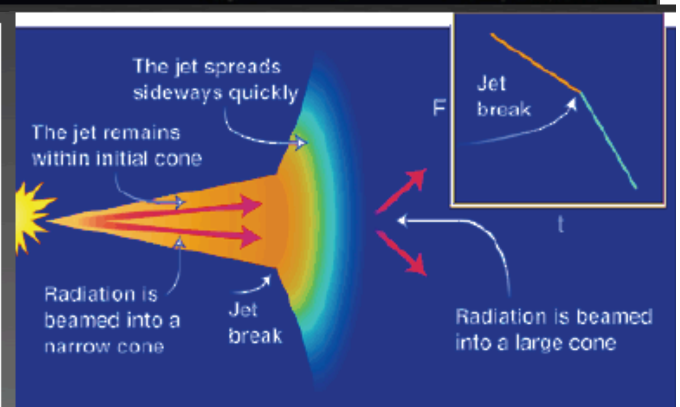
Gamma Ray Bursts

- Long GRBs
  - Relativistic expansion required for optically thin, non-thermal spectrum
  - Lorentz factors 100-1000
  - Internal shocks/mag. Dissipation
  - External shocks, reverse shock
  - Association with star-forming galaxies and supenova -> death of massive stars
  - Beaming 3-15 degrees
  - 10^48-10^52 (E_gamma)



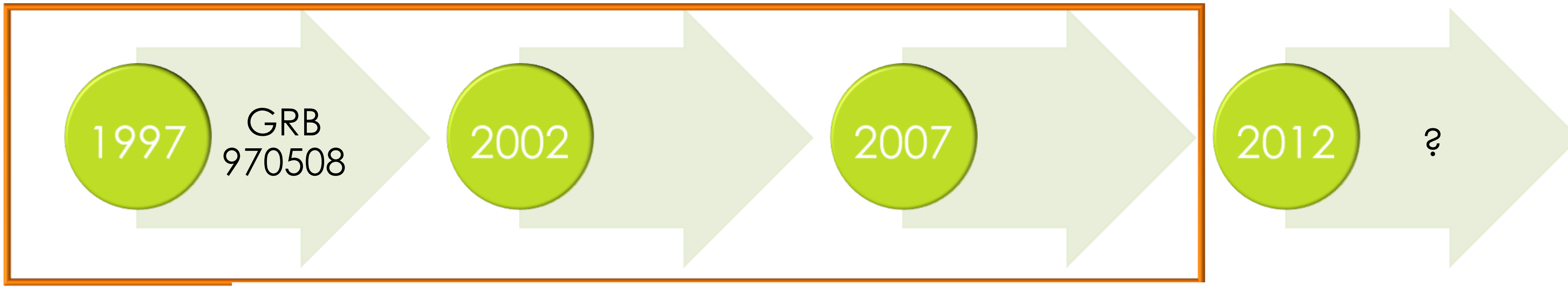


Frail et al. 2001; Bloom et al. 2003; Berger et al. 2003



Fruchter et al. 2006; Wainwright, Berger, & Penprase 2007

Long GRBs



A RADIO-SELECTED SAMPLE OF GAMMA RAY BURST AFTERGLOWS

Poonam Chandra,[1] & Dale A. Frail,[2]

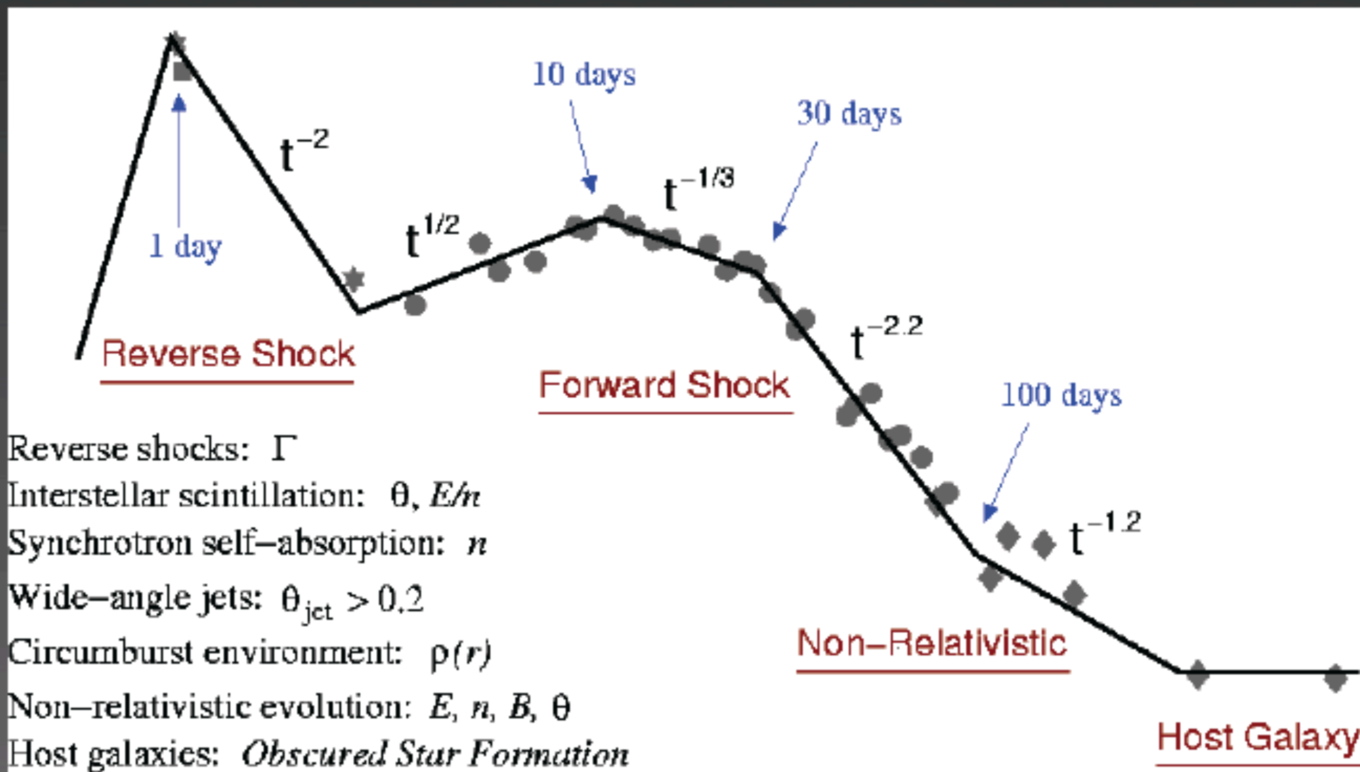
304 afterglows
2995 flux density measurements, 1539 measurements at 8.5 GHz

Detection rate 31%
Long-duration GRBs peak 3-6 days (rest frame) at 8.5 GHz

Median peak luminosity of 10^{31} erg/s/Hz

See overview paper
by Chandra & Frail
ApJ, 2012, 746, 156

I hour ⟷ ~few years

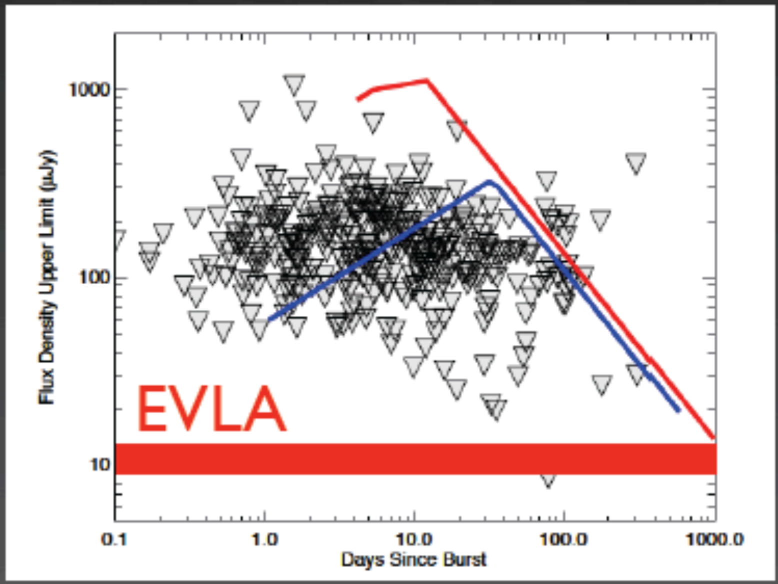


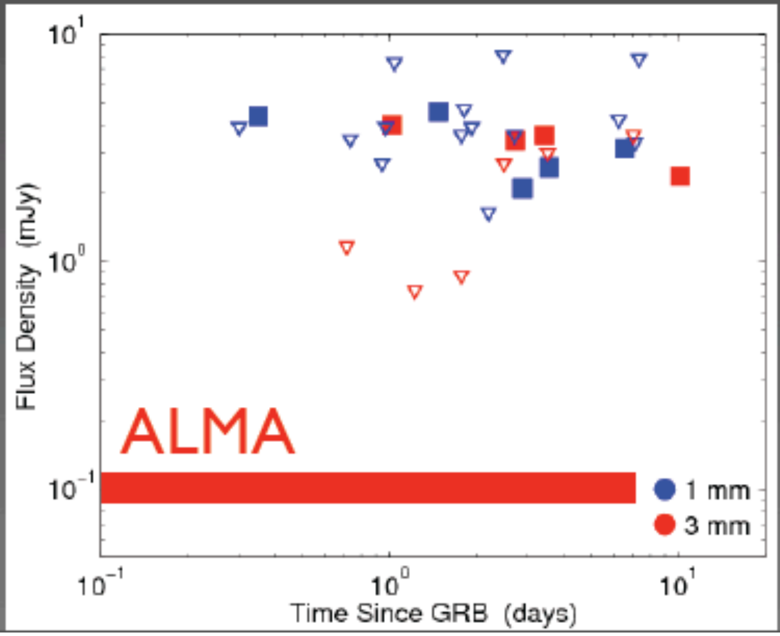
Berger PhD thesis

Radio observations provide information on energy, expansion, geometry, local environment, galactic environment

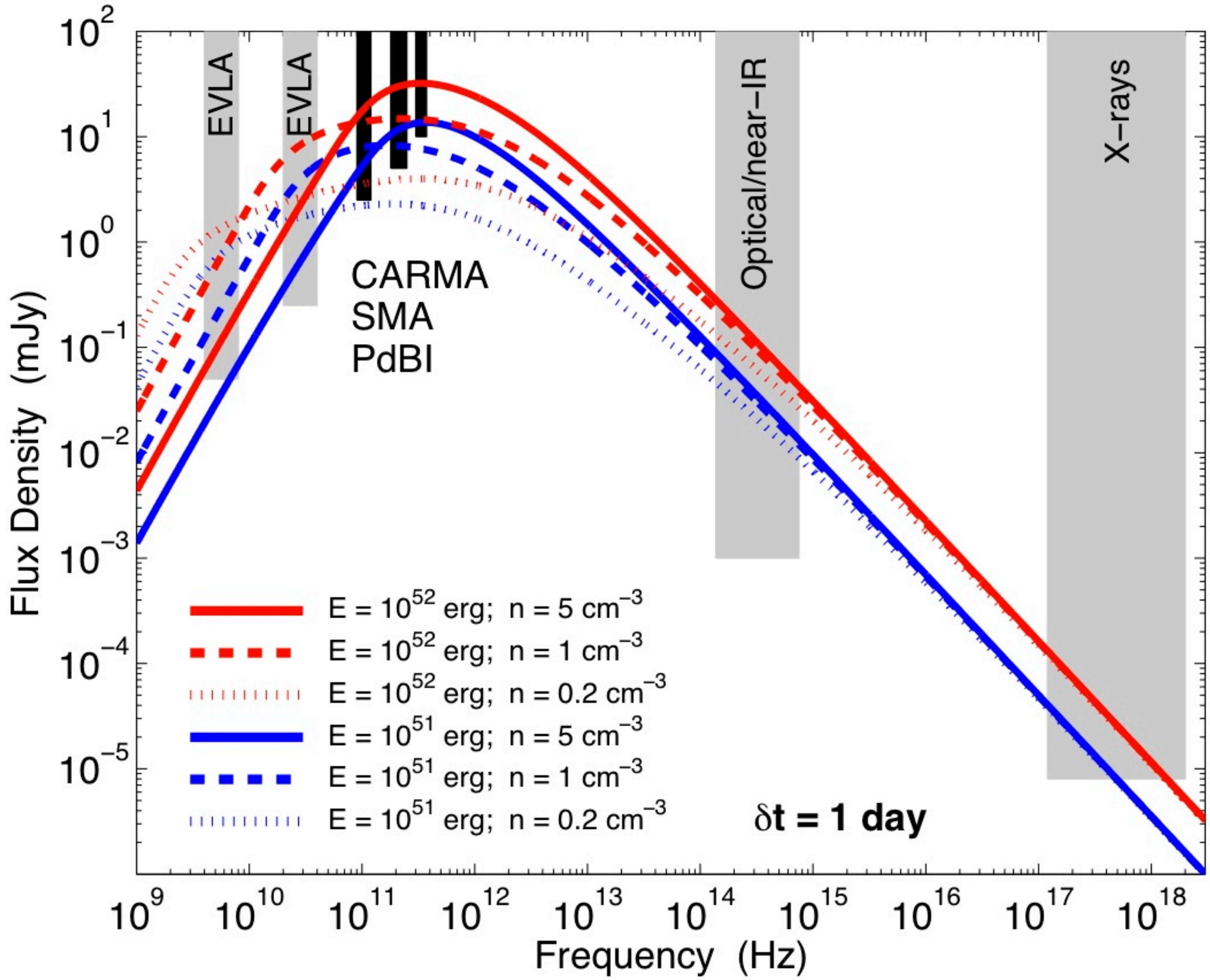
Long GRBs

Chandra & Frail 2012



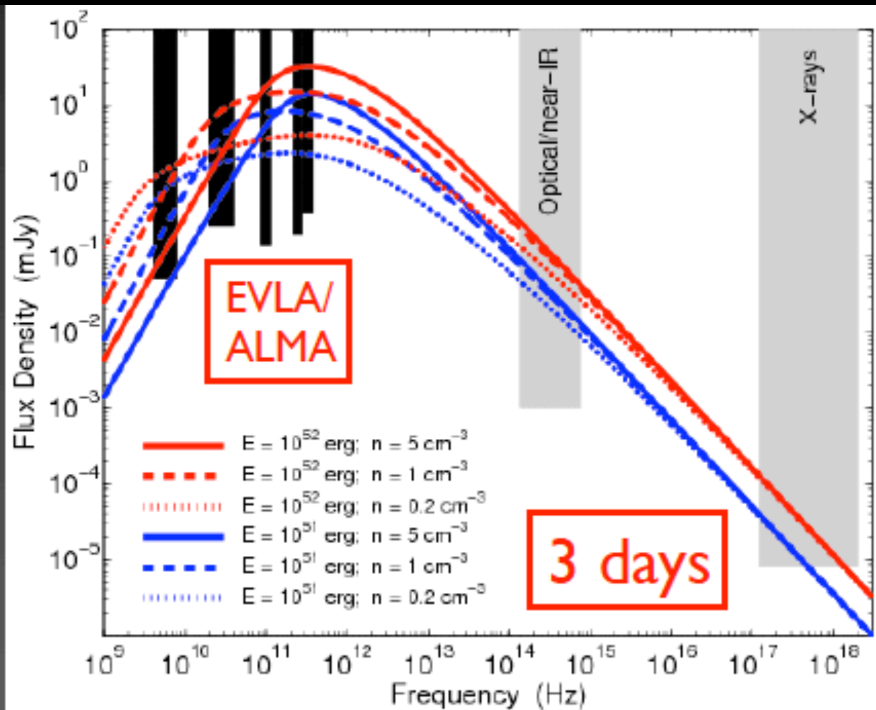


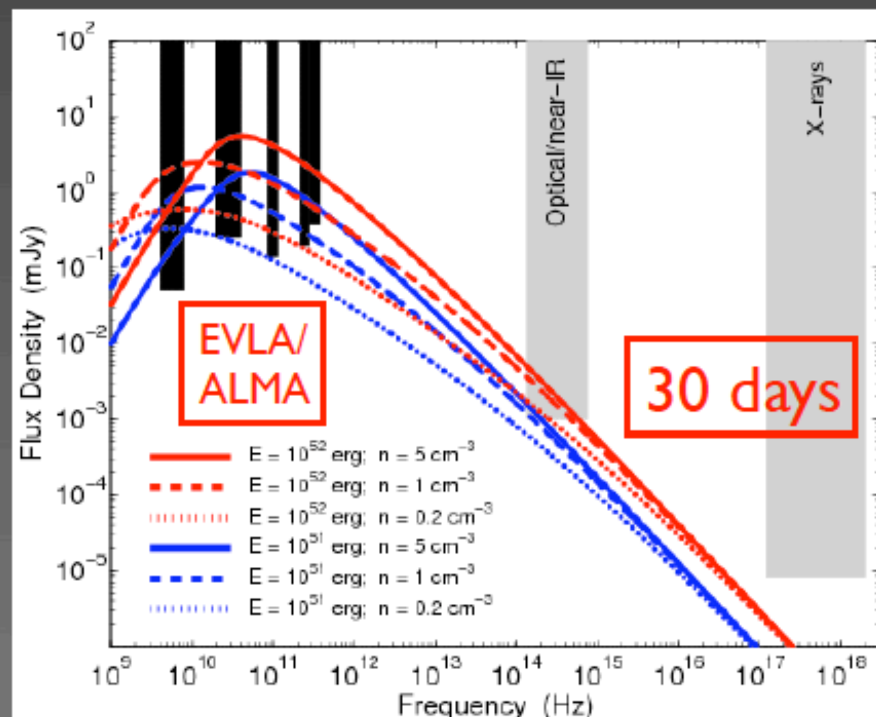
Radio-Optical/NIR/X-ray Synergy - Constrain Energy/Density



Looking Forward…

cm/mm observations (EVLA/ALMA) uniquely determine the density profile (optical/X-ray degenerate)



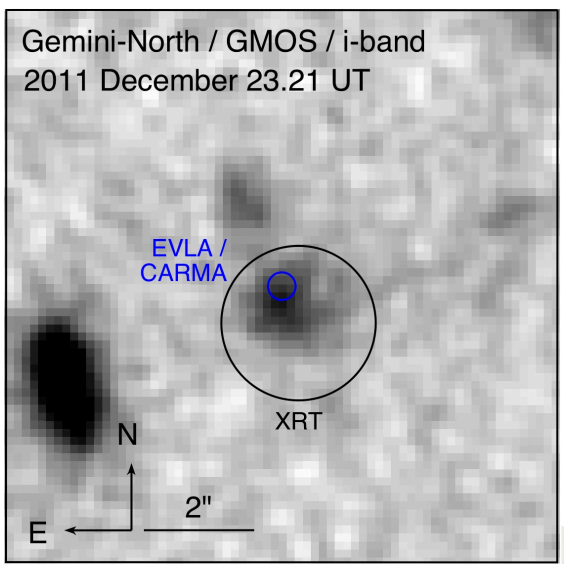


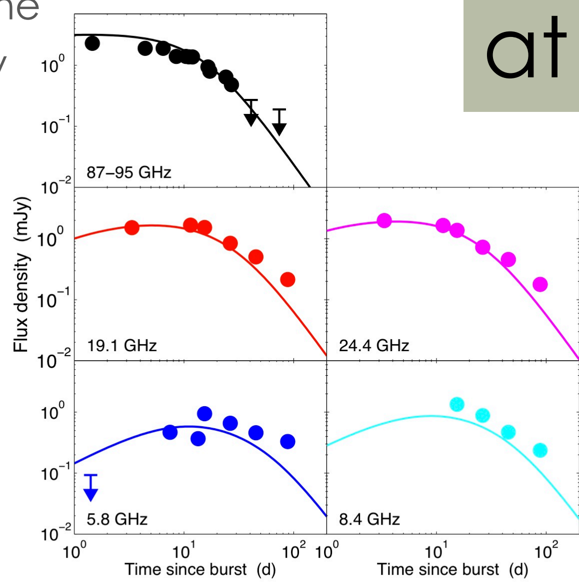
Dark Bursts

- Dark bursts lack "optical afterglows"
  - High redshift
  - Dust extinction

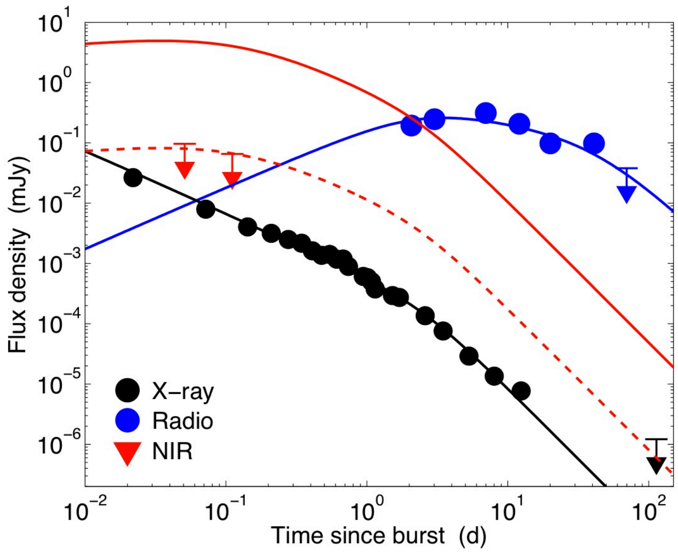
Using radio + X-rays, we can infer required extinction and determine positions for host galaxy searches

Hosts of dark bursts are potential sites for the study of obscured star formation at z>1

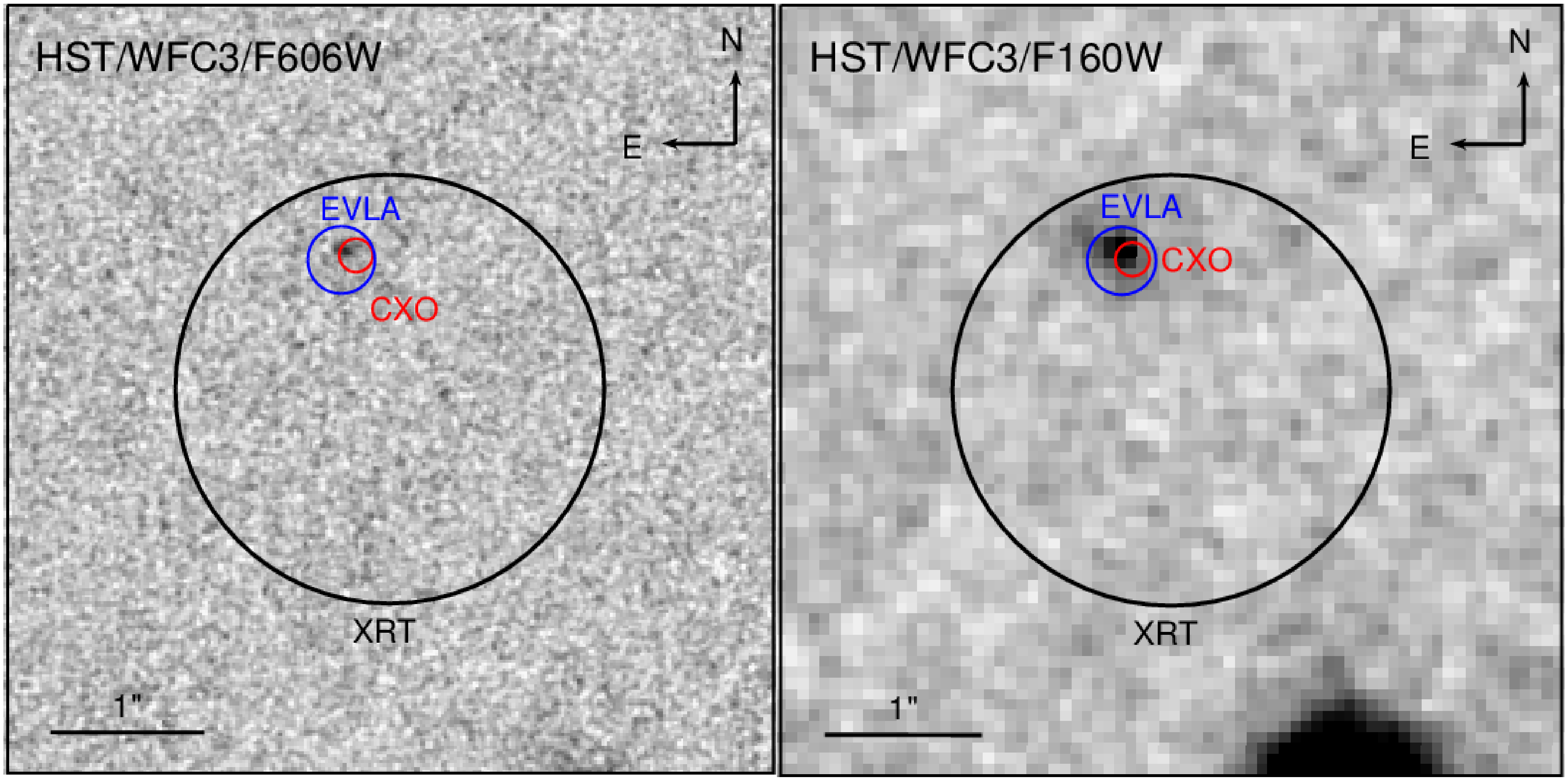




Figures from Zauderer et al. 2013

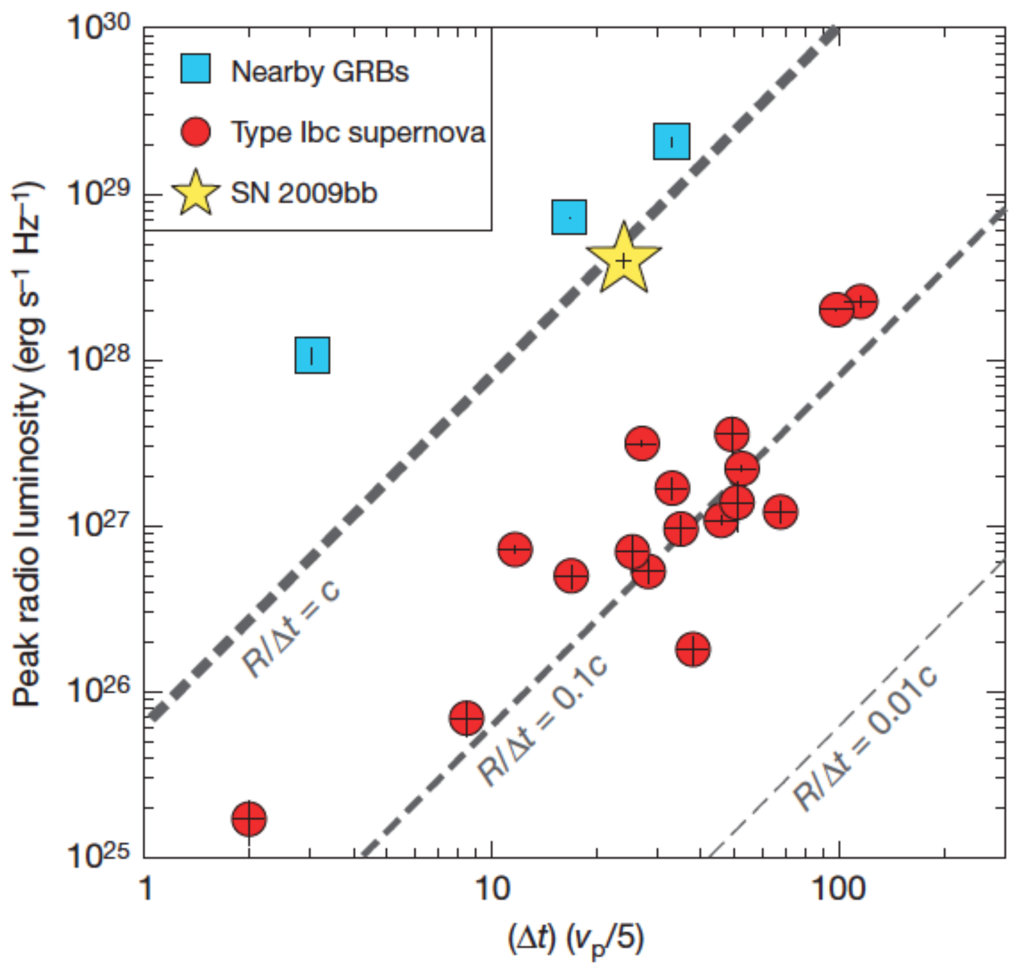


GRB 110709B - localization



Figures from
Zauderer et al. 2013

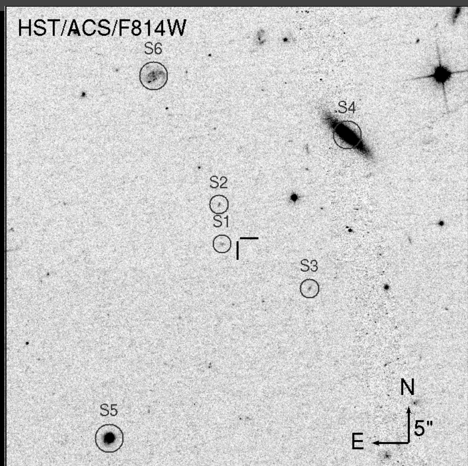
GRB-SNe

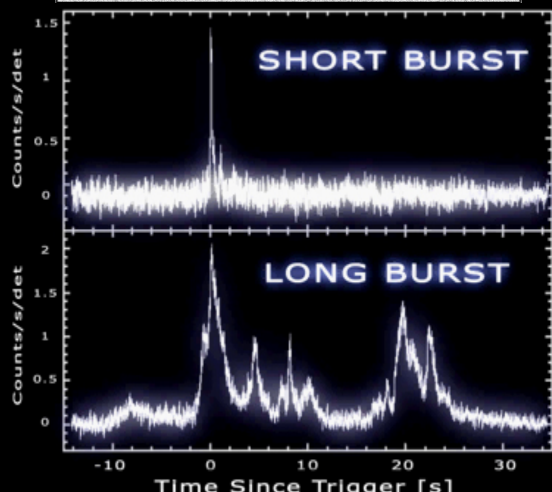


A continuum in blast wave velocities between normal SNe Ib/c and GRBs

(Soderberg et al. 2010, more in prep)

Short GRBs / Gravitational Waves



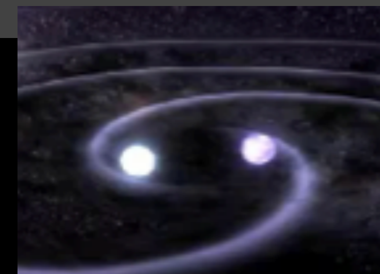


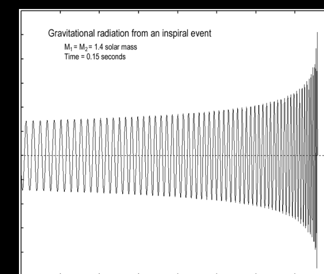
Short GRBs have a similar flux to long GRBs, but short duration leads to less photons

⇒ *more difficult to localize*

- No active star formation
- Stellar population >1 Gyr

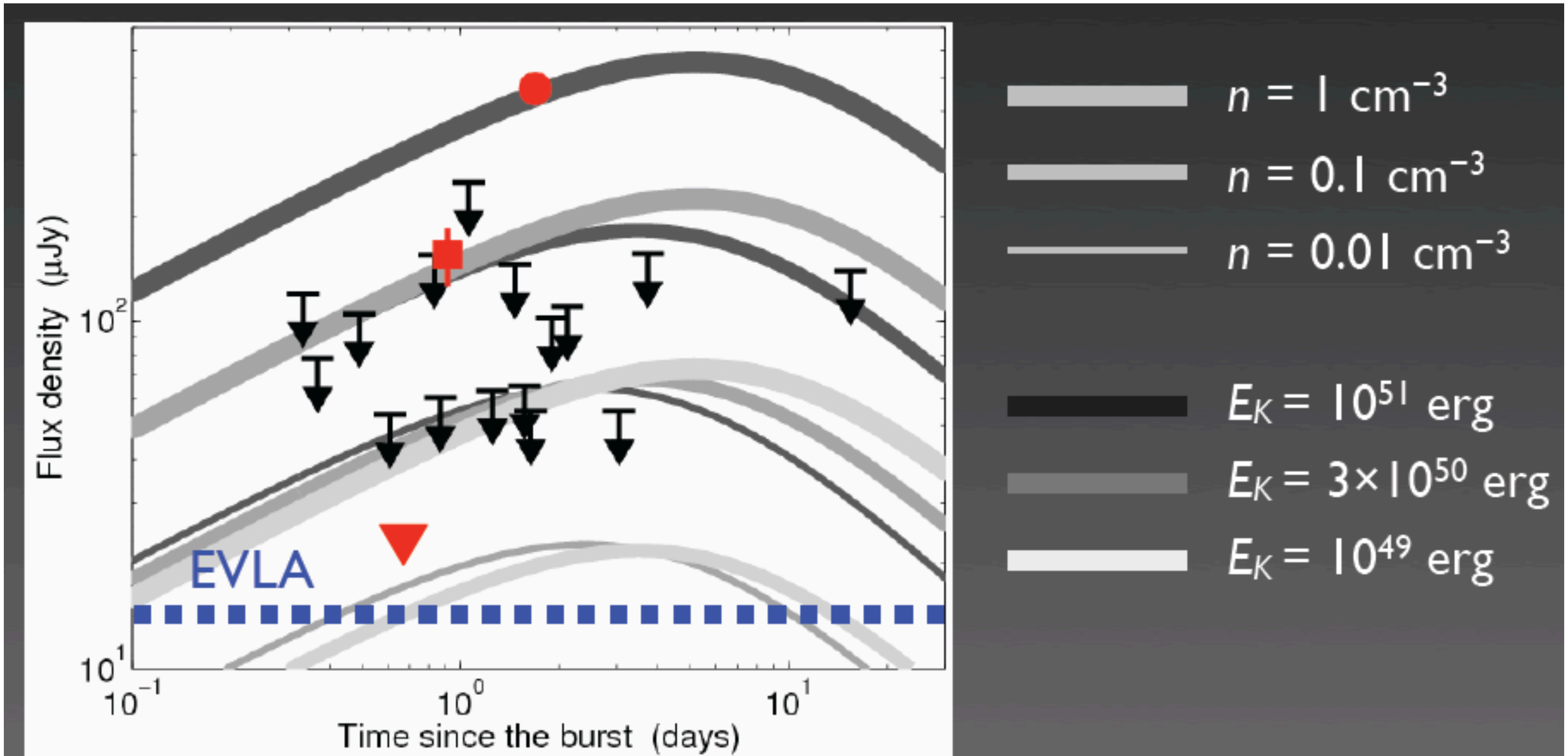
⇒ short GRBs are produced by an old stellar population





NS-NS binaries?

Short GRBs – Radio followup



Fong et al. in prep.

Existing radio data*: $n_0^{1/2} E_{K,51}^{5/6} \lesssim 0.03$

Tidal Disruption Events

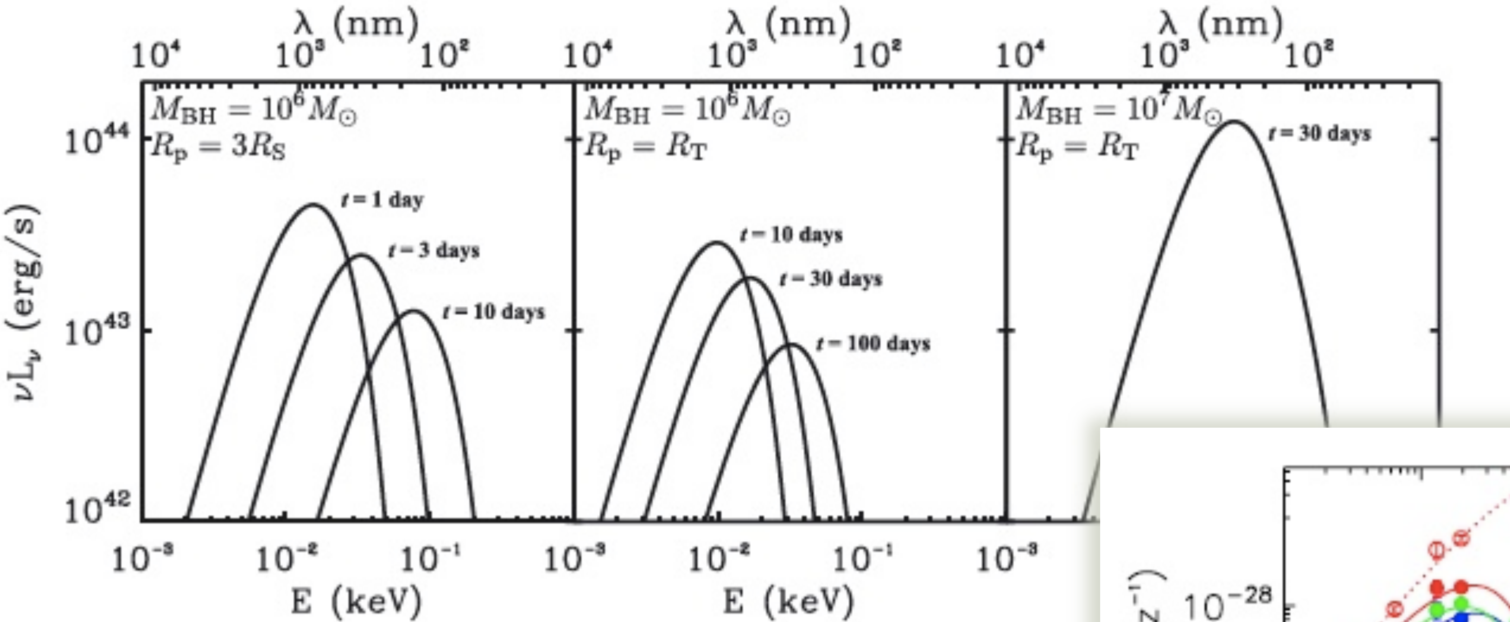
NATURE VOL. 333 9 JUNE 1988 — ARTICLES — 523

Tidal disruption of stars by black holes of 10^6–10^8 solar masses in nearby galaxies

Martin J. Rees

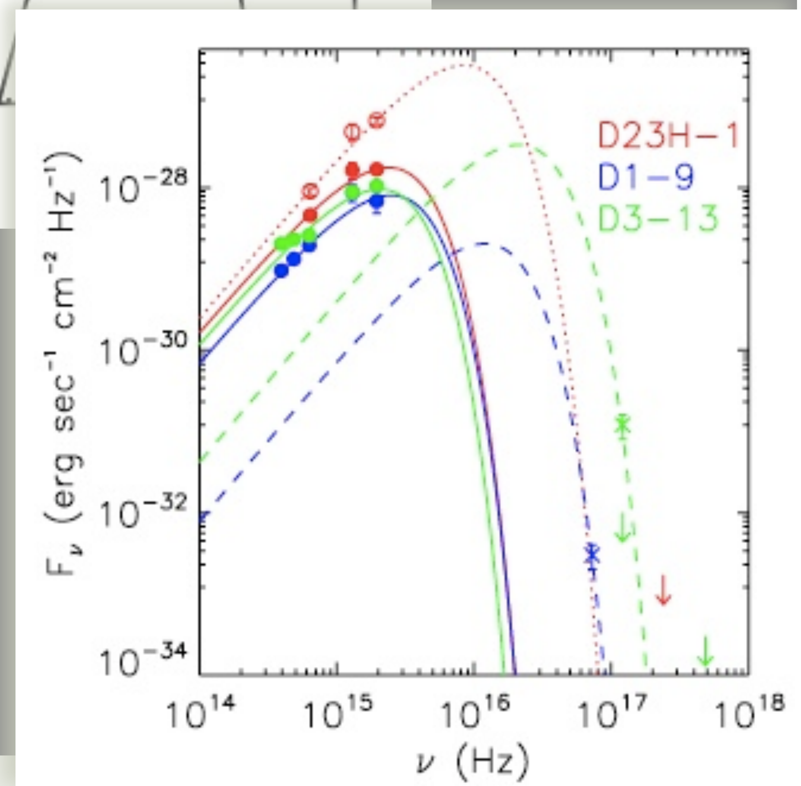
$$r_T \simeq 5 \times 10^{12} M_6^{1/3} (r_*/r_\odot)(m_*/m_\odot)^{-1/3} \text{ cm}$$

Theoretical Prediction



Strubbe & Quataert; Giannios & Metzger

Gezari et al.

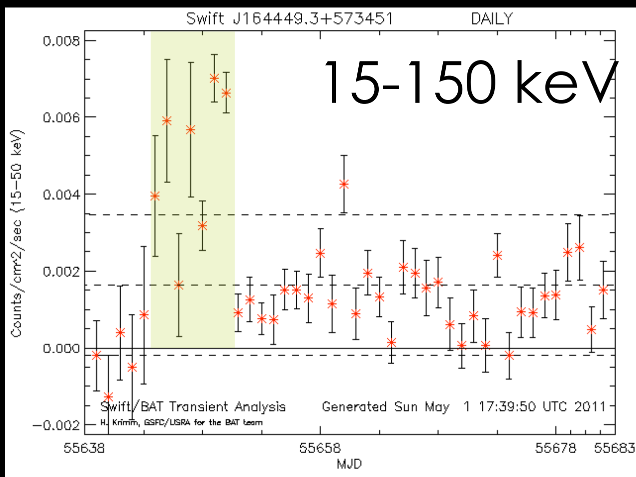


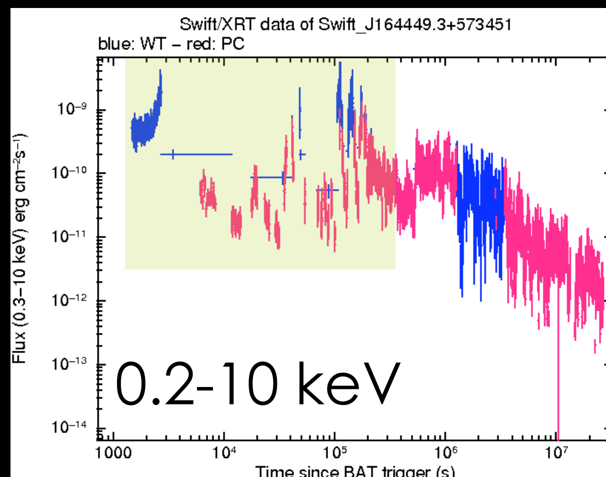
-UV/optical/soft X-rays with $L \sim L_{edd}$

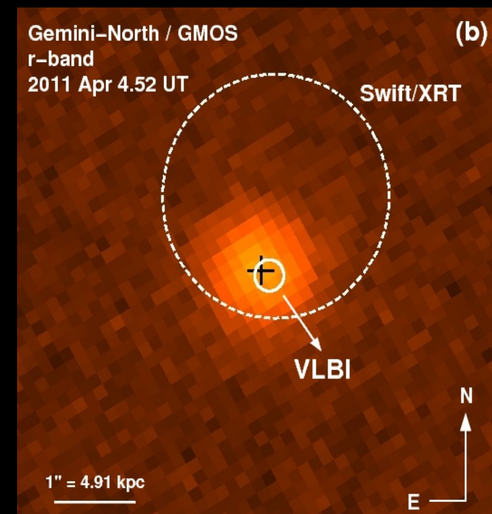
-finite duration, very luminous, reside in non-active galaxy (Komossa 2002)

Swift 1644+57 Overview

- *Swift* discovery on 2011 March 28.5 UT; multiple triggers; emission on 3/25
- Long-lived X-ray source; $L \propto t^{-5/3}$ at >10 days; beaming of 0.1 rad; extinction





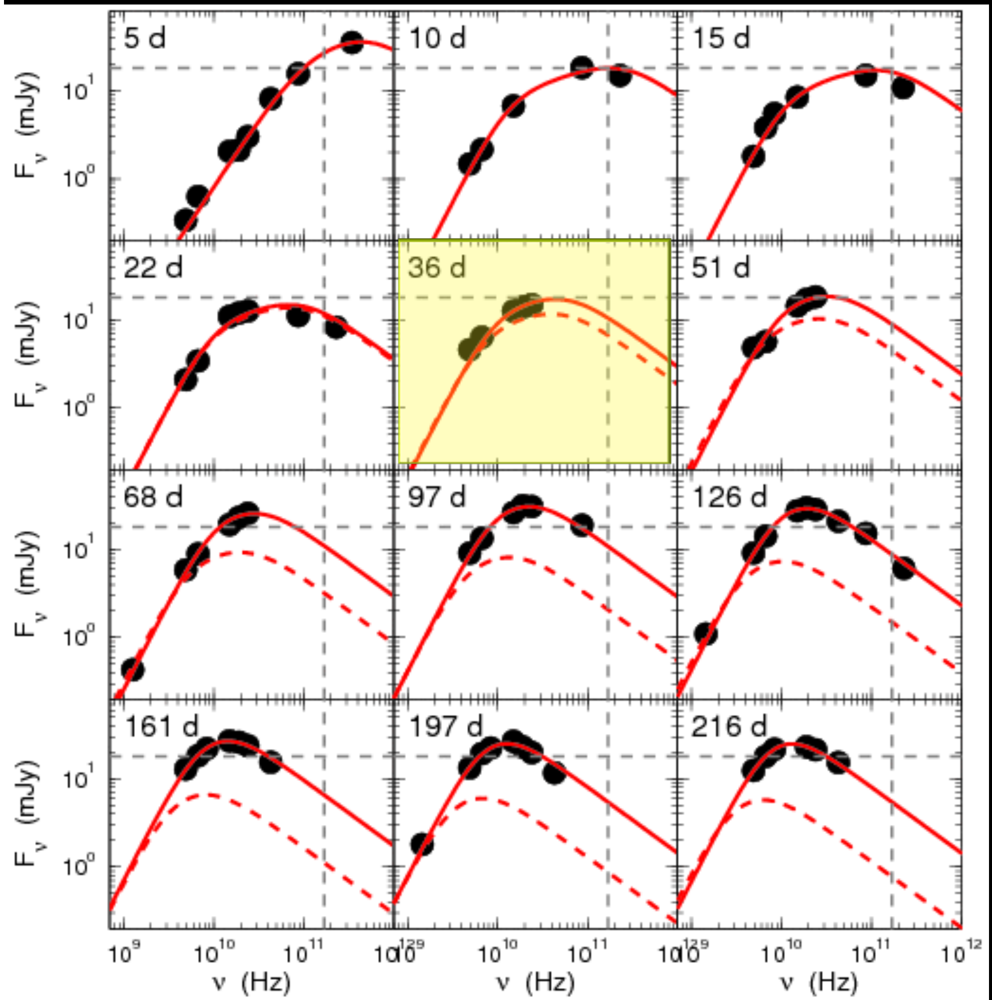


<u>Early radio observations</u>:

- Linked the γ-ray/X-ray transient to the nucleus of a galaxy at z = 0.354 (Zauderer et al. Nature 2011)
- Demonstrated a relativistic outflow (equipartition, interstellar scintillation)
- Tied the outflow formation time to the onset of γ-ray emission

Interpretation: tidal disruption of a star by a ~ few × 10^6 $M_\odot$ SMBH

Swift 1644+57 Synchrotron Modeling



Model each "snapshot" spectral energy distribution with a synchrotron model (cf GRBs)

⇒ determine time evolution of *E, ρ, R, Γ*

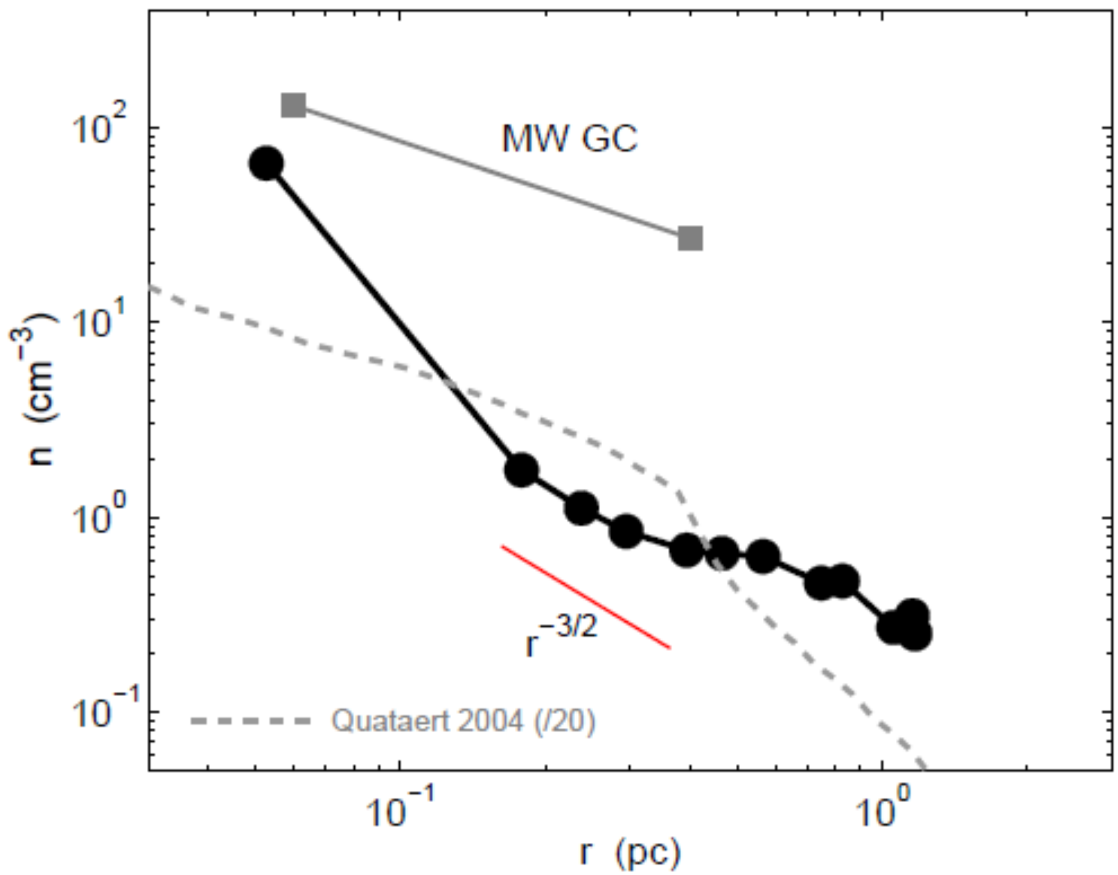
no change in *E, ρ*

Berger et al. ApJ (2012)

Tracing environment

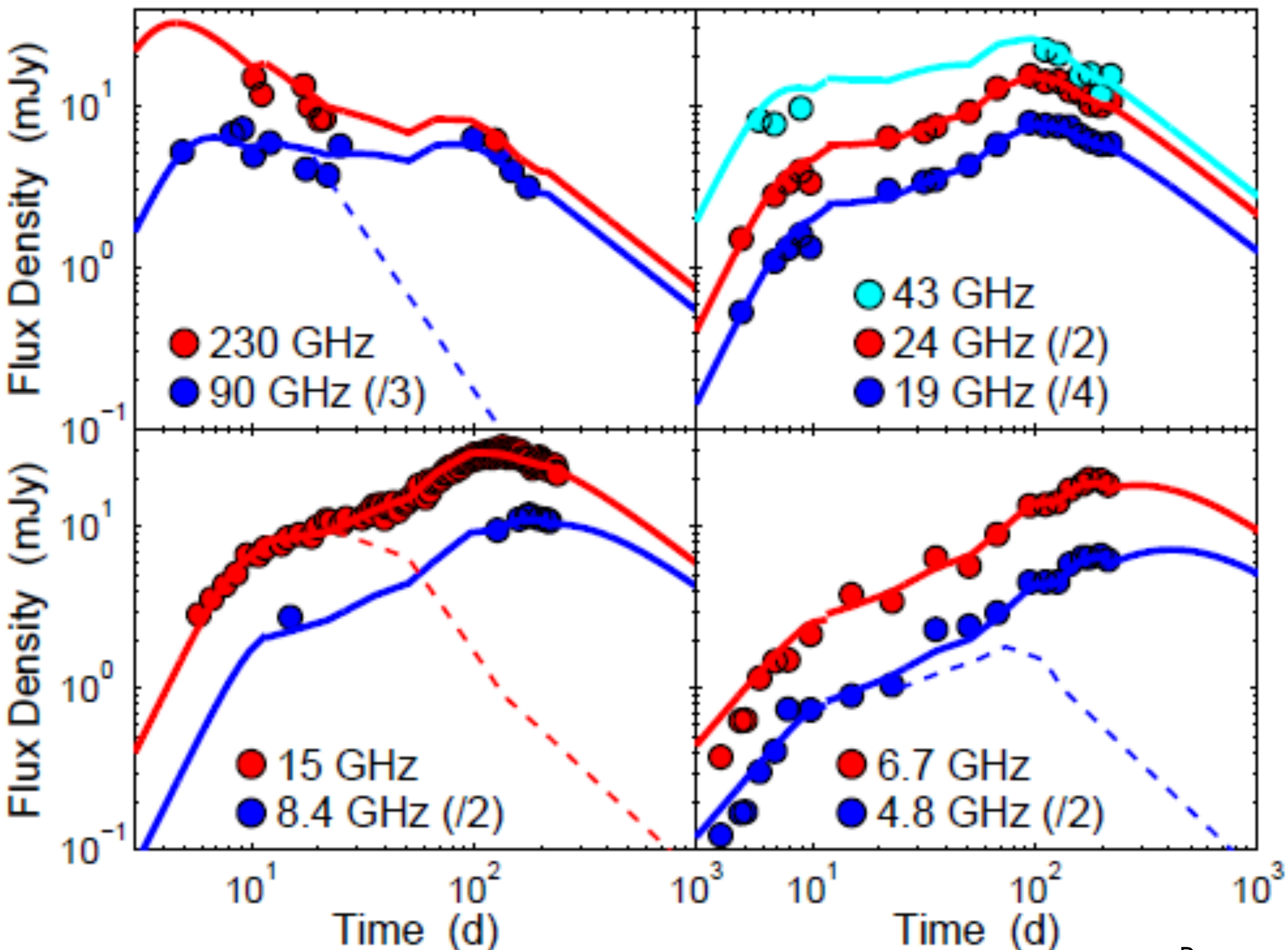
-ability to trace environment around pristine BH

-Detection of linear polarization at ~1% level



Berger et al. (2012)

Sw1644+57 Radio Light Curves



Berger et al. 2012

Bower et al. X-ray selected TDEs

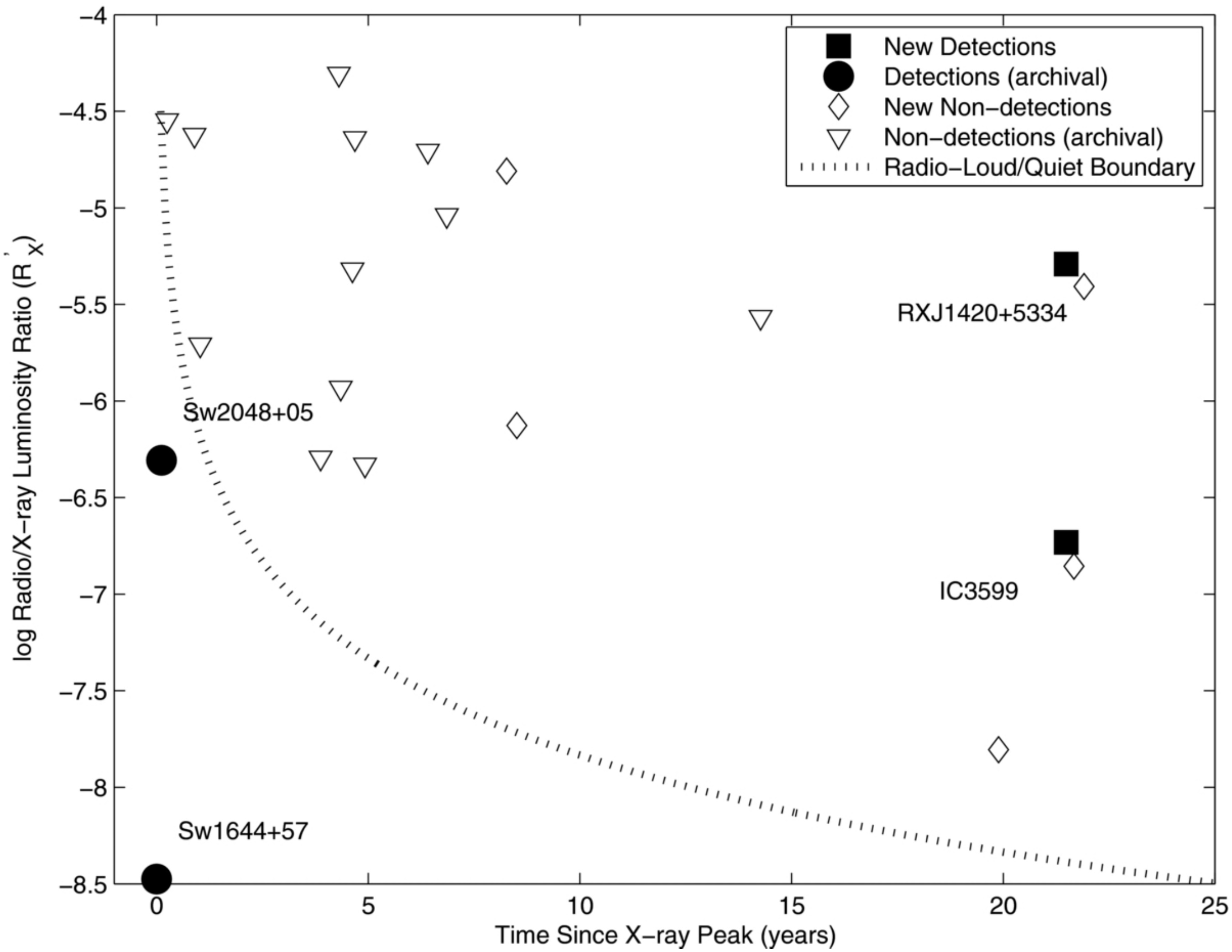


Figure 4 from Late-time Radio Emission from X-Ray-selected Tidal Disruption Events
Geoffrey C. Bower et al. 2013 ApJ 763 84 doi:10.1088/0004-637X/763/2/84

Van Velzen 2011
rate of TDEs from SDSS

Table 5
Detection Rates of Other Optional Surveys

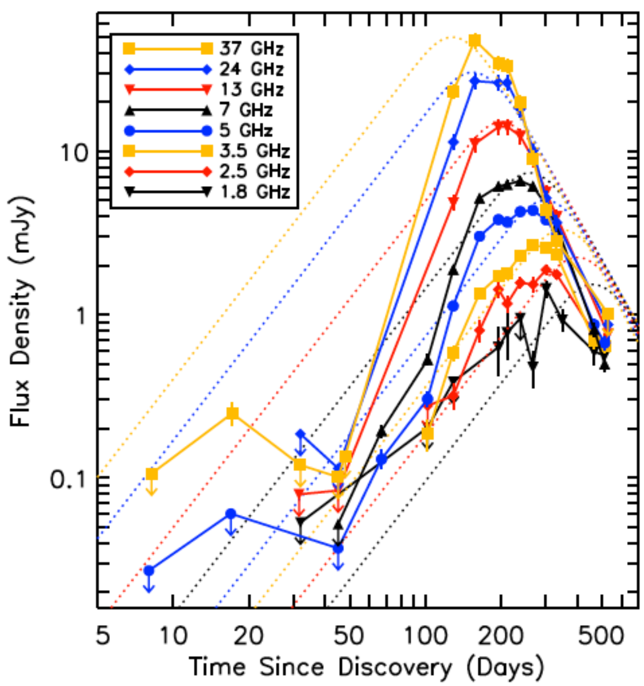
Survey Name	Cadence	F_{lim} (mag)	f_{sky}	$\dot{N}_{obs}$ (yr^{-1})
CSS (1)	14 days	19.5	0.6	5
MLS (1)	14 days	21.5	0.09	12
QUEST (2)	hours to years	20.5	0.36	12
Palomar Transient Factory (3)	5 days	21.0	0.2	13
Pan-STARRS Medium Deep Survey (4)	4 days	24.8	0.0012	15
Pan-STARRS 3π Survey (4)	6 months	23.5	0.75	1557
Large Synoptic Survey Telescope (5)	3 days	24.5	0.5	4131

Notes. The survey plus reference used to obtain or estimate the cadence, flux limit (F_{lim}) and fraction of the sky covered (f_{sky}) are listed. We scale the detection rate using Equation (7) and $\dot{N}_{obs} = 1.9\,yr^{-1}$ for the analysis presented here. We have used 300 deg^2 as the angular area for Stripe 82. Since the cadence of the observations of Stripe 82 decreases toward the edges, Sesar et al. (2007) have used 290 deg^2 for this area. However, the total area of Stripe 82 that is imaged is 312 deg^2; we thus adopted 300 deg^2 as a reasonable value to obtain f_{sky}.

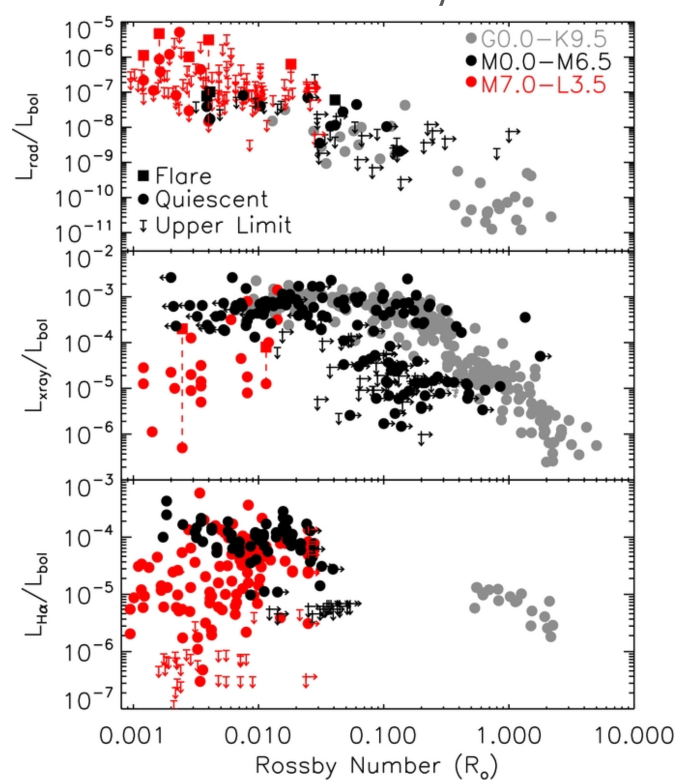
References. (1) Drake et al. 2009; (2) Hadjiyska et al. 2011; (3) Law et al. 2009; (4) Gezari et al. 2008; (5) Ivezić et al. 2008.

Comments on other transients

- Novae – wide field radio surveys
  - T Pyx (Nelson et al. 2012 arXiv 1211.3112)



- Brown Dwarfs / Flare stars
  - Followup in radio when position known (McLean, Berger & Reiners 2012)



- Exotic / unknown?
  - e.g. PTFagg11 (Cenko et al.)

Summary

- Deep all-sky radio survey
- LSST to discover transients (trigger) and to supply supplementary information on objects and their environment (e.g. host galaxy) when discovery is made at higher energies or in the radio
- Keep pushing on what is working
  - Multi-wavelength
  - Timed followup according to science goals (e.g. rapid response to study supernovae, RS, short GRBs