Astronomy 404
Solar System and ISM

Lecture 23
The Interstellar Medium

October 21, 2013

What's out there? What physical descriptions?

Radiation

photons

(Planck function
Blackbody spectrum)

Matter

ionization
(Saha Equation)

free electron	bound electron	nuclei/ions
kinetic energy	excitation	kinetic energy
(Maxwell–Boltzmann distribution)	(Boltzmann Equation)	(Maxwell–Boltzmann distribution)

In the interstellar medium (ISM), we do not worry about dark matter or dark energy at scales of pc to kpc.
(1 pc = 3.08×10^{16} m)

Planck Function (Carroll & Ostlie, p.73)

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1}$$

or

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}$$

Note: $B_\nu(T) \neq B_\lambda(T)$, but $B_\lambda(T)d\lambda = B_\nu(T)\,d\nu$, because:

$$B_\lambda(T)d\lambda = B_\lambda(T)\;\; d\left(\frac{c}{\nu}\right) = \frac{2h\nu^5/c^3}{e^{h\nu/kT}-1}\,\frac{c}{\nu^2}\,d\nu = \frac{2h\nu^3/c^2}{e^{h\nu/kT}-1}\,d\nu = B_\nu(T)\;d\nu$$

What’s out there? What physical descriptions?

Radiation

photons

(Planck function
Blackbody spectrum)

Matter

ionization
(Saha Equation)

free electron	bound electron	nuclei/ions
kinetic energy	excitation	kinetic energy
(Maxwell–Boltzmann distribution)	(Boltzmann Equation)	(Maxwell–Boltzmann distribution)

In the interstellar medium (ISM), we do not worry about dark matter or dark energy at scales of pc to kpc.
(1 pc = 3.08 x 10^{16} m)

Saha Equation (Carroll & Ostlie, p.214)

Ionization stages i and i+1

$$\frac{N_{i+1}}{N_i} = \frac{2Z_{i+1}}{n_\mathrm{e}\, Z_i}\left(\frac{2\pi m_\mathrm{e} kT}{h^2}\right)^{3/2} e^{-\chi_i/kT}$$

χ_i : ionization energy of the ionization stage i

Z: partition function;   g: statistical weight

$$Z = g_1 + \sum_{j=2}^{\infty} g_j\, e^{-(E_j - E_1)/kT}$$

What's out there? What physical descriptions?

Radiation

photons

(Planck function / Blackbody spectrum)

Matter

ionization (Saha Equation)

free electron	bound electron	nuclei/ions
kinetic energy	excitation	kinetic energy
(Maxwell–Boltzmann distribution)	(Boltzmann Equation)	(Maxwell–Boltzmann distribution)

In the interstellar medium (ISM), we do not worry about dark matter or dark energy at scales of pc to kpc.
(1 pc = 3.08 x 10^{16} m)

Maxwell-Boltzmann Distribution

(Carroll & Ostlie, p.206)

$$n_v dv = n \left(\frac{m}{2\pi kT}\right)^{3/2} e^{-mv^2/2kT} 4\pi v^2 dv$$

Number of particles with velocities within *v* to *v*+*dv*

Boltzmann Equation (Carroll & Ostlie, p.212)

$$\frac{N_b}{N_a} = \frac{g_b e^{-E_b/kT}}{g_a e^{-E_a/kT}} = \frac{g_b}{g_a} e^{-(E_b - E_a)/kT}$$

g: statistical weight
E: energy

In the interstellar medium (diffuse matter), densities are so low and interactions between radiation and matter and collisions between particles are so infrequent that thermal equilibrium is no longer valid.

Radiation and matter need to be considered separately.

Ionization

Ionization can be carried out by absorbing a photon or through collision with another particle.

The ionization state is determined by balancing the number of ionizations and the number of recombinations.

Excitation

Similarly, excitation is carried out by photon or collision.
Boltzmann equation is applicable at high energy levels when densities are high.

What is the “temperature” then?

You can count on electrons establishing Maxwell-Boltzmann distribution very quickly. Therefore, electron temperatures or kinetic temperatures are used.

ISM in Galaxies

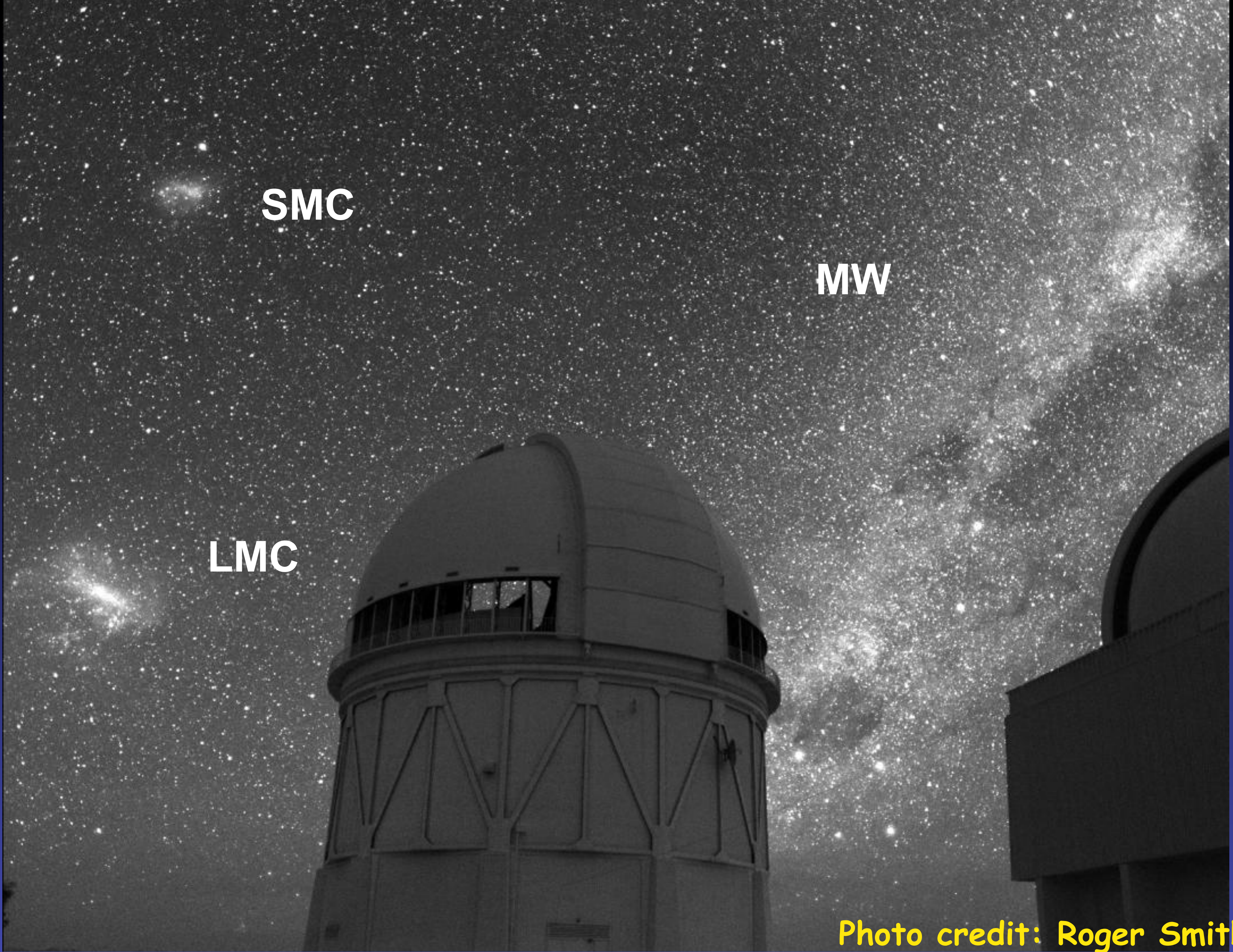
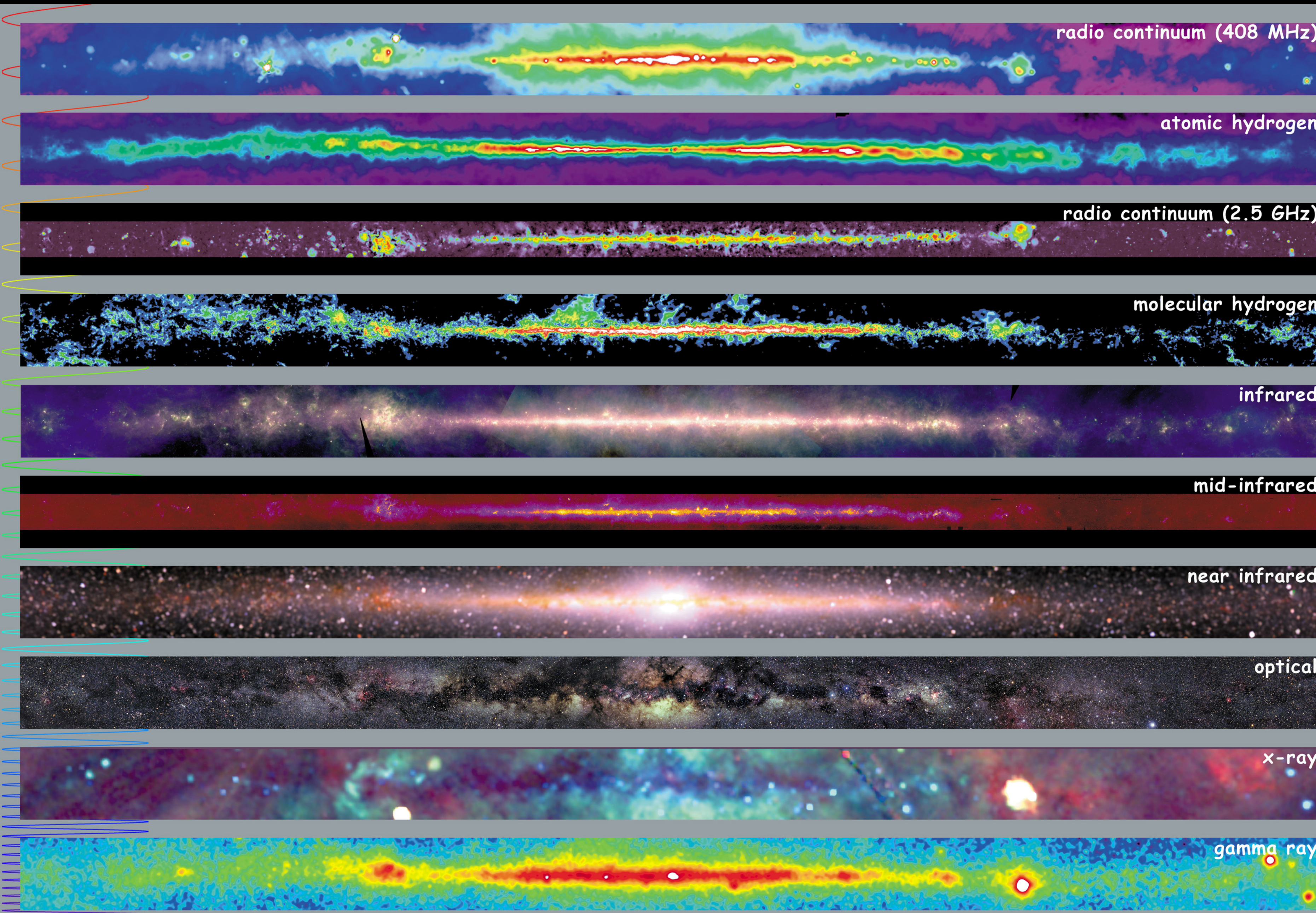


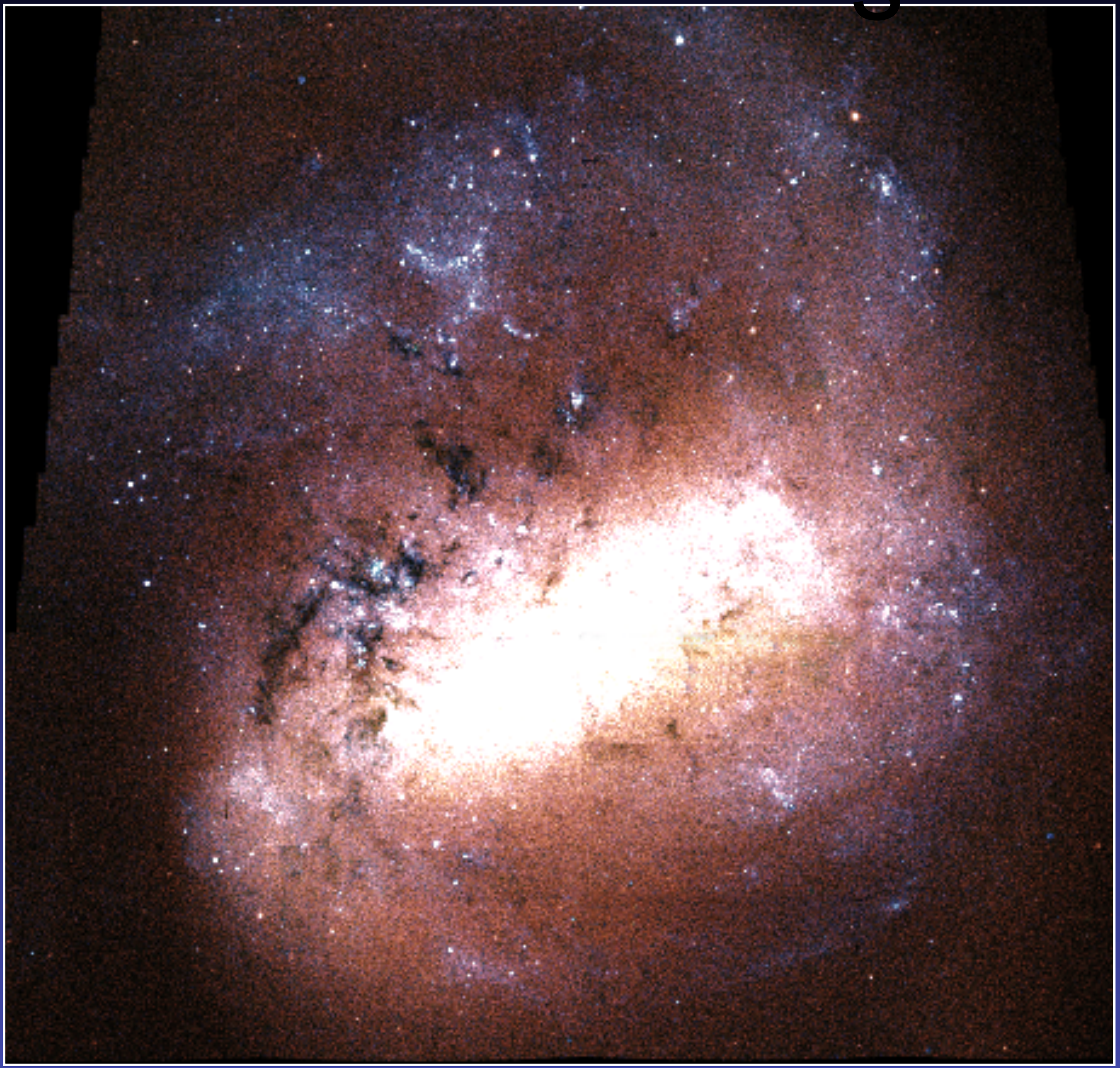
Photo credit: Roger Smith



http://adc.gsfc.nasa.gov/mw

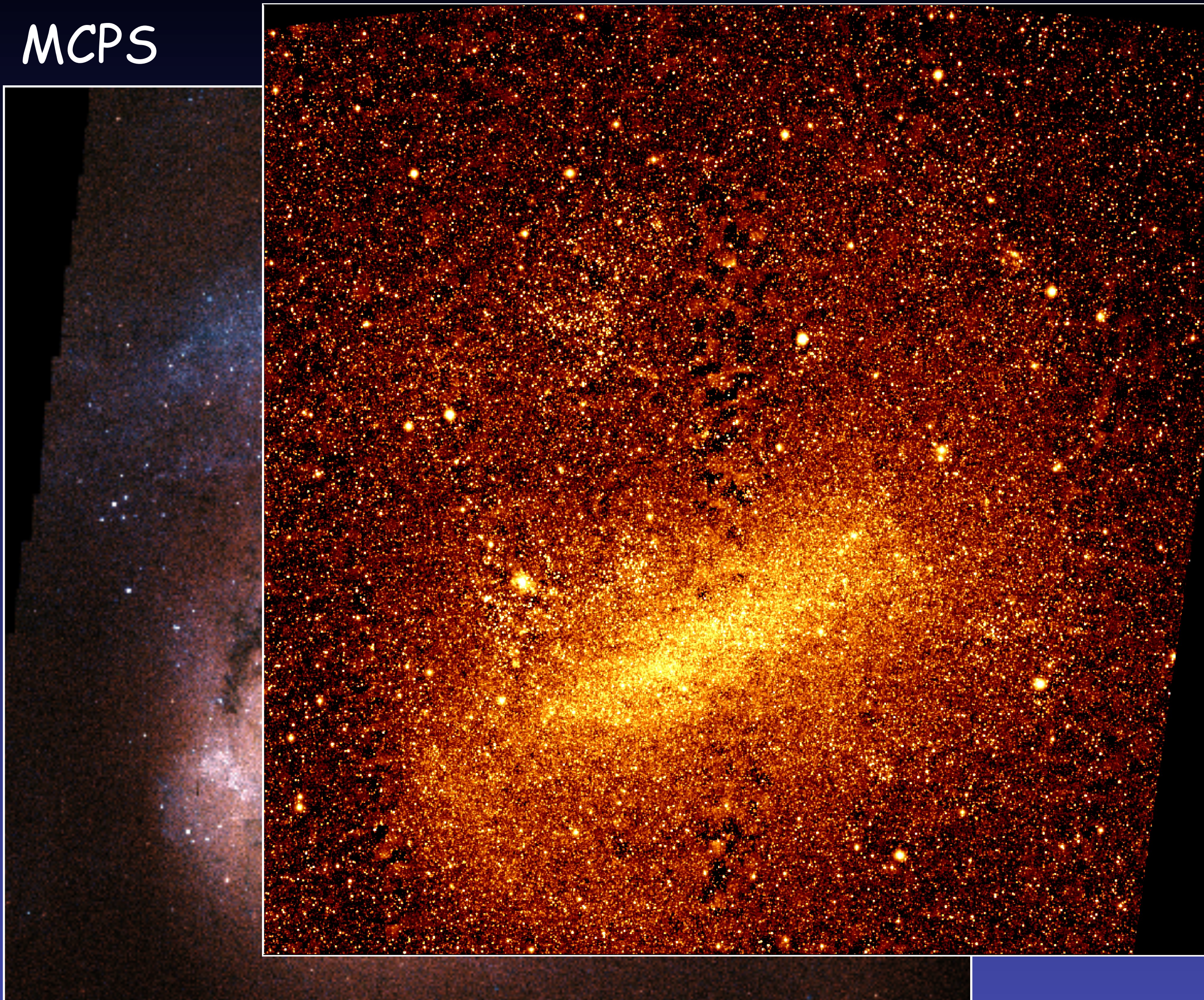
Multiwavelength Milky Way

MCPS (UBVI)



2MASS (JHK)

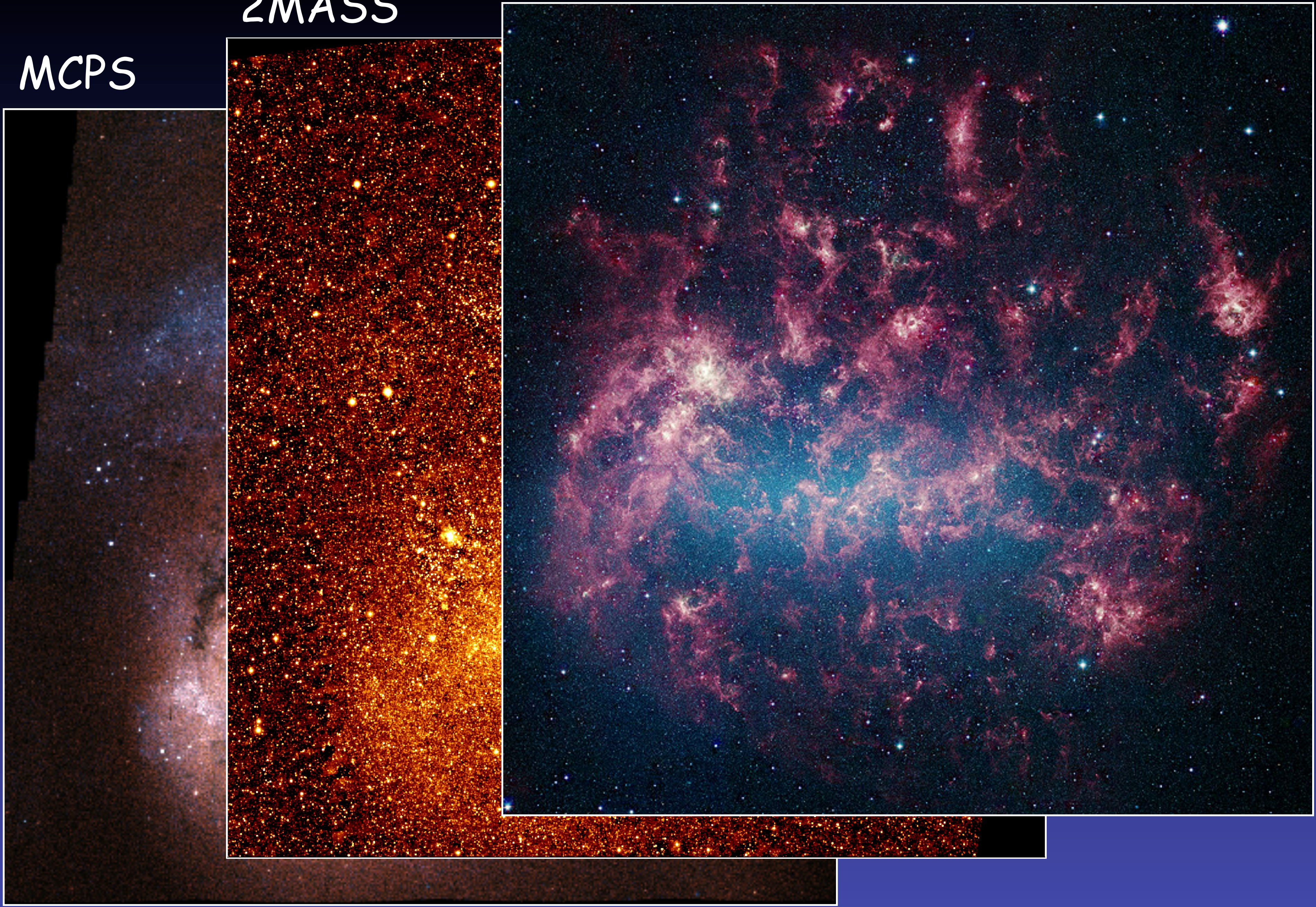
MCPS



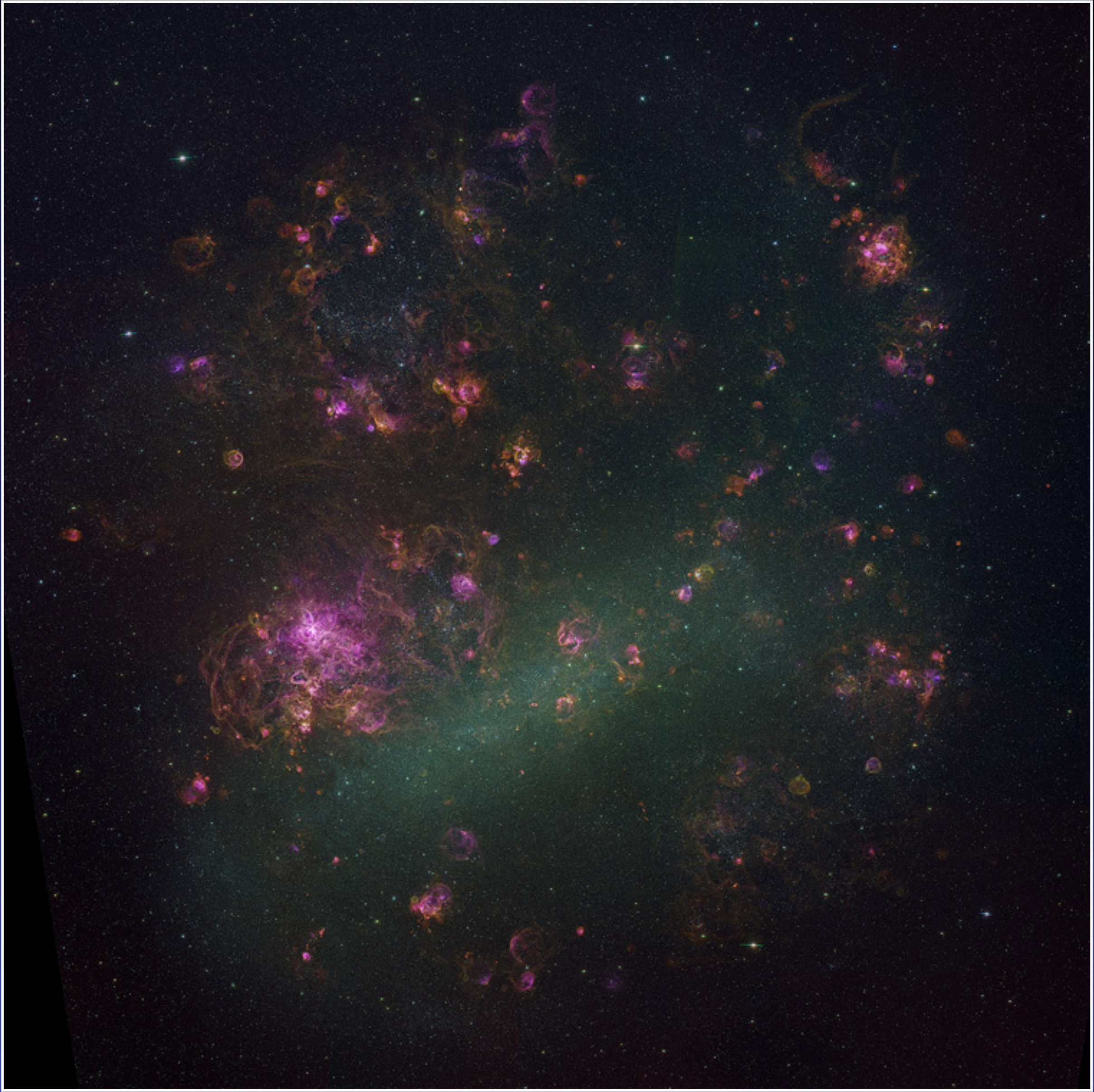
SAGE (3.6, 4.5, 5.8, 8.0, 24 μm)

2MASS

MCPS

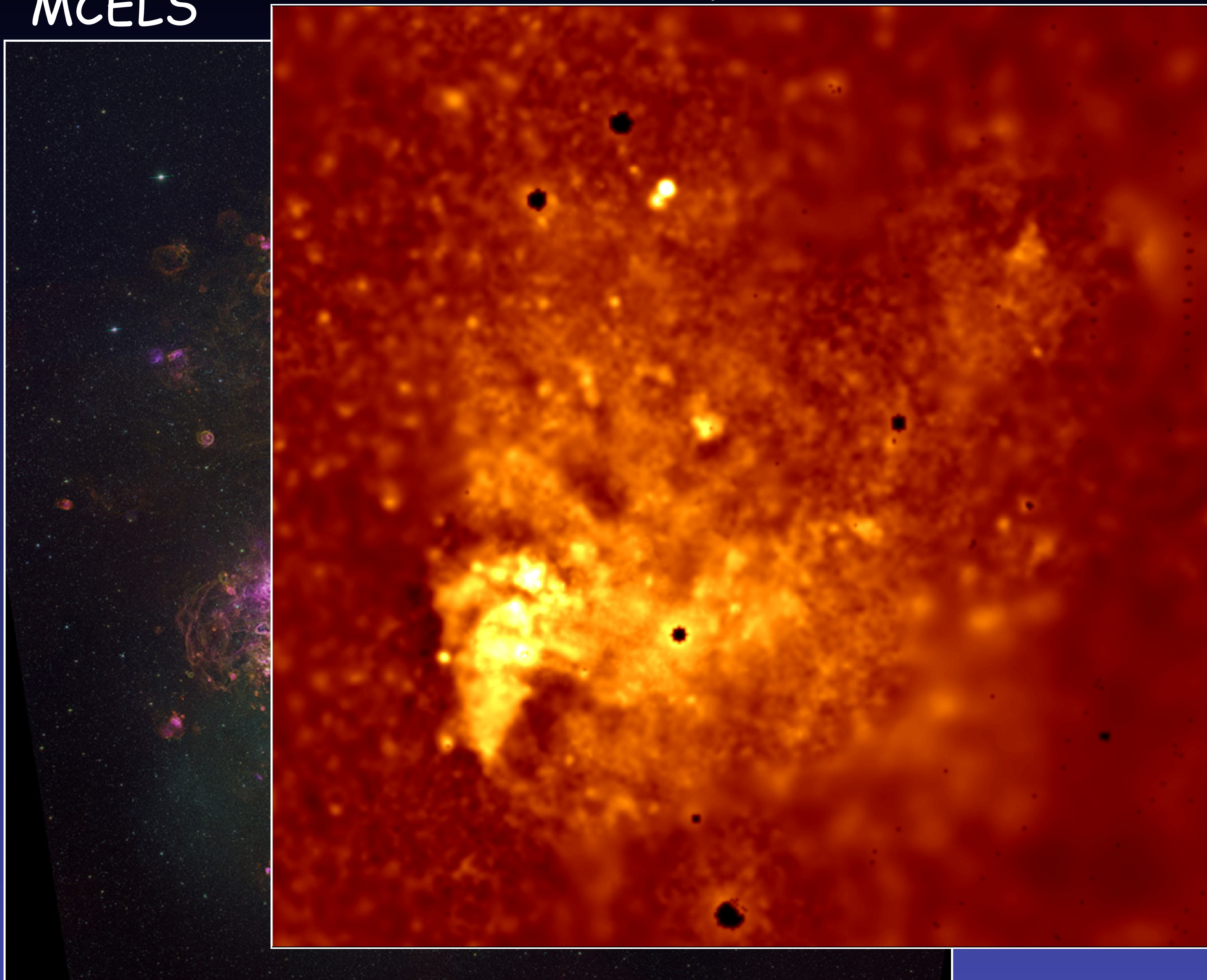


MCELS (Hα, [O III], [S II])



ROSAT (X-ray, 0.1-2.4 keV)

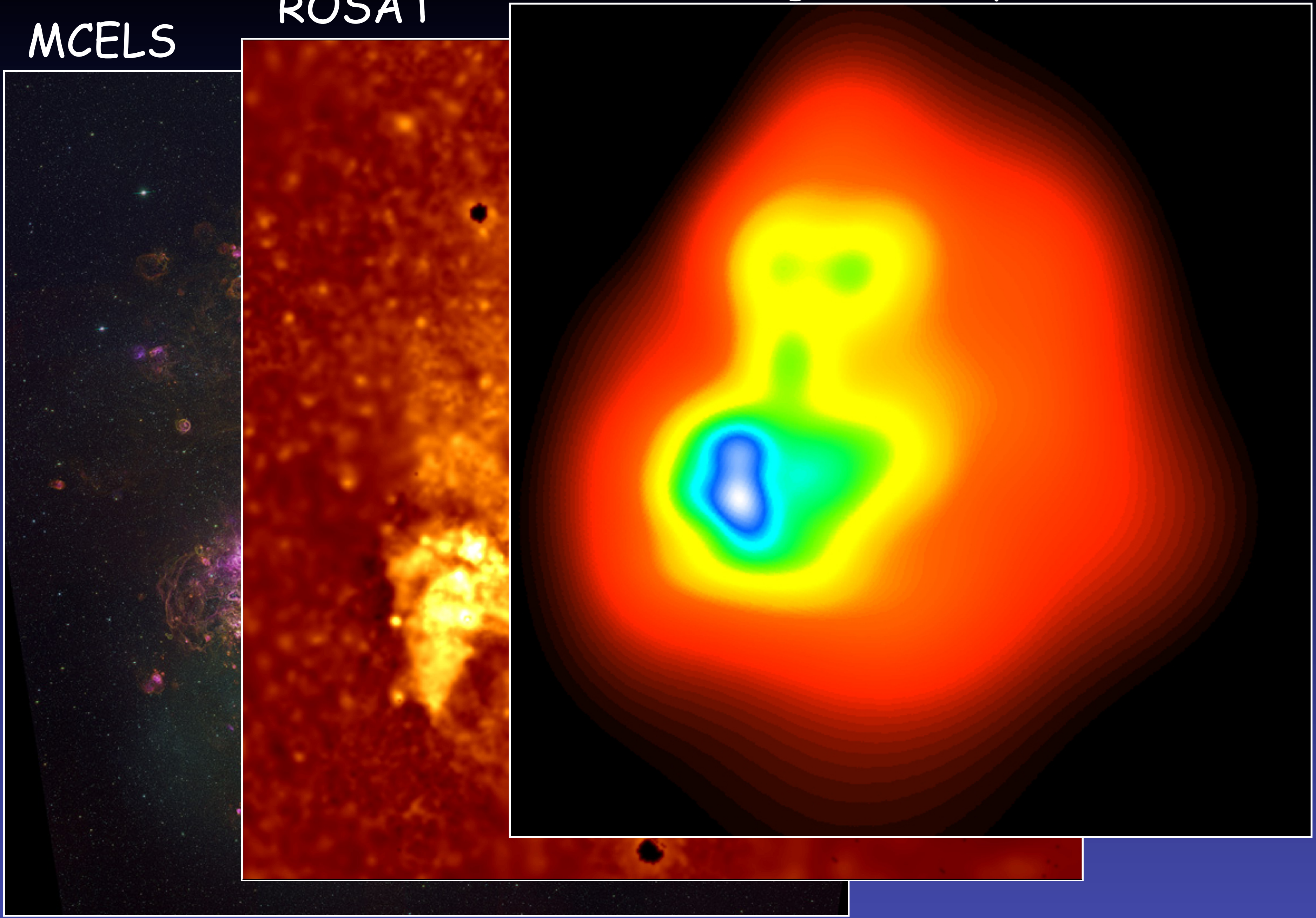
MCELS



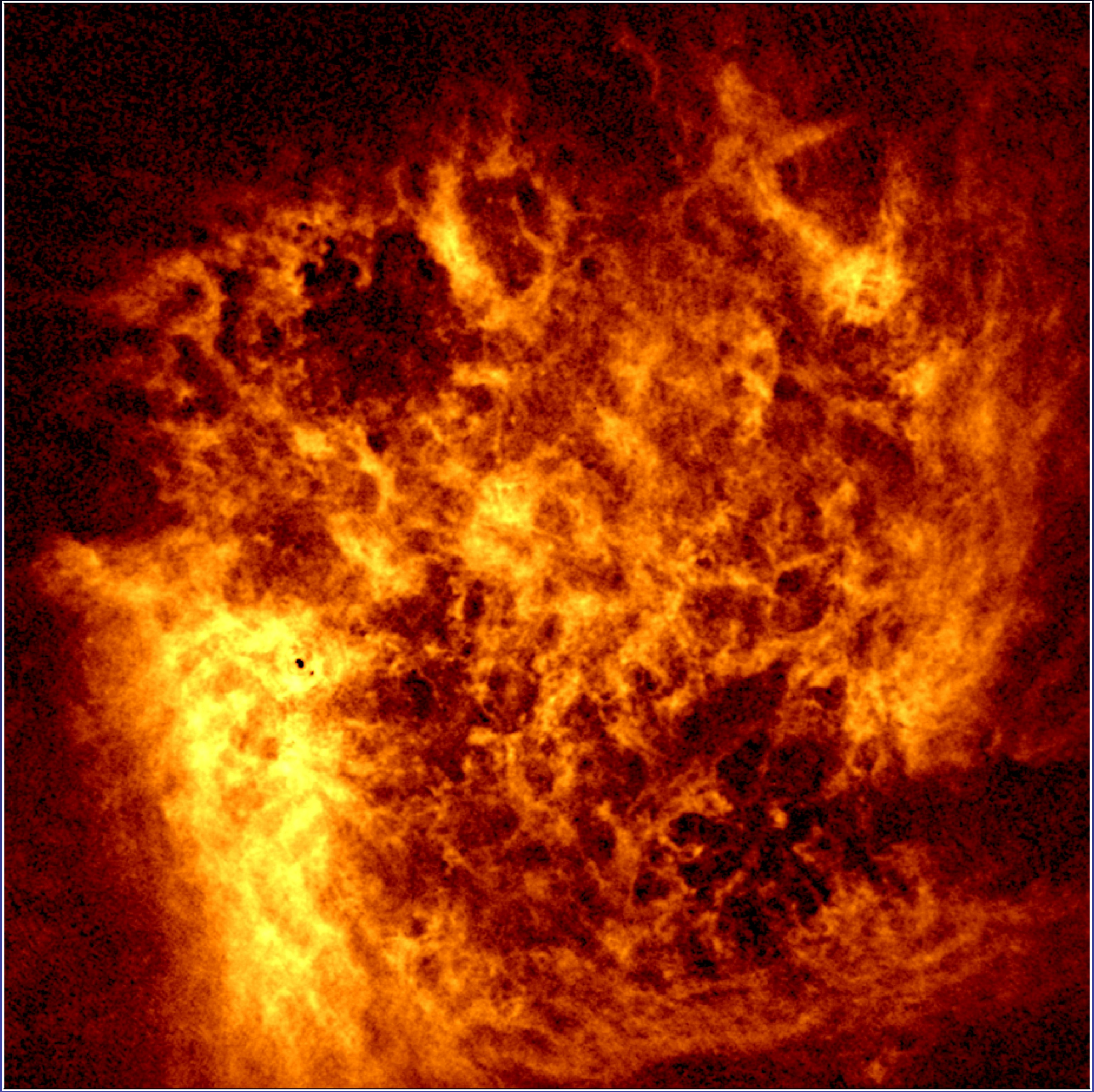
Fermi (gamma-ray)

ROSAT

MCELS

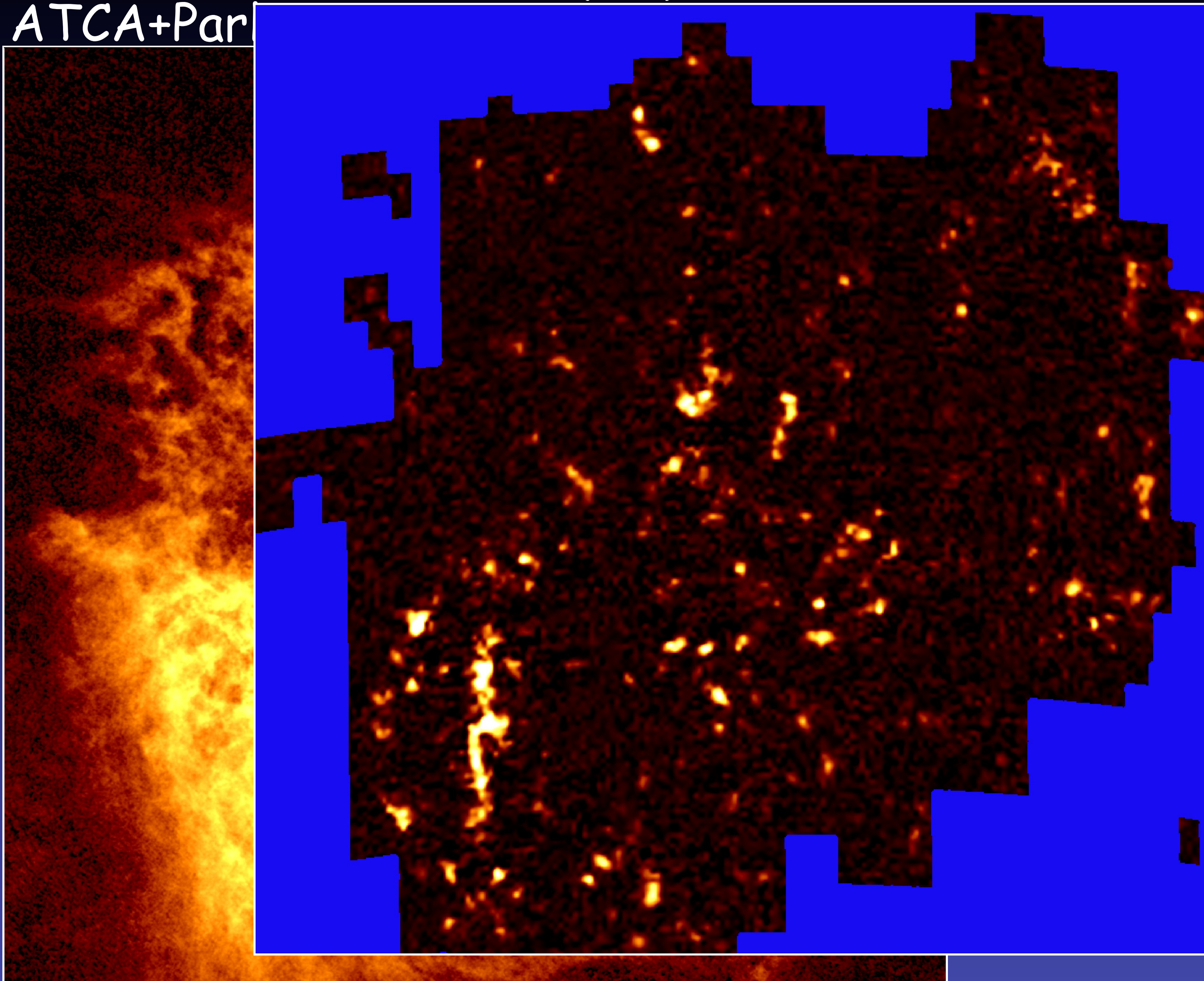


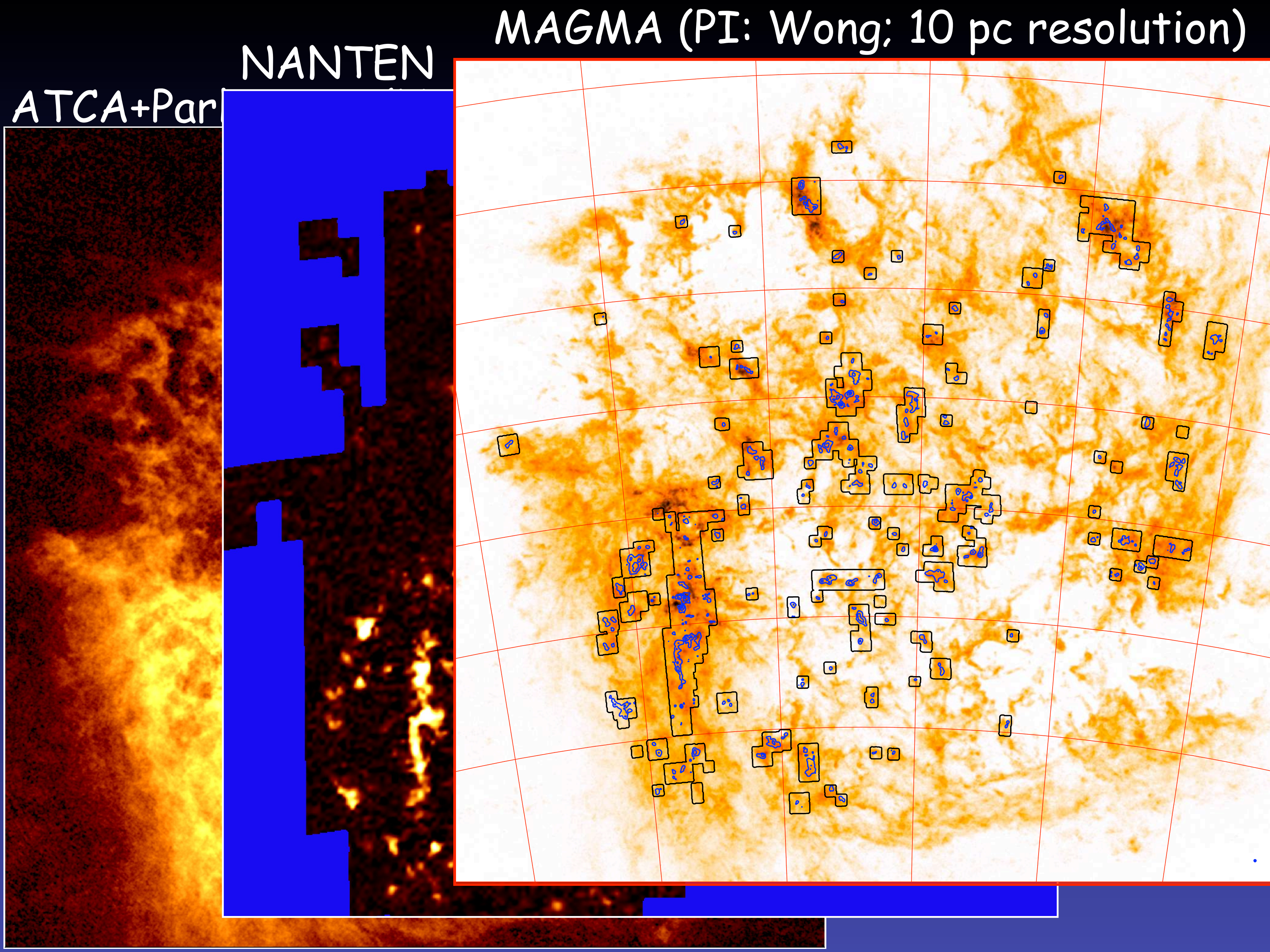
ATCA+Parkes (H I)



NANTEN (CO)

ATCA+Par




MAGMA (PI: Wong; 10 pc resolution)
NANTEN
ATCA+Par

Heating and cooling of the ISM

Heating:

HII - UV radiation from massive stars and
photoionization of H

H I - UV radiation and photoionization of C

H_2 - cosmic rays

Hot 10^6 K ISM -- SNR shocks

Cooling:

recombination

free-free emission

collisional excitation and radiative de-excitation

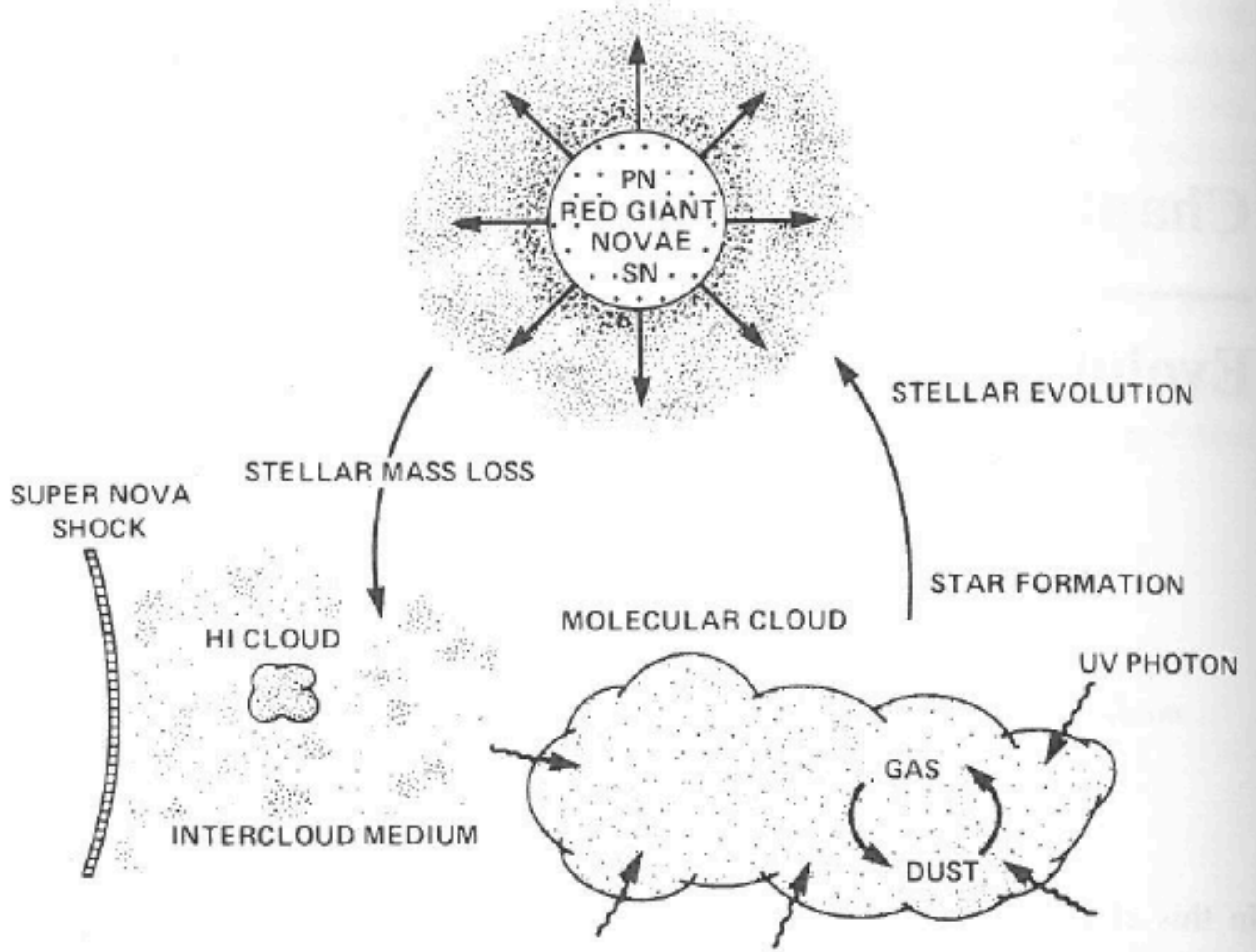
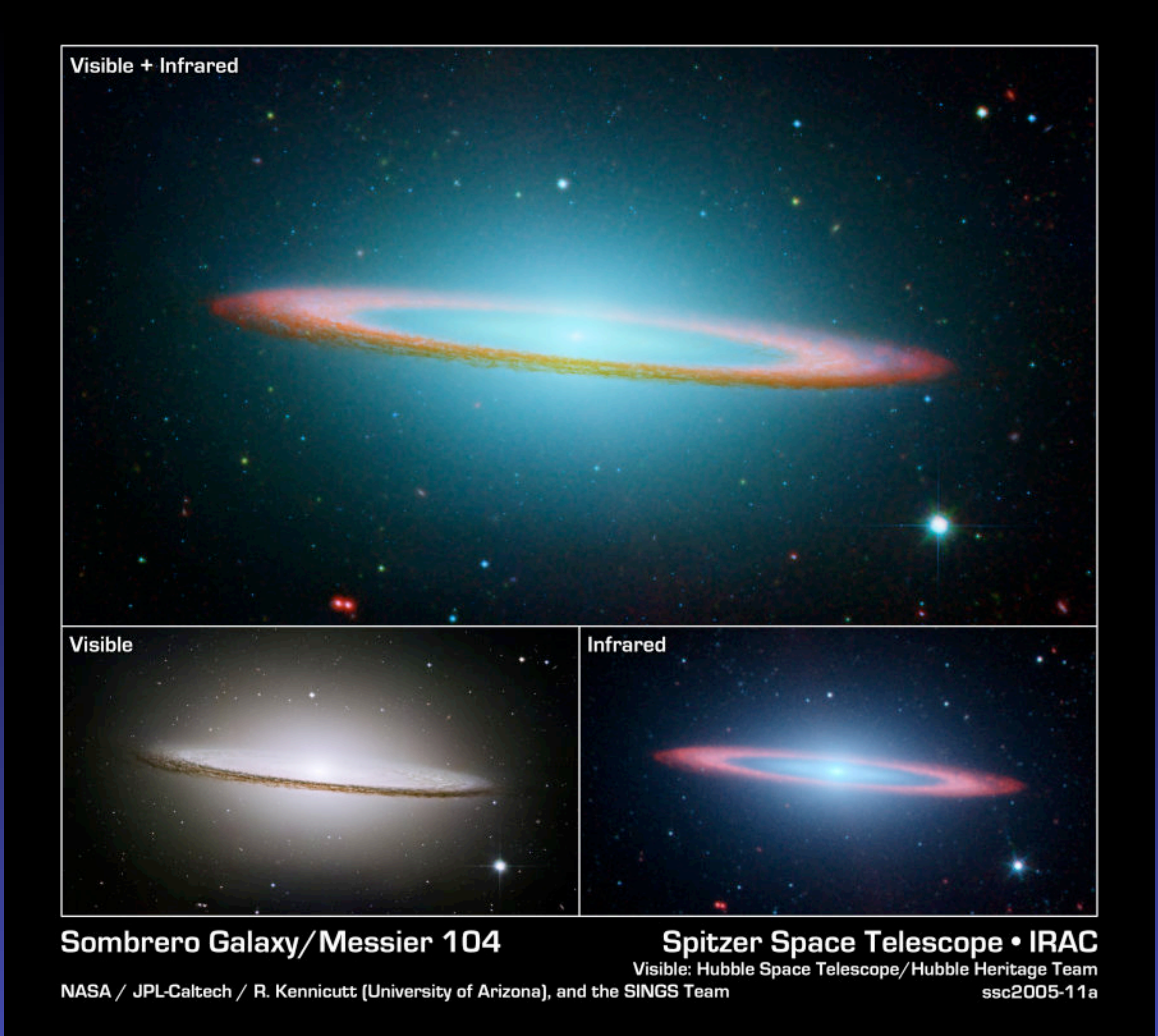


Figure 8.1. Schematic representation of the lifecycle of cosmic dust. Grains of 'stardust' originating in the atmospheres and outflows of evolved stars (red giants, planetary nebulae, novae and supernovae) are ejected into low-density phases of the interstellar medium, where they are exposed to ultraviolet irradiation and to destruction by shocks. Within molecular clouds, ambient conditions favour the growth of volatile mantles on the grains. Subsequent star formation leads to the dissipation of the molecular clouds. (From Tielens


© Stéphane Guisard


Visible + Infrared
Visible
Infrared
Sombrero Galaxy/Messier 104
Spitzer Space Telescope • IRAC
Visible: Hubble Space Telescope/Hubble Heritage Team
NASA / JPL-Caltech / R. Kennicutt (University of Arizona), and the SINGS Team
ssc2005-11a

Pre-Collapse Black Cloud B68 (visual view)
(VLT ANTU + FORS 1)