Australian National University

Gravitational Lensing as the Source of Enhanced Strong MgII Absorption Towards GRBs

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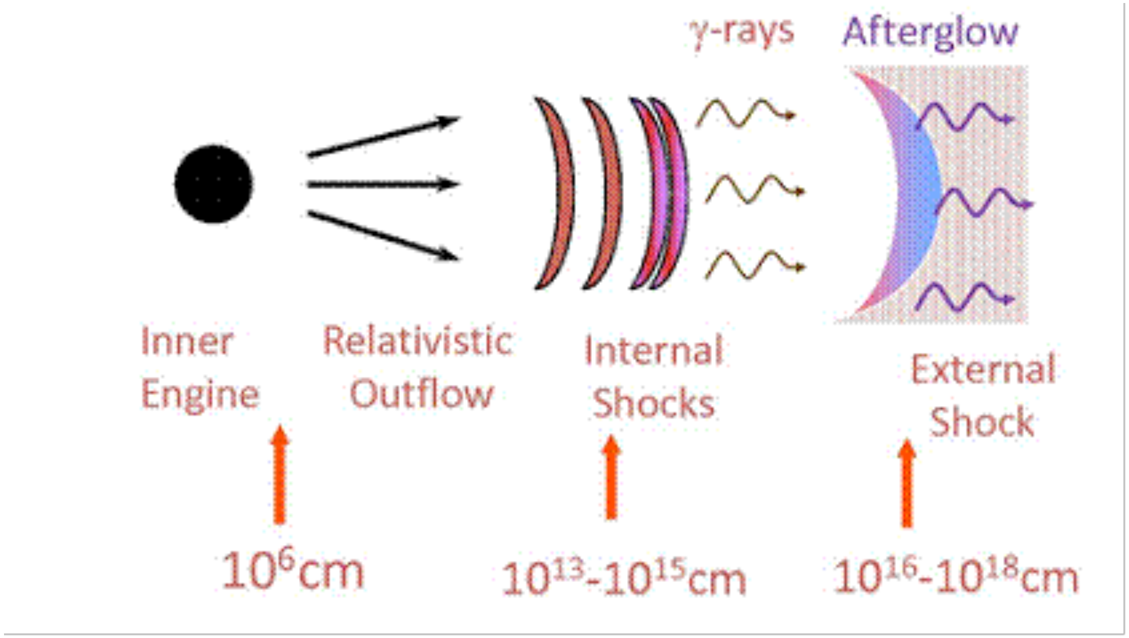
Today

- Gamma-ray bursts (GRBs)
- Quasi-stellar objects (QSOs)
- The MgII problem
- Failed Solutions
- Gravitational Lensing
  - Multi-band bias
  - Statistical Analysis
  - Individual source analysis
- Conclusions

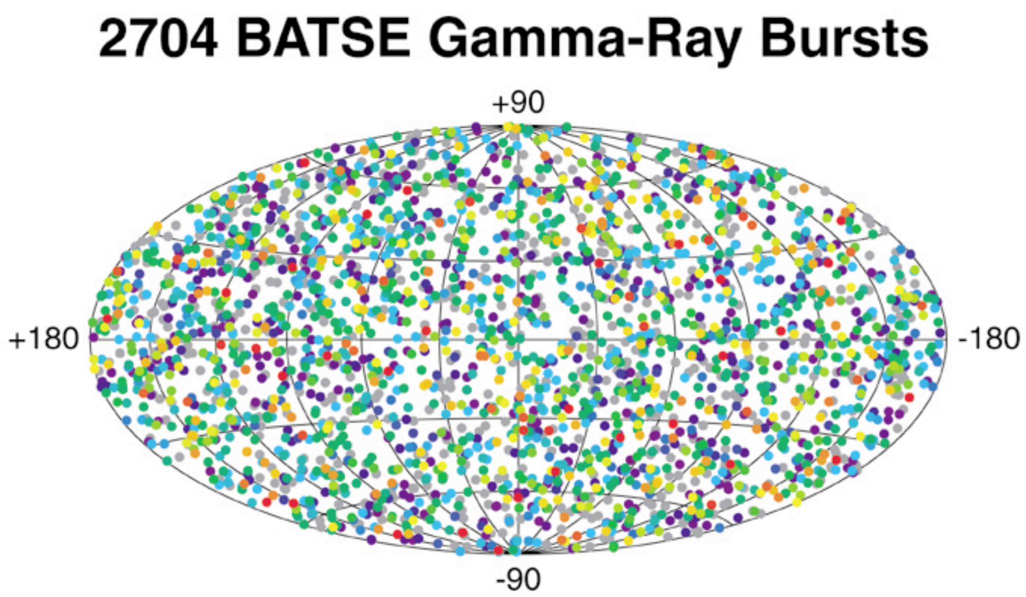
GRBs



http://physicaplus.org.il/zope/home/en/1223030912/piran_en

GRBs

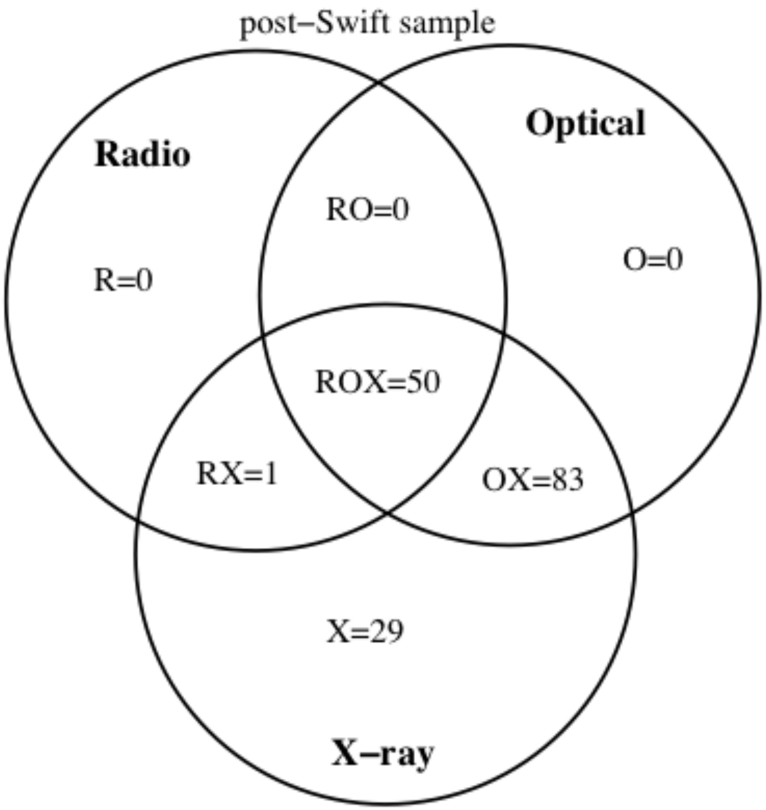
- First detected in Gamma-rays
- ~40% detected in optical
- > 3000



http://heasarc.gsfc.nasa.gov/docs/cgro/cgro/batse_src.html

GRBs - Observations

- 304 GRBs followed up in Radio between 01/1997-01/2011
- Total:
  - X-ray 163
  - Optical 133
  - Radio 51



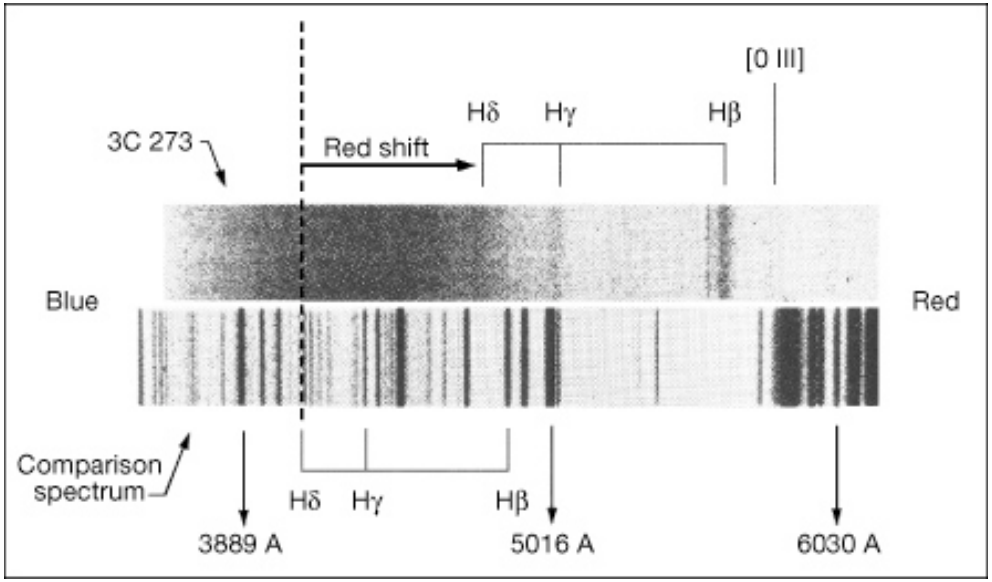
Chandra & Frail 2011

QSOs

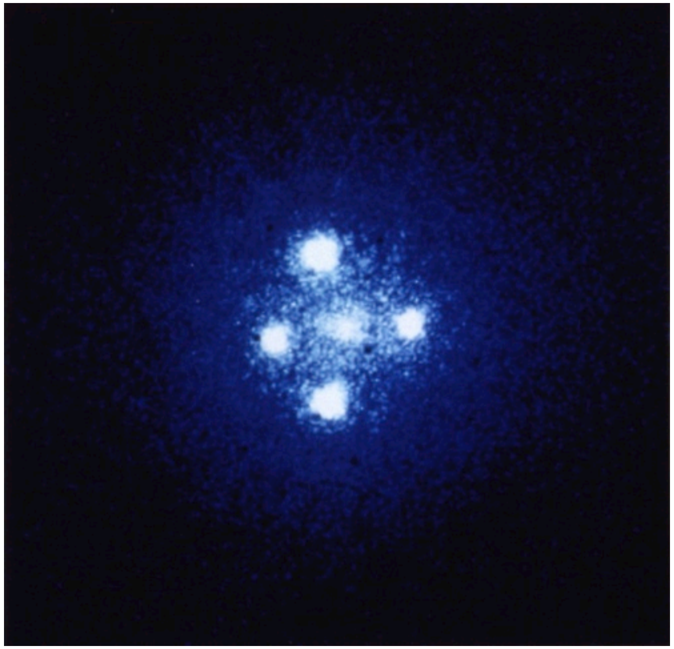
- Detected via UV-excess, multi-color selection, IR color, radio spectral slope…

QSOs

- >100s of thousands
- ~0.1% strongly lensed

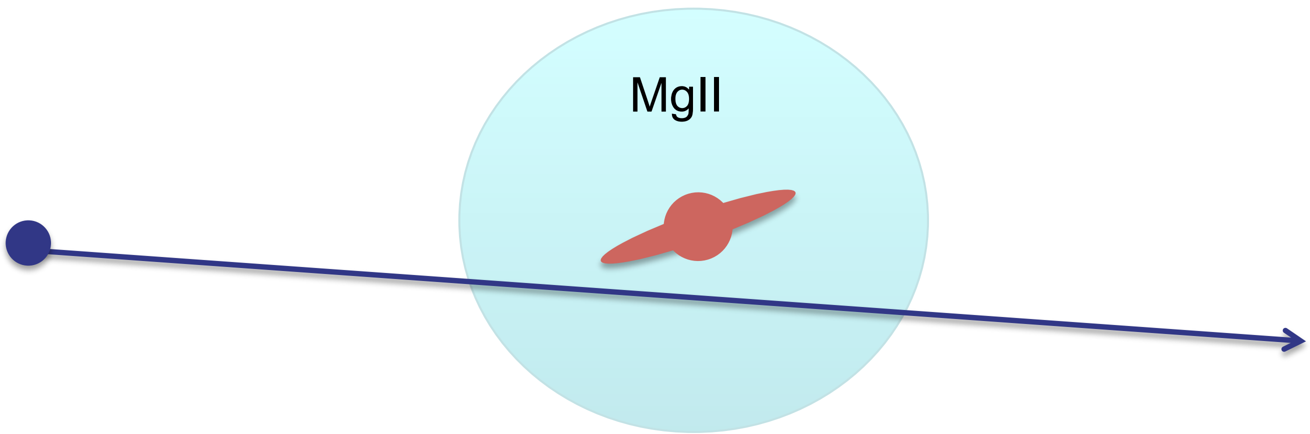


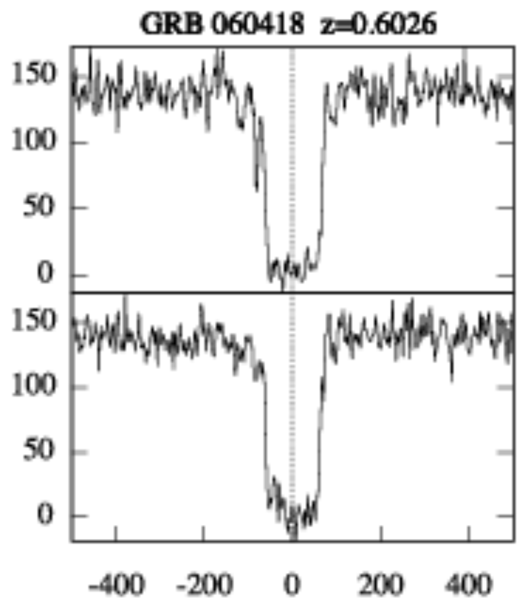
http://www.ast.cam.ac.uk/~regan/quasars.html



QSO 2237+0305 sits directly behind *ZW 2237+030*

MgII absorbers

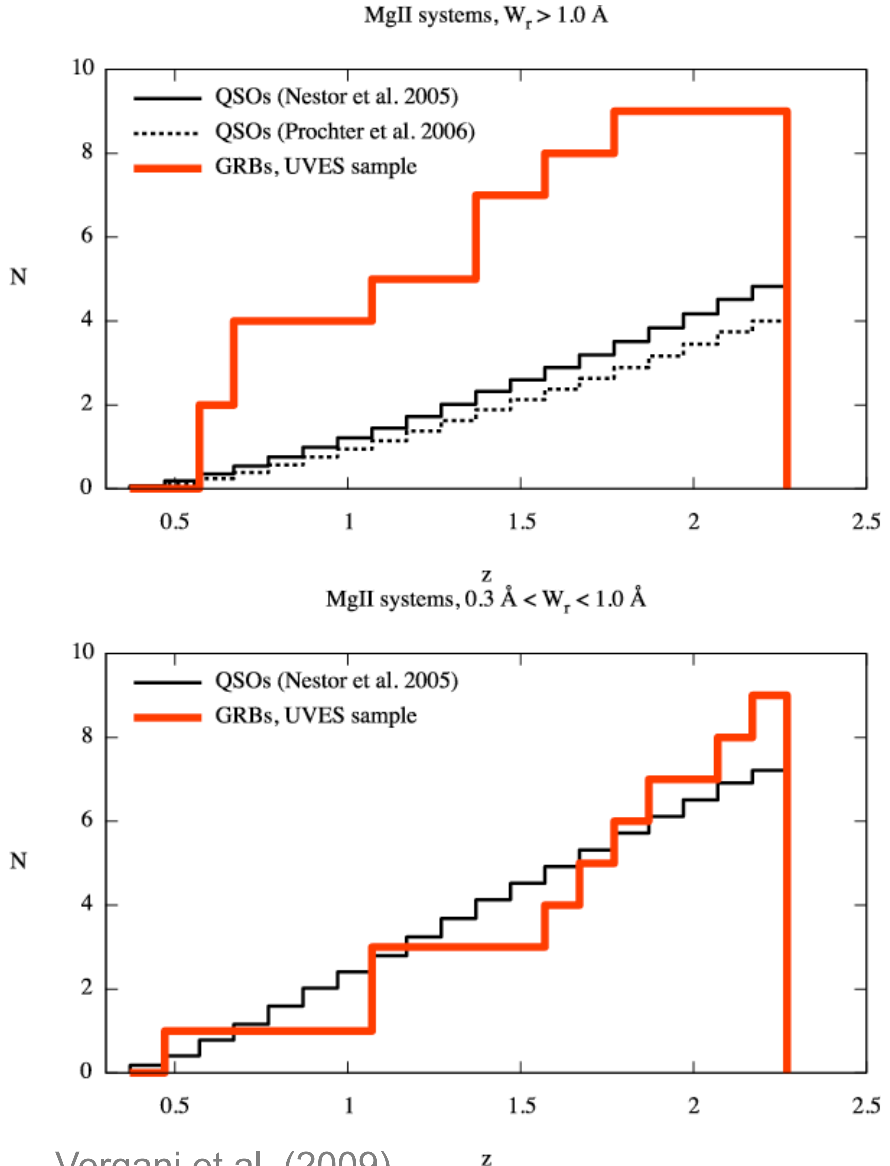




Prochter et al 2006

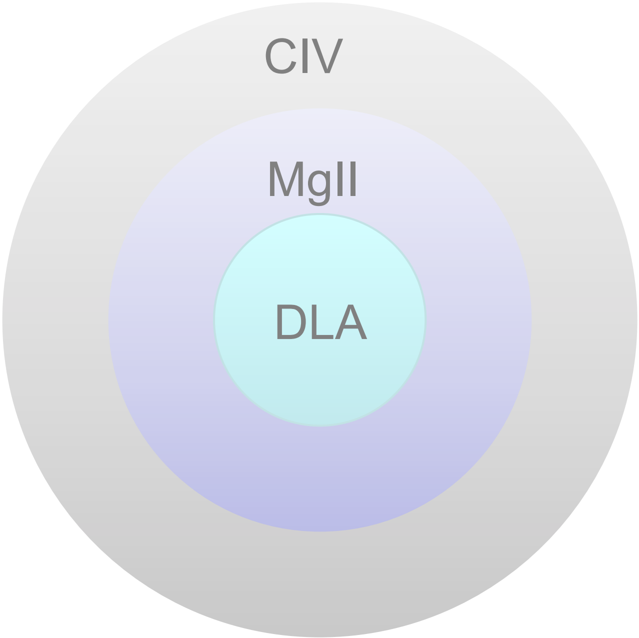
MgII Problem

- GRB – QSO difference only seen in STRONG MgII systems (EW>1Å)



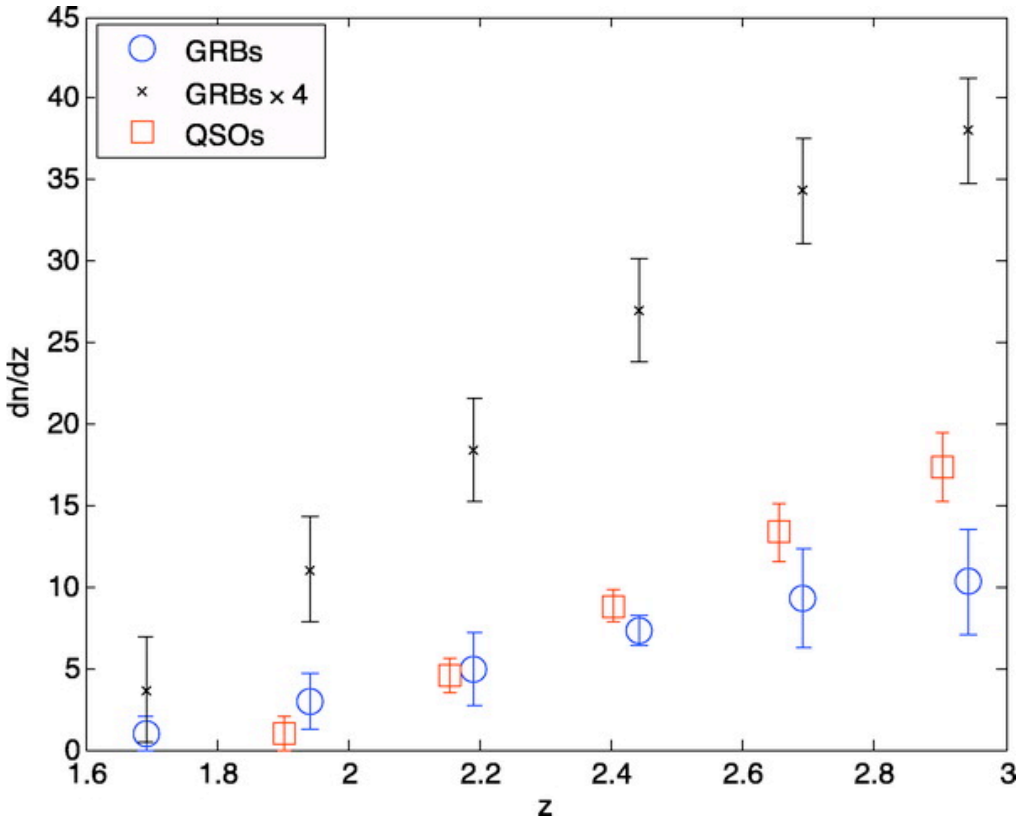
Vergani et al. (2009)

Galaxy Gas Cross Section



CIV Comparison

- No discrepancy found
- CIV probes higher redshifts, higher ionization states, lower densities than MgII

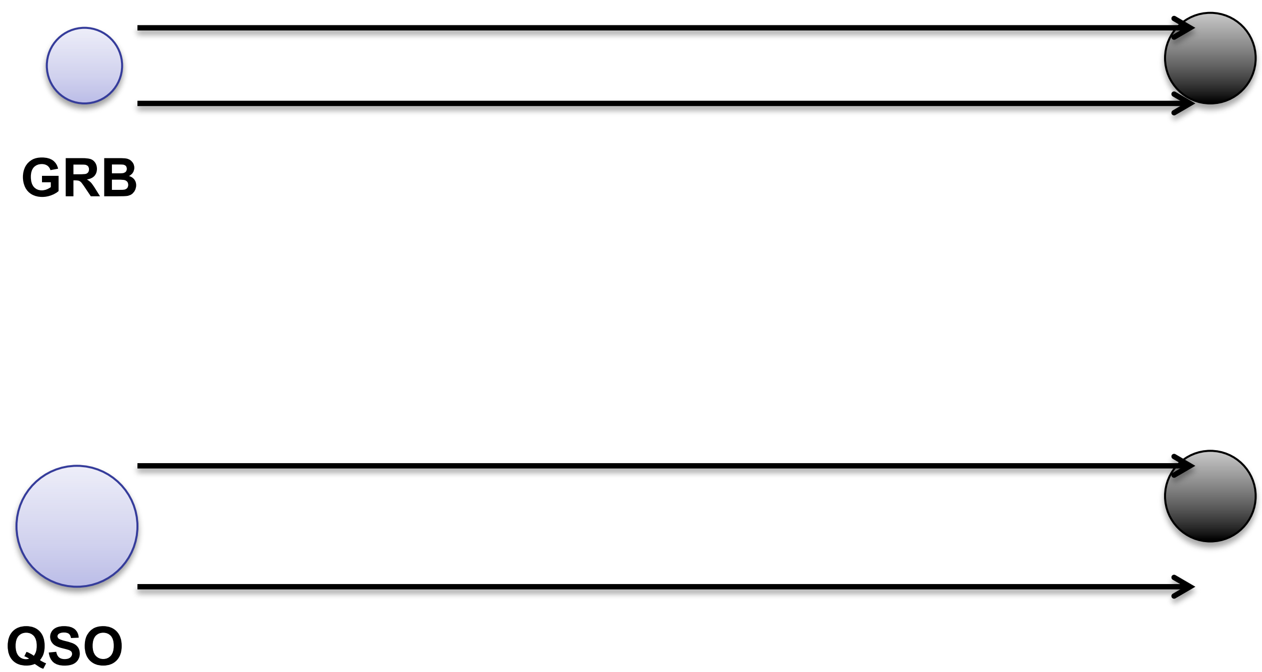


Sudilovsky et al. (2007)

Possible Solutions

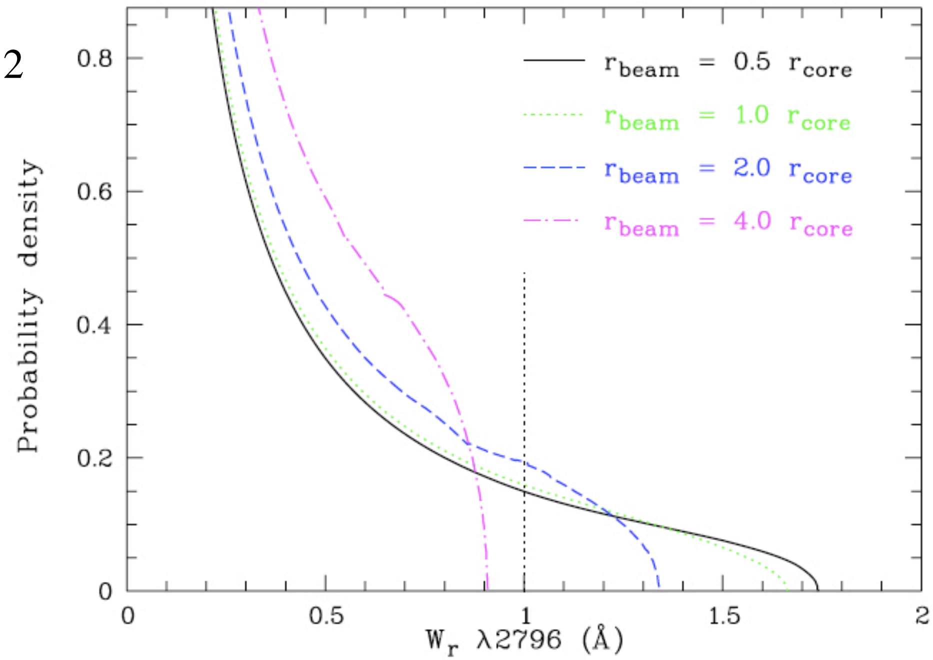
- Beam size
- Proximate environment
- Dust obscuration
- Gravitational lensing

Beam Size Differences



Beam Size Differences

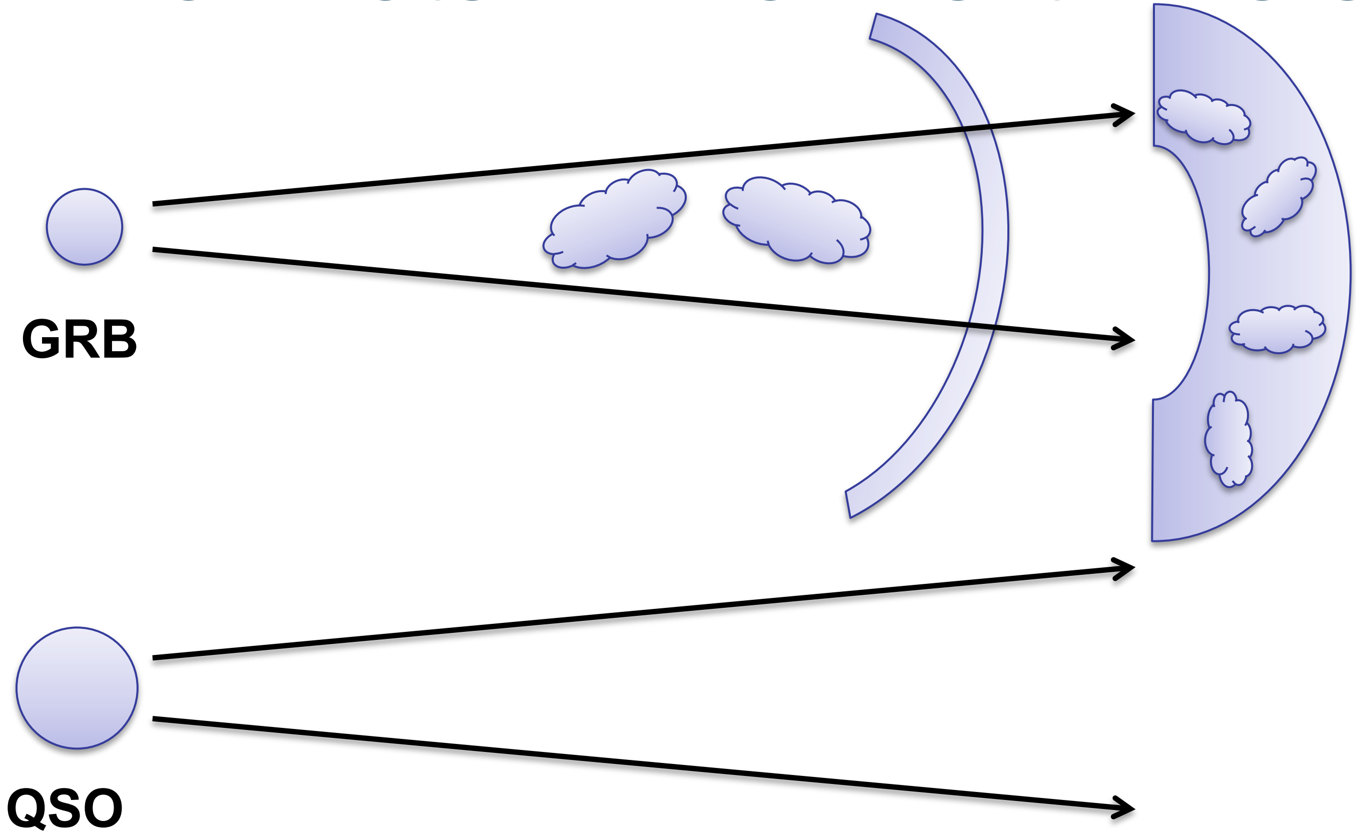
- MgII absorber $\leq 10^{16} cm^2$
- The absorbing systems are likely to be much larger than either beam
  - Porciani et al. 2007



Frank et al. (2007)

$$\rho(r) = \begin{cases} \rho_0; & r \leq r_0, \\ \rho_0 (r/r_0)^{-k}; & r > r_0. \end{cases}$$

Proximate Environment Differences

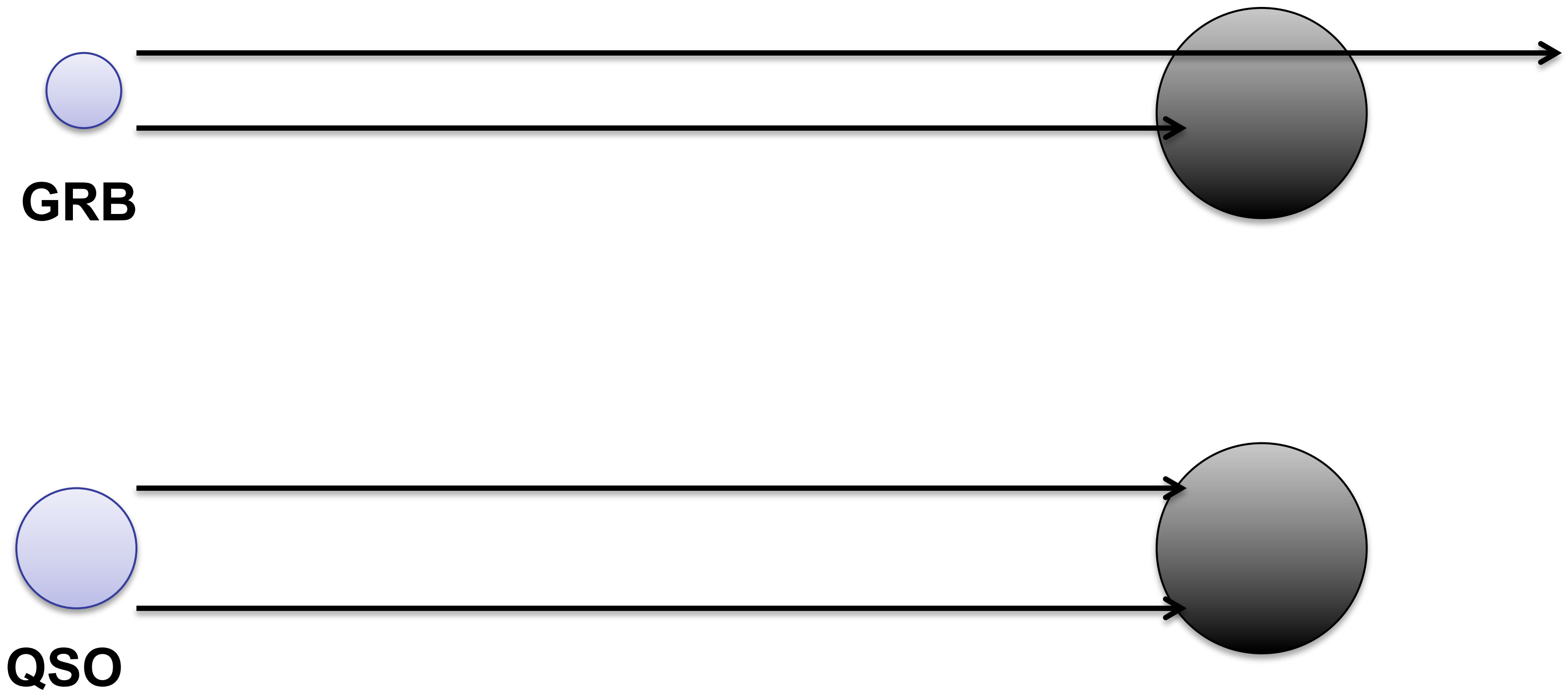


Proximate Environment Differences

- Some of the MgII systems in GRB spectra could be associated with the GRB

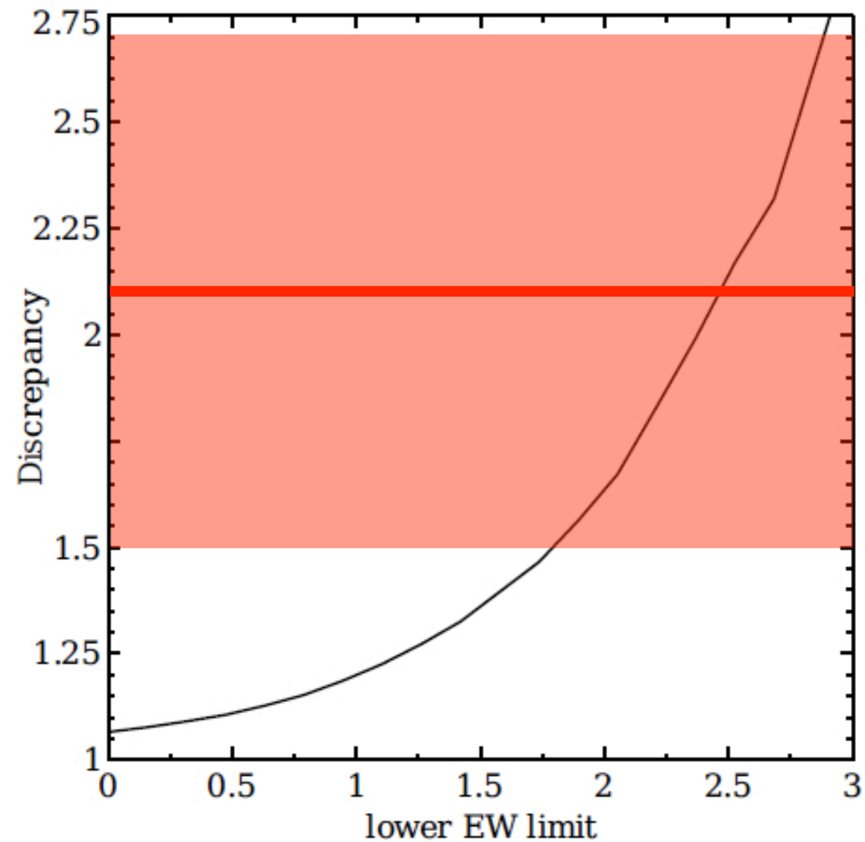
- Would require cold gas with metals to be moving at 20% c
  - need to stay below 10^4k

Dust Obscuration Bias



Dust Obscuration Bias

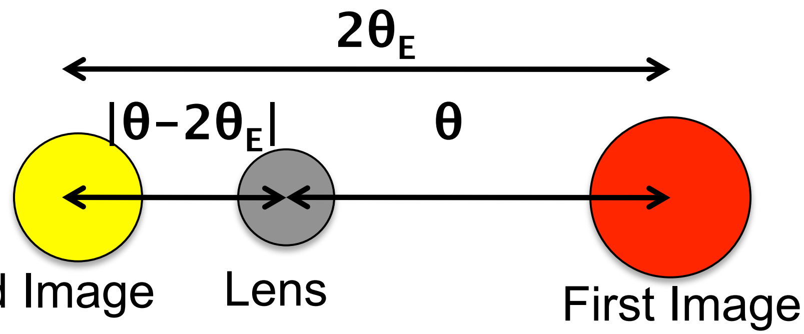
- GRBs intrinsically brighter than QSOs
- If strong MgII systems are dusty, fewer such systems will be seen towards QSOs due to extinction
- Recent analysis of extinction in QSO spectra suggests dust to be more prevalent than assumed
  - Budzynski & Hewett (2011)
- Applied to the MgII problem, hard to explain full discrepancy



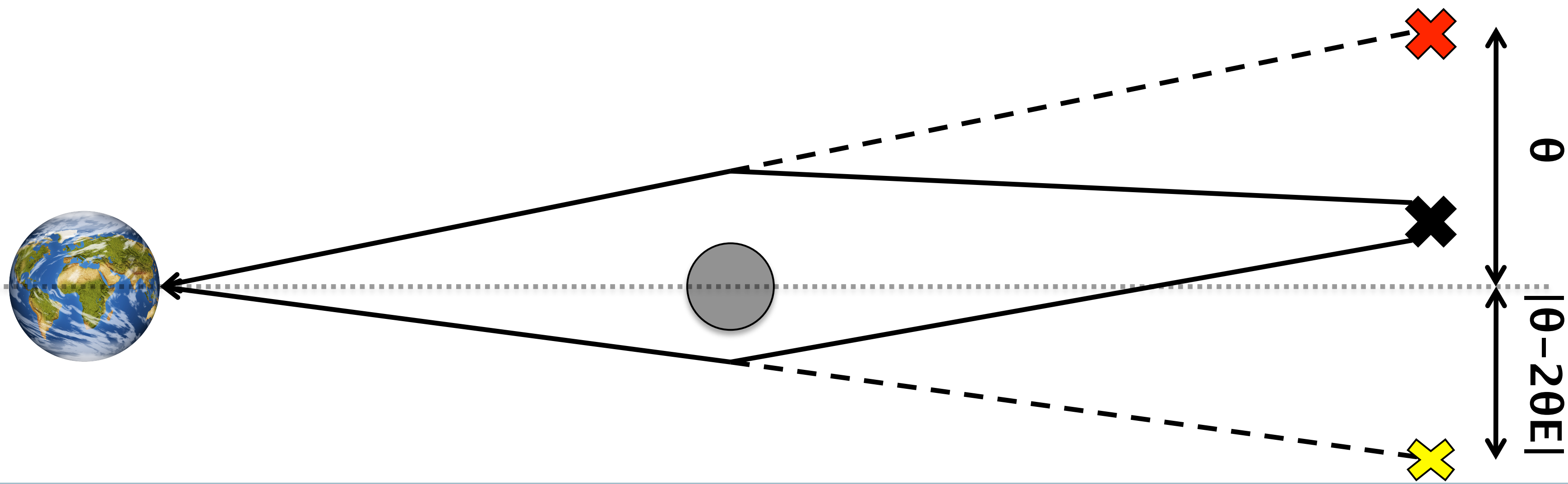
Budzynski & Hewett (2011)

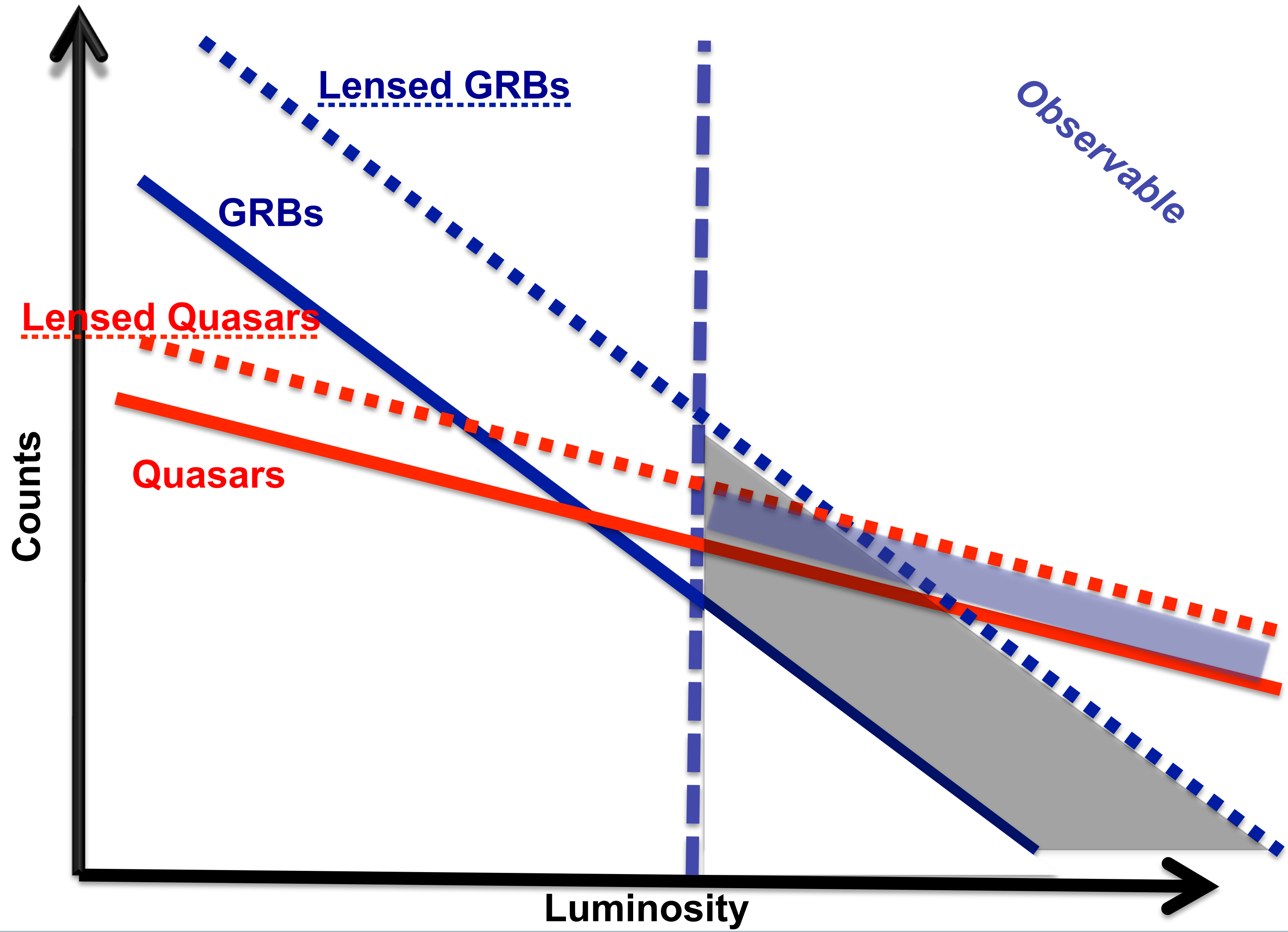
Gravitational Lensing Bias – Lensing Basics (SIS)

$$\rho(r) = \frac{\sigma_v^2}{2\pi G r^2}$$



$$\theta_E = 4\pi\left(\frac{\sigma_v}{c}\right)^2 \frac{D_{ls}}{D_s}$$




Lensed GRBs
Observable
GRBs
Lensed Quasars
Quasars
Counts
Luminosity

Single Band Magnification Bias

$$B_1(L_1,z) = \frac{\int_0^\infty (d\mu/\mu)(dP/d\mu)\Phi_1(L_1/\mu,z)}{\Phi_1(L_1,z)} = \int_2^\infty \frac{d\mu}{\mu}\frac{8}{\mu^3}\frac{1}{\mu^{\alpha_1}} = \frac{8}{3+\alpha_1}2^{-(3+\alpha_1)}$$

Isothermal Sphere
For Multiple Images

$$dP/d\mu = 8/\mu^3, \Phi_1 \propto L_1^{\alpha_1}$$

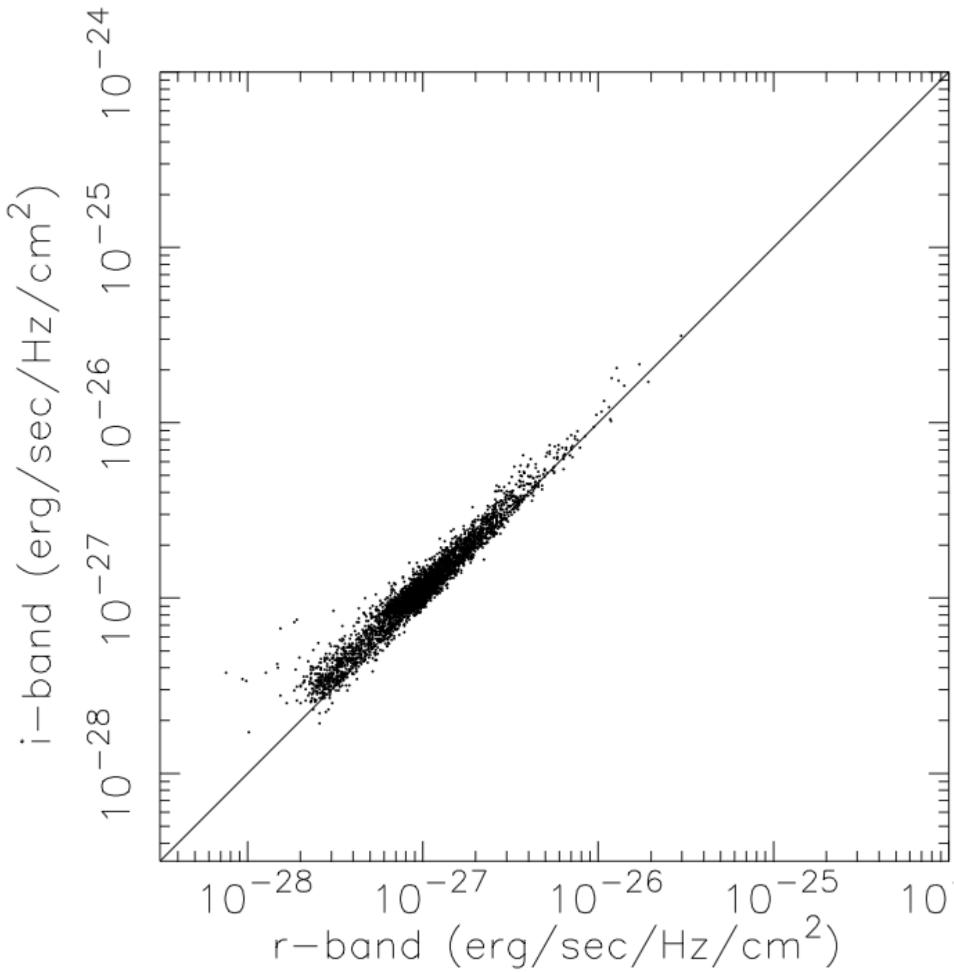
$$\mu \geq 2$$

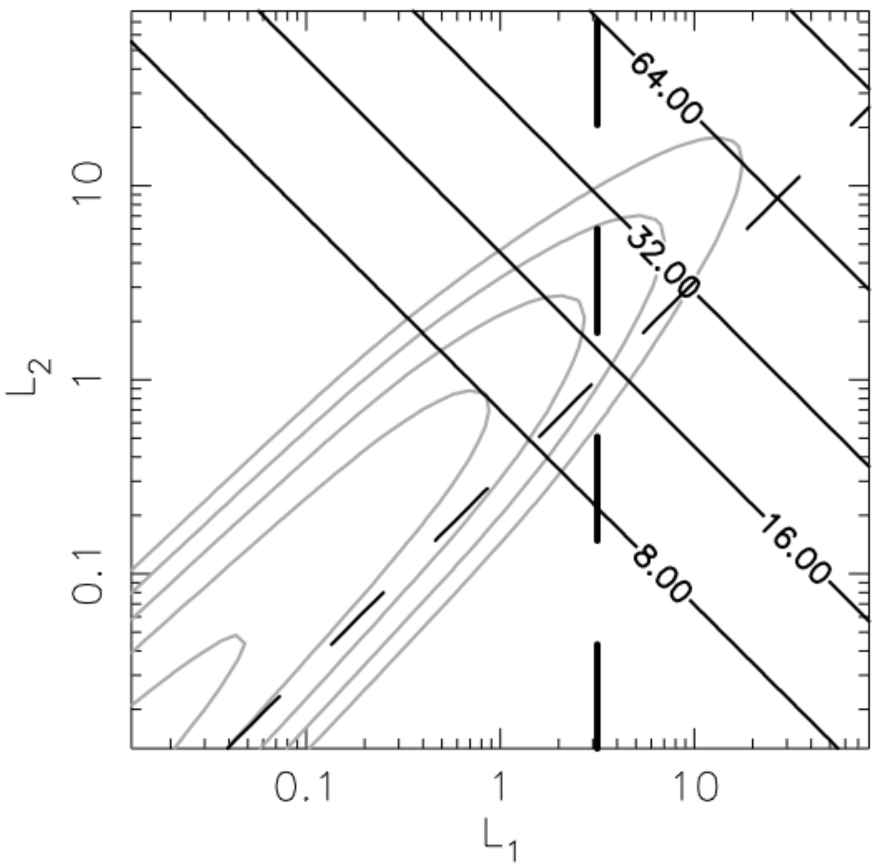
Wyithe et al. 2003

Australian National University

Multi-band Magnification Bias – QSO

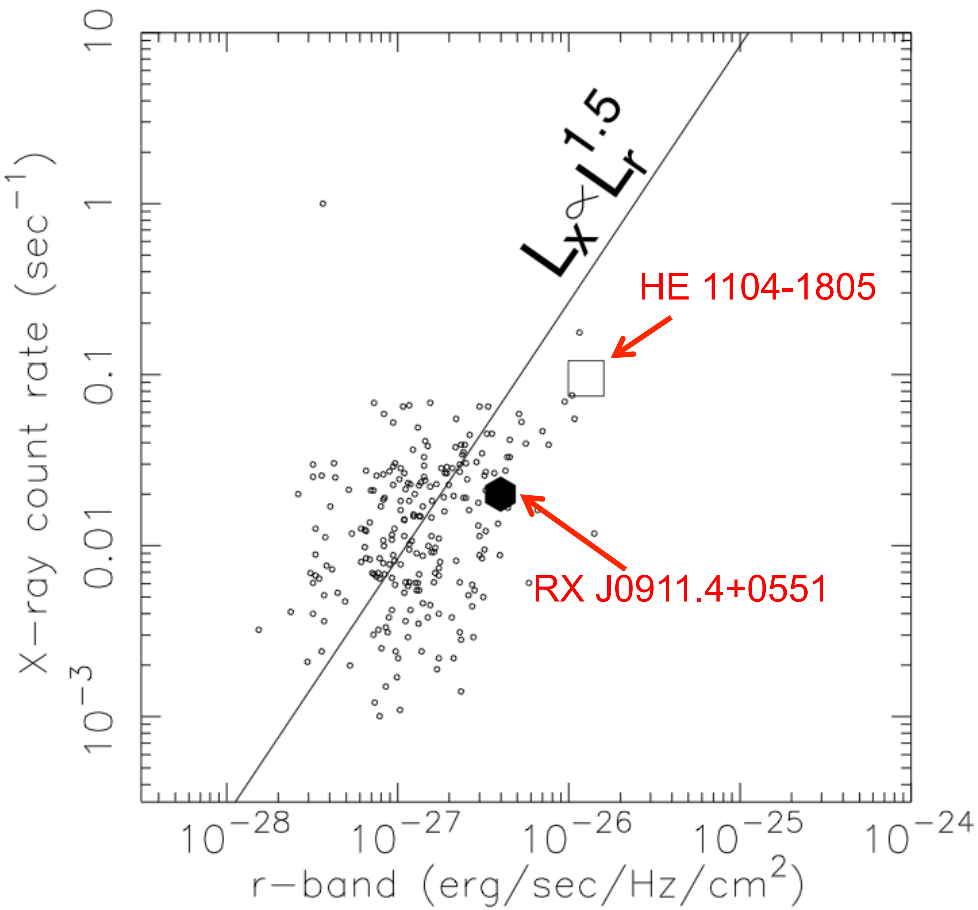
Wyithe et al 2003

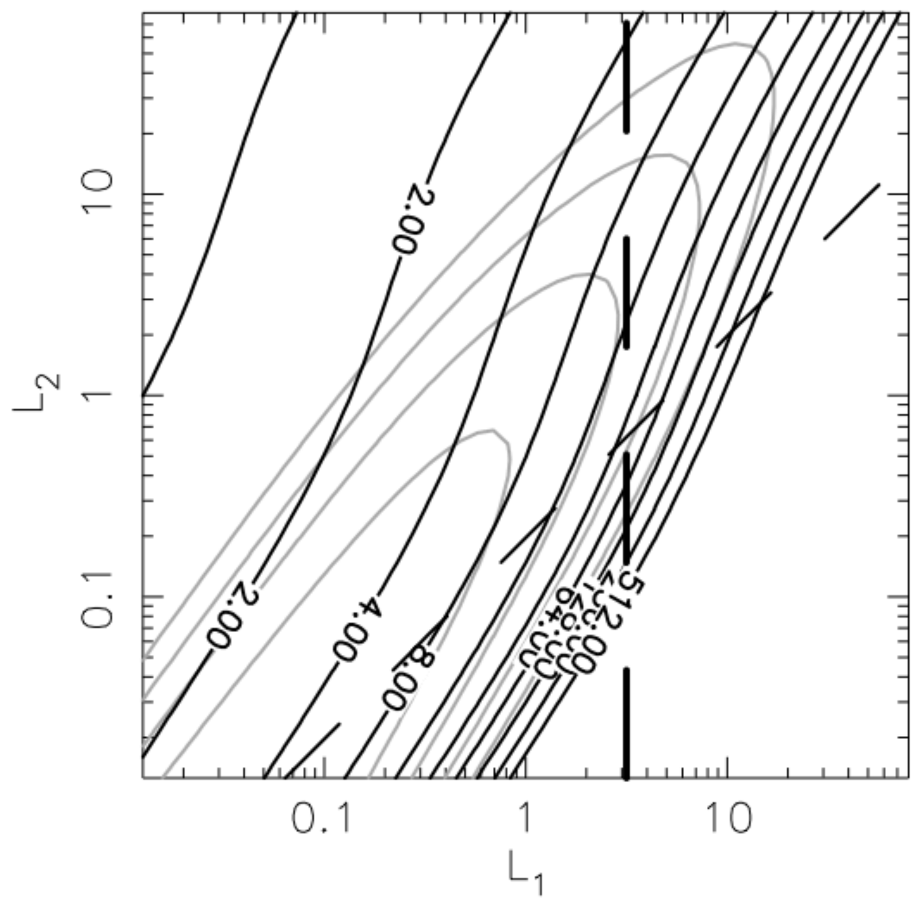




Multi-band Magnification Bias – QSO

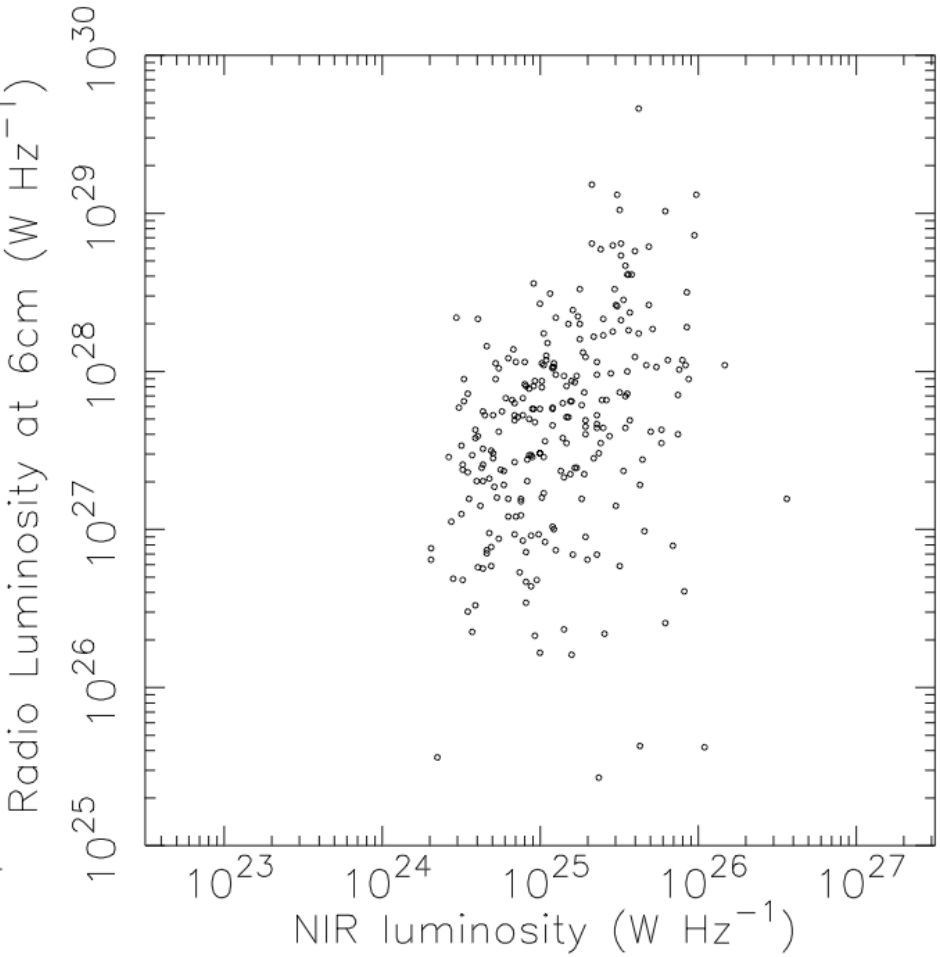
Wyithe et al 2003

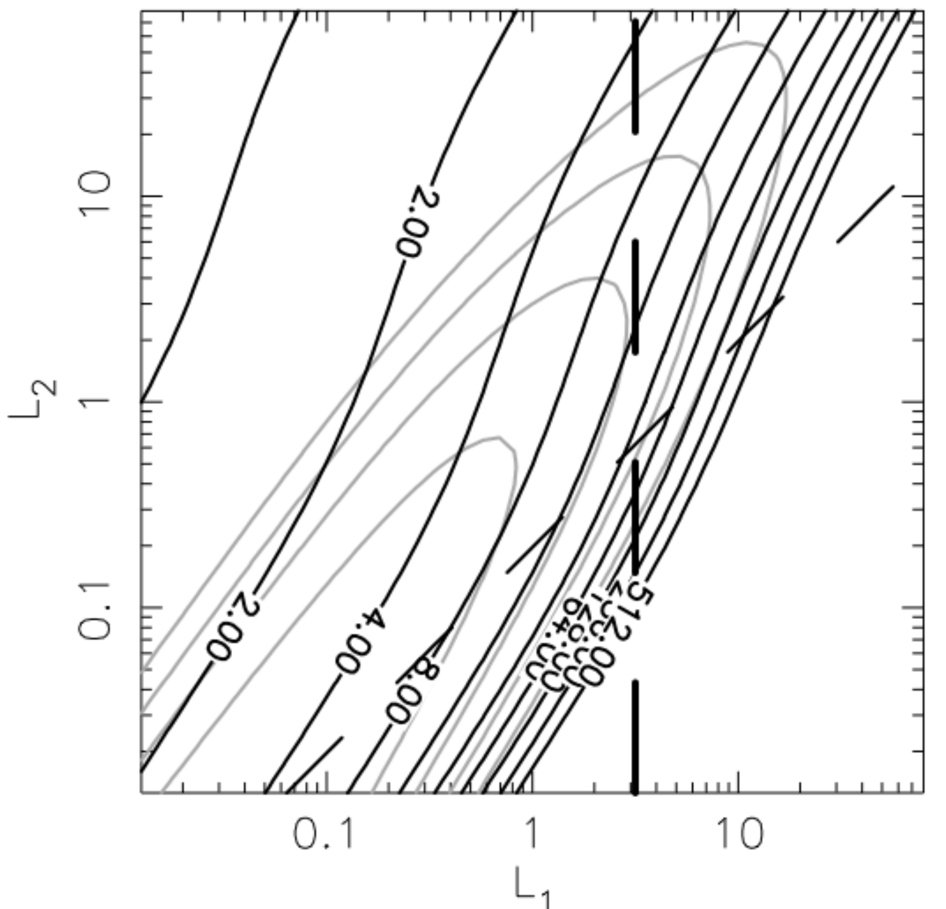




Multi-band Magnification Bias – QSO

Wyithe et al 2003





Multi-band Magnification Bias – GRBs

Wyithe et al 2011

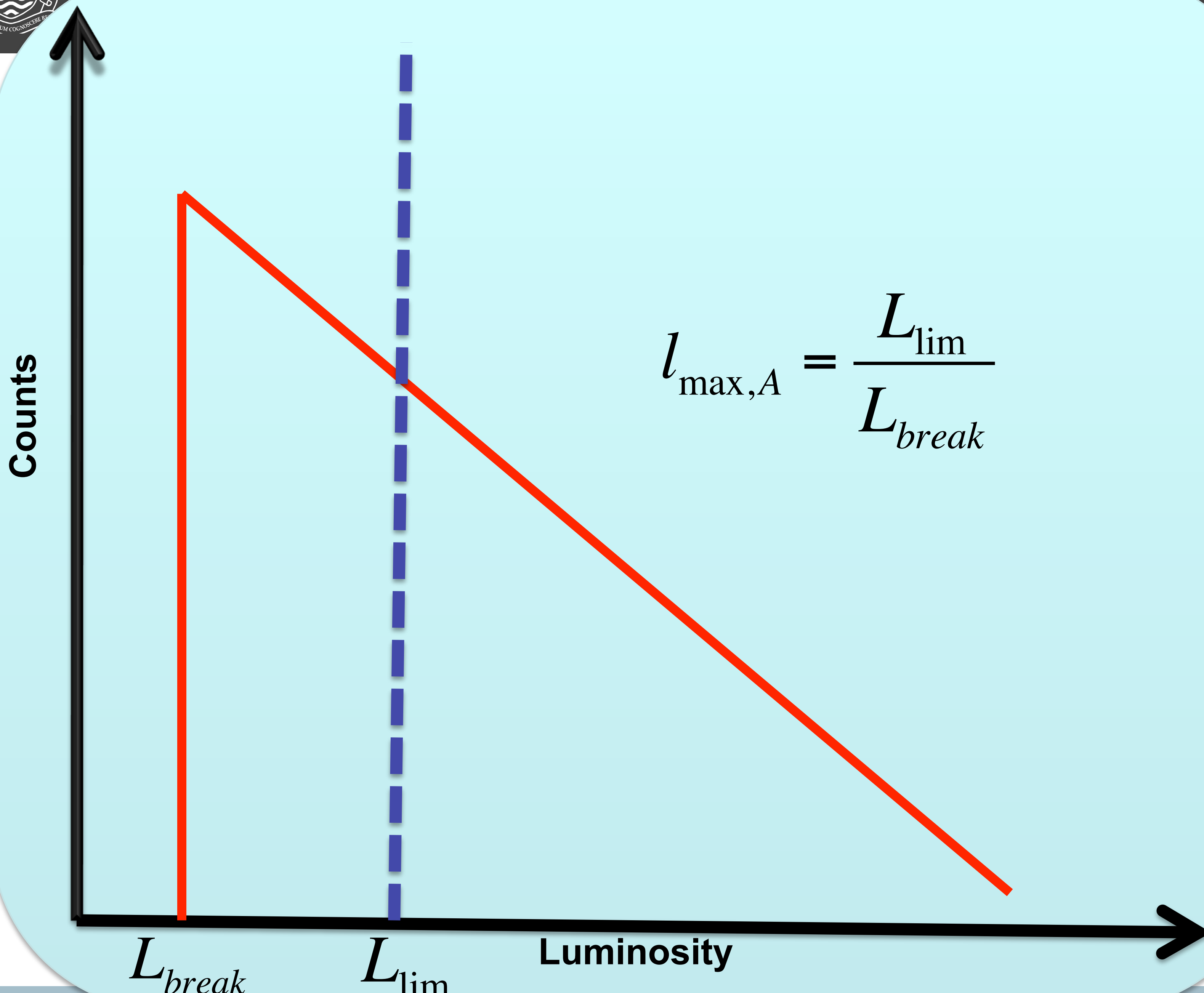
- Assumptions:
  - >1Å EW for $R \leq R_0 \left(\frac{\sigma}{200 km/s} \right) (1+z)^{-1}$
  - SIS model
  - Cumulative luminosity functions

$$\Psi_\gamma(L_\gamma) \propto (L_\gamma)^{-\alpha_\gamma} \quad \text{set } \alpha_\gamma = 0.7$$

$$\Psi_A(L_A) \propto (L_A)^{-\alpha_A} \Rightarrow$$

$$\Psi_{\gamma,A}(L_\gamma, L_A) \propto (L_\gamma)^{-\alpha_\gamma} \left(\frac{L_A}{L_{break}}\right)^{-\alpha_A} \quad \text{where} \quad L_A > L_{break}$$

$$\Psi_{\gamma,A}(L_\gamma, L_A) \propto (L_\gamma)^{-\alpha_\gamma} \quad \text{where} \quad L_A < L_{break}$$

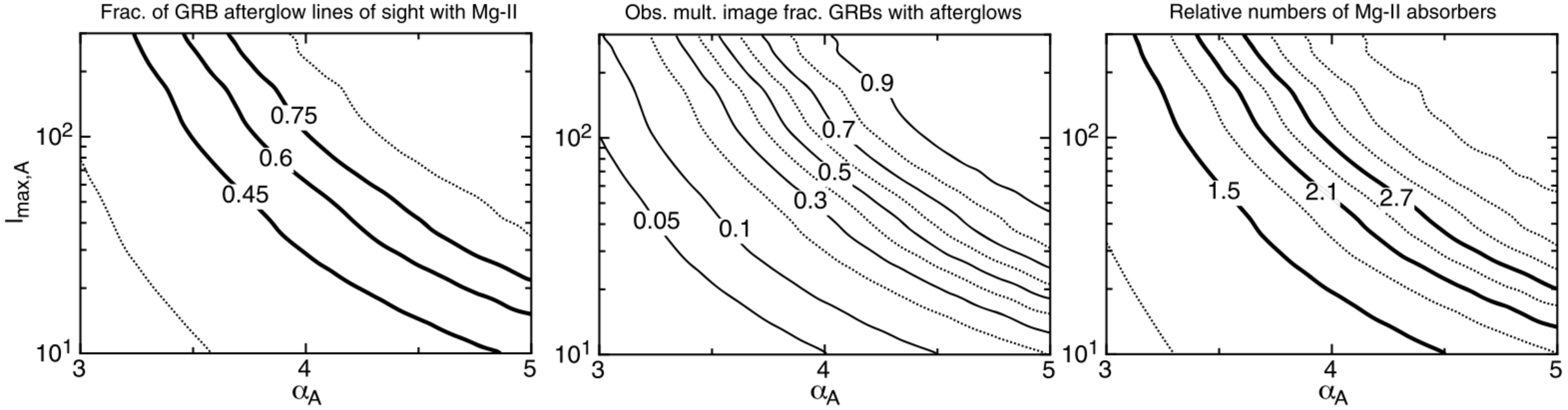


$$l_{\max,A} = \frac{L_{\lim}}{L_{break}}$$

Multi-band Magnification Bias – GRBs

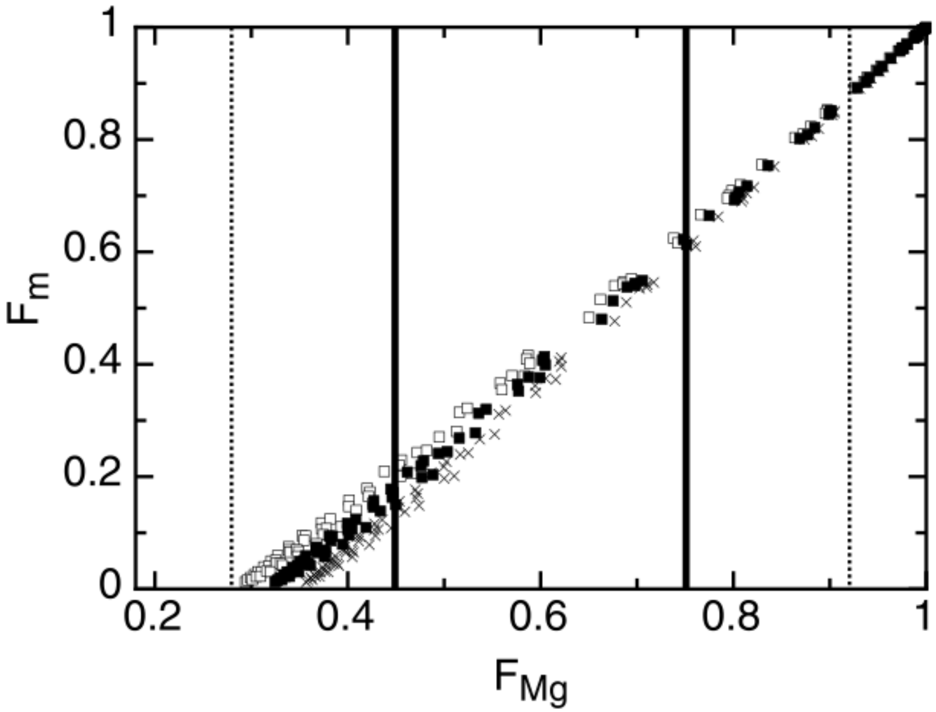
Wyithe et al 2011

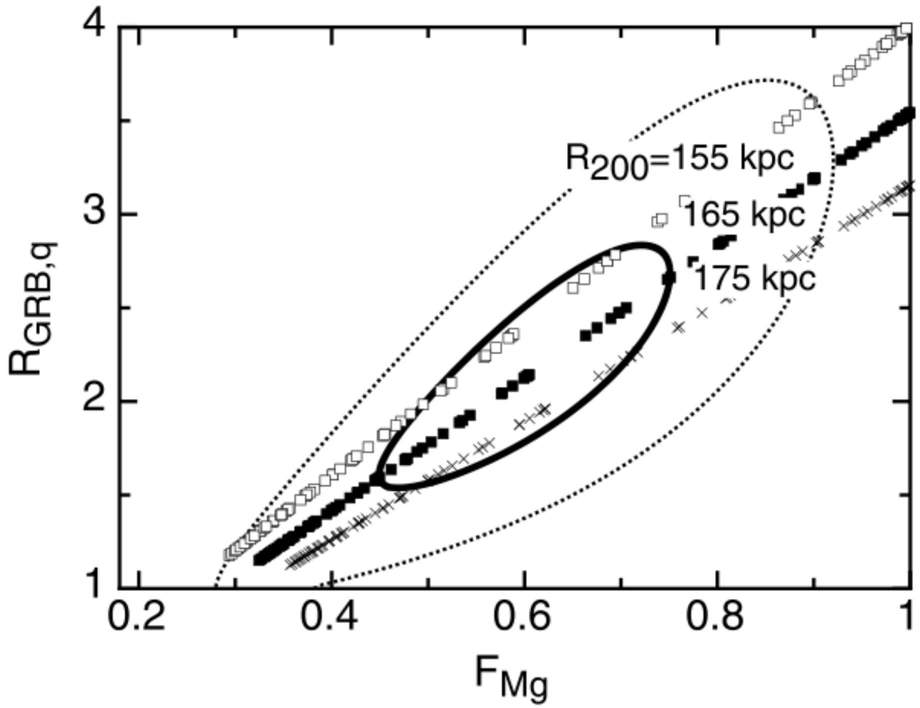
- R_0 ~ 165 kpc
  - consistent with QSO studies of MgII impact parameters
  - gives correct F_{MgII}(QSO)=0.25



Multi-band Magnification Bias – GRBs Results

Wyithe et al 2011





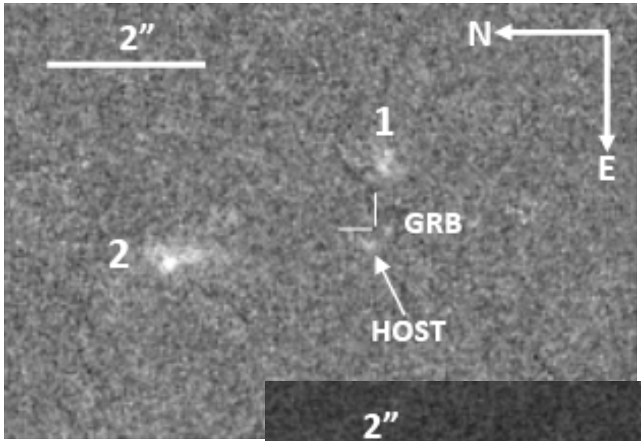
Multi-band Magnification Bias – GRBs Prediction

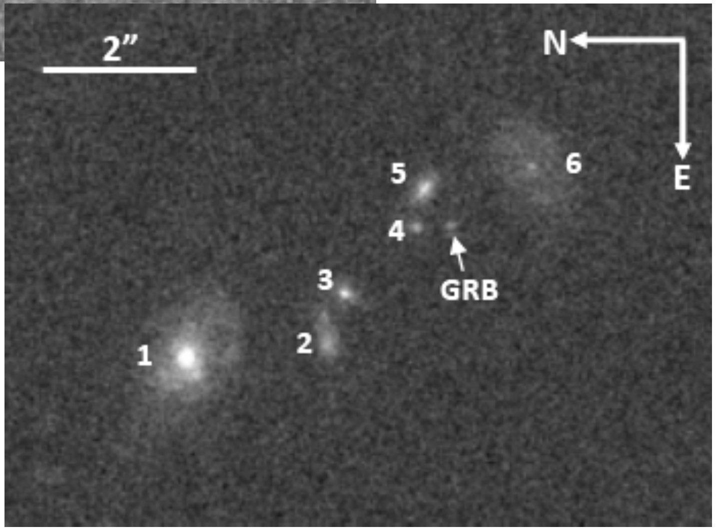
Wyithe et al 2011

20-60% of all GRBs with observed afterglow are multiply imaged

Our Analysis of the V09 Sample

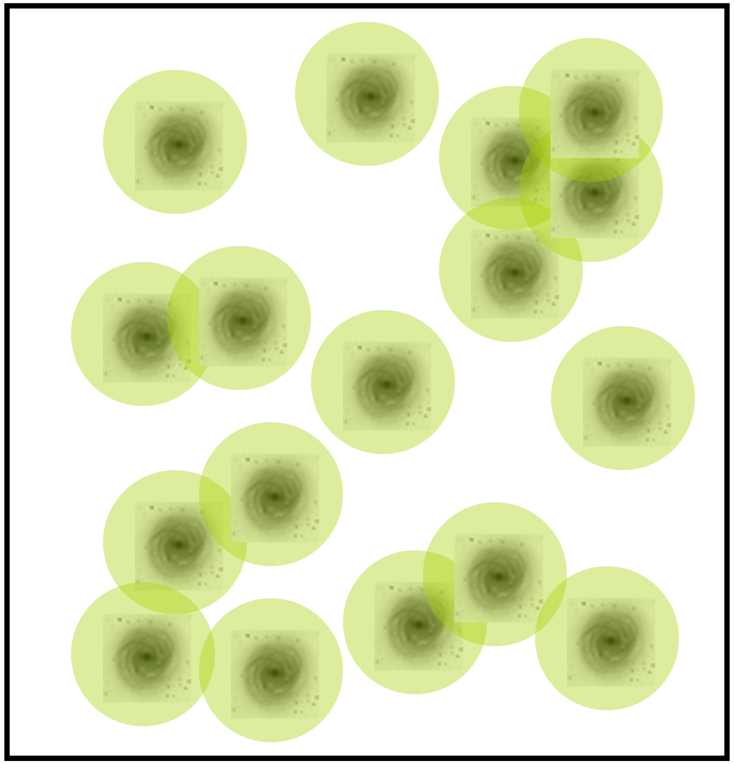
- If 30% of GRBs are multiply imaged, chance of seeing 0 with *Swift* is 47%.
- Vergani et al. sample:
  26 GRBs with spectra
- 15 with MgII (60%)
  – 11 have high resolution images that are needed (HST, Gemini, VLT)
- Identified sources near the GRB position
- Compared against random l.o.s.
  – generated from UDF





Statistical Analysis 1 – UDF Framework

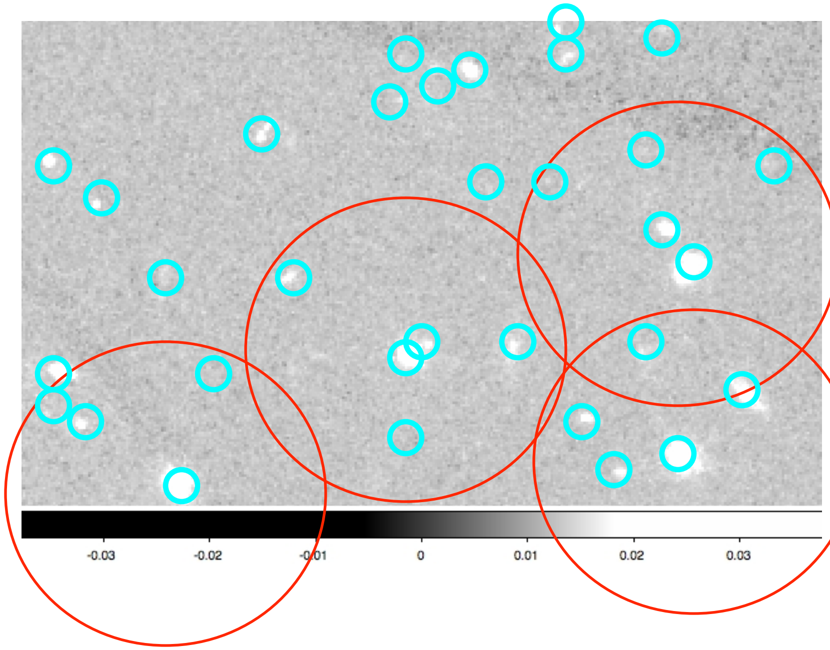
- For each of the 4 UDF filters (BVIz), calculate the radius required to cover 60% of the sky → θ_{MgII}
- Will be a function of the limiting magnitude
  - deeper limit = smaller θ_{MgII}
- 10,000 trials to determine radial distribution of galaxies within θ_{MgII}
- Compare against actual GRB fields



θ_{MgII} Considerations

- Limiting mag too bright...
  - θ_{MgII} too large
  - Many random galaxies in trial area
  - Dilutes any lensing signal

- Limiting mag too faint...
  - θ_{MgII} too small
  - Only random galaxies fall in trial area
  - Also dilutes lensing signal

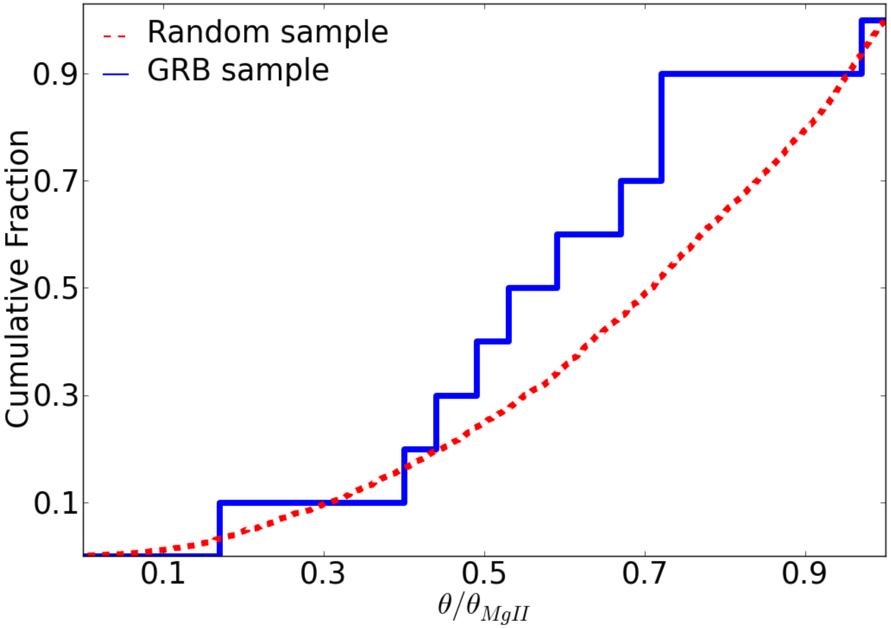


Statistical Analysis 1

- Found all galaxies within θ_{MgII} for each GRB
- Used a MC simulation to compare to a random line of sight

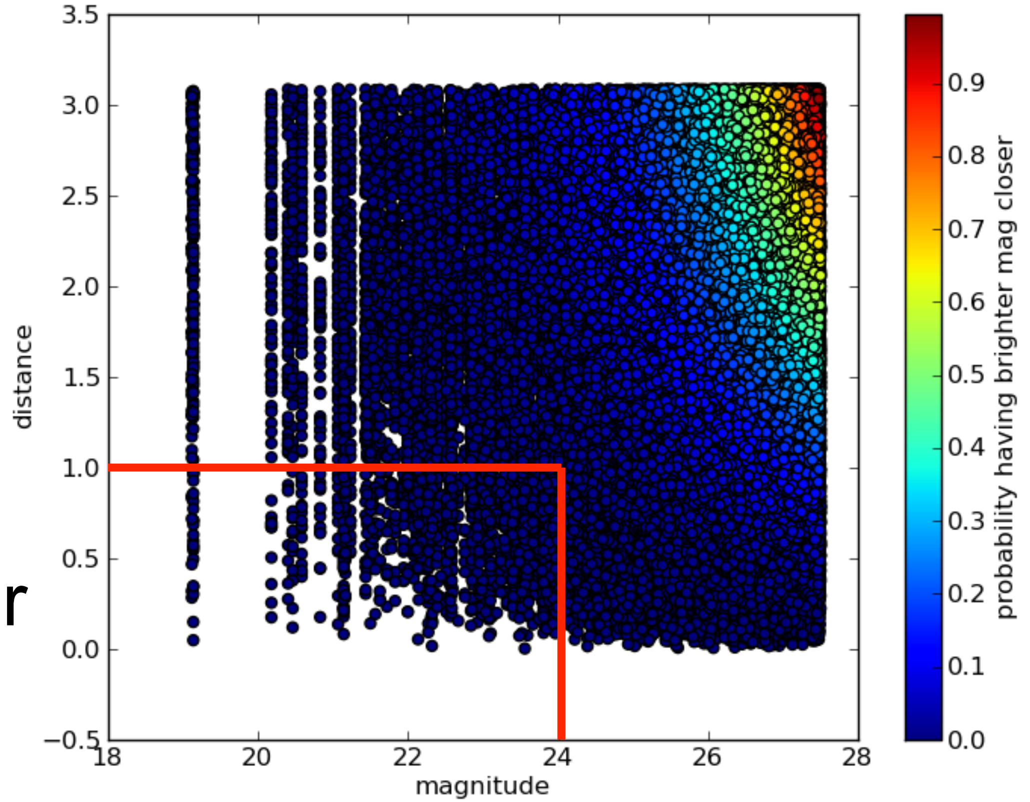
Statistical Analysis 1 – Results

- GRBs with MgII show a a possible excess of galaxies within θ_{MgII}
- K-S test of GRBs vs. random l.o.s. shows >90% chance of being drawn from different parent distributions

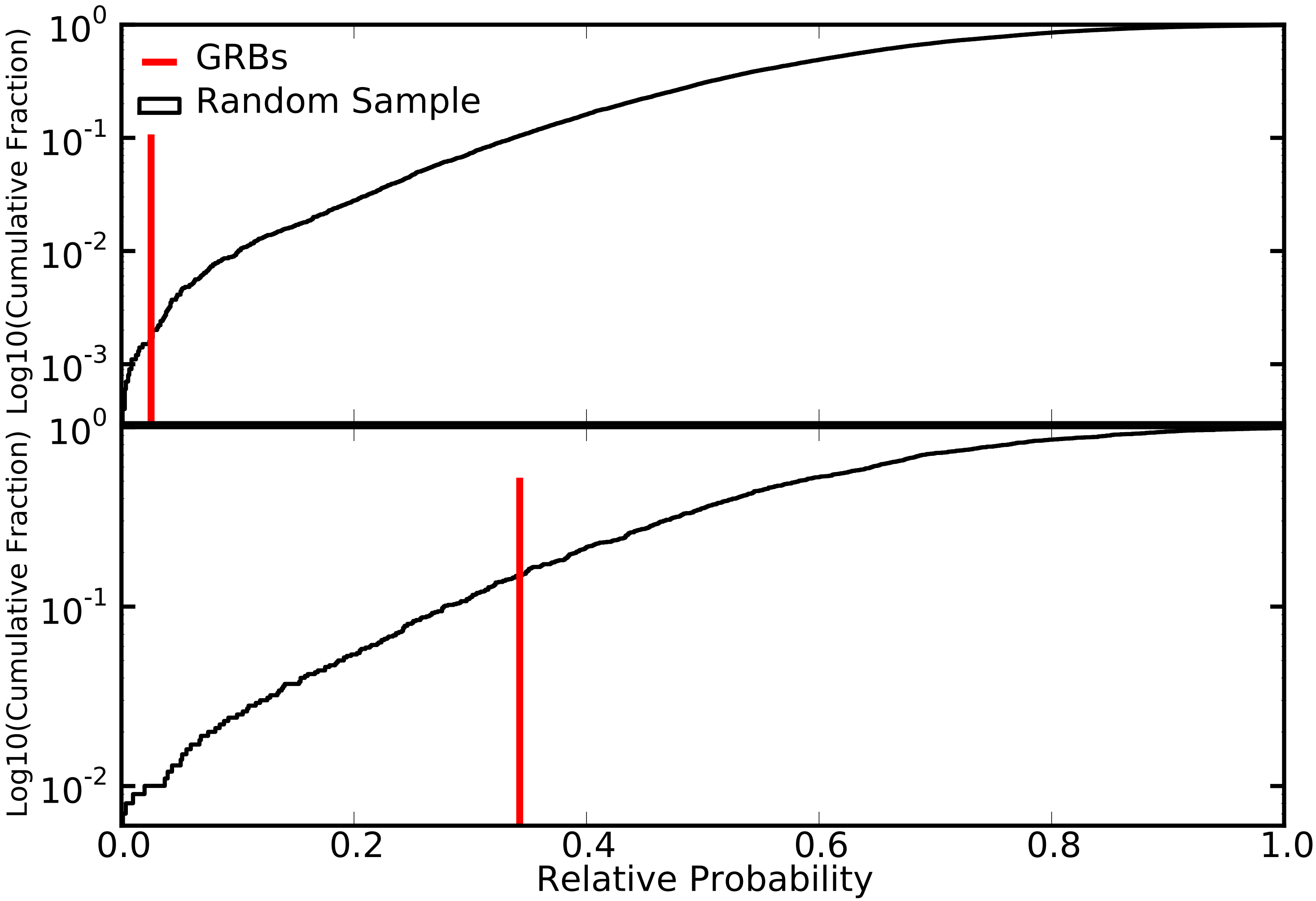


Statistical Analysis 2

- Choose 11 galaxies with the same brightness as the GRB host
- Use MC to find probability
- Multiply probabilities for each set of 11



Statistical Analysis 2 – Results



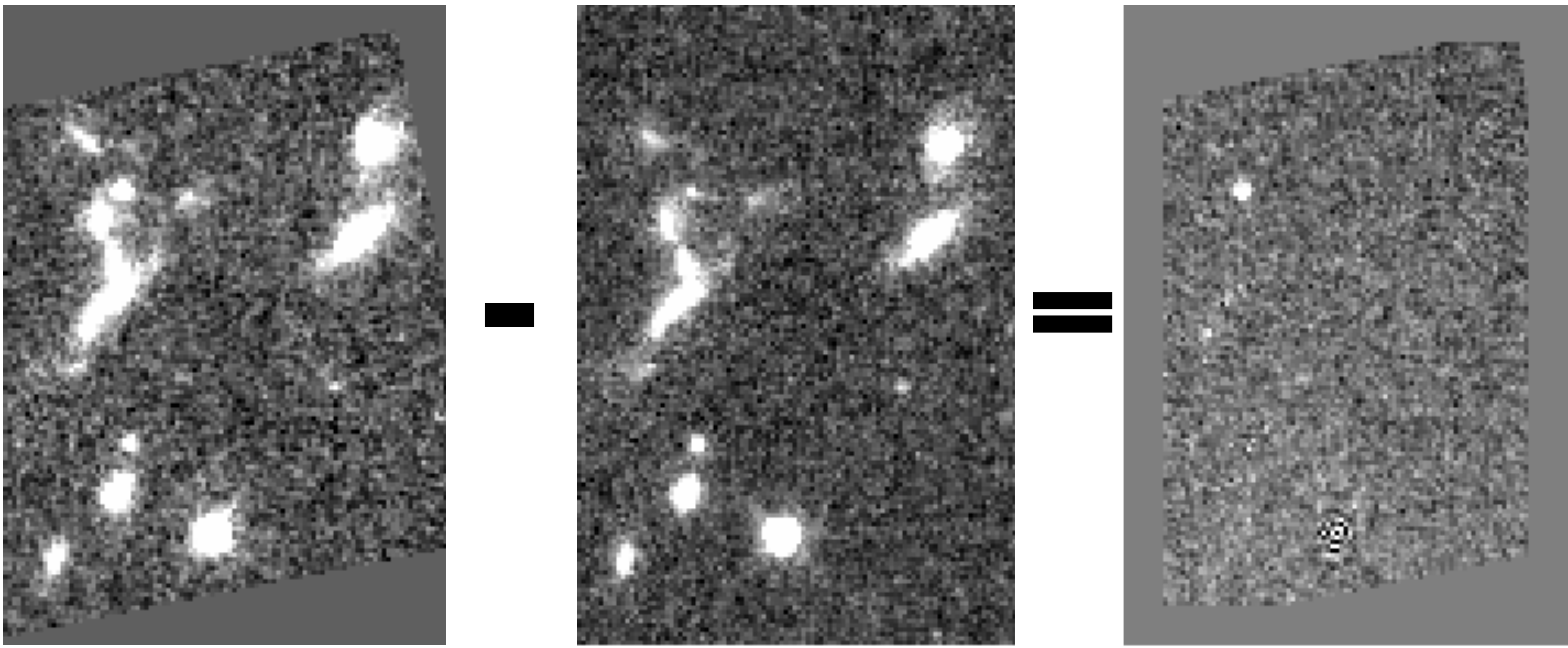
Individual GRB Fields

- Analyse lensing likelihood of each of the 11 GRB fields
- Model the galaxies in the images as SIS
- z(GRB) known
- z(gal) ≡ z(MgII)
- Angular size distances from the redshifts
- SED fitting to constrain galaxy type
- Faber-Jackson or Tully-Fisher to estimate σ_v from magnitude
- UDF galaxy catalogue to estimate P(z|mag)
  - Coe et al. (2006)
- Complex systems modelled with GRAVLENS
  - Keeton (2001)

Individual GRB Fields

- GRB020405
- GRB030429
- GRB010222
- GRB021004
- GRB991216

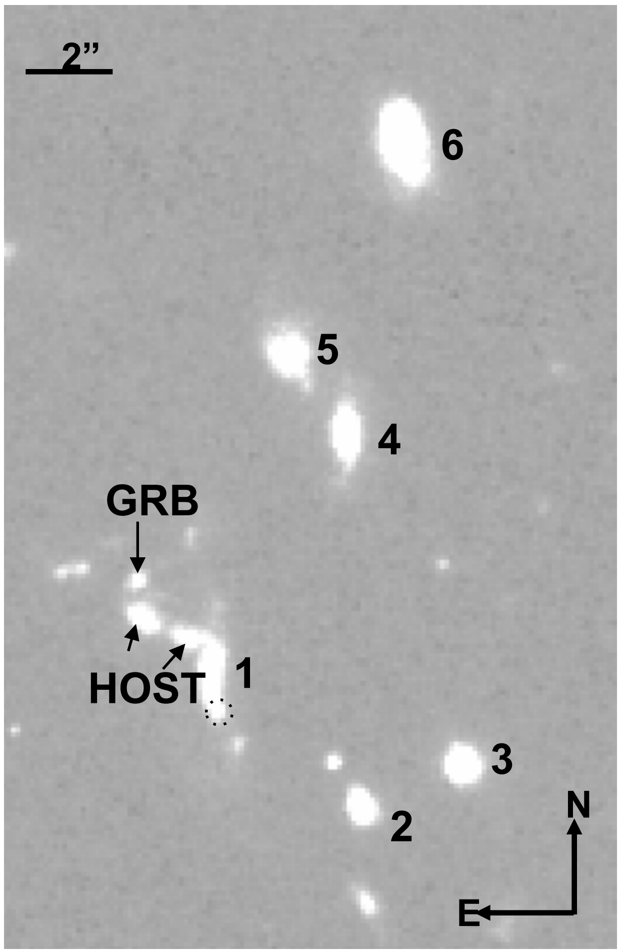
GRB020405



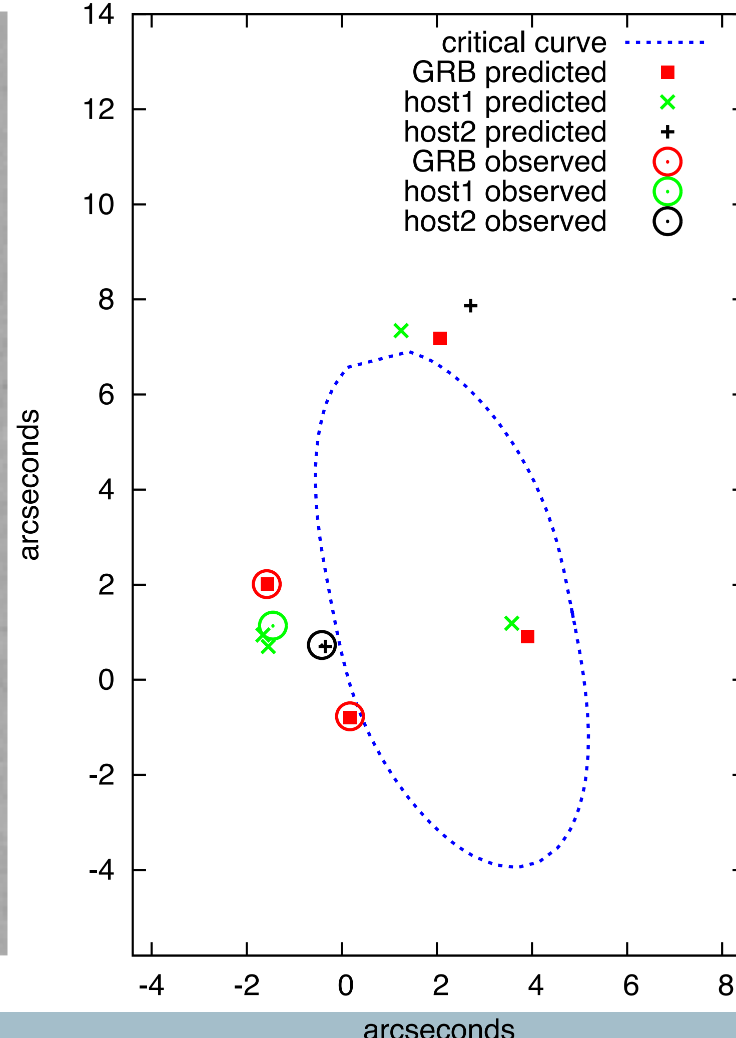
GRB020405 (Gemini Proposal 2012A)

- z(GRB)=0.695
- z(MgII)=0.472
- First HST image (23 days post-GRB) found second transient 3” away
  - Masetti et al. (2003)
- Modelling as SIE with shear shows possible solution with observed GRB as the 2nd image
  - ~120 days later and less magnified
- Predicted host images not in conflict with observations
  - Rapoport et al., 2011 on astro-ph

GRB020405

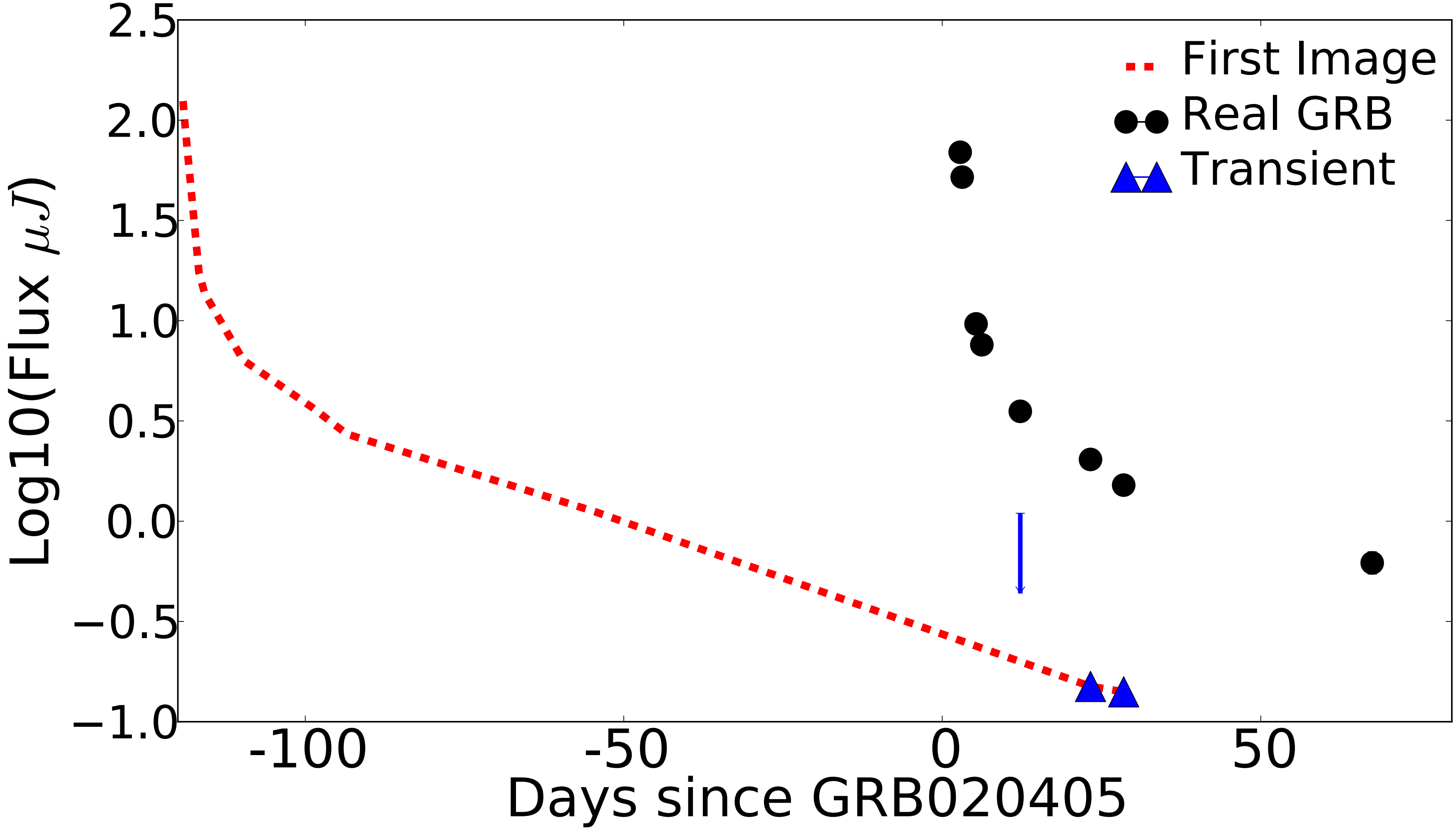


2"
6
5
4
GRB
HOST
1
3
2
N
E



critical curve
GRB predicted
host1 predicted
host2 predicted
GRB observed
host1 observed
host2 observed
arcseconds
arcseconds
14
12
10
8
6
4
2
0
-2
-4
-4
-2
0
2
4
6
8

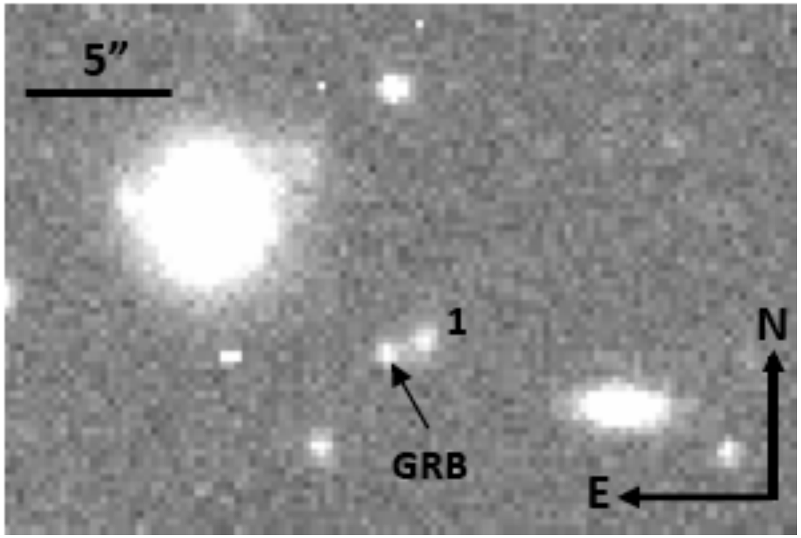
GRB020405


First Image
Real GRB
Transient
Log10(Flux μJ)
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
-100
-50
0
50
Days since GRB020405

GRB030429

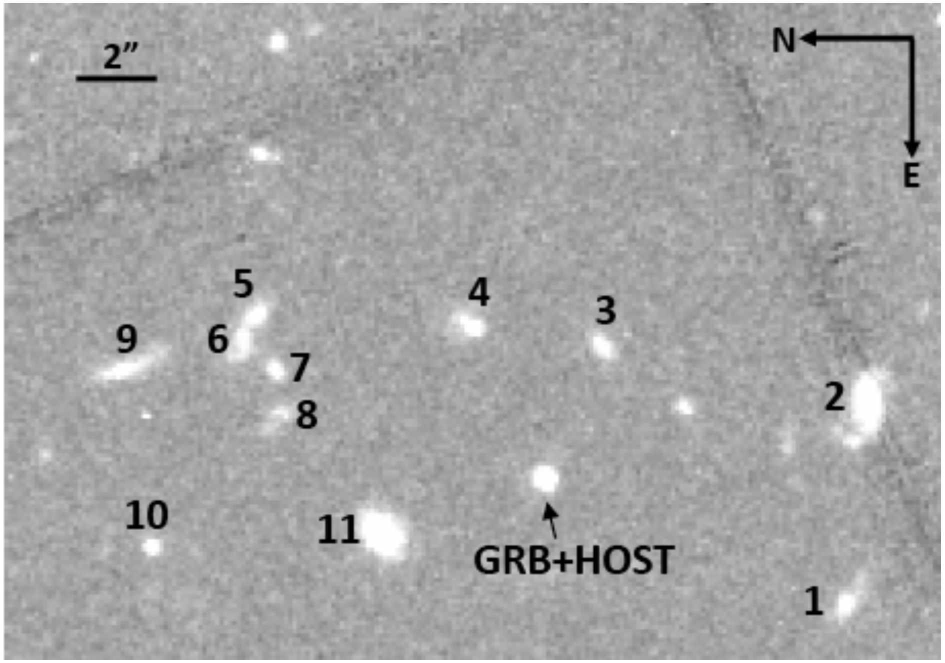
- z(GRB)=2.66
- z(MgII)=0.842
- Distance ratio makes lensing likely
- Galaxy at MgII redshift
- UDF-estimated probability of chance alignment: 0.4%
  - chance of one such system in 11 GRBs: <5%
- Lensing requires σ>200 km/s
  - Tully-Fisher implies 160±65 km/s
- Would be 1st image
  - ~4 month time delay
  - no observations that late

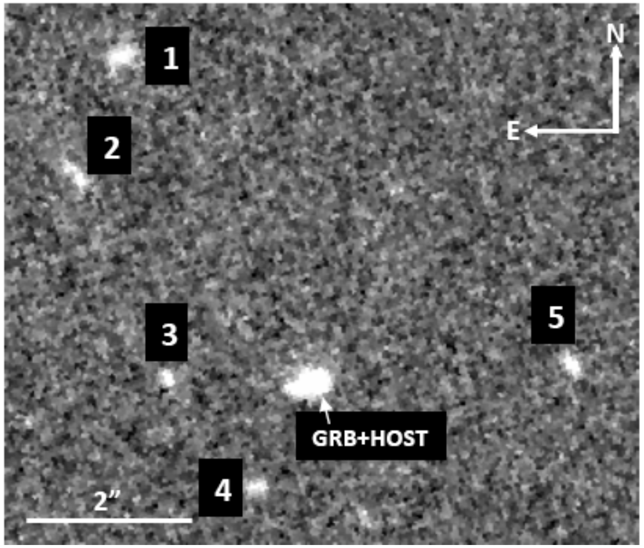
FORS2 R-band



GRB021004/GRB010222

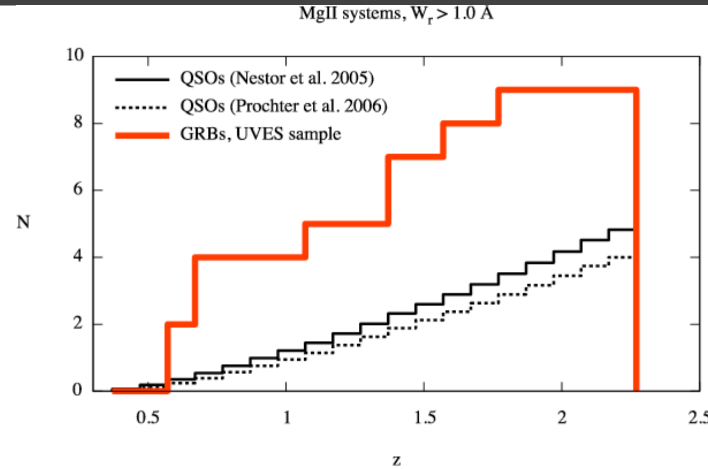
- Some possible lenses, but few galaxy redshifts
  - hard to confirm galaxy groups





Interpretation

- Wyithe et al. model predicted ~2-7 multiply-imaged GRBs from the 11 we studied
- We find 2 systems with a reasonable chance of lensing, 2 with lower likelihood, and little chance for the others



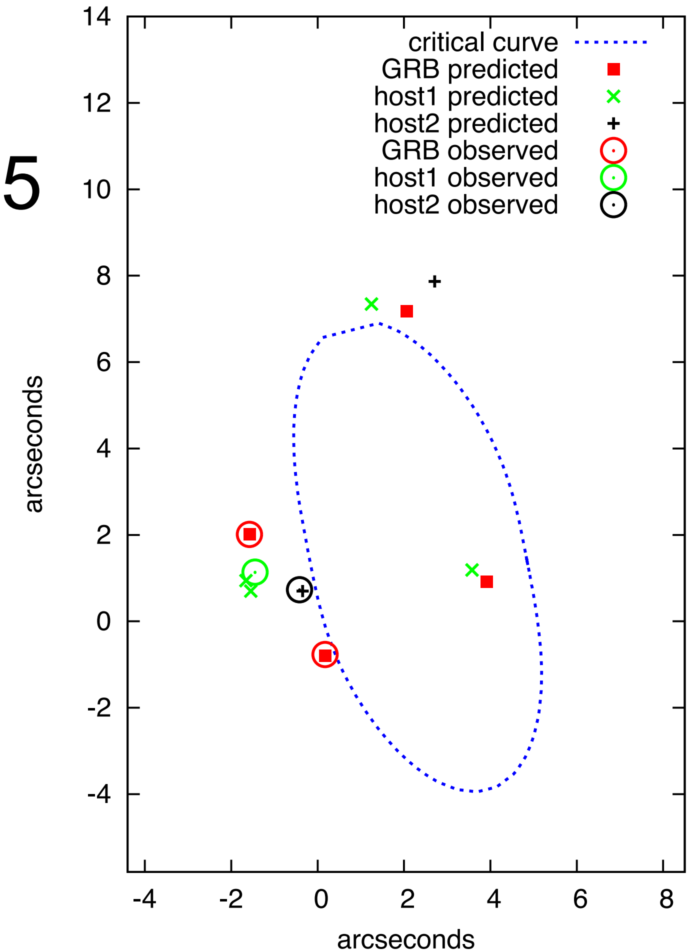
- Higher chance of finding a bright galaxy near a GRB showing MgII lines
- Results are entirely consistent with gravitational lensing as the main factor in the GRB-QSO difference
- Consistent with no difference in weak MgII and CIV
- Follow-up work is underway on the most promising case

Implications

- More than resolving MgII difference...
  - precision timing of multiply imaged GRBs would constrain mass models and/or cosmology
  - knowing GRB location would allow for early epoch multiwavelength observations not otherwise possible
    - giving better insight into GRB progenitors
  - X-ray follow-up may be especially helpful
    - since 2nd image lies closer to lens

Future Work

- Verify the model for GRB020405
- Study QSOs



Questions?