# ORPHAN AFTERGLOWS: THE OFF-AXIS VIEW OF GAMMA RAY BURSTS

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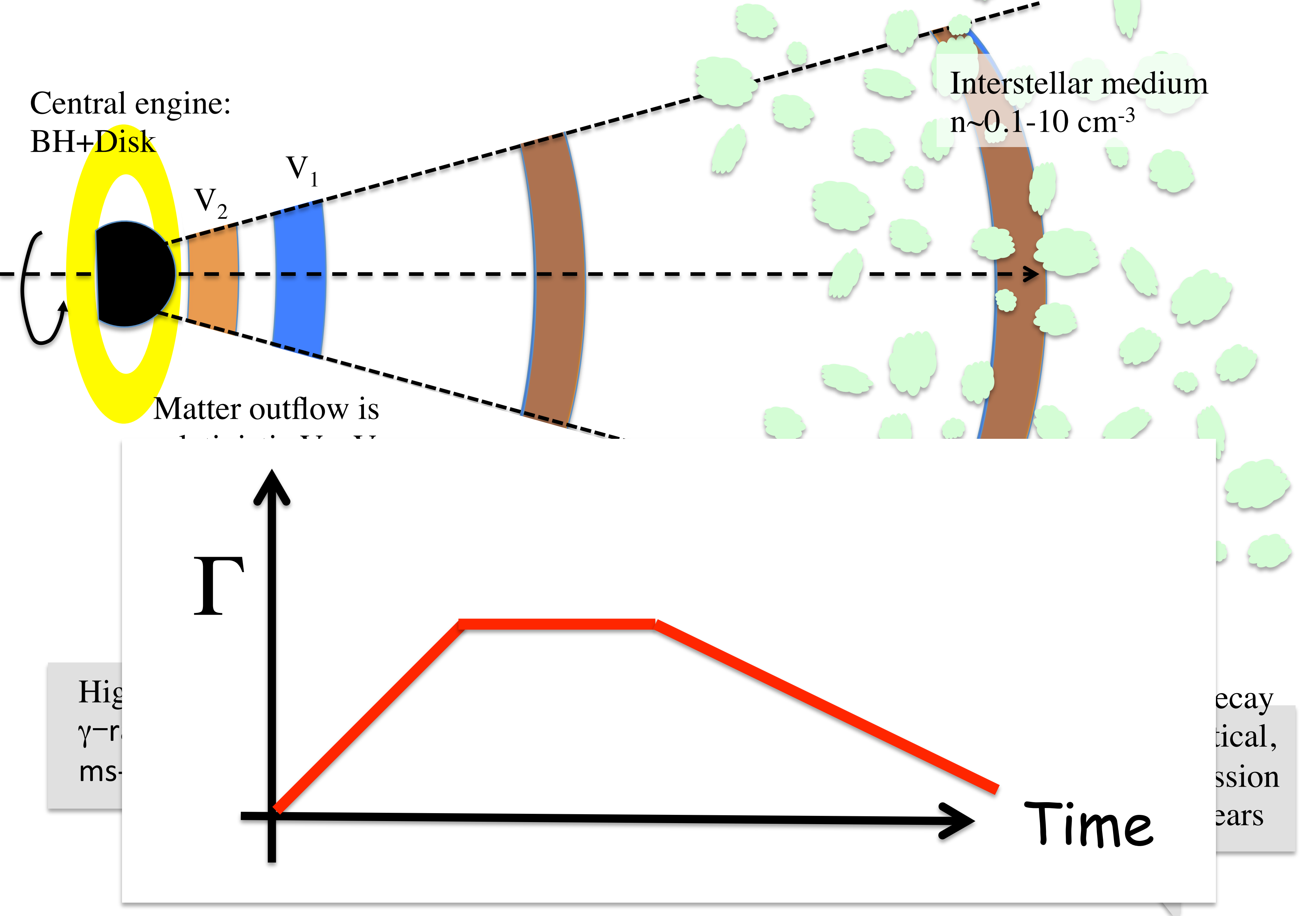
- Gamma Ray Bursts: jetted/relativistic transients
- Orphan afterglows (OA) the parent population of GRBs, characteristics (time/flux space)
- Detectability prospects & identification issues
- Conclusions

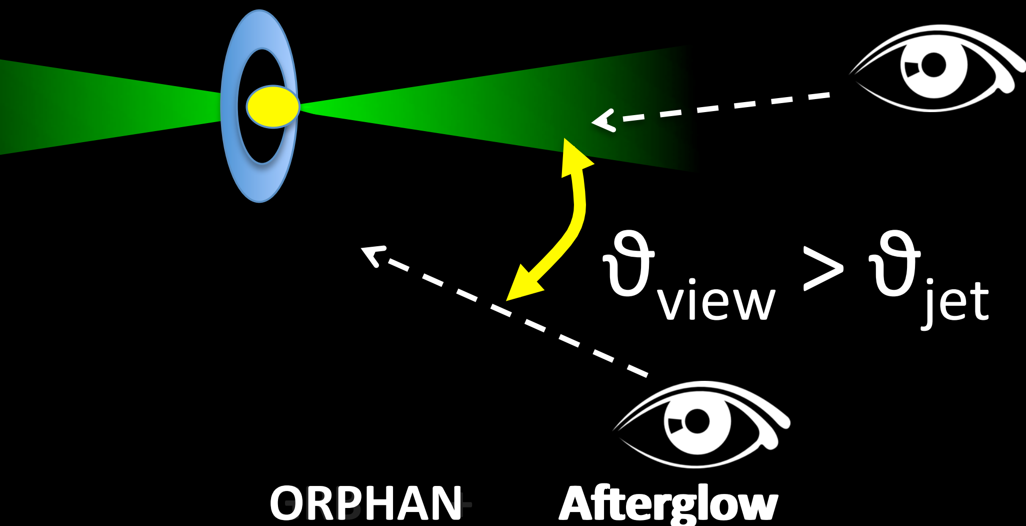
*Bologna – IRA 20/10/2015*

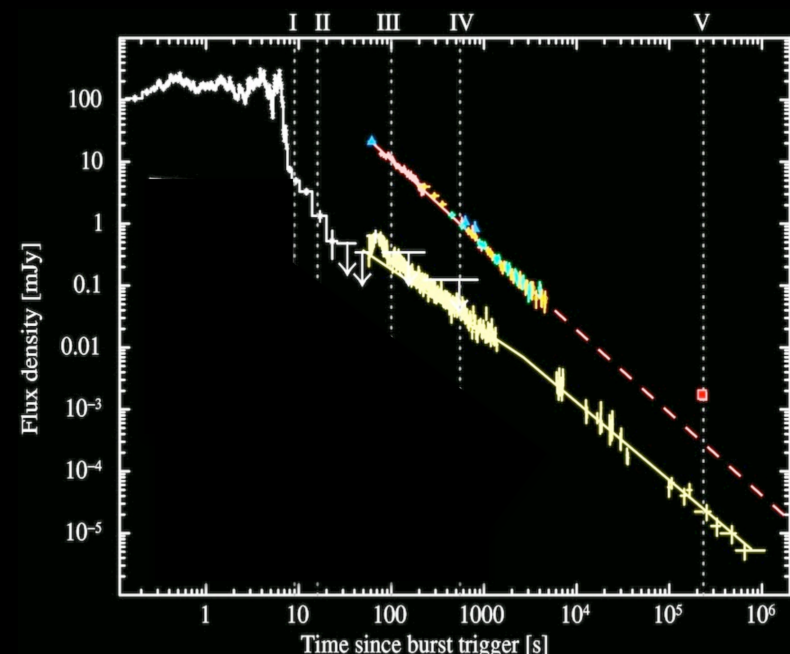
# Standard model of GRBs

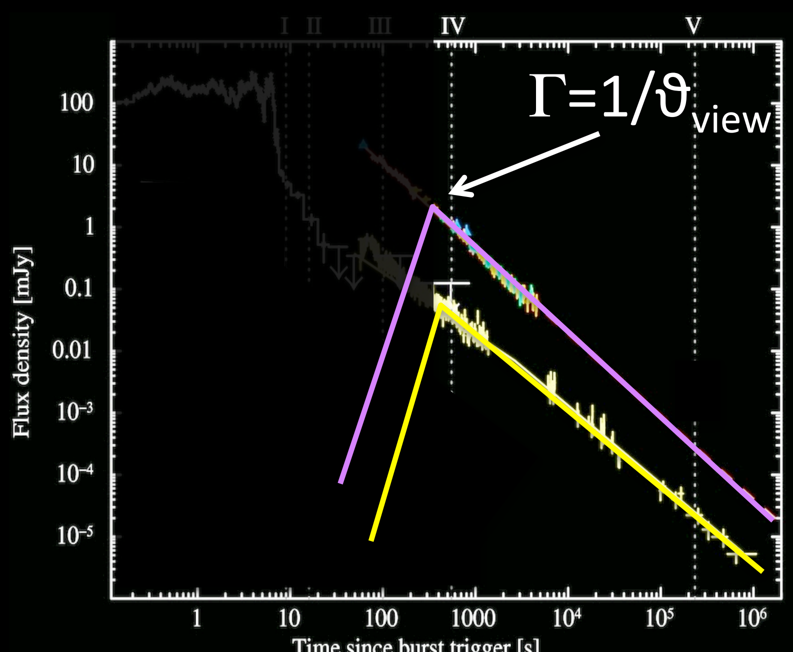


# Orientation & relativistic beaming

**GRB + Afterglow**



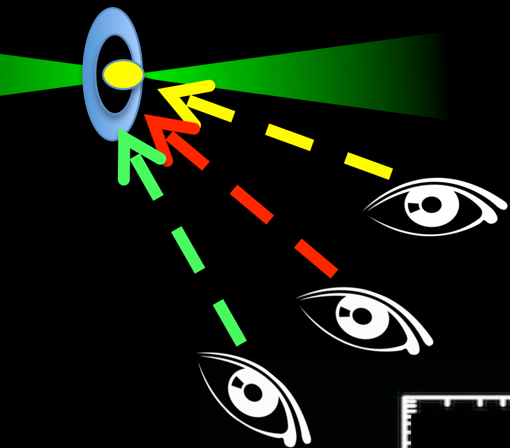

During afterglow $\Gamma(t) \sim t^{-3/2}$
Start to see the emission when:
BEAMING = VIEWING ANGLE

$$N_{orph} \sim \frac{2}{\theta_{jet}^2} N_{GRB}$$

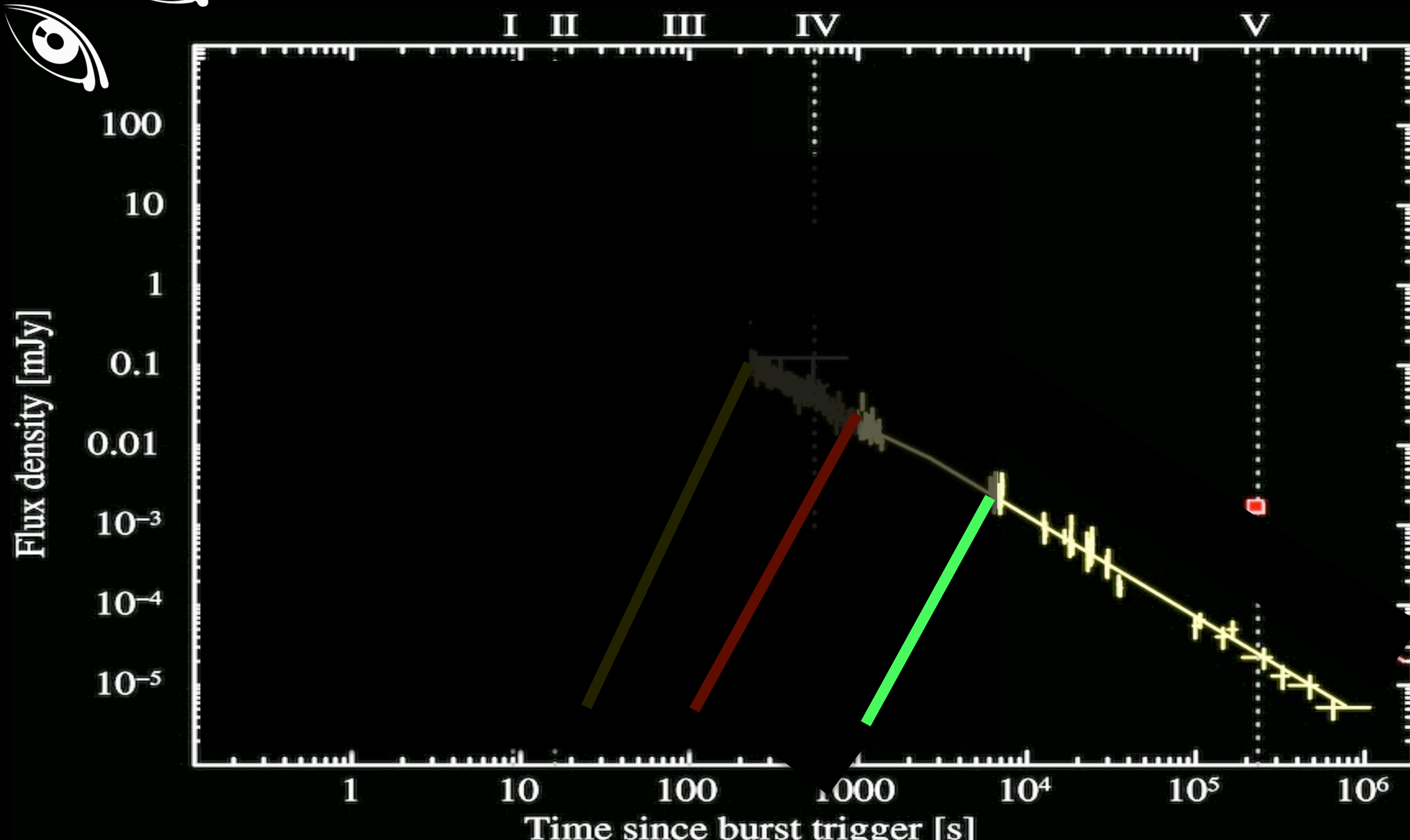
$\vartheta_{jet} = 5^\circ$ for each GRB → ~ 260 Orphans

# ORPHAN GRBs

1. Gamma-Ray DARK parent population of GRBs
2. Dominating in number >100-200 X each GRB
3. “Unavoidable’’ if: GRB are relativistic & jetted



The more off—axis … (a) the later the emission peaks and (b) the dimmer the flux at peak



# Orphan afterglows searches as transients in (blind) surveys

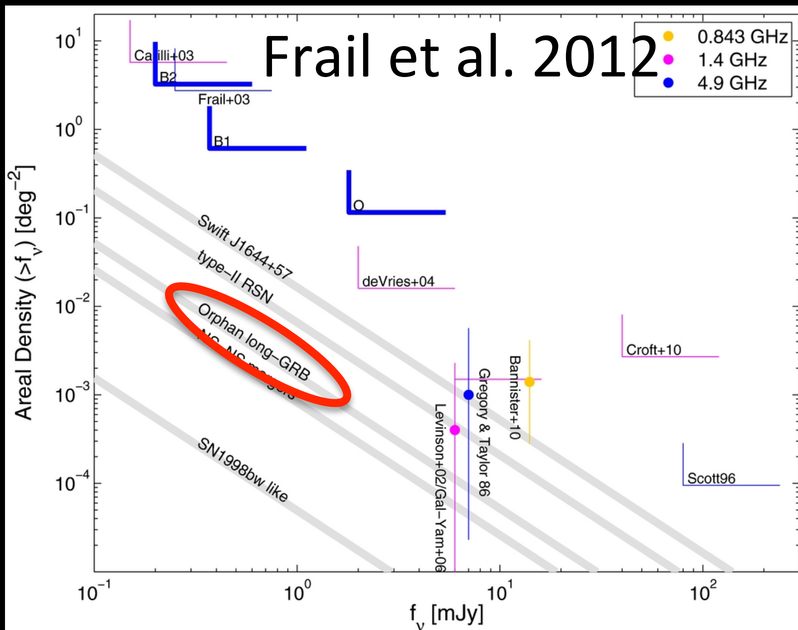
| Band | Ref | Results |
|---|---|---|
| X-ray | Grindlay 1999; Greiner et al. 2000 | 23 candidates → flare stars |
| Optical/NIR | Rau et al. 2006 (12 $deg^2$, R=23) | 4 candidates → flare stars |
| | Malacrino et al. 2007 (490 $deg^2$, r=22.5) CFTHLS | 3 candidates → flare stars |
| Radio | Levinson et al. 2002 (1.4 GHz NVSS vs FIRST, 6000 $deg^2$) | 9 candidates → 5 false positive, 2 non transients (Gal-Yam et al. 2006) |

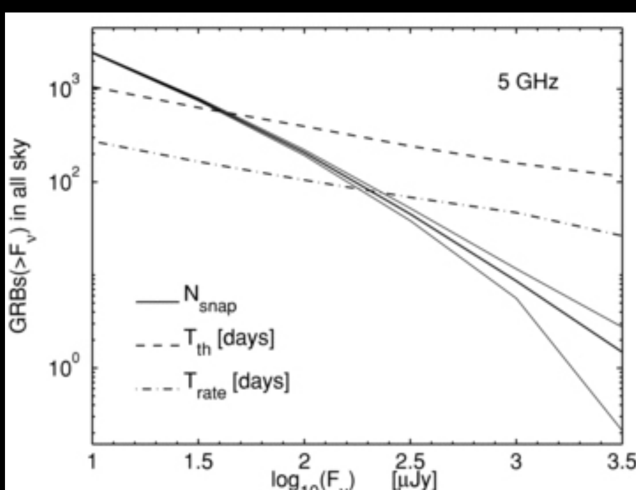
Table 3: Summary of snapshot rates for transient and variables radio sources reported in the literature. The results are organised according to upper limits based on non-detections (top section); transient detections (middle section); and detections of highly variable radio sources (bottom section).

| Survey/Reference | $S_{Min}$ (mJy) | $S_{Max}$ (mJy) | Rate ($deg^{-2}$) | Timescale | Frequency (GHz) | Epochs (N) |
|---|---|---|---|---|---|---|
| Bower et al. (2007) | >0.09 | — | <6 | 1 year | 4.8 & 8.4 | 17 |
| Bower et al. (2007) & Frail et al. (2012)† | 0.2 | — | <3 | 2 months | 4.8 & 8.4 | 96 |
| Bower et al. (2007) & Frail et al. (2012)† | >0.37 | — | $< 6 \times 10^{-1}$ | 20 mins - 7 days | 4.8 & 8.4 | 944 |
| PiGSS-I/Bower et al. (2010)(A)* | >1 | — | <1 | 1 month | 3.1 | 75 |
| PiGSS-II/Bower et al. (2011)(B)* | > 5 | — | <0.18 | 1 month | 3.1 | 78 |
| FIRST-NVSS/Gal-Yam et al. (2006) | >6 | — | $<1.5\times10^{-3}$ | days to months | 1.4 | 2 |
| Bell et al. (2011) | >8 (8$\sigma$) | — | <0.032 | 4.3 - 45.3 days | 1.4, 4.8 & 8.4 | 5037 |
| PiGSS-I/Bower et al. (2010)(A)* | >10 | — | <0.3 | 1 month | 3.1 | 75 |
| PiGSS-II/Bower et al. (2011)(B)* | > 15 | — | <0.025 | 1 day | 3.1 | 78 |
| ATATS - I/Croft et al. (2010) | >40 | — | <0.004 | 81 days - ~ 15 years | 1.4 | 12 |
| Bower & Saul (2011)(A)* | >70 | — | $<3\times10^{-3}$ | 1 day | 1.4 | 1852 |
| ATATS - II/Croft et al. (2011) | >350 | — | $<6\times10^{-4}$ | minutes to days | 1.4 | 12 |
| Bower & Saul (2011)(B)* | >3000 | — | $>9\times10^{-4}$ | 1 day | 1.4 | 1852 |
| Lazio et al. (2010) | $>2.5\times10^{6}$(5$\sigma$) | — | $<9.5\times10^{-8}$ | 5 mins | 0.0738 | ~1272 |

No conclusive detection so far

# How many Orphan GRBs in radio surveys ?



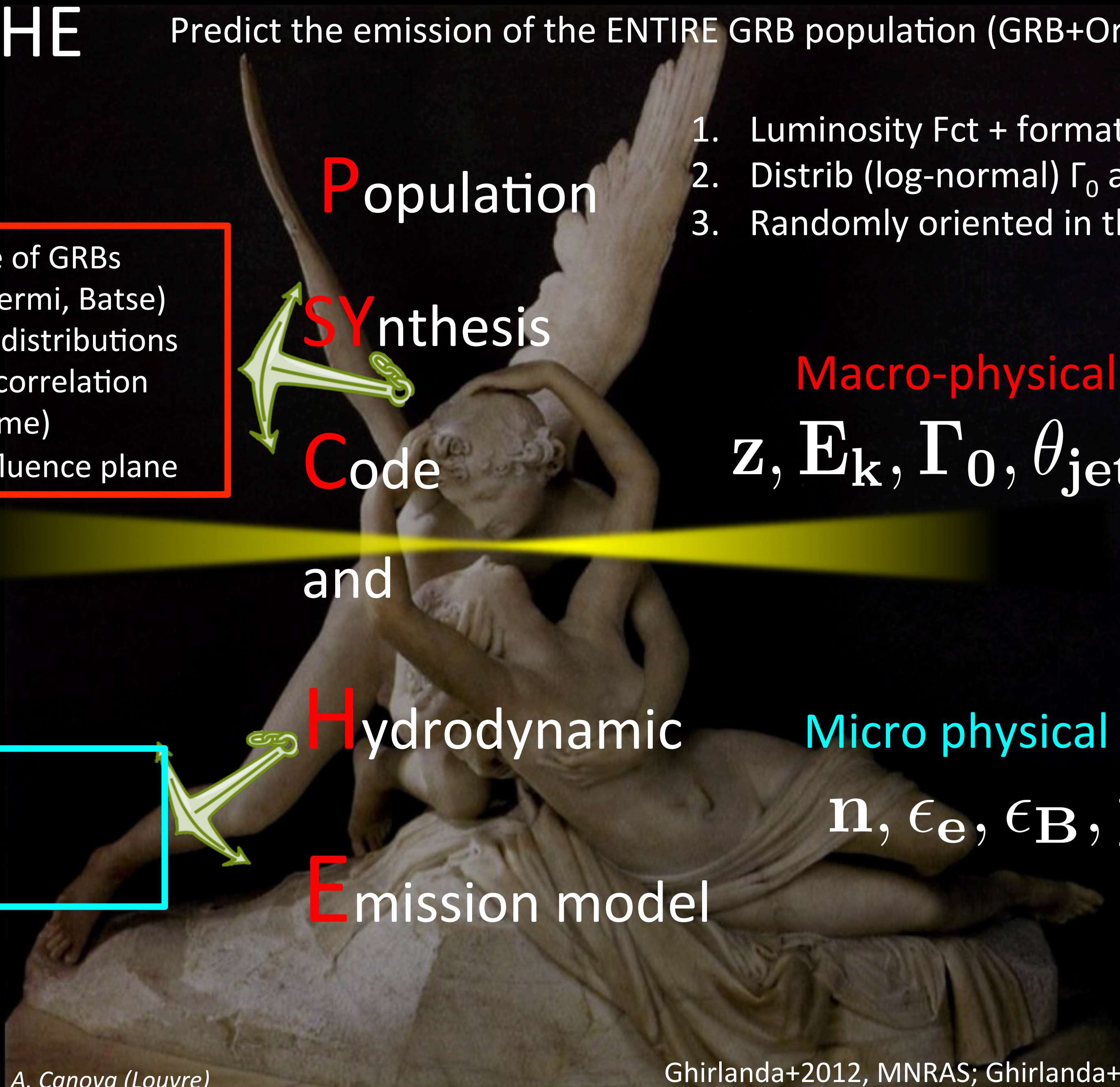

Rossi et al. 2008

Past studies [e.g. Frail+12, Totani+02, Rossi+08] … simplifying assumptions

1) Jet (e.g. unique value rather than distribution
2) Extrapolation of bright GRB properties
3) No realistic cosmological effects
4) No full jet dynamics included
5) No radiative evolution (and not complete emission mechansims, e.g. no SSC or IC)

# PSYCHE

Predict the emission of the ENTIRE GRB population (GRB+Orphans)



**P**opulation

1. Luminosity Fct + formation rate(z)
2. Distrib (log-normal) $\Gamma_0$ and $\vartheta_{jet}$
3. Randomly oriented in the sky

**SY**nthesis

**C**ode

1. Obs rate of GRBs (Swift, Fermi, Batse)
2. Fluence distributions
3. Ep-Eiso correlation (rest frame)
4. Ep,obs-fluence plane

Macro-physical param

$$\mathbf{z}, \mathbf{E_k}, \mathbf{\Gamma_0}, \theta_{\mathbf{jet}}, \theta_{\mathbf{view}}$$

and

**H**ydrodynamic

**E**mission model

5. Optical
6. X-ray
7. Radio

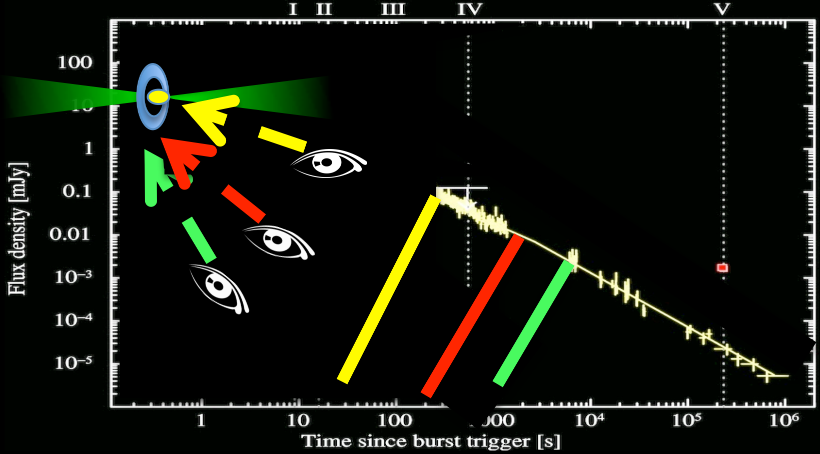
Micro physical param

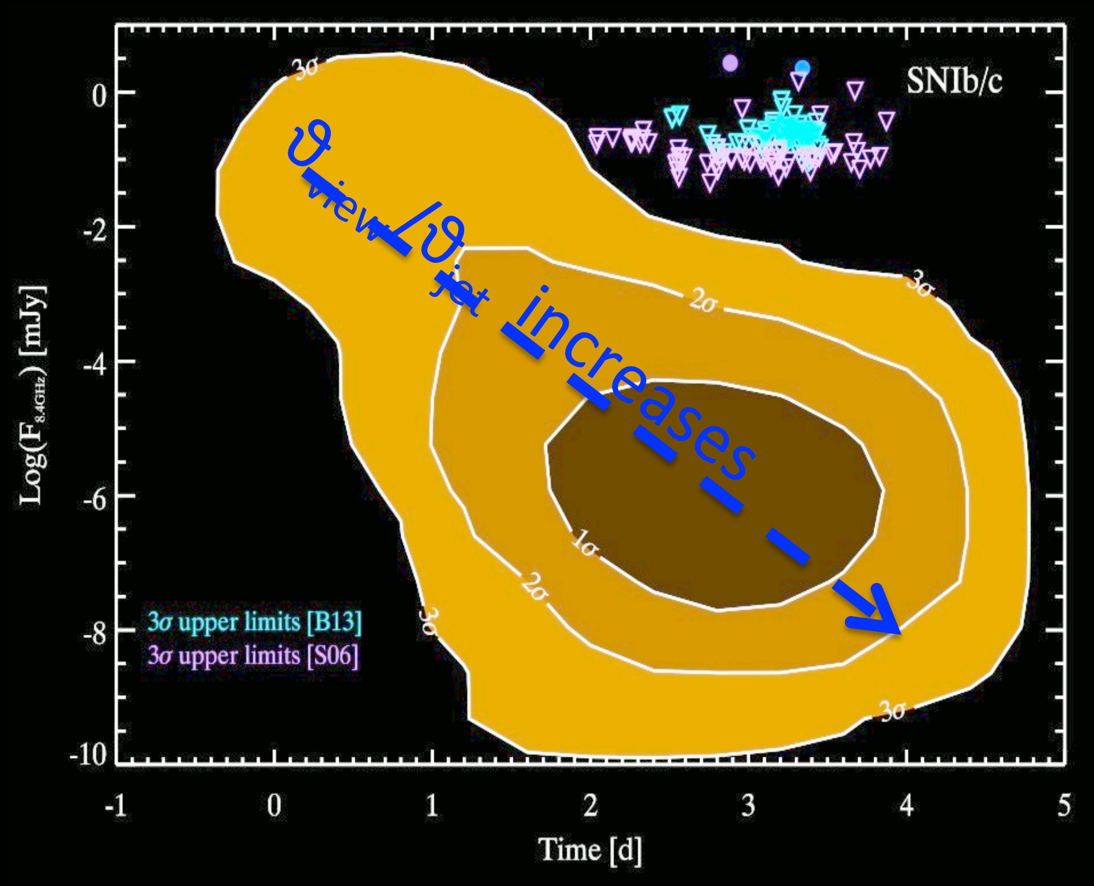
$$\mathbf{n}, \epsilon_{\mathbf{e}}, \epsilon_{\mathbf{B}}, \mathbf{p}, \mathbf{k}$$

*A. Canova (Louvre)*

Ghirlanda+2012, MNRAS; Ghirlanda+2013, MNRAS; Ghirlanda+2014,PASA; Ghirlanda+2015, A&A

# Orphan GRB population: DIM and SLOW transients

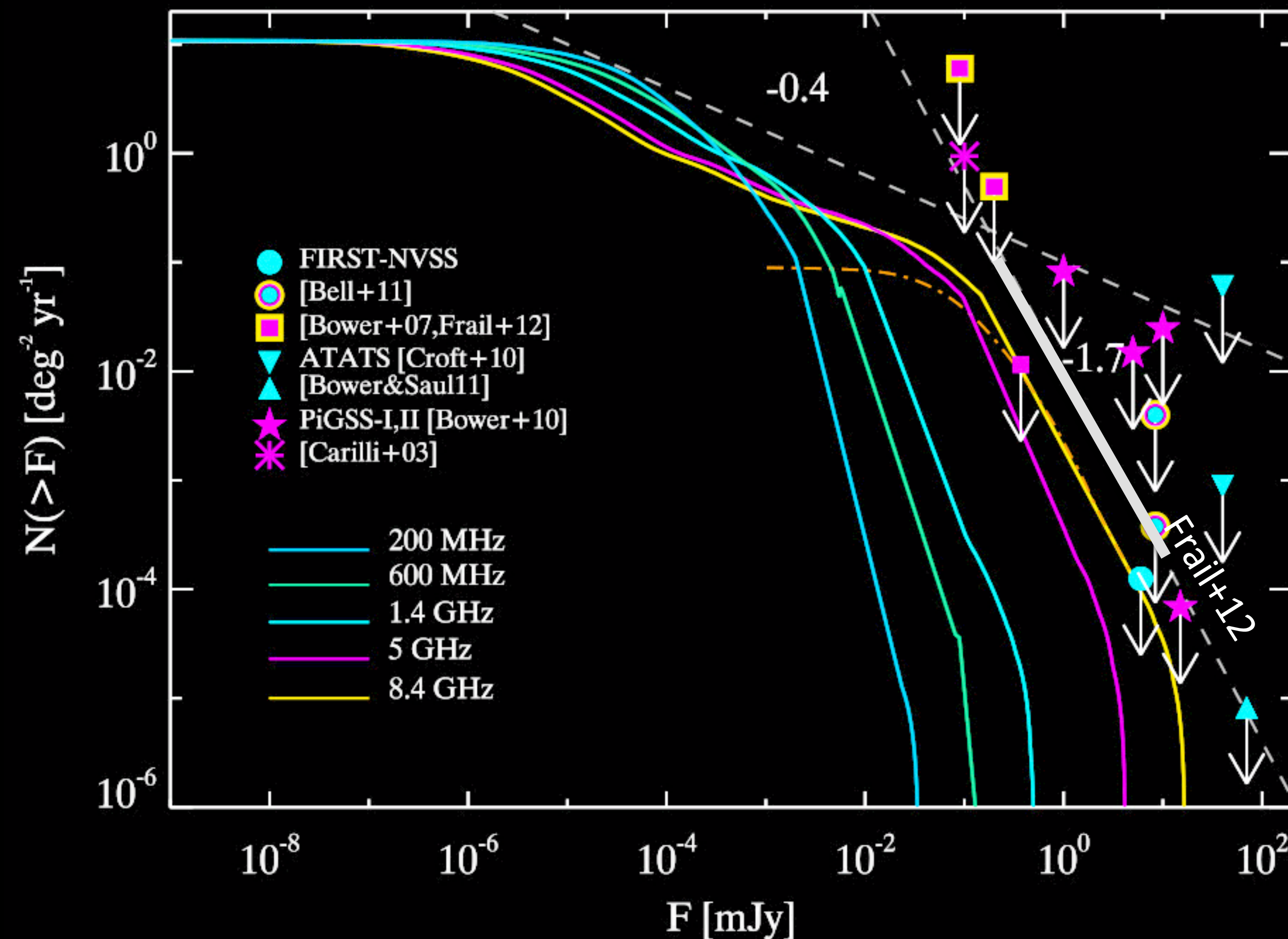



Ghirlanda et al. 2014, PASA

# Orphan GRBs

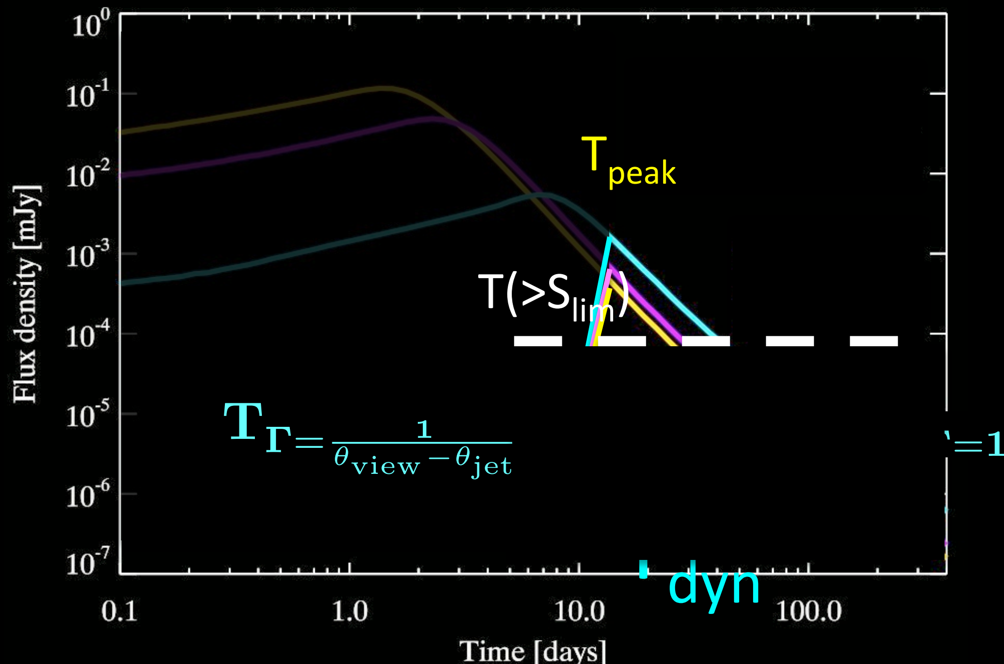
PSYCHE

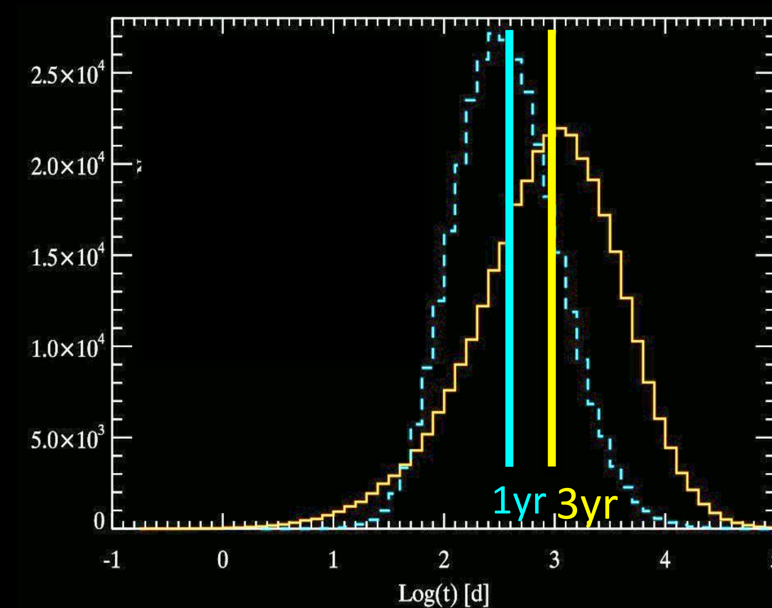


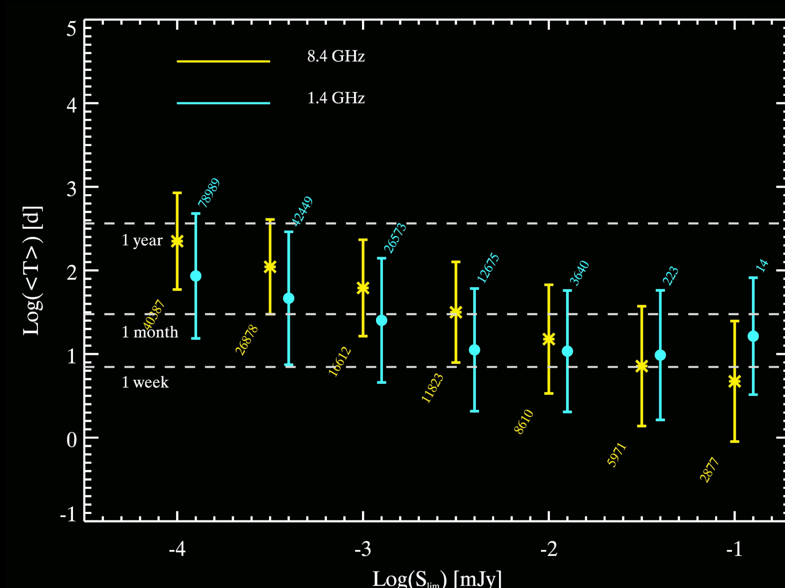

Ghirlanda et al. 2014 PASA

Simulated Orphan Afterglow population consistent with current radio upper limits (from surveys) and past estimates limited to the bright end of the flux distribution (e.g. Frail et al. 2012, Panaitescu et al. 2002; Rossi et al. 2008)

# Orphan Afterglows timescales




Average physical duration ($T_{dyn}$) = 1yr
Same order of time of peak
(with respect to T0, i.e. unknown)

Survey sensitivity → bias duration towards lower values

$$Ts \ll T_{dyn} \leq T_{peak}$$

PSYCHE

# Orphan GRBs: predicted detection rates

Radio surveys

Ghirlanda+2014

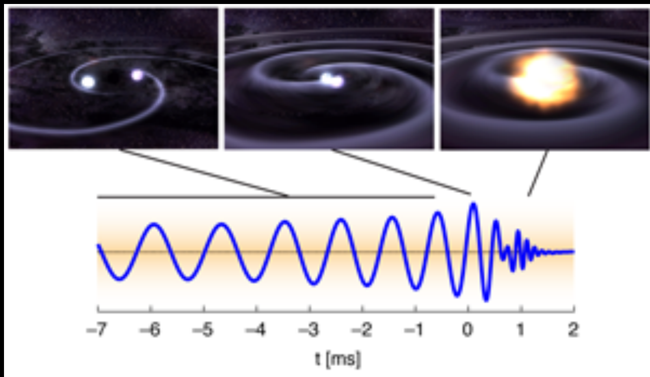
| Telescope name | $\nu$ [GHz] | $S_{\rm lim}$ [mJy] | Rate [$\rm deg^{-2}\ yr^{-1}$] |
|---|---|---|---|
| ASKAP | 1.4 | 0.05 | $3 \times 10^{-3}$ |
| MeerKAT/Ph1 | 1.4 | 0.009 | $10^{-1}$ |
| MeerKAT/Ph2 | 8.4 | 0.006 | $3 \times 10^{-1}$ |
| SKA/Ph1 | 1.4 | 0.001 | $6 \times 10^{-1}$ |
| SKA/Ph2 | 1.4(8.4) | 0.00015 | $1.5(2 \times 10^{-1})$ |
| WSRT/AperTIF | 1.4 | 0.05 | $3 \times 10^{-3}$ |
| EVLA | 8.4 | 0.005 | $3 \times 10^{-1}$ |
| LOFAR | 0.2 | 1.3 | ... |
| MWA | 0.2 | 1.1 | ... |
| GMRT | 0.6 | 0.1 | $10^{-5}$ |
| GMRT | 1.4 | 0.15 | $2 \times 10^{-4}$ |

Rate for a given sensitivity limit at 5σ significance

Number of OA [$yr^{-1}$] ~ Rate x Survey Coverage x Ts

| | | | |
|---|---|---|---|
| ~150 MHz (LOFAR, MWA) | LOFAR/MWA | 1500 $deg^2$ @ 0.12 mJy (rms) | No Orphan |
| 1.4 GHz | VAST-Wide<br>VAST-Deep-SF<br>SKA-1 SURV | $10^4$ $deg^2$ @ 0.5 mJy<br>30 $deg^2$/d @ 0.05 mJy<br>3x$10^3$ $deg^2$ @ 0.9 μJy | 1-2 $yr^{-1}$<br>0.5 $yr^{-1}$<br>380 $yr^{-1}$ |
| 3 GHz | VLASS-AS | 34000 $deg^2$ (2 ep) 0.12 mJy | 20 $yr^{-1}$ |

# Short Gamma Ray bursts (←→ GW)



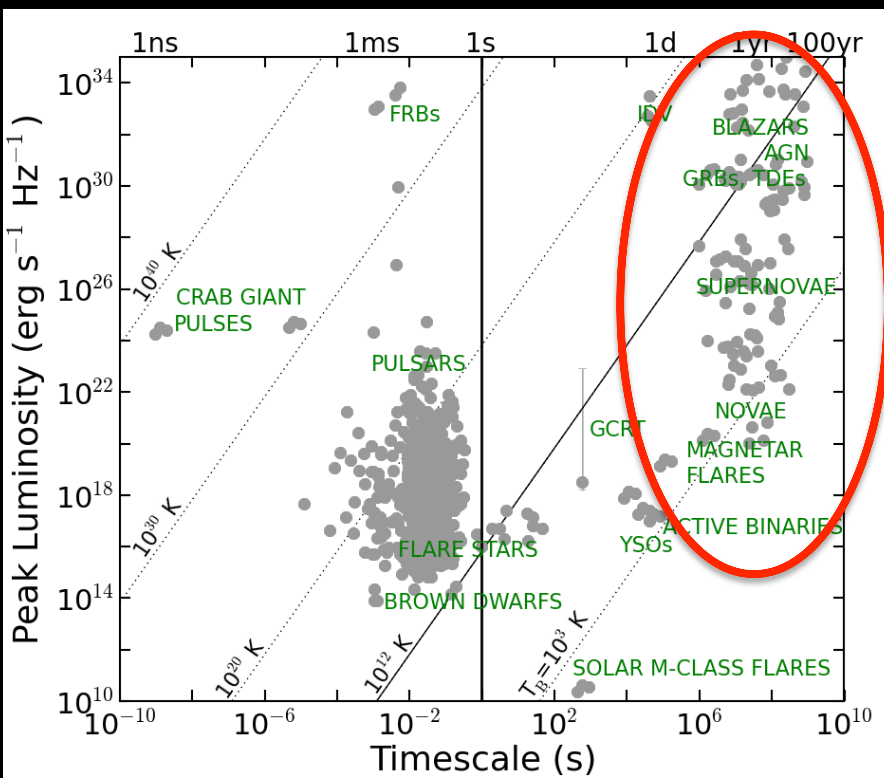

Current predictions for short are obtained by rescaling long GRBs by factors 10-100


PSYCHE extension to short GRBs in progress … more estimates to come soon. (GG+16, Salafia+2016)

| | LGRB On-Axis | LGRB θ=0.4 | LGRB θ=0.8 | LGRB θ=1.57 | LLGRB (SN 1998bw) | SGRB On-Axis | SGRB θ=0.4 | SGRB θ=0.8 | SGRB θ=1.57 | NSM Prompt BH | NSM Magnetar/AIC | TDE On-Axis | TDE Off-Axis | SN Ib/c | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SKA-Expanded | 2060 | 1300 | 1900 | 860 | 64 | 420 | 170 | 20 | 1 | 12 | 5200 | 8 | 240 | 2 | 1.3 GHz |
| SKA | 140 | 150 | 270 | 160 | 7 | 66 | 30 | 4 | 0.2 | 2 | 1090 | 3 | 72 | 0.8 | 1.3 GHz |
| SKA-Low | 5 | 12 | 45 | 320 | 18 | 22 | 28 | 28 | 7 | 48 | 6200 | 2 | 280 | 2 | 150 MHz |
| CMB-Stack2 | 32 | 8 | 0.4 | | | | | | | | 0.6 | 2 | 0.2 | | 150 GHz |
| CMB-Stack1 | 36 | 6 | 0.1 | | | | | | | | 0.2 | 0.9 | | | 150 GHz |
| CMB | 8 | 1 | | | | | | | | | | 0.2 | | | 150 GHz |
| VLASS-Deep | 0.5 | 2 | 2 | 0.3 | | 0.6 | 0.2 | | | | 2 | | 0.1 | | 3 GHz |
| VLASS-AS | 2 | 5 | 10 | 4 | | 2 | 0.9 | 0.1 | | | 48 | 2 | 13 | | 3 GHz |
| VAST-Deep-SF | | | 0.5 | | | | | | | | 0.4 | | | | 1.3 GHz |
| VAST-Deep | 1 | 4 | 12 | 13 | 0.2 | 2 | 1 | 0.2 | | 0.1 | 108 | 0.8 | 20 | | 1.3 GHz |
| VAST-Wide | | 0.2 | 0.4 | 0.4 | 0.4 | 0.1 | | | | | 6 | | 2 | | 1.3 GHz |
| LOFAR-E | | | | | | | | | | | 5 | | 0.2 | | 150 MHz |
| LOFAR | | | | | | | | | | | | | | | 150 MHz |

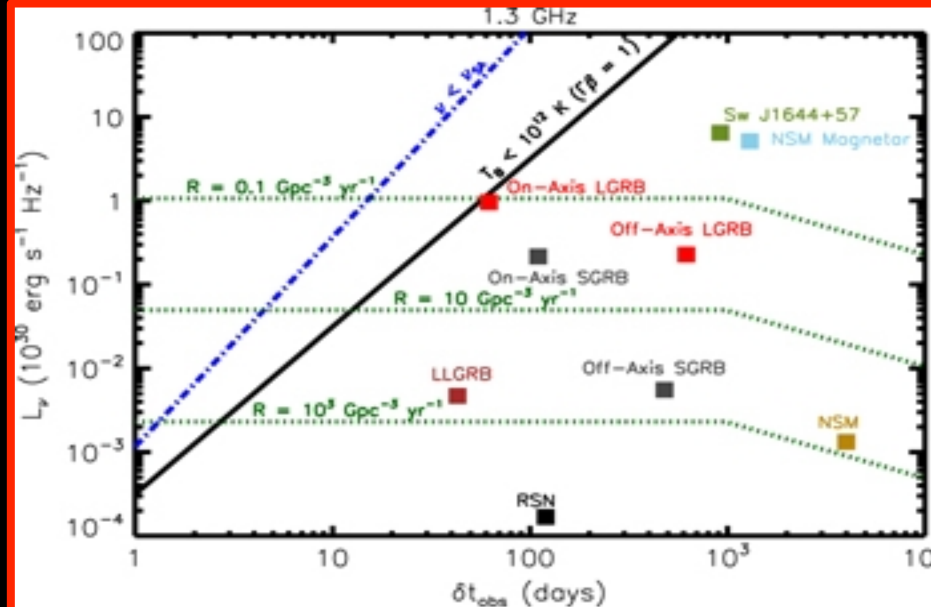
Metzger+2015

# Competing transients




K. Mooley (PhD Thesis)

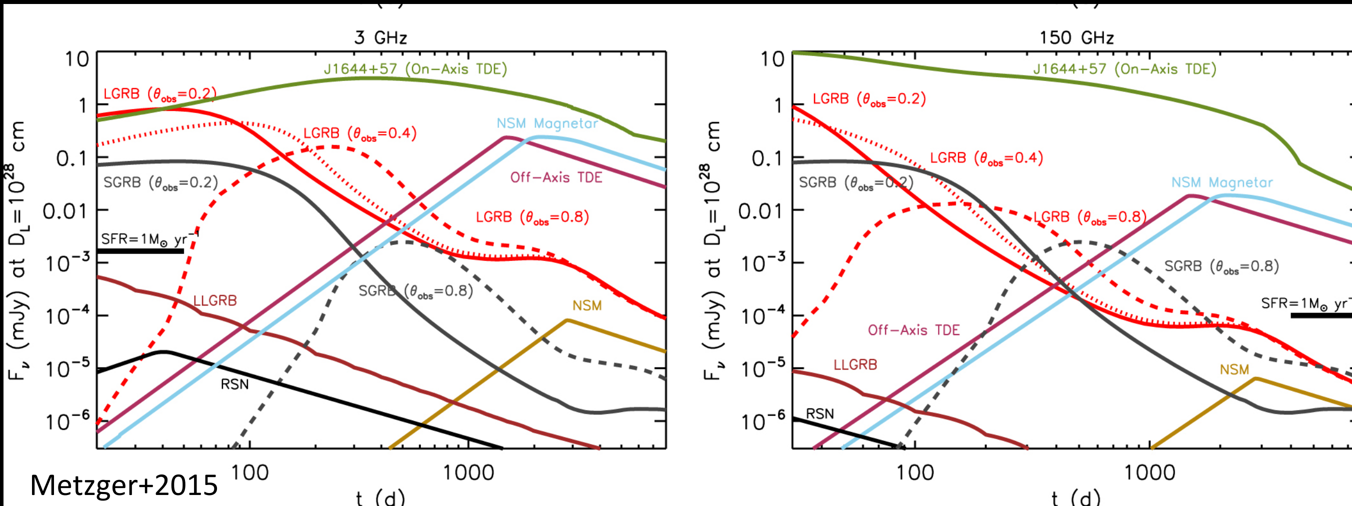
Extragalactic synchrotron radio transients




Metzger et al. 2015

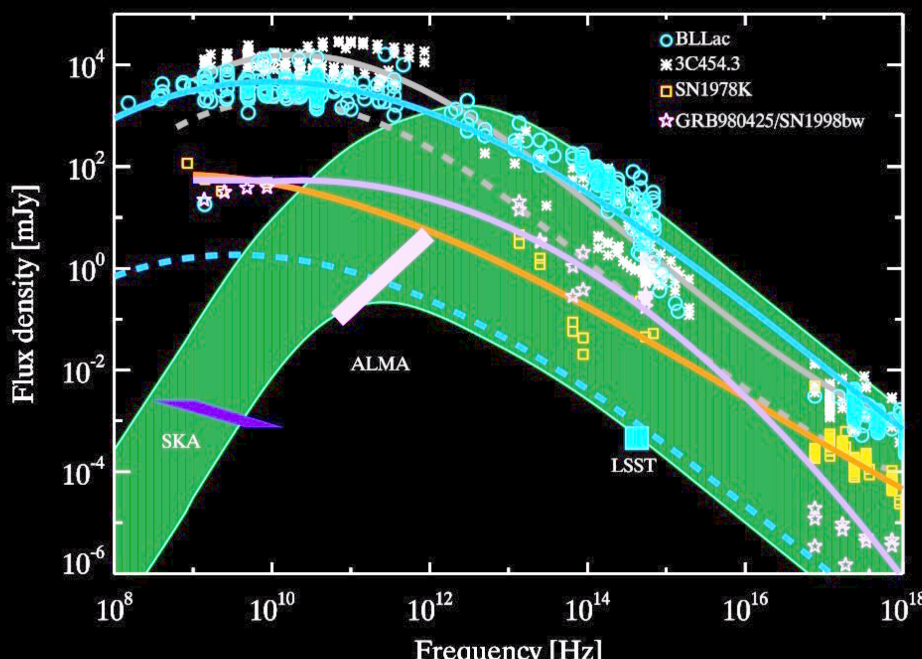
Four different source classes within two decades of duration and four orders of magnitude in luminosity

# Classification problem




Metzger+2015

Time domain: follow up could help (but not alone) to classify




Ghirlanda+2015

Spectral characterization:

1) Optical spectra (features)
2) Broad band SED → mm and radio peculiarities
3) If distance is known (e.g. spectro-z) → energetic argument

# Conclusions

Orphan Afterglows (OA): GRBs without Gamma-ray detected emission

- Natural consequence of GRBs being jetted-relativisitic sources
- Outnumber GRBs (i.e. OA = 100-200 x GRBs)

GRBs and OA form a continuus population (same progenitors, physics) … only an orientation effect.

PSYCHE → characterizing OA properties:

- Sub-mJy
- slow (several months – years transients)

OA detection in the radio: VAST-W (few) … VLASS (>few) … → SKA SURV (hundreds)

Combined temporal and spectral studies (e.g. SED) to identify them among competing extragalactic transients