Radio Astronomy

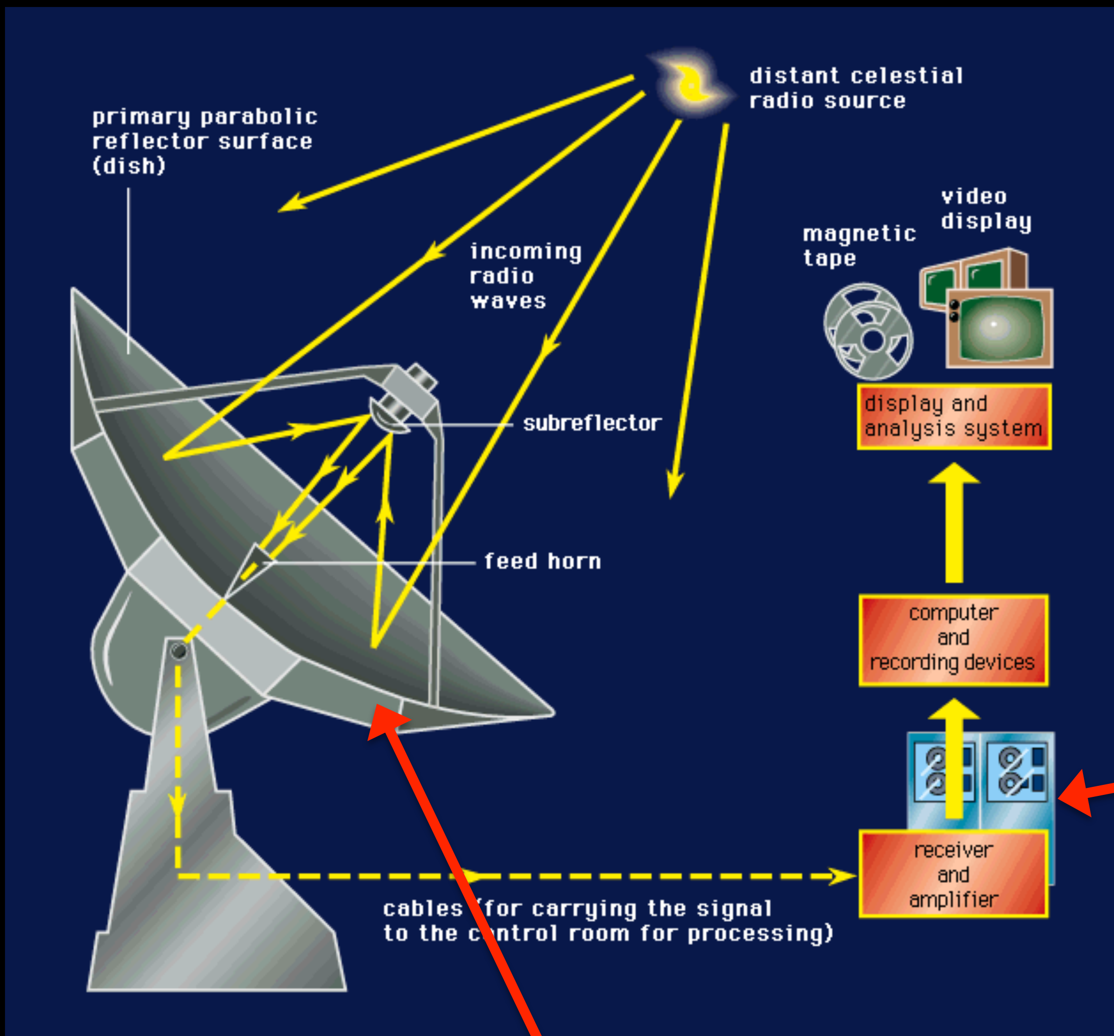
Dr. Deidre Hunter
Lowell Observatory

NAU Observational Astronomy Class, 4 Sept 2014

Antenna

Receiver

Choose your station frequency



Receiver; frequency selection

Antenna

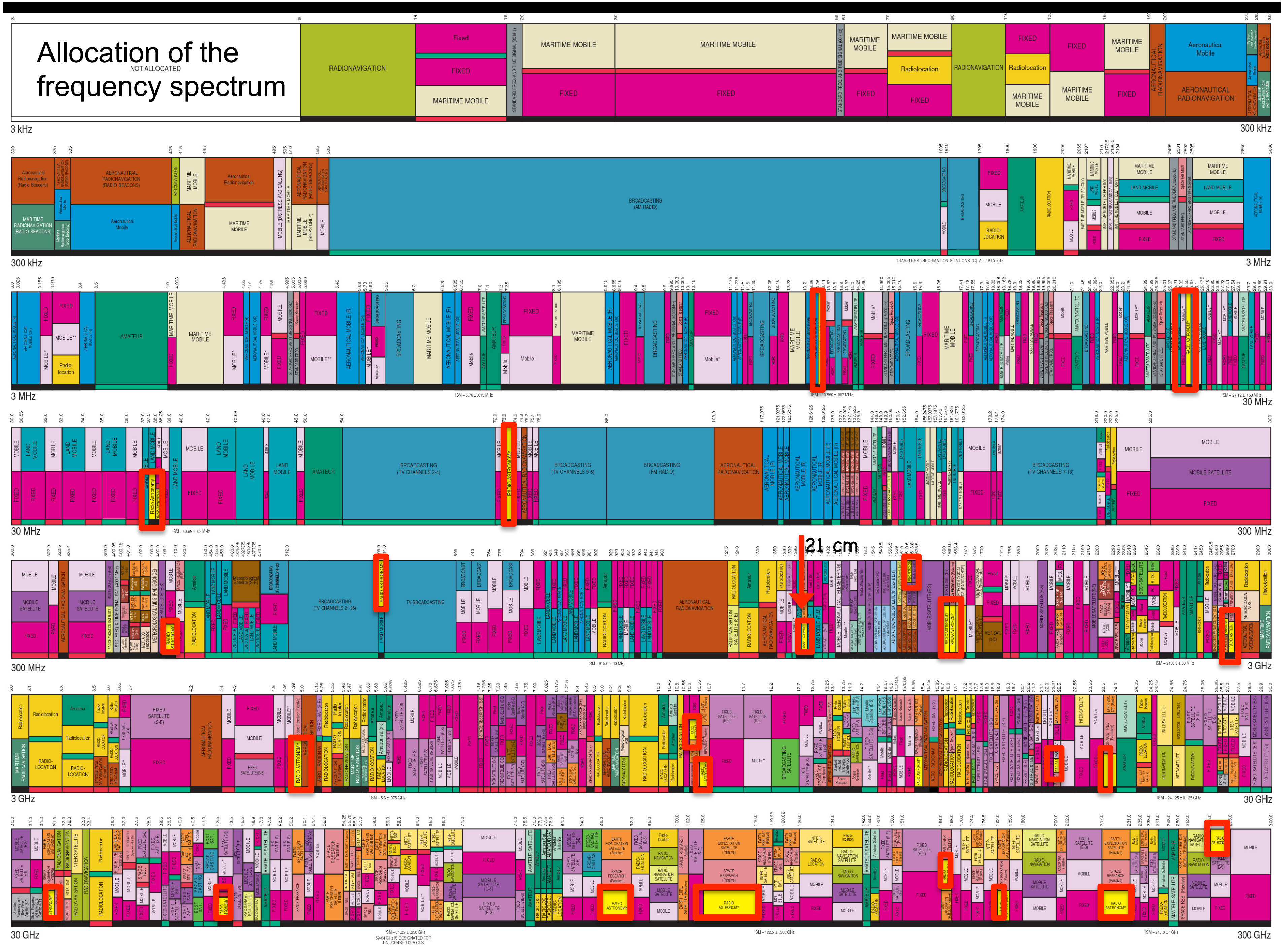

From the Academy Award-Winning Director of "Forrest Gump" and Pulitzer Prize-Winning Author of "Contact."
JODIE FOSTER
MATTHEW McCONAUGHEY
A message from deep space.
Who will be the first to go?
A journey to the heart of the universe.
CONTACT

Radio astronomers think in frequencies; optical astronomers, in wavelengths.

Frequency (Hz) = c ⁄ lambda,
where c is the speed of light

A few key frequencies/wavelengths:

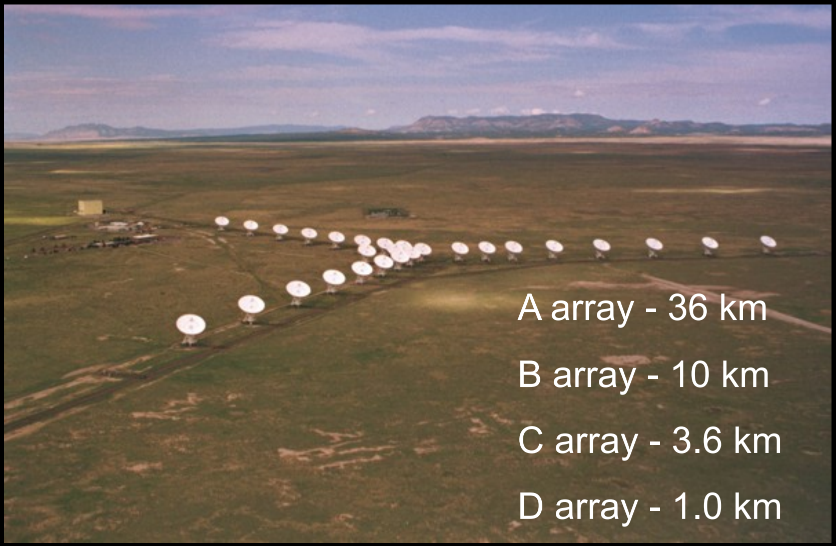
Hydrogen atom --- 1420 MHz = 21 cm
^{12}CO (1-0) --- 115 GHz = 2.6 mm


Allocation of the frequency spectrum
NOT ALLOCATED
3 kHz
300 kHz
300 kHz
3 MHz
3 MHz
30 MHz
30 MHz
300 MHz
300 MHz
3 GHz
3 GHz
30 GHz
30 GHz
300 GHz
21 cm
RADIONAVIGATION
MARITIME MOBILE
FIXED
BROADCASTING (AM RADIO)
AMATEUR
BROADCASTING (TV CHANNELS 2-4)
BROADCASTING (TV CHANNELS 5-6)
BROADCASTING (FM RADIO)
BROADCASTING (TV CHANNELS 7-13)
AERONAUTICAL RADIONAVIGATION
MOBILE SATELLITE
BROADCASTING (TV CHANNELS 21-36)
TV BROADCASTING
RADIO ASTRONOMY
EARTH EXPLORATION SATELLITE (Passive)
SPACE RESEARCH (Passive)
TRAVELERS INFORMATION STATIONS (G) AT 1610 kHz
59-64 GHz IS DESIGNATED FOR UNLICENSED DEVICES

Single dish: Green Bank Telescope

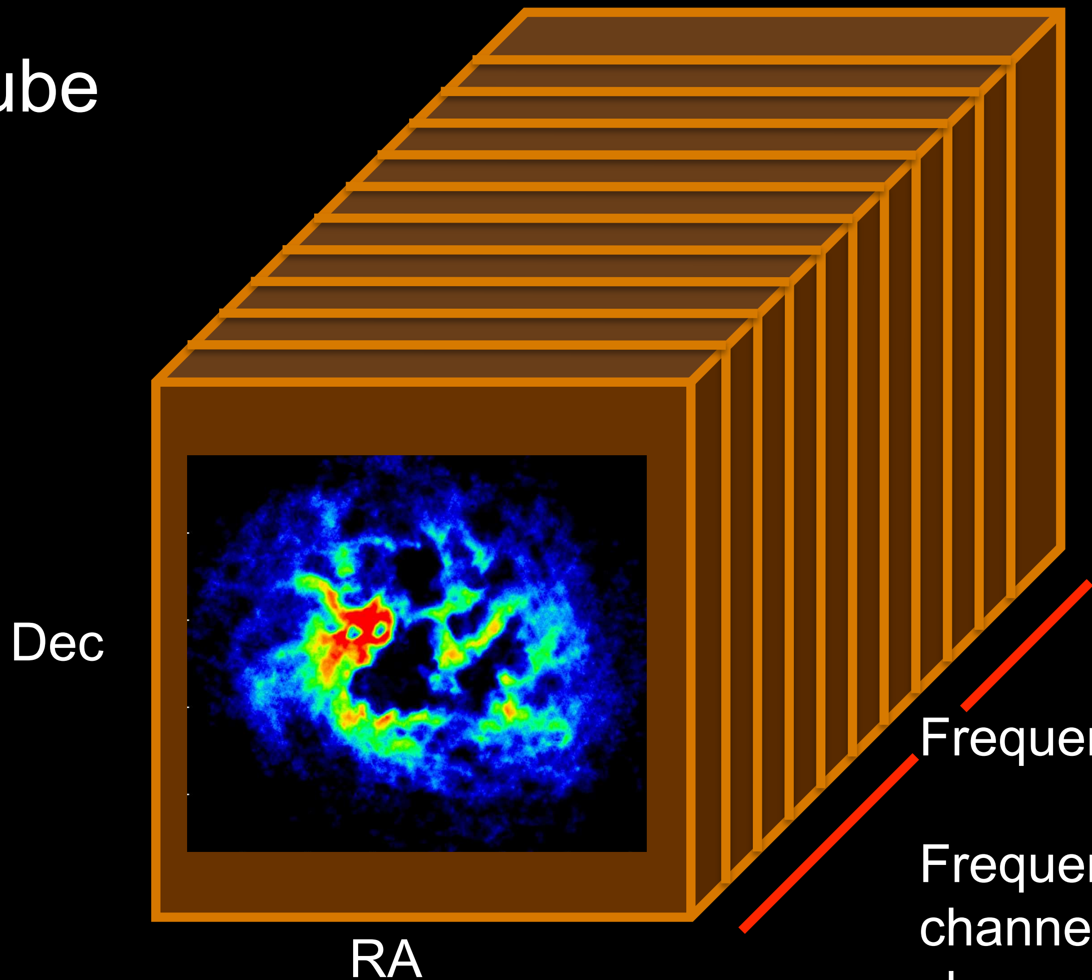
NRAO/AUI

Interferometers: Very Large Array



Really big interferometers: VLBI

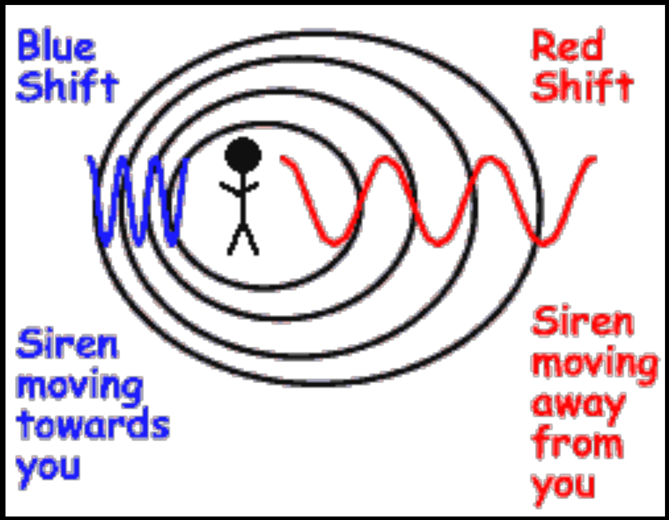
Data cube

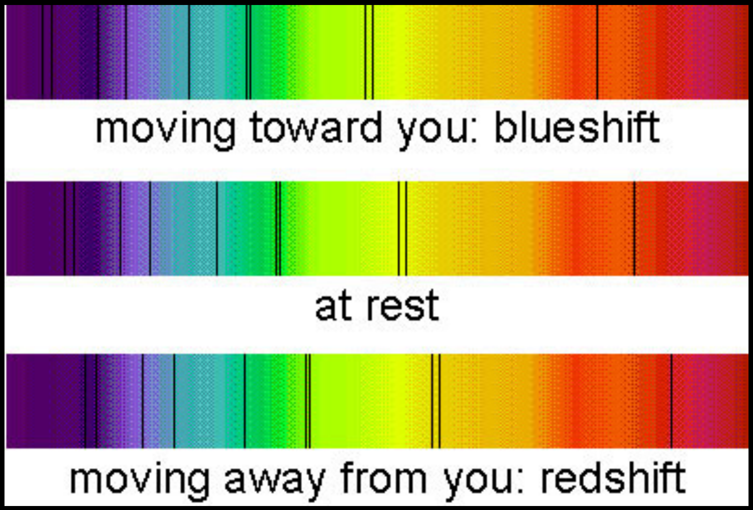


Frequency channels

Frequency width of channel and number of channels are usually selectable.

Can convert frequency to velocity with Doppler Shift if observing a particular spectral line.





HI: Observing the Hydrogen atom

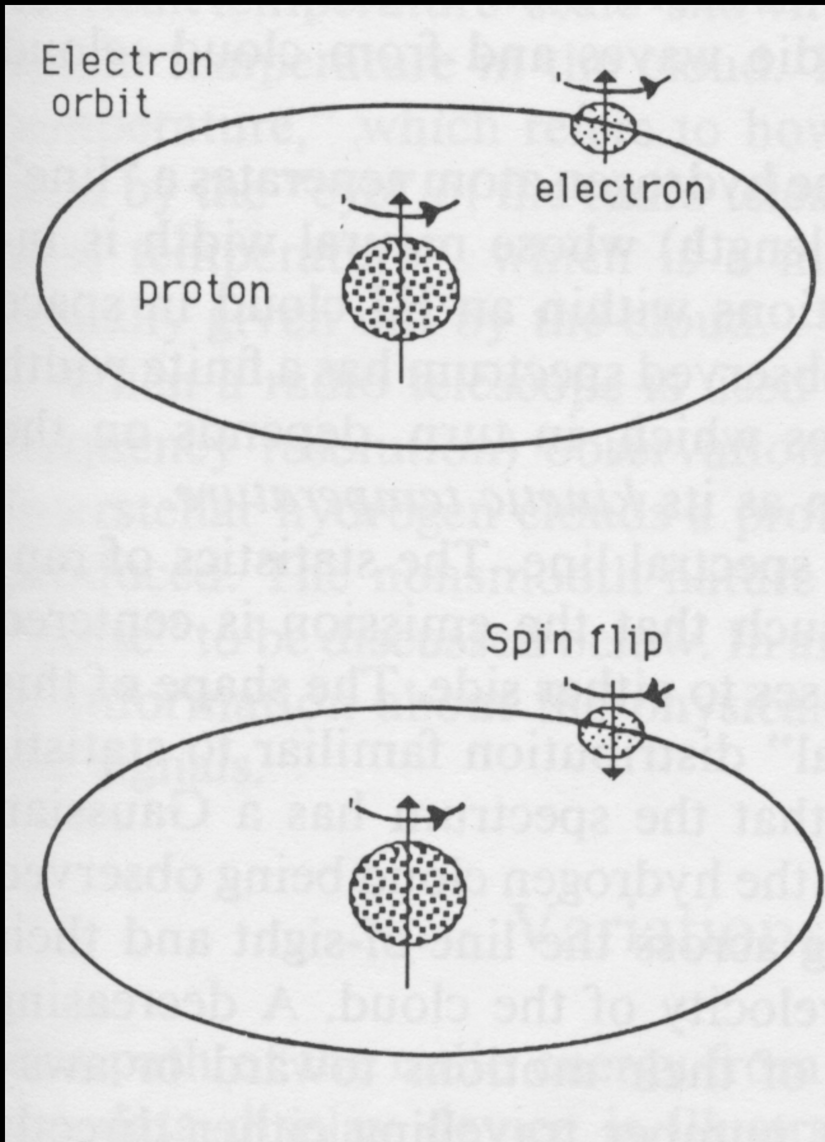


Figure 16.4/Verschuur/Interstellar Matters

High energy

Hyperfine line: 1420.405751 MHz
~ 21 cm

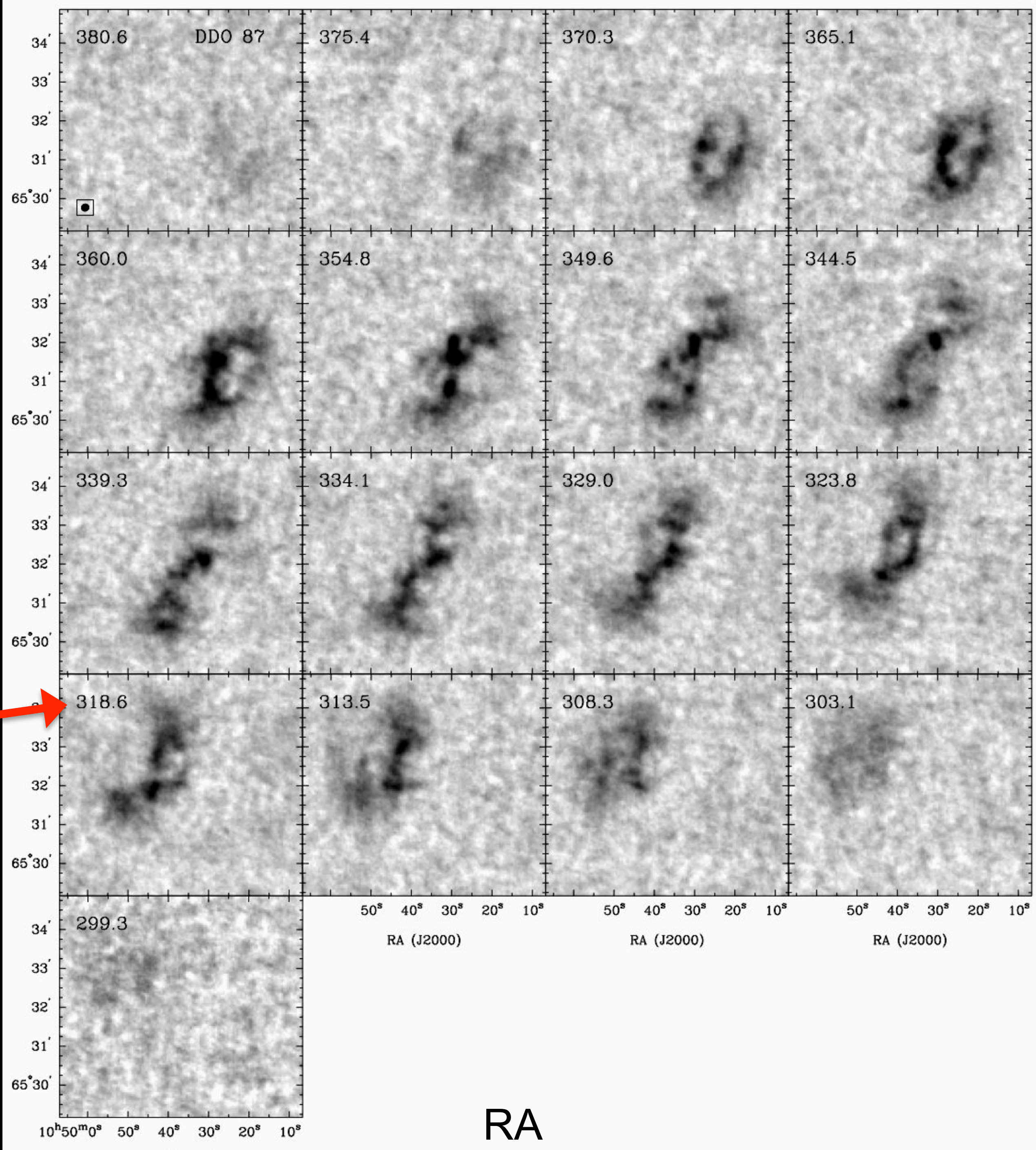
Low energy

(This is also how an MRI machine works in medicine).

HI Data Cube: DDO 87

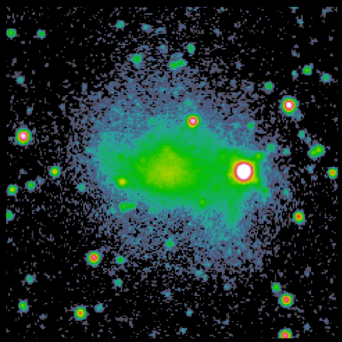
Dec

Velocity of channel in km/s

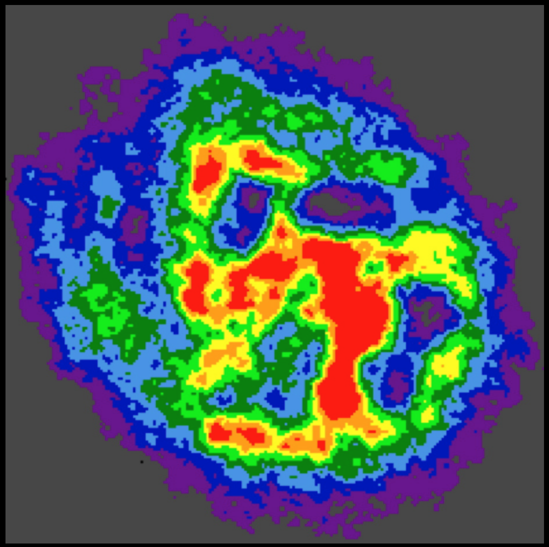


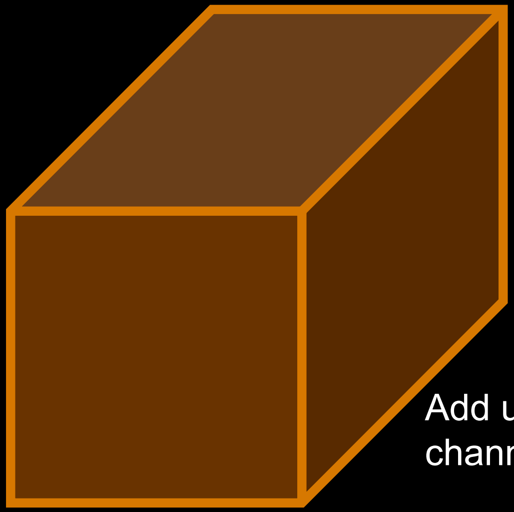
DDO 87 -- the atomic hydrogen gas

Stars (optical image)



Integrated atomic hydrogen: Collapse the cube, add up all the frequency channels with galaxy emission

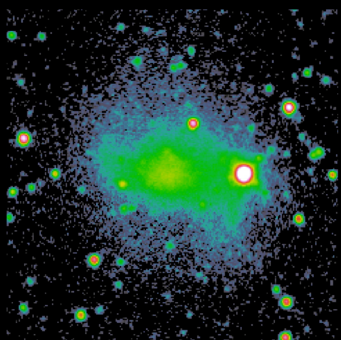




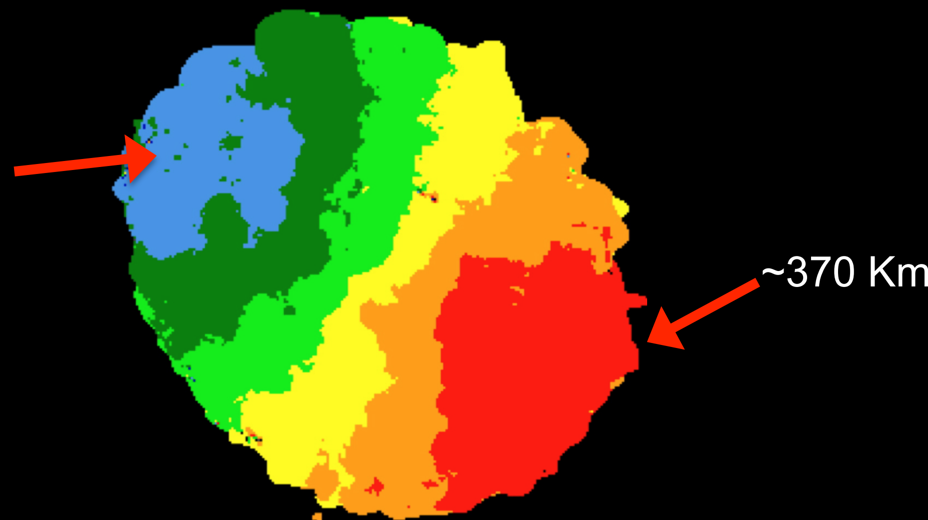
Add up all the channels

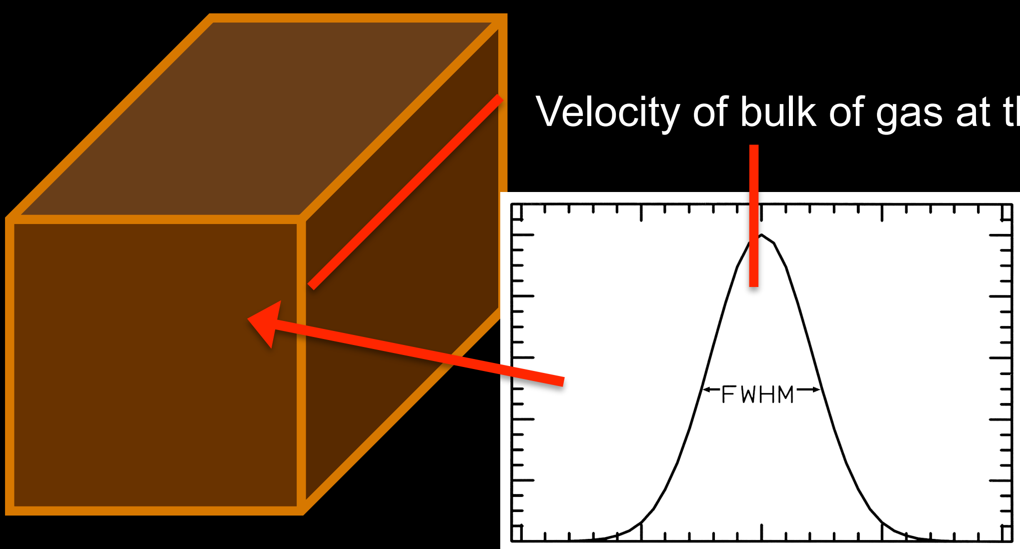
DDO 87 -- the atomic hydrogen gas

Stars (optical image)



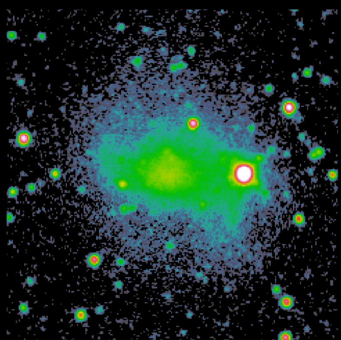
Velocity field: At each point in the galaxy, the velocity of the bulk of the gas → Rotation



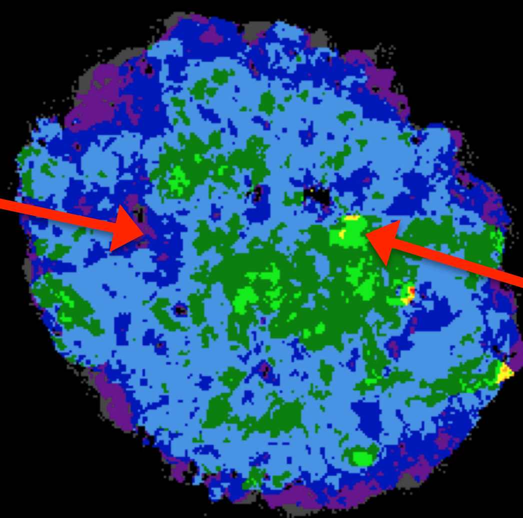


DDO 87 -- the atomic hydrogen gas

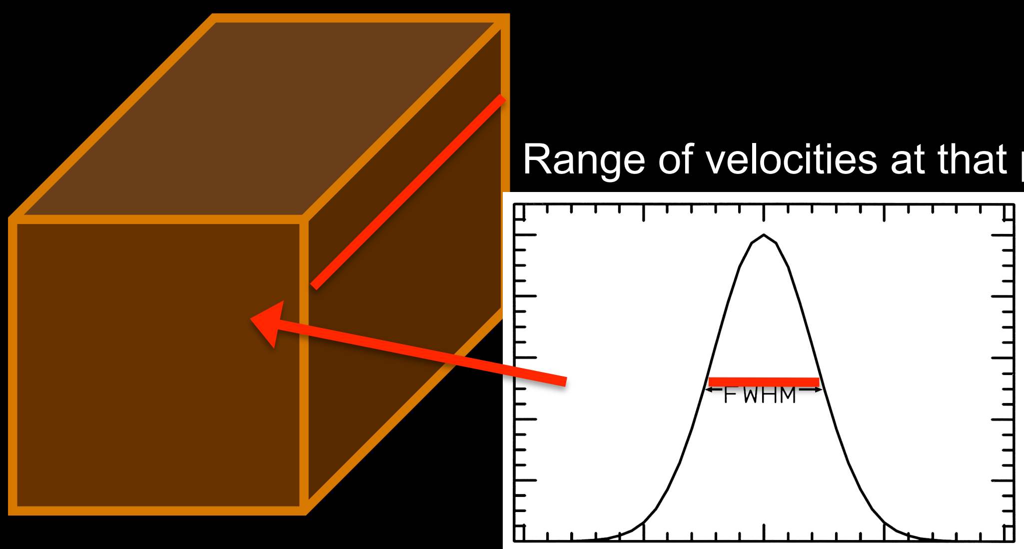
Stars (optical image)



Velocity dispersion: At each point in the galaxy, the range of velocities of the gas → Random motions



Range of velocities at that point

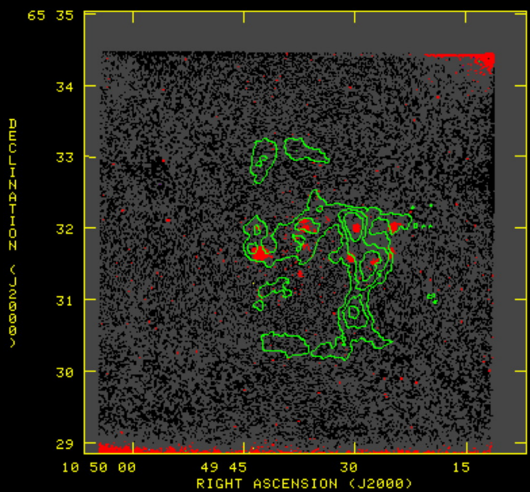


Intensity of HI emission

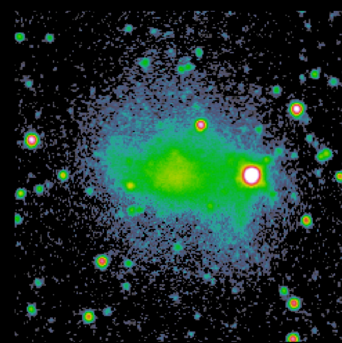
Velocity

DDO 87 -- the atomic Hydrogen gas

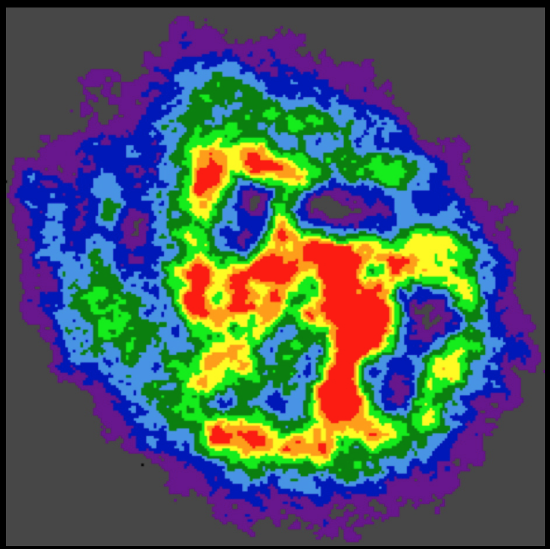
Nebulae: recent star formation



Stars (optical image)

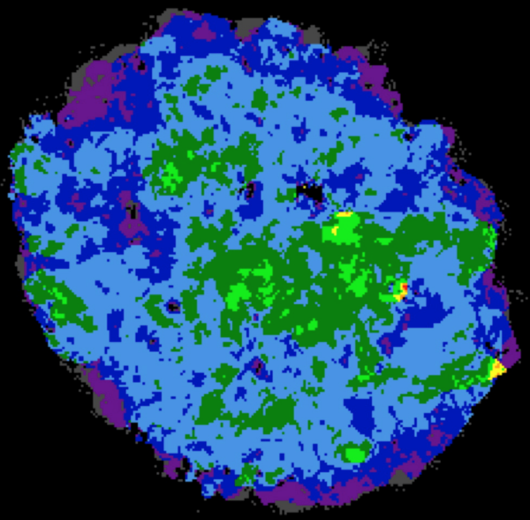


Integrated atomic hydrogen



Velocity field

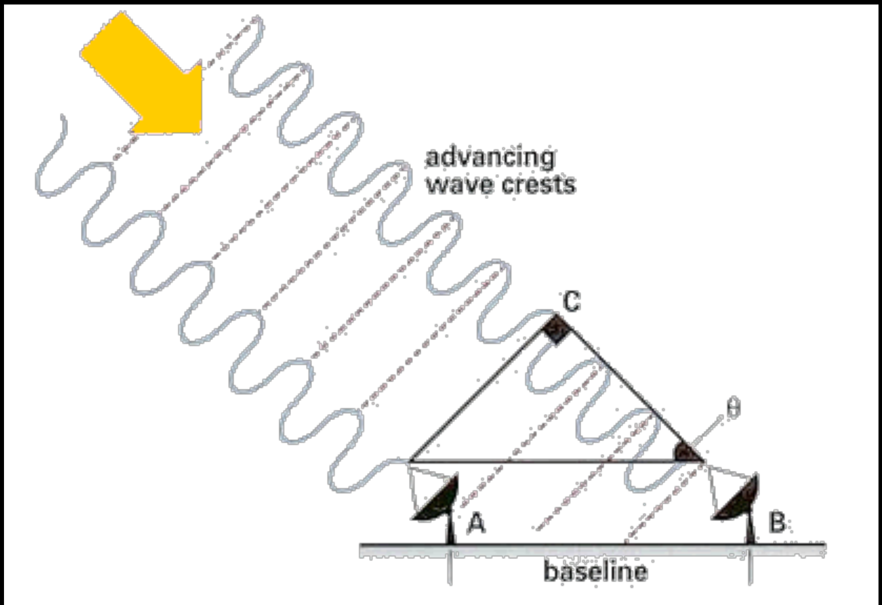
Velocity dispersion



Observing considerations: HI

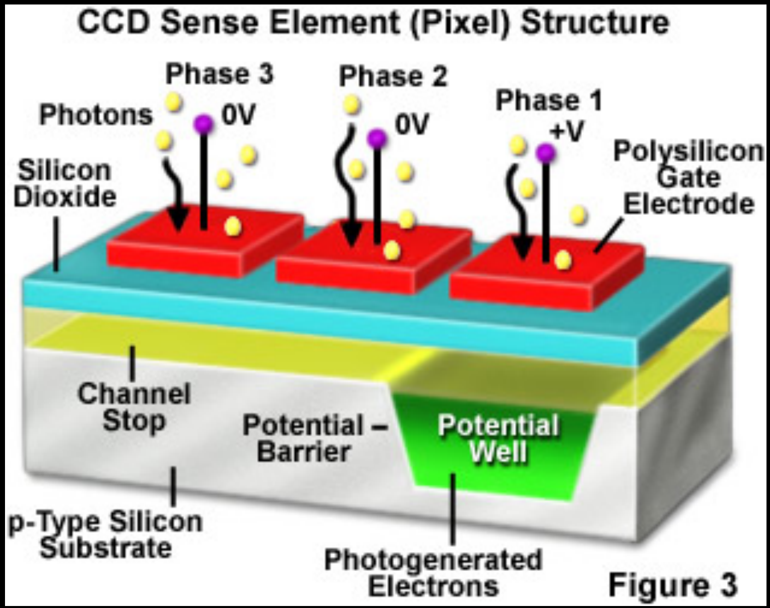
Radio:

Detecting waves: amplitude and phase



Optical:

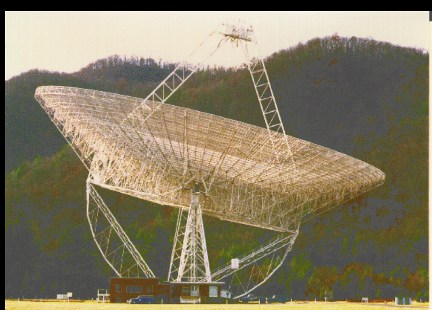
Detecting photons: efficiency



Observing considerations: HI

Radio:

Need dish to be smooth to 1/4λ, but photons can be big so dish can be mesh.



300-ft

Green Bank Telescope

Nov 15, 1988

Optical:

Need mirror to be smooth to 1/4λ, but photons are small so mirror needs to be polished to ~ 0.1 μm.

DCT mirror

Observing considerations: HI

Radio:

Can be cloudy/snowing (for HI). At mm wavelengths, worry about water vapor in atmosphere.

Can be daytime (sky is dark at radio wavelengths).

Optical:

Need clear skies

Must be nighttime (daytime sky is very bright in the optical)

Observing considerations: HI

Radio:

Angular resolution determined by size of configuration/dish (λ/D) (fixed)

A array - 36 km – 1.4” at 21 cm

B array - 10 km – 4”

C array - 3.6 km – 12.5”

D array - 1.0 km – 44”

Optical:

Angular resolution determined by size of primary mirror of telescope (λ/D) and CCD pixel (fixed) and seeing (variable)

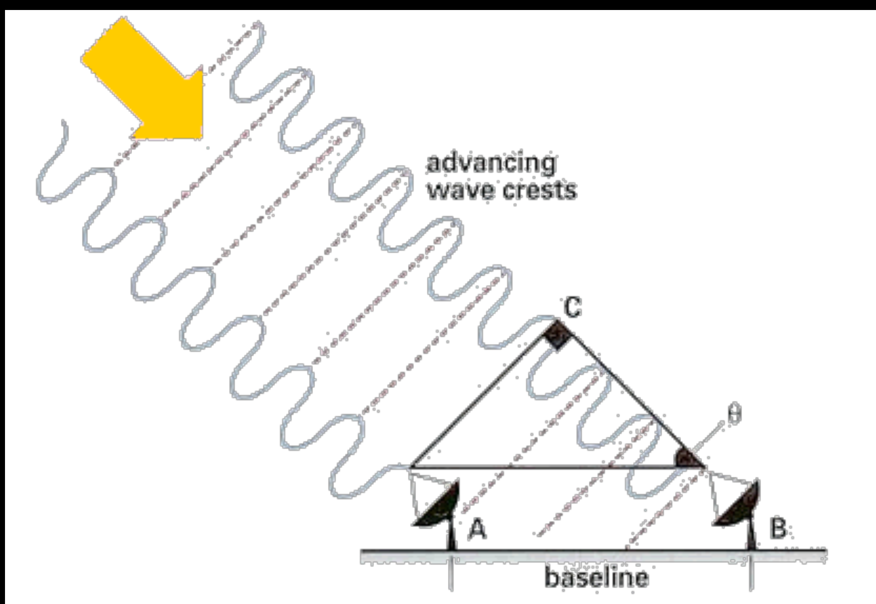
Observing considerations: HI

Radio:

Calibration: Flux calibrator (quasars), periodic observations of phase calibrator

Optical:

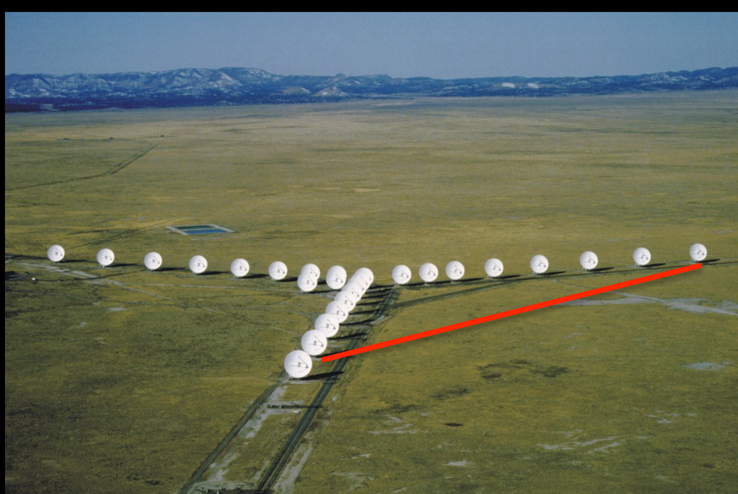
Calibration: Standard stars



Observing considerations: HI

Radio:

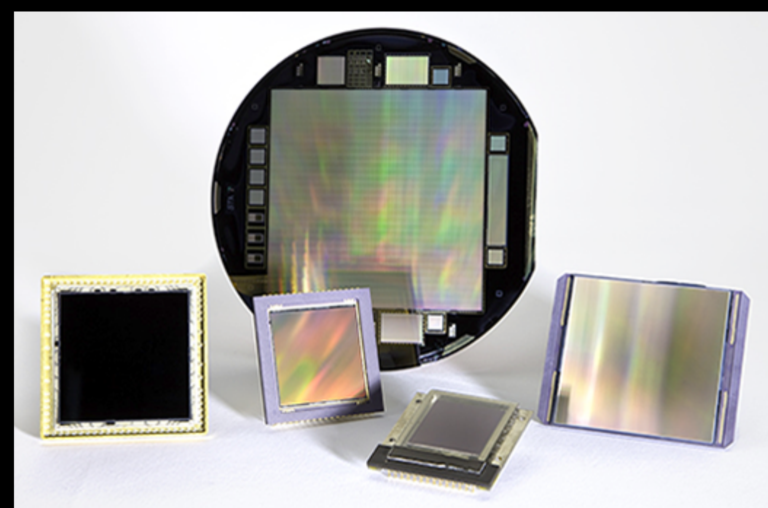
Imaging: Reconstruct image from baselines (interferometry) or map one point at a time (single dish)



One baseline

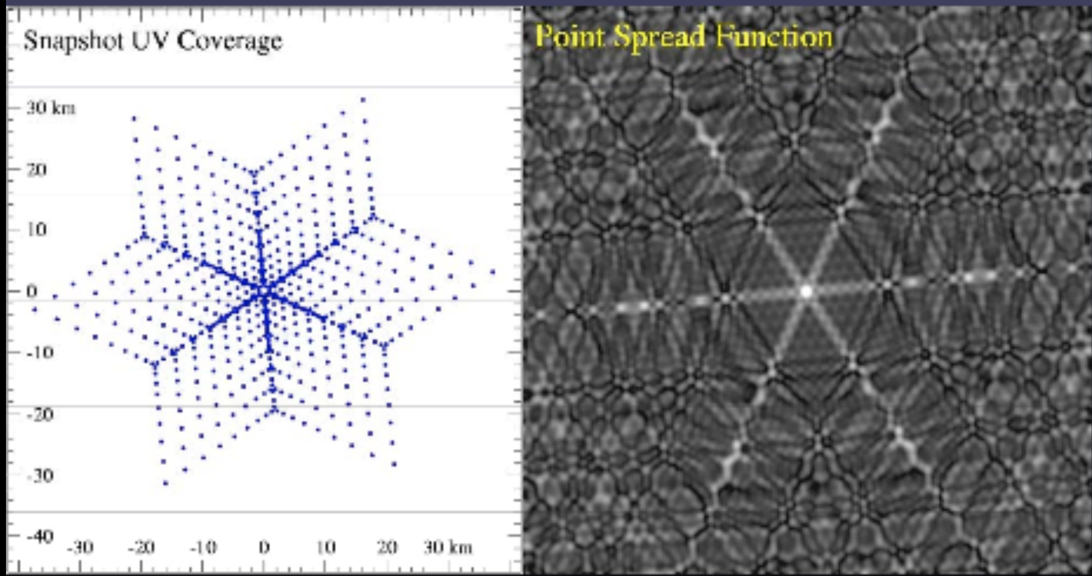
Optical:

Imaging: What you see is what you get (with flat-fielding)

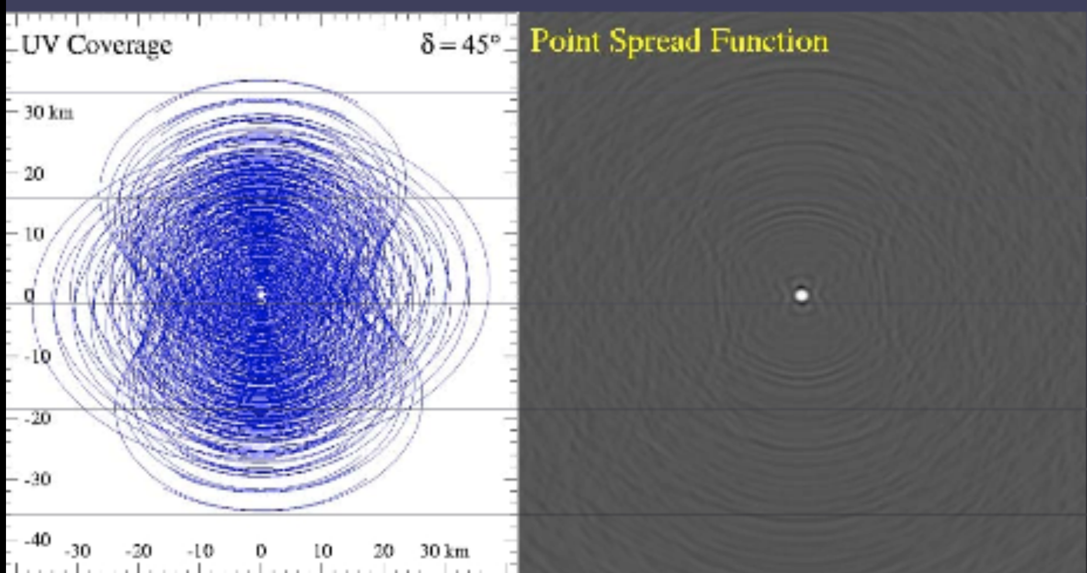


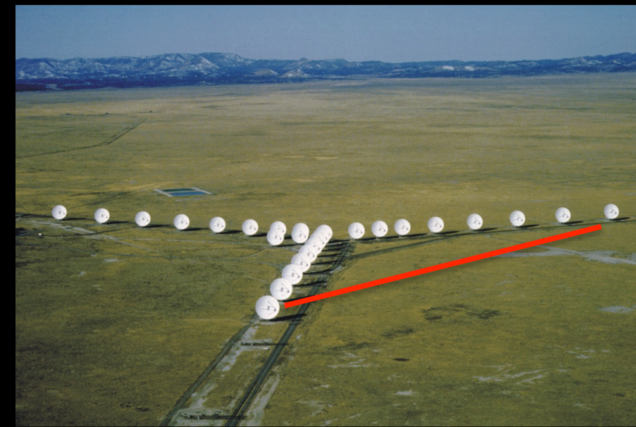
The uv-coverage is the set of all baseline vectors.

The synthesized beam (PSF) is the sensitivity pattern of all baselines.



12 Hour Synthesis Observation



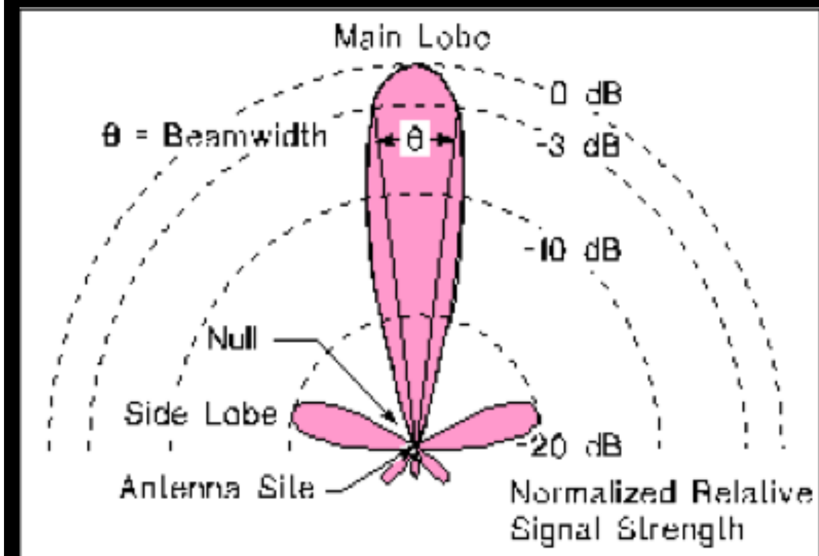


One baseline

Observing considerations: HI

Radio:

Issue: Side-lobe emission

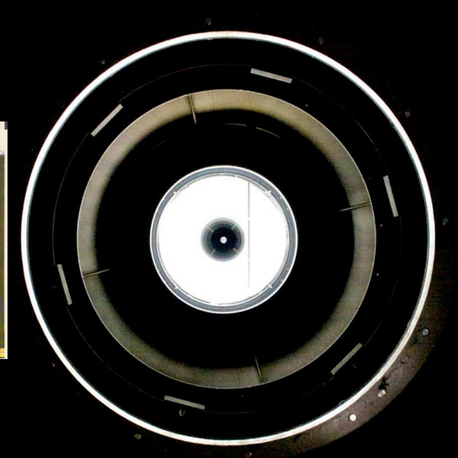


Beam from a paraboloid has sharp maximum in the forward direction, but also smaller maxima in other directions (side lobes).

Optical:

Issue: Scattered light in instrument/telescope

Scattered light in DCT telescope tube



Observing considerations: HI

Radio:

Issue: Structures bigger than a certain size are invisible(interferometer). Structures smaller than beam-size are smeared out.

Structures on angular scales significantly larger than the fringe spacing formed by the shortest baseline are not measured.

Largest visible structures

Primary beam (=FOV) = 30’

A array - 36 km – 38” at 21 cm

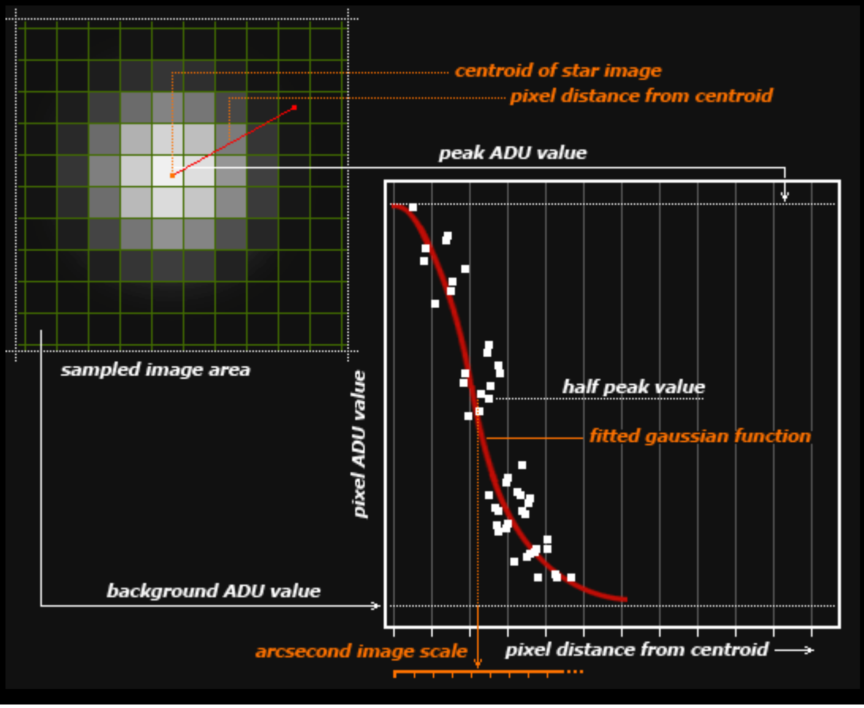
B array - 10 km – 120”

C array - 3.6 km – 900”

D array - 1.0 km – 900”

Optical:

Issue: Can see any structure up to FOV of CCD. Structures smaller than seeing are smeared out.



Radio telescope I have known and loved (or not)

VLA: Most recently got ~400 hours to observe HI in LITTLE THINGS

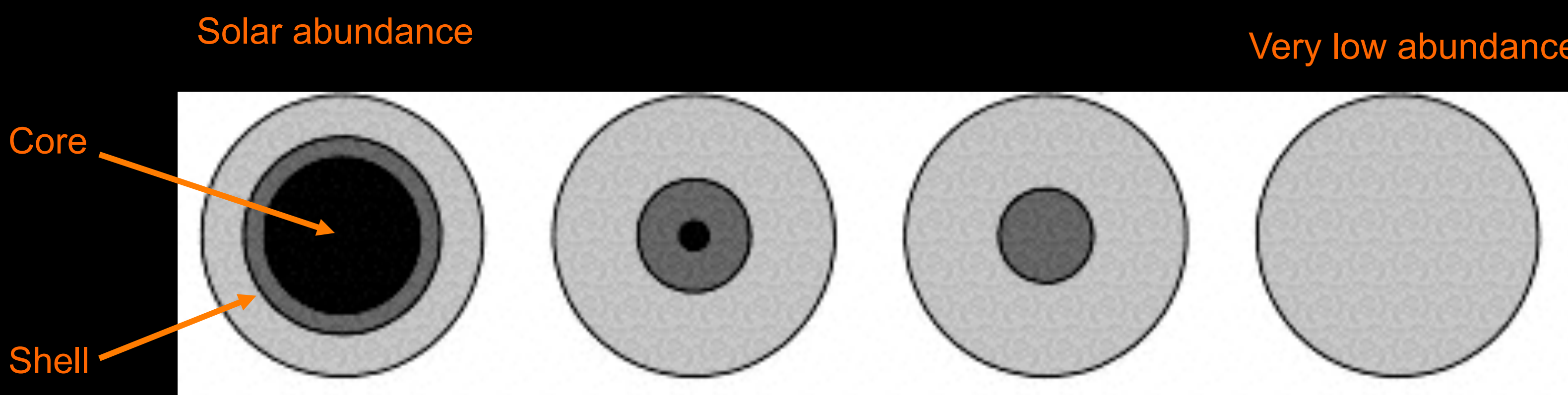
GBT: HI around LITTLE THINGS, but watch out for snow storms

Nobeyama (45m mm telescope): CO in a few dwarfs, cafeteria closes on weekends

ALMA (mm interferometer): CO in dwarfs, at 16,400 ft and driest place on earth

Consequence of low abundances: change in structure of molecular cloud

Theory



Bolatto et al. 1999

Core usually traced by CO.
Shell bright in [CII]λ158 μm.

Shrinking CO core means they are harder to detect: CO "detection barrier" of 20%×solar abundance

Bérengčre Parise

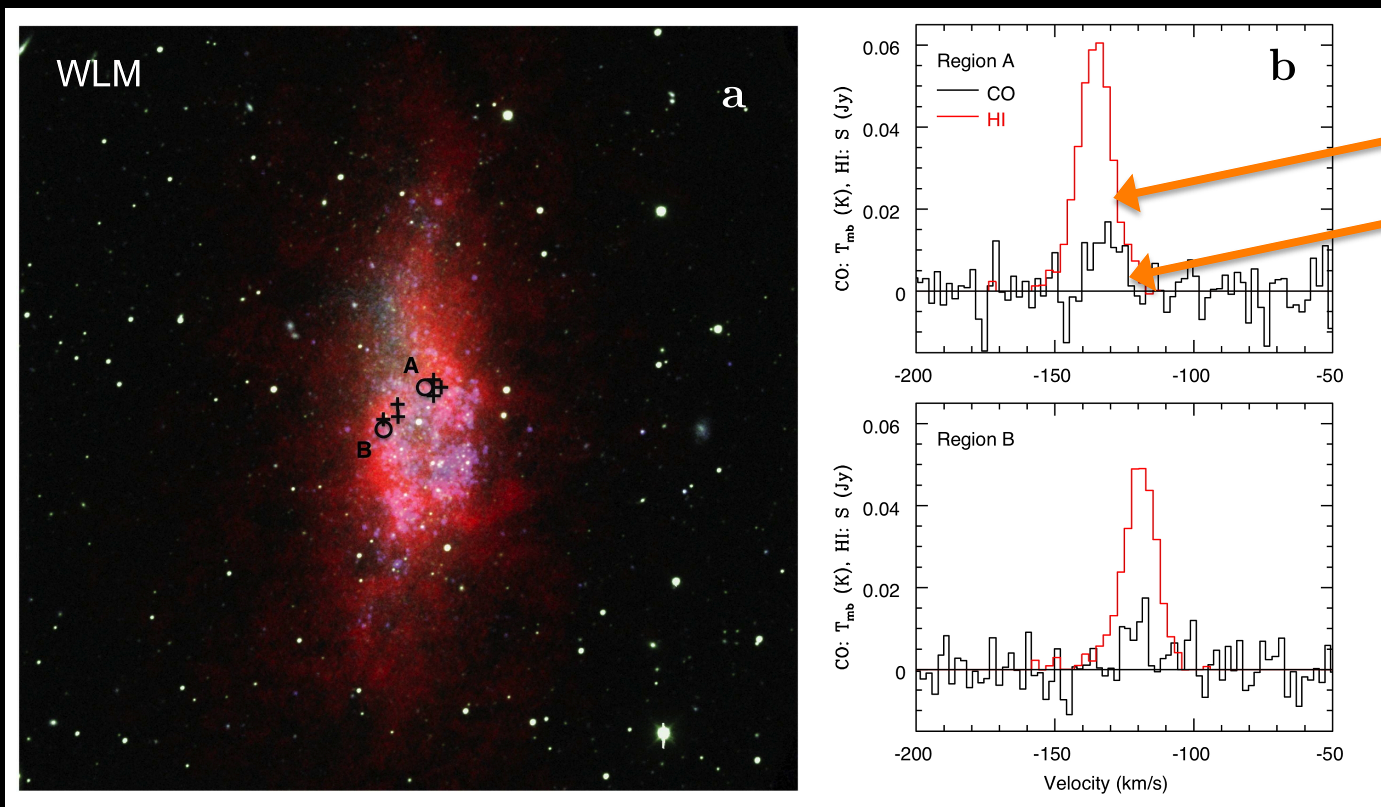
APEX – sub-millimeter telescope in the Atacama Desert

CO (3-2)

Beam of 18" = 87 parsecs at WLM

We detected molecules in the most metal poor galaxy ever!

8x lower abundances than the Sun



Atomic gas

Molecular gas

Intensity of emission

Elmegreen et al. 2013

Velocity of gas

The molecular clouds in WLM

Masses of H_2 are $1\text{-}2 \times 10^5\ M_\odot$

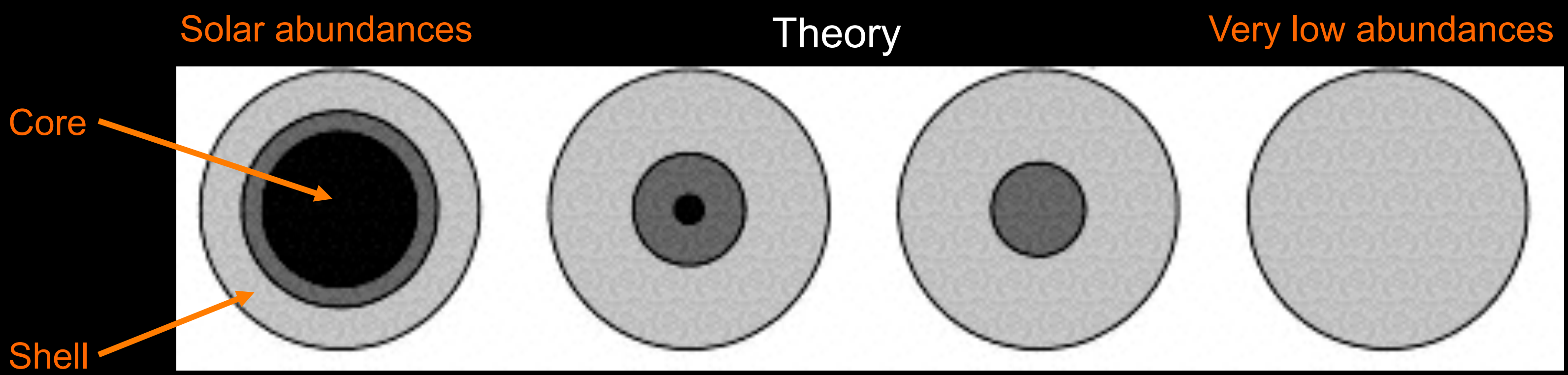
➔ Star formation is occurring in giant molecular clouds even at 13%×solar abundances.

Elmegreen et al. 2013

Herschel observations of the shells of molecular clouds in 5 abundance-poor dwarf galaxies

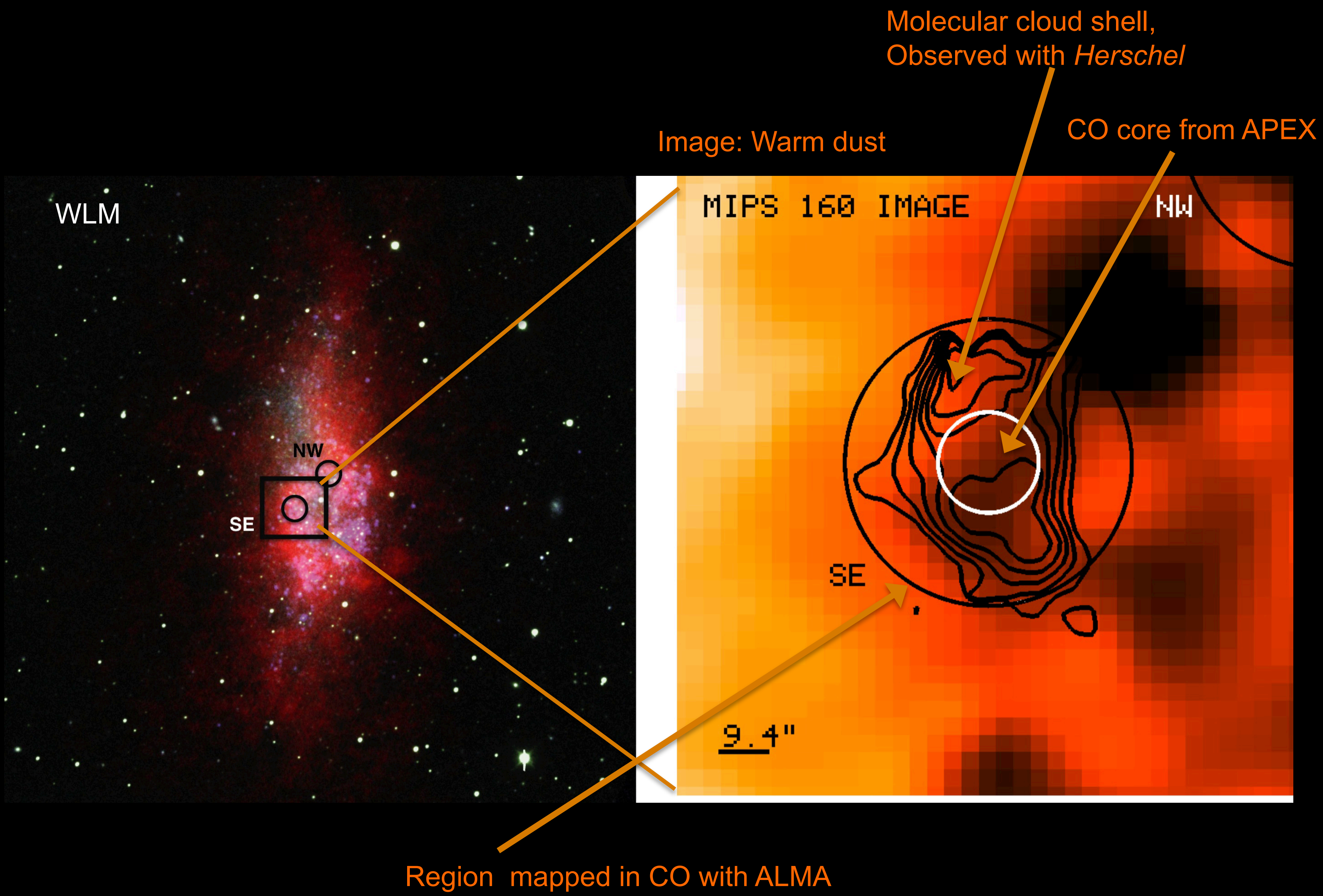
Cigan et al., in prep

Theory



Bolatto et al. 1999

Molecular core + shell – like a baseball in a glove

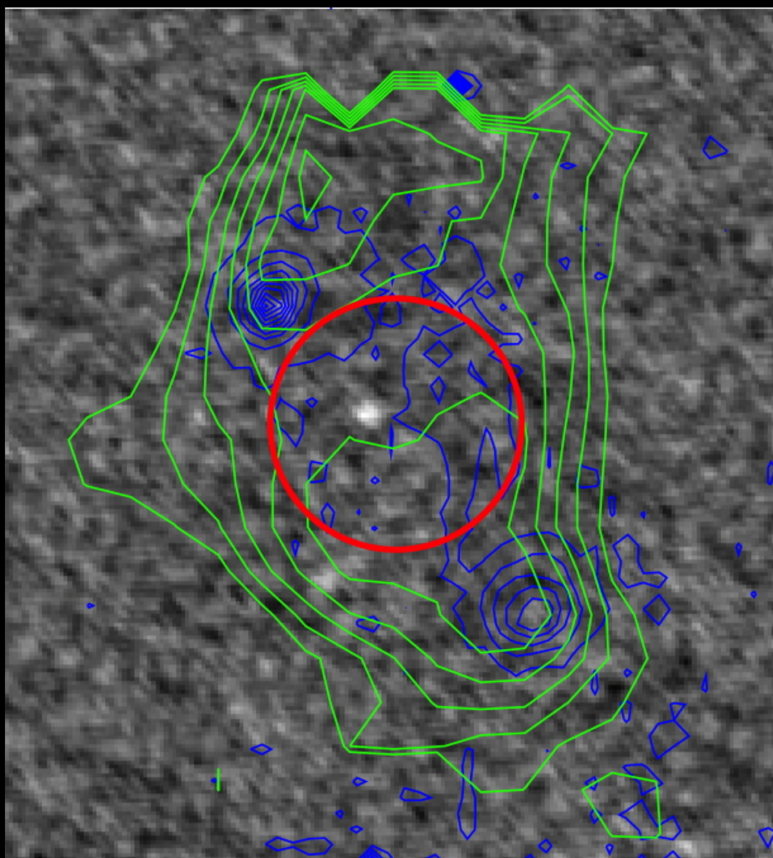


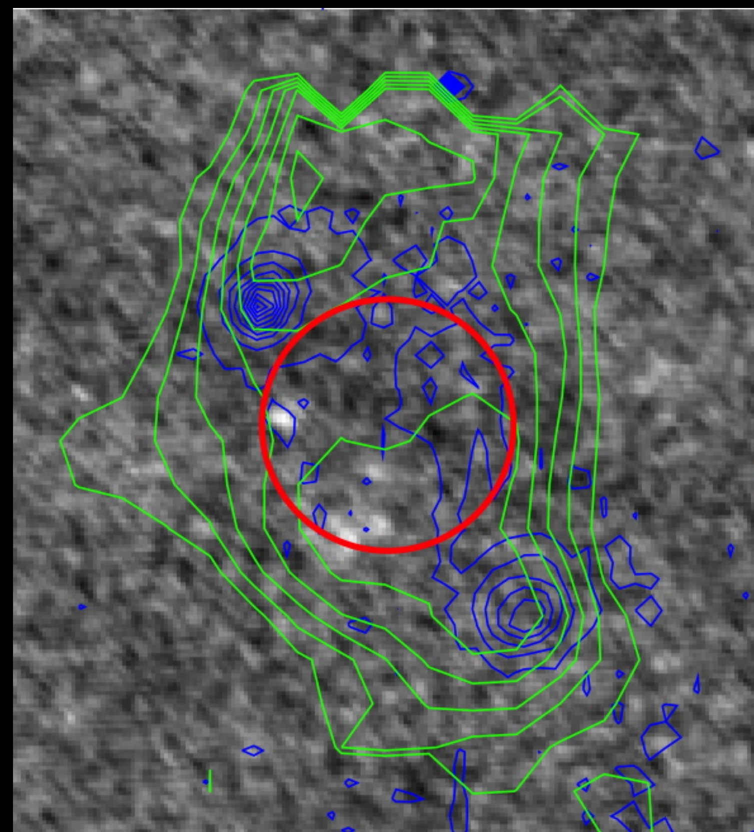
WLM - Region B:

Shell annulus $\geq$ core diameter

Theoretical prediction: Size of shell $\propto$ 1/abundance

SE molecular cores observed by ALMA





Different frequency channels

Size ~ 1-3 arcseconds = 1.4-4.2 pc

To come…

Molecular cloud structure:

	abundance relative to solar
WLM –	13%
DDO 155 –	10%
DDO 75 –	6%
DDO 69 –	5%

➔ How does the molecular cloud structure change with abundance?
➔ What difference does it make to the star formation?