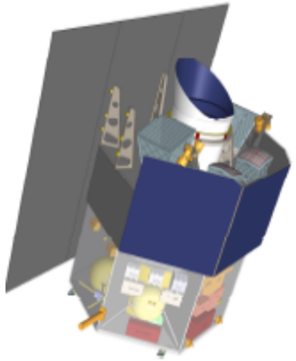
THESEUS and the star formation near and far



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L.G. Balázs, T. Kovács, I. Rácz,

Zs. Bagoly, D. Burgarella, I. Horváth, P. Pinczés, S. Pintér, D. Szécsi, B. Tóth, P. Veres, et al.

Think globally act locally(*) ?

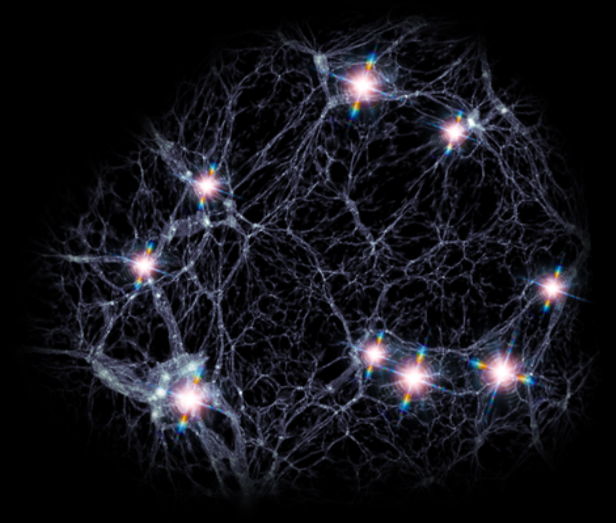
- What we always wanted to know about the distribution of matter and star formation
- Where do stars form (incl. GRB progenitors)?
- SFRD at moderate redshifts – do we actually know it well enough?
- ISM at the very location of star (eg. GRB progenitor) formation
- (*) THESEUS is a mission for the benefit of the whole astronomer community.

Vega C fairing (THESEUS YB Figure 5-1) + Greek coin with labyrinth

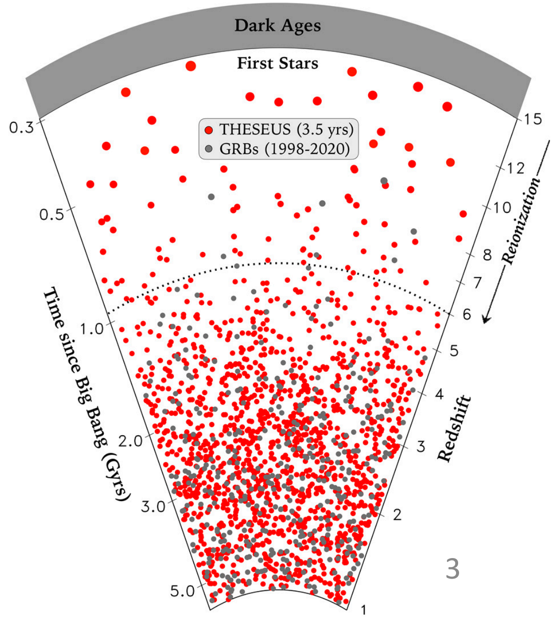
LGRBs as tracers of structure?

- Giant GRB Ring
  - 1.72 Gpc, at 0.78 < z < 0.86 (Balázs + 2015, 2018)
- Hercules–Corona Borealis Great Wall
  - 2.6 Gpc, at 1.6 < z < 2.1 (Horváth + 2014, 2015, 2020)
- Significance of patterns in space-time
  - Size of the sample to be increased by 2 orders of magnitude
  - **will be done by THESEUS**
- See also the posters by I. Horváth and L.G. Balázs
- Origin of the anisotropies
  - set by the cosmological screening length? (Canay & Eingorn 2020)
  - by a direction-dependent Hubble constant? (Migkas + 2020)
  - by a wave in star formation rate? (Balázs + 2015, Horváth + 2020)
- **What is the type of star formation that results LGRBs?**

Artist's view of the Giant GRB Ring



by P. C. Budassi
https://en.wikipedia.org/wiki/File:Giant_grb_ring.png



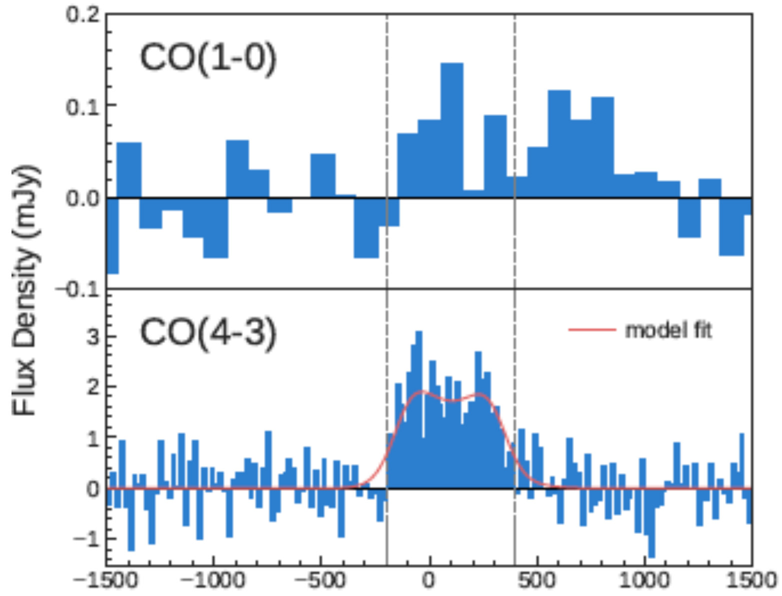
THESEUS YB Figure 1-1

LGRB progenitors (as shown by Dorottya Szécsi)

- no large envelope – jet should be able to penetrate through
- fast rotation at the moment of collapse
- iron core… massive star
- massive 20−30 $M_\odot$ stars (Yoon + 2006; Dessart + 2008; van Marle + 2008)
- rotate fast & undergo chemically homogeneous stellar evolution (Szécsi + 2015)
- a metallicity of $Z \leq 0.5\ Z_\odot$ is required for such a massive star to maintain its sufficiently fast rotational rate & form a LGRB
- → Low metallicity pre-progenitor ISM, at least locally or the whole galaxy

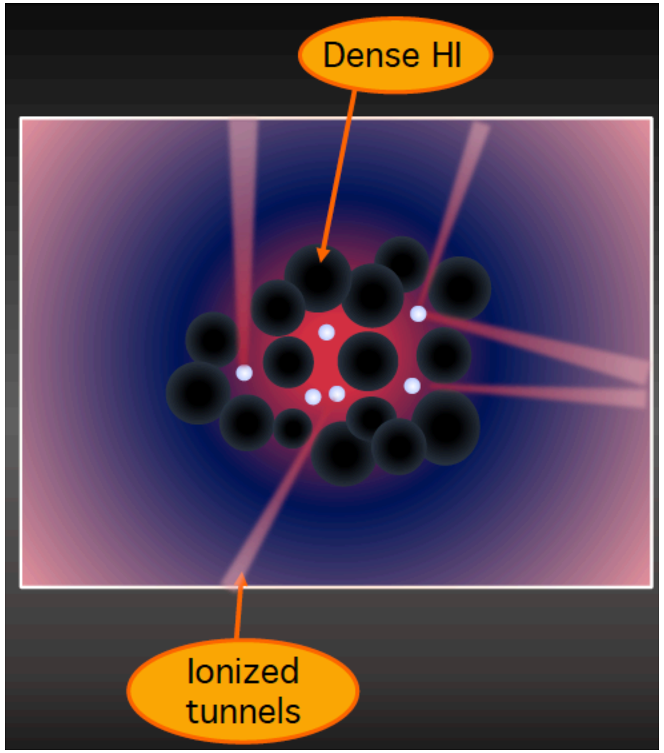
Star formation and ISM

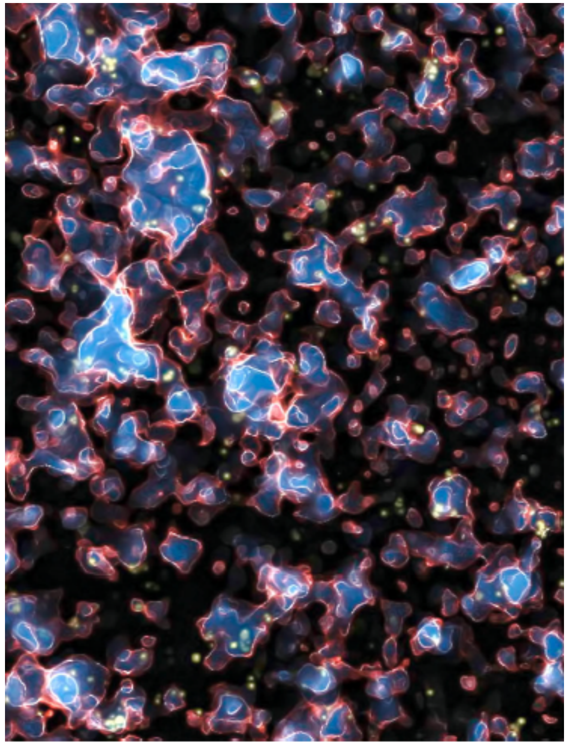
- Cold ISM
  - position of galaxies in the SFR vs. $M_{stellar}$ plane can be explained mostly by their global cold gas reservoirs + (Saintonge + 2016)
  - HI and CO as tracers (C+) of gas
  - Dust (FIR and sub-mm)
  - How is it distributed?
  - **ngVLA may resolve it – another type of follow-up**
- LGRBs seems to trace metal-poor star formation activity (also in non metal-poor hosts)
- Note that with LGRBs we sample the massive tail of IMF (10%?)
- Note that the “universal” IMF is metallicity dependent



GRB080207 (z = 2.0858) host galaxy CO(1–0) (top) and CO(4–3) (bottom) line profiles of the host galaxy. Continuum emission is subtracted. (Hatsukade+ 2019ApJ...876...91)

Post-reionization Universe – structure matters

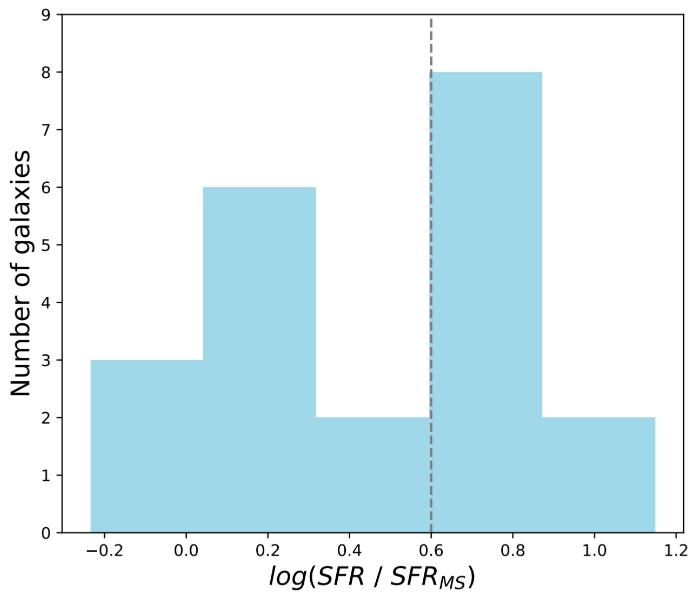




See it in Nial Tanvir's talk

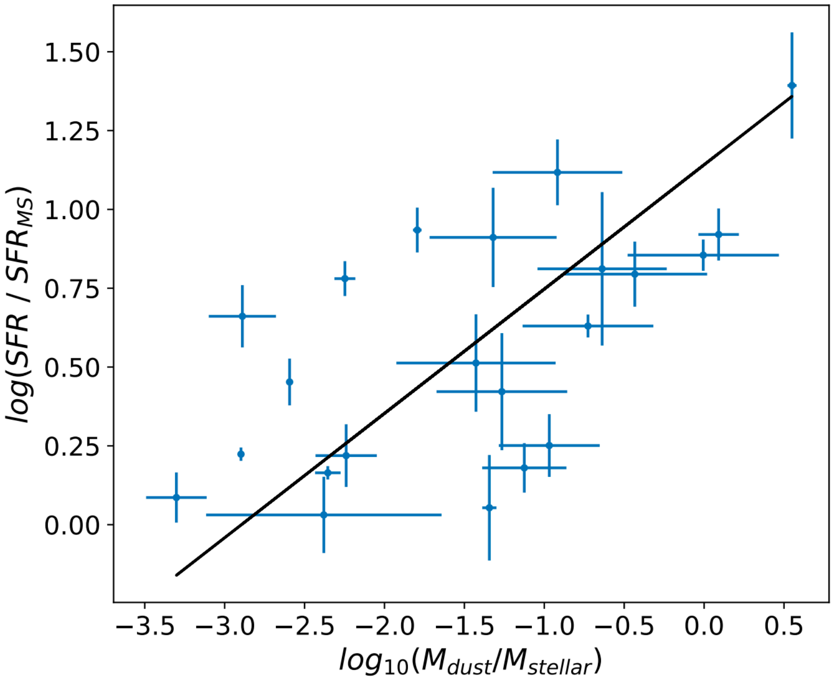
- Reionization is inhomogenous
  - Bubbles
  - Tunnels
- so metallicity should be as well
- Large scale anisotropies in metallicity? – **trace it with THESEUS!**
- See also: Did the first galaxies and the first stars form along dark matter filaments? (Mocz + 2019)

Deviation from the SF main sequence for Herschel detected GRB hosts, 0 < z < 2.5



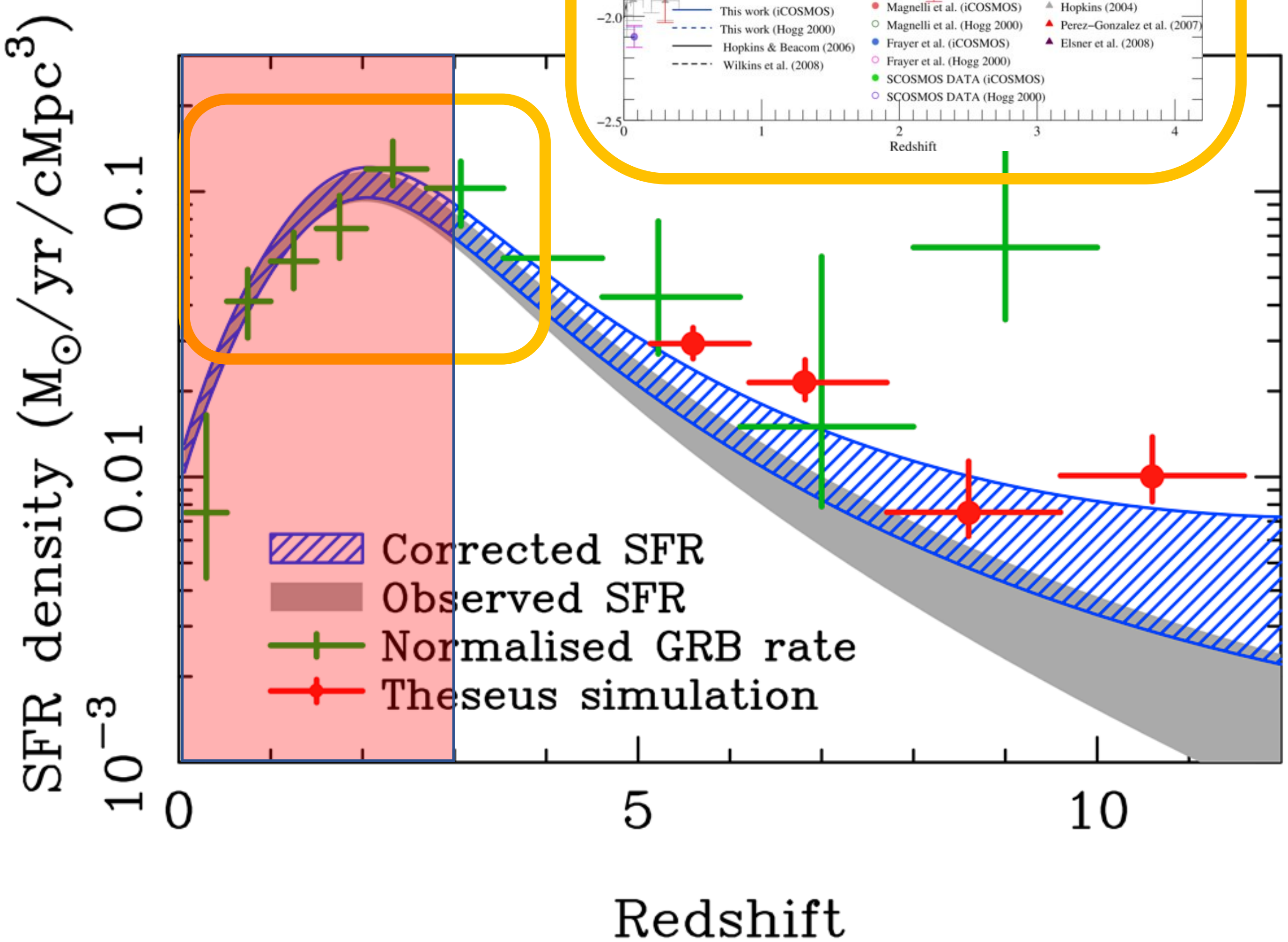
L. V. Tóth, T. Kovács, N. Suleiman + in prep.

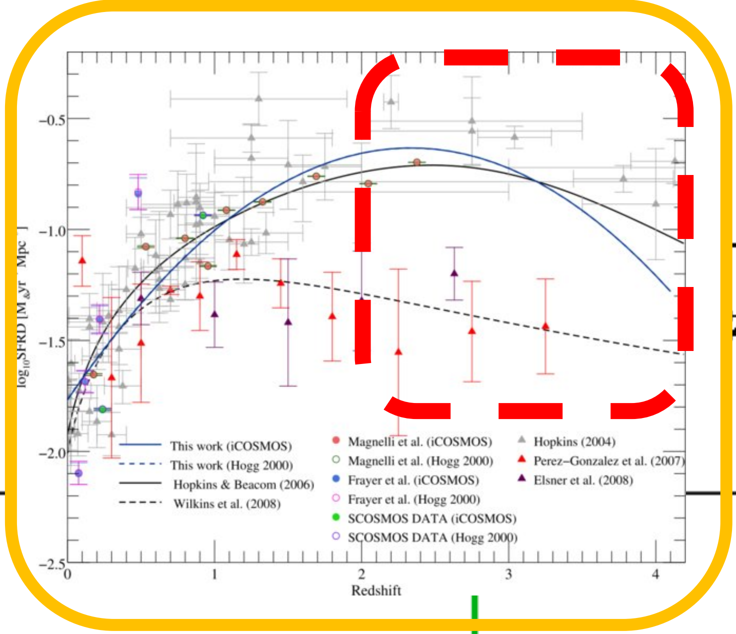
- SED modelling of Herschel detected GRB host galaxies
- SFR excess relative to the MS of the same redshift (21/45)
- Follow the talk by Nofoz Suleiman 16:15 today!

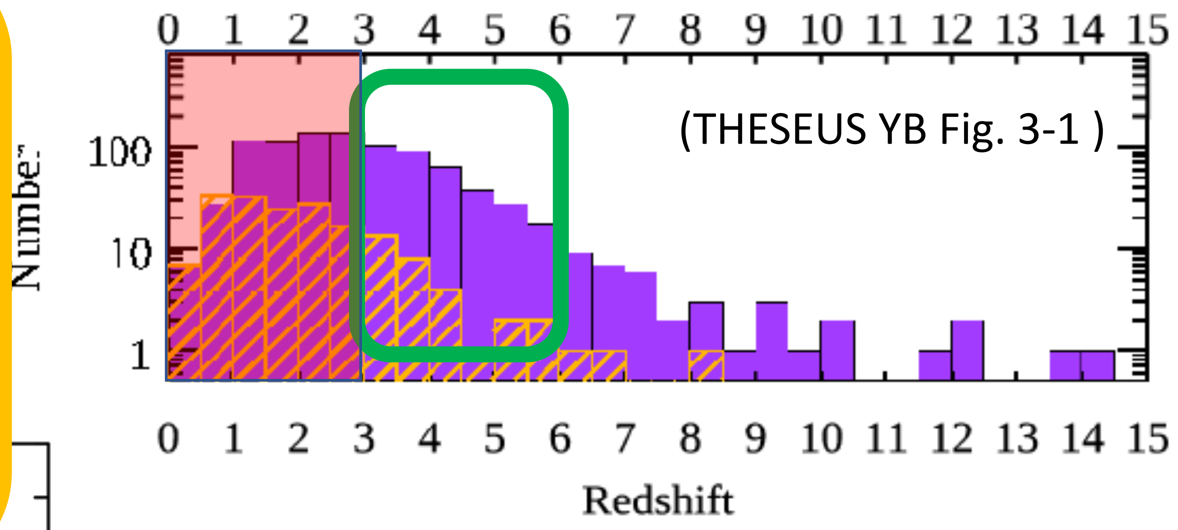


- Excess SFR vs. dust-to-stellar mass ratio
- a higher dust-to-stellar mass ratio means also a higher excess SFR over the value at the SF main sequence of the given redshifts
- **Importance of global ISM parameters**

SFRD “over the hill”



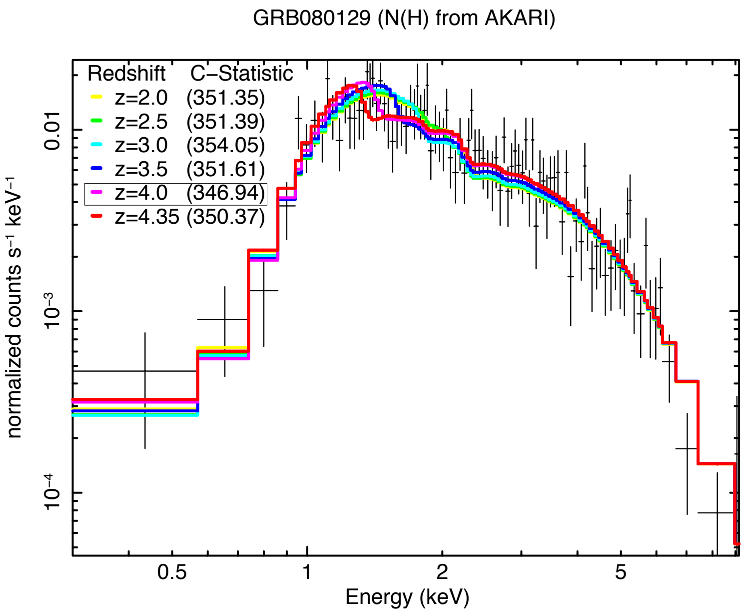


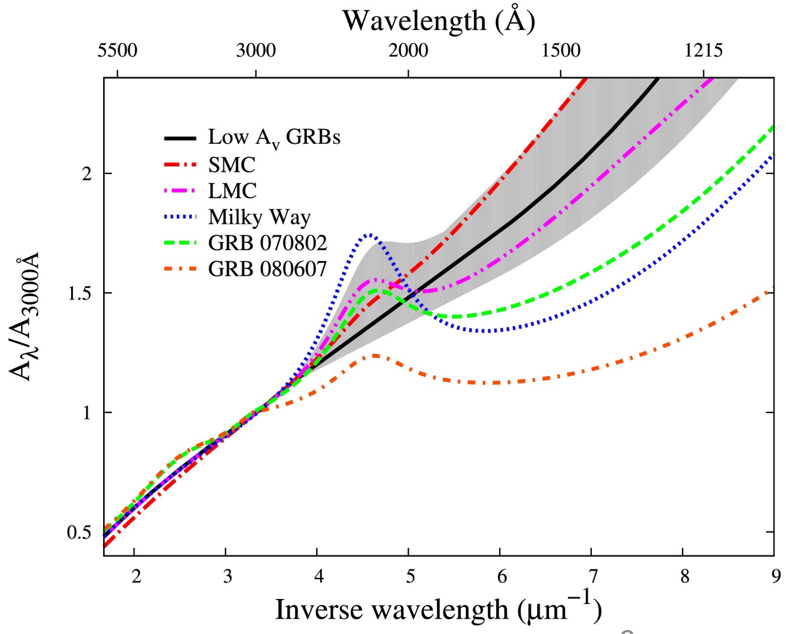


- Comoving Star Formation Rate density (THESEUS YB Figure 2-5)
- **LGRBs are not pure tracers** of SFR (Palmerio + 2019 A&A 623. 26)
- **SFRD peak confirmed** from Spitzer COSMOS Legacy survey, but **z > 3**? (Jo + 2021 Astrophys Space Sci)
- **SFRD over the peak** will be checked by GBRs (THESEUS YB Fig. 3-1)
- **z > 3 GRBs are SFR tracers** (Z < 0.7)
- **THESEUS will be a game changer**

Intrinsic ISM parameters (H density, metallicity) at the GRB jet (< 200 pc)?

- GRB jet impacts the surrounding medium → afterglow (e.g. Mészáros + Rees 1992; Sari+1998)
- Afterglow: continuum radiation in all wavelengths
- Afterglow X-ray spectrum
  - Bright and “simple”: approx. as power-law continuum modulated by absorption (Behar+2011; Schady+2011; Zafar+2011; Campana+2012 …)
- Rest frame optical and UV abs. lines (eg. Fynbo+2009 gas; Elíasdóttir+2009 dust; Perley+2011, Schady+2011)
  - Metallicity and extinction peculiarities
- Absorption: intrinsic, CGM, IGM, MW (eg. Schady 2015 JHEA)
  - **THESEUS+ATHENA may help to improve models**
  - 100s of new sightlines, X-ray and NIR spectra

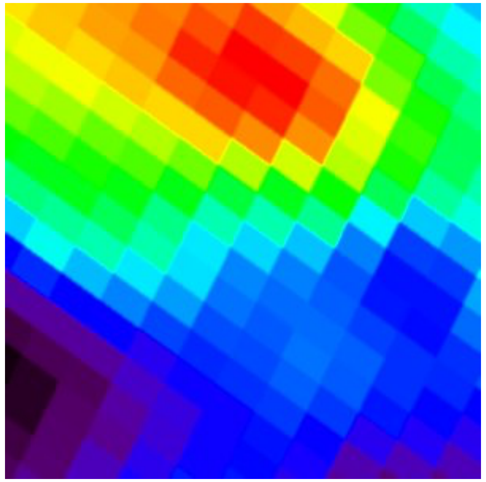




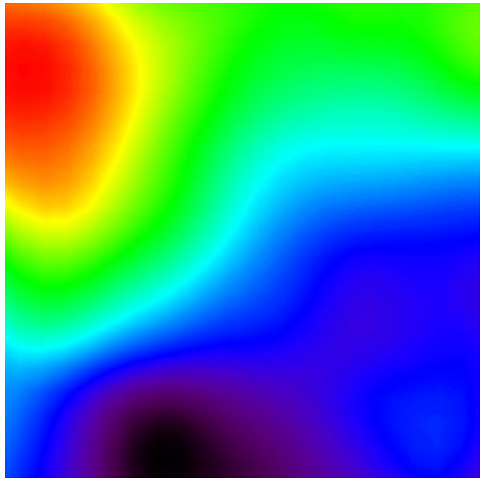
Improving the Milky Way foreground N(H) estimation

Tóth + [2019PASJ.71.10]

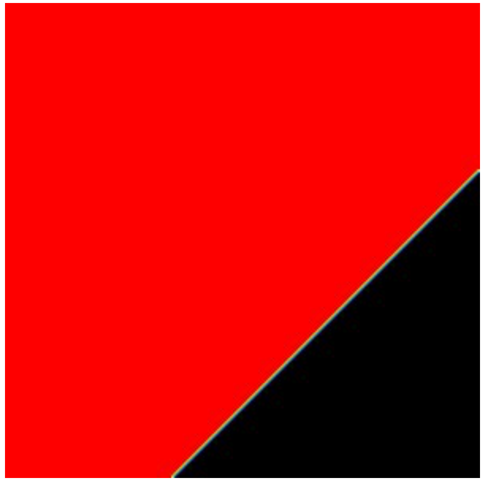
IRAS based N(H)
Schlegel et al. 1998



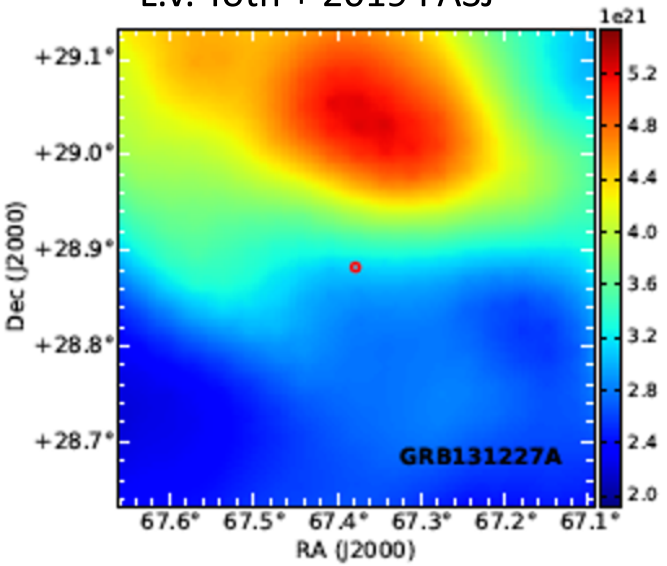
HI 21cm line intensity
Winkel et al. 2016



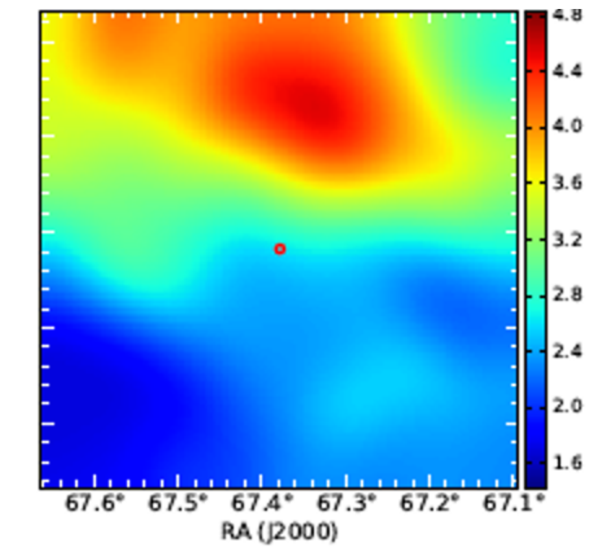
HI 21cm line intensity
Dickey & Lockmann 1990



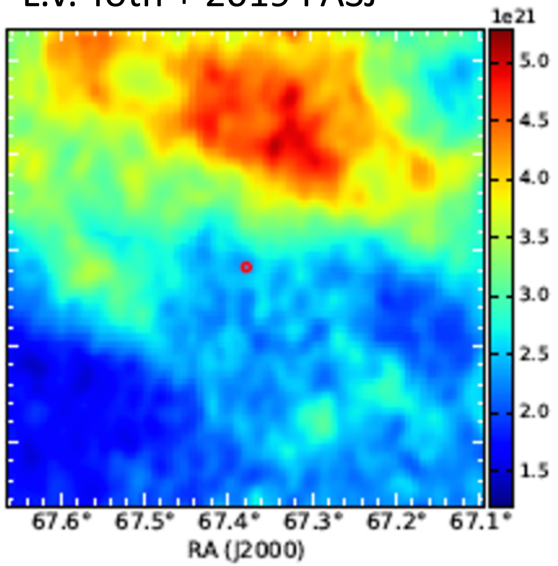
Planck based N(H)
L.V. Tóth + 2019 PASJ



AKARI based smothed N(H)
L.V. Tóth + 2019 PASJ



AKARI based N(H)
L.V. Tóth + 2019 PASJ



GRB 131227A, z=5.3; N(H) down 20%

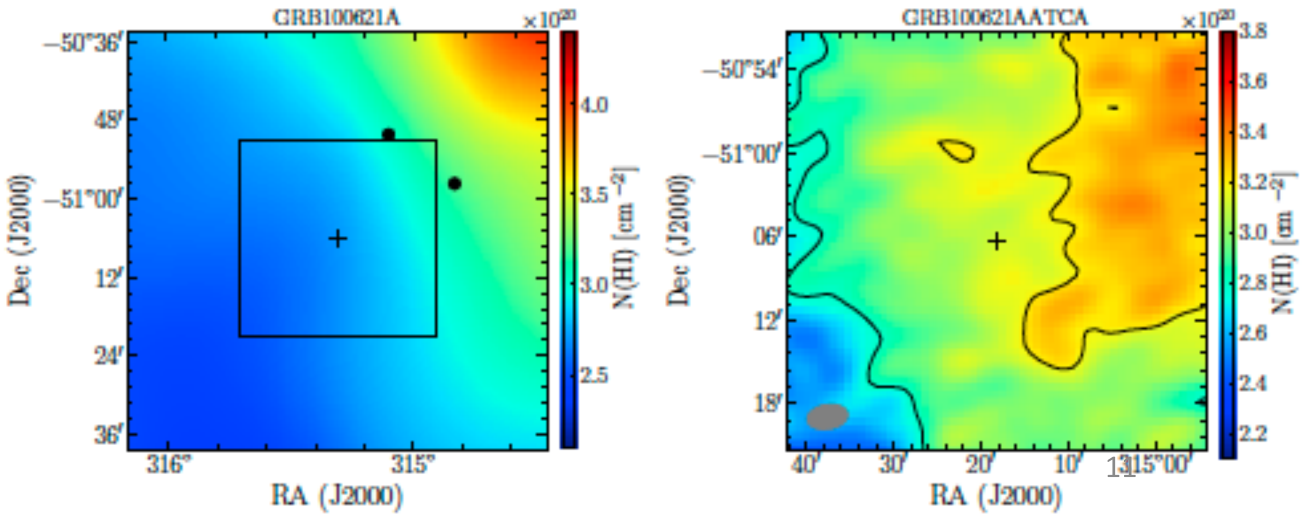
See also ATCA 21cm foreground of GRBs ([Dénes+ 2019 MNRAS])

Towards an improved intrinsic N(H)

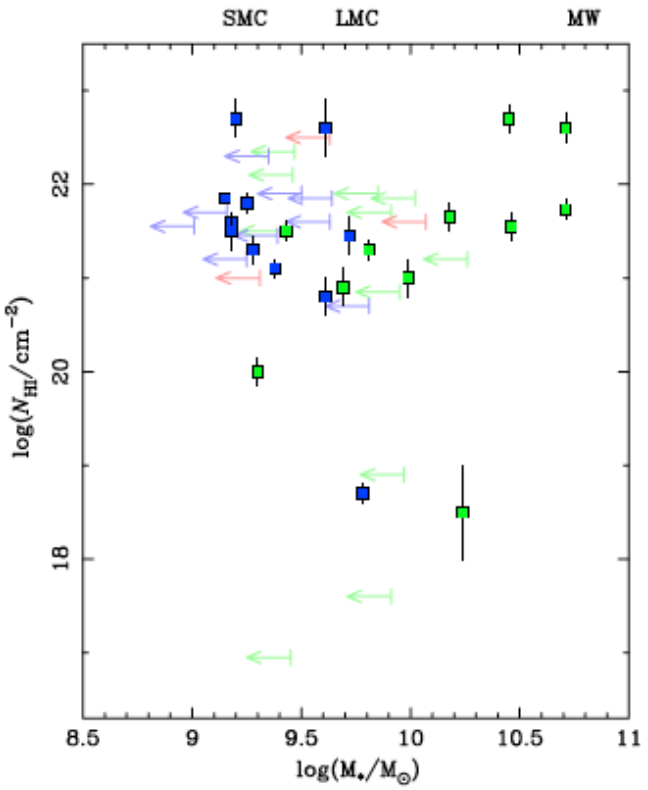
High resolution probes of the Galactic foreground + **THESEUS**

- AKARI and Planck based estimates of $N(H)_{gal}$
  - Low column density ISM is not smooth (!)
  - filaments and all sort of structures in diffuse ISM
  - intrinsic N(H) is usually $\geq$ compared to the values calculated based, e.g., on the low-resolution Leiden/Argentine/Bonn survey data
  - Tóth + [2019PASJ.71.10]()
- ATCA 21cm pilot observations of 4 GRB hosts
  - line of sight optical depth
  - Low filling factor of dense parts
  - Planck based galactic foreground is OK
  - Dénes, Jones, Tóth + [2019MNRAS.489.3778]()
- Accuracy is limited by the X-ray sp. Fitting
- **THESEUS + ATHENA will help**

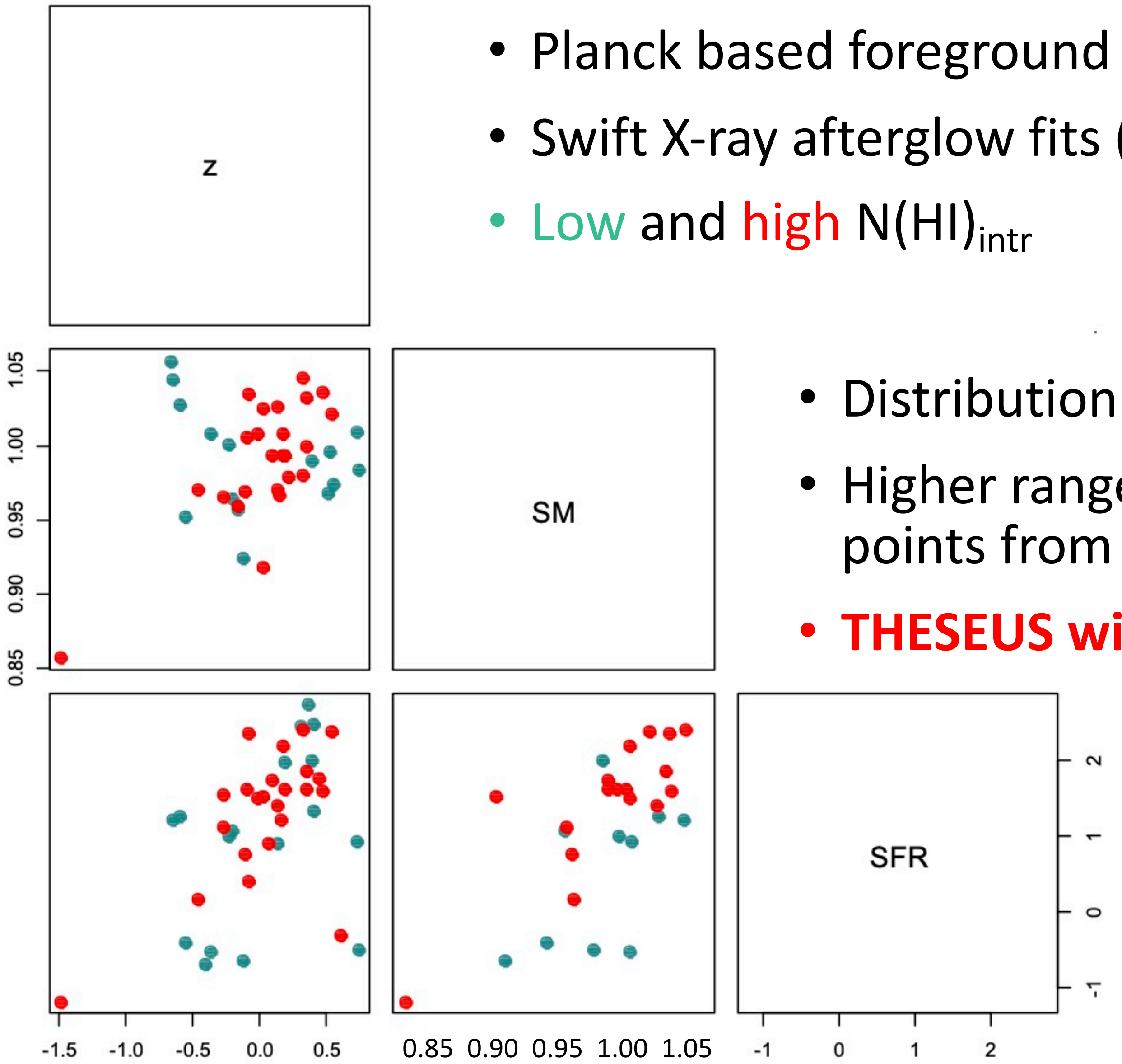
GASS (left) and the combined ATCA+GASS (right) data. square on the left: the size of the ATCA image (0.5 deg). + marks the position of the GRB



Is the intrinsic N(HI) related to global parameters?



See it in Nial Tanvir's talk



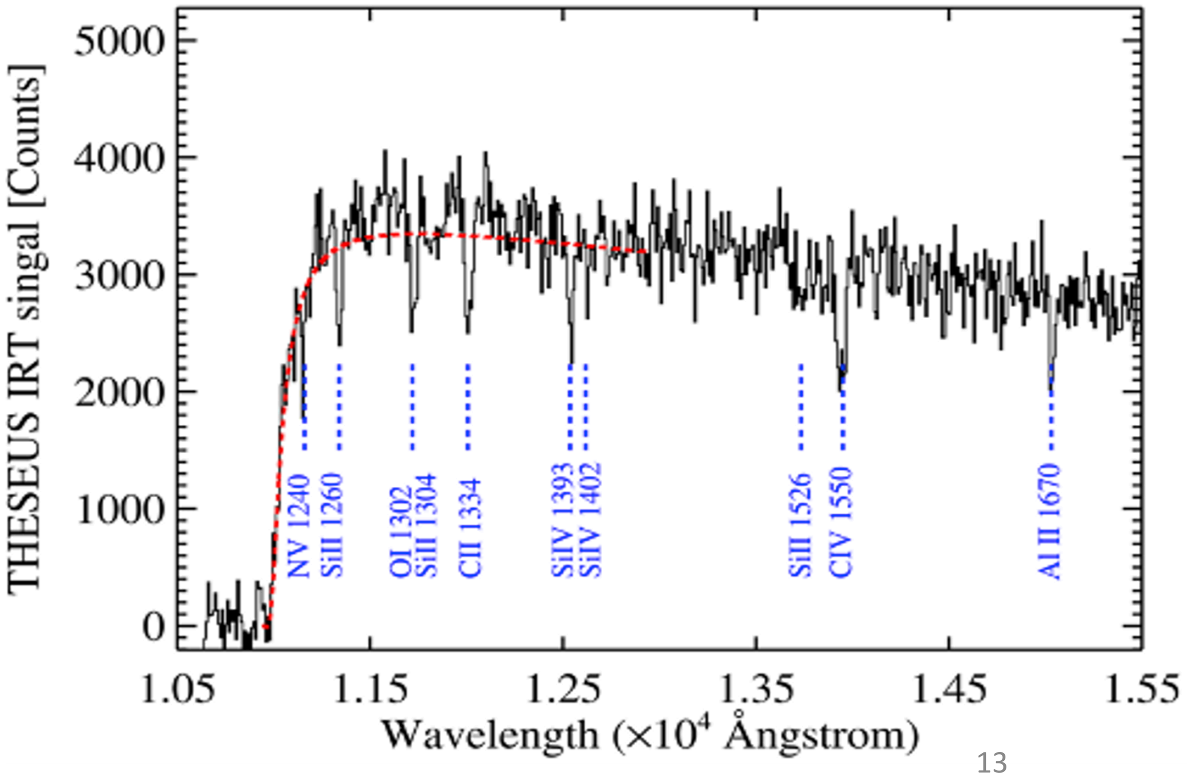
- Planck based foreground estimation
- Swift X-ray afterglow fits (power-low +)
- Low and high $N(HI)_{intr}$

- Distribution difference?
- Higher ranges, 100x more points from THESEUS obs.
- **THESEUS will help**

Balázs, Tóth + in prep

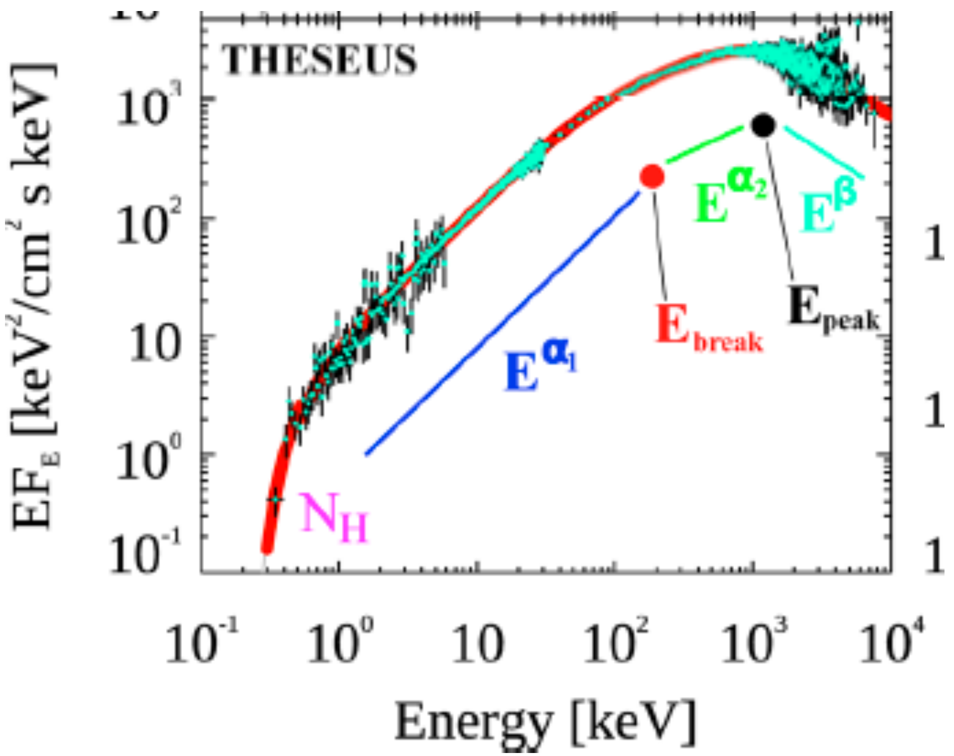
IRT and intrinsic ISM

- Follow-up of the brightest afterglows (H < ~17.5 mag) with the IRT spectroscopic mode will provide constraints within ~0.2 dex on the hydrogen column density along the GRB line of sight.
- estimate the intrinsic N(H) in the host
- identification of metal absorption lines
- estimate the host metallicity at the GRB
- Example for GRB at z = 8



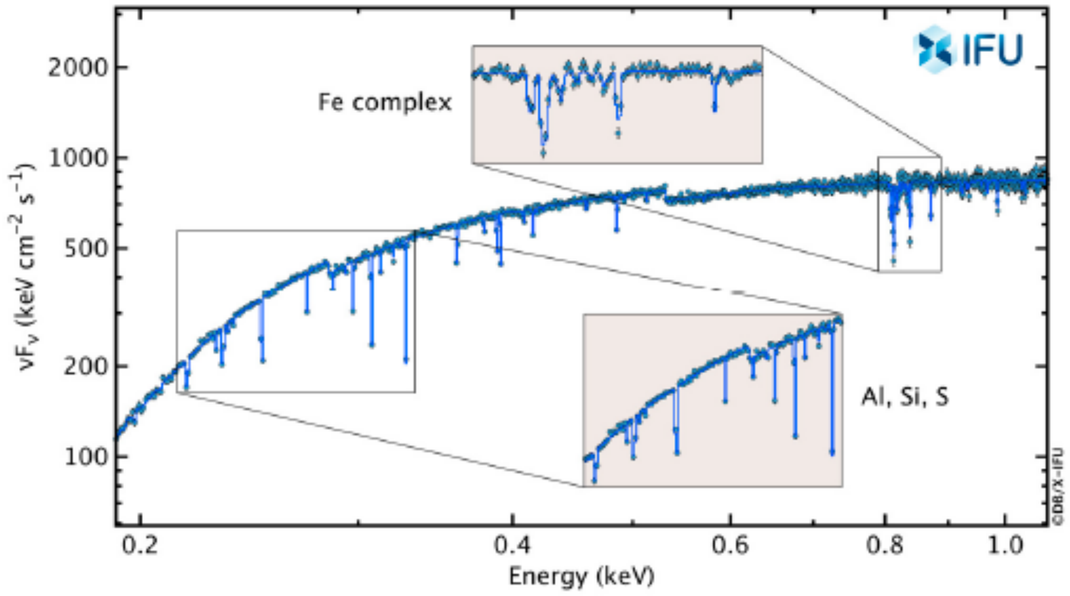
SXI+XGIS and ATHENA/X-IFU

SXI+XGIS: N(H)&Metallicity



Simulated THESEUS/SXI+XGIS prompt emission spectrum of GRB 180720B with three power-law components and two smooth breaks and a total absorption NH=10^{22} cm^{-2} (solar metal abundances). (THESEUS YB Figure 2-19)

ATHENA/X-IFU: N(H) & chem. composition



A simulated ATHENA/X-IFU spectrum of a medium bright (fluence: 4×10^{-7} erg cm^{-2}) z=7 GRB afterglow (THESEUS YB Figure 2-27)

Summary: Measure both globally and locally (*)!

- THESEUS will “3D print” a new Universe prove/disprove inhomogeneity
- (*) THESEUS + follow-ups
  - will uncover SF – ISM relations in locations inside galaxies also at high redshifts
  - will probe Galactic ISM as well
- SFRD at redshifts ($3<z<6$) will be well traced by THESEUS LGRBs
- Intrinsic ISM parameters may be related to global ones – THESEUS will result a statistical sample (mind the foreground!)

***Athena** ushers **Theseus** off to the left while Dionysus leads Ariadne off to the right. Syleus Painter (c 470 BCE)* http://www.goddess-athena.org