Radio Fireworks

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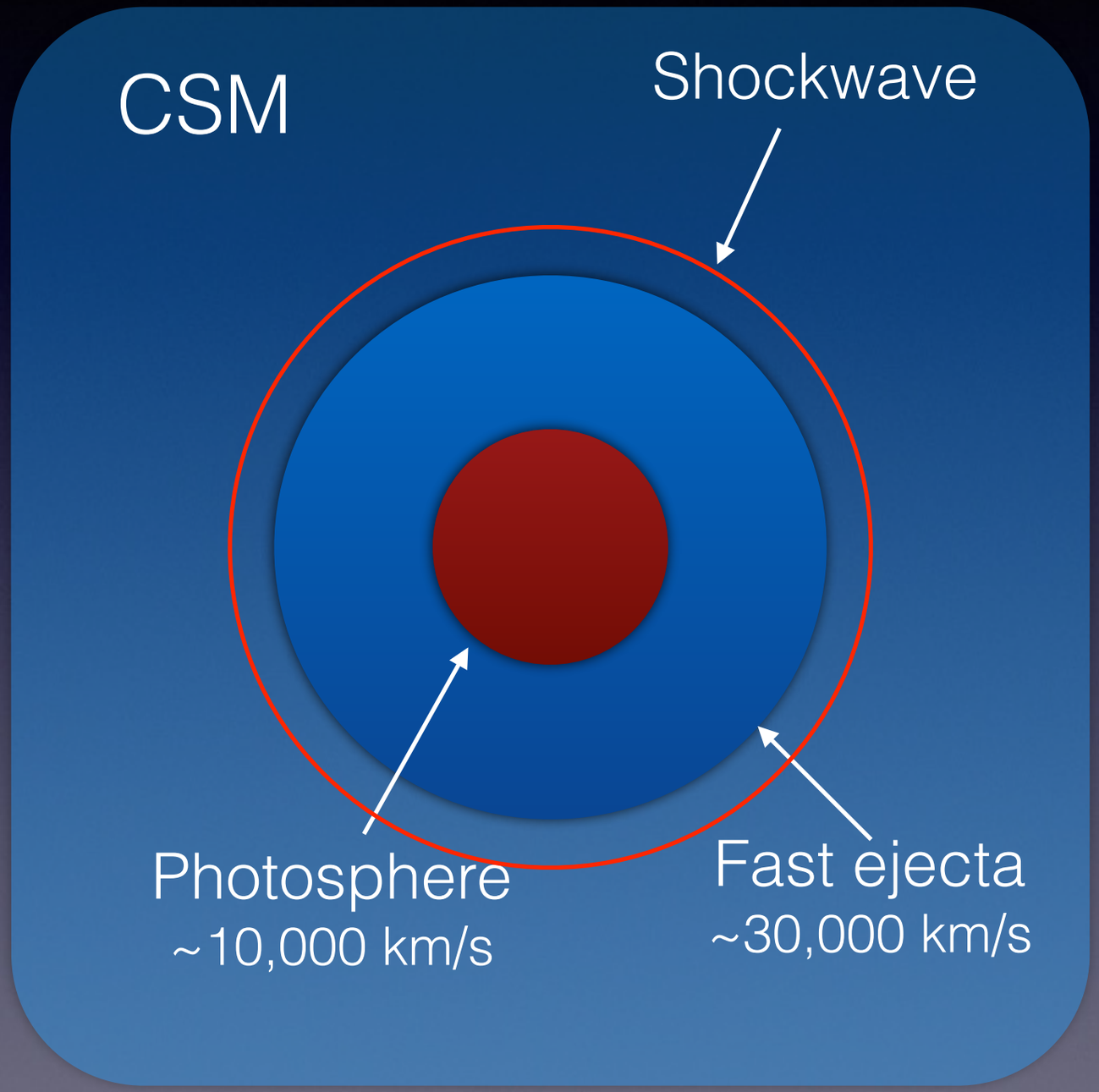
Why Radio?

- Trace fastest ejecta
- Trace high-energy particles
- Trace magnetic fields
- Measure CSM density (Mass-loss history)
- Optical emission might be obscured
- Late radio emission is not beamed



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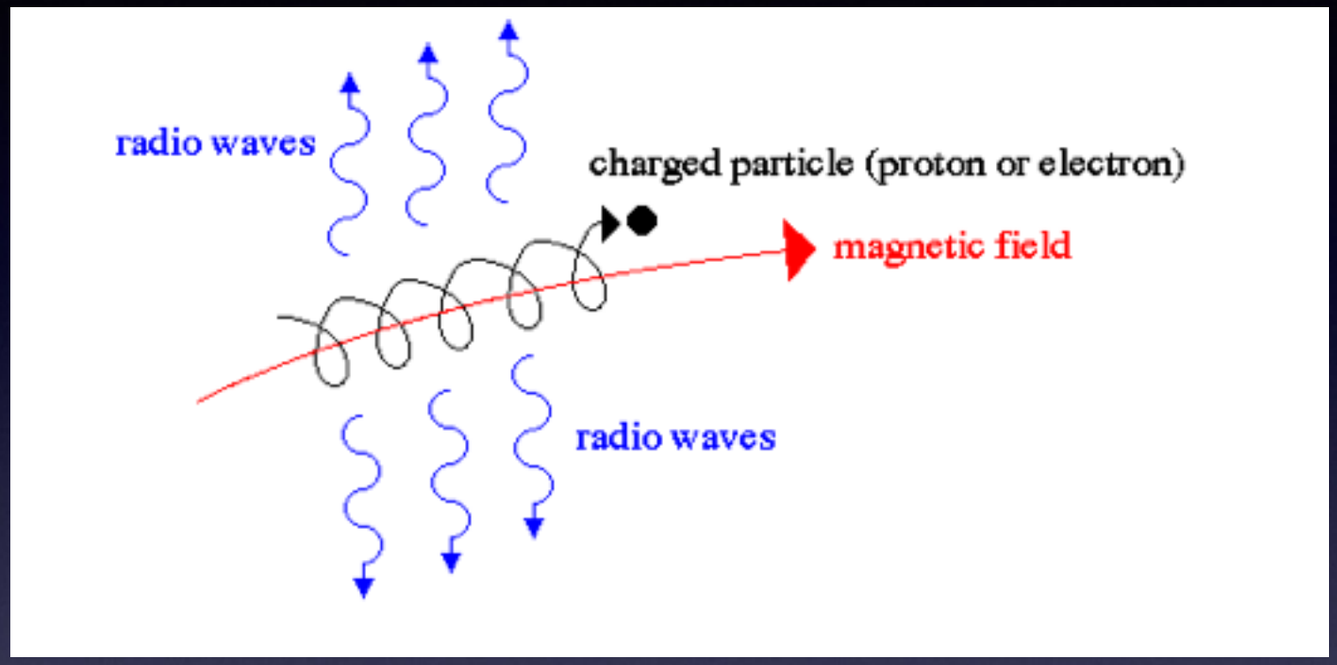

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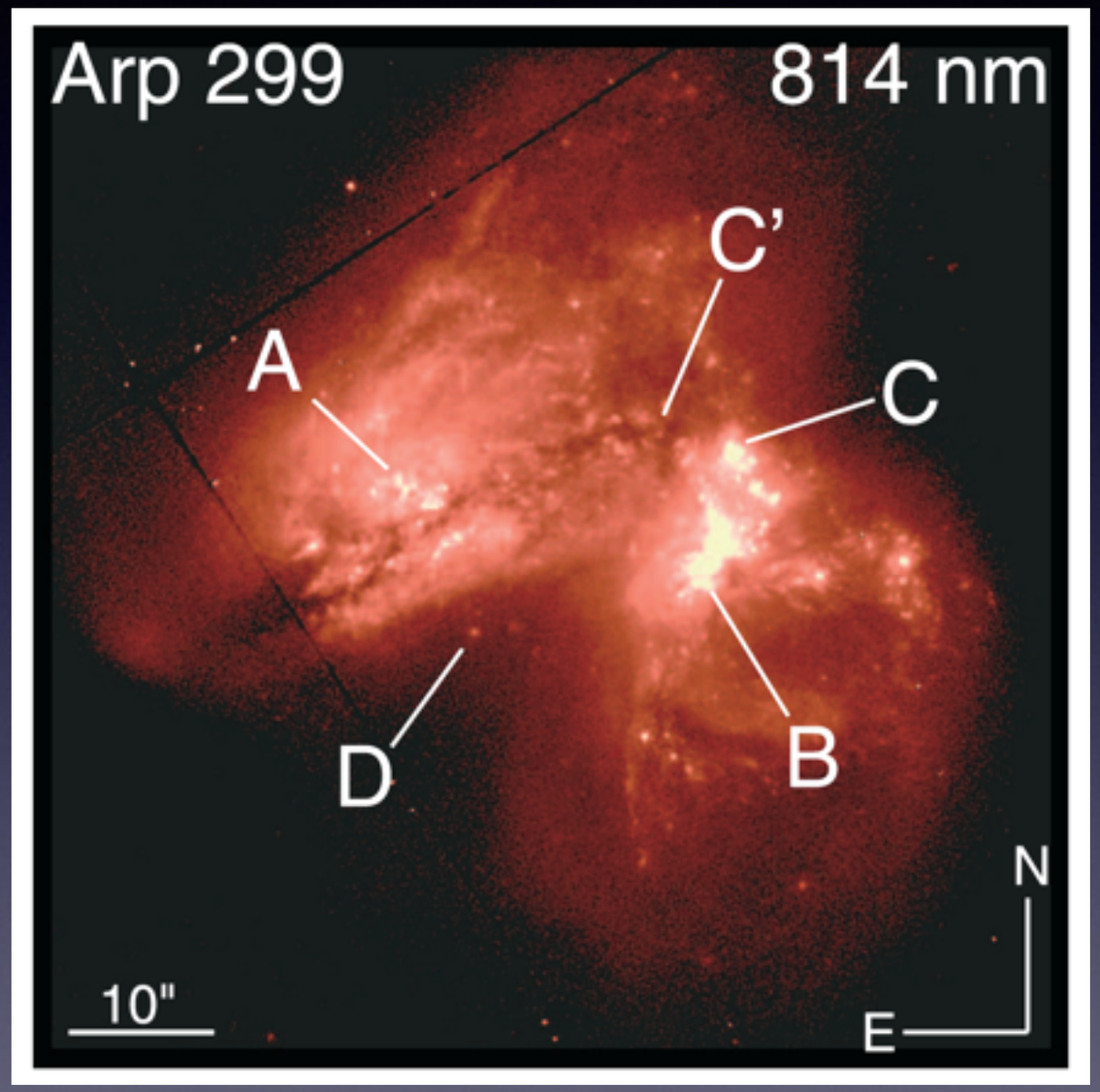

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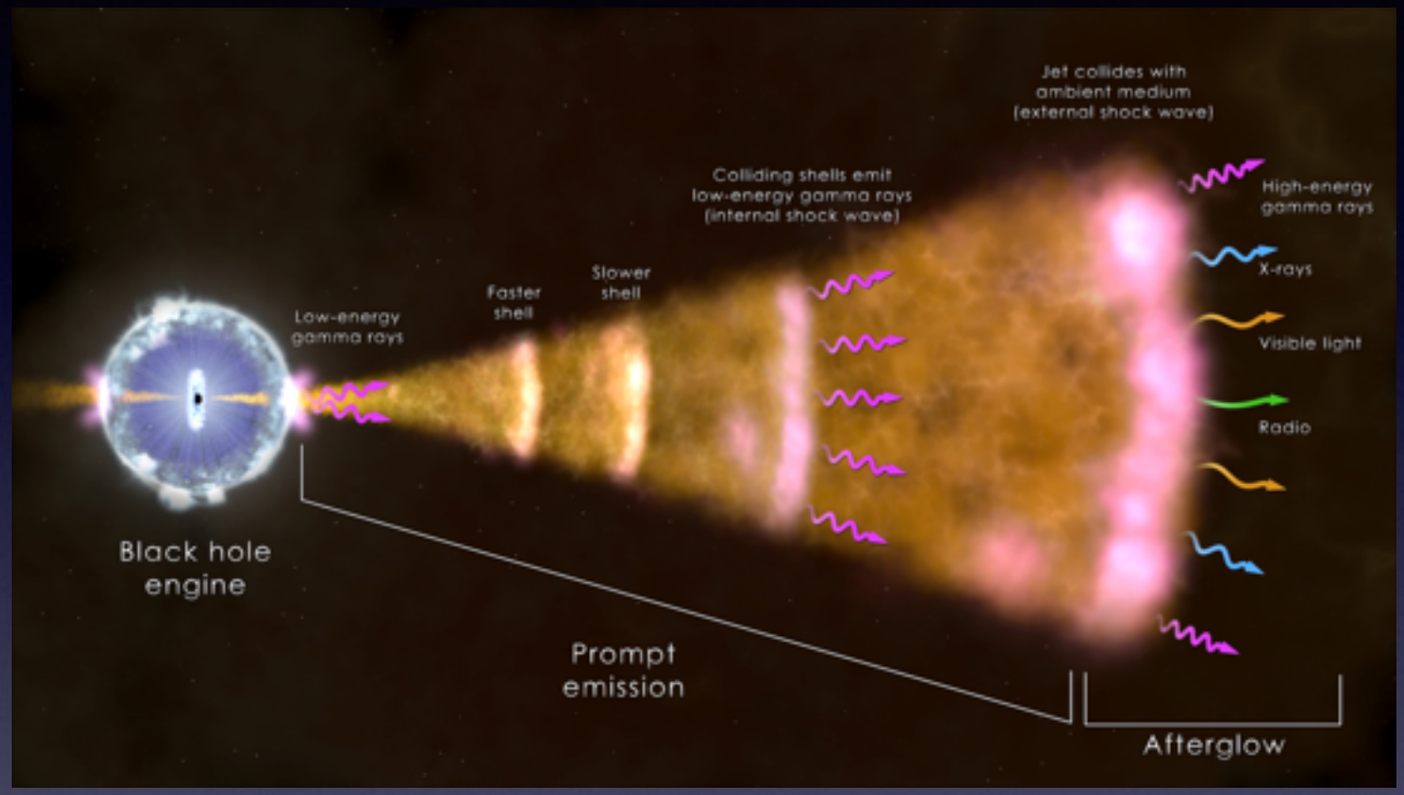

Type Ia supernovae

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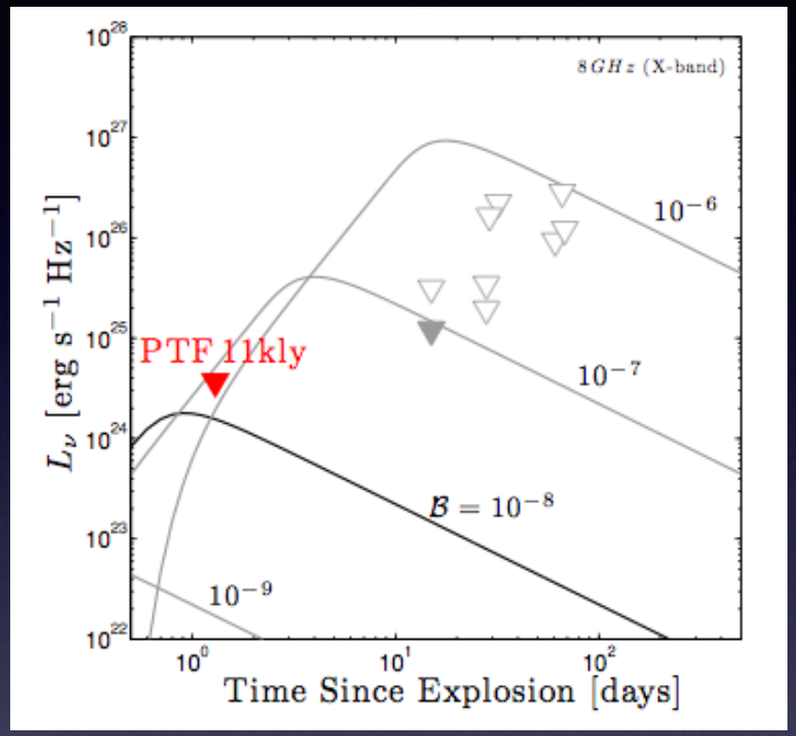
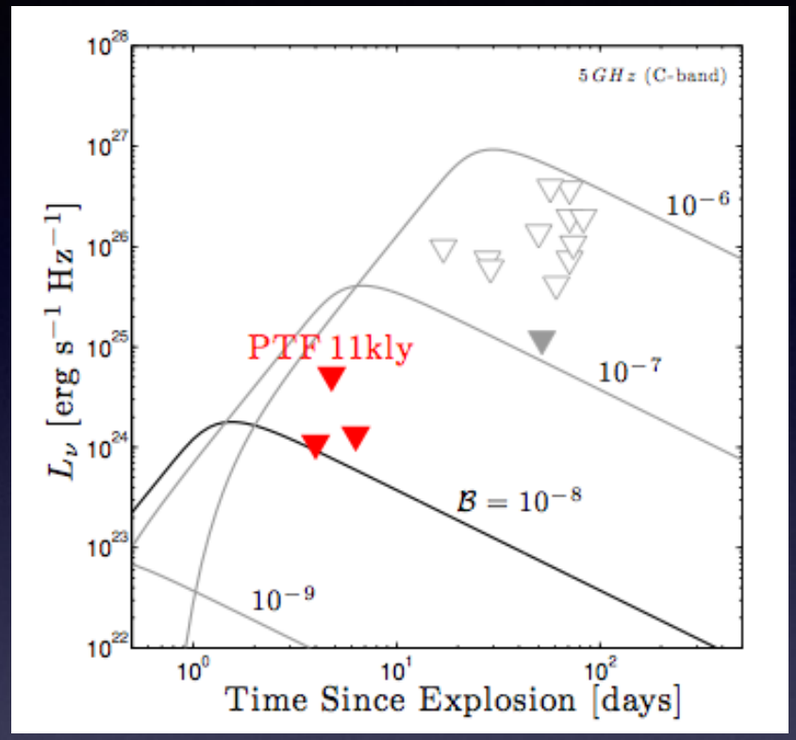
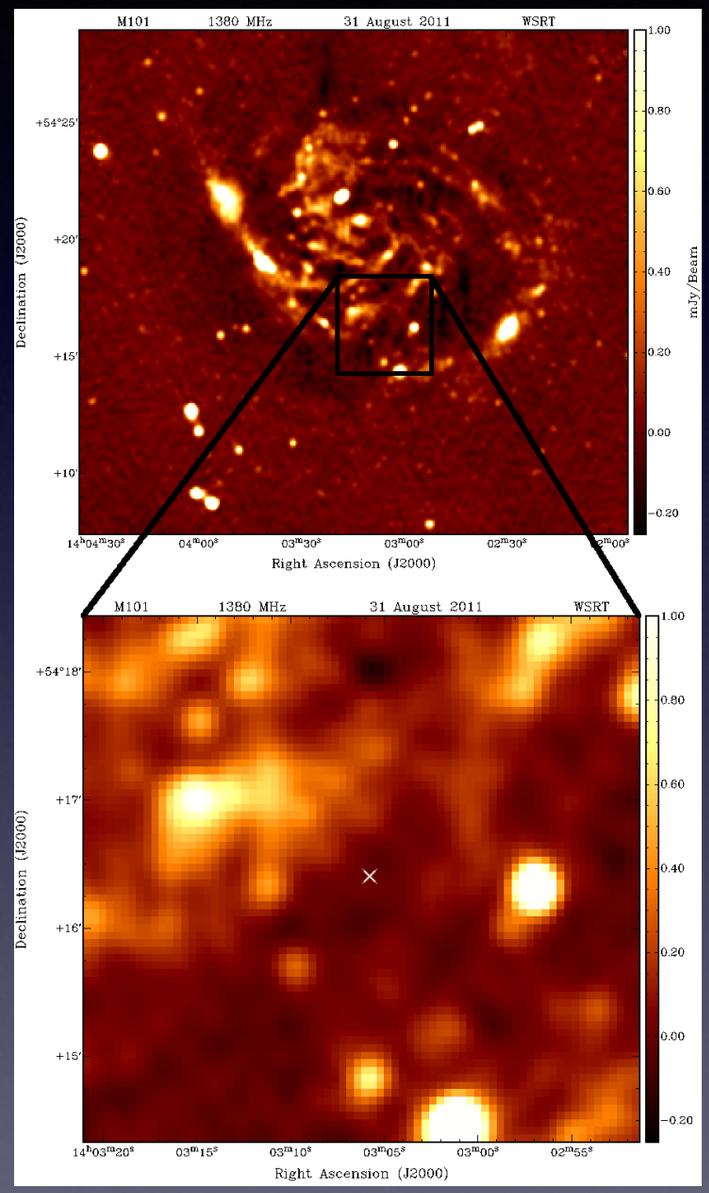




Horesh et al. 2012

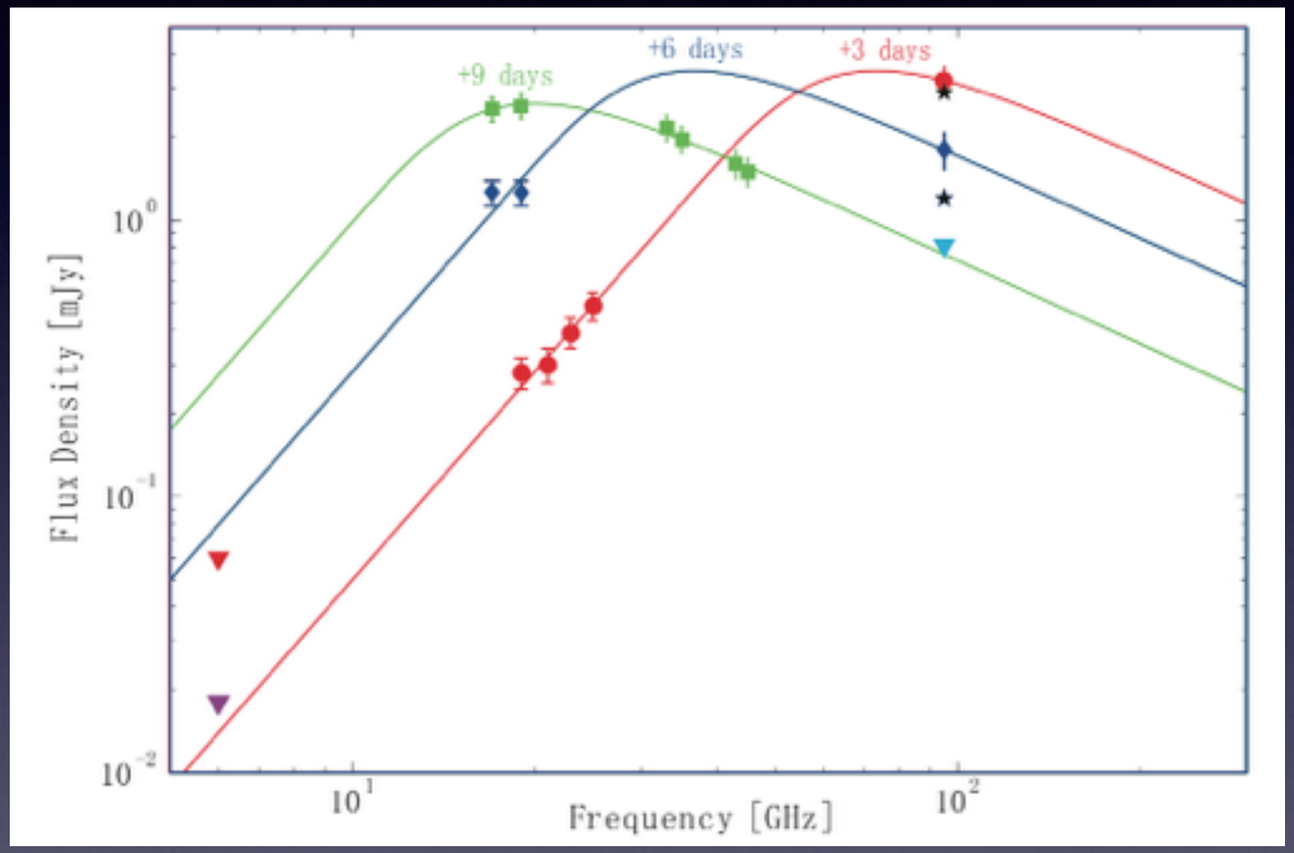


Mass loss ≤ 10^{-8} (w/10^{7} cm/s) M /yr

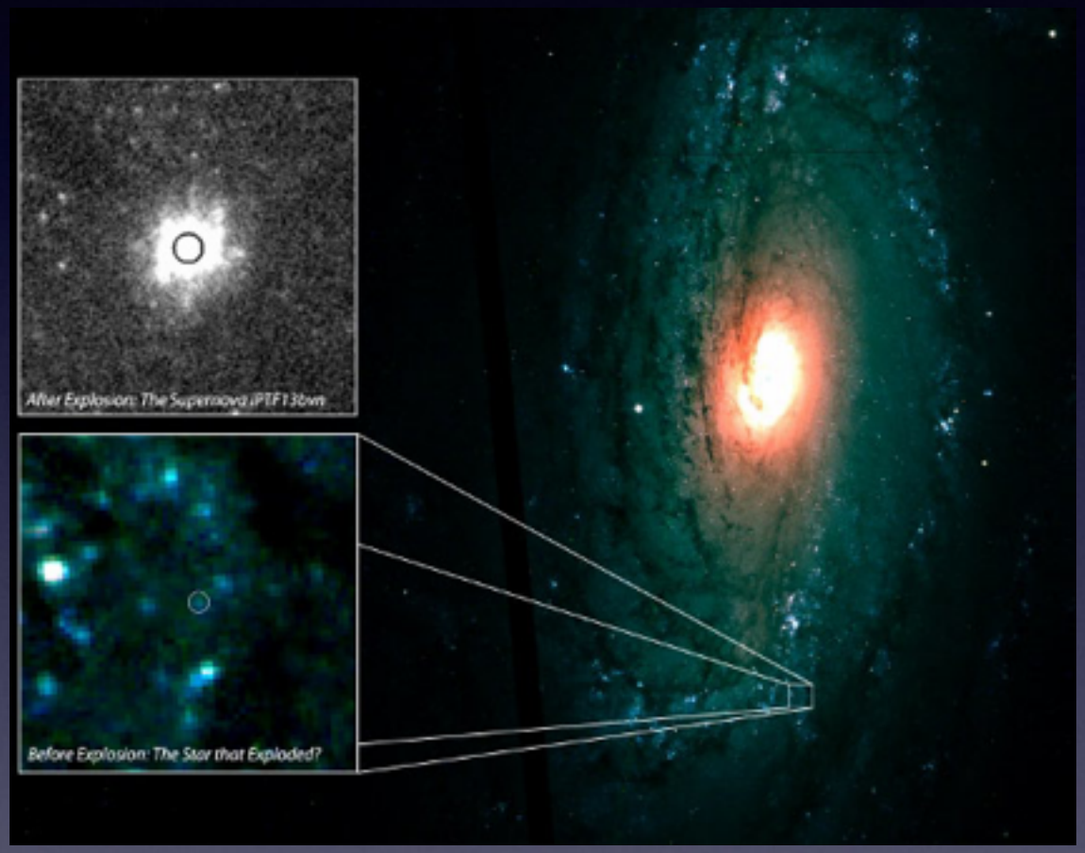
Probably a double degenerate

(see also Chomiuk et al. 2012)

Stripped Envelope Supernovae



VLA/CARMA/ATCA observations (PI Horesh)



Cao, Kasliwal, Arcavi, Horesh et al. (2013)

First identification of the progenitor of a Type Ib SN: Compact WR star

Radio observations independently suggest WR star properties

Stripped Envelope Supernovae

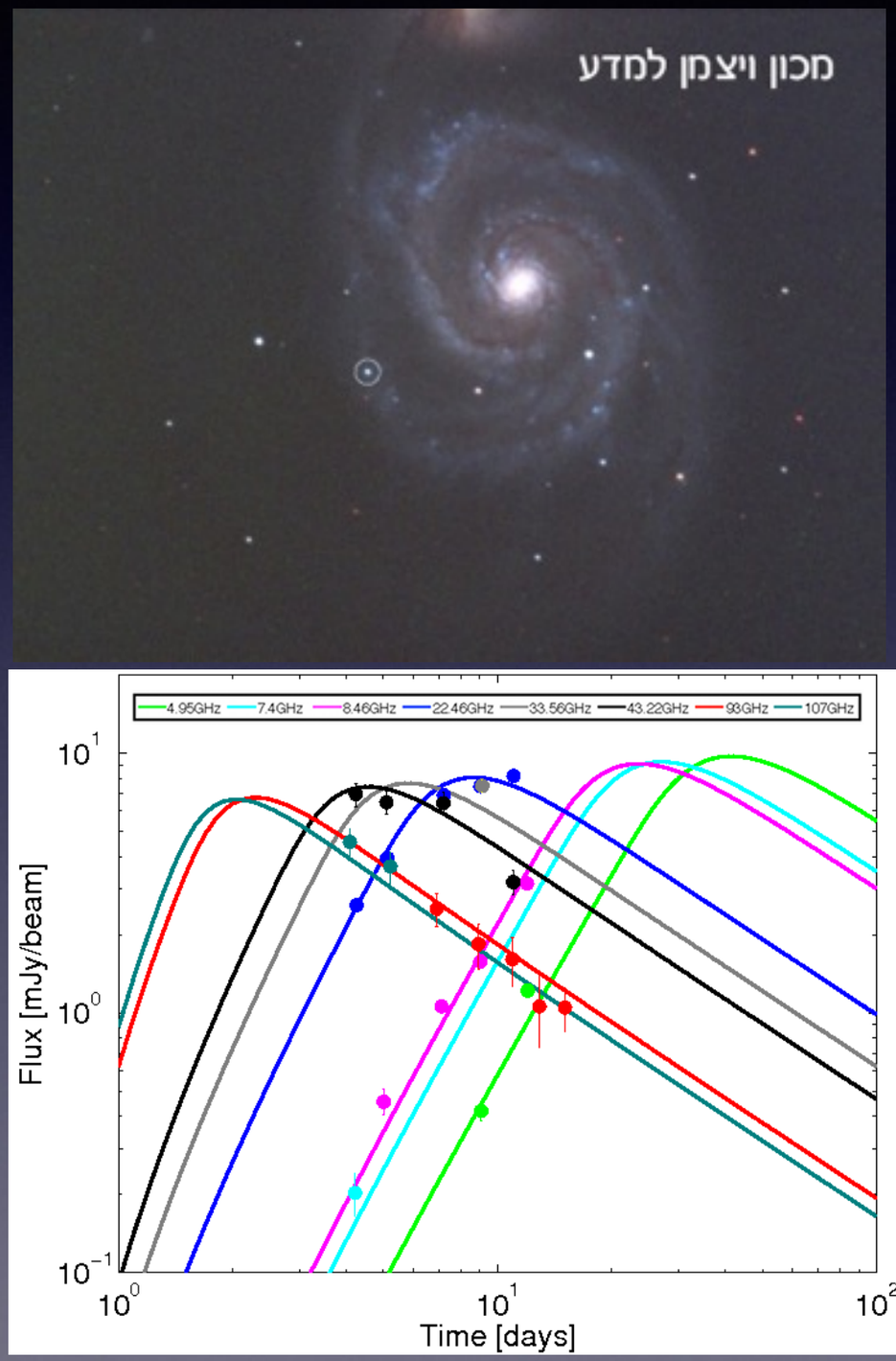
SN 2011dh:

- **Radio - synchrotron emission**
- **X-ray - Inverse Compton**

Combined optical / X-ray / radio analysis can test micro physics

In the case of SN 2011dh showed large deviation from equipartition

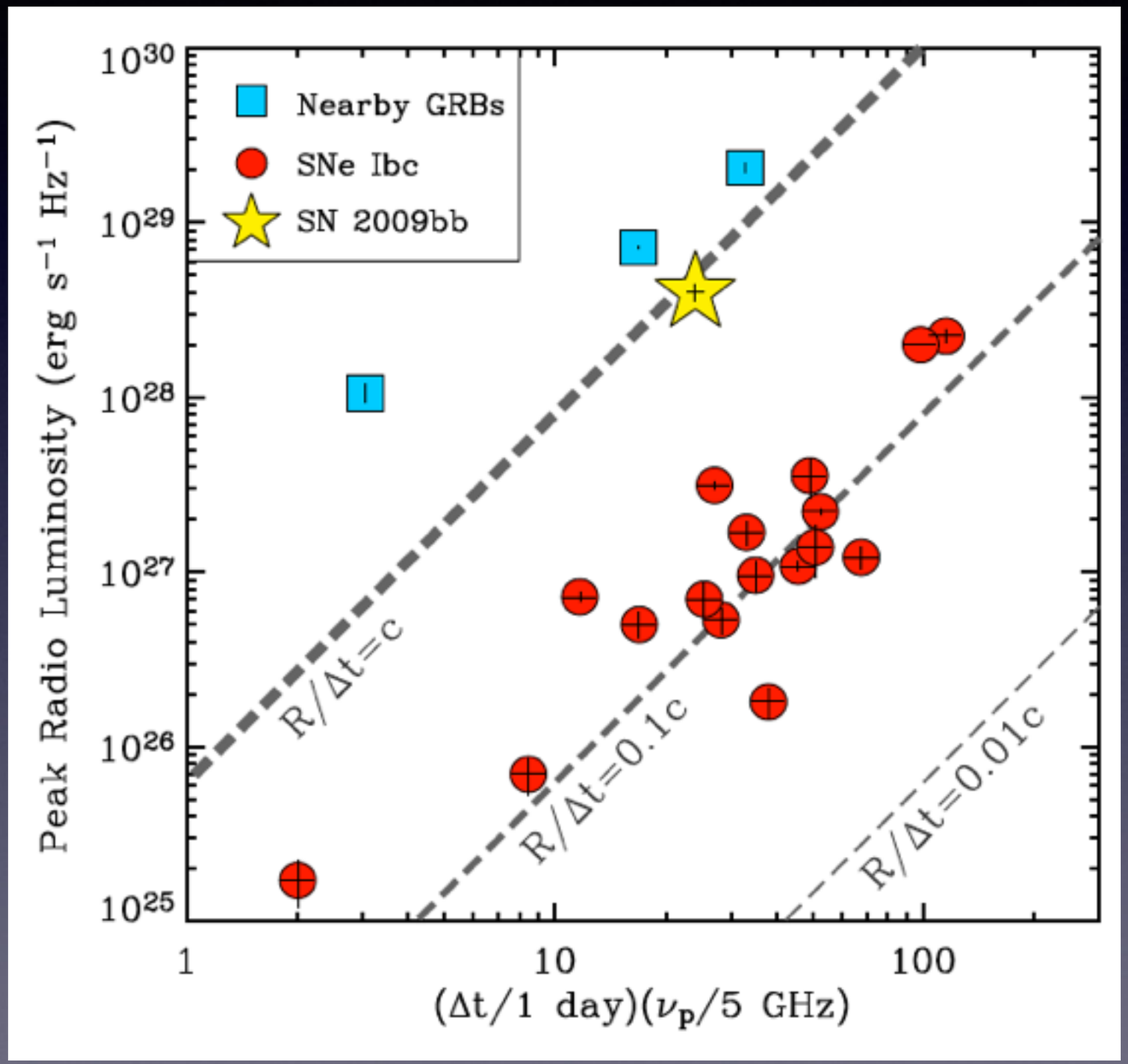
(Soderberg et al. 2012, Horesh et al. 2013)



Horesh et al. (2013)

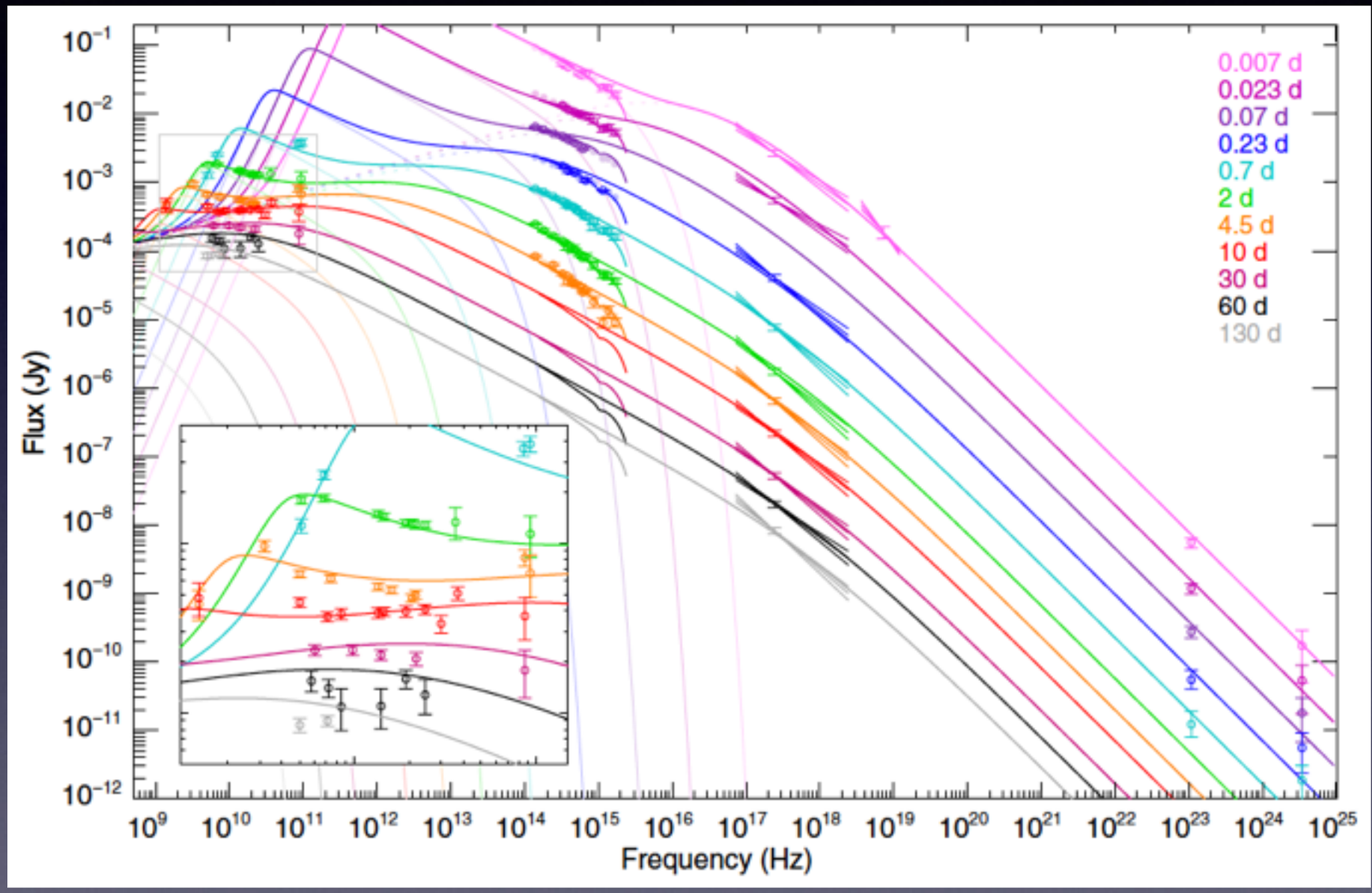
Additional examples and details in talk by Perez-Torres

Relativistic SNe



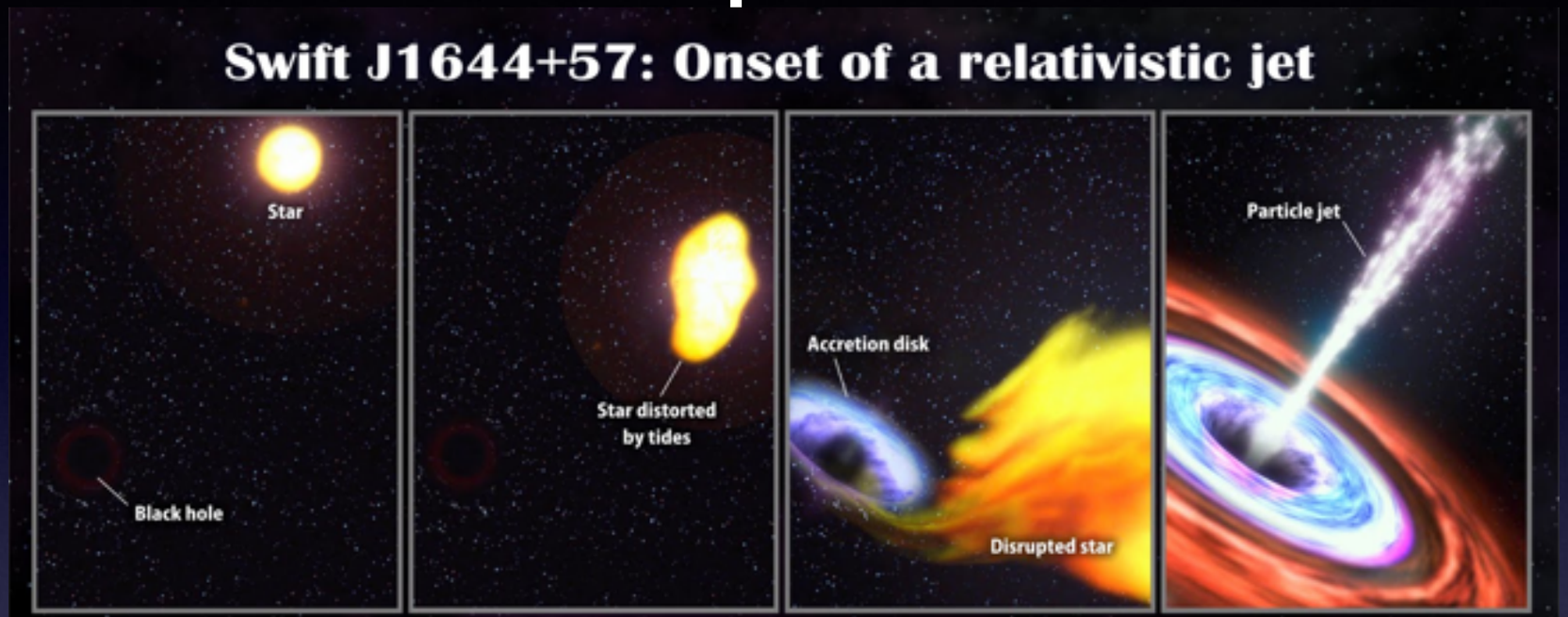
SN2009bb - Soderberg et al. 2010

Relativistic Events



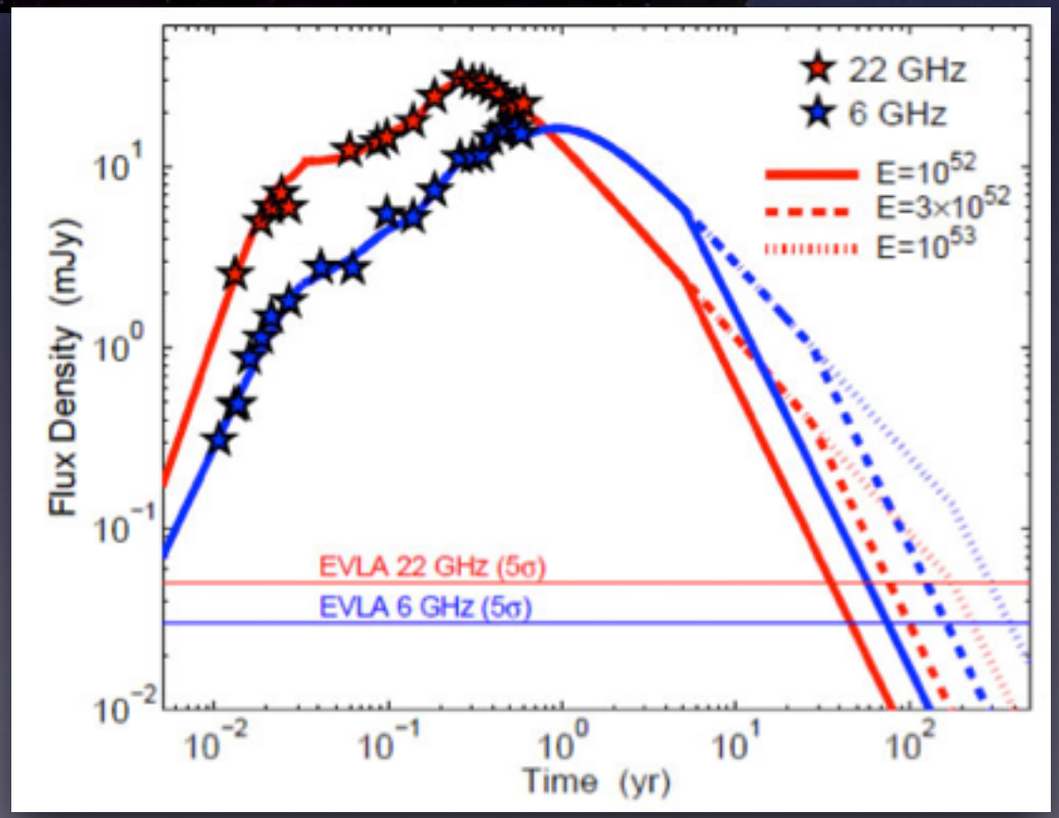
GRB130427A - Perley et al. 2014; Laskar et al. 2014

Tidal Disruption Events



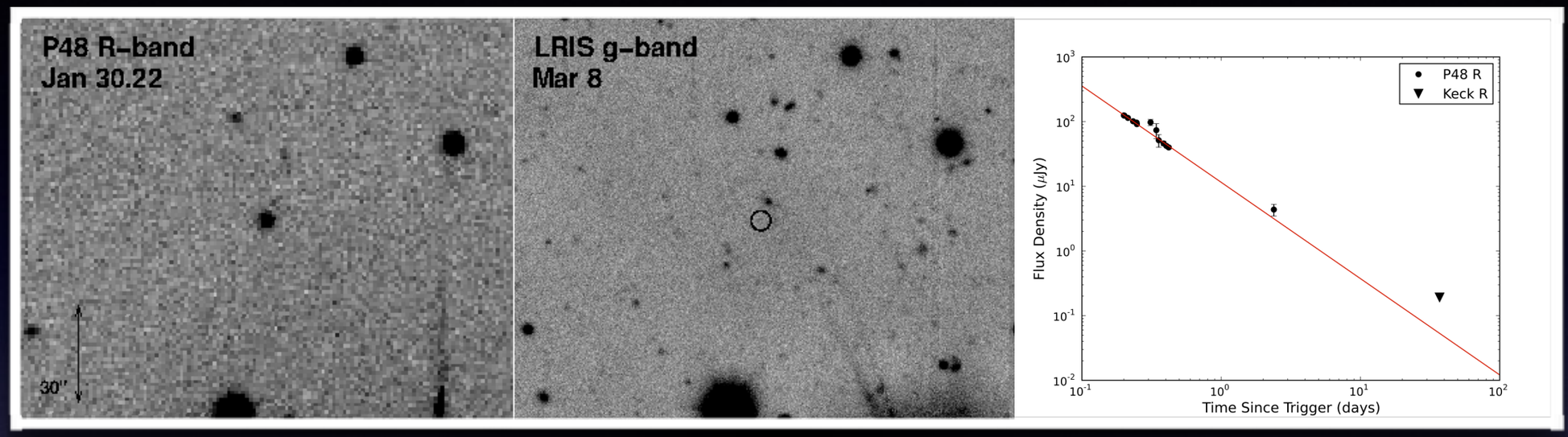
Do they all launch relativistic jets?

(see van-Velzen et al. 2013, Arcavi et al. 2014)



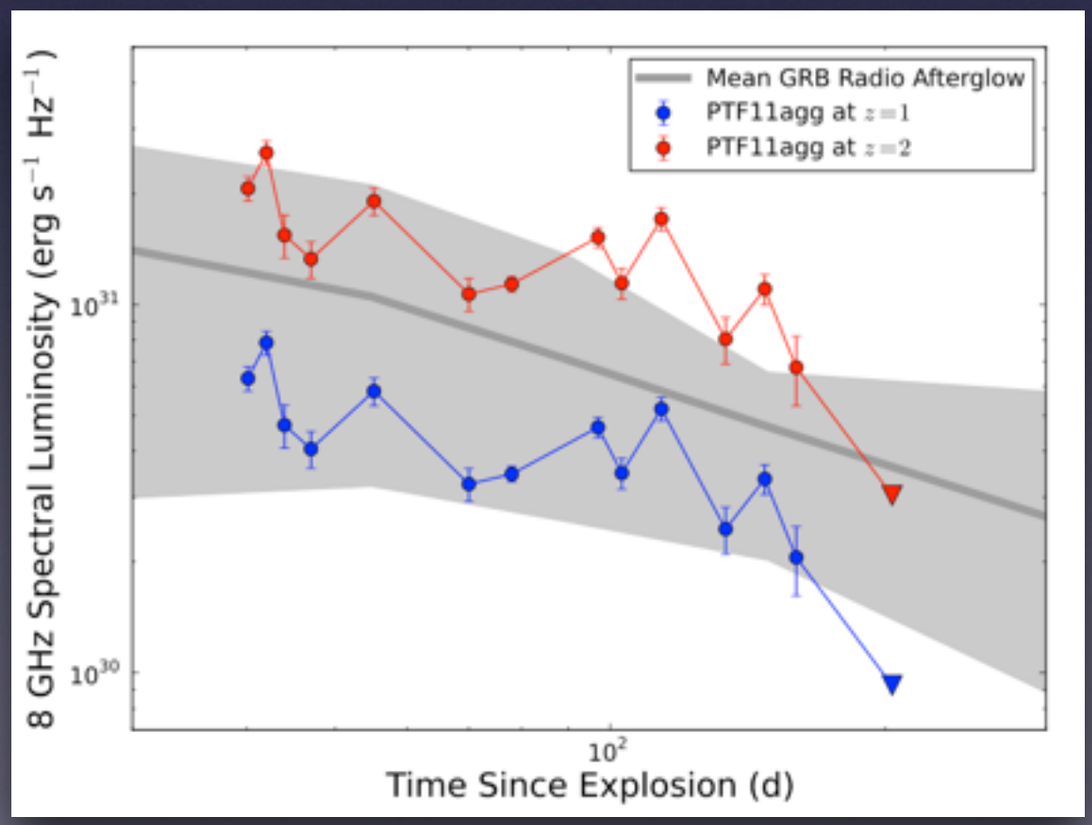
(Zauderer et al. 2011, Berger et al. 2012)

New Classes



PTF11agg (Cenko, Kulkarni, Horesh et al. 2013)

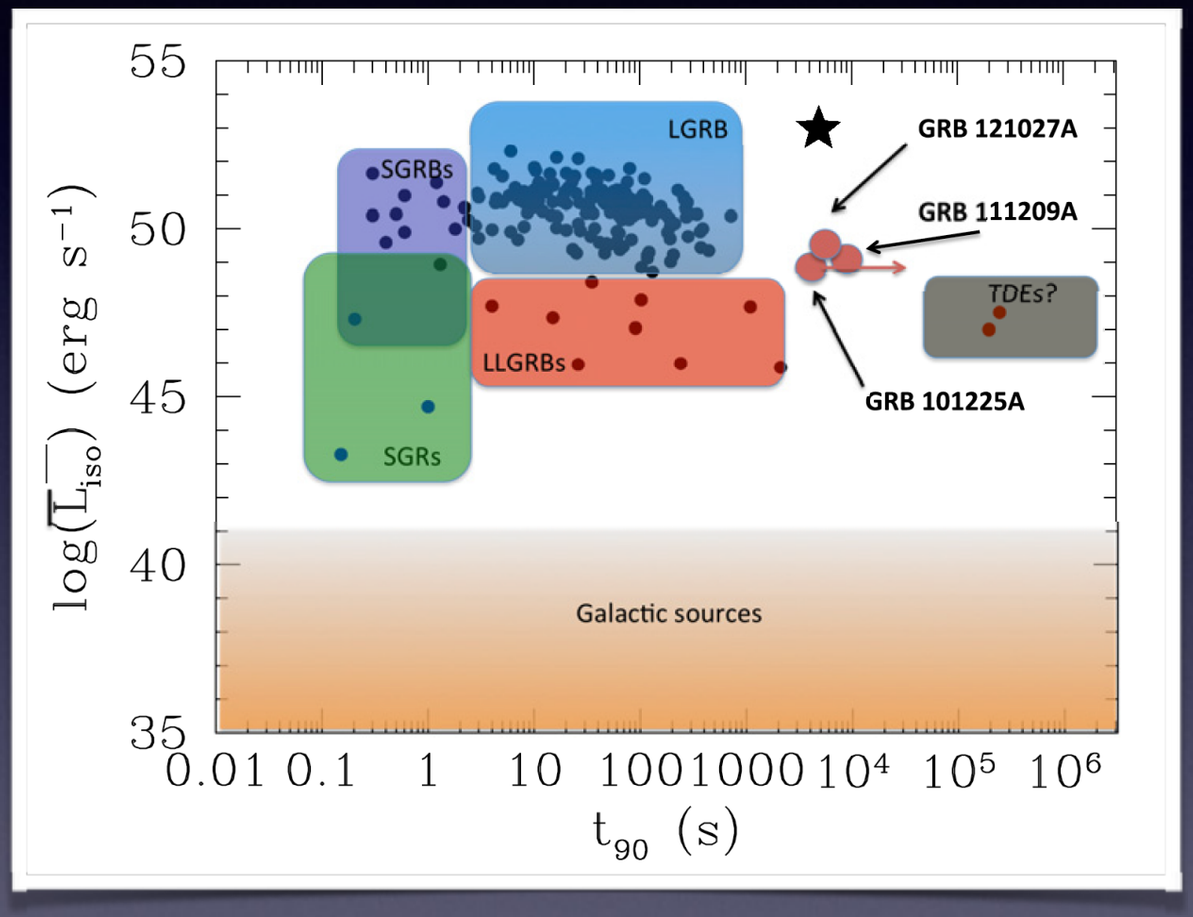
- Fast optical transient: Faded by 1.5 mag in 2 hours
- Long lived scintillating radio emission: angular size of 20 mas at 40 days.
- Mildly relativistic: Lorentz factor > 1.5
- No obvious detection of high-energy emission
- Low probability of missed on-axis GRB
- May be a new type of relativistic transient



New Classes

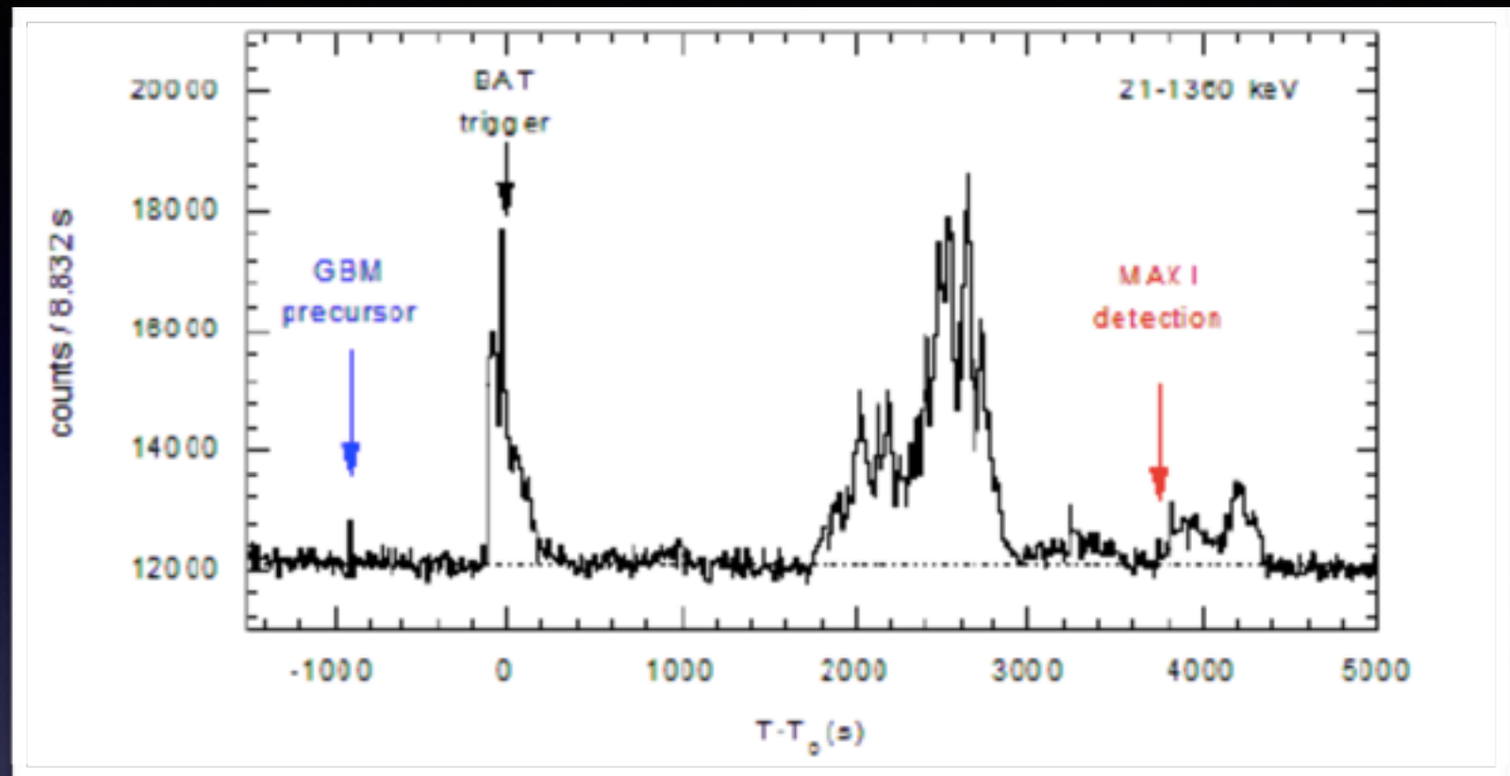
Ultra-long GRB:

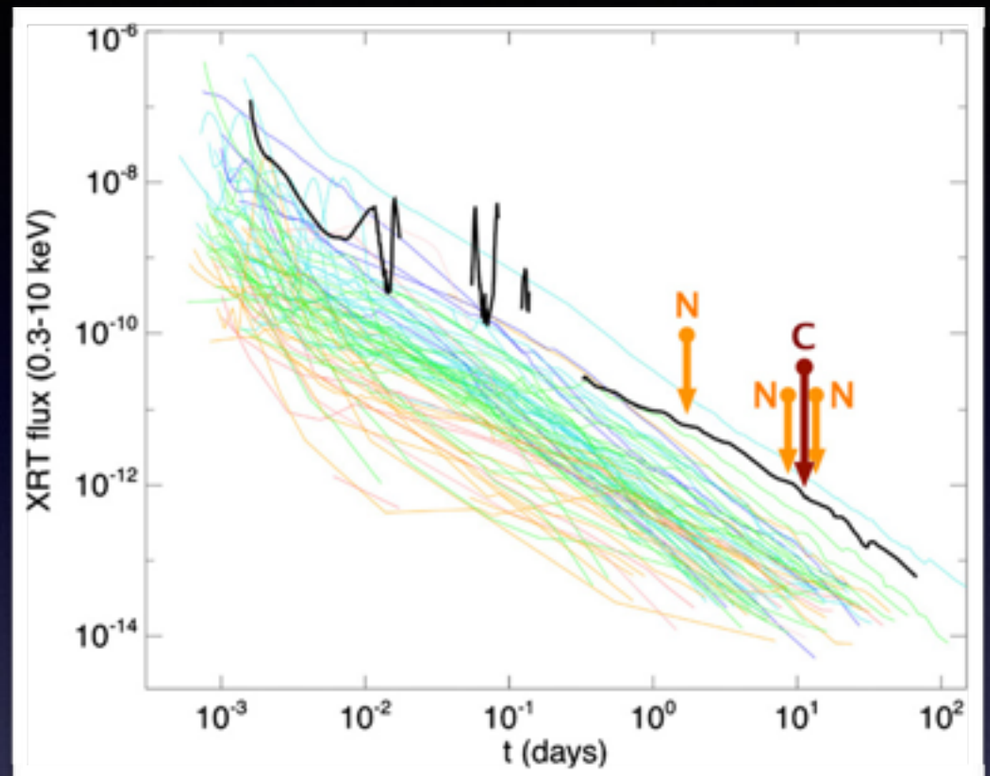
- Ultra-long gamma-ray emission (>1000 sec)
- X-ray flaring on a time-scale of 10,000 sec
- Suggested scenarios:
  1. TDEs
  2. collapse of extremely extended stars



Levan et al. 2013

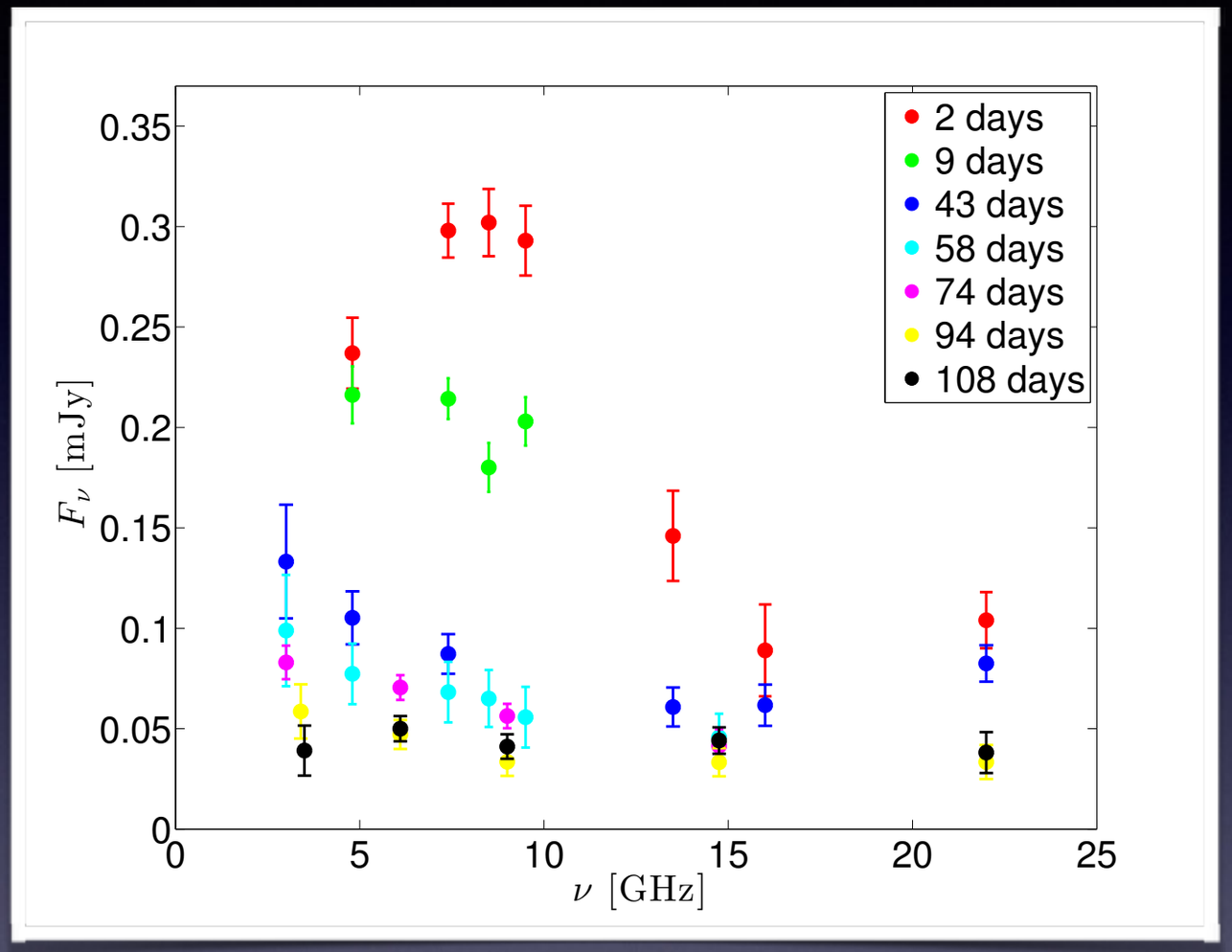
GRB130925A





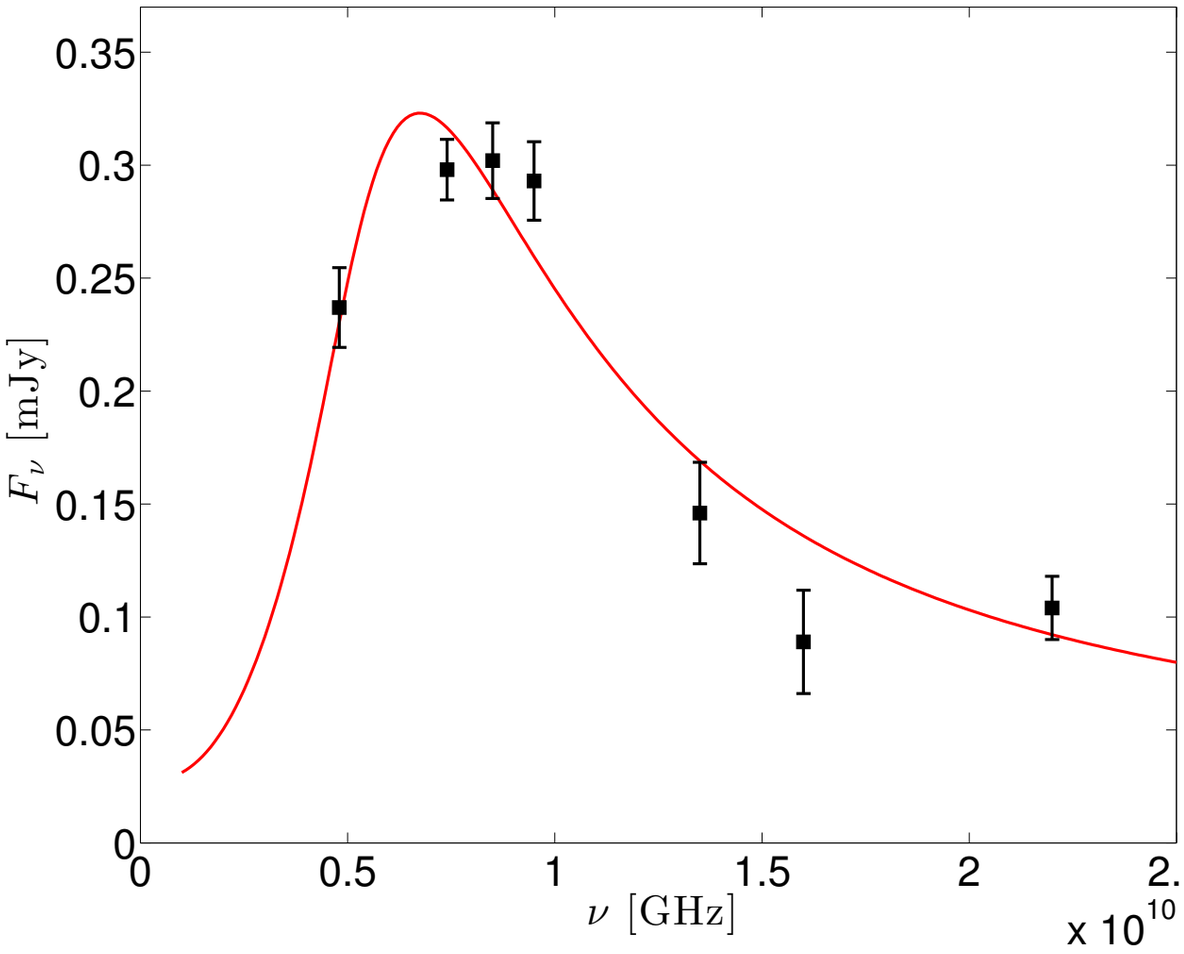
- High energy emission up to 4000 sec, E_iso ~ 10^53 erg
- X-ray flaring up to 10,000 sec
- One of the brightest in X-ray “afterglows”
- NuStar detects “absorption feature” at ~ 6 kev (Bellm et al. 2013)
- Relatively shallow decay of X-ray emission
- XMM observations suggest X-ray emission dominated by black-body emission at “fixed” small radius (Piro et al. 2013)
- Overall X-ray analysis suggests low-density CSM (Piro et al. 2013; Evans et al. 2013)

GRB130925A

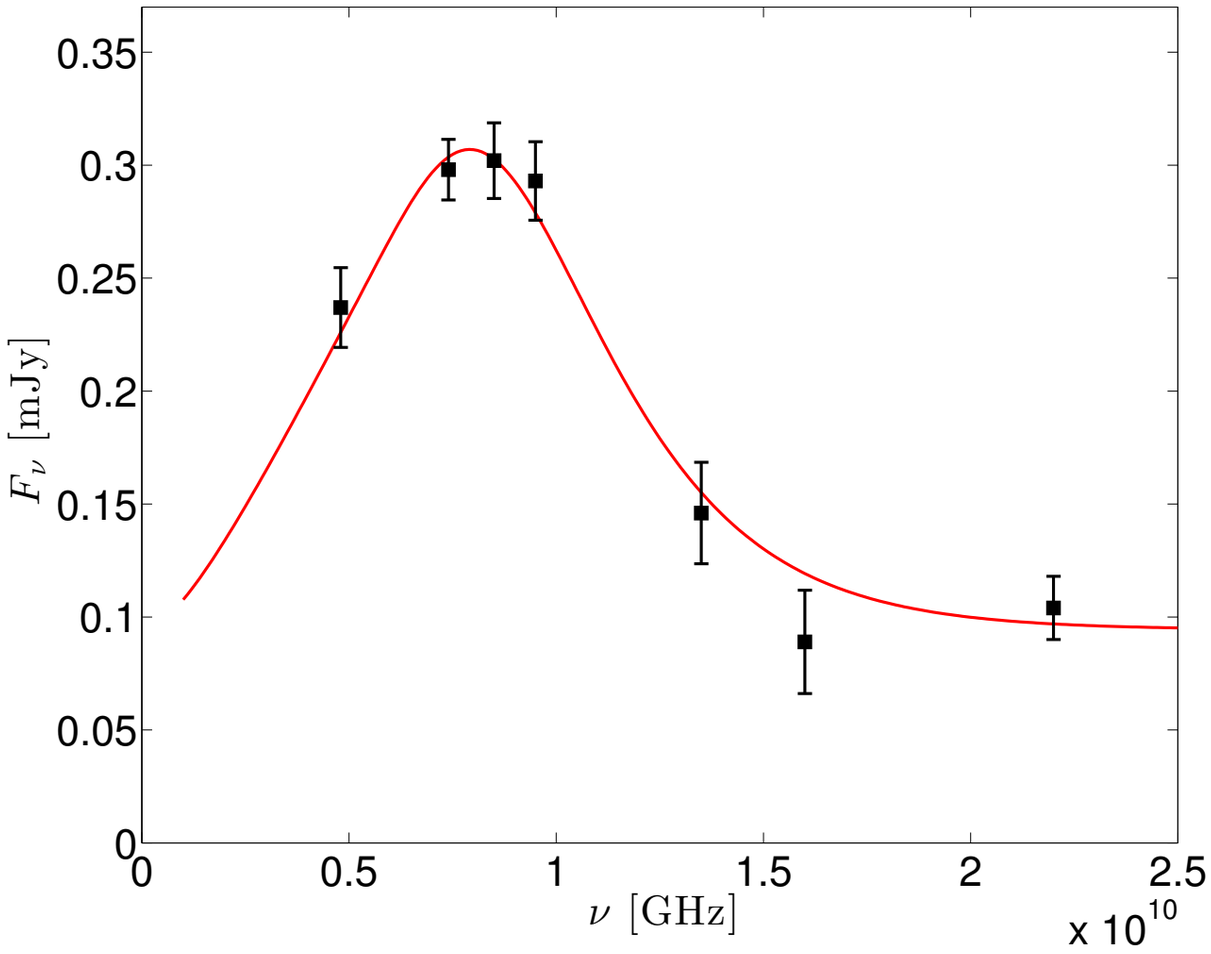


Horesh et al. (in prep)

GRB130925A



Power-law distribution



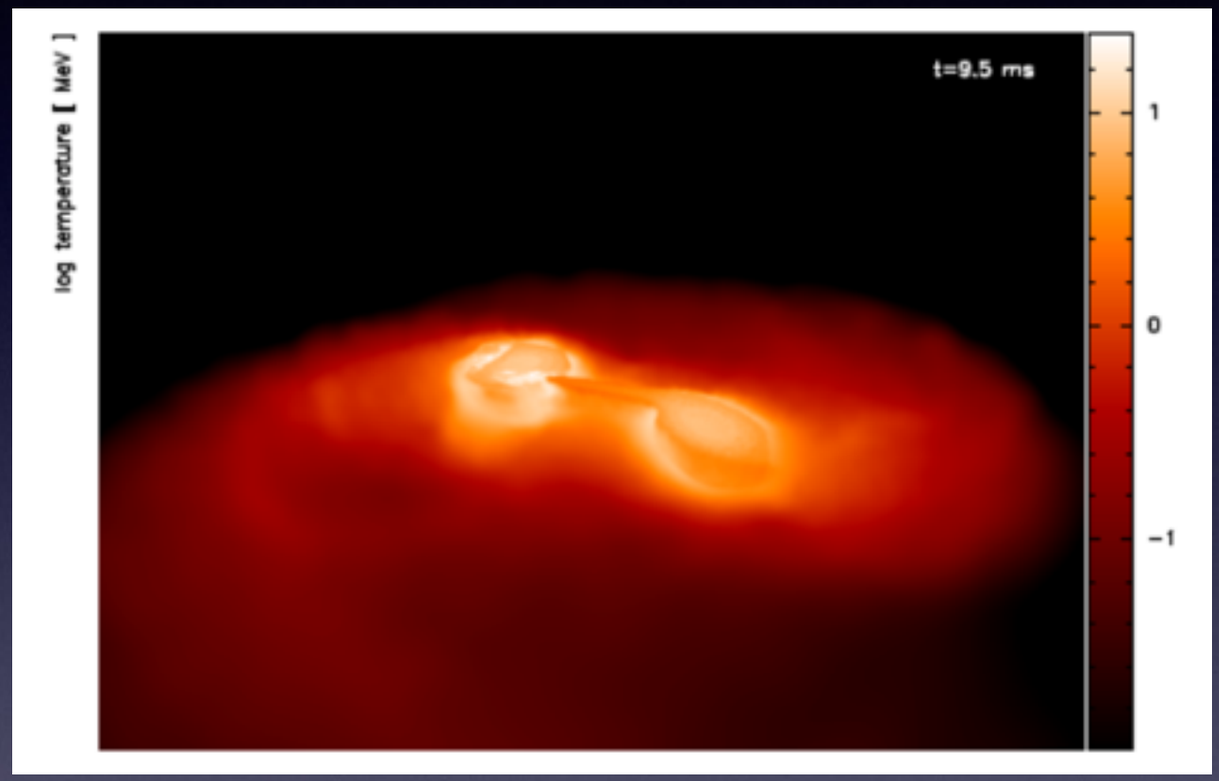
Monoenergetic

Radio emission suggests high CSM density

Radio emission suggests steep electron energy density

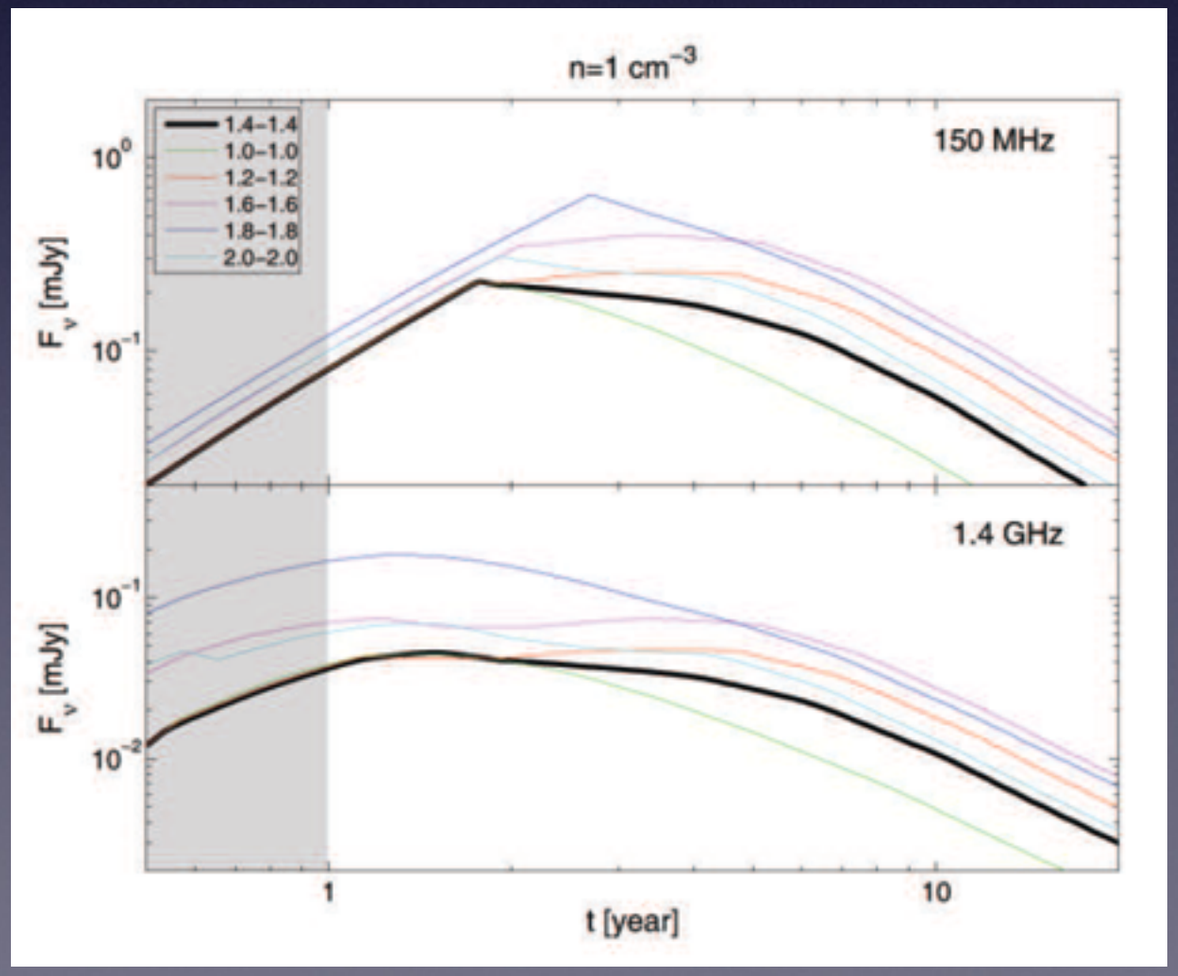
What is the electron acceleration mechanism?

GW source counterparts?



Rosswog, Piran, Nakar (2012)

Piran, Nakar, Rosswog (2012)



Lessons

- Early observations - More constraining in some cases. Also probe closest environment of progenitor. In some cases crucial to detect “fast” radio transients in time.
- Wide-band spectrum provide valuable information (e.g., shockwave properties, electron energy distribution, etc.)
- Panchromatic observations can test basic assumptions
- Radio observations play a key role in uncovering the nature of known transients and discovering new ones.

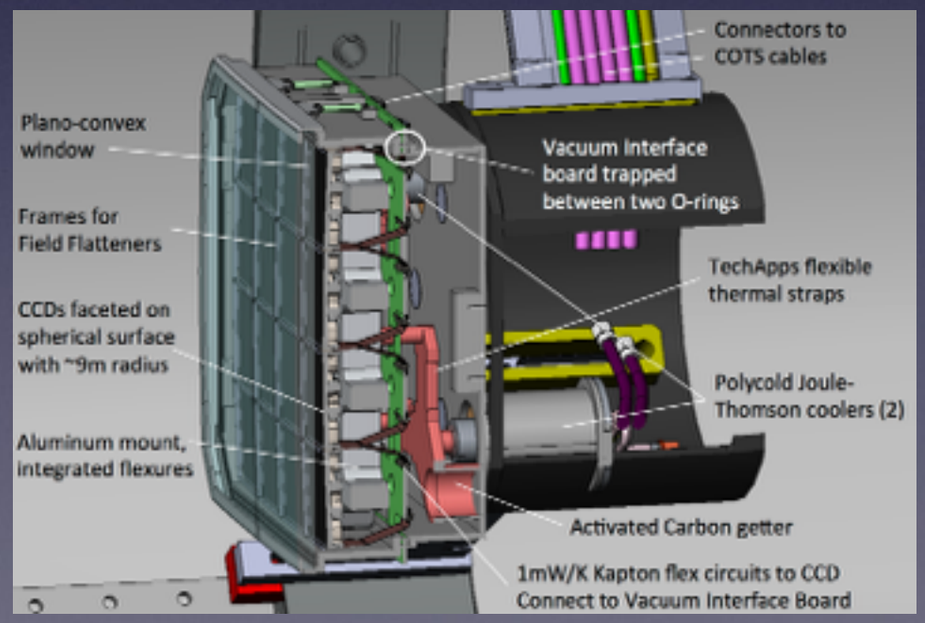
Future of Time-Domain Radio Astronomy

- Triggered radio observations - Following discovery in optical / X-ray / gamma-ray

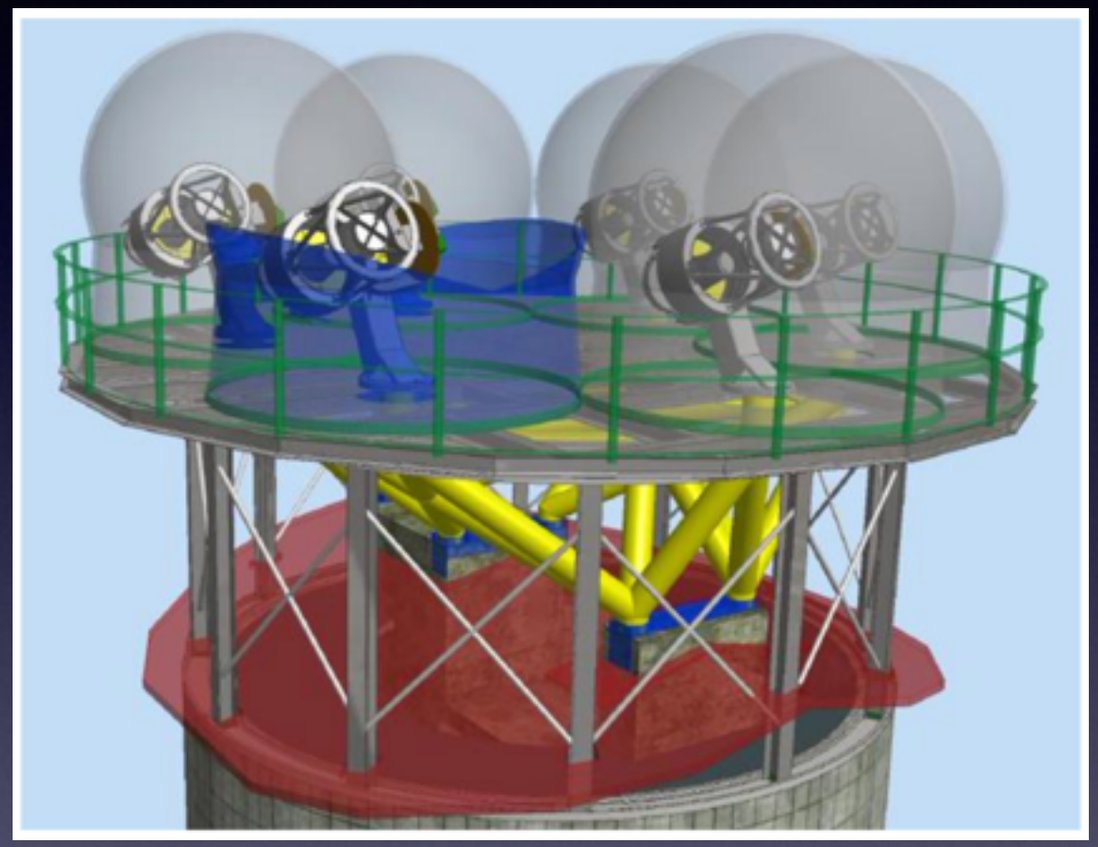
- Radio systematic survey (Stripe 82 as pilot) - followup or coordinated optical (or other wavelength) observations

- Simultaneous observation in radio and other wavelengths (e.g., Meerlicht) - Dedicated experiments

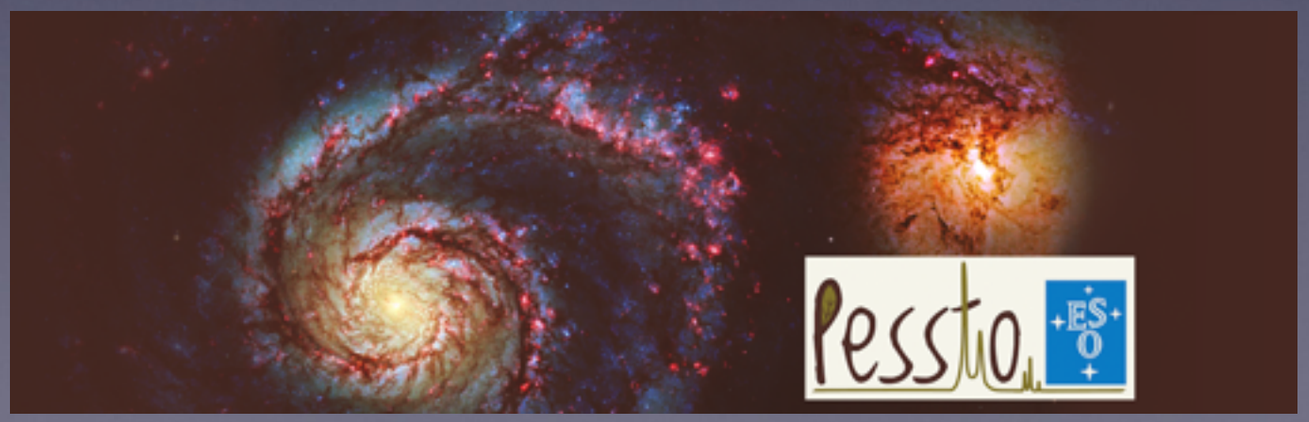
Future Synergy Between Optical and Radio



ZTF



BlackGEM



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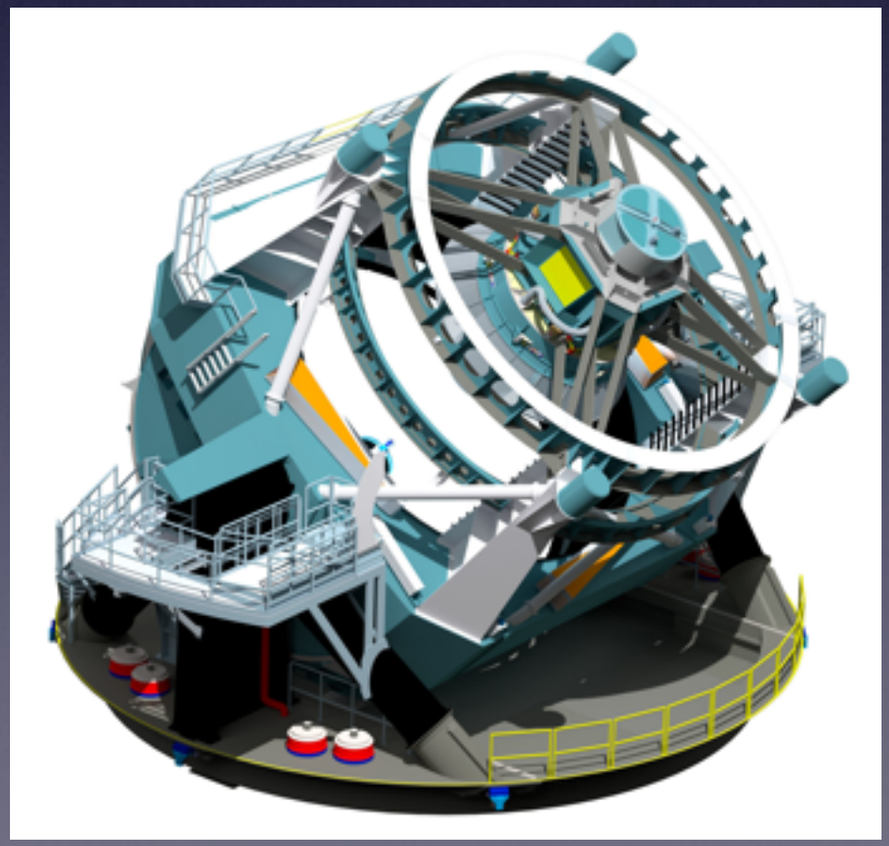

Rapid Response

AMI collaboration

(Rob Fender, Gemma Anderson, Tim Staley, Kunal Mooley)

Radio Sky Surveys

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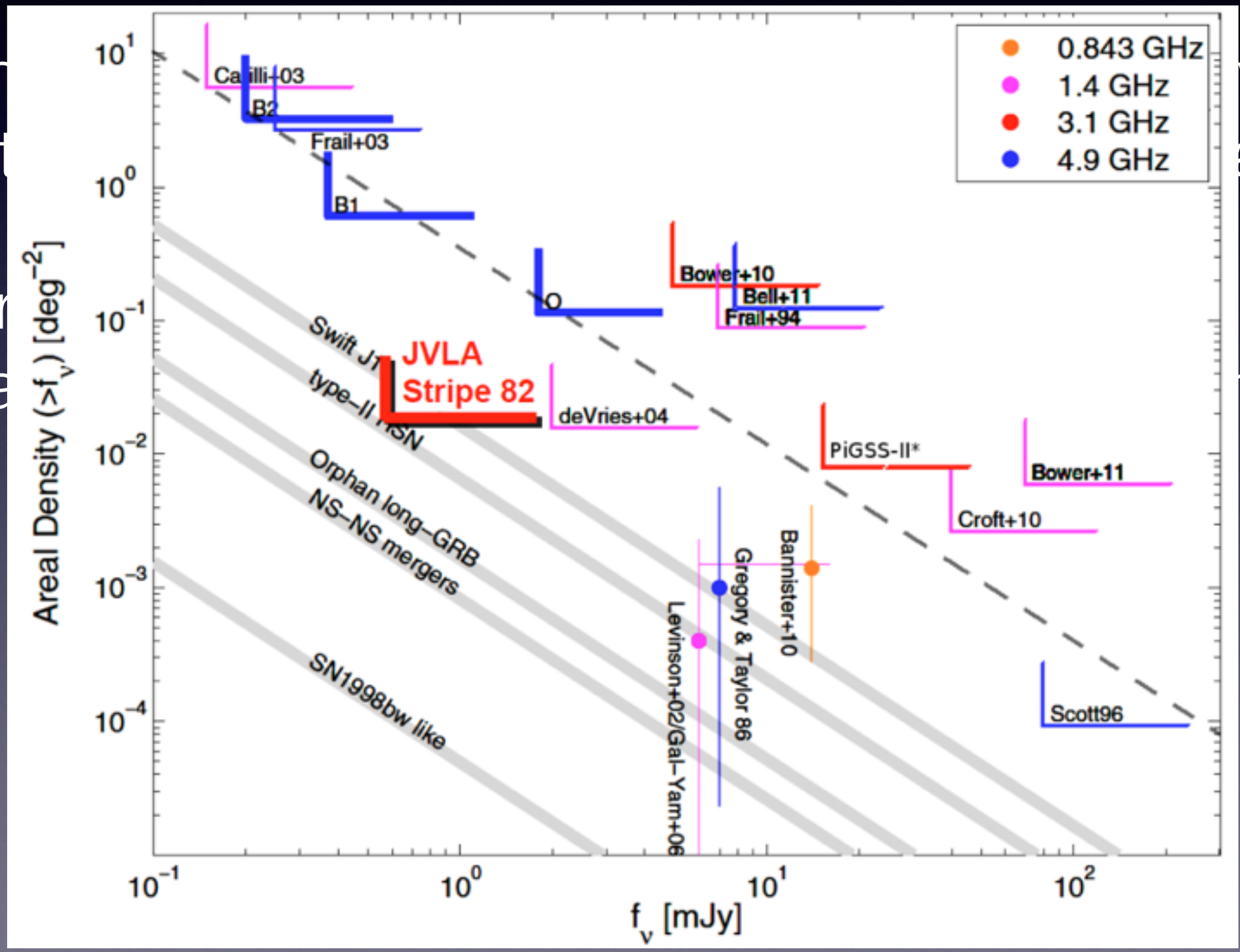
- Ur… …veys wit… …age
- Str… …n) Ha…



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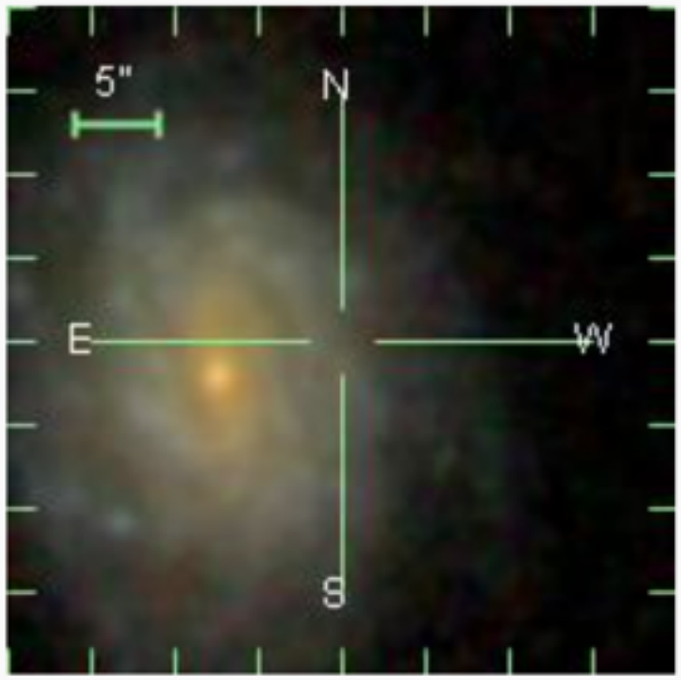

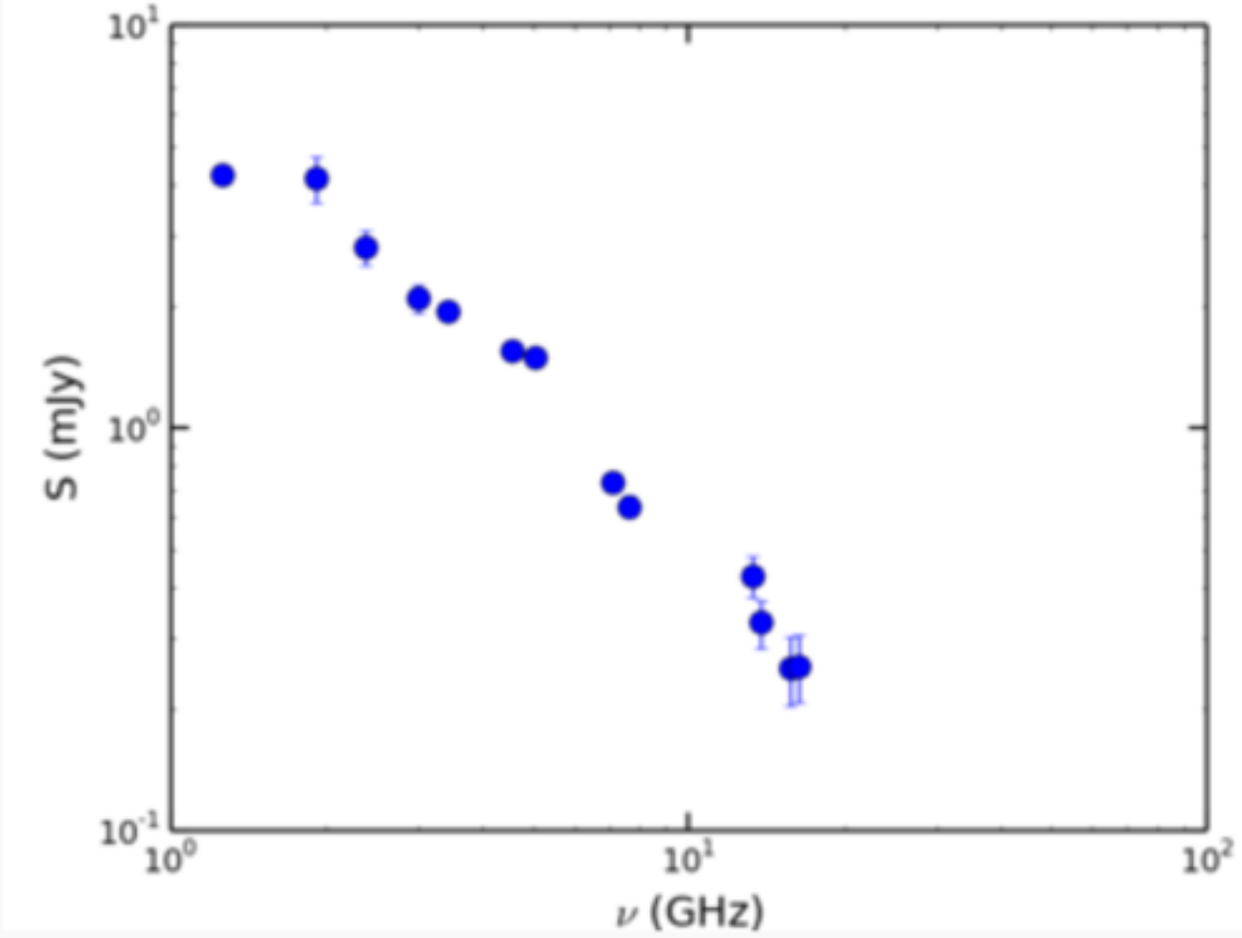

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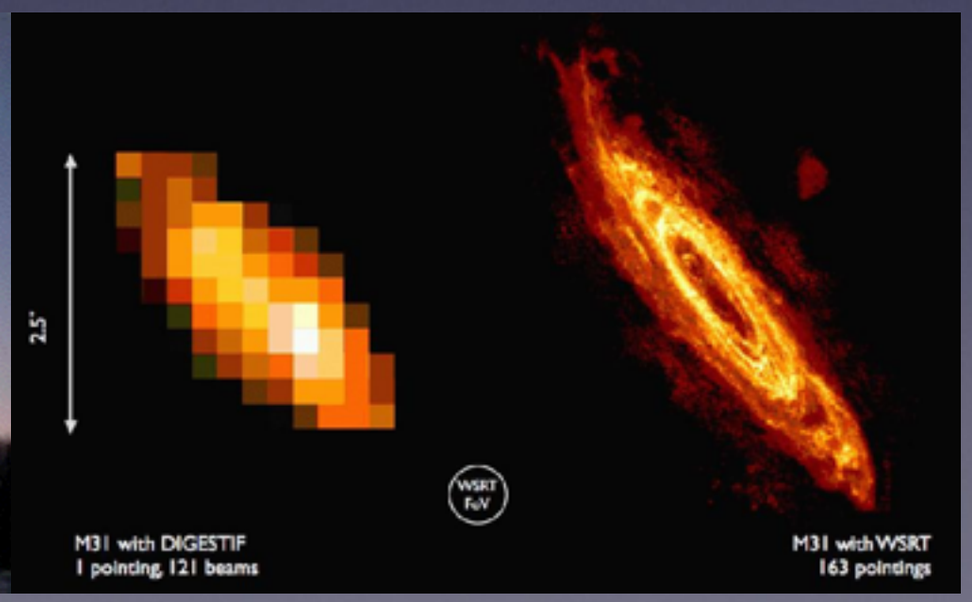
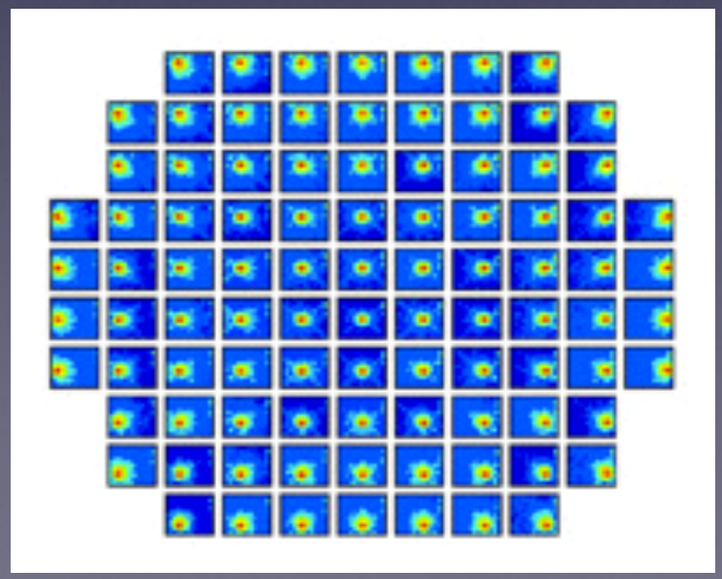
- All Sky Surveys with new radio facilities

WSRT

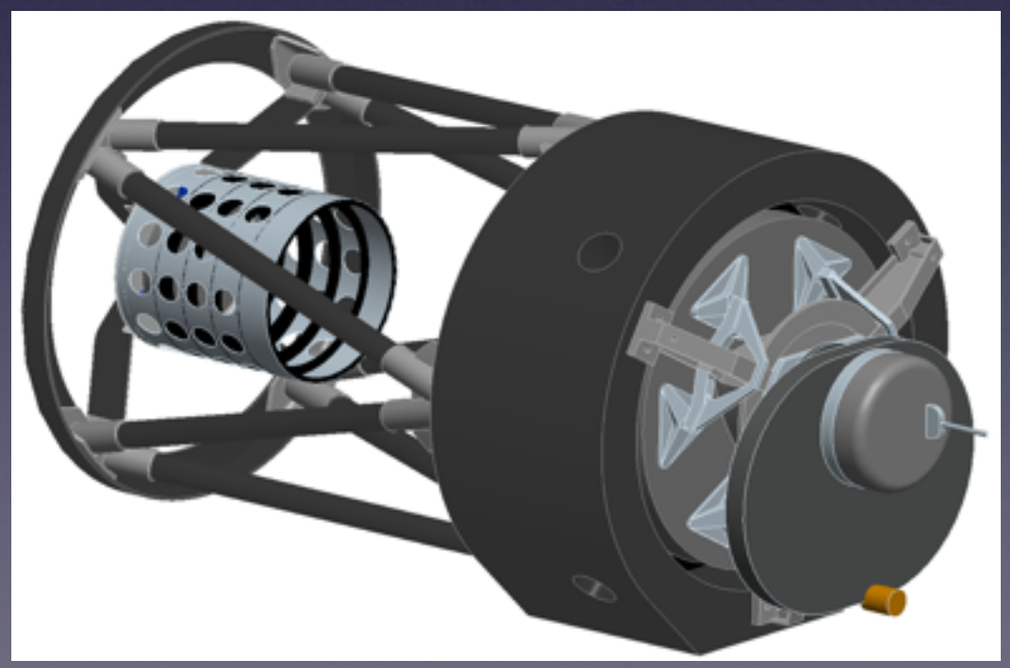

2.5°
M31 with DIGESTIF
1 pointing, 121 beams
M31 with WSRT
163 pointings

ASKAP



MeerKat

MeerLicht



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Motivation for simultaneous observations

- Fast events:

1. Optical prompt emission from GRBs? Followed by prompt or reverse shock radio emission?

2. Fast radio burst - short term emission in other wavelength? No counterpart discovered so far

- Beaming fractions and “dark” SNe - continues coverage of same area for a long period of time will reveal radio SN and GRBs with no optical counterpart

Summary

- Future synergy between optical and radio - ZTF , BlackGEM, LSST
- New radio facilities will be used for all-sky surveys, including time-domain surveys - VLASS
- New experiments such as Meerlicht