A deep *Chandra* observation of the interacting star-forming galaxy Arp299

Konstantina Anastasopoulou[1,2]

A. Zezas[1,2], R. Della Ceca[3], L. Ballo[3]

(1) University of Crete, Department of Physics, Heraklion 71003, Greece
(2) Foundation for Research and Technology - Hellas (FORTH), Heraklion 71003, Greece
(3) INAF-Osservatorio Astronomico di Brera, via Brera 28, I-20121 Milano, Italy

Introduction

- X-ray emission from galaxies is key for understanding compact object populations, accreting X-ray binaries, ULXs
- High star-formation rate galaxies often host large populations of ULXs → useful for studying the scaling relations of ULXs with galaxy parameters
- Information on the X-ray emission of high-z star-forming galaxies.

NGC 2207 and IC 2163; image credit: X-ray – NASA / CXC / SAO / S.Mineo et al; optical – NASA / STScI; infrared: NASA / JPL-Caltech.

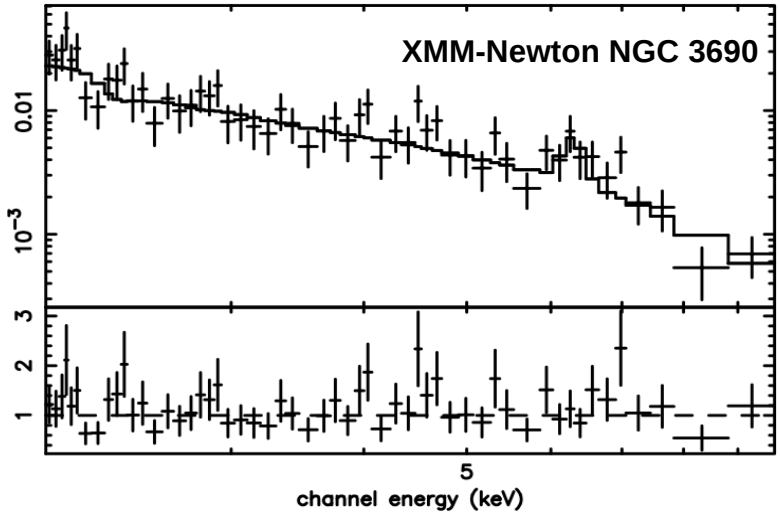
Why Arp 299?

- One of the most powerful starbursts in the local Universe, consists of two galaxies (NGC 3690, IC 694, Hibbard & Yun 1999) separated by 22".
- One of the nearest luminous merging system (44Mpc; Heckman et al 1999) belonging to the class of LIRGS ($L_{42\text{-}123\mu m}$=2.86x10^{11}Lsun).
- Remarkable similarity with high-z ULIRGs (star-forming activity, integrated mid-IR spectrum; Alonso-Herrero et al 2009).
- One of the largest population of ULXs observed in the local Universe. (Zezas et al. 2003)

Credit: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

Observations

- Short 24 ks Chandra observation → only a fraction of the overall ULX population (Zezas et al. 2003)
- BeppoSAX, XMM-Newton →important information on the nature of the nuclei (Della Ceca et al. 2002, Ballo et al. 2004)
- Chandra observed Arp 299 with the ACIS-S camera for a total of 90 ks.
  - 2 segments of 38 ks and 52 ks in 2013



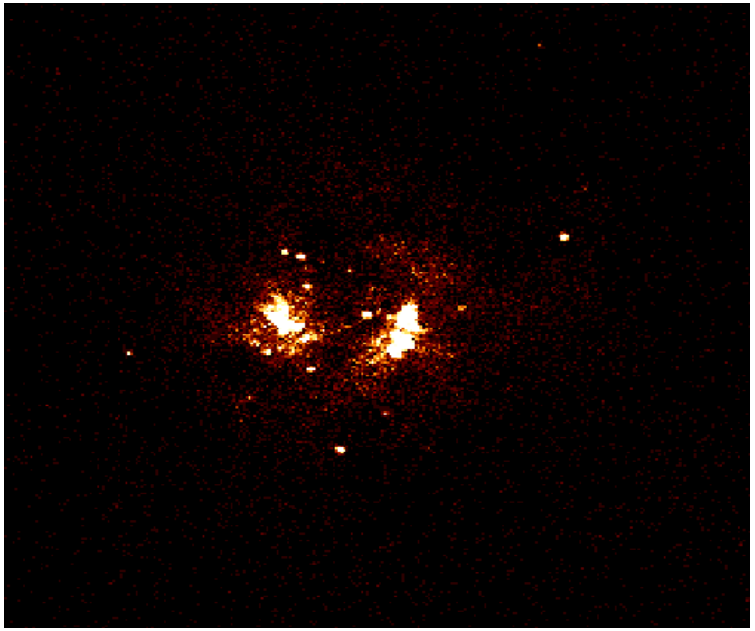
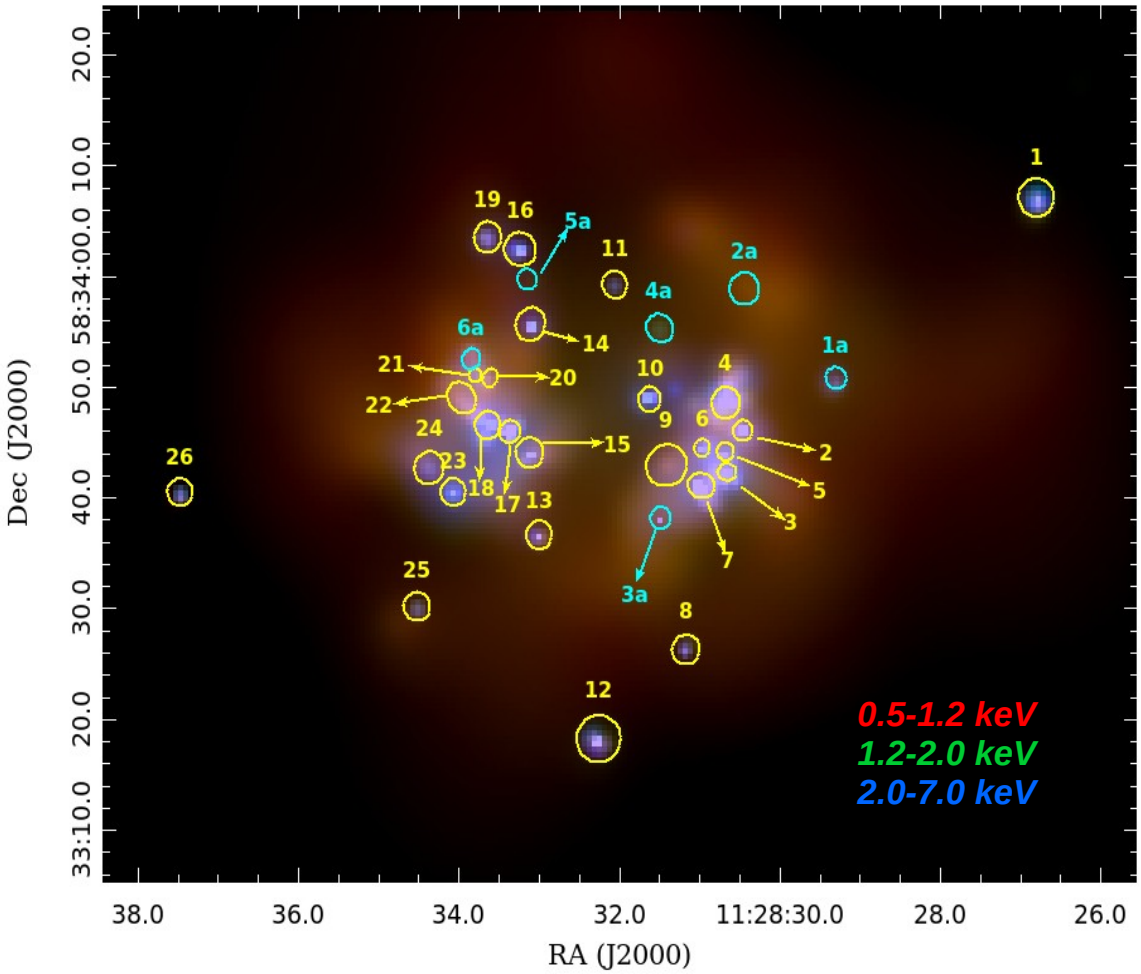


Image of Arp 299 of the 90ks merged observation in the broad band (0.5-7.0 keV).

Results

Source detection

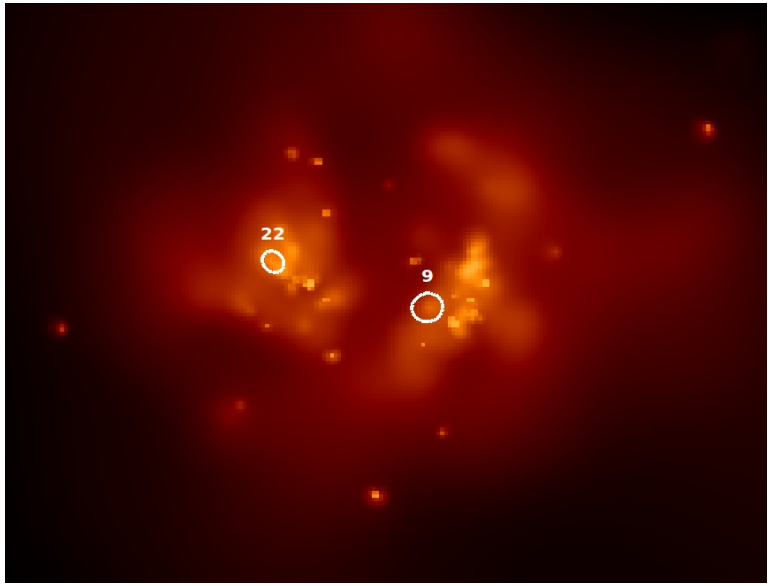
- 42 detections
- 26 discrete sources exceeding S/N = 3.0
- Photometry of all sources
- Mean aperture radius ~1.3” (90% of the encircled energy)
- 9 extended sources (0.1-10.0 keV, 90% confidence level)

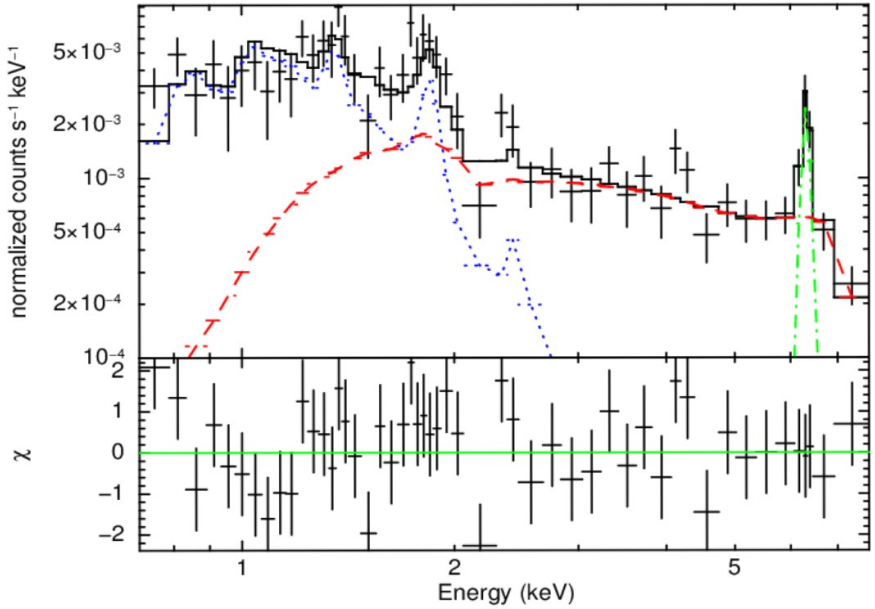


Adaptively smoothed true color image of the merged 90ks Chandra observation of Arp299. With cyan circles are noted 6 possible sources (1a-2a; 2.0< SNR <3.0).

Spectra

- 20 sources (>50 net counts) absorbed power-law model.
- 3 sources require additional or only thermal-plasma model.
- Source 9 (po+apec) one or more binaries embedded in a diffuse emission region
- Source 22 (only apec) diffuse emission region.
- Source 7 (NGC 3690 nucleus) is an AGN with prominent FeKα line at 6.4 keV. (consistent with NuSTAR results, Ptak et al. 2014)
- Source 18 (IC 694 nucleus) hint of emission line at ~6.0-7.0 keV
- Photon index Γ=0.9-3.9
  N_H greater than Galactic.





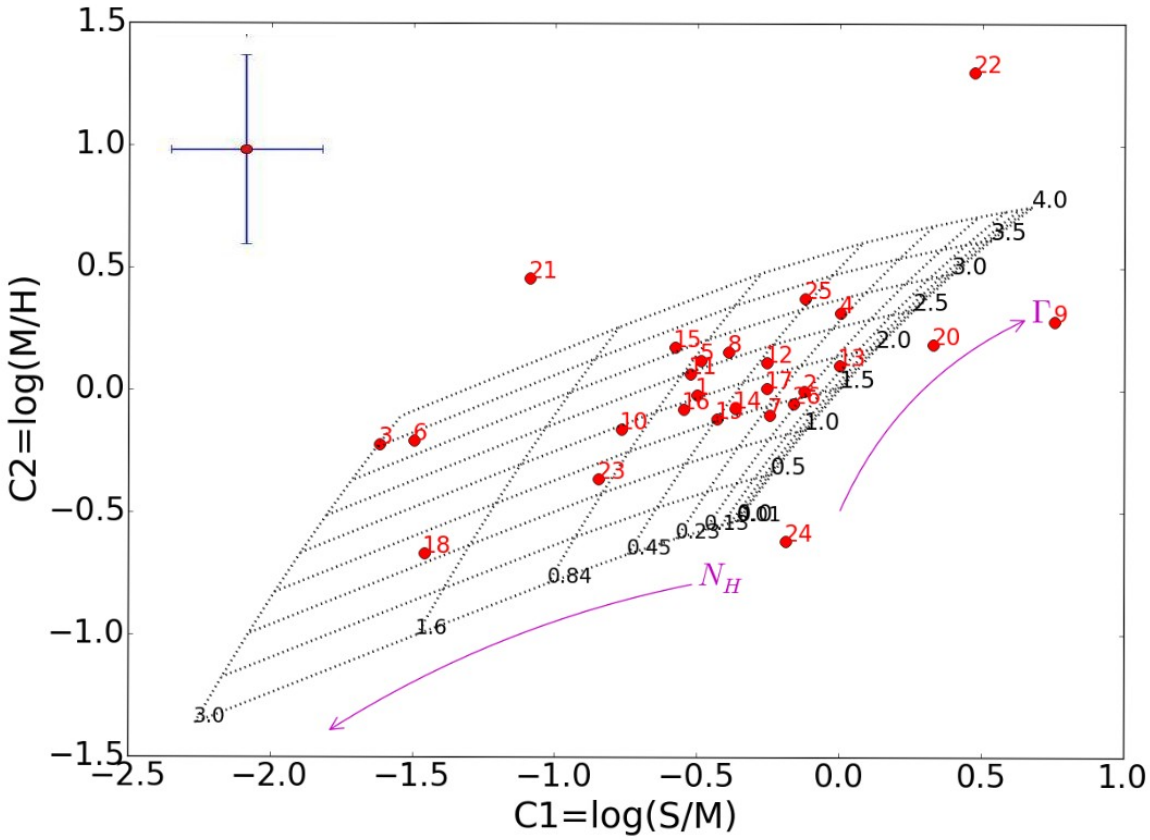
X-ray colors and grid

X-ray colors:

C1=log(S/M)
C2=log(M/H)
C3=log(S/H)

S=counts at (0.5-1.2) keV
M=counts at (1.2-2.0) keV
H=counts at (2.0-7.0) keV

- Most sources are in the locus of X-ray binaries (Γ=1.5-2.0)



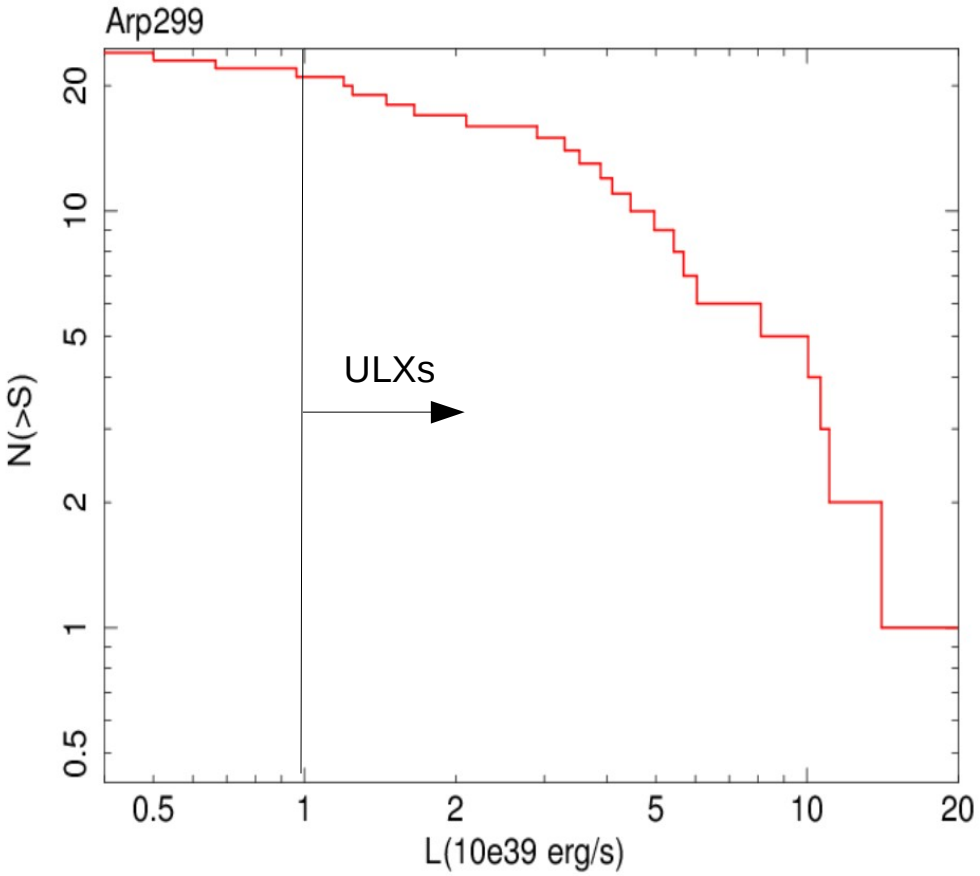
Grid of simulated absorbed power-law spectra on hardness-ratio hardness ratio plot.

Luminosity distribution

- Luminosity range:
  L(0.1-10 keV)=4x10^{38} -6x10^{40}erg s^{-1}
  (D=44Mpc)

- 20 off-nuclear sources above the ULX limit.

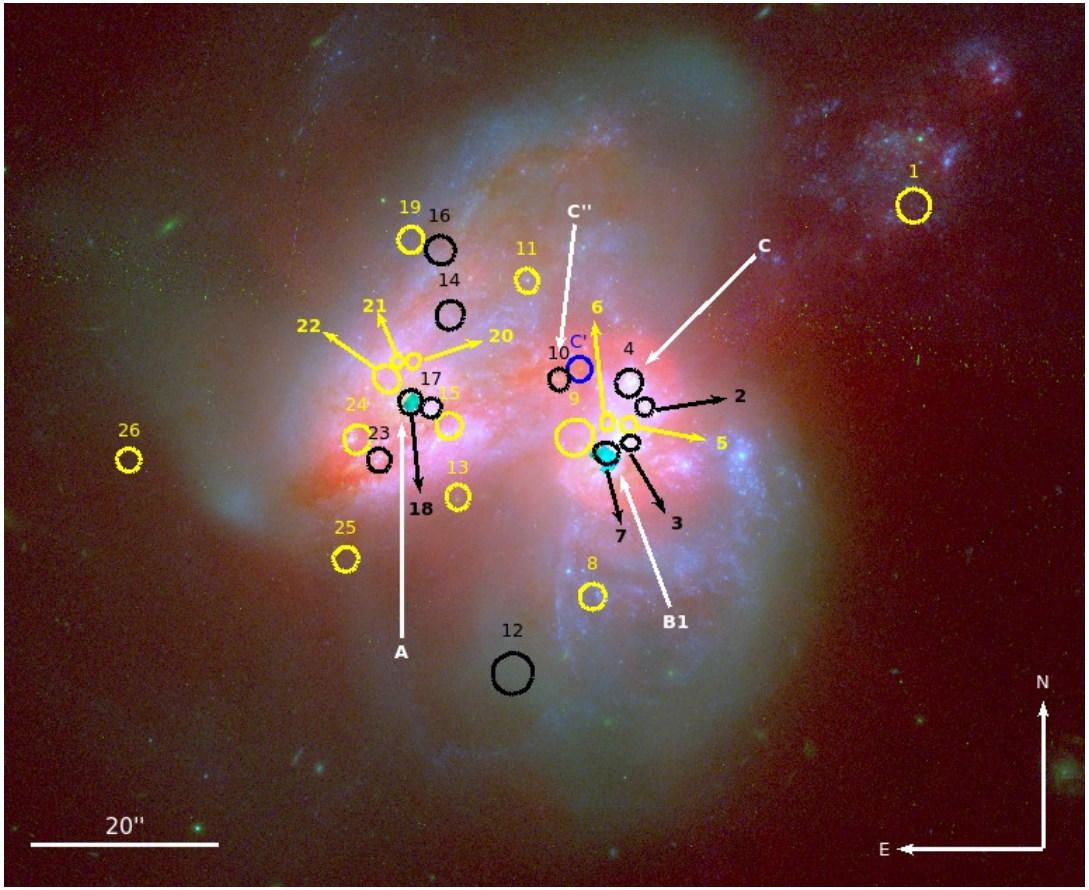
- 14 point-like ULXs.



Multi-wavelength comparisons

- Red=8μm (IRAC non stellar image from Brassington et al. 2015)
- Green=814nm (ACS HST)
- Blue=435nm (ACS HST)
- Black circles for L>5x10^{39} erg s^{-1}
- Yellow for L<5x10^{39} erg s^{-1}

- ★ Most luminous ULXs are associated with star-forming regions.



Integrated properties

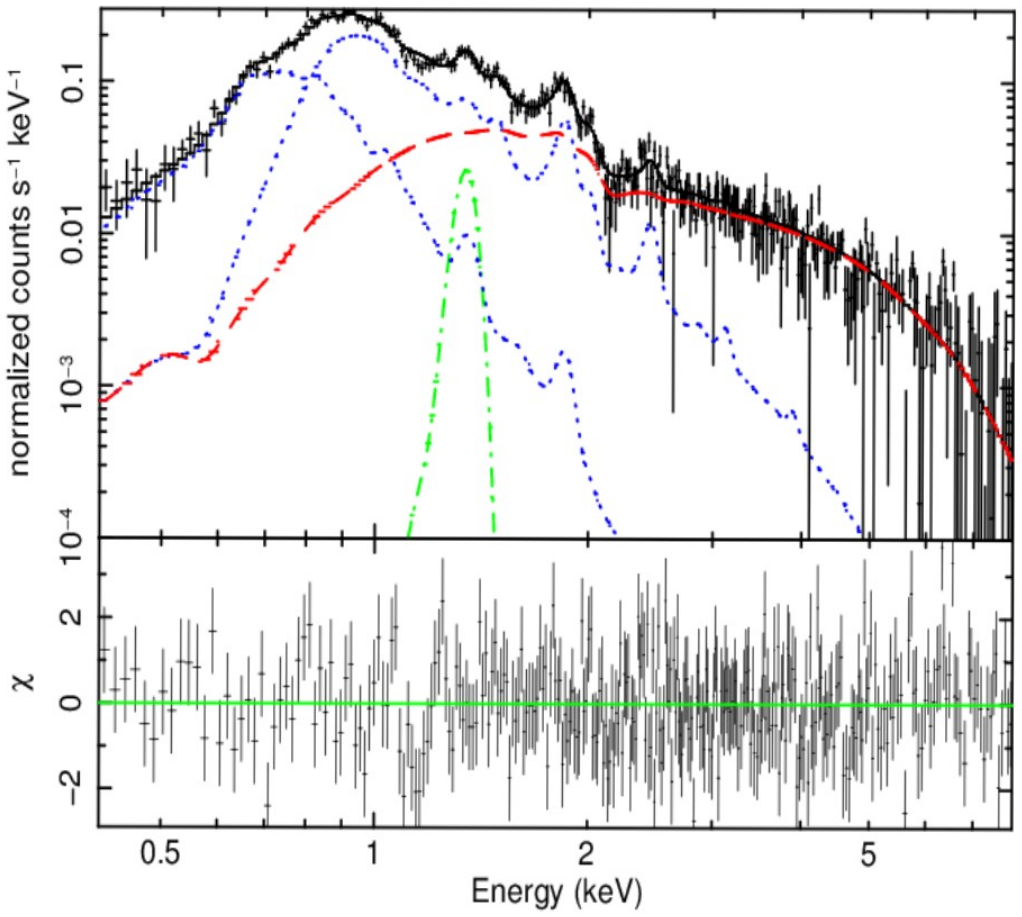
- Integrated spectrum of Arp299:

  Γ=1.67
  nH1=9.5x10^{19} cm^{-2}
  nH2=0.55x10^{22} cm^{-2}
  KT1=0.32 keV
  KT2=0.83 keV

- Total Luminosity:
  Lx (0.1-10.0keV)=4.9x10^{41} erg s^{-1}
  Lx (2.0-10.0keV)=2.6x10^{41} erg s^{-1}

- Binaries:
  52% of Lx (0.1-10.0keV)
  77% of Lx (2-10.0keV)

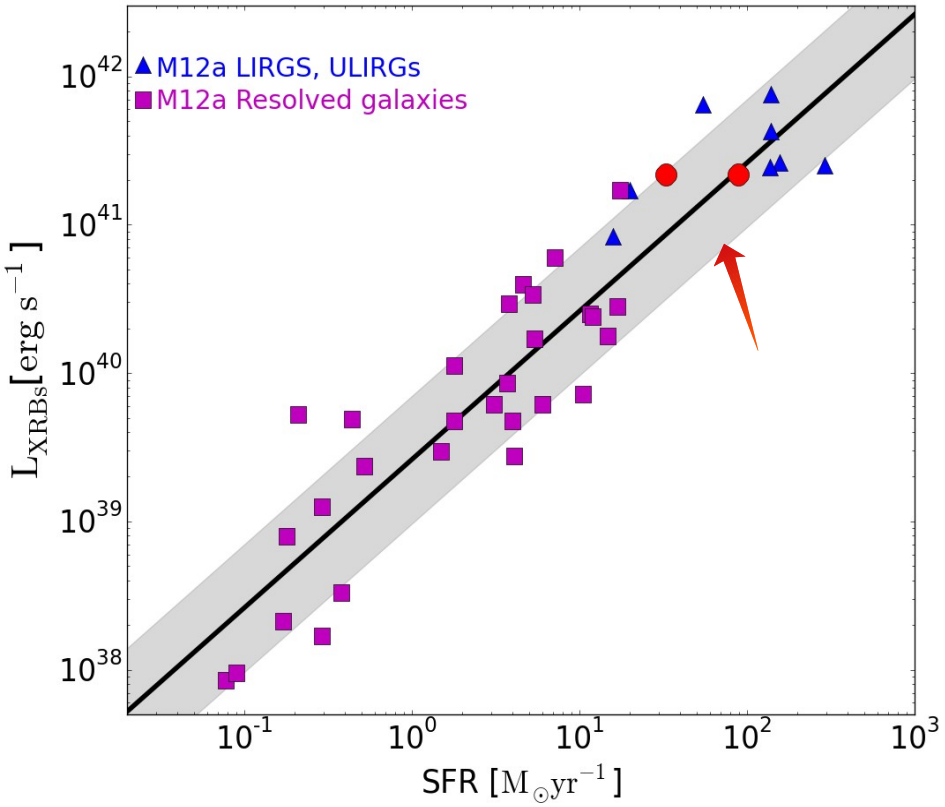
- AGN:
  13% of Lx (0.1-10.0keV)
  22% of Lx (2-10.0keV)



Reduced χ^2=1.12

L_{XRBs}-SFR correlation and Arp299

- Based on IRAS flux densities: SFR_IR= 88.89 Msun/yr (Kennicutt et al. 2012)
- Based on PAH (8microns IRAC image) emission: SFR_PAH=33.06 Msun/yr (Wu et al. 2005)
- Scaling relations from Mineo et al. 2012a and b.



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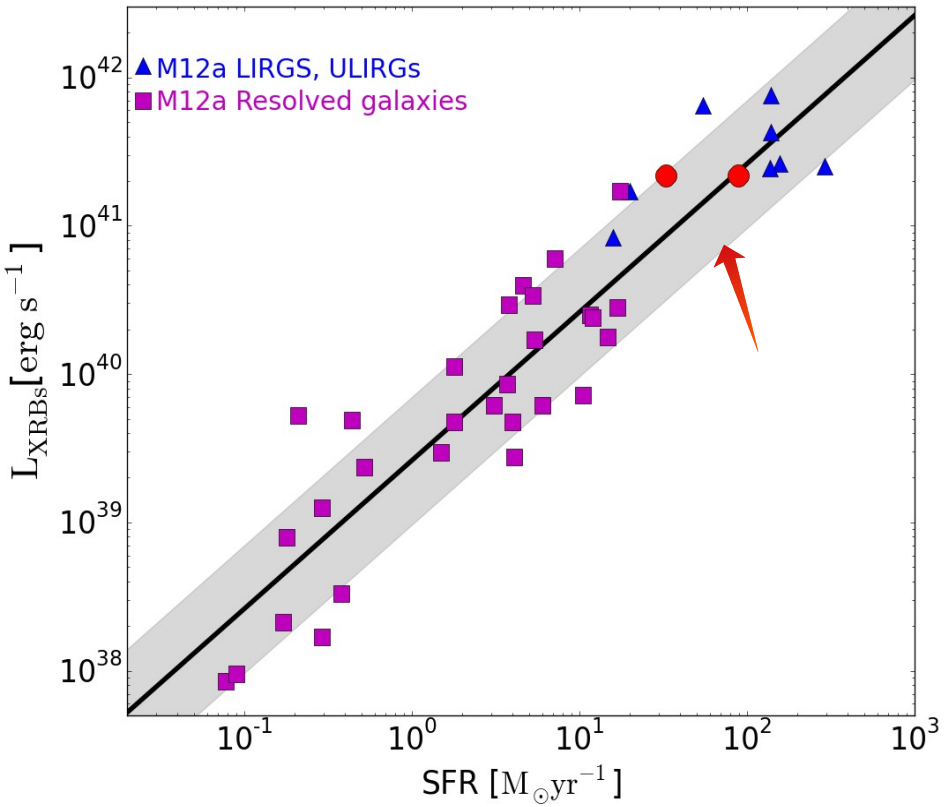
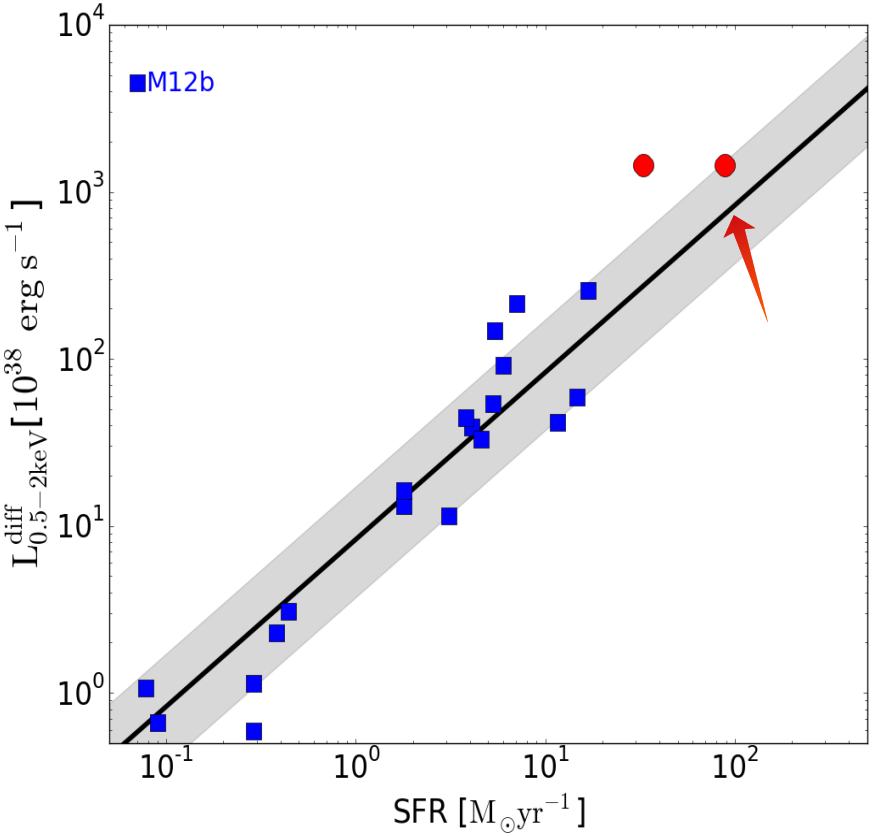


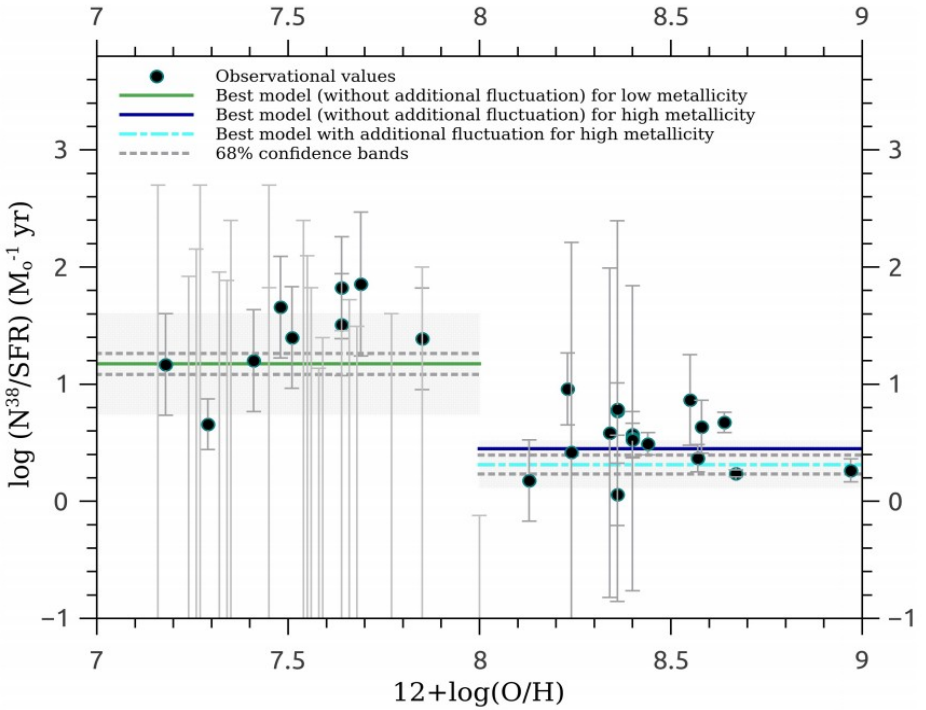


Deficit in the number of ULXs?

- XLF from Mineo et al. 2012: NULXs/SFR=0.66
- Swartz et al. 2011: NULXs/SFR=2.0
- Arp 299: NULXs/SFR= 0.16-0.60

  marginally significant deficit in the number of ULXs
- Also discussed in other works (e.g Luangtip et al. 2015) → main cause high obscuration

  What is the reason for this deficit?
- High columns of gas and dust?
  - ★ Expected luminosity of ULXs and HMXBs (Mineo et al. 2012) agrees with the observed one.
- Metallicity?
- Confusion of sources?
  - ★ At a distance of 44 Mpc the typical scale of sf region (<= 0.5 kpc--> 2arcsec). HST data show star-forming regions with size 0.5-1.0 arcsec



Douna et al. 2015

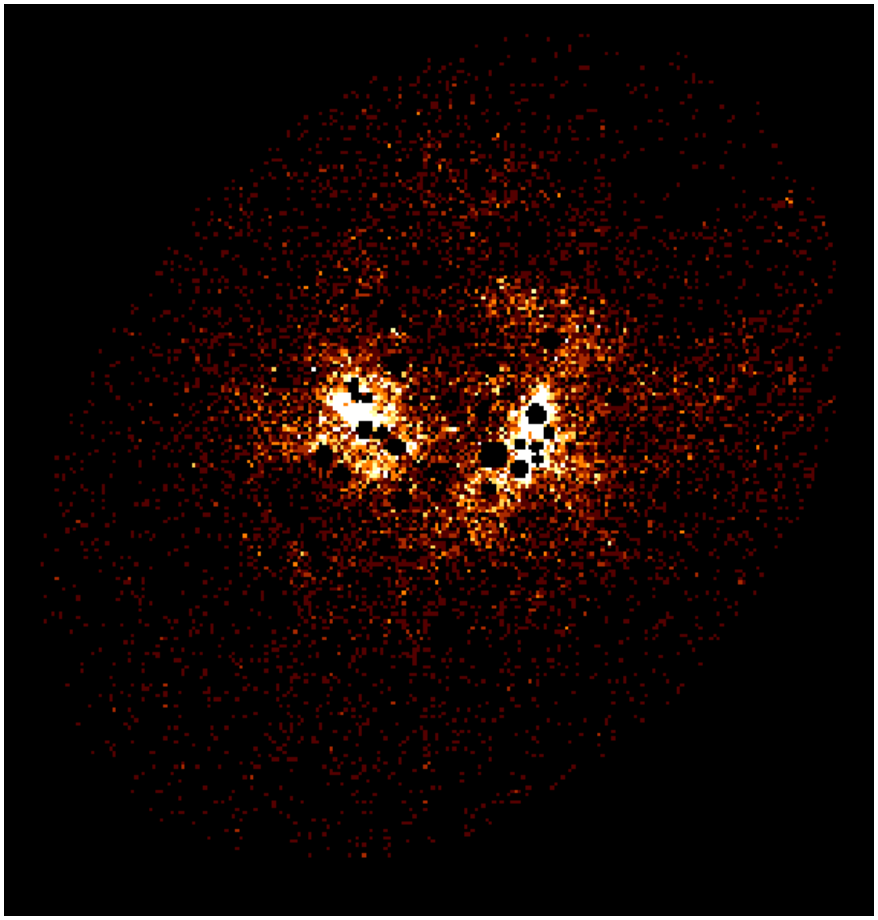
Conclusions

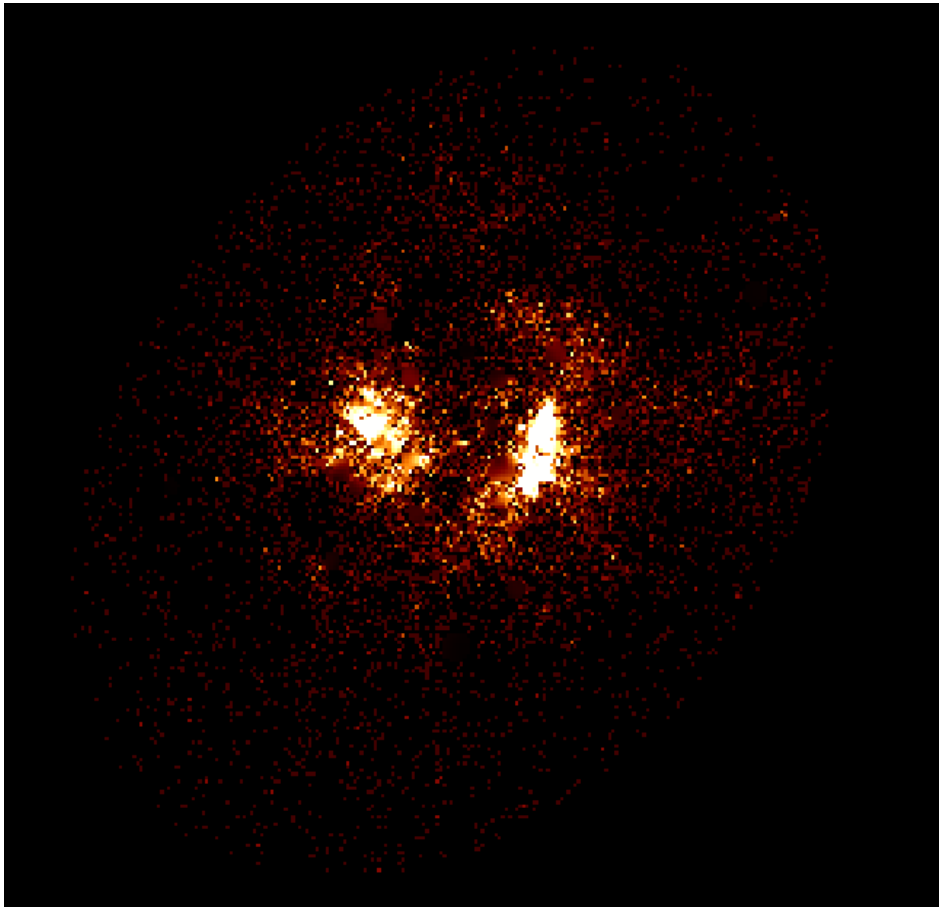
- 25 sources with luminosities up to 6×10^{40} erg s^{-1} for S/N>3.0 and a diffuse emission component
- AGN at the nucleus of NGC 3690.
- Contribution of binaries to the hard observed luminosity 77% and of AGN 22%.
- 14-20 ULXs
- Arp 299 verifies scaling relation L_{XRBs}-SFR and Ldiff-SFR for higher SFR.
- Deficit in the number of ULXs/SFR → Main cause confusion of sources
- Arp299 even though a local extreme sf galaxy its observed hard X-ray luminosity per unit SFR is similar to that of higher-z galaxies and can represent a good analogue

Thank you!

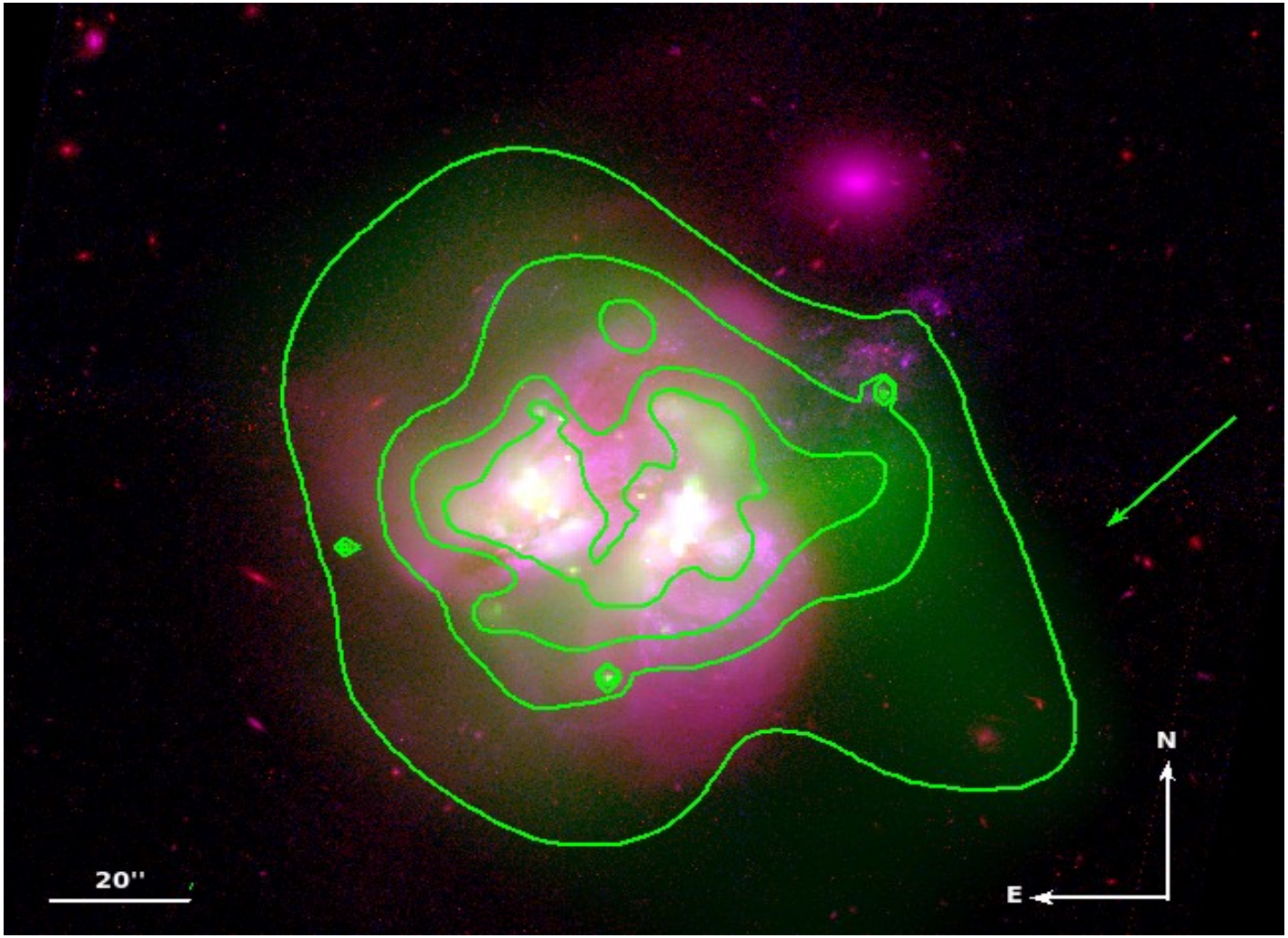
Extra slides

Diffuse emission





KT=0.72keV



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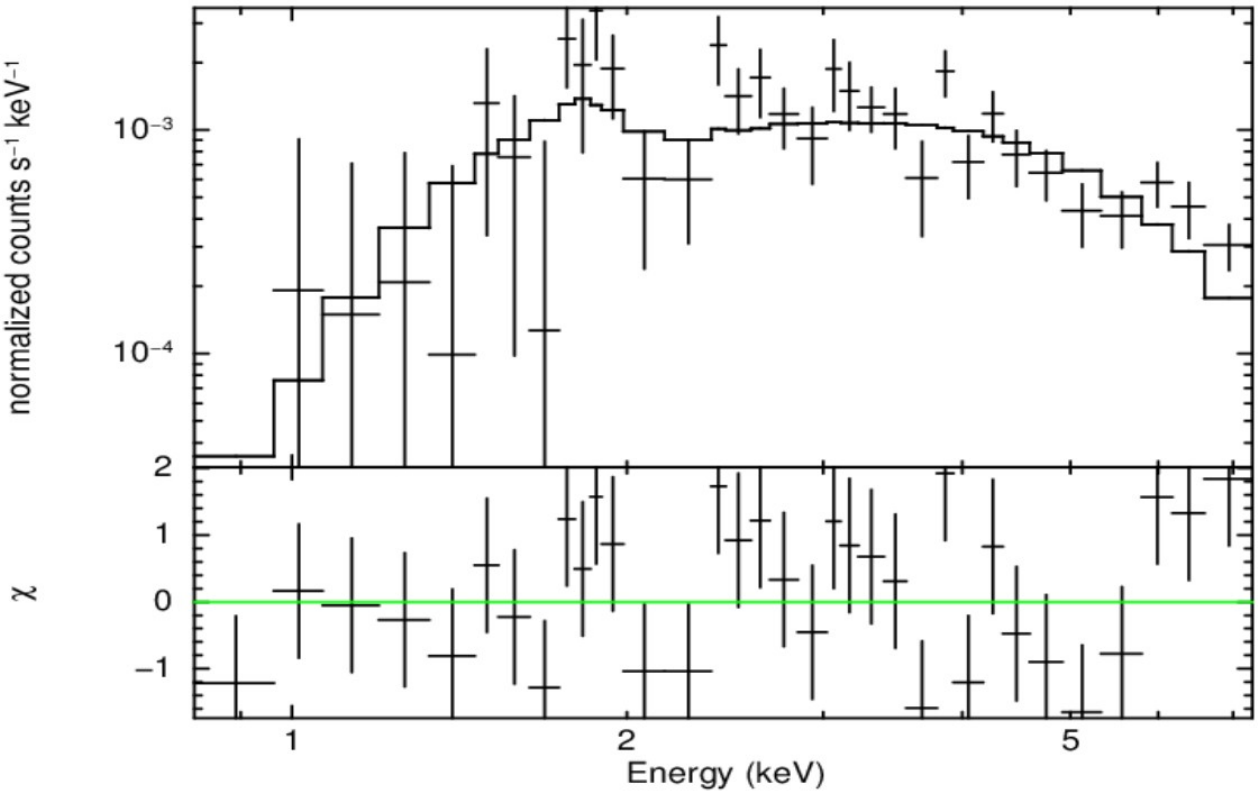
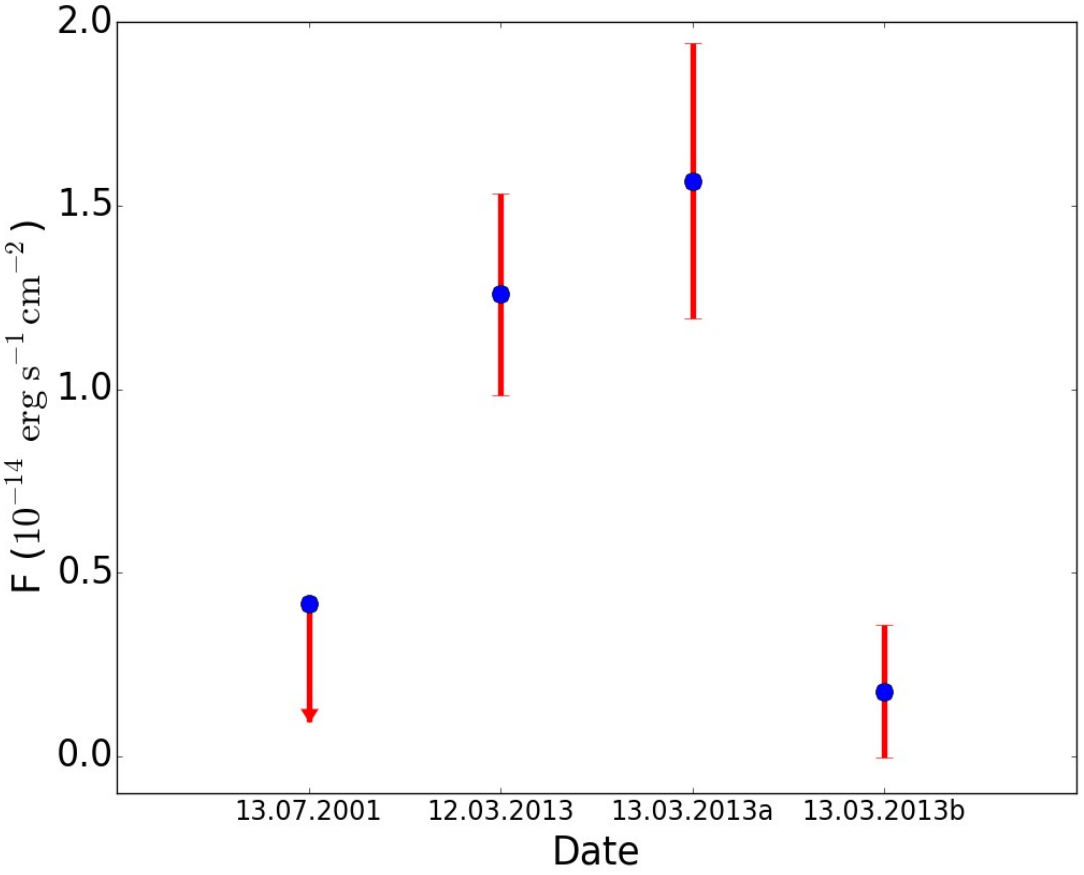
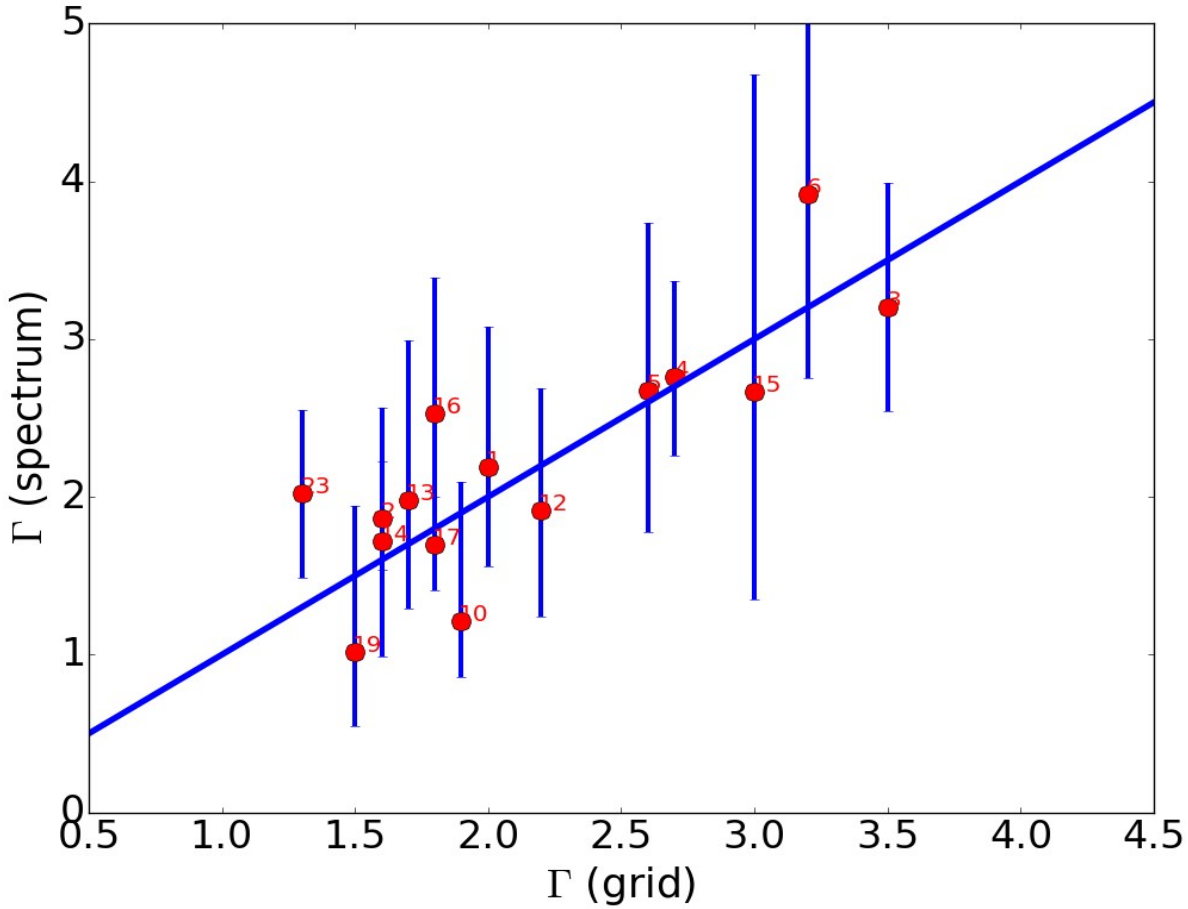
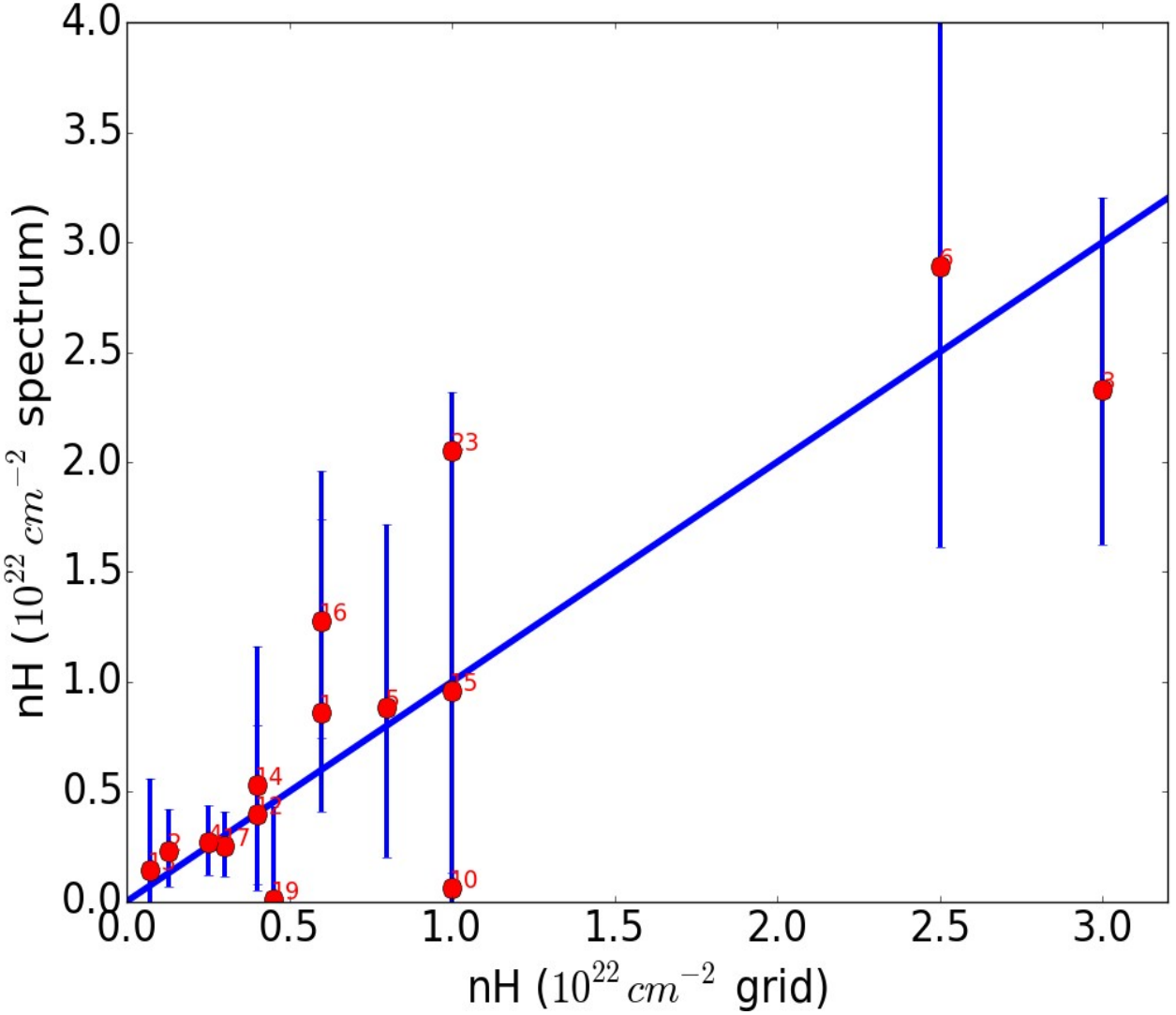


variability




5
4
3
2
1
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Γ (spectrum)
Γ (grid)
23
16
13
12
15
10
19


4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
nH ($10^{22}\,cm^{-2}$ spectrum)
nH ($10^{22}\,cm^{-2}$ grid)