Time-evolving photoionisation in GRB afterglows

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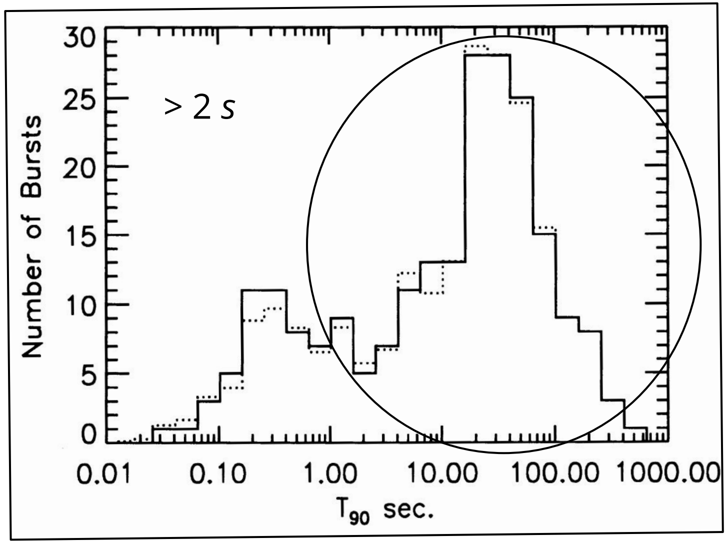
Long gamma-ray bursts

Kouveliotou+93



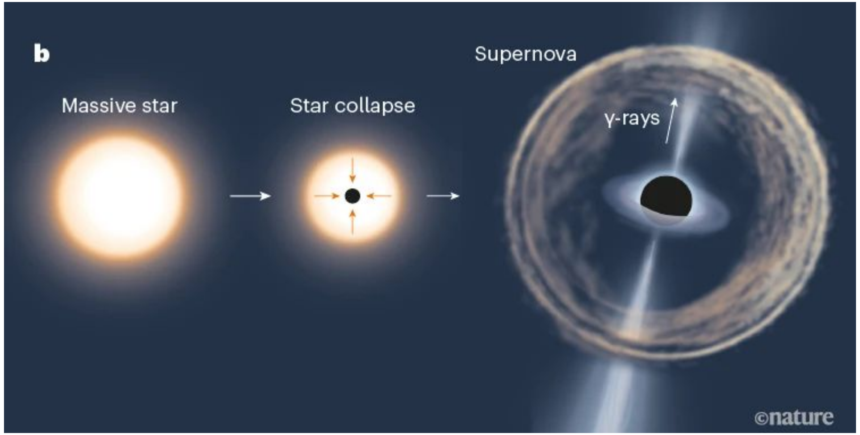


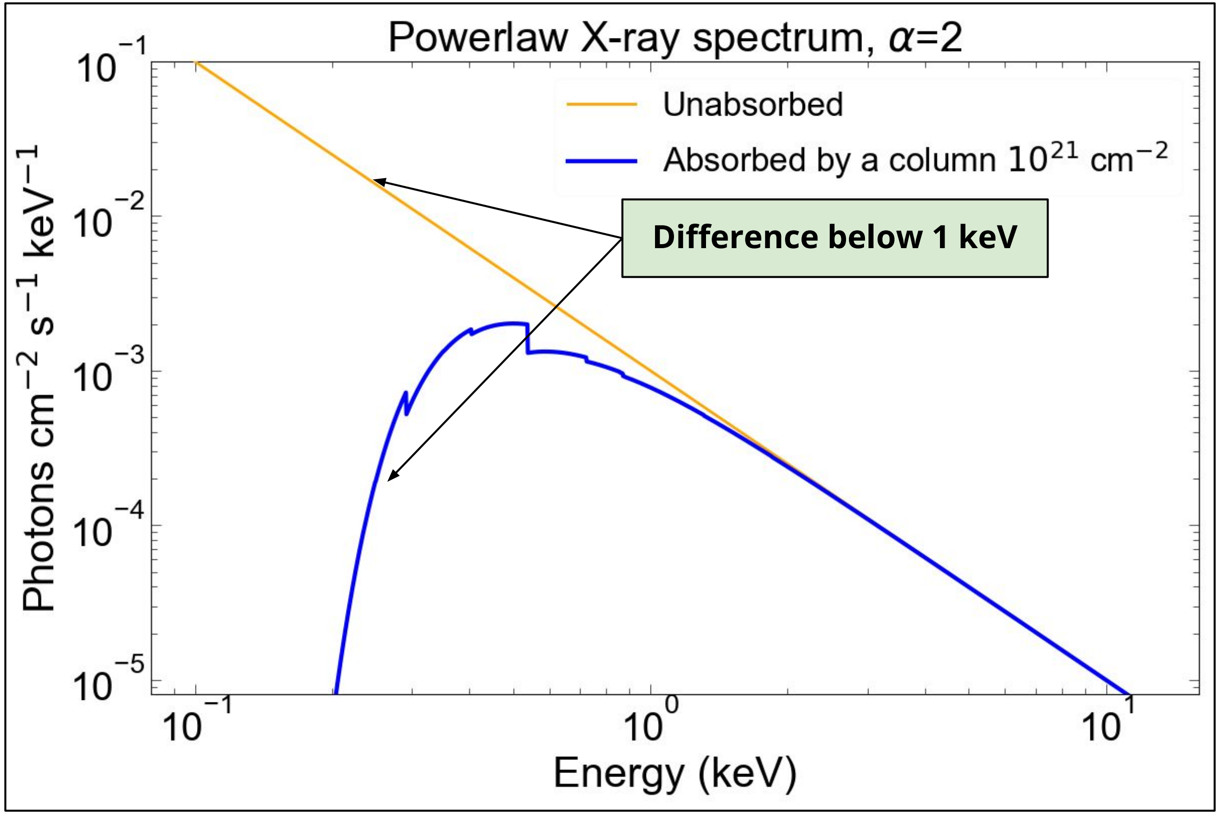
Image credits: https://www.nature.com/articles/d41586-022-04165-7

Observable up to large *z* + host galaxy actively star-forming

↓

Perfect as probes of star formation in the early Universe!

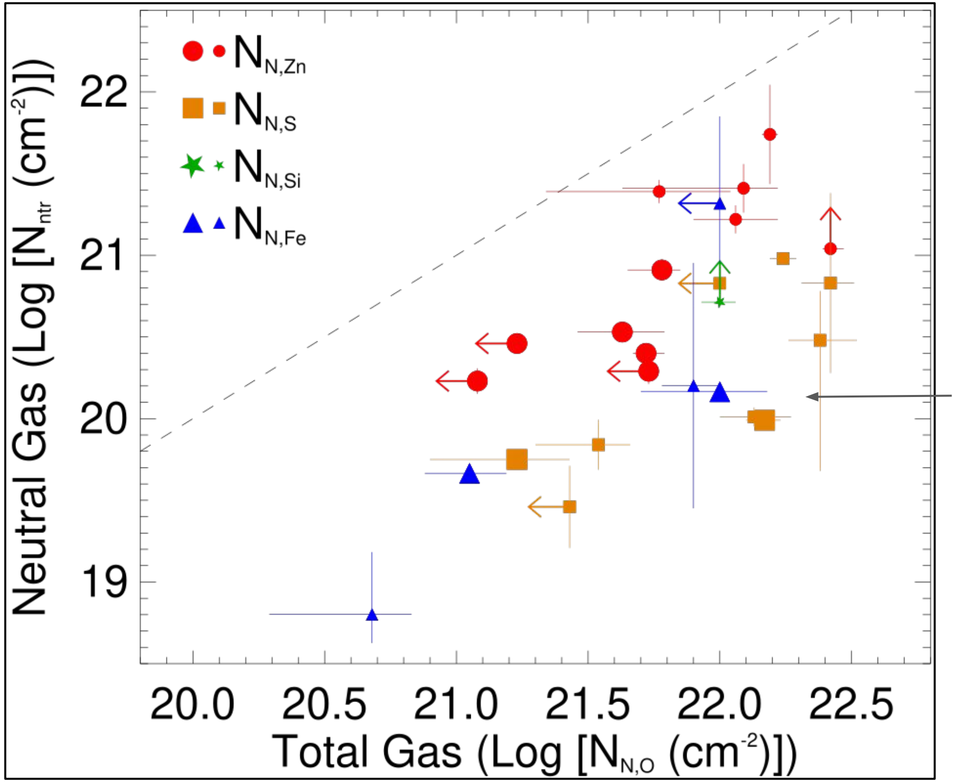
GRB X-ray afterglow spectra



Quantitative estimation by fitting absorber models

But why X-ray?

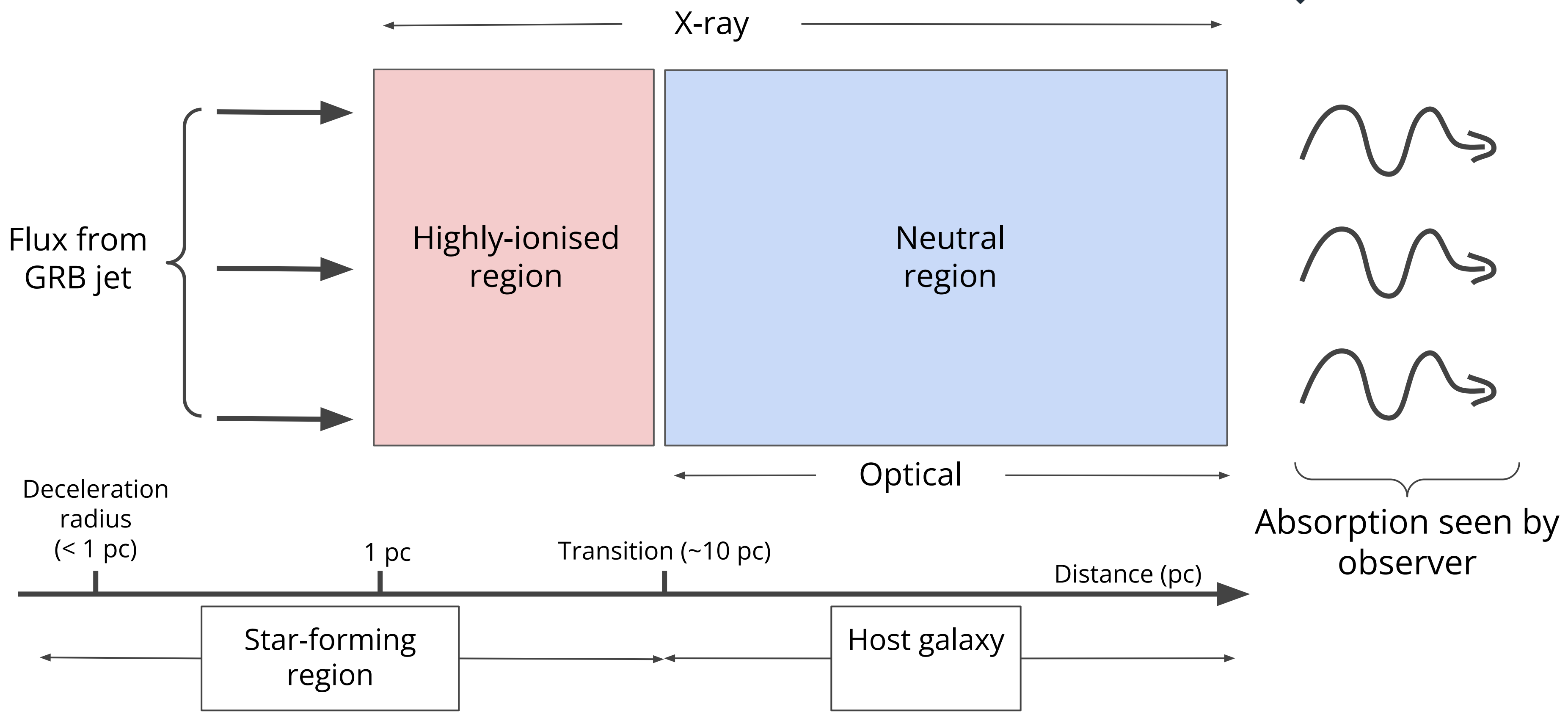
Watson+07,Schady+11



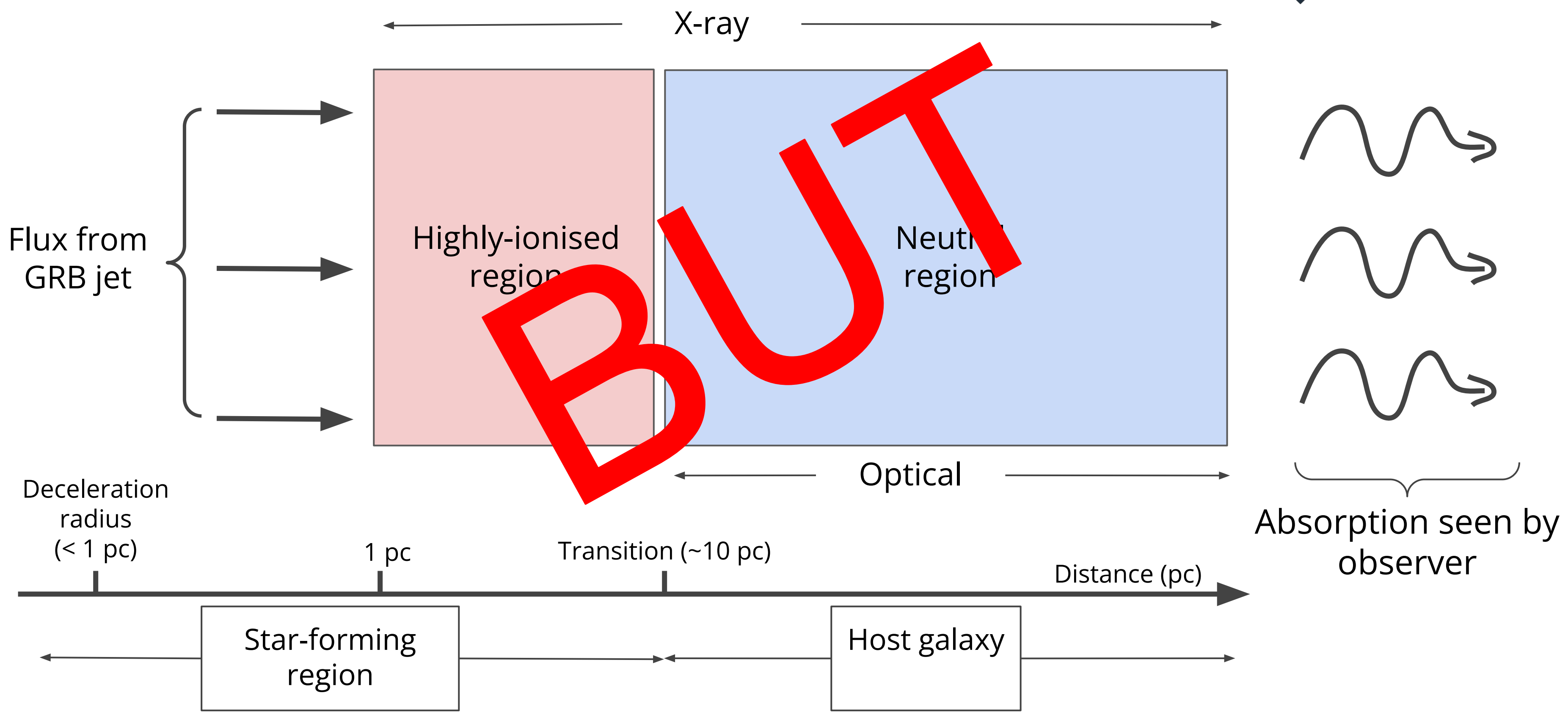
~ 10x discrepancy when comparing optical & X-ray absorption columns

GRB X-ray column density probes the entirety of the material along LOS

Stratification of medium within host galaxy

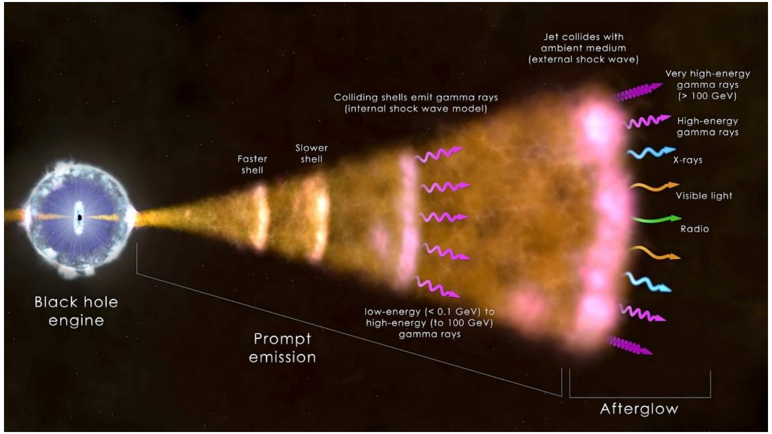


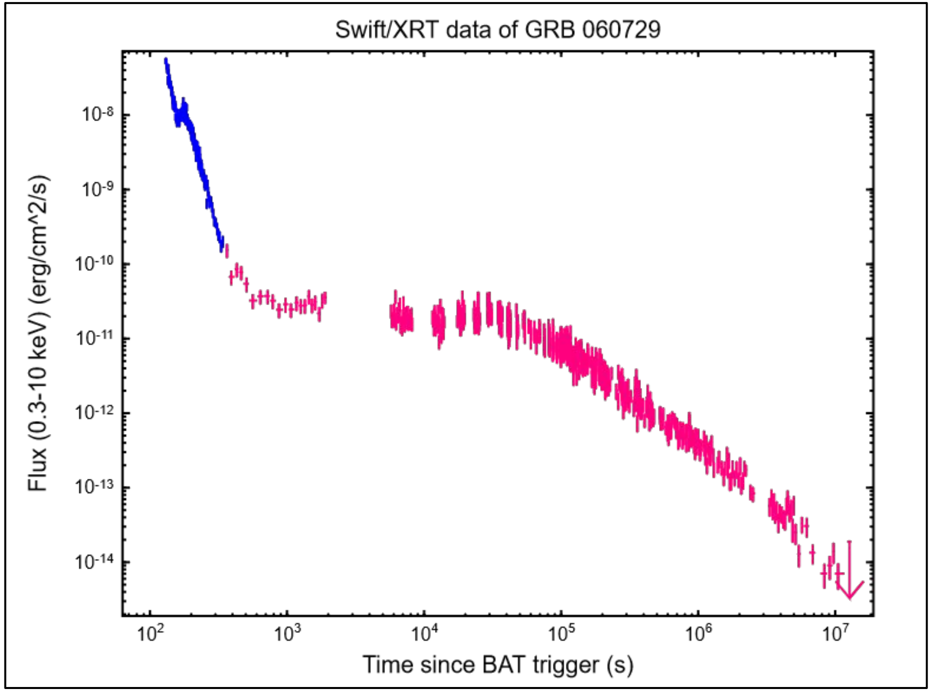
Stratification of medium within host galaxy



GRBs are time-evolving sources!

GRB are intrinsically transient, non-equilibrium sources:





Piro+02, D'Elia+09 , Krongold+13, Heintz+18

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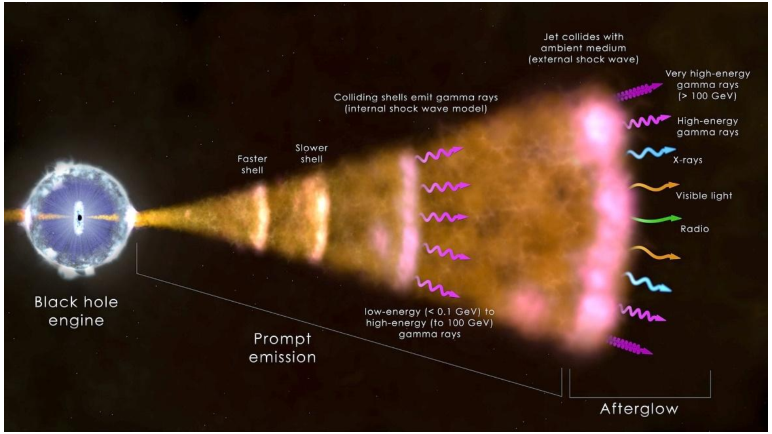
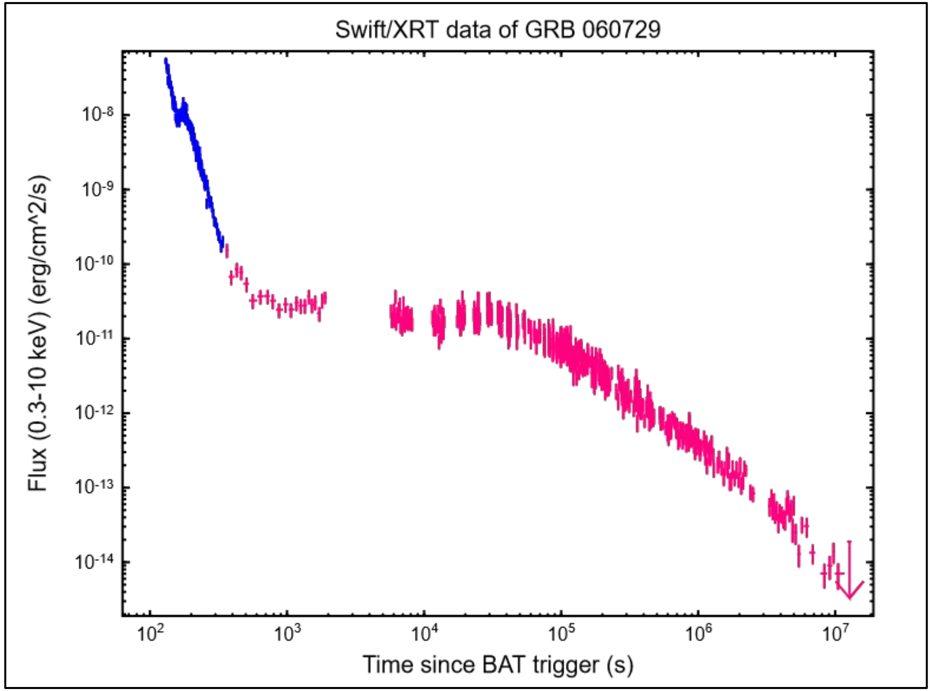




Illuminated gas is out of photoionisation equilibrium: Need for time-evolving modelling!

Piro+02, D'Elia+09 , Krongold+13, Heintz+18

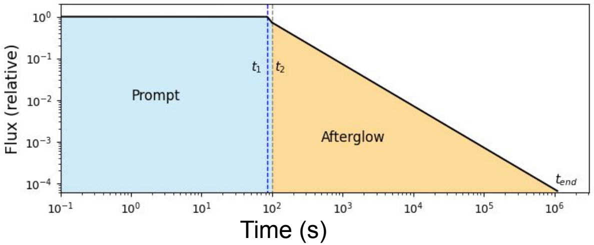
TEPID: Code outline

Time-**E**volving **P**hoto**I**onisation **D**evice

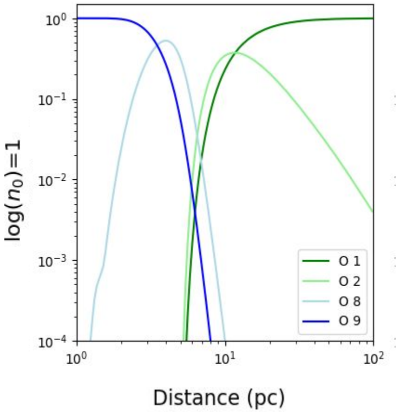
Luminari+23

1. Input quantities:

i. Lightcurve
ii. Gas density
iii. Initial ionic abundances

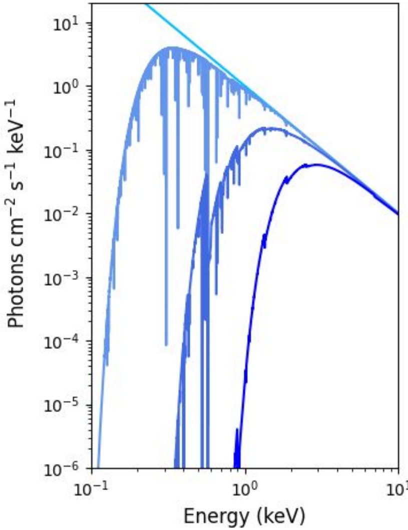


2. Time evolving computations:



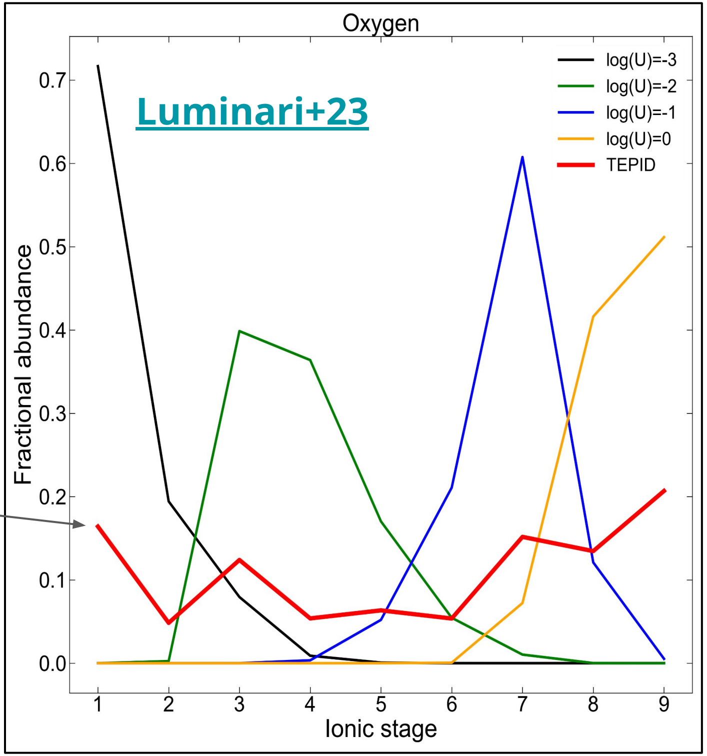
Temporal evolution of the ionisation and temperature of the surrounding ISM

3. Absorption spectrum:



Time-resolved optical to X-ray spectra as a function of the ISM density and distance (or NH)

Unique distribution of ionic abundances



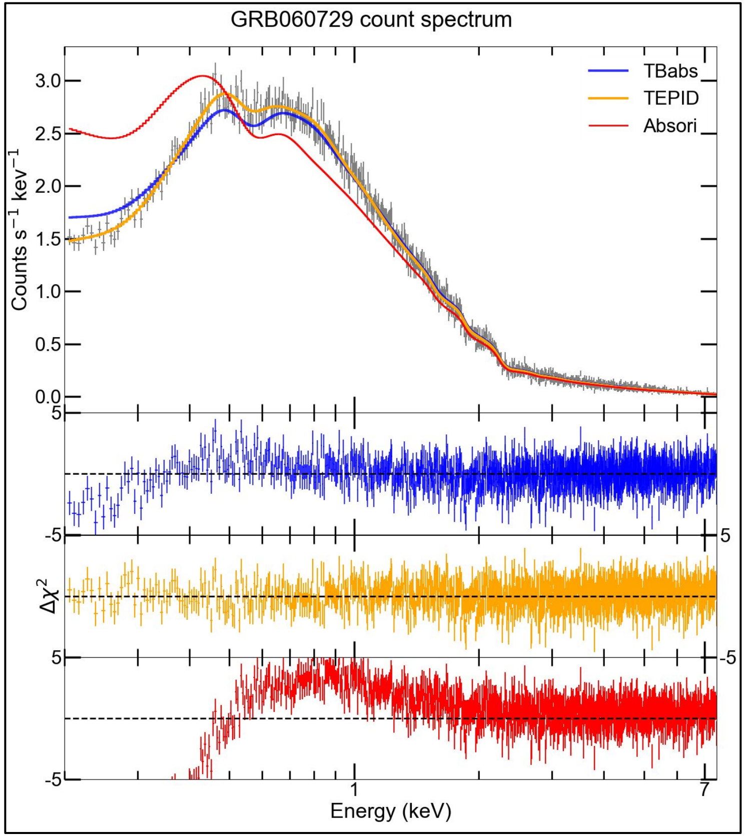
Non-negligible contributions of several ionic stages

Observed abundance pattern is unique for specific number density

Direct consequence of temporal evolution of the GRB ionising flux

And now we fit!

- Computations per GRB
- XMM ‘Golden Sample’,
  - Known ***z***
- Neutral column from optical

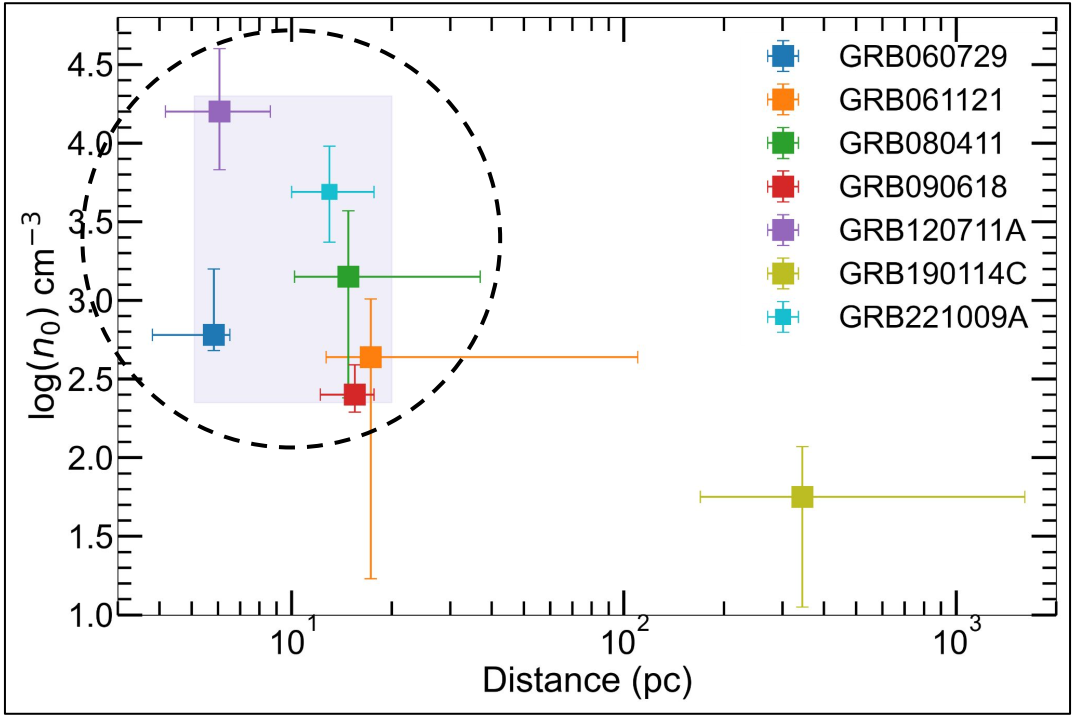


NH_{TBabs} = 9e20 cm^{-2}

NH_{TEPID} = 9e21 cm^{-2}

$logn_0$ = 2.8 cm^{-3}

What does this mean?

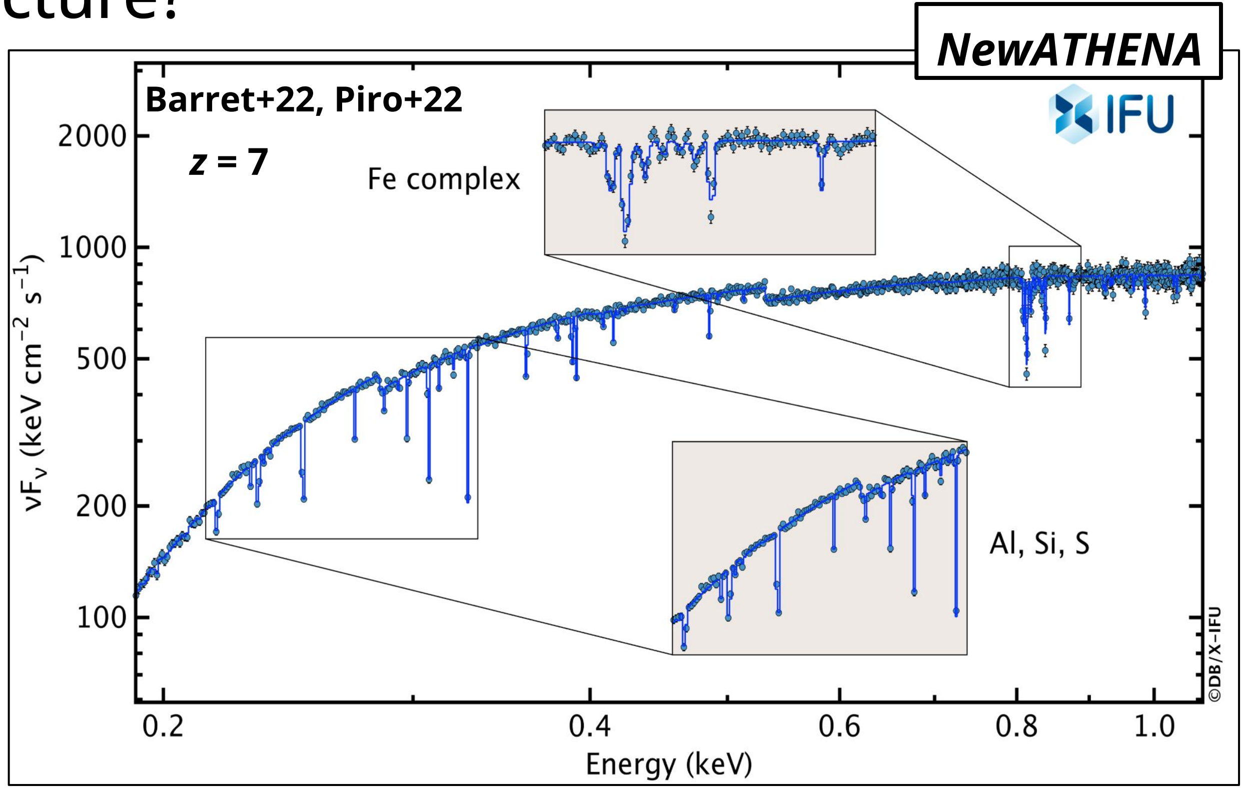


$$N_H = \delta r \cdot n$$

$$\rightarrow \delta r = N_H / n$$

All burst-fits independently recover a best-fit region of size ~ 10 pc

Bigger picture?



Improved energy resolution and sensitivity for study of high-*z* medium:

- **Composition? Metallicity? Progenitors: Pop-III v/s Pop-II?**

Conclusions

- TEPID: Time-integrated X-ray spectra as a function of number density and distance
- Fits to CCD spectra of 'Golden Sample' of XMM afterglows
    - ➢ **Environment consistent with star-forming region**: n = 10^{2-4} cm^{-3} , r ~ 6 - 20 pc
- Application to high-resolution calorimeter X-ray spectra
    - ➢ Diagnostics of star-forming environment at high ***z***

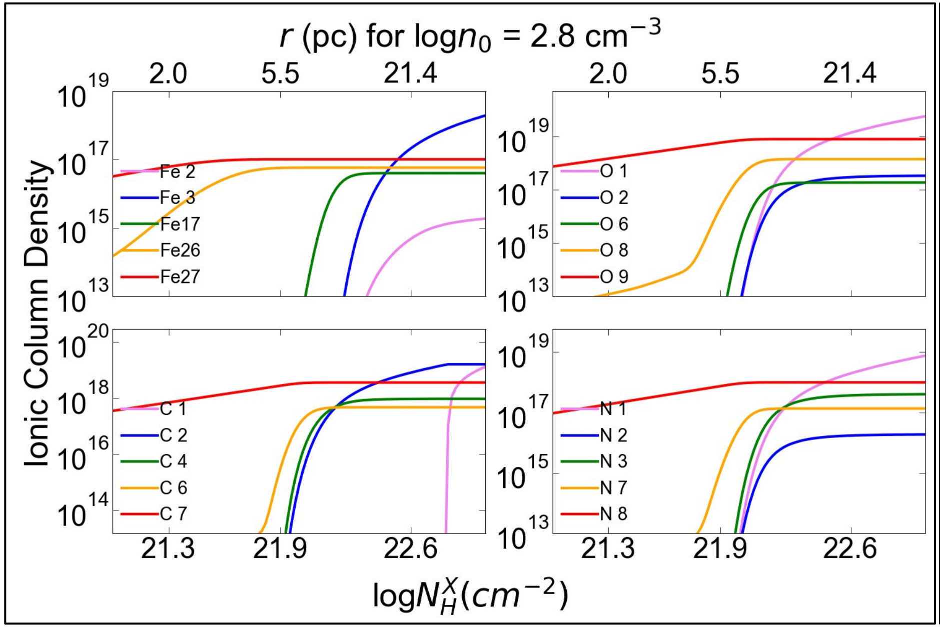
And keep an eye out for these papers:

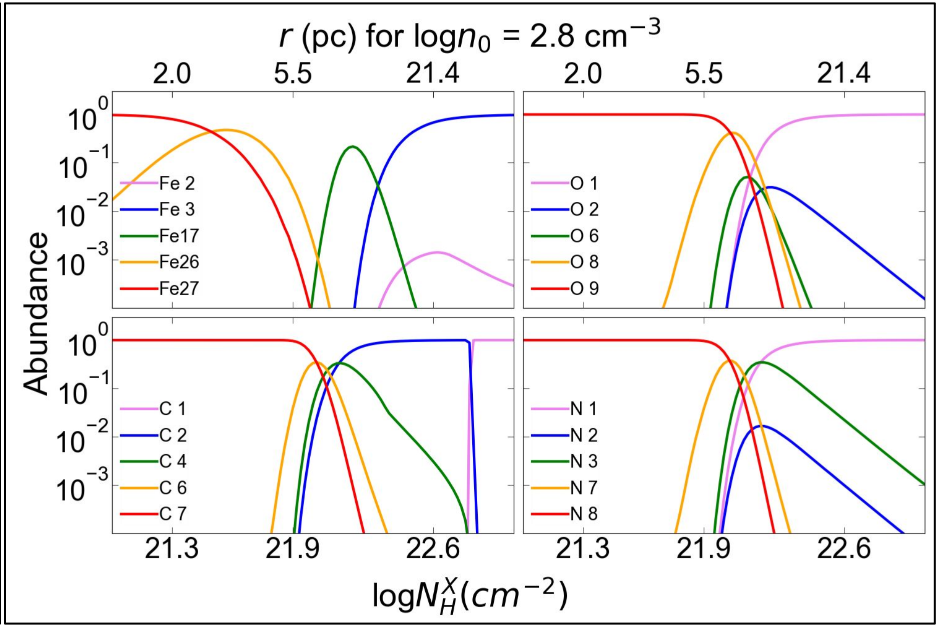
- **The TEPID model**:
  Luminari A, Nicastro F, Krongold Y, Piro L, *Thakur AL*, accepted August 2023, A&A
- **TEPID for GRBs:**
  Thakur AL, Piro L, Luminari A, Nicastro F et al., 2023, in prep
- **TEPID for hi-resolution X-ray spectroscopy**:
  Piro L, *Thakur AL*, Nicastro F, Luminari A et al., in prep

Backup slides

Distribution of ionic abundances & columns

GRB060729

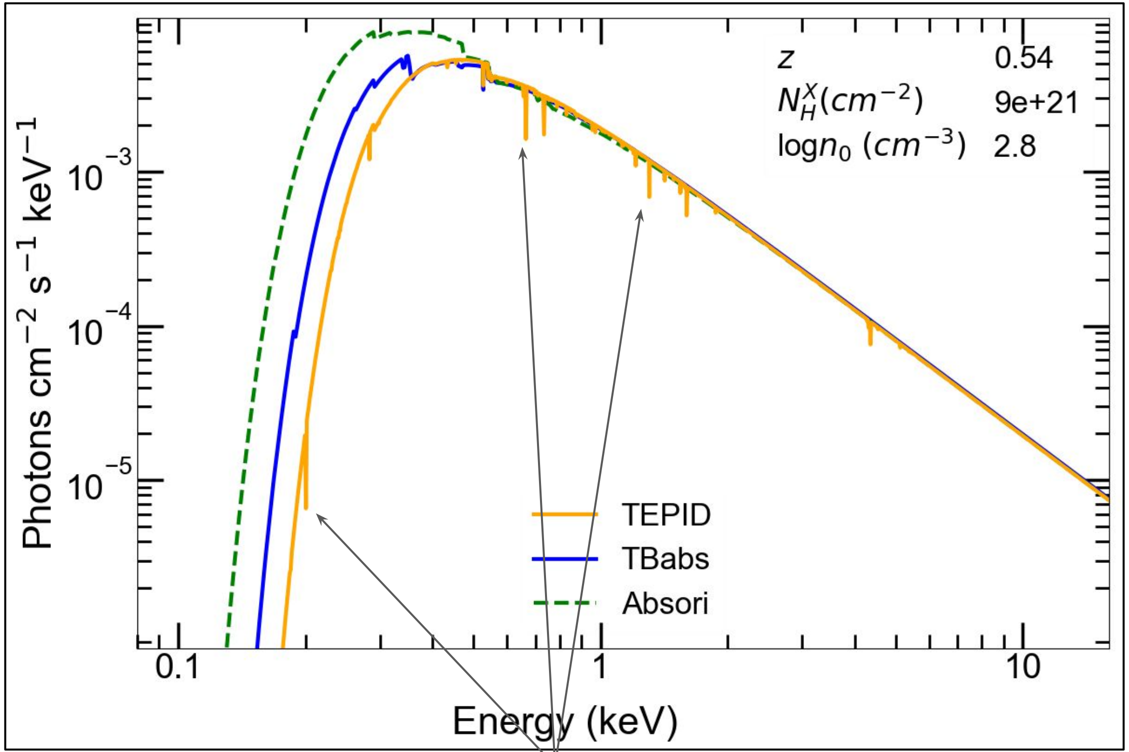




$NH_{TEPID} = 9e21\ cm^{-2}$

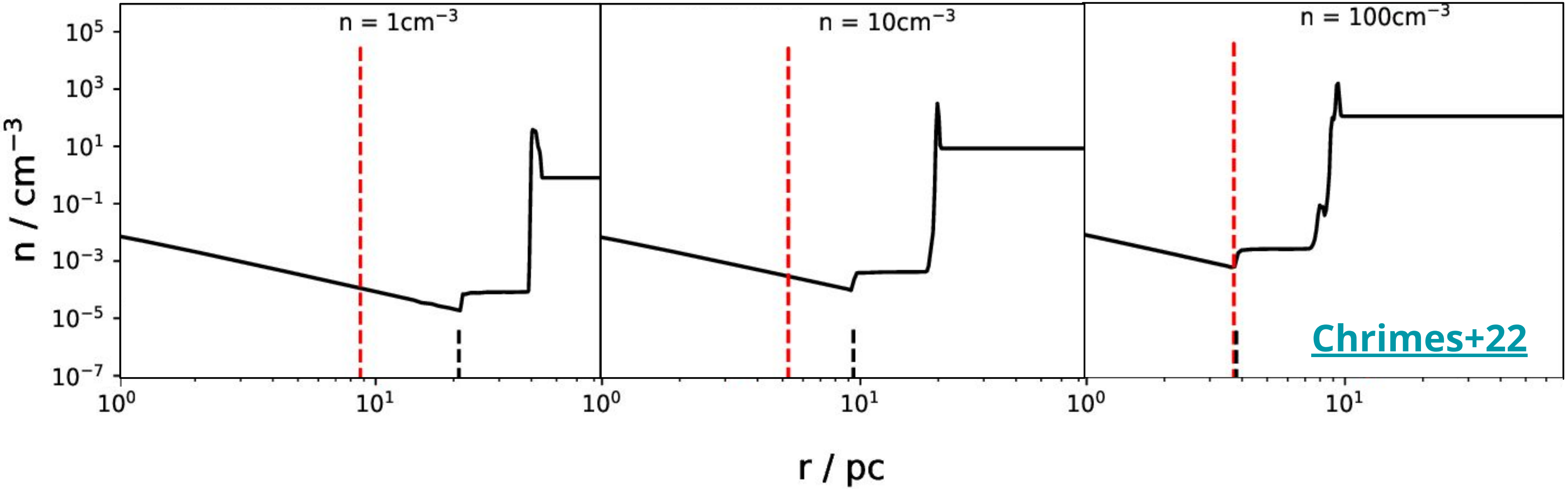
Model spectra

GRB060729



Several narrow absorption lines, but cannot be resolved in CCD spectra

But why so high?



Medium is cleared by progenitor wind up to a distance inversely scaling with pre-burst number density