Interferometry and Targeted Follow-up Observations

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Undergraduate ALFALFA Team Workshop

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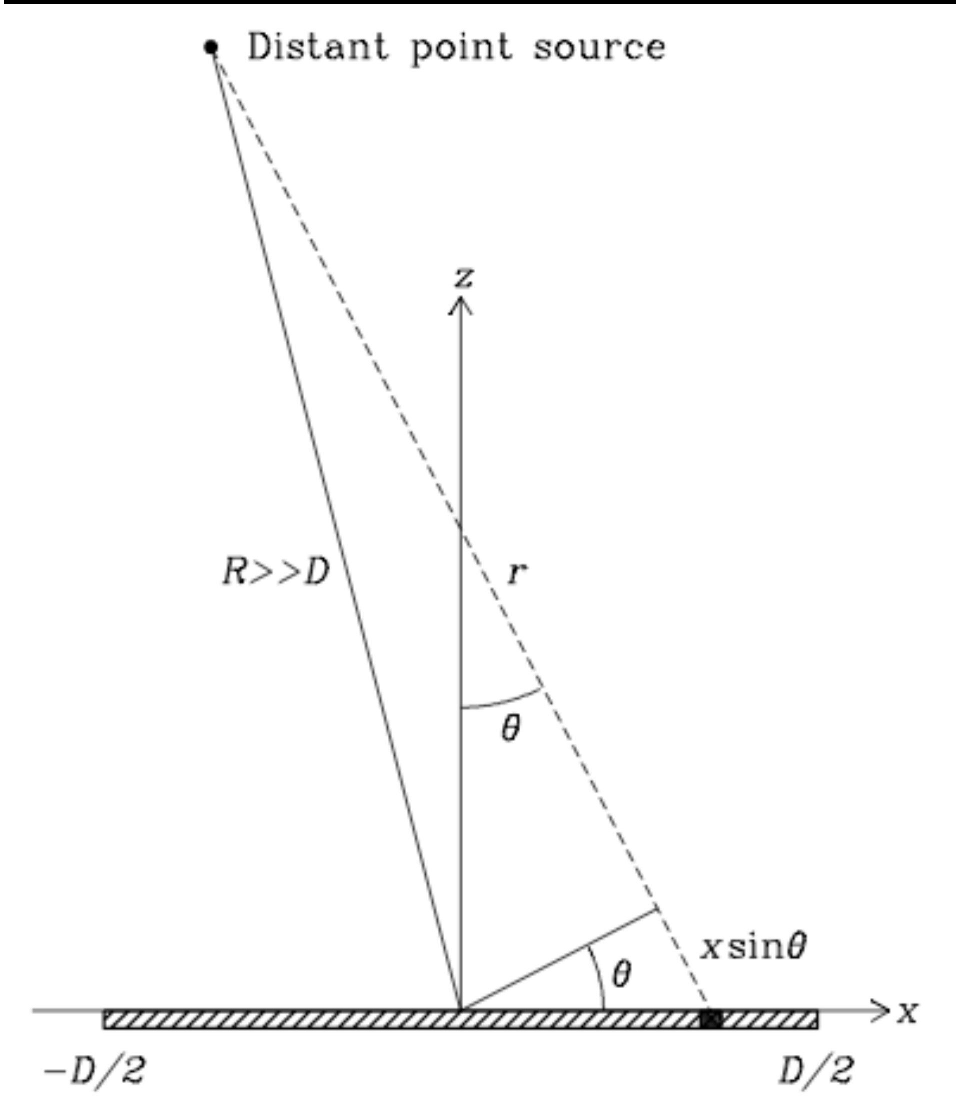
Outline

- Interferometry Fundamentals
- Recent Advances in Radio Technologies
- Types of Emission in the Radio Regime
- HI Spectral Line Observations
  - Example targeted HI observations of a nearby galaxy
- Specific ALFALFA Applications
  - SHIELD
  - "Dark galaxies"

Interferometry Fundamentals

- Antenna: device for converting EM waves into current
  - Antenna is the essence of a radio telescope; the dish just focuses radiation onto it
  - Radiation pattern of antenna same for transmitting and receiving
  - An antenna *IS* a radio telescope
    - You only need a "dish" if the collecting area of your antenna is small (Area ~ λ^2)

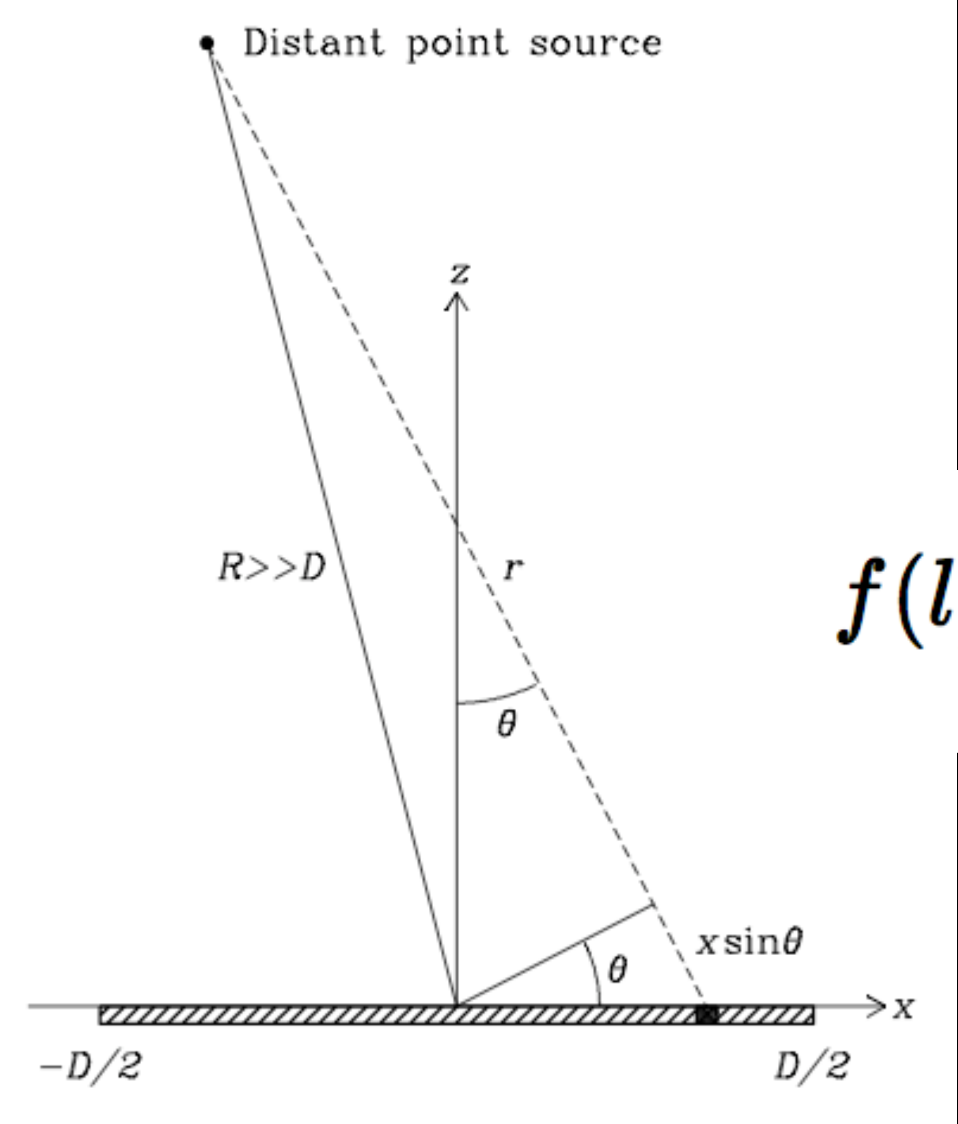
Interferometry Fundamentals



Incident (sinusoidal) EM wave induces (sinusoidal) current in antenna

$$J \propto g(x)\exp(-i\omega t)$$

Interferometry Fundamentals

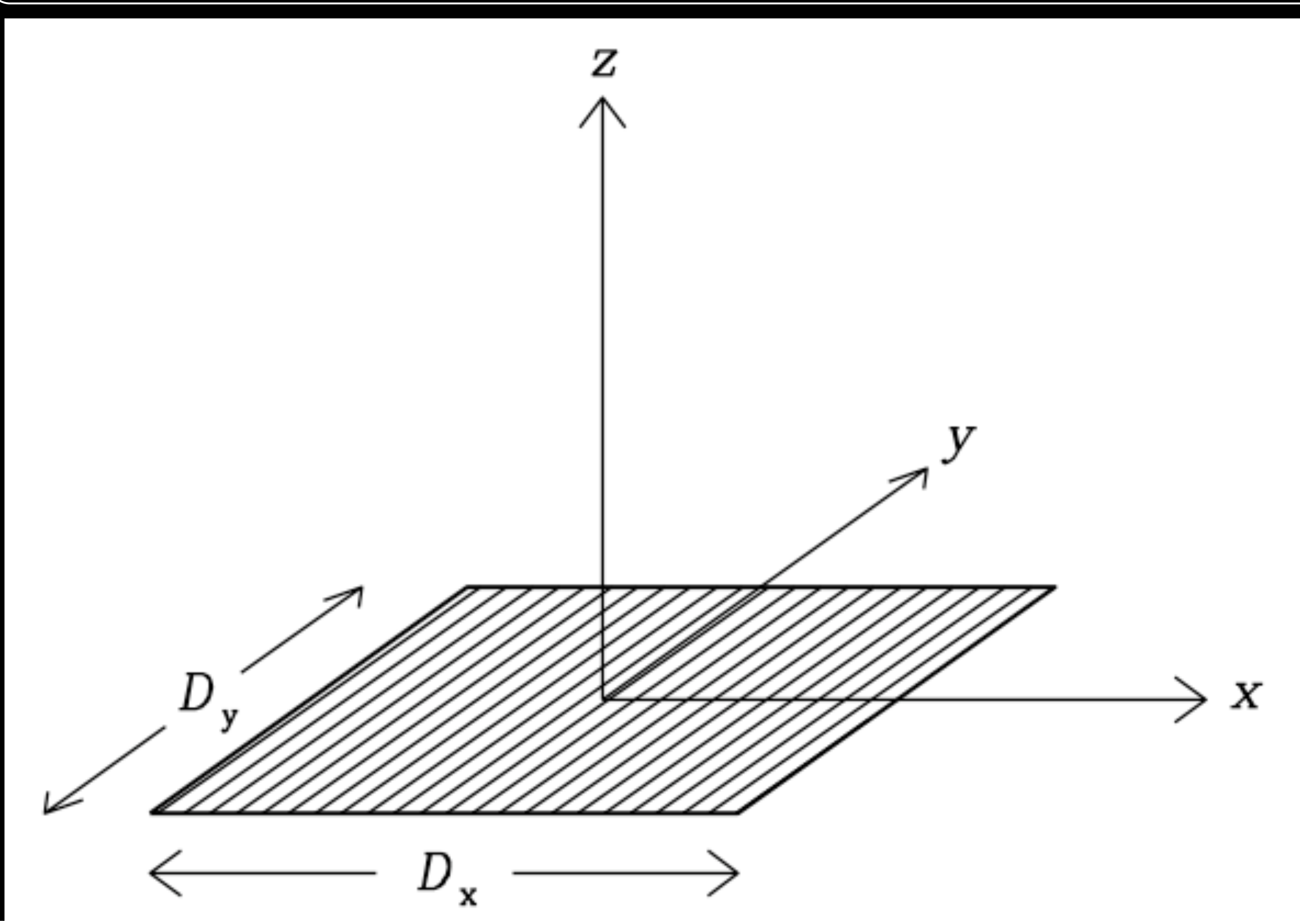


$$u \equiv \frac{x}{\lambda}$$

$$f(l) = \int_{\text{aperture}} g(u) e^{-i2\pi l u} du$$

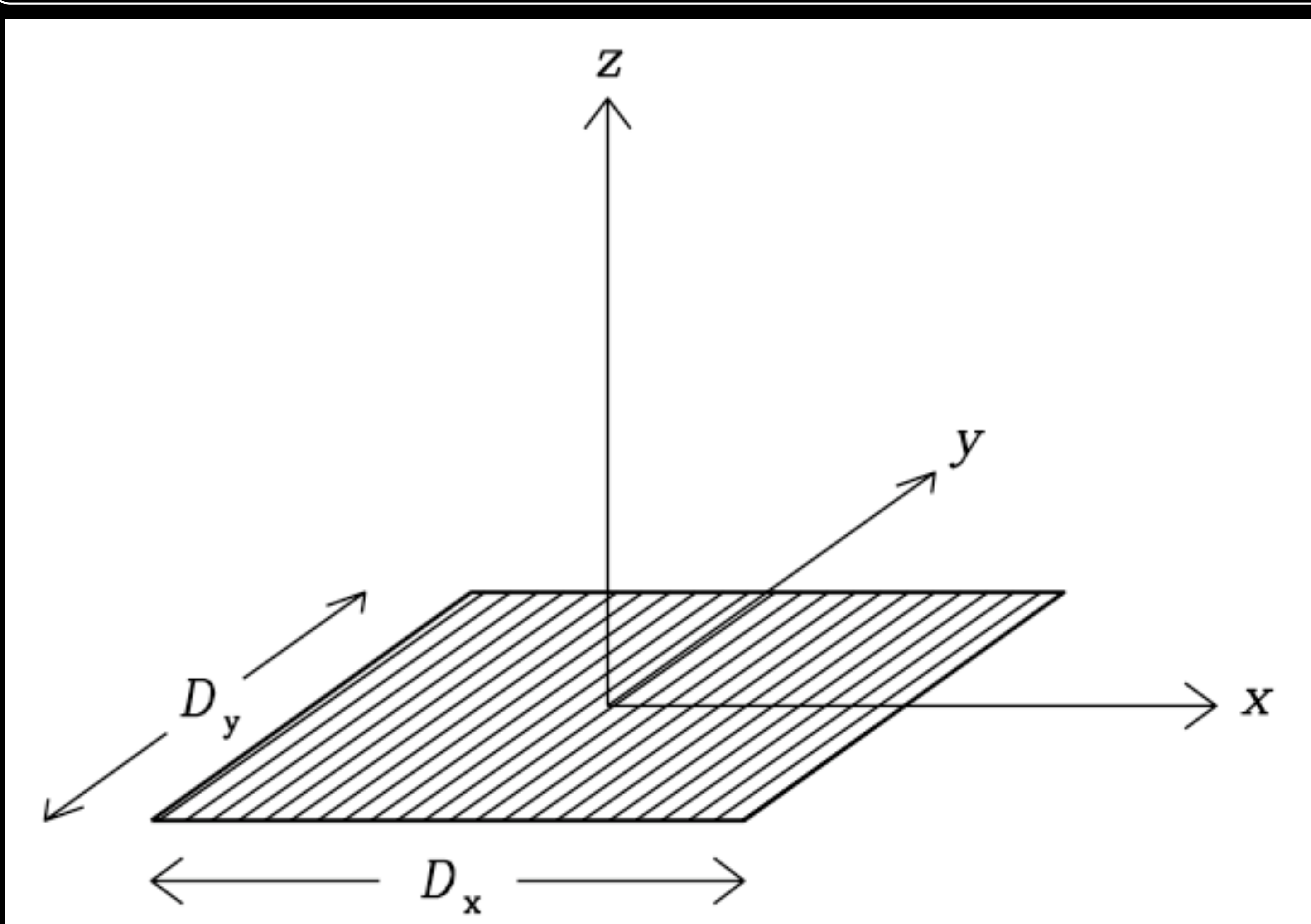
In the far field, the electric-field pattern of an aperture antenna is the Fourier transform of the electric field illuminating the aperture.

Interferometry Fundamentals



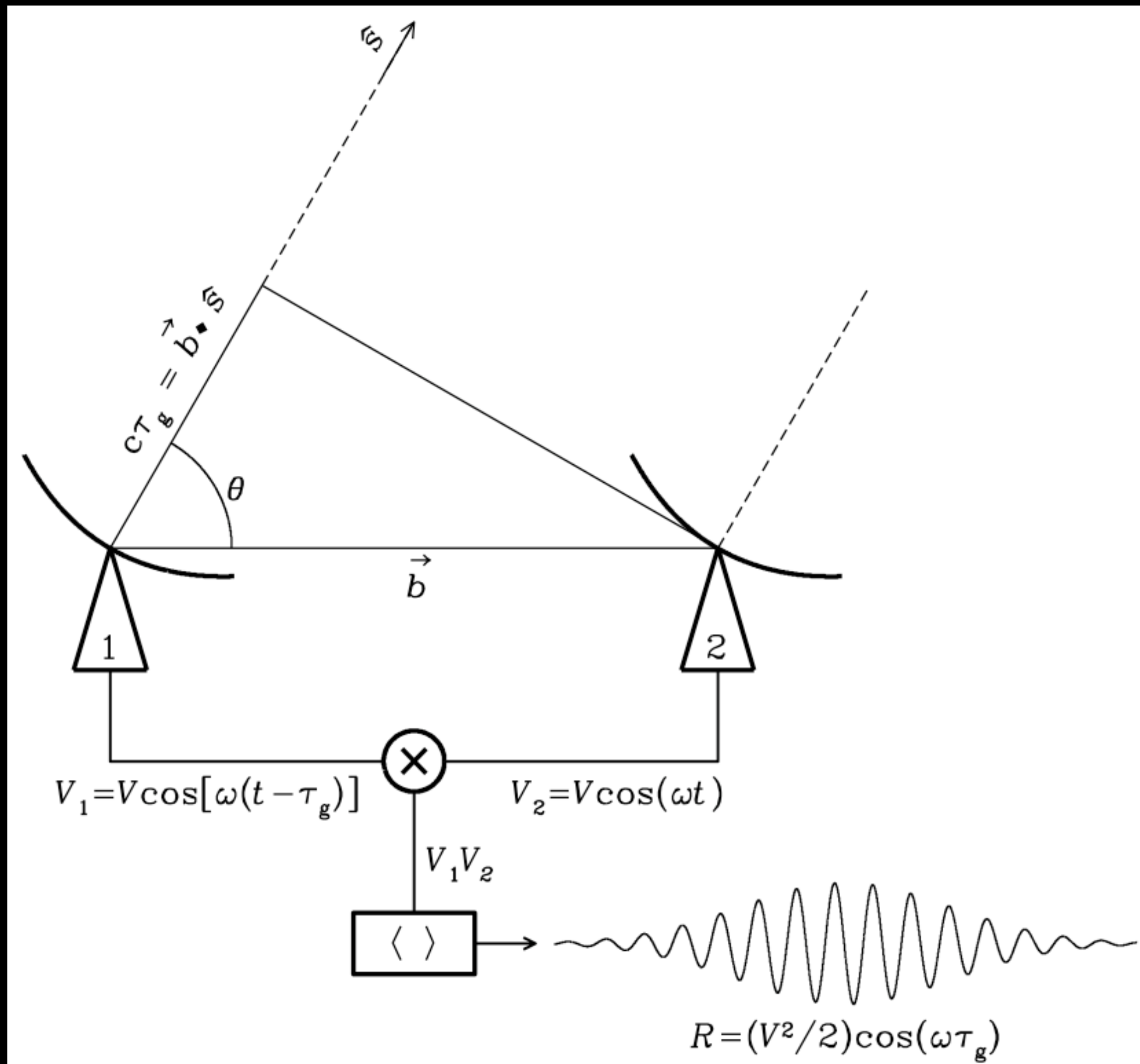
$$f(l,m) \propto \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(u,v)e^{-i2\pi(lu+mv)}dudv$$

Interferometry Fundamentals



The electric field pattern of a two-dimensional aperture is the two-dimensional Fourier transform of the aperture field illumination.

Interferometry Fundamentals



Interferometry Fundamentals

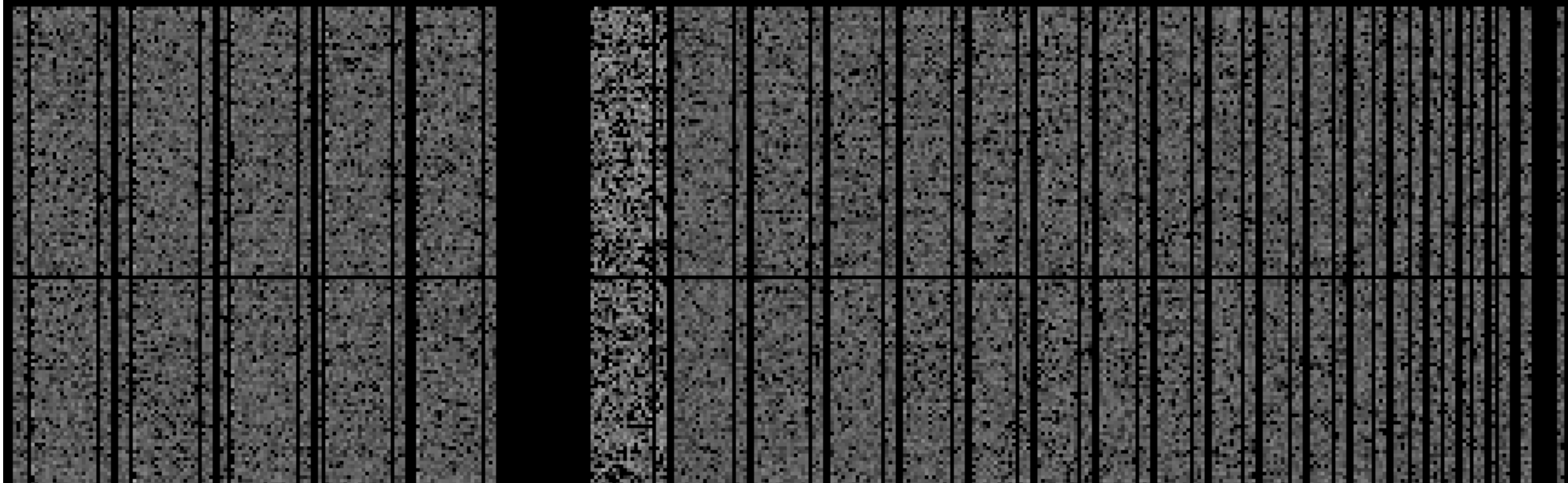
- The response of a two-element interferometer to an extended source with brightness distribution $I_\nu(s)$ is the complex *visibility:*

$$V_\nu = \int I_\nu(\hat{s}) \exp(-i2\pi\vec{b}\cdot\hat{s}/\lambda)\, d\Omega$$

- Each *visibility* gives a measure of the source brightness at a specific time, in a specific direction
- More *visibilities* mean a more complete and accurate representation of the source. Increase # of *visibilities* by
  - Using more antennas
  - Moving the antennas (changing the baselines)
  - Letting the Earth rotate under the source

Interferometers in Operation

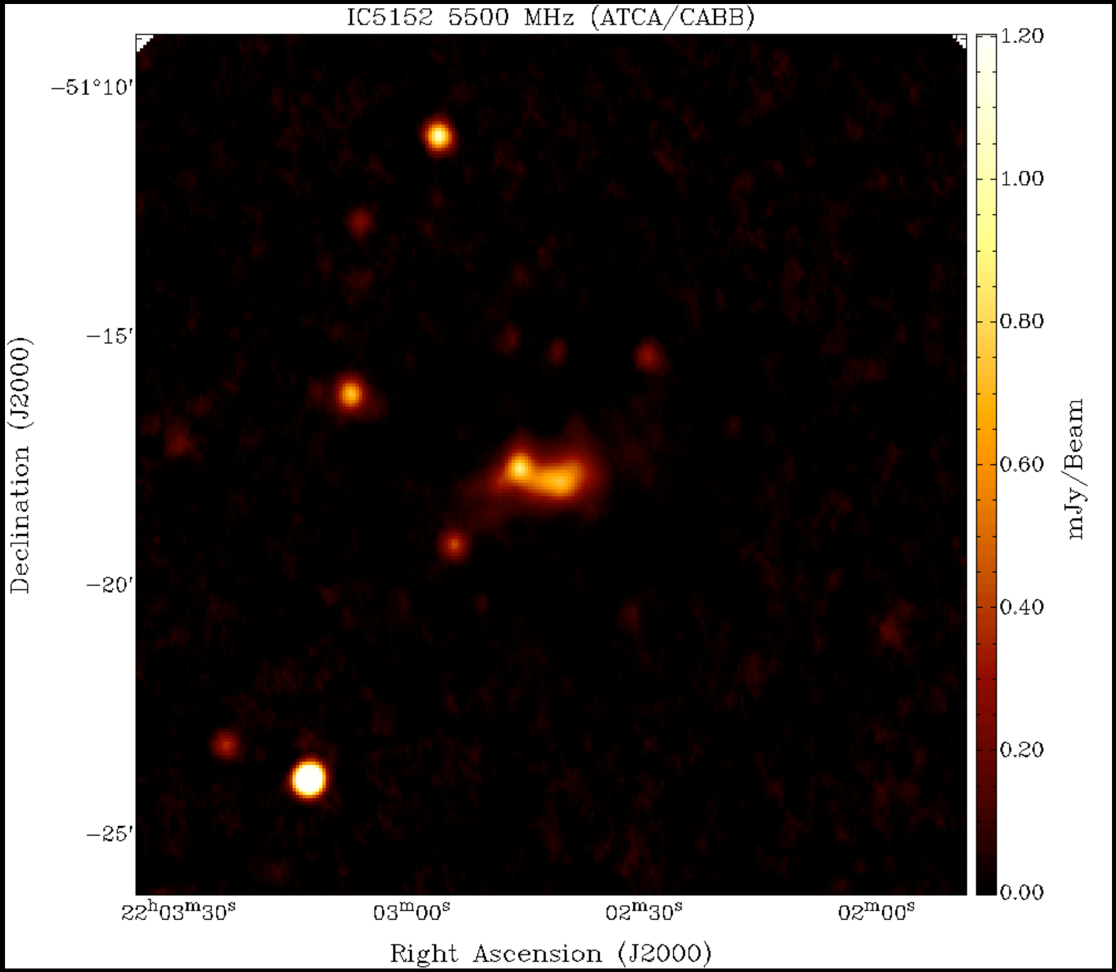
- The inverse Fourier transform of a collection of *visibilities* is an image of the source



$$V_\nu(u,v,w) = \int\int \frac{I_\nu(l,m)}{(1-l^2-m^2)^{1/2}} \exp[-i2\pi(ul+vm+wn)]dldm$$

Interferometers in Operation

- The Fourier transform of an image is a collection of *visibilities*

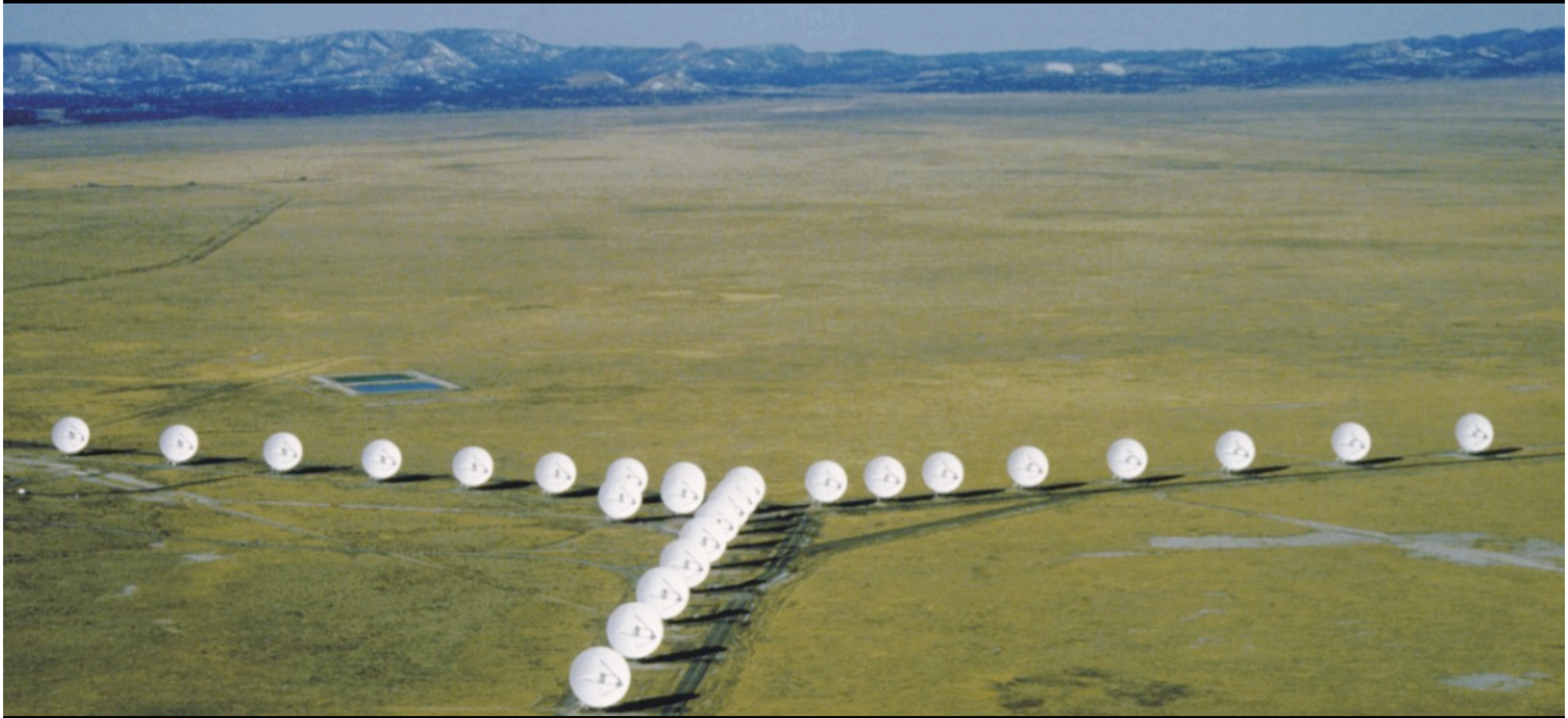


Liu & Cannon, AAS 219

$$\frac{I_\nu(l,m)}{(1-l^2-m^2)^{1/2}} = \int\int V_\nu(u,v,0)\exp[-i2\pi(ul+vm)]dldm$$

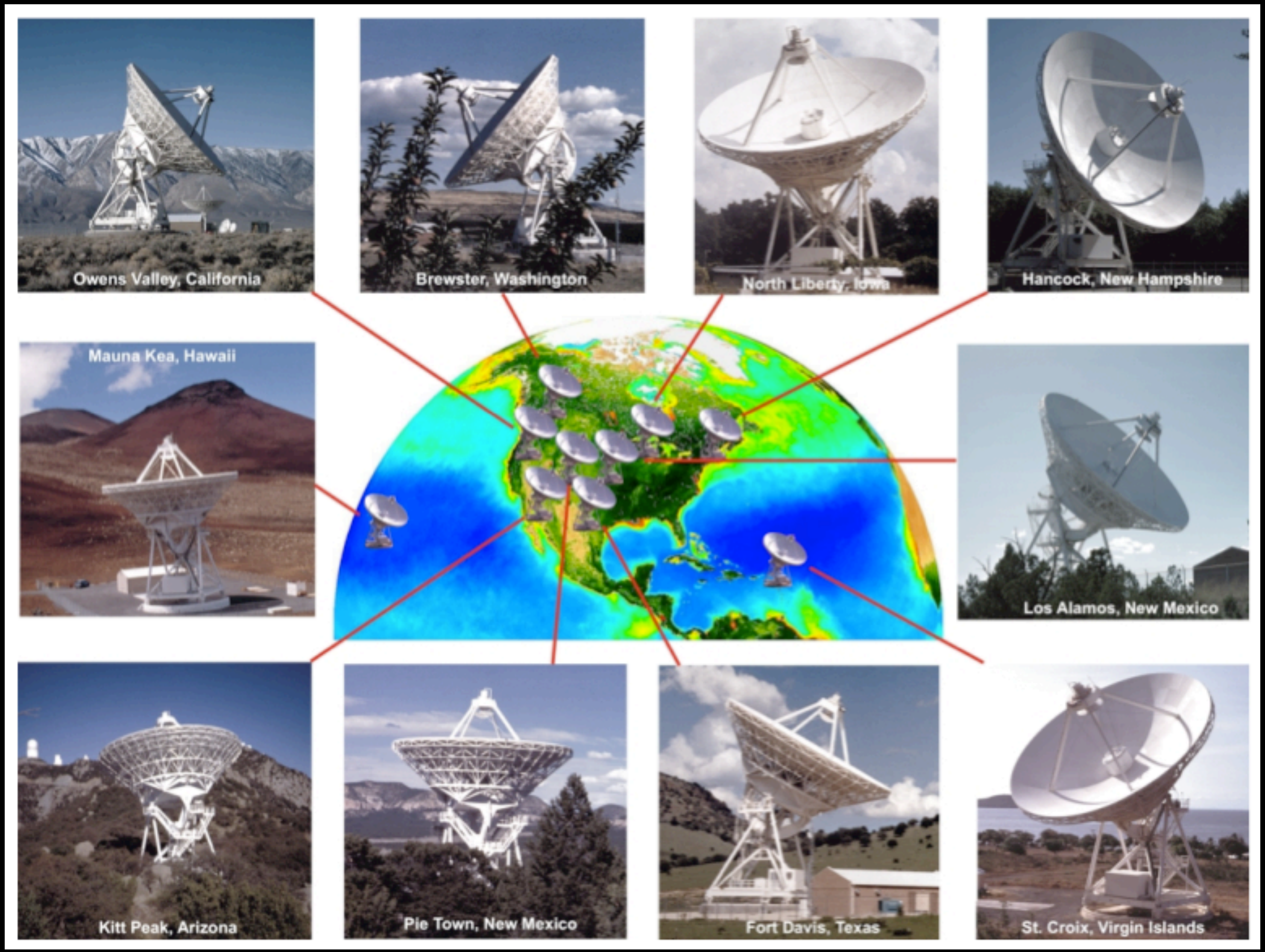
Interferometers in Operation

Interferometers in Operation

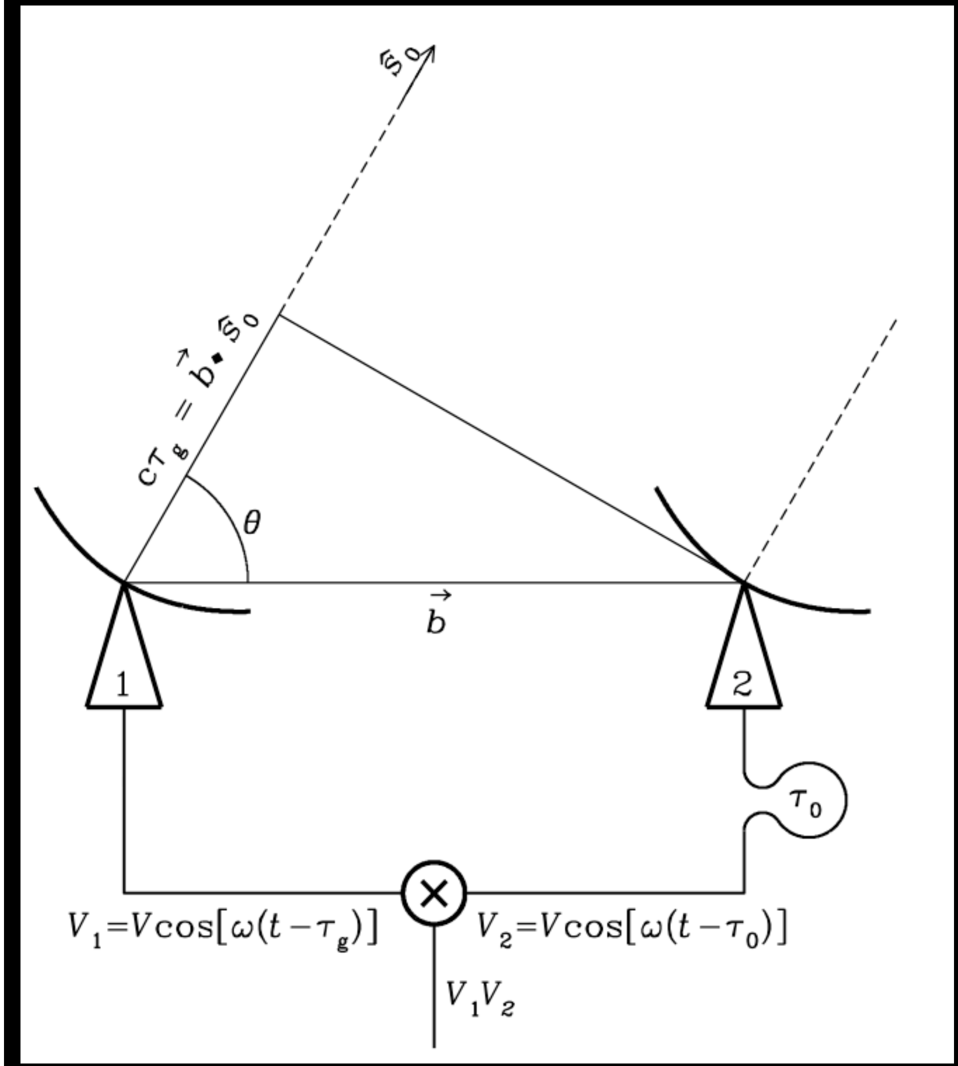


Interferometers in Operation

Interferometers in Operation

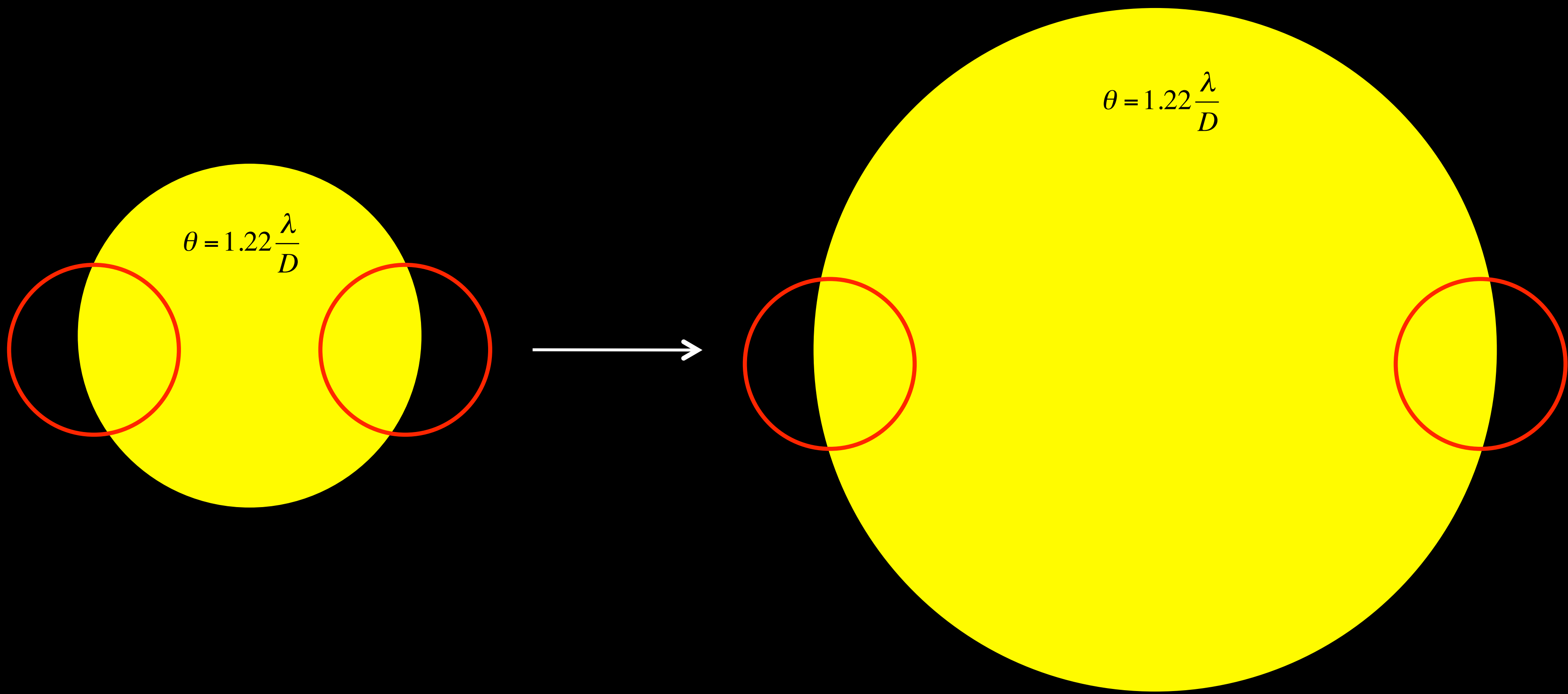


Why an Interferometer and not *Arecibo*?



- Small telescopes (large field of view)
- Separate these by large distances (improves spatial resolution)
- Interferometer measures *both* position *and* intensity
  - Allows one to map a source at the *synthesized beam* size over the entire field of view of the *primary beam*
- But there is a cost: higher resolution requires higher source brightness

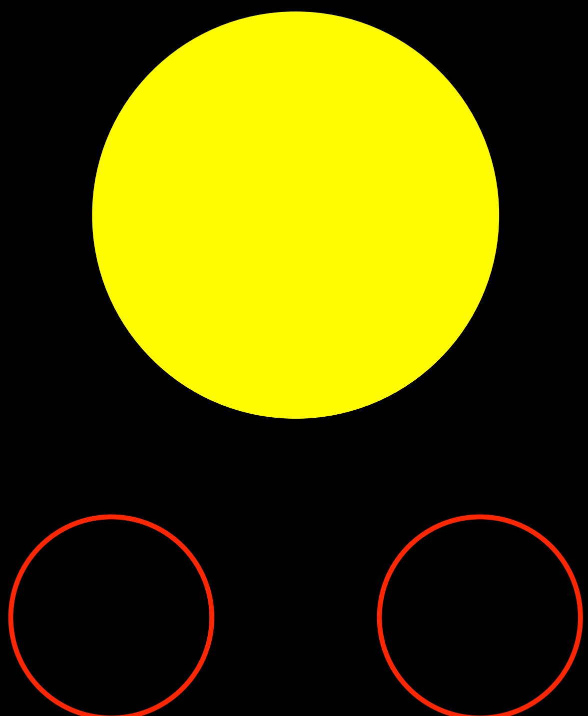
Disadvantages of an Interferometer vs. *Arecibo*



Filling factor decreases

Disadvantages of an Interferometer vs. *Arecibo*

$$\theta = 1.22\frac{\lambda}{D}$$



These two telescopes have the same "D" but very different primary beam sizes and surface brightness sensitivities

Recent Advances

- Correlators
  - Wide bandwidths (measured in GHz!), some with *zoom* capabilities (simultaneous wide-band continuum and spectral line data acquisition)
    - Examples: *EVLA/WIDAR, ATCA/CABB*
- Phased array technologies
  - Allows measurements of sources from area of sky much larger than primary beam
    - Examples: *AO40*, *ASKAP, APERTIF, MUSTANG-II*
- Long-wavelength arrays
  - *Collections of dipoles!*
  - Examples: *LWA, LOFAR*

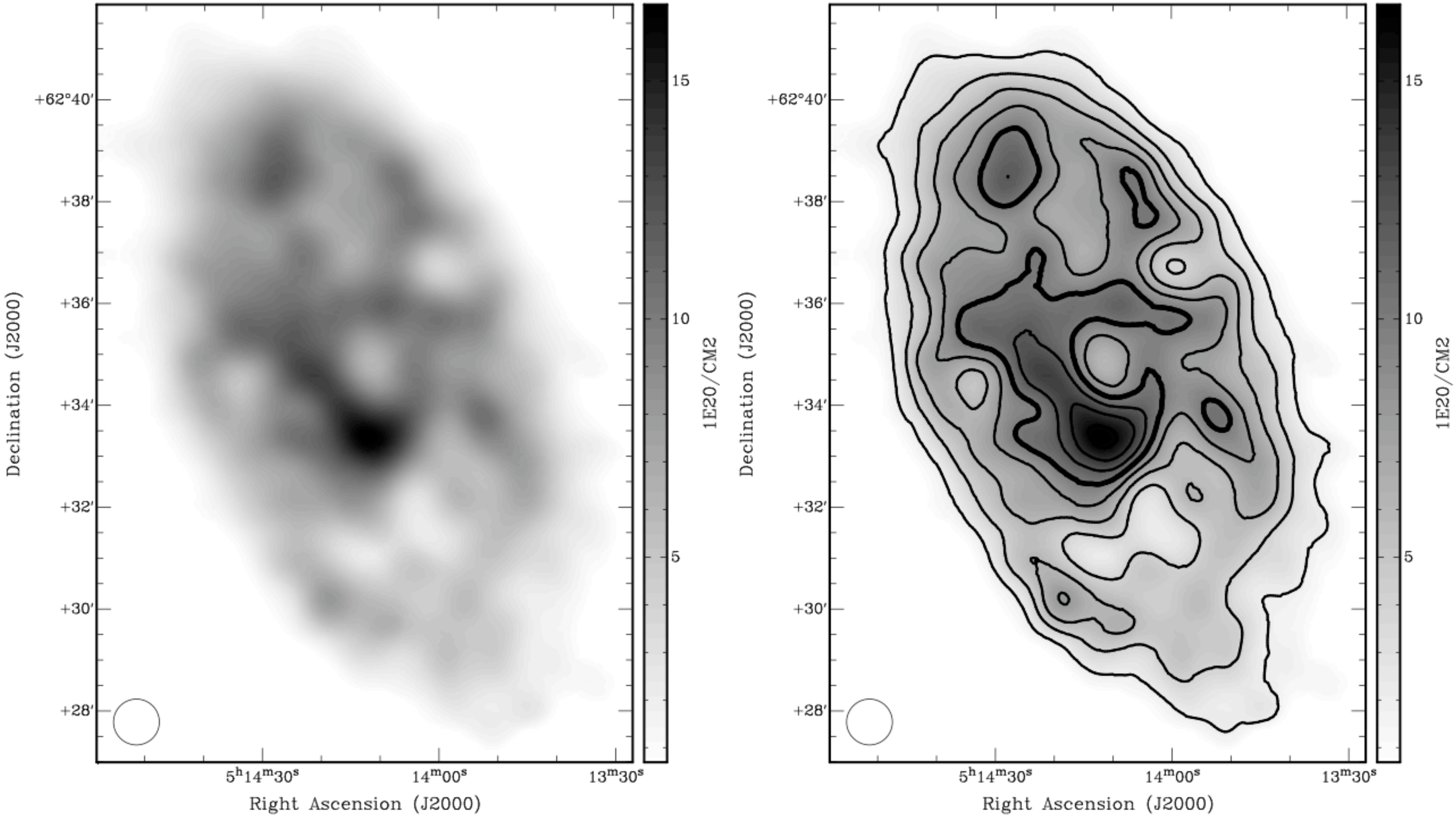
Recent Advances

Observing for University Classes

- Program to use NRAO facilities to acquire new data to use in college classes
- Free to anyone teaching an appropriate-level class
- Easy to apply

- Do this in your classes!

HI Spectral Line Emission: UGCA 105



Cannon et al. (2012)

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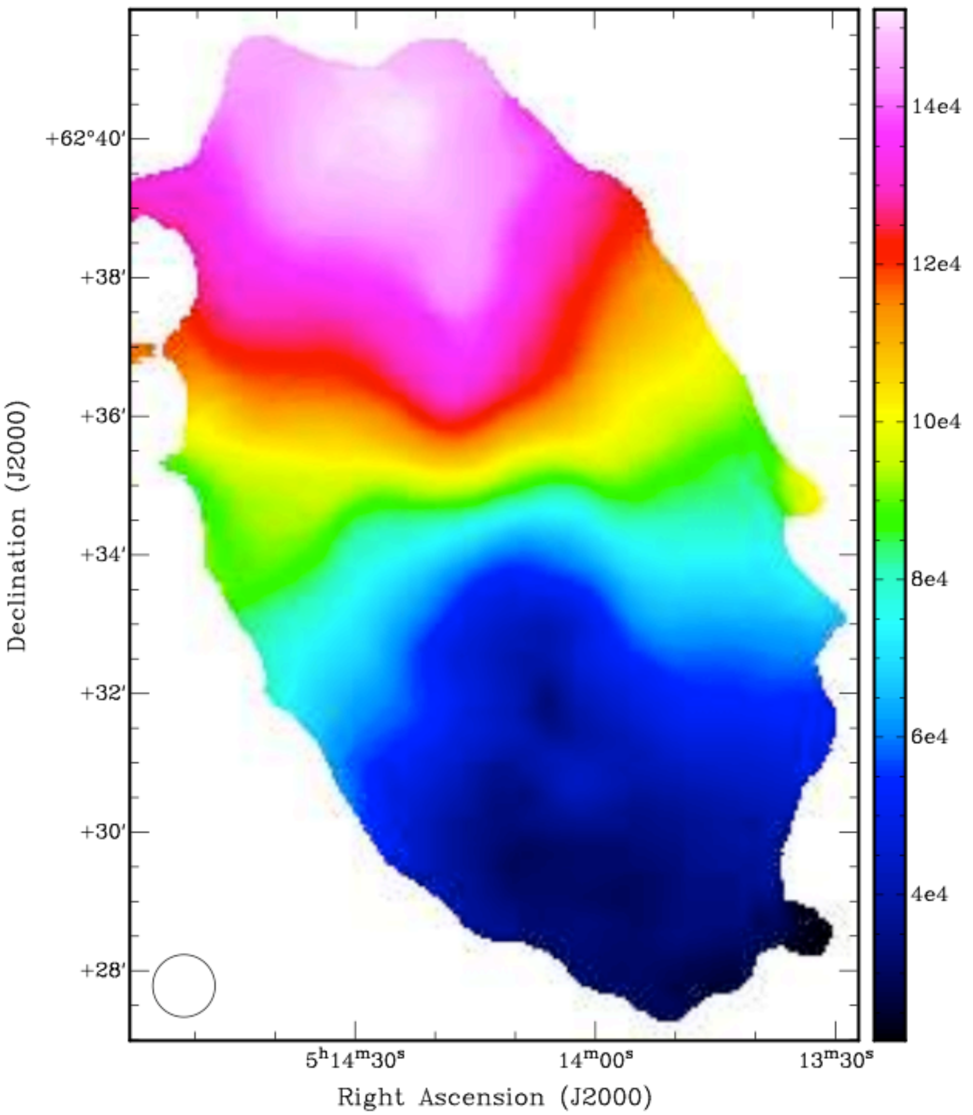

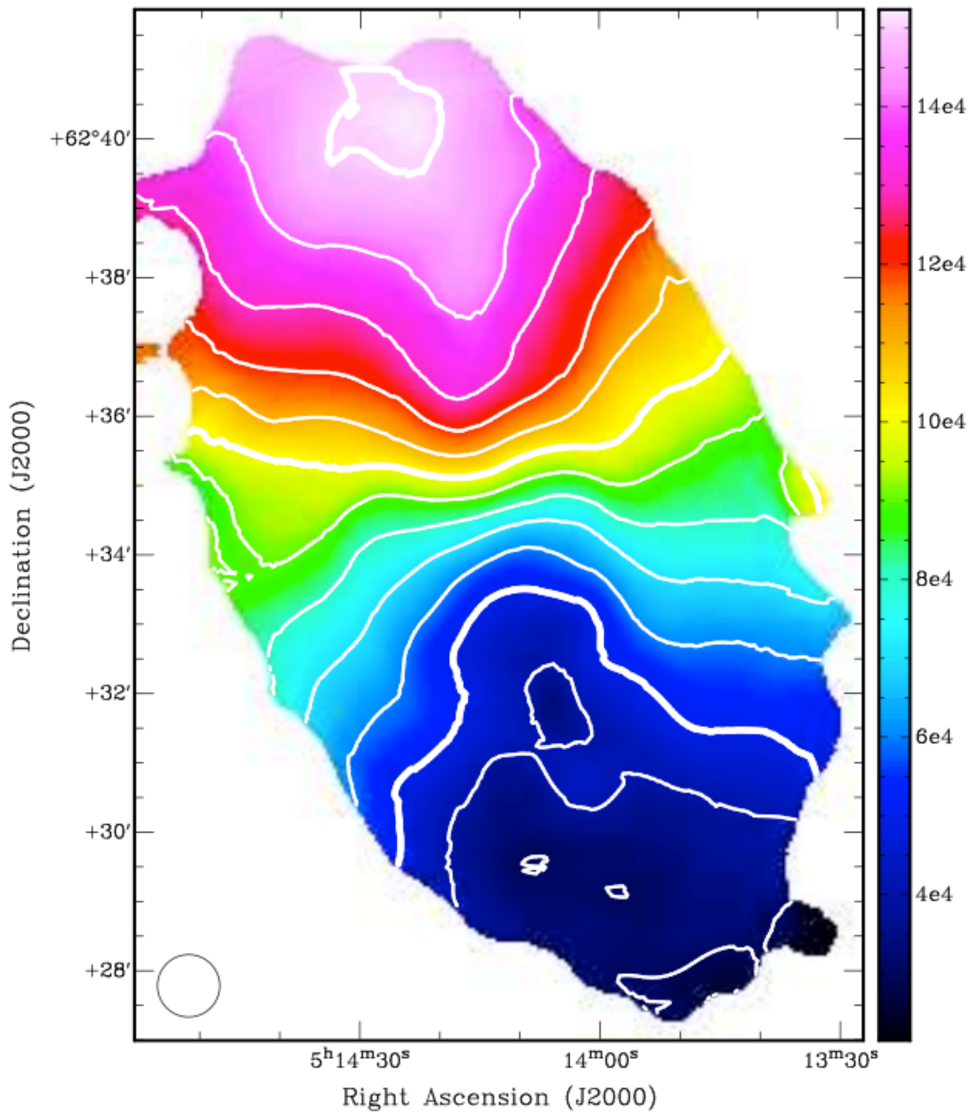

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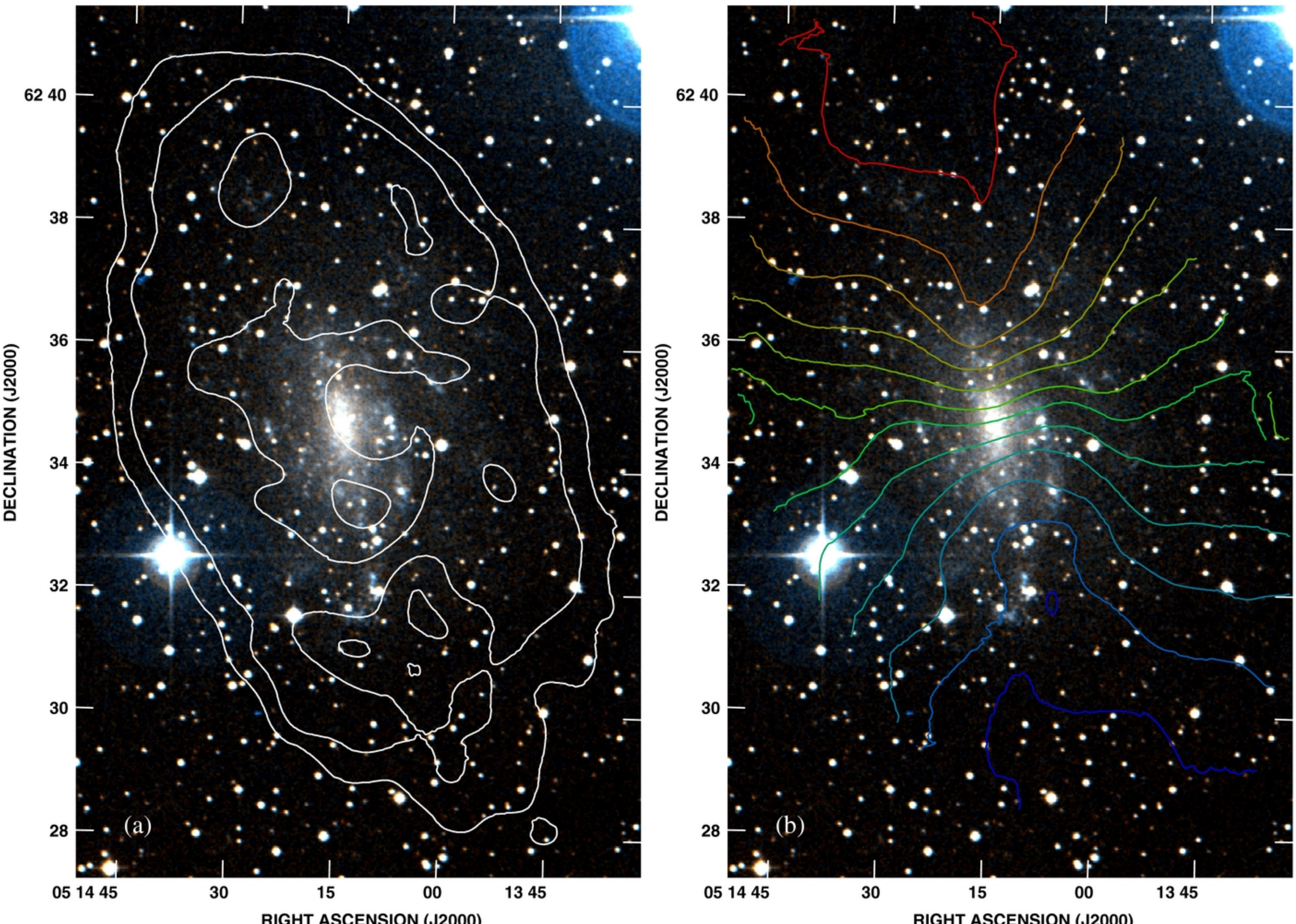

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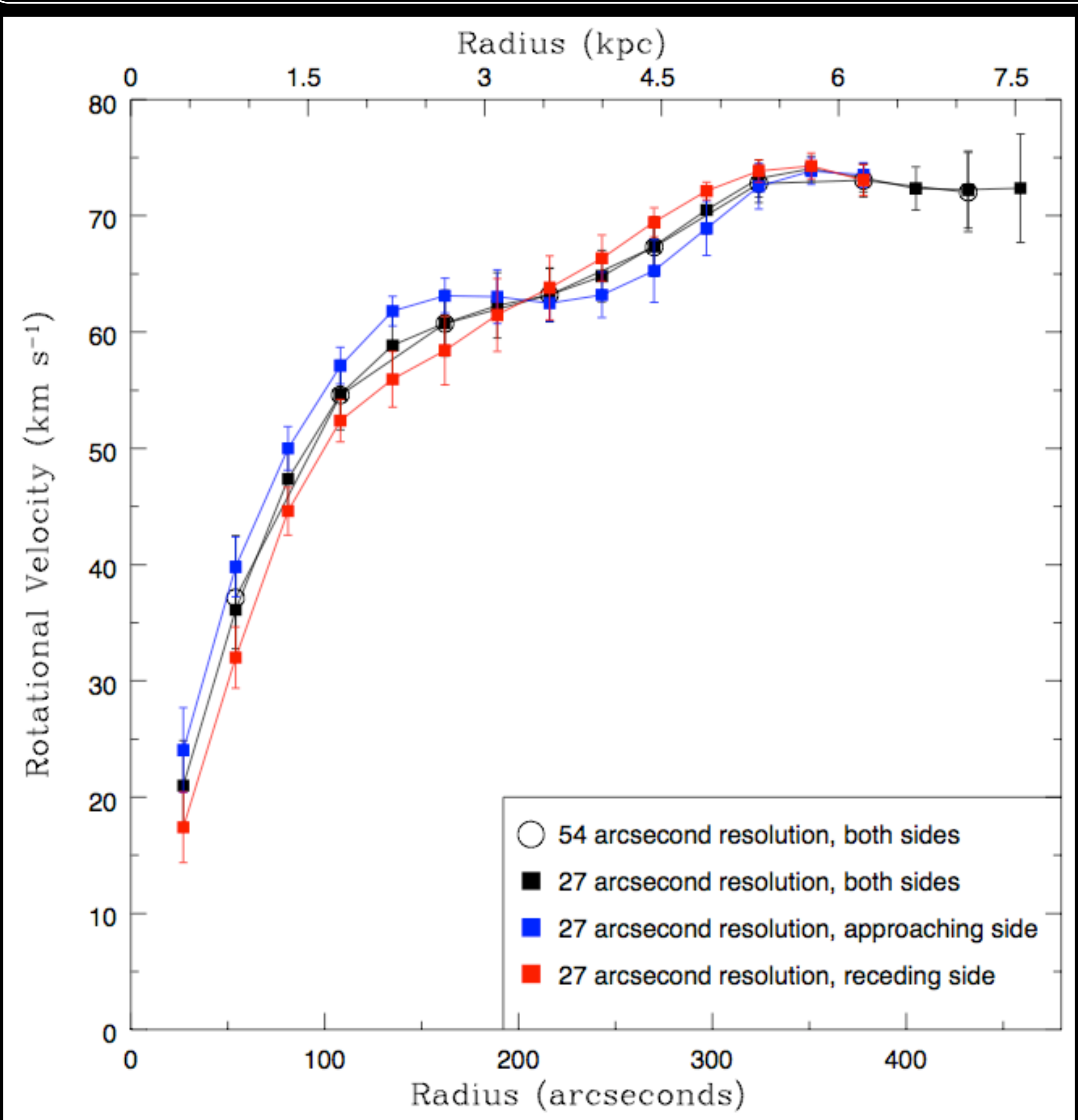

$$M = \frac{v^2 \cdot r}{G}$$

Cannon et al. (2012)