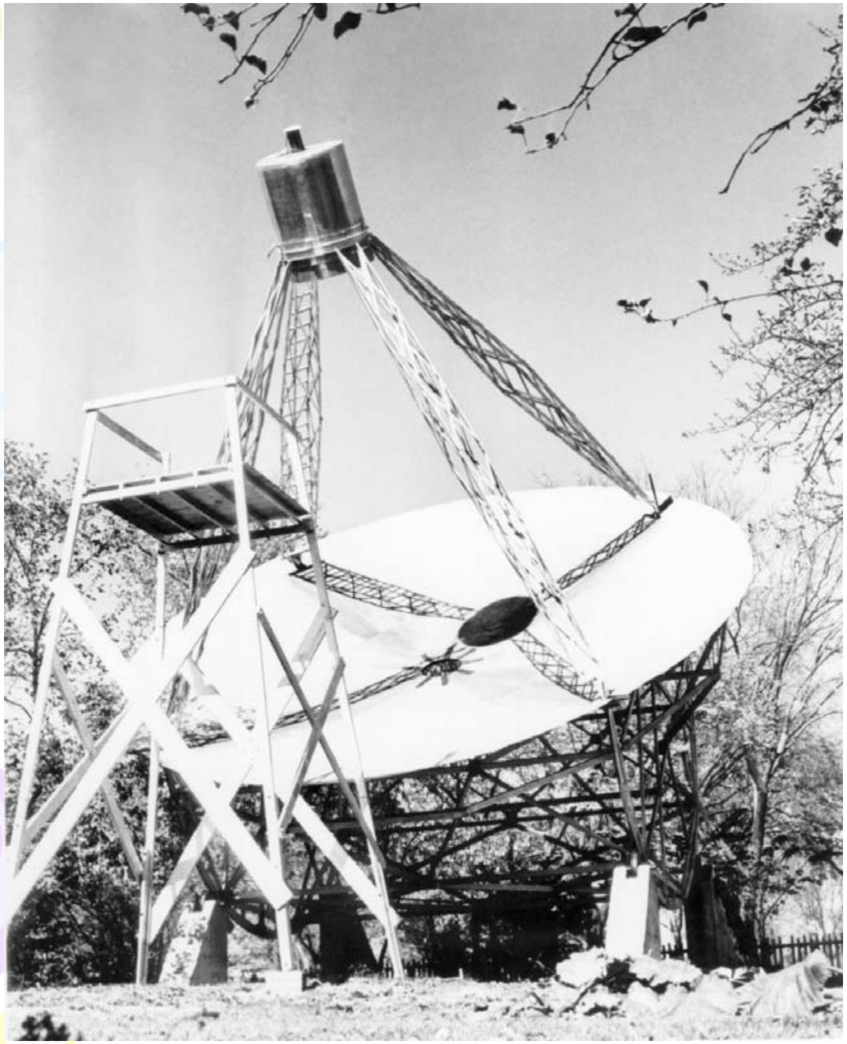
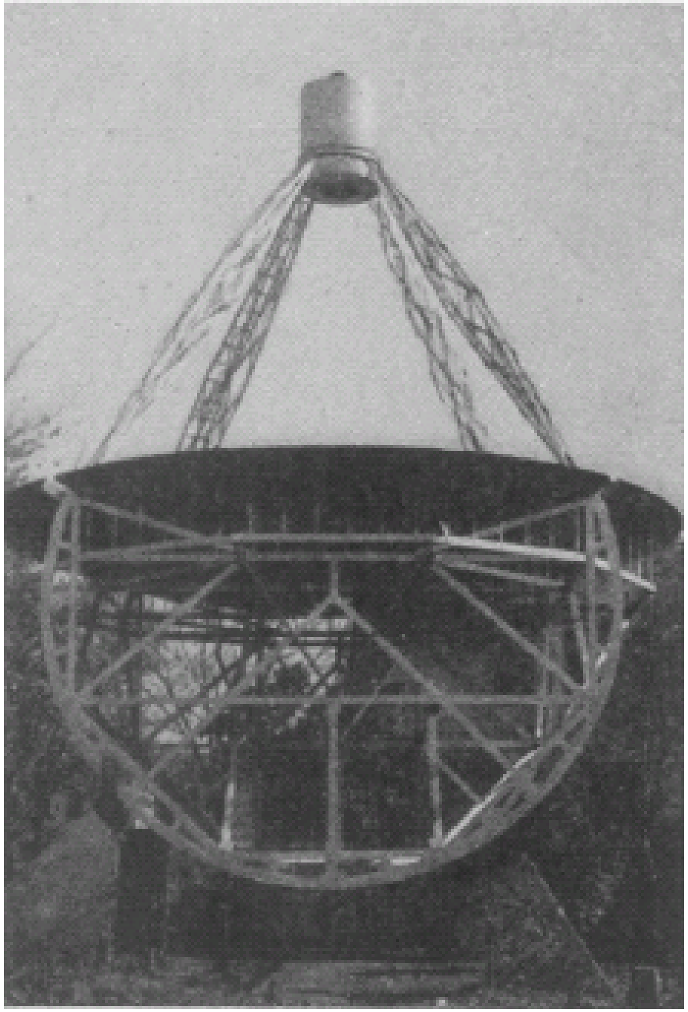
Lectures on radio astronomy: 5

Richard Strom
NAOC, ASTRON and University of Amsterdam

Unusual or special types of telescope

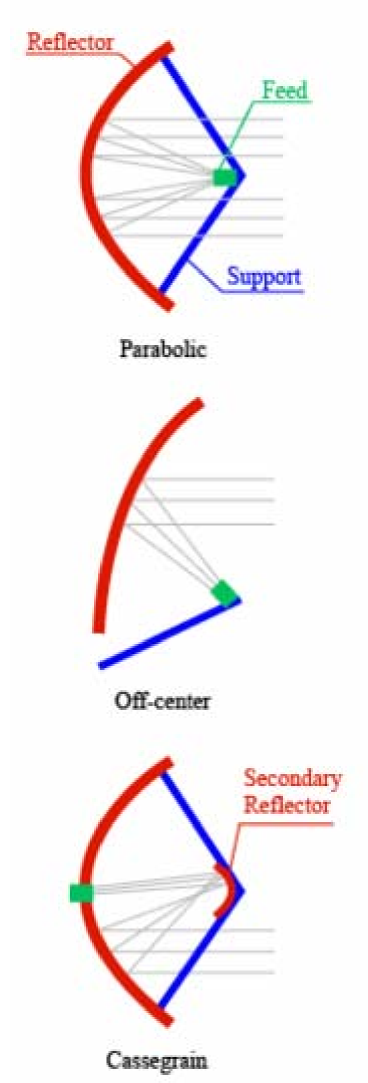
Reber's parabolic reflector is standard in radio astronomy



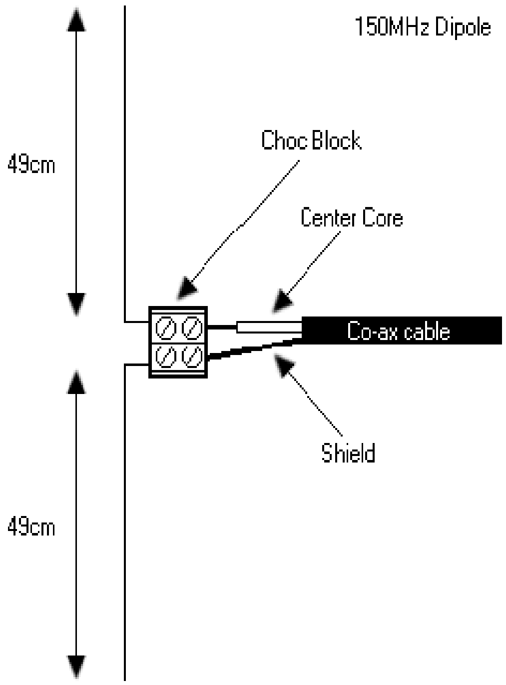


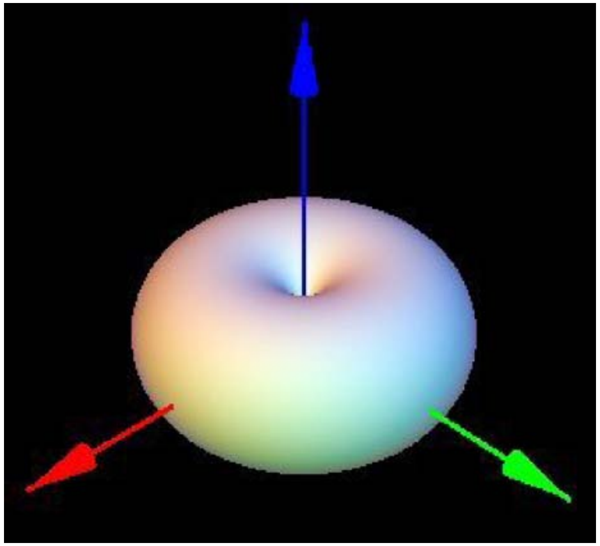
Many radio telescopes (including WSRT) are fed from the prime focus

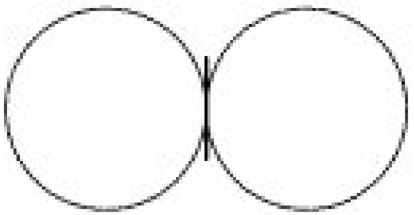
But whether primary or secondary, need to feed dish



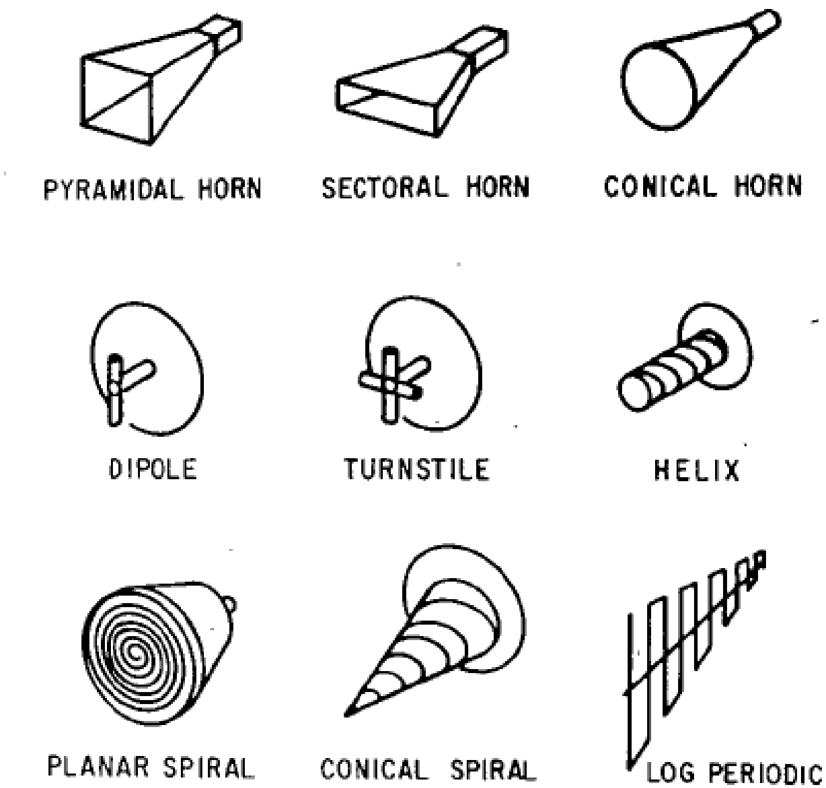
Radiation pattern of simple dipole





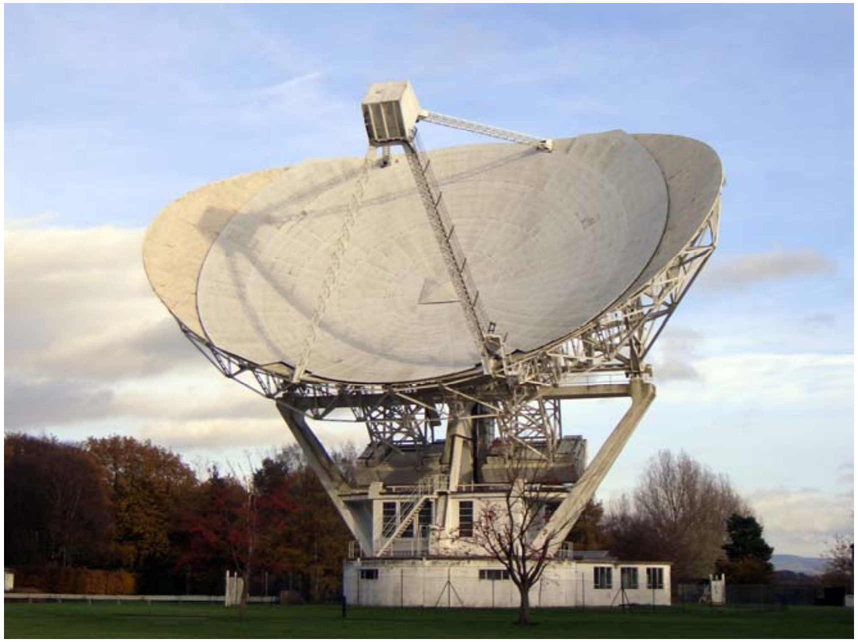


Simple dipole is not a good way to feed a large reflector



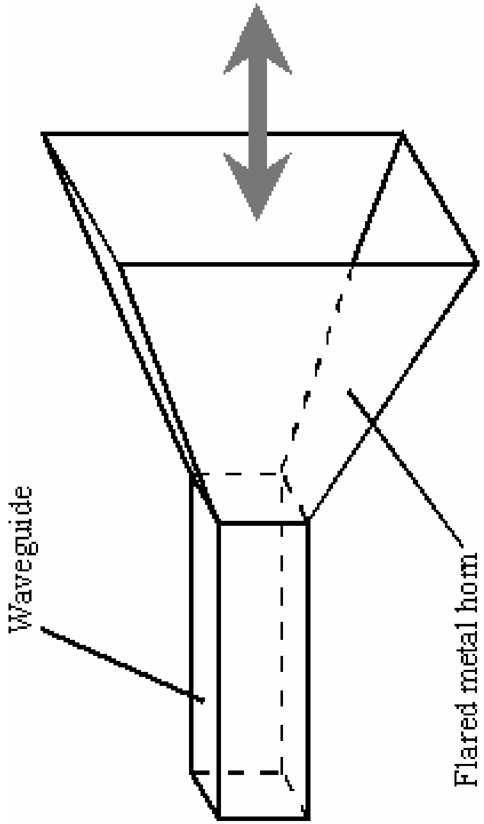
Elongated horns can feed noncircular dishes

- The Mark II telescope at Jodrell Bank
- Elliptically shaped surface, 125’ × 83’4” (for historical reasons)
- Horn can produce illumination pattern which is well matched to dish

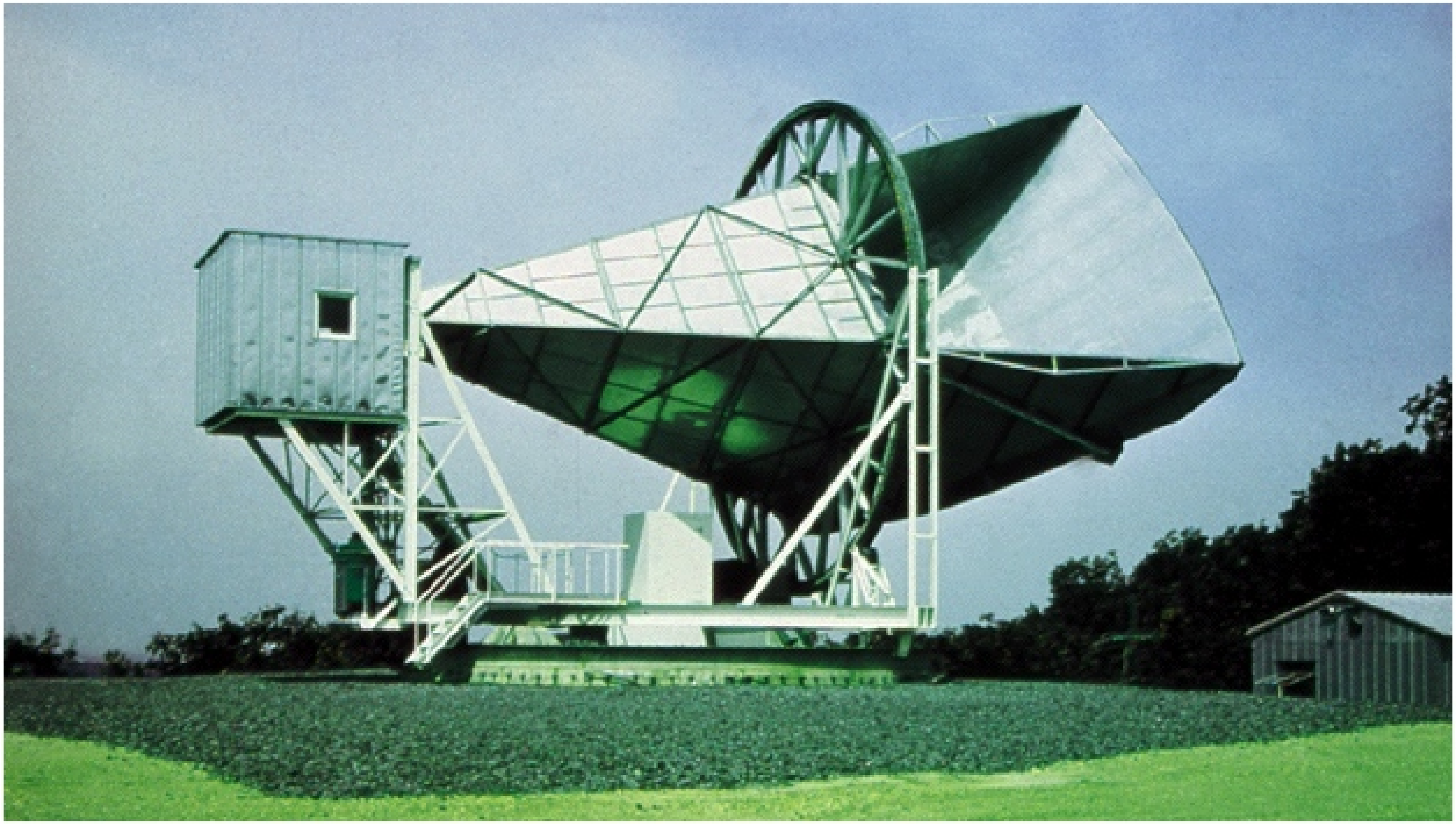


Characteristics of some feeds

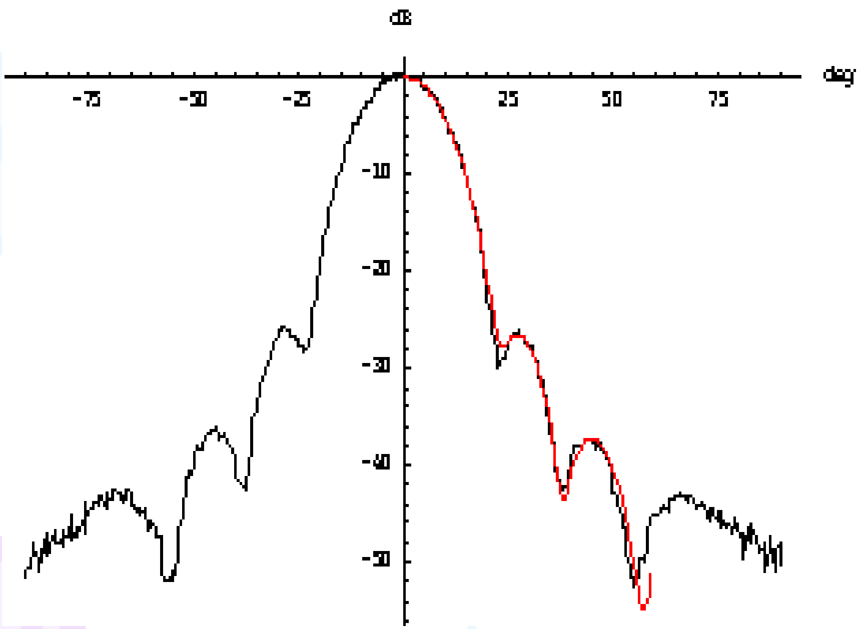
- Horns can be readily attached to wave guides (low loss, but too large for low frequencies: size ≥ λ)
- Dipole patterns can be improved by adding a reflector plate
- Helical feeds give circular polarization
- Log-periodic feeds can cover a wide range of wavelengths

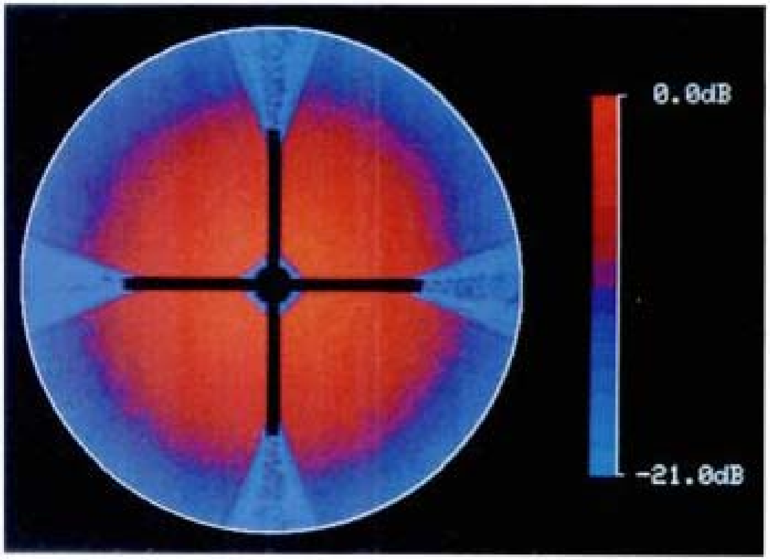


Horns can also be used by themselves (though unusual)



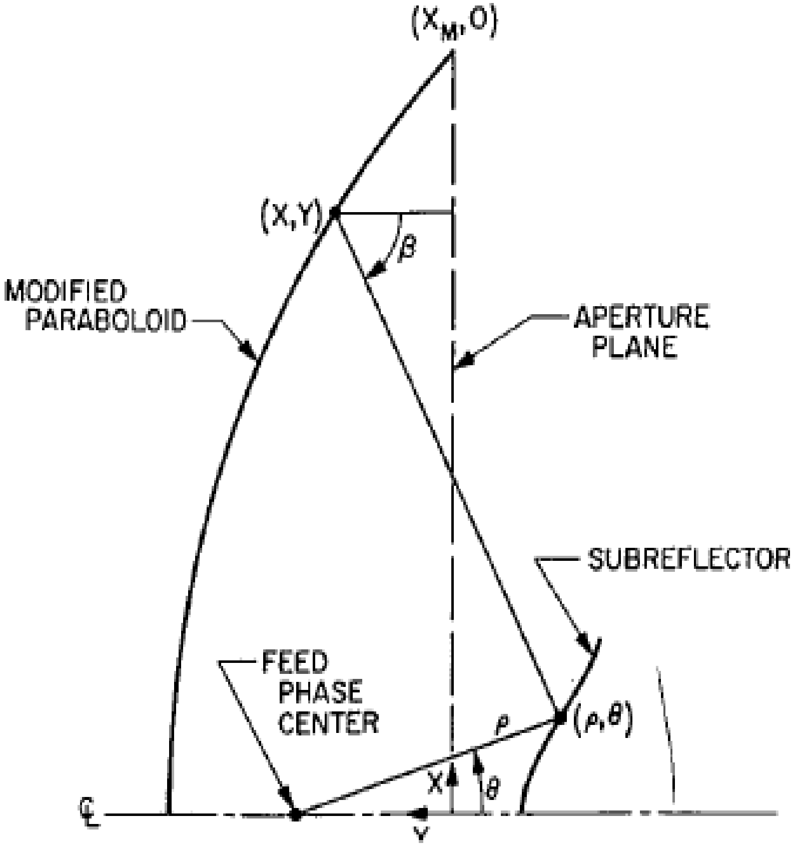
To minimize spillover, and because of geometry, edge of dish under illuminated



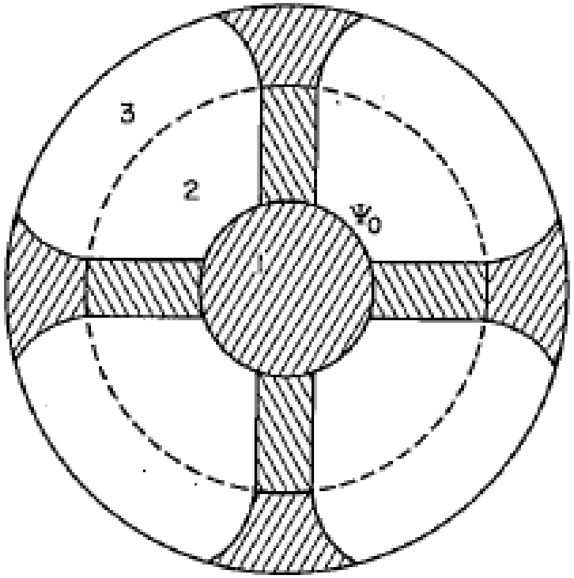


For this reason, “shaped dish” was invented

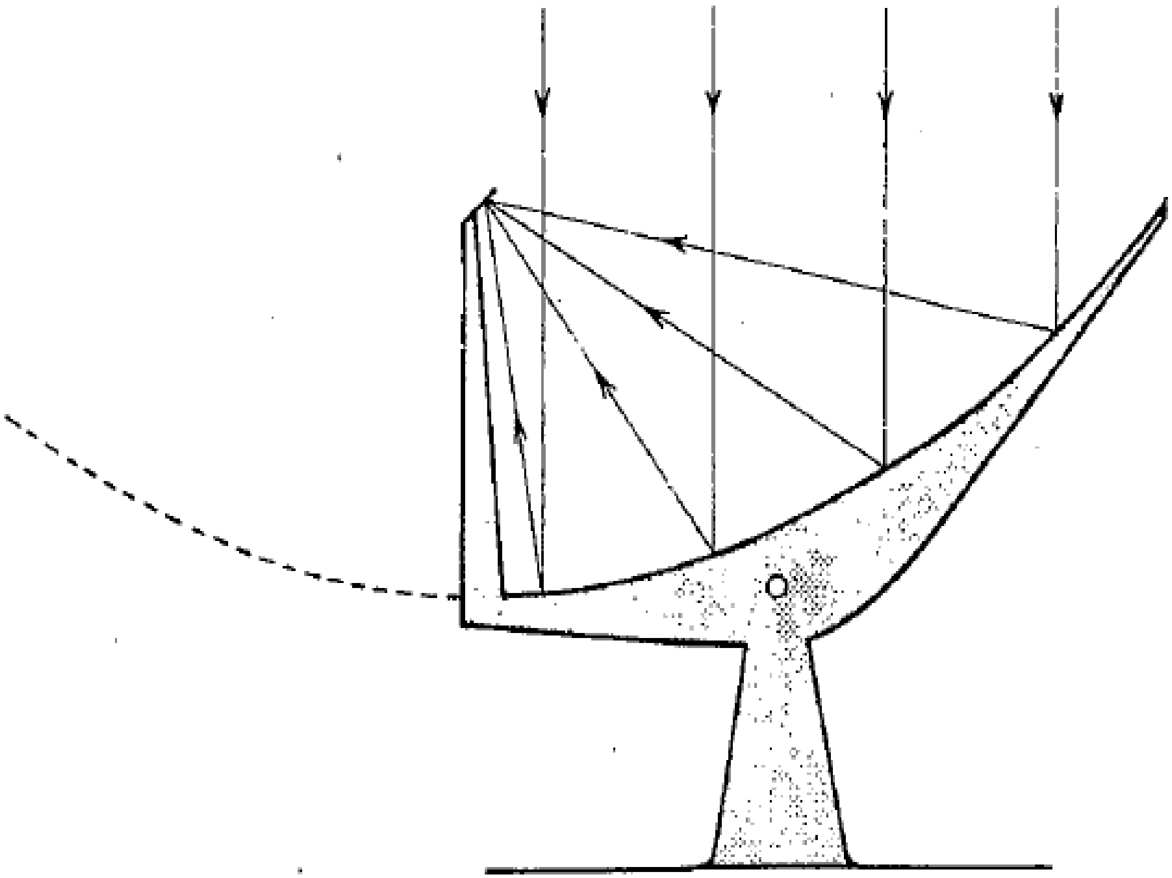
- Shaped dish deviates from a paraboloid
- Secondary reflector is shaped to increase radiation reaching outer part of dish
- Primary shaped too
- Can raise efficiency from ~55% to >70 %



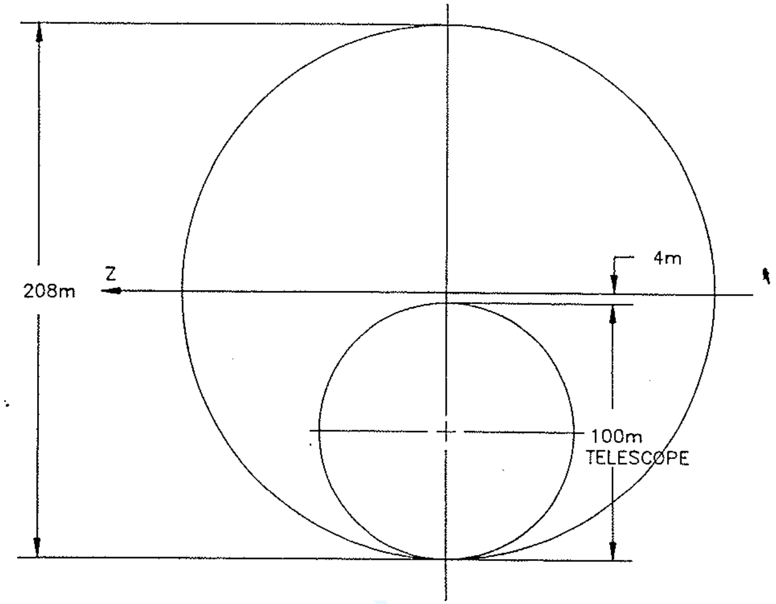
Feed or secondary support blocks some of the radiation



To get around blockage, offset designs can be used



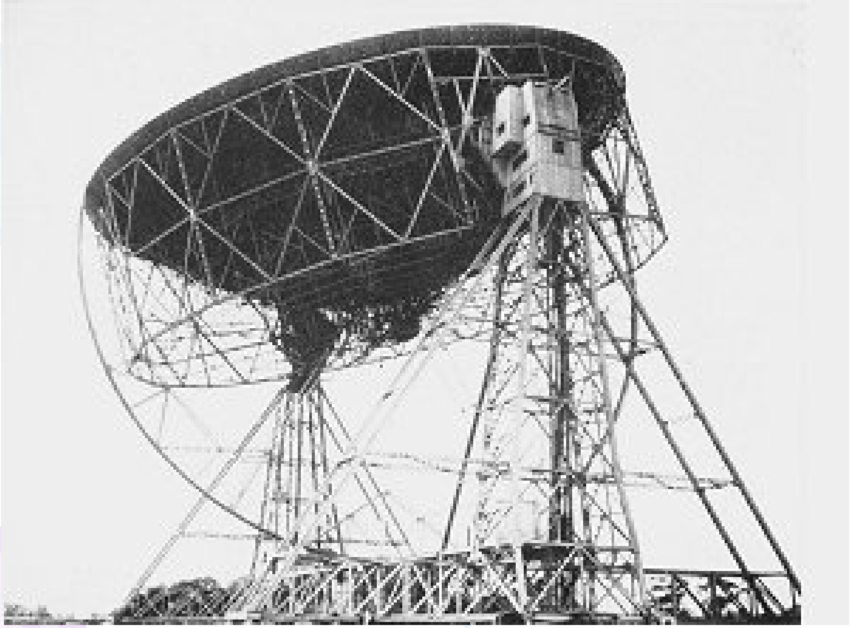
The 100 m Greenbank Telescope (GBT) uses this idea

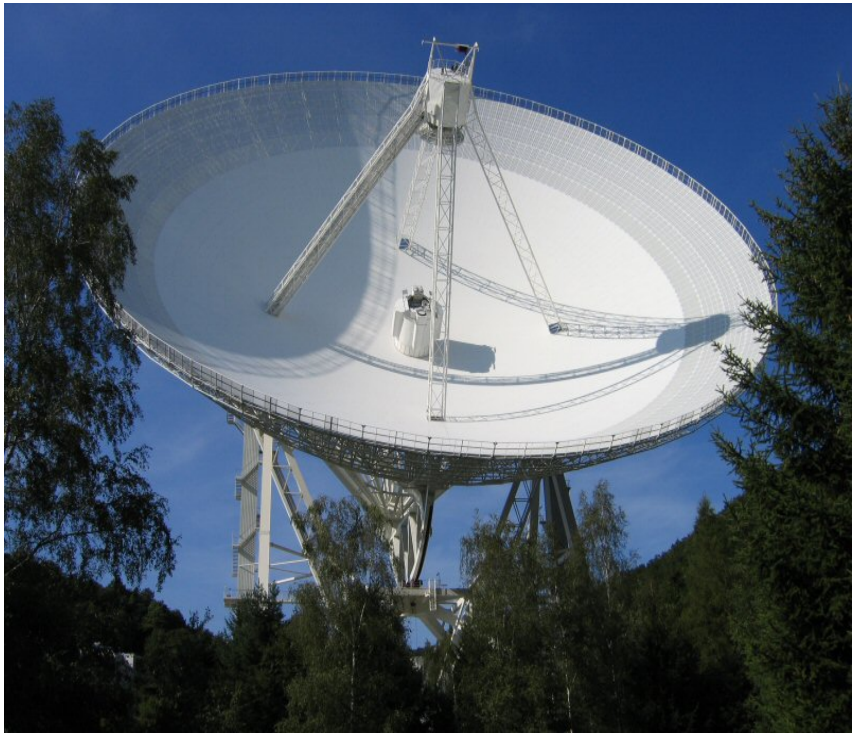


However, GBT was expensive!

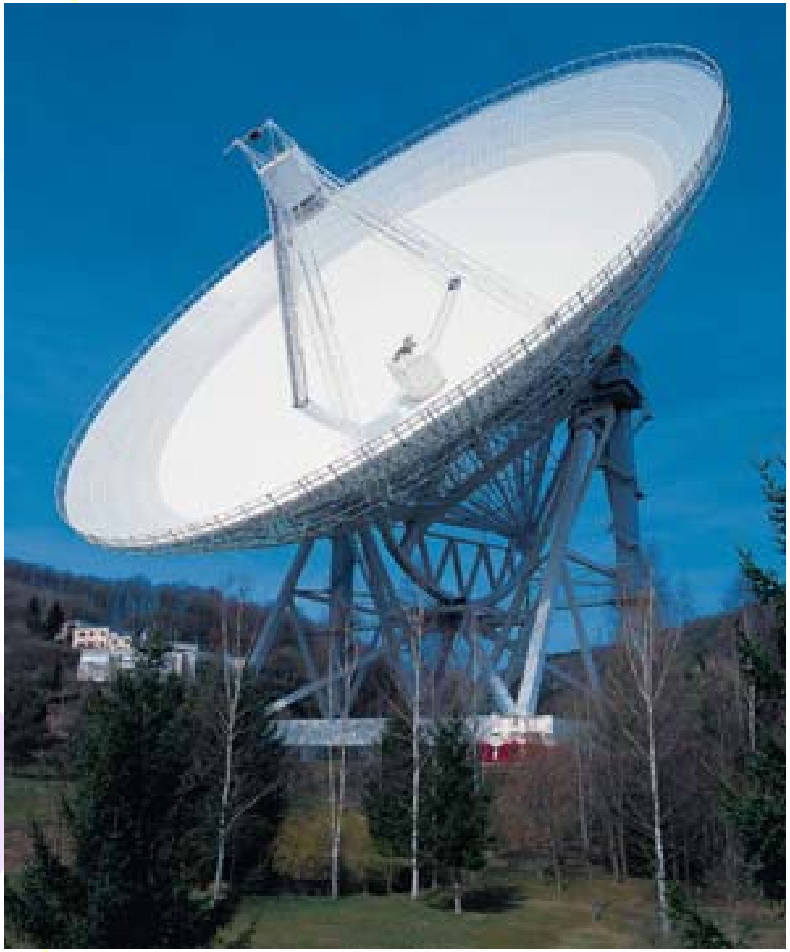
- The cost of large reflectors is mainly determined by the need to move a large structure with tiny allowed distortion
- There are several solutions which have been pursued
- One is to ensure parabolic shape is always maintained, despite distortion
- Another is to keep the reflector fixed

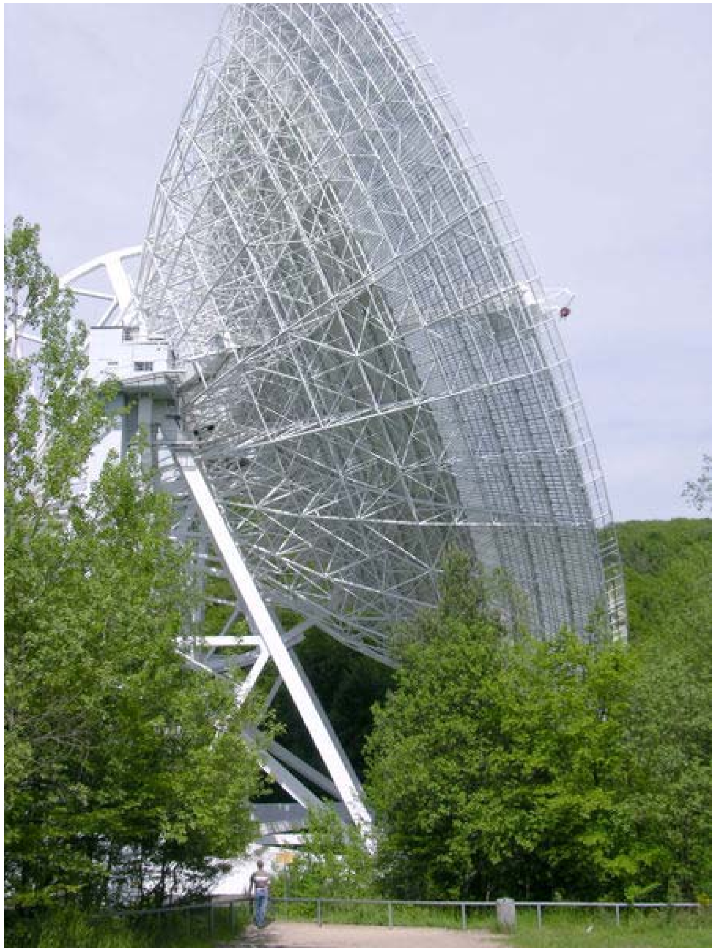
Jodrell Mk I (76 m), 1956 & Bonn 100 m, 1970



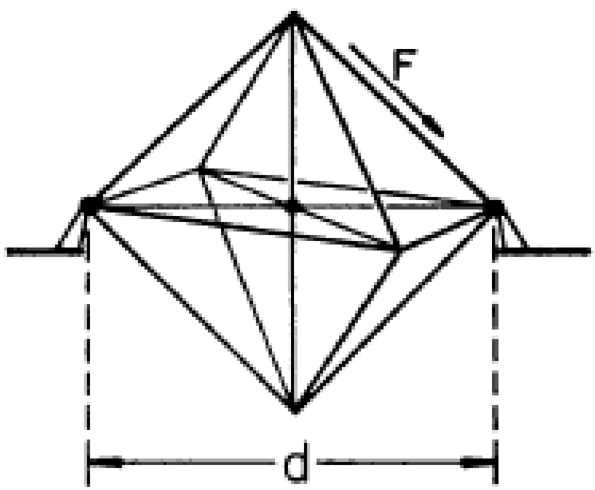


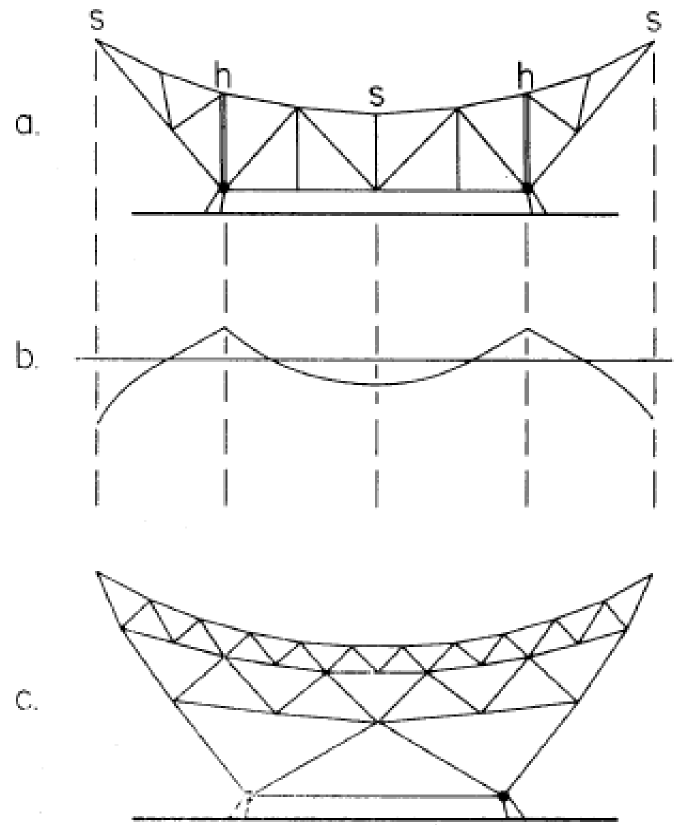
Effelsberg, first large antenna built using homology principal





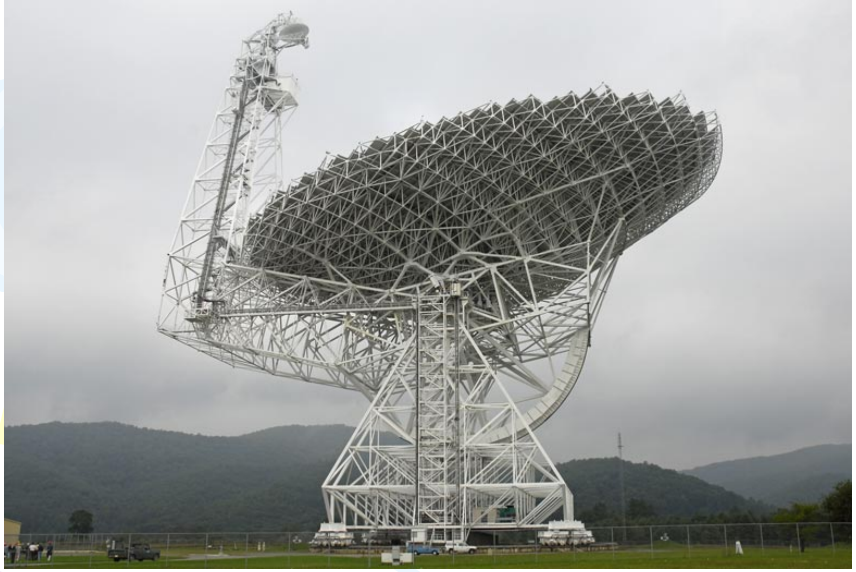
According to Von Hoerner, best geometry is octahedron. And backing structure should not be too rigid.





All the supporting forces brought to a single point

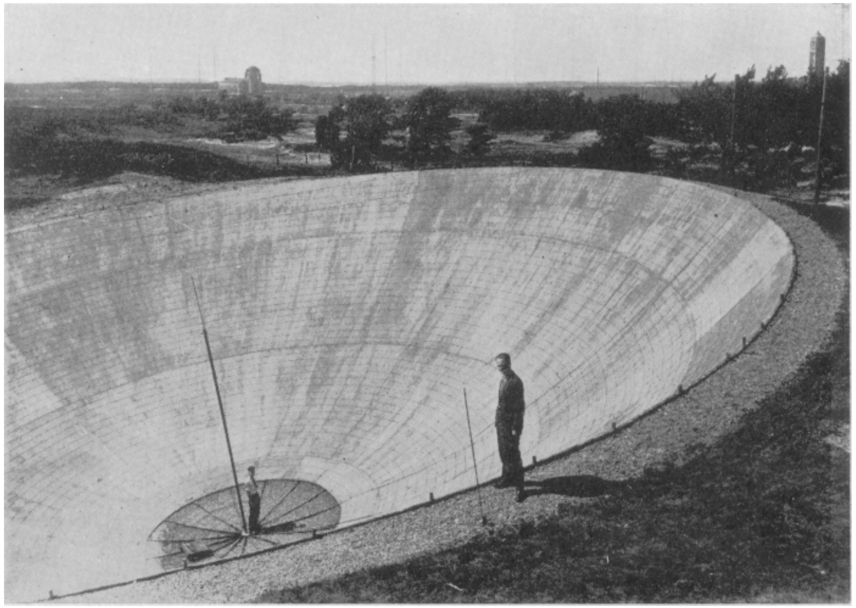
GBT also uses homology principal



And actuators to adjust an active surface

In early days, several fixed reflectors, as Jodrell 218 foot

In Holland, a 30 m reflector in ground, tilted 10º south

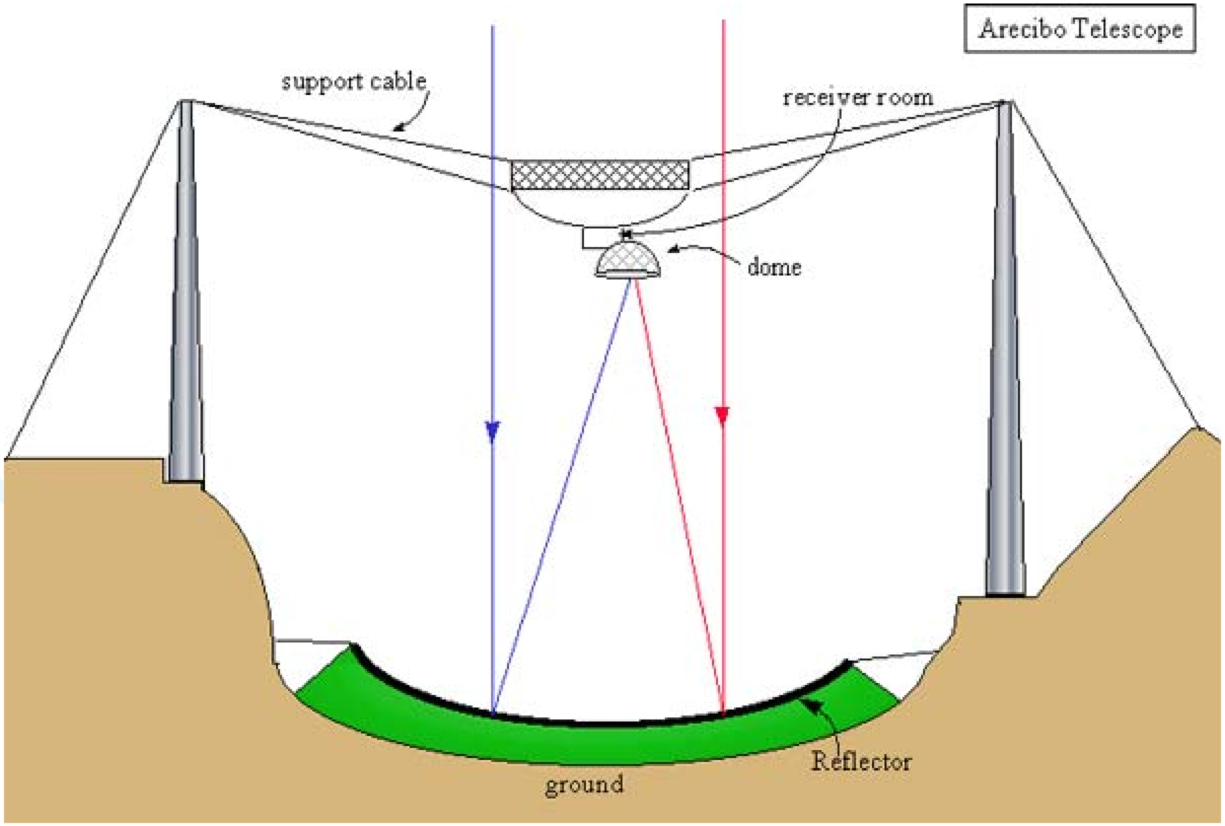


Sydney, Australia, 22 m "hole-in-ground" reflector

- These early fixed dishes were all of parabolic shape
- Beam could be moved a bit, with loss of gain
- Scientifically, Jodrell and Sydney were the most productive

Arecibo was built in a natural depression (karst sinkhole)

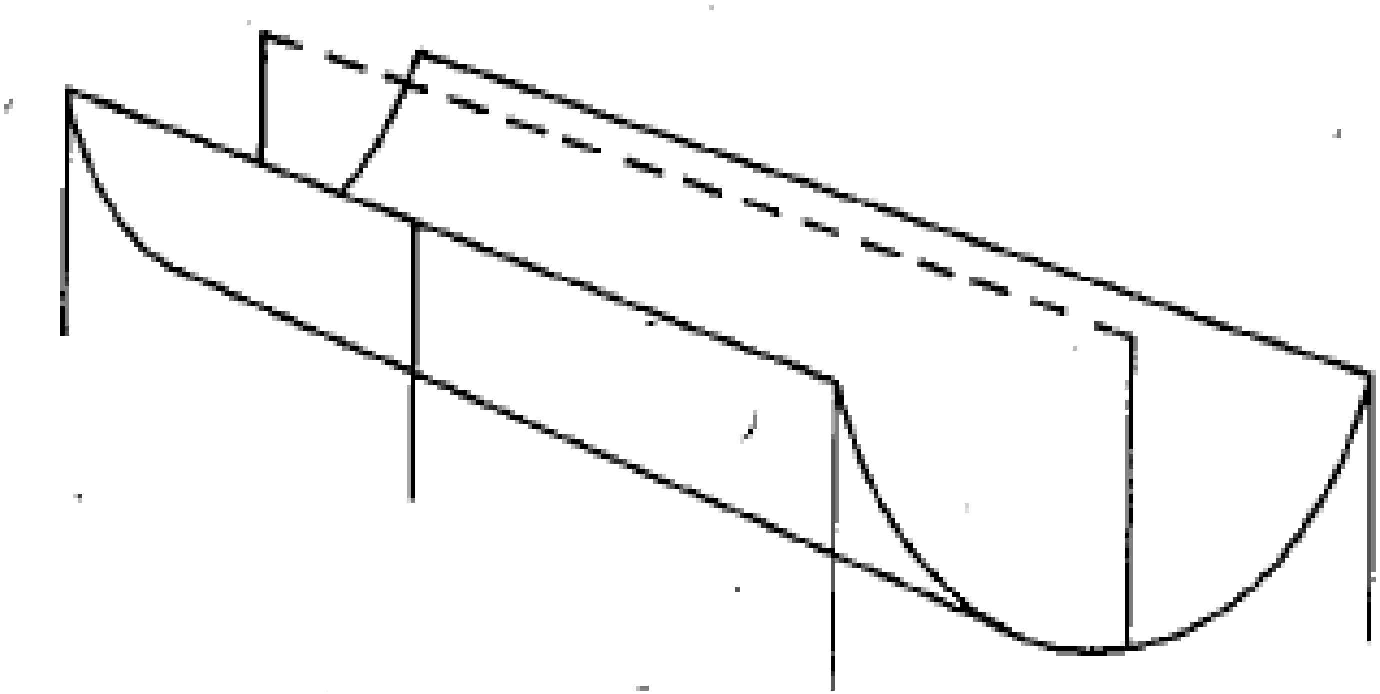
The Arecibo geometry: spherical reflector allows beam to be pointed ±20° from vertical



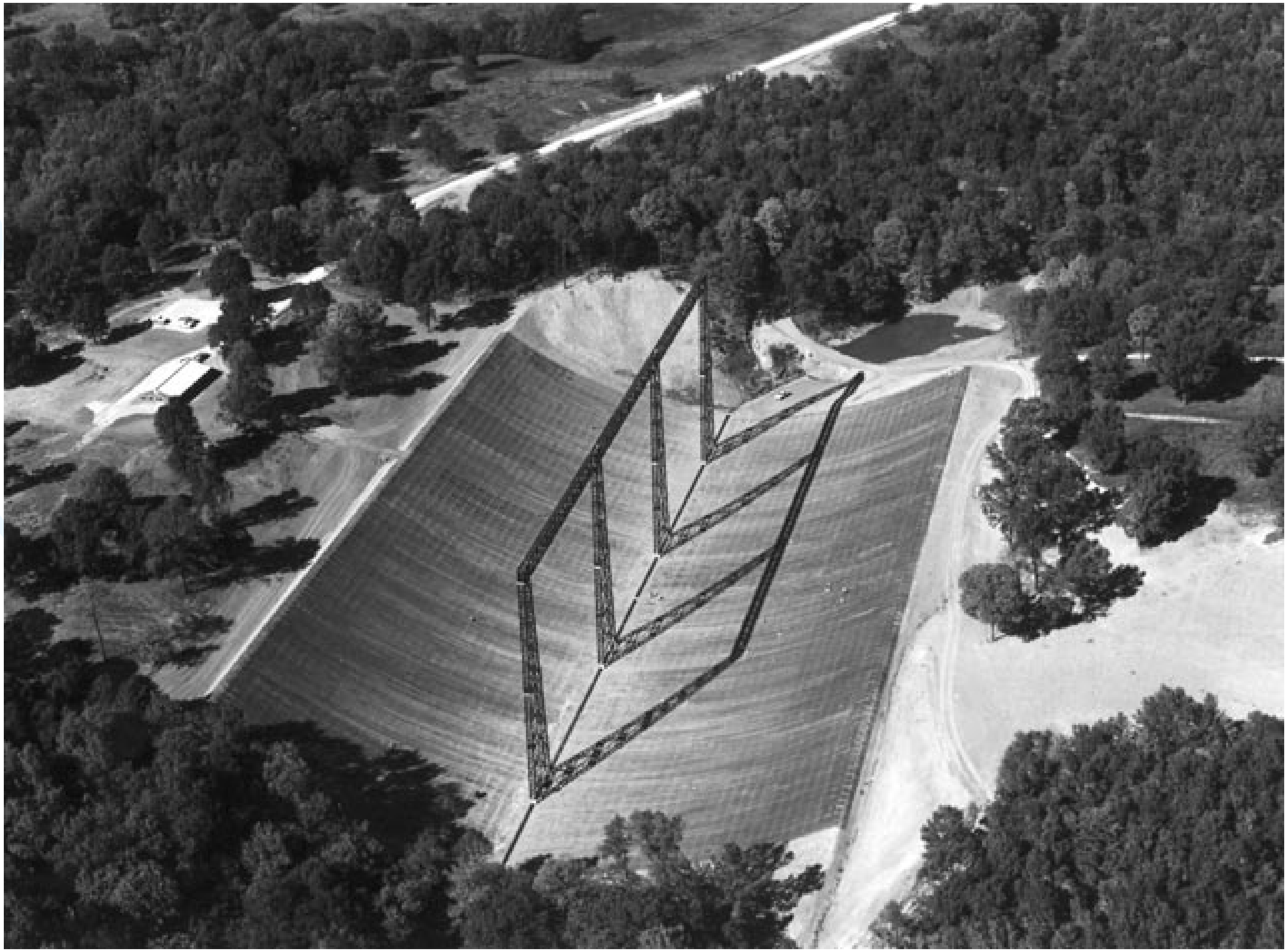
How the dish is fed from the focal line

And the reflecting surface (from underneath)

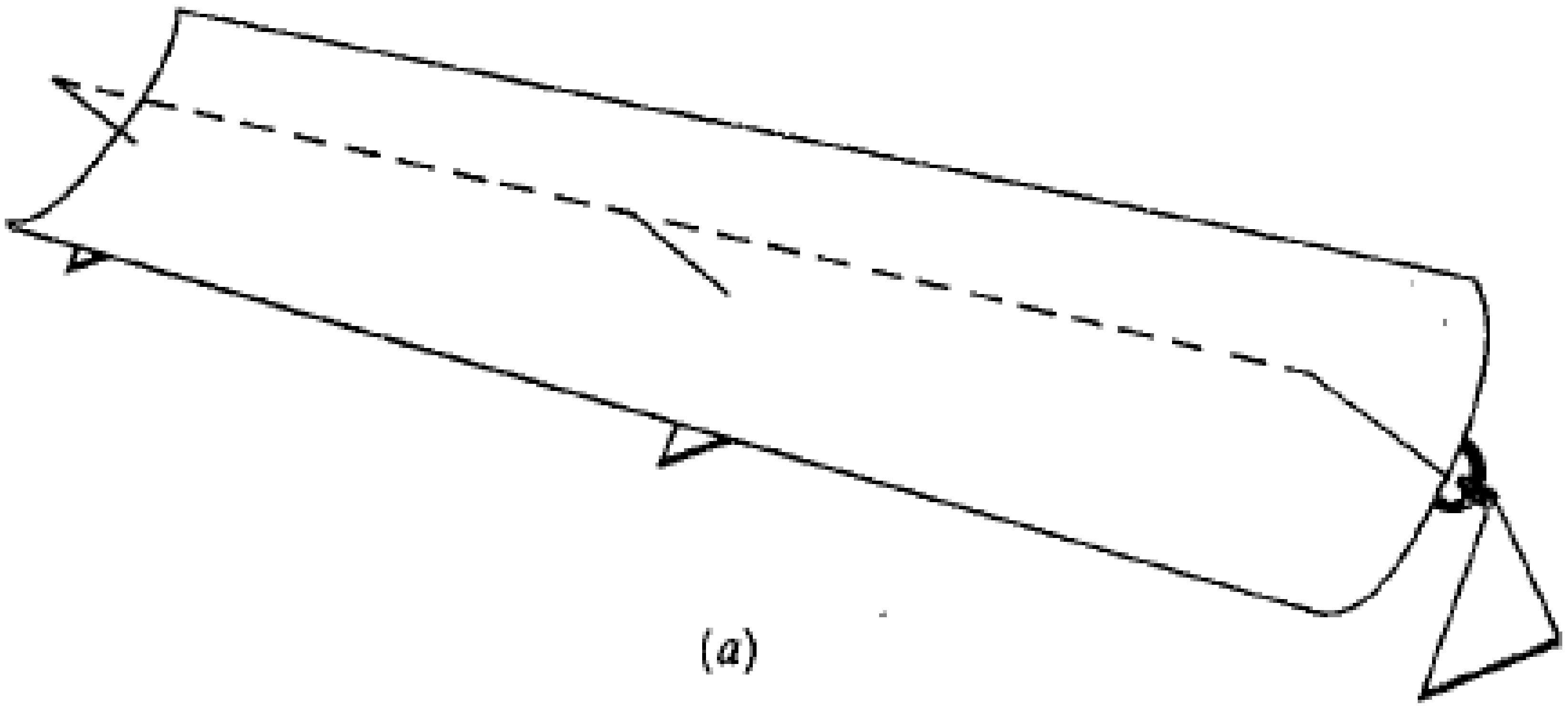
Another idea: cylindrical paraboloid, line focus – electronic steering



Vermillion River Observatory: used natural valley, transit telescope



Cylinder can also be made so it can rotate



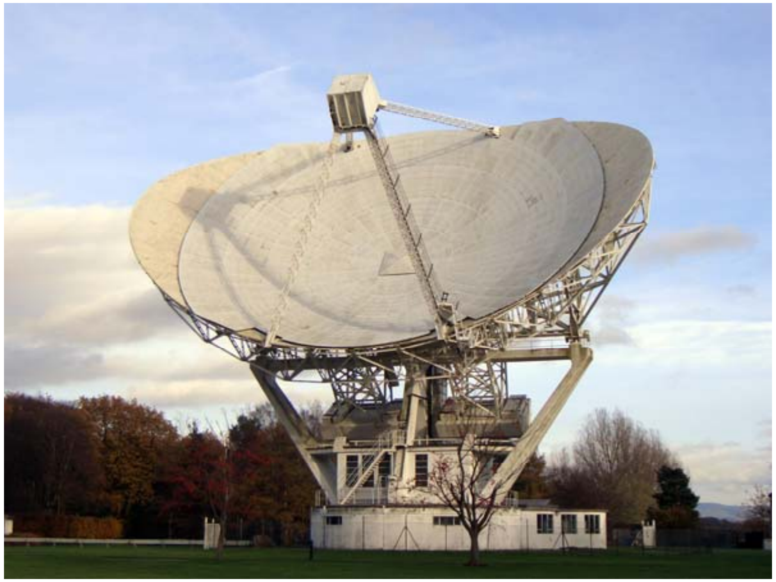
(a)

Used in Russian steerable parabolic reflector, operating from λ 2.5 - 10 m

One arm of cross antenna: Molonglo (1.6 km long)

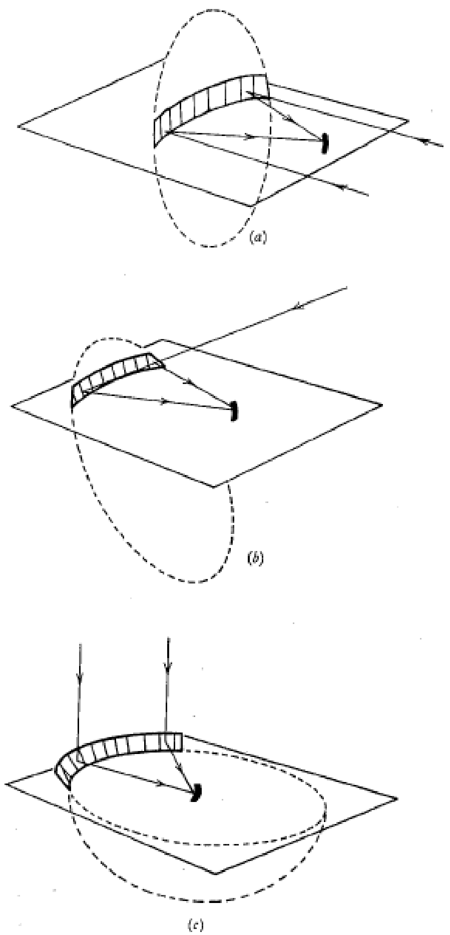
Actually, reason for Jodrell Bank Mk II's elliptical shape was...

- Lovell's engineer Husband thought he could get a larger area for the same money by making the reflector long and thin
- Not very successful (see new circular surface), though his idea was used in other instruments

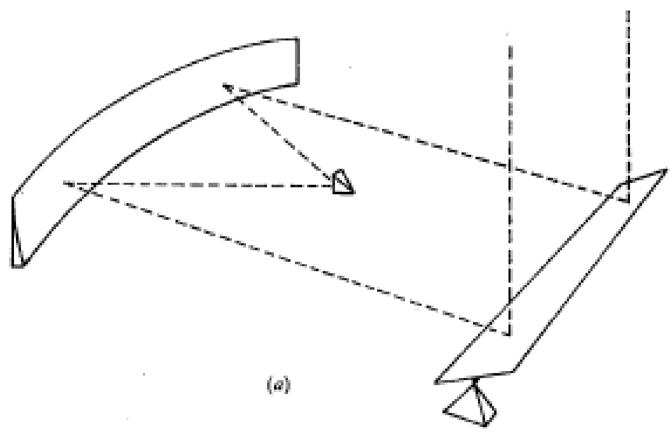


One can also use different sections of a parabolic surface

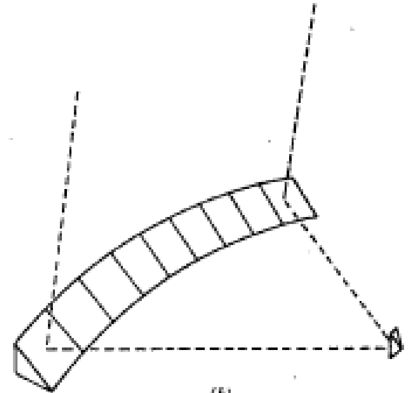
- This is principle of Kraus antenna
- To steer beam, may need movable reflector
- However, easier to keep flat mirror from bending
- Used in more general way in Russian telescopes



Two possible solutions to the beam steering problem

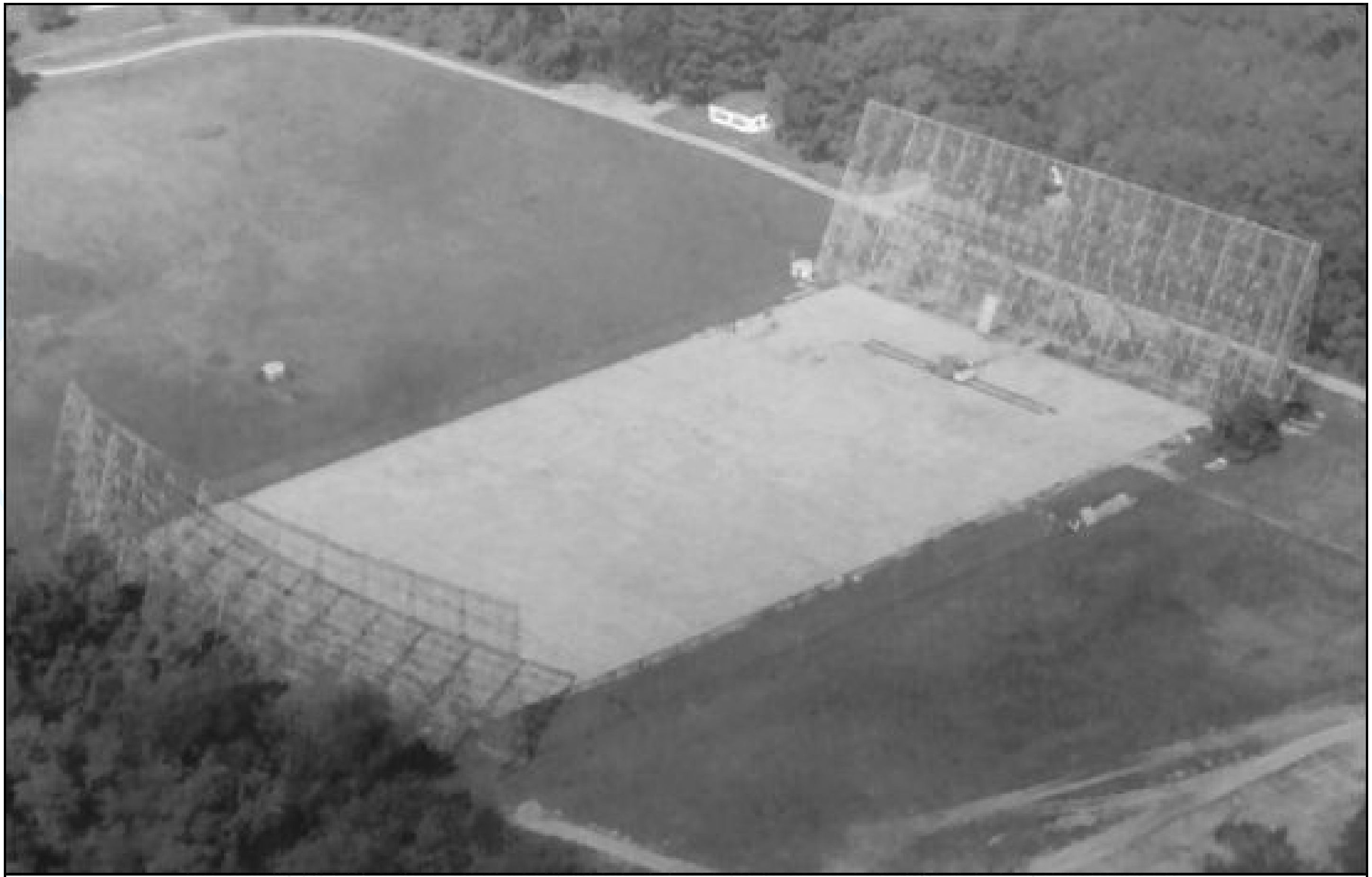


(a)



(b)

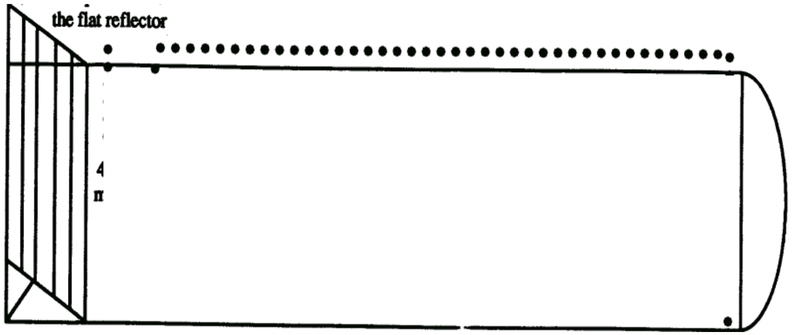
Large telescope ("big ear") built by John Kraus in Ohio

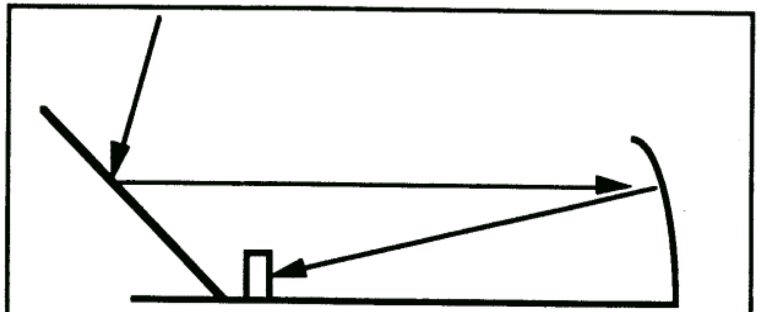


BIG EAR RADIO TELESCOPE (OHIO STATE UNIVERSITY)

How the Kraus design works

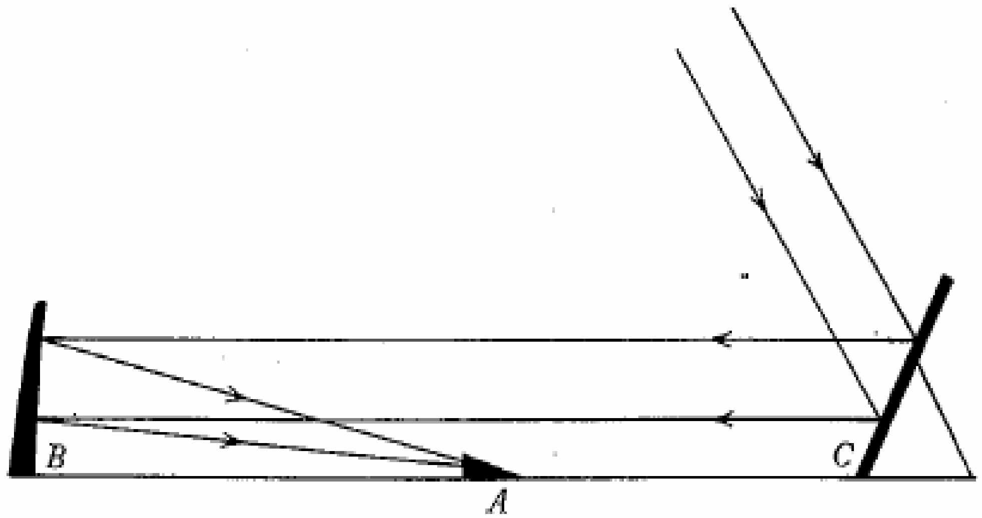
- Fixed parabolic mirror at one end (right) concentrates radio waves at focal point near the ground
- Tiltable plane mirror (left) directs radio emission from point on sky to parabola
- Rotation of the Earth provides sky coverage



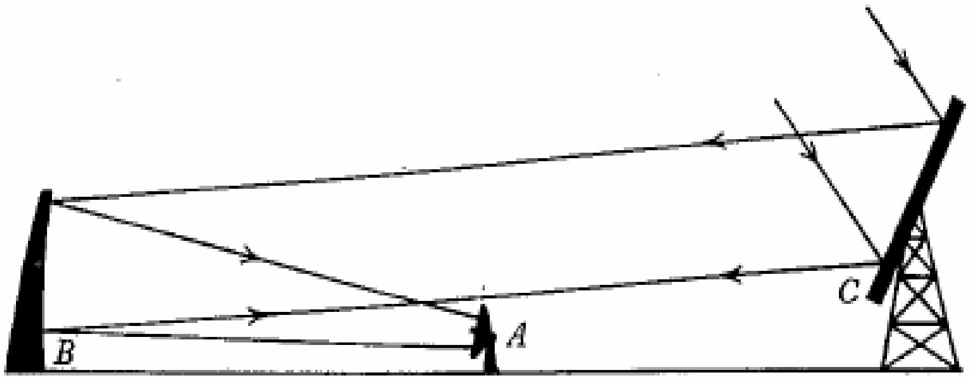


The signals from space are first reflected from the large flat reflector to the curved parabolic reflector. The curved reflector directs the signal to the movable feed horns where the signal is then transmitted to the underground focus room and is recorded on the computers.

Two different approaches



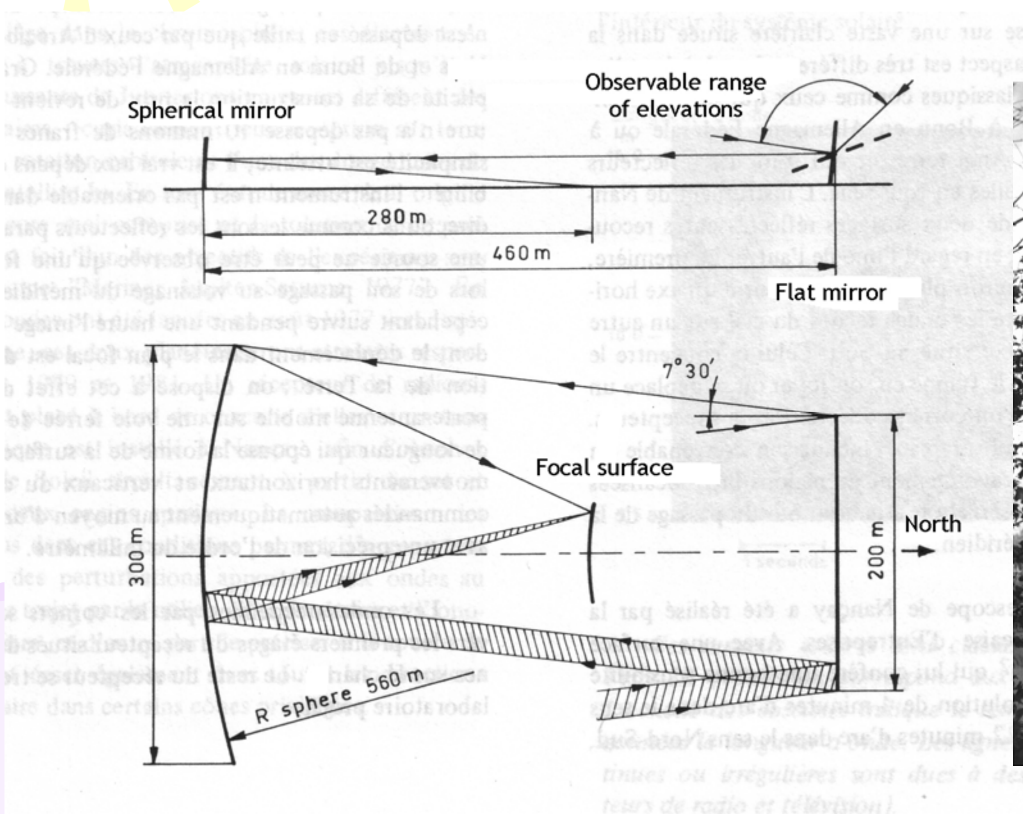
(a)

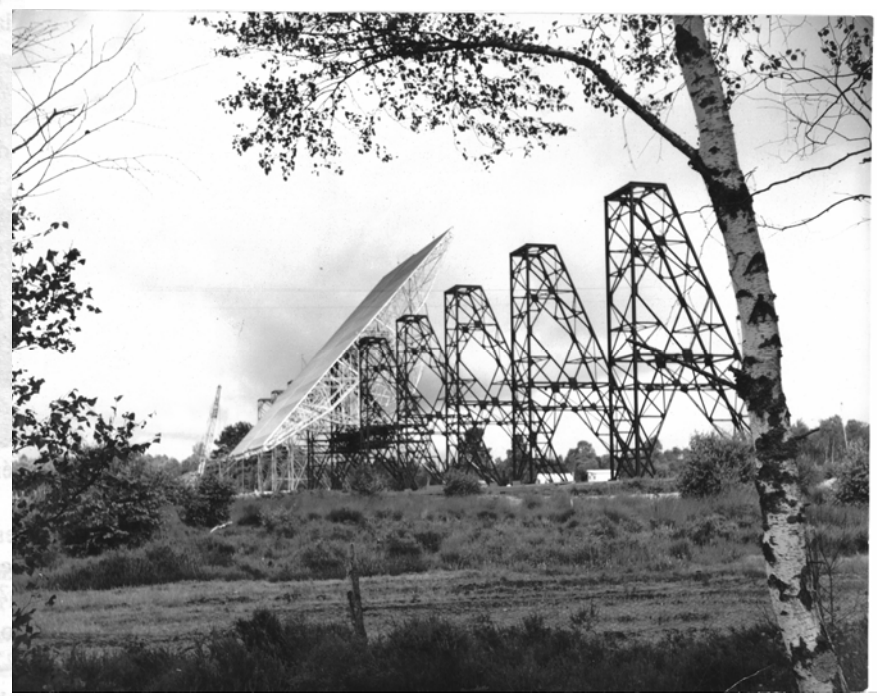


(b)

Nançay, France, the largest Kraus-type antenna

Nançay geometry, and a limitation: foreshortening of the tiltable reflector



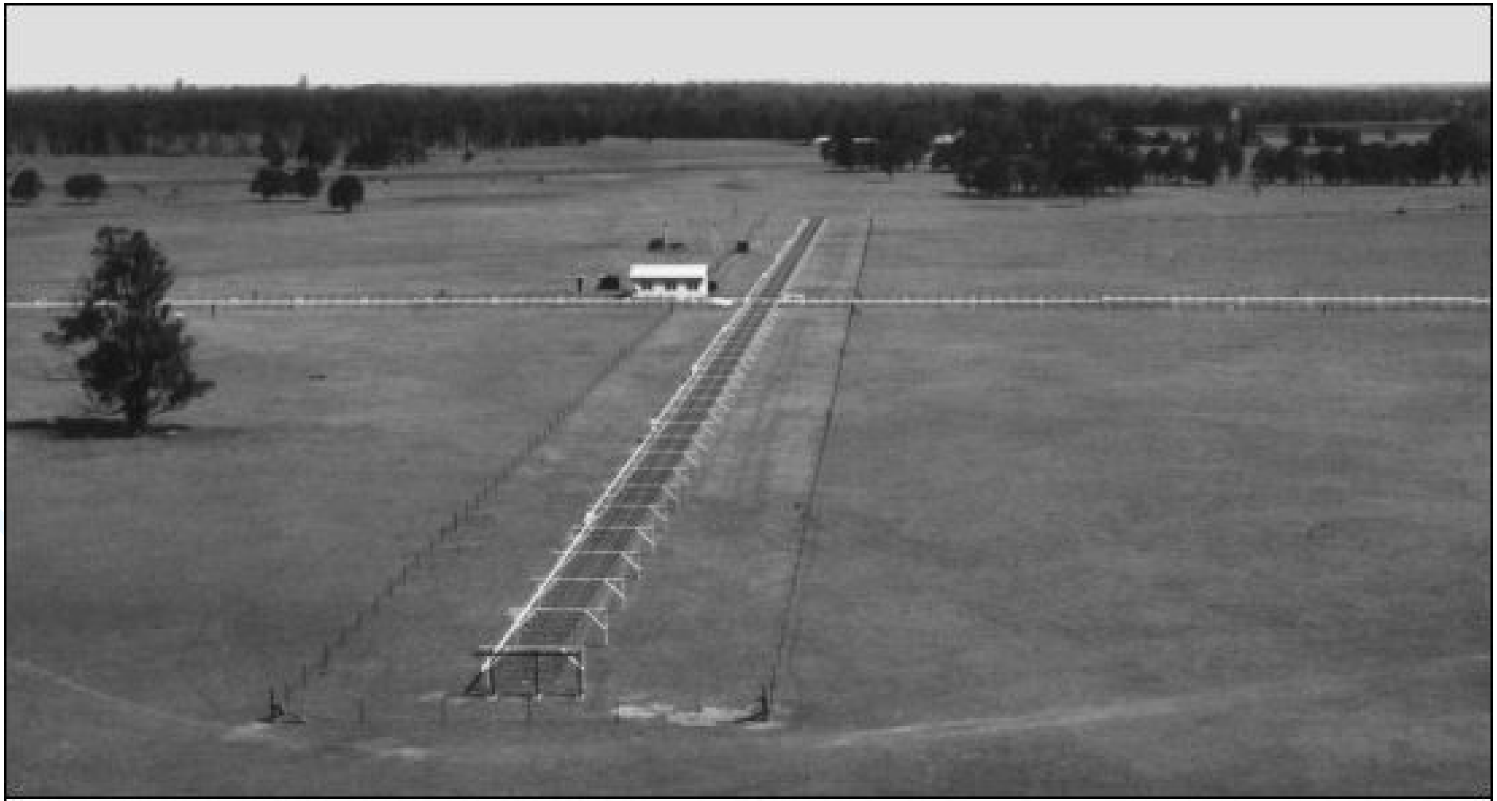


Pulkovo – tiltable reflecting elements, parabolic section

RATAN 600 – circular section

Secondary reflectors of RATAN 600

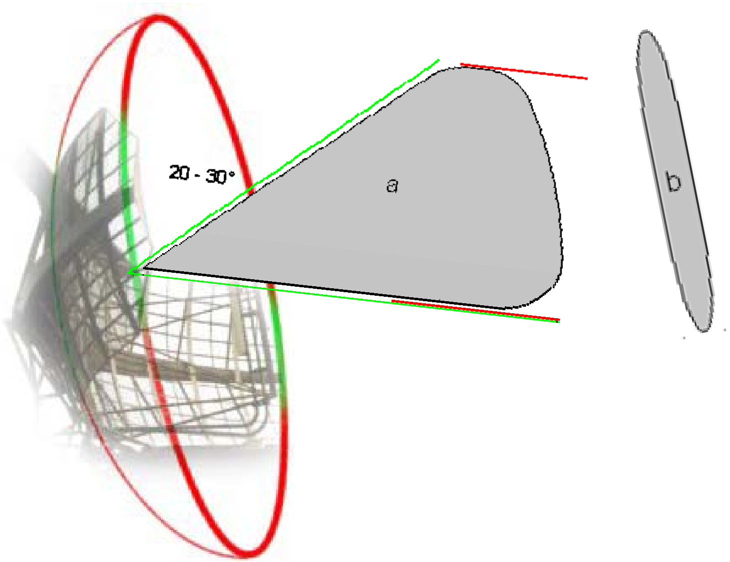
Original cross antenna of Bernie Mills in Australia

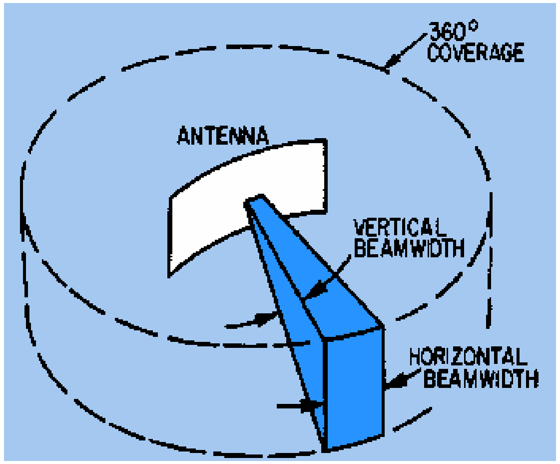


MILLS CROSS (CSIRO)

How does a cross antenna work? First, narrow antenna & its "fanbeam"

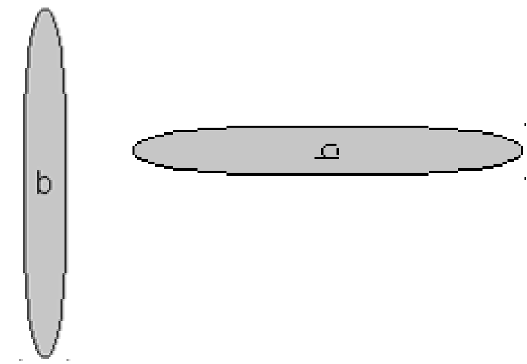
- If instead of building an entire parabola (red) we only build a narrow section (green), we get a beam narrow in the antenna's wide direction, and broad in the other
- The fanbeam shape is shown relative to antenna
- The beam size in each direction is just given by wavelength/diameter

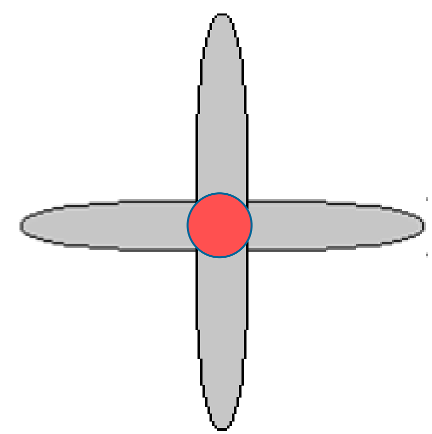




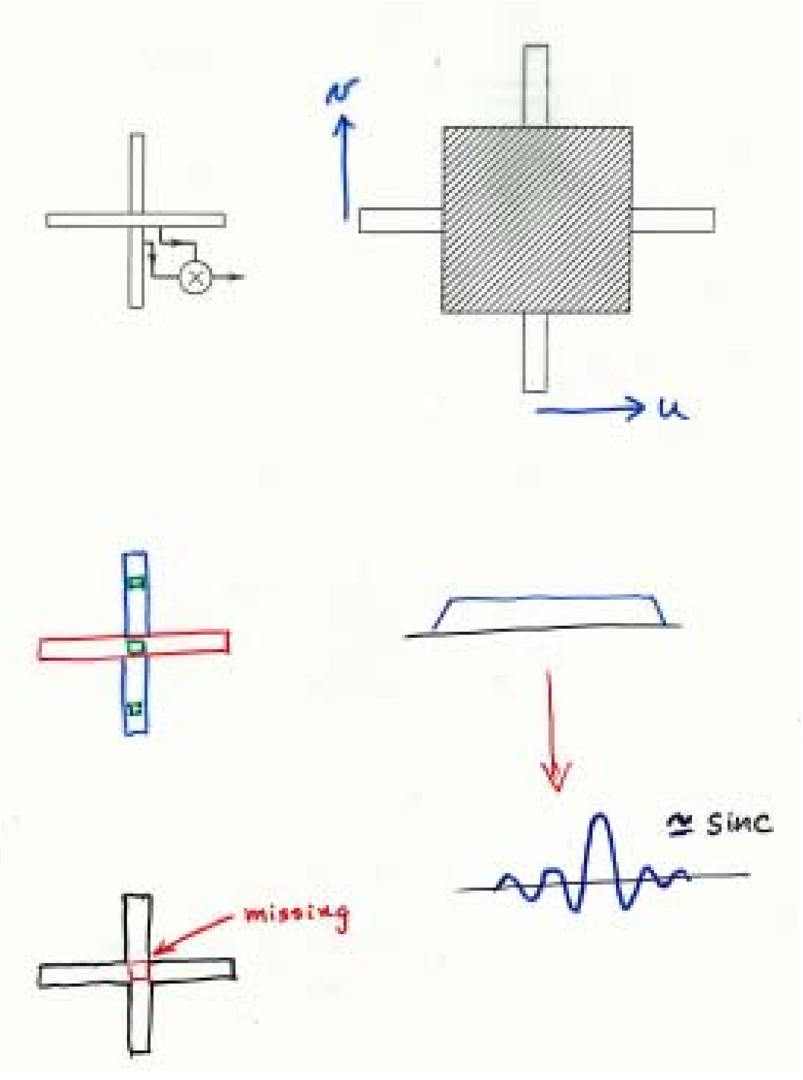
By observing a source twice with orthogonal beams, can get 2-d image

- We could first scan the sky in one direction...
- ...then rotate the antenna and scan in the orthogonal direction
- But we could also combine two crossed antennas
- Their response is similar to the crossing point of the two beams

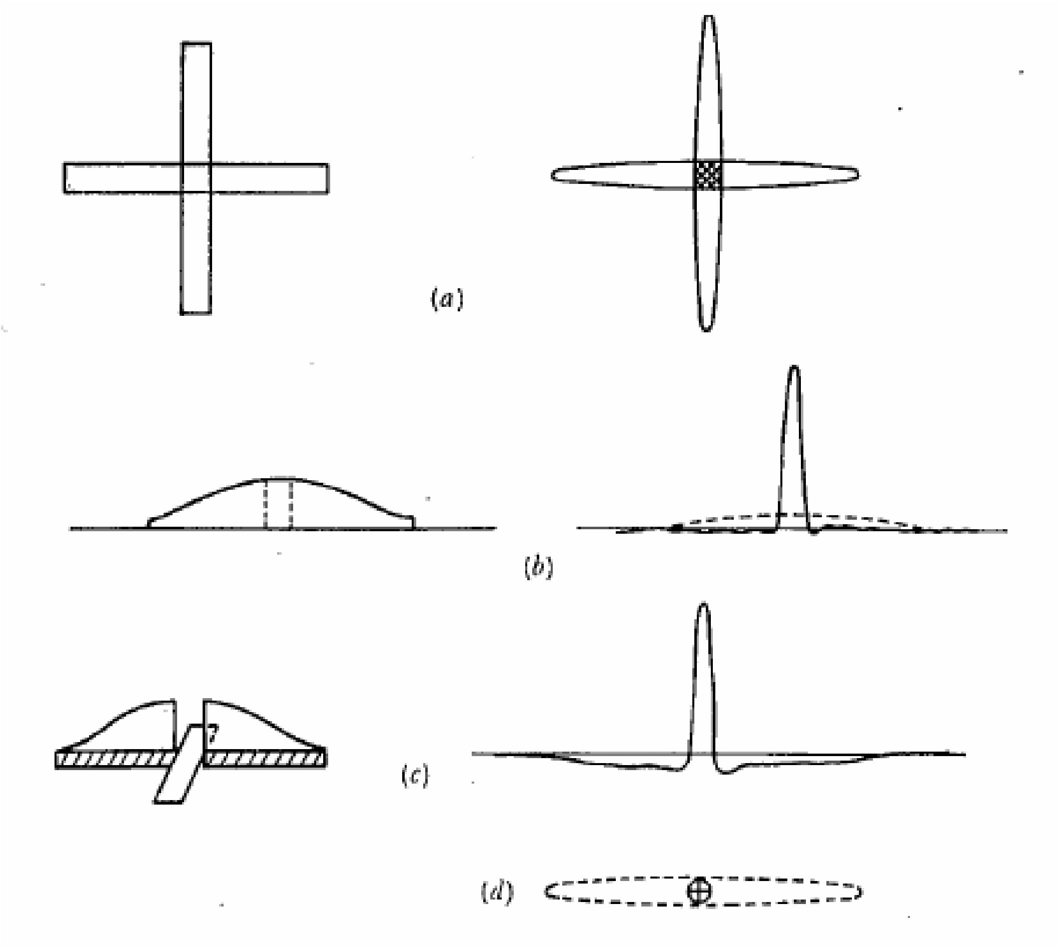




We cross-correlate each arm of cross – square in visibility plane

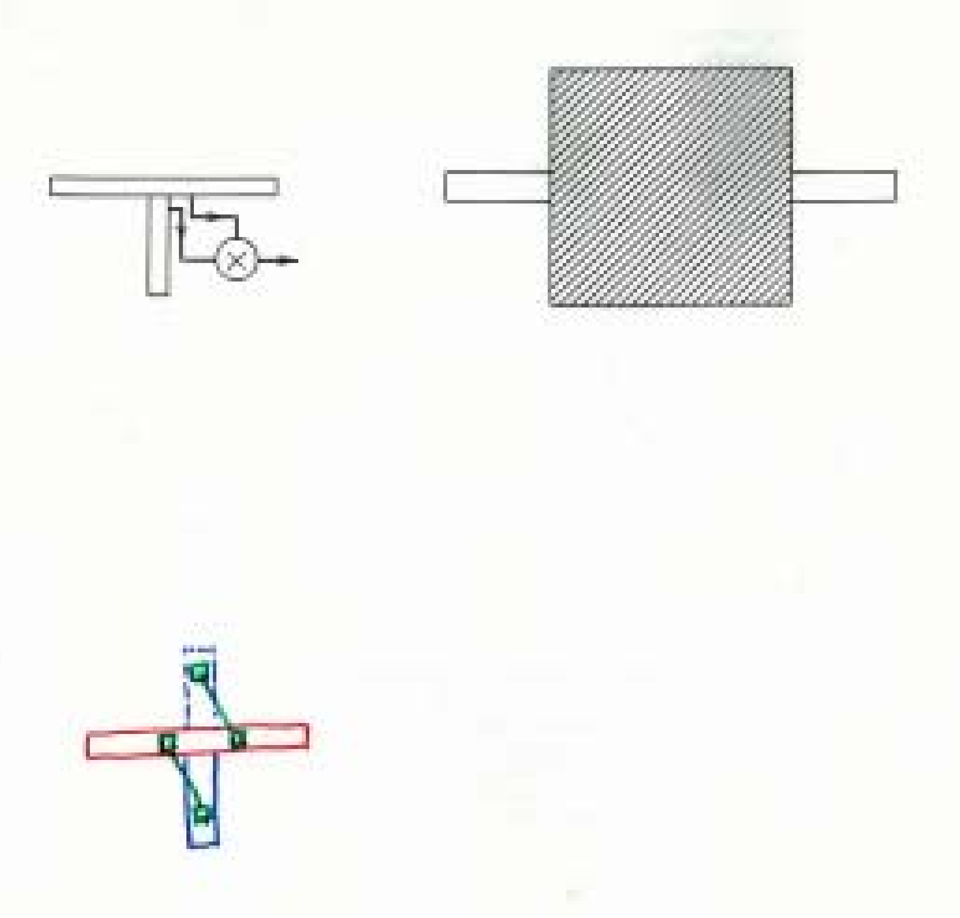


A problem with cross antennas: sidelobe responses



Later cross antenna: Molonglo (each arm 1.6 km)

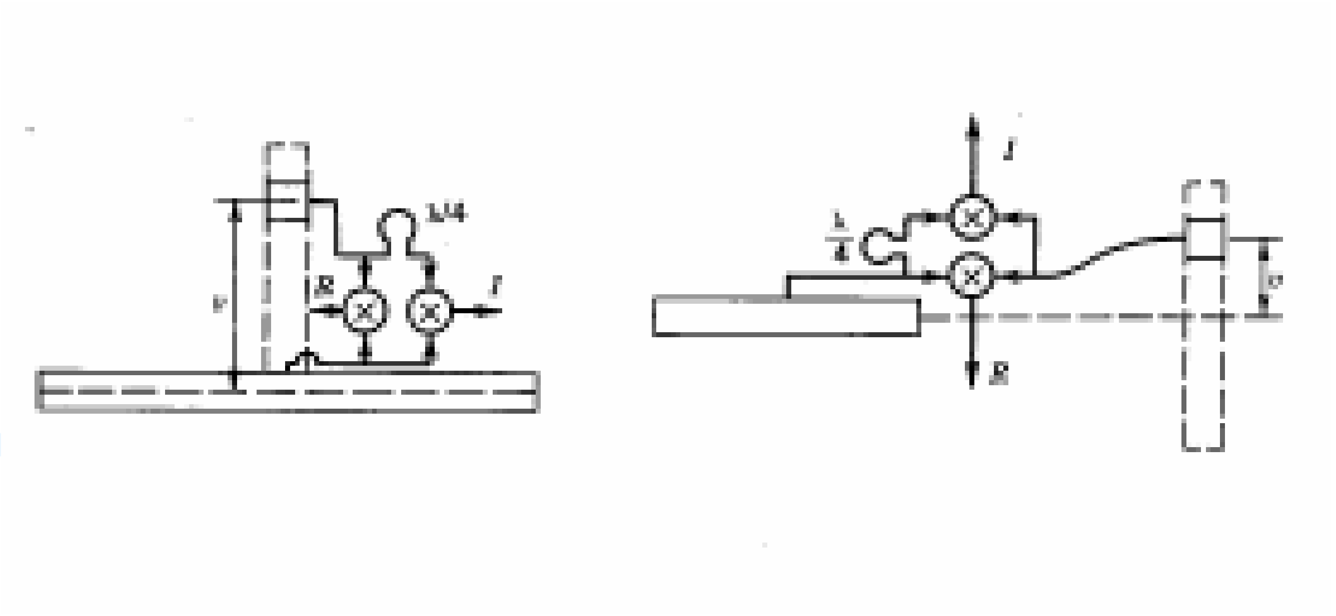
But you don’t even need full cross: a T-shaped antenna will do



Large cross-type 'T' antenna near Bologna, Italy

Details of the Bologna cross antenna

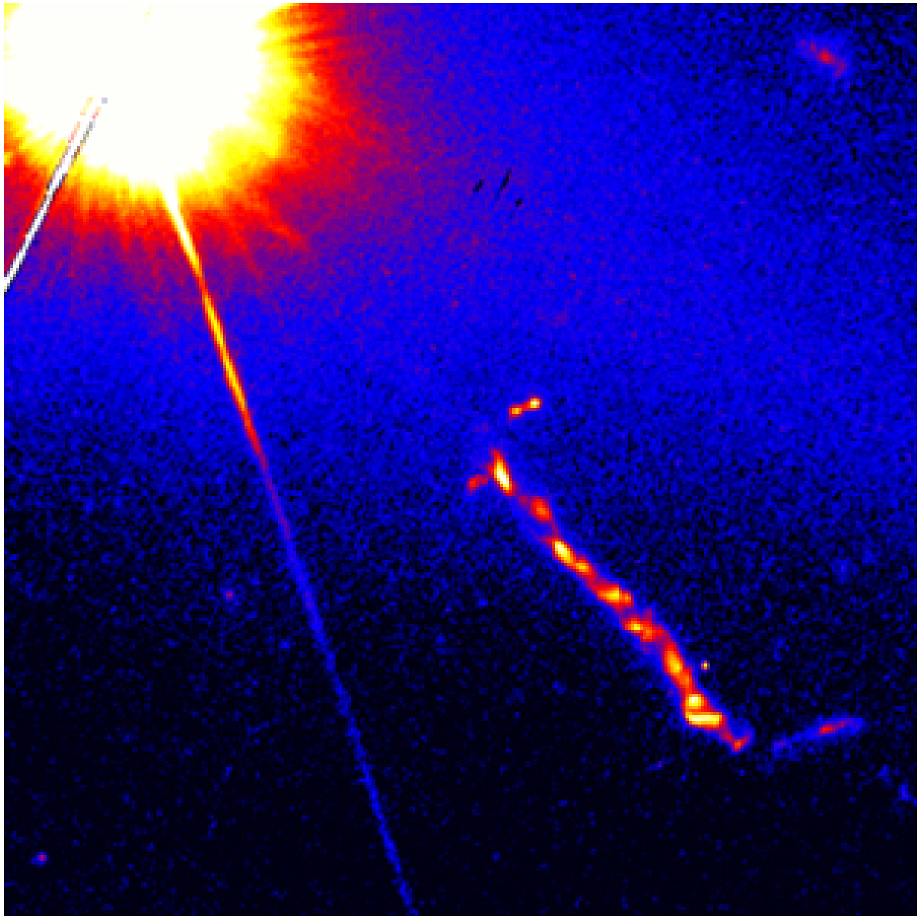
Martin Ryle's solution: use 1 arm & movable element, synthesize



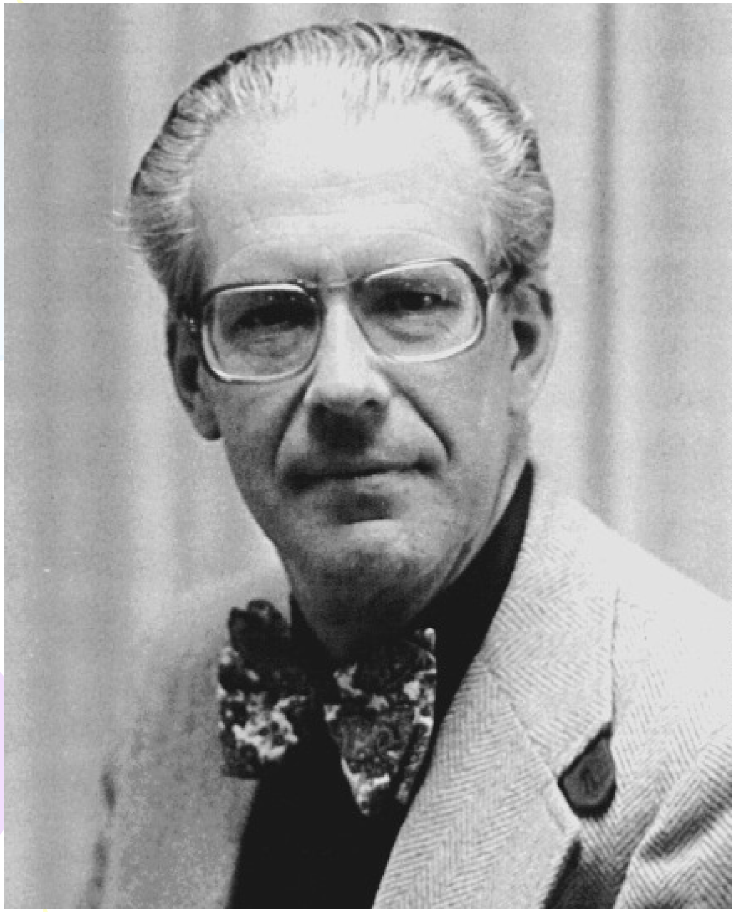
Lunar occultation: another way to get better angular resolution

- Any sharp edge at a distance can be used
- If edge location is known, can determine an object's position by timing when signal disappears
- If object extended, signal disappears gradually – can reconstruct brightness
- First use: quasar 3C 273

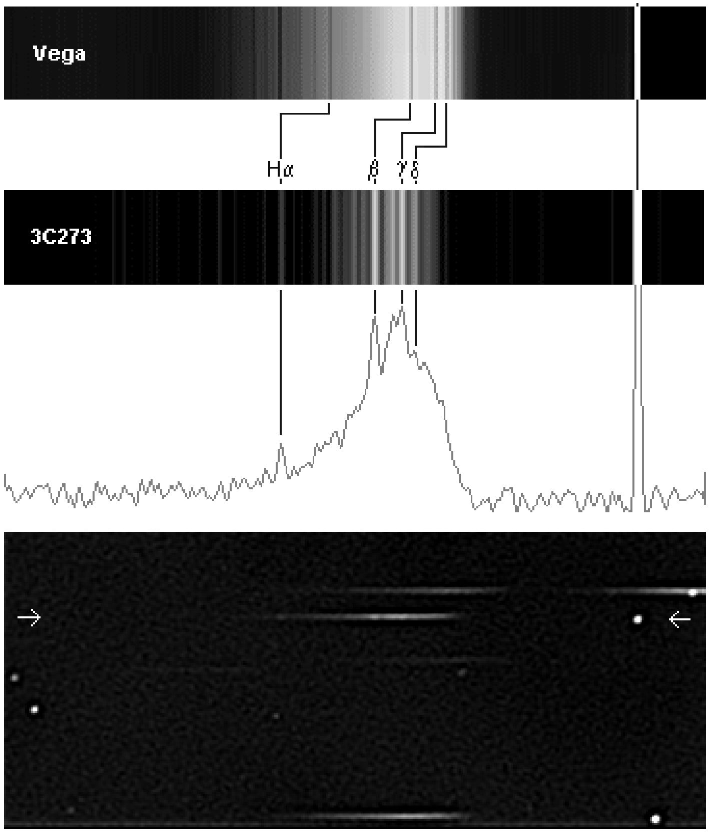
In the case of 3C273, a large telescope was used



With the accurate position, 3C273 could be identified & redshift found

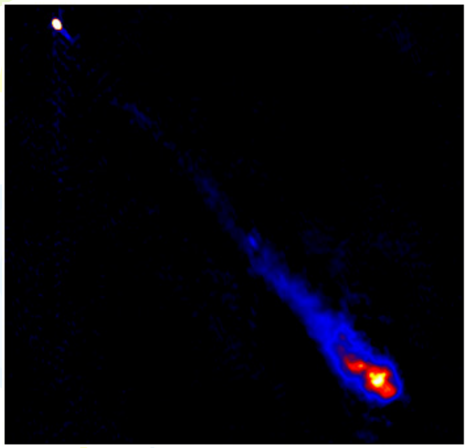


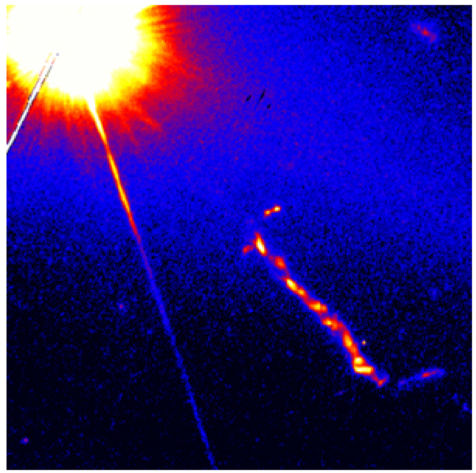
Spectrum of quasar showing cosmological redshift....

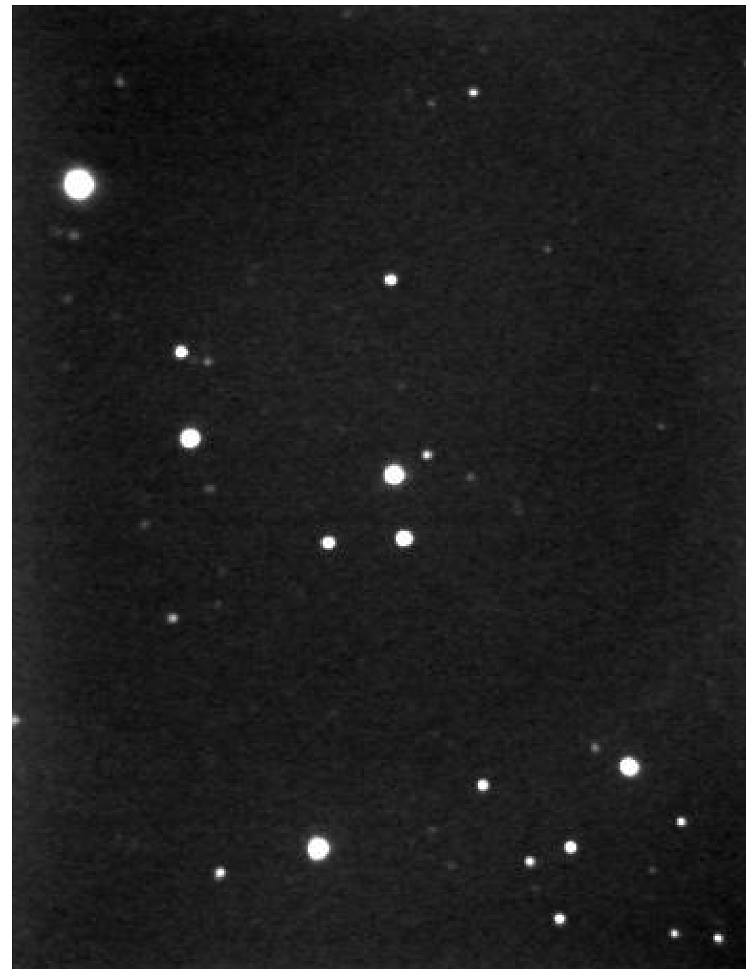


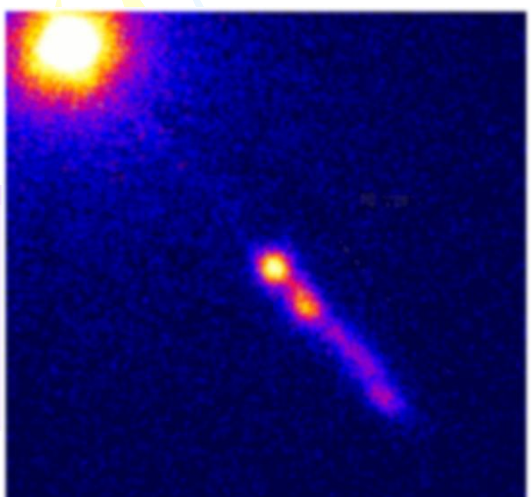
Partial CCD frame showing real image (zero order) and spectrum of quasar.
1998 Dec 21 - 30cm Meade LX200 + grating + MX9 CCD; 24m exp. [c] Maurice Gavin

Discovery of 3C273 was the beginning of active galaxy studies



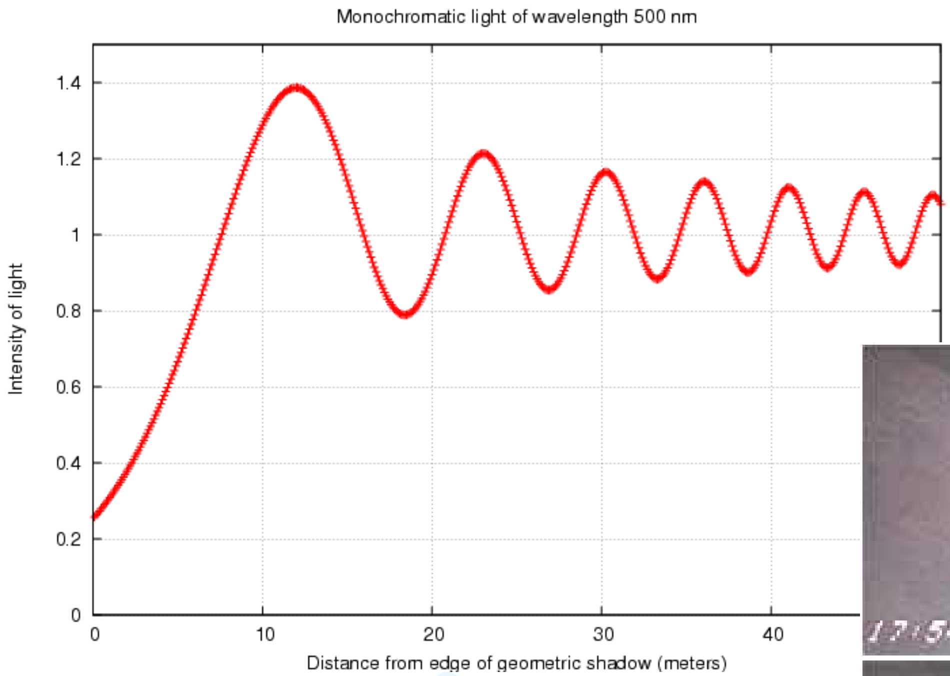






Radio, optical & X-ray images

Lunar occultation of a point source gives a characteristic signal



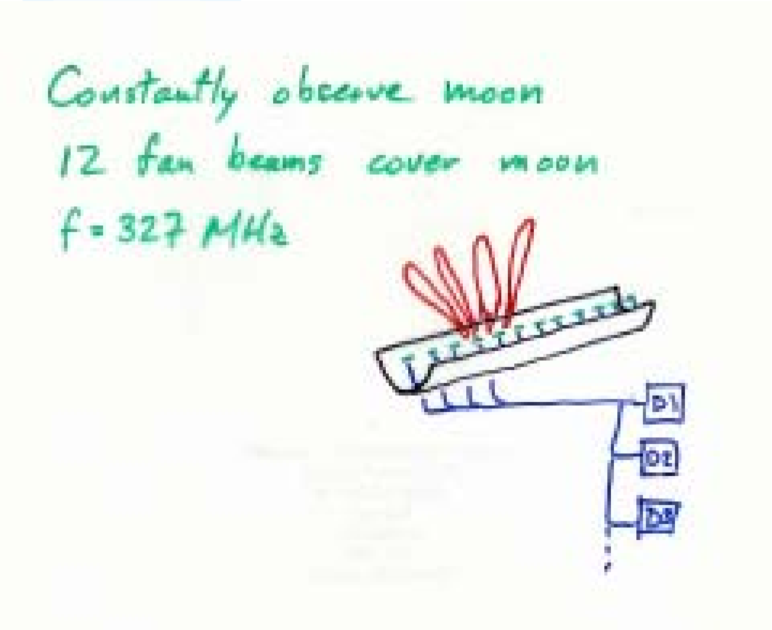
Lunar Occultation (R) of SAO159021 . On 02/02/2005 by Dave Gault

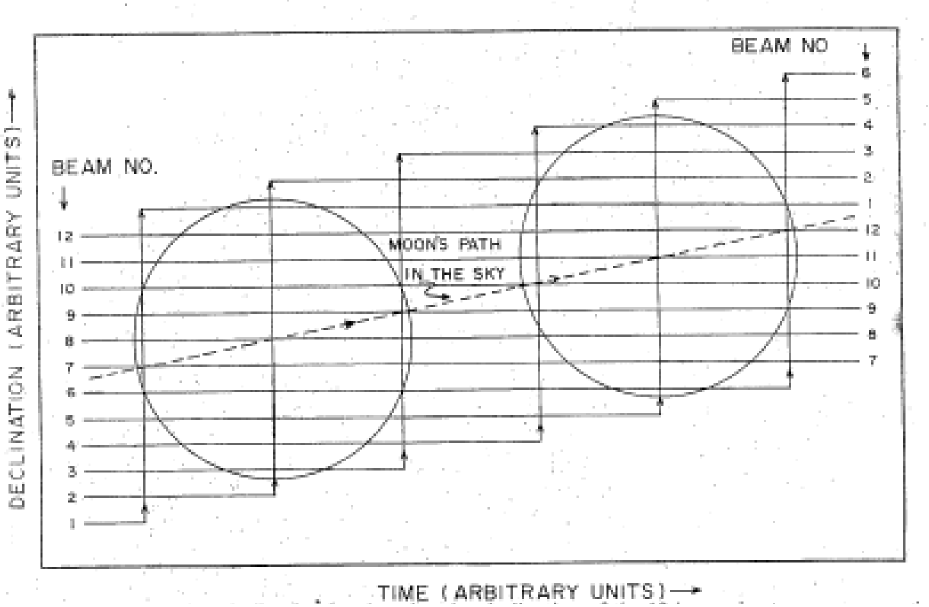
Ooty: clever radio telescope for lunar occultation, near equator

Ooty: some considerations

- Occultation observation requires good instantaneous sensitivity, short time constant; therefore large area
- Having moon in beam adds lots of noise (T_{moon} ~ 200 K)
- Most effective at low frequencies: T_{noise} higher anyway, sources are stronger, and more difficult to get high angular resolution (long λ means large antenna size)

Ooty observes moon with many adjacent fan beams simultaneously, as long as the moon is up





Result: 1-d strip brightness

- Each strip gives fanbeam response
- Immersion and emersion usually give different position angles
- As with cross antenna, can use information to construct 2-d brightness distribution

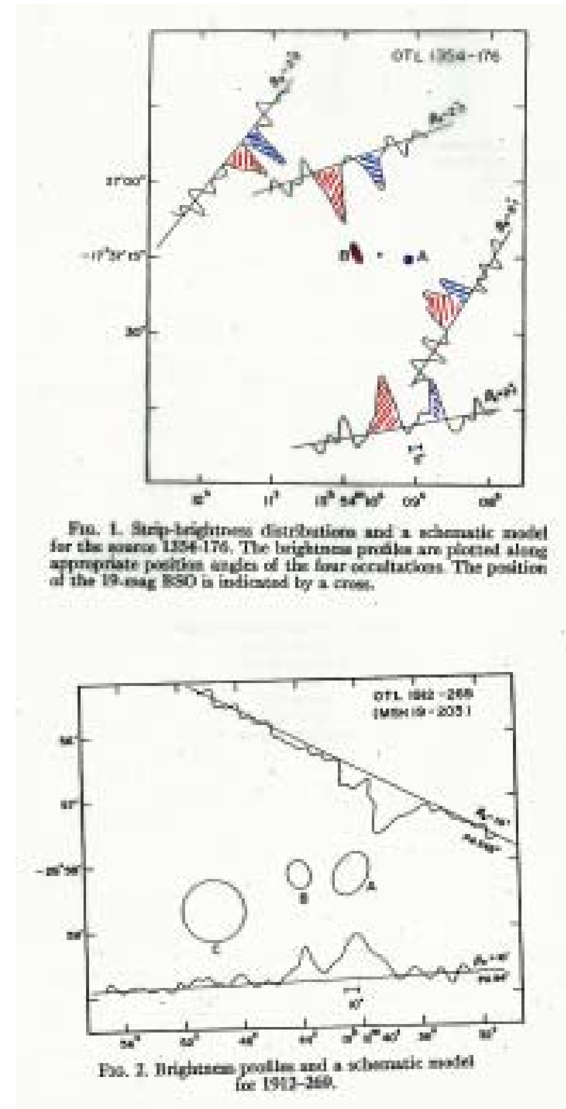


Fig. 1. Strip-brightness distributions and a schematic model for the source 1354-176. The brightness profiles are plotted along appropriate position angles of the four occultations. The position of the 19-mag BSO is indicated by a cross.

Fig. 2. Brightness profiles and a schematic model for 1912-269.

Next lecture (not 25 Oct!)

Some highlights from galactic and extragalactic radio astronomy