The Radio Sky at 4.85 GHz

- 4.85 GHz radio image
- 45 degrees wide
- brightest irregular sources are clouds of ionized hydrogen

The Radio Universe

Dr. Chuck Higgins
Middle Tennessee State University

- Supernovae remnants appear as faint radio rings
- Radio "stars" scattered over the sky - most are luminous radio galaxies or quasars (average distance > 5 x 10^9 ly)

- 4.85 GHz radio image
- 45 degrees wide
- brightest irregular sources are clouds of ionized hydrogen

The Radio Sky at 4.85 GHz

Outline

1. The Radio Sky and the EM Spectrum
2. Radio Telescopes
3. What We Learn and Major Discoveries
4. Sources of Radio Emission
5. Examples – Sun, Planets, Stars, Pulsars, Galaxies, etc.
6. Radio JOVE

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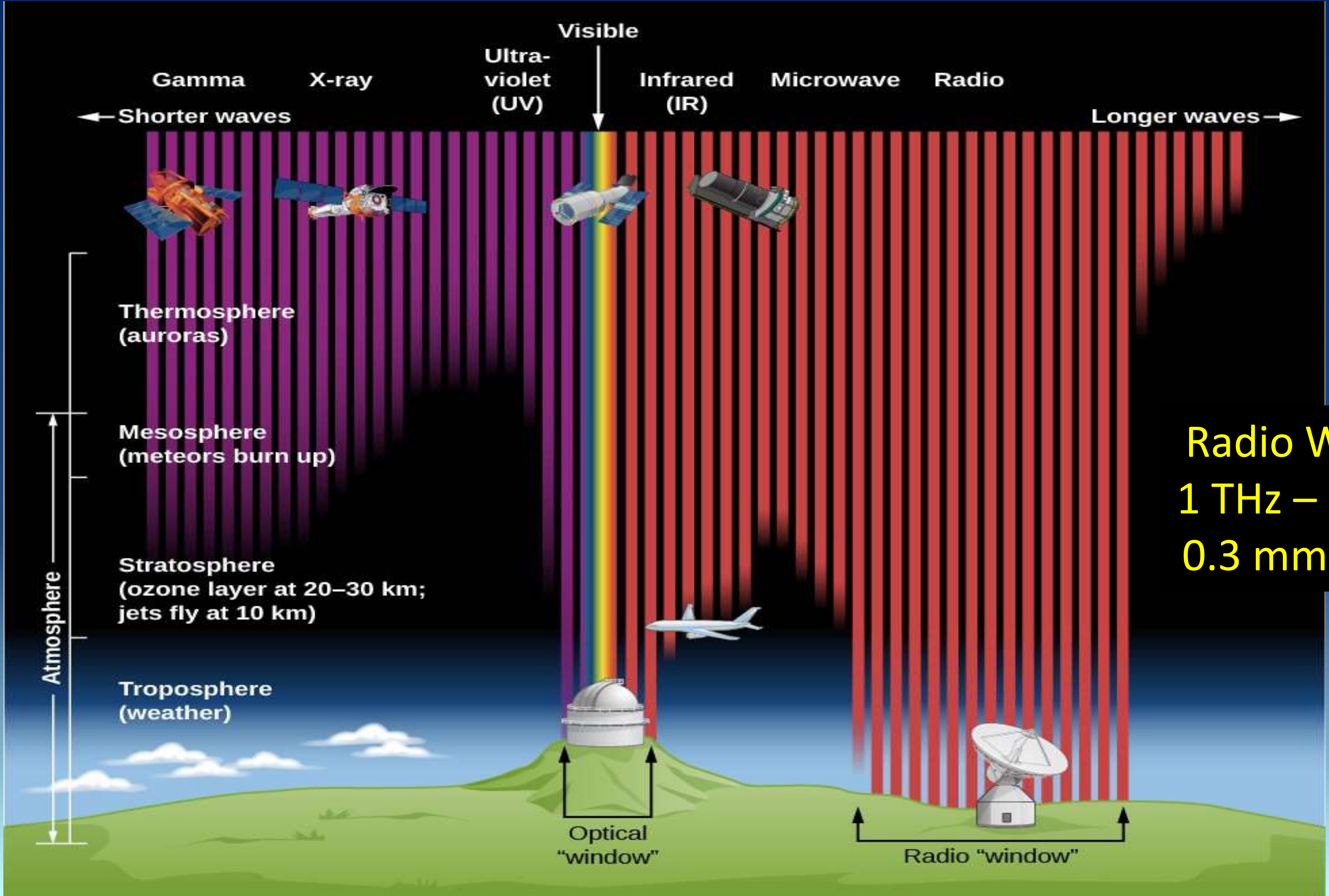
- Radio "stars" scattered over the sky - most are luminous radio galaxies or quasars (average distance > 5 x 10^9 ly)

Radio Astronomy

the study of radio waves originating outside Earth's atmosphere



Radio Window
1 THz – 10 MHz
0.3 mm – 30 m

Credit: Adapted from STScI/JHU/NASA

Radio Telescopes

Concept Drawing of the Square Kilometer Array, Australia

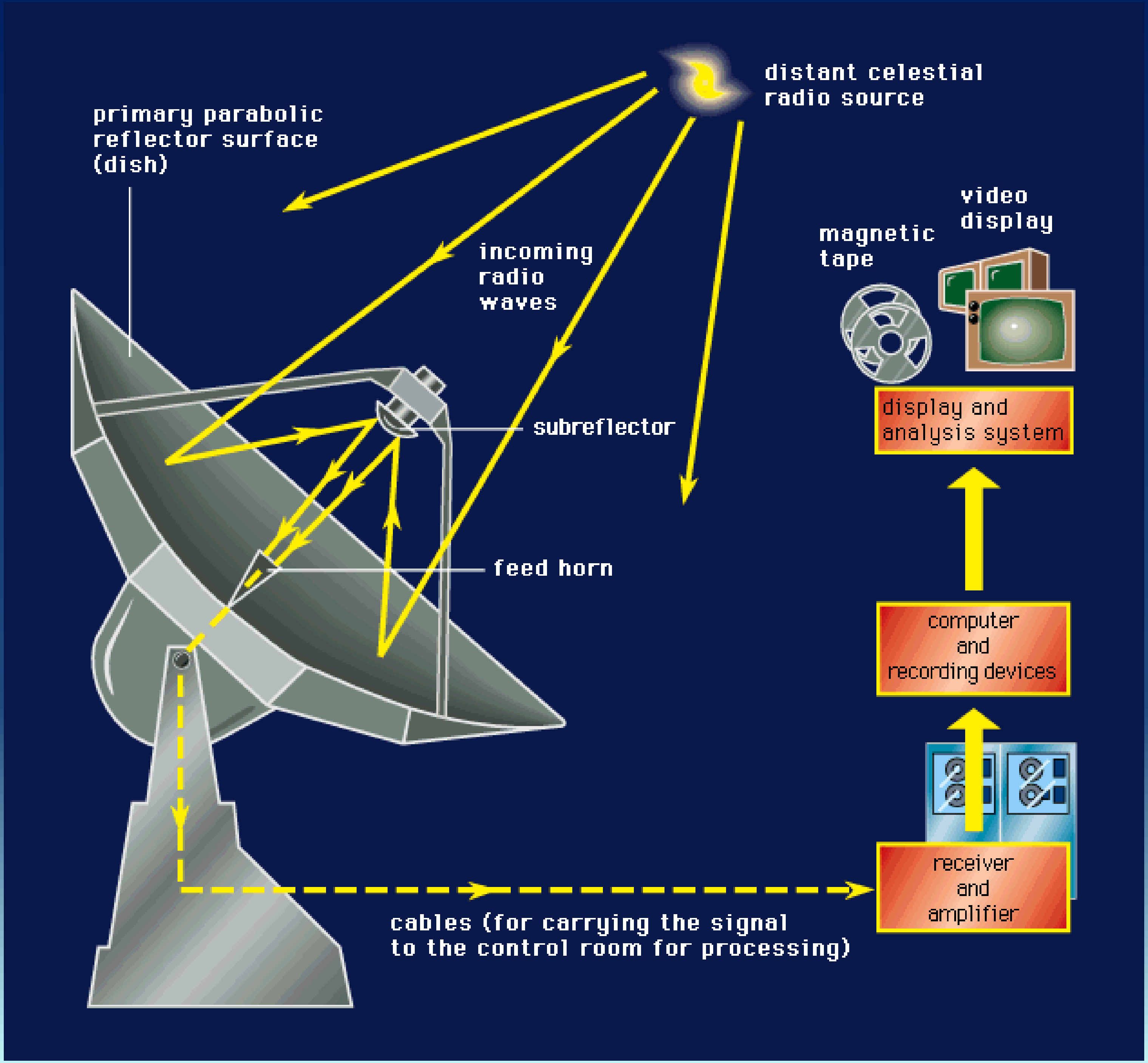
Green Bank Telescope (NRAO, NSF)

VLA, New Mexico (NRAO, NSF)

Itty Bitty Radio Telescope

Fast Radio Telescope (China)
500 m dish

Radio Telescopes



Radio Waves

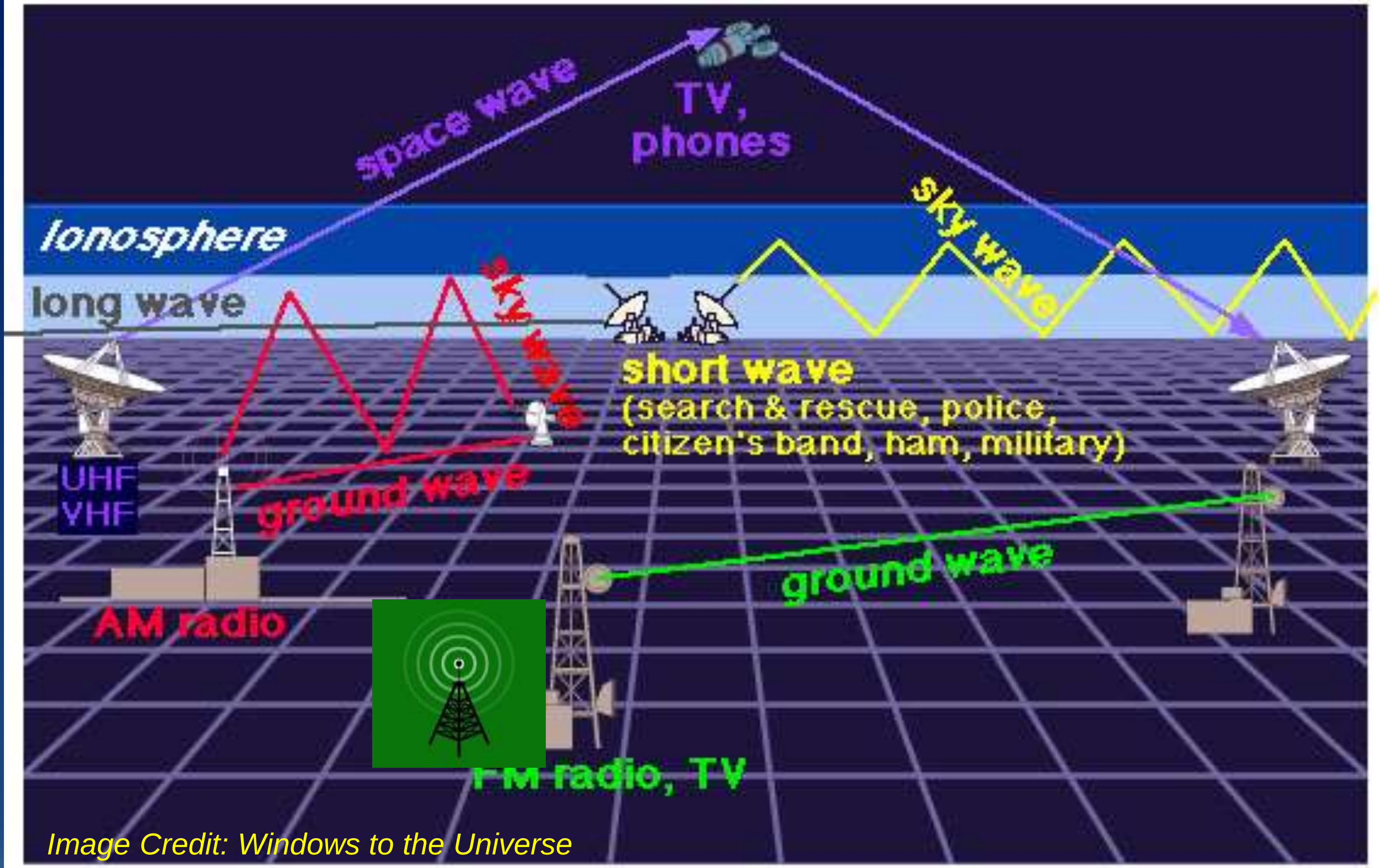
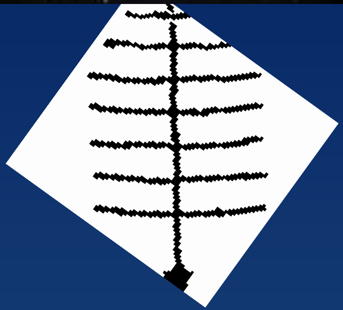


Image Credit: Windows to the Universe



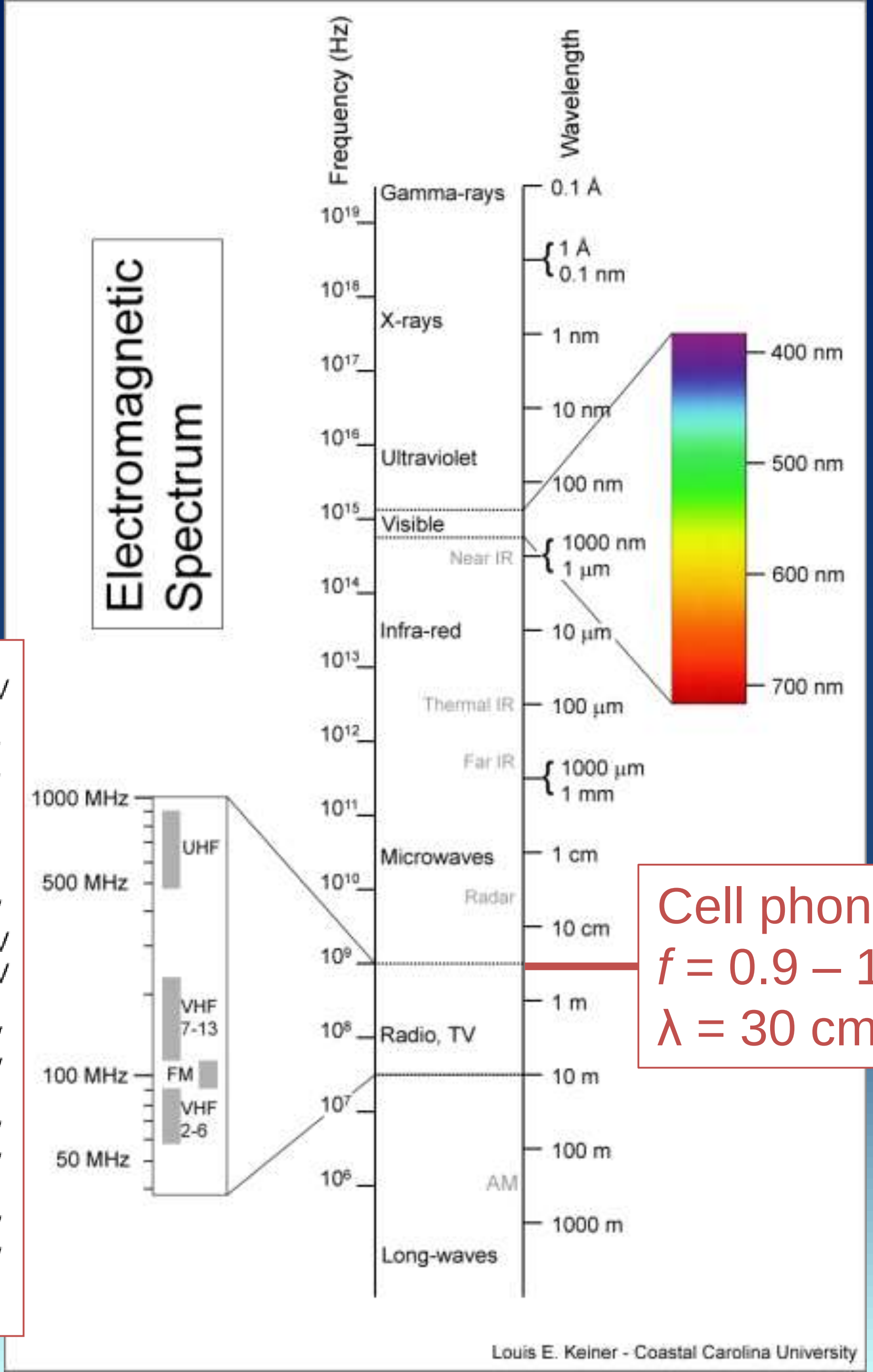
Radio waves = electromagnetic waves generally caused by moving charged particles.
Sources:
1) human-made electrical equipment: sparks, radios, generators, phones, etc.
2) natural radio waves: lightning, Earth's ionosphere, planets, Sun, stars, pulsars, galaxies, black holes, and the Universe!

Radio Bands

HF: below 30 MHz decameter (3 - 30 MHz)
Shortwave radios, CBs
AM band (0.5 - 1.7 MHz)
VHF: 30-300 MHz meterwave (TV/FM)
UHF: 300 – 3000 MHz decimeter
(phones, LAN, cable TV, microwave ovens, GPS)
Microwave: 1000-30,000 MHz
SHF: microwave (3 - 30 GHz) radars
EHF: millimeter (30 - 300 GHz)
Infrared: sub-millimeter (300 - 700 GHz)

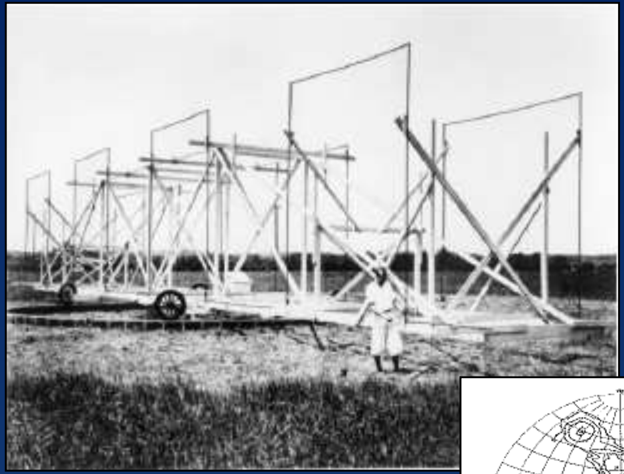
Microwave Bands
L-band ~ 20 cm
S-band ~ 10 cm
X-band ~ 3 cm
Ku(or U)-band ~ 2 cm
K-band ~ 1 cm

CLASS	FREQUENCY	WAVELENGTH	ENERGY
	300 EHz	1 pm	1.24 MeV
Y	30 EHz	10 pm	124 keV
HX	3 EHz	100 pm	12.4 keV
SX	300 PHz	1 nm	1.24 keV
	30 PHz	10 nm	124 eV
EUV	3 PHz	100 nm	12.4 eV
NUV	300 THz	1 μm	1.24 eV
NIR	30 THz	10 μm	124 meV
MIR	3 THz	100 μm	12.4 meV
FIR	300 GHz	1 mm	1.24 meV
EHF	30 GHz	1 cm	124 μeV
SHF	3 GHz	1 dm	12.4 μeV
UHF	300 MHz	1 m	1.24 μeV
VHF	30 MHz	10 m	124 neV
HF	3 MHz	100 m	12.4 neV
MF	300 kHz	1 km	1.24 neV
LF	30 kHz	10 km	124 peV
VLF	3 kHz	100 km	12.4 peV
VF/ULF	300 Hz	1 Mm	1.24 peV
SLF	30 Hz	10 Mm	124 feV
ELF	3 Hz	100 Mm	12.4 feV



Cell phones
$f = 0.9 – 1.9$ GHz
$\lambda = 30$ cm

History of Radio Astronomy



1930s

1932 – Karl Jansky, extraterrestrial "hiss" (MW at 20 MHz)

1938 – Grote Reber, maps the Galaxy at 160 MHz (non-thermal emission) ["Controversial" paper published in 1940]

1940s

- 1942 Hey and Southwood - intense solar radio interference
- 1944 Oort, van de Hulst predict the 21-cm line of H
- 1945 end of WWII – radio telescopes built in Holland, England, and Australia (Interferometers)
- radar reflections off the Moon
- Cygnus A and Cassiopeia A sources identified
- 1949 optical and radio sources identified

1950s

- synchrotron mechanism proposed
- 1951 Ewen and Purcell find the 21-cm line of H
- 1955 Radio emission from Jupiter accidentally discovered
- Radar studies of planets and the 1st satellite!

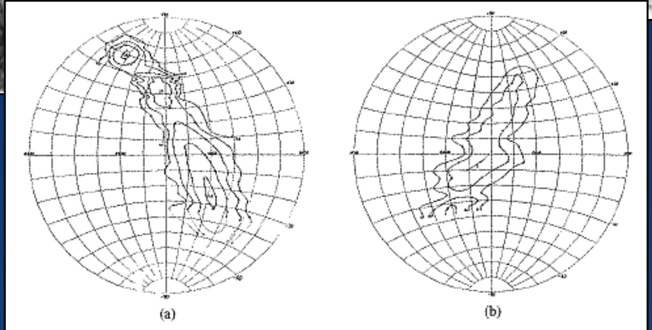


Fig. A3.1. Reber's 1944 map of the radio sky.

1960s

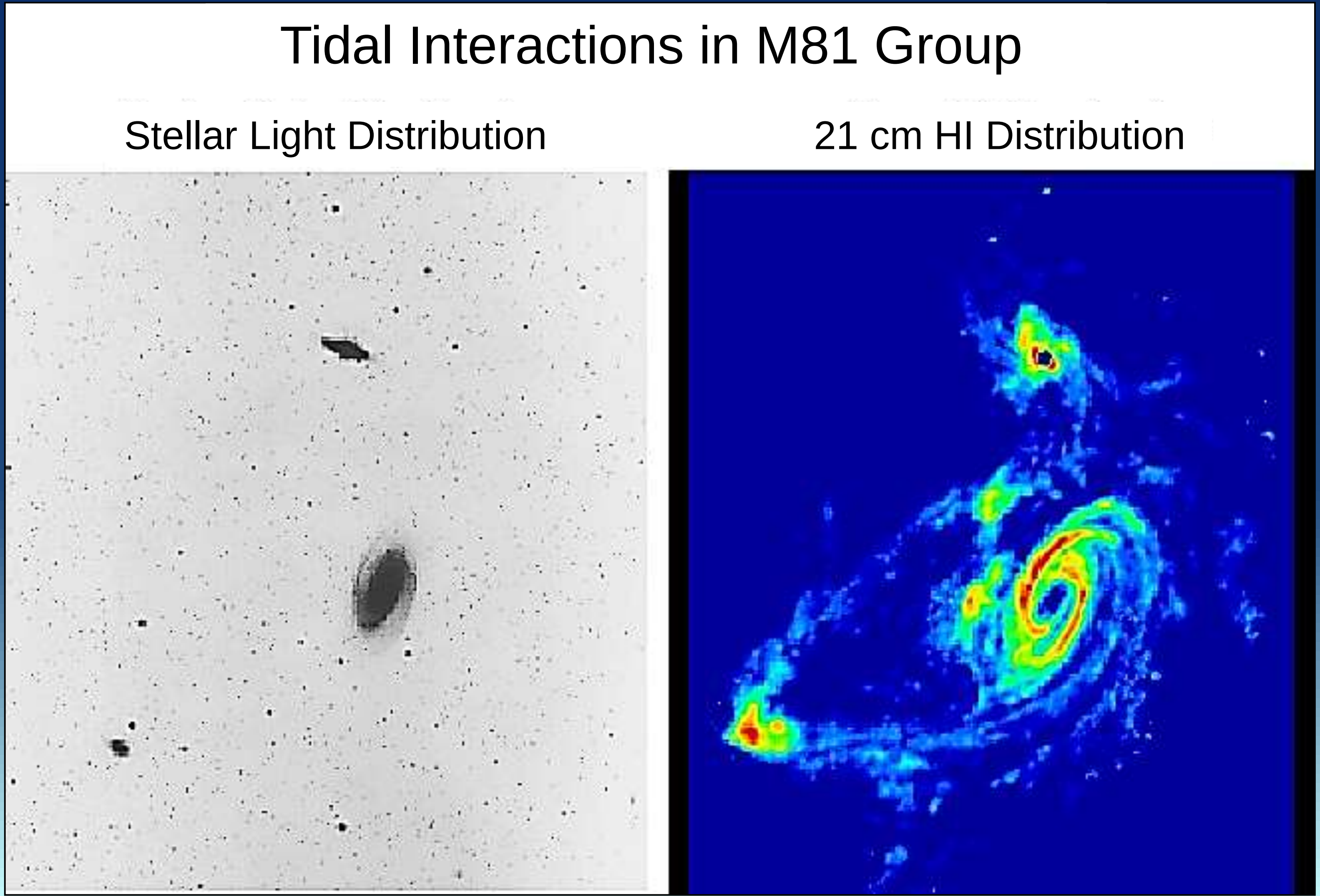
- Quasars discovered
- SETI begins
- Interstellar molecular lines
- 1965 Cosmic microwave background
- 1967 Pulsars discovered

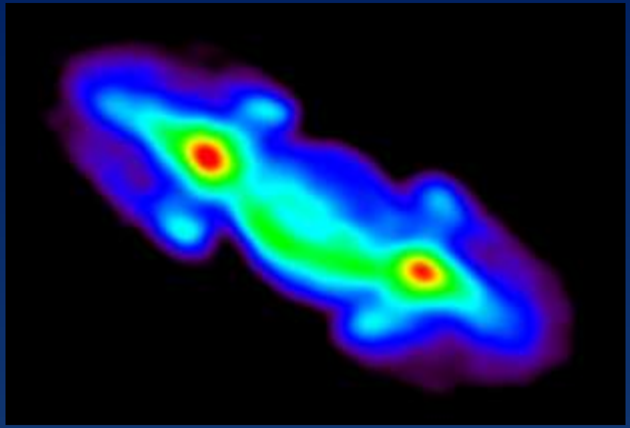
1970s, 1980s, 1990s, 2000s

Technology and large arrays

Why Radio Astronomy?

- Some objects are “invisible” at Earth and in space
- We can learn something new about the universe



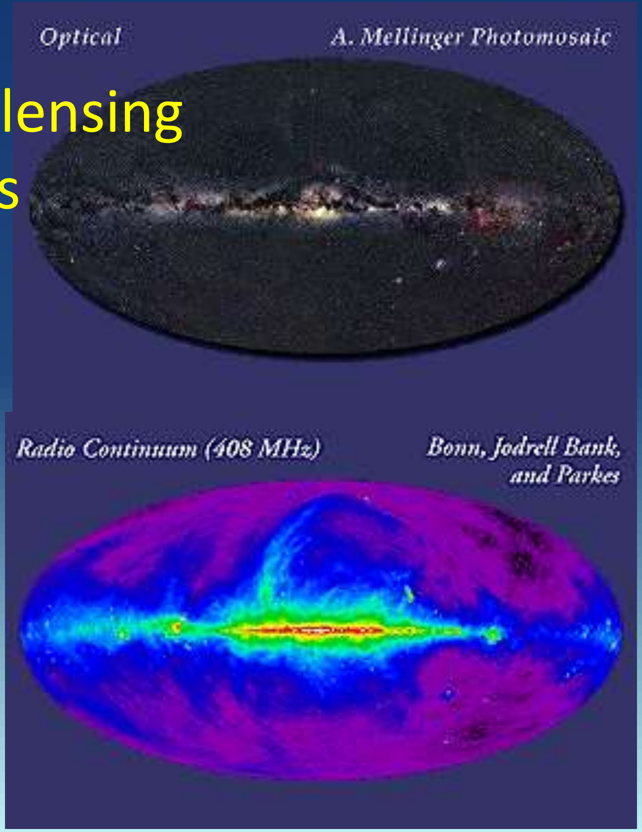


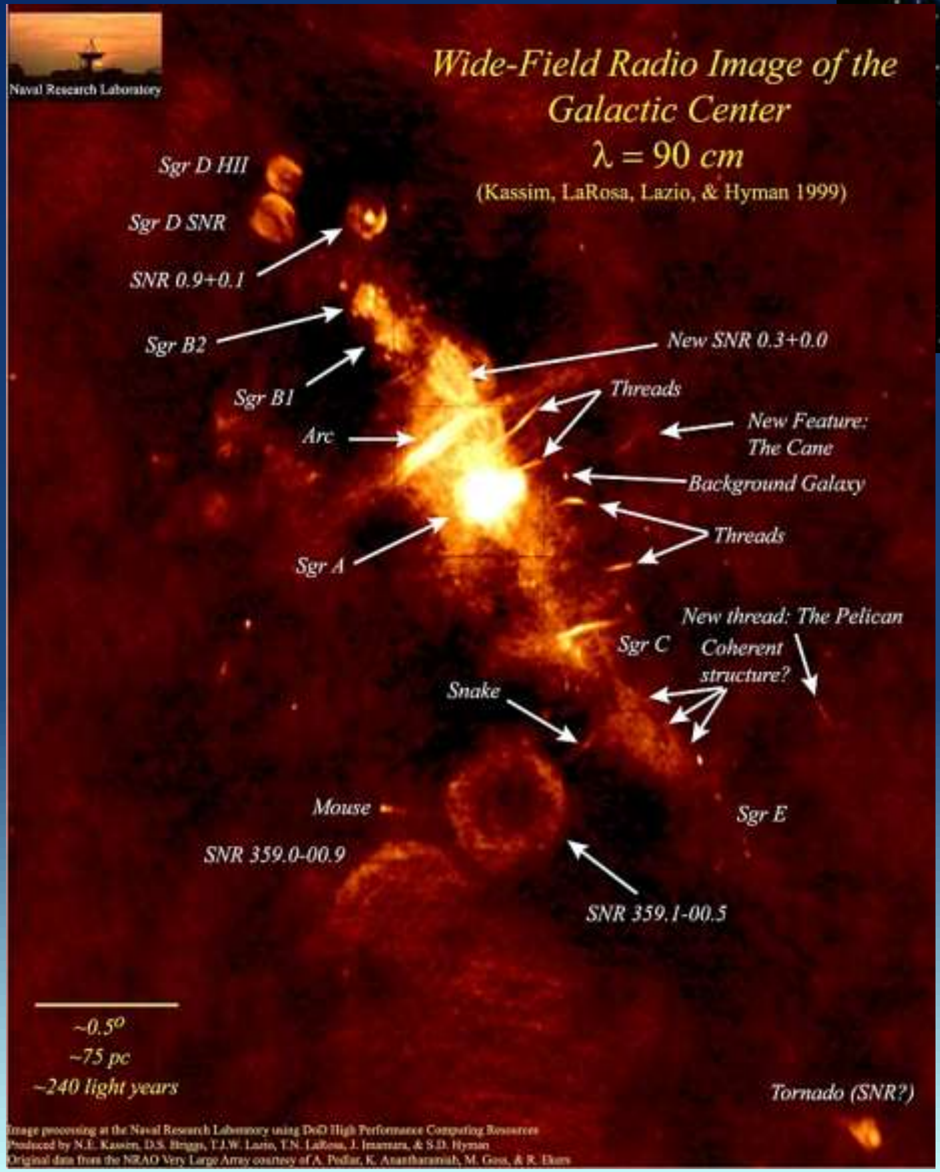
Jupiter (GHz)

M81
Galaxy Group

Major Discoveries

- Radio Galaxies – powered by black holes
- Cosmic Microwave background
- Gravitational radiation
- Cold interstellar gas
- Neutron stars (pulsars)
- Exoplanets
- Gravitational lensing
- Gravity Waves

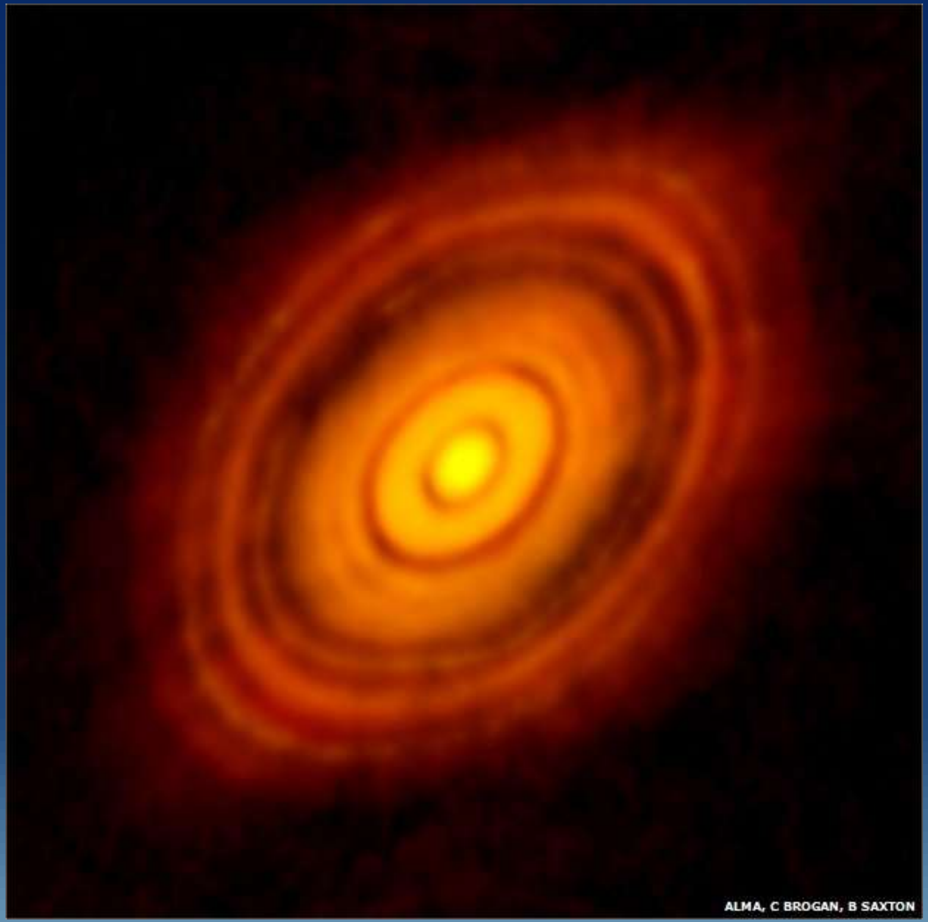




The Galaxy and galactic center

Centaurus A

Protoplanetary Disk



ALMA image of HL Tau (near the Pleiades) and its protoplanetary disk

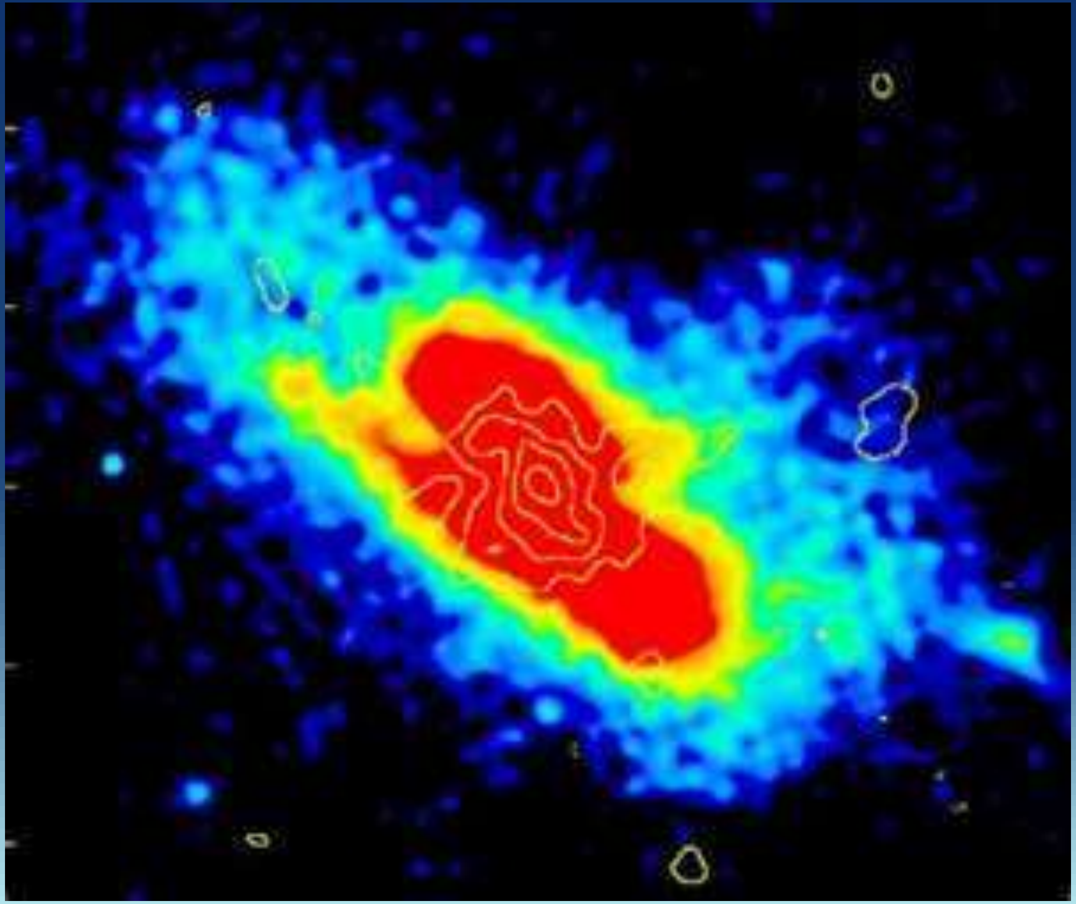
Atacama Large Millimeter Array (ALMA)

- ALMA observes from a few hundred micrometers to about 1 millimeter
- Best image ever of planet formation
- 450 light-years from Earth in the constellation Taurus
- Very young system (< 1 million years old)
- Released Nov. 6, 2014. ALMA (NRAO/ESO/NAOJ); C. Brogan, B. Saxton (NRAO/AUI/NSF)

Sources of Radio Emission

- Solar System - sun, planets
- Milky way - star forming regions, old stars, supernova remnants
- Extragalactic - quasars, radio jets
- Molecules

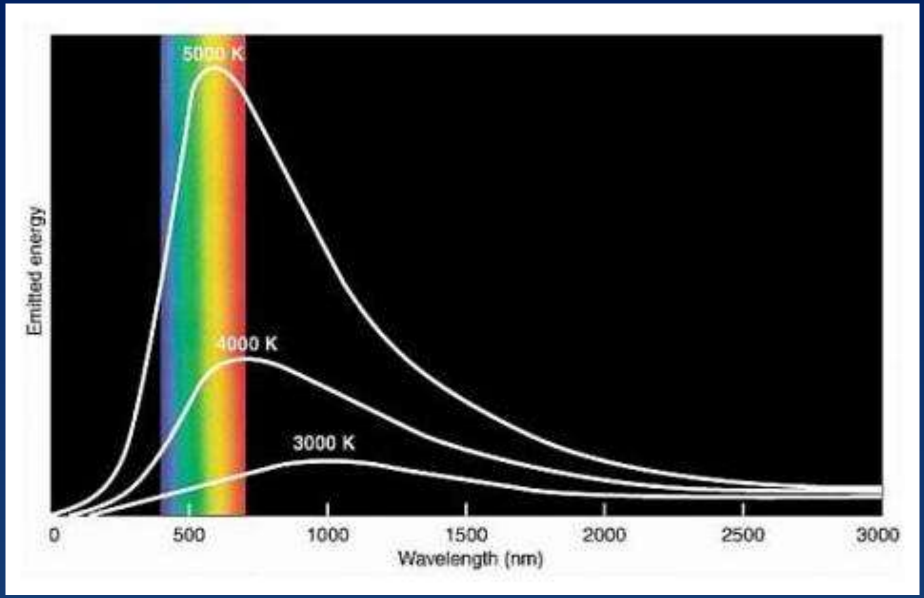
Quantitatively, a picture is really a radio intensity distribution map

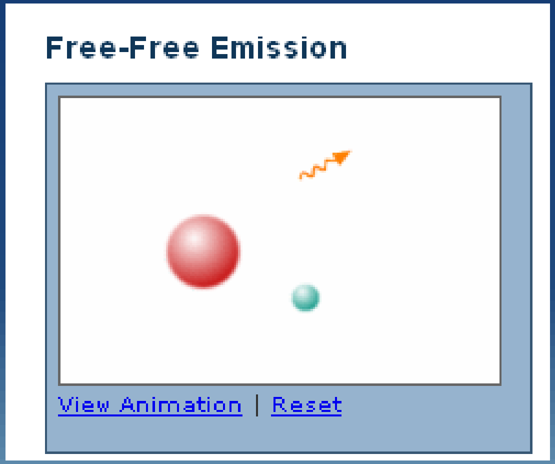


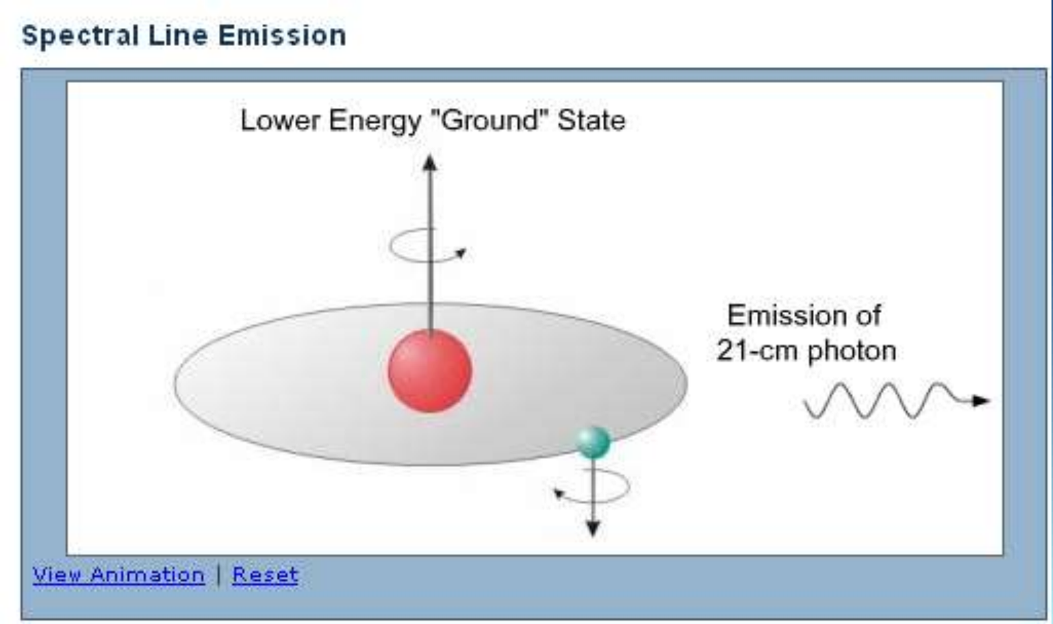
Mechanisms of Radio Emission

Thermal Emission

1. Thermal Emission – blackbody radiation
2. Free-free emission – thermal 'bremsstrahlung' radiation (for local thermodynamic equilibrium (LTE)
3. Spectral Line Emission – i.e. 21 cm line of H



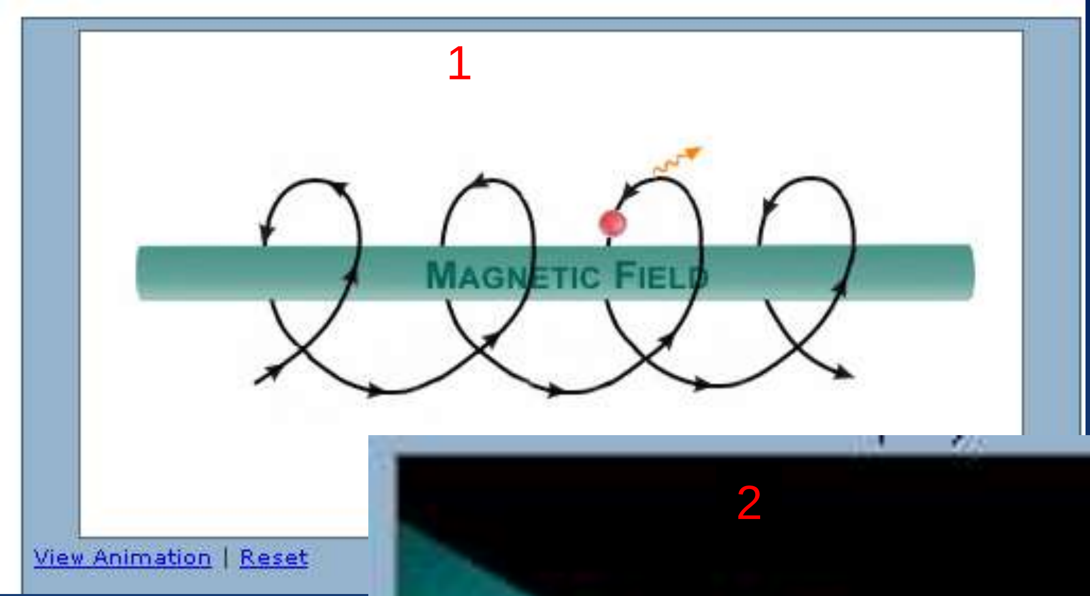


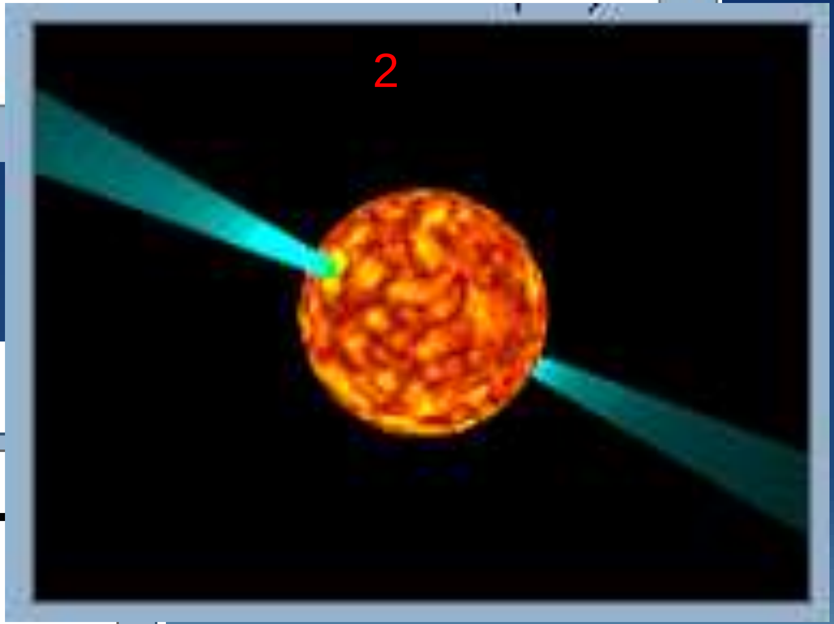


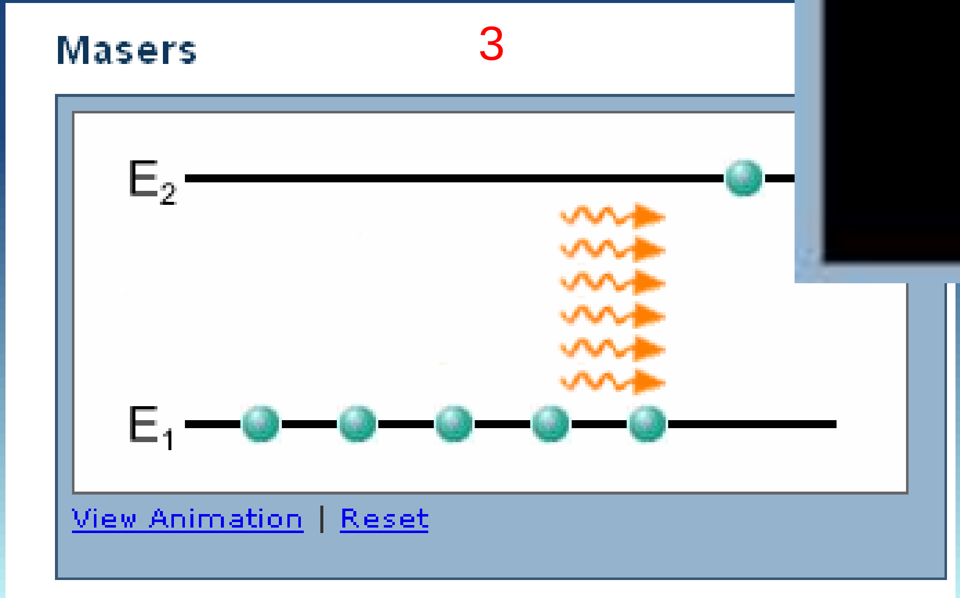
Mechanisms of Radio Emission

Non-thermal Emission

1. Cyclotron/Synchrotron emission – magnetobremsstrahlung radiation
2. Gyrosynchrotron – pulsars
3. Masers – stimulated emission associated with molecules (in molecular clouds or envelopes of old stars)







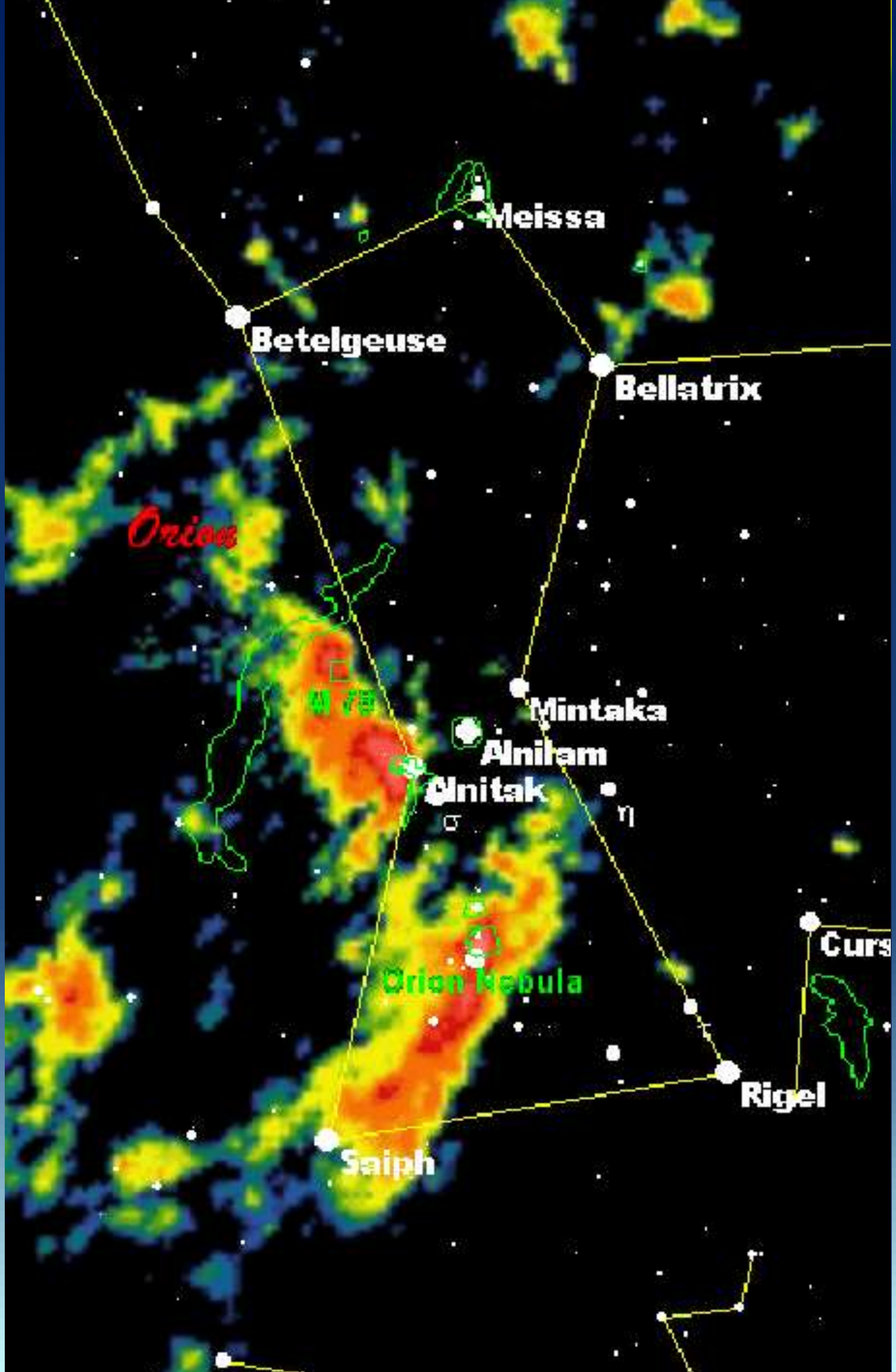
Nebulae in Orion

Image 1: Optical "image" from a planetarium program showing the stars of Orion – green outlines the nebulae

Image 2: Radio image showing ionized hydrogen – good agreement with the nebulae.

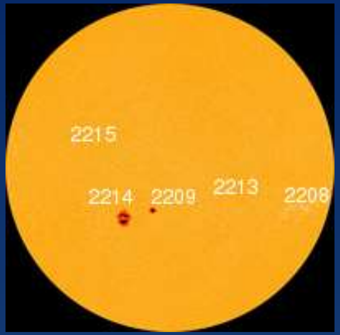
Image 3: Atomic hydrogen. Very different. Galactic plane begins in the upper left.

Image 4: Molecules (Carbon monoxide) shows giant molecular (H_2) clouds where new stars form.

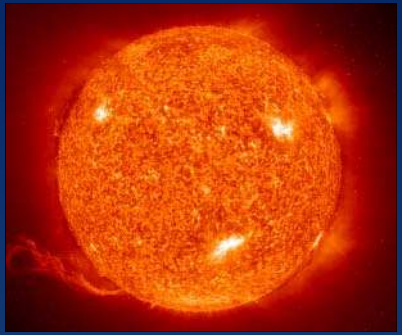


Radio Sun

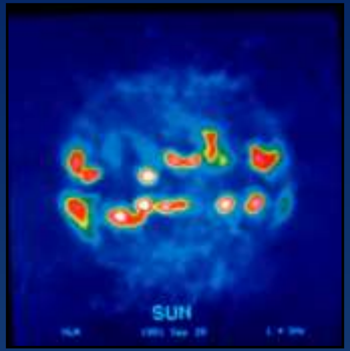
Optical



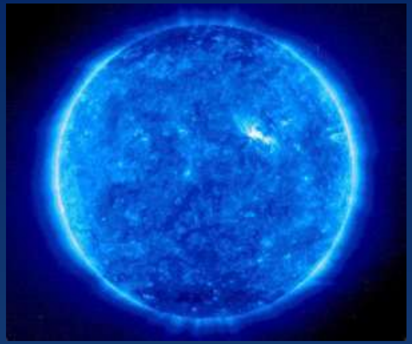
H-alpha



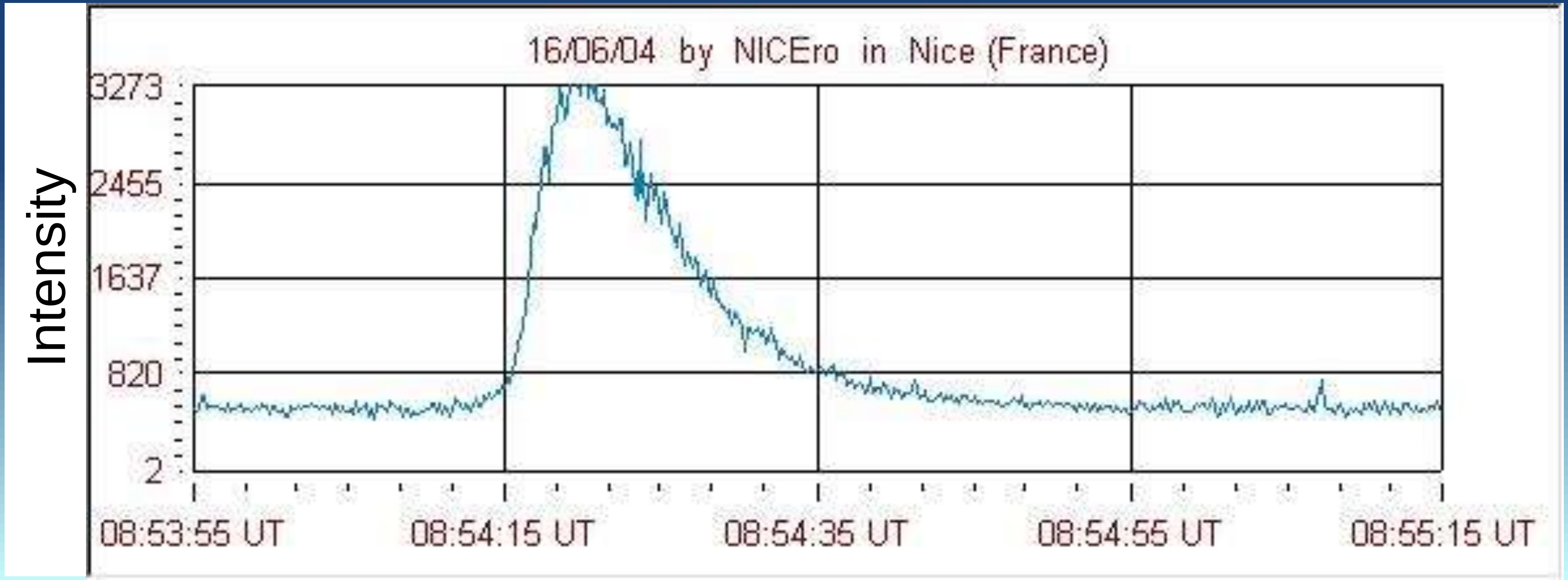
Radio



X-ray

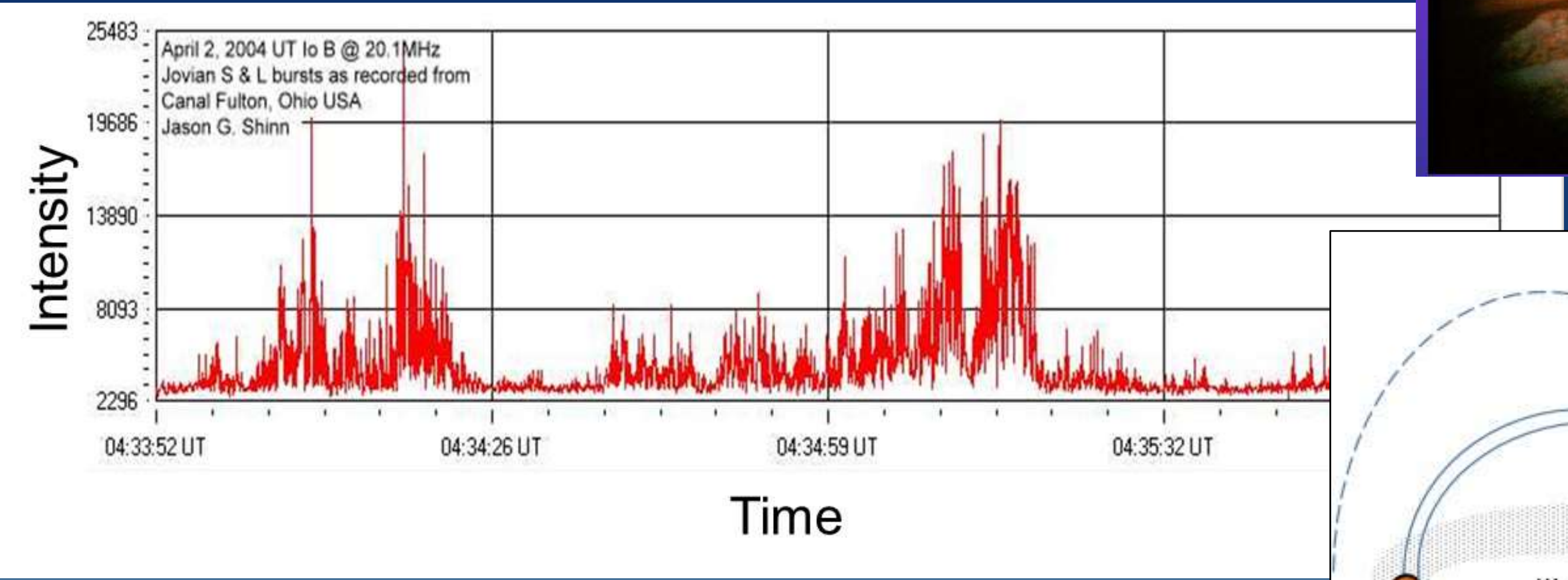


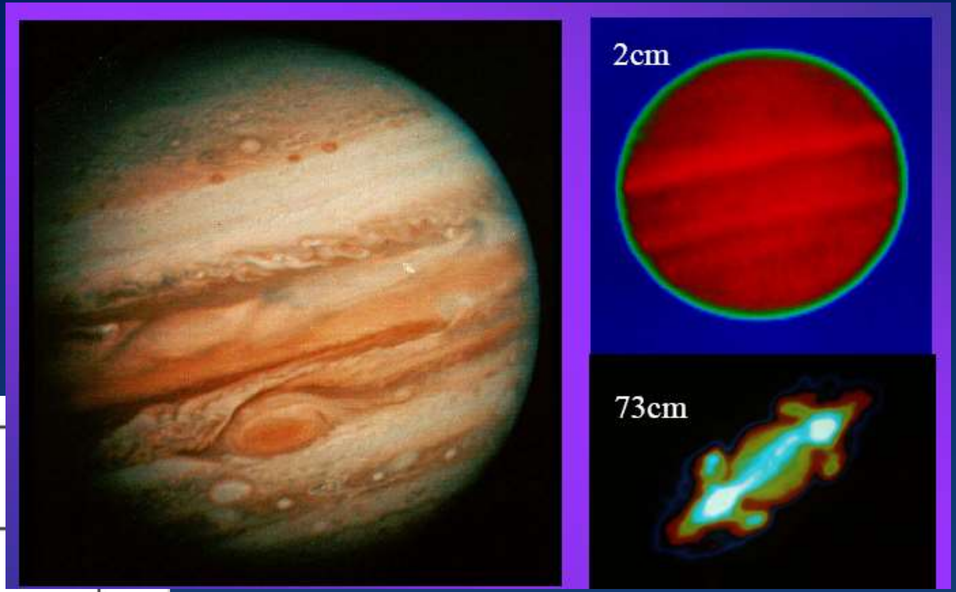
Solar Radio Burst – notice the sharp rise and the gradual decline of the burst. This is typical of Type III solar bursts.

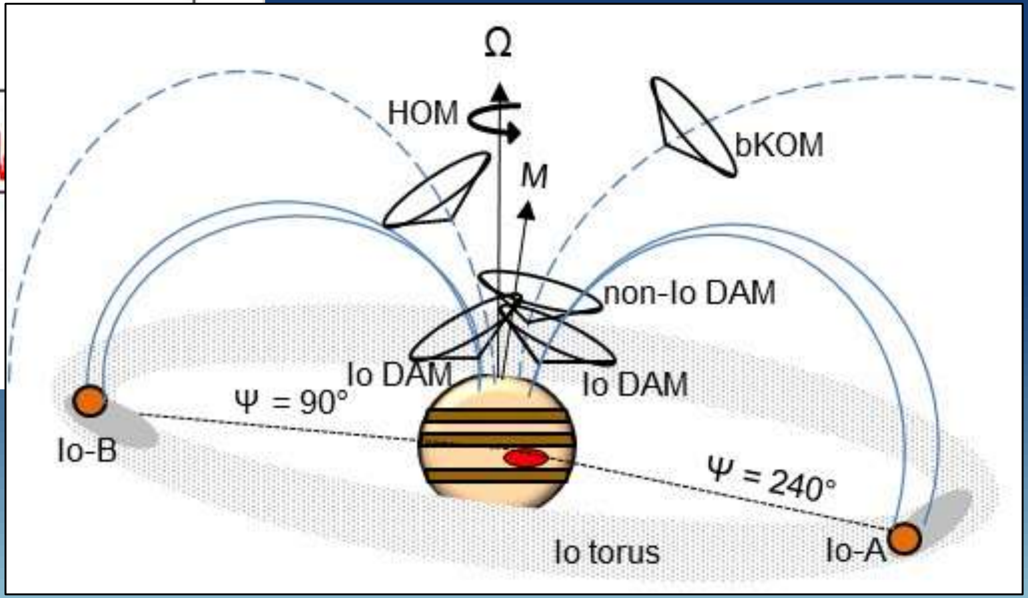


Radio Jupiter

Jupiter S-bursts are the short popcorn popping sounds in this Io-B storm





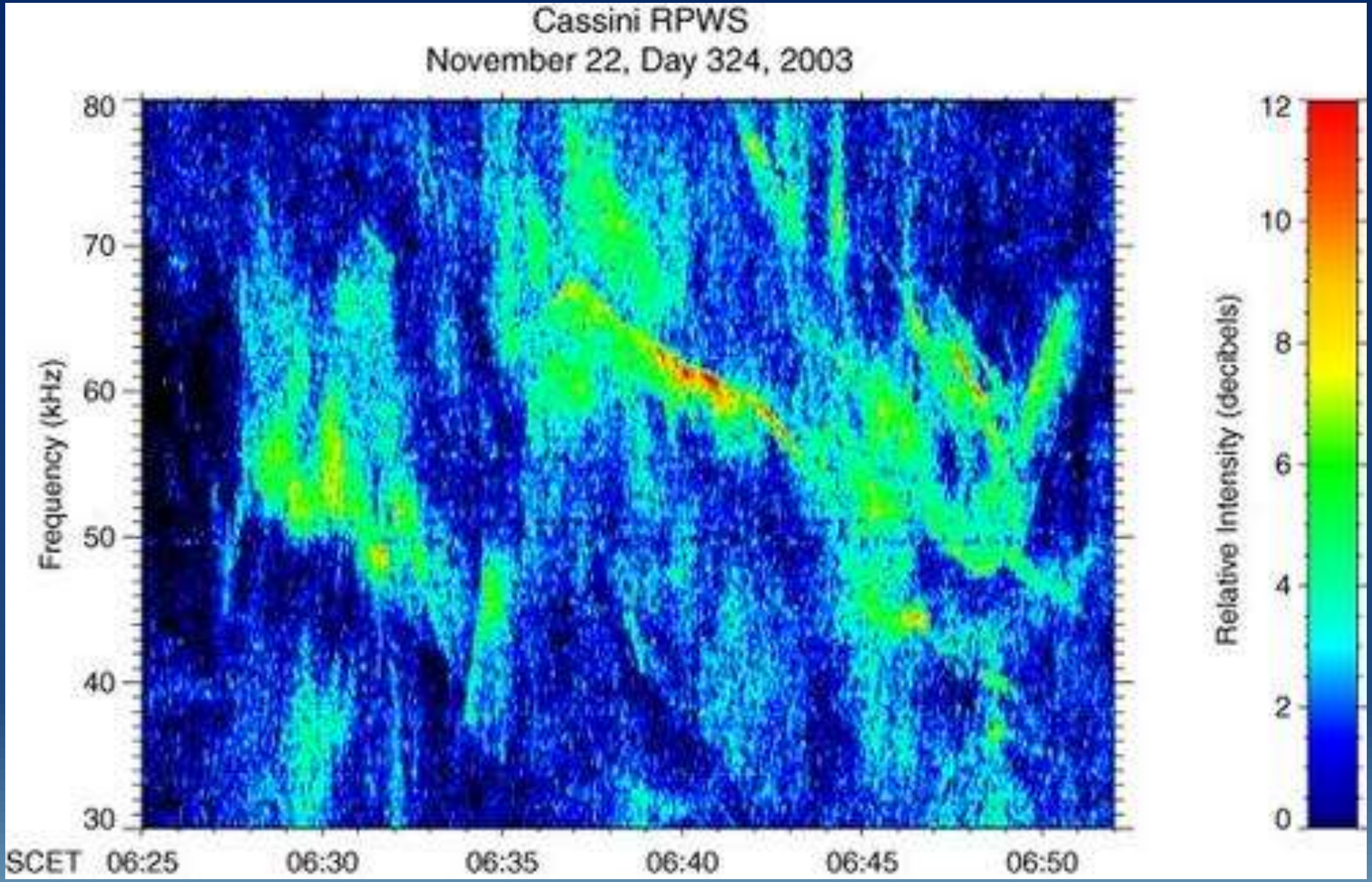


Jupiter S-bursts

Slowed down by 128x

Plasma Waves at Saturn

Radio Emission
Plasma Waves
Lightning

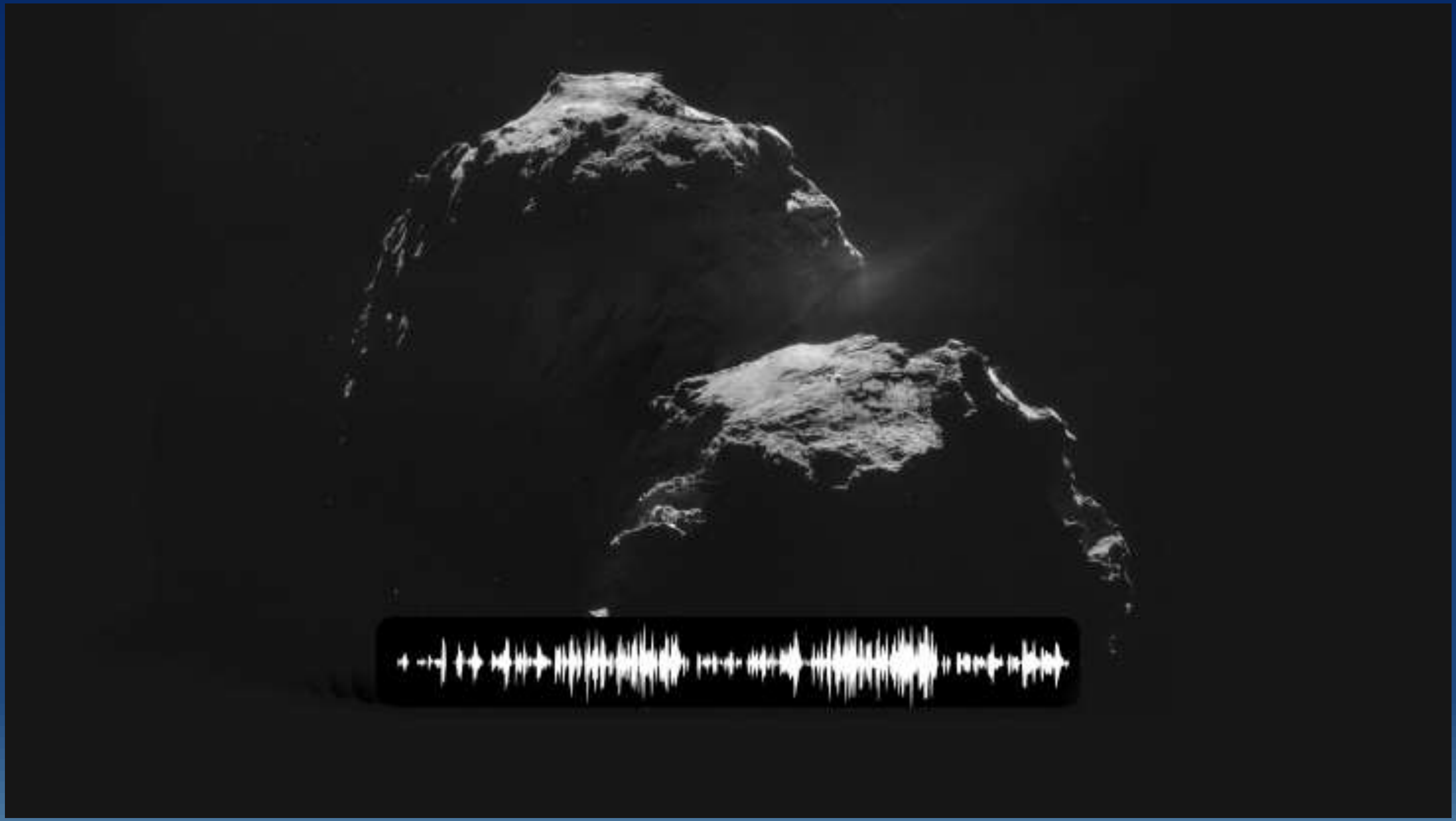


Eerie radio sounds

Credit: Cassini RPWS/U. of Iowa

A Singing Comet?

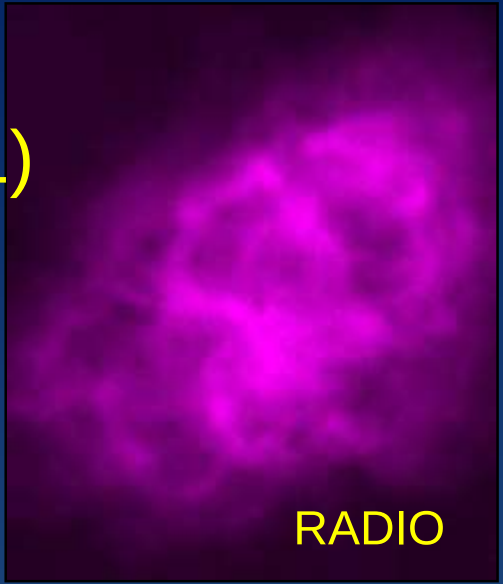
- Sounds are oscillations in the magnetic field around the comet
- Freq = 40-50 mHz
- To make the sounds audible frequencies are increased by 10,000 times

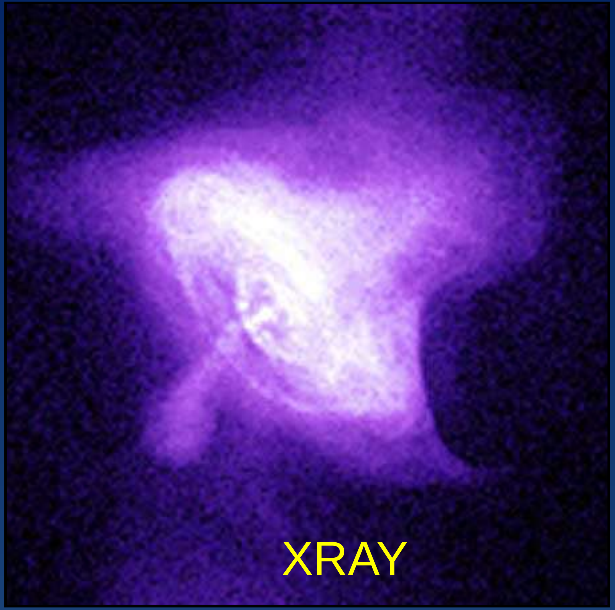


Comet 67P/Churyumov-Gerasimenko.
Image credit: ESA/NASA/JPL-Caltech

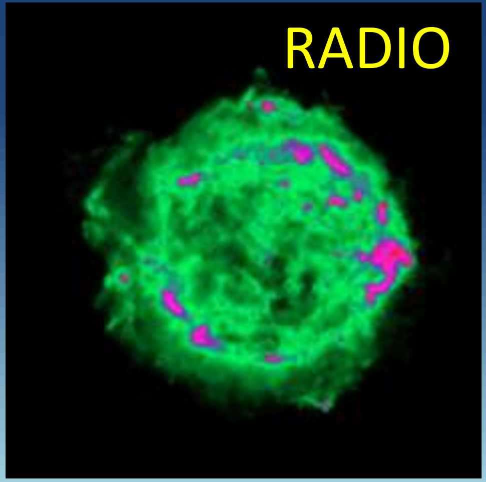
Stellar Nebulae

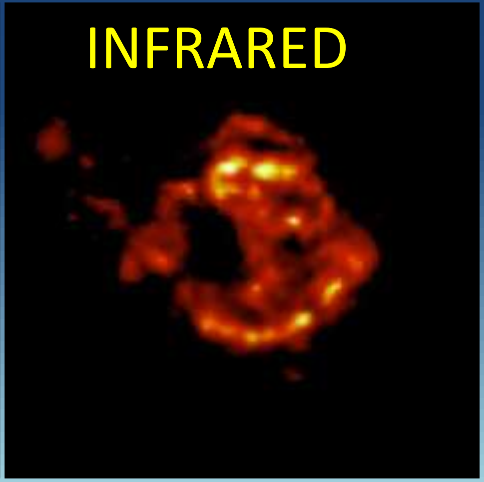
Crab Nebula (M1)

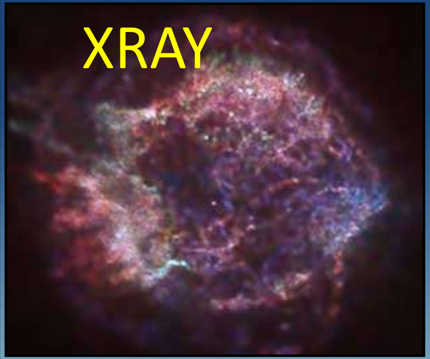




Cas A

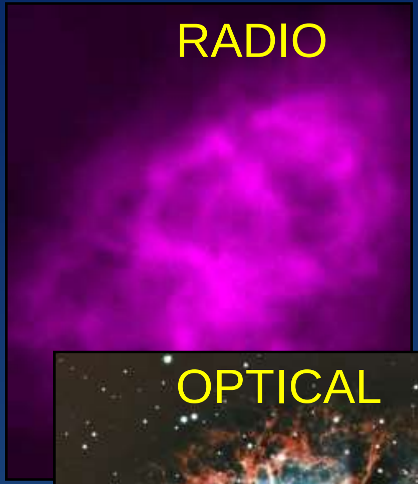


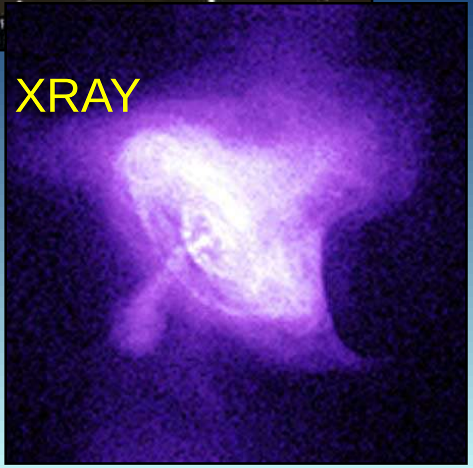


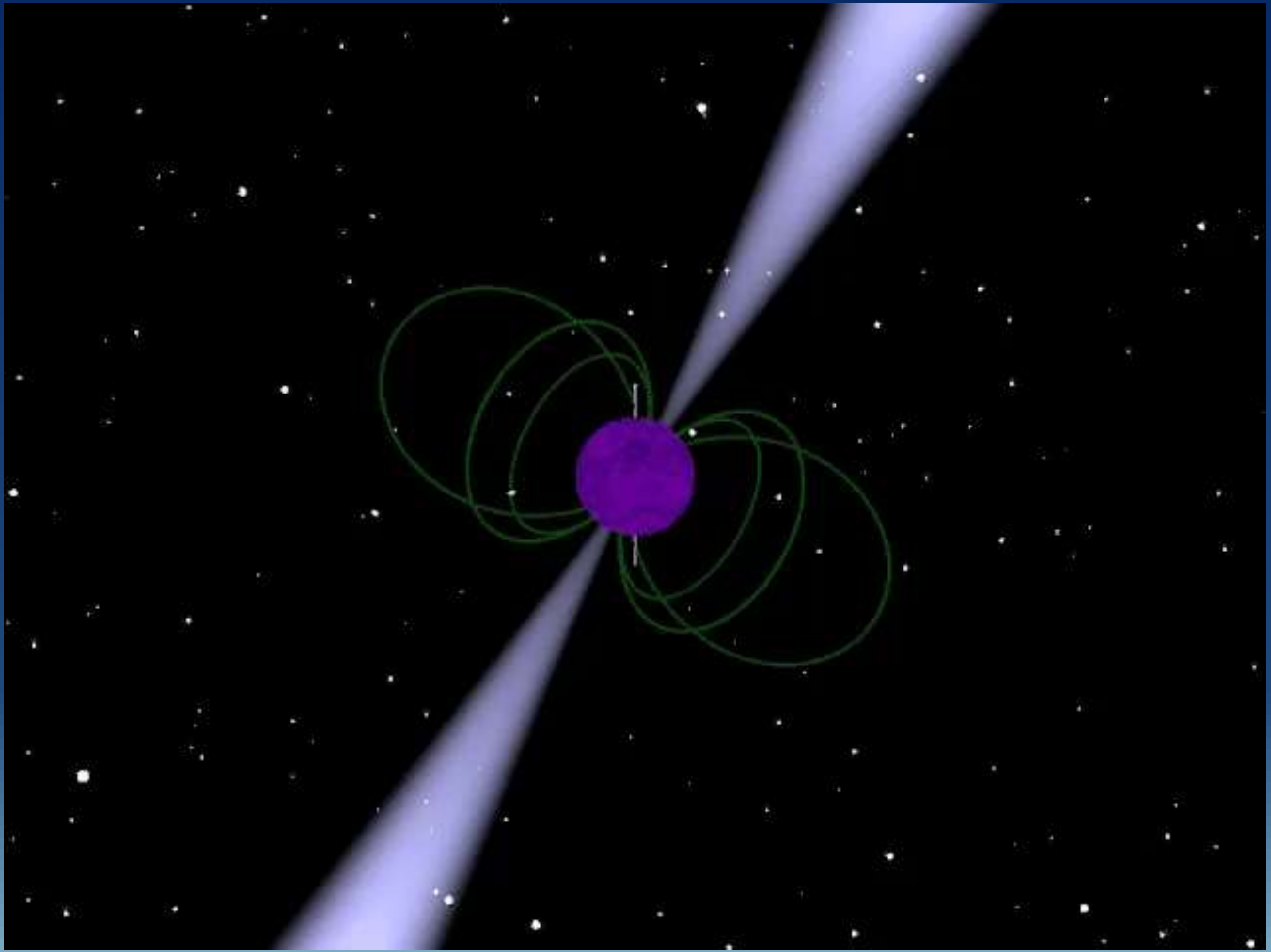


Crab Nebula (M1): a star that died in 1054

Pulsars







PSR B0329

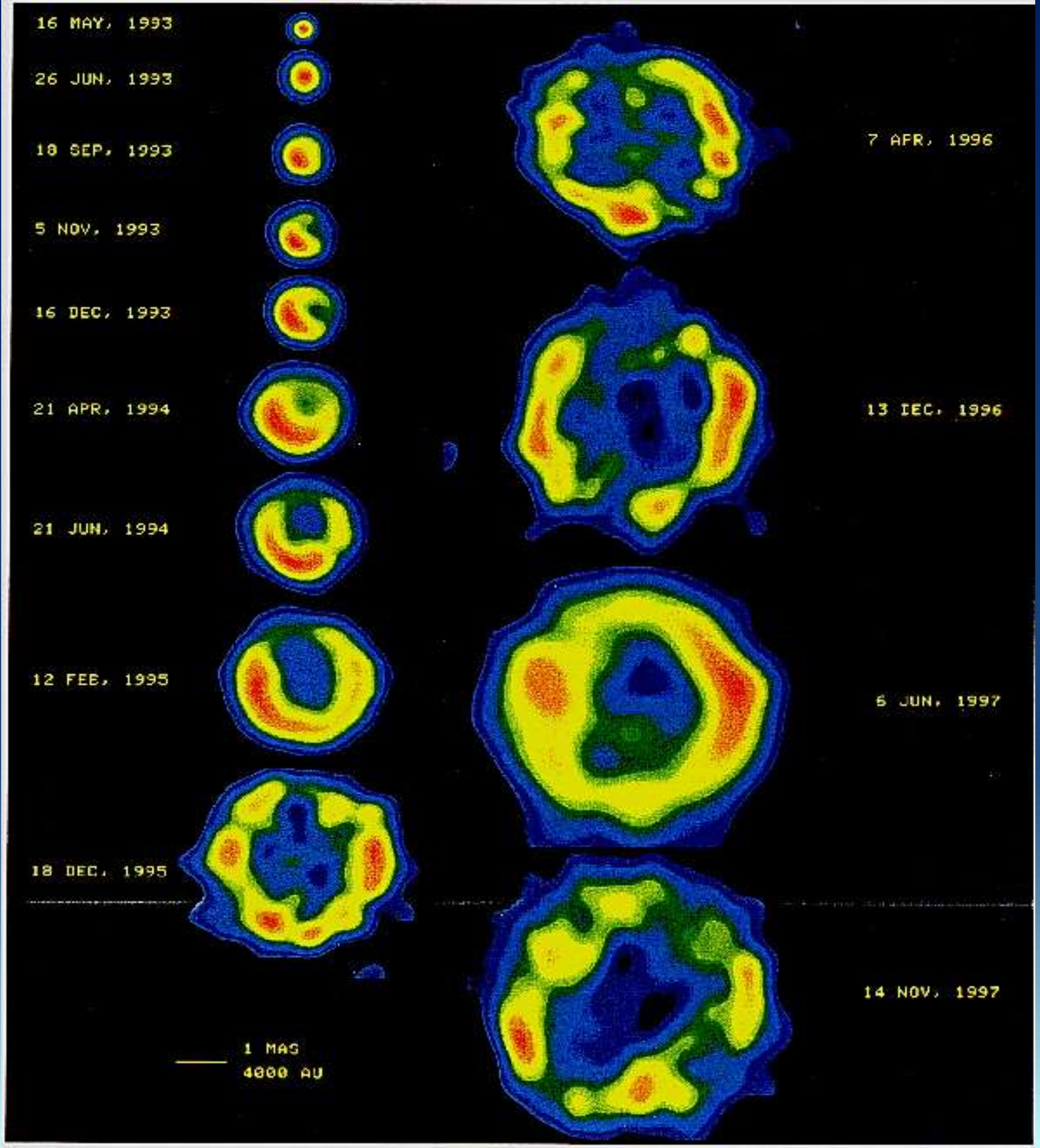
PSR 0883

PSR B0531 crab M1

PSR B1937

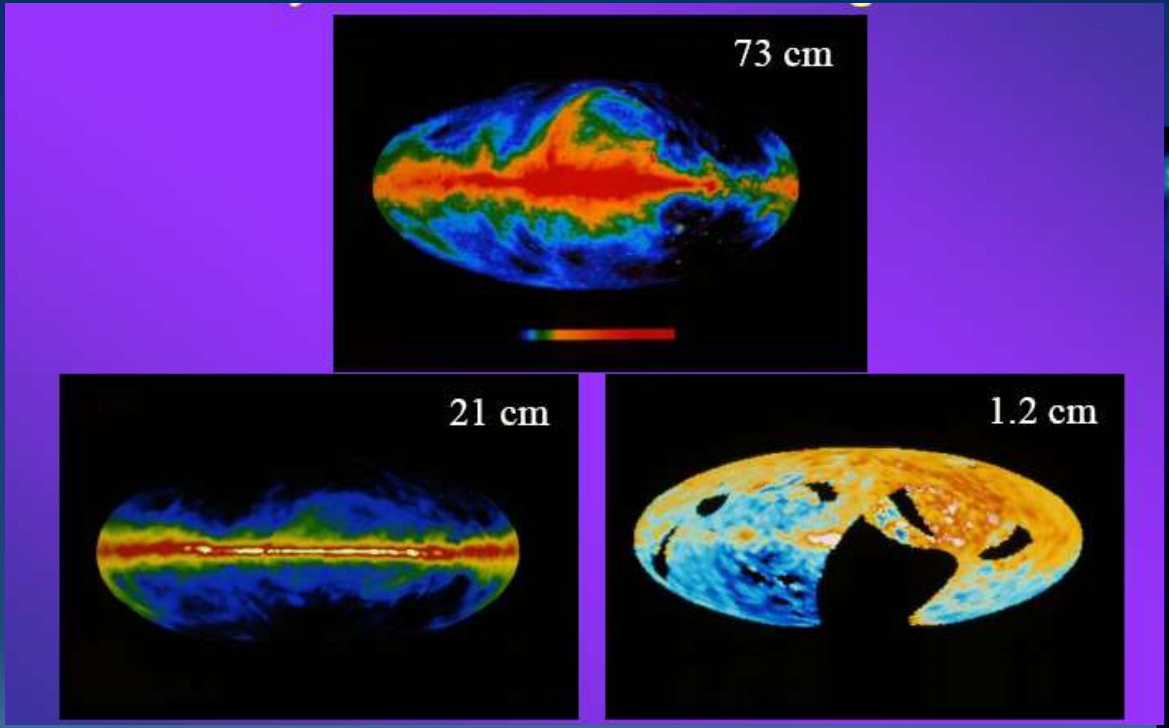
Supernova

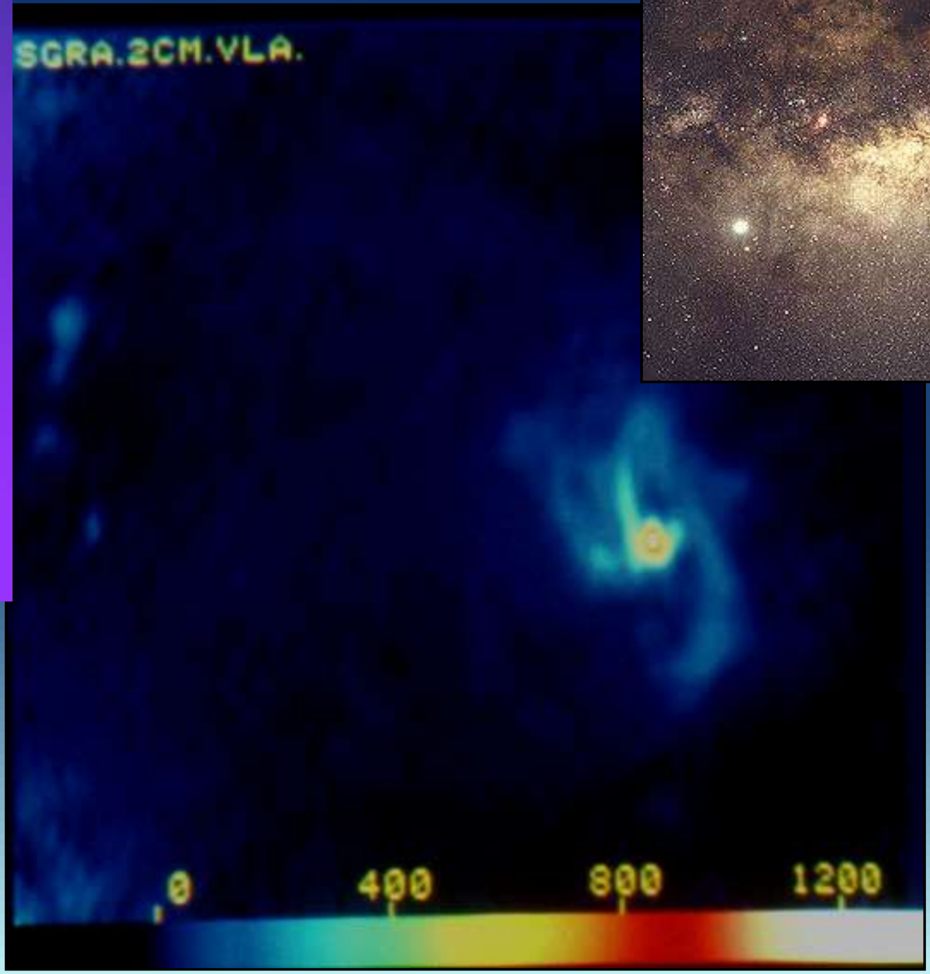
• VLBI sequence of a supernova in M81 (1993-1997)
• 8 GHz images
•Note the 1 milli-arcsec scale (MAS)
1 MAS = 4000 AU



The Milky Way and the Galactic Center

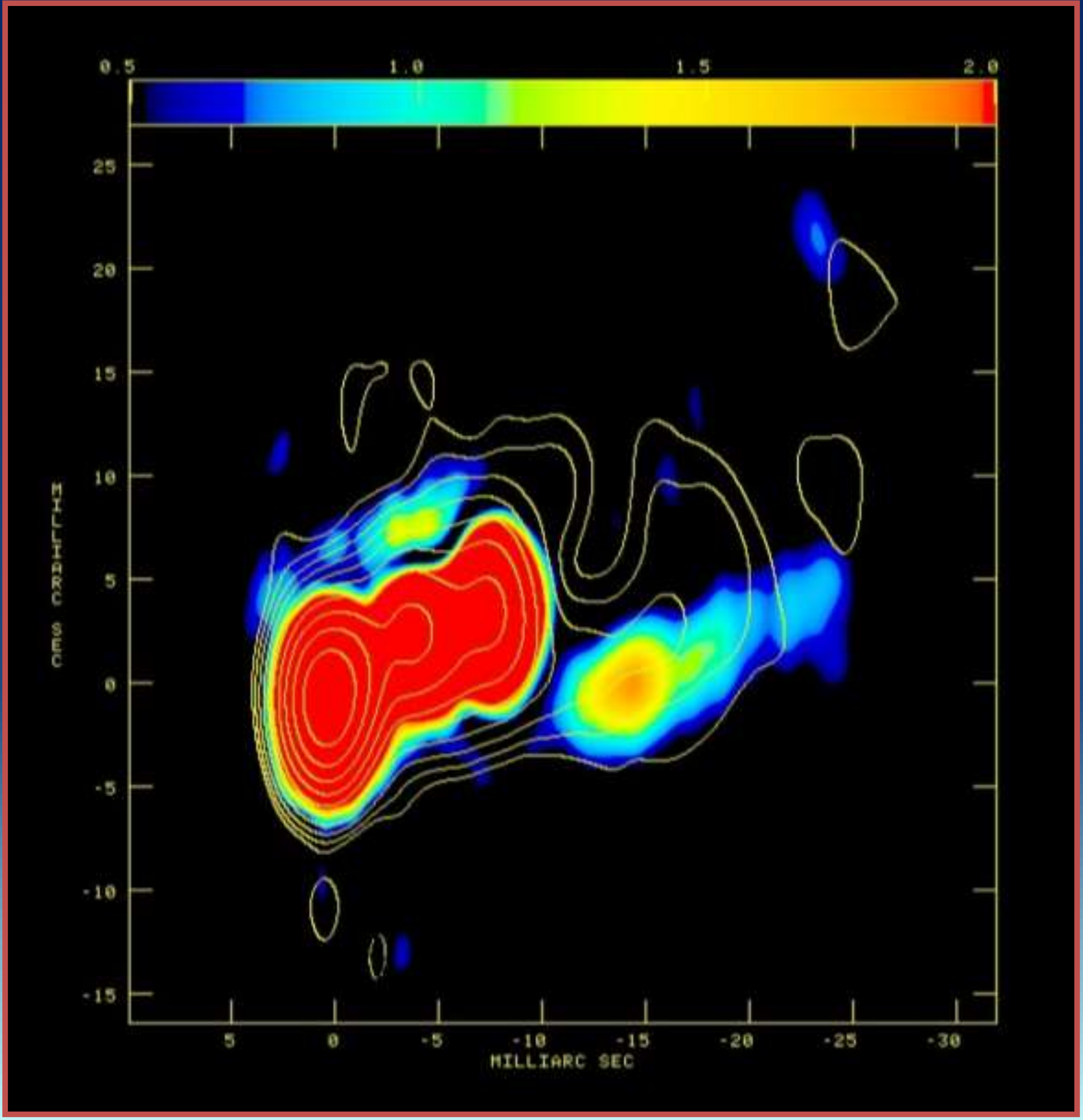
RADIO





OPTICAL

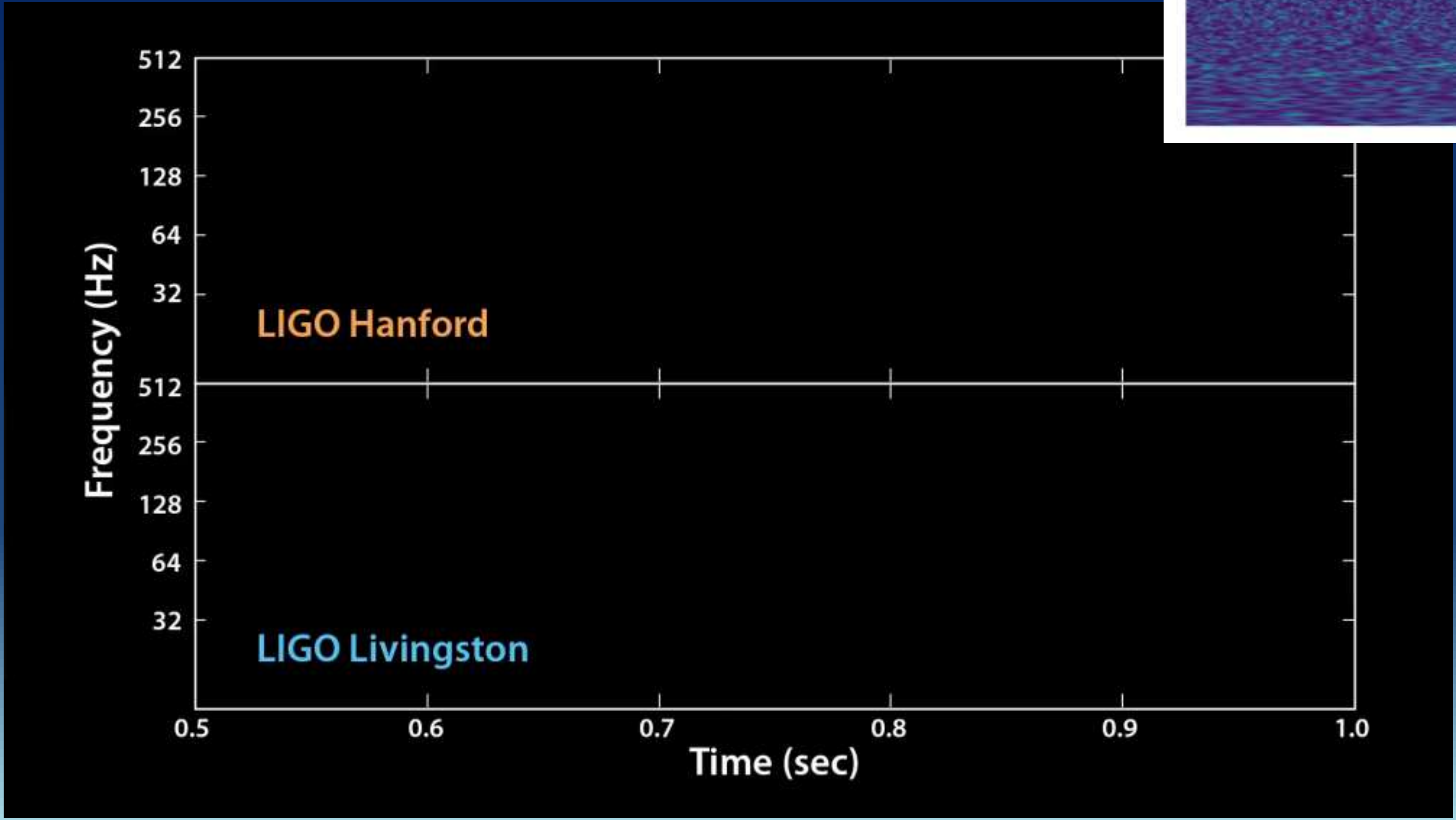
Magnetic Fields in Active Galactic Nuclei

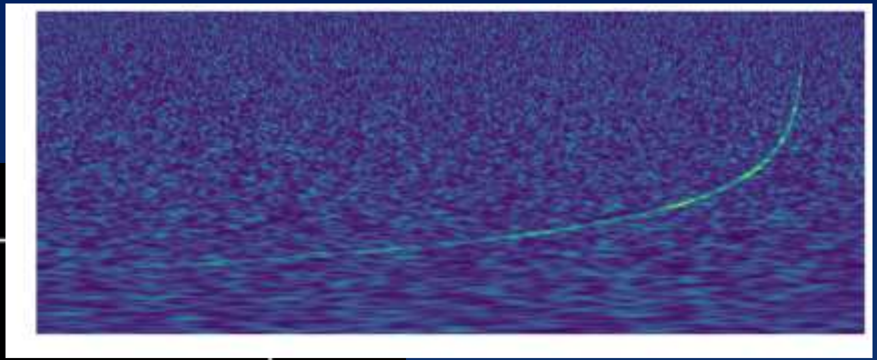


Blazar 1055+018

- Active Galactic Nuclei
- 15 billion light years distant
- AGN are 40 times more luminous and 10,000 times larger than the brightest “normal” galaxies
- Displays a colossal jet of relativistic plasma
- Powered by a supermassive, rotating black hole

Neutron Star Merger

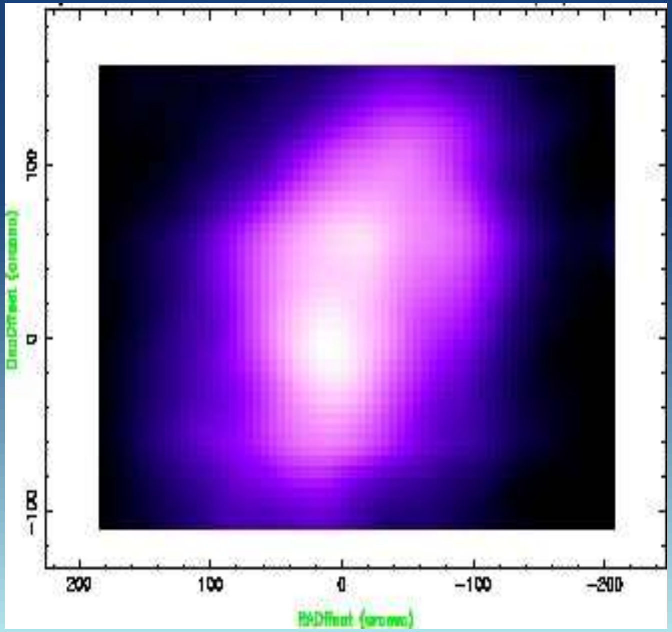




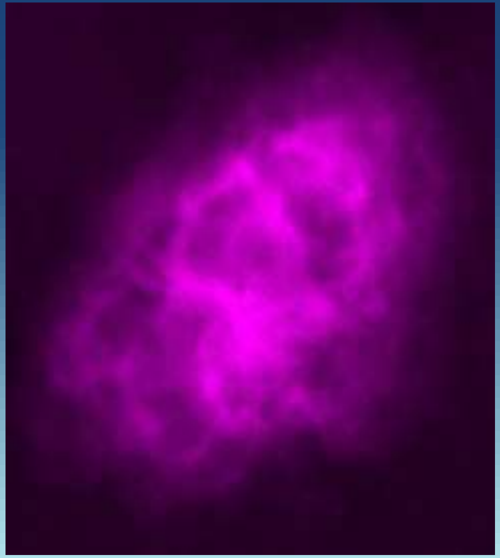
https://youtu.be/_SQbaILipjY

Resolution - Interferometry

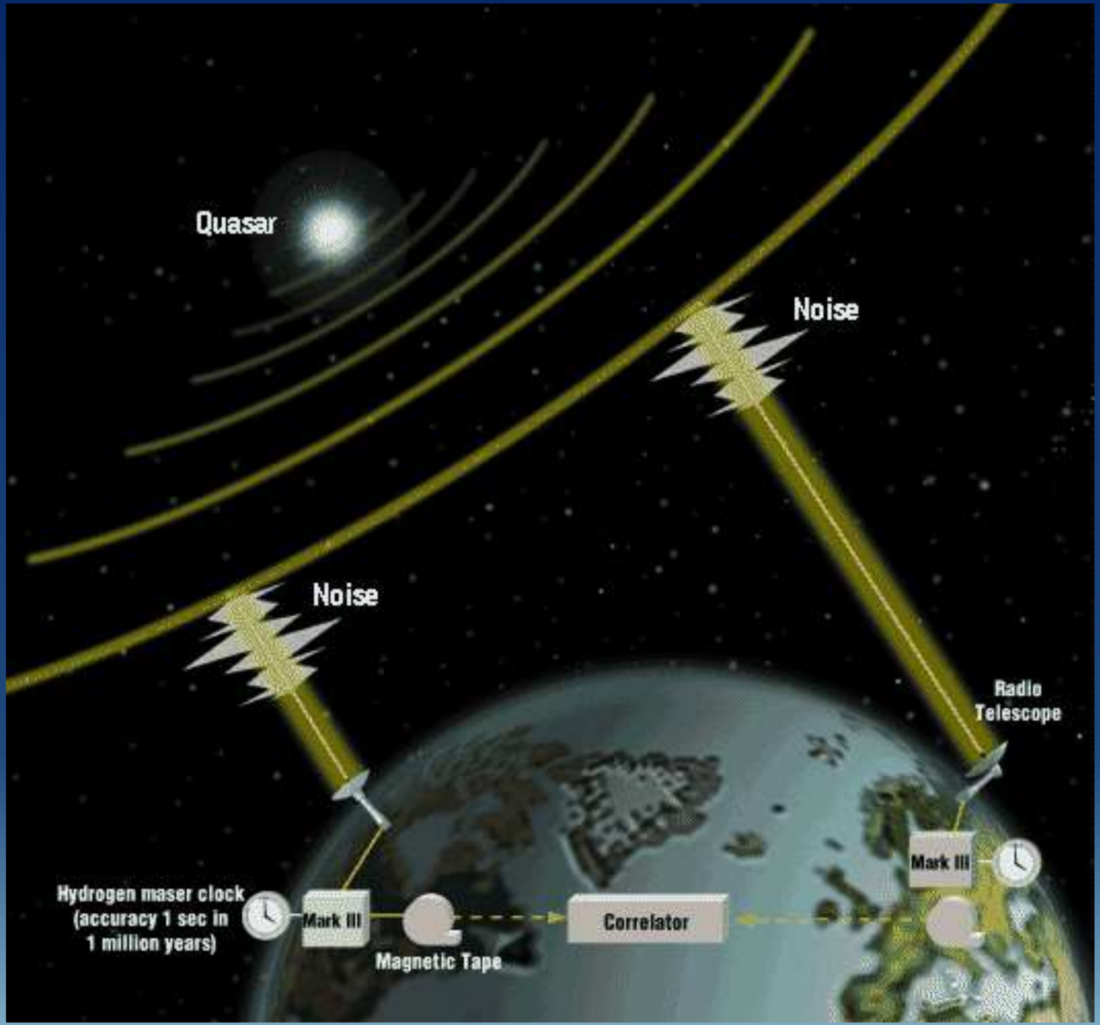
Radio image from Haystack 37-m single dish telescope at a frequency of 43 GHz



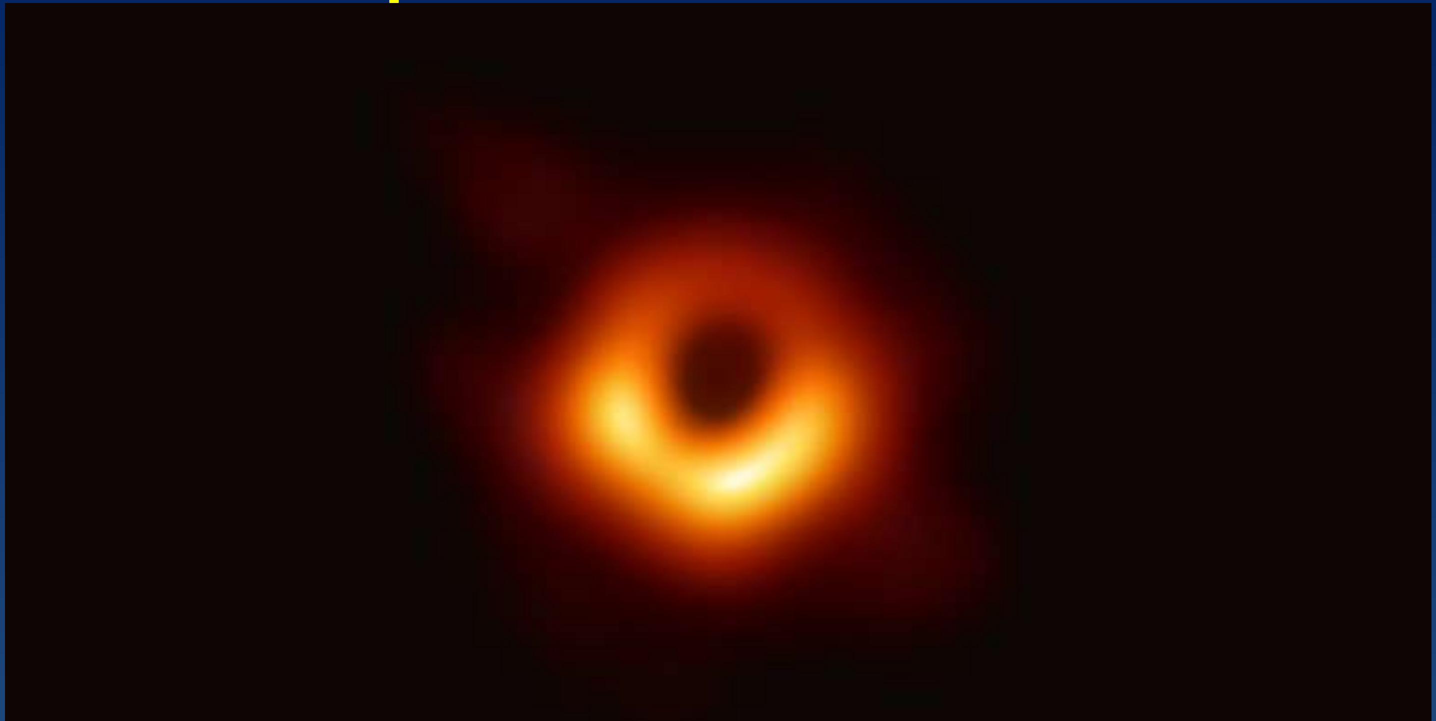
Radio image made with the 27-element Very Large Array.



M1 Supernova Remnant



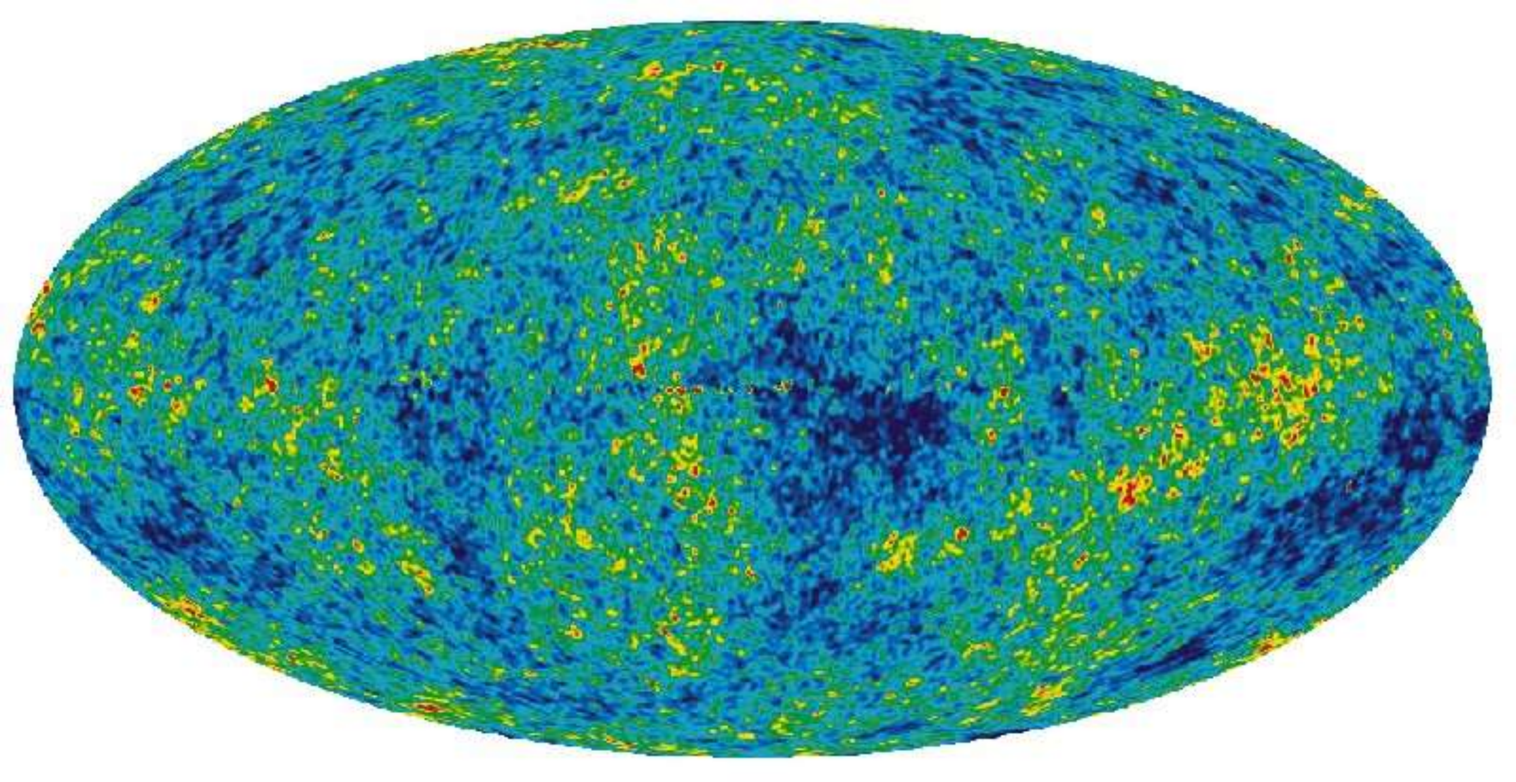
Supermassive Black Hole



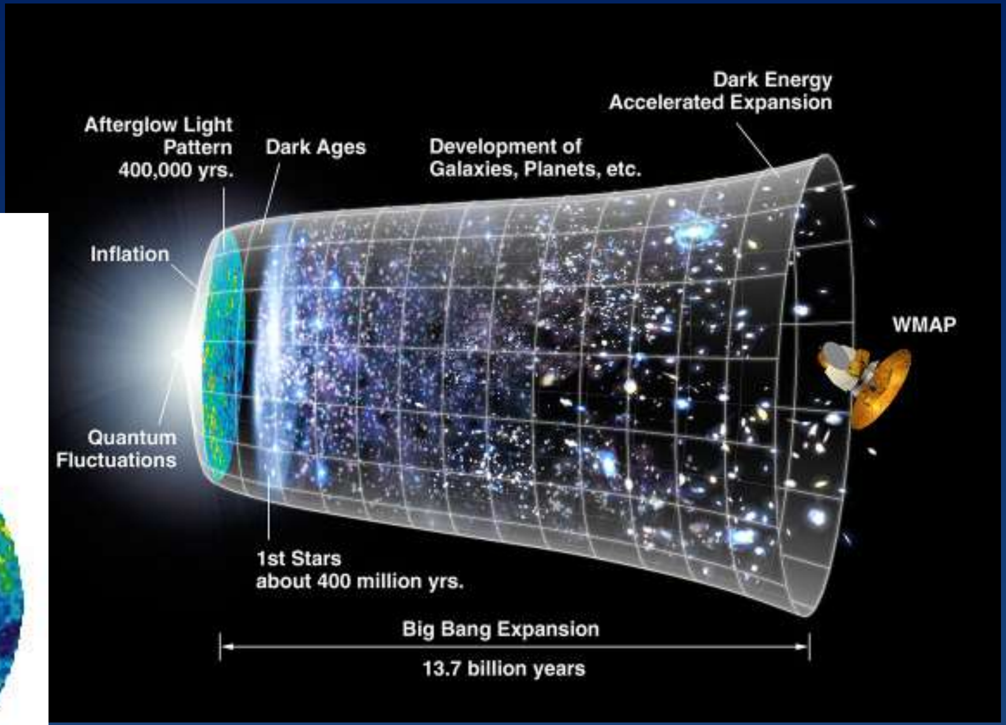
Credit: Event Horizon Telescope Collaboration
https://eventhorizontelescope.org/

First Image of a Supermassive Black Hole
A supermassive black hole lies at the heart of the galaxy M87, about 55 million light-years distant in the Virgo cluster of galaxies. A glowing disk of light is bent around the black hole by its enormous gravity.

The Universe



Cosmic Microwave Background



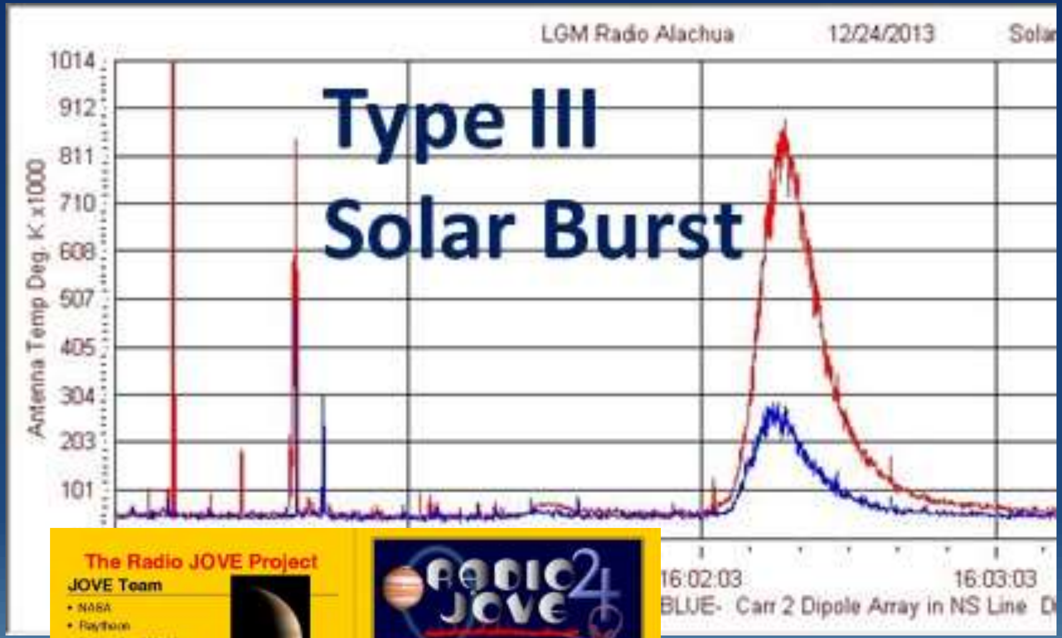
Credit: NASA/WMAP Science Team

radiojove.gsfc.nasa.gov

The Radio Jove Project

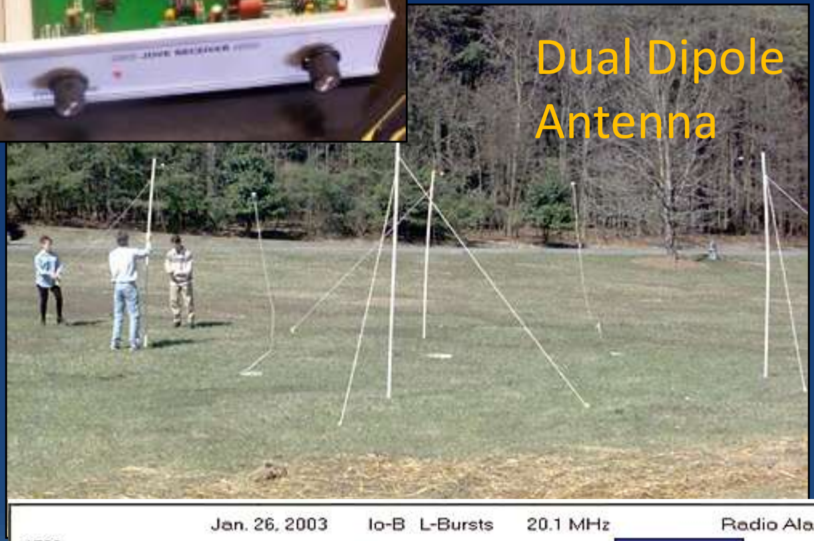
<u>Goals:</u>

- Citizen Science via radio astronomy and space physics
- Science literacy
- Provide a hands-on experience in radio astronomy
- Enable access to Online observatories and real data
- Facilitate the exchange of data and ideas



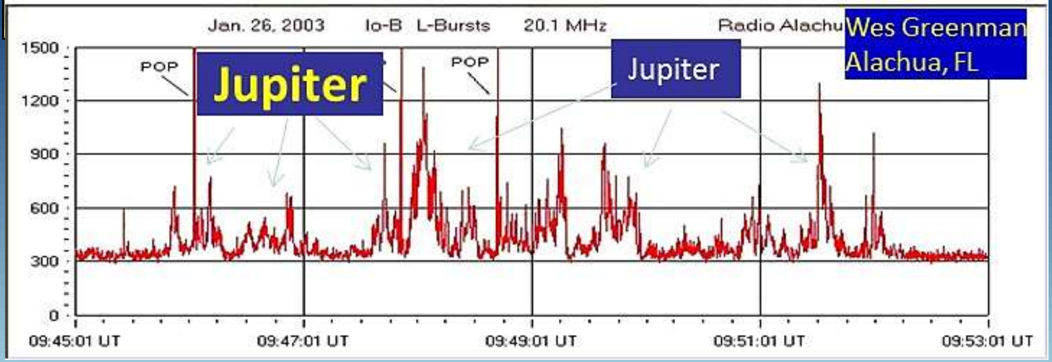
Hardware and Software

Radio Jove
20 MHz Receiver



Dual Dipole
Antenna

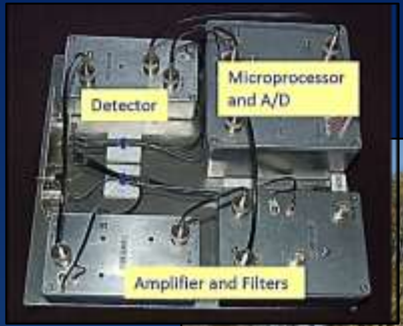
- You build it
- You operate it
- You collect data
- You analyze data
- You archive data
- You do science



Observing Software from **Radiosky.com**

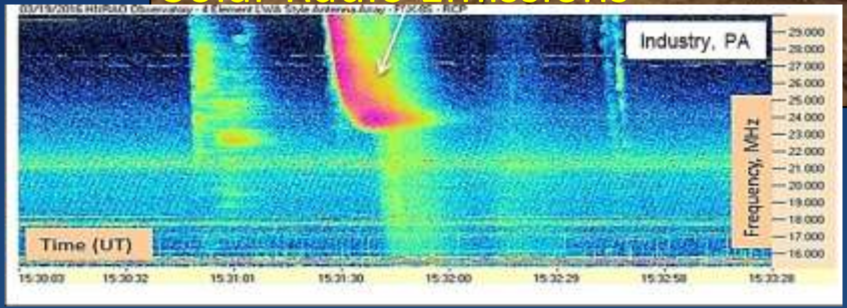
<u>Basic System</u>

- 20 MHz Receiver
- Dipole Antenna
- Recording and Analysis Software
- $300 + computer



Spectrograph and
Wide Band Antenna

Solar Radio Emissions



Observing Software from **Radiosky.com**

<u>Advanced Systems</u>

- 15-30 MHz Radio Spectrograph
- Software Defined Radio (SDR)
- Spectrograph Software
- $2500 + computer

The End

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Thank you!

2017 Solar Eclipse
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