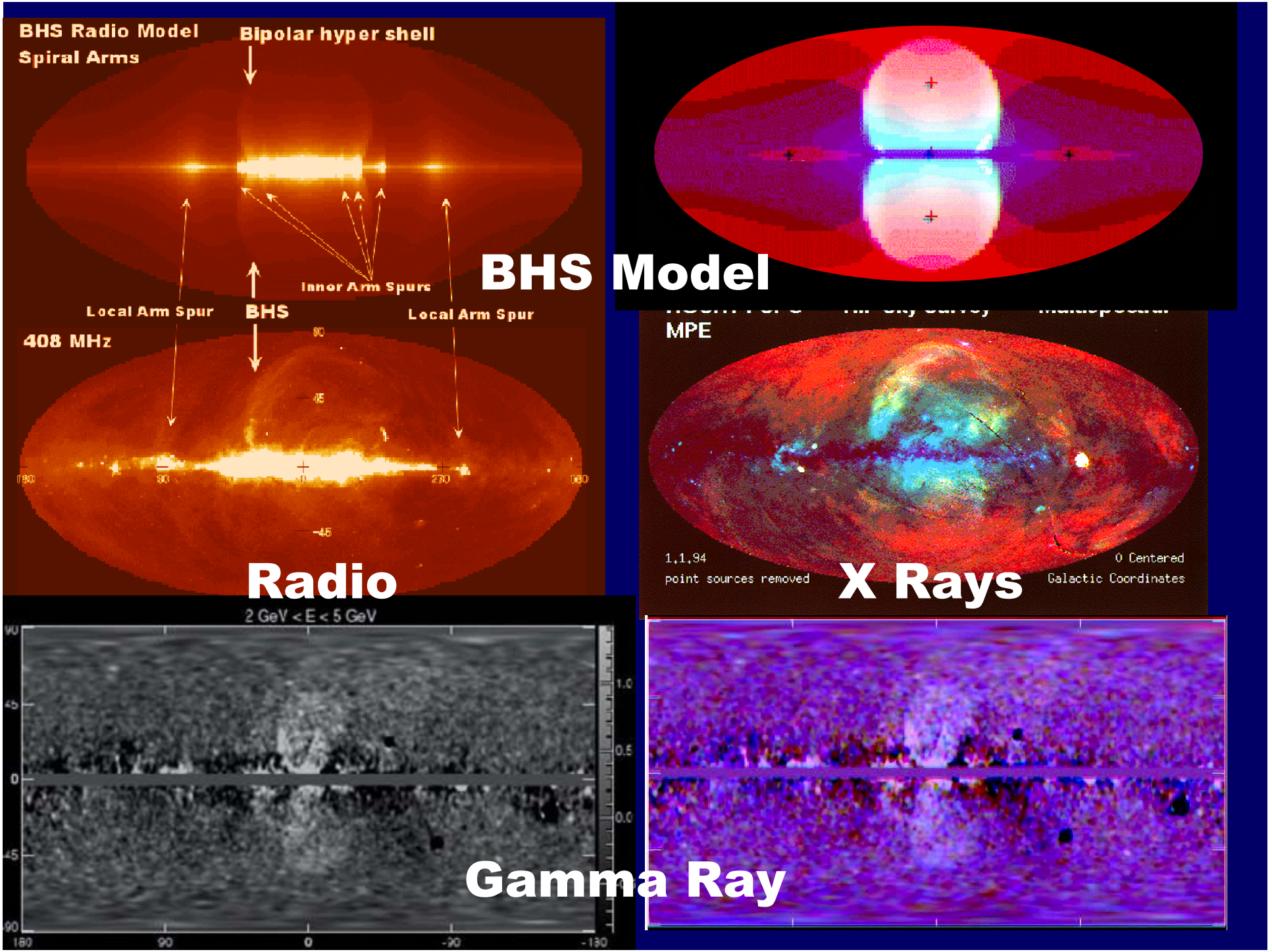
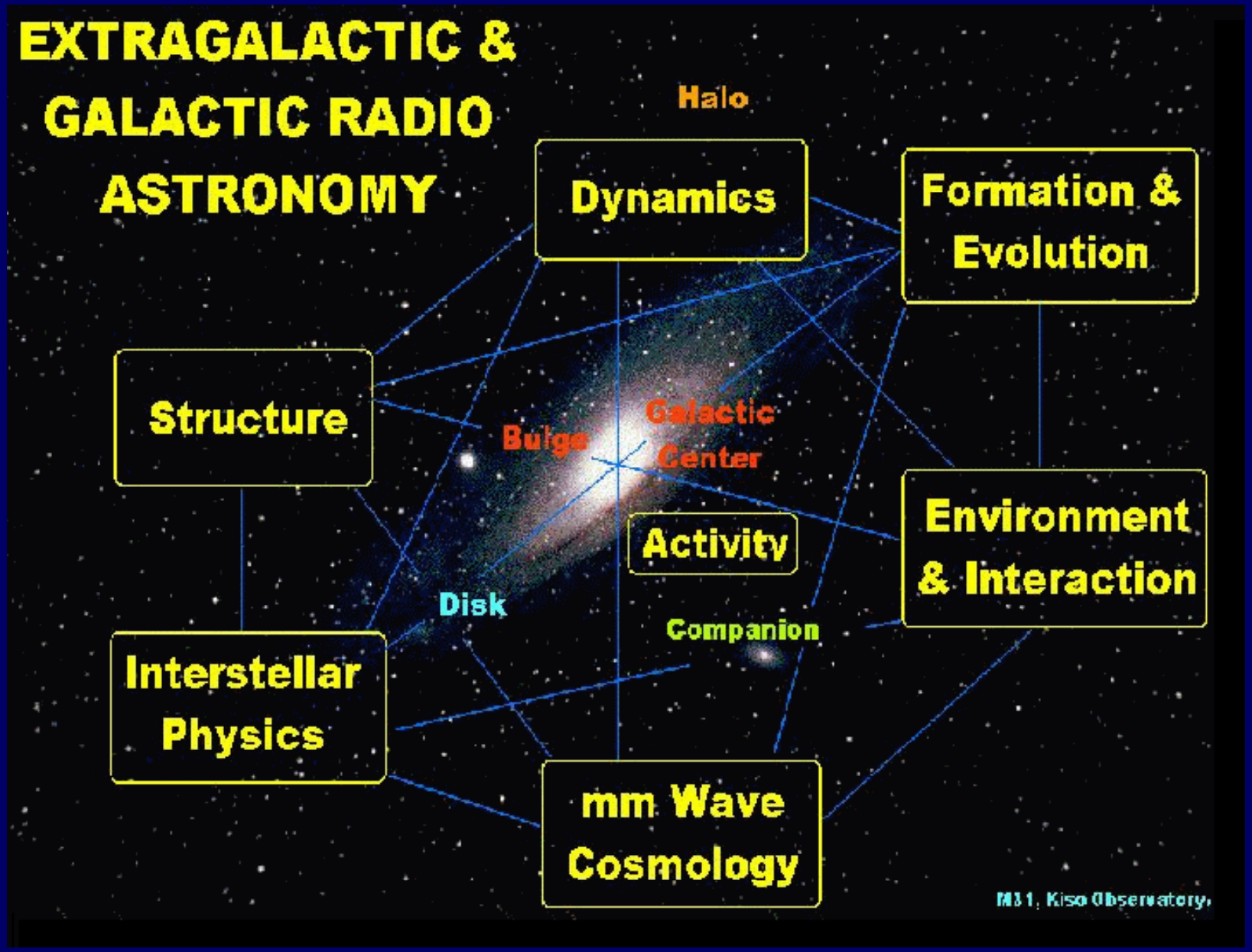
Galactic Big Bang : MW Explosion

Yoshiaki SOFUE

2013

銀河系の大爆発

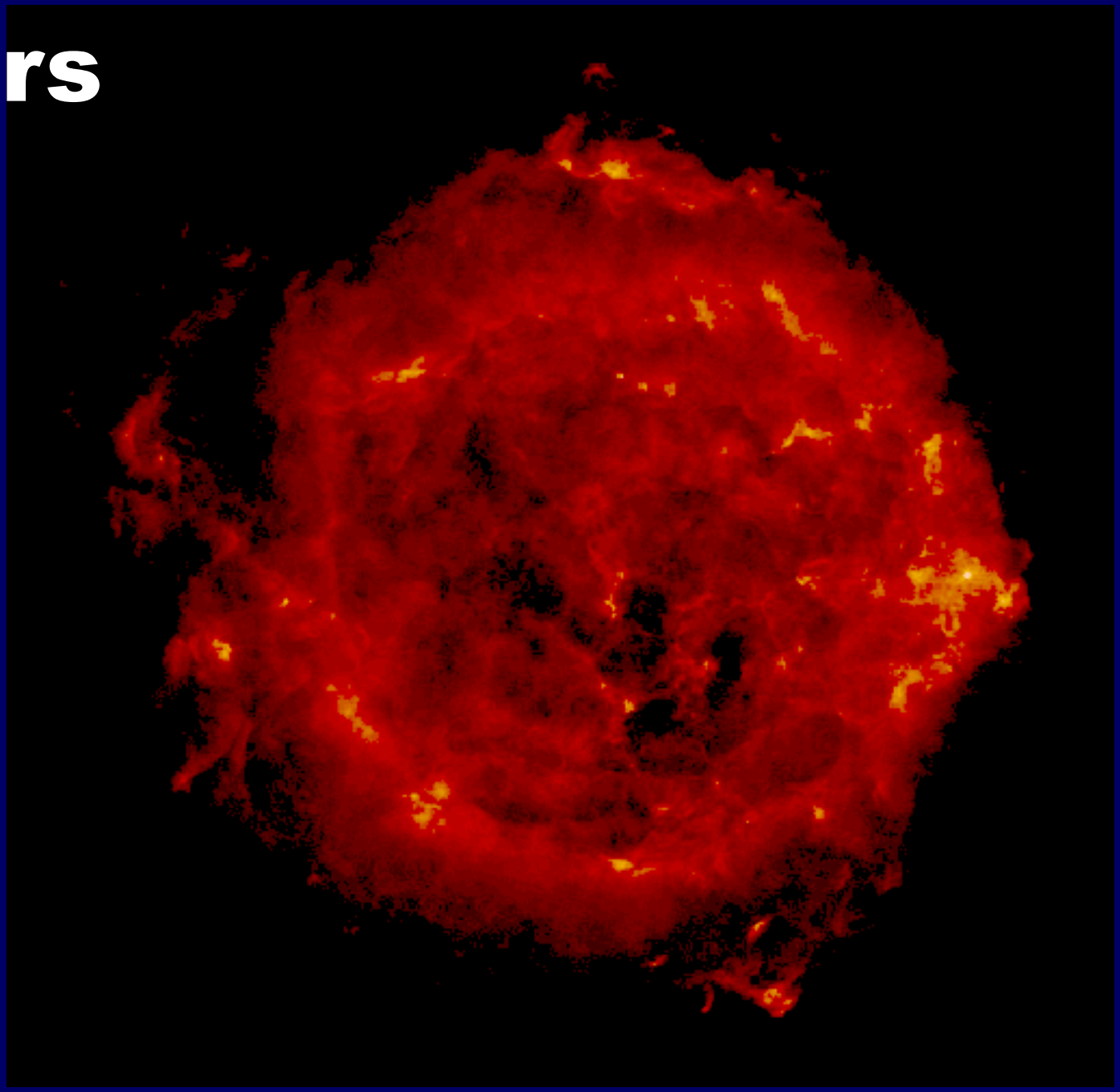

BHS Radio Model
Spiral Arms
Bipolar hyper shell
Inner Arm Spurs
Local Arm Spur
BHS
Local Arm Spur
408 MHz
Radio
BHS Model
MPE
1,1,94
point sources removed
0 Centered
Galactic Coordinates
X Rays
2 GeV < E < 5 GeV
Gamma Ray


EXTRAGALACTIC &
GALACTIC RADIO
ASTRONOMY
Halo
Dynamics
Formation &
Evolution
Structure
Bulge
Galactic
Center
Activity
Environment
& Interaction
Disk
Companion
Interstellar
Physics
mm Wave
Cosmology
M31, Kiso Observatory

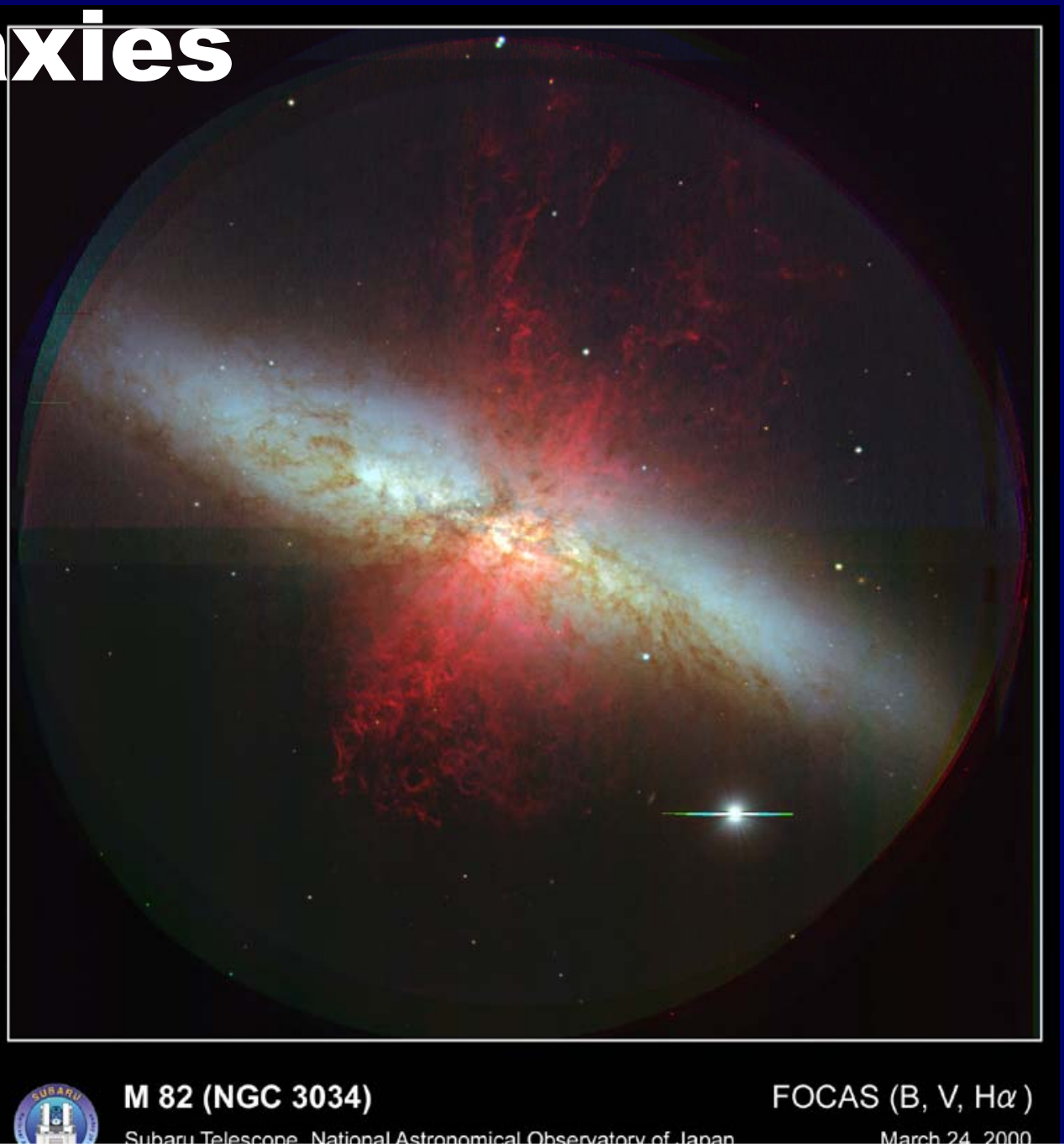
Astronomical Explosions

The Sun

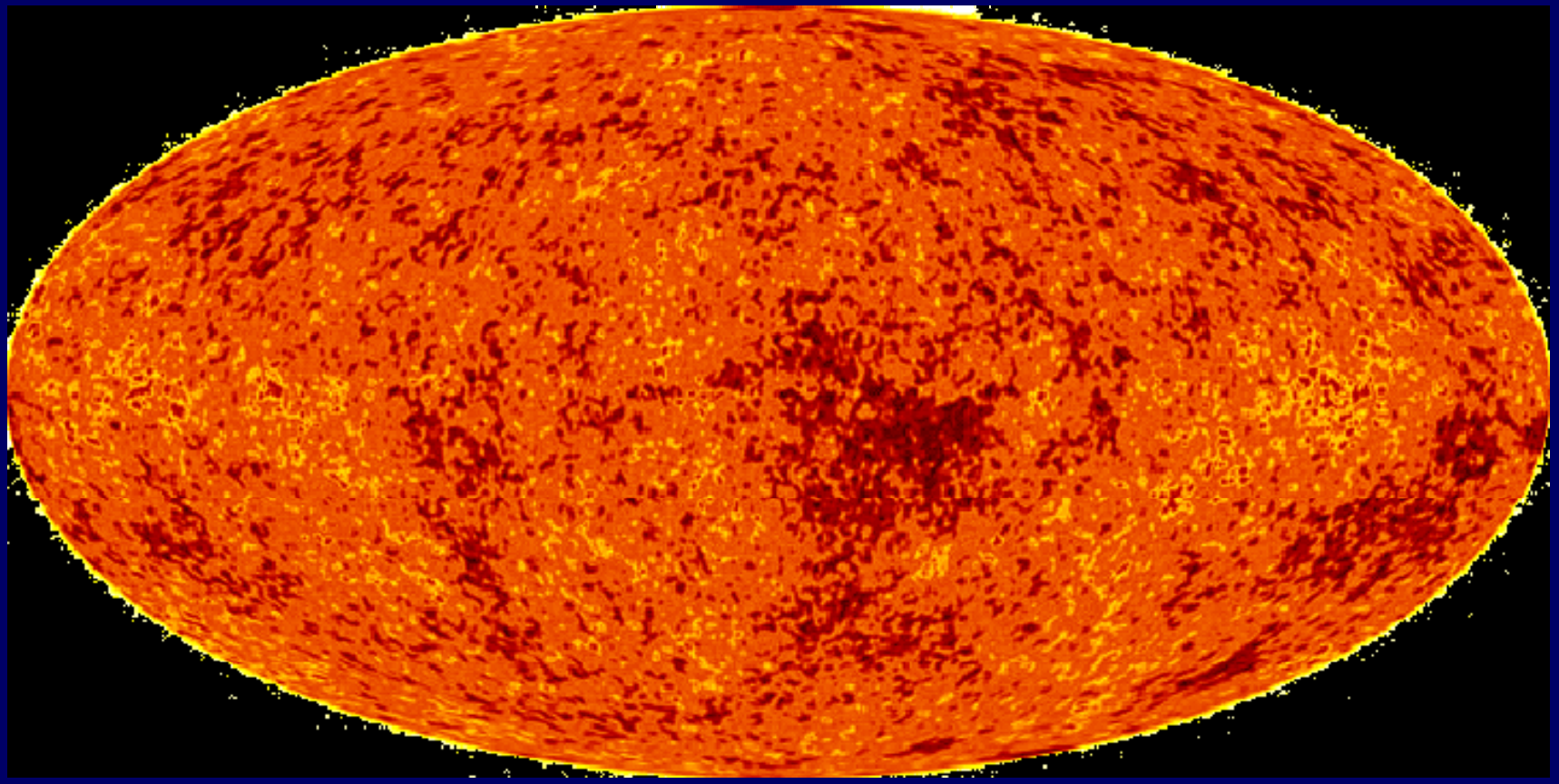
Stars



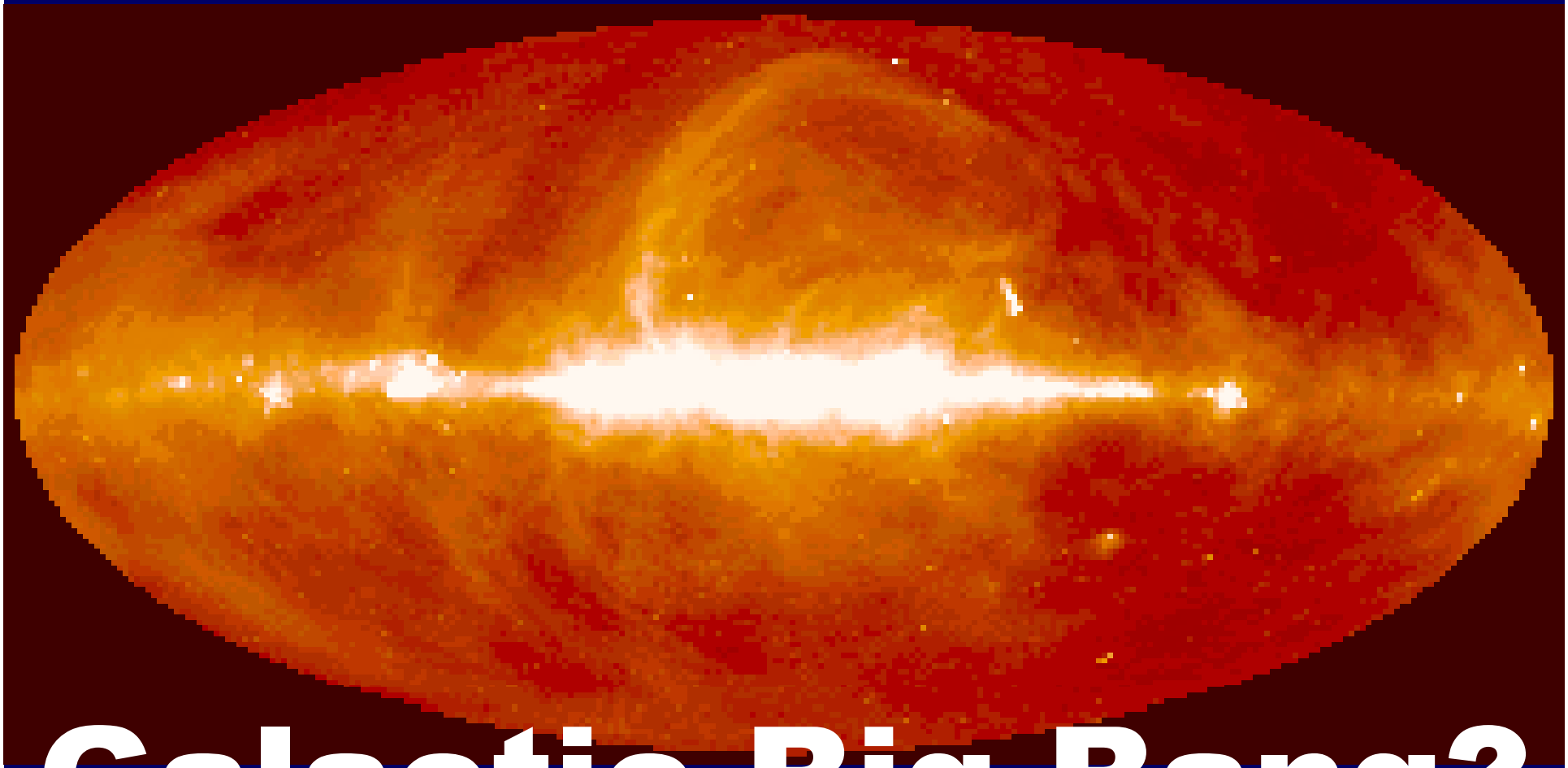
Galaxies


M 82 (NGC 3034)
FOCAS (B, V, Hα)
Subaru Telescope, National Astronomical Observatory of Japan
March 24, 2000

The Universe



How about the MW?



Galactic Big Bang?

The North Polar Spur:

SNR 説

Prof. Oort' suggestion,

Spoelstra,

Berkhuijsen,

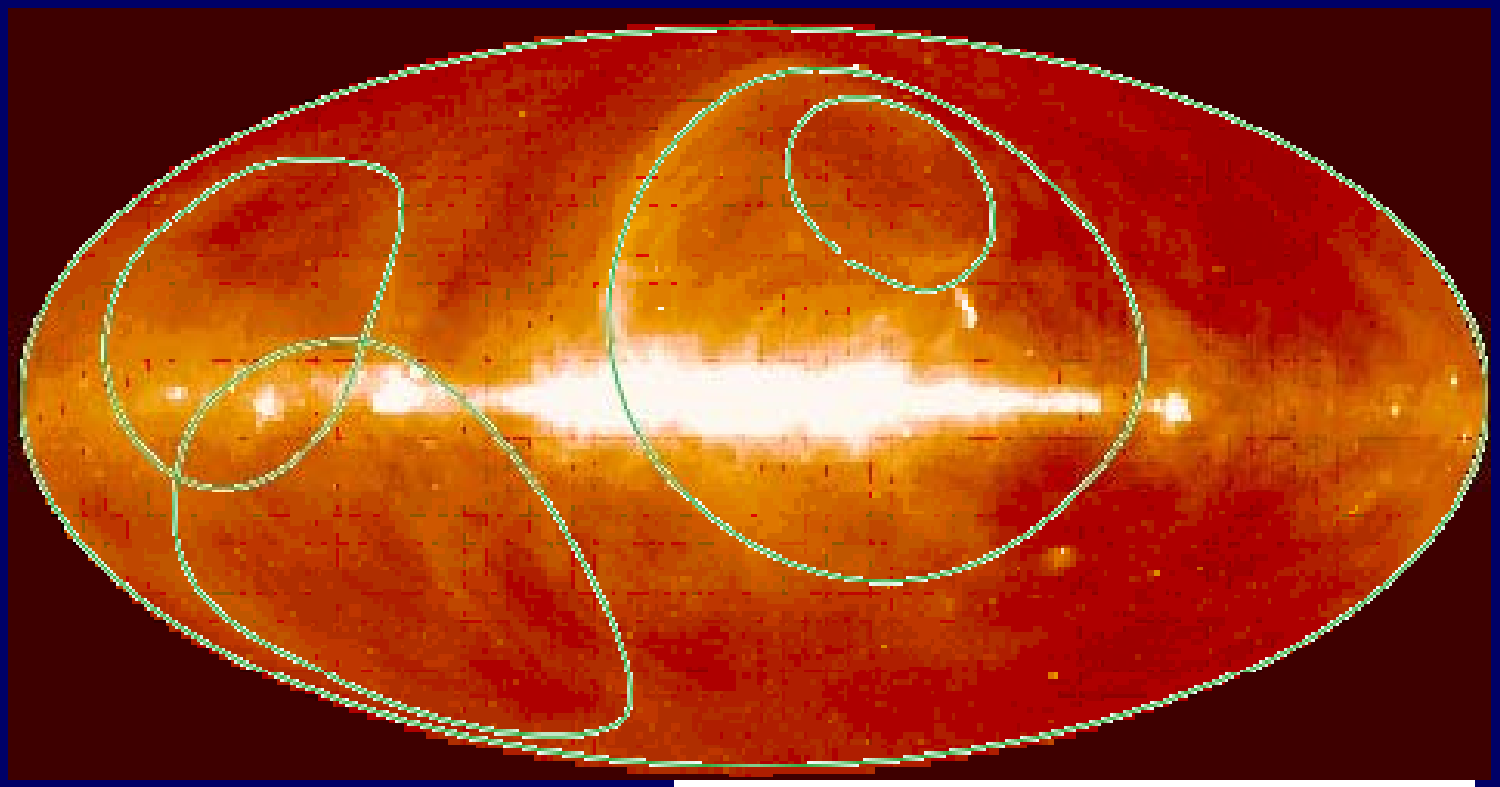
ROSAT PhD Thesis (SNR)..... et al.

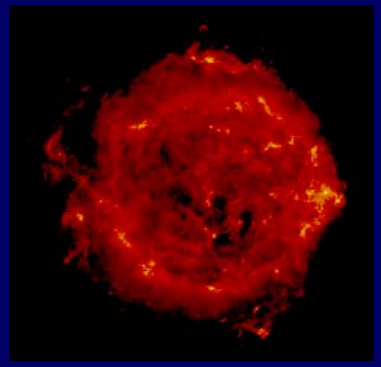
Even in Japan,

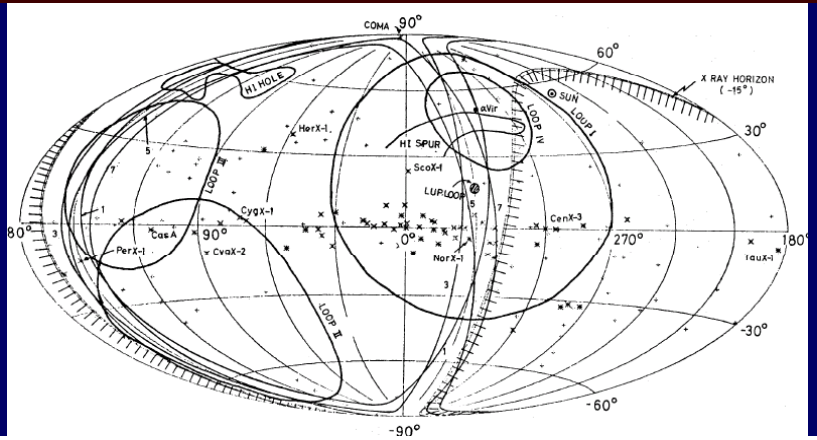
Oda, Hayakawa, ... et al

Galactic Radio Loops I, II, III, IV

Hayakawa et al. 1977







1.Galaxies

Starburst

Shell / Outflow

M82

M 82 (NGC 3034)
FOCAS (B, V, Hα)
Subaru Telescope, National Astronomical Observatory of Japan
March 24, 2000
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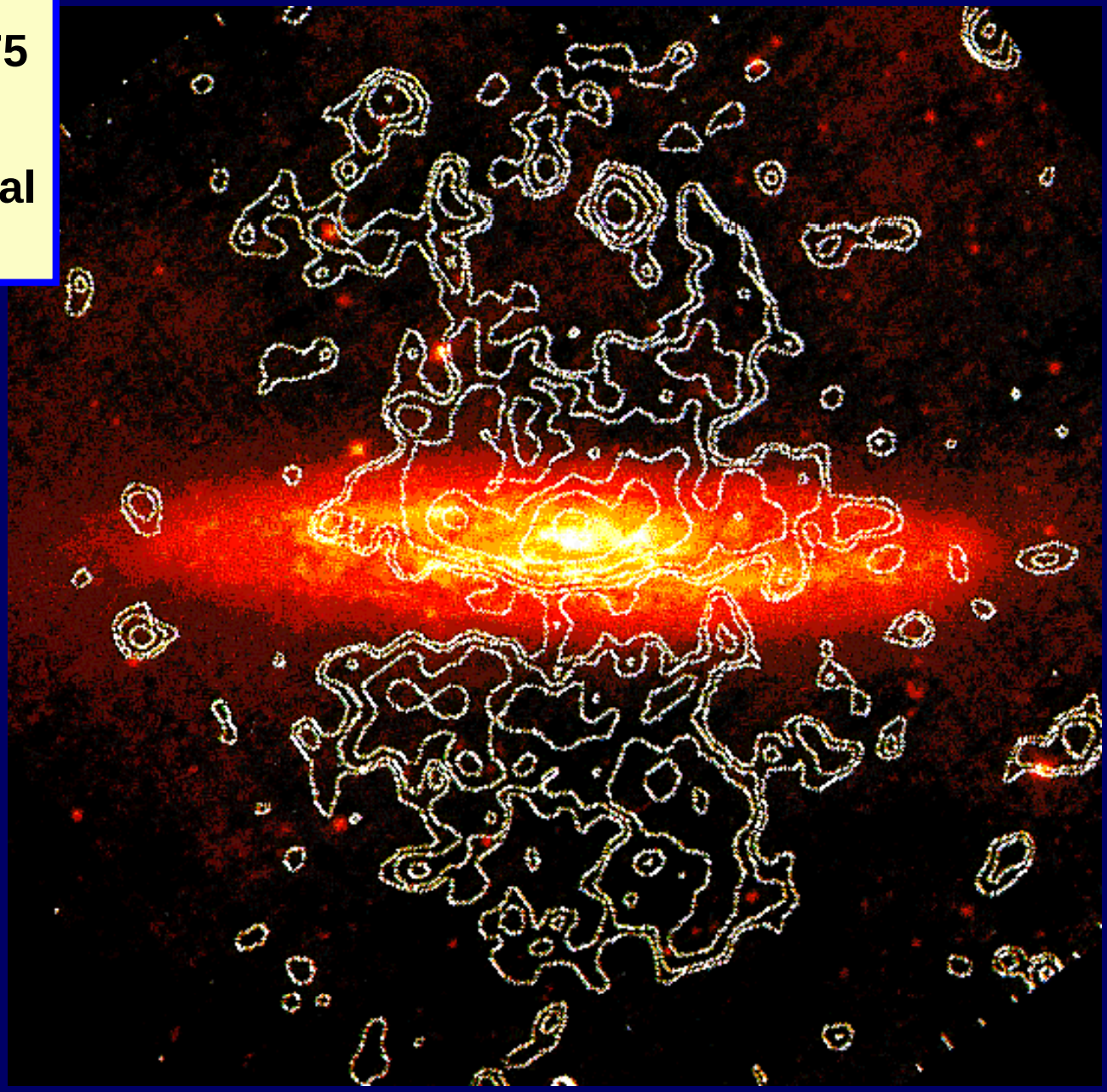
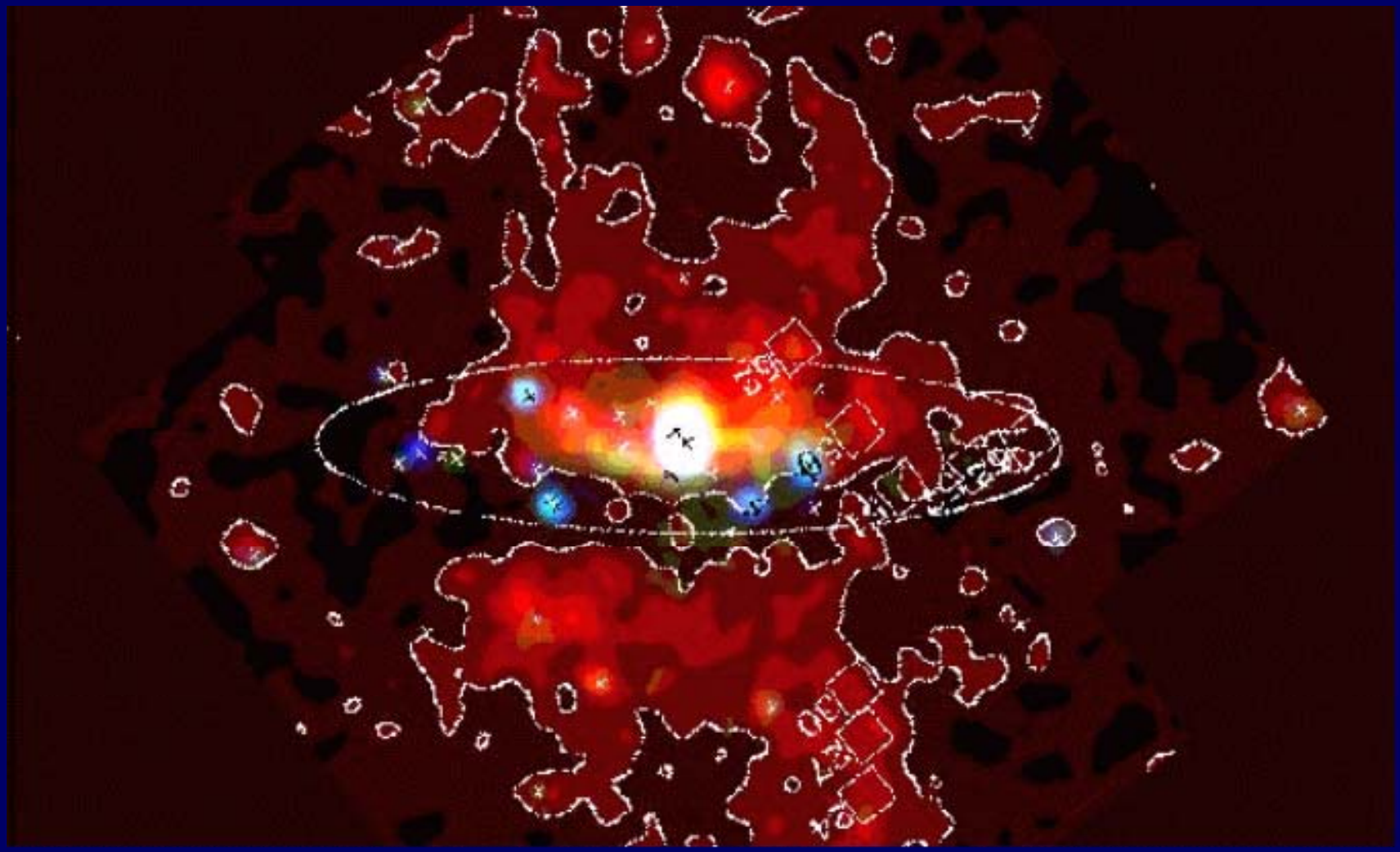
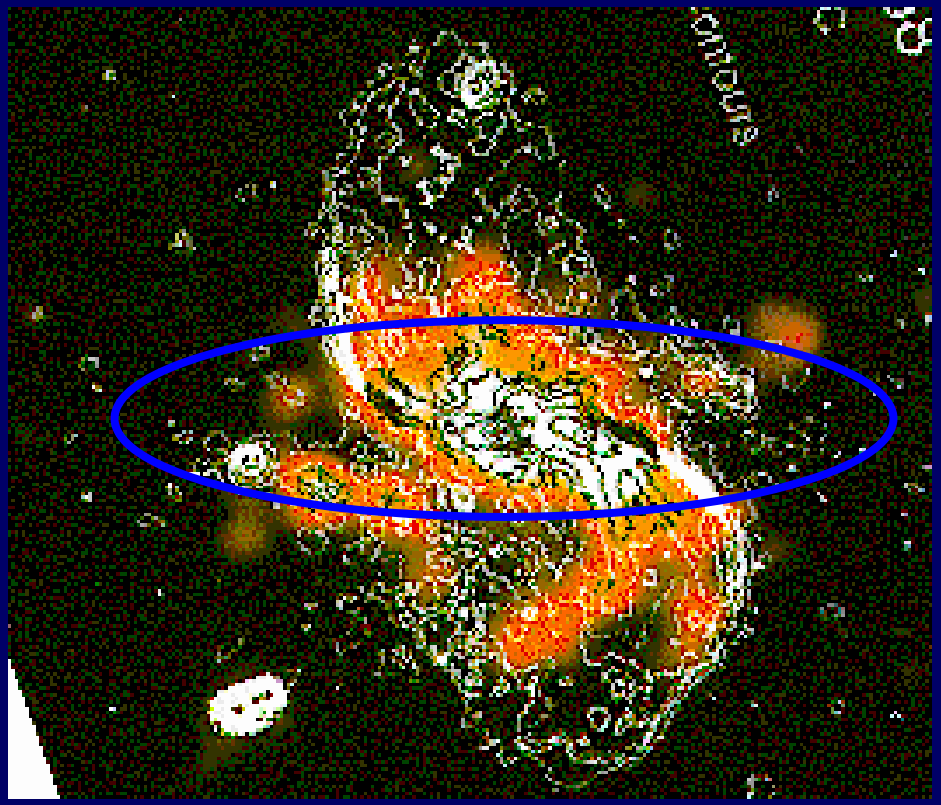
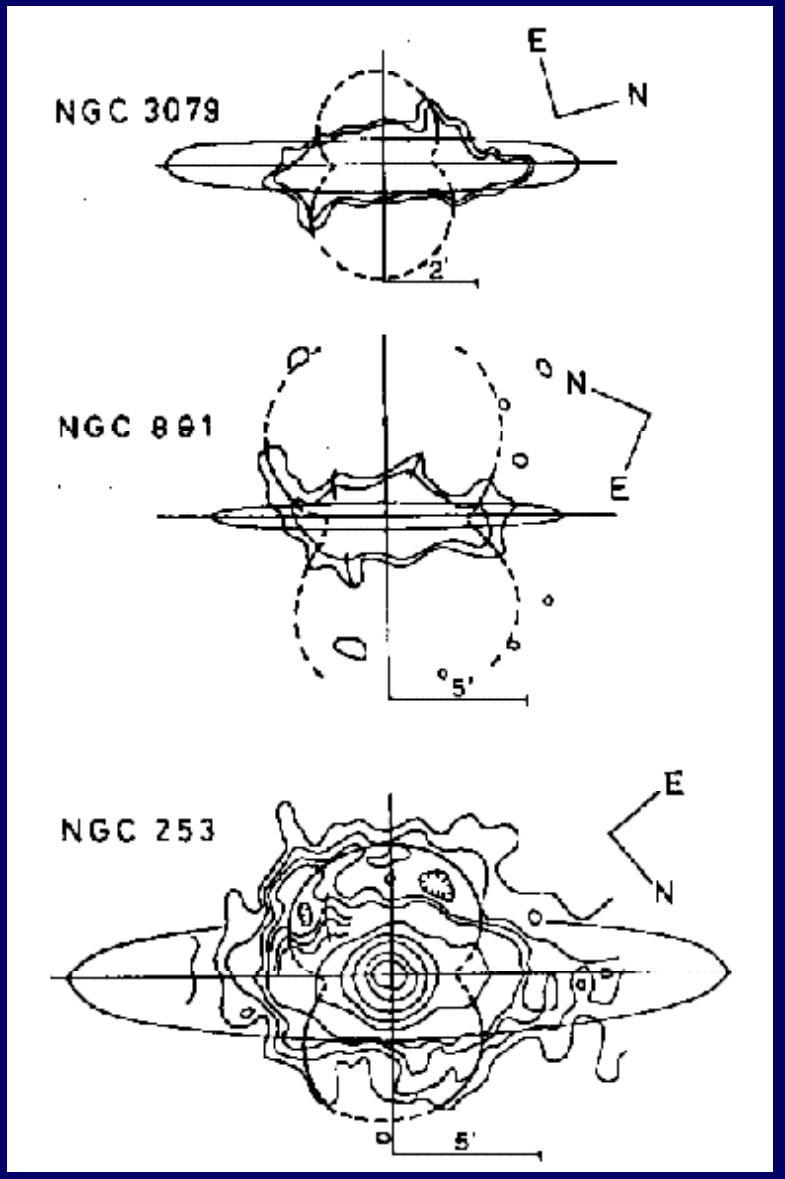
- **NGC 253**
- **ROSAT 0.75 keV**
- **Pietsch et al 1999**



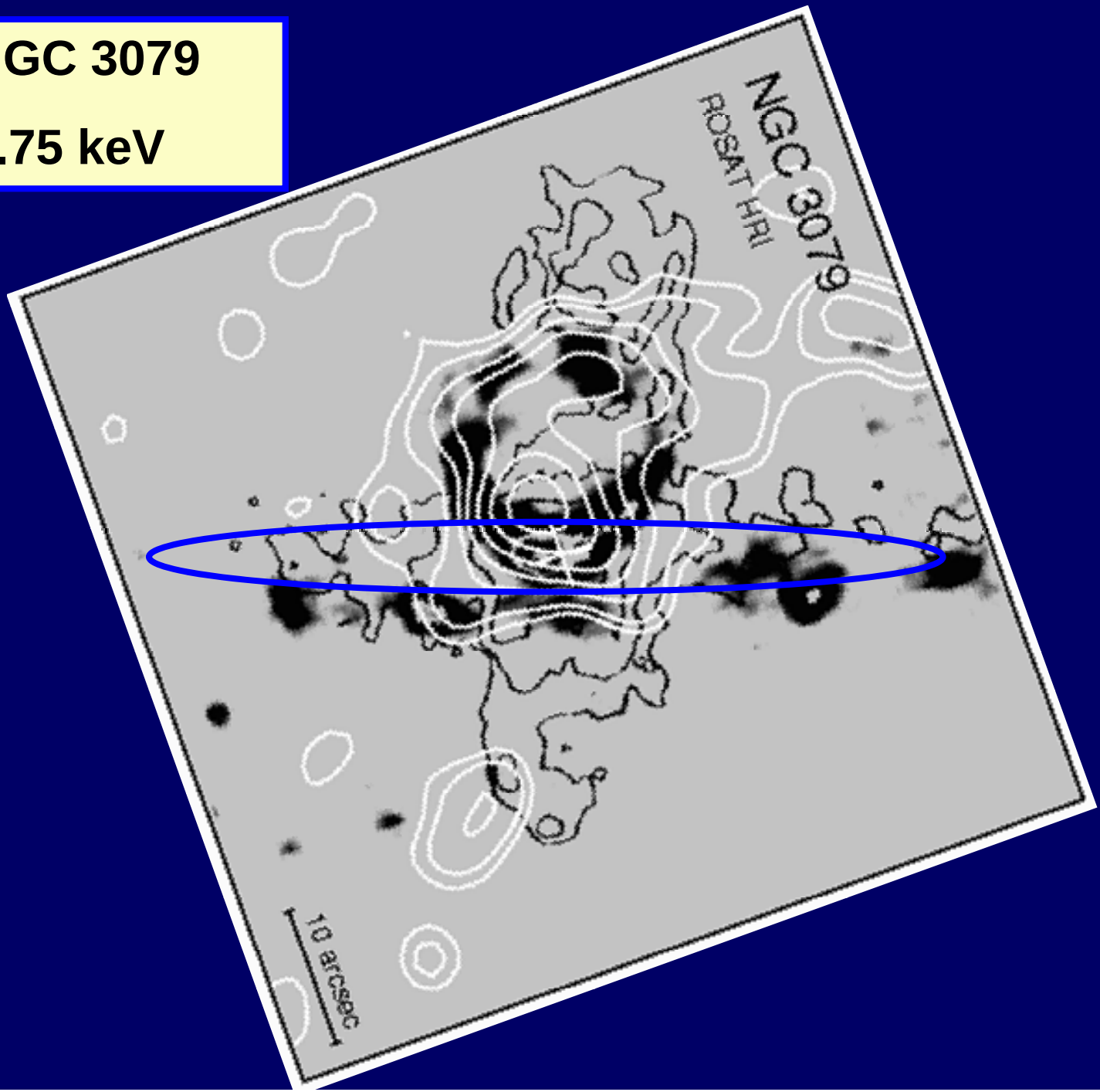


NGC 253
NGC 3079
NGC 891
NGC 4258



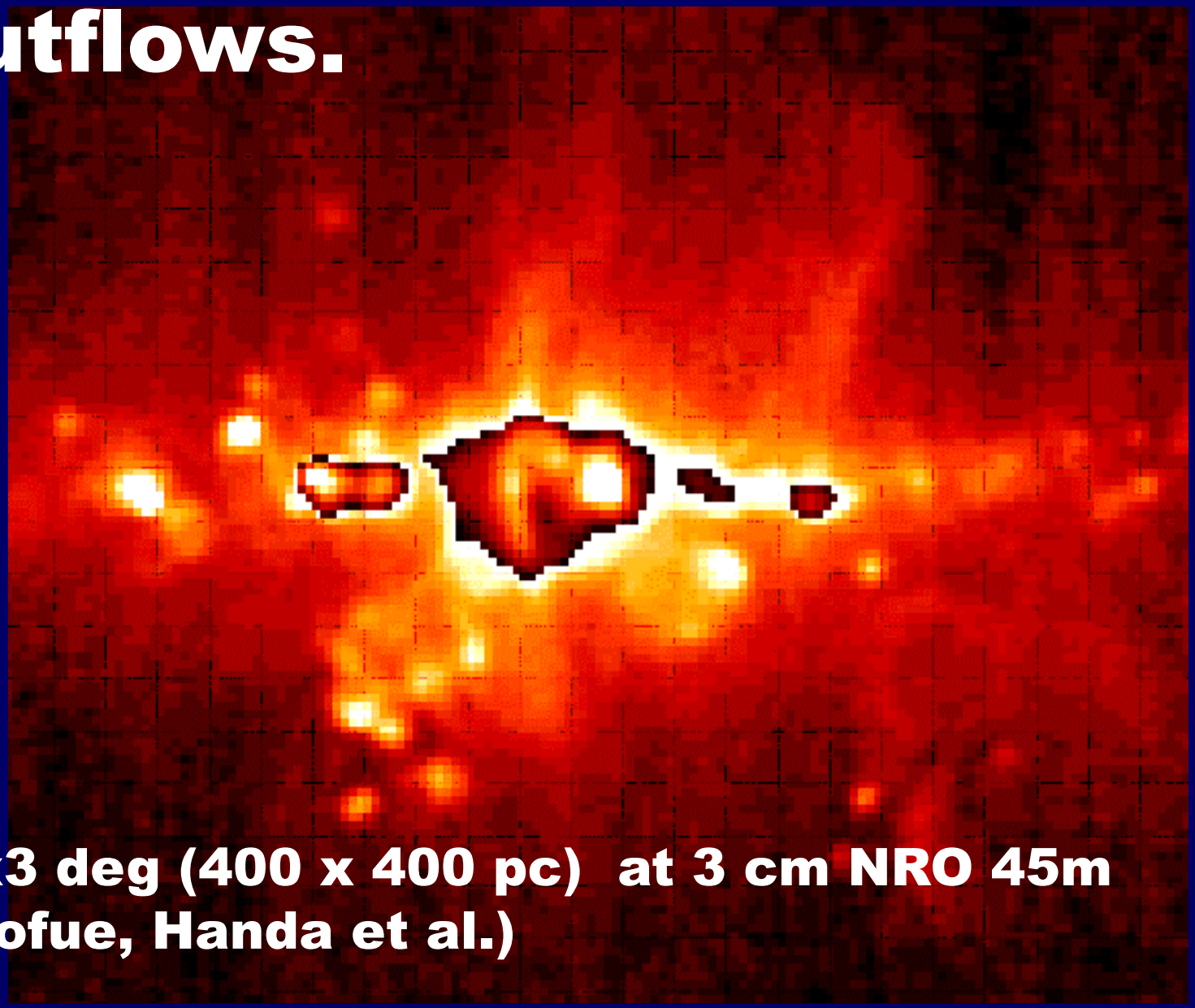


- NGC 3079
- 0.75 keV



2. Galactic Center

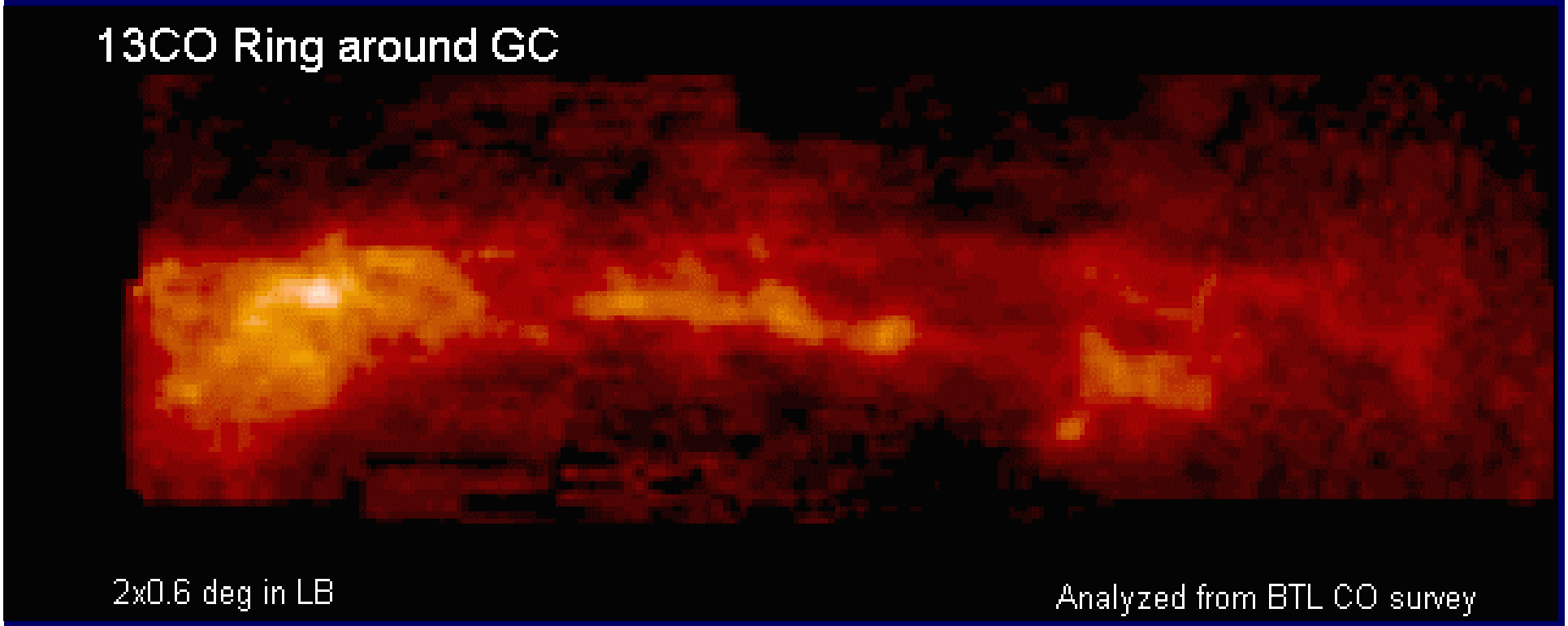
Gas, Mag. Fields, Cosmic rays outflows.



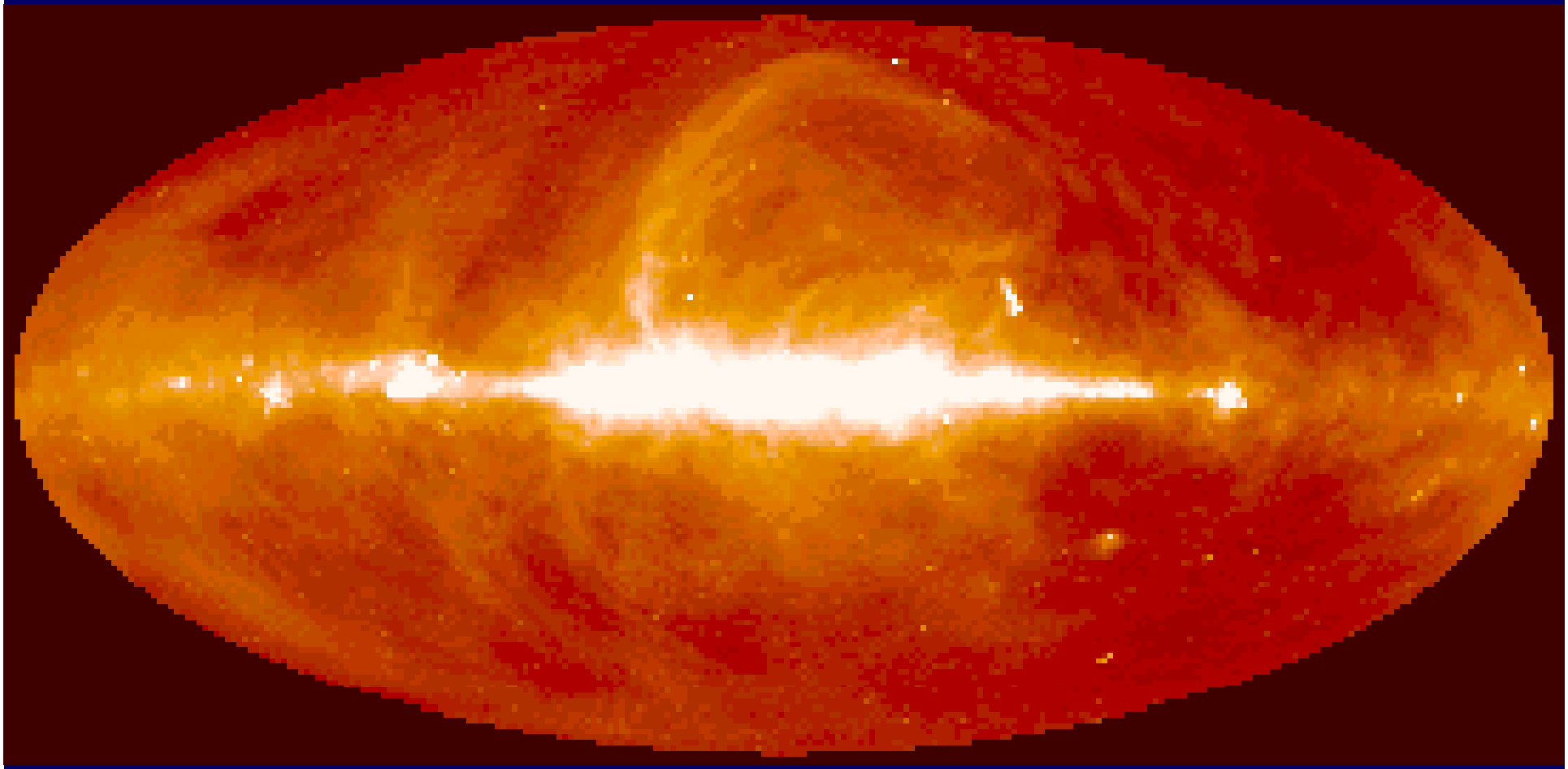
3x3 deg (400 x 400 pc) at 3 cm NRO 45m
(Sofue, Handa et al.)

Cold gases are quiet: ring, clouds

2x0.5 deg (300 x 60 pc) (BTL 7m Bally et al.)

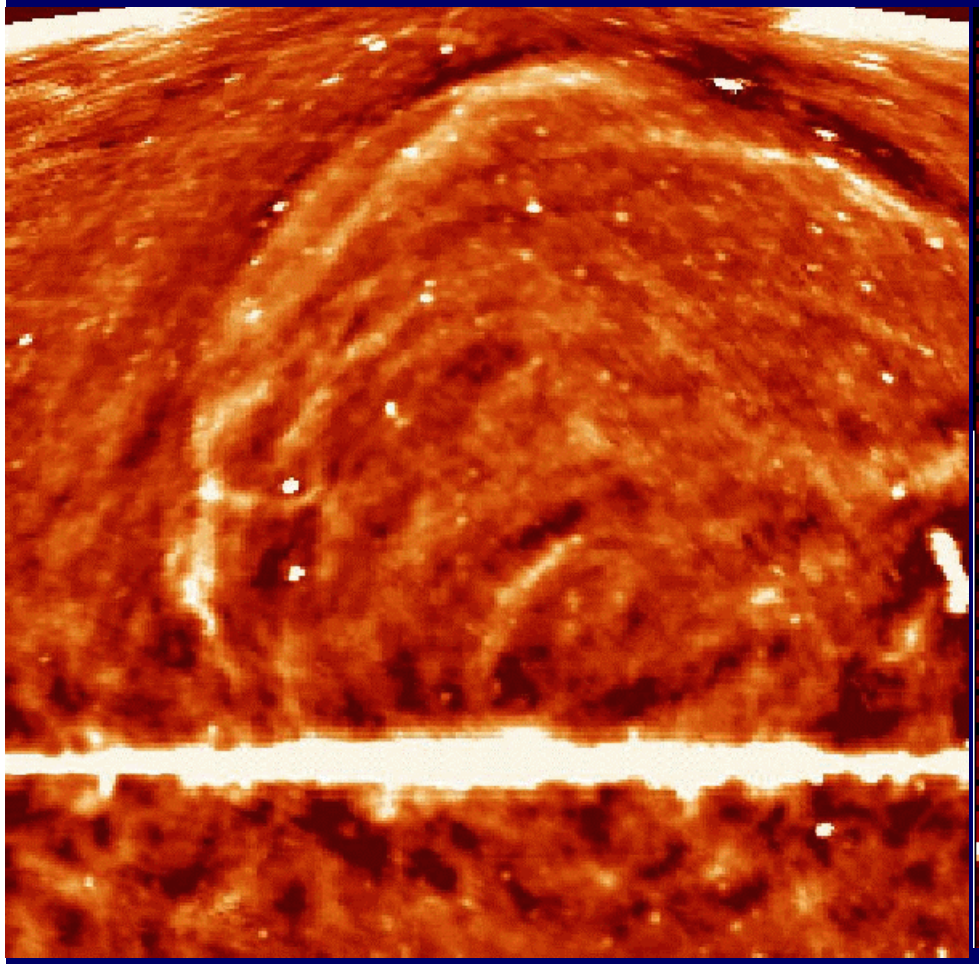


North Polar Spur 408 MHz

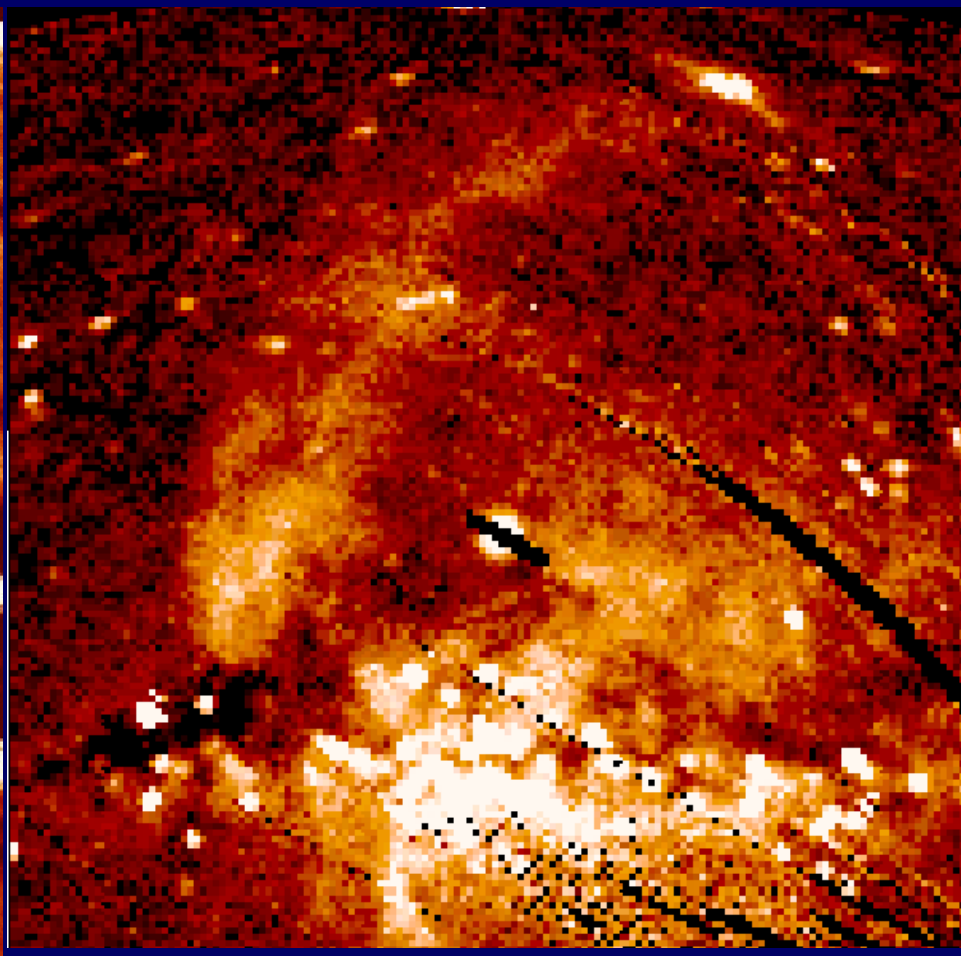


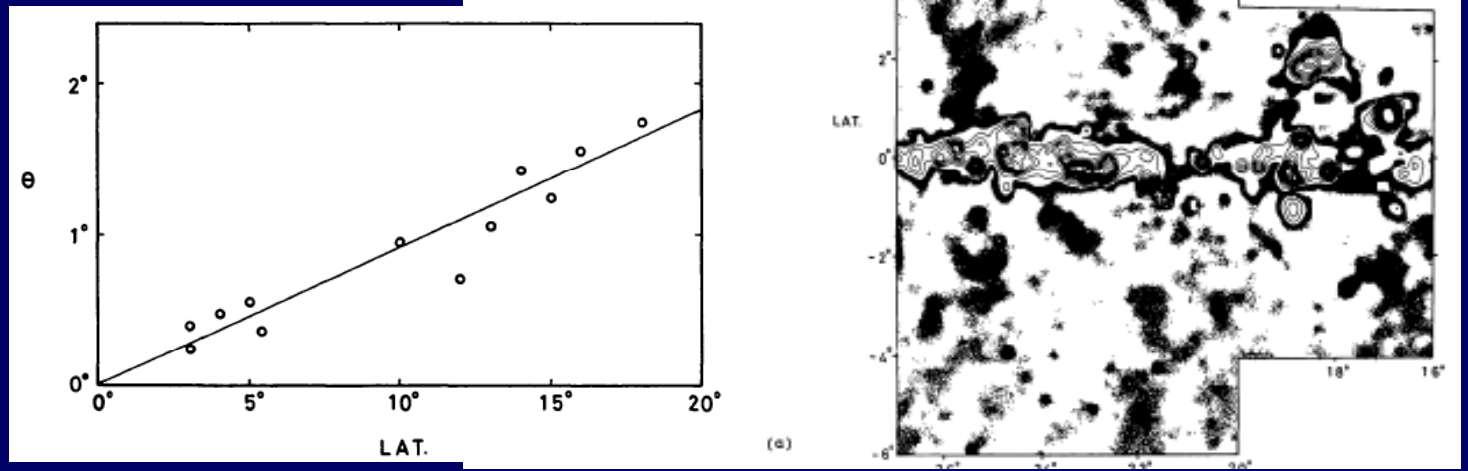
- 408MHz Radio
- Haslam et al 1982

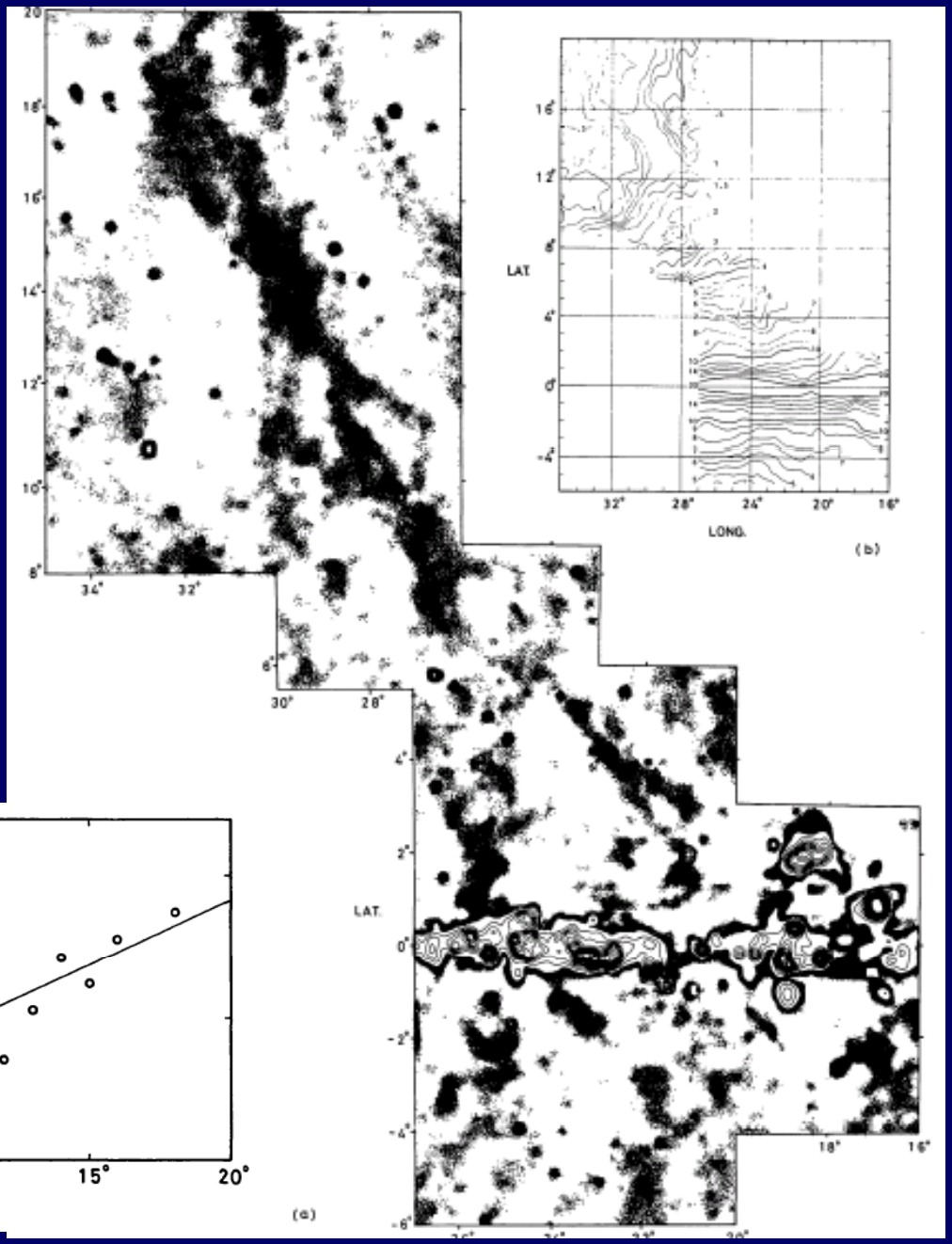
- 408 MHz

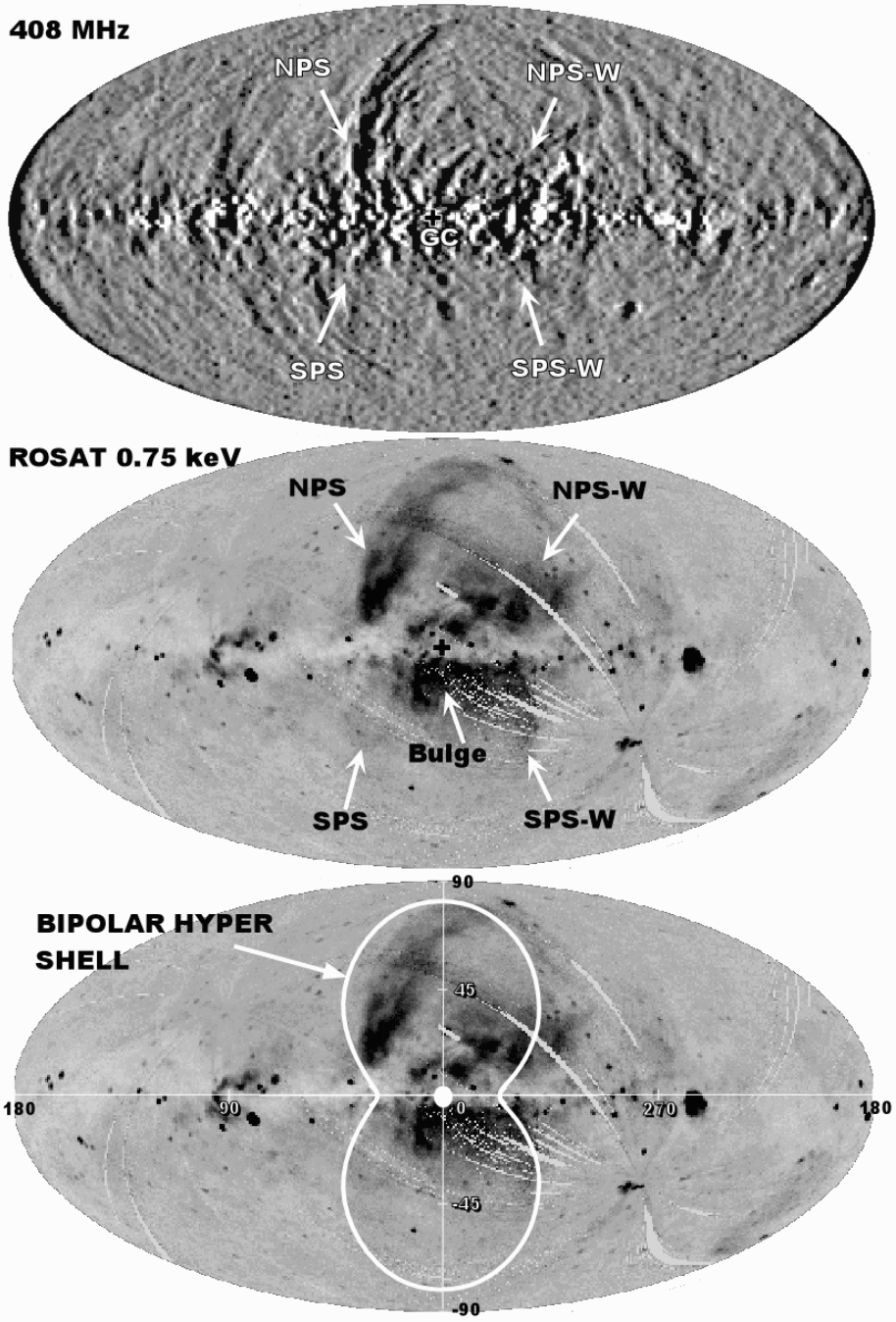


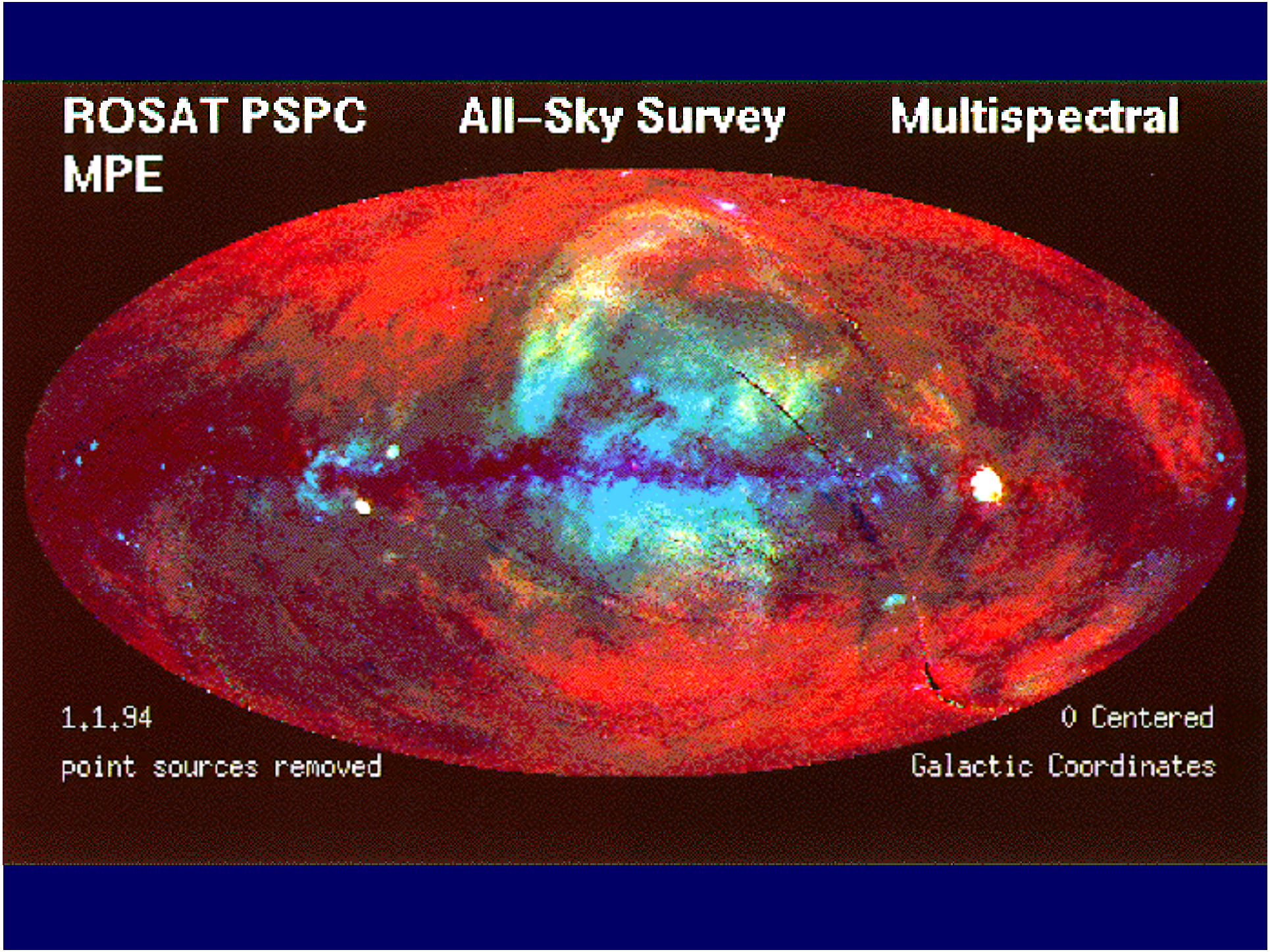
- ROSAT 0.75 keV




θ
2°
1°
0°
0°
5°
10°
15°
20°
LAT.


LAT.
LONG.
(b)
(a)


408 MHz
NPS
NPS-W
GC
SPS
SPS-W
ROSAT 0.75 keV
NPS
NPS-W
Bulge
SPS
SPS-W
BIPOLAR HYPER
SHELL
90
45
180
90
0
270
180
-45
-90


ROSAT PSPC All-Sky Survey Multispectral
MPE
1.1.94
point sources removed
0 Centered
Galactic Coordinates

2. Bipolar Hyper Shell Model for NPS

- Sofue 1977

• Fast MHD (compression) wave

$$\frac{dr}{dt} = V\, p_r/p,$$

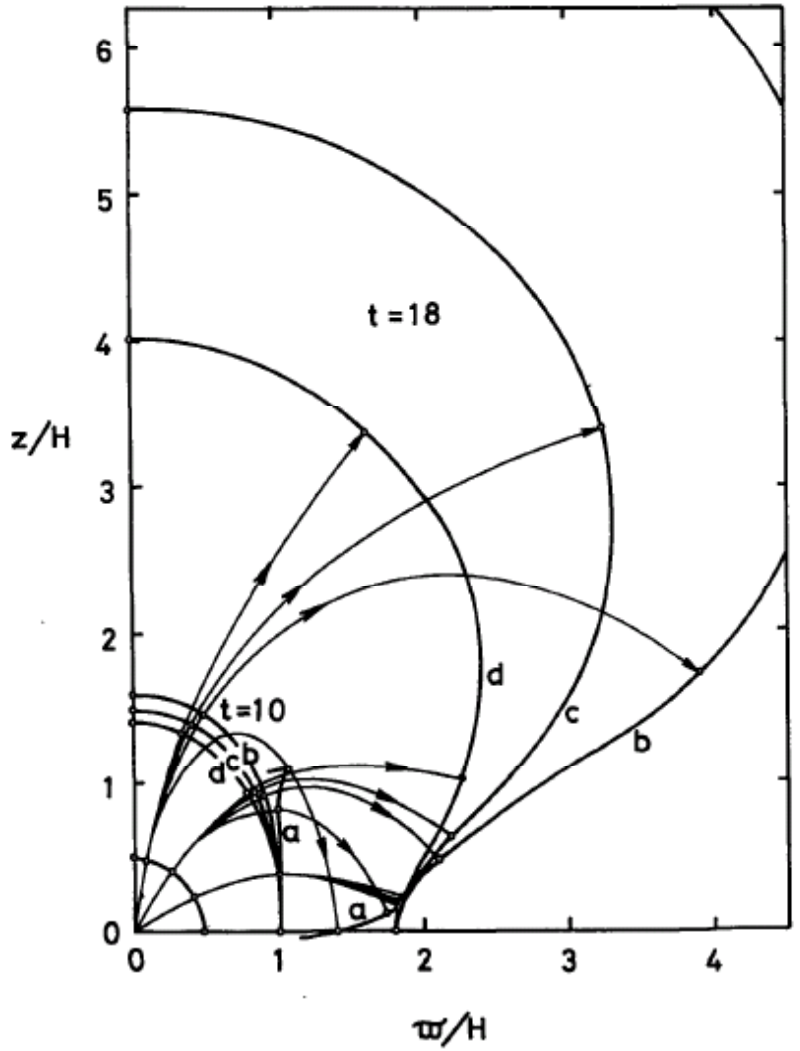
$$\frac{d\theta}{dt} = V\, p_\theta/rp,$$

$$\frac{d\phi}{dt} = V\, p_\phi/rp \sin\theta,$$

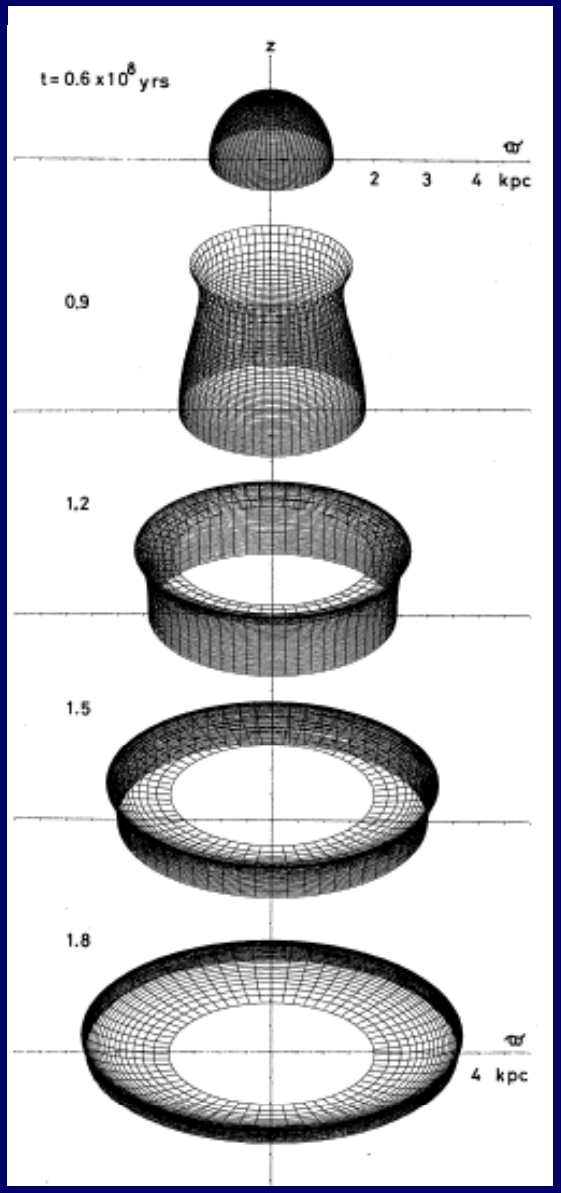
$$\frac{dp_r}{dt} = -p\frac{\partial V}{\partial r} + \frac{V}{rp}(p_\theta^2 + p_\phi{}^2),$$

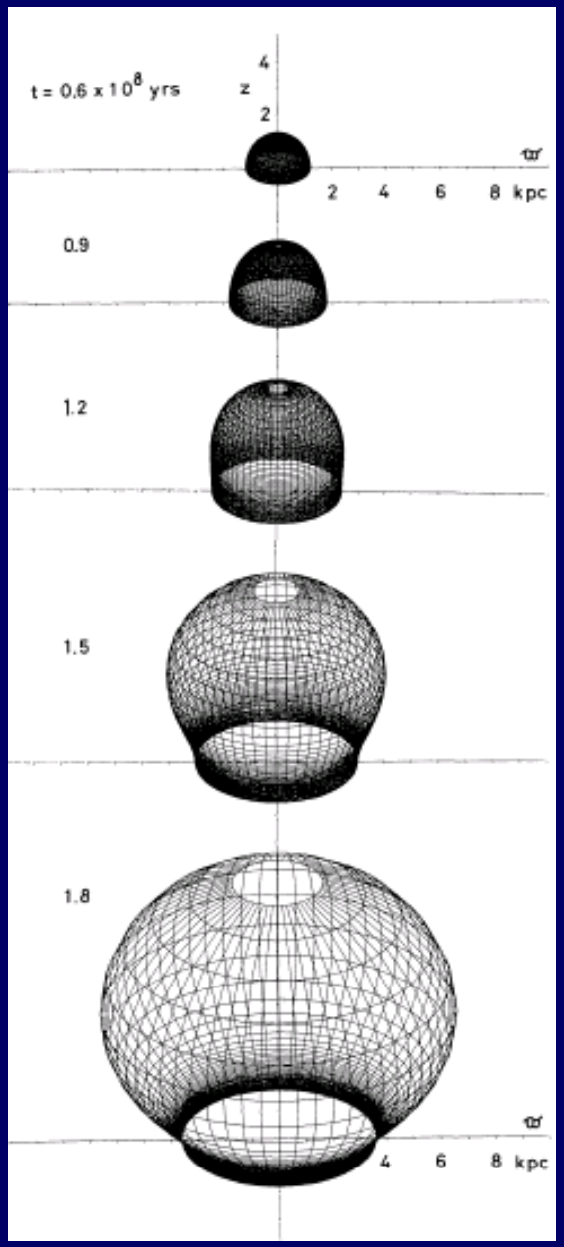
$$\frac{dp_\theta}{dt} = -\frac{p}{r}\frac{\partial V}{\partial \theta} - \frac{V}{rp}(p_\theta p_r - p_\phi{}^2 \cot\theta),$$

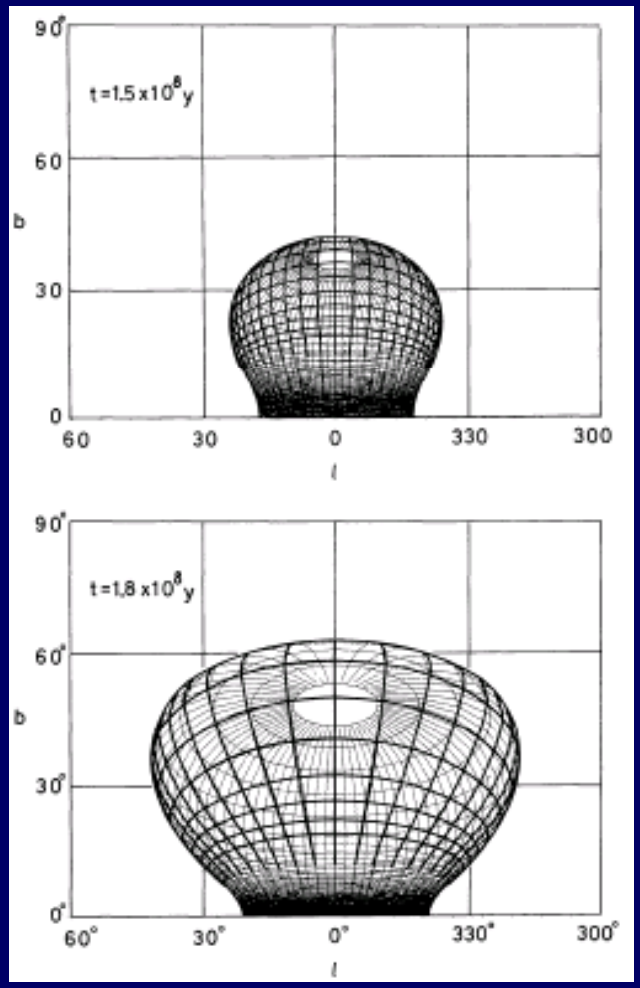
$$\frac{dp_\phi}{dt} = -\frac{p}{\sin\theta}\frac{\partial V}{\partial \phi} - \frac{V}{rp}(p_\phi p_r + p_\phi p_\theta \cot\theta),$$

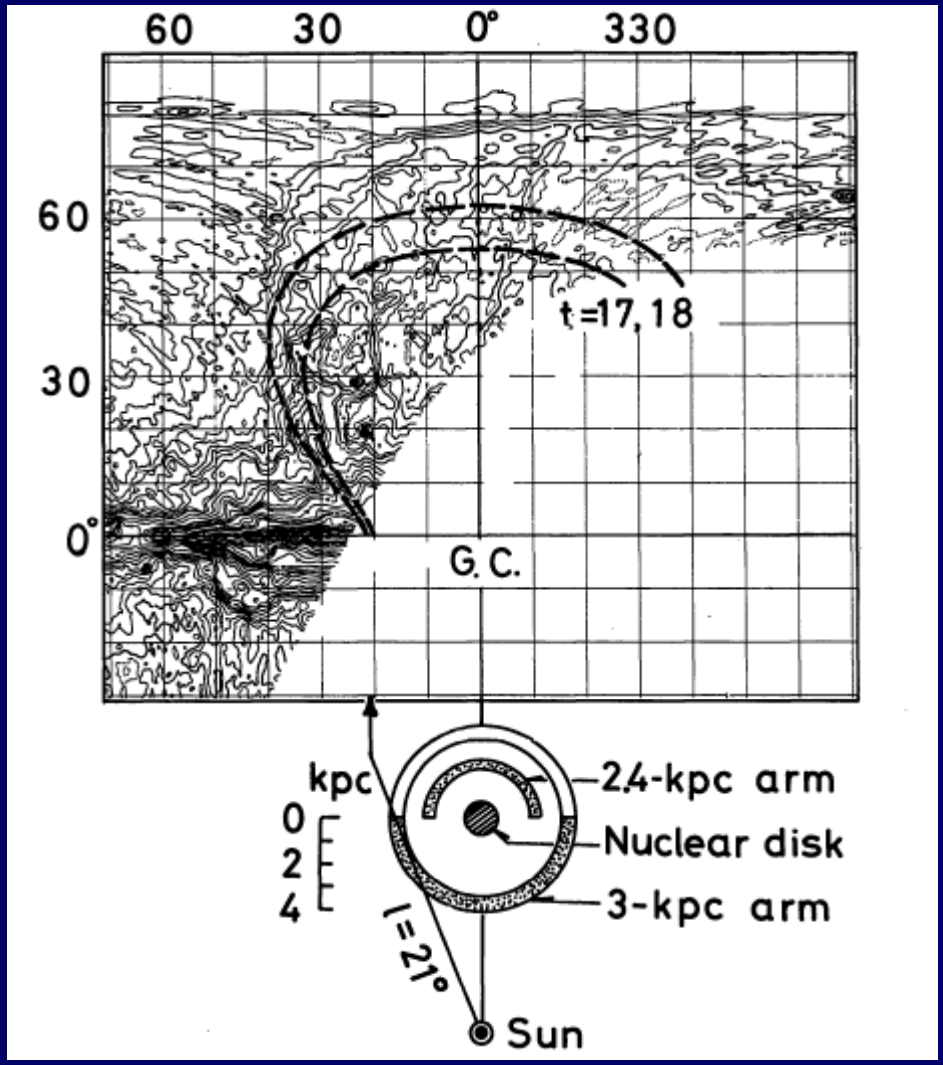


•Sofue 1977


t = 0.6 x 10^8 yrs
z
ϖ
2 3 4 kpc
0.9
1.2
1.5
1.8
4 kpc


t = 0.6 x 10^8 yrs
z
4
2
ϖ
2 4 6 8 kpc
0.9
1.2
1.5
1.8
4 6 8 kpc


t=1.5 x 10^8 y
90°
60
30
0
b
60 30 0 330 300
l
t=1.8 x 10^8 y
90°
60°
30°
0°
b
60° 30° 0° 330° 300°
l


60
30
0°
330
60
30
0°
t=17, 18
G.C.
kpc
0
2
4
l=21°
Sun
2.4-kpc arm
Nuclear disk
3-kpc arm

- Sofue 1977

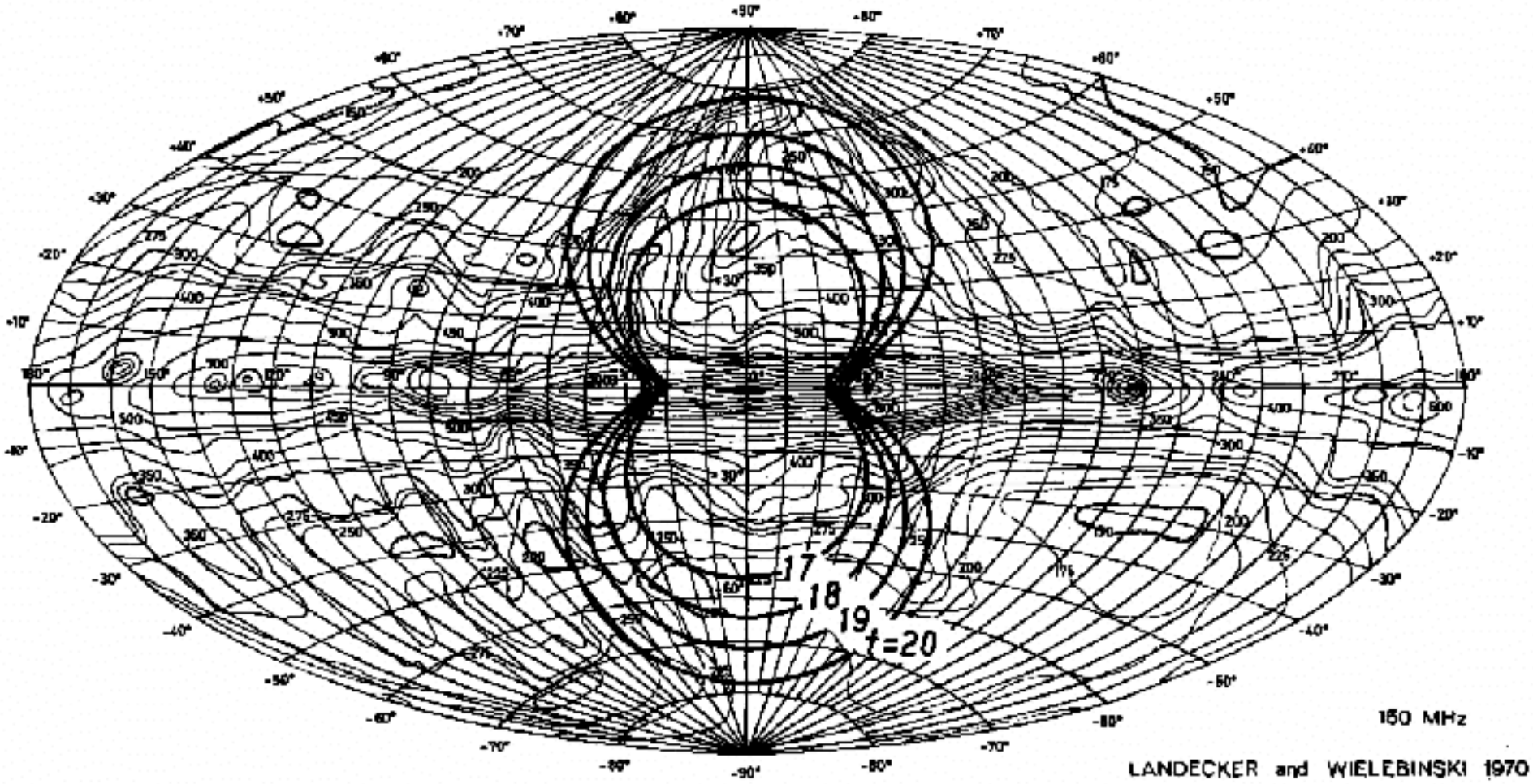


Fig. 8. The same as Figure 7, but for the front at $t = 17 - 20.10^7$ years superposed on the 150 MHz map by Landecker and Wielebinski (1

- **Sofue 1977**

$E \sim 10^{55\text{-}56}$ ergs $\sim 10^{4\text{-}5}$ SN

$t \sim 10^{6\text{-}7}$ yr

Shock waves

$E \sim 1/2\ Mv^2 \sim 4\pi/3\ \rho r^3 v^2$

$\rho \sim 10^{-3}$ H/cc (Halo)

$r \sim 5$ kpc, $M \sim 10^7 M_\odot$

$v \sim$ 200-300 km/s

$T \sim 10^7$ K $\rightarrow$ Soft X rays

Radial-ray adiabatic Shock

Sakashita, Moellenhoff method

$$E = \int_0^R \frac{P}{\gamma - 1} 4\pi r^2 dr + \int_0^R \frac{1}{2} \left(\frac{\partial r}{\partial t}\right)^2 \rho_0 4\pi r_0^2 dr_0 .$$

$$E = \frac{1}{3(\gamma+1)^2} \left(\frac{4(2\gamma-1)}{(\gamma-1)} JR\ddot{R} + \left\{ \left[2IR + \frac{8\gamma}{(\gamma+1)} + 3 \right] J + \frac{2M(\gamma+1)}{(\gamma-1)} \right\} \dot{R}^2 \right)$$

Here,

$$I = \left(\frac{4\pi}{r_0} \frac{d\rho_0}{dr_0} \right)_R ,$$

$$J = \int_0^R \rho_0 4\pi r_0^2 dr_0 ,$$

and

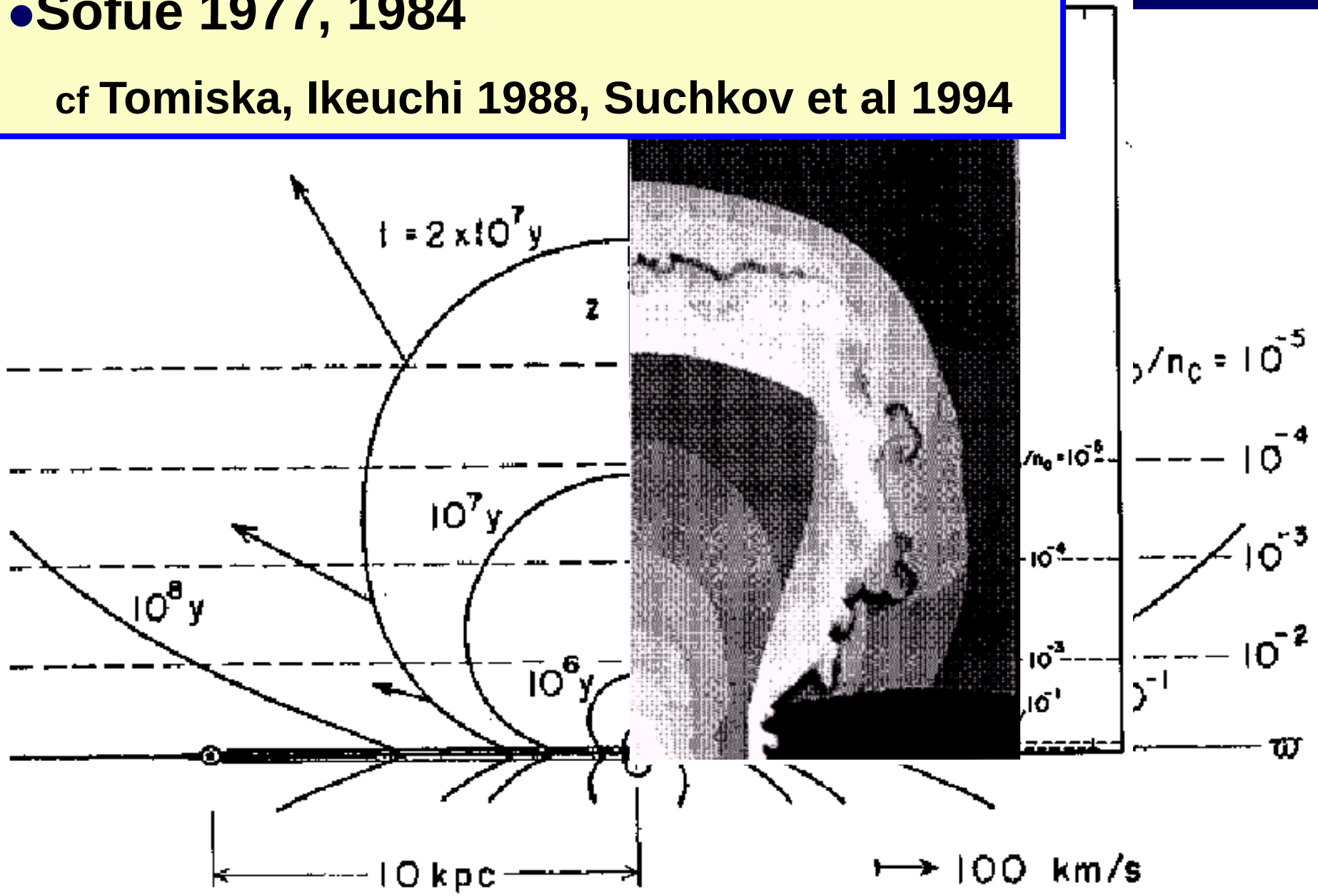
$$M = \rho_0 \frac{4\pi}{3} R^3 .$$

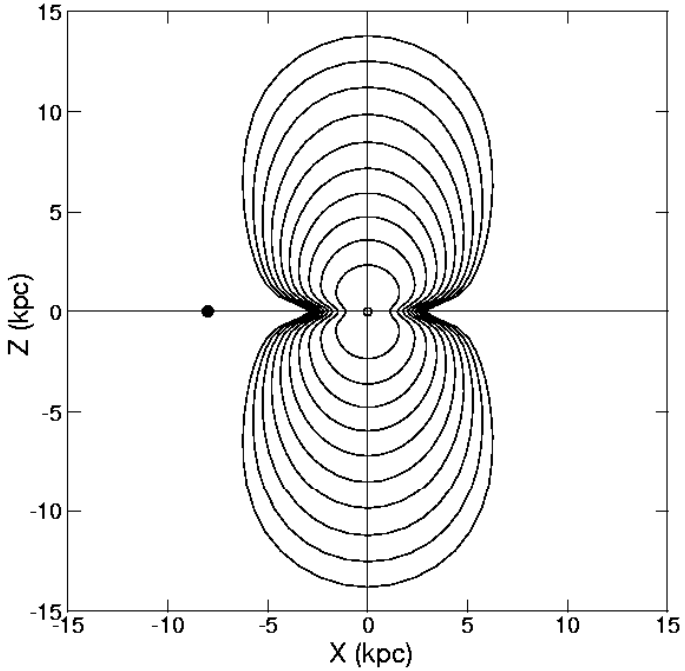
$$\rho_0 = \rho_1 \exp(-z/z_1) + \rho_2 \exp(-z/z_2) + \rho_3 .$$

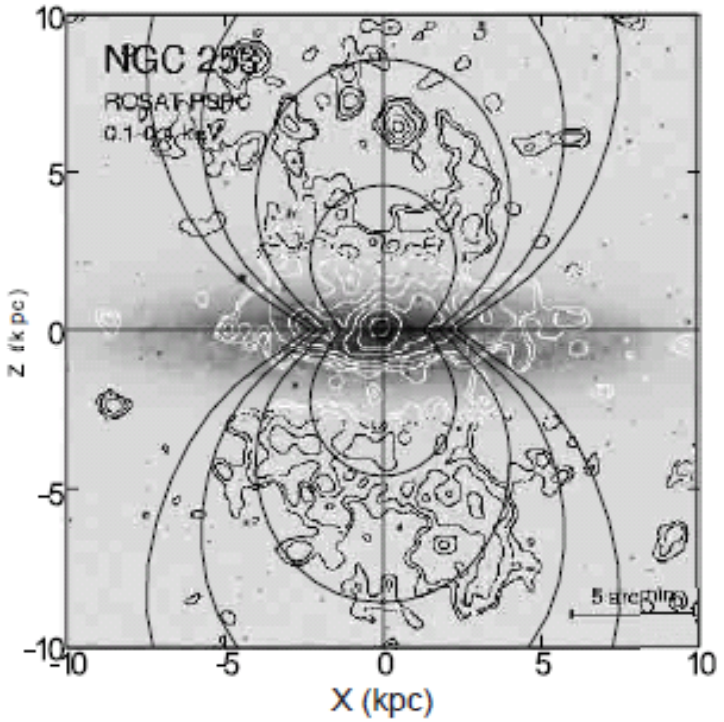
Bipolar Hyper Shell Model

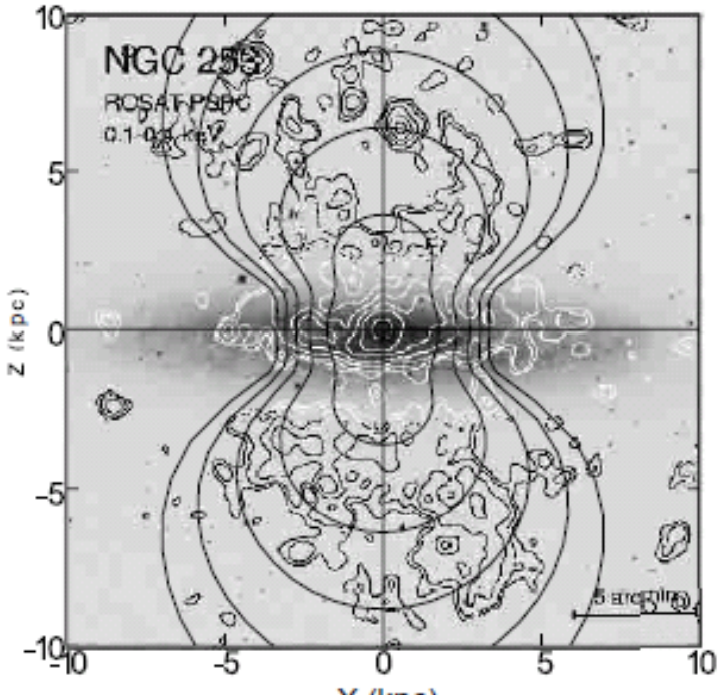
- **Sofue 1977, 1984**

  cf Tomiska, Ikeuchi 1988, Suchkov et al 1994

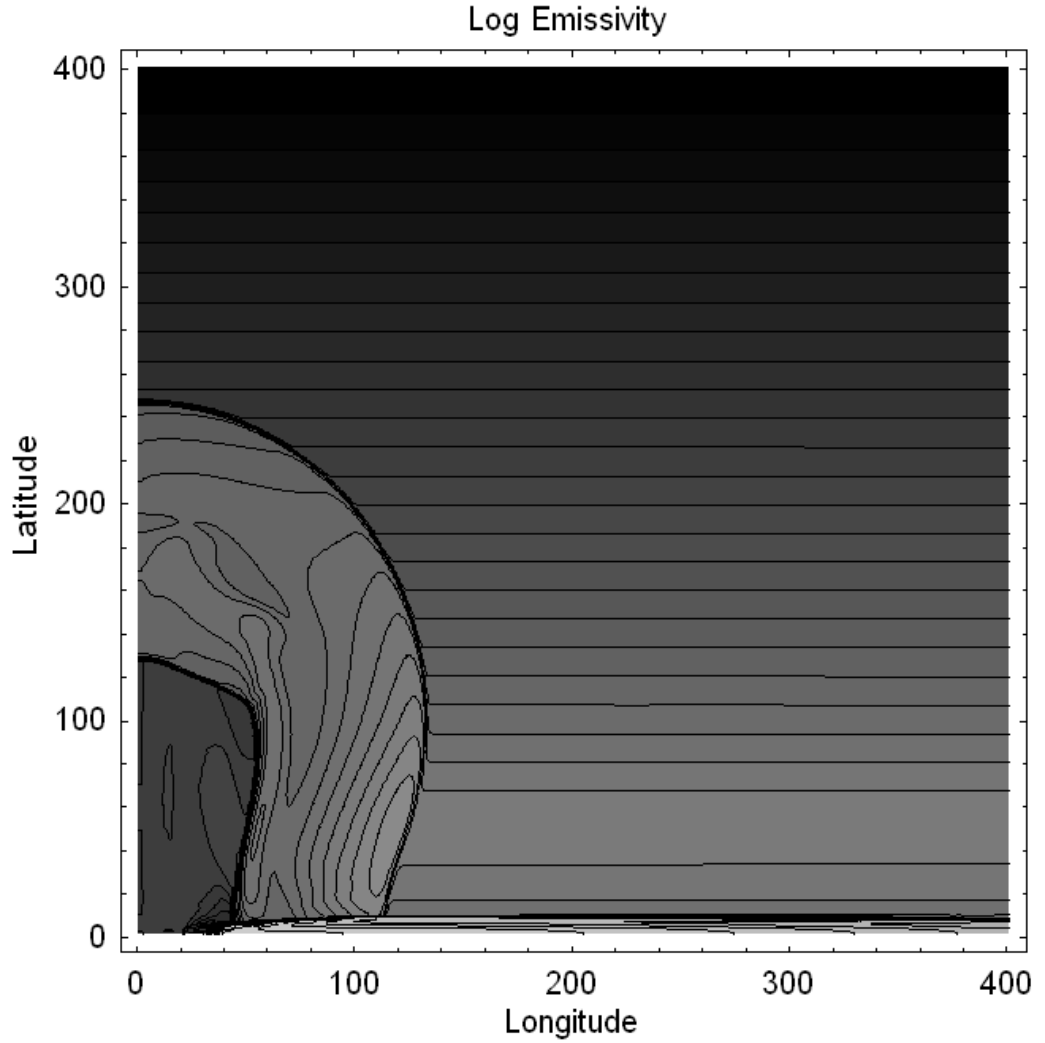


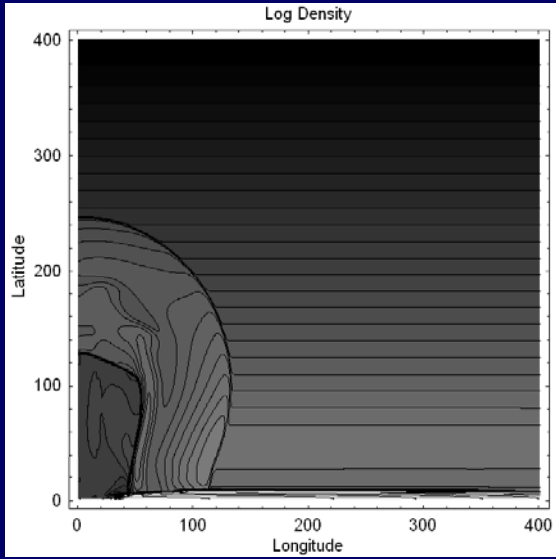

15
10
5
0
-5
-10
-15
Z (kpc)
-15
-10
-5
0
5
10
15
X (kpc)

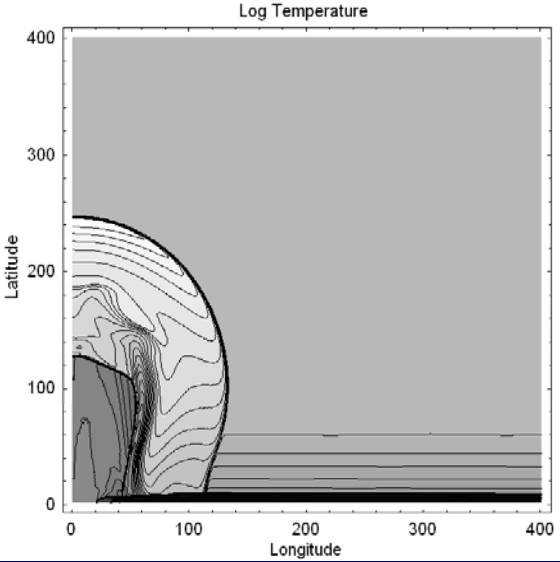

NGC 253
ROSAT-PSPC
10
5
0
-5
-10
Z (kpc)
-10
-5
0
5
10
X (kpc)

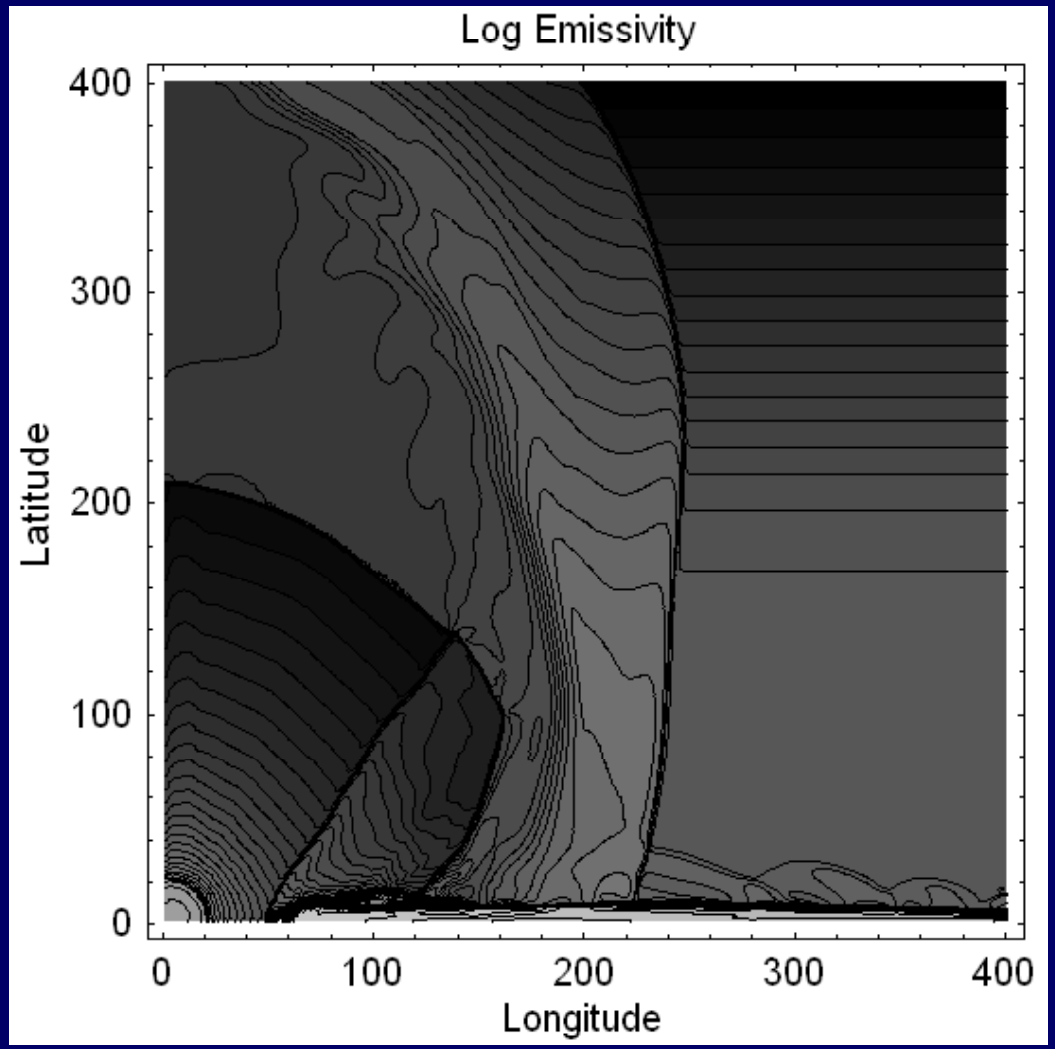

NGC 253
ROSAT-PSPC
10
5
0
-5
-10
Z (kpc)
-10
-5
0
5
10

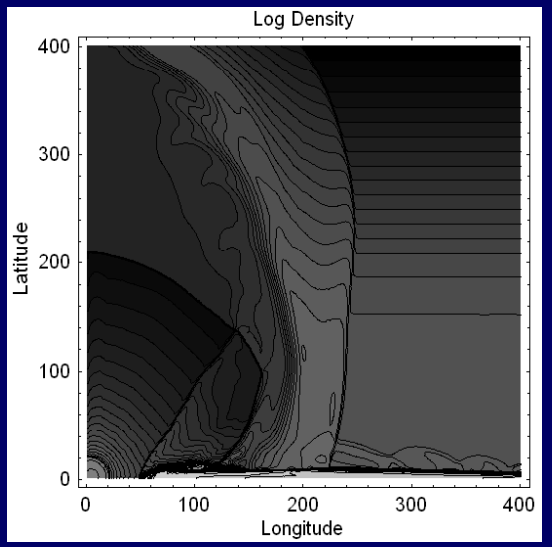
Numerical Hydrodynamics:
Sofue & Habe 2013 (in prepa)

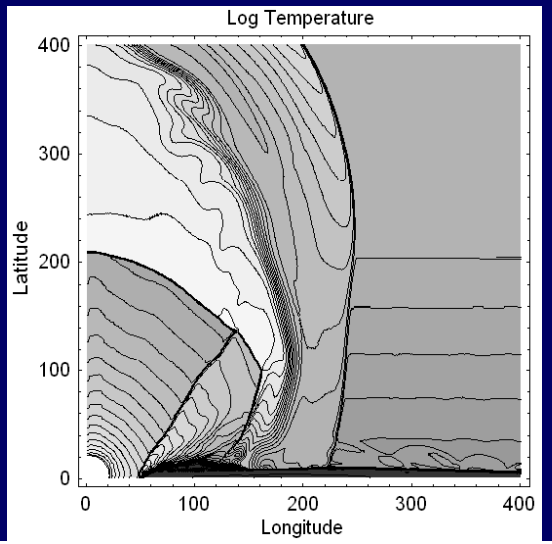







Log Emissivity
Latitude
Longitude
0
100
200
300
400


Log Density
Latitude
Longitude
0
100
200
300
400


Log Temperature
Latitude
Longitude
0
100
200
300
400

3. Simulation of Observations

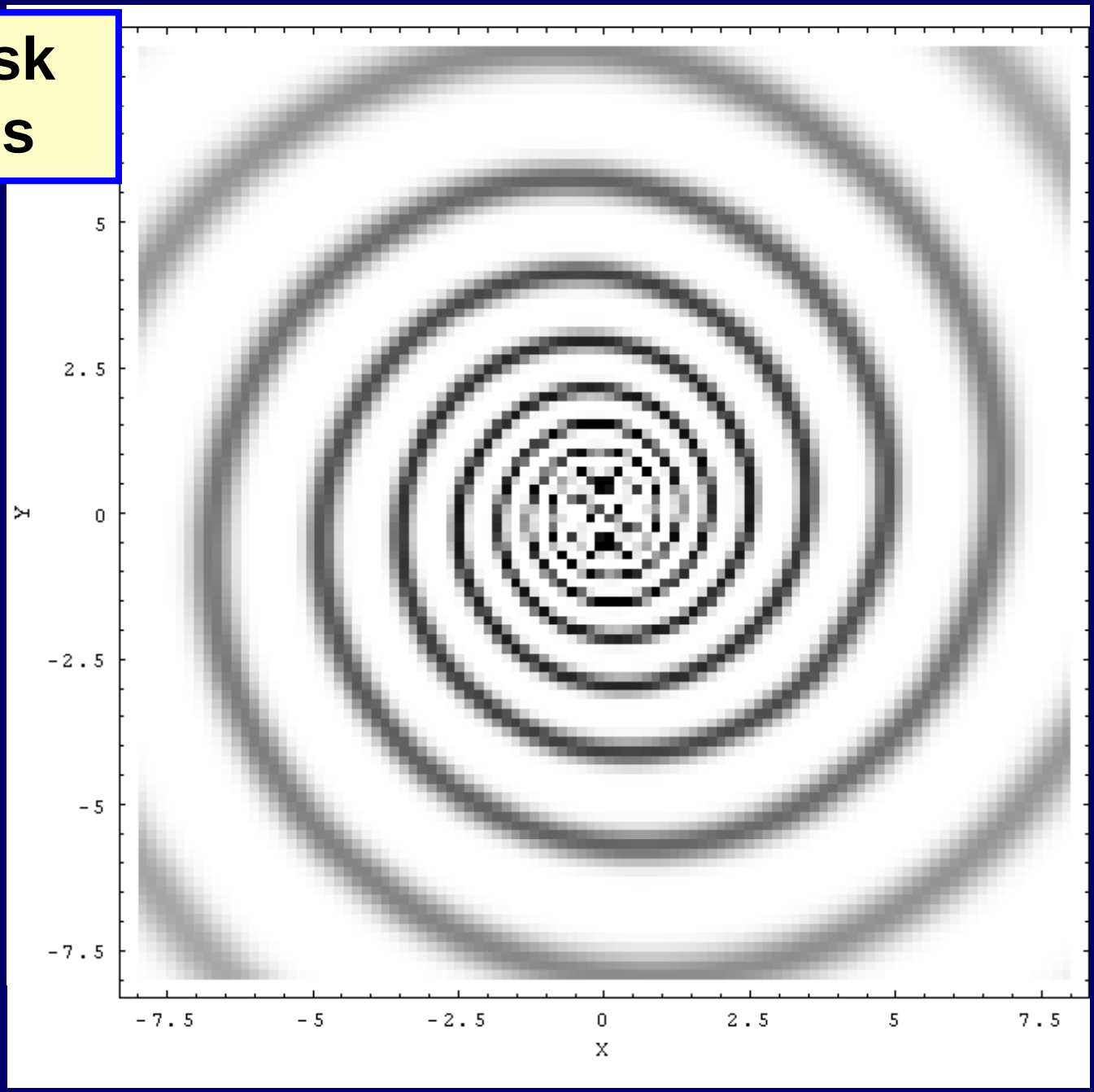
Radio synchrotron

Radio emissivity

B-CR equipartition

$$\varepsilon \propto B^{\gamma} \propto \rho^{\alpha}$$

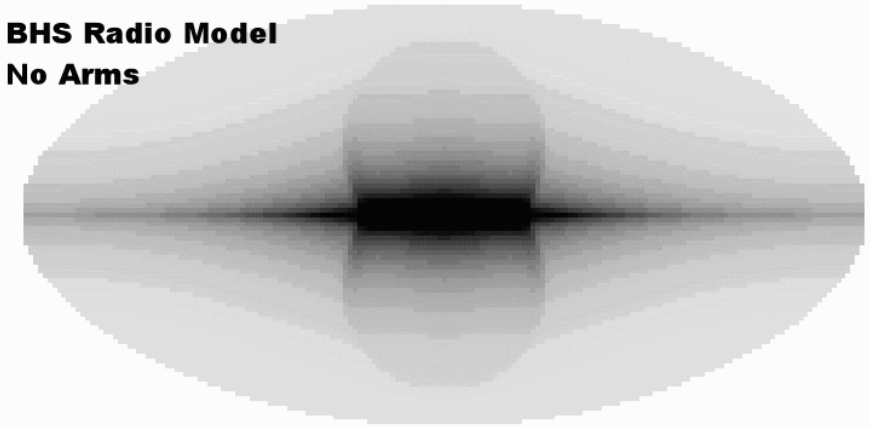
- HI Disk & Arms

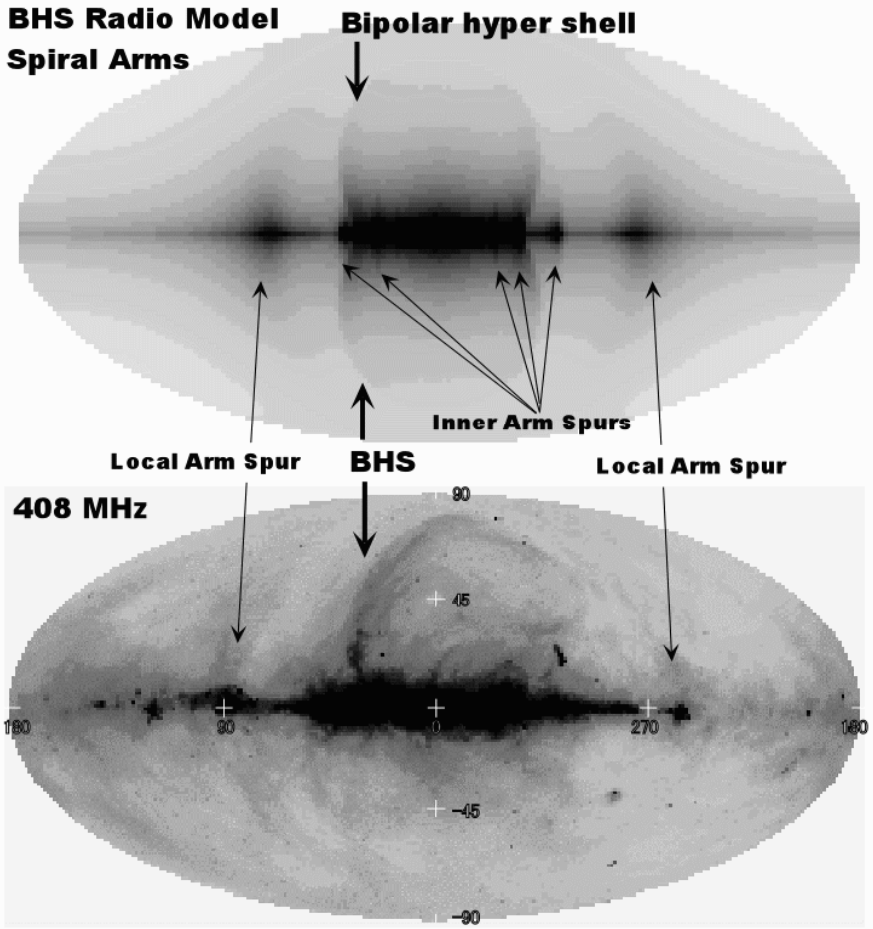


- Radio
- No arm

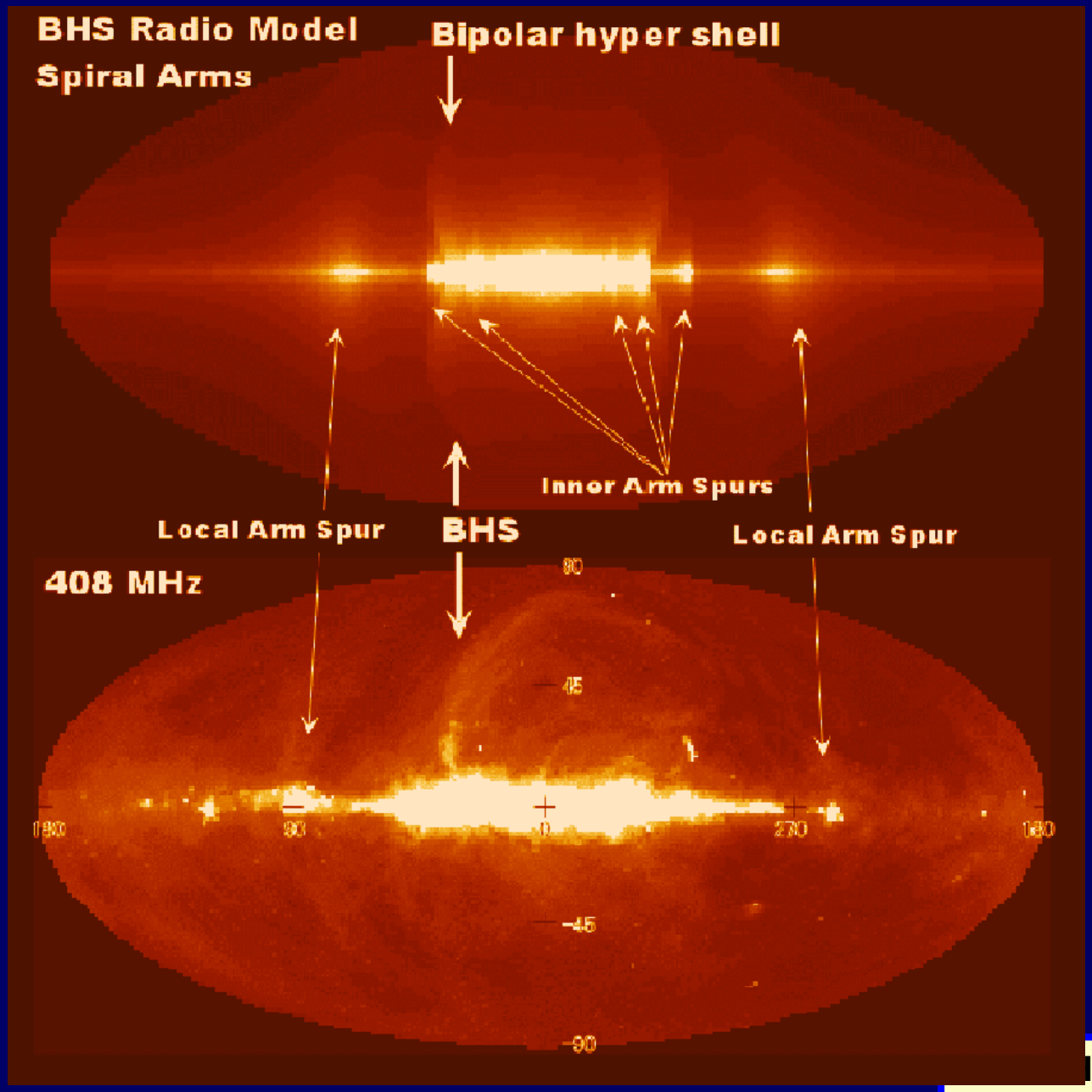
- Radio
- Arms

- Obs.
- 408 MHz Obs.





- Radio



lz Radio

- Haslam et al 1982

X-rays

0.25, 0.75, 1.5 keV Soft X-rays

X-ray emissivity

Brehmsung

$\varepsilon \propto \rho^2 T^{0.5}$

Transfer: Absorption by metals in HI Disk

$dI/ds = \varepsilon - \kappa I$

$\kappa ds = d\tau = n_H ds / N_{H,0}$

X-ray Absorption κ

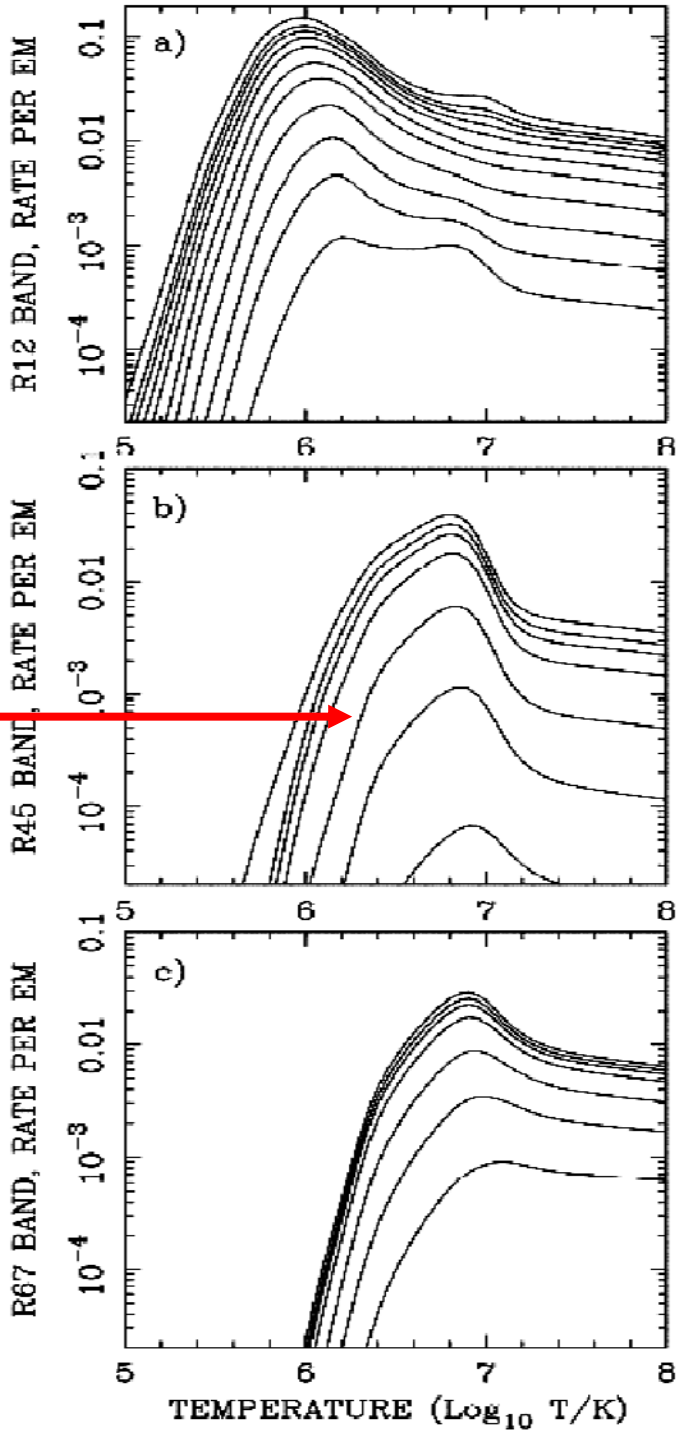
at 0.25, 0.75, 1.5 keV

0.75 keV:

Tau=1 for

$N_{H,0}=3\times10^{21}$ H cm^{-2}

=1 kpc x 1 H cm^{-3}



Snowden et al. 1993

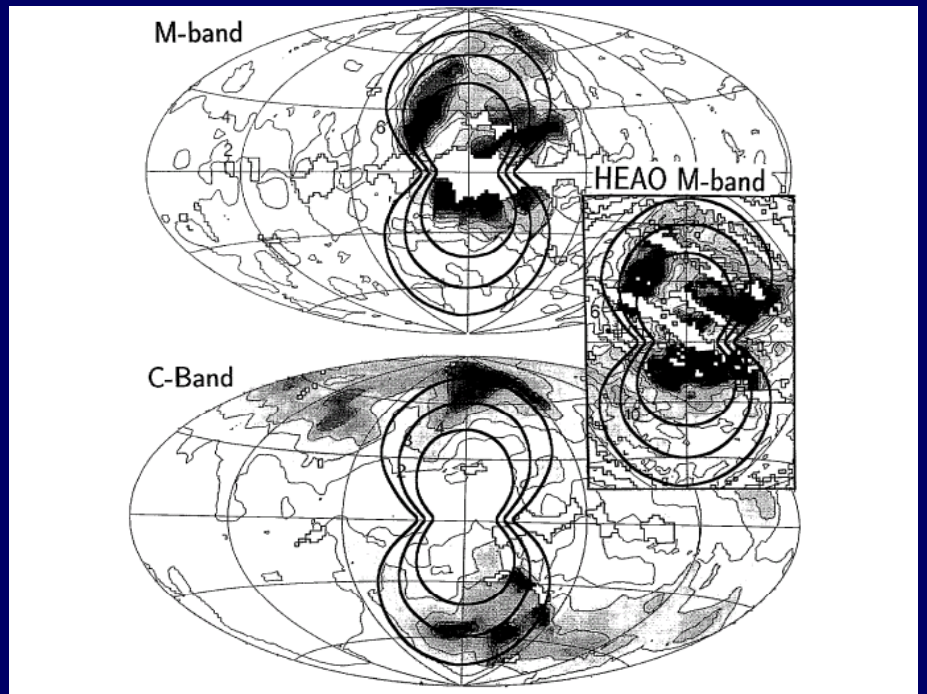
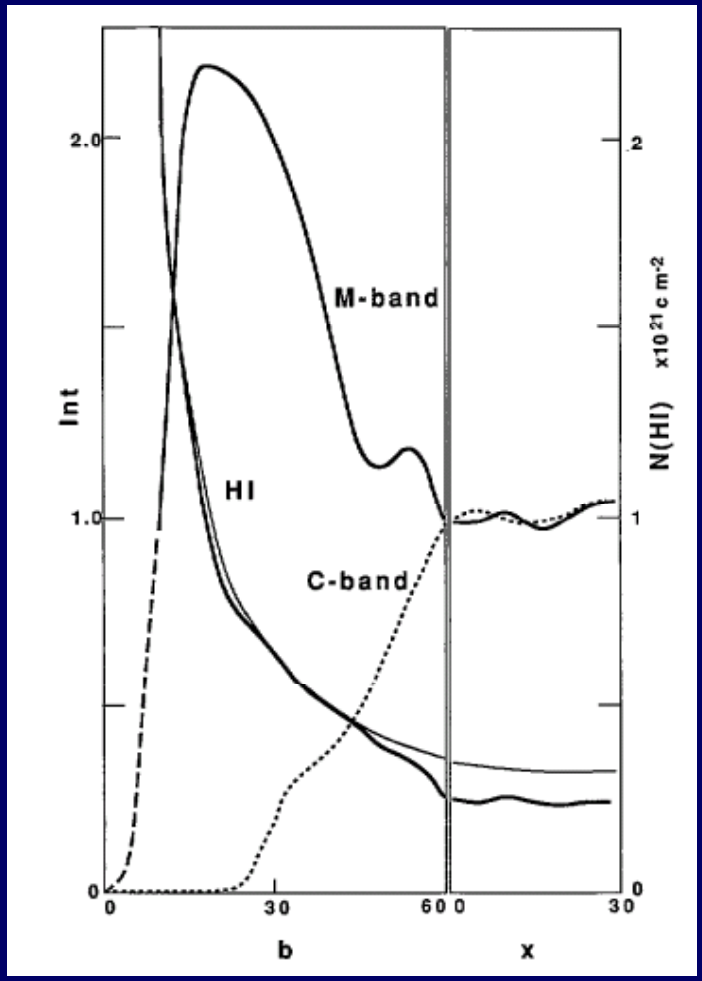


FIG. 1.—Calculated shock front in the Galactic halo at 1, 1.5, and 2 × 10^7 yr after an explosion and/or a starburst at the nucleus with a total energy of 3 × 10^{56} ergs. The front is superposed on the *M*- and *C*-band X-ray maps (McCammon et al. 1983).



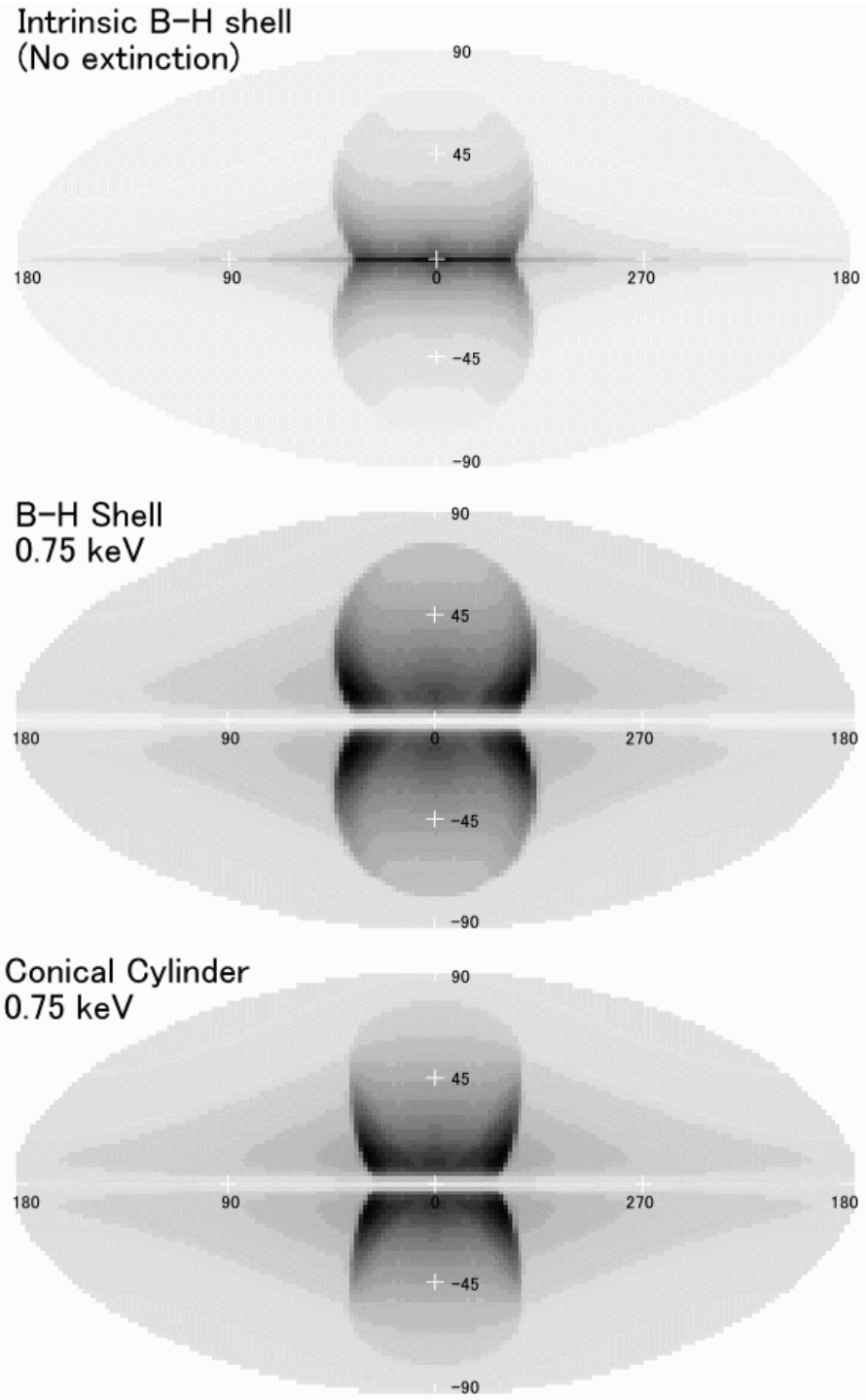
Sofue 1994 ApJL

- 1.5 keV
- No arm

- 0.75 keV
- No arm

- 0.75 keV
- No arm

- Cylinder/ Cone



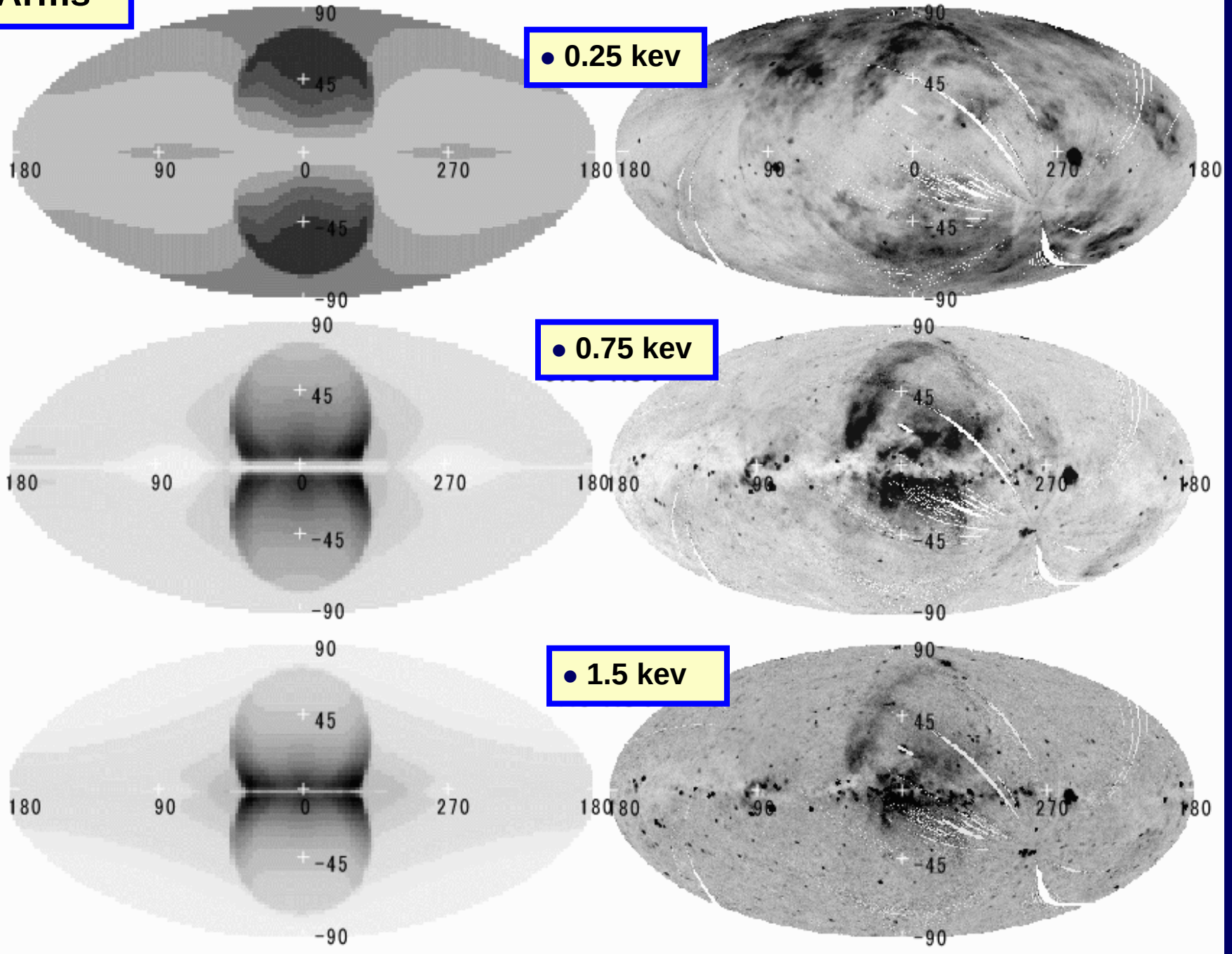
- Soft X

• Arms

Bipolar Hyper Shell Model

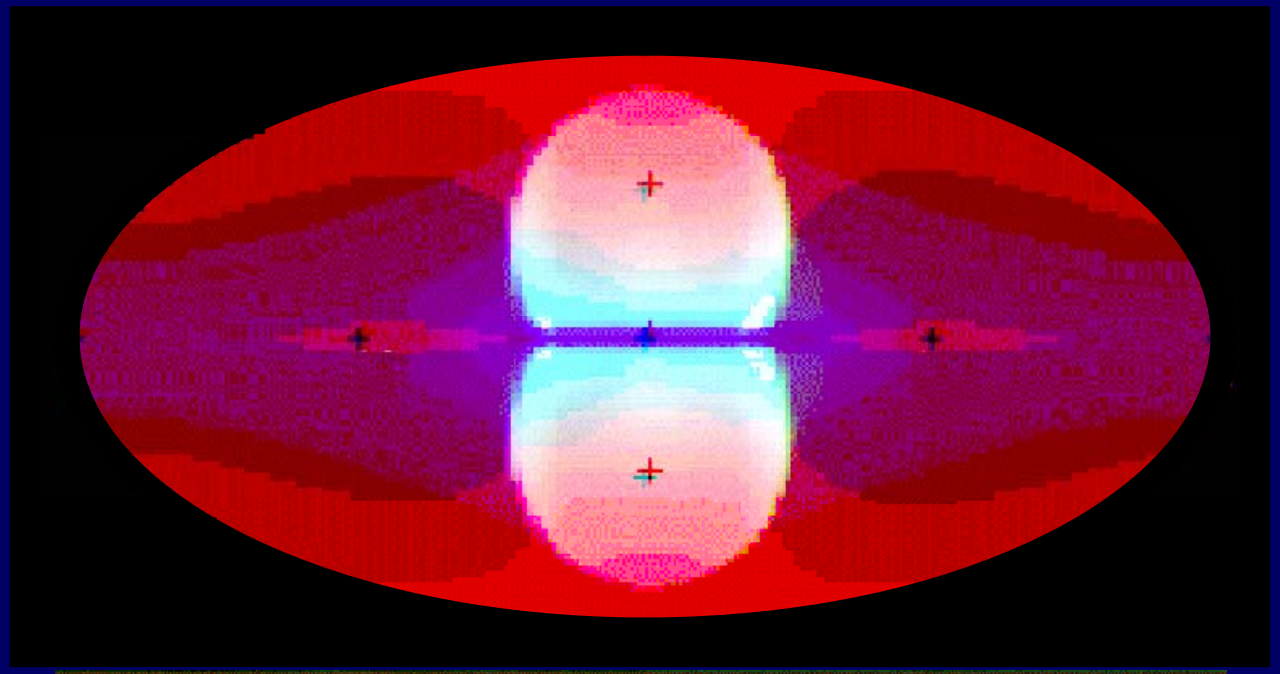
ROSAT

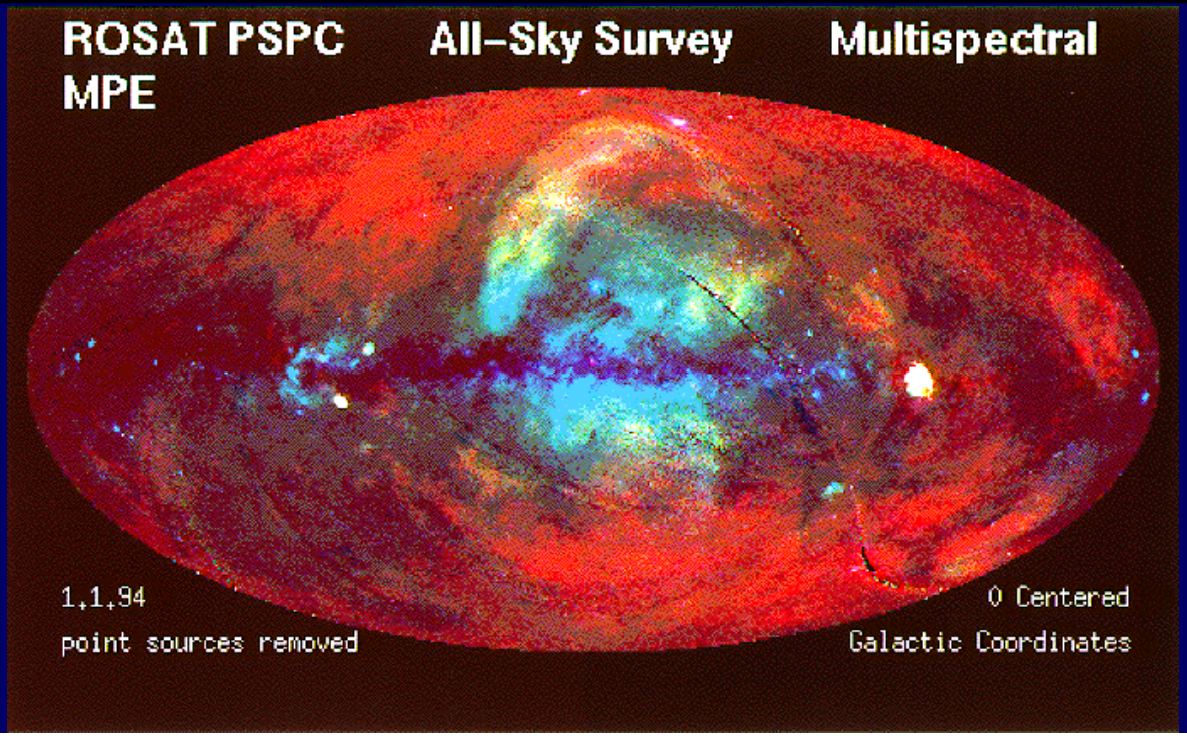
• 0.25 kev



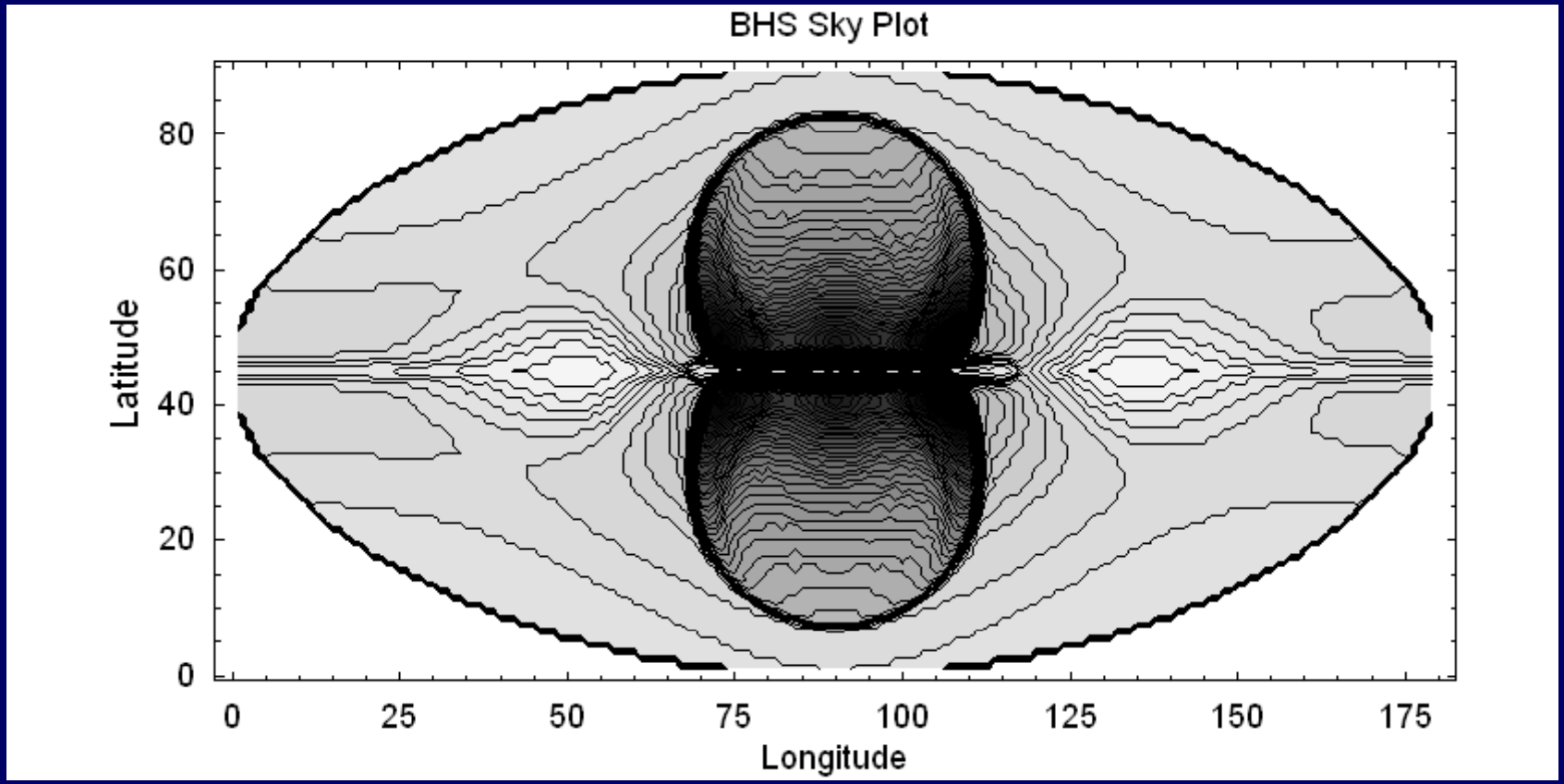
• 0.75 kev

• 1.5 kev

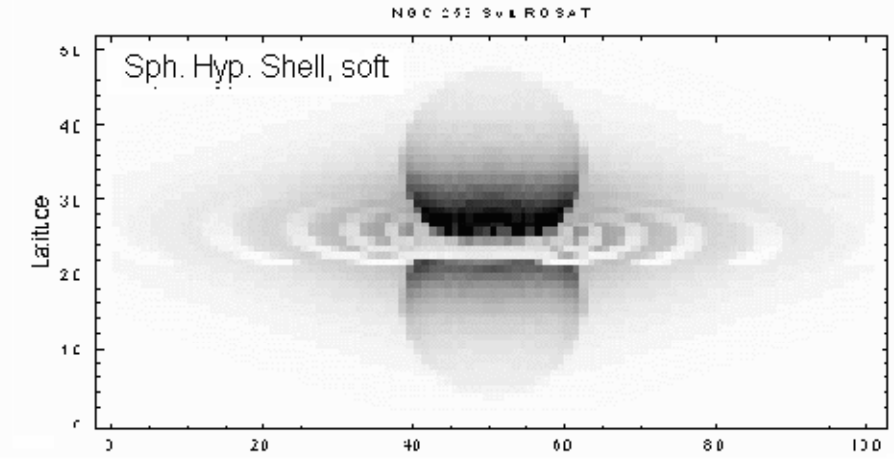


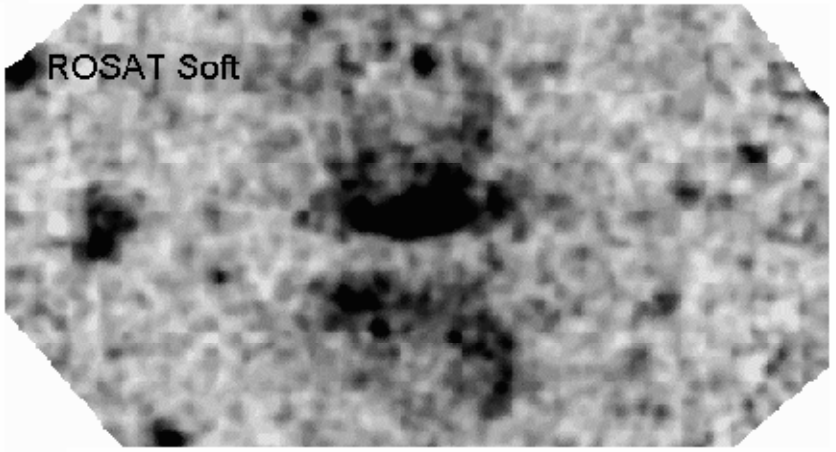

ROSAT PSPC All-Sky Survey Multispectral
MPE
1.1.94
point sources removed
0 Centered
Galactic Coordinates

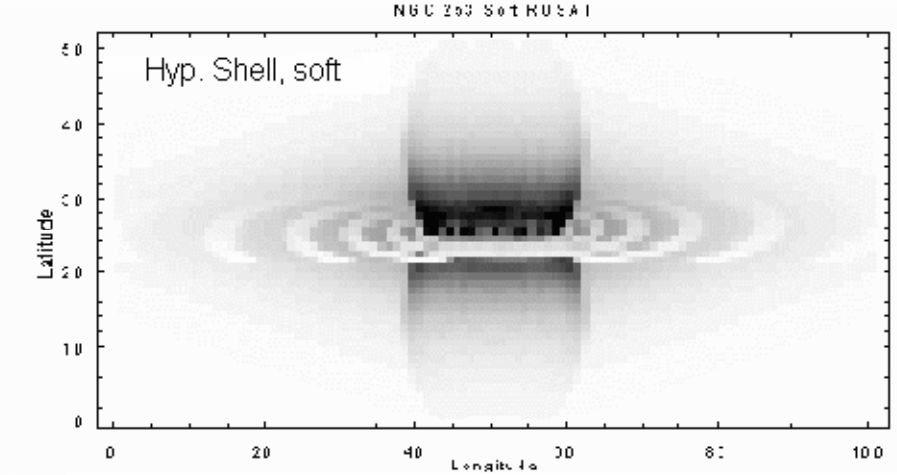
Galactic Big Bang
15 Myr ago,
10^{56} ergs.

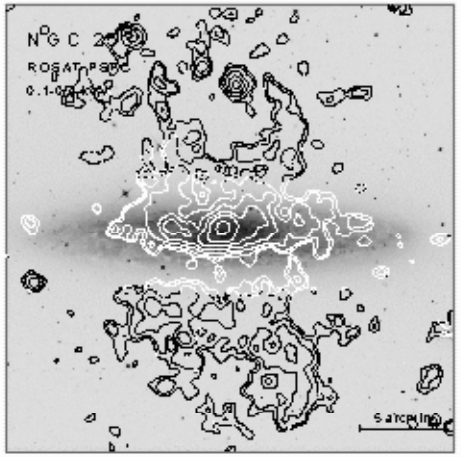


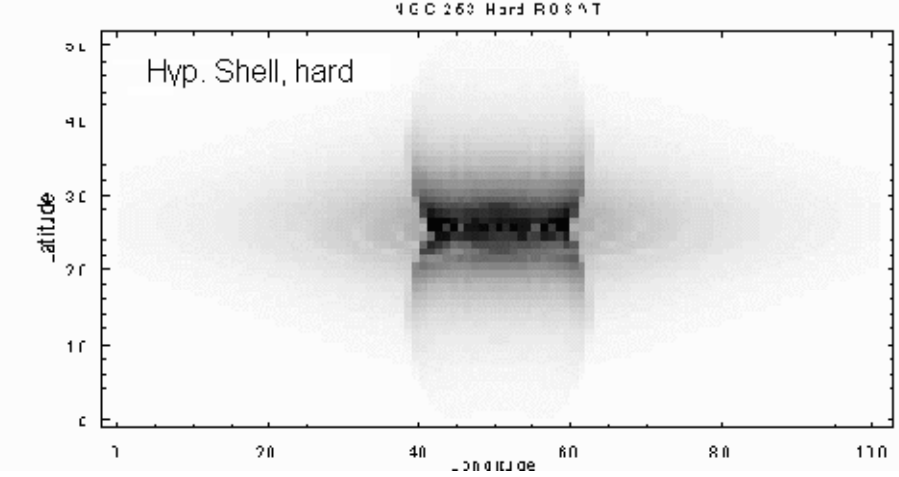
Galxies: NGC 253

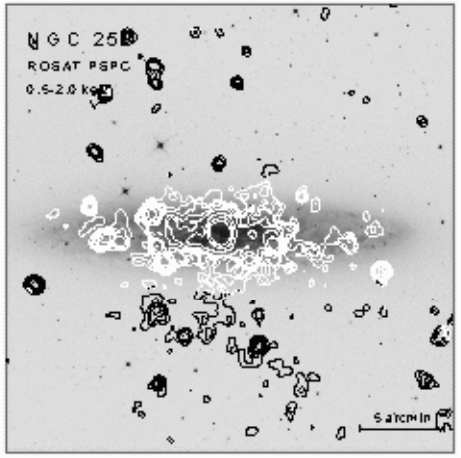

Sph. Hyp. Shell, soft
Latitude
0
20
40
60
80
100

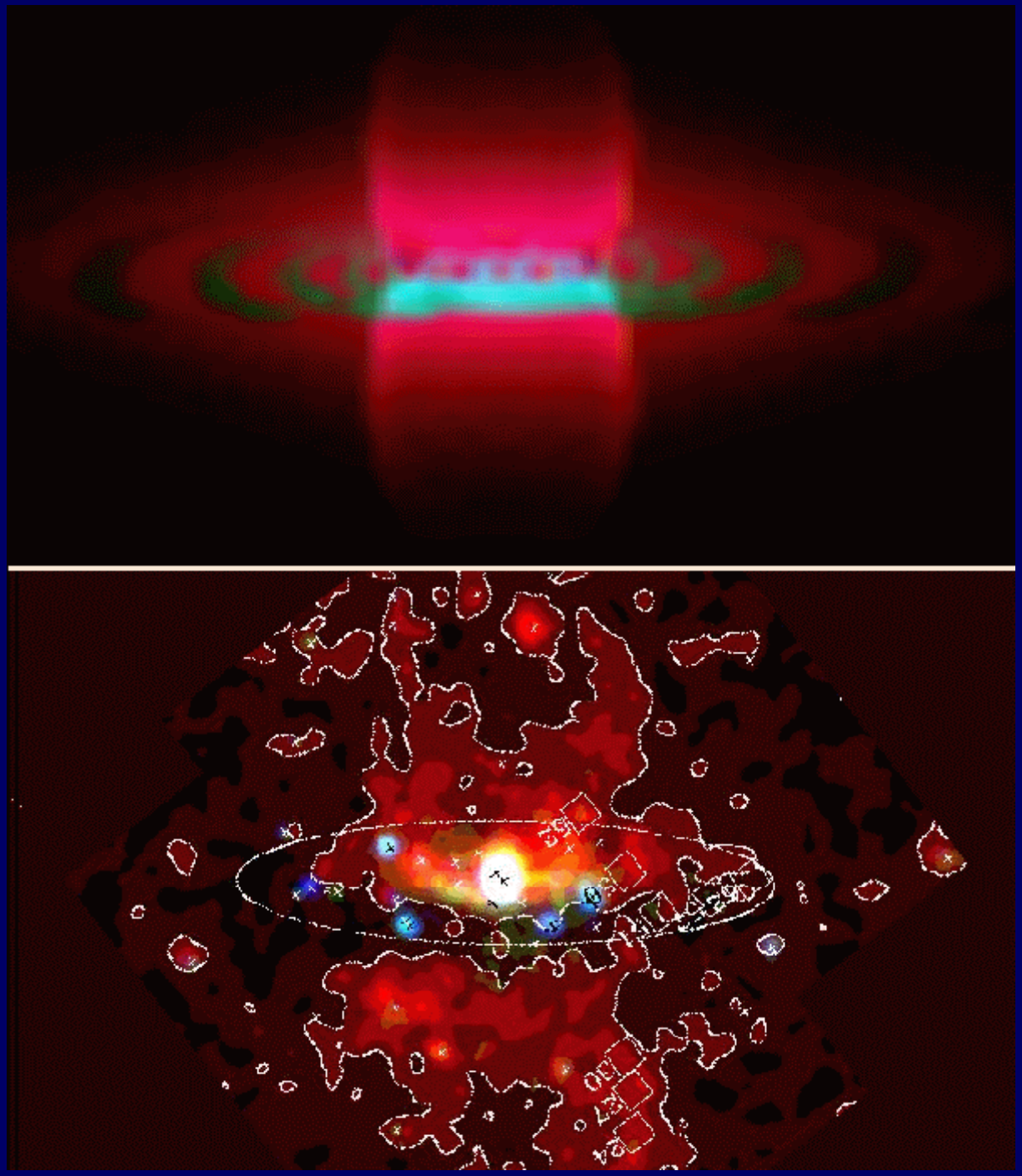

ROSAT Soft

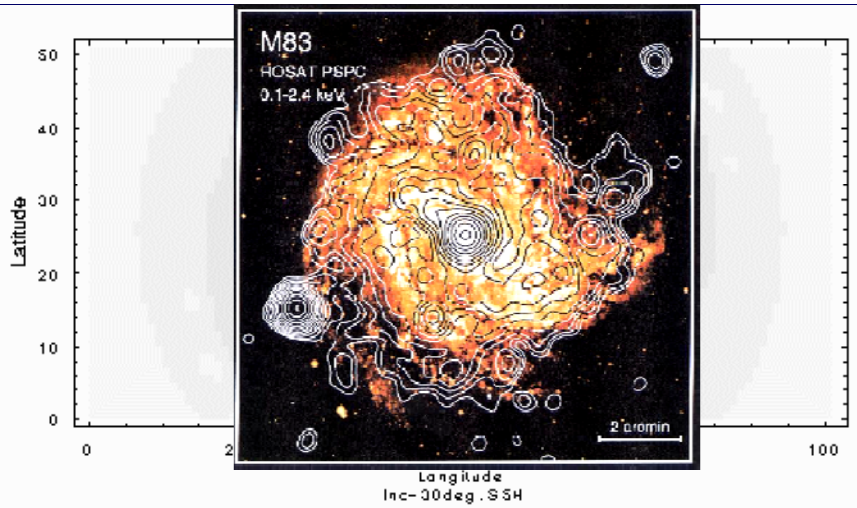

Hyp. Shell, soft
Latitude
0
20
40
60
80
100

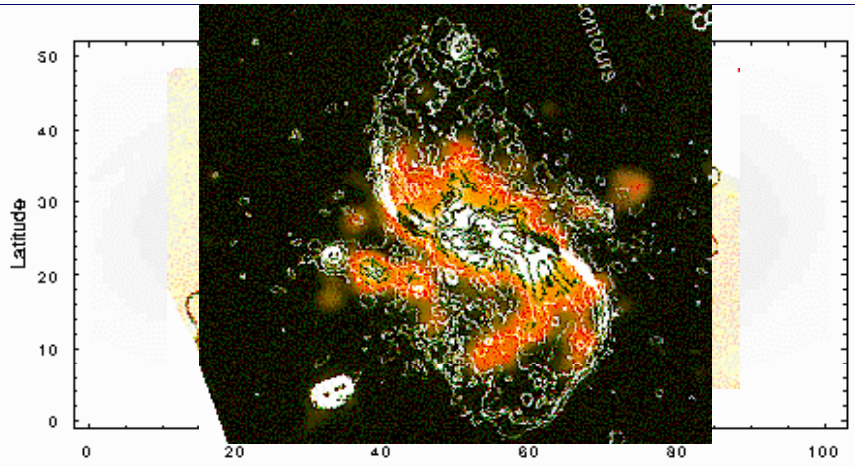

ROSAT PSPC

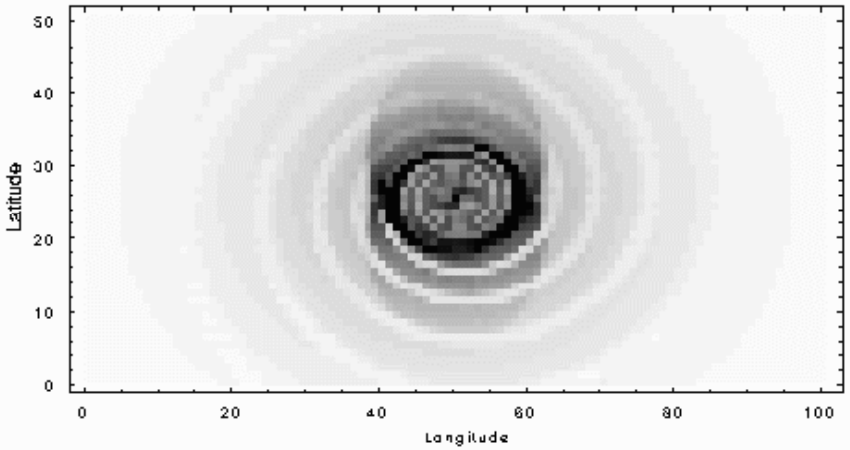

Hyp. Shell, hard
0
20
40
60
80
100

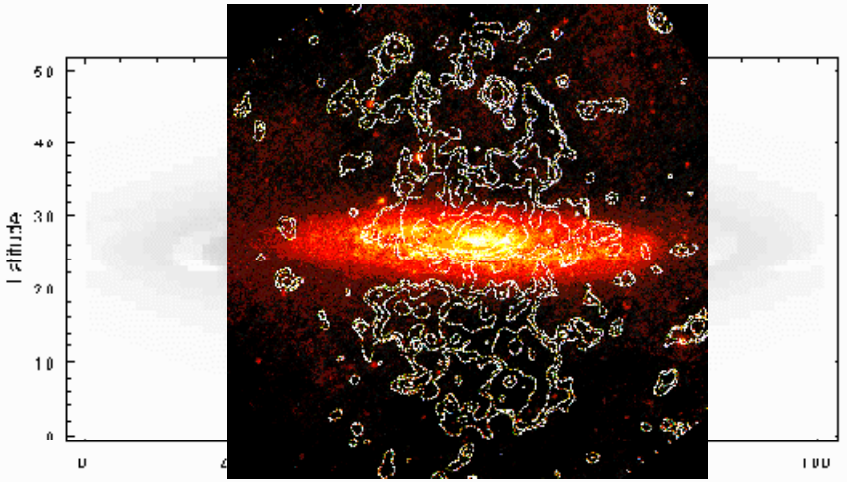

ROSAT PSPC

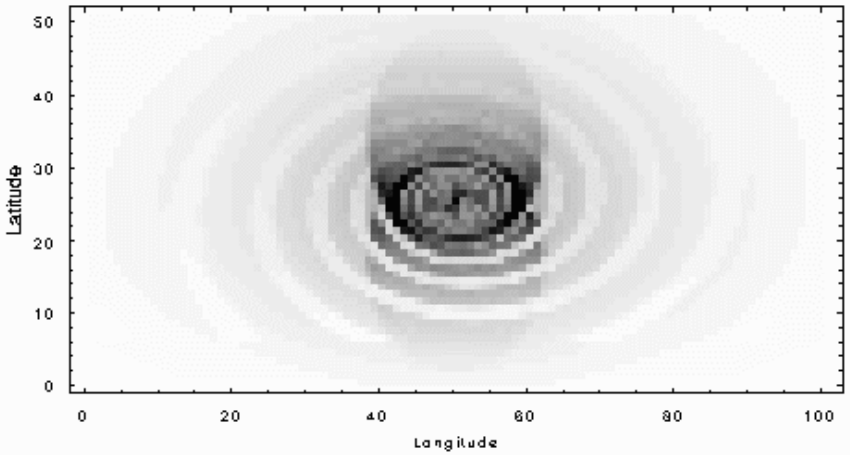


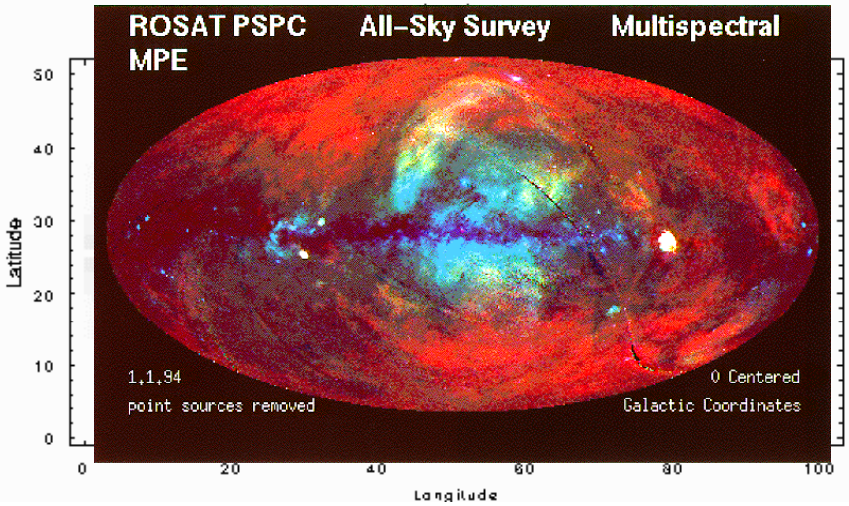

M83
ROSAT PSPC
0.1-2.4 keV
2 arcmin
Latitude
Longitude


Latitude
Longitude


Latitude
Longitude
Inc-30deg.SSH


Latitude
Longitude


Latitude
Longitude
Inc-45deg.SSH

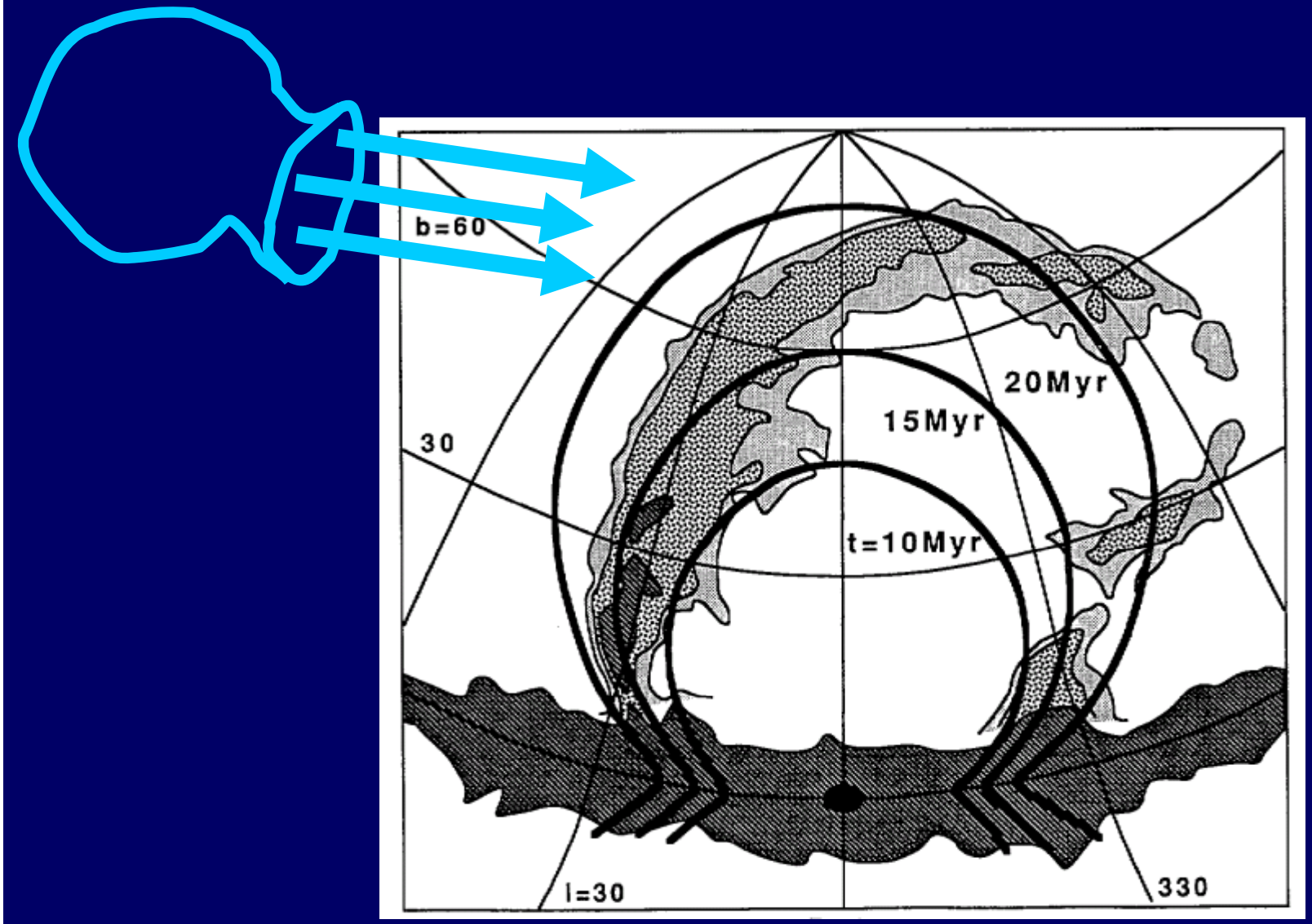

ROSAT PSPC All-Sky Survey Multispectral
MPE
1,1,94
point sources removed
0 Centered
Galactic Coordinates
Latitude
Longitude

4. Implications

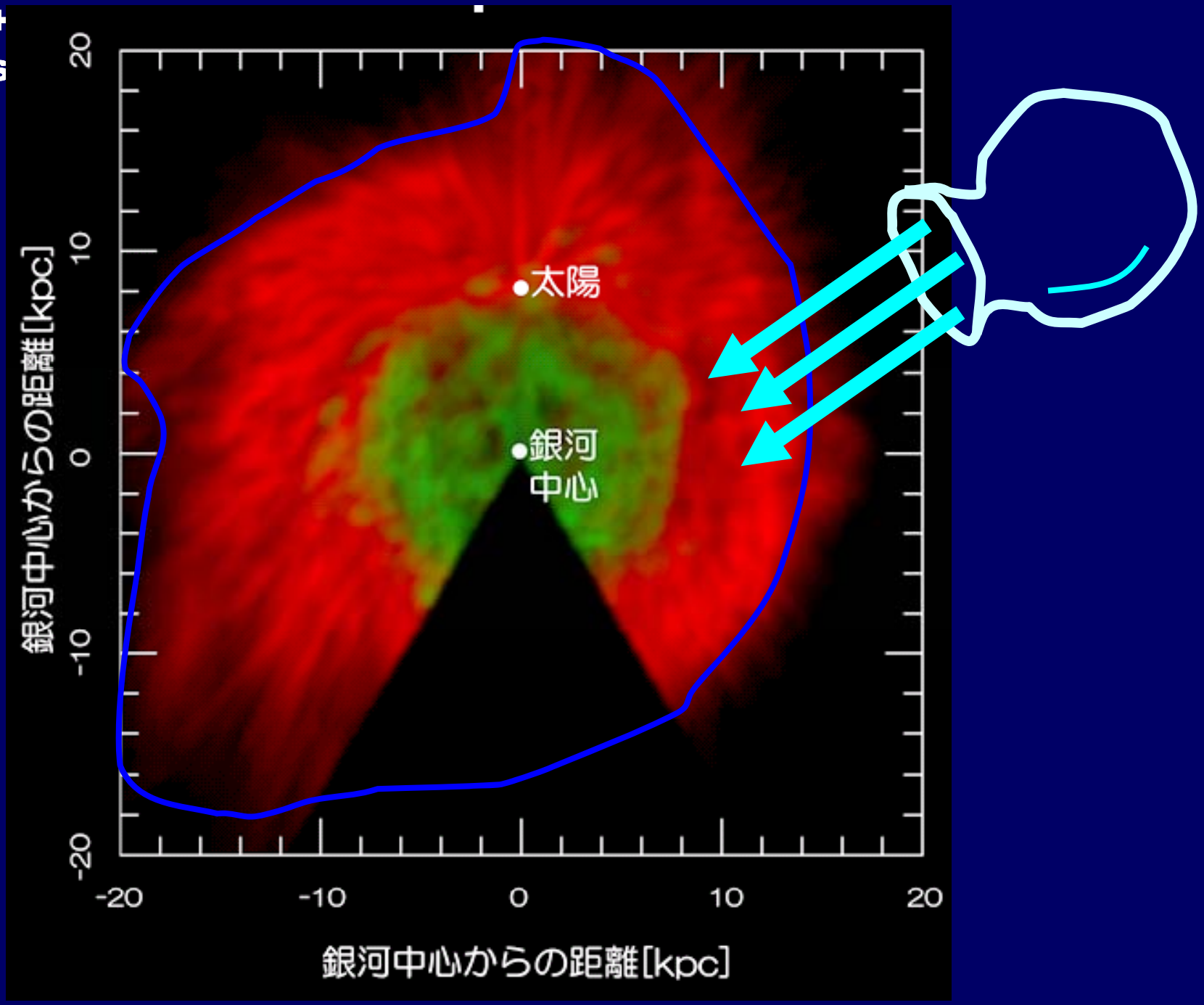
MW Big Bang 15 Myr ago, $10^{55\text{-}56}$ ergs.

Implication

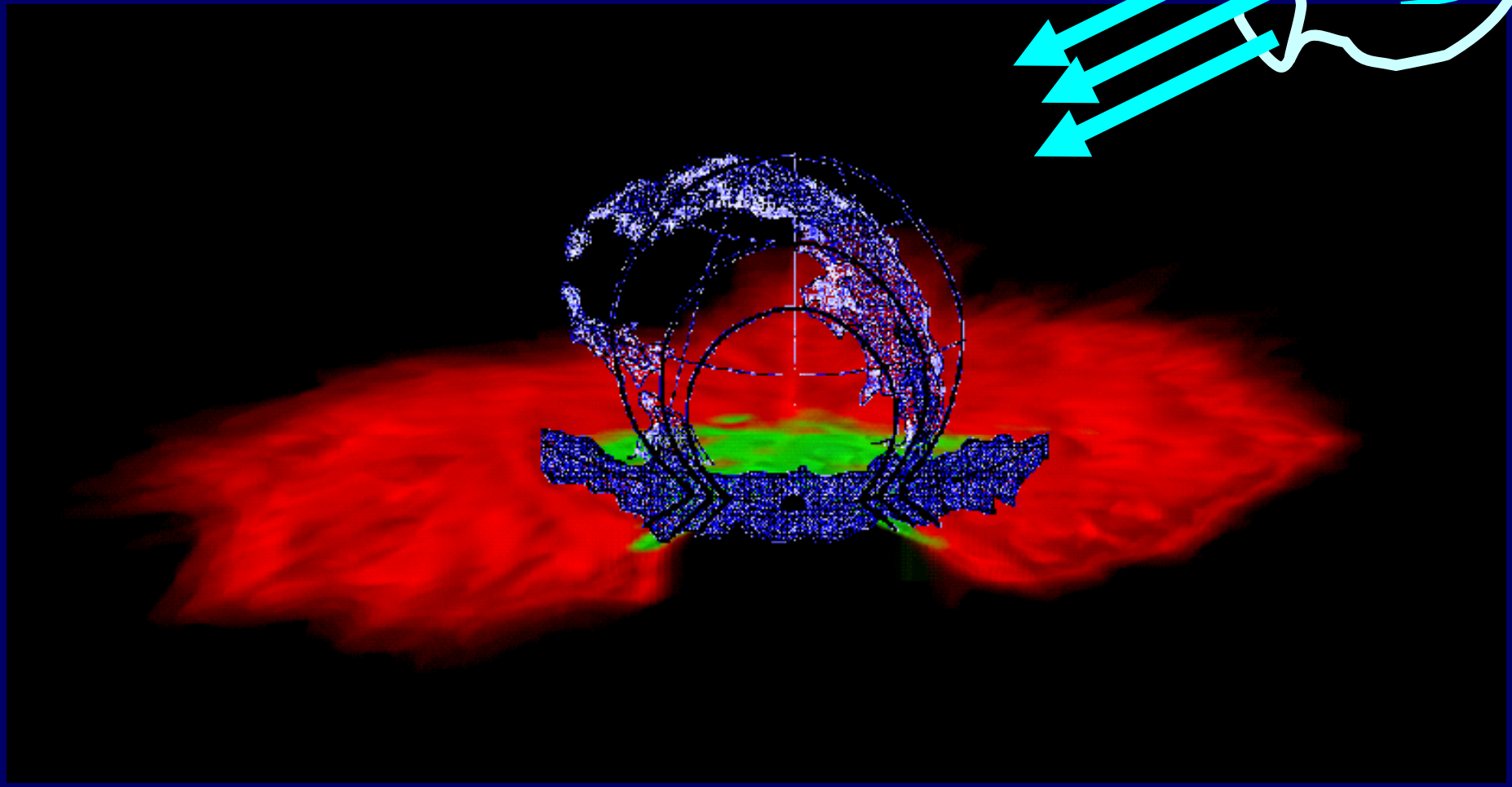
- Probing Starburst
- Probing HI disk
- Probing Gas Halo
- Probing Halo-IG Interface
- Probing ICM, IGM
- Probing Halo Window


b=60
20Myr
15Myr
t=10Myr
30
l=30
330

HI(red)+
Nakanis
2006



Galactic big bang in an intergalactic wind



5. The End
of 40 yrs Debate
vs SNR hypothesis!

Fermi Bubble

Fermi Gamma rays
1, 2, 5, 10 GeV

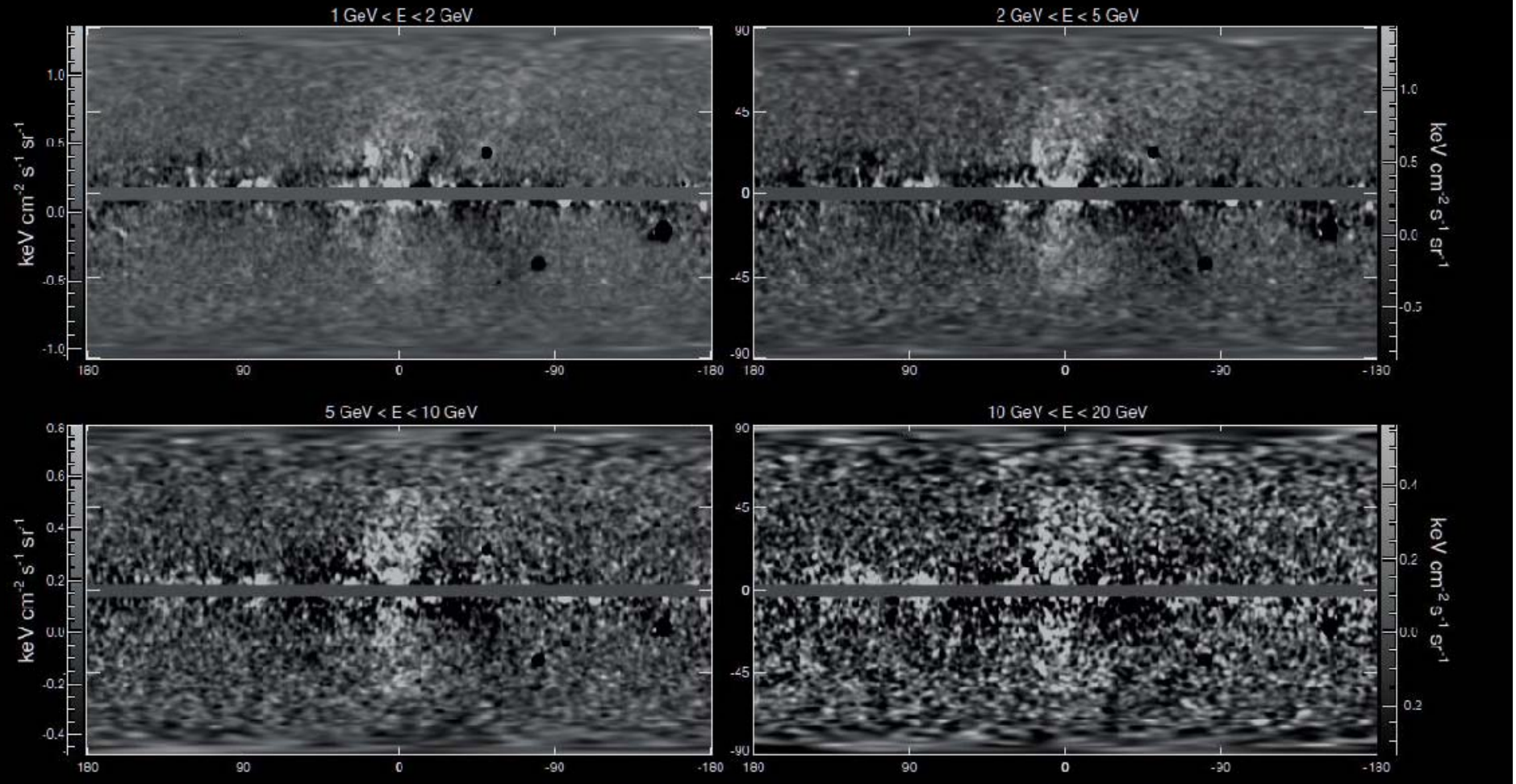
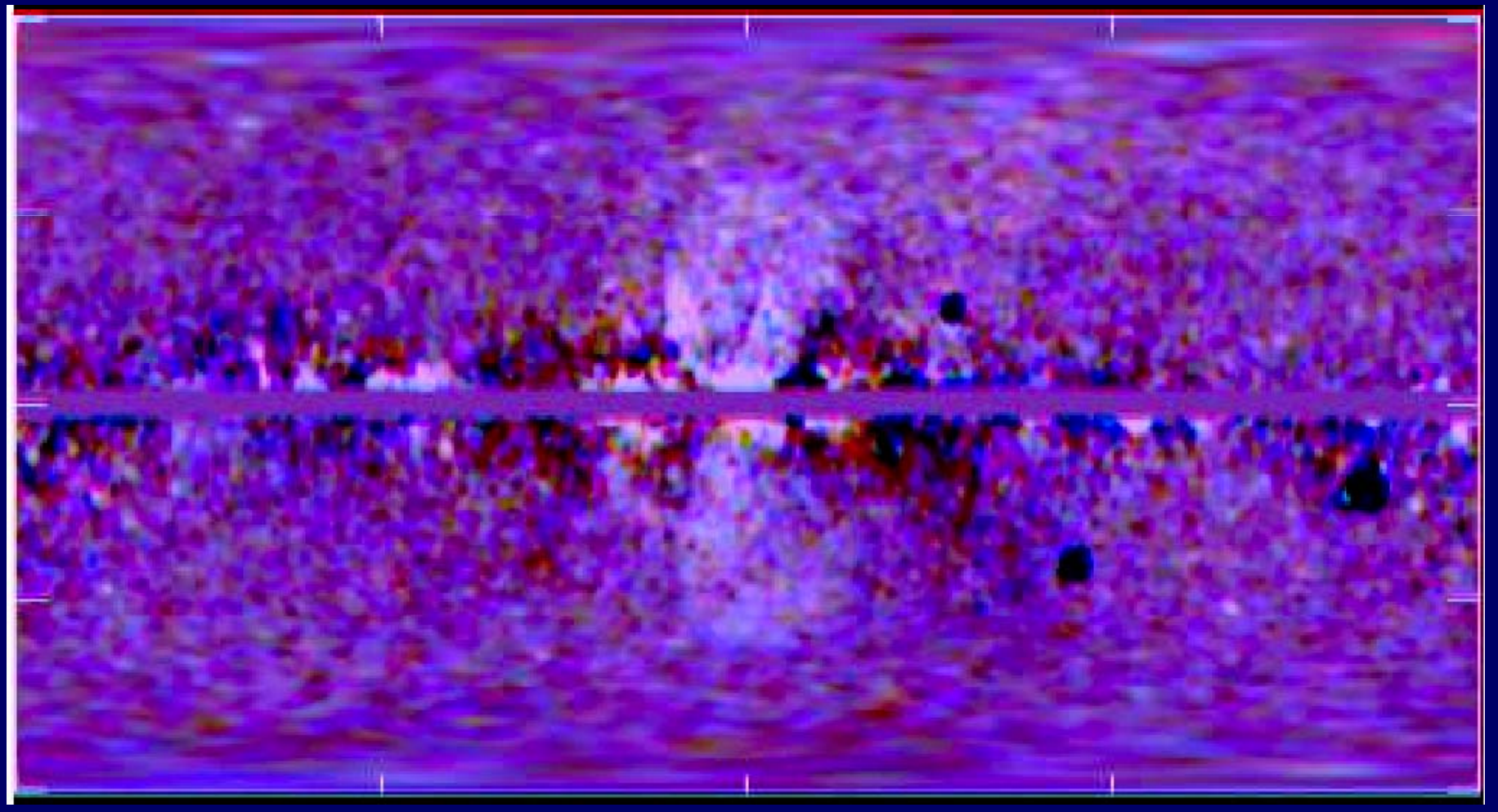
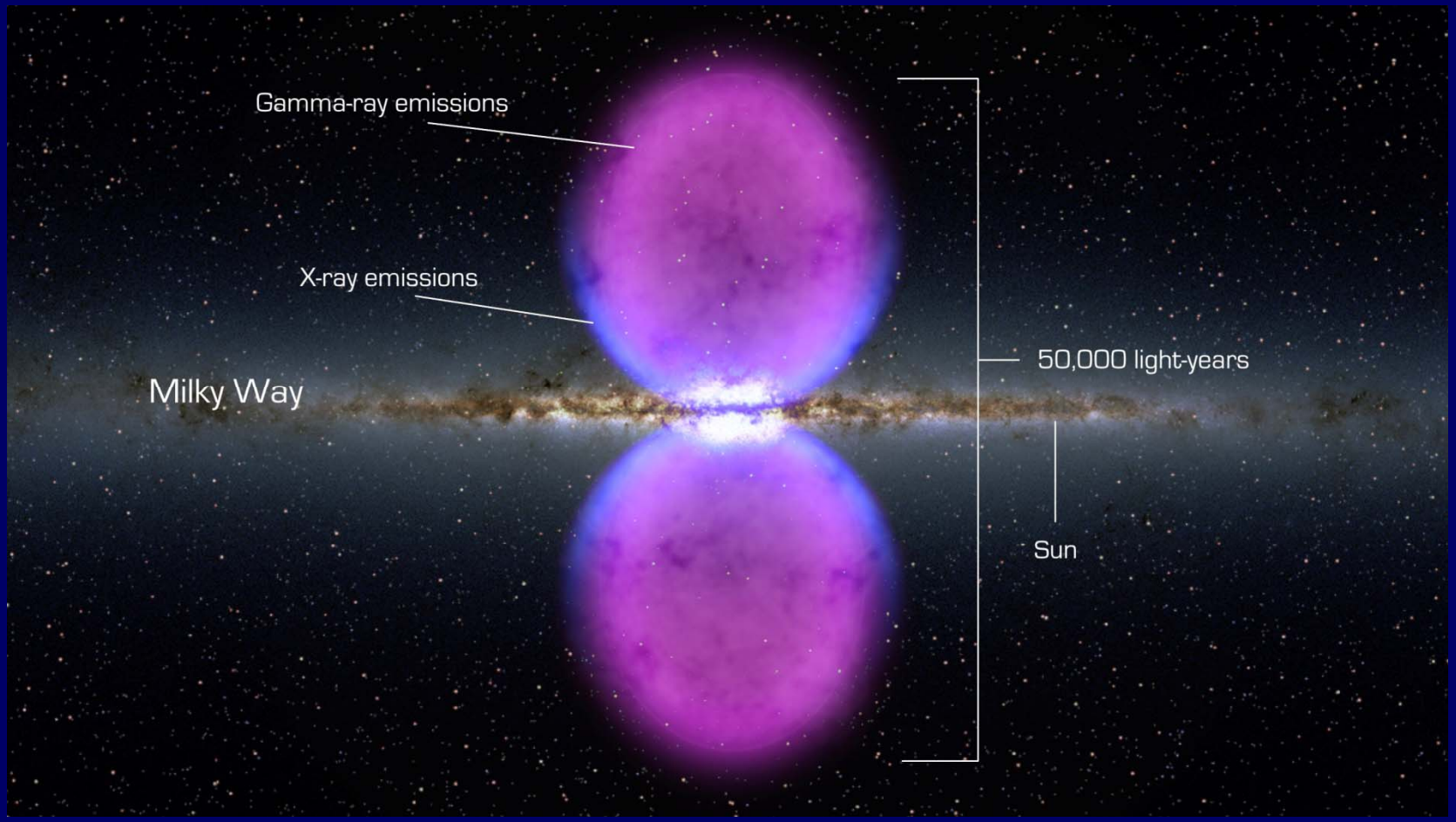
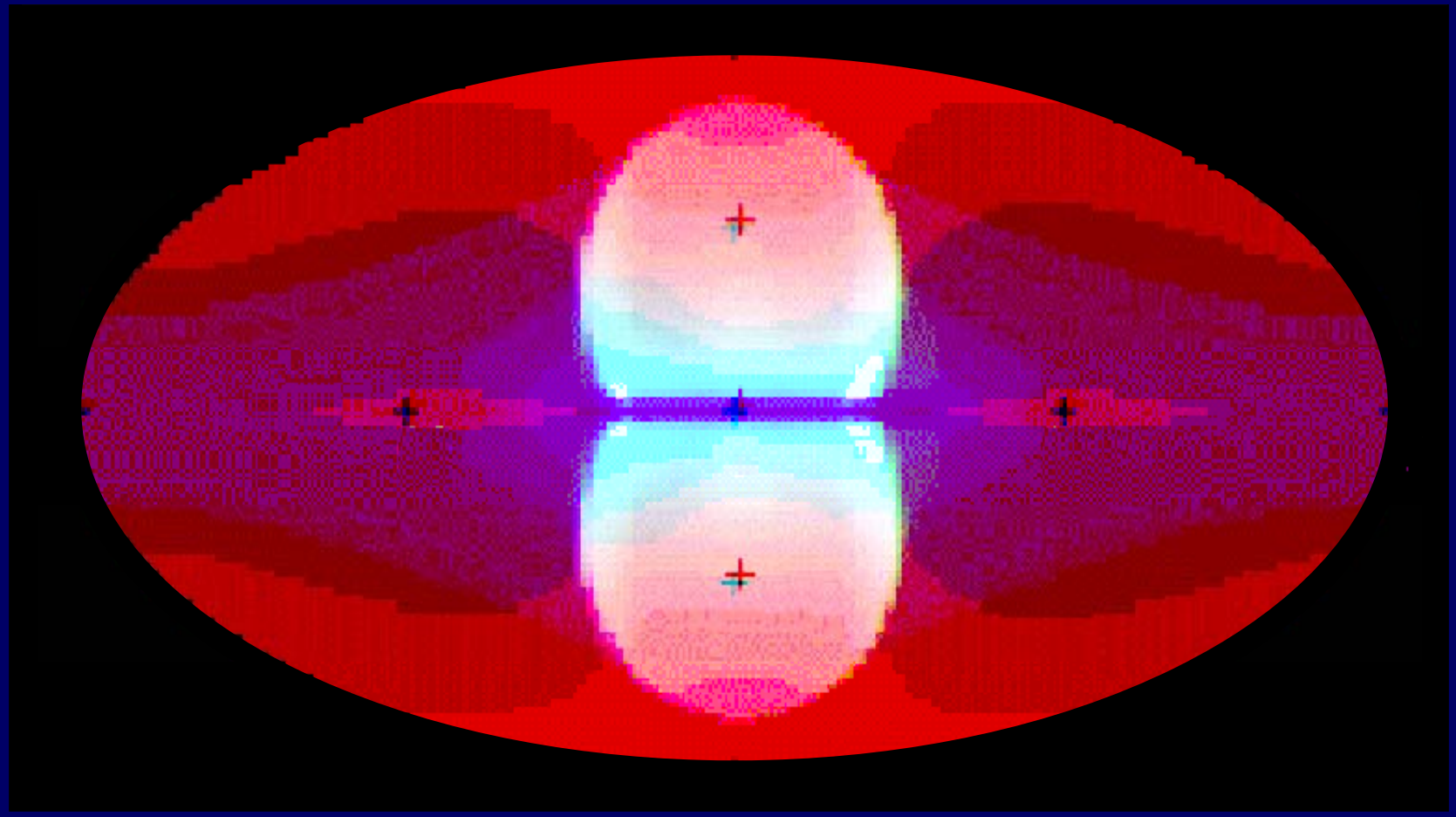


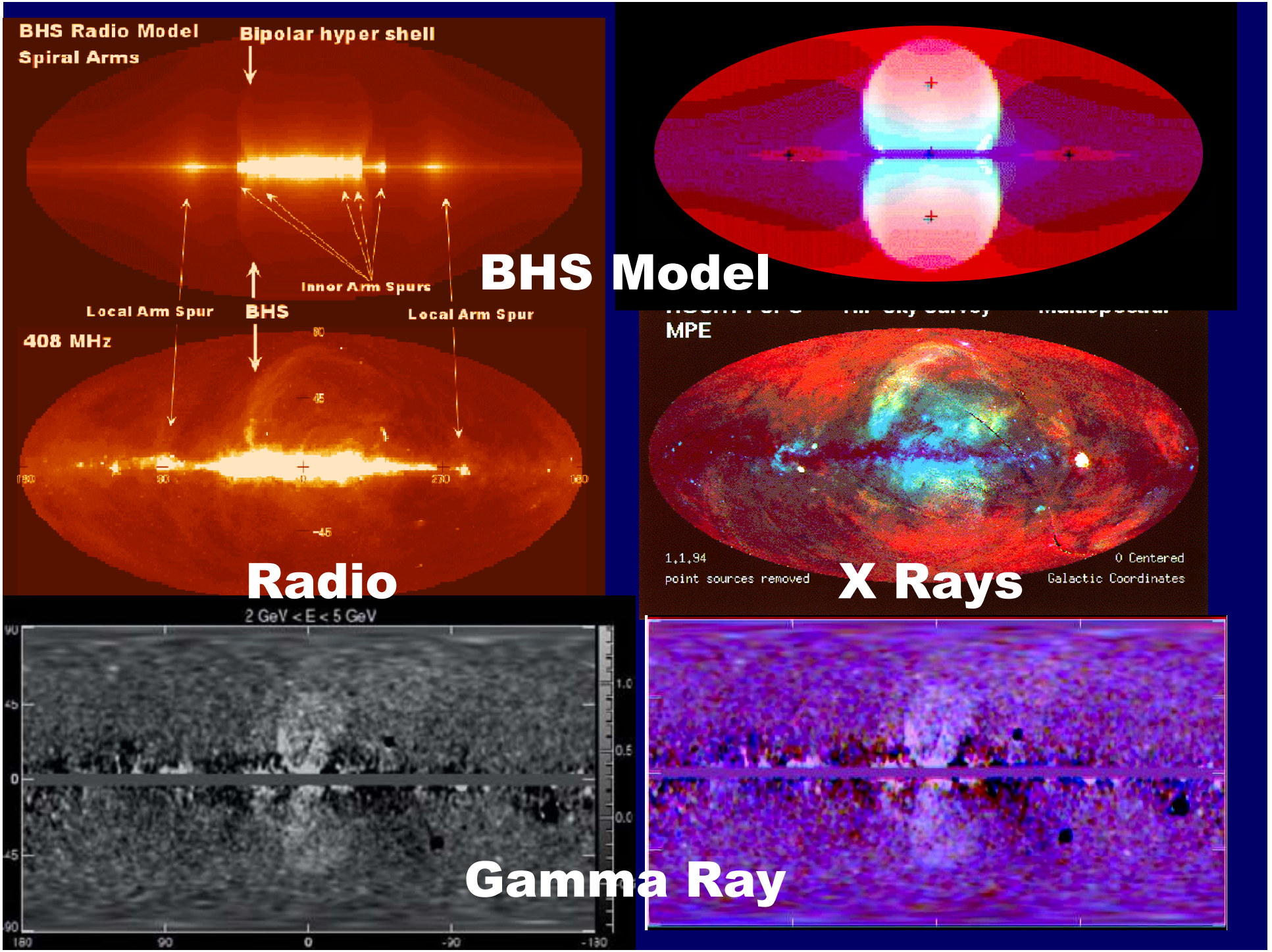
Figure 2. All-sky residual maps after subtracting the *Fermi* diffuse Galactic model from the LAT 1.6 year maps in four energy bins (see Section 3.1.1). Two bubble




Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun

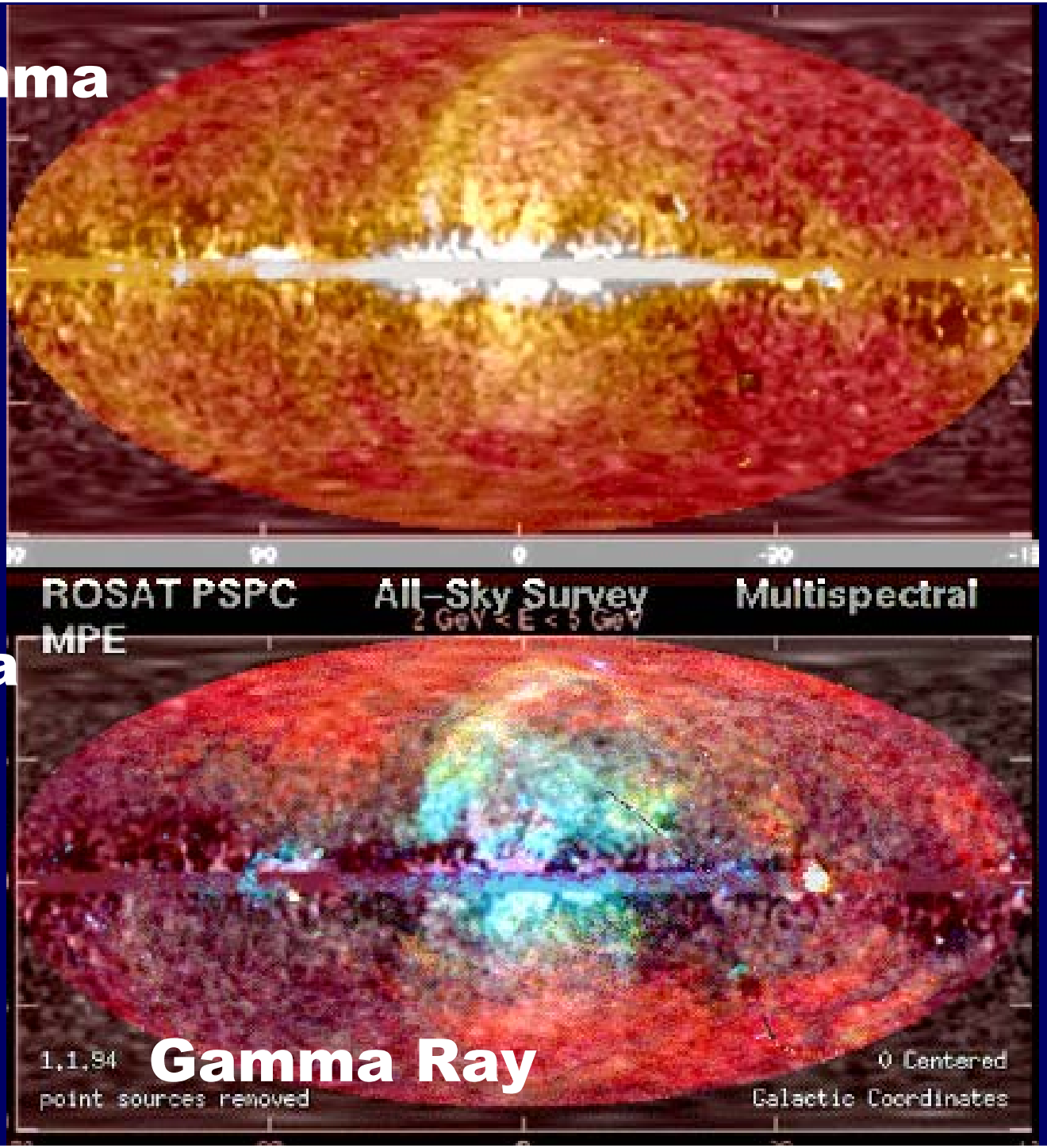
MW big bang model: 15 Myr ago, 10^{56} ergs. Sofue since 1970’




BHS Radio Model
Spiral Arms
Bipolar hyper shell
Inner Arm Spurs
Local Arm Spur
BHS
Local Arm Spur
408 MHz
Radio
BHS Model
MPE
1,1,94
point sources removed
0 Centered
Galactic Coordinates
X Rays
2 GeV < E < 5 GeV
Gamma Ray

Radio+Gamma

X + Gamma



Further models to appear