X-ray astronomy in the multimessenger era: Synergy Athena-CTA

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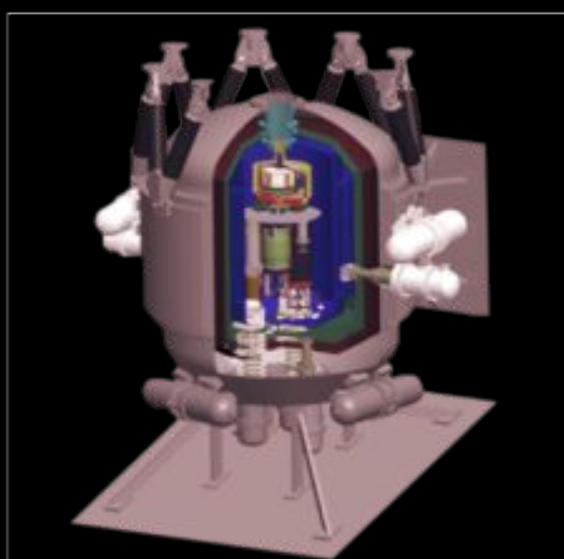
The Athena Observatory

Willingale et al, 2013
arXiv1308.6785

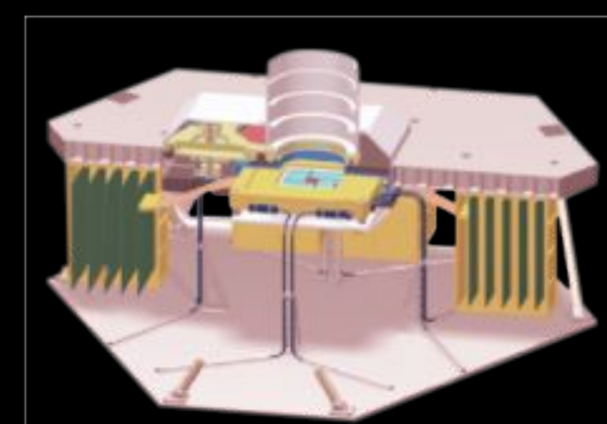
L2 orbit Ariane V
<5100 kg
power 2500 w
4 (goal 10) year mission
FoR>50%
TOO in 4hrs

Silicon Pore Optics:
1.4 m^2 at 1 keV
5 arcsec HEW
Focal length: 12m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}



X-ray Integral Field Unit:
ΔE: 2.5 eV
Field of View: 5 arcmin
Operating temp: 50 mk

Barret et al., 2013 arXiv:1308.6784

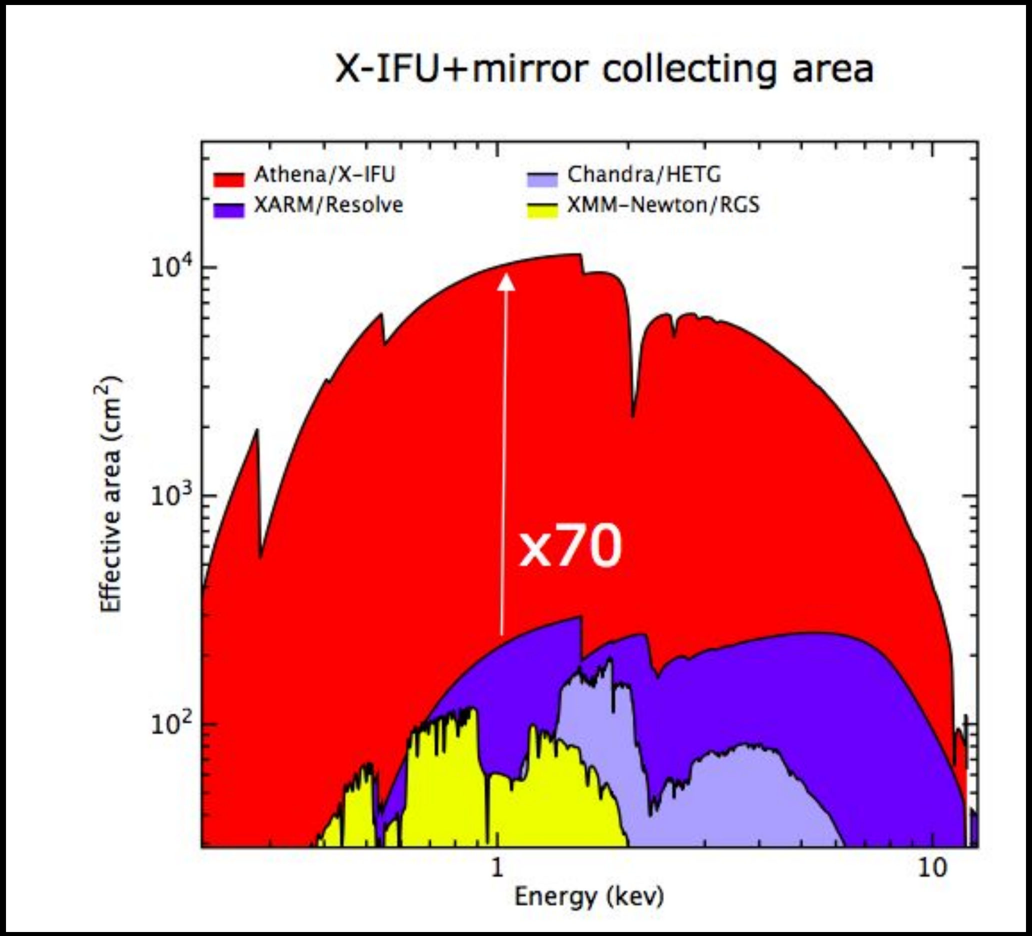


Wide Field Imager:
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

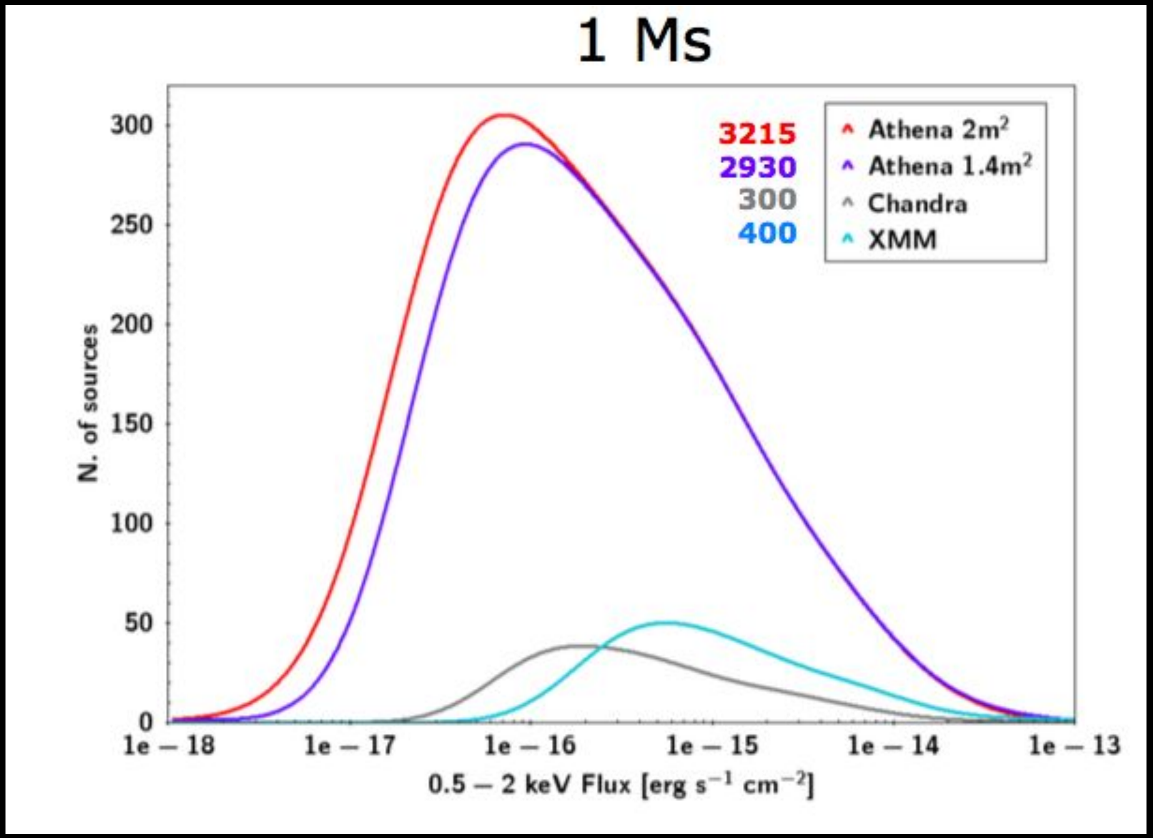
Rau et al. 2013 arXiv1307.1709

The first Deep Universe X-ray Observatory

Athena has vastly improved capabilities compared to current or planned facilities, and will impact on virtually all areas of astrophysics

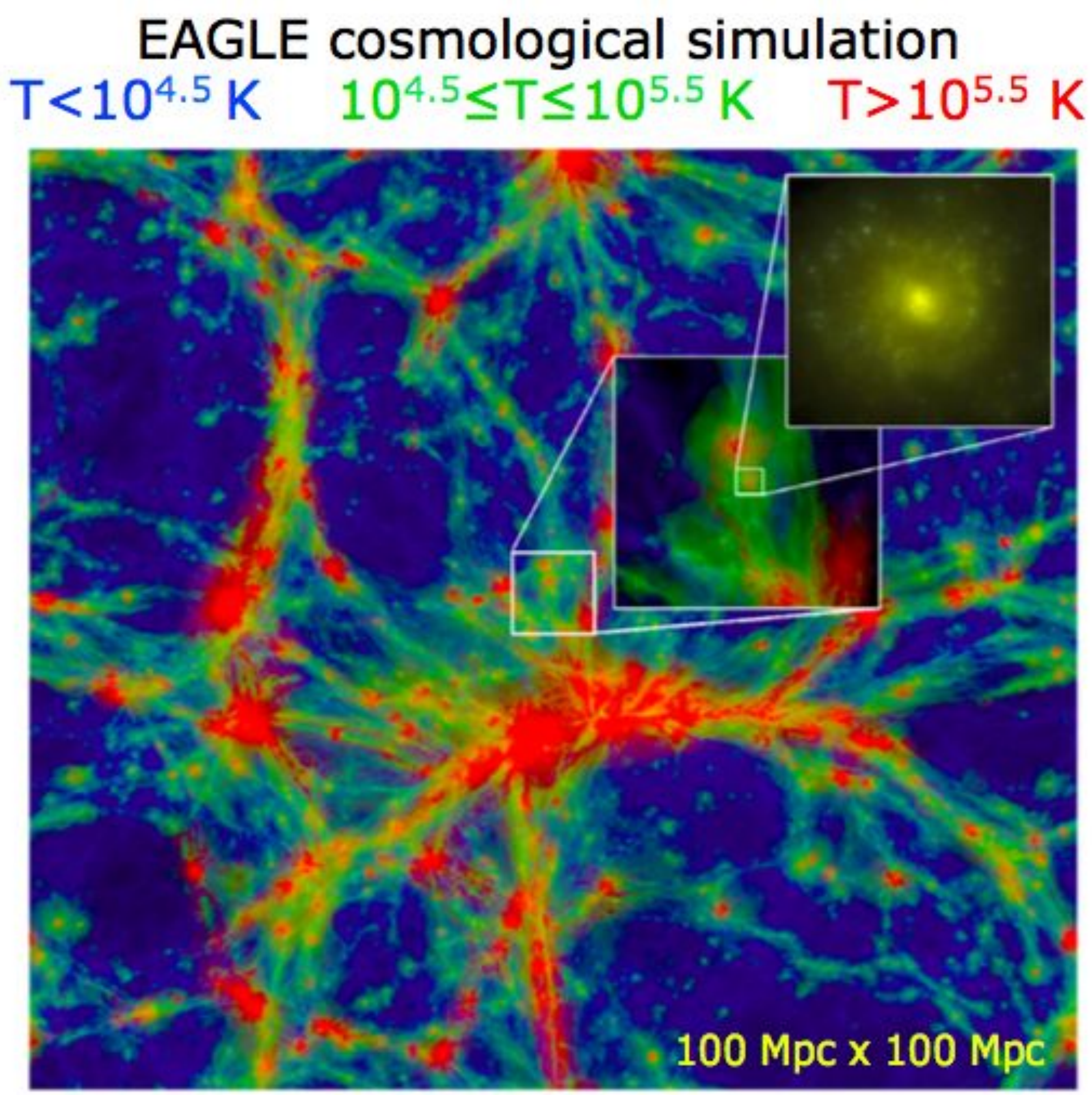


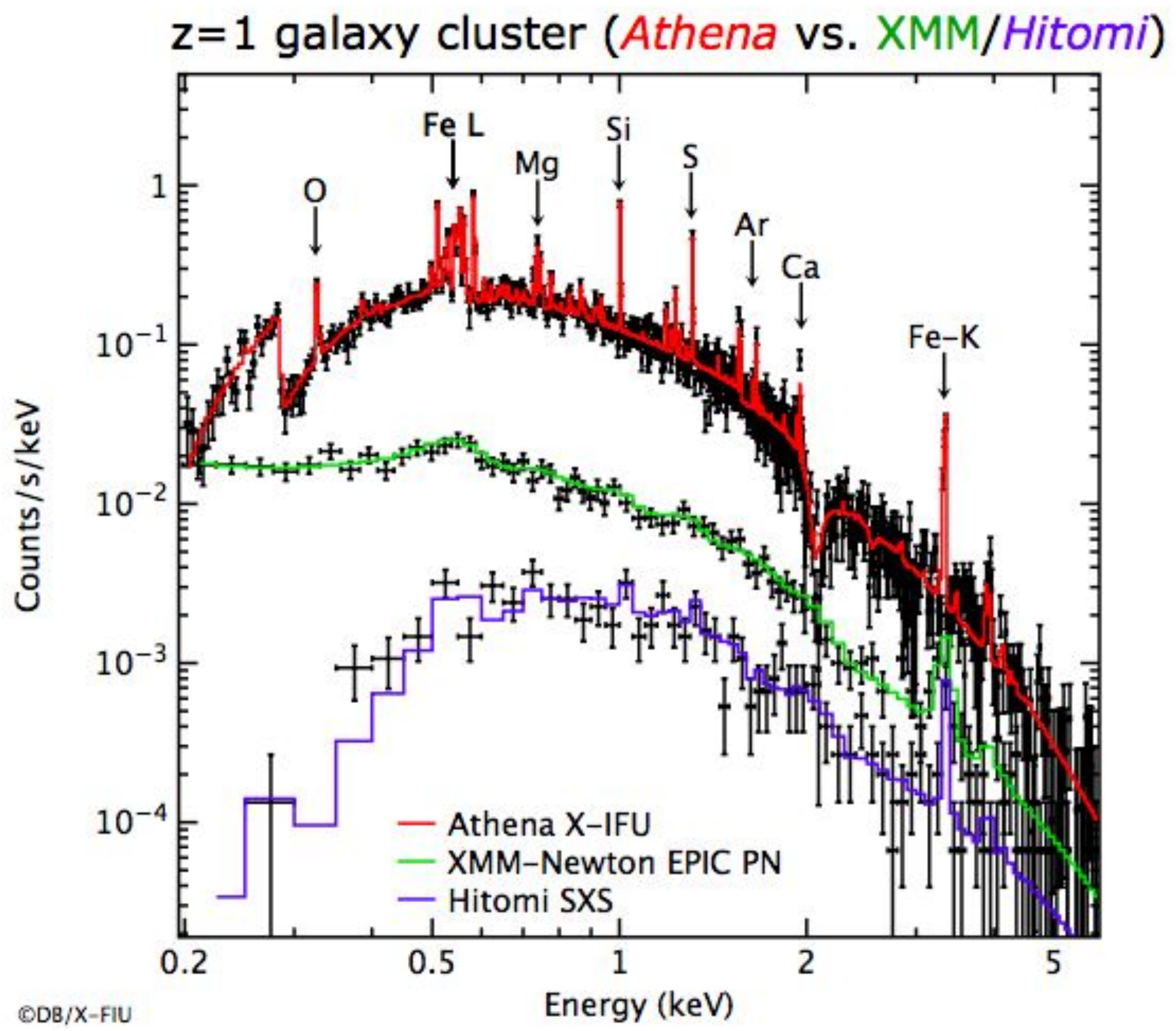
X-ray spectroscopy at the peak of the activity of the Universe



Deep survey capability into the dark ages and epoch of reionization

The chemical evolution of hot baryons

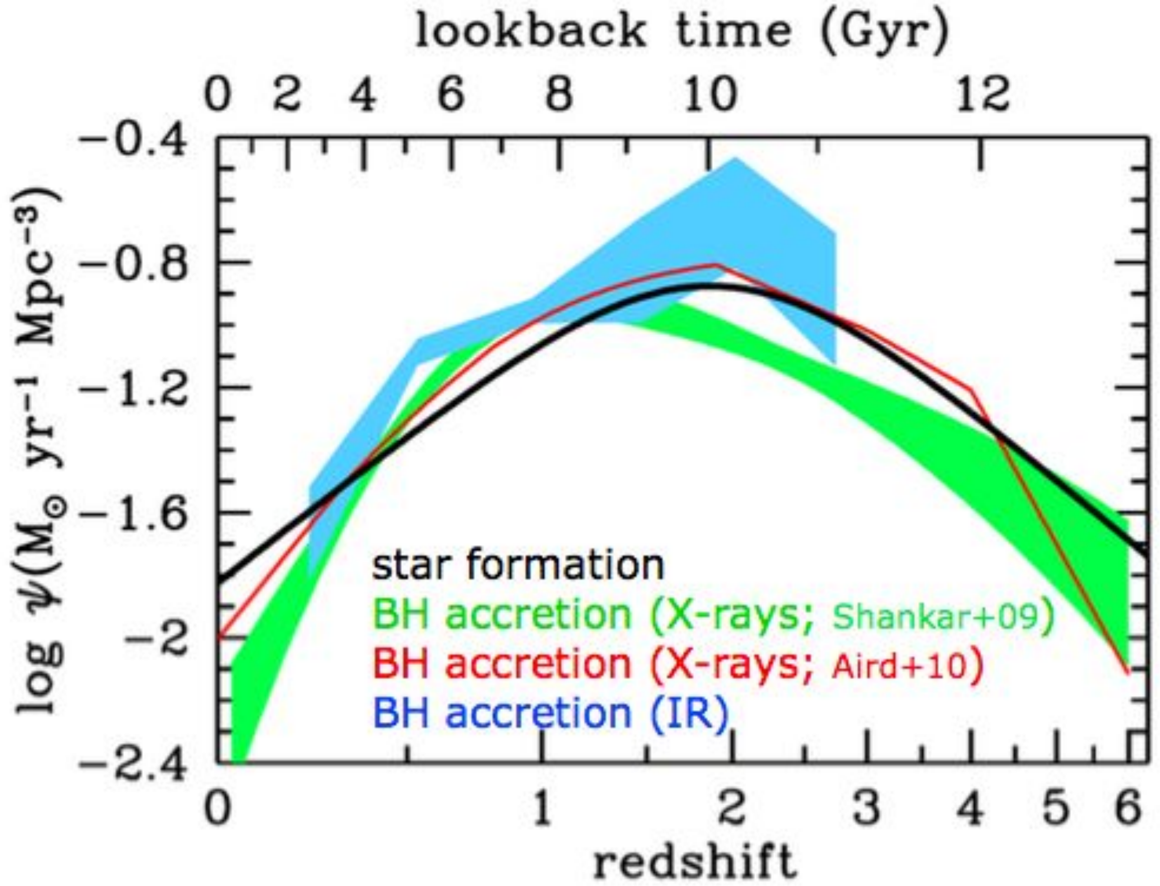




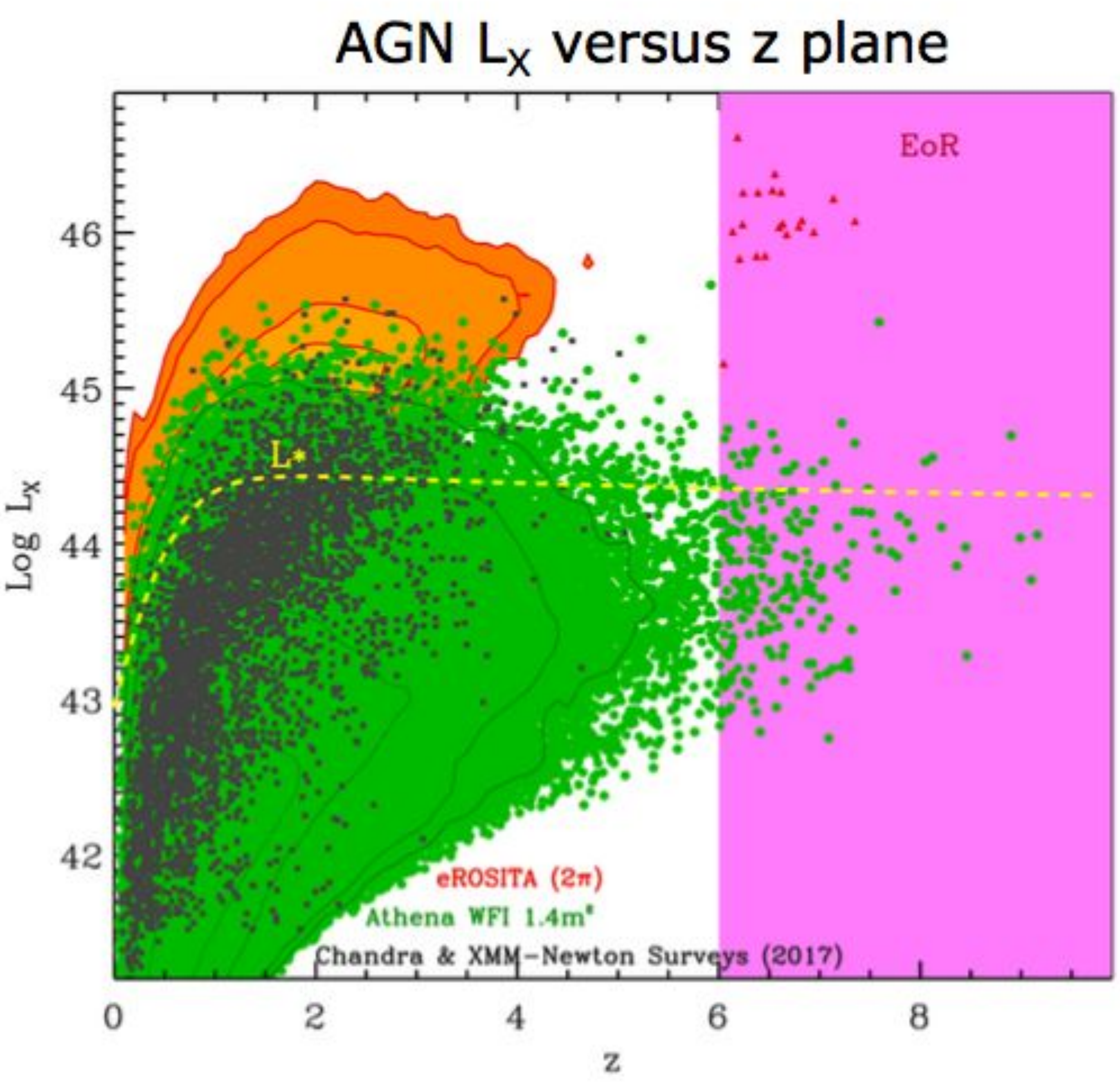
Athena will trace the evolution of heavy elements from z~2 to the local Universe

How does ordinary matter assemble into the large-scale structures that we see today?

The Energetic Universe

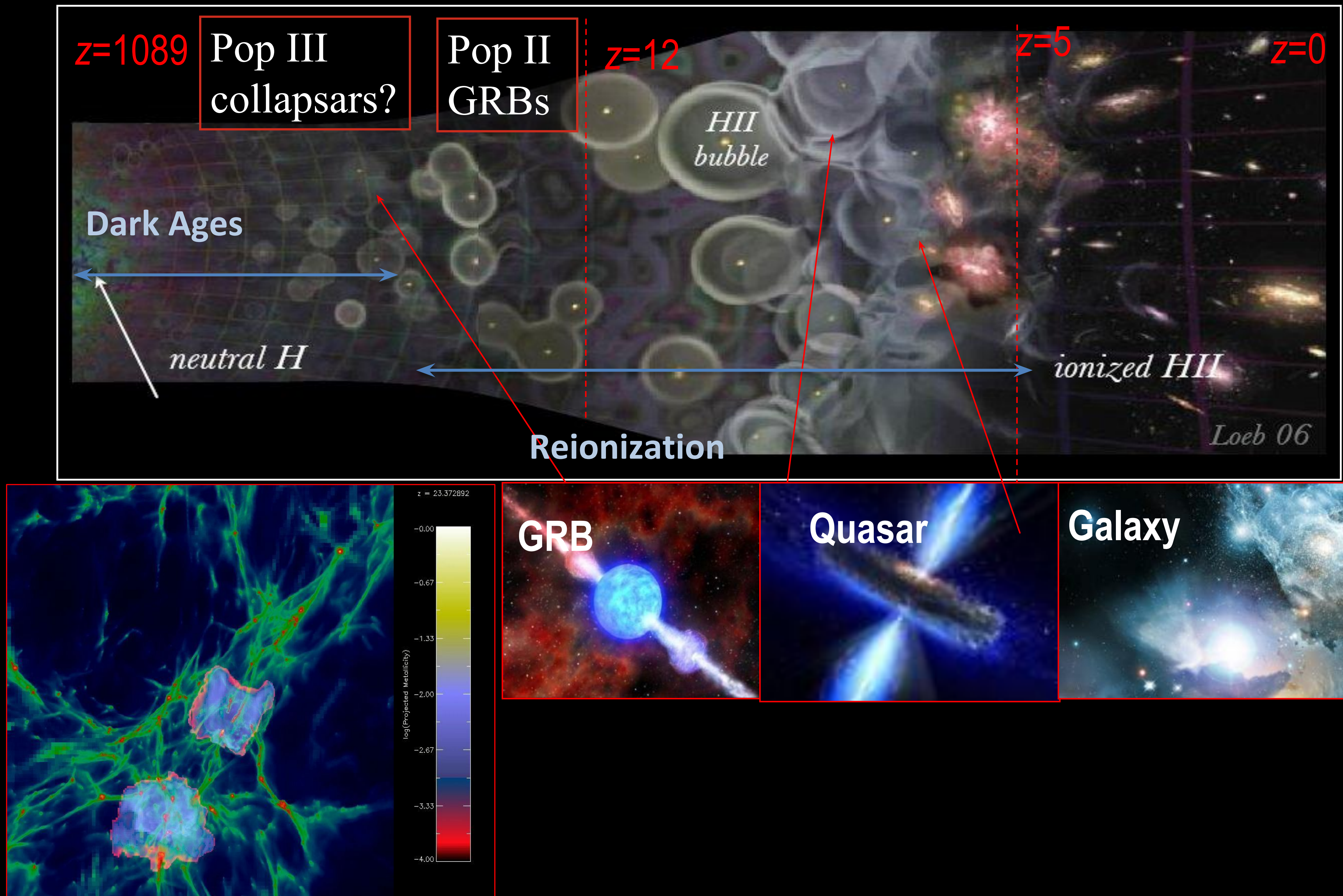


The cosmological history of black hole accretion is **uncertain** at z>3, **unknown** at z>6



ATHENA

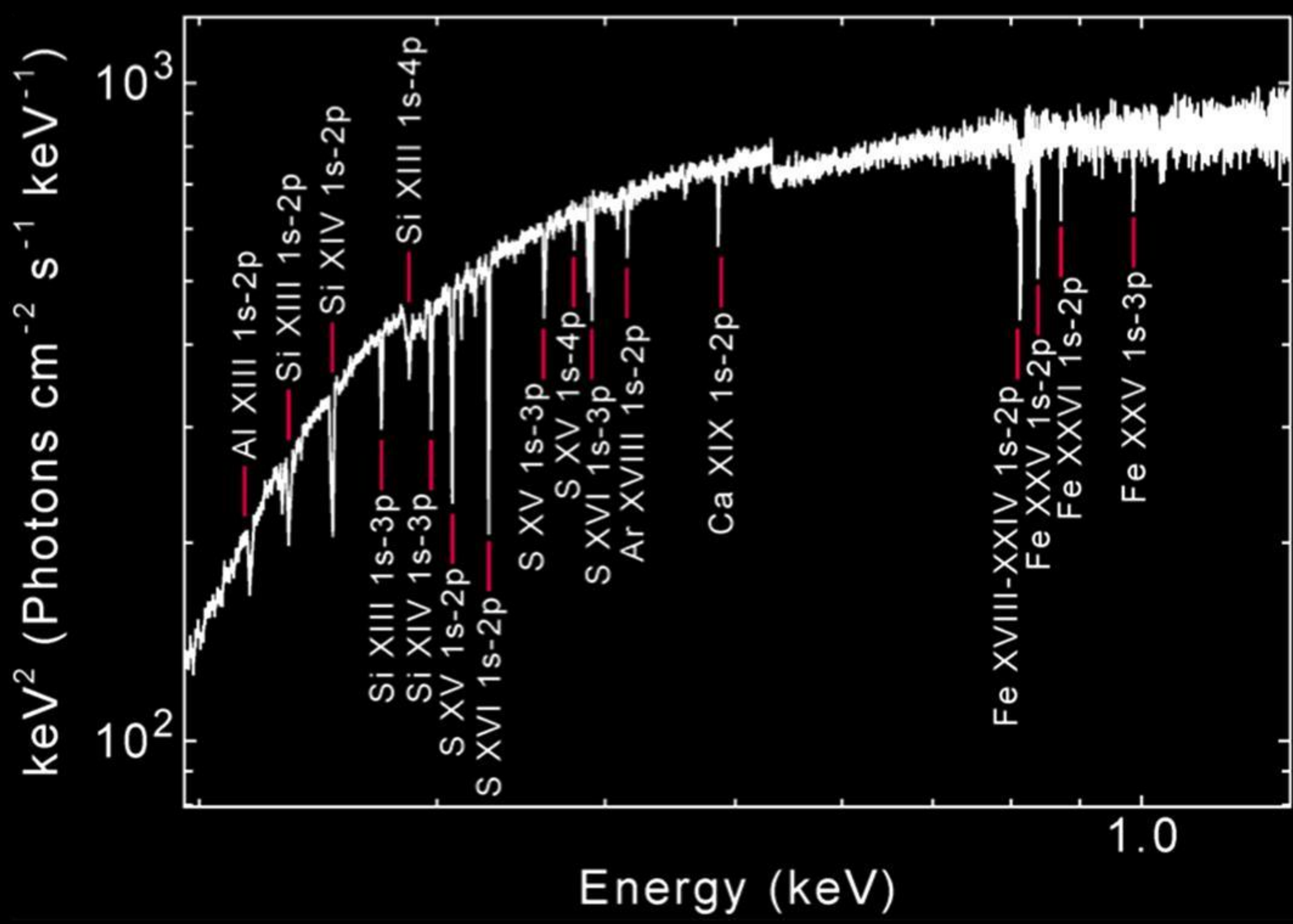
The first stars, the first BH, the first metals

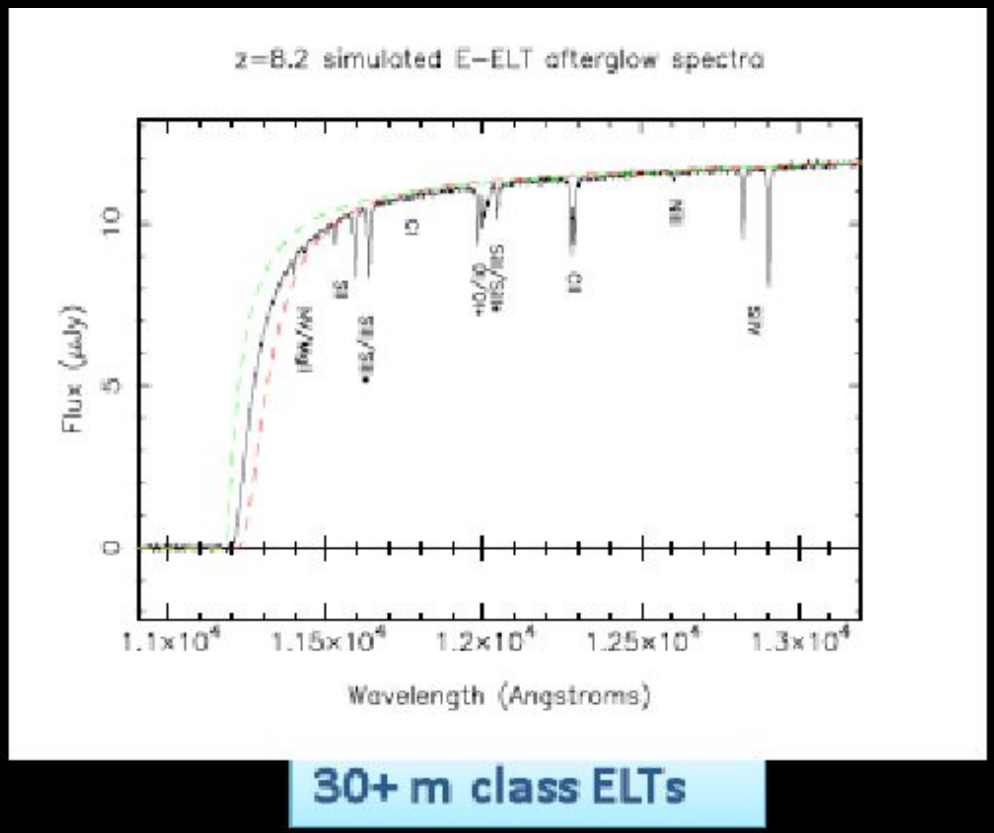


High-Z GRBs: The first stars and black holes

When did the first generation of stars explode to form the first seed black holes and disseminate the first metals in the Universe?

Gamma Ray Burst at z=7





Jonker, O'Brien et al., 2013 arXiv1306.2336

Athena science in context

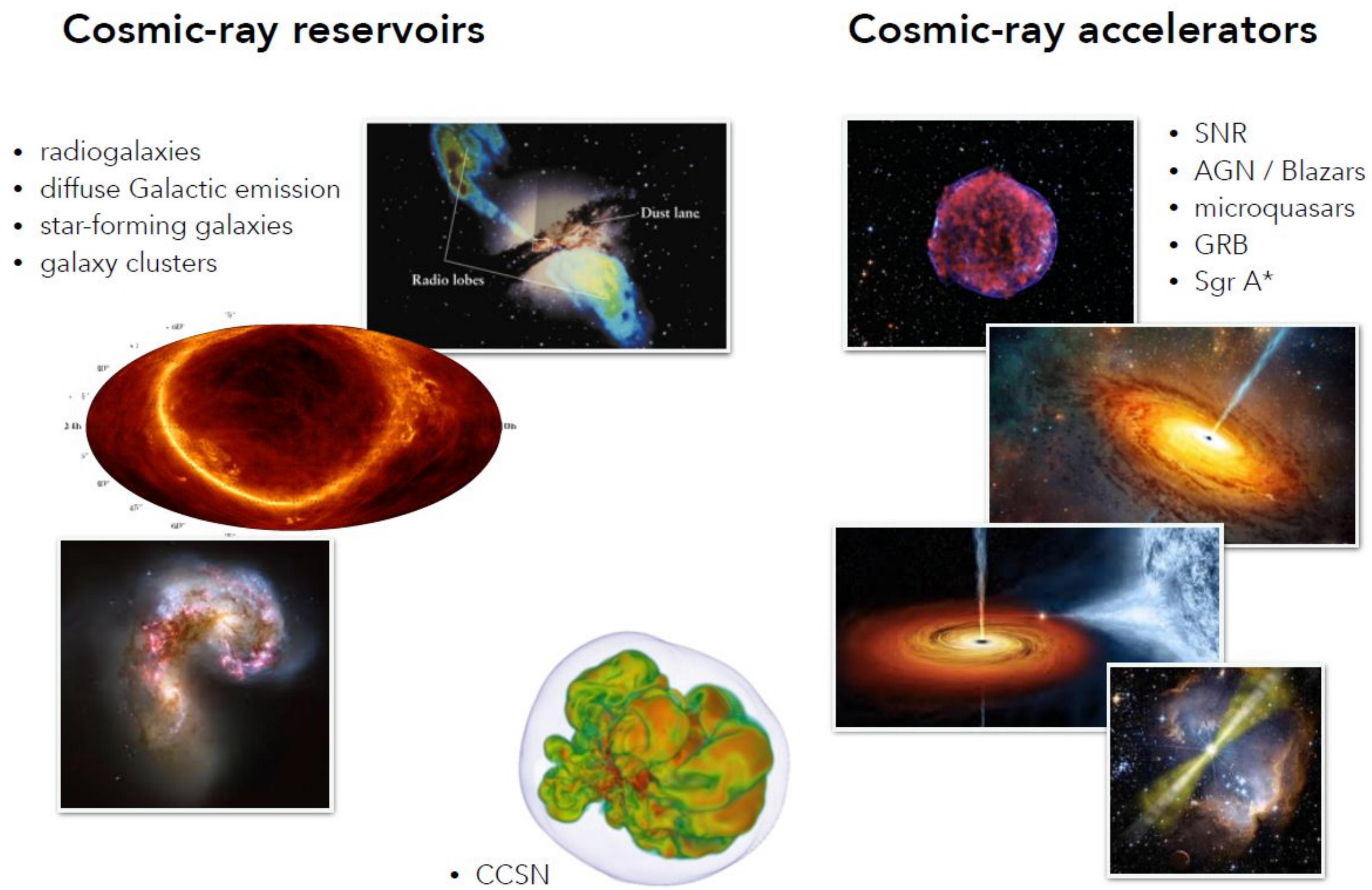
Athena is a crucial part of the suite of large observatories needed to reach the science objectives of astronomy in the coming decades

Athena as a multimessenger tool

- Energetic phenomena => explosions, accelerations sites, transients
- Athena X-rays probe the above with the following assets
  - fewer field sources (per sq degree) compared to lower frequencies
  - Wide field (40 arcmin) (+mosaic/raster scan covering several sq degrees in few hours)
  - arcsec imaging (location accuracy 1arcsec)
  - sensitivity down to few 10^{-17} erg/cm2/s
  - Integral field spectroscopy with high spectral resolution (R=1000@2.5keV)
  - Fast Too (4hrs) , large FoR(>50%)

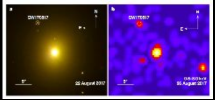
Athena and CTA synergies

- Overaching theme: Cosmic Accelerators, Cosmic Ray Researvoir
  - – Sources of CR’s
  - – Hadronic vs Leptonic
- Sources:
  - Blazars
  - SNR
  - Sne (ν’s from CC)
  - Magnetars
  - TDE
  - PWN
  - GRBs
  - Clusters as CR reservoirs



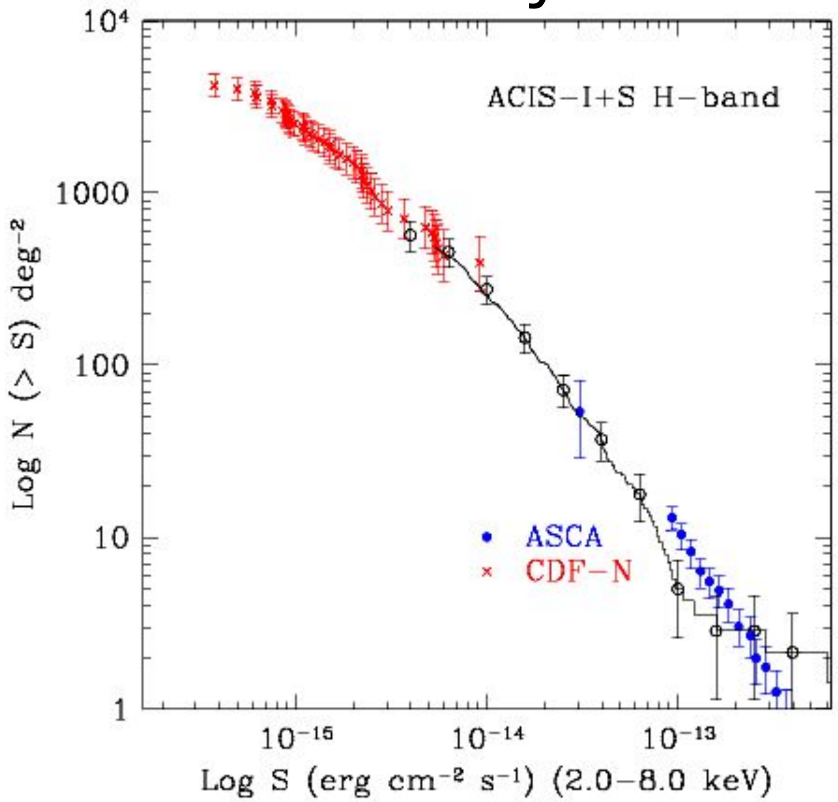
CTA (and ν's) benefit of Athena/X-ray observations

- Source identification
- Determine what the radiation mechanism is:
  - pion decay (hadronic) → need local density estimate
  - Proton sync (hadronic) vs IC (leptonic)
  - inverse Compton (leptonic) → need local radiation field and B-field (synchrotron) Lsyn/LIC ≈ UB/Urad
  - bremsstrahlung (leptonic) → need local density estimate + B-field (synchrotron)
- Determine how particles are accelerated:
  - First order Fermi acceleration (shocks)
  - → study in detail in radio,optical, X-rays (measure vs, kT (line broadening) and get acceleration efficiency;
  - Second order Fermi acceleration (turbulence) → line broadening

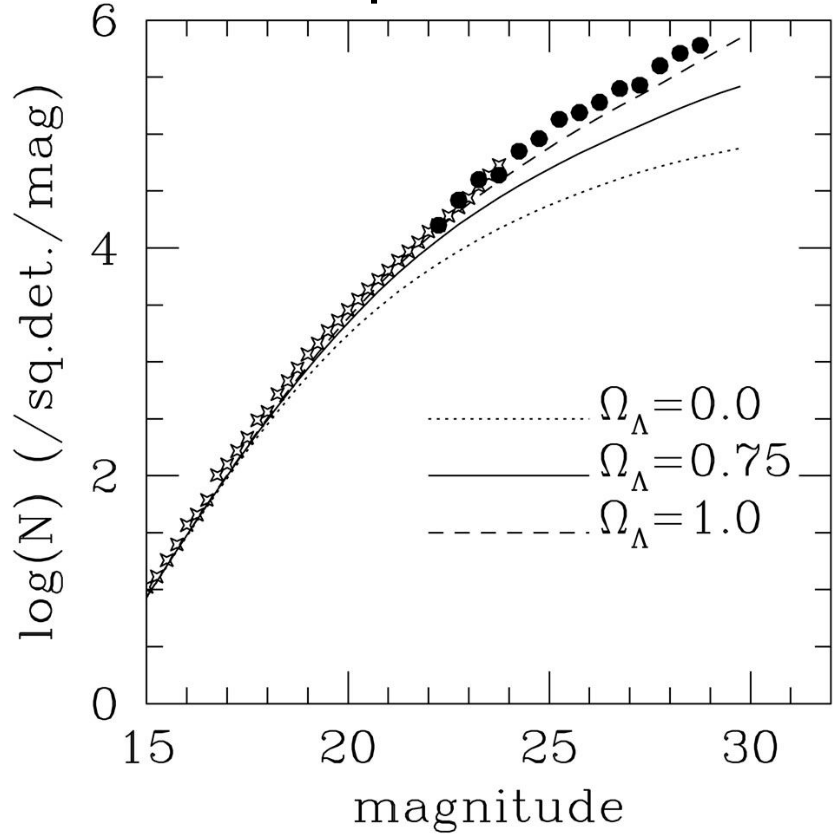


Number of field sources

X-rays

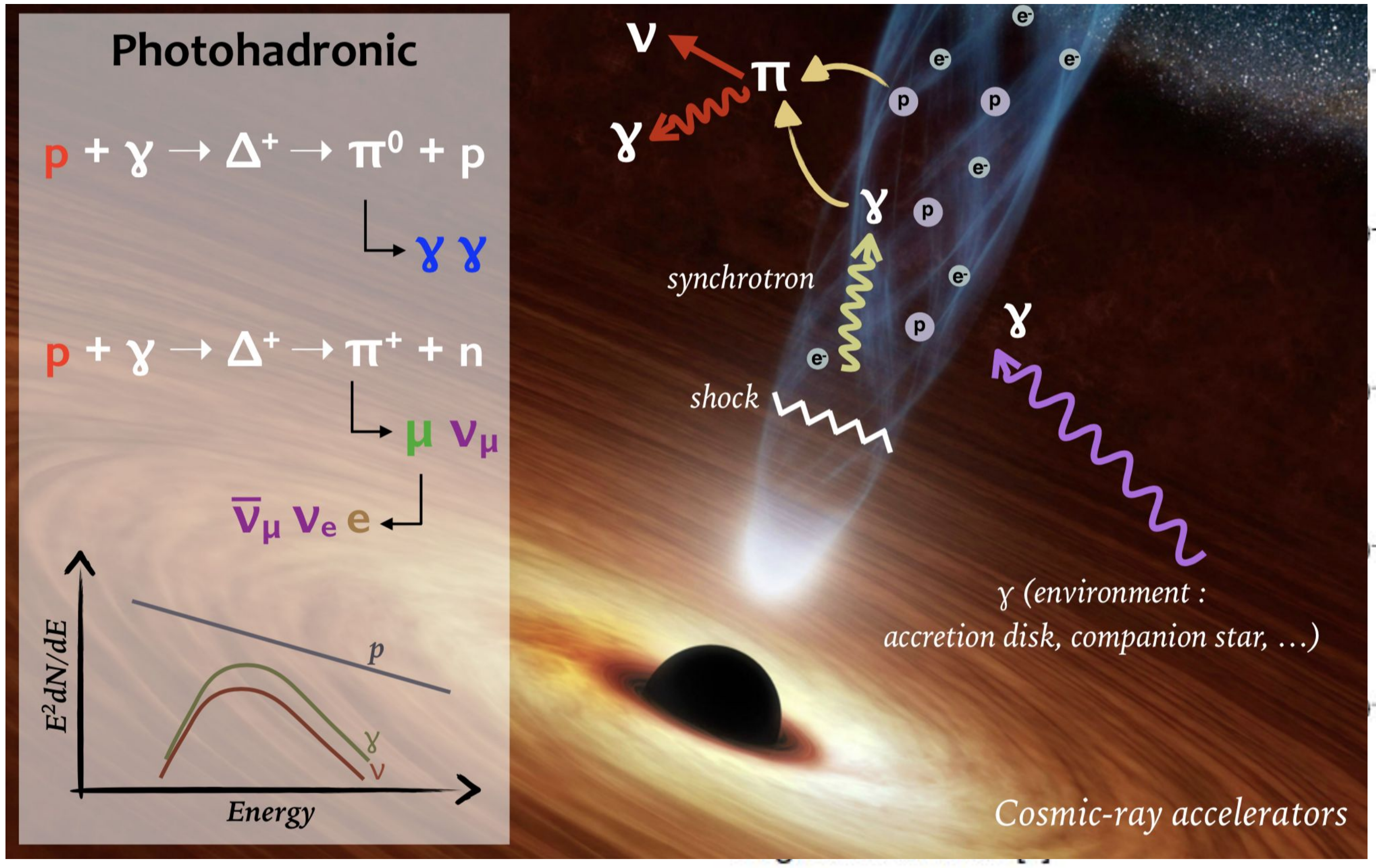


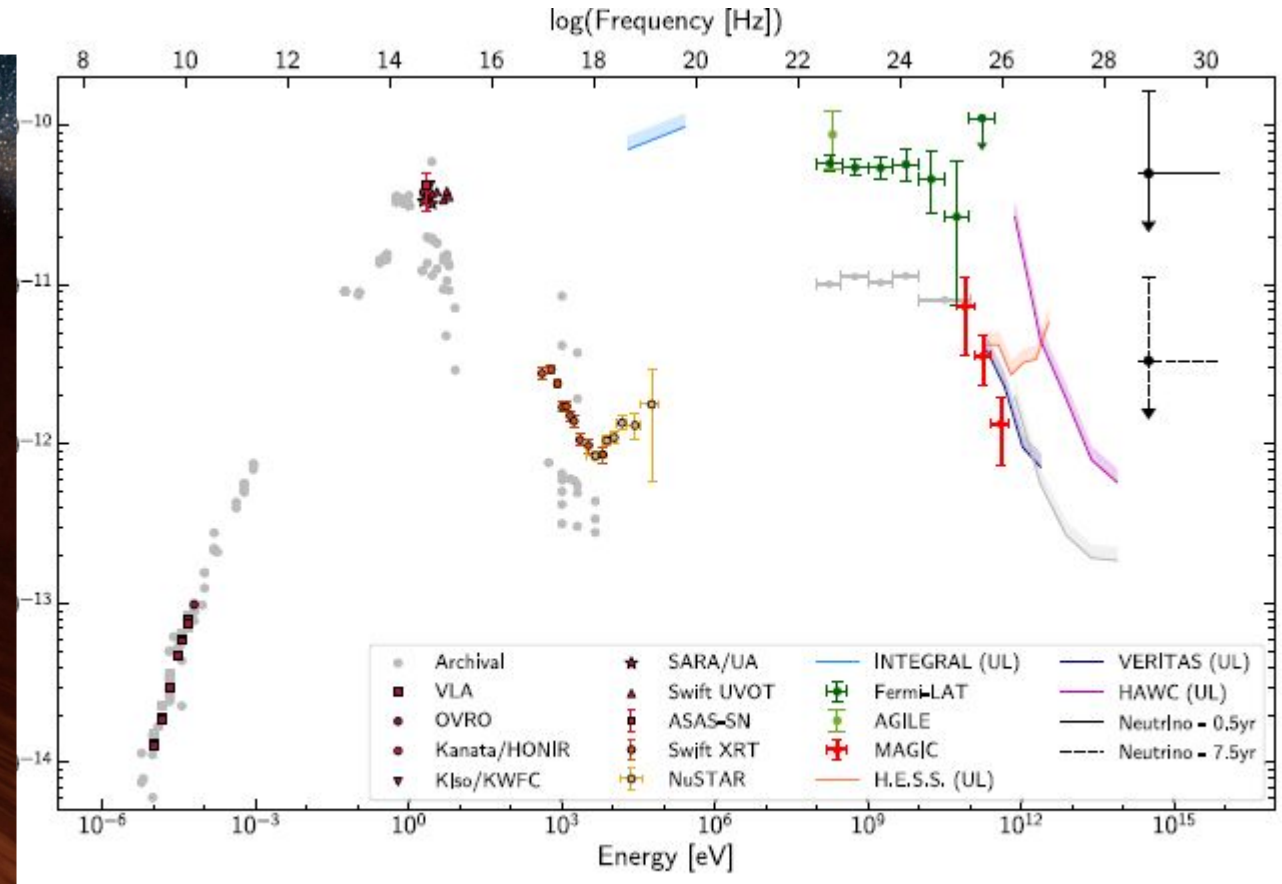
Optical



- α_{ox}=1.3 (AGN-like)
- m=26.7-2.5 log ($F_X/10^{-16}$)
- m(Fx=10^{-15} c.g.s.)=24.2:
- 3000 X-ray vs 100.000 in the optical per square degree

X-ray, VHE and ν's synergy



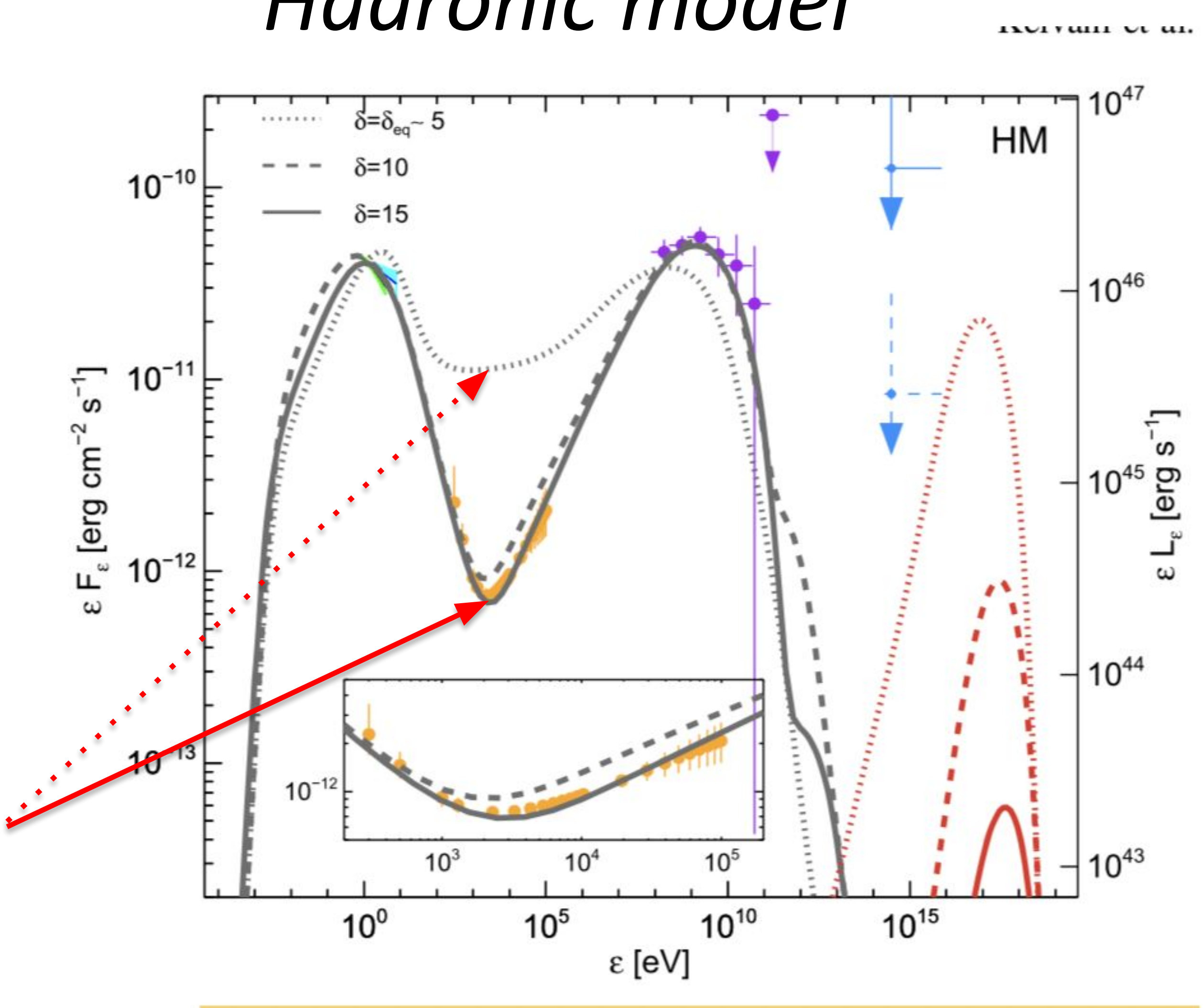


[Science 361 (2018) no.6398, eaat1378]

- IceCube ν's in TXS 0506+056 => hadronic origin
- Photon SED can be modelled with lepto-hadronic and proton-synchrotron models.
- Neutrino flux limited by theoretically feasible proton luminosity and X-ray data.
- Neutrino flares should be accompanied by broadband cascade emission in X-ray and γ-rays → X-ray observations critical to test hadronic emission

Blazar TXS 0506+056
X-ray, VHE and ν's synergy

Hadronic model

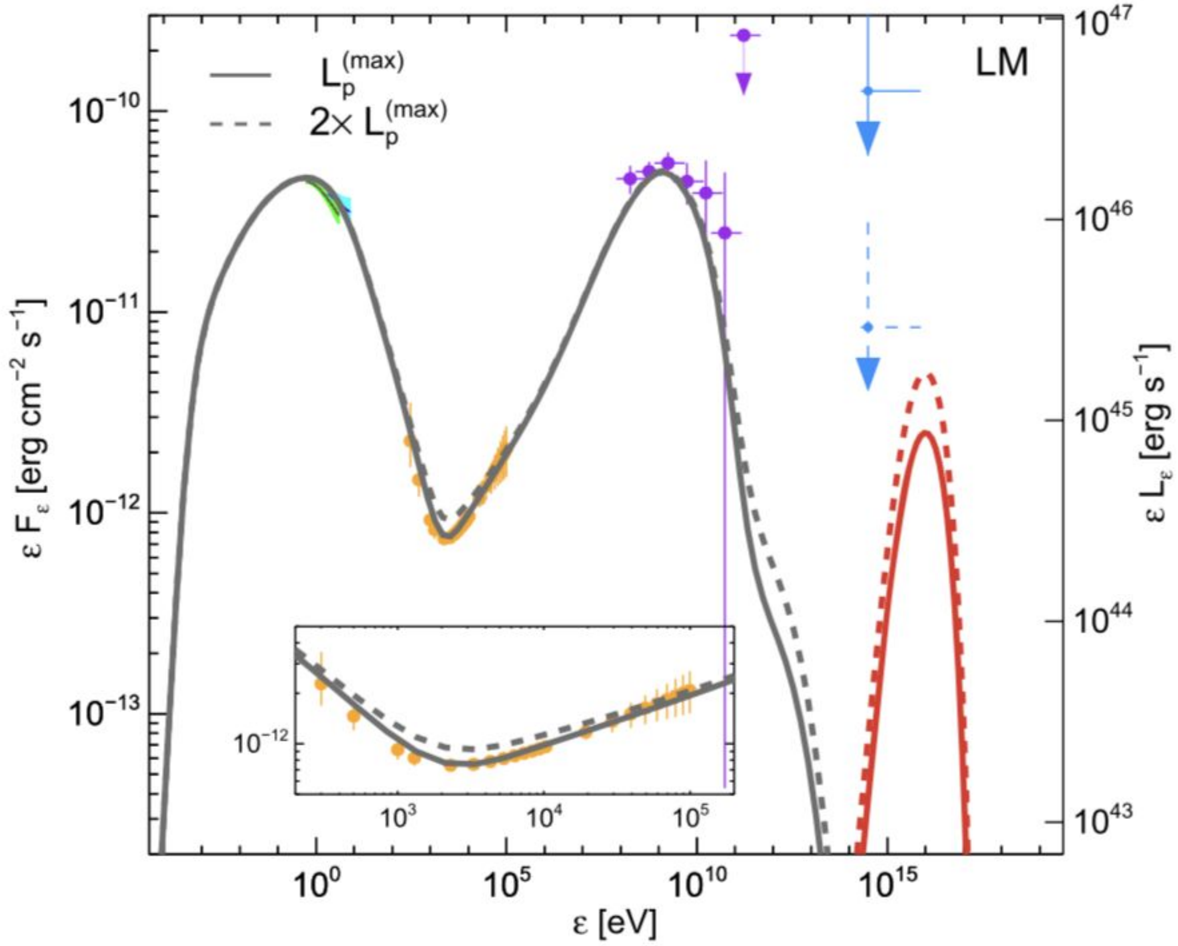


γ-ray -> X-ray cascade emission

Keivani et al 2018

Blazar TXS 0506+056
X-ray, VHE and ν's synergy

Leptonic model



Keivani et al 2018

SNR

- Ion temperature + shock velocity measurements of SNRs with Athena: used to quantify SNR ability to accelerate cosmic rays
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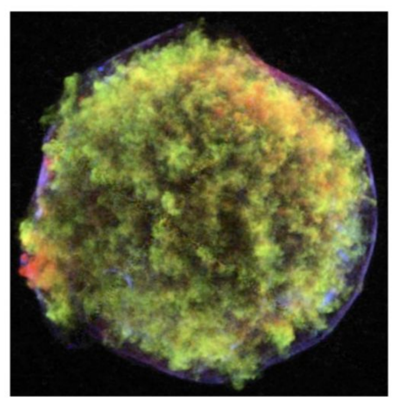
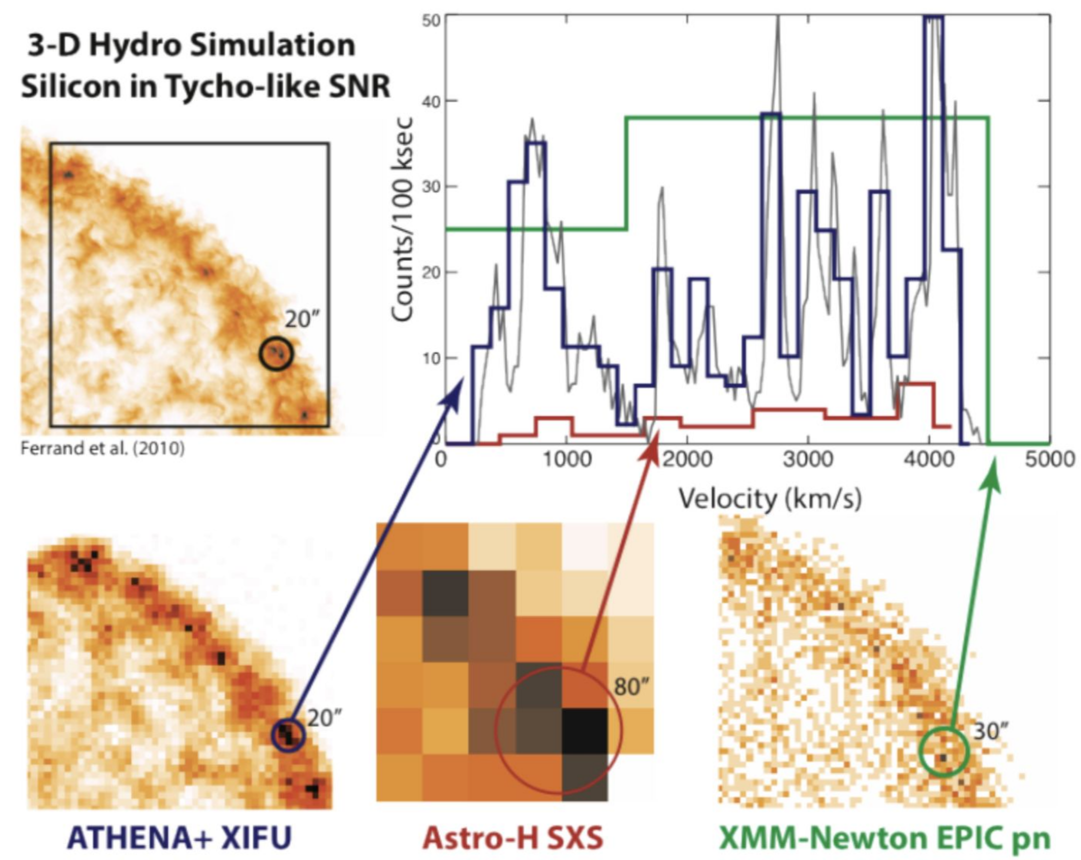
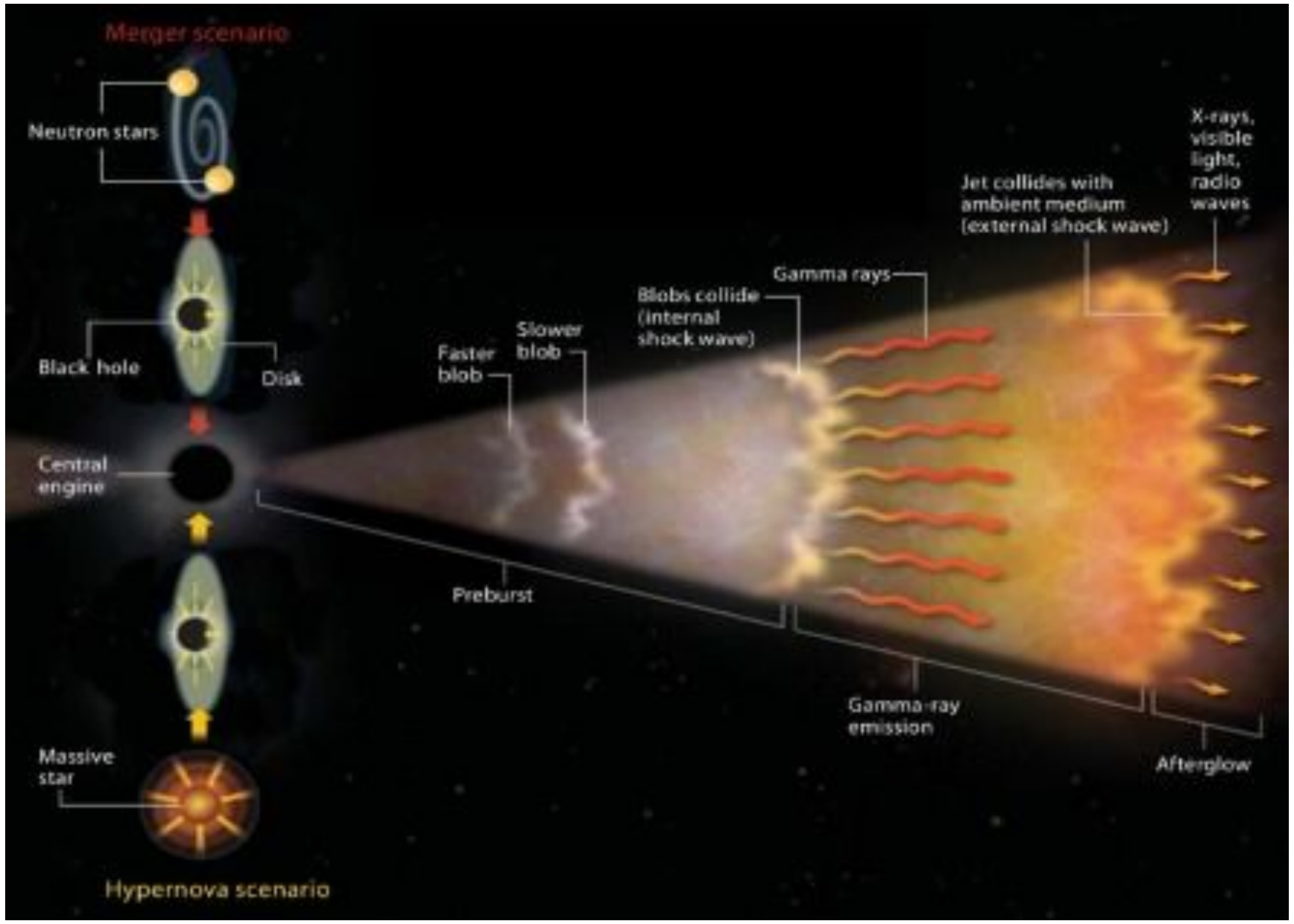




Athena XIFU simulations Decourchelle et al 2013

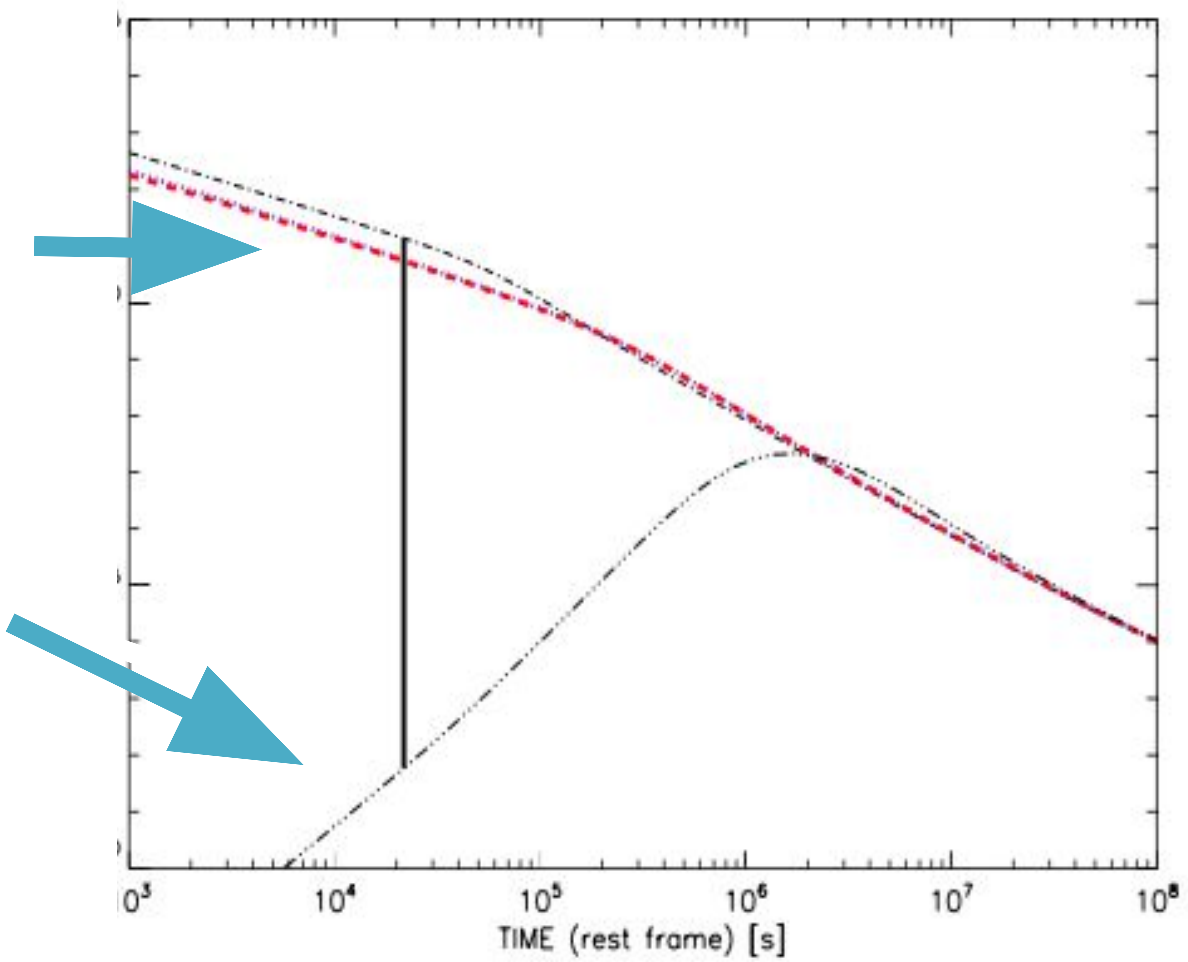
Relativistic jets in GRBs

- Beaming angle ~ $1/\Gamma$



N. Gehrels, LP & P. Leonard 2004

$\theta_V \sim 30$ deg

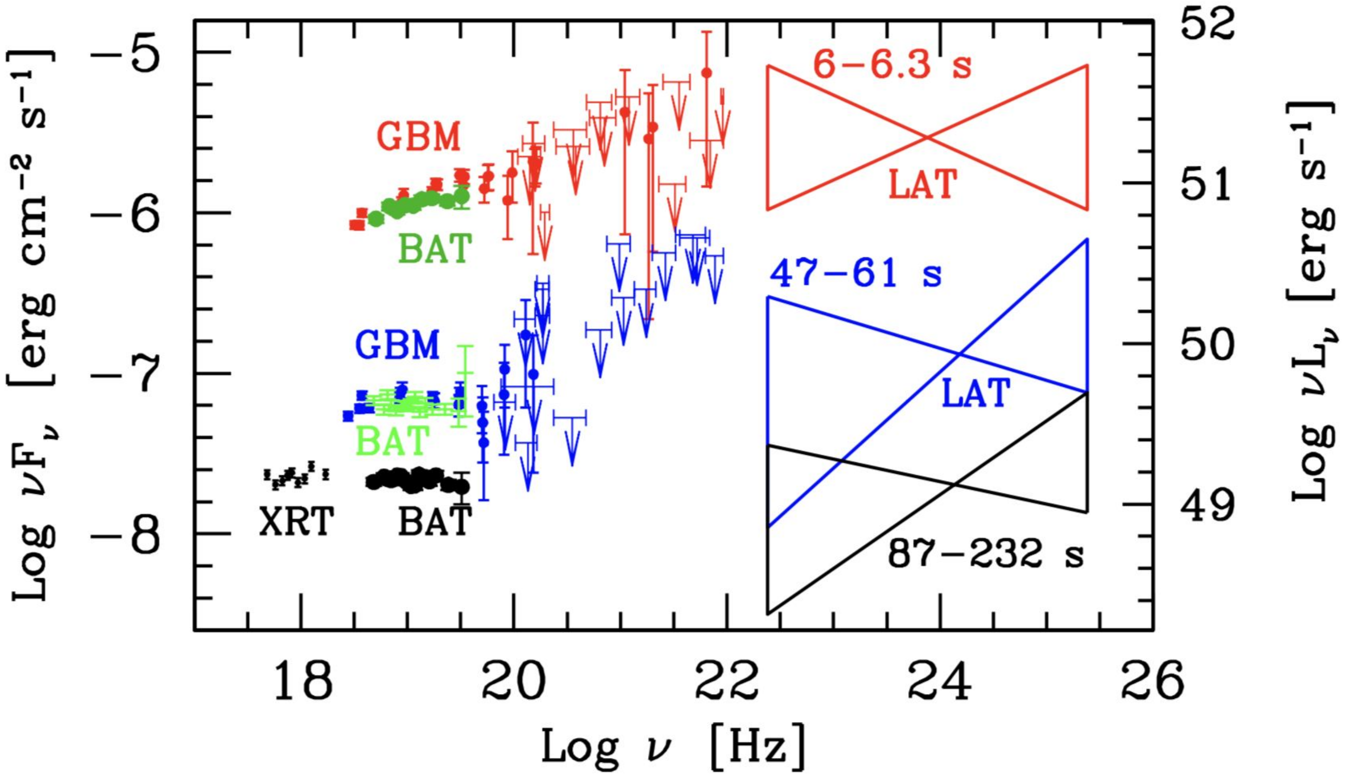


D'Alessio, LP & Rossi 2006

GRB190114C: the First VHE detection

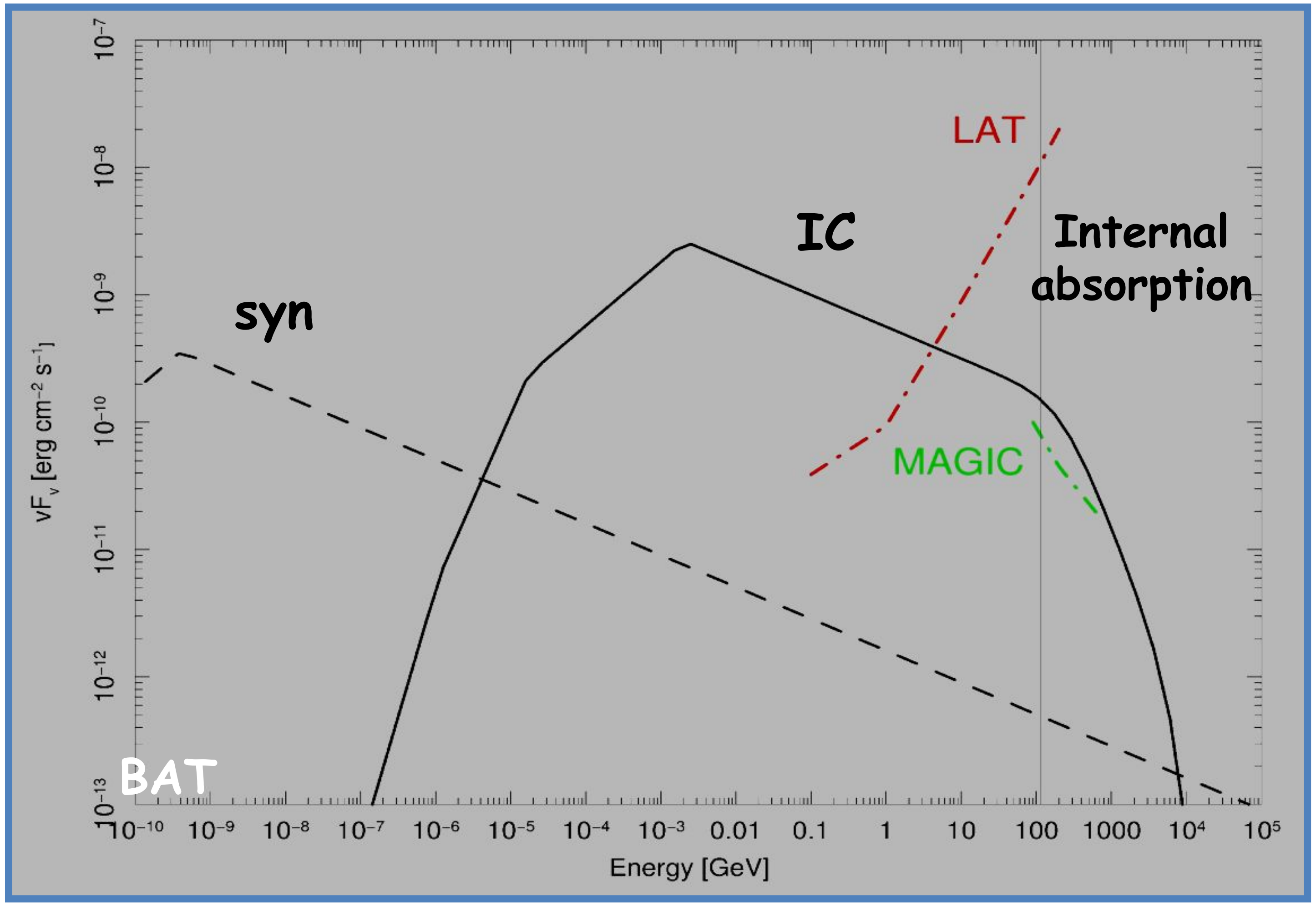
- MAGIC detection at ~50-100 sec at 300 GeV (Myrzoyan+19)
- Max Synchrotron energy (Acceleration scale/Larmor=radiation losses)= $m_e c^2/a_F$= 70 MeV
- => IC component

Ravasio et al 19, see also Wang et al 19)



VHE predictions for the afterglow phase

MAGIC can detect HE emission from the afterglow of a GRB



T=10 ksec

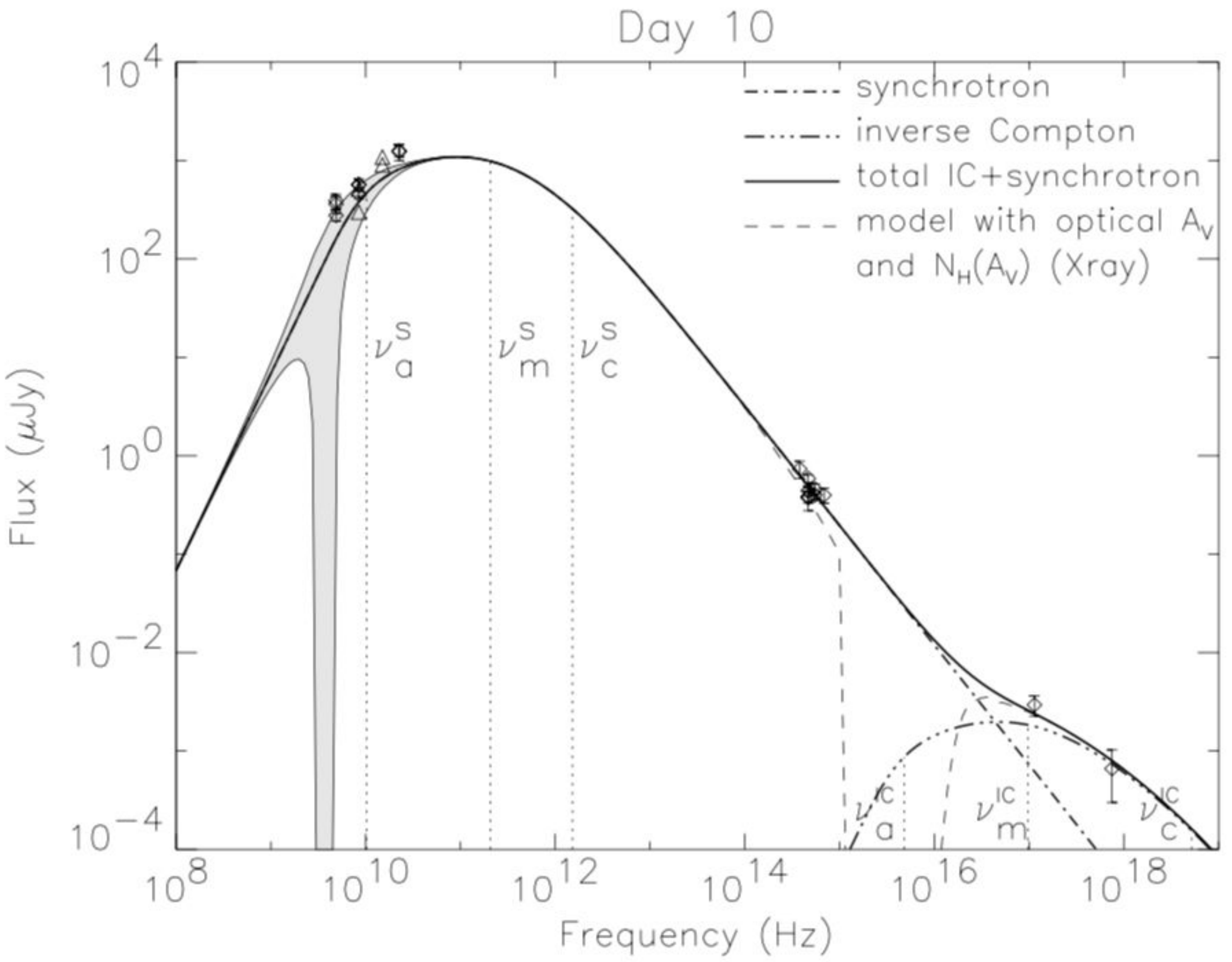
$E_{53}=0.1, n=300, \varepsilon_e=0.2, \varepsilon_B=10^{-3}, p=2.5, z=0.1$

Galli&Piro (2008)

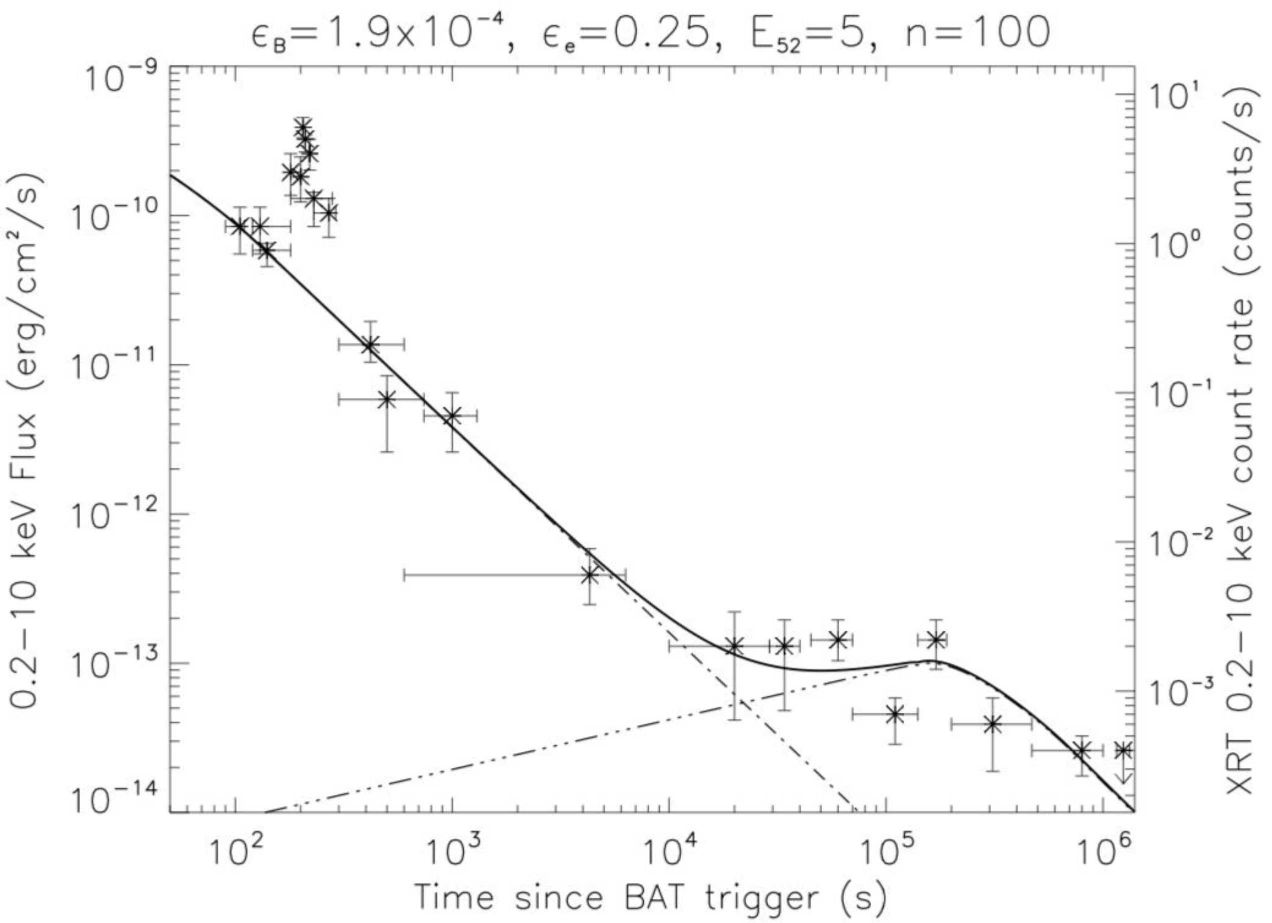
From LP presentation at CTA workshop in Bologna 2011

Evidence for IC emission

- Mostly from X-rays and hard X-rays



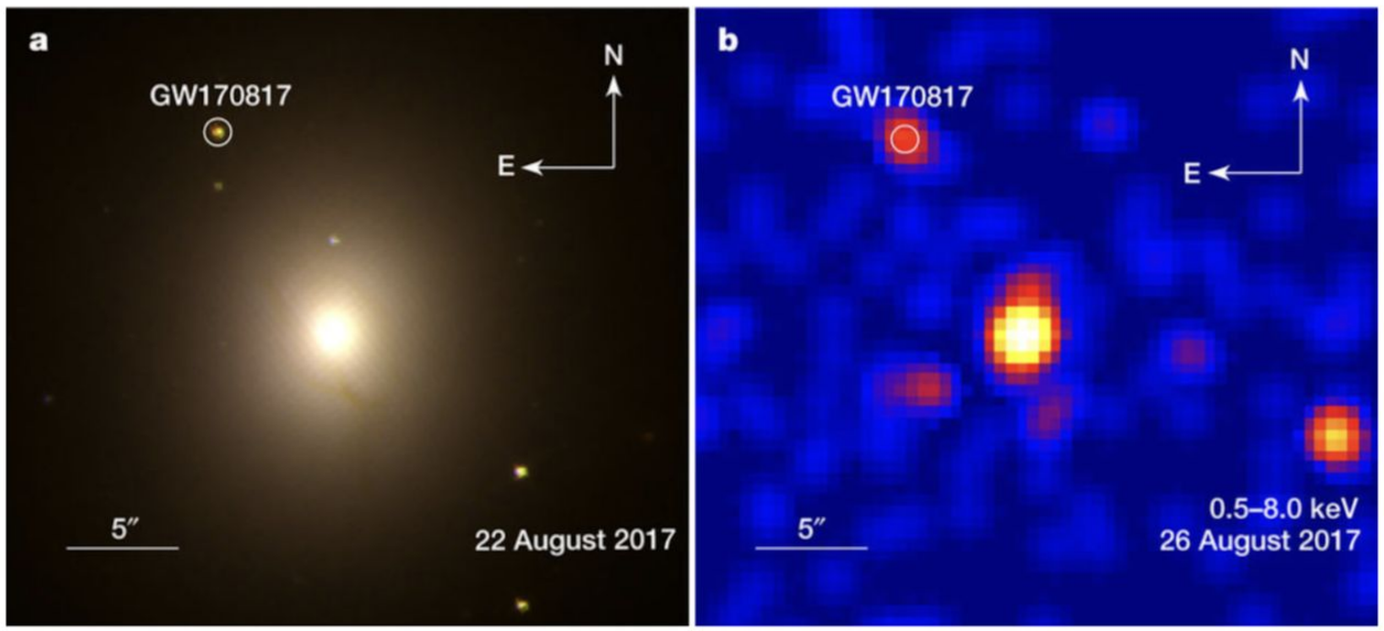
Harrison + 2001



Corsi & LP 2006

X-ray counterparts of GW mergers

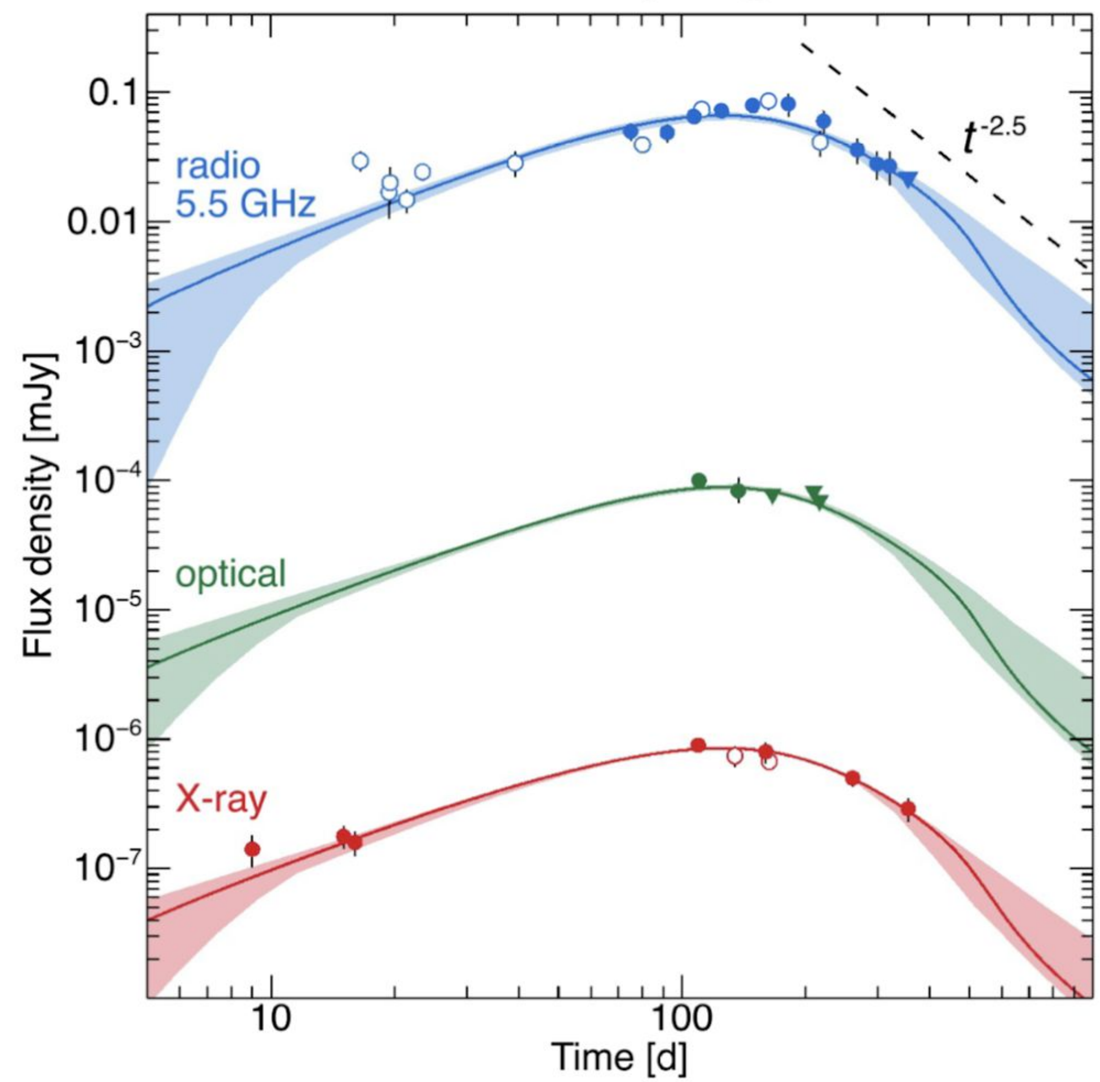
GW170817 EM counterpart



HST Chandra

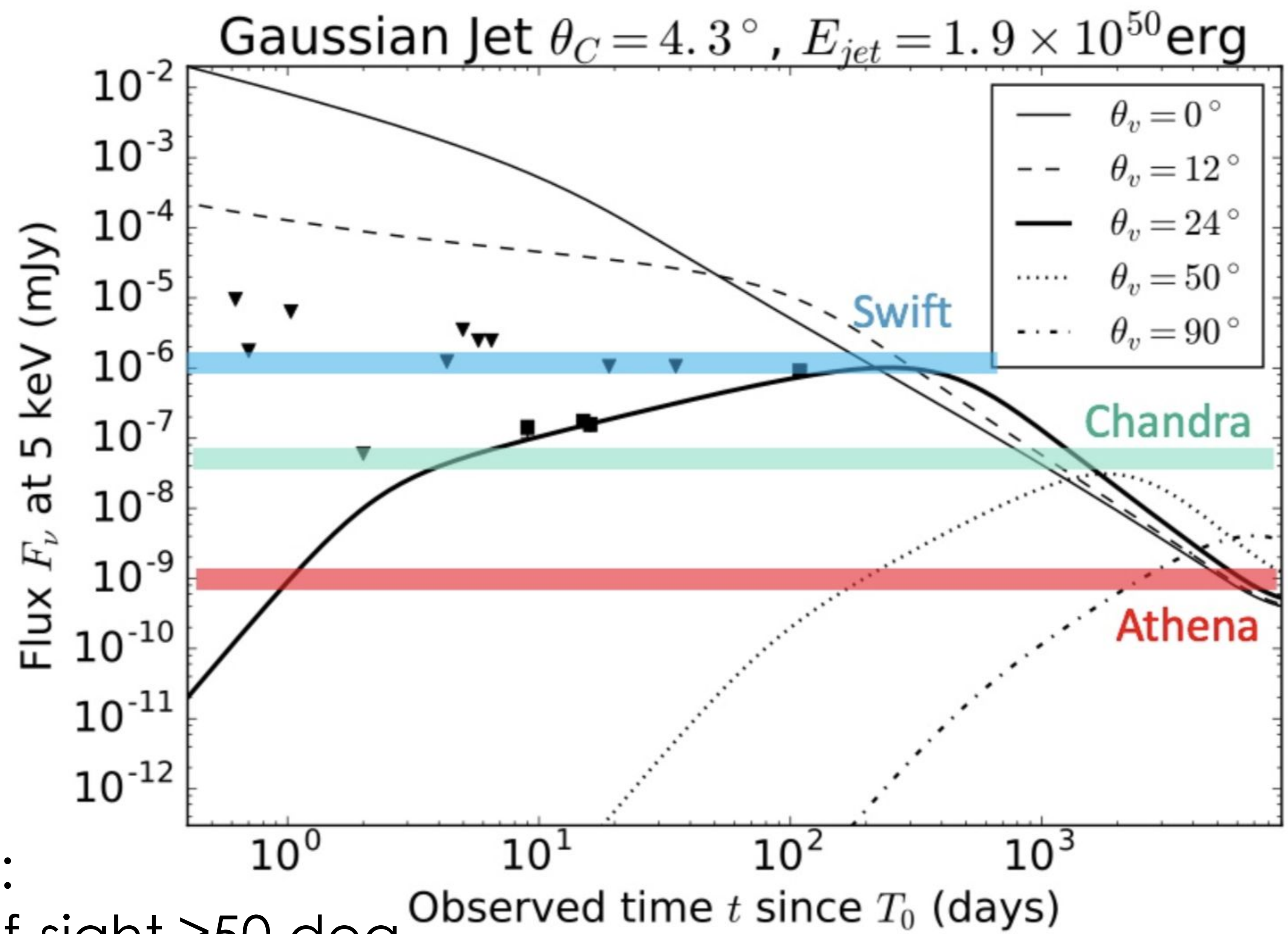
Discovery image of GW170817 Left HST, right Chandra

Radio and X-ray light curves



Troja, LP et al, Nature 2017

X-ray counterparts of GWs
Athena will see them all



Athena needed:

- for any line-of-sight ≥50 deg
- to sample the most distant
- counterparts sampled by GW facilities

Conclusions

- X-rays providing crucial information to pin down origin of VHE emission
- Synergy of Athena with CTA, ν's facilities (Icecube, KM3net), GWs (ALIGO,AVIRGO,+, LISA) and Transient Universe (Theseus)
- Athena Multimessenger and HE synergy White Paper, supported by AHEAD (H2020), in preparation