The hunt for GRB host galaxies

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Outline

Long GRBs (lGRBs)

1. low-mass star-forming galaxies with sub-solar metallicity
2. trace the evolution of the cosmic star-formation rate (at least at high redshift)
3. though very peculiar cases exist (e.g. dark GRBs).

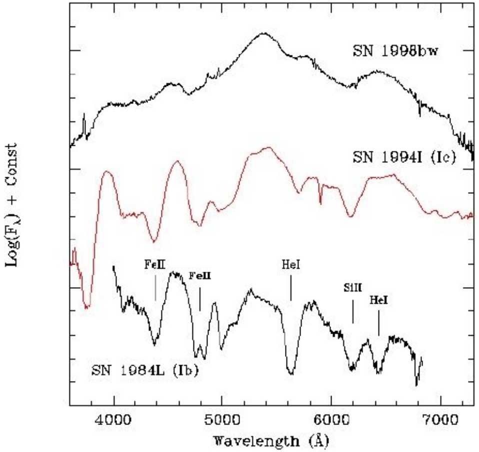
Short GRBs (sGRBs)

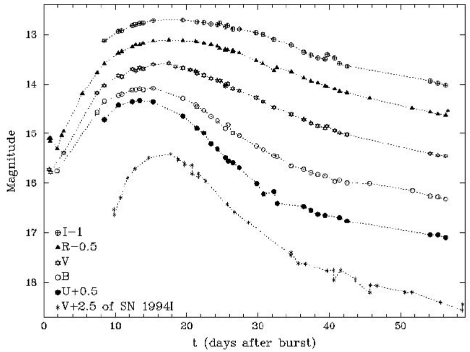
1. afterglows are fainter
2. sGRBs have larger offsets from their hosts
3. Both faintness and large offsets makes the search for sGRB hosts much difficult or even impossible

An enormous observational effort is necessary to understand the sGRB host population in a way comparable to the one of lGRBs

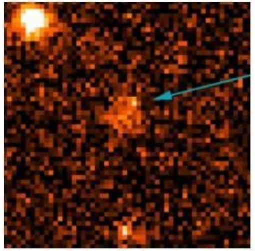
Long GRBs -SN connection

GRB 980425-SN1998bw
z=0.0085



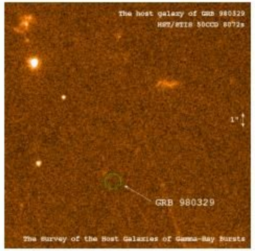


GRB hosts are faint

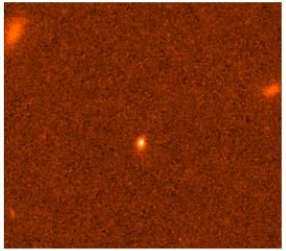


GRB 970228
z = 0.695
Day 200
R_{host} = 24.6

Scale: 1.37”/side

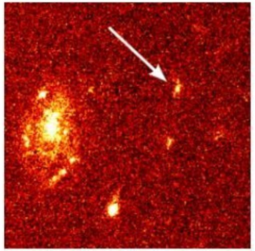


GRB 980329
z > 2 (probable)
Day 880
R_{host} = 28.
Galaxy-radio offset ~ 0.75”
Scale: 17.5”/side

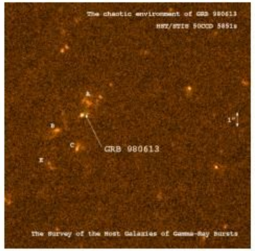


GRB 970508
z = 0.835
Day 200
R_{host} = 25.8
Nucleus-OT offset < 0.01”
Scale: 9.3” x 10.5”

GRB 980519
z: unknown
Day 750
R_{host} = 27.5
Galaxy-OT offset ~ 1.5”
Scale: 6.5”/side

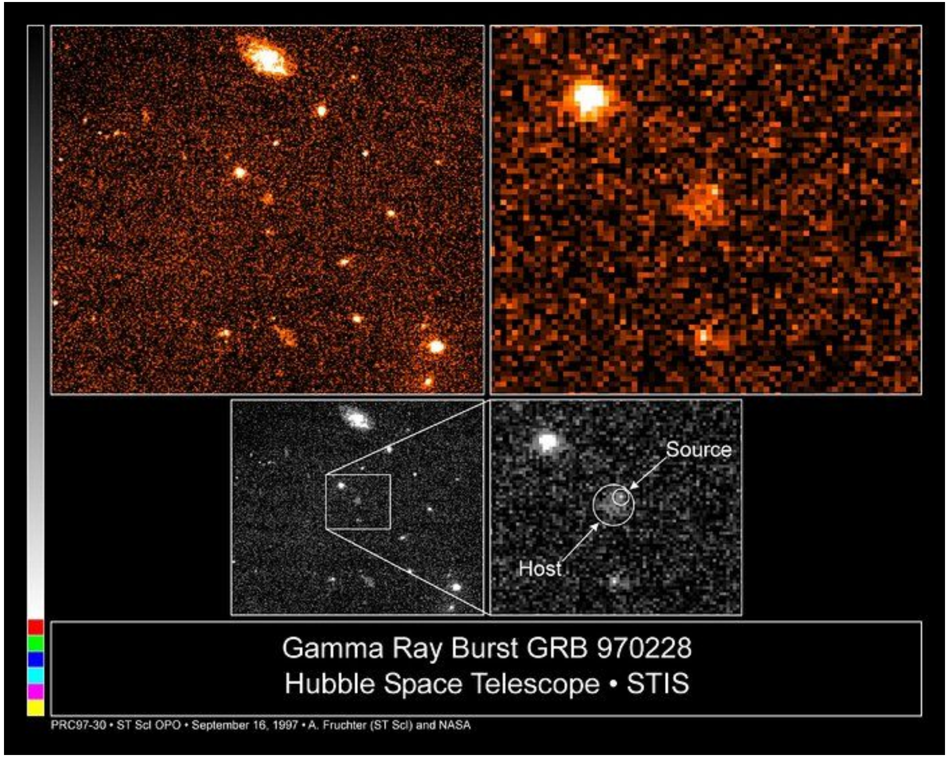


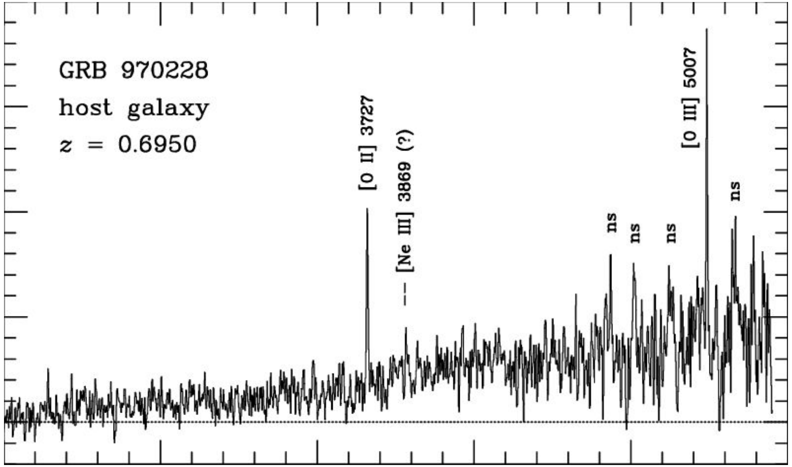
GRB 971214
z = 3.418
Day 144
R_{host} = 25.5
Nucleus-OT offset ~ 0.06”
Scale: 6.35”/side



GRB 980613
z = 1.097
Day 799
R_{host} = 26.
Field ~ 6 galaxies; tidal interactions
Scale: 18.4”/side

Can provide redshift: GRB 970228



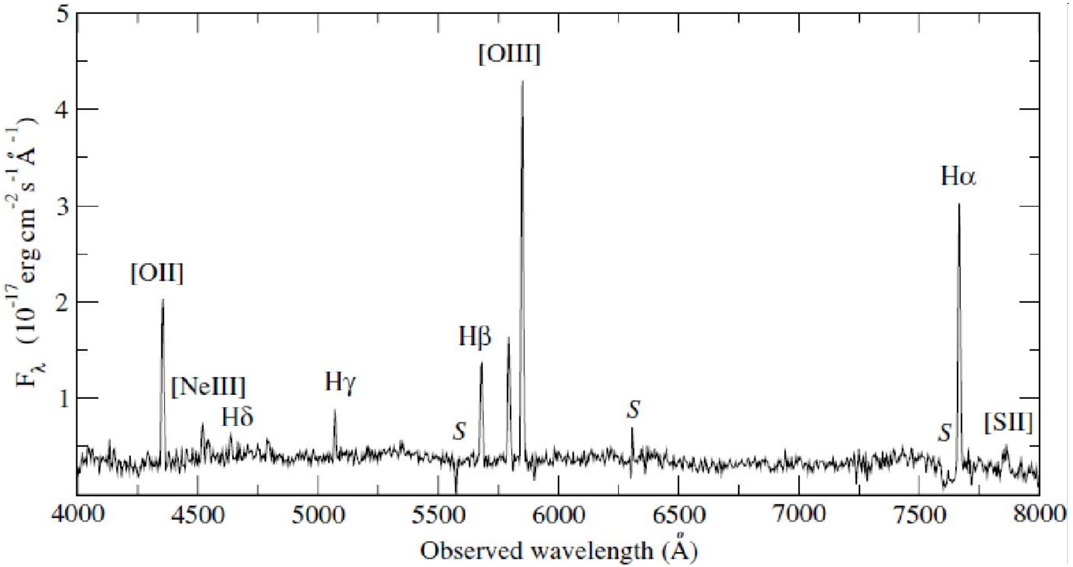


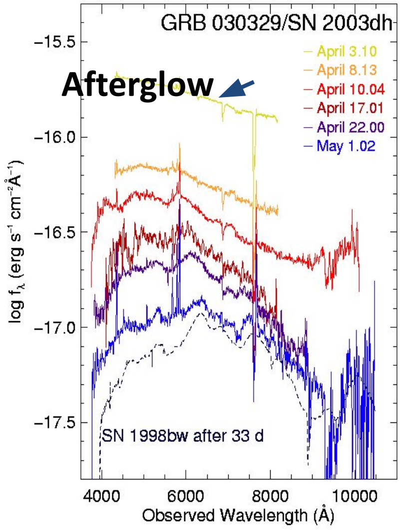
Fruchter+99

Long GRB hosts are star-forming galaxies

Hjorth et al. 2003

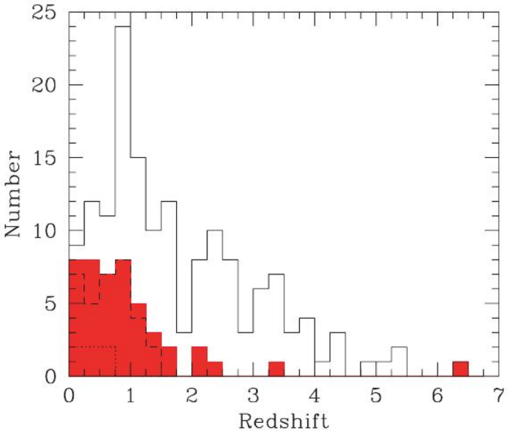
Host GRB 030329, Gorosabel, et al., 2005

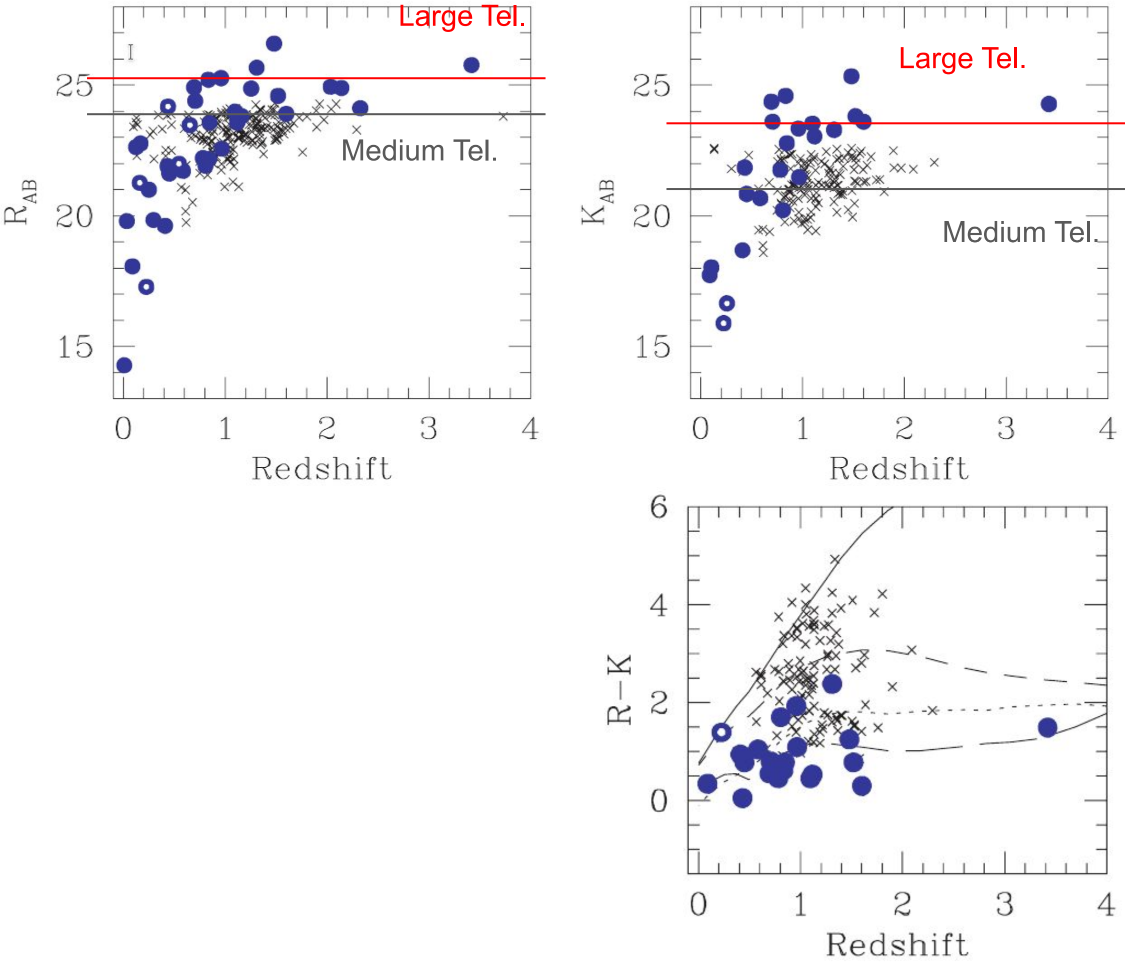




- Star formation, metallicity, global extinction

Not an easy job



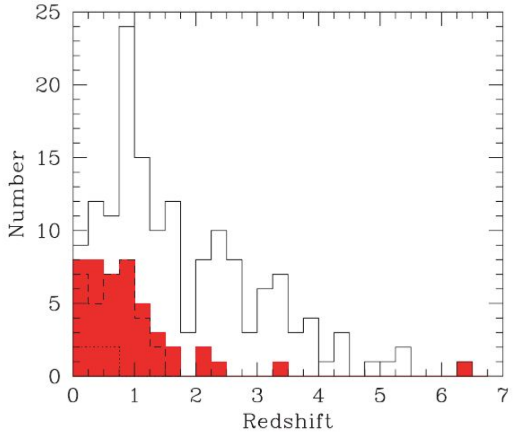


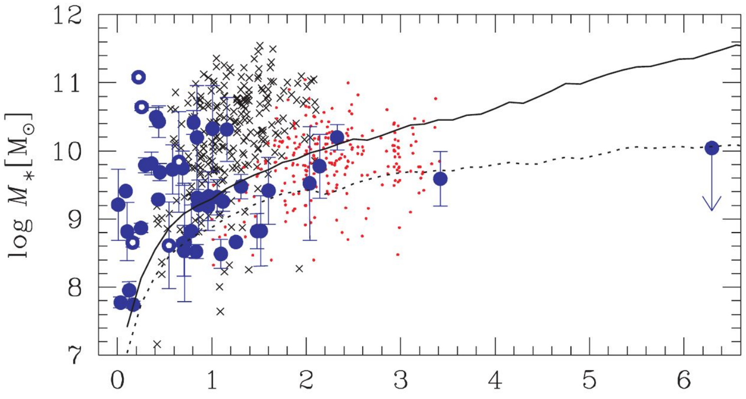
Savaglio+09

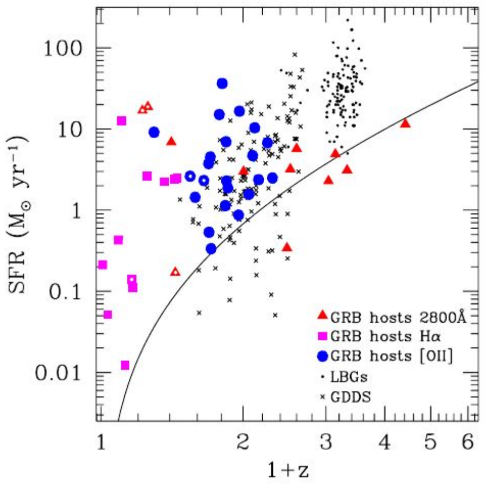
154 GRBs with redshift

Only 46 hosts (33 w em. lines)

Not an easy job







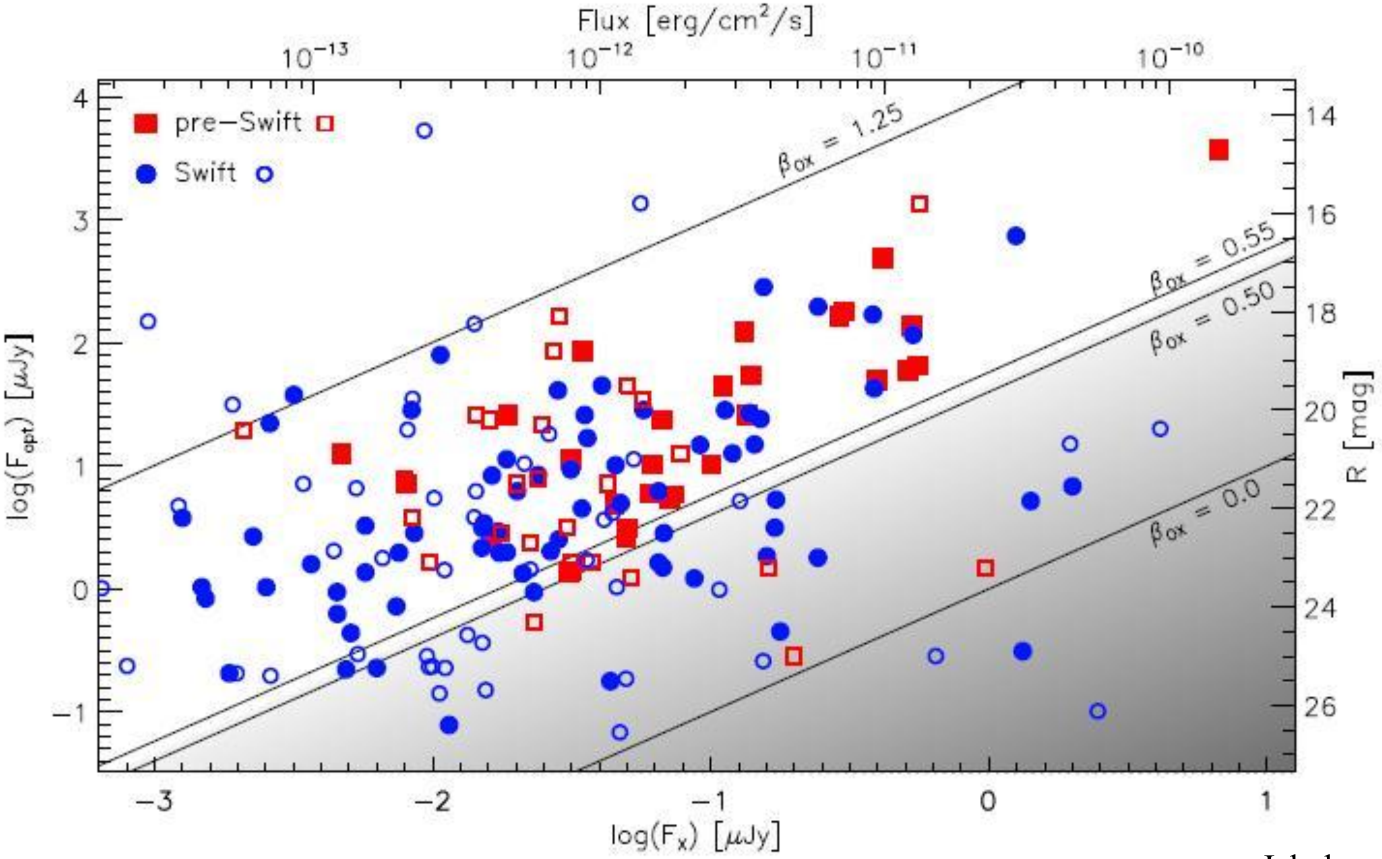
Savaglio+09

154 GRBs with redshift

Only 46 hosts (33 w em. lines)

Most GRB hosts are faint blue star forming galaxies … but …

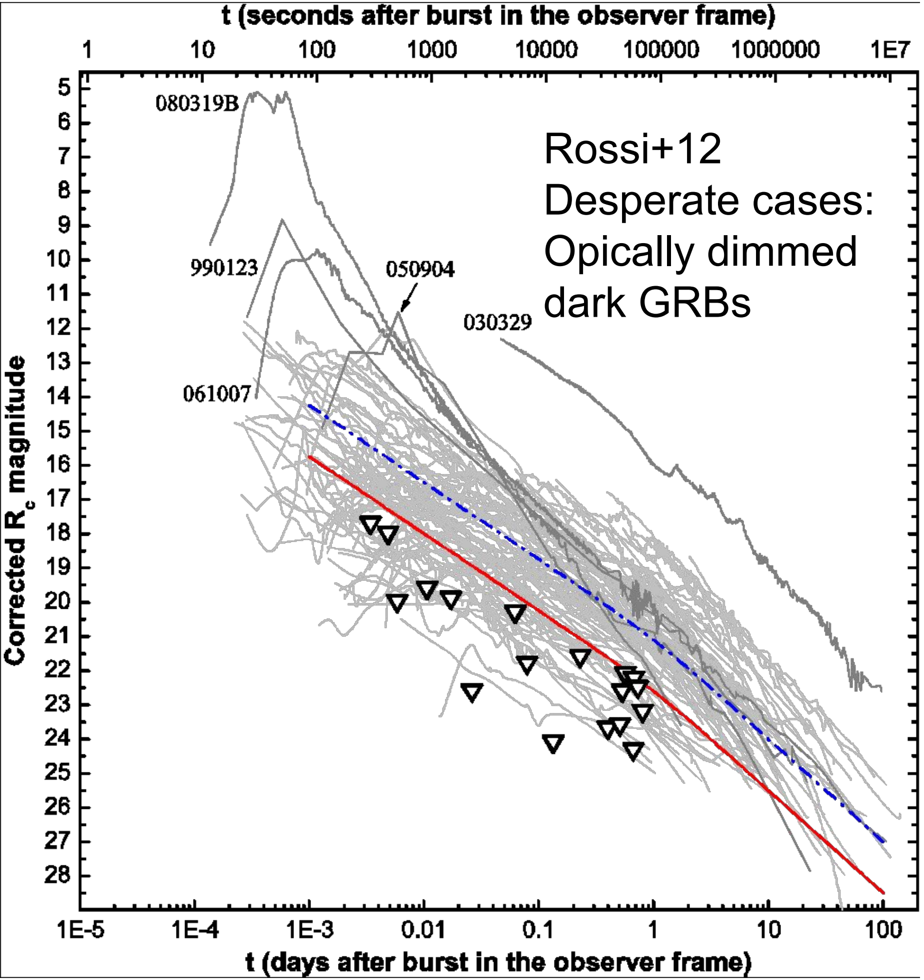
Physical definition of dark bursts



Optically dim because of dust and/or moderate/high-redshift

See e.g Greiner+11, Melandri+12

Jakobsson, et al., 2004



Total: 17 targets

2.2 MPG-ESO: GROND
g'r'i'z'JHK bands

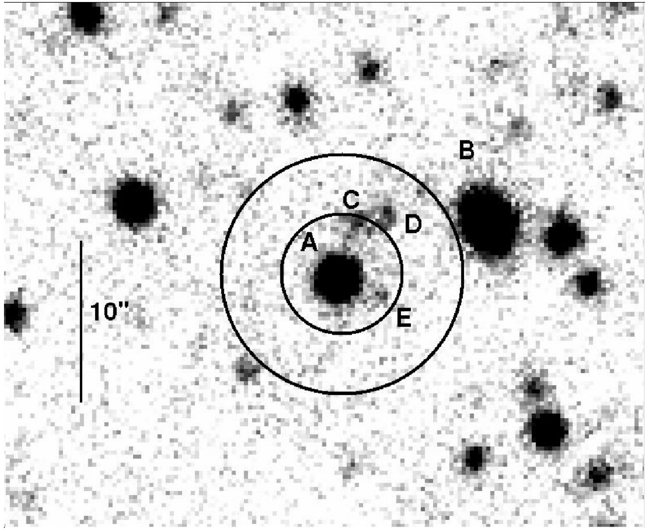
8m, ESO/VLT:
R, K bands

40 hours
observing time

Selection of the host candidates

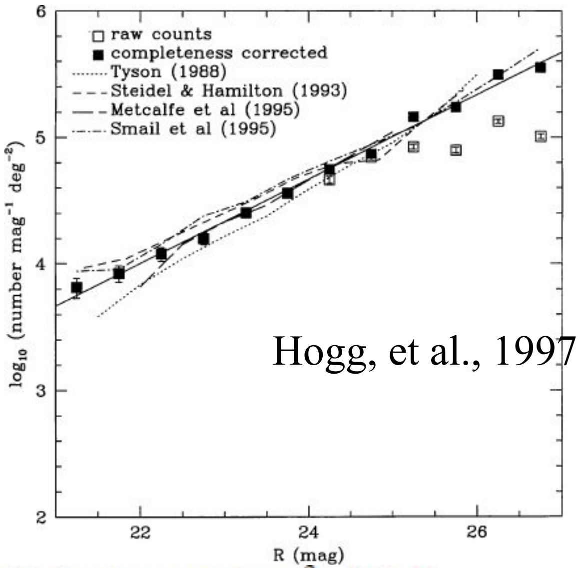
According to the position with respect to the Swift/XRT error circle

(a) Distance criterion



Bloom, et al., 2002 => AG-host distance

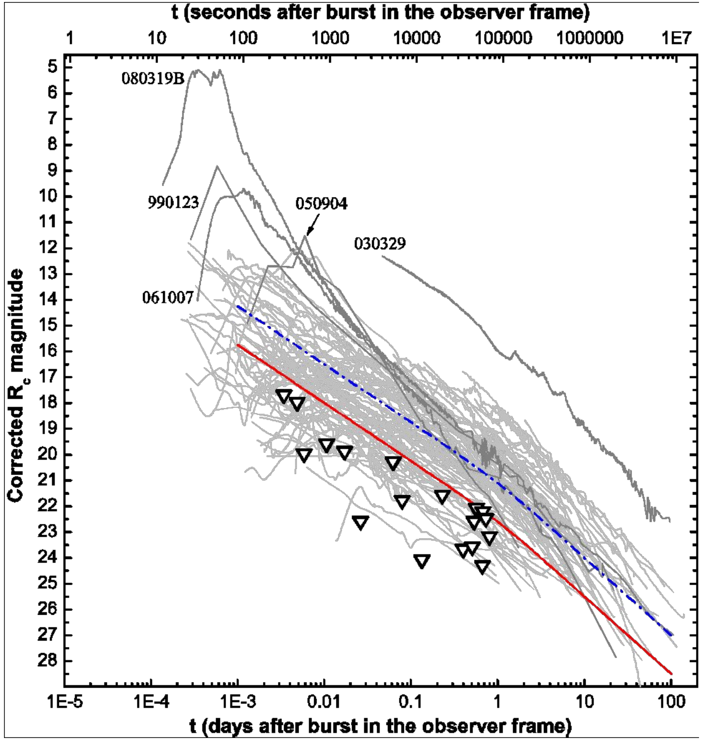
(b) Statistical criterion

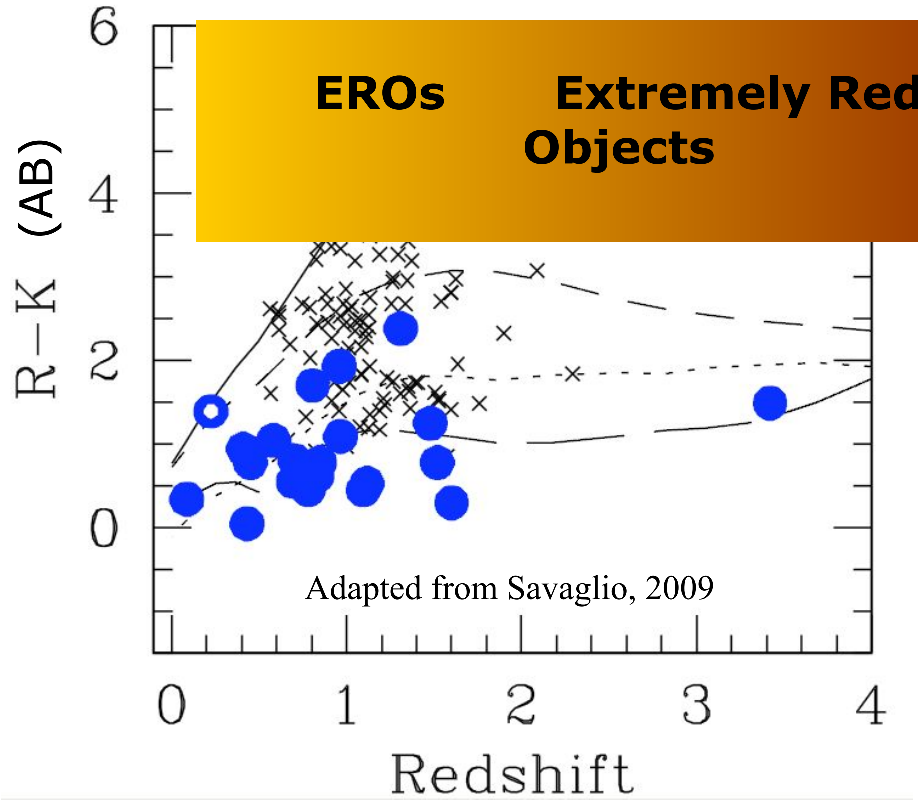


Hogg, et al., 1997

$$p(m) = 1 - \exp(-\pi r^2 \sigma(\leq m))$$

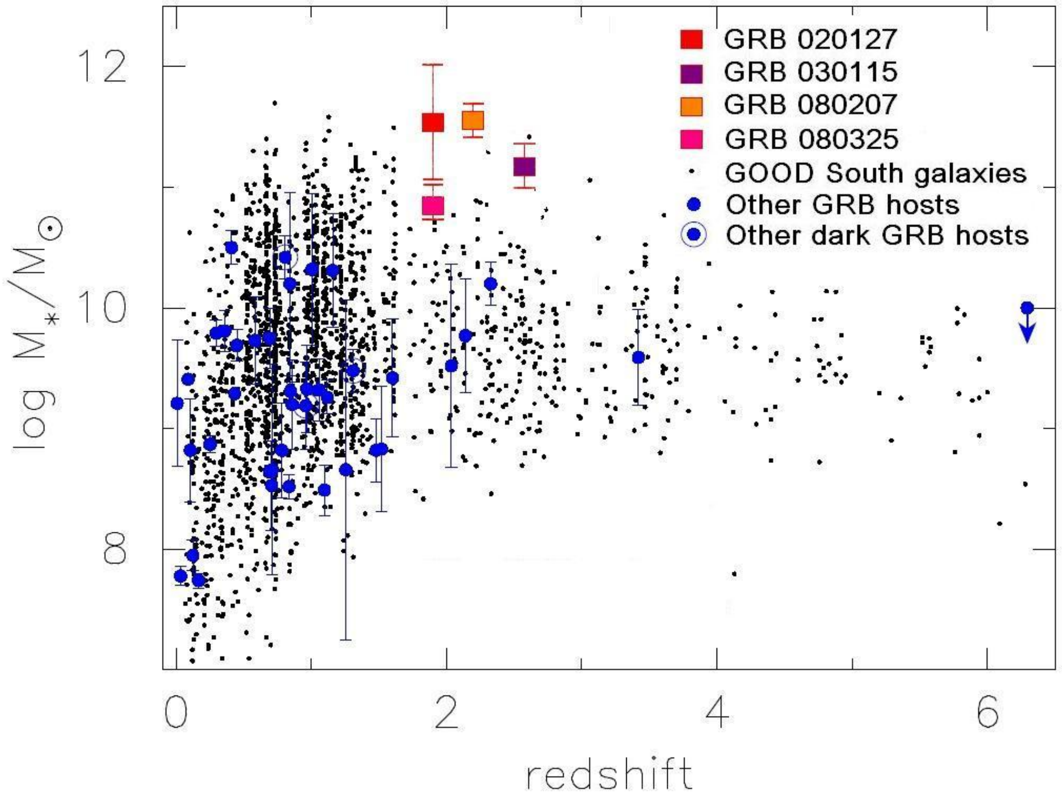
Extremely red objects (EROs)





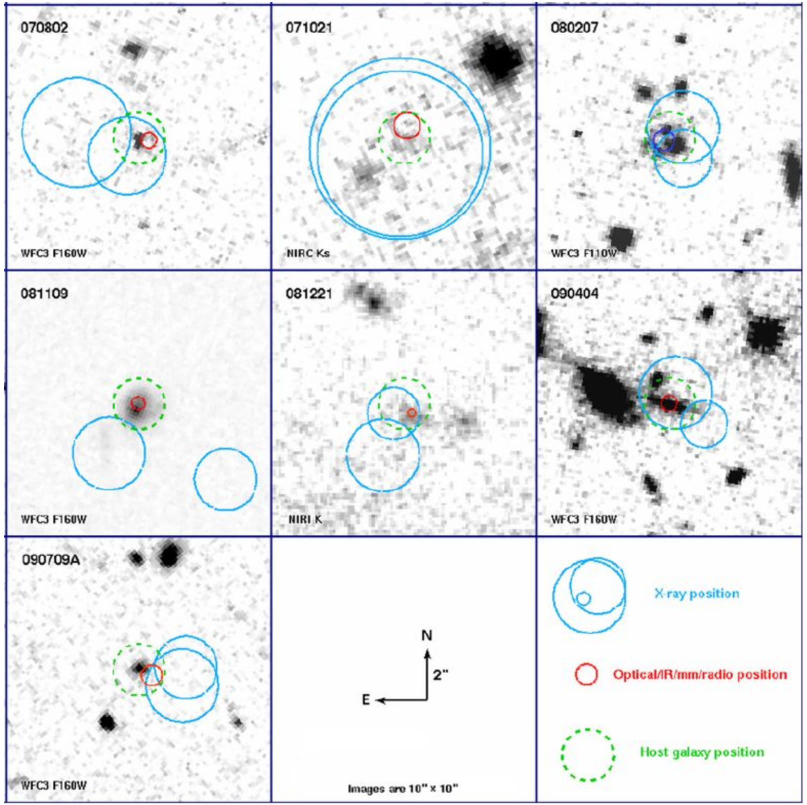
EROs Extremely Red Objects

GRB EROs are massive galaxies

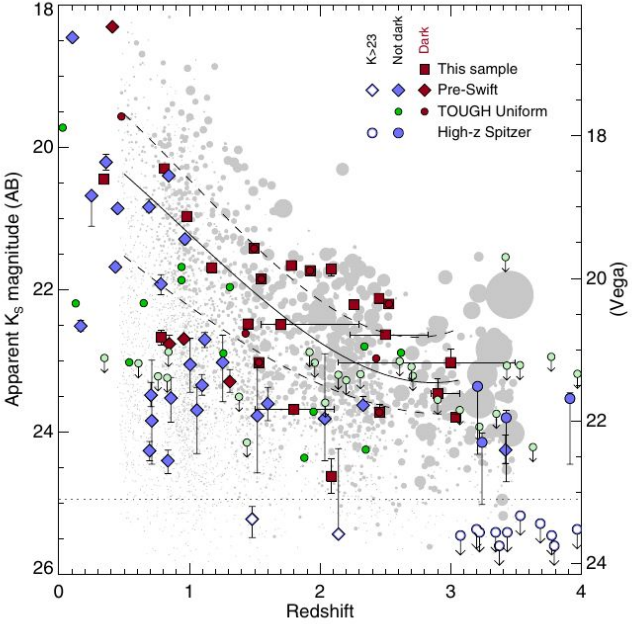


Adapted from Hunt, …, Rossi, et al. Astroph. J. Lett., 736, L36, 2011

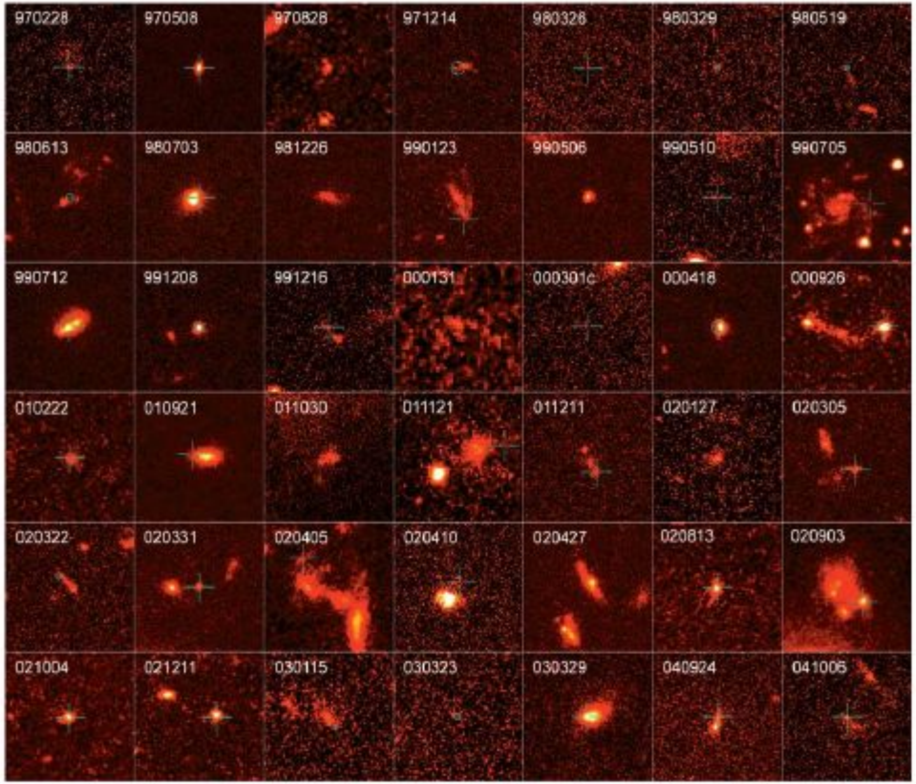
A POPULATION OF MASSIVE, LUMINOUS HOSTS OF HEAVILY DUST-OBSCURED GRBs

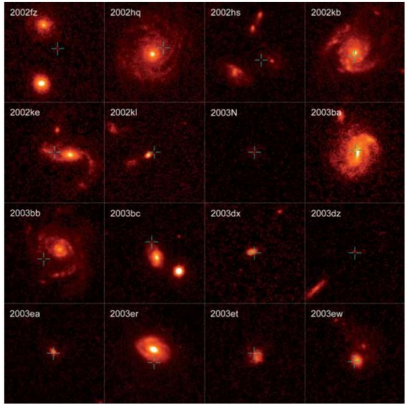


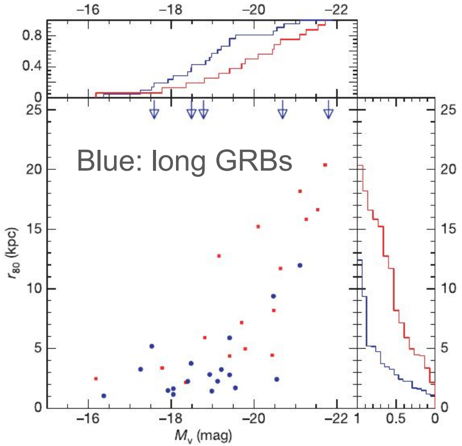
Perley+13,
23 hosts of AV_grb>1 GRBs
A lot of time with the largest glasses: Keck, Gemini, VLT, HST, Spitzer



Are long GRB hosts typical star forming galaxies?



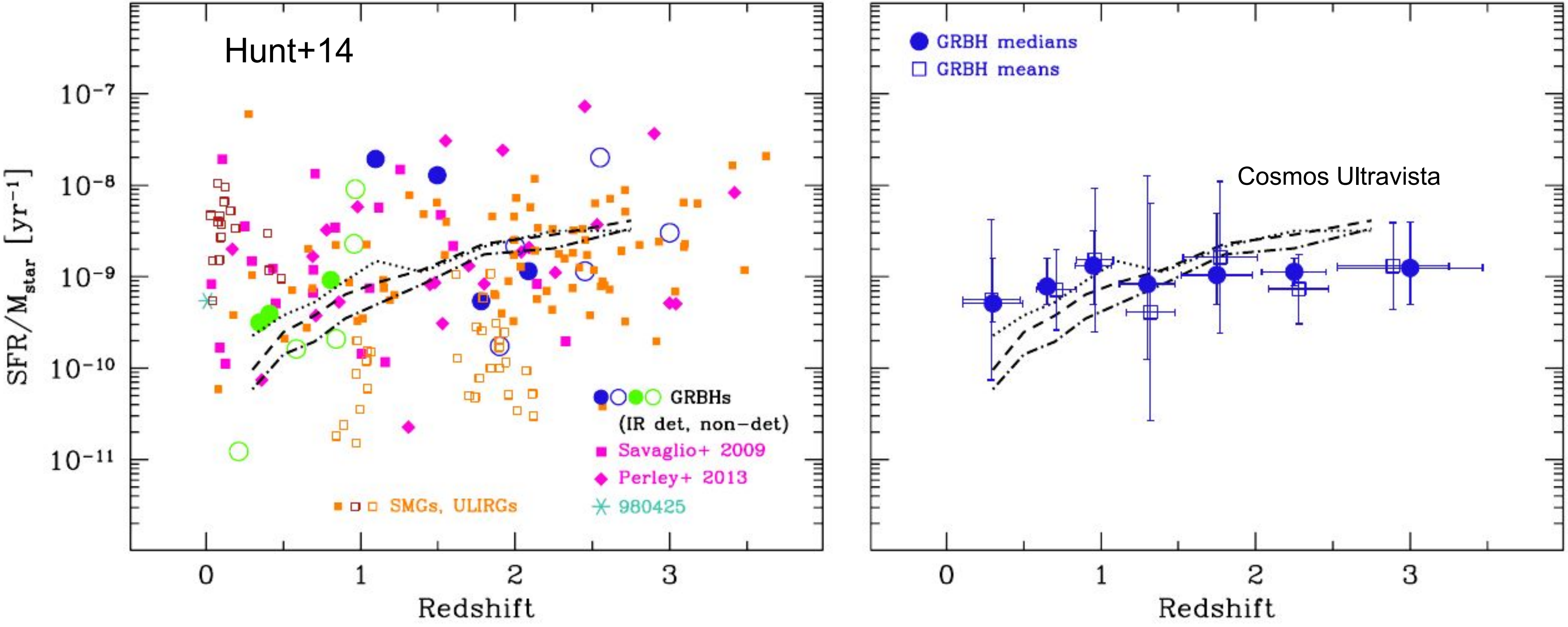




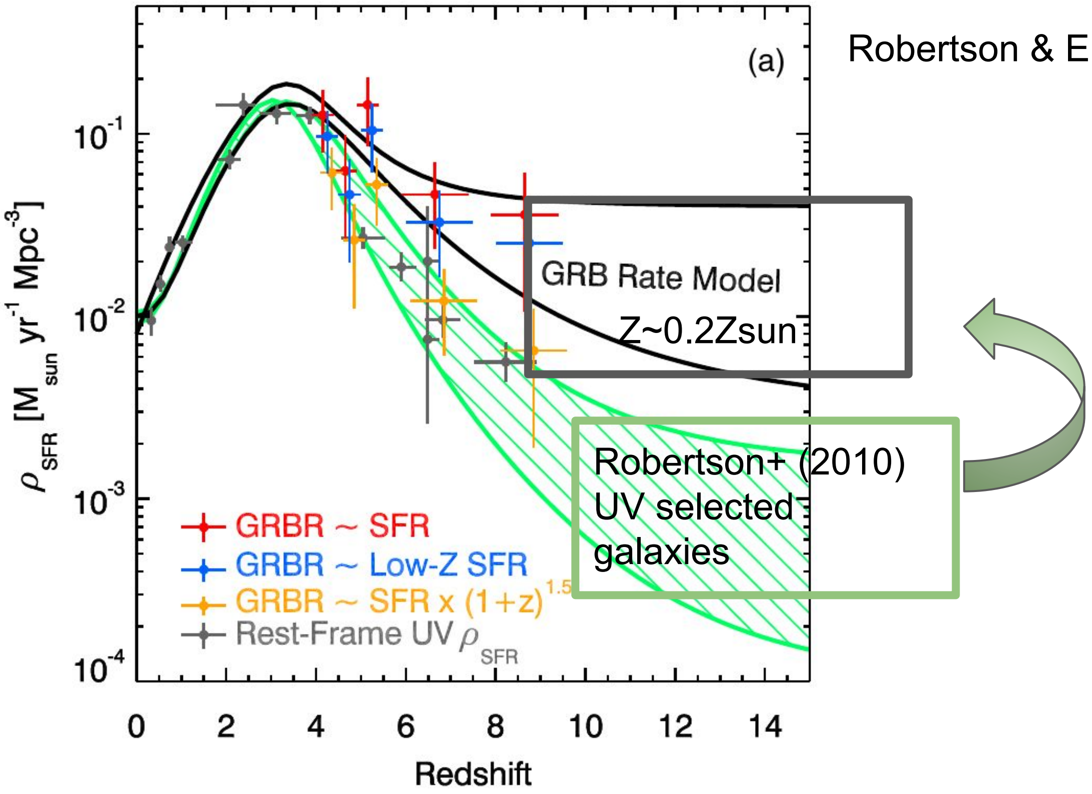
Fruchter+06 (with HST!)

Long GRBs vs core-collapse supernovae

Not an easy job: to avoid dust try to use Hershel to measure SFR of dark GRB hosts



GRBs can trace cosmic SFR density...



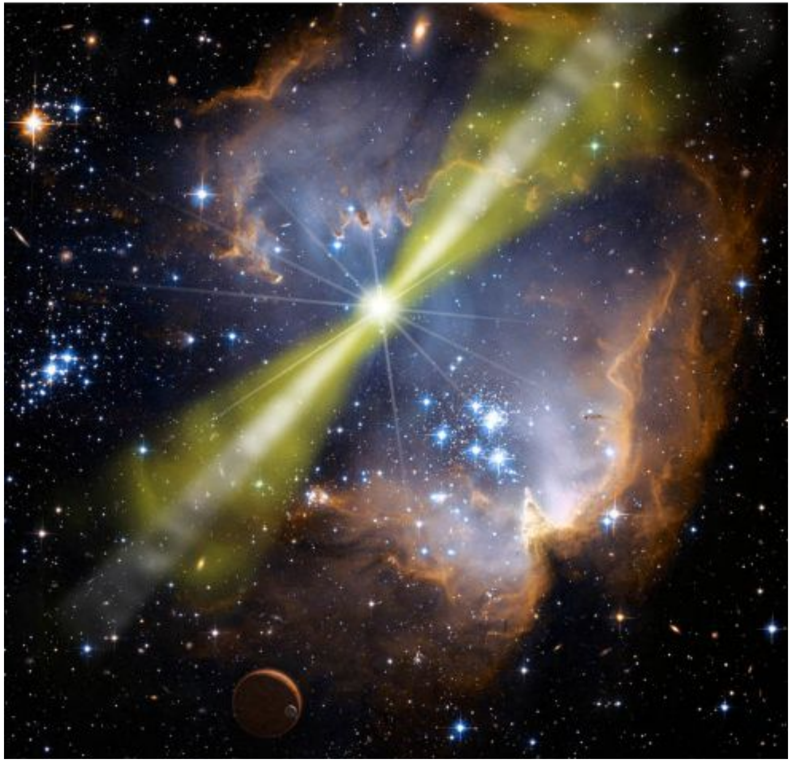
Robertson & Ellis (2012)

Using 112 GRBs above a fixed luminosity limit.
taking into account various restrictions on GRB rates (GRBR).
including a metallicity restriction.

Conclusions:
only a modest metallicity threshold is required

Metallicity bias

NASA/Swift artist impression of naked-eye GRB080319B



- To launch a jet one needs a sufficient angular momentum (necessary to launch collapsar jets)
- Rotating single-star progenitors
- Aided by metallicity dependence of massive stellar winds to expel the outer shell

- … But the metallicity thresholds are expected to be low ≈ 0.1 Zsun (Woosley 1993, MacFadyen & Woosley 1999, Woosley & Bloom 2006)
- Yoon 2006 Z<0.3 Zsun
- Possibly binary metallicity-independent channels could overcome, at least partially, the metallicity aversion (see e.g., Trenti+ 2013, 2015, and Metha&Trenti 20) and raise the threshold metallicity

Complete samples

year, hour-angle, and XRT-response time, AV, fluence cut+ some exception

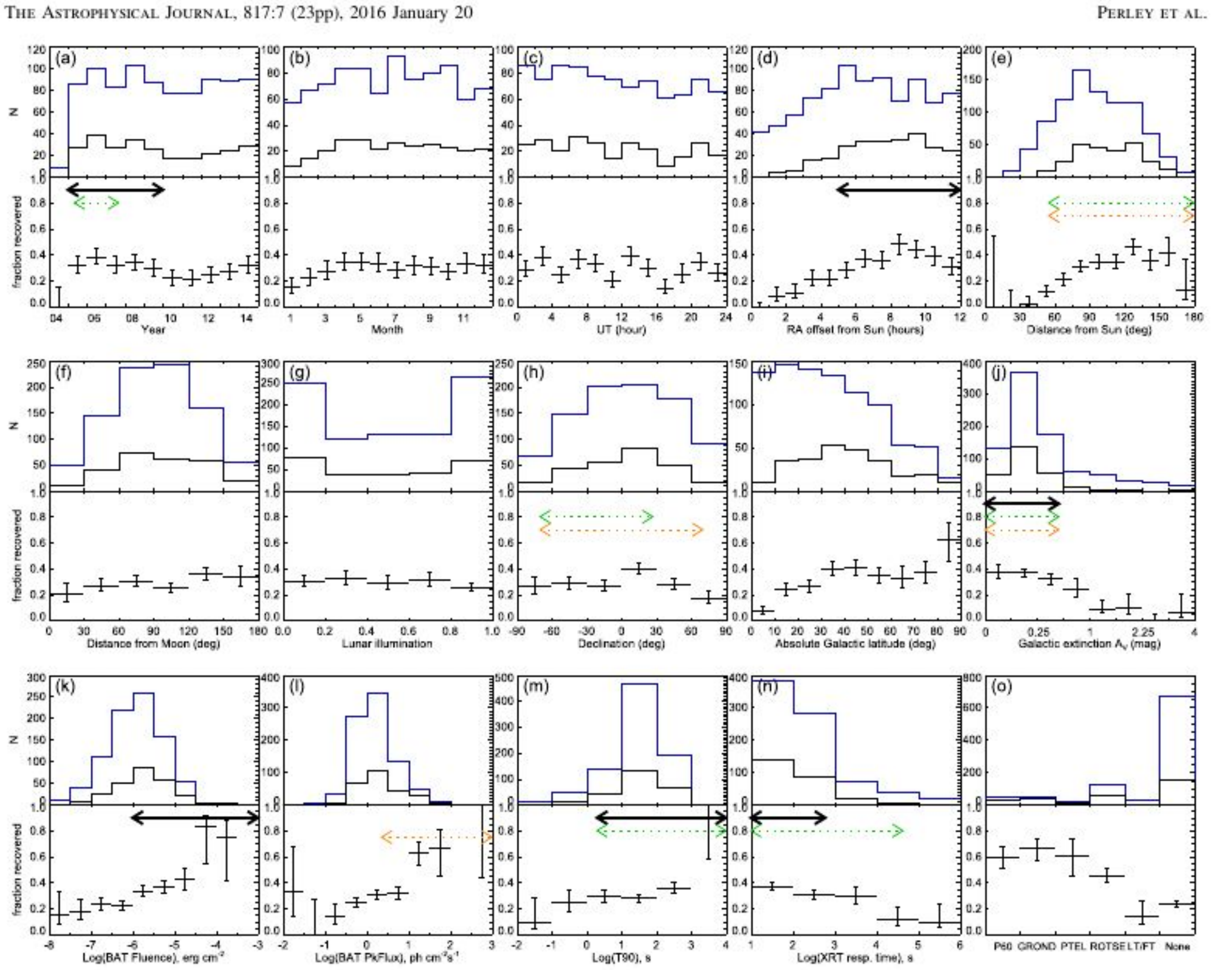
THOUGH, Hjorth+12 (69)

BAT6, Salvaterra+12 (58)

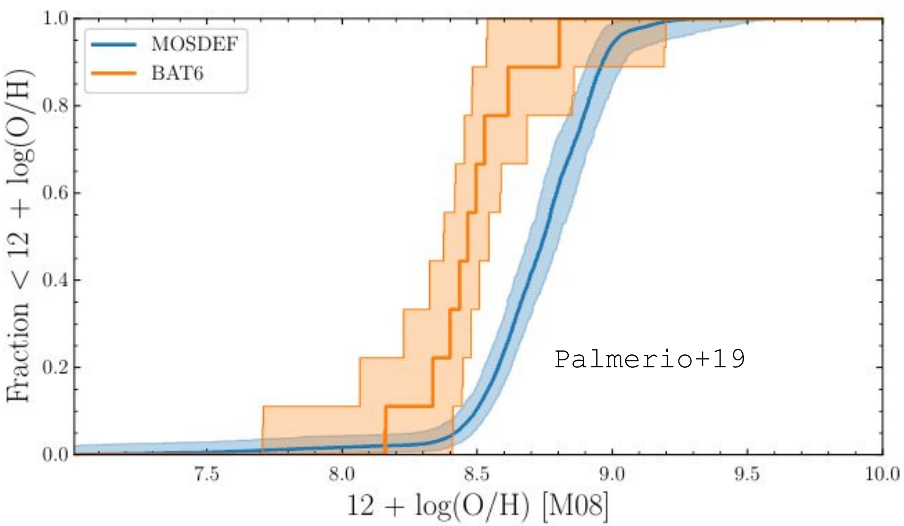
SHOALS, Perley+16

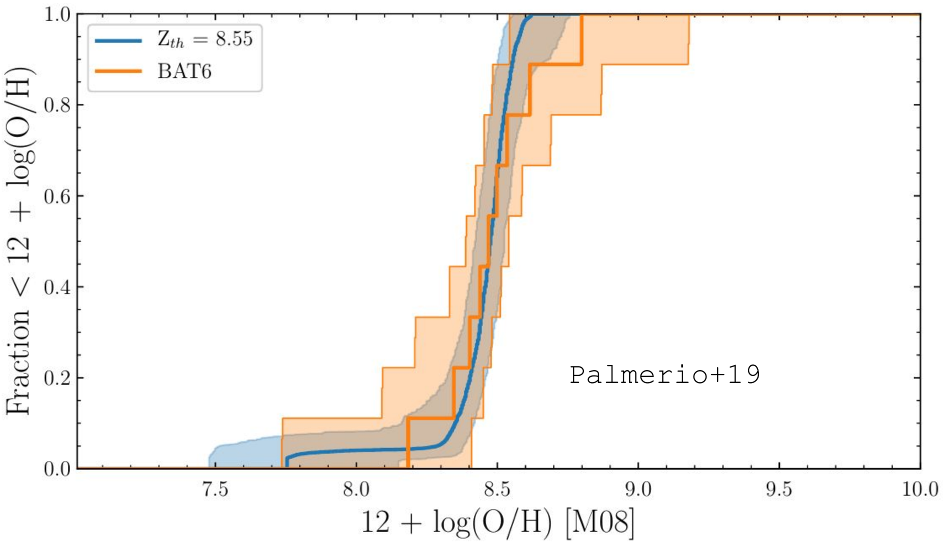
119 hosts

See also Truong+20 for a bias in parent Swift sample



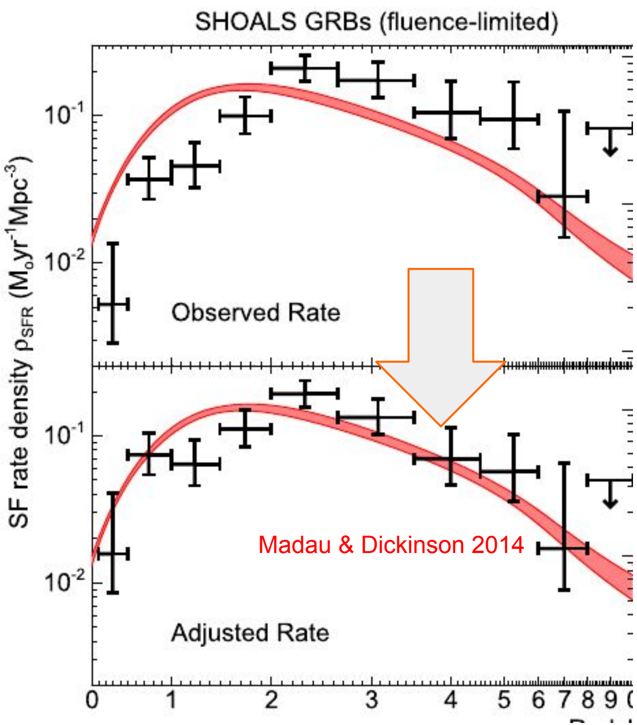
Long GRB host population (metallicity threshold)





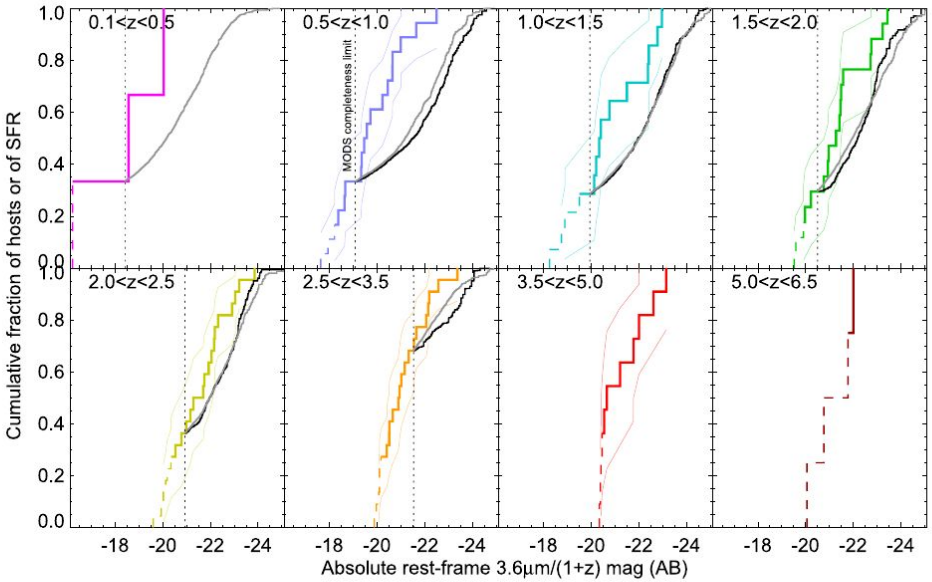
Palmerio+19, se also, Japeli+16, Schulze+15, Vergani+15,17, Trenti+15,17, Metha+20, …
MOSDEF: a large program on the Keck I telescope, targeted the regions that are covered by CANDELS and 3D-HST

Long GRB host population (metallicity threshold)



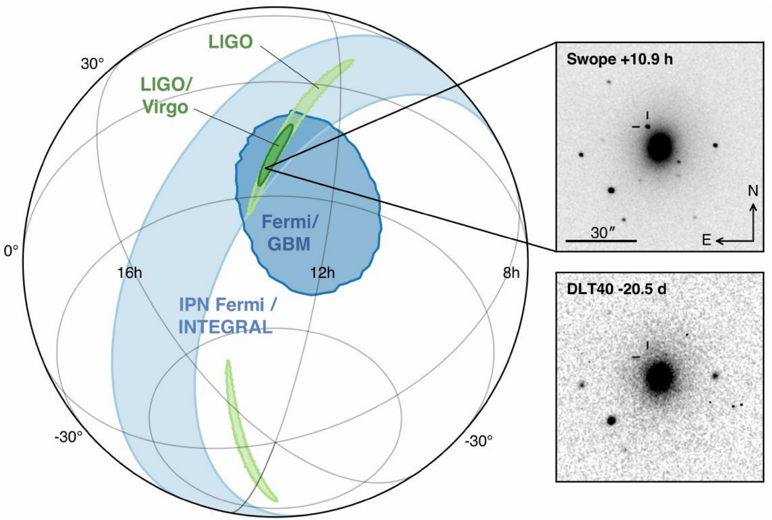
Perley+16

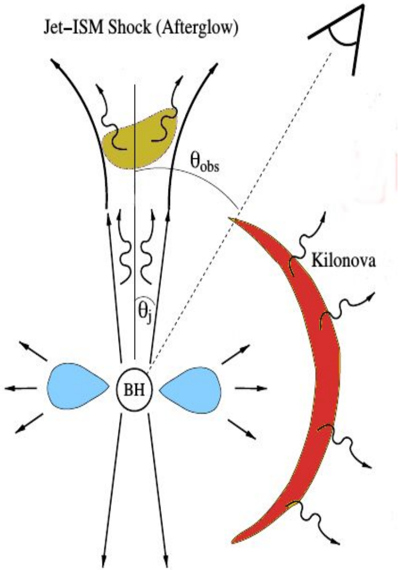
SHOALS/Perley+16 => Z<~1 Zsun
Comparison w GOODS North
Correcting for fraction of missed SF



Short GRB - merger origin

Three-In-One Event: GW 170817, a short GRB, and a kilonova



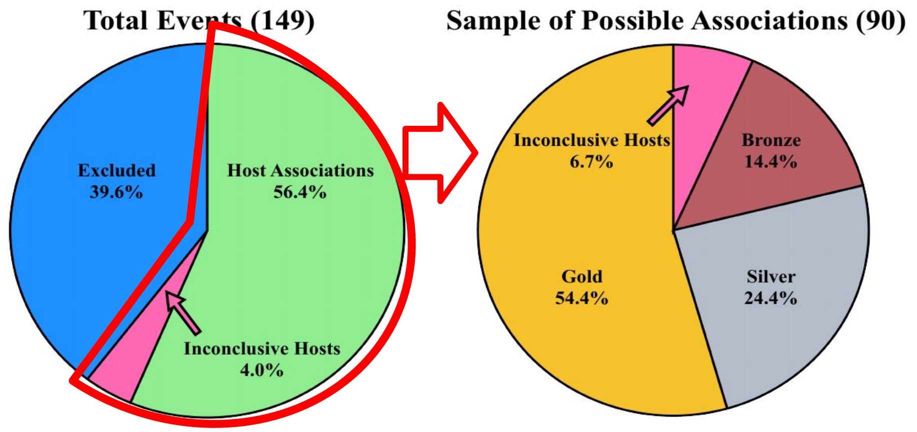


Abbot+17

Pian, et al., 2017, X-Shooter, FORS2

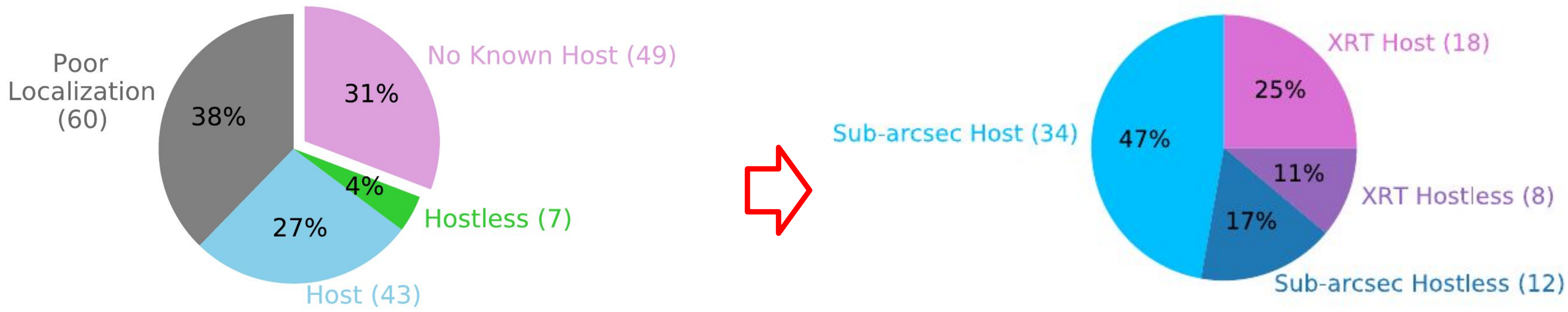
Metzger & Berger 2012

Most recent developments:
large samples doubled known redshifts

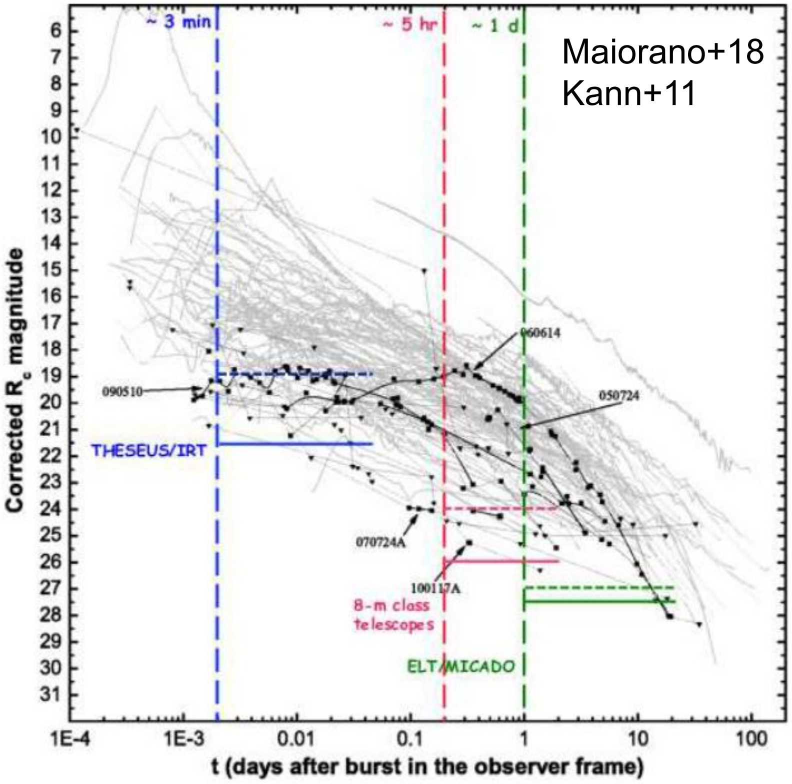


Fong+22
Gold, bronze silve samples: **~70 events w redshift**
Pcc<0.02,0.1,0.2

O'Connor+22
~70 events

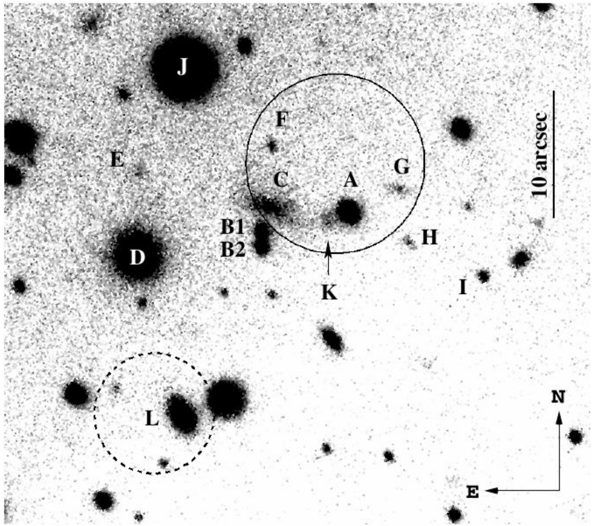


Fainter afterglow, difficult localization

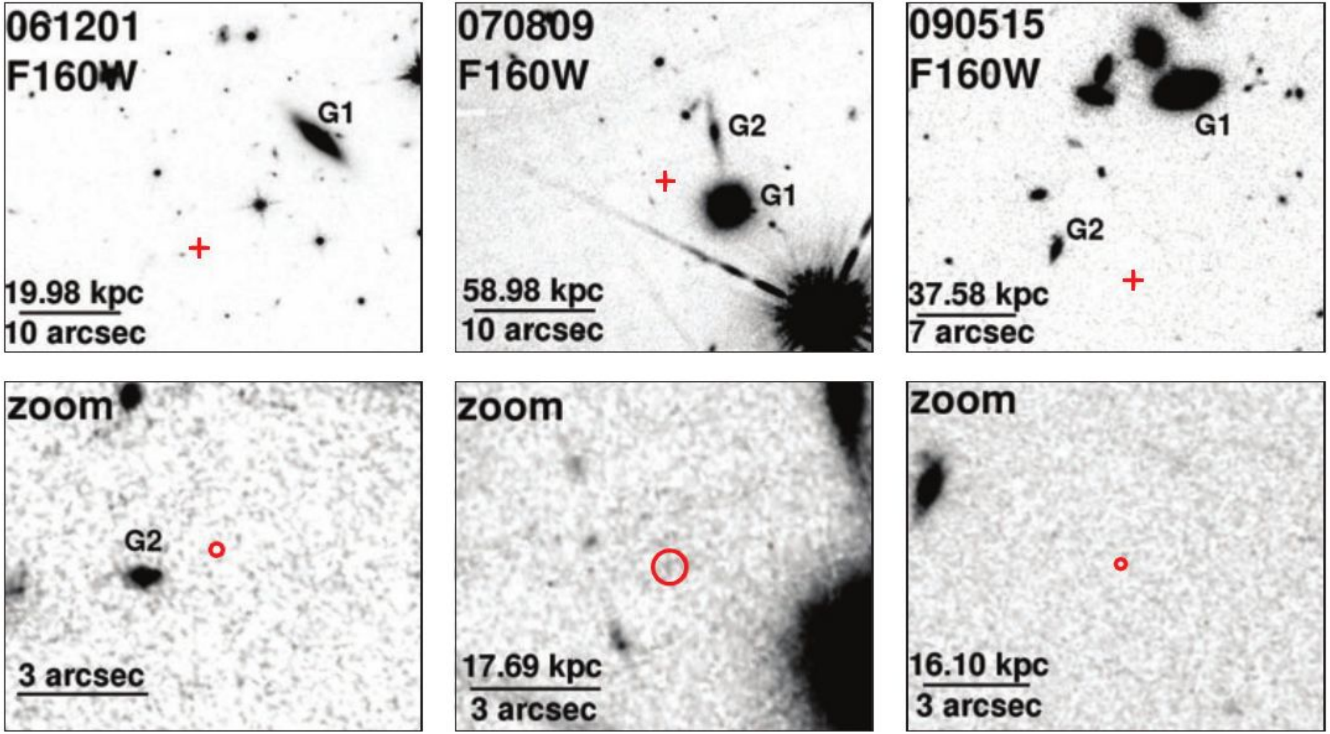


Redshift measurements from afterglow spectroscopy are rarely successful

GRB 100628A
Nicuesa Guelbenzu+15



A new problem: hostless (~10%)



HST WFC3 images of the locations of 3 short GRBs

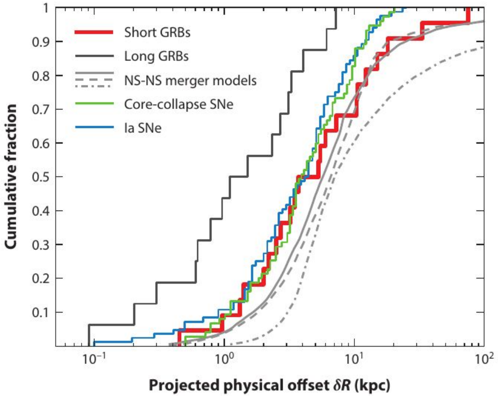
Host-less bursts:
Subarcsecond positions
no coincident host galaxies.

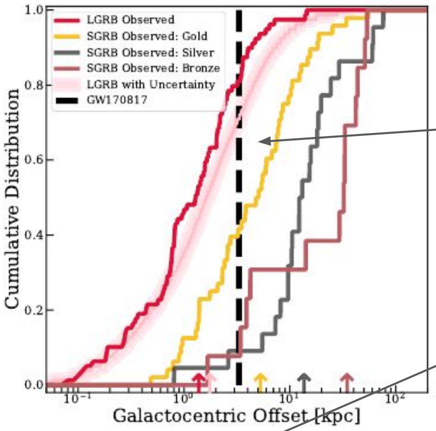
See Matteo Ferro talk

Berger,14

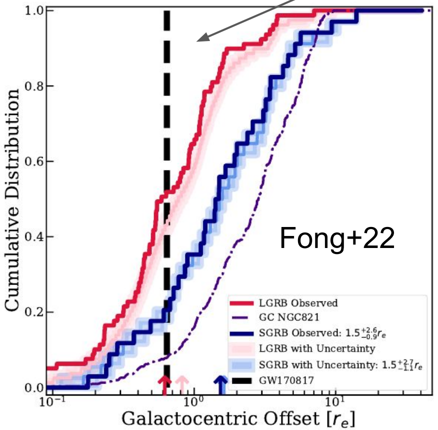
Offsets confirmed

Berger+14, (Fong&Berger+13)

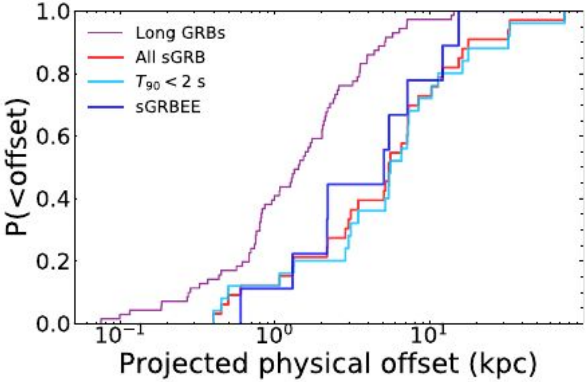


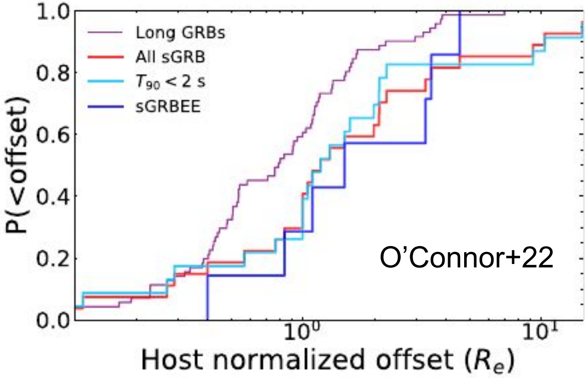


globular clusters in the elliptical galaxy NGC821



Fong+22



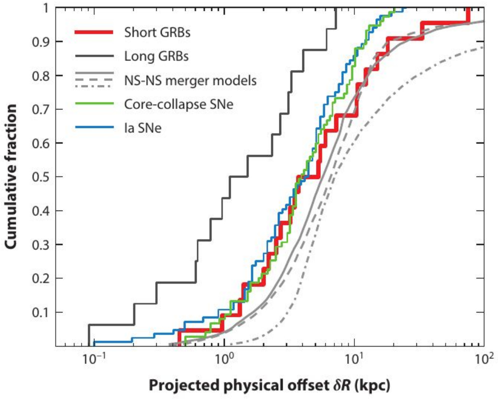


O'Connor+22

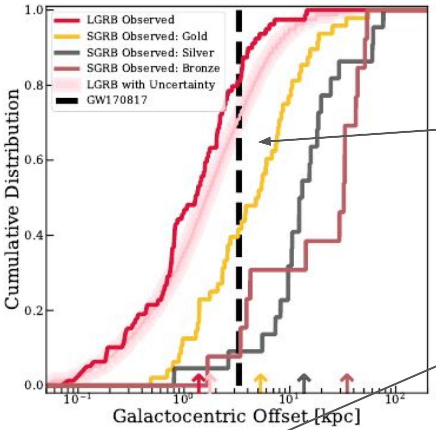
Long GRBs <8kpc ~1" at z >0.5
<2kpc (**within host**)

Short GRBs 50% >~5kpc ~ > 1" at z>0.5
30% >~10kpc > 2" at z>0.5
Outside host

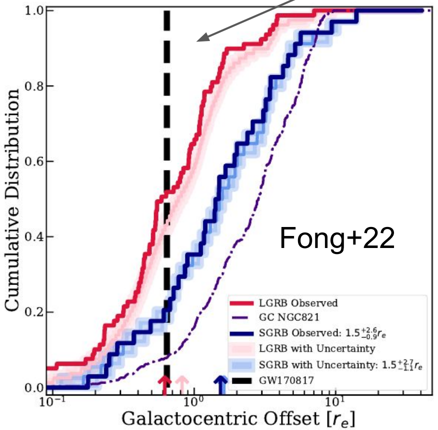
Offsets confirmed

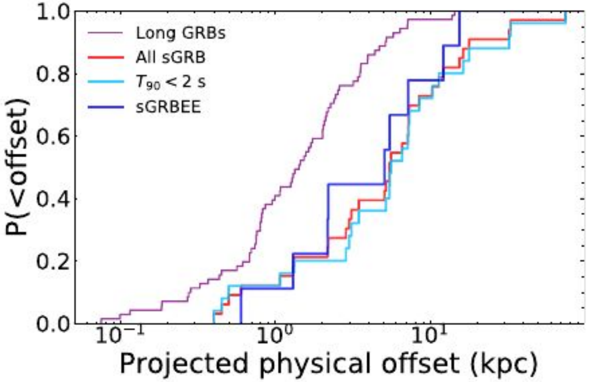


Berger+14, (Fong&Berger+13)



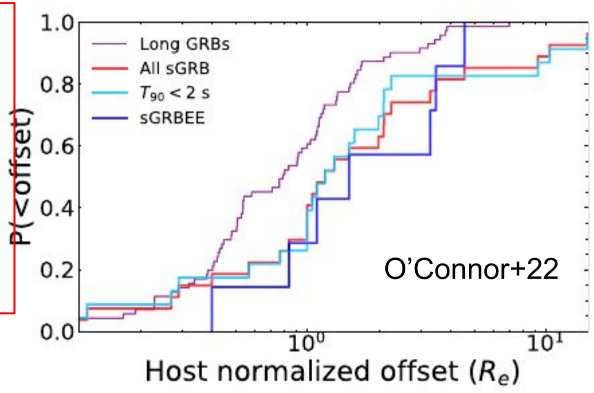
globular clusters in the elliptical galaxy NGC821





Kicks:
The remnants of core-collapse SNe can give a “kick”

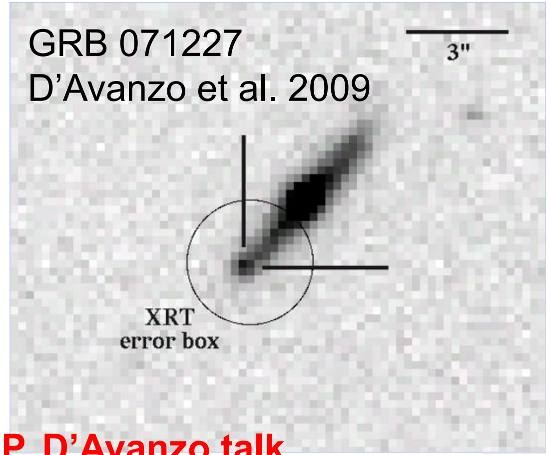
Escape from the HG (birthsite)-> **OFFSET!**
(1 ~ 100 kpc)



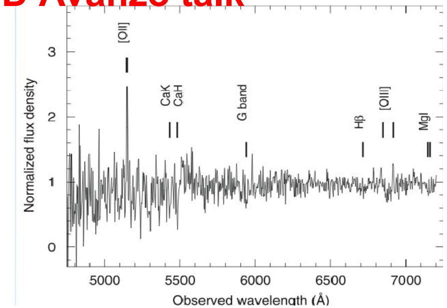
See P. D’Avanzo talk

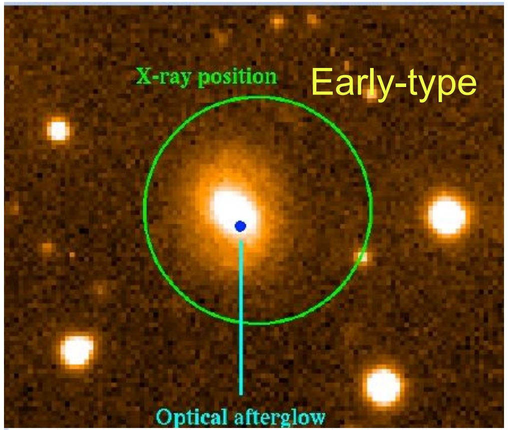
Short GRB hosts are of different type: range of delay times

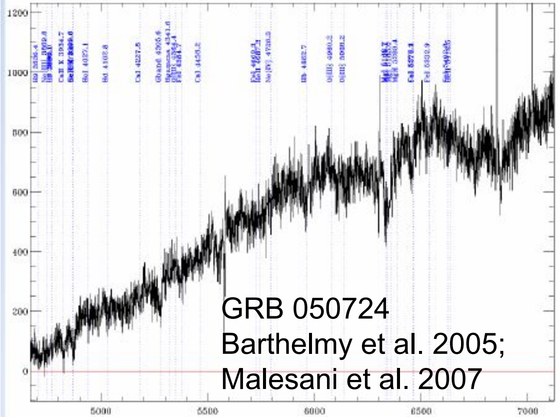
Late-type : emission lines, SFR

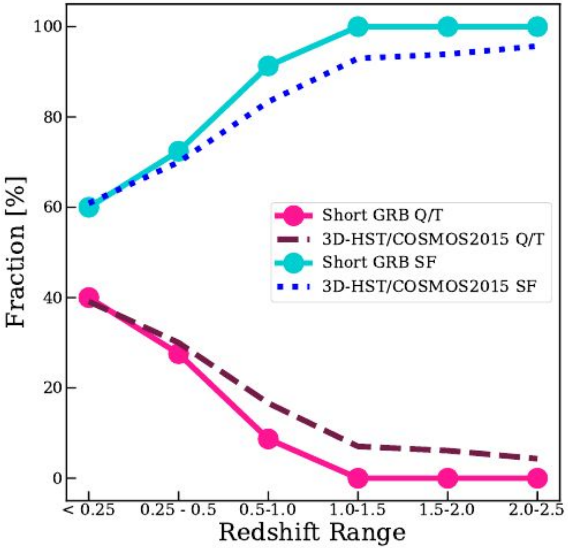


See P. D'Avanzo talk



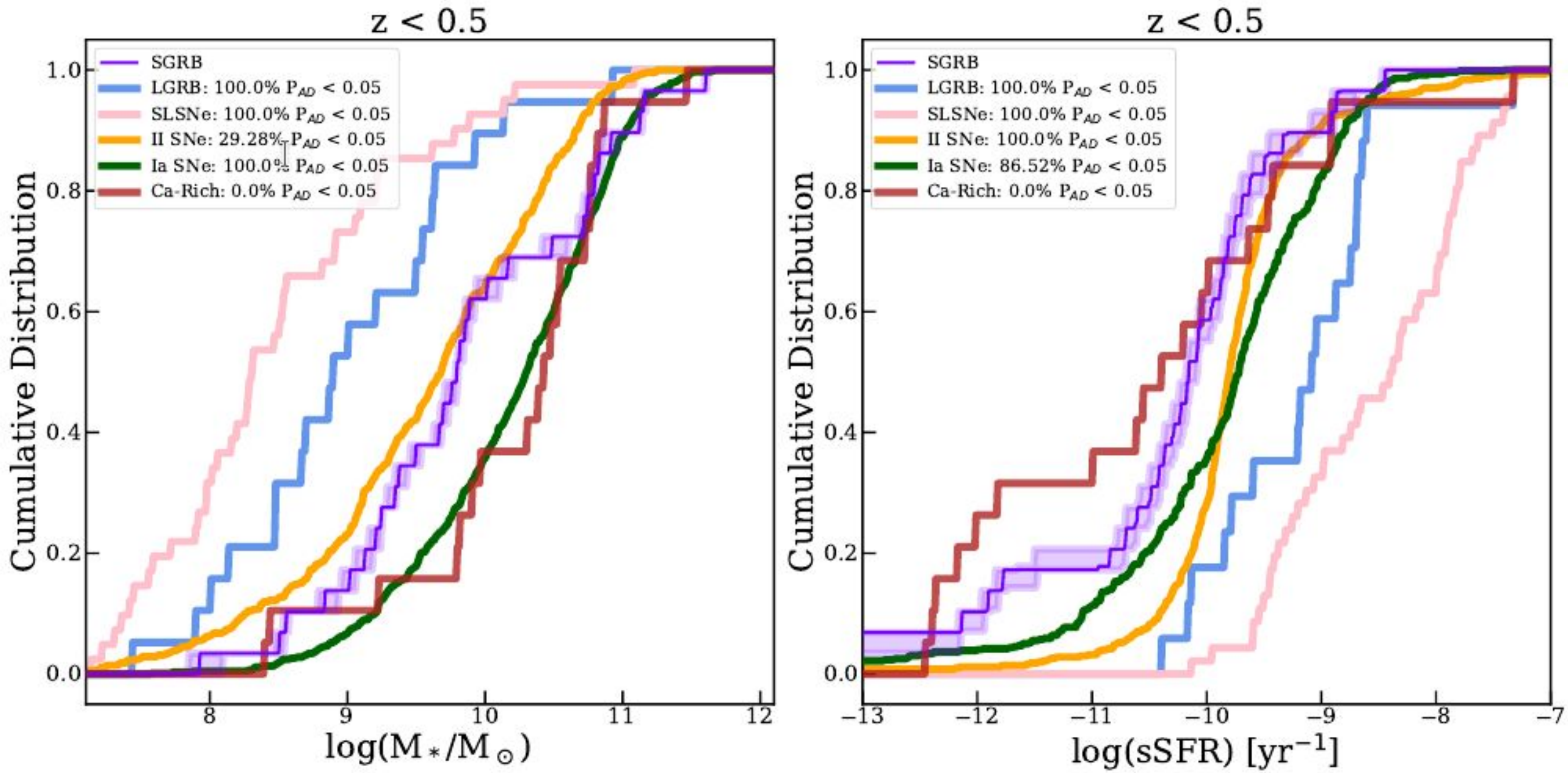






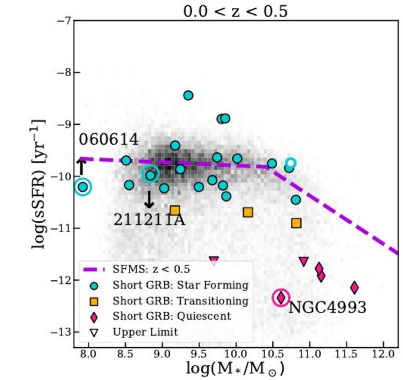
Nugent+22

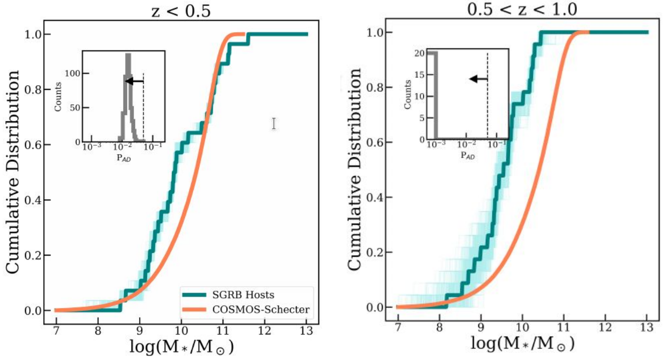
Short and long GRB Hosts are different

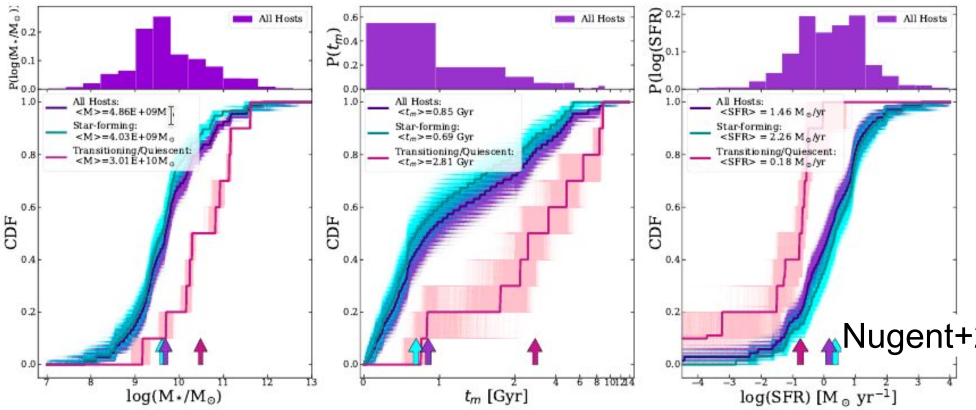


Nugent+22

Short GRB hosts are massive but …







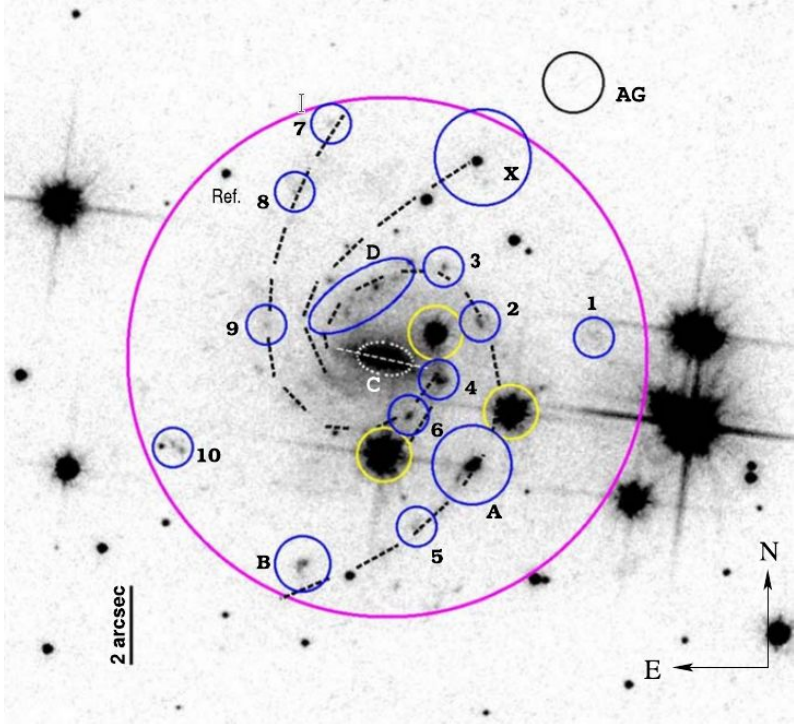
Nugent+22

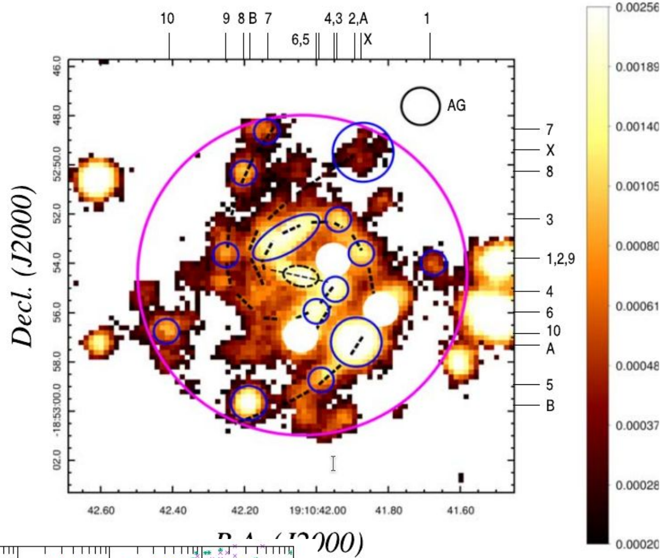
86% of short GRB hosts are star-forming galaxies.

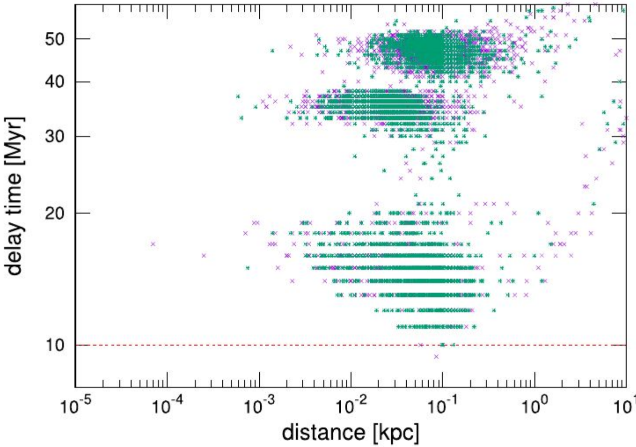
Short GRBs trace a combination of recent star formation and stellar mass:
SFR consistent w stellar mass and star formation MS
they do not trace the stellar mass of field galaxies alone!

Wide range of ages (≈ 0.1 − 9 Gyr),
-> wide range of progenitor delay times.

Explosion sites are not visible anymore





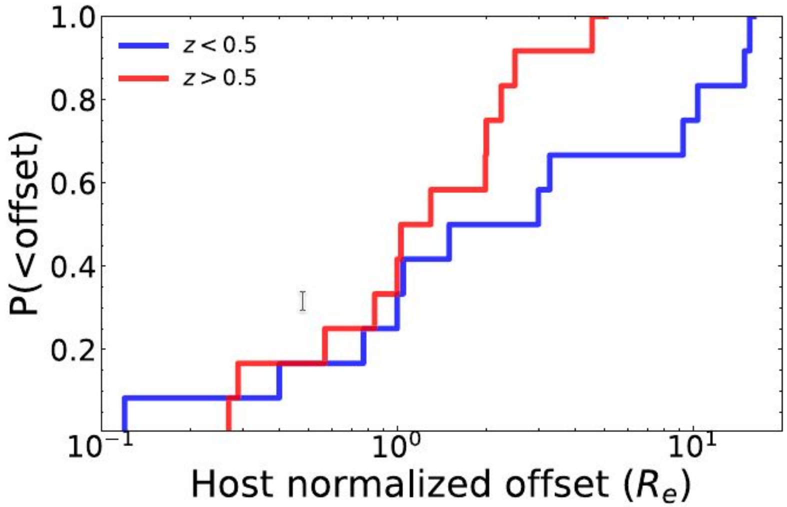


The SF regions are too young for the possible delay times

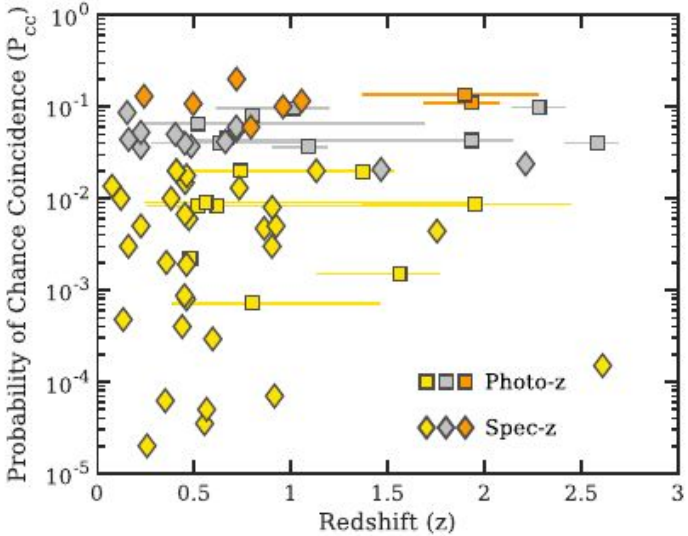
Nicuesa Guelbenzu+21,
see also Klose+19 for radio non detections

Problem: robustness of the association

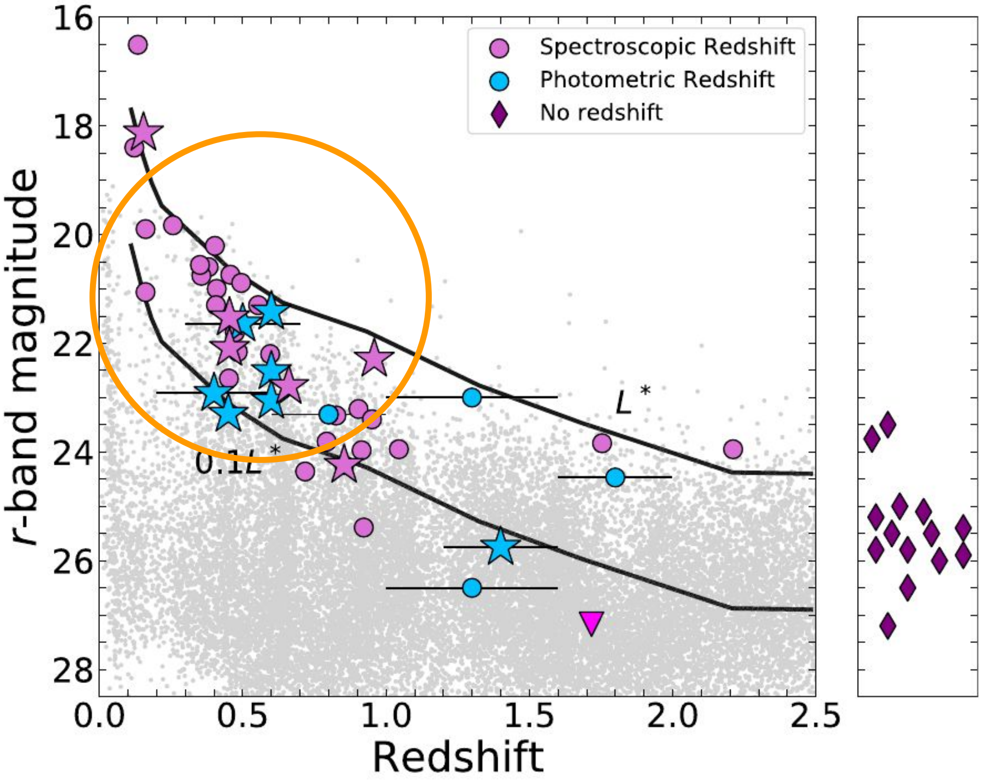
O'Connor+22
Offset evolution w redshift?



Fong+22
the robustness of association decreases with increasing redshift.



Problem: robustness of the association



O’Connor+22

- Decrease in host galaxy apparent magnitude with z
- z > 1 the r > 23.5 mag,
- In order to associate a GRB to such faint galaxies (Pcc<0.1) offset of □3”(25 kpc, z ≈ 1).
- Pcc<0.5 -> 2.2”

It is difficult to associate high-z sGRBs to galaxies at large physical offsets

Summary

The search for GRB hosts galaxies is difficult task: they can be faint, or dusty

Sometimes we miss a precise localization of their afterglows, especially in case of dark GRBs and **short GRBs**

Thanks to enormous observational effort (optical, NIR, FIR, radio, IFU, from space) we have a better of the properties of long and GRB hosts

Careful sample selection is essential to clarify the properties of long GRB hosts in comparison with field galaxies: **long GRBs trace low-metallicity cosmic SFR**

Short GRBs trace a combination of recent star formation and stellar mass

TBD:

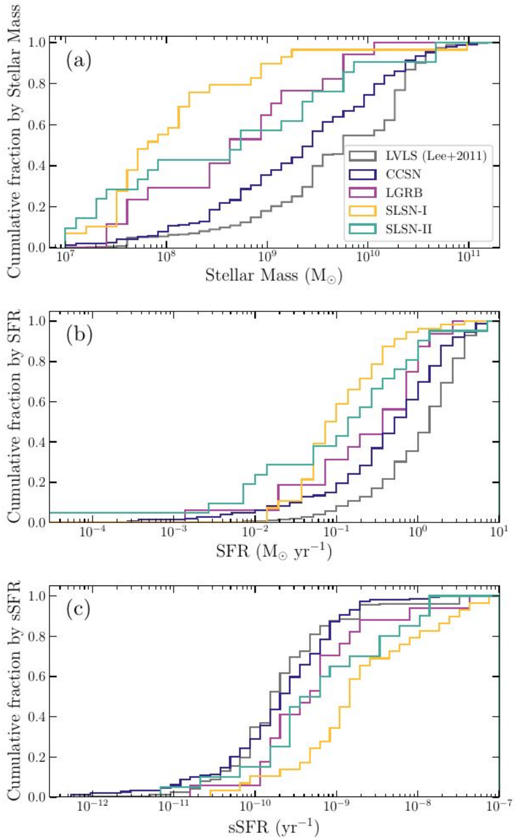
Comparison with simulated BNS-NSBH hosts, events are selected simply based on their T90 (really a problem?), check Amati relation (see Ferro's Talk)?

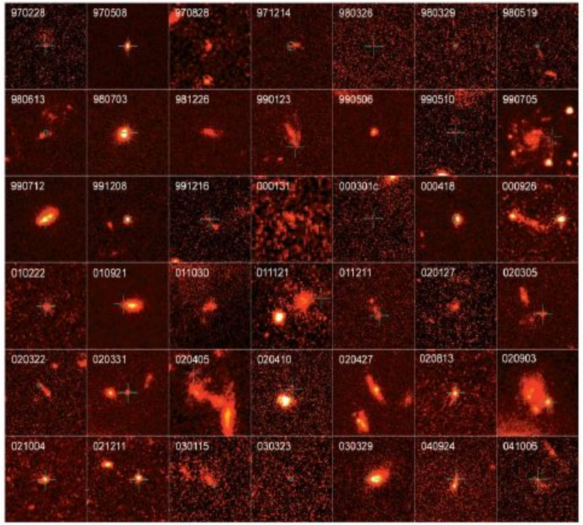
For short GRBs HOSTS(!): this is not yet been done (only 16->24 events, D'Avanzo talk!) and the large offsets introduce an additional problem for the correct host-association.

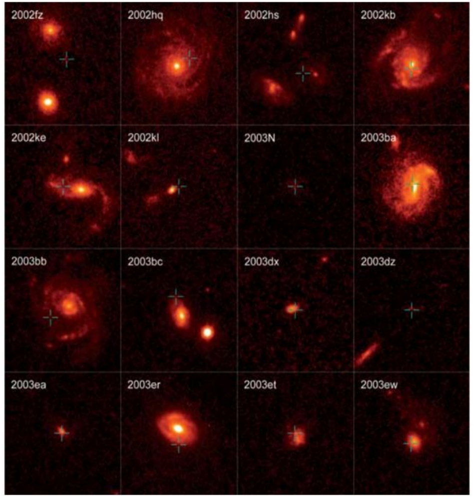
GRAZIE !

Long GRBs do not easily trace cosmic star formation

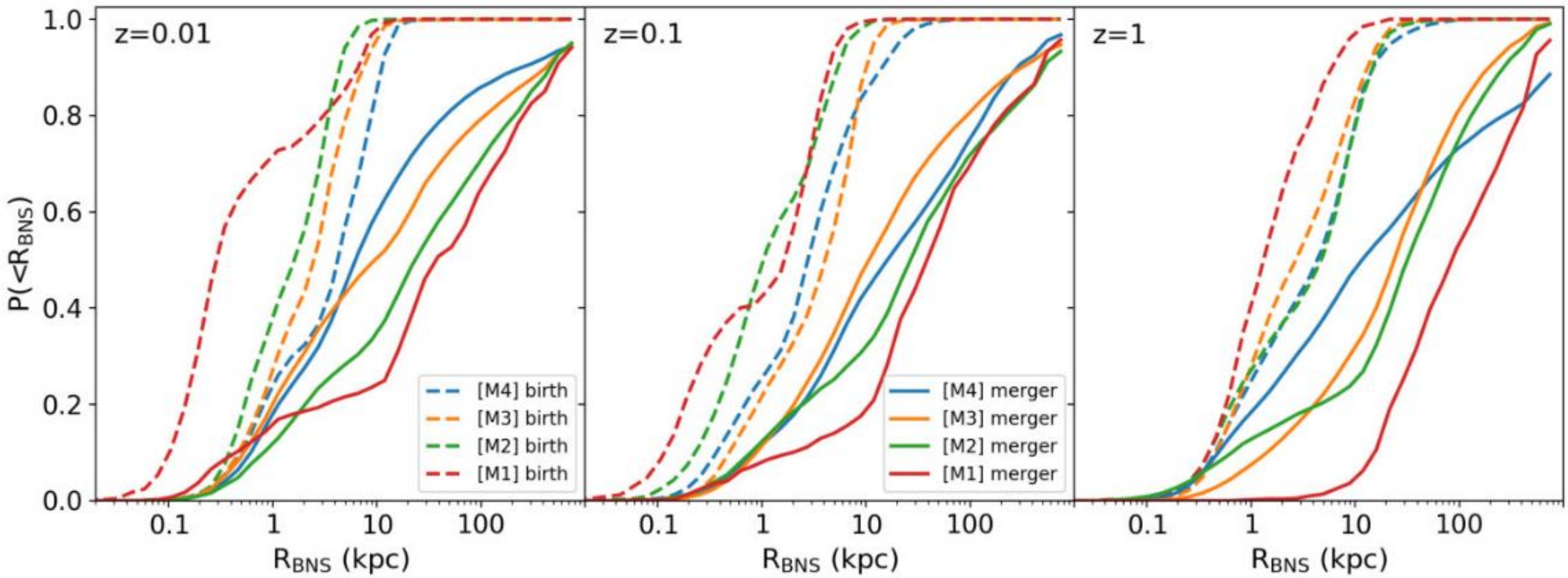
Taggart & Perley, 2021







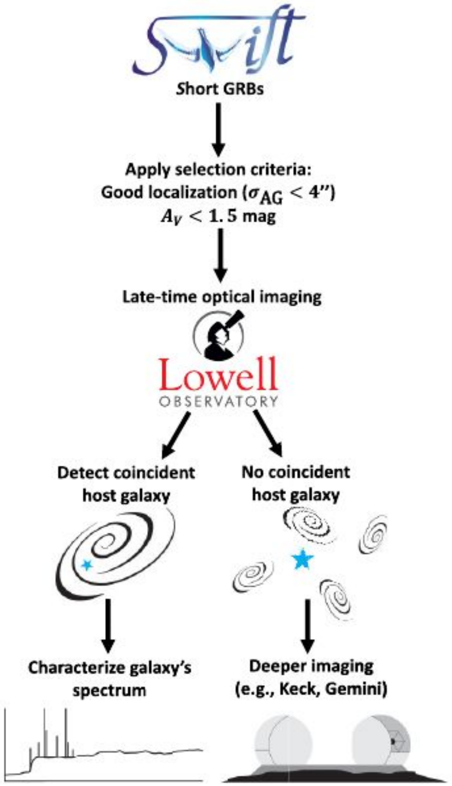
Simulations?



Perna+22

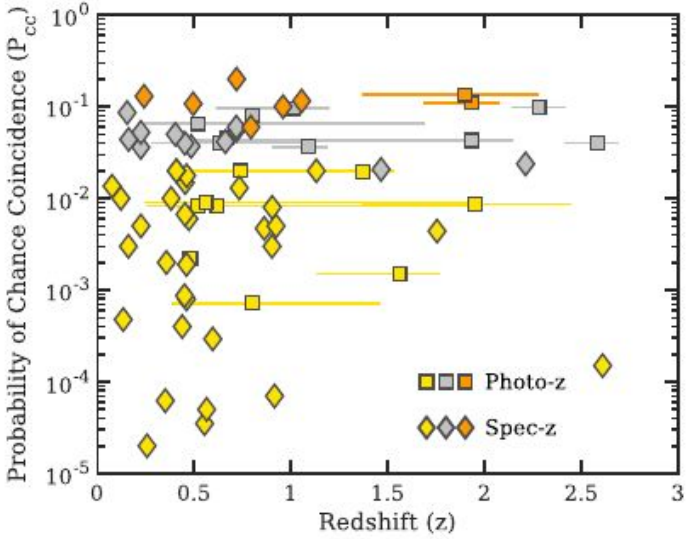
[M3]: $9.5 < \log[M_{gal,3} / M] < 10.25$,
[M4]: $10.25 < \log[M_{gal,4} / M] < 11$

Most recent developments: large samples



Very similar to search for hosts of dark long GRBs - optically dim

… but larger offsets

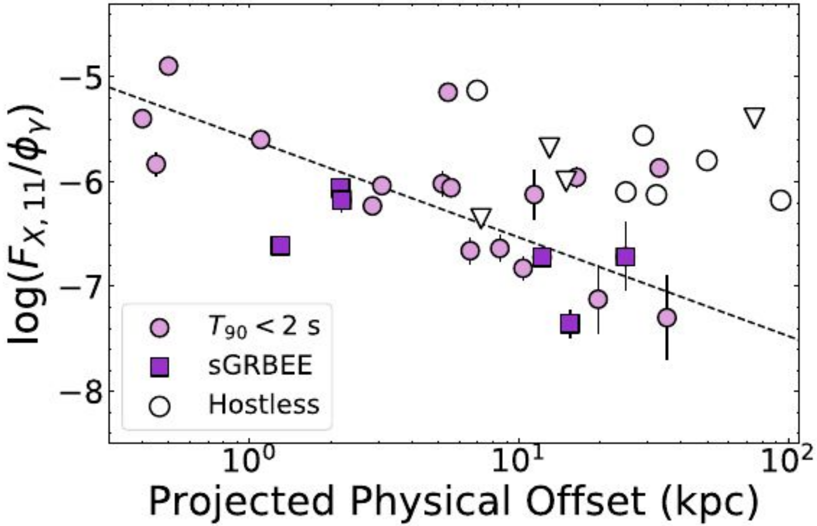


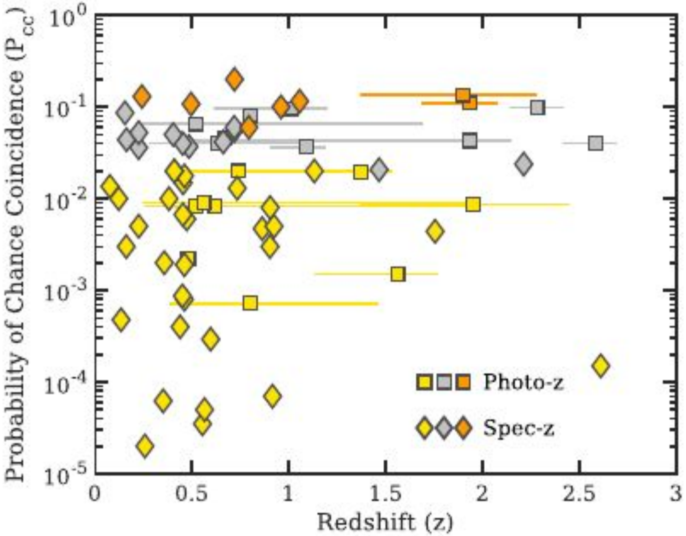
Most recent developments: large samples

O'Connor+22

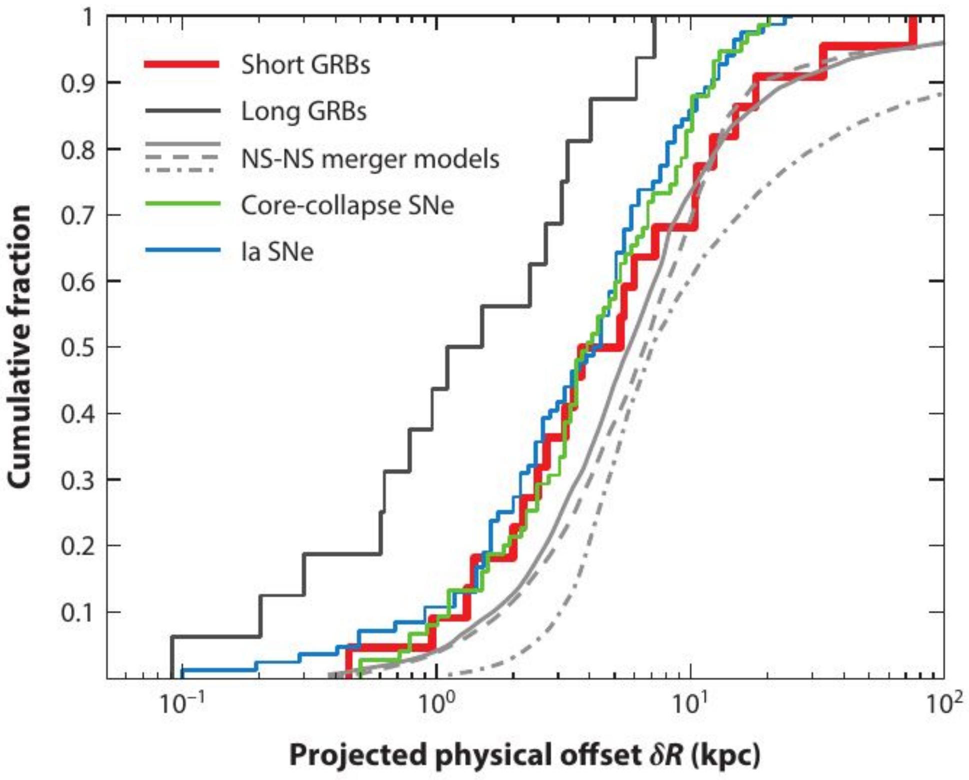
the ratio of the X-ray flux at 11-h to the prompt gamma-ray fluence

Very similar to search for hosts of dark long GRBs - optically dim
… but larger offsets





Offset distribution



Berger+14, (Fong&Berger+13)

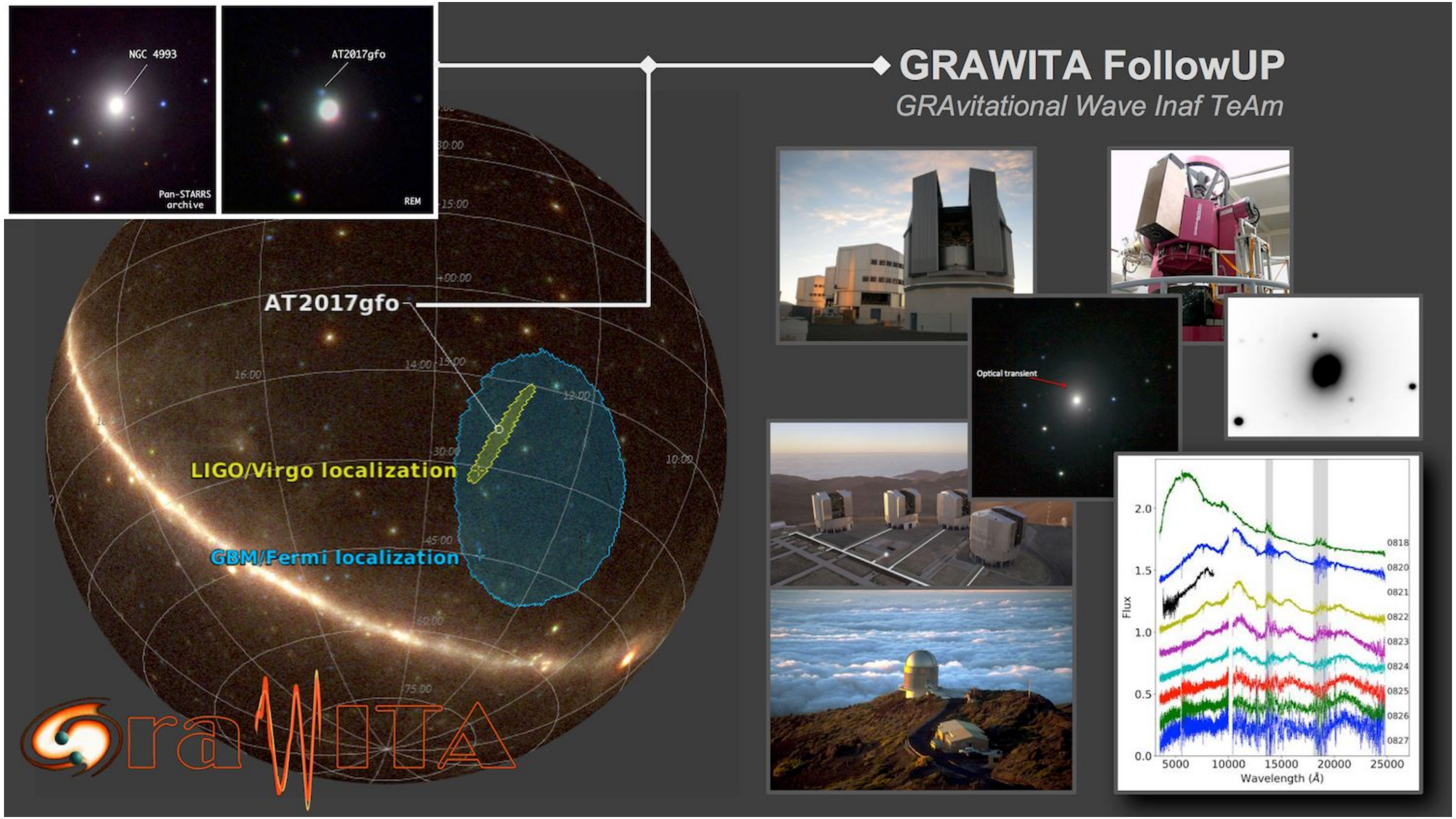
Long GRBs <8kpc ~1” at z >0.5
<2kpc (within/close host)

Short GRBs 50% >~5kpc ~ > 1” at z>0.5
30% >~10kpc > 2” at z>0.5
Outside host

Kicks:
The remnants of core-collapse SNe can give a “kick”

Escape from the HG (birthsite)-> **OFFSET!**
(1 ~ 100 kpc)

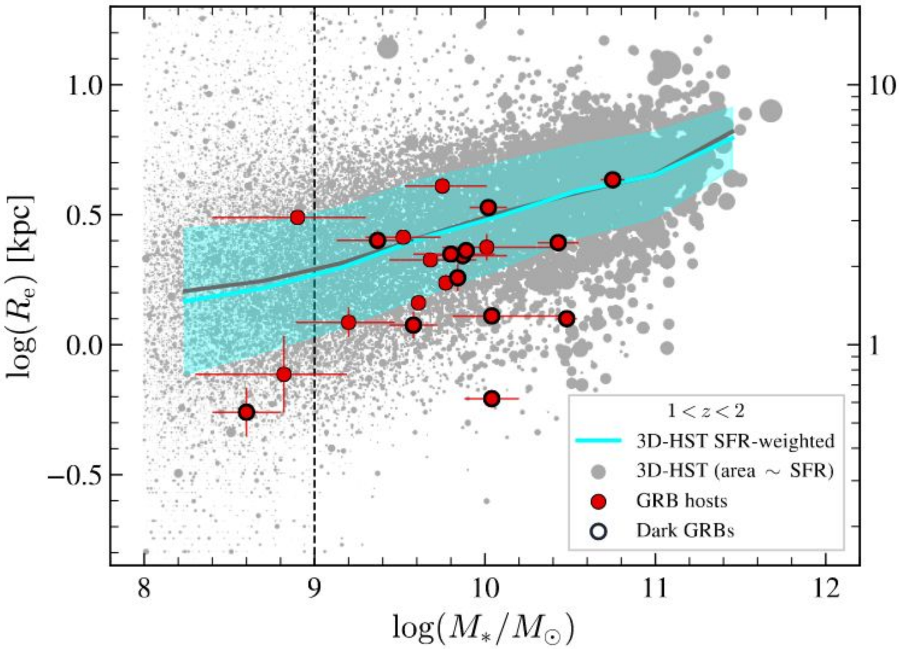
GRAWITA



Pian, et al., 2017,
X-Shooter, FORS2

Recent developments:

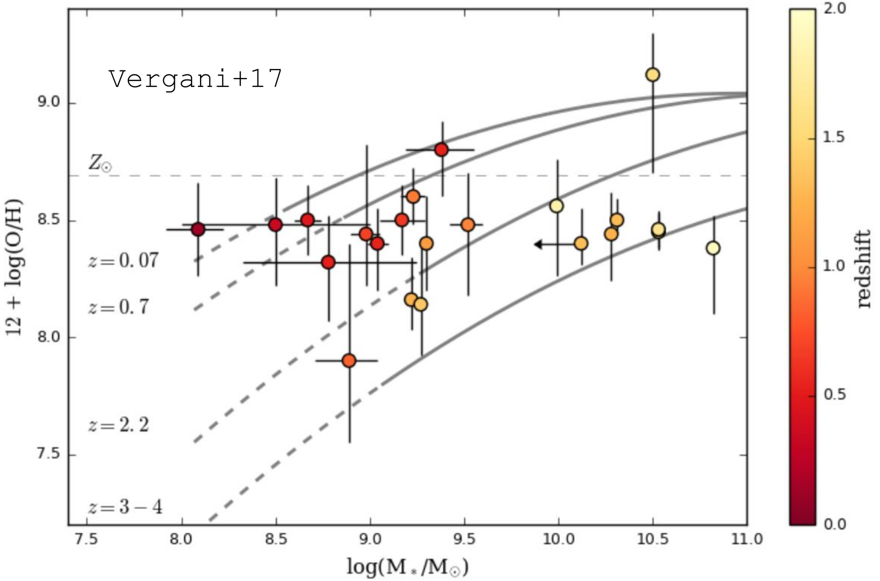
Are the hosts of Long GRBs more compact?

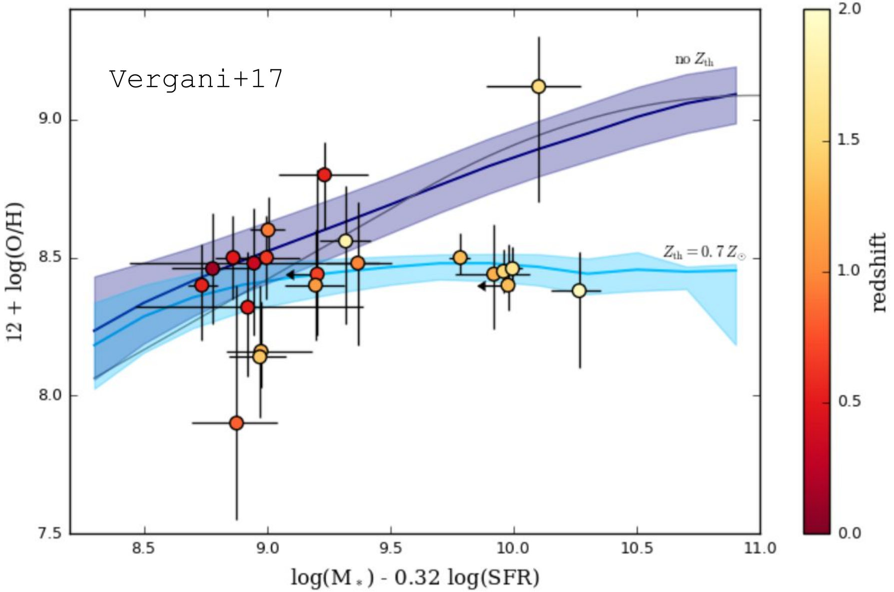


- **Schneider+22 arxiv: 2206.14873**
- HST GRB hosts, not complete sample, dominated by dark GRB hosts!
- 3D-HST survey (nir survey covers COSMOS GOODS ecc..)

- z<1 GRB hosts are smaller in size (higher stellar mass and SFR surface densities than field galaxies)
- Not clear at larger redshifts (sample dominated by darkGRBs)
- GRBs require special environments to be produced?

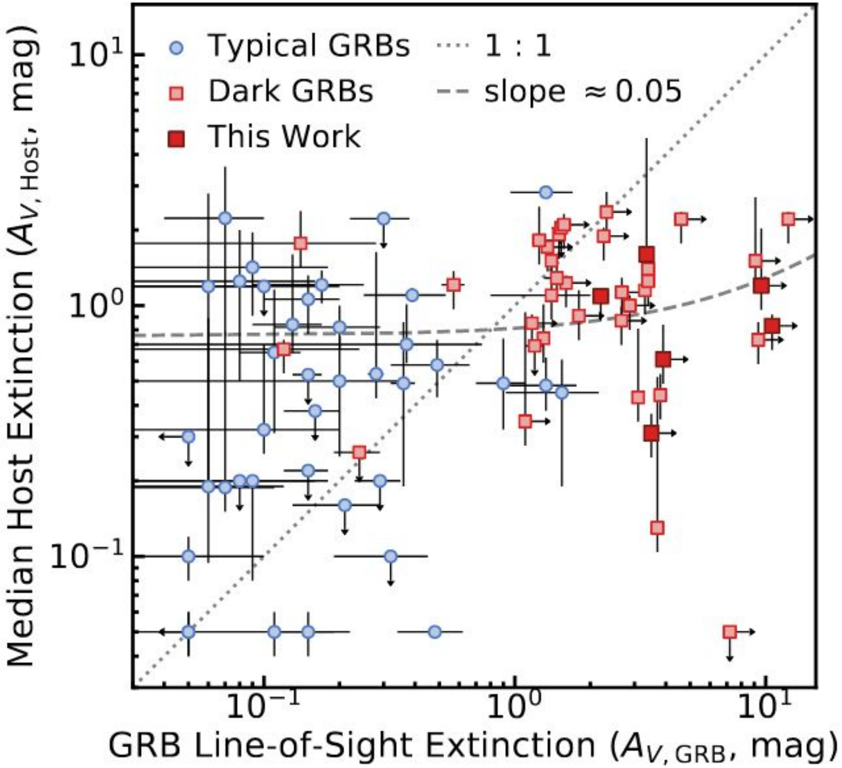
Long GRB host population (metallicity threshold)





FMR, see Mannucci+10,+11;
simulation see Campisi+11

Patchy dust

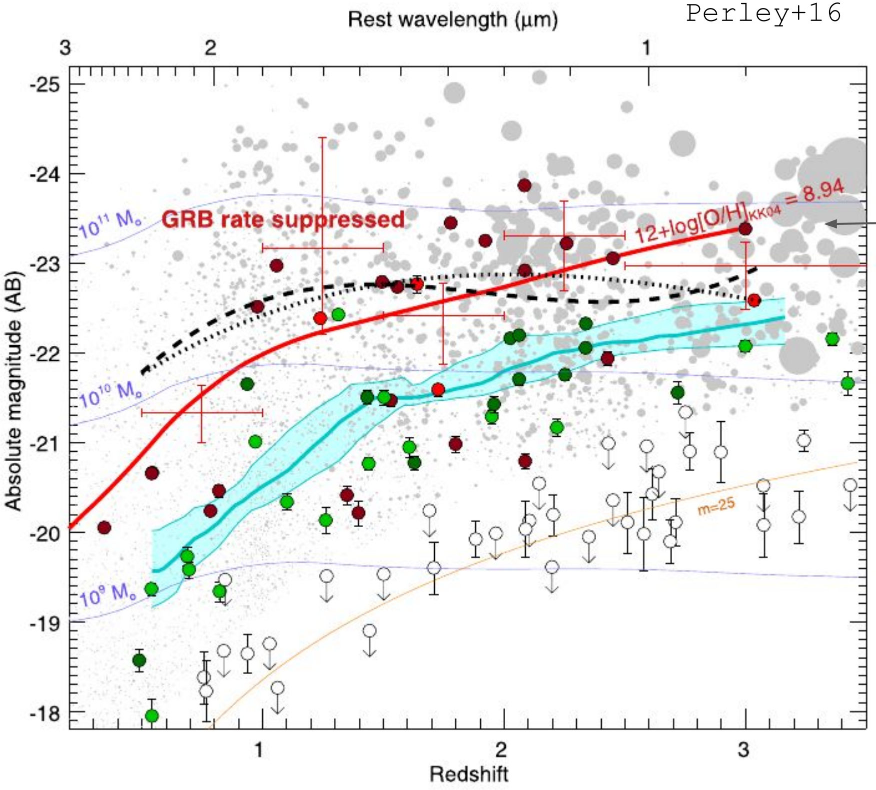


Schroeder+22
A Radio-selected Population of Dark, Long GRBs:

- $A_{V,GRB}$ is not related to $A_{V,Host}$
- nor to the local environment: $A_{V,GRB}$ does not correlate with density n !
- indicating that a large scale patchy dust distribution is the cause of the high line-of-sight extinction (see Kruheler+11)

Long GRB host population (metallicity threshold)

Perley+16



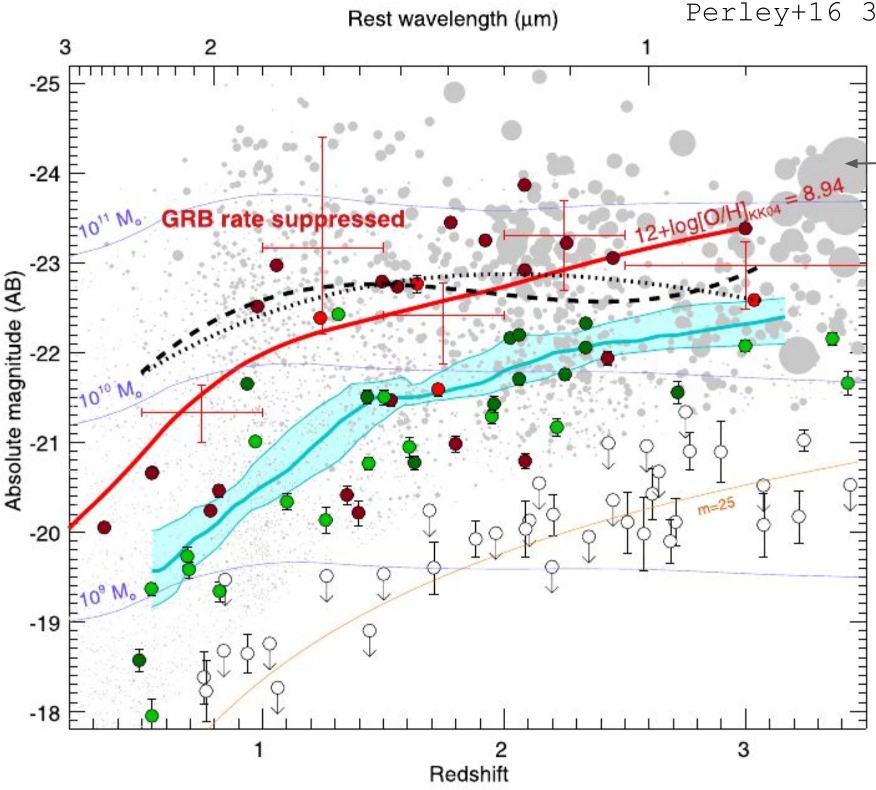
SHOALS/Perley+16 => Z<~1 Zsun

GOODS North in gray - area scaled with SFR

A mettallicity bias can be seen as a mass bias !

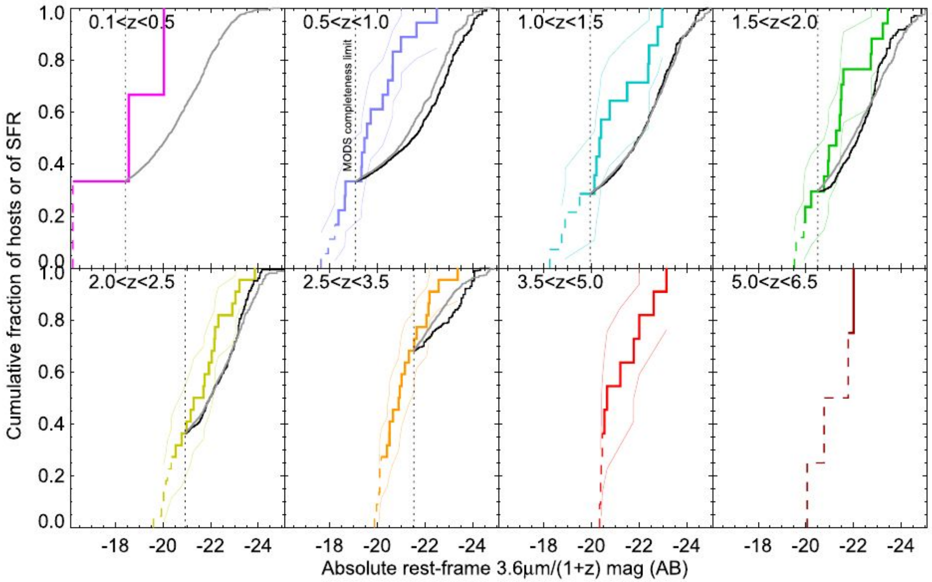
Long GRB host population (metallicity threshold)

Perley+16 3.6um survey w SPITZER



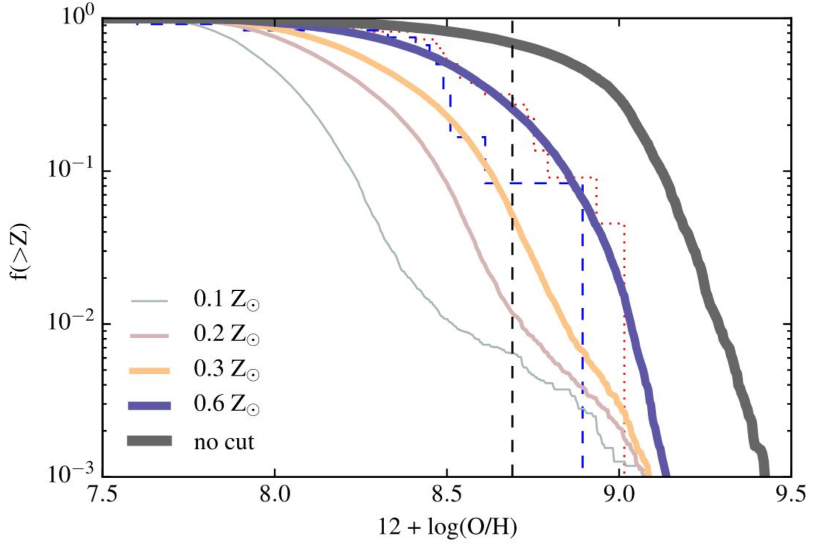
SHOALS/Perley+16 => Z<~1 Zsun

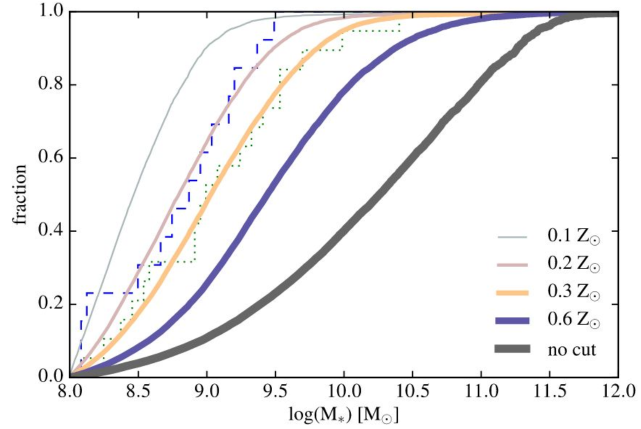
GOODS North in gray

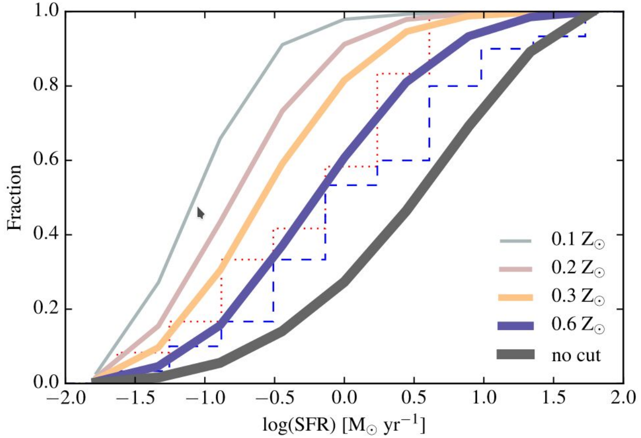


Long GRB host population (metallicity threshold)

Bignone+17, ILLUSTRIS simulation with metallicity cut off

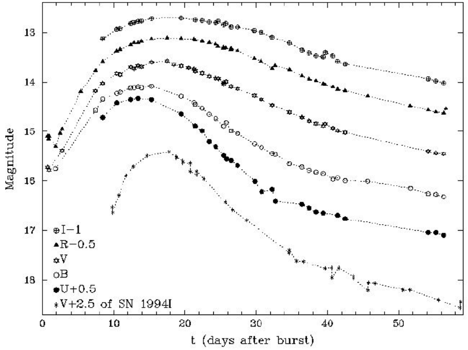


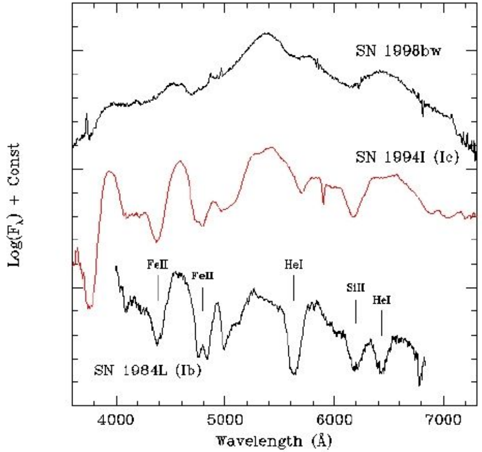


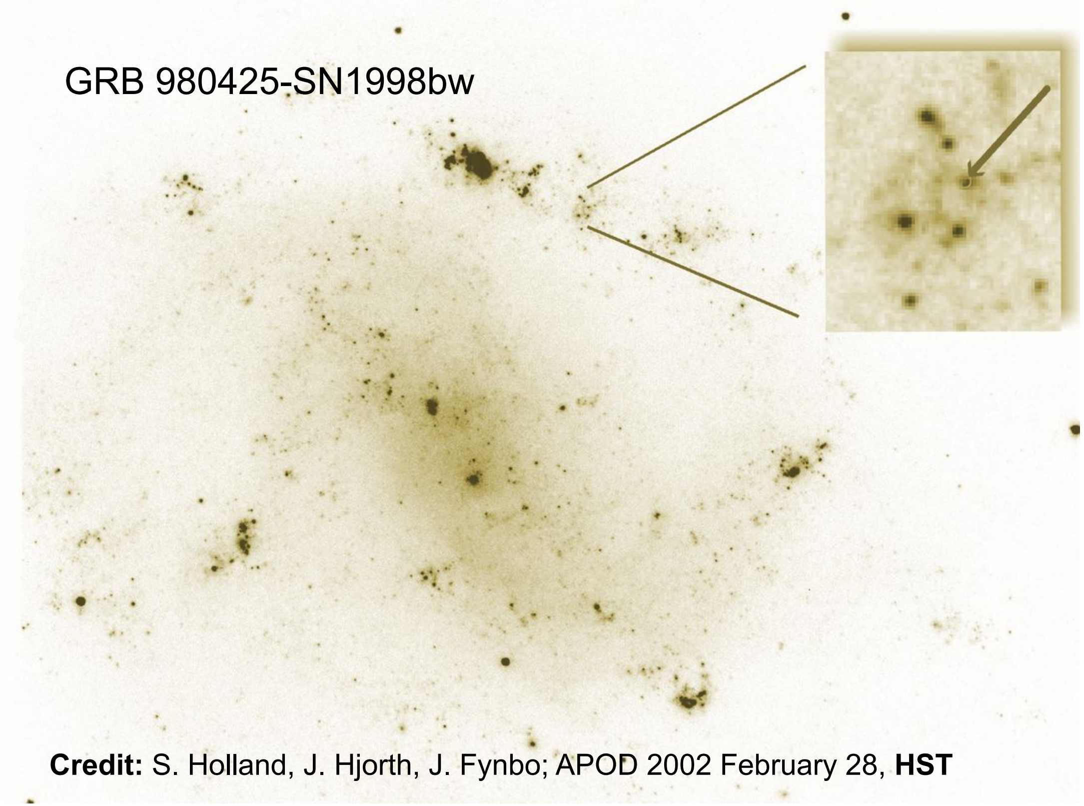


But see Metha+Trenti+20 (Z<0.35),
based on IllustrisTNG in agreement with Yoon+06
Both need an increased sample of objects!

Long GRBs -SN connection







Credit: S. Holland, J. Hjorth, J. Fynbo; APOD 2002 February 28, **HST**

Hosts of optically detected GRB afterglows

- SELECTION:
  - X-ray/optical afterglow detected
  - Host detection in more than 1 filter
  - *R* < 25
  - Known redshift
    - (afterglow or host)

- RESULTS:
  - low-mass
  - young
  - star-forming
  - blue
  - low dust extinction

e.g., Christensen et al., Astron. & Astroph., 425, 913, 2004;
Fruchter et al., Nature, 441, 463, 2006

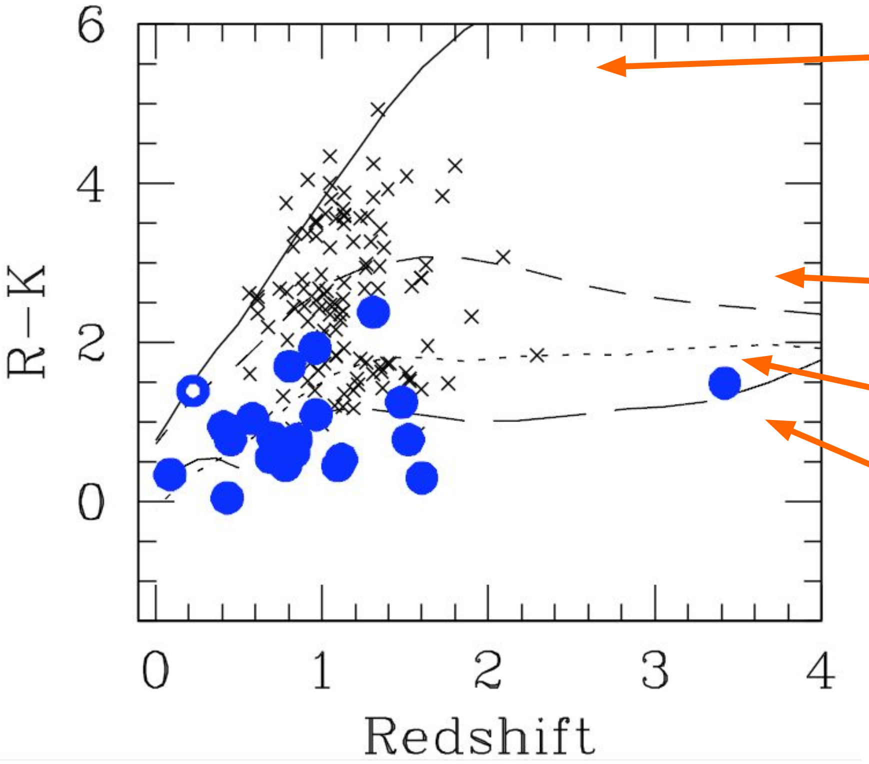
A different approach: host galaxies of optically non-detected afterglows

- SELECTION:
  - X-ray afterglow detected
  - DARK GRBs:
    no optical detection despite deep optical follow-up
  - no host detected

- GOALS:
  - identify the host
  - SED ?
  - redshift ?

- RESULTS:
  - mass
  - SFR
  - AV

Long GRB
Host galaxies: sub-luminous and blue



Red passive galaxies (Ellipticals, low star formation)

Massive active galaxies R-K <3

Irregular star-forming galaxies

Starburst galaxies (high SFR)

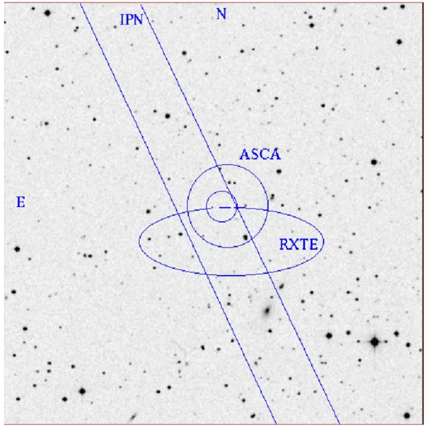
Adapted from Savaglio et al. 2009; GRBs HG and Gemini GDDS

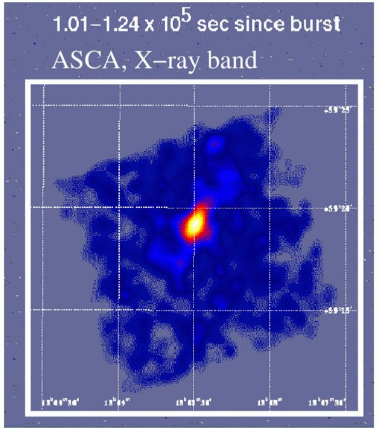
GRB 970828 – first obvious dark GRB

- No optical afterglow
  - R>24.5 (dt=4 hours)

- Detection of radio flare:

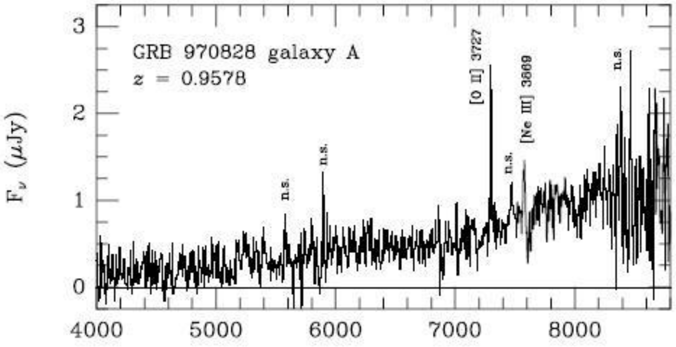
  Precise position





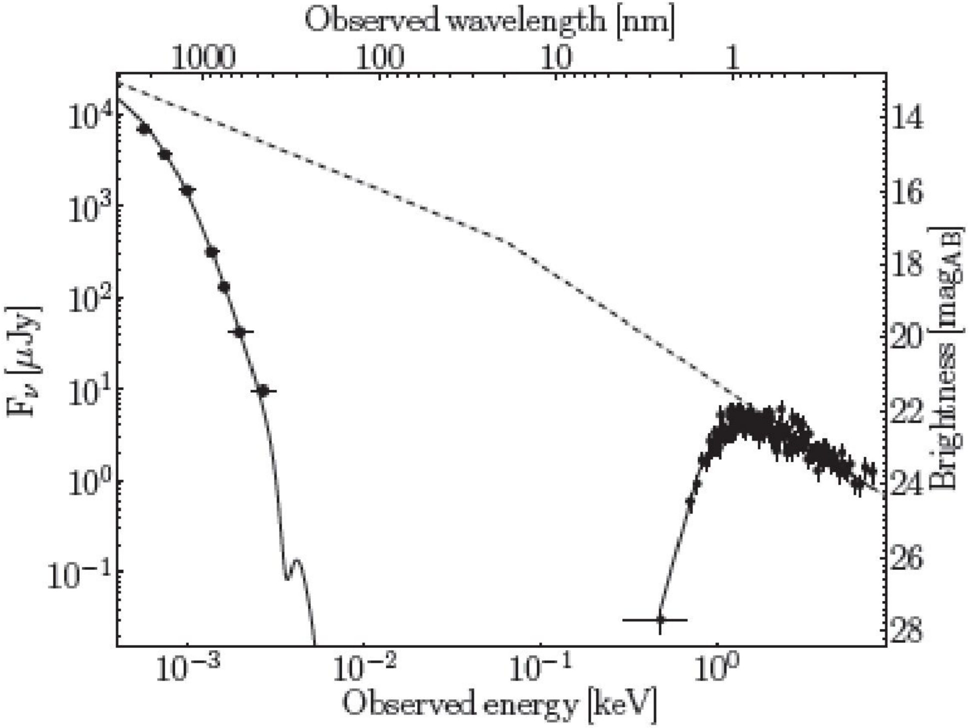
- Identification of the host galaxy z=0.9578 (Djorgovski 2001);

- Upper limits explained by dust extincti within the host galaxy (AV>3.8 mag)



• Dust absorption

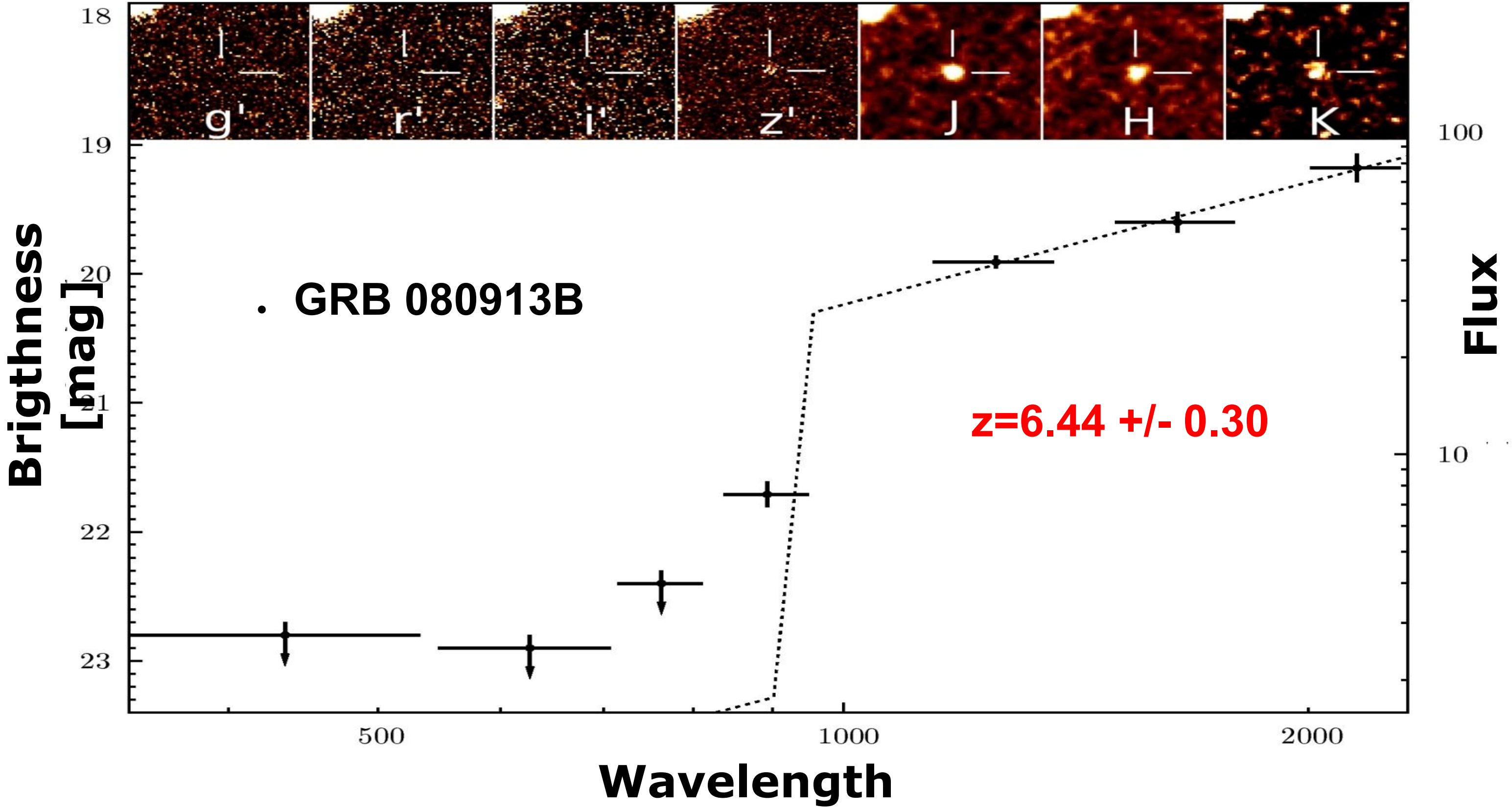
- The local material in the GRB environment can strongly absorb the afterglow emission.



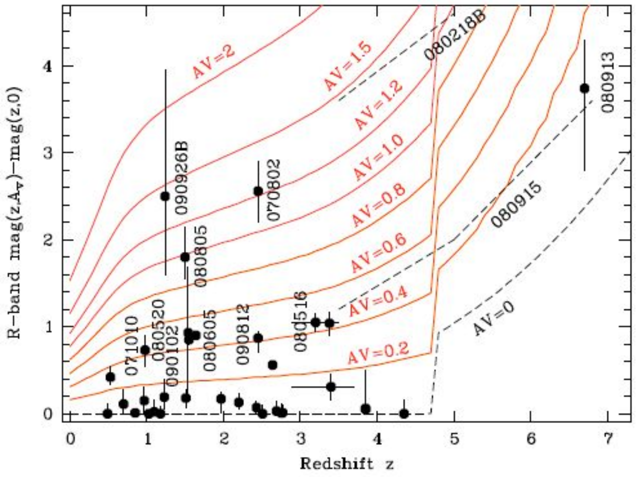
GRB 100621A, adapted from Krühler et al., 2011

High redshift

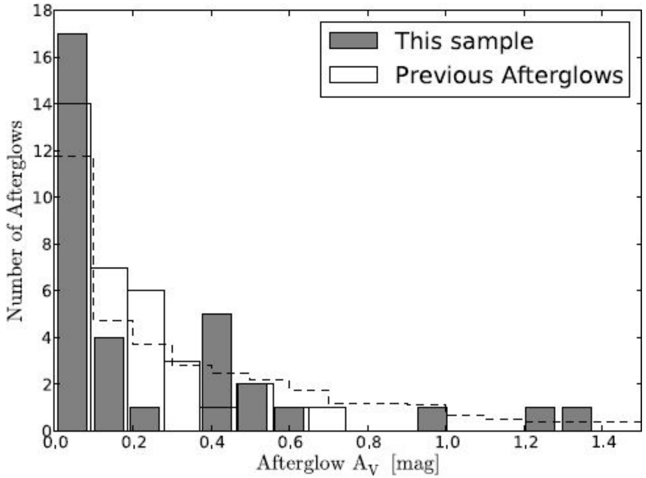
- The Lyman-α blanketing and absorption results in detections only beyond the R-I bands.



- **GROND: SED of the afterglow of GRB 080913B**, Rossi et al., 2008, Greiner et al., 2008

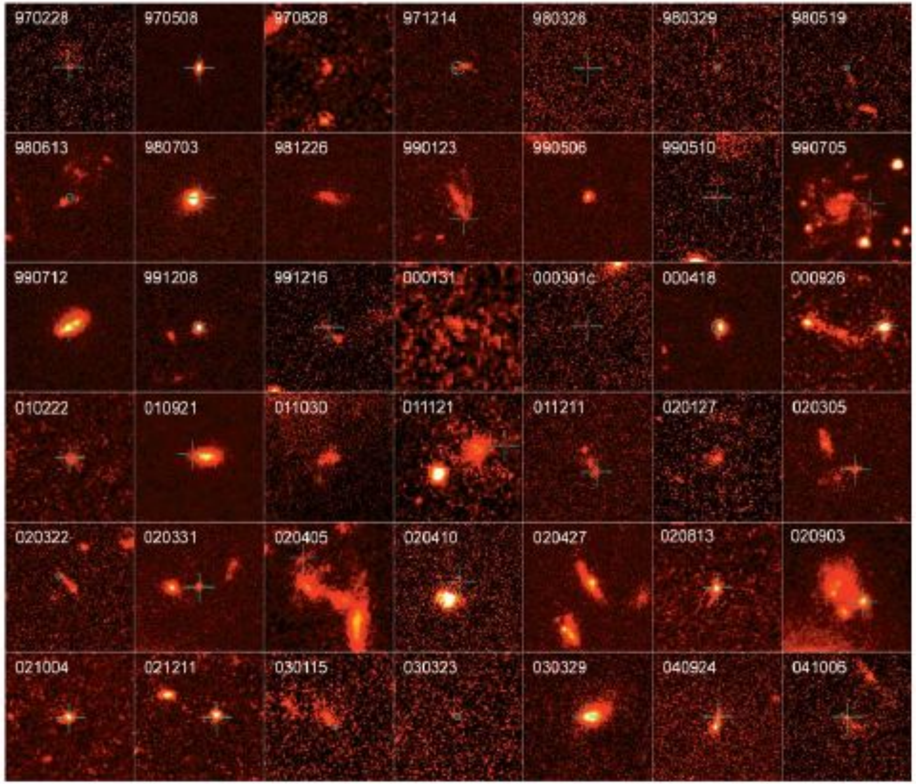


- It is the dust
+
the redshift

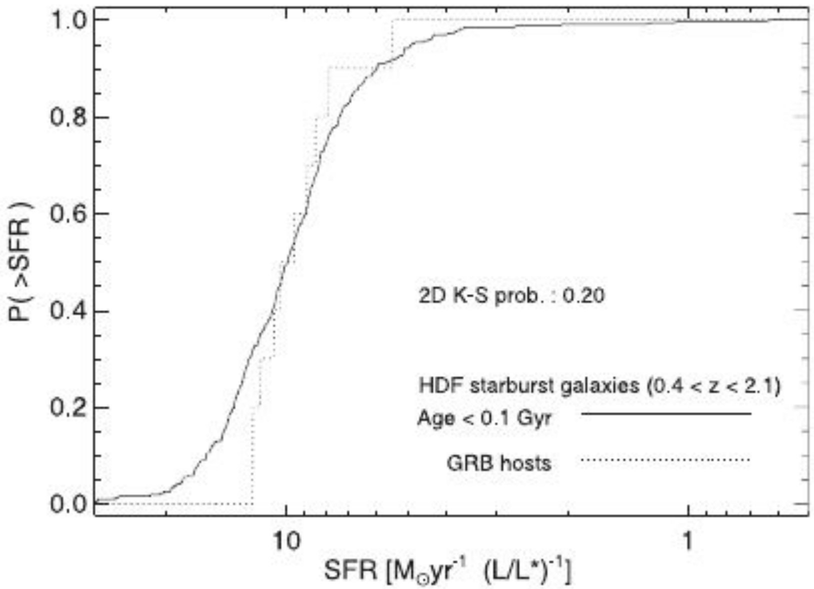


Greiner et al., 2011

Not an easy job



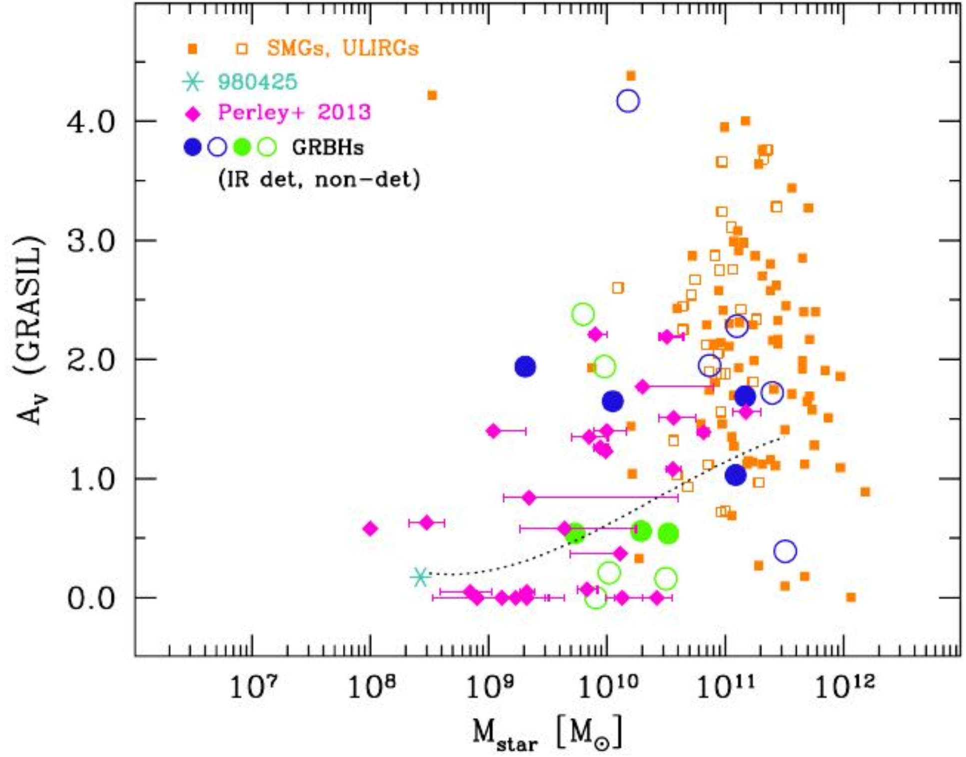
Fruchter+06



Christensen+04: 10 galaxies!

sSFR similar to young high-z hosts

Not an easy job: try to use Hershel …
… but on dark GRB hosts



Hunt+14