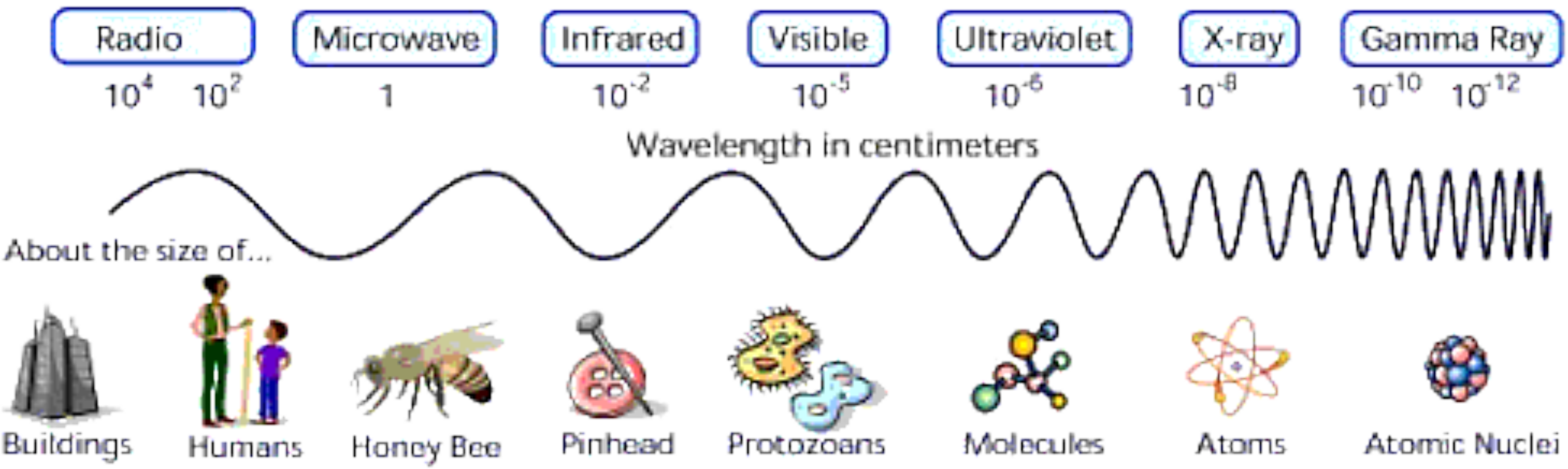
Multiwavelength Astronomy

(things that have called my attention over the years)

Luis F. Rodríguez, CRyA, UNAM, Morelia

Until a few decades ago, an observational astronomer could survive knowing only about one of the windows to the Universe (i. e. optical). This is no longer the case…

The electromagnetic spectrum



$\lambda \nu = c$ (wave eqn.)

$E = h \nu$ (Energy)

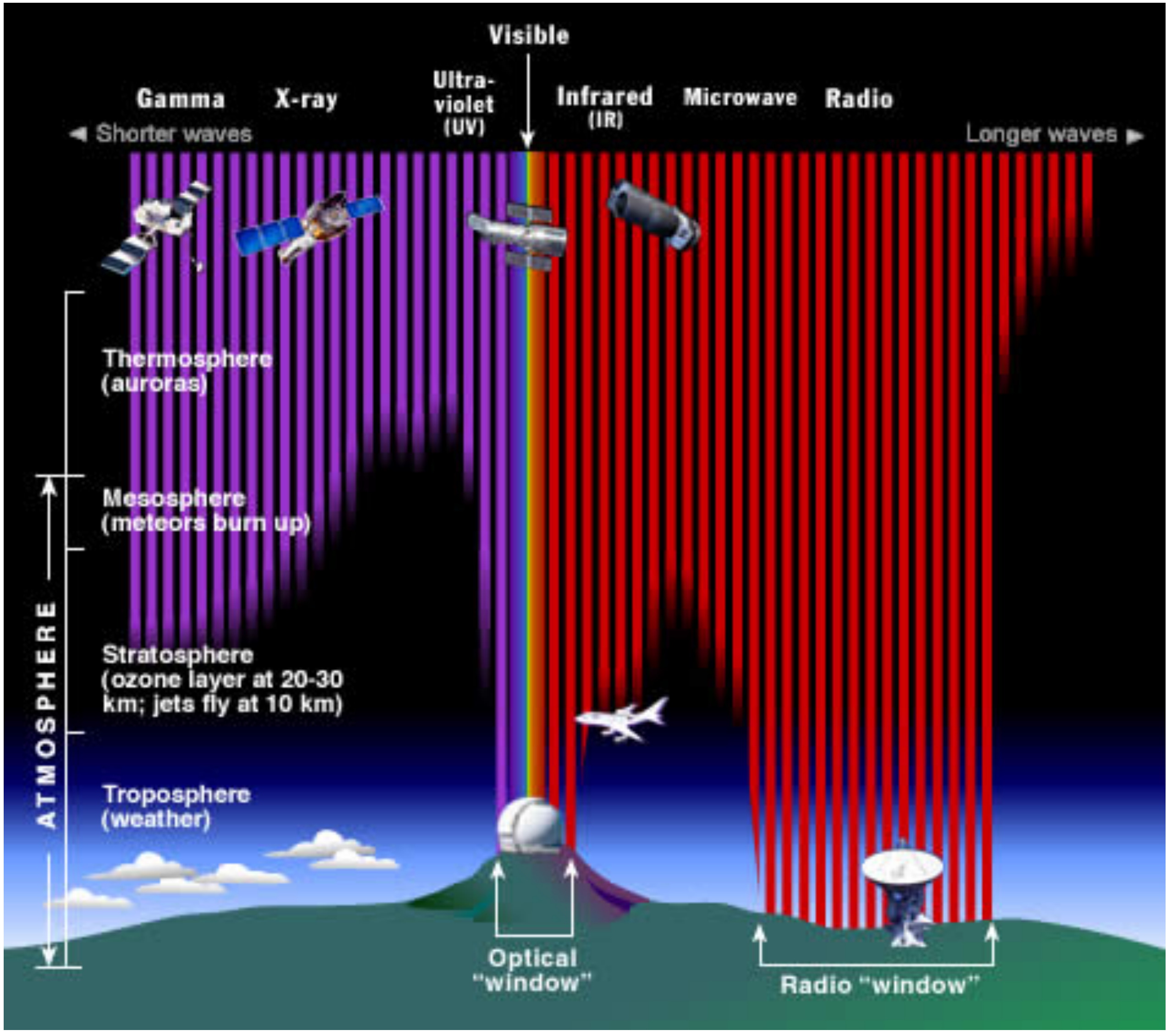
Photon energy

- Optical photons: from 1.8 eV (red) to 3.1 eV (blue).
- X-rays: 0.1 keV to 512 keV.
- γ−rays: 512 keV and higher. Astronomical photons of up to 10 TeV have been detected.
- Optical astronomy covers a factor of only 2 in energies, while γ–rays cover a range of 10^7!
- Different telescopes needed to cover, for example, γ−rays.

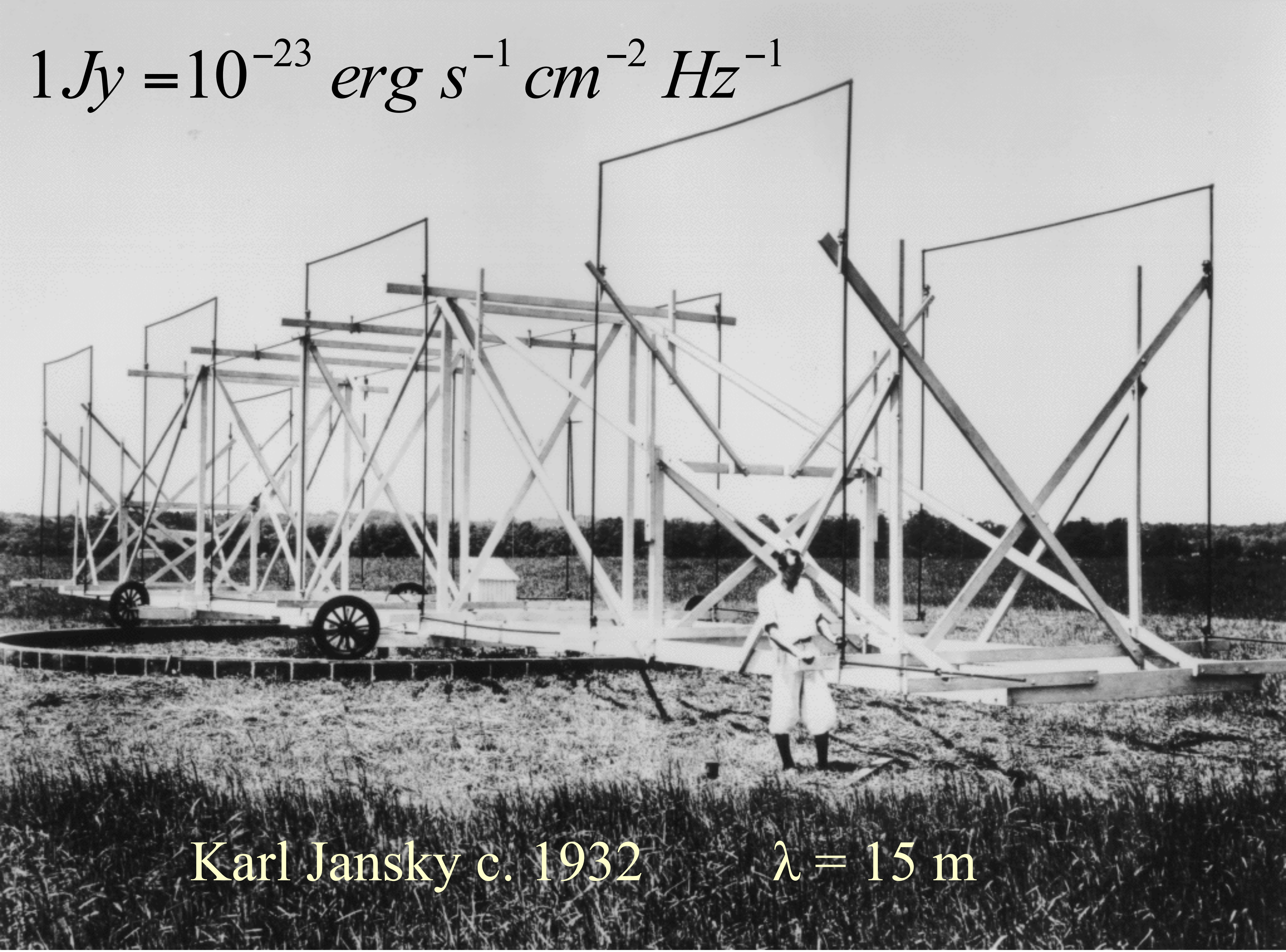
What came after optical astronomy?

- Maxwell theory of electromagnetism predicted bodies could emit other forms of radiation.
- In the early years of the XX century inventors such as Edison and Tesla tried to detect radio waves from the Sun, unsuccessfully.

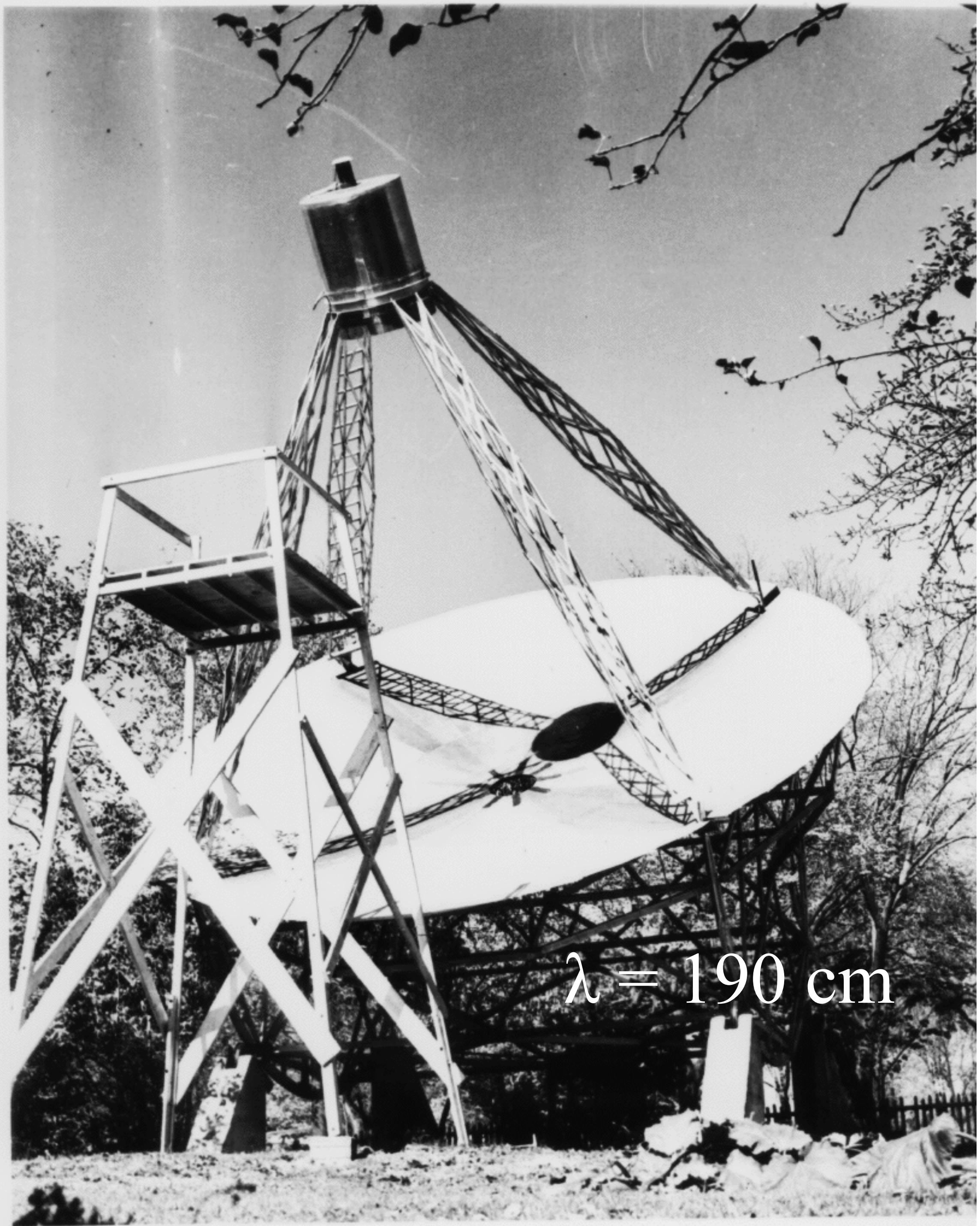
Why radio astronomy?



$$1\,Jy = 10^{-23}\ erg\ s^{-1}\ cm^{-2}\ Hz^{-1}$$



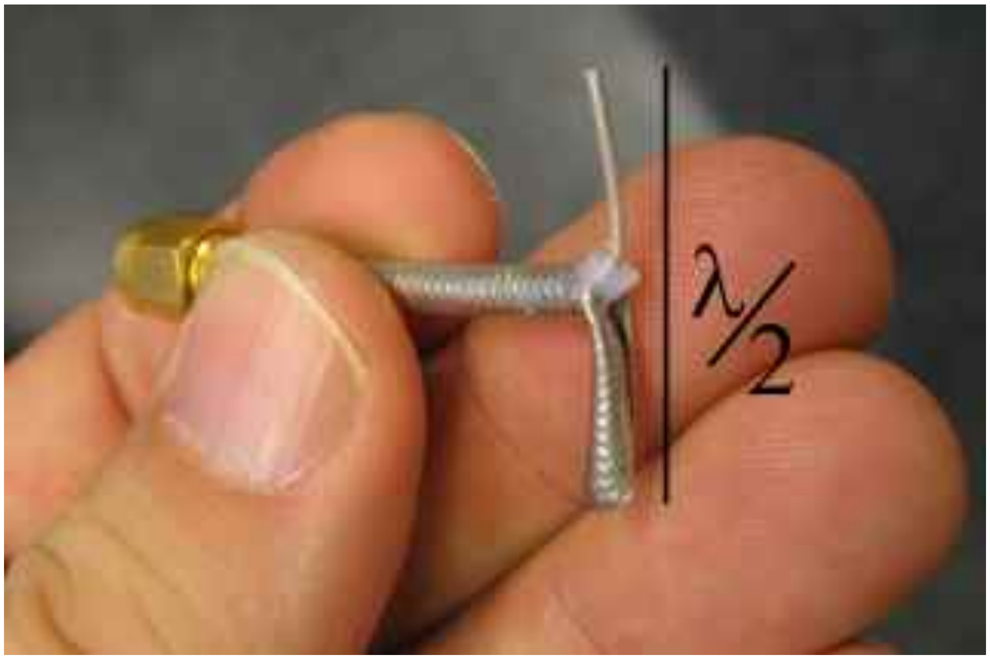
Karl Jansky c. 1932 $\lambda = 15$ m



—Grote Reber, about 1937.

Grote Reber
(1911-2002)
W9GFZ

Going from a dipole to a parabolic surface



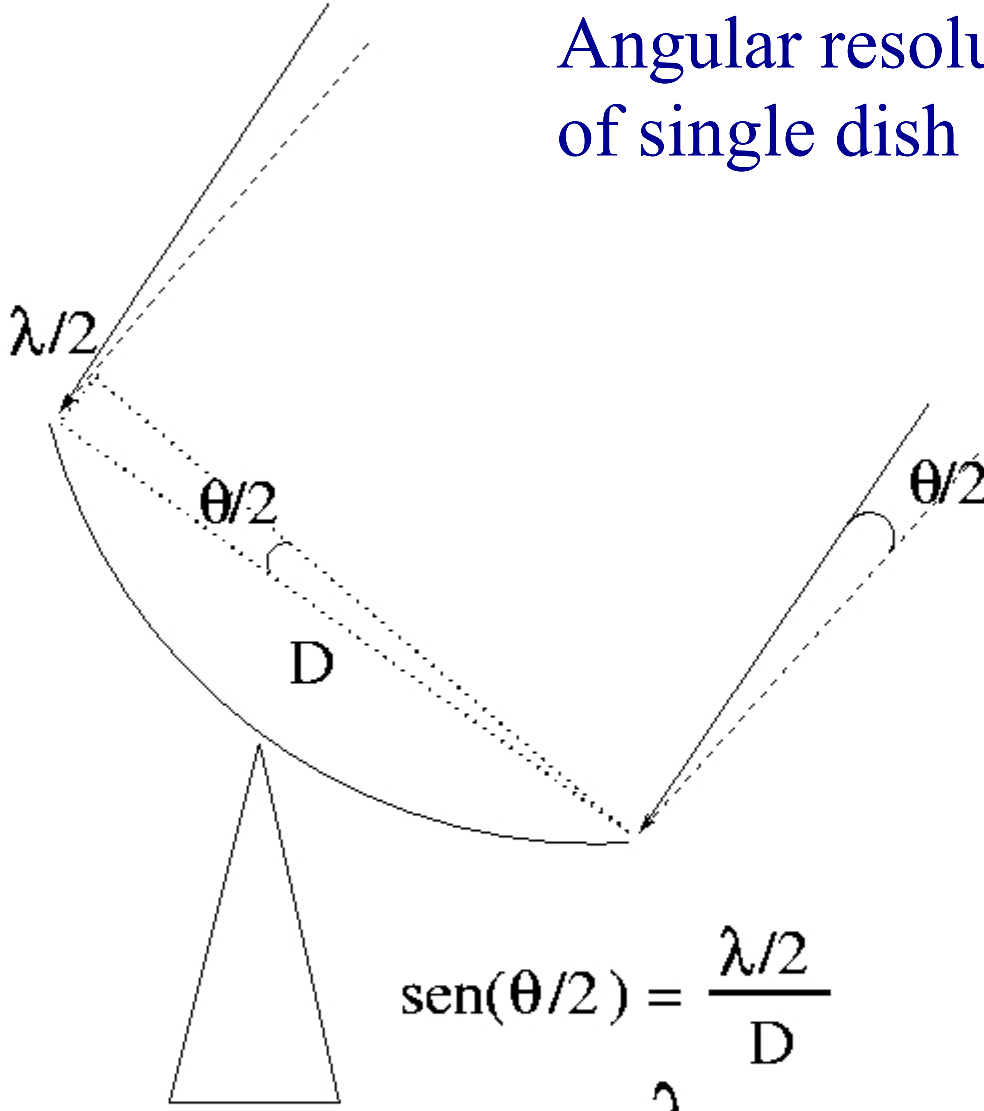
Area ≈ const. λ^2

$\lambda \geq 1$ meter: use dipoles

$\lambda \leq 1$ meter: use parabolic surface

Green Bank Telescope (100 m)

Angular resolution of single dish



$$\mathrm{sen}(\theta/2) = \frac{\lambda/2}{D}$$

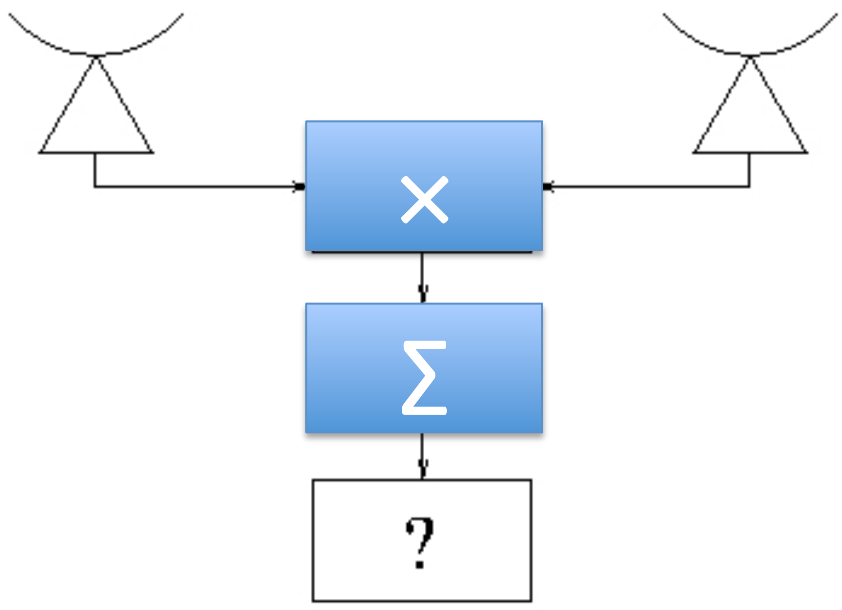
$$\theta = \frac{\lambda}{D}$$

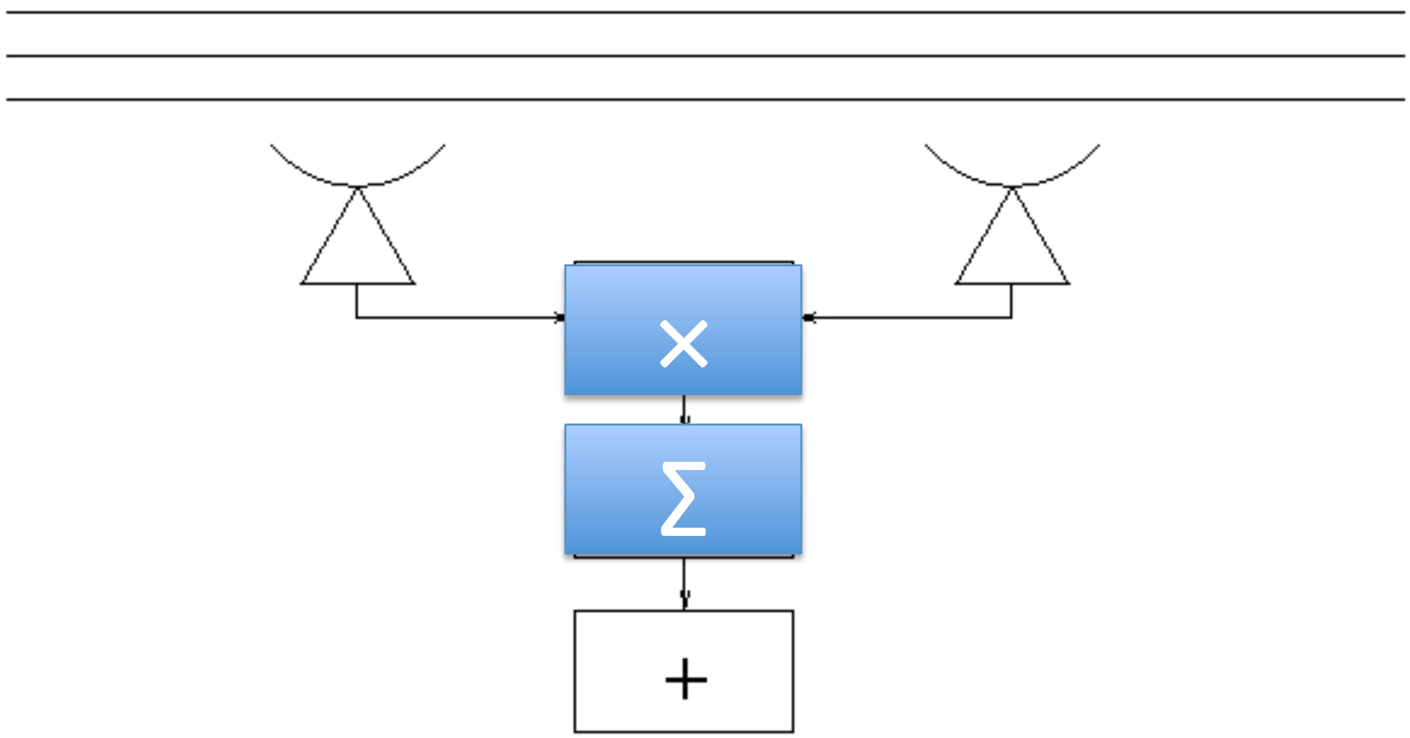
This sounded like bad news for radio astronomy. Wavelengths are the longest used and this would suggest bad angular resolutions.

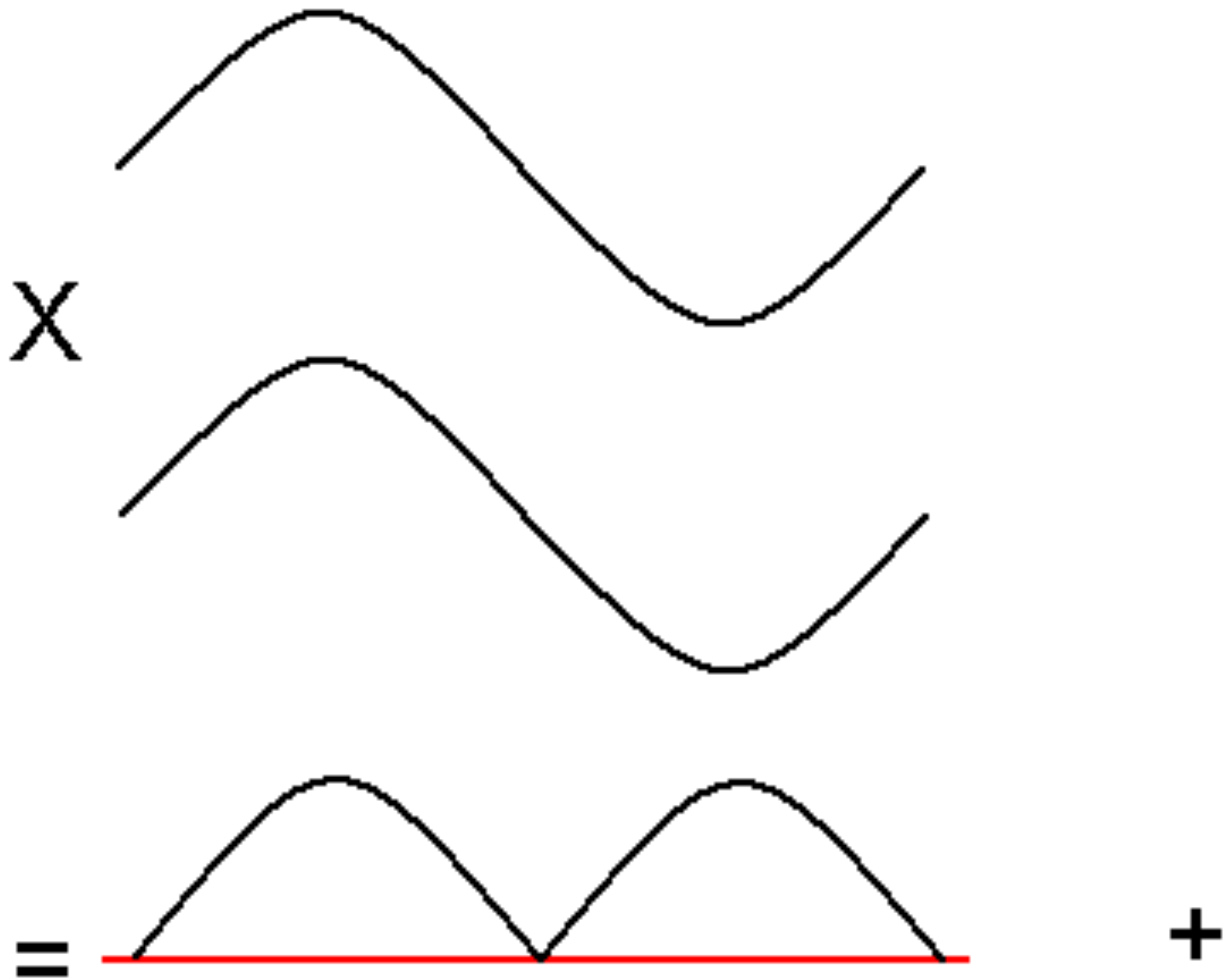
Of course, this was circumvented with the development of interferometry.

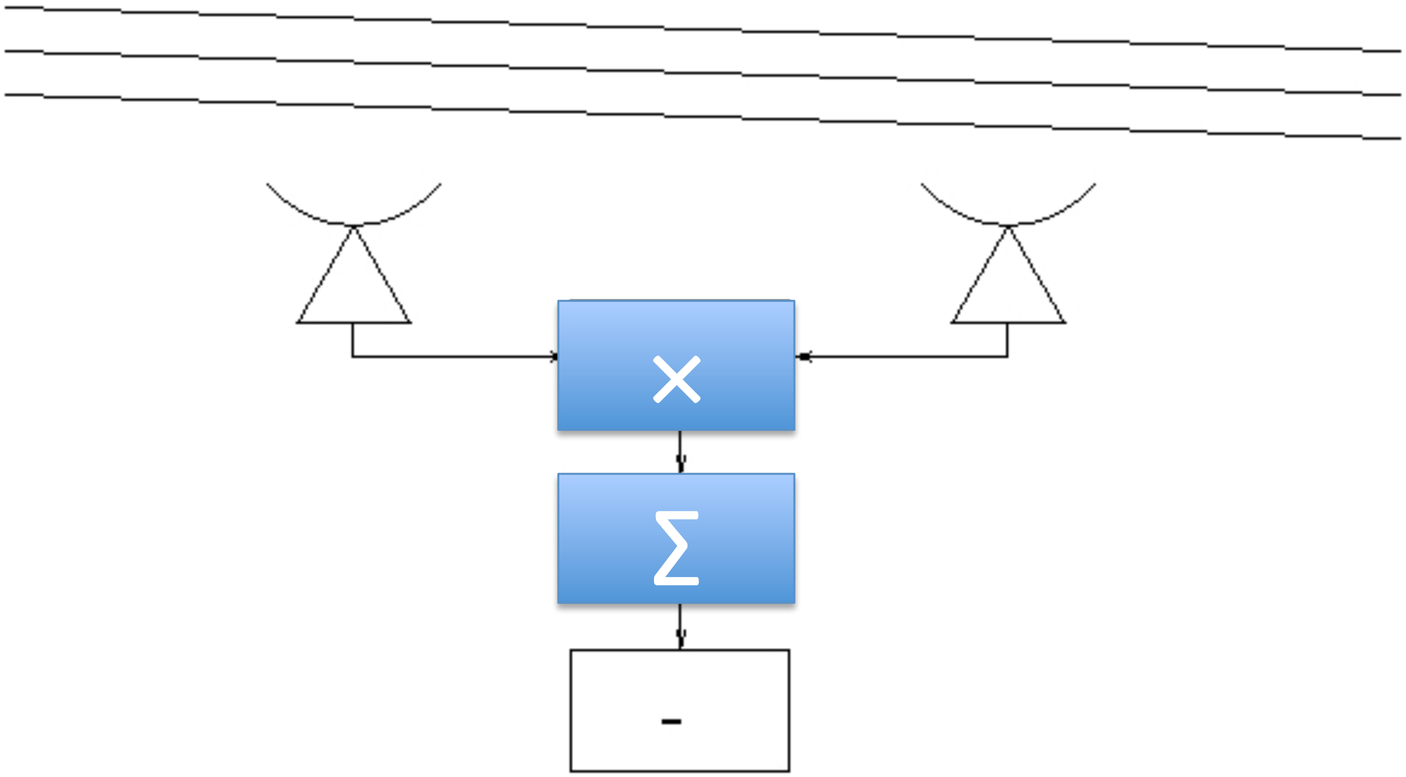
Consider two-element interferometer.

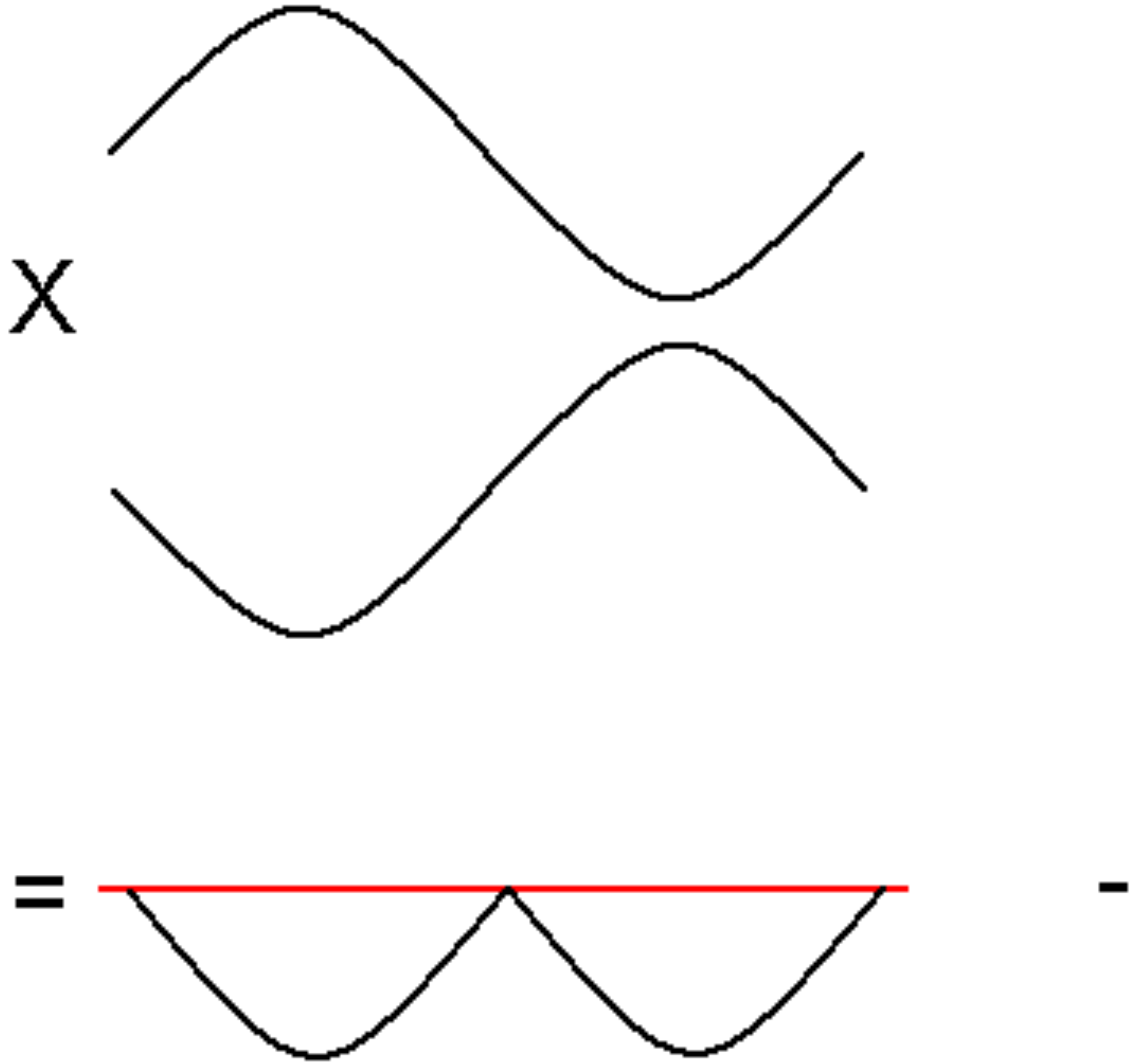
The signal of each antenna pair is multiplied and product is integrated in time. What sign does the resulting number has?



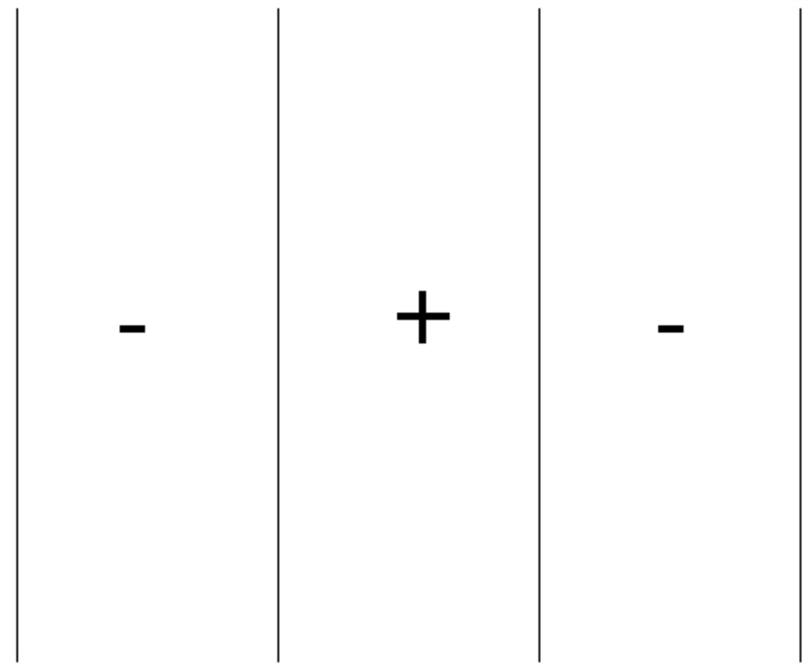




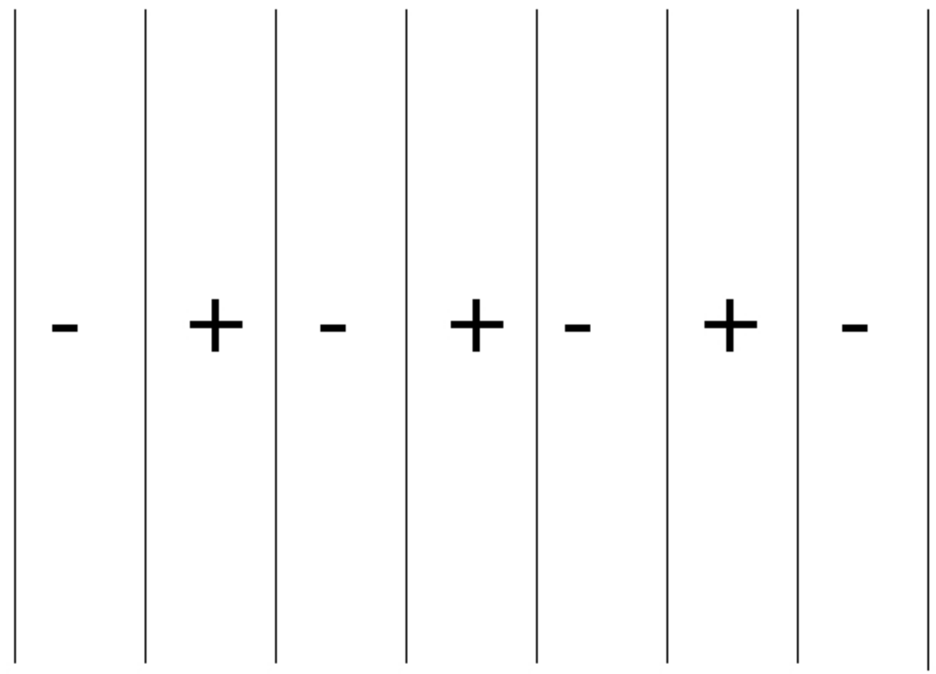



X
=
-

Sinusoidal response in plane of sky



Sinusoidal response in plane of sky

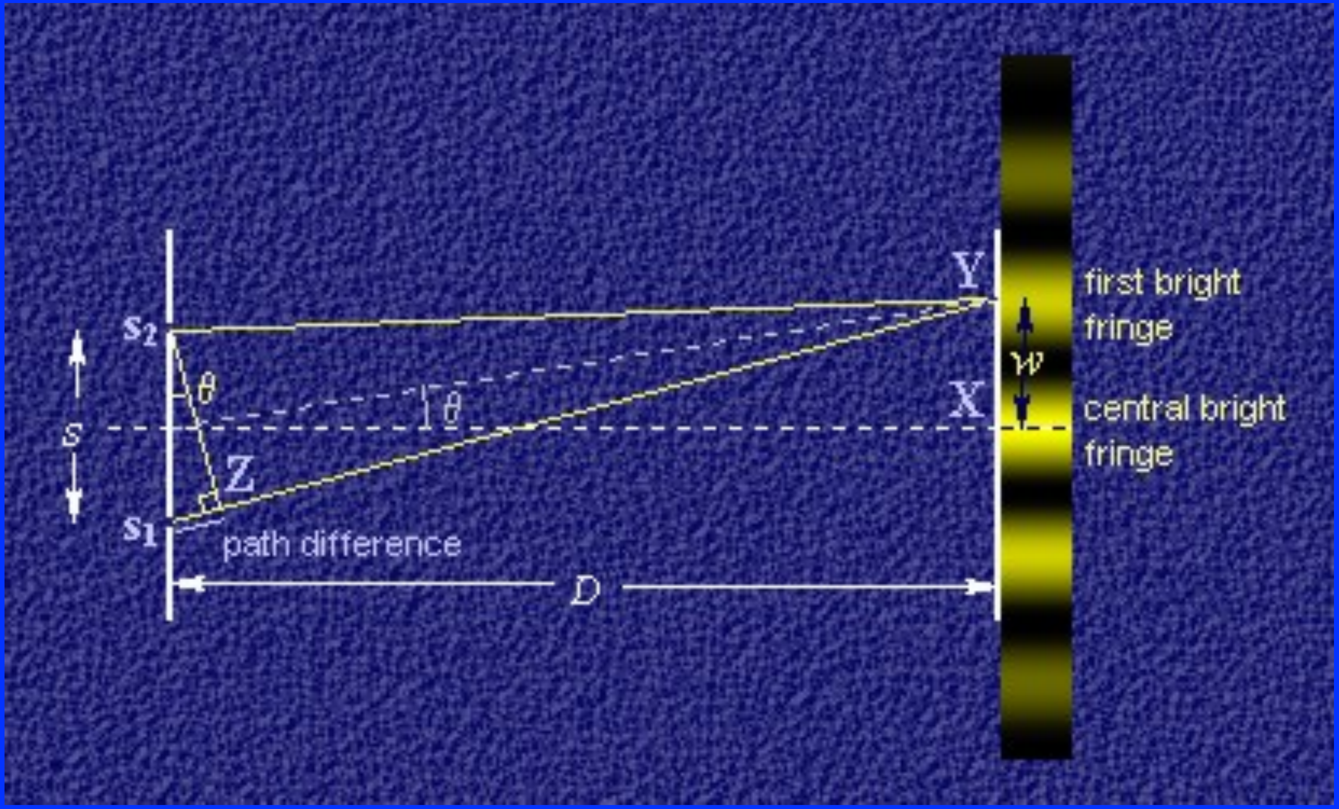


The more distant the two radio telescopes, the closer the fringes…
Now angular resolution is

$$\theta \approx \frac{\lambda}{B}$$

More graphically…

Young's double slit experiment: constructive interference occurs when path difference is an integer number of wavelengths.



from Dave McConnell

The interferometer measures "visibilities":

$$V(u, v) = \int I(x, y)\mathrm{e}^{2\pi j(ux+vy)}\mathrm{d}x\mathrm{d}y,$$

Fourier transform recovers "image", I(x,y)

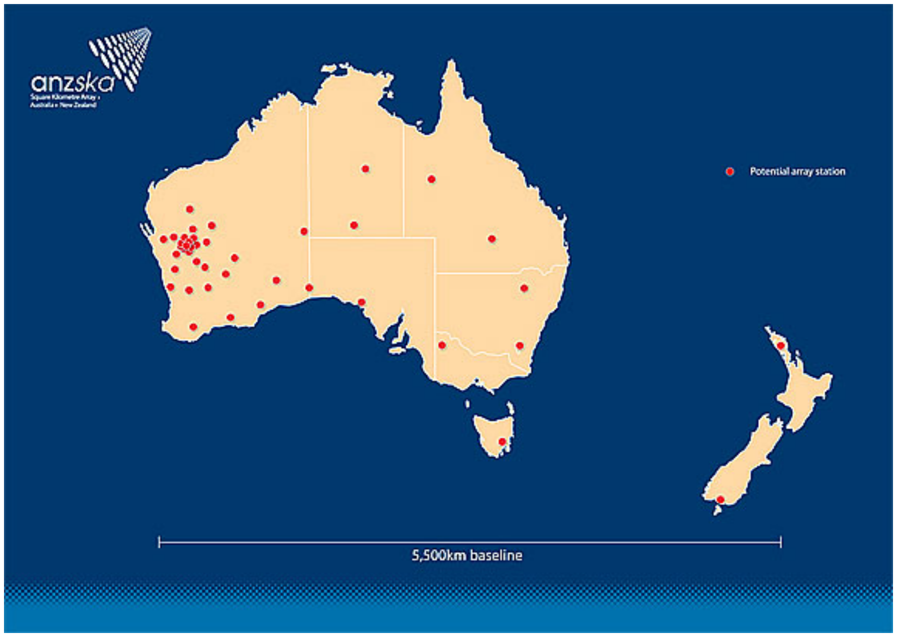
$$I(x,y) = \int V(u,v)e^{-2\pi j(ux+vy)}du\,dv$$

Now best angular resolutions are obtained in the radio despite large λs.

Some contributions of radio astronomy

Radio galaxies
Pulsars
Molecular emission
Masers
Cosmic Microwave Background (classes by M. Zaldarriaga)
Perhaps more importantly, it convinced astronomers that there were exciting things to do outside the optical window

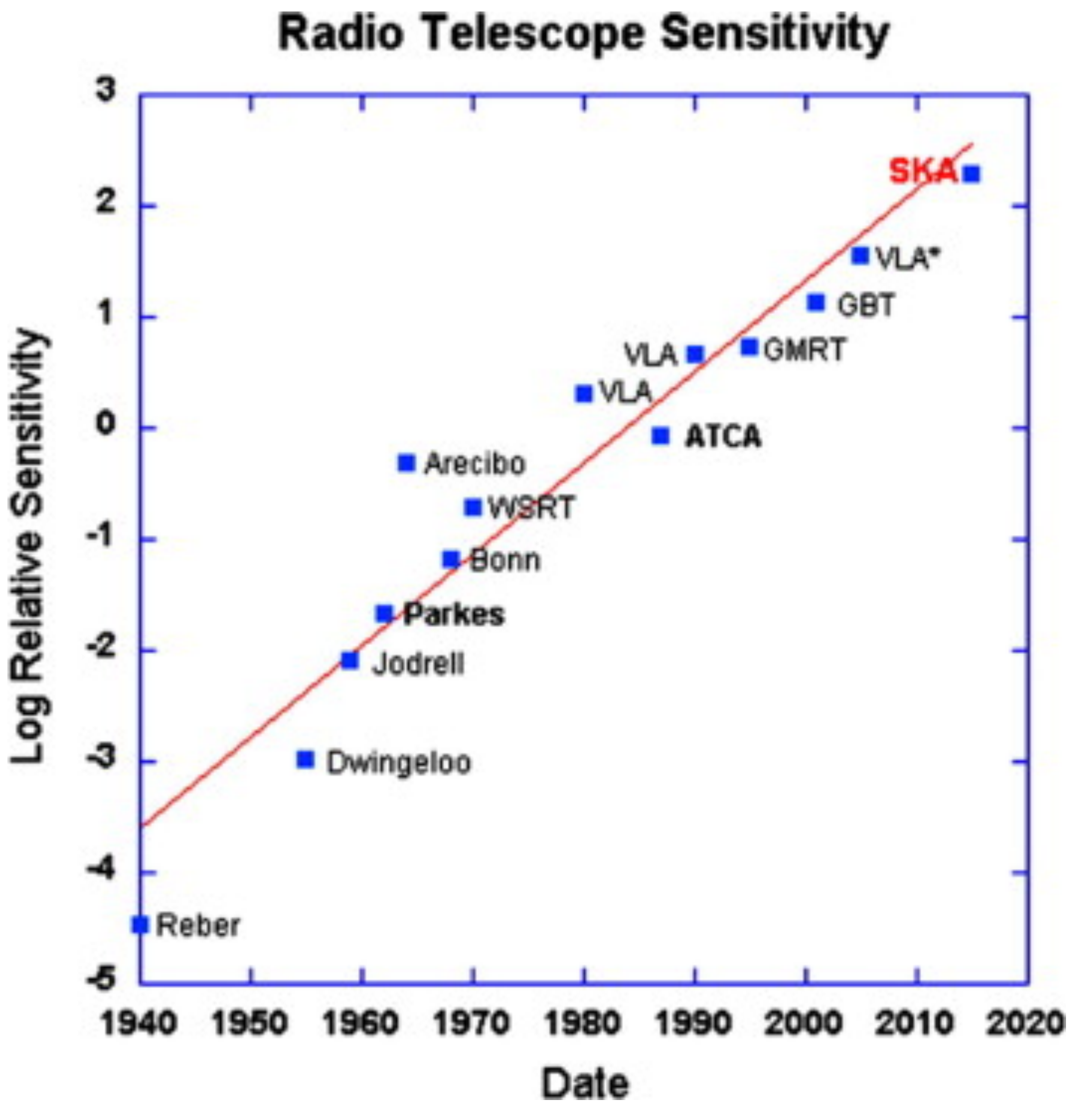
Next: Square Kilometer Array (SKA)



Low frequency: below 1 GHz

High frequency: above 1 GHz

SKA will maintain the trend…



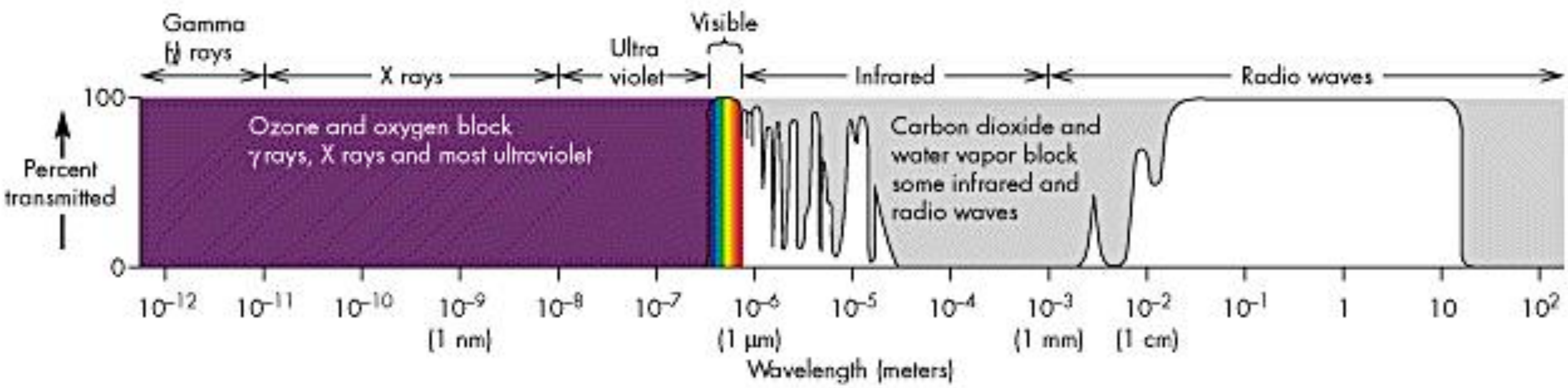
…similar to Moore´s law.   Ekers(2013)

Atacama Large Millimeter Array (ALMA) for the highest radio frequencies (mm and sub-mm bands)

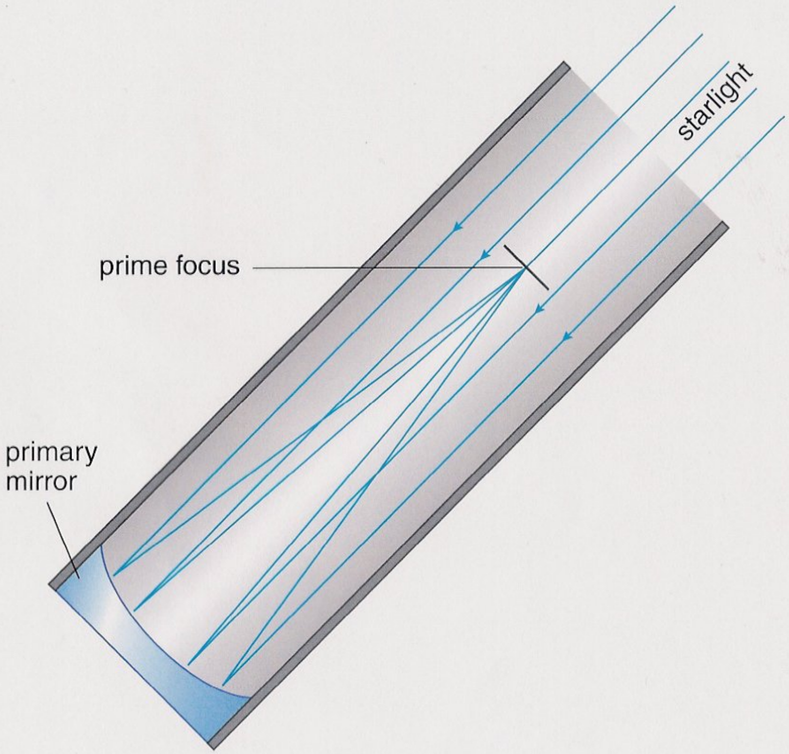
Optical astronomy is well and alive

- Two of the most exciting results of the last two decades come mostly from optical astronomy: dark energy and exoplanets.

Since our atmosphere is opaque to X-rays and γ-rays, these astronomies have to wait until the 1950s, with the development of aerospatial industry (balloons, rockets and finally satellites.)

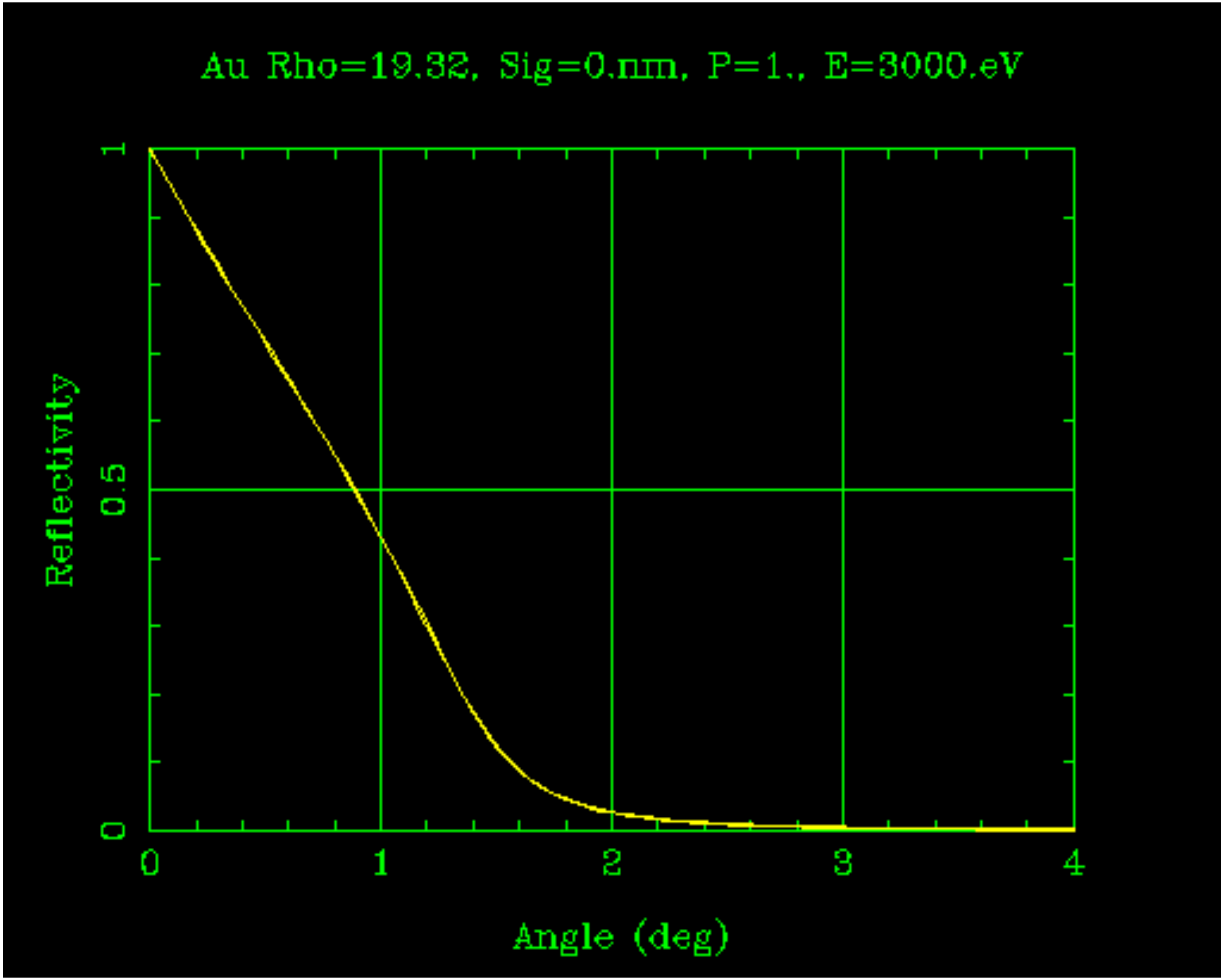


Parabolic surfaces from radio to UV



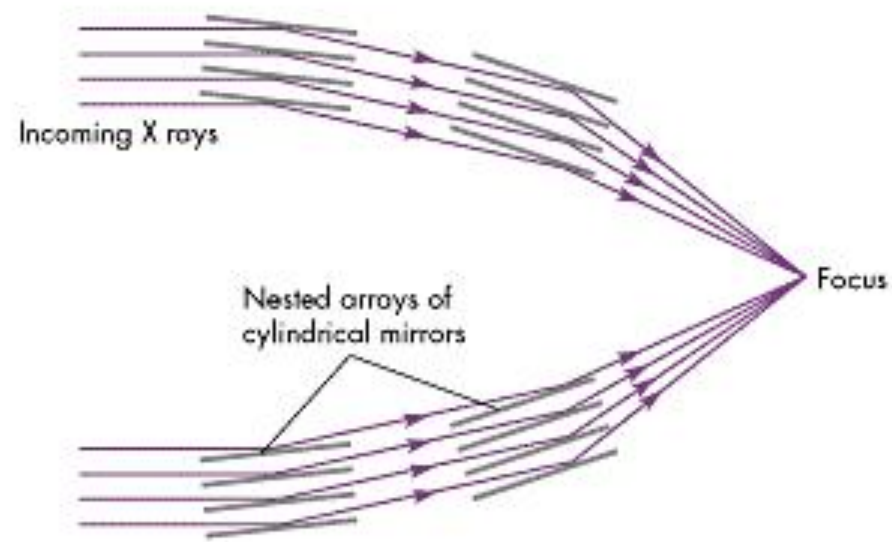
However, for X-rays and γ-rays this basic idea does not work.

These radiations are so penetrating that they do not reflect and instead penetrate into the mirror.



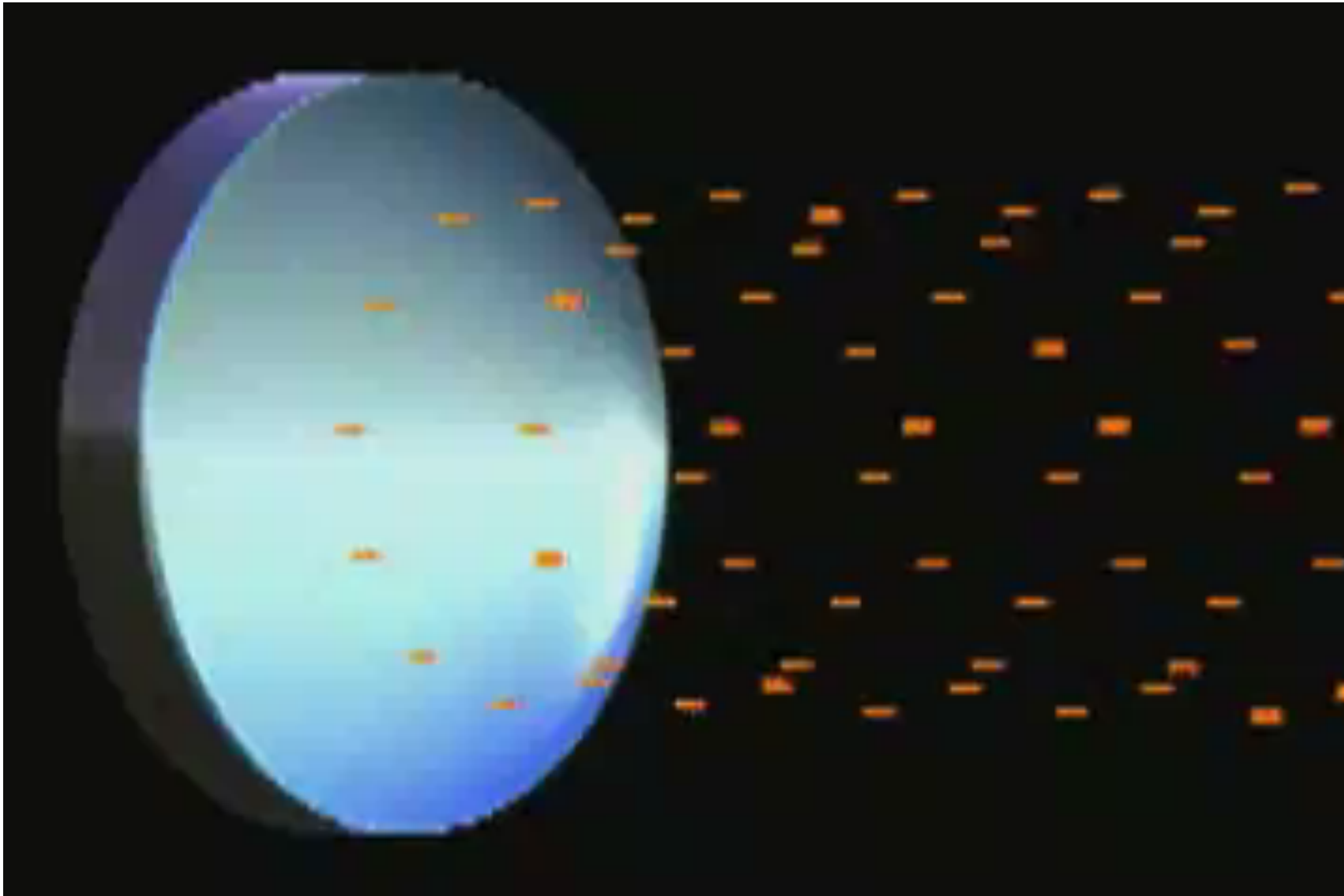
Au Rho=19.32, Sig=0.nm, P=1., E=3000.eV
Reflectivity
0
0.5
1
0
1
2
3
4
Angle (deg)

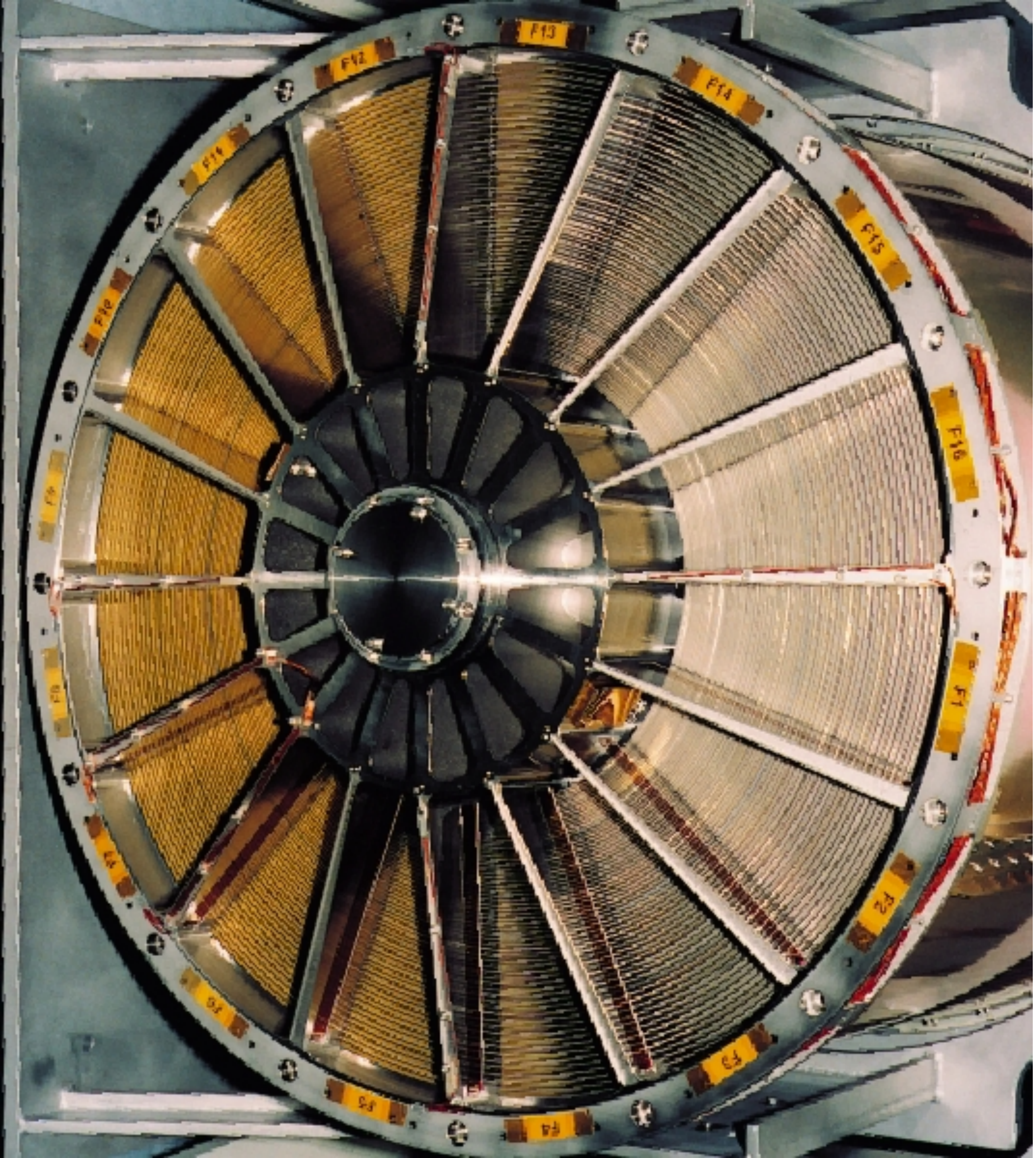
A The cylindrical mirrors of the Einstein X-ray telescope



B Cross sectional view of Einstein's grazing-incidence mirrors showing how they focus X rays.

Riccardo Giacconi came with the solution: grazing incidence cylindrical mirrors.





One of the telescopes of XMM-Newton

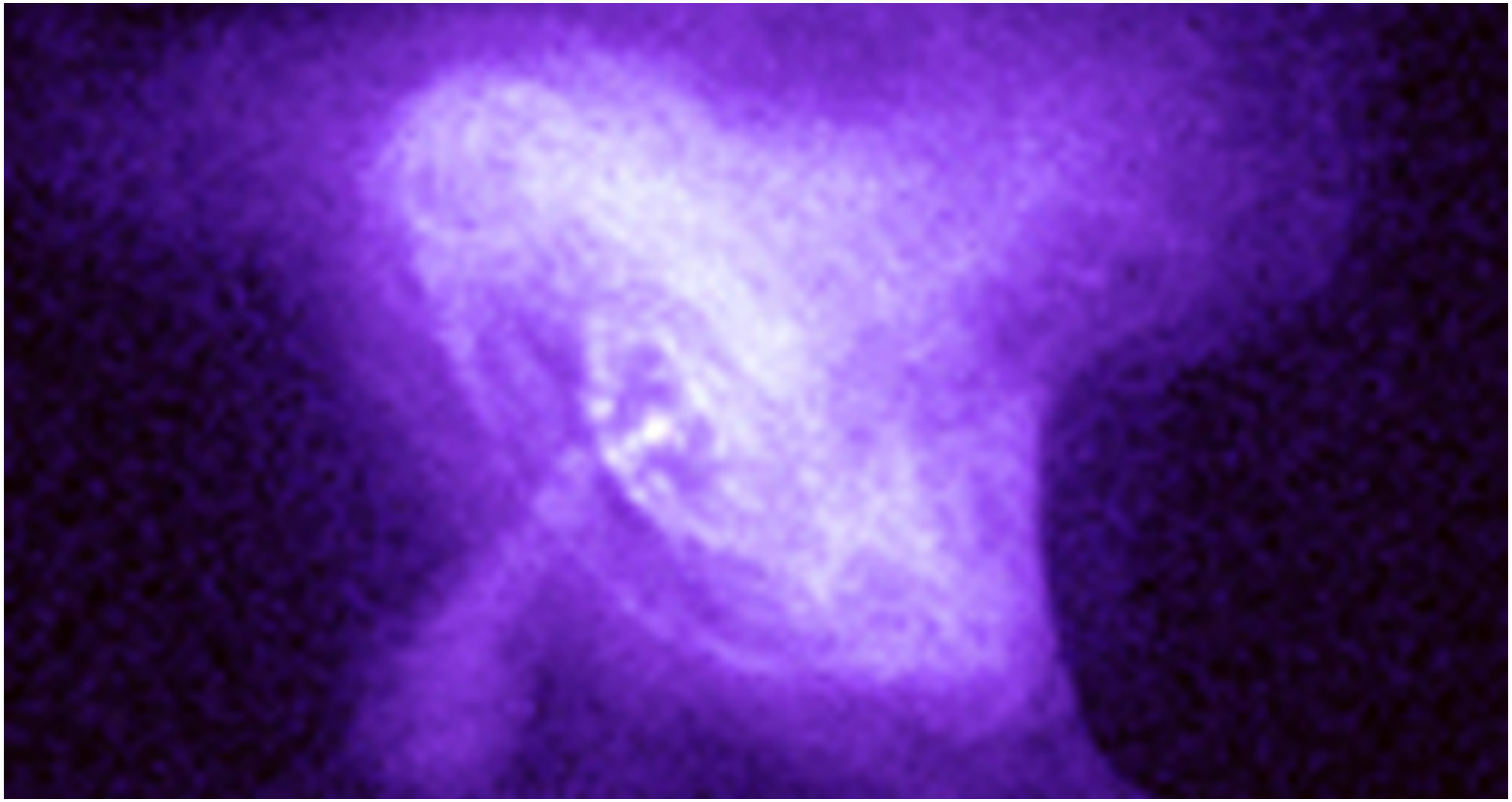
D=70 cm

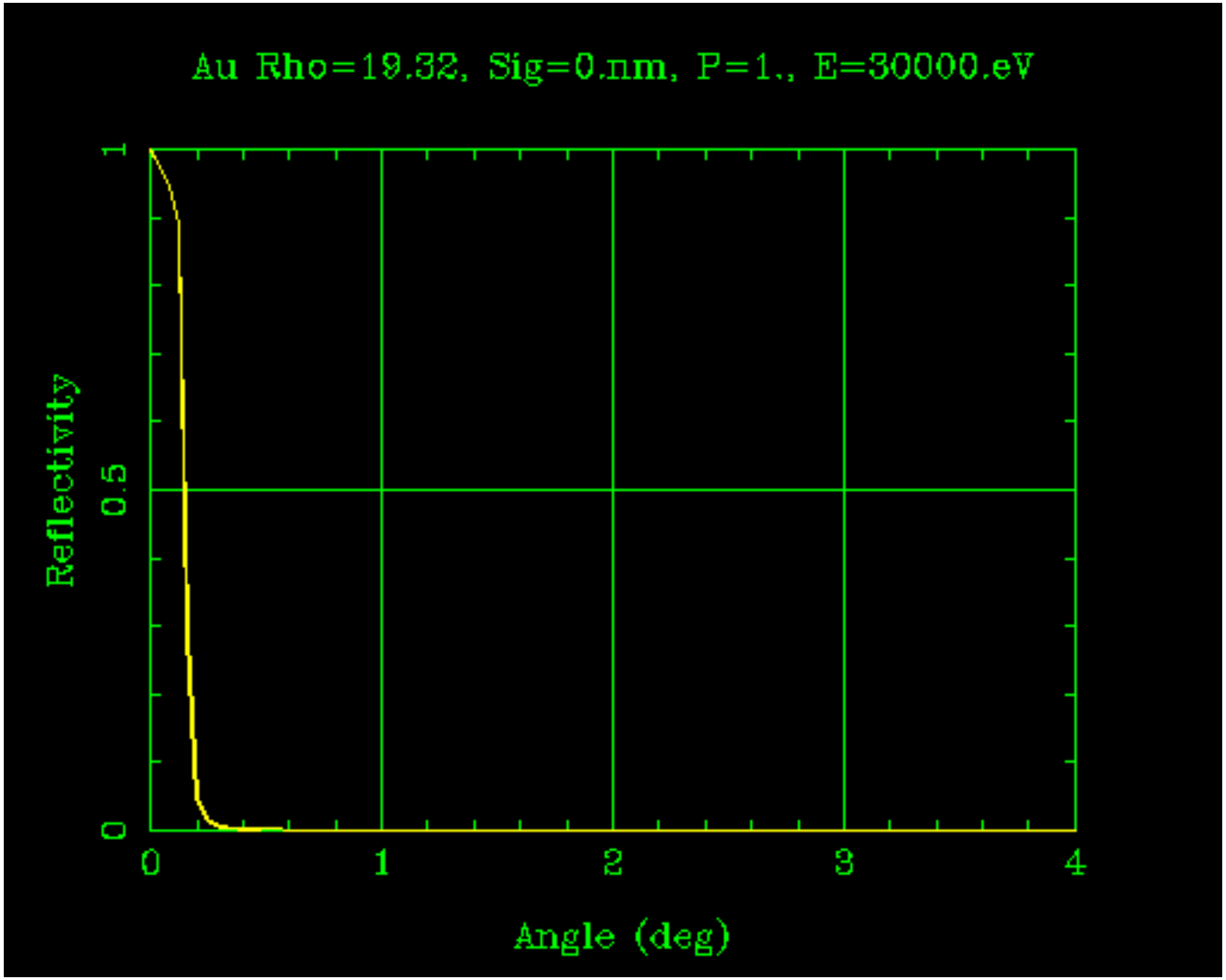
58 grazing cylindrical mirrors

Incidence angle = 0.5 degrees.

Gold plated

Chandra image of Crab

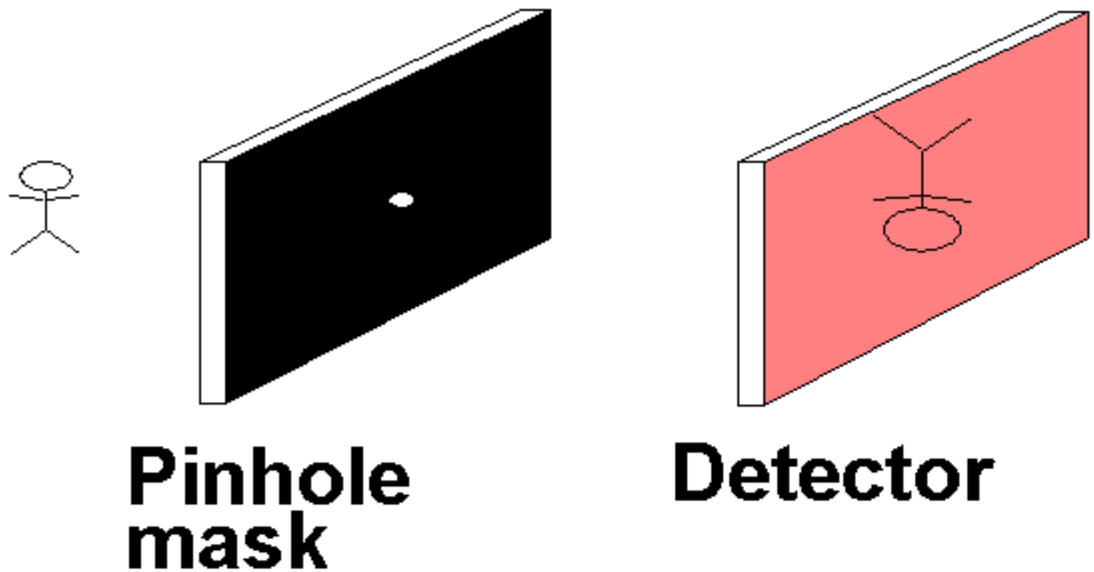




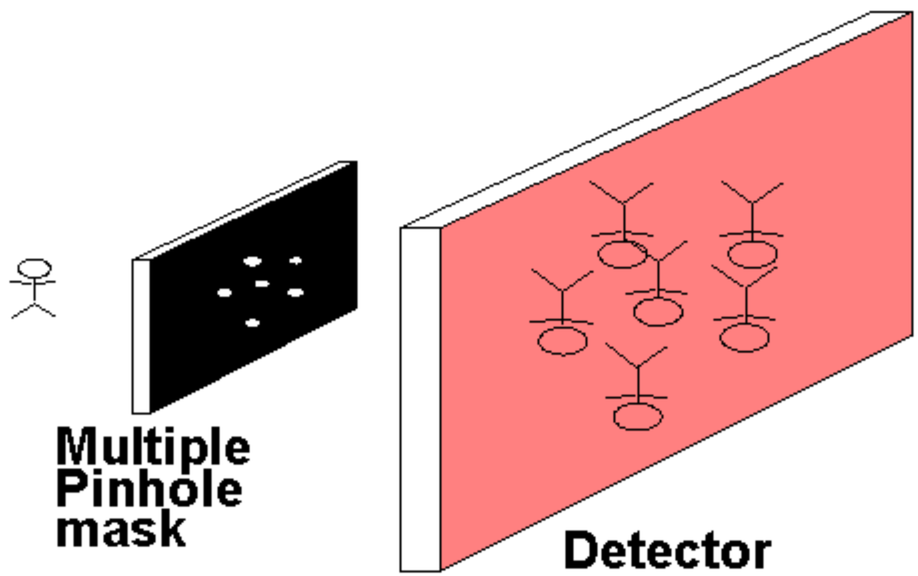
For γ−rays the effect is so limiting that you have to look for a different technique.

IBIS-INTEGRAL coded mask (made of tungsten alloy)

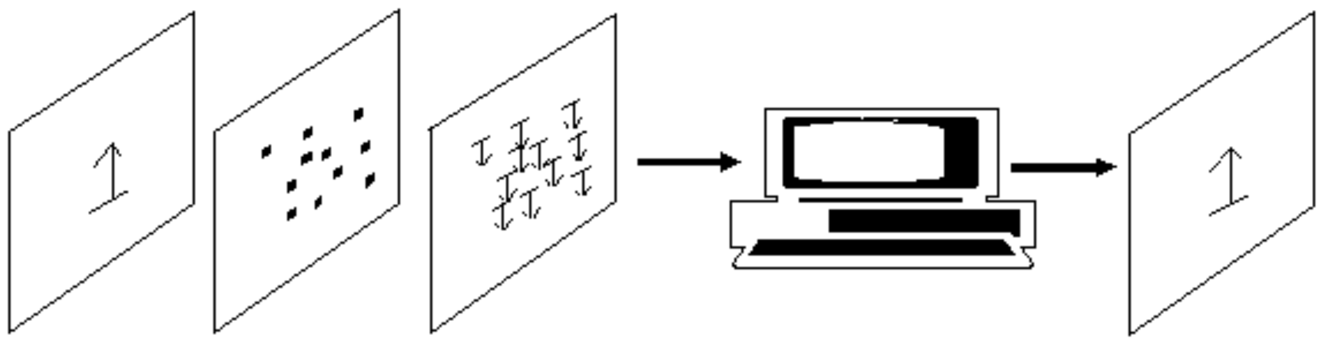
SIMPLE PINHOLE CAMERA



MULTIPLE PINHOLES



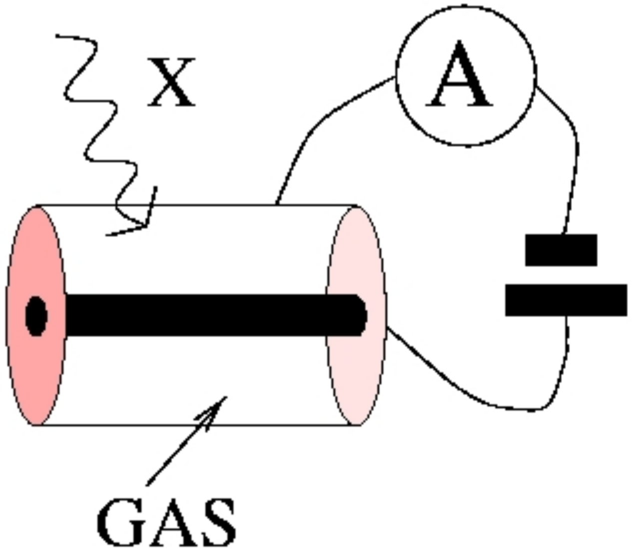
COMPUTER RECONSTRUCTION



The computer reconstructs the image from the detector plane image. Note that the detector plane image is *not a replica* of the object as in conventional optical systems

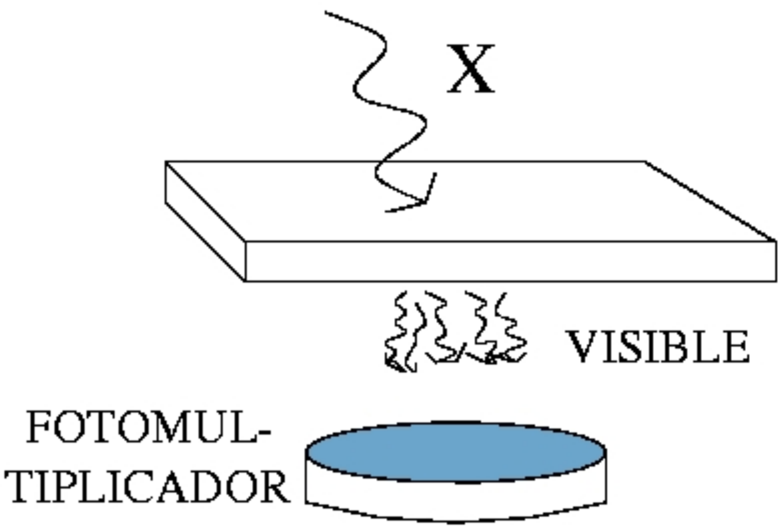
Ya hablamos de como enfocar…

- Ahora, ¿como los detectamos?



CONTADOR PROPORCIONAL

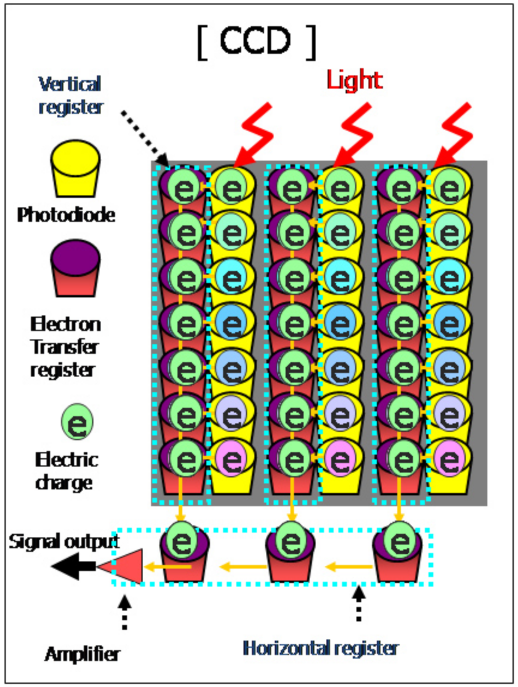
$h\nu < 20$ keV

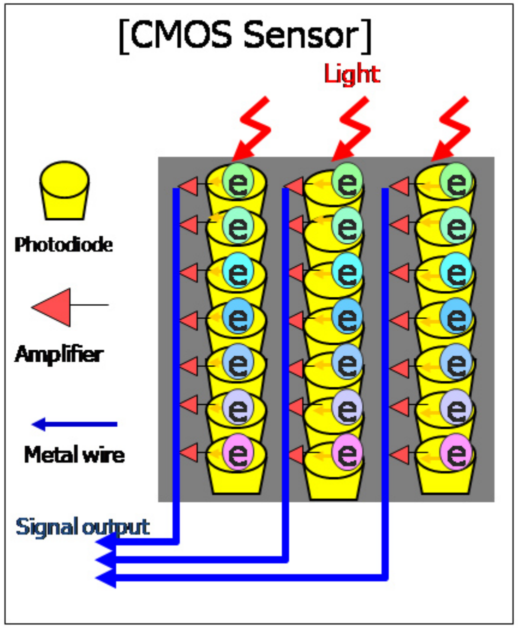


DETECTOR DE CENTELLEO

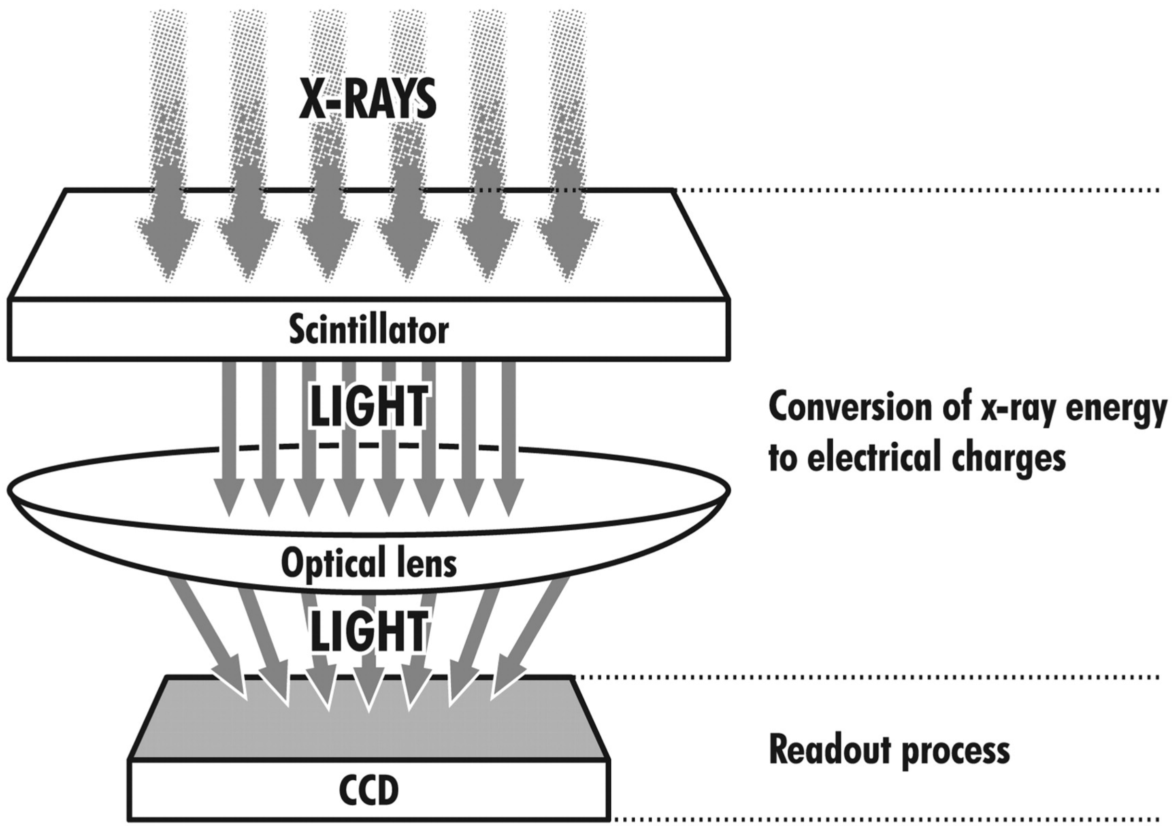
$h\nu > 20$ keV

CCDs y CMOSs

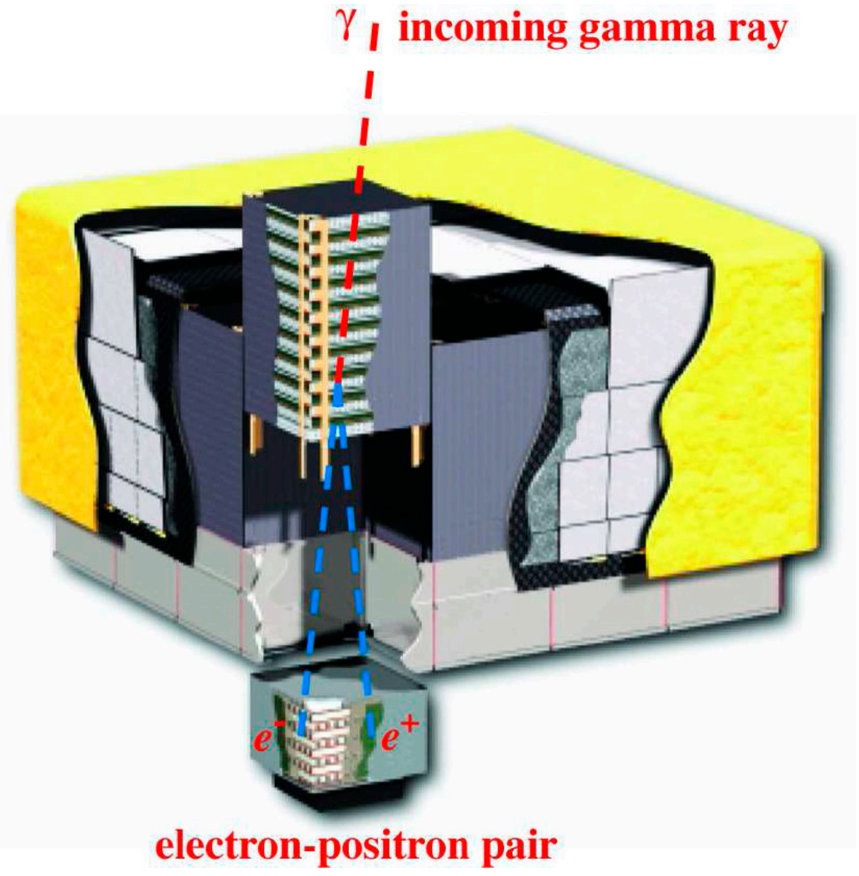

[CCD]
Vertical register
Light
Photodiode
Electron Transfer register
Electric charge
Signal output
Amplifier
Horizontal register


[CMOS Sensor]
Light
Photodiode
Amplifier
Metal wire
Signal output

X-rays


X-RAYS
Scintillator
LIGHT
Conversion of x-ray energy
to electrical charges
Optical lens
LIGHT
Readout process
CCD

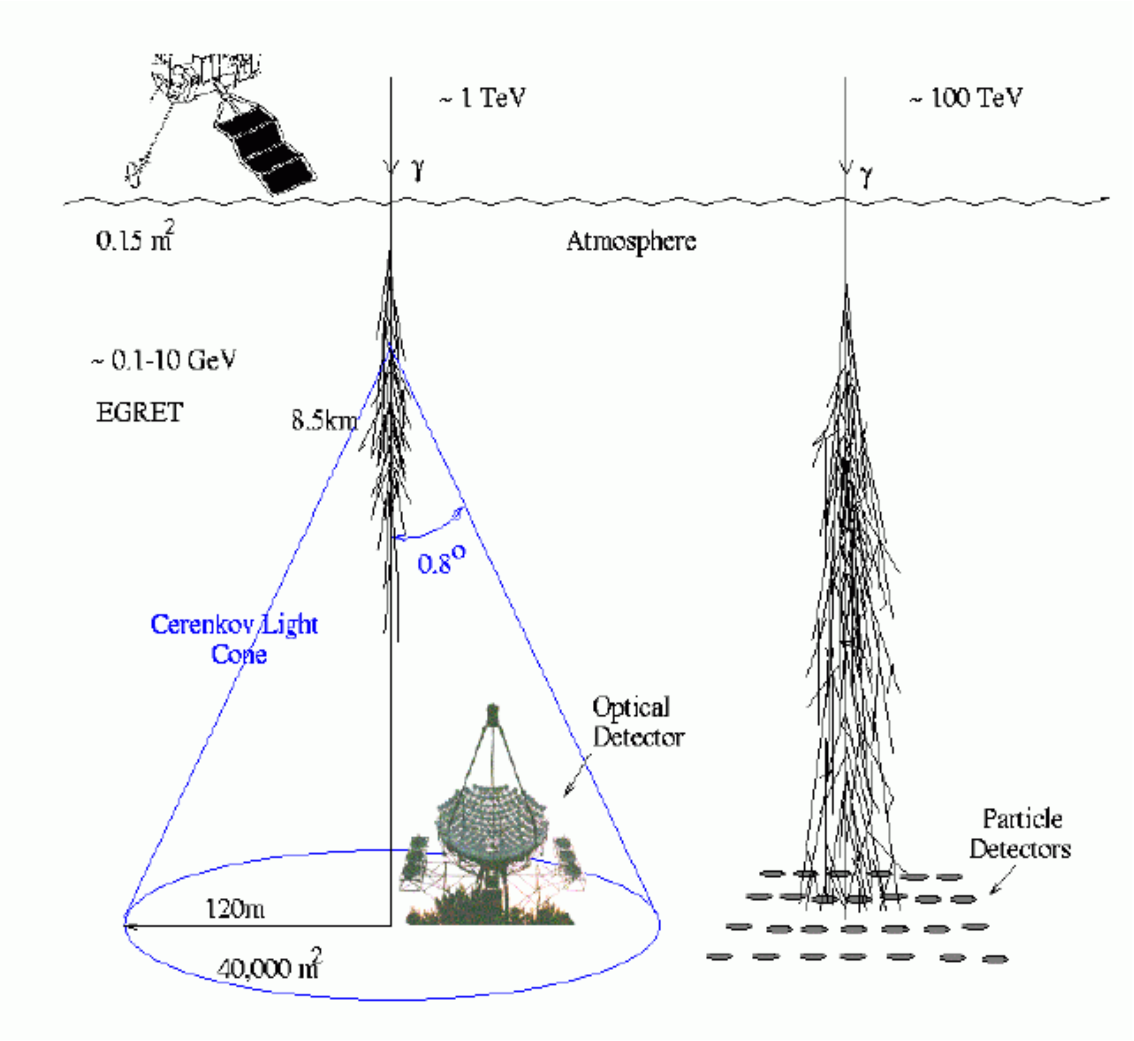
Large Area Telescope (LAT) in Fermi satellite

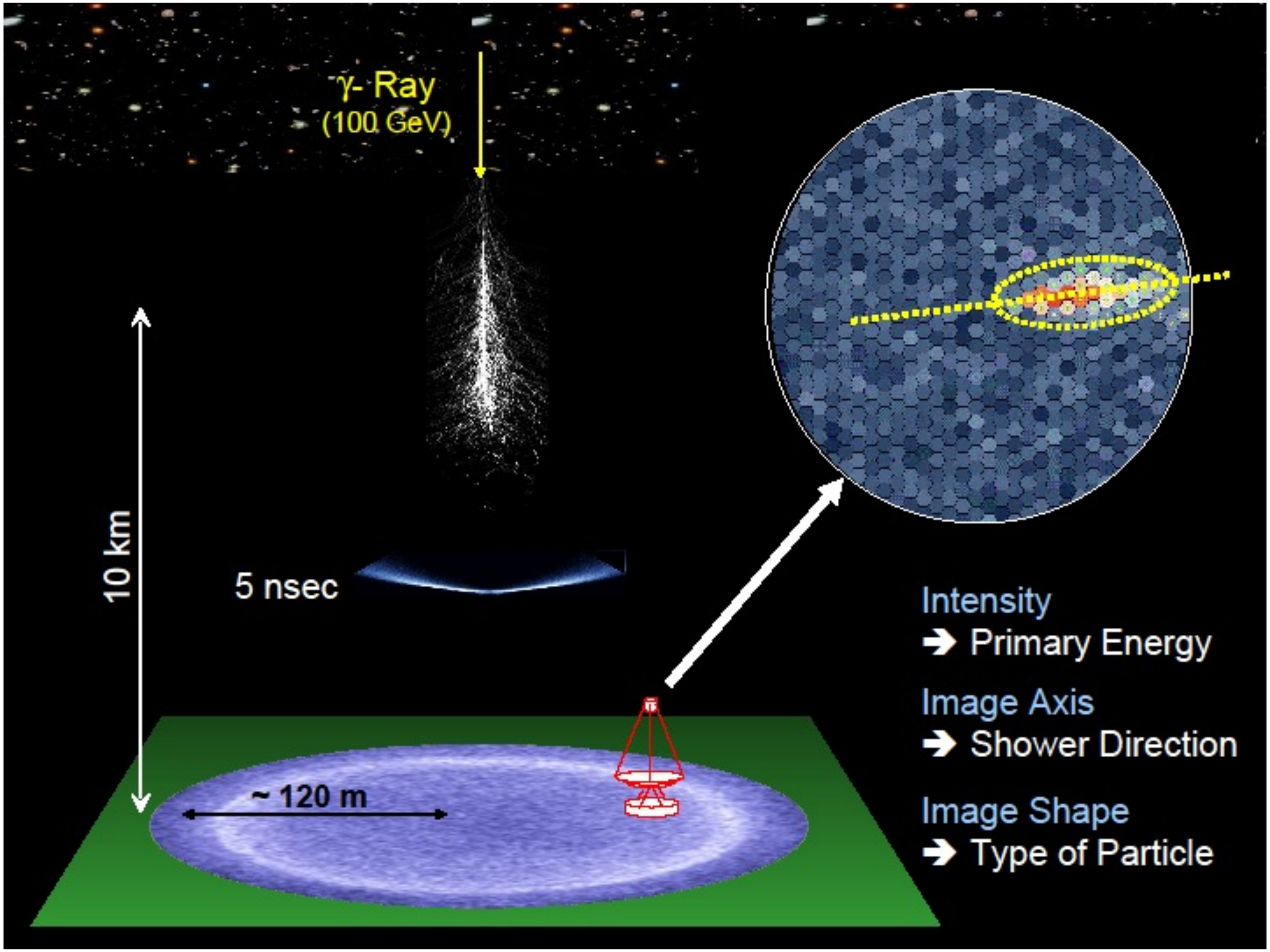


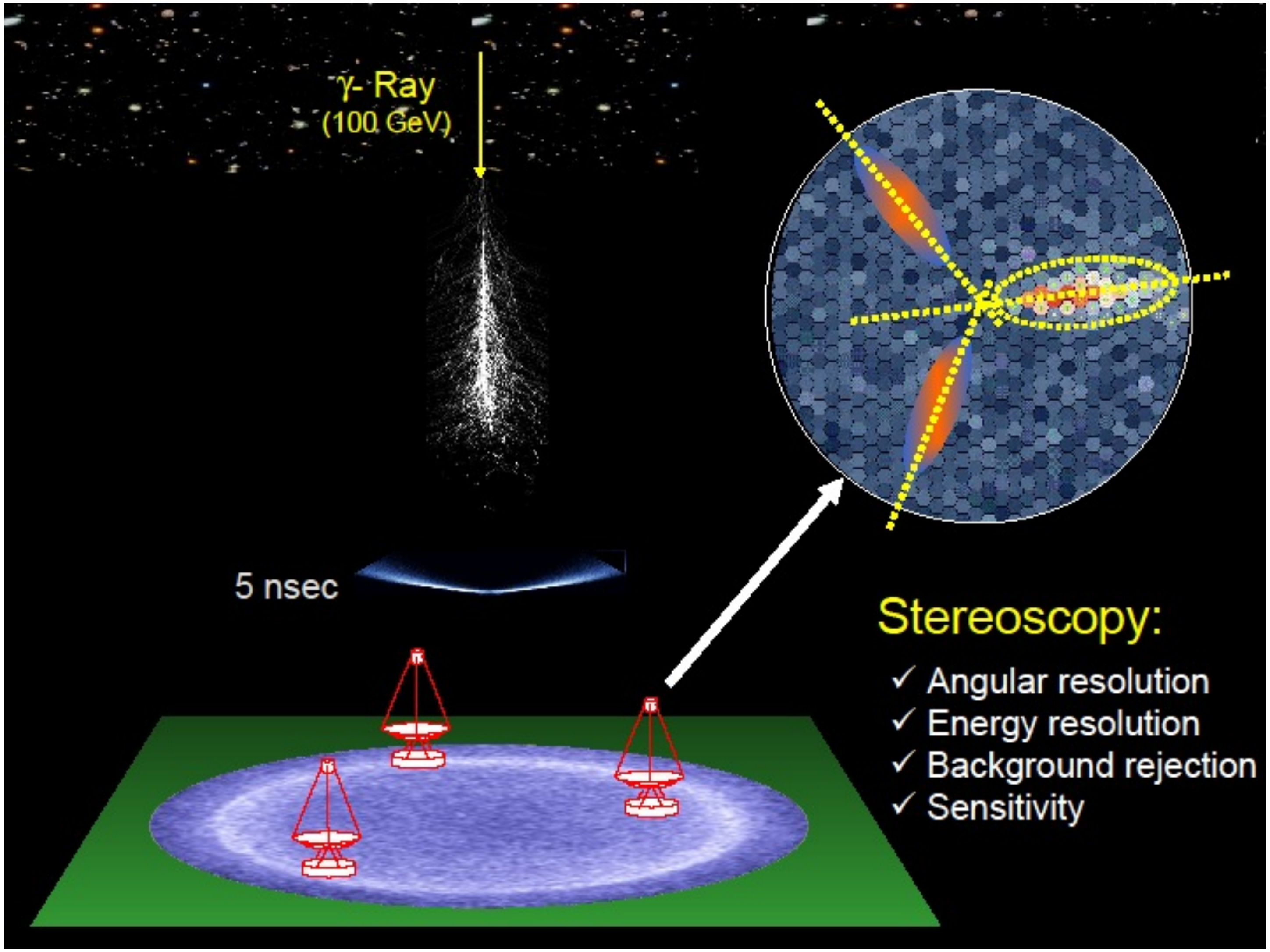
At the very highest energies you can do γ–ray astronomy from the Earth´s surface

- Detection is indirect, via the cascades of particles and photons that are produced in the atmosphere…
- Related to Auger telescope, but this telescope is specialized in the detection of cosmic rays.

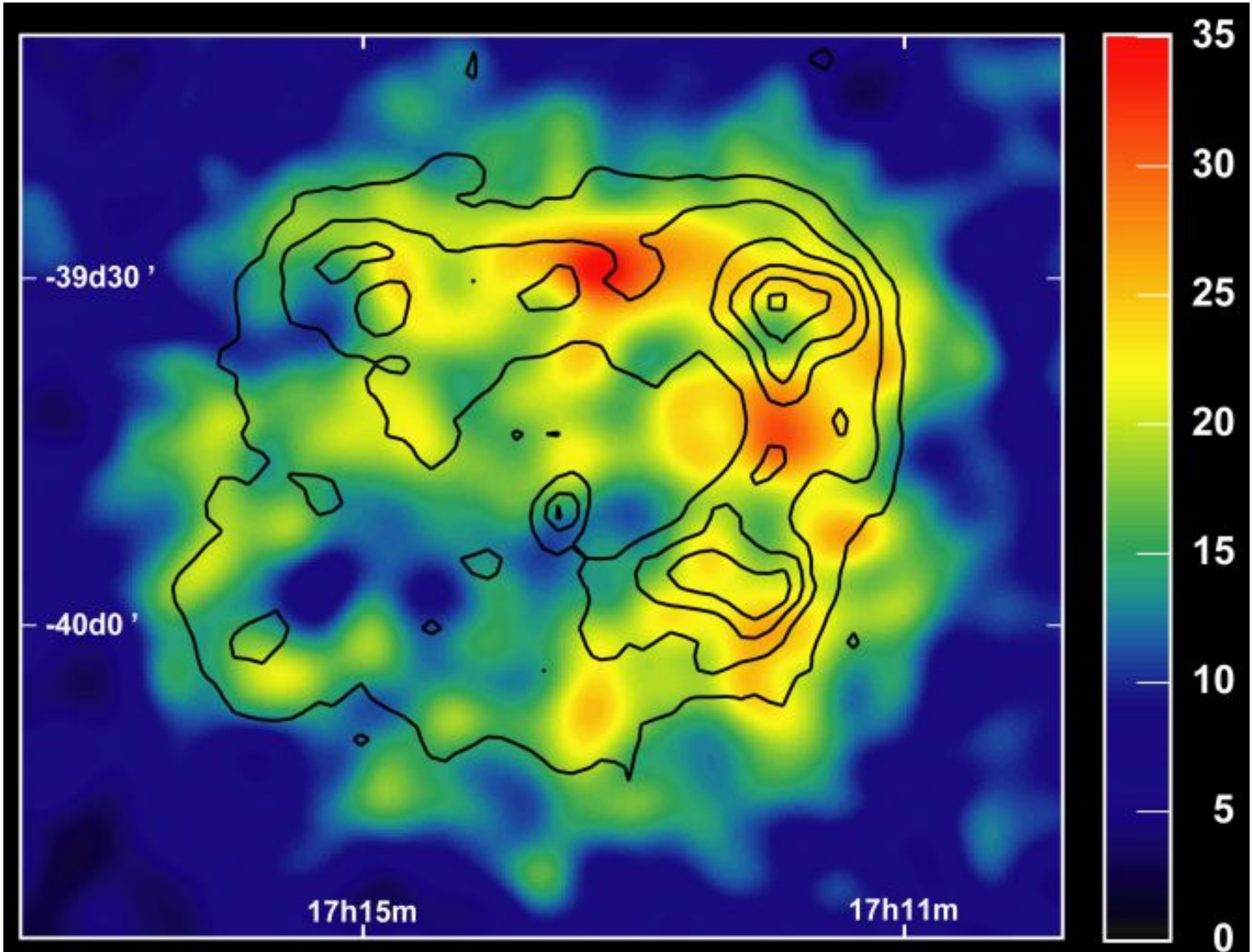
Electromagnetic cascades



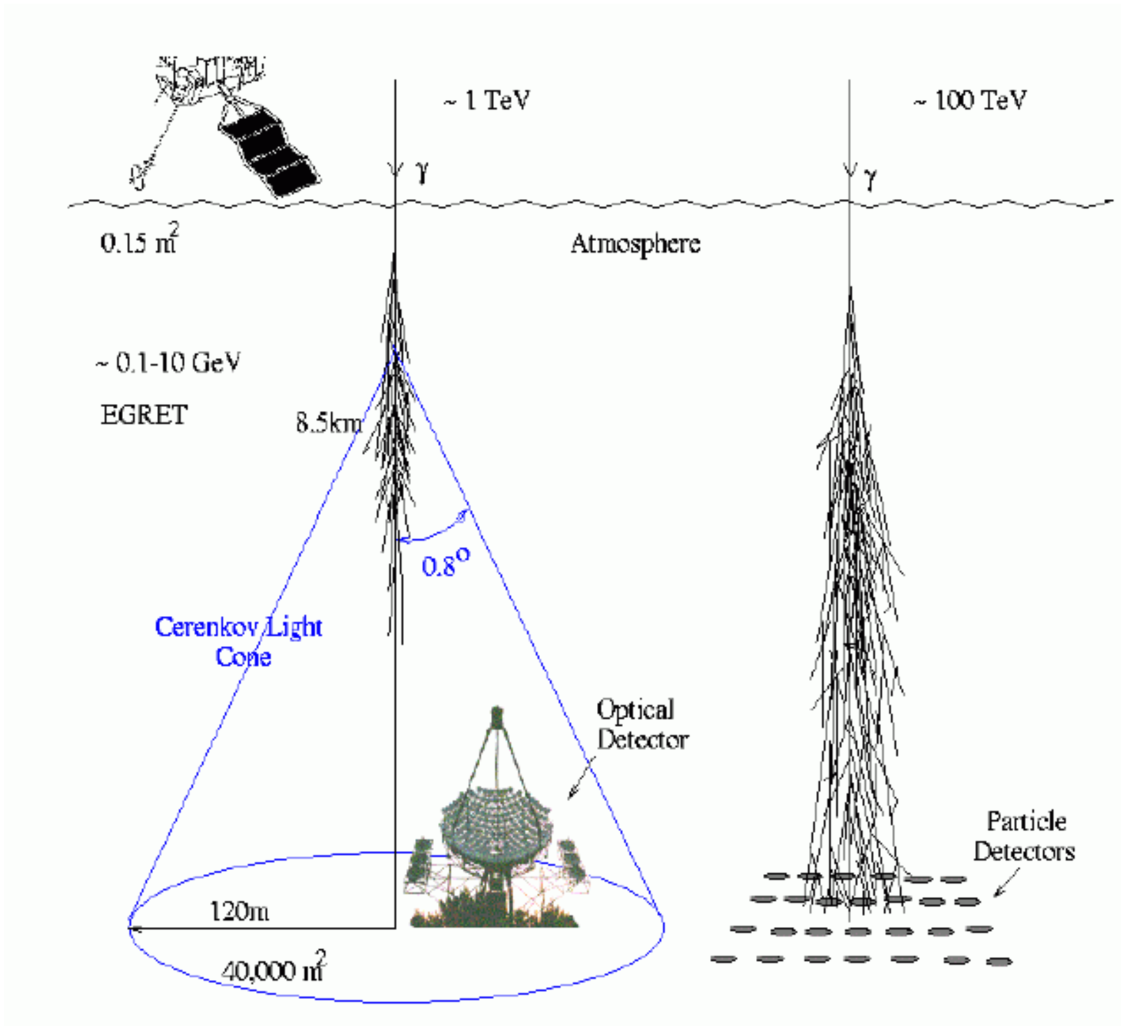

γ- Ray
(100 GeV)
10 km
5 nsec
~ 120 m
Intensity
➔ Primary Energy
Image Axis
➔ Shower Direction
Image Shape
➔ Type of Particle


γ- Ray
(100 GeV)
5 nsec
Stereoscopy:
✓ Angular resolution
✓ Energy resolution
✓ Background rejection
✓ Sensitivity

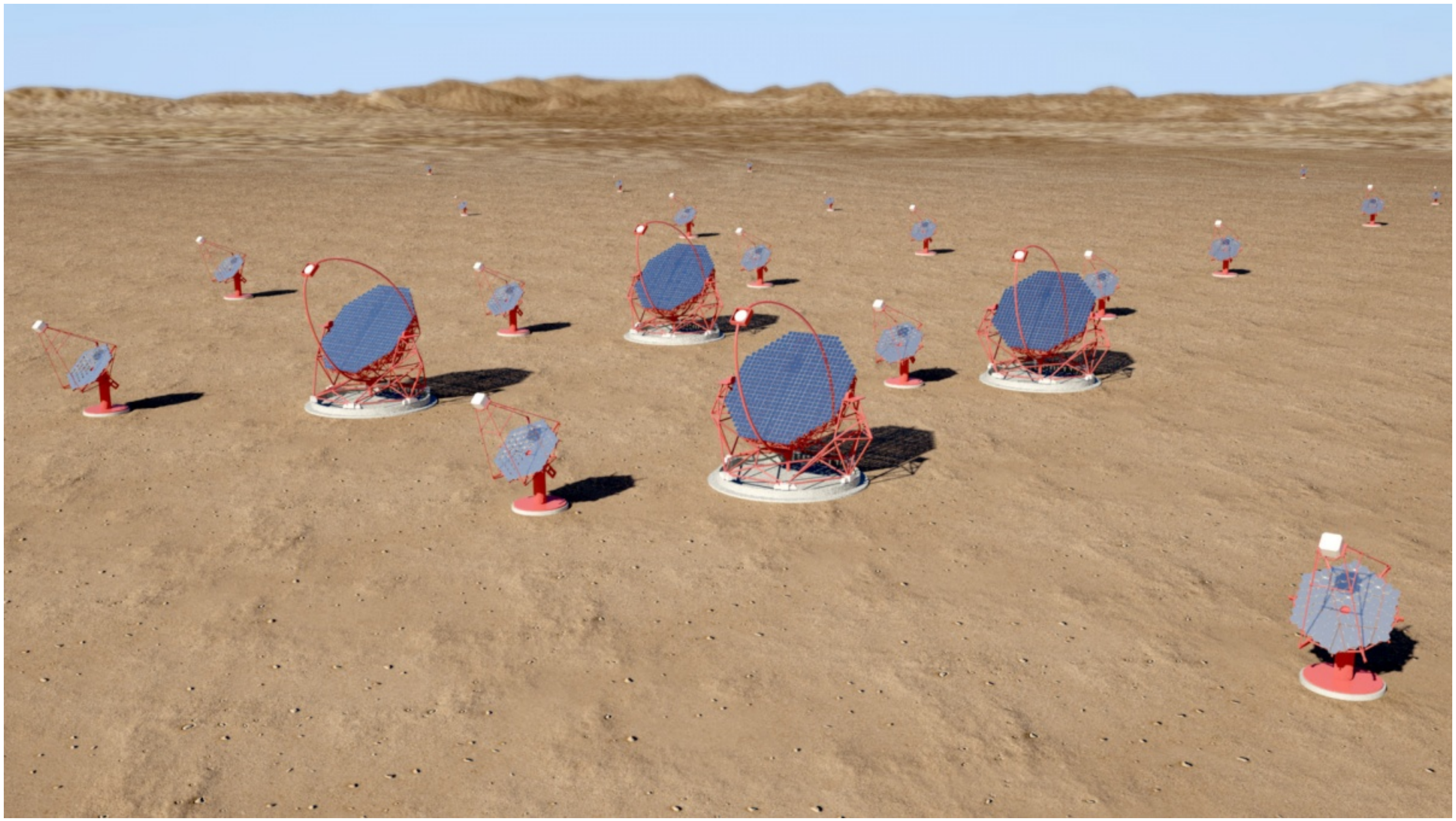
HESS image of supernova



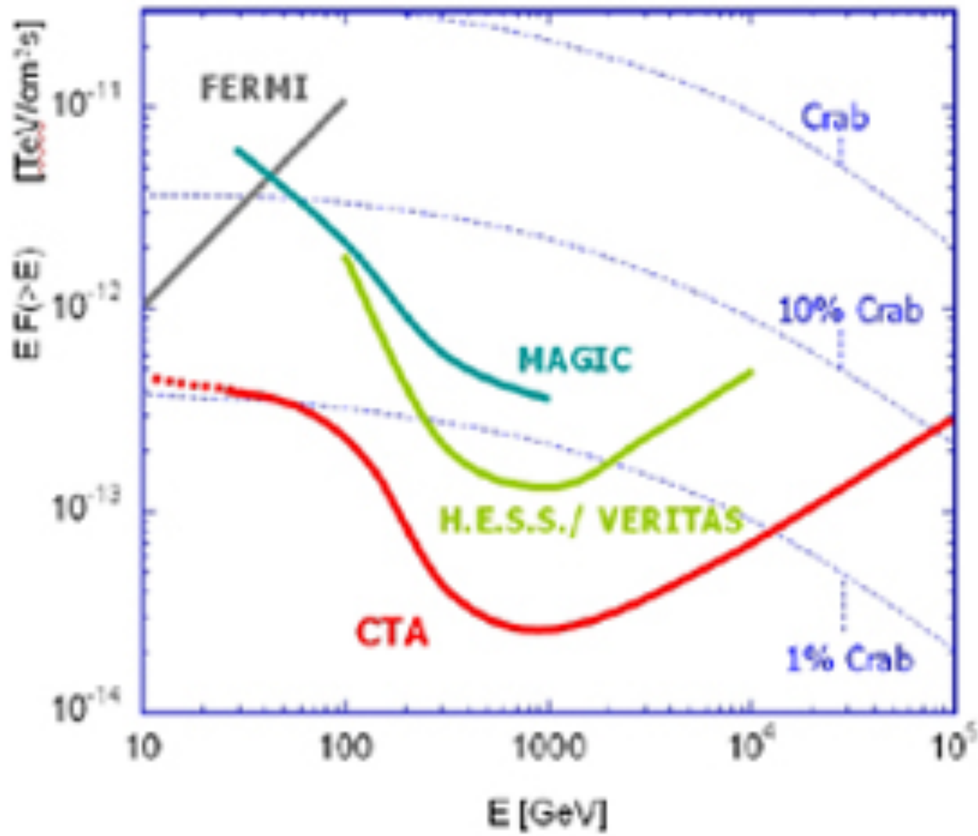
Electromagnetic cascades



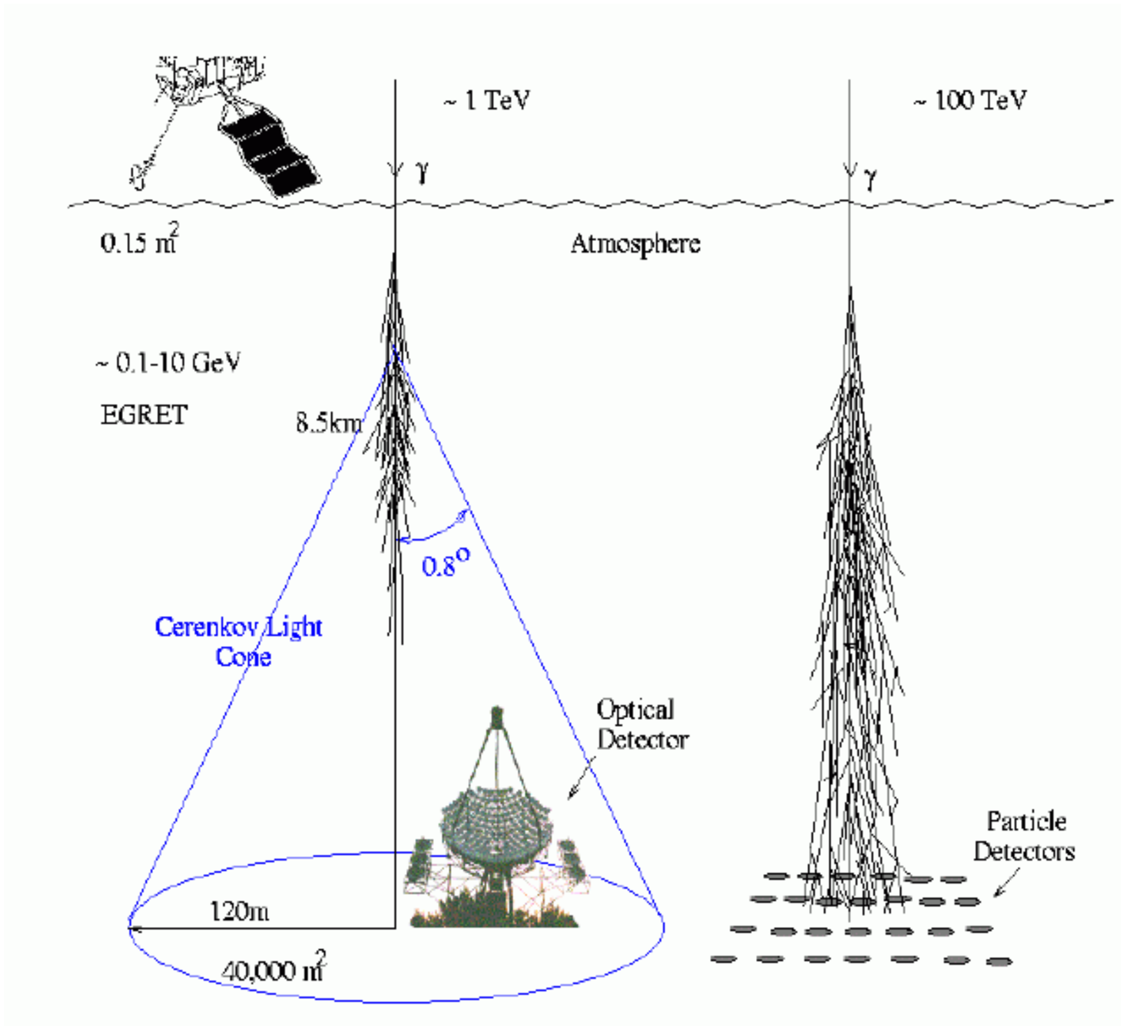
CTA (Cherenkov Telescope Array)



Cherenkov Telescope Array

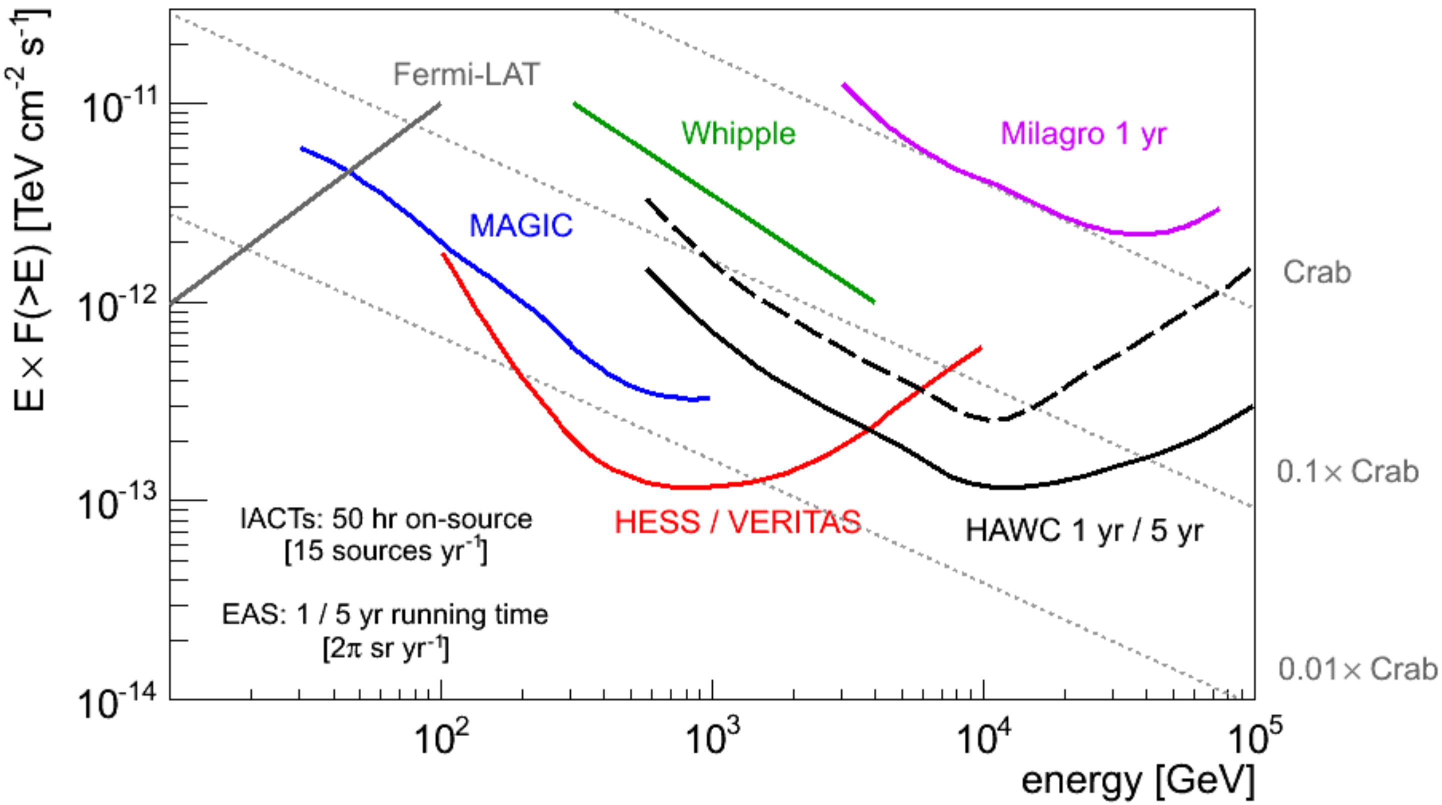


Particle cascades



HAWC (High-Altitude Water Cherenkov Observatory)

Comparing sensitivities



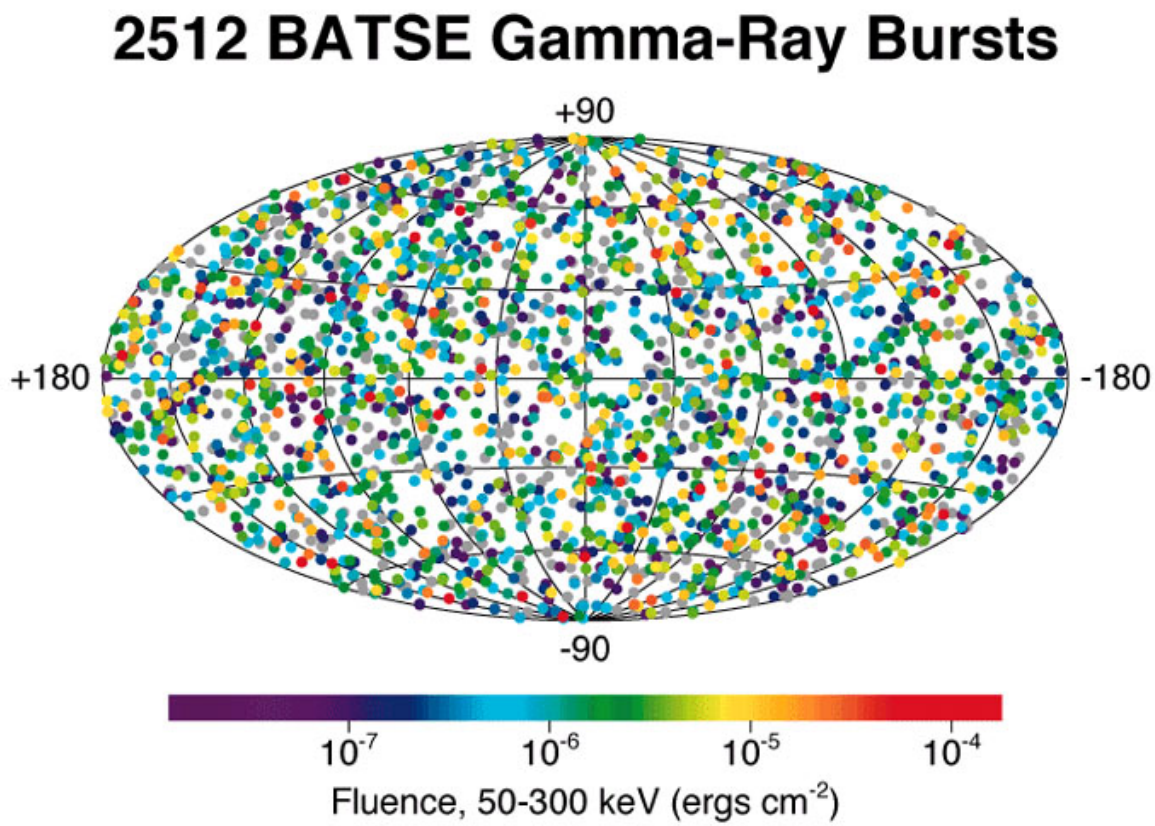
Some contributions of X-ray astronomy

- X-ray binaries
- Active galactic nuclei
- Intracluster medium
- Supernova
- Now sensitivity is so high that many types of objects (i.e. stars) are easily detected.

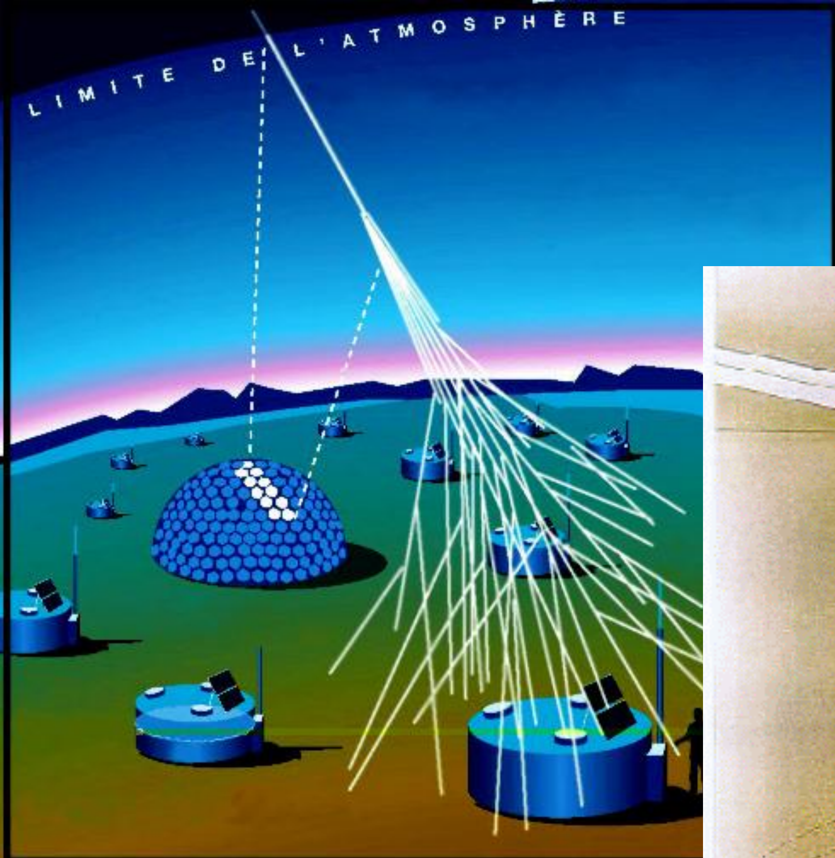
Gamma-ray Bursts (GRBs)

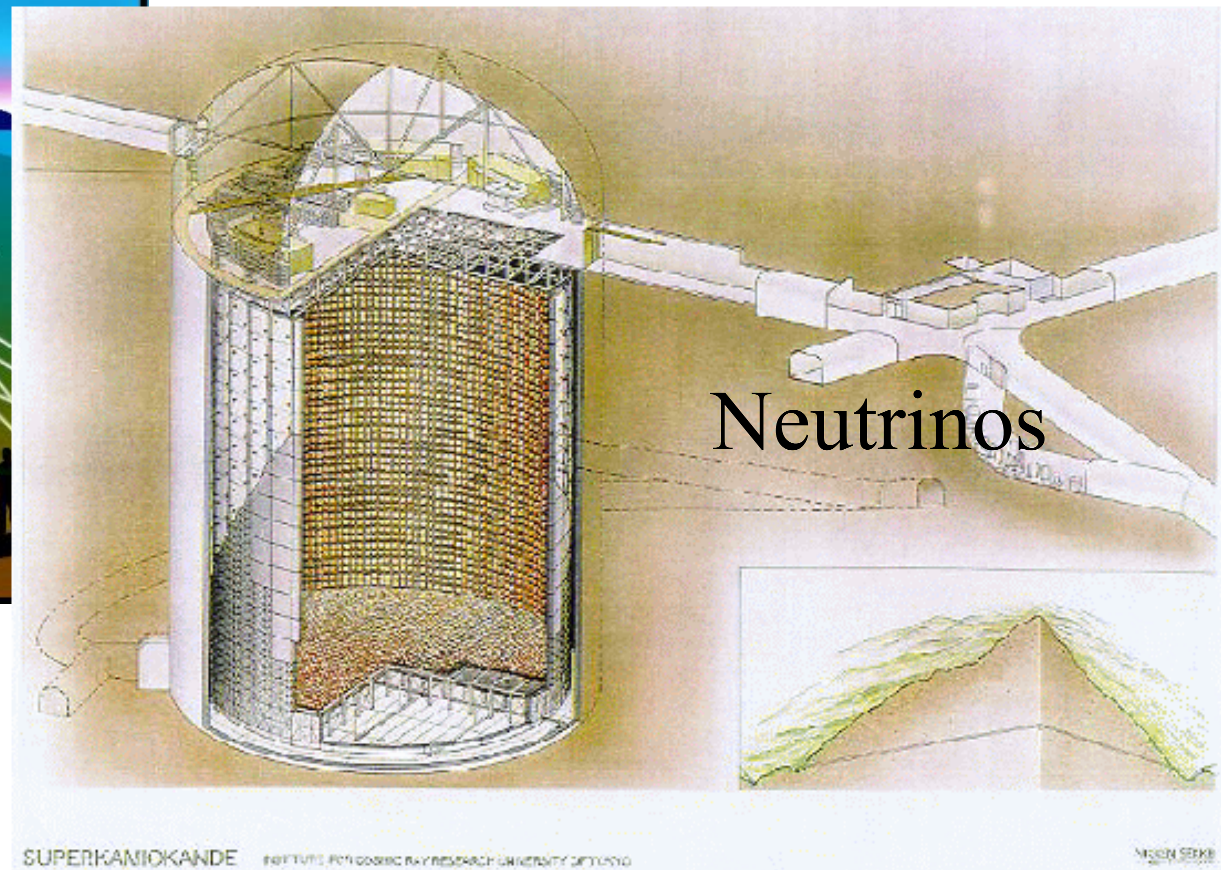
- Perhaps best example of the power of multiwavelength astronomy.
- Its nature became clear only after coordinating observations of afterglows covering most of the electromagnetic spectrum.

Gamma-ray bursts



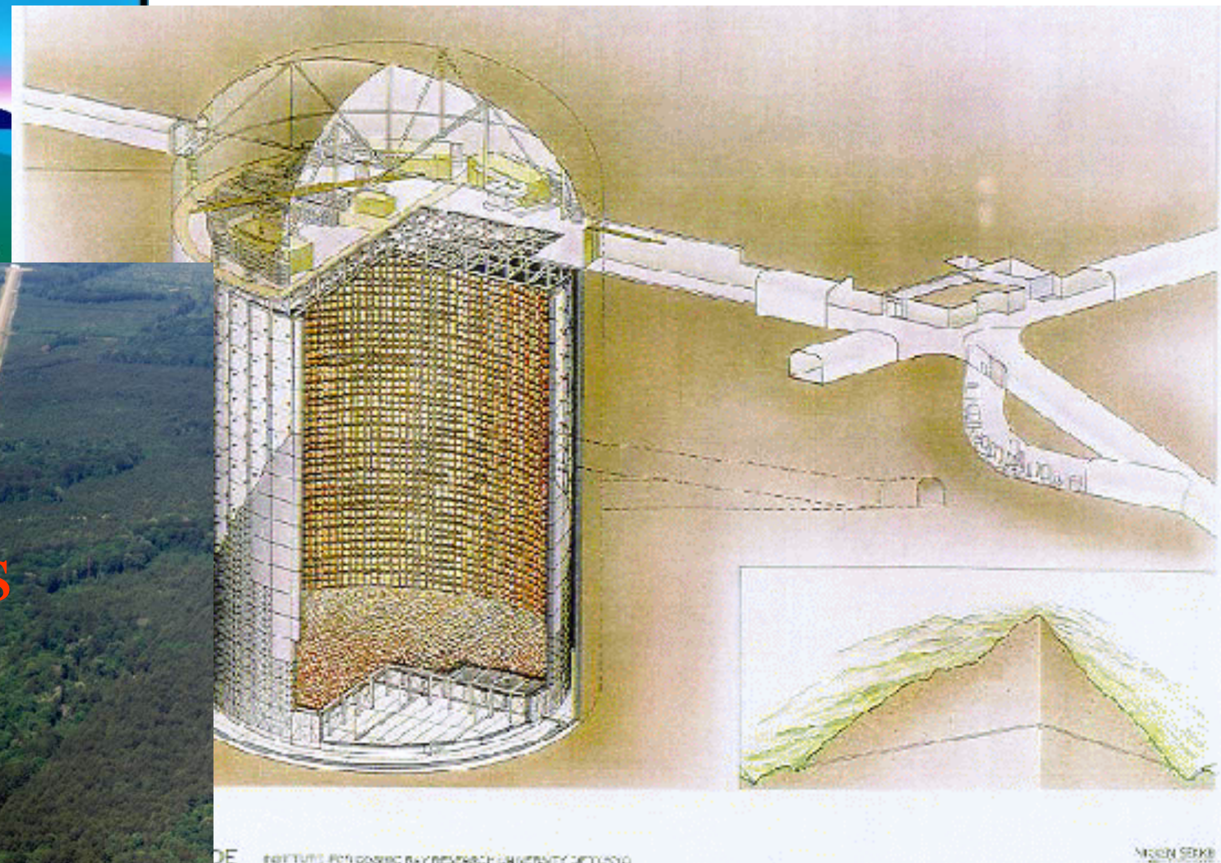

LIMITE DE L'ATMOSPHÈRE
Cosmic rays





Neutrinos

Gravitational waves



Multimessenger astronomy!

Conclusions

- Multiwavelength astronomy is very important these days.
- Specialize in one of the windows but keep informed and have collaborators in the other windows.
- The same applies for the theoreticians.

Conclusiones Rayos-X y -γ

- La mayor parte de las observaciones se tienen que hacer desde el espacio.
- Se usan técnicas diversas para enfocar y detectar la radiación dependiendo de su energía.
- A energías muy altas (TeV) la detección se hace mediante las cascadas atmosféricas que se producen.

Poder de penetración