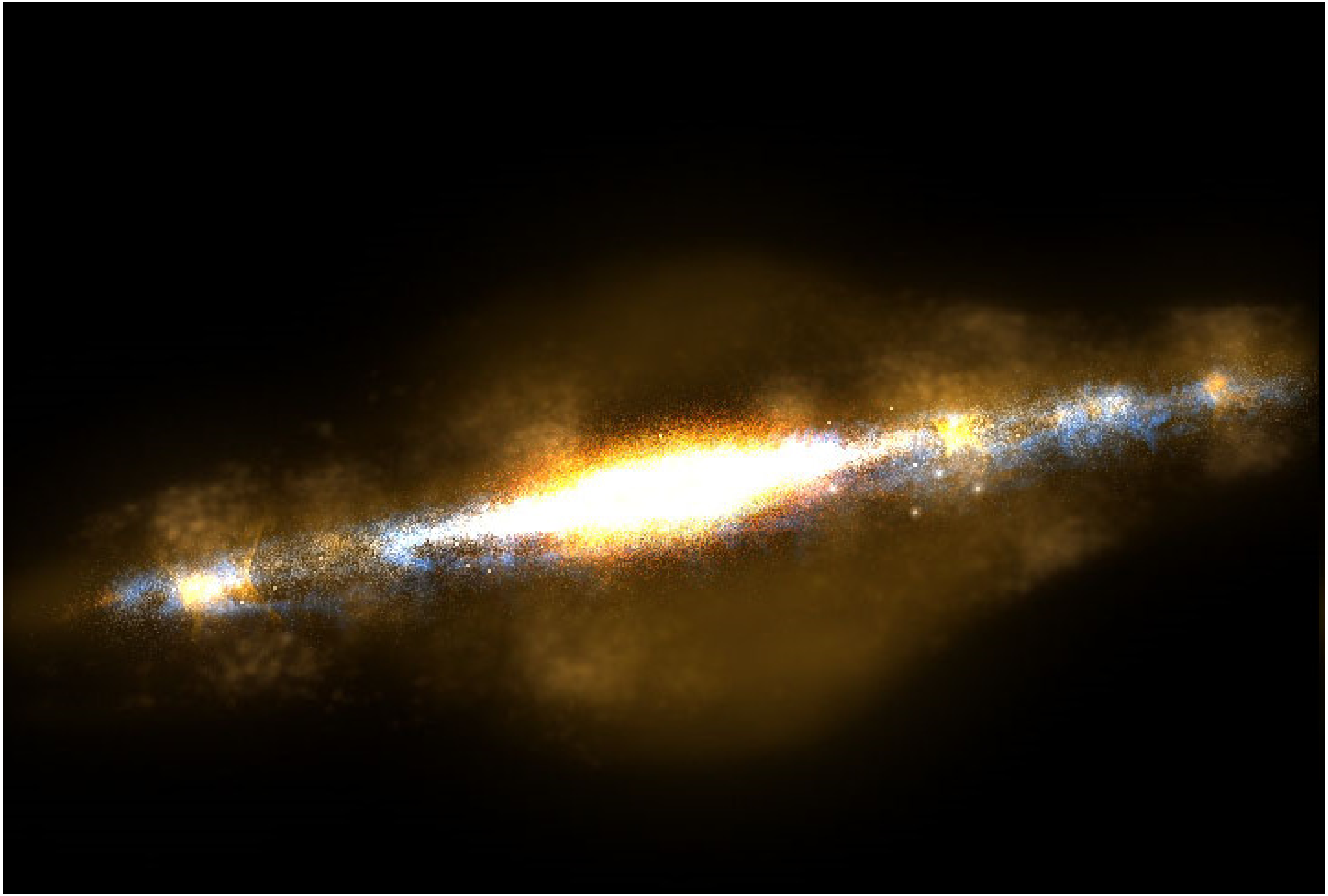
Different Gas Phases of the ISM

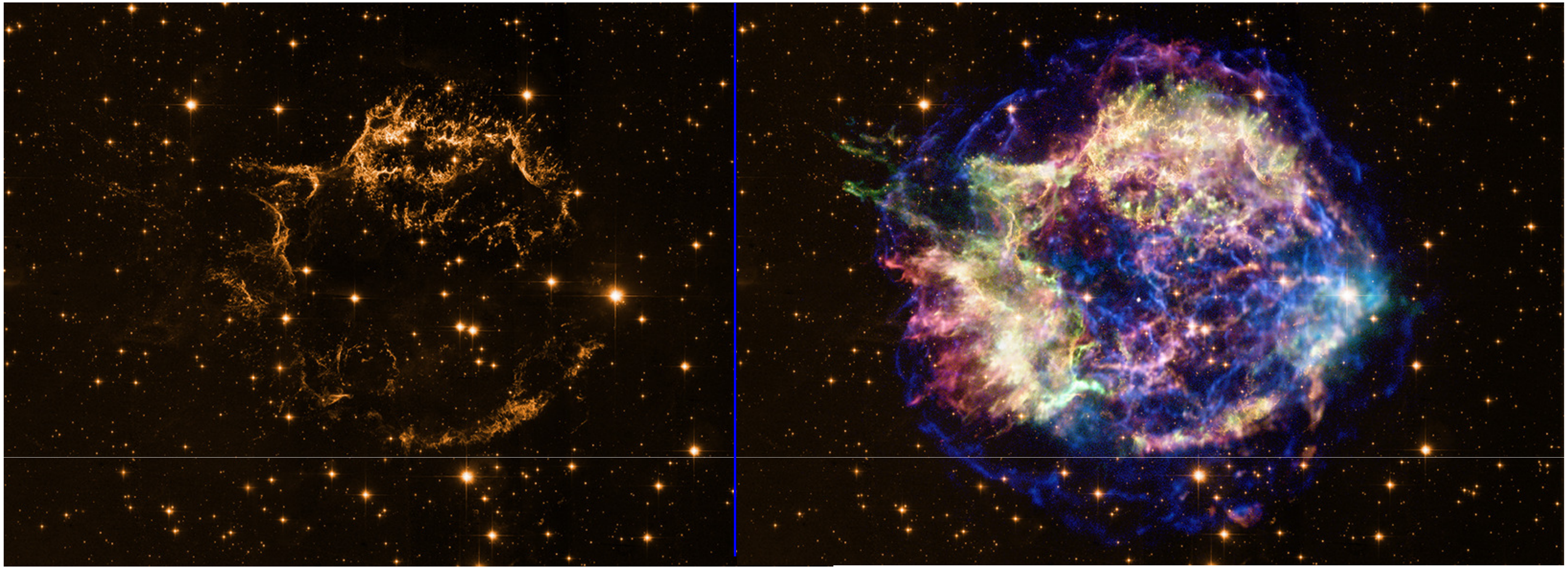
Phase	Temperature K	Density cm^{-3}	Fraction of Volume	Mass in 10^9 $M_\odot$
Hot ionised medium	$3–20 \times 10^5$	3×10^{-3}	0.4–0.7	0.003
Warm ionised medium	10,000	3×10^{-1}	0.15–0.4	0.05
Warm neutral medium	8000	4×10^{-1}	0.2–0.6	0.2
Cold neutral medium	40–100	6×10^1	0.01–0.04	3
Molecular Clouds	3–20	3×10^2	0.01	3

The numbers listed in the table suggest that much of the interstellar volume in our Galaxy (and possibly in other similar galaxies) is filled by the hot ionized medium, though the mass in this phase is only a small fraction of the total ISM mass. The hot phase of the ISM is hence very diffuse. At the other extreme, the giant molecular clouds occupy only a tiny fraction of the Galaxy's volume, but a lot of mass is locked up in them. They correspond to the densest regions in the ISM and are sites where stars form.

Hot Ionized Medium of the ISM



Supernova Heating of ISM



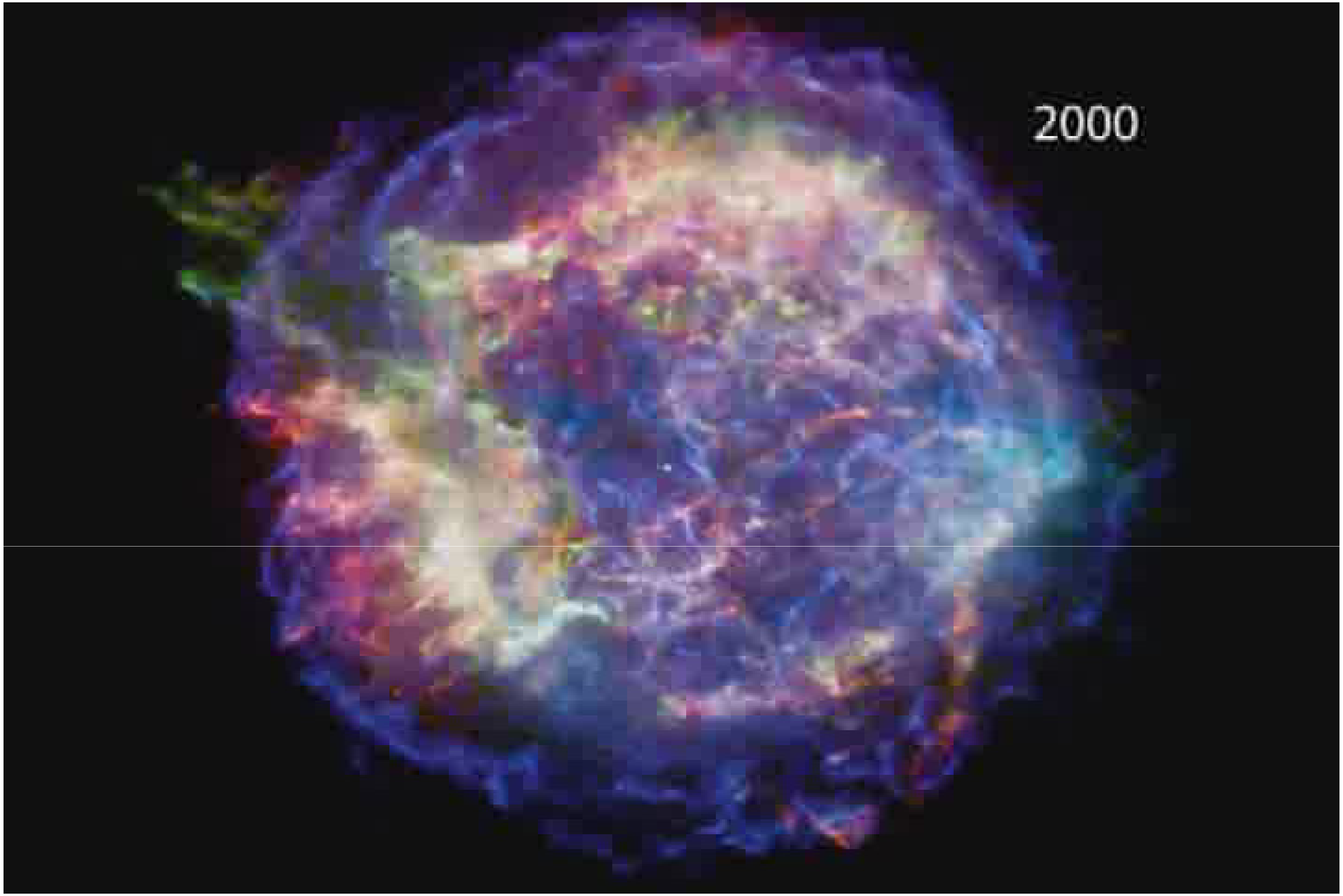
The image on the left panel shows the supernova remnant Cassiopeia A (Cas A) at optical (visible) wavelengths as seen by Hubble Space Telescope (HST). The image on the right panel shows the same source as imaged by Chandra at X-ray wavelengths. Located within the Galaxy, Cas A is the remains of a massive star that exploded about 330 years ago, as measured in Earth's time frame.

Table 1 Properties of supernovae

	Type I	Type II
Ejected mass ($M_\odot$)	0.5	5
Mean velocity (km sec^{-1})	10 000	5000
Kinetic energy (erg)	5×10^{50}	1×10^{51}
Visual radiated energy (erg)	4×10^{49}	1×10^{49}
Ionizing radiated energy (erg)	10^{44} or 10^{48}–10^{49}	10^{48}–10^{49}
Frequency (yr^{-1})	1/60	1/40
Stellar population	old disc	young disc

Chevalier, R. A. 1977, ARAA

- **Type IIs contribute more towards heating up the ISM as they are contemporaneous**
- **Most of the supernova energy emerges as kinetic energy of the ejecta. More than the light, it is the high velocity ejecta which alters the phase of the ISM.**
- **The broadening of spectral lines (emission and absorption lines) yield a measure of the line-of-sight velocity with which the supernova ejecta is expanding.**

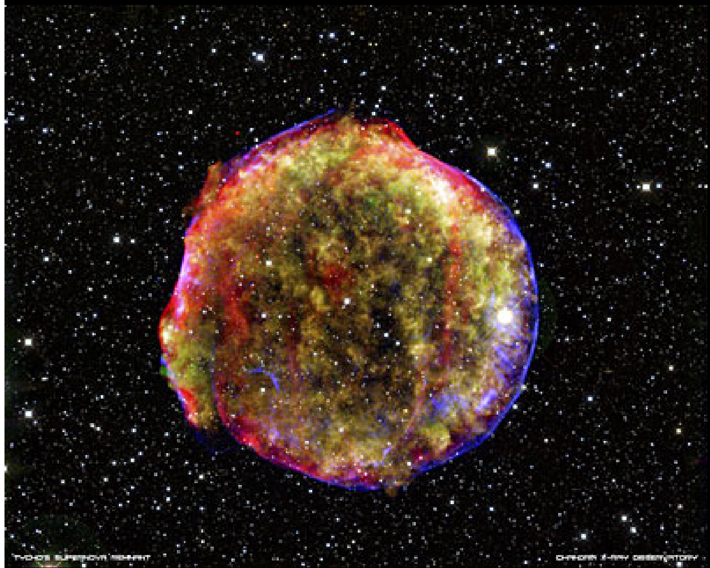


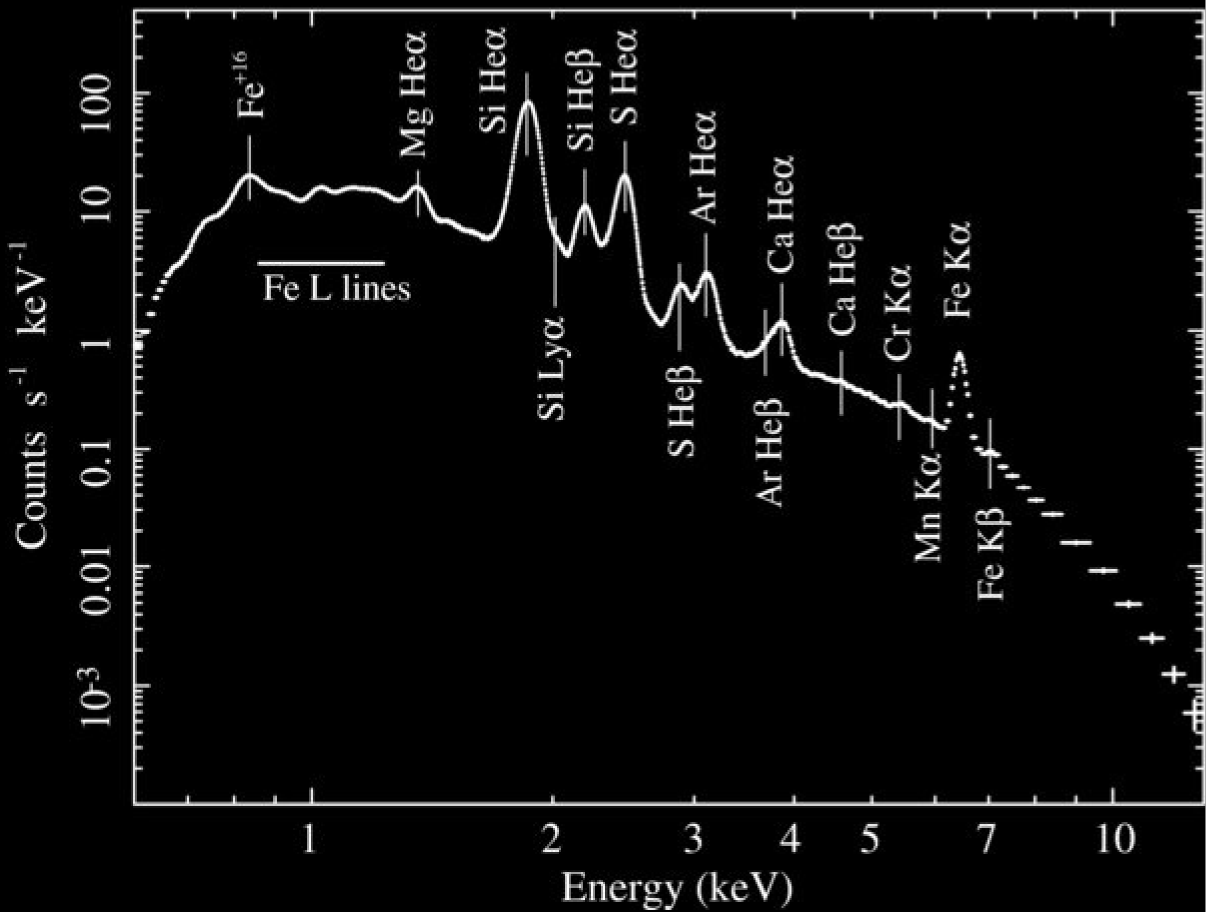
One approach to measure the velocities of the supernova ejecta is through long time line observations. The growth in angular size of the SNR can be translated into a velocity perpendicular to the line of sight (provided the distance to the SNR is known)

Measuring Shock Velocities from Supernova

Hayato *et al.* 2010 *ApJ* **725** 894

Tycho SNR (1572)





$$\frac{E_{rest} - E_{obs,i}}{E_{obs,i}} = \frac{v_r}{c}$$

Suzaku data : expansion velocities of ejecta from Doppler broadened emission lines; line-of-sight velocities of 4000 km/s.

See this page

http://chandra.harvard.edu/photo/category/snr.html

for a number of CHANDRA X-ray telescope images of SNR

Visit the page

http://***hea-www.cfa.harvard.edu/ChandraSNR/snrcat_gal.html***

for a CHANDRA catalog of Galactic SNRs. Click on each SNR id to see a preview of their spectrum at X-ray wavelengths.

Simulating the Origin & Evolution of the *Hot phase* of the ISM

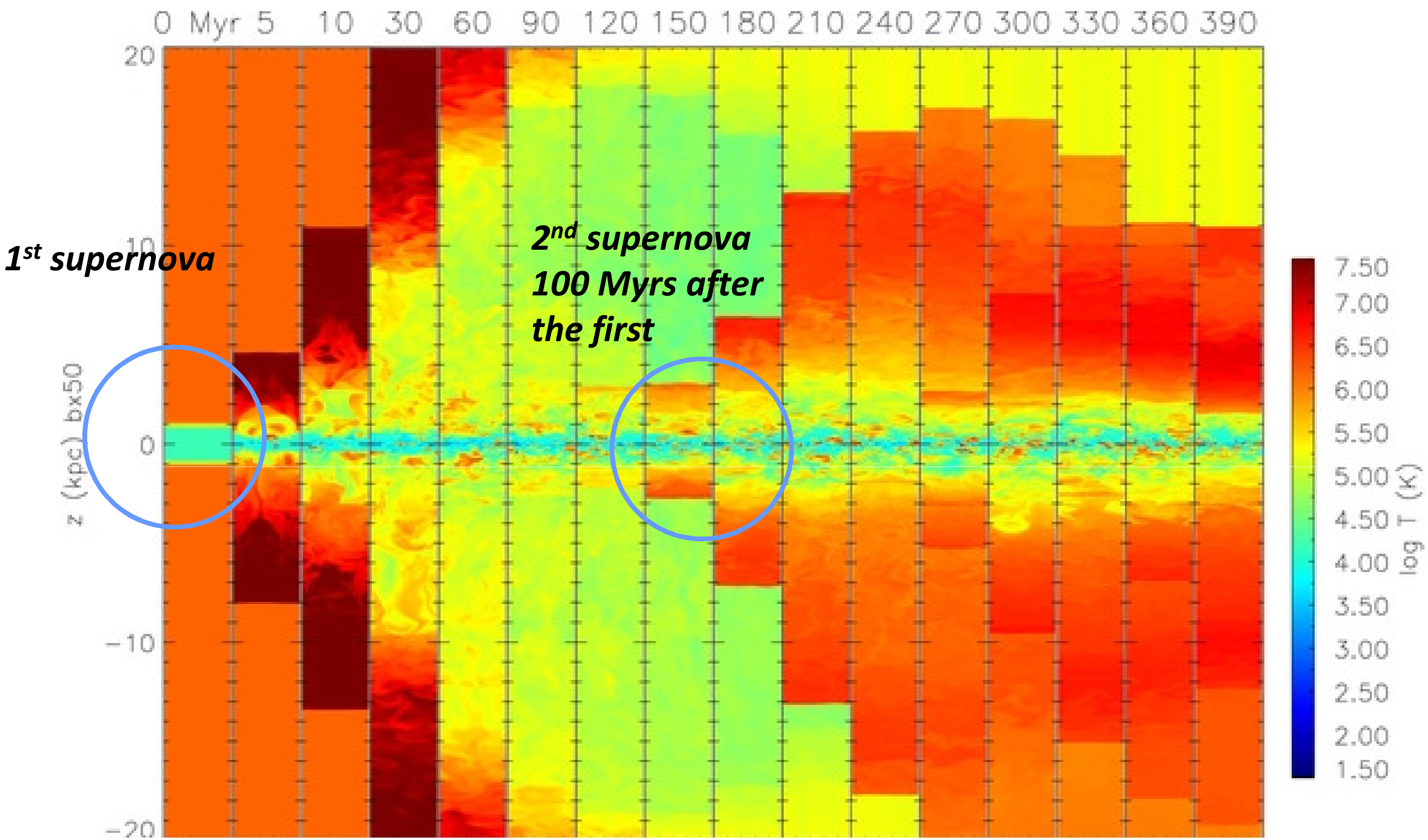
Computer simulations involving the hydrodynamics of plasmas are used to develop a theoretical understanding of the energetics of supernova explosions in a galaxy, how it affects the ambient interstellar gas etc.

The next slide shows slices from such a simulation. Each vertical strip in the figure is a snapshot from a simulation taken at equal time steps of roughly 5 million years.

$z = 0$ kpc is the mid-plane of the Galaxy. At t = 0 time, the first supernova explodes and 100 Myrs later, two other supernovas explode almost simultaneously. The simulation shows what happens to the ambient gas because of the injection of energy and momentum from the supernova.

SNe Heating & Ejection of ISM Gas

Hill et al. 2012 ApJ 750 104



A snapshot from a MHD simulation showing the evolution along vertical direction of a region of the ISM affected by supernova driven turbulence.

Galactic Corona

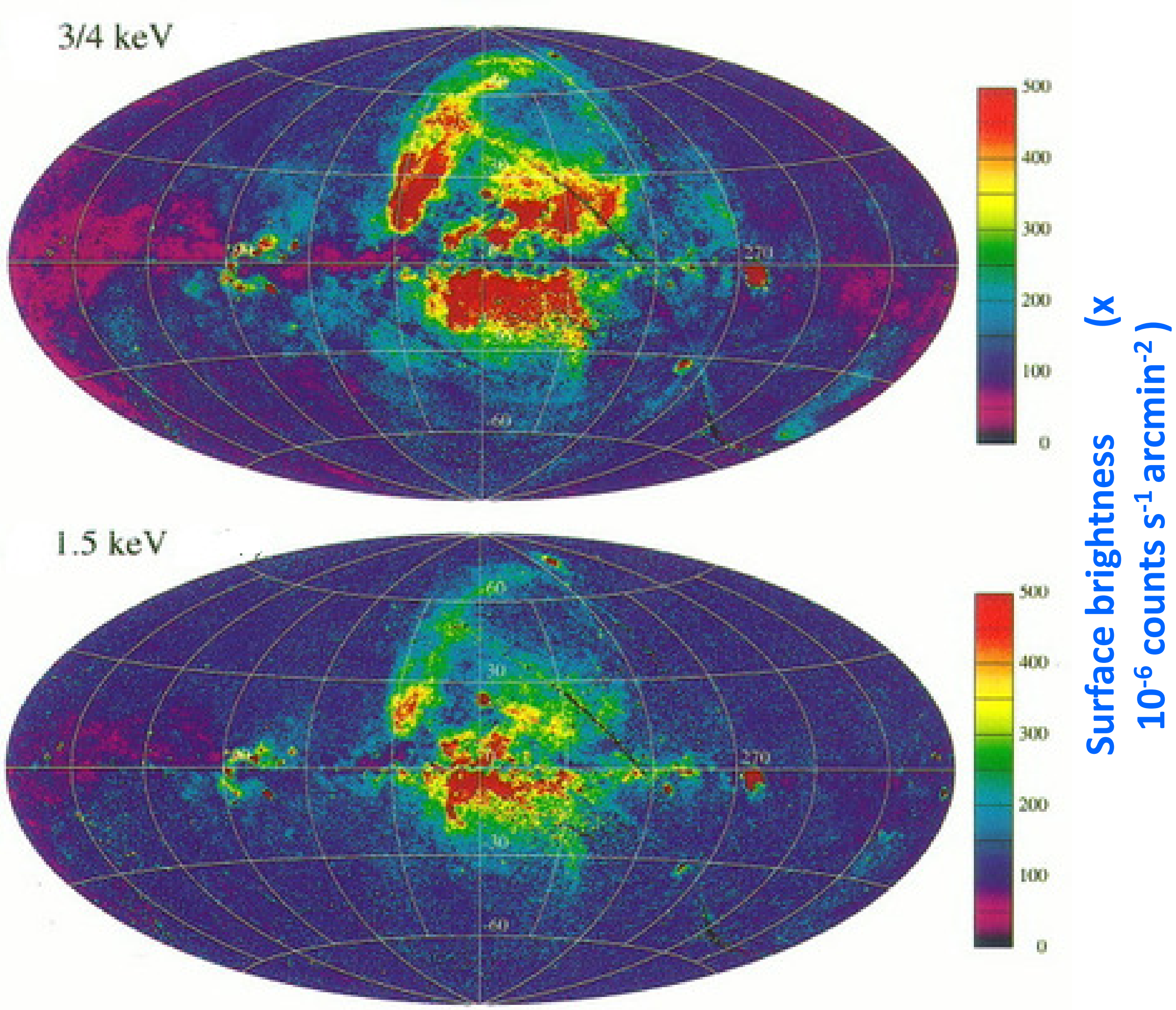
- The hot ionized gas in the halo of the Galaxy is commonly referred to as the Galactic Corona (analogy with Sun's million K coronal gas)

- The presence of the hot coronal gas is inferred via

(a) intervening absorption of lines of highly ionized atoms seen in the spectrum of high Galactic latitude stars. In the coronal gas, much of the hydrogen is collisionally ionized. Hence hydrogen absorption lines are not seen.

(b) detection of soft X-ray emission from this hot gas (this is very faint because of the diffuse nature of the gas)

Snowden et al. 1997



ROSAT (X-ray Telescope) All Sky Survey Map

Soft X-ray diffuse emission from the Galactic halo indicating the presence of coronal gas

The energy of the photons correspond to gas temperatures of ~ 10^6 K