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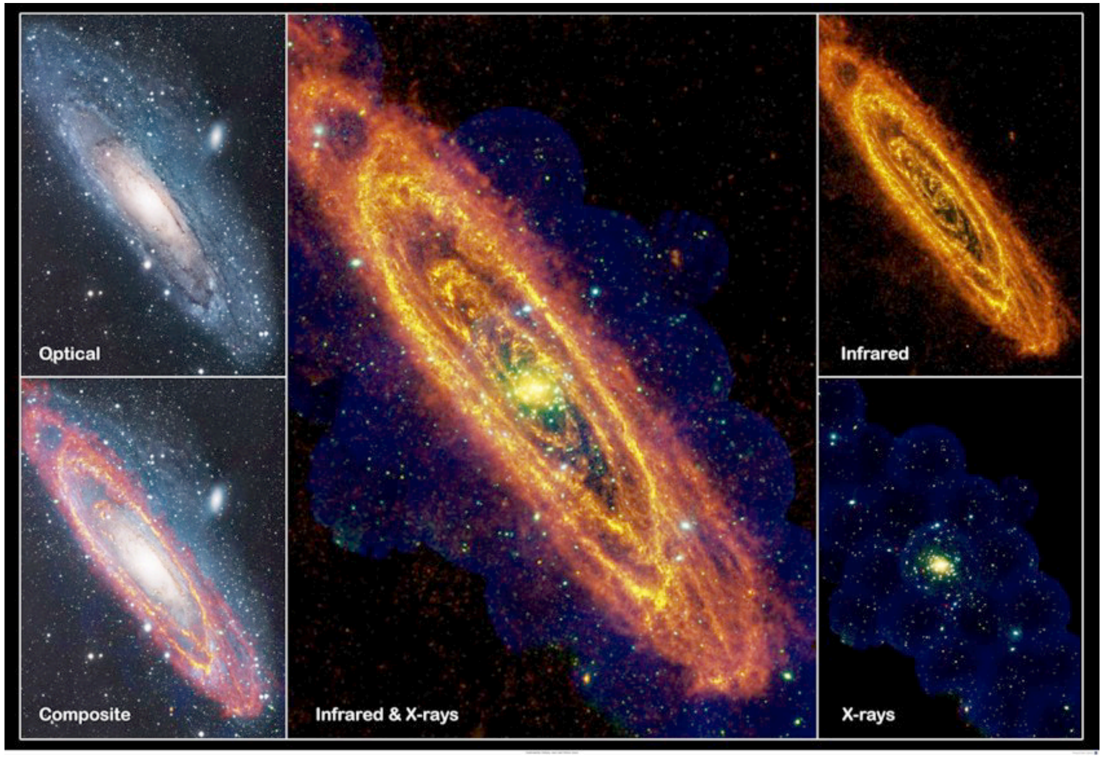

Optical identification of X-ray sources in nearby galaxies

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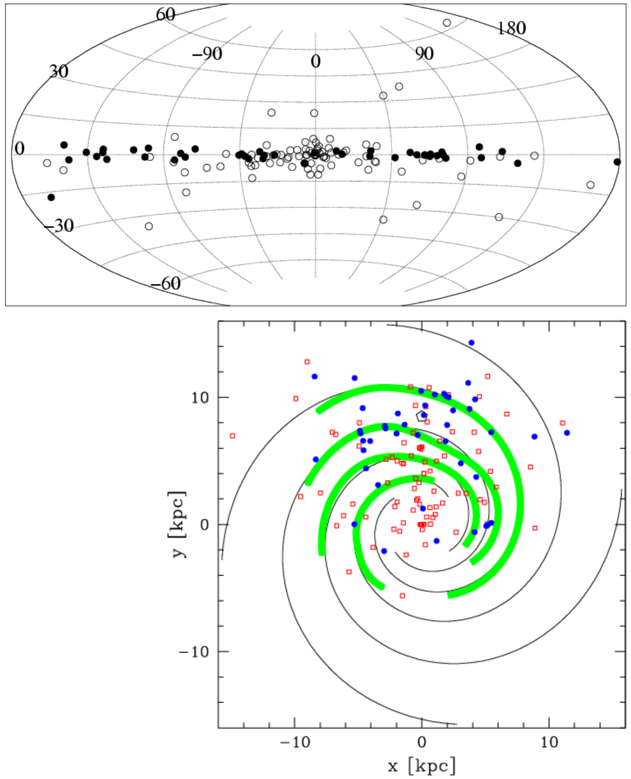
4MOST Workshop, 2012, Potsdam

X-ray sources in nearby galaxies

- X-ray sources in galaxies: binary systems with white dwarfs, neutron stars, and black holes, as well as supernova remnants.
- Cataclysmic variables (CVs), X-ray binaries (XRBs):
  - thermonuclear burning on the surface,
  - acceleration and scattering processes in the accretion stream,
  - accretion disk.
- Pulsar wind nebulae, in which particles are accelerated in their strong magnetic fields.
- Supernova remnants (SNRs):
  - hot ($10^{6\text{-}7}$ K) gas and
  - accelerated particles.

X-ray binary population studies

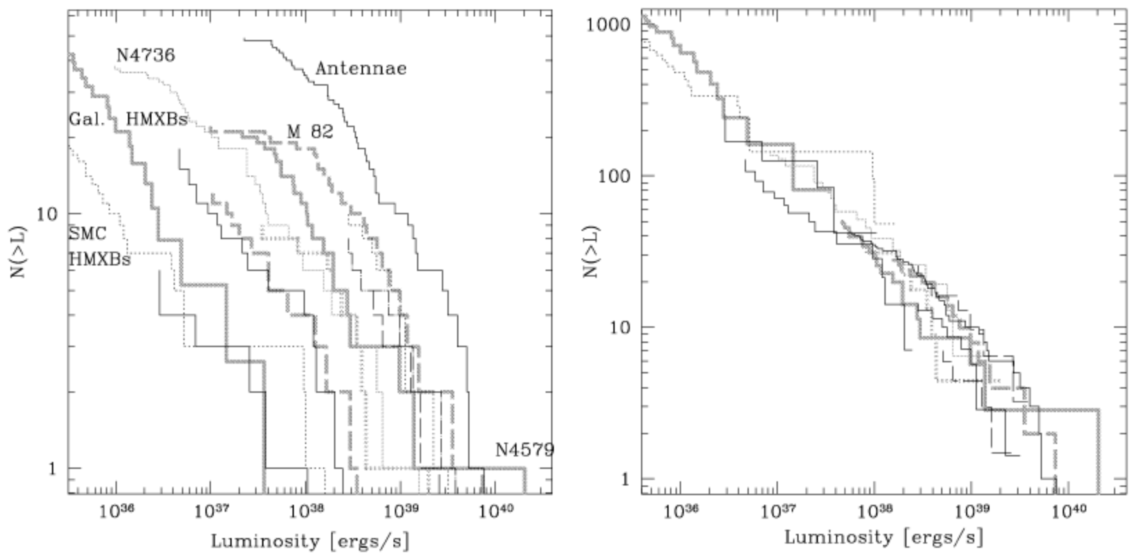
- A neutron star or a black hole accretes matter from a normal star.
- There are two major types of XRBs:
  1. High-Mass X-ray Binaries (HMXBs): massive companion (OB star), age = 10^{6-7} a.
  2. Low-Mass X-ray Binaries (LMXBs): low-mass companion (~ 1 M_{sun}), age = 10^{9-10} a.
- Populations of HMXBs and LMXBs are indicative of young and old stellar population in a galaxy, respectively.



Distribution of HMXBs (filled circles) and LMXBs (open circles) in the Milky Way (Grimm et al., 2002).

X-ray binary population studies

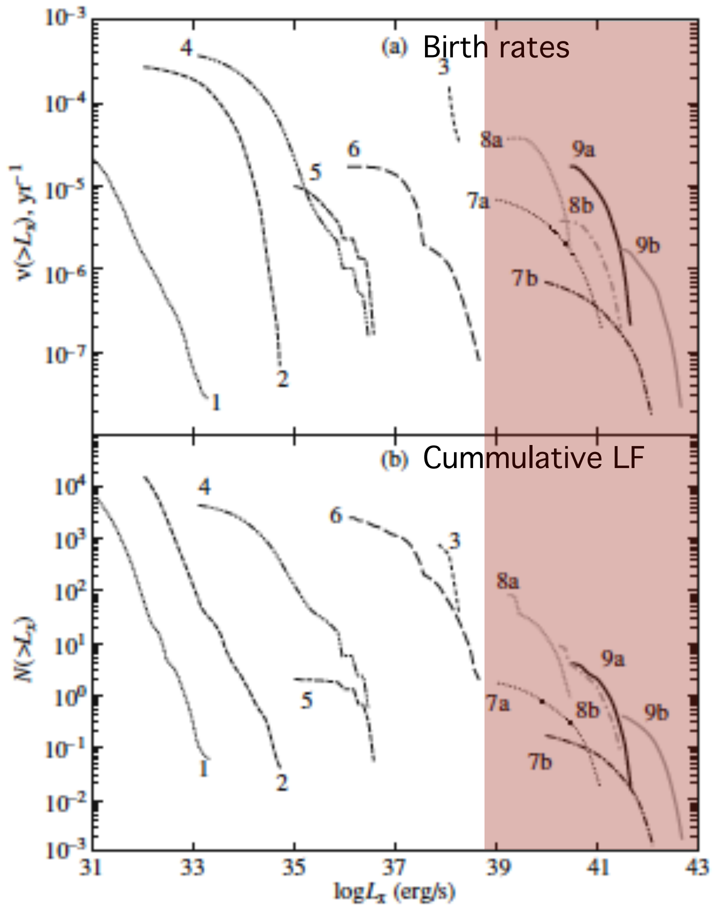
- X-ray luminosity functions (XLFs) of HMXBs scale with star-formation rate in a galaxy.
- XLF of LMXBs scale with the mass of a galaxy.
- XLFs of different galaxies have a similar shape (Grimm et al. 2003, Zezas & Fabbiano 2002, Prestwich et al. 2009, etc.).



Grimm et al., 2003

X-ray binary population studies

- Comparison of XLFs to those calculated with population synthesis models for compact sources and their binary systems (e.g., “Star Track”, Belczynski et al. 2008; “Scenario Machine”, Bogomazov & Lipunov, 2008).
- Improve simulations of binary synthesis and evolution.
- Derive the populations from observed XLF of further distant galaxies.



Bogomazov & Lipunov, 2008

How to classify X-ray sources

1. X-ray parameters:
   1. Detection likelihood
   2. Position
   3. Fluxes (+ upper limits) in the total band and sub-bands
   4. Hardness ratios (C_i is number of counts in the energy band i):

$$HR_i = \frac{C_{i+1} - Ci}{C_{i+1} + C_i}$$

2. Variability: short-term, long-term (multiple observations)
3. Spectral analysis
4. Counterparts at other energies
5. Optical to X-ray flux ratio: $log\left(\frac{f_{\rm X}}{f_{\rm opt}}\right) = log(f_{\rm X}) + \frac{m_V}{2.5} + 5.37$

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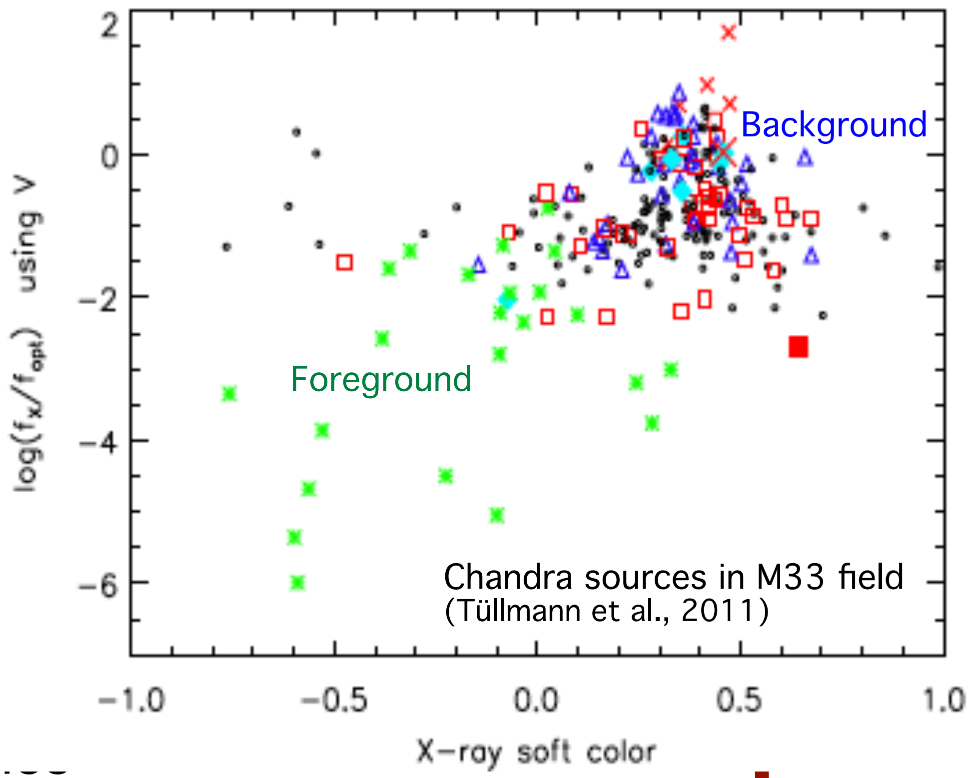

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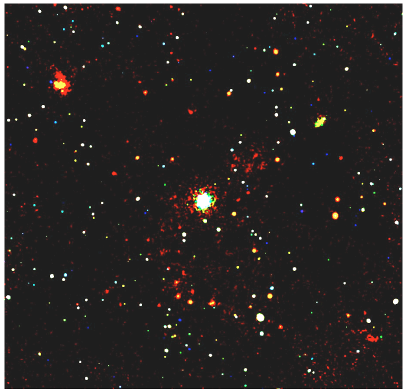
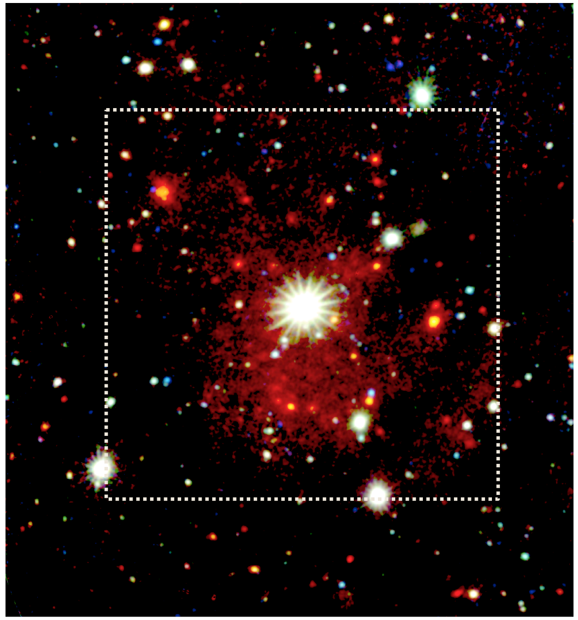
X-ray surveys of M33

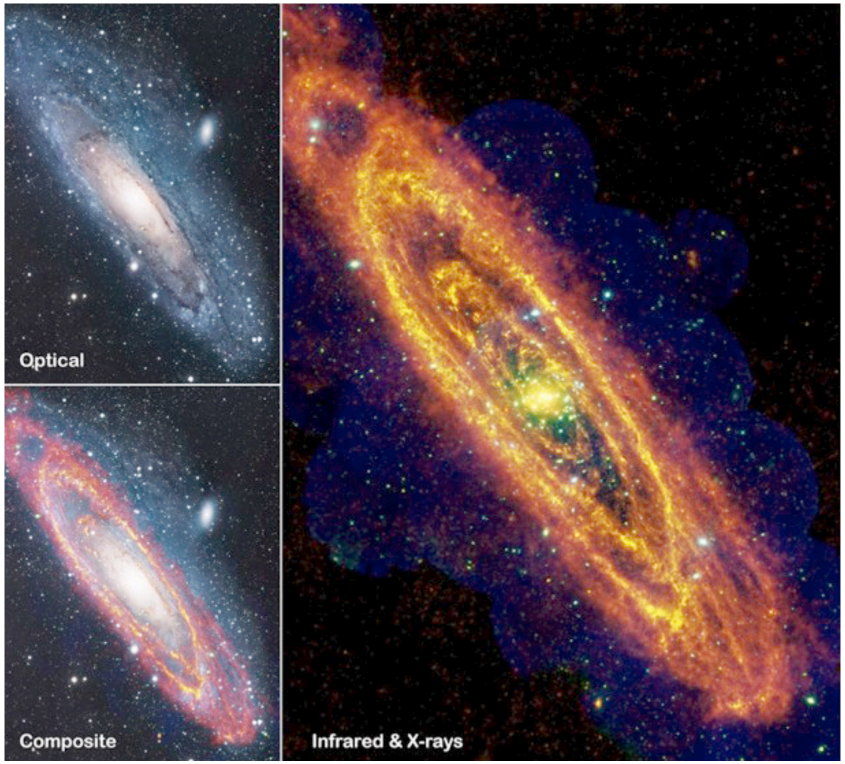


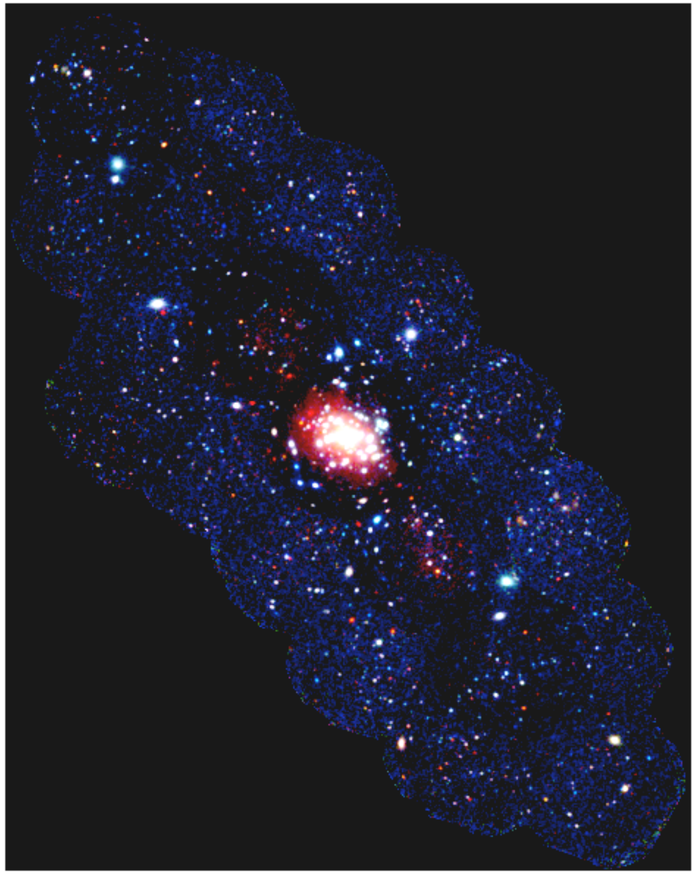
Chandra ACIS
Survey of M33
(ChASeM33)
Plucinsky et al., 2008,
Tüllmann et al., 2011:
662 sources,
$L_X > 2.4 \times 10^{34}$ erg/s



XMM-Newton surveys
1. Pietsch et al., 2004, Misanovic et al., 2006:
   350 sources, $L_X > 10^{35}$ erg/s
2. Williams et al.

XMM-Newton survey of M31





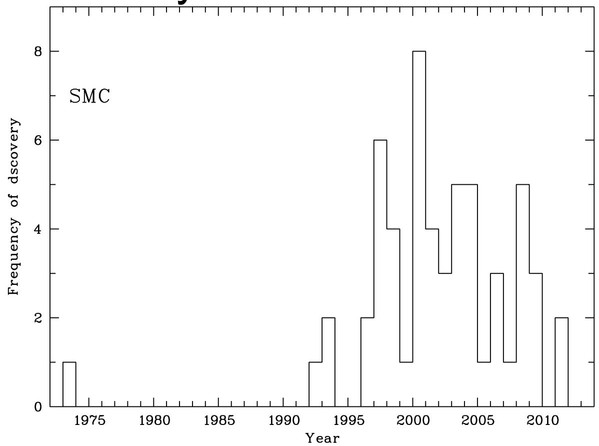
Pietsch et al., 2005, Stiele et al., 2011: 1897 sources, $L_X > 10^{35}$ erg/s

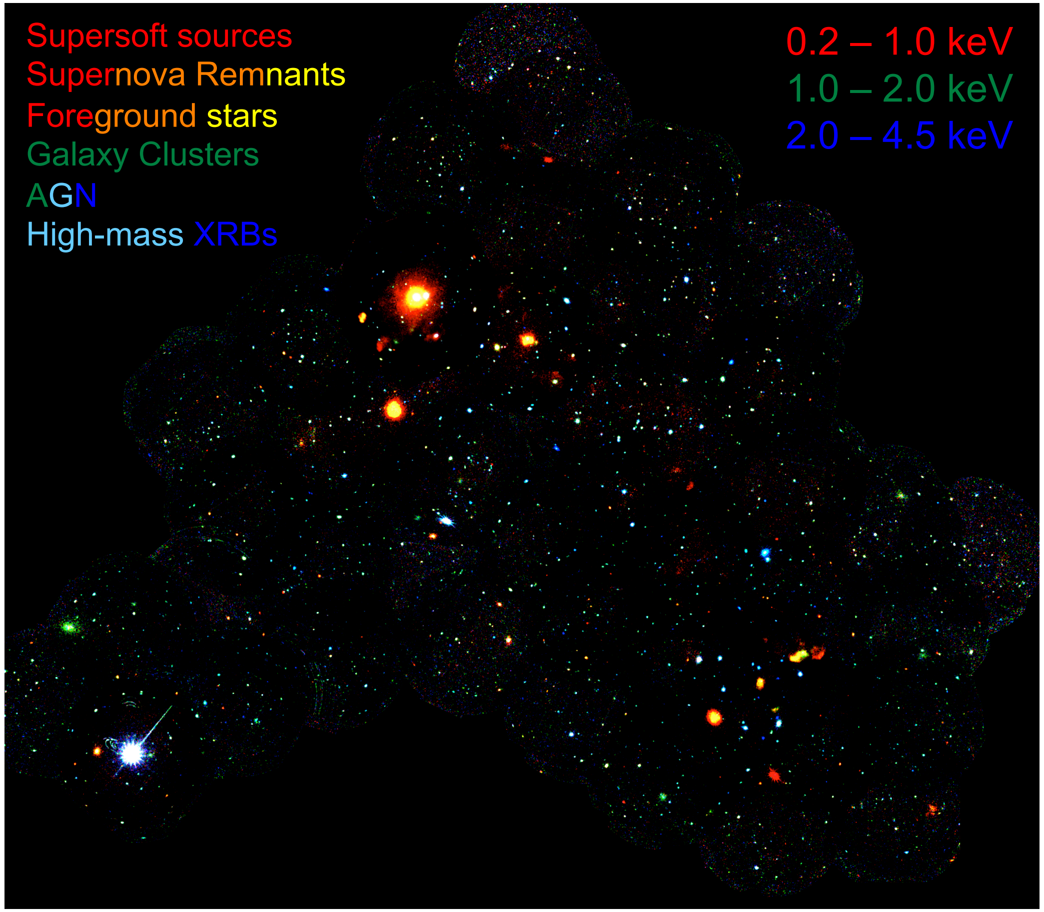
X-ray surveys of the SMC

XMM-Newton survey
Haberl et al., 2012,
Sturm et al., 2012:

- > 40 pointings
- 3053 sources, $L_X > 4.3 \times 10^{33}$ erg/s

Be/X-ray binaries: detections

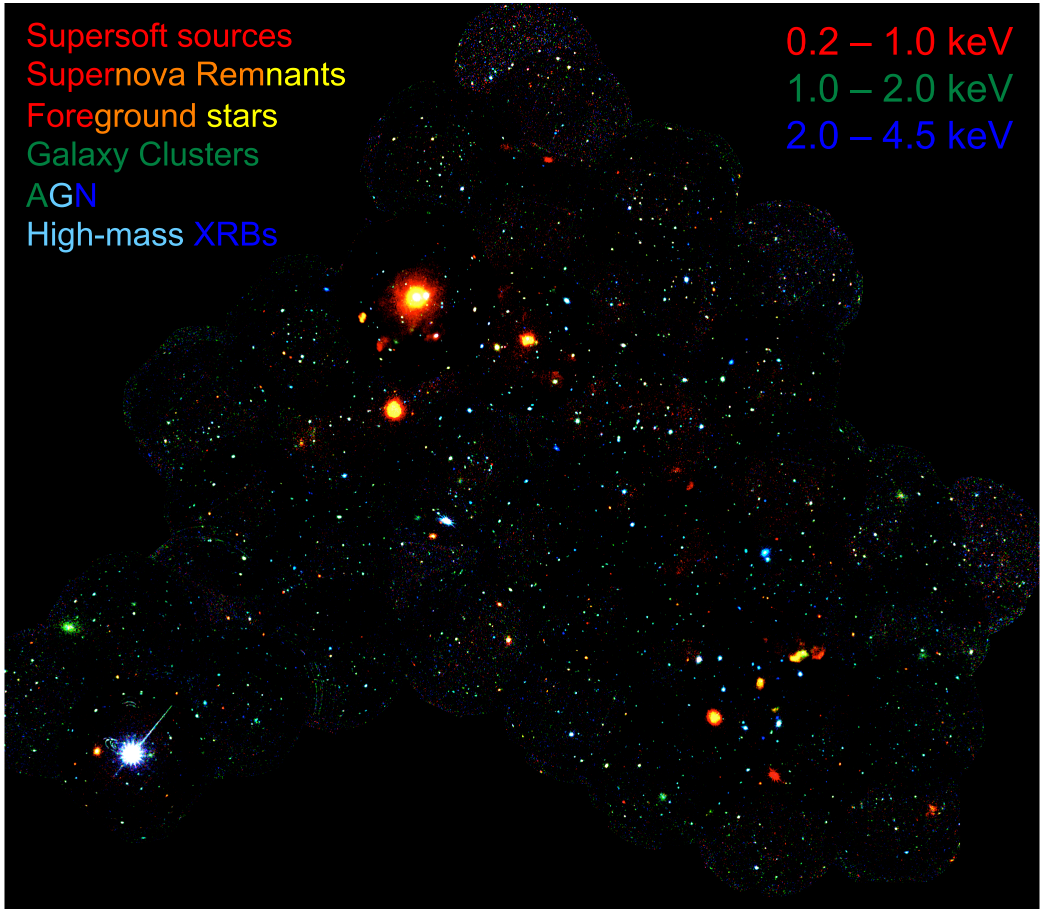




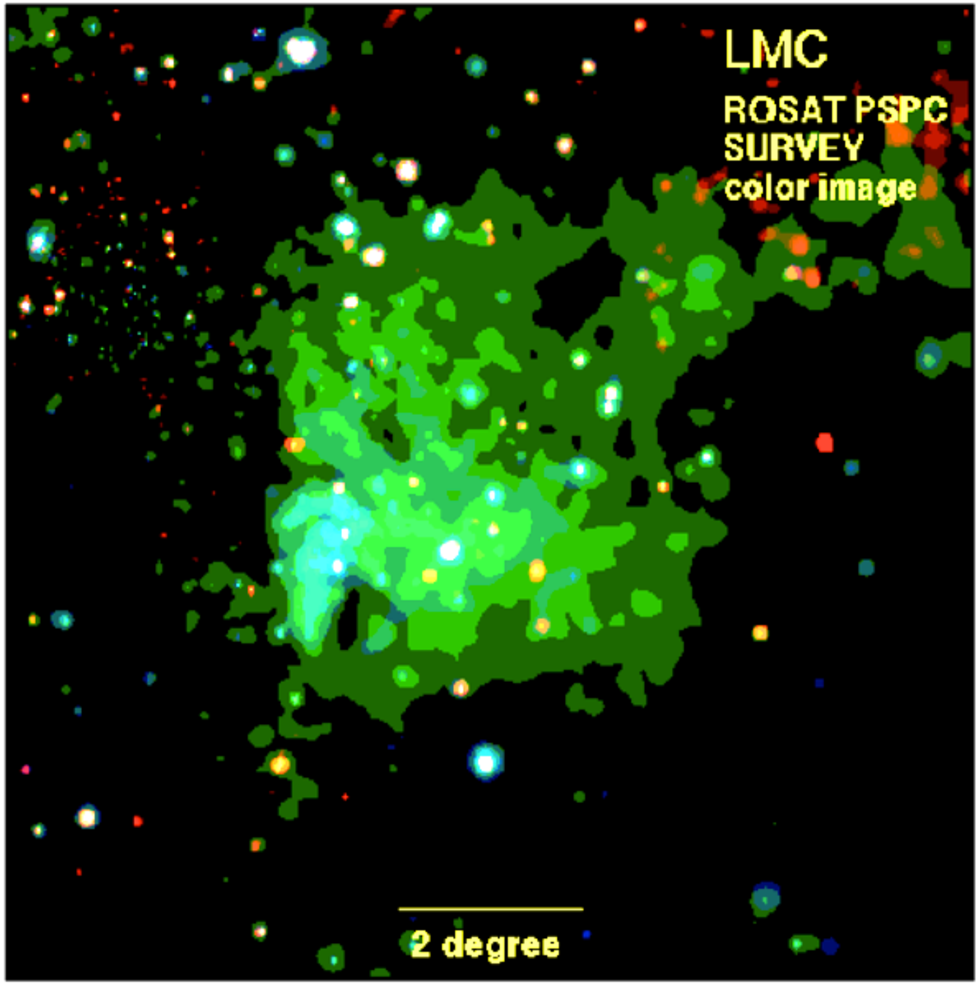
X-ray surveys of the SMC

Supersoft sources

- Old population (white dwarfs)
- Best observable in the Magellanic Clouds
- Classical SSS (stable H burning)
- Planetary Nebulae (cooling central star)
- Symbiotic Binary Systems (cool red giant)
- Be/WD X-ray binary (Sturm et al. 2012)

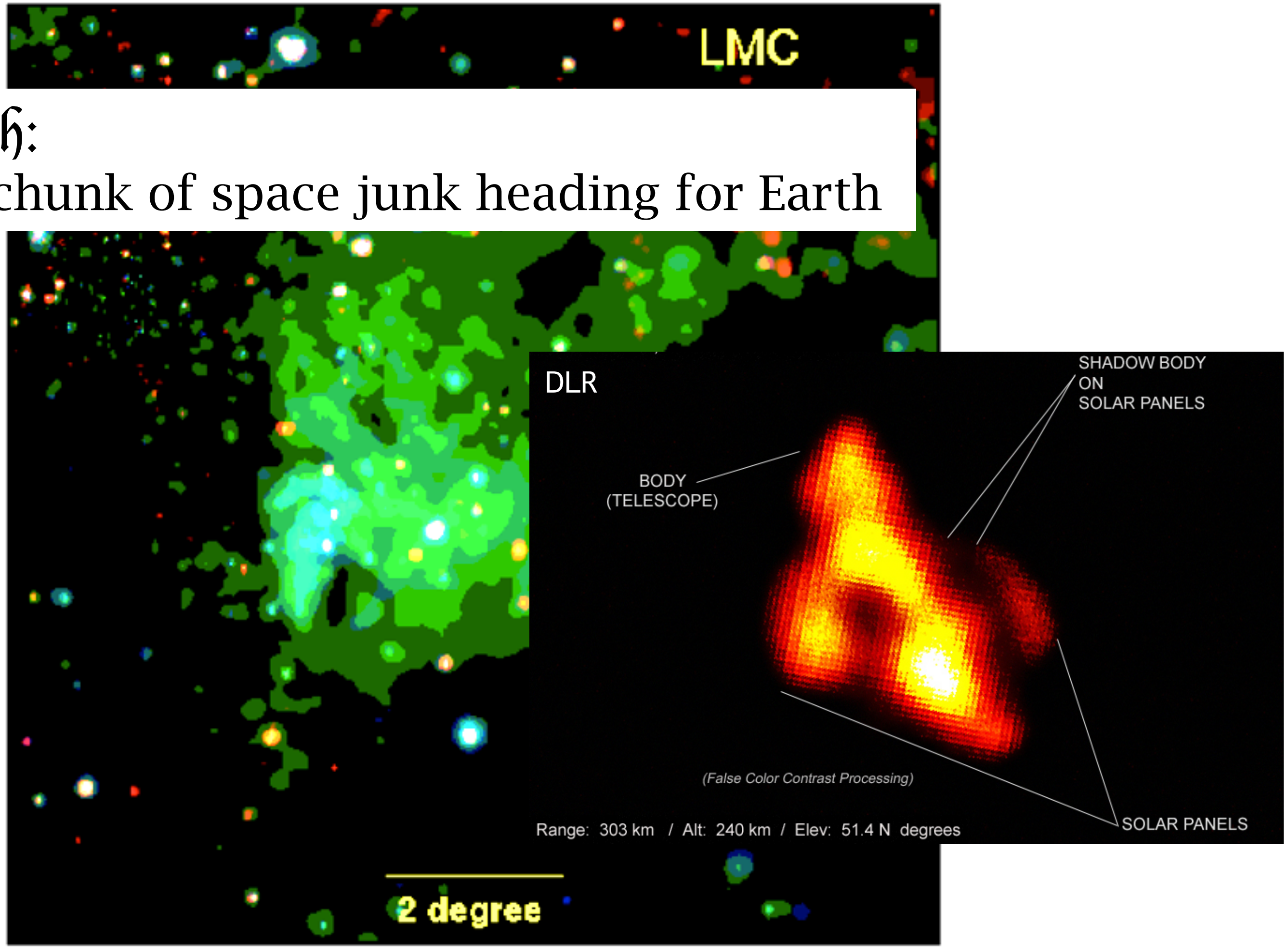


X-ray surveys of the LMC

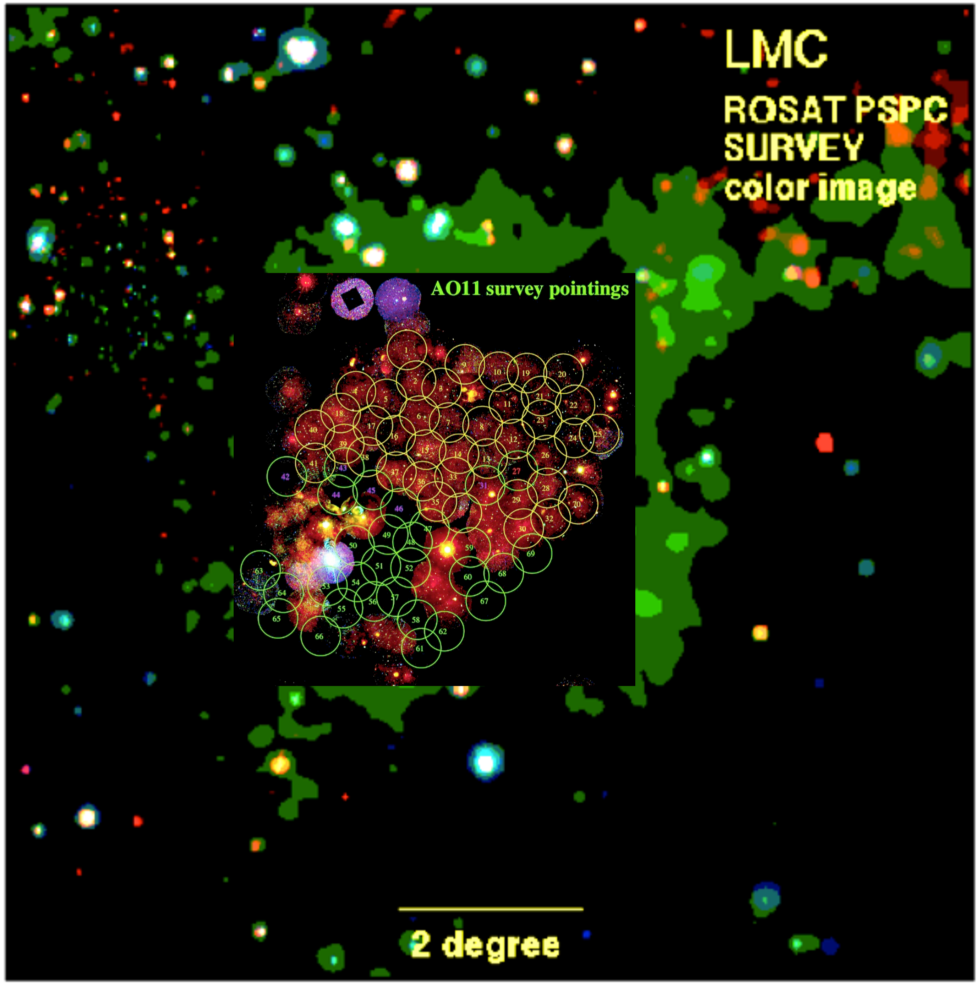


X-ray surveys of the LMC

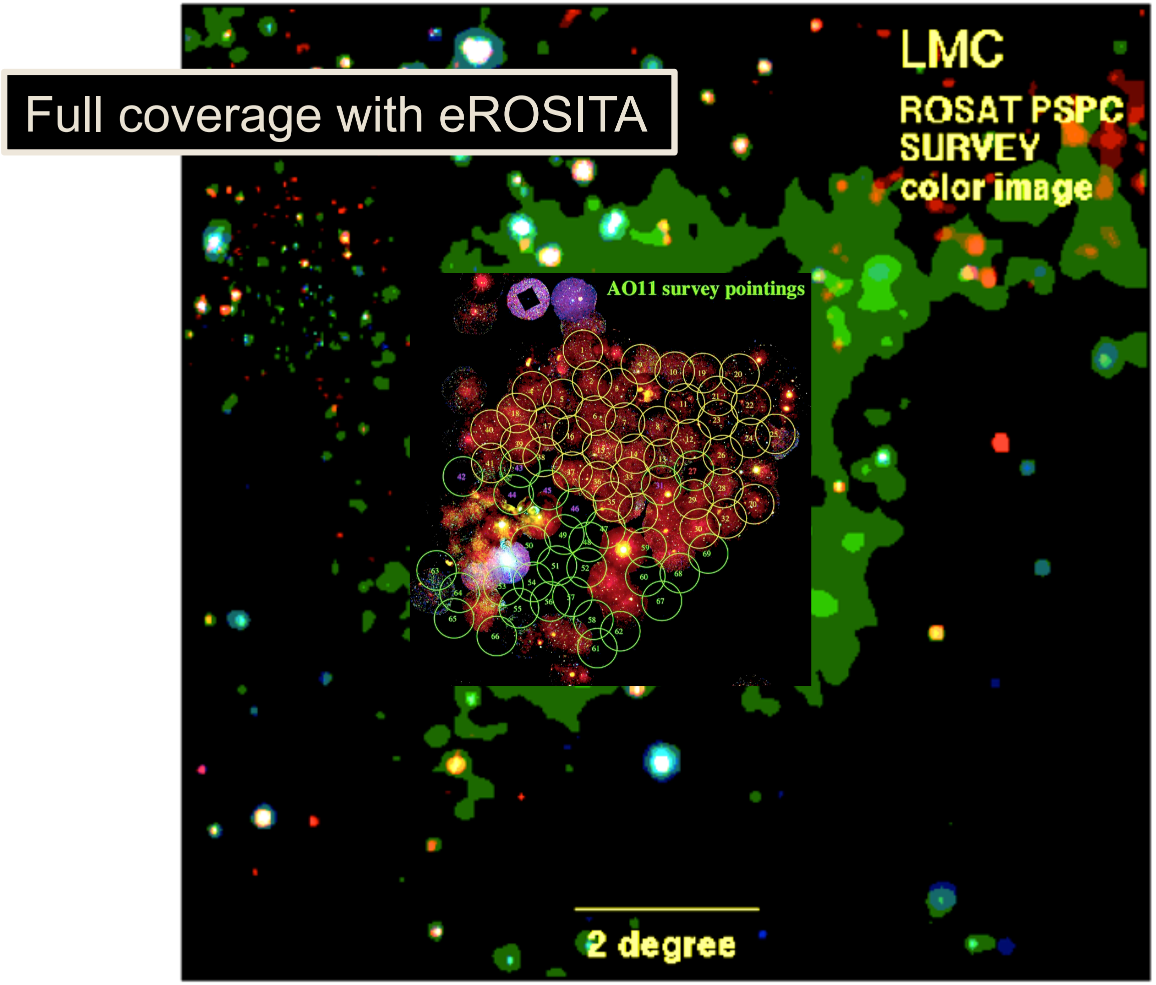
The Telegraph:
Second giant chunk of space junk heading for Earth



X-ray surveys of the LMC



X-ray surveys of the LMC



Optical spectroscopy

- Optical follow-up observations necessary to
  1. rule out foreground stars and background sources,
  2. detect optical emission of SNRs or HII regions, and
  3. find companion stars in binary systems.

- Chandra survey of M33: spectroscopy of the brighter X-ray sources with the HECTOSPEC spectrograph of the MMT.
- XMM-Newton survey of M31: imaging and spectroscopy of selected sources using the Dual Imaging Spectrograph of the 3.5 m telescope at the Apache Point Observatory.

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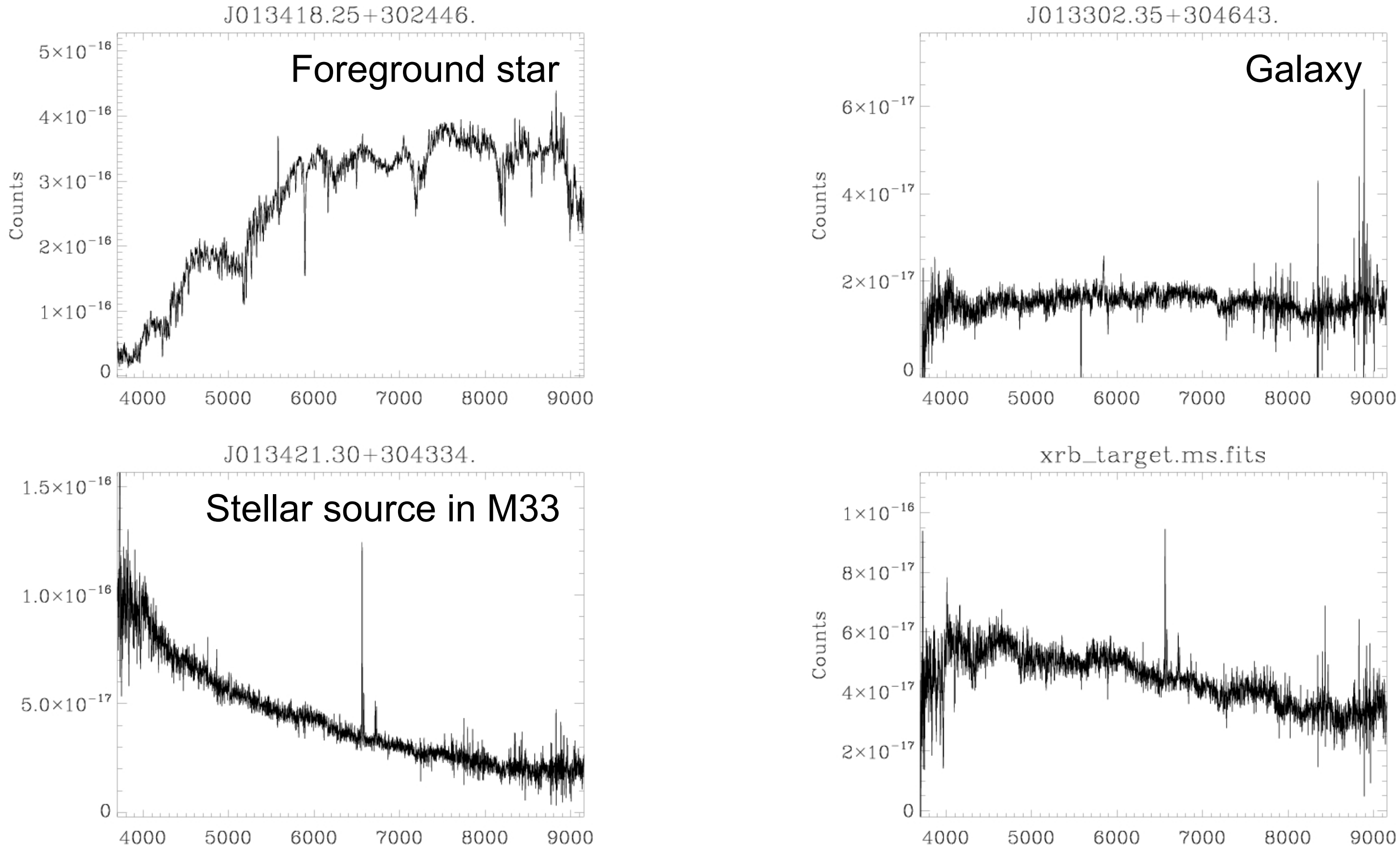
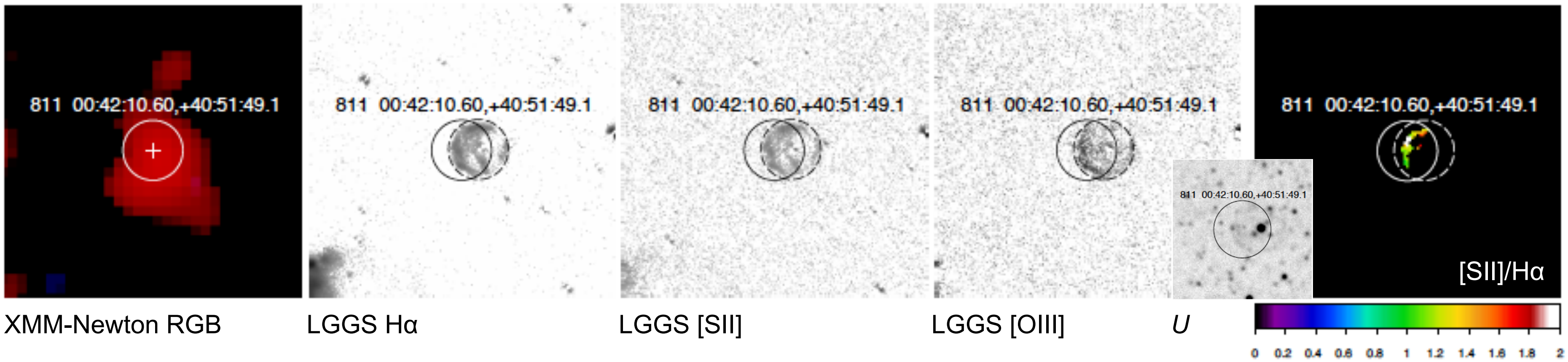
Spectra of sources in the M33 field



Courtesy P. Challis

Identification of SNRs in the optical



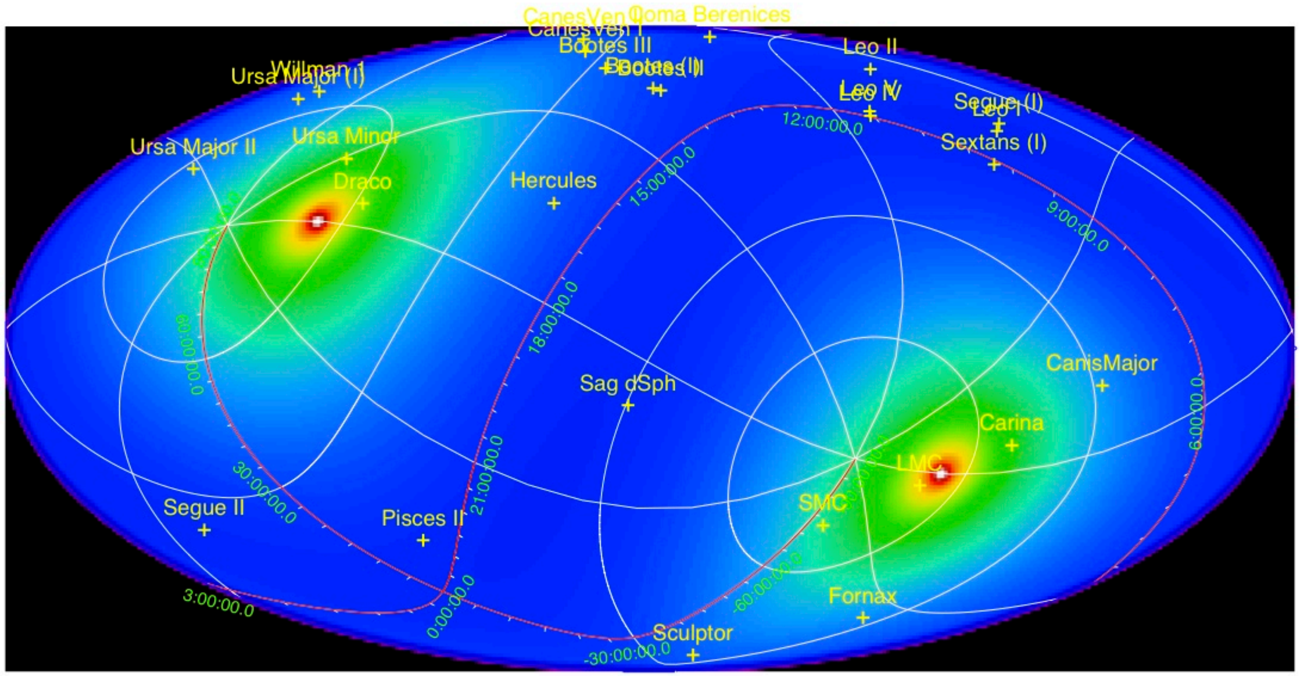
- Shocks of SNRs produce line emission like Hα, [SII], or [OIII] emission.
- Compared to HII regions, the flux ratio [SII]/Hα is higher (> 0.5 – 0.6).
- However, a bright, in particular, early-type star, can also be source of significant X-ray emission (e.g., source [SPH11] 811 in M31).

Observing galaxies with eROSITA

Estimates by Prokopenko and Gilfanov, 2009:

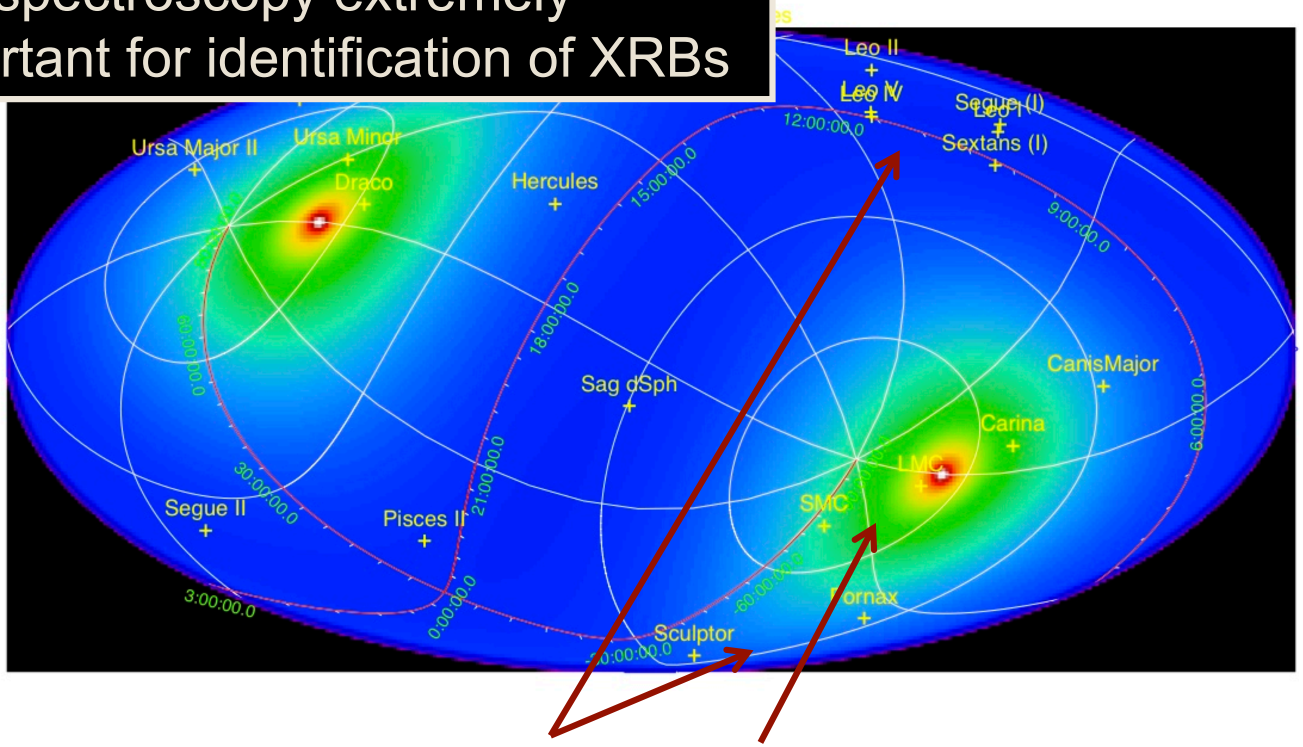
- Galaxies at D < 50 – 70 Mpc will be observed as extended sources.
- For D < 20 Mpc, the brightest sources in galaxies will be resolved.
- 7000 – 10000 late-type and about 8400 early-type galaxies will be detected.
- Ultra-luminous X-ray sources (ULXs) with L_X(0.5 – 8 keV) = 10^{40} erg/s at a distance of D = 35 Mpc will have a flux of 2 x 10^{-14} erg/s/cm^2, twice the sensitivity threshold of the all-sky survey. About 100 ULXs are expected within D = 35 Mpc.

Satellite galaxies of the Milky Way



Satellite galaxies of the Milky Way

Optical spectroscopy extremely important for identification of XRBs



- Obtain complete samples of old and young populations of X-ray sources.
- Test binary population synthesis models for NS and BH binaries.