# Radio Science: Lecture 2

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February 12, 2015

1. The Radio Sky

2. Radio Emission Mechanisms
   - Continuum Emission
   - Spectral Line Emission

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RATT

# The Radio Sky

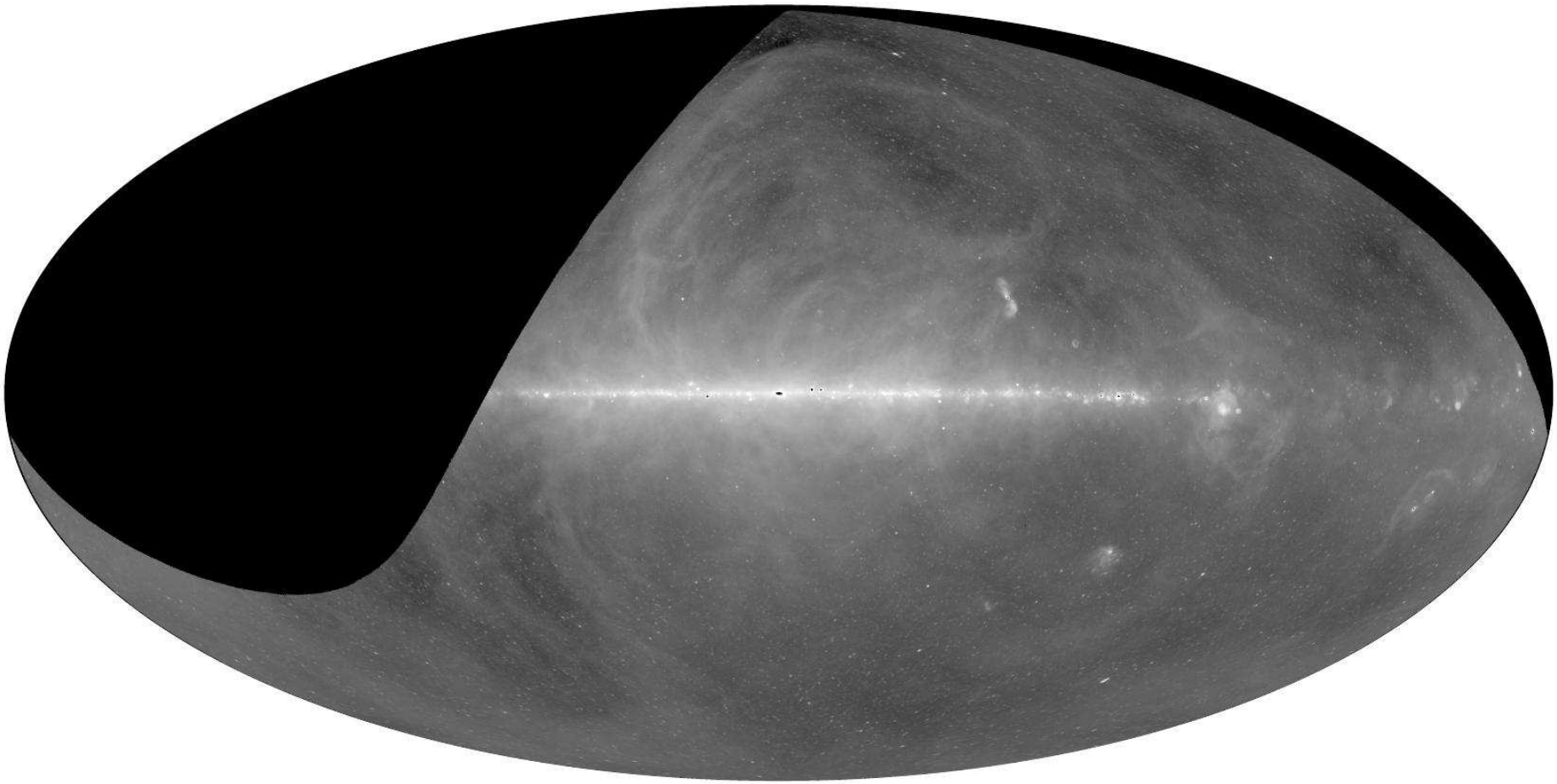

Figure : Radio Continuum Image of the Sky at 1.4 GHz, Calabretta et al. 2013

# Common Types of Radio Sources

- AGN Powered Radio Sources
  - Radio Quasars
  - Radio Galaxies
  - BL-Lac Type Radio Sources
- Non-AGN powered radio sources
  - Supernova Remnants
  - Star-forming Galaxies
  - HI gas
  - Molecular Clouds
  - HII regions
  - etc

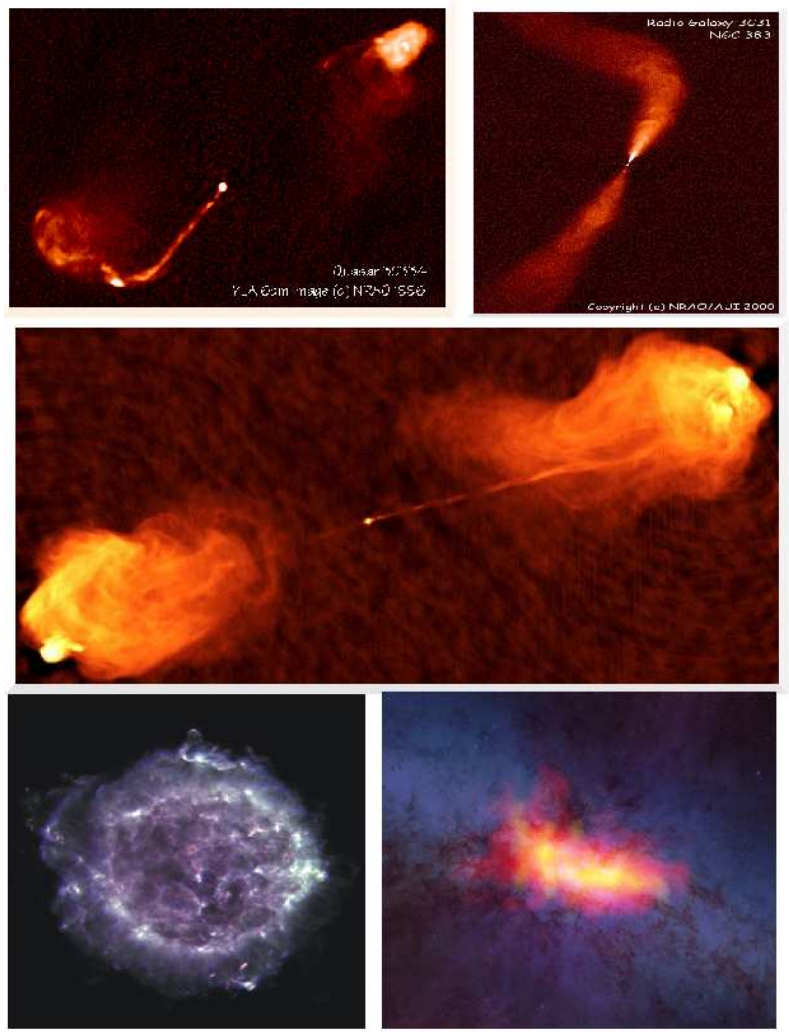


Figure : Image courtesy of NRAO/AUI,Bill Saxton (NRAO/AUI/NSF); Hubble/NASA

# Units and Typical Scales

- Flux density: Jansky - 1 Jy $= 10^{-26} Wm^{-2} Hz^{-1}$
- Typical Flux density ranges $\sim 10^{-9}$ Jy to $\sim 100$ Jy for radio sources in the sky.
- Distance: Parsec - 1 pc $= 3.08 \times 10^{16}$ m
- Typical Observational Frequencies: $\sim 10$ MHz to $\sim 1000$ GHz

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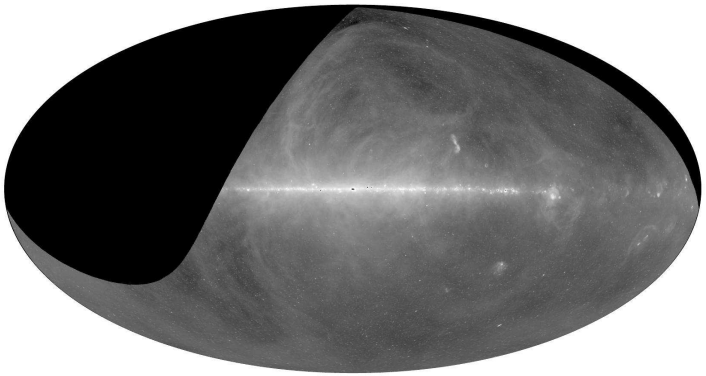
# All we see is light !



Change in specific intensity

$$\frac{dI}{ds} = \kappa I + \varepsilon$$

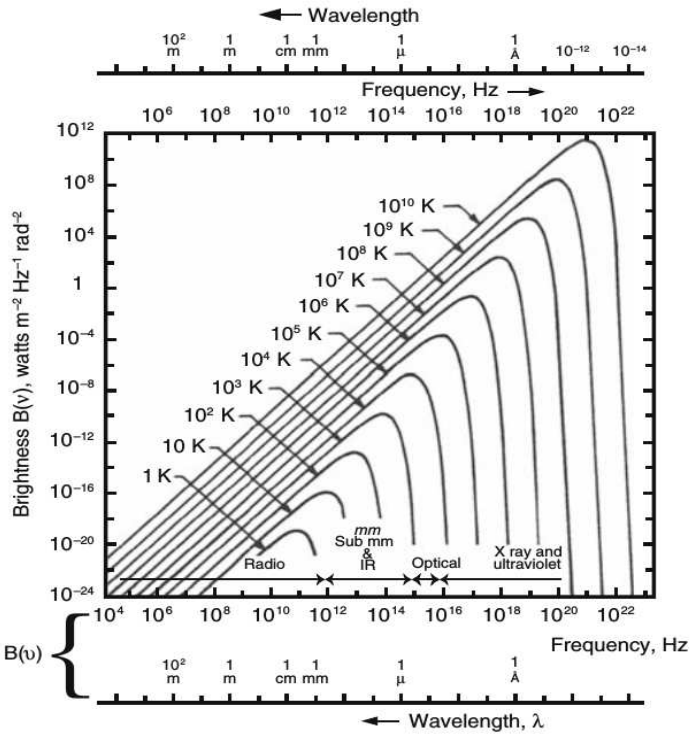
Magnetic fields
ISM
IGM
ICM

Absorption

Emission

# Black Body Radiation I

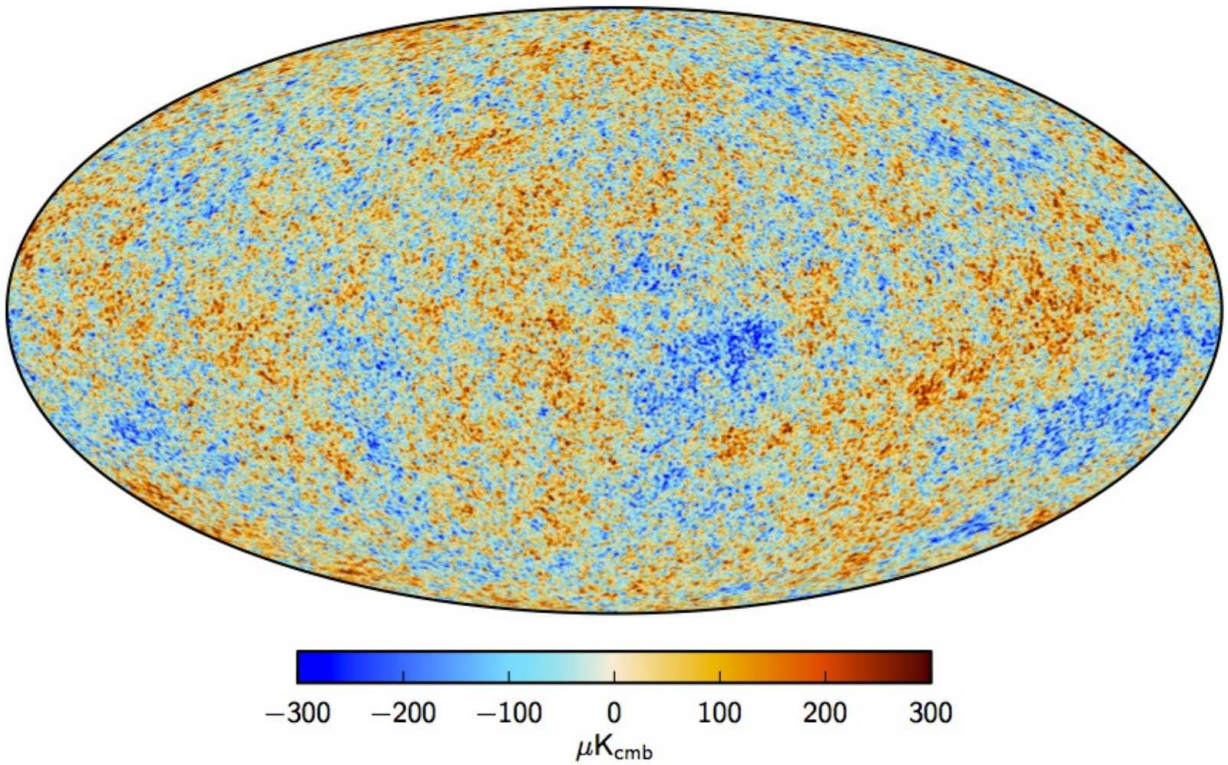
- Emission conforming to the Planck spectrum.
- Wien approximation gives *brightness temperature* $T_b = \frac{\lambda^2}{2k} I_\nu$




[0]Tools of Radio Astronomy, Chapter 1.4

# Black Body Radiation II

- Cosmic Microwave Background (Roger's talk)
- $T \approx 2.725K$
- Anisotropies - cosmological parameters.



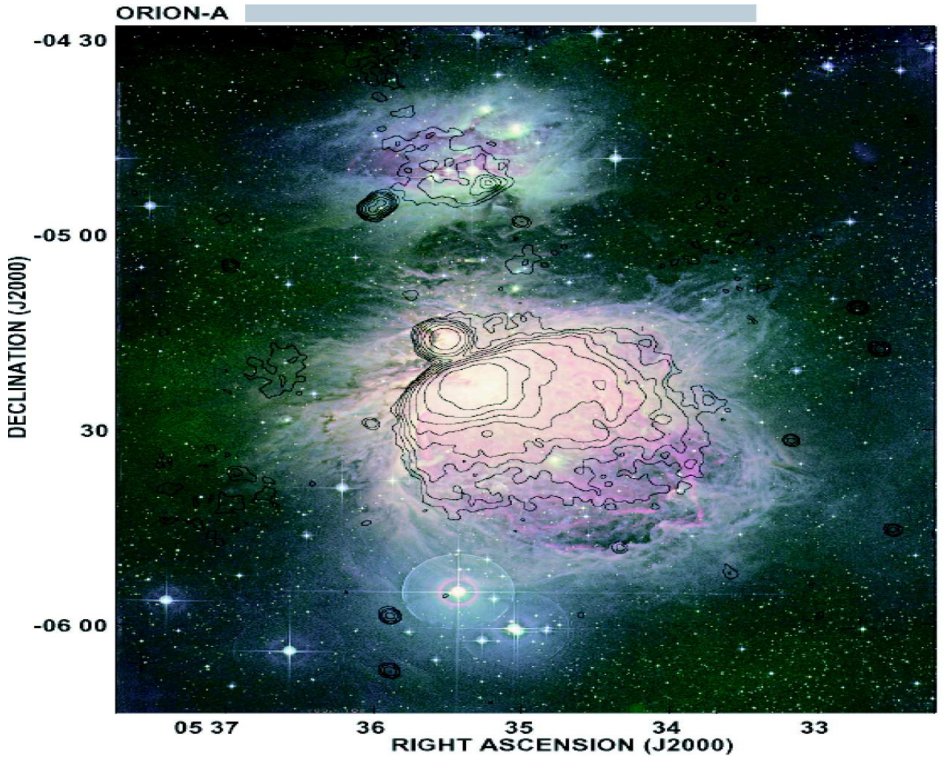
# Bremsstrahlung II

- Emission produced by accelerating charge - in most cases in an electric field.
- Larmor's formula : $P = \frac{2q^2}{3c^3}a^2$
- With flat spectral density for the radiation below a frequency $\omega \propto \frac{v}{b}$
- Velocity distribution determines the final spectrum for a collection of particles.

[0] Tools of radio astronomy, Chapter 10.2-4

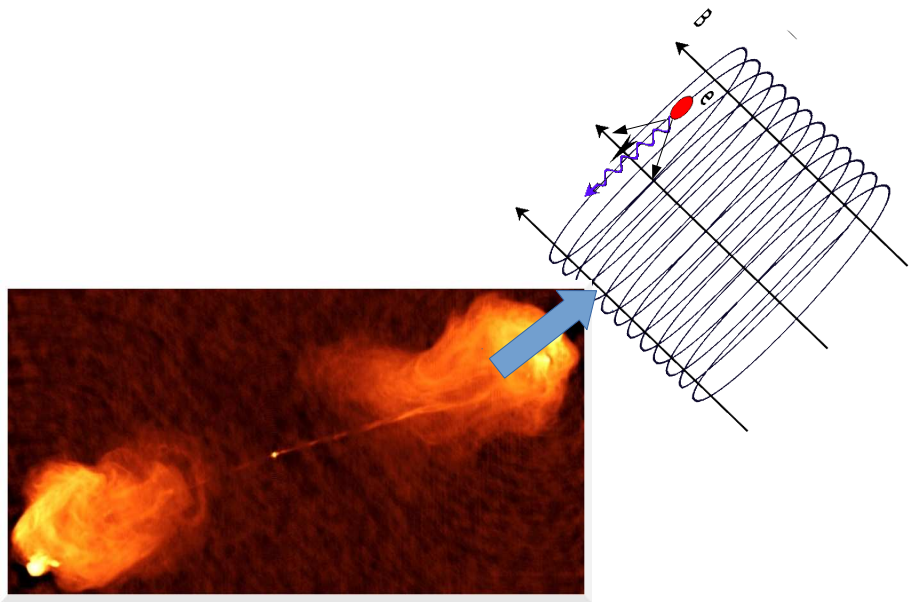
# Bremsstrahlung II

- Thermal Bremsstrahlung : charged particles in thermodynamic equilibrium.
- Velocity distribution of charged particles given by Maxwellian distribution.
- HII regions - around bright, young stars.



# Synchrotron Emission I

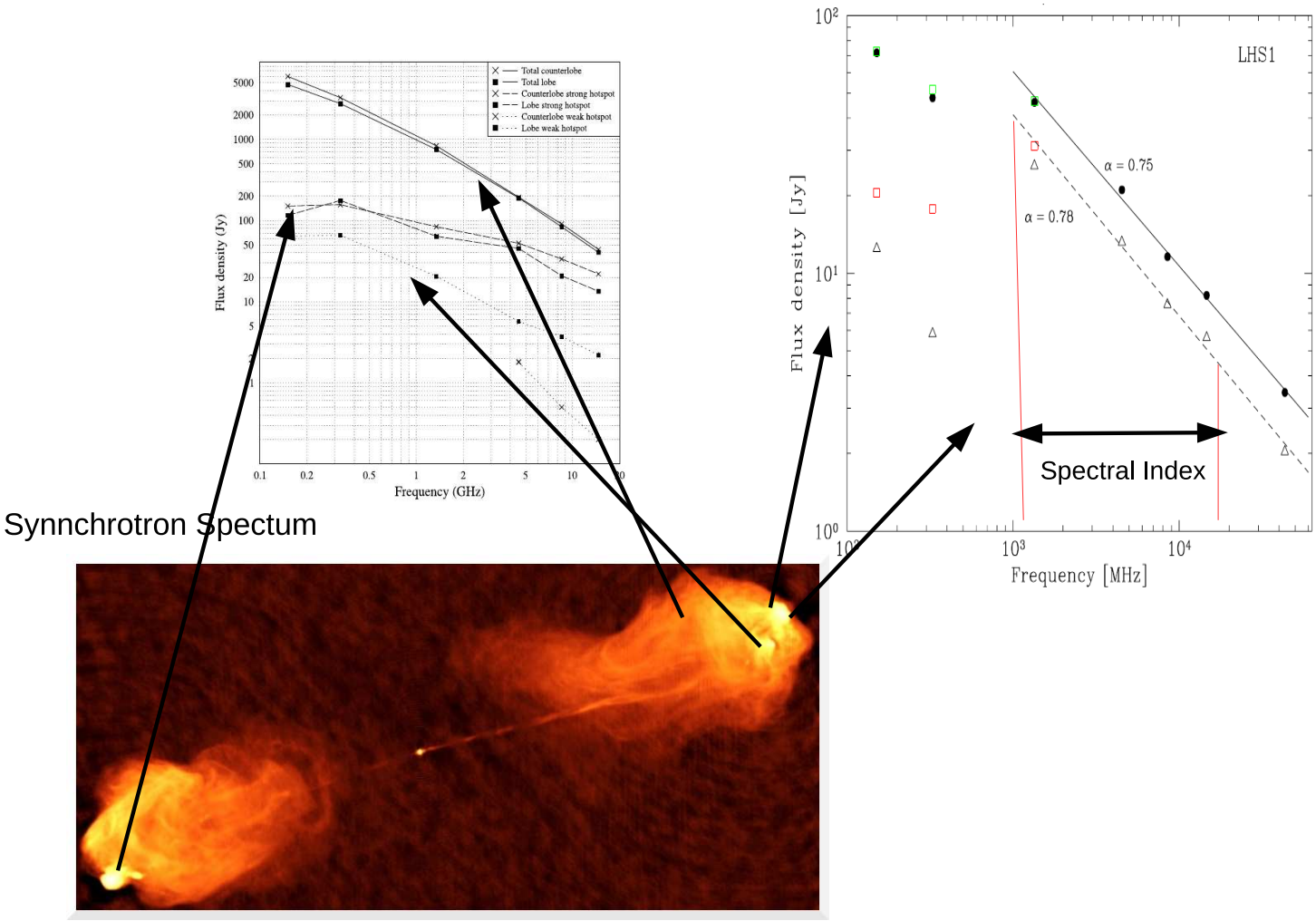
- Synchrotron emission - radiated by *relativistic* charged particles ($e^-$ and $p^+$) *accelerated* in magetic fields.
- Relativistic charged particles in magnetic field: $\omega_c = \frac{qB}{mc}$.



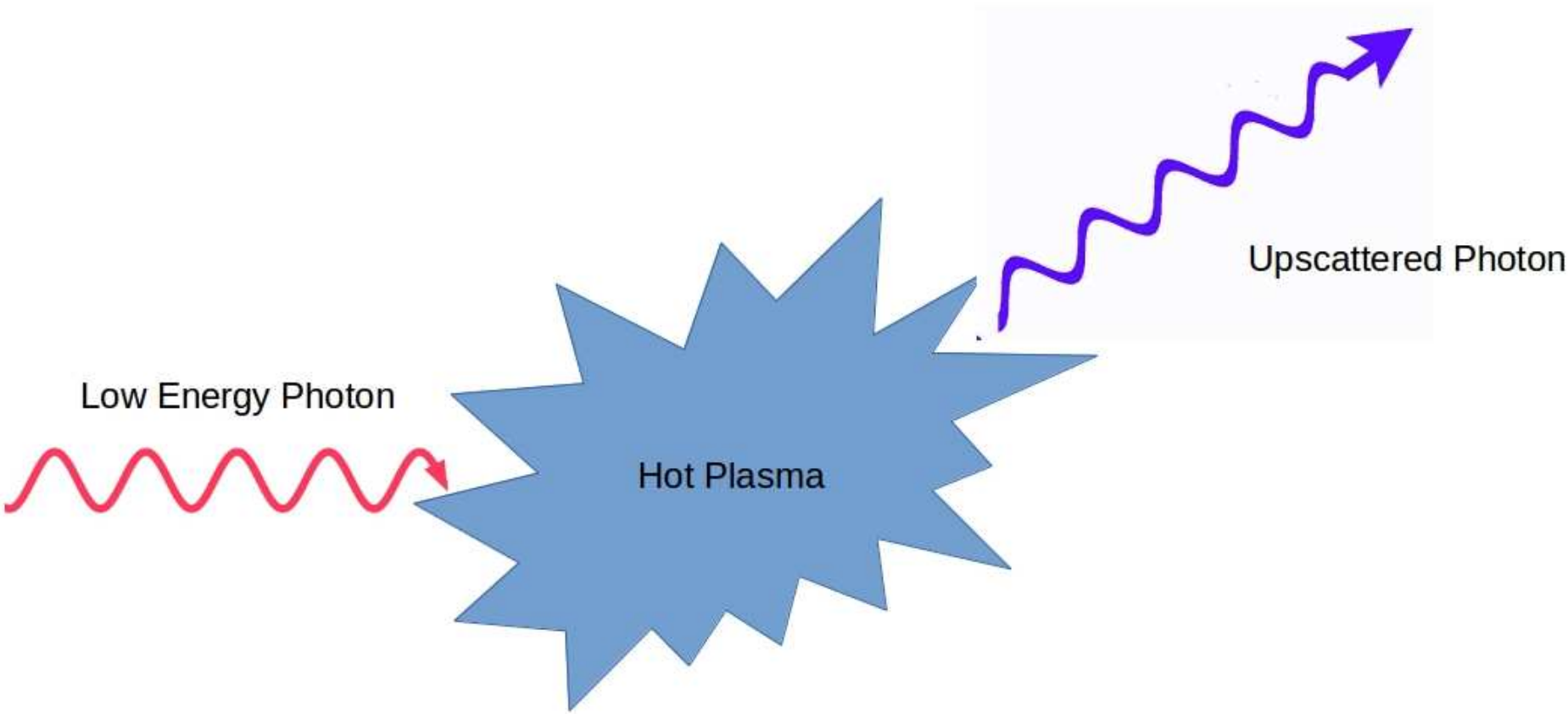
# Synchrotron Emission II

- In astrophysical scenarios, collections of charged particles participate to produce total emission.
- E.g. $N(E)dE \propto E^{-\alpha}dE$ - cosmic rays
- Examples: SNRs, Radio galaxies.

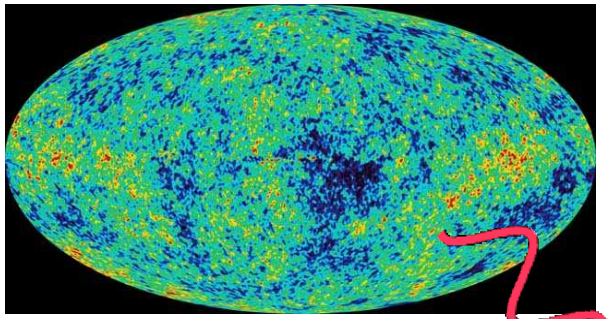
# Synchrotron Emission III : Radio Galaxies



# Inverse Compton I



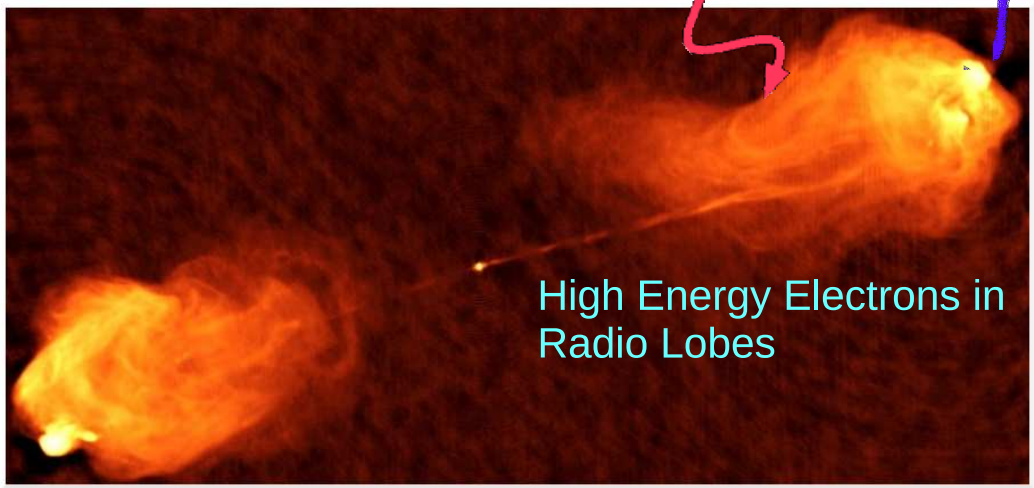
# Inverse Compton II



CMB

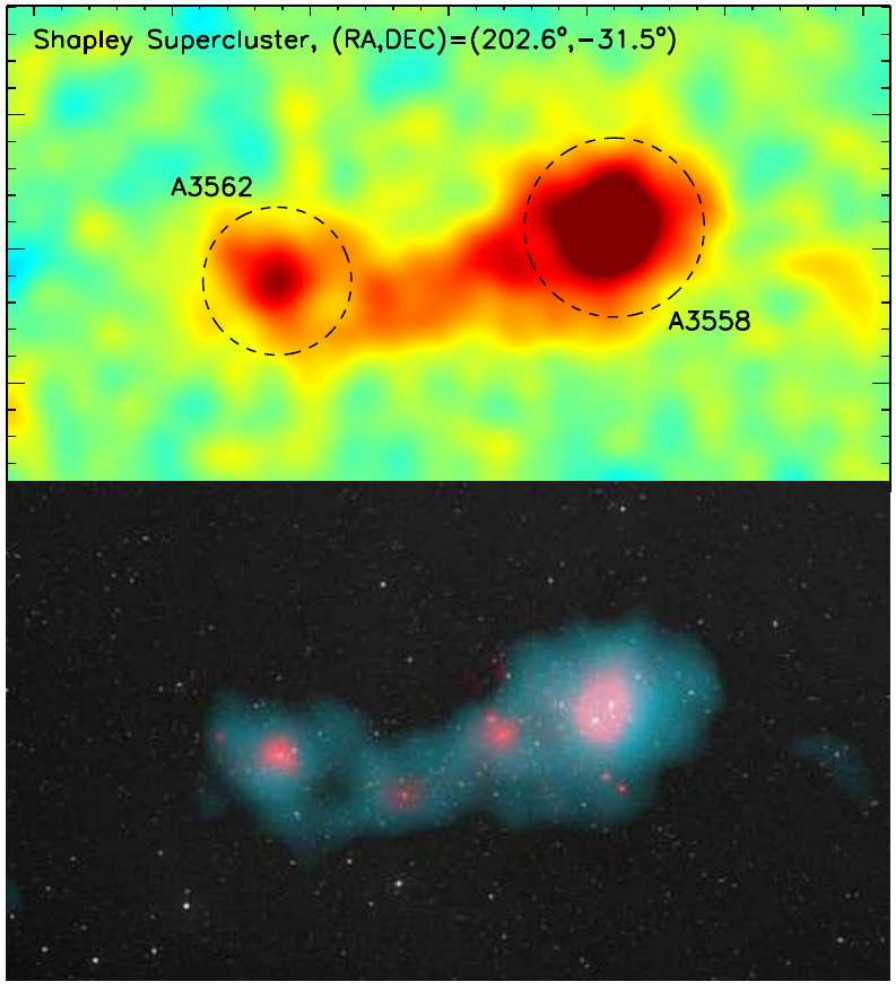
Low Energy Photon

High Energy Photon



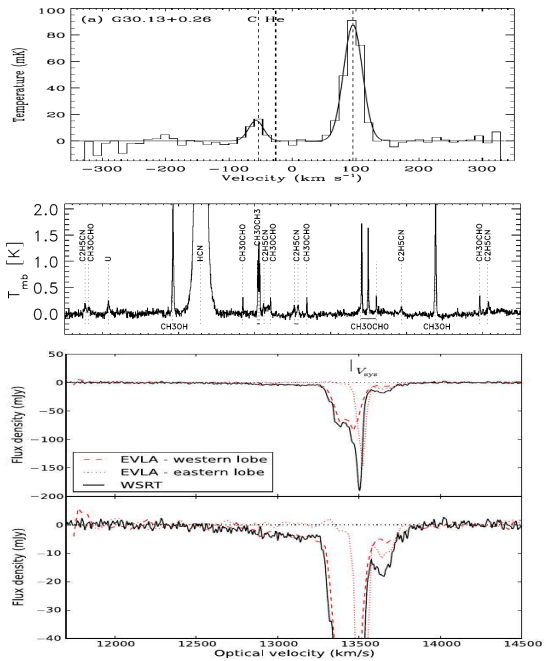
# Inverse Compton III - SZ effect

- Galaxy clusters and CMB
- $\frac{\Delta T_{cmb}}{T_{cmb}} \propto T_e N_e$



# Spectral Lines

- Originate from discrete energy level transitions
- Characterized by emission/absorption in a narrow range in frequencies.
- Defined by population numbers of different levels and *temperature*.



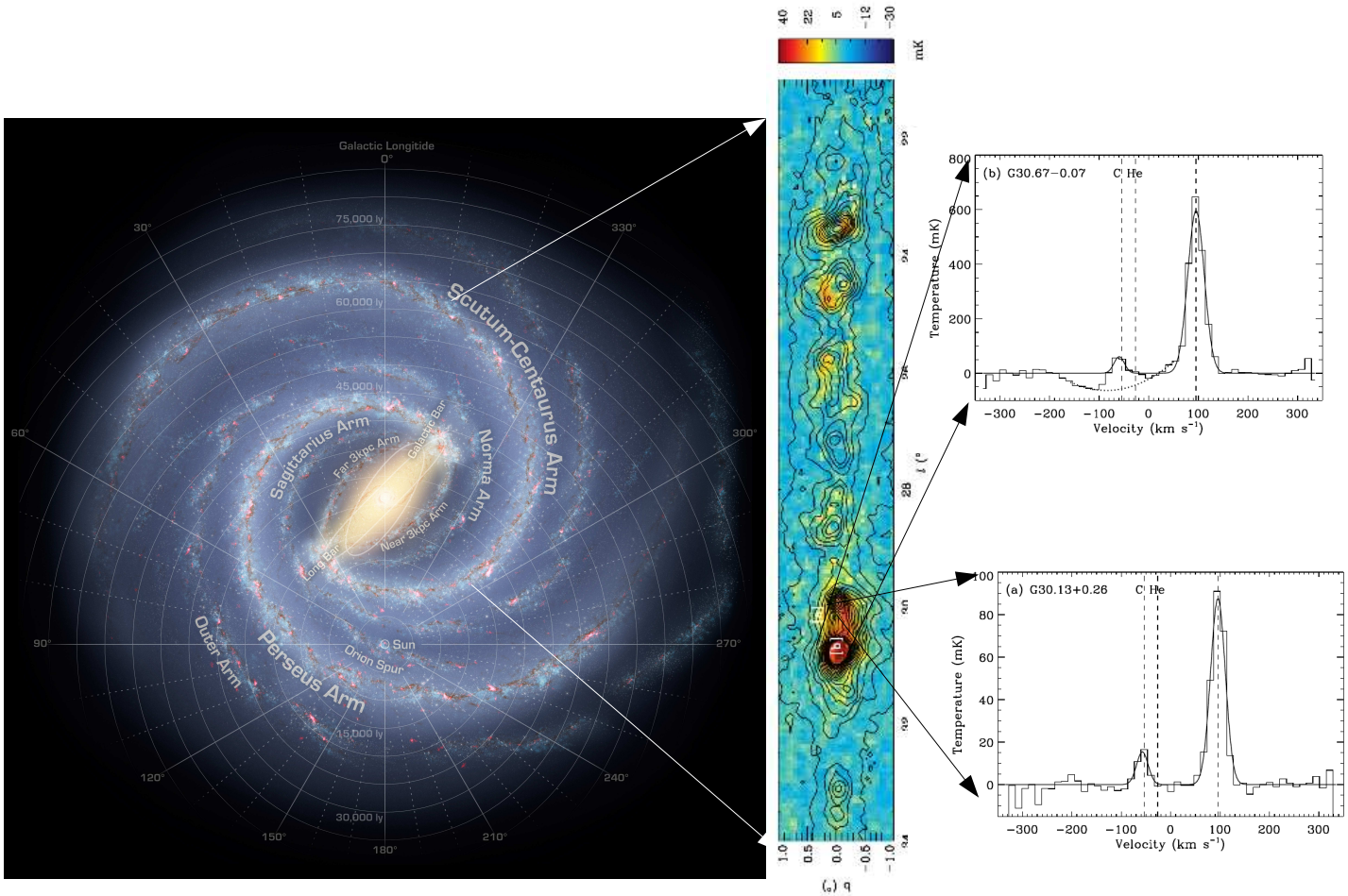

Recombination Lines

Molecular Lines

Hyperfine Lines

# Recombination Line

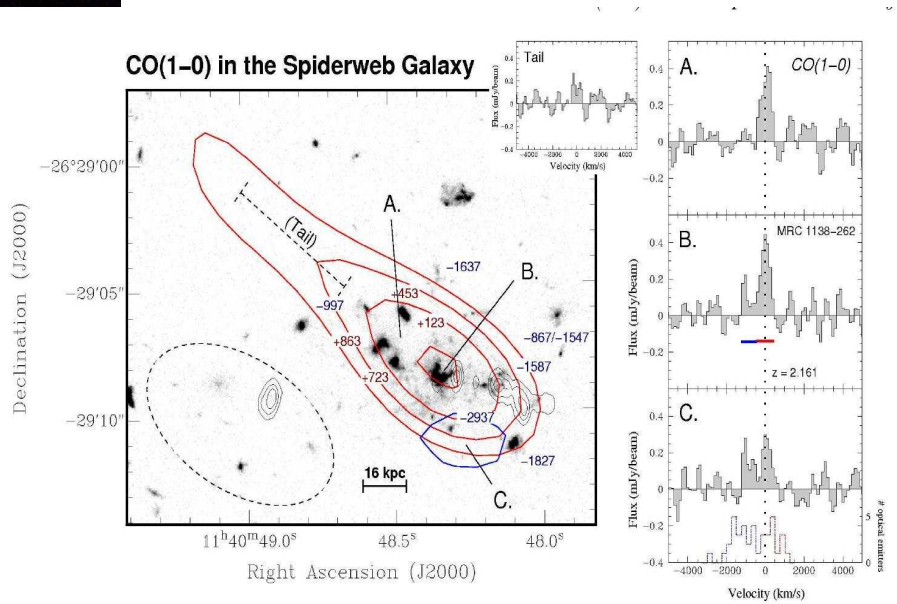
- 'Recombination' of free electrons with nuclei.
- As tracers of electron temperature.



# Molecular Lines

- Rotational transitions in molecules - cold gas.
- Water masers, molecular clouds.
- CO line - star-formation tracer.

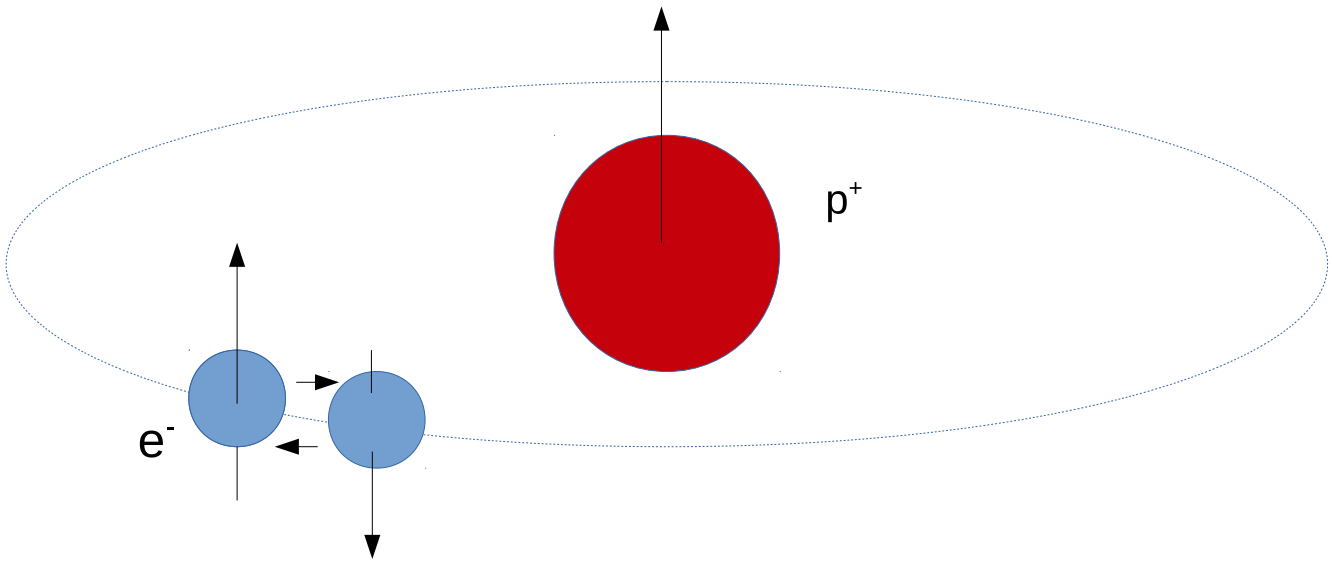
Spiderweb Galaxy



# HI 21cm

- Hyperfine transition in hydrogen atom.
- 'Forbidden' transition - HI in astrophysical scenarios.
- Redshifted HI '21 cm'.

Hyperfine Transition Line from neutral H: 1420.405 MHz

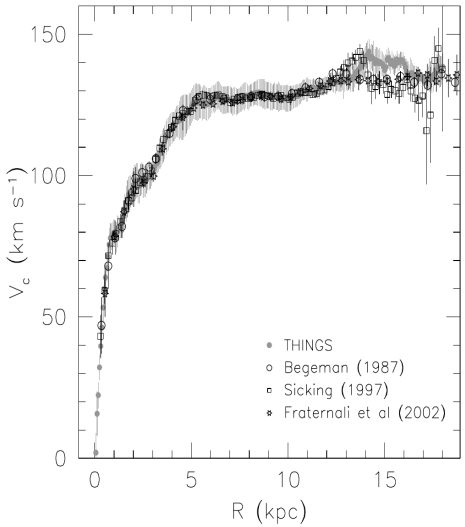



Transitional Probability = 2.87 x 10^-15 s^-1

# HI 21cm: Rotation Curves

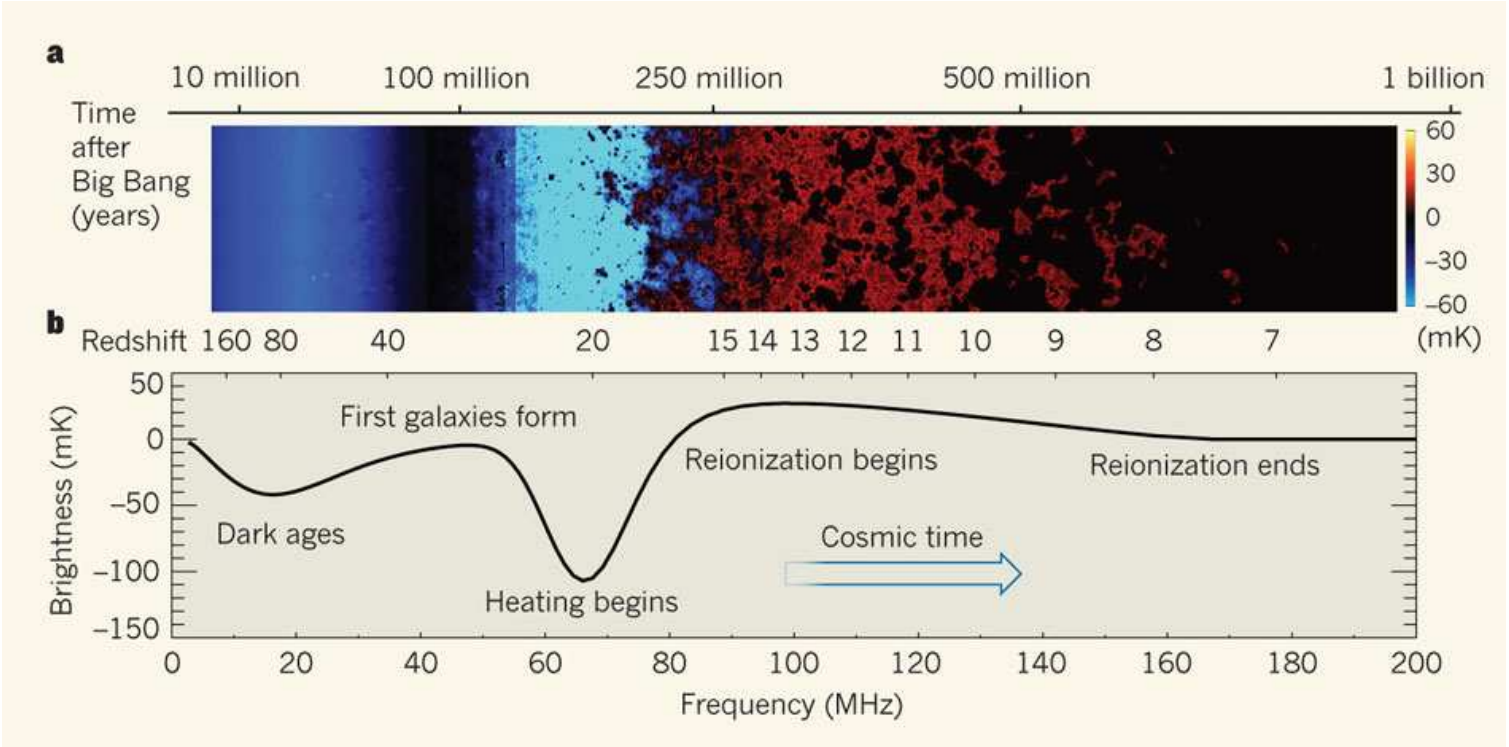
- Rotation curve and the mass of galaxies
- Rotation curves from neutral hydrogen
- Rotation curves and dark matter

Rotation Curve of NGC 2403



# Epoch of Reionization

- Epoch of Reionization (Roger's talk)
- Structure formation and EOR
- Brightness temperature of HI 21 cm emission from EOR.




[0]Can the reionization epoch be detected as a global signature in the cosmic background? - Shaver et.al. 1999

# References


- Tools of Radio Astronomy, Thomas L. Wilson, Kristen Rohlfs, Susanne Httemeister
- Essential Radio Astronomy Course, NRAO : http://www.cv.nrao.edu/course/astr534/ERA.shtml