The Gamma-Ray Burst – Supernovae Connection

(in under 20 minutes)

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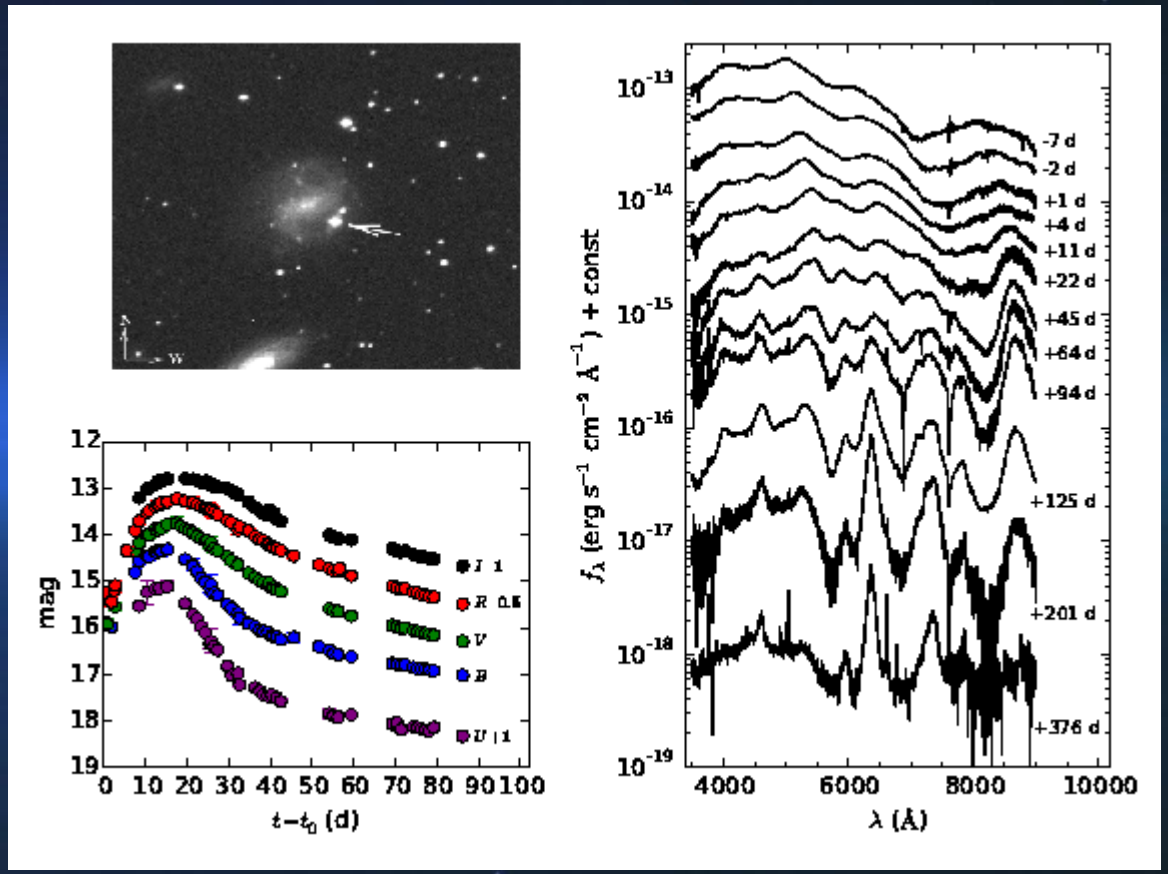
Some history:

- 1968: Stirling Colgate suggests SNe can emit prompt X-rays and gamma rays (Can. J. Phys., 46, 476)
- 1973: Klebesadel, Strong & Olson report existence of GRBs (ApJL, 182, 85)
- 1997: Beginnng of the Afterglow Era: GRB 970228 (van Paradijs et al., Nature, 386, 686; Costa et al., Nature, 387, 783) GRB 970508 (Metzger et al., Nature, 397, 878; Frail et al., Nature, 389, 261)
- 1998: Bohdan Paczyński asks: Do GRBs come from star-forming regions? (ApJL, 494, 45)

1998: GRB 980425/SN 1998bw



In the X-ray error circle of BeppoSAX GRB 980425: SN 1998bw

- very luminous: $M < -19$
- very high expansion speed, ca. 0.1c
- "Hypernova" (Broad-lined Type Ic SN)
- No classical GRB afterglow
- Chance coincidence unlikely
- Highly subluminous GRB

(Galama et al., Nature, 395, 670; Iwamoto et al., Nature, 395, 672; Kulkarni et al., Nature, 395, 363)

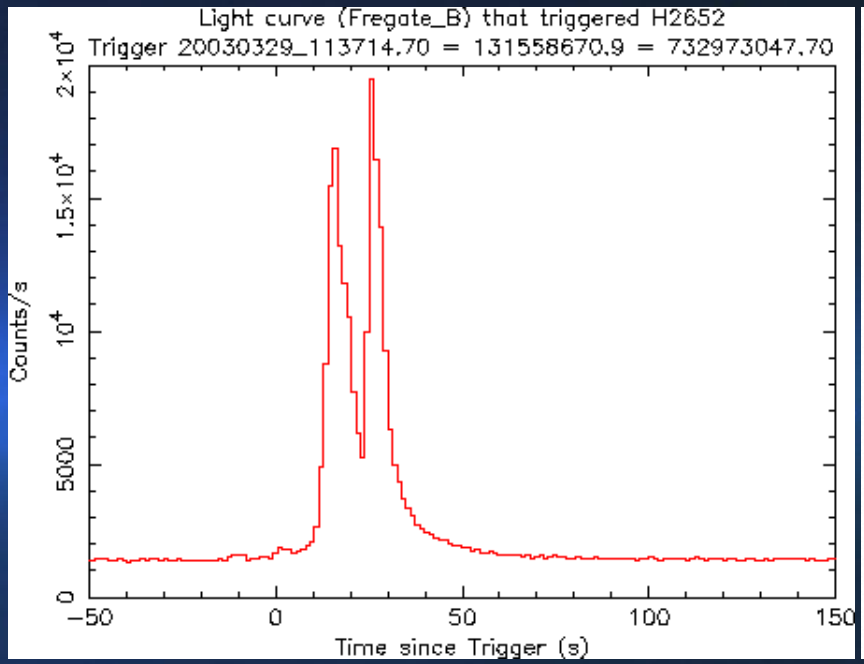
Further evidence:
Bump in GRB 980326 (Bloom et al. 1999, Nature, 401, 453)
SN in GRB 970228 (Reichart, 1999, ApJL. 521, 111; Galama et al. 2000, ApJ, 536, 185)

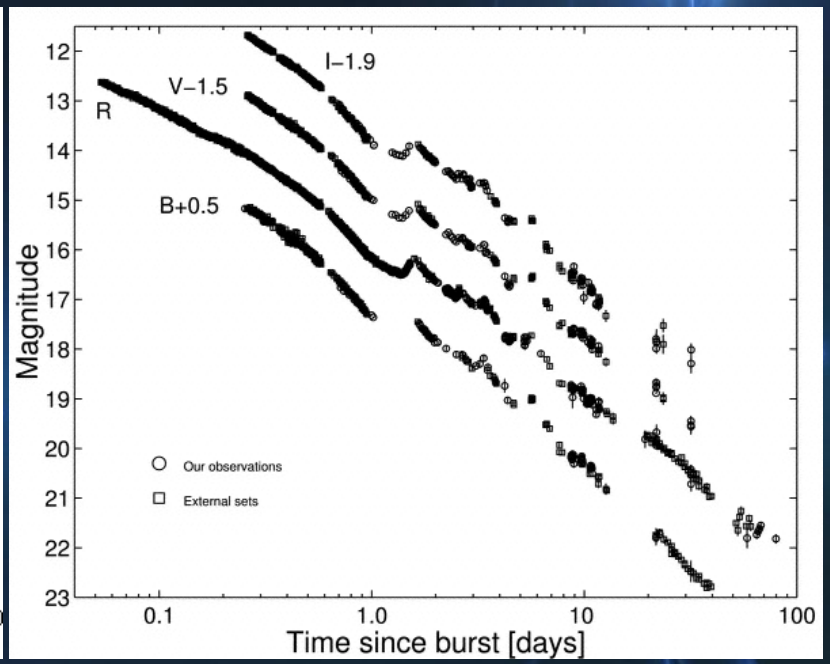
Image credit: Cano et al. 2017, Adv. Astron. 8929054

1999 – 2002: Slow progress

- Weak bumps: GRBs 990712, 991208, 000911
  (Björnsson et al. 2001, ApJL, 552, 121; Castro-Tirado et al. 2001, A&A, 372, 438; Lazzati et al. 2001, A&A, 378, 996; Masetti et al. 2005, A&A, 438, 841)
- Strong bump, failed spectrum: GRB 011121
  (Bloom et al. 2002, ApJL, 572, 45; Garnavich et al. 2003, ApJ, 582, 924; Greiner et al. 2003, ApJ, 599, 1223)
- Weak bump, weak spectrum: GRB 021211 (Della Valle et al. 2003, A&A, 406, 33)
- Strong bump: GRB 020405 (Price et al. 2003, ApJ, 589, 838; Masetti et al. 2003, A&A, 404, 465)

2003: GRB 030329/SN 2003dh: Rosetta Stone Burst

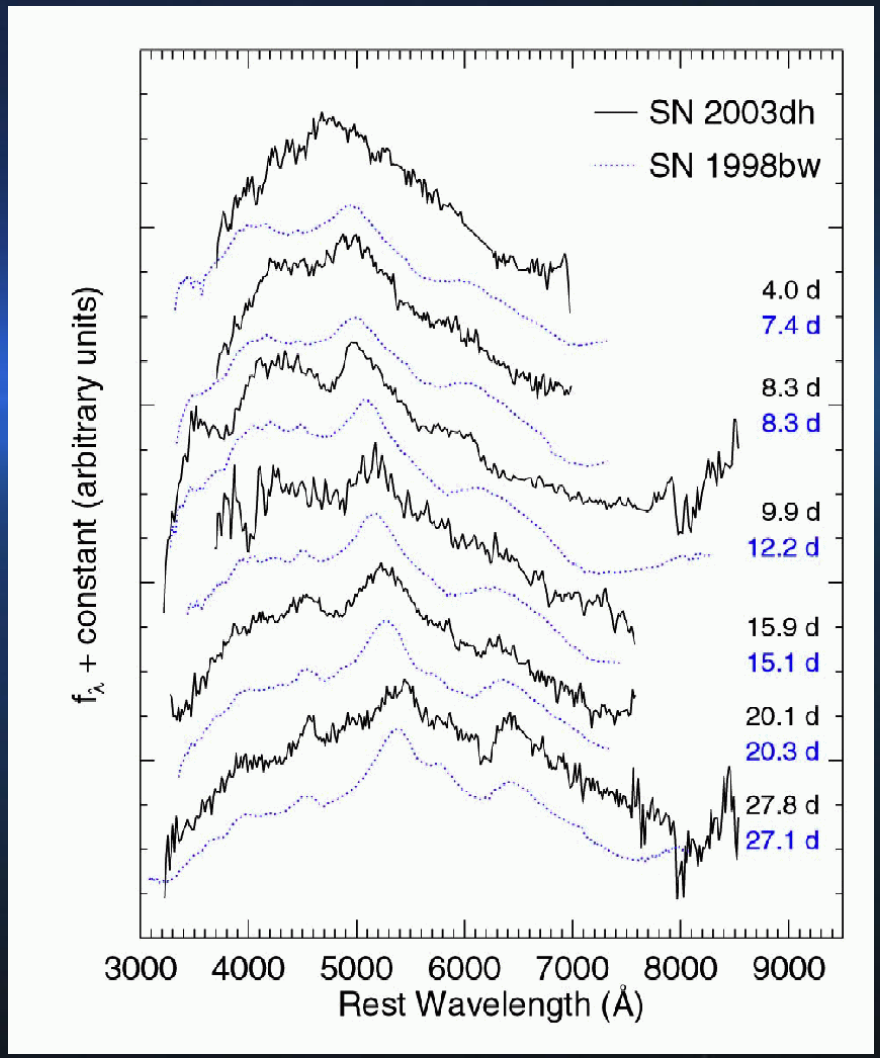




Detected by HETE-2, very bright, $z = 0.169$, long-term brightest afterglow, extremely complex, most observations ever

(Vanderspek et al. 2004, ApJ, 617, 1251; and e.g., Lipkin et al. 2004, ApJ, 606, 381; Uemura et al. 2003, Nature, 423, 843; Torii et al. 2003, ApJL, 597, 101; etc.)

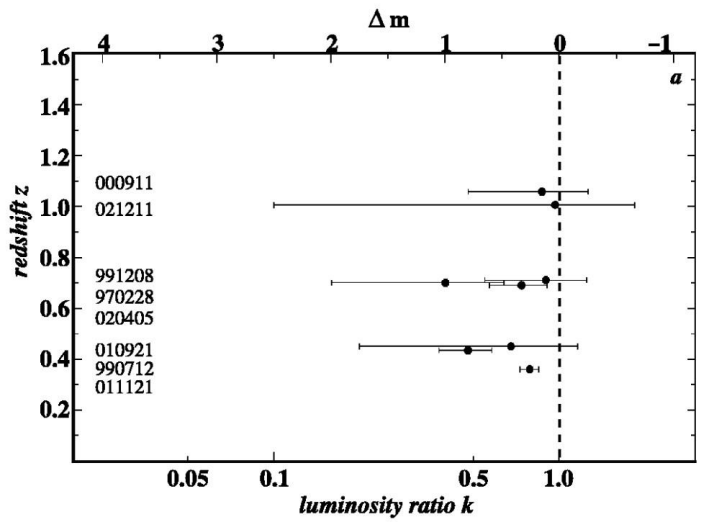
2003: GRB 030329/SN 2003dh: Rosetta Stone Burst

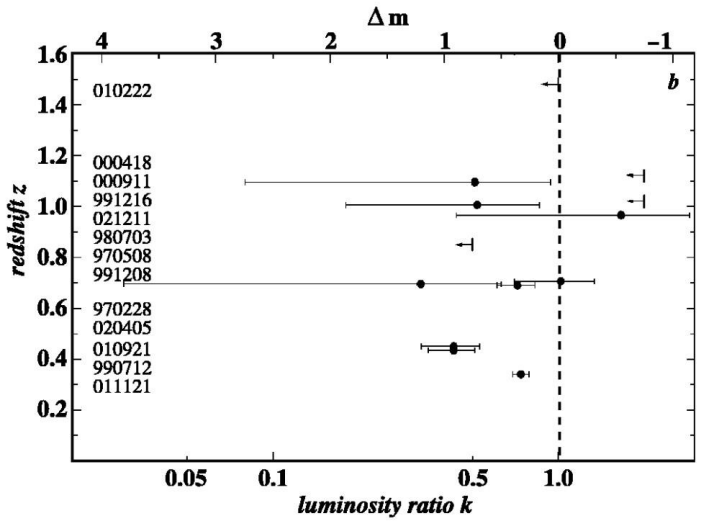


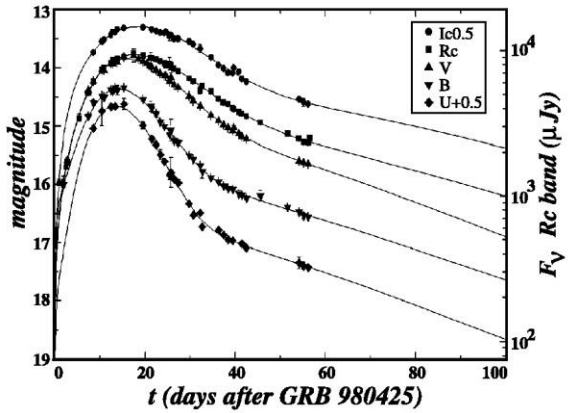
Spectroscopic sequences revealed the development of a Type Ic BL photometrically covered by the bright afterglow (Stanek et al. 2003, ApJL, 591, 17; Hjorth et al., 2003, Nature, 423, 847; Matheson et al., ApJ, 599, 394)

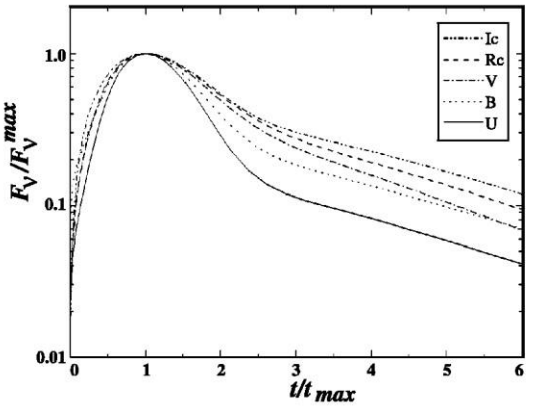
Establishes the link between "cosmological" GRBs and Type Ic BL SNe

But still a rather weak and soft GRB…









2004: Zeh, Klose & Hartmann (ApJ, 609, 952) perform a systematic study of afterglows, fitting SN bumps with a SN 1998bw model:

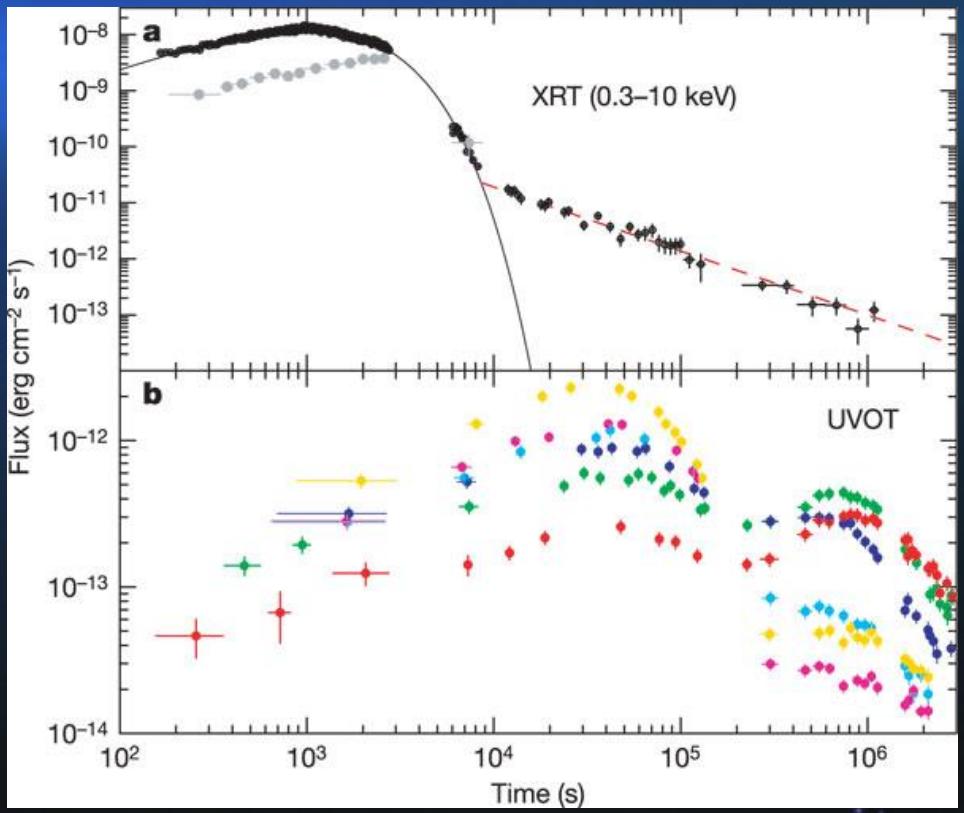
- 98bw shifted to correct *z*
- *k*: luminosity factor
- *s*: stretch factor

- Conclusion: All GRBs at $z < 0.7$ are accompanied by SNe similar to SN 1998bw, and likely *ALL* GRBs are.

Further progress:

2003: another low-z, low-luminosity event, GRB 031203/SN 2003lw (Soderberg et al. 2004, Nature, 430, 648; Malesani et al. 2004, ApJL, 609, 5; etc.)

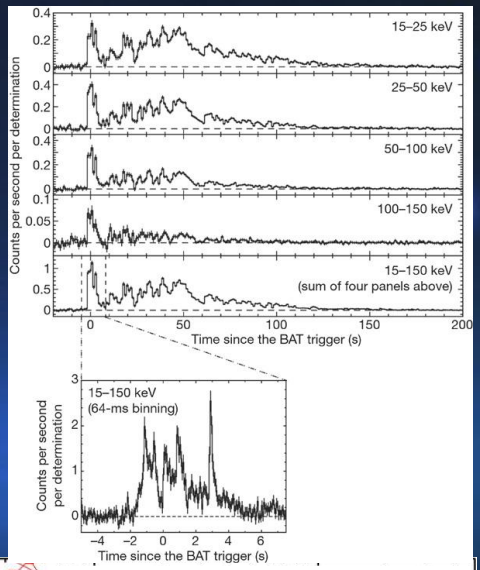
2006: Very long, soft, nearby XRF 060218 and SN 2006aj

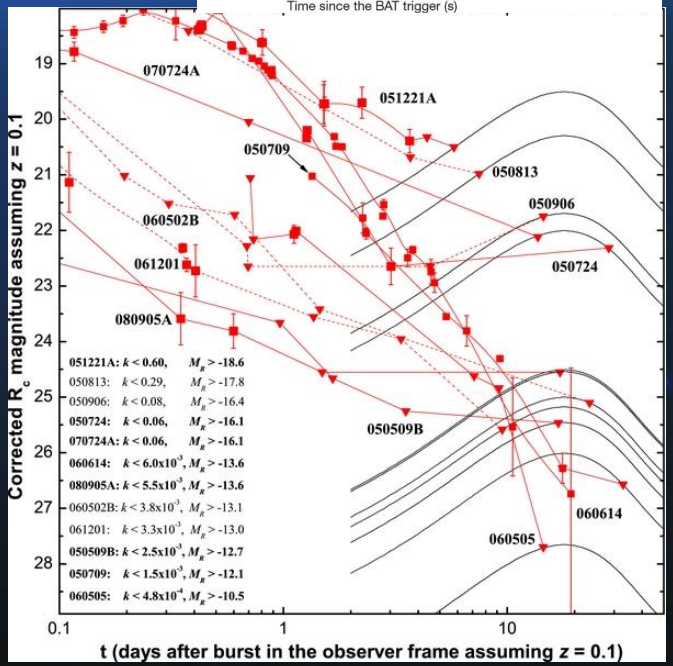


Accompanied by a bright UV flash, likely SN shock breakout, very well studied SN, fainter than SN 1998bw (Pian, … Kann et al. 2006, Nature, 442, 1011; Campana et al. 2006, Nature, 442, 1008; Soderberg et al. 2006, Nature, 442, 1014; Mazzali et al. 2006, Nature, 442, 1018)

Ferrero, Kann, et al. (2006, A&A, 457, 857) First large comparative study in *k,s* context, correction for host-galaxy extinction

2006: What if there is NO supernova?





GRBs 060505 & 060614: Temporally long, nearby, no accompanying SNe! (Della Valle et al., Nature, 444, 1050; Fynbo et al., Nature, 444, 1047; Gal-Yam et al., Nature, 444, 1053; Gehrels et al., Nature, 444, 1044)

Comparative study of *short* GRBs by Kann et al. (2011, ApJ, 734, 96) shows deepest SN non-detection, afterglows faint compared to long GRBs

GRB 060614 seems to show a "kilonova" (Yang et al. 2015, Nature Communications, 6, 7323)

GRB 060505 remains a mystery, a true "hybrid indicator" event (Thöne, … Kann et al. 2008, ApJ, 676, 1151; McBreen, … Kann et al. 2008, ApJL, 677, 85)

Since then, no more truly similar cases have occurred!

2007-2017: Just some highlights...

Several well-observed GRB-SNe:

- XRF 100316D/SN 2010bh (Chornock et al. 2010, arXiv:1004.2262; Cano et al. 2011, ApJ, 740, 41; Olivares E., ... Kann et al. 2012, A&A, 539, 76; Bufano et al. 2012, ApJ, 753, 67)
- GRB 120422A/SN 2012bz (Melandri et al. 2012, A&A, 547, 82; Schulze, ... Kann et al. 2014, A&A, 566, 102)
- GRB 130702A/SN 2013dx (D'Elia et al. 2015, A&A, 577, 116; Toy et al. 2016, ApJ, 818, 79; Volnova et al. 2017, MNRAS, 467, 3500)
- GRB 140606B (Cano et al. 2015, MNRAS, 452, 1535)
- GRB 161219B/SN 2016jca (Ashall et al. 2017, arXiv:1702.04339; Cano, ... Kann et al. 2017, arXiv:1704.05401)

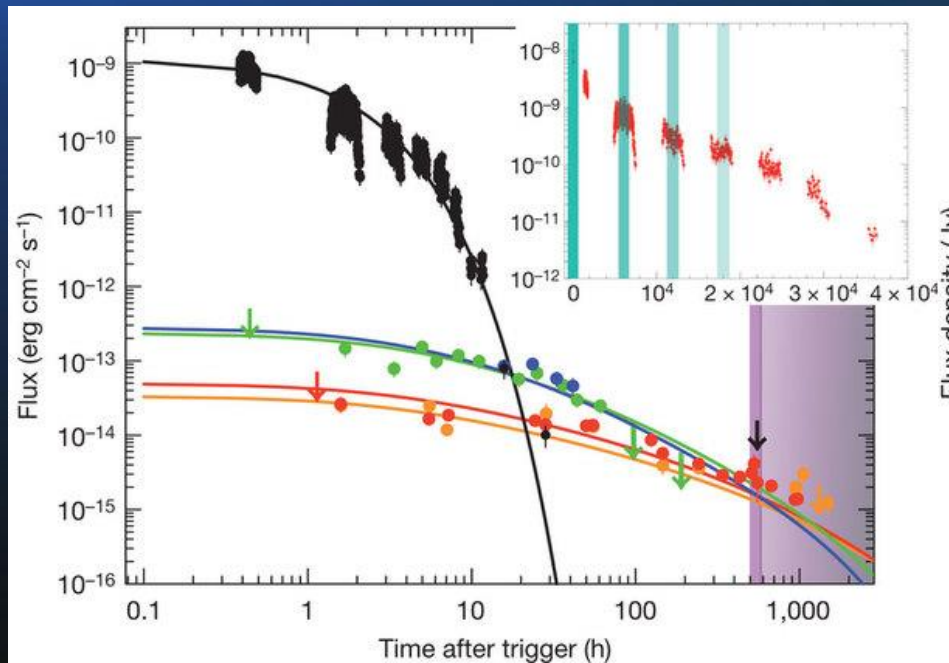
2007-2017: Just some highlights...

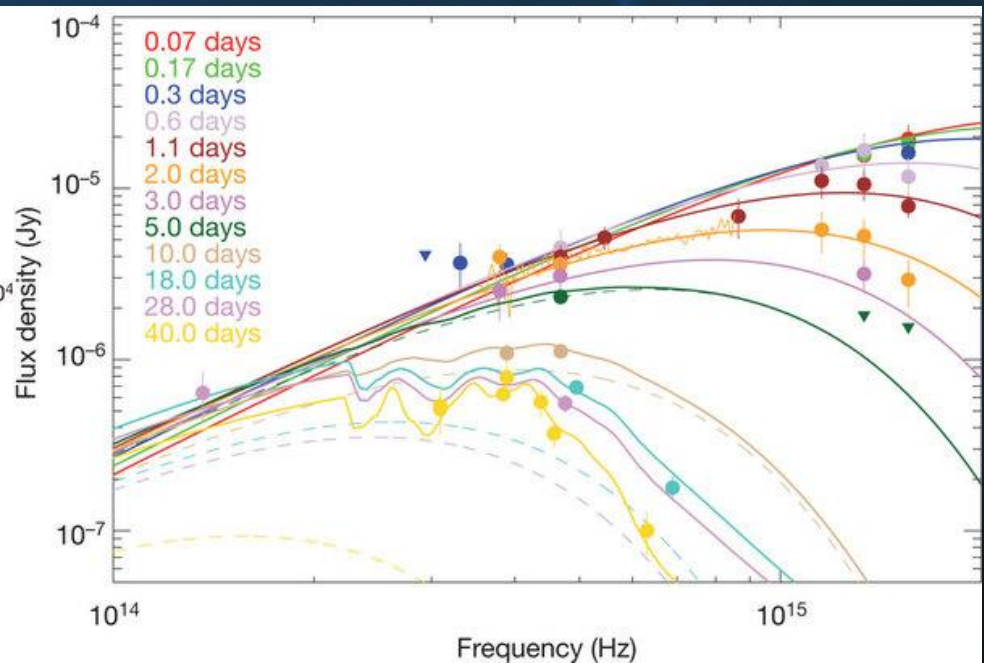
Finally, associating true "cosmological" GRBs with broad-lined Type Ic SNe:

- "naked-eye burst" GRB 080319B (Racusin et al. 2008, Nature, 455, 183; Bloom, … Kann et al. 2009, ApJ, 691, 723) with only weak bump (Tanvir et al. 2010, ApJ, 725, 625)
- "nearby monster" GRB 130427A (e.g., Maselli et al. 2014, Science, 343, 48; Perley, … Kann et al. 2014, ApJ, 781, 37) with spectrally observed SN 2013cq (Xu et al. 2013, ApJ, 776, 98; Melandri et al. 2014, A&A, 567, A29; Levan et al. 2014, ApJ, 792, 115, Becerra et al. 2017, ApJ, 837, 116)

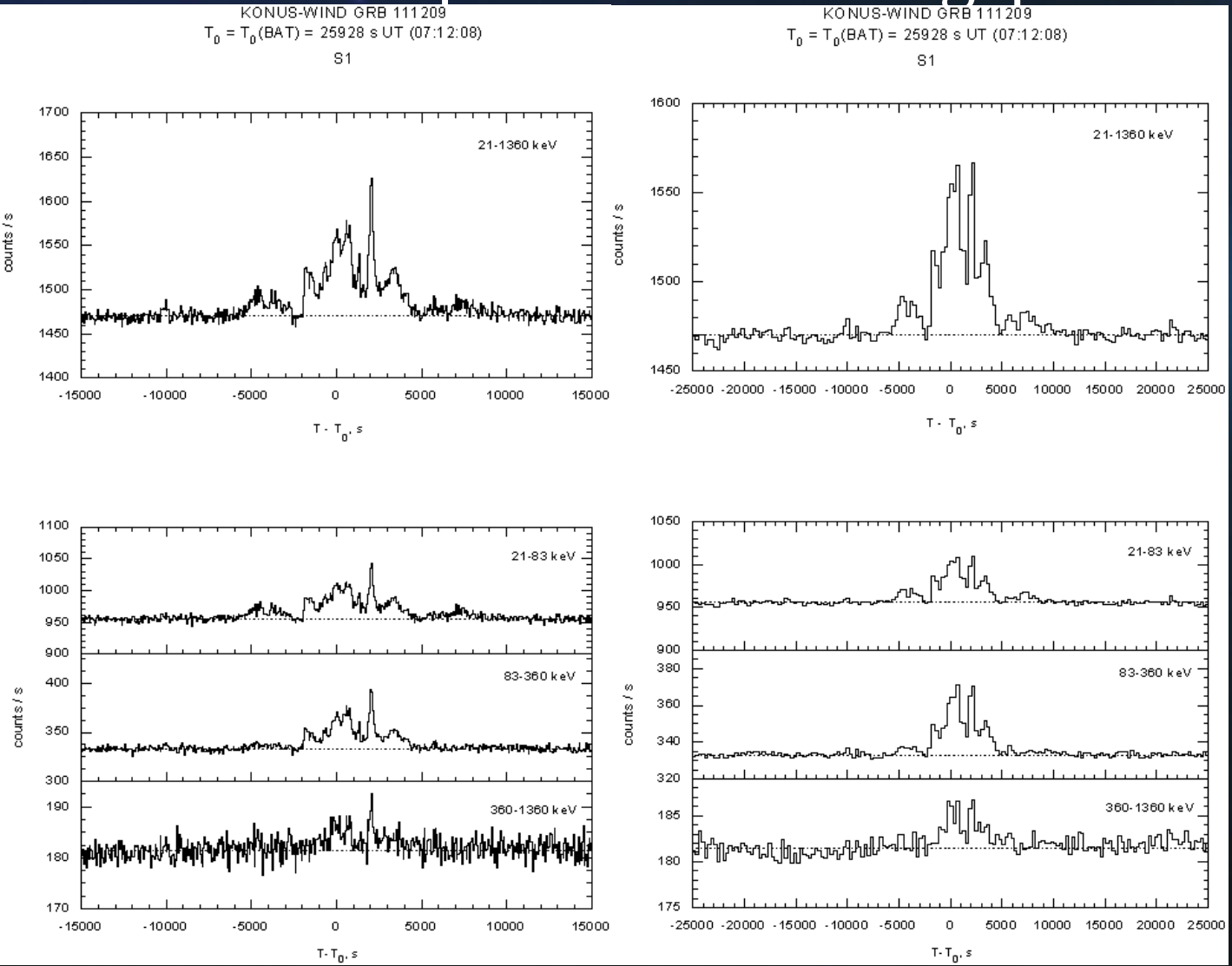
2010: Rise of the Ultralong Gamma-Ray Bursts

Christmas GRB 101225A (Thöne, ... Kann et al. 2011, Nature, 480, 72): Extreme duration, thermal afterglow, probable SN bump, slower but about as luminous as SN 1998bw if placed at correct redshift (Thöne, ... Kann et al., in prep.)





2011: GRB 111209A/SN 2011kl: Bridging the GRB/superluminous SN gap?



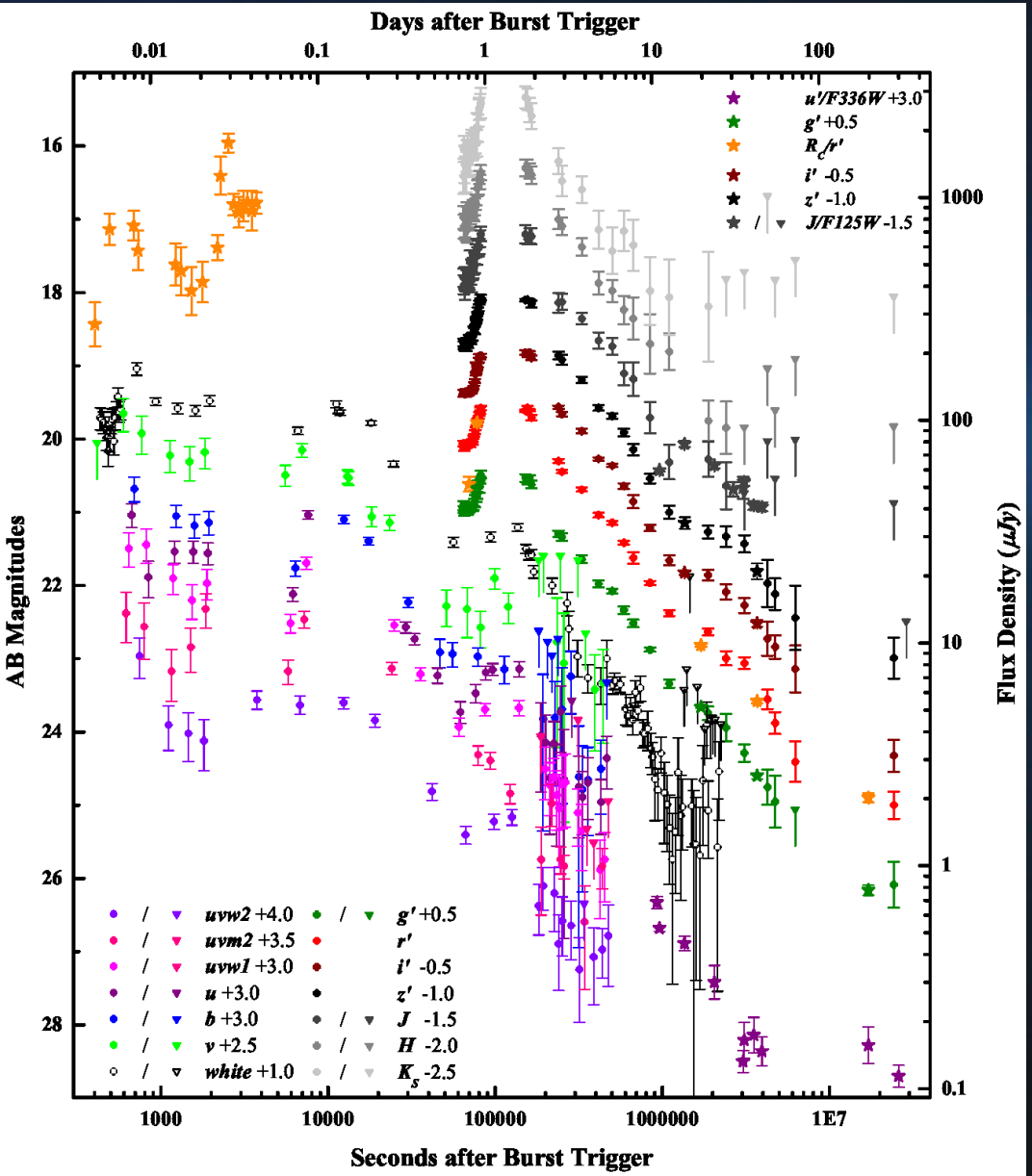
$z = 0.677$

25,000 s duration!

Complex early afterglow during prompt emission (Gendre et al. 2013,ApJ, 766, 30; Stratta et al. 2014, ApJ, 779, 66; Levan et al. 2014, ApJ, 781, 12)

Very southerly, not well observed, but…

2011: GRB 111209A/SN 2011kl: GROND!



GROND could not observe right after trigger

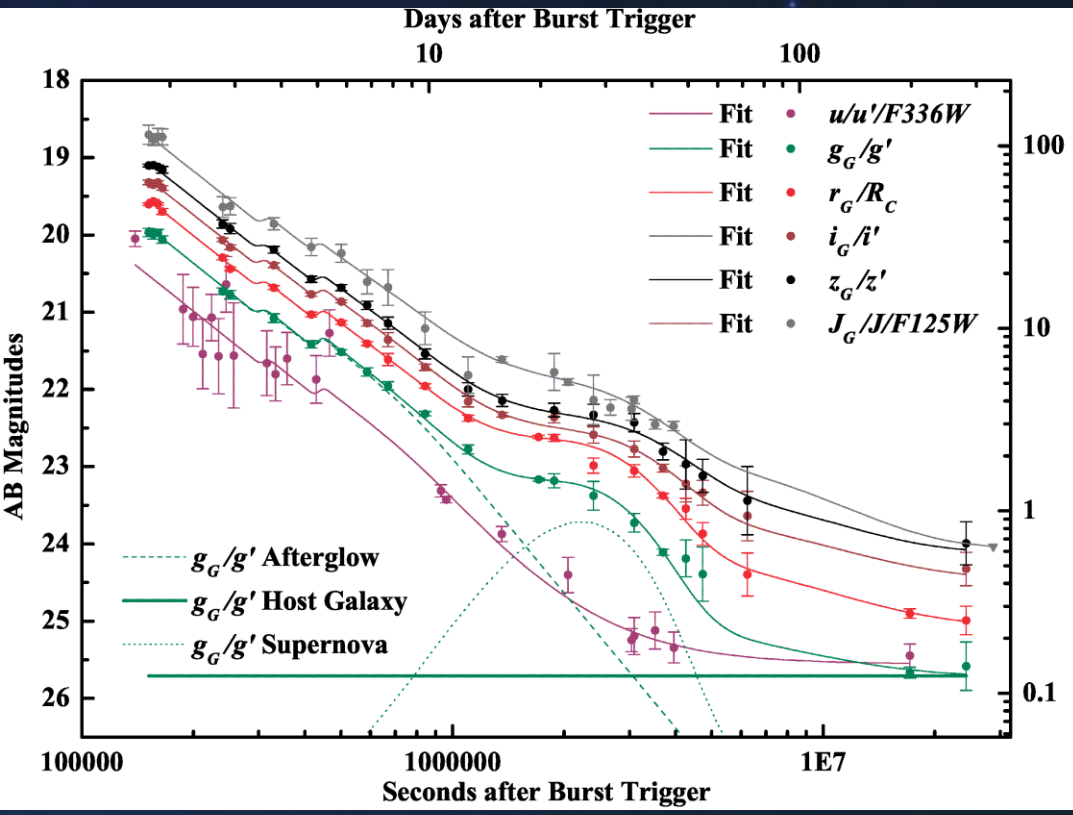
Following night: strong rebrightening, followed by energy injections

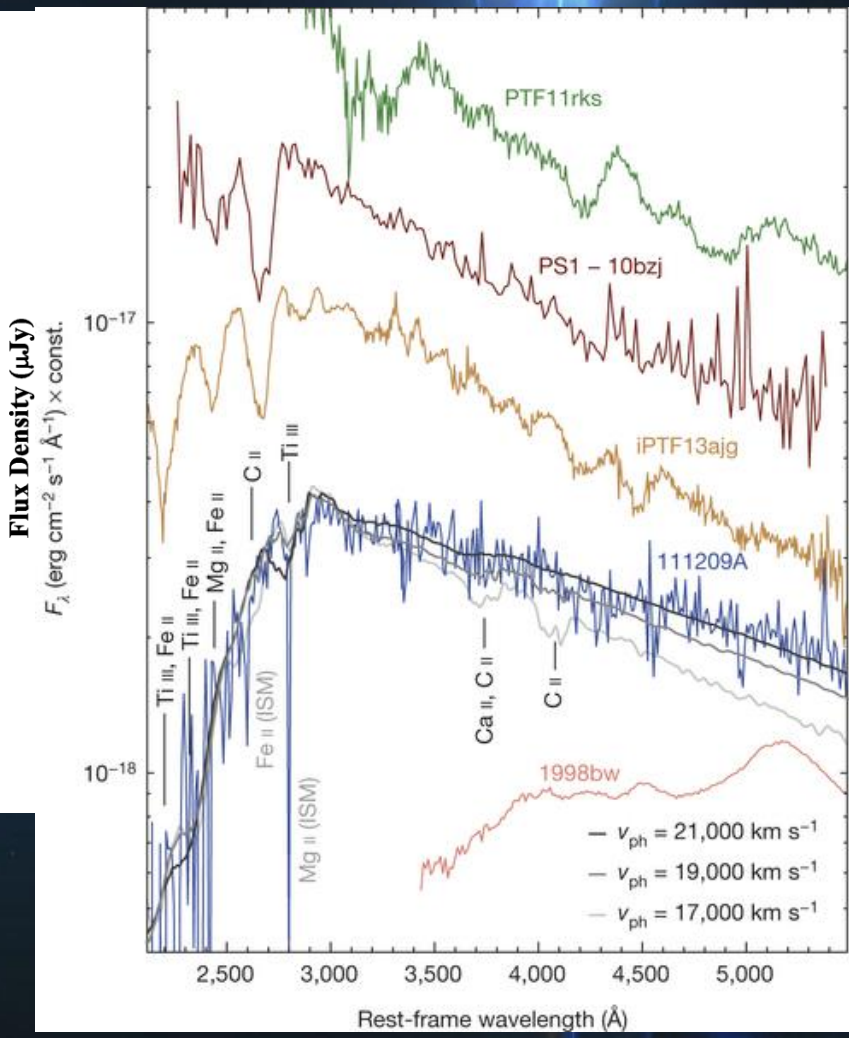
Discovery of a very luminous, very blue SN bump

Spectroscopically different from all known GRB-SNe

(Greiner, … Kann et al. 2015, Nature, 523, 189; Kann et al. 2017, arXiv:1606.06791v2; Kann et al. 2017, arXiv:1706.00601)

2011: GRB 111209A: SN 2011kl

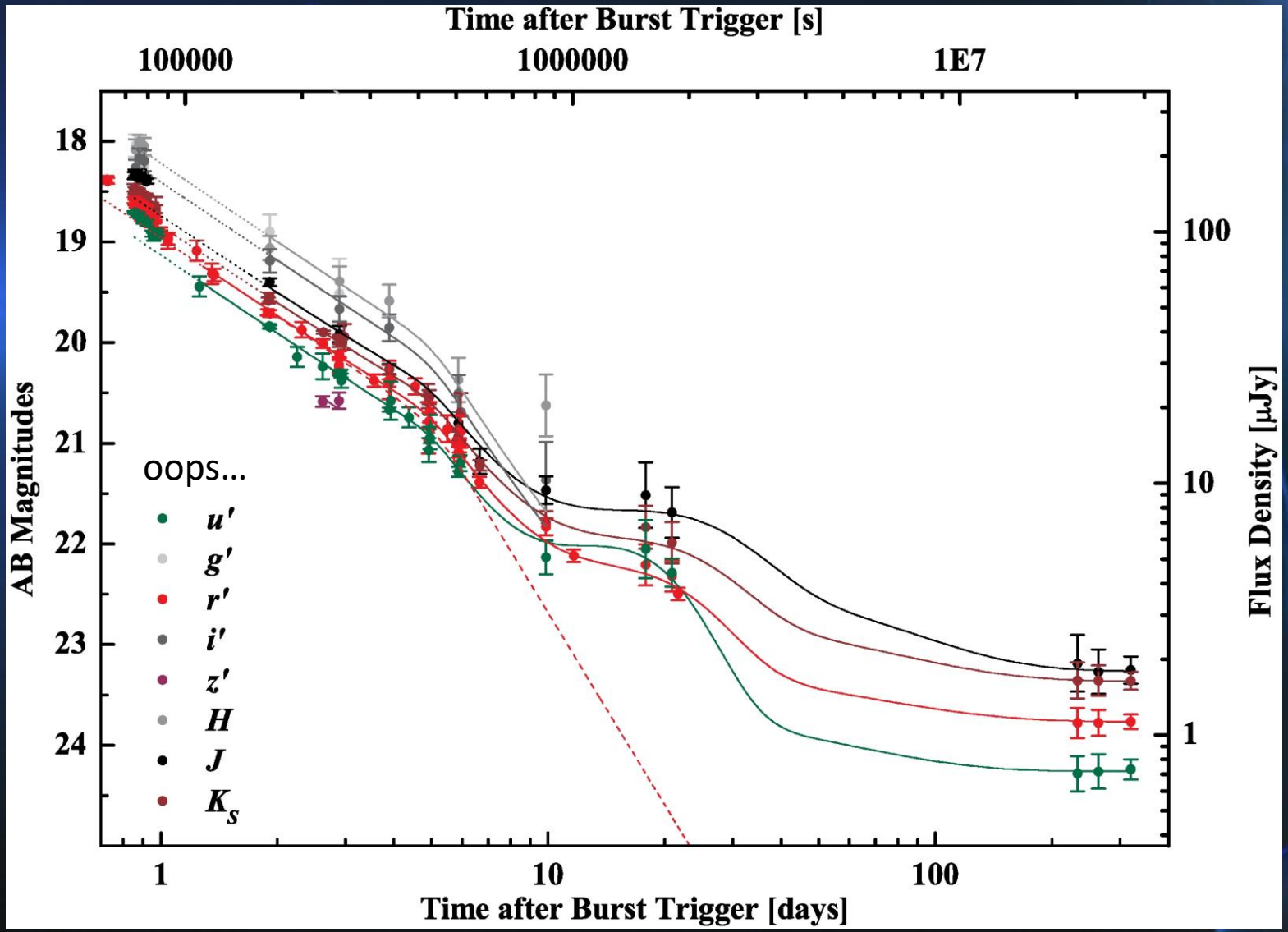




Spectrally more similar to SLSN spectra → powered by a magnetar

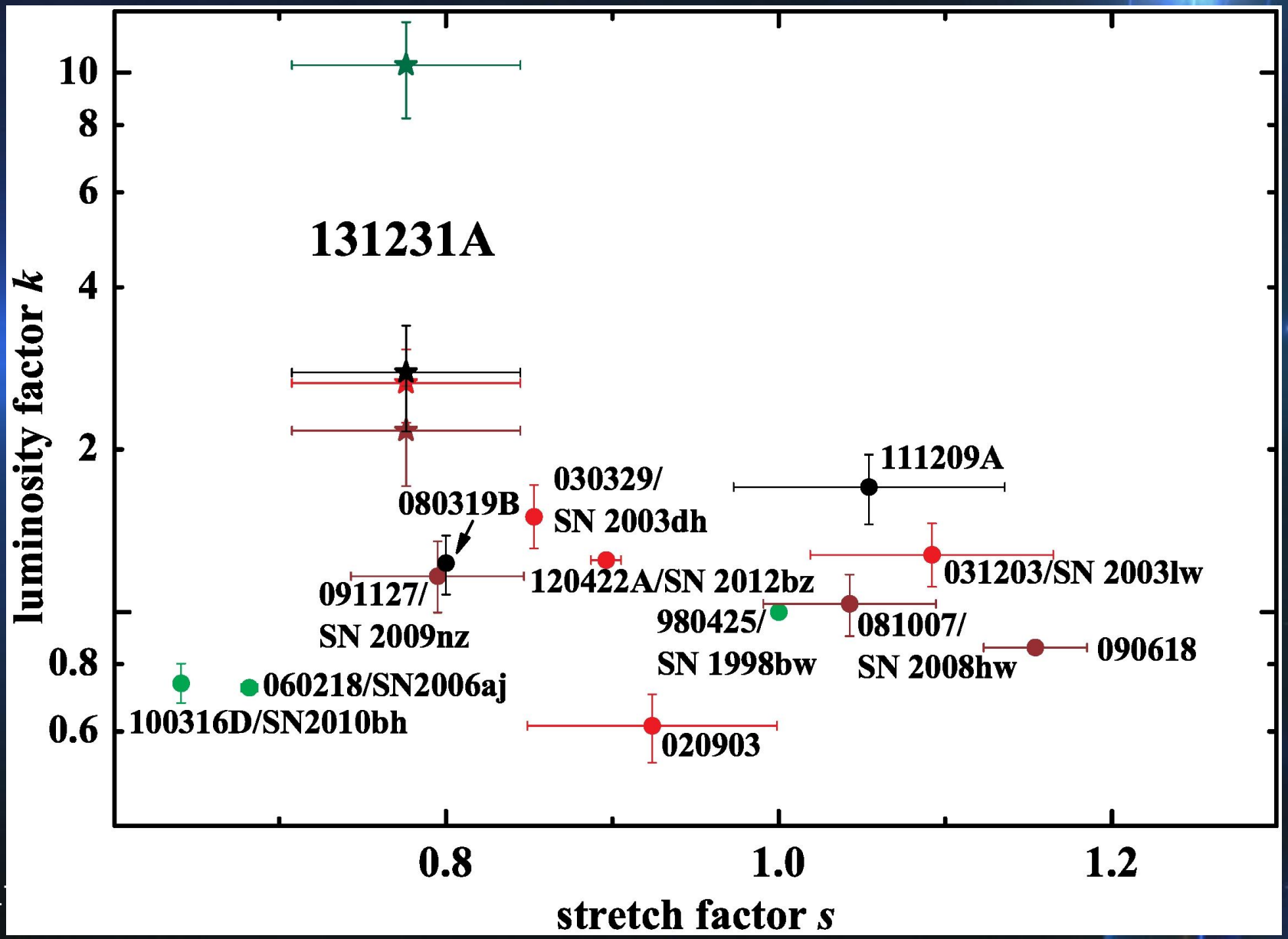
(Greiner, … Kann et al. 2015, Nature, 523, 189; Mazzali, … Kann 2016, MNRAS, 458, 3455; Kann et al. 2017, arXiv:1606.06791v2)

2017+: GRB 131231A: SLSNe for ordinary GRBs?



Bright but ordinary Fermi GBM/LAT Event, $z = 0.642$, Afterglow discovered by iPTF (Singer, … Kann et al. 2015, ApJ, 806, 52)

2017+: GRB 131231A: Brightest! Bluest!



2017+: HETH Studies on the GRB-SN Connection

- Cano et al. on GRB 161219B/SN 2016jca soon accepted
- Kann et al.: GRB-SNe in Multi-Color
- Kann et al.: GRB 131231A
- Kann et al.: GRB 111211A, first AGILE GRB with SN
- de Ugarte Postigo et al.: XRF 100418A, faintest GRB-SN?
- GRBs 150518A, 150818A, 170519A, 170607A…
- GTC GRB+SN sample study

Conclusions:

- Gamma-Ray Bursts are associated with Supernovae: Probably all massive-star collapse GRBs produce SNe, but most SNe do not produce GRBs.
- These SNe are luminous and exhibit very rapid expansion speeds and high kinetic energies
- GRB-SNe are quite homogenous, despite the GRB properties being vastly different
- But now we have an ultralong GRB with a “faint SLSN”
- … and possibly a normal GRB with a not quite so faint SLSN!

Clearly, there is more to come!