

Probing the Diversity of GRB-Associated Supernovae: Is There Any Correlation or Clustering?

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Introduction: GRBs

Detection

Swift: Burst Alert Telescope (~3 arcminutes), X-Ray Telescope (~several arcseconds), Ultra-Violet and Optical Telescope sub-arcseconds)

The detection rate is 1 GRB per ~ week

Fermi: Gamma-ray Burst Monitor (tens of square degrees), Large Area Telescope (~square degrees)

The detection rate is 1 GRB per ~2 days

Einstein Probe (EP): Wide-field X-ray Telescope (~arcminutes), Follow-up X-ray Telescope (~tens of arcseconds)

The detection rate is ~100 per year

Space Variable Objects Monitor (SVOM): Gamma-ray Burst Monitor (~tens of degrees; ~100 GRBs per year), ECLAIRs (~tens of arcmin; ~200 GRB in 3 years), Microchannel X-ray Telescope (~tens of arcseconds; ~50 GRB per year), Visible Telescope (sub-arcseconds; ~40 GRBs per year)

Introduction: GRBs

Classification

Short GRBs

Duration less than ~ two seconds

NS+NS or NS+BH mergers

Long GRBs

Duration more than ~ two seconds

Core-collapse supernova (Ic-BL)

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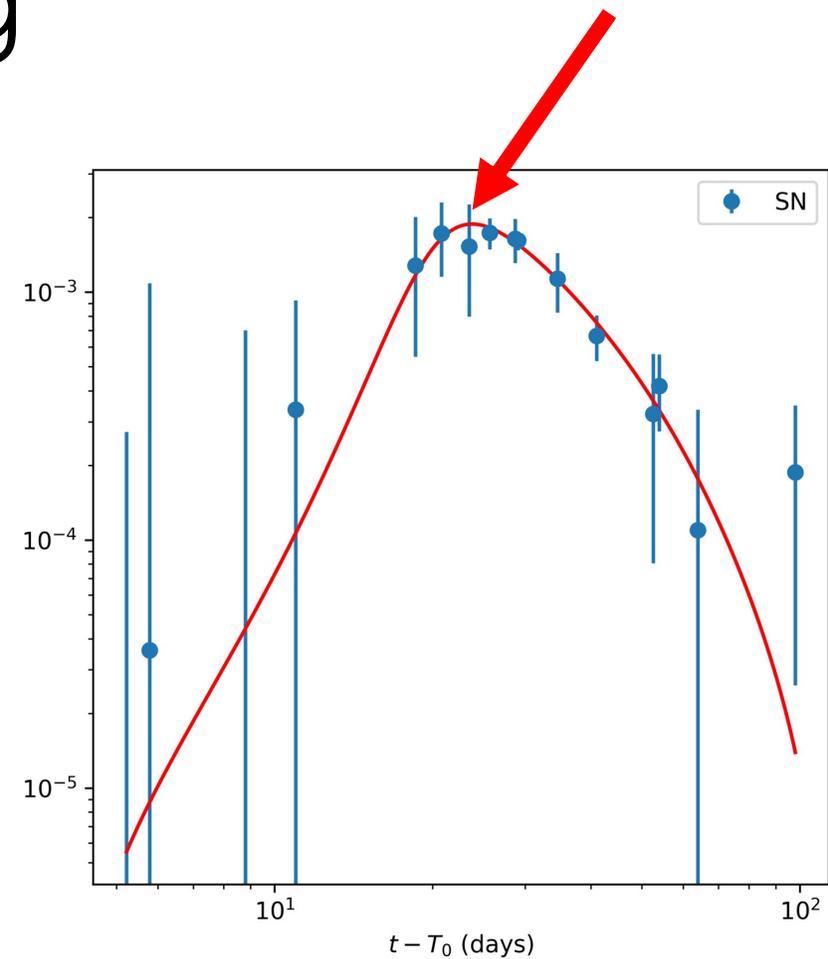
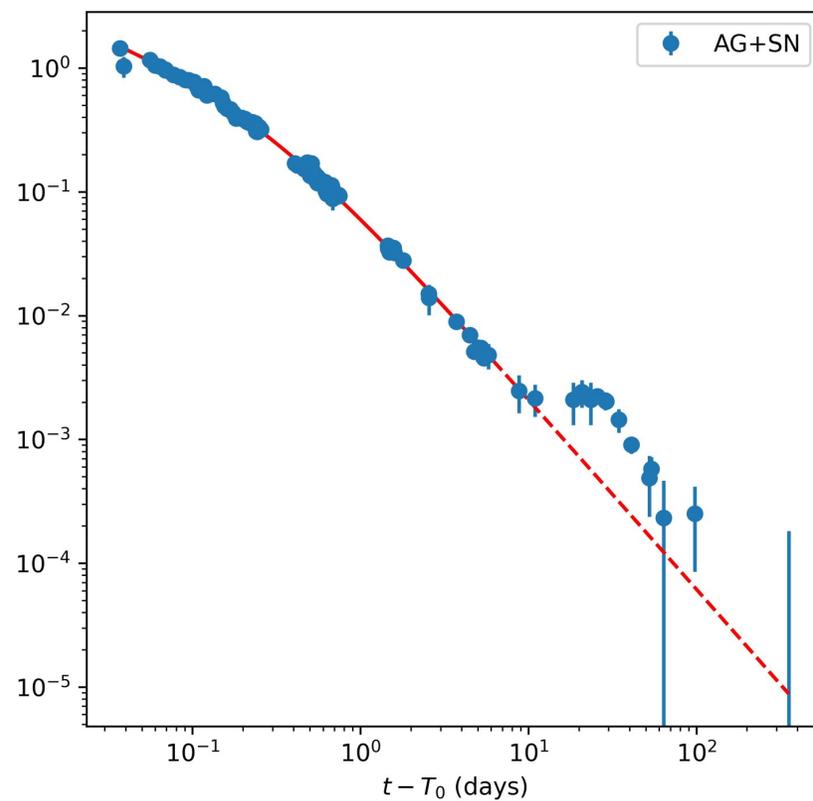
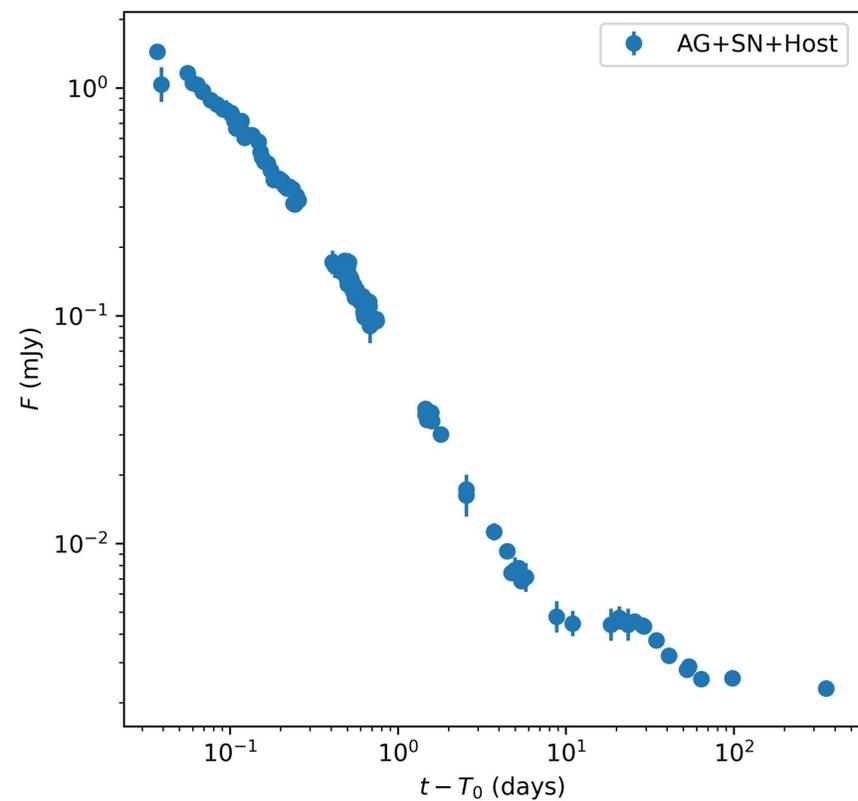
SN-GRBs: prerequisites

Table 3: GRB-SN Master Table II: SN properties

GRB	SN	type	z	S?	Grade	(mag) M_V^*	(mag) $\Delta m_{15,V}$	(d) $t_{V,p}^*$	(erg s^{-1}) $L_{p,\text{Bol}}$	(d) $t_{p,\text{rest}}$	(mag) $\Delta m_{15,\text{Bol}}$	(10^{51} erg) E_K	(M_\odot) M_{ej}	(M_\odot) M_{Ni}	(km s^{-1}) v_{ph}	\bar{k}	\bar{s}	Filters
970228		GRB	0.695		C													
980326		GRB			D													
980425	1998bw	<i>l</i> GRB	0.00866	S	A	-19.29 ± 0.08	0.75 ± 0.02	16.09 ± 0.18	7.33×10^{42}	15.16	0.80	$20 - 30$	$6 - 10$	$0.3 - 0.6$	18000	1	1	<i>R</i>
990712		GRB	0.4331		C							$26.1^{+24.6}_{-15.0}$	$6.6^{+3.5}_{-2.9}$	0.14 ± 0.04		0.36 ± 0.05	1.10 ± 0.20	<i>R</i>
991208		GRB	0.7063		E							$38.7^{+44.6}_{-26.0}$	$9.7^{+5.8}_{-5.6}$	0.96 ± 0.48		2.11 ± 0.58	1.10 ± 0.20	<i>R</i>
000911		GRB	1.0585		E													
011121	2001ke	GRB	0.362	S	B				$\sim 5.9 \times 10^{42}$	~ 17		$17.7^{+8.8}_{-6.4}$	4.4 ± 0.8	0.35 ± 0.01		1.13 ± 0.23	0.84 ± 0.17	<i>BV^*</i>
020305					E													
020405		GRB	0.68986		C							$8.9^{+5.4}_{-3.8}$	$2.2^{+0.6}_{-0.5}$	0.23 ± 0.02		0.82 ± 0.14	0.62 ± 0.03	<i>R</i>
020410					D													
020903		<i>l</i> GRB	0.2506	S	B							$28.9^{+32.2}_{-18.9}$	$7.3^{+4.9}_{-4.0}$	0.25 ± 0.13		0.61 ± 0.19	0.98 ± 0.02	<i>R</i>
021211	2002lt	GRB	1.004	S	B							$28.5^{+45.0}_{-13.0}$	$7.2^{+7.4}_{-6.0}$	0.16 ± 0.14		0.40 ± 0.19	0.98 ± 0.26	<i>R</i>
030329	2003dh	GRB	0.16867	S	A	-19.39 ± 0.14	0.90 ± 0.50	10.74 ± 2.57	1.01×10^{43}	12.75	0.70	$20 - 50$	$5 - 10$	$0.4 - 0.6$	20000	1.28 ± 0.28	0.87 ± 0.18	<i>UBV^*</i>
030723					D													
030725					E													
031203	2003lw	<i>l</i> GRB	0.10536	S	A	-19.90 ± 0.16	0.64 ± 0.10	19.94 ± 1.48	1.26×10^{43}	17.33	0.62	60.0 ± 15	13.0 ± 4.0	0.55 ± 0.20	18000	1.65 ± 0.36	1.10 ± 0.24	<i>VRI^*</i>
040924		GRB	0.858		C													
041006		GRB	0.716		C							$76.4^{+39.8}_{-28.7}$	$19.2^{+3.9}_{-3.6}$	0.69 ± 0.07		1.16 ± 0.06	1.47 ± 0.04	<i>R</i>
050416A		INT	0.6528		D													
050525A	2005nc	GRB	0.606	S	B	-18.59 ± 0.31	1.17 ± 0.88	11.08 ± 3.37				$18.9^{+10.7}_{-7.5}$	$4.8^{+1.1}_{-1.0}$	0.24 ± 0.02		0.69 ± 0.03	0.83 ± 0.03	<i>R</i>
050824		GRB	0.8281		E							$5.7^{+9.3}_{-3.7}$	$1.4^{+1.6}_{-0.6}$	0.26 ± 0.17		1.05 ± 0.42	0.52 ± 0.14	<i>R</i>
060218	2006aj	<i>l</i> GRB	0.03342	S	A	-18.85 ± 0.08	1.08 ± 0.06	9.96 ± 0.18	6.47×10^{42}	10.42	0.83	1.0 ± 0.5	2.0 ± 0.5	0.20 ± 0.10	20000	0.58 ± 0.13	0.67 ± 0.14	<i>UBVR^*</i>
060729		GRB	0.5428		D							$24.4^{+14.3}_{-9.9}$	$6.1^{+1.6}_{-1.4}$	0.36 ± 0.05		0.94 ± 0.10	0.92 ± 0.04	<i>RI</i>
060904B		GRB	0.7029		C							$9.9^{+5.1}_{-3.7}$	2.5 ± 0.5	0.12 ± 0.01		0.42 ± 0.02	0.65 ± 0.01	<i>R</i>
070419A		GRB	0.9705		D													
080319B		GRB	0.9371		C							$22.7^{+19.1}_{-11.9}$	$5.7^{+2.6}_{-2.2}$	0.86 ± 0.45		2.30 ± 0.90	0.89 ± 0.10	<i>I</i>
081007	2008hw	GRB	0.5295	S	B				$\sim 1.4 \times 10^{43}$	~ 12		19.0 ± 15.0	2.3 ± 1.0	0.39 ± 0.08	12600	0.71 ± 0.10	0.85 ± 0.11	<i>riz</i>
090618		GRB	0.54		C	-19.34 ± 0.13	0.65 ± 0.17	17.54 ± 1.64				$36.5^{+20.0}_{-14.2}$	$9.2^{+2.1}_{-1.9}$	0.37 ± 0.03		1.11 ± 0.22	0.98 ± 0.20	<i>B^*</i>
091127	2009nz	GRB	0.49044	S	B				$\sim 1.2 \times 10^{43}$	~ 15	~ 0.5	13.5 ± 0.4	4.7 ± 0.1	0.33 ± 0.01	17000	0.89 ± 0.01	0.88 ± 0.01	<i>I</i>
100316D	2010bh	<i>l</i> GRB	0.0592	S	A	-18.89 ± 0.10	1.10 ± 0.08	8.76 ± 0.37	5.67×10^{42}	8.76	0.89	15.4 ± 1.4	2.5 ± 0.2	0.12 ± 0.02	35000	0.53 ± 0.15	0.53 ± 0.11	<i>VRI^*</i>
100418A		INT	0.6239		D/E													
101219B	2010ma	GRB	0.55185	S	A/B				1.5×10^{43}	11.80	0.99	10.0 ± 6.0	1.3 ± 0.5	0.43 ± 0.03		1.16 ± 0.63	0.76 ± 0.10	<i>griz</i>
101225A		ULGRB	0.847		D							32.0 ± 16.0	8.1 ± 1.5	0.41 ± 0.03		0.96 ± 0.05	1.02 ± 0.03	<i>i</i>
111209A	2011kl	ULGRB	0.67702		A/B				2.91×10^{43}	14.80	0.78	$20 - 90$	$3 - 5$		21000	1.81 ± 0.19	1.08 ± 0.11	<i>iz</i>
111211A			0.478	S	B/C													
111228A			0.71627		E													
120422A	2012bz	<i>l</i> GRB	0.28253	S	A	-19.50 ± 0.03	0.73 ± 0.06	14.20 ± 0.34	1.48×10^{43}	14.45	0.62	25.5 ± 2.1	6.1 ± 0.5	0.57 ± 0.07	20500	1.13 ± 0.25	0.93 ± 0.19	<i>BV^*</i>
120714B	2012eb		0.3984	S	B													
120729A		GRB	0.8		D/E													
130215A	2013ez	GRB	0.597	S	B									0.42 ± 0.11		1.02 ± 0.26	1^\ddagger	<i>ri</i>
130427A	2013cq	GRB	0.3399	S	B									$0.25 - 0.30$	6000	$0.6 - 0.75$	1^\ddagger	<i>ri</i>
130702A	2013dx	INT	0.145	S	A	-19.26 ± 0.24	1.05 ± 0.08	13.86 ± 0.70	1.08×10^{43}	12.94	0.85	64.0 ± 7.0	6.3 ± 0.7	0.28 ± 0.02	35000	0.85 ± 0.03	0.77 ± 0.03	<i>r</i>
130831A	2013fu	GRB	0.479	S	A/B							8.2 ± 0.4	3.1 ± 0.1	0.37 ± 0.01	21300	0.98 ± 0.07	0.78 ± 0.05	<i>griz</i>
140606B		GRB	0.384	S	A/B							18.7 ± 9.0	4.7 ± 0.8	0.30 ± 0.07		0.95 ± 0.19	0.82 ± 0.19	<i>B^*</i>
150518A			0.256		C/D							19.0 ± 11.0	4.8 ± 1.9	0.42 ± 0.17	19800	1.04 ± 0.24	0.81 ± 0.13	<i>V^*</i>
150818A		INT	0.282	S	B													

- Zeh et al., 2004
- Woosley & Bloom, 2006
- Richardson, 2009
- Hjorth & Bloom, 2012
- Modjaz et al., 2016
- **Cano et al., 2017**
- Kumar & Sharma, 2024
- Many more...

SN-GRBs: sample gathering



SN-GRBs: sample

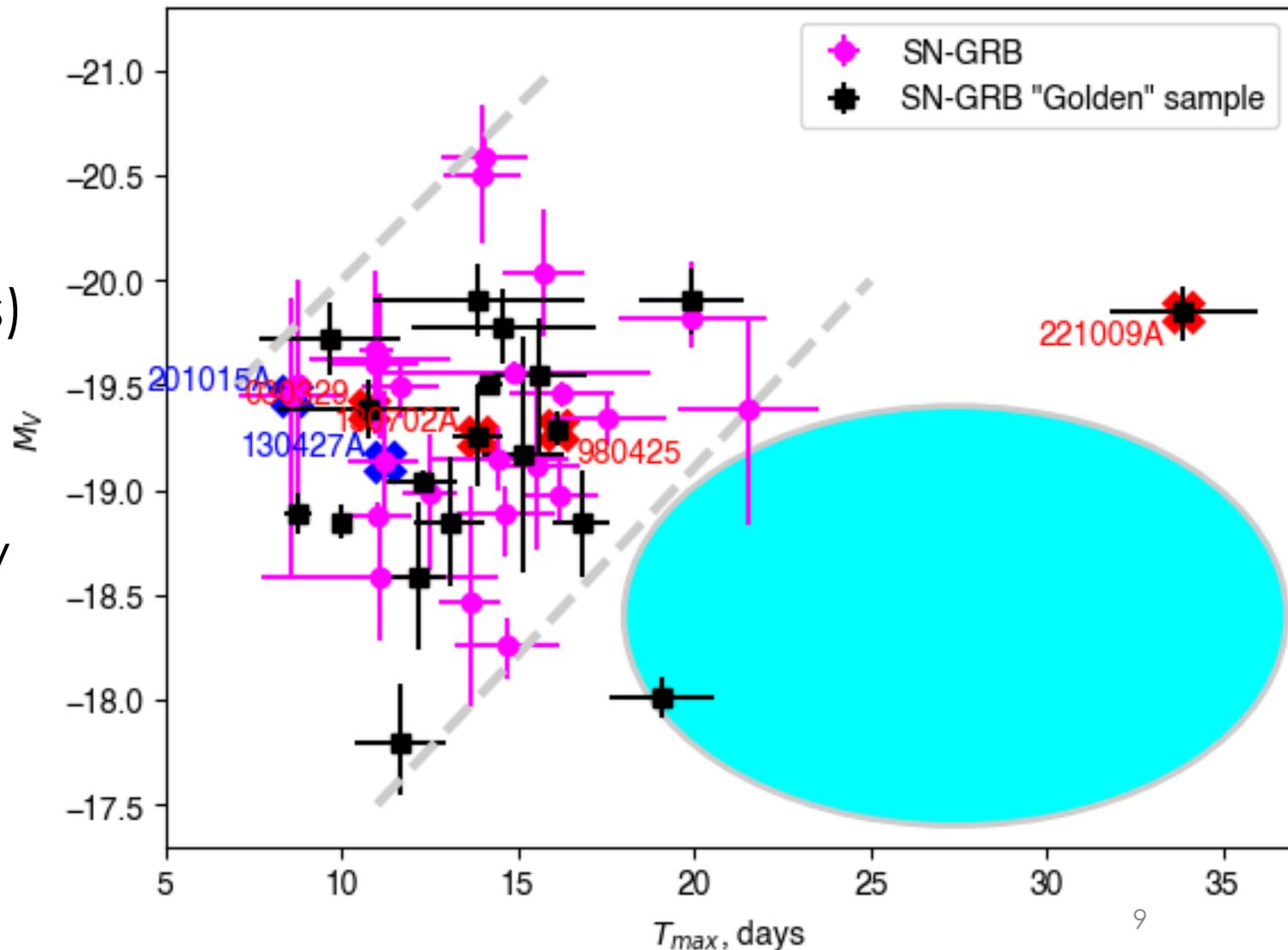
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- GRB 040924
- GRB 041006
- GRB 050525A
- GRB 060218
- GRB 060729
- GRB 071112C
- GRB 080319B
- GRB 081007
- GRB 090618
- GRB 091127
- GRB 100316D
- GRB 101219B
- GRB 111209A
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- GRB 130702A
- GRB 130831A
- GRB 140606B
- GRB 150818A
- GRB 161219B
- GRB 171010A
- GRB 171205A
- GRB 180728A
- **GRB 181201A**
- GRB 190114C
- GRB 190829A
- GRB 200826A
- **GRB 201015A**
- **GRB 211023A**
- **GRB 220219B**
- GRB 221009A
- GRB 230812B

SN-GRBs: distributions

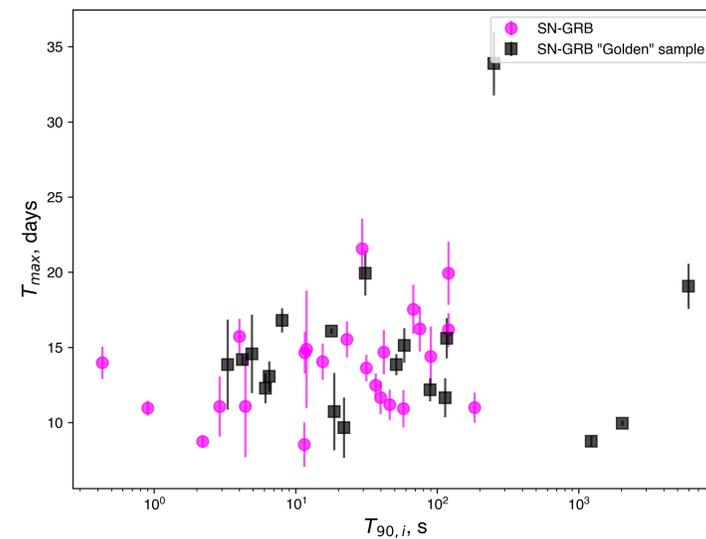
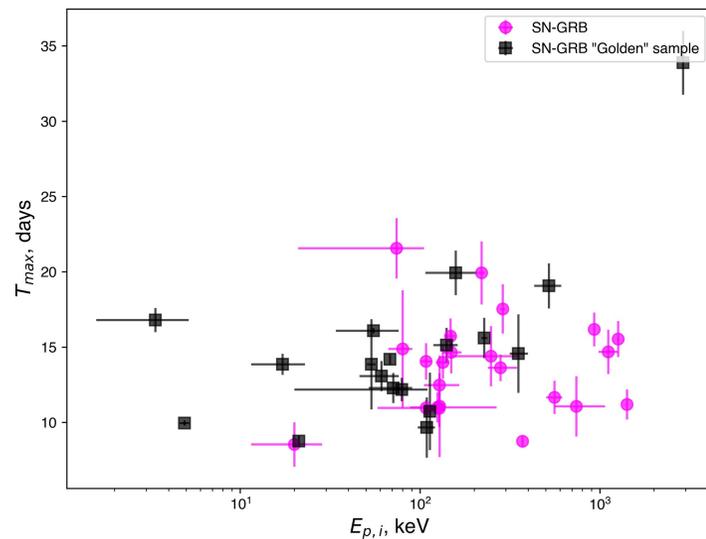
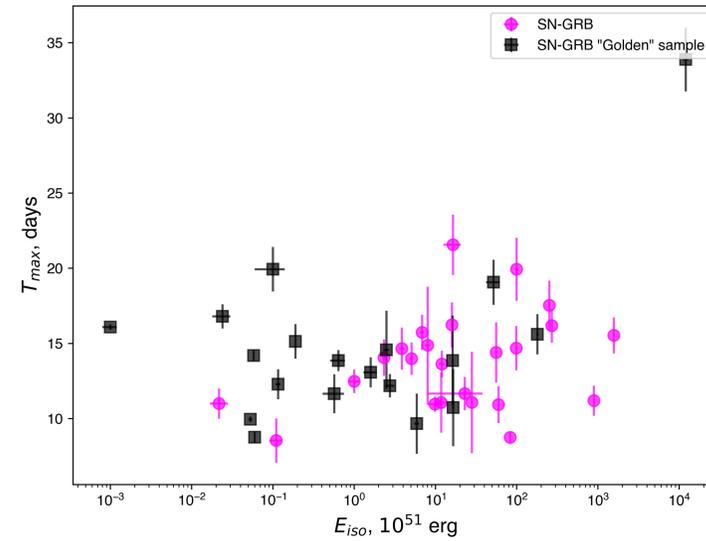
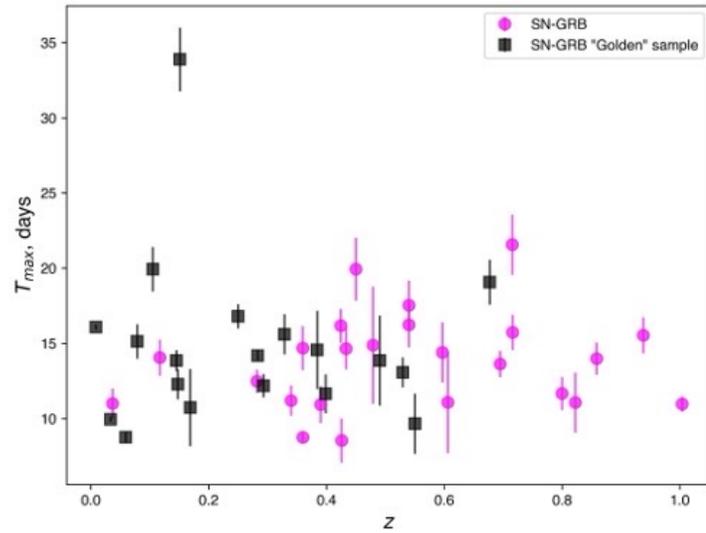
- SN parameters
 - M_V — the absolute magnitude at peak brightness of the associated supernova, indicating its intrinsic luminosity
 - T_{max} — the time of the supernova's peak brightness relative to the GRB trigger
- GRB prompt emission parameters
 - E_{peak} — The energy at which the prompt GRB spectrum (νF_ν) peaks
 - E_{iso} — The isotropic-equivalent energy released during the GRB prompt phase, assuming emission in all directions
 - T_{90} — The duration over which 90% of the GRB's total prompt emission fluence is observed

SN-GRBs: M_V - T_{max}

- Spearman's rank correlation coefficient:
-0.104 (p-value=0.511)
-0.138 (p-value=0.382; no outliers)
- “Golden” means spectroscopy + V rest frame filter

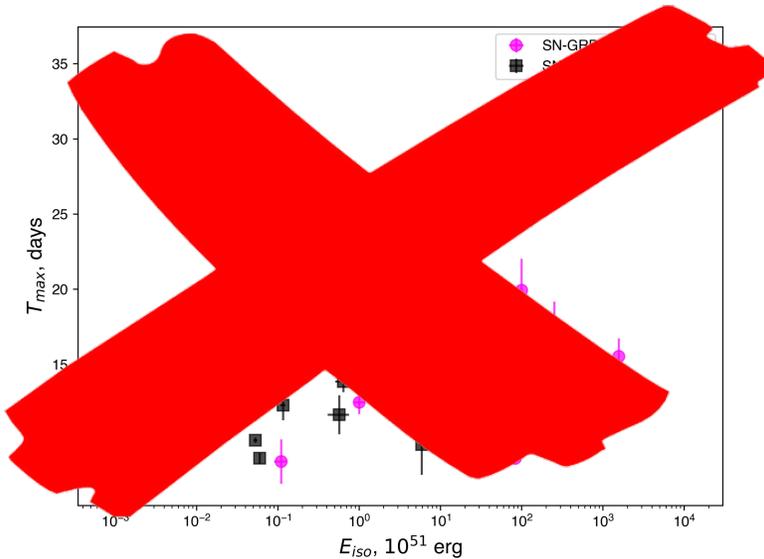
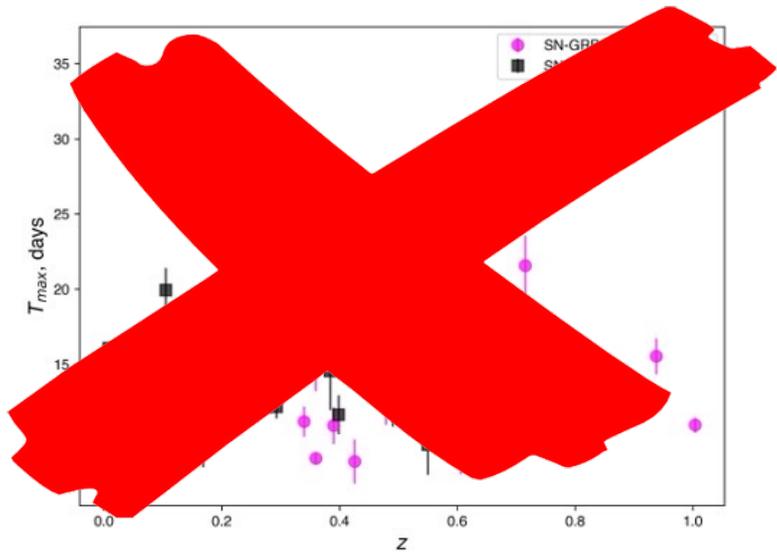


SN-GRBs: distributions T_{max}



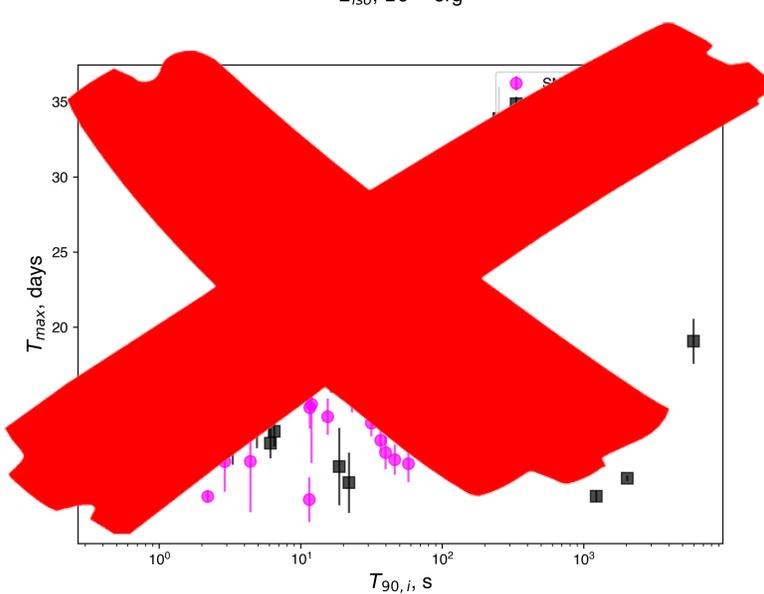
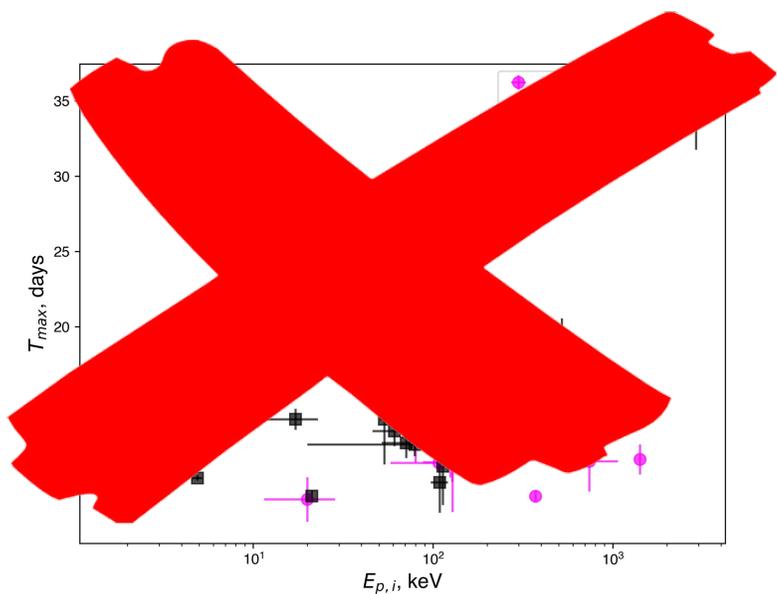
SN-GRBs: distributions T_{max}

0.058 (0.710)
0.102 (0.517)^a



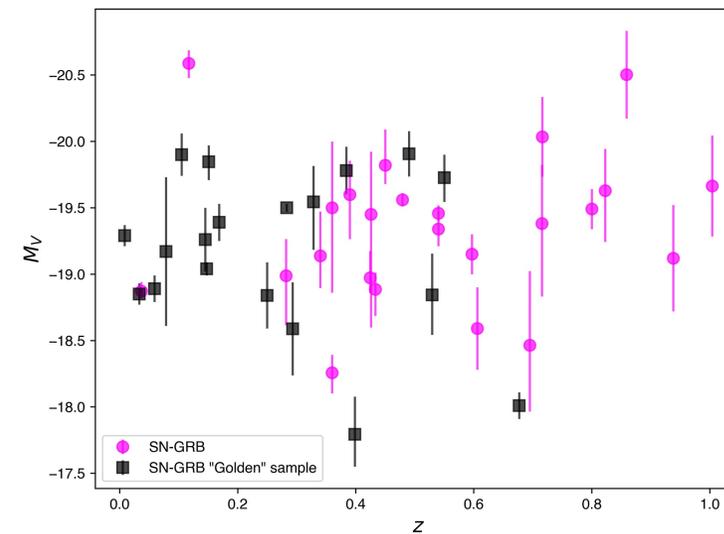
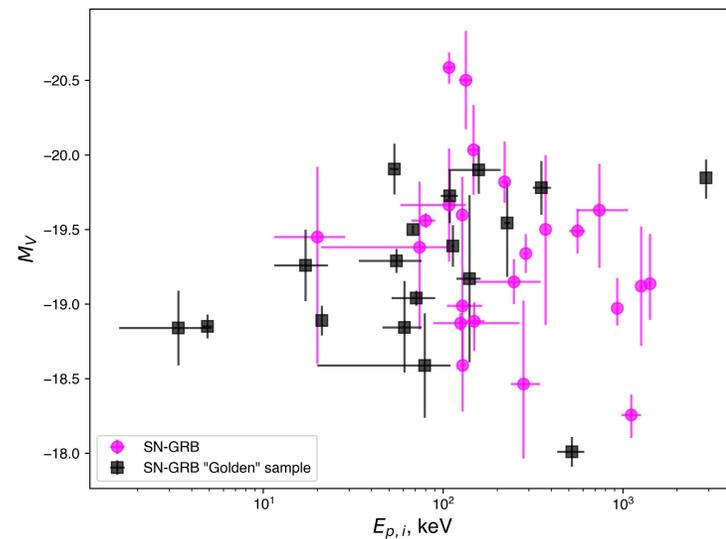
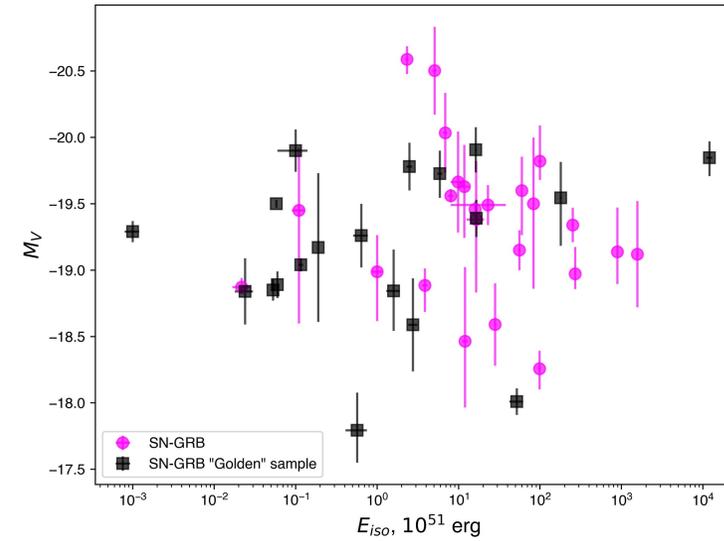
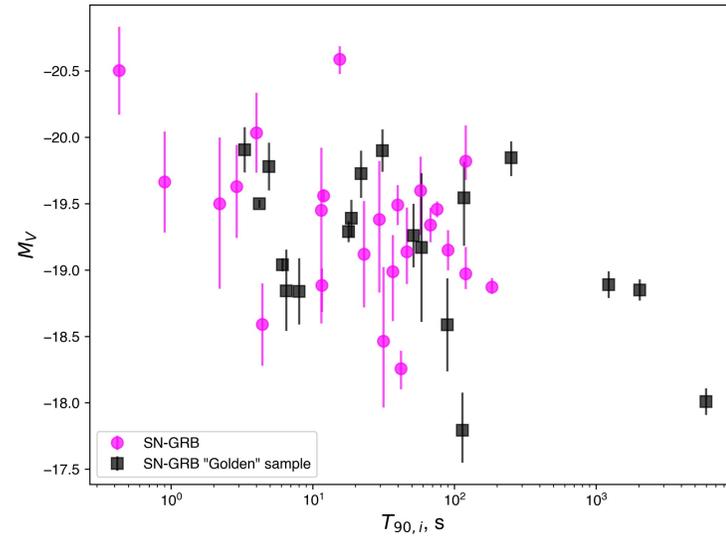
0.218 (0.165)

0.292 (0.061)



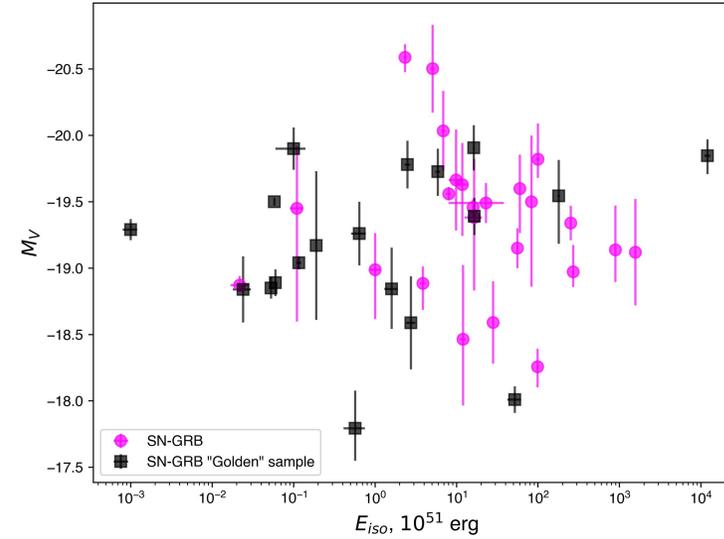
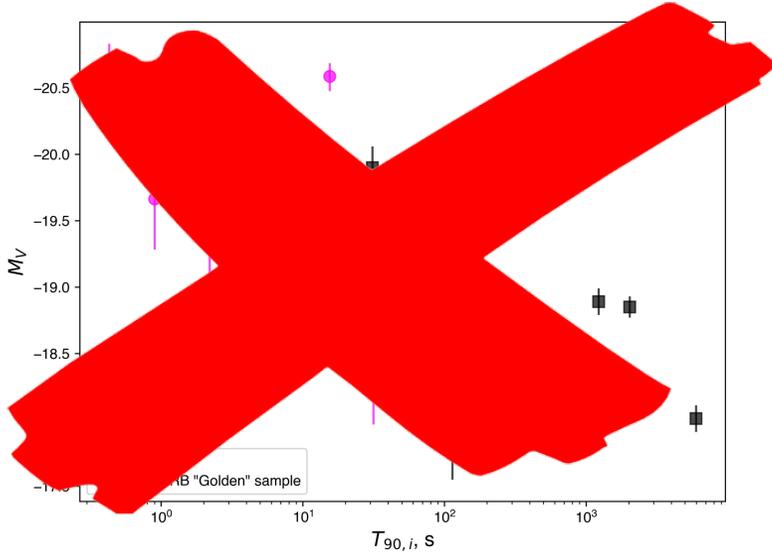
0.199 (0.205)

SN-GRBs: distributions M_V



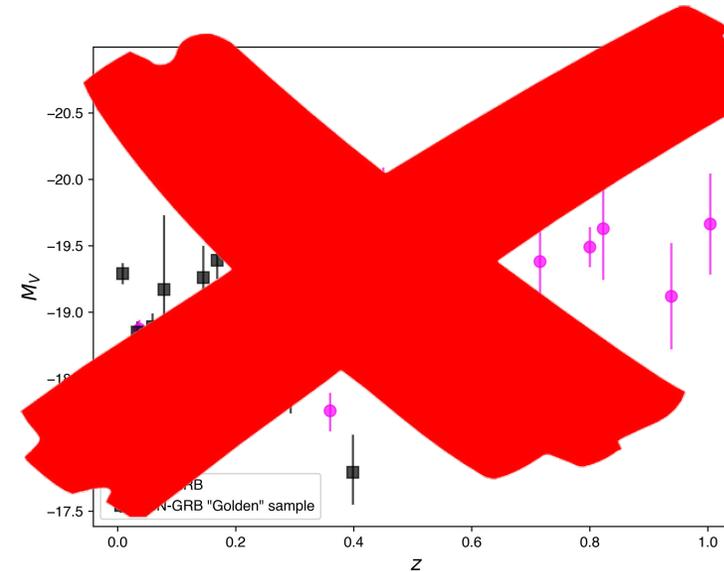
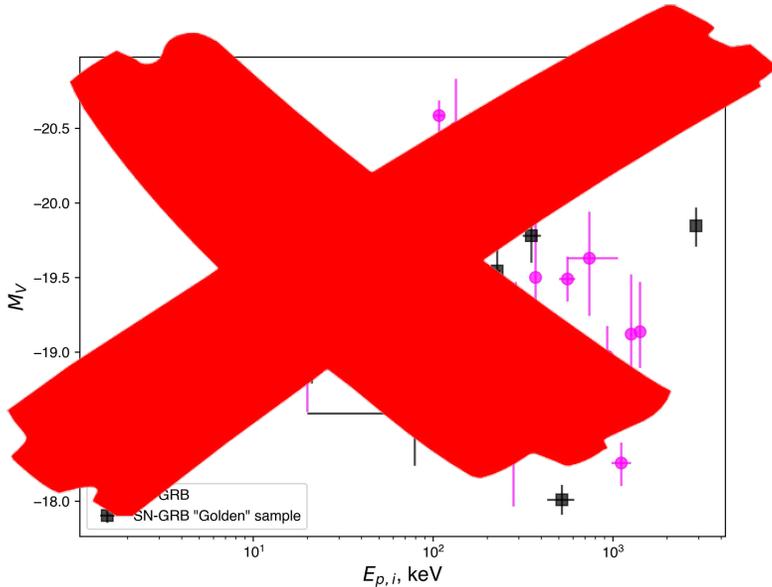
SN-GRBs: distributions M_V

0.408 (0.006)
0.270 (0.096)^a



-0.132 (0.395)

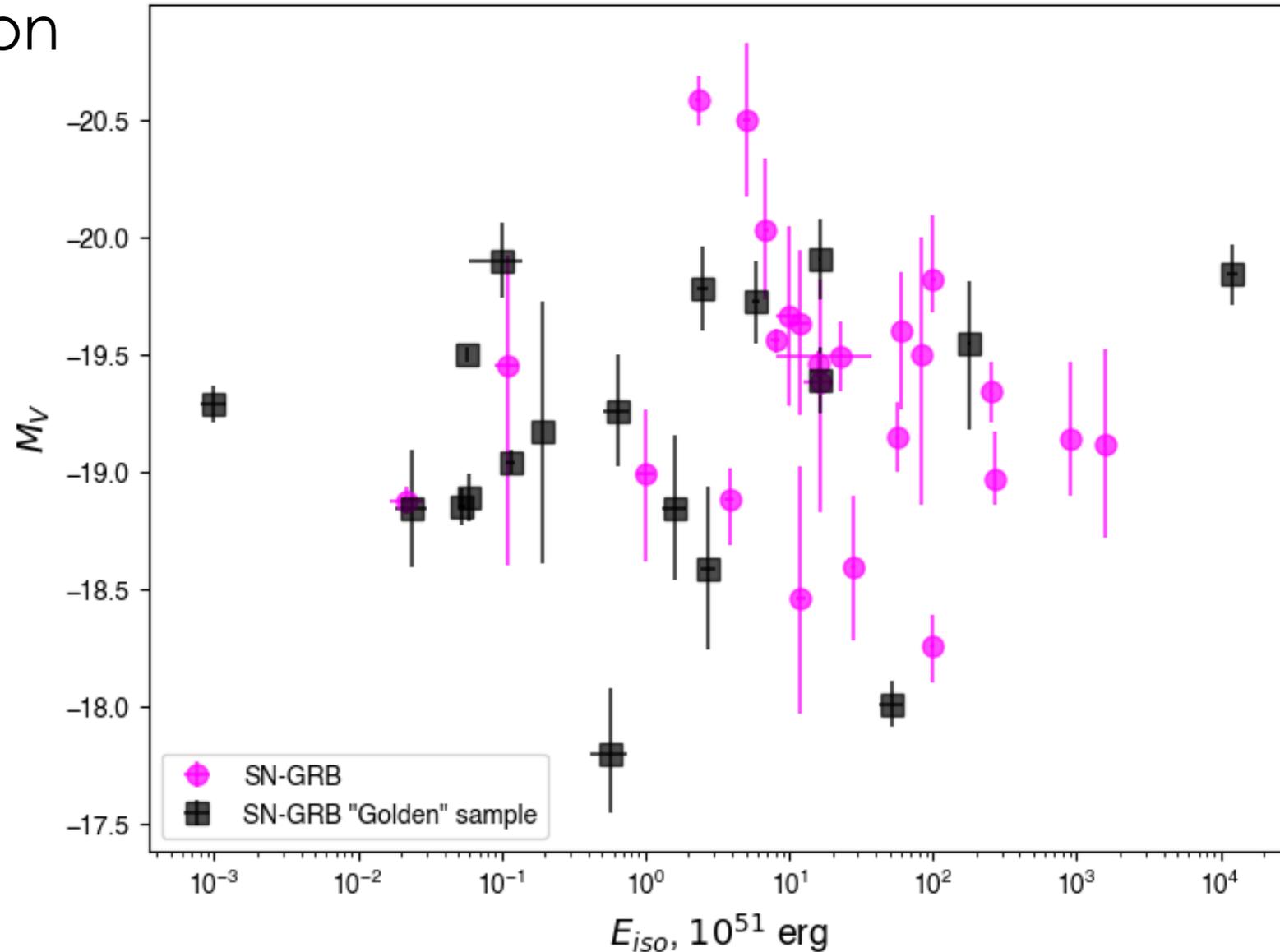
-0.049 (0.760)



-0.172 (0.275)

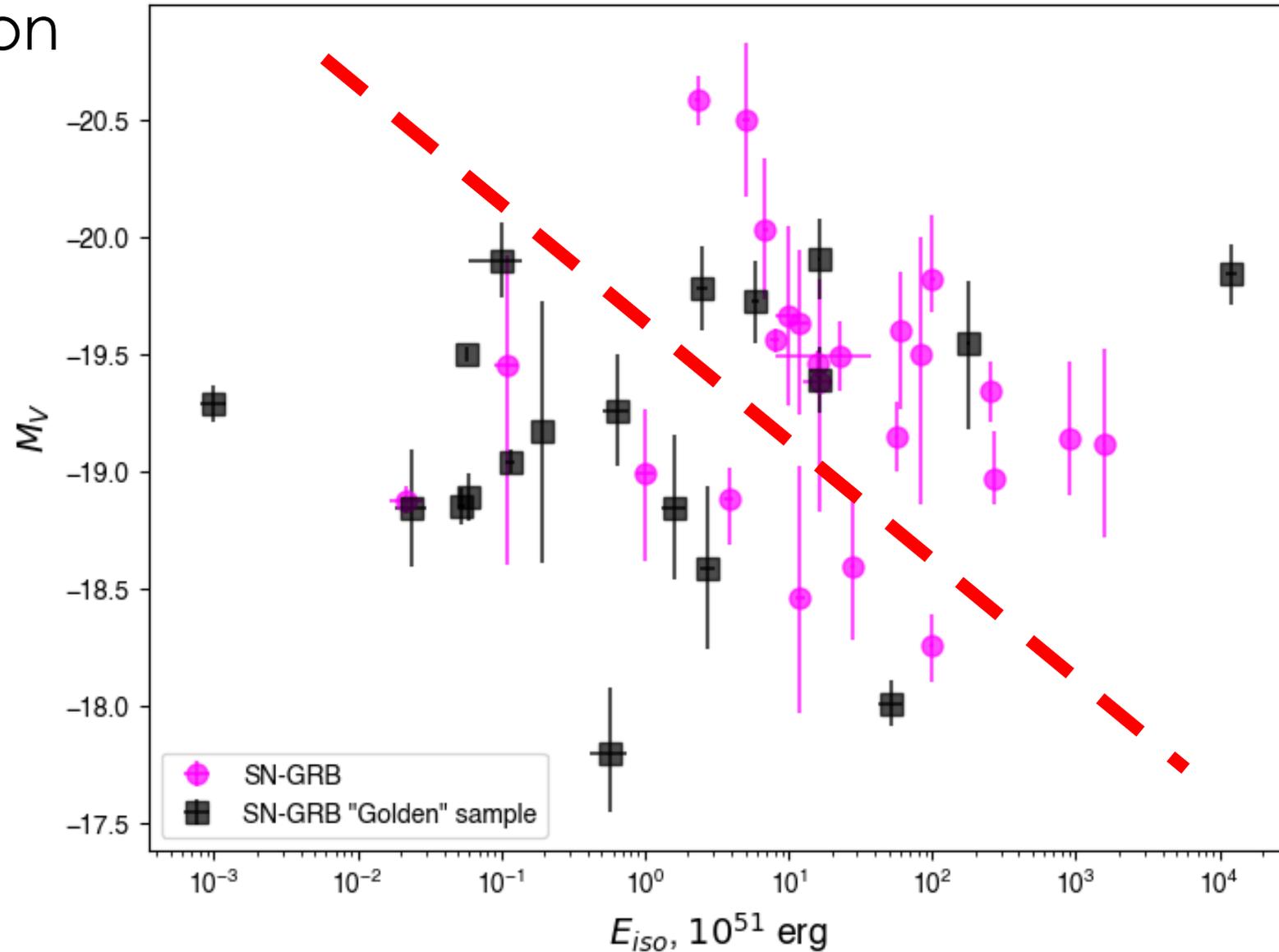
SN-GRBs: M_V - E_{iso}

Detection



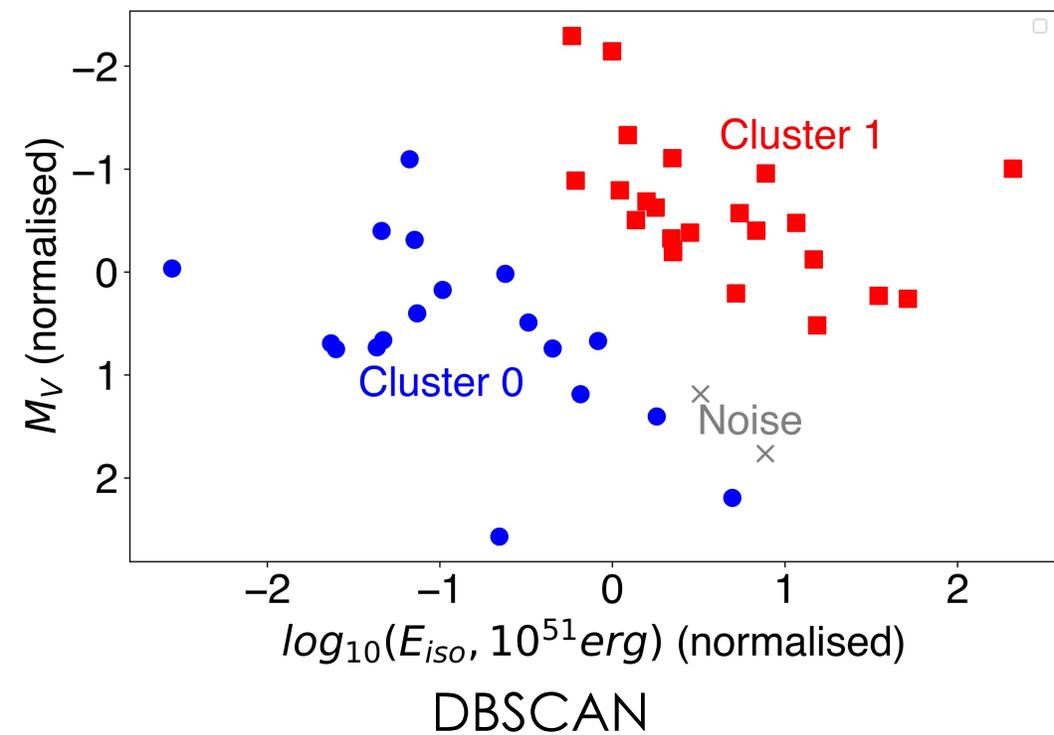
SN-GRBs: M_V - E_{iso}

Detection

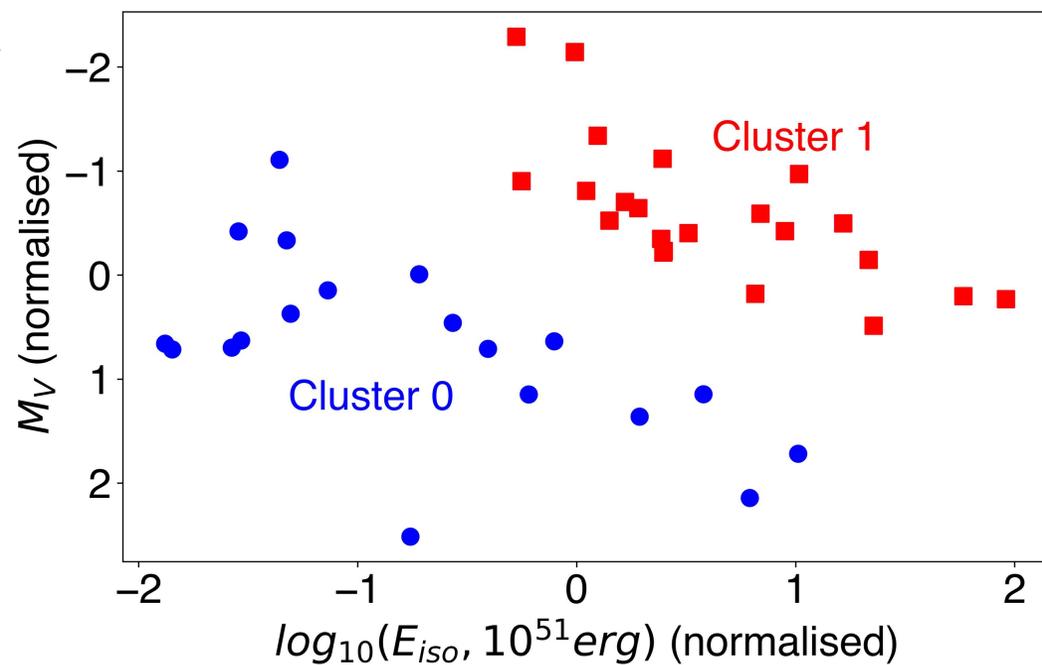


?

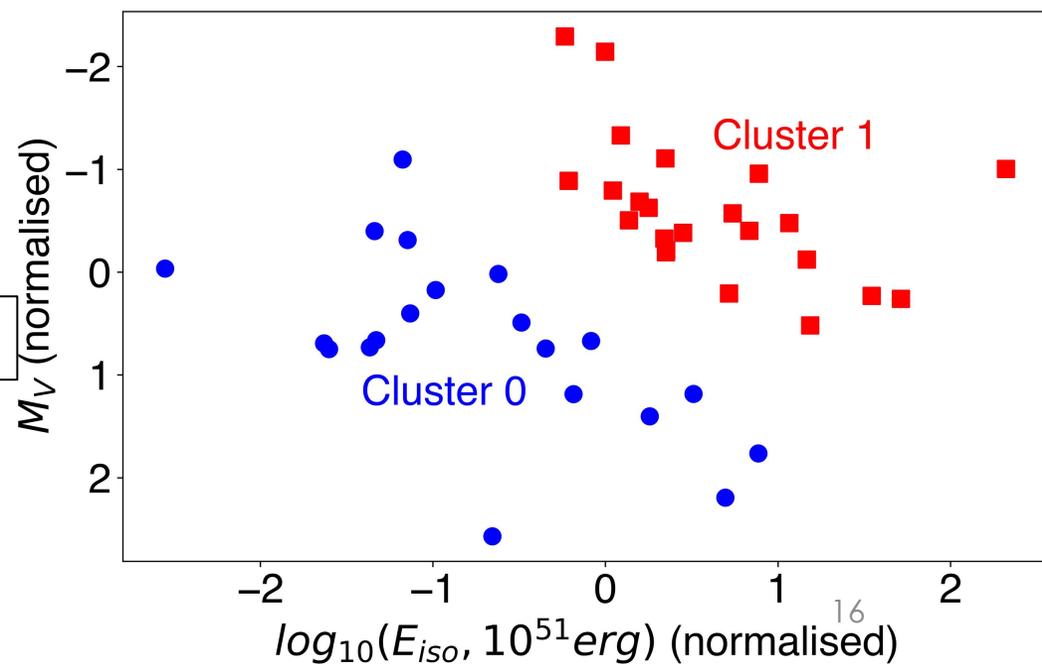
SN-GRBs: M_V - E_{iso} Clustering



GMM



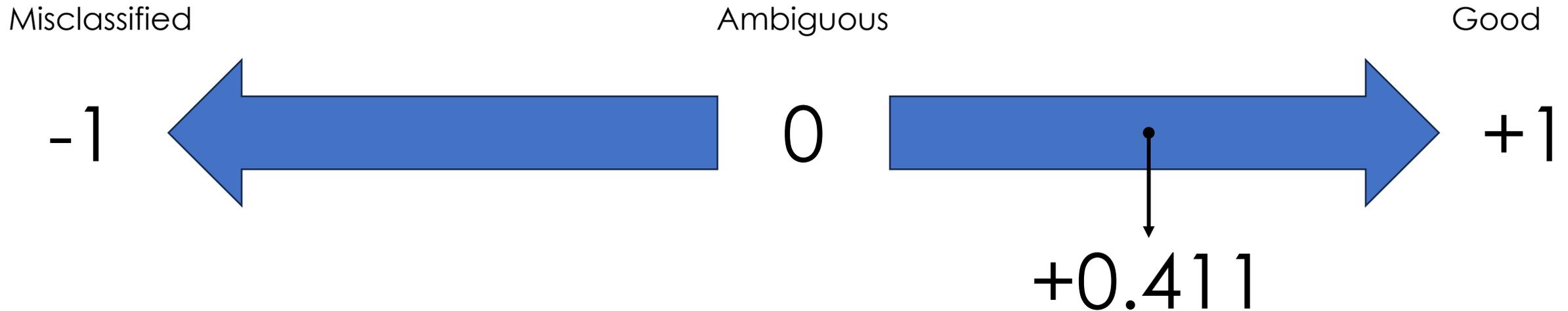
K-means



SN-GRBs: M_V -Eiso

Silhouette metric (SM)

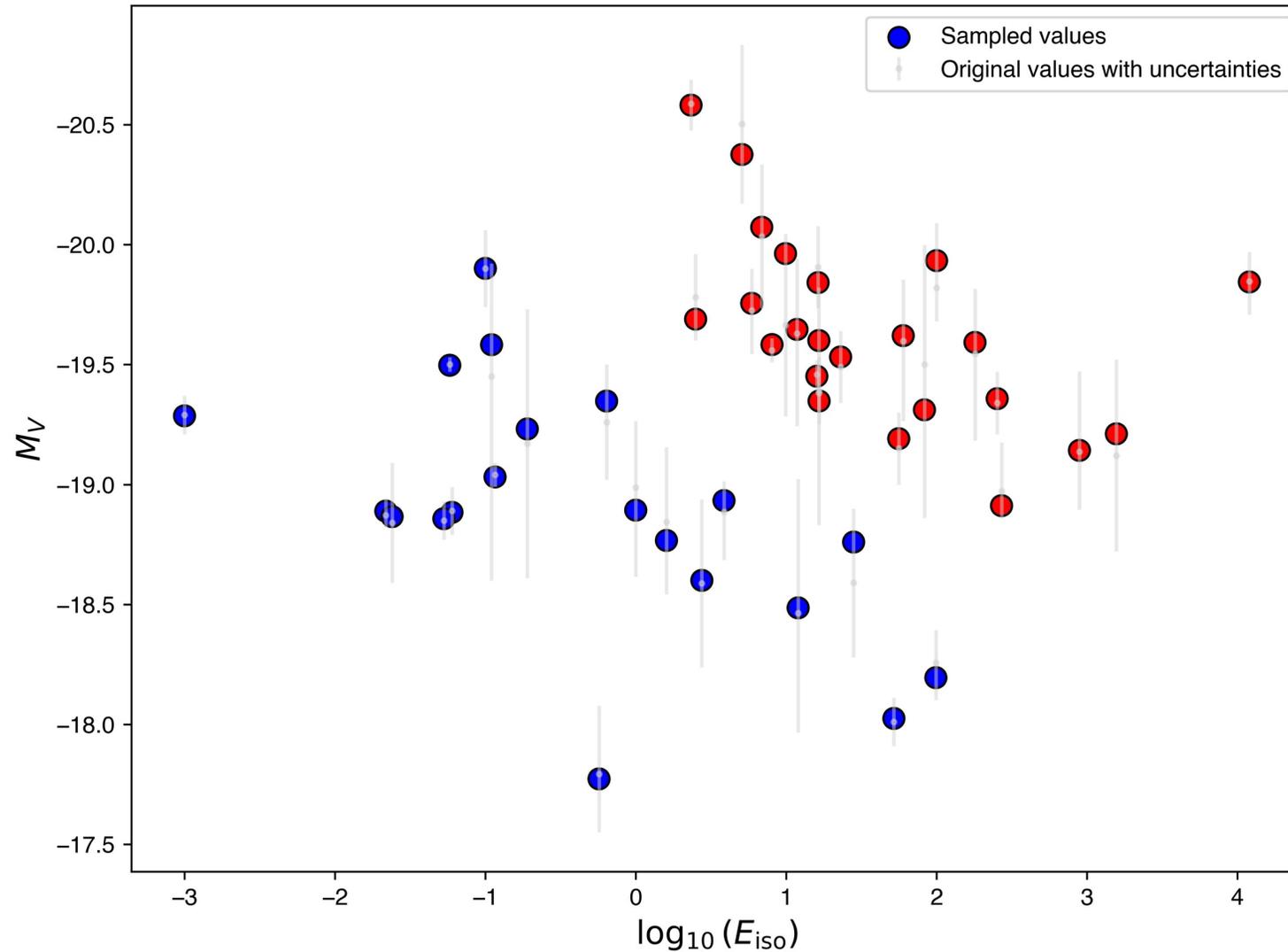
- Measures how similar an object is to its own cluster compared to other clusters



Although the clustering is not sharply defined, the structure is still meaningful and non-random

SN-GRBs: M_V - E_{iso}

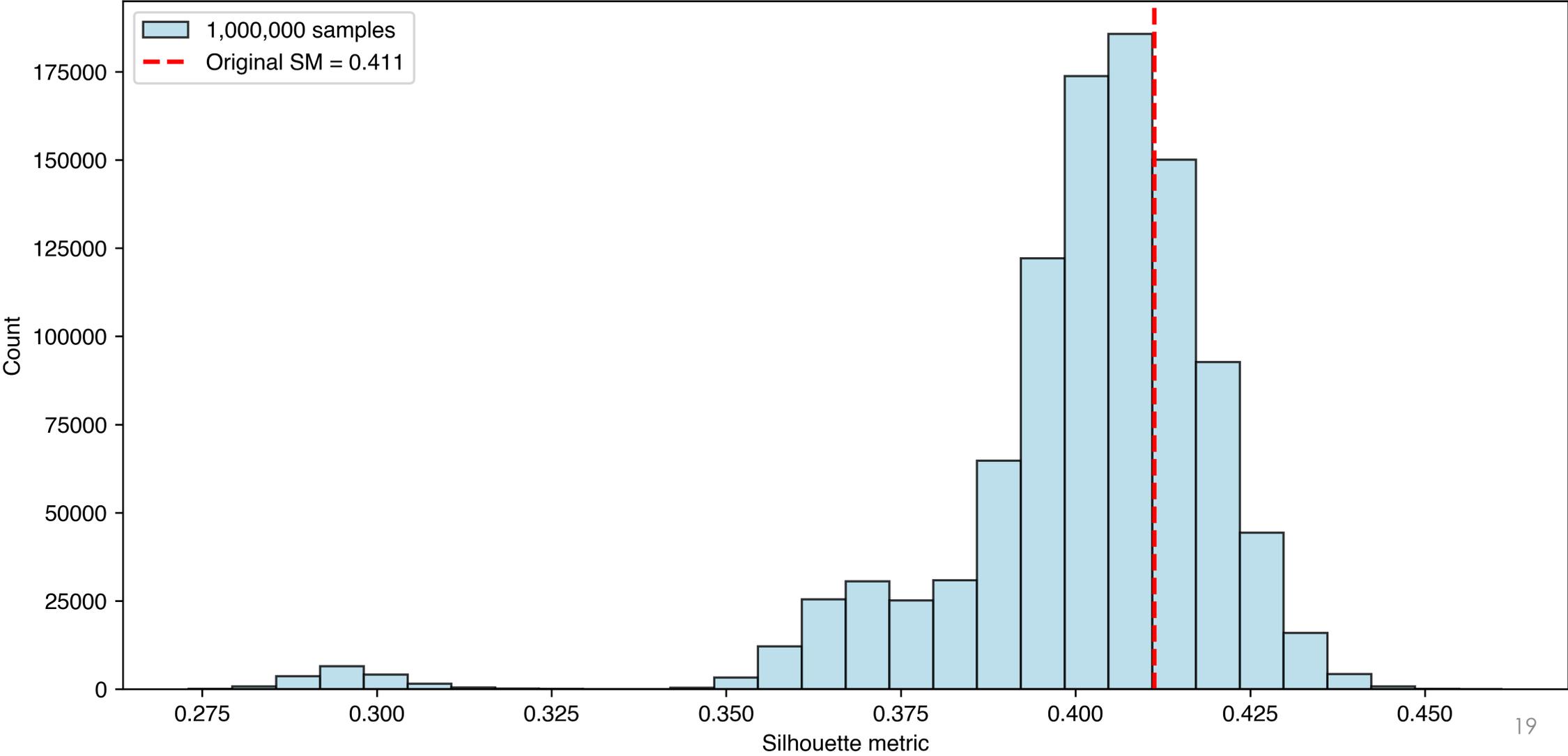
MC Sampling example



SN-GRBs: M_v -Eiso

Silhouette metric probability

p-value: 30%



SN-GRBs: M_V - E_{iso}

Silhouette metric probability: edge GRBs

- GRB 031203 (59.89%)
- GRB 201015A (2.51%)
- GRB 050525A (0.33%)

- Spearman's rank correlation coefficient:

Cluster 0:

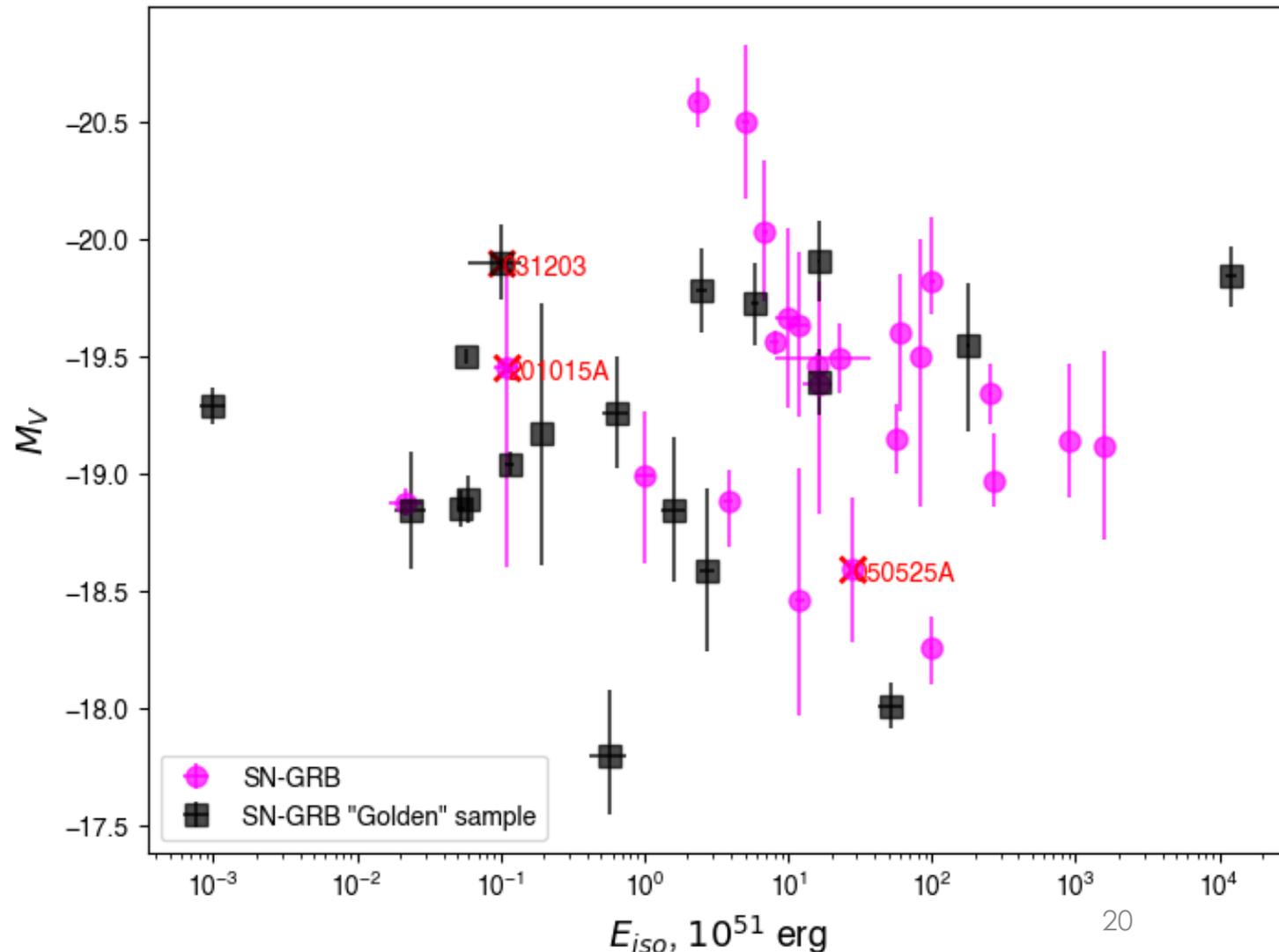
0.564 (0.010)

0.521 (0.022)^a

Cluster 1:

0.620 (0.001)

0.766 (2×10^{-5})^a



SN-GRBs: M_V -Eiso

Why?

- Intrinsic differences in progenitor properties?
- Explosion energetics and central engine effects?
- Jet collimation and viewing angle?
- Selection effects and observational biases?
- There is no clustering. Sample is too small...

Side thoughts

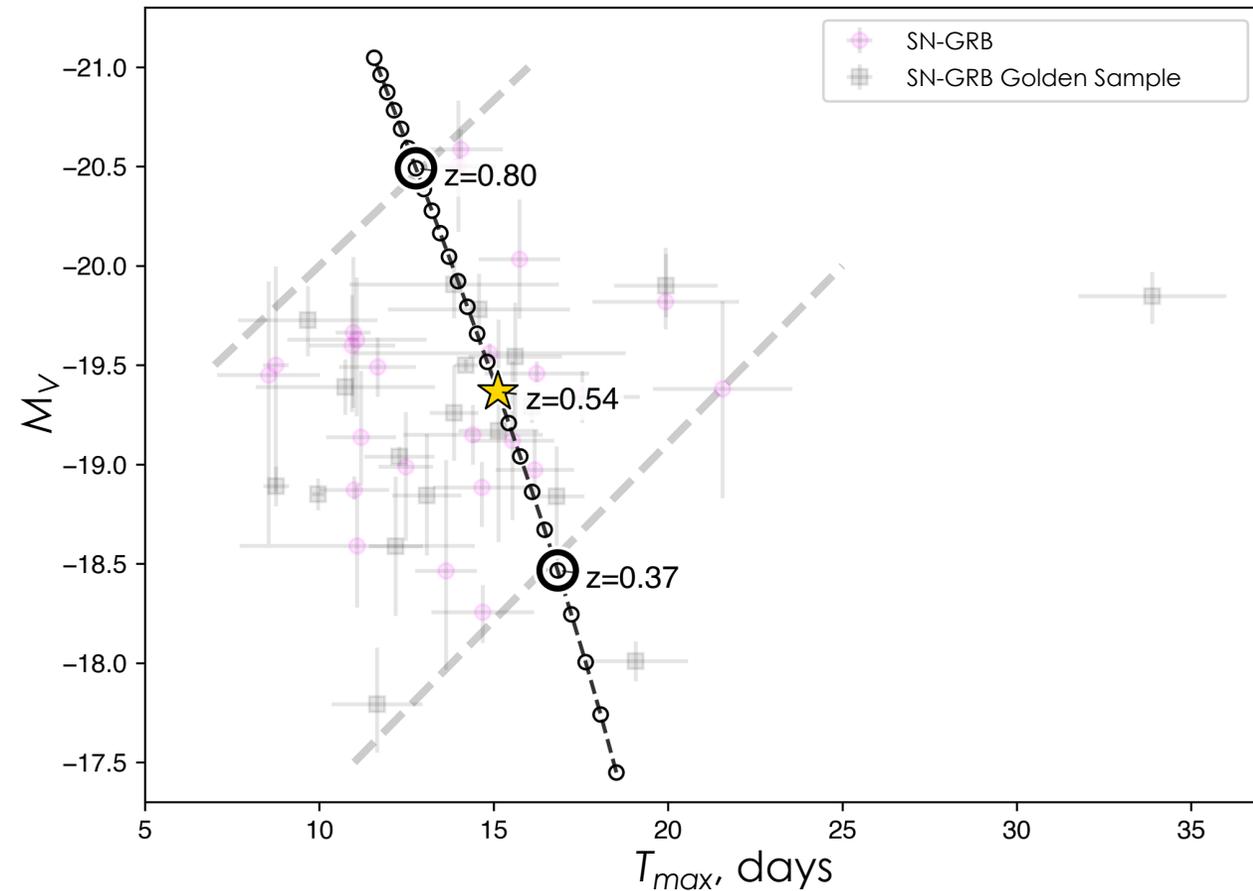
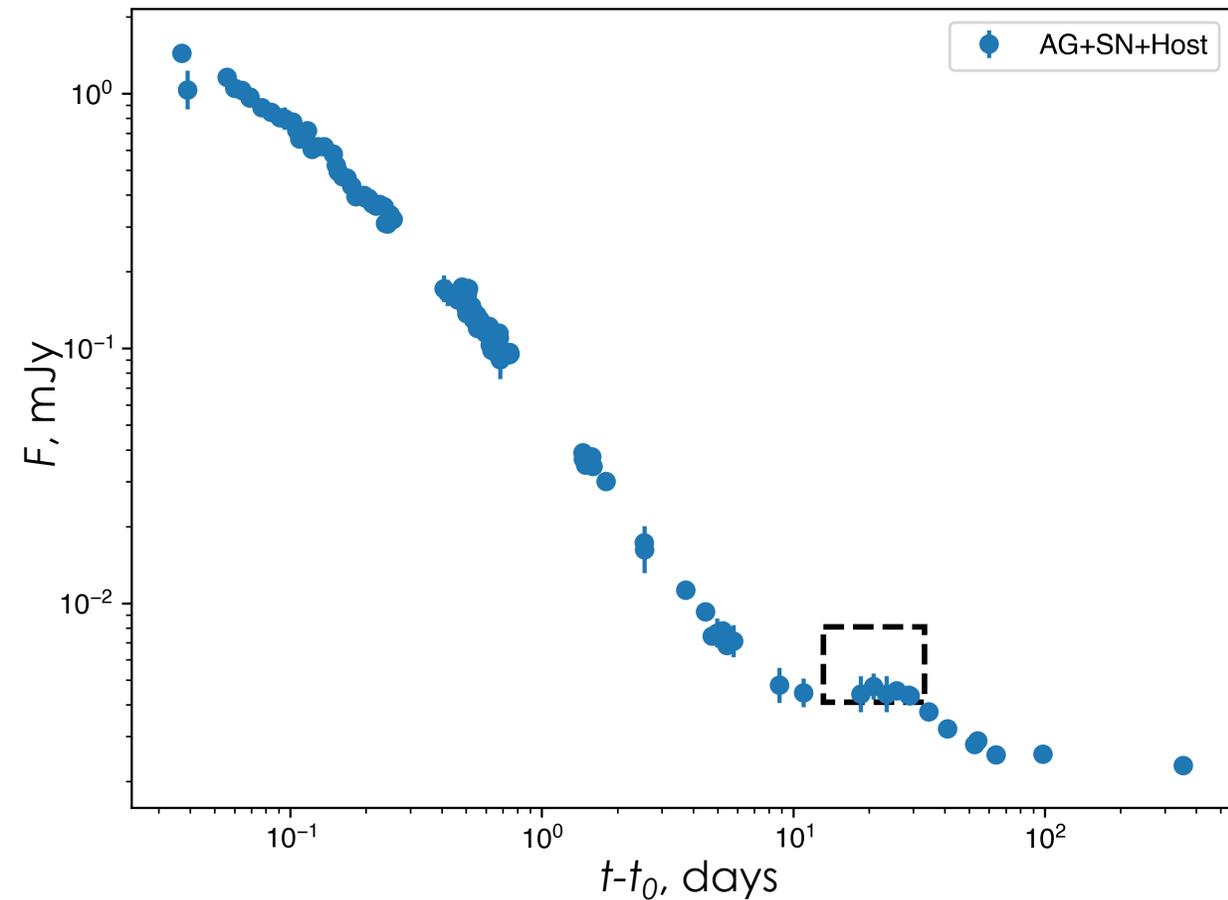


Betteridge's law of headlines:

Any headline that ends in a question mark can be answered by the word no

Meanwhile, our title is “Probing the Diversity of GRB-Associated Supernovae: Is There Any Correlation or Clustering?” Coincidence?

Practical application



Conclusion

- Sample is sampled, ok
- Correlations don't correlate :(
- Clustering? Well, 50-50 :)
- But practically used 👍



Paper is here :)

A black and white illustration of a landscape. In the center, a large, thick black circular frame is superimposed over the scene. The background shows a mountainous terrain with jagged peaks and a lightning bolt striking down from the top left. The overall style is reminiscent of a woodcut or a high-contrast graphic print.

Thank you for
your attention!

SN-GRBs: other samples

- **Paper:** Li et al. 2023, *MNRAS*, 524, 1096–1112
- **Scope:** Literature-compiled GRBs labelled as SN or KN; analysis focuses on prompt gamma-ray and X-ray afterglow properties
- **Example:** GRB 100418A
 - With SN: de Ugarte Postigo et al., 2018
 - Without SN: Marshall et al., 2011; Jia et al., 2012; Niino et al., 2012

SN-GRB: statistics

