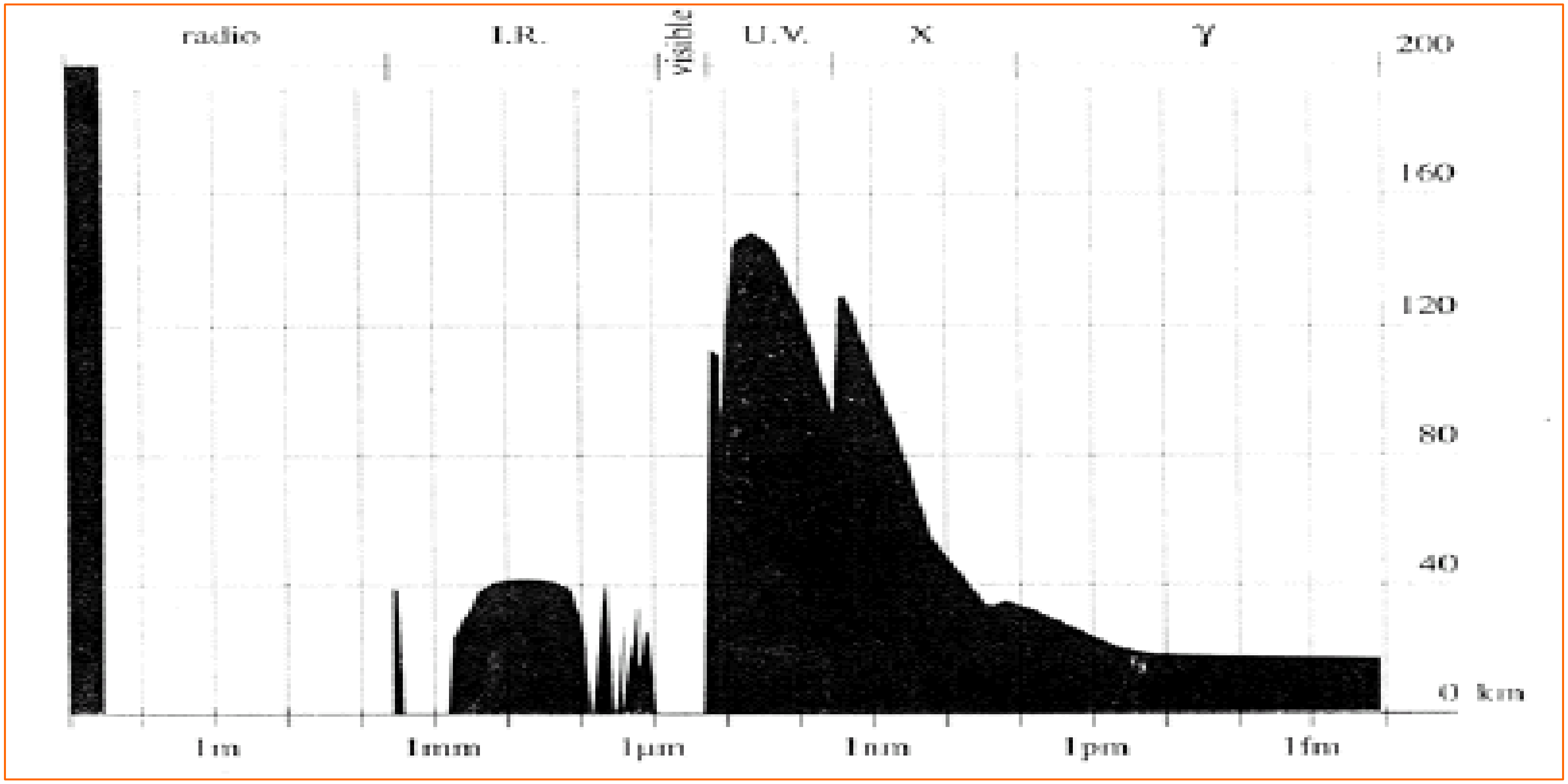
# Instrumentation in Ground and Space Astrophysics

An elementary introduction




Apart from the visible and radio windows,
observation at other wave lengths
usually requires going to space

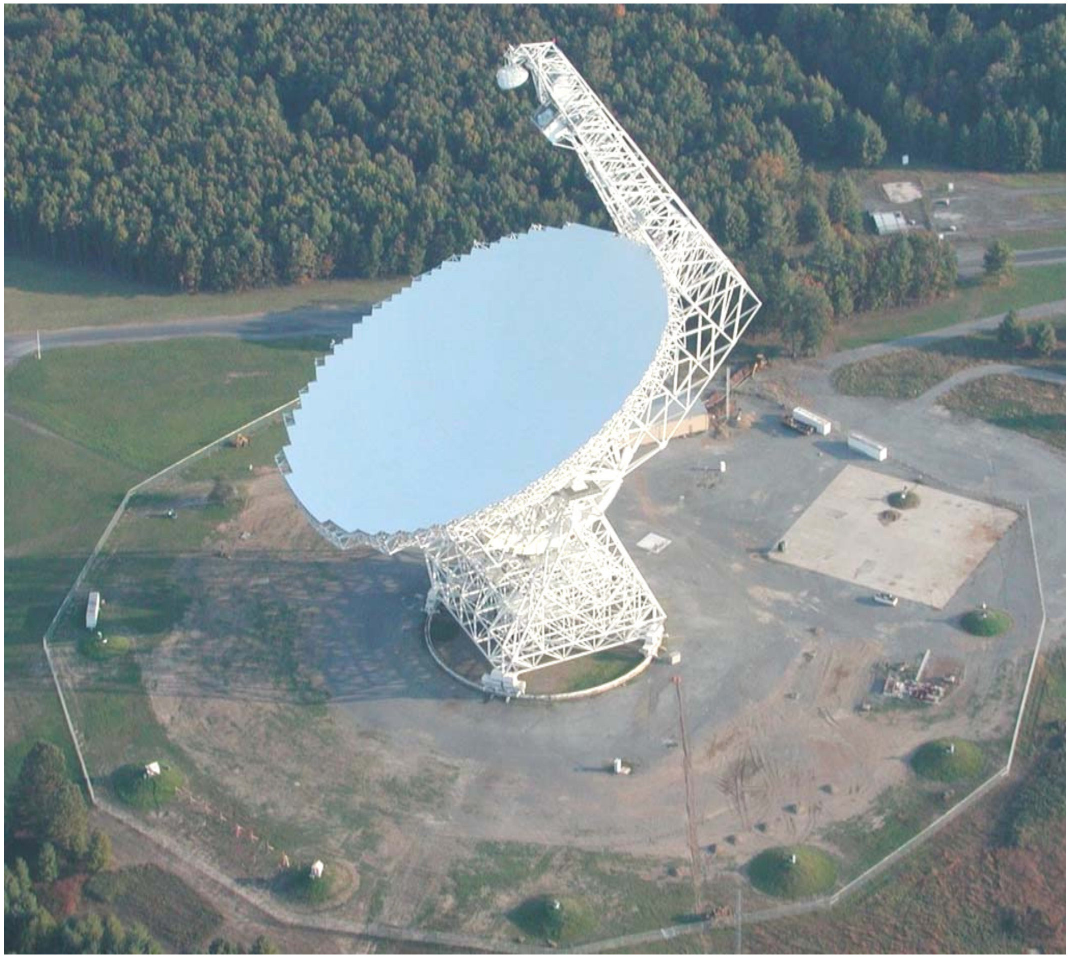
# RADIO MICROWAVES

# The Very Large Array (VLA)

# VLA

# The Jodrell Bank antenna

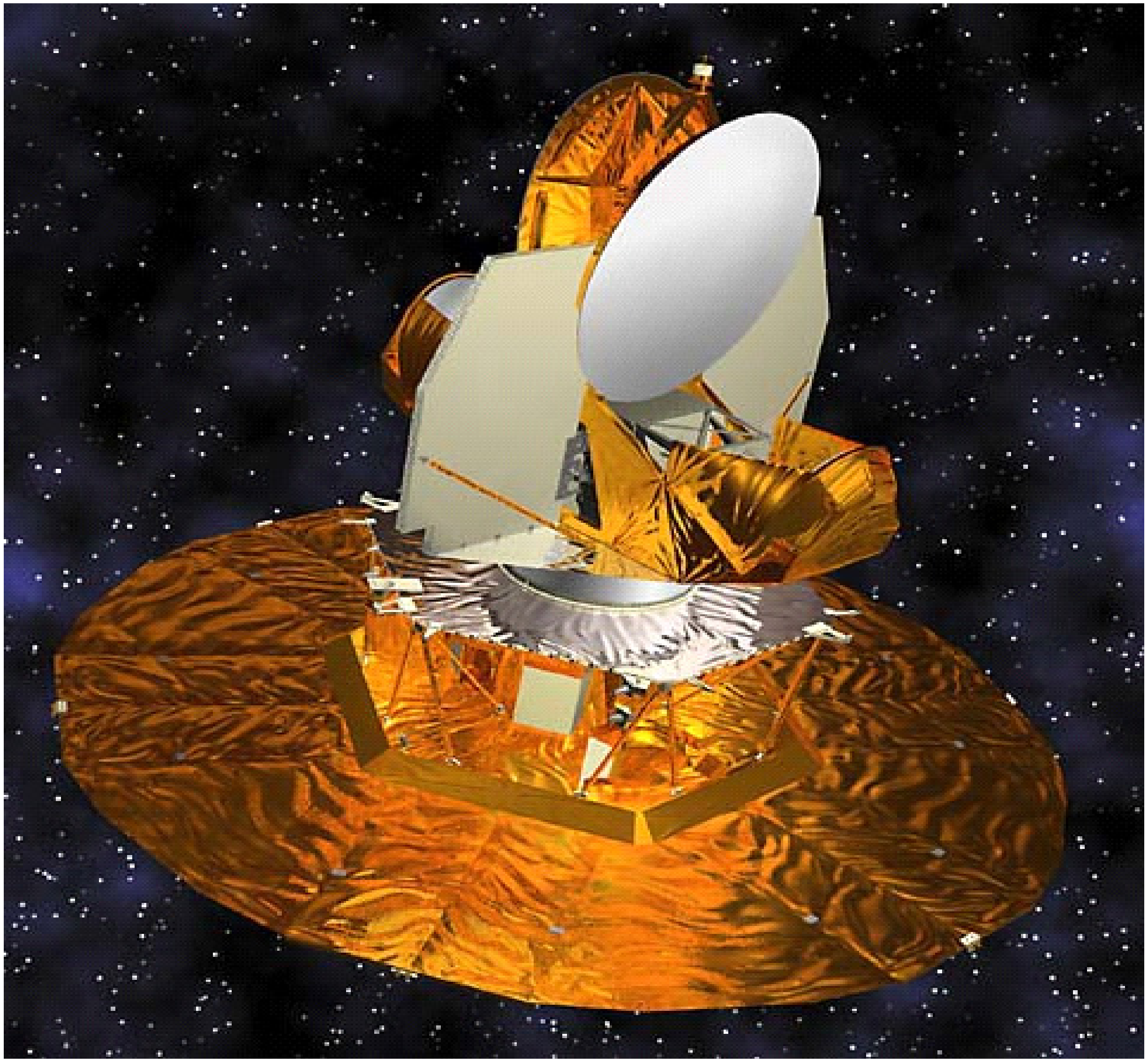
# 100 m Green Bank radio telescope in West Virginia (USA) (0.6 to 30 cm)



Very Long Baseline Array (VLBA) is an array of ten 25 m diameter radio telescopes spread over the northern hemisphere from Hawaii to the Virgin Islands. All telescopes can operate between 90 cm and 7 mm wavelengths.

# The Arecibo antenna

# Wilkinson Microwave Asymmetric Probe, WMAP



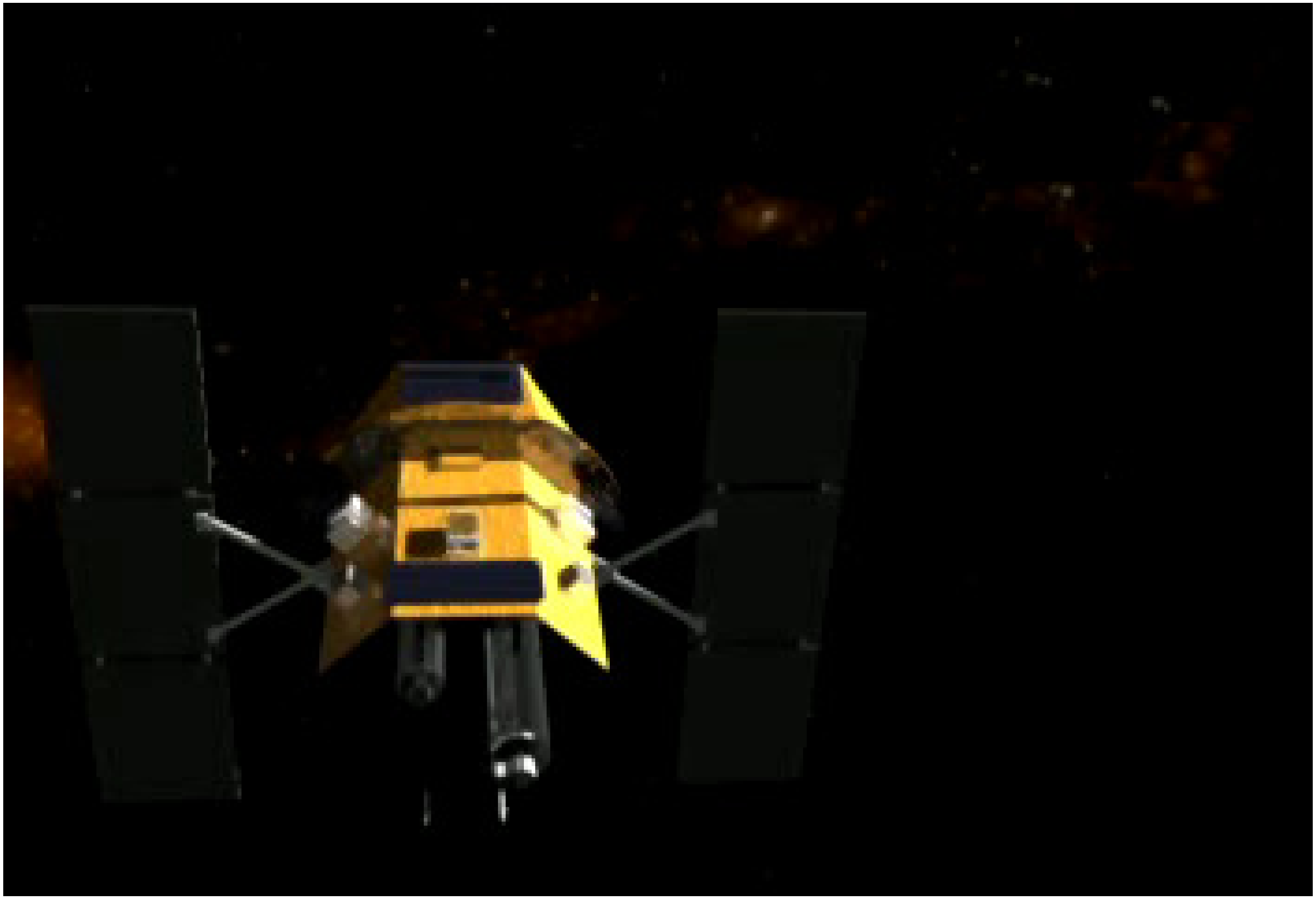
VISIBLE

INFRARED

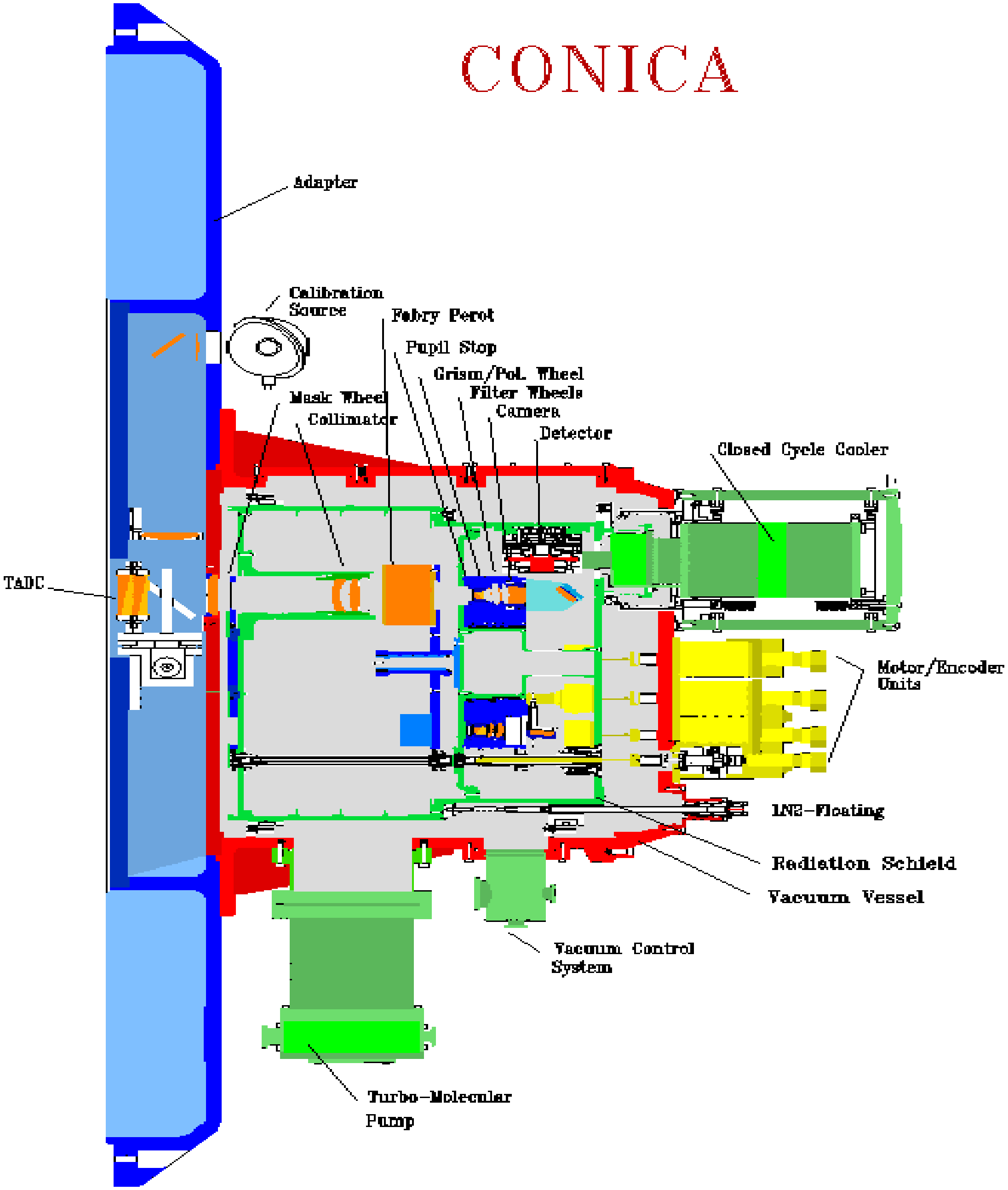
ULTRAVIOLET

# The Hubble Space Telescope

# GRB's : SWIFT watching a baby black hole



# The Very Large Telescope




# Coudé Near Infrared Camera

1 to 5µm

256×256 HgCdTe (1-2.5µm)

1024×1024 InSb (1-5µm)

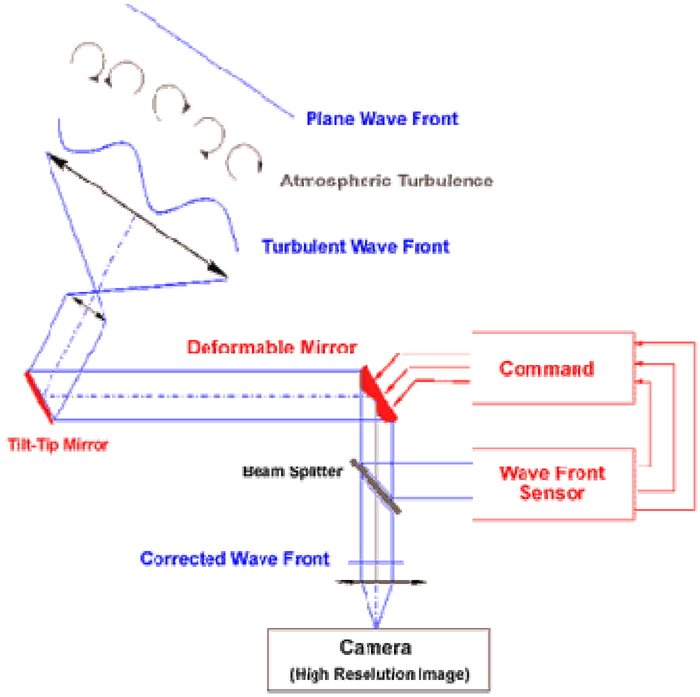
35K

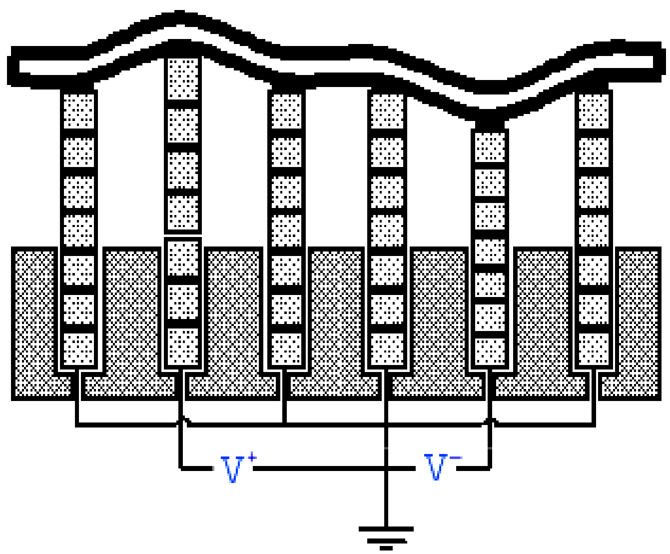
NAOS-CONICA at VLT YEPUN

ESO PR Photo 33l/01 (3 December 2001)

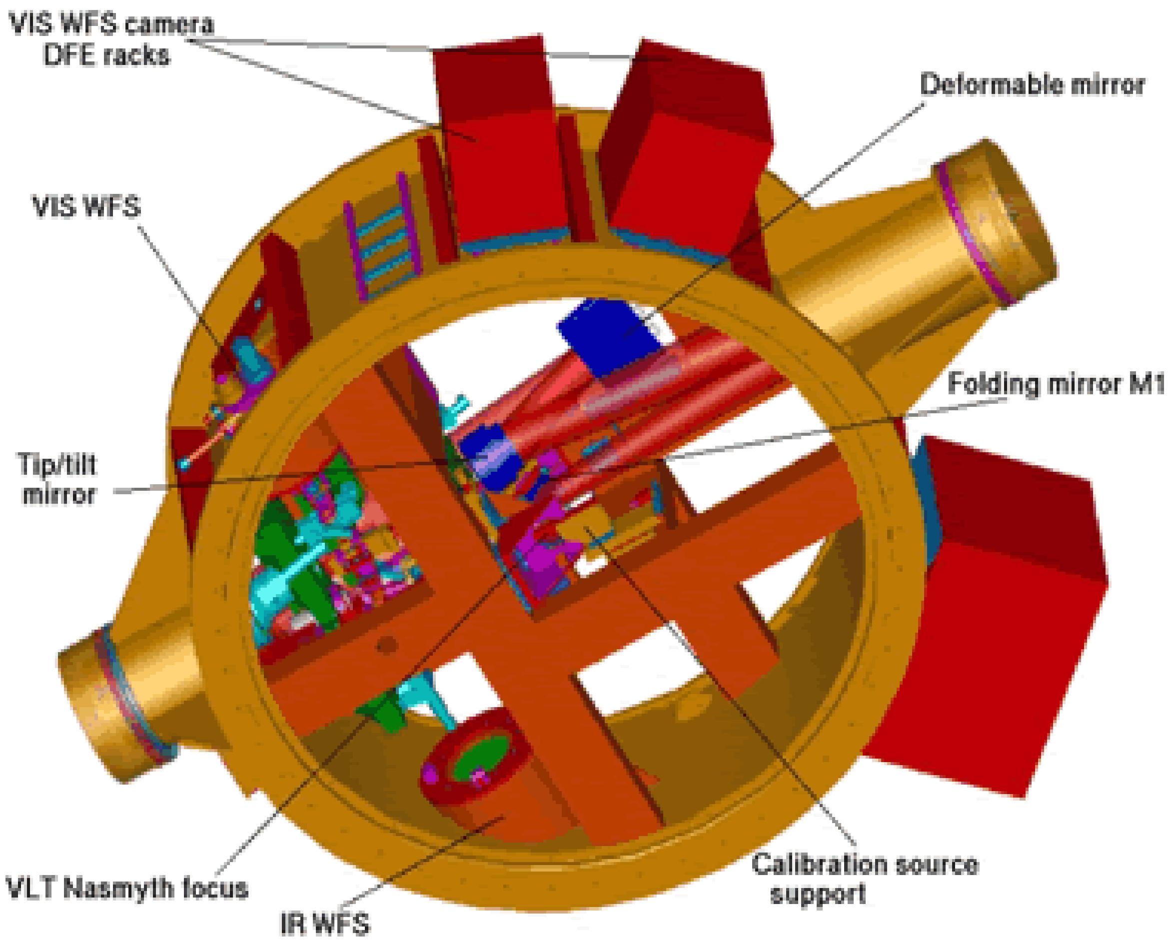


From left to right: the telescope adapter (dark blue), NAOS (light blue), and the CONICA cryostat (red). The control electronics is located in the white cabinet.

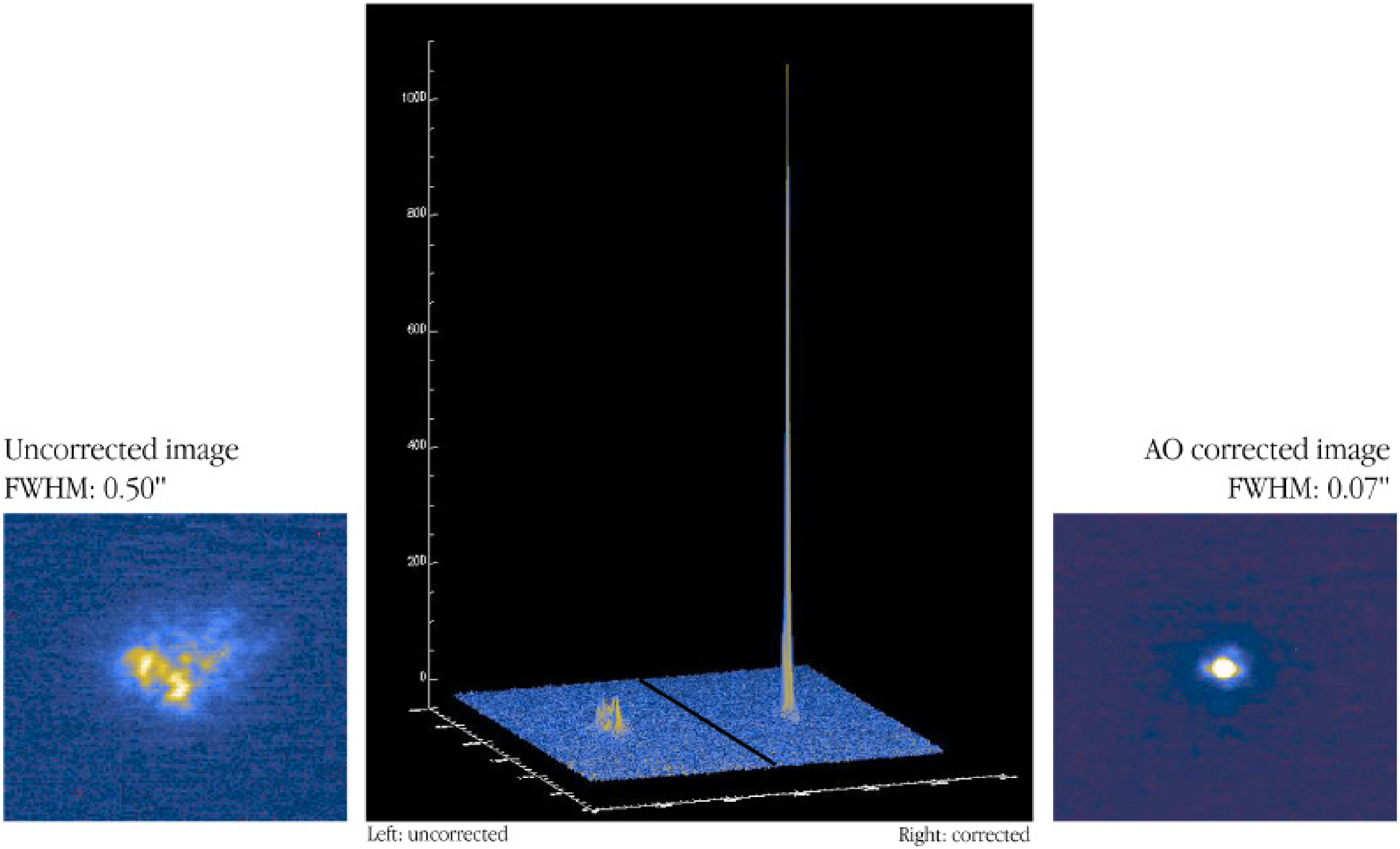



NAOS (Nasmyth Adaptive Optics System) uses a flexible mirror that can be deformed very rapidly (faster than the characteristic frequency of atmospheric turbulences). A star is used as reference. Part of the light collected in the telescope is deviated by a dichroic plate toward a pixel array through a corresponding array of micro-lenses, each micro-lens focusing the image on the associated pixel. The mirror – a reflective membrane stretched on a circular ring – is deformed to bring the reference star image in the centre of each pixel using 185 piezoelectric fingers that can stretch over 10 µm with a precision of 30 nm.

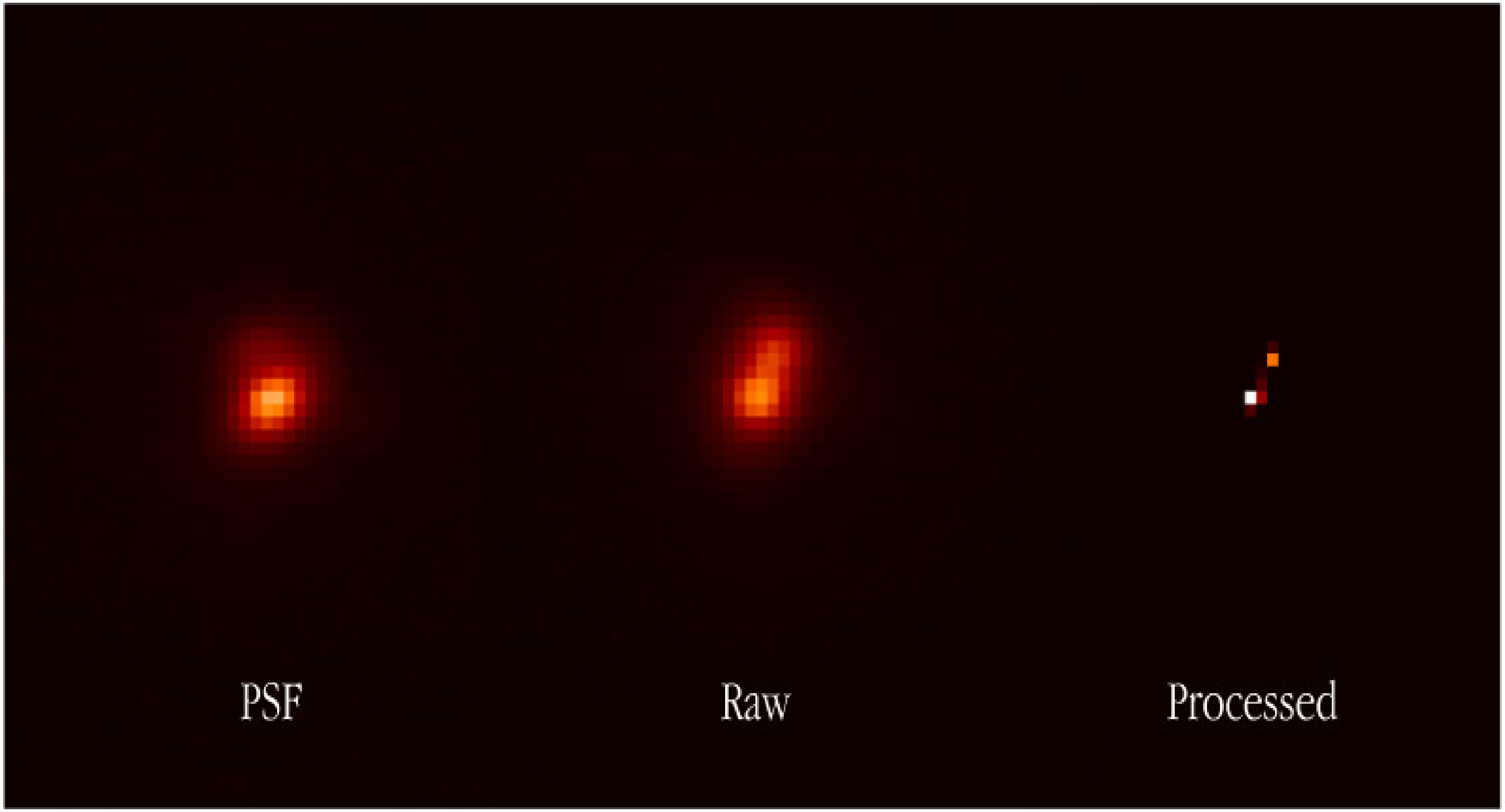



NAOS field of view varies between 14 and 73 arc sec. NAOS uses two wave front sensors, one in the visible and one in the near-infrared spectral range. One speaks of diffraction limited imaging.

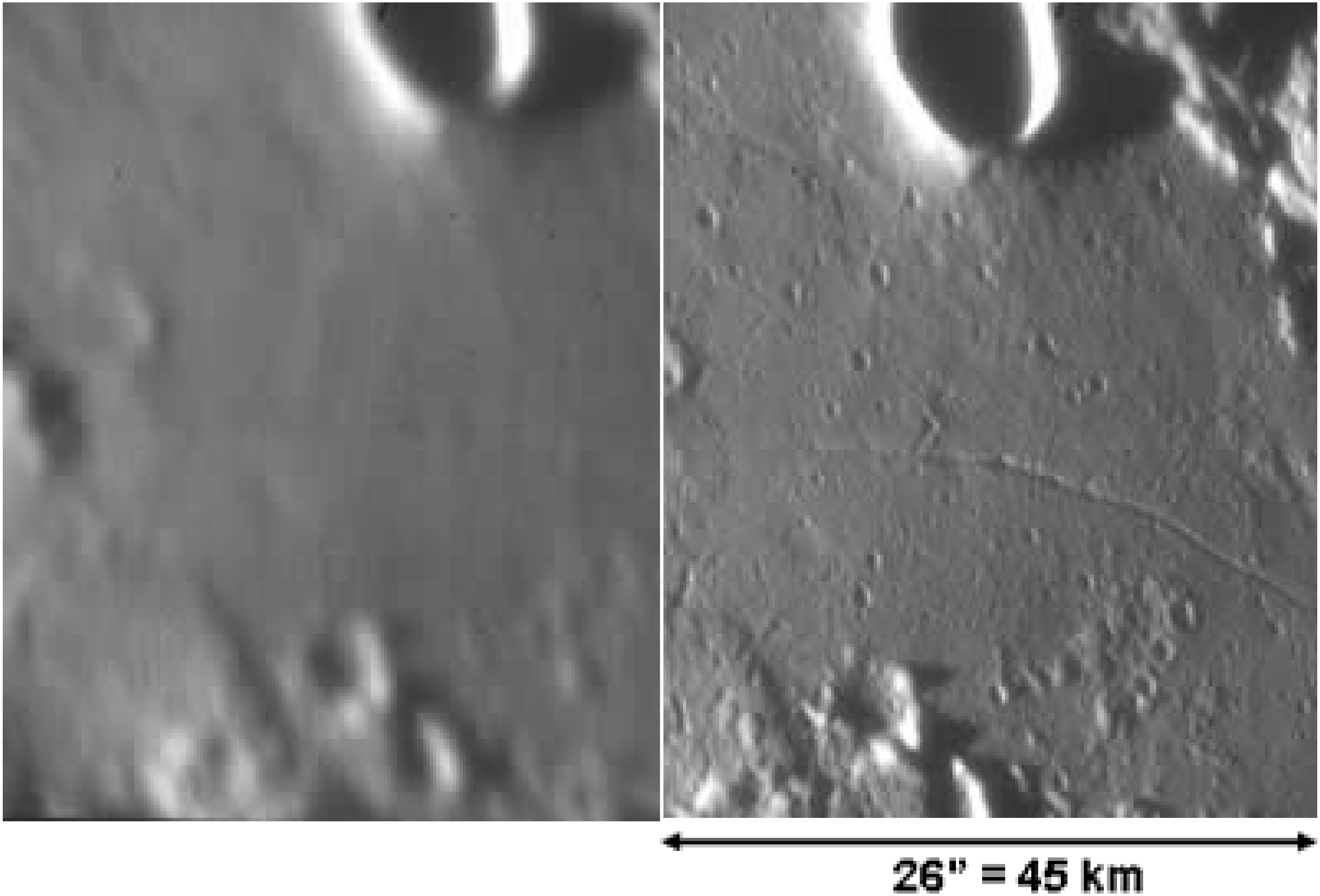


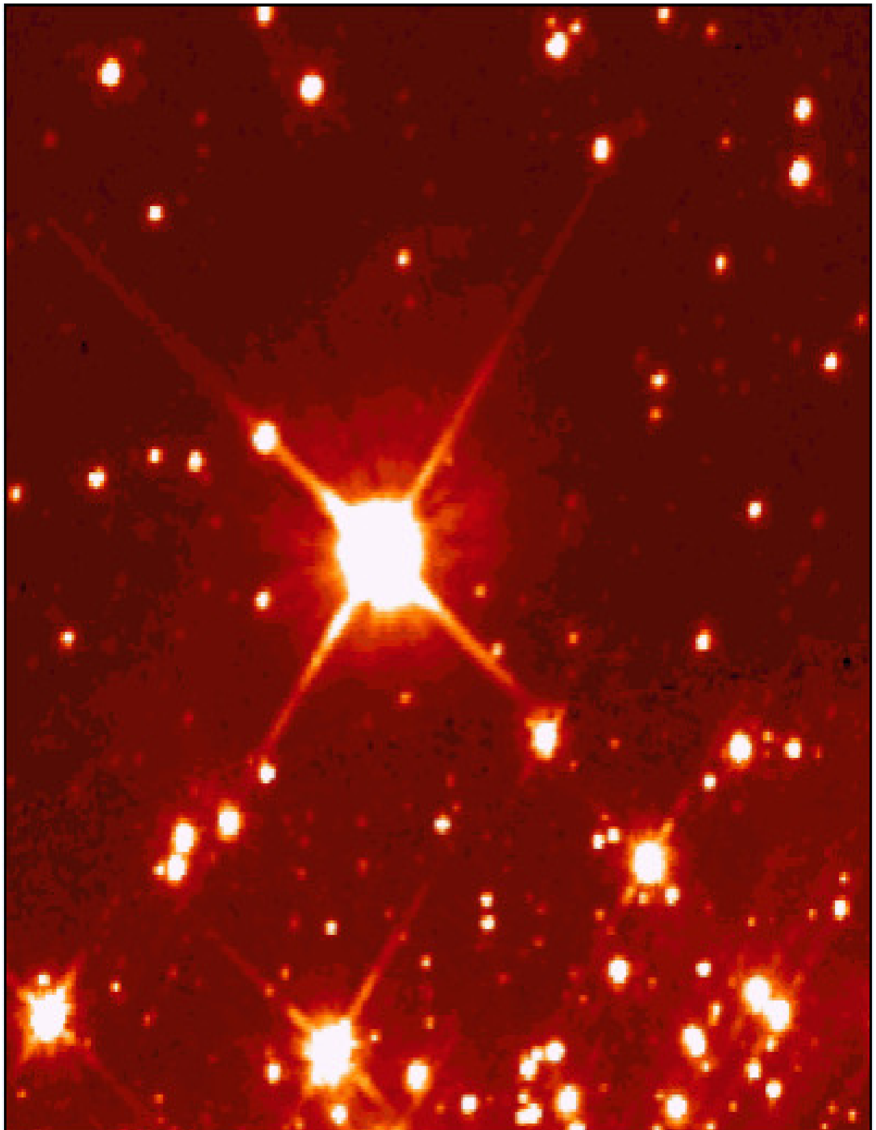

"First Light" for NAOS-CONICA at VLT YEPUN
(November 25, 2001)

ESO PR Photo 33a/01 (3 December 2001)

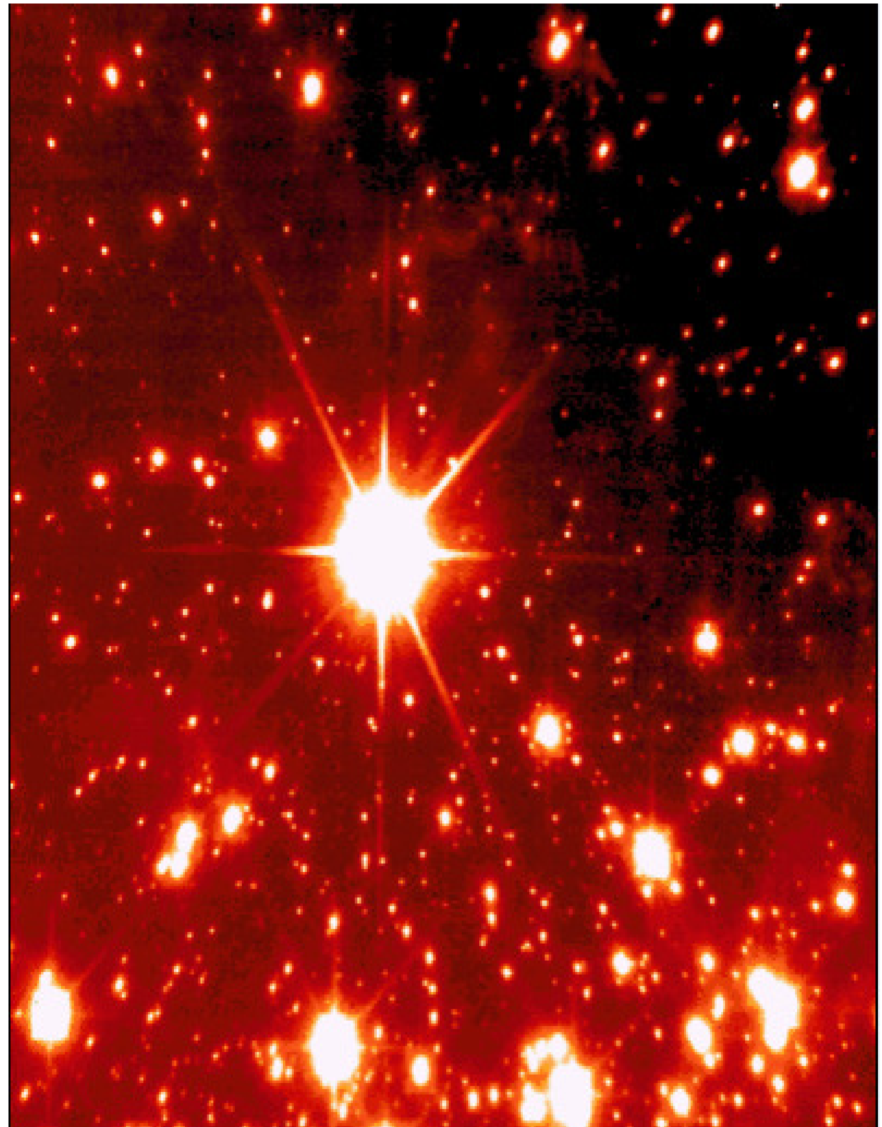



Separation of a Very Close Double Star
(VLT YEPUN + NAOS-CONICA)

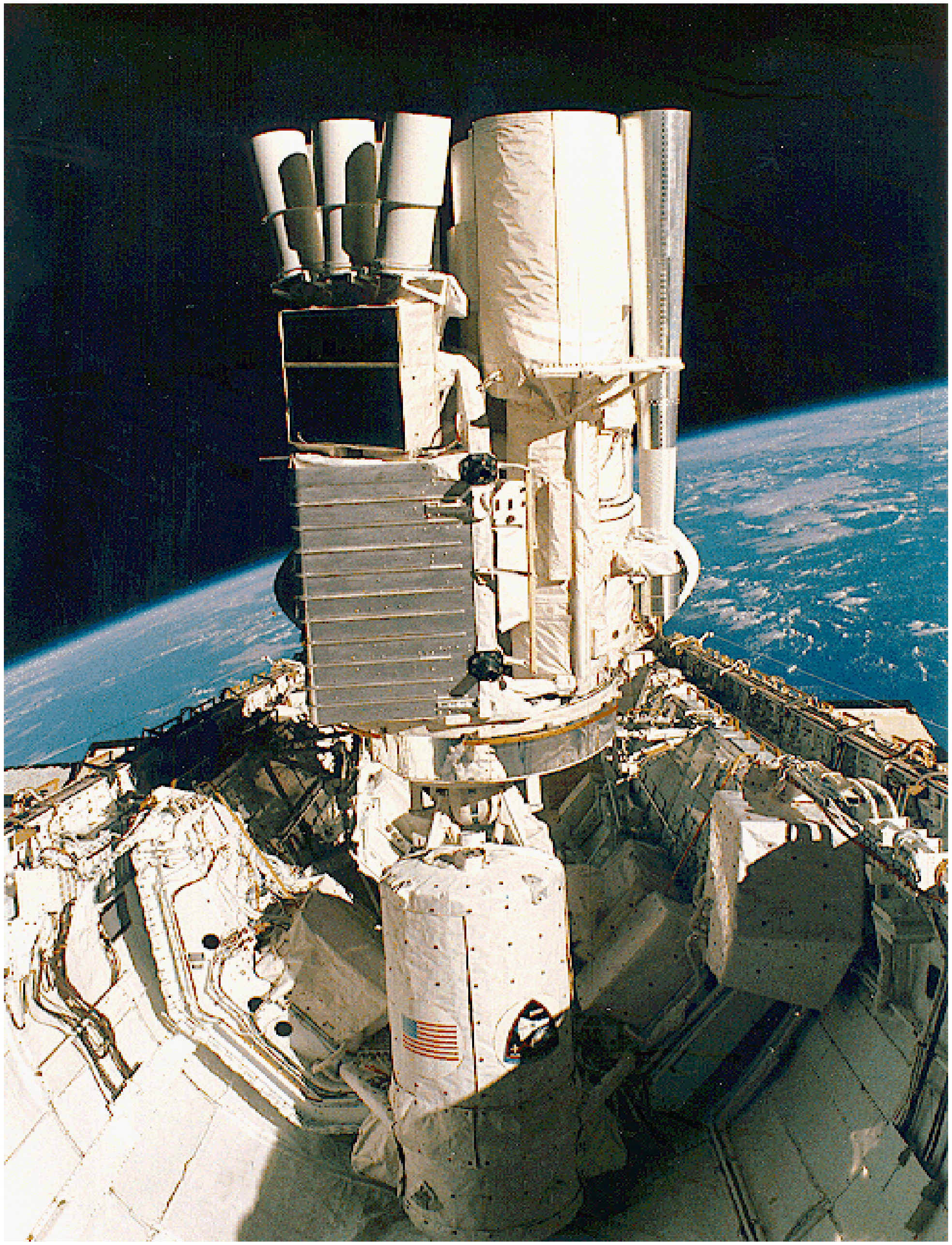

26" = 45 km



HST - WFPC2 (I-band)



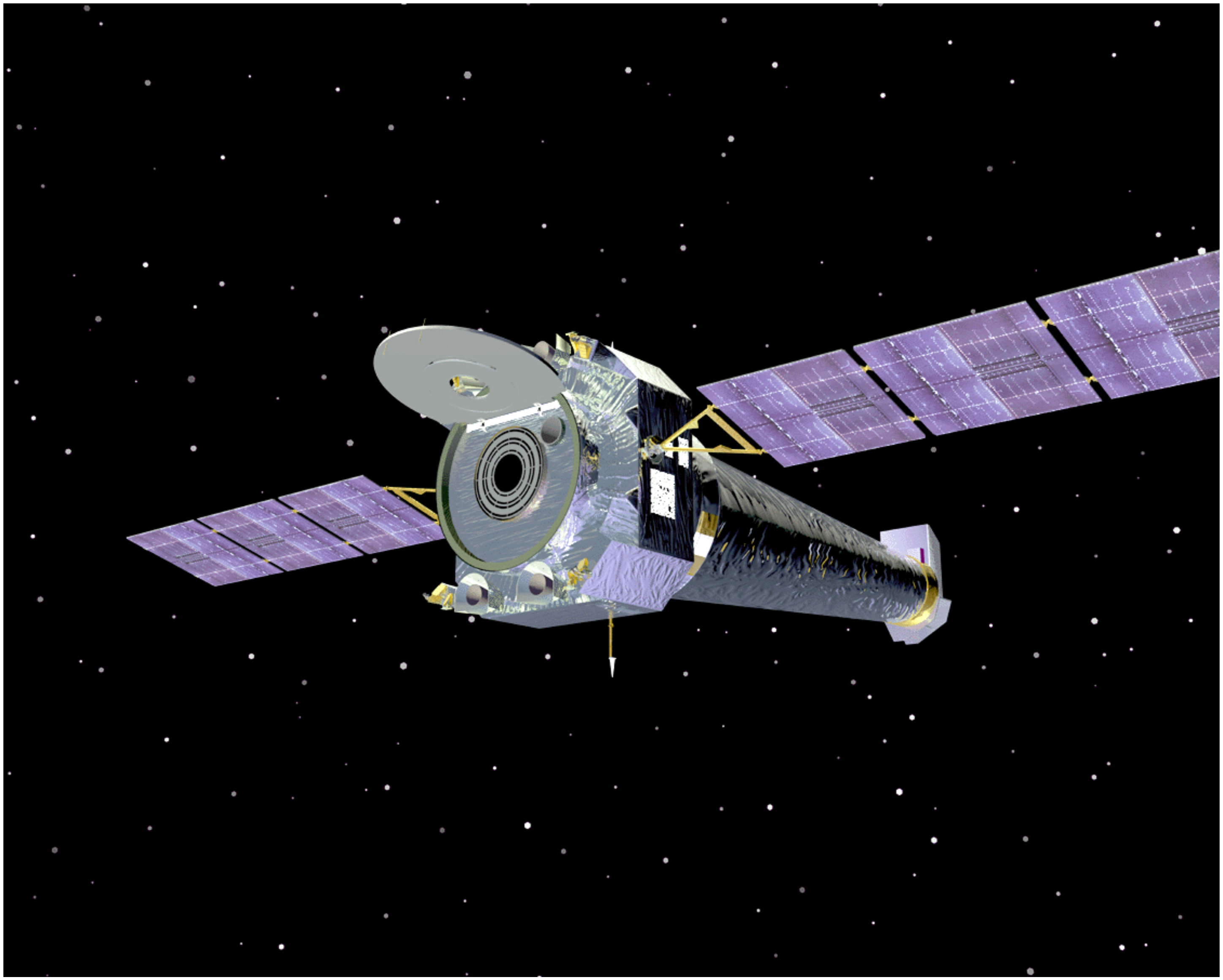
VLT YEPUN - NAOS - CONICA (K-band)



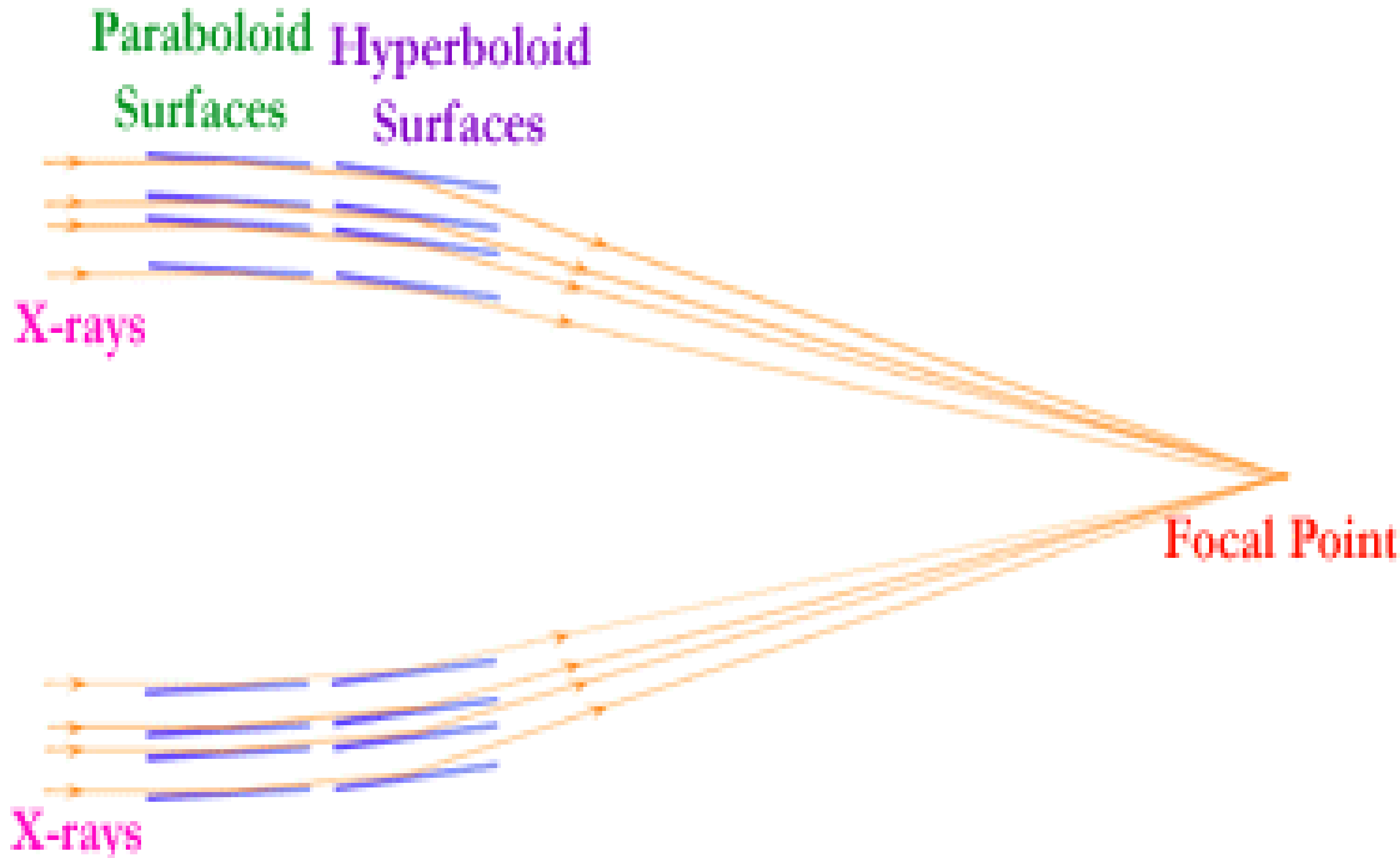
The
Ultraviolet
Imaging
Telescope

# X RAYS

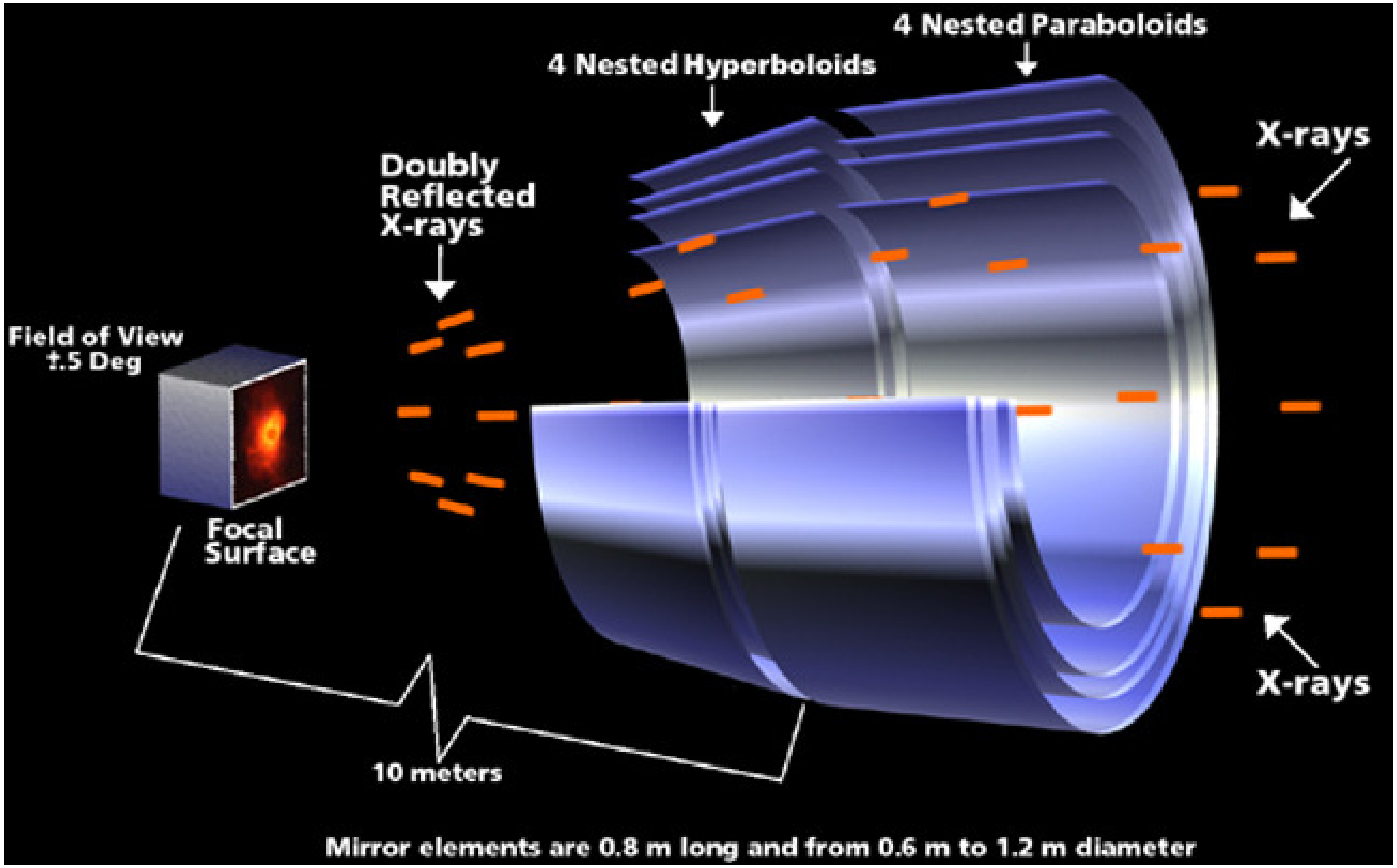
# CHANDRA



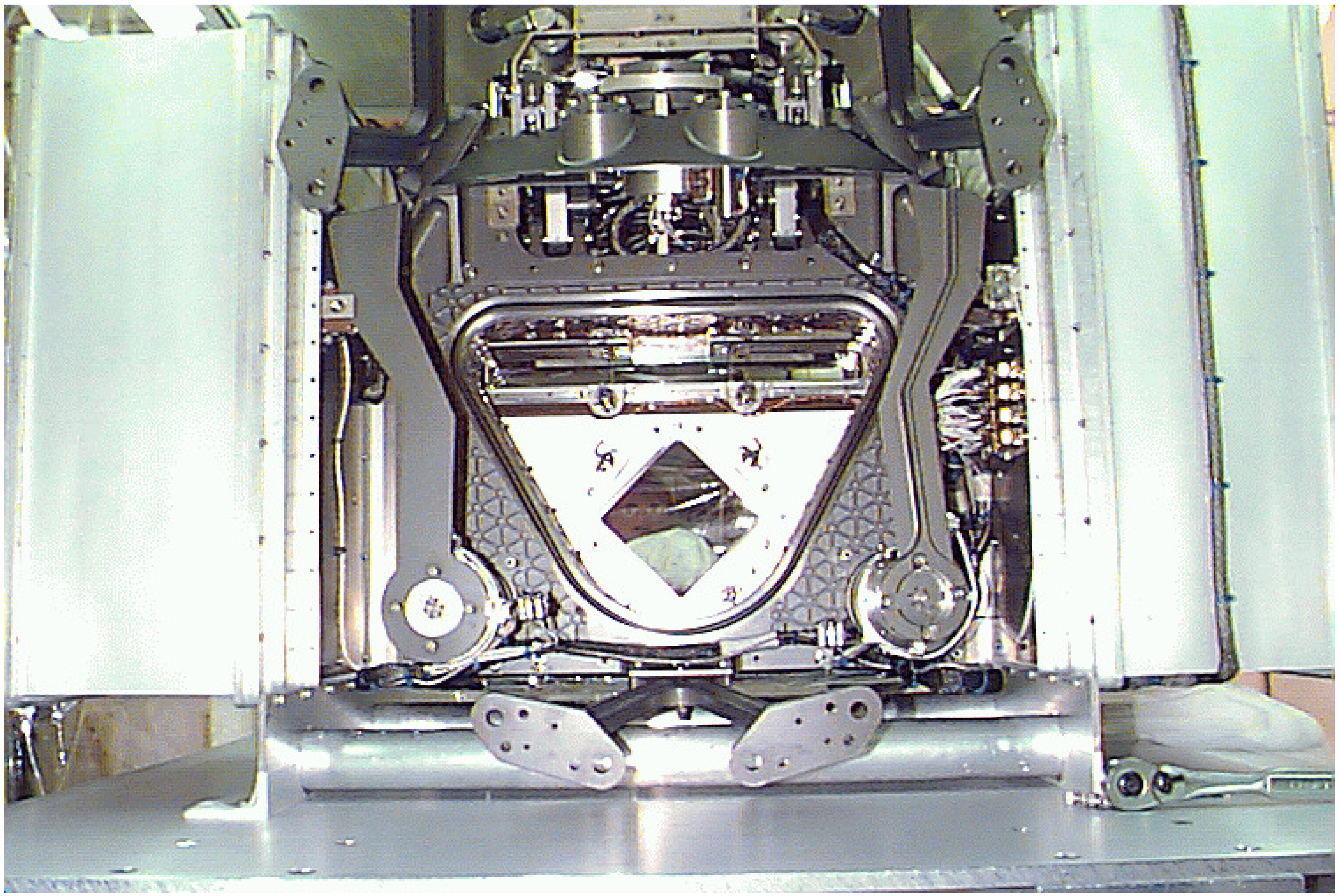
# Schematic arrangement of the CHANDRA mirrors



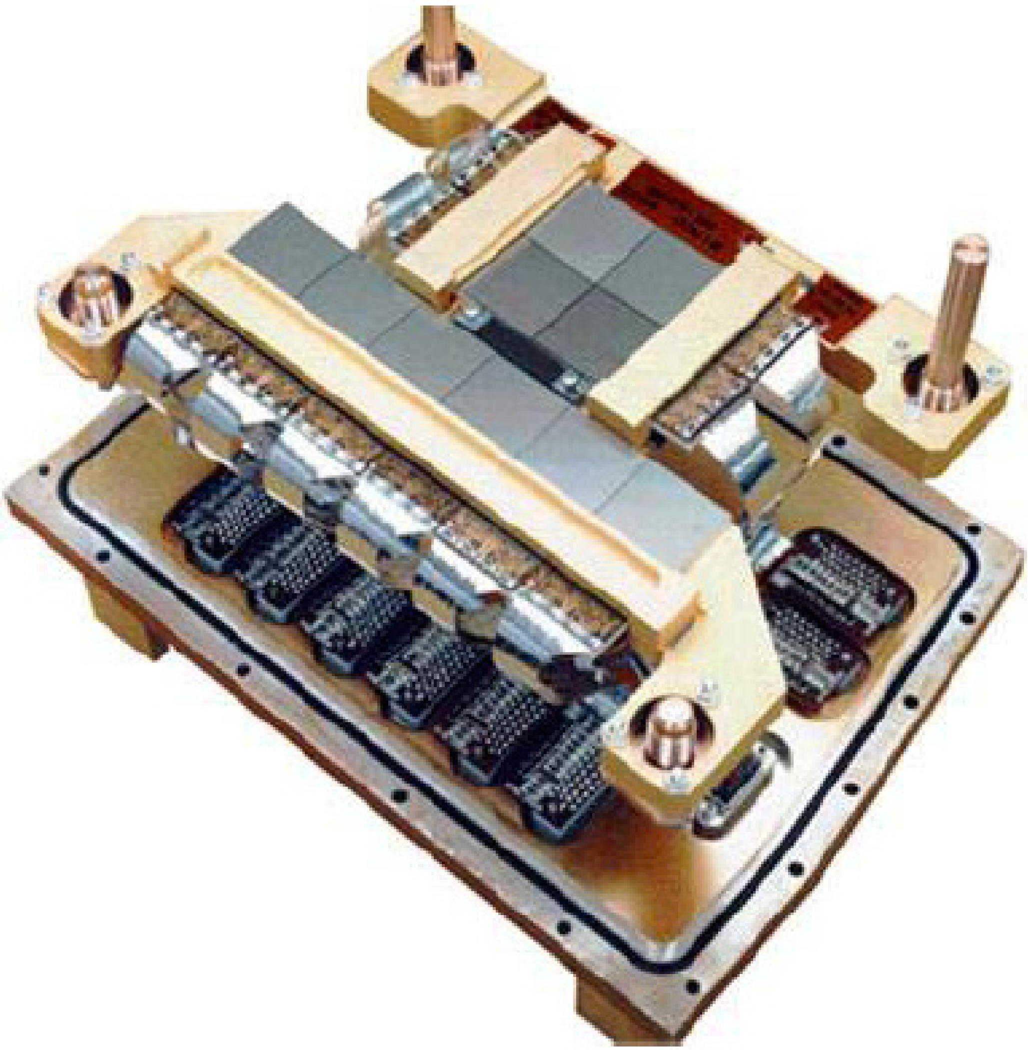
# The CHANDRA optics



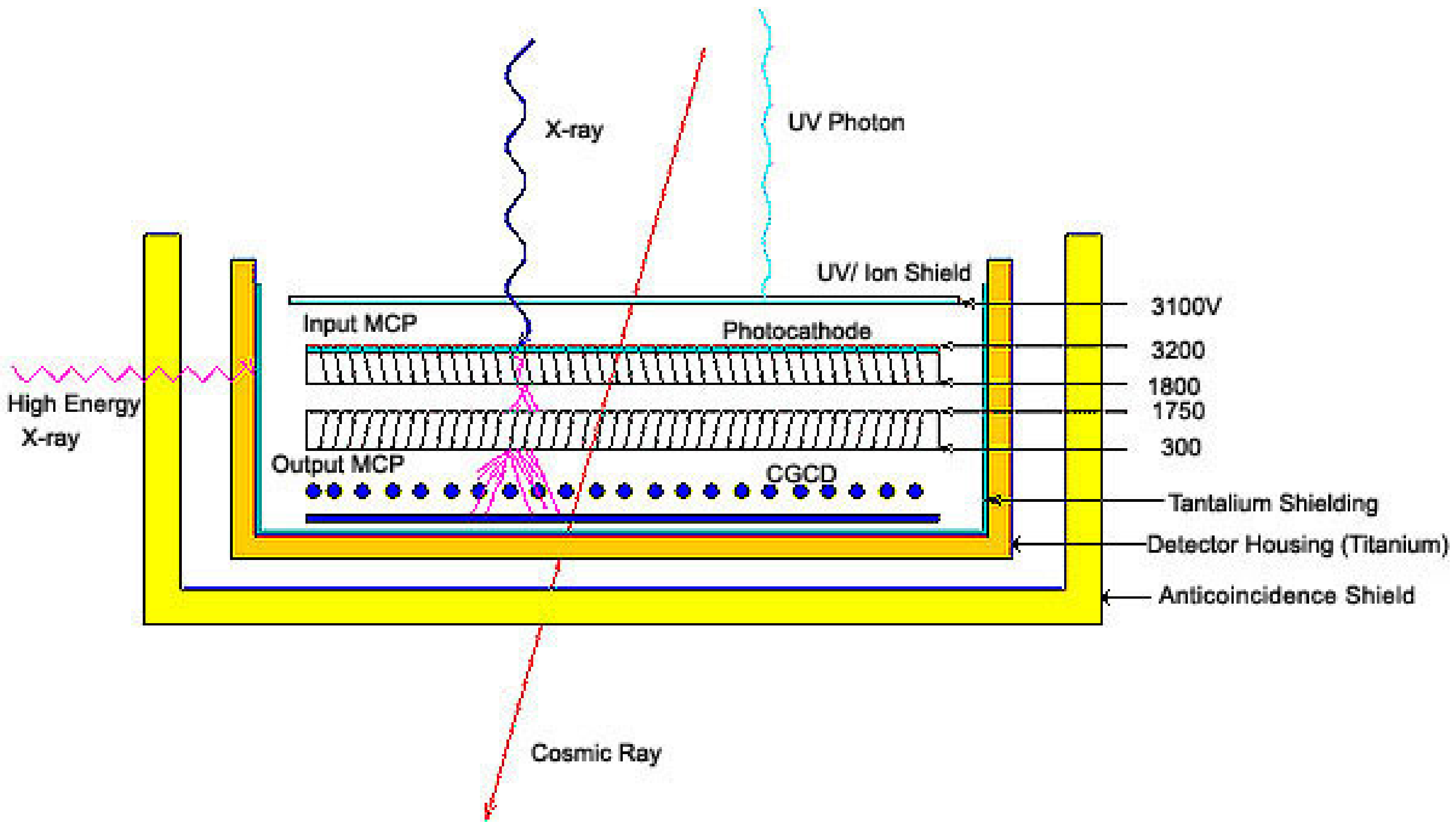
# CHANDRA's High Resolution Camera (HRC)



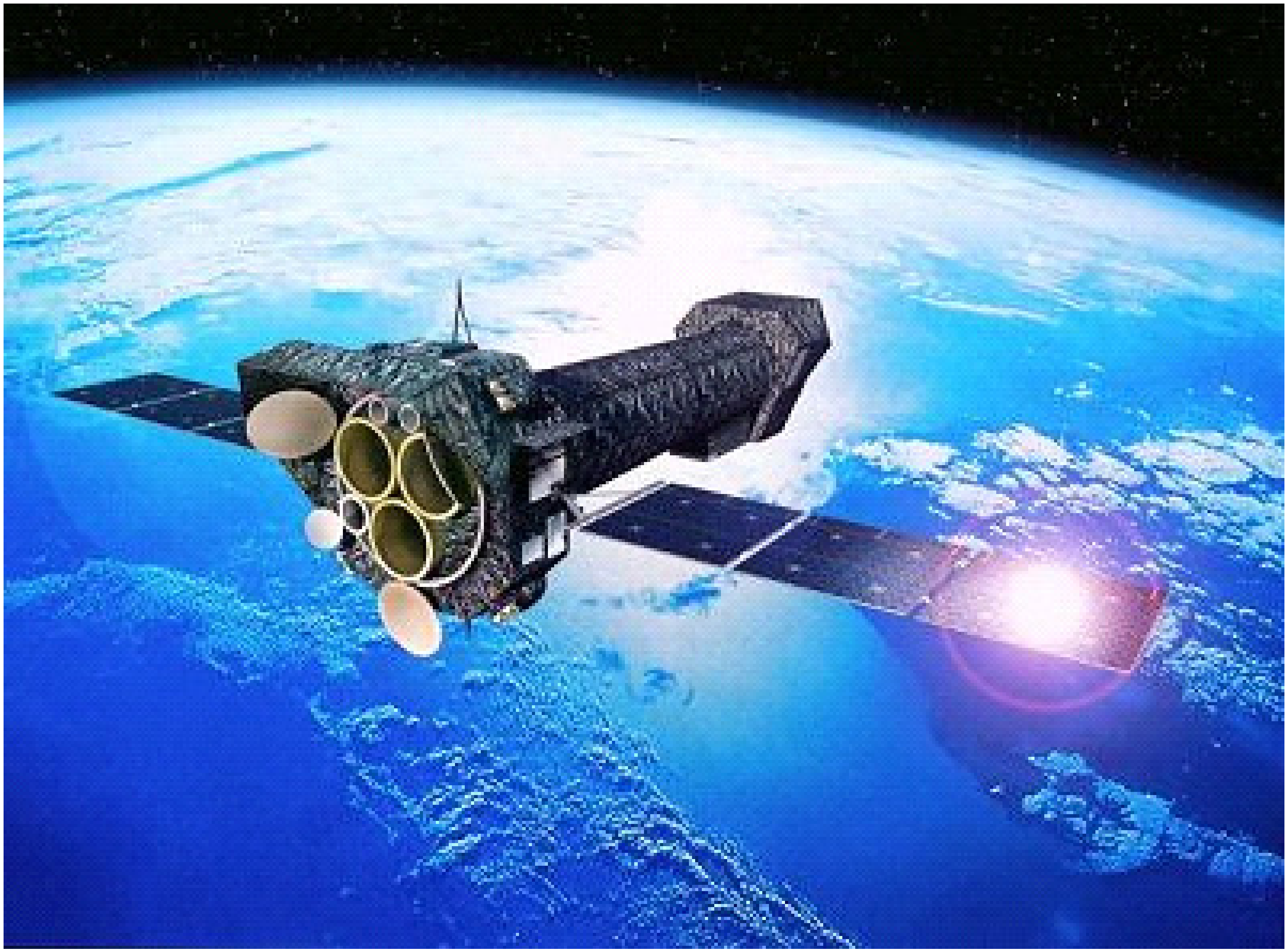
# Advanced CCD Imaging Spectrometer
# High resolution



# Schematic drawing of a multichannel plate



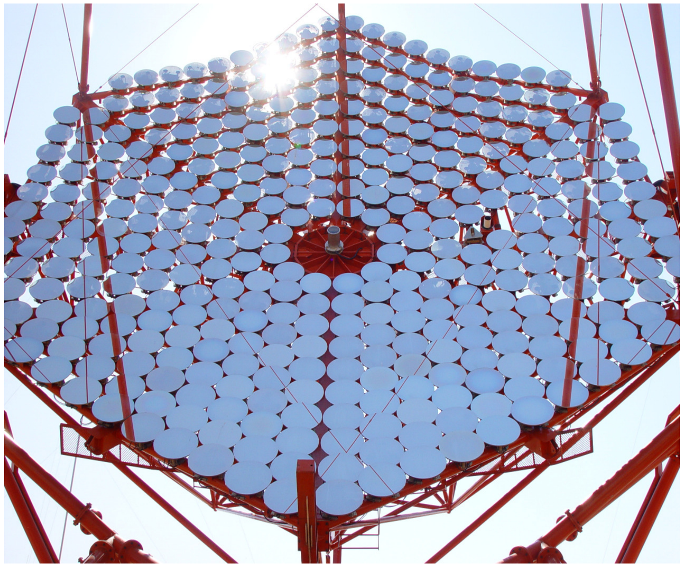
# XMM NEWTON

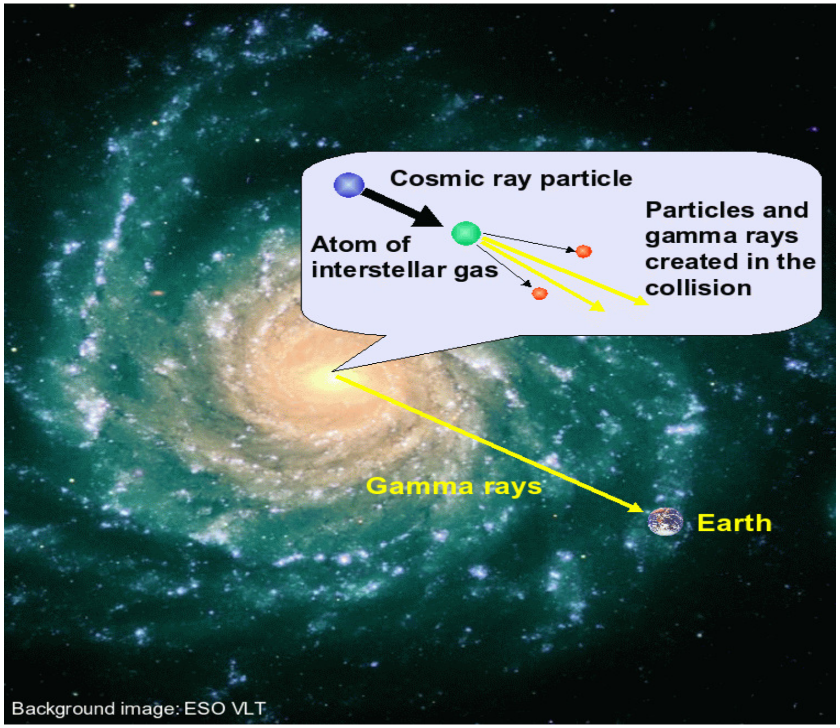


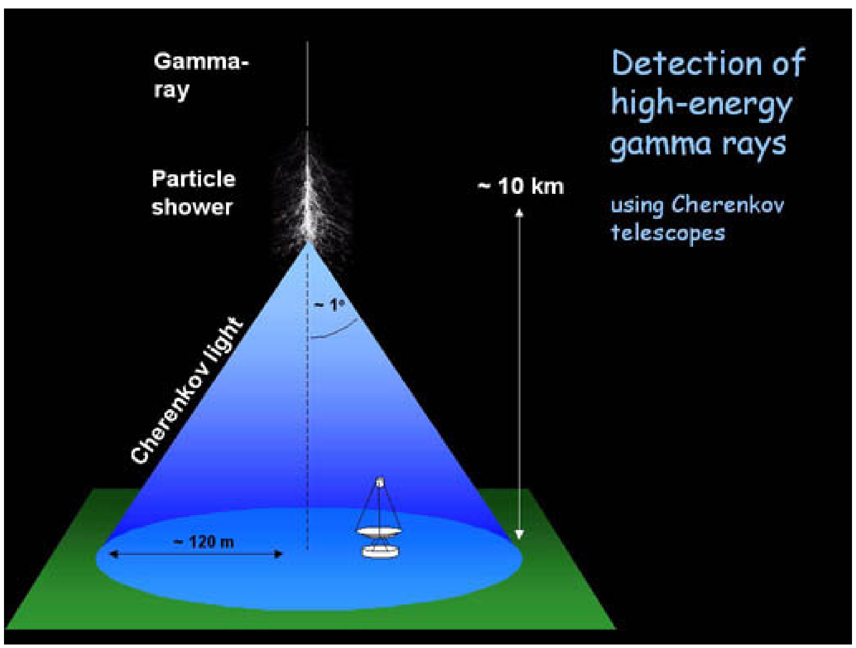
# GAMMA RAYS

The High Energy Stereoscopic System (HESS, Namibia)

A gamma ray observatory detecting the Cherenkov light produced by the showers indiced by the interaction of the gamma rays with the atmosphere






# Gamma ray astronomy as a tracer of cosmic ray sources

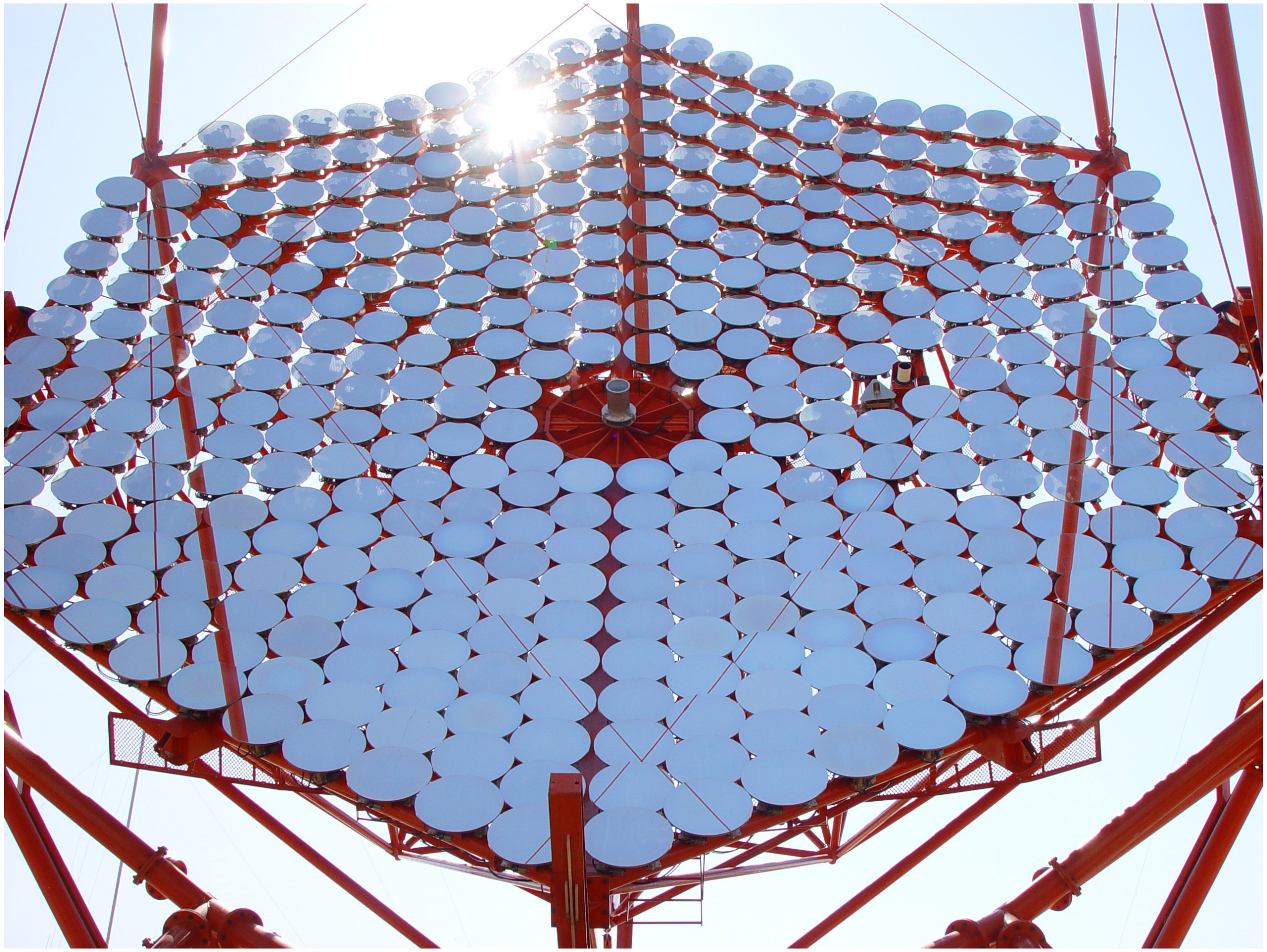
Contrary to cosmic rays, gamma rays travel straight in the universe and point back to the sources.
They are good at detecting the high energy decay photons coming from neutral pions produced in the interaction of very high energy cosmic rays with interstellar matter.

High Energy Stereoscopic System (HESS, Namibia): four telescopes at the corners of a $120 \times 120$ m$^2$ square, operating above 100 GeV. Field of view of 5$^o$ and resolution of a few arc minutes. It takes only 30 seconds to take a picture of the Crab while it was taking 50 hours a few years ago.

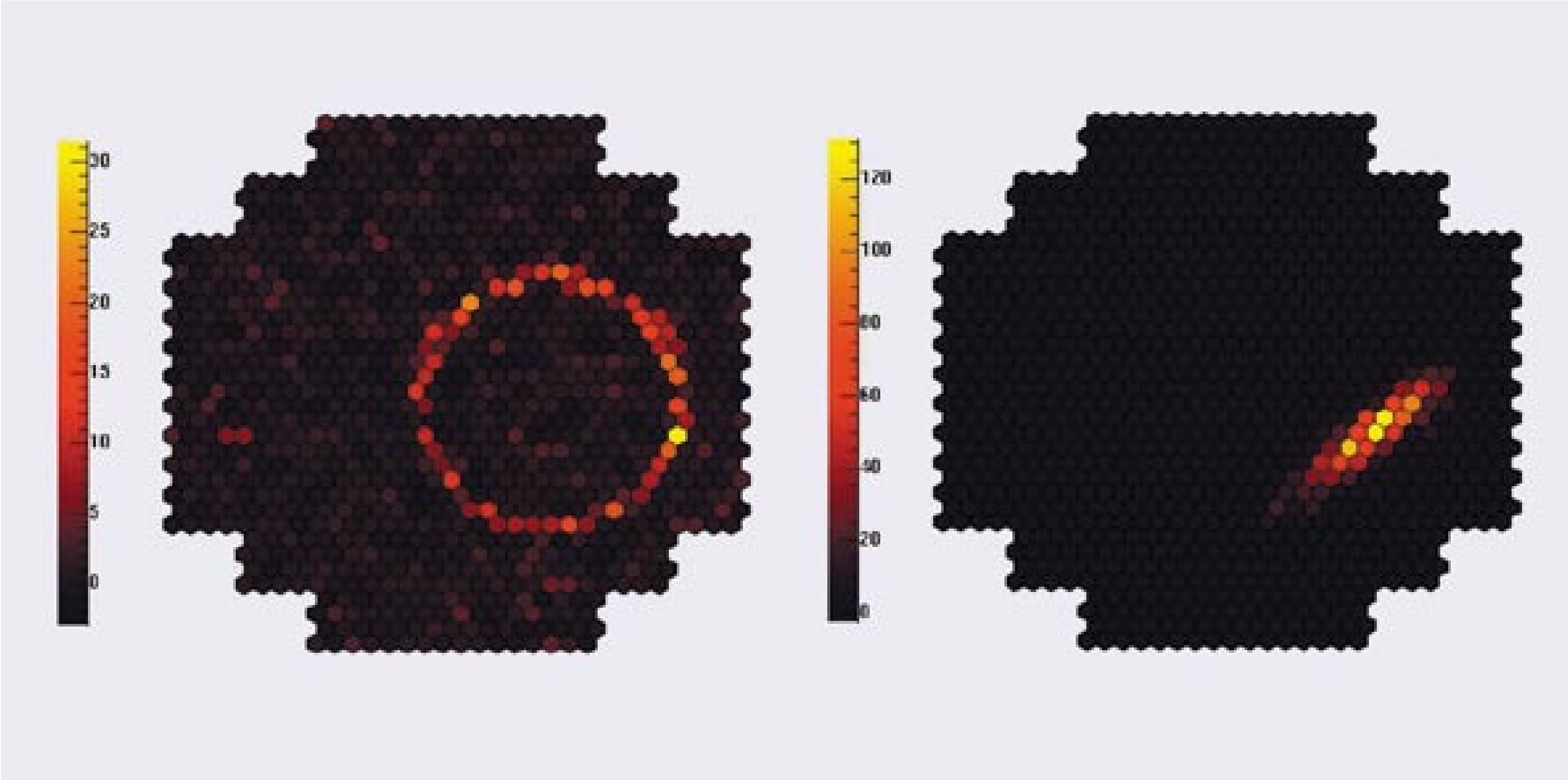
# HESS

A HESS mirror

HESS mirrors are 108 m$^2$ in area and have a reflectivity >80%. The telescope can only be operated during clear moonless nights.



Each is made of 382 smaller mirrors of 60 cm diameter each (quartz coated aluminized glass). Their orientations are individually adjusted.

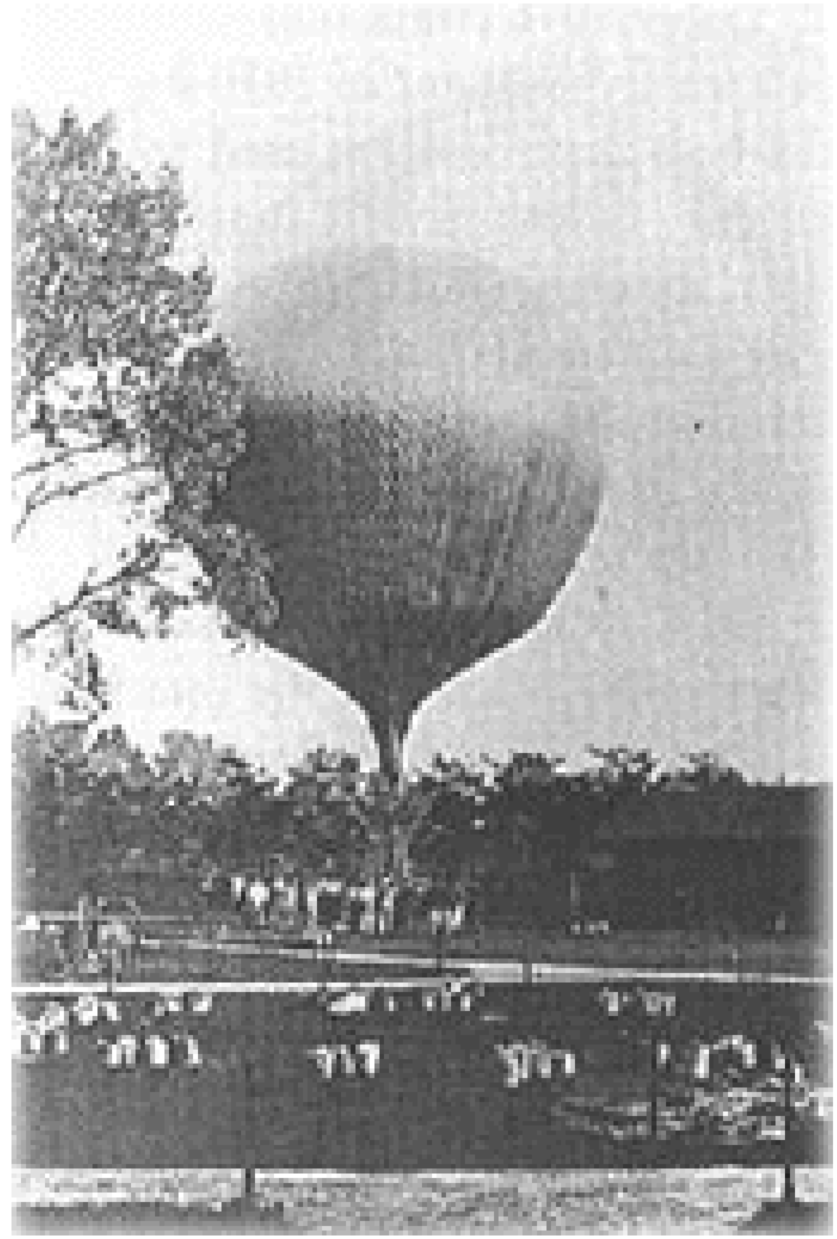



Left: an image of a muon captured by the mirror of a Hess telescope.

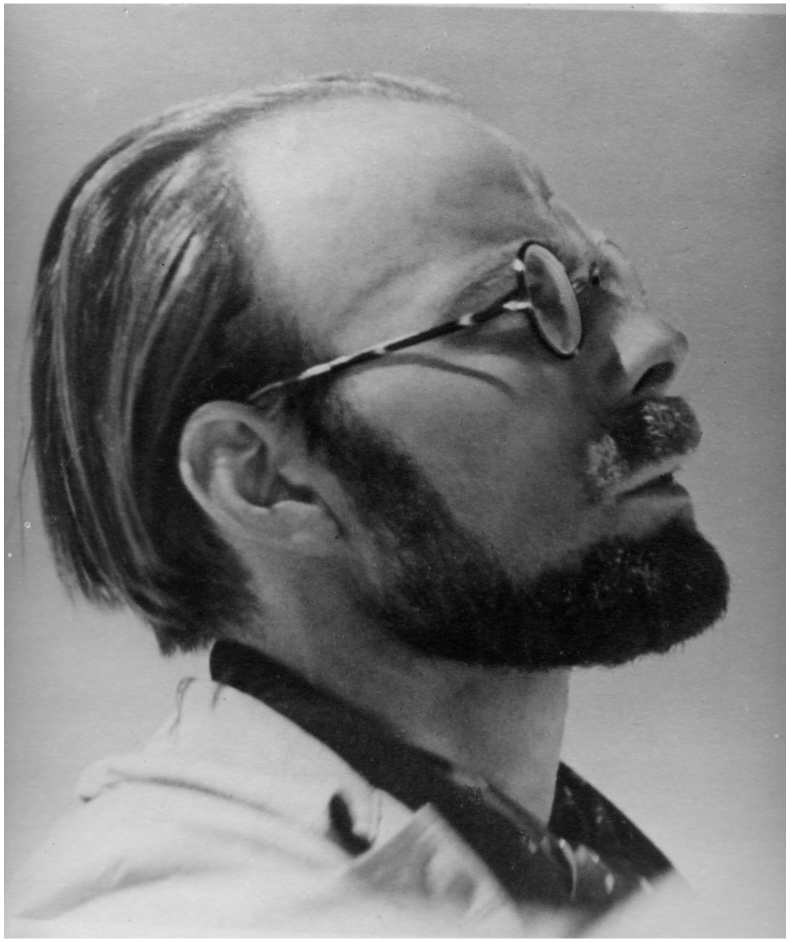
Right: a typical image of a shower.

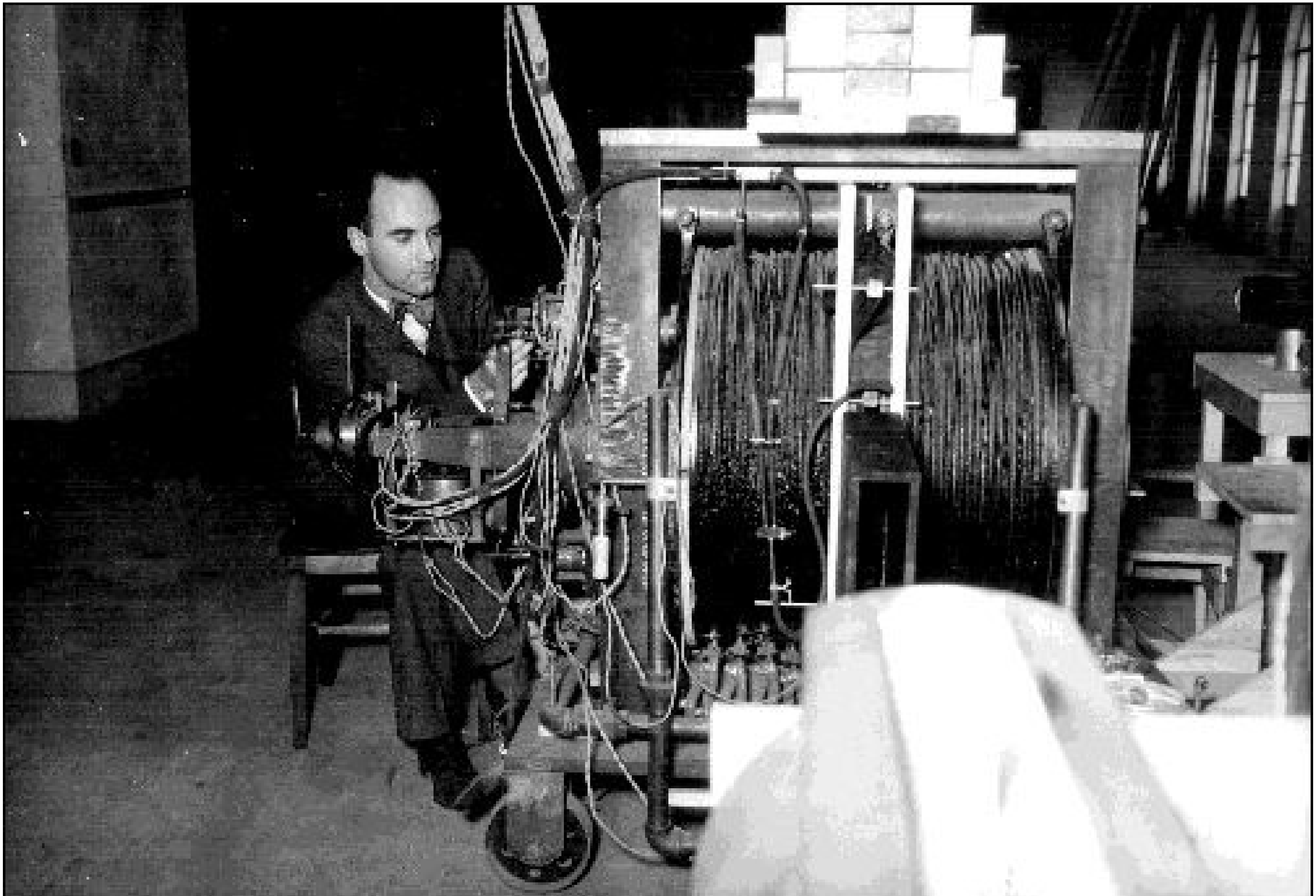

The HESS camera includes 960 PMT arranged as a pixel array. The electronics samples and records the signals of the light detectors at 1 GHz. A trigger circuit is used to select good candidates that are recorded for further analysis.

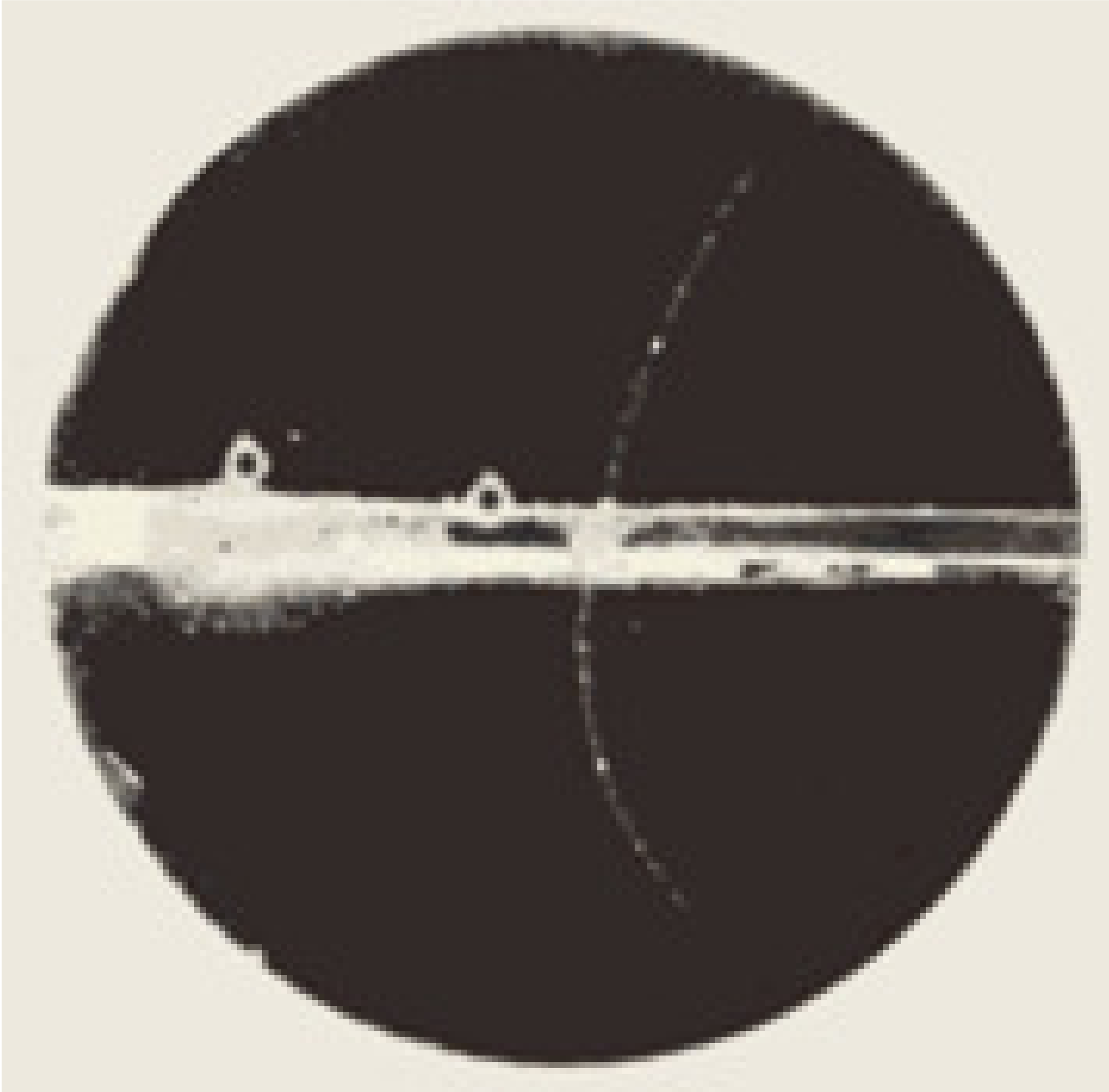
# COSMIC RAYS



# Robert Millikan at Pikes Peak and Pierre Auger at the Jungfrau Joch

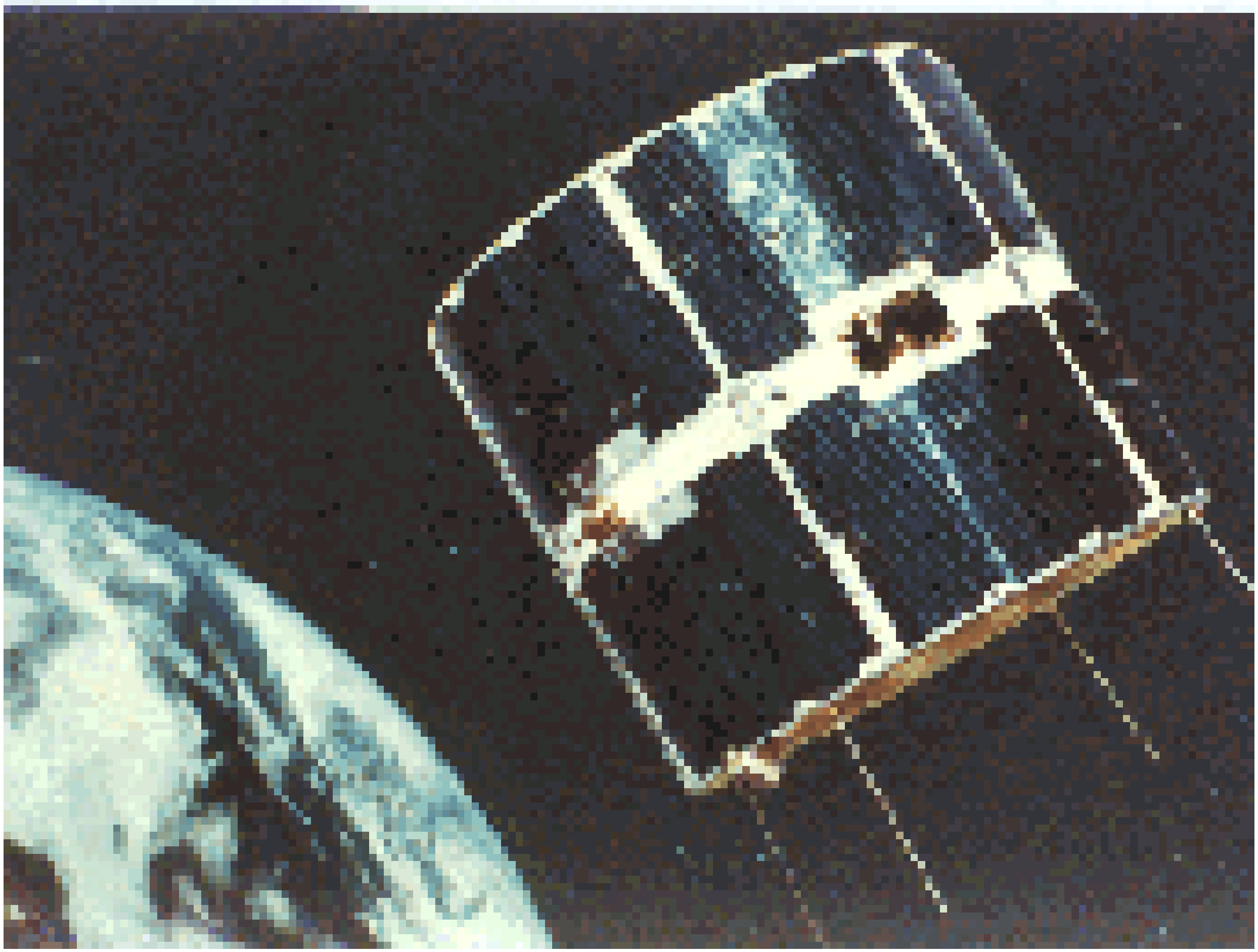



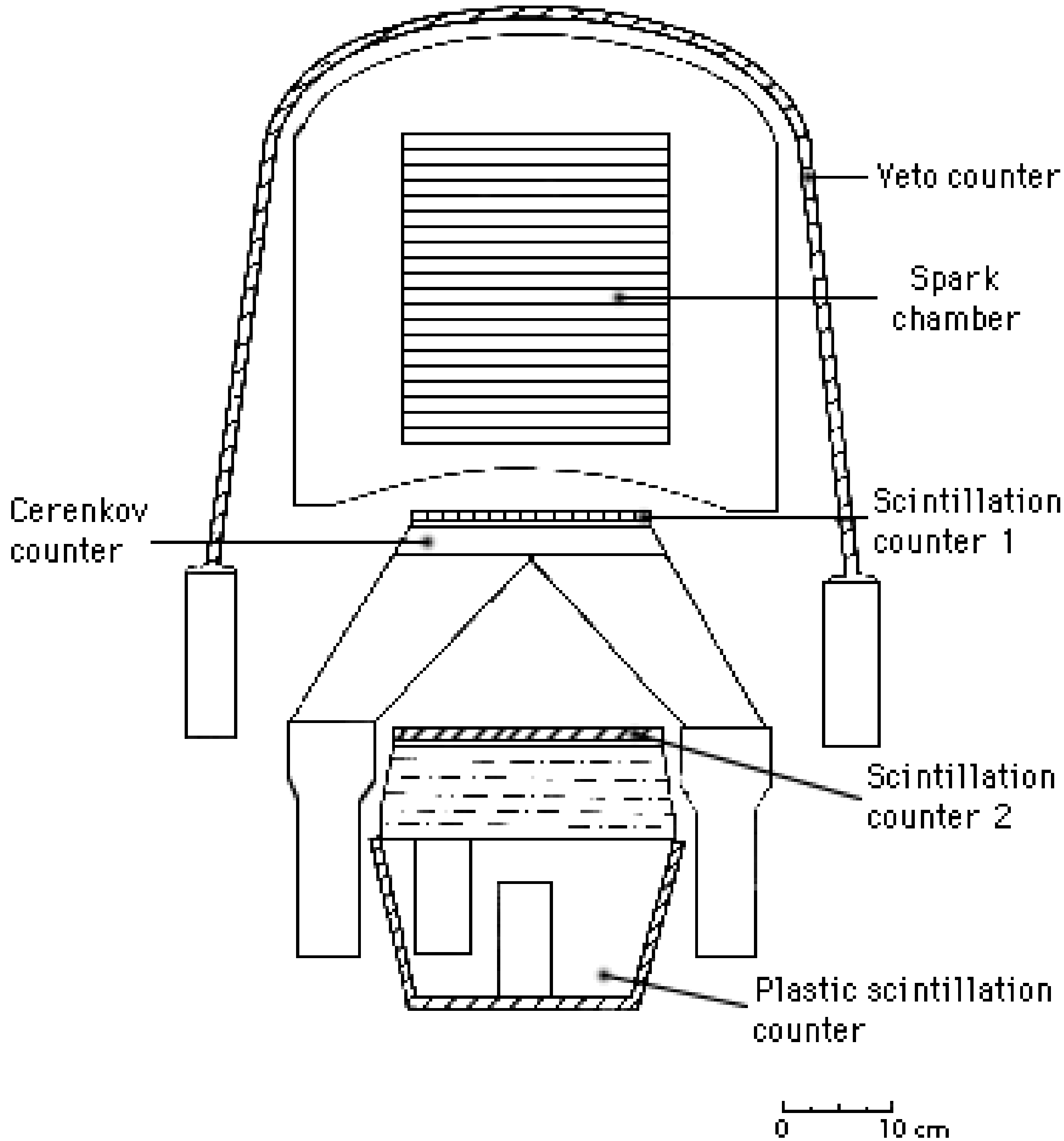


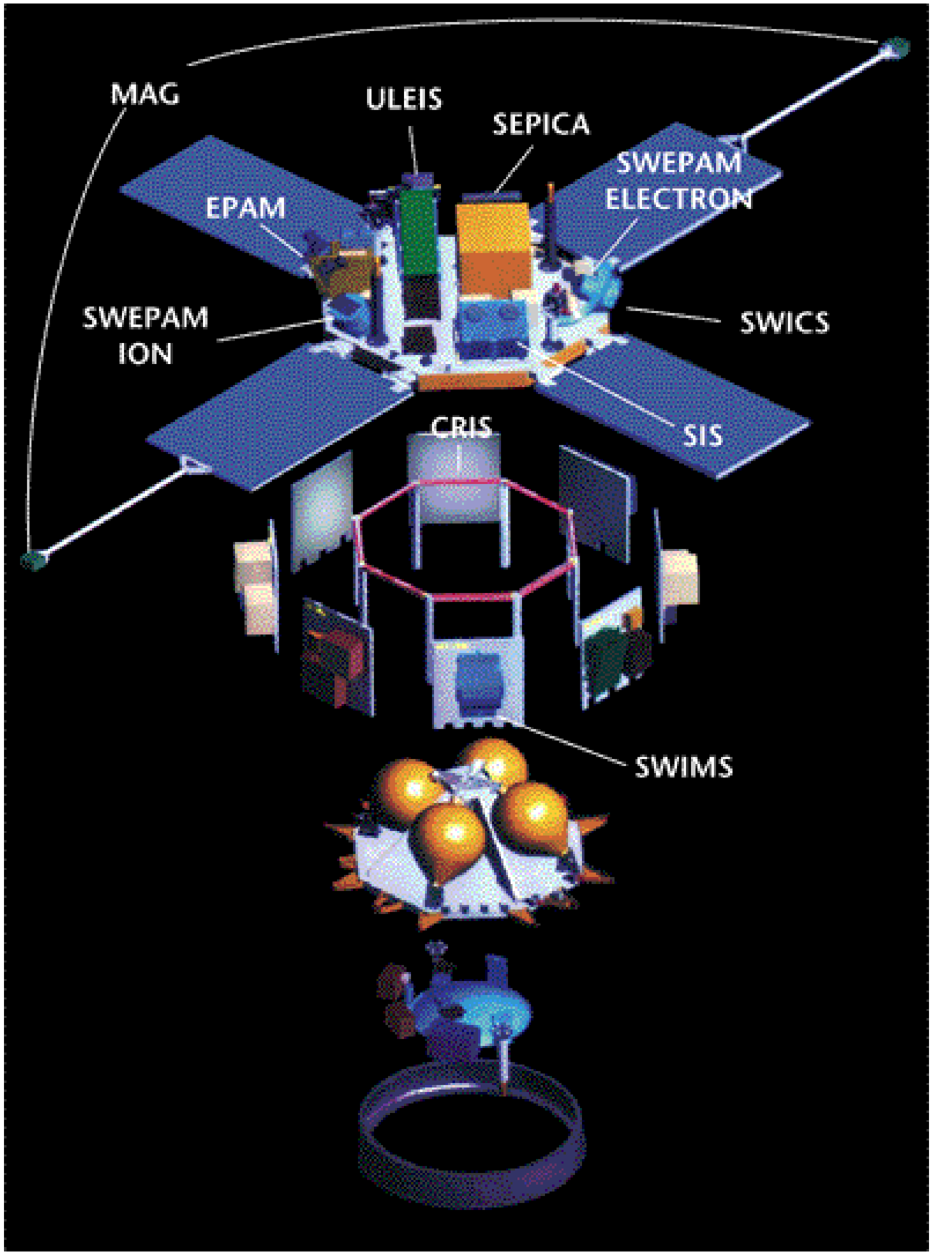


# Casa in Utah

# COS-B, a pioneer in space



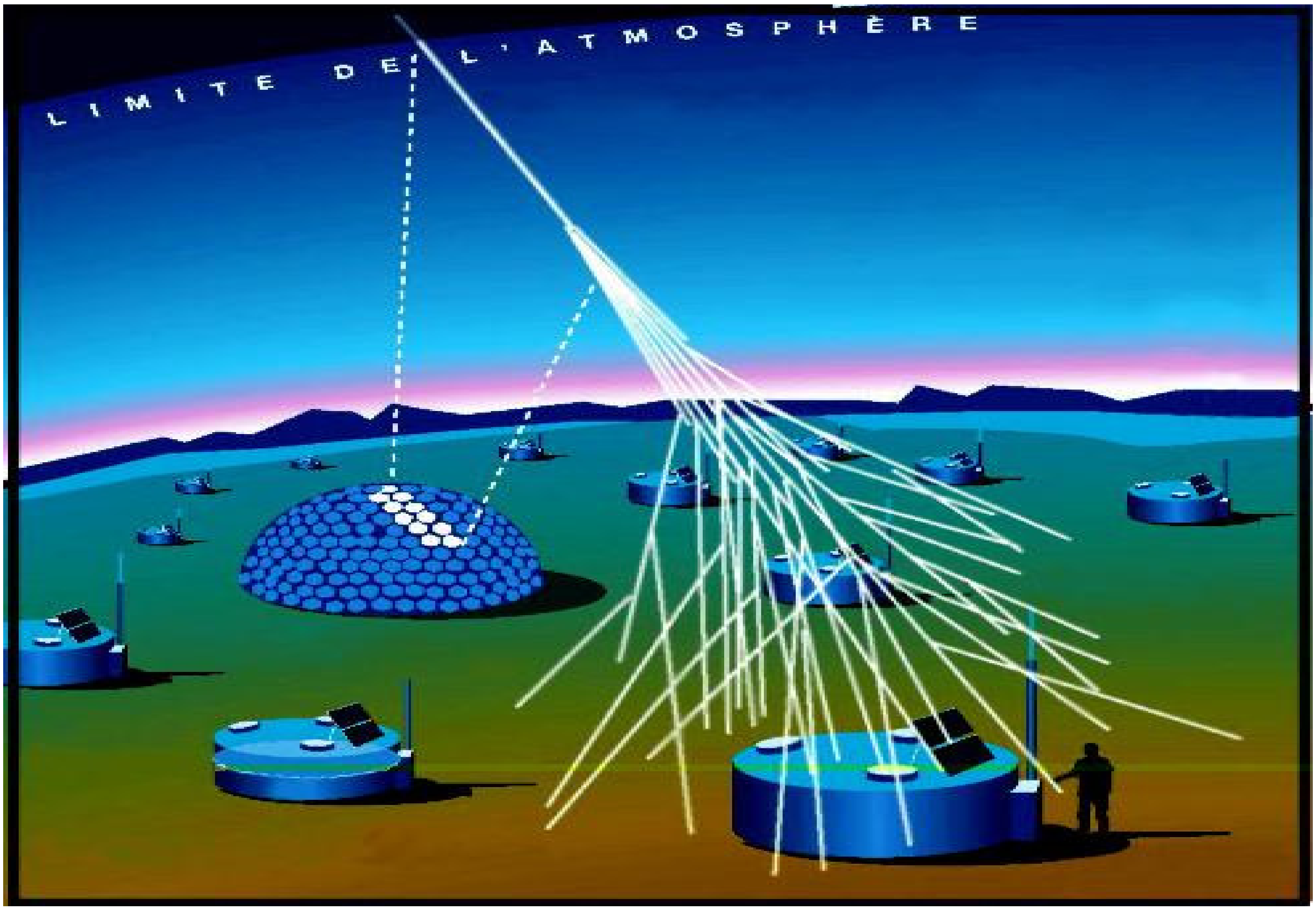

Veto counter
Spark chamber
Cerenkov counter
Scintillation counter 1
Scintillation counter 2
Plastic scintillation counter
0
10 cm



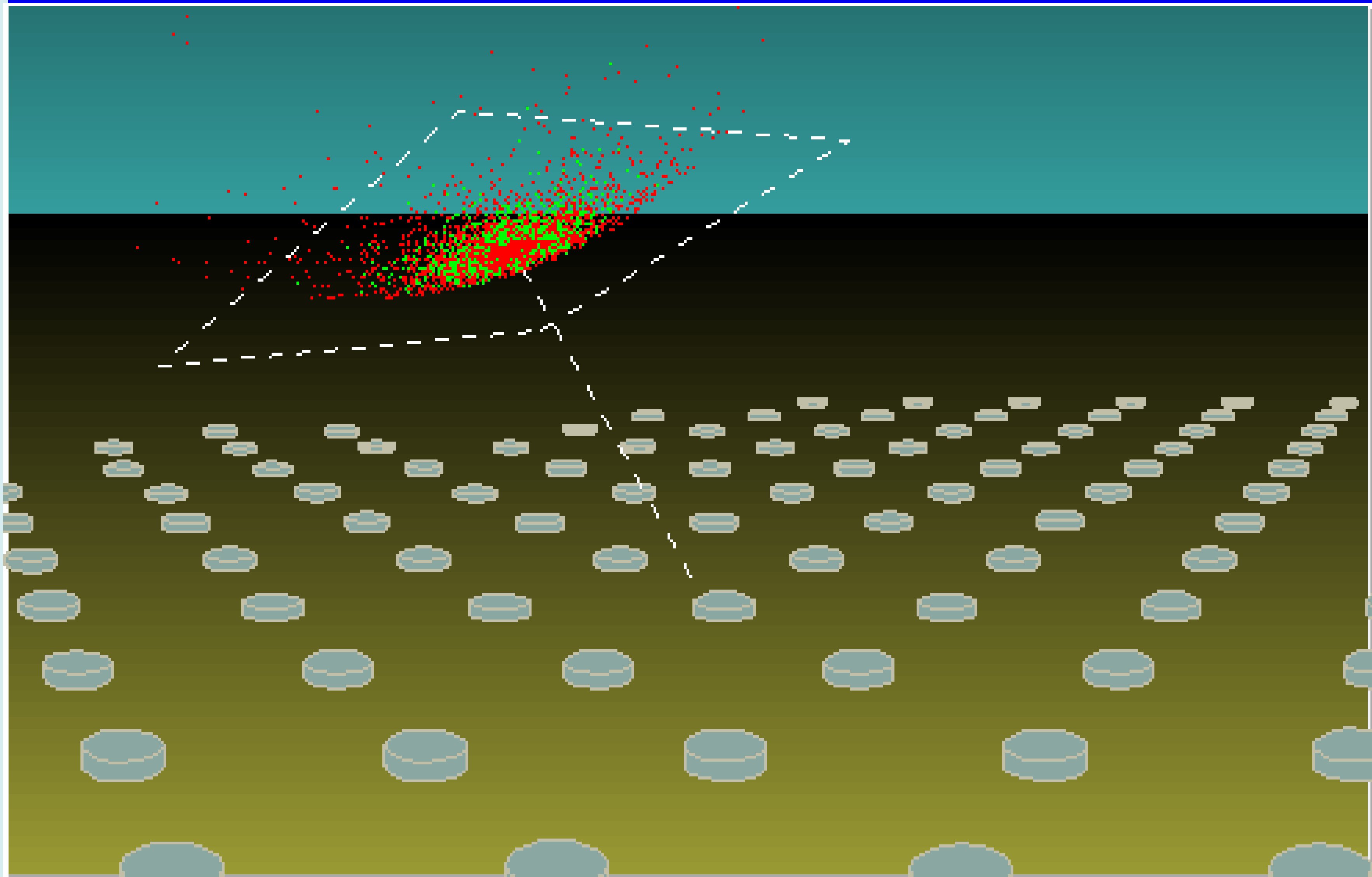

A recent example of space measurements in solar astronomy:

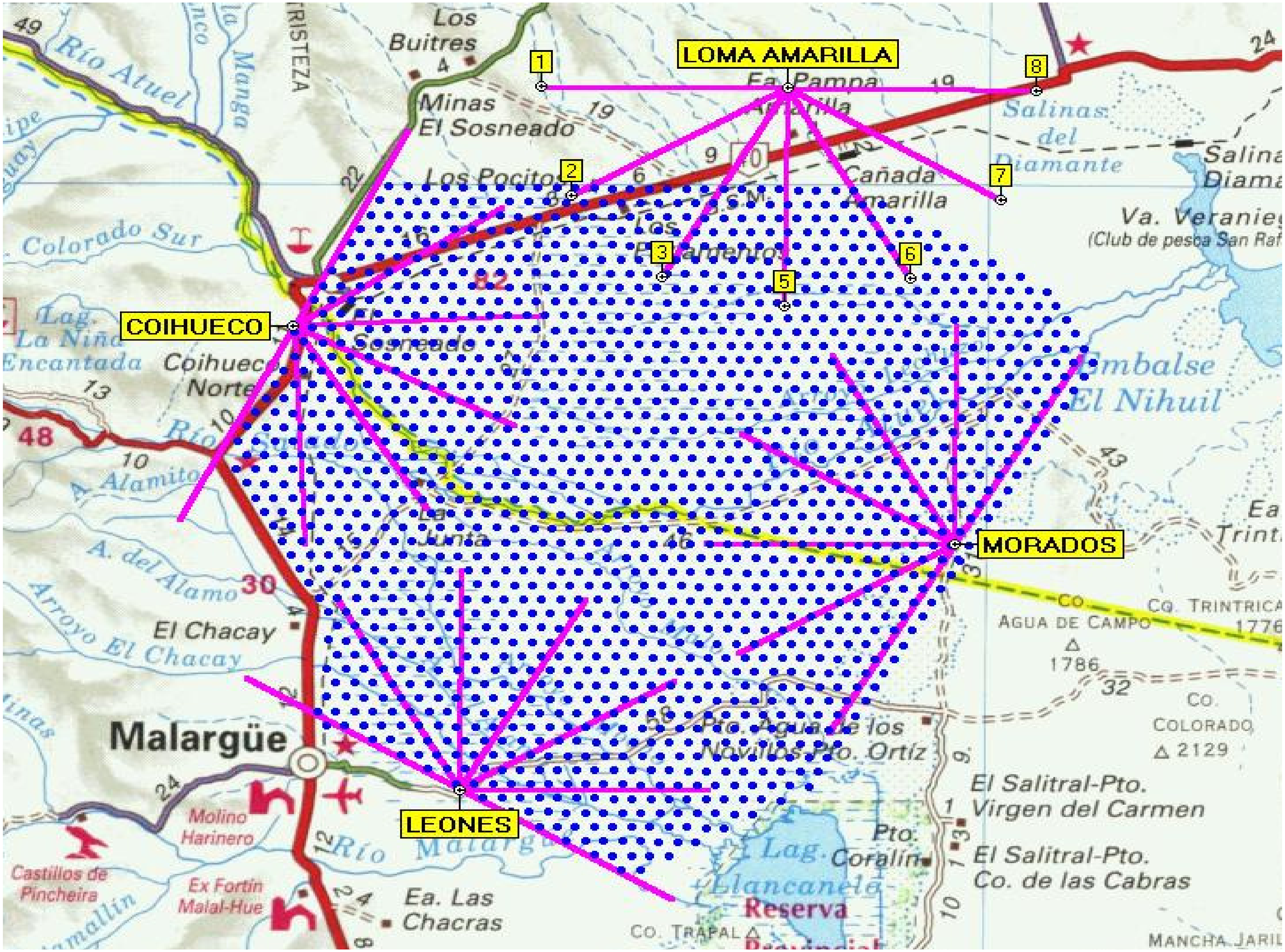
NASA's Advanced Composition Explorer ACE was launched from Cape Canaveral in 1997 to the Lagrange point between Sun and Earth

# Pierre Auger Observatory



# A developing shower

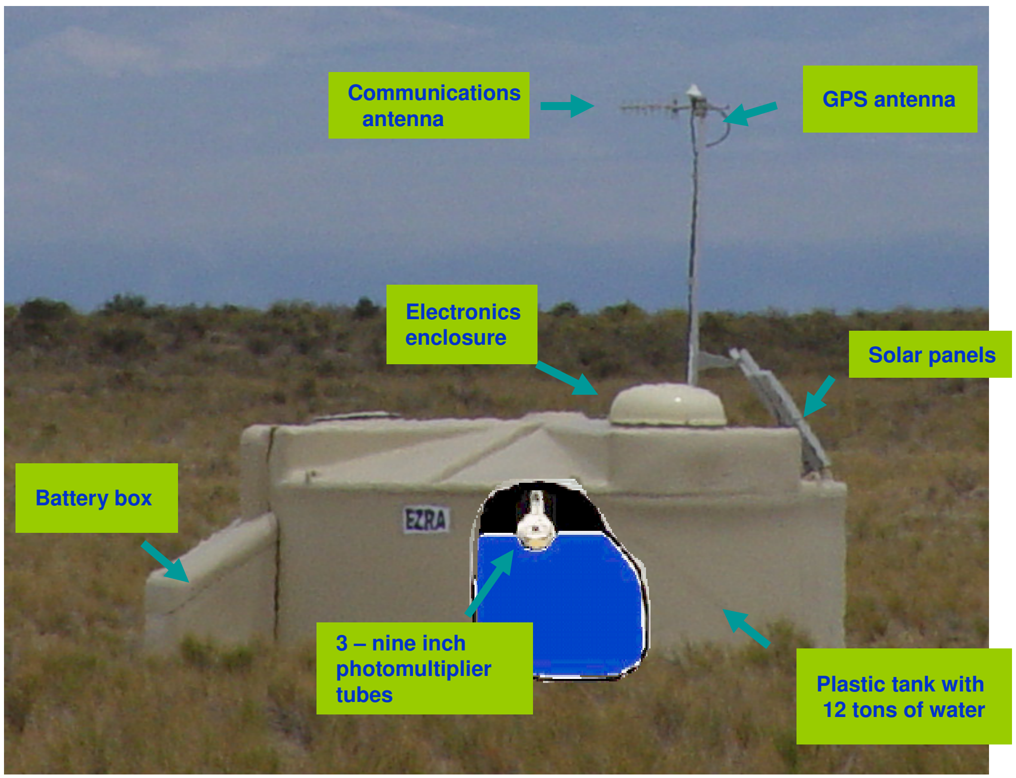


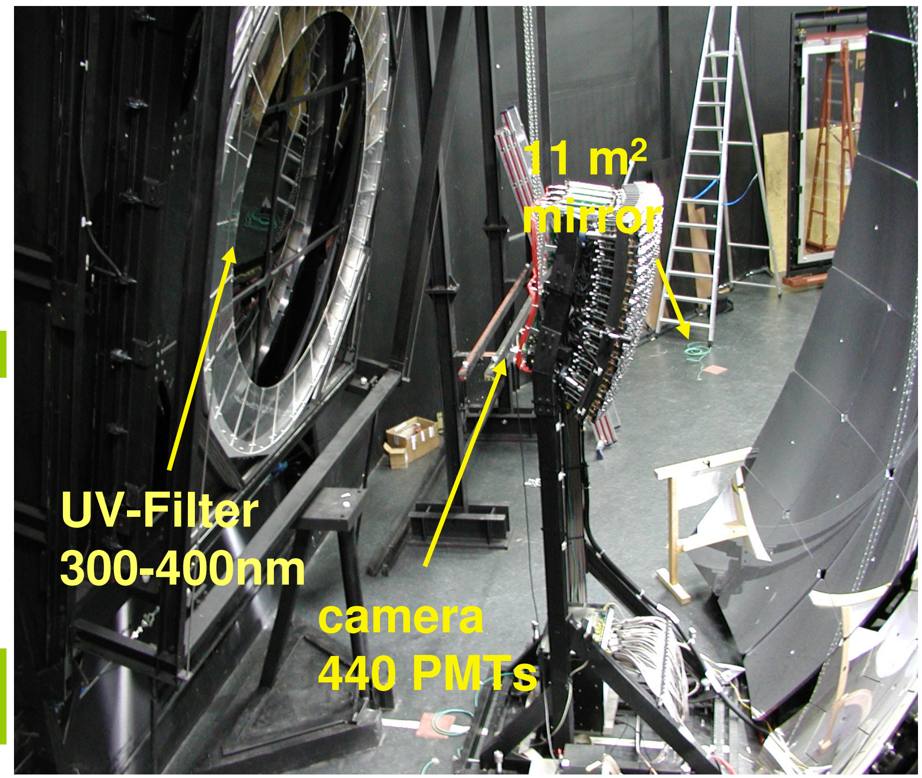


LOMA AMARILLA
COIHUECO
MORADOS
LEONES
1
2
3
4
5
6
7
8
Ea. Pampa Amarilla
Los Buitres
Minas El Sosneado
Los Pocitos
Cañada Amarilla
Salinas del Diamante
Va. Veraniega
(Club de pesca San Rafael)
Embalse El Nihuil
Río Atuel
Manga
Colorado Sur
Lag. La Niña Encantada
Coihueco Norte
El Sosneado
Los Parlamentos
La Junta
A. Alamito
A. del Alamo
Arroyo El Chacay
El Chacay
Malargüe
Molino Harinero
Castillos de Pincheira
Ex Fortín Malal-Hue
Ea. Las Chacras
Río Malargüe
Lag. Llancanelo
Reserva
Pto. Coralino
El Salitral-Pto. Virgen del Carmen
El Salitral-Pto. Co. de las Cabras
Pto. Agua de los Novillos
Pto. Ortíz
Co. Agua de Campo
1786
Co. Trintrica
Co. Colorado
2129
Co. Trapal
Mancha Jarilla
Ea. Trinta
Salina Diamante

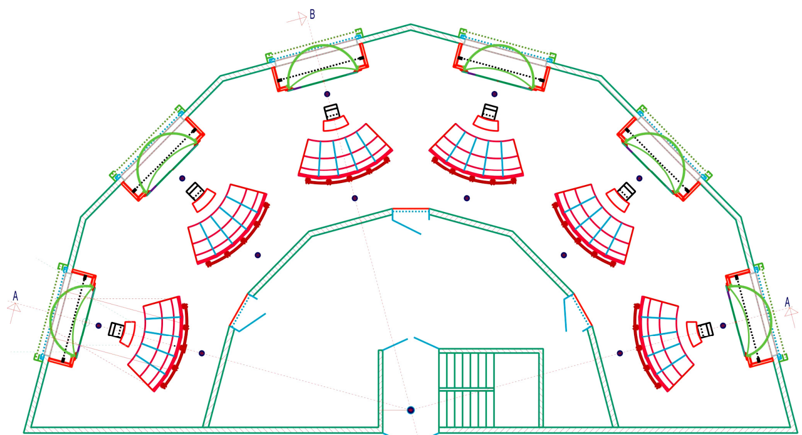
1600 Cherenkov counters on ground measure the shower transverse profile and 4×6 fluorescence telescopes measure the longitudinal profile with a 10% duty cycle (clear moonless nights)

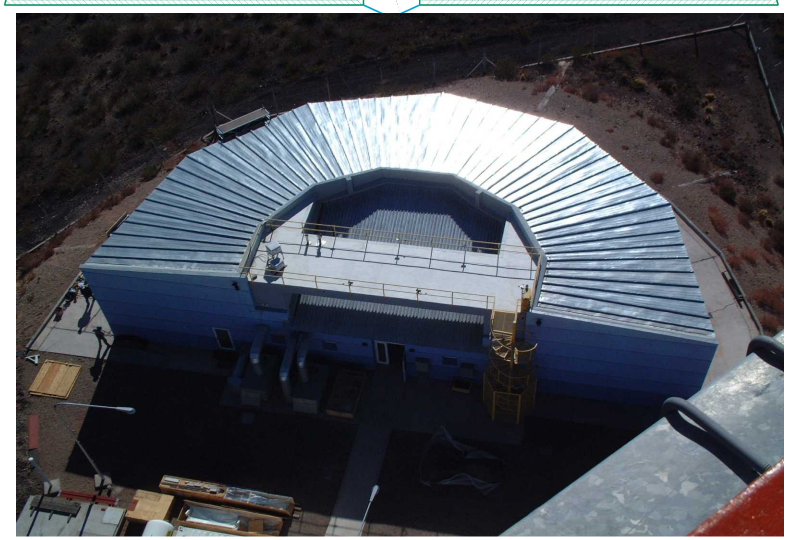
In both cases timing gives the direction (1°) and intensity gives the energy (10%)

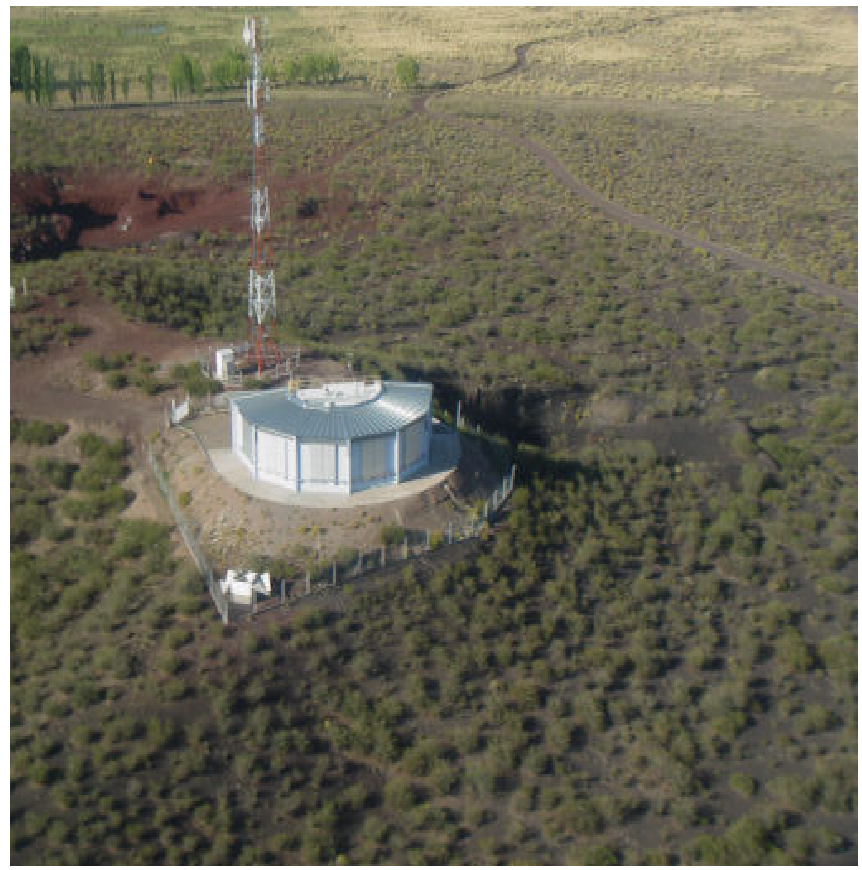


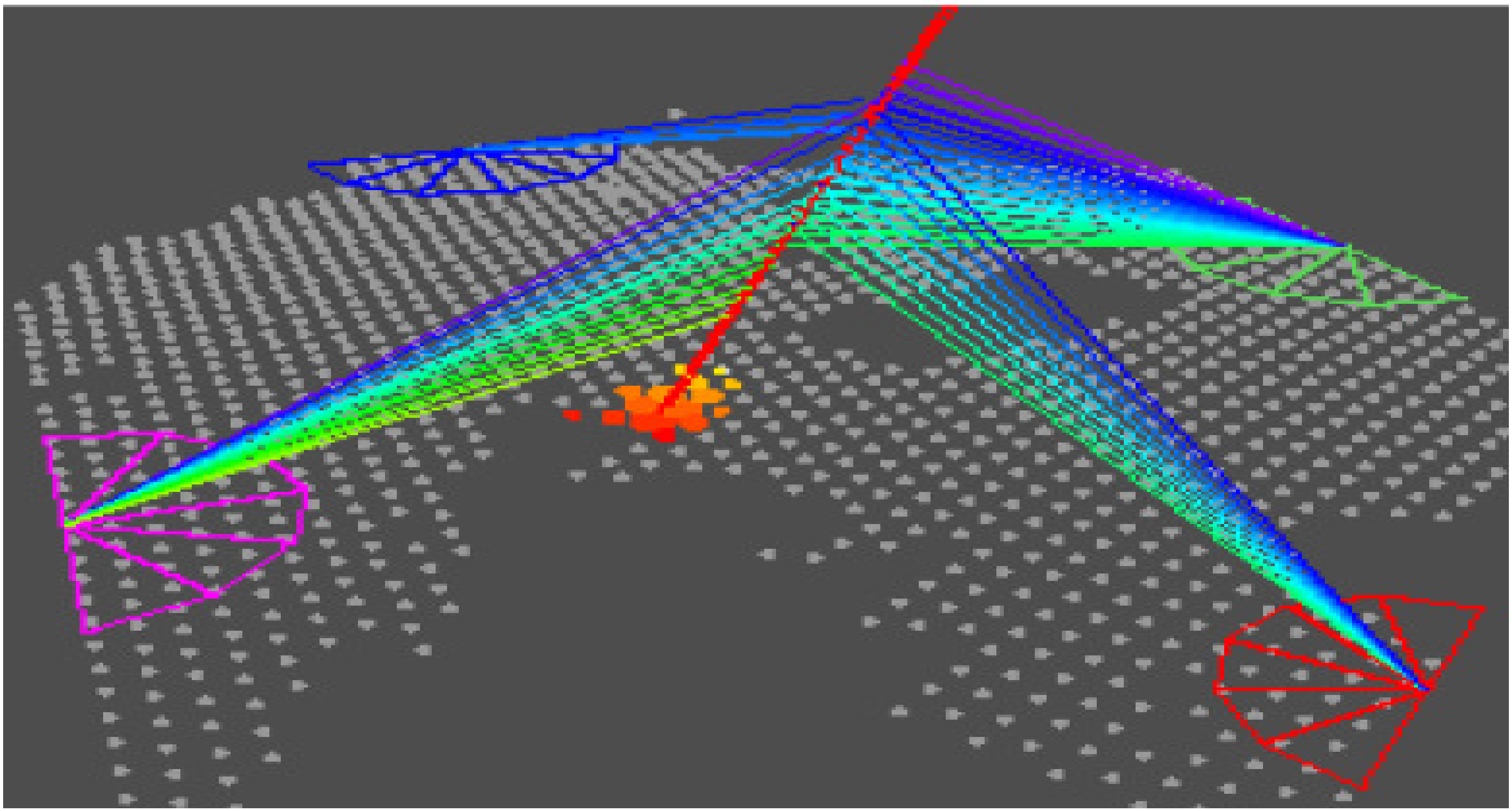
**Four stations of six eyes each, each eye covering a field of view of 30°×28° with a mirror focusing on an array of 22×20 pixels (PMTs), each having 1.5° aperture. Measure the induced fluorescence of nitrogen molecules (near UV).**

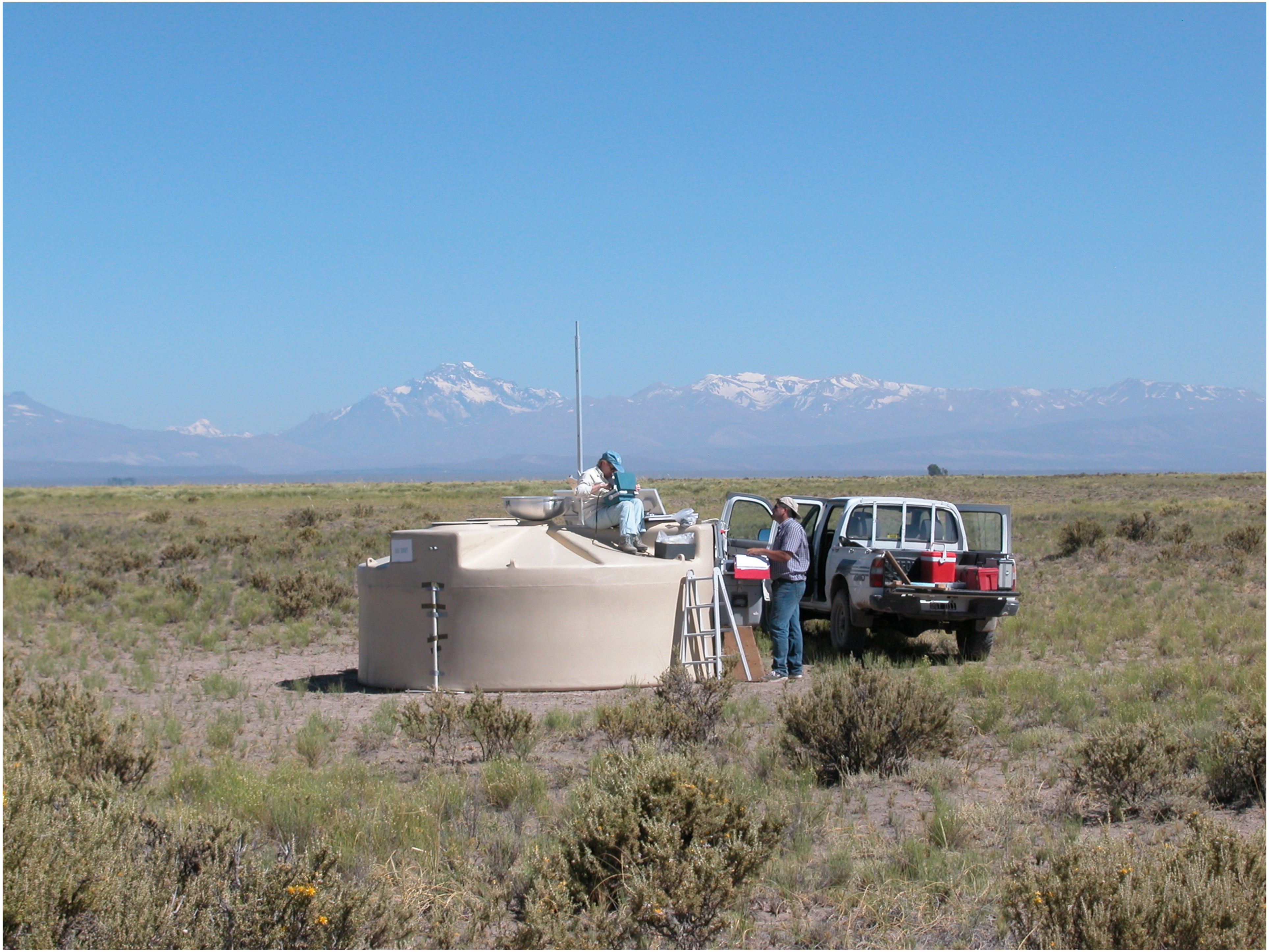






# The first four-fold event
# May 2007, ~$10^{19}$ eV

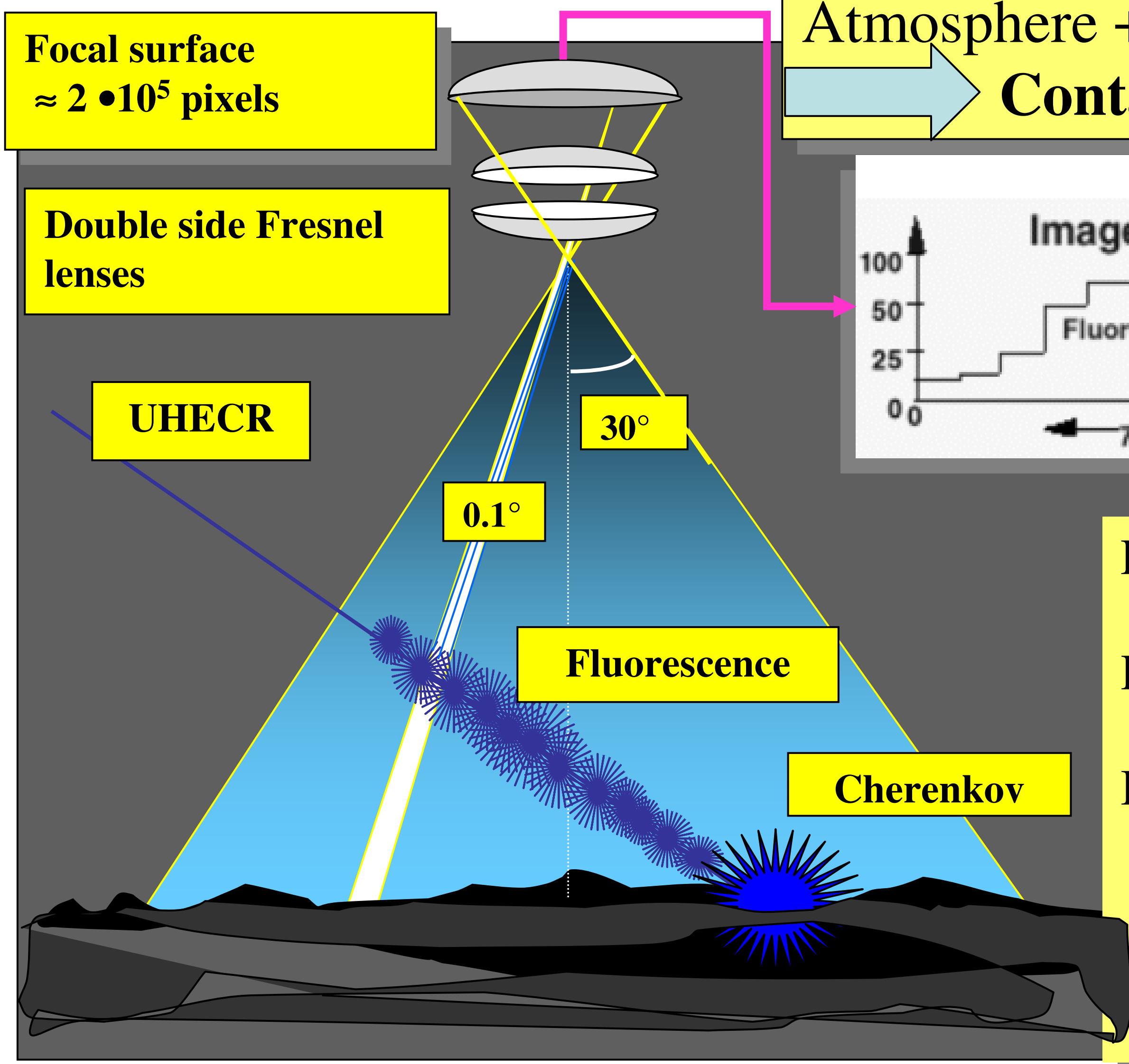




Looking into the future:

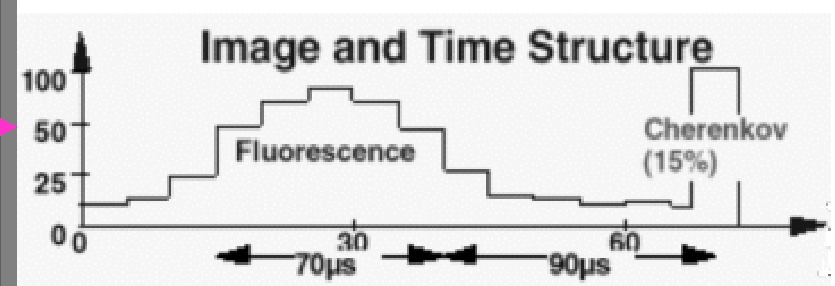
# The EUSO project

# EUSO concept: a space TPC




Atmosphere + EUSO = Calorimeter

⇨ **Contained EAS**




Energy

Fluorescence + Cerenkov

Position

X,Y,Z (t): 0.3 - 1 km

Direction

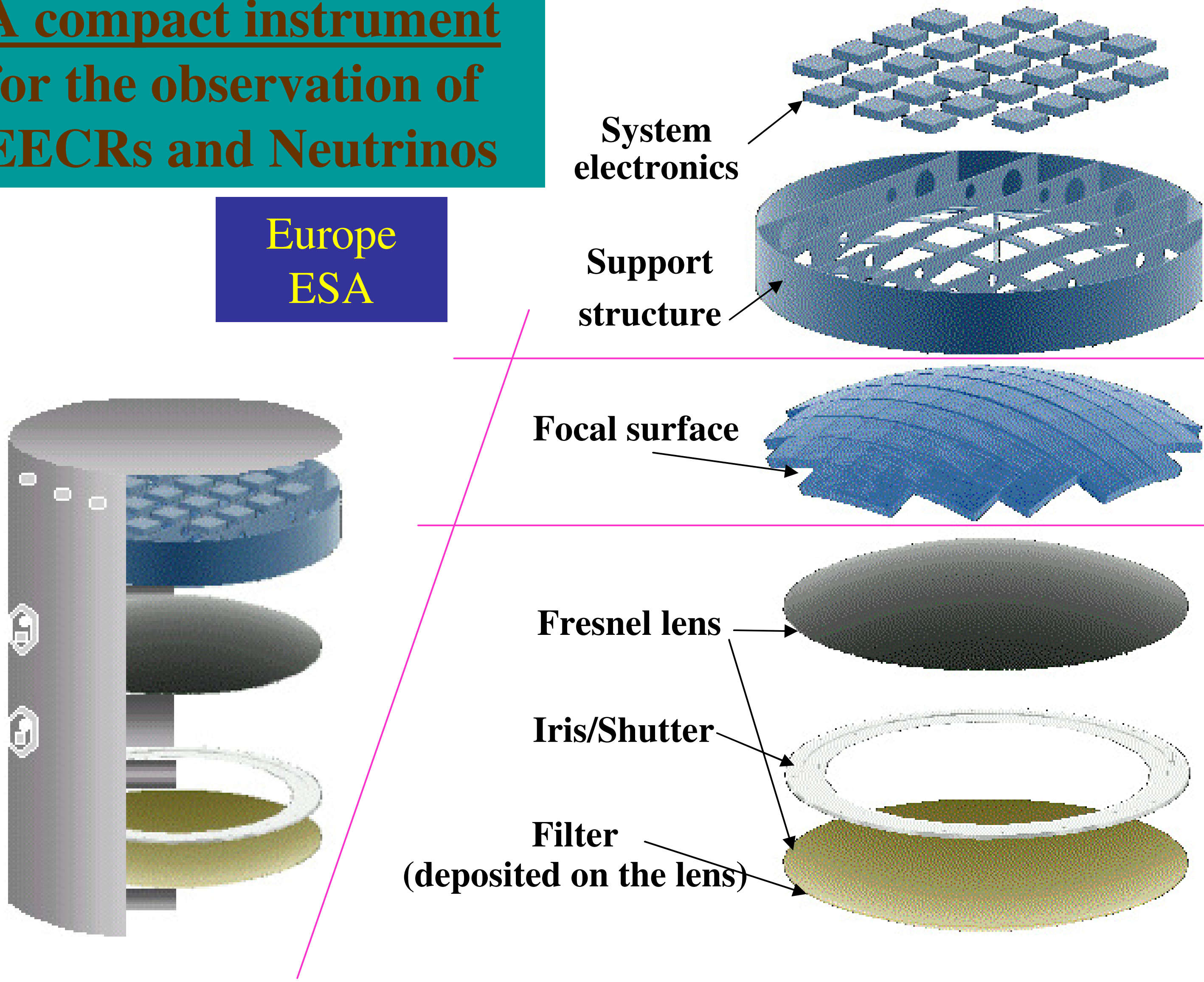
Multi-hits tracks

.$\sigma_\theta$ ~ 0.3°(h) - 3°(v)

# EUSO Collaboration

**A compact instrument**
**for the observation of**
**EECRs and Neutrinos**

Europe
ESA




**France**
(IN2P3/CNES)
**Italy:**
(INFN/ASI)
**Portugal:**
(ICCT/FCT)
**D/UK/CH**

**Japon**
RIKEN
NASDA

**USA**
OWL
NASA