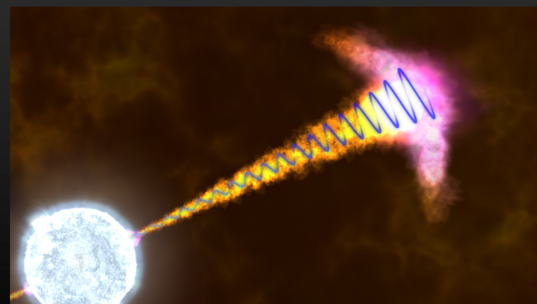
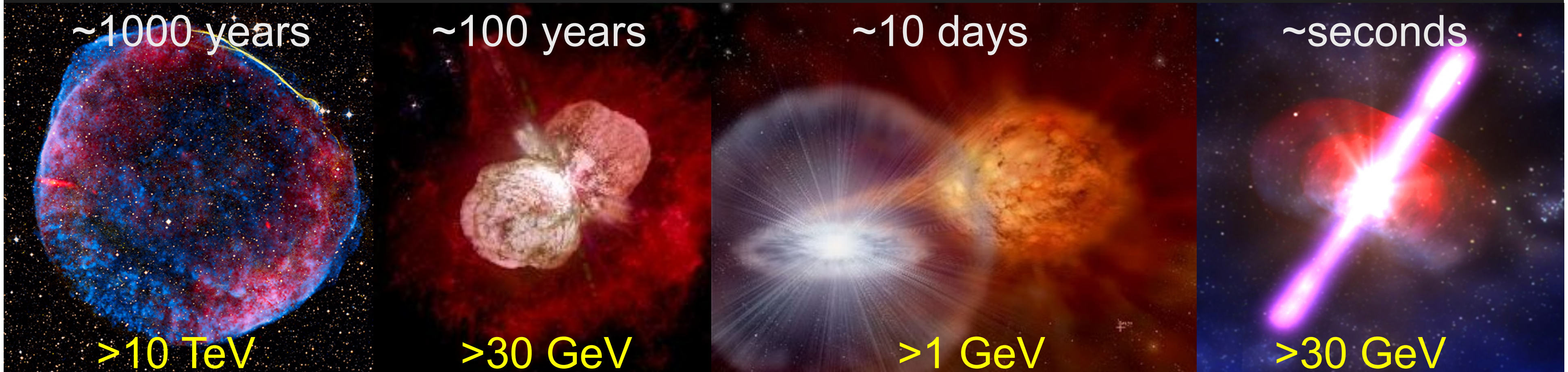
Fast Transients in the SKA Era

Carole Mundell



High-energy Transients

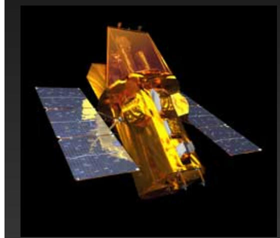
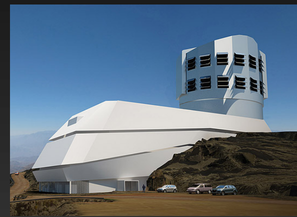


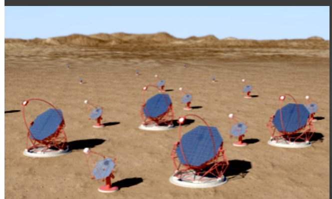
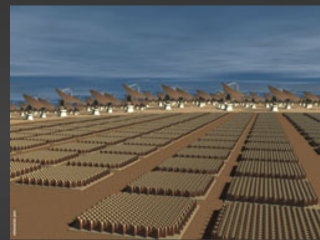
- Explosive events in distant Universe
  - Timescales down to seconds so far…
  - Many black-hole driven processes
  - Time-dependent probes of space-time
  - Discovery plus follow-up key but challenging

Fast Transients

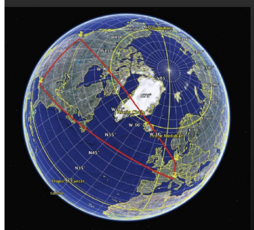
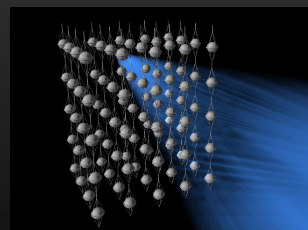
- Gamma Ray Bursts
- AGN flares
- Choked jets/failed GRBs
- Fast radio bursts
- Compact binary mergers
- Gravitational wave counterparts
- Supernovae (shock breakout)
- Soft Gamma Ray Repeaters
- Tidal disruption events

Non-thermal transients

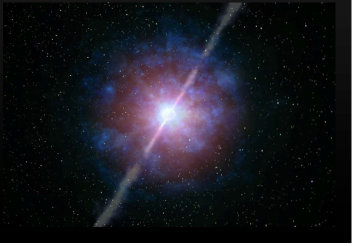



- Extreme physics
  - Strong gravity
  - High Lorentz factors
  - Large magnetic fields
- Jet physics/emission mechanisms
- New observational windows
  - the multi-messenger landscape
- GRBs as a working example

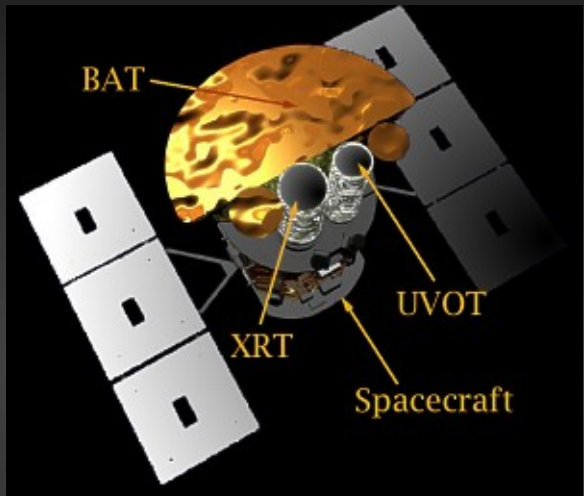



Localisation and Response

- Identification and localisation
- Trigger and response
- Distance and classification
- Multi-messenger followup is key
- Gamma ray bursts as case study…

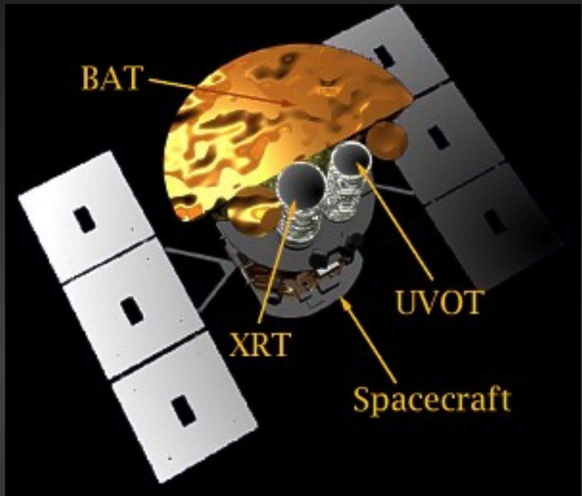


2004 - Era of Rapid Followup



- Dedicated GRB satellite: SWIFT
  - Burst Alert Telescope (BAT): 15-150 keV
  - X Ray Telescope (XRT): 0.3-10 keV
  - Ultraviolet Optical Telescope (UVOT): 150-650 nm
- Real-time GRB sky map at: **http://grb.sonoma.edu/**

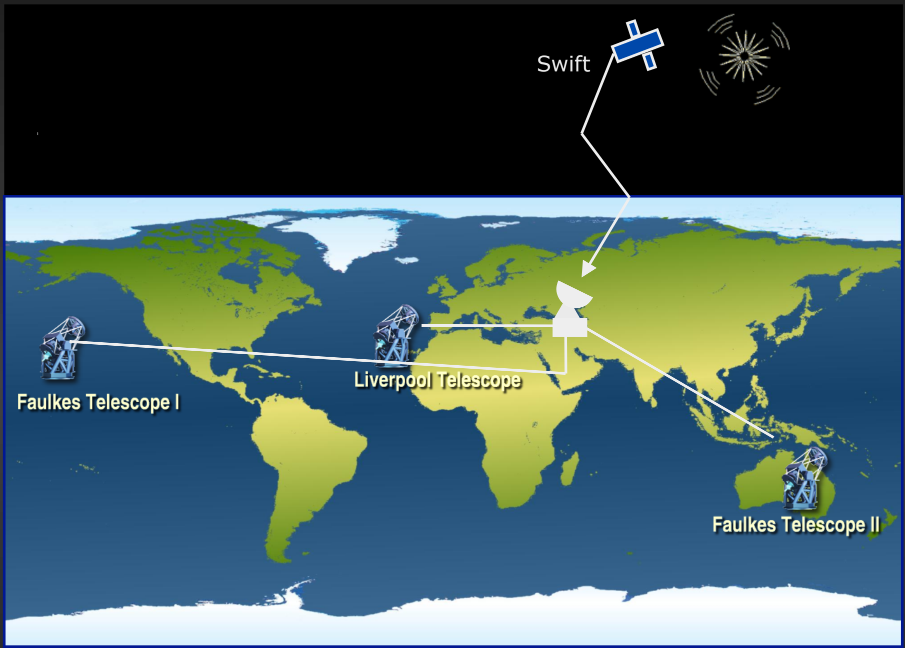
2004 - Era of Rapid Followup

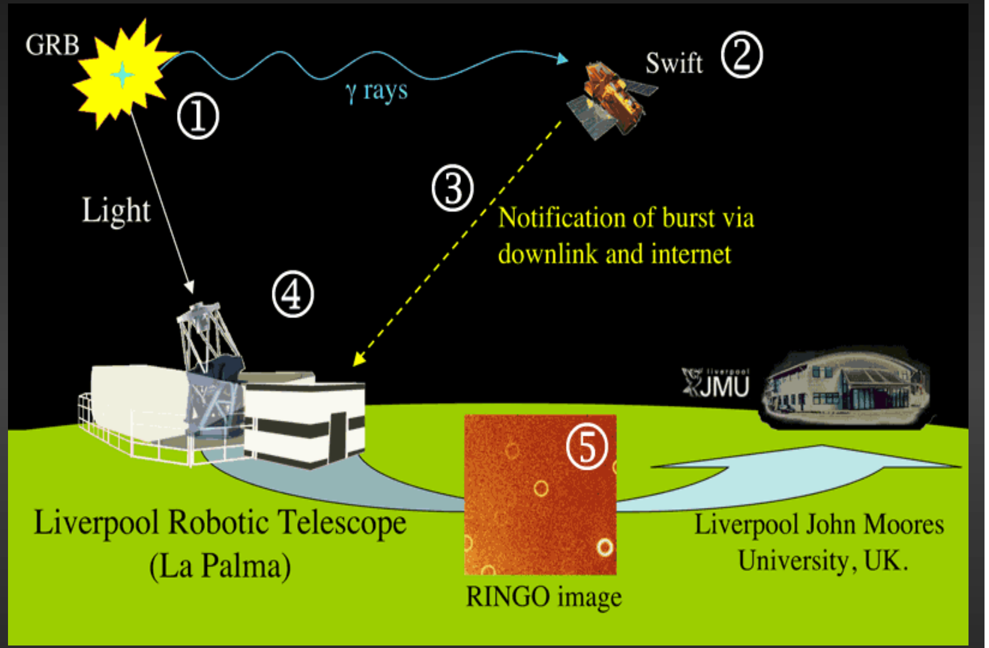


> 1000 GRBs discovered in past decade

- Dedicated GRB satellite: SWIFT
  - Burst Alert Telescope (BAT): 15-150 keV
  - X Ray Telescope (XRT): 0.3-10 keV
  - Ultraviolet Optical Telescope (UVOT): 150-650 nm
- Real-time GRB sky map at: **http://grb.sonoma.edu/**

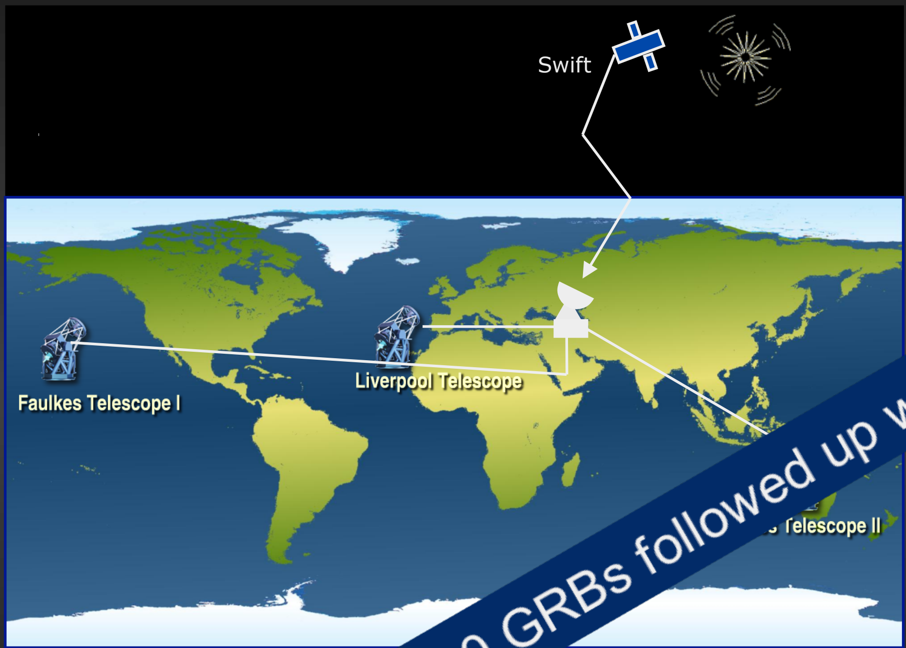
GRB Robotic Followup

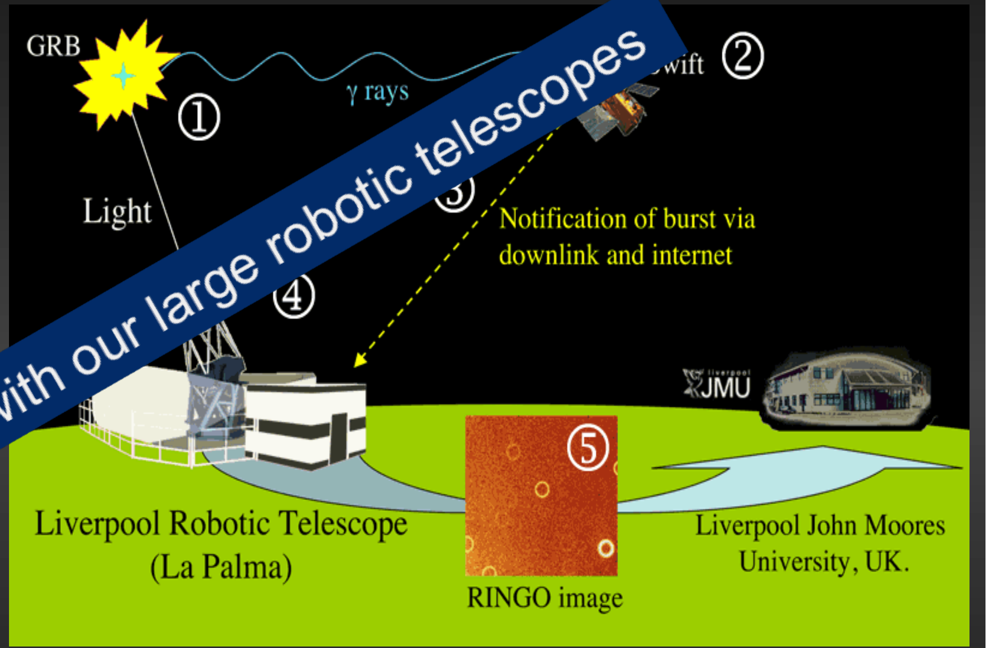




- Optimisation for GRB science goals:
  - Immediate automatic response (over-ride), data analysis & interpretation strategy
  - No human intervention from receipt of alert ➜ observations ➜ automatic object ID ➜ choice and execution of subsequent observations

GRB Robotic Followup

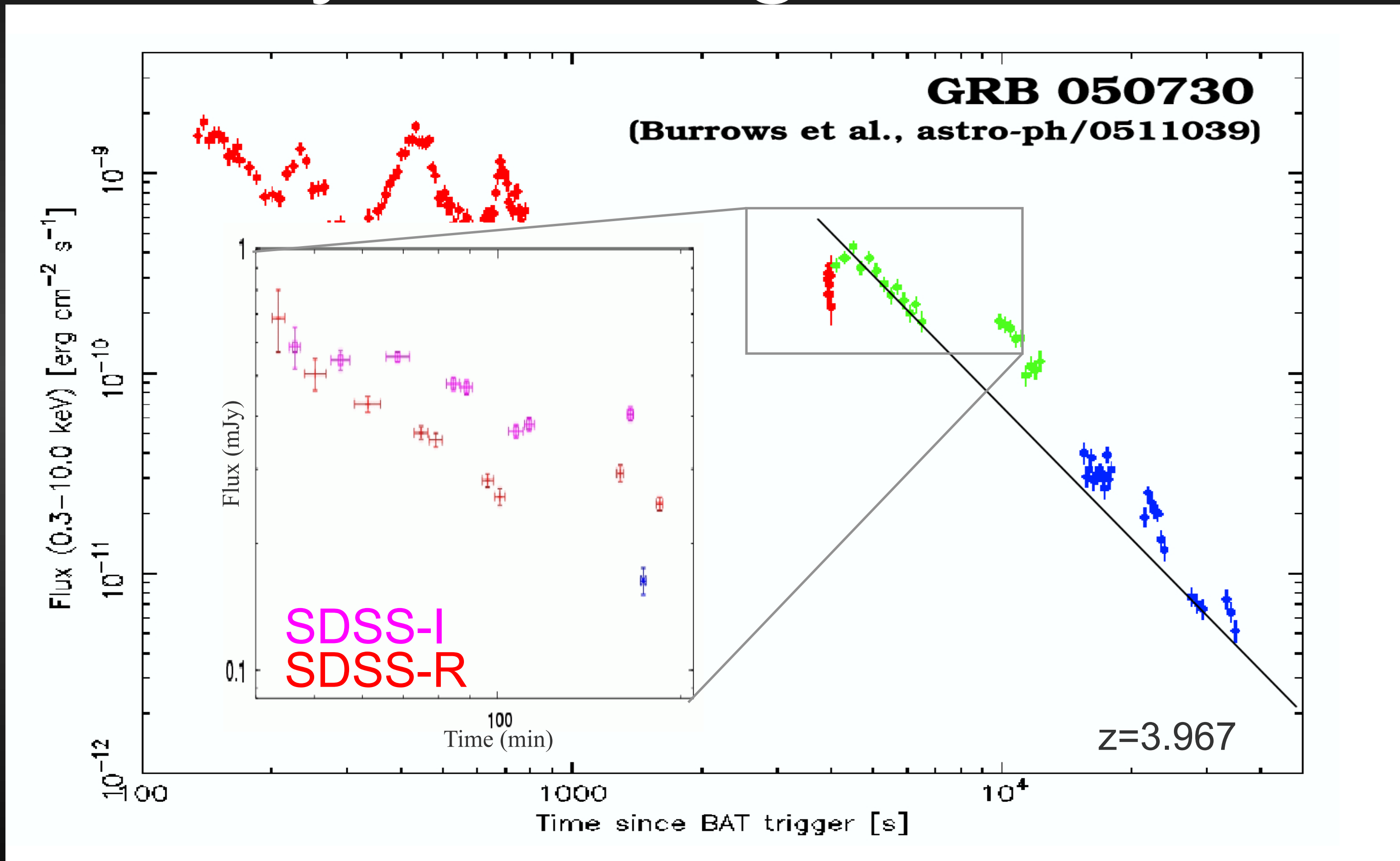




> 220 GRBs followed up with our large robotic telescopes

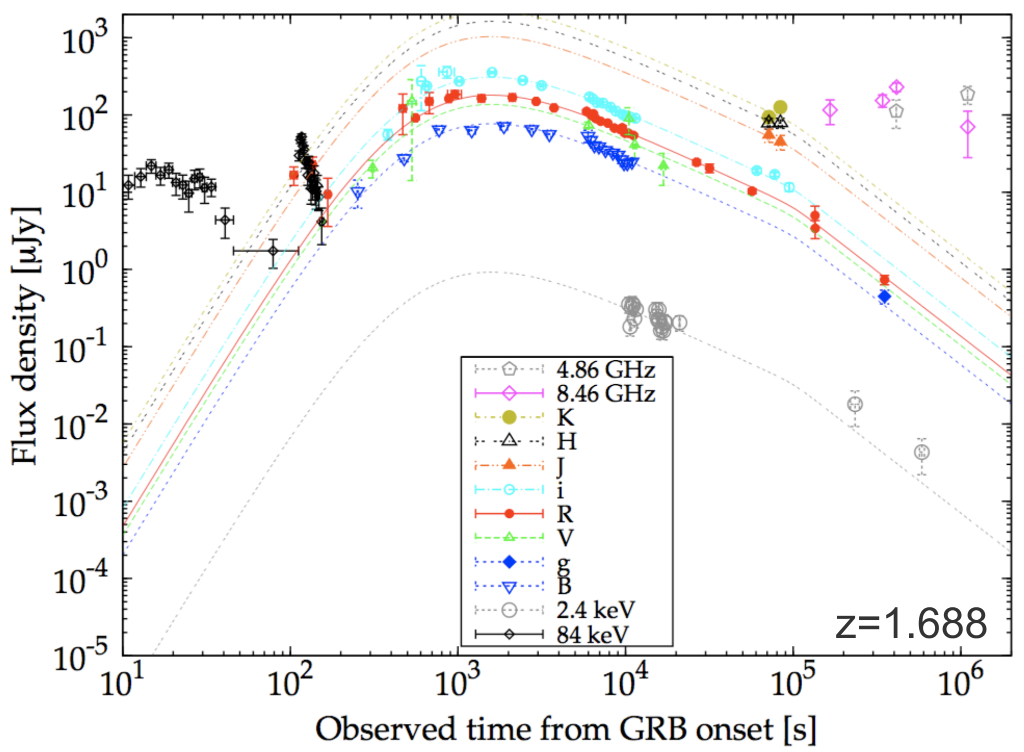
- Optimisation for GRB science goals:
  - Immediate automatic response (over-ride), data analysis & interpretation strategy
  - No human intervention from receipt of alert ➜ observations ➜ automatic object ID ➜ choice and execution of subsequent observations

Early-Time Light Curves

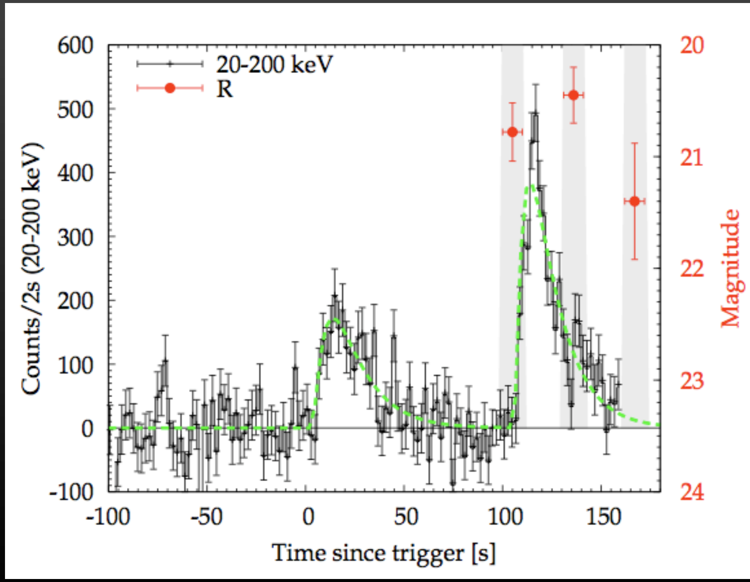


Optical/X-ray flares; energy injection and long-lived central engines a surprise (Monfardini+06, ApJ, 648, 1125; Melandri+09, MNRAS, 395, 1941)

GRB 080603A

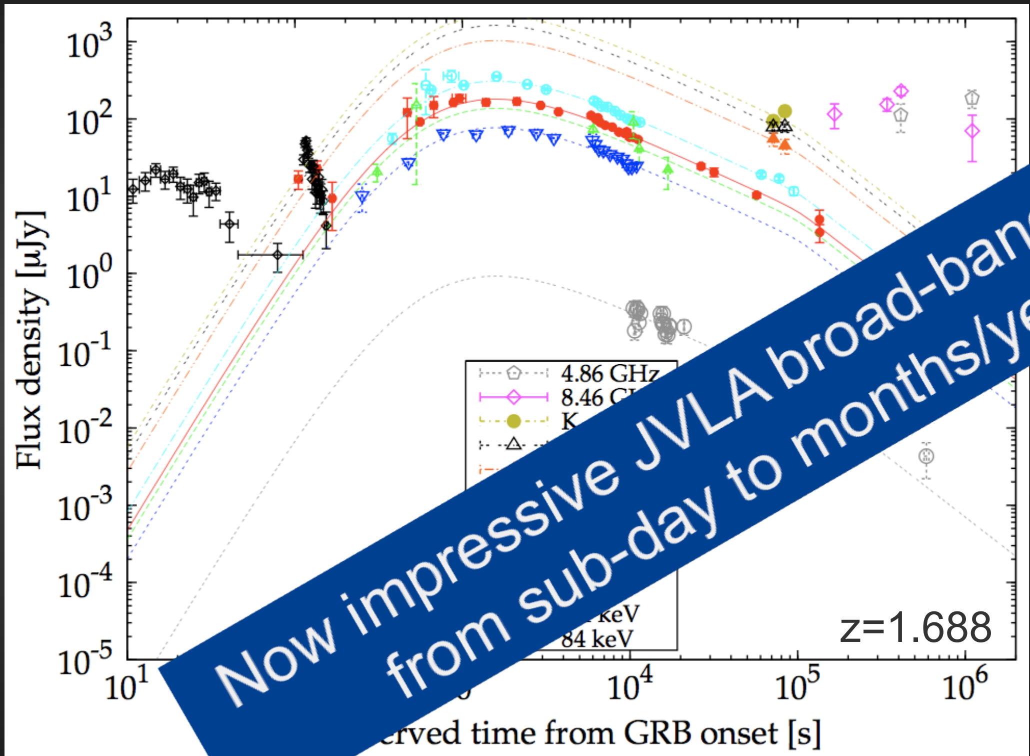


Gamma to radio light curves
T= -100 sec to 23 days
Direct estimates of Γ
Compare with gamma and neutrino estimates



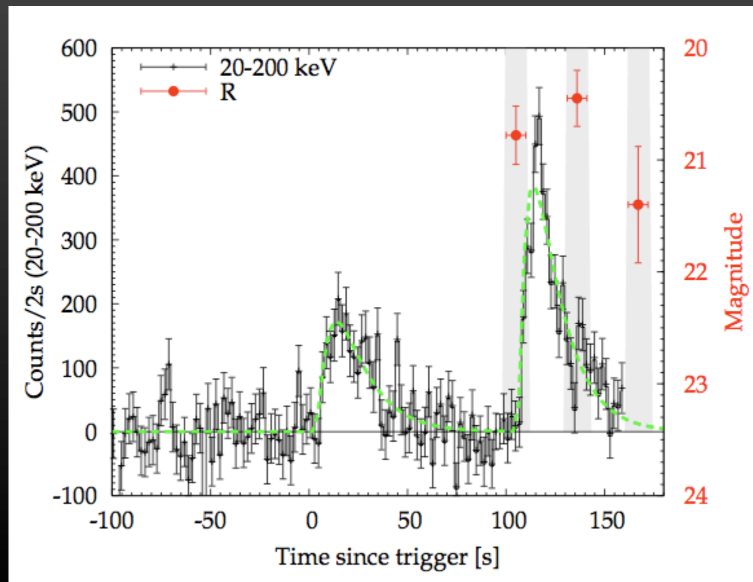
Guidorzi+11, MNRAS, 417, 2141

GRB 080603A



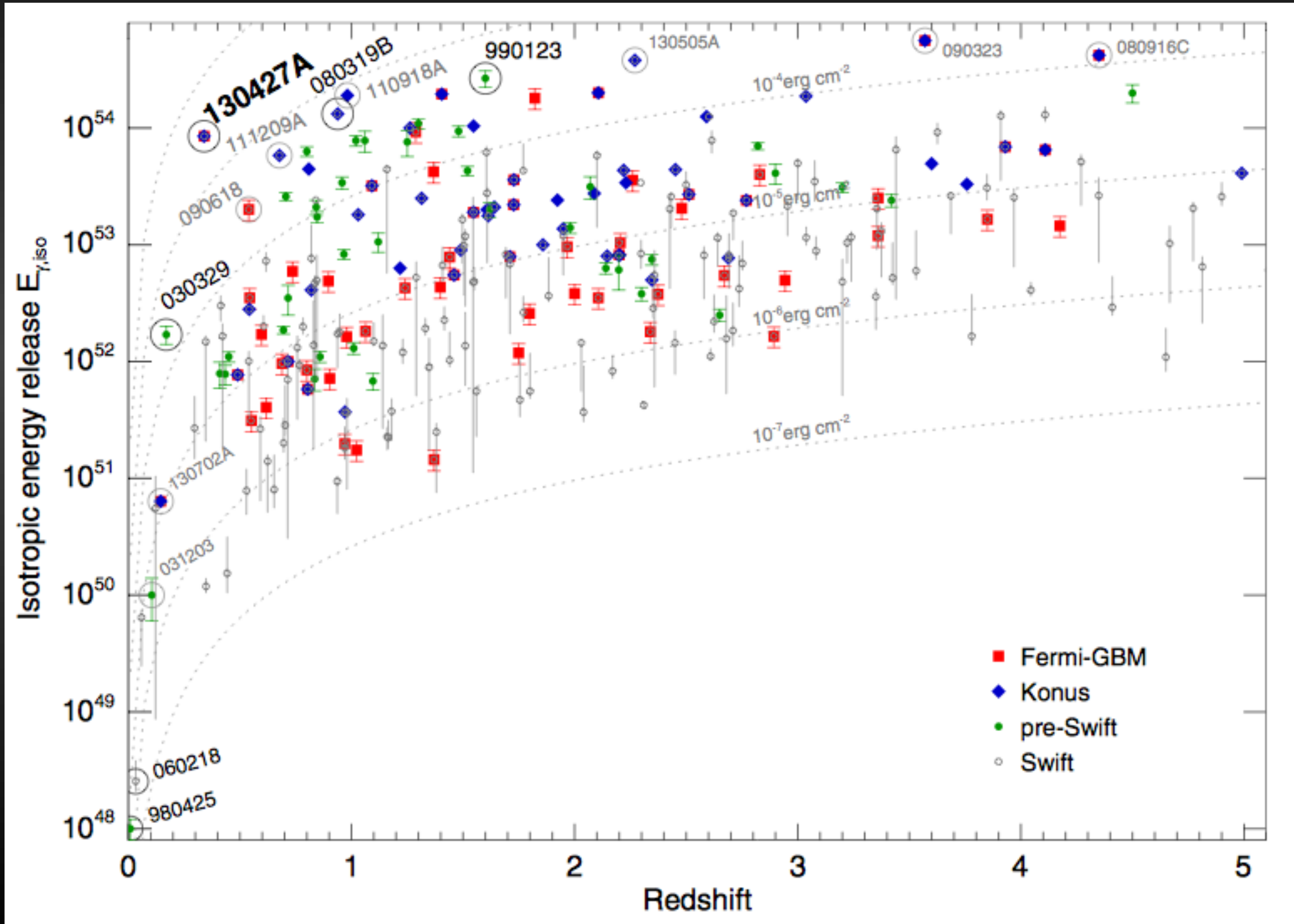
Now impressive JVLA broad-band SED monitoring from sub-day to months/years post burst

- C... ...o light curves
- ... sec to 23 days
- ...irect estimates of Γ
- Compare with gamma and neutrino estimates



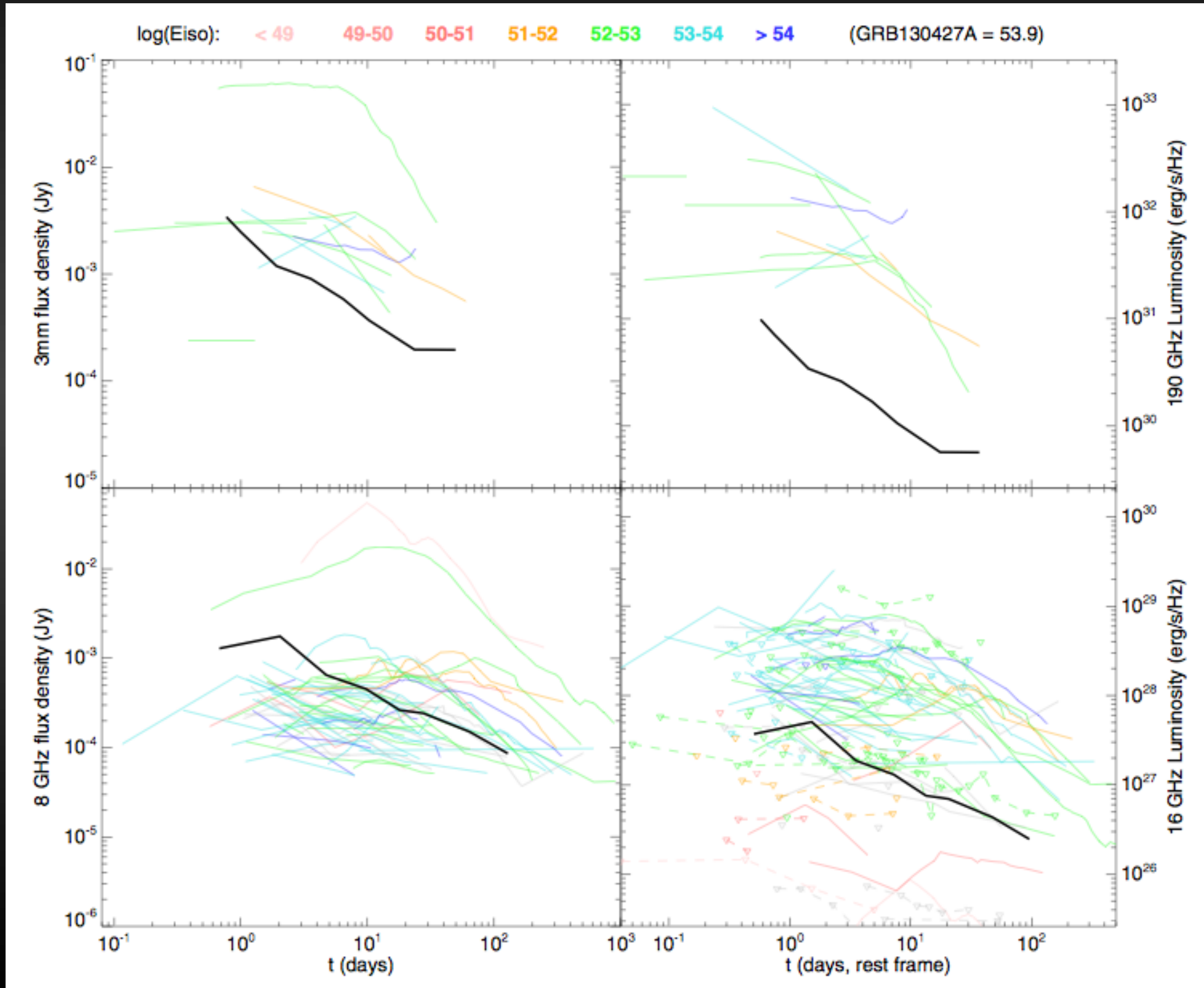
Guidorzi+11, MNRAS, 417, 2141

GRB 130427A



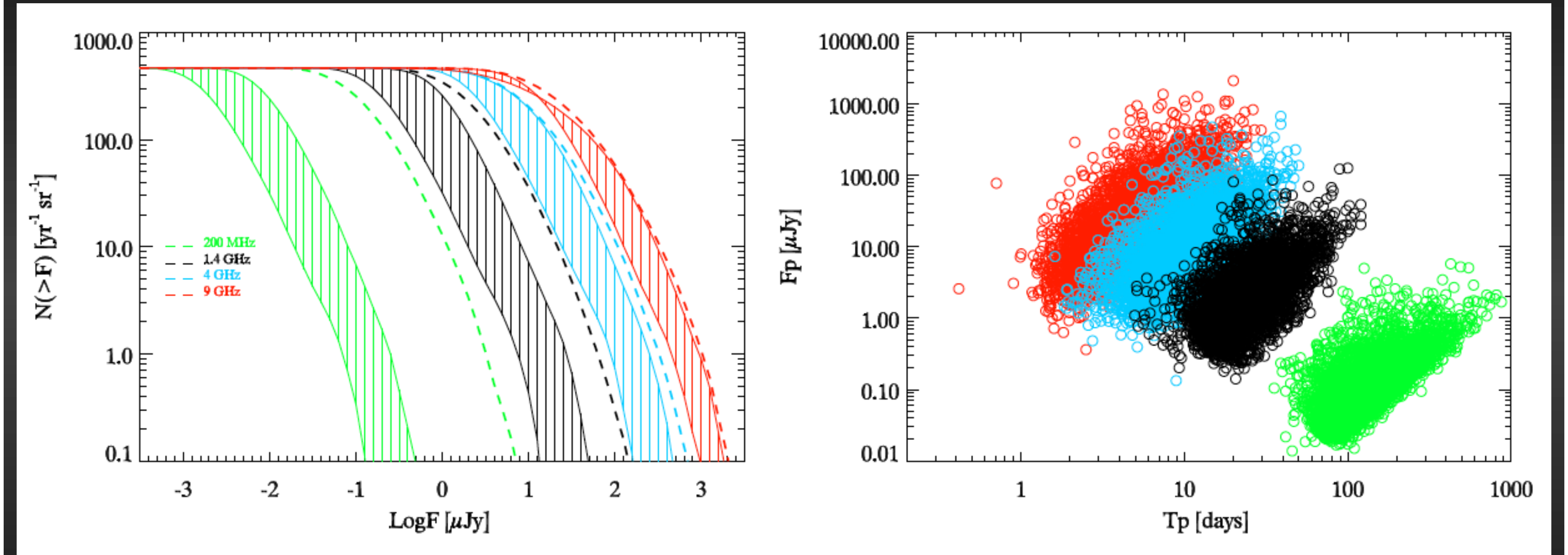
Perley+14, ApJ, 781, 37

GRB 130427A



Perley+14, ApJ, 781, 37

GRBs with the SKA?



Cumulative afterglow flux distribution

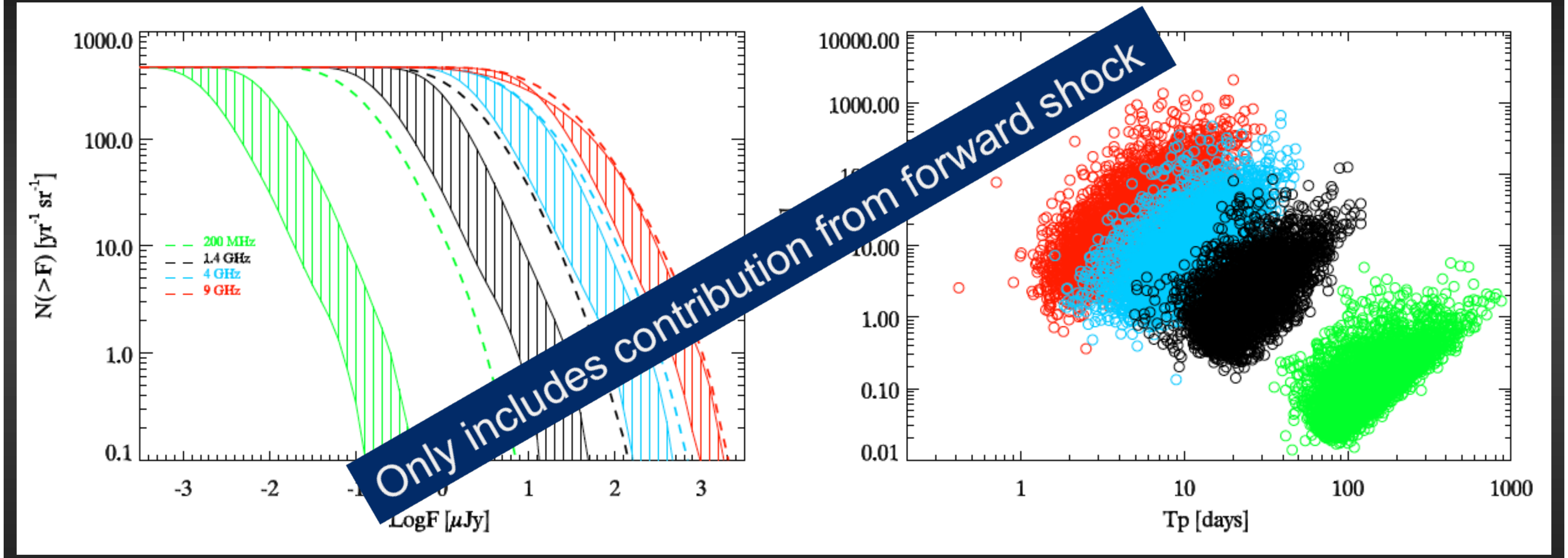
Afterglow peak flux vs peak time

Shaded = 2 – 10 days

\- - - = peak time

Burlon et al. 2015

GRBs with the SKA?



Cumulative afterglow flux distribution

Afterglow peak flux vs peak time

Shaded = 2 – 10 days
- - - = peak time

Burlon et al. 2015

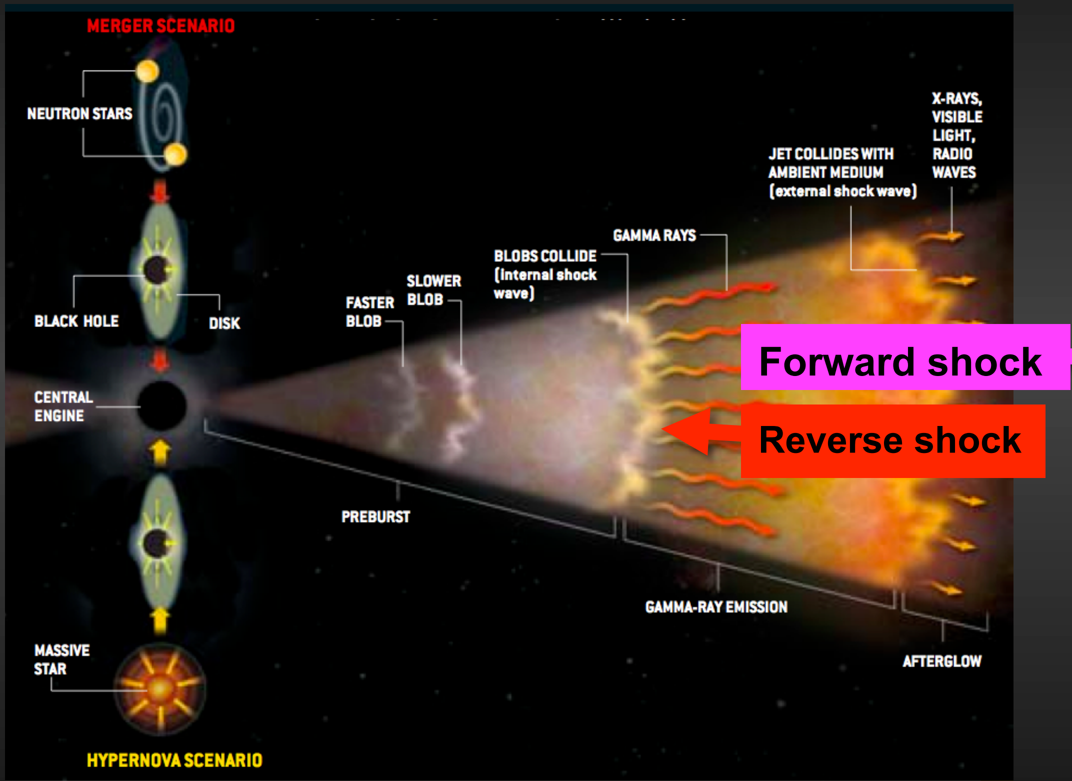
Fireball Magnetization

- Standard (internal shock) synchrotron model
  - Baryon-dominated jet creates tangled B-field in shock layer
  - Inefficient conversion of bulk:radiated energy
- Alternative: Poynting flow
  - Large-scale ordered magnetic fields in flow
  - Powerful acceleration and collimation
- Origin of magnetic fields unknown
  - Energy dissipation key for explosion energetics
  - Energy transfer details still unknown

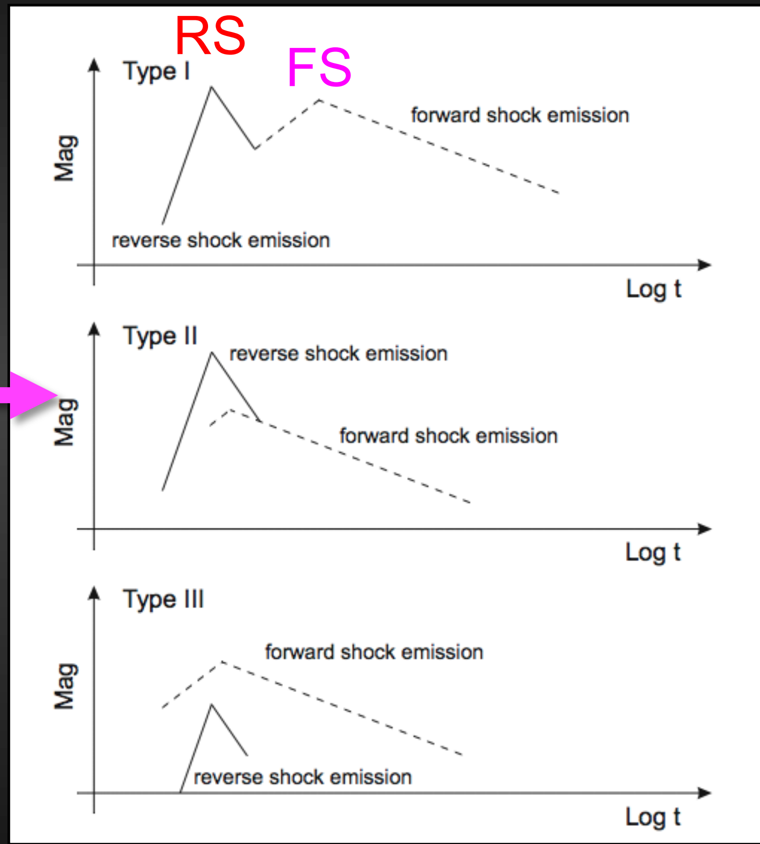
Model Afterglow Predictions

- Reverse shock = *polarised*
- Forward shock = low or no polarisation

Short



Long



Gomboc et al. 2009

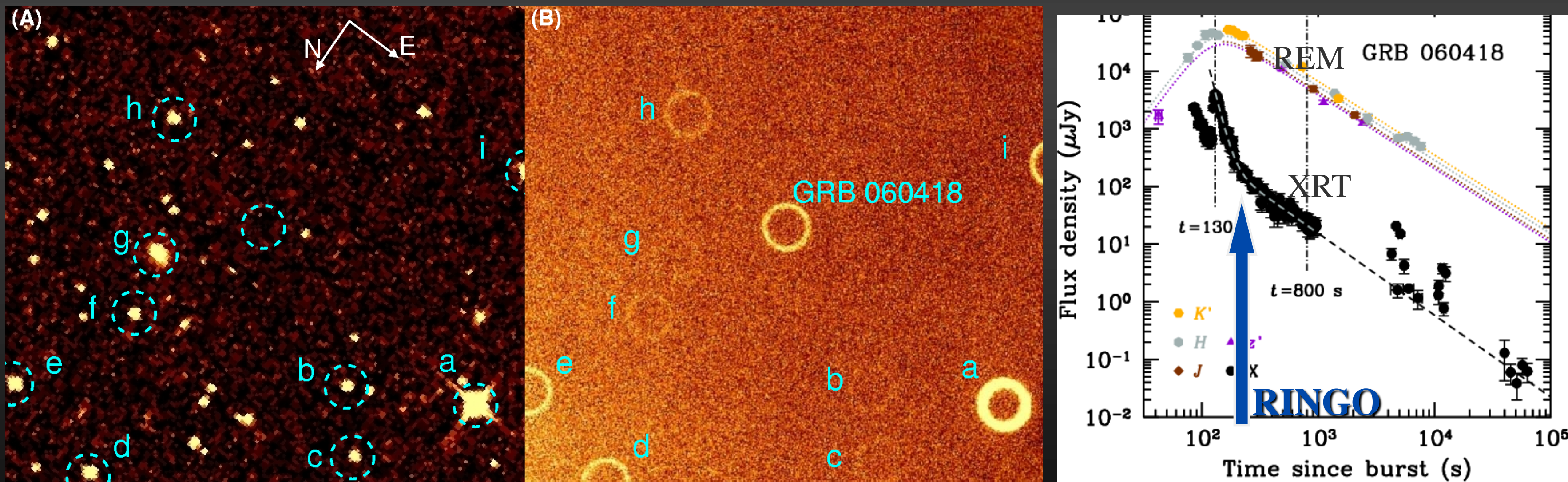
Observe early to glimpse primordial magnetic fields from central engine

Degree of magnetisation from relative strengths of RS/FS

(Gomboc+09, AIPC, 1133, 145; Harrison & Kobayashi 2013 ApJ, 772, 101)

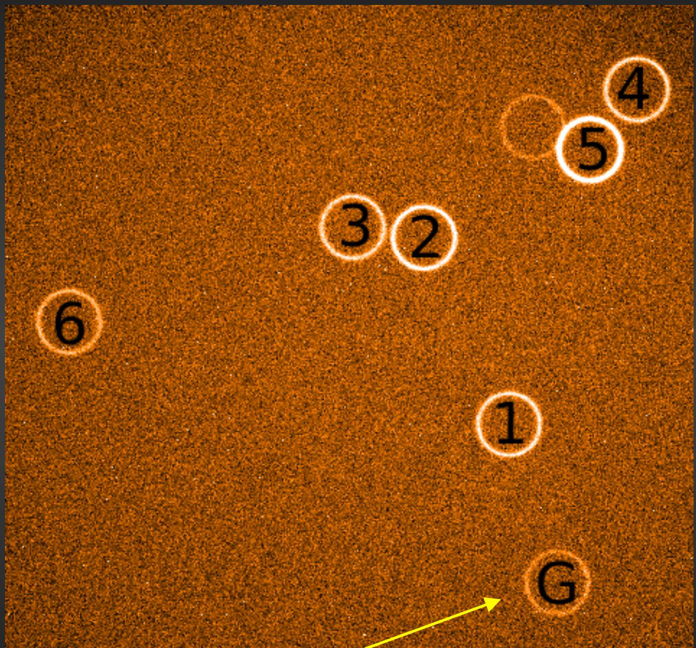
GRB 060418

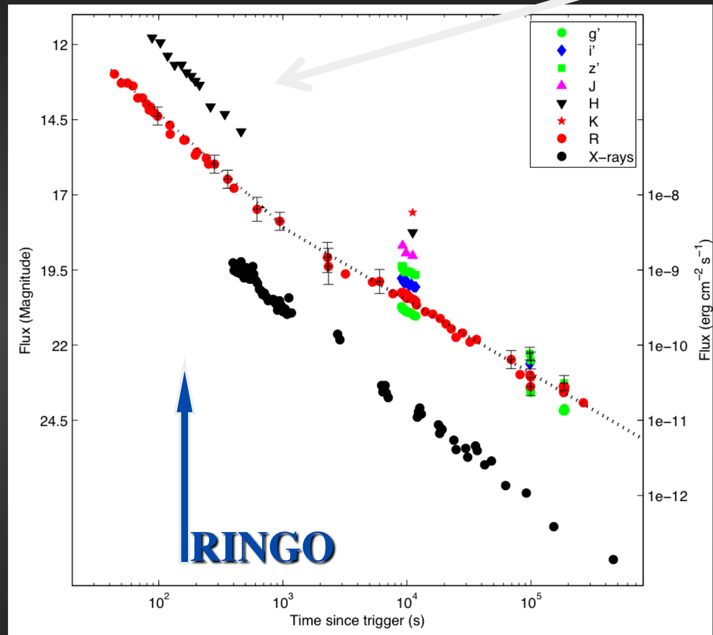
- RINGO polarimetry of GRB 060418 at ***t = 203 sec***
    - Measurement coincided with deceleration of fireball
        - (Γ_0~400; R_{dec}~ 10^{17}) cm
    - Strongly-constrained upper-limit: **P<8%**
    - Equal contribution from forward and reverse shocks



Steele et al. 2006, SPIE, 6269 ,179;
Mundell et al. 2007, Science, 315, 1822

GRB 090102



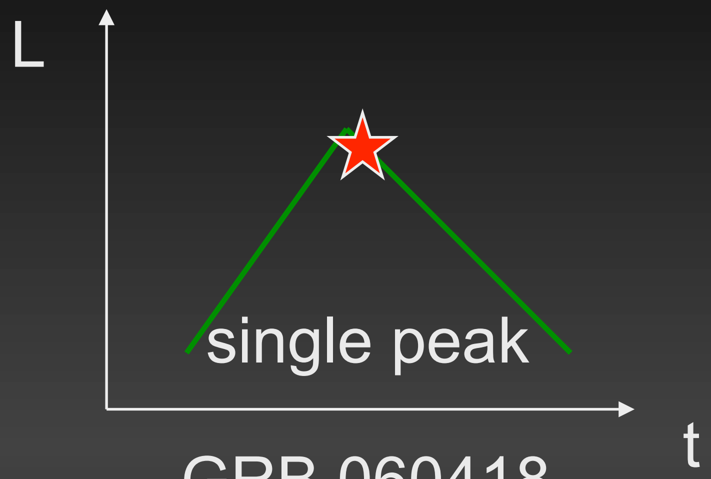


- 60-s RINGO exposure began ***t = 160 s*** post-burst
- Stars in field provide additional calibration
- First detection of optically polarized GRB afterglow **P=10.2 ±1.3%**

Steele et al. 2009, Nature, 462, 767

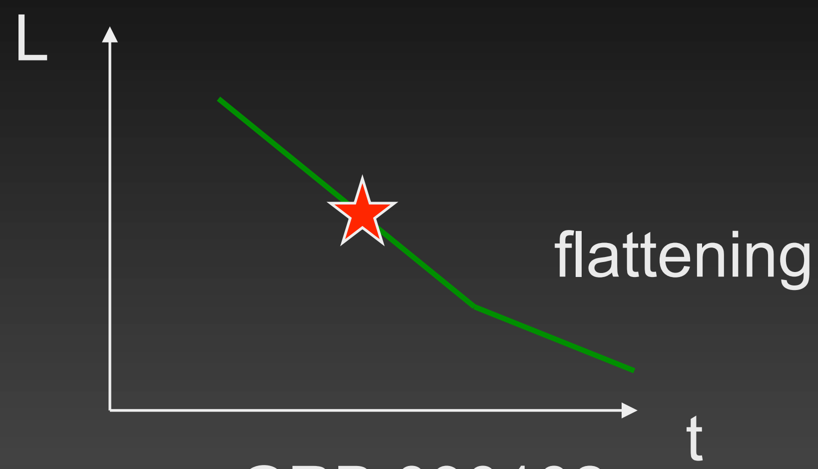
Interpretation and Unification

Mundell et al. Science 2007



GRB 060418
P < 8%

Steele et al. Nature 2009



GRB 090102
Detection: 10.2%

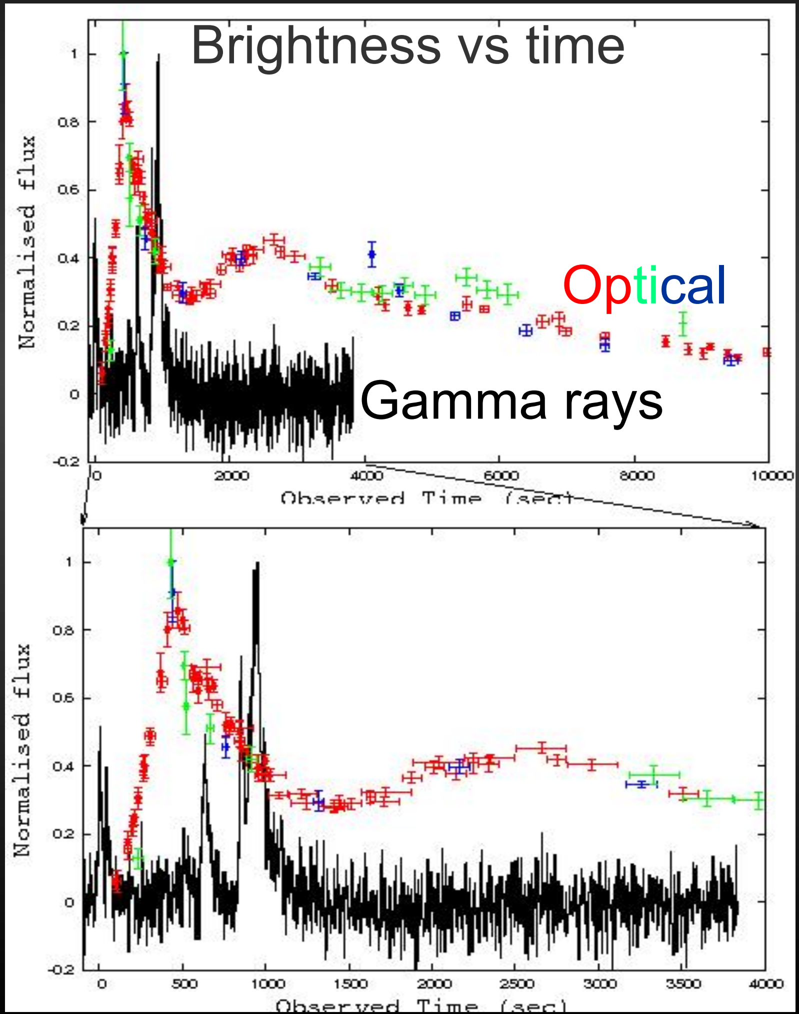
Ordered magnetic fields plus ratio of magnetic to kinetic energy flux, $\sigma \sim 0.1$

GRB 060418: σ slightly higher to suppress RS

GRB 090102: σ slightly lower for bright RS

Or, each has completely different B-field structure (sample of 2!)

Temporal Coverage

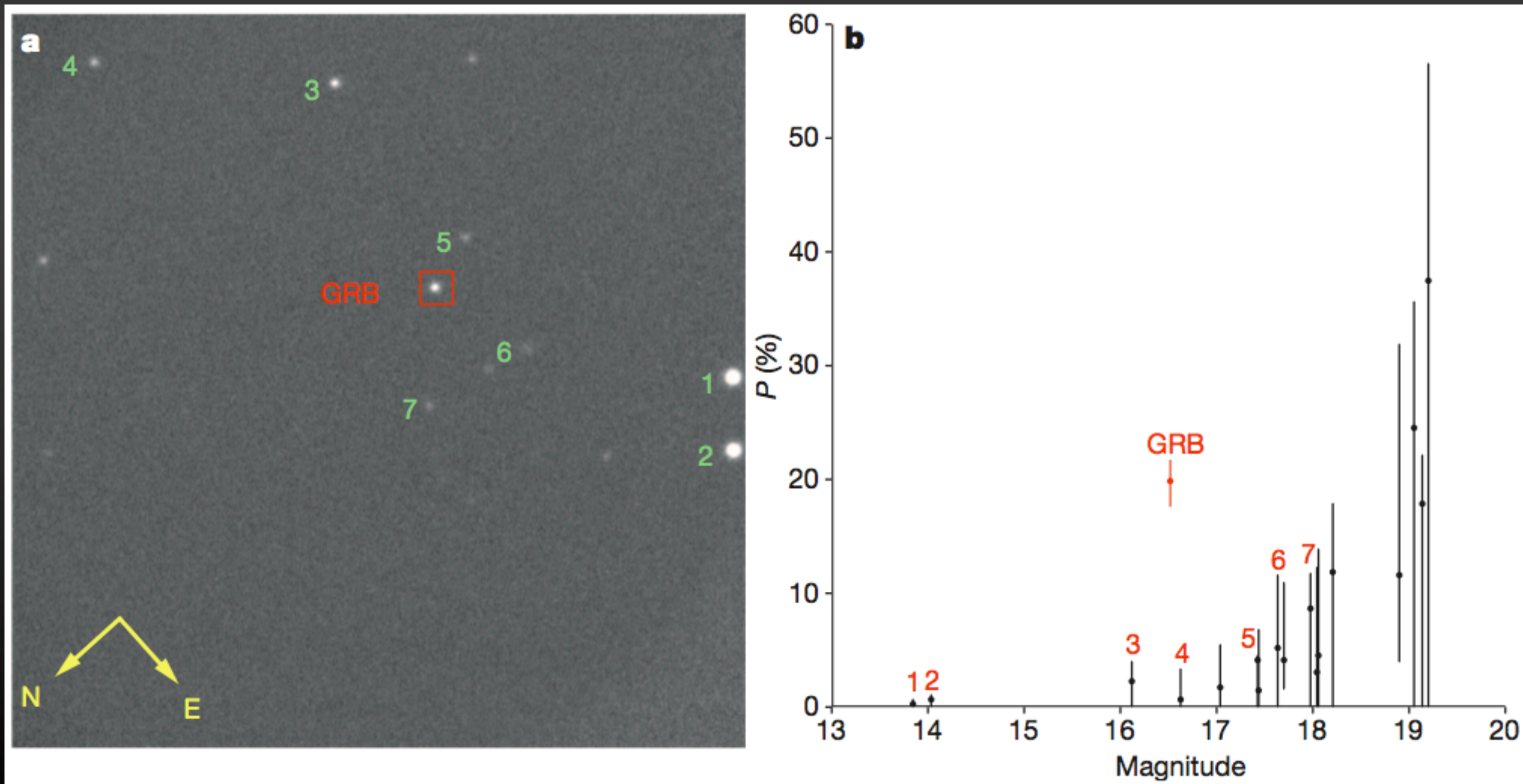


Virgili et al. 2013, ApJ, 778, 54

- Complex light curves
- *Single-shot inadequate*
- *Time-resolved* polarimetry
- Recycled RINGO into: RINGO2
  - fast read-out EMCCD
  - Polaroid 8 rotations per sec
  - 125 millisecond exposures
  - Images not rings!

GRB 120308A with RINGO2

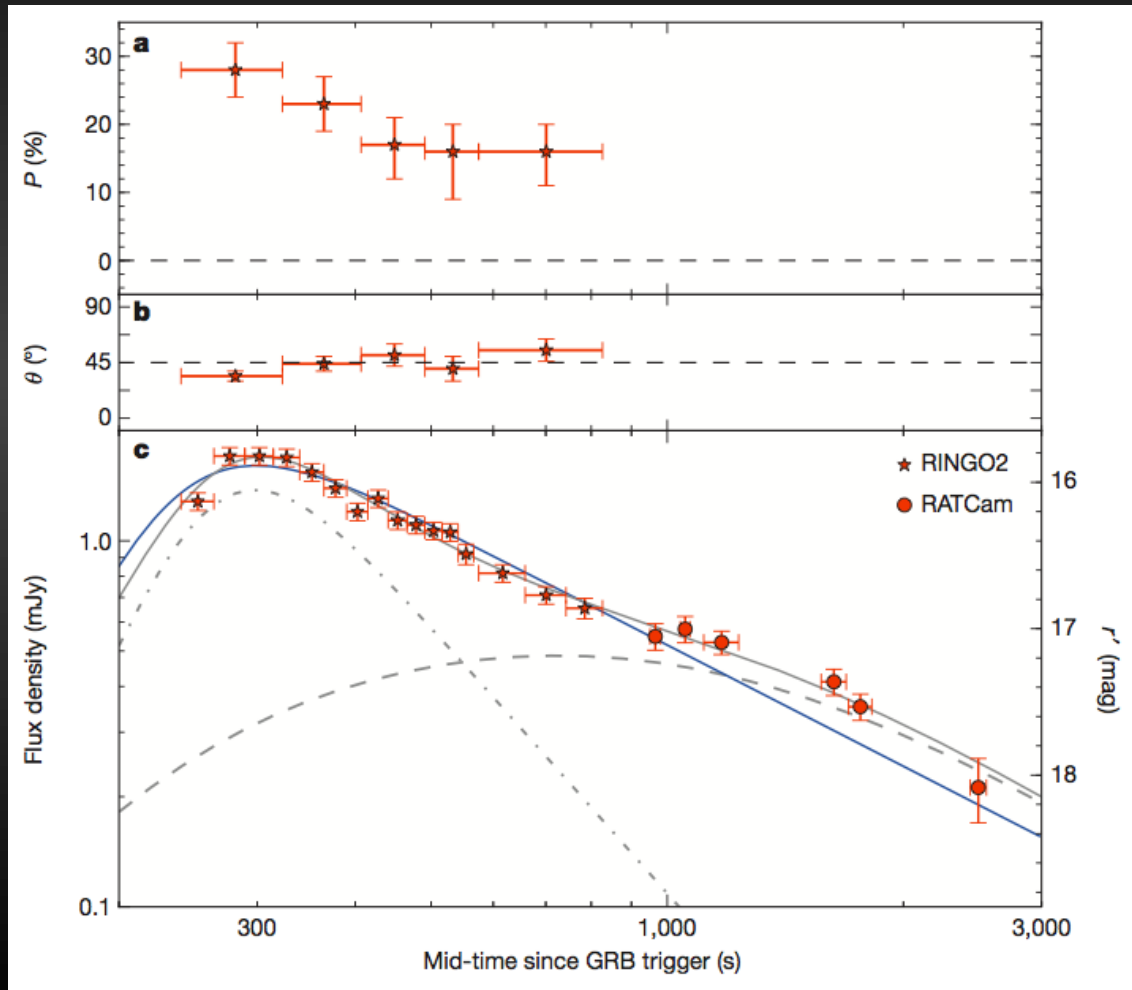
- SED modeled z ~ 2.22; RINGO2 at t=240 s (restframe 74 s); ~4000 calibration stars



Mundell+13 Nature, 504, 119

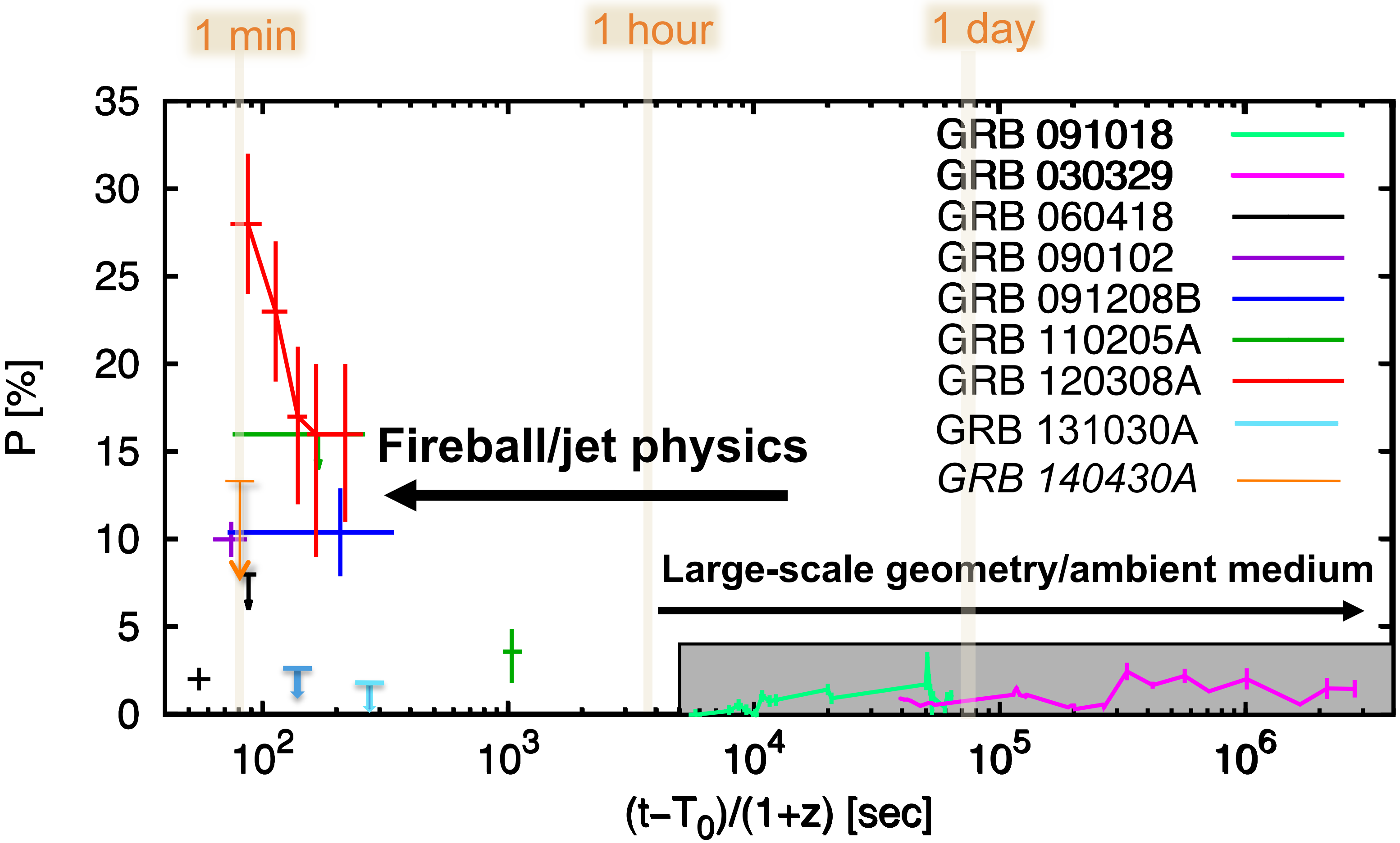
GRB 120308A with RINGO2

- Time-resolved polarization
- High, declining %
- Stable position angle
- Forward and reverse shocks
- Magnetic energy density in RS higher than FS by factor ~30 or 500



Mundell+13 Nature, 504, 119

Current state of the art in optical polarization measurements



Time in GRB restframe (sec)

Highest measured optical polarization
Long-lived, large-scale ordered magnetic fields

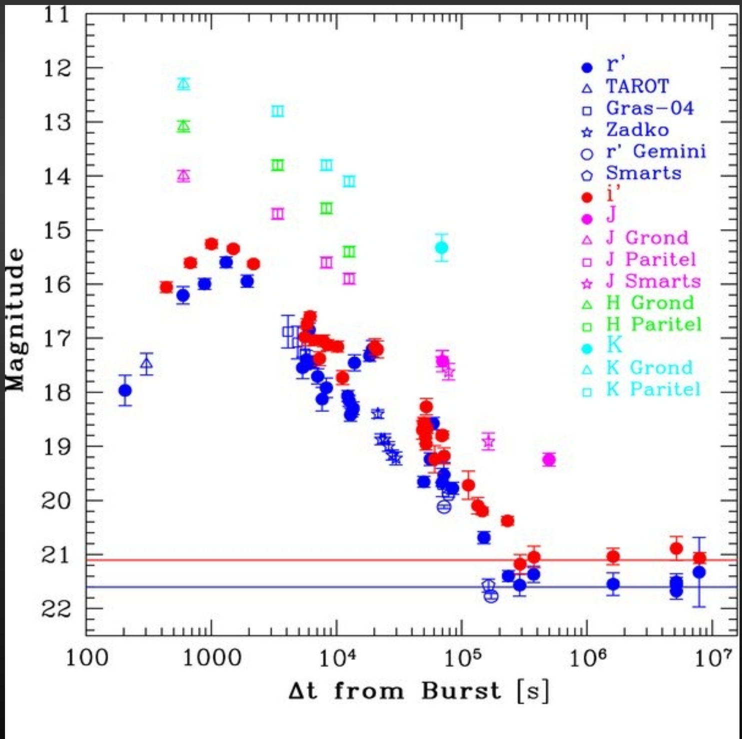
Adapted from Mundell+13 Nature, 504, 119

Dearth of RS Optical Flashes

- Bright RS-optical flashes *not* ubiquitous
  - Strongly magnetized flows suppress RS emission (Zhang & Kobayashi 2005; Japelj et al. 2014)
  - Prompt optical from internal shocks outshines external shock RS emission – polarized optical prompt? (Kopač et al. 2013)
  - Early time RS emission peaking at lower frequencies - e.g. IR, mm (Mundell et al. 2007, Melandri et al. 2010; Kopač et al. 2015)

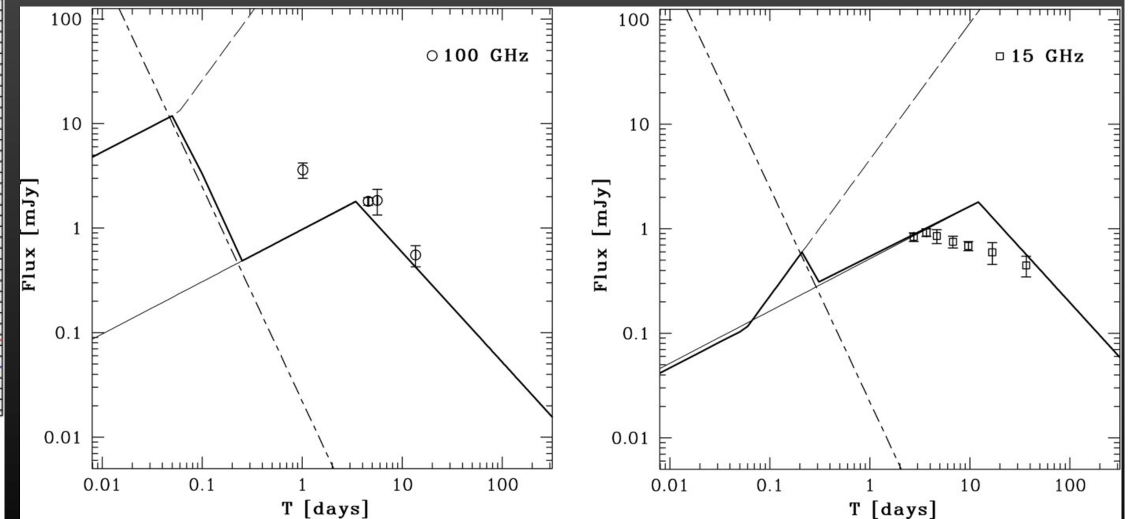
Radio Flares

Forward Shock; deceleration, Γ



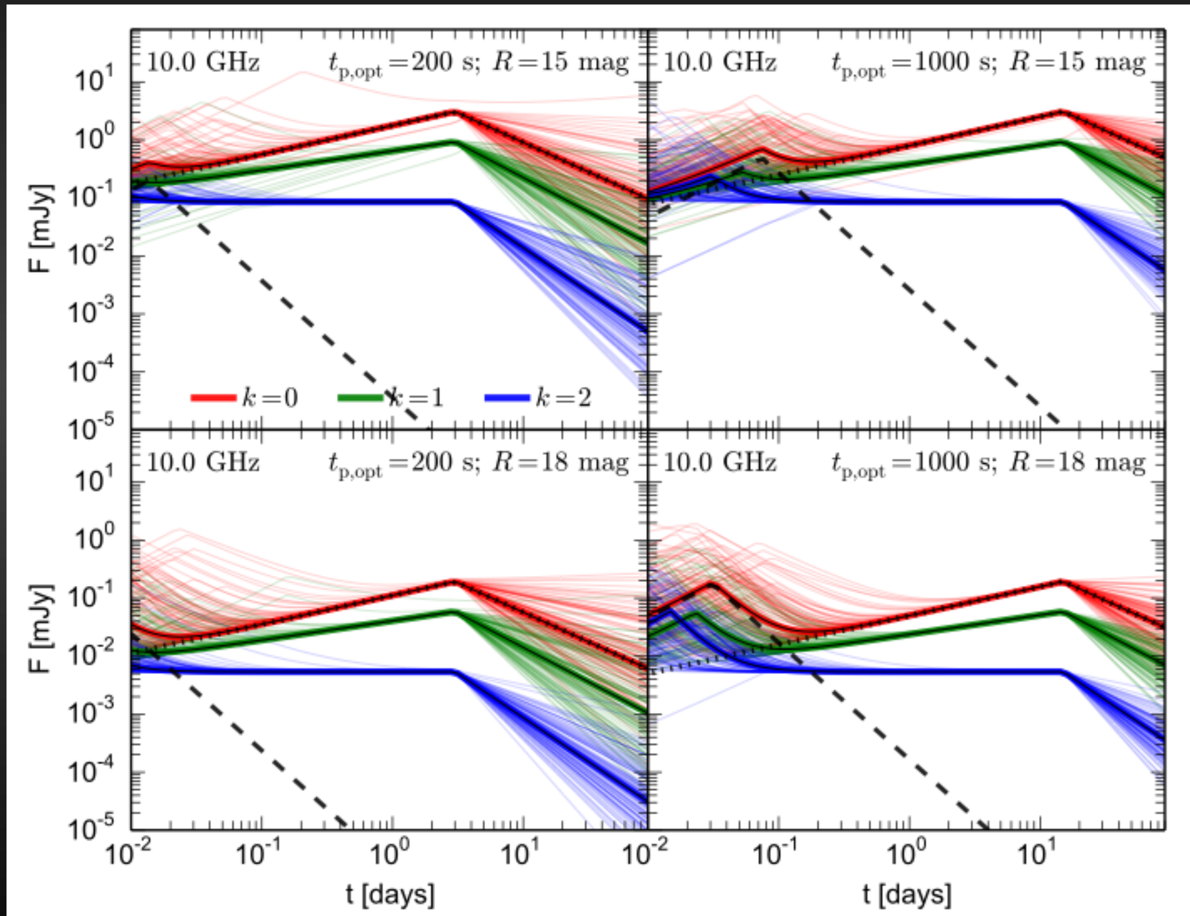
Dearth of reverse-shock optical flashes
GRB 090313 – radio predictions vs data

Simple model: Synchrotron self-absorption, reverse & forward shock evolution



Melandri et al. 2010 ApJ 723 1331

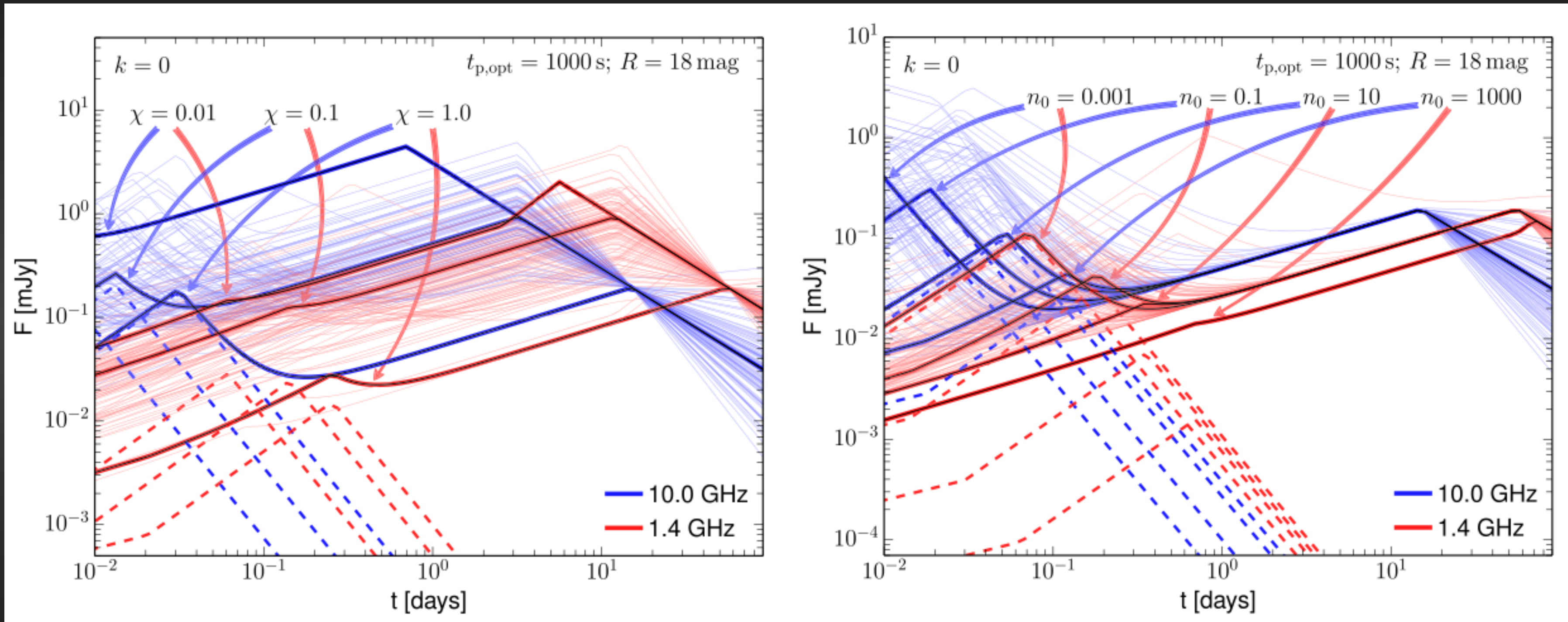
Radio Flares with the SKA



Simulations at 1.4, 10, 100 GHz

Kopač et al. 2015 ApJ, 806, 179

Radio Flares with the SKA



$\chi = \nu_{m,f} / \nu_{opt}$ $\chi = 0.01, 0.1, 1.0$

n_0 = 0.001, 0.1, 10, 1000 cm−3; for n = 1 cm^{-3}

k = 0, $t_{p,opt}$ = 1000 s, R = 18 mag

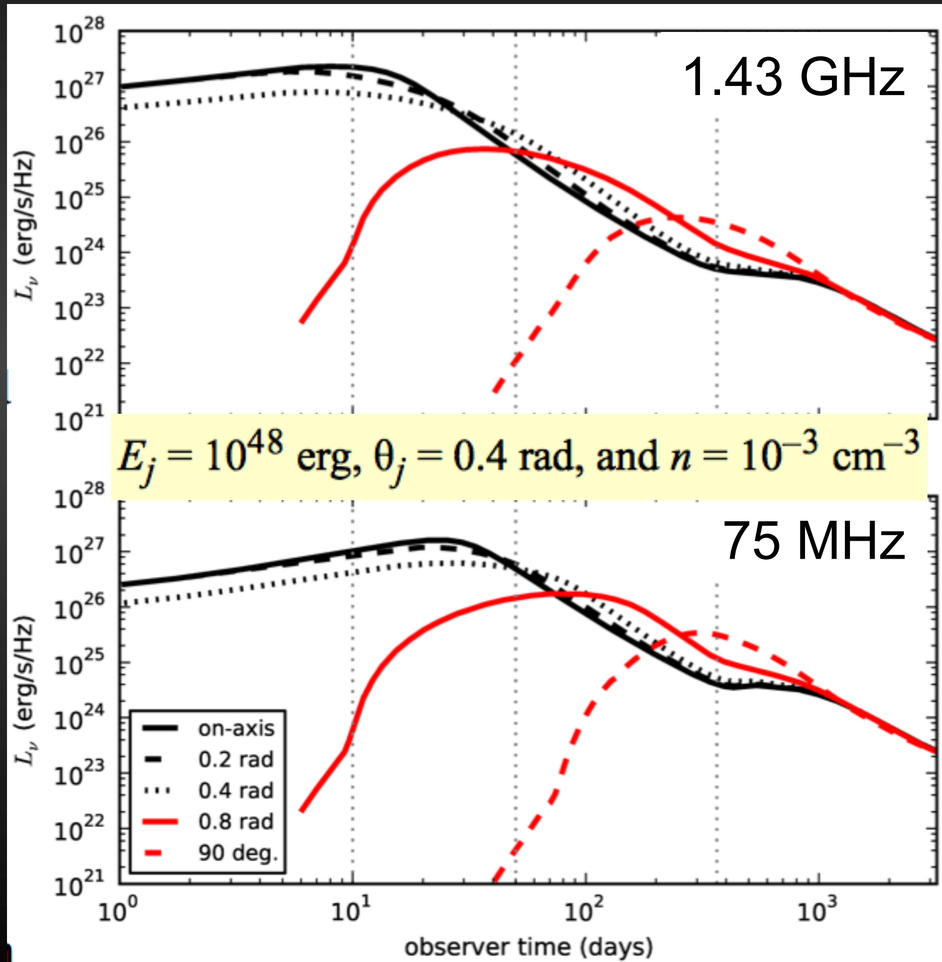
Kopač et al. 2015 ApJ, 806, 179

Radio RS Detectability

- Radio RS detectable between 0.1-1 day
- Detection is easier for bursts with
  - later optical peaks
  - high isotropic energies
  - lower circumburst medium densities
  - observing frequencies > GHz to avoid SSA
- F ~ 0.1 − 10mJy at 10 GHz, t ~ 2 hr

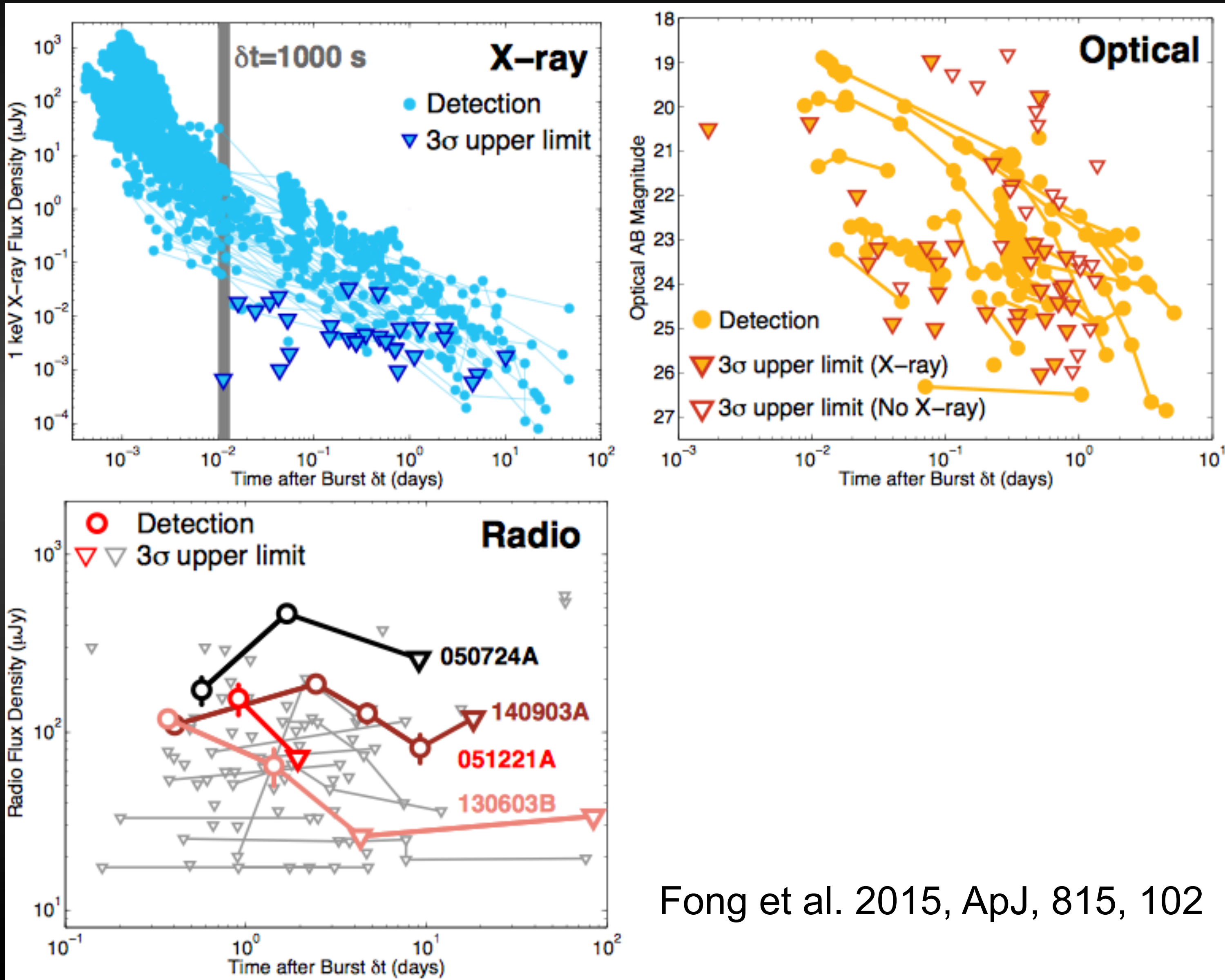
Radio Flares from short GRBs

- Magnetically driven outflows before NS-NS merger
- Relativistic post-merger plasma could produce short, strong radio flare (< 30 min)
- SGRB radio afterglows ~100μJy at 1 day after burst
- Further radio flares on weeks/year timescales due to exernal shocks in ISM
- Kilonovae radio emission ~100μJy over weeks



van Eerten & MacFadyen 2011

A Decade of Short GRBs



Fong et al. 2015, ApJ, 815, 102

Radio Summary I

- Optical light curves enable real-time radio flare predictions
- Radio reverse shocks now being detected
- Radio polarization upper limits so far at cm wavelengths (Taylor+04, Granot & Taylor 05, van der Horst +14) - sensitivity & speed limitations
- Coherent radio emission at very early time predicted in magnetically dominated models

Radio Summary II

- Long-term light curve monitoring
- Burst calorimetry
- Probe ambient medium
- Radio loud vs radio quiet?
- Radio probes micro and macrophysics
- Hundreds orphan afterglows per week (Burlon et al. 2015)
- Gravitational wave counterparts?

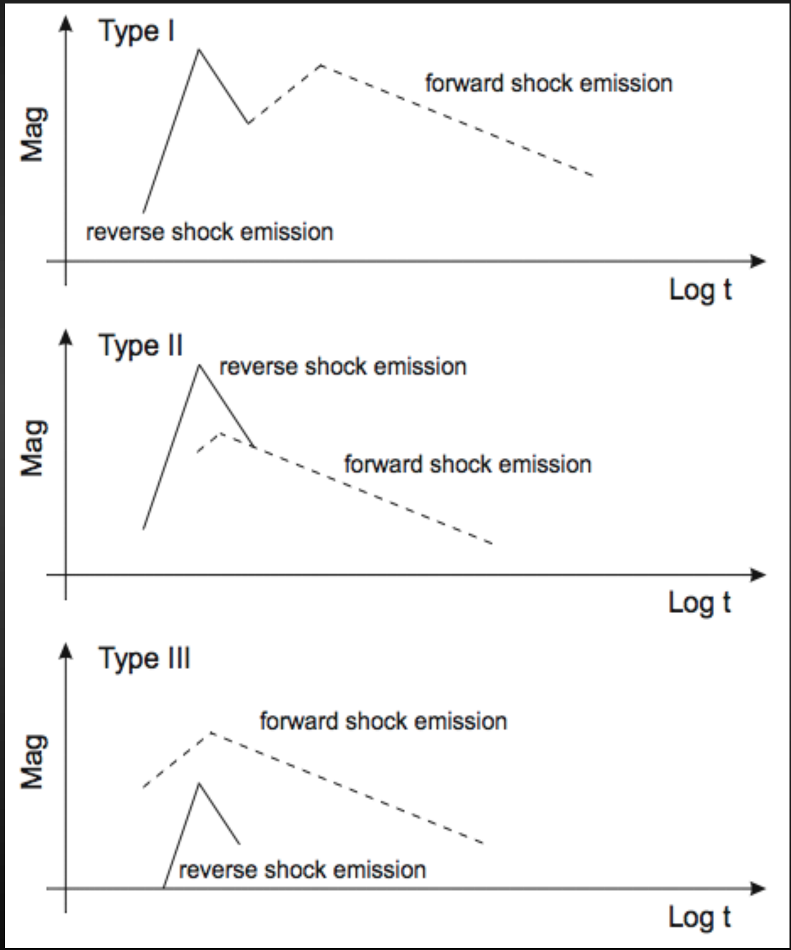
For Discussion

- Radio follow-up of external triggers well-established
  - SKA era – what high-energy missions?
- SKA for self-consistent discovery, ID, follow-up?
  - Timescales msec – decades
  - Full imaging vs fast searches? Feedback within TM?
  - Radio ID alone? What portion of Ic?
- Confusion with weak AGN?
  - Variable at same level (Mundell+09)
- Star formation/HI in host galaxies; VLBI?

Extra Slides

Reverse Shock Sample

- Parent sample: 118 GRBs
  - 10 reverse shocks with z
  - Fainter than average FS emission @ t>10ks
  - High magnetization:
    $R = \varepsilon_{B,r}/\varepsilon_{B,f} \sim 2 - 10^4$
  - Magnetized baryonic jets

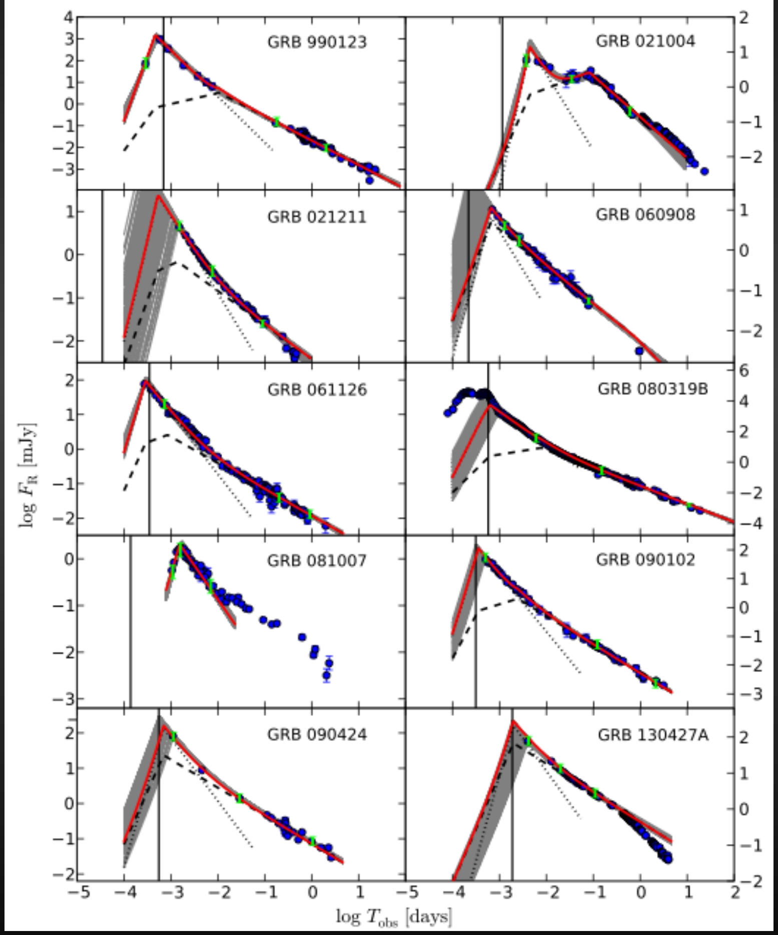


Japelj+2014, ApJ, 785, 84

See also: Gomboc+09, AIPC, 1133, 145; Harrison & Kobayashi 2013 ApJ, 772, 101

Reverse Shock Sample

- Parent sample: 118 GRBs
  - 10 reverse shocks with z
  - Fainter than average FS emission @ t>10ks
  - High magnetization:
    $R = \varepsilon_{B,r}/\varepsilon_{B,f} \sim 2 - 10^4$
  - Magnetized baryonic jets



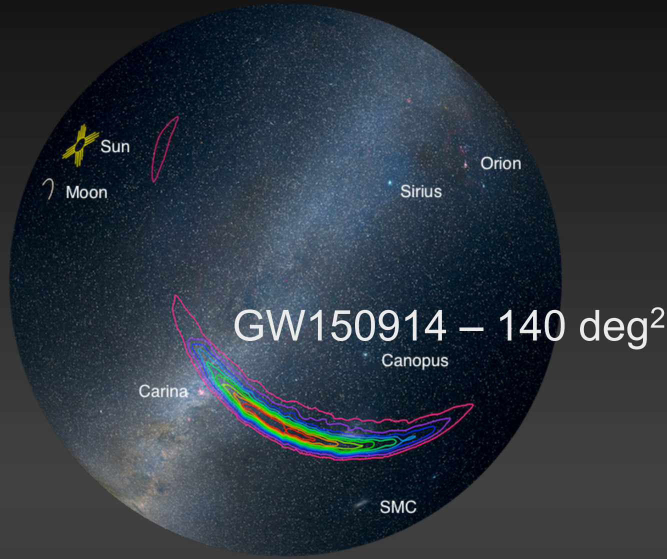
Japelj+2014, ApJ, 785, 84

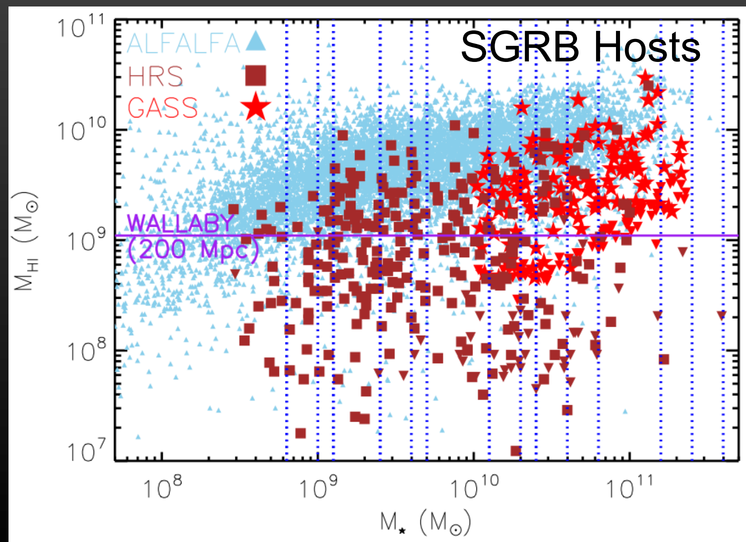
See also: Gomboc+09, AIPC, 1133, 145; Harrison & Kobayashi 2013 ApJ, 772, 101

GW hosts with the SKA?

- GW sources
  - Many unrelated transients likely
  - GW150914
    - D = $410\pm^{160}_{180}$Mpc
  - Hα + HI surveys – e.g. WALLABY on ASKAP
  - ~50% completeness
  - Radio continuum too?

Or radio silent?





Metzger, Kaplan, Berger 2013, ApJ, 764, 149