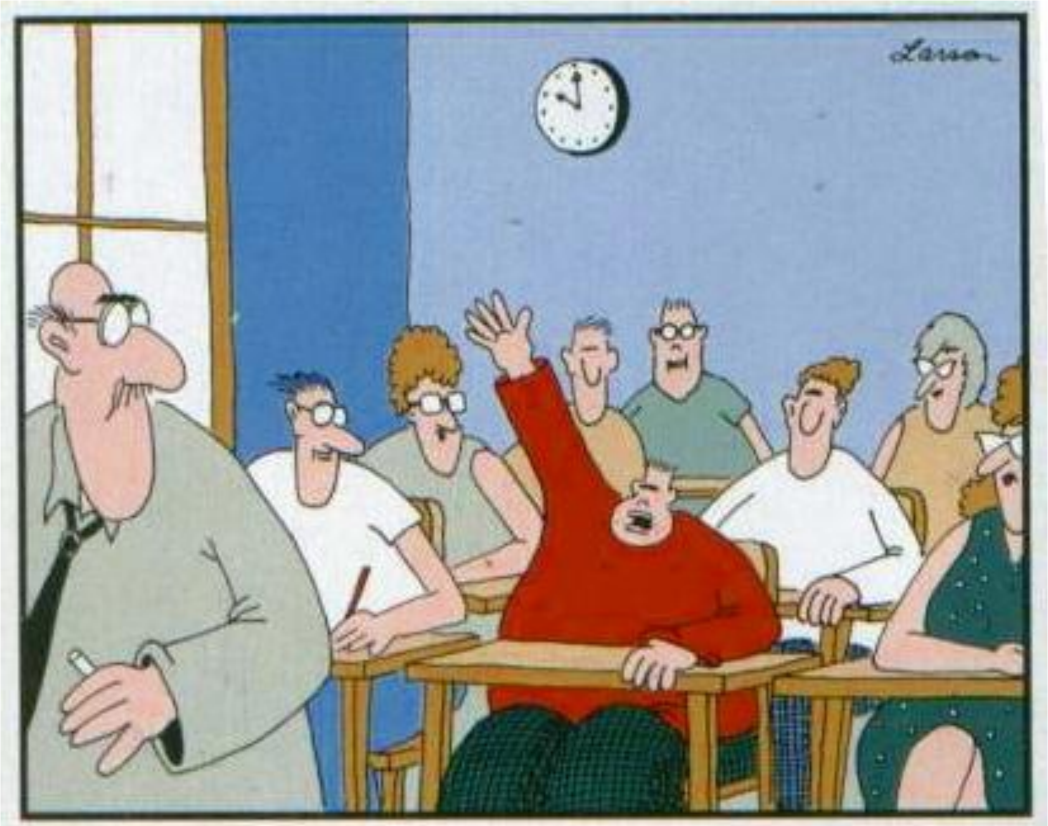
Extragalactic Science

Jim Condon

Twelfth Synthesis Imaging Workshop

2010 June 8-15



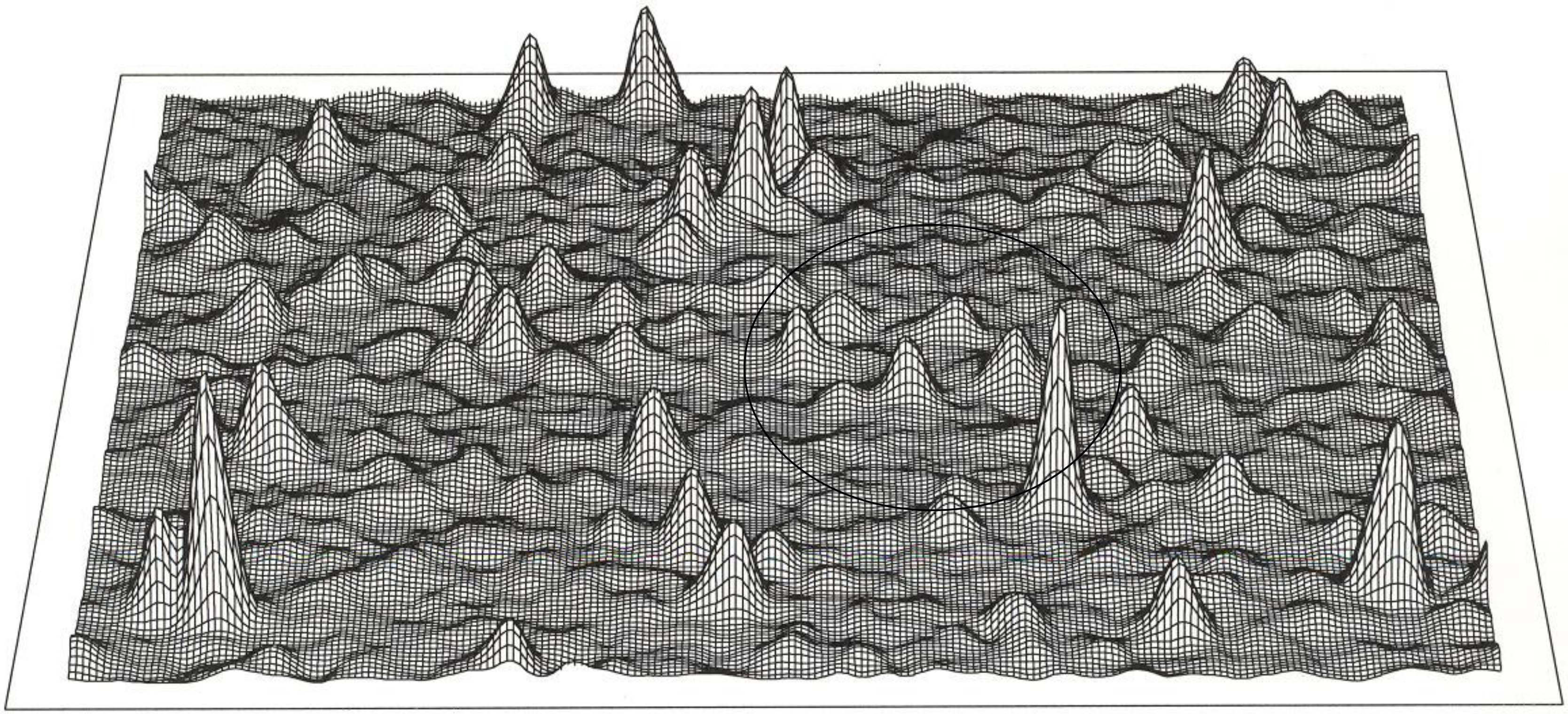
"Mr. Osborne, may I be excused?
My brain is full."

How can synthesis imaging help me do better science?

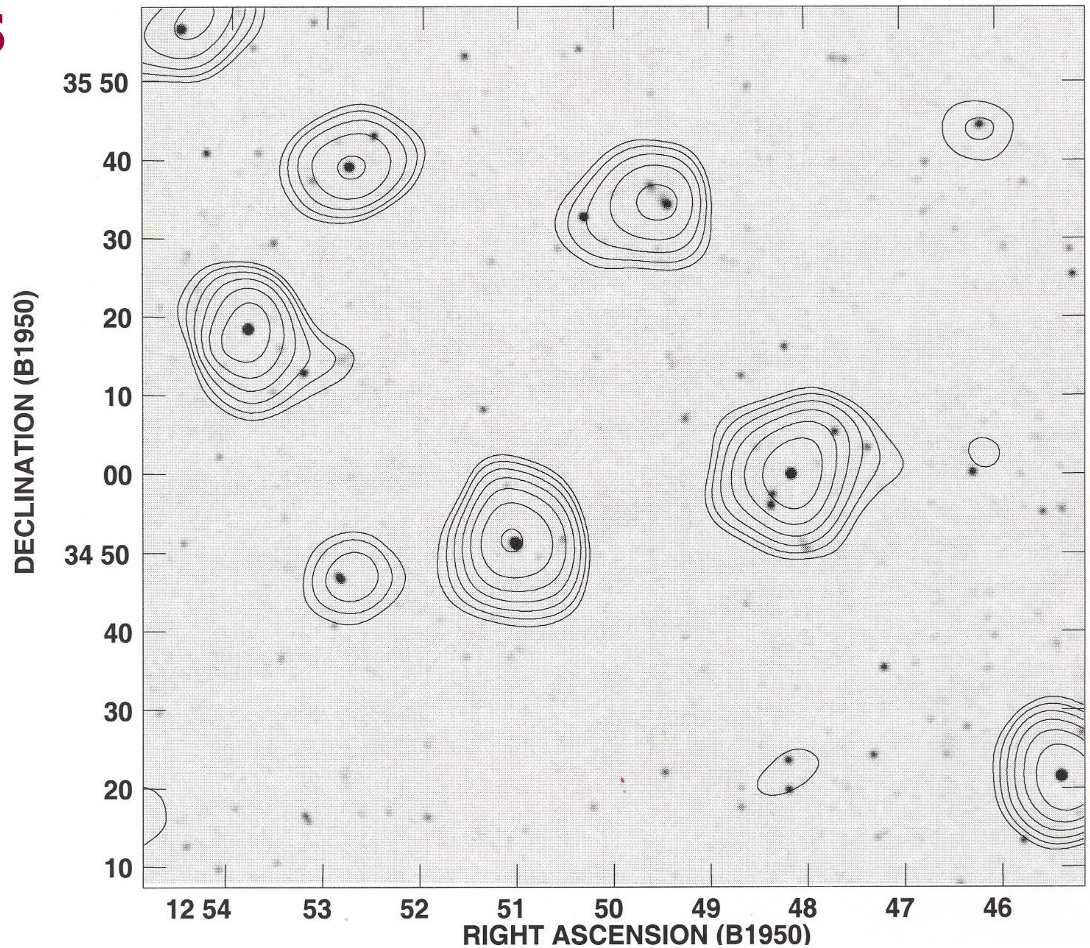
Science benefits of synthesis imaging

- Higher angular resolution: diffraction limited by the size of the array, not by the size of each telescope
- Correlation zeros or differentiates out most unwanted effects (e.g., varying atmospheric emission, ground radiation, "1/f" noise, RFI, …)
- Higher sensitivity is reached via longer practical integration times and lower "confusion" caused by unresolved background sources
- Higher spectral resolution: lag correlators measure frequencies very accurately with clocks, not wavelengths with rulers.
- Higher dynamic range is possible because the point-source response can be controlled and modified (e.g., selfcal, clean) and is nearly independent of mechanical pointing errors.
- Higher astrometric accuracy by using clocks instead of rulers to determine angles, and eliminating plane-parallel atmospheric refraction

Beating Confusion (GB 300-ft at 1.4 GHz)



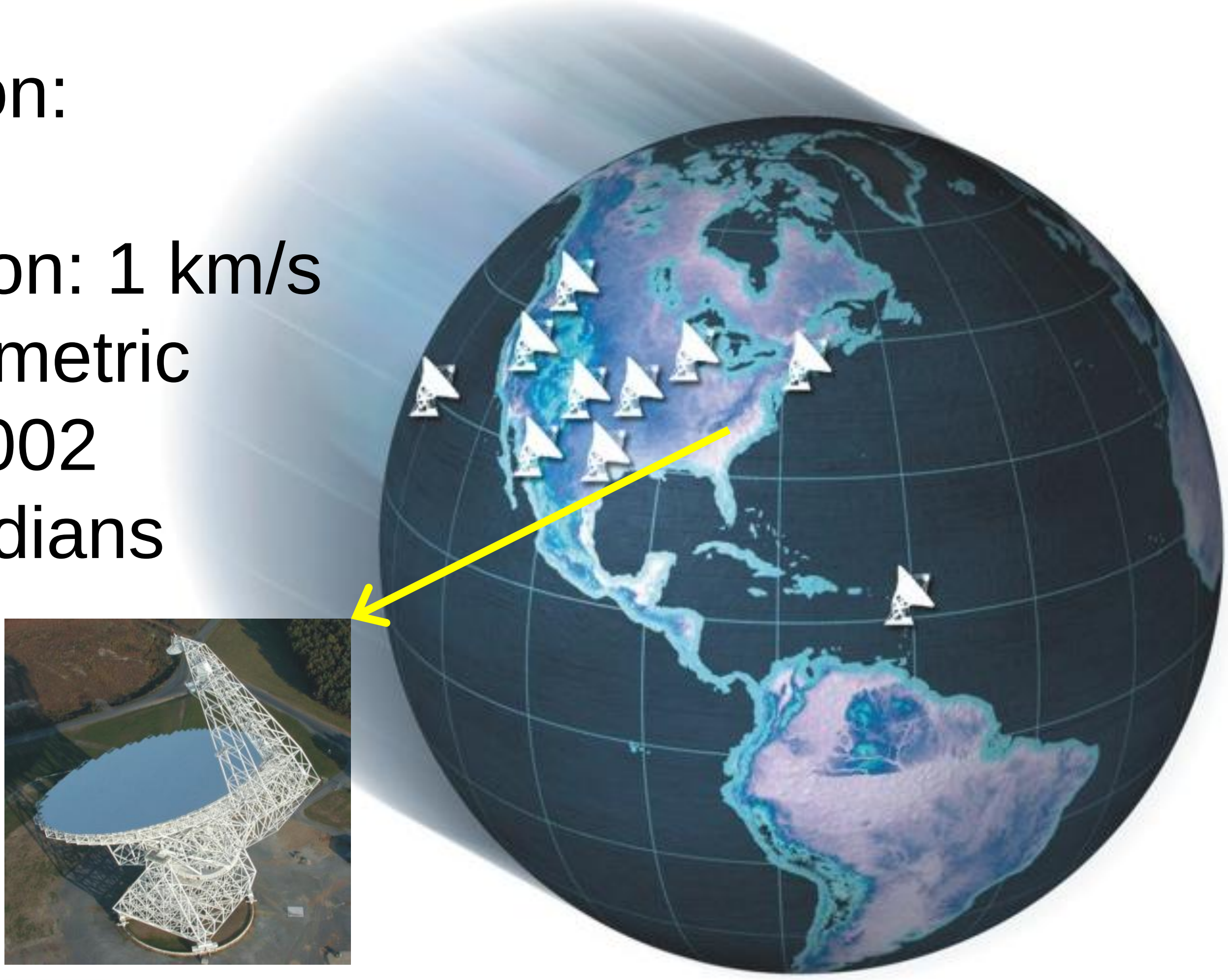
NVSS (45 arcsec beam) grayscale under GB 300-ft (12 arcmin beam) contours



$\sigma_c \sim 1$ μJy/beam ×
$(\theta$ / 5 arcsec$)^2$ ×
$(\nu$ / 1.4 GHz$)^{-0.7}$

22 GHz H_2O maser disk imaging and astrometry with the HSA = GBT + VLBA

Angular resolution:
0.0003 arcsec
Spectral resolution: 1 km/s
Differential astrometric precision: 0.000002 arcsec ≈ 10^{-11} radians



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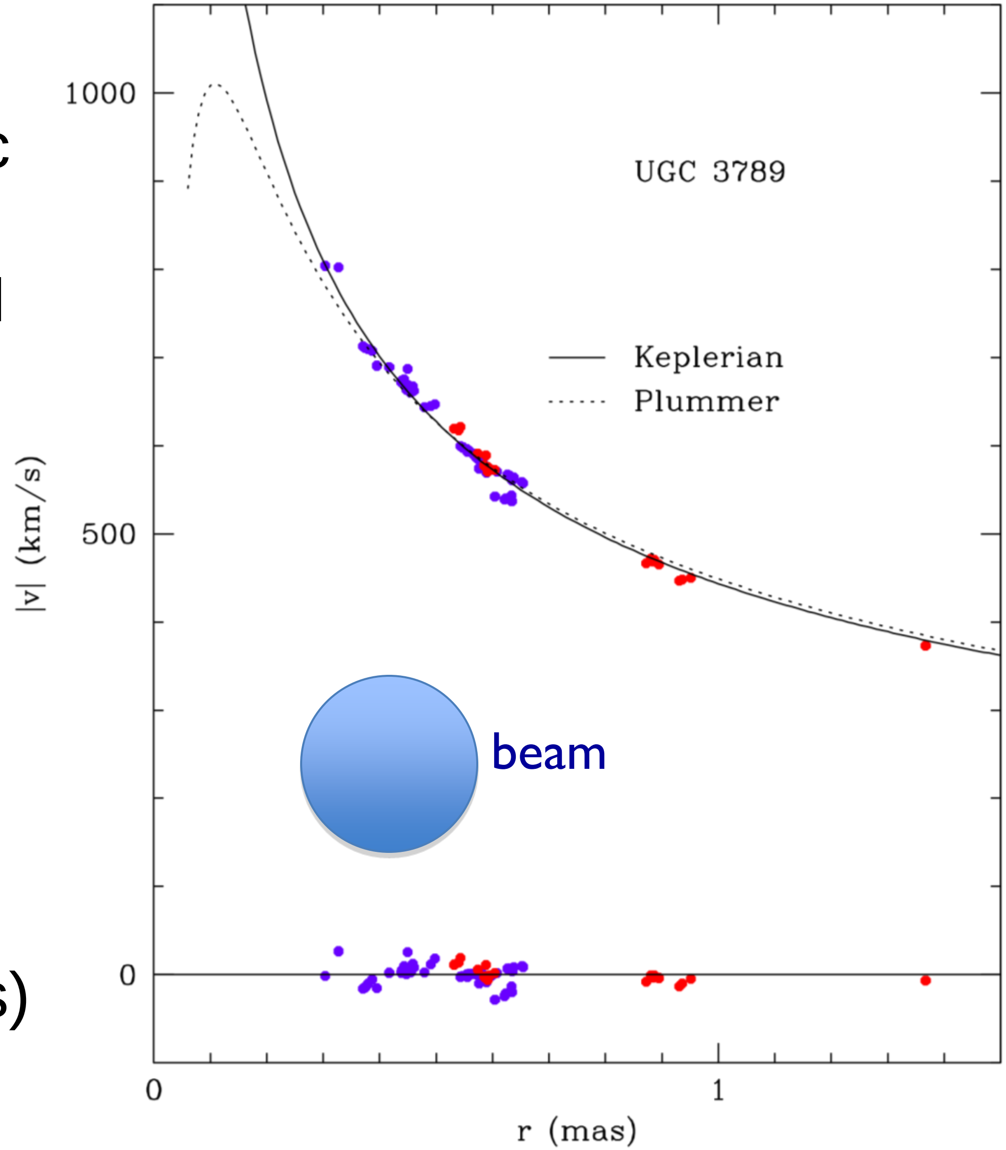
Maser rotation curve of UGC 3789

Distance = 50 ± 7 Mpc
so H_0 = 69 ± 11 km/s/Mpc

1.09 × 10^7 solar mass BH
or dense "star" cluster?
Plummer distribution:
$\rho(r) = \rho_0\,(1 + r^2/\,c^2)^{-5/2}$
1. Evaporation if N small
2. Collisions if N large

$\rho_0 > 4 \times 10^{11}\ M_{sun}/pc^3$
$m_* < 0.08\ M_{sun}\quad N_* > 10^8$

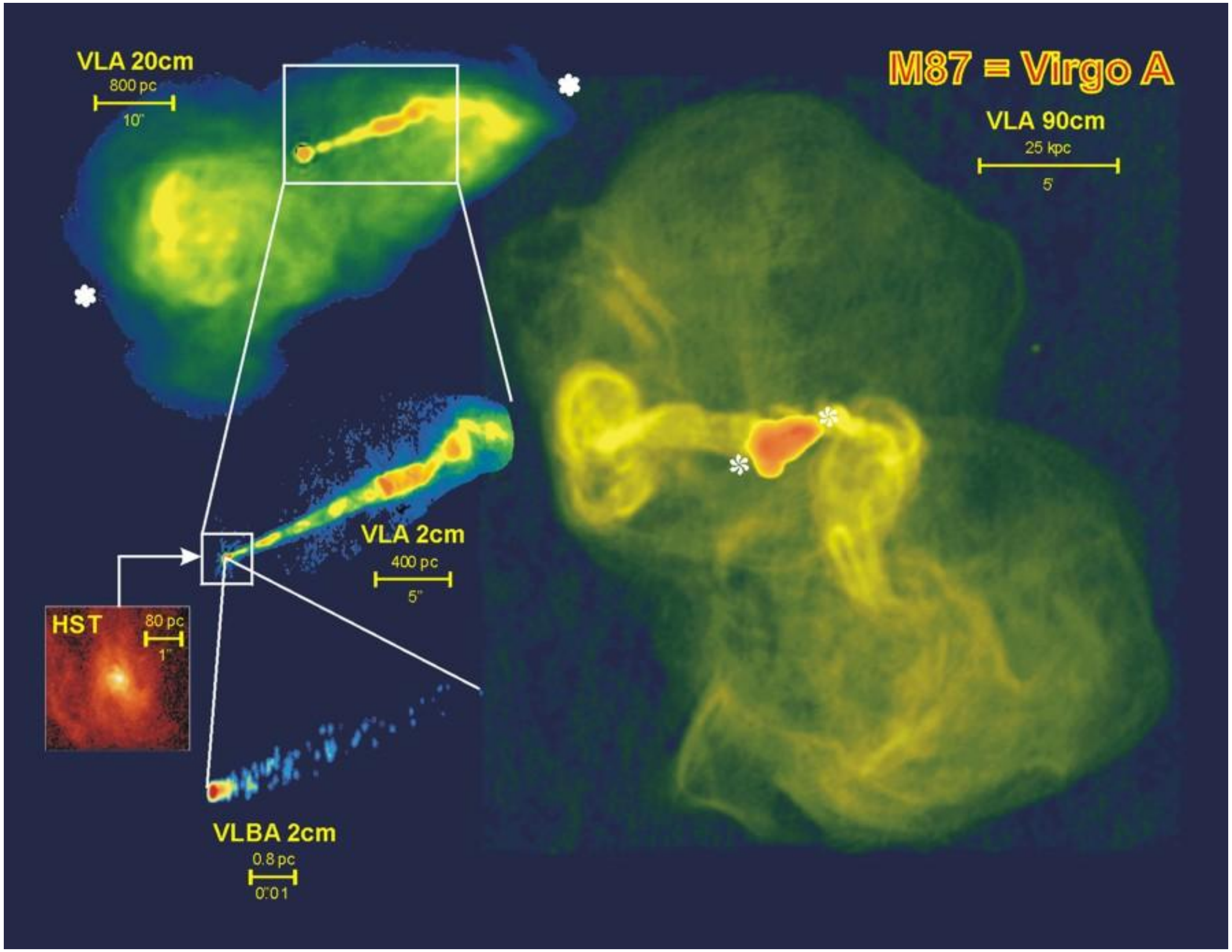
(Braatz et al. ApJ in press)



Science costs of synthesis imaging

- Loss of "zero spacing" flux on extended sources (this is primarily a problem for nearby Galactic sources)
- Poor surface-brightness sensitivity at high angular resolution because the array area "filling factor" is low
- Computational costs may limit total bandwidth, spectral resolution, time resolution, field-of-view, … Complexity also limits multibeaming, pulsar observations, etc.
- Quantum noise limits sensitive synthesis imaging to radio frequencies!

Resolution versus surface-brightness sensitivity



The quantum noise limit for coherent amplification

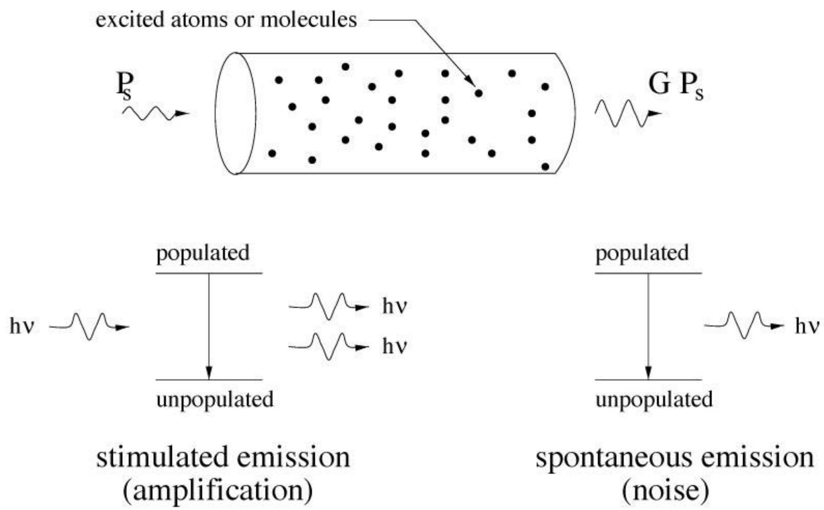


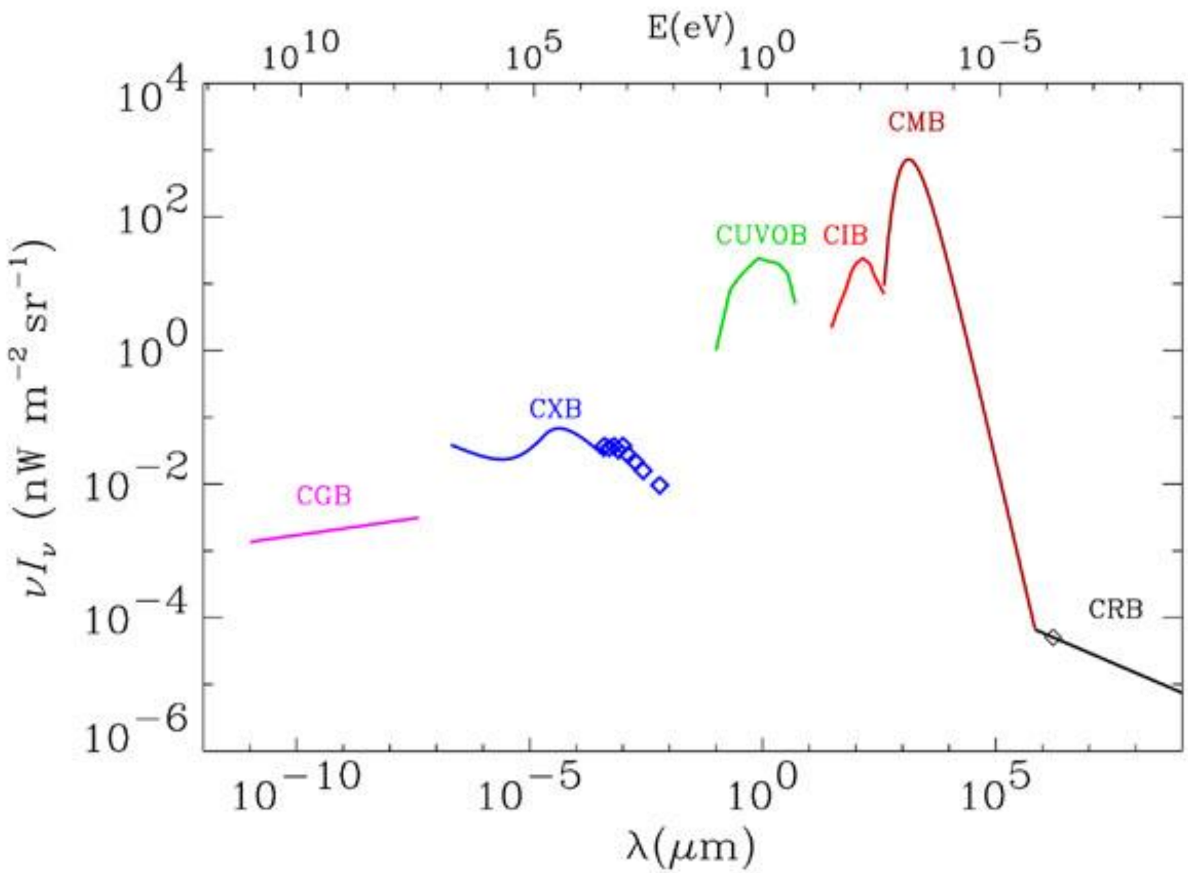
Fig. 2: An illustration of quantum noise in a maser amplifier. This (fictitious) maser amplifier consists of a tube filled with a gas of molecules or atoms, which are pumped in a way that causes some transition with frequency ν to be inverted. A signal arriving at the input with power P_s is amplified by stimulated emission and emerges with power GP_s, where G is the power gain of the amplifier. However, due to spontaneous emission, noise photons emerge from the amplifier output even when $P_s = 0$.

T / ν = h / k = 48 K / THz

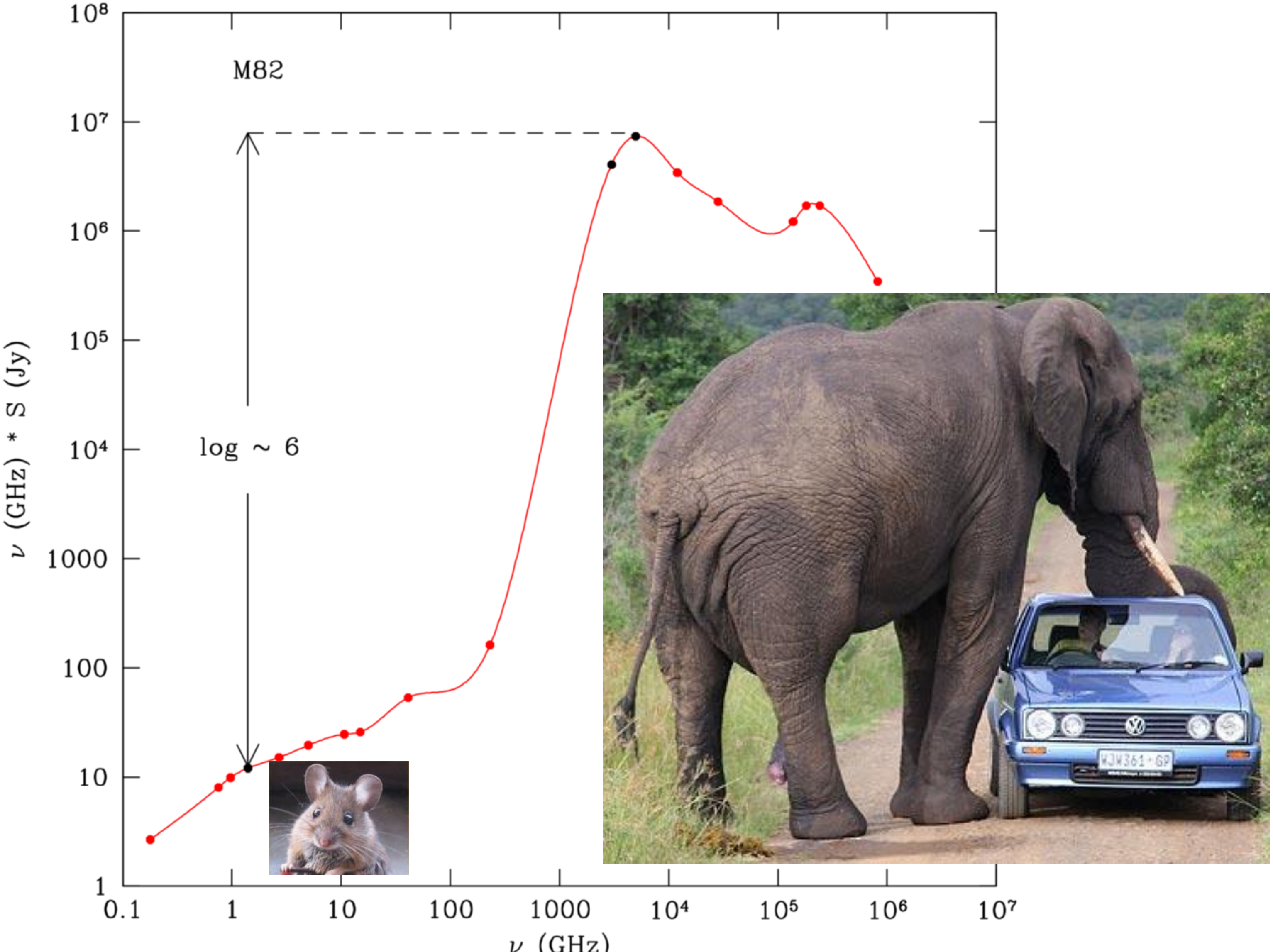
e.g., ~ 150 K at λ = 100 μm

~ 15000 K at λ = 1 μm

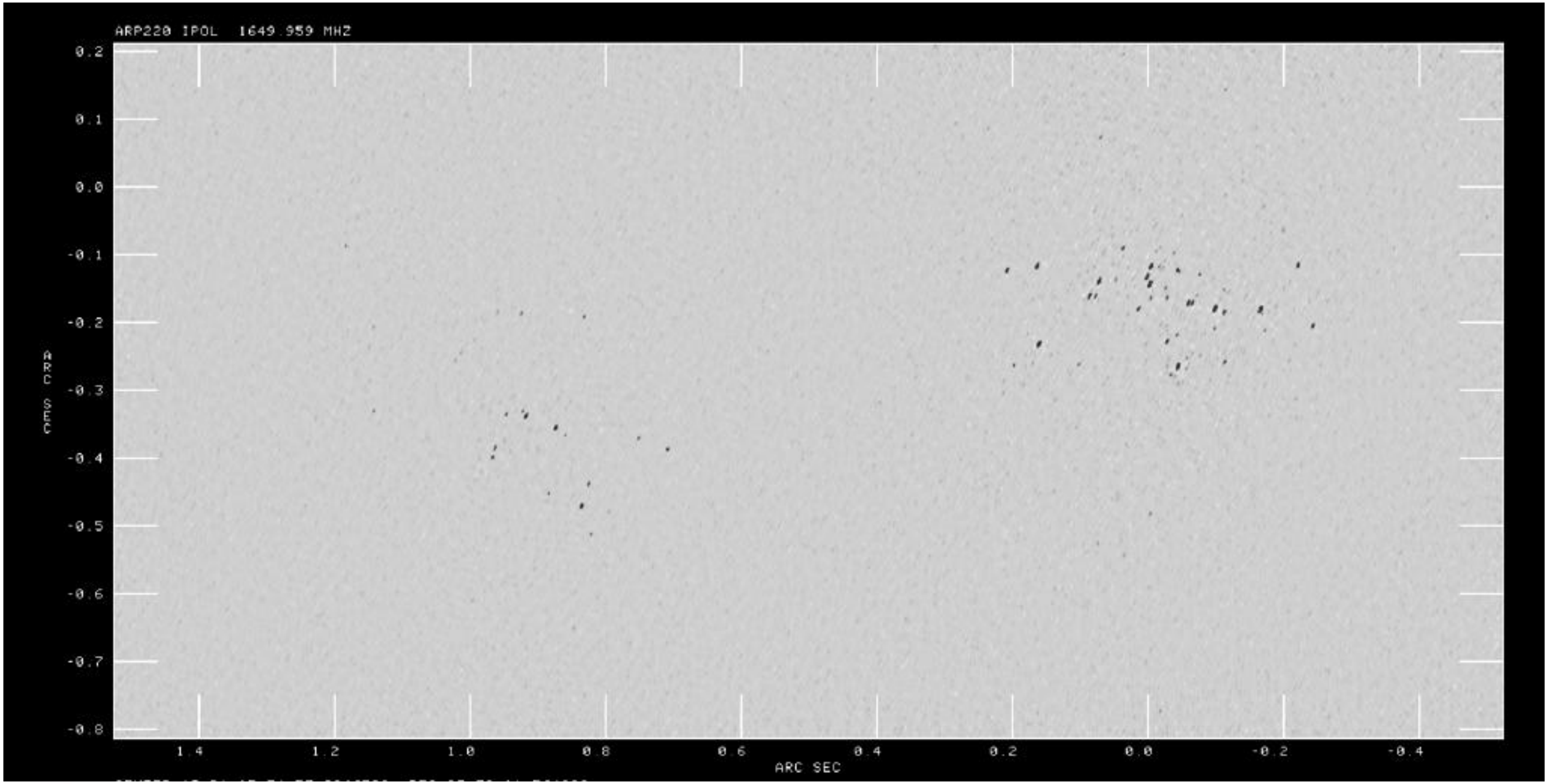
What is the main limitation of <u>radio</u> astronomy?



Normal galaxies example: Mouse vs. elephant



VLBA/HSA Image of the Starburst Nuclei in the ULIRG Arp 220



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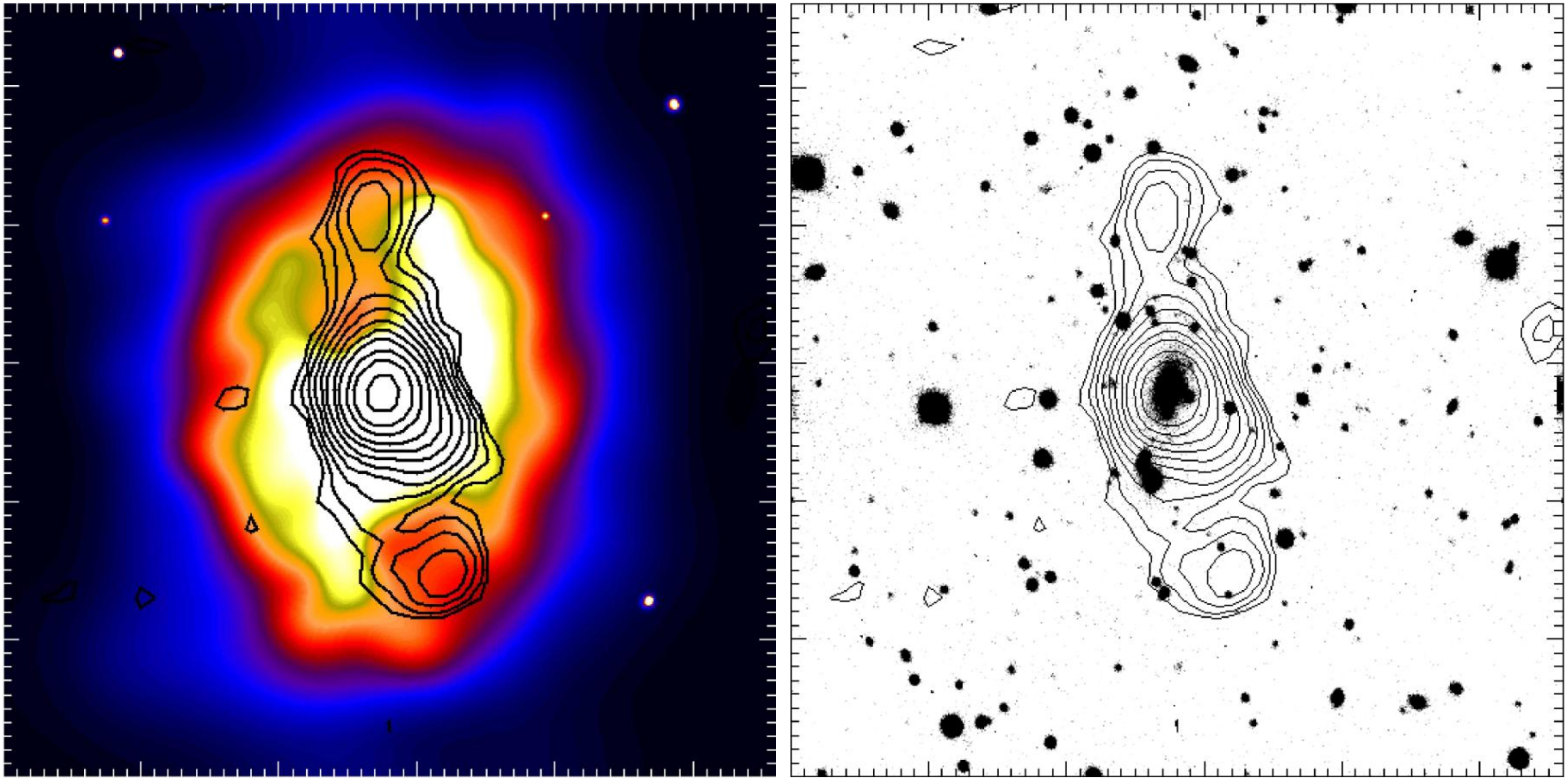
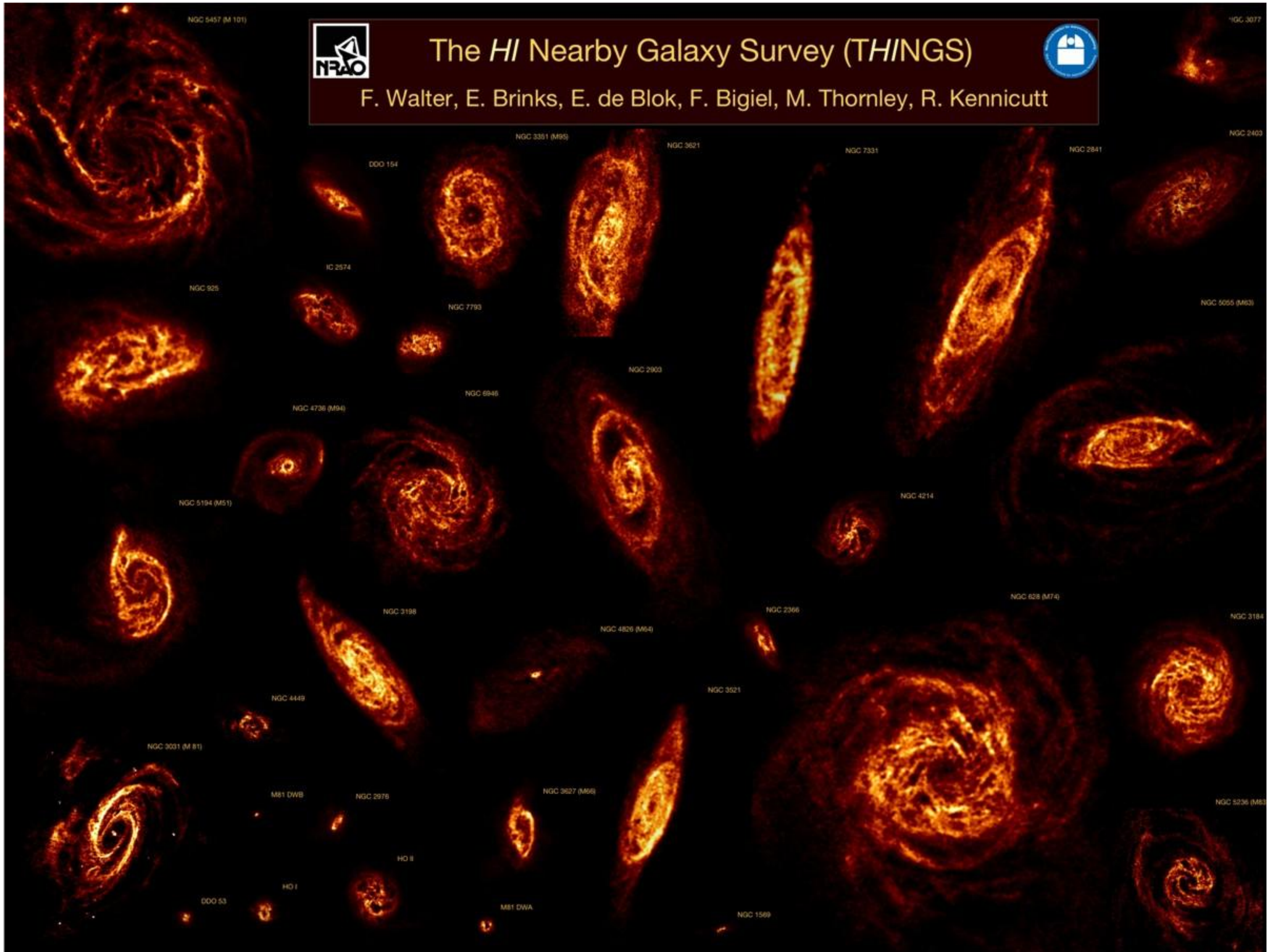
Jet Energy via Radio Bubbles in Hot Cluster Gas



Radio Spectral Lines: Cold Gas



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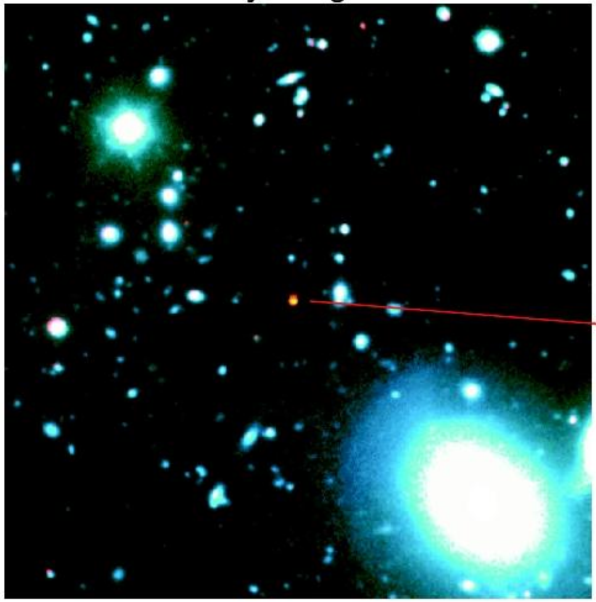
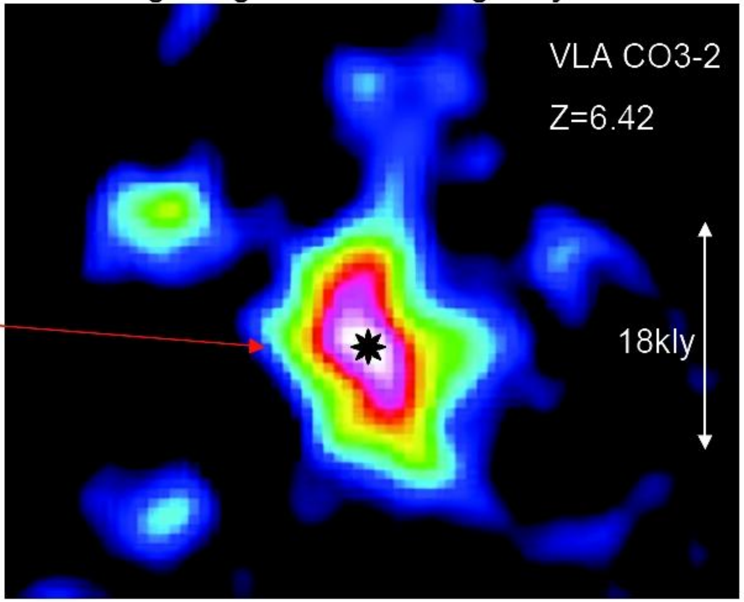
The EOR Quasar at z = 6.42

Sloan Discovery Image



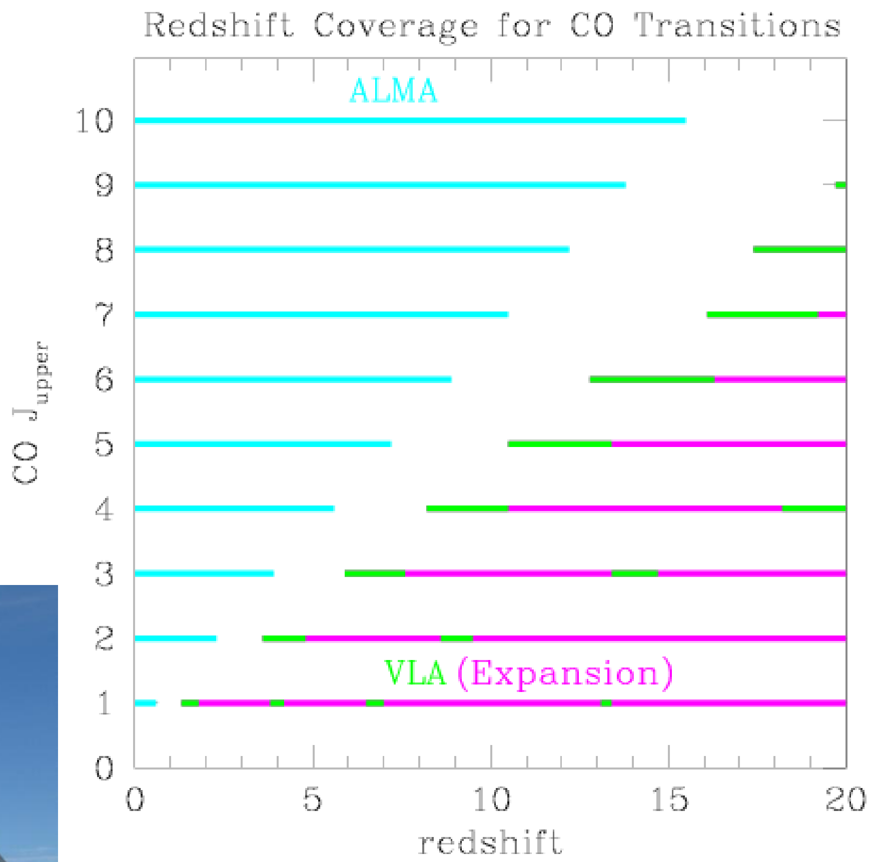
VLA image of giant molecular galaxy



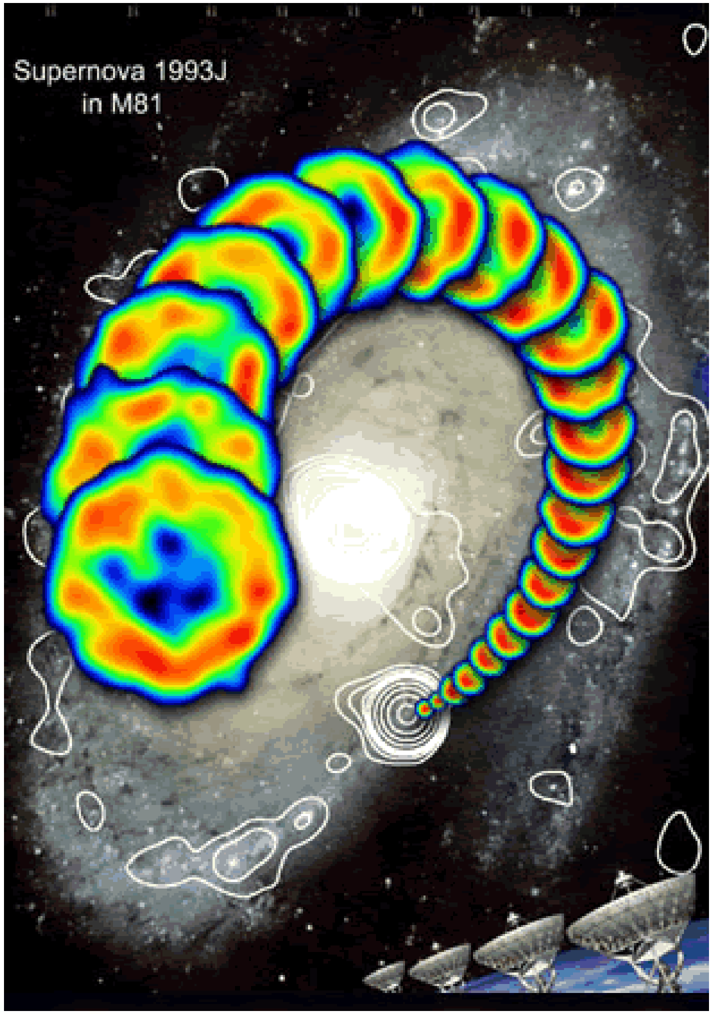
J1148+5251: Coeval formation of a super massive black hole and giant elliptical galaxy within 870Myr of the Big Bang

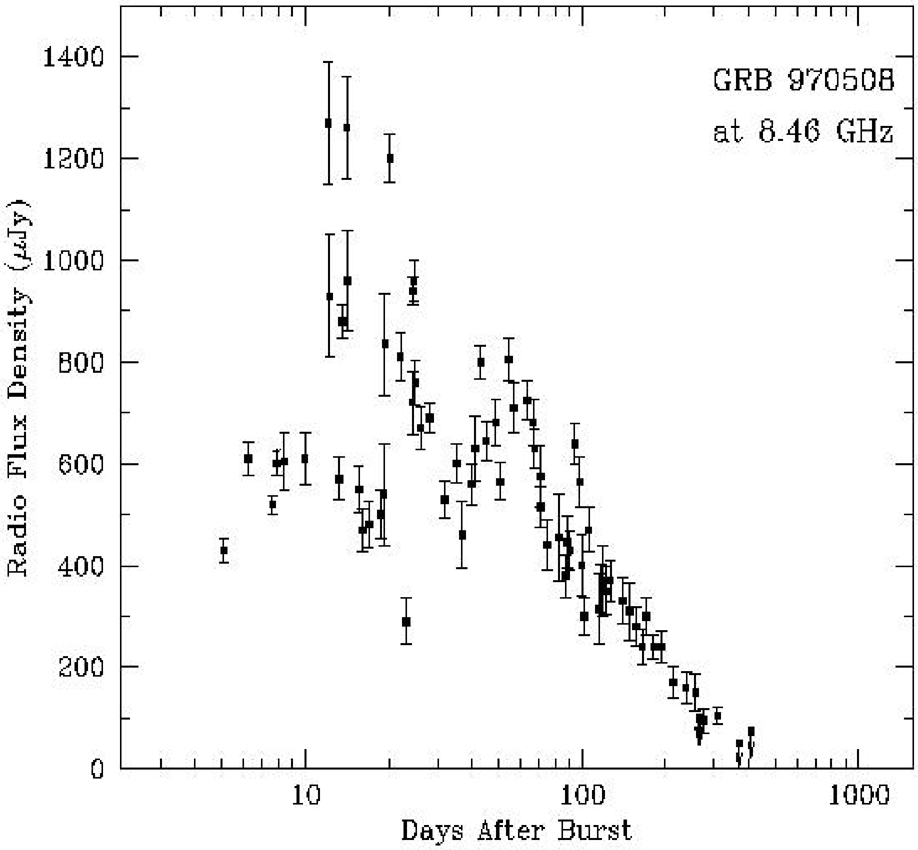
EVLA and ALMA together

- EVLA continuous frequency coverage from 1 GHz to 50 GHz
- Detect CO at almost any redshift
- Study excitation of star-forming gas in distant galaxies

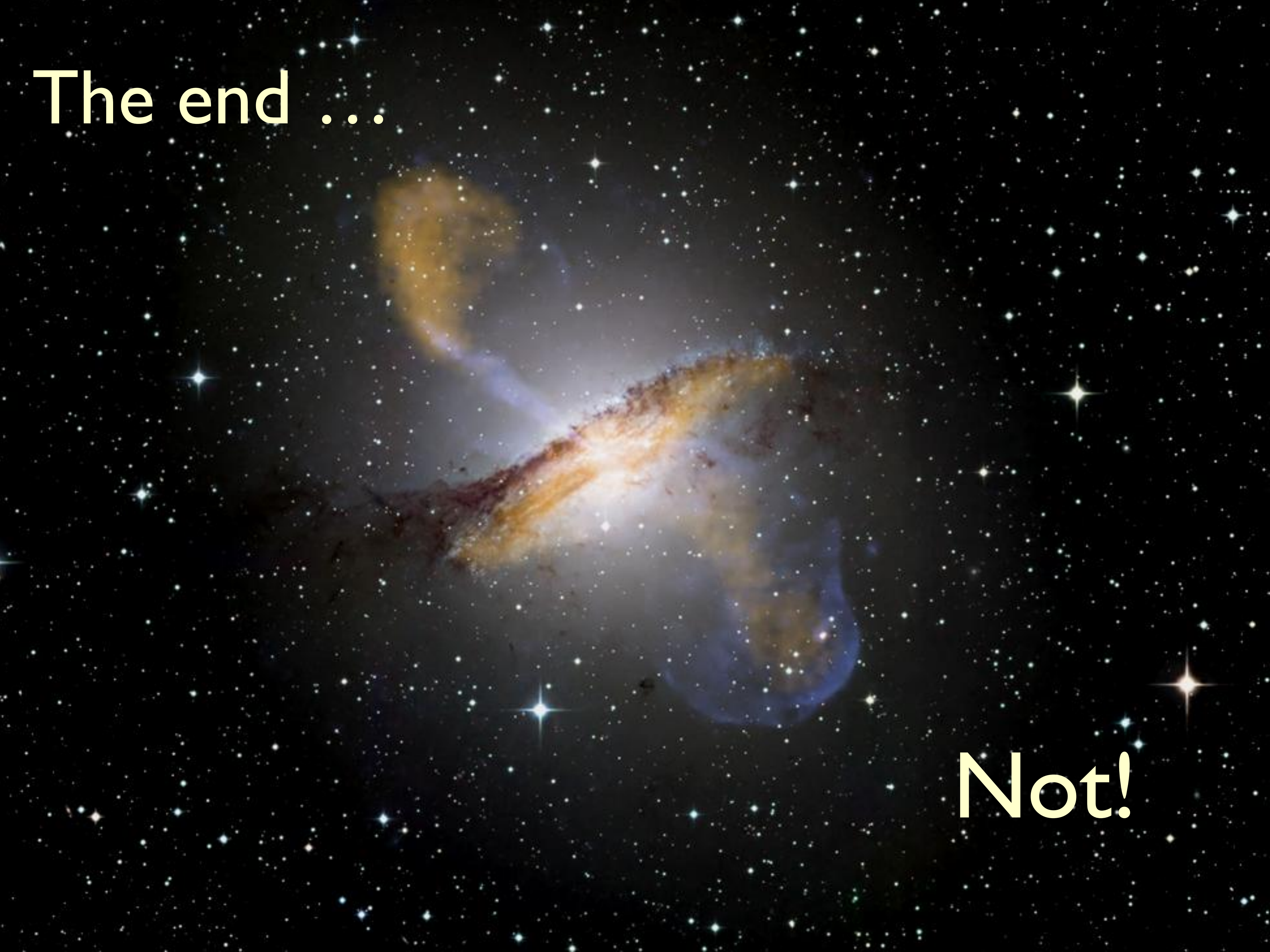


Parts of external galaxies: SNe and GRBs





Take-away message: Synthesis imaging is the secret weapon of radio astronomy


The end ...
Not!