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

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Introduction

Interactions and mergers are the key mechanisms that:

- drive gas into the nuclear regions of galaxies
- fuel active galactic nuclei (AGN)
- fuel circumnuclear star formation

NGC 3256 Credit:Hubble/ESA

The interplay between starbursts and AGN activity can reveal the nature of high-redshift "normal" galaxies.

The study of the X-ray properties of local highly star-forming galaxies can provide information on the X-ray emission of high-z star-forming galaxies.

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).
- Most luminous population of ULXs observed in the local Universe. (Zezas et al. 2003)

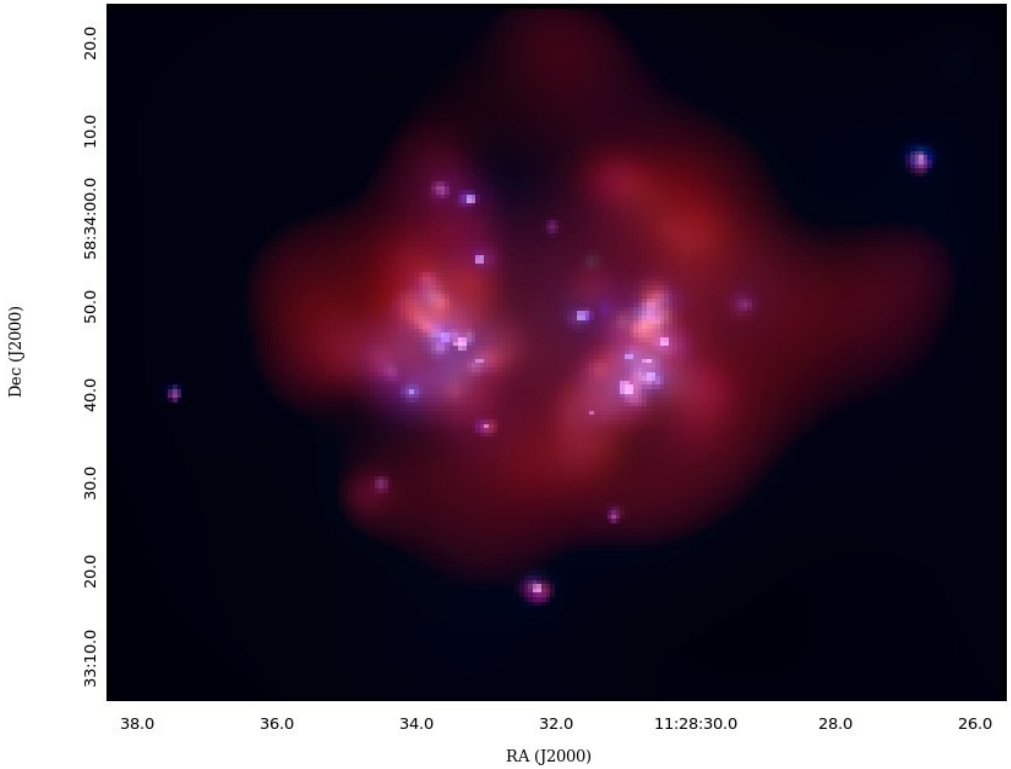
Credit: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

Data and Techniques

Chandra X-Ray observatory (spatial resolution~0.492”, energy range 0.1-10keV) observed Arp299 with the ACIS-S camera in two occasions (12.03.13 and 13.03.13) for a total of 90ks.

The tools we used for our analysis:

- CIAO v.4.7 and CALDB v.4.6.5
- XSPEC v.12.8.2
- BEHR



red=soft (0.5-1.2keV)
green=medium (1.2-2.0keV)
blue=hard (2.0-7.0keV)

contact:kanast@physics.uoc.gr

Results

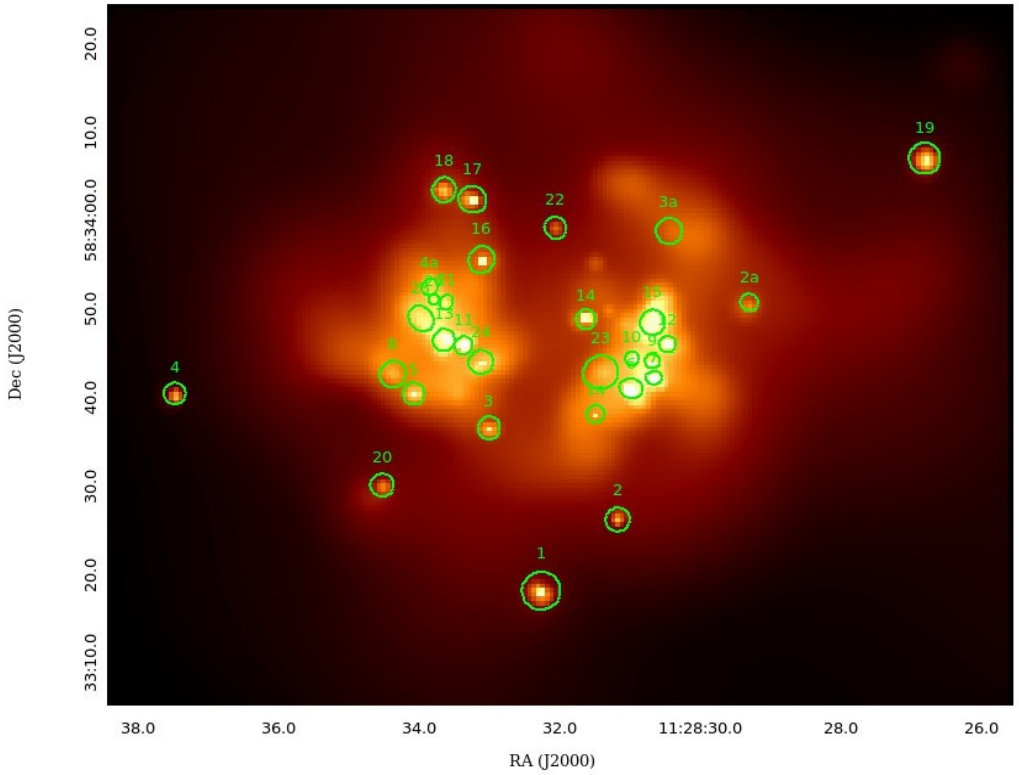
Source detection

CIAO *wavdetect* tool:

- 42 detections
- 26 discrete sources exceeding S/N = 3.0

CIAO *dmextract* tool:

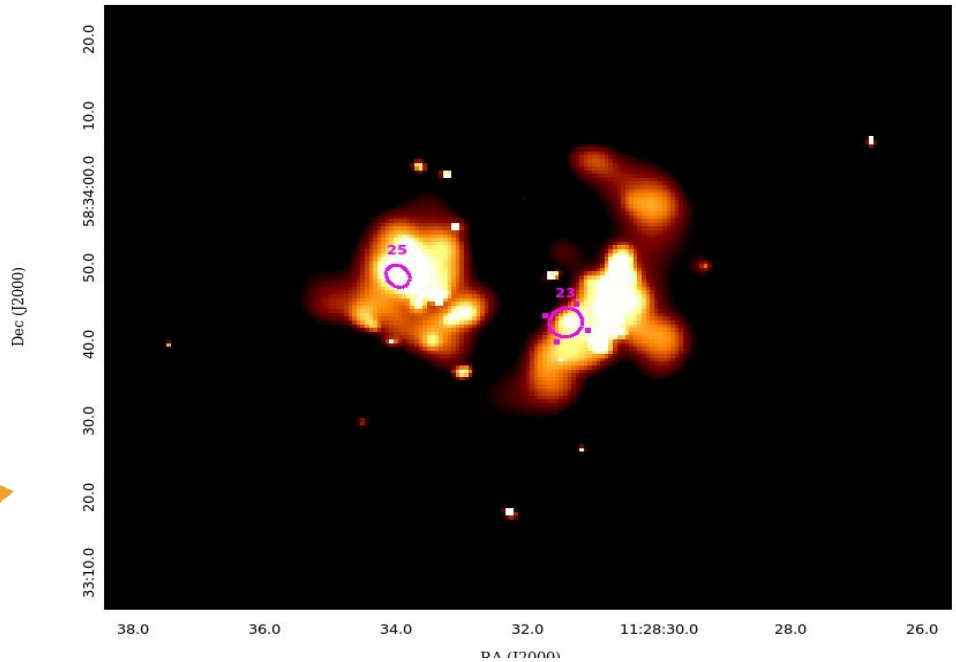
- Photometry of the 26 sources.
- Mean aperture radius ~1.3” (90% of the encircled energy).



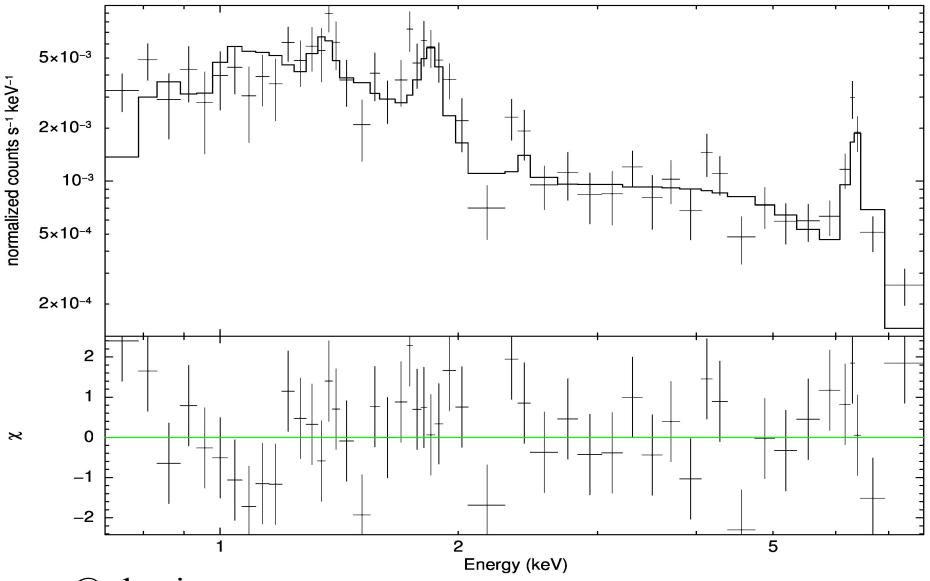
0.5-7.0 keV adaptively smoothed image of the merged 90ks Chandra observation of Arp299.

Spectra

- 20 sources (>50counts)
- absorbed power-law model
  3 sources require additional or only thermal-plasma model.
- sources 23,25 diffuse emission regions.
- source 6 (NGC 3690 nucleus) is an AGN with prominent FeKα line at 6.4 keV. (consistent with NuSTAR results, Ptak et al. 2014)
- Photon index Γ=0.9-3.9
  nH greater than Galactic.



source 6

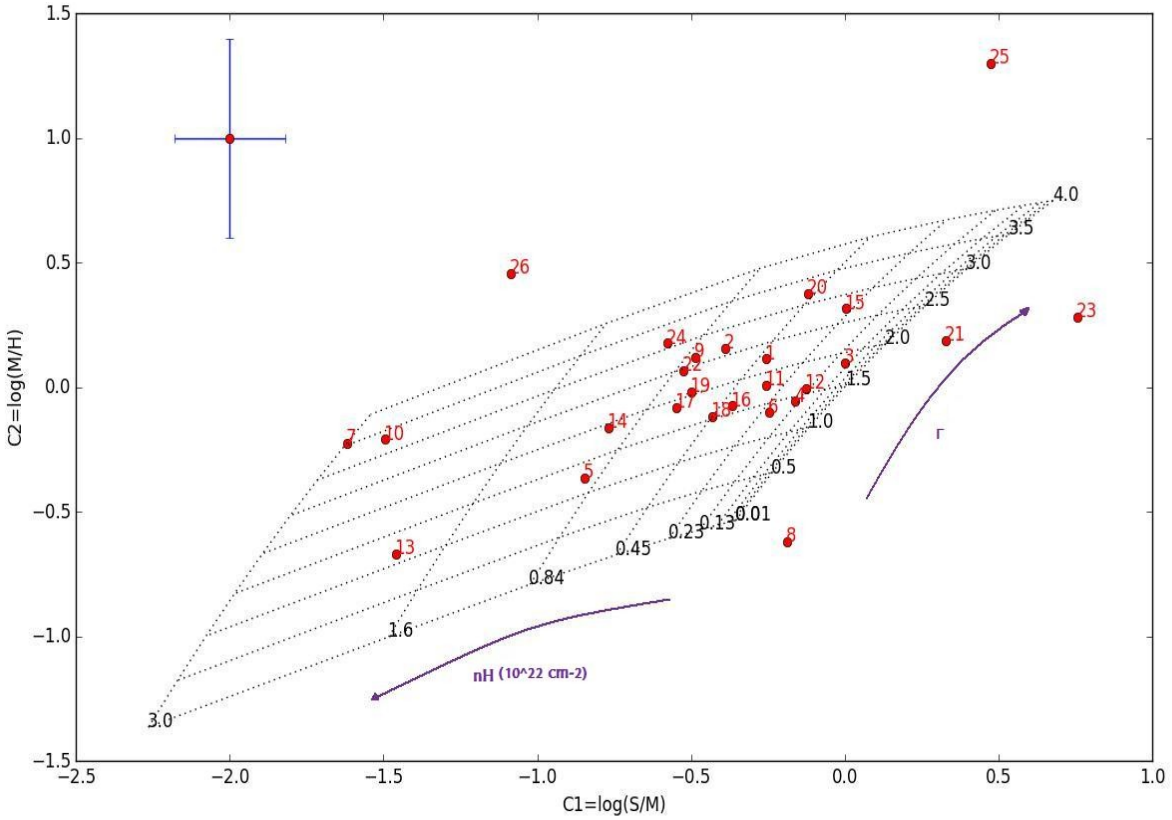


Hardness ratios and grid

Color Hardness ratios:

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



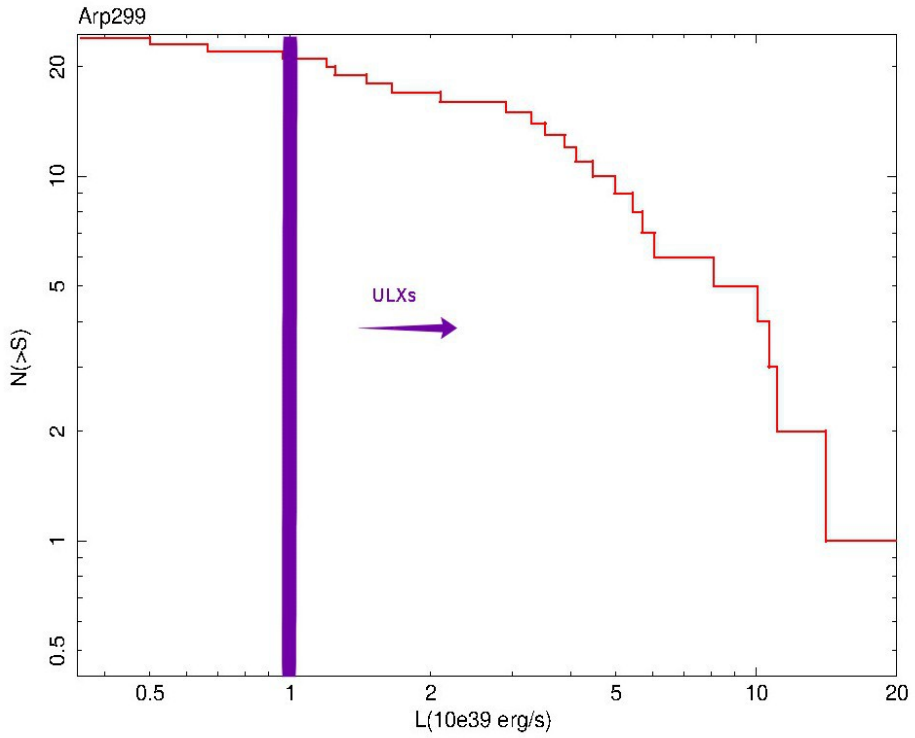
Grid of simulated absorbed power-law spectra on hardness-ratio hardness ratio plot.

Luminosities

- Luminosity range:
  $L=4x10^{38}$ -$5x10^{40}$erg s^{-1}
  (D=44Mpc)

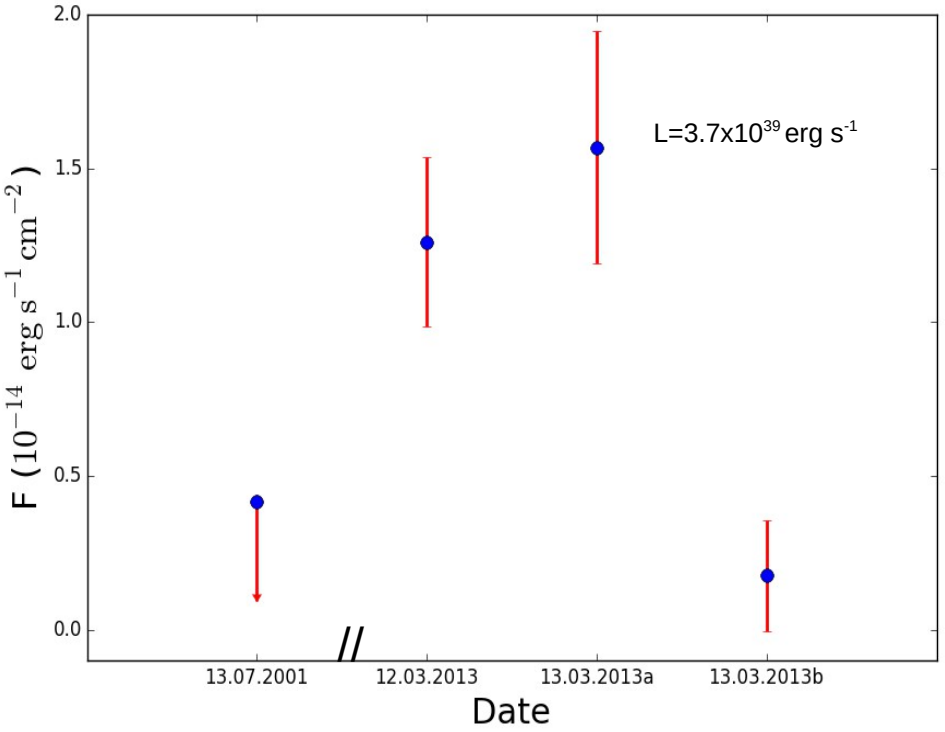
- CIAO *srcextent* tool :
  9 extended sources
  (90% confidence level)

- 21 Ultra Luminous X-Ray sources (ULXs).



Variability

- CIAO *glvary* tool (Gregory Loredo algorithm).
- 1 variable source (source 18) on 13.03.2013.
- Calculation of flux and upper flux limit for the other 2 observation dates (13.07.2001,12.03.2013).



Total Luminosity

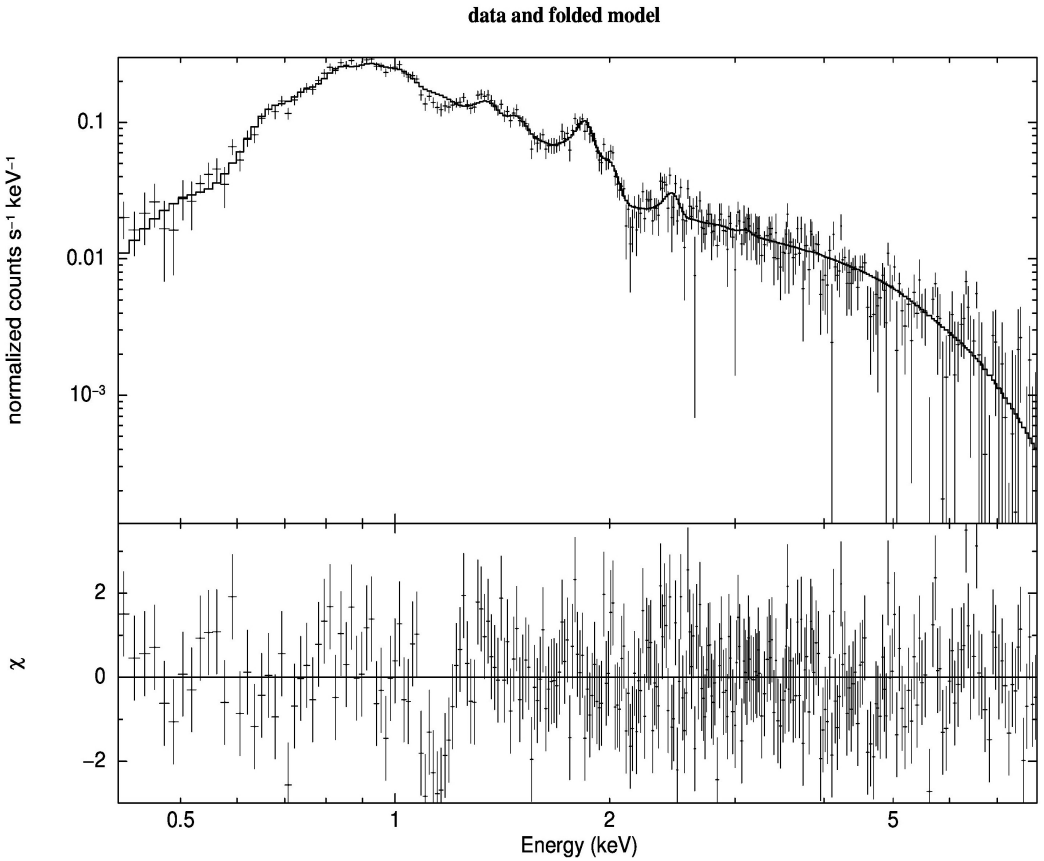
- Integrated spectrum of Arp299:

  Γ=1.4
  nH1=0.17x$10^{22}$$cm^{-2}$
  nH2=0.52x$10^{22}$$cm^{-2}$
  KT1=0.31 keV
  KT2=0.86 keV

- Total Luminosity:
  Lx(0.1-10.0keV)=4.9x10^{41} erg s^{-1}
  Lx(2.0-10.0keV)=2.9x10^{41} erg s^{-1}

- Binaries:
  60% of Lx (0.1-10.0keV)
  79% of Lx (2-10.0keV)

- AGN:
  10% of Lx (0.1-10.0keV)
  16% of Lx (2-10.0keV)



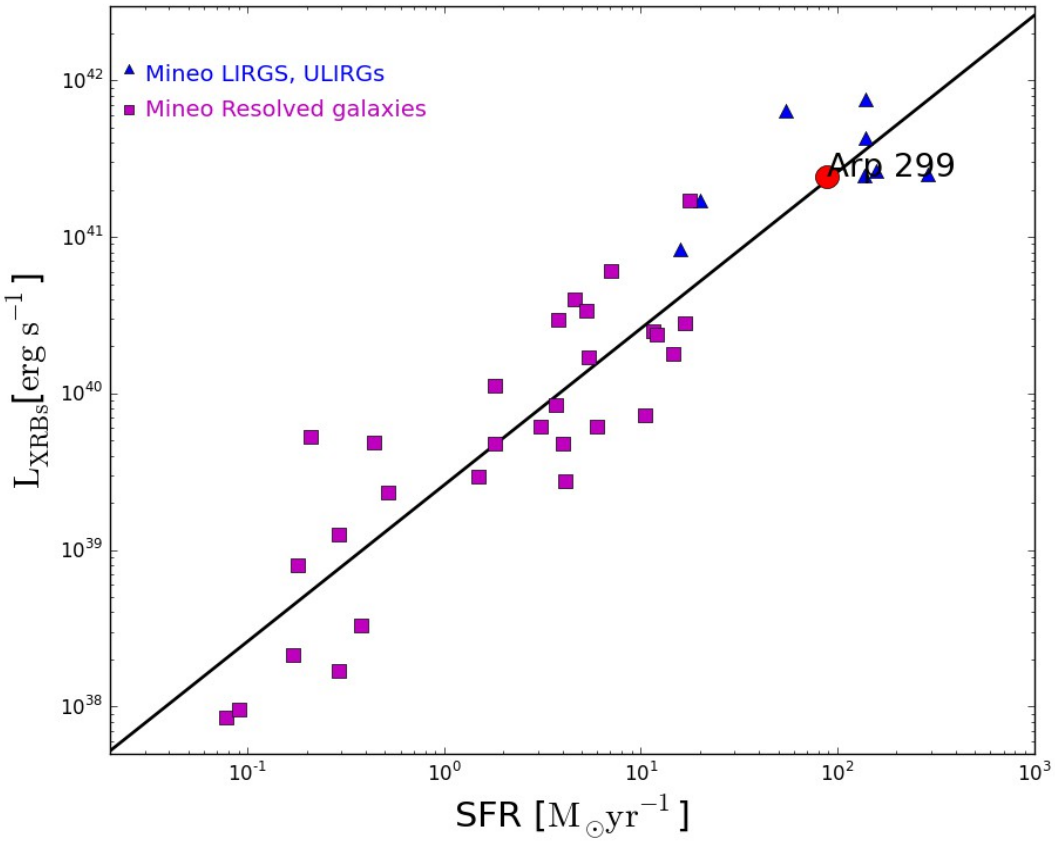
Reduced χ^2=1.18

L_{XRBs}-SFR correlation and Arp299

- From IRAS flux densities :

  Lir(8-1000μm)=5.9x10^{11}Lsun (Helou et al. 1988)

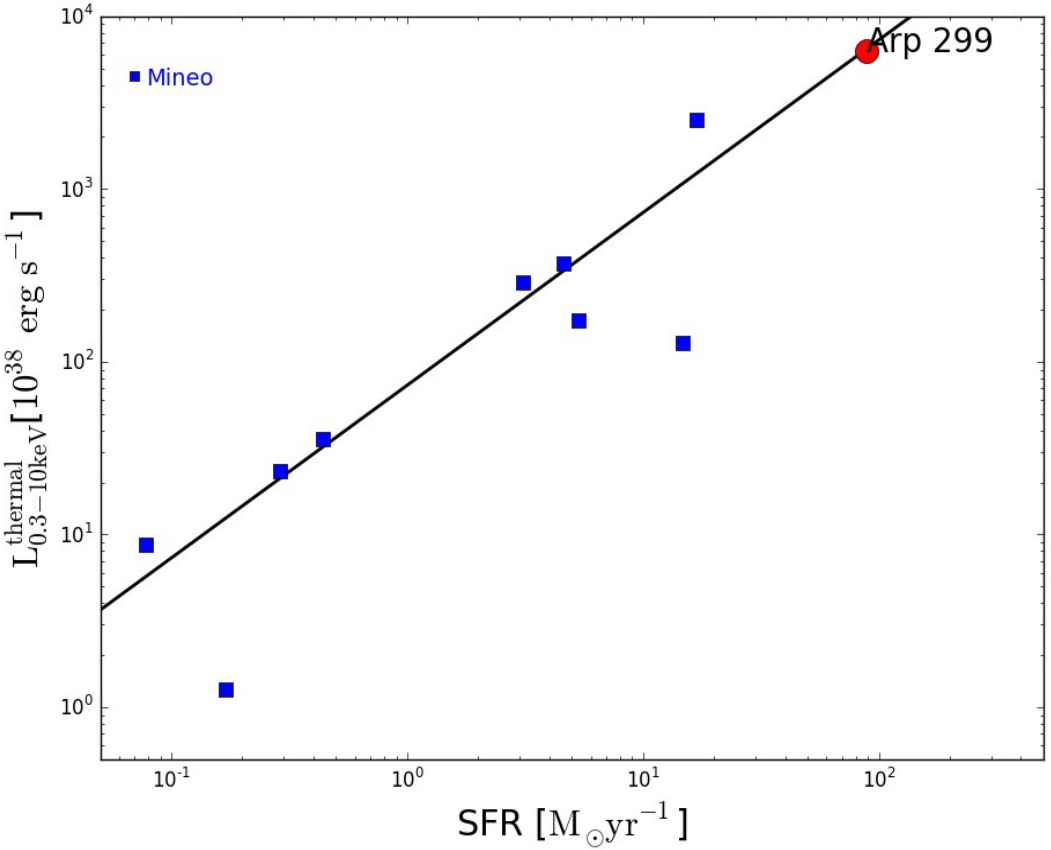
- From Lir(8-1000μm): SFR= 88.89 Msun/yr (Kennicutt et al. 2012)



The position of Arp299 on the Lx(XRBS) -SFR correlation of Mineo et al. 2012.

$L_{thermal}$-SFR correlation and Arp299

- **Arp299:**
  L**th**=6.27x10^{41} erg s^{-1}



The position of Arp299 on the Lth-SFR correlation of Mineo et al. 2012.

Number of ULXs/SFR

- **Arp299:**

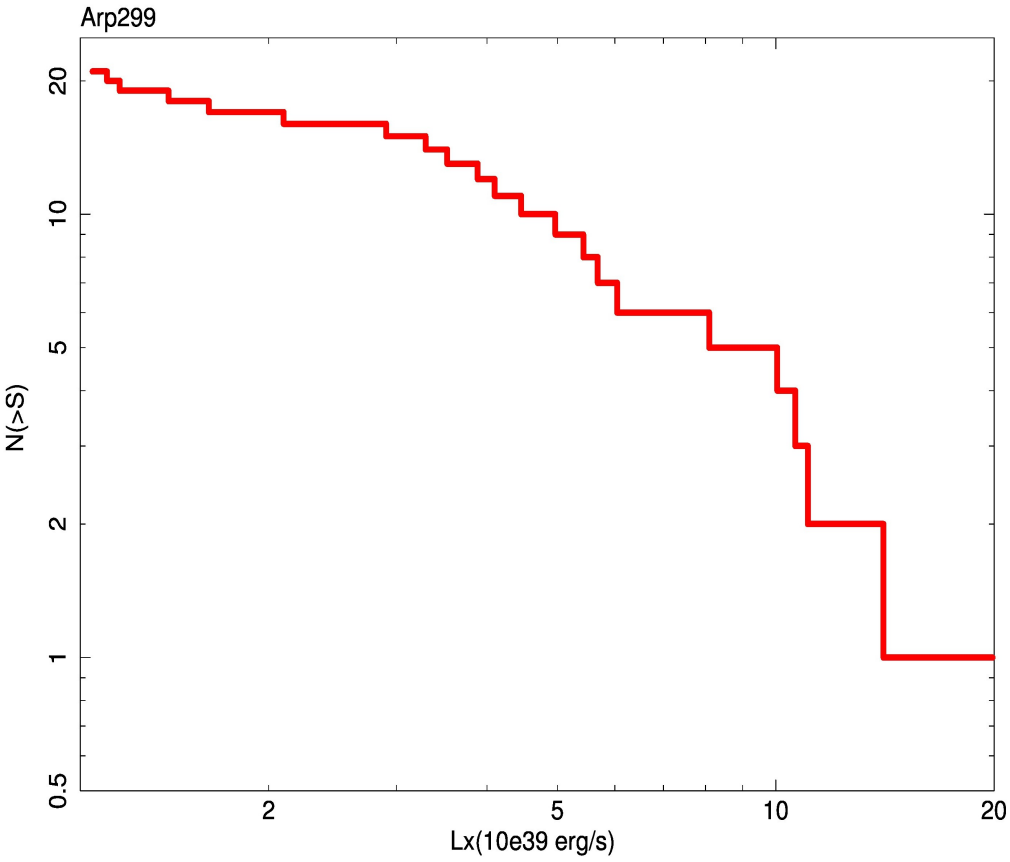
Nulxs/SFR=0.24 systems/Msun/yr

Lulxs(0.5-8.0 kev)=1.3x10^{41} erg s^{-1}

- **X-Ray Luminosity function from Mineo et al.2012 :**

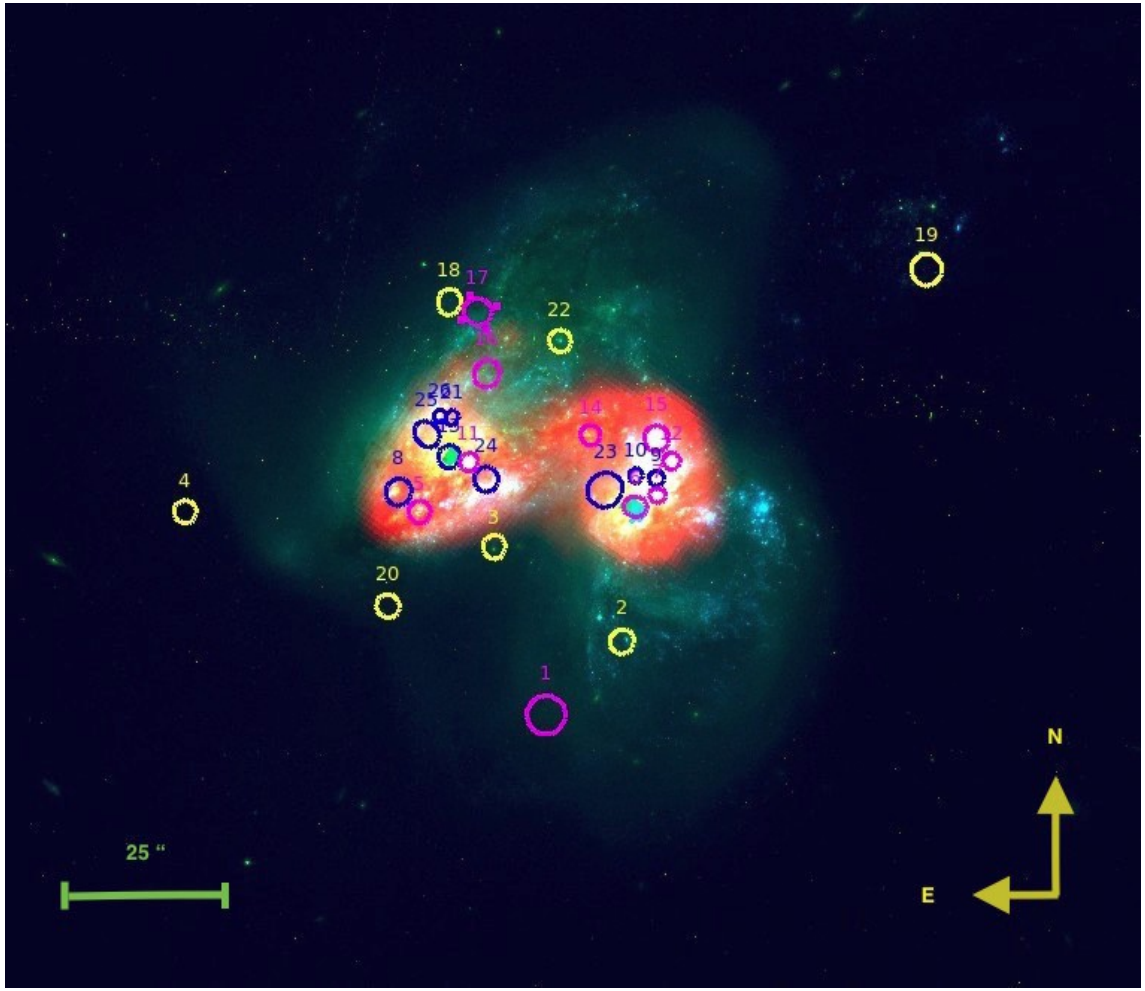
Nulxs /SFR=0.62 systems/Msun/yr

Lulxs=(1.75+/-0.3)x10^{41} erg s^{-1}



Multi-wavelength comparisons

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



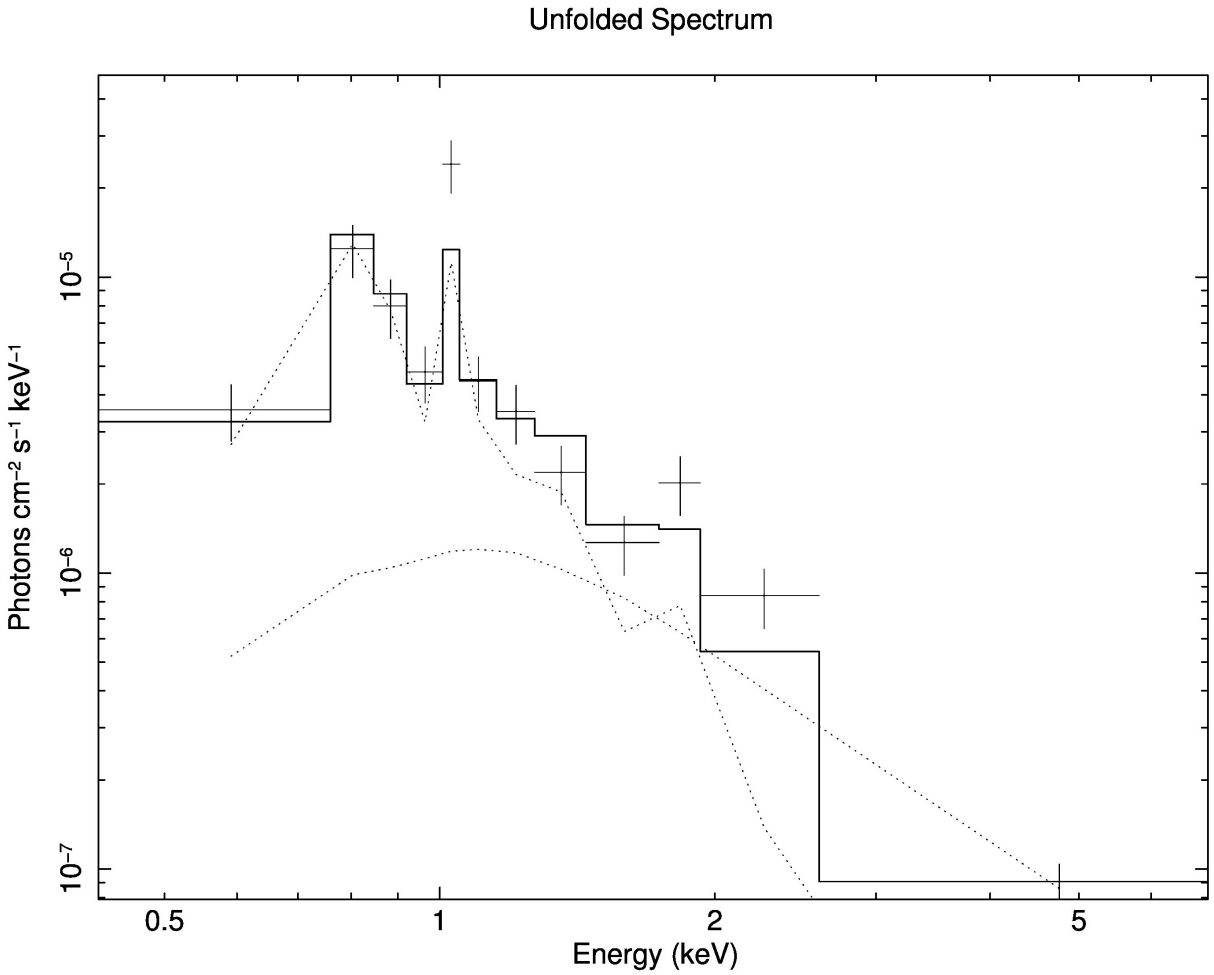
- Most luminous ULXs are associated with star-forming regions.

Conclusions

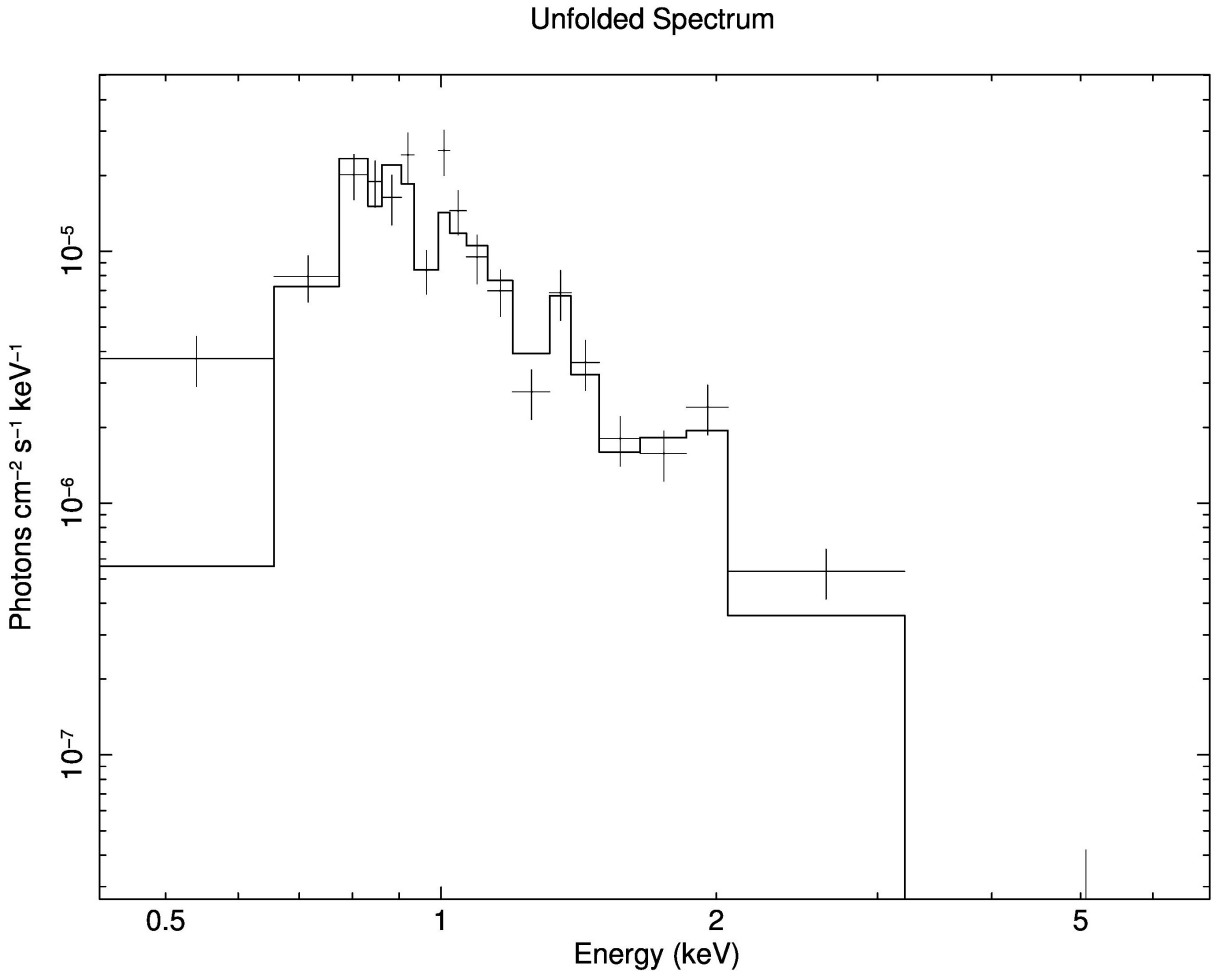
- 26 sources with Luminosities up to 5×10^{40} erg s^{-1} for S/N>3.0.
- AGN at the nucleus of NGC3690.
- 21 ULXs (probably confusion).
- Lx (0.1-10 keV)=4.9×10^{41} erg s^{-1} with L_{XRBs}=60%Lx and L_{AGN}=10%Lx.
- Arp 299 verifies relation L_{XRBs}-SFR and Lth-SFR for higher SFR.
- Most of the sources have hard spectra and are associated with young star forming regions (bluer areas) and are most probably HMXBs.

Thank you

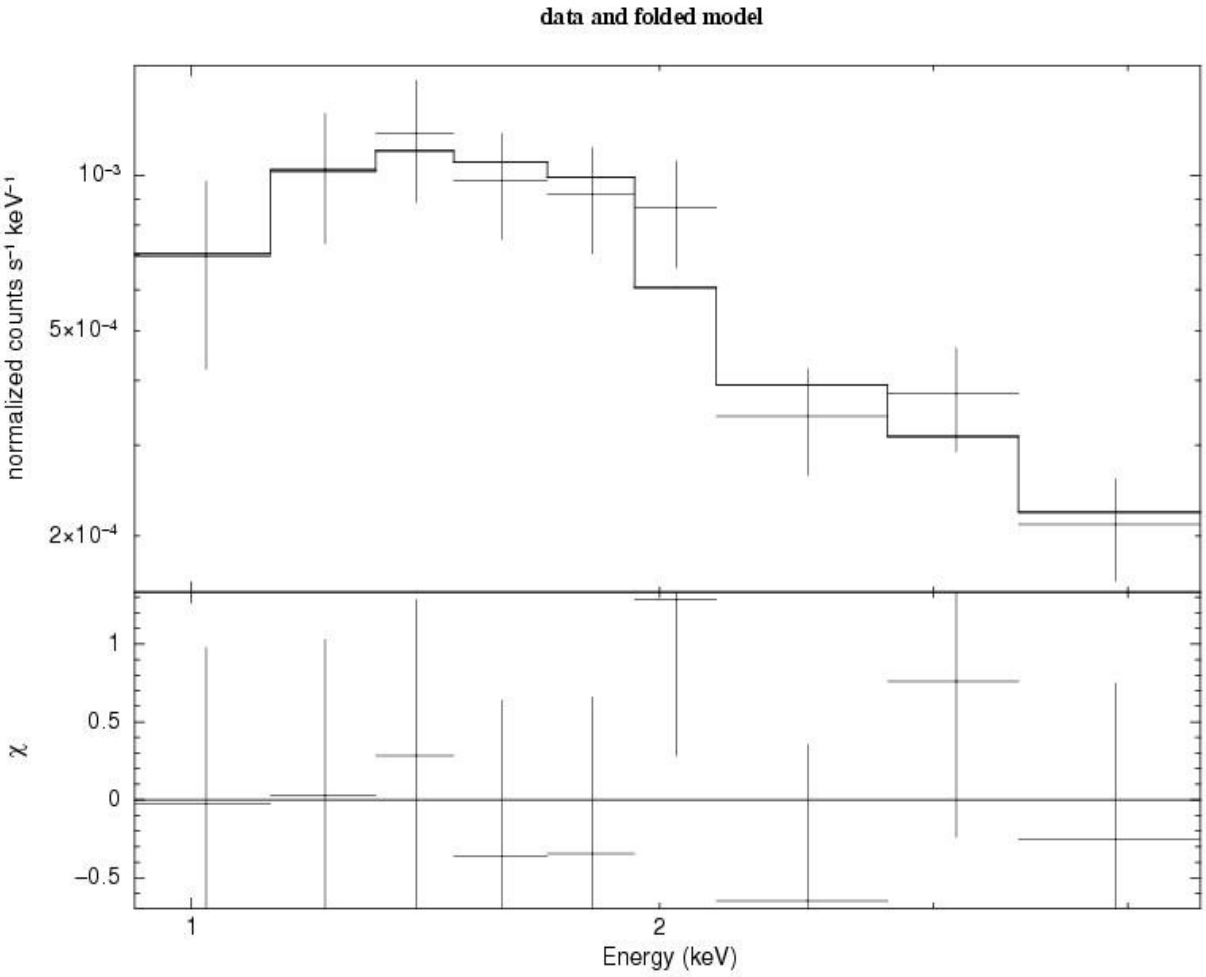
Extra slides



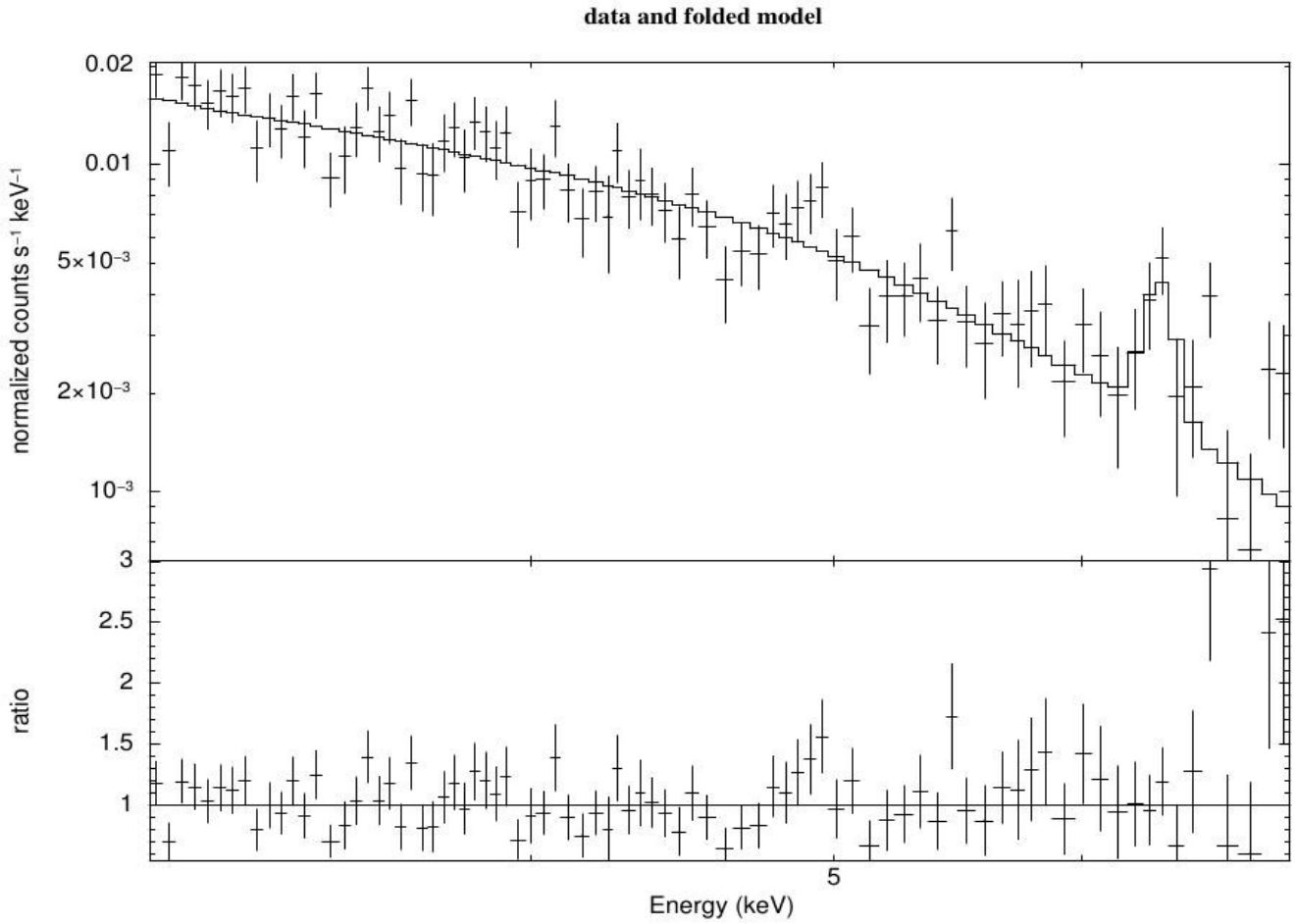
Source 23 reduced χ^2=1.9



Source 25, reduced χ^2=2.1



Source 16 reduced χ^2=0.6



Ptak et al. 2015:Power-law plus Gaussian fit to the 3–8 keV Chandra spectrum from a 1' region corresponding to the NuSTAR Arp 299 spectral source extraction region.