# *from* RF *to* Optics

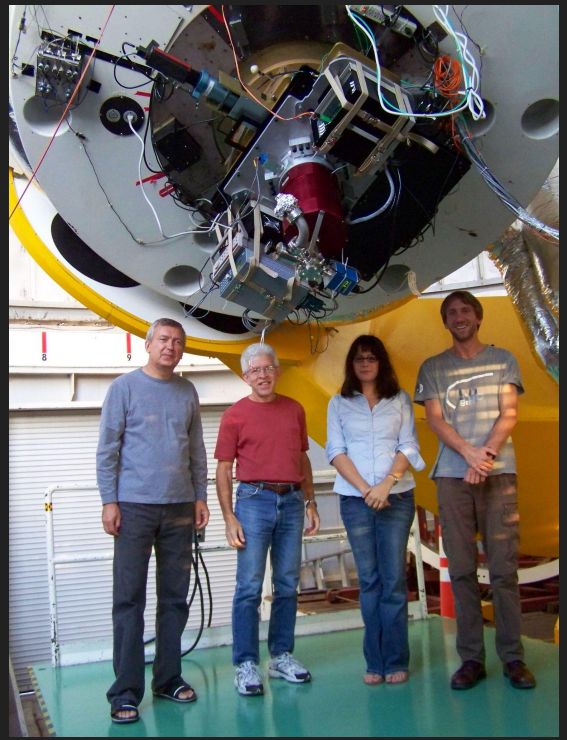
*Astronomy at the intersection of light and radio*

Justine Haupt-van Popering

βNL

# My path

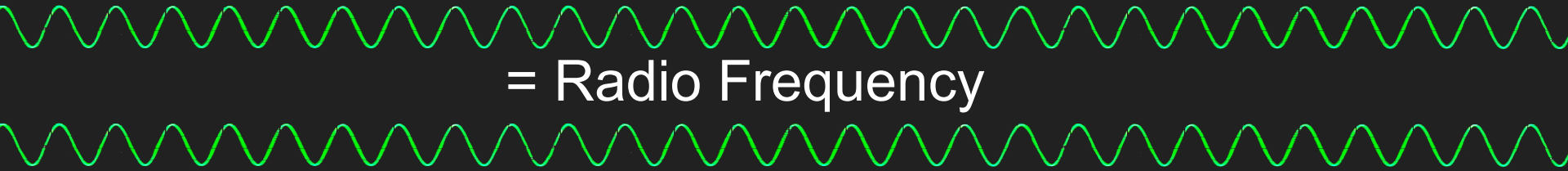
START HERE



# Currently:

## Free Space Link for Entangled Photon Distribution Over Long Distances

# What's "RF"?

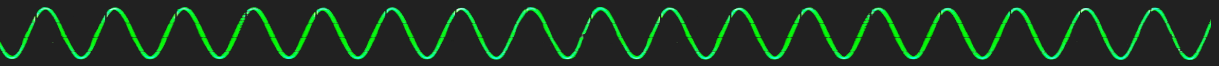


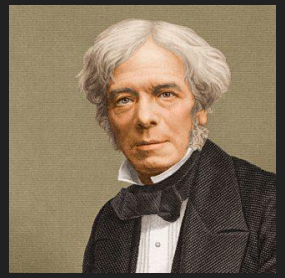
= Radio Frequency

Means:

- AC electricity at frequencies where radio propagation is useful
- Or just radio technology in general

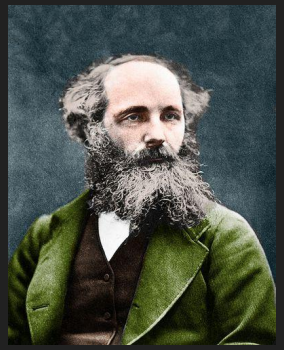
# History of RF





1850s: Faraday proposes concept of electric fields

1873: Maxwell makes powerful mathematical prediction that fields can propagate in open space and that light is an example of this effect. *Math is cumbersome.*

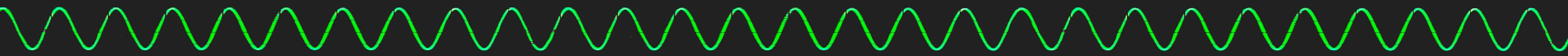


1884: O. Heaviside clarifies Maxwell's theory.

1880s: D. Hughes & H. Hertz separately prove Maxwell correct with experimental demonstrations.

"Hertzian Waves"

# History of RF



People realize “Hertzian Waves” could be used to communicate.
Like light signaling.

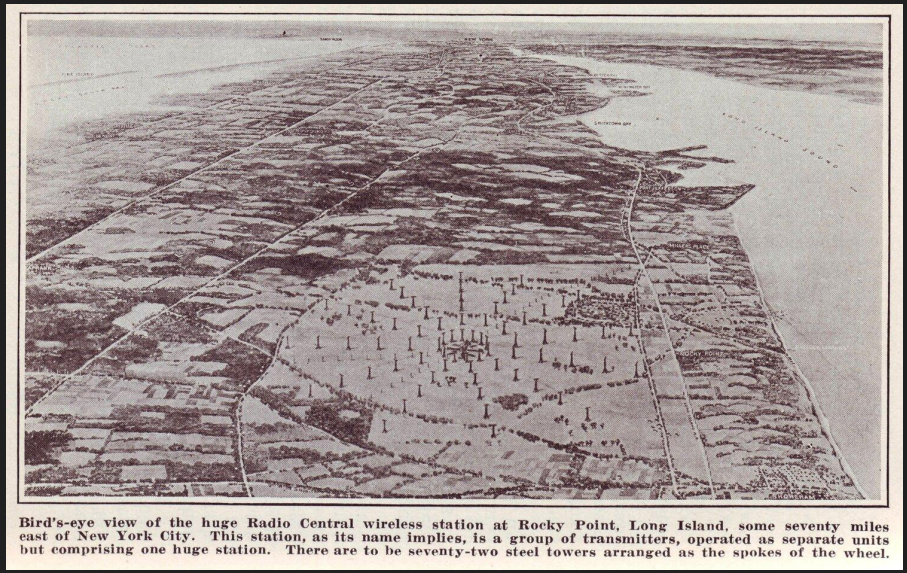
1890s: Simple signaling commercialized (Morse adopted from telegraphy)

1900s: First demonstrations of analog sound (e.g. voice) over radio, and first radio navigation systems created

1920: First broadcast radio stations start transmitting

# History of RF

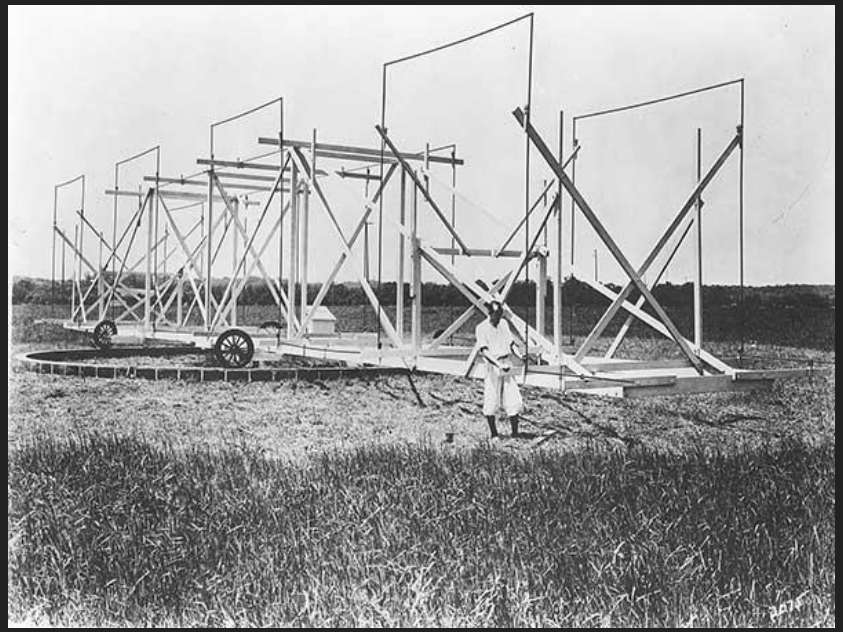
1927: Transatlantic “radio telephone” service goes online

Bird's-eye view of the huge Radio Central wireless station at Rocky Point, Long Island, some seventy miles east of New York City. This station, as its name implies, is a group of transmitters, operated as separate units but comprising one huge station. There are to be seventy-two steel towers arranged as the spokes of the wheel.

# History of ~~RF~~ radio astronomy

1932: Karl Jansky's 20.5 MHz rotating beam antenna starts looking for sources of communications interference and notices "a very steady hiss-type static"

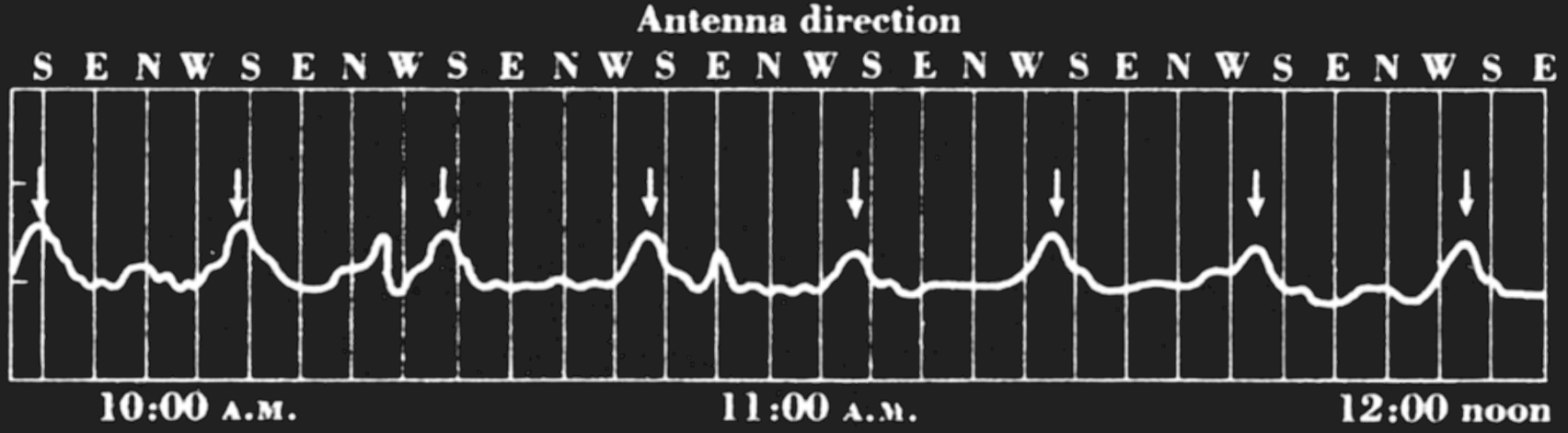


Jansky's "merry-go-round"

Karl Jansky

# History of radio astronomy

- Finds direction-dependent noise with interesting periodicity



# History of radio astronomy

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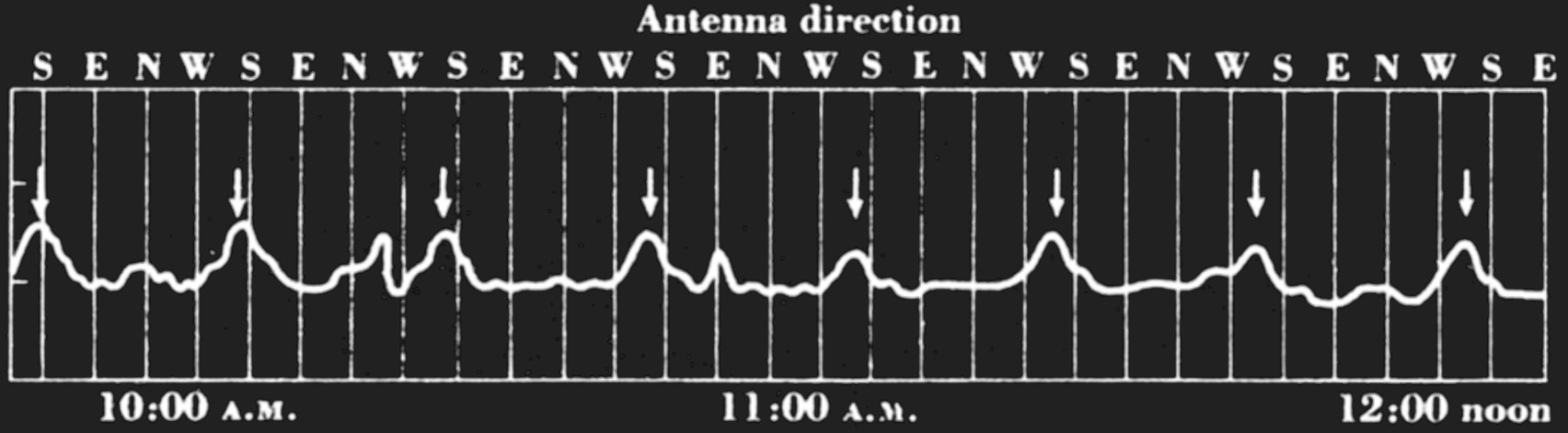


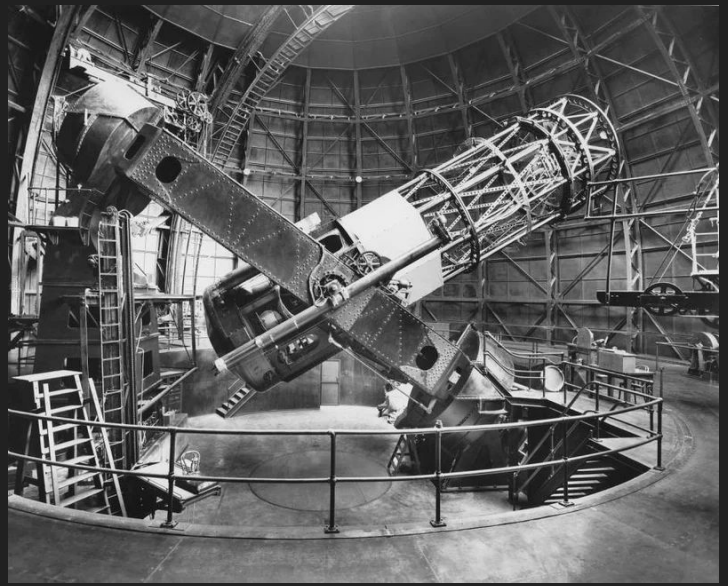

**Birth of radio astronomy!**

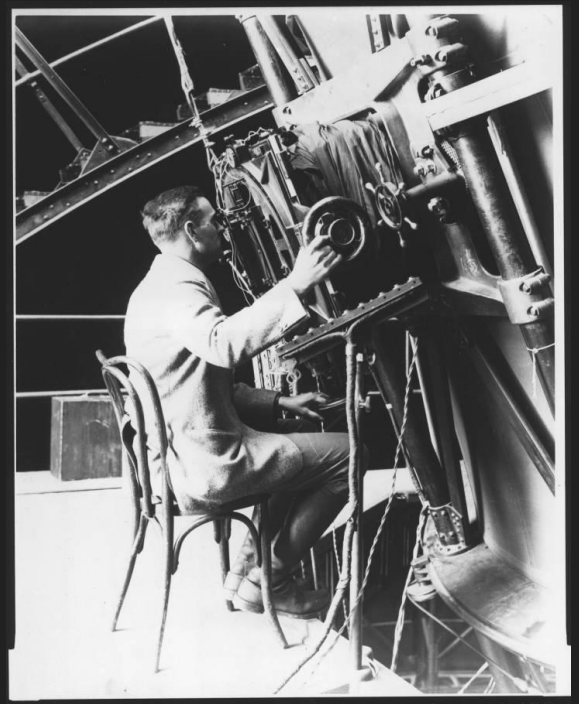
# History of radio astronomy

Having identified the noise source, Bell labs discontinued project, and…

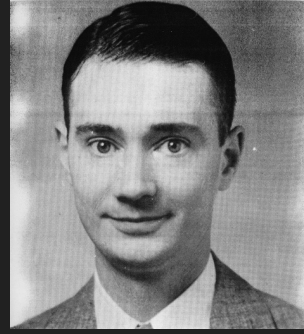
**non-reaction**

**from the astronomy community**



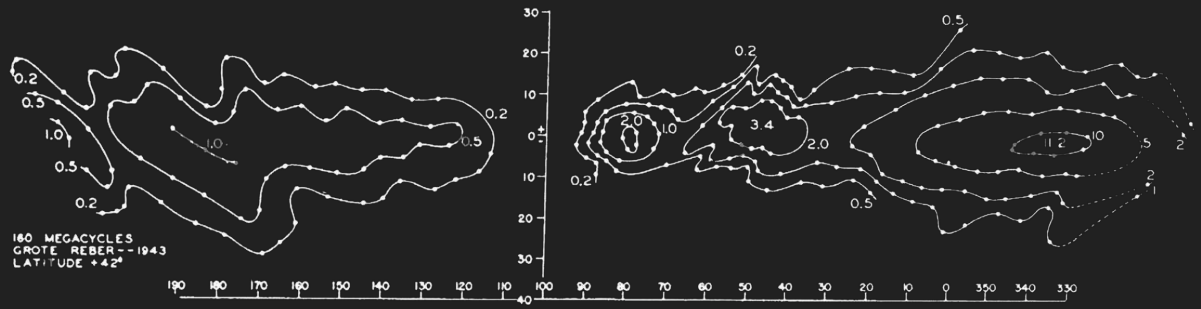


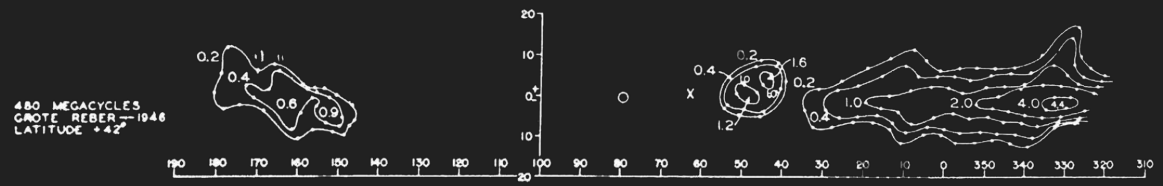
# History of radio astronomy

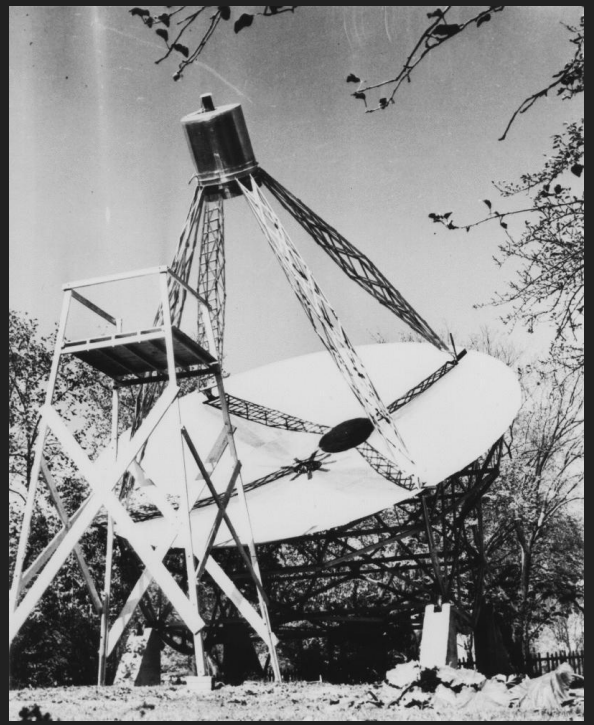


1935-1941: Grote Reber (W9GFZ), built (at home) first dedicated, steerable dish antenna for radio astronomy and made first radio sky survey.

- Negative results at 3.3GHz and 900MHz
- Success at 160MHz, first sky map made



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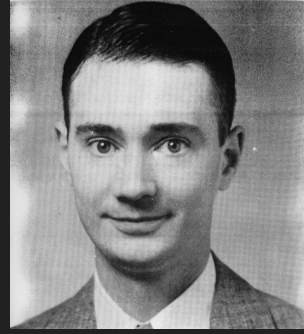

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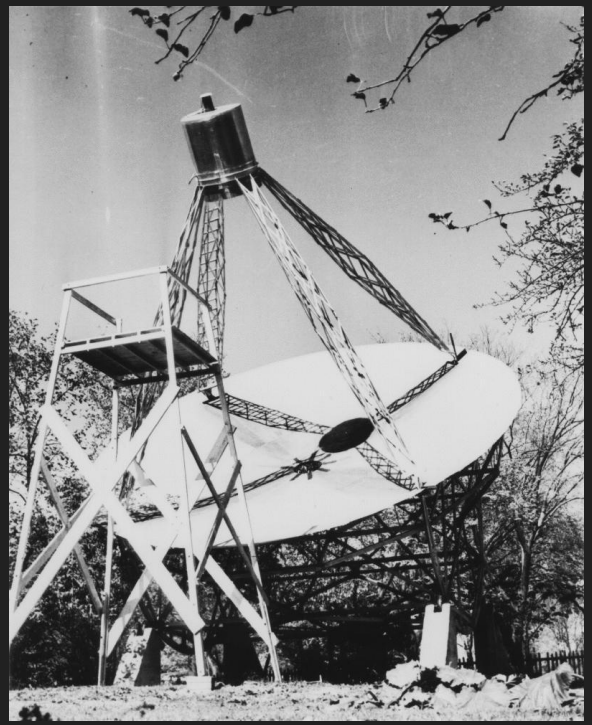
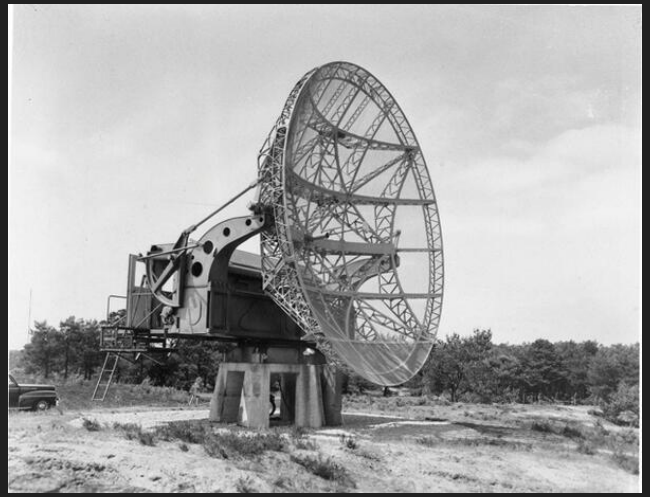


Reber:

...[astronomers] could not dream up any rational way by which the radio waves could be generated, and since they didn't know of a process, the whole affair was (considered by them) at best a mistake and at worst a hoax.

# History of radio astronomy



- Post WWII, excellent new radio telescopes readily available (surplus war radars)
- Many radio astronomy programs begin in earnest and the science grows

# History of radio astronomy

By 1950s:

- Several radio sources optically identified but frustrating lack of optical candidates for others.
- Sources that are ID'd are confusing. E.g. Dim nearby galaxies and bright distant ones.
- Separate naming convention for radio objects based on constellation.
- Radio astronomy discoveries still suspicious to traditional astronomers.

From Gerrit L. Verschuur:

...radio astronomers were greatly impressed by the almost total lack of connection between radio observations and the visual sky. It did not seem impossible then that there were two separate kinds of celestial objects, each requiring distinct research techniques.

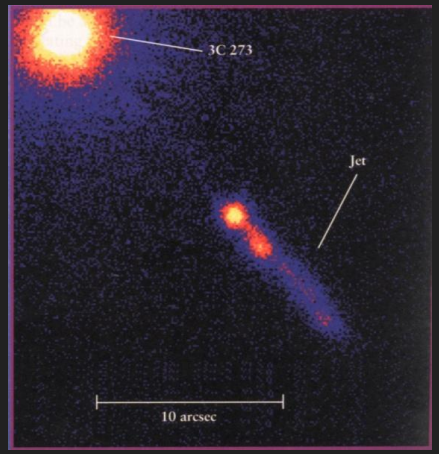
# History of radio astronomy

Early 1960s: Optical counterparts become common, scenario clarifies

1962: Quasars discovered

1964: Arno Penzias and Robert Wilson discover CMB

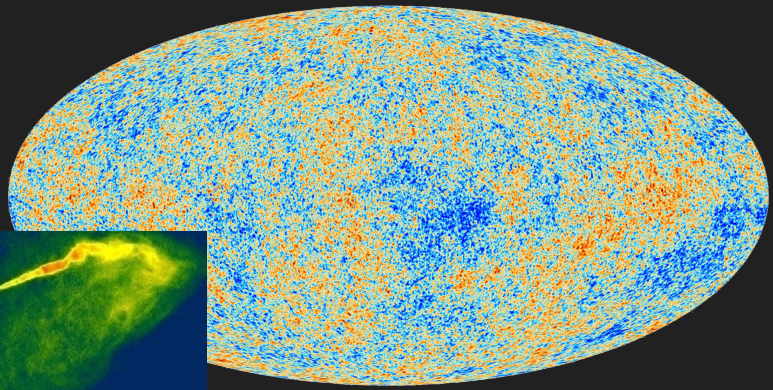
1967: Jocelyn Bell discovers first pulsar

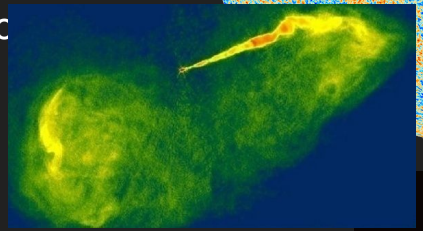



# Radio astronomy today

1970s to present:

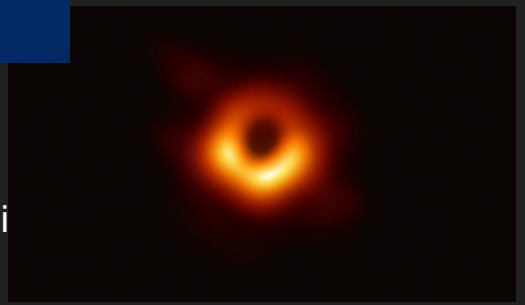
Leaps in receiver technology and high resc





Galactic jets observed

Theories of pulsars and quasars refined



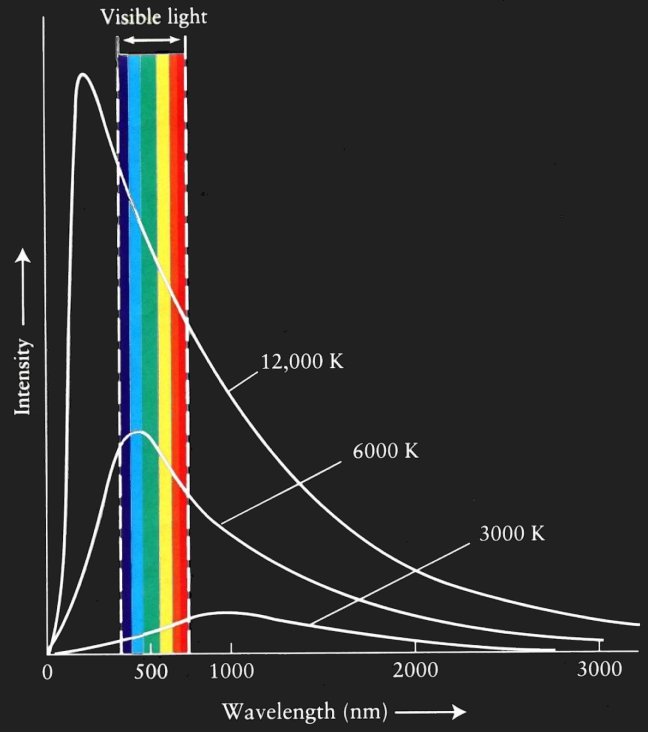
Satellites observe CMB, big bang cosmology refined

Increasingly high frequency observations (millimeter and sub mi
observation gap almost all the way to the IR)

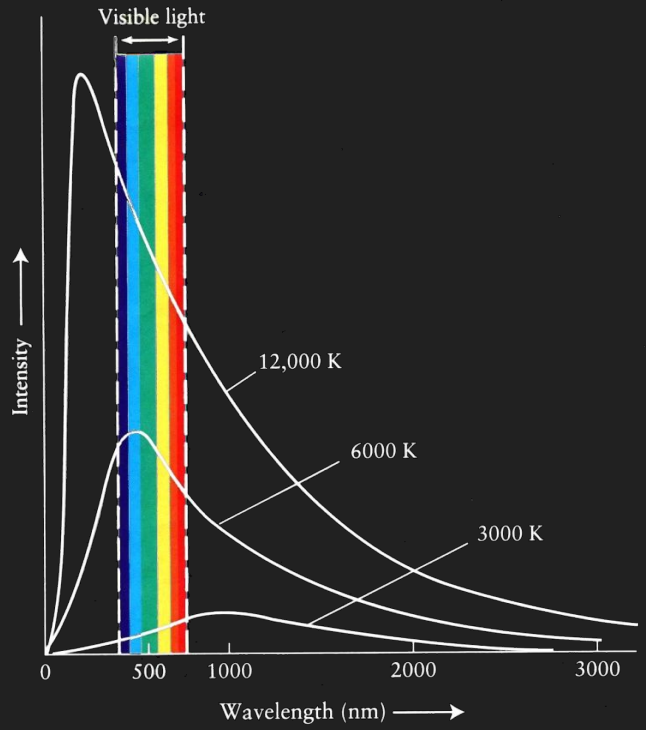
SETI

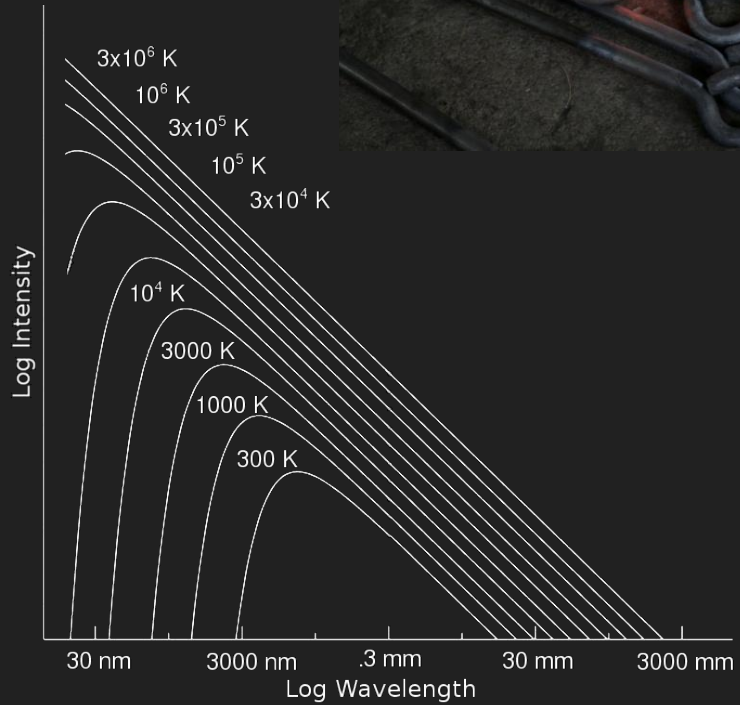
2010: new kind of radio source discovered (Fast Radio burst)

# Light from nature



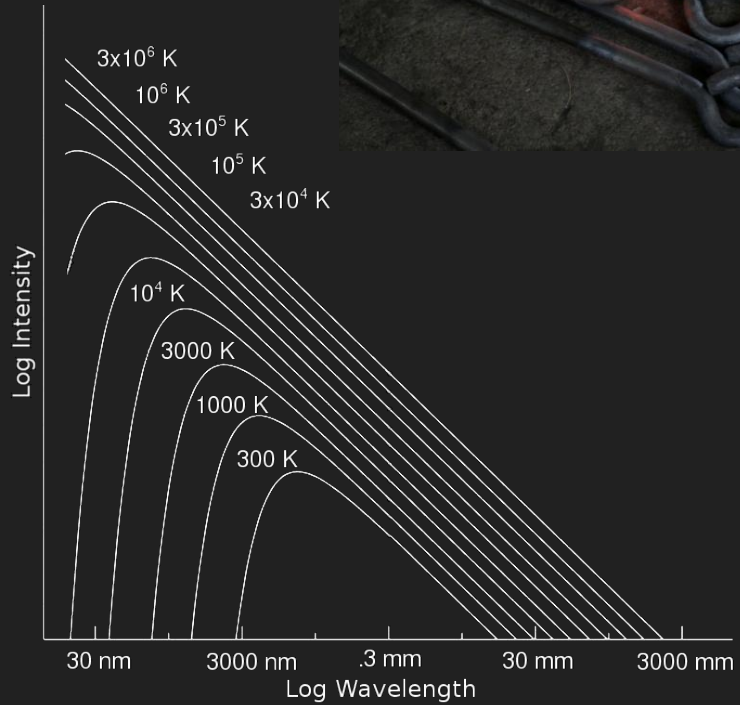

# Light and radio from nature



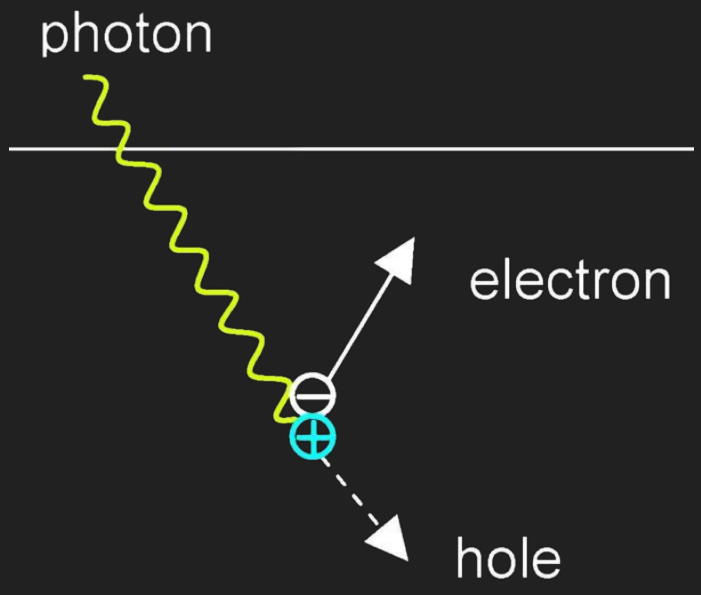
# Light and radio from nature

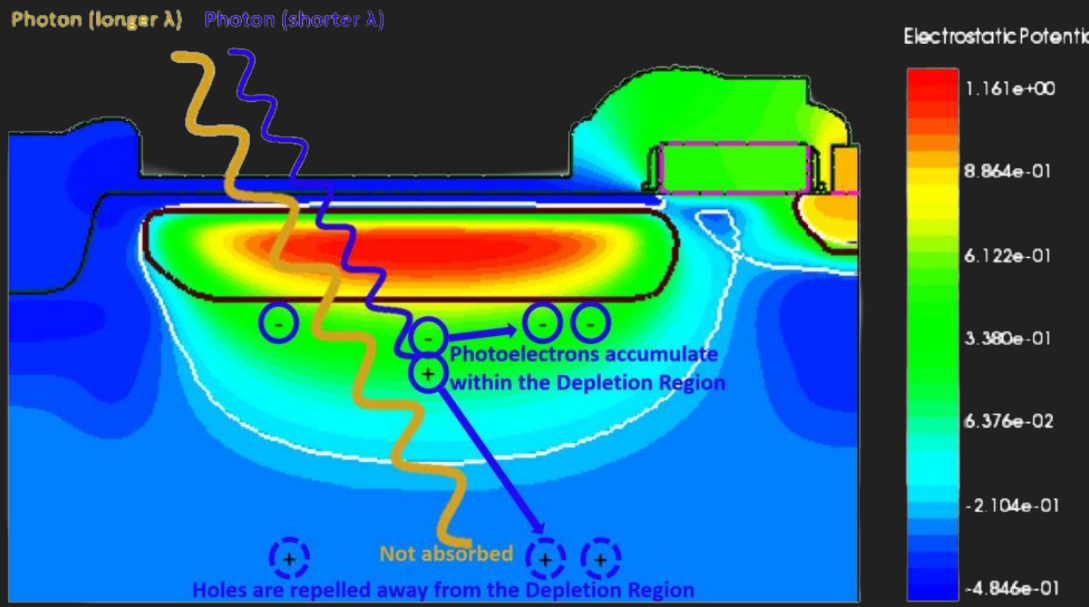
- Blackbody most common
- Synchrotron radiation
- Natural masers
- Fluorescence
- CMB is redshifted blackbody



# Light detectors

- Detect photons by exploiting photoelectric effect



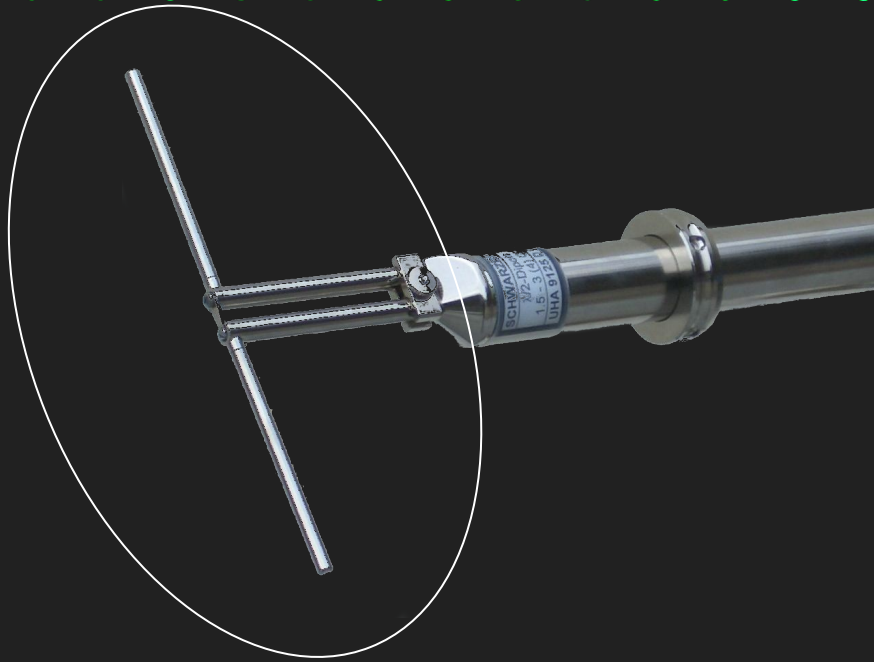



What's another kind of light detector?

# Antennas

Electron tank excited into oscillation by external perturbation

Fundamental antenna form is the dipole: divided wire of certain length resonates with passing EM radiation



# Antennas

Sample case: Log Periodic Dipole Array (LPDA)
Array of dipoles decreasing in size (increasing in resonant frequency) toward the front

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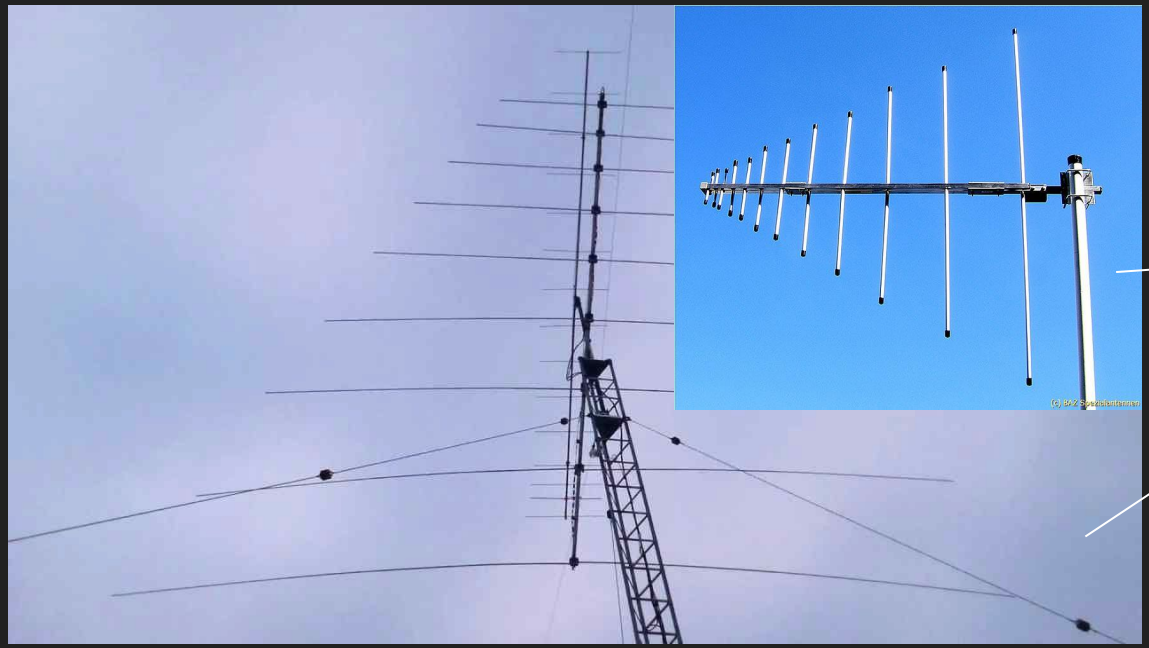

Same design, different frequency:

500 MHz

40 MHz

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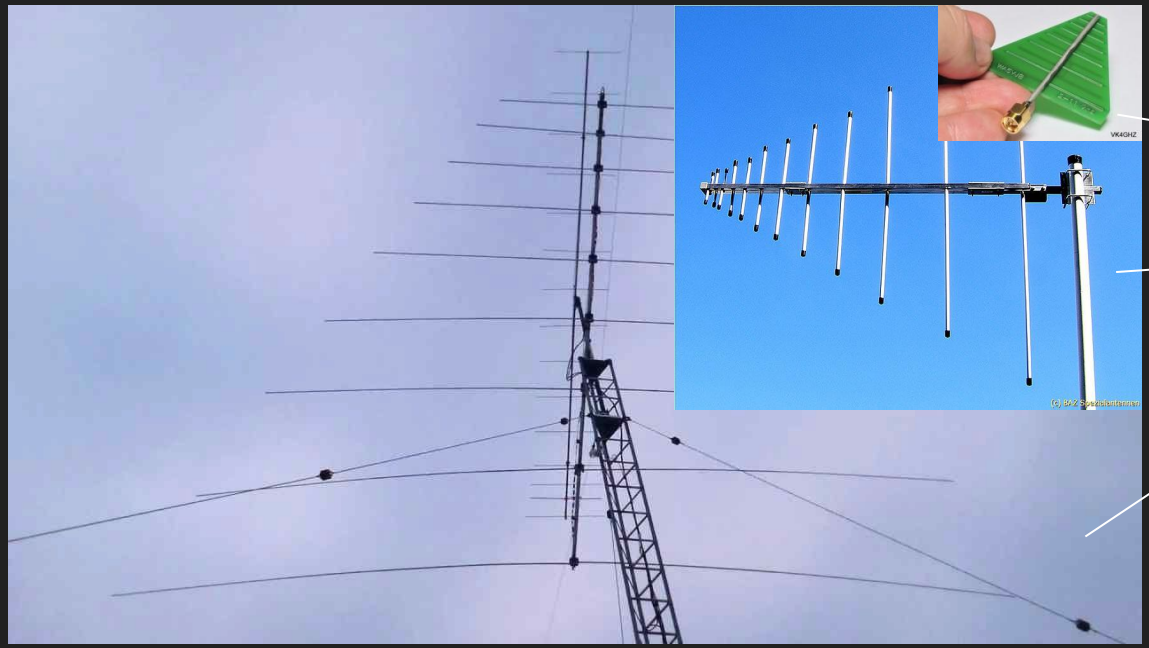
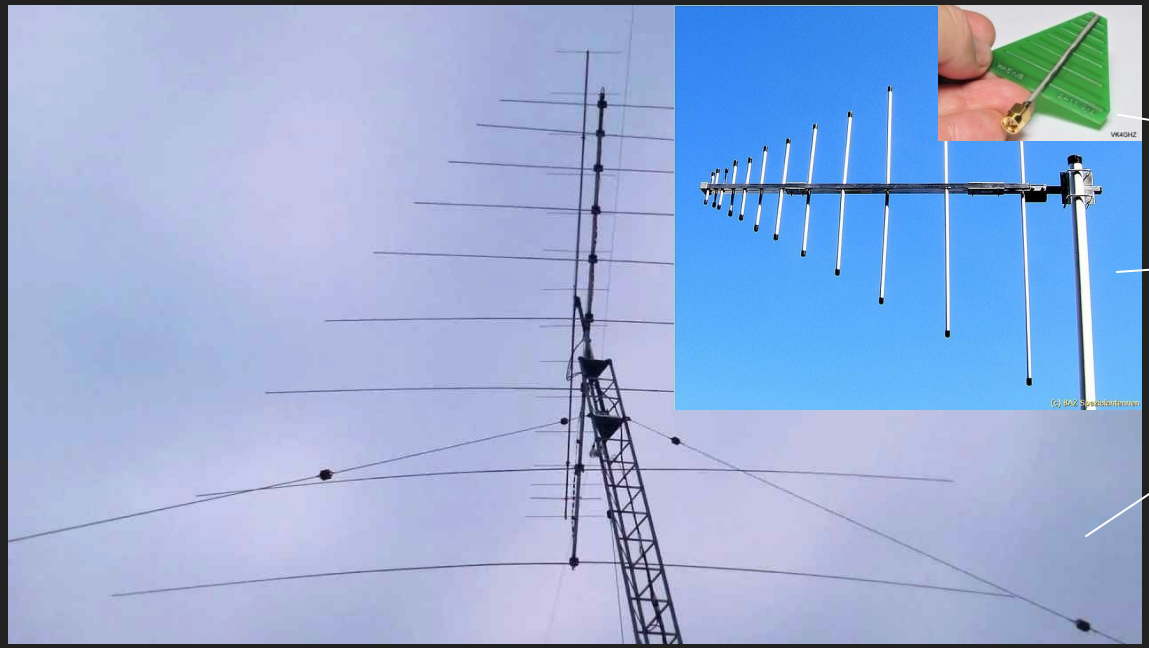


Same design, different frequencies:

- 2 GHz
- 500 MHz
- 40 MHz

# Antennas

Sample case: Log Periodic Dipole Array (LPDA)
Array of dipoles decreasing in size (increasing in resonant frequency) toward the front



Same design, different frequencies:

2 GHz

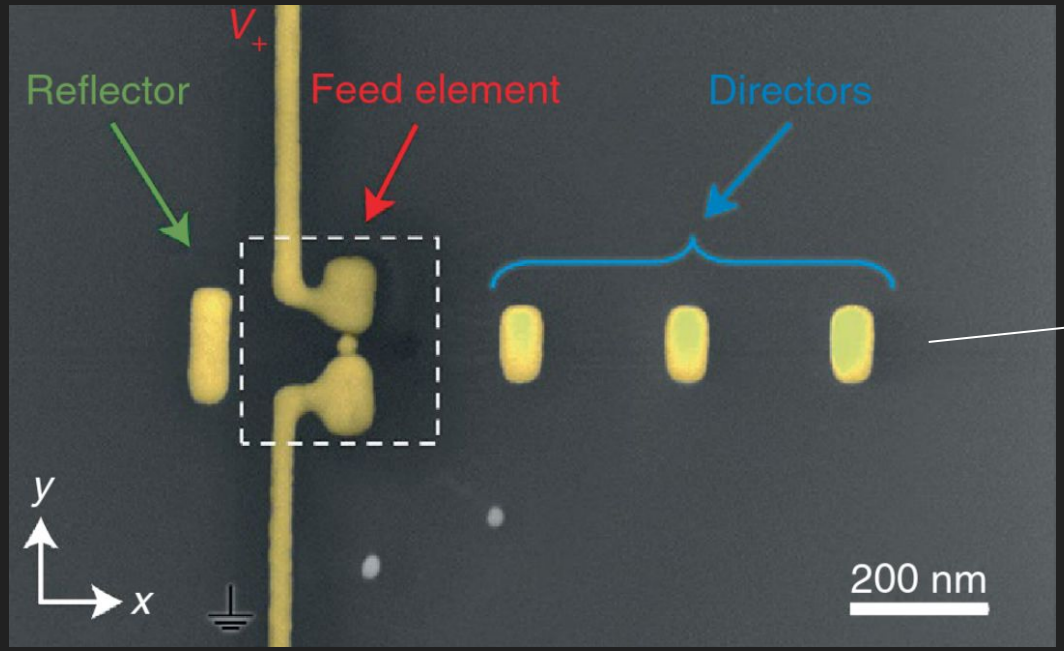
500 MHz

40 MHz

How far can scaling go?

# Antennas

An optical antenna!




Similar design, optical frequencies:

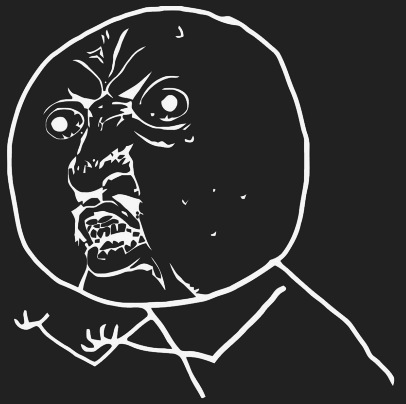
366THz [820nm]

How far can scaling go?

# Optics *v.* Radio

(Radio optics?)

# Why you no explain optics?



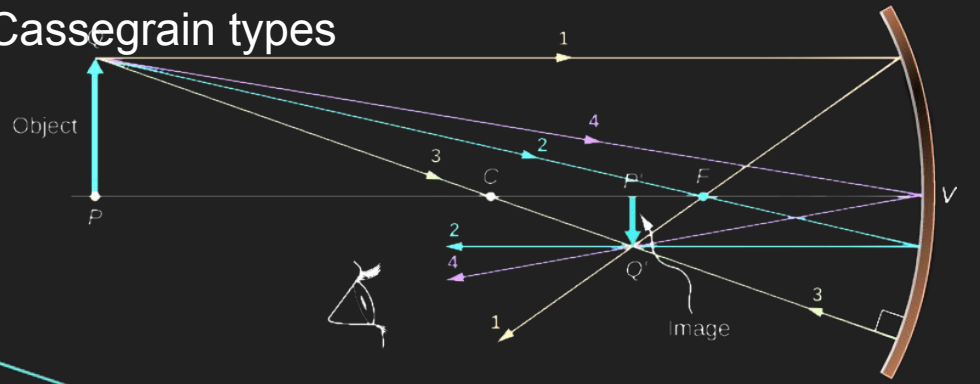
My categories:

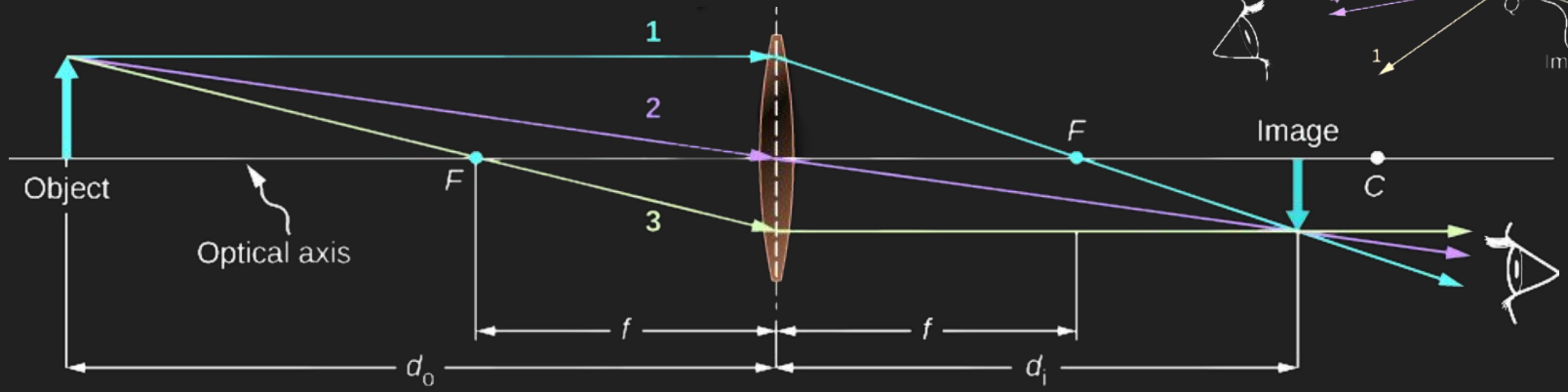
- Geometric/ imaging optics (whole EM)
- Laser optics (mainly optical)
- Fiber optics (applies to whole EM)
- Photonics and integrated photonics (not sure)
- Physical optics (whole EM, radio-centric)
- Quantum optics (whole EM)

# Optics

Both radio and visible light focused with lenses or mirrors
- Lenses impractical for radio
- Same optical formulae apply: image height = f tan(θ)
- Mirror (dish) obvious choice
- Most radio telescopes are prime focus or Cassegrain types

Cement?



# Optics

Feed (antenna): Located at focal point. Often a feed horn but any antenna type is possible. On consumer satellite dishes usually called an LNB.

Dish / reflector / mirror: Usually parabolic. Made from any radio reflective material (metalized plastic, wire mesh, solid metal, wire mesh in fiberglass). Weave size must be << wavelength.

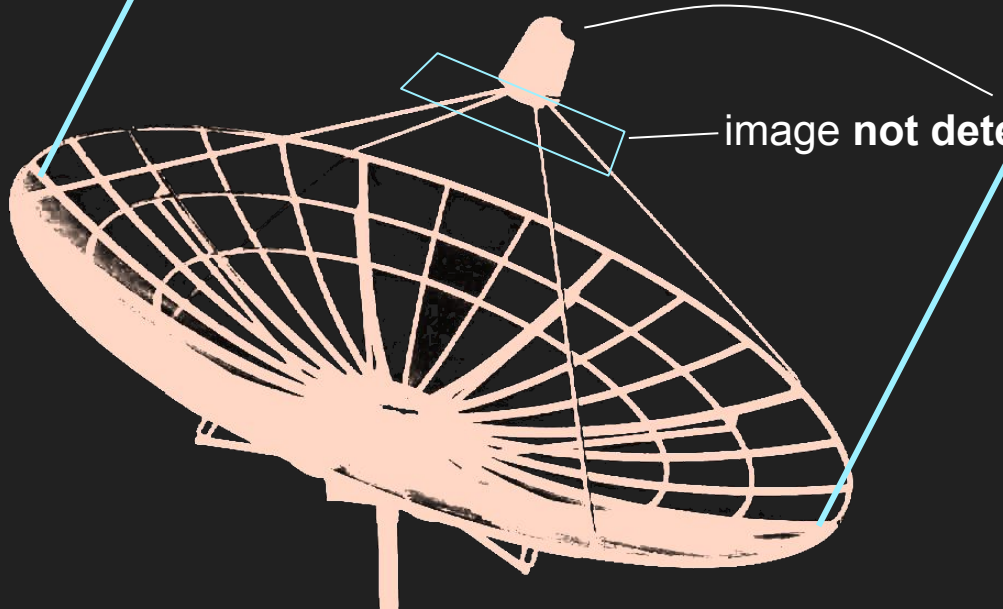


image **not detected by single-pixel detector**

Dish's image resolving potential limited by diffraction

$\lambda/d$

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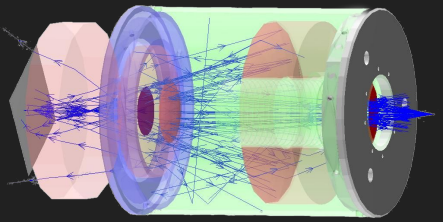
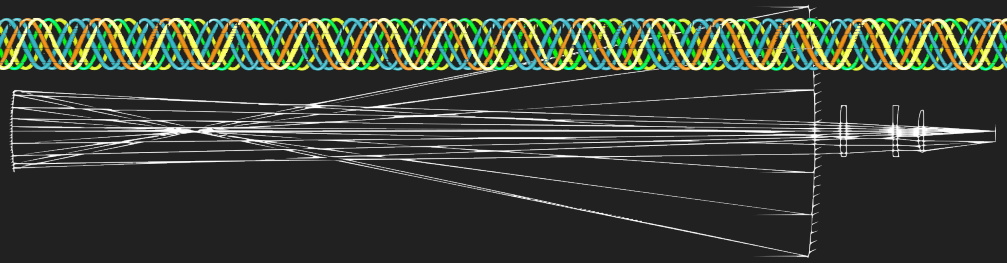
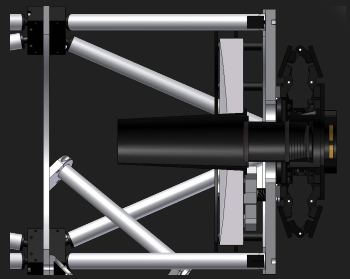
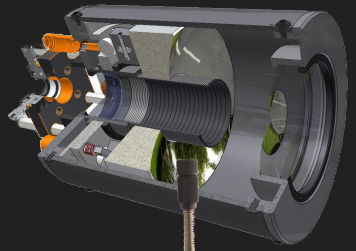
## *Cassegrain telescope morphogenesis:*

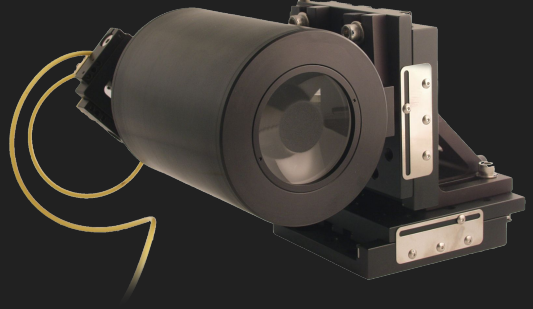
# Optics











# Optics

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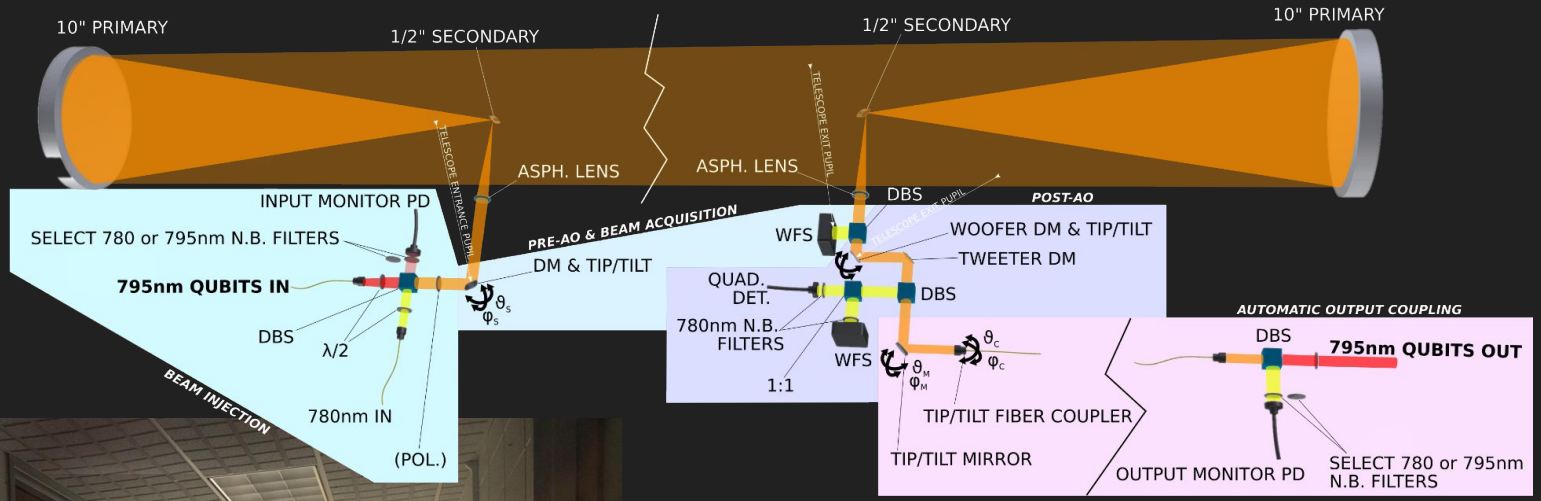
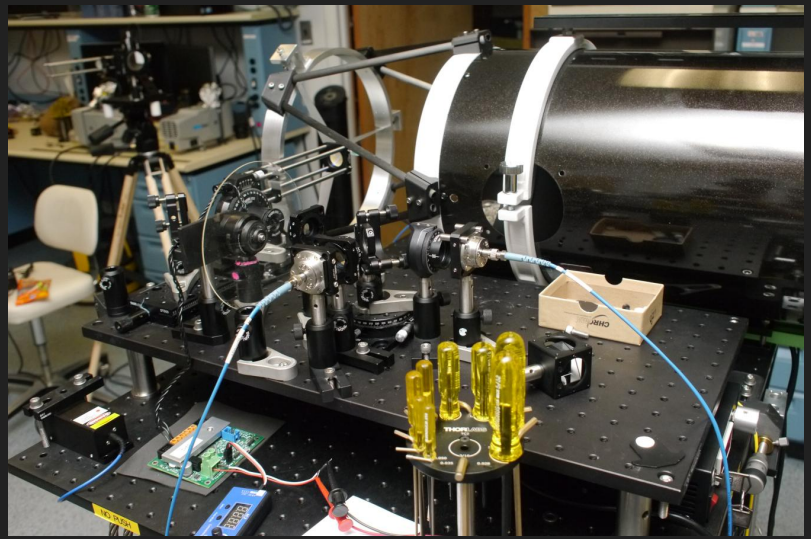

10" PRIMARY
1/2" SECONDARY
1/2" SECONDARY
10" PRIMARY
TELESCOPE ENTRANCE PUPIL
TELESCOPE EXIT PUPIL
ASPH. LENS
ASPH. LENS
INPUT MONITOR PD
SELECT 780 or 795nm N.B. FILTERS
795nm QUBITS IN
DBS
λ/2
780nm IN
(POL.)
BEAM INJECTION
PRE-AO & BEAM ACQUISITION
DM & TIP/TILT
DBS
POST-AO
WFS
WOOFER DM & TIP/TILT
TWEETER DM
QUAD. DET.
DBS
780nm N.B. FILTERS
WFS
1:1
AUTOMATIC OUTPUT COUPLING
DBS
795nm QUBITS OUT
TIP/TILT FIBER COUPLER
TIP/TILT MIRROR
OUTPUT MONITOR PD
SELECT 780 or 795nm N.B. FILTERS



# References


- Nano-scale antenna fabrication:
  https://www.nature.com/articles/s41467-019-14011-6

- On the function of imaging detectors:
  https://scientificimaging.com/knowledge-base/photoelectric-effect/