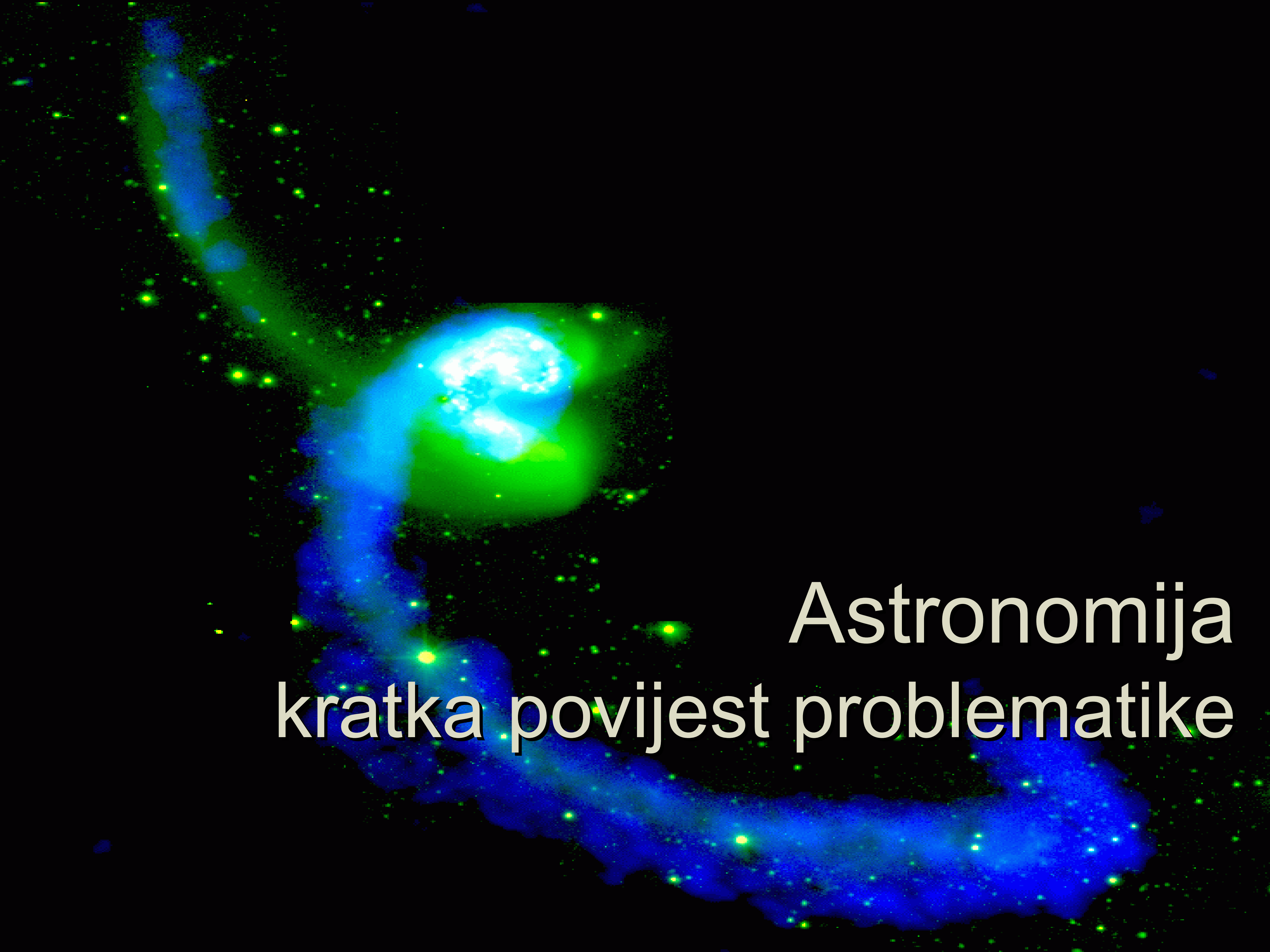


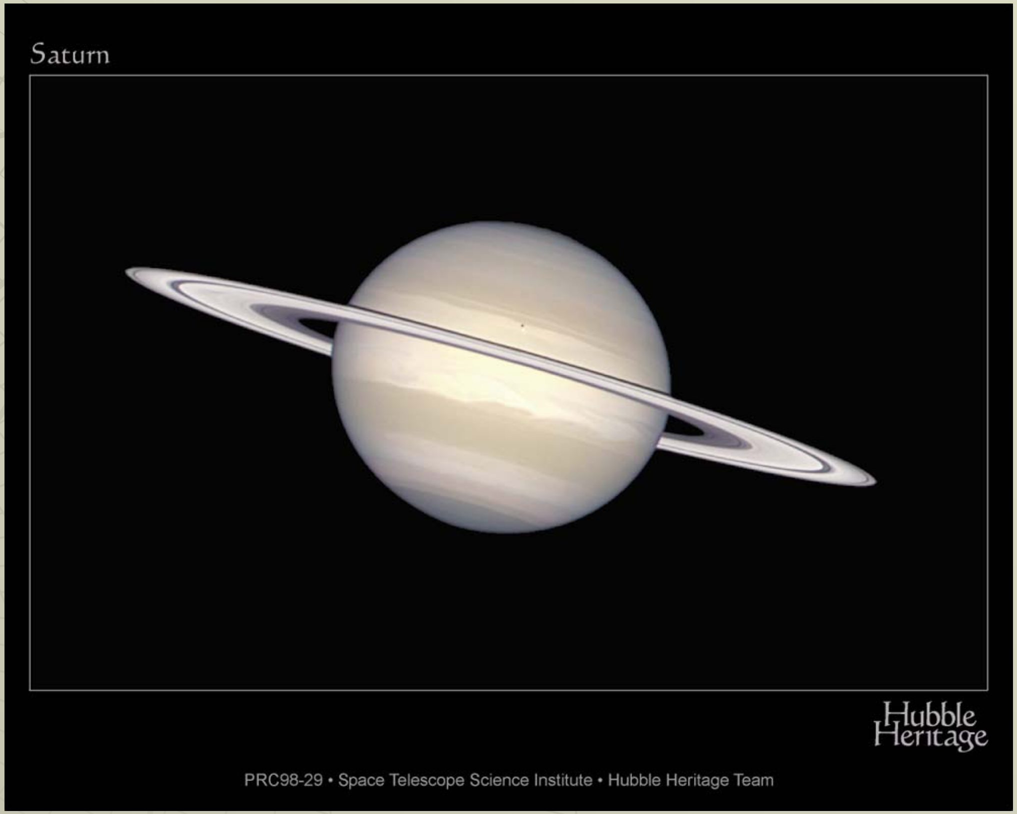
Astronomija
kratka povijest problematike

Područje interesa

- Planeti
- Sunčev sustav
- Zvijezde
- Međuzvjezdani prostor
- Galaksije
- Aktivne galaktičke jezgre (AGN)
- Kvazari (eng. quasar - quasi-stellar radio source)
- Klasteri galaksija
- Pulsari (brzorotirajuće neutronske zvijezde)
- Svemir

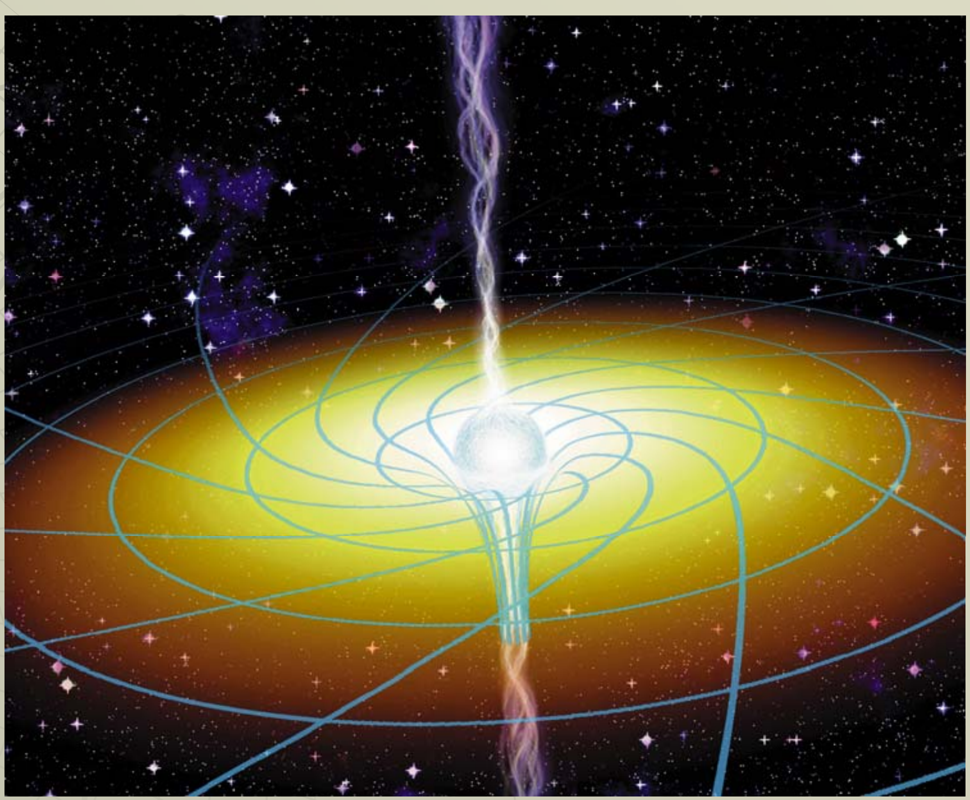
Sunčev sustav

- Fizika Sunca
- Solarni vjetar
- Planeti
- Njihovi sateliti
- Asteroidi
- NEOs (eng. Near eart objects)
- Pojasi
- Interplanetarna prašina



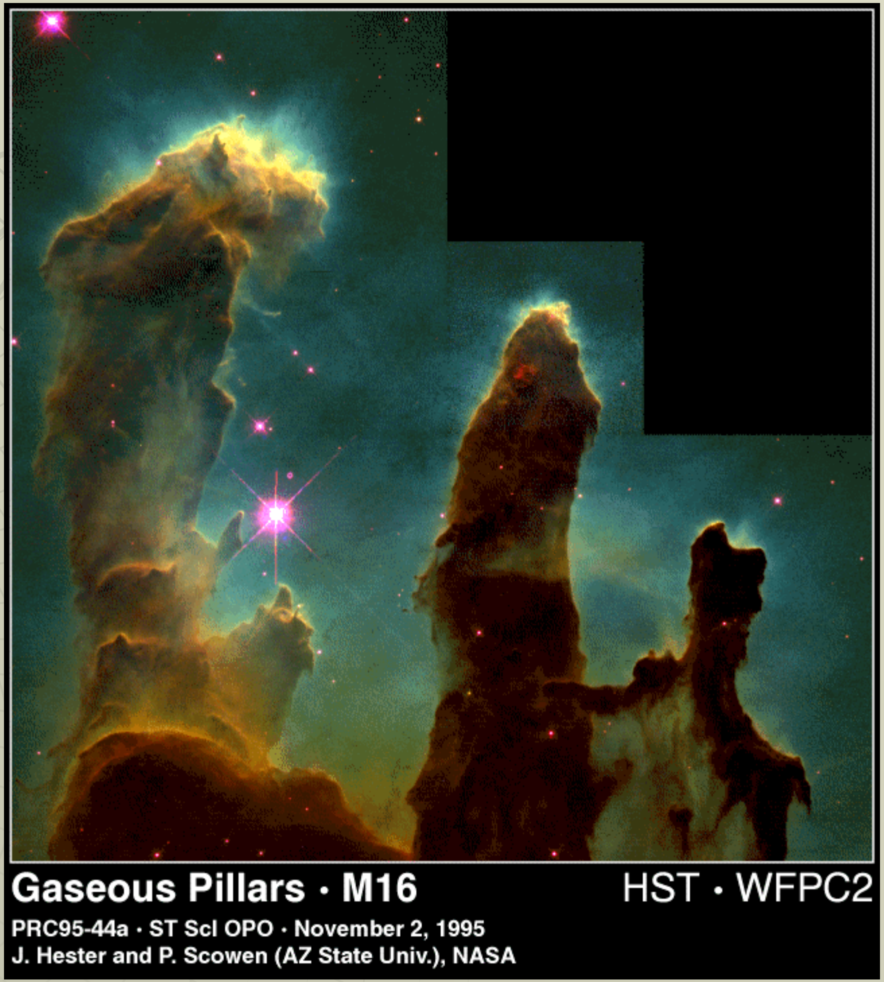
Zvijezde

- promjenjive zvijezde
- dvojne zvijezde
- patuljci, divovi
- Supernove
- kompaktni objekti (crne rupe, bijeli patuljci, neutronske zvijezde)



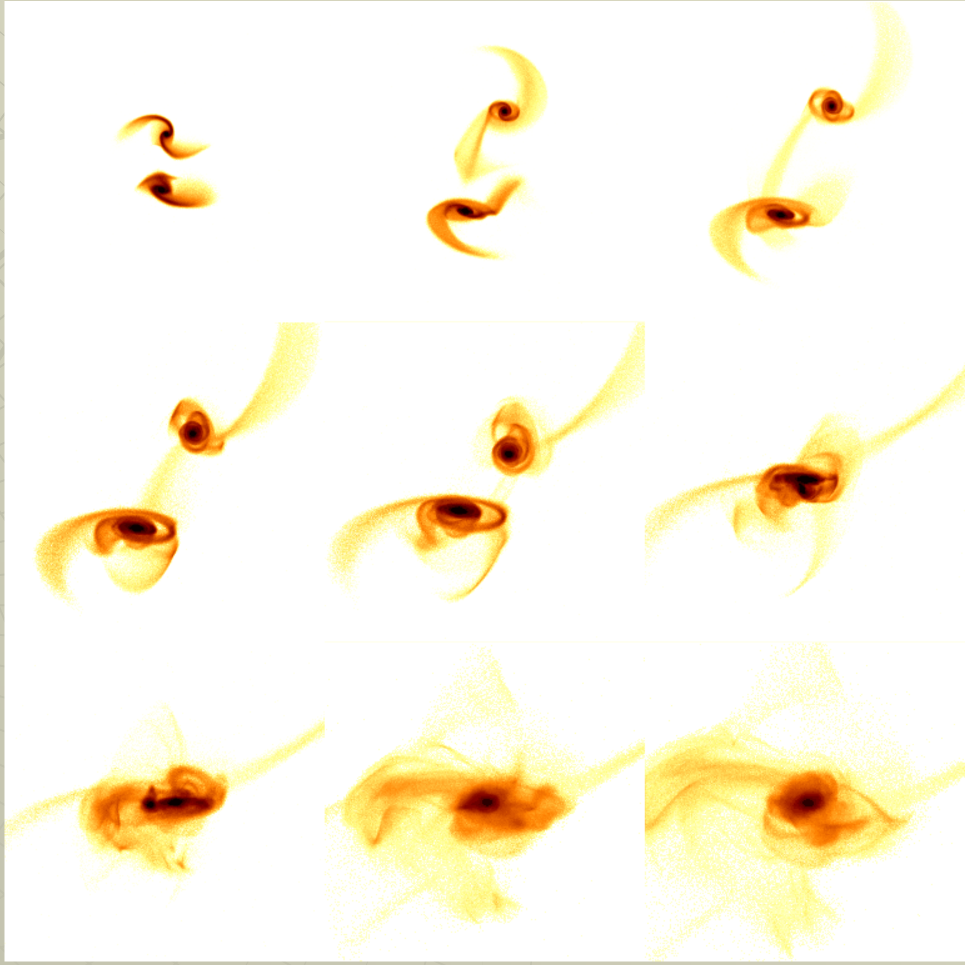
Međuzvjezdani prostor

- Nastanak zvijezda
- Astro-kemija
- Struktura i razvoj zvijezda
- Nuklearna astrofizika



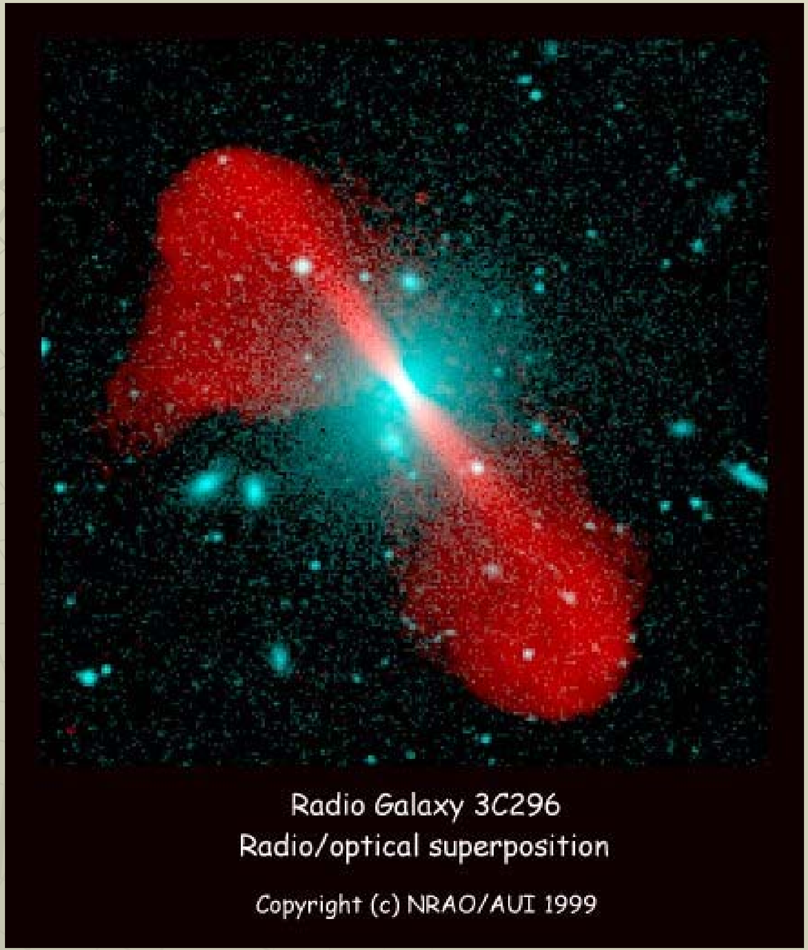
Galaksije

- Nastanak i formiranje
- Struktura
- Naseljenost
- Dinamika



AGN (Aktivne galaktičke jezgre) Kvazari

- nastanak
- klasifikacija
- gorivo
- evolucija
- gustoća



Klasteri

- Nastanak i razvoj
- Struktura
- Tamna tvar
- Gravitacijske leće

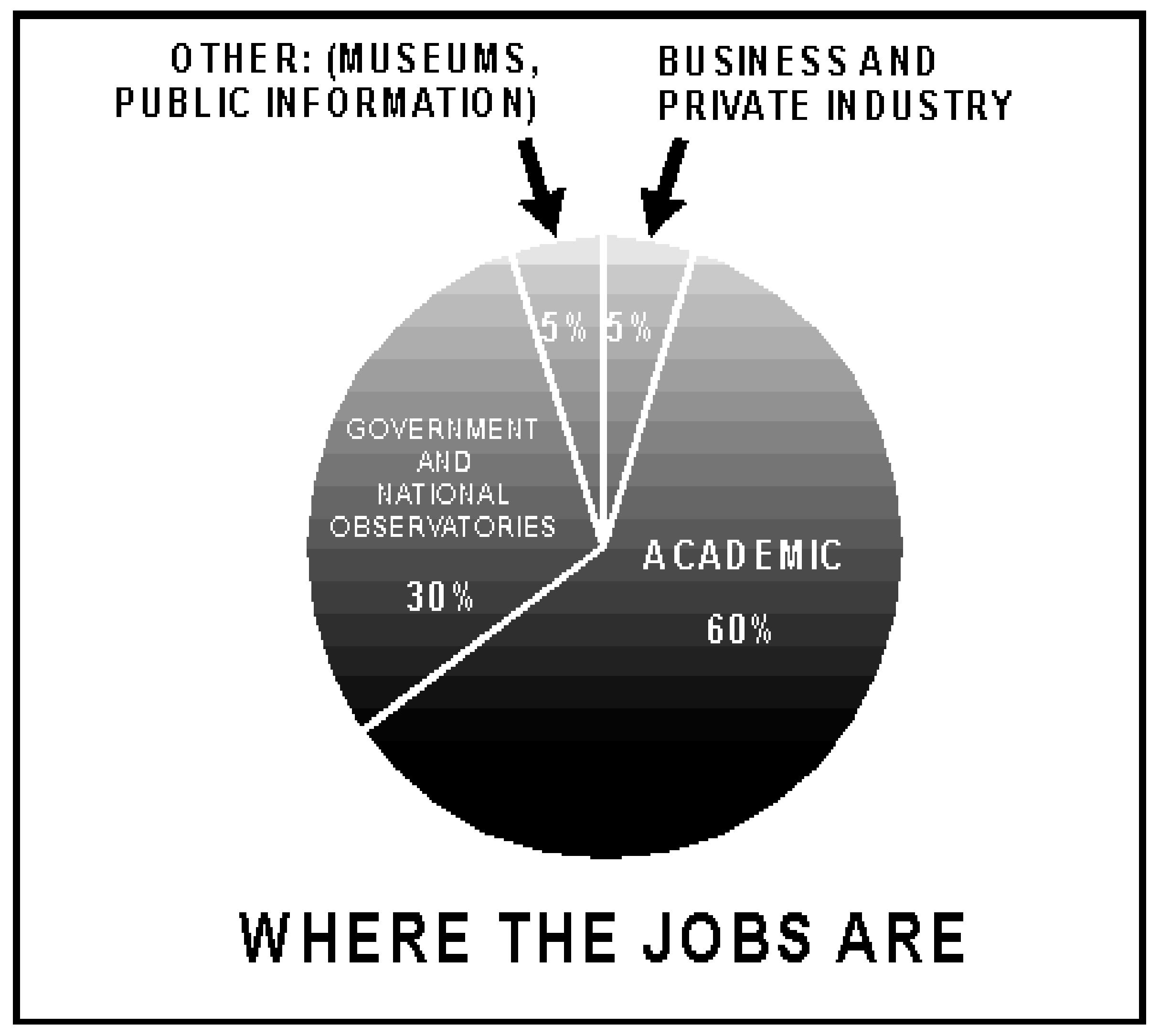
Svemir

- Starost i veličina
- Nastanak i razvoj
- Tamna materija , stringovi, egzotične čestice
- Topologija (oblik)

Znanstveni elementi u astronomiji

- Promatranje
  - Zemaljsko (optičko, infracrveno, radio)
  - Vanplanetarno (sateliti i satelitske platforme; UV, x-ray)
- Računanje
  - Analiza podataka
  - Kompleksni problemi
  - Numeričke simulacije
- Analiza
  - objektivnost
  - asimiliranje formi i podataka
  - linearno & nelinearno razmišljanje
- Pisanje
  - publikacija
  - prijedloga
  - prezentacija

Zapošljavanje (danas)



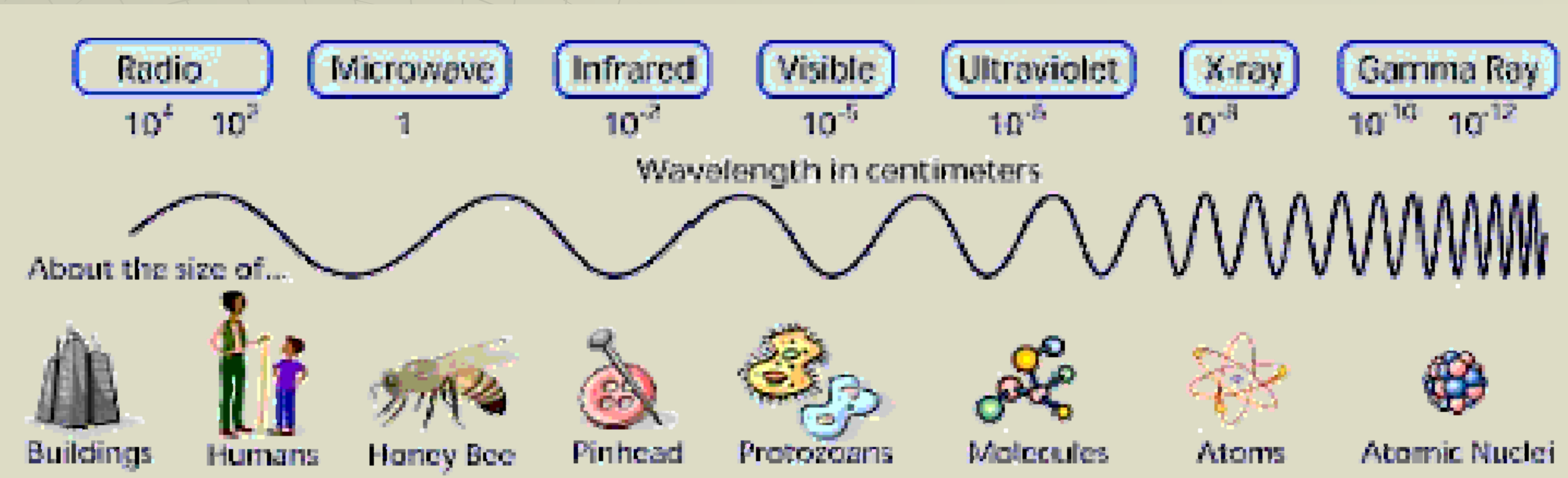
Što astronomi <u>ne</u> rade

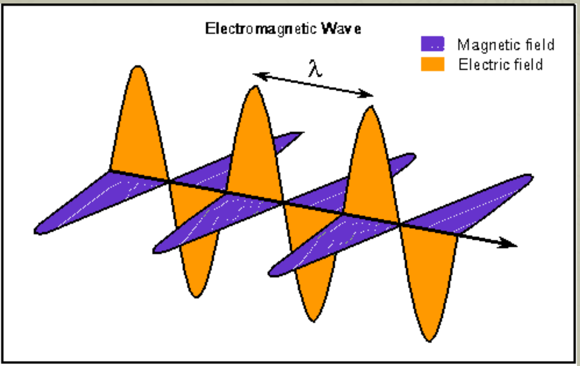
- Pišu horoskope
- Imaju vezu s vanzemaljskim civilizacijama
- Memoriraju konstelacije
- Cijelo vrijeme gledaju kroz teleskop

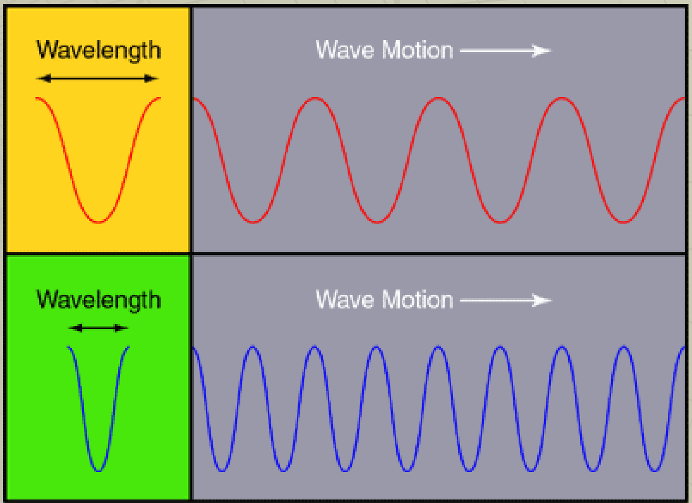
Radioastronomija

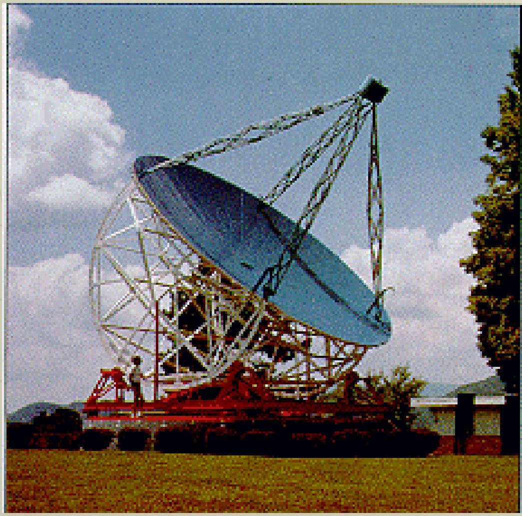
Kozmičko zračenje 3K

Elektromagnetski valovi

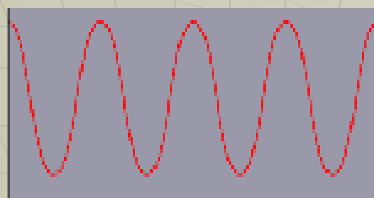




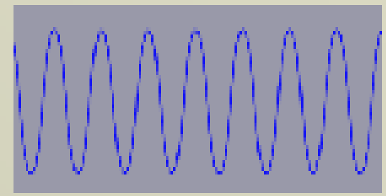




$E=h\nu$ $c=\lambda\nu$

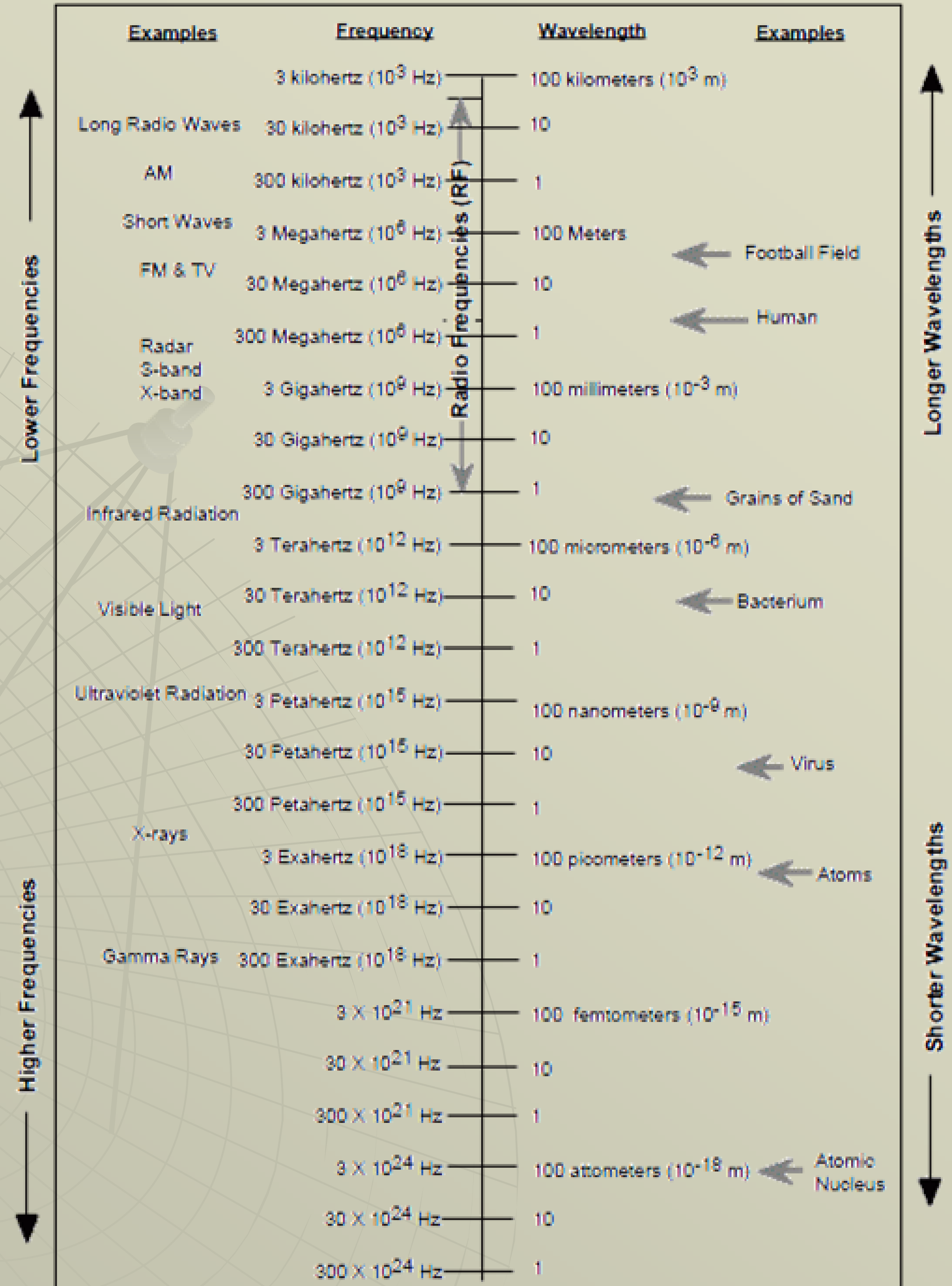


Duži valovi
Niža energija
Niža frekvencija

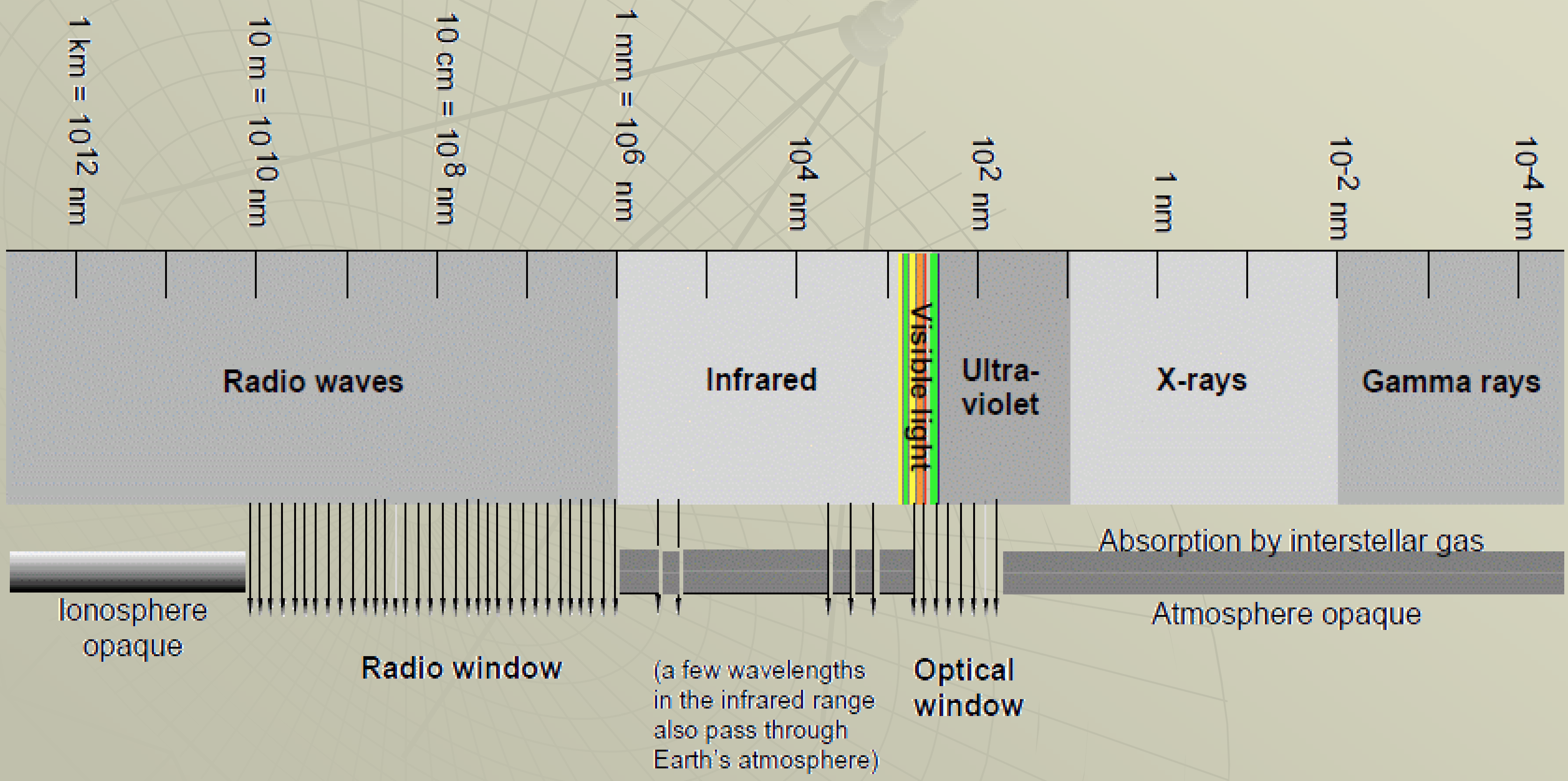


Kraćo valovi
Veća energija
Viša frekvencija

Elektromagnetski spektar



Elektromagnetski prozor kroz atmosferu!



Izvori elektromagnetskog zračenja

- Termalni
  - Zračenje crnog tijela
  - Kontinuirana emisija ioniziranog plina (plazma)
  - Emisija spektralnog zračenja atoma i molekula
- Netermalni
  - Sinkrotronsko zračenje
  - MASERS

$u(\nu,T) = 4\pi I(\nu,T) / c$

Plankov zakon

$$I(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}}-1}. \quad I'(\lambda,T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}.$$

to je $h\nu/kT \ll 1$) proporcionalna je temperaturi. Za različite teleskope konstanta proporcionalnosti je različita, no poznata je proporcionalnost primljene snage i temperature. Prema Planckovu zakonu spektralni intenzitet zračenja I_ν jest:

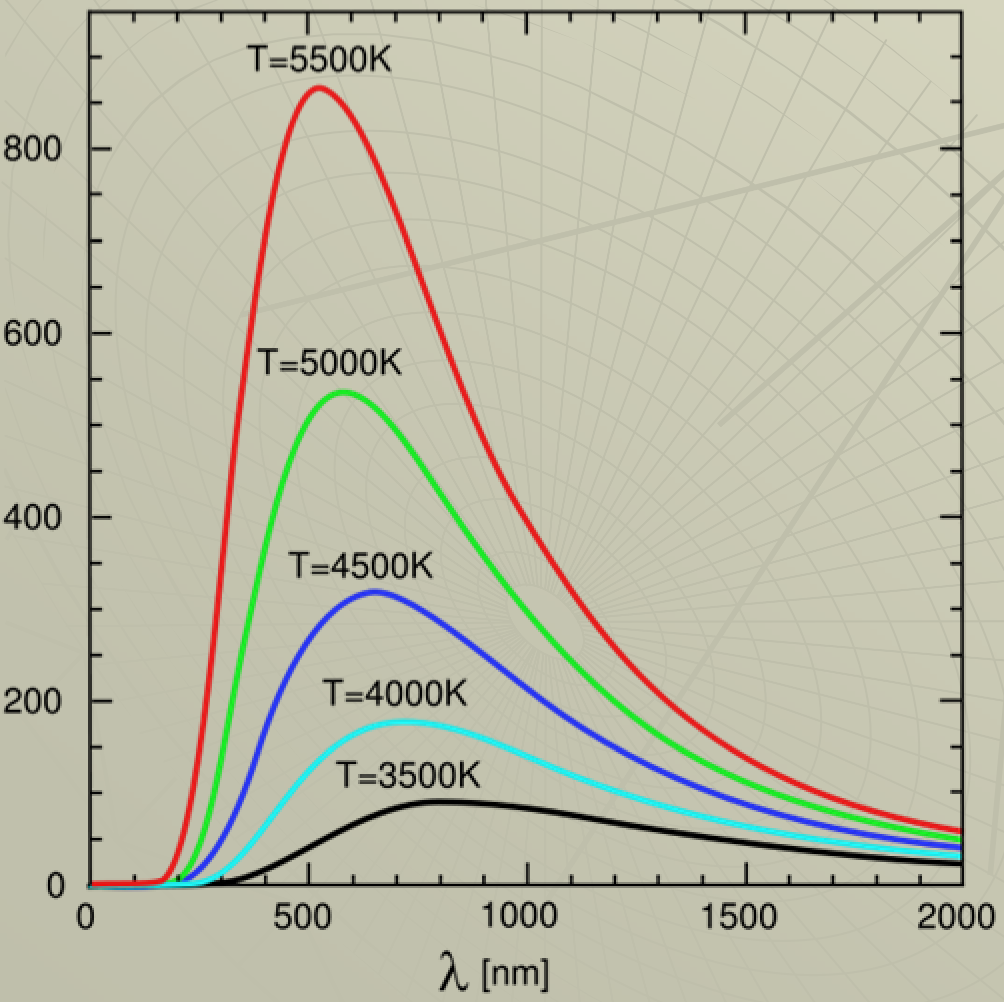
$$I_\nu = \frac{8\pi h}{c^3}\frac{\nu^3}{e^{\frac{h\nu}{kT}}-1} = \frac{8\pi h}{c^3}\frac{\nu^3}{1+\frac{h\nu}{kT}+\cdots-1} \approx \frac{8\pi}{c^3}\nu^2 kT = T \cdot \text{konst.} \qquad (10.1)$$

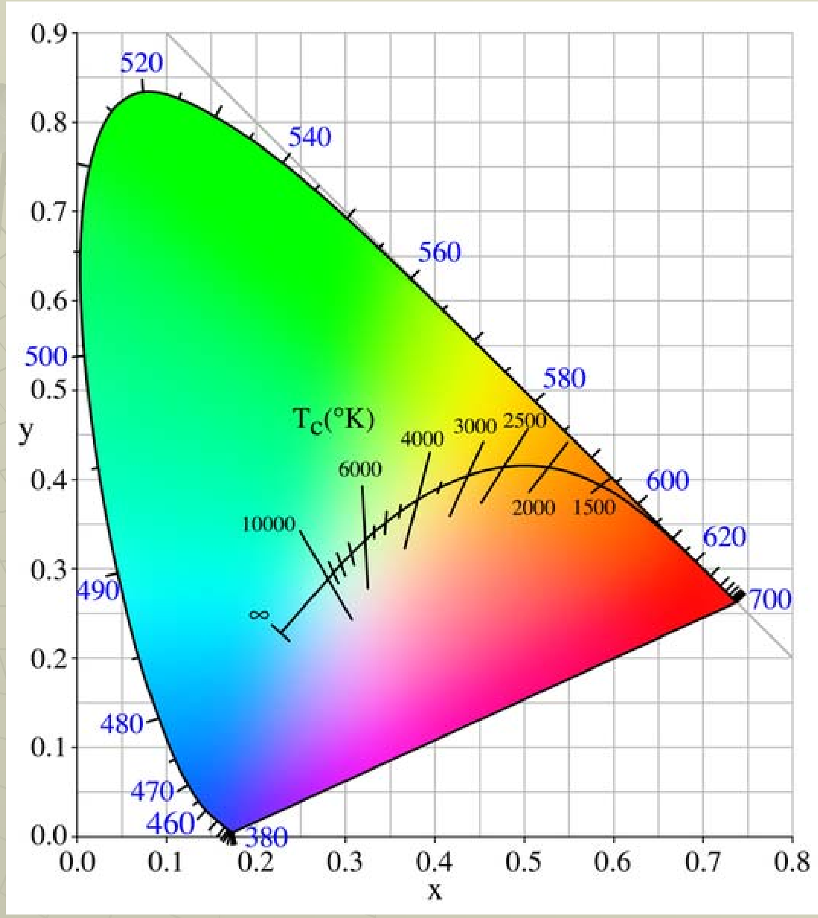
Vidimo da spektralni intenzitet zračenja (snaga po intervalu frekvencije) možemo karakterizirati antenskom temperaturom. Kalibraciju radioteleskopa očito je moguće ovako načiniti: antenu treba obaviti oklopom jednolike temperature T_A. Tada je u radioteleskopu registrirana snaga po jedinici frekventnog intervala P_ν prema (10.1) razmjerna temperaturi. Konstanta K karakterizira radioteleskop:

$$P_\nu \, d\nu = K T_A \, d\nu \qquad (10.2)$$

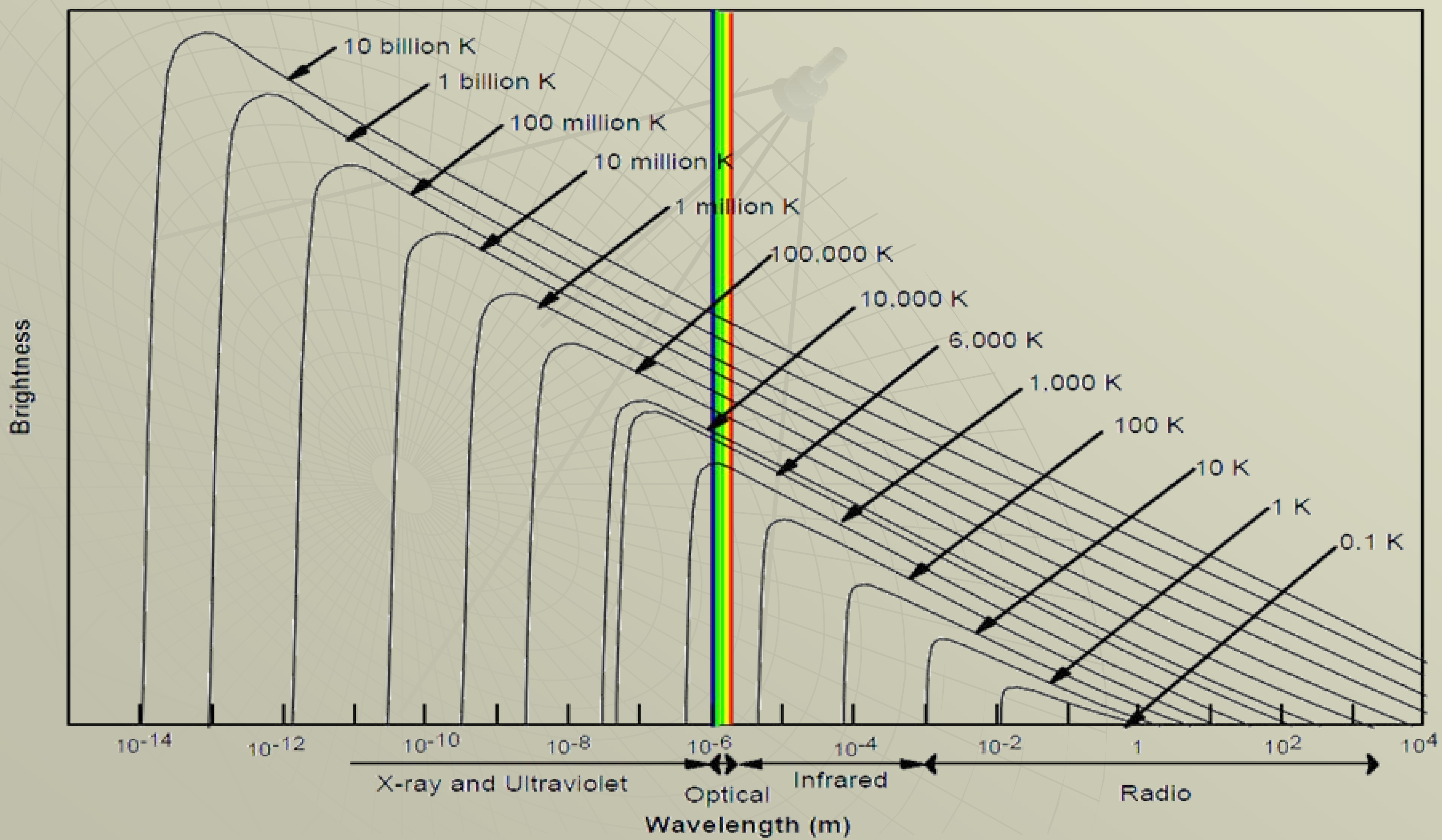
Sa dva ili više takva postupka može se dobiti kalibracijska ljestvica ekvivalentnih antenskih temperatura, tj. skala za mjerenja.

Zračenje crnog tijela - Sjaj

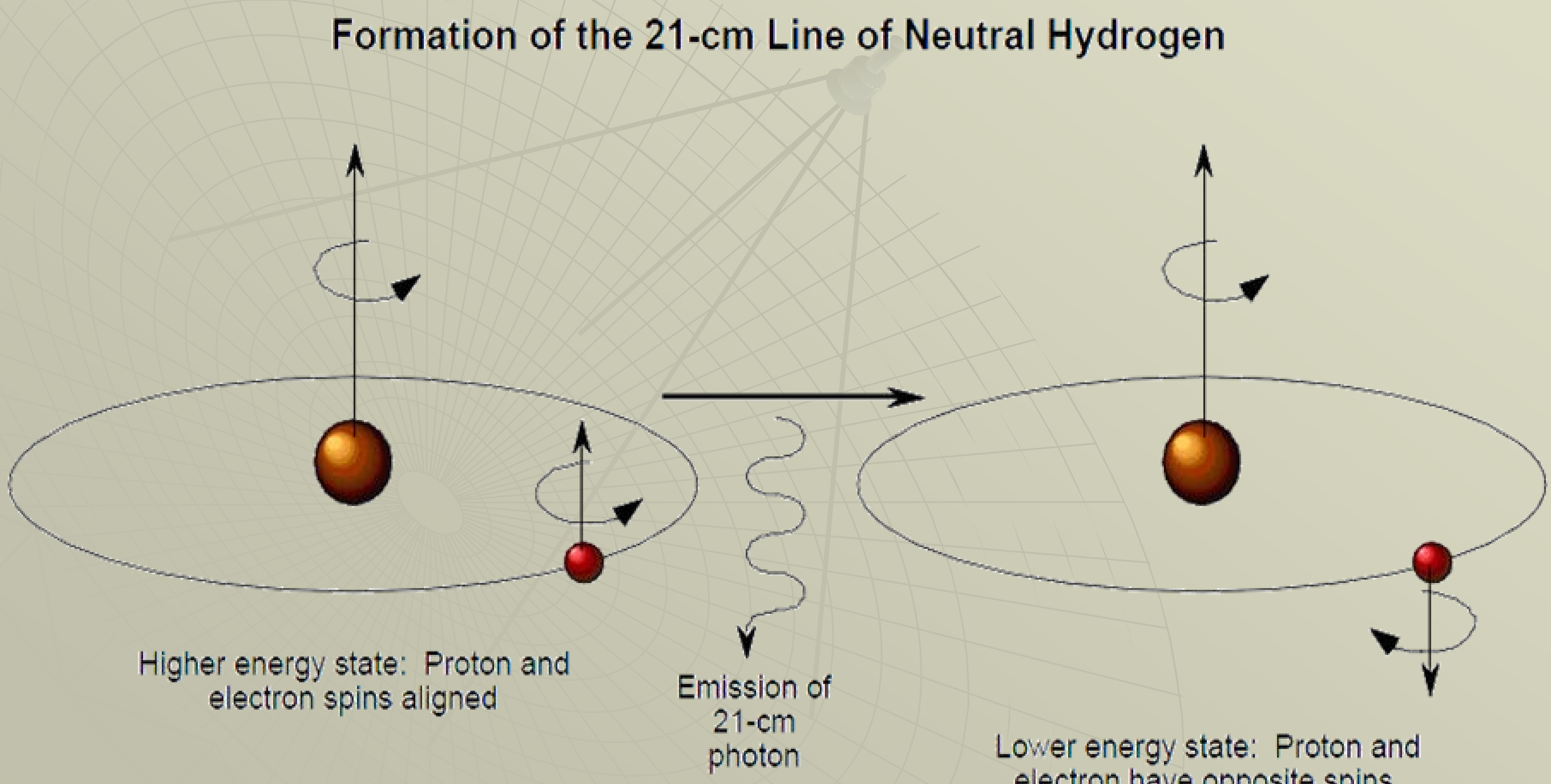




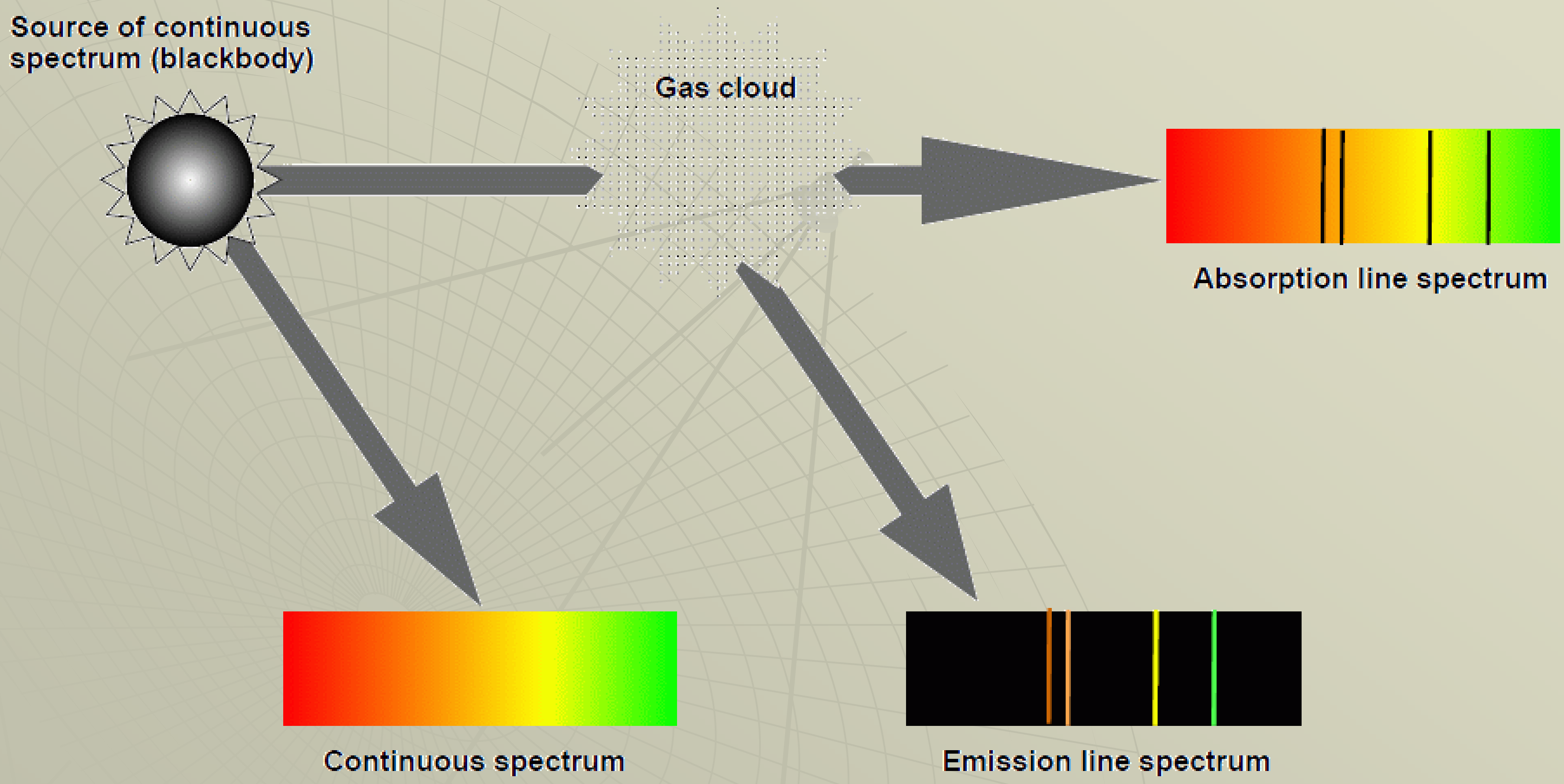
Sjaj elektromagnetskog zračenja različitih valnih dužina za crno tijelo na različitim temperaturama



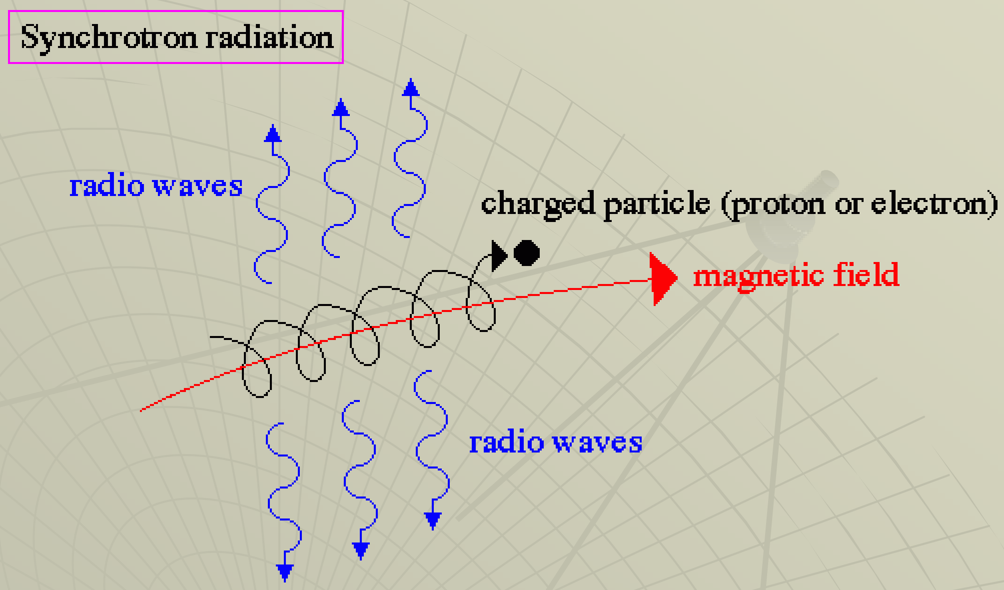
MASER


Formation of the 21-cm Line of Neutral Hydrogen
Higher energy state: Proton and electron spins aligned
Emission of 21-cm photon
Lower energy state: Proton and electron have opposite spins.

Kirchhoff's Laws of Spectral Analysis



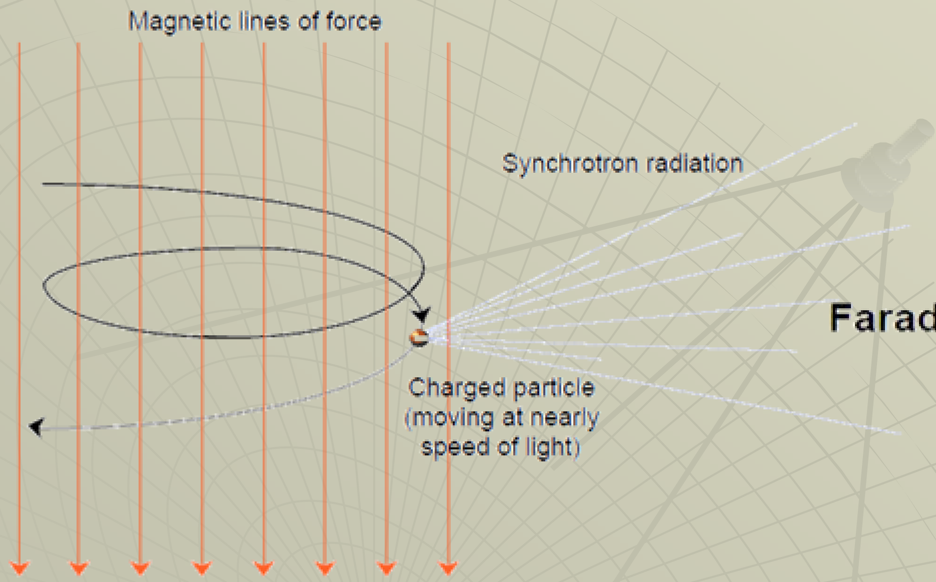
Sinkrotronsko zračenje

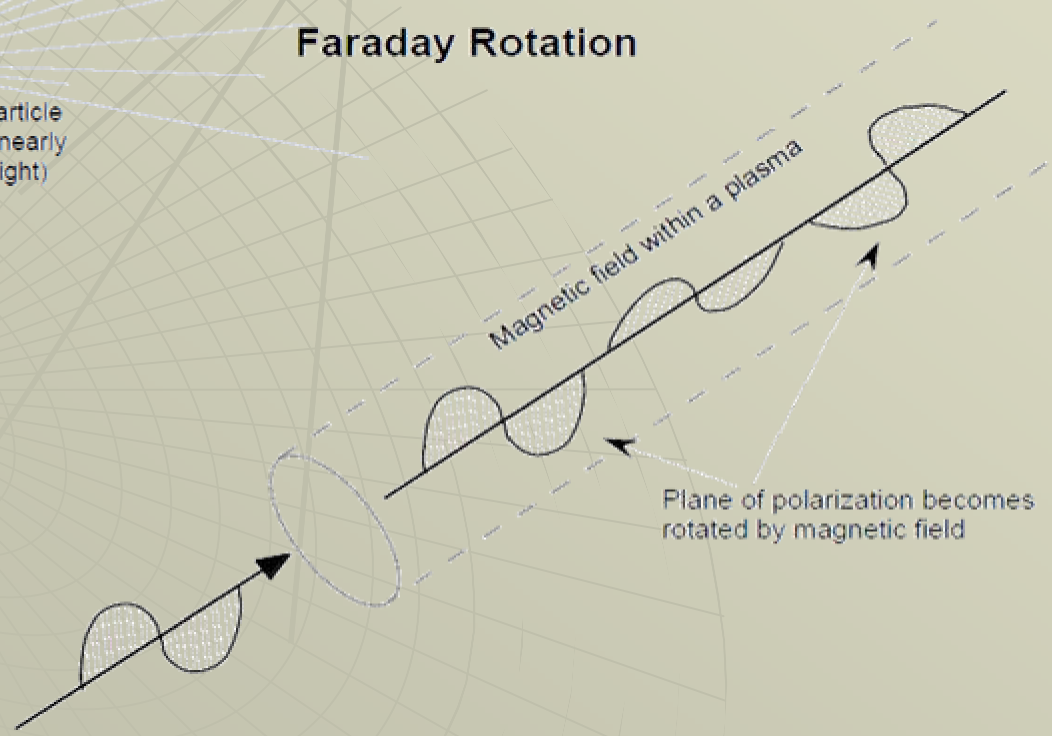


synchrontron radiation occurs when a charged particle encounters a strong magnetic field – the particle is accelerated along a spiral path following the magnetic field and emitting radio waves in the process – the result is a distinct radio signature that reveals the strength of the magnetic field

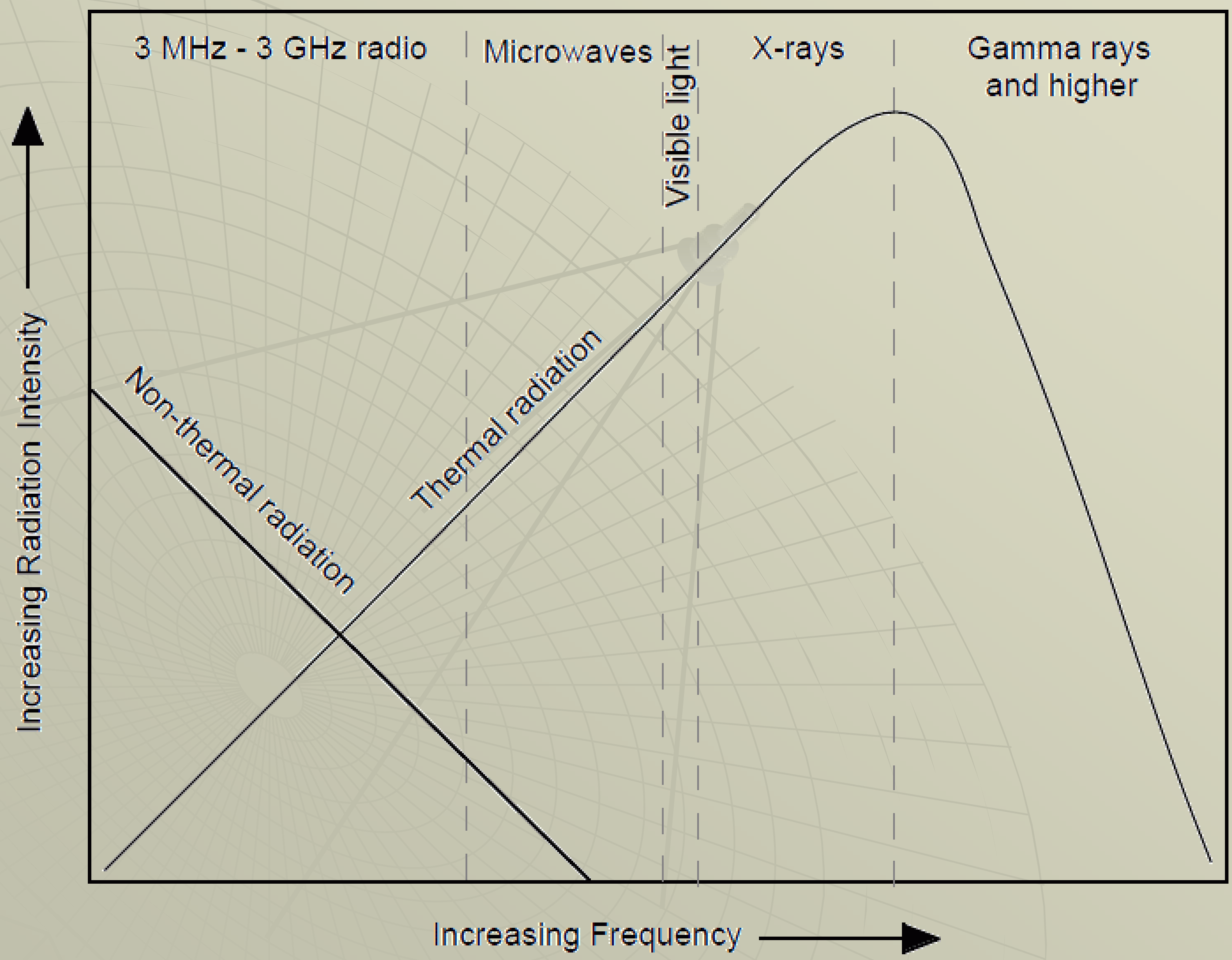
Polarizacojska svojstva EM zračenja daju informacije o geometriji magnetskog polja

Sinkrotronsko zračenje

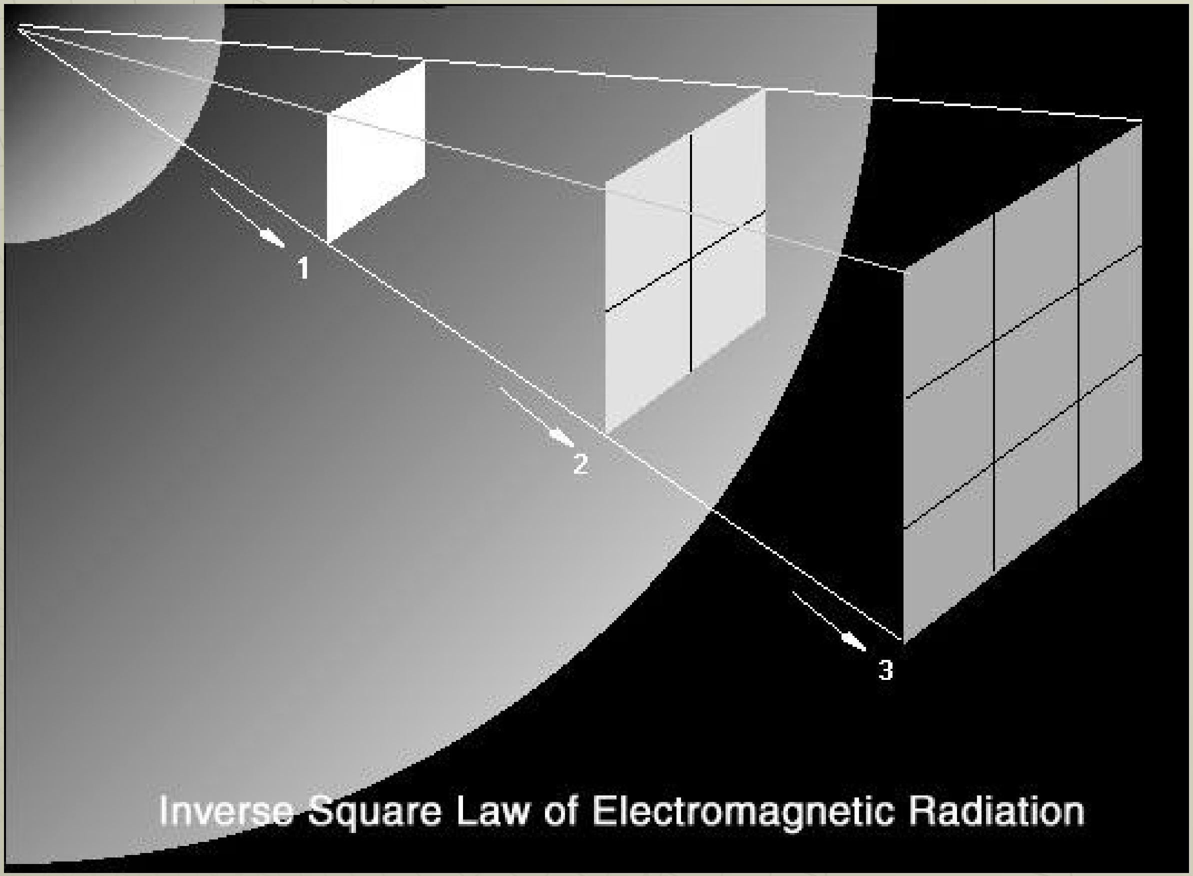




Relative Variation of Thermal and Non-thermal Radiation Emissions

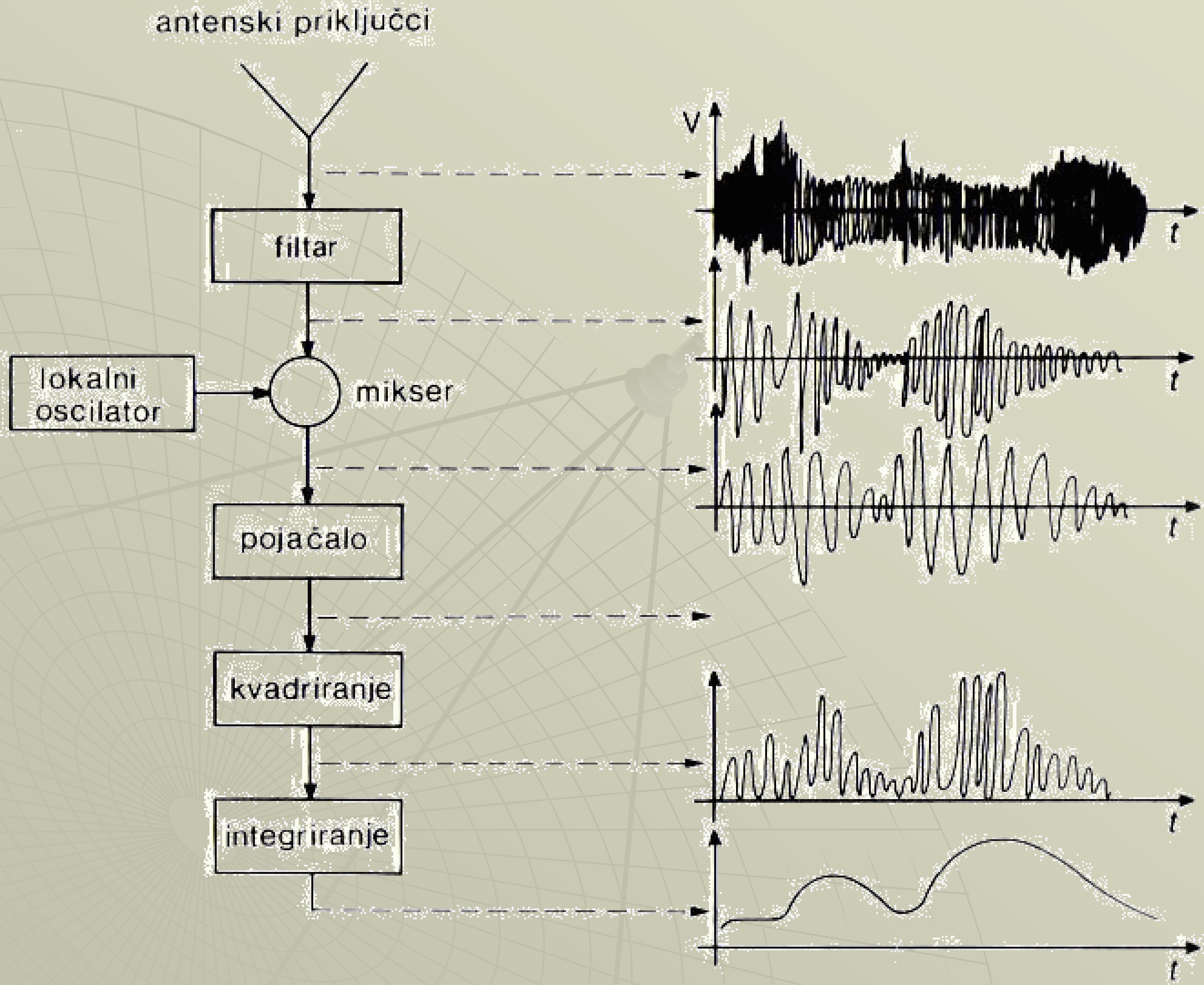


Zakon obrnutog kvadrata !



Zabluda

Radio program koji se ne sluša!



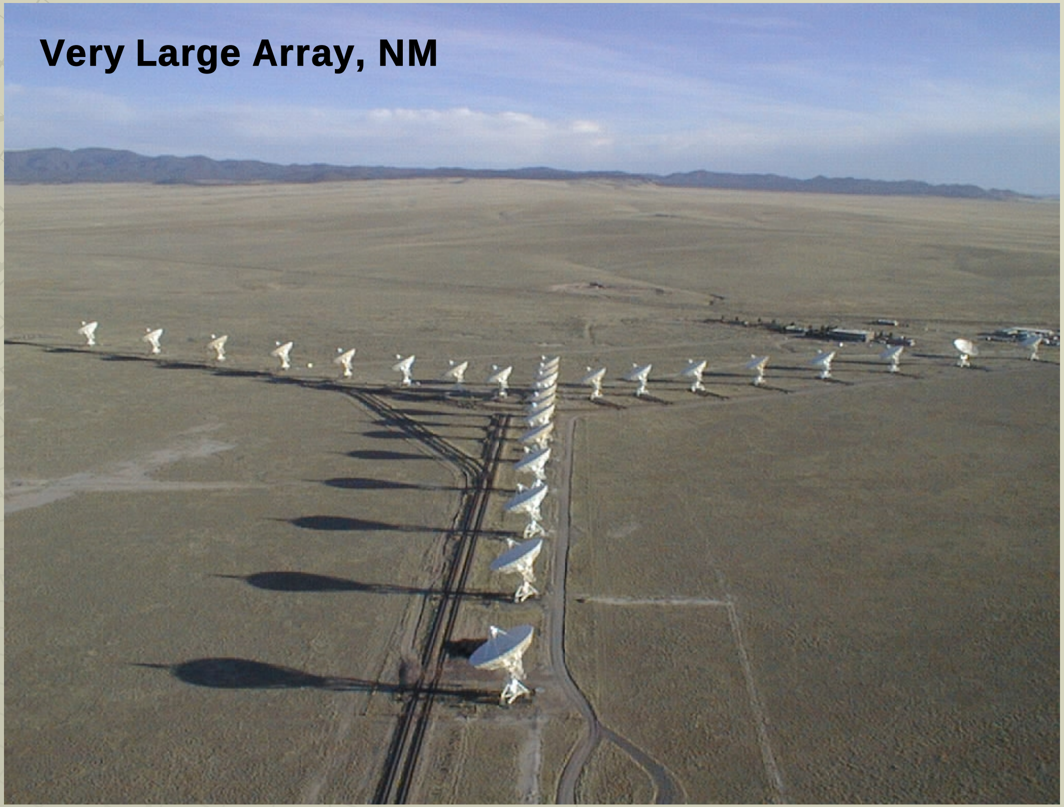
Slika 10.2. Radiometar

a) Prikazane su najbitnije komponente radiometra.

b) Za svaku komponentu ilustriran je njezin učinak na spektar signala.

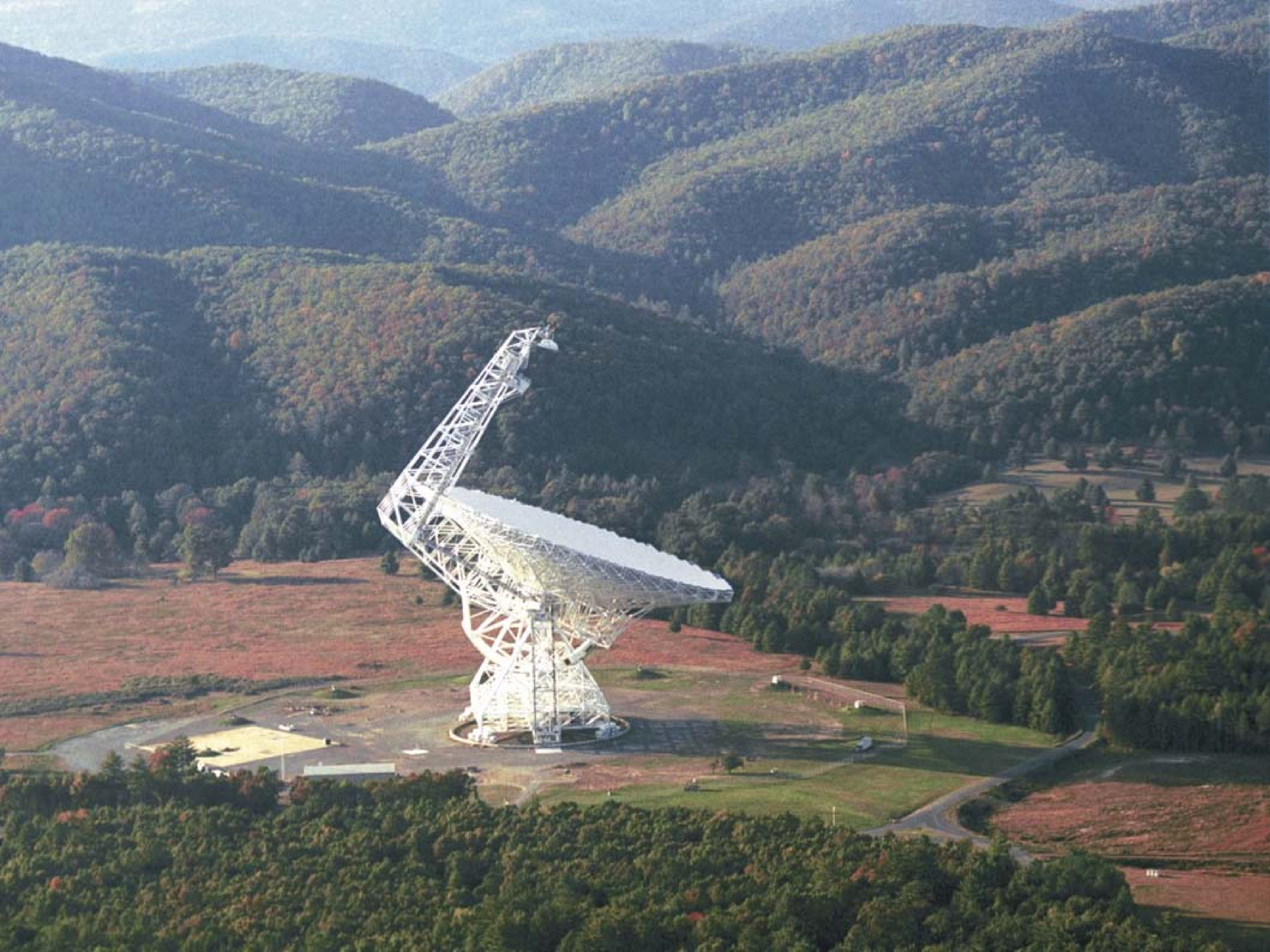
Radio Teleskopi

Dvije izvedbe:



Radio antena

Polje radio antena

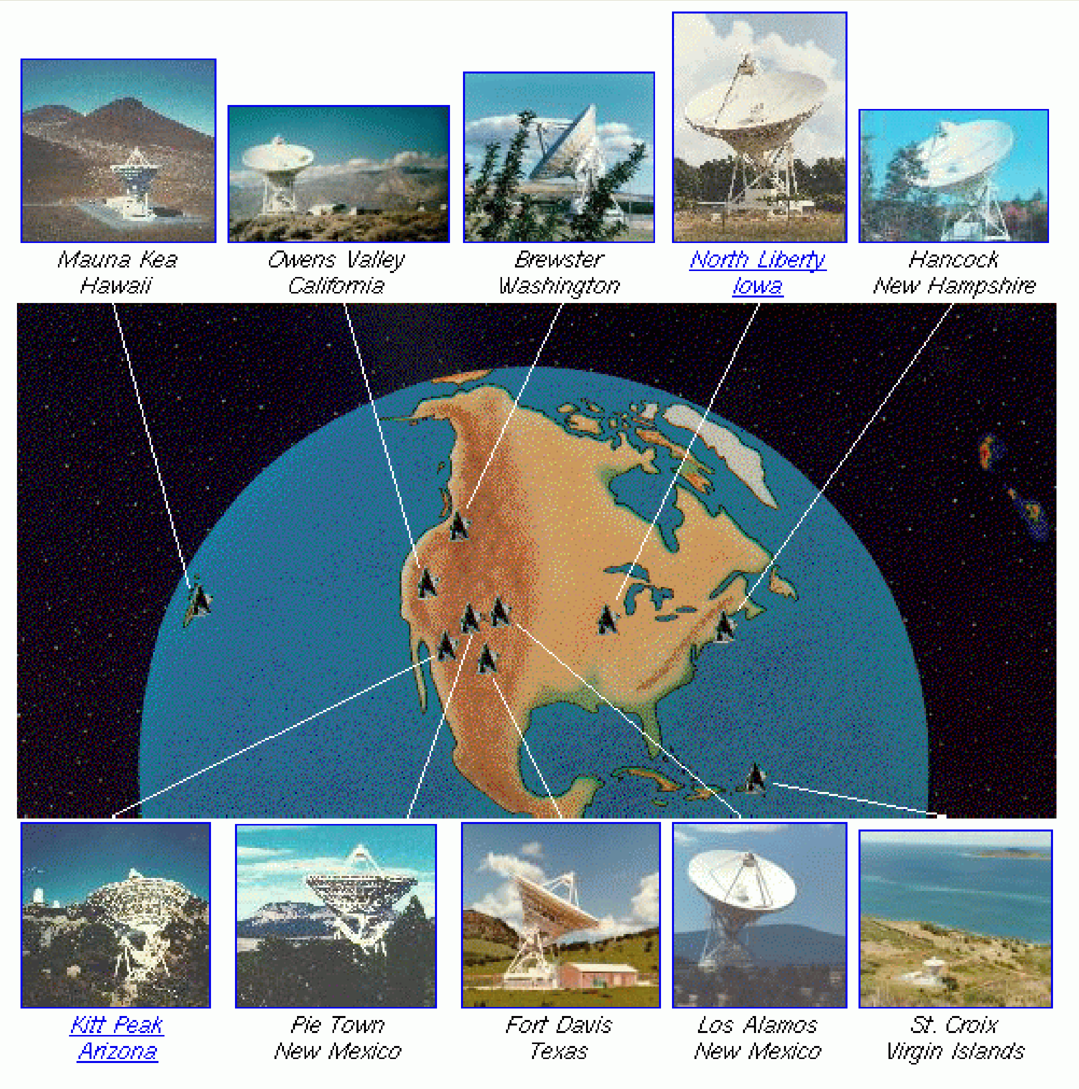


The Very Large Array (VLA)

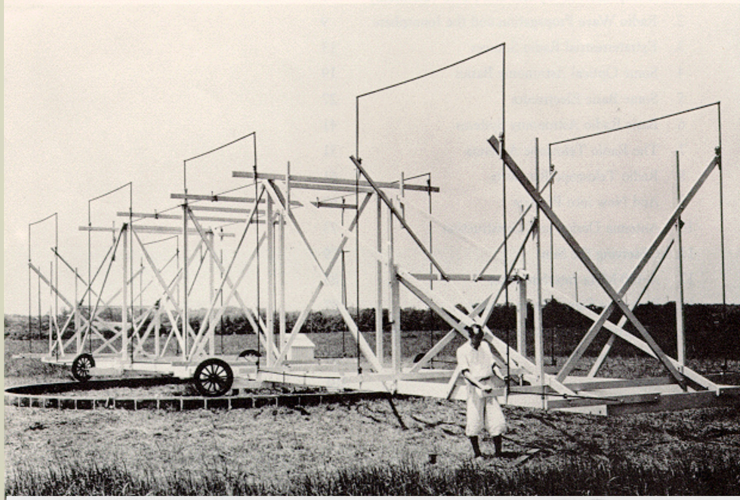
- 1980 godine
- Dvadest sedam 25-metarskih rekonfigurabilnih antena; Socorro, NM
- Više publikacija od bilo kojeg teleskopa na svijetu

Very Long Baseline Array (VLBA)

- 1993 godine
- Operirane oz Socorro-a
- Deset 25-m antennas diljem SAD, Kanade, P.R.
- Najviša rezolucija



Počeci eksperiment Janskog



- Promatra nemodulirani doprinos RF (static)
- Postepeno s mijenja intenzitet s
- periodom od gotovo 24h
- Sunce izvor?
- maksimum 4 minute rani svaki dan
- Izvor izvan Sunčeva sustava
- Izvor u Mlječnoj stazi!
- 1933 objavljuje rezultate

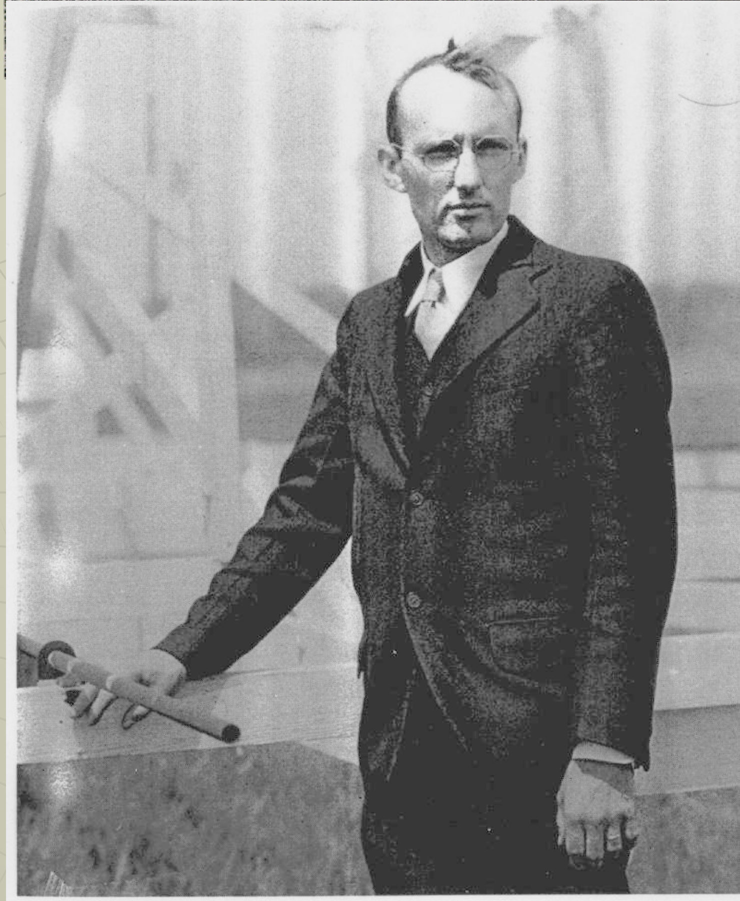


Fig. 1—Karl Guthe Jansky, about 1933.

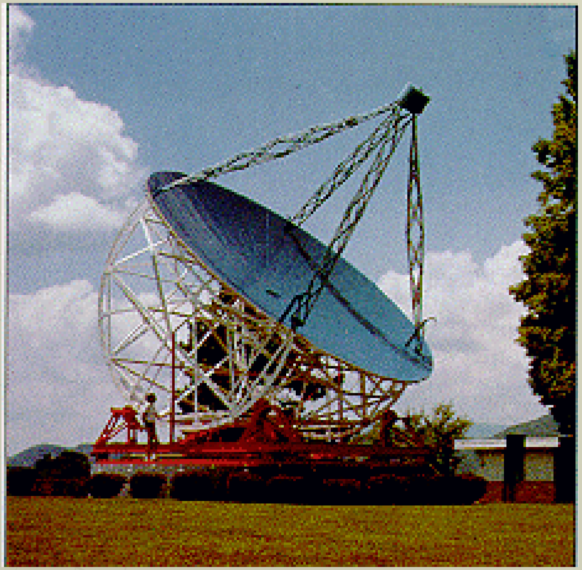
Karl G. Jansky (1905-1950)

Reberov tip radioteleskopa

Despite the implications of Jansky's work, both on the design of radio receivers, as well as for radio astronomy, no one paid much attention at first.

Then, in 1937, Grote Reber, another radio engineer, picked up on Jansky's discoveries and built the prototype for the modern radio telescope in his back yard in Wheaton, Illinois.

He started out looking for radiation at shorter wavelengths, thinking these wavelengths would be stronger and easier to detect. He didn't have much luck, however, and ended up modifying his antenna to detect radiation at a wavelength of 1.87 meters (about the height of a human), where he found strong emissions along the plane of the Milky Way.

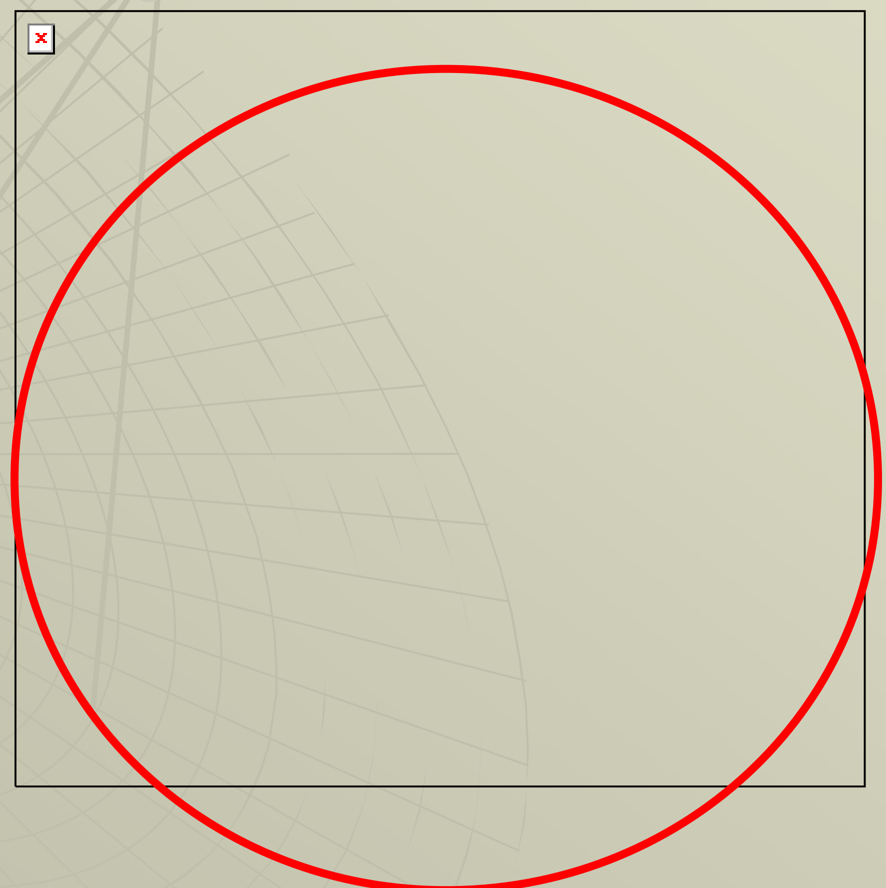


Reconfigurable Arrays: Zoom Lens Effect

- Više detektora – bolja rezolucija

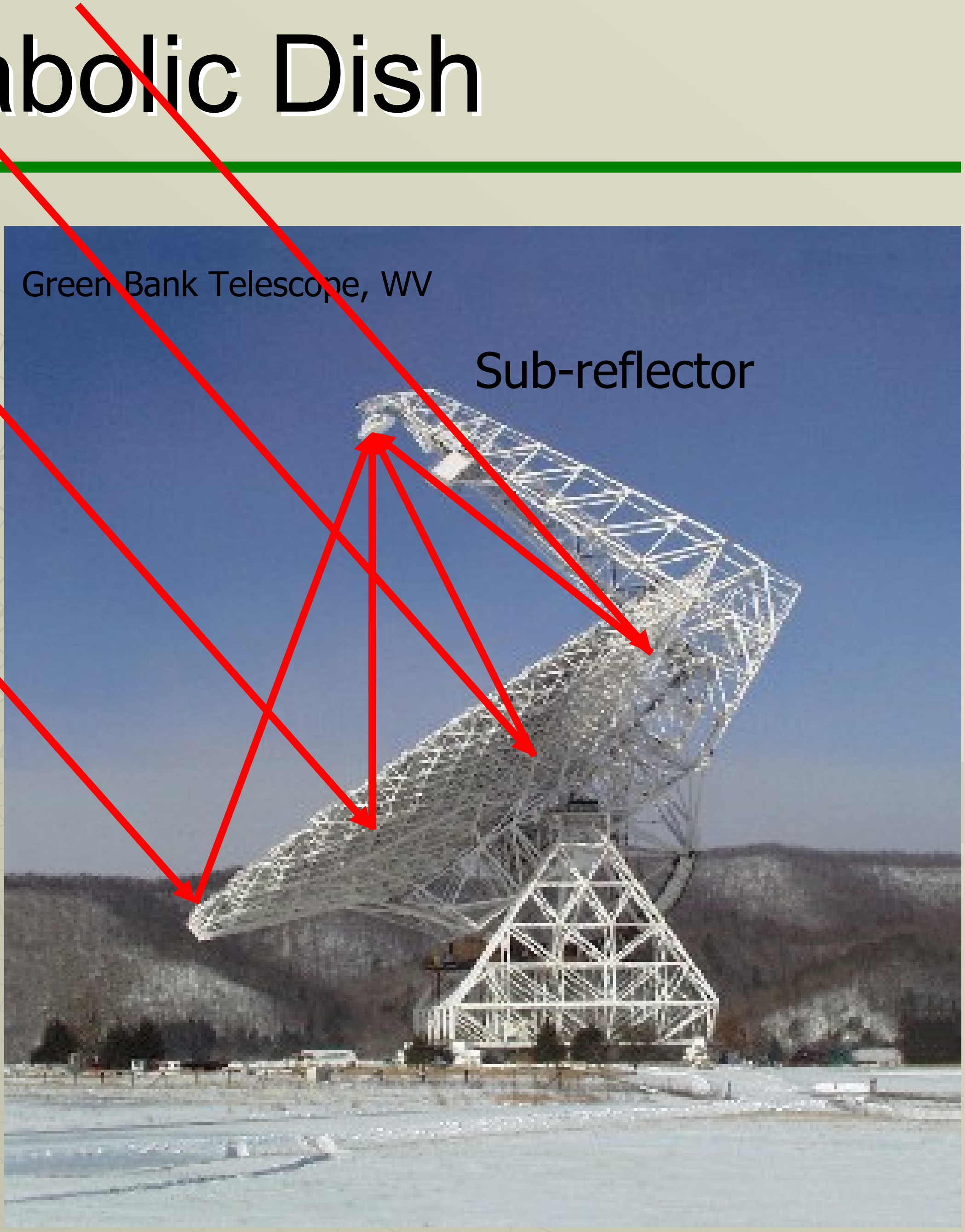
Radio Telescopes: Sensitivity

- Sensitivity (how faint of a thing you can "see") depends on how much of the area of the telescope/array is actually collecting data
  - VLA B-array: Total telescope collecting area is only 0.02% of land area
- More spread-out arrays can only image very bright, compact sources



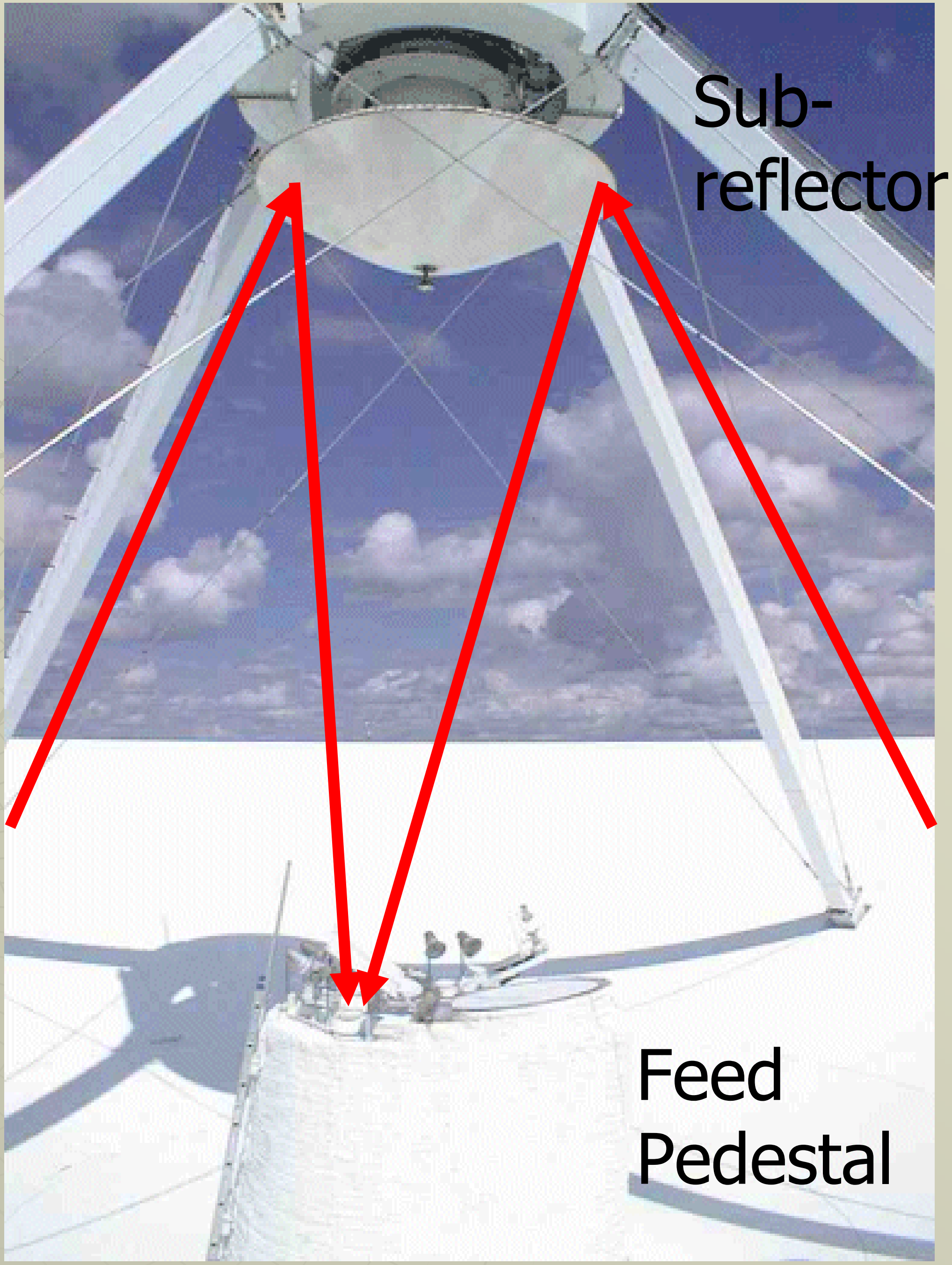
Parabolic Dish

- Aluminum reflecting surface
- Focuses incoming waves to prime focus or sub-reflector



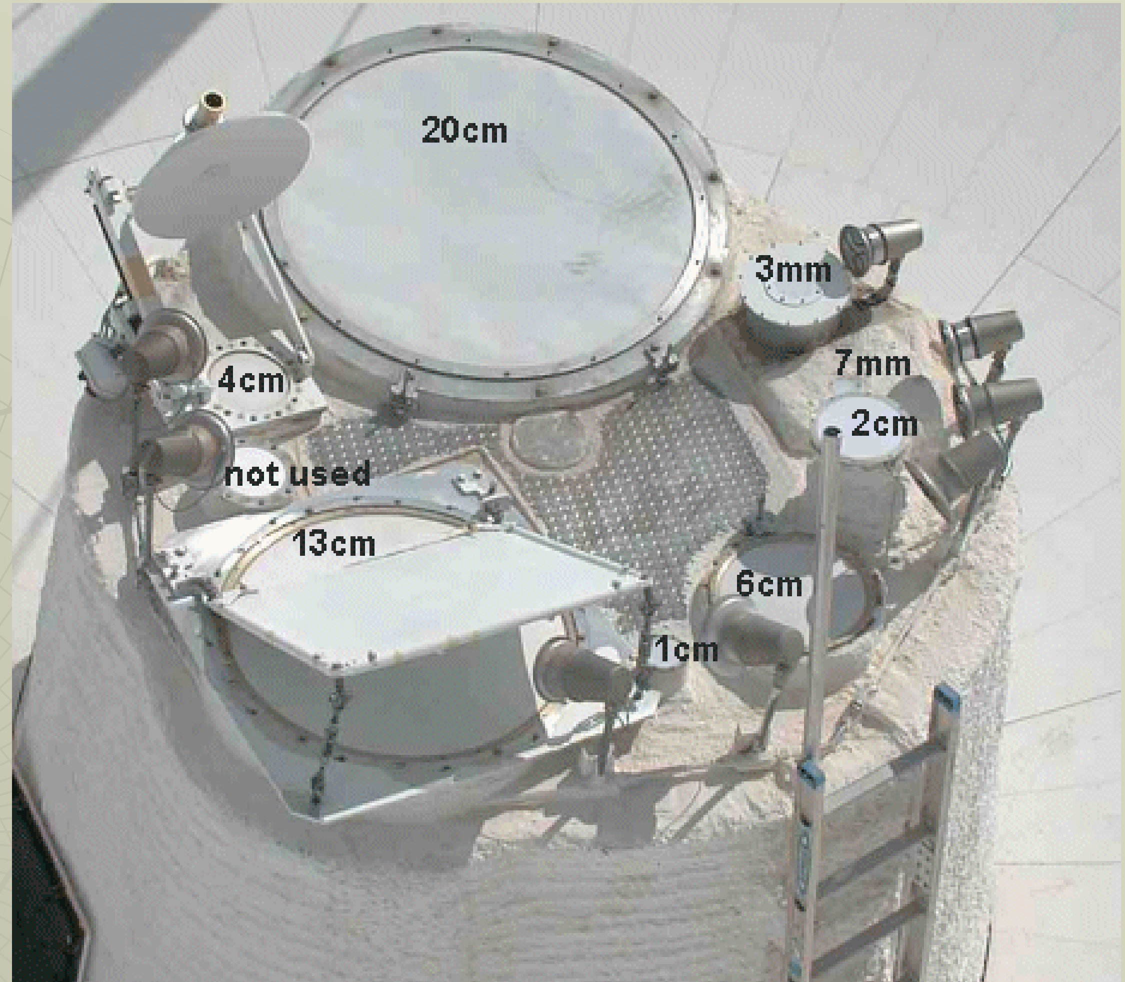
Sub-reflector

- Re-directs incoming waves to Feed Pedestal
- Can be rotated to redirect radiation to a number of different receivers



Feed Pedestal

1.5GHz	20cm
2.3GHz	13cm
4.8GHz	6cm
8.4GHz	4cm
14GHz	2cm
23GHz	1.3cm
43GHz	7mm
86GHz	3mm



327MHz	90cm
610MHz	50cm

Antenna Feed and Receivers

Benefits of Observing in the Radio

- Track physical processes with no signature at other wavelengths
- Radio waves can travel through dusty regions
- Can provide information on magnetic field strength and orientation
- Can provide information on line-of-sight velocities
- Daytime observing (for cm-scale wavelengths anyway)

Primary Astrophysical Processes Emitting Radio Radiation

When charged particles change direction, they emit radiation

- Synchrotron Radiation
  - Charged particles moving along magnetic field lines
- Thermal emission
  - Cool bodies
  - Charged particles in a plasma moving around
- Spectral Line emission
  - Discrete transitions in atoms and molecules

Thermal Emission

- Emission from warm bodies
  - "Blackbody" radiation
  - Bodies with temperatures of ~ 3-30 K emit in the mm & submm bands
- Emission from accelerating charged particles
  - "Bremsstrahlung" or free-free emission

Nobelova nagrada za otkriće kozmičkog mikrovalnog pozadinskog zračenja

Arno Allan Penzias

Robert Woodrow Wilson

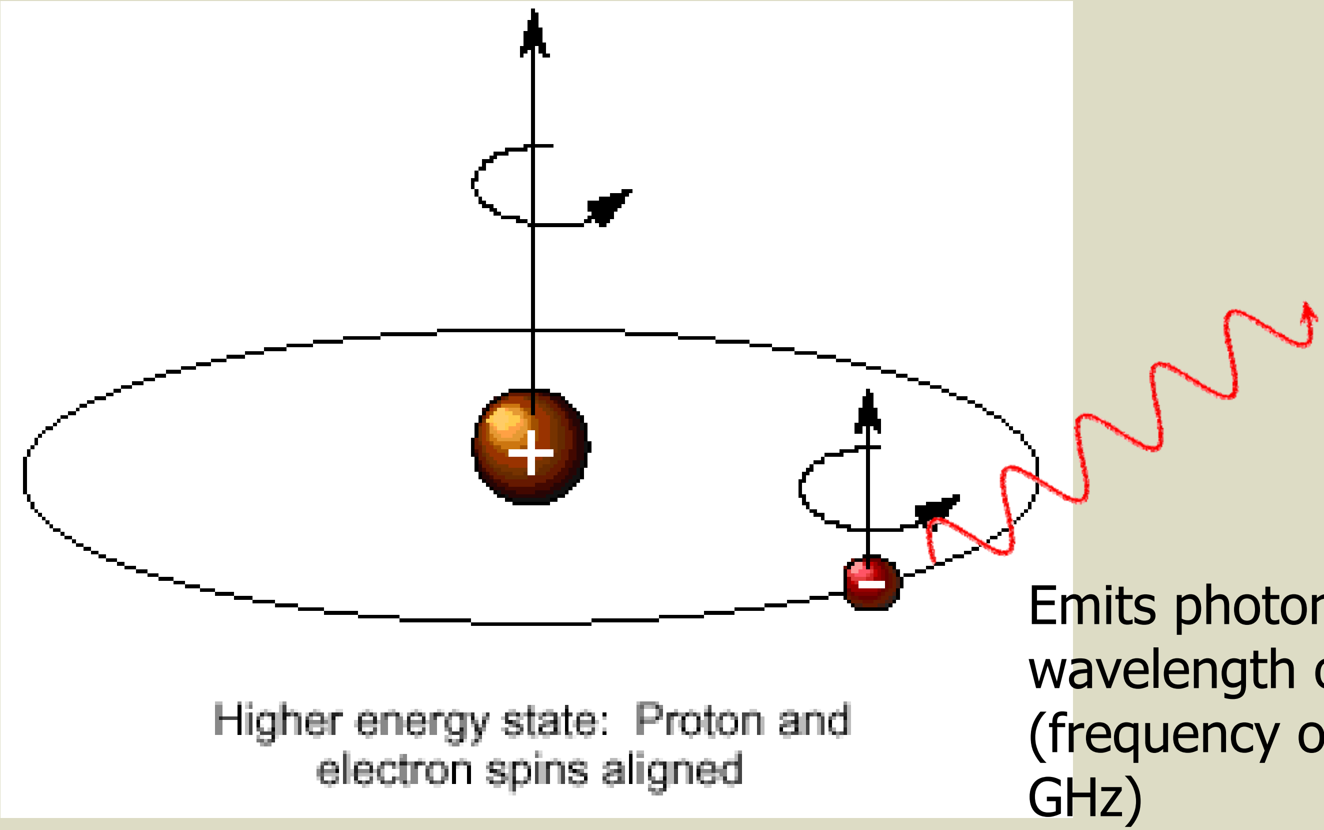
The Nobel Prize in Physics 1993

- for the discovery of a new type of pulsar, a discovery that has opened up new possibilities for the study of gravitation"

Russell A. Hulse

Joseph H. Taylor Jr

Spectral Line emission: hyperfine transition of neutral Hydrogen

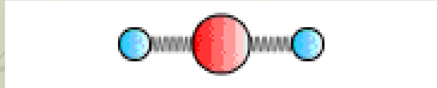
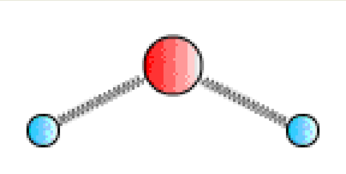
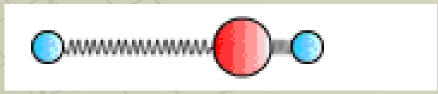
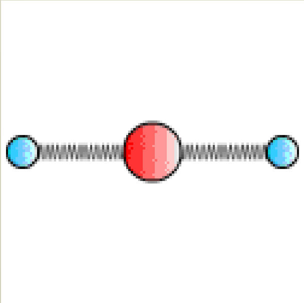


Emits photon with a wavelength of 21 cm (frequency of 1.42 GHz)

Transition probability=3×10^{-15} s^{-1} = once in 11 Myr

Spectral Line emission: molecular rotational and vibrational modes

- Commonly observed molecules in space:
    - Carbon Monoxide (CO)
    - Water (H_2O), OH, HCN, HCO^+, CS
    - Ammonia (NH_3), Formaldehyde (H_2CO)
- Less common molecules:
    - Sugar, Alcohol, Antifreeze (Ethylene Glycol), …

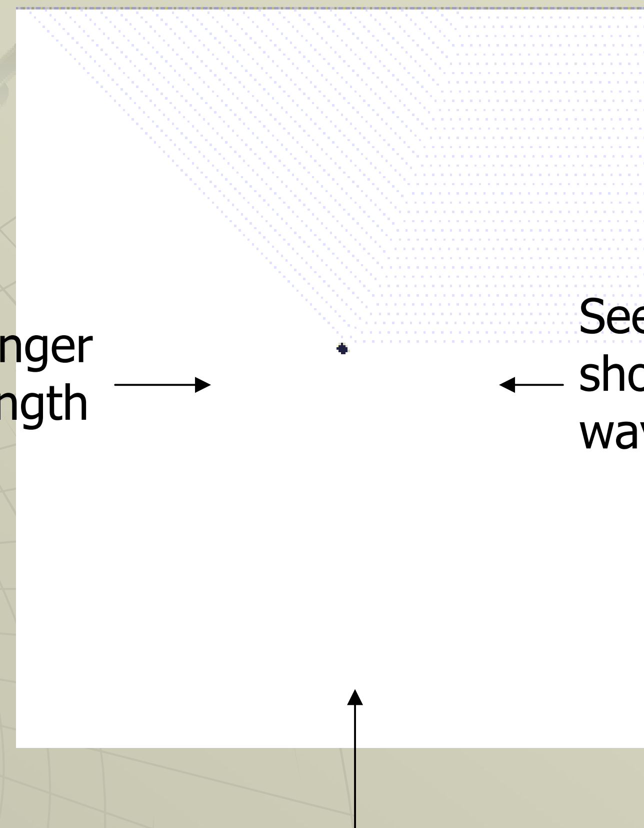






malondialdyde

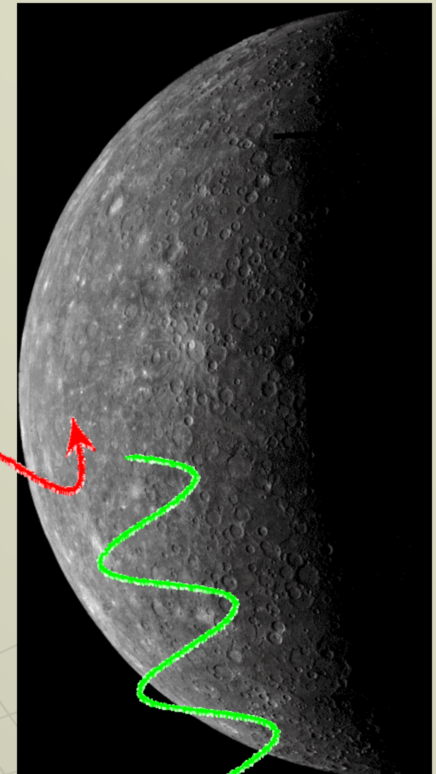
Spectral Line Doppler effect

- Spectral lines have fixed and very well determined frequencies
- The frequency of a source will changed when it moves towards or away from you

- Comparing observed frequency to known frequency tells you the velocity of the source towards or away from you



Special example of Spectral Line observation: Doppler Radar Imaging

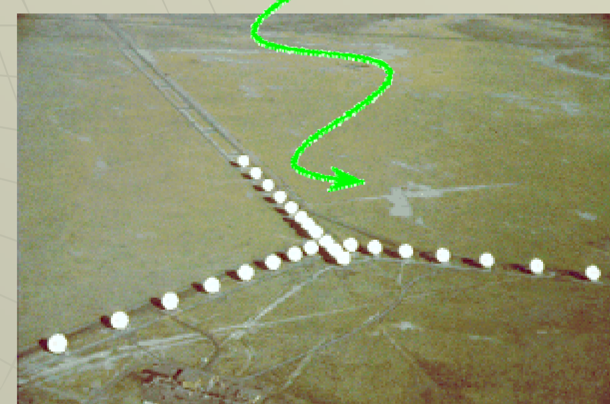


…bounce off object…

Transmit radio wave with well defined frequency…

..observe same frequency

NASA's Goldstone Solar System Radar



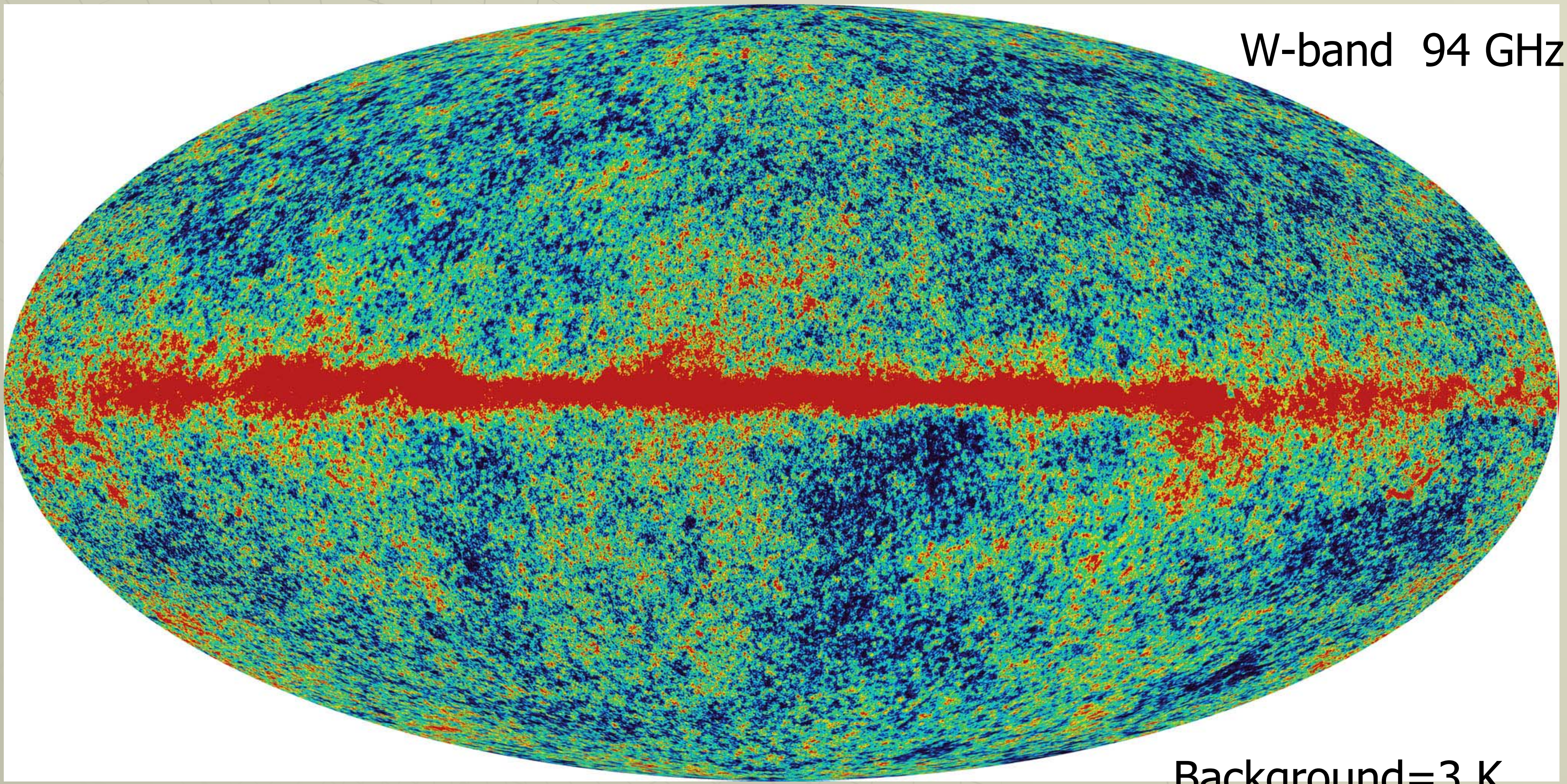
Very Large Array

Brief Tour of the Radio Universe

- Solar System
  - Sun, Planets, Asteroids
- Galactic objects
  - Dark clouds, proto-stellar disks, supernova remnants,
- Galaxies
  - Magnetic fields, neutral hydrogen
- Radio Jets
- The Universe

Wilkinson Microwave Anisotropy Probe (WMAP)

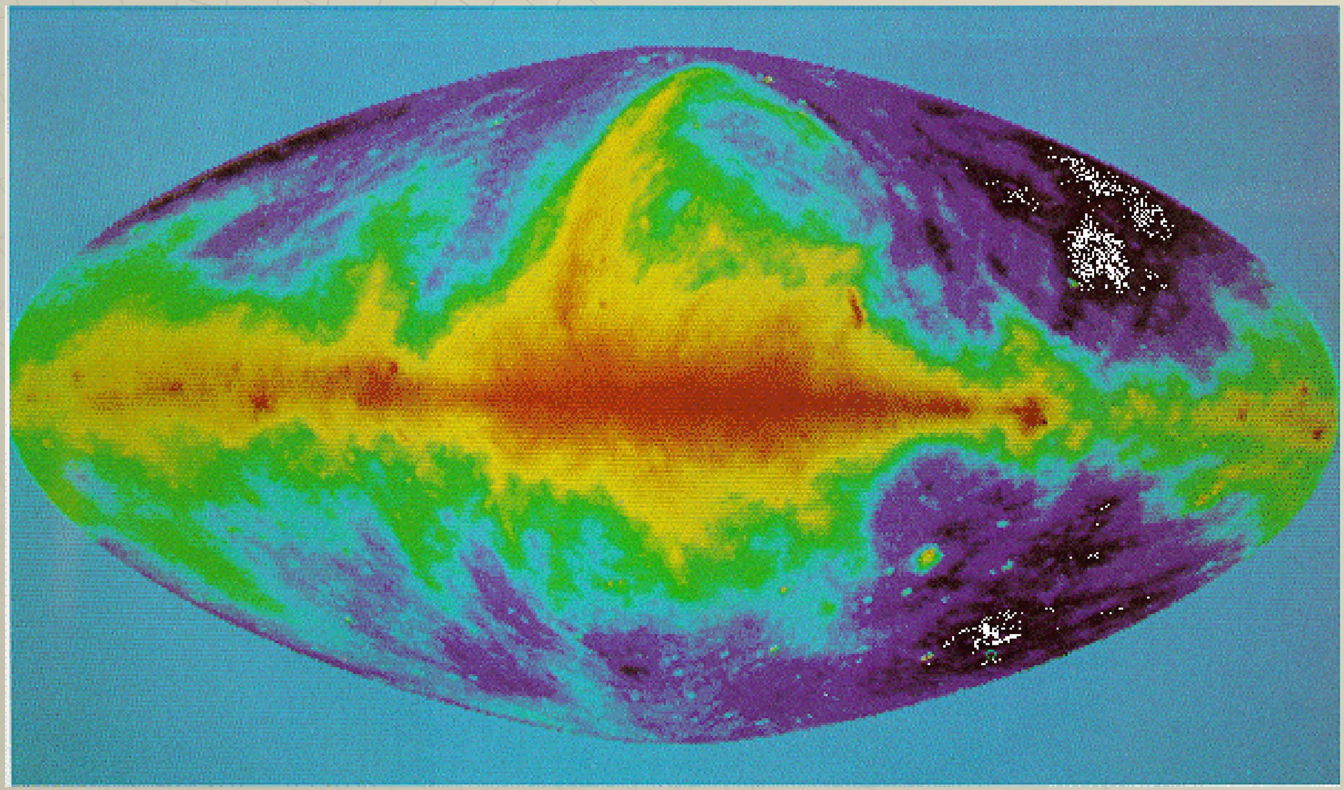
map.gsfc.nasa.gov



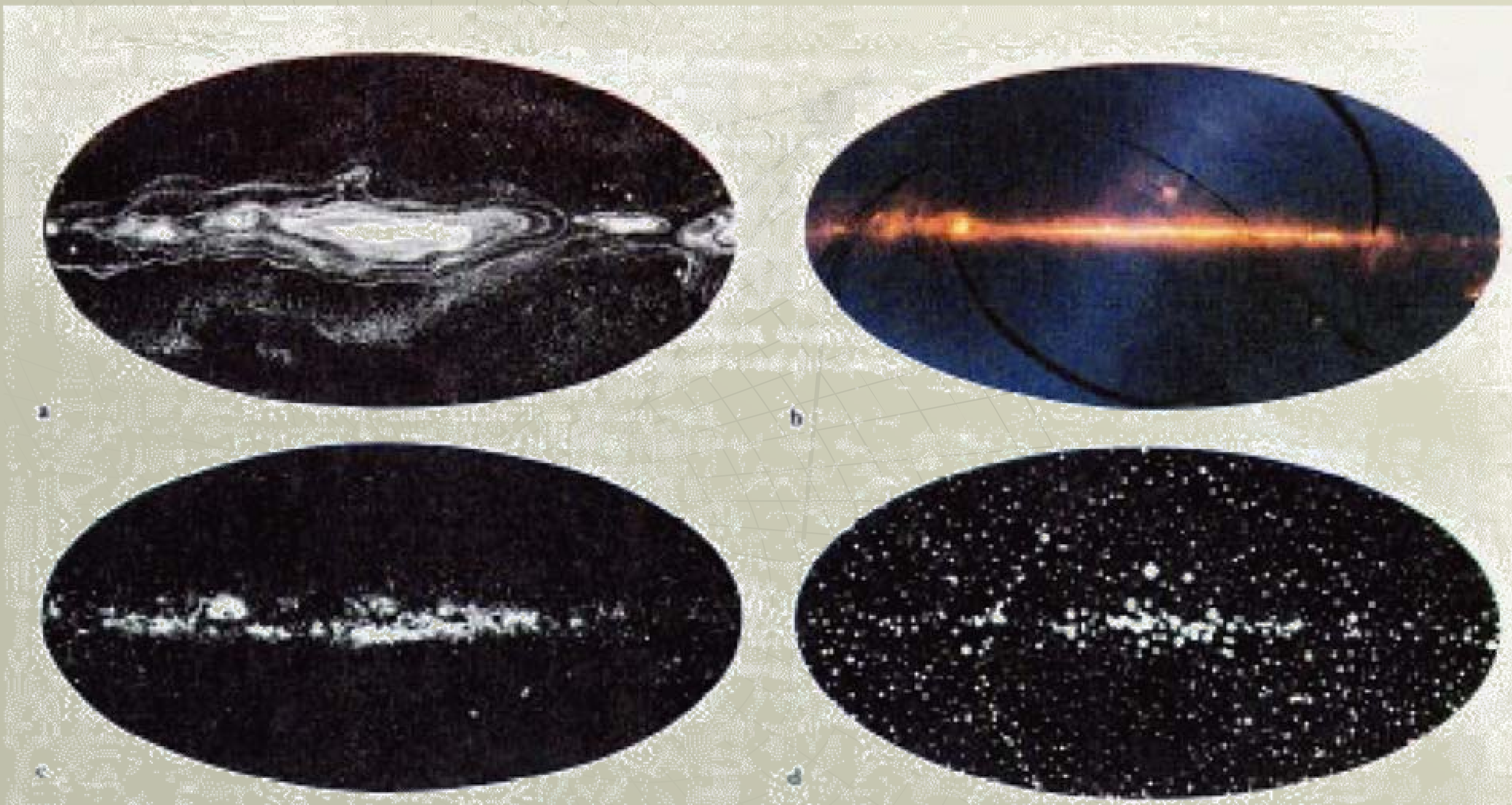
Background=3 K
blackbody radiation

Shepherding in the era of "Precision Cosmology"

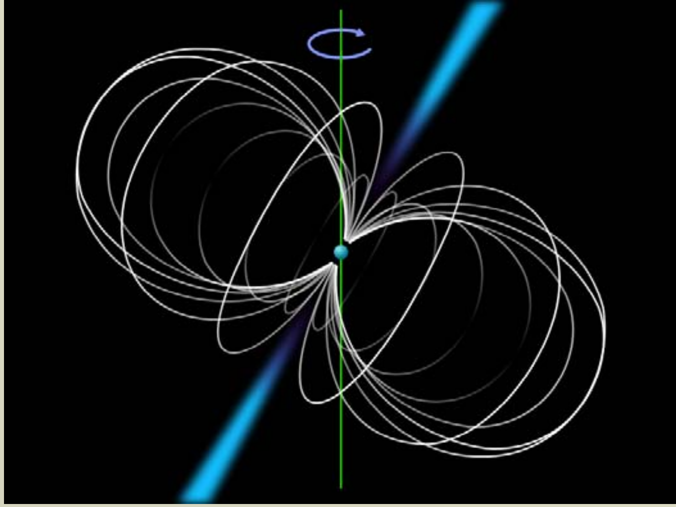
Radio pregled Mlječne staze



(a) radio
(b) infrared,
(c) visible
(d) X-ray
Each illustration shows the Milky Way stretching horizontally across the picture.



Pulsar



- **Pulsars** are highly magnetized, rotating neutron stars that emit a beam of electromagnetic radiation. The observed periods of their pulses range from 1.4 milliseconds to 8.5 seconds. The radiation can only be observed when the beam of emission is pointing towards the Earth. This is called the lighthouse effect and gives rise to the pulsed nature that gives pulsars their name. Because neutron stars are very dense objects, the rotation period and thus the interval between observed pulses are very regular. For some pulsars, the regularity of pulsation is as precise as an atomic clock.
- Pulsars are known to have planets orbiting them, as in the case of PSR B1257+12. Werner Becker of the Max-Planck-Institut für extraterrestrische Physik said in 2006, "The theory of how pulsars emit their radiation is still in its infancy, even after nearly forty years of work."

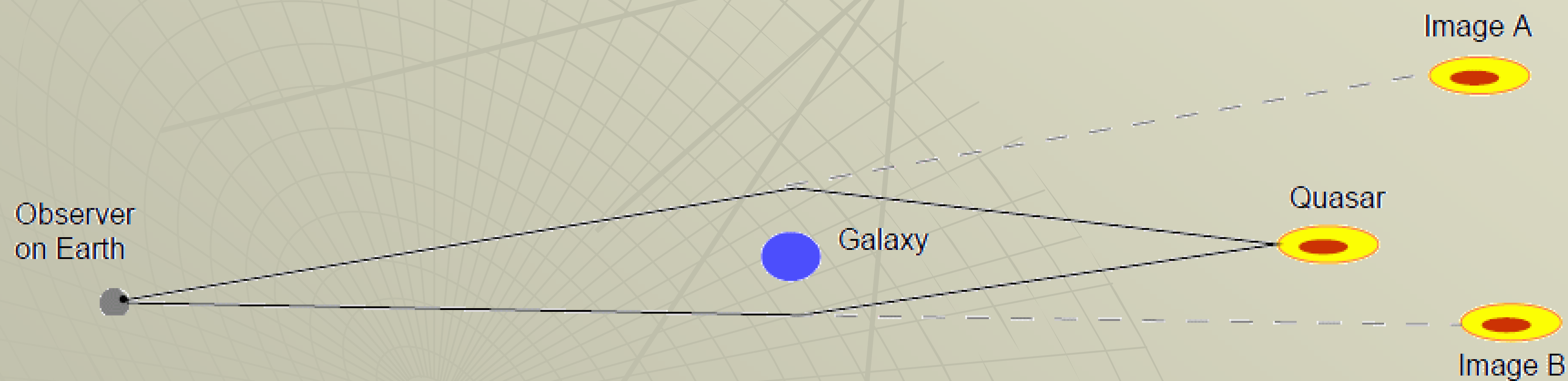
Kvazar

- A **Quasi-stellar radio source** (**Quasar**) is a powerfully energetic and distant galaxy with an active galactic nucleus. Quasars were first identified as being high redshift sources of electromagnetic energy, including radio waves and visible light, that were point-like, similar to stars, rather than extended sources similar to galaxies.
- While there was initially some controversy over the nature of these objects — as recently as the 1980s, there was no clear consensus as to their nature — there is now a scientific consensus that a quasar is a compact region 10-10,000 Schwarzschild radii across surrounding the central supermassive black hole of a galaxy, powered by its accretion disc.

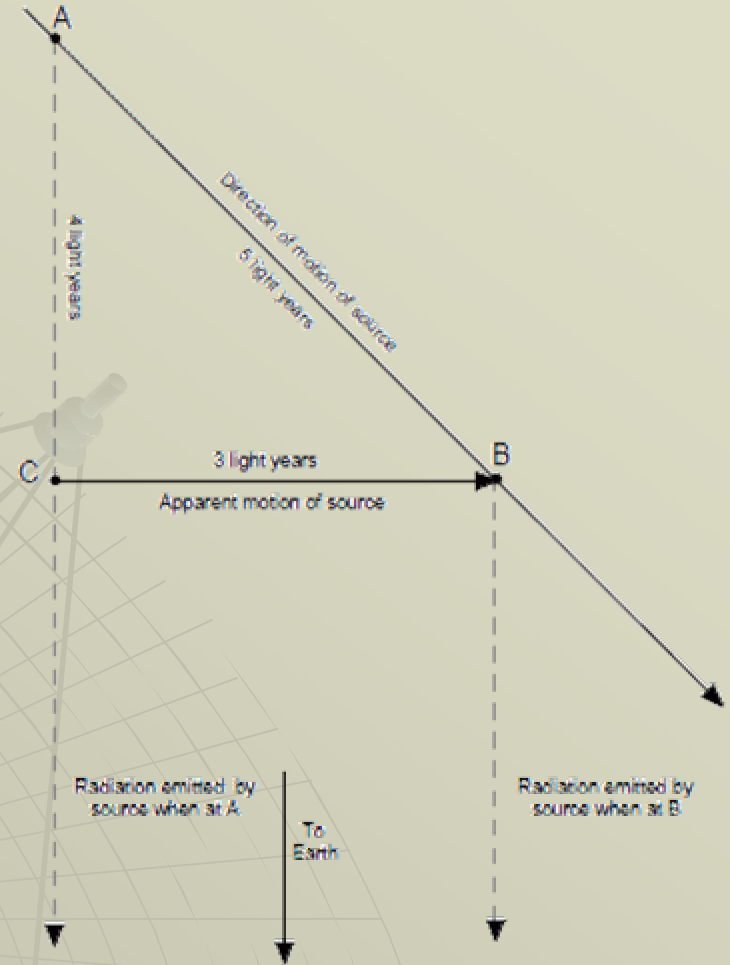
Maser Historical background

- In 1965 an unexpected discovery was made by Weaver *et al.* - emission lines in space of unknown origin at a frequency of 1665 MHz. At this time many people still thought that molecules could not exist in space, so the emission was at first put down to an interstellar species named *Mysterium*, but the emission was soon identified as line emission from OH molecules in compact sources within molecular clouds. More discoveries followed, with H2O emission in 1969, CH3OH emission in 1970 and SiO emission in 1974[7], all coming from within molecular clouds. These were termed "masers", as from their narrow line-widths and high effective temperatures it became clear that these sources were amplifying microwave radiation.
- Masers were then discovered around highly evolved *Late type stars*; First was OH emission in 1968, then H2O emission in 1969 and SiO emission in 1974. Masers were also discovered in external galaxies in 1973, and in our own solar system in comet halos.
- Another unexpected discovery was made in 1982 with the discovery of emission from an extra-galactic source with an unrivalled luminosity about 106 times larger than any previous source. This was termed a *megamaser* because of its great luminosity, and many more megamasers have since been discovered.
- Evidence for an *anti-pumped* (dasar) sub-thermal population in the 4830 MHz transition of formaldehyde (H2CO) was observed in 1969 by Palmer *et al.*

Gravitational Lensing

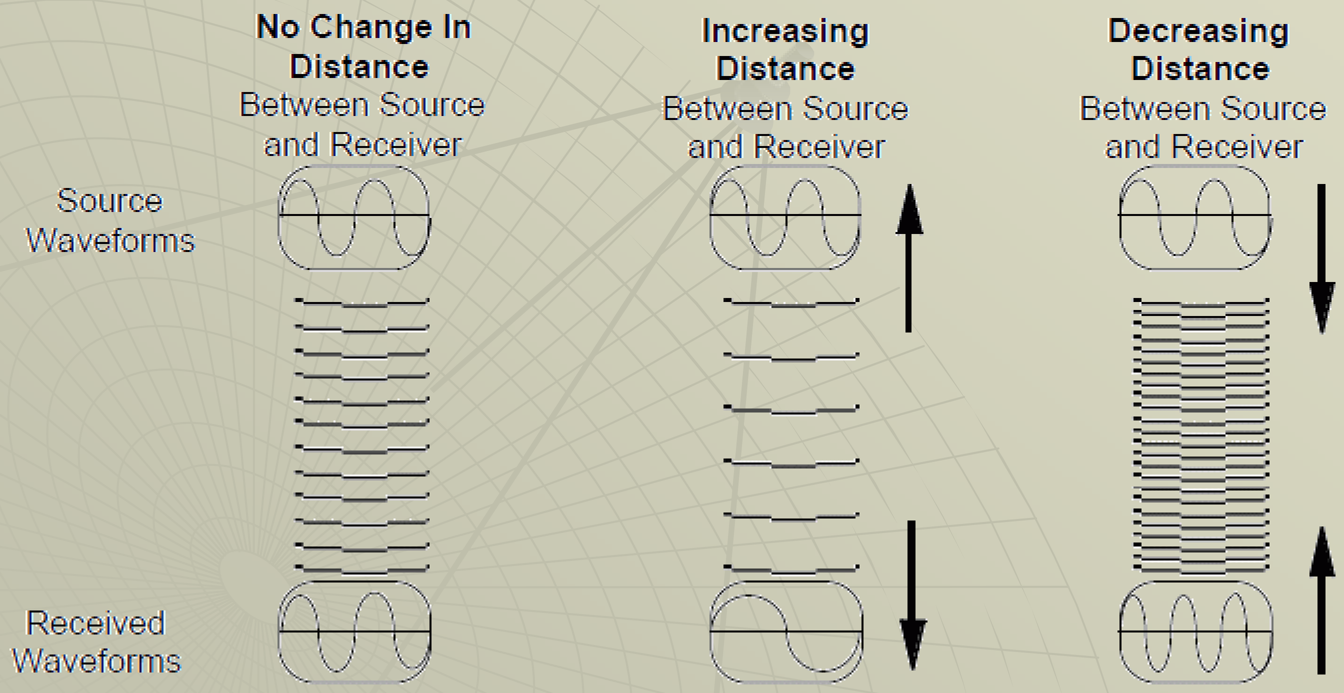


Superluminal Velocity



Suppose A is 4 light years (LY) farther from Earth than B (that is, AC is 4 LY). Moving just a bit under the speed of light, the object takes just over 5 LY to travel from A to B. However, the radiation it emitted at A reaches C in 4 years. As that radiation continues toward Earth, it is one year ahead of the radiation emitted toward us by the object when it arrived at B. When it finally (after several billion years) reaches Earth, the radiation from A is still one year ahead of the radiation from B. It appears to us that the object has moved tangentially out from the center of the quasar, from C to B and (from the Pythagorean theorem) has gone 3 LY in just over one year! That the object appears to travel at nearly three times light speed is only because of the projection effect, with its radiation travelling from A to C in 4 years, while the object itself went from A to B in 5 years.

Doppler Effects



has the most precise [thermal emission](#) spectrum known and corresponds to a temperature of 2.725 [kelvin](#) (K) with an emission peak at 160.2 [GHz](#)