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CSTB Workshop: "Improving Spectrum Management Through Economic or Other Incentives"

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Why Radio Astronomy?

Science

Radio Observations Provide Unique Information on the Cosmos, That Cannot Be Obtained at Other Wavelengths (e.g. by Optical Astronomy, or other means)

- ***Many Important Physical Processes in the Universe Can Be Observed Only at Radio Frequencies (e.g. Energetic Electrons In Magnetic Fields, Jets in Radio Galaxies, Most Pulsars, Clouds of Neutral Hydrogen, Molecular Clouds, etc.)***

- ***Radio Waves Are More Penetrating Than Optical Wavelengths and Many Regions of the Universe Can Be Observed Only at Radio Wavelengths (e.g. The Galactic Center, Regions of Dust Clouds, etc.)***

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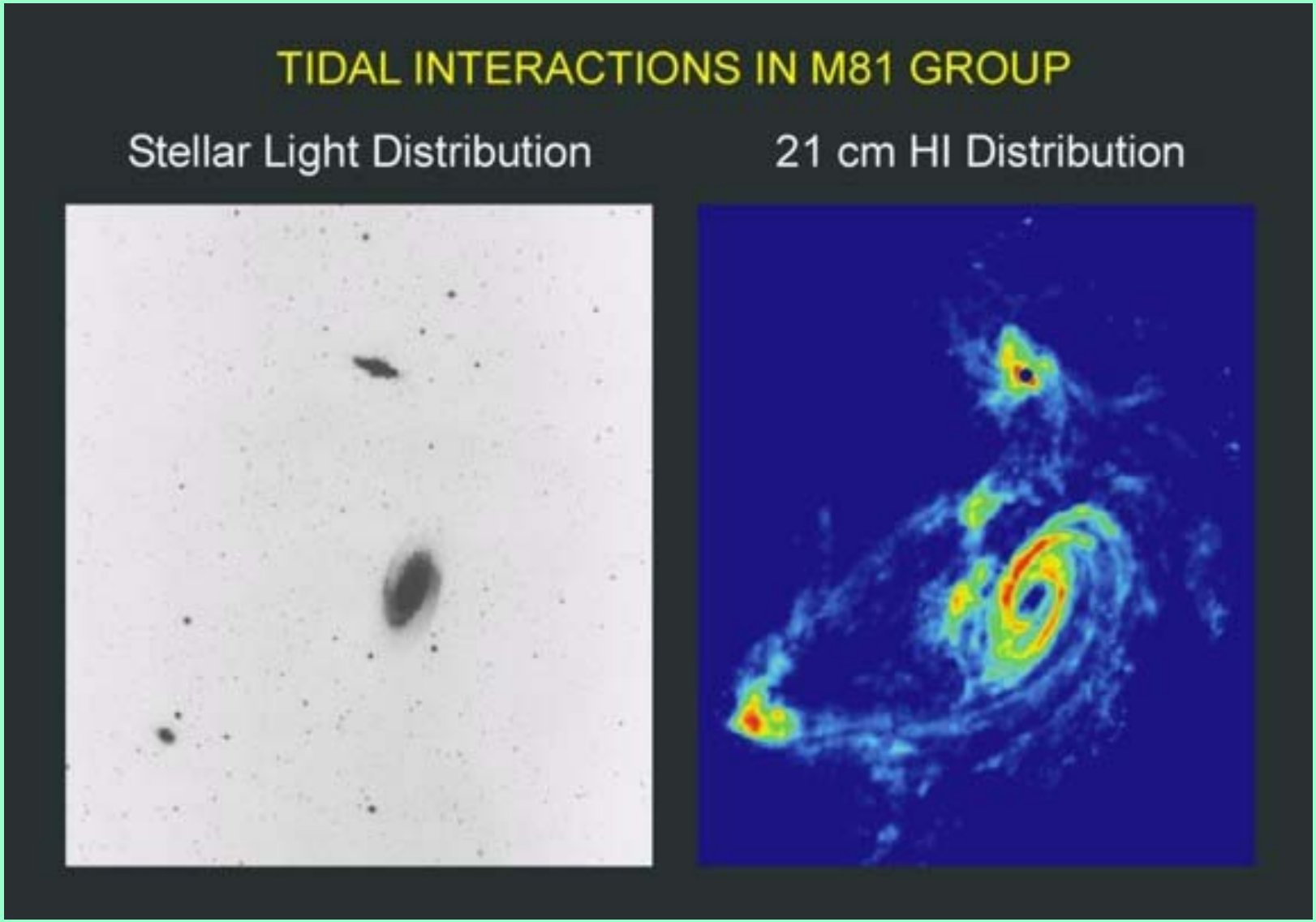

Radio Image courtesy of NRAO/AUI
Optical Image: Digitized Sky Survey

Note

Interconnections Between Galaxies

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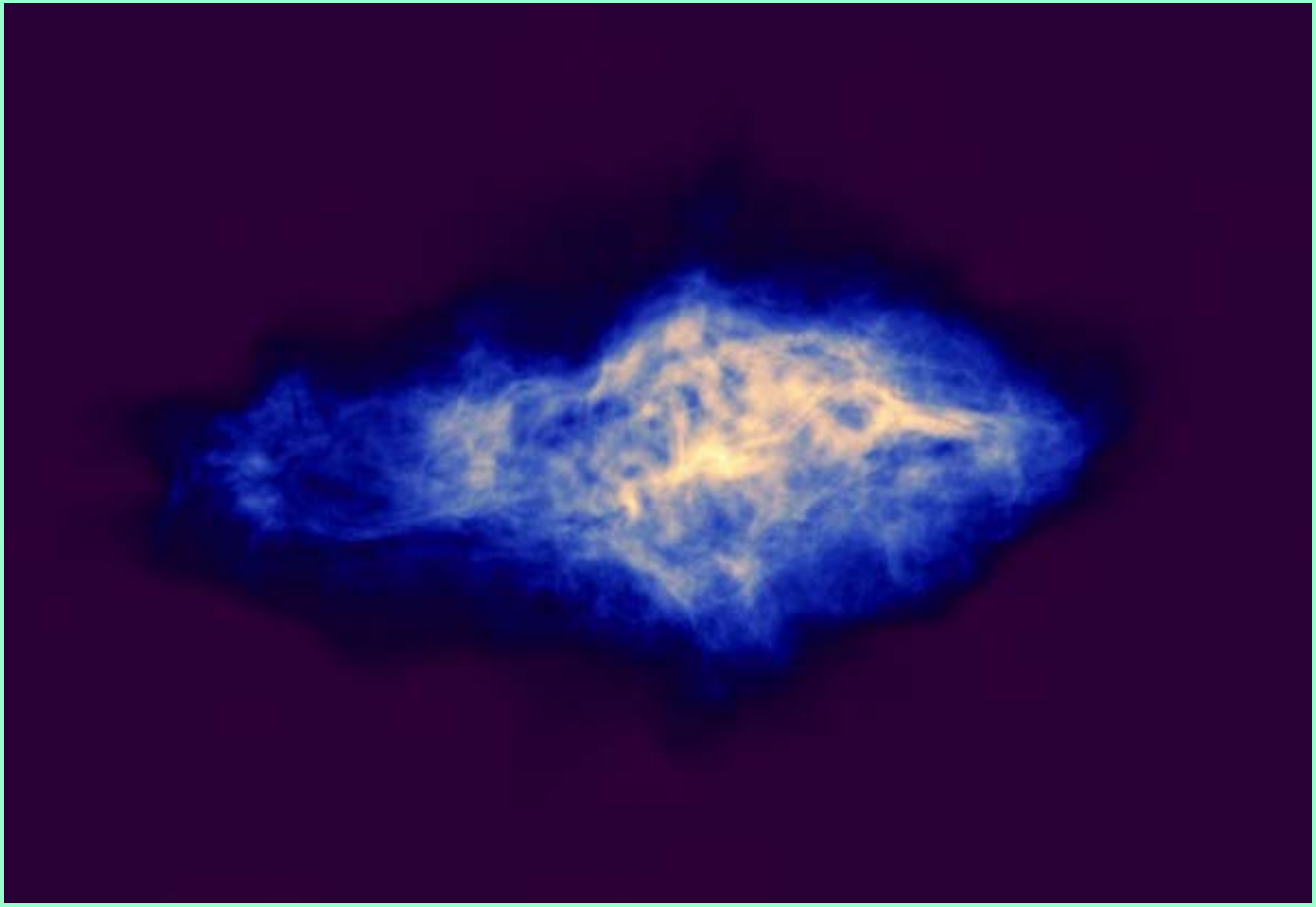
Radio Image of the Supernova Remnant 3C58



Note: Image courtesy of NRAO/AUI and Michael Bietenholz, York University

The Radio nebula is energized by a recently discovered pulsar

Filamentary Structure

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The HI Disk of NGC 2403

Radio Image courtesy of NRAO/AUI and Tom Oosterloo, Astron, The Netherlands
Optical Image based on Digital Sky Survey

Note:

Gas Disk Far More Extended than Optical Disk

Large Holes (Black Areas) Created by Large Supernova Explosions

Spiral Structure of Gas Disk

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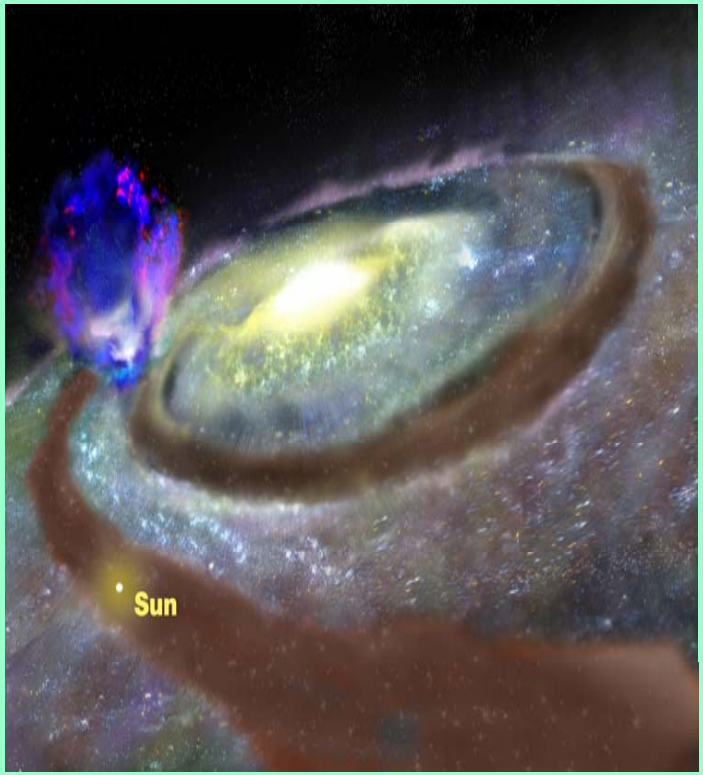
Recent Discoveries in Radio Astronomy



Huge "Superbubble" of Gas Blowing Out of Milky Way
http://www.nrao.edu/pr/2006/plume/

Still-Forming Solar System May Have Planets Orbiting Star in Opposite Directions
http://www.nrao.edu/pr/2006/counterdisk/

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Why Radio Astronomy?

Spin-offs or applications

- **Low noise amplifiers**
- **Aperture synthesis- SAR and x-ray tomography**
- **Remote sensing satellites**
- **Maximum entropy analysis – sharpening of images**
- **Position determination: TDOA technique with origins in Very Long Baseline Interferometry (VLBI), a technique in which data from multiple radio telescopes at different locations are electronically combined to produce the resolving power of one giant telescope**
  - > **GPS**
  - > **911 calls** **http://web.mit.edu/newsoffice/2002/cellphone-0206.html**

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Why Radio Astronomy?

Education

> Electrical Engineers, Physicists, Astronomers

Prestige

> US is a World Leader in Radio Astronomy

> 4 US Nobel Prize winners (A. Penzias and R. Wilson, 1978; J. Taylor and R. Hulse, 1993)

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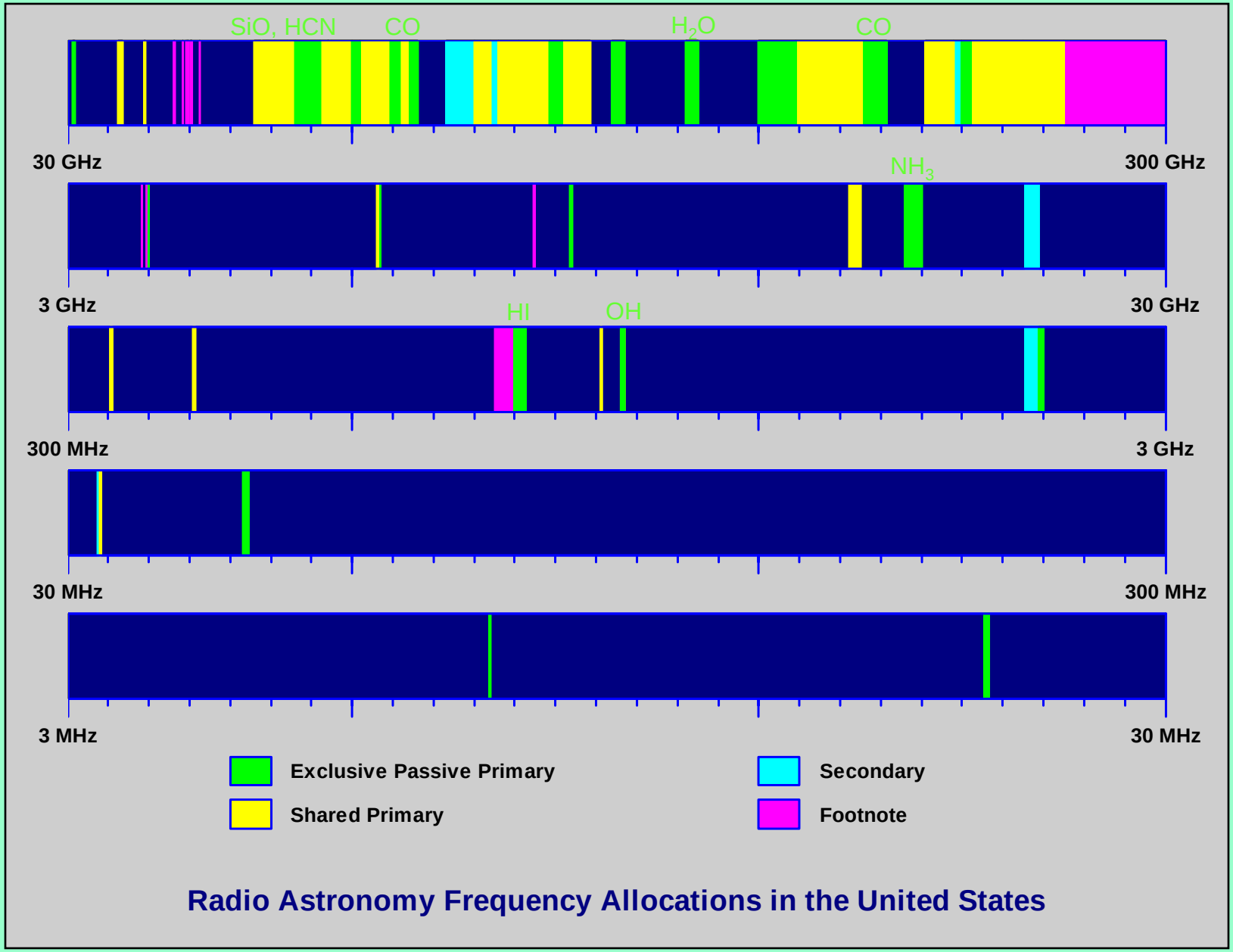

Radio Astronomy Frequency Allocations in the United States

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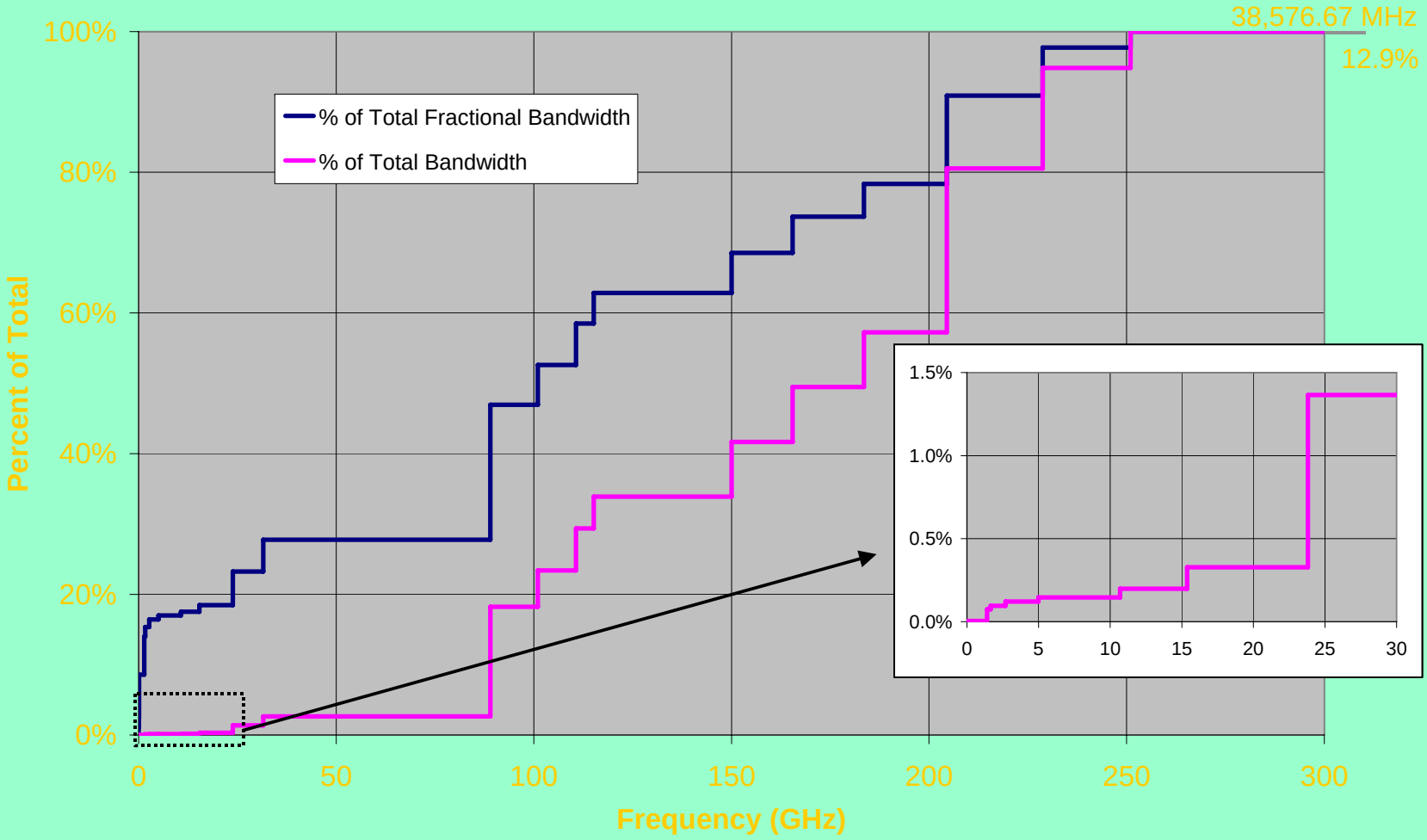
Cumulative Distribution of Exclusive Passive Spectrum Allocations



Less than 1.5% of exclusive passive spectrum is below 30 GHz

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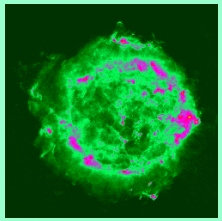
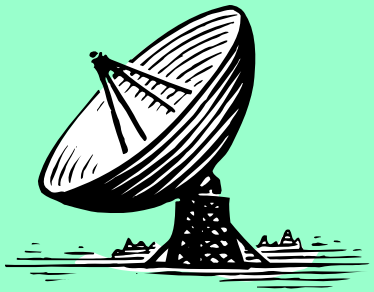
Sensitivity of Radio Astronomy Observations

Cosmic radio sources are ~ 10^6 to 10^{12} times weaker than celestial radio sources.



A cell phone on the Moon, (operating at 1 W of power in a 1 MHz BW, at 960 MHz) is ~ 200 times stronger than the MOST powerful radio source on the sky (Cas A)



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Value of Radio Astronomy Spectrum?

- 34.9 MHz of spectrum is allocated **exclusively** to the passive services between 100 MHz and 2 GHz (less than 1 % of total), (presumably the commercially most valuable portion of the spectrum)
- **Spectrum auctions below 2 GHz brought in ~ $500 M/MHz in this range (20 yr leases)**
- A somewhat larger fraction of the spectrum is allocated to radio astronomy (shared with other passive applications) at higher frequencies. However, in the absence of auctions or other mechanisms of valuation, it is difficult to price this spectrum, even tentatively
- Based on the above, radio astronomy spectrum is valued at ~ $17.5 B

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Difficulties With Pricing

- How to Value the Benefits of Radio Astronomy?
  - > Contribution in Astronomical Knowledge and View of Our Place in the Universe
  - > Spin-offs Are Not Easily Valued
- All Exclusive Passive Spectrum Is Shared With EESS. How to Determine the Radio Astronomy Share of Usage?

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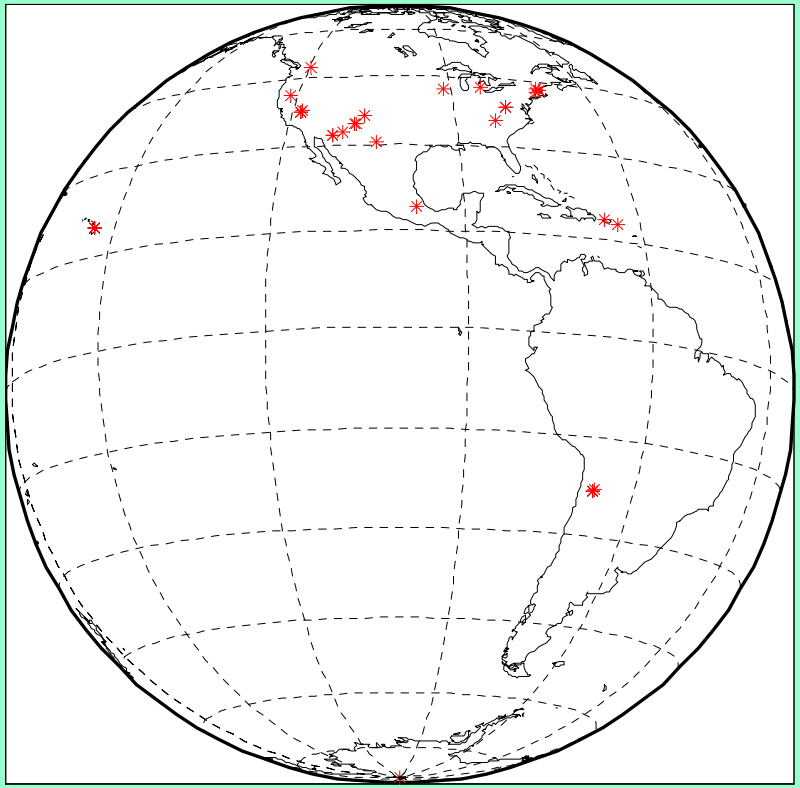
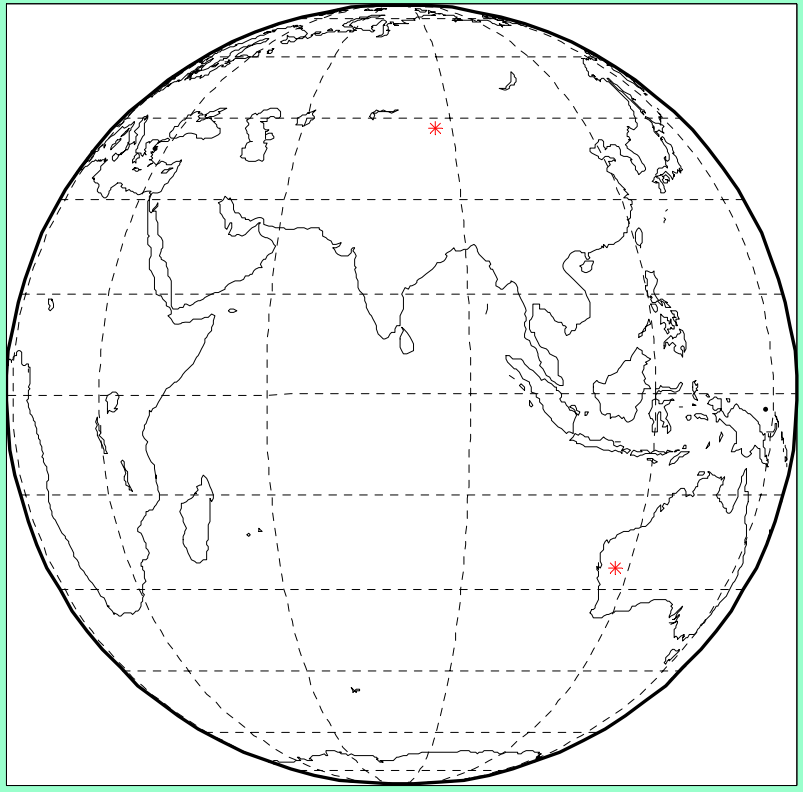
Radio Astronomy Observatories With Significant U.S. Investment





Frequency Span:
17 MHz – 1.5 THz
(~50 dB spread)

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EFFICIENCY

Beauty Is In the Eye of the Beholder!

There Is NO Universally Accepted Definition of Spectrum Efficiency!

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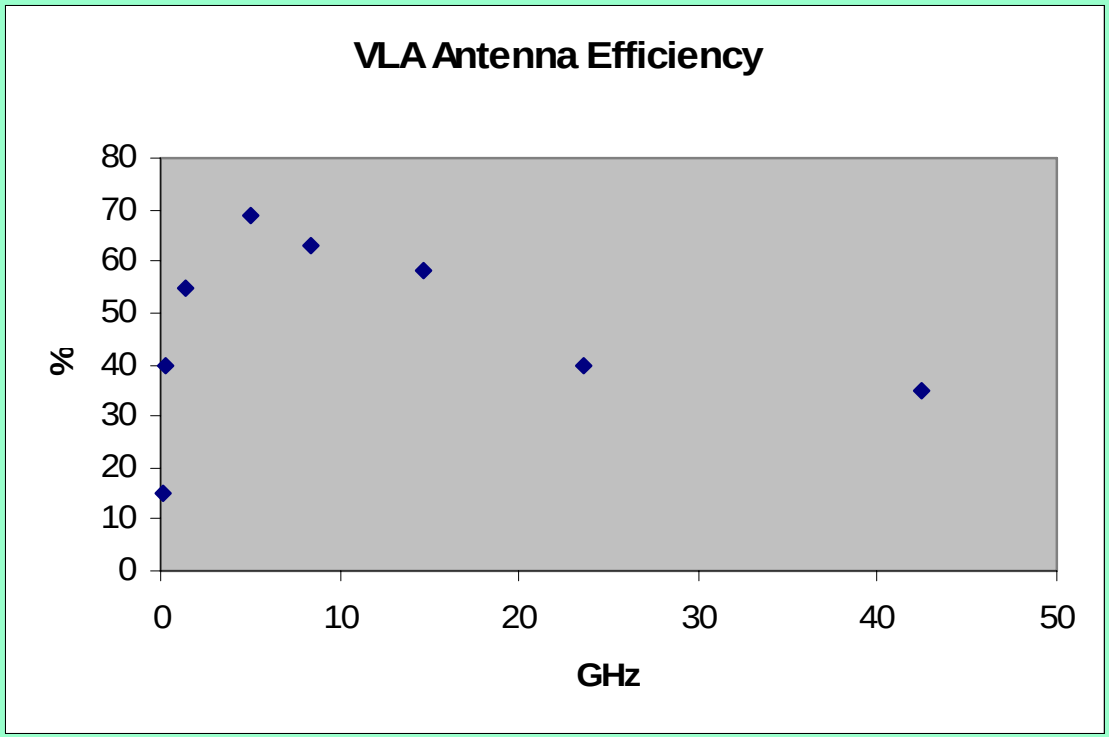
Efficiency of Radio Telescopes

Antenna Efficiency: Surface Deformations and Irregularities Degrade Antenna Performance, Resulting in Some of the Power Taken Out of the Main Beam and Deposited in the Sidelobes



Receiver Efficiency: radio astronomy receivers operate close to the quantum limit

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Science Efficiency 1

- Measuring Scientific Productivity and Impact Is Difficult
- Cost Effectiveness Comparison Between Radio, Optical and Space Based Telescopes (1994):

Year	Radio	Optical	Space
1990	0.26 +/-0.05	0.76+/0.12	0.22+/-0.02
1994	0.15+/-0.03	0.52+/-0.09	0.13+/-0.02

Defined as N/C, where N is the number of highly cited papers per year and C is the capital write-off cost (10 years)

- Includes all American, British Radio and Optical Ground Based and all American, British and ESA Space Based

Source: "The Cost and Citation-Based Effectiveness of Observational Astronomical Facilities Since 1958", D. Leverington, Ph.D Thesis, Open U., 1997

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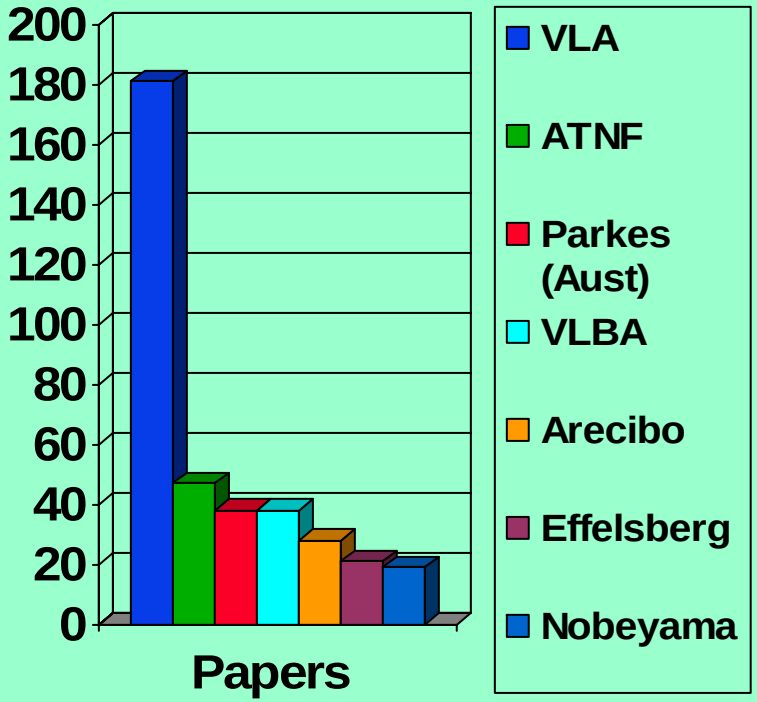
Science Efficiency 2



- Weighted number of papers published in the year 2002.
- Very Large Array (VLA) is the world ‘s most productive radio telescope and arguably most productive astronomical instrument.
- Source: “Productivity and Impact of Radio Telescopes.” V. Trimble and P Zaich, 2005 submitted to Pub. of the Astron. Soc. of the Pacific

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Some Radio Astronomy Trends

- Increasing tendency towards broadband receivers that are required by the science, as opposed to receivers confined to radio astronomy allocations. The tendency is accentuated for interferometers, that are considerably less sensitive to interference than single dish telescopes.
- Dynamic scheduling. Telescopes are scheduled to observe in the band with the best prevailing atmospheric conditions, particularly at shorter wavelengths, where the atmosphere matters most.

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SUMMARY

- The value of spectrum used by Radio Astronomy (and other passive services) is difficult to evaluate in $ terms
- Spectrum fees are likely to stifle or even make these services unviable (not unique to radio astronomy!). There are lost opportunities (E.g. in lost innovation and scientific knowledge associated with such an outcome
- Dynamic sharing offers more promise, but details must be carefully thought out with the involvement of the science community