THE TRANSIENT UNIVERSE: TIME-DOMAIN ASTRONOMY

S. Bradley Cenko (GSFC) - January 39 2014

Thanks to Paul O’Brien and Julian Osborne

SETTING THE STAGE: I

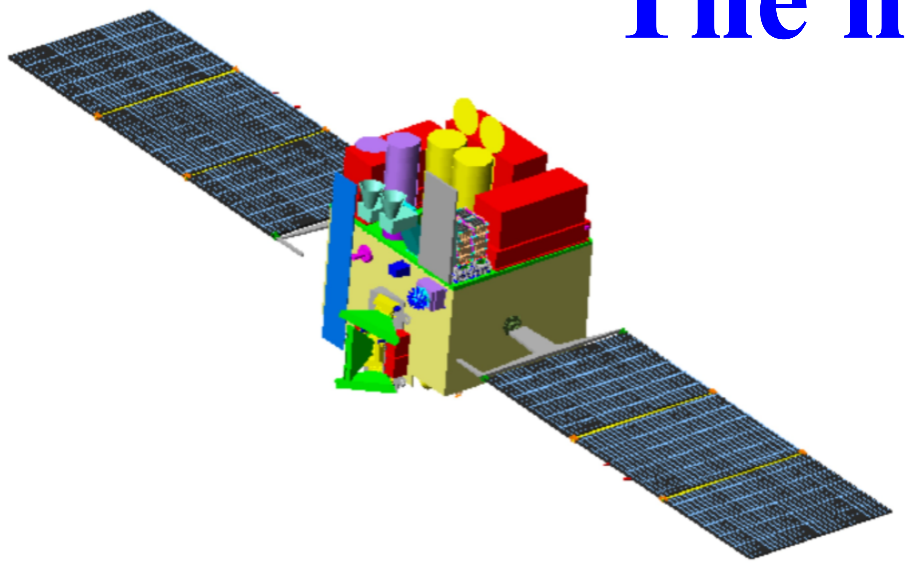
- Gamma-Ray Bursts:
  - Gamma-ray: $E_{iso} \sim 10^{53}$ erg, $\Delta t \sim 0.1$-100 s (ultra-longs?), $E_{pk} \sim 200$ keV
- Magnetars:
  - Gamma-ray: $E_{iso} \sim 10^{46}$ erg, $\Delta t \sim 0.1$ s, $E_{pk} \sim 200$ keV

Current high-energy space missions

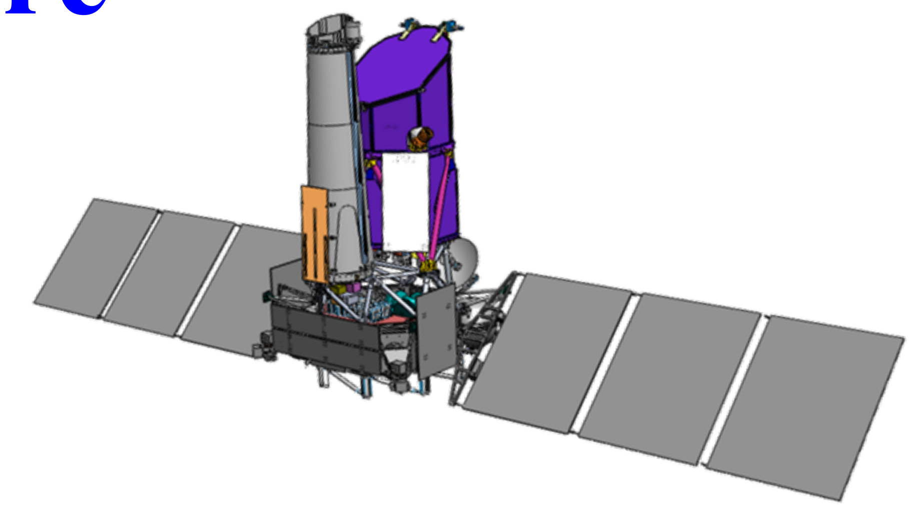
Mission	Launch	Bandpass	Advantages	Disadvantages
Chandra	1999	0.3-10 keV	High resolution imaging and spectroscopy, good timing	Modest area
XMM-Newton	1999	0.2-12 keV plus optical monitor	Good effective area + high resolution low-energy spectra	Fair angular resolution
Integral	2002	3 keV–10 MeV plus optical monitor	Broad bandpass, good high energy spectral resolution	Modest area and angular resolution
Swift	2004	0.3-150 keV plus UV/optical monitor	Broad bandpass, rapid accurate localisation (arcsec)	Low area and spectral resolution
Suzaku	2005	0.2-600 keV	Good timing, broad bandpass [XRS calorimeter failed in orbit]	Modest area and angular resolution
Agile	2007	18 keV-50 GeV	All-sky survey, good timing	Low area, modest angular resolution
Fermi	2008	10 keV-300 GeV	Broad bandpass, all-sky survey, good timing and high-energy angular resolution	Modest sensitivity and spectral resolution
MAXI-ISS	2009	0.5-20 keV	"All-sky "survey per orbit	Low effective area
NuSTAR	2012	3-79 keV	Hard X-ray imaging	Modest angular resolution

(missions that can provide triggers in red + IPN)

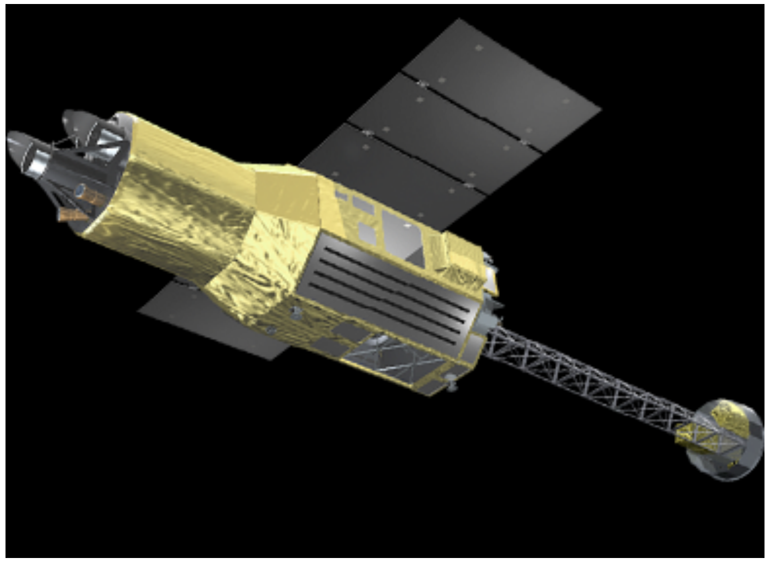
The near future



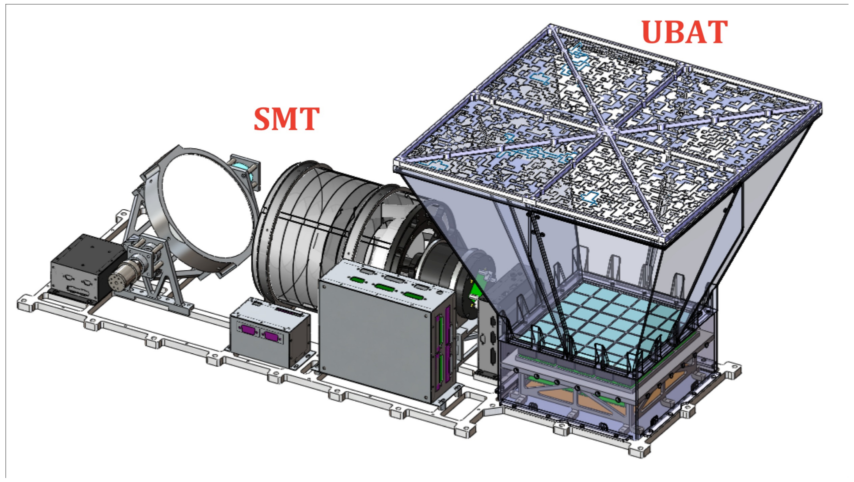
Astrosat, India, Canada, Leicester, launch 2014, 0.3-150 keV and UV



SRG, Russia, Germany, launch 2014, 0.5-10 keV (eRosita) + 3-120 keV (ART) in L2 orbit – all-sky survey

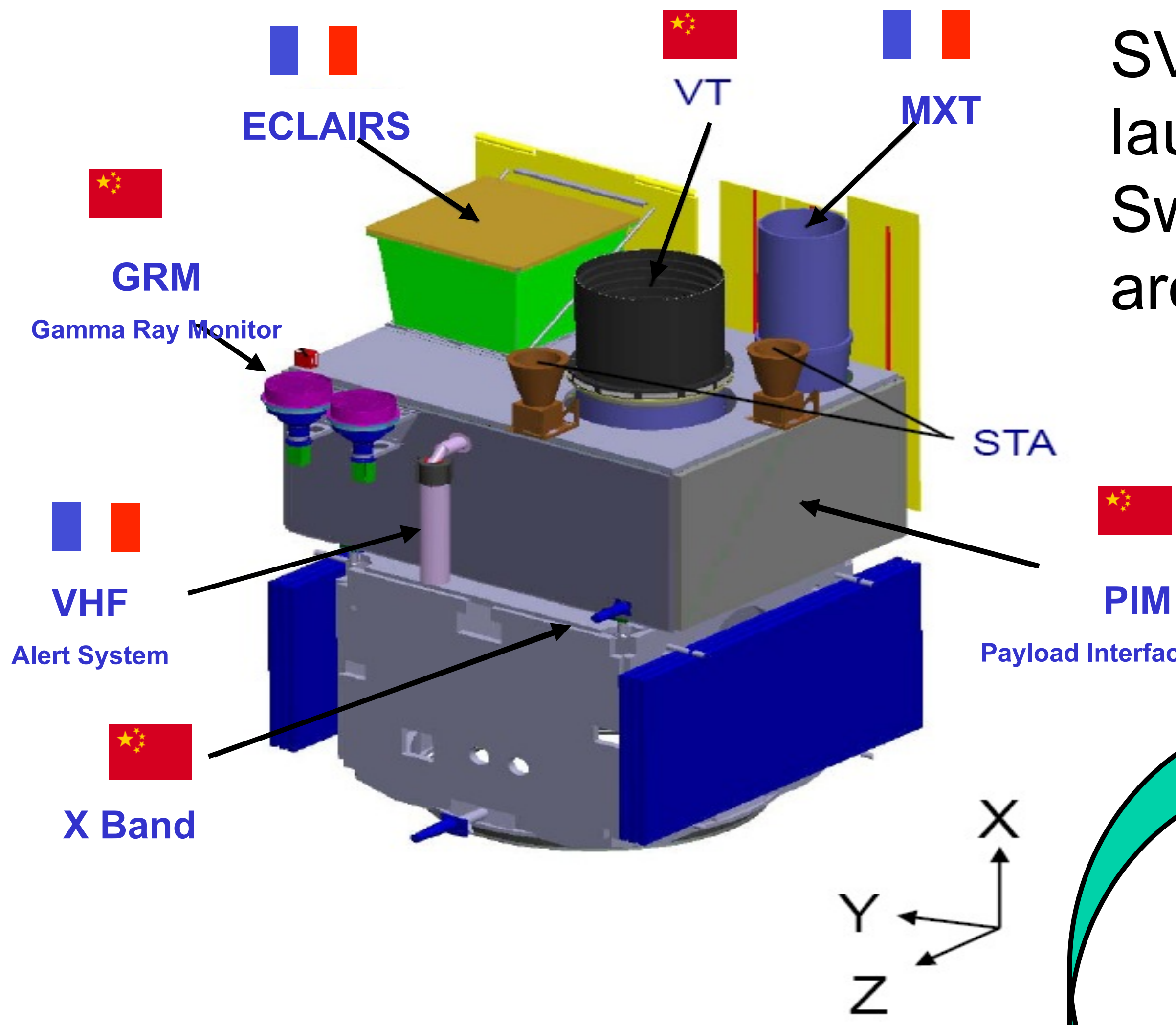


Astro-H, JAXA launch 2014, 0.5-600 keV with soft X-ray calorimeter (7eV)

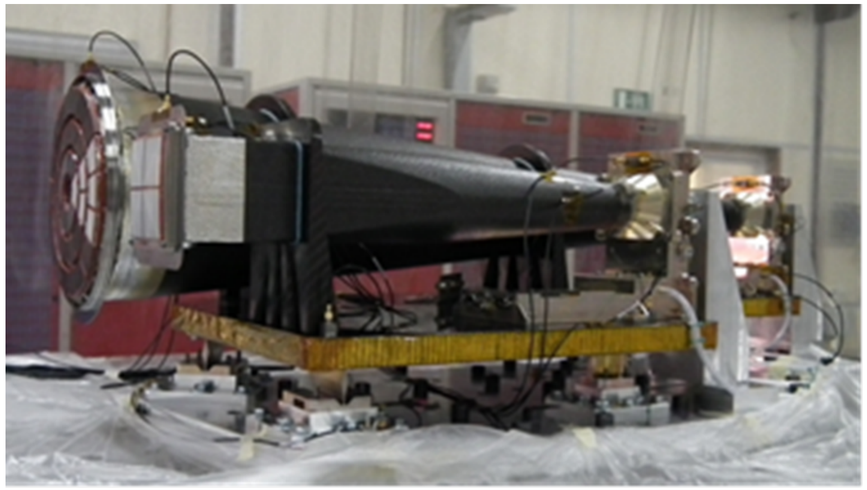


UFFO Pathfinder, launch 2014, 10cm optical (200-600nm) and UBAT GRB finder (5-200keV) ~40 GRBs/yr.

SVOM



SVOM, China, France (+Leicester!), launch 2017-18, rapid repointing – Swift-like GRB search with rapid sub-arcmin localisation



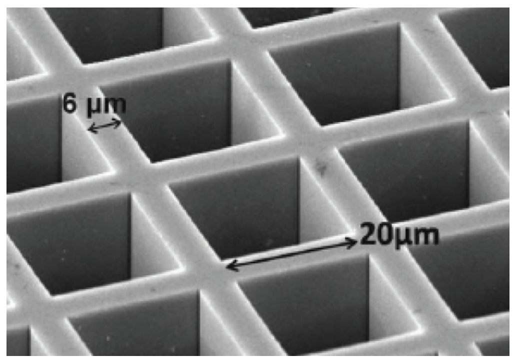
ESA BepiColumbo MIXS-T/S telescopes

Copy of MIXS-T will be on SVOM

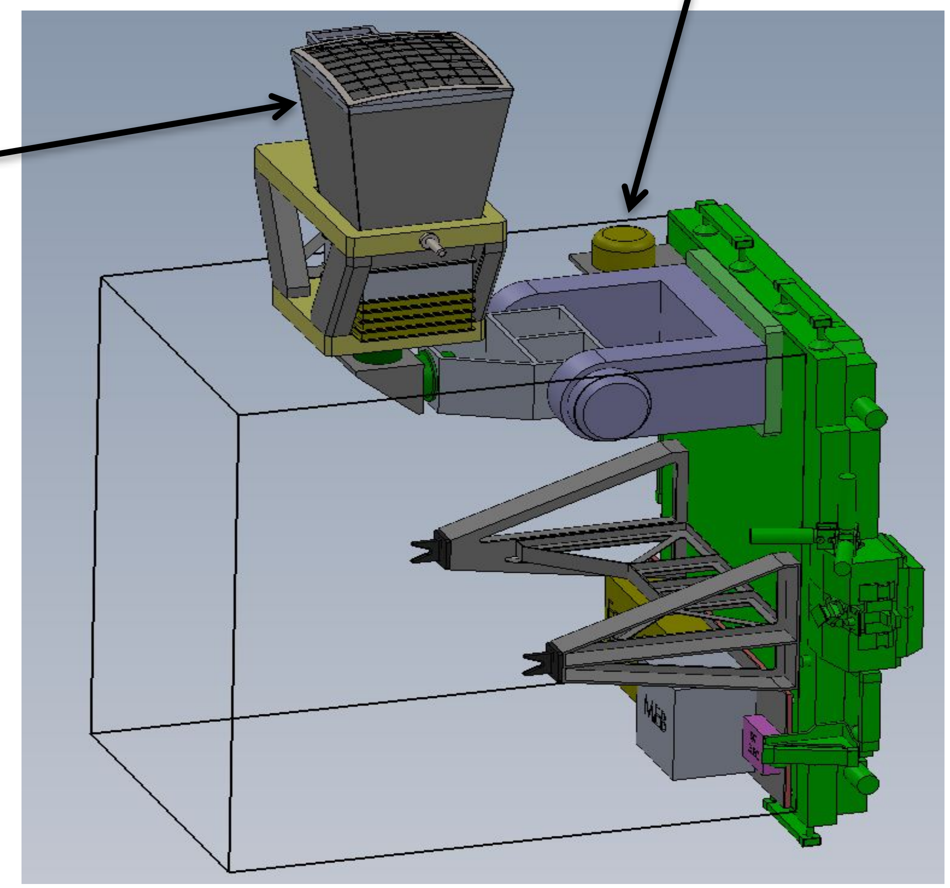
Lobster style – see later…

ISS-Lobster

microchannel plate



γ-ray detector



30° x 30° FOV (0.3 sr)
0.3 – 6 keV
sensitivity is 10X better than BAT

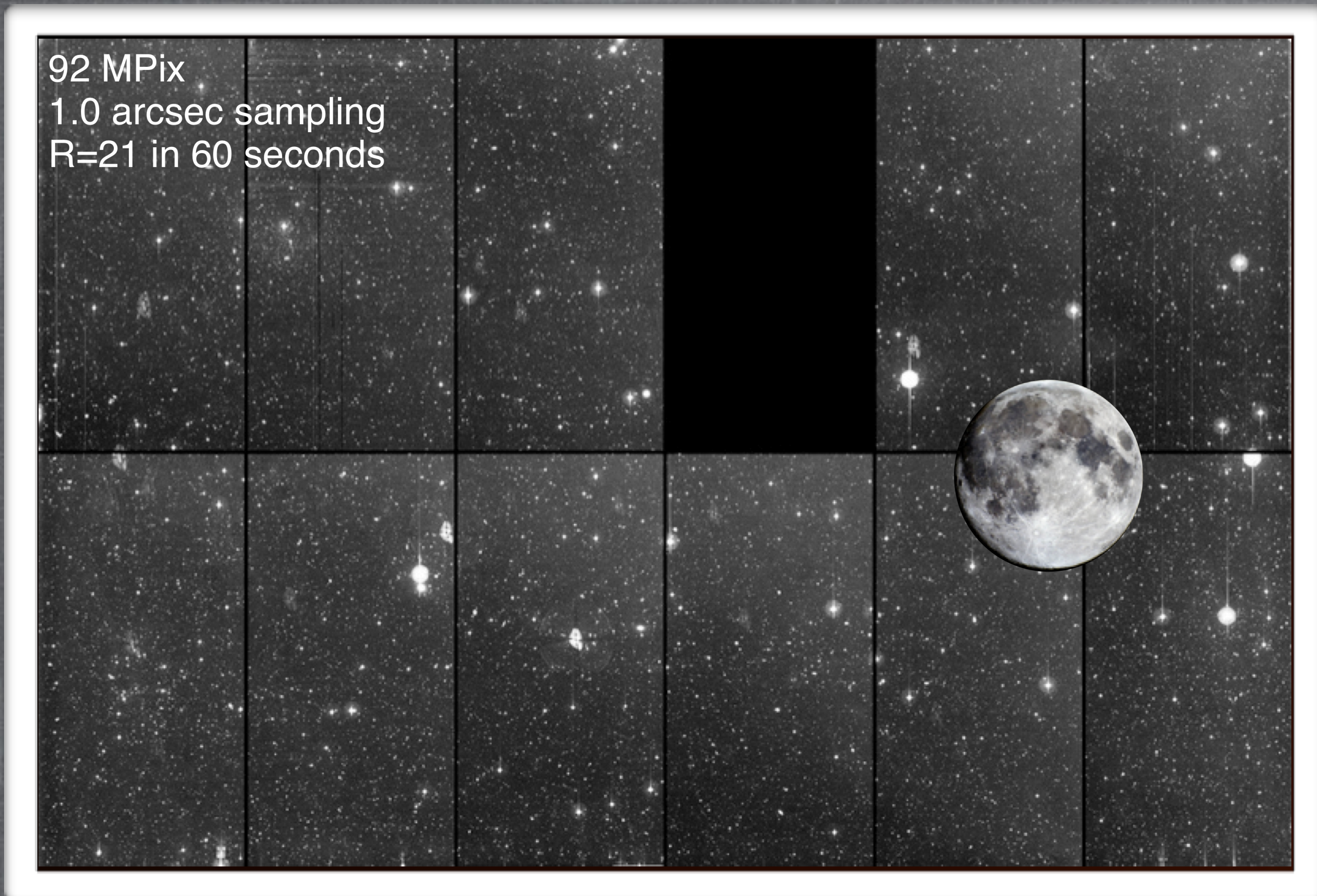
ISS - ELC attach point

SETTING THE STAGE: II

- Gamma-Ray Bursts:
  - Gamma-ray: E_{iso} ~ 10^{53} erg, Δt ~ 0.1-100 s (ultra-longs?), E_{pk} ~ 200 keV
  - Optical: $M_R > -34$ mag (limited by neutral H), Δt ~ hours
- Magnetars:
  - Gamma-ray: E_{iso} ~ 10^{46} erg, Δt ~ 0.1 s, E_{pk} ~ 200 keV
  - Optical: Faint (limited to MW, hence Galactic plane)

NEW WIDE-FIELD CAPABILITIES

The Palomar Transient Factory (PTF), et al.



Over 1900 spectroscopically confirmed supernovae to date

- Palomar 48 inch Schmidt telescope + CFHT12k ⇒ 7.2 deg^2 field-of-view
- Supernova search (2-3 day cadence) + more regular monitoring of nearby galaxies
- Automated discovery + multi-color photometry (P60)
- Large spectroscopic follow-up programs (Keck, Gemini, P200, Lick, etc.)

PALOMAR TRANSIENT FACTORY

Wide-Field Discovery + Automated Multi-Color Follow-Up

Summit of Palomar Mountain

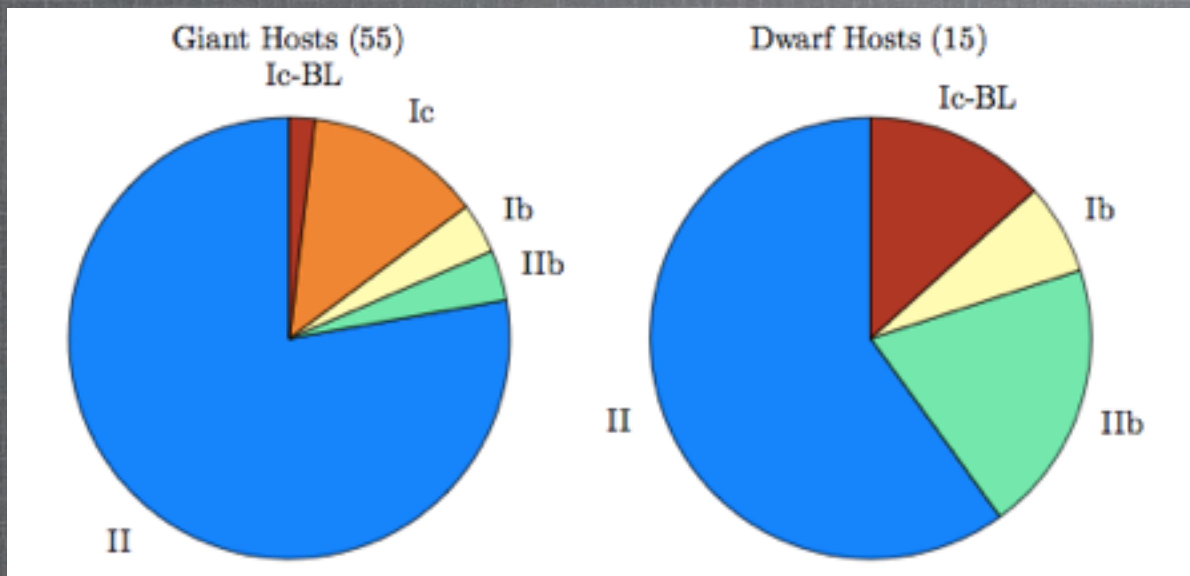
P48 = Discovery

P200+Keck+Lick+Gemini = Spectroscopy

P60+PAIRITEL = Filtered Photometry

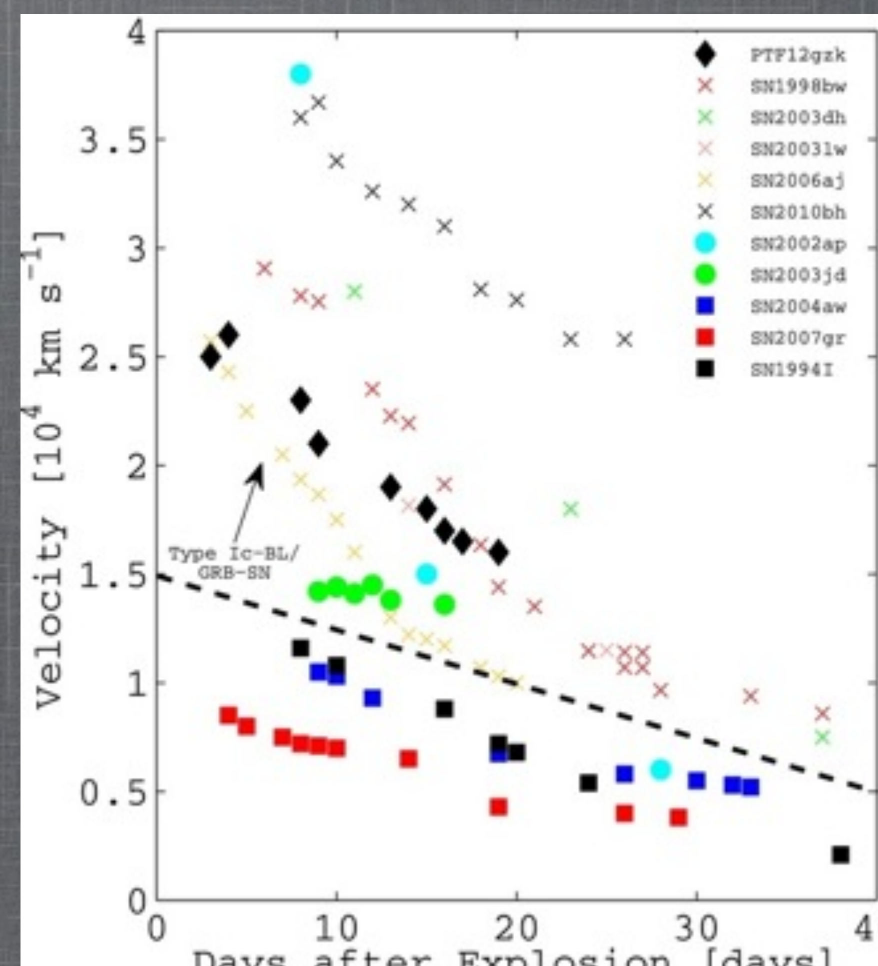
Factory = Fully automated, end-to-end discovery + follow-up

SN Ic-BL FROM PTF

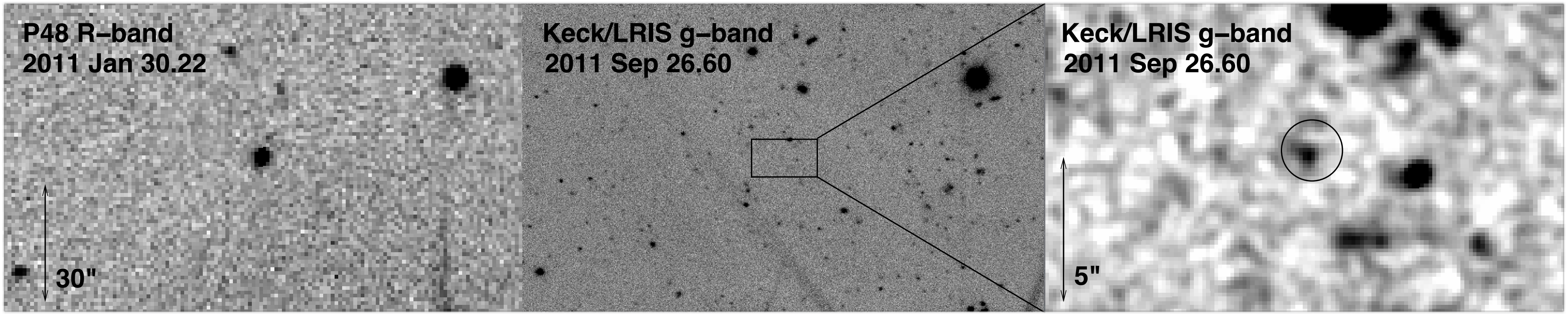


SN Ic-BL favor sub-luminous hosts (Arcavi et al., 2011)

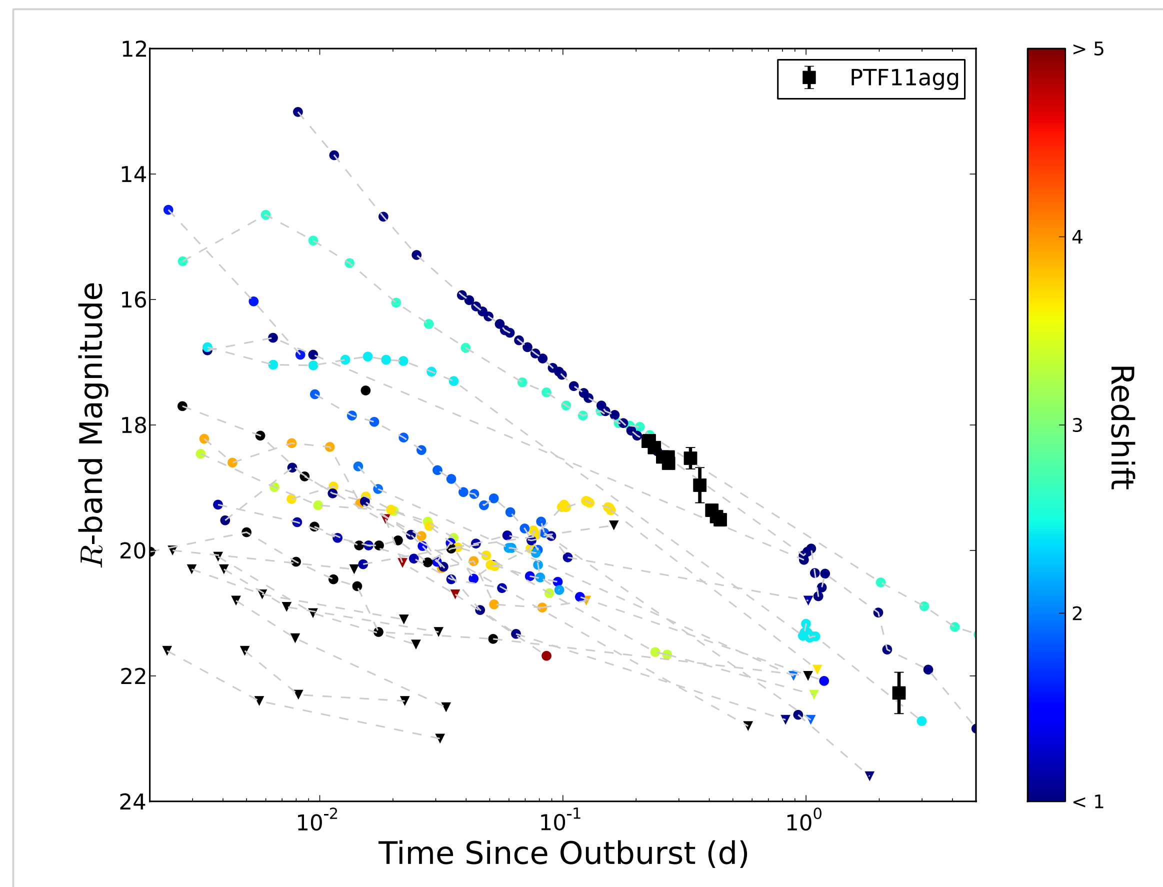
PTF12gzk: A high-velocity (~ 25,000 km s^{-1}) SN Ic without broad lines (Ben-Ami et al., 2012)



PTF11AGG: DISCOVERY

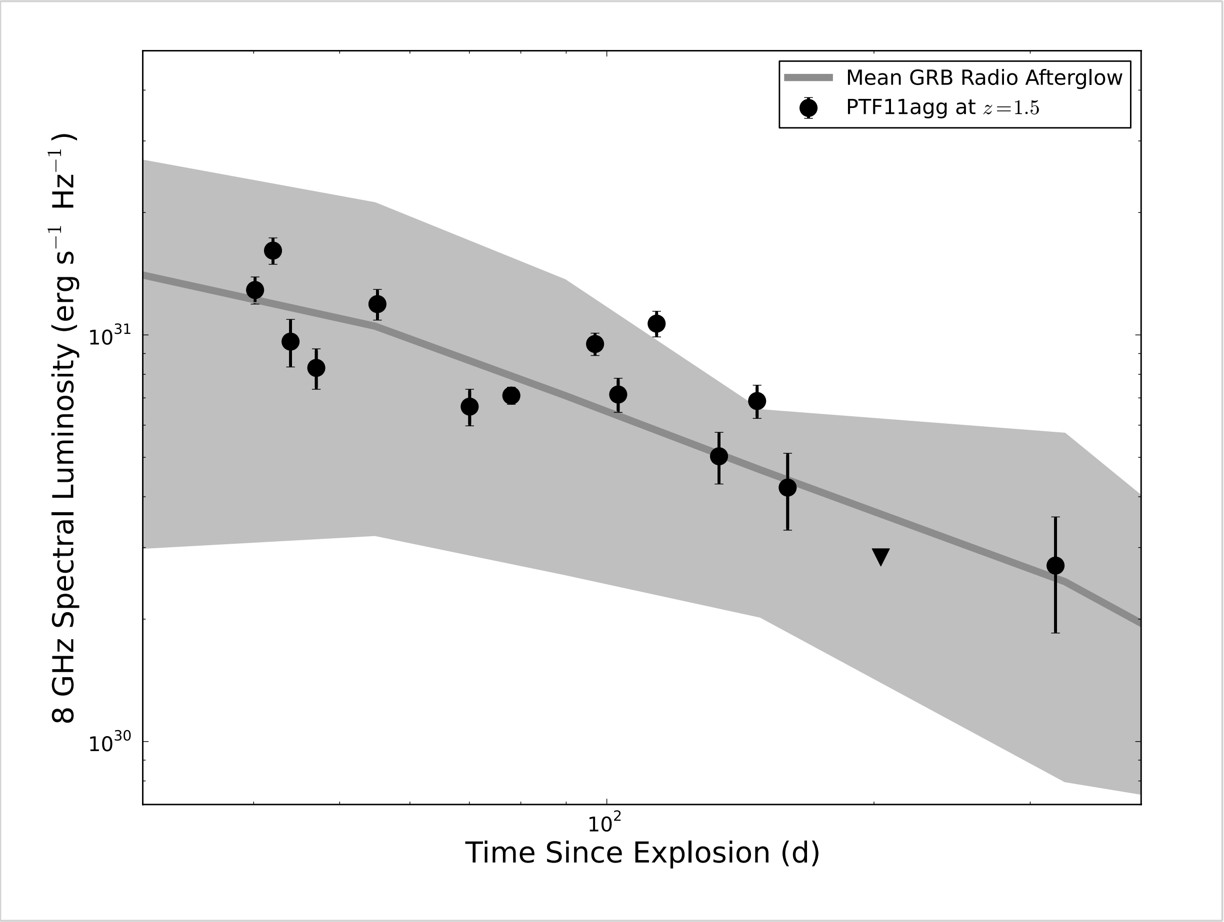


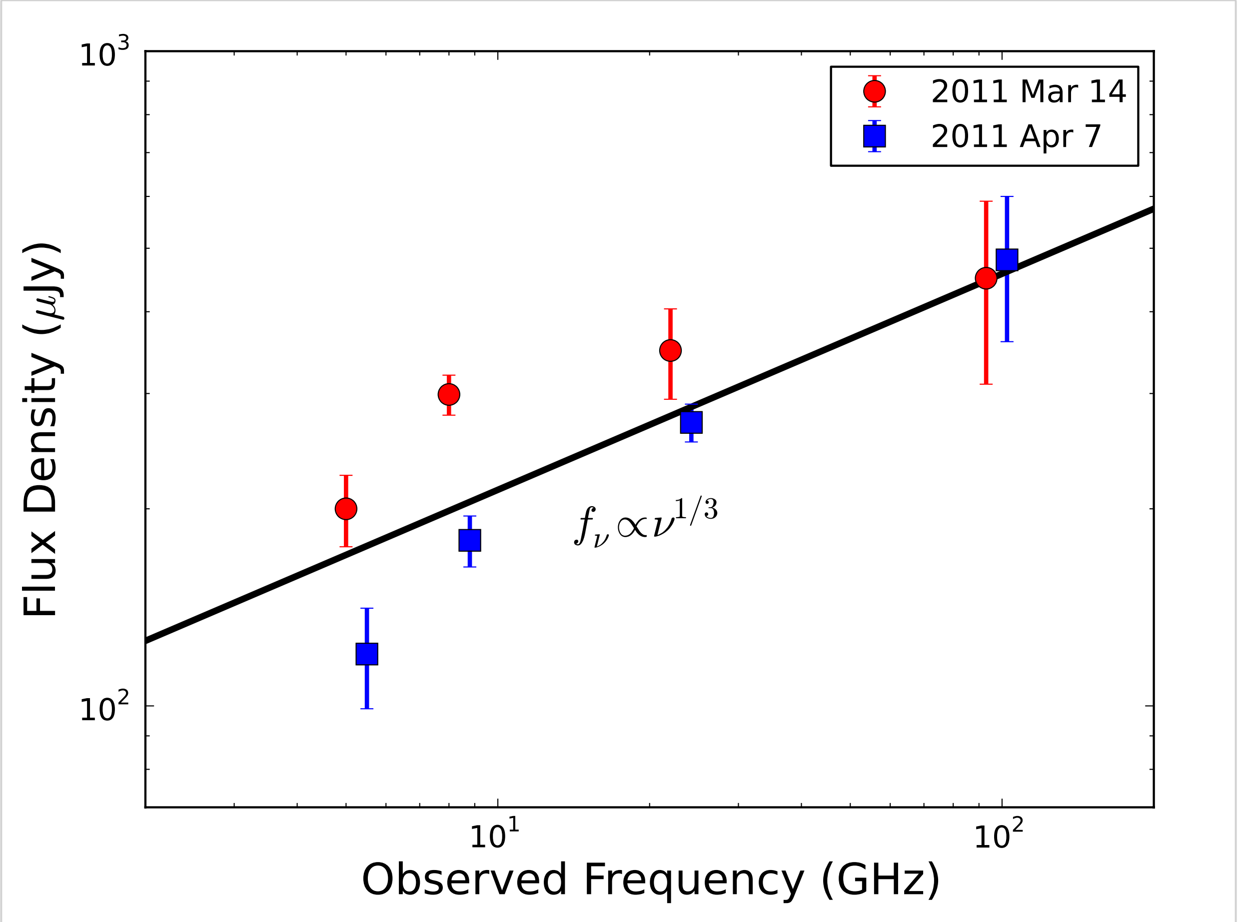
Discovered at R = 18.0 mag on Jan 30, faded by 1.5 mag in 5 hours, 4 mag in 2 days, 8 mag in 2 weeks. Quiescent counterpart with R = 26.0 mag, blue color.



SBC+, 2013

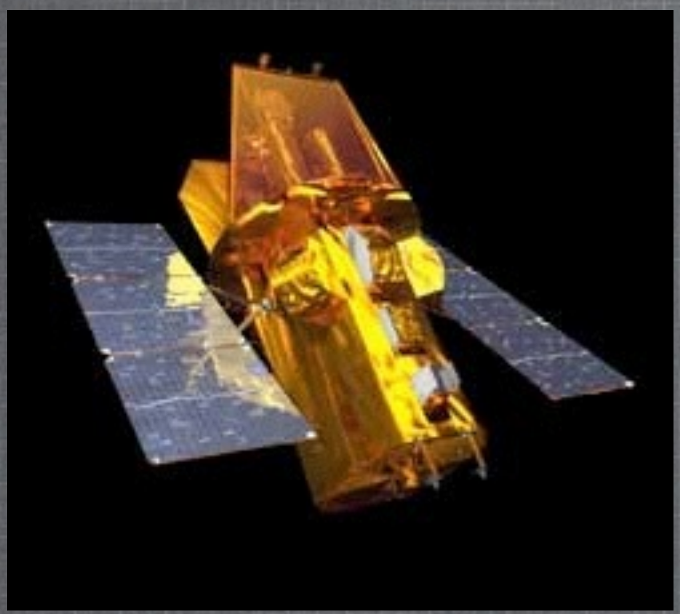
LONG-LIVED RADIO COUNTERPART





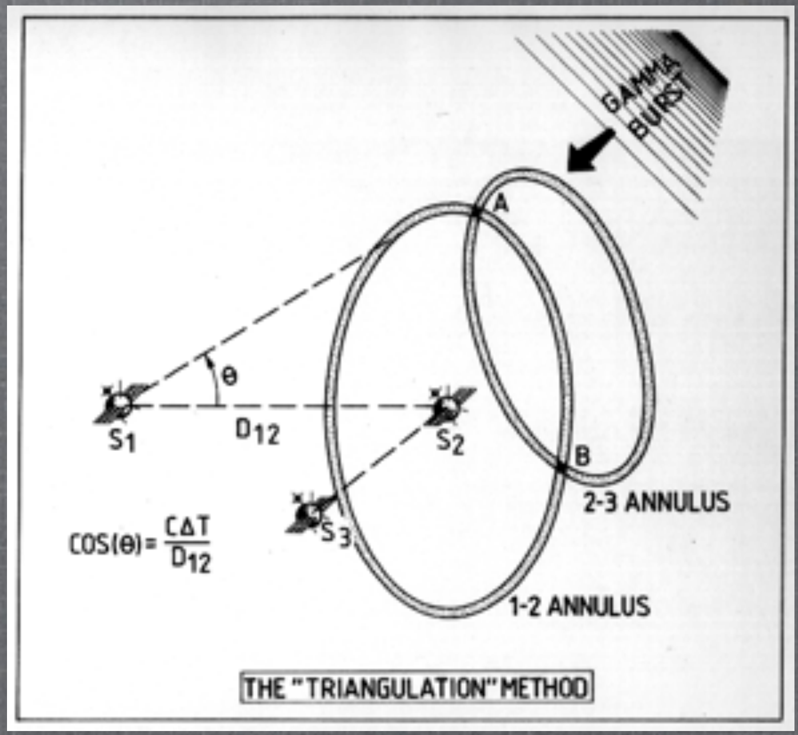
Scintillation and rising radio spectrum both indicative of a compact source from a young jet

“UNTRIGGERED” GRB?



Swift/BAT: 2 sr FOV,
f > 6 x 10^{-9} erg cm^{-2}

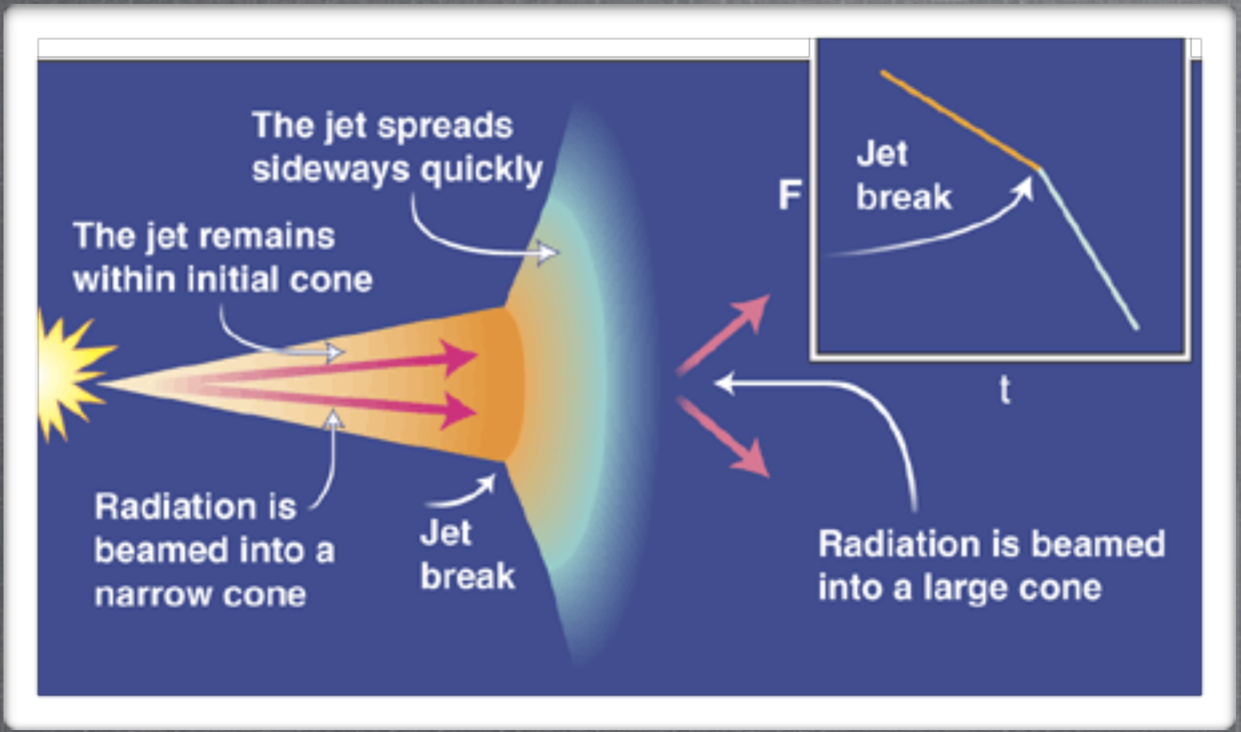
Fermi/GBM: 8 sr FOV,
f > 4 x 10^{-8} erg cm^{-2}



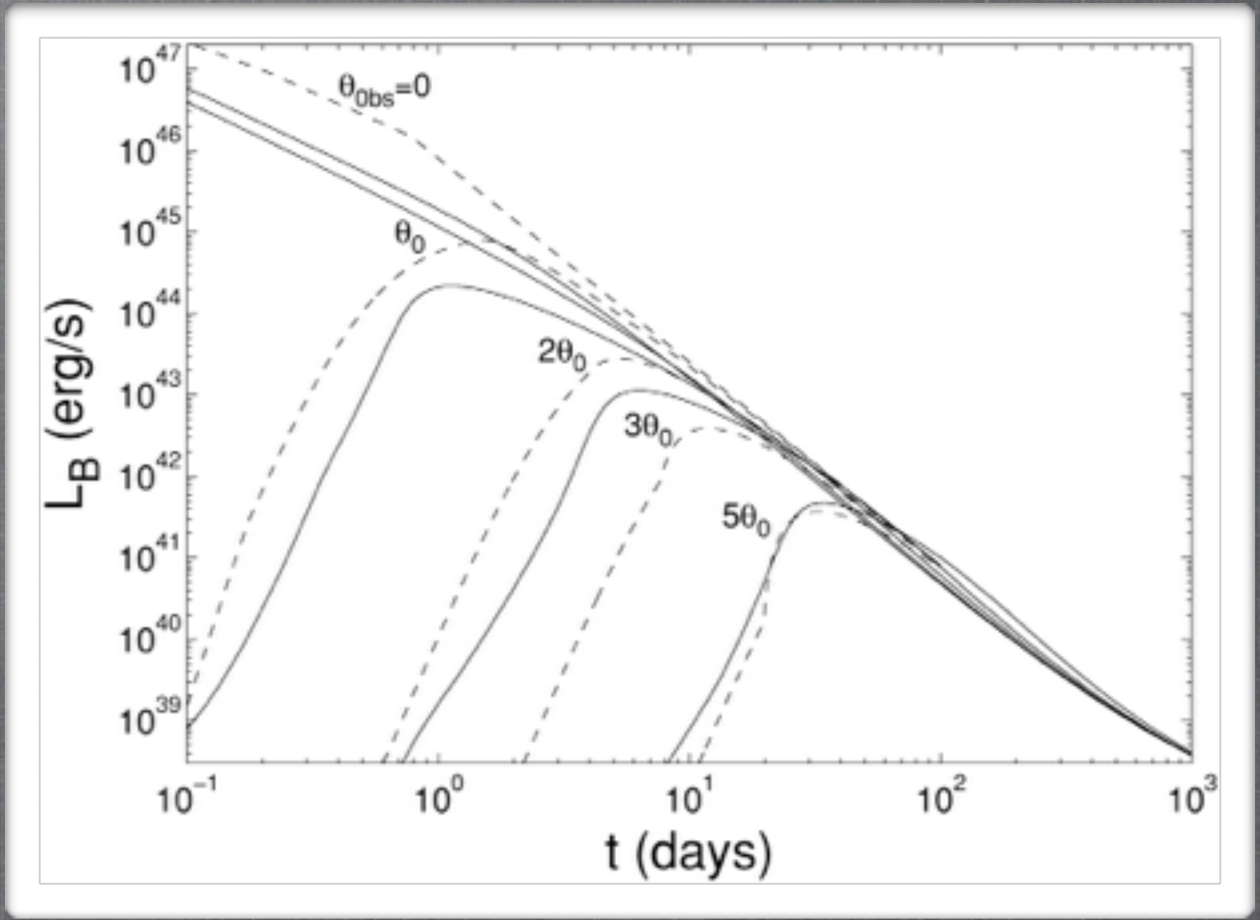
Inter-Planetary Network:
all-sky, f > 6 x 10^{-7} erg cm^{-2}

~ 40% of non-detection by both *Swift* and *Fermi* for events with fluence below IPN sensitivity

BEAMING EFFECTS IN GRBS



Piran 2004

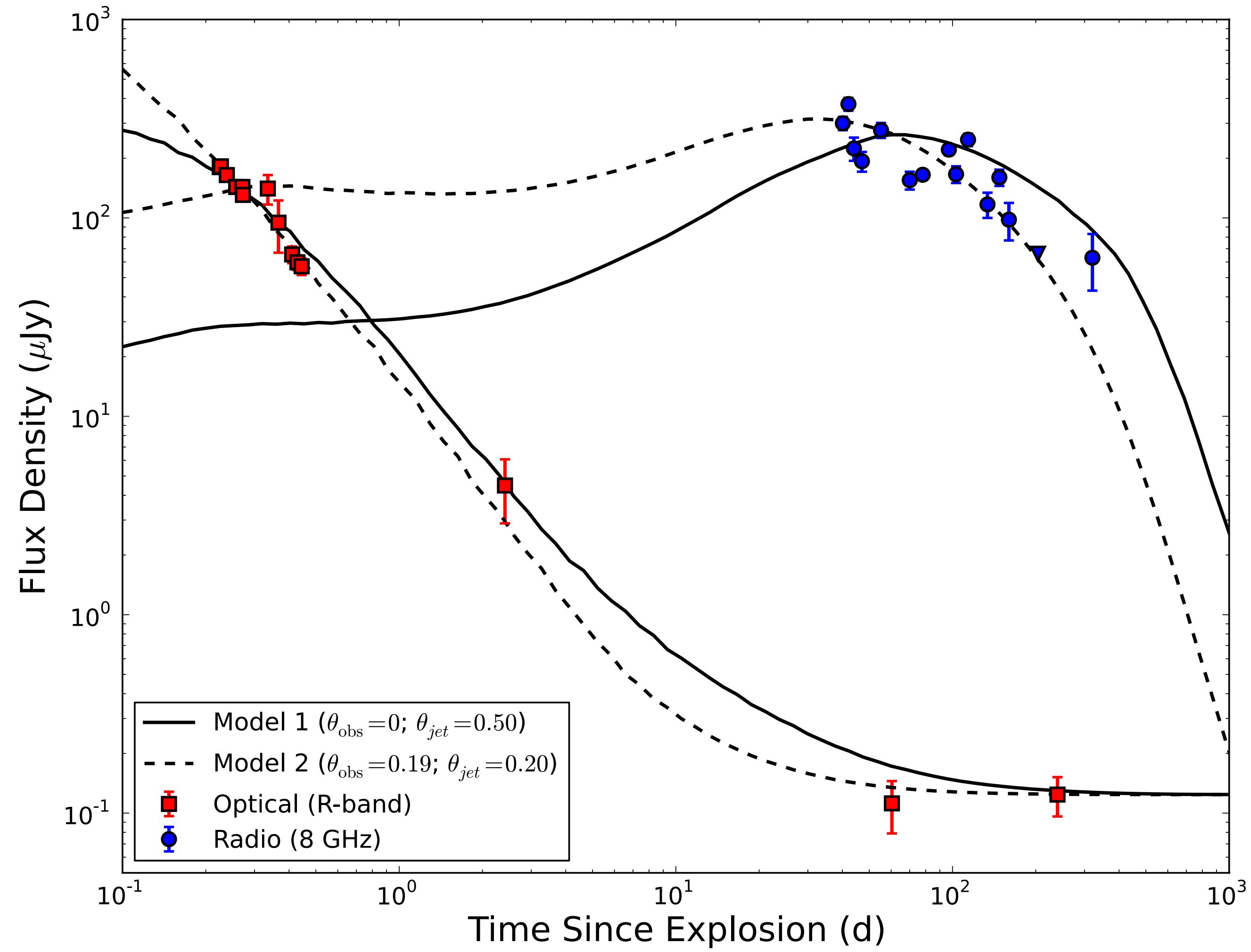


Granot et al., 2002

While initially highly collimated, lateral spreading of jet and decrease in relativistic beaming lead to illumination of increasing fraction of sky

For every on-axis event, ~ 10-100 "orphan" GRB afterglows. Off-axis observers should see fast rise and rapid decline.

GRB AFTERGLOW MODELS



Radio and optical emission can be well modeled by an on-axis GRB with (mostly) normal properties (E, n, etc.)

RATE OF UNTRIGGERED GRBS

Field-of-View

All-sky Rate

Duration

Number of Observations

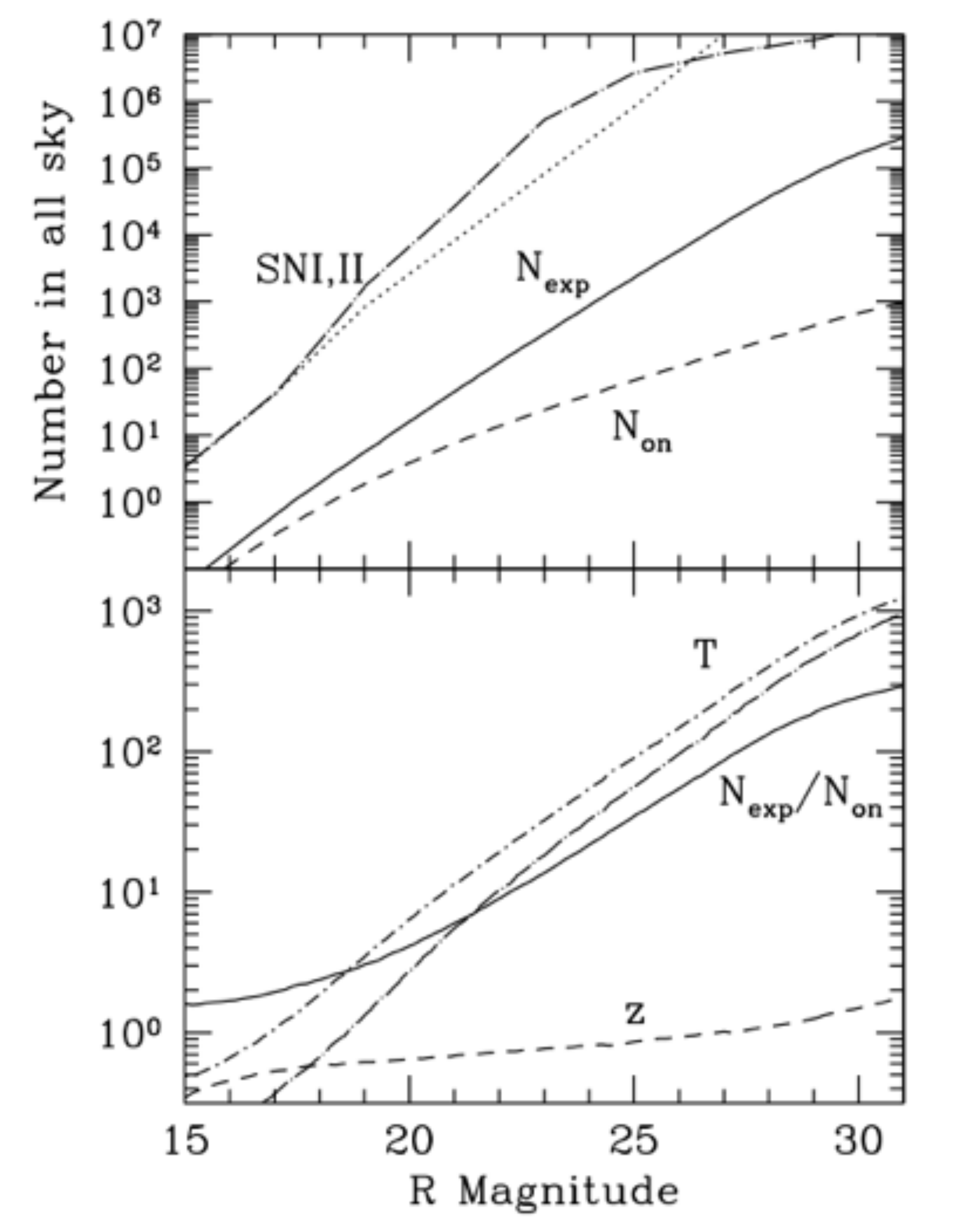
$$\lambda = \frac{\Omega \mathcal{N} \tau \mathrm{N}_{\mathrm{Obs}}}{4\pi}$$

Expected number of detections

N	N_{Obs}
1	11376
2	40101
3	5889
4	825
5	693
6	305
7	189
8	113
9	54
> 10	426

For entire survey, likelihood of untriggered GRB afterglow detection quite high ($\lambda \approx 3.3$). *But for high-cadence fields, likelihood of untriggered detection only ≈ 2%*

ORPHAN OPTICAL AFTERGLOWS

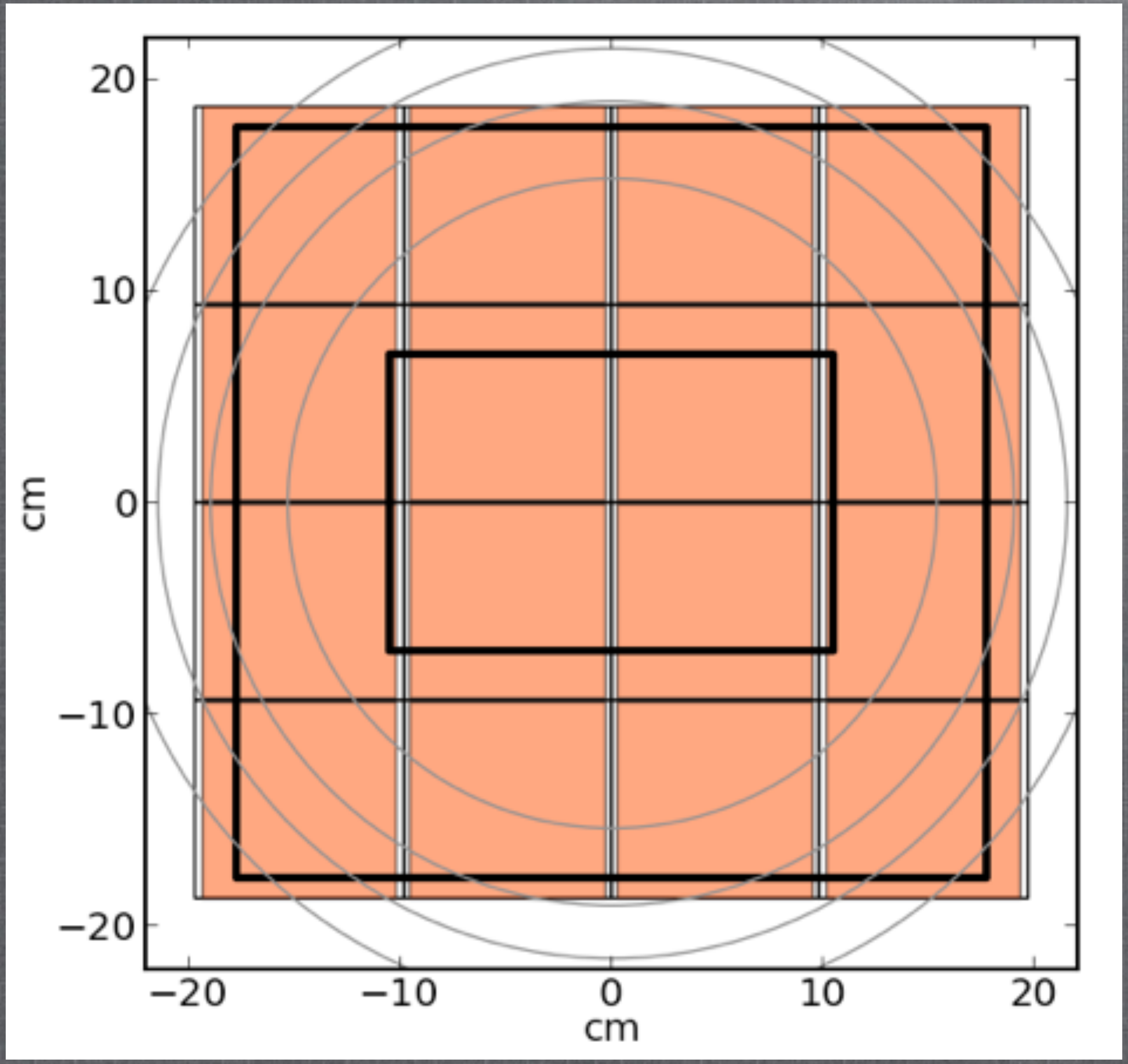


Totani & Panaitescu, 2002

- Ratio of off-axis to on-axis events only ~ 3 at PTF limits
- Only visible for a few days
- Should be some in the SN cadence fields, but again these are very hard to identify reliably
- By the time you reach LSST depths, off-axis events outnumber on-axis by > 10:1

FUTURE I: ZTF

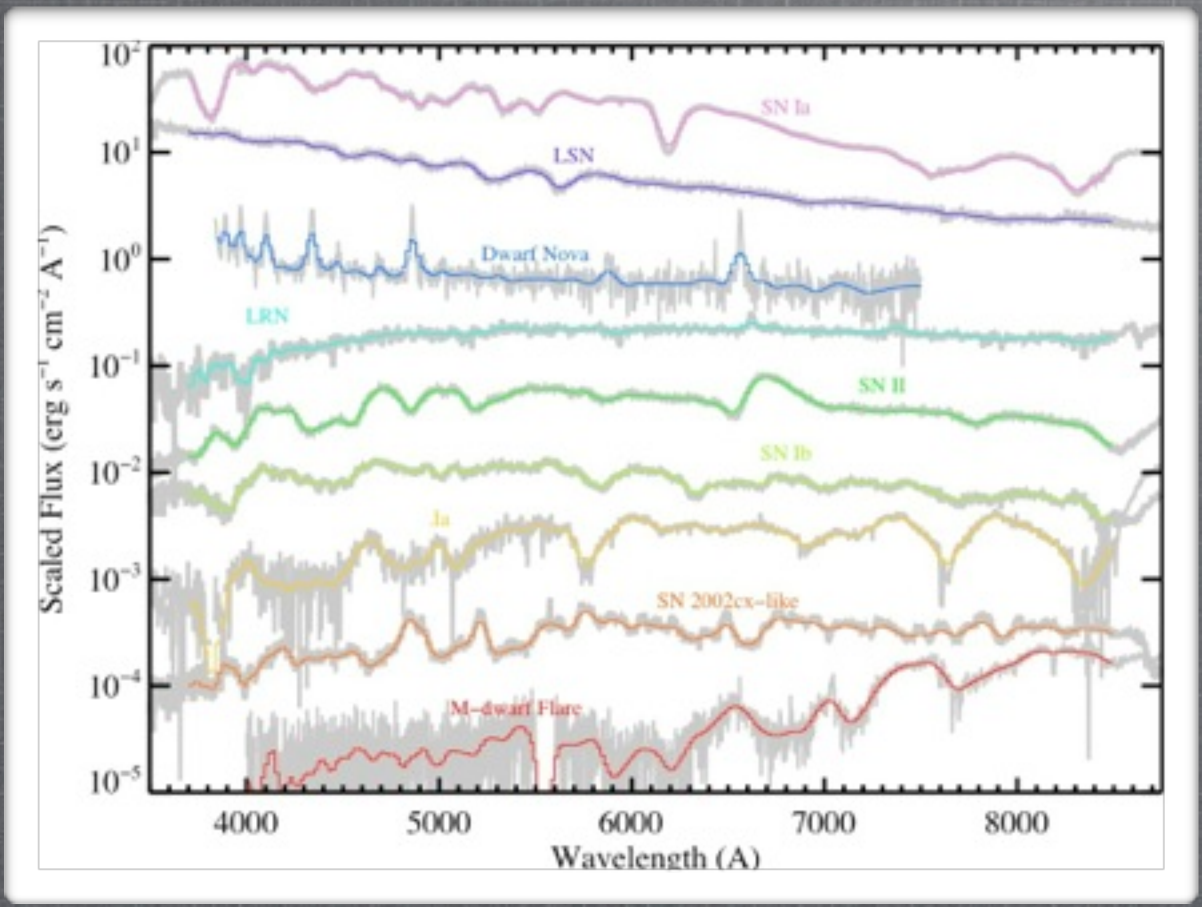
Zwicky Transient Facility (ZTF)

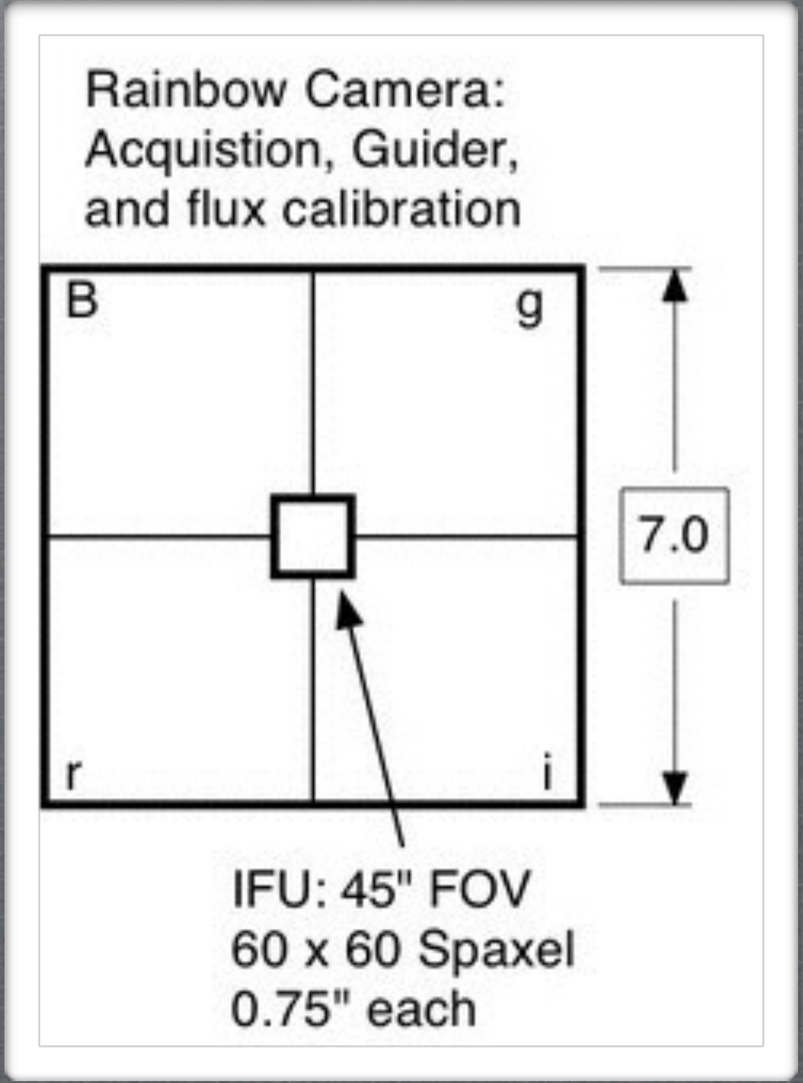


- New camera populating entire focal plane of P48, ~ 45 deg^2 (i.e., a factor of 6 larger area than current camera)
- With faster readout and shorter (30 s) exposures, survey volume increases by ~ 14x
- Expected Discoveries:
  - 1 young (< 24 hr) SN per night
  - 5 orphan afterglows per year
  - 20 11agg-like events per year
  - > 250 pointings of all Northern sky

FUTURE II: SED MACHINE

PI: Nick Konidaris





Low-resolution (R~150), high-throughput (objective prism) spectroscopy of PTF discoveries

SETTING THE STAGE: III

- Gamma-Ray Bursts:
  - Gamma-ray: $E_{iso} \sim 10^{53}$ erg, $\Delta t \sim 0.1\text{-}100$ s (ultra-longs?), $E_{pk} \sim 200$ keV
  - Optical: $M_R > -34$ mag (limited by neutral H), $\Delta t \sim$ hours
  - Radio: $L_\nu \sim 10^{31}$ erg s^{-1}, $\Delta t \sim$ months to years
- Magnetars:
  - Gamma-ray: $E_{iso} \sim 10^{46}$ erg, $\Delta t \sim 0.1$ s, $E_{pk} \sim 200$ keV
  - Optical: Faint (limited to MW, hence Galactic plane)
  - Radio: $L_\nu \sim 10^{22}$ erg s^{-1}, $\Delta t \sim$ weeks (again, probably limited to MW)

THE RADIO TRANSIENT SKY

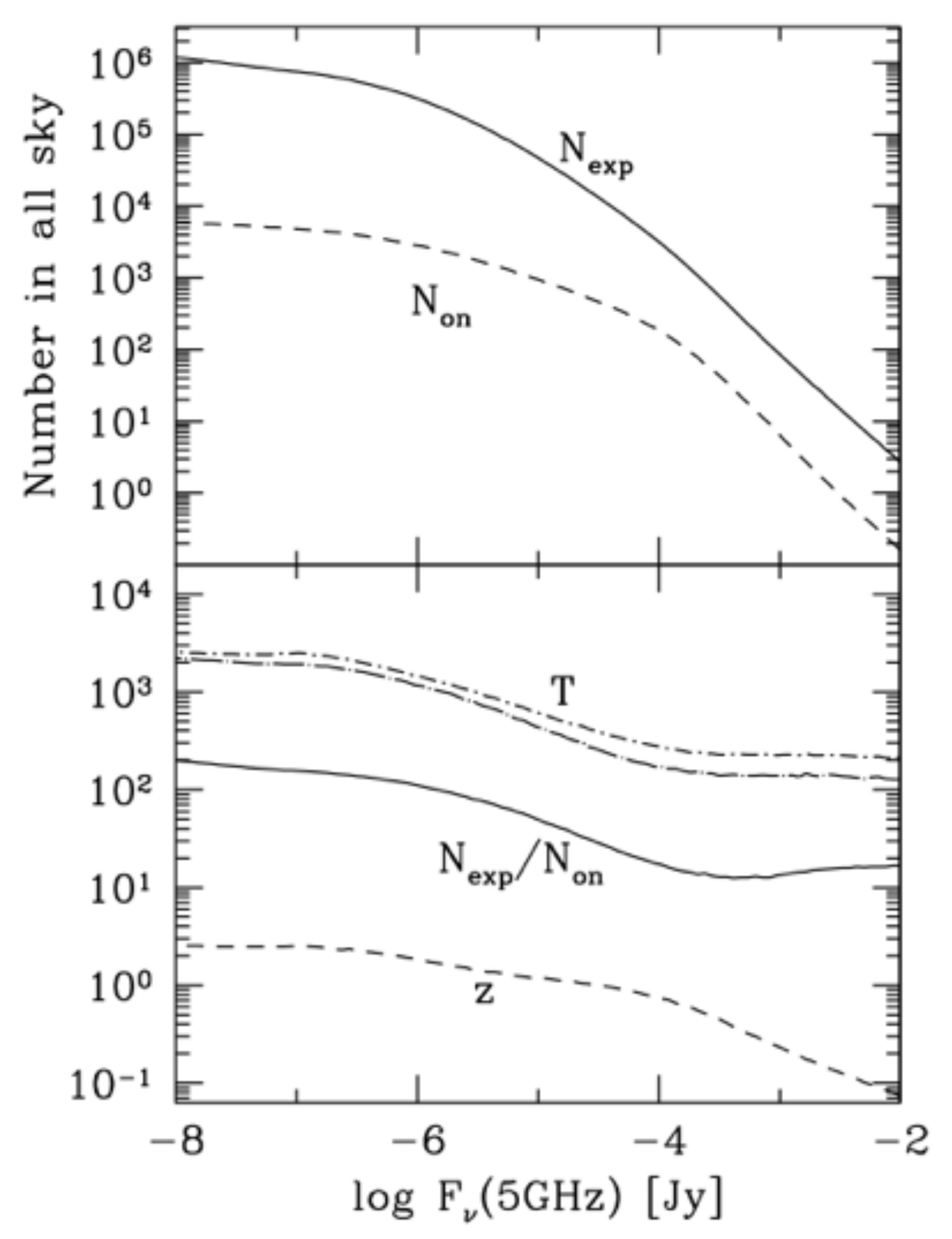
Table 1
Long-duration Transient Populations

Class	Rise (yr)	Decay (yr)	D	Host (mag)	Rate (deg^{-2})	Reference
Type II SNe	0.1–1	10	100 Mpc	16	0.04	Gal-Yam et al. (2006)
Type Ib/c SNe	0.1	0.3	50 Mpc	14.5	5×10^{-6}	Berger et al. (2003)
SN1998bw-like	0.1	0.1	300 Mpc	18.4	3×10^{-4}	Soderberg et al. (2006)
Sw J1644+57-like	0.1	1	$z \sim 1.8$	21.7	0.1	Zauderer et al. (2011)
Orphan afterglows	1	1	1 Gpc	21.0	10^{-2}	Levinson et al. (2002)
NS–NS mergers	0.1–1	0.1–3	800 Mpc	20.5	5×10^{-3}	Nakar & Piran (2011)

Notes. Detectability distance and rates have been calculated assuming a single snapshot at a flux density threshold of 0.3 mJy. See Section 5 for details. D is the distance at which the typical transient will have a specific flux of 0.3 mJy. Host is the apparent magnitude of a galaxy with −19 absolute magnitude at distance D.

Frail *et al.*, 2012

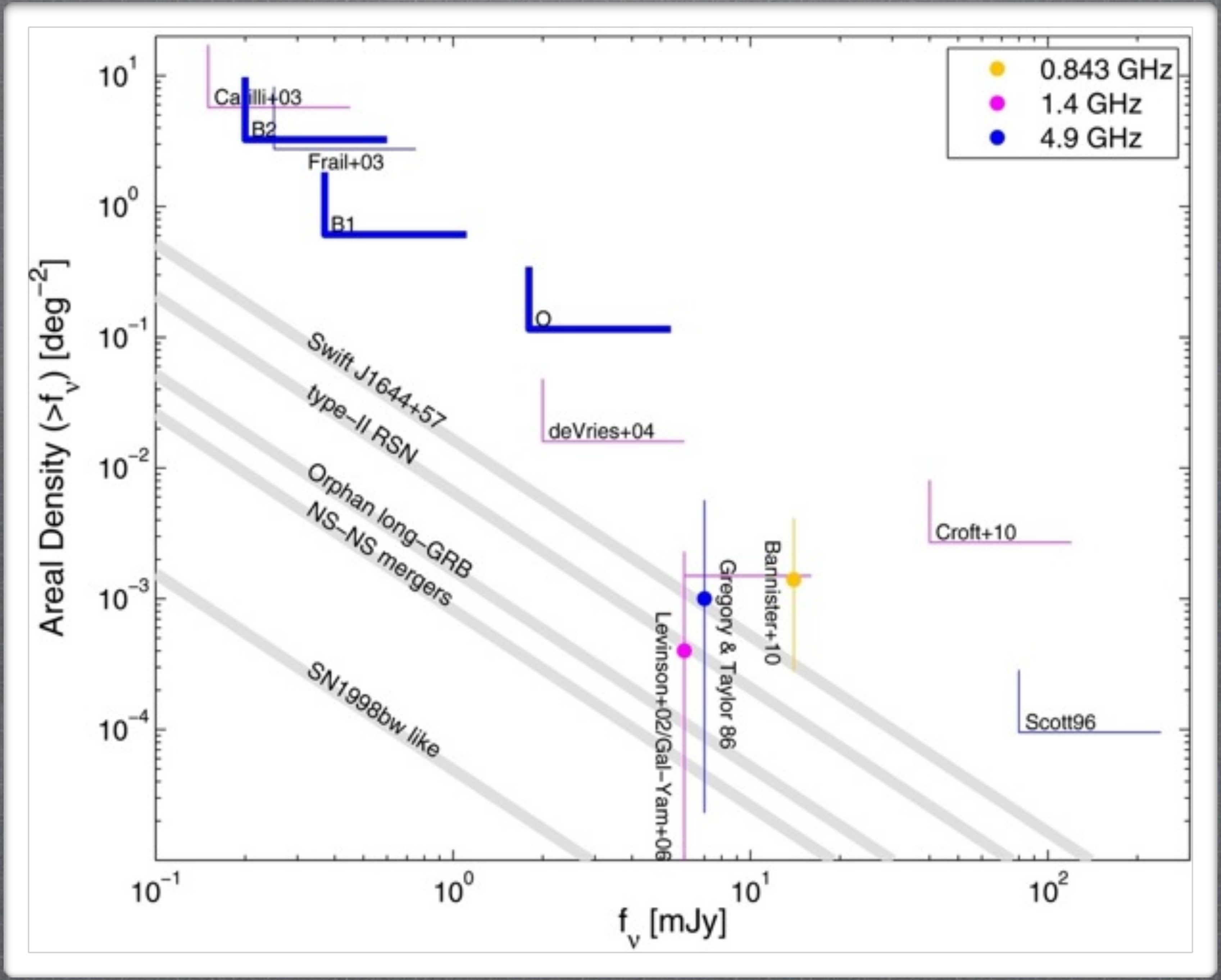
ORPHAN RADIO AFTERGLOWS



Totani & Panaitescu, 2002

- Independent of flux, radio orphans outnumber on-axis GRBs by more than an order of magnitude!
- Can (hopefully) be distinguished from radio SN (distance) and TDFs/AGN (off-nuclear)
- Problem will be waiting for them to vary (particularly at low frequency) - time scale > 100 d
- n.b. - above only applies to "cosmological" population

RADIO TRANSIENT SURVEYS

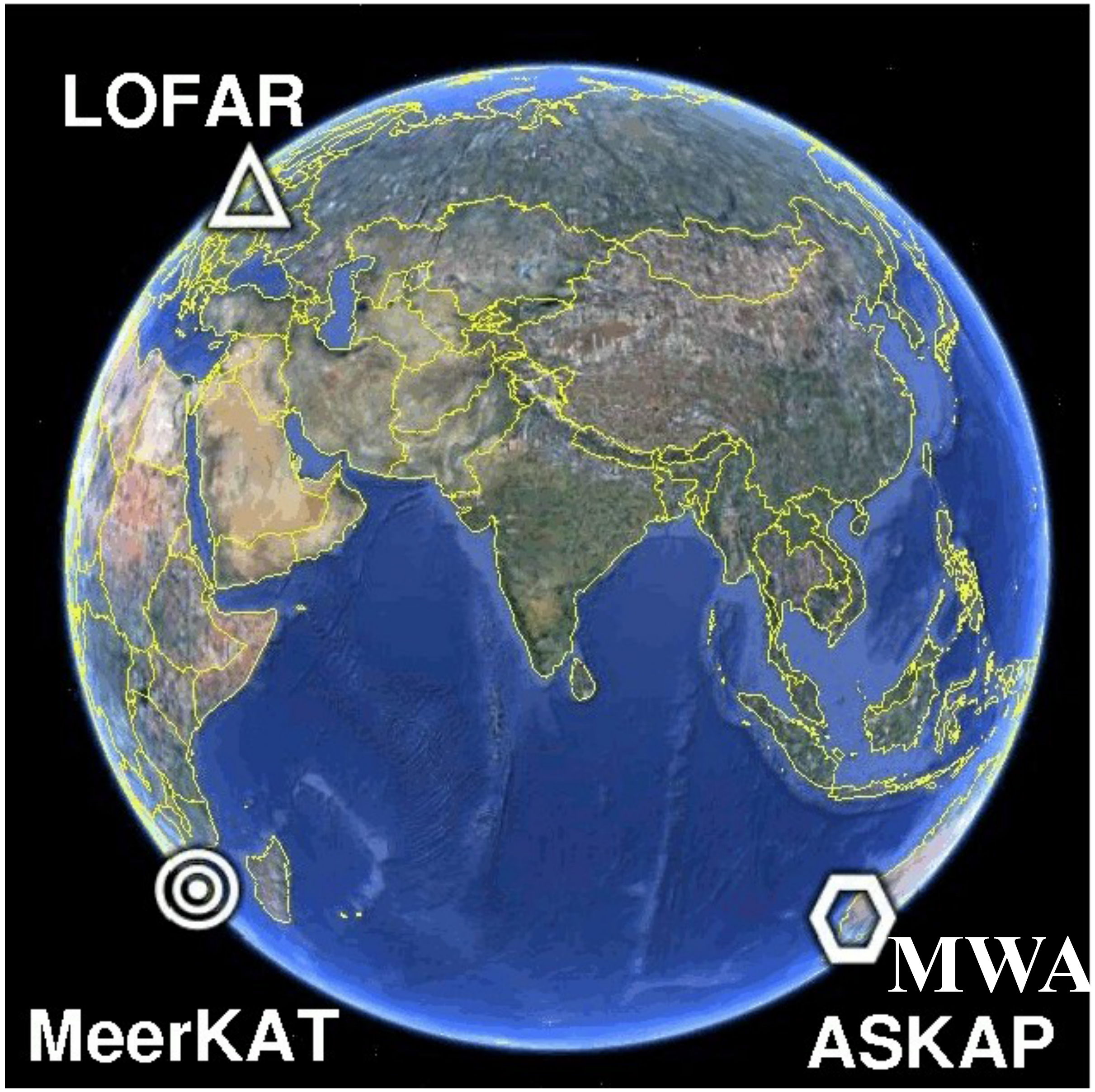


Frail *et al.*, 2012

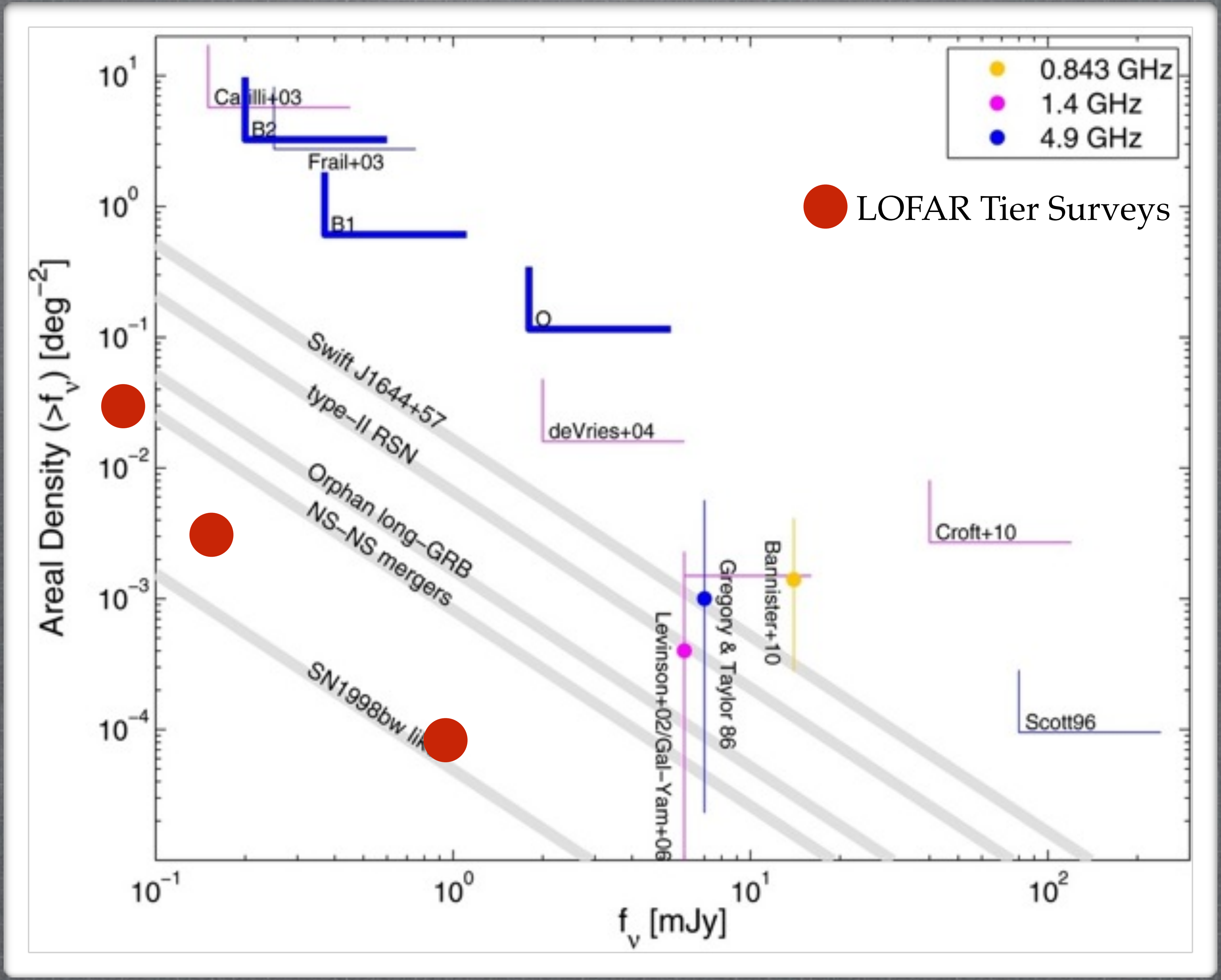
NEW WIDE-FIELD CAPABILITIES

Radio domain –pathway to SKA

Low (~100Mhz, e.g. LOFAR) and high frequency (~1Ghz, e.g. ASKAP)



LOFAR CAPABILITIES



van Haarlem *et al.*, 2013

CONCLUSIONS

- In terms of high-energy missions (i.e., wide-field, 100 keV, with good localization), without the selection of new missions, we are likely towards the tail end of a “golden age” in our capabilities to discover and follow-up GRBs and magnetars.

- Possibly in the next five years (and definitely in the next decade), the number of relativistic outbursts detected from the ground will outnumber the results from space. This offers a variety of opportunities, but numerous challenges as well.