Introduction to Radio Astronomy

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Metropolitan State University of Denver

Undergraduate Alfalfa Workshop 2017

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Hey Tweeters: the proper hashtags for this meeting are:

#UAT17 #GBO #GBT

#METROBATHANDTILE

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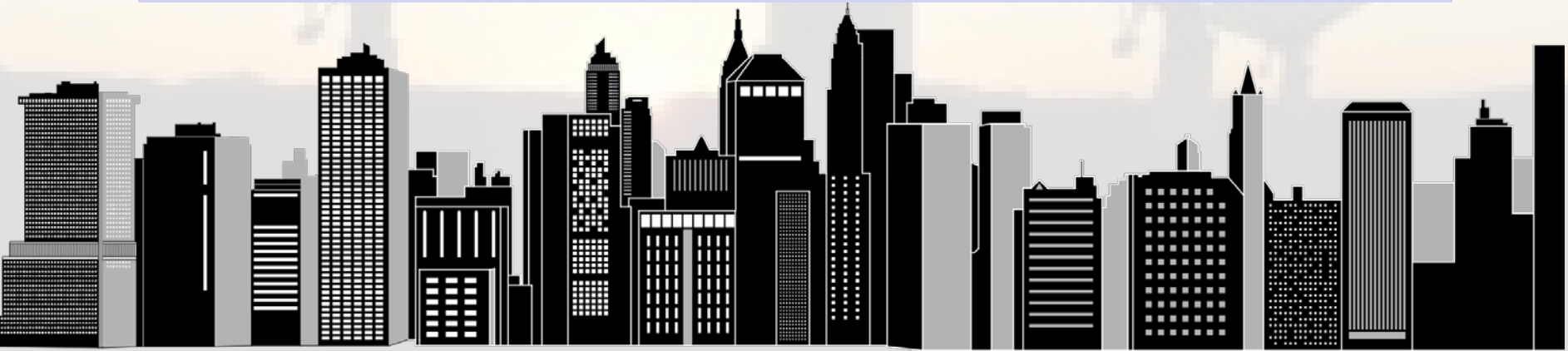
Metro Bat Hand Tile

Your Artisan Remodeling Warehouse



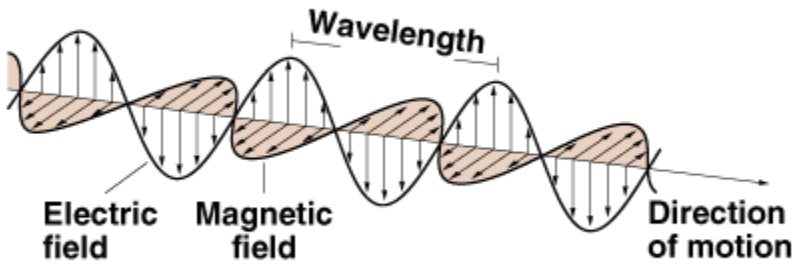
Introduction to Radio Astronomy

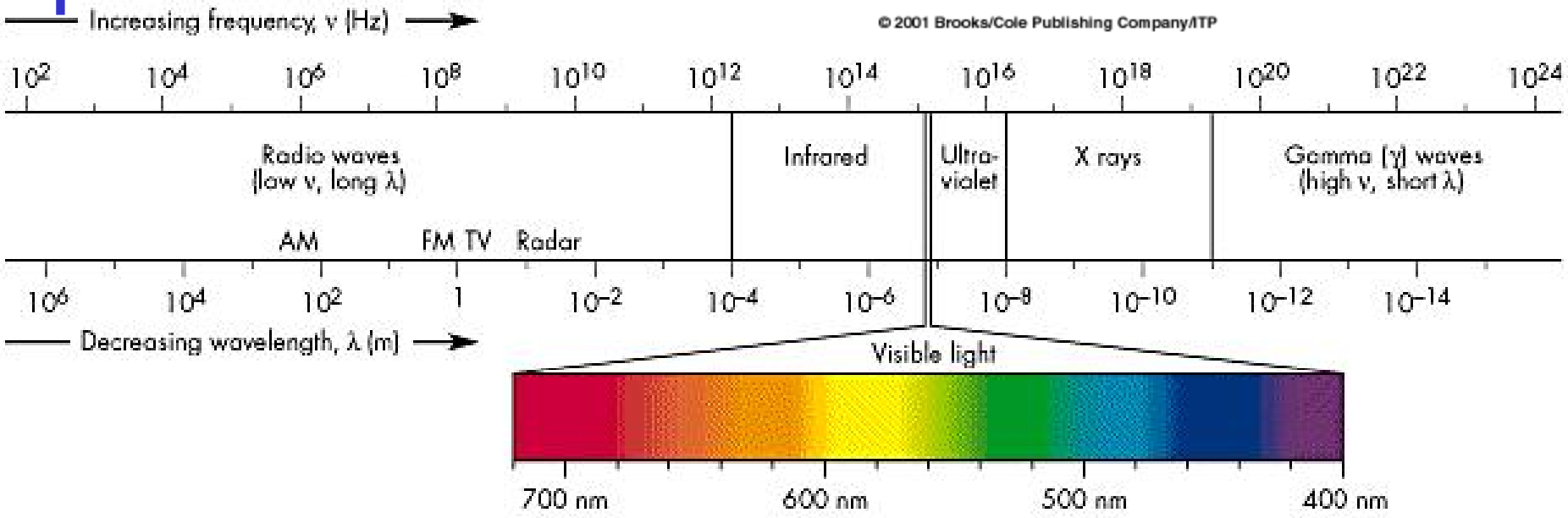
1) Stuff in space
2) Telescopes
3) Physics

For an excellent rigorous introduction to radio astronomy:

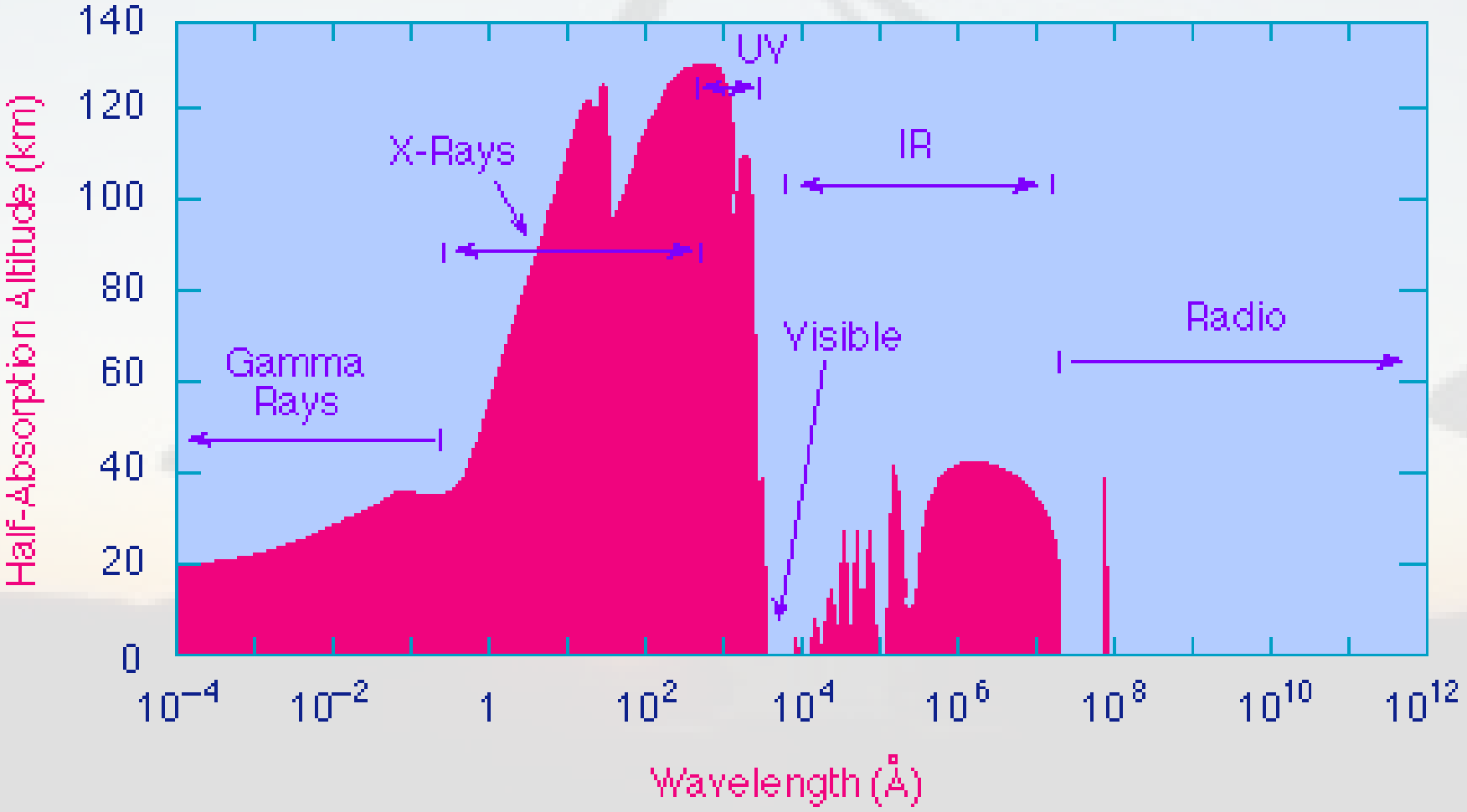
https://science.nrao.edu/opportunities/courses/era

The Electromagnetic Spectrum

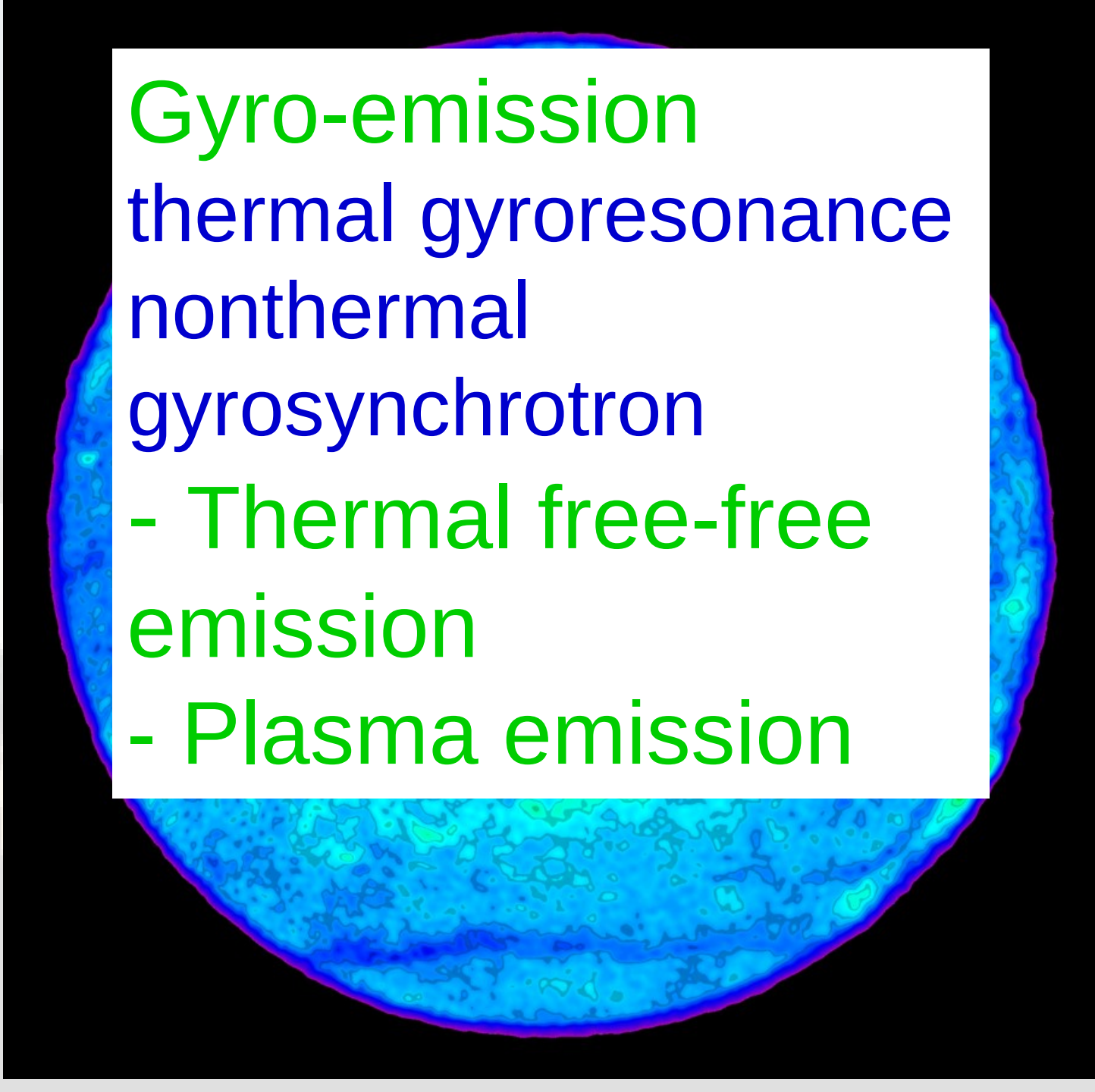




Atmospheric windows



The Sun at 5 GHz



Gyro-emission

thermal gyroresonance

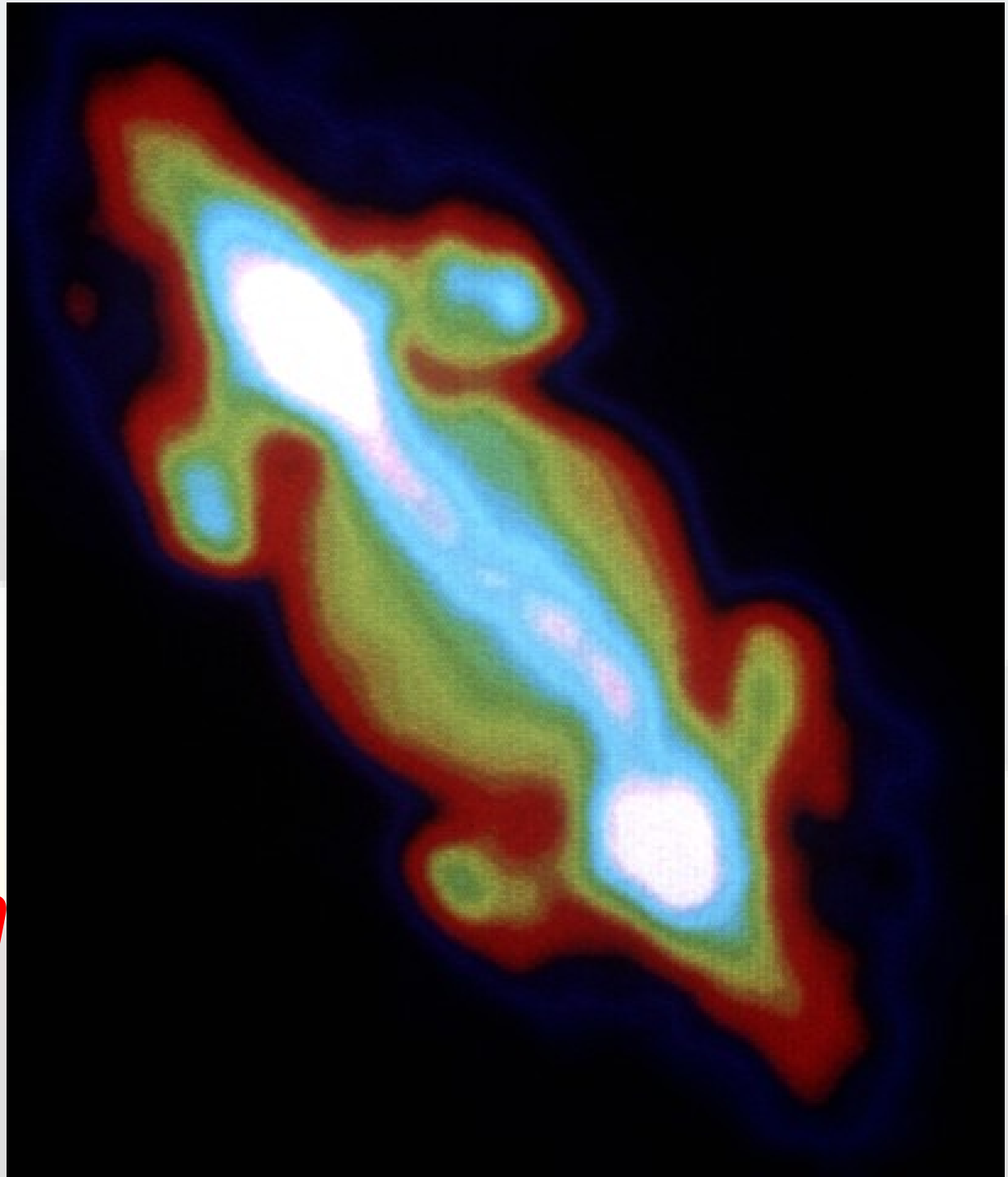
nonthermal gyrosynchrotron

- Thermal free-free emission
- Plasma emission

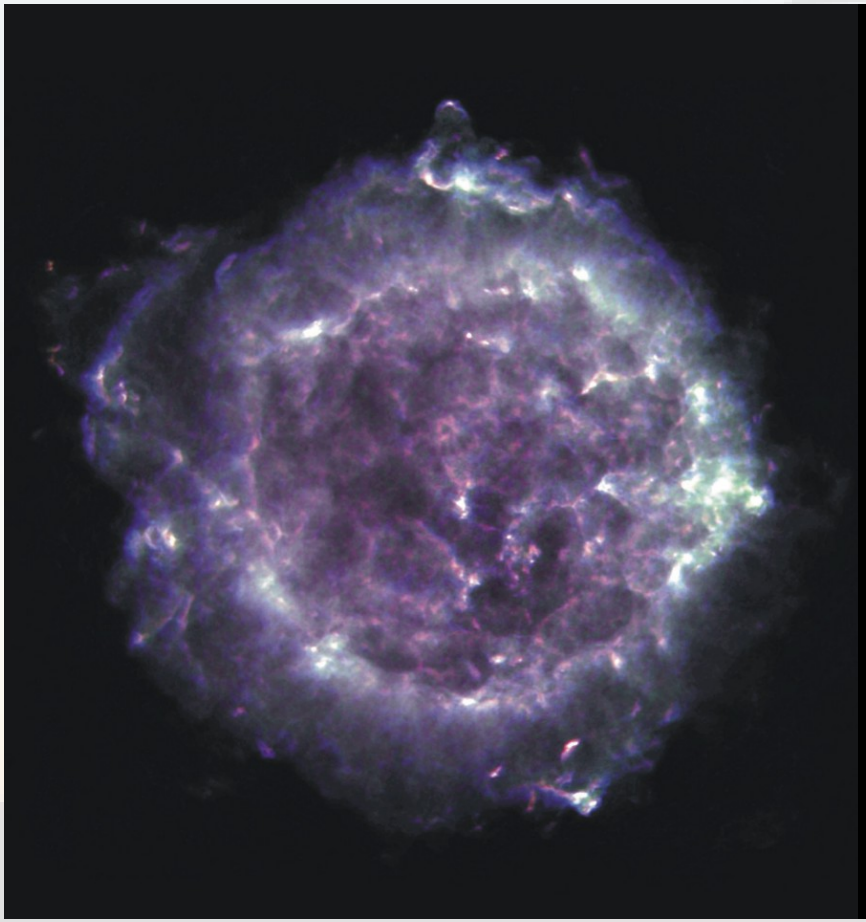
Jupiter

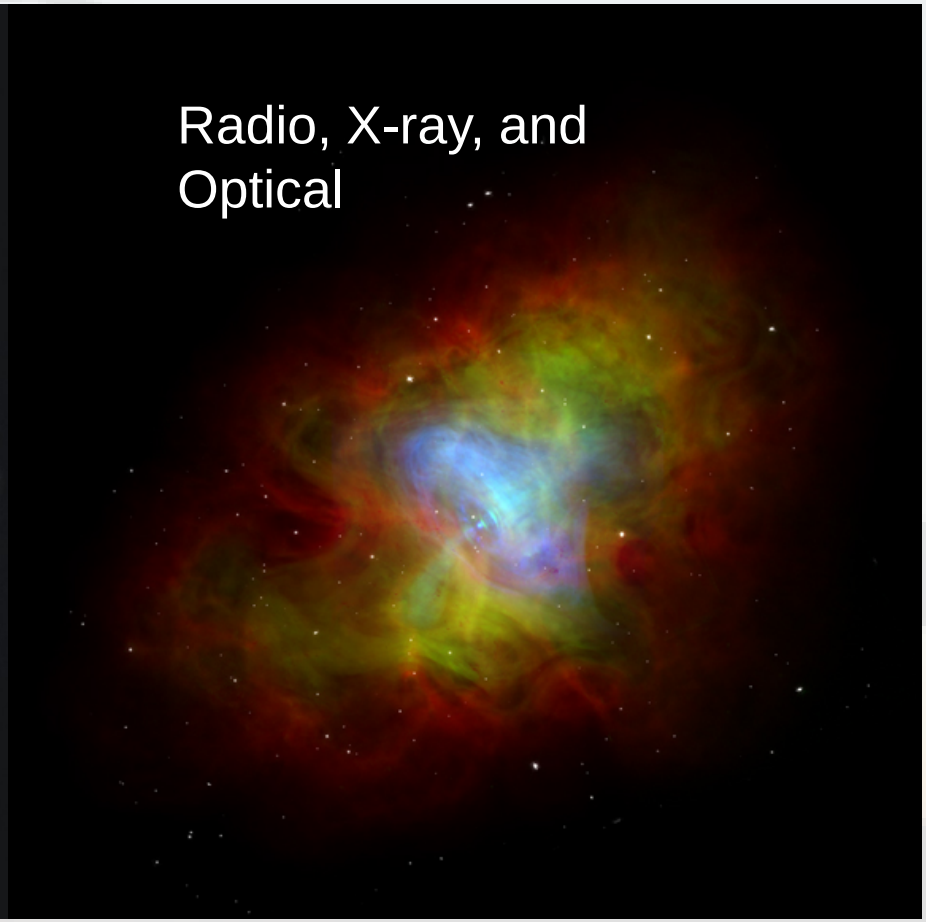
Students:
What do you think is causing the radio emission of Jupiter?

Synchrotron Radiation



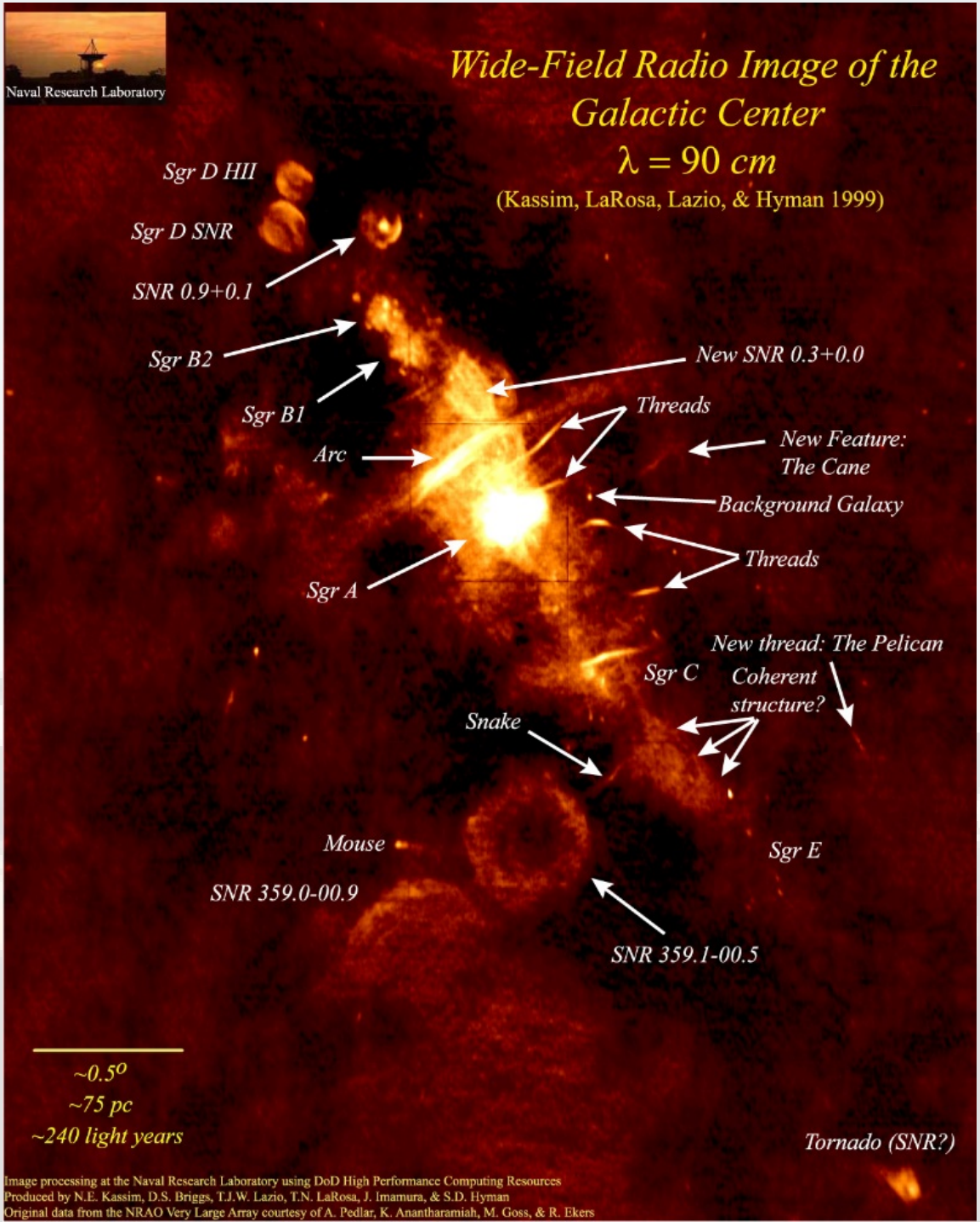
Supernova Remnants



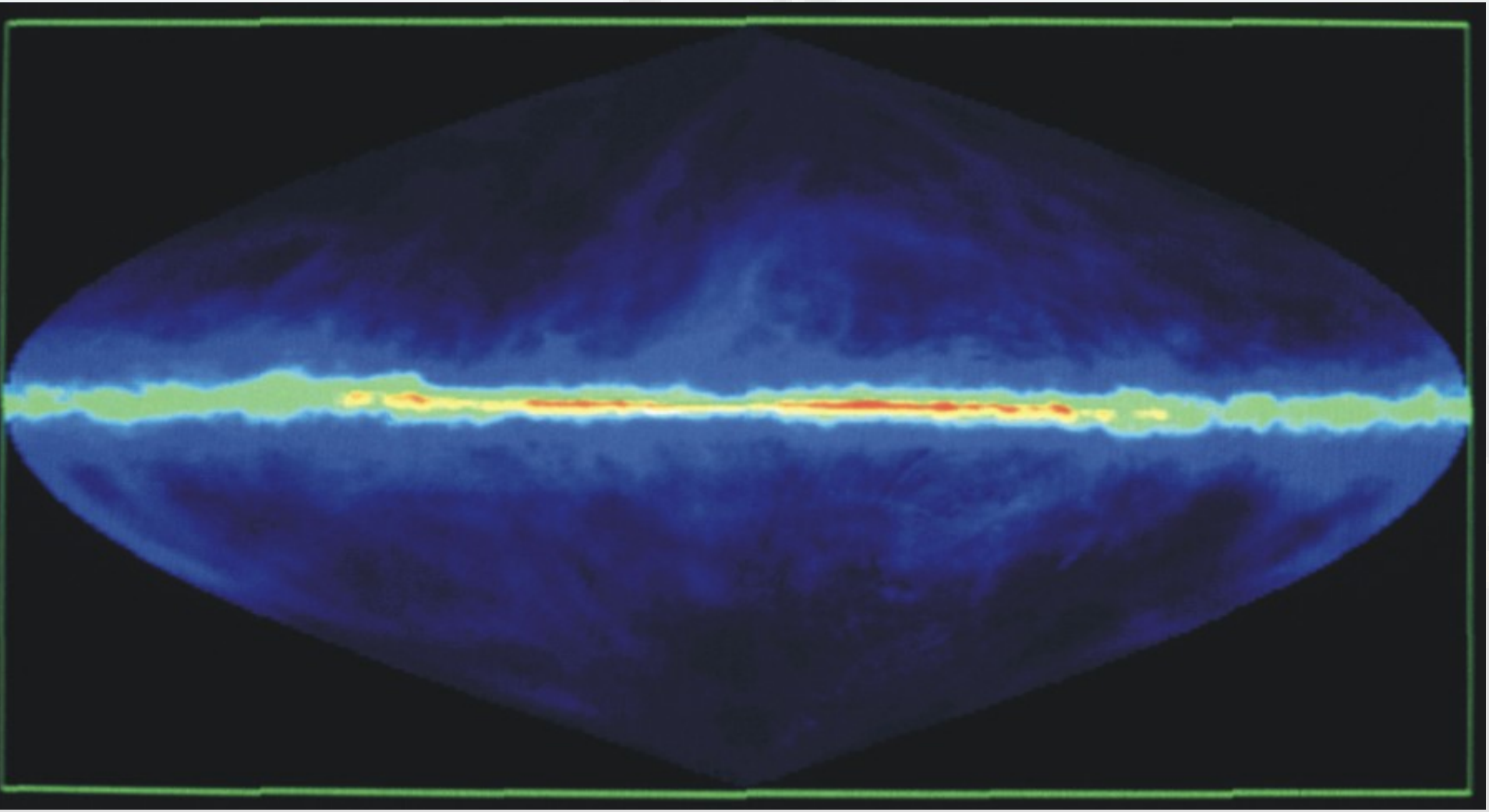


Cassiopiea A

Crab Nebula


Naval Research Laboratory
Wide-Field Radio Image of the Galactic Center
λ = 90 cm
(Kassim, LaRosa, Lazio, & Hyman 1999)
Sgr D HII
Sgr D SNR
SNR 0.9+0.1
Sgr B2
Sgr B1
New SNR 0.3+0.0
Threads
Arc
New Feature: The Cane
Background Galaxy
Threads
Sgr A
New thread: The Pelican
Sgr C
Coherent structure?
Snake
Mouse
Sgr E
SNR 359.0-00.9
SNR 359.1-00.5
~0.5°
~75 pc
~240 light years
Tornado (SNR?)
Image processing at the Naval Research Laboratory using DoD High Performance Computing Resources
Produced by N.E. Kassim, D.S. Briggs, T.J.W. Lazio, T.N. LaRosa, J. Imamura, & S.D. Hyman
Original data from the NRAO Very Large Array courtesy of A. Pedlar, K. Anantharamiah, M. Goss, & R. Ekers

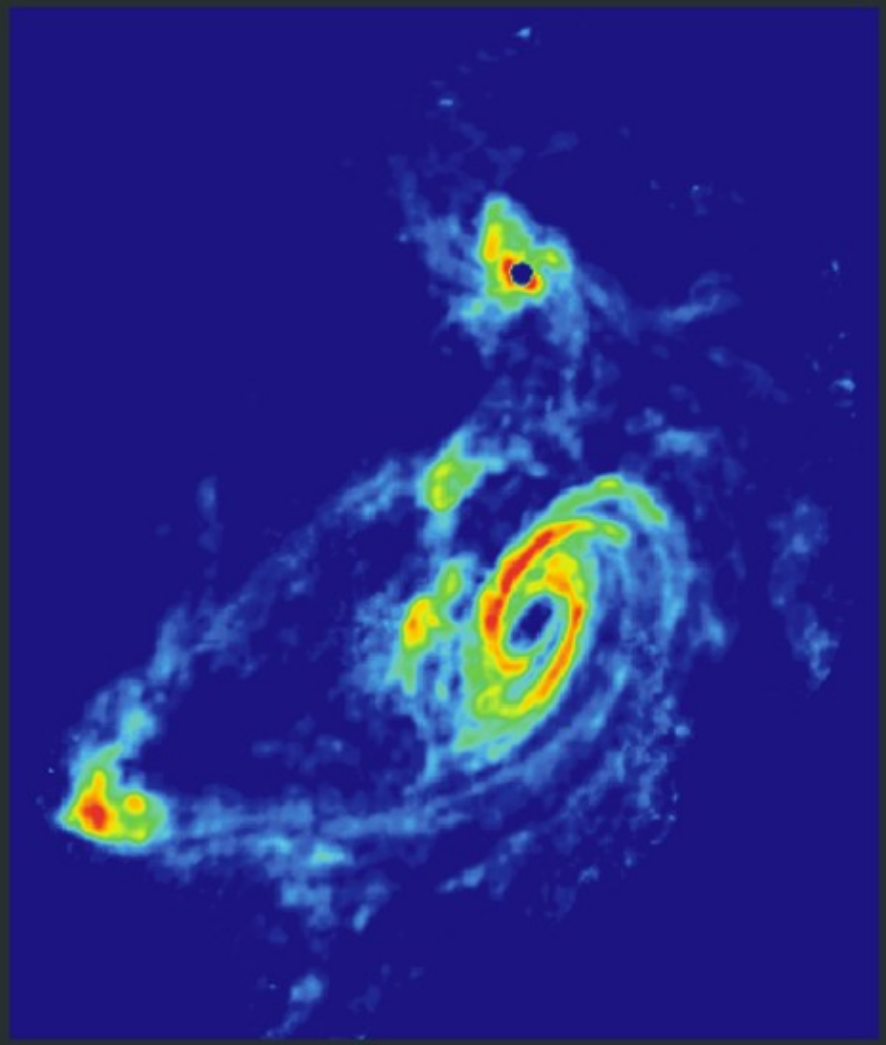
Neutral Hydrogen (HI) in galactic coordinates



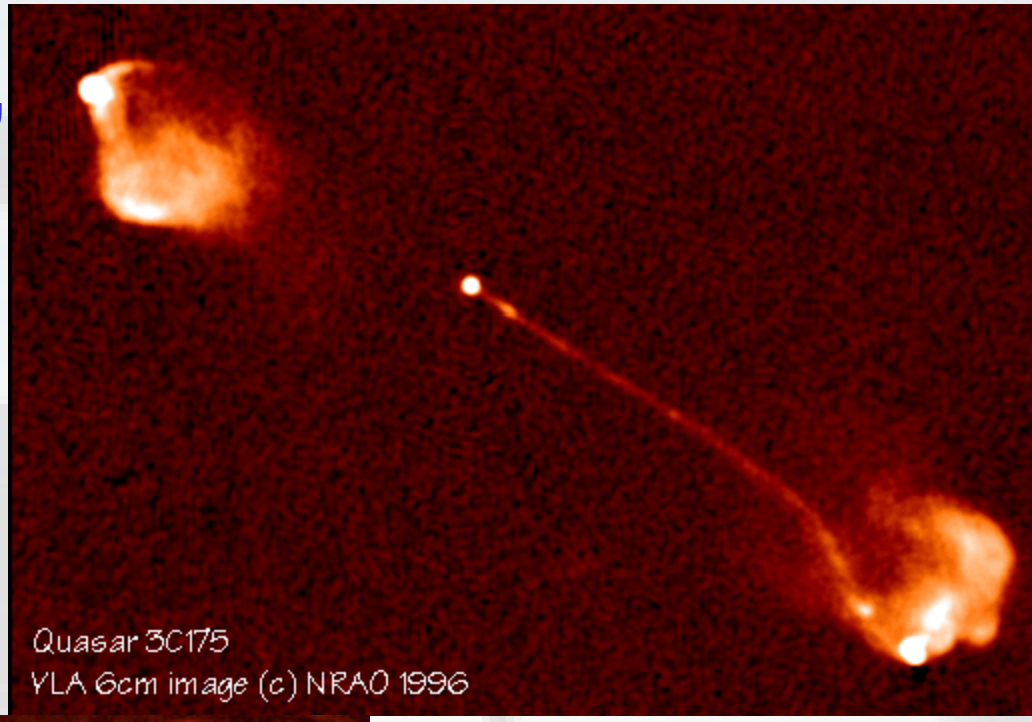
TIDAL INTERACTIONS IN M81 GROUP

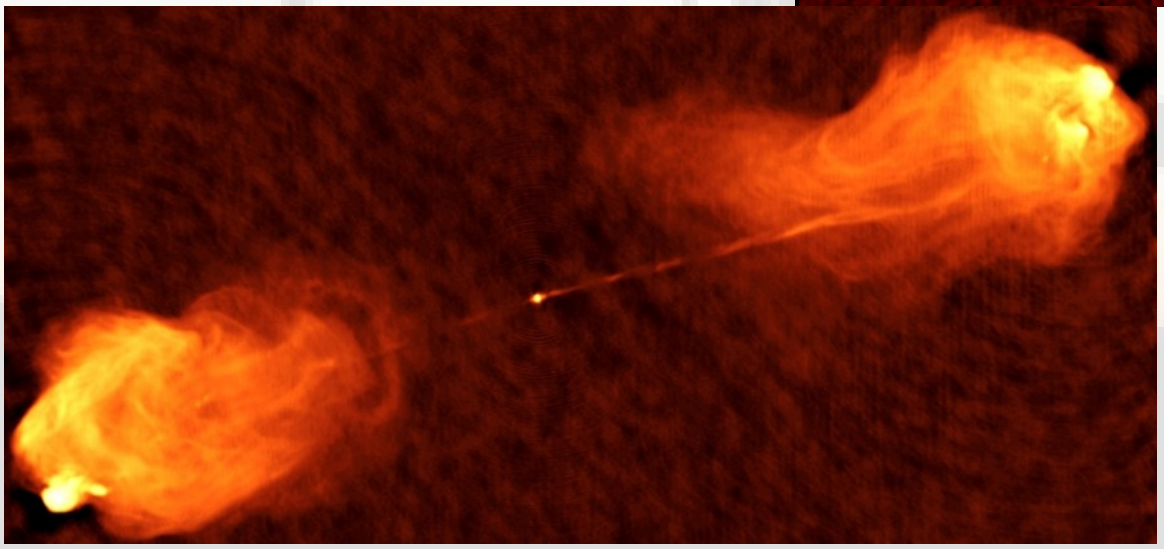
Stellar Light Distribution

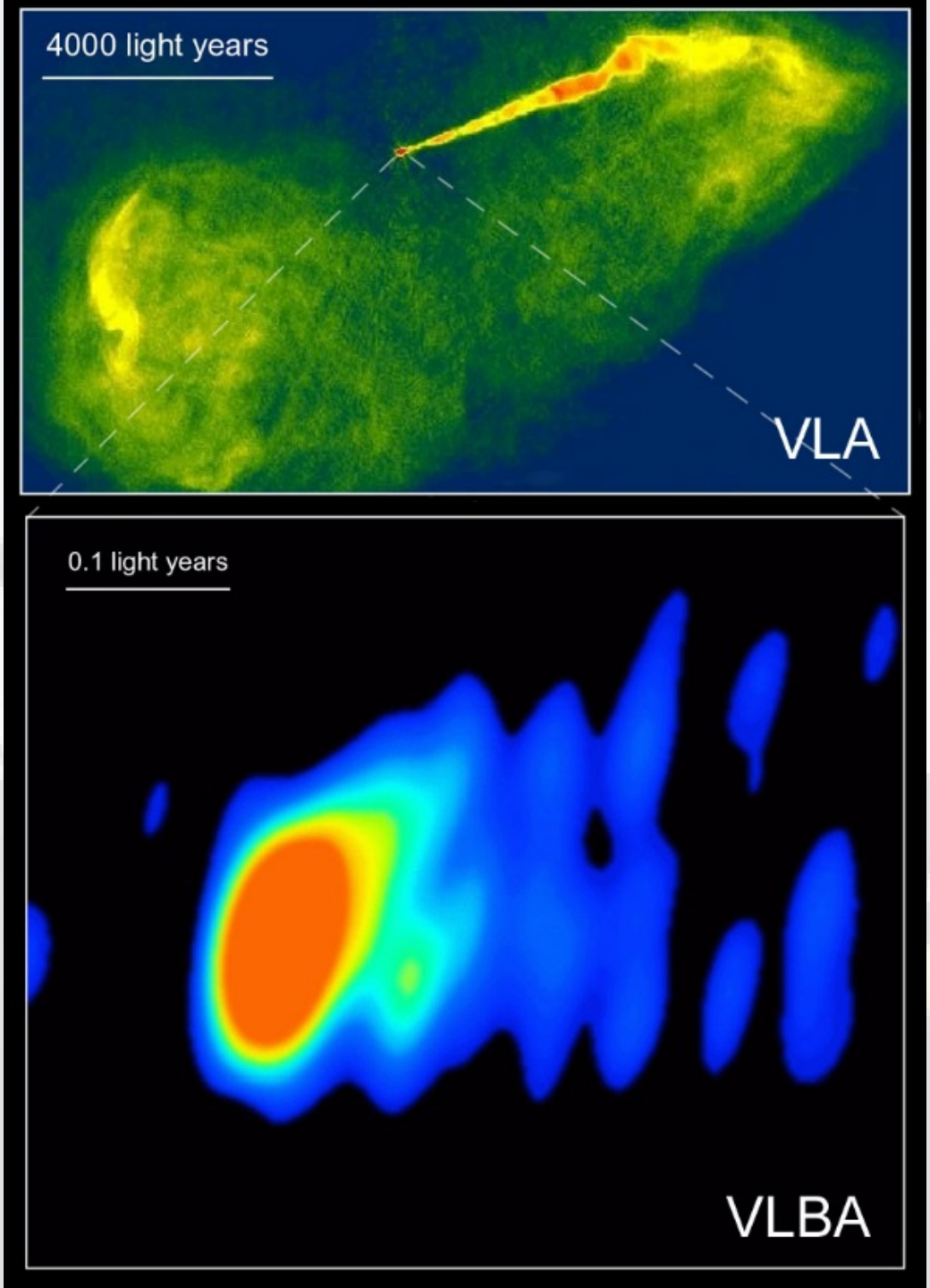
21 cm HI Distribution

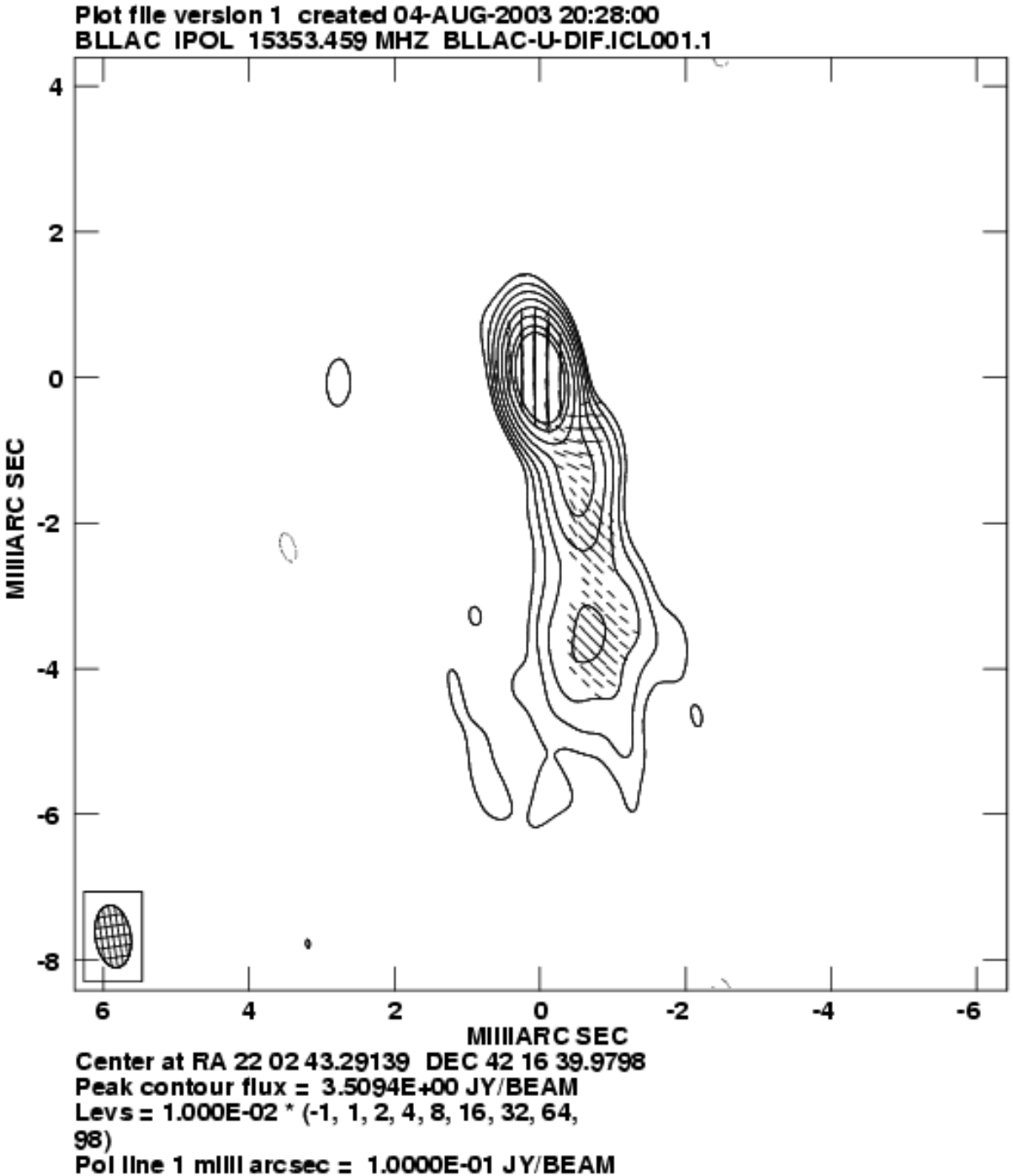


"Radio Galaxies"
Lobes are
100000 l-yr
across






4000 light years
VLA
0.1 light years
VLBA


Plot file version 1 created 04-AUG-2003 20:28:00
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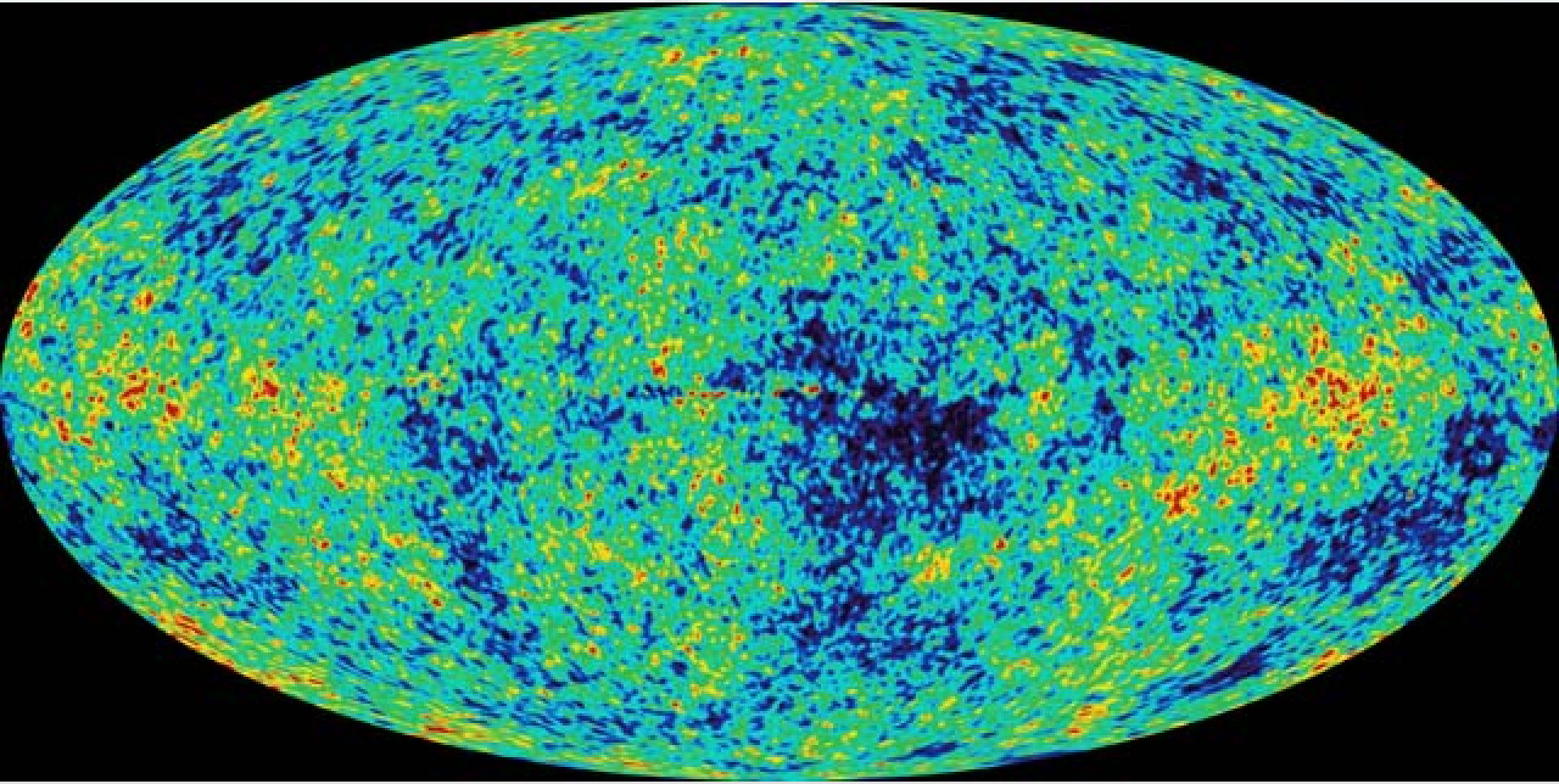
4
2
0
-2
-4
-6
-8
MILLIARC SEC
6
4
2
0
-2
-4
-6
MILLIARC SEC
Center at RA 22 02 43.29139 DEC 42 16 39.9798
Peak contour flux = 3.5094E+00 JY/BEAM
Levs = 1.000E-02 * (-1, 1, 2, 4, 8, 16, 32, 64,
98)
Pol line 1 milli arcsec = 1.0000E-01 JY/BEAM

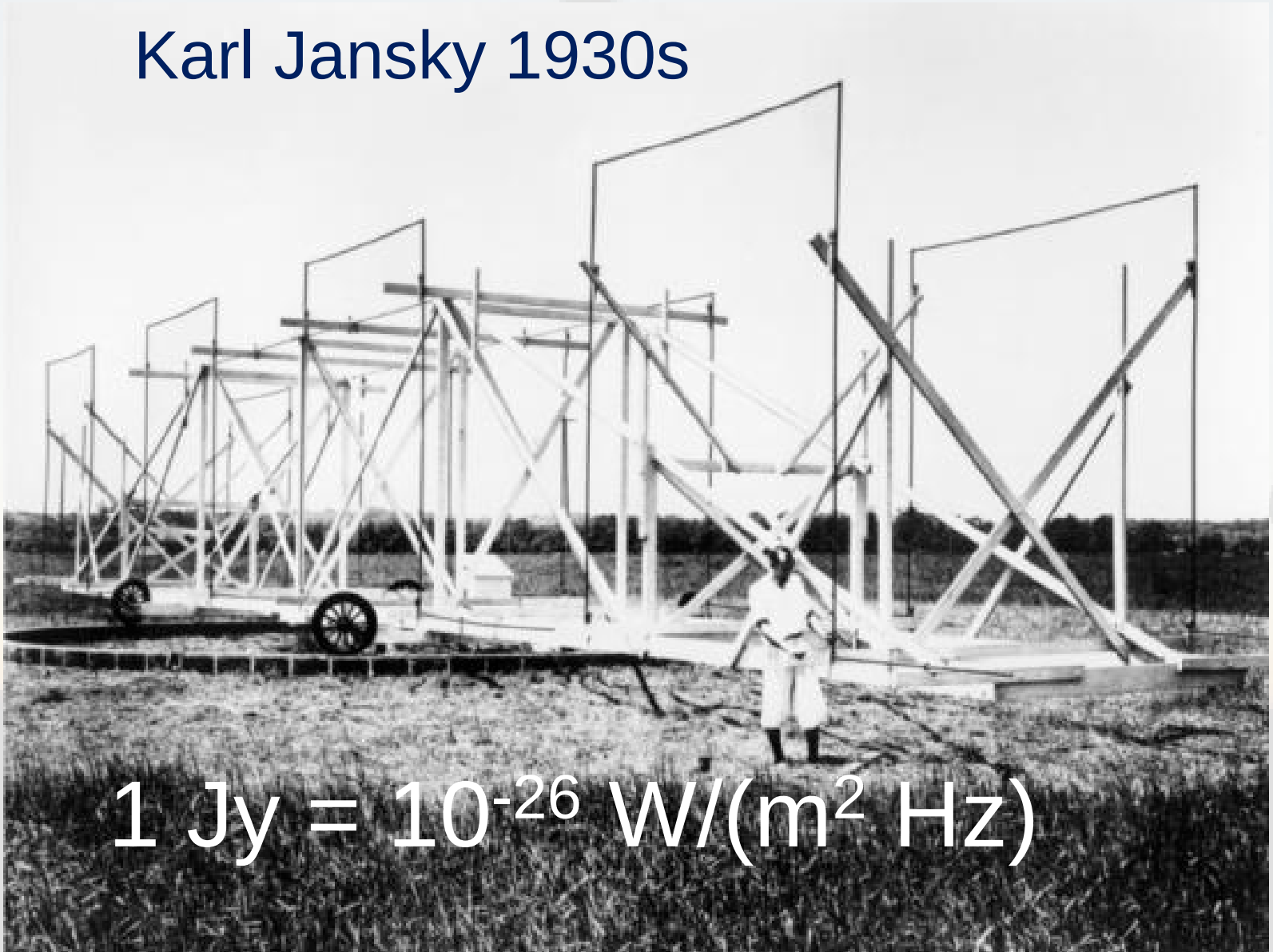

3C75 in
radio and
X-ray

Cosmic Microwave Radio Background



Telescopes

Karl Jansky 1930s

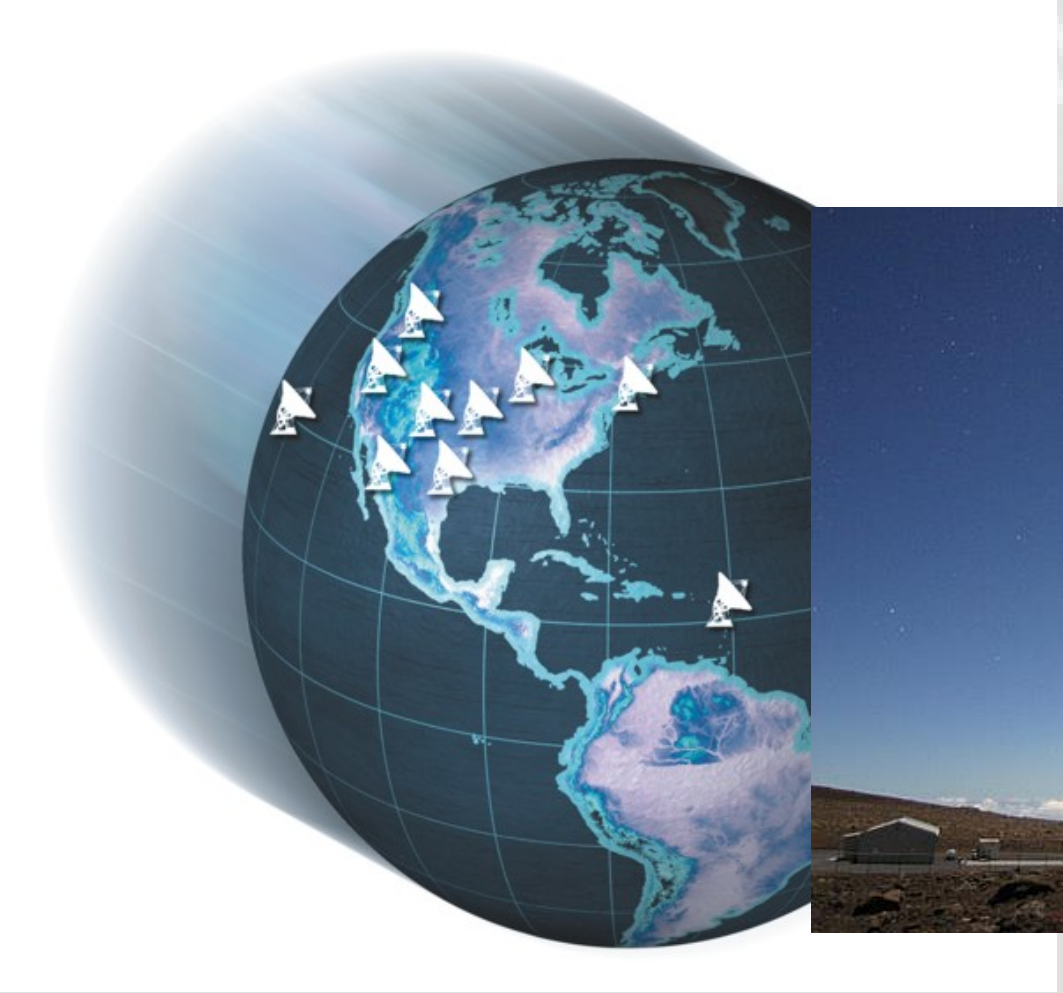


$1\ \mathrm{Jy} = 10^{-26}\ \mathrm{W/(m^2\ Hz)}$

Arecibo (Puerto Rico) 300m (1963)

The VLA in Socorro, NM (1975, upgraded 2010)

Very Long Baseline Array - VLBA (1994)



Robert C. Byrd Green Bank Telescope (2000) (110 m)


ALMA (Atacama Large Millimeter/Submillimeter Array)
2013


FAST: Five-hundred-meter Aperture
Spherical Telescope (2016)

How do we see the jets in AGN?

Recall from optics that the resolution of a telescope is

$\Theta = 1.22 \lambda/D$ where

λ is the wavelength of light

D is the diameter of the telescope

Resolutions

For a typical optical telescope:

$\lambda = 5 \times 10^{-7}$ m D = 1 m

$\Theta \cong 10^{-6}$ rad = 0.2” (arc seconds)

BUT the atmosphere blurs all point sources into seeing disks of > 1”.

How do we overcome poor resolution due to the long radio wavelengths?

With big telescopes like Arecibo?

300 m dish

(world's largest)

Resolution of Arecibo

$\lambda = 6 \times 10^{-2}$ m (6 cm)

D = 300 m

$\Theta \cong 10^{-4}$ rad = 20” (arc seconds)

(Compared to 1” for optical telescopes)

Interferometry does better!

Interferometry

An interferometer measures the Fourier Transform of the brightness distribution on the sky.

Ex) A musical signal hits your ear as a wave that can be expressed as P(t), or power as a function of time. But you could analyze it in terms of P(f), a function of frequency. Frequency and time are called conjugate variables, and the mathematics to get from one to another is the Fourier Transform. Likewise, sky brightness can be described as a function of the conjugate variable to position, called spatial frequency.

Fourier Transforms in Interferometry

We want I(x,y), the intensity as a function of position and measure V(u,v), the visibility as a function of spatial frequency. They are related by the Fourier Transforms:

$$I(x,y) = \iint V(u,v) e^{2\pi i(ux+vy)} du dv$$

$$V(u,v) = \iint I(x,y) e^{-2\pi i(ux+vy)} dx dy$$

Although I is real, V is complex

Interferometry

An interferometer uses connected antennas to measure the interference pattern, and the effective diameter of the telescope is the distance between the antennas.

Resolution of the VLA

$\lambda = 6 \times 10^{-2}$ m (6 cm)

D = 30000 m

$\Theta \cong 10^{-6}$ rad = 0.5” (arc second)

Already better than optical telescopes,

but why stop there...

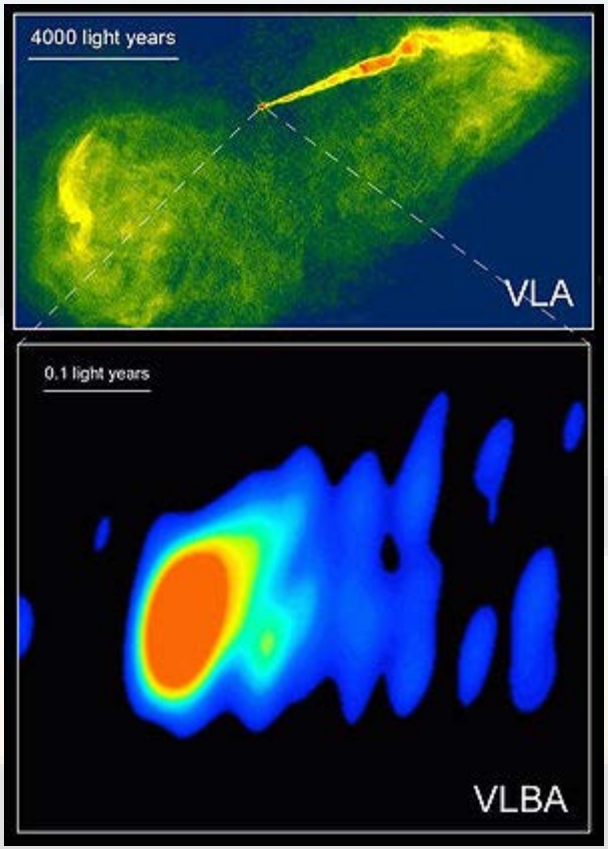
Resolution of the VLBA

$\lambda = 6 \times 10^{-2}$ m (6 cm)

$D = 10^{7}$ m

$\Theta \cong 10^{-9}$ rad = 0.001”

(milliarcseconds!!)



Radio Emission from Celestial Objects

Thermal Emission

- H II Objects: Free-Free emission

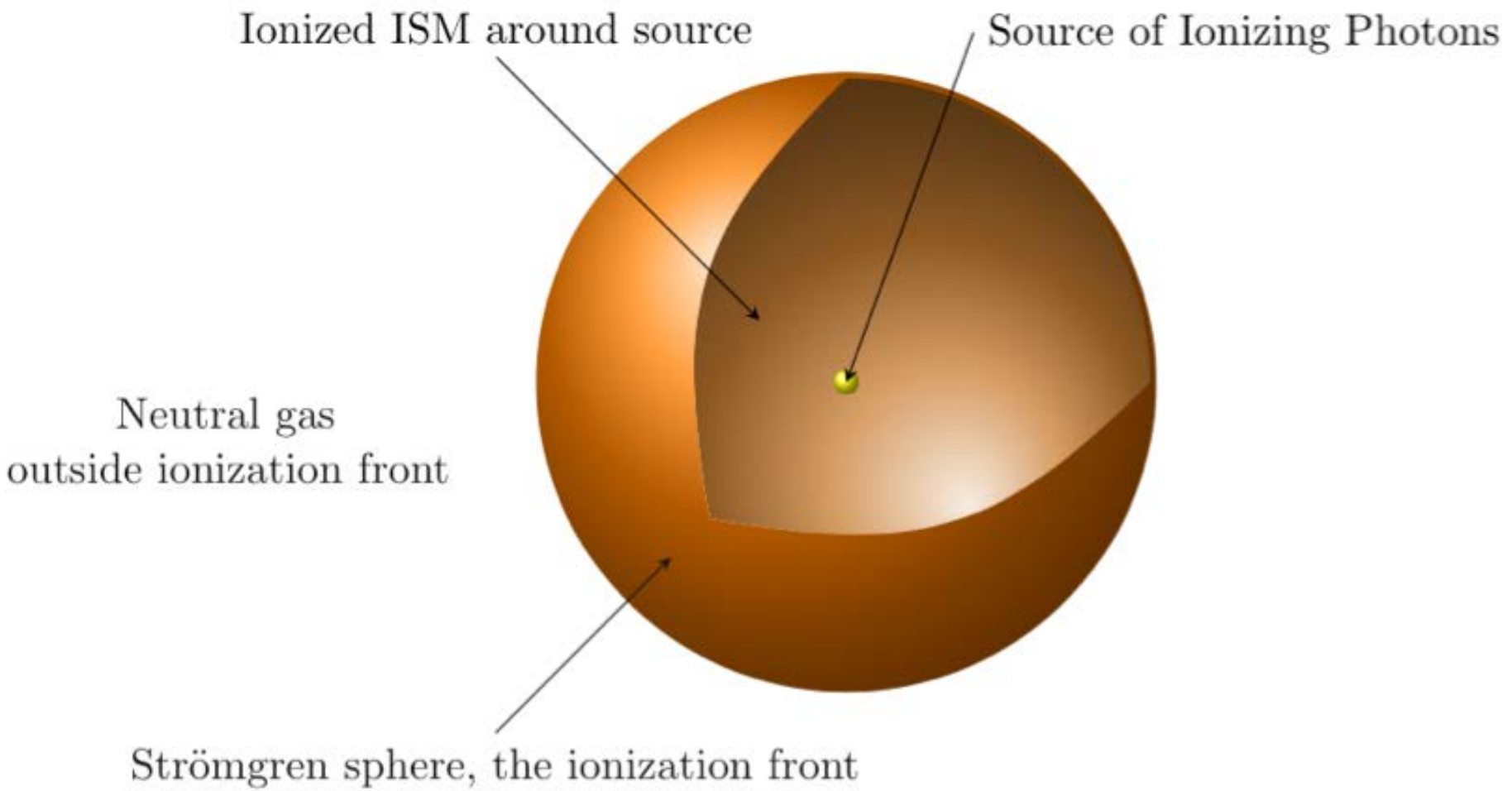
Non-Thermal Emission

- Synchrotron

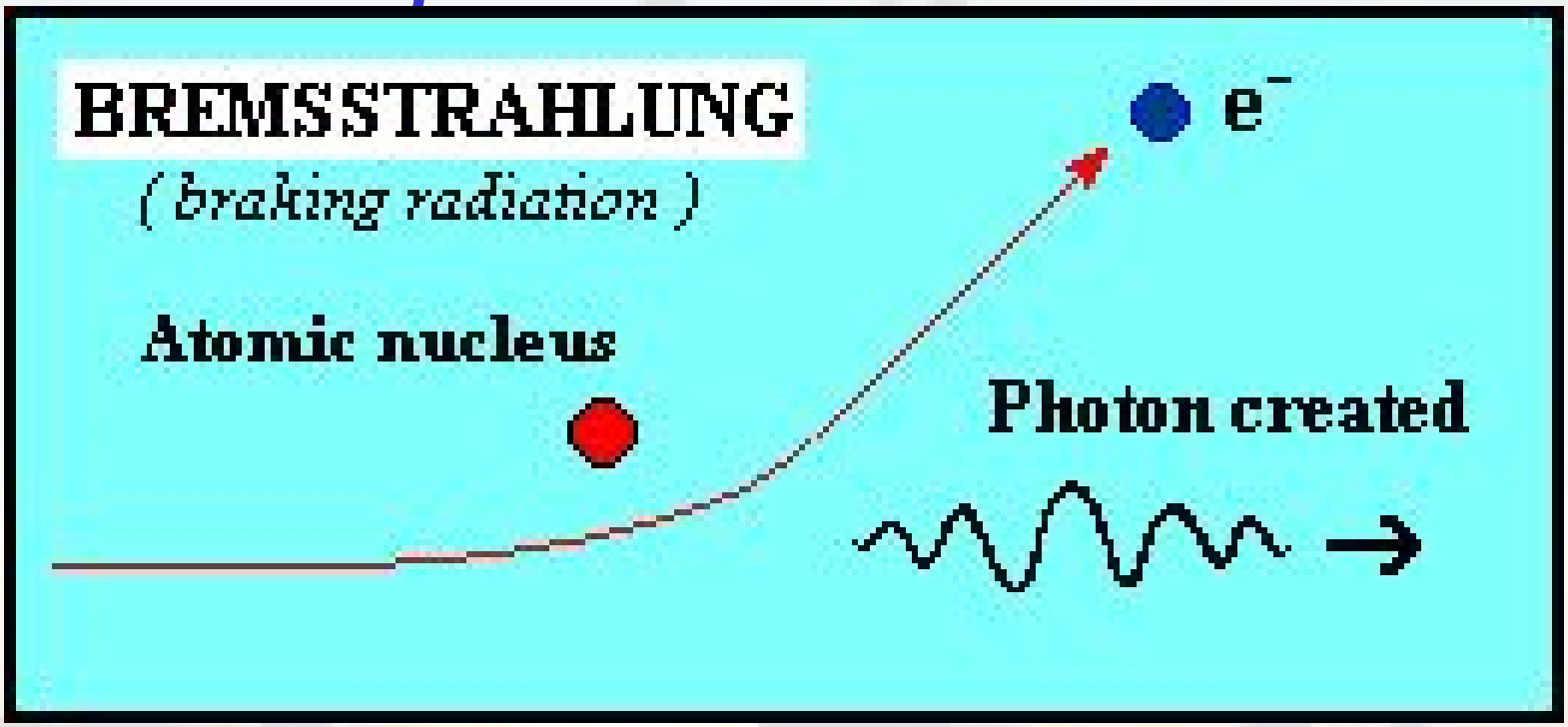
Spectral Lines

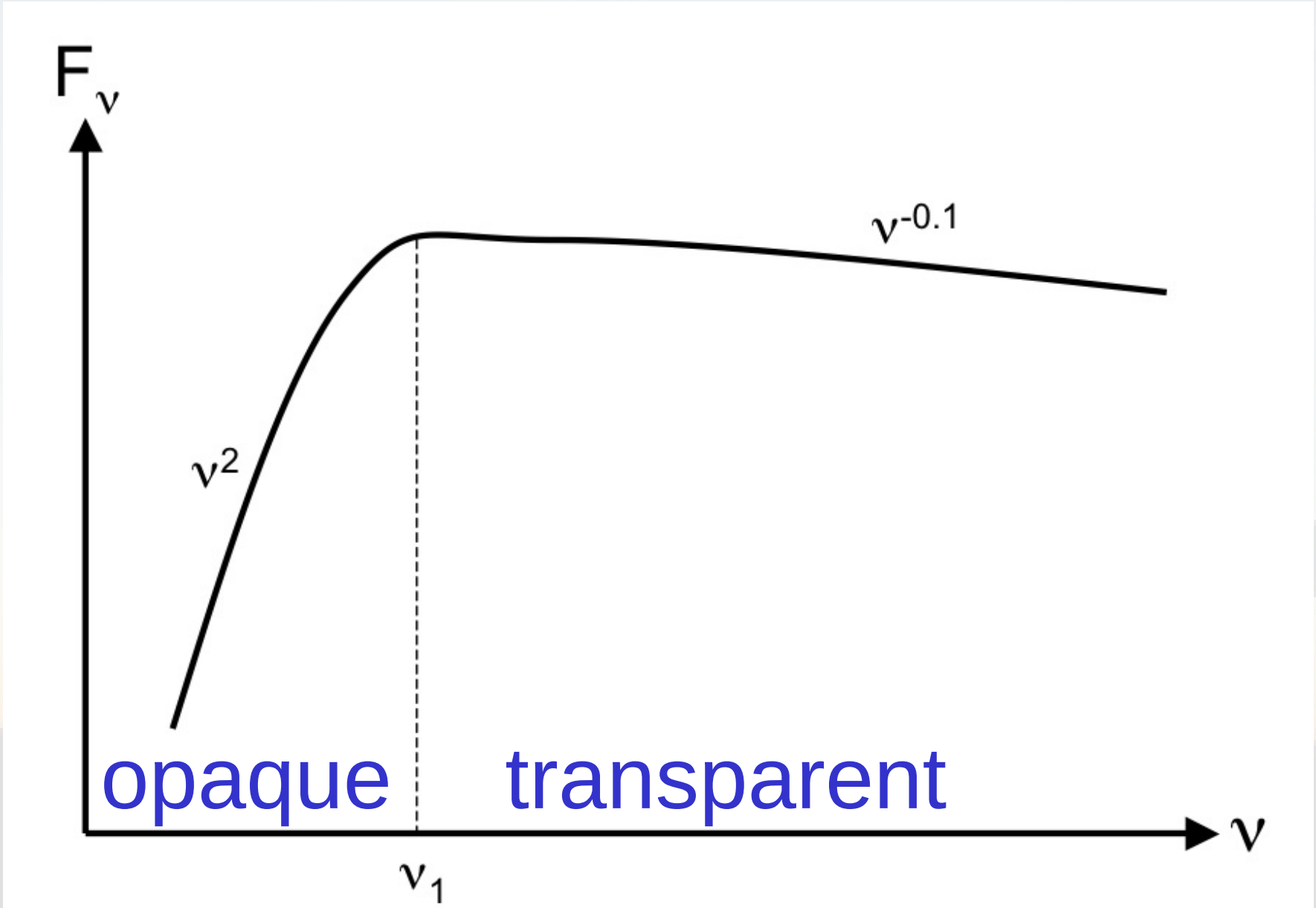
- HI, Molecules (CO)

H II regions

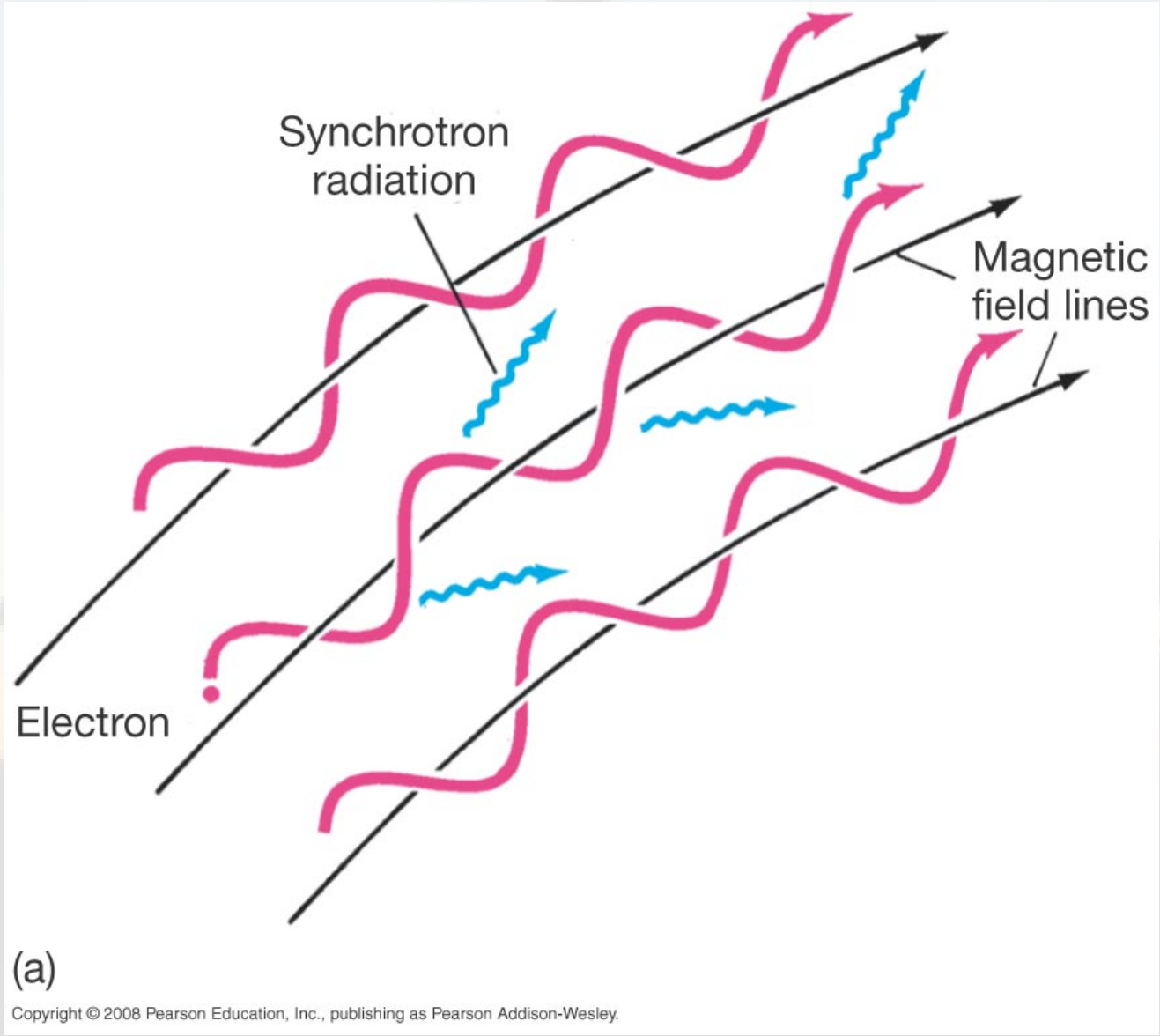

Ionized ISM around source
Source of Ionizing Photons
Neutral gas
outside ionization front
Strömgren sphere, the ionization front

Bremsstrahlung a.k.a Braking Radiation

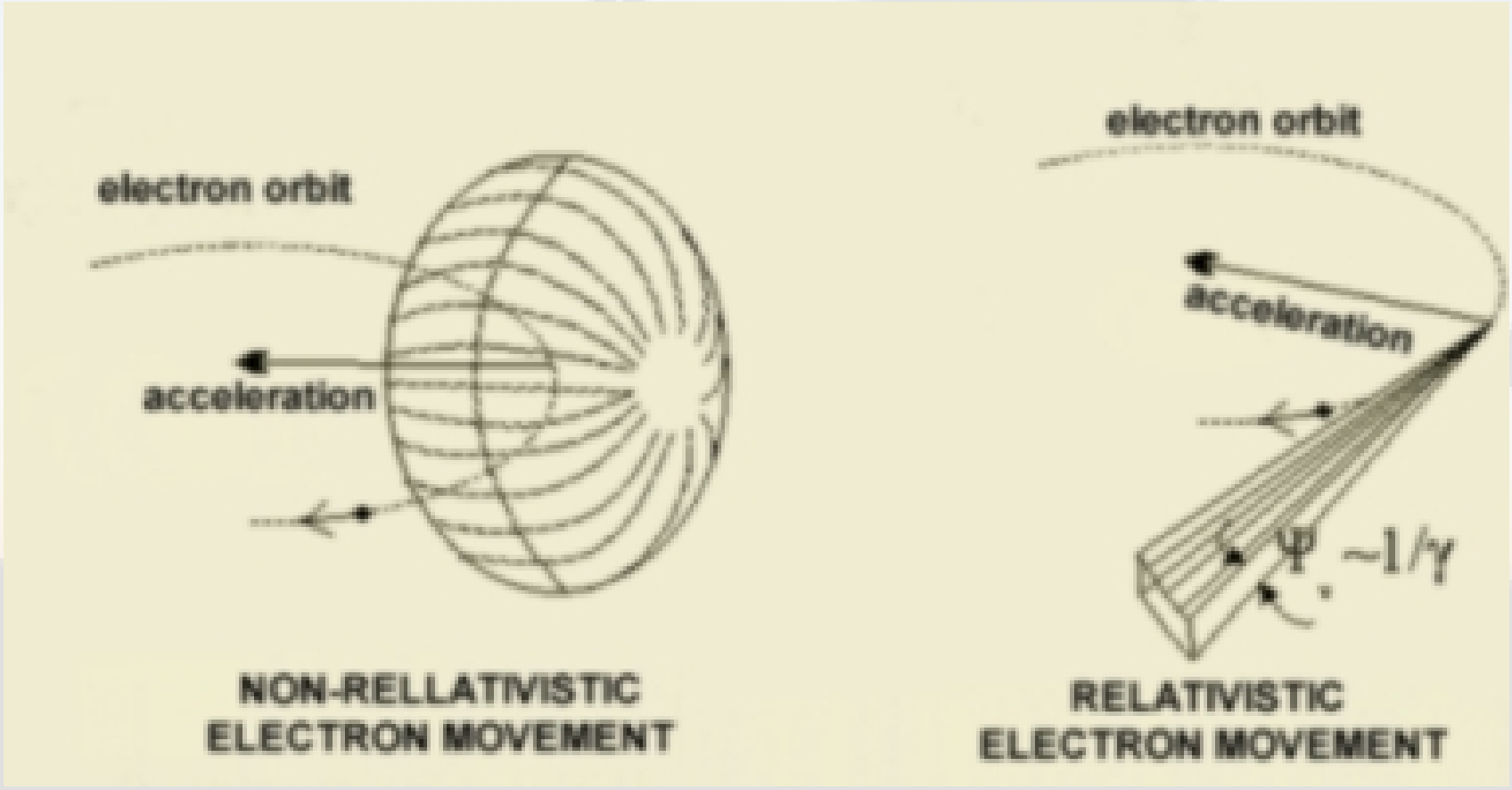



F_ν
$\nu^{-0.1}$
ν^2
opaque
transparent
ν
ν_1

Synchrotron Emission



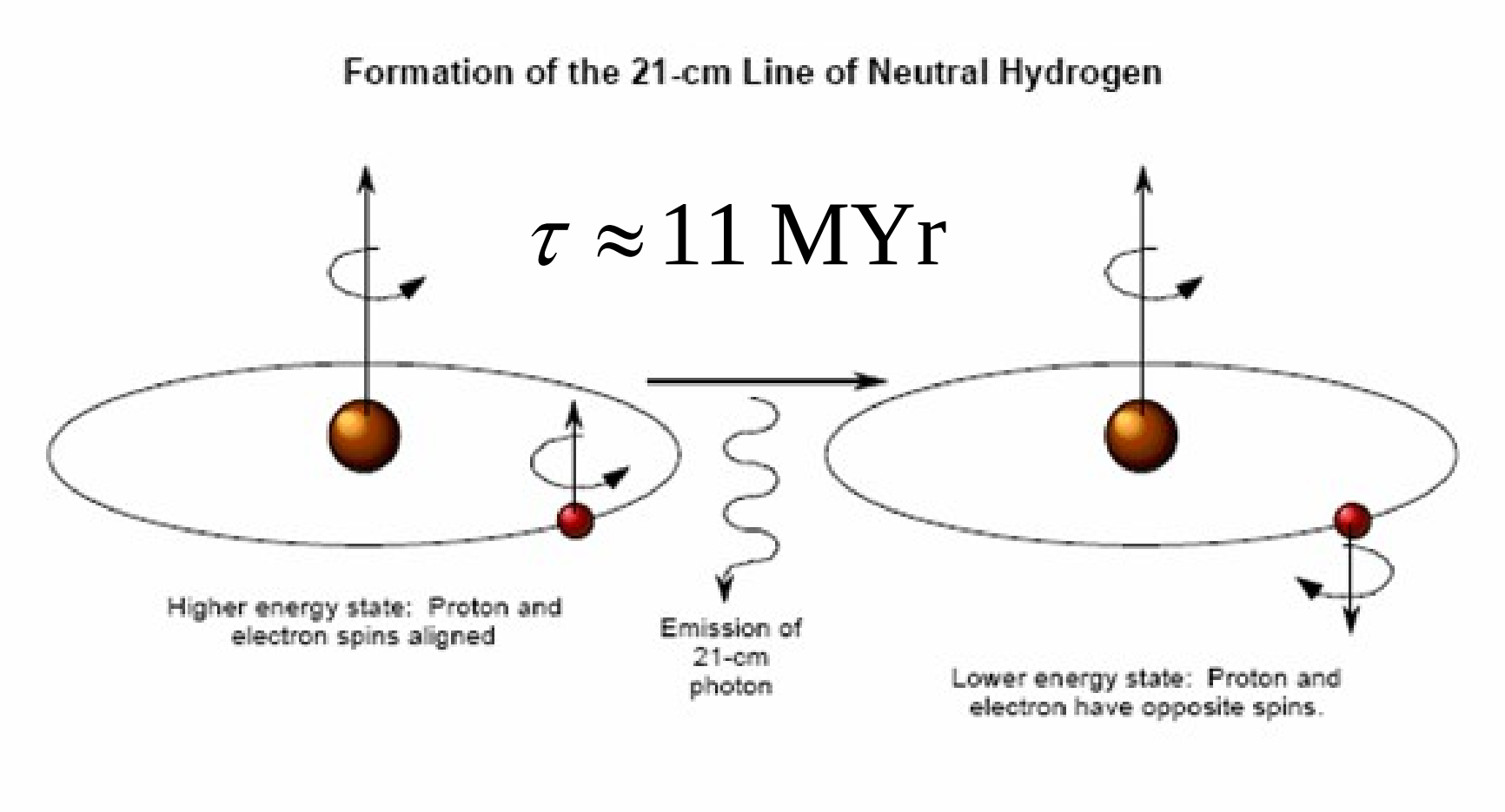
Relativistic electrons in magnetic fields



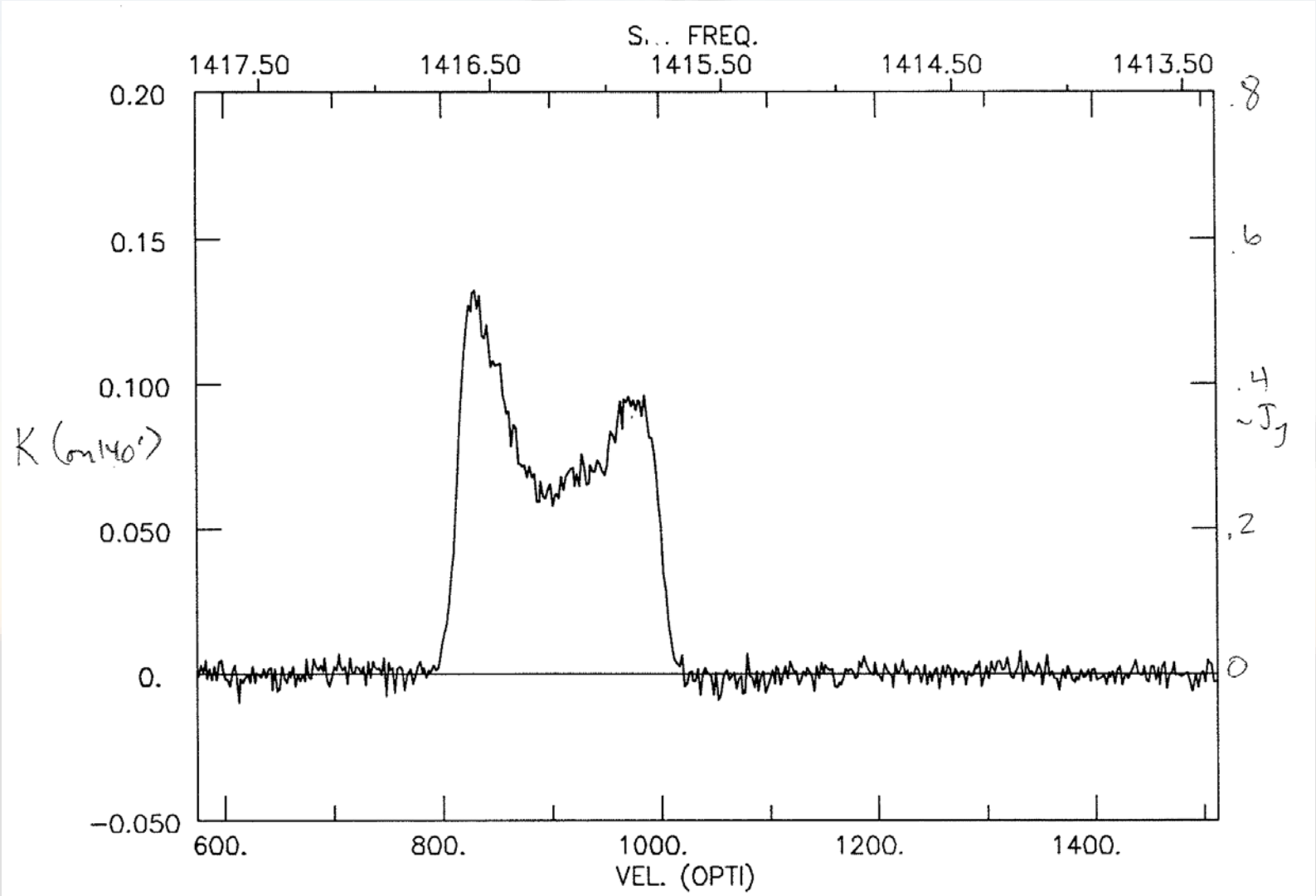
Spectral Lines

- Recombination (e.g. H 109α at 5 GHz)
- Molecular (e.g. $^{13}C^{16}O$ at 110.2 GHz)
- H I Hyperfine at 21 cm (1420 MHz)

21 cm <=> 1420 MHz



UGC 11707- spiral galaxy



Note to self: insert some grandiose comment about how radio astronomy is the bees knees here for a nice conclusion.