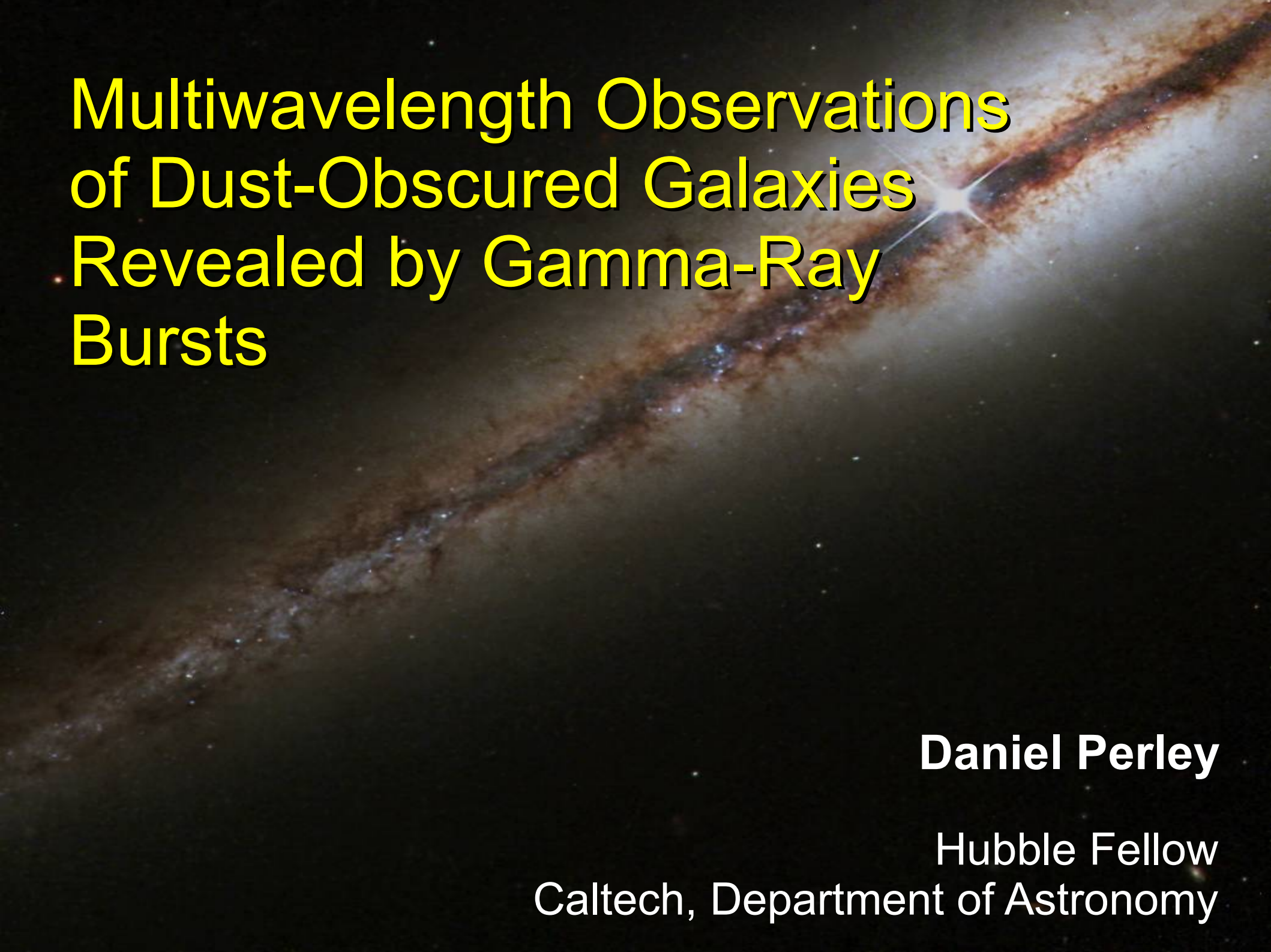


Multiwavelength Observations of Dust-Obscured Galaxies Revealed by Gamma-Ray Bursts

Daniel Perley

Hubble Fellow
Caltech, Department of Astronomy

Collaborators

Brad Cenko	UC Berkeley
Joshua Bloom	UC Berkeley
Adam Morgan	UC Berkeley
Nial Tanvir	Univ. of Leicester
Andrew Levan	Univ. of Warwick
Hsiao-Wen Chen	Univ. of Chicago
Jason Prochaska	UC Santa Cruz
Nat Butler	Univ. of Arizona
Maryam Modjaz	New York Univ.
Rick Perley	NRAO Socorro
Shri Kulkarni	Caltech
Jens Hjorth	DARK Cosmology Centre
Johan Fynbo	DARK Cosmology Centre
Daniele Malesani	DARK Cosmology Centre
Thomas Krühler	DARK Cosmology Centre

Outline

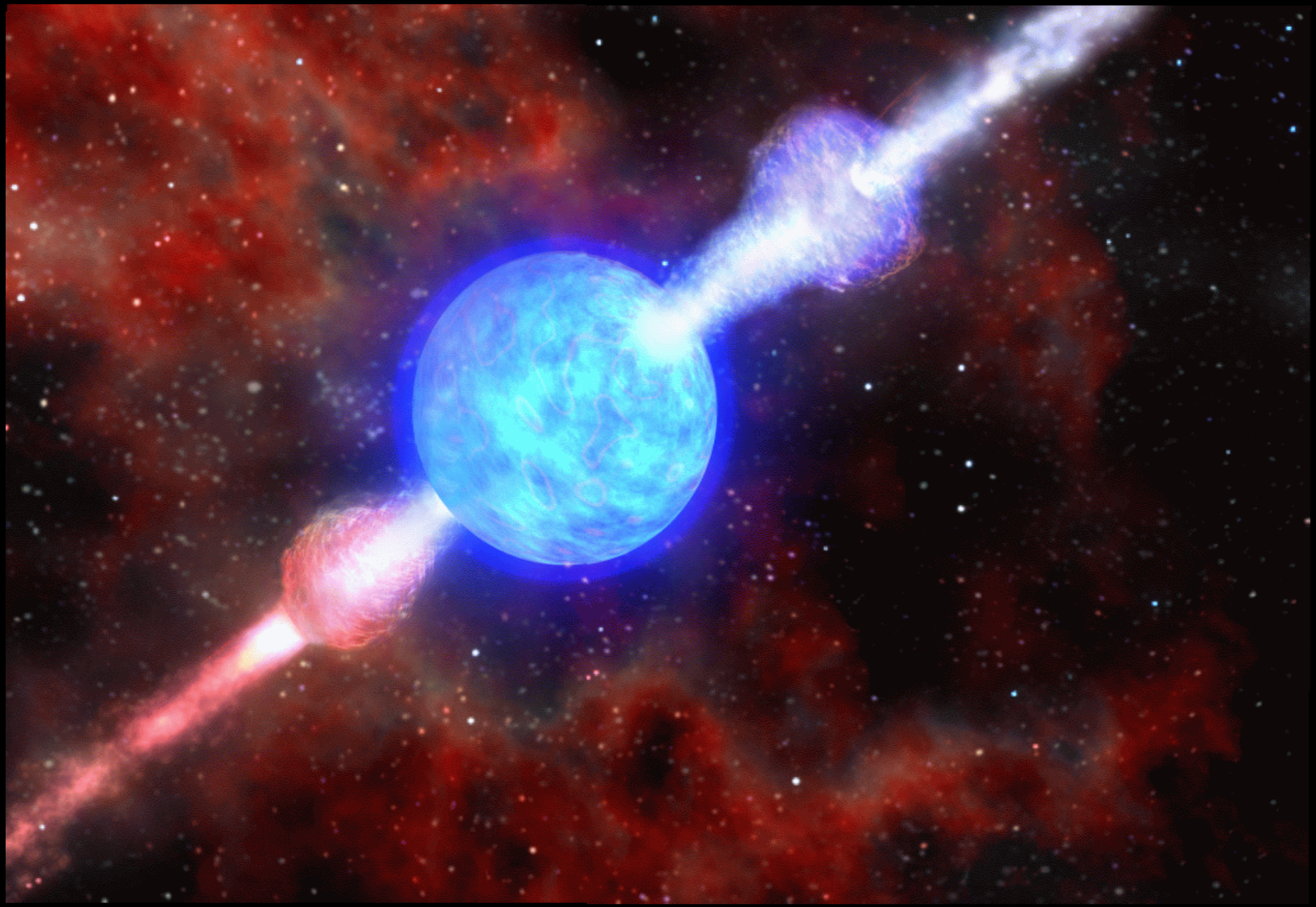
Gamma-Ray Bursts

Motivation
- Where are the dust-obscured GRBs?
- Pre-Swift host galaxy results

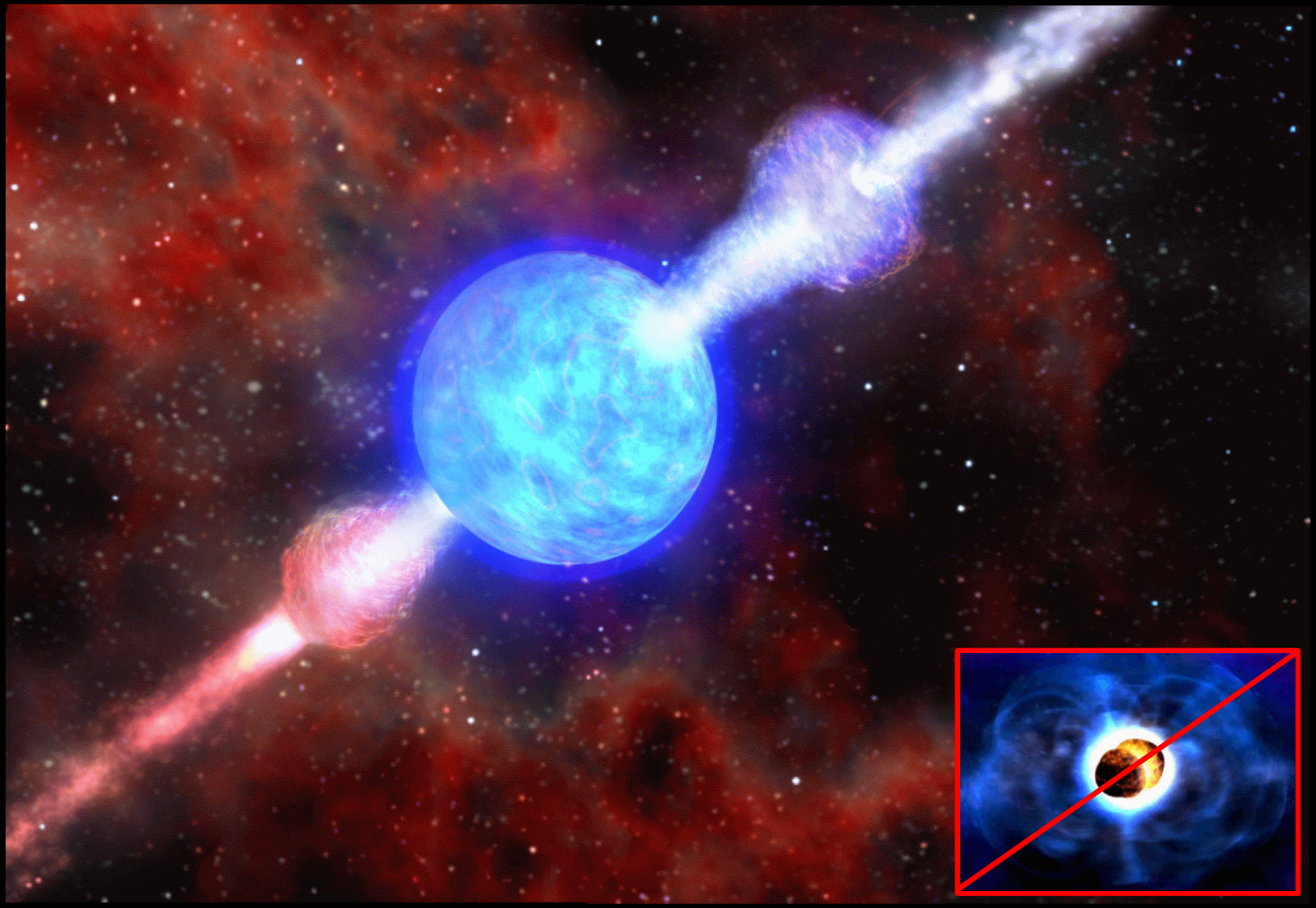
Dark Bursts
- Dark GRB afterglows and dust extinction

Dark GRB host galaxies

Gamma-Ray Bursts



(Long) Gamma-Ray Bursts



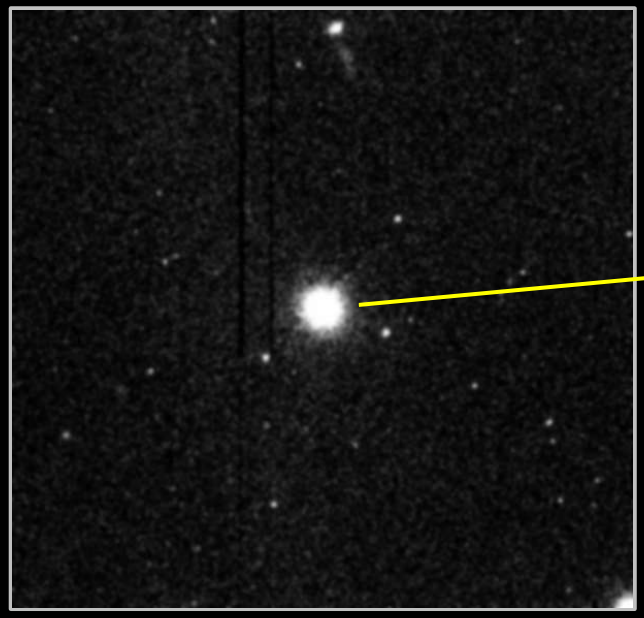
GRBs: Massive Stellar Core-Collapse

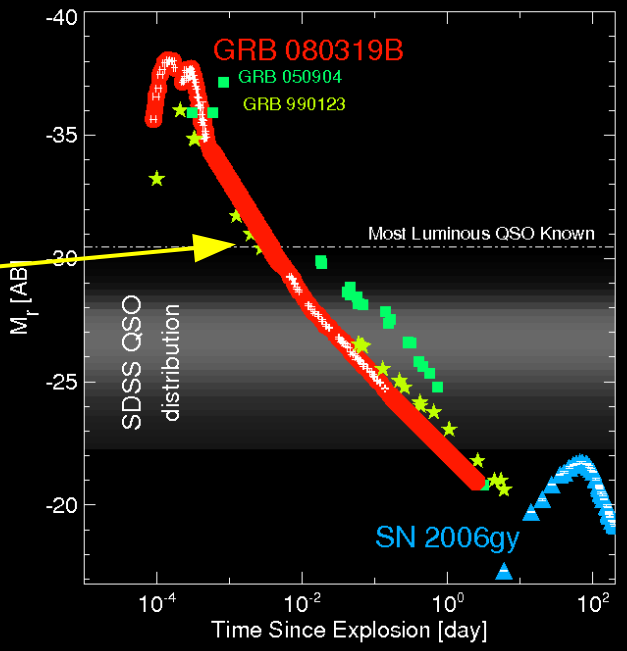
ESA, Stephen Holland

Lighthouses for the High-z Universe

GRB 080319B:

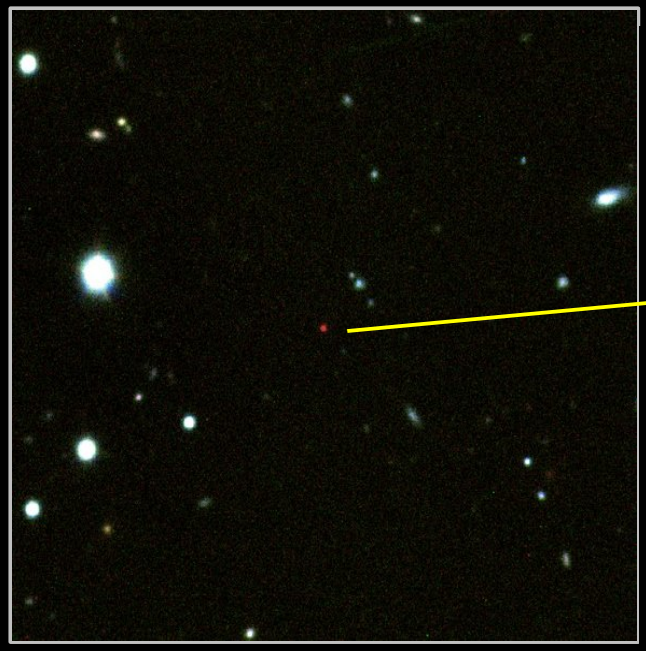
M_R = -39 mag
at peak

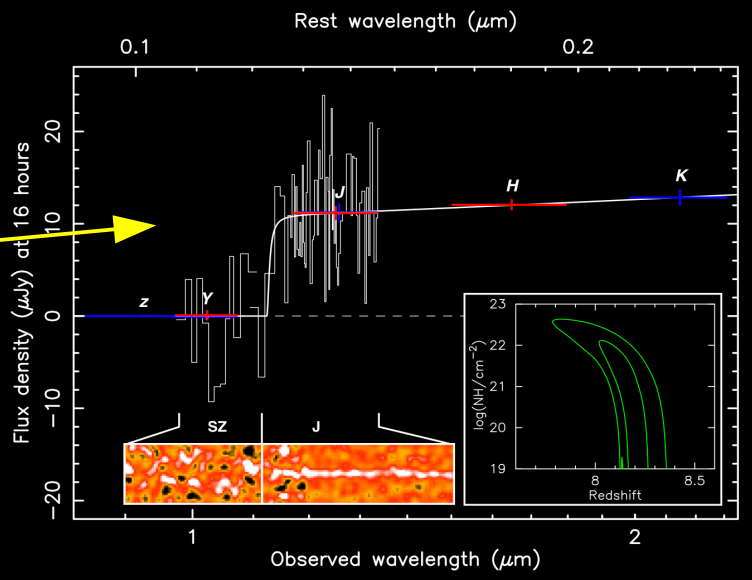




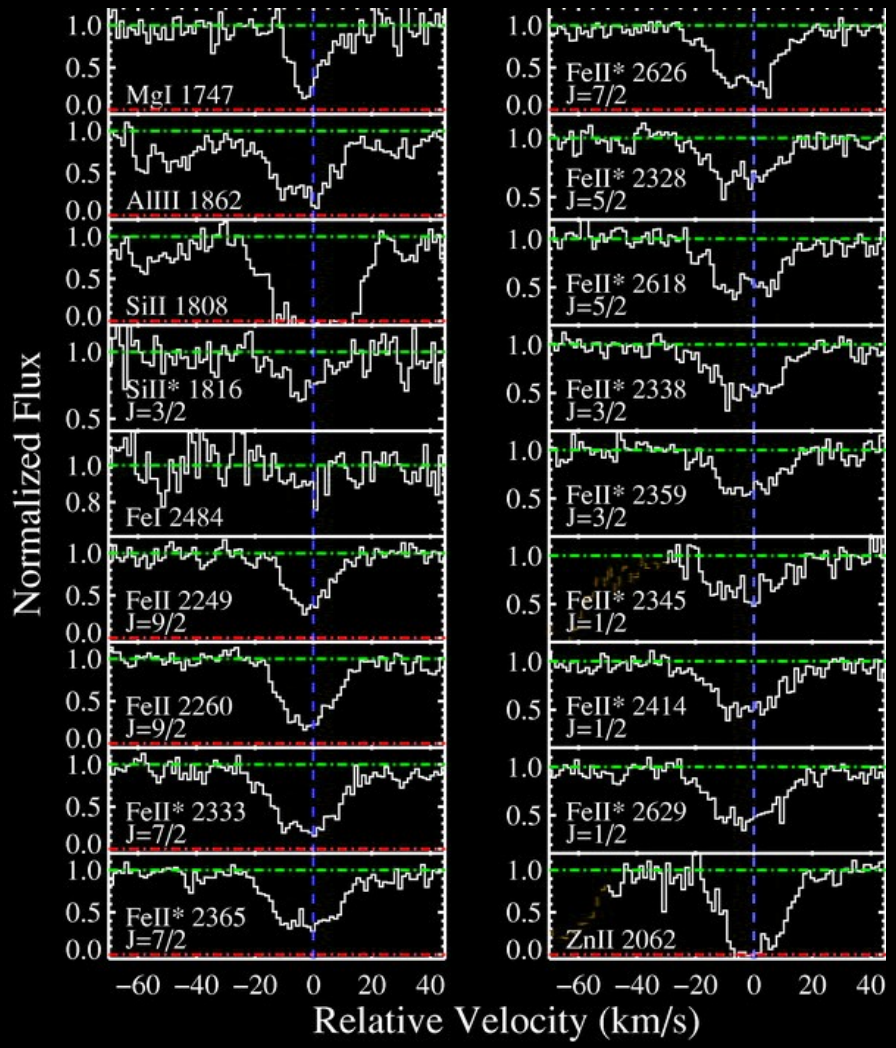
GRB 090423:

redshift z = 8.3

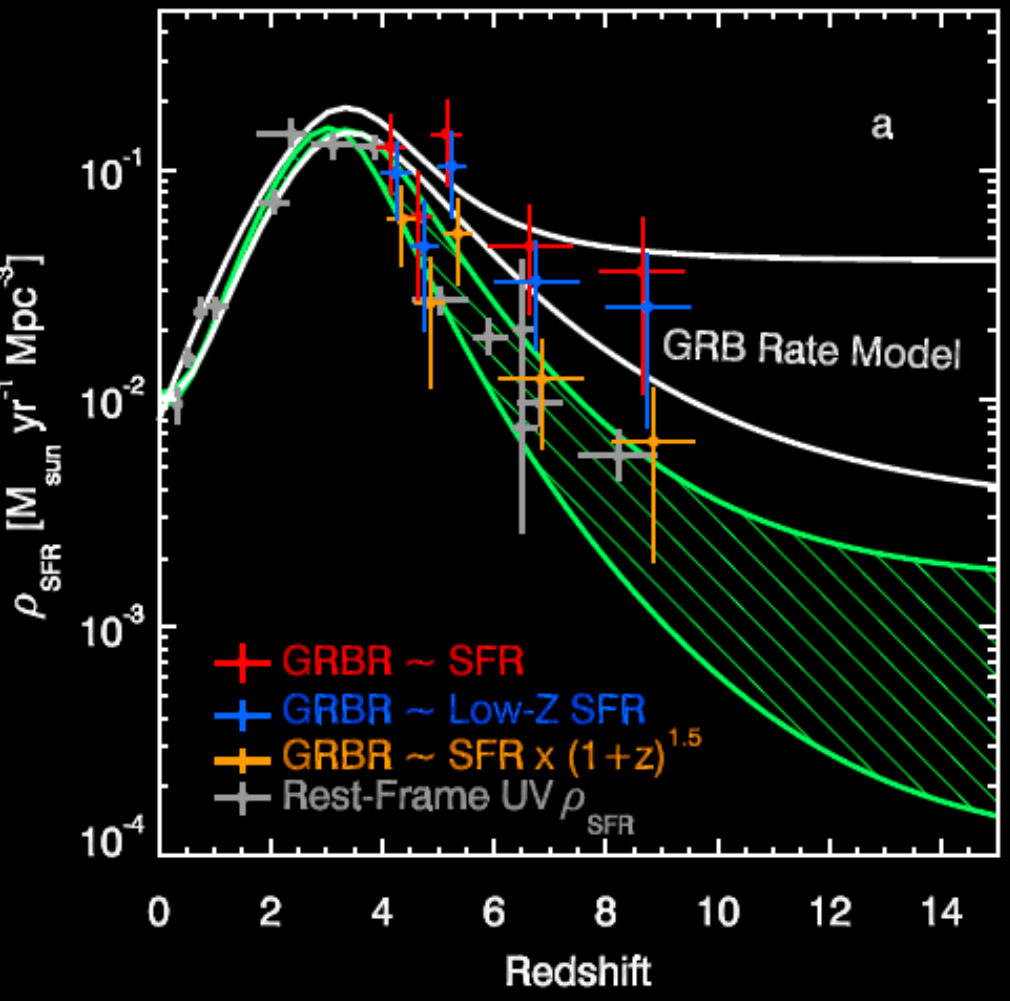




Probes of High-z SFR

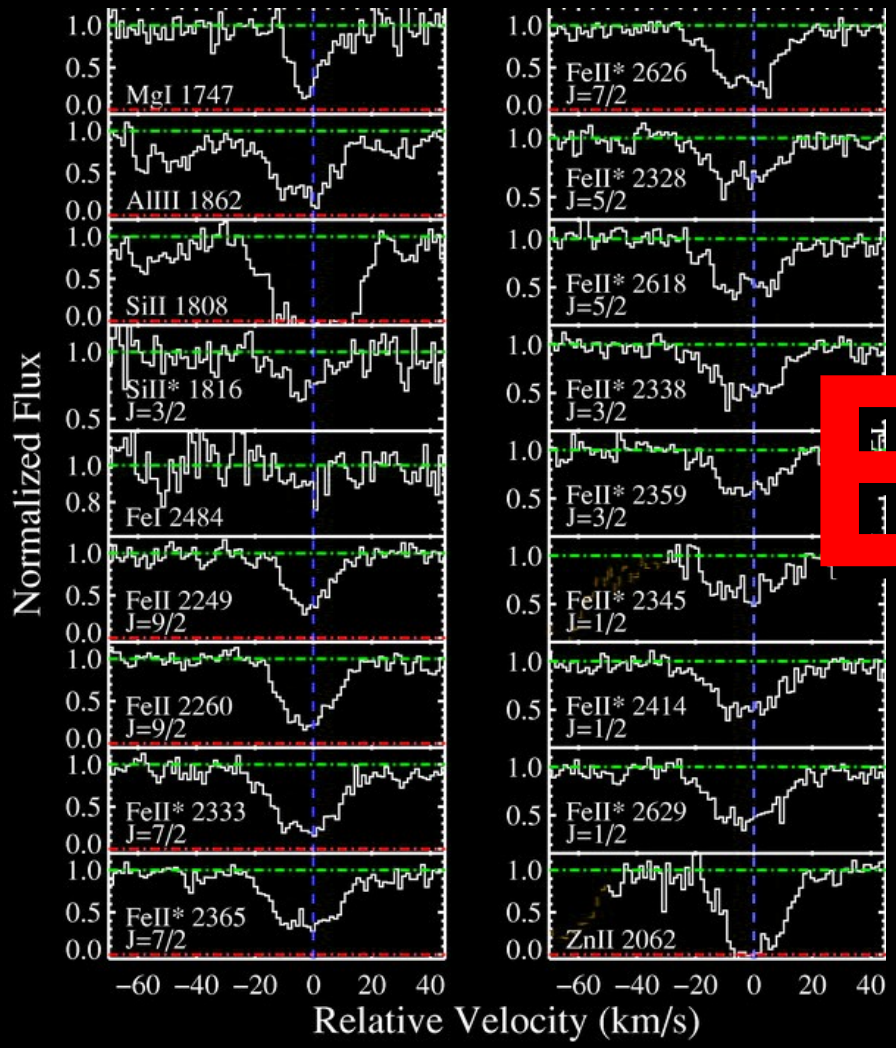


Prochaska et al. 2006



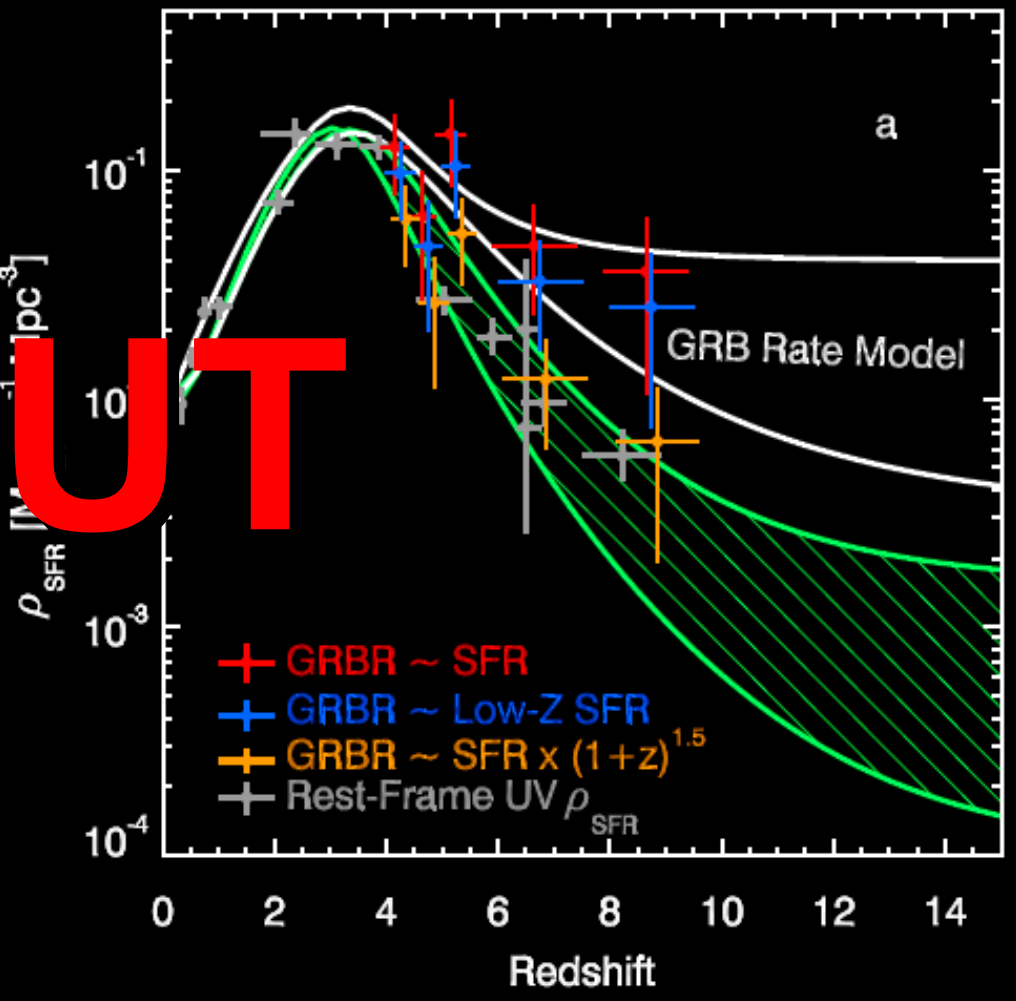
Robertson & Ellis 2011

Probes of High-z SFR



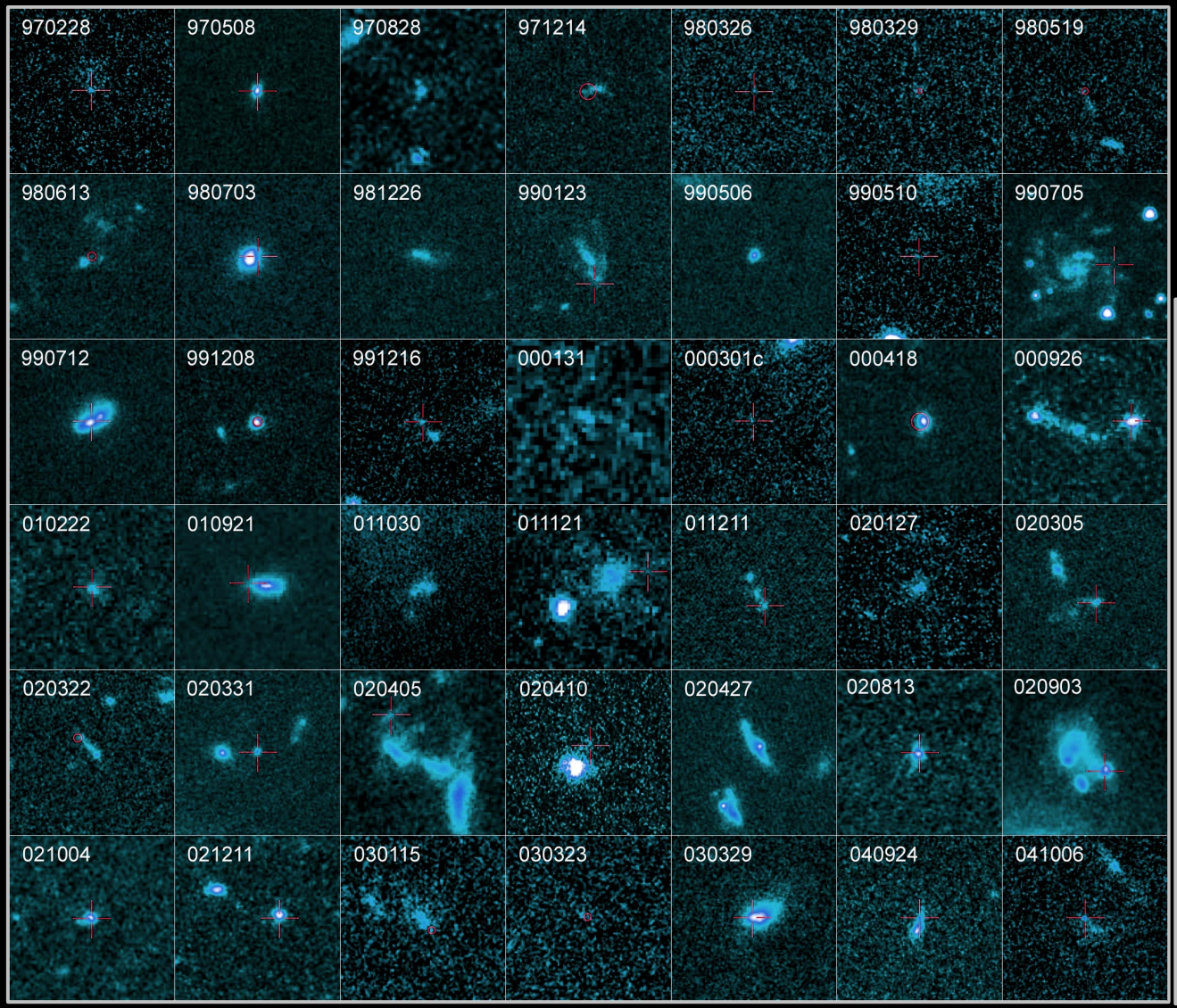
Prochaska et al. 2006

BUT



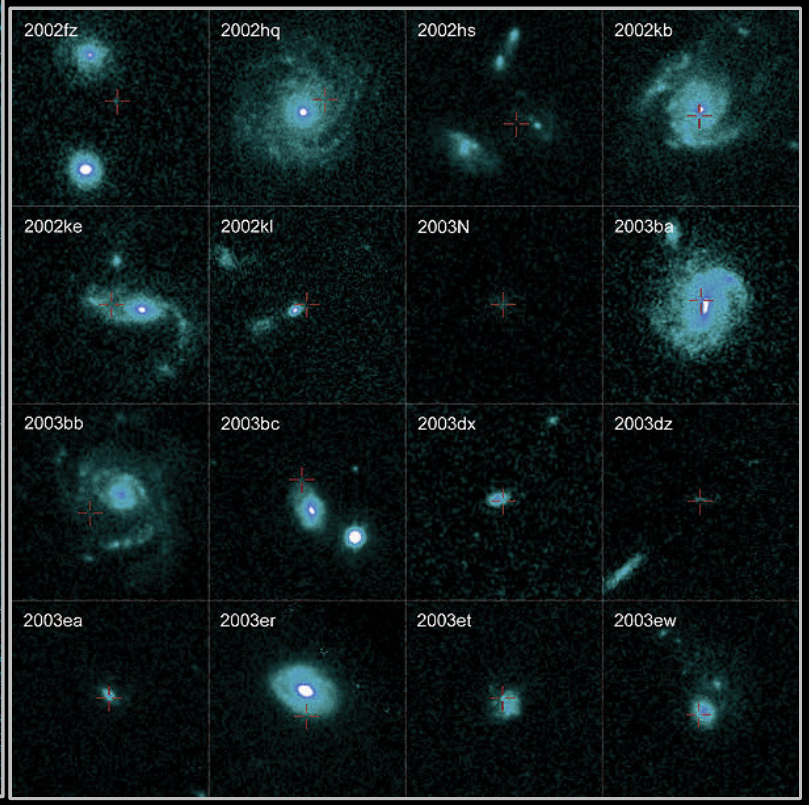
Robertson & Ellis 2011

Morphology Differences



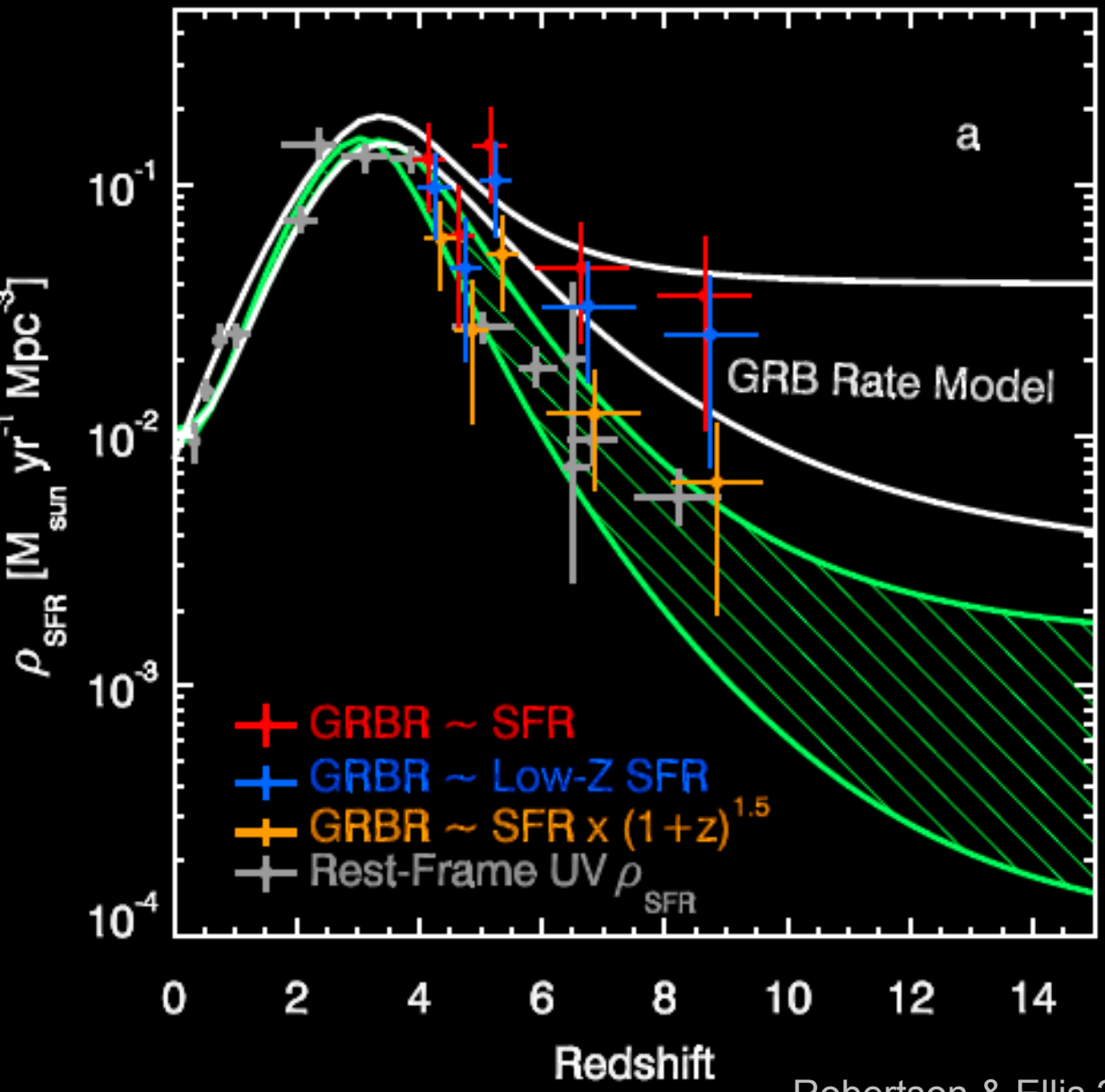
GRB hosts

SN hosts



Fruchter et al. 2006

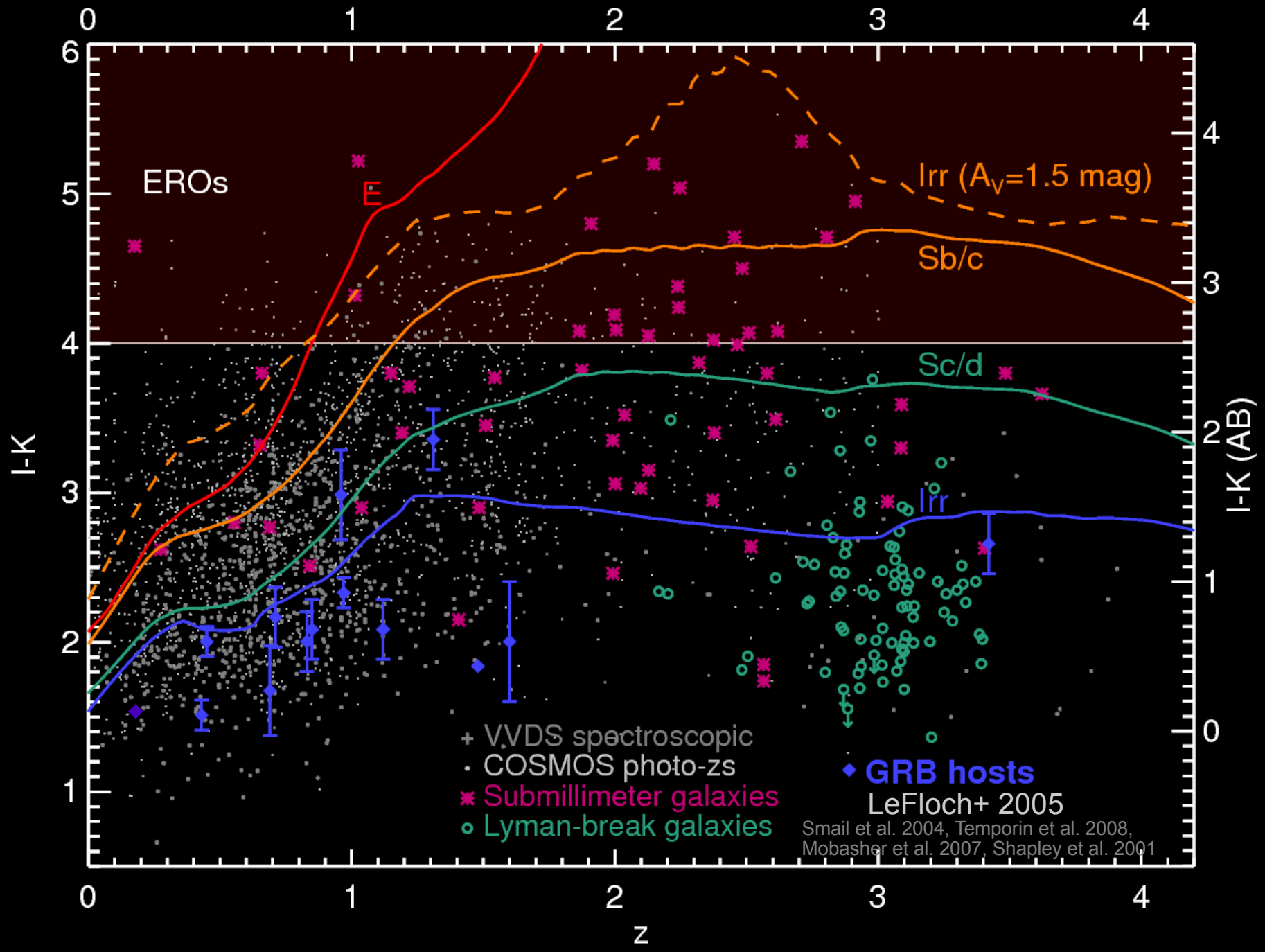
Redshift Differences



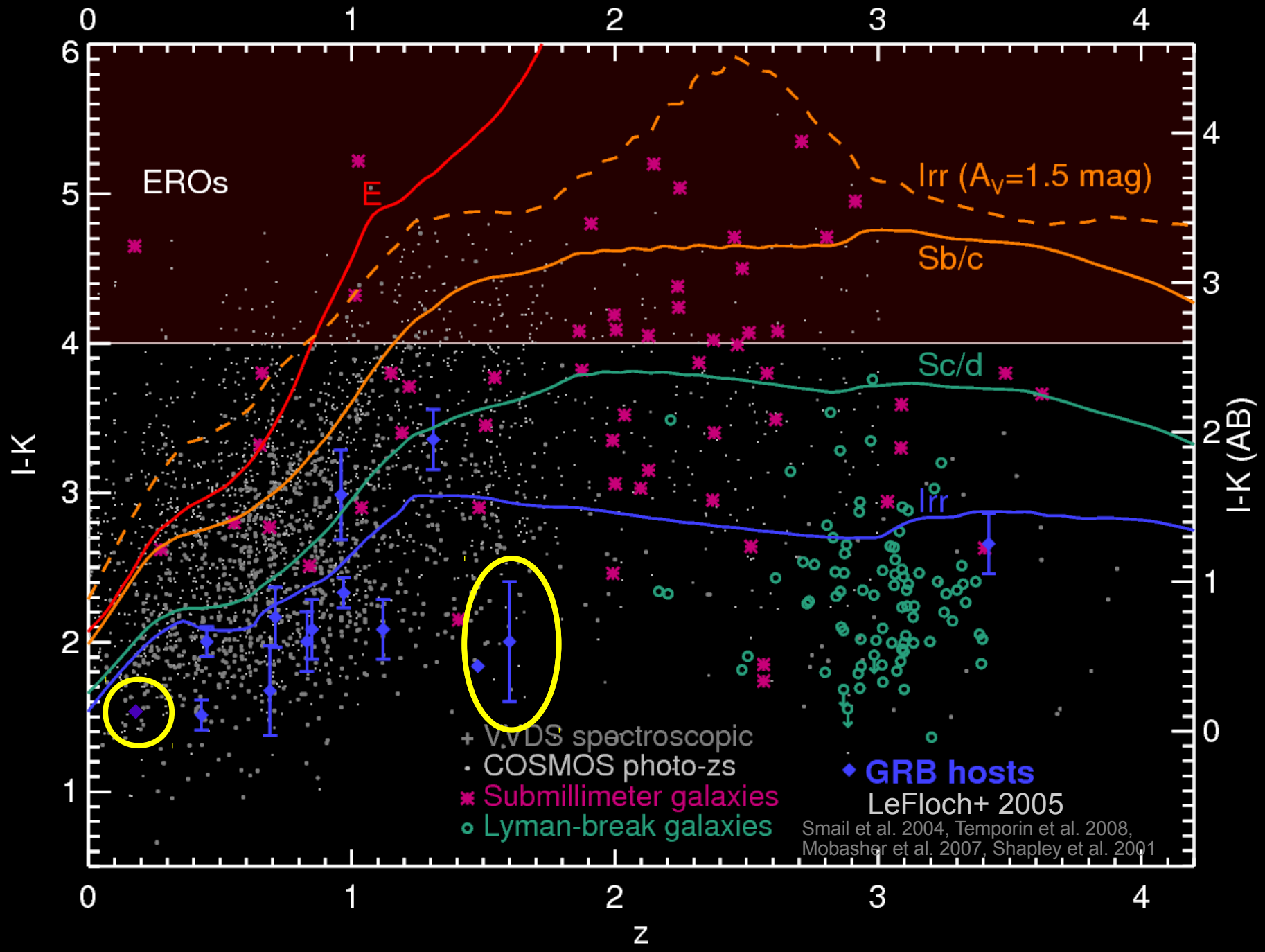
Robertson & Ellis 2011

See also
Kistler et al. 2008,
Kistler et al. 2009,
Butler et al. 2009

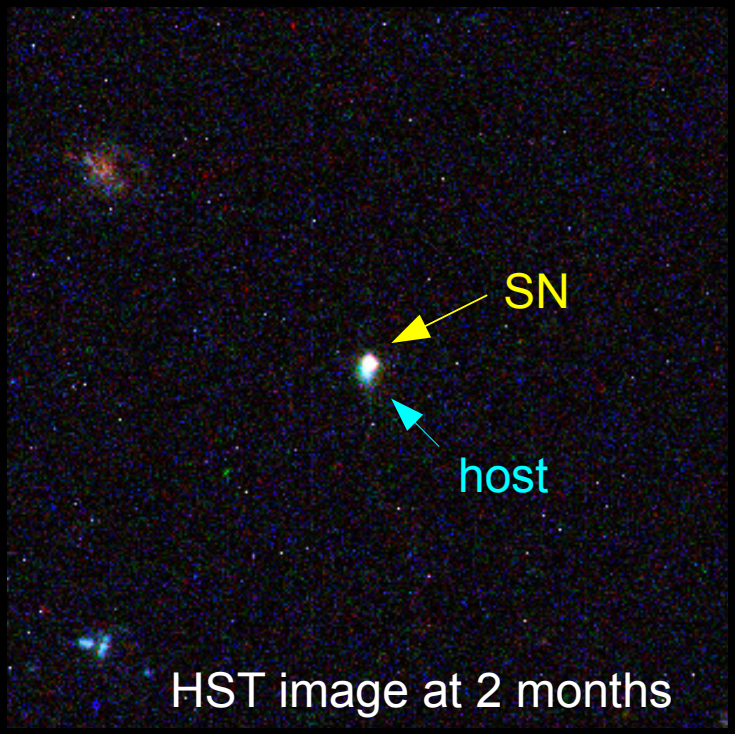
Color Differences



Color Differences



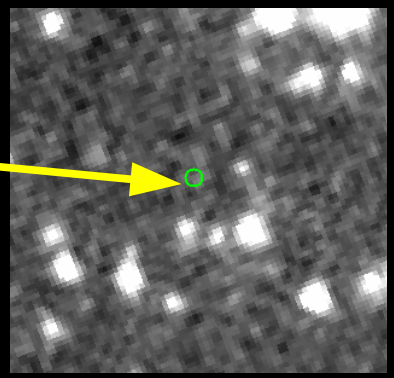
SED Differences

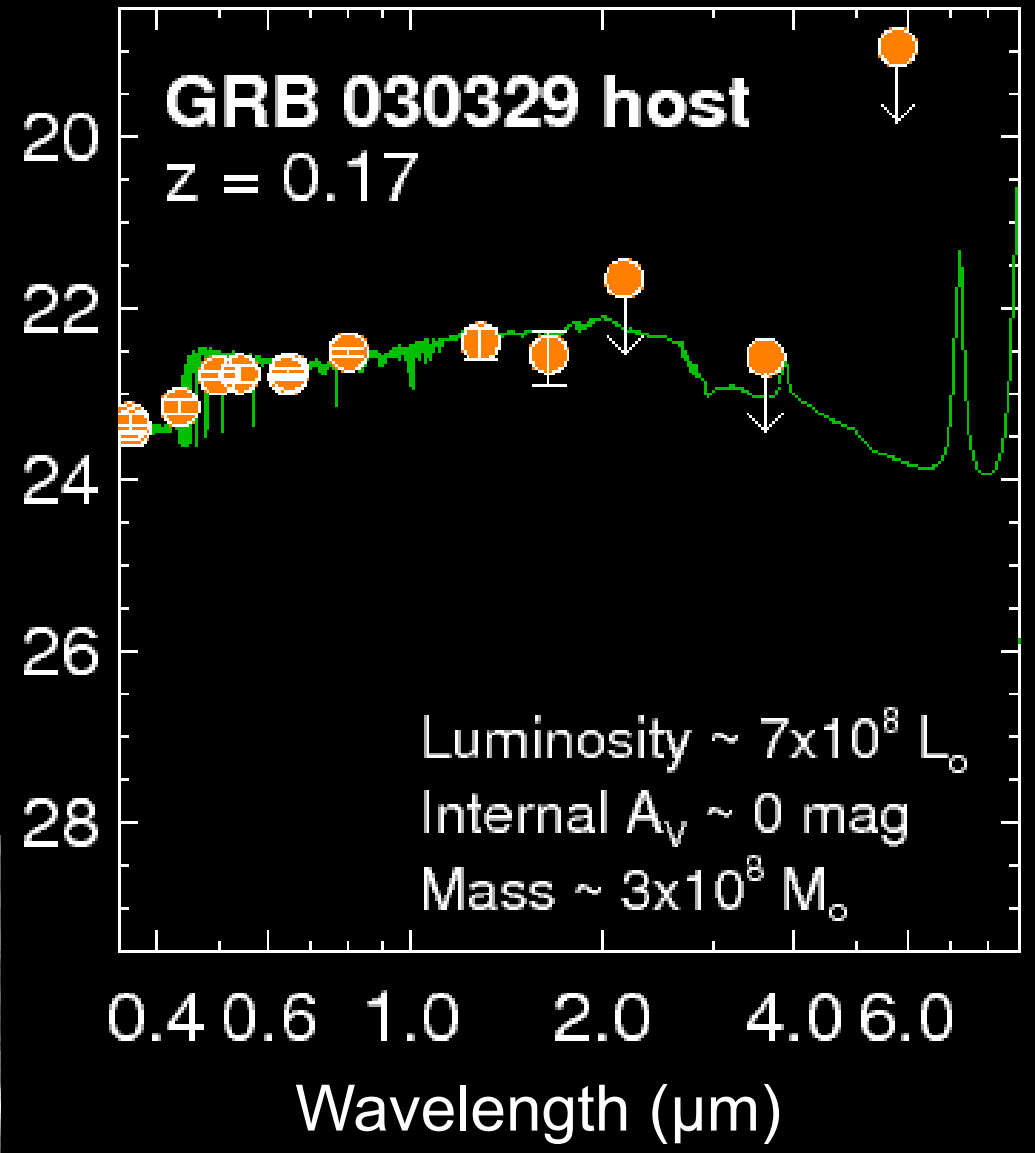


Fruchter et al. 2003

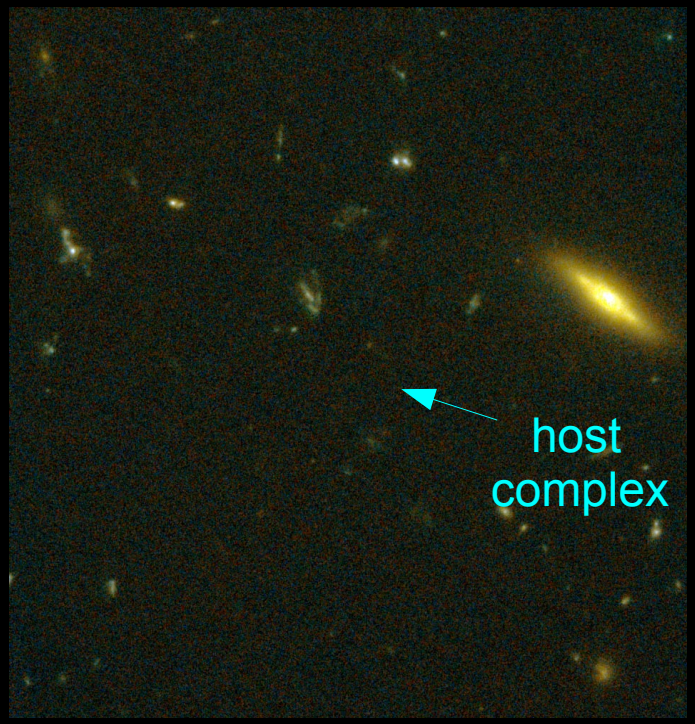
Host of GRB 030329
at **z = 0.17:**

No detection at 2.2 μm, 3.6 μm, 5.8 μm...





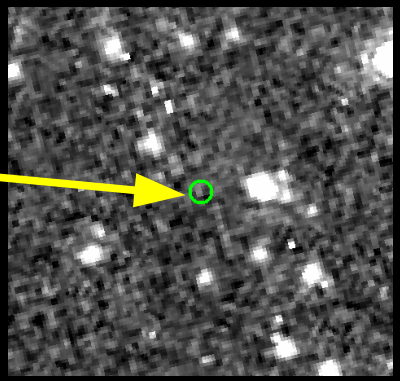
SED Differences

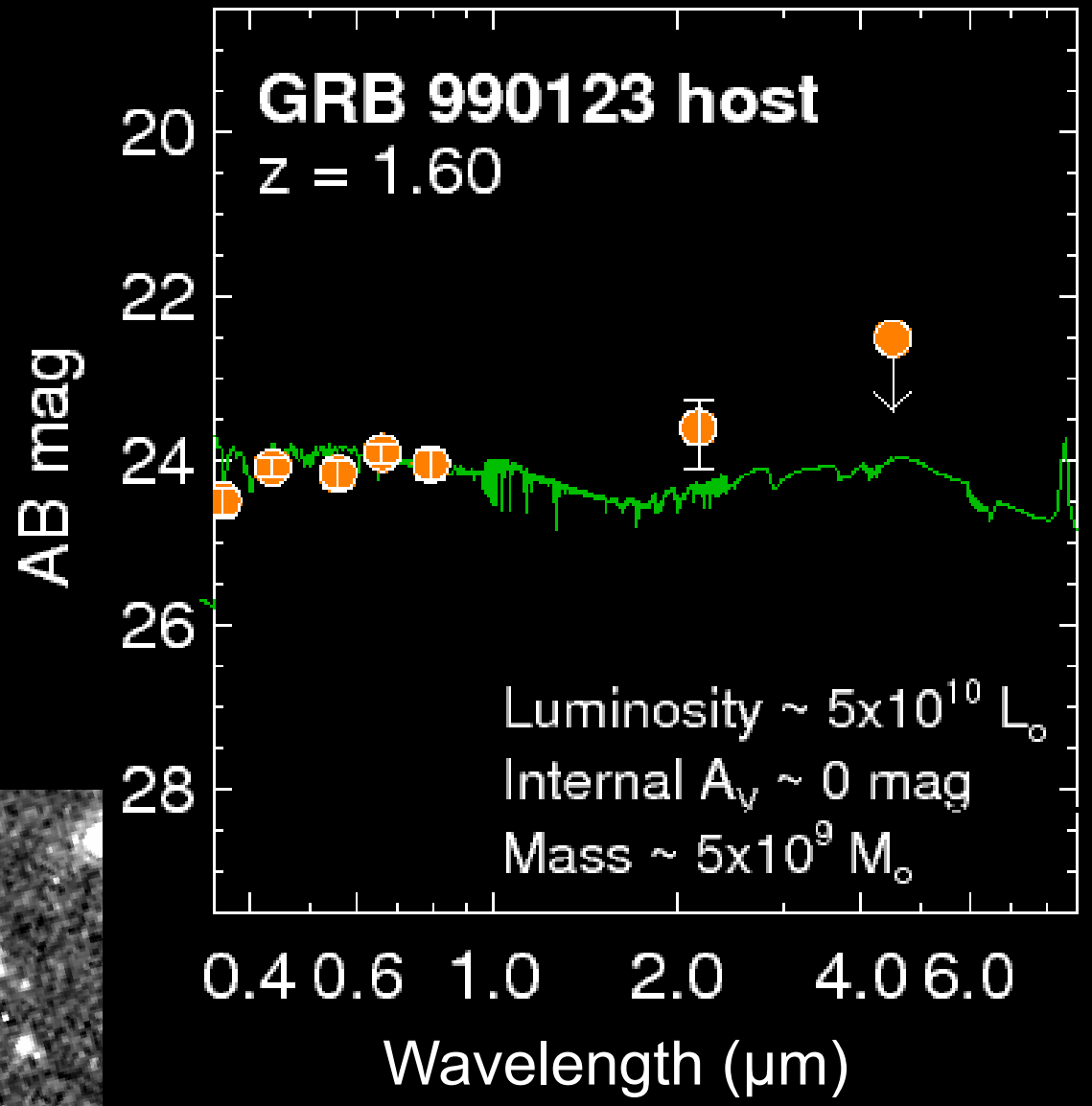


Fruchter et al. 2003

Host of GRB 990123
at **z = 1.60:**

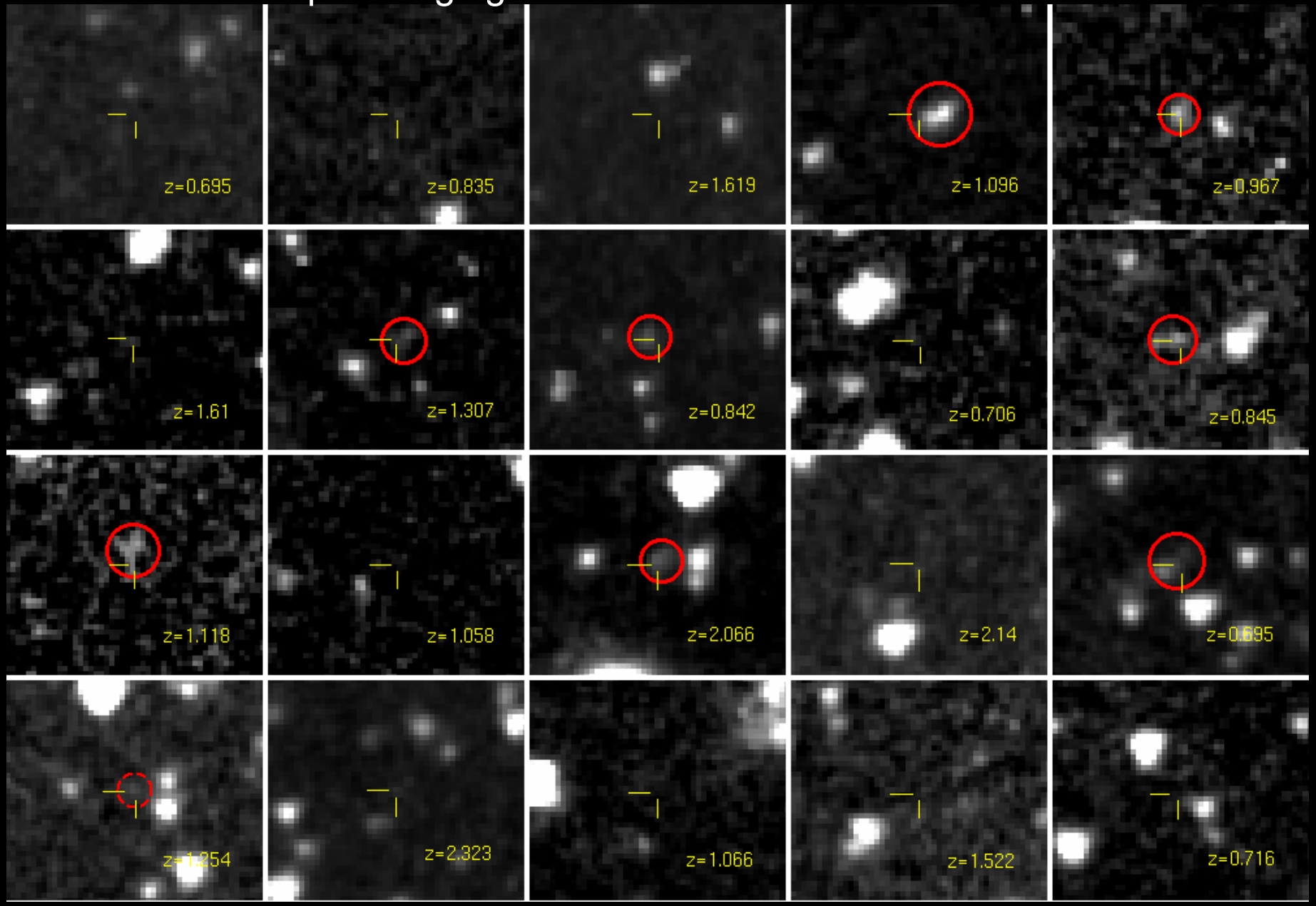
No detection at 2.2 μm, 3.6 μm, 5.8 μm...



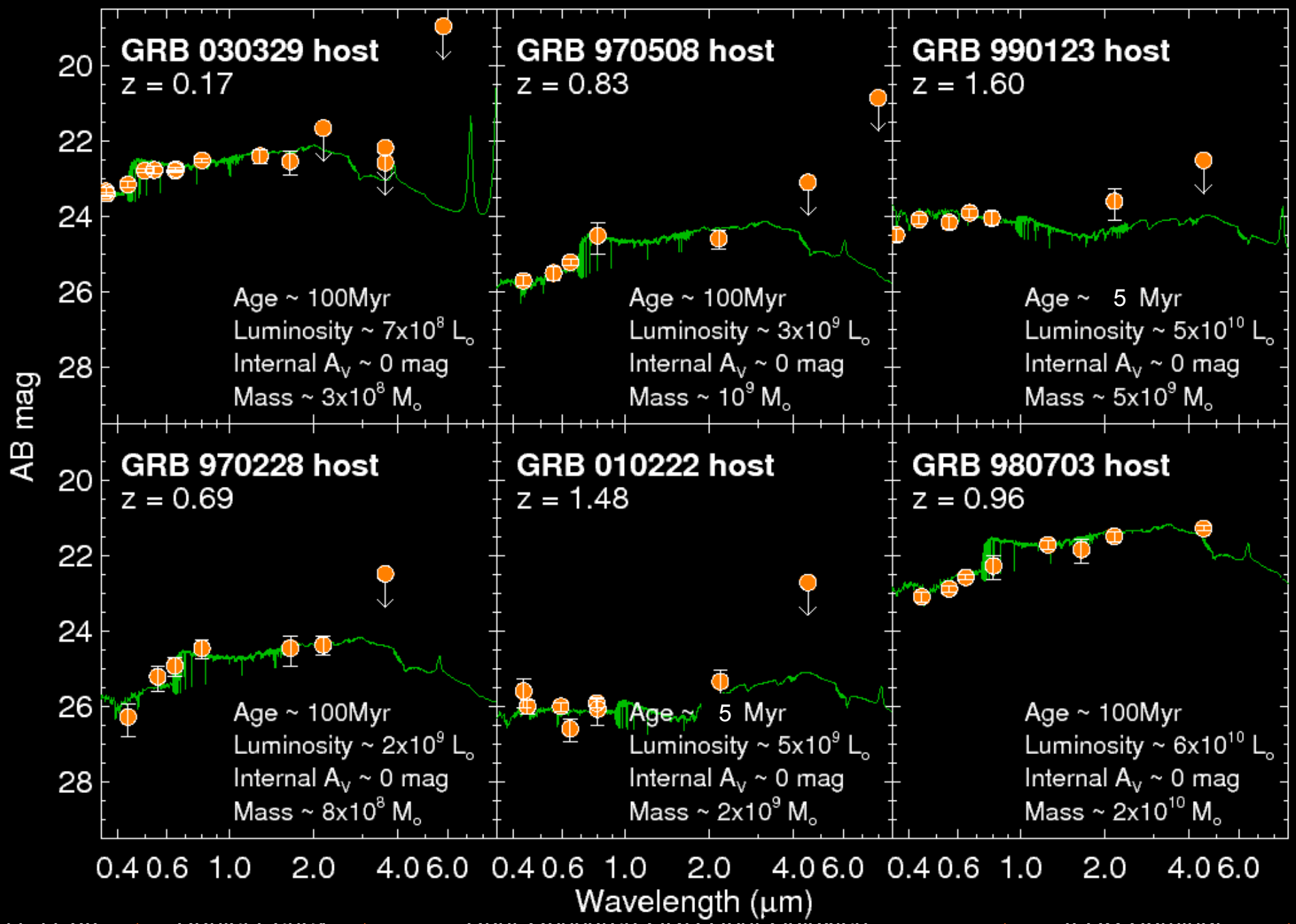


SED Differences

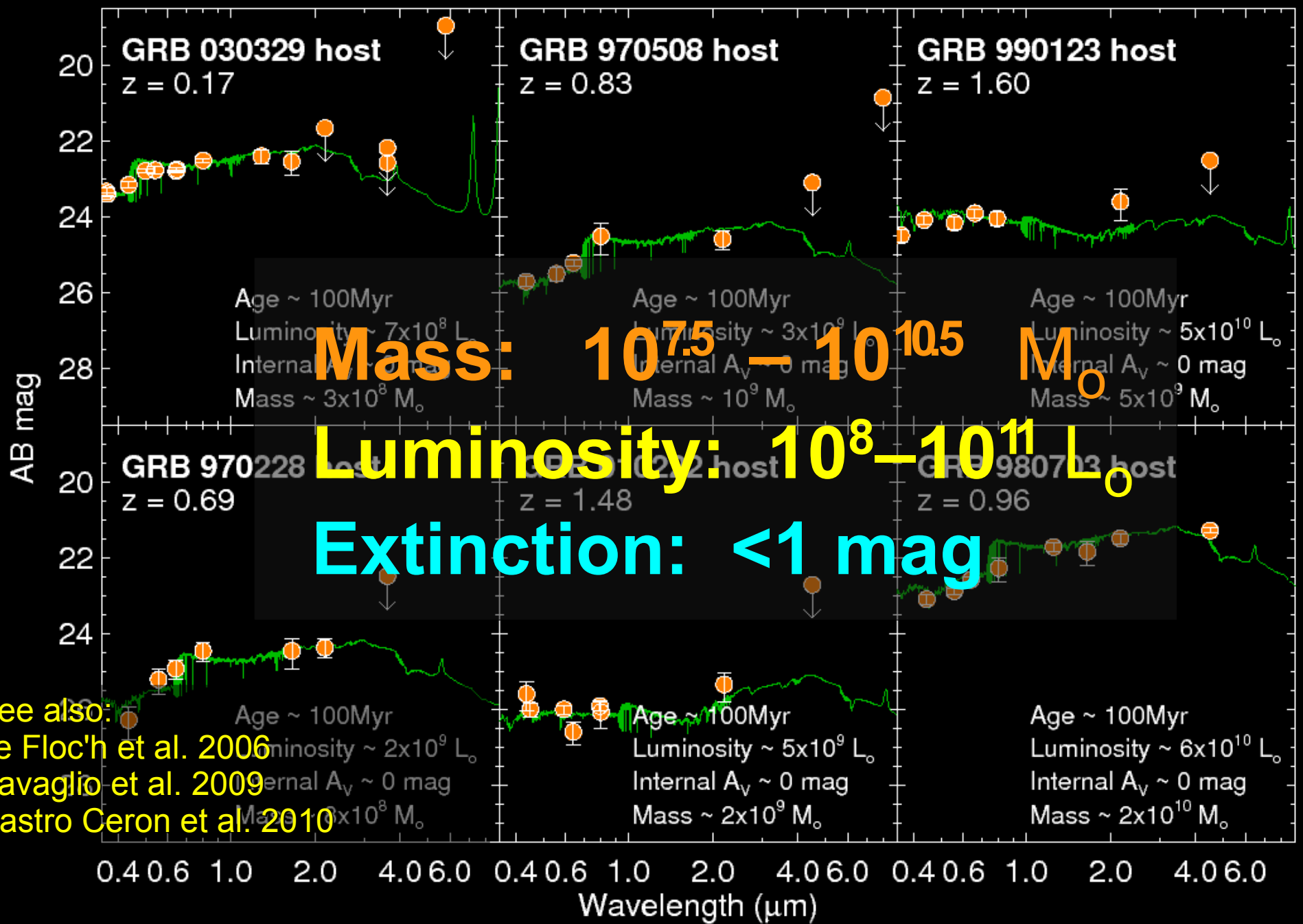
Pre-Swift IRAC 3.6/4.5 μm Imaging



SED Differences



Mass/Luminosity Differences



Mass: $10^{7.5}$ – $10^{10.5}$ M_o

Luminosity: 10^{8}–10^{11} L_o

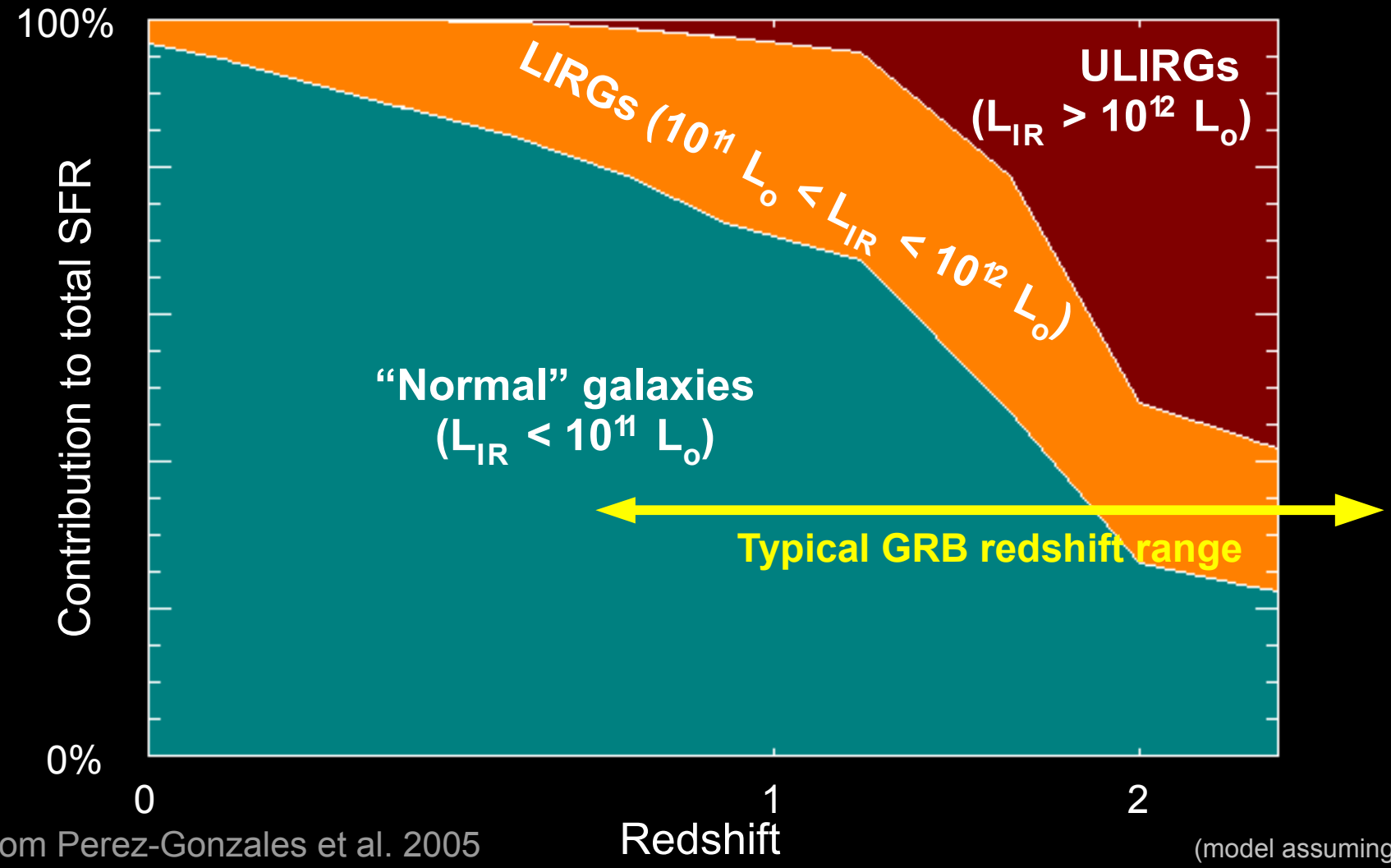
Extinction: <1 mag

See also:
Le Floc'h et al. 2006
Savaglio et al. 2009
Castro Ceron et al. 2010

Pre-Swift SED data points from grbhosts.org

Mass/Luminosity Differences

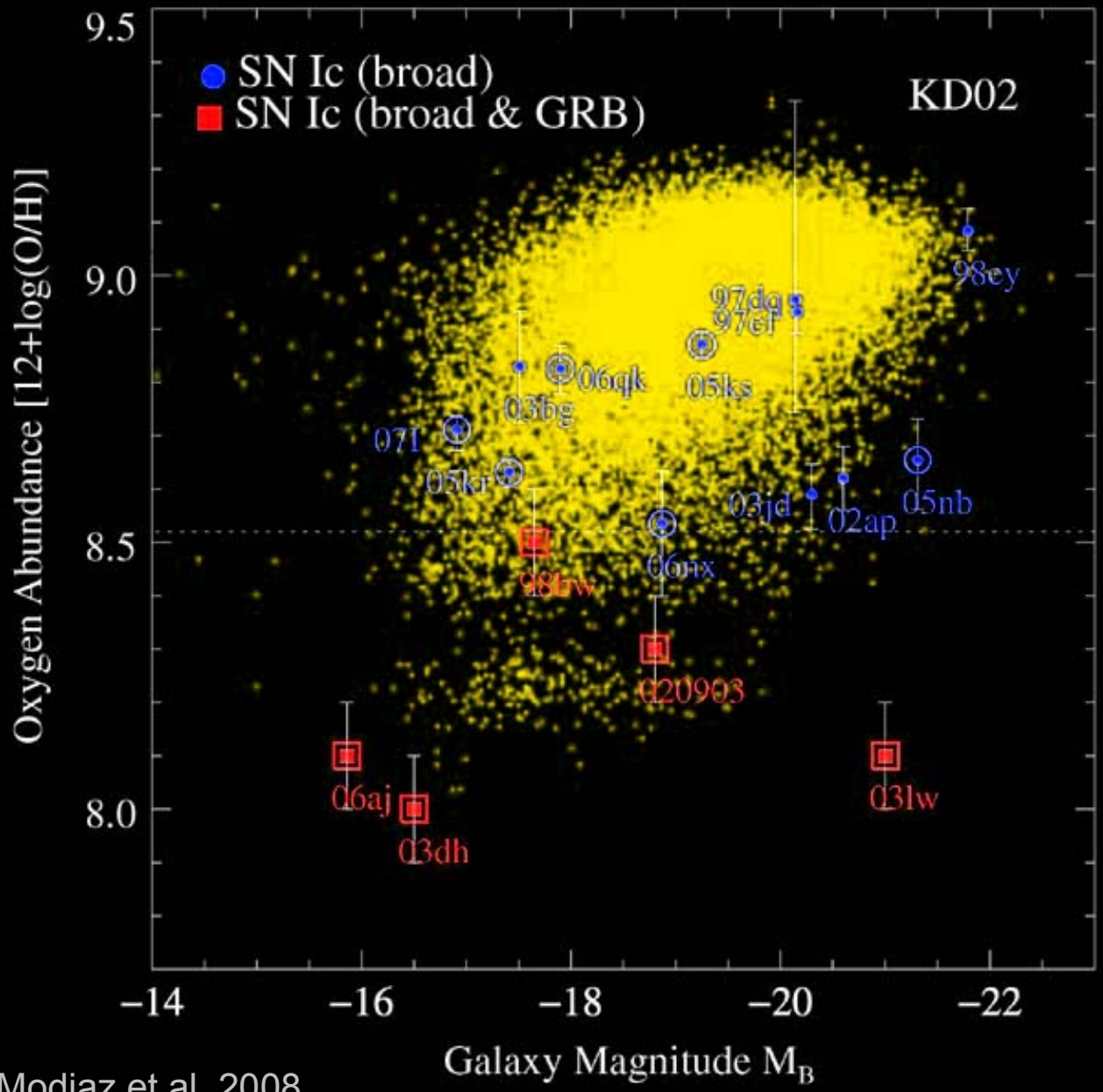
Luminous, obscured galaxies dominate at z>1.5



Modified from Perez-Gonzales et al. 2005

(model assuming α=-1.7)

Metallicity Differences



Modjaz et al. 2008

GRBs: a "Biased" Tracer?

Metallicity cut-off —

$$Z_{GRB} \lesssim 0.4\text{-}0.9\ Z_{Solar}$$

Stanek et al. 2006,
Wolf & Podsiadlowski et al. 2007,
Modjaz et al. 2008

But, c.f. Savaglio et al. 2008, Chen et al. 2009, Kocevski et al. 2010, etc.

GRBs: a "Biased" Tracer?

Metallicity cut-off —

$$Z_{GRB} \lesssim 0.4\text{-}0.9\ Z_{Solar}$$

Stanek et al. 2006,
Wolf & Podsiadlowski et al. 2007,
Modjaz et al. 2008

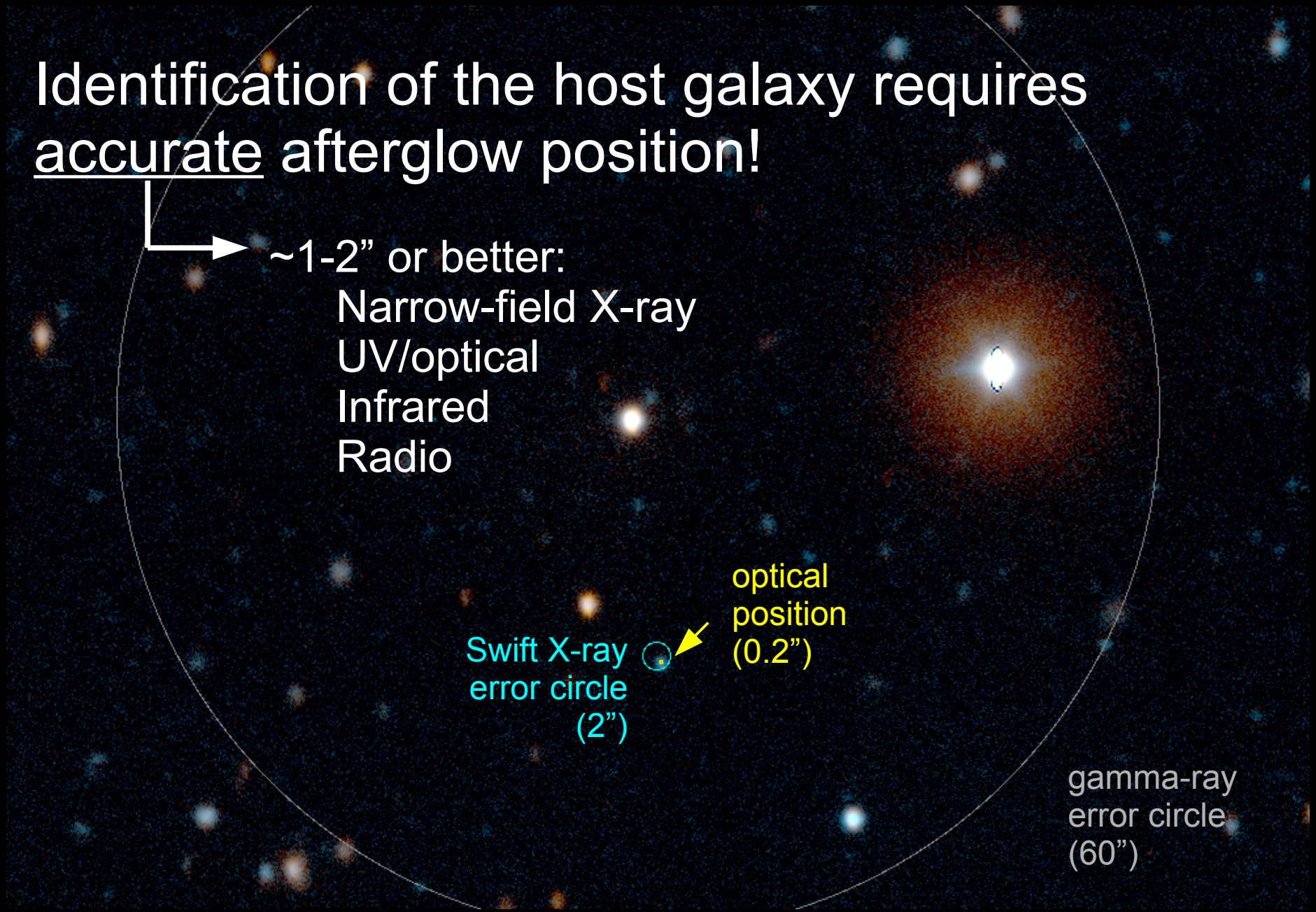
Real? Or selection effect?

But, c.f. Savaglio et al. 2008, Chen et al. 2009, Kocevski et al. 2010, etc.

Host Selection Biases

Identification of the host galaxy requires accurate afterglow position!

→ ~1-2” or better:
- Narrow-field X-ray
- UV/optical
- Infrared
- Radio



Host Selection Biases

Identification of the host galaxy requires accurate afterglow position!

~1-2” or better:

- Narrow-field X-ray
- **UV/optical**
- Infrared
- Radio

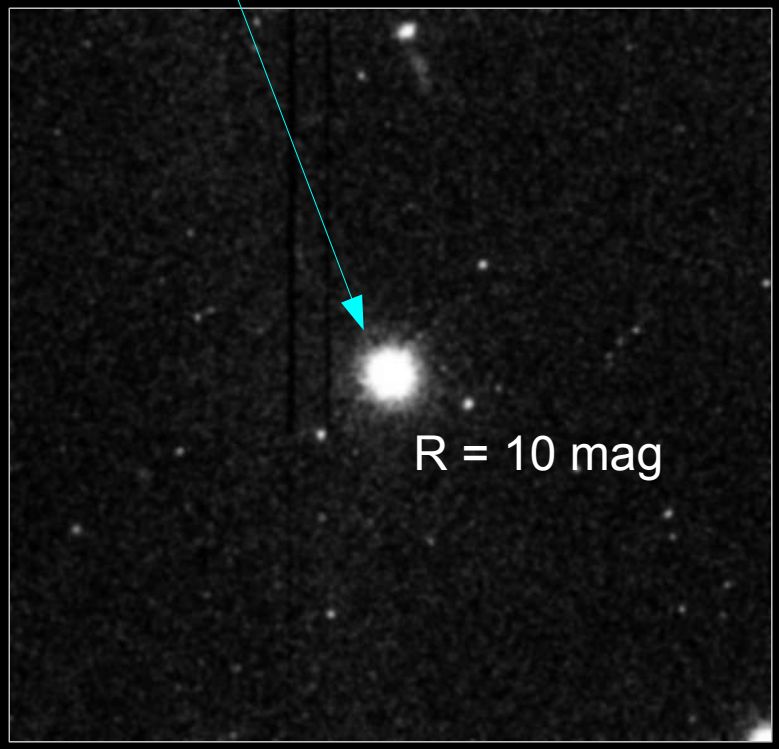
Not commonly available pre-Swift (before 2005)

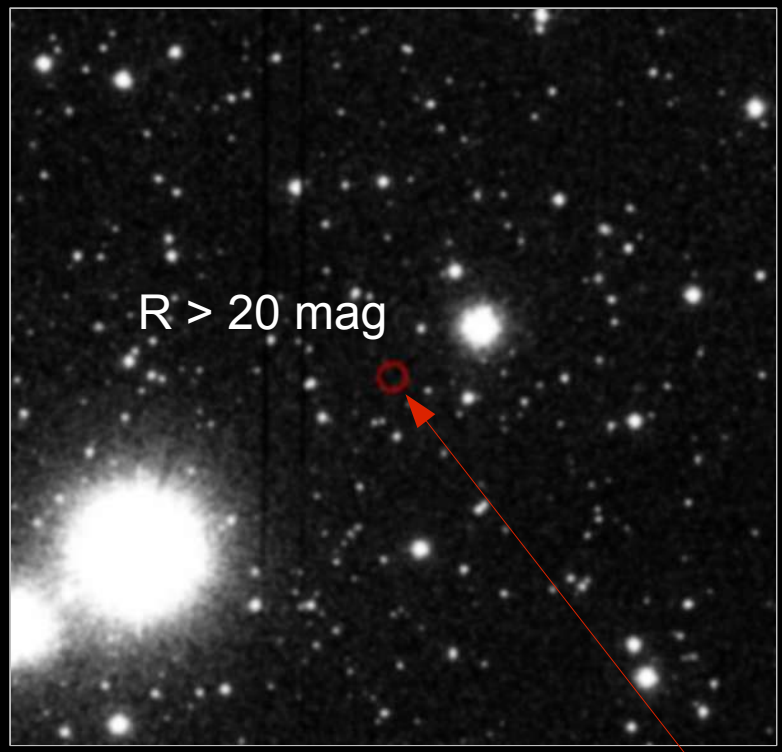
Not commonly available pre- or post-Swift (<20% of GRBs)

Dark Bursts

Some GRBs have exceedingly faint optical afterglows.

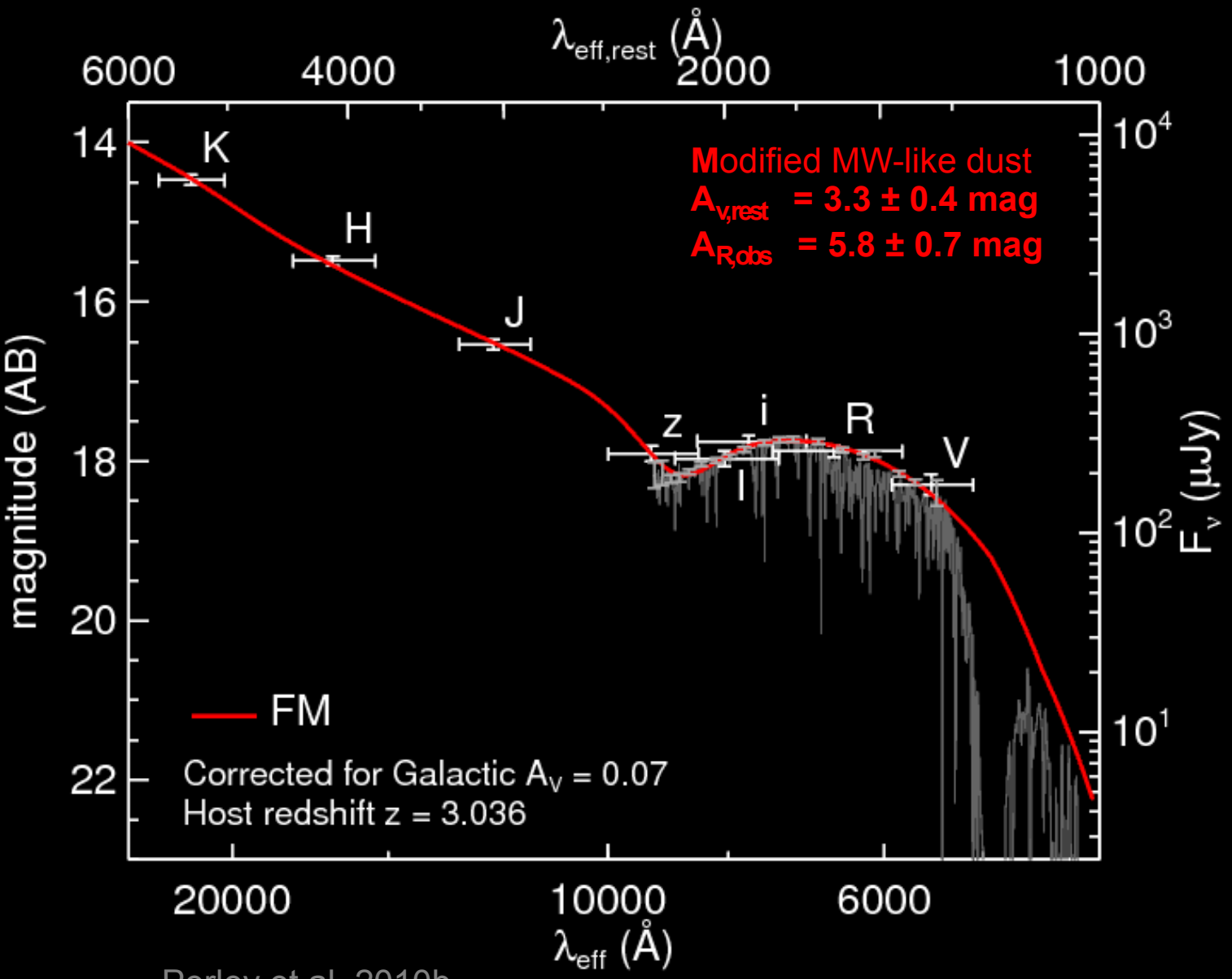
GRB 080319B
at ~200 sec





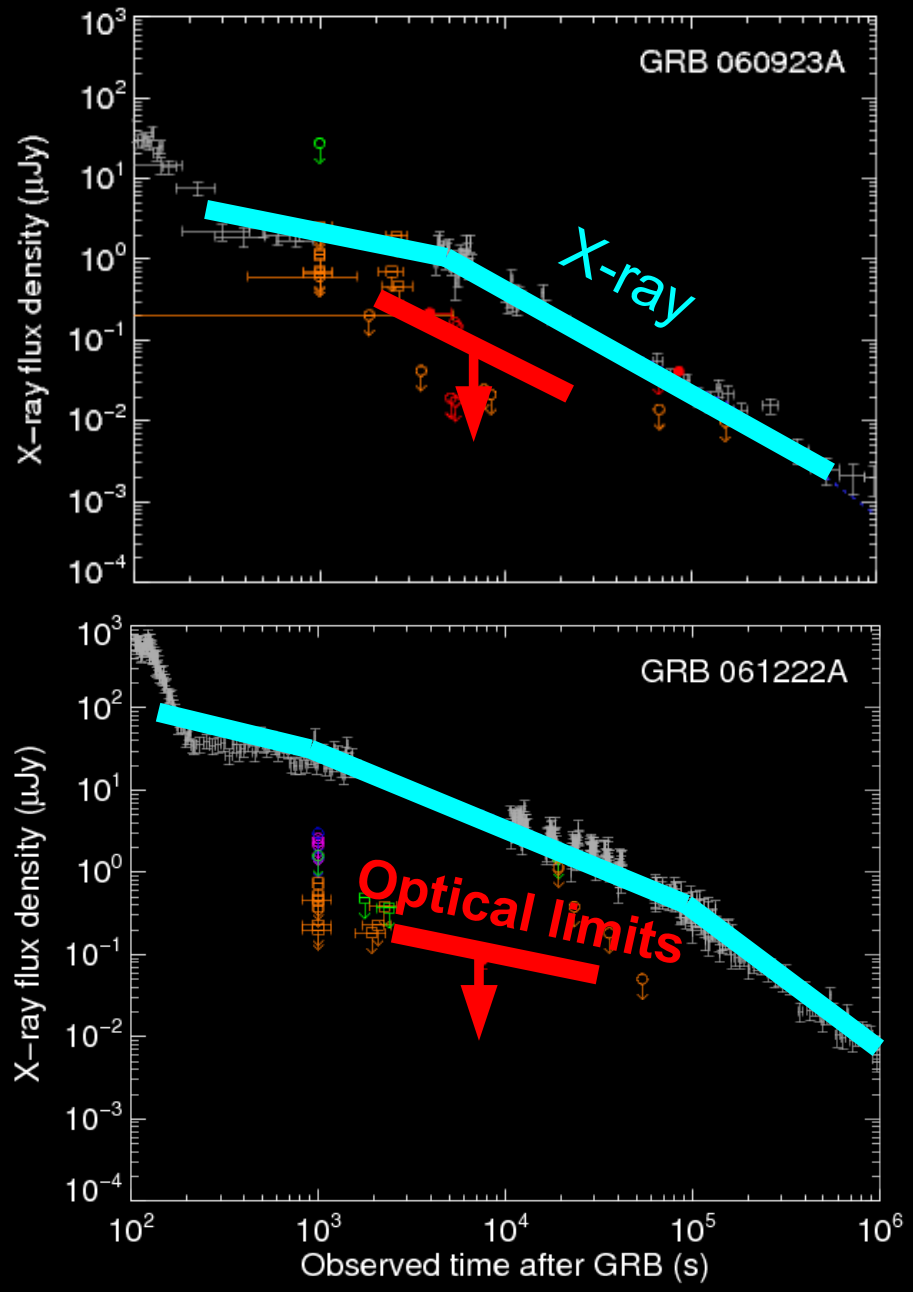
X-ray position of
GRB 061222A
at ~200 sec

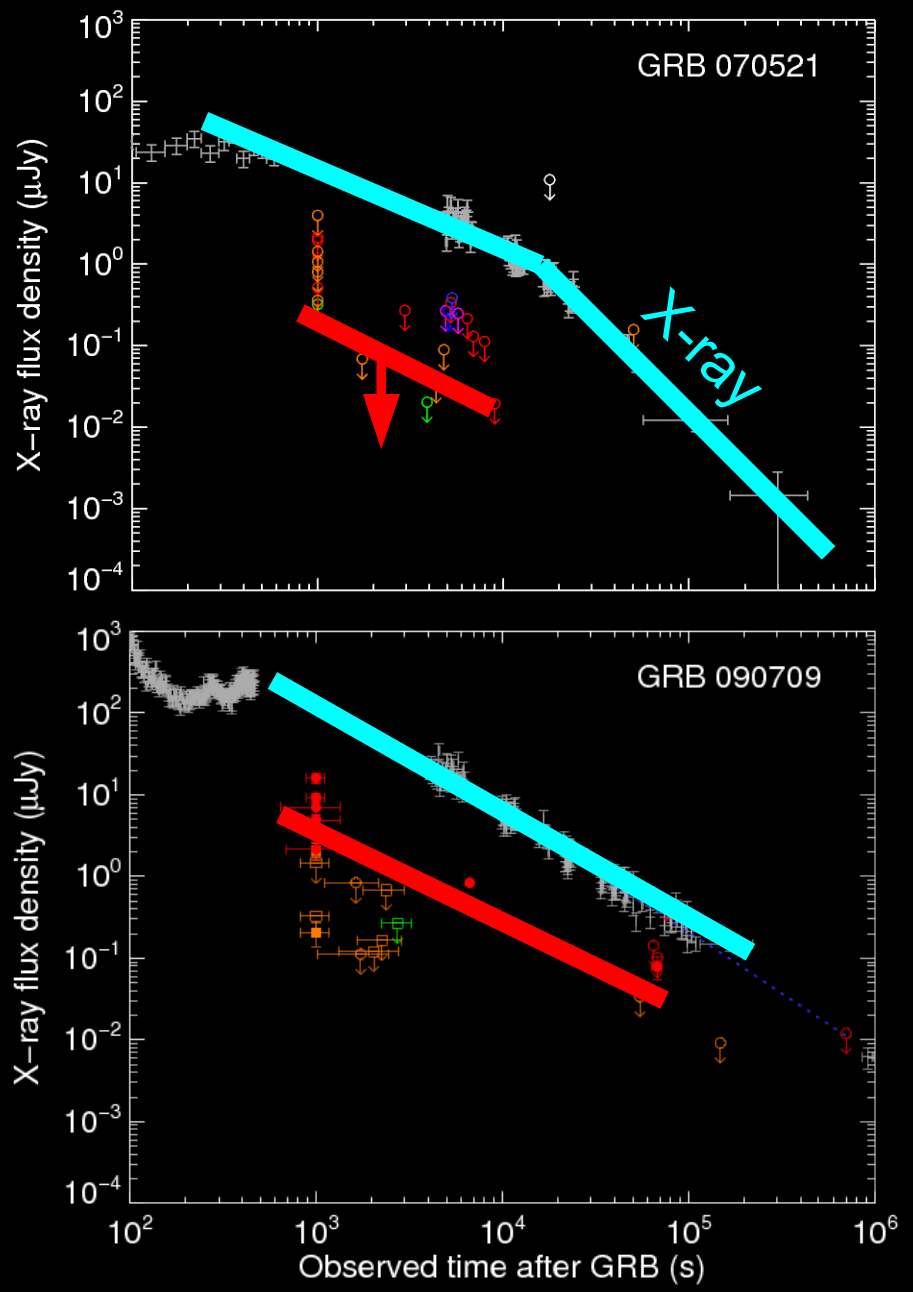
Direct Evidence for Extinction



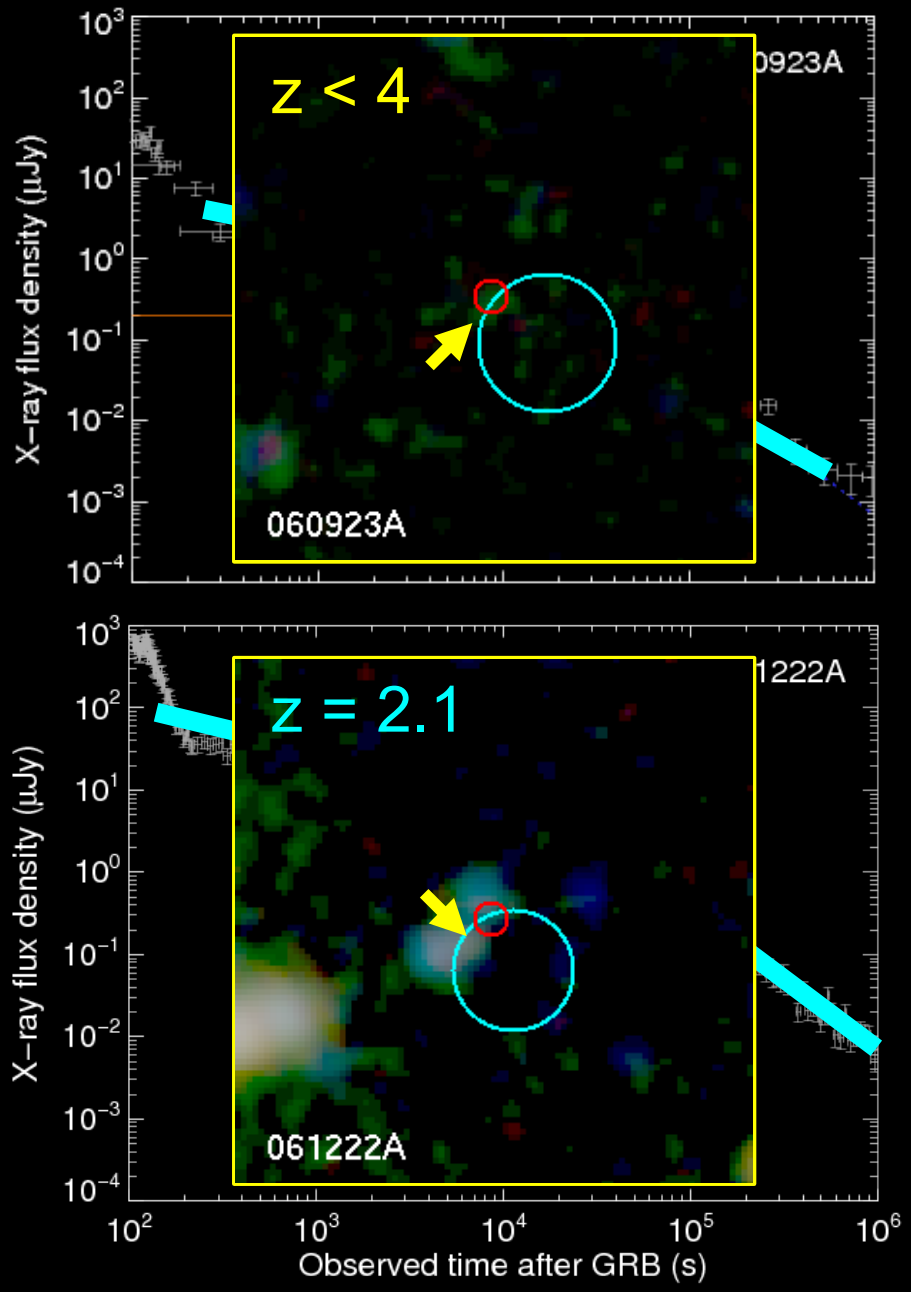
Perley et al. 2010b

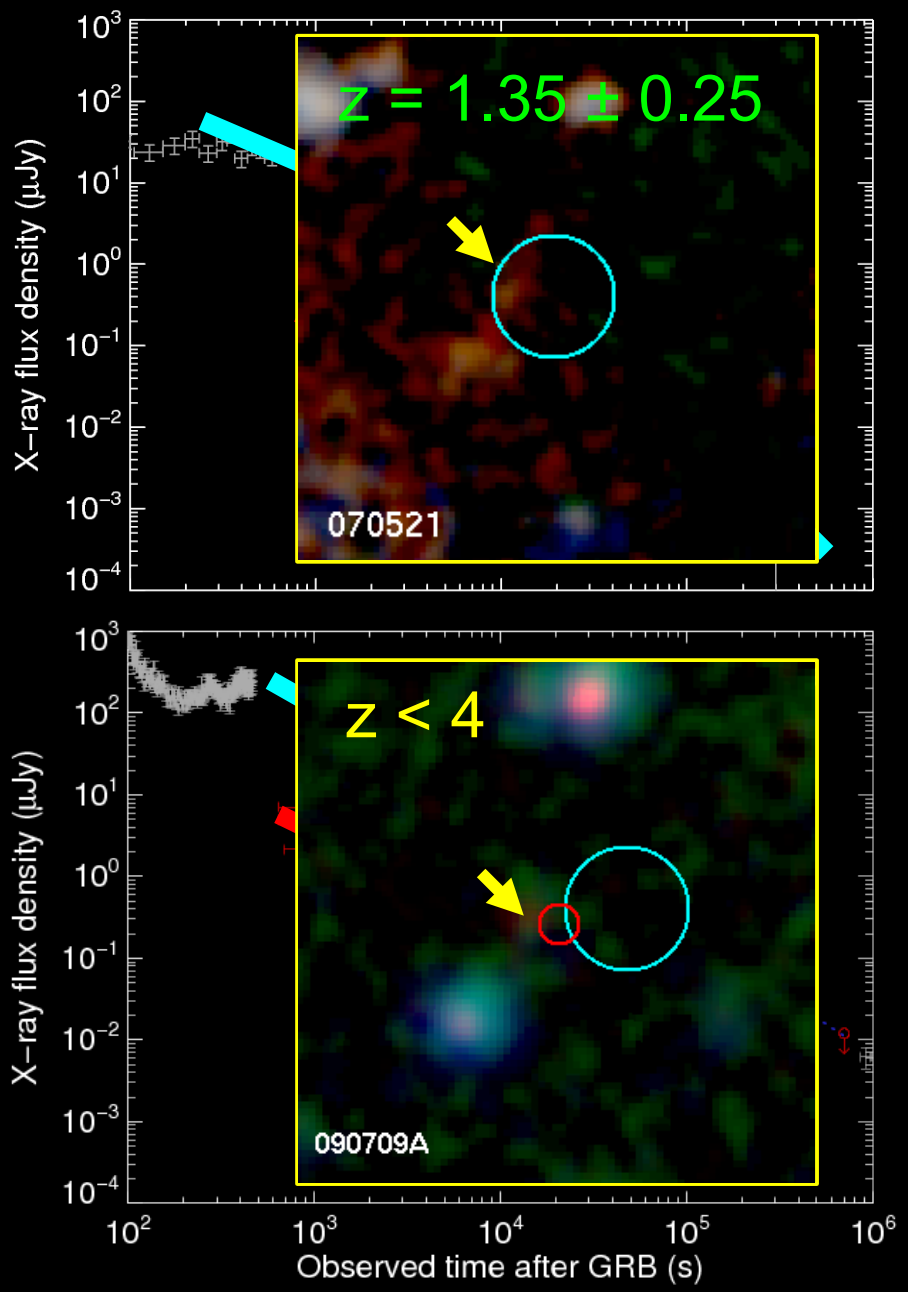
Indirect Evidence for Extinction





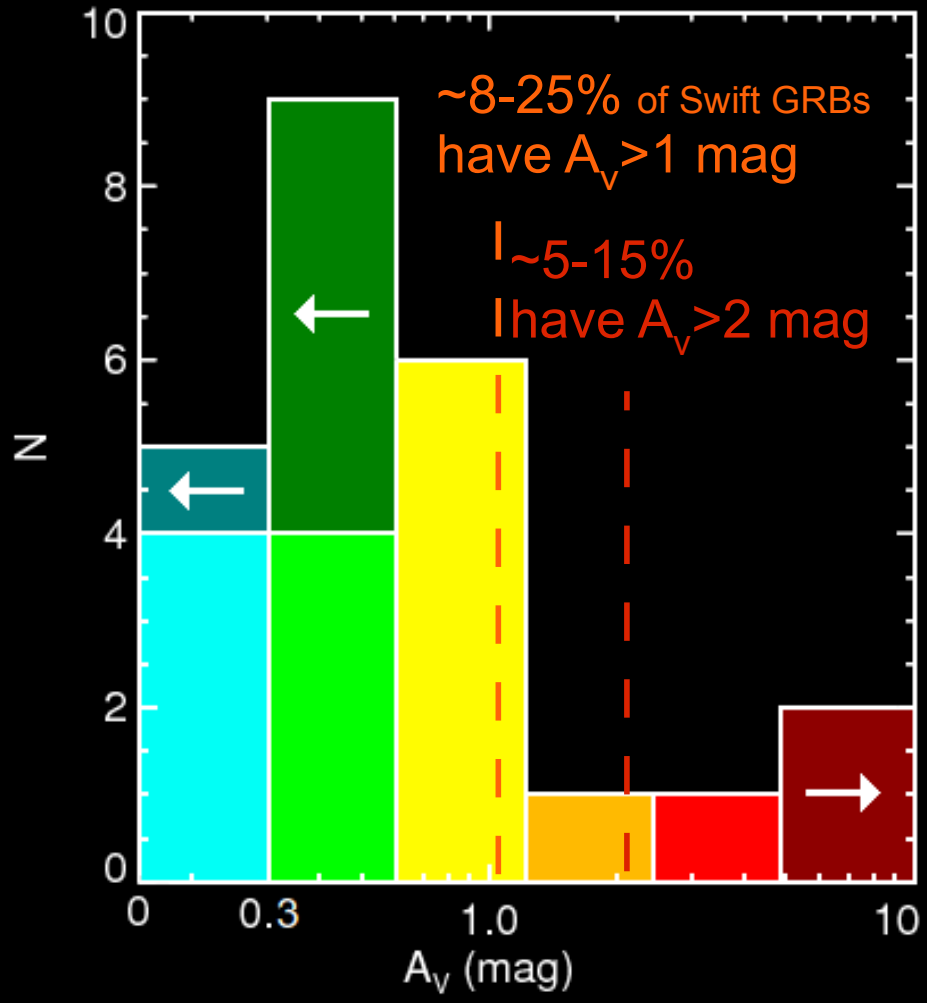
Indirect Evidence for Extinction





Extinction Distribution

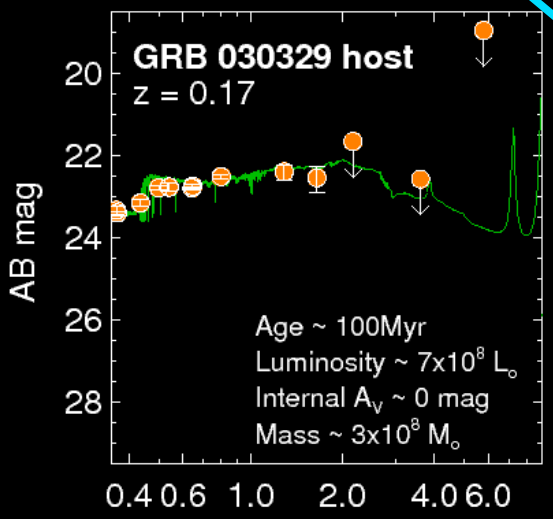
Many (but not most: ~20%) GRBs are highly extinguished.



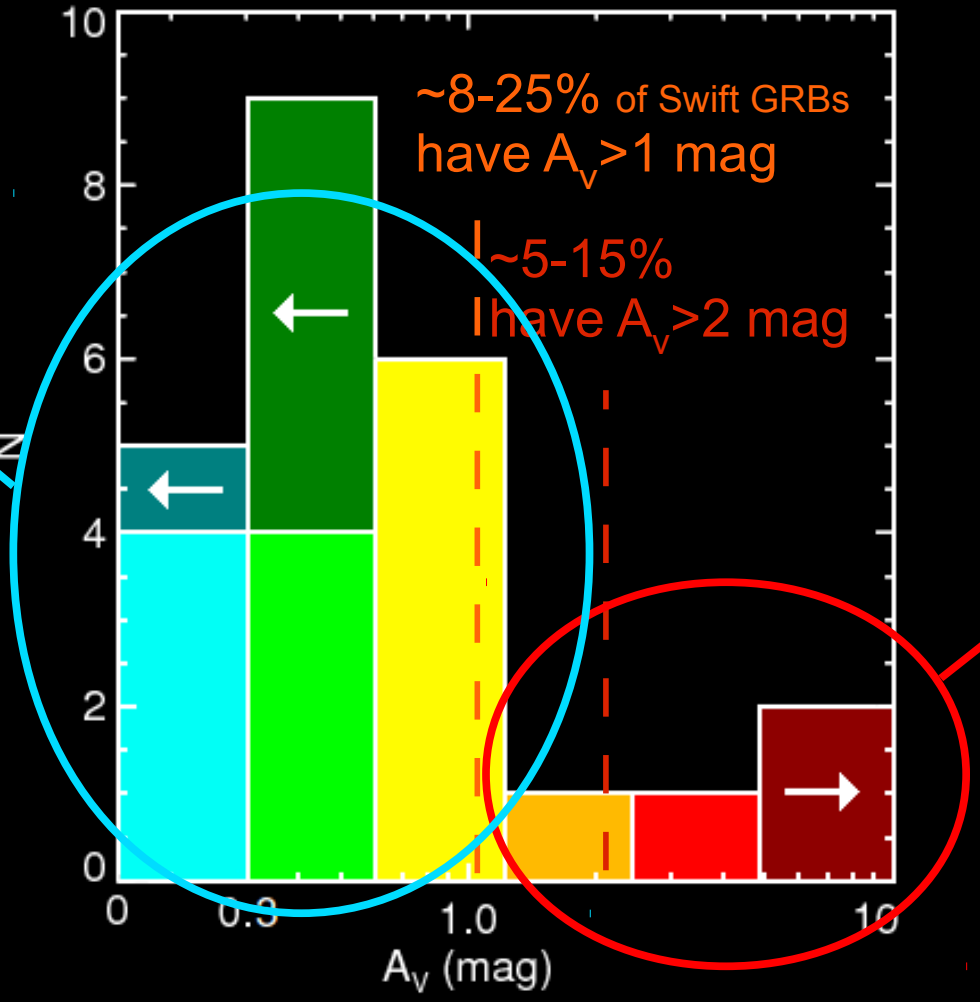
Perley et al. 2009
+ Kruehler et al. 2011

Extinction Distribution

The 80 percent



The 20 percent



?

Optical Extinction Bias?

Dusty galaxies should (in general) be:

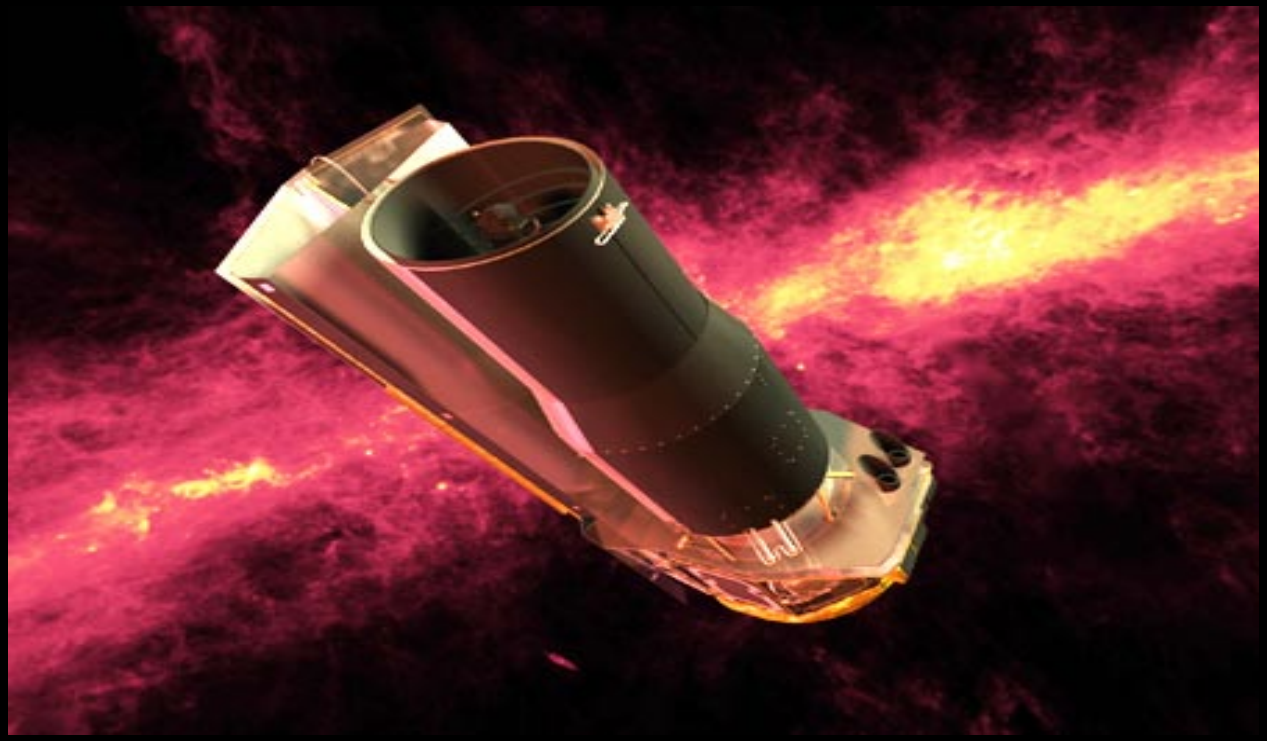
more massive
more metal-rich
more luminous
redder

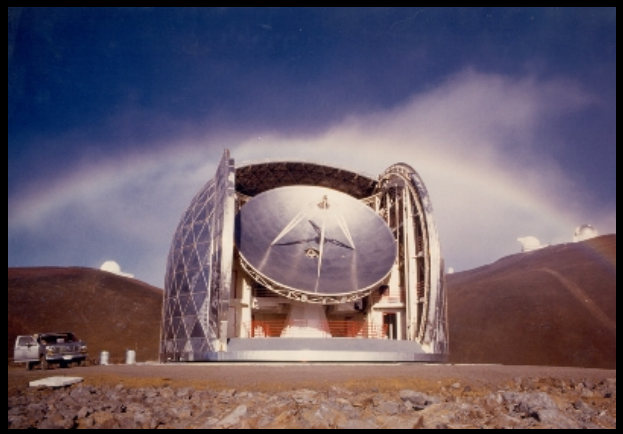
than unobscured galaxies.

Are dark bursts concealing a population of luminous, red, metal-rich galaxies?

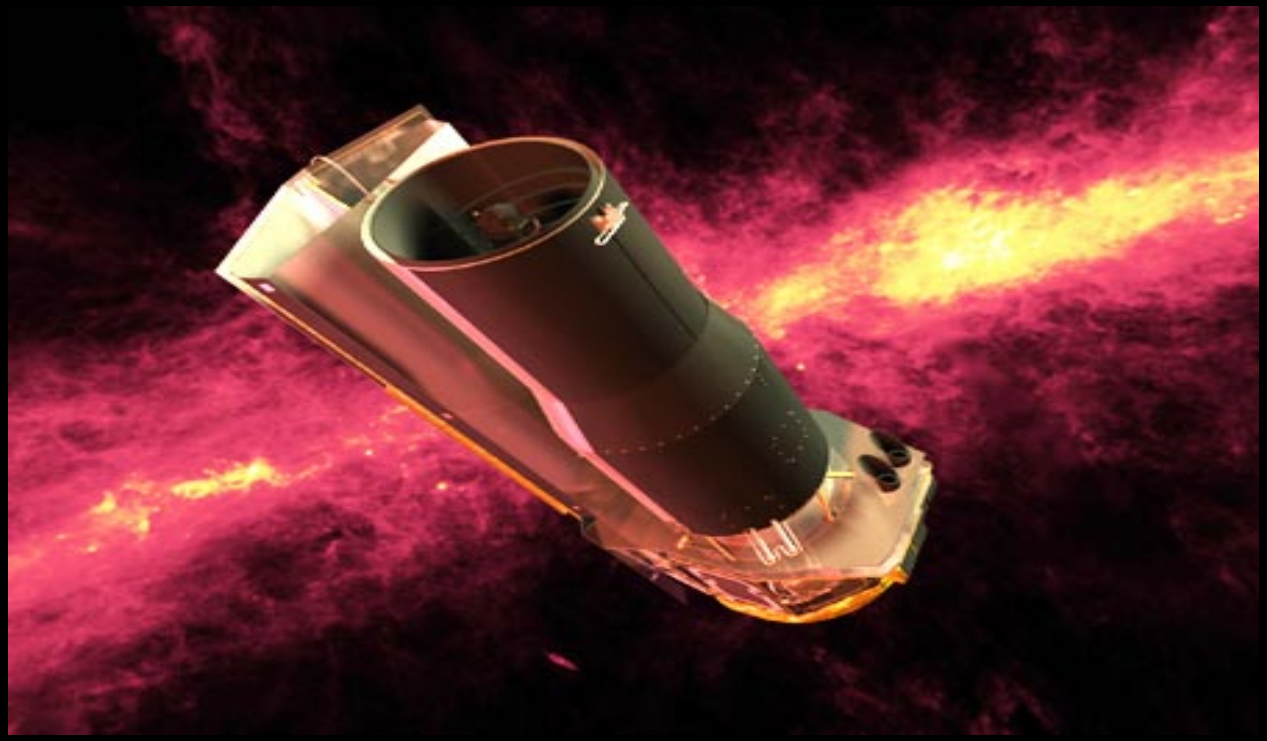
OR, darkness could be entirely geometric
(i.e., does the GRB sightline happen to pierce a molecular cloud or dust lane)

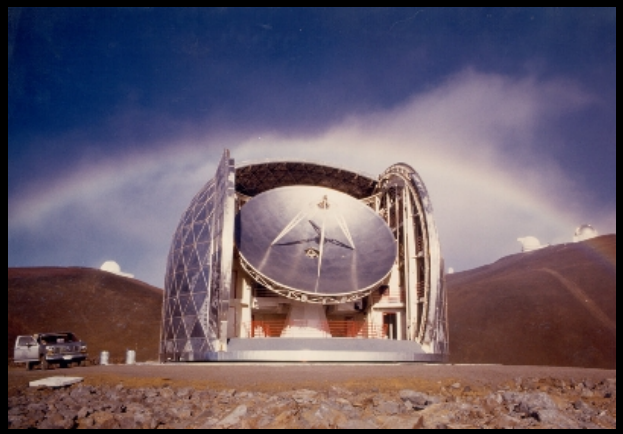
Dark Burst Host Survey



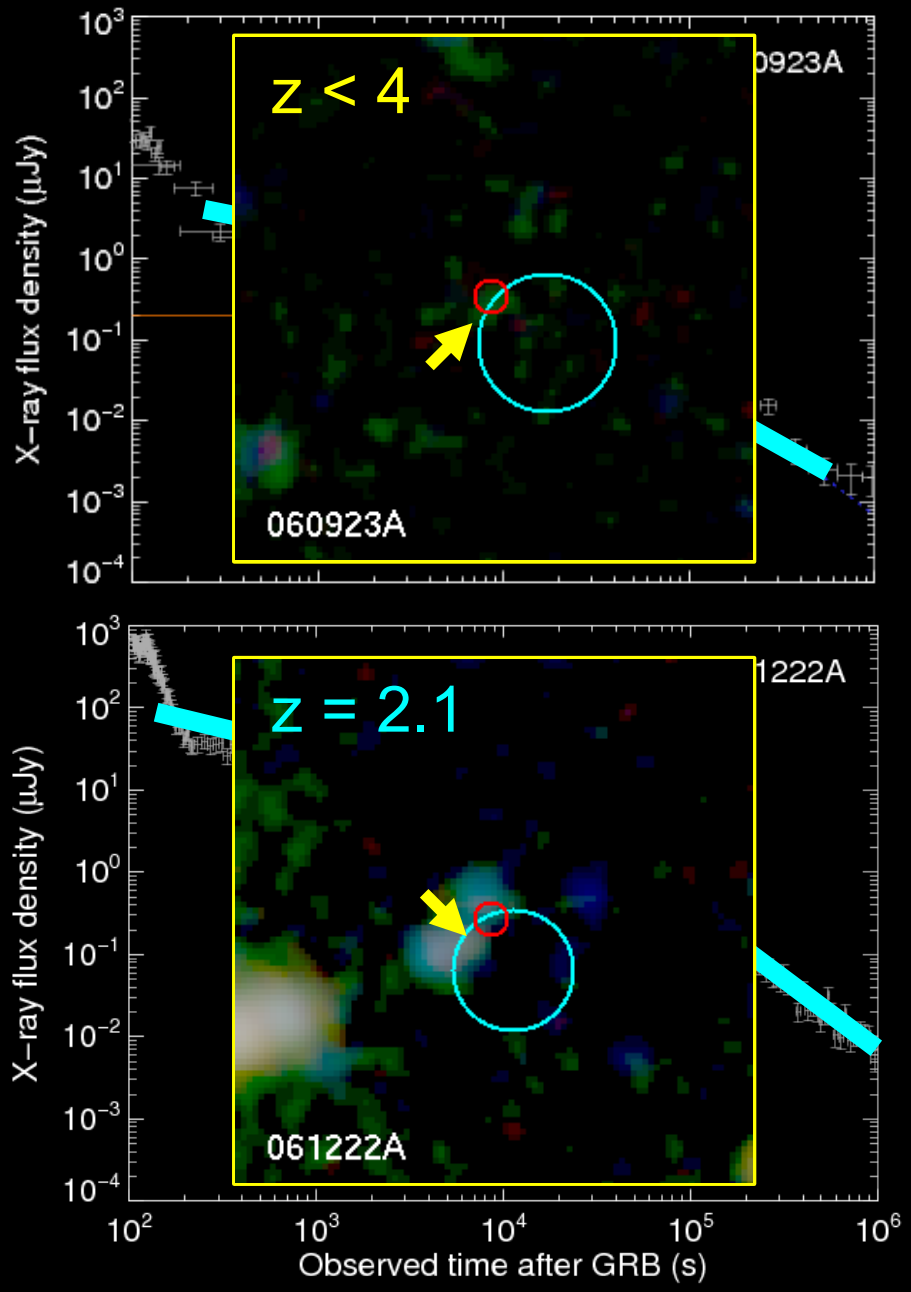


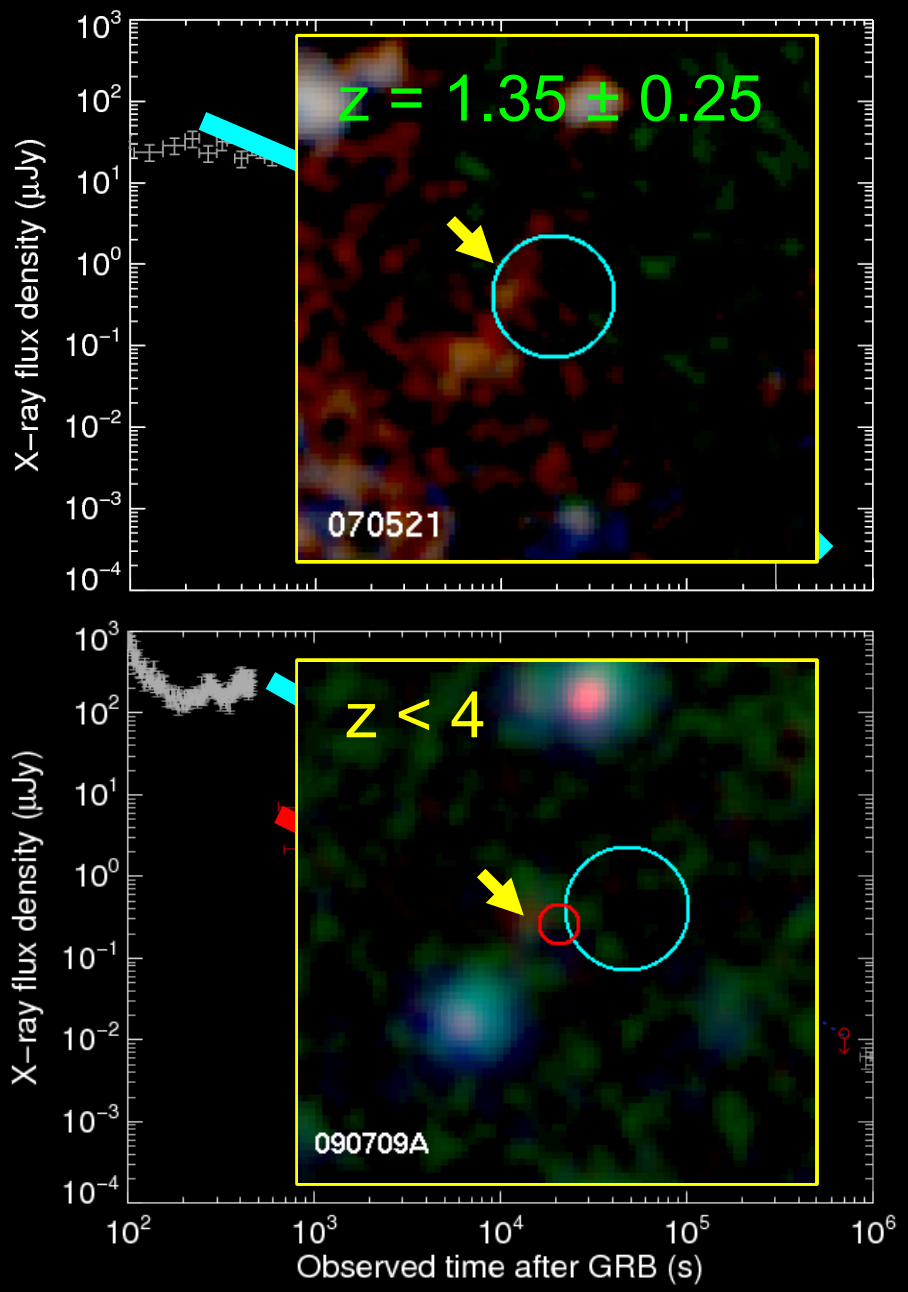
Dark Burst Host Survey



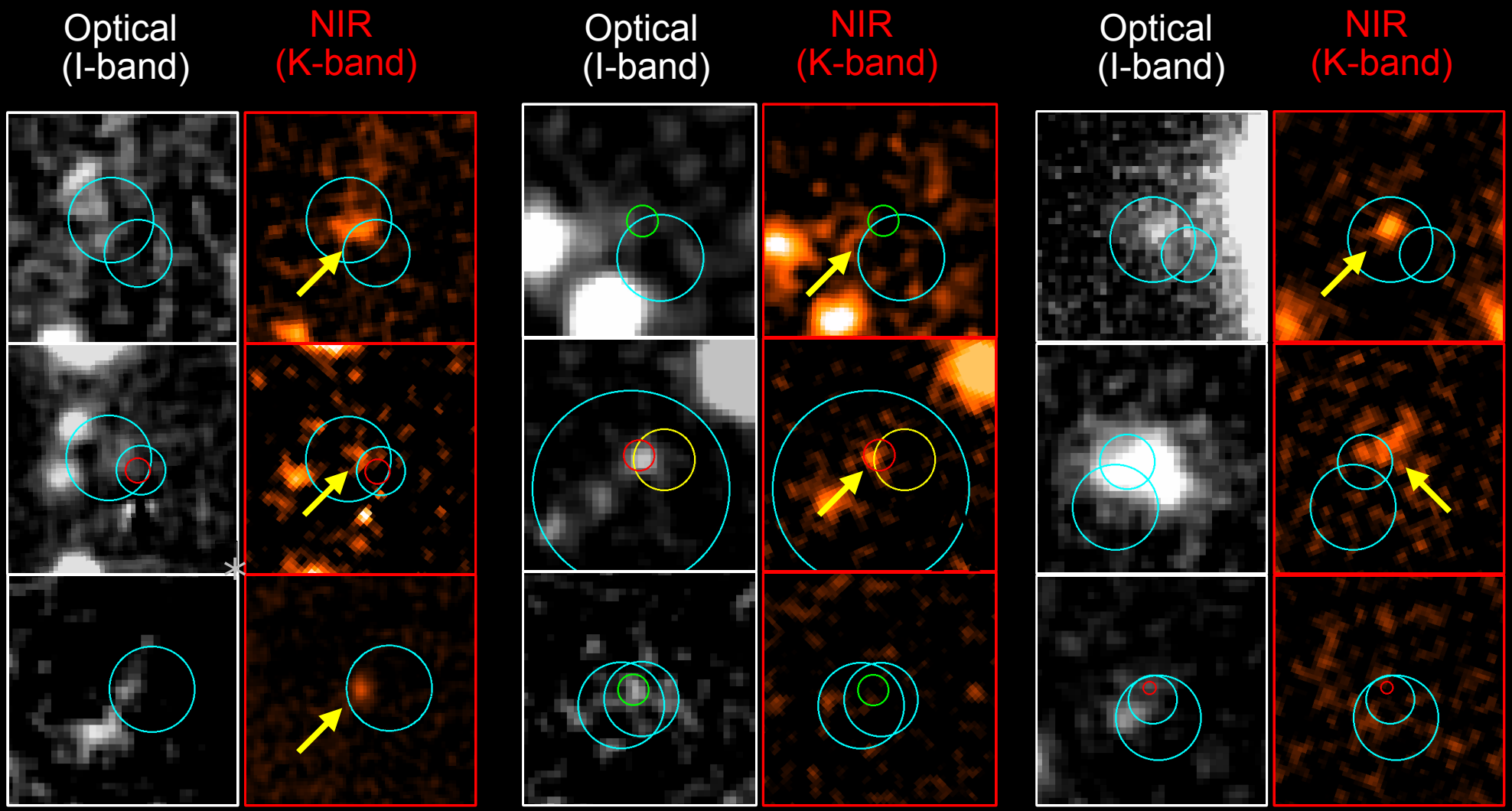


Optically Ordinary-Looking...

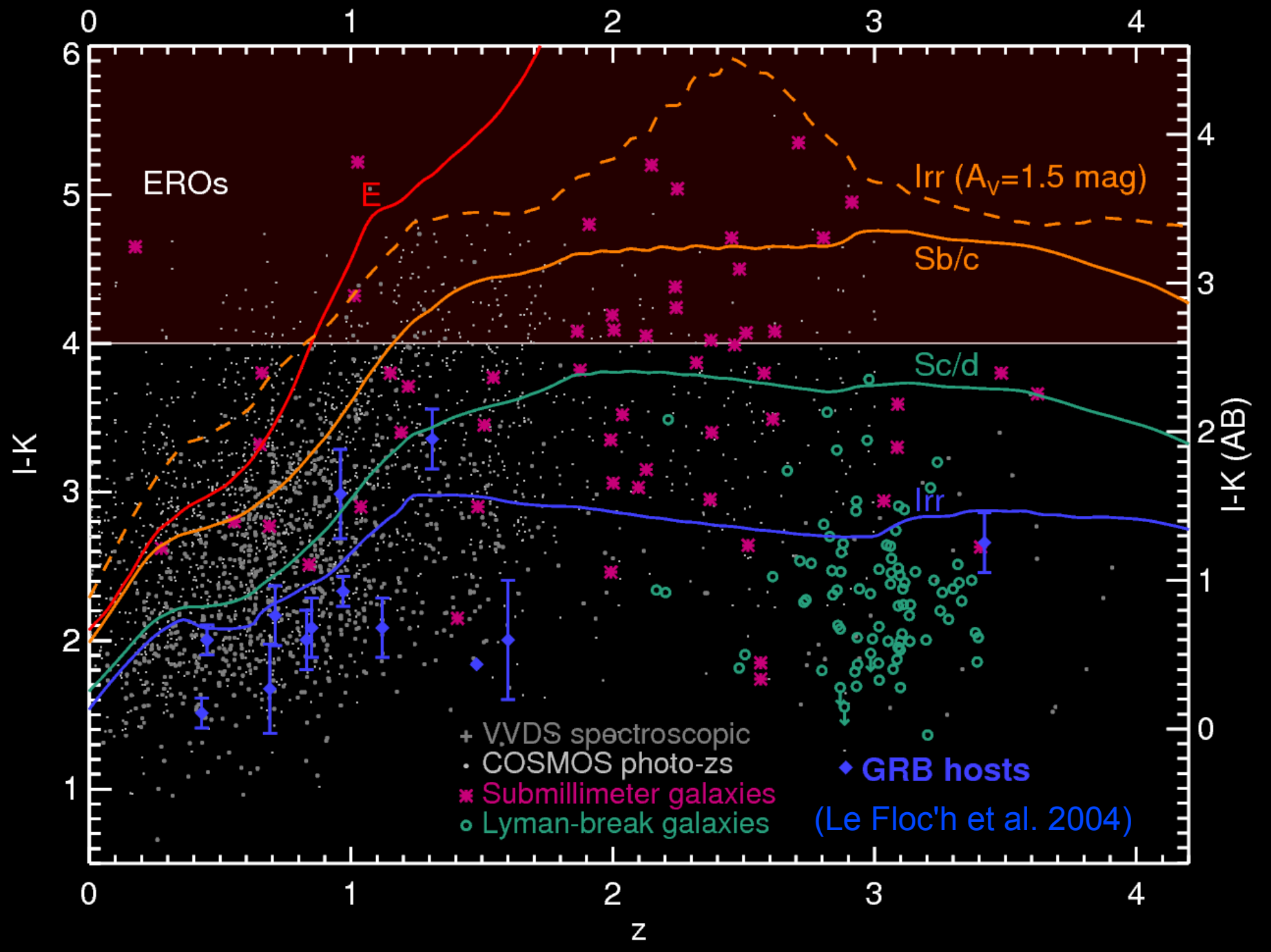




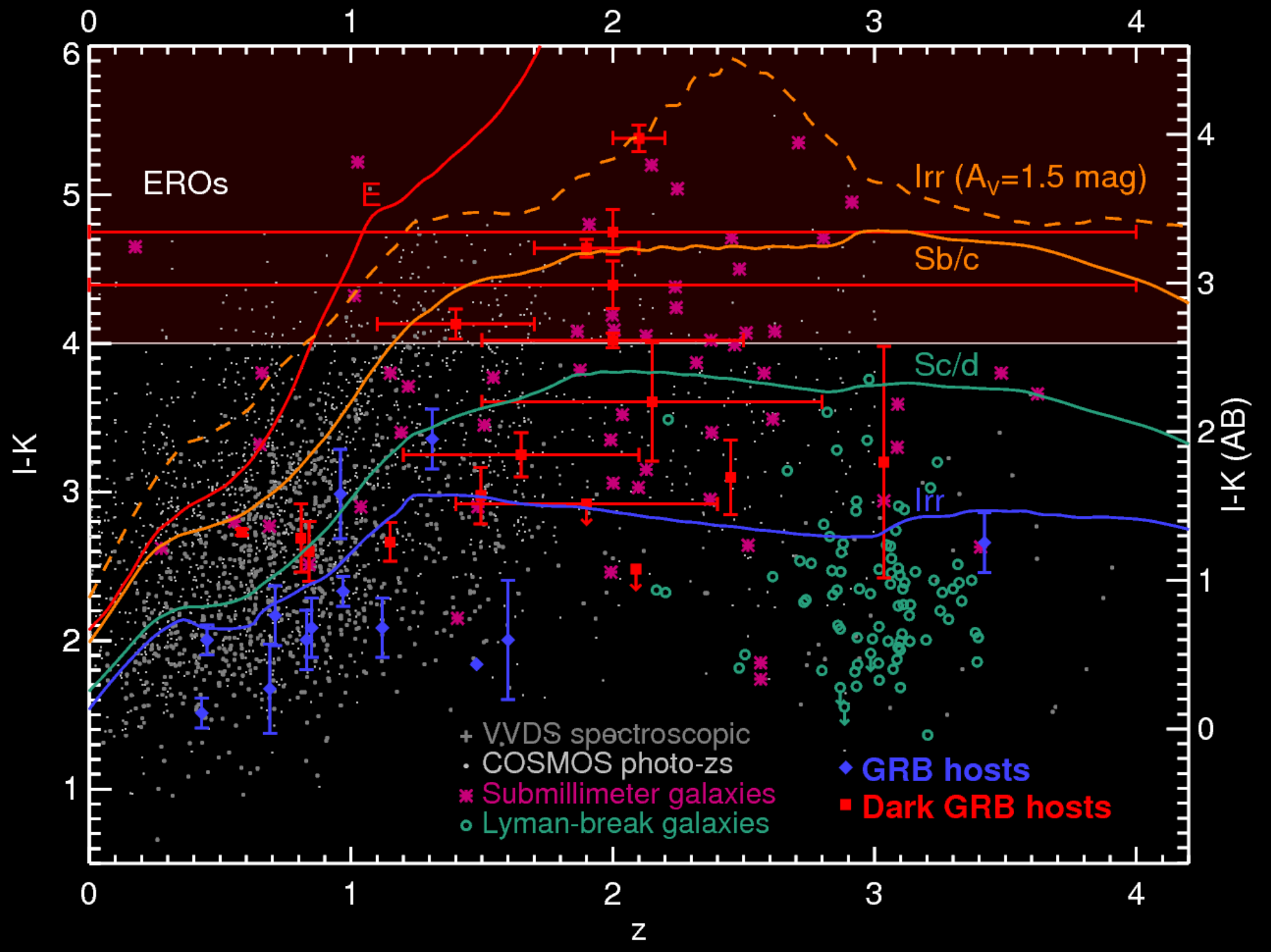
Often Infrared Bright



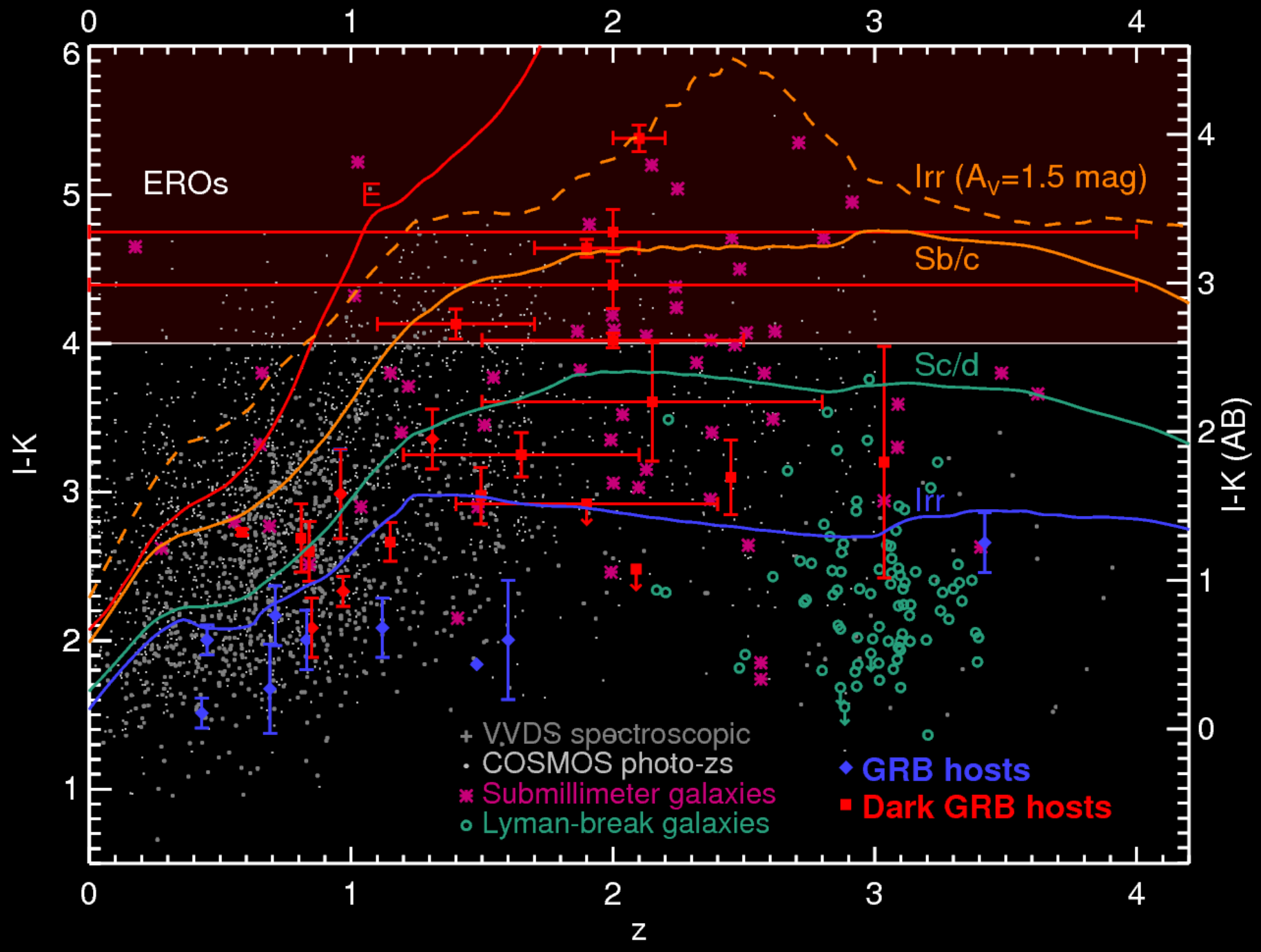
Dark Burst Host Colors



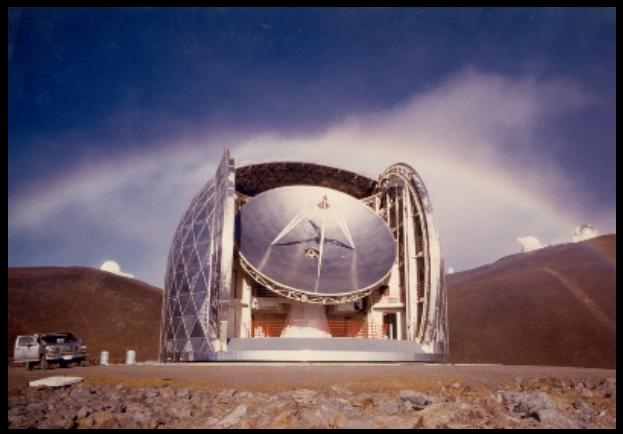
Dark Burst Host Colors



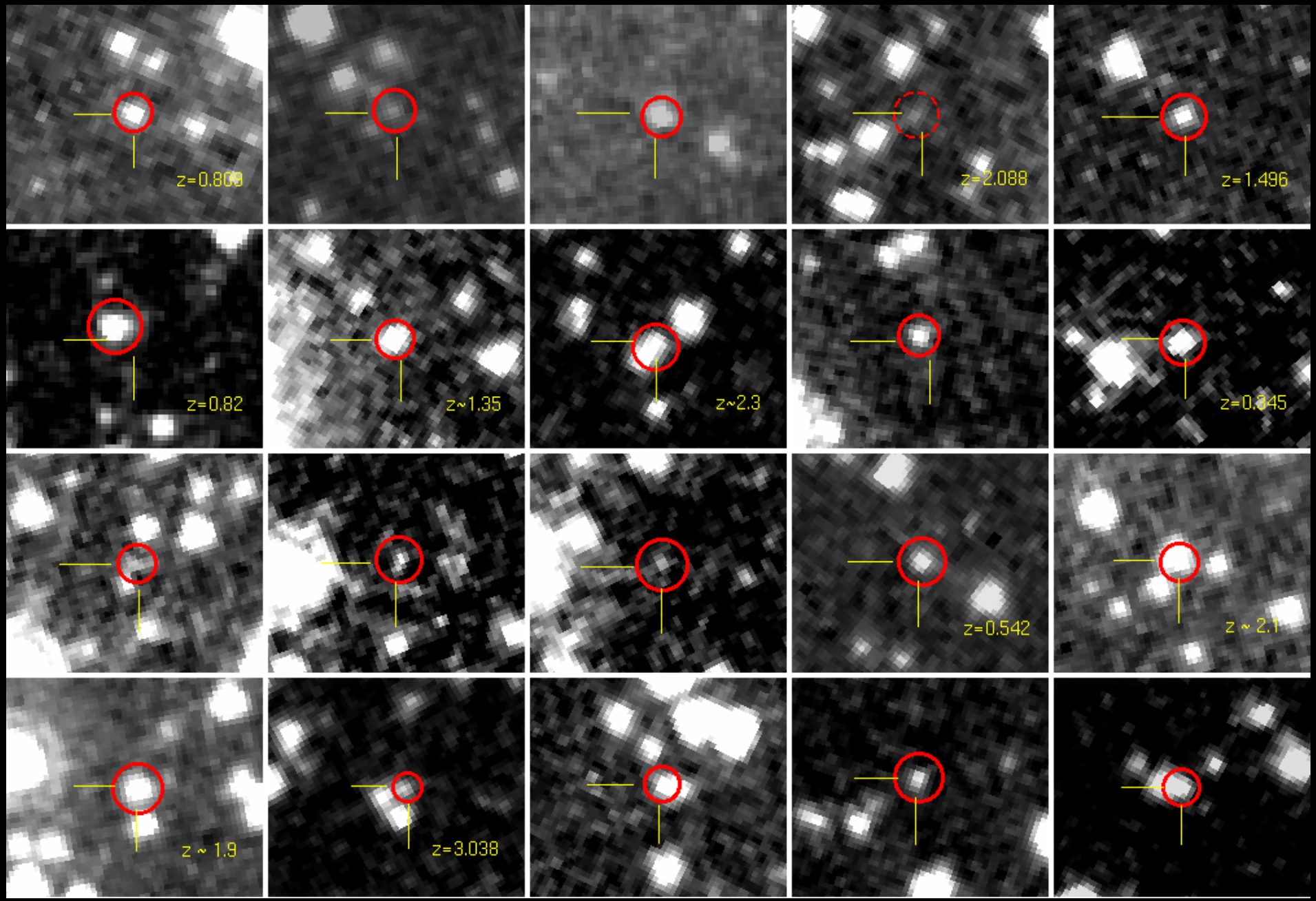
Dark Burst Host Colors



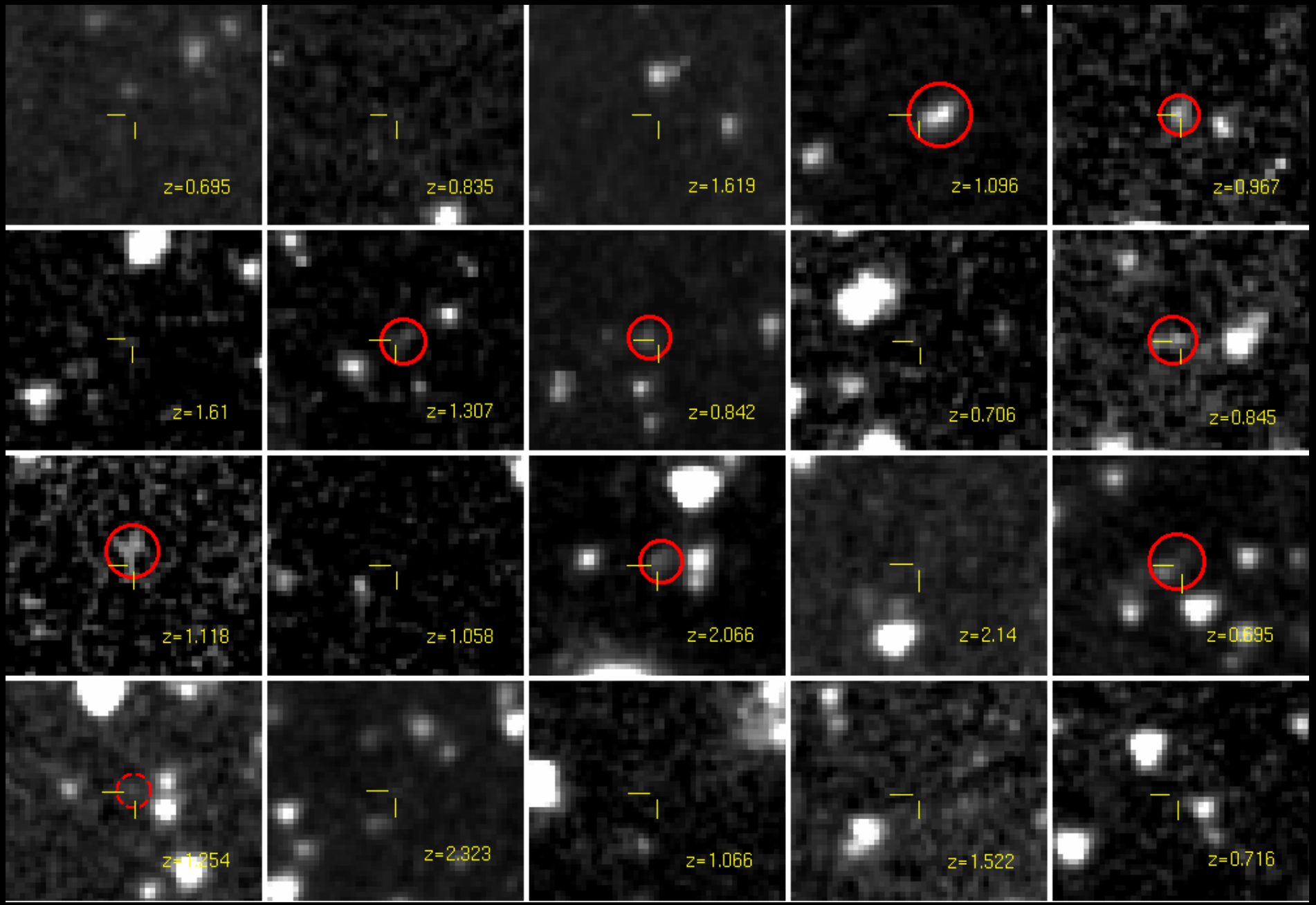
Dark Burst Host Survey



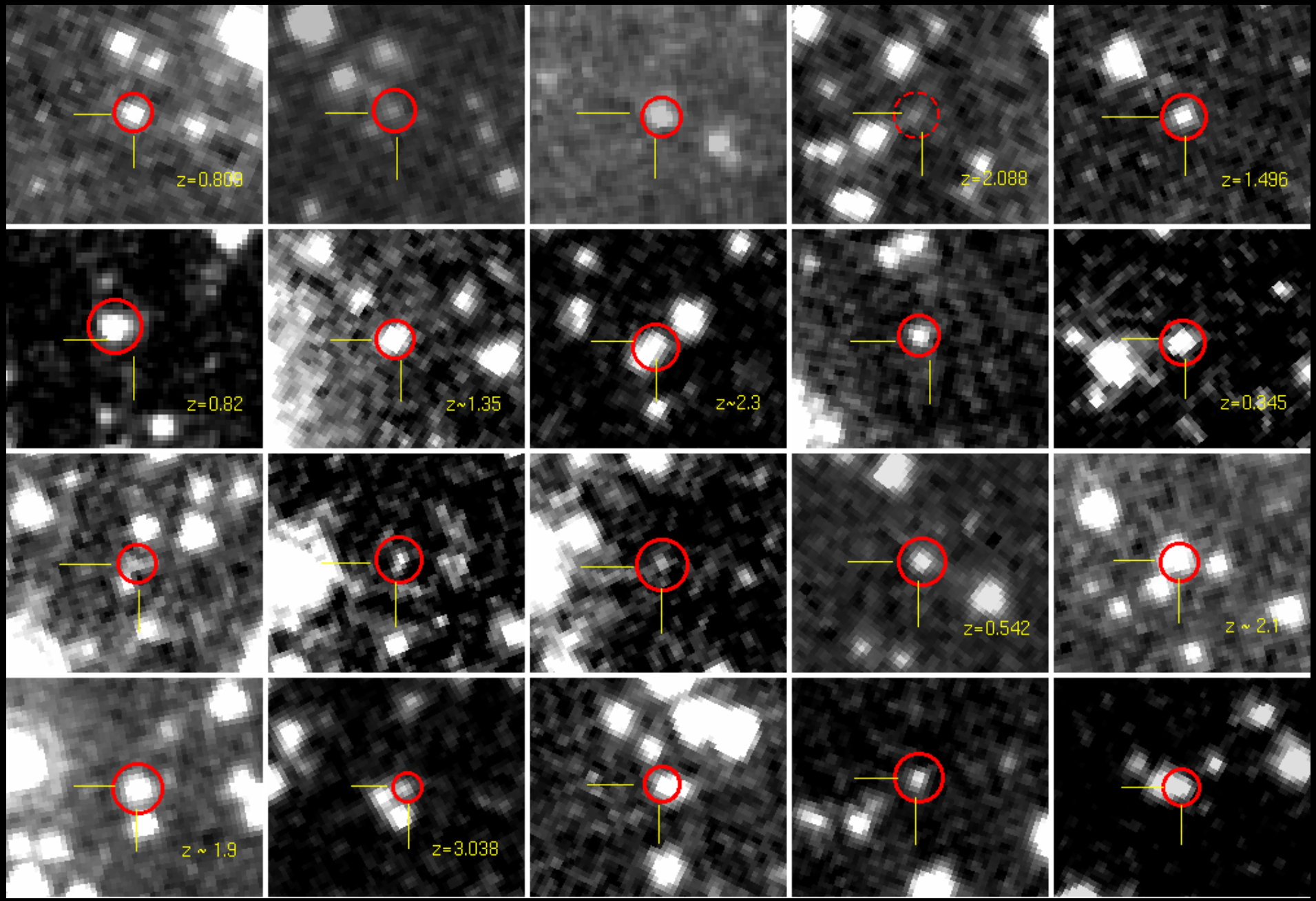
Swift Dark GRB 4.5 μm Imaging



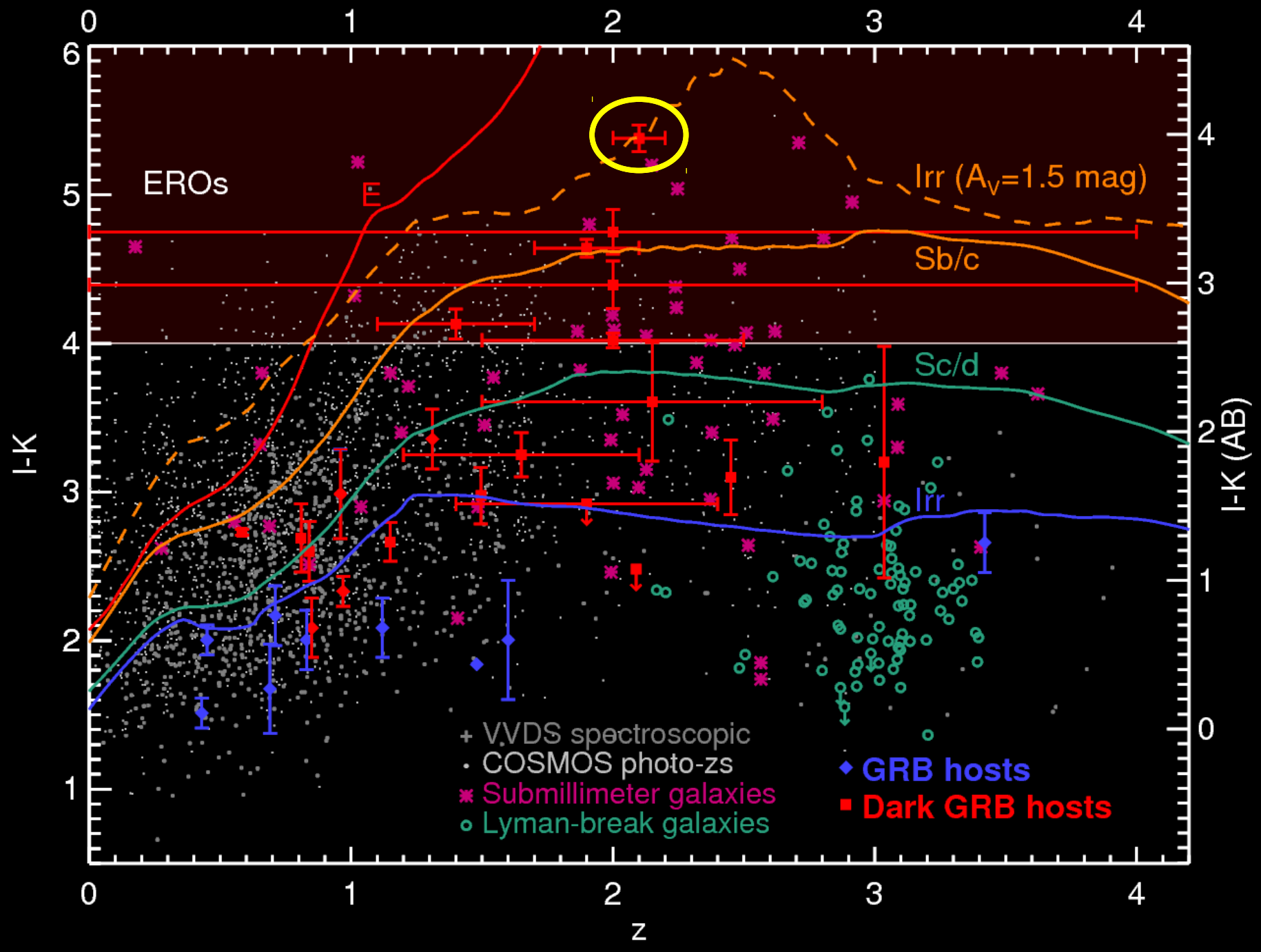
Pre-Swift Non-Dark GRBs



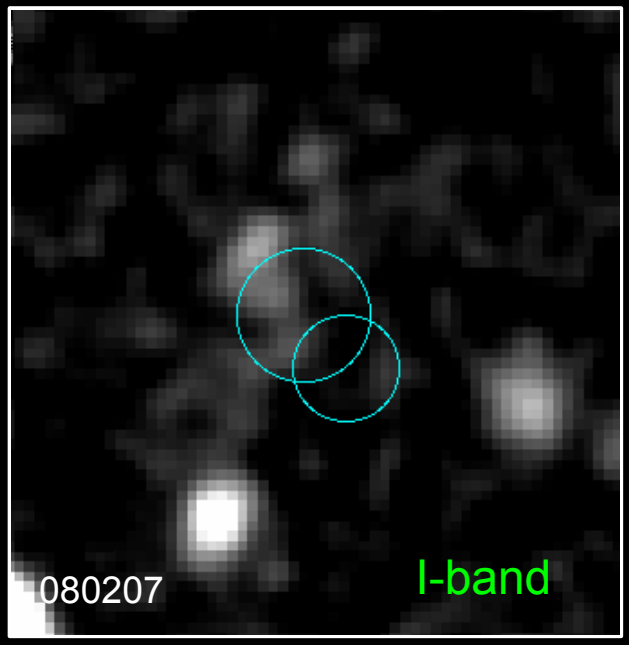
Swift Dark GRB 4.5 μm Imaging

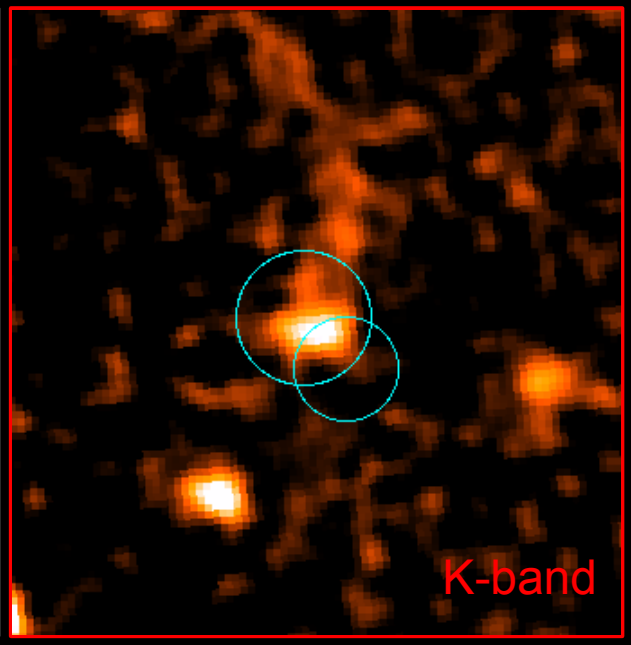


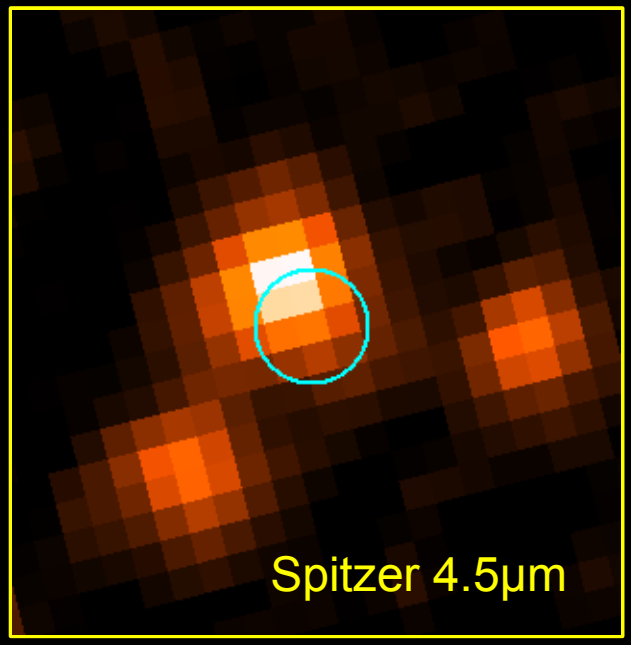
Dark Burst Host Colors



Dark GRB 080207







Fairly dark burst with...

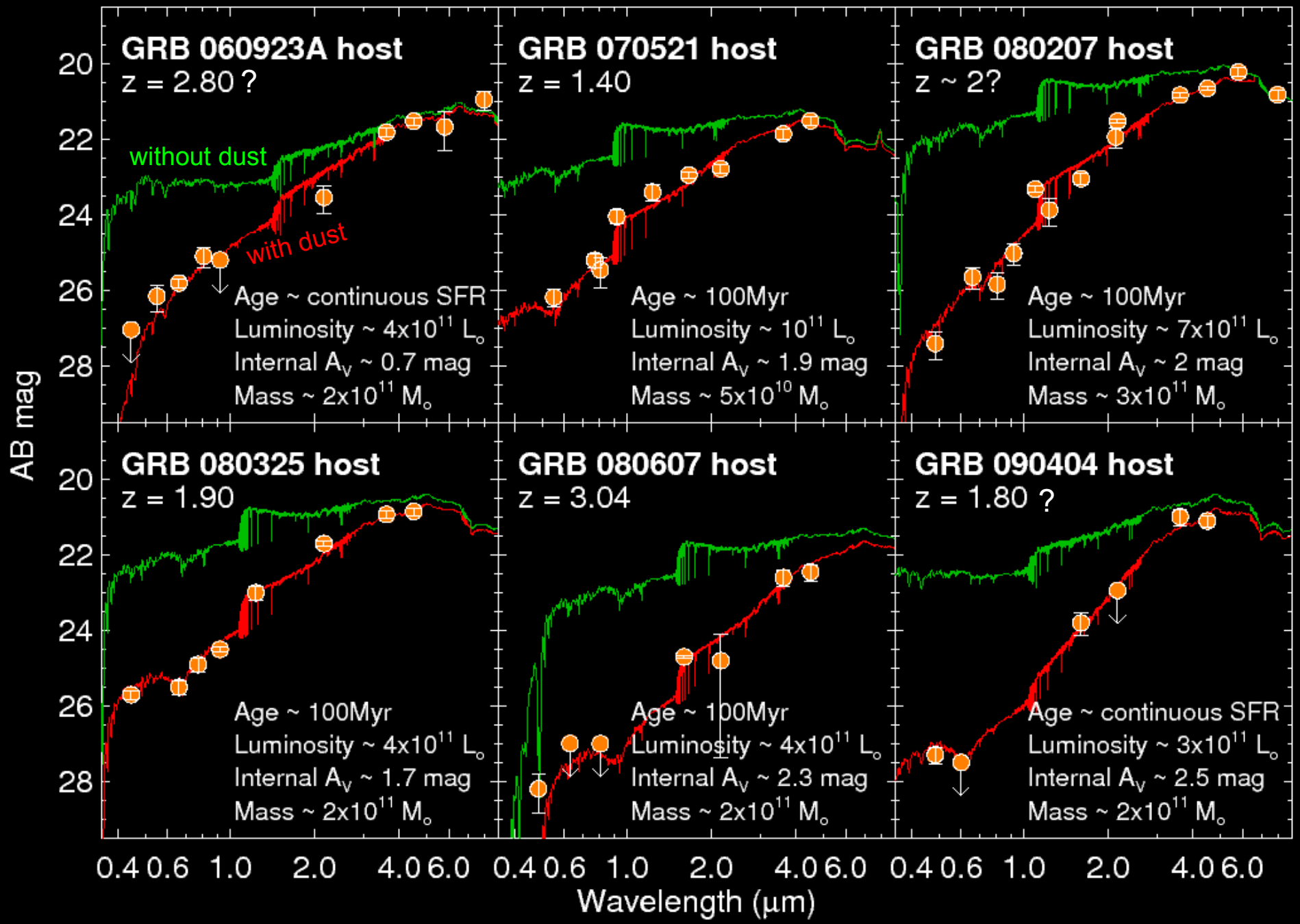
Extremely **red** host:

I-K ~ 5.5 mag

In top ~5% of brightest hosts observed by IRAC,
also detected at 24μm with MIPS

Photo-z = 1.8-2.1 (Svensson et al. 2011, Hunt et al. 2011)

Red Dark Burst Host Galaxies



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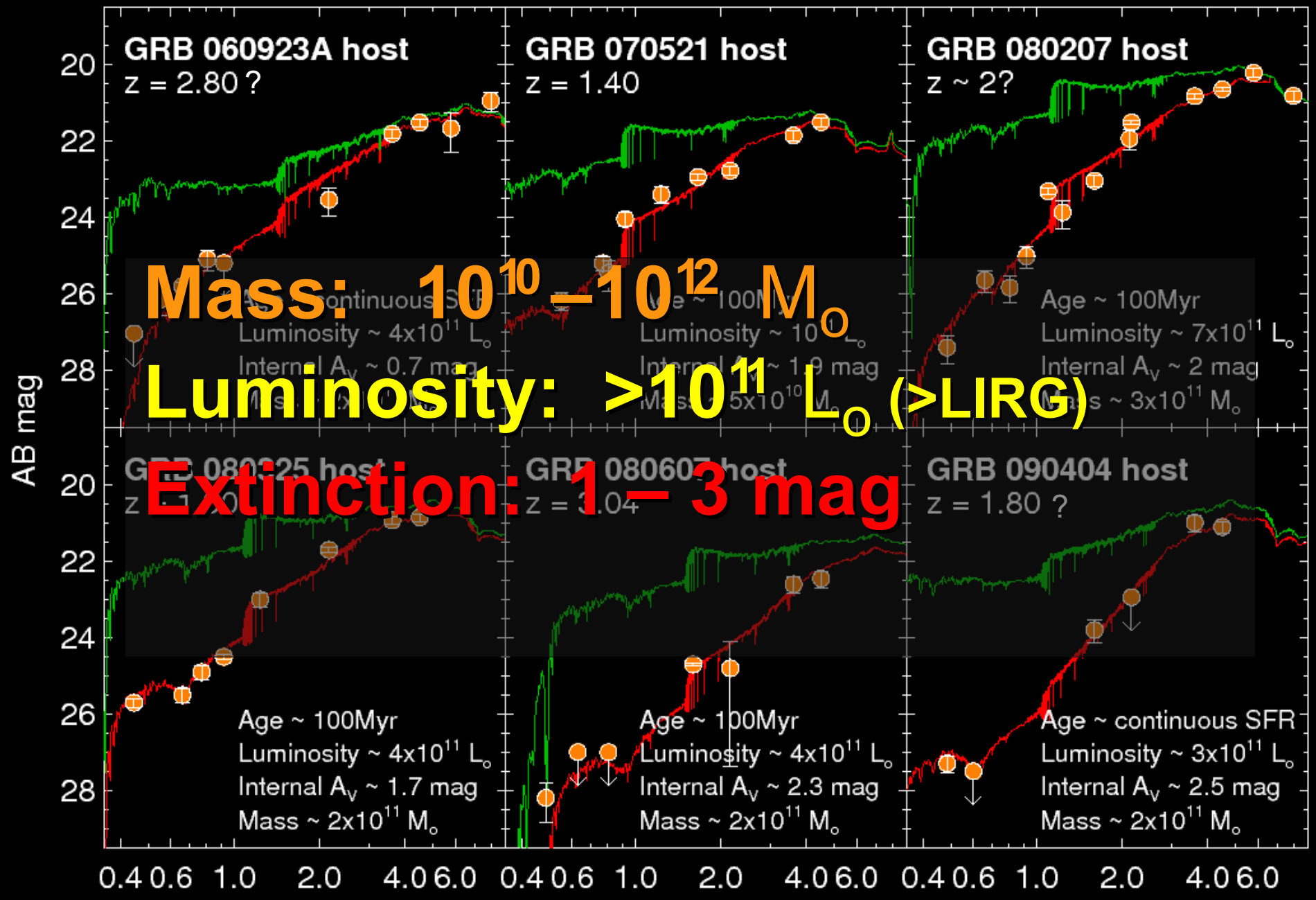
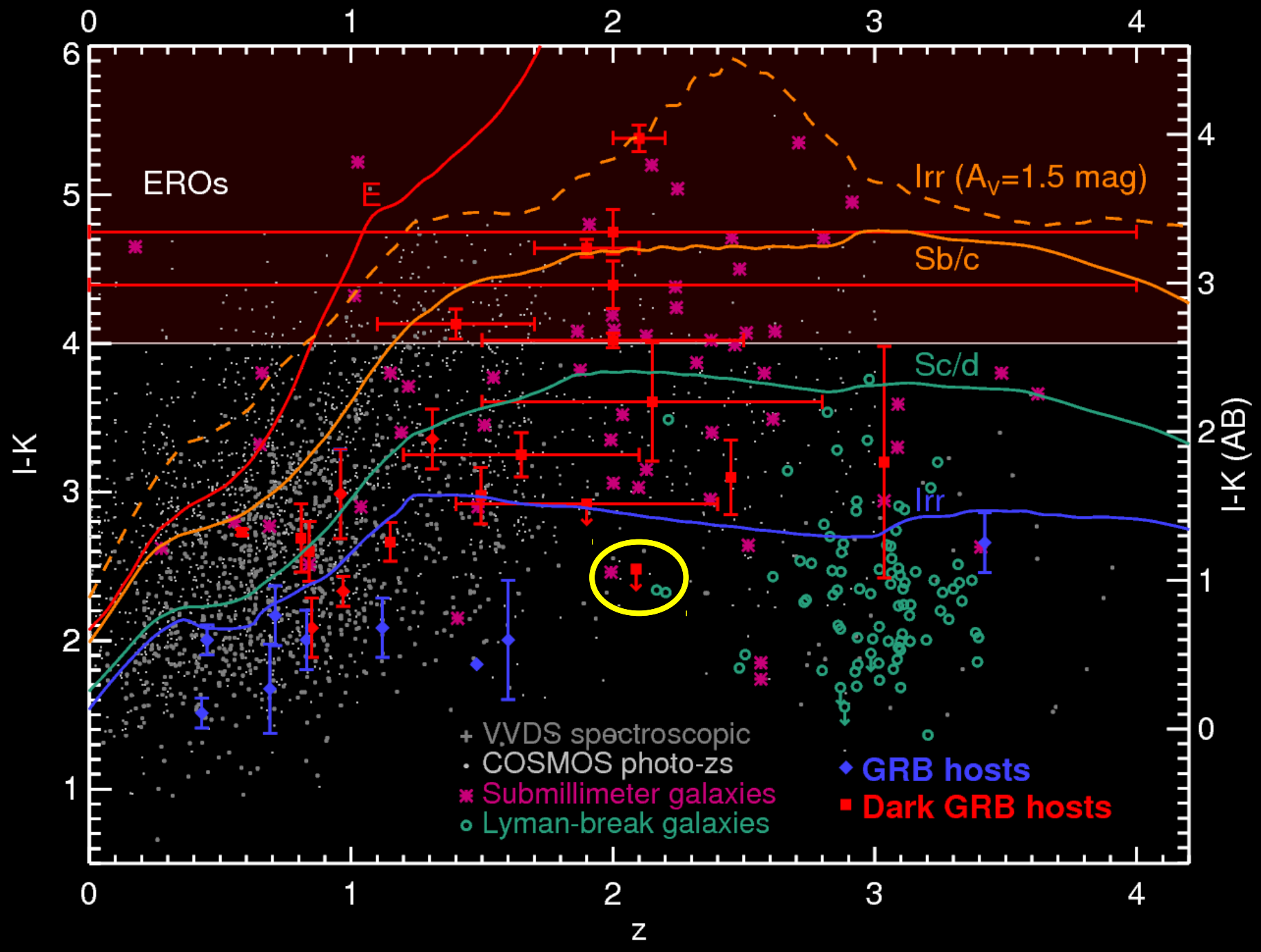


Mass: 10^{10}–10^{12} M_o

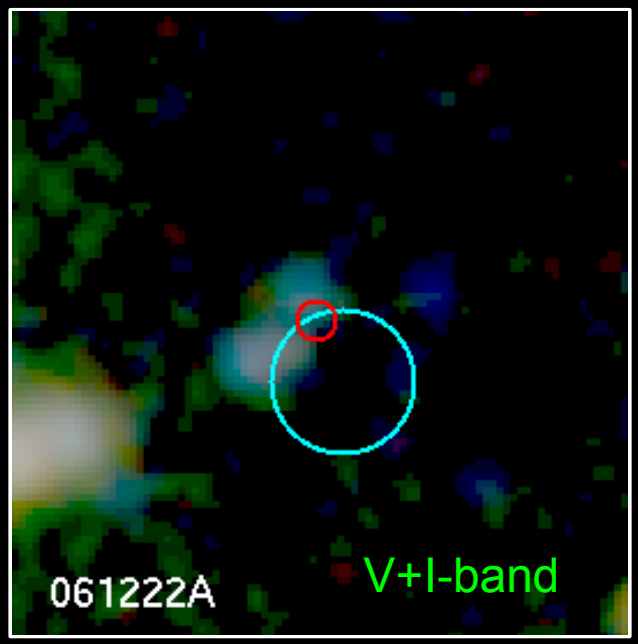
Luminosity: >10^{11} L_o (>LIRG)

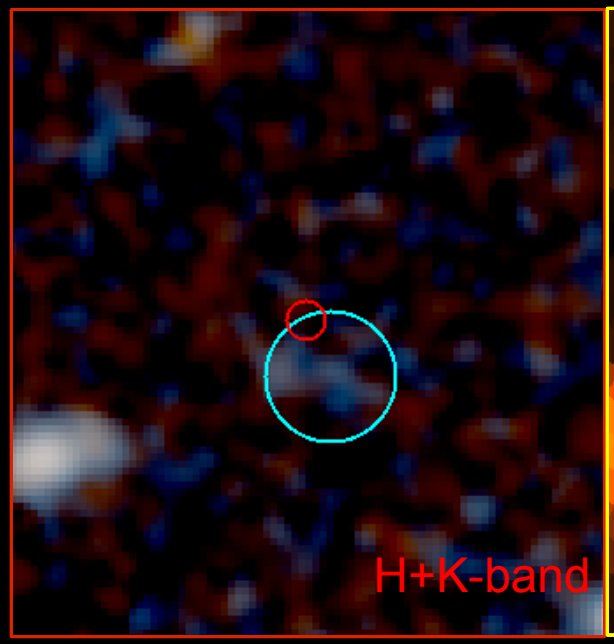
Extinction: 1– 3 mag

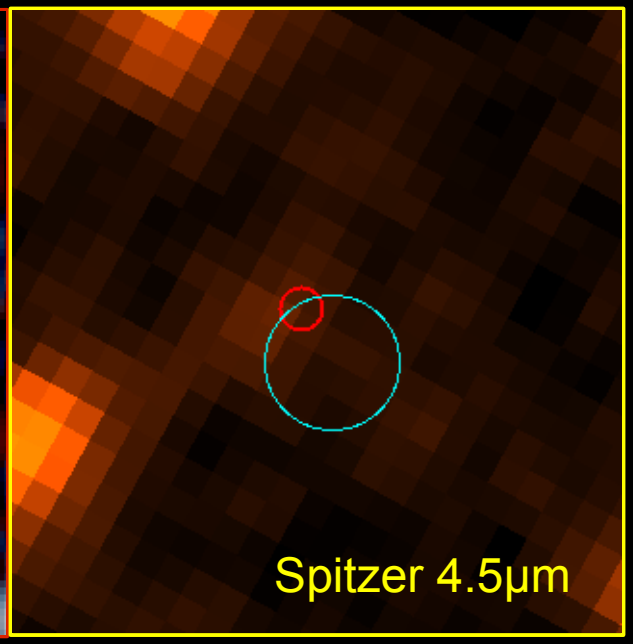
Dark Burst Host Colors



Dark GRB 061222A







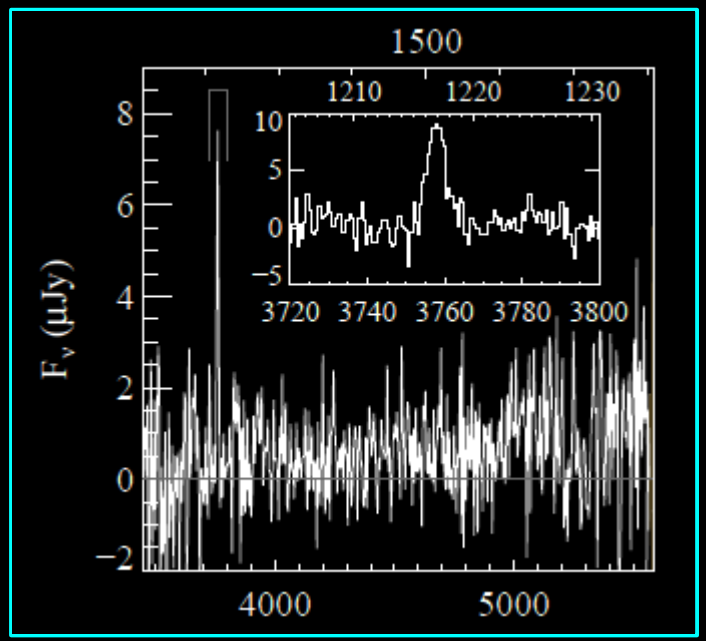
Ultra-dark burst (Av > 5 mag), but

Extremely **blue** host:

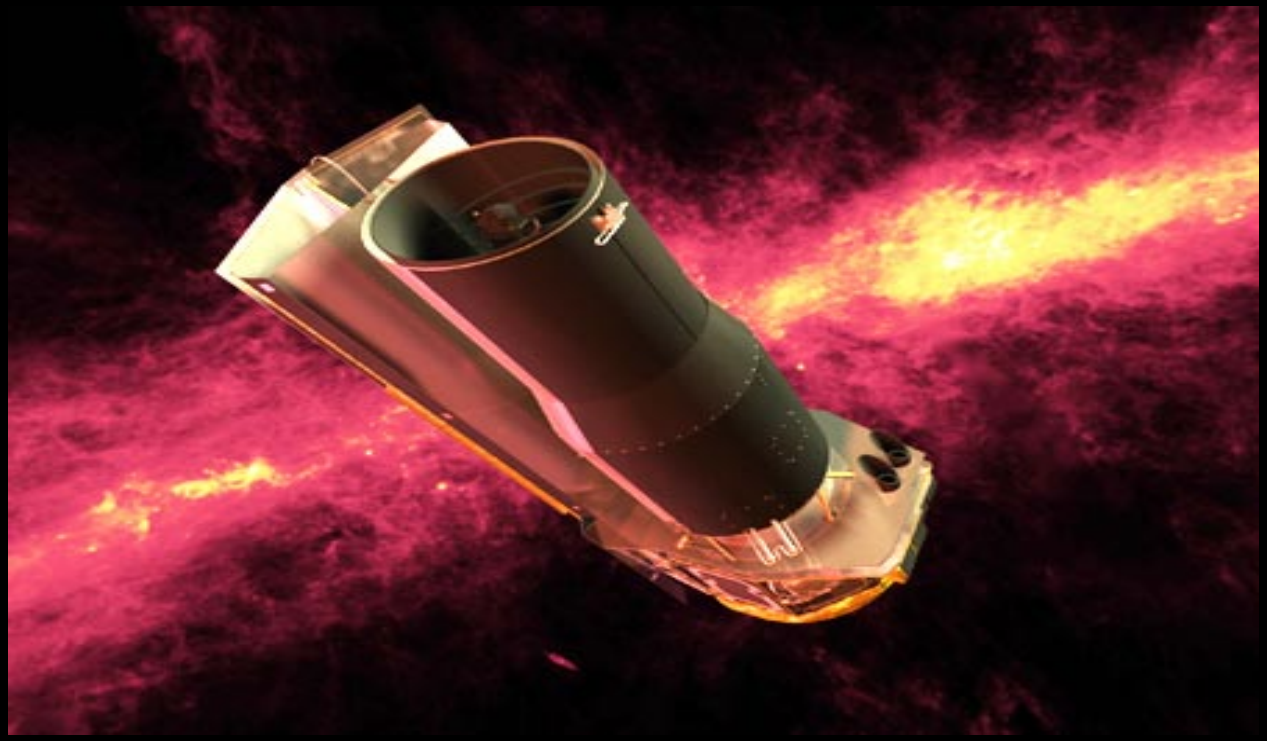
I-K ~ 2 mag

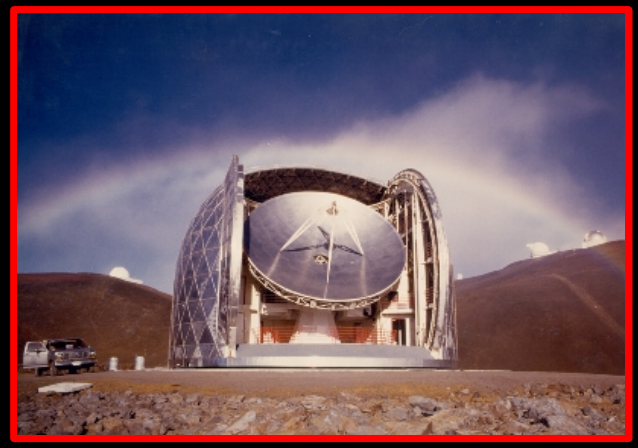
marginal or no Spitzer detection

Ly-α emitter at z=2.1

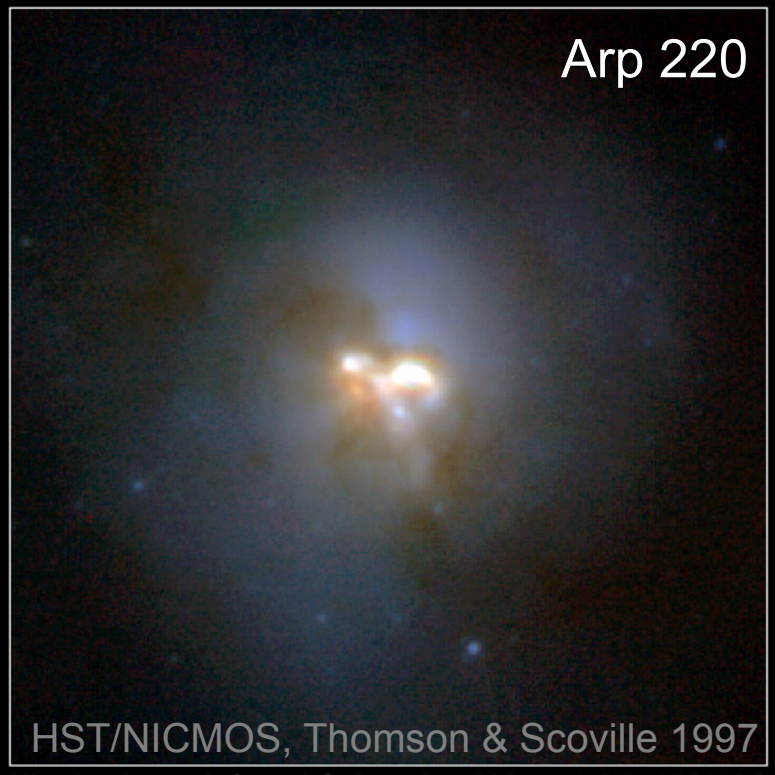


Dark Burst Host Survey



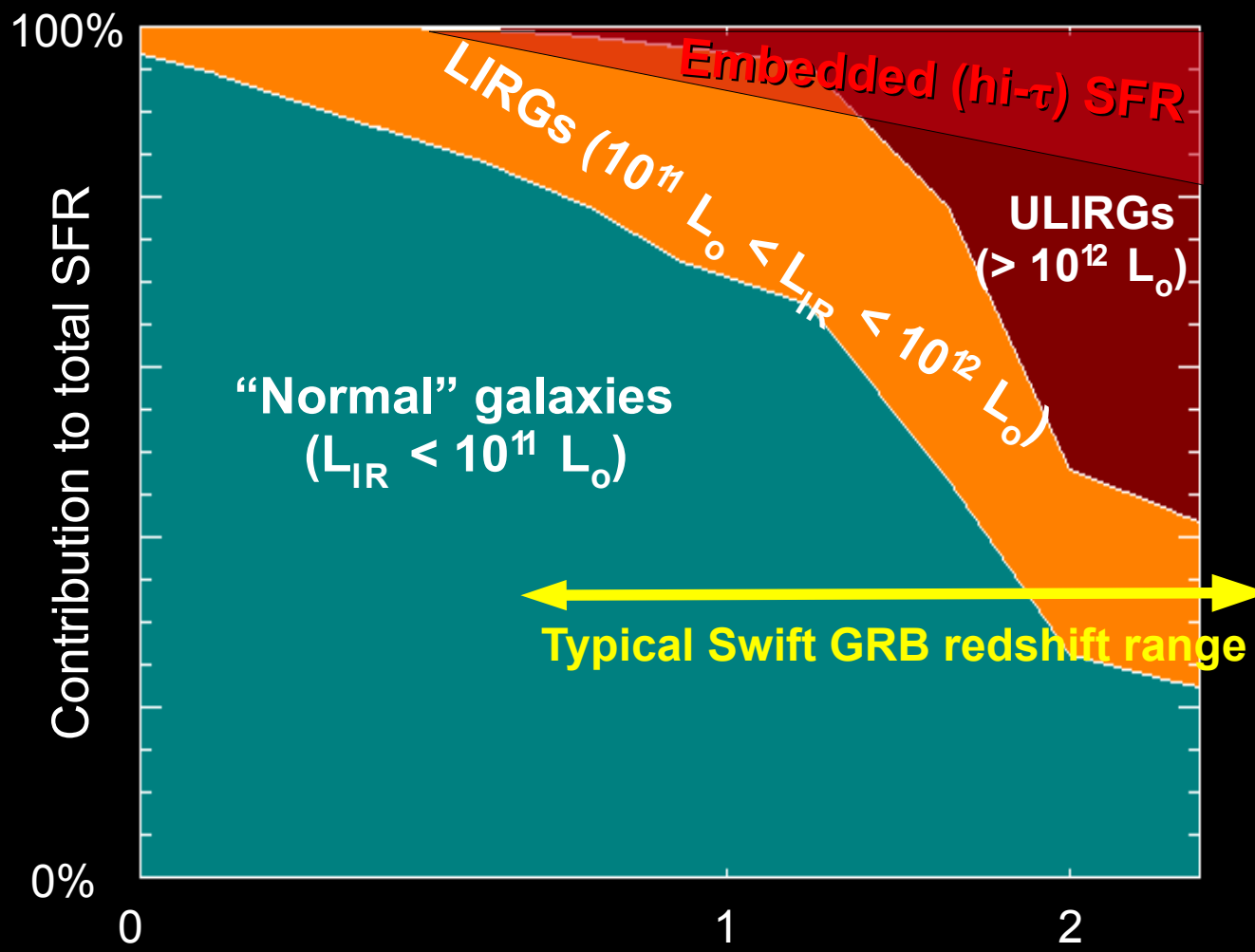


Highly-Embedded Star Formation?



SFR >> dust-corrected optical SFR

Low-z: ULIRGs High-z: SMGs

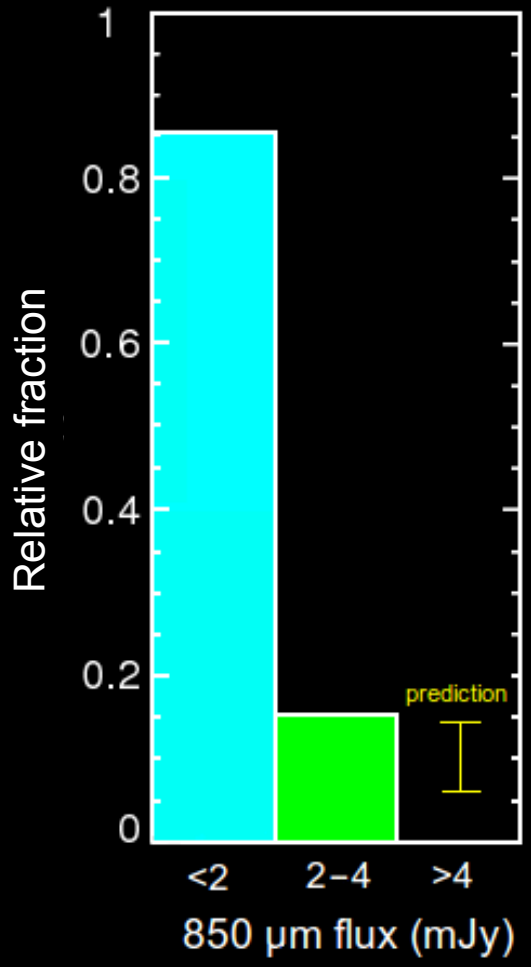


~20% of cosmic SFR at z~2

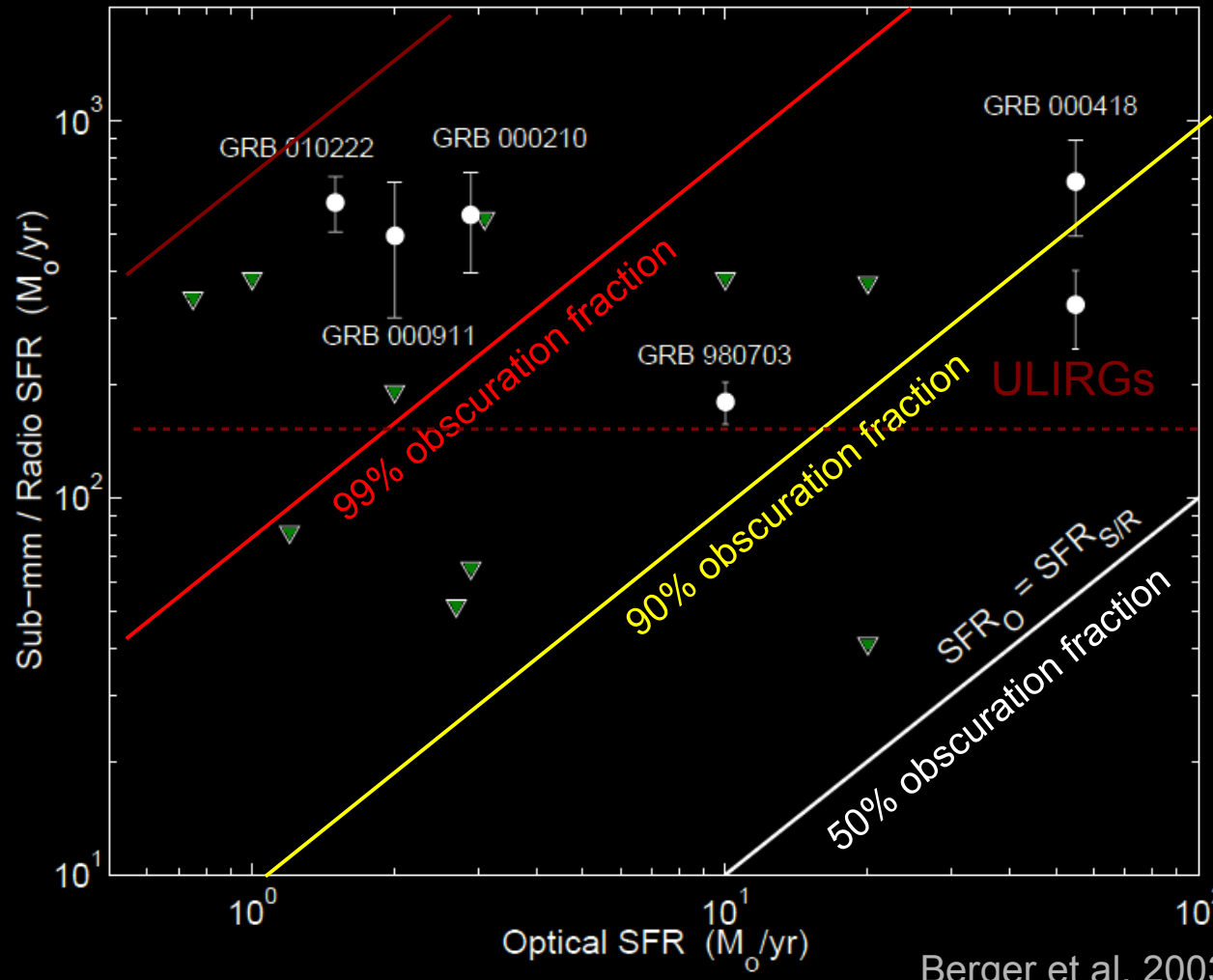
Michalowski et al. 2010, also Chapman et al. 2004

Pre-Swift Submillimeter Observations

Only a few pre-Swift detections (blue galaxies!)



Tanvir et al. 2004

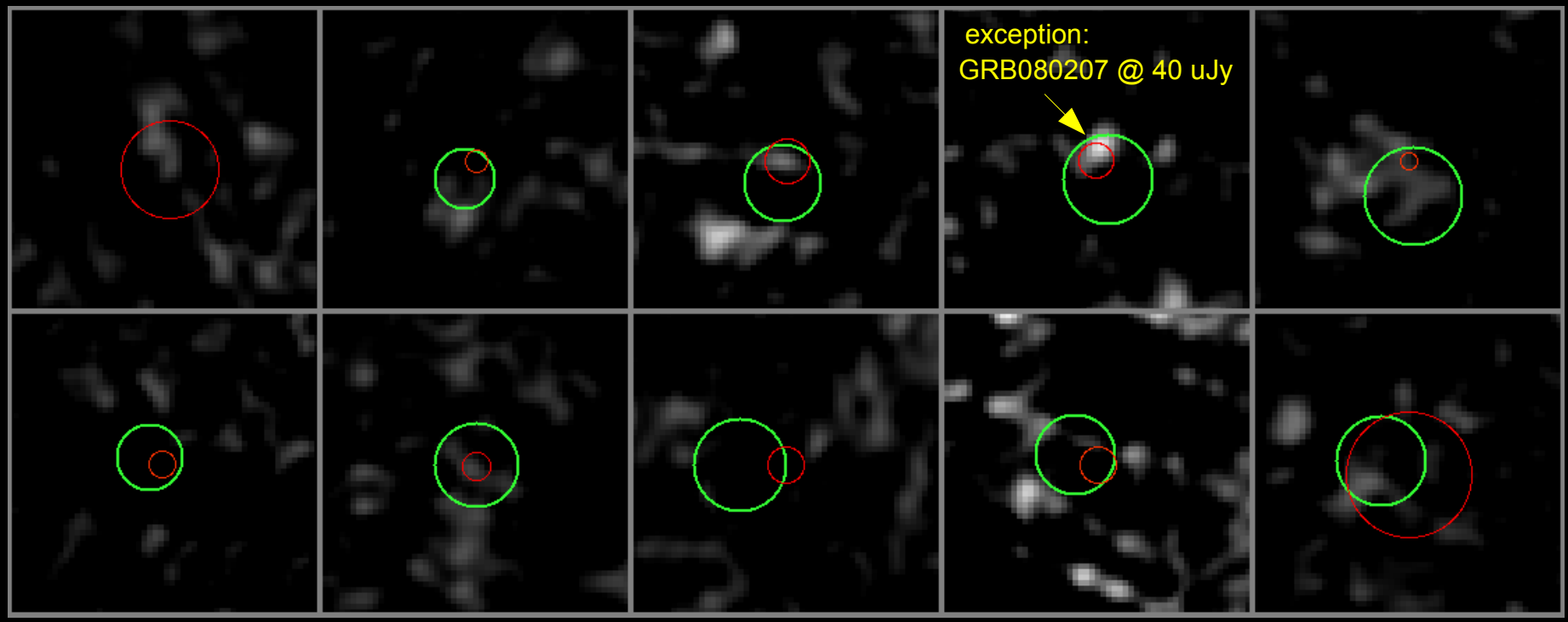


Berger et al. 2003

Radio/submm observations

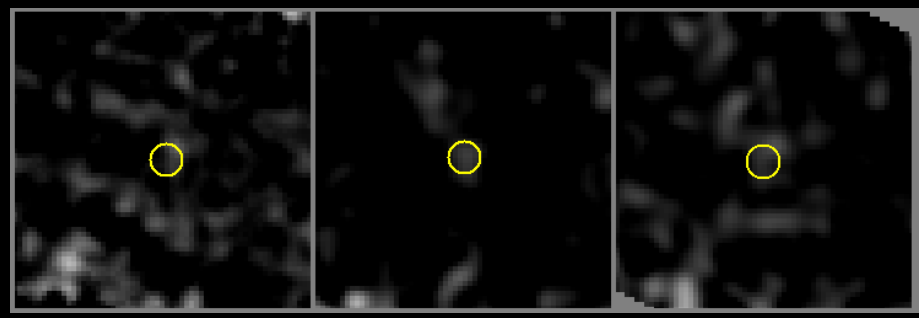
No EVLA detection (to ~15 μJy @ 5 GHz) for 9 out of 10 Spitzer-brightest hosts

1 hr integration/target
(equiv. Of 20 hr/target
on old VLA)



No CSO detection (to ~10 mJy) for 3 Spitzer-bright hosts

5-15 hr integration/target



LIRGs, not ULIRGs

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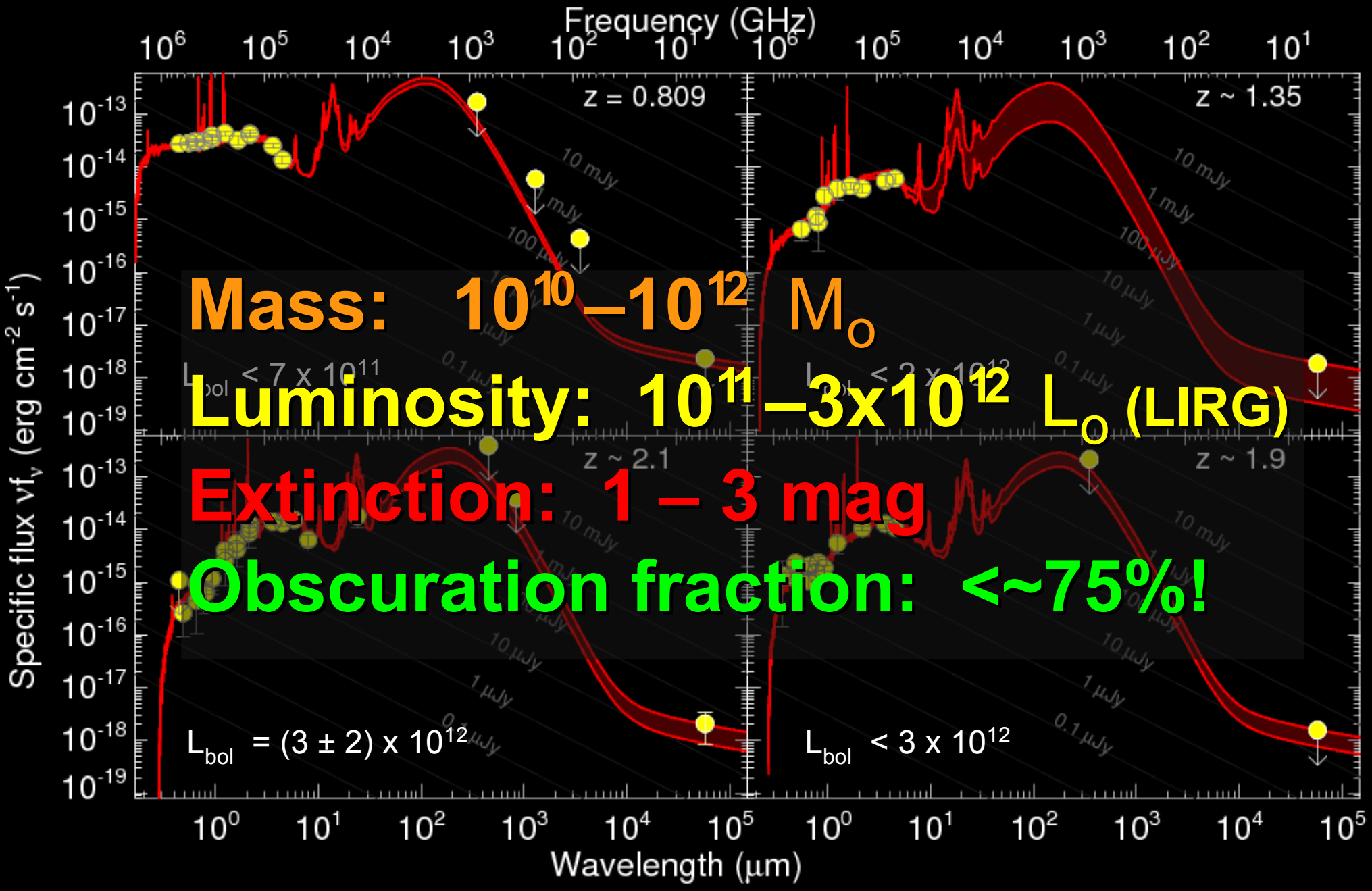


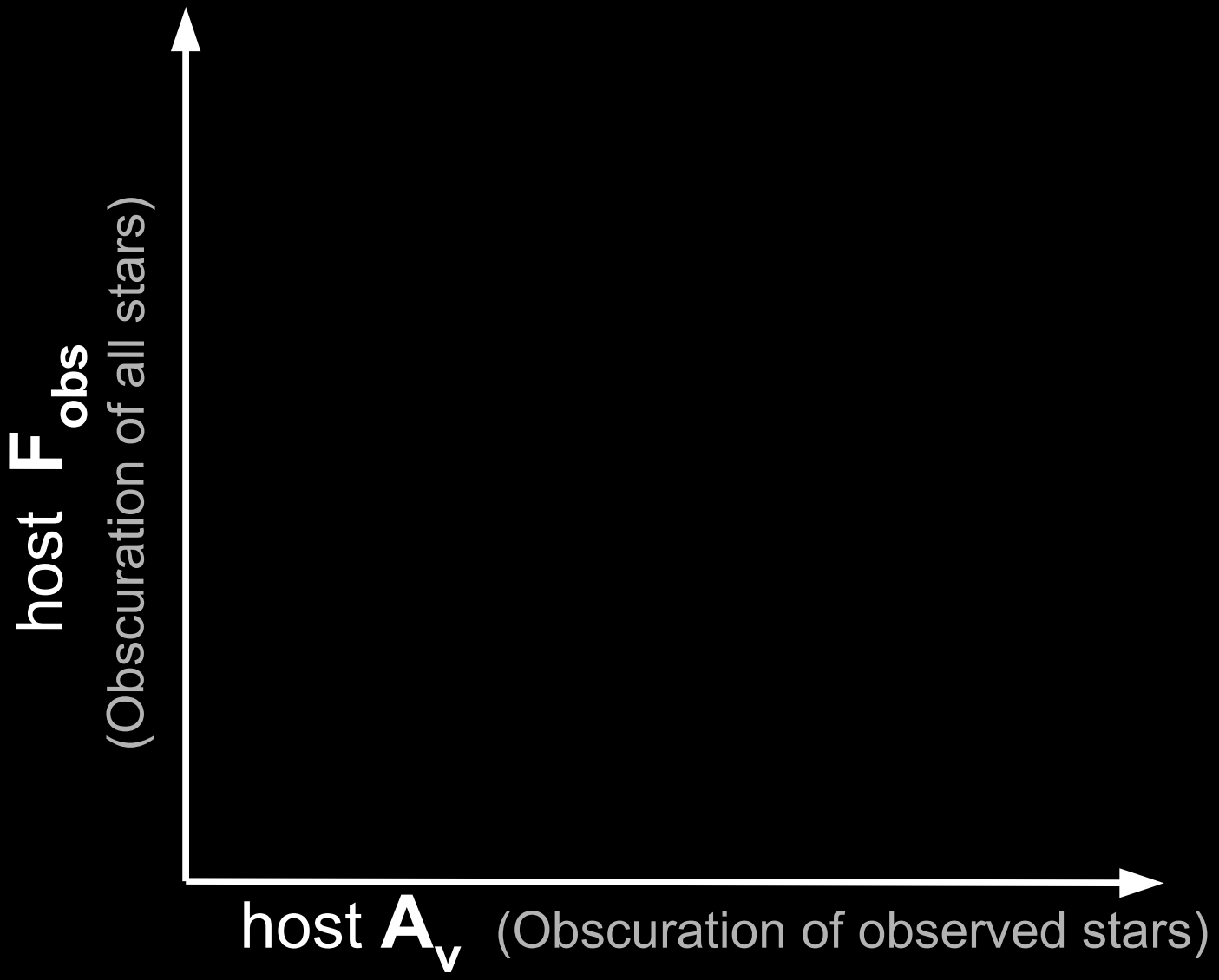
Mass: 10^{10}–10^{12} M_O

Luminosity: 10^{11}–3x10^{12} L_O (LIRG)

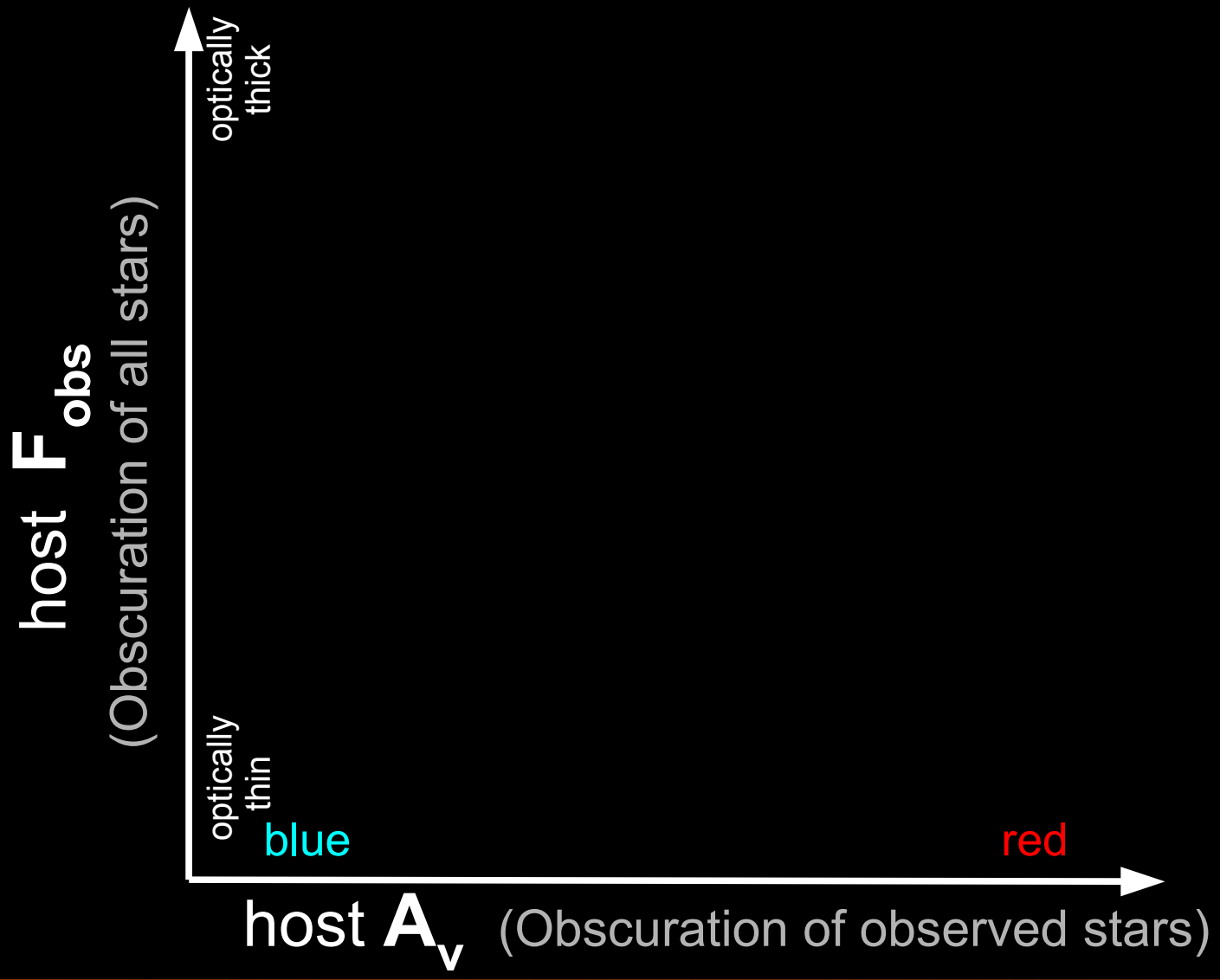
Extinction: 1 – 3 mag

Obscuration fraction: <~75%!

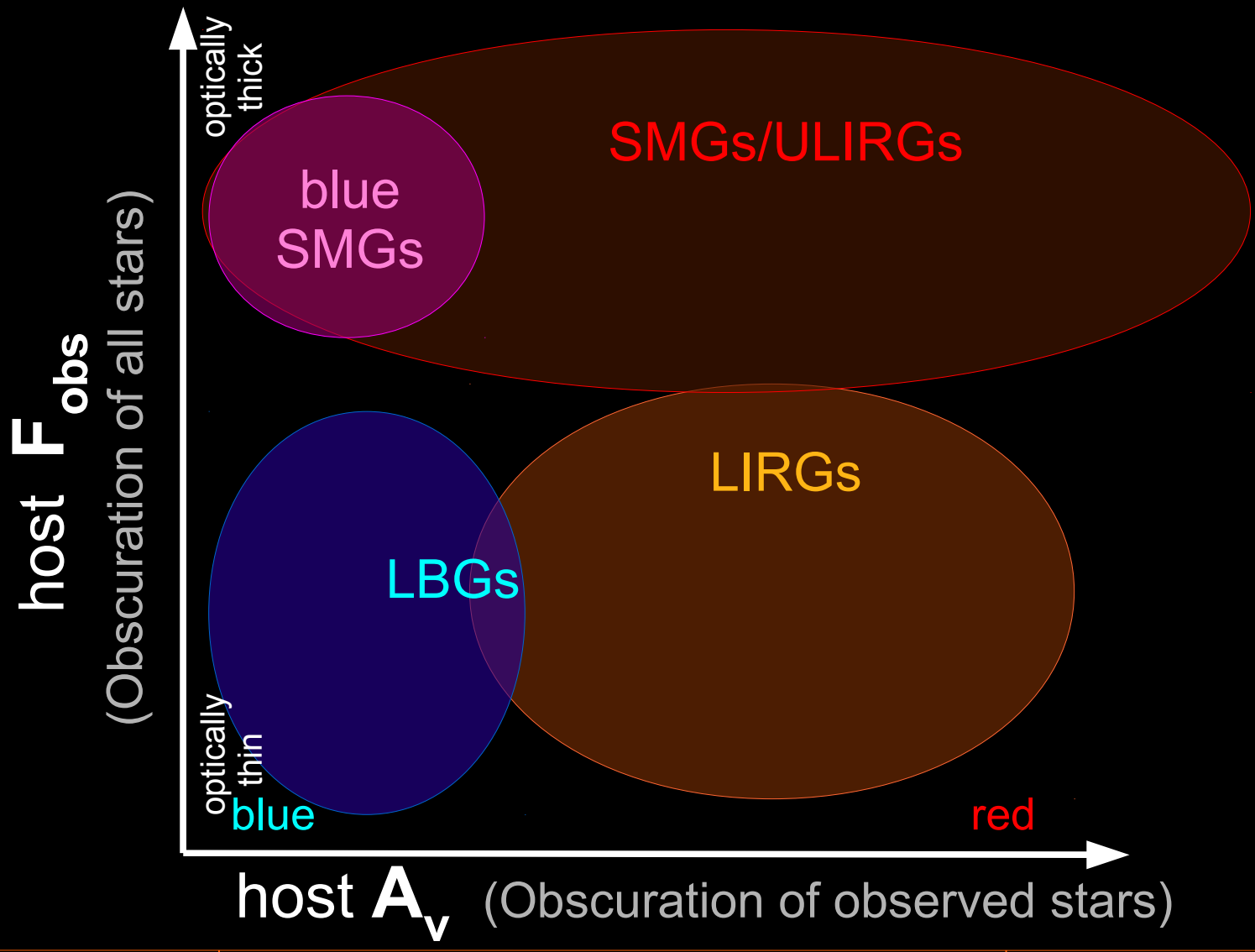
Interpretation



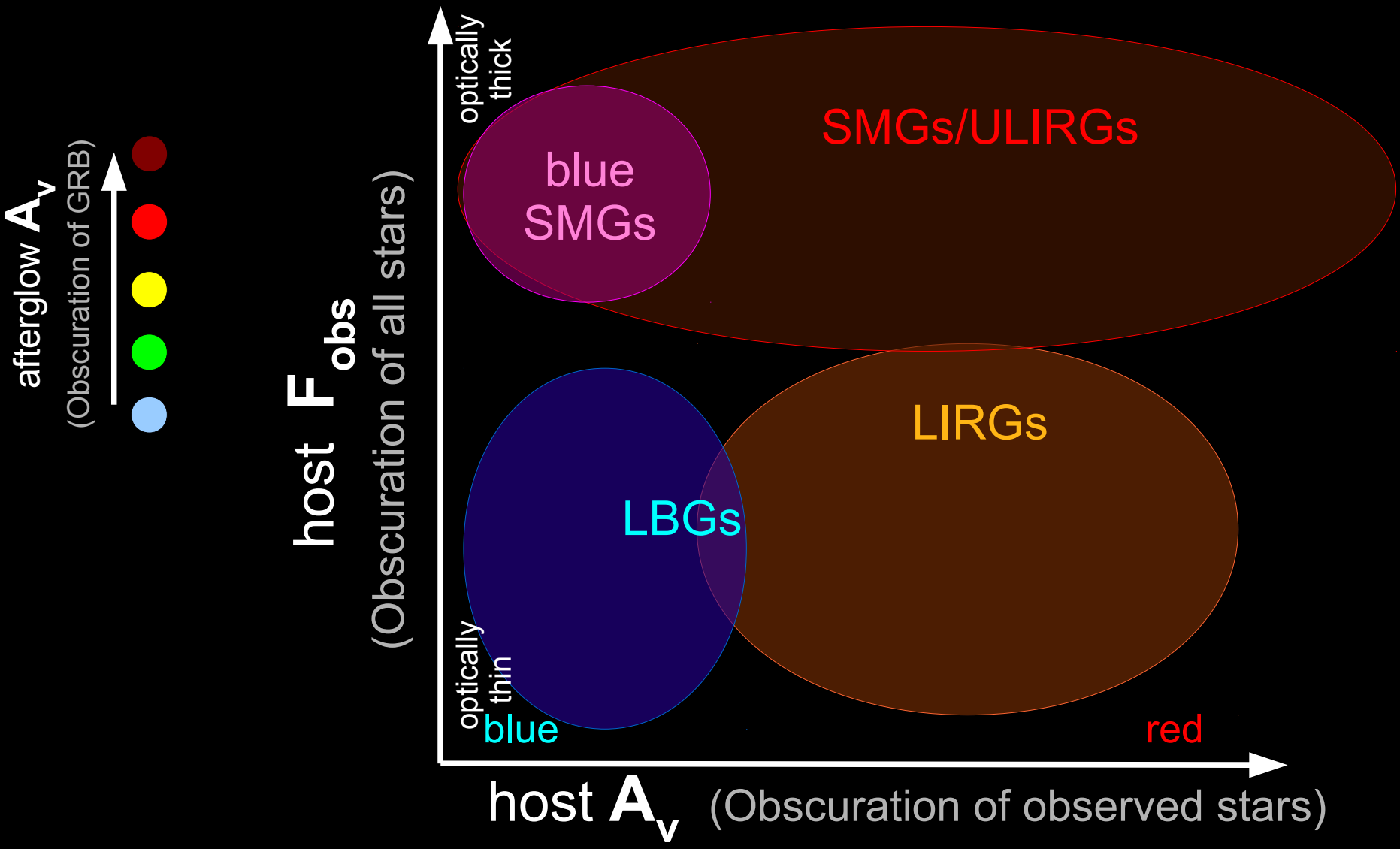
Obscuration Correlations



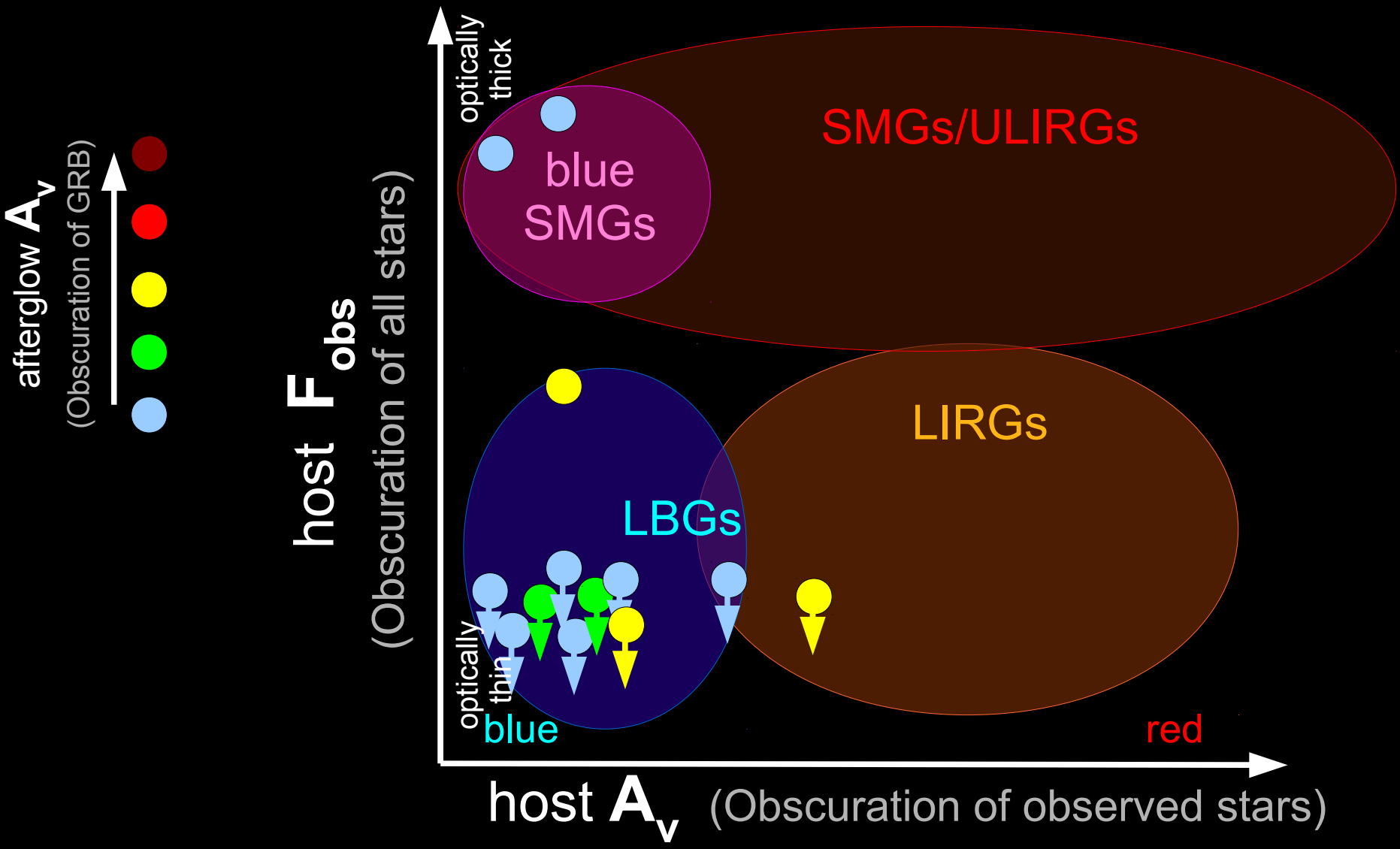
Obscuration Correlations



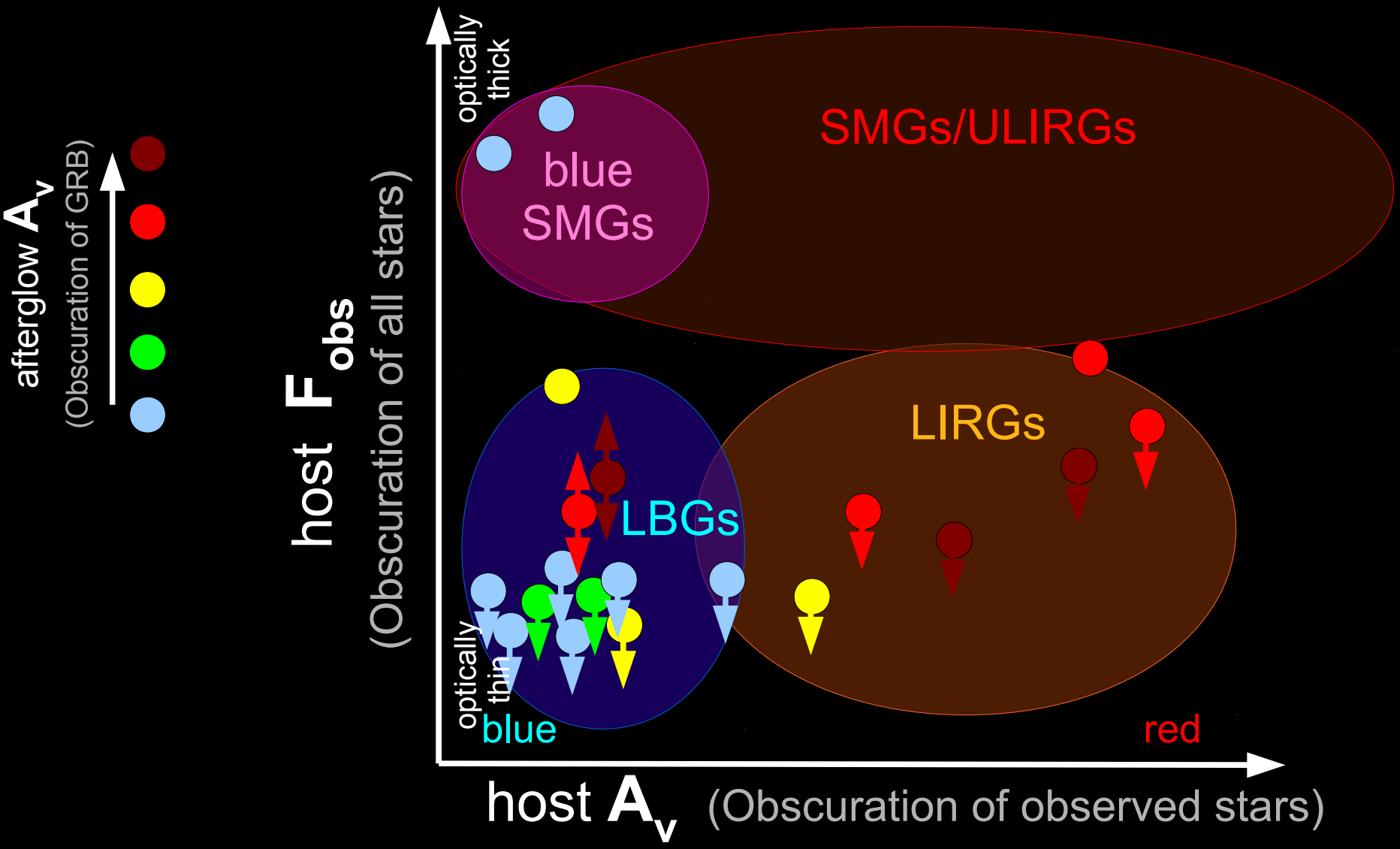
Obscuration Correlations



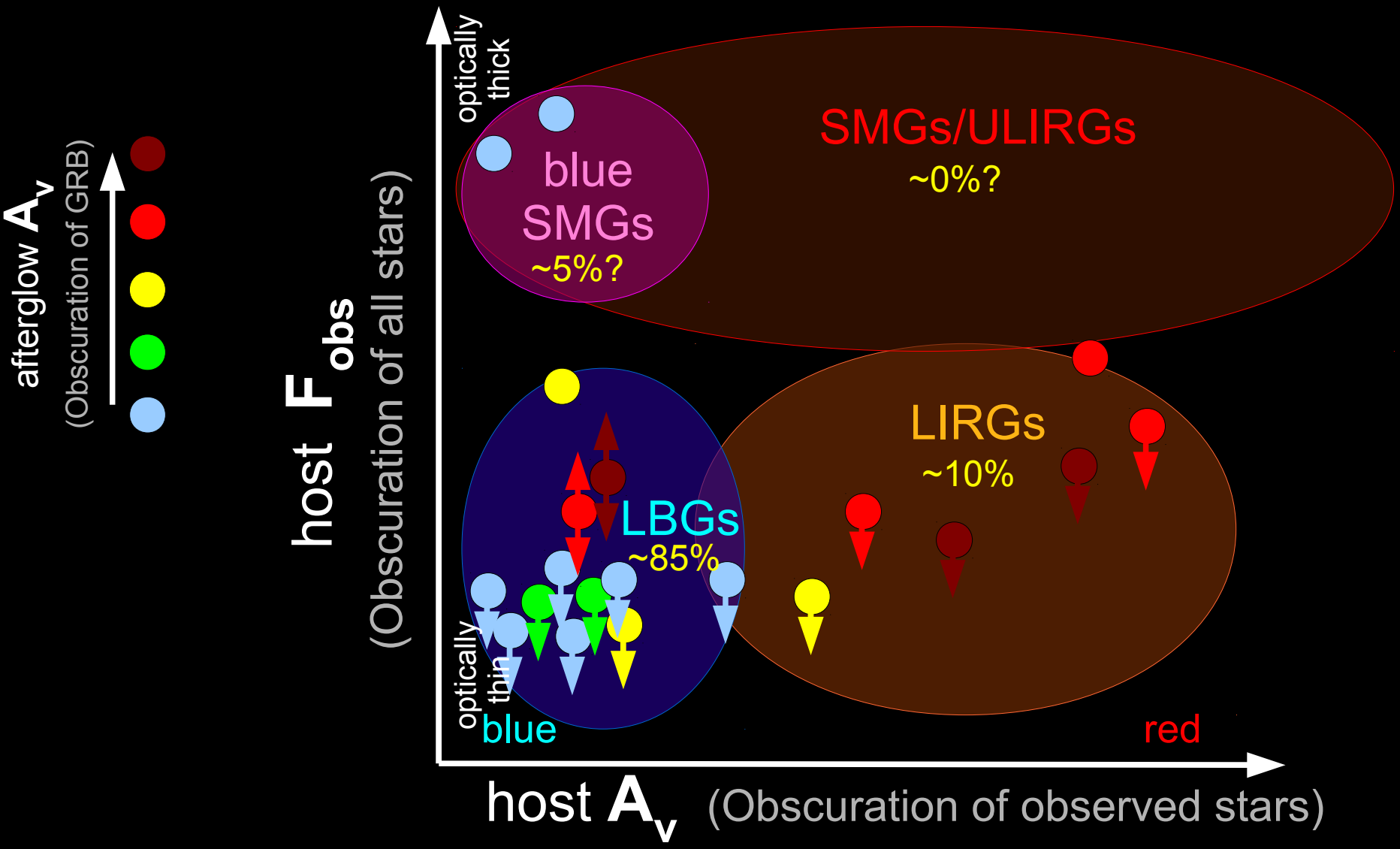
Obscuration Correlations



Obscuration Correlations

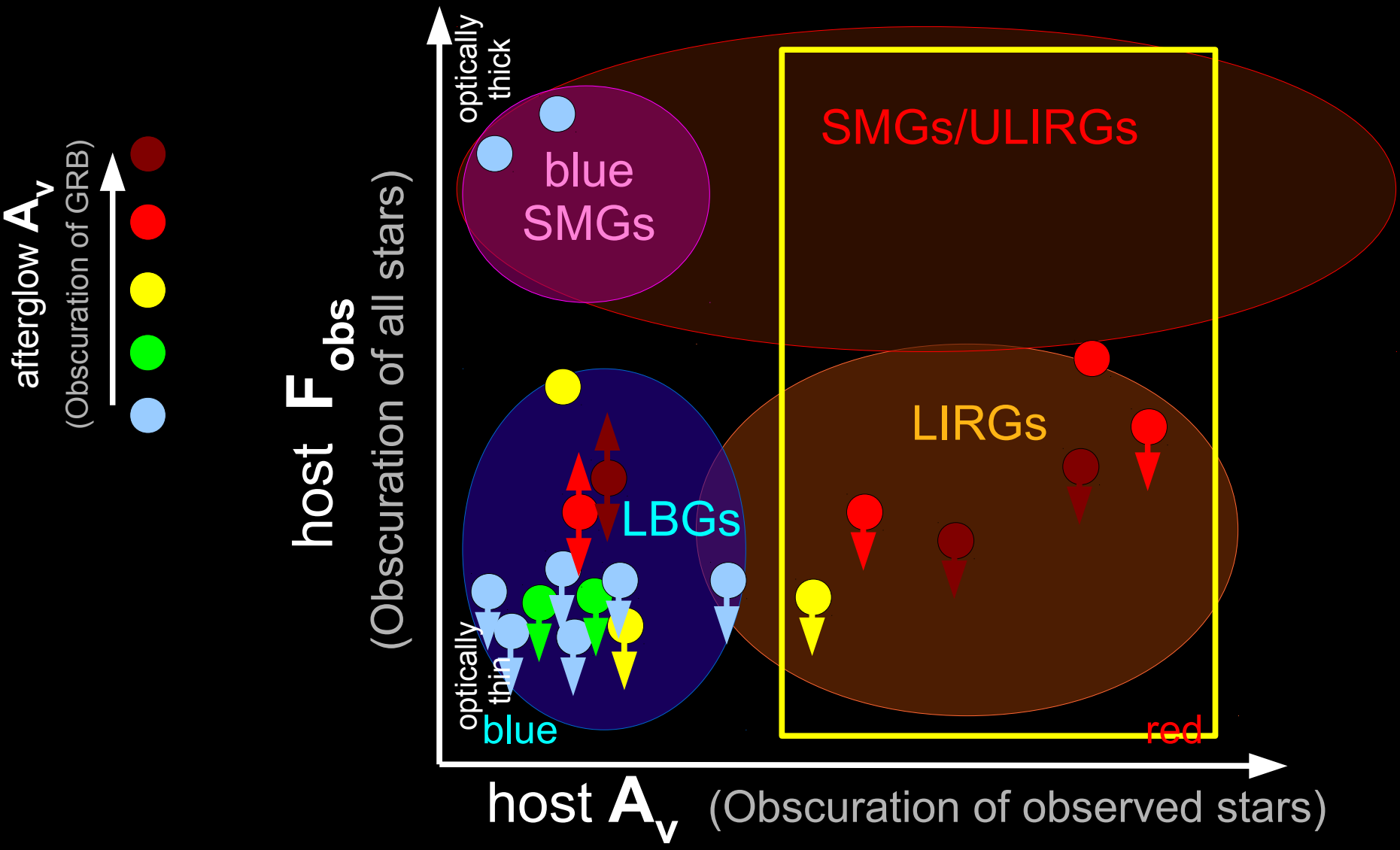


Obscuration Correlations



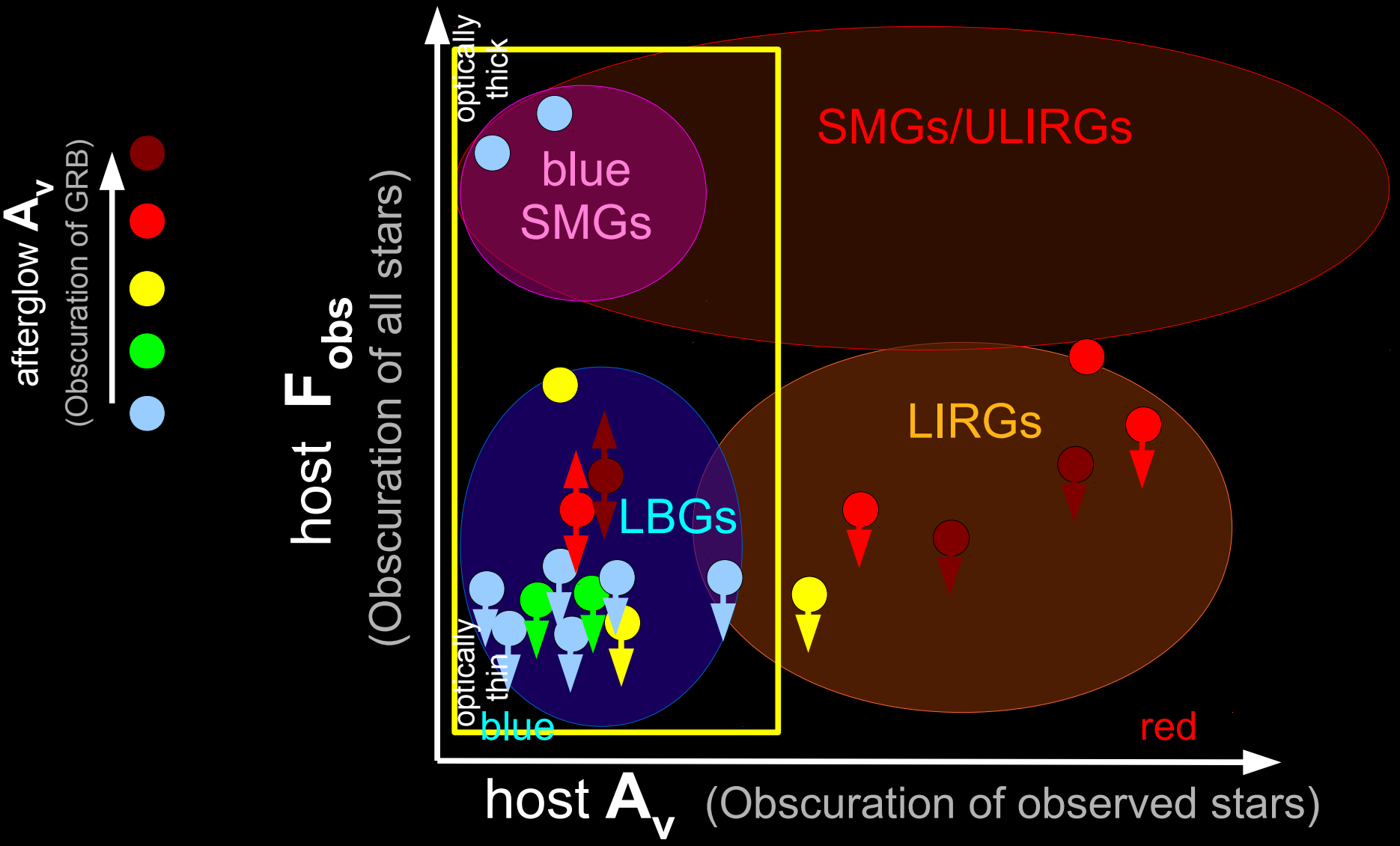
Obscuration Correlations

1. Red hosts produce red GRBs, not blue GRBs.



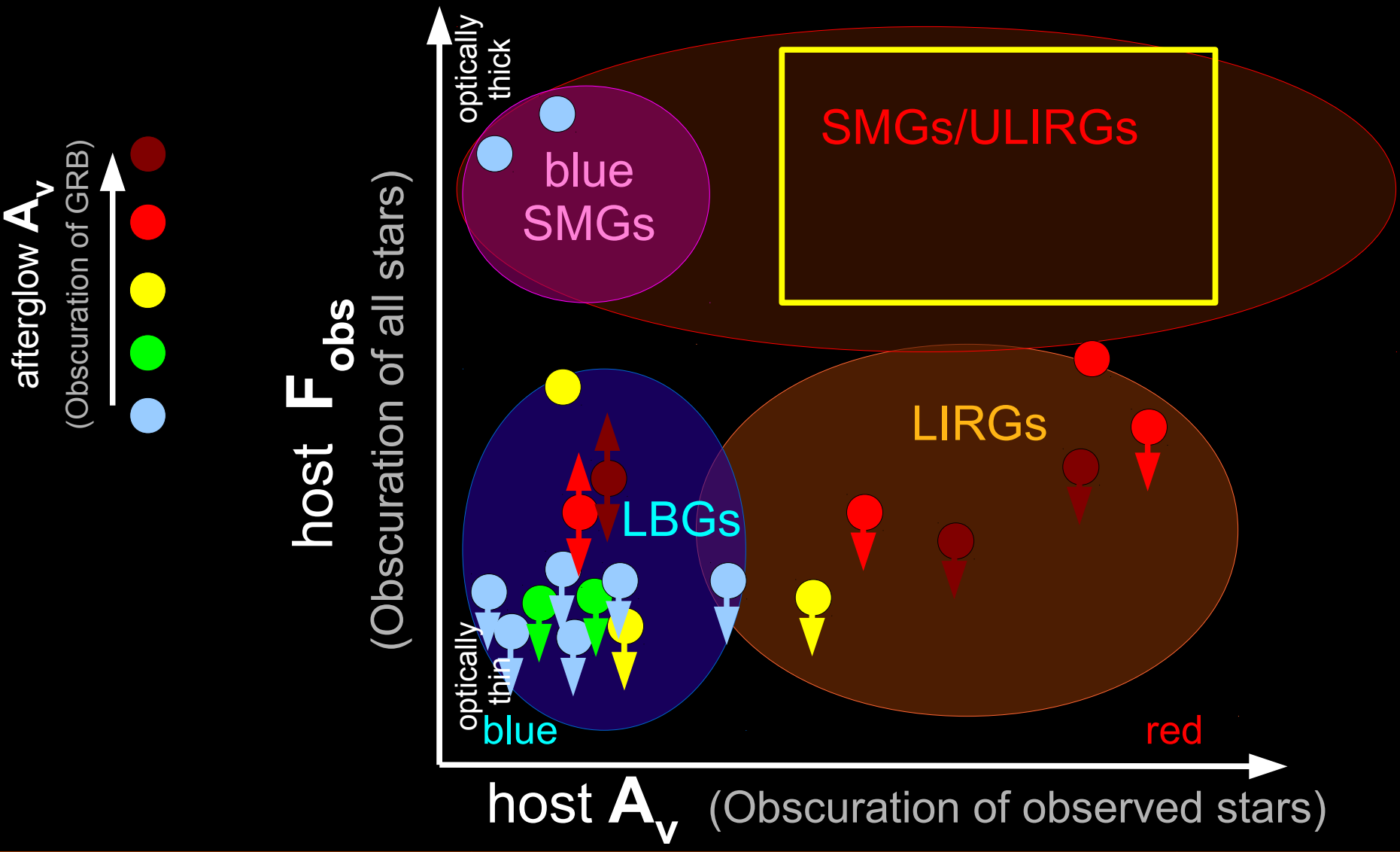
Obscuration Correlations

2. Blue hosts produce red GRBs and blue GRBs.

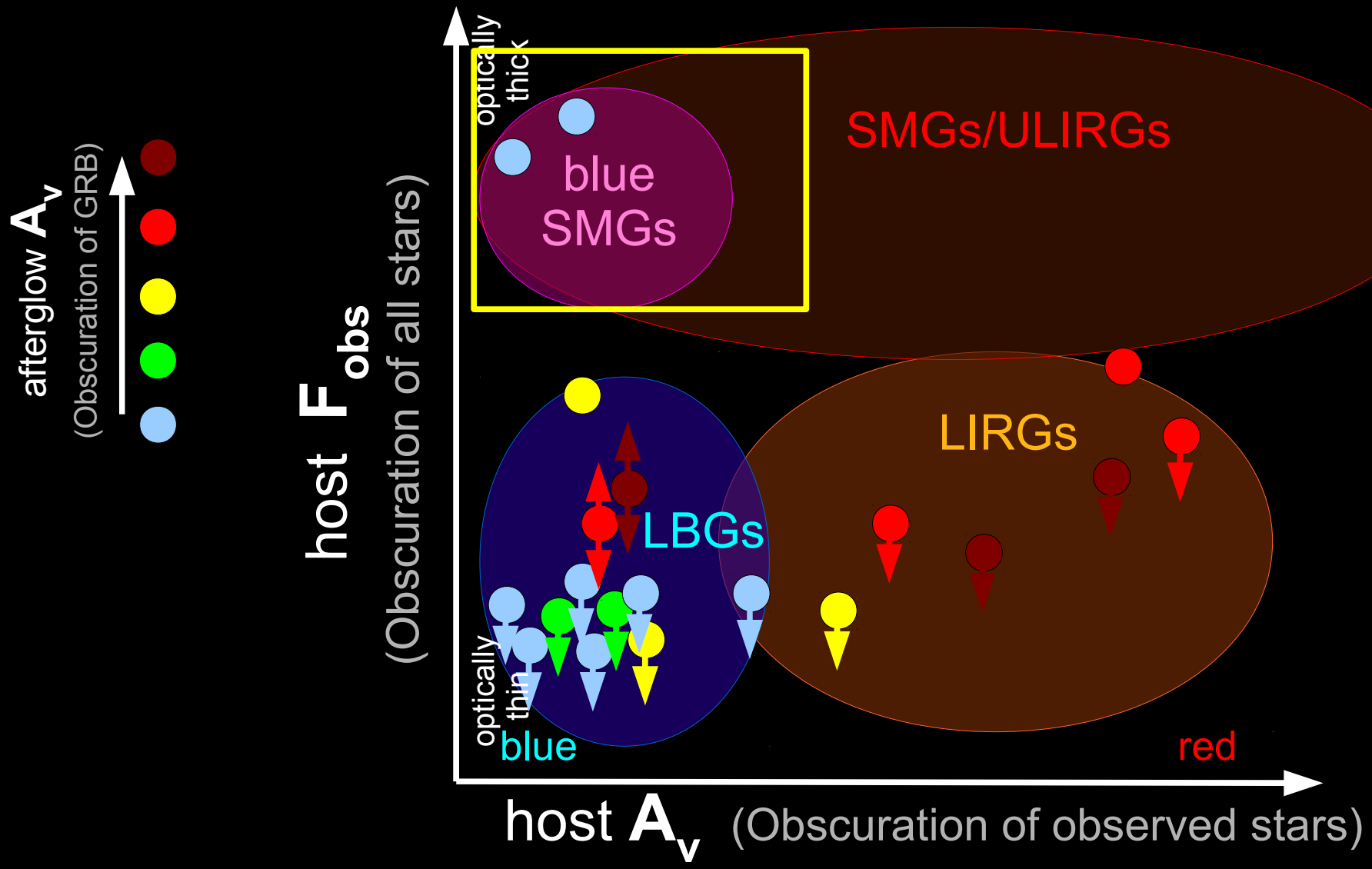


Obscuration Correlations

3. Red SMGs *do not produce many* GRBs.



4. Blue SMGs ***do*** *produce* GRBs (but not red GRBs?)



Conclusions

1. Red hosts produce red GRBs, not blue GRBs.
   → Dust in massive galaxies is globally distributed.
   Moderately metal-rich systems produce a few GRBs.

2. Blue hosts produce red GRBs and blue GRBs.
   → Dust in low-mass galaxies *is present,* but heterogeneous:
   Some sightlines are dusty, others dust-free (geometry)

3. Red SMGs *do not produce many* GRBs.
   → Chemically homogeneous, very metal-rich systems:
   GRB production is stifled? (IMF effect? SMG age effect?)

4. Blue SMGs ***do*** *produce* GRBs (but not red GRBs?)
   → Chemically heterogeneous systems:
   GRB production can still occur in blue, outer parts

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Conclusions

Dark GRB hosts are *diverse*.

Some hosts are blue, low-luminosity:

Dust geometry within small galaxies

Majority are red, high-luminosity

GRBs *can* form in massive galaxies

Luminous hosts are still uncommon

~10-20% of sample >= LIRG

(vs. ~50% of SFR >= LIRG at z>1)

No GRBs from highly embedded galaxies

High metallicity + chemical homogeneity,
or age/evolution effect?