Unveiling the Secrets of the Cosmos with the Discovery of the Most Distant Object in the Universe

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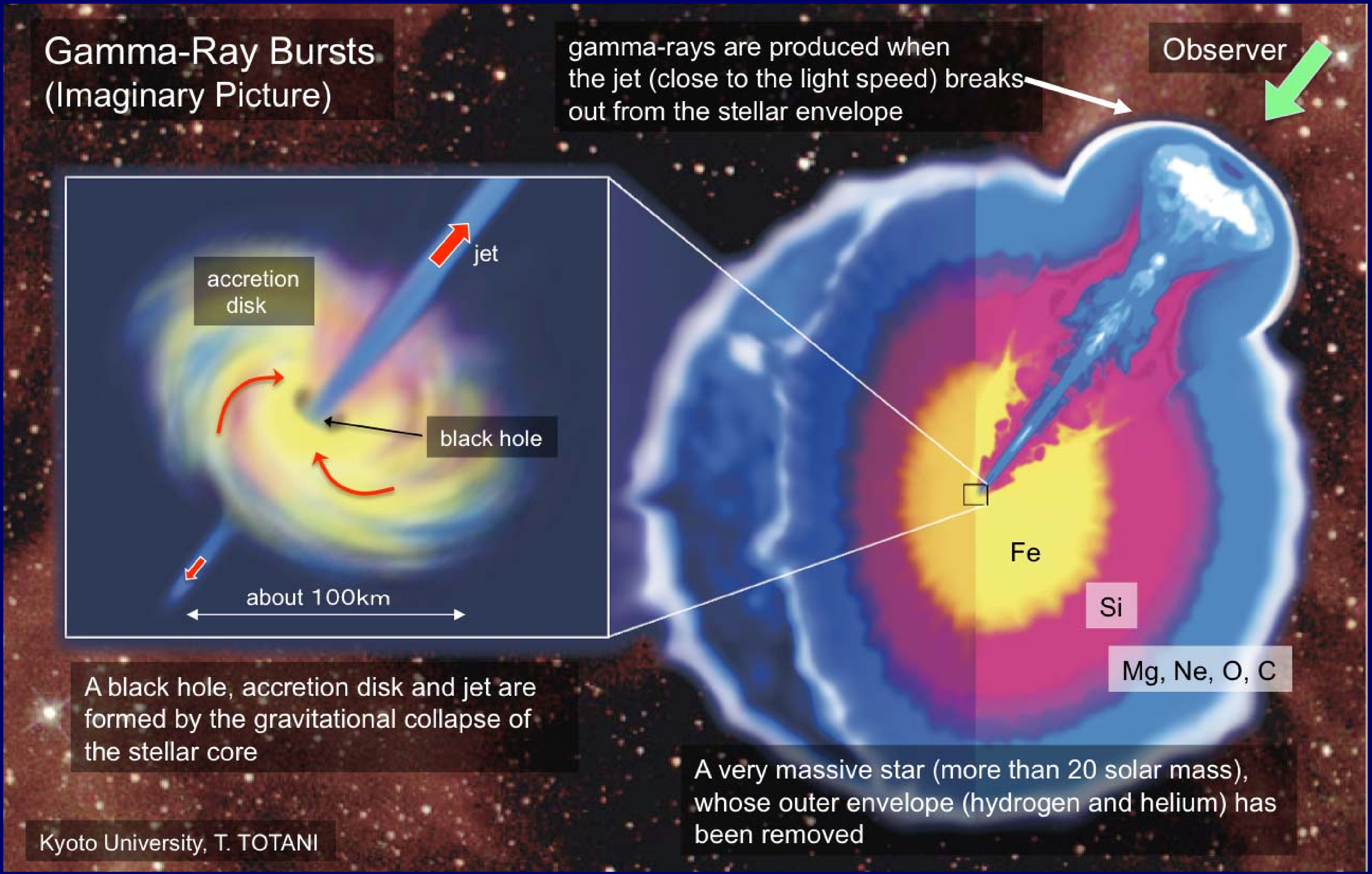
Cucchiara et al. 2011, ApJ, 736, 7

Outline

- Introduction
- Probing the high-redshift universe: why and how
- Discovery of the most distant object in the universe
- Conclusions

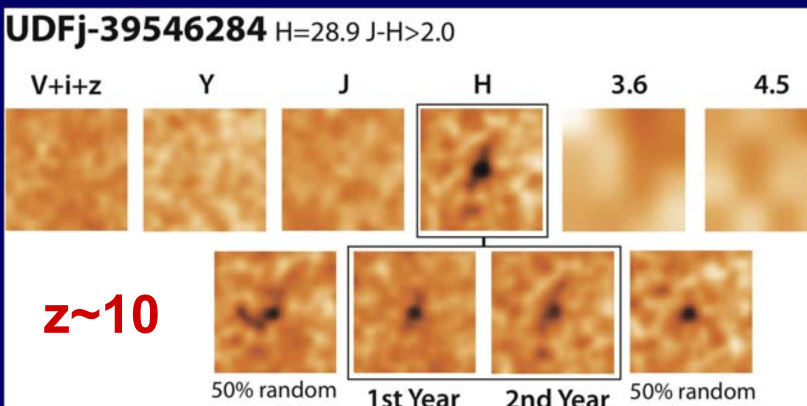
Sketch of a GRB

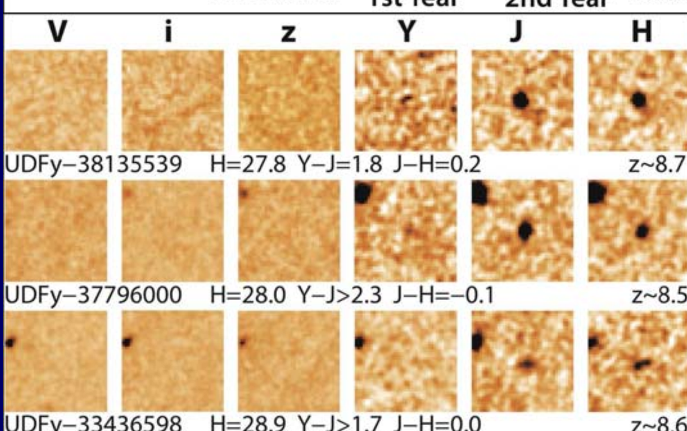


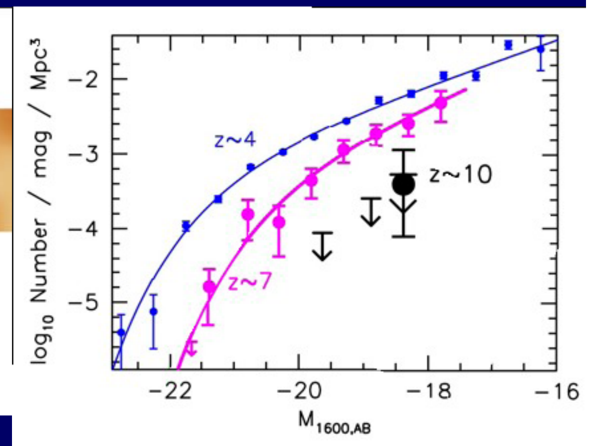
What is the best probe at high-z?

- Poor understanding of early universe (<1 Gyr after Big Bang)
- Galaxies/quasars probe e.g.: baryon content, SFR, UV BG, re-ionization
- New (refurbished) instruments of HST/ACS+WFC3 allow to study

LF and galaxy evolution up to z~10 with Ly-α break

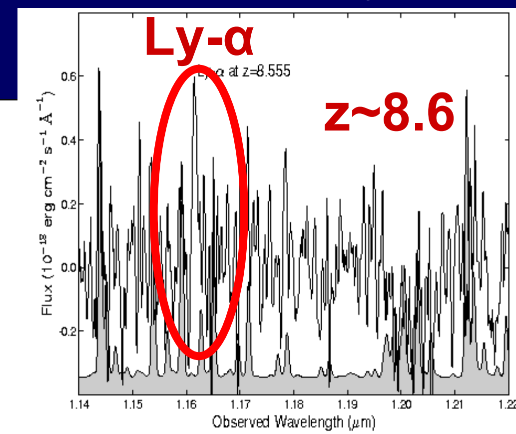




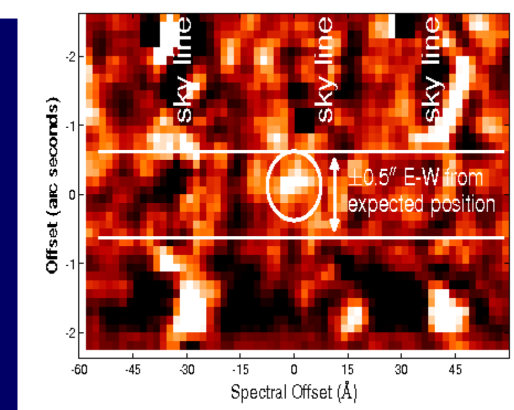


Bouwens et al. 2010, 2011

z~8.6



Lehnert et al. 2010



What is the best probe at high-z?

Galaxies

PROS

- Multi-band data available (some)
- Refurbished *HST*
- Do not fade(-out)
- Different technique (LBG, Ly-α em)

CONS

- Small sky area
- Very faint objects
- Several hours of deep observations
- Galaxy populations complex

(SFRs, age/metallicities, dust, etc)

Gamma-ray bursts

PROS

- Very bright
- Random location and time
- Fast follow-up (space & ground)
- Simple spectrum (synchrotron, PL)
- Better constraints on τ_{HI} possible

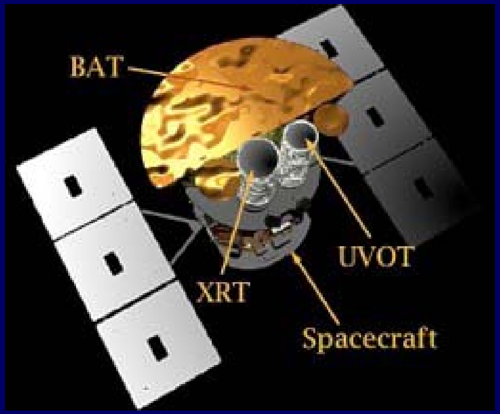
CONS

- Rare objects (few good ones)
- Fade fast, identify position in ~min
- Require multi-band observations

"SWIFT STRIKES AGAIN!"

Multi-wavelength campaign for GRB 090429B

2.2M/GROND

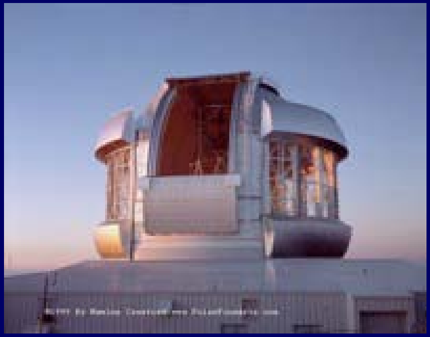


SWIFT

HST

UKIRT

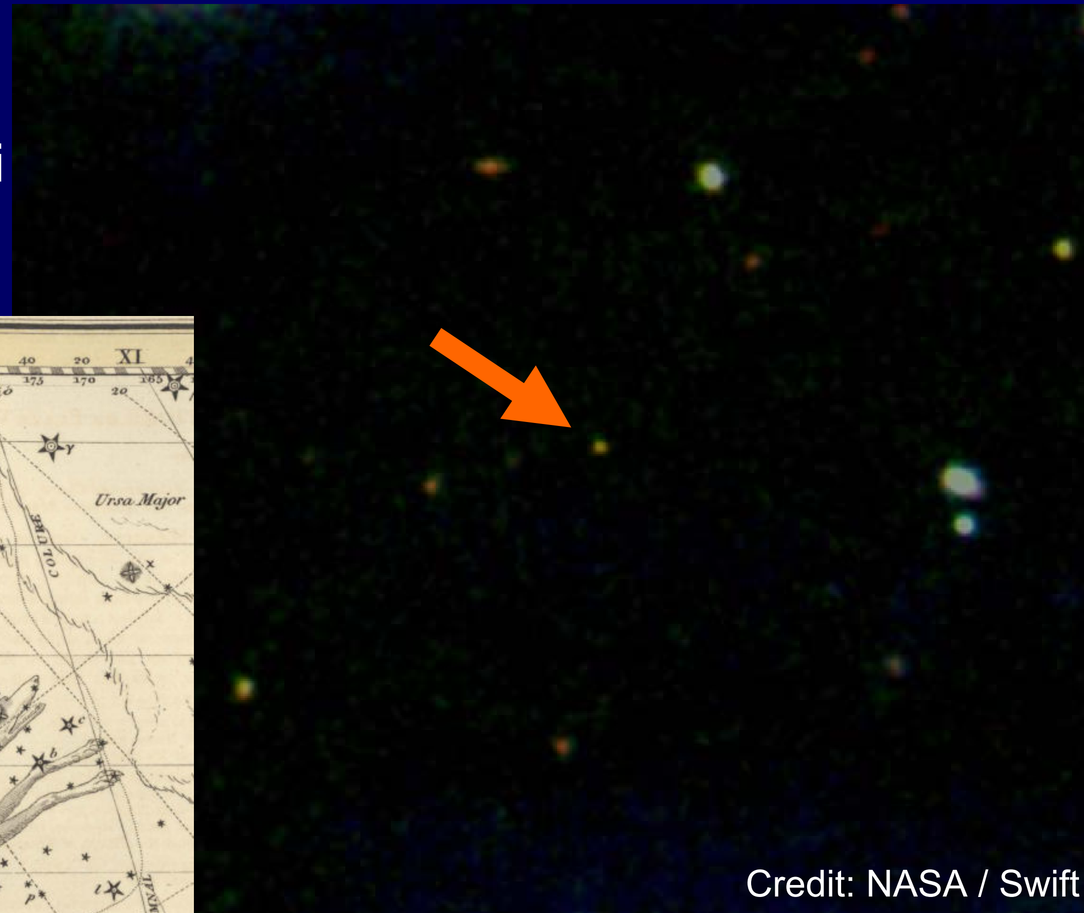
VLT



GEMINI

GRB 090429B: A brief history of its discovery

- Swift alert: April 29, 2009
  - Constellation Canes Venatici

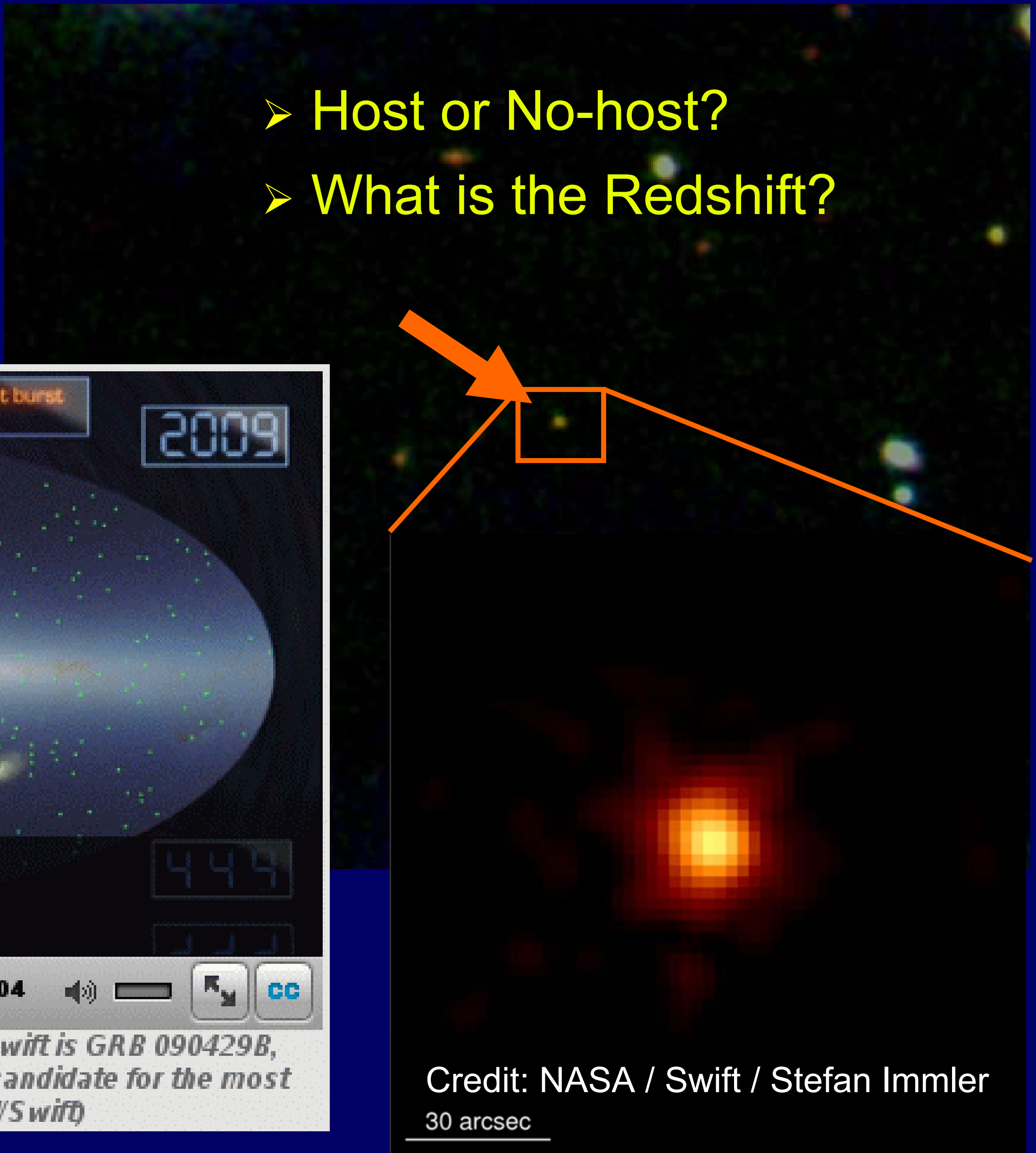


GRB 090429B: A brief history of its discovery

- Swift alert: April 29, 2009
  - Constellation Canes Venatici
  - T_{90} = 5.5 sec burst
    - $\Rightarrow$ Long-GRB

Among the first 500 gamma-ray bursts detected by Swift is GRB 090429B, currently the farthest explosion ever detected and a candidate for the most distant object in the universe. (Credit: NASA Goddard/Swift)

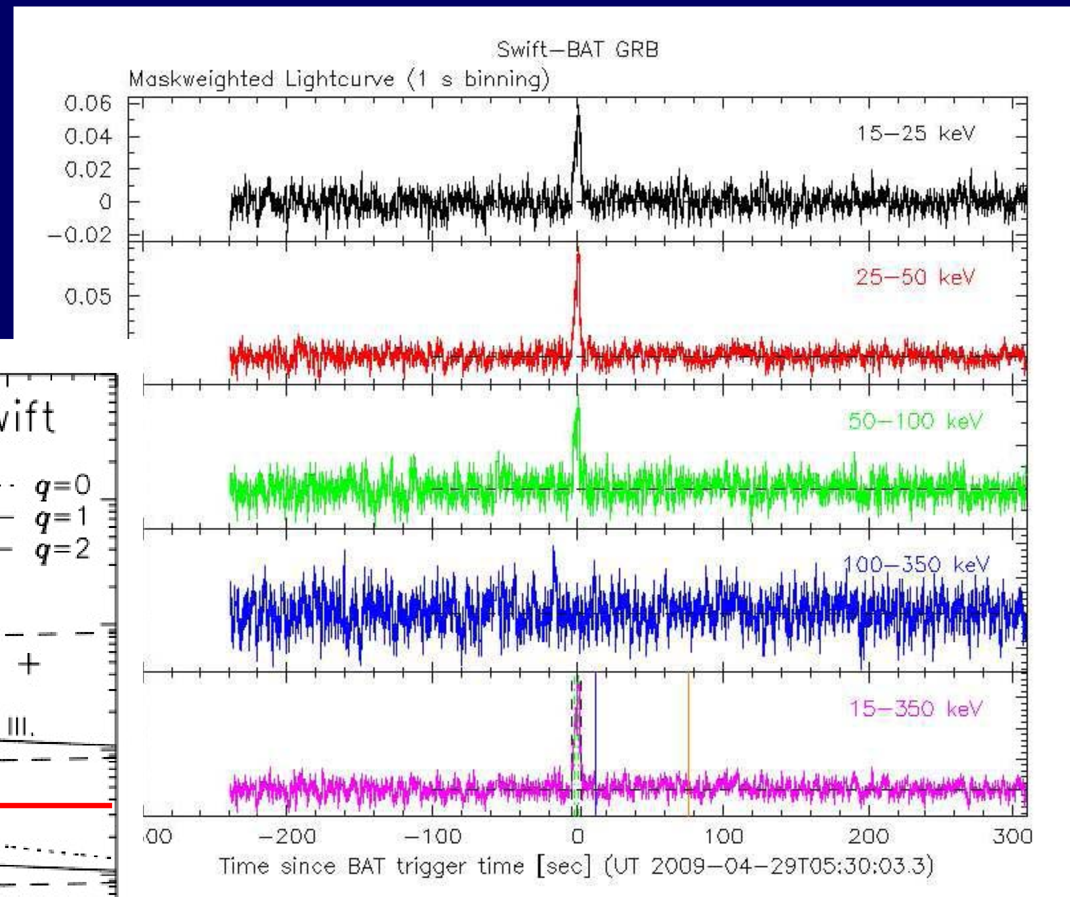
- Host or No-host?
- What is the Redshift?

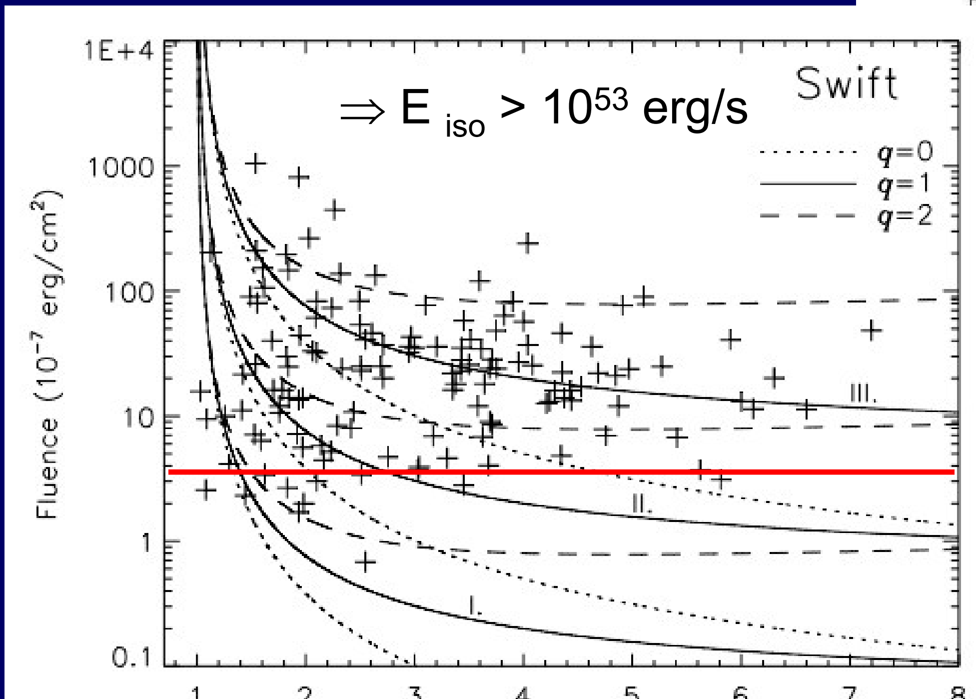


Credit: NASA / Swift / Stefan Immler

Swift - BAT

- Swift alert: April 29, 2009
  - T_{90} = 5.5 sec
  - BAT fluence: 3.1 x 10^{-7} erg/cm^2
  - E_{peak} = 49 keV
  - lag32/(1+z) = 58 ± 27 ms

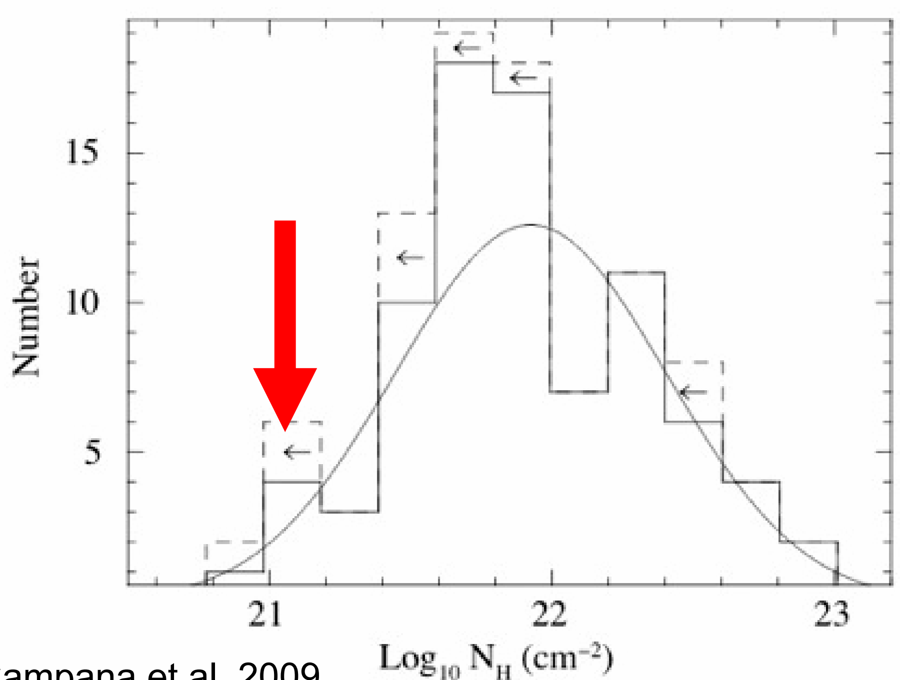




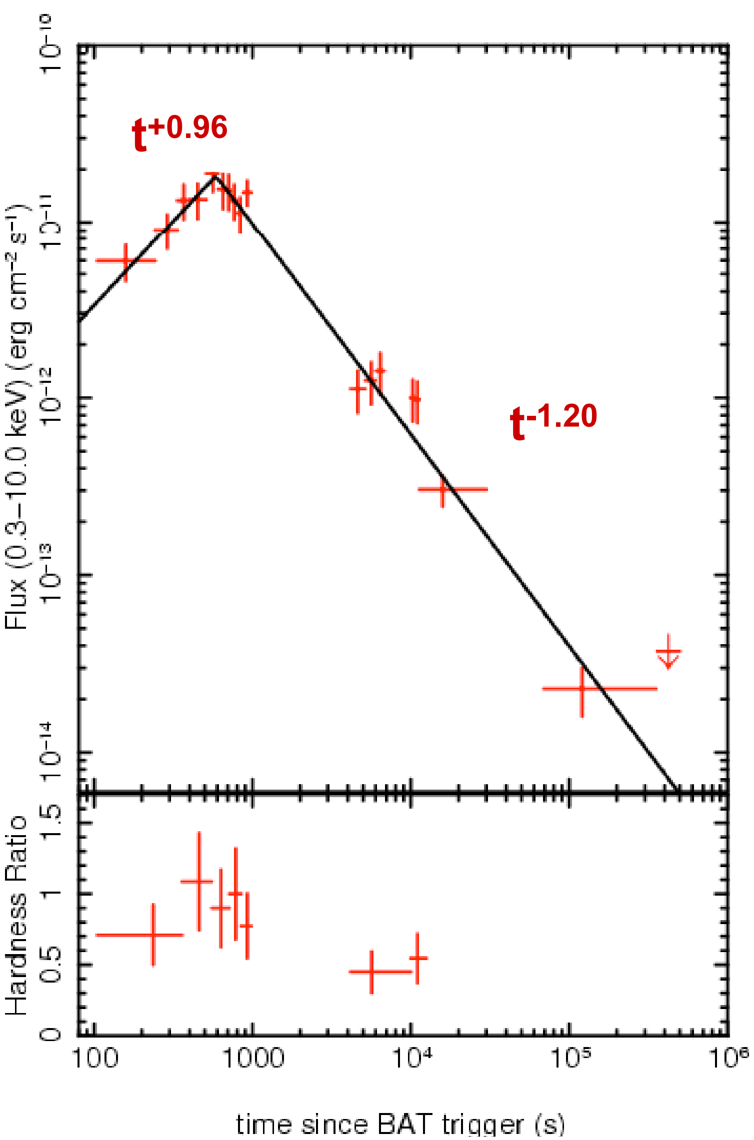
Meszaros et al. 2011

Swift - XRT

- Observations began 104 sec after trigger
- Rising as $t^{+0.96}$ followed by $t^{-1.20}$
- N(HI) excess: 10.1 (-5.3,+4.6) x 10^{20} cm^{-2}
  - $\Rightarrow$ 2.7 σ higher than galactic N(HI) (1.2 x 10^{20} cm^{-2})



Campana et al. 2009

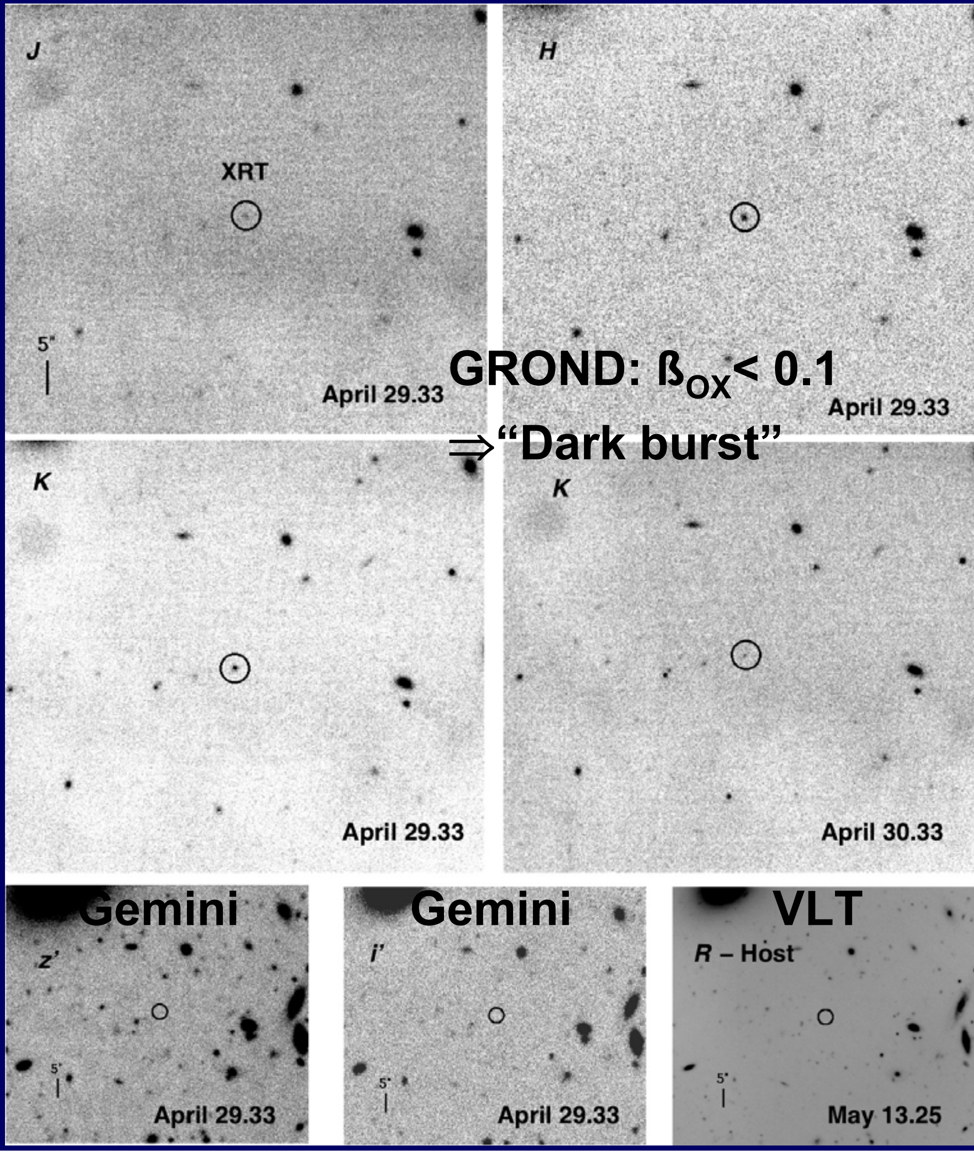


Optical and X-ray data

- UVOT observed right after XRT
- GROND observed within 14 min
- VLT observed at T ~ 1 hr after (R, z´)
- Gemini-GMOS obs at T ~ 3 hr (z´, i´)

Only upper limits in Optical and NIR

We activated our Gemini ToO program
Using NIRI in *JHK* we identified a fading counterpart (two days apart)



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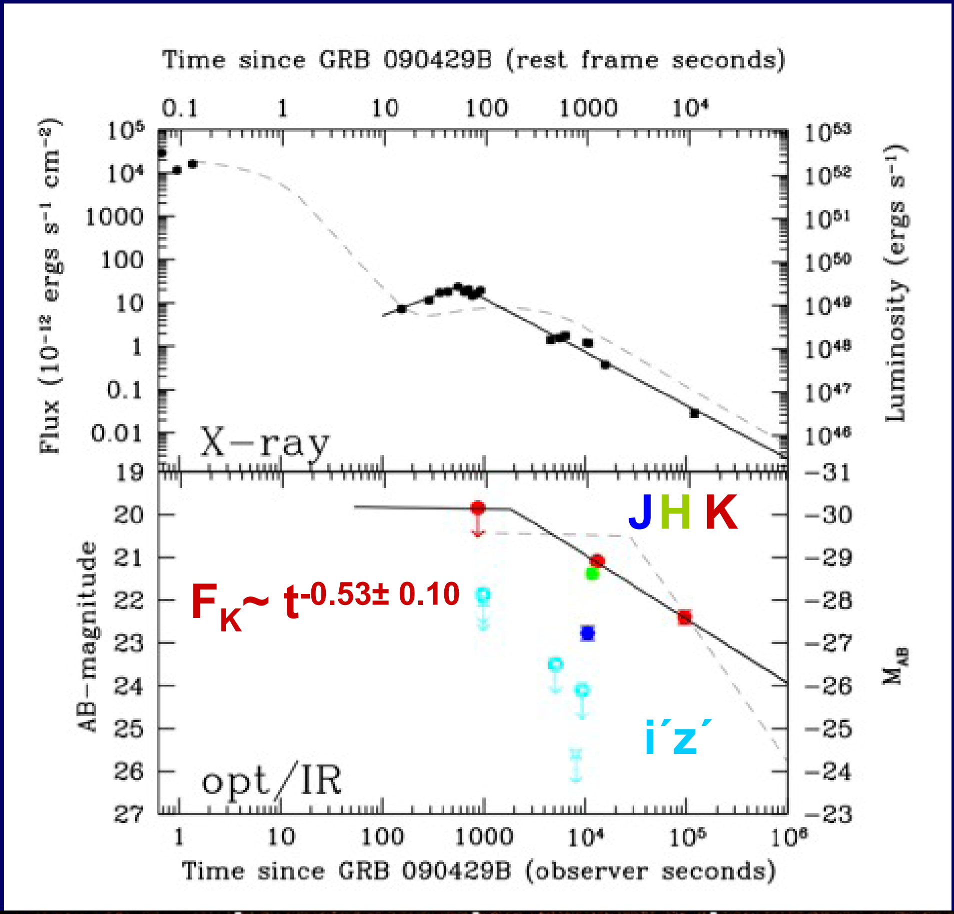
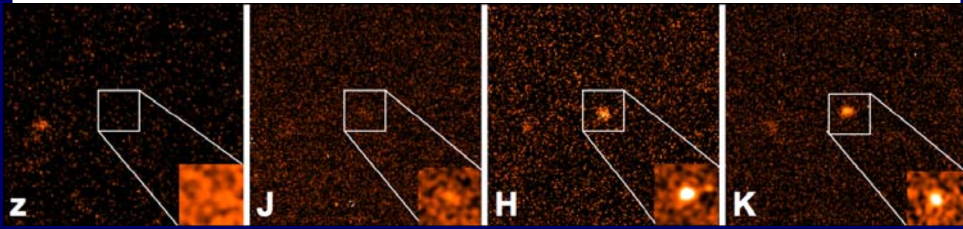
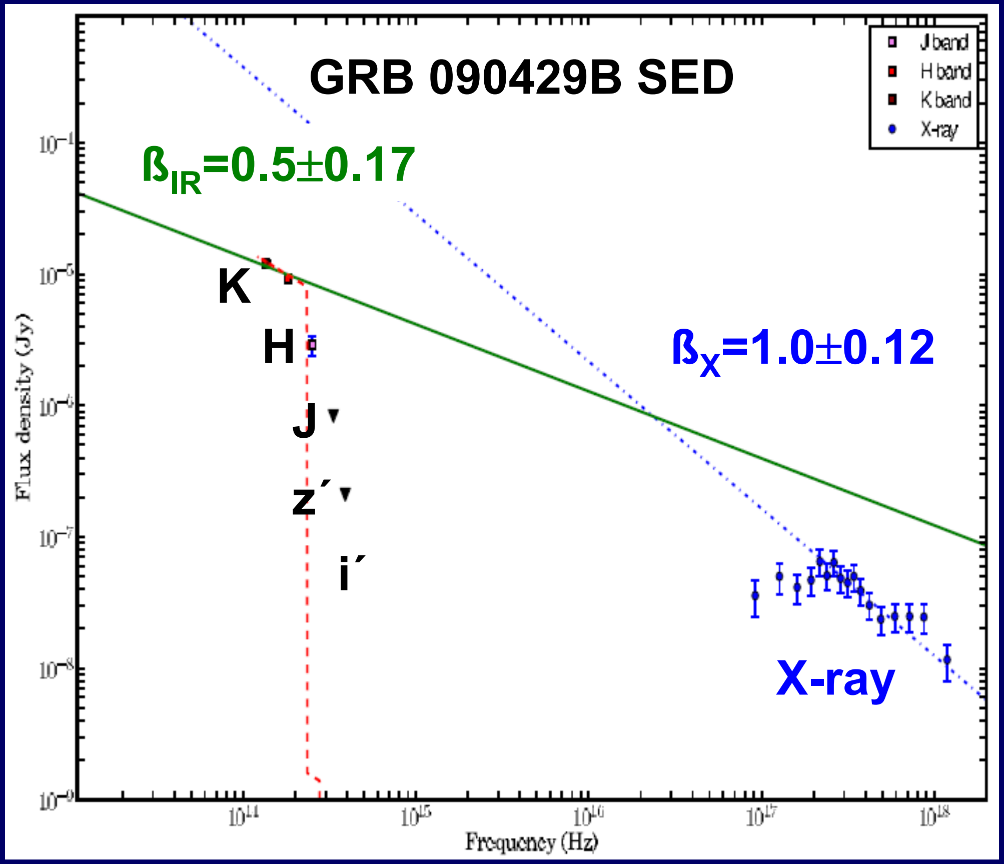
Using NIRI in *JHK* we identified a fading counterpart (two days apart)
→ Bad weather → No spectrum





Photometric redshift model

- Photometric redshift analysis of the first night data using the Hyperz tool (Bolzonella et al. 2000) by modeling the *JHK* detections using different dust extinction laws



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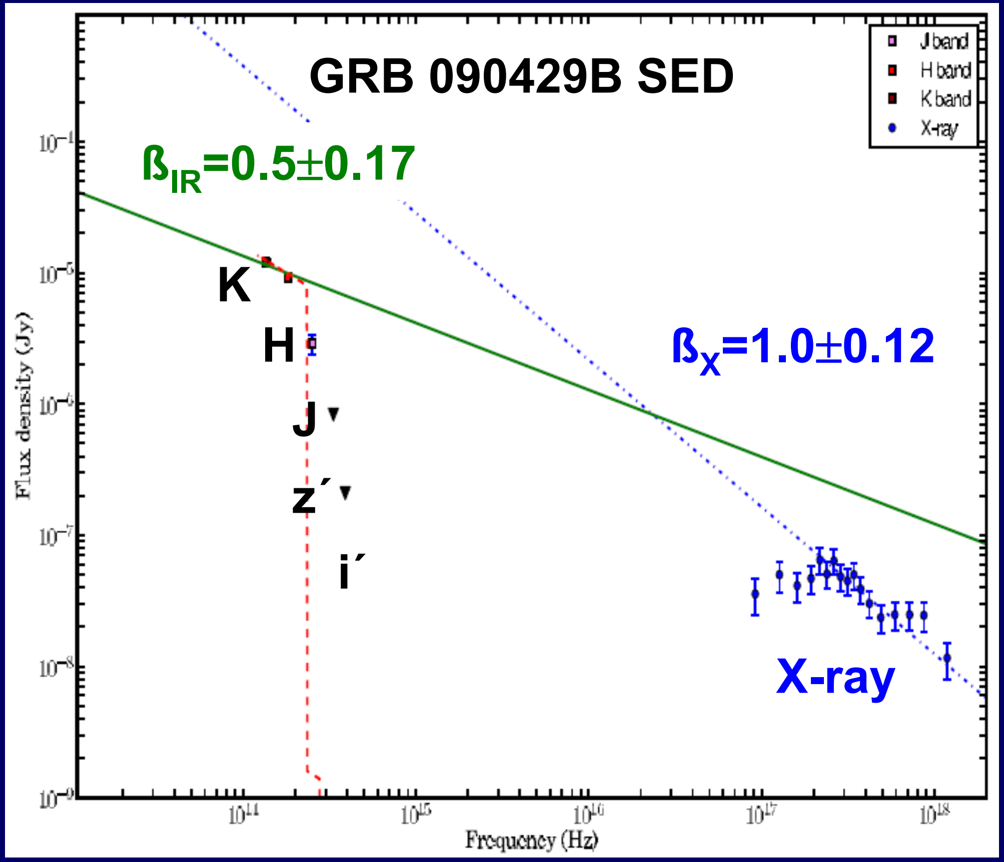
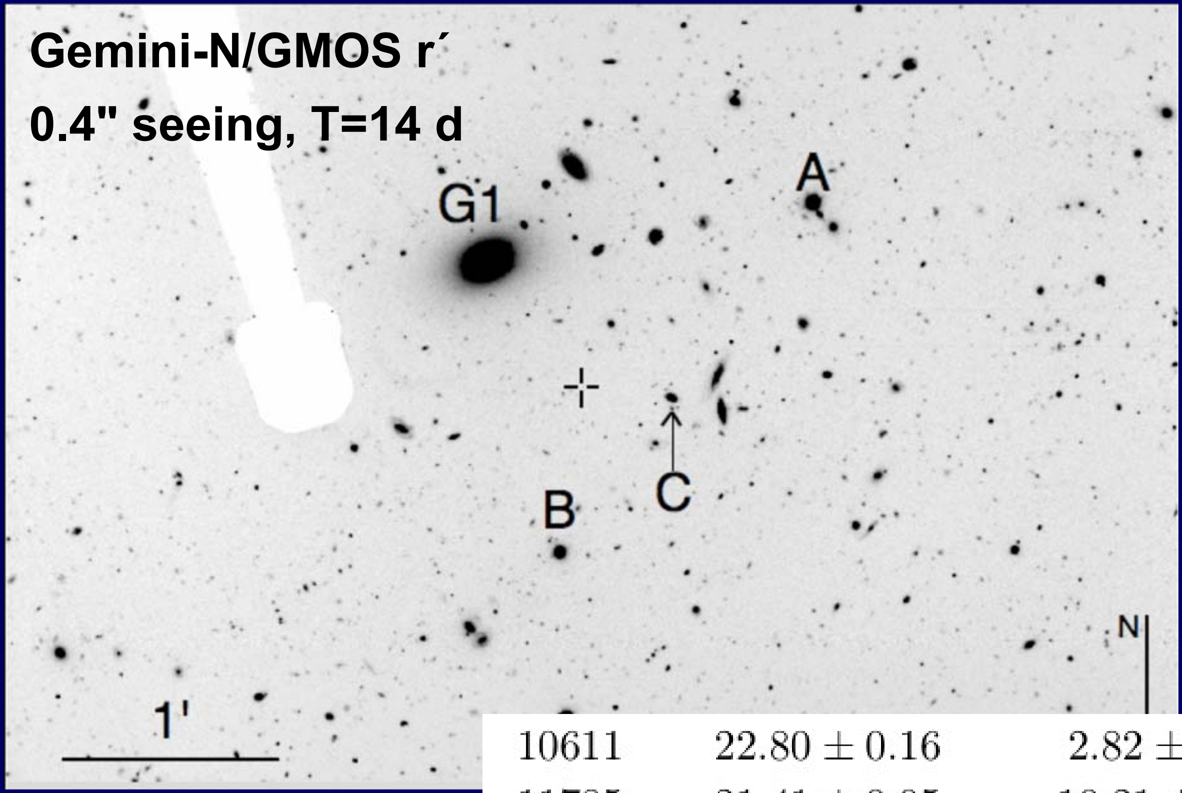


Need to understand:

- Error budget → NIR $\delta_K=0.04^m$
- Intrinsic dust and extinction-laws
- Temporal decay index (α)
- Opt-NIR spectral index (ß)

Photometric calibration



GBR properties:

- Gemini-N/GMOS: r´ >27.07^{m}
- No evidence for host galaxy

10611	22.80 ± 0.16	2.82 ± 0.44	J	Gemini-N/NIRI
11785	21.41 ± 0.05	10.21 ± 0.50	H	Gemini-N/NIRI
13280	21.12 ± 0.04	13.26 ± 0.51	K	Gemini-N/NIRI
95658	22.42 ± 0.16	4.0 ± 0.6	K	Gemini-N/NIRI

- Using UKIRT/WFCAM, GROND, Gemini-NIRI acq images, and stars B + C photometric errors were reduced to: δ_J=0.16, δ_H=0.05, δ_K=0.04

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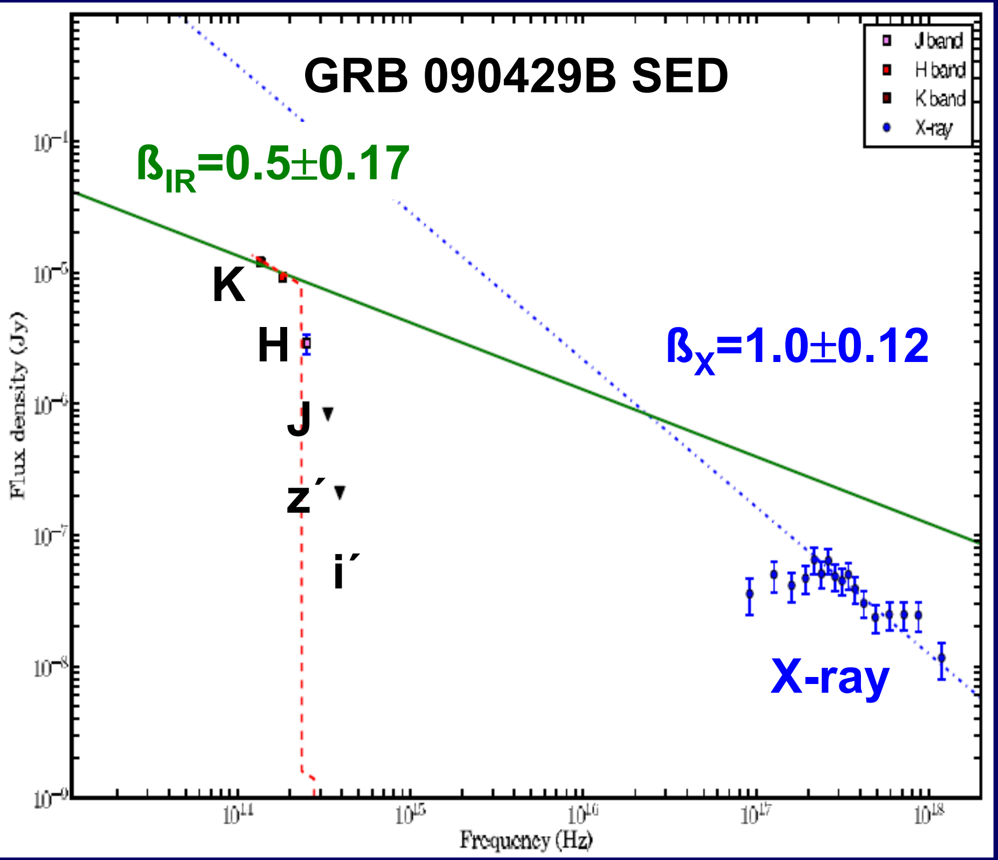

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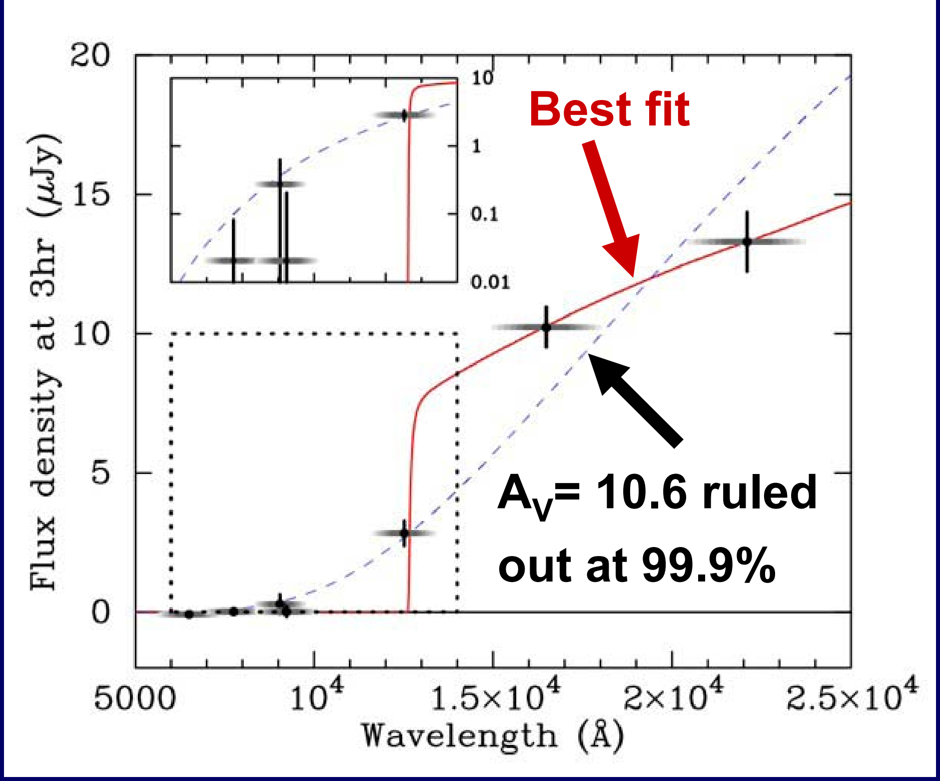
Infer from data:

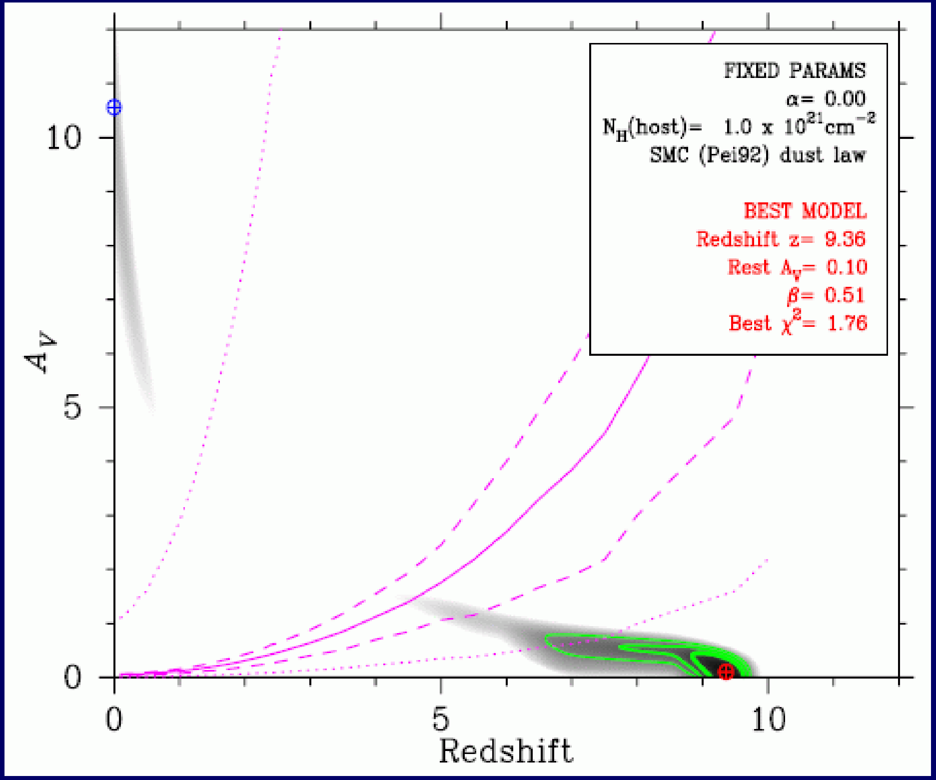
- Absence of optical afterglow z >6.3
- If J-H color Ly-break: 8 < z < 10.5

→ Explore different extinction-laws, α and ß ranges

SED of GRB 090429B

- SMC dust extinction-law and tested most challenging scenarios: **$0 < A_V < 12$**
- Based on previous observations and assuming a break between optical and X-ray (e.g. $\Delta\beta \sim 0.5$): **$0.3 < \beta < 0.85$**
- No assumption on temporal index (excluding steep rising/decay): **$-1 < \alpha < +1$**





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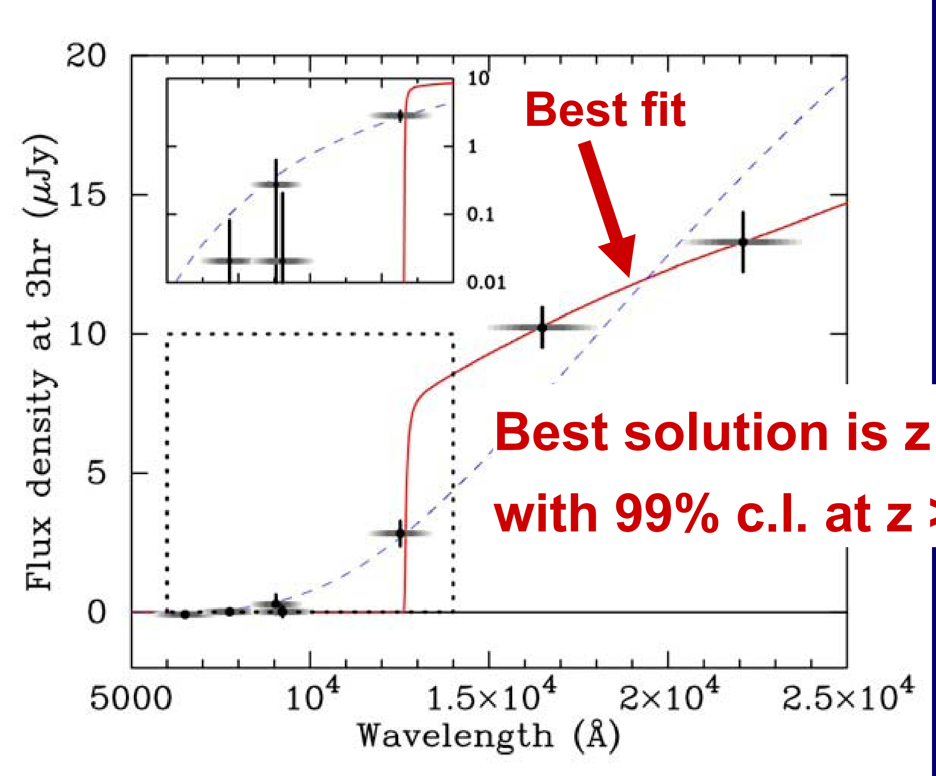
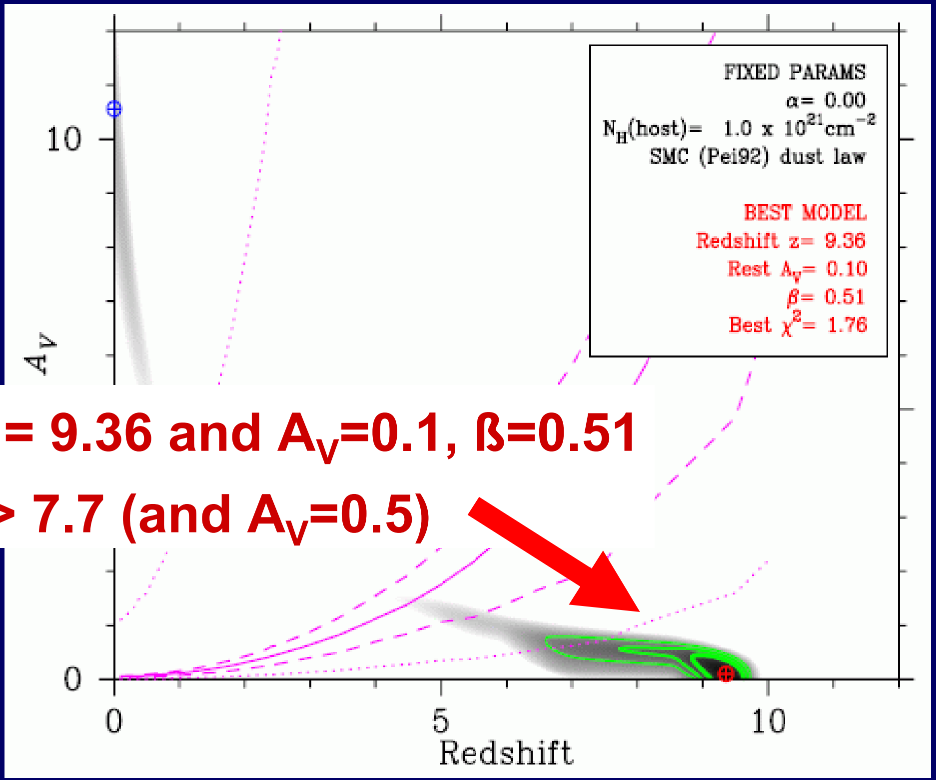
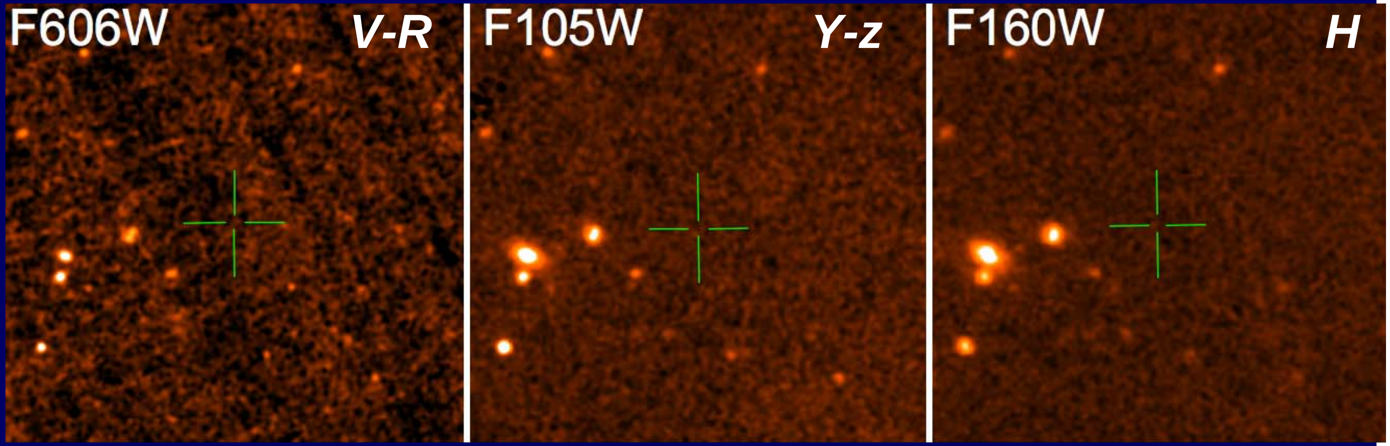


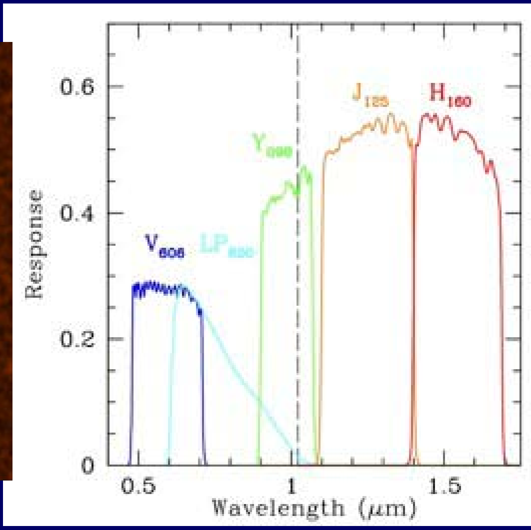


Best solution is z = 9.36 and A_V=0.1, ß=0.51 with 99% c.l. at z > 7.7 (and A_V=0.5)

The low-z solution

- The low-redshift solution describes a highly extincted host galaxy
- Thanks to ACS/WFC3 *HST* program by Nial Tanvir and Andrew Levan
- No z<1 host detected! Even a dusty host at z<1 is very unlikely fainter





M_B > -15.5 ($L \leq 0.001\ L^*$ @ z=1)

→ At z = 9.4 $M_{1500Å}$ > -19.95

Consistent with Bouwens et al. 2010

Non detection of the host down to deep limits allows us to exclude the low-z solution!!

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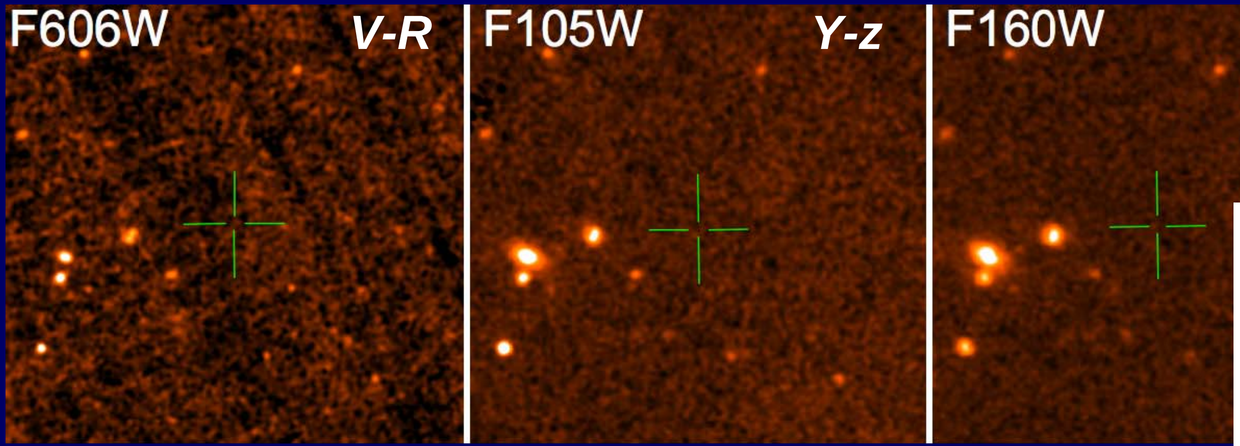

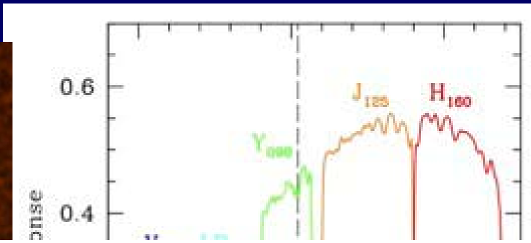

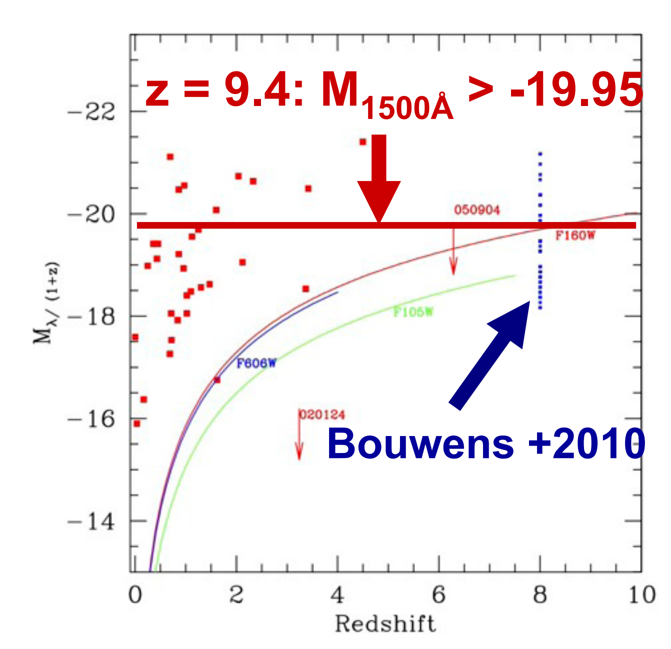

M_B > -15.5 (L ≤ 0.001 L* @ z=1)

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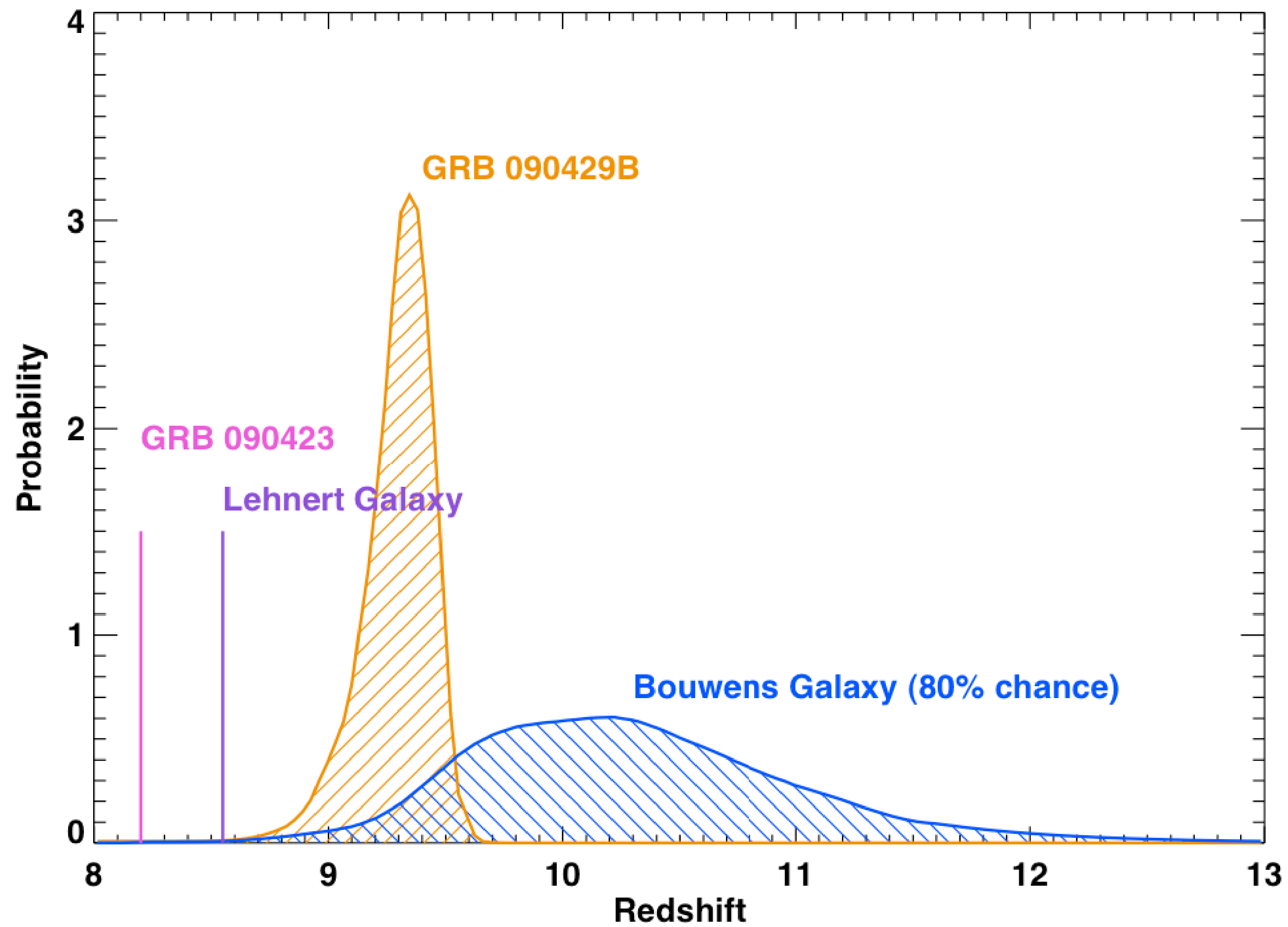
Comparison with other probes



Credit: Fox / Cucchiara / Levan / Tanvir

Conclusions

- We detected the afterglow of GRB 090429B with Gemini-NIRI in *JHK*
- No host galaxy has been found with *HST*: **$M_B > -15.5$ ($L \leq 0.001\ L^*$ @ z=1)**
- We performed a photometric redshift analysis and tested a large range of physical parameters for the afterglow and different dust extinction laws: NIR + high-energy data exclude $z < 5$, photometric fit: $7.7 < z < 9.5$ (99%)
- Dust properties of the host or extreme physical parameters of the afterglow emission do not significantly impact our results (no high dust destruction)
- GRB properties similar to other long-duration GRBs: progenitor Pop II star

GRB090429B is z = 9.36 (-0.3/+0.14 @ 90% c.l.)

Age of Universe = 520 Myrs, size < 10%