Radiative Processes in Astrophysics

6 CFU

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1. Basics of Radiative Transfer
   - 1.1 Radiation and Radiative Transfer
   - 1.2 Thermal Radiation and Black Body Spectrum
   - 1.3 The Einstein Coefficients

2. Basics of radiation field
   - 2.1 Maxwell Eqs
   - 2.2 EM waves
   - 2.3 Radiation spectrum
   - 2.4 Polarization of EM radiation

3. Radiation from moving charges
   - 3.1 Retarted potentials
   - 3.2 Velocity and Radiation Fields
   - 3.3 Emission from non-relativistic particles
   - 3.4 Thomson Scattering
   - 3.5 Emission from Relativistic Particles

4. Bremsstrahlung
   - 4.1 Emission from single-v electrons
   - 4.2 Thermal Brems. Emission
   - 4.3 Thermal Brems. Absorption
   - 4.4 X-ray emission from Galaxy Clusters

5. Synchrotron
   - 5.1 Total emitted power
   - 5.2 Spectrum of Synchrotron
   - 5.3 Power-law electron distribution
   - 5.4 Synchrotron polarization
   - 5.5 Synchrotron self-absorption

6. Compton Scattering
   - 6.1 Cross-section and energy transfer
   - 6.2 Inverse Compton for single scattering
   - 6.3 Inverse Compton for Thermal Electron Population
   - 6.4 The Sunyaev-Zeldovich Effect and Galaxy Clusters

Textbooks:

Radiative Processes in Astrophysics – Rybicki & Lightman (1987, Wiley)

The Sunyaev-Zeldovich Effect – Birkinshaw (Phys. Rep. 1999, 310, 97 – arXiv:astro-ph/9808050

Electromagnetic Spectrum

- EM radiation behaves as waves: refraction, diffraction, interference

$$\lambda = c/\nu$$

- Energy is given to or taken from the radiation field in discrete quanta, the photons (e.g. photo-electric effect)

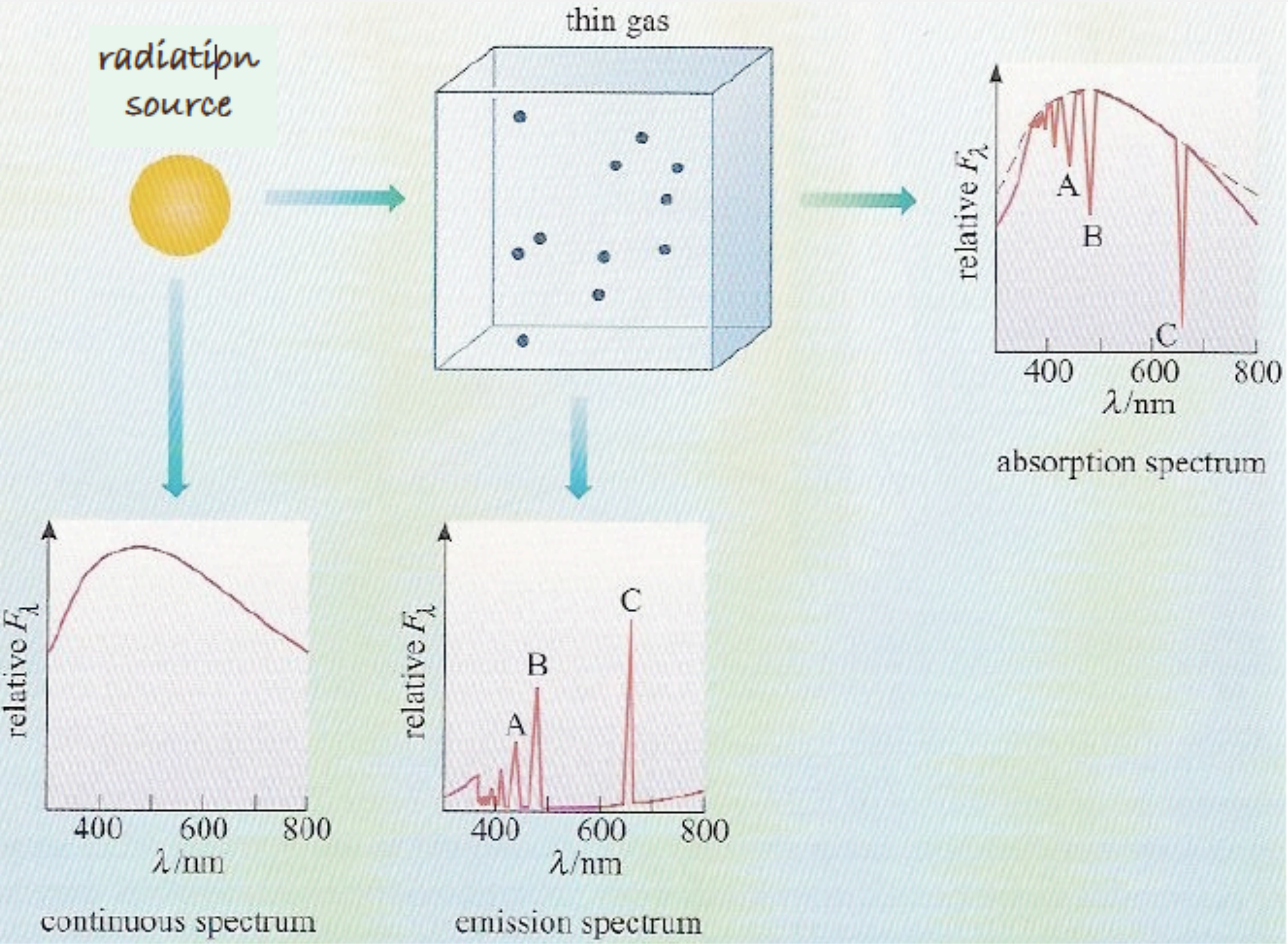
$$E = h\nu$$

- For thermal energy emitted by matter in thermodynamic equilibrium, the characteristic photon energy is related to the temperature of the emitting material

$$T = E/k$$

gamma-rays	$T \geq 10^{10} K$
X-rays	$10^9 K \leq T \leq 10^6 K$
UV	$10^6 K \leq T \leq 10^5 K$
optical	$T \sim 3 \times 10^4 K$
IR	$10^4 K \leq T \leq 100 K$
radio	$10 K \leq T \leq 1 K$

The formation of a spectrum



<u>Radiative flux:</u> when the scale of the system largely exceeds the wavelength of radiation, we consider that radiation travels in a straight line (a ray) and from this radiative transfer theory can be developed

<u>Macroscopic description of radiation</u>: describe the energy flux associated with EM radiation
The relationship between intensity and the energy flux, momentum flux, radiation pressure and energy density

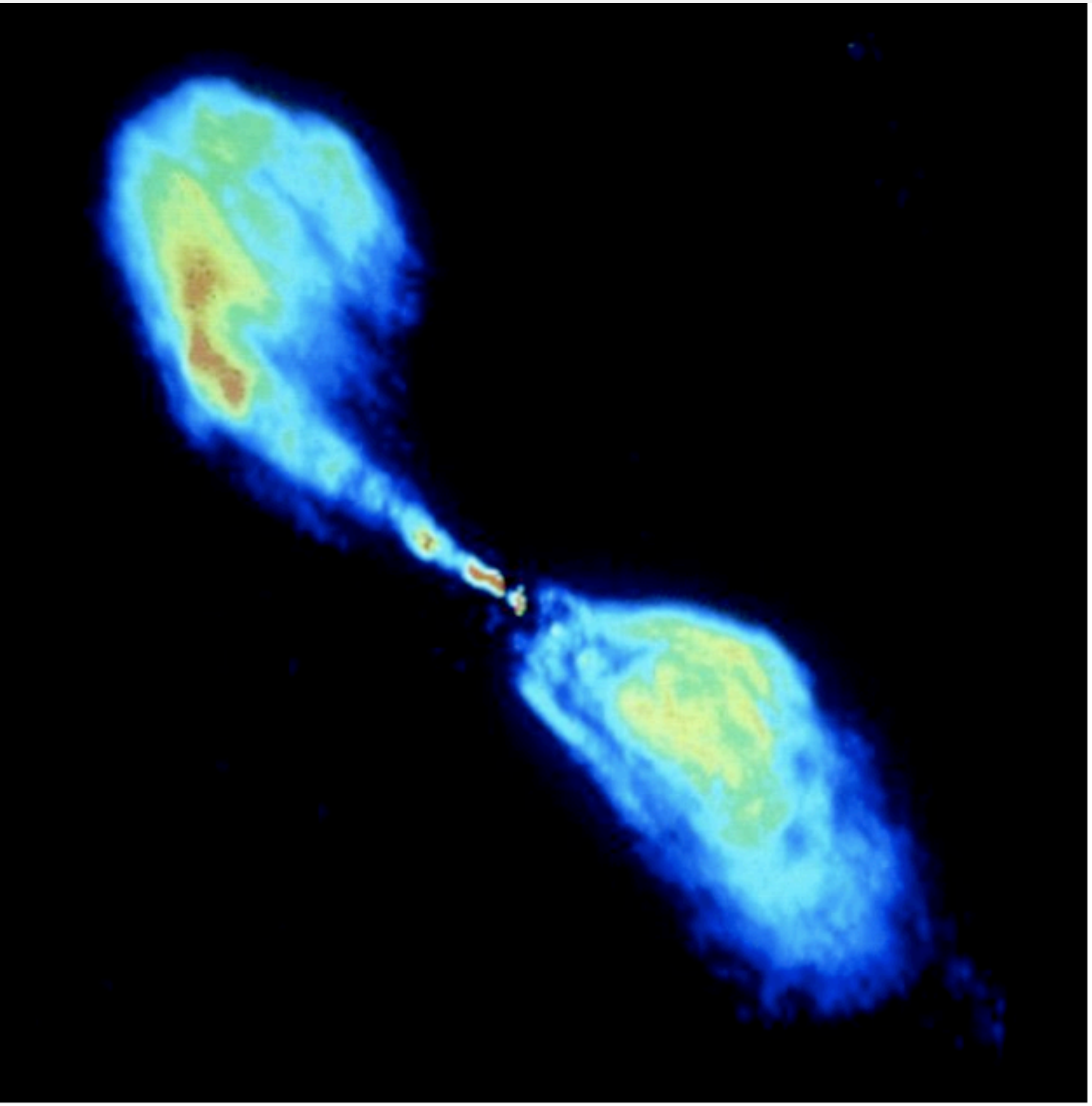
The case of Centaurus A

Optical: thermal bremsstrahlung (free-free) emission from stars and gas, line emission, dust scattering.

The case of Centaurus A

Near infrared: thermal emission, mainly from stars, similar to optical, but with dust less apparent. Opacity of dust in the IR less apparent

The case of Centaurus A

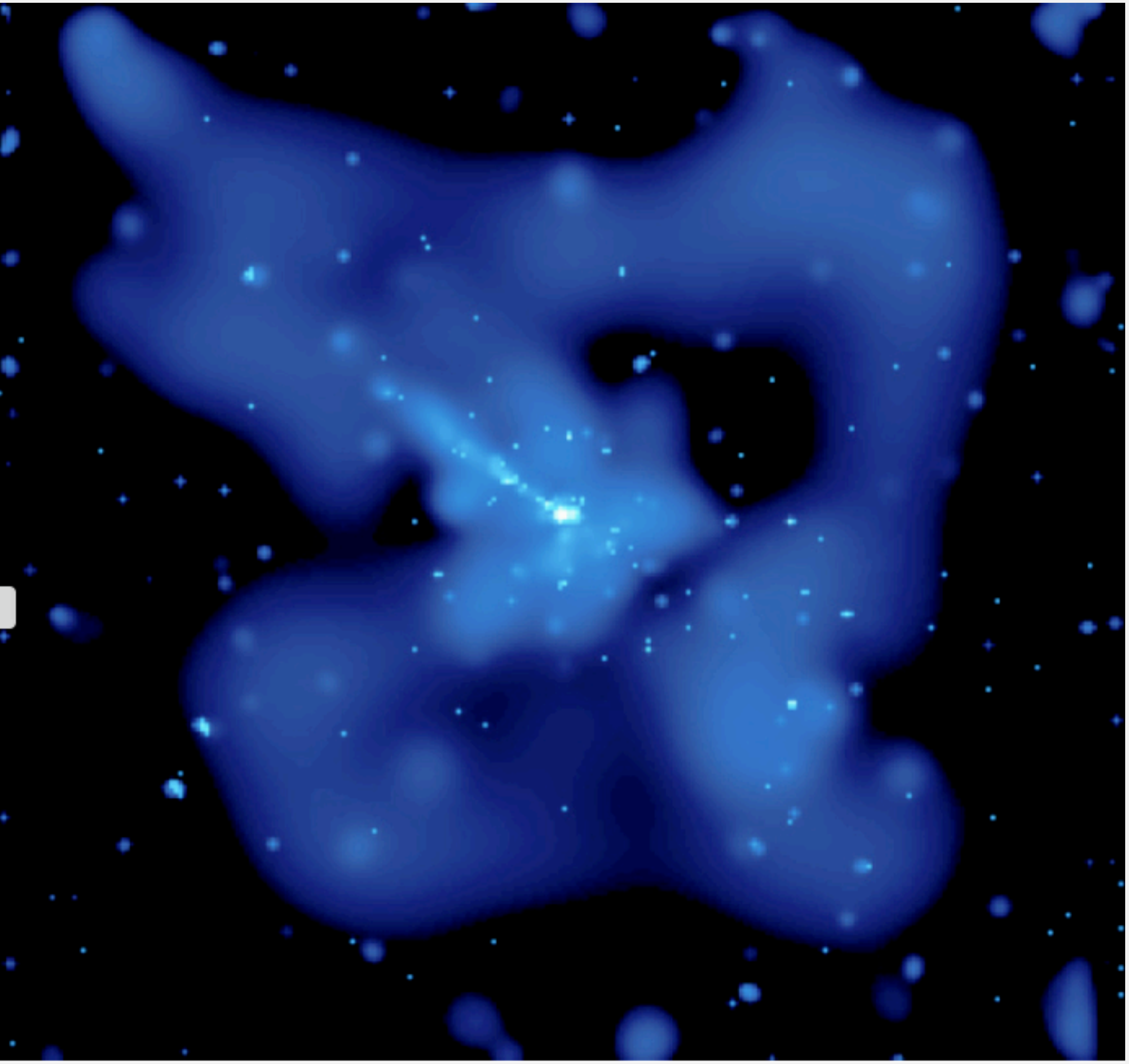


VLA Observations at 6cm

Neutral Hydrogen (HI line emission)

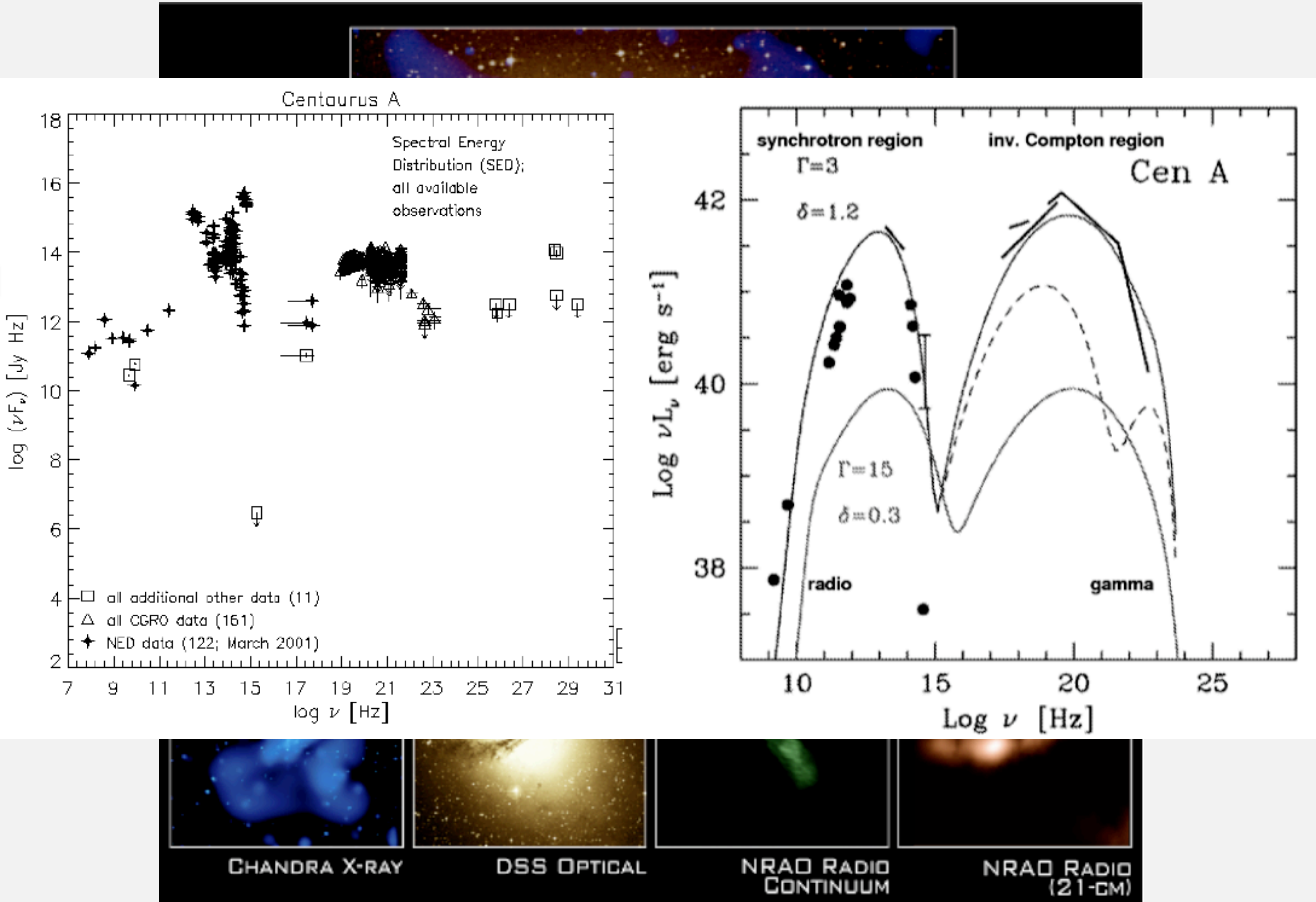
Synchrotron radiation from jets and Black Hole

The case of Centaurus A

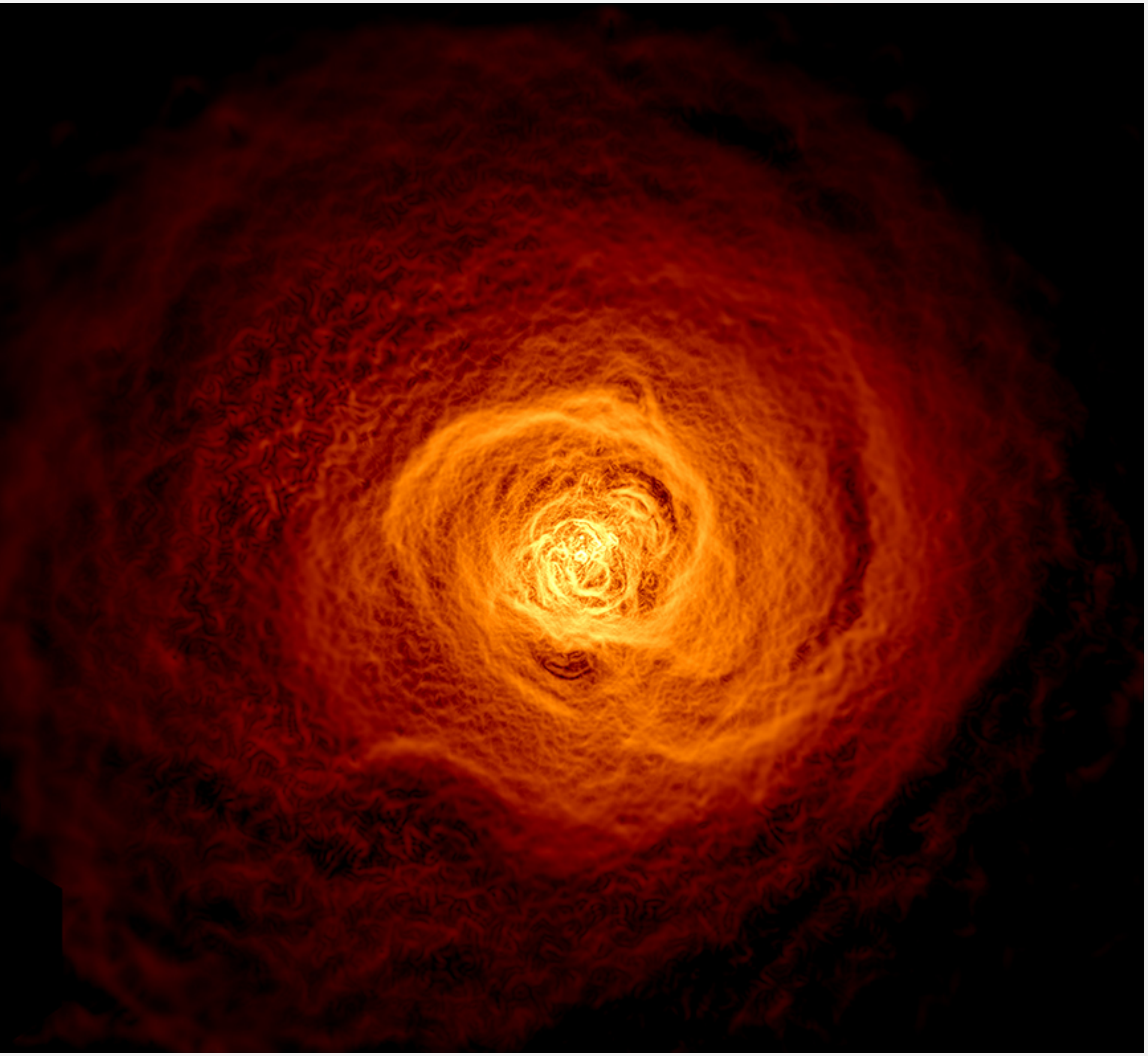


X-rays: Syncrotron radiation from jets, Comptonized photons from Black Hole, Thermal Radiation from stars

Cen-A – Multiwavelength picture



The Perseus Cluster of Galaxies Observed with Chandra X-ray Telescope



- X-ray emission in the [1-10] keV band
- Dominated by thermal bremsstrahlung from hot ionized plasma at a temperature of several keV

Invaluable information on:

- Thermodynamical properties of the intra-cluster plasma
- Chemical (metal enrichment) properties
- Astrophysical processes determining the gas properties