DARA
DEVELOPMENT IN AFRICA WITH RADIO ASTRONOMY

Unit 1

Radio Astrophysics

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DARA Overview

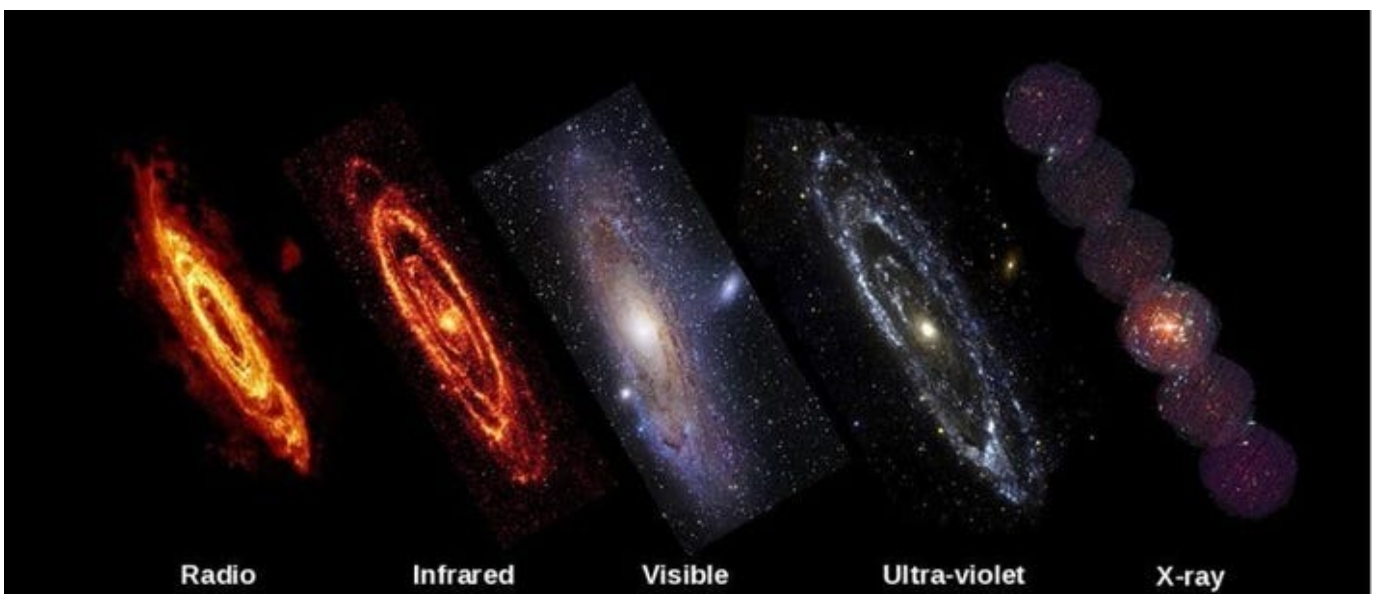
- Computer Training
  - Linux and python skills
- Unit 1
  - Astrophysics of radio sources
- Unit 4
  - Radio astronomy data reduction
- Unit 2/3
  - Radio observational techniques and technology
- Virtual Network Meeting
  - Opportunities in business and industry

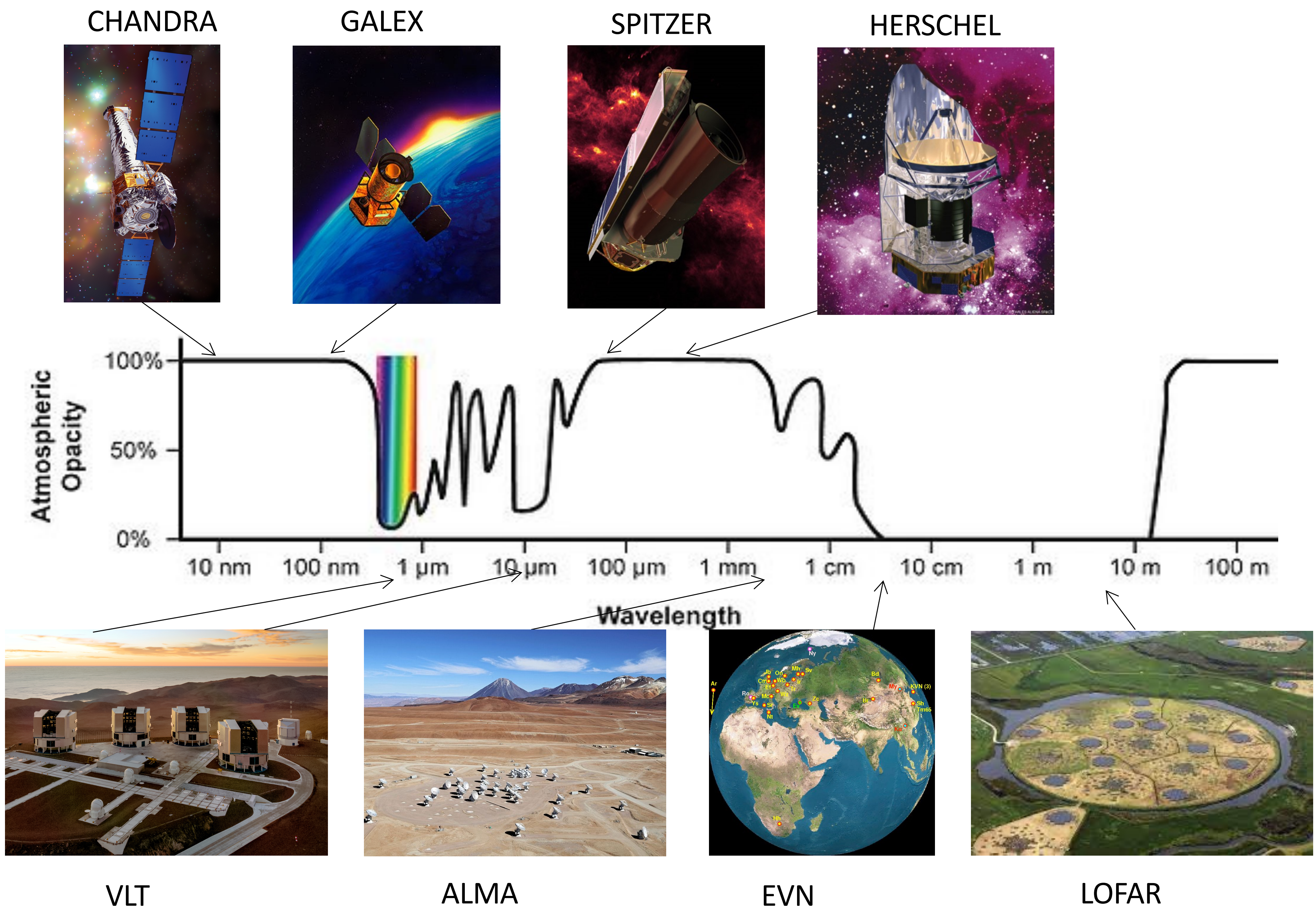
Unit 1

- Aims
  - Astrophysics underpinning the various types of radio sources
  - Physics of the emission mechanisms and radiation concepts
  - Different ways of utilizing radio emission
    - Continuum
    - Spectral line
    - Polarization
    - Time variation
  - Background to key SKA science goals

Multi-Wavelength Astronomy

- Modern astronomy uses the whole electromagnetic spectrum
- Some wavebands can be done from the ground
- Others need to be done from space





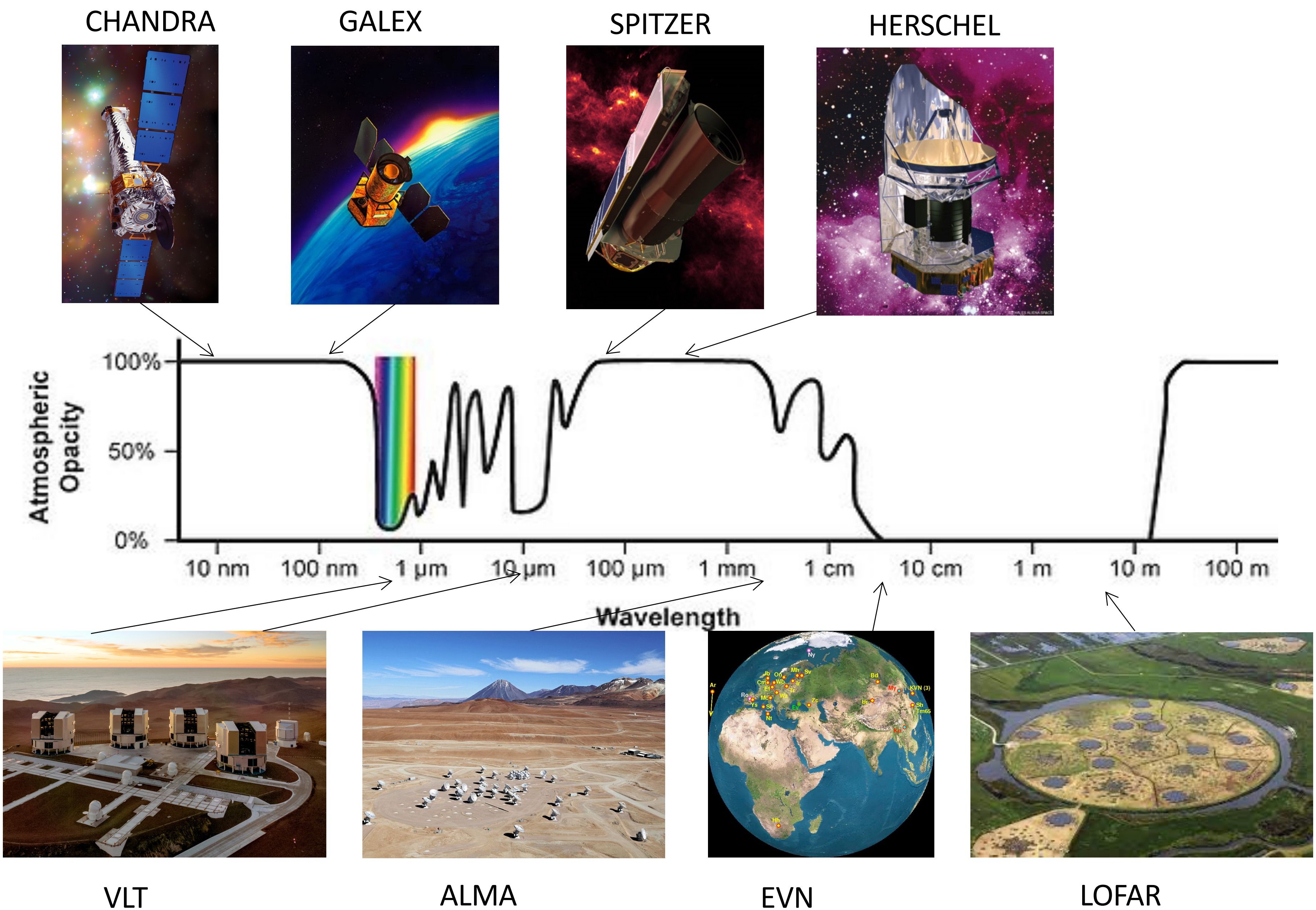
CHANDRA
GALEX
SPITZER
HERSCHEL
Atmospheric Opacity
100%
50%
0%
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
Wavelength
VLT
ALMA
EVN
LOFAR

Multi-Wavelength Astrophysics

- Different parts of the spectrum are useful for probing different aspects
- E.g.
  - X-rays probe high energy phenomena
  - Ultra-violet probes hot stars
  - Optical/near-IR probe stars
  - Infrared probes warm dust
  - Millimetre probes cool dust and molecules
  - Radio probes…

Brief Discussion

- What are the advantages and disadvantages of ground-based versus space-based telescopes?



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Radio Astronomy

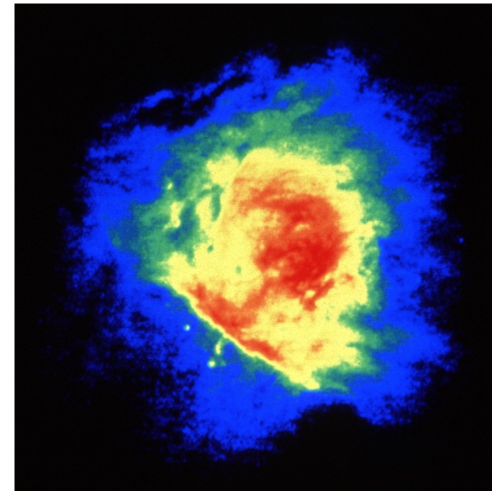
- The primary role of radio astronomy is to probe interstellar gas in its various forms
- Ionized gas
- Atomic gas
- Molecular gas

Ionized Gas

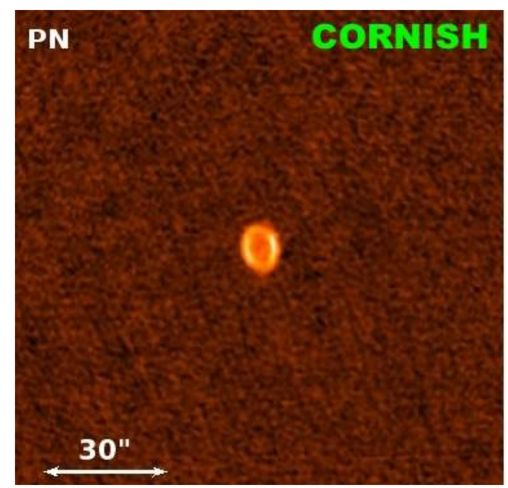
- The majority of radio observations target ionized gas
- Gas can be ionized in two ways
  - Photo-ionized by a source of extreme ultra-violet radiation, i.e. a hot source
  - Collisionally-ionized by shocks when fast moving gas collides with slow moving gas

Photo-Ionized Nebula

- H II Regions
  - Hot, young stars in massive star forming regions

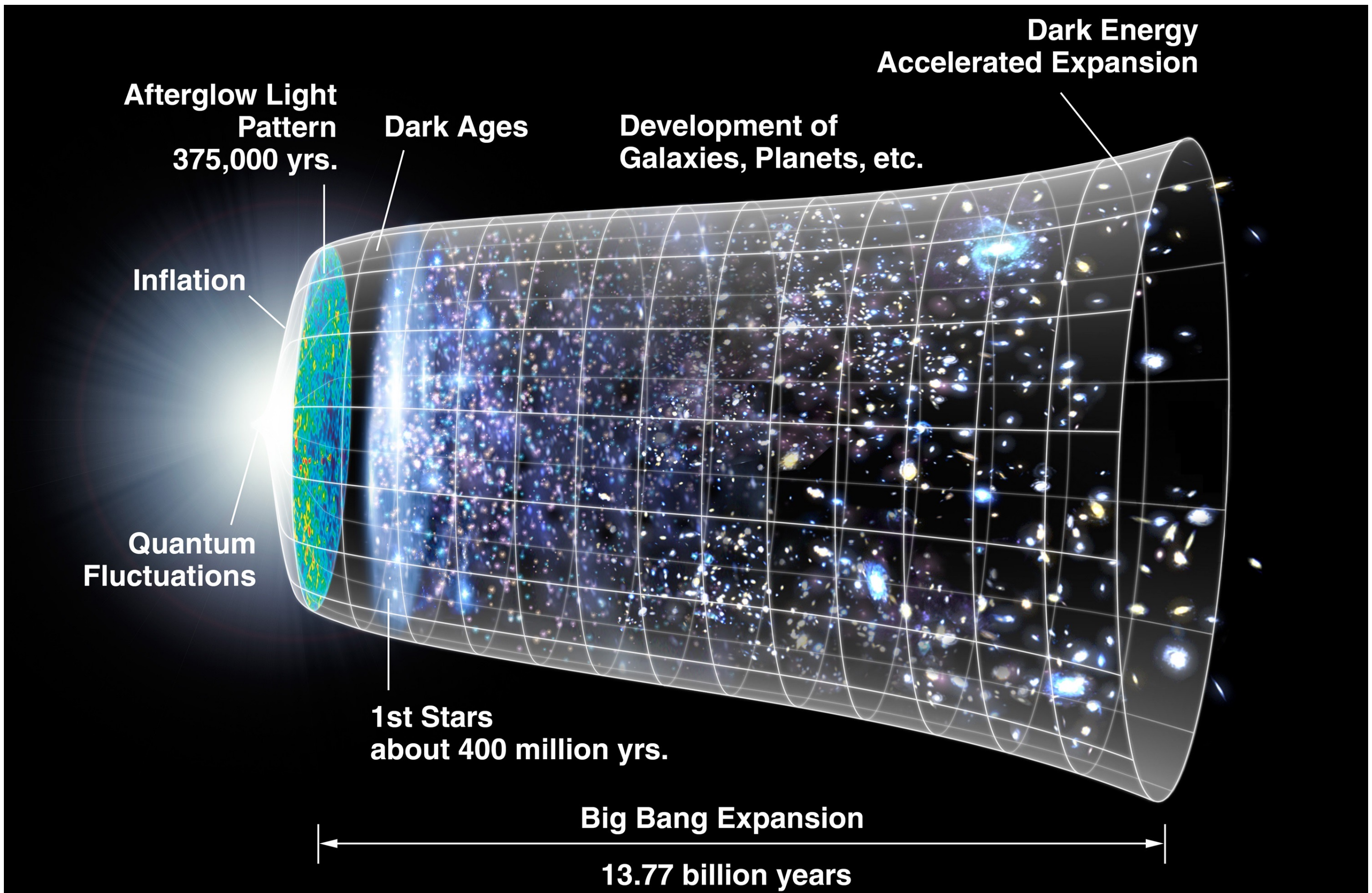


- Planetary Nebulae
  - Ejected envelopes of dying stars ionized by hot stellar remnant

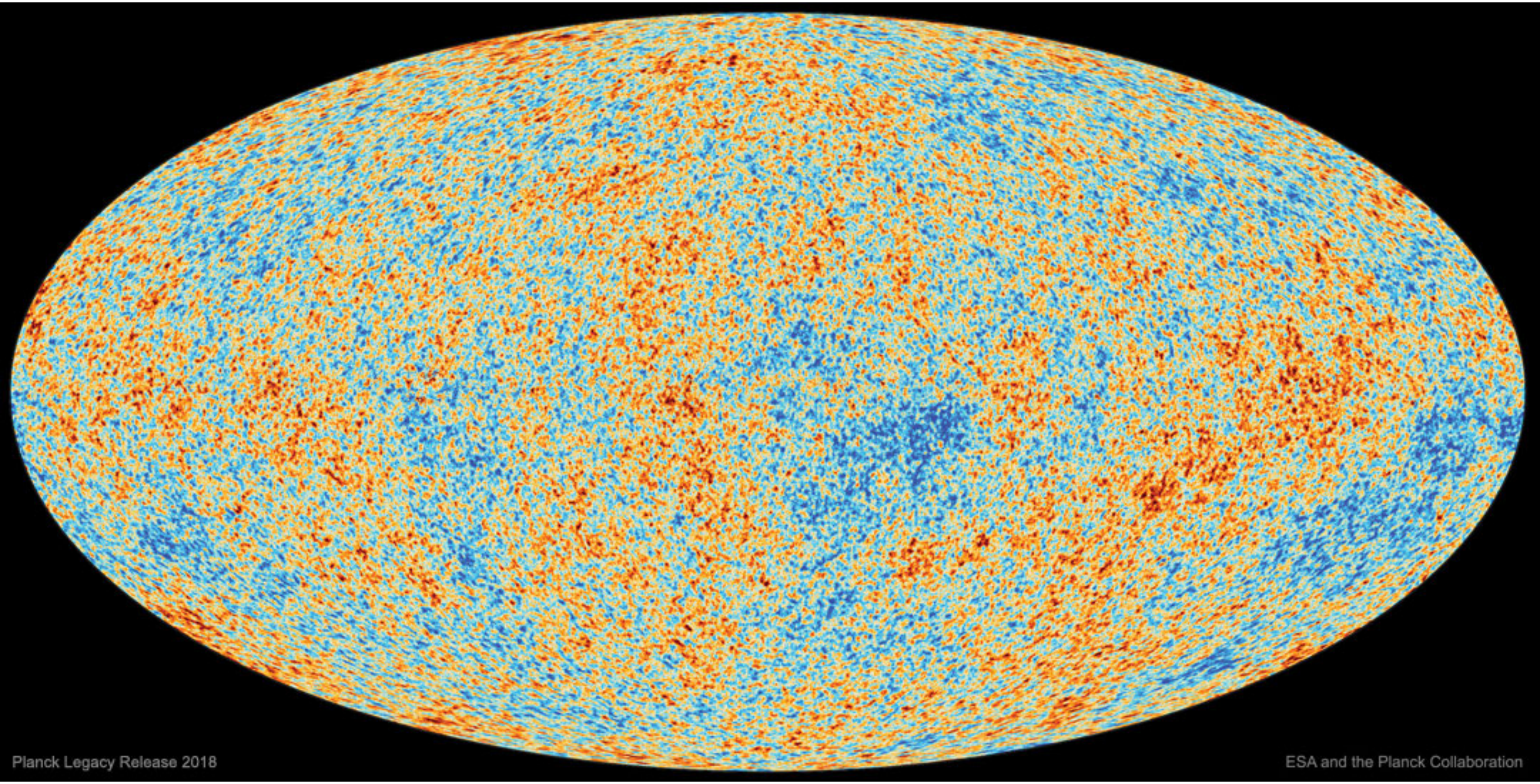


Irabor et al. (2018)

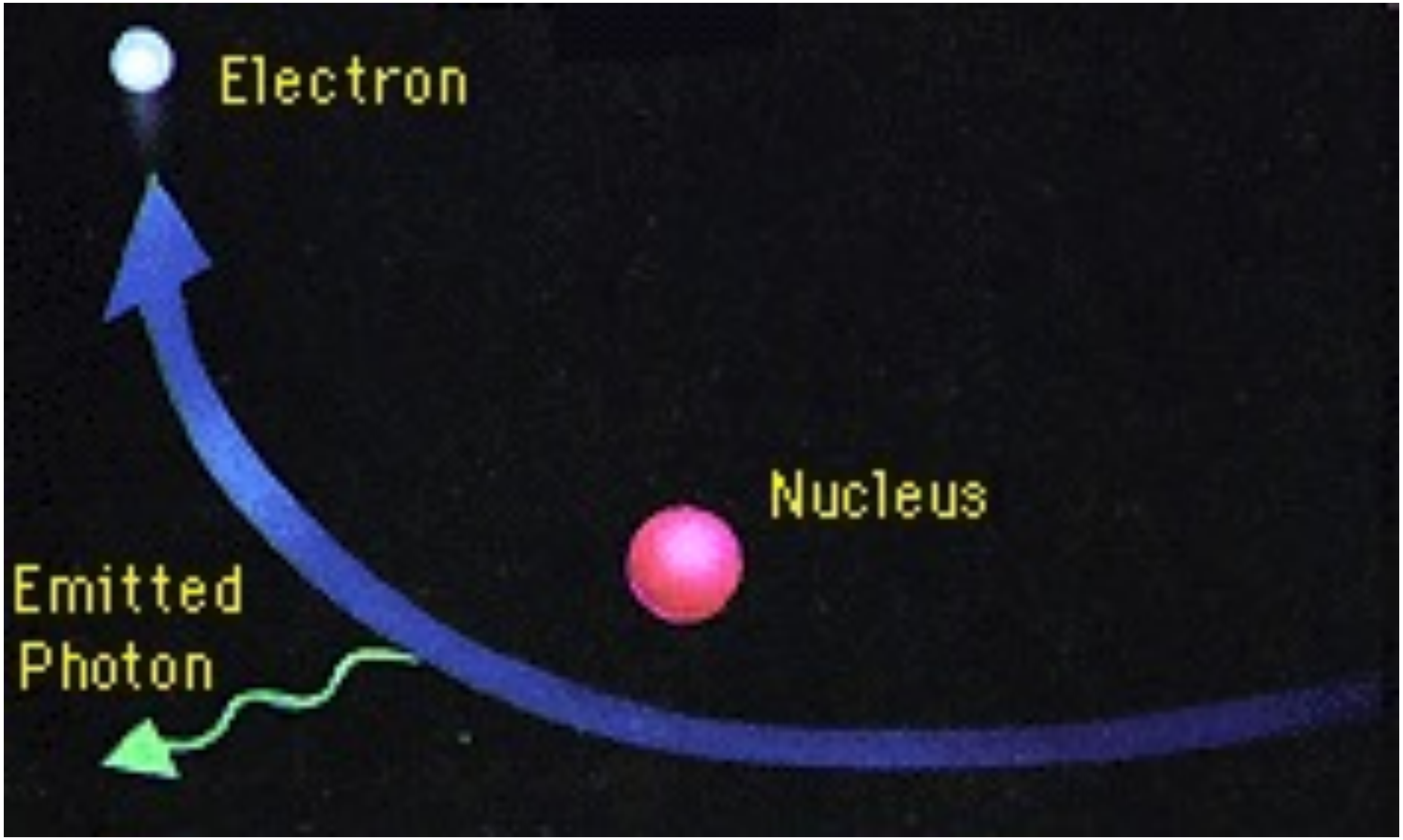
- The Big Bang
  - The glow of the gas left over from the hot Big Bang



- The Cosmic Microwave Background



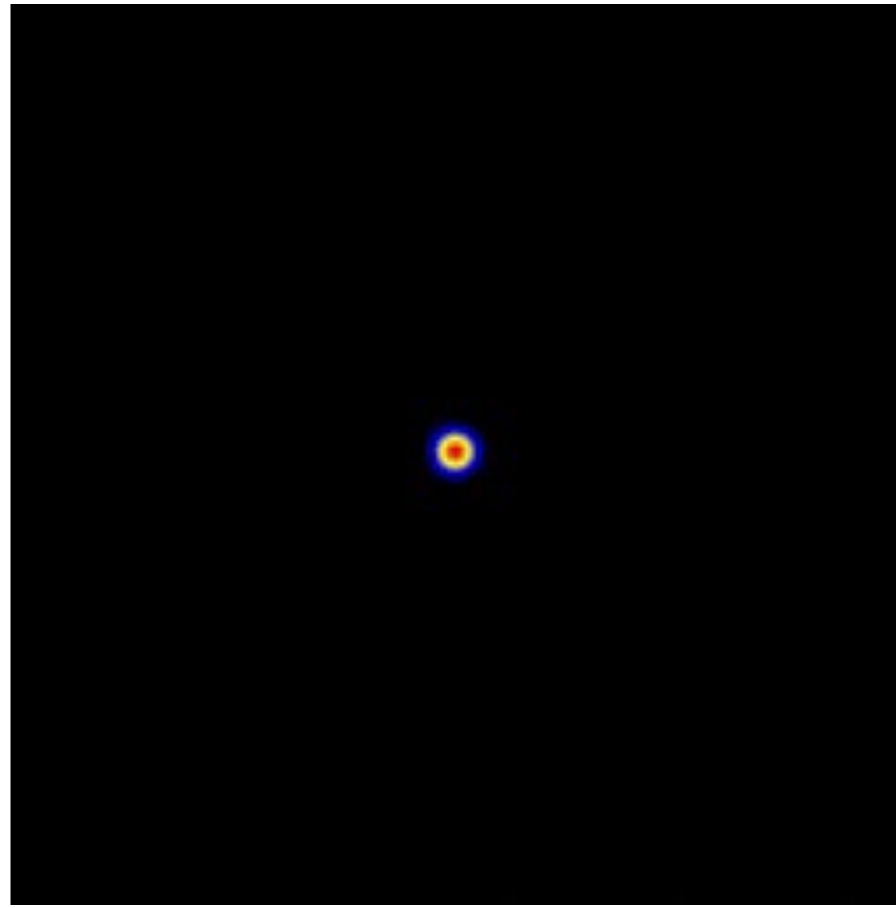
- Photo-ionized sources usually emit radio continuum radiation via the **thermal** free-free or Bremsstrahlung process



Bremsstrahlung mechansim. NASA Goddard Space Flight Center.

Collisionally-Ionized Sources

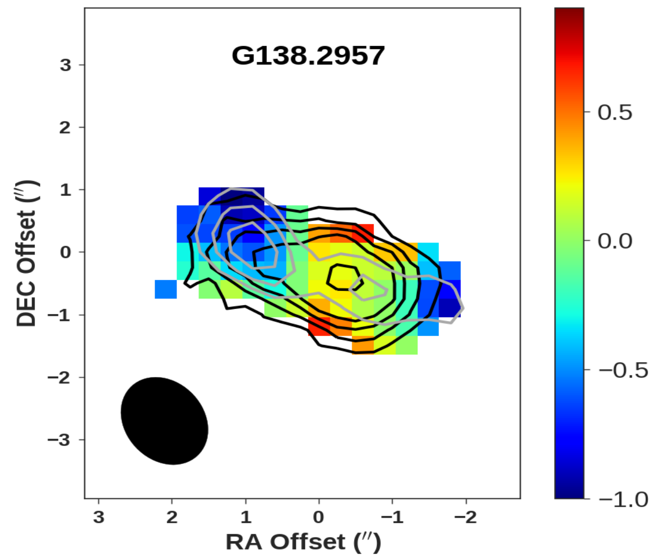
- Supernova Remnants
  - Shells of gas ejected at mildly relativistic speeds
  - Either from exploding single massive stars at the end of their lives
  - Or from accreting white dwarfs being forced over their mass limit



http://www.yorku.ca/bartel/index.html

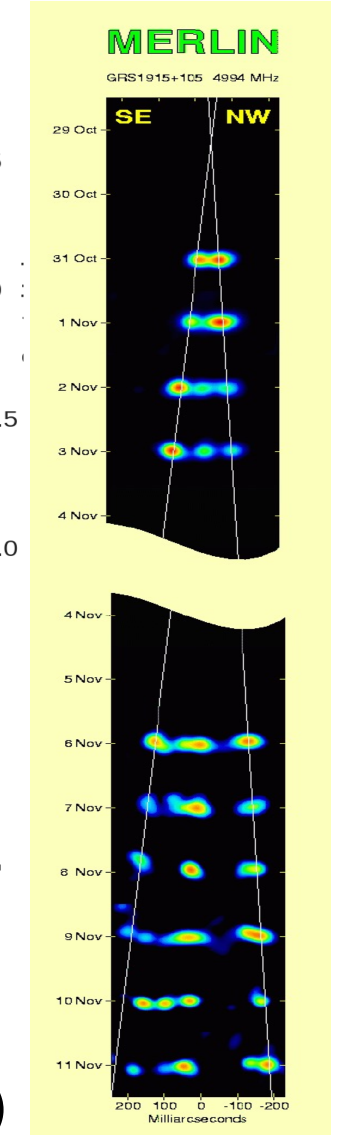
Collisionally-Ionized Sources

- Proto-stellar Jets
  - Fast jets arising from accreting stars in the process of forming



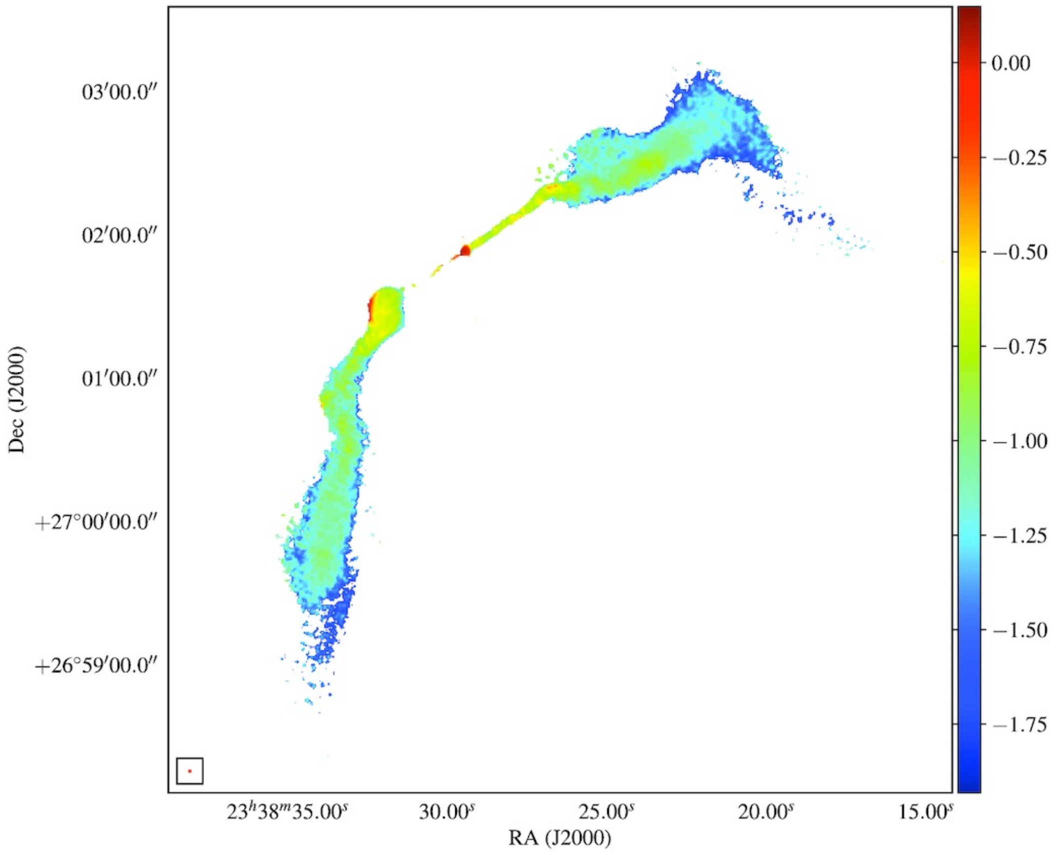
Obonyo et al. (2018)

- Interacting Binary Jets
  - Relativistic jets arising from accreting super-neutron stars or black holes in binary systems



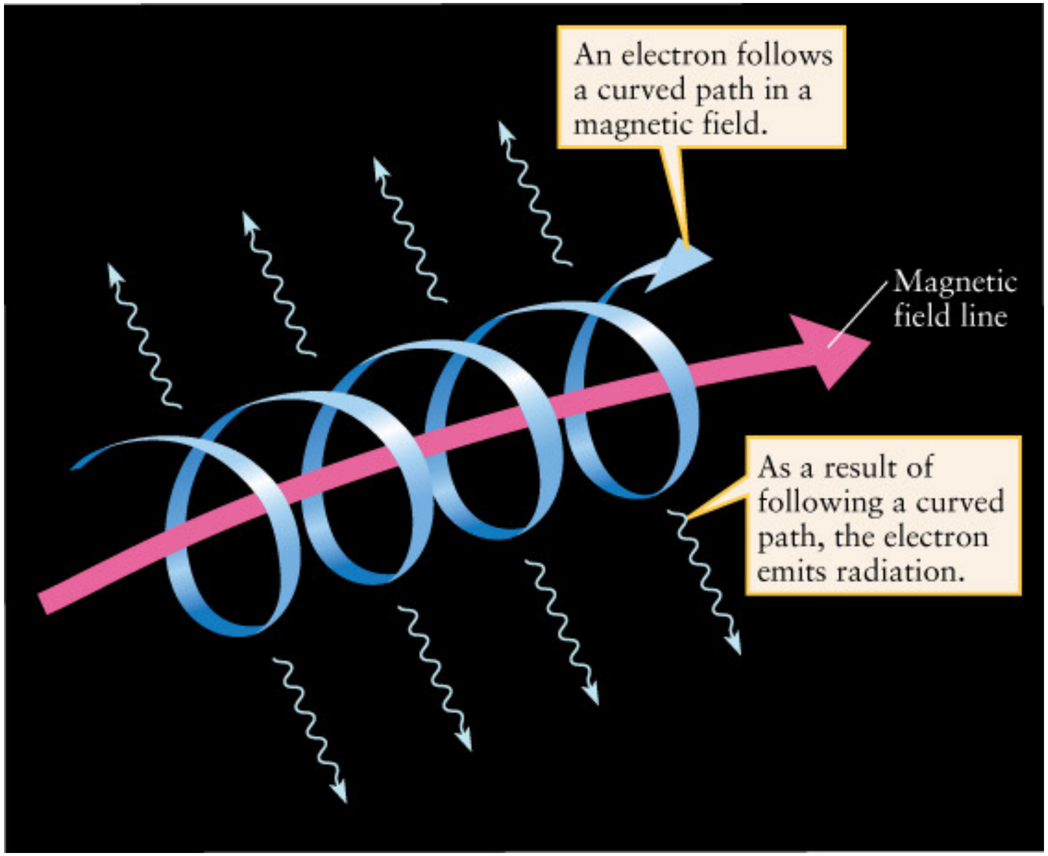
Fender et al. (1999)

- AGN Jets
  - Relativistic jets arising from accreting super-massive black holes at the centres of active galaxies



Bempong-Manful et al. (2018)

- Collisionally-ionized sources usually emit radio continuum radiation via the **non-thermal** synchrotron process



From Universe textbook

Exercise

- You can distinguish between thermal and non-thermal radio sources by the slope of their radio continuum spectrum. This is usually characterized by the spectral index, $\boldsymbol{\alpha}$, where

$$S_\nu \propto \nu^\alpha$$

If as source has a flux of 0.65 mJy at 1.5 GHz and 0.26 mJy at 5.8 GHz what is its spectral index?

$$S_\nu \propto \nu^\alpha$$

$$\frac{S_{\nu_1}}{S_{\nu_2}} = \left(\frac{\nu_1}{\nu_2}\right)^\alpha$$

$$log\left(\frac{S_{\nu_1}}{S_{\nu_2}}\right) = \alpha log\left(\frac{\nu_1}{\nu_2}\right)$$

$$\alpha = \frac{log\left(\frac{S_{\nu_1}}{S_{\nu_2}}\right)}{log\left(\frac{\nu_1}{\nu_2}\right)}$$

$$\alpha = \frac{log\left(\frac{0.65}{0.26}\right)}{log\left(\frac{1.5}{5.8}\right)}$$

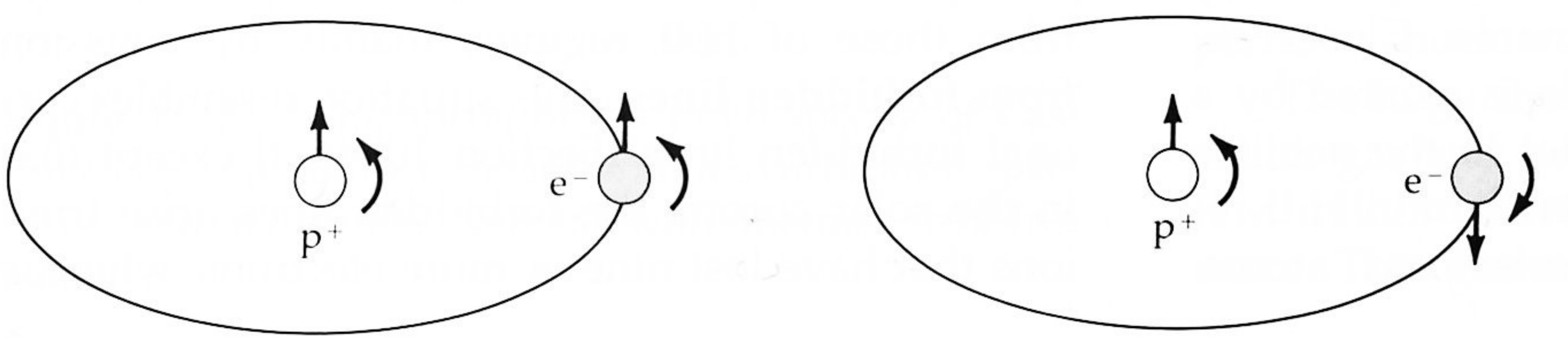
$$\alpha = -0.68$$

Atomic Gas

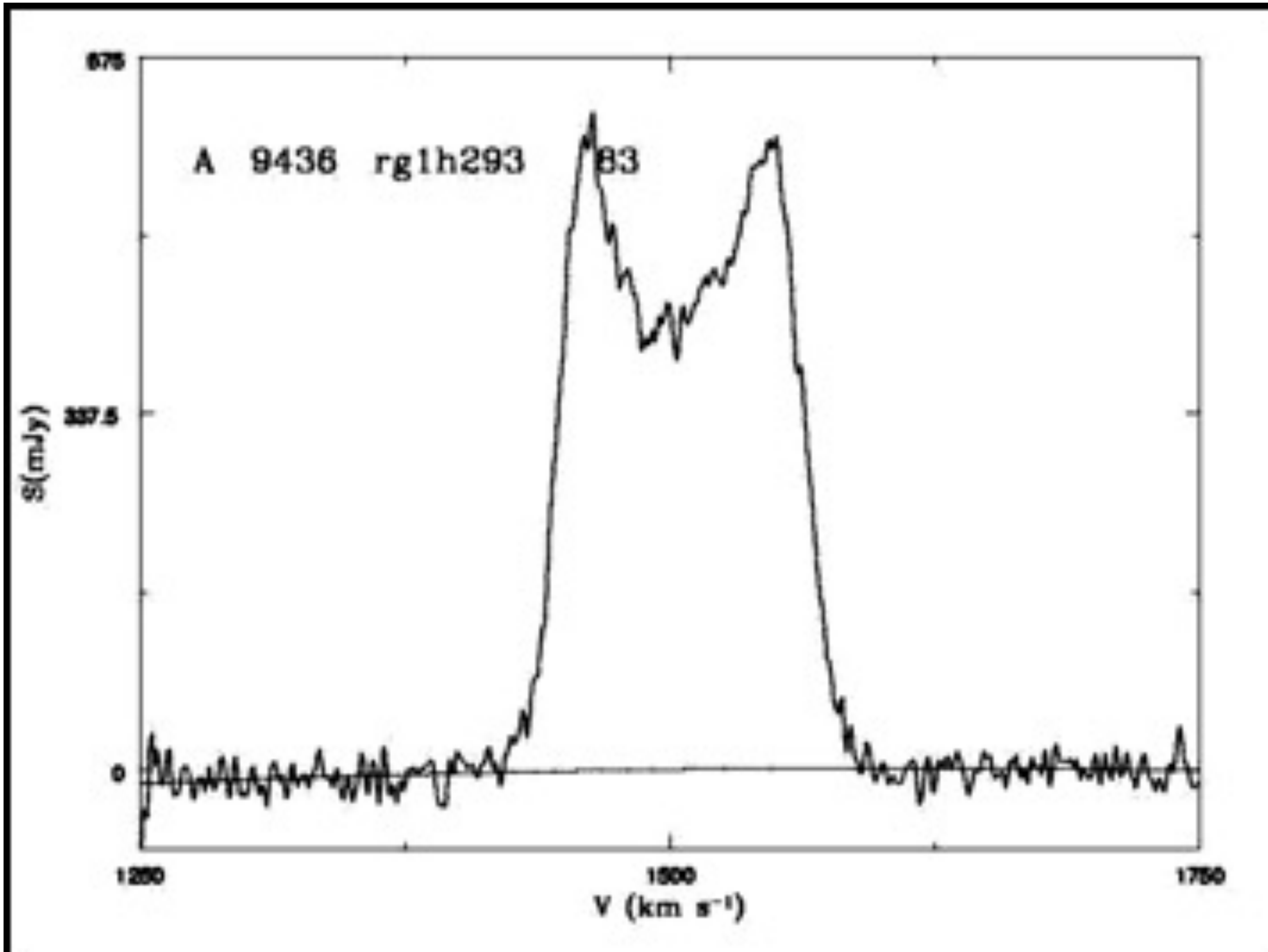
- A unique feature of radio astronomy is the ability to detect cool atomic hydrogen gas
- Hydrogen is the most abundant element
- Atomic hydrogen gas makes up most of the mass of interstellar gas
- It is the raw material required to form stars and galaxies

21 cm Transition

- Atomic hydrogen (H I) visible via hyperfine (spin-flip) transition at frequency of 1.4 GHz or wavelength of 21 cm

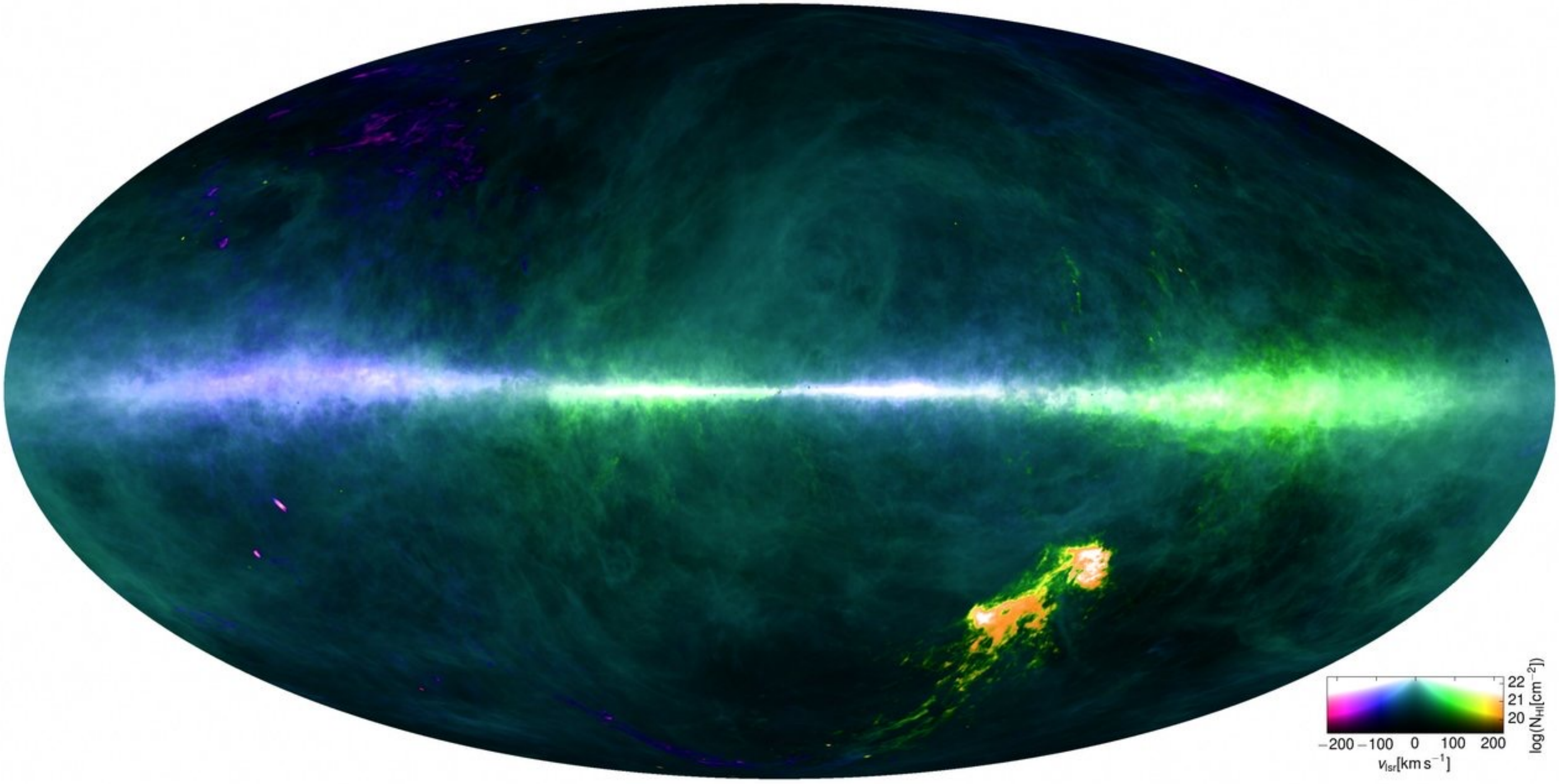


Zeilik & Gregory Fig 15-12



Example H I line profile for a galaxy

alfalfasurvey.wordpress.com/2009/01/

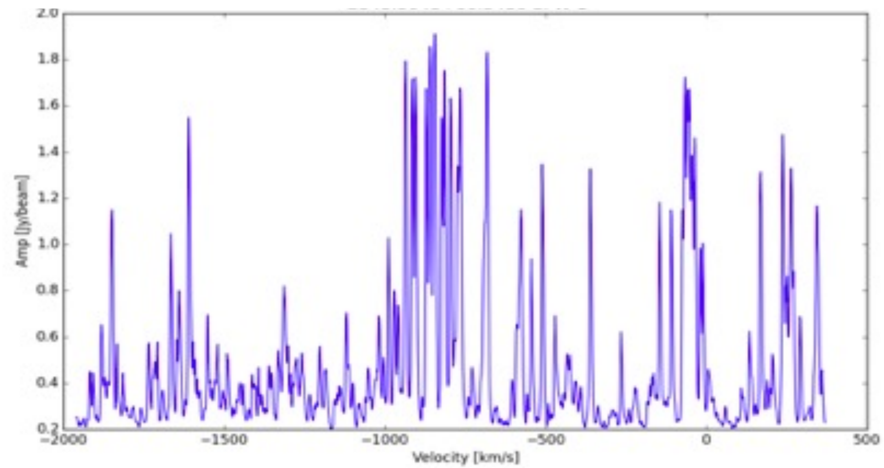


All sky view of H I emission

https://www.mpifr-bonn.mpg.de/pressreleases/2016/13

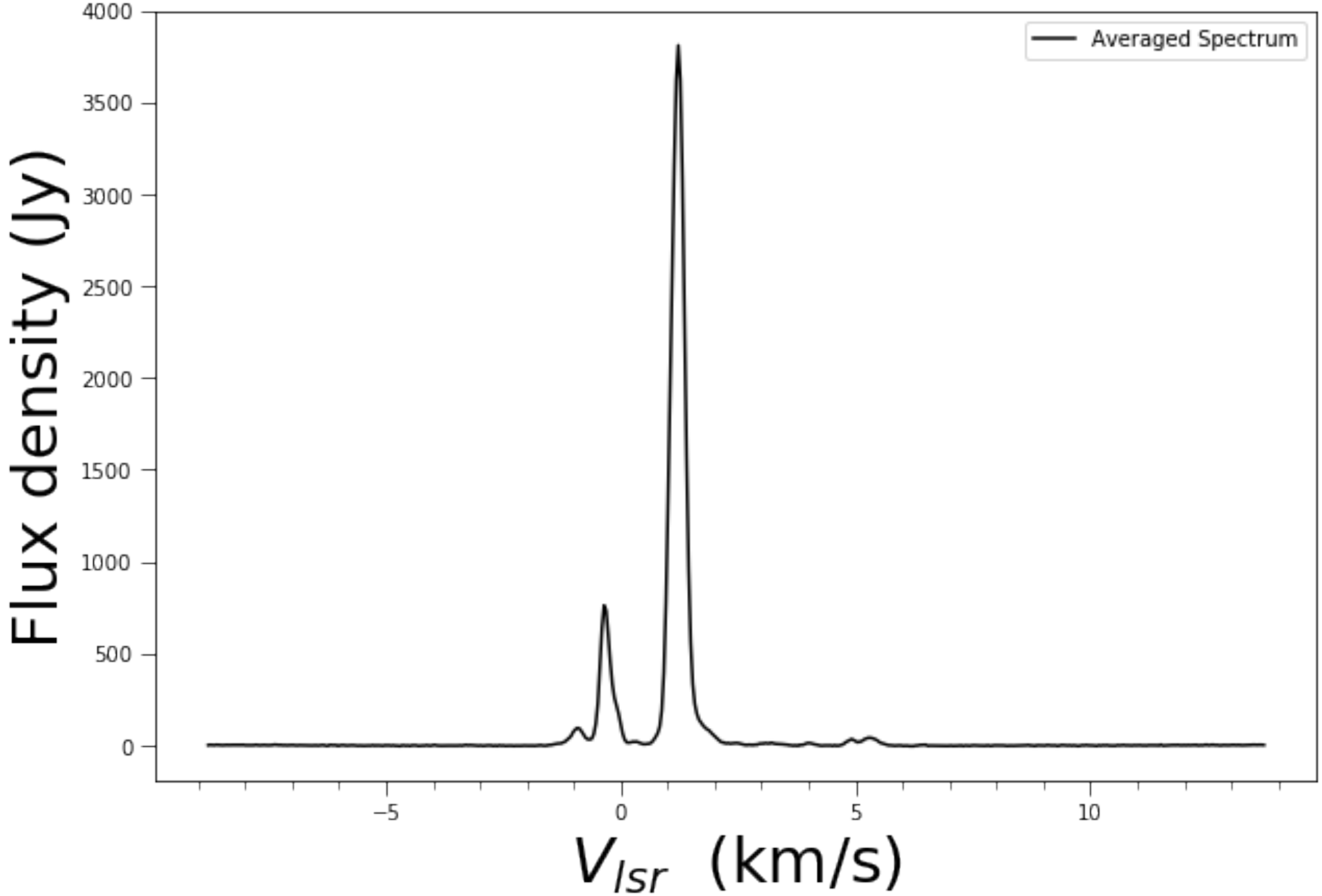
Molecular Gas

- Molecules in space mostly emit thermally in the millimetre waveband



Asabre-Frimpong (2020) PhD Thesis

- A few are seen in emission or absorption at radio (cm) wavelengths
- Some molecules emit non-thermally due to maser action (cf laser) at radio wavelengths

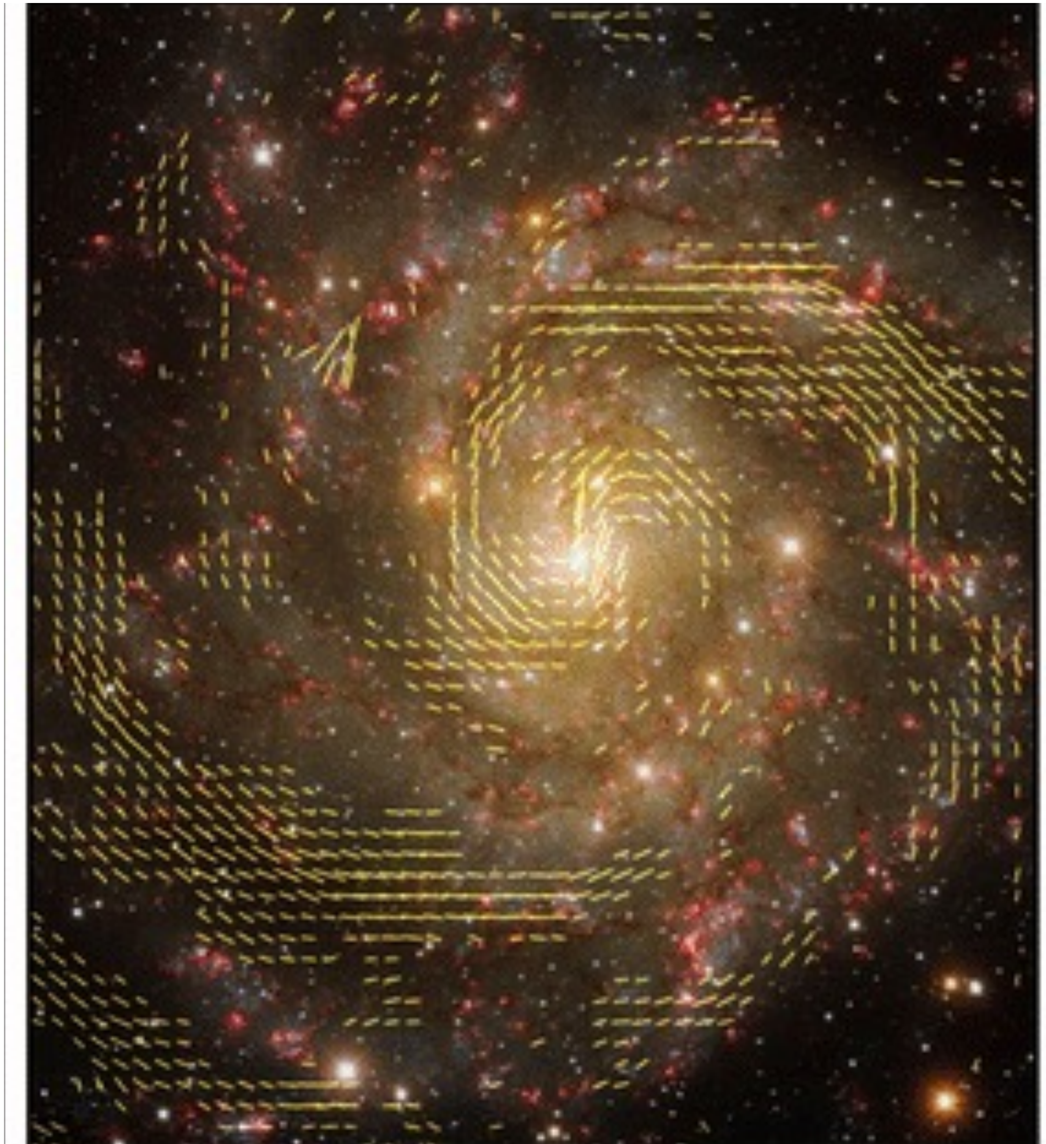


Example methanol (CH_3OH) maser spectrum from a star forming region

Woode (2020) PhD Thesis, University of Ghana

Magnetic Fields

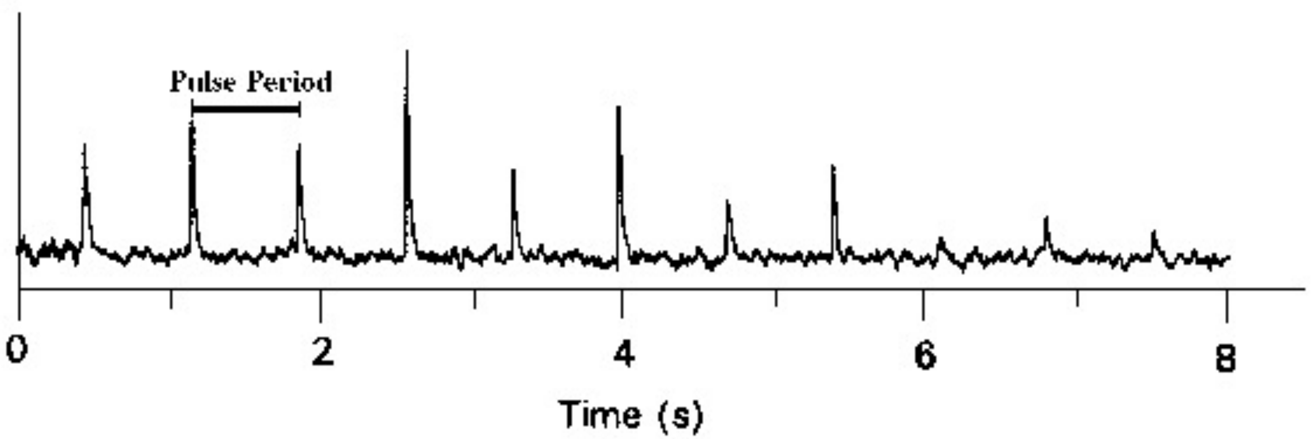
- Another key feature of radio astronomy is the ability to trace magnetic fields
- This is achieved via the polarization of radio waves
- Can trace geometry of magnetic fields via linear polarization patterns
- Can measure magnetic field strengths via Zeeman effect

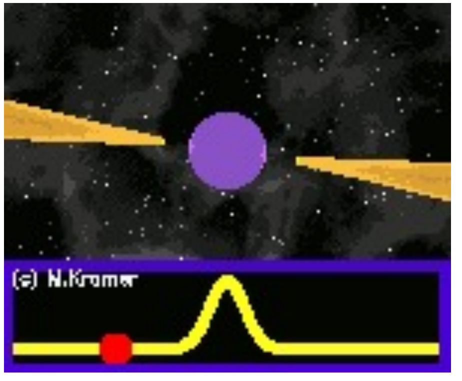


Example of polarization pattern of the radio continuum emission overlaid on an optical view of a spiral galaxy
(Johnston-Hollitt et al. (2015)

Time Domain

- Time variable radio sources also give unique insights
- E.g. pulsars are rapidly spinning neuton stars emitting pulses of radio emission





SKA Key Science Goals