The Darkest GRBs of the Swift Era

Daniel Perley
(Hubble Fellow, Caltech)

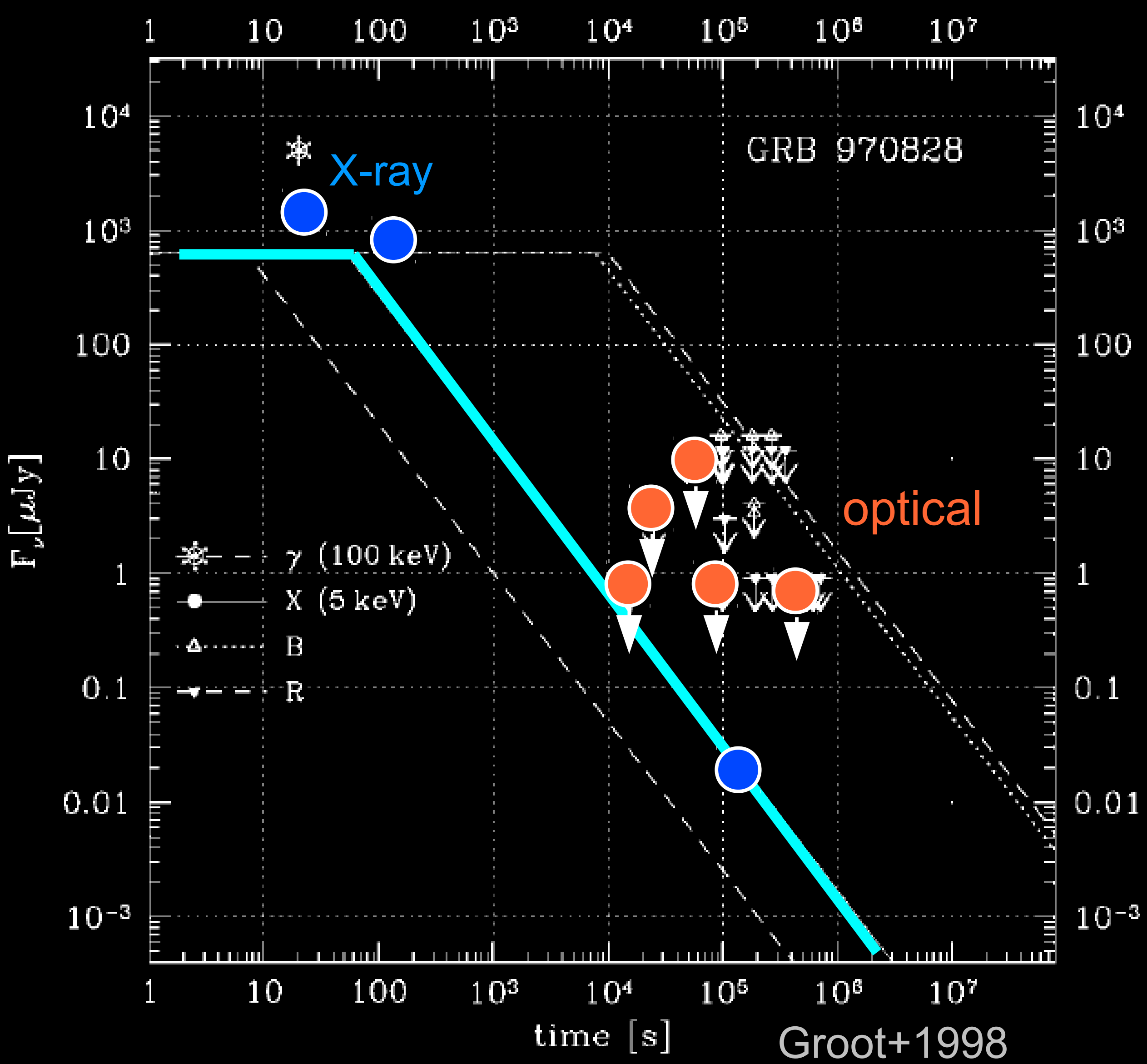
Brad Cenko
Nial Tanvir
Andrew Levan

Joshua Bloom
Jens Hjorth
Johan Fynbo
Daniele Malesani
Thomas Krühler
Adam Morgan
Nat Butler
Maryam Modjaz

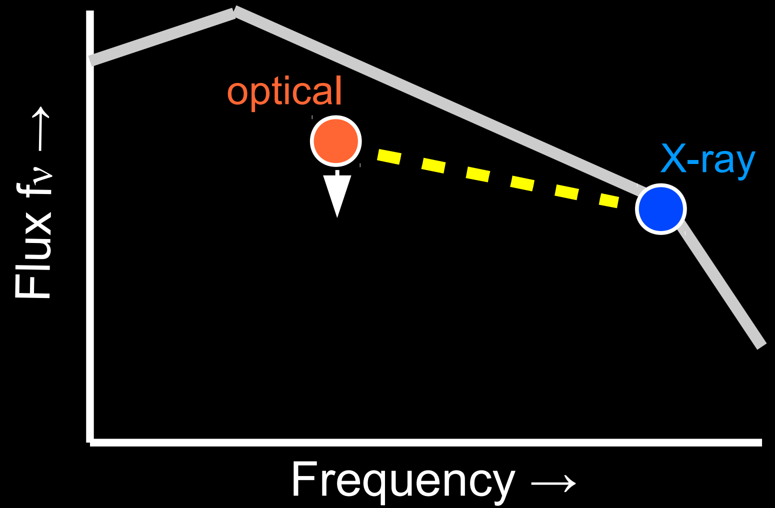
Dark Gamma-Ray Bursts

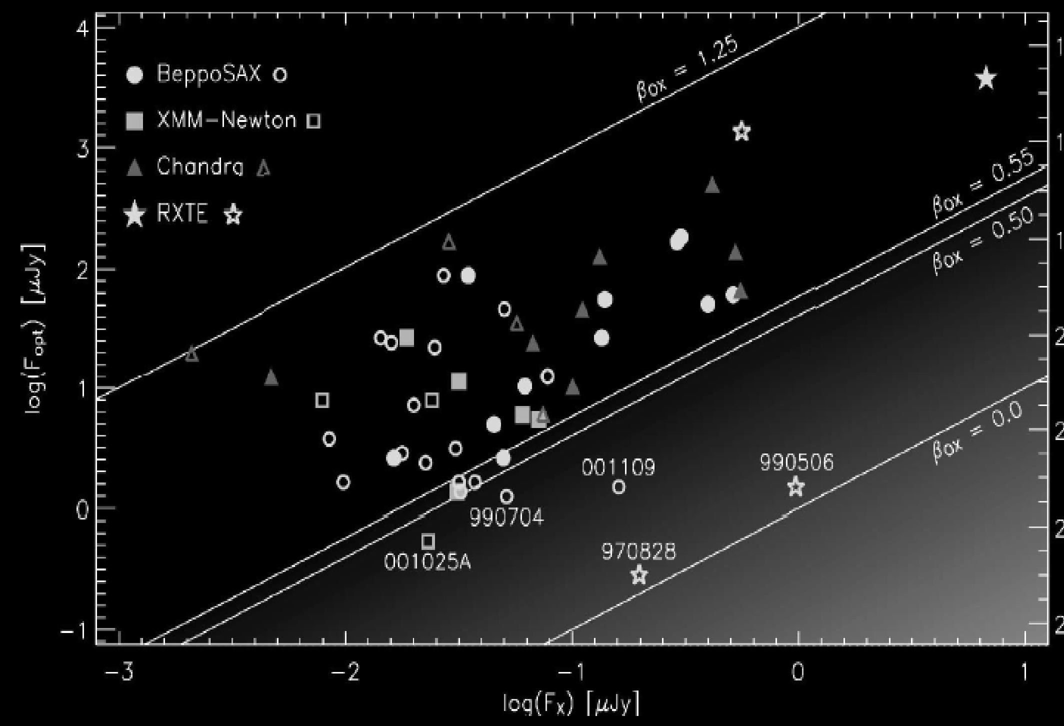
Generically:

Events with surprisingly faint (generally, undetected) optical afterglows.



Dark Gamma-Ray Bursts





Jakobsson+2004: use **βox**

If flatter than synchrotron permits (βox<0.5), burst is absorbed (or nonsynchrotron).

Van der Holst+ 2009: βox<βx-0.5
(but typical βx~1.0; very similar in practice)

The Origins of Dark GRBs

Intrinsic causes:

- Low-luminosity afterglow

Extrinsic causes:

- Obscured by dust in host
- Obscured by IGM at $z > 6$

All appear to contribute to some degree:
need a *uniform, complete* sample
to quantify frequencies!

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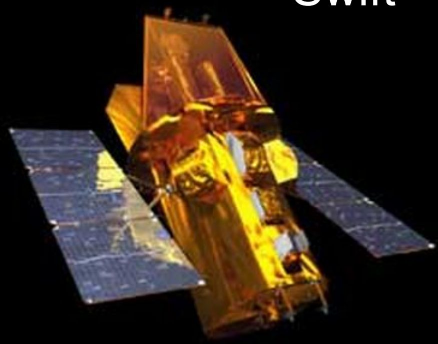
Swift

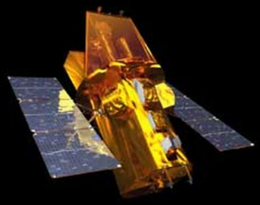


+

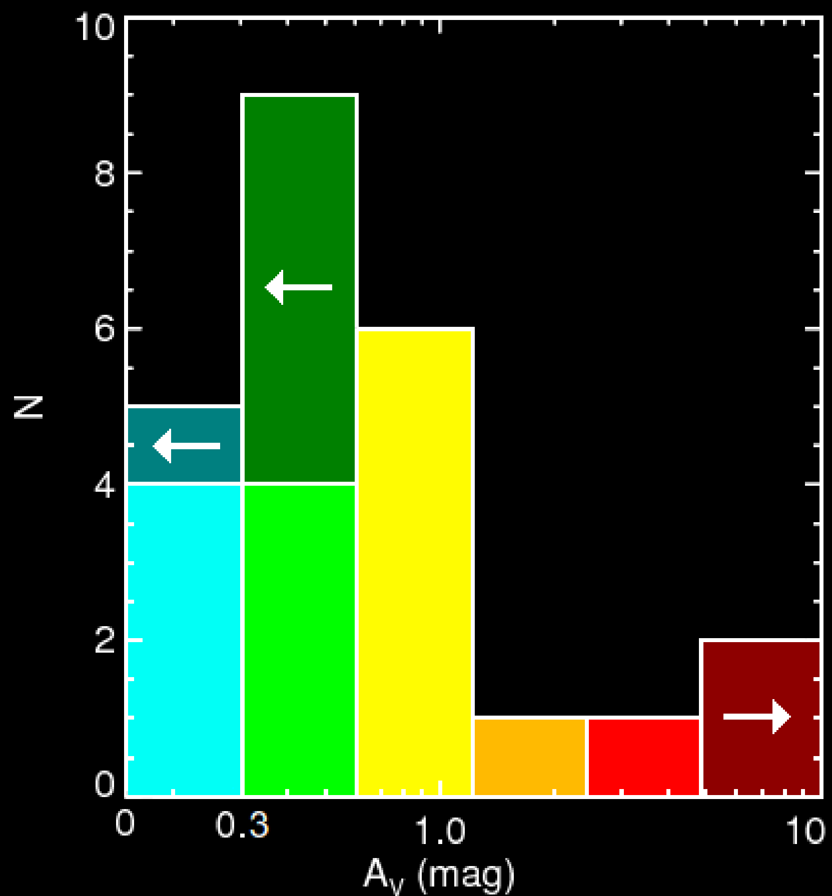
Cenko+ 2009
Perley+ 2009

Greiner+ 2011
Kruhler+ 2011

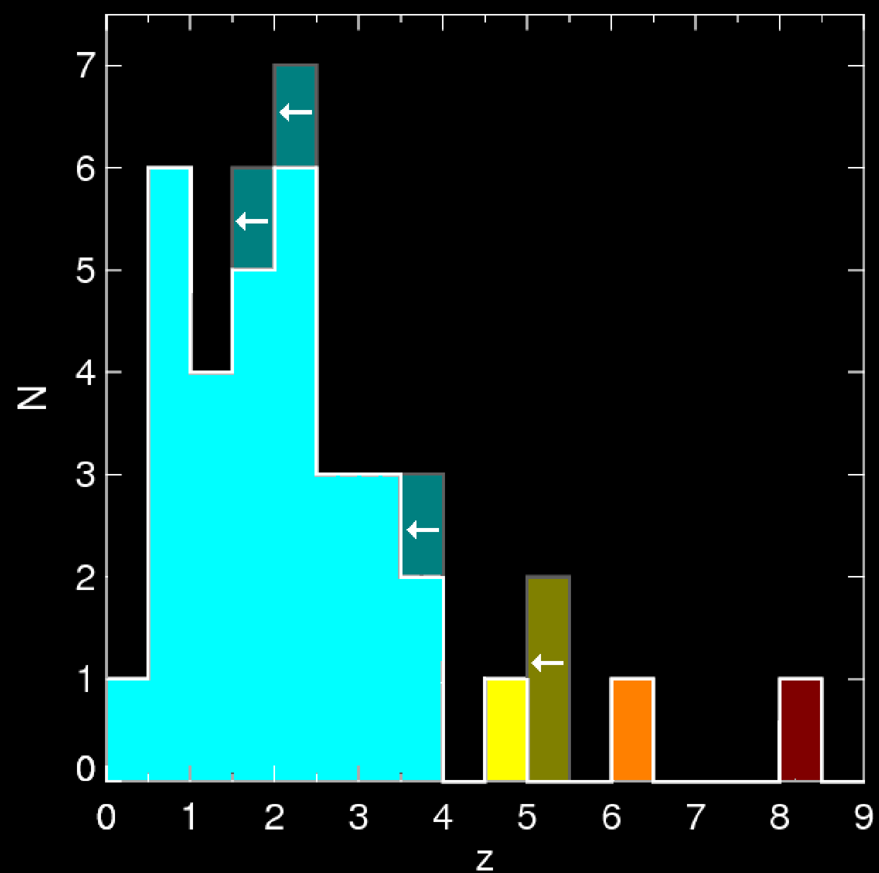
Origins of Dark Bursts



P60 extinction histogram



P60 redshift histogram



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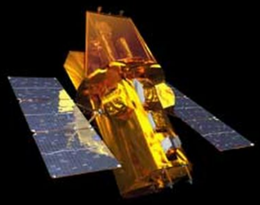
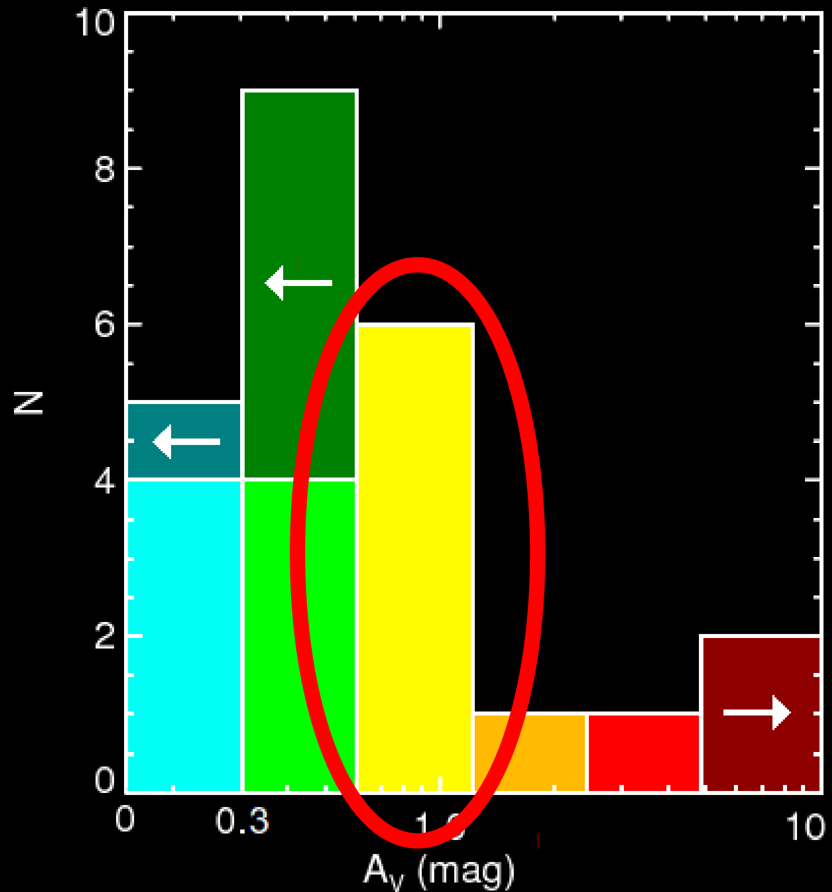
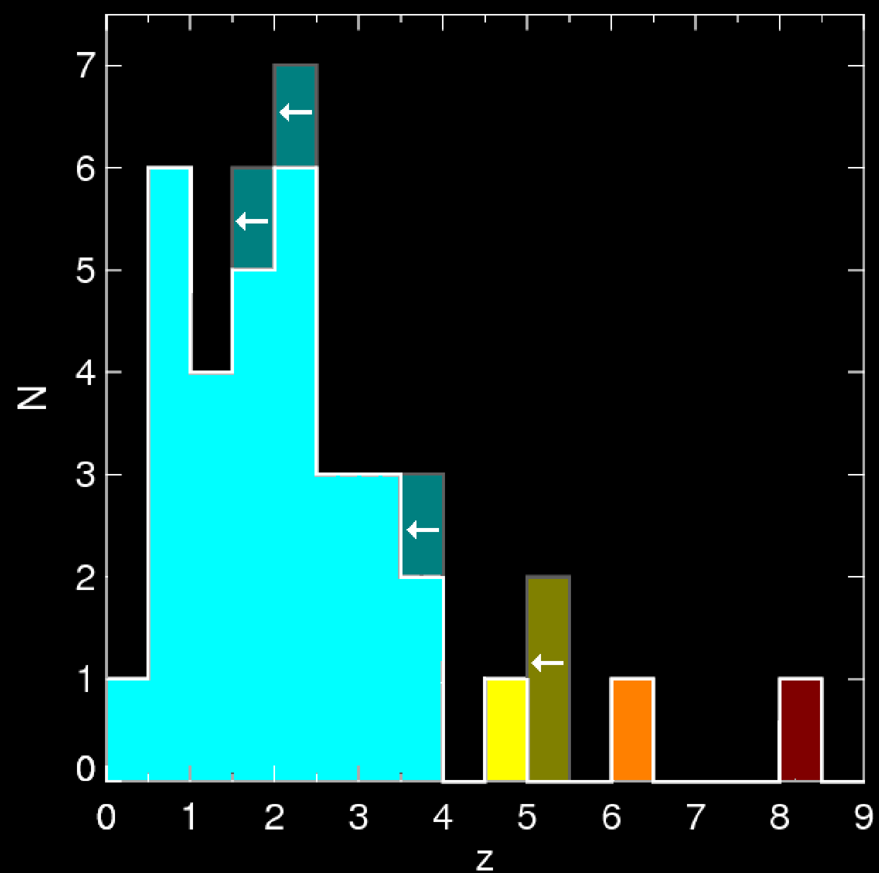


Mostly moderately (Av = 0.5-1.5) dust-obscured at moderate-z.





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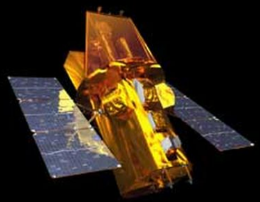
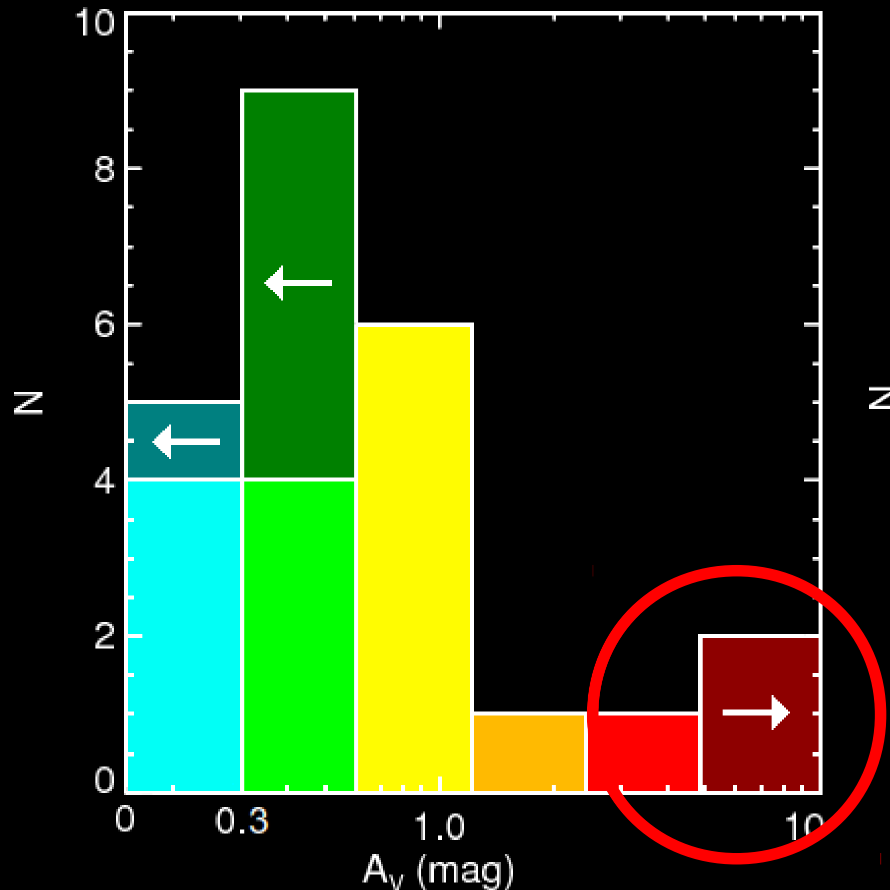
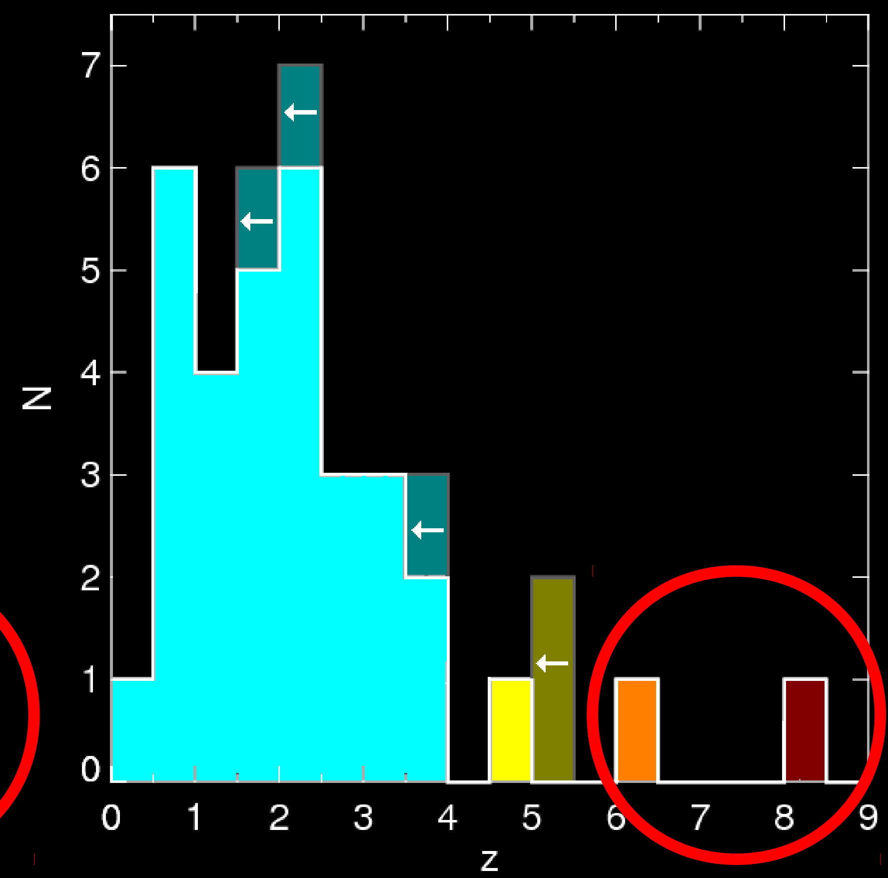


Fewer very highly obscured events.
Very few high-z events.





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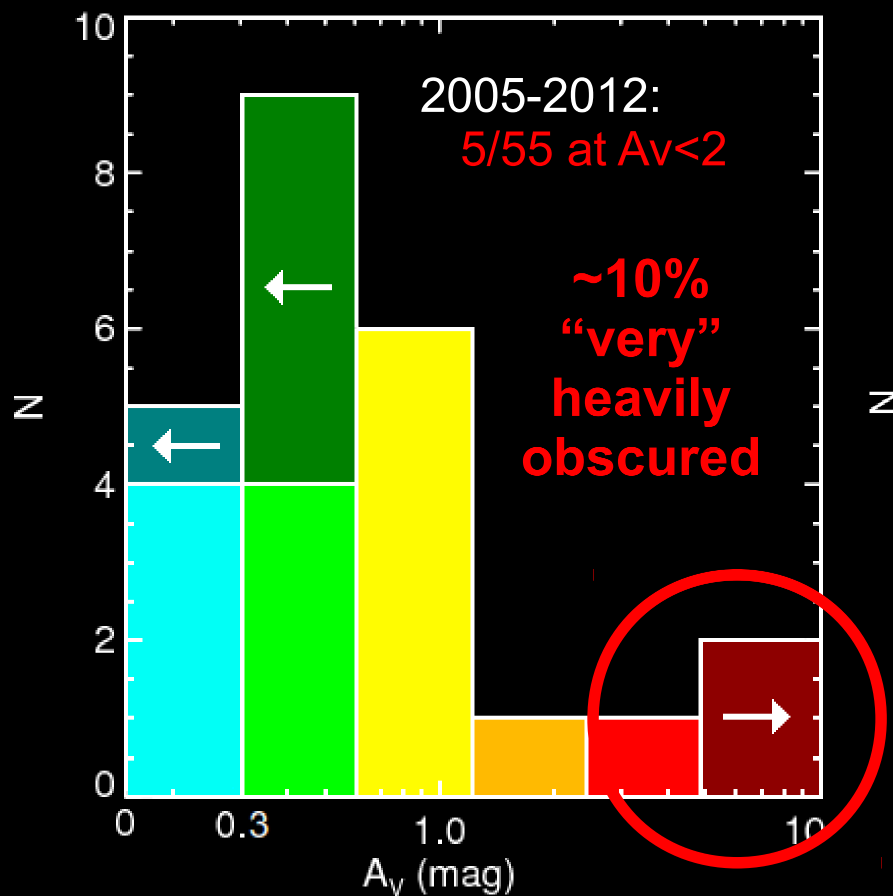

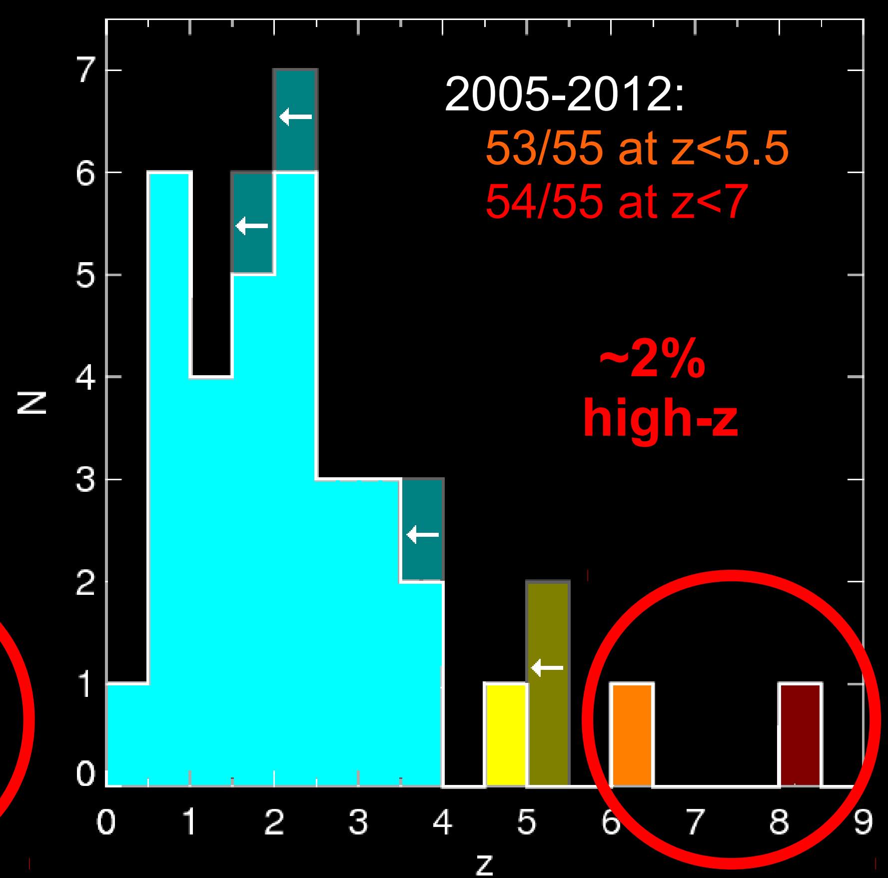

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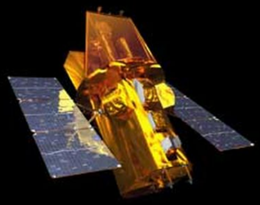

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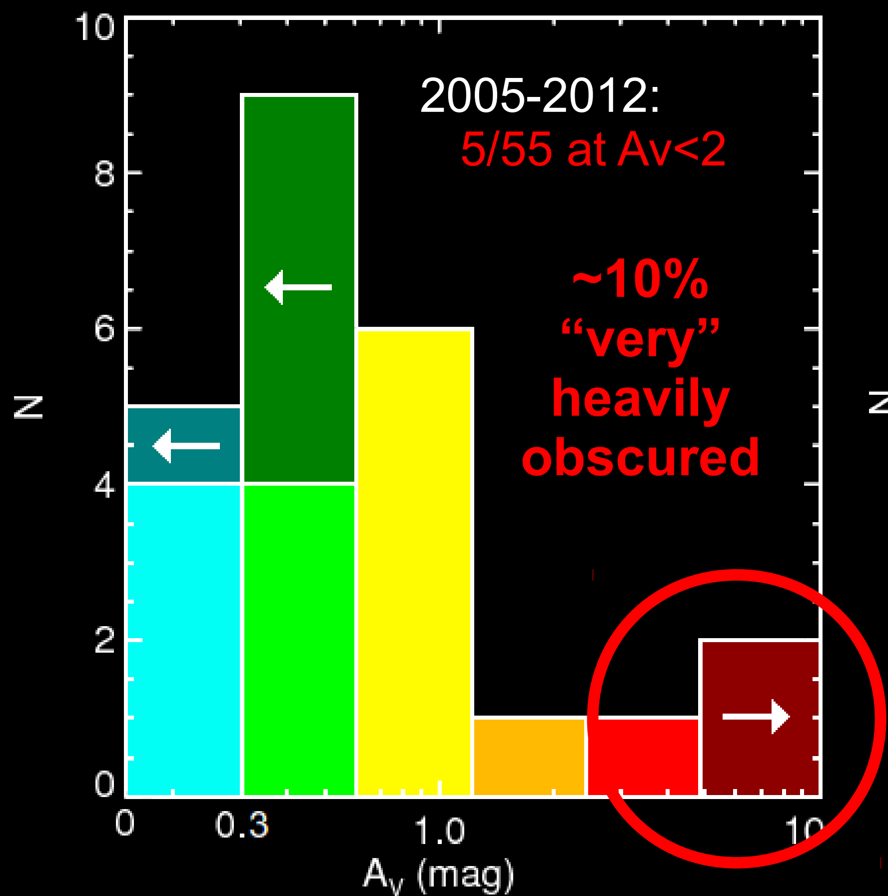
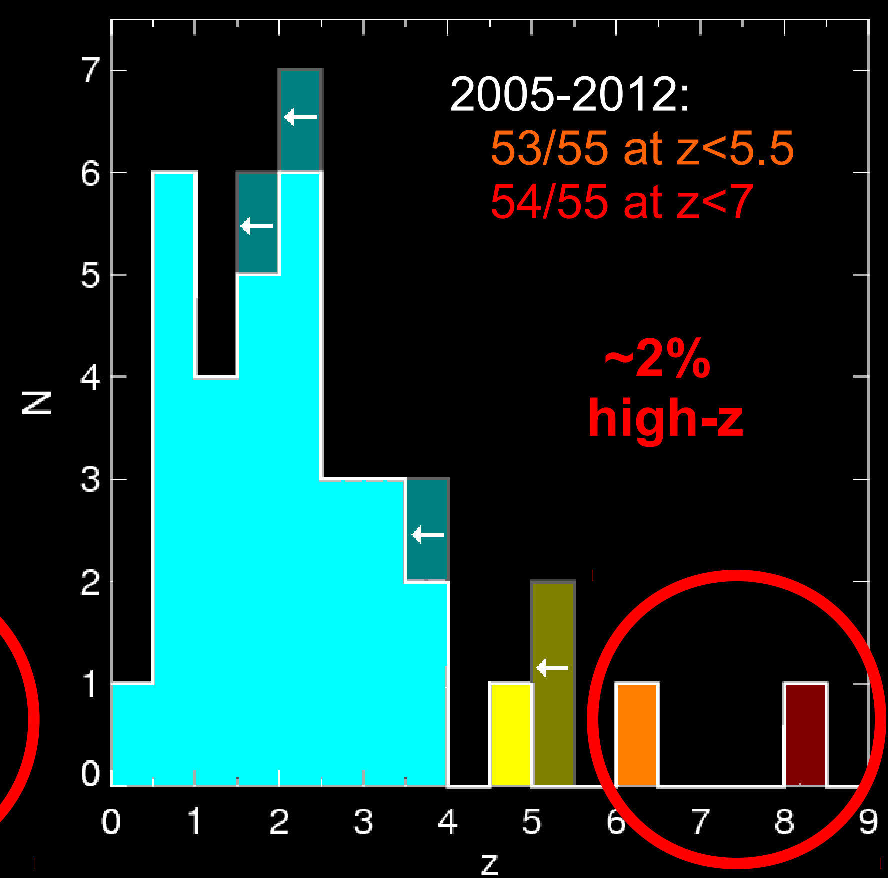




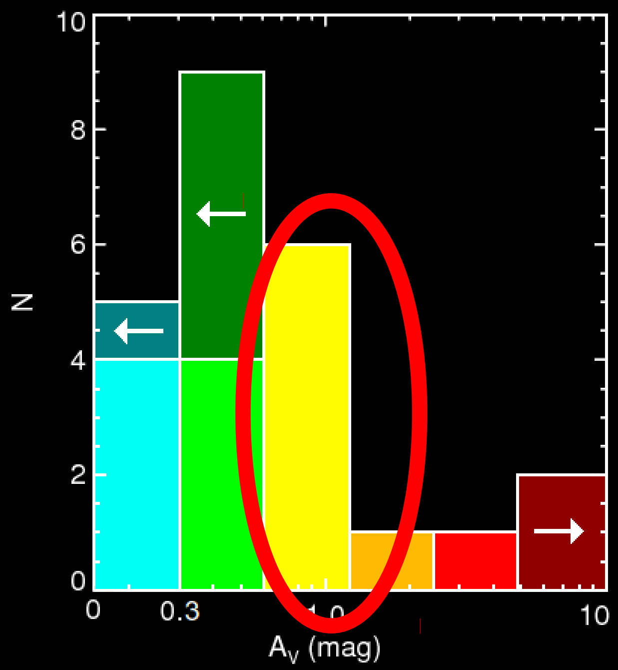
Only a handful in single-telescope samples.
How to find more?

Finding the Darkest Bursts

Search through GCN circulars and published literature for reports of events with...

No optical detection (1m+ class at early times,
4m+ class at late times)
Unusually faint optical or NIR detection
Bright NIR detection, fainter optical detection
Reports of red color
… etc.

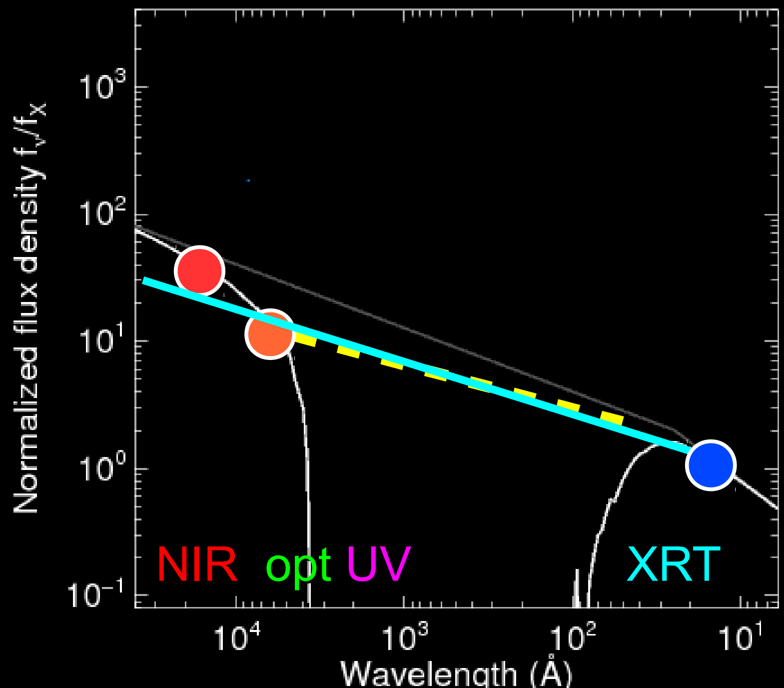
Many of these ***aren't*** (very) ***dark!***



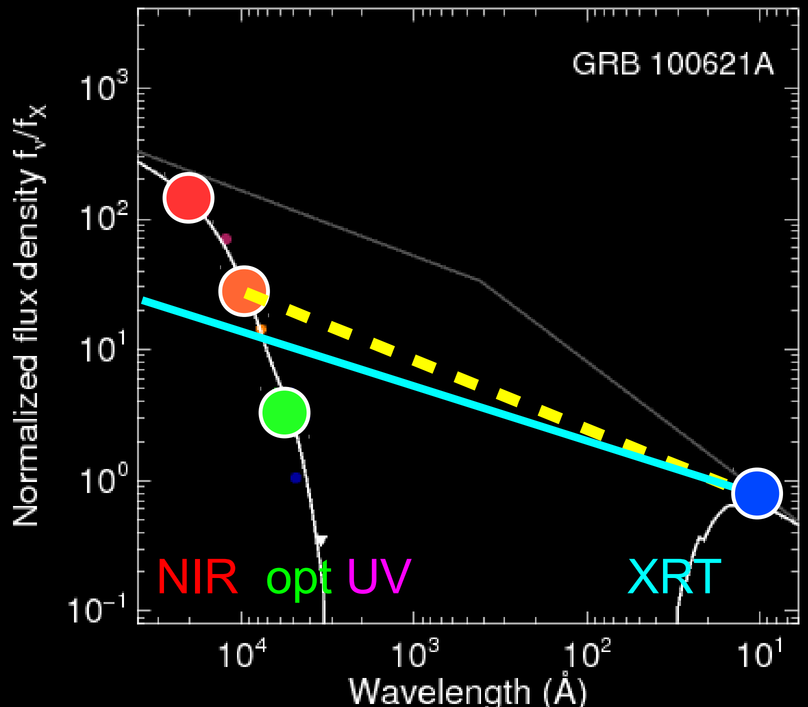
Limitations of βox

Minimum condition only: says little about *degree* of extinction

Very mild obscuration can easily produce βox < 0.5 at moderate-z



Fairly dusty events can have “normal” βox (if at low-z and/or $\beta_{intrinsic}$ ~ 1)

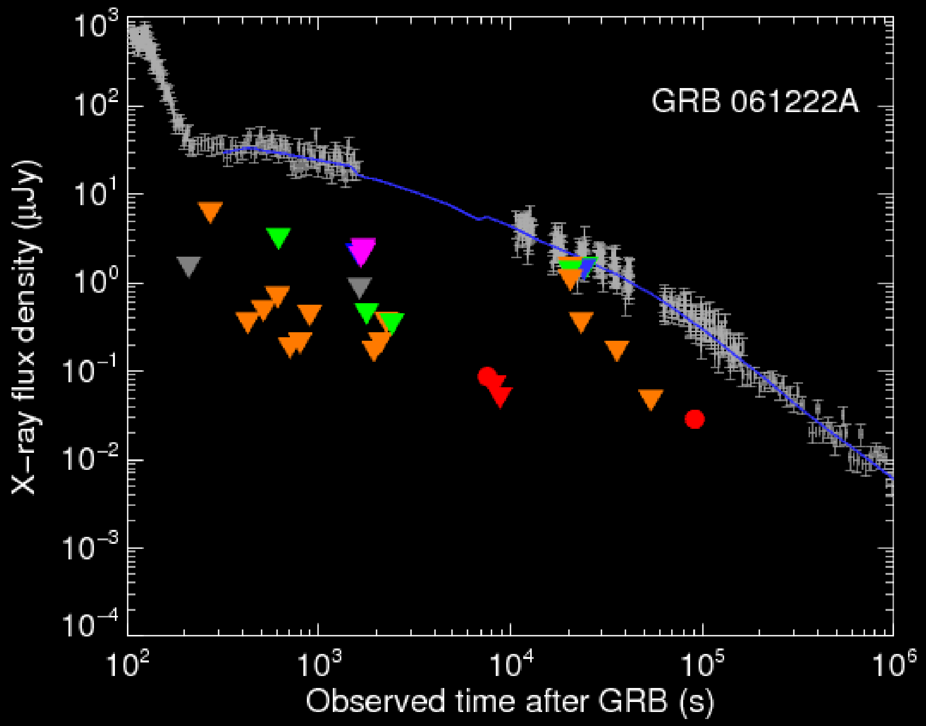


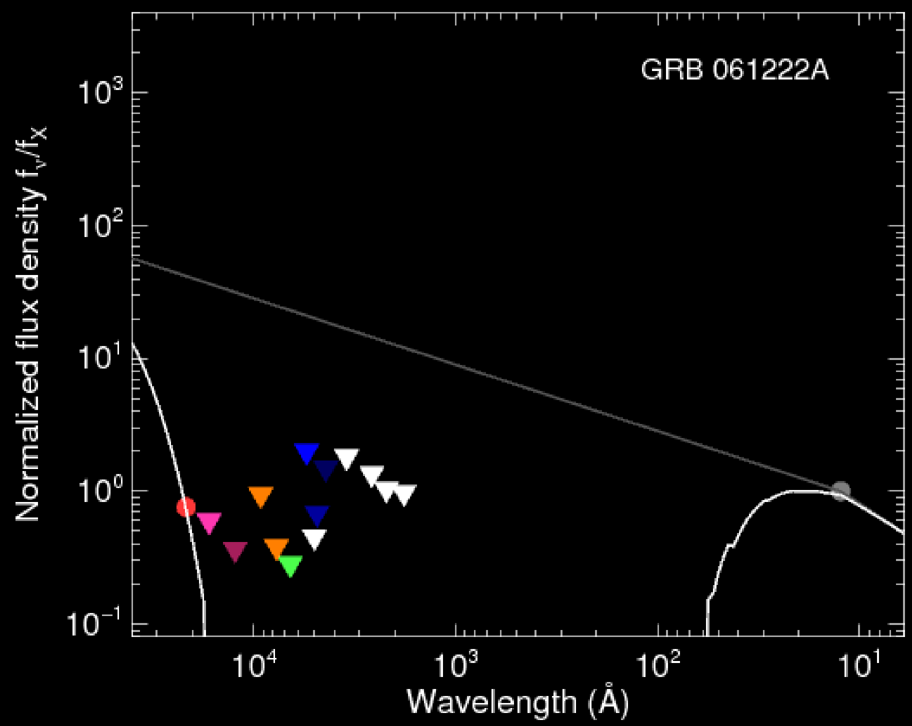
Defined for R-band only (arbitrary) but extinction is *extremely* wavelength (and therefore redshift) dependent – e.g. J-band limit “worth” more than V-band, and colors are clinching!

Identifying and Ranking the Darkest Bursts

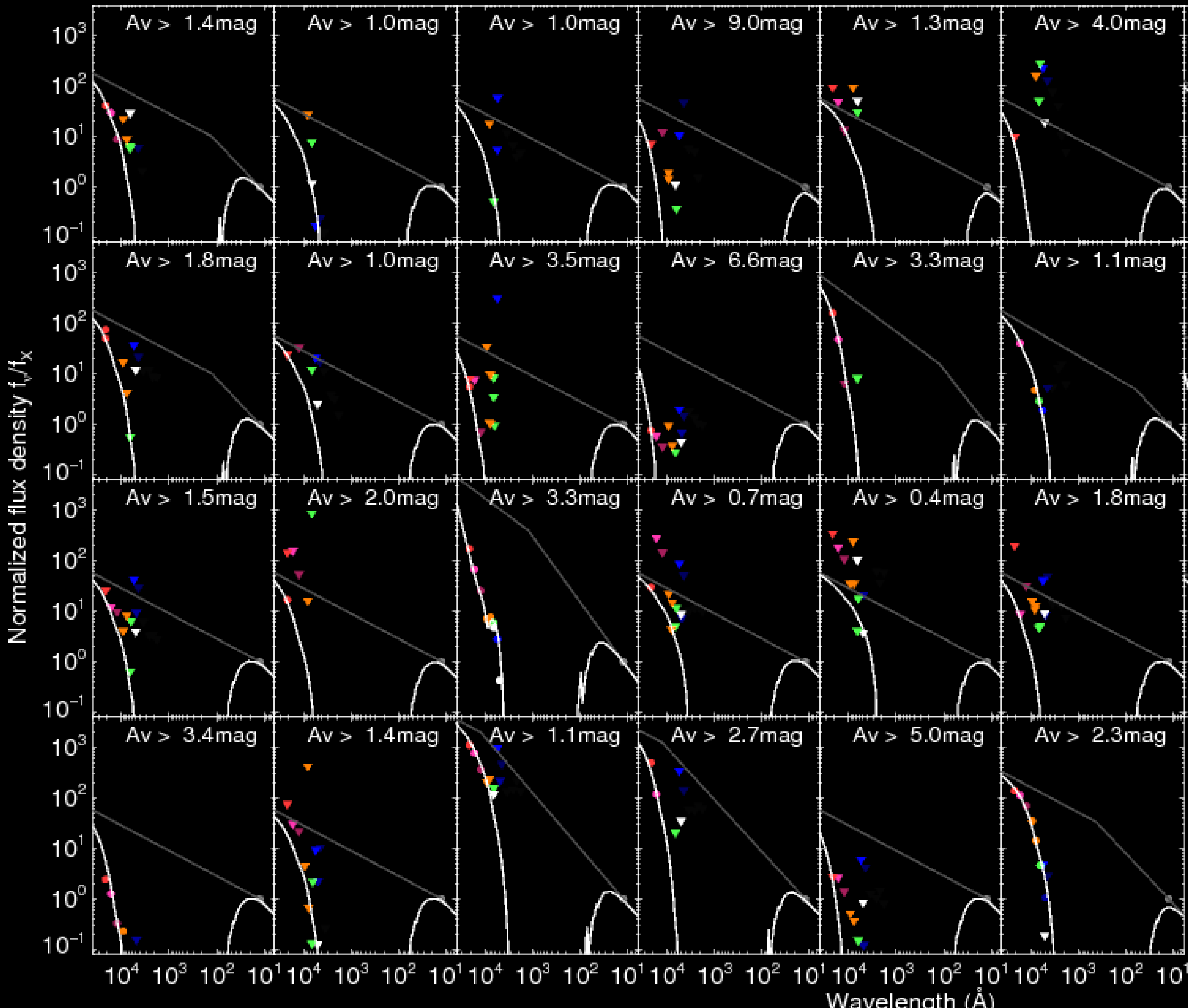
Most dark bursts are dusty: treat as an extinction fitting problem (even with limited data).

Construct “minimum coeval SED” and fit with extinction.





Many very dusty Swift GRBs

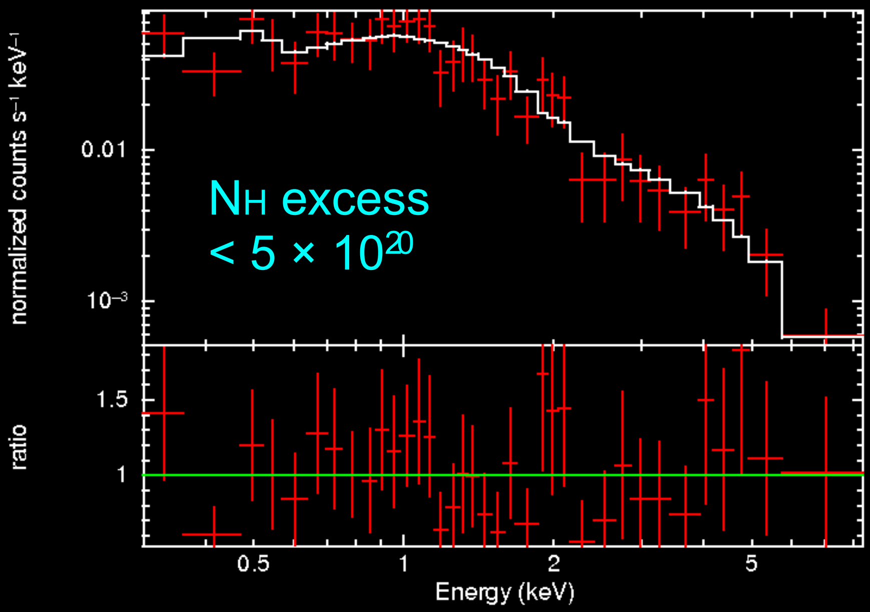


40 with Av > 1.0 found so far (likely several others from qualitative afterglow reports)

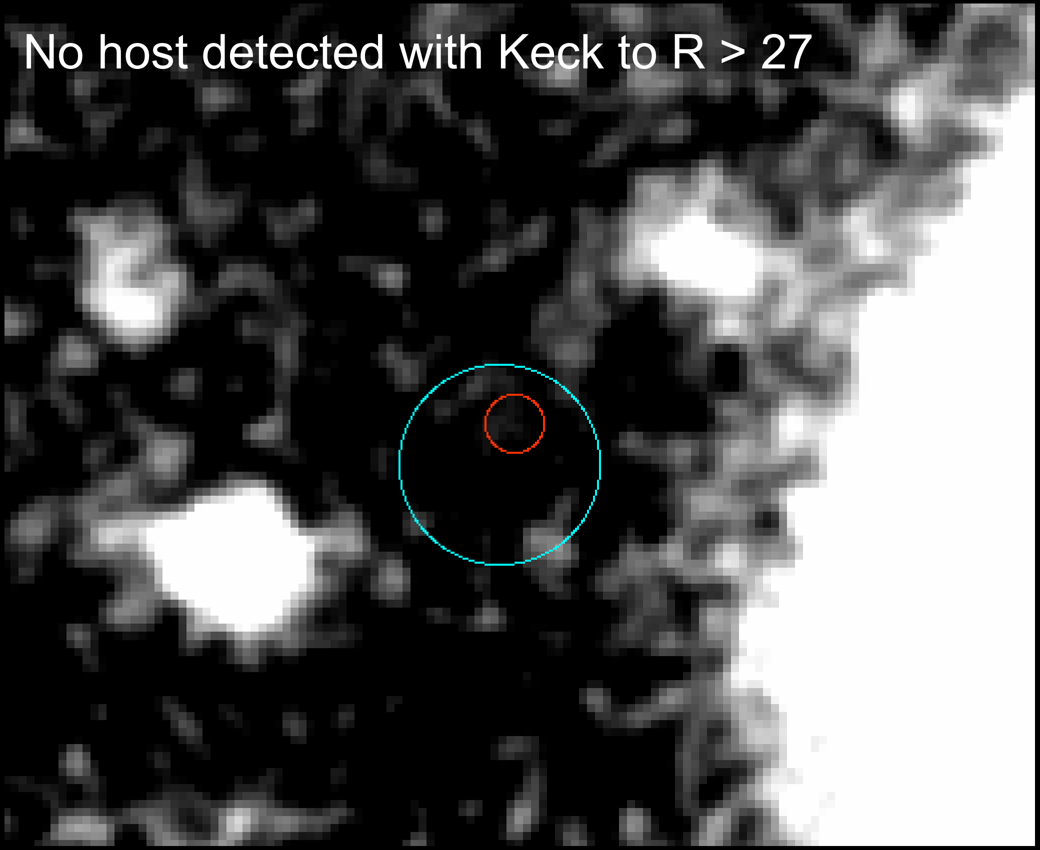
High-z Bursts

GRB 100205A: Very likely at z ~ 10

If photo-z from afterglow is not available, still separable from dusty events with X-ray N_H and deep host follow-up.



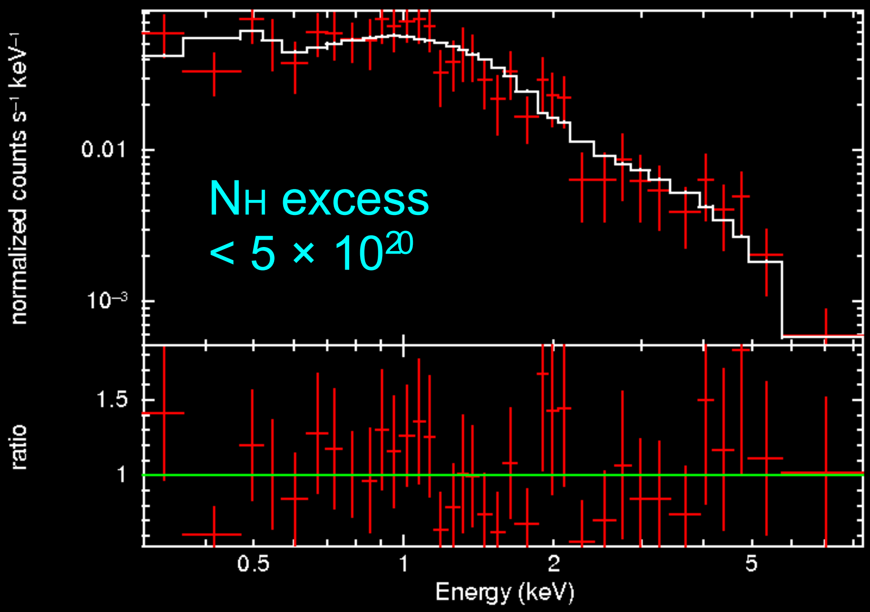
No host detected with Keck to R > 27



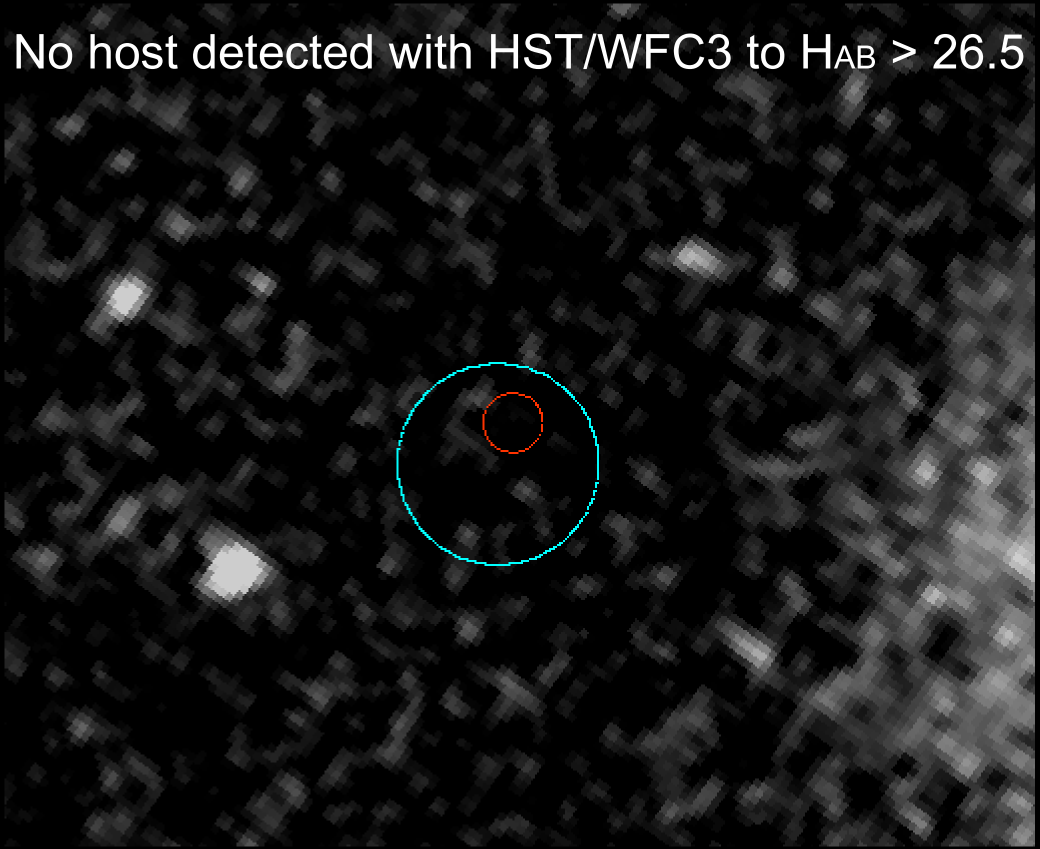
High-z Bursts

GRB 100205A: Very likely at z ~ 9

If photo-z from afterglow is not available, still separable from dusty events with X-ray N_H and deep host follow-up.



No host detected with HST/WFC3 to H_{AB} > 26.5



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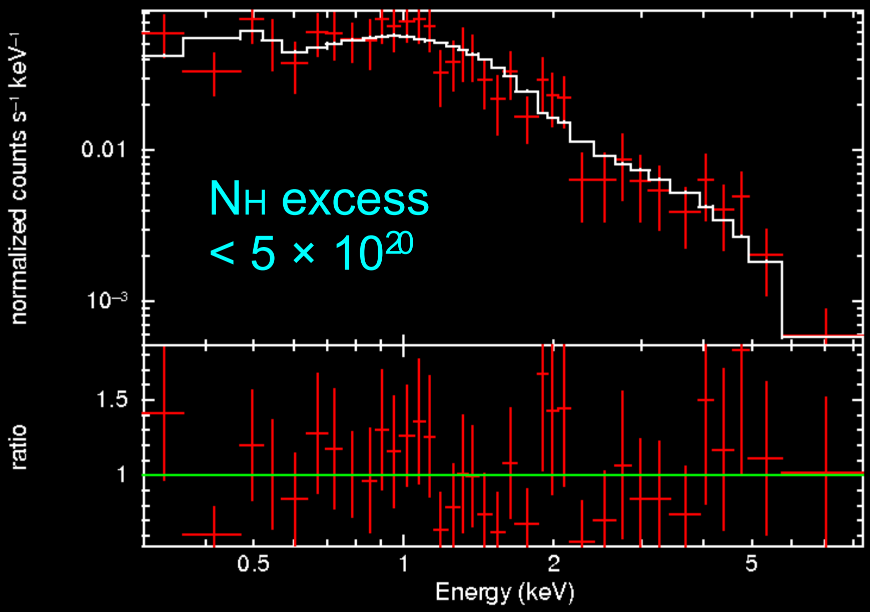

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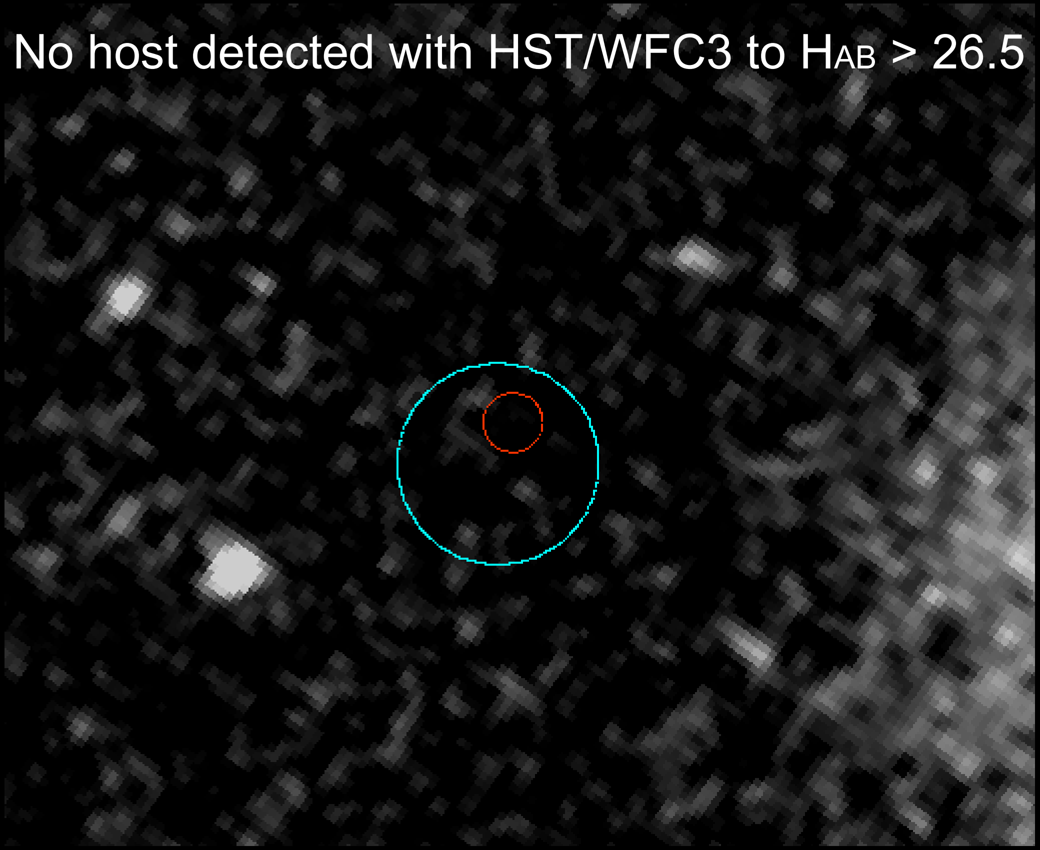


~5 such events in entire Swift sample to date.

Rates of the Darkest Bursts

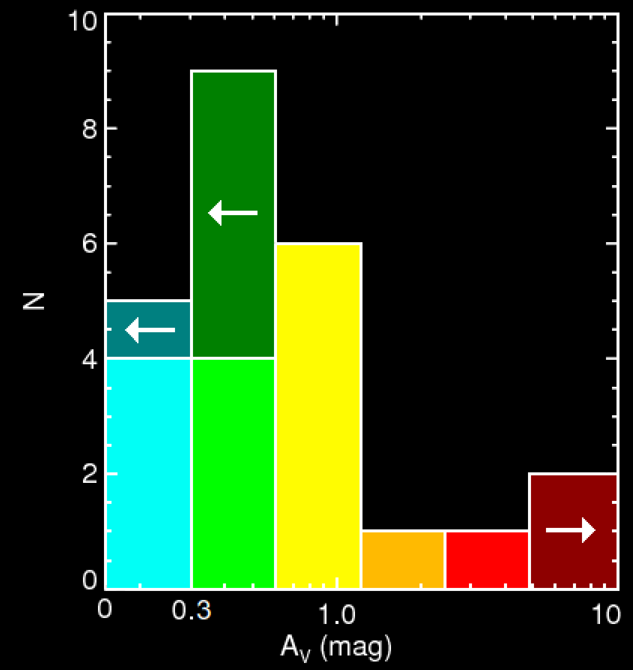
643 Swift GRBs (by end 2011)

~ 40 observed Av > 1
~ 5 observed z > 7 (likely)

>5% heavily obscured (P60: 7-20%)
>~1% very high-z (P60: 0.2-5%)

Conclusions (Part I)

Moderately dusty (Av ~ 0.5 mag) events are quite common **(~25%)**, and explain most β_{OX} dark bursts.
(Not a qualitatively different distribution from optically-bright bursts.)

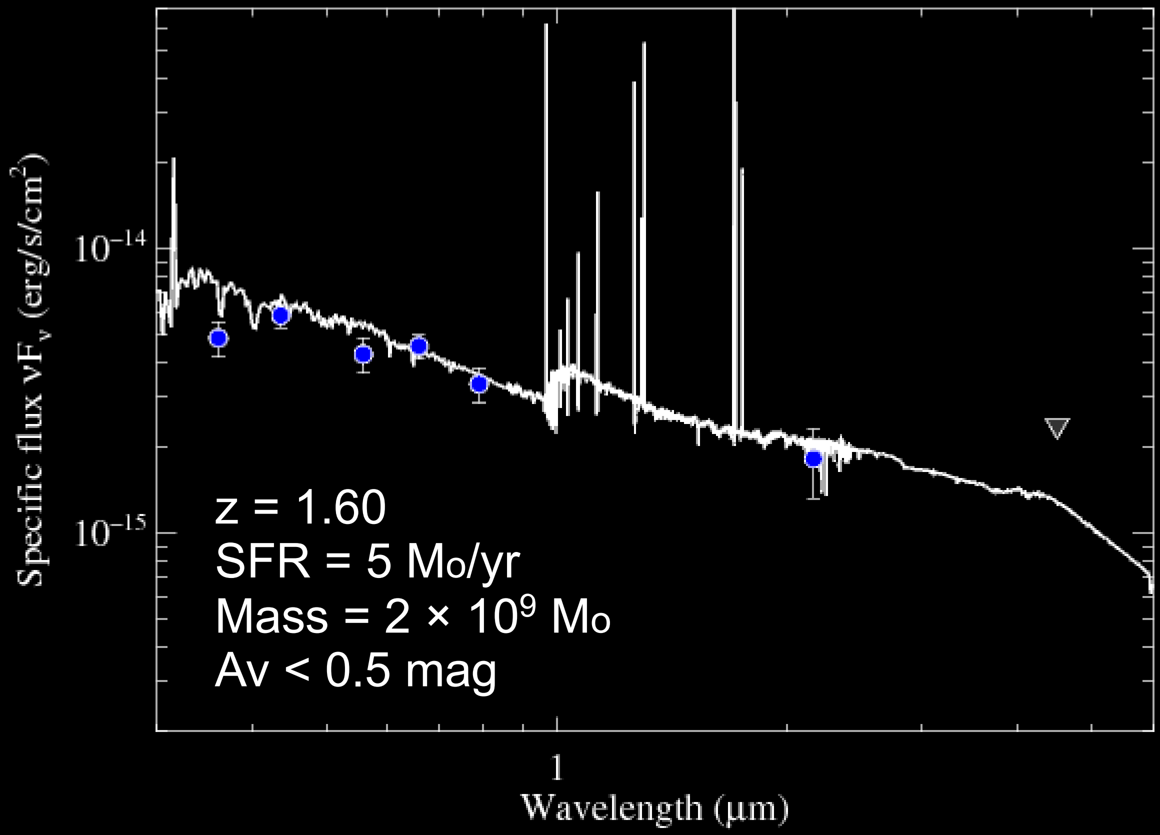


Extremely obscured events (Av ~ 2-10 mag) are also present, but in small numbers **(~10%)**.
Thanks to Swift, the sample of these events is now quite large. **(~40+)**

High-z events remain extremely rare **(~1-2%)**

Where are the dusty, luminous, massive hosts?

GRB 990123, a "typical" (non-dark) host galaxy:



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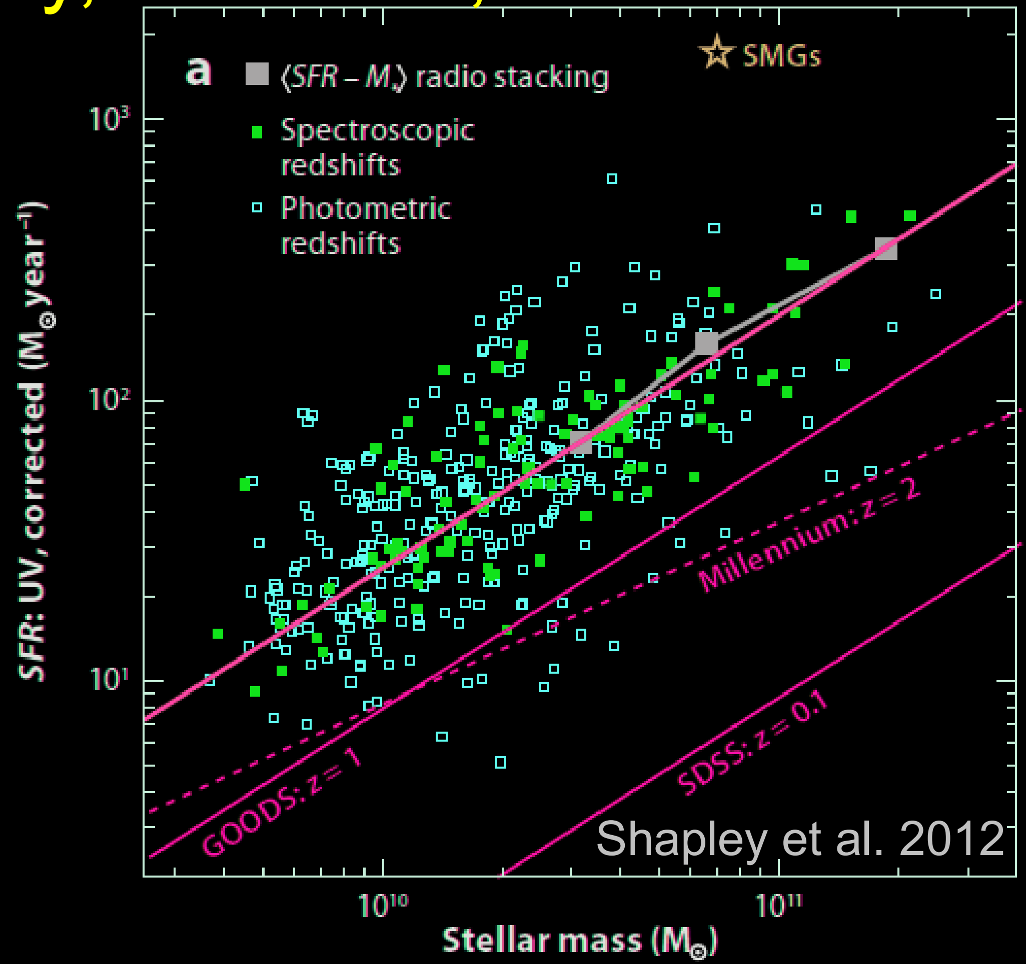

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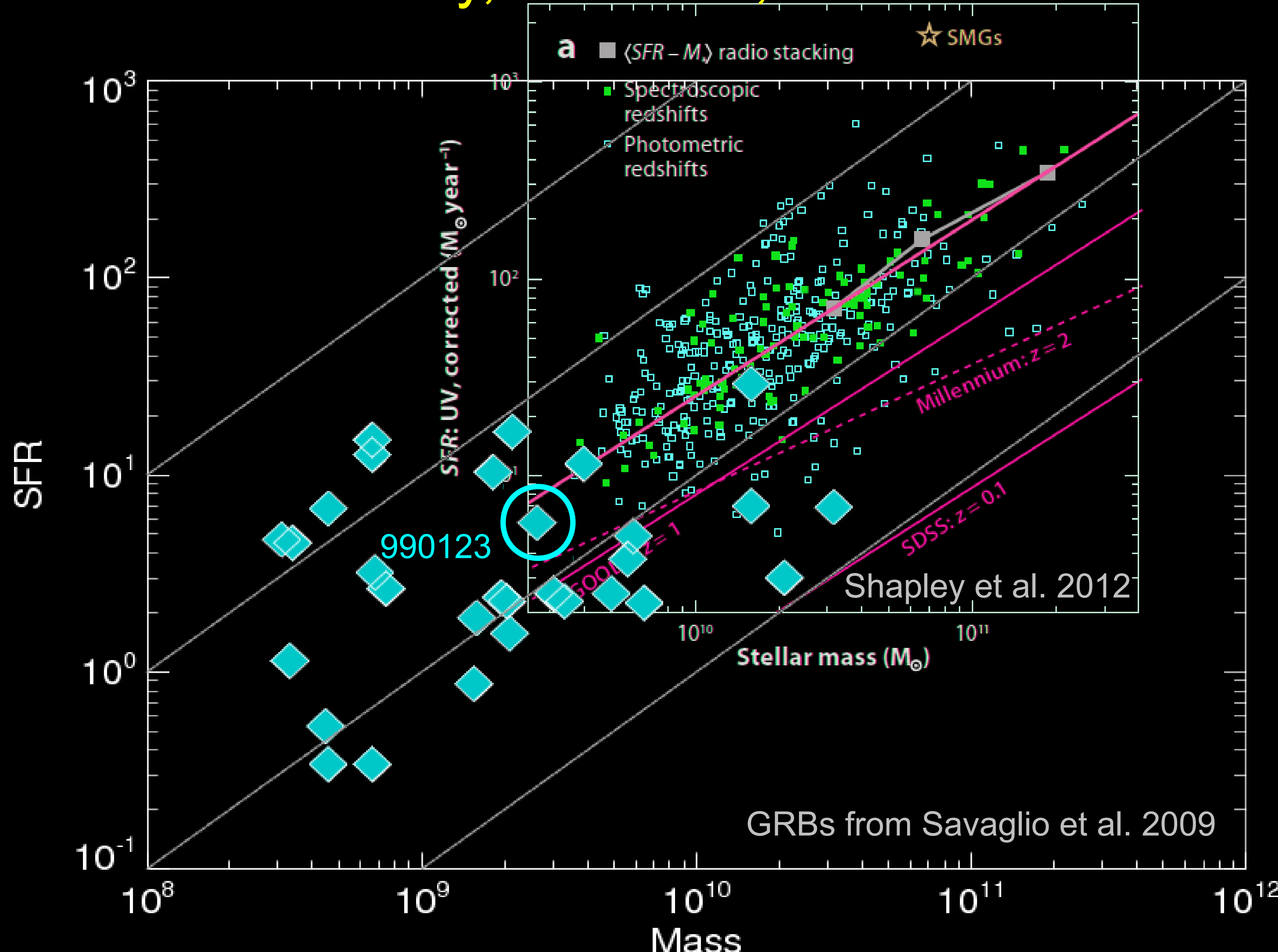
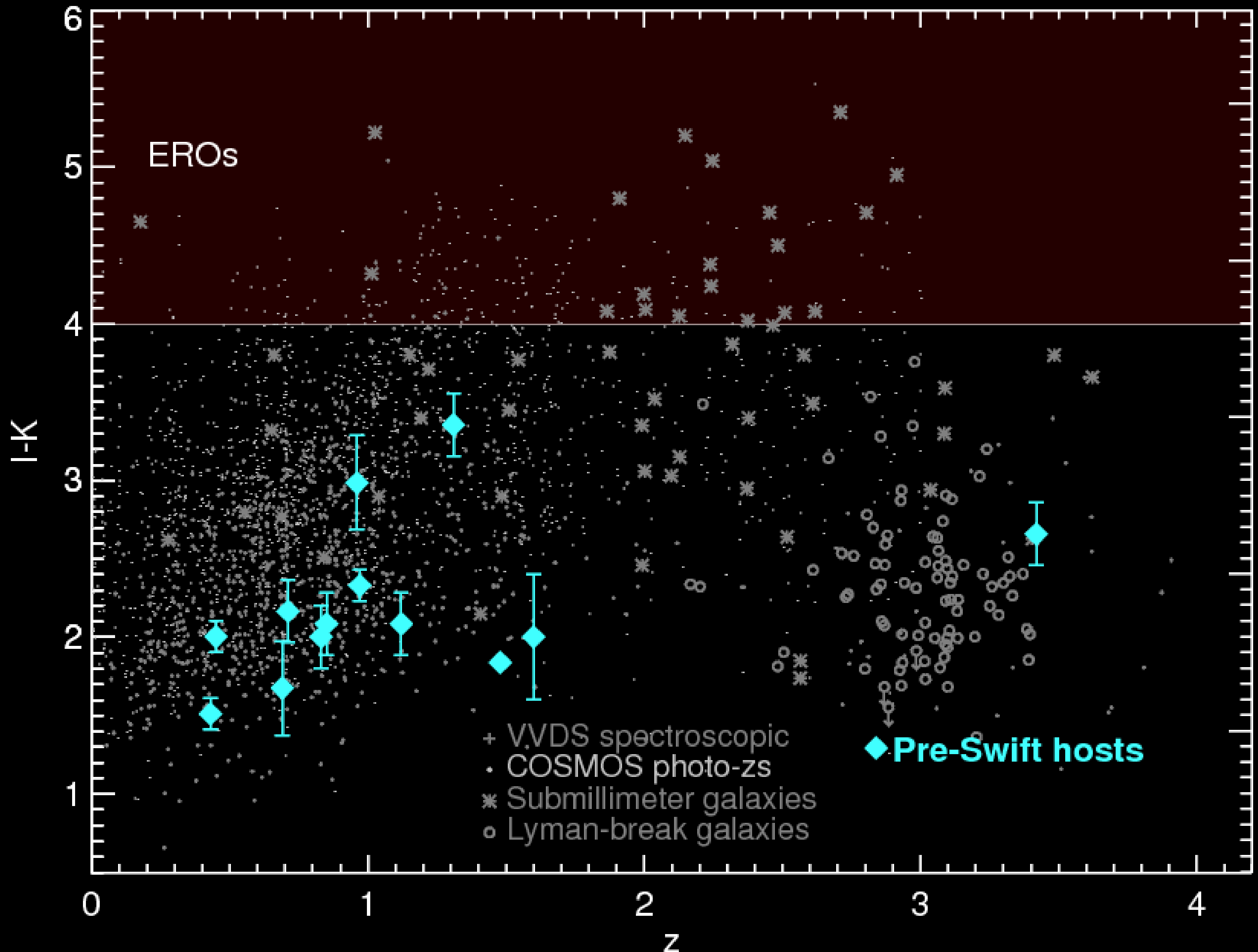


Pre-Swift GRB Colors



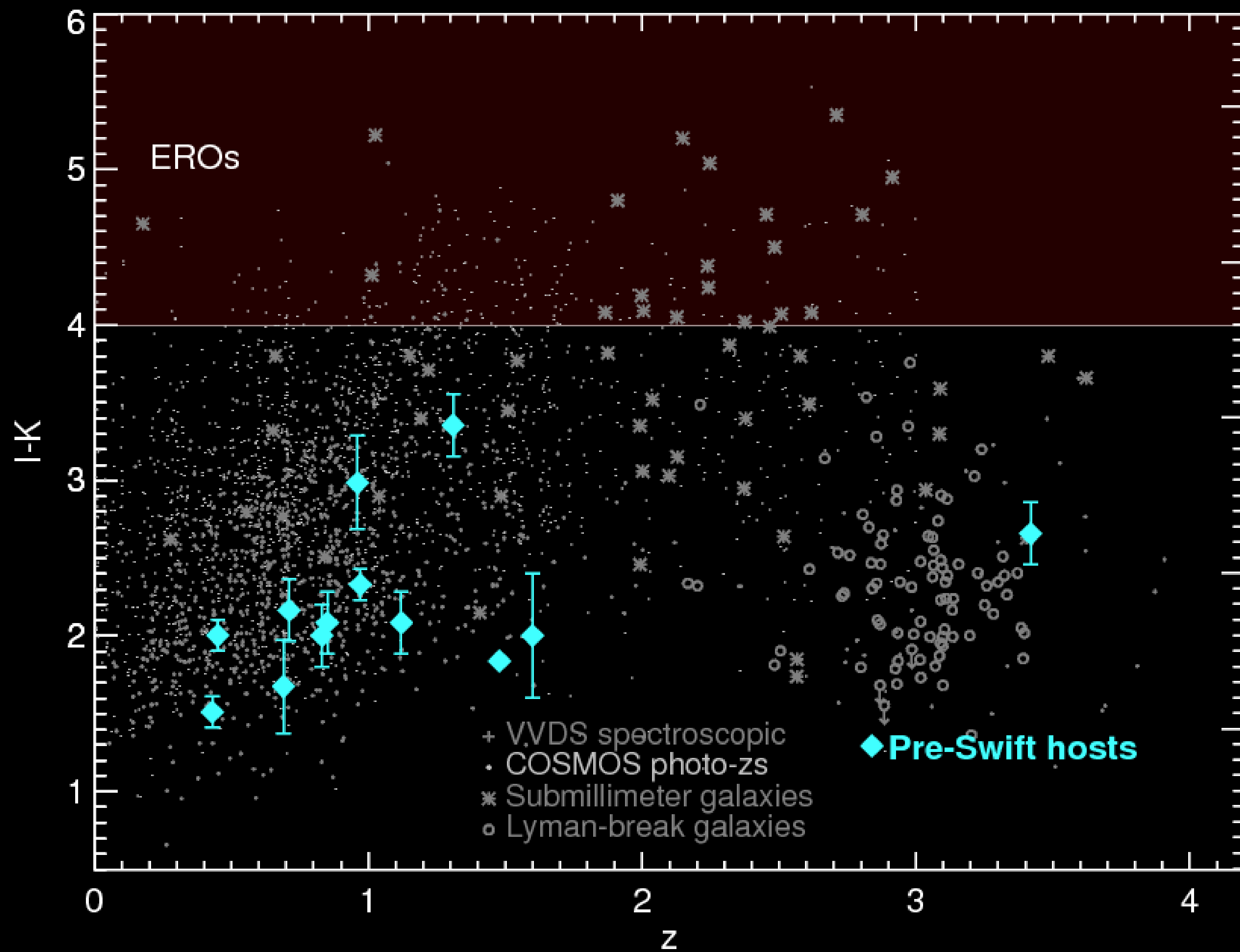
Dark GRB Host Campaign

Observe **every**
Av >~ 1.5 mag event
we can find.

2005-2009 sample

30 dark host fields (29 30 detected!)
19 with spectroscopic redshift
2 with photometric redshift

Dramatic difference in optical-NIR colors



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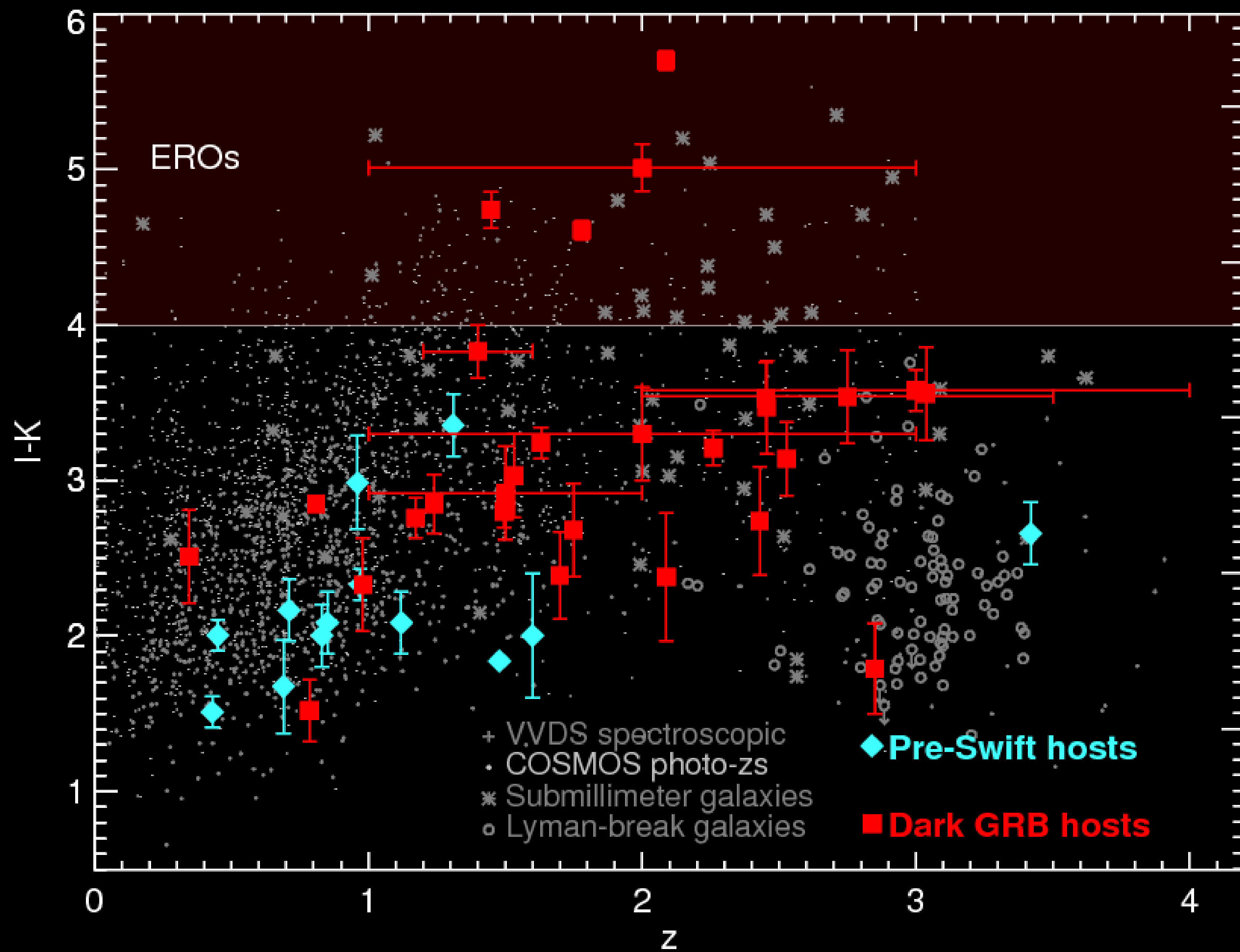
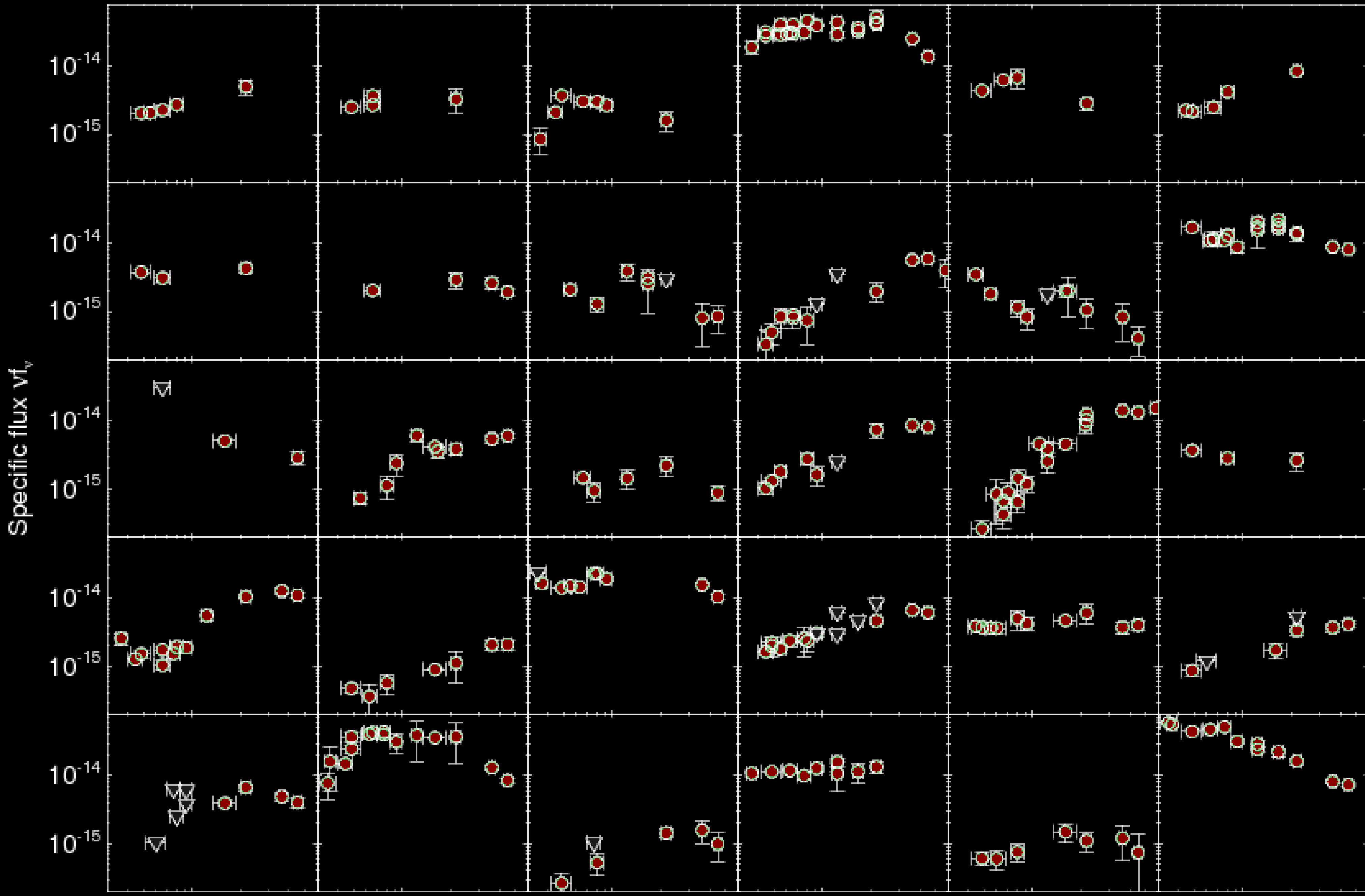


Modeling host galaxy properties



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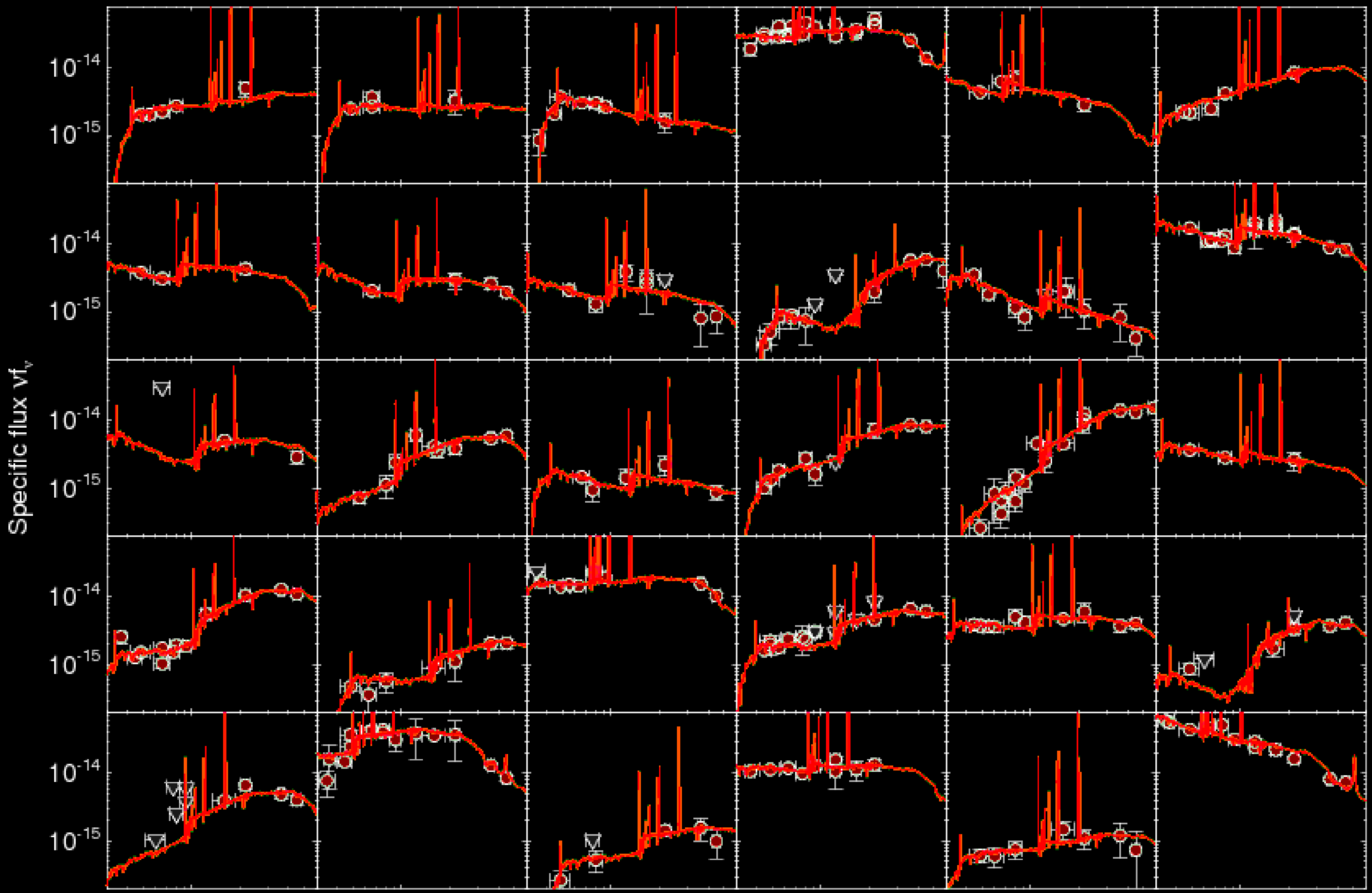
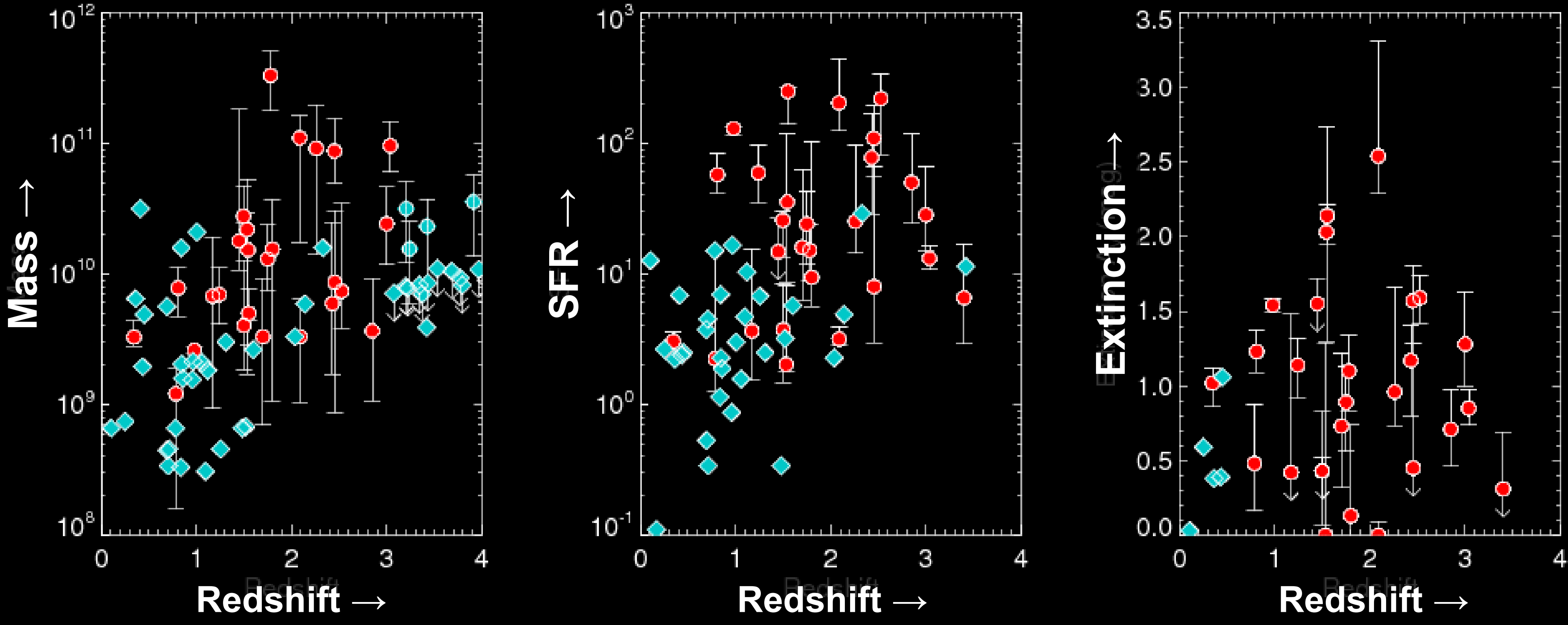


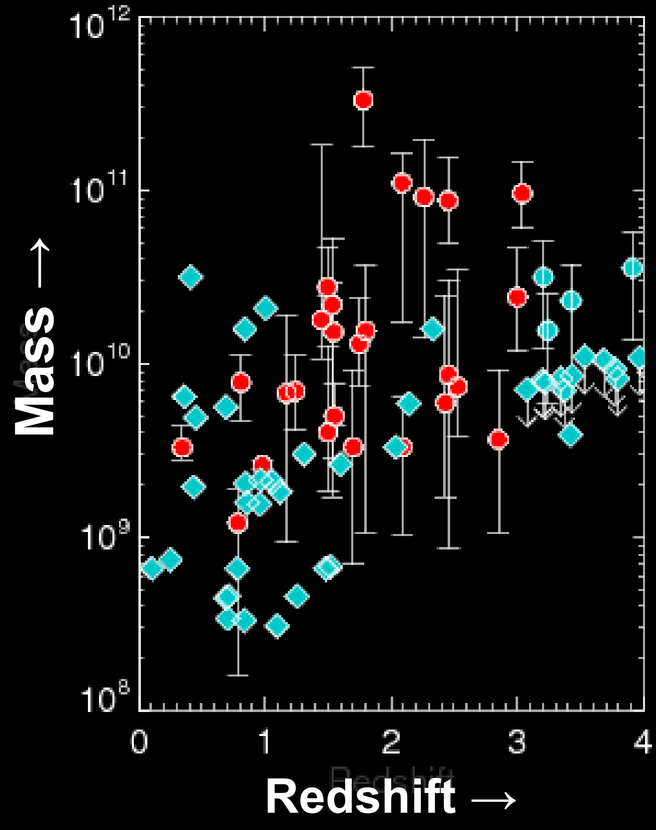
Differences in every parameter



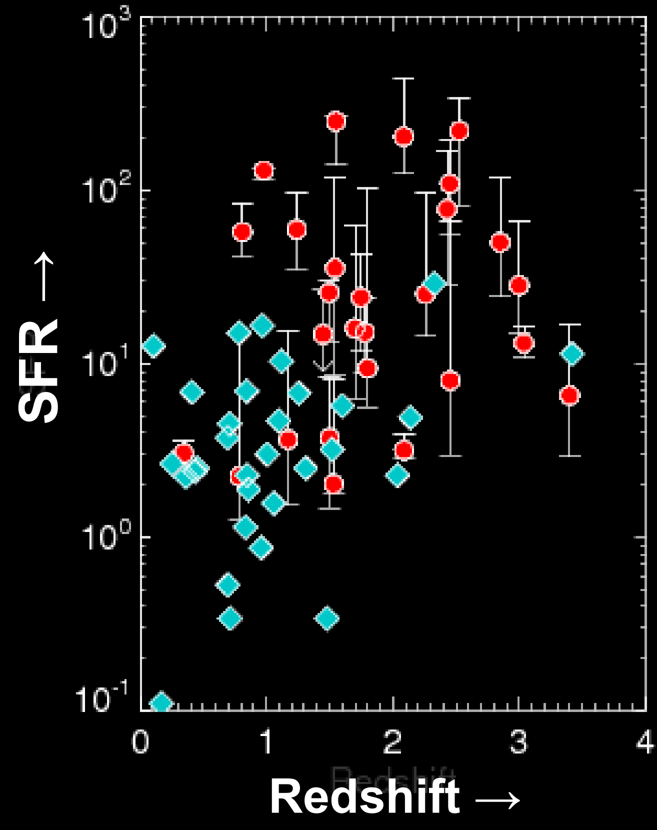
Differences in every parameter

Dark GRB hosts are...

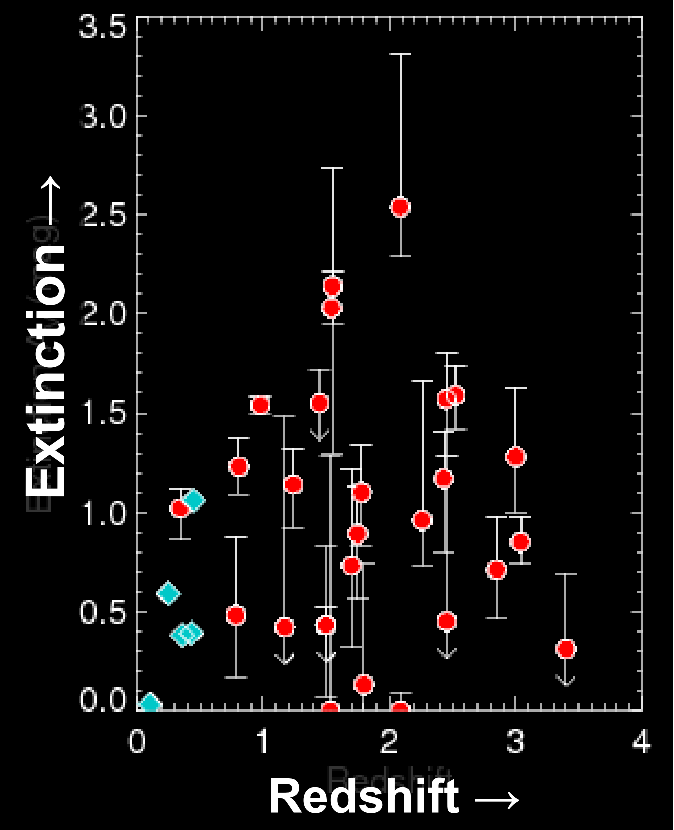
More massive



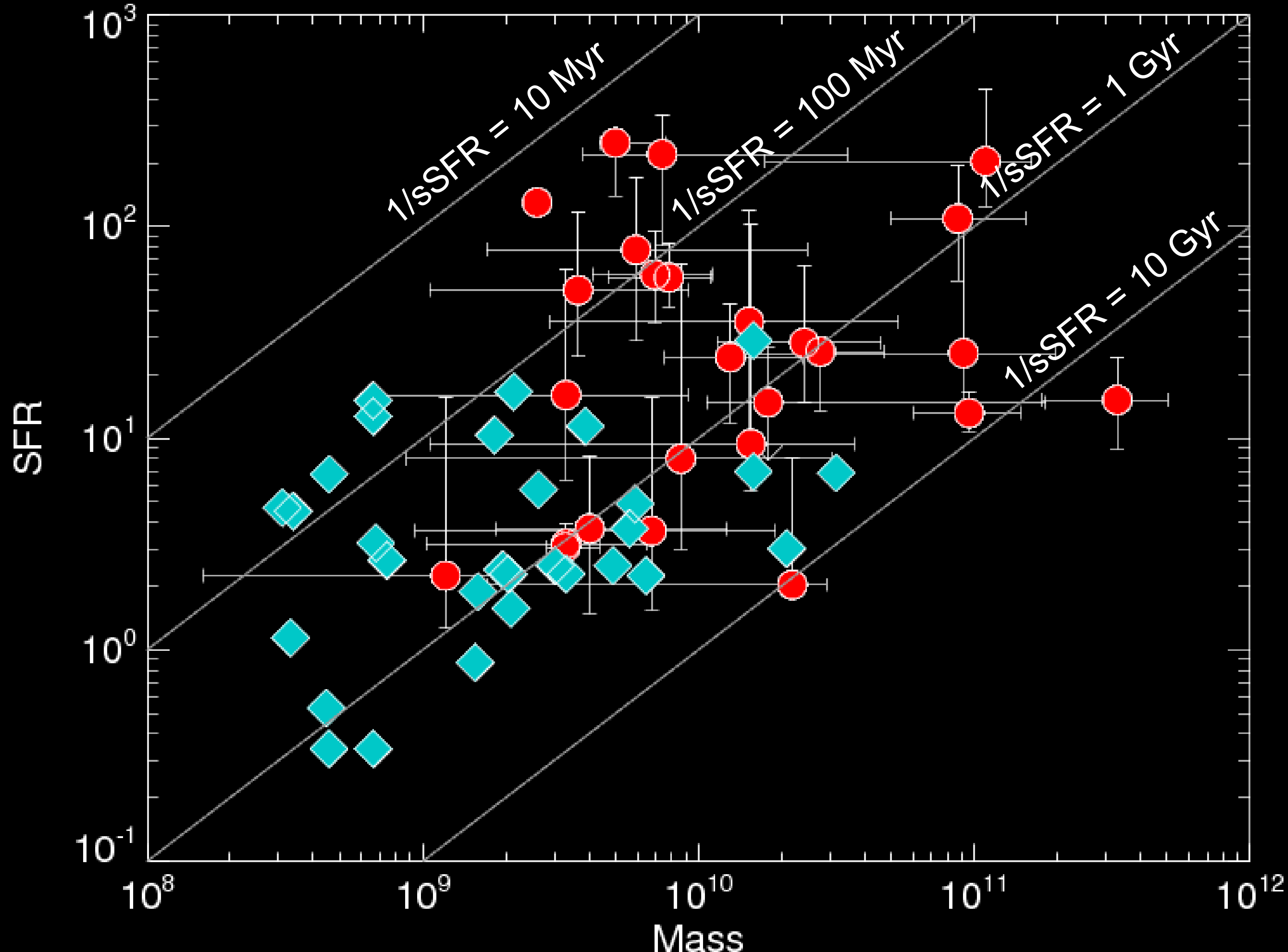
More rapidly star-forming



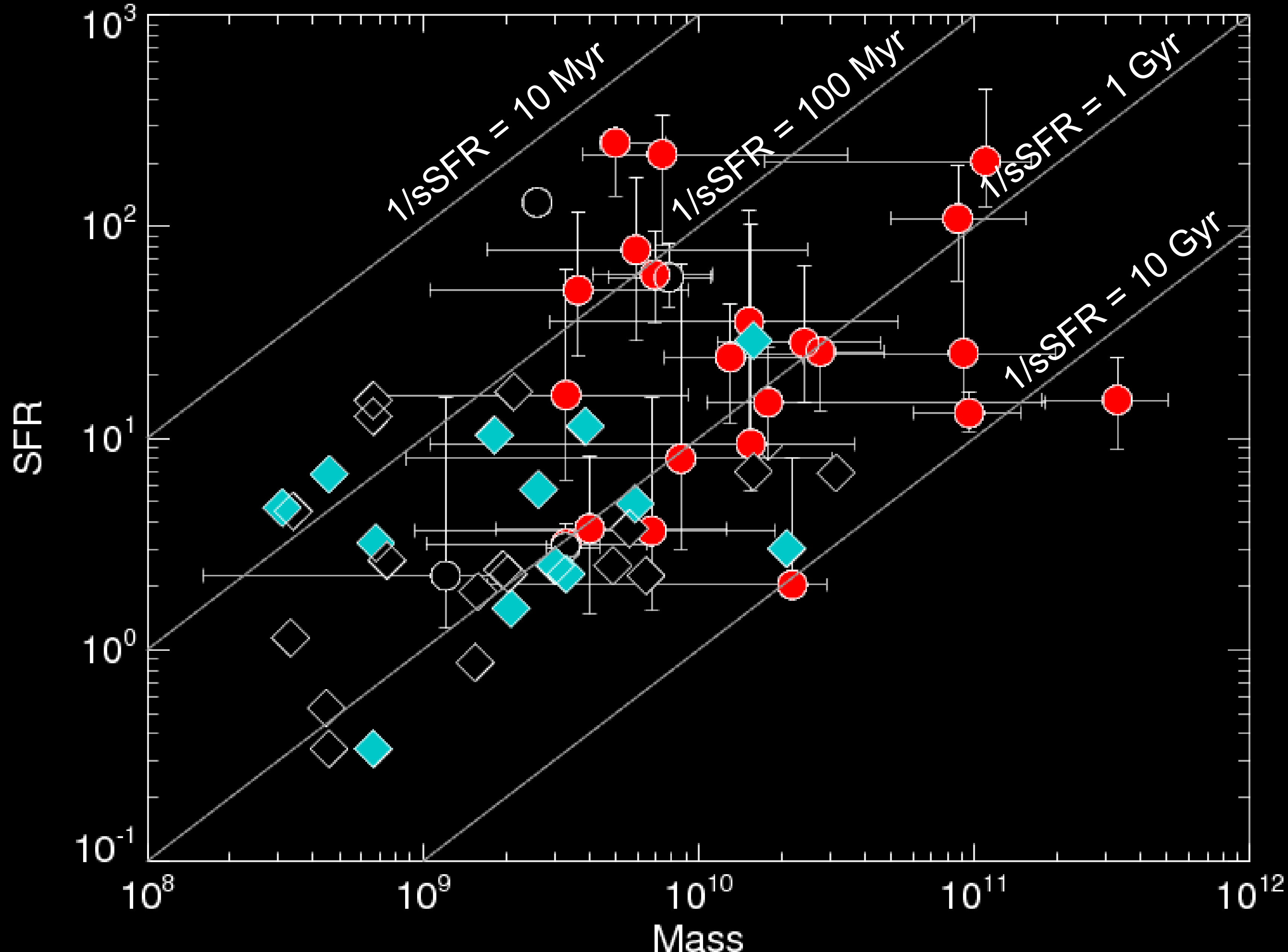
Redder and dustier



SFR vs. stellar mass



SFR vs. stellar mass (z>1)



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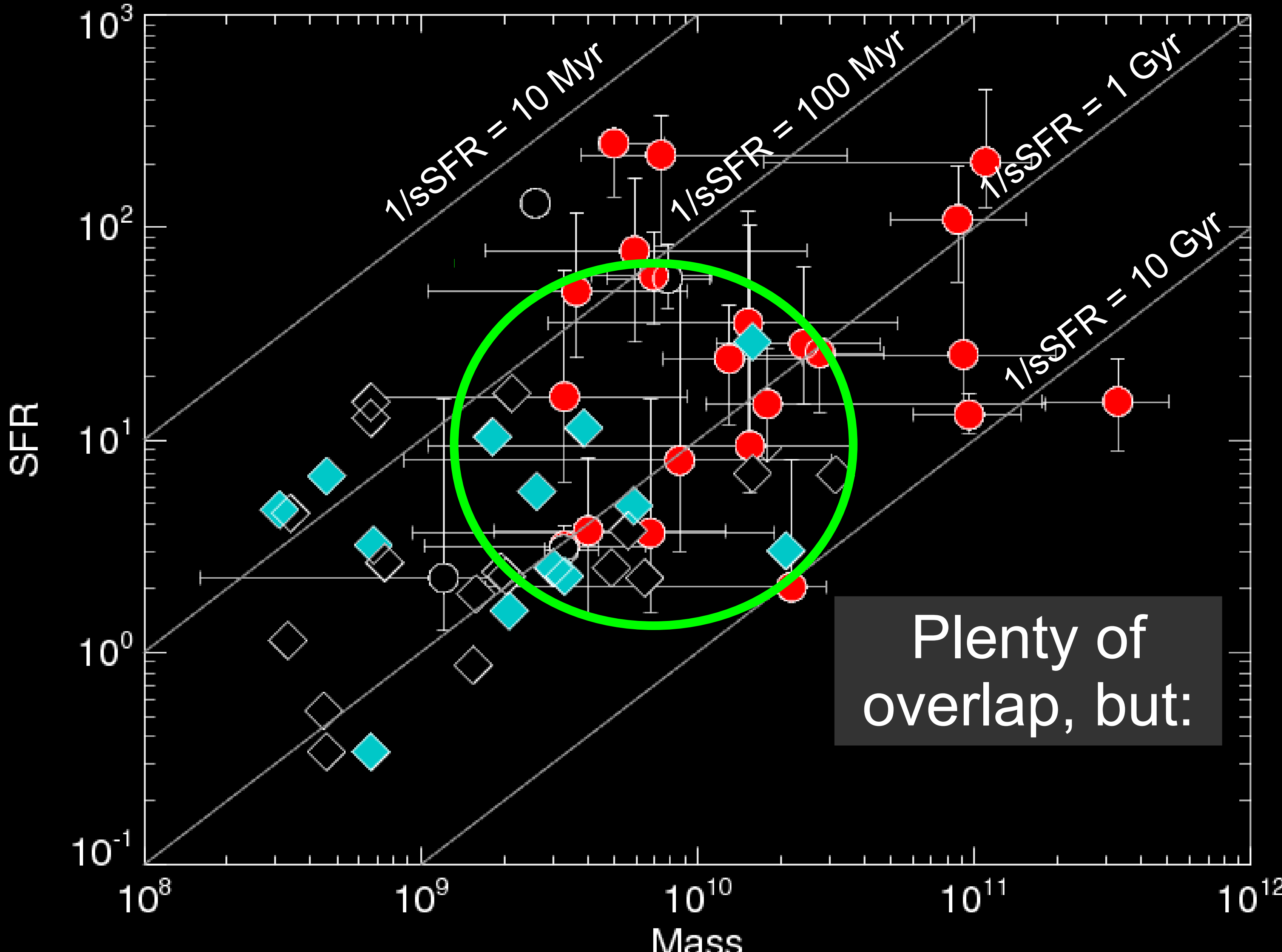

Plenty of overlap, but:

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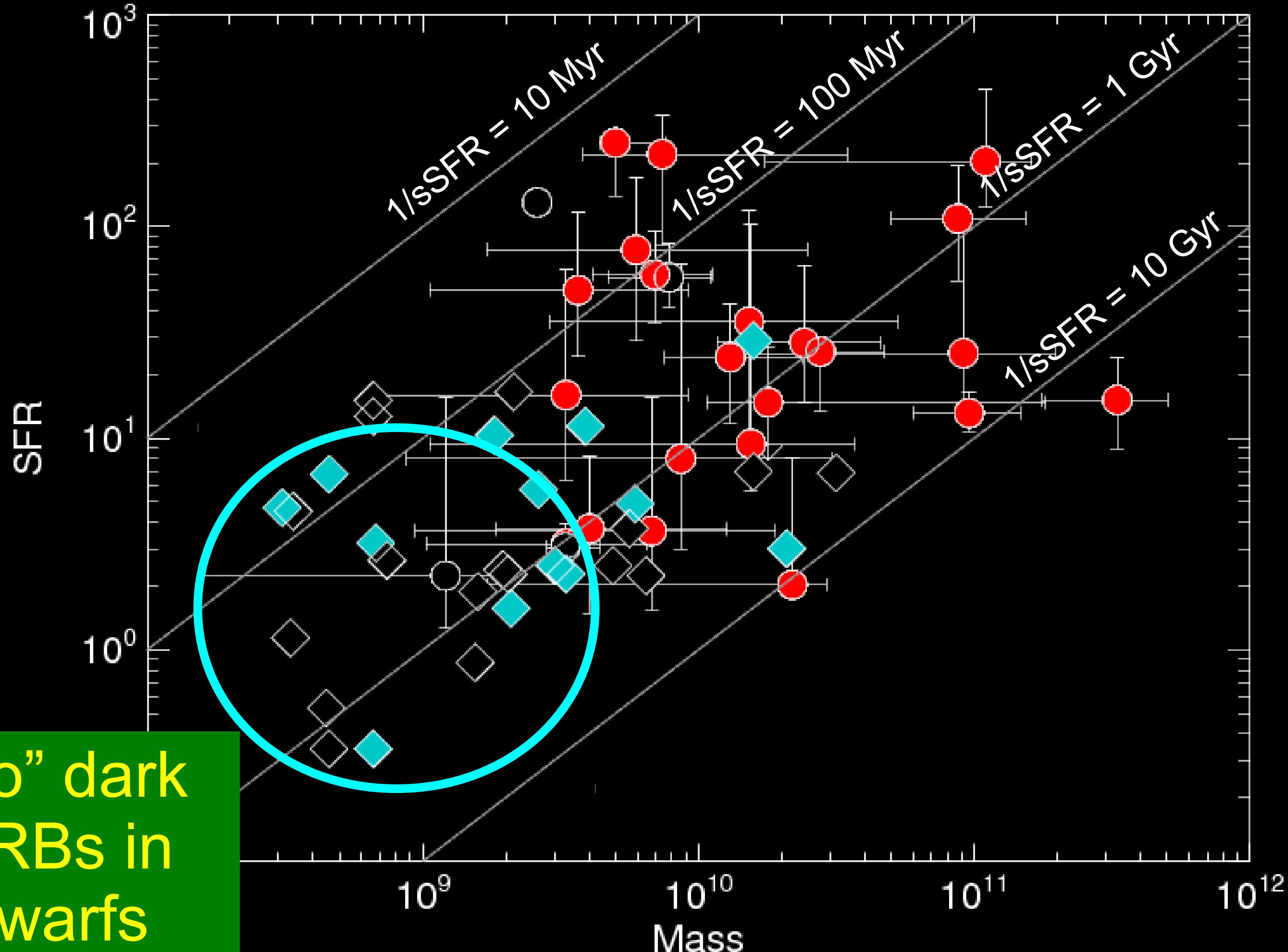

"No" dark GRBs in dwarfs

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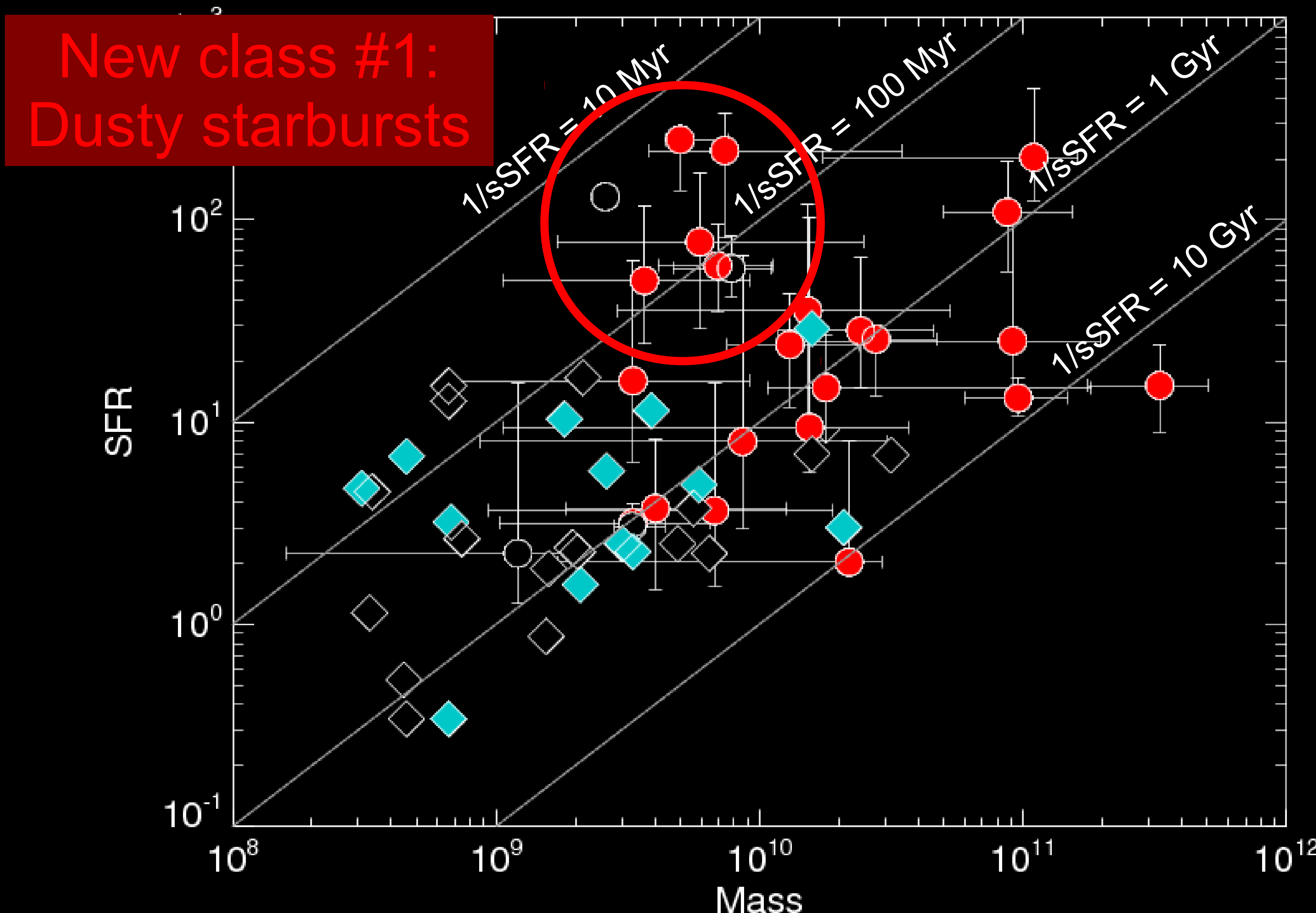

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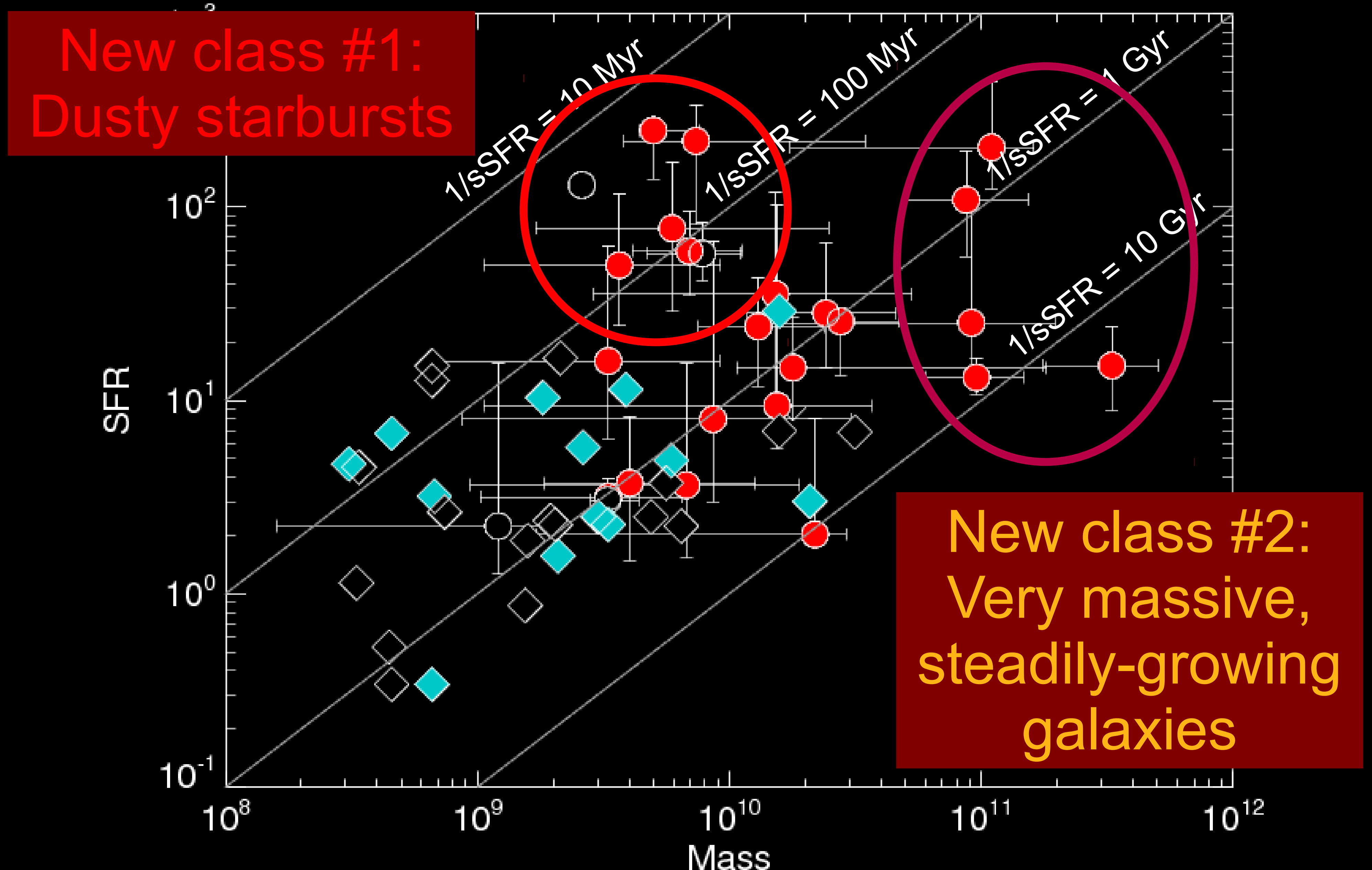

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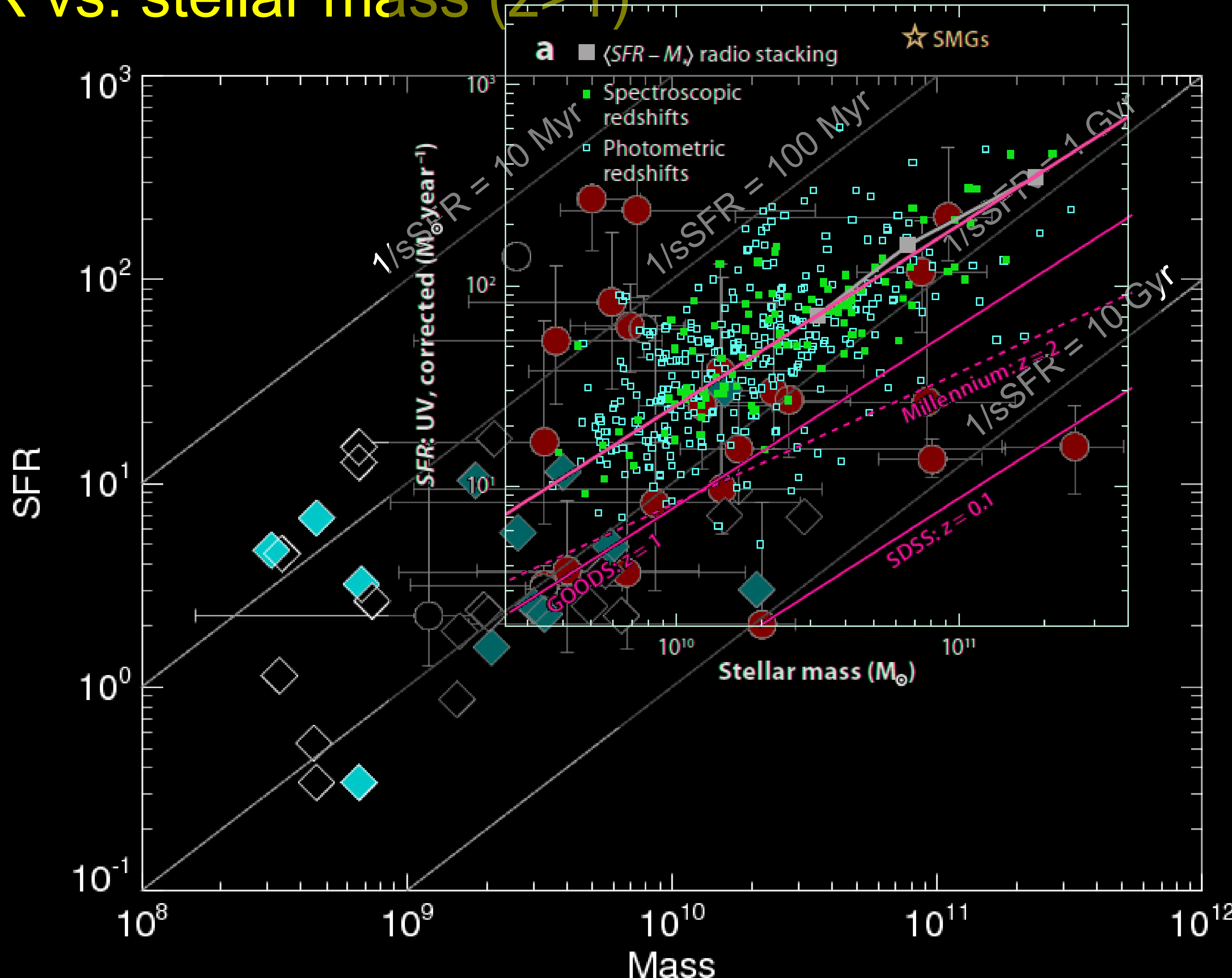

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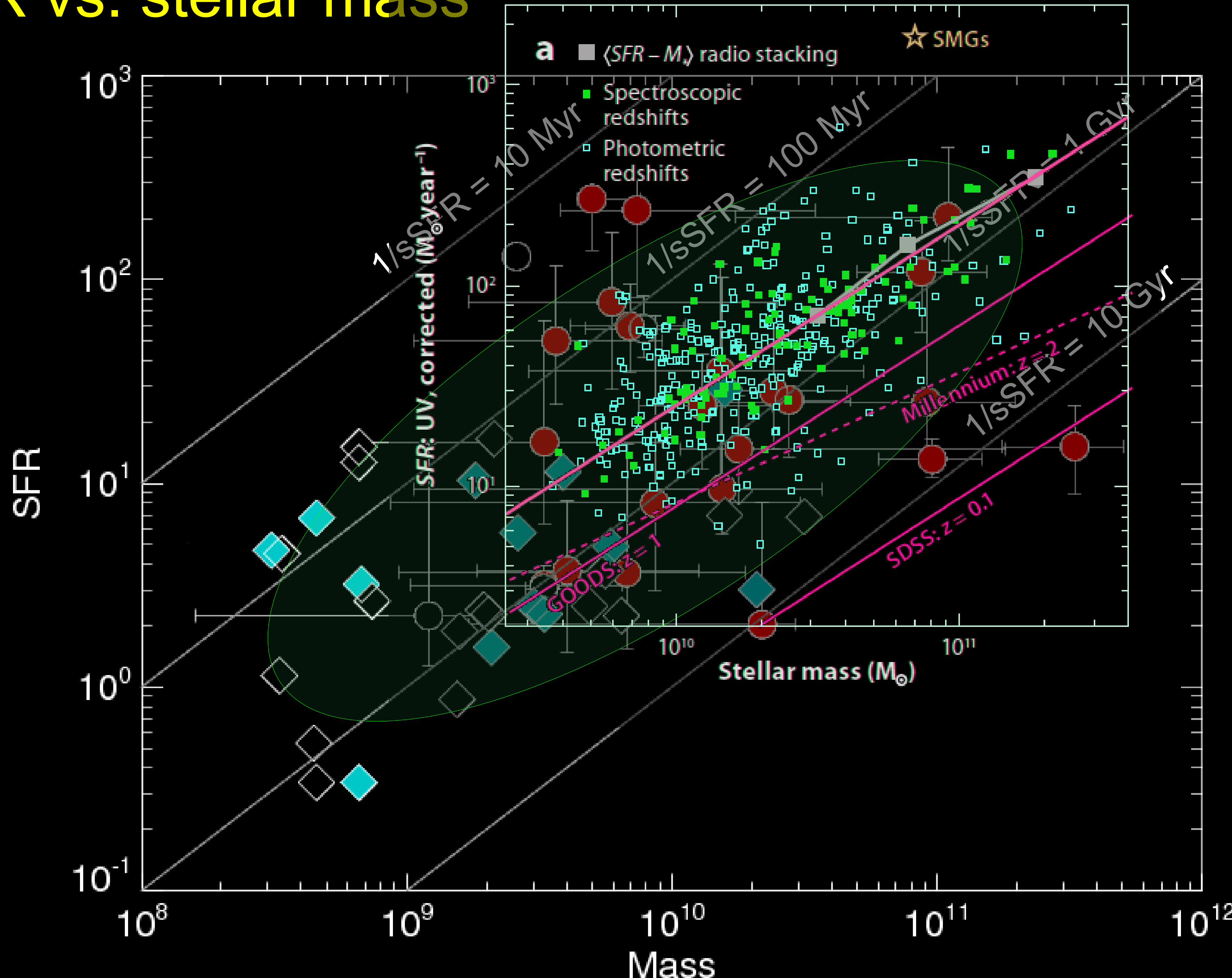

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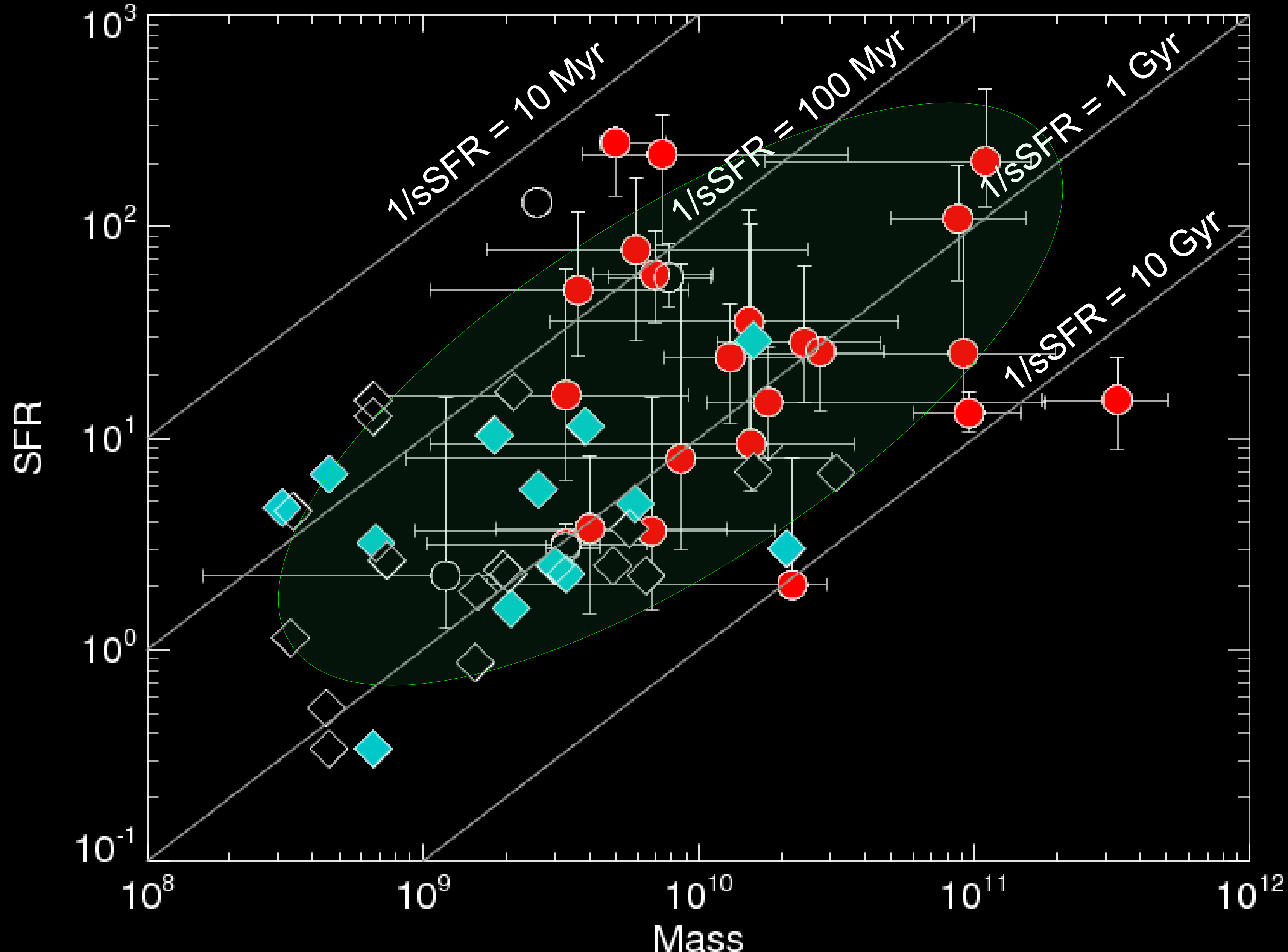
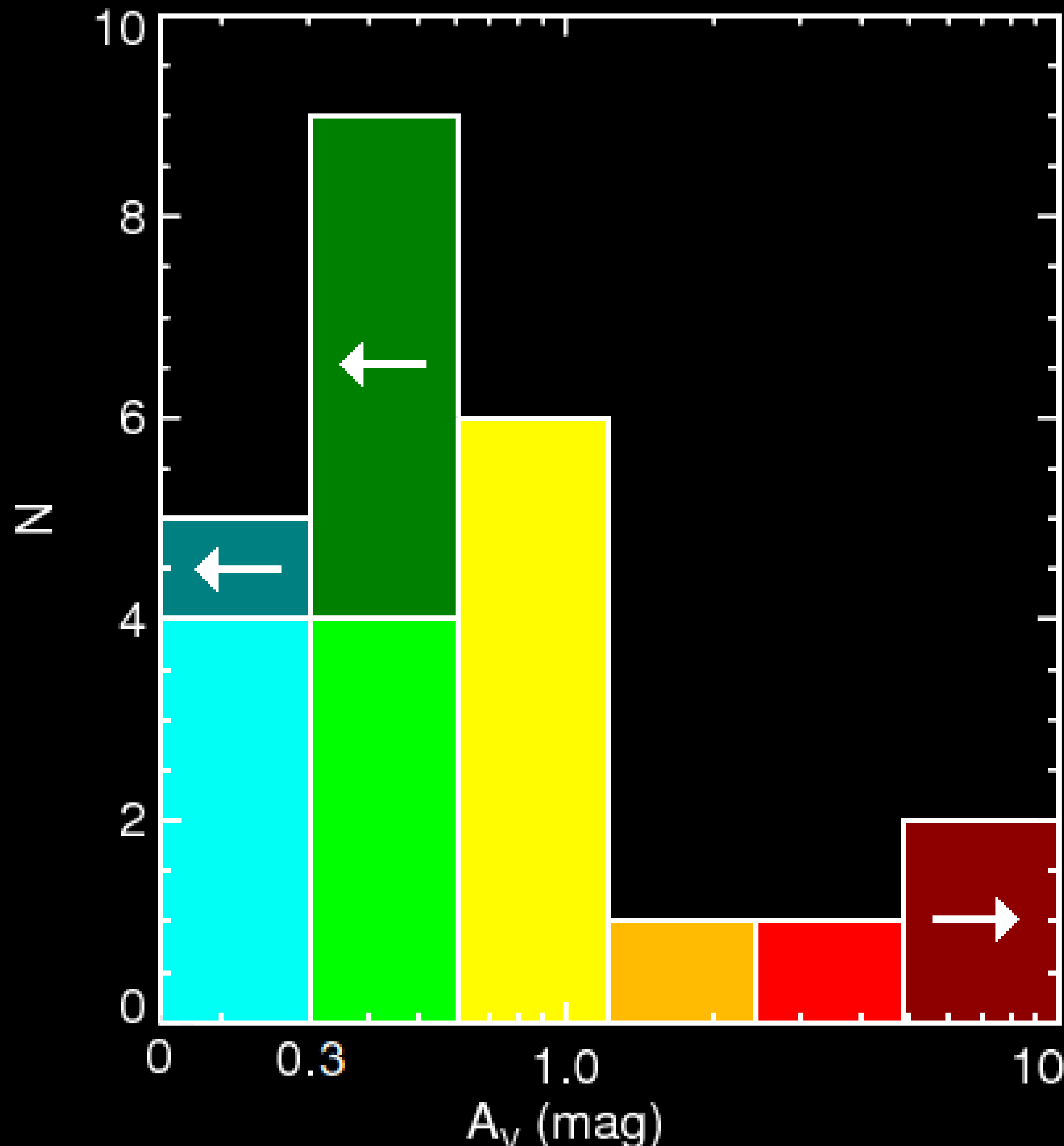


Dark bursts are a minority



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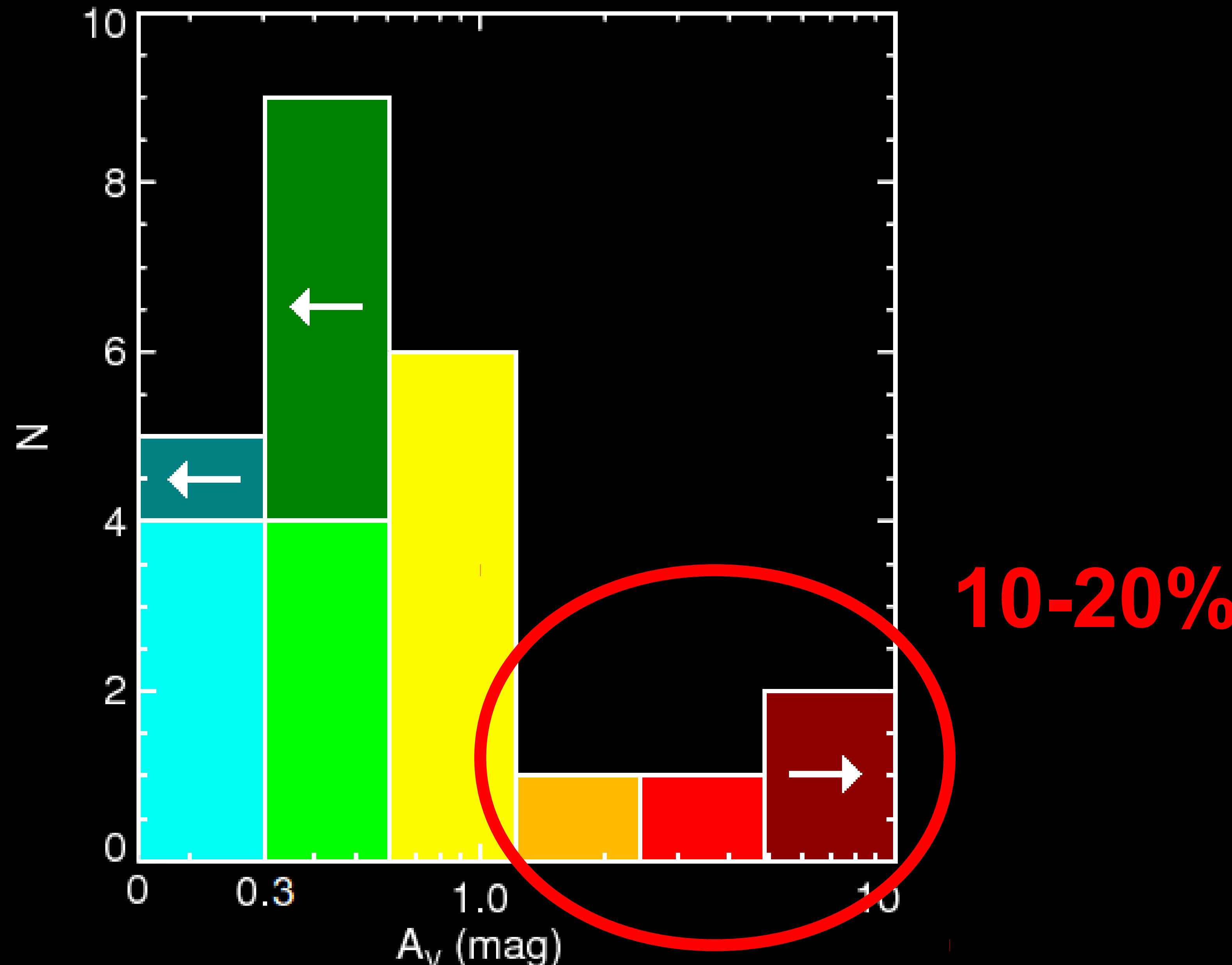
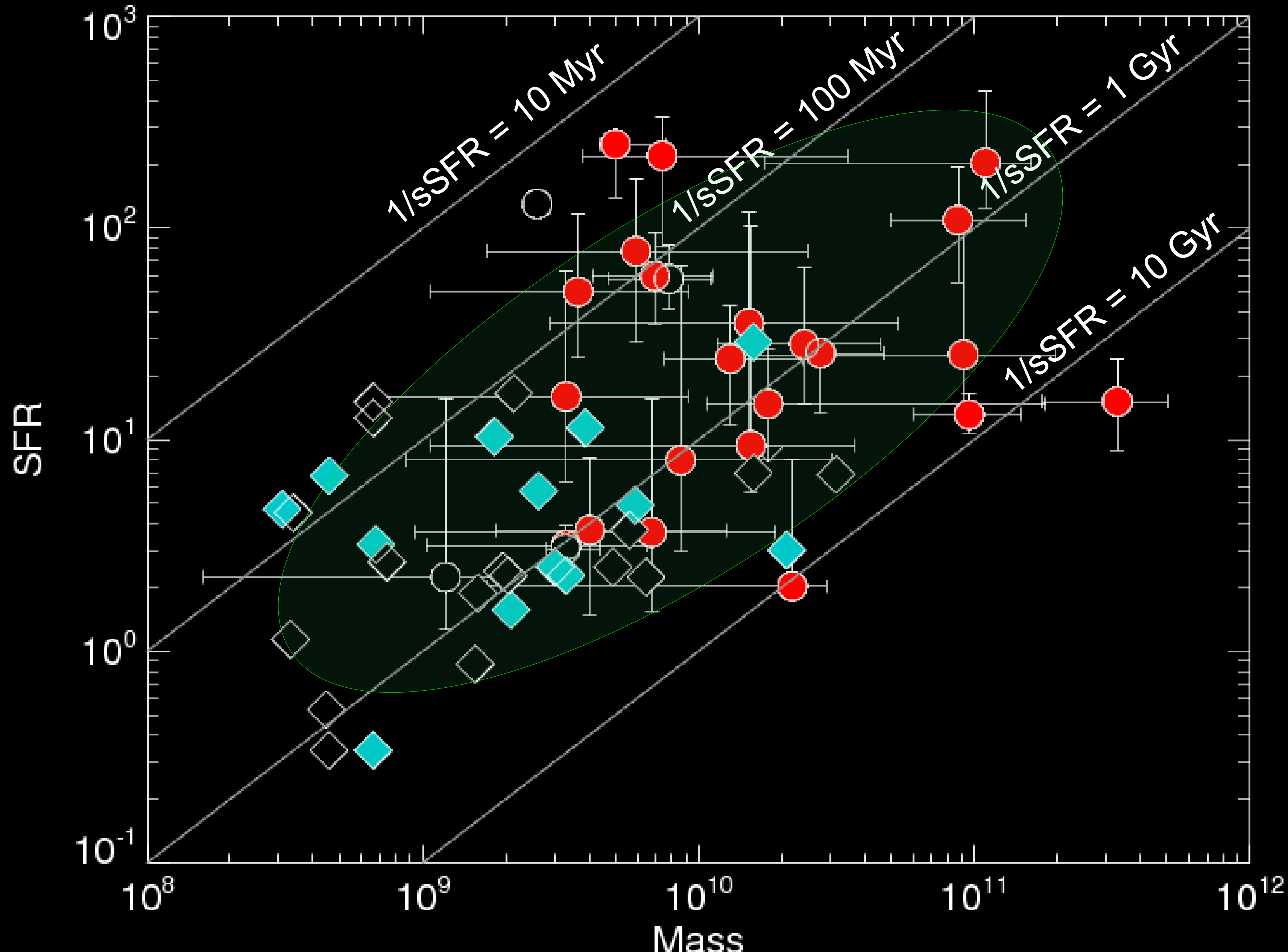
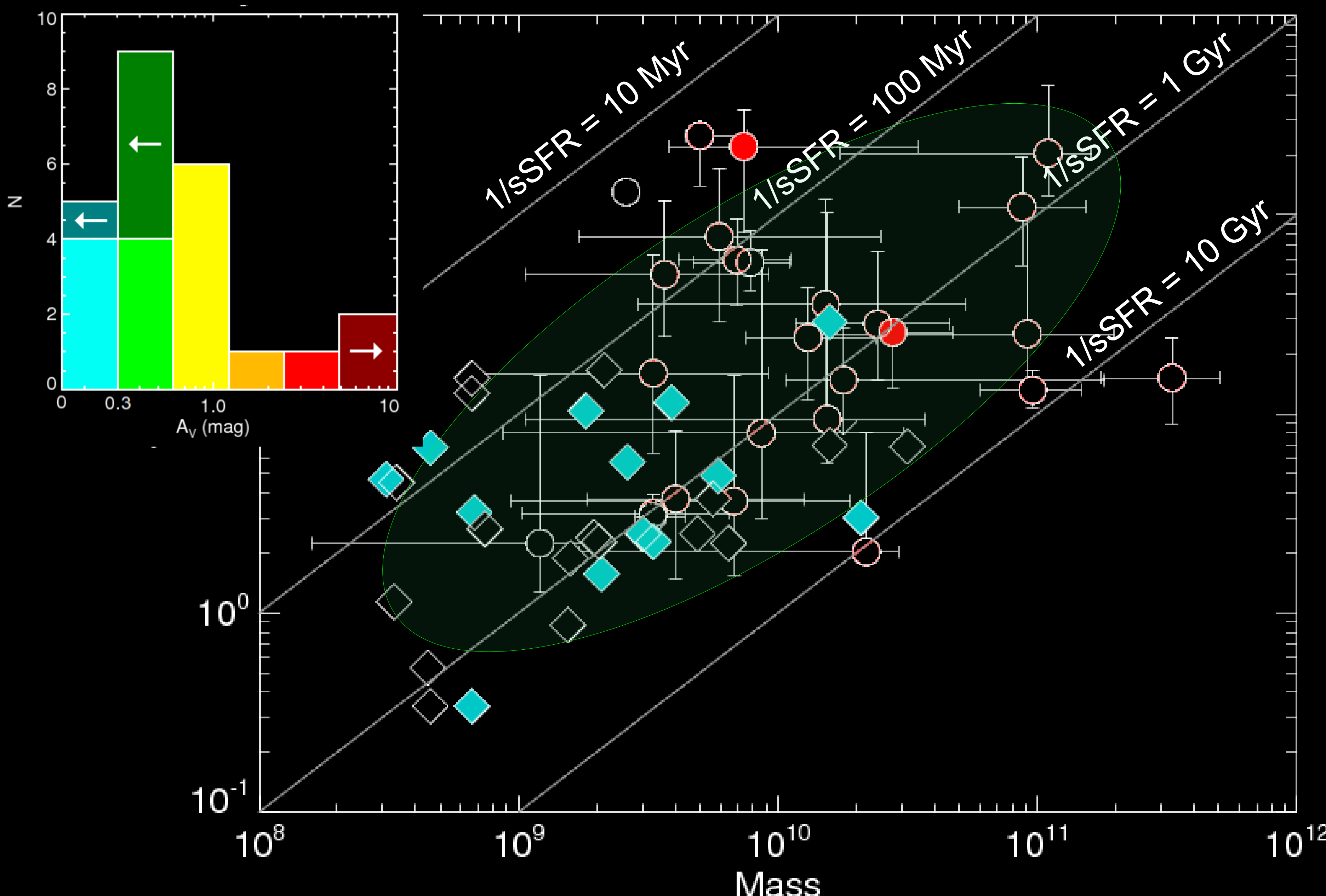


Luminous, red hosts have been found, but...



… there still aren't many.



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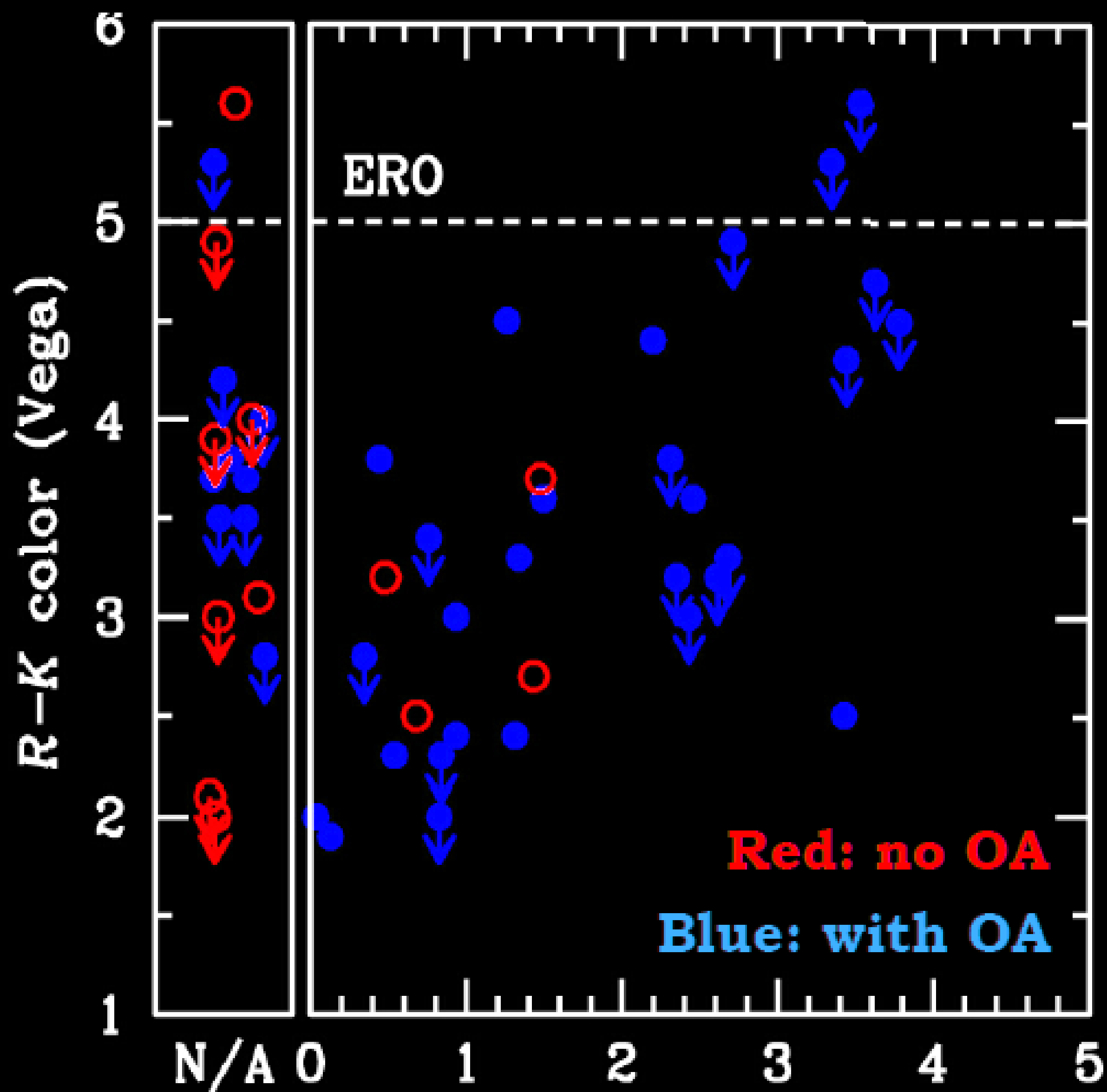

Jakobsson+2011
& Hjorth talk

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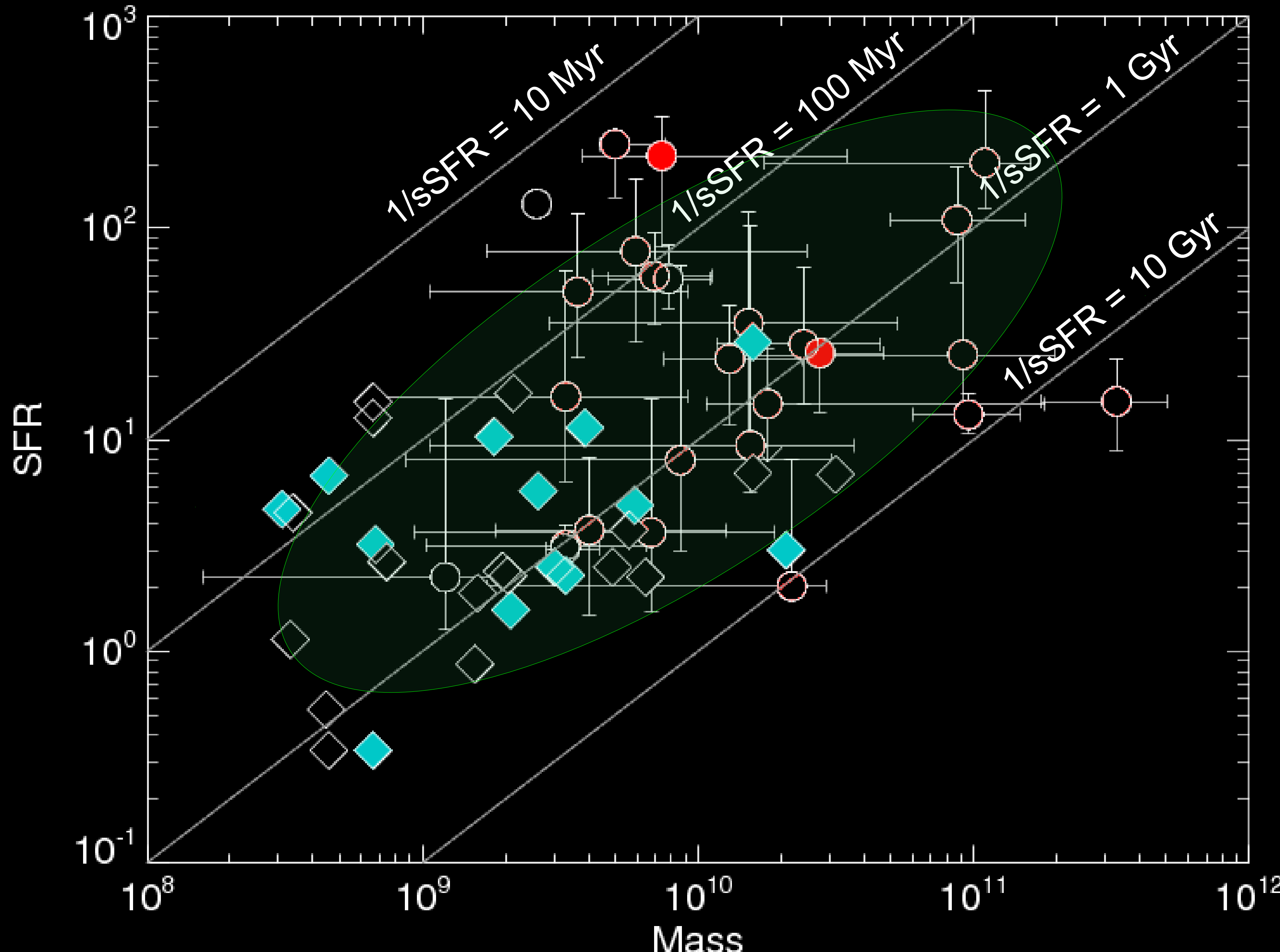
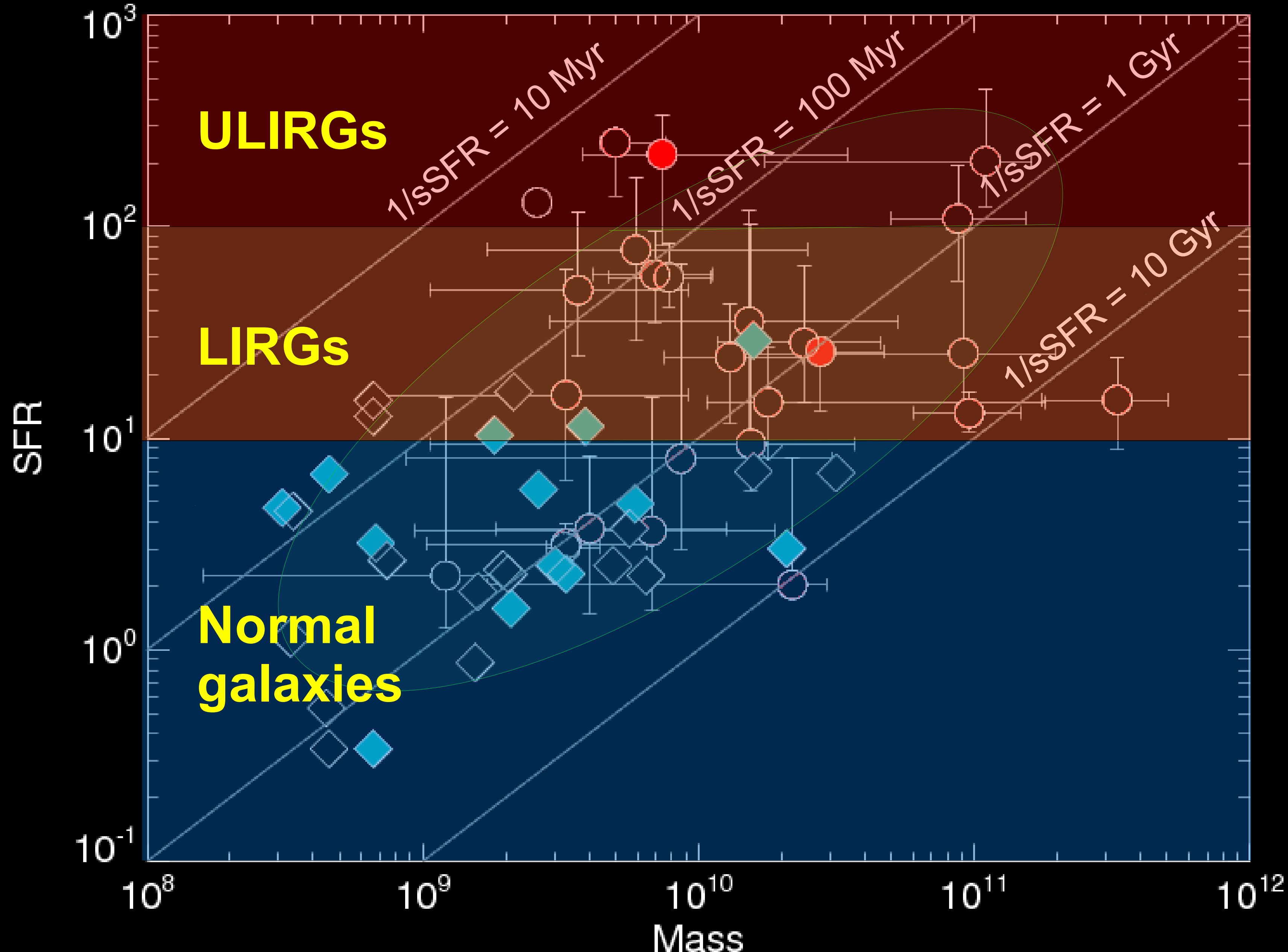


… and there still aren't enough.



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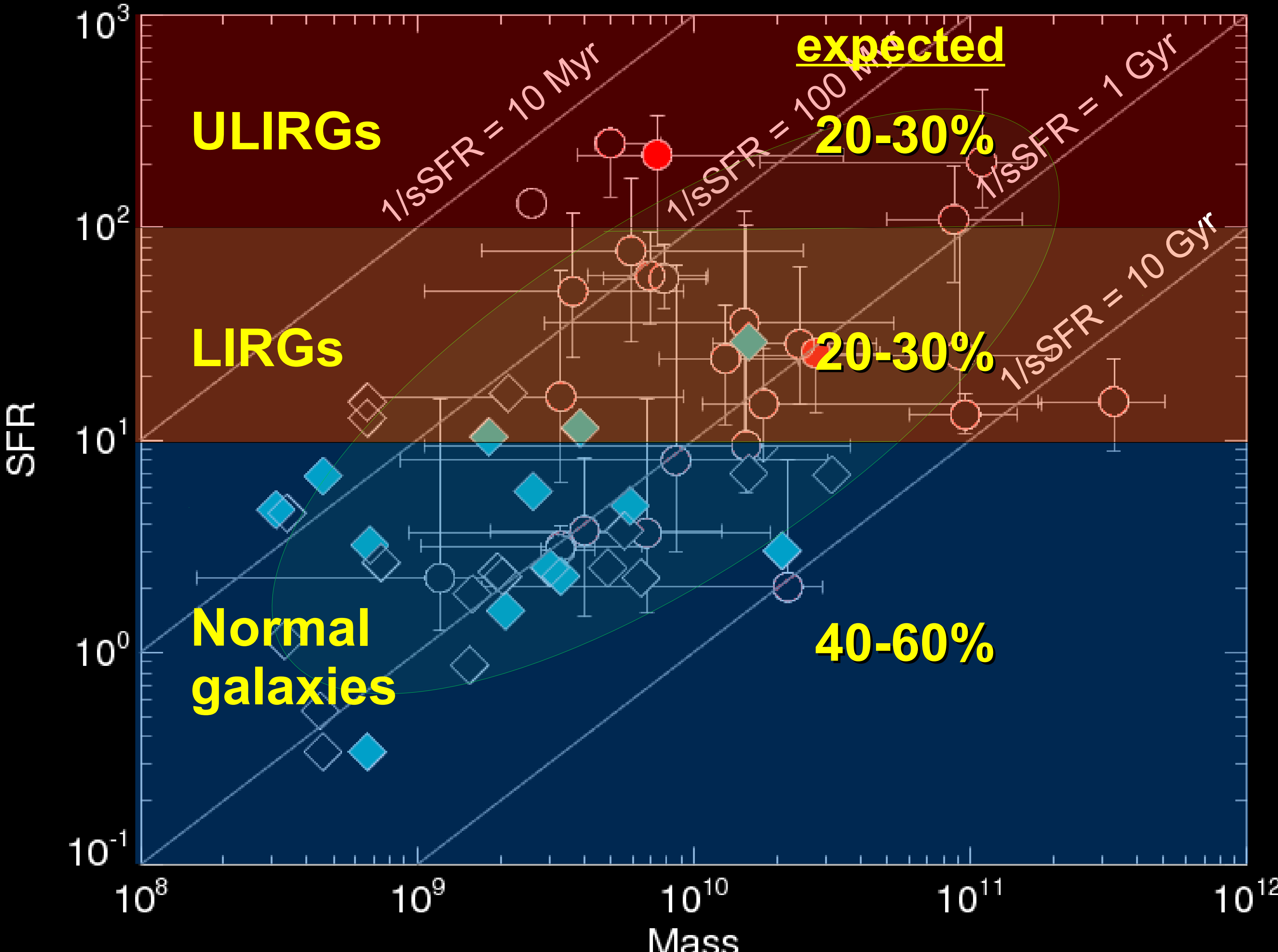

Perez-Gonzales et al. 2008, Shapley et al. 2012

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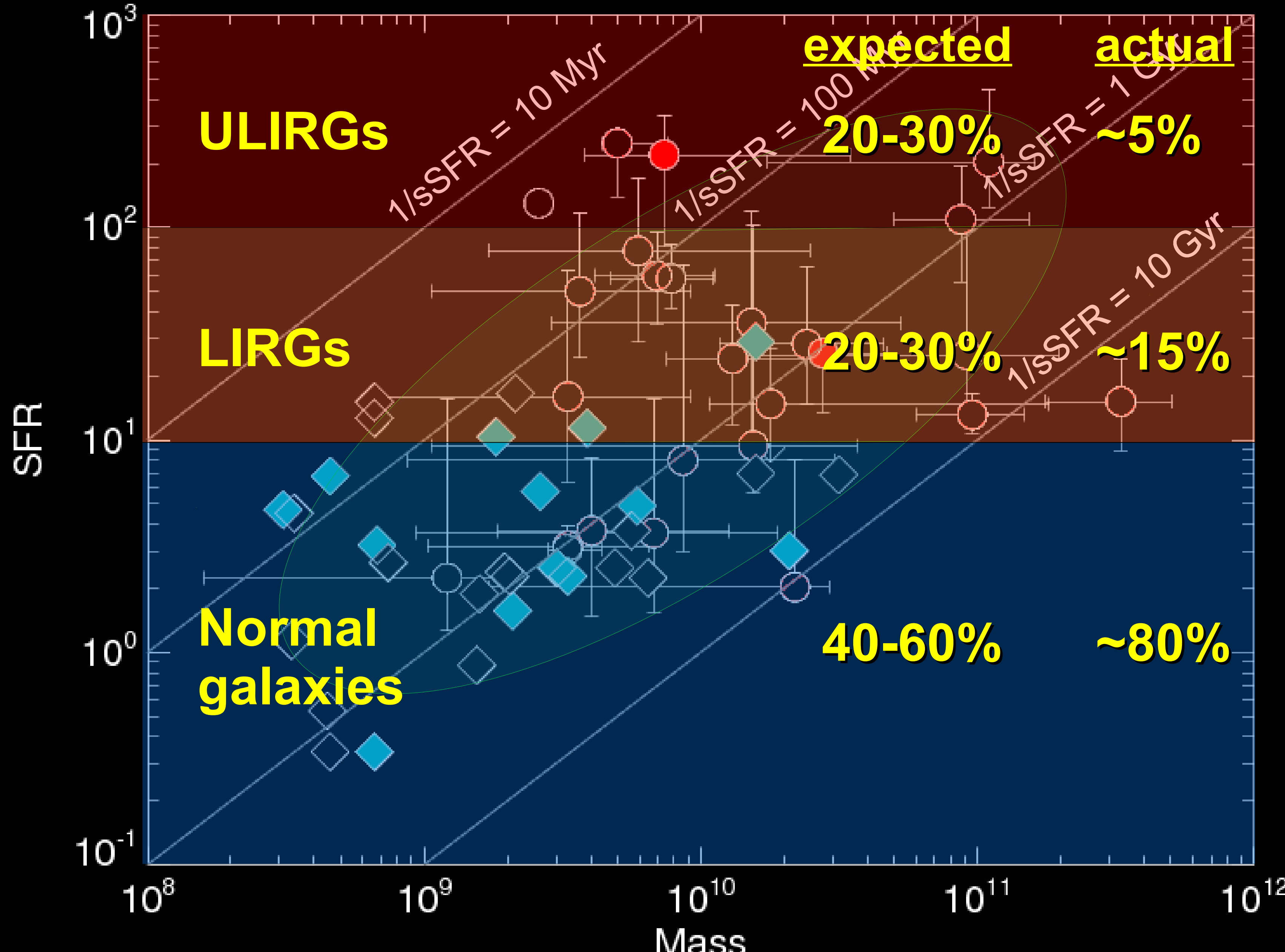

Perez-Gonzales et al. 2008, Shapley et al. 2012

Implications

$$R(GRB) = \text{const?} \times R(SFR)$$

GRBs form in all galaxy environments after all!

Implications

$$R(GRB) = \cancel{\text{const?}} \times R(SFR)$$

GRBs form in all galaxy environments after all!
… but not at the relative rates you would expect.

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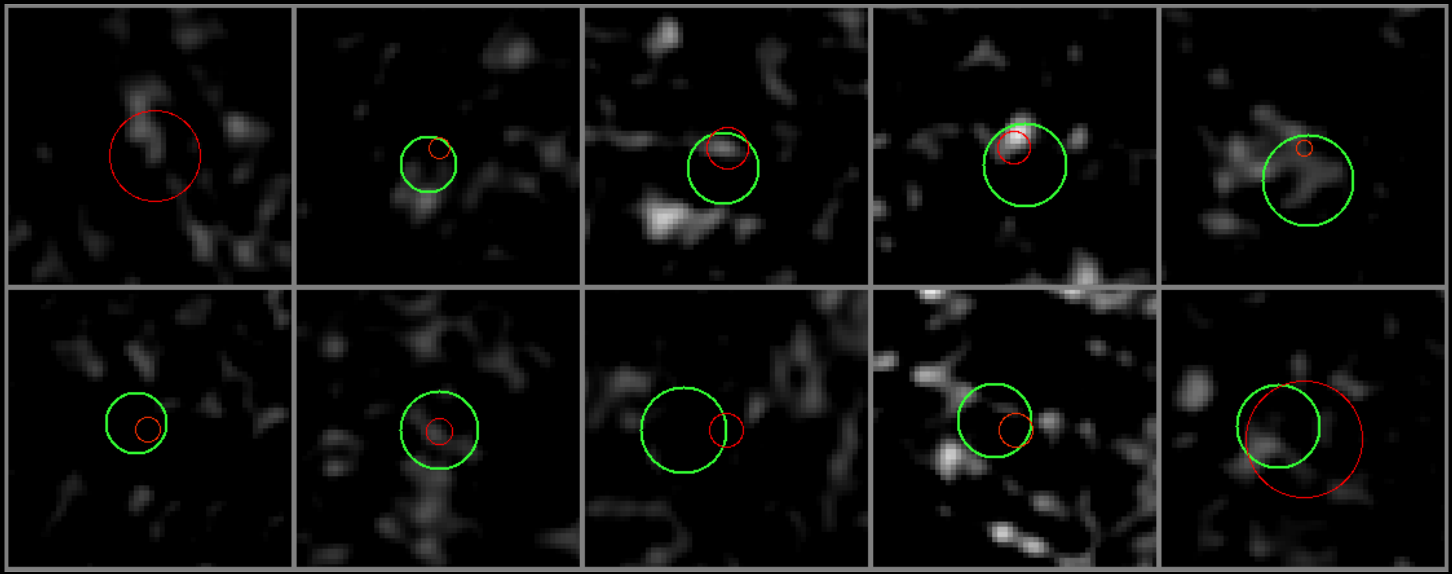
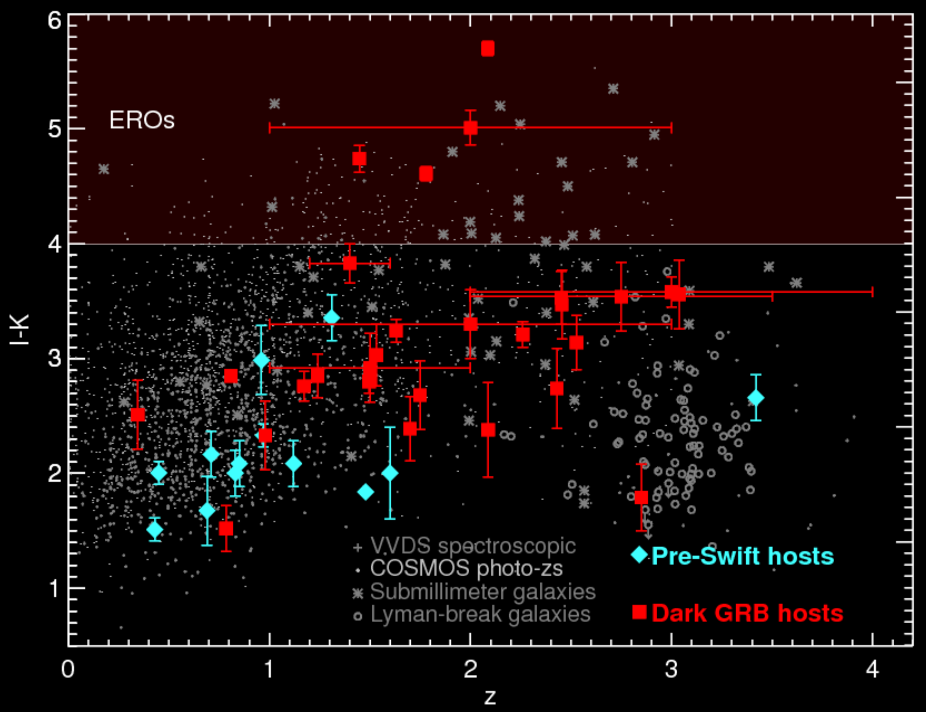
GRBs form in all galaxy environments after all!
… but not at the relative rates you would expect.
… and long-wavelength observations do not change this.

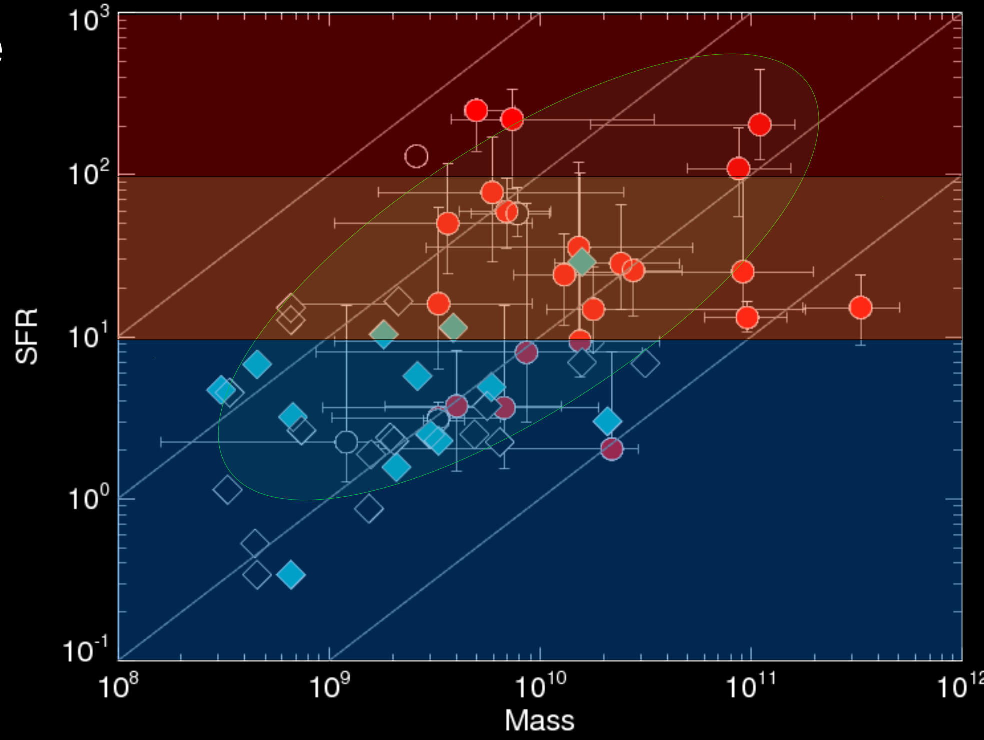


Conclusions (Part II)

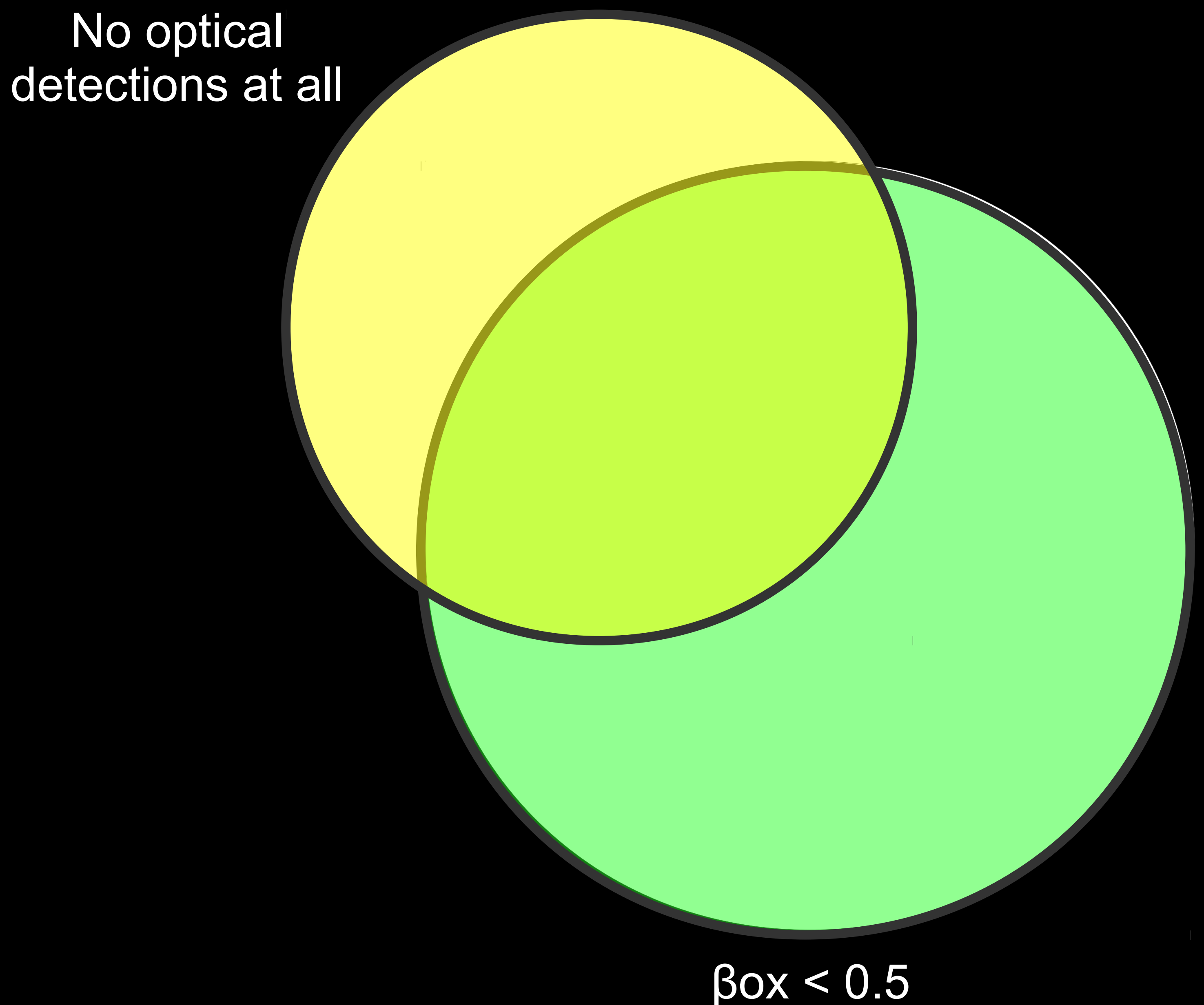
1. Dark GRB hosts are different: systematically higher mass, SFR, *and* reddening.
   → No *obscured* GRBs from ultra-faint dwarfs (SMCs) so far.
   → No *unobscured* GRBs from very massive/luminous galaxies.
   → Optical extinction is galaxy-wide (nonlocal), with few exceptions.

2. GRBs form in all star-forming galaxies at z>1, but not at uniform rates.
   → Complex connection to metallicity (or other factor): no obvious “cutoff”

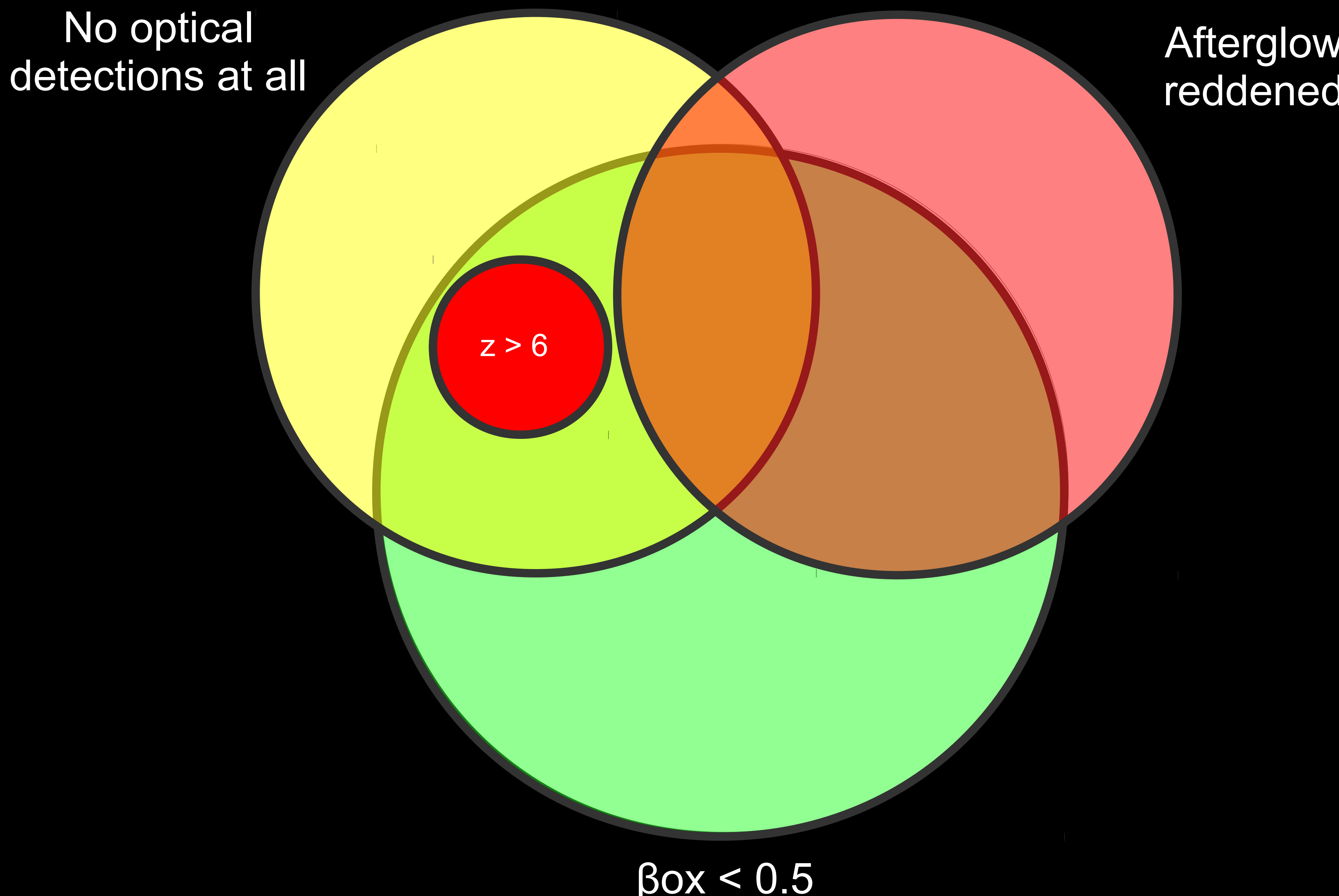




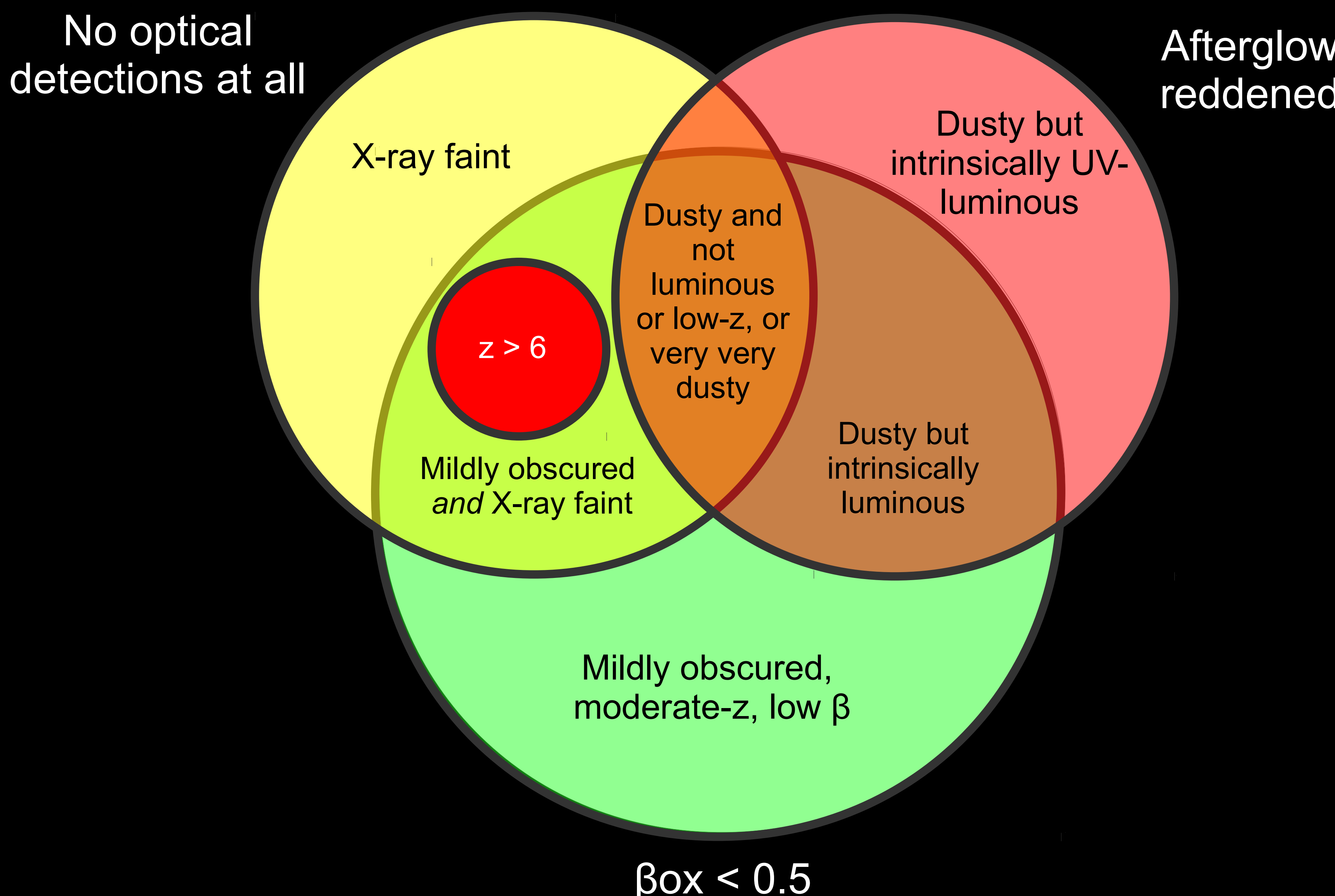
One Criterion is Not Enough!



One Criterion is Not Enough!



One Criterion is Not Enough!



One Criterion is Not Enough!