IRT on-board software
Scientific performance

Florent Robinet – Nov. 04, 2025

On-board features: status

Starting point: corrected images exploitable for scientific purposes

- Astrometry
- Image integration 6 x 25 = 150 s
- Photometry (apparent magnitude + errors)
- Identify and localize the afterglow (removing known NIR sources)
- WIP • Photometric redshift

Done
Not done
Simple procedure
WIP Work in progress

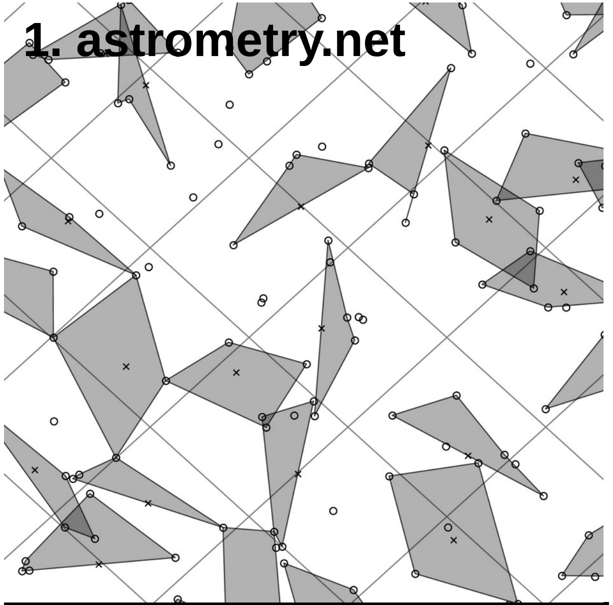
From Shaymaa Hussein - Tuebingen

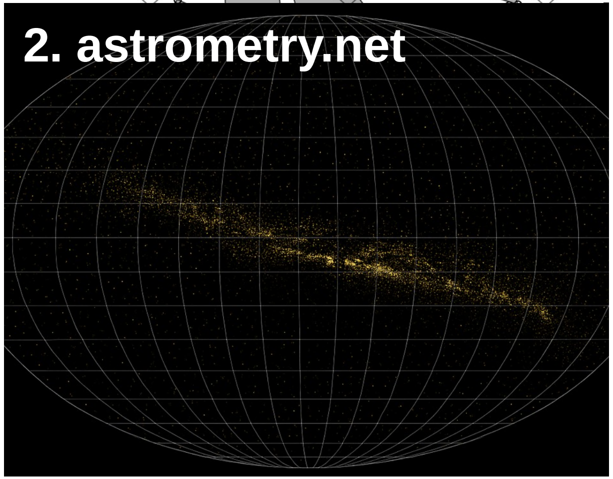
Astrometry

Operational Context:
- Each IRT band (H, I, Z, Y, J): 150 s total exposure
- Astrometric processing must finish well below 25 s per frame
- Onboard constraints: 32 GB flash | <4 GB RAM for science tasks

Objective
- Real-time astrometry for GRB afterglow localization
- Accuracy requirement: <5″
- Must not saturate onboard memory or exceed timing budget

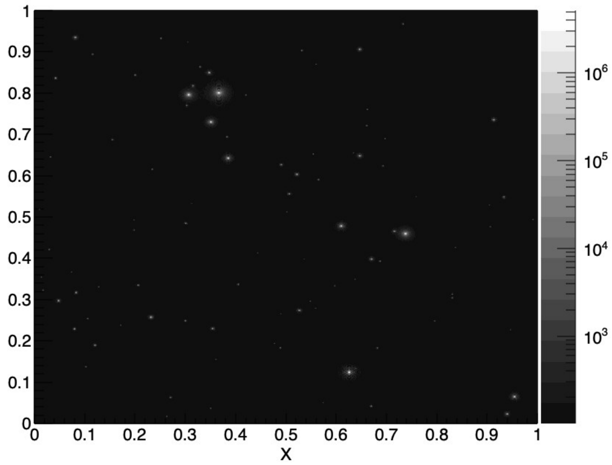
Suggested methods
1. Astrometry.net: rely on pattern extraction and matching with reference
2. SCAMP + tiled catalogue : direct cross matching of detected source with a reference catalog





From Shaymaa Hussein - Tuebingen

Astrometry



<u>→ Performance measured using simulated images based on Gaia DR3 sources</u>

<u>→ The pointing information is known -> guided search</u>

<u>Pattern Recognition (M<14):</u>

- Index size: ~5–8 GB + size of the catalogue (~25 GB)
- RAM: 1–1.5 GB
- Processing time: up to 10 s based on field crowdedness
- Accuracy: ~ 0.3’’
- Reliability: depends on the pointing (poles or galactic plane)

<u>SCAMP + Tiled Gaia Catalogue:</u>

- Loads N tiles around pointing (tile count under discussion until memory mapping finalized)
- Storage: ~25 GB predictable | Active RAM: ≤200 MB
- Processing time: 5–8 s onboard
- Accuracy: < 2’’ for 98% of sources (M < 20)

<u>Recommendation</u>

→ Adopt SCAMP + Tiled Gaia solution

Photometric redshift: sources

Photometric redshifts for GRB afterglows from GROND and *Swift*/UVOT

T. Krühler[1,2], P. Schady[1], J. Greiner[1], P. Afonso[1], E. Bottacini[1], C. Clemens[1], R. Filgas[1], S. Klose[3], T. S. Koch[4], A. Küpcü-Yoldaş[5], S. R. Oates[6], F. Olivares E.[1], M. J. Page[6], S. McBreen[7], M. Nardini[1], A. Nicuesa Guelbenzu[3], A. Rau[1], P. W. A Roming[4,8], A. Rossi[3], A. Updike[9], and A. Yoldaş[1]

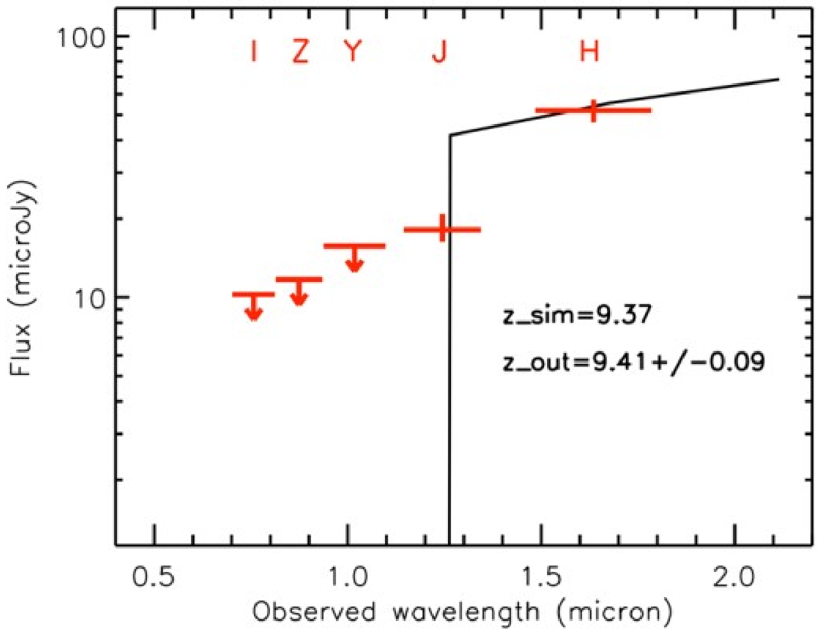
Old paper (2010)
→ χ2 method with hyperZ code
→ Application to GRB afterglows

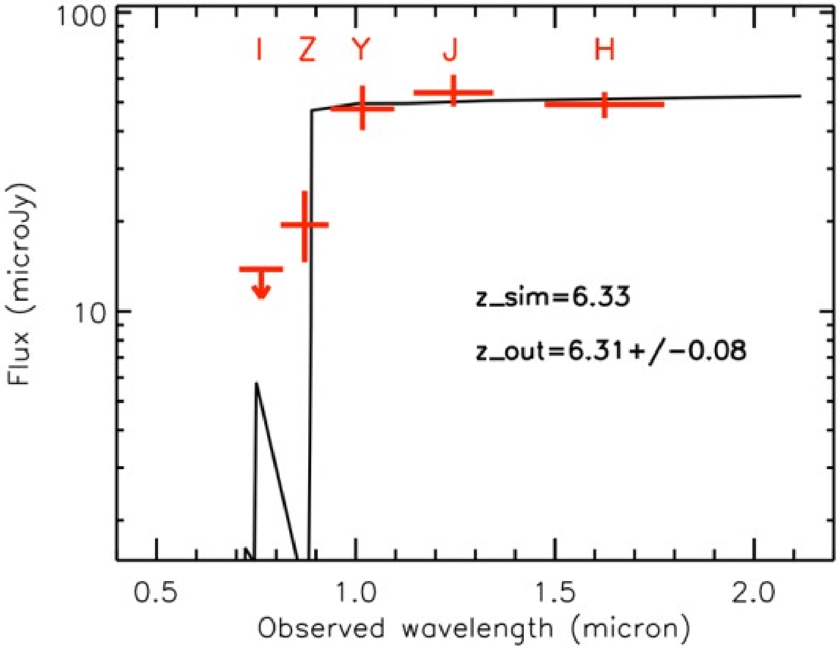
Photometric Redshift Estimation for Gamma-Ray Bursts from the Early Universe

H.M. Fausey,[1⋆] A.J. van der Horst,[1] N.E. White,[1] M. Seiffert,[2] P. Willems,[2] E.T. Young,[3] D.A. Kann,[4†] G. Ghirlanda,[5,6] R. Salvaterra,[7] N.R. Tanvir,[8] A. Levan,[9] M. Moss,[1] T-C. Chang,[2] A. Fruchter,[10] S. Guiriec,[1] D. H. Hartmann,[11] C. Kouveliotou,[1] J. Granot,[12,13,1] A. Lidz[14]

Recent paper (2023)
→ MCMC method with phozzy code

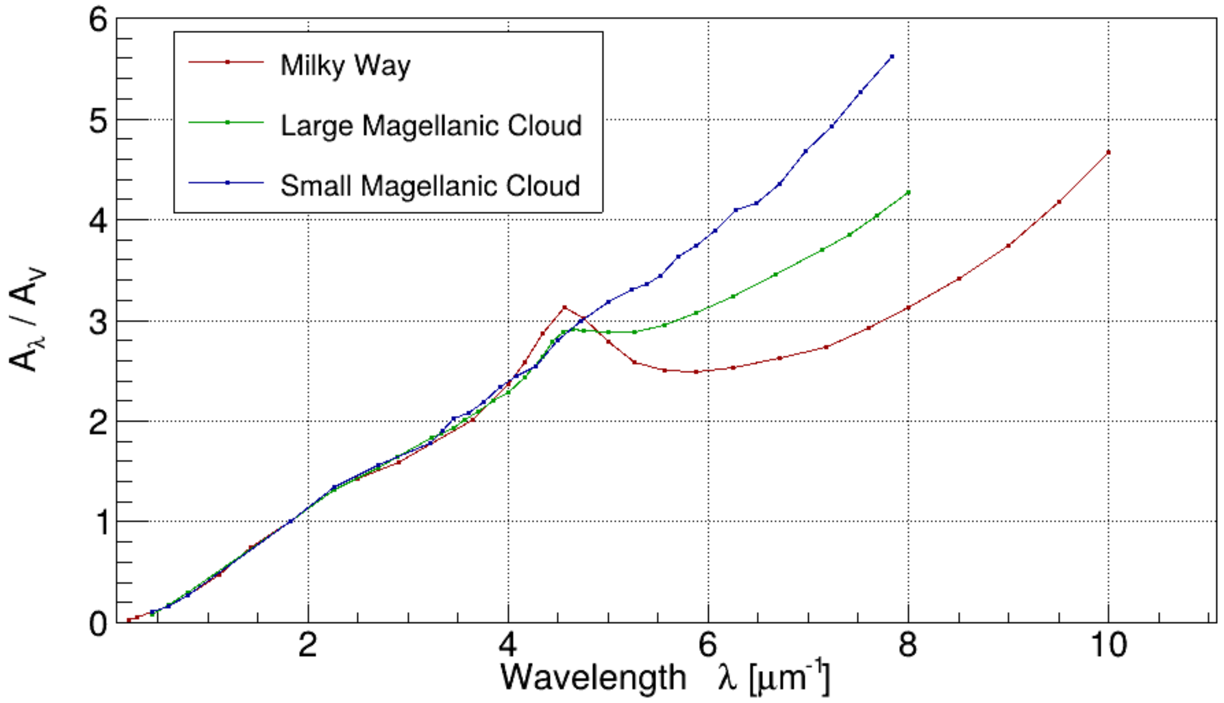
Photometric redshift: principle





Target: achieve a redshift accuracy < 10%

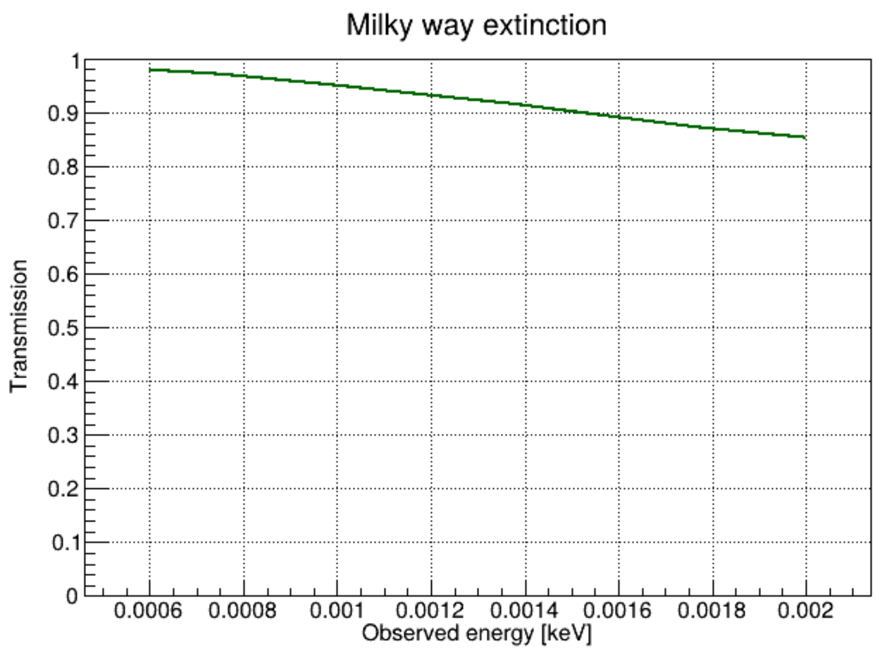
Pei 1992 galaxy extinction model

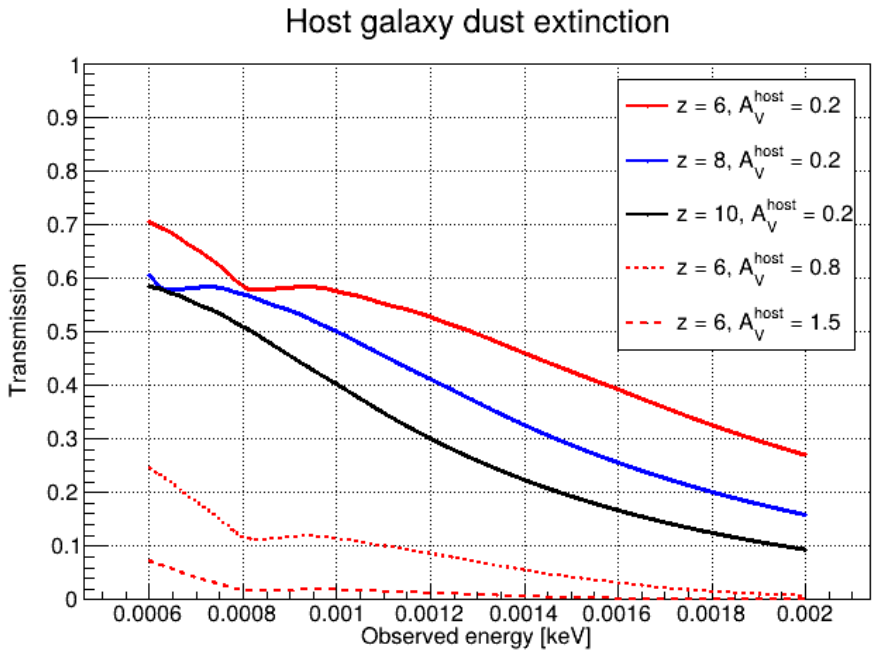


Galaxy extinction:

$$\exp\left(-0.92 \times A_V^{gal} \times \frac{A_\lambda}{A_V}\right)$$

Pei 1992 galaxy extinction model



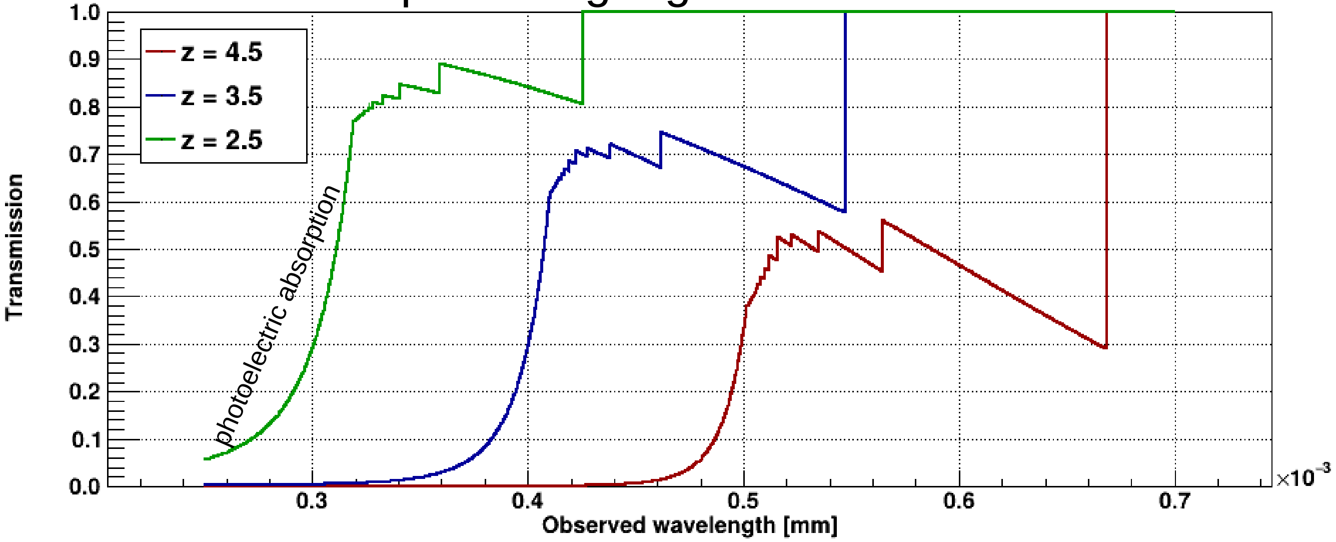


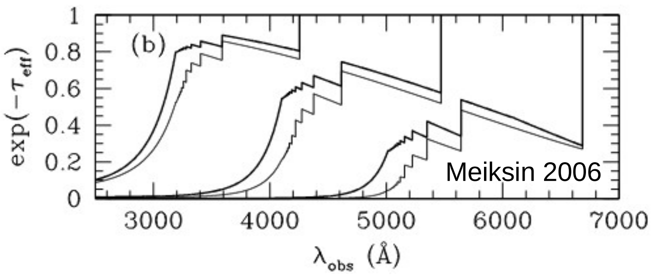
The MW extinction is limited in the NIR

The extinction from the host galaxy must be taken into account (redshifted energies)

Meiksin 2006 intergalactic extinction

Plot reproducing Fig. 1 in Meiksin 2006



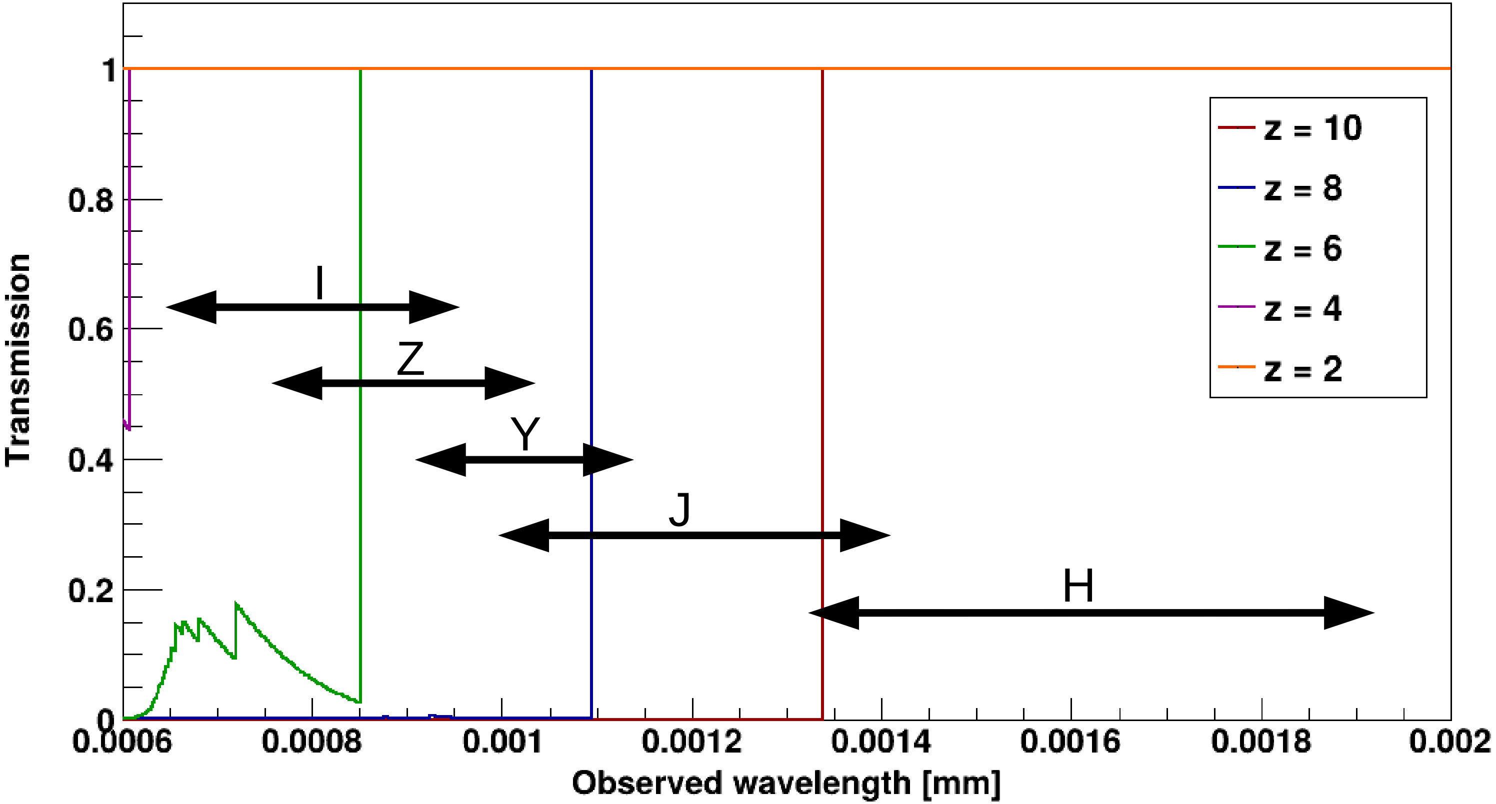


“He II will contribute only at wavelengths λ < 228(1+z)A for a source at redshift z”

→ Contribution in NIR?

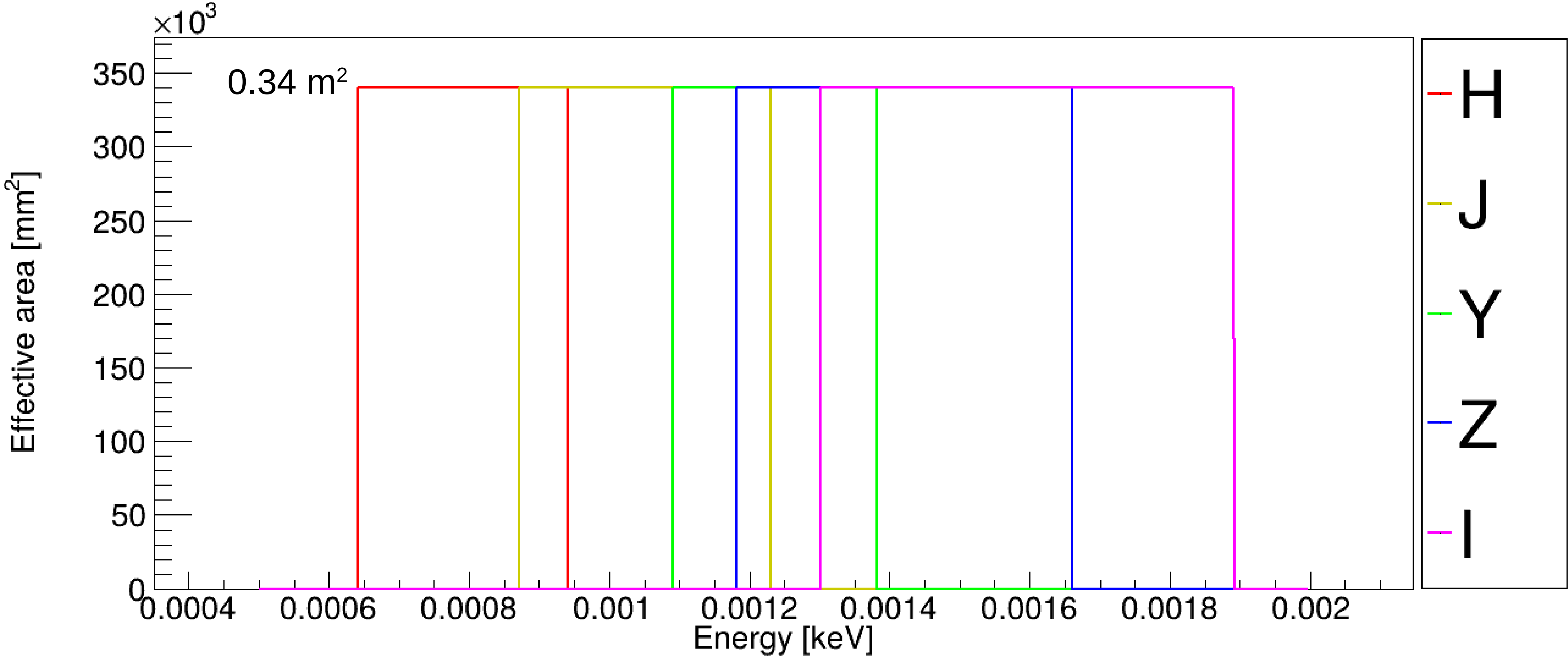
More recent models?

Meiksin 2006 intergalactic extinction



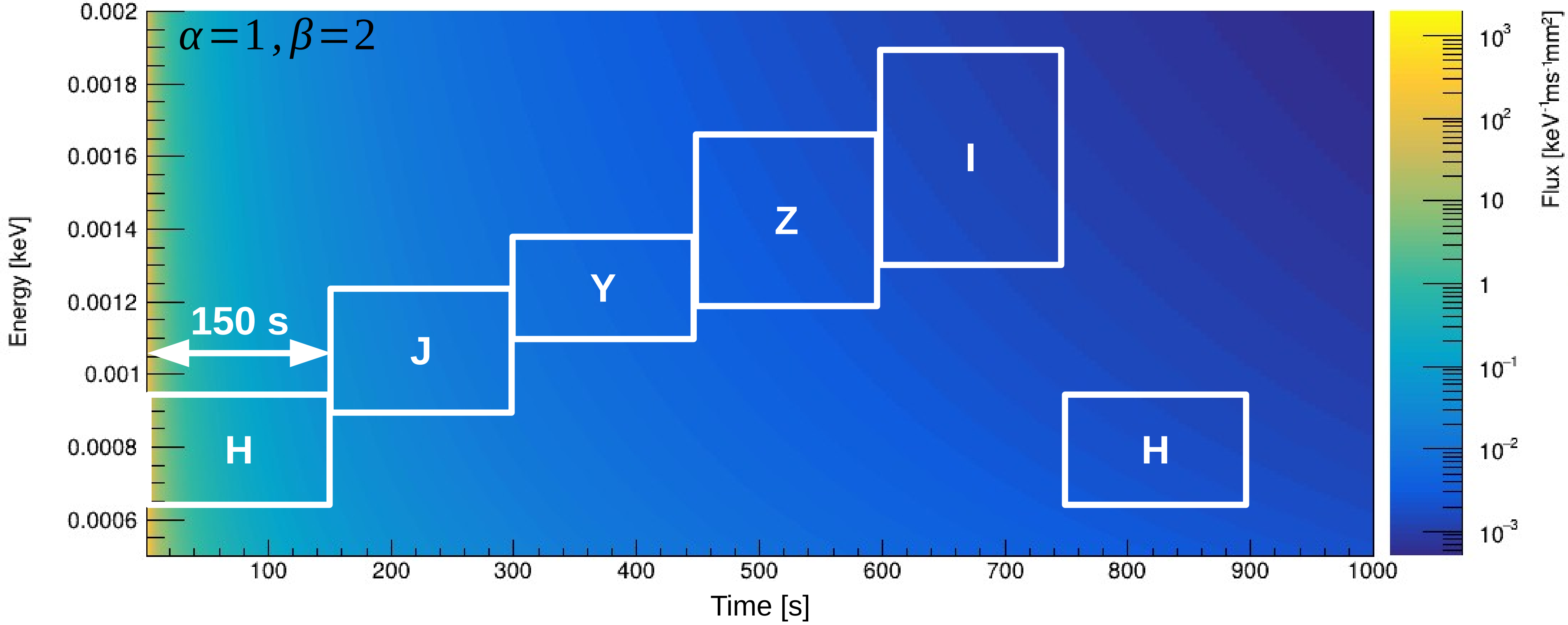
- H > J > Y > Z > I > H
- H: hardly no extinction
- No photo-redshift for z<6

IRT color filters



GRB afterglow (1)

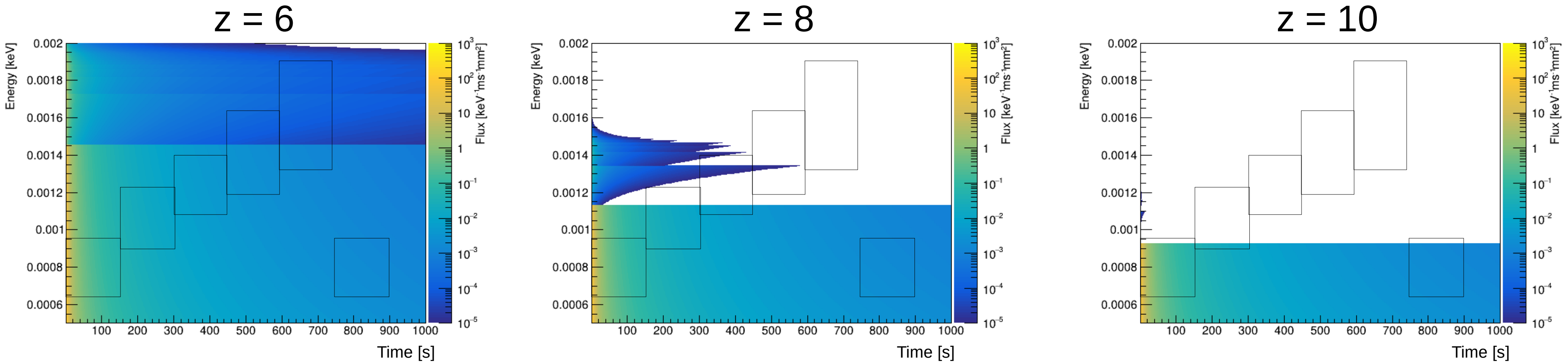
GRB afterglow intrinsic flux: $F^{grb}(t, E; F_0, \alpha, \beta) = F_0 \times \left(\frac{t}{t_0}\right)^{-\alpha} \times \left(\frac{E}{E_0}\right)^{-\beta}$



GRB afterglow (2)

Extinction: galactic (Pei 1992 MW) + IGM (Meiksin 2006) + Host galaxy (Pei 1992 MEAN)

$Ext\left(E\,;z\,,A_V^{host}\right)$



$A_V^{host}=A_V^{MW}=0.2\,mag$

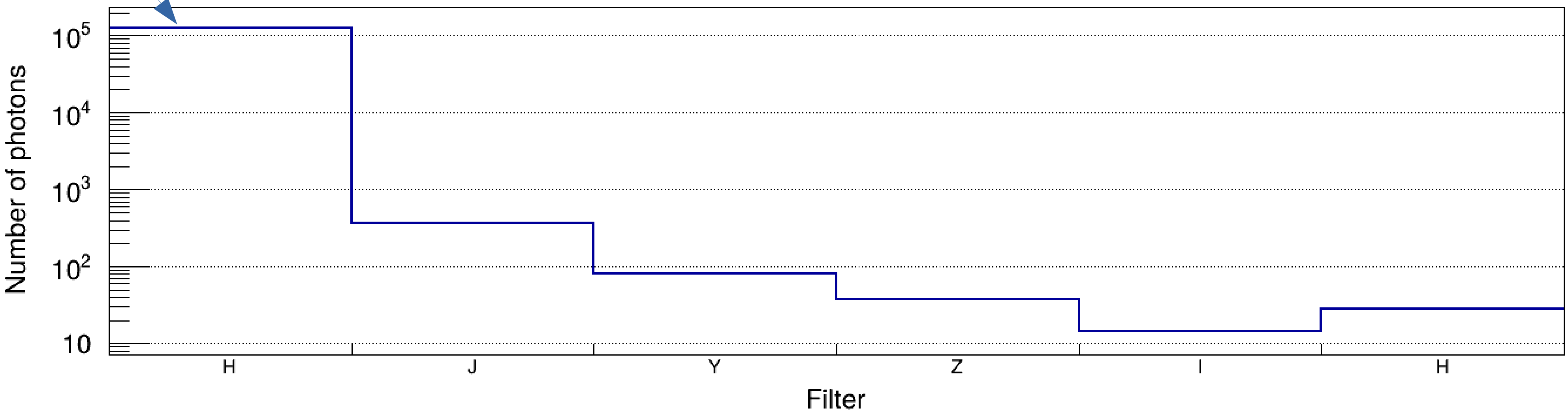
$$F^{ext}\left(t\,,E\,;F_0,\alpha\,,\beta\,,z\,,A_V^{host}\right)=F^{grb}\left(t\,,E\,;F_0,\alpha\,,\beta\right)\times Ext\left(E\,;z\,,A_V^{host}\right)$$

GRB afterglow (3)

Integrated flux for one filter i:

$$F_i^{ext} = \iiint F^{ext}(t, E; F_0, \alpha, \beta, z, A_V^{host})\, dt \times dE \times dS$$

Exposure time = 150 s   All energies   Filter effective area $S_i(E)$



Photometric templates

A bank of templates is generated: $F_i^{ext}\left(F_0, \alpha, \beta, z, A_V^{host}\right)$

Each template is given the integrated flux for 6 filters i = H, J, Y, Z, I, H

Parameter space

- $0.1 < F_0^* < 10$, 15 samples (log-uniform)
- $0 < \alpha < 3$, 15 samples (uniform)
- $0 < \beta < 3$, 15 samples (uniform)
- **$5 < z < 12$, 50 samples (log-uniform)**
- $0 < A_V^{host} < 2$, 15 samples (uniform)

Number of templates = 2,531,250

* we fix t_0 = 1 ms and E_0 = 1 keV

Chi-squared minimization

A Chi-squared is minimized over the bank of templates

$$\chi^2 = \sum_i \left[\frac{\ln(F_i^{obs}) - \ln(F_i^{ext}(F_0, \alpha, \beta, z, A_V^{host}))}{\sigma_i^{obs}} \right]^2$$

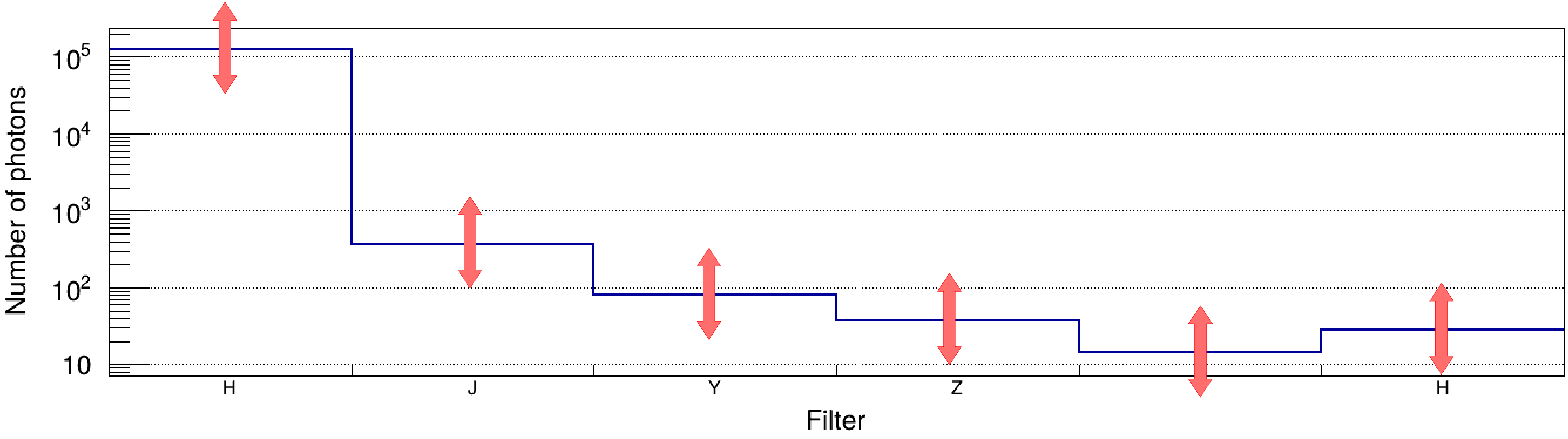
Photometric measurements: $\ln(F_i^{obs}) \pm \sigma_i^{obs}$

Photometric measurement

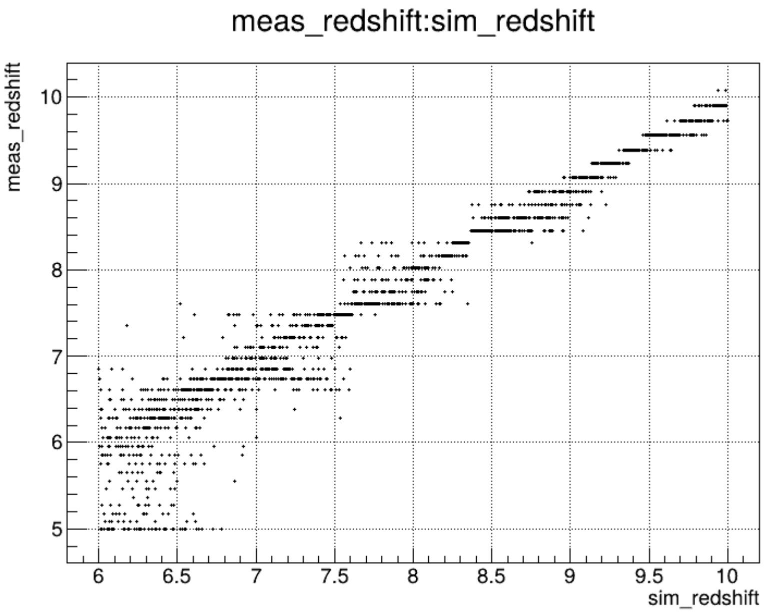
Same model as for templates + Random draw of $(F_0, \alpha, \beta, z, A_V^{host}) \rightarrow F_i^{ext}(F_0, \alpha, \beta, z, A_V^{host})$

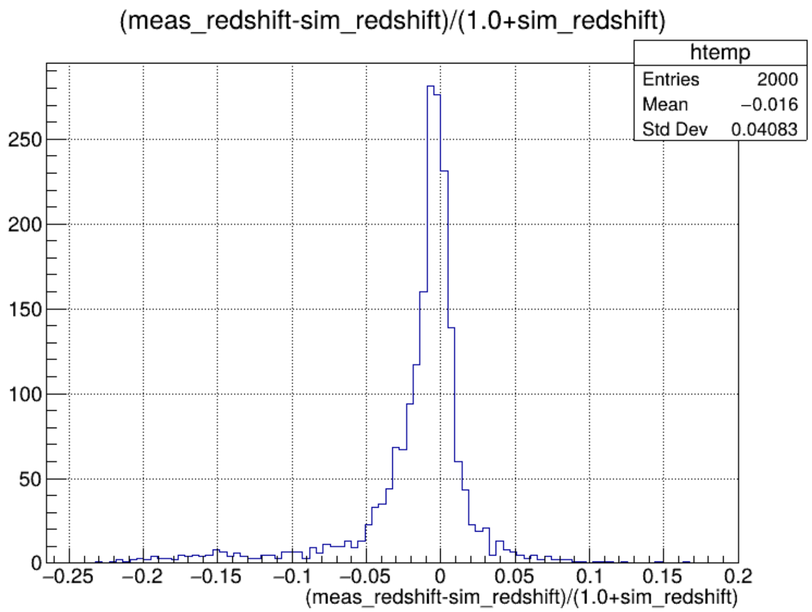
Measurement uncertainty = 5% on the magnitude (ln(F), Gaussian) $\rightarrow \ln(F_i^{obs}) \pm \sigma_i^{obs}$

For now, we assume a <u>detection in every band</u>.



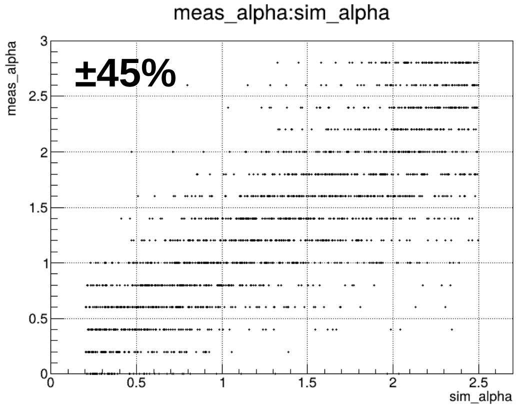
First characterization: z

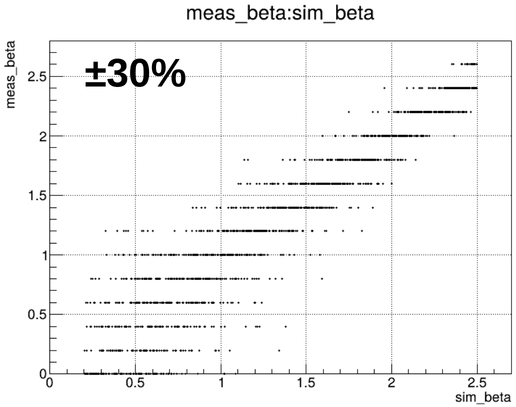


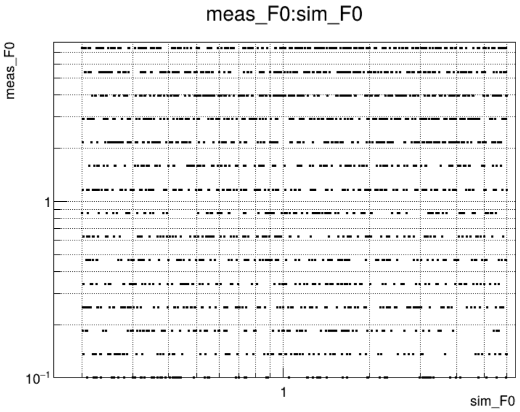


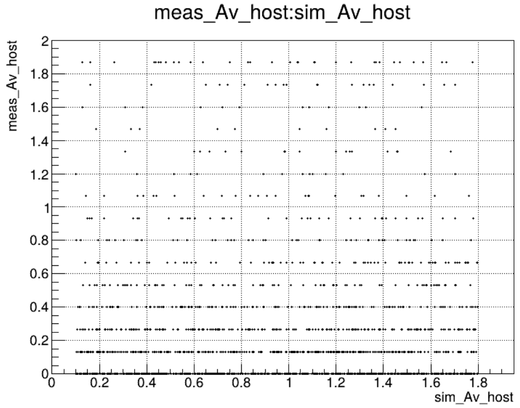
→ **Overall redshift uncertainty = 4%** (<10%)
→ The uncertainty could be improved by increasing the number of templates
→ Small systematic effect below z<6.5 (consistent with the IGM extinction model)

First characterization: other parameters









F_0 and A^v_{host} cannot be resolved (???)

Non detection

Limit AB magnitude / filter ~ 21

If the source magnitude is above that limit → no signal in IRT → upper limit on the flux

→ discard templates above the upper limit

→ Ignore filters where no detection

$$\chi^2 = \sum_i \left[\frac{\ln\left(F_i^{obs}\right) - \ln\left(F_i^{ext}\left(F_0, \alpha, \beta, z, A_V^{host}\right)\right)}{\sigma_i^{obs}} \right]^2$$

Preliminary studies in progress

→ This will degrade the current performance

→ Can this be compensated by template optimization?

Performance summary

- Redshift determination ~ 4% (ideal case)
- Study the filter profiles → no big impact expected
- Optimize the template bank → improve processing time and redshift accuracy
- Current template bank size (2.5M templates) = 170 MB
- Chi-squared computing time: no show stopper
- The template bank generation takes time but it is performed on the ground

Next steps

- Manage non-detection cases (work in progress)
- Test with real images from IRT simulation
  - Simulation tool developed for the CAGIRE camera
  - Use a realistic population of GRB afterglows
  - Test photometry methods on images
- Test new, more recent, extinction models