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Deutsche Forschungsgemeinschaft
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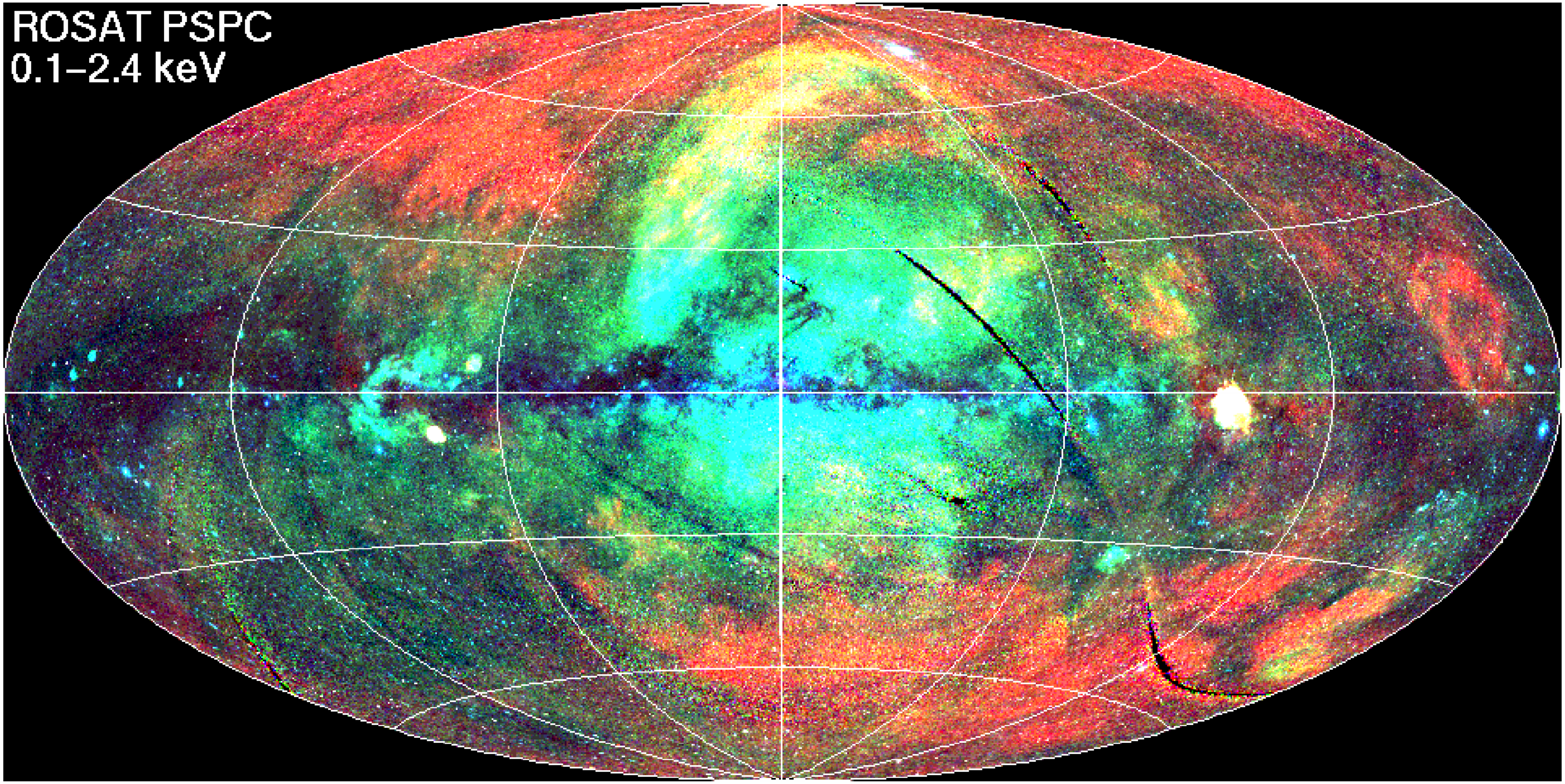
Manami Sasaki

# Shock-heated Plasma in the Interstellar Medium

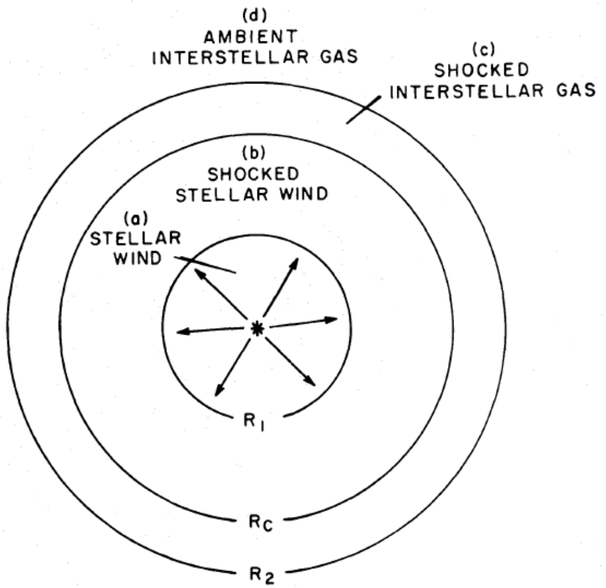
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

# ROSAT All-Sky Survey



# The Hot Interstellar Medium

- Shock waves caused by stellar winds of massive OB stars and supernova (SN) explosions are primary sources of matter and energy for the interstellar medium (ISM).
- Heat the ISM up to temperatures of ~$10^{6\text{-}7}$ K.
- Standard model for stellar wind-blown bubbles by Weaver et al. (1977).
- Multiple stellar bubbles form superbubbles of the scale of 100 - 1000 pc (Mac Low & McCray, 1988), in some cases also in combination with supernova explosions (Chu & Mac Low, 1990).




Main engines for the chemodynamical evolution of galaxies!



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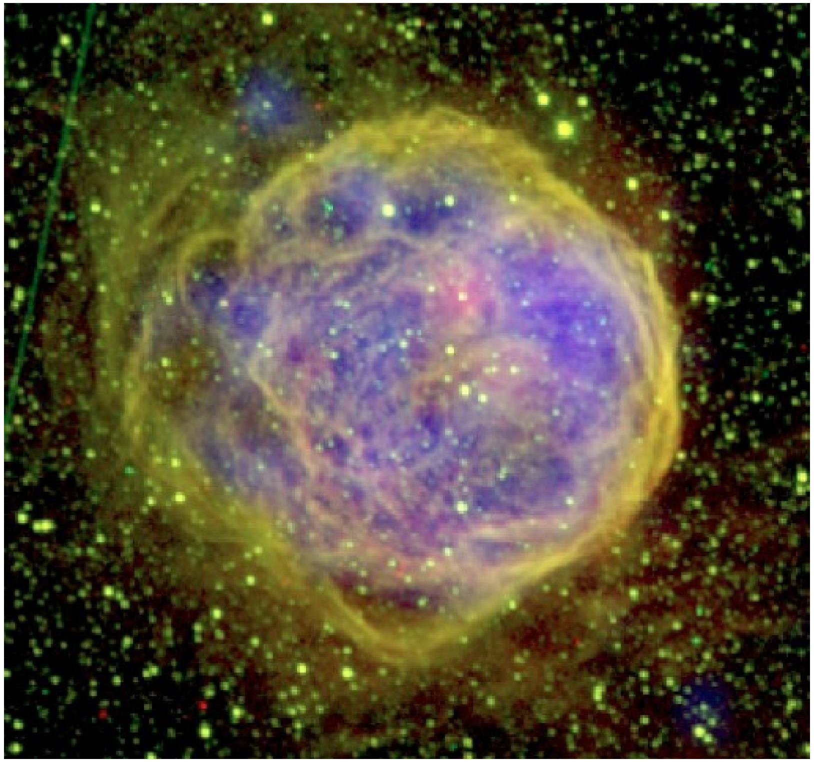
# X-ray Bright Superbubbles in the LMC

N44



N70

red: MCELS Hα, green: [O III], blue: X-rays



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# Ionization in Shocked Interstellar Plasma

- Supernova remnants, interstellar bubbles, and superbubbles are driven by the expansion of strong shock waves propagating into an inhomogeneous ISM.
- It takes $10^3$ to $10^4$ years to establish a collisional equilibrium:
  - After the ions have been shock-heated, electrons and ions each have to establish a Maxwellian distribution first.
  - Subsequently, electrons and ions have to reach equilibrium through Coulomb collisions.
- Time scales of fast adiabatic cooling and compression in such a dynamic environment can be much shorter than the atomic time scales for recombination and ionization.
- Turbulence between the hot plasma and the cooler ambient medium can cause intermediate temperatures.

# Study of X-ray Emission from the Hot ISM

Shocked interstellar plasma is characterized by non-equilibrium ionization!

Observe the hot interstellar medium in galaxies:

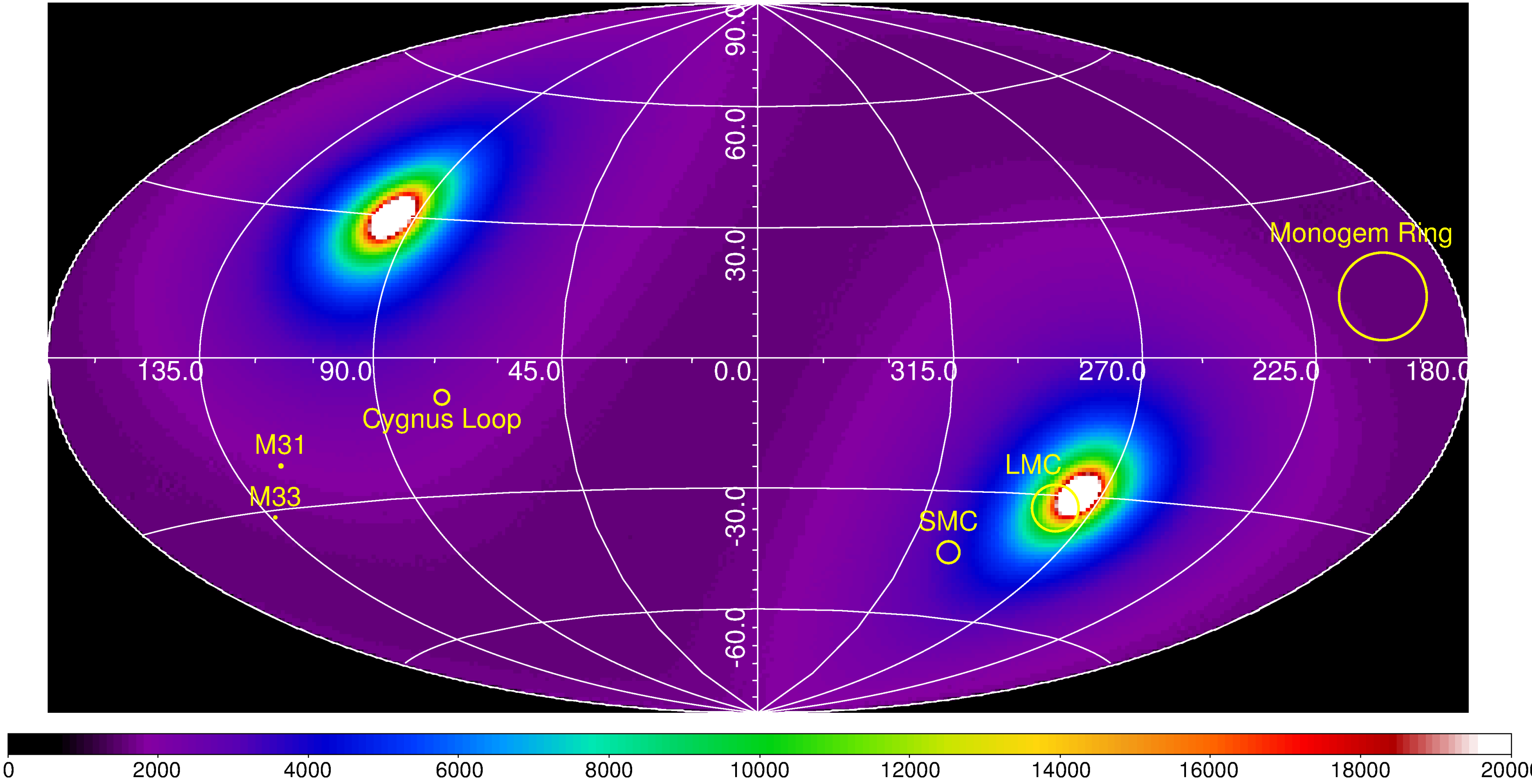
- globally (e.g., in the Magellanic Clouds),
- particular sources, i.e., SNRs and superbubbles in our Galaxy and the Magellanic Clouds.

Study the physics of the hot ISM:

- distribution of temperature, ionization states/ages, densities,
- chemical abundances, and
- turbulent mixing.

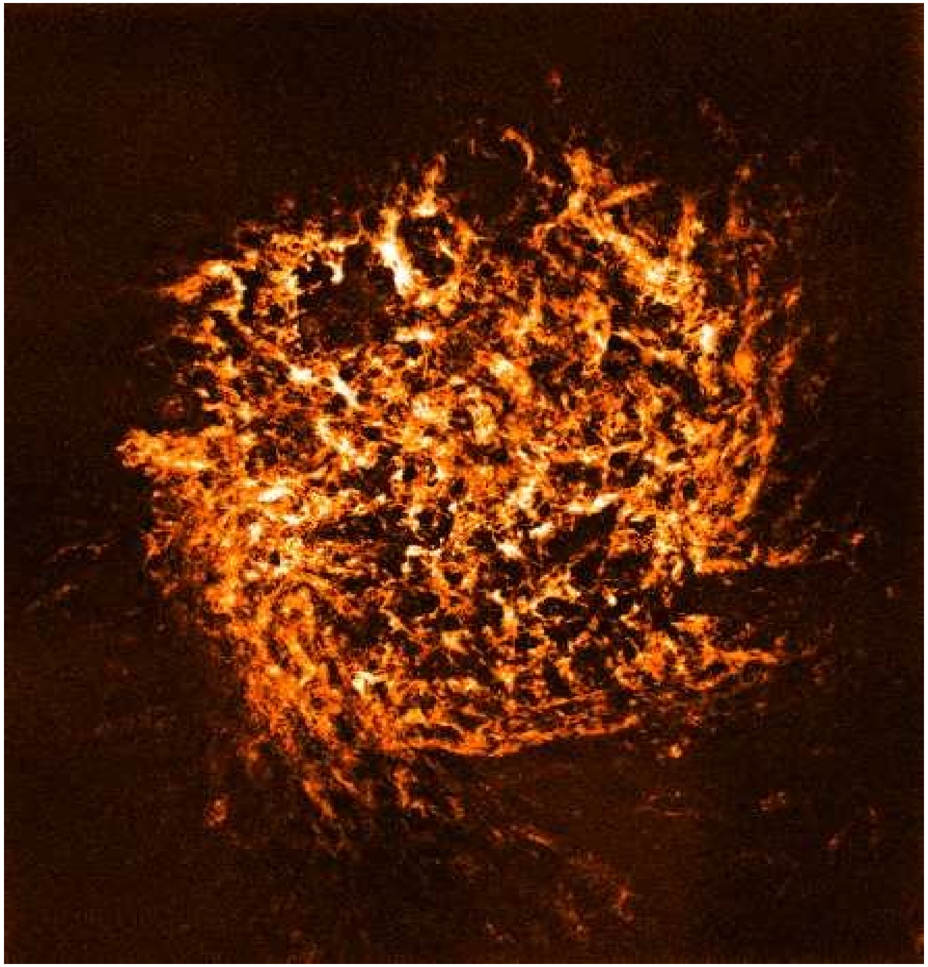
→ Posters by Patrick Kavanagh and Gabriele Warth!

# Why eROSITA



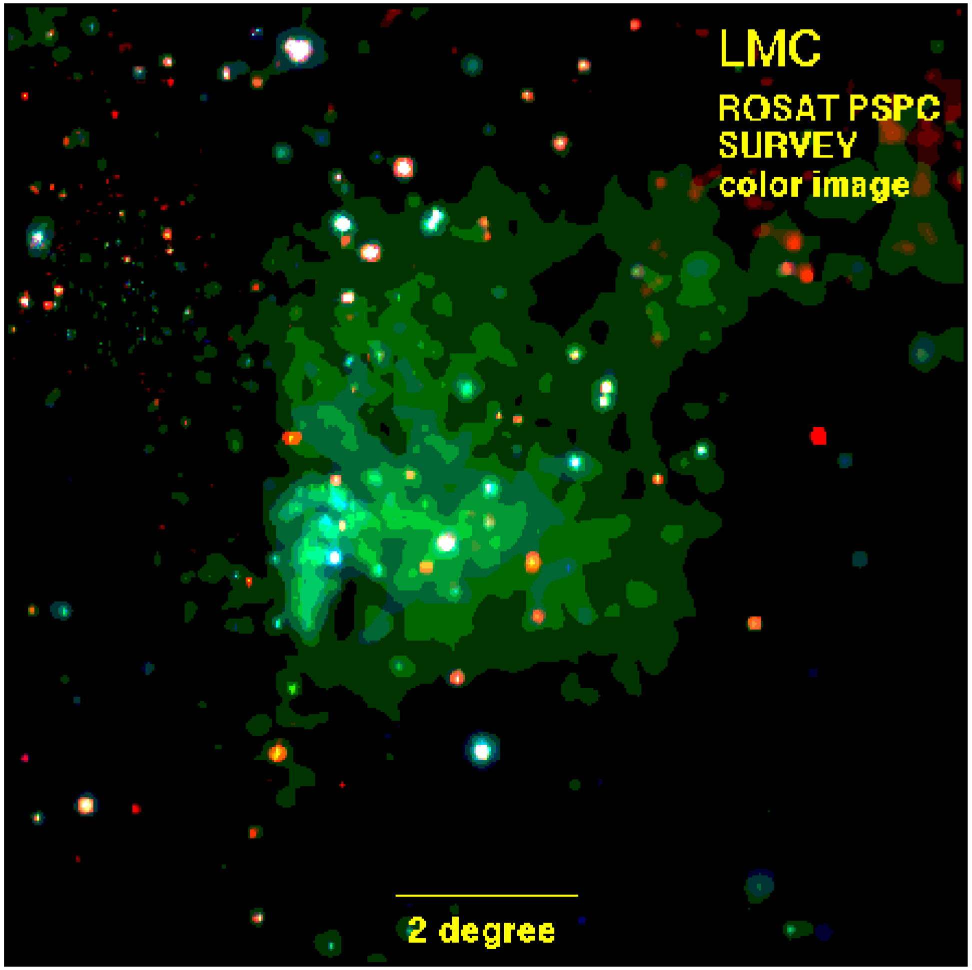
90.0
60.0
30.0
-30.0
-60.0
135.0
90.0
45.0
0.0
315.0
270.0
225.0
180.0
Monogem Ring
Cygnus Loop
M31
M33
LMC
SMC
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000

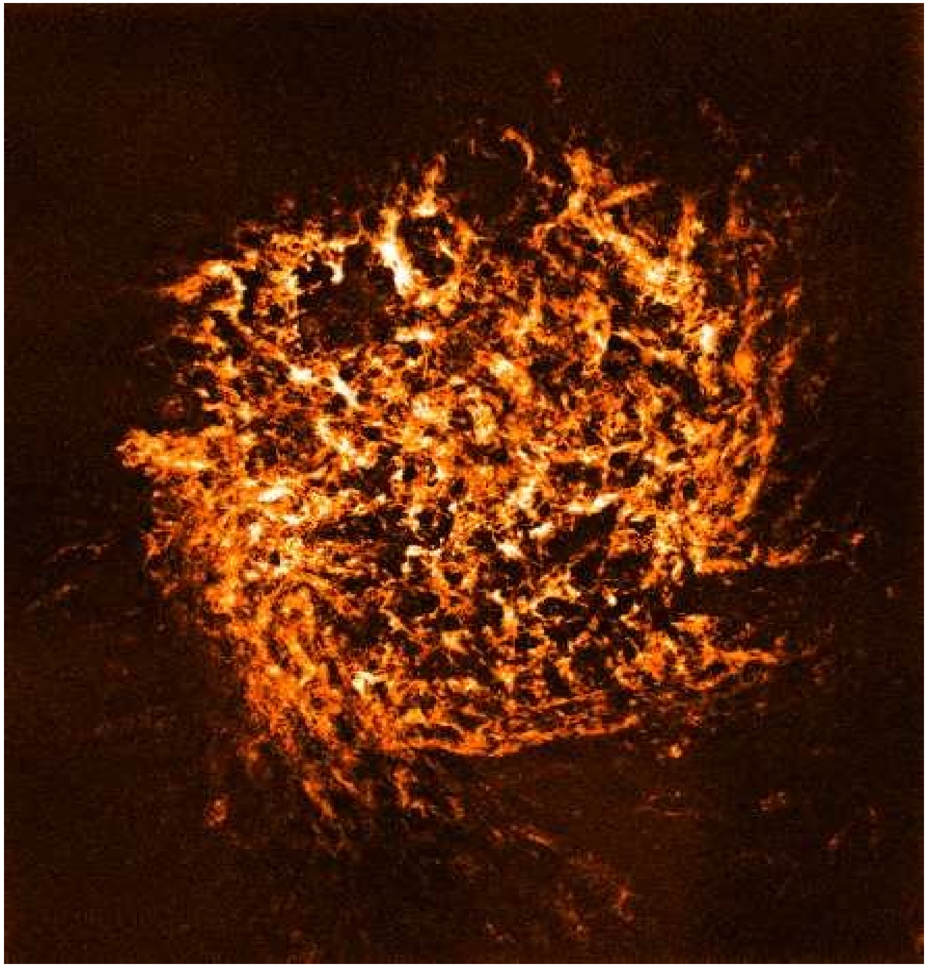
# The Large Magellanic Cloud

H I map of the LMC (Australia Telescope Compact Array, Kim et al. 1998).

# The Large Magellanic Cloud





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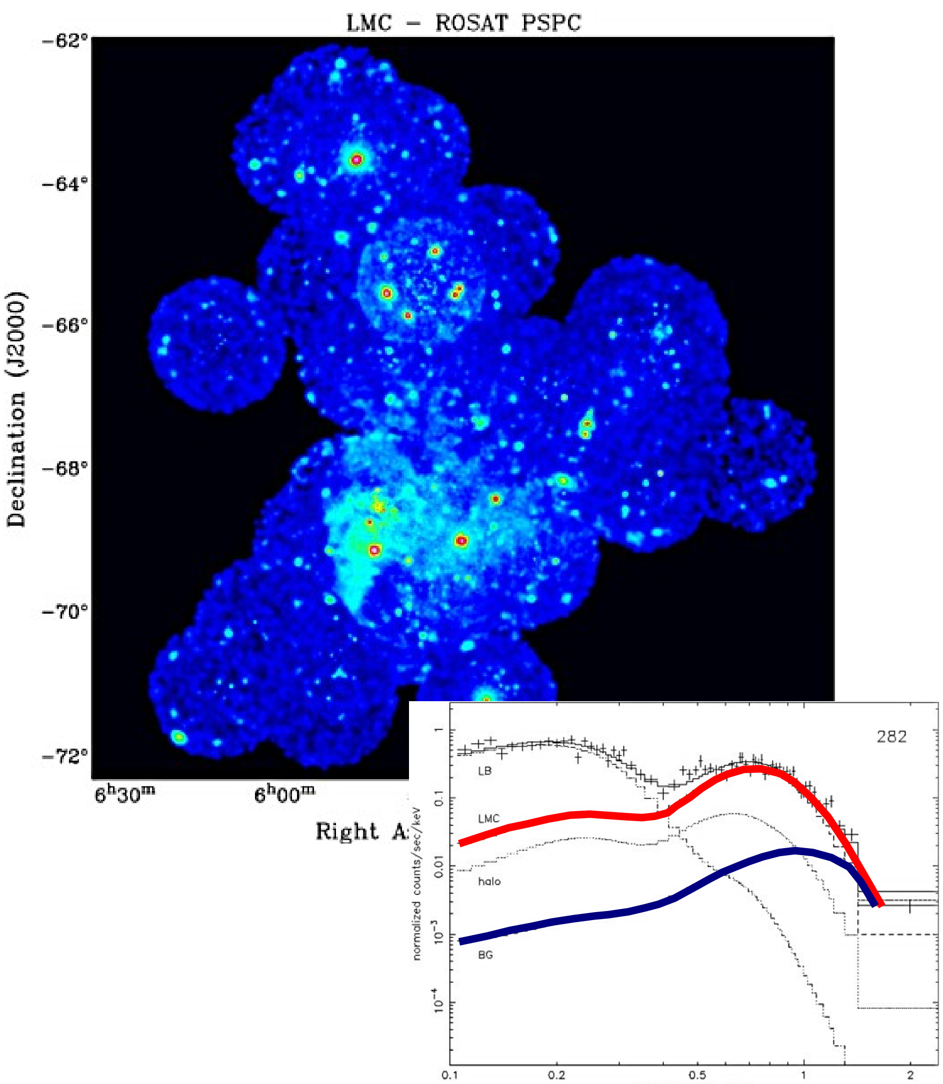
# The Hot ISM in the LMC a Decade ago




- Diffuse X-ray emission observed with ROSAT PSPC.
- Spectral analysis with 15' resolution (Sasaki et al., 2002).
- PSPC spectrum of the diffuse emission can be well reproduced by a thermal emission model for gas in collisional ionization equilibrium (Raymond & Smith, 1977).

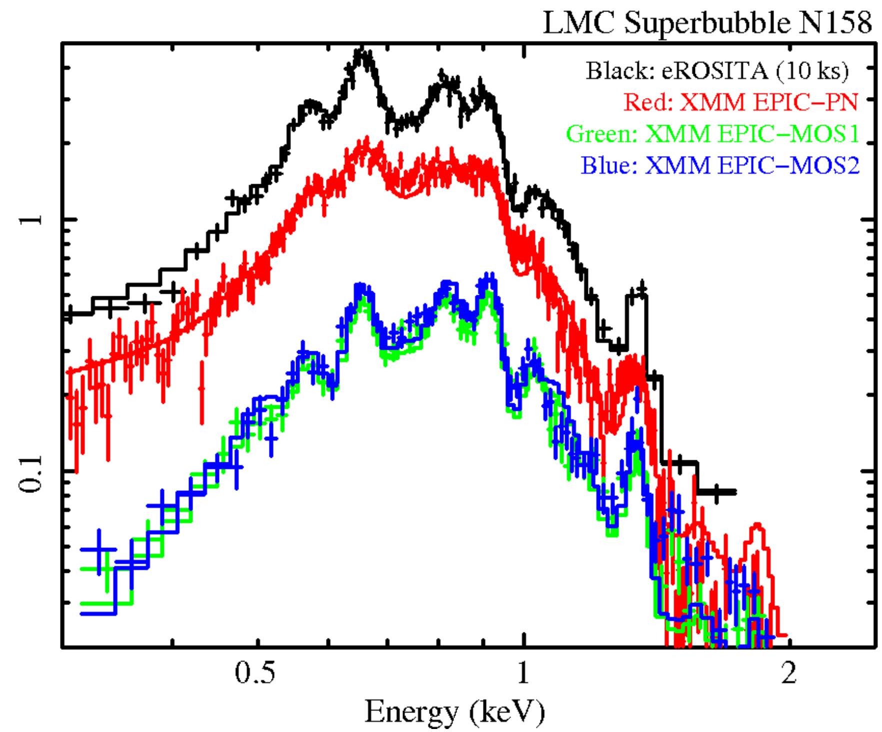
  ⇨ From hot thin gas in SNRs, bubbles, and superbubbles in the LMC.

# LMC Superbubble N158

ions

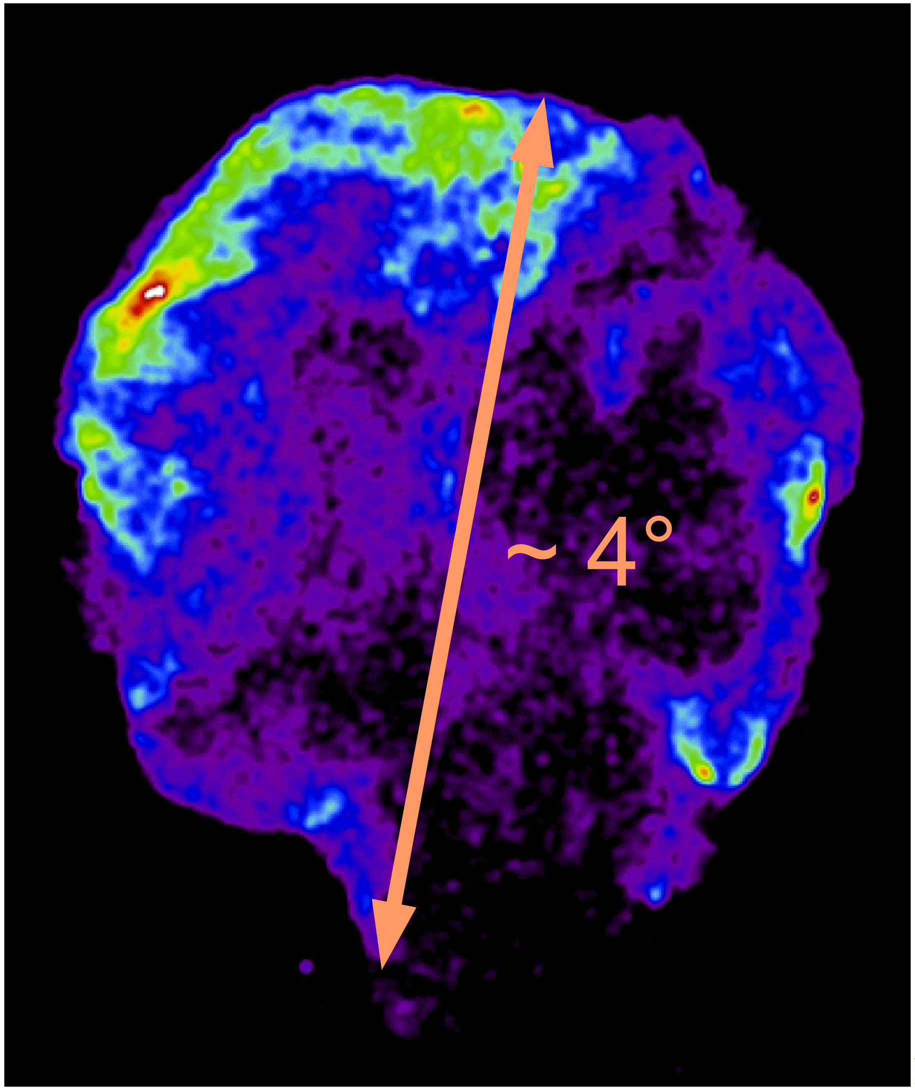
| NPSHOCK | |
|---|---|
| $N_H$(LMC) [$10^{22}$ cm$^{-2}$] | 0.29 (0.20 – 0.33) |
| $kT_a$ [keV] | 1.0 (0.74 – 1.2) |
| $kT_b$ [keV] | 0.13 (0.00 – 0.57) |
| $n_e t$ [$10^{11}$ s cm$^{-3}$] | 1.3 (1.0 – 2.3) |
| norm [$10^{-4}$ cm$^{-5}$] | 11 (9 – 13) |
| Reduced $\chi^2$ | 1.3 |
| d.o.f. | 99 |

electrons




MCELS

# Large SNRs in Our Galaxy

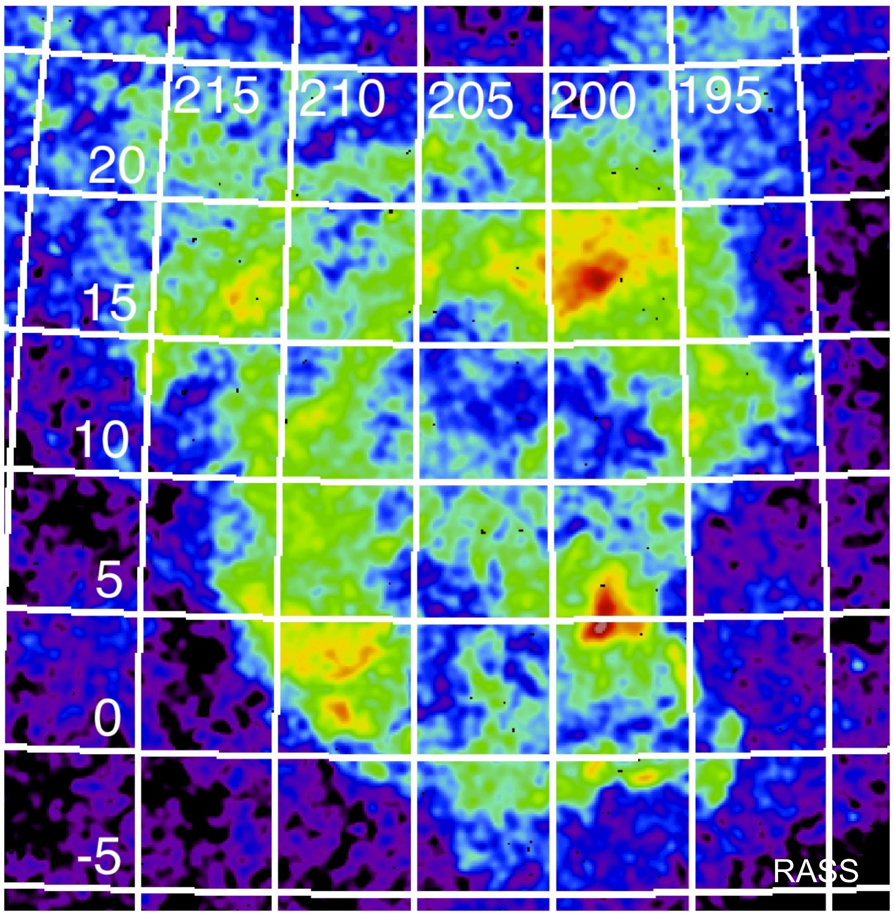


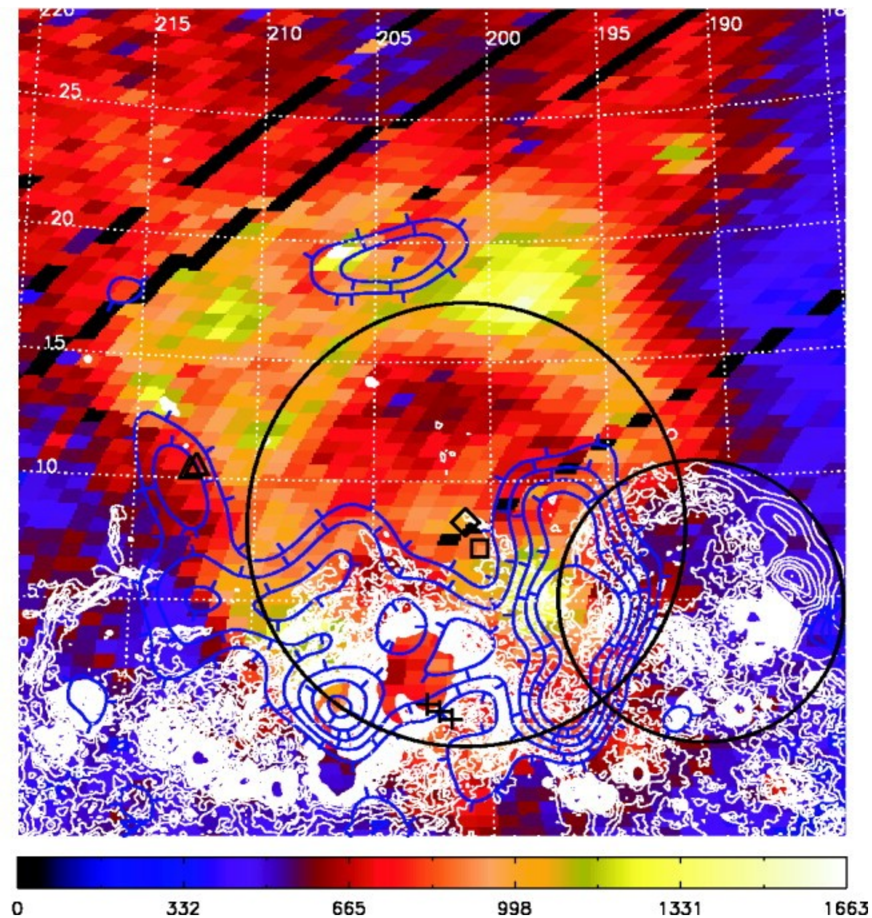

eROSITA simulation
Courtesy Christian Schmid, University of Erlangen

Obtain spectral information of the entire Cygnus Loop SNR!

# Large SNRs in Our Galaxy

Monogem Ring



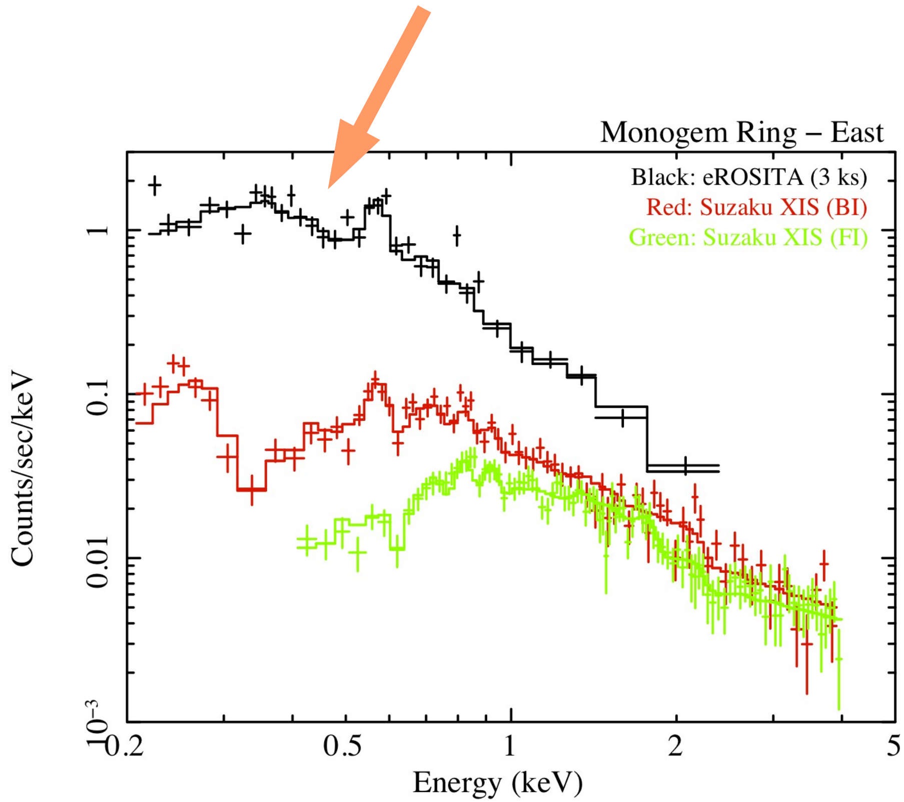




Kim et al. 2007

# Spectrum the Monogem Ring SNR

- Will obtain an image of the entire Monogem Ring.
- Spectra with improved sensitivity in soft X-rays (0.3 – 1.0 keV):

  Detect emission lines of C, N, O, and Ne, which are tracers of coronal plasma (T = $10^{5-6}$ K).
- Study the plasma conditions at different Galactic latitudes, thus different environments.
- Search for indication of turbulent mixing.



# Summary

X-ray observations of galaxies revealed the hot phase of the ISM created by stellar winds and SNe.

The thermal emission of the hot thin plasma is best visible in soft X-rays.

eROSITA will enable us to study

- the hot ISM globally in nearby galaxy like the LMC,
- a large sample of bubbles, superbubbles, and SNRs in detail,
- and nearby, evolved, and thus highly extended SNRs and bubbles

and thus allow to better understand the entire chemodynamical evolution history of the ISM including the non-equilibrium ionization effects in interstellar plasma.