Extragalactic Science

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Eleventh Synthesis Imaging Workshop
Socorro, June 10-17, 2008
Why Synthesis Imaging?

Angular resolution can be specified by the observer (to reduce “confusion,” match angular scales of the source or multiwavelength data -- but trade off surface-brightness sensitivity)

Extremely accurate absolute astrometry (high angular resolution, clocks instead of rulers, no plane-parallel refraction)

High dynamic range via deconvolution and self-calibration “fixing” telescope

High sensitivity via long integrations, suppression of “baseline” errors and RFI

(Figures from Brunthaler et al. 2005, Science, 307, 1440)
Extragalactic Science: The radio continuum sky at 45 arcsec resolution — Where’s our Galaxy?

$$\delta > -40^\circ$$
$$S > 100 \text{ mJy}$$
“It’s turtles all the way down”

\[ \delta > +75^\circ \]

\[ S > 2.5 \text{ mJy} \]
Flux density versus luminosity of radio sources

- Evolution 10X in luminosity → few nearby sources, <z> ~ 1
- “shell” → L ∝ S
- AGNs at high L, S
- Star-forming galaxies at low L, S
Centaurus A at radio (purple), optical, and X-ray wavelengths
Jet Energy via Radio Bubbles in Hot Cluster Gas

\[6 \times 10^{61} \text{ ergs} \sim 3 \times 10^7 \text{ solar masses} \times c^2\] (McNamara et al. 2005, Nature, 433, 45)
Resolution and Surface-brightness Sensitivity

M87 = Virgo A

VLA 20cm
800 pc
10"

VLA 2cm
400 pc
5"

VLBA 2cm
0.8 pc
0.1"

HST
80 pc
1"

VLA 90cm
25 kpc
5"
Superluminal Motion in Compact Jets
Resolving the circumnuclear disk in NGC 4258 and directly measuring the black-hole mass
Beating Confusion
“RMS” confusion

\[ \sigma_c \approx 0.2 \nu^{-0.7} \theta^2 \]

where

- \( \sigma \) is in mJy/beam,
- \( \nu \) is in GHz, and
- \( \theta \) is in arcmin
Low Luminosity: AGN+Starbursts

\[ \theta = 5 \text{ arcsec} \]
\[ \sigma = 23 \text{ mJy/beam} \]
\[ (\sigma_c \sim 1 \text{ mJy/beam}) \]
Low Luminosity: Star-forming Galaxies

[Diagram showing emission at different wavelengths and frequency]
SNe and GRBs


de_\text{1993J in M81}

\begin{align*}
E_0 & \approx 5 \times 10^{50} \text{ erg} \\
n_0 & \approx 1 \text{ cm}^{-3}
\end{align*}

GRB 970508

at 8.46 GHz

Radio Flux Density (\mu Jy)

Days After Burst

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VLBA/HSA Image of the Starburst Nuclei in Arp 220

[Image of the VLBA/HSA image of the starburst nuclei in Arp 220]
Evolution of star formation

- Radio “Madau diagram”
- Free from dust extinction

![Graph showing the evolution of star formation with markers for CIRB, 1.4 GHz counts, 1.4 GHz LLF, and UV counts. The graph includes the Hubble constant $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, E-dS notation.]
Star Formation at High Redshift
Primordial Starbursts

I  K  LE 850.1
I  K  LE 850.2
I  K  LE 850.3

Galaxies z<1.5

Galaxies z>1.5
Radio Spectral Lines: Cold Gas

The HI Nearby Galaxy Survey (THINGS)
F. Walter, E. Brinks, E. de Blok, F. Bigiel, M. Thornley, R. Kennicutt
EVLA and ALMA

- Continuous frequency coverage from 1 GHz to 50 GHz
- Detect CO at almost any redshift
- Study excitation of star-forming gas in distant galaxies
The Most Distant Quasar

• VLA image of CO (4-3) from the first known star formation – Redshifted to 46 GHz

• Optical Image

Walter et al. 2003

• Artist’s conception of disk of molecules and dust

SDSS Discovery Image of J1148+5251: Quasar is Red Dot Pointed Out by Arrow
Geometric Distances, $H_0$, and Dark Energy

**Preliminary Properties of UGC 3789 Maser Disk**

- $R \sim 0.09 - 0.20$ pc (0.40 - 0.87 mas)
- $V \sim 750 - 450$ km/s
- $M_{bh} \sim 1.2 \times 10^7 M_{\odot}$
- $a \sim 3.6$ km s\(^{-1}\) yr\(^{-1}\) (mean value)
- $D \sim 51$ Mpc (15%)
- $H_0 \sim 64$ km s\(^{-1}\) Mpc\(^{-1}\)$
The End...

...NOT!