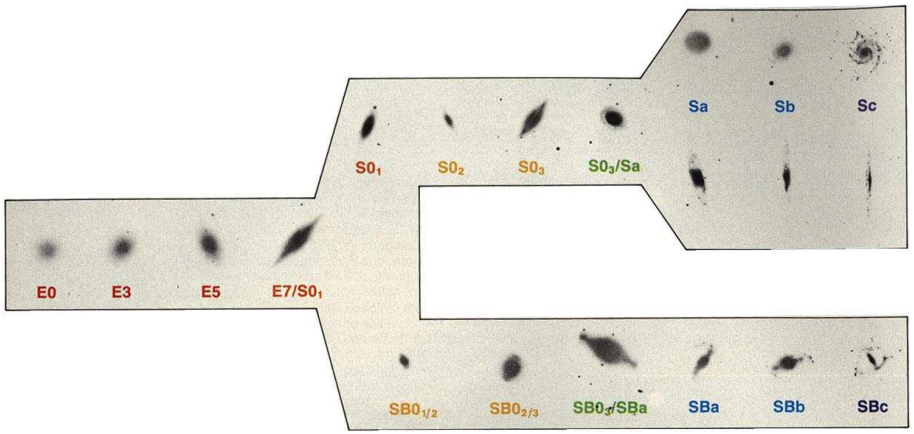
X-Rays from Normal Galaxies

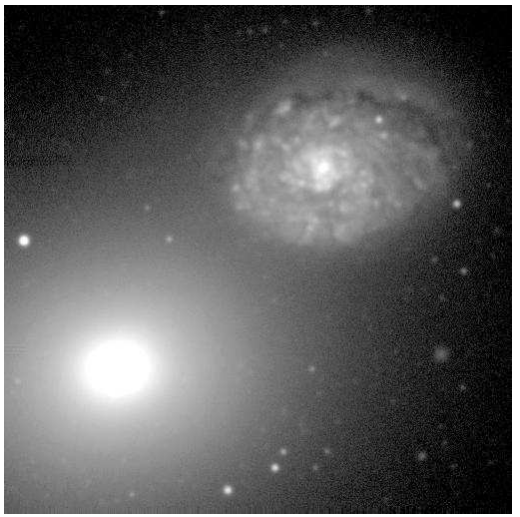
Galaxy Classification



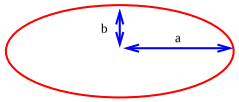
Galaxy classification via the Hubble “tuning fork diagram”

courtesy George Lake, U. of Washington.

Elliptical Galaxies



M60 (NGC 4649), E1, U. of Alabama



Elliptical galaxies: Classification as Ex where $x = 10(a-b)/a$ (integer part; between 0 and 7);

Low on dust and gas, red color ($B-V \sim 0.9$) (=old stars), typically low luminosity and low mass ($10^6\,M_\odot$)

Monsters: Elliptical galaxies from mergers in galaxy clusters (e.g., M87 in Virgo), M up to $10^{12}\,M_\odot$, designated cD.

Spiral Galaxies

M51 (NGC 5194 and 5195), Sc and Irr, Kitt Peak 0.9 m

Spiral Galaxies: Elliptical nucleus plus spiral arms, designated Sa, Sb, Sc depending on opening angle of spiral (Sa: $\sim 10^\circ$, Sc: $\sim 20^\circ$) and dominance of nucleus.

Bluer than ellipticals.

Mass content $\sim 3 \times 10^{11}\,M_\odot$, with $M/L \sim 20$,

Gas content increases from Sa to Sc from 1% to 8%.

Spiral arms probably due to density wave.

Barred Galaxies

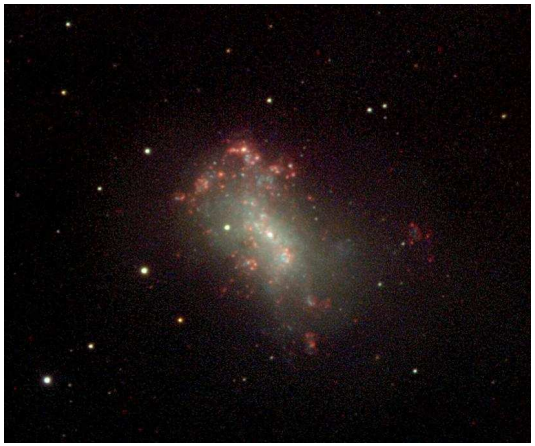
M93, SABc, ESO-VLT

Barred Galaxies: Classification as SBa, SBb, SBc similar to Sx galaxies, but additional presence of a bar (cause of bar production and stability are still debated).

Similar masses and gas content as in normal spirals.

Milky Way is a barred spiral.

Irregular Galaxies



NGC 4449, Univ. Bonn

Irr I: no symmetry or spiral arms, bright knots of O- and B-type stars, very blue ($B - V \sim 0.5$), high dust content ($\sim$ 16%), $M/L \sim 3$, masses vary appreciably from 10^6 to $10^{10}\ M_\odot$.

Examples: SMC, LMC

$\Longrightarrow$ "Magellanic type irregulars".

Irregular Galaxies: Irr II

M82, HST-WFPC

Irr II: asymmetric and "abnormal"

$\Longrightarrow$ All objects that do not fit in the rest of the classification: starburst galaxies, interacting galaxies, Active Galactic Nuclei,. . .

X-Ray Emitting Objects

All objects spoken about so far in this class are within our Galaxy

$\Longrightarrow$ X-ray emissivity of the galaxy as a whole is sum over X-ray emitting objects.

Therefore, X-ray emissivity is dominated by point sources:

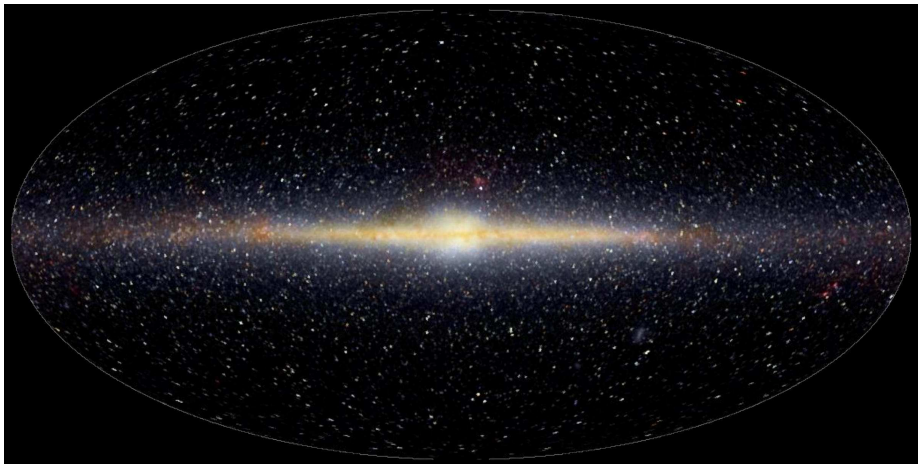
- Stars
- Supernova Remnants
- Low Mass X-Ray Binaries
- High Mass X-Ray Binaries

and by continuum sources

- Nuclear Decay

On the next few slides we will look at some examples.

Milky Way



COBE image (IR): white: stars, red: dust

image in galactic coordinates.

Aluminum

At higher energies: emission lines from radioactive nuclei

Review: Diehl & Timmes, 1998, PASP, 110, 637

short lived nuclei: evidence of *in situ* nucleosynthesis. Best example: ^{26}Al.

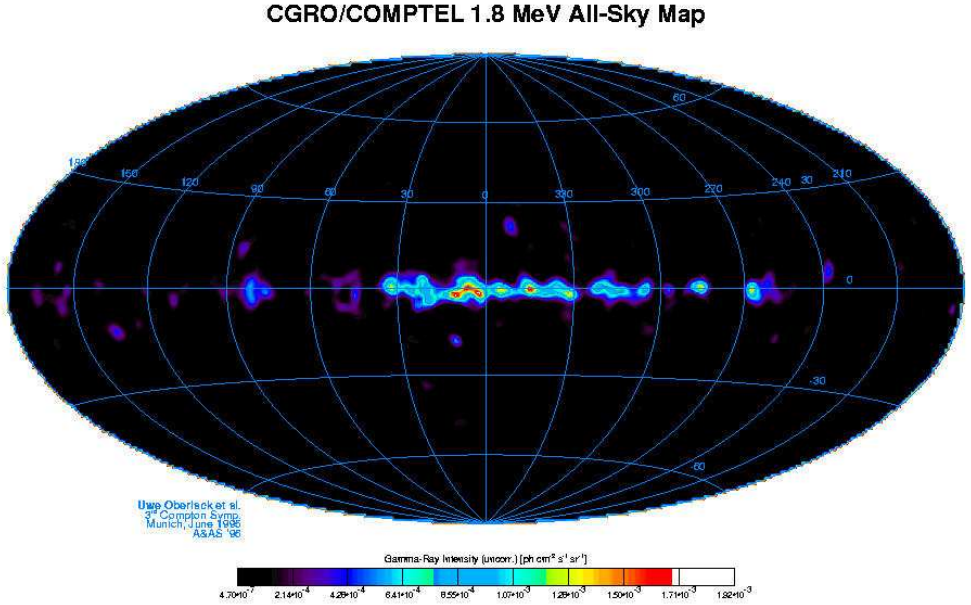
Produced by proton capture reactions, mainly ^{25}Mg, in

- hydrogen burning in massive stars ($M > 11\,M_\odot$)
- shell burning on the AGB
- explosive H burning in novae

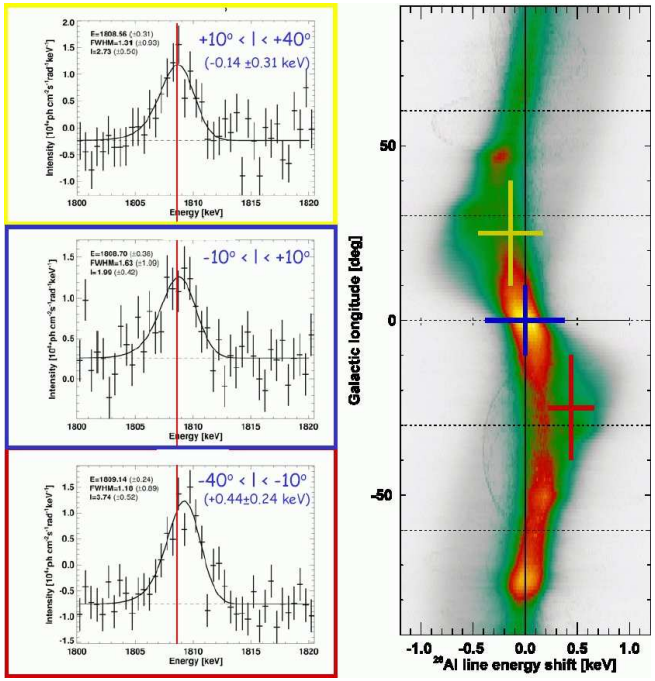
and ejected with stellar wind.

^{26}Al traces massive stars.

Detection: decays with half life of 7.5×10^5 yr into ^{26}Mg, emitting 1.809 MeV gamma-rays.



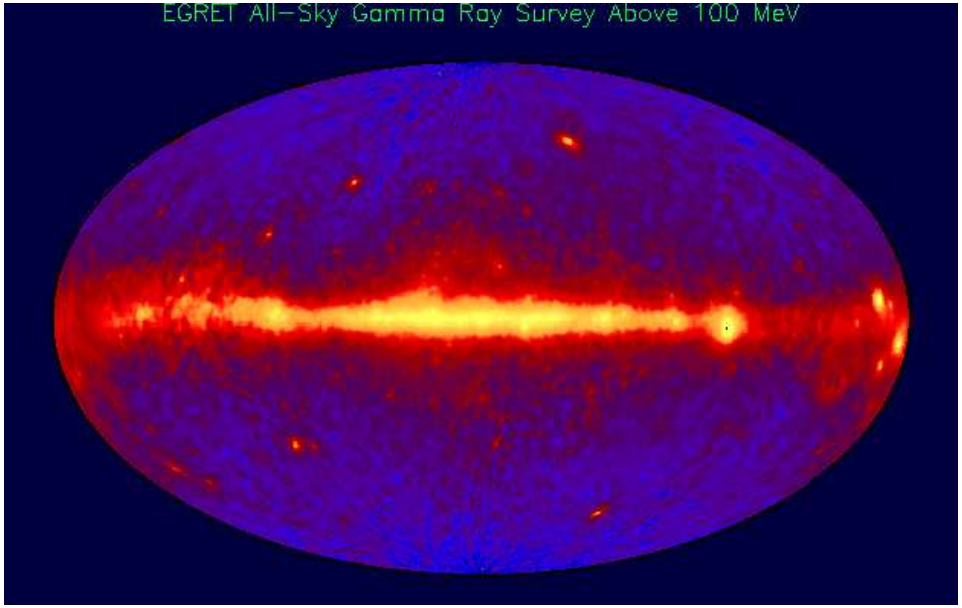
Distribution of ^{26}Al emission from CGRO/COMPTEL; concentrated on starbirth regions.



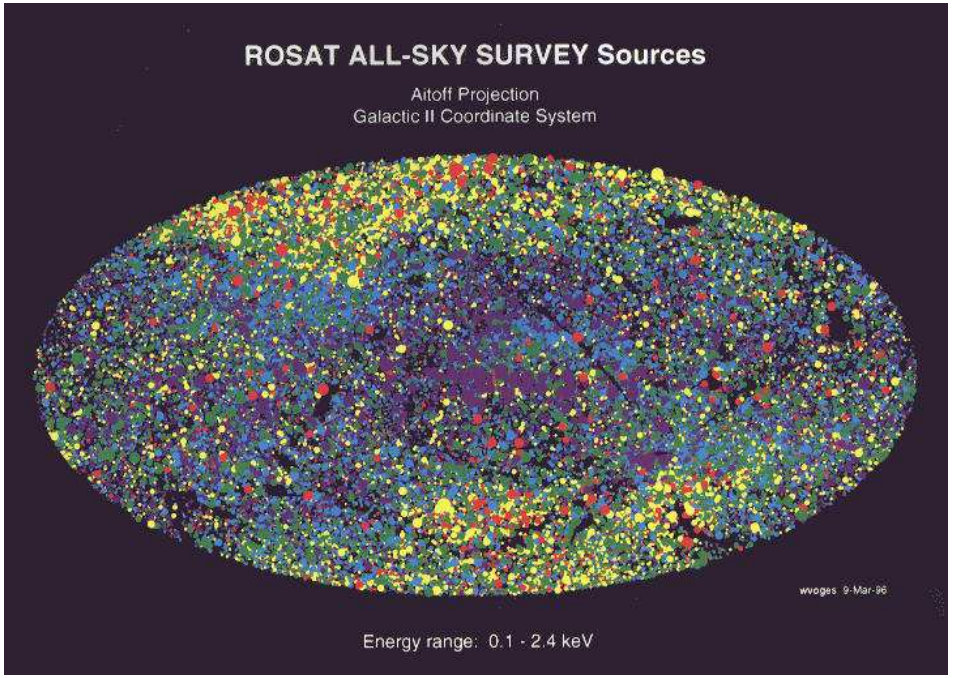
With high resolution spectroscopy (*INTEGRAL*-SPI):

- Rotation of the Milky Way seen in ^{26}Al.
- Equilibrium mass of ^{26}Al: $2.8 \pm 0.8\,M_\odot$
- Rate of core collapse supernovae: 1.9 ± 1.1 events per century.

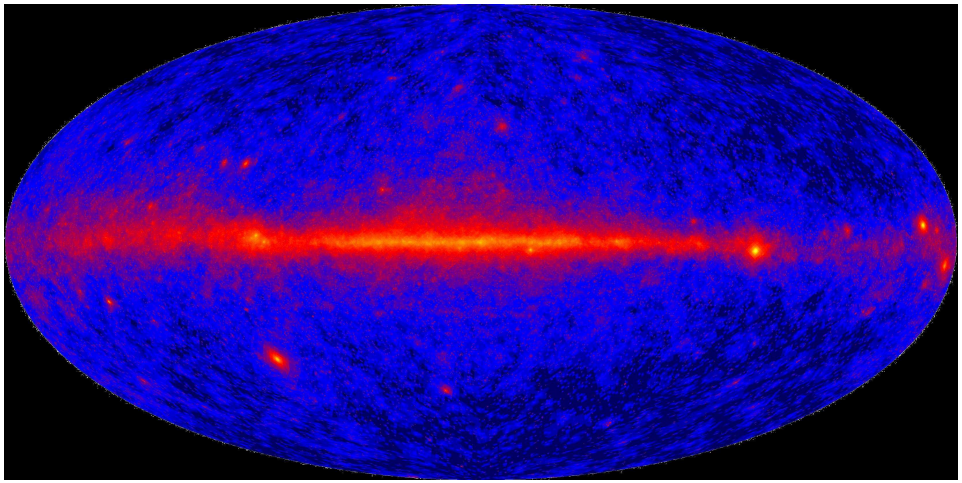
(Diehl et al., 2006)



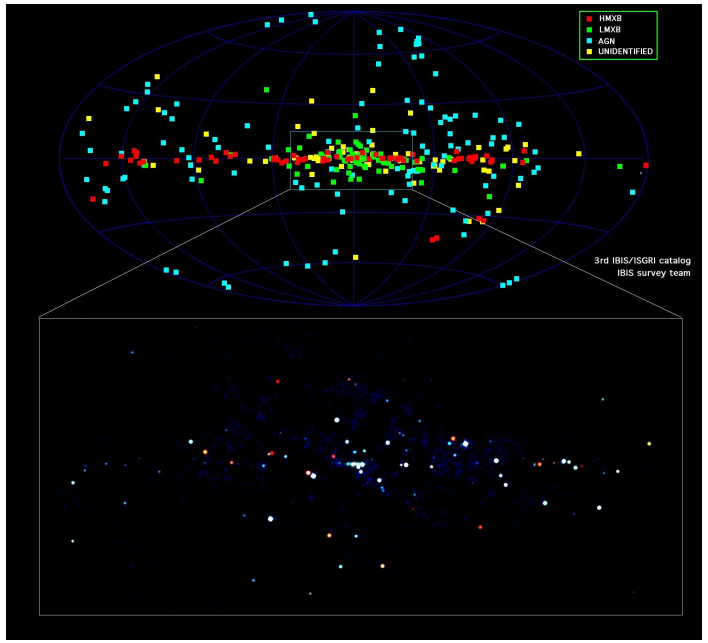
At even higher energies (CGRO/EGRET; >100 MeV):
emission from Milky Way due to the interaction of cosmic rays with the ISM.



Low latitudes dominated by stellar X-ray sources, high latitudes by hard extragalactic sources.



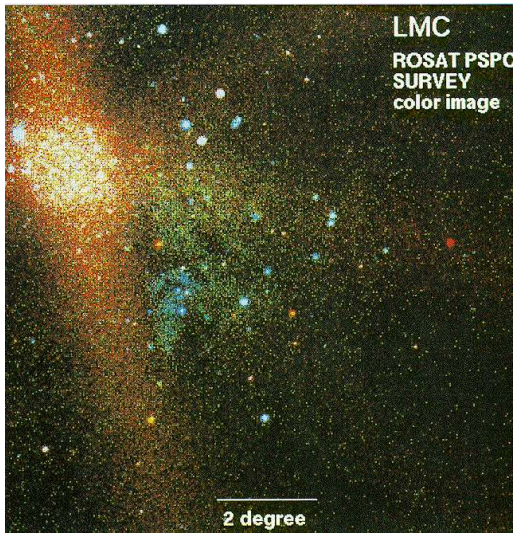
NASA/GSFC/Stanford
Fermi (formerly *GLAST*) can now produce similar skymaps in about one week



Distribution of gamma-ray point sources
$\Longrightarrow$ High Mass X-Ray Binaries are disk population!

(3rd *INTEGRAL* source catalogue)

The Large Magellanic Cloud



The LMC, an irregular galaxy, from the RASS, colors are hardness ratio $(H-S)/(H+S)$; very red: Super Soft Sources.

Super Soft Sources

Super Soft Sources (SSS) are X-ray binaries characterized by

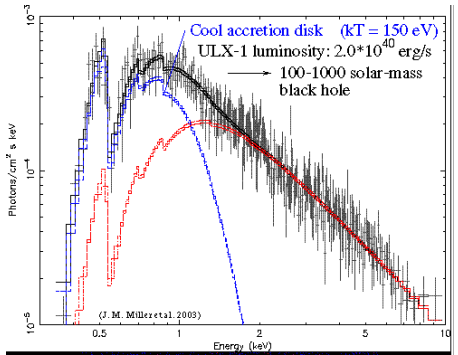
- extremely steep thermal spectra, $T_{\rm BB} \sim 3 \times 10^5\,{\rm K}$
- high luminosity (close to $L_{\rm Edd}$ for $M = 1\,M_\odot$)

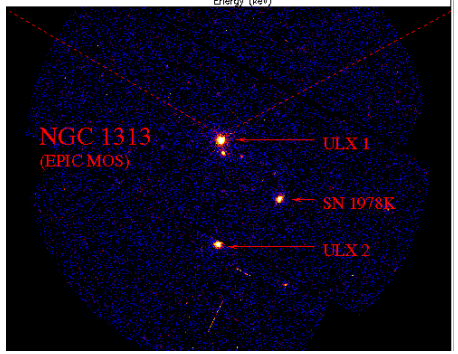
Five sources in the LMC (Cal 83, Cal 87, and others), two in the SMC, 15 in M31.

Theories for their nature (Kahabka, Pietsch & Hasinger, 1994):

- accretion disks around white dwarfs
- steady hydrogen burning on accreting WDs

Other models appear to be ruled out due to the high luminosity.





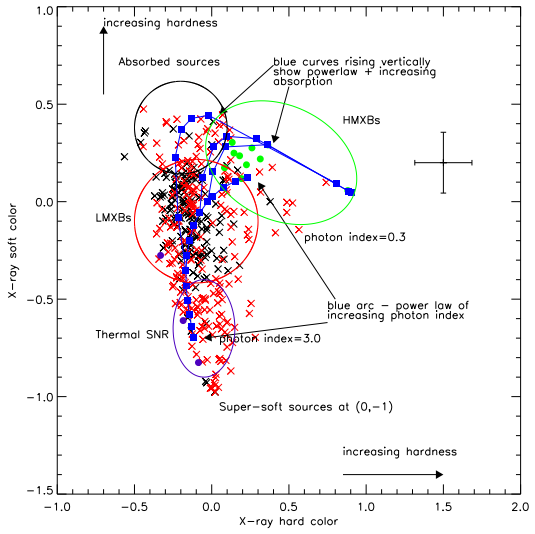
Ultraluminous X-ray Sources (ULX): Soft sources with luminosities comparable to Eddington for a 1000 $M_\odot$ black hole

$\Longrightarrow$ intermediate mass black holes?

Origin and interpretation still unclear

J.Miller/ESA

Color Color Diagrams

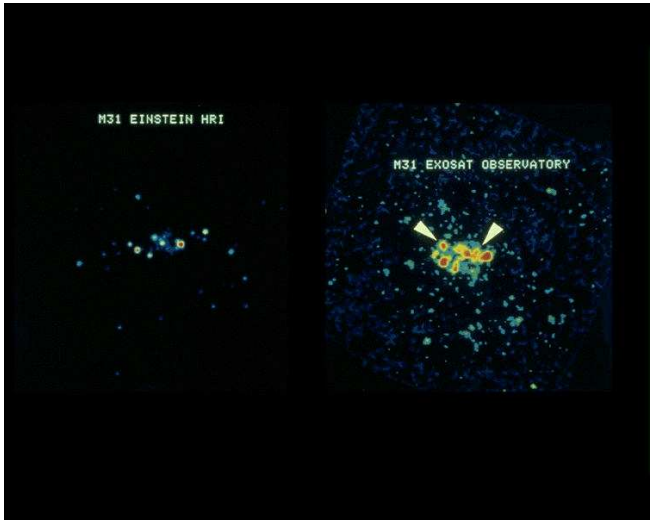


The location of sources in an X-ray color-color diagram depends on the source type and the intrinsic absorption.

(Prestwich et al., 2003, Fig. 4)

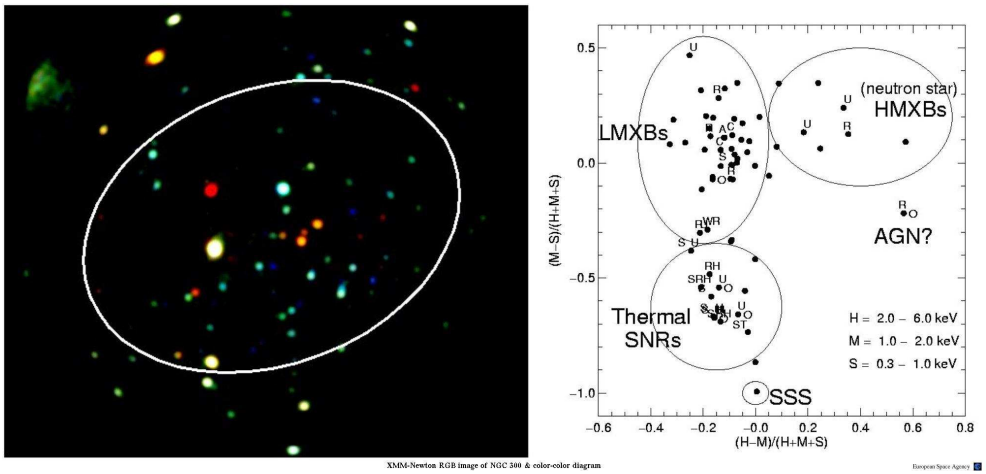
NGC 300 (Sc), M. Schirmer/ESO/2.2 m

Andromeda Galaxy



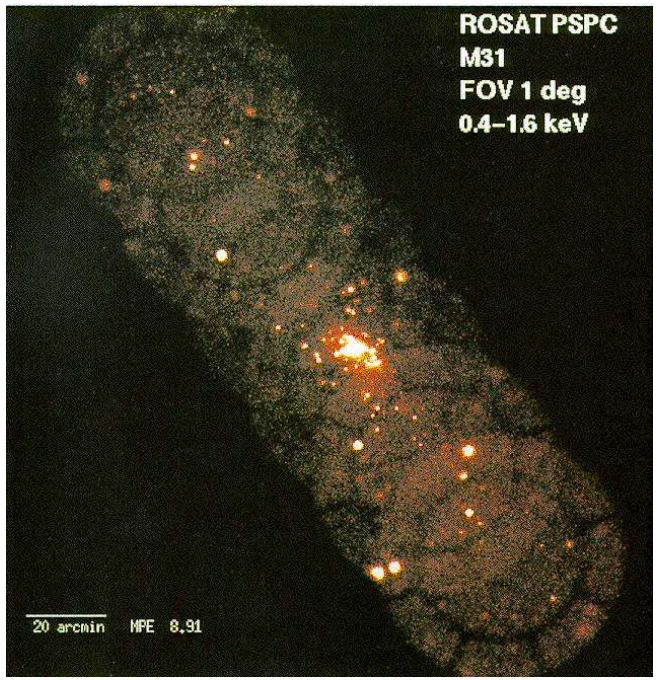
M31 as seen from *Einstein* and *EXOSAT*.

Andromeda nebula: At $d = 690$ kpc closest spiral galaxy to milky way.
First studies of Andromeda nebula with early imaging instruments.
Einstein: 108 individual point sources, L_X between 5×10^{36} erg s^{-1} and $> 10^{38}$ erg s^{-1} (Trinchieri et al., 1991), a few coincidences with SNRs.
Total X-ray luminosity: 3×10^{39} erg s^{-1}

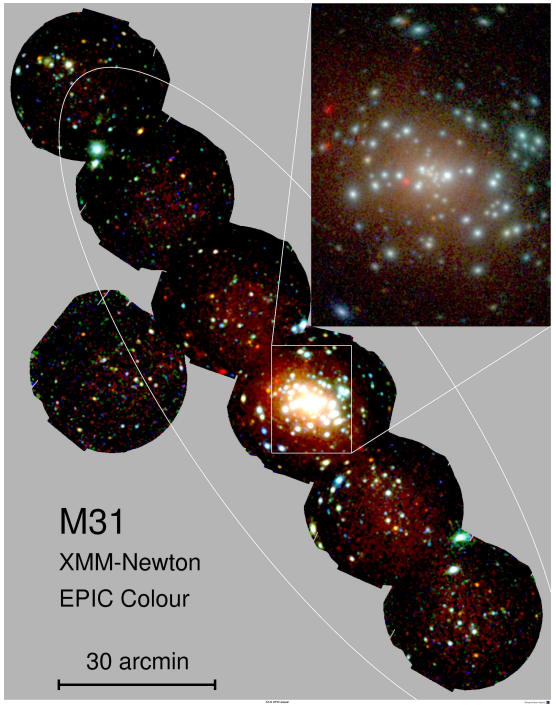


(Carpano et al., 2005)

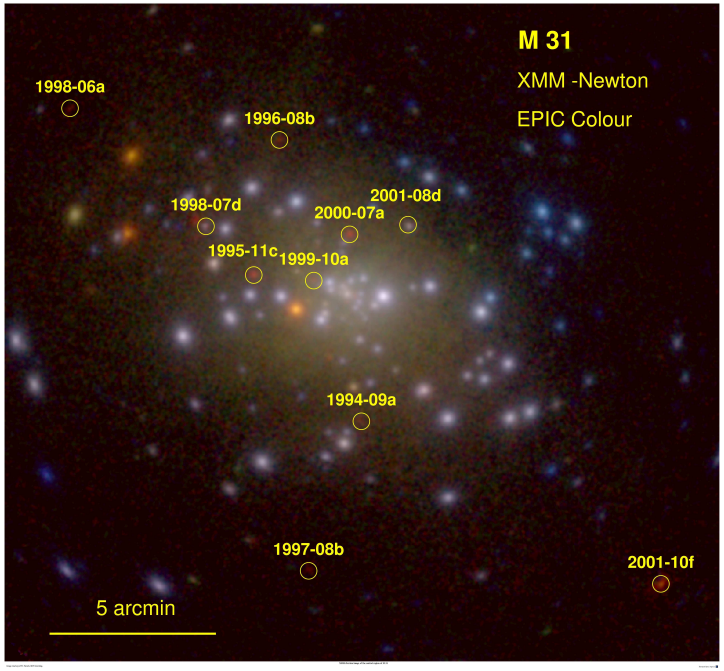
NGC 300: nearby galaxy, point sources classified with Color-Color diagram



M31, different deep *ROSAT* pointings (note characteristic PSPC fingerprints; Supper et al. (1997)). About 400 sources detected, 50 of which are foreground (more than in *UHURU* catalogue!). Spectra or hardness ratios are compatible with accreting objects ($\Gamma \sim 2$, $N_{\rm H} \sim 10^{21}\,{\rm cm}^{-2}$); 15 SSS found; residual diffuse emission from hot gas.

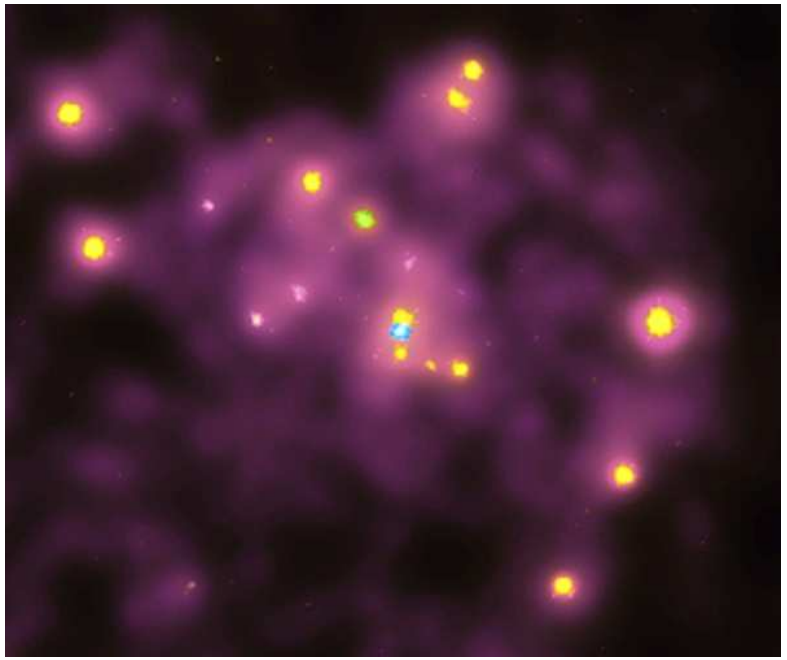


M31 with *XMM-Newton* (courtesy W. Pietsch and ESA)



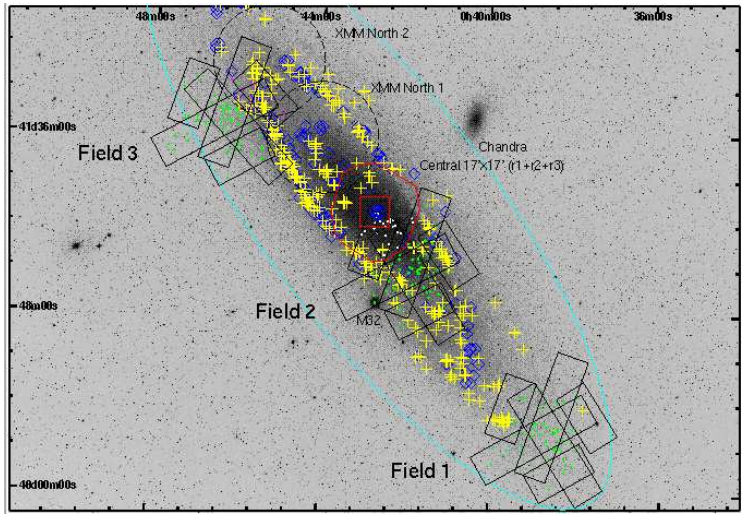
Novae in M31 with *XMM-Newton* (2000–2004; courtesy W. Pietsch and ESA)

X-ray: NASA/CXC/MPE/W.Pietsch et al; Optical: NOAO/AURA/NSF/T.Rector & B.A.Wolpa



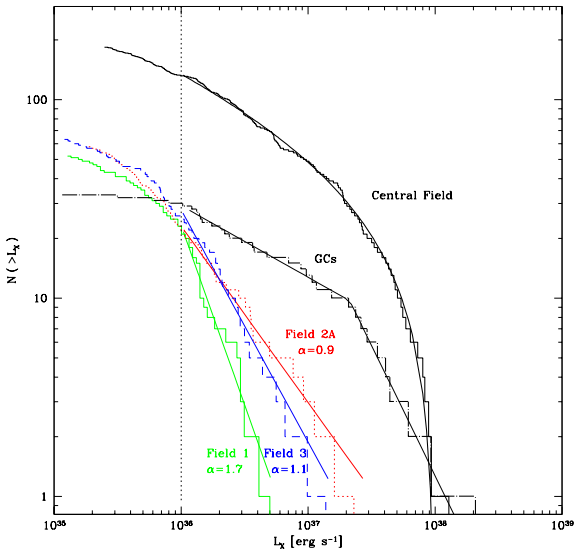
Center of Andromeda with Chandra: blue: very soft source close to supermassive black hole in center ($M \sim 10^7\, M_\odot$); other sources: XRBs

Andromeda Galaxy



Kong et al. (2003): XRB populations in different places in M31

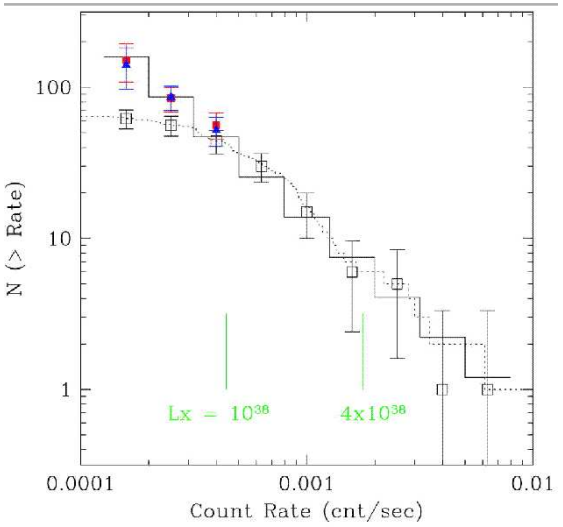
Andromeda Galaxy



Study of different fields of M31 with *Chandra* using the X-ray luminosity function (XLF): X-ray binary population depends on location.

(Kong et al., 2003)

Andromeda Galaxy



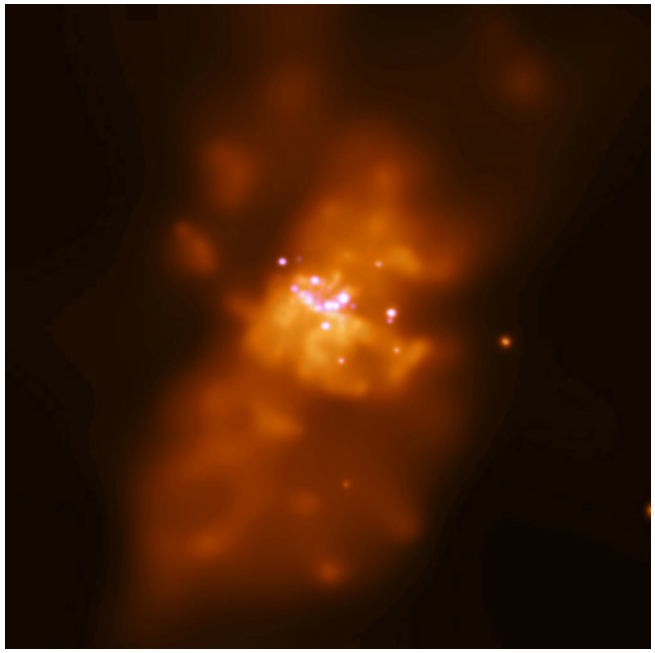
XLF for NGC 1316: similar to M31

(Kim & Fabbiano, 2004)

M82 (R. Gendler)

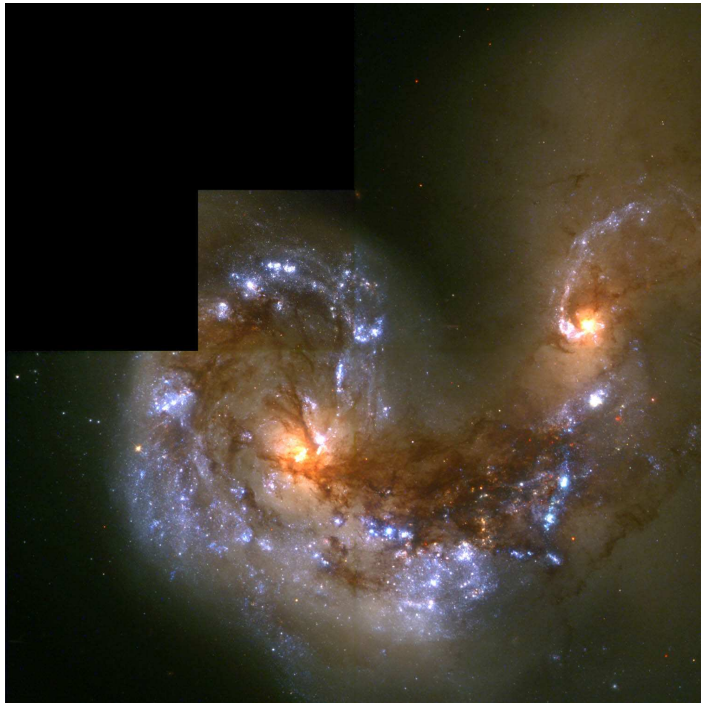
M82 (R. Gendler)

M82 (Chandra/CXC)

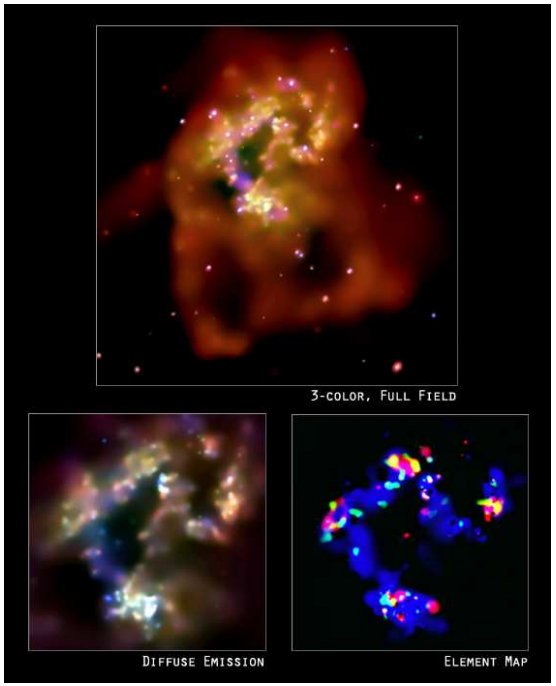


M82: Large population of XRBs in starburst region, hot gas flowing outwards.
(Starburst caused by close encounter with M81?)

The Antennae (NGC 4038/4039) © David M. Jurasevich



STScI/NASA

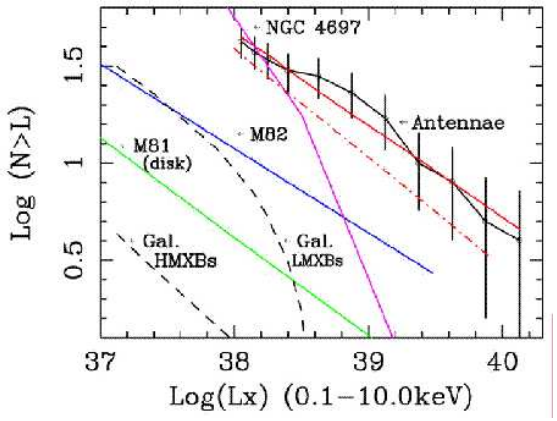


The Antennae: an extreme example for galaxy interaction

CXC/NASA (note, image flipped compared to previous ones)

STScI/NASA

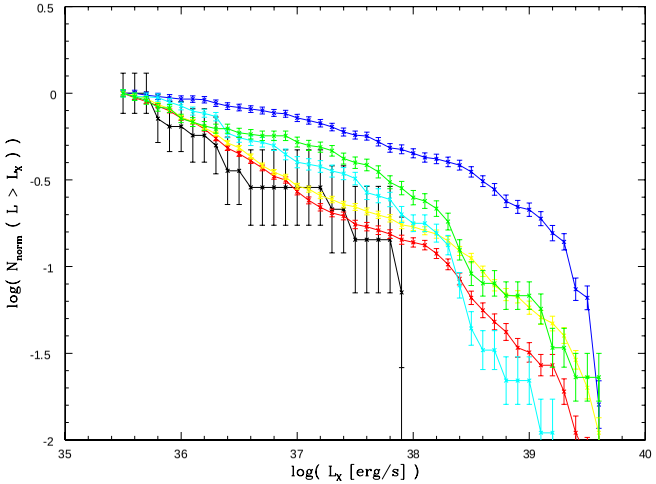
The Antennae



Antennae (Fabbiano & White, 2006)

Interacting galaxies show strongly increased number of XRB due to triggered star formation.

The Antennae



(Fabbiano & White, 2006)

For starbursts, predicted evolution of XLF (colors) and data agree well.

Figure shows XLF evolution for NGC 1569, starburst is 105–110 Myr old.

Carpano, S., Wilms, J., Schirmer, M., & Kendziorra, E., 2005, A&A, 443, 103

Diehl, R., et al., 2006, Nat, 439, 45

Fabbiano, G., & White, N. E., 2006, in Compact stellar X-ray sources, ed. W. Lewin, M. van der Klis, (Cambridge: Cambridge Univ. Press), 475–506

Kahabka, P., Pietsch, W., & Hasinger, G., 1994, A&A, 288, 538

Kim, D.-W., & Fabbiano, G., 2004, ApJ, 611, 846

Kong, A. K. H., DiStefano, R., Garcia, M. R., & Greiner, J., 2003, ApJ, 585, 298

Prestwich, A. H., Irwin, J. A., Kilgard, R. E., Krauss, M. I., Zezas, A., Primini, F., Kaaret, P., & Boroson, B., 2003, ApJ, 595, 719

Supper, R., Hasinger, G., Pietsch, W., Trümper, J., Jain, A., Magnier, E. A., Lewin, W. H. G., & van Paradijs, J., 1997, A&A, 317, 328