Radio Observations and Techniques

http://www.aoc.nrao.edu/tourist/visit.vla.html

Karl Guthe Jansky (1905-1950)

- Bell Telephone Laboratories, late 1920s
- Studied static interference of phone reception → thunderstorms and more
- 'Signal' peak moved at sidereal rate ➔ extraterrestrial! (1932)

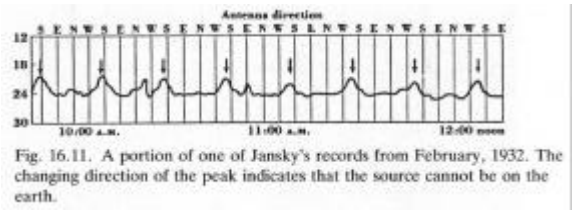


Fig. 16.11. A portion of one of Jansky's records from February, 1932. The changing direction of the peak indicates that the source cannot be on the earth.

Jansky Antenna

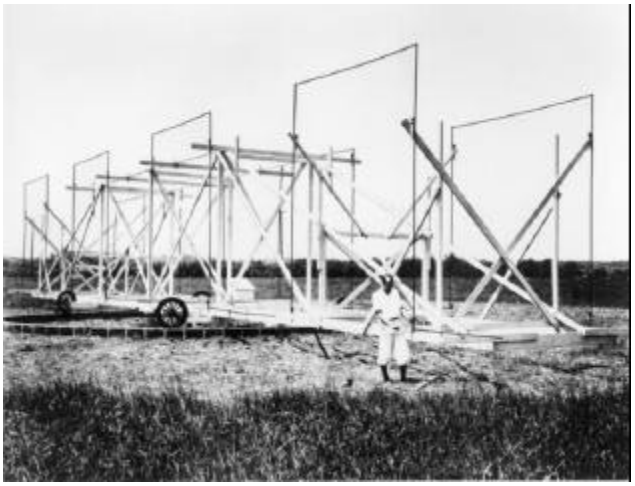


Image courtesy of NRAO/AUI

- Source toward Sagittarius (1936); paper published in engineering journals!!
- Assigned to other project; pursue no more
- Jansky's serendipitous discovery gave birth to a new branch of astronomy
  ➔ **radio astronomy**.
- In Jansky's honor, astronomers named the unit of radio flux the **jansky**
  (1 Jy= 10^{-26} W/m^2/Hz).

Grote Reber

Image courtesy of NRAO/AUI http://www.nrao.edu/imagegallery/php/level3.php?id=106

Grote Reber

- A radio engineer, lived in Wheaton, Illinois, near Chicago
- Learned about Jansky's result, and built a 9.5 m reflector
- Felt he needed astronomy background; took a course in University of Chicago, where he met Otto Struve, Bengt Stromgren, Gerald Kuiper
- They knew Reber was onto something
- Struve, then Editor of Astrophysical Journal, ensured Reber's paper got published (1940)

Grote Reber's original dish today at the NRAO in West Virginia

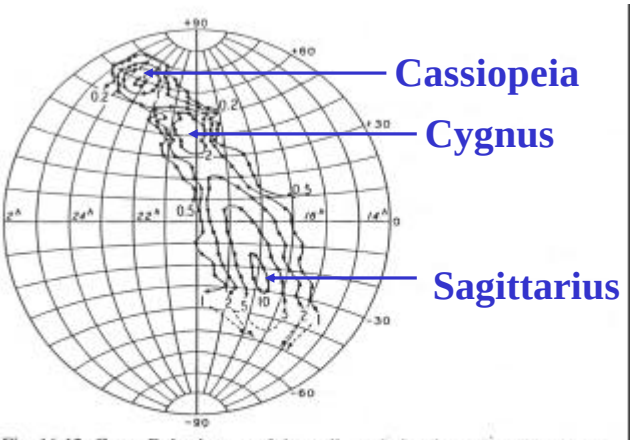


Fig. 16.12. Grote Reber's map of the radio emission from the Milky Way. This was published by Reber in 1944. (Reprinted with permission from *The Astrophysical Journal*.)

Contour ➔ Milky Way!

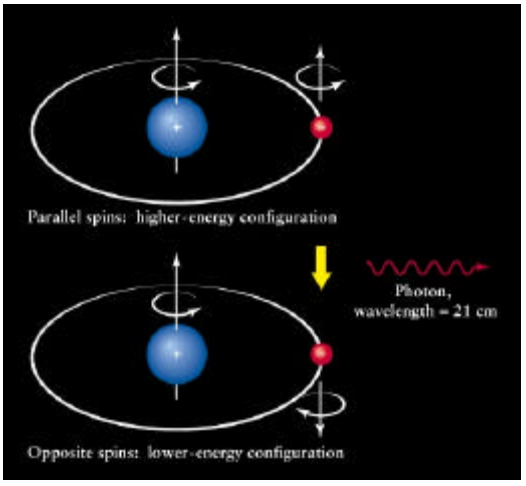
Radio Astronomy Elsewhere …

Meanwhile, in Leiden, Neitherlands

- 1944, Jan Oort, director, showed Reber's paper to colleagues and asked J. C. van de Hulst to study it and pursue further
- van de Hulst proposed possible transition → **21 cm line of hydrogen**
- Useful as a tool to study gas motion
- Started to build equipment

Efforts in USA and Australia, too …

21 cm line of hyperfine transition of hydrogen



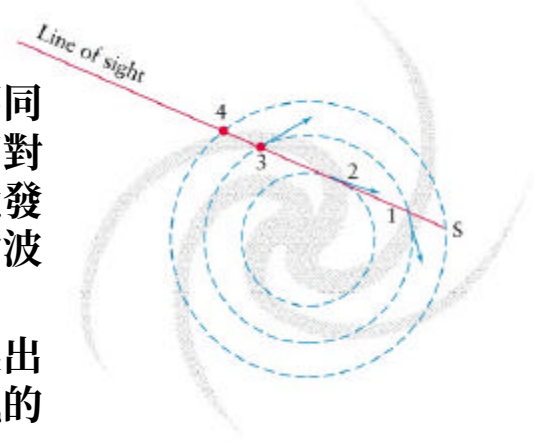
電子與質子有如小型的自轉 (spin) 磁鐵，它們的自轉方向不是相同就是彼此相反。

21 cm Line of Hydrogen

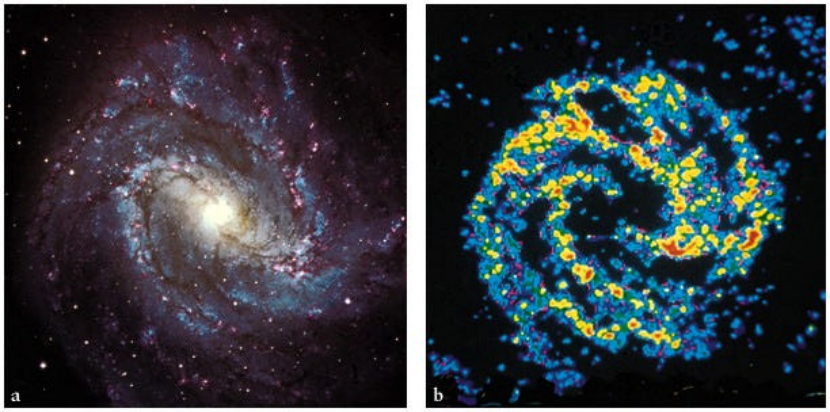
- 當原子從 parallel 狀態，變成 anti-parallel 狀態 (hyperfine structure) → 原子放出這兩種自轉狀態的（微小）能量差
- 在 1951 年首先偵測到星際氫氣的 21 公分輻射 (1420 MHz)
- 銀河系中不同位置的氫氣雲氣運動狀態不同
  → 21 公分輻射波長稍許不同
  → 描繪出銀河系裡氫氣雲分佈的情形
  ➔ 銀河系在旋轉 (galactic rotation)，且轉速內外不同 ➔**differential rotation**

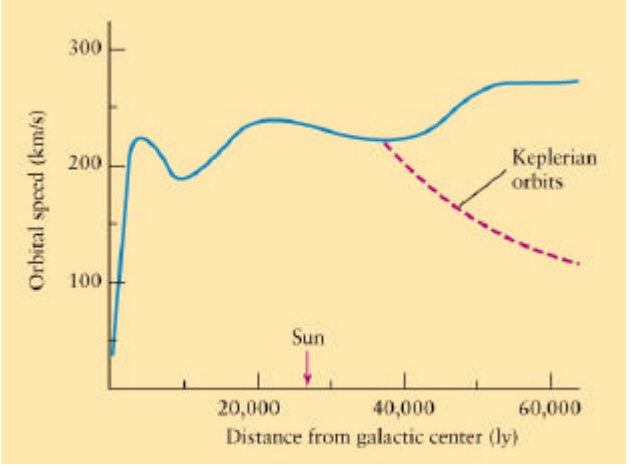
利用21公分電波輻射探討銀河盤面結構

- 銀盤在自轉，不同位置與觀測者相對速度不同，因此發出的21公分輻射波長稍有不同
- 利用此原理繪製出銀河盤面上氫氣的分佈

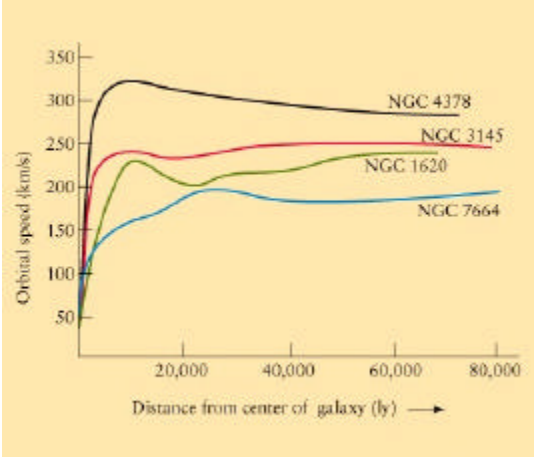


Spiral Galaxy M83 observed in both visible light and radio wavelengths.





Rotation curve flat beyond optical range
→ **dark matter**!



- A fire hazard of the detector hampered the Dutch group
- Initial detection by H. I. Ewen and E. M. Purcell in the USA
- Confirmation by Dutch and Australians followed in weeks
  (but who remembers the followers anyway!)

→ **There must be an abundance of hydrogen in space**

➔ Birth of Radio Astronomy

Radio Wavebands

Band	Frequency	Wavelength
AM	55-160 KHz	5454-1875 m
SW	3-30 MHz	100-10 m
FM/TV	30-30,000 MHz	10 m – 1 cm

Celestial Radio Sources

- **Thermal radiation 熱輻射** (continuum)
  arises from the thermal energy of an object
  (1) ***blackbody radiation***
  (2) ***free-free radiation***
- **Line radiation**
  arises from quantum transitions (e.g., electronic, rotational, vibrational, etc.)
- **Synchrotron radiation 同步輻射**
  radiated by a charged particle (often an electron) moving in a magnetic field at a velocity close to that of light

Observing at Radio Bands

$\lambda_{radio}/\lambda_{optical}$ ~ [cm]/[a few hundred nm]
~ 10^5-10^6

Consequences:

- **Resolution** –
- **Imaging Difficulty**
  because wavelength ~ size of instrument
  → diffraction → aberration

For a simple, single radio telescope
→ mapping at different positions (grids) and construct a contour map of equal intensity

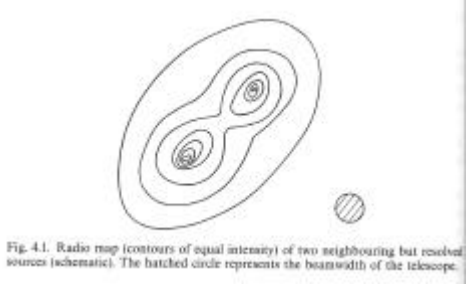


Fig. 4.1. Radio map (contours of equal intensity) of two neighbouring but resolved sources (schematic). The hatched circle represents the beamwidth of the telescope.

Detection of Radio Emission

- Detection by alternating EM field, rather than by photons
- Wave → **amplitude** + **phase**

Strength of the wave

Which part of the wave is passing at a given moment

For a wave of a single frequency *w*, the voltage varies with time *t* as

$$V = V_0 \sin(w t - j)$$

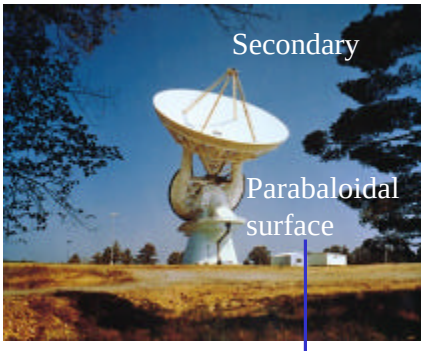
V_0 : amplitude

j : phase --- how waves add together

→ possibility of interferometry

Radio Telescopes

- **Antenna** (equivalent to the primary mirror of an optical telescope)
  - points to the target, collects radiation, and converts it to an AC signal
- **Receiver** (equivalent to optical detector and analyser)
  - chooses signal frequency, bandwidth, spectral resolution
  - processes and records the signal



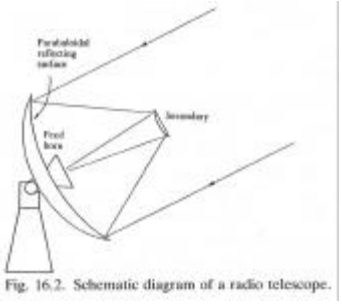
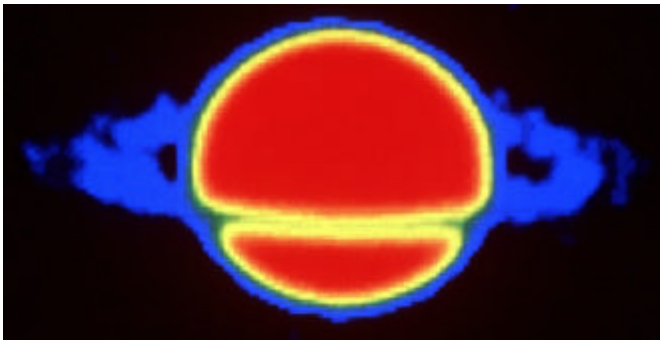


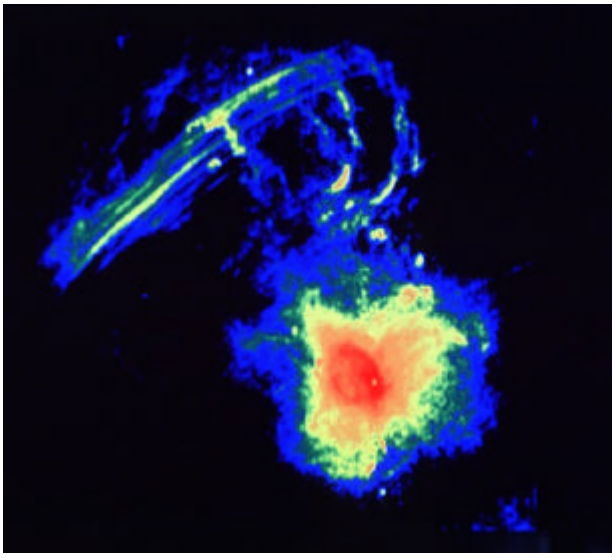
Fig. 16.2. Schematic diagram of a radio telescope.

- Collecting signal
- Blocking ambient radiation

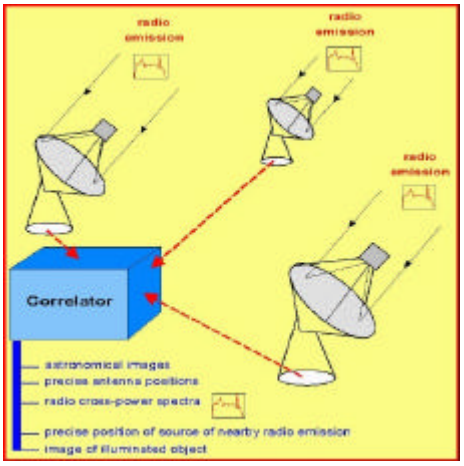
Saturn



Sagittarius A



Radio Interferometry



http://www.drao.nrc.ca/science/vlbi/principles/principles.shtml

- If the antennas are close to each other
  → the signals are sent to the correlator and processed immediately
- If antennas are separated by long distances
  →**Very Long Baseline Interferometry (VLBI)**
  then the signals are recorded on magnetic tape and the tapes are shipped to the correlator for processing at a convenient time
- A radio interferometer produces images by **aperture synthesis**

Millimeter & Centimeter Wave Radio Telescopes in the USA

Green Bank Telescope, WV

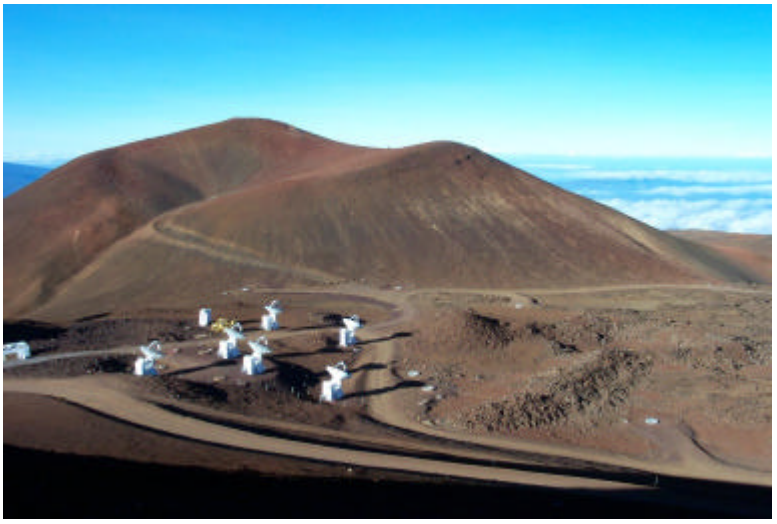
Owens Valley Radio Observatory, CA

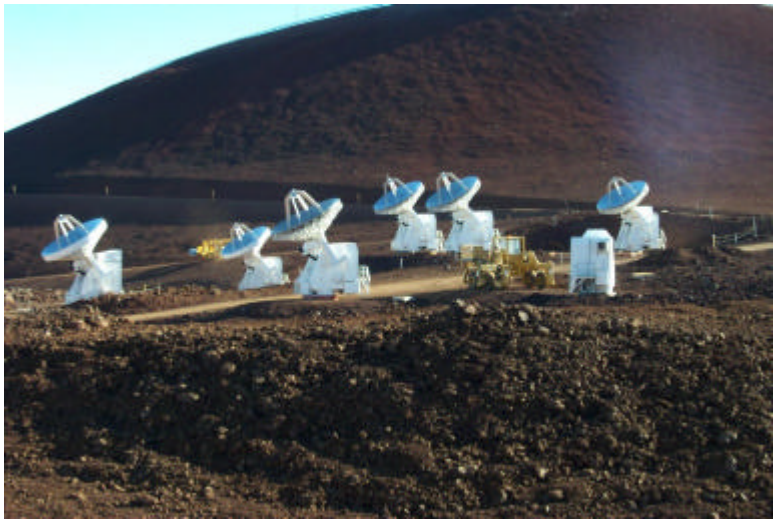
Very Large Array, NM

Berkeley-Illinois-Maryland Array, CA

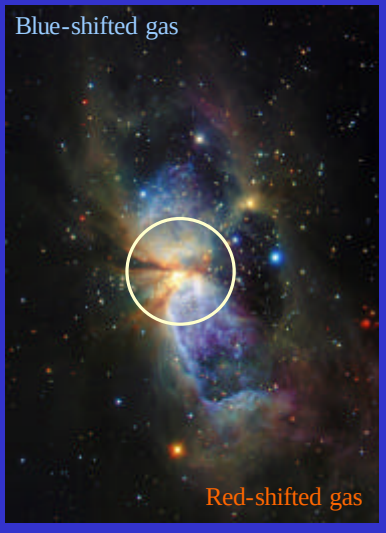
Very Long Baseline Array, USA

Sub-Millimeter Array (SMA) atop Mauna Kea in Hawaii

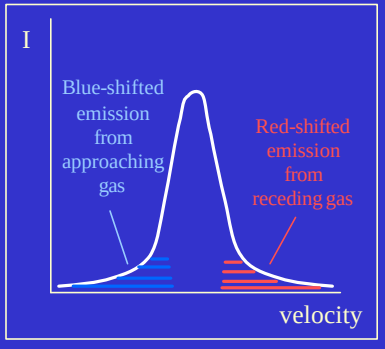




Outflow Radio Emission - 1



S106, IR Subaru Telescope, Japan

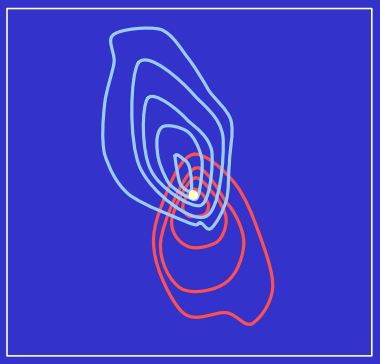


Plot a spectrum in "wavelength space" or "velocity space" because of Doppler Formula:

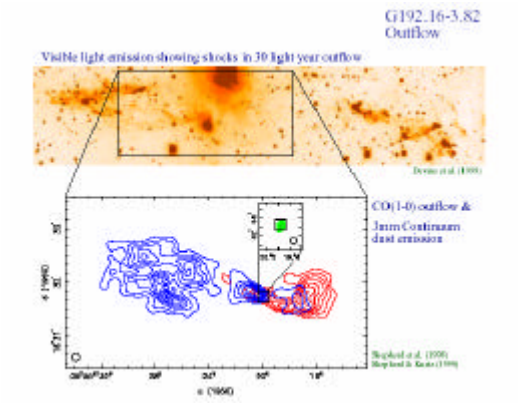
$$D1/1 = v/c$$

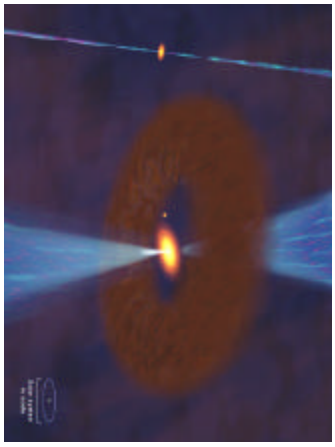
Outflow Radio Emission - 2

S106, IR Subaru Telescope, Japan



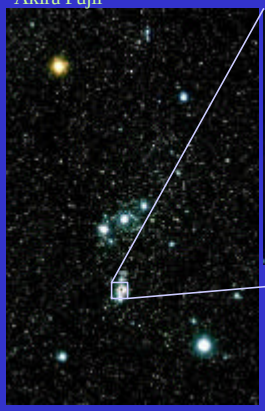
Simulated “9 point” radio map of the S106 bipolar outflow





Accretion Disks: Solar Type Stars

Akira Fujii



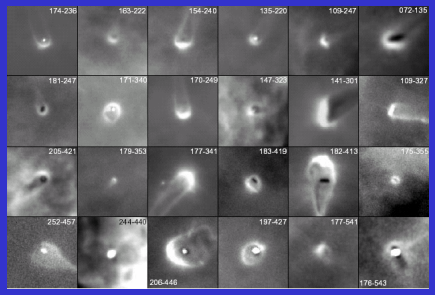
David Malin

HST image (O'Dell 1995)

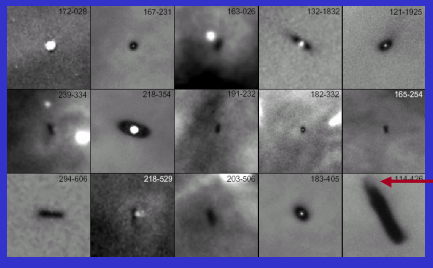
Consider nearest massive star forming region: Orion

Visible nebula created by reflected light from "Trapezium Cluster" of hot, massive stars. Low-mass stars are still forming near massive stars.

Disks in the Orion Nebula



Irradiated by the Trapezium stars (left) & in silhouette against bright nebular emission (bottom).
Bally, O'Dell, McCaughrean 2000



Translucent edge in disk: Measured opacity at 3 wavelengths ➔ large grains (cm sized – protoplanetary?) (Bally et al. 2002)