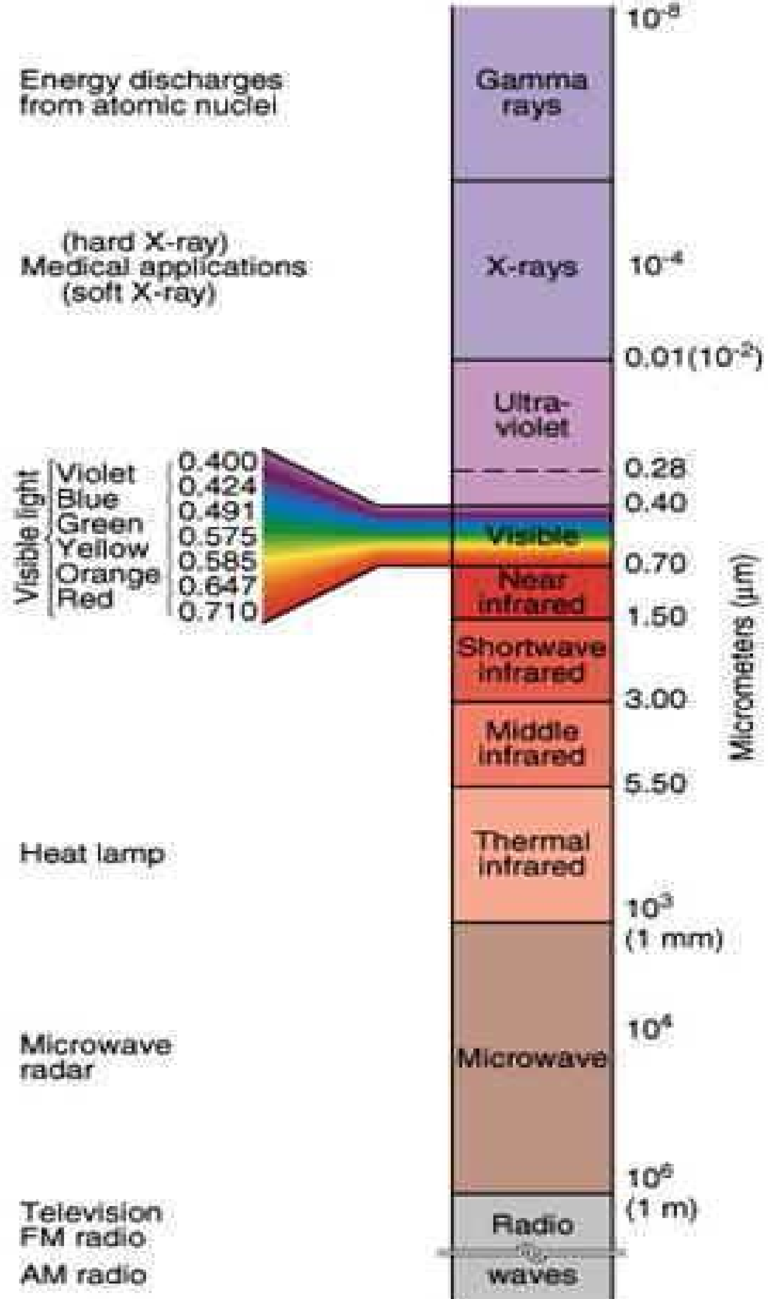
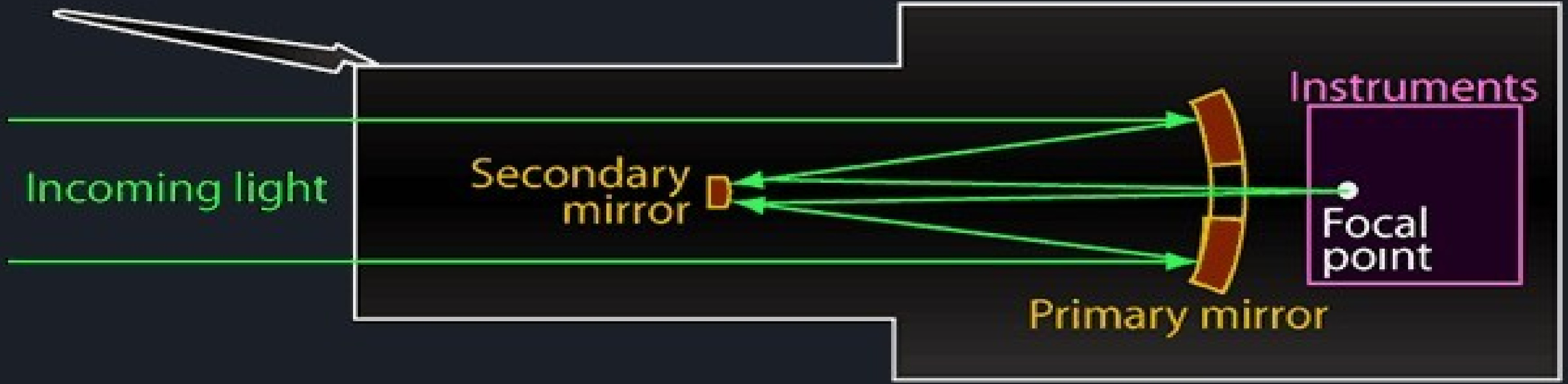
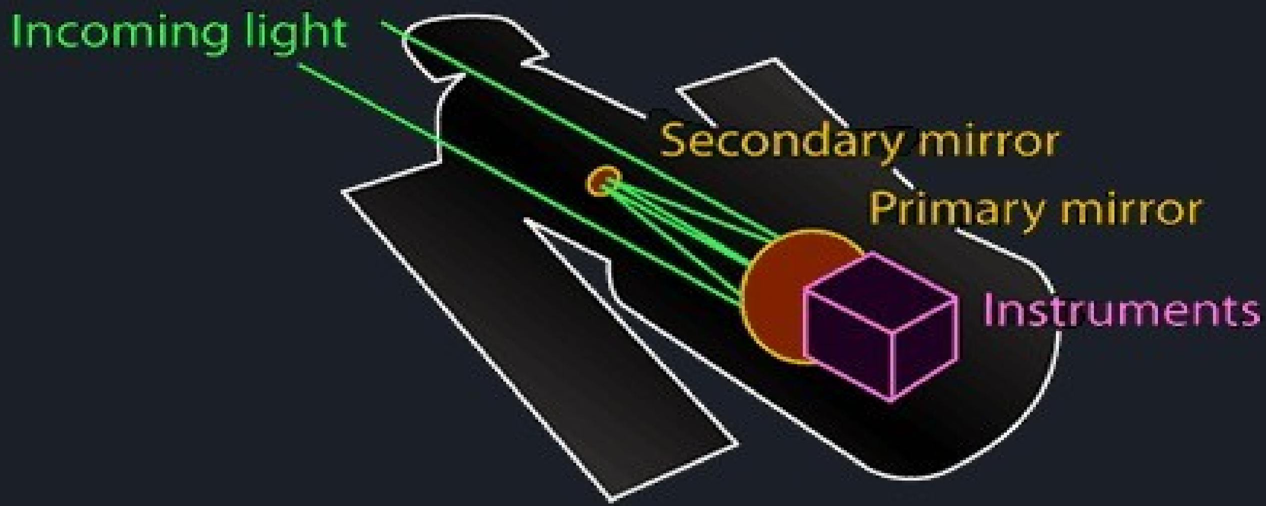
Astronomical instruments



Energy discharges from atomic nuclei
(hard X-ray)
Medical applications
(soft X-ray)
Visible light
Violet
Blue
Green
Yellow
Orange
Red
0.400
0.424
0.491
0.575
0.585
0.647
0.710
Heat lamp
Microwave radar
Television
FM radio
AM radio
Gamma rays
X-rays
Ultra-violet
Visible
Near infrared
Shortwave infrared
Middle infrared
Thermal infrared
Microwave
Radio waves
10^-6
10^-4
0.01(10^-2)
0.28
0.40
0.70
1.50
3.00
5.50
10^3 (1 mm)
10^4
10^6 (1 m)
Micrometers (μm)

Optical telescopes





When light strikes the concave primary mirror of the Hubble Space Telescope, it is reflected to the convex secondary mirror, then back through a hole in the center of the primary mirror. There, the light comes to the focal point and passes to one of Hubble's instruments. Telescopes of this design are called Cassegrain telescopes, after the person who designed the first one.

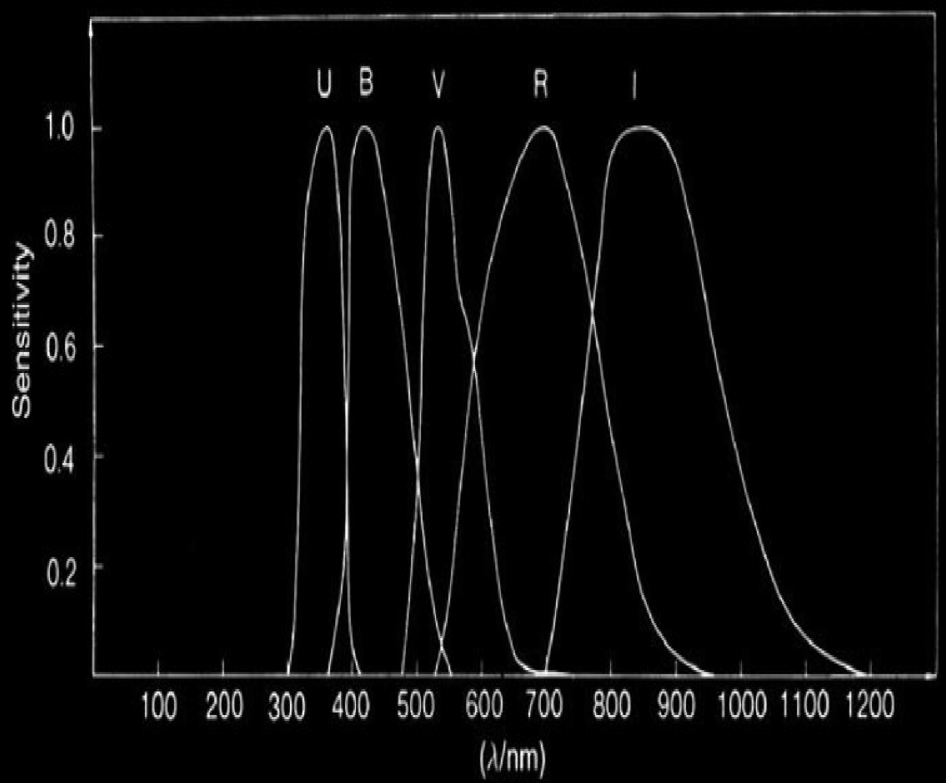
Fluxes in the optical and near infrared bands : Magnitudes

Apparent Magnitude :

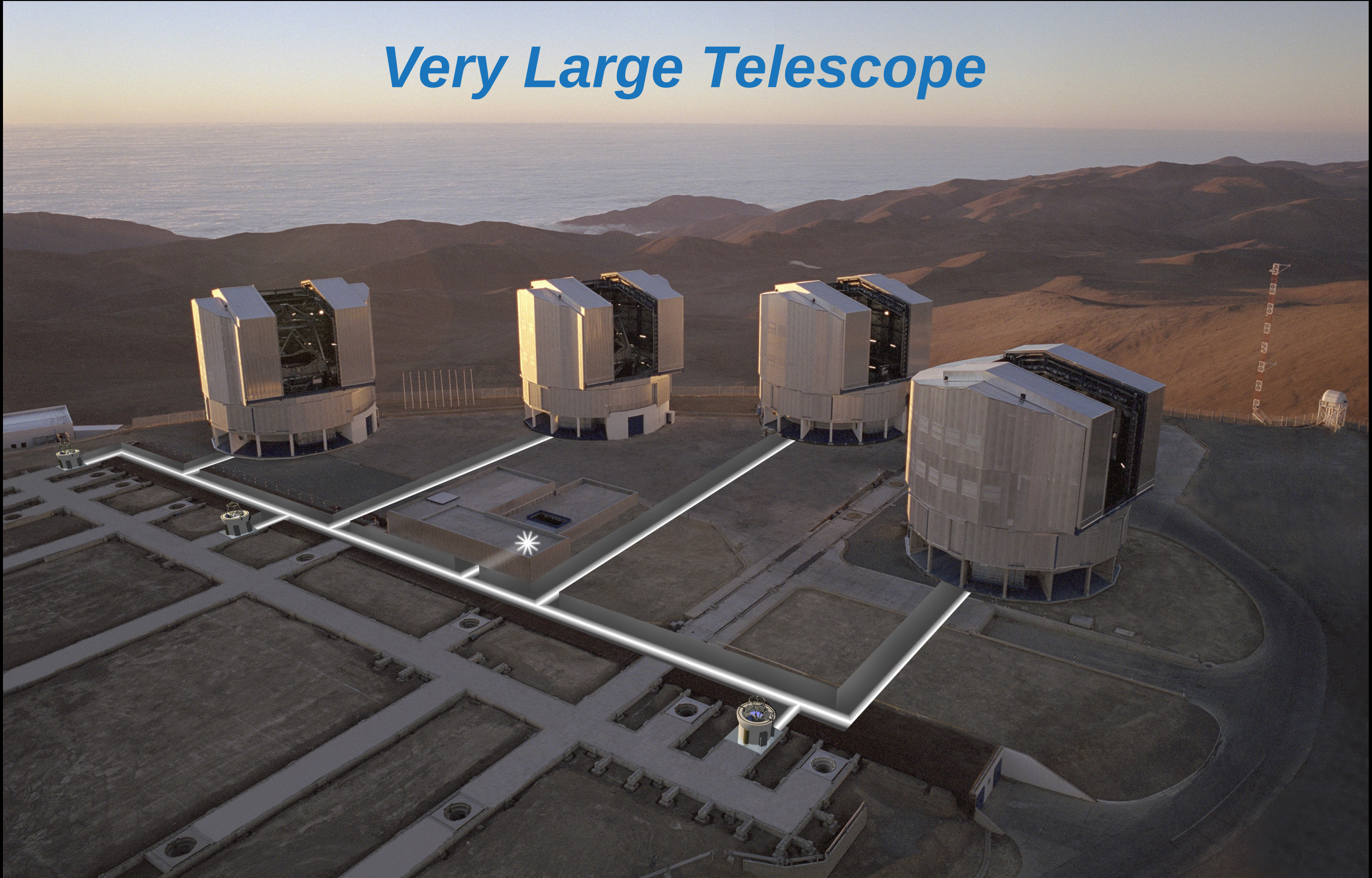
$$m - m_0 = -2.5\ Log_{10}(F/F_0)$$

Absolute Magnitude :

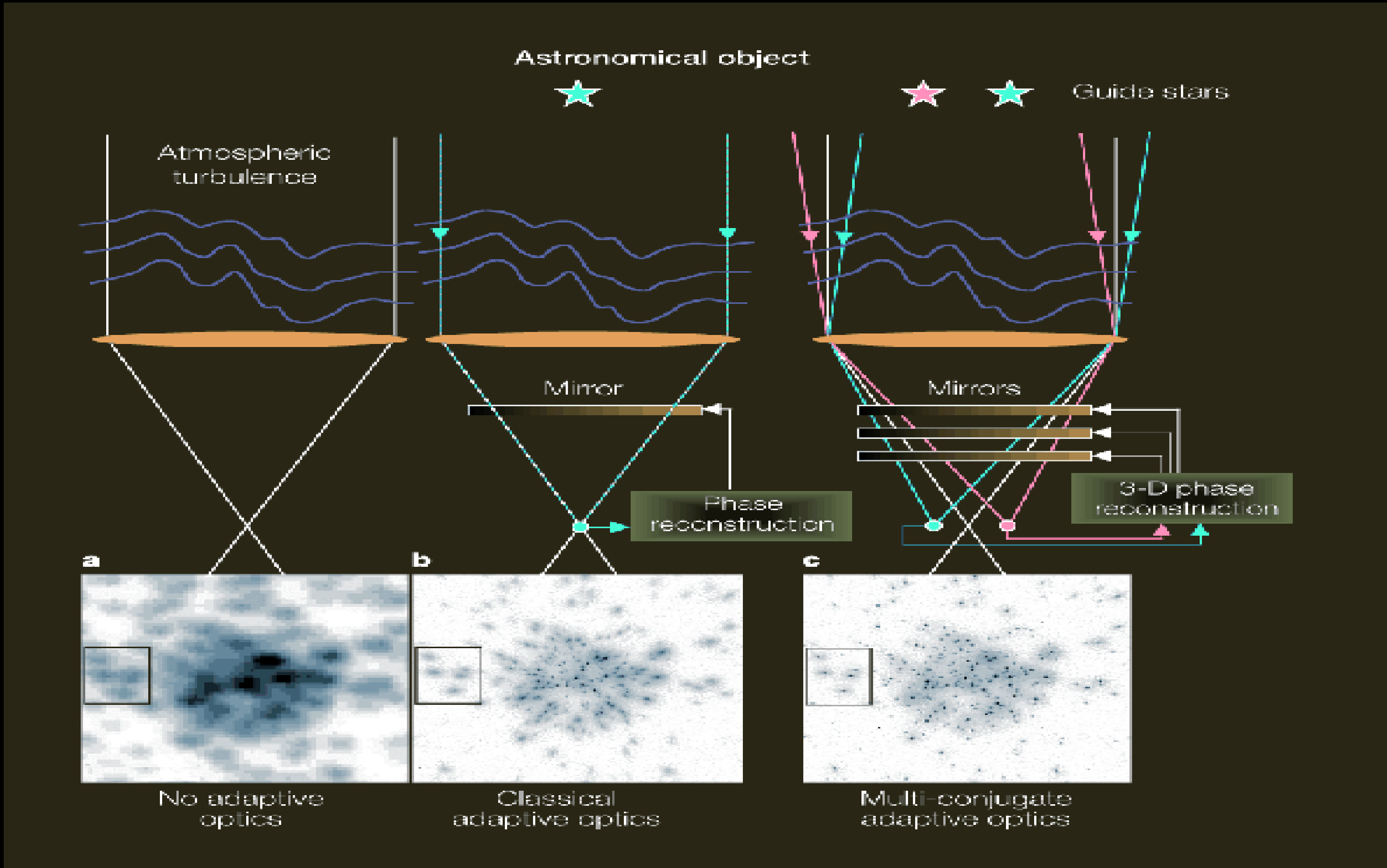
$$M = m - 5\ Log\frac{D}{10\ pc}$$



Very Large Telescope

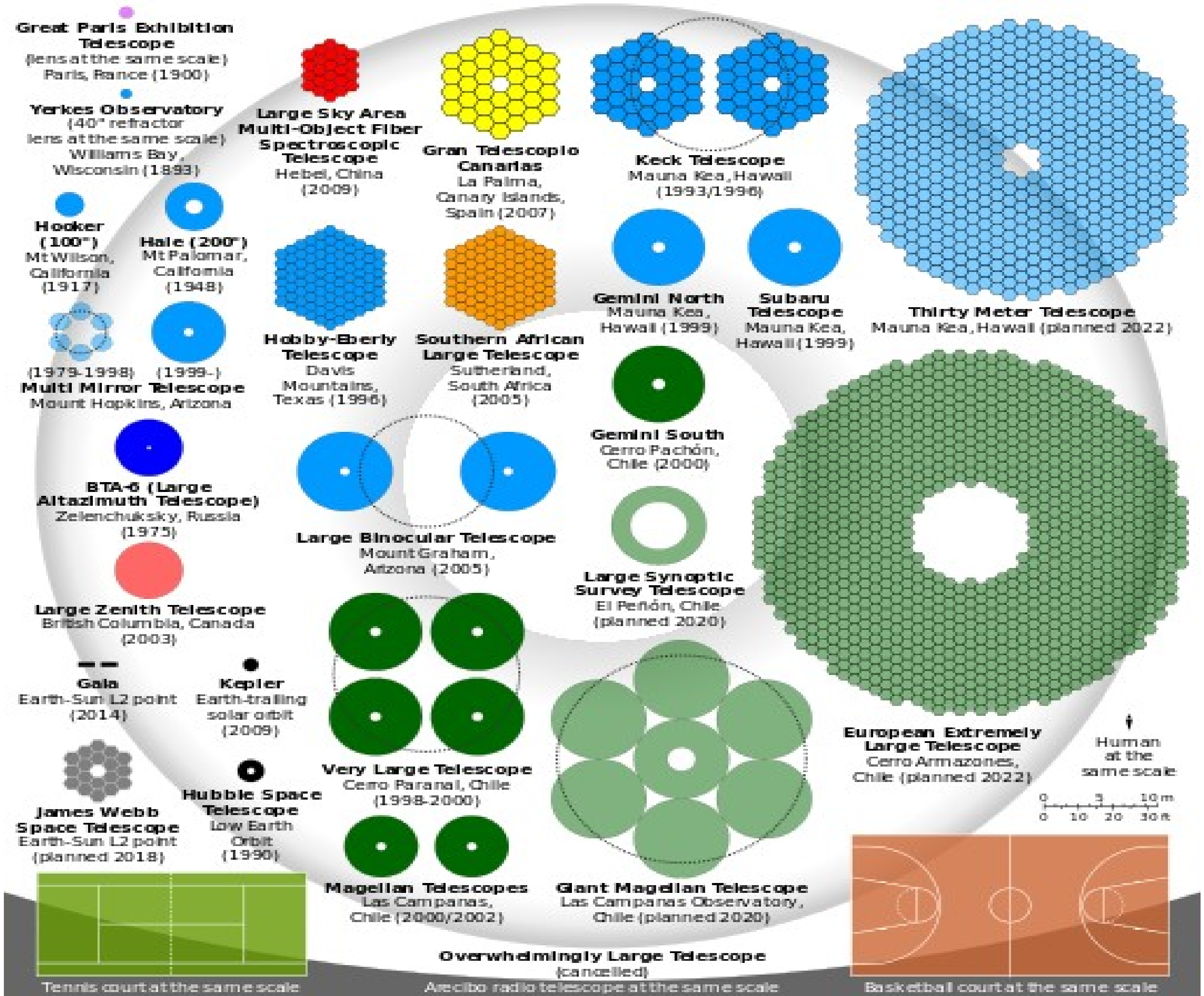


Adaptive optics

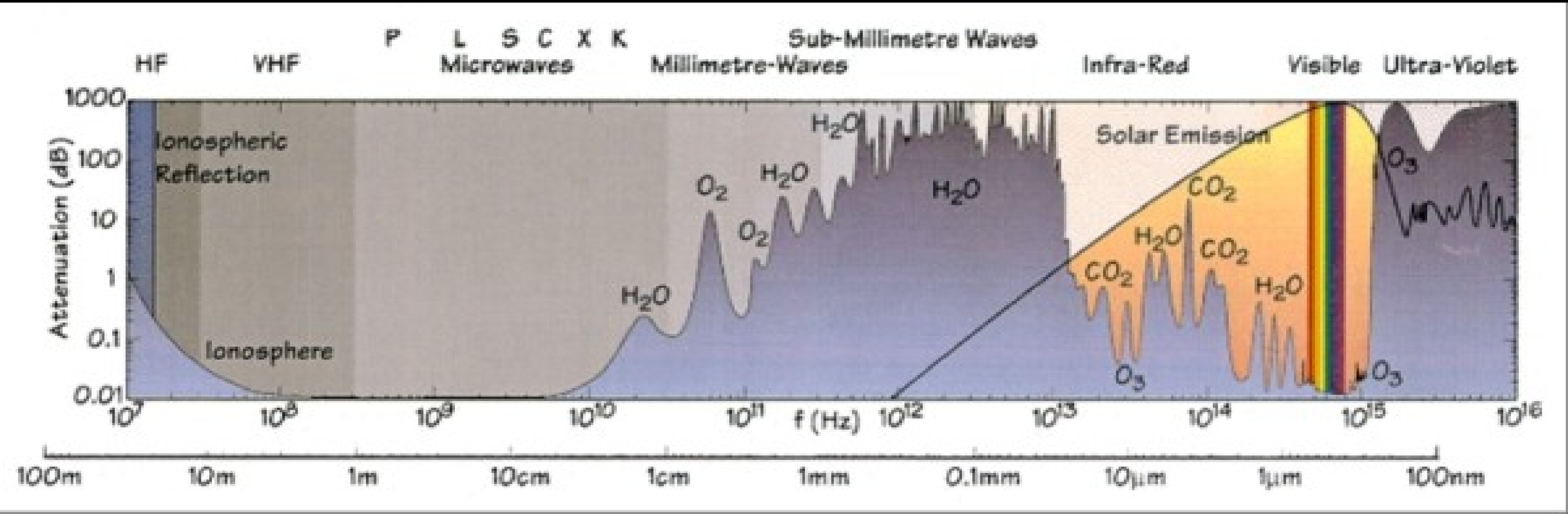


Extremely Large Telescope

Astronomical Mirrors



Atmosphere transparency




SOFIA
STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY
NASA
DLR
N747NA


OBSERVATORIO NOBEYAMA
1.350 mts. de altitud
Japón
VERY LARGE ARRAY (VLA)
2.124 mts. de altitud
EE.UU.
OBSERVATORIO LA SILLA
2.40 mts. de altitud
Chile
VERY LARGE TELESCOPE (VLT)
2.635 mts. de altitud
Chile
OBSERVATORIO KECK
4.145 mts. de altitud
EE.UU.
OBSERVATORIO ALMA
5.000 mts. de altitud
Chile

ALMA as an Interferometer

66 antennas working as one radiotelescope.

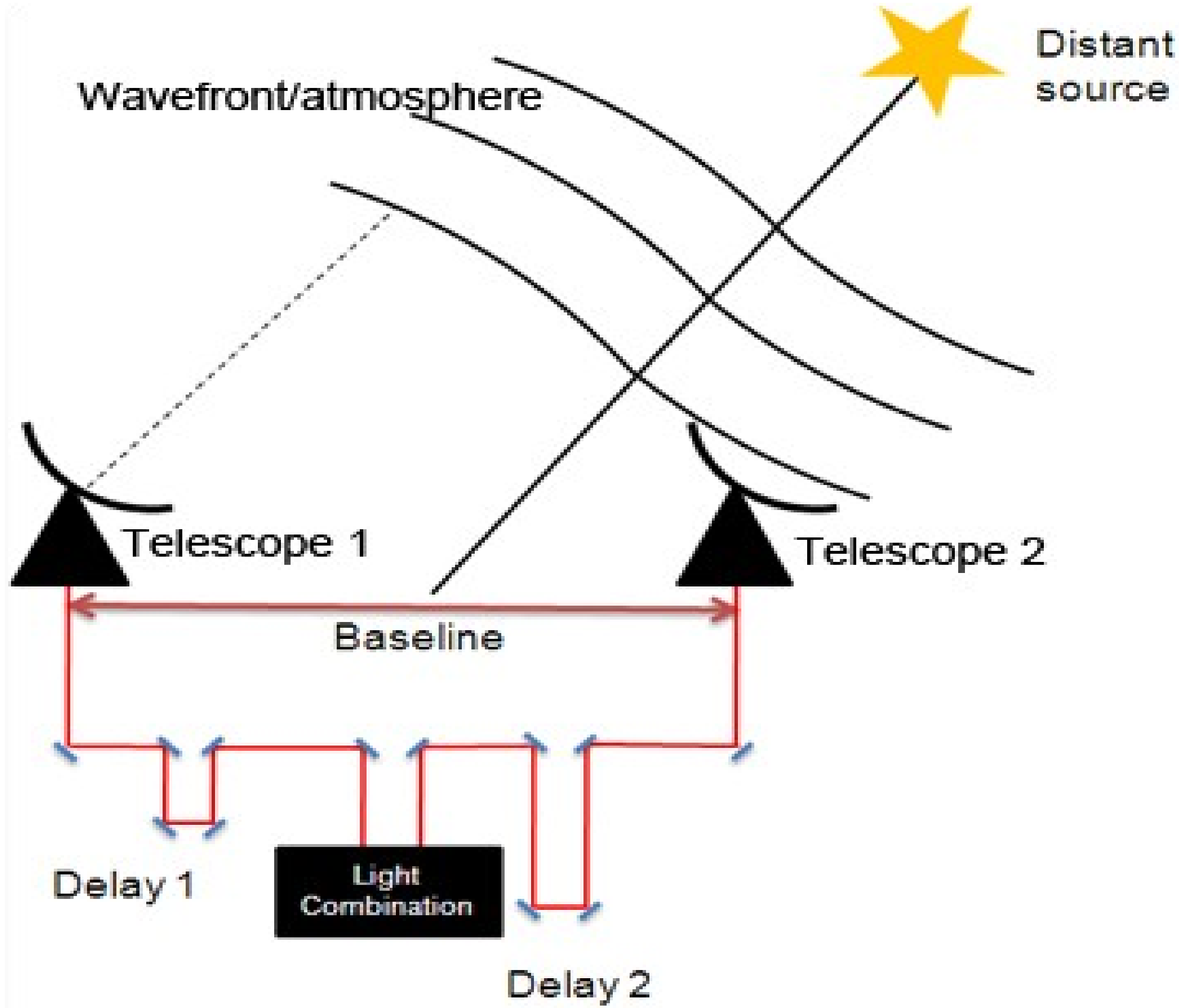
Is as if we had a 15km radiotelescope.

How interferometry works

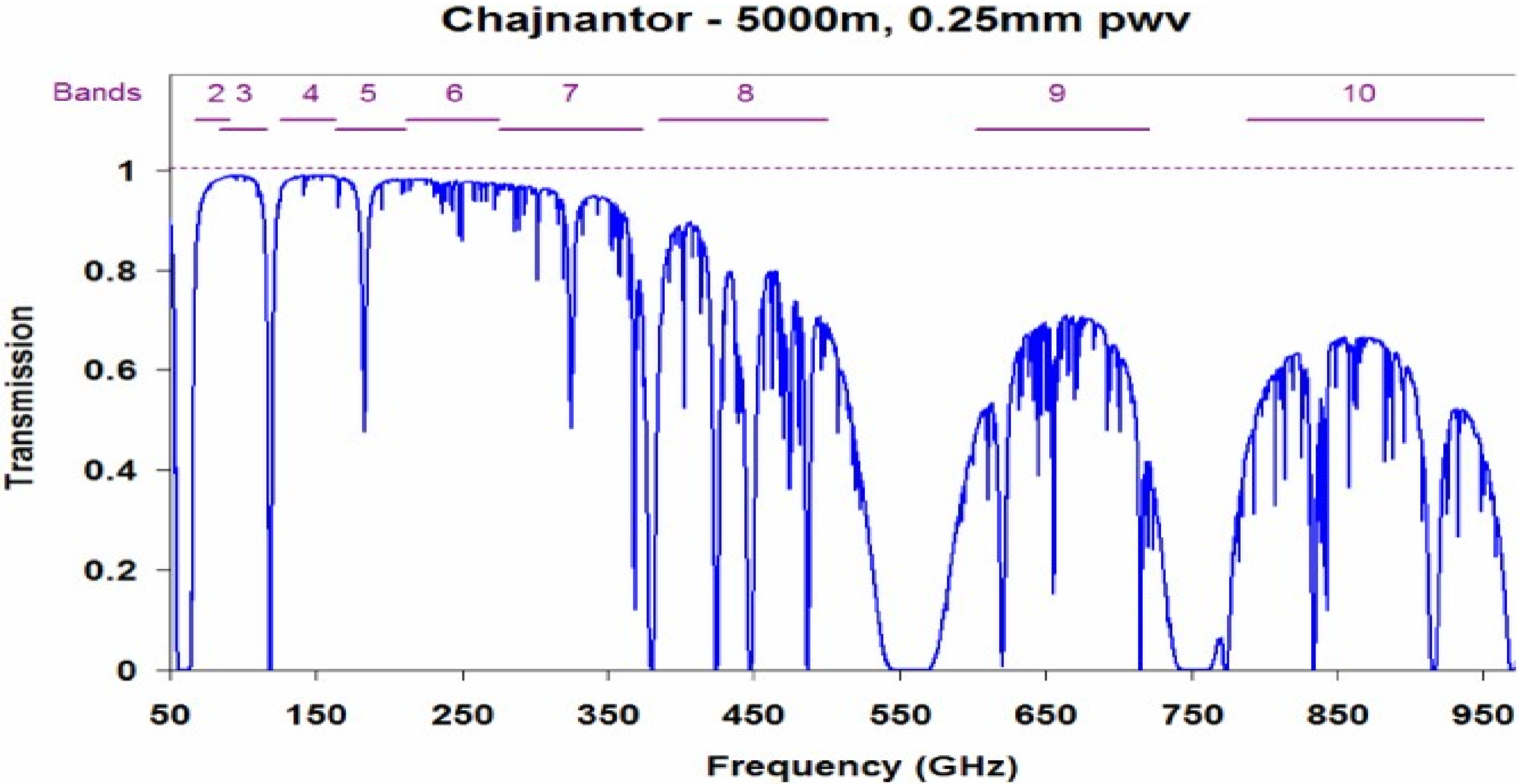
One antenna the resolution goes λ/D, where D is the diameter of the antenna.

Two antennas the resolution goes λ/B, where B is the baseline between the two antennas.

How interferometry works



ALMA bands



Chajnantor - 5000m, 0.25mm pwv
Bands
2 3
4
5
6
7
8
9
10
1
0.8
0.6
0.4
0.2
0
Transmission
50
150
250
350
450
550
650
750
850
950
Frequency (GHz)

Main molecules per band

ALMA Band	Frequency (GHz)	Main Lines
1	31 - 45	
2	67 - 90	
3	84 - 116	CO(1-0)
4	125 - 163	H_2O
5	163 - 211	
6	211 - 275	CO (2-1)
7	275 - 373	CO (3-2), [CII] z=5
8	385 - 500	CO (4-3), [CII] z=3
9	602 - 720	CO (6-5), [CII] z=2
10	787 - 950	CO (7-6), CO (8-7)

Quick Picker

- [x] CO v = 0
- [x] ^{13}CO v = 0
- [x] $C^{17}O$
- [x] $C^{18}O$
- [ ] CH_3OH v_t = 0
- [x] H_2CO
- [ ] HCN v = 0
- [ ] HNC v = 0
- [ ] $H^{13}CN$ v = 0
- [ ] $HC^{15}N$ v = 0
- [ ] DCN v = 0
- [ ] HCO^+ v = 0
- [x] CS
- [ ] $H^{13}CO^+$
- [x] NH_3
- [ ] C I
- [ ] C II
- [ ] O I
- [ ] O III
- [ ] N II
- [ ] H_2O v = 0
- [ ] HDO
- [x] SiO v = 0

splatalogue

database for astronomical spectroscopy

Search:

Telescope Bands: Any / ALMA Band 3 (84-116 GHz) / ALMA Band 4 (125-163 GHz) / ALMA Band 5 (163-211 GHz)

Redshift:

Energy Range: Min Max (•) E_L (cm^{-1}) ( ) E_L (K)

Frequency Range: Frequency Unit: GHz

Min Max

+ Frequency − Frequency

Search

Astronomical Filters

(Double click to unselect)

- Top 20 list
- Planetary Atmosphere
- Hot Cores
- Dark Clouds
- Diffuse Clouds
- Comets
- AGB/PPN/PN
- Extragalactic

Scan to Mobile Splat

Found 15 lines in ALMA Band 3 (84-116 GHz), showing 1 - 15

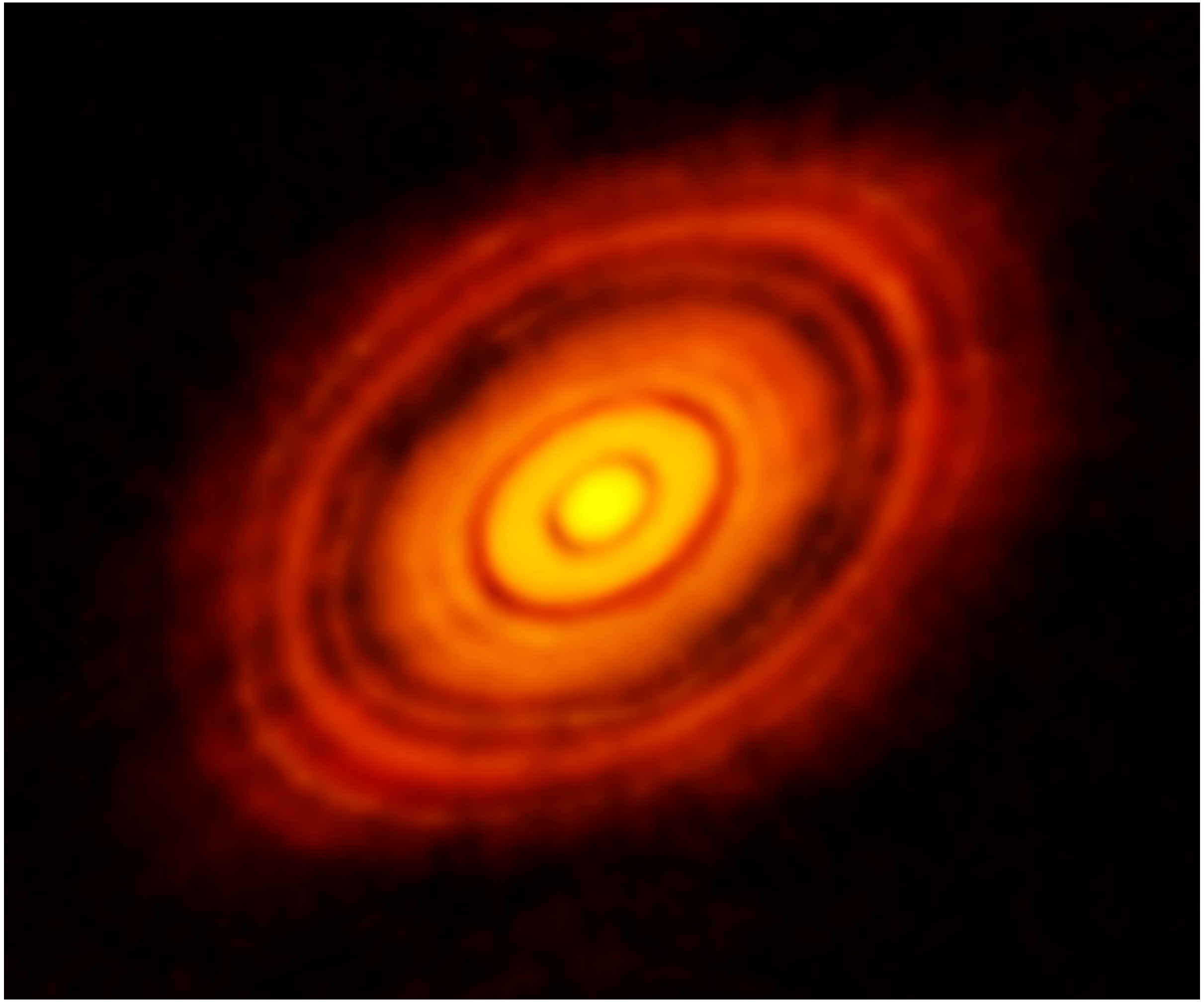
Click on the chemical formula below for more information about that species.

	Species	Chemical Name	Ordered Freq (GHz) (rest frame, redshifted)	Resolved QNs	CDMS/JPL Intensity	Lovas/AST Intensity	E_L (cm^{-1})	E_L (K)	Linelist
1	H_2CO	Formaldehyde	85.31068, 85.31068	50(6,44)-50(6,45)	-11.01730		3390.2754	4877.8220	CDMS
2	SiO v = 0	Silicon Monoxide	86.84696, 86.84696	2- 1	-2.48320	1.5	1.4485	2.0841	CDMS
3	H_2CO	Formaldehyde	89.56506, 89.56506	13(2,11)-13(2,12)	-4.78500		253.2493	364.3672	CDMS
4	H_2CO	Formaldehyde	89.93780, 89.93780	45(2,43)-44(4,40)	-10.82770		2564.5250	3689.7582	CDMS
5	H_2CO	Formaldehyde	95.93231, 95.93231	31(4,27)-31(4,28)	-6.77550		1338.2468	1925.4276	CDMS
6	CS v = 0	Carbon Monosulfide	97.98095, 97.98095	2 - 1	0.00000	6.94	1.6340	2.3509	SLAIM
7	H_2CO	Formaldehyde	100.51110, 100.51110	22(3,19)-22(3,20)	-5.00180		689.1894	991.5841	CDMS
8	H_2CO	Formaldehyde	101.33299, 101.33299	6(1, 5)- 6(1, 6)	-4.04410	<0.1	57.4804	82.7010	CDMS
9	H_2CO	Formaldehyde	104.15793, 104.15793	41(5,36)-41(5,37)	-8.16510		2298.5855	3307.1328	CDMS
10	H_2CO	Formaldehyde	104.93181, 104.93181	51(6,45)-51(6,46)	-11.11150		3514.0612	5055.9211	CDMS
11	$C^{18}O$	Carbon Monoxide	109.78218, 109.78218	1- 0	0.00000	2.1	0.0000	0.0000	SLAIM
12	^{13}CO v = 0	Carbon Monoxide	110.20135, 110.20135	1-0	-5.06620	9.3	0.0000	0.0000	CDMS
13	H_2CO	Formaldehyde	110.93421, 110.93421	21(3,18)-22(1,21)	-6.30110		634.5972	913.0386	CDMS
14	$C^{17}O$	Carbon Monoxide	112.35928, 112.35928	J= 1- 0	0.00000	0.20	0.0000	0.0000	SLAIM
15	CO v = 0	Carbon Monoxide	115.27120, 115.27120	1- 0	0.00000	60.0	0.0000	0.0000	SLAIM

Found 15 lines in ALMA Band 3 (84-116 GHz), showing 1 - 15

ALMA discoveries

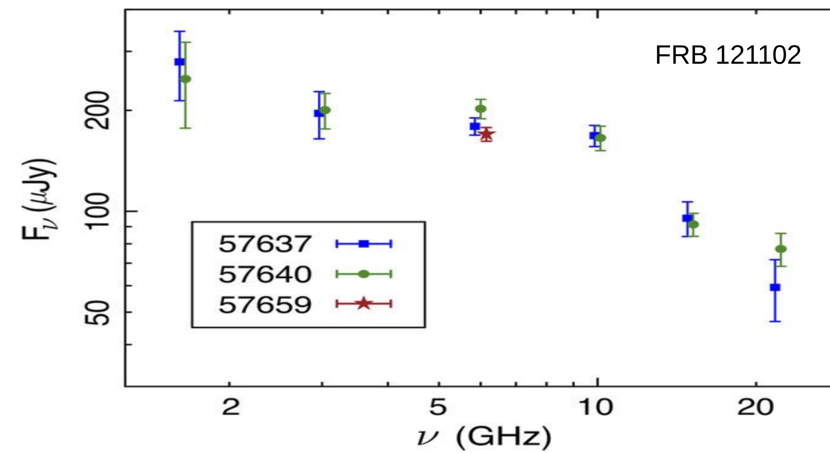
- The sharpest image ever taken by ALMA. It shows the protoplanetary disc surrounding the young star HL Tauri. These new ALMA observations reveal substructures within the disc that have never been seen before and even show the possible positions of planets forming in the dark patches within the system.



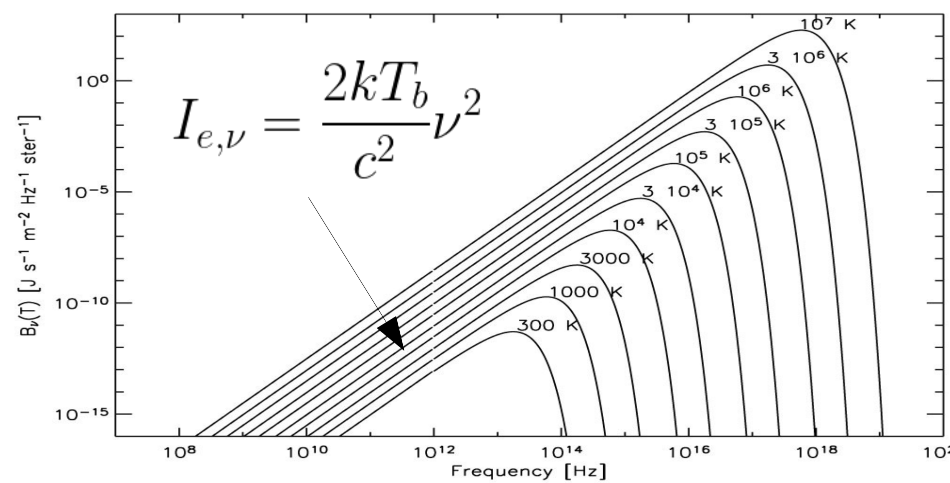
Fluxes in the Radio band

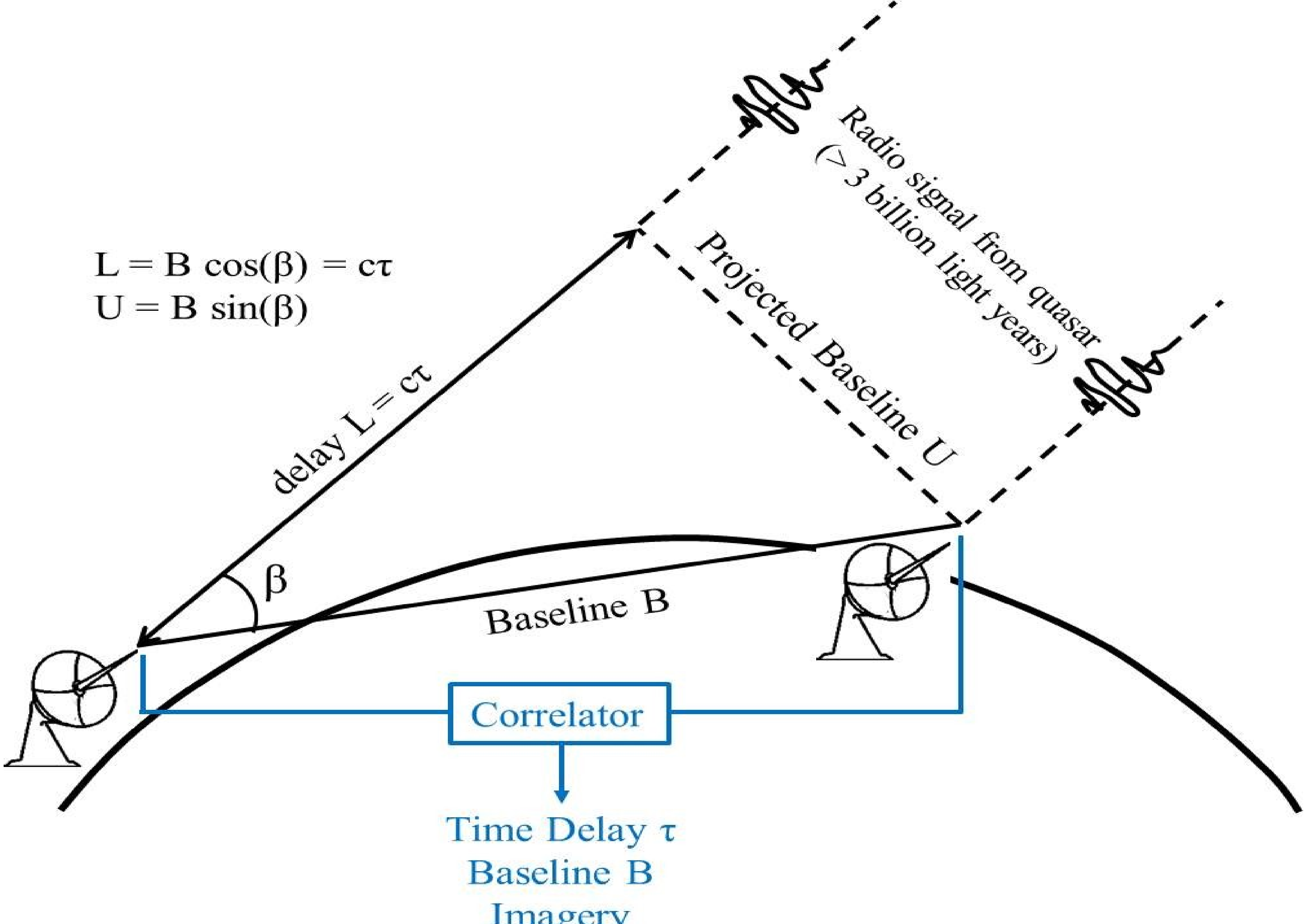
$$1\ Jy = 10^{-23}\ \mathrm{erg\ cm^{-2} s^{-1} Hz^{-1}}$$

Nature volume 541, pages 58–61 (2017)

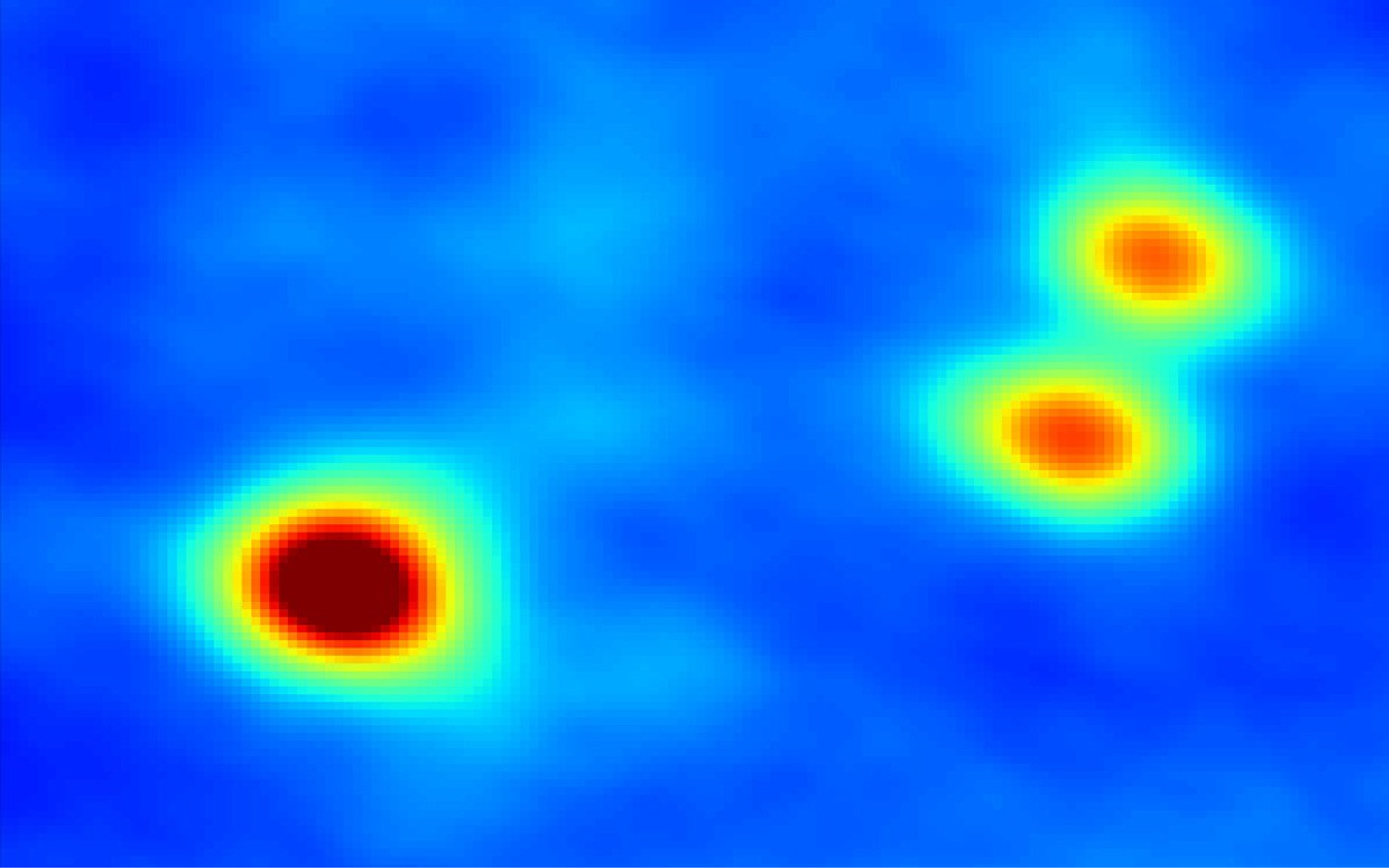


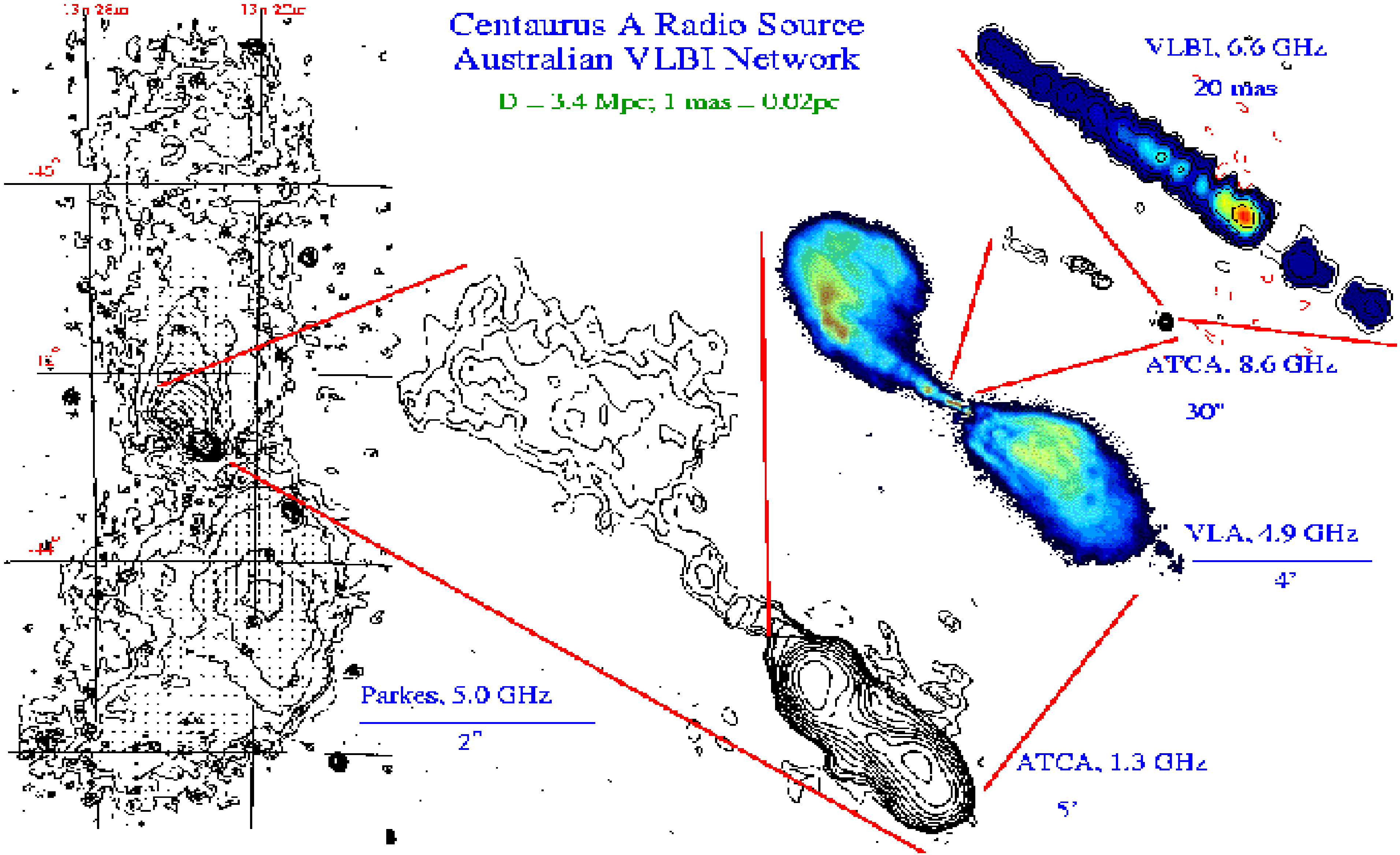
$$I_{e,\nu} = I_\nu h\nu = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT_b}} - 1} \quad \left[\frac{erg}{cm^2 s\ sr Hz}\right]$$

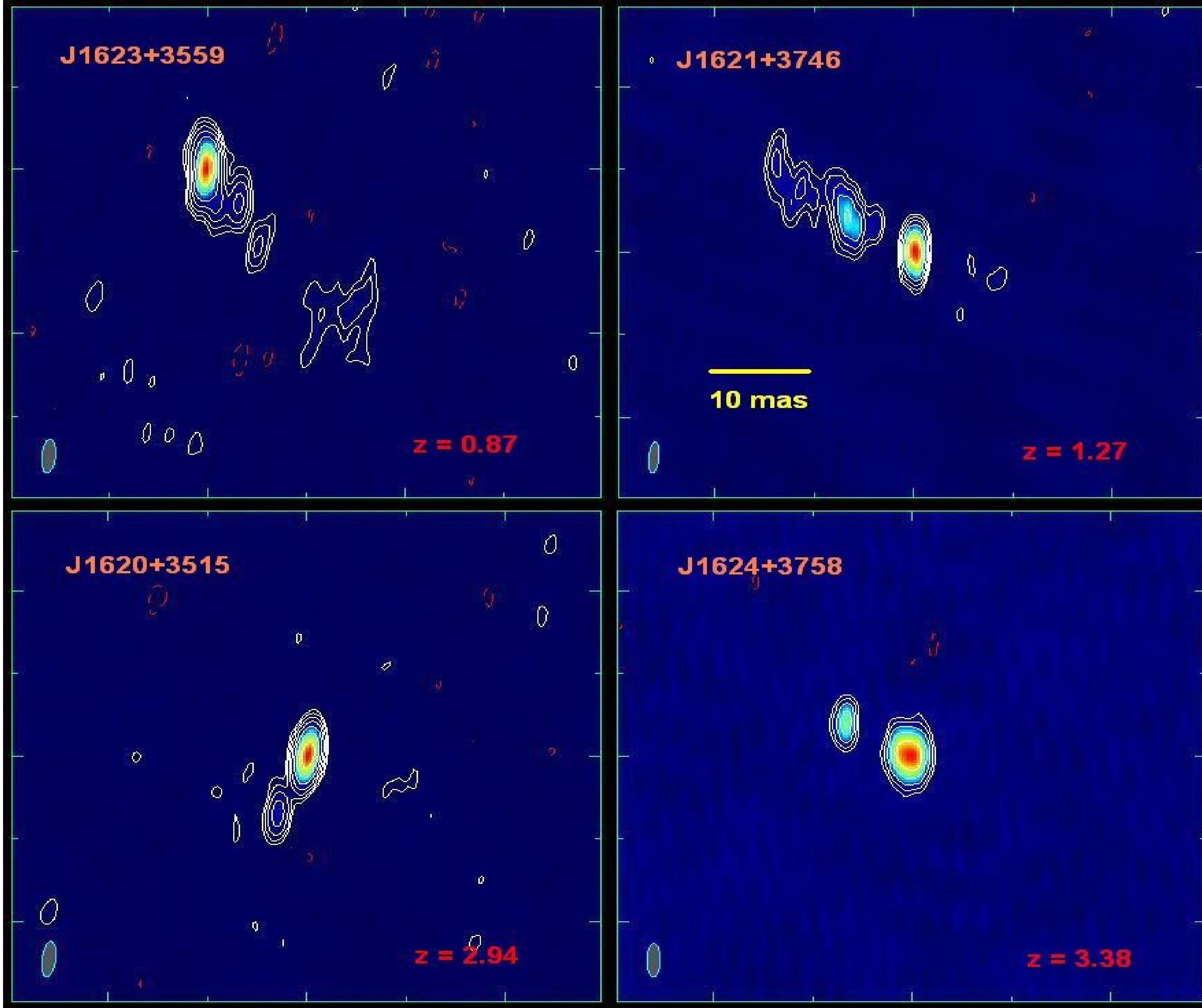




L = B cos(β) = cτ
U = B sin(β)
delay L = cτ
Radio signal from quasar
(> 3 billion light years)
Projected Baseline U
β
Baseline B
Correlator
Time Delay τ
Baseline B
Imagery



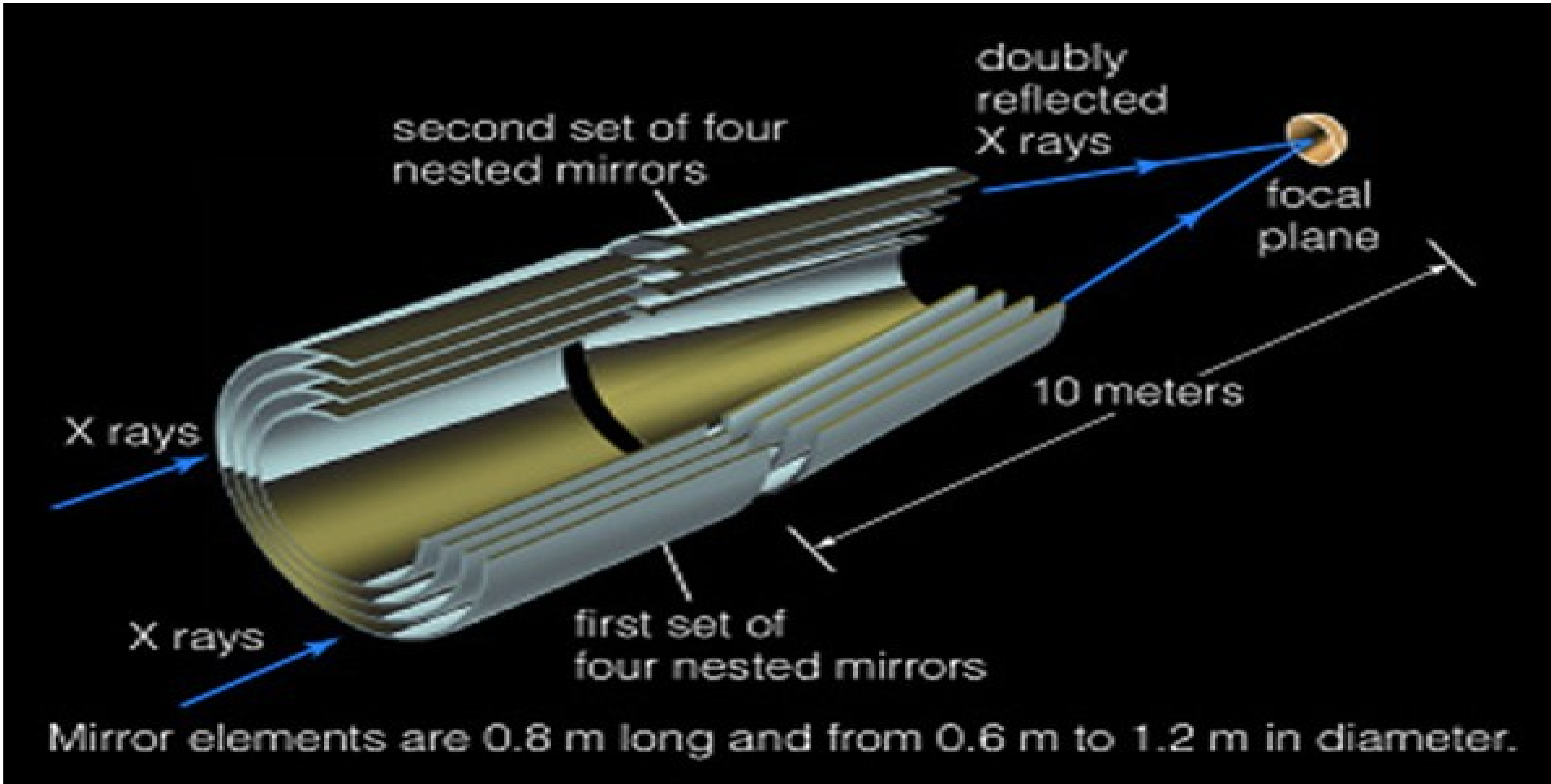

Centaurus A Radio Source
Australian VLBI Network
D = 3.4 Mpc; 1 mas = 0.02pc
VLBI, 6.6 GHz
20 mas
ATCA, 8.6 GHz
30"
VLA, 4.9 GHz
4'
ATCA, 1.3 GHz
5'
Parkes, 5.0 GHz
2°

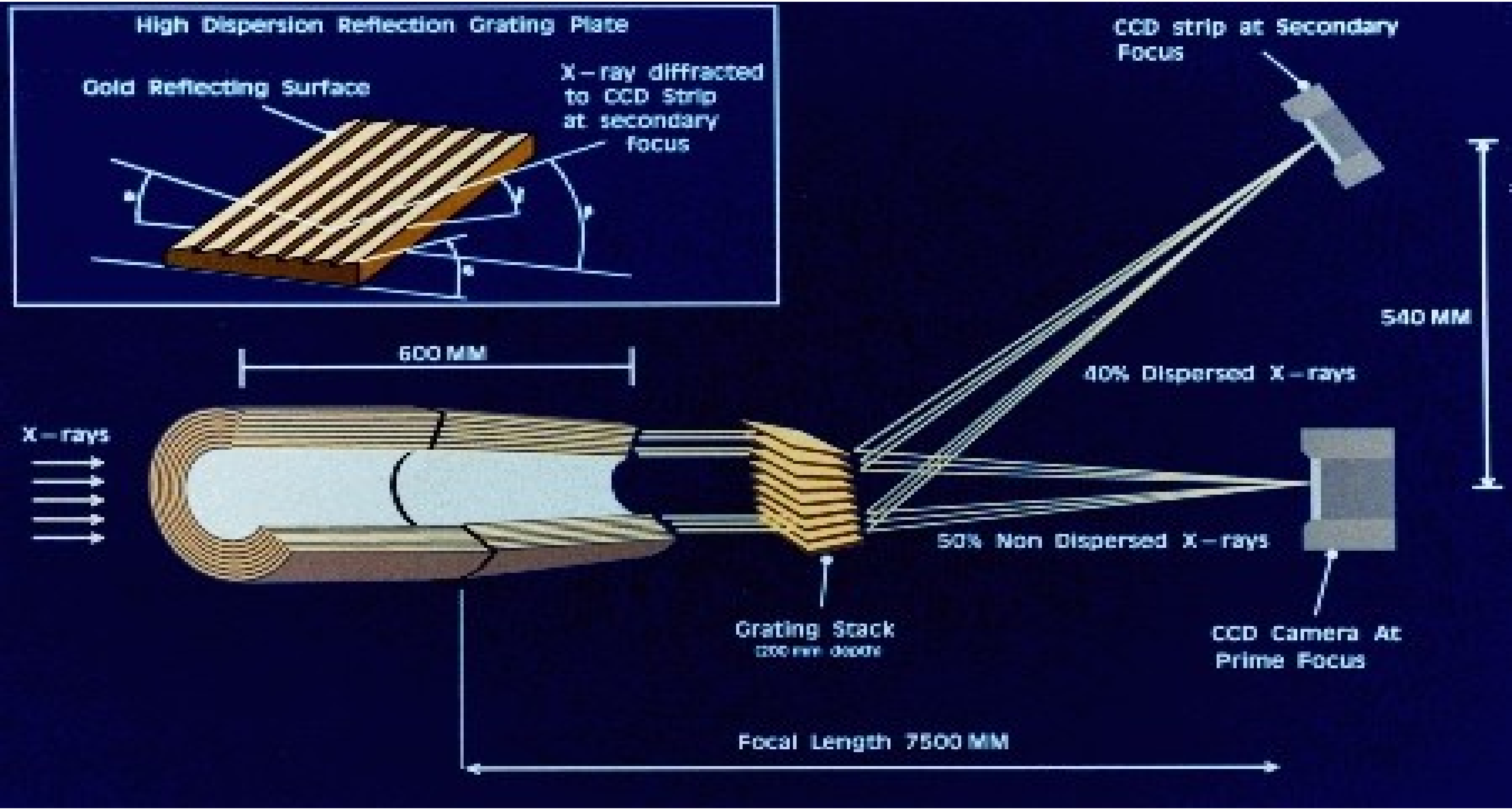


J1623+3559
z = 0.87
J1621+3746
10 mas
z = 1.27
J1620+3515
z = 2.94
J1624+3758
z = 3.38

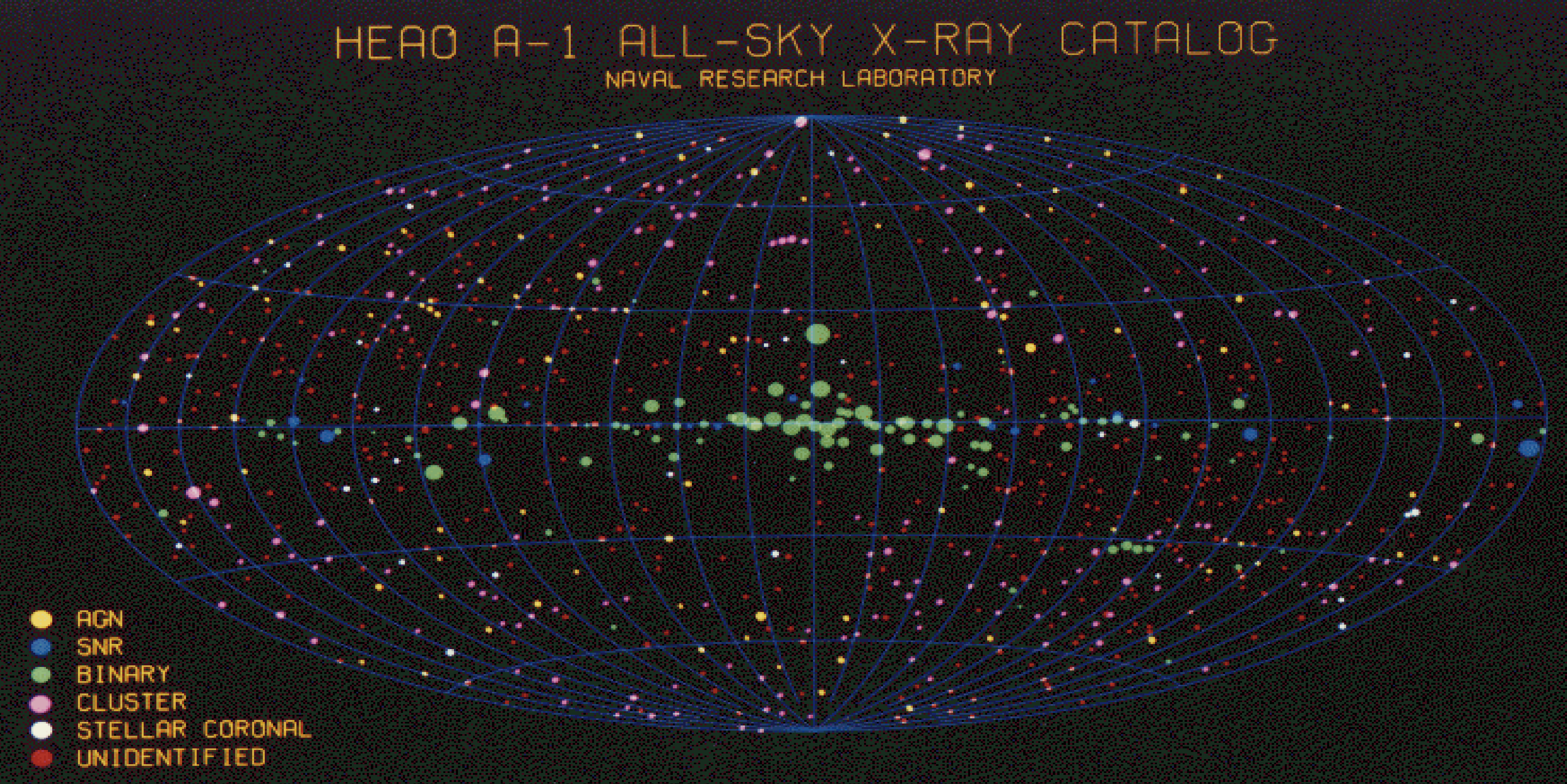
Gamma-rays telescopes

X-rays telescopes





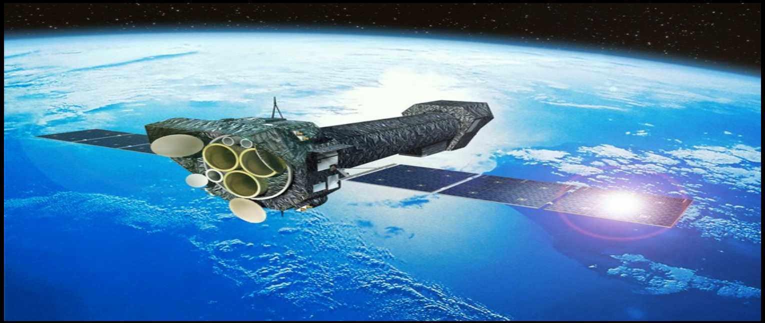
High Dispersion Reflection Grating Plate
Gold Reflecting Surface
X-ray diffracted to CCD Strip at secondary focus
CCD strip at Secondary Focus
540 MM
600 MM
40% Dispersed X-rays
X-rays
50% Non Dispersed X-rays
Grating Stack
(200 mm depth)
CCD Camera At Prime Focus
Focal Length 7500 MM


HEAO A-1 ALL-SKY X-RAY CATALOG
NAVAL RESEARCH LABORATORY
AGN
SNR
BINARY
CLUSTER
STELLAR CORONAL
UNIDENTIFIED

X-rays telescopes in space

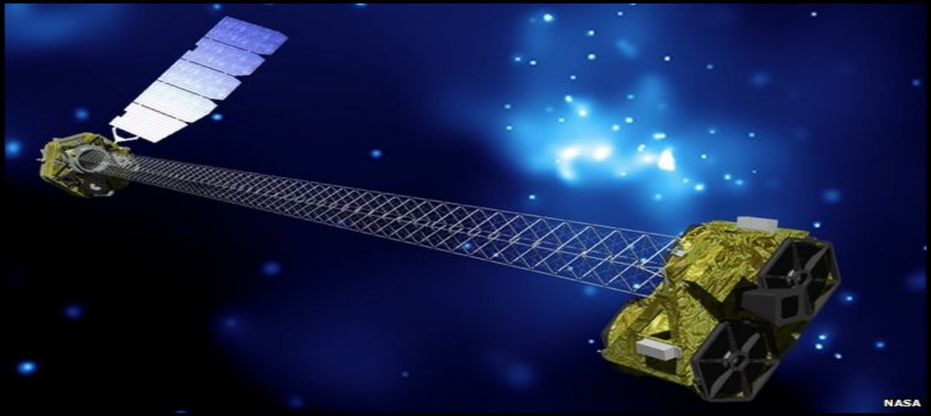
Chandra Xrays Observatory (NASA)
1999 -

Energy range : < 10 keV
Ang. Res : 0.5''



XMM-Newton Telescope (ESA)
2000 -

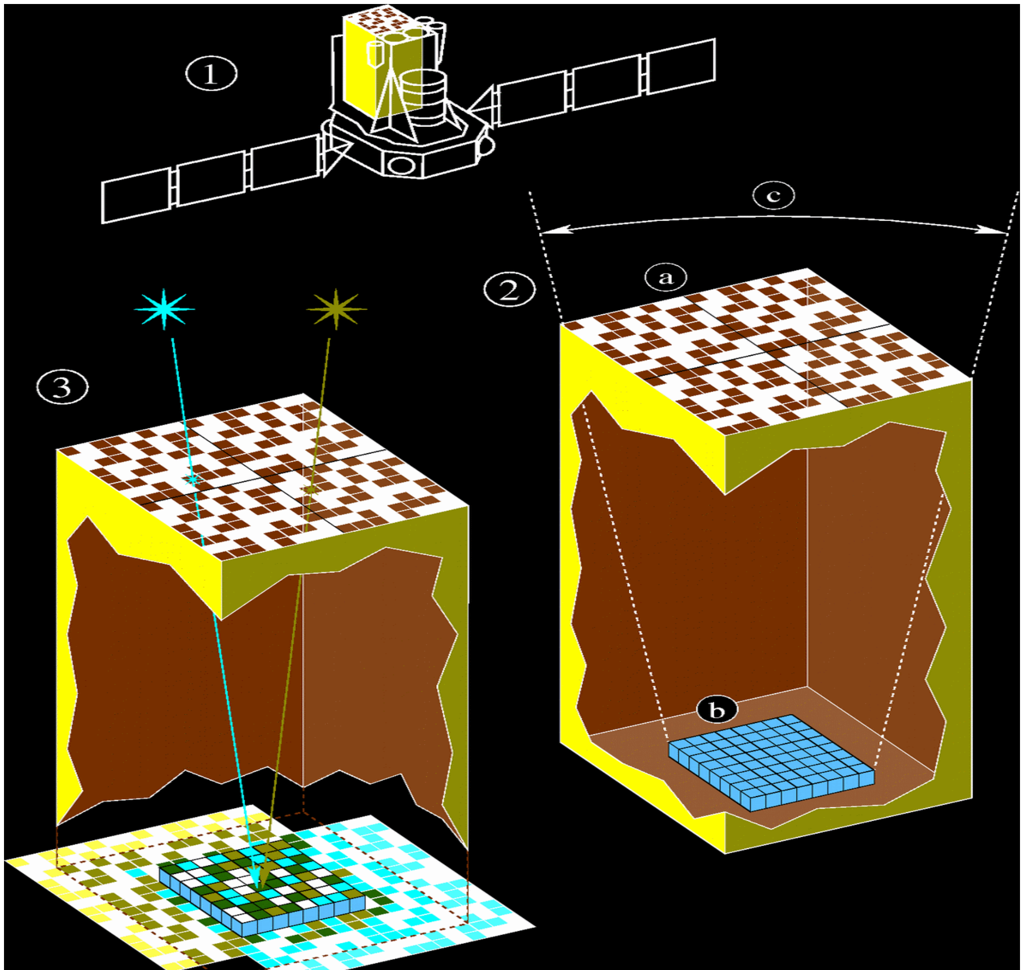
Energy range : < 15 keV
Ang. Res : 5'' – 10 ''



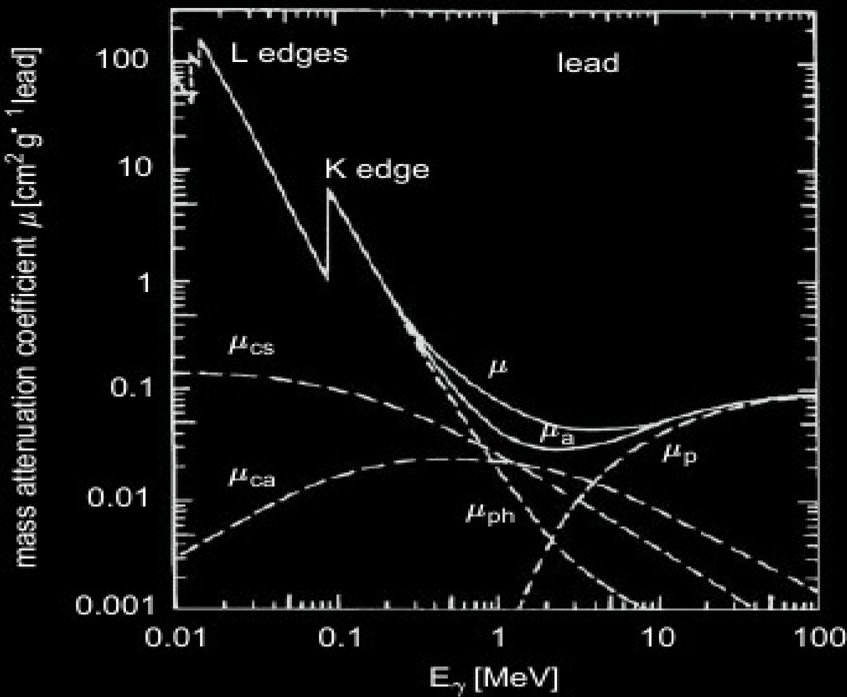
NuSTAR (NASA)
2014 -

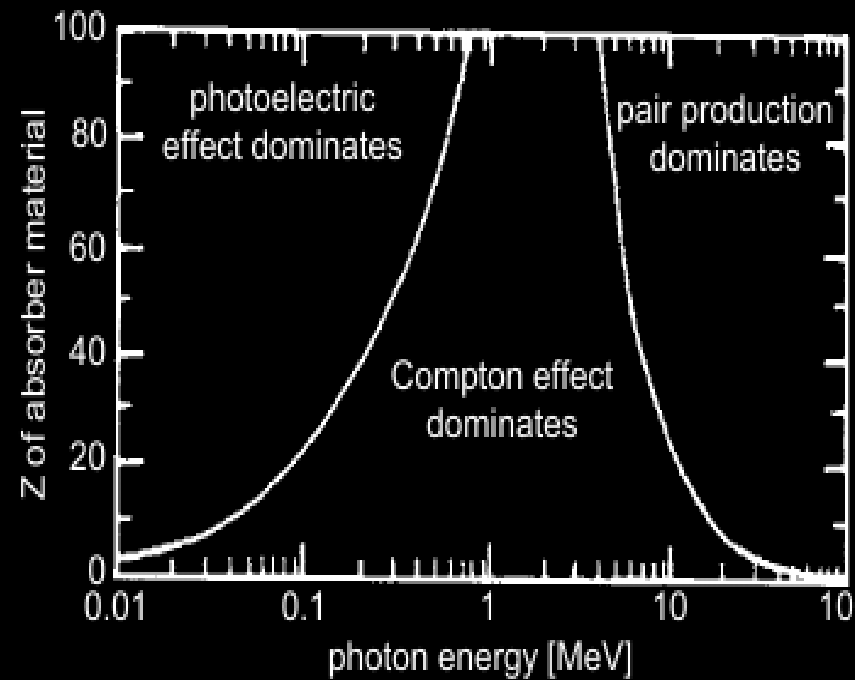
Energy range : < 80 keV
Ang. Res : 10 ''

Coded Mask Telescopes



Photons interaction with matter

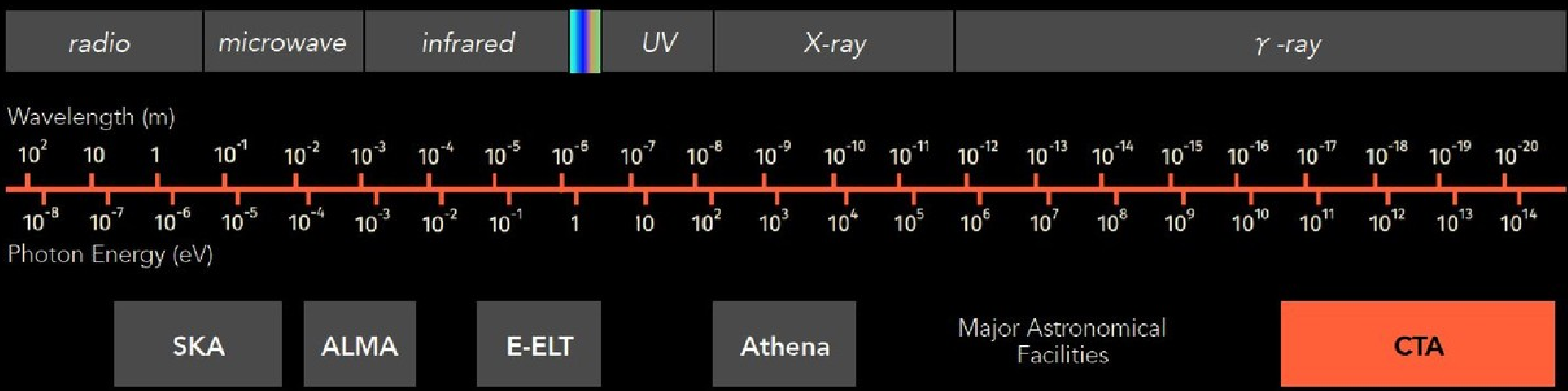


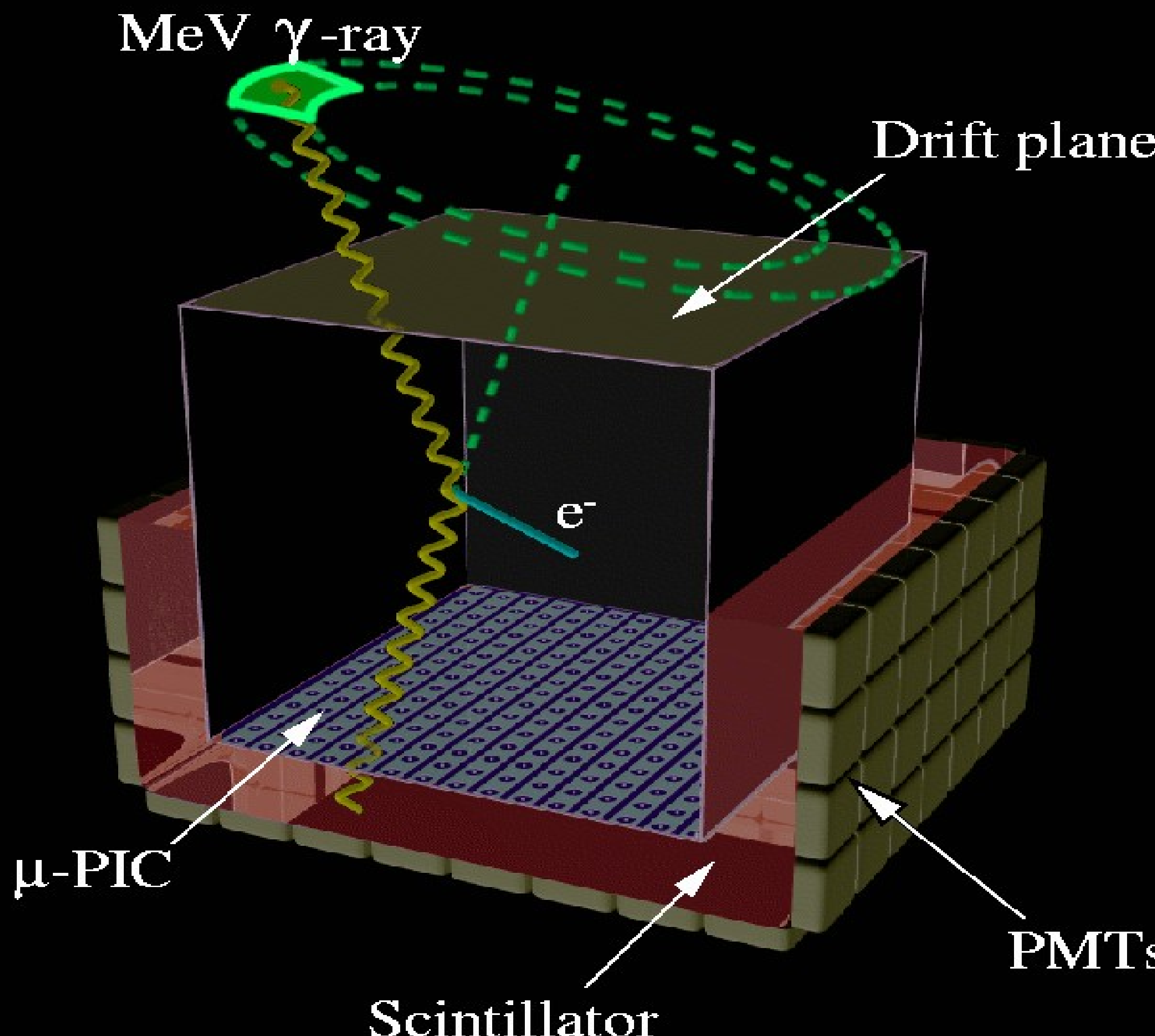


μ_{ph} → photoelectric effect,
μ_{cs} → Compton scattering,
μ_{ca} → Compton absorption
μ_p → pair production.
μ_a → total mass absorption coefficient ($\mu_a = \mu_{ph} + \mu_p + \mu_{ca}$)
μ → total mass attenuation coefficient ($\mu = \mu_{ph} + \mu_p + \mu_c$ where $\mu_c = \mu_{cs} + \mu_{ca}$).

(from Grupen, Particle Detectors)

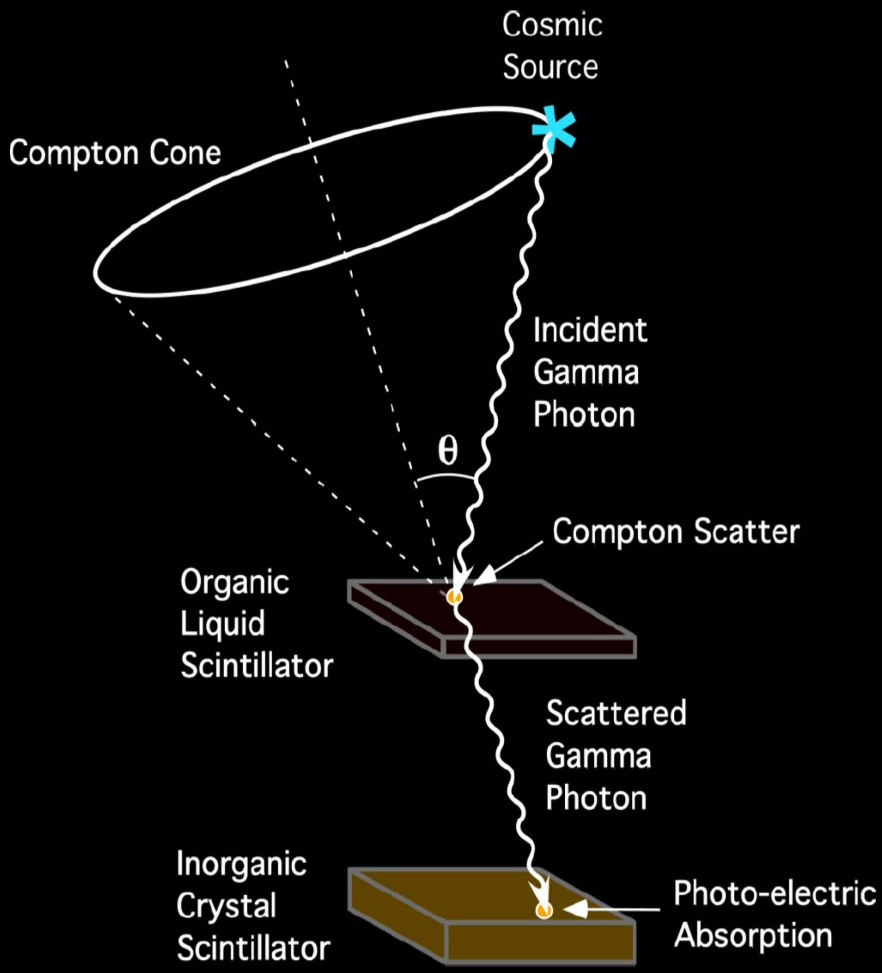
Astronomical bands

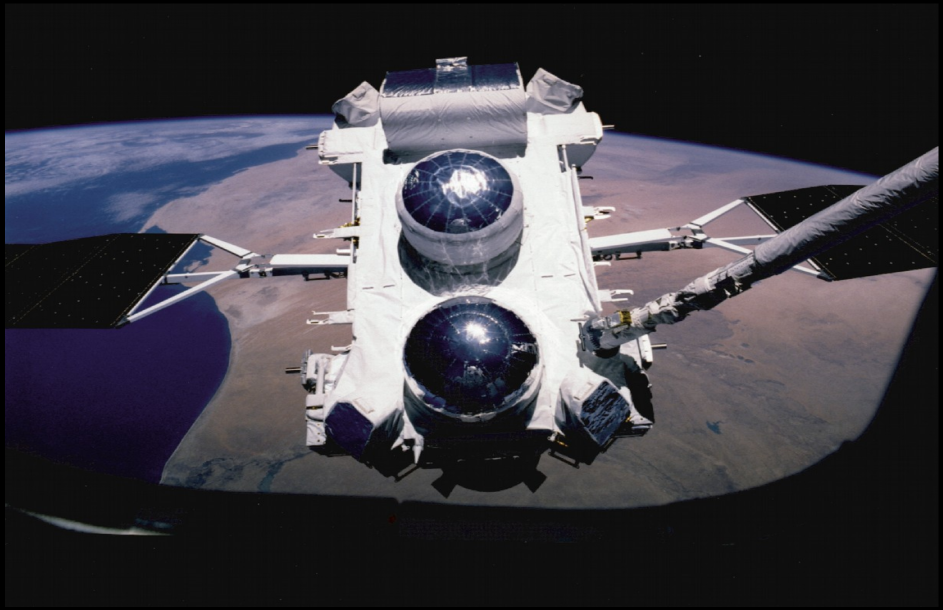




MeV γ-ray
Drift plane
e-
μ-PIC
Scintillator
PMTs

Compton Telescopes





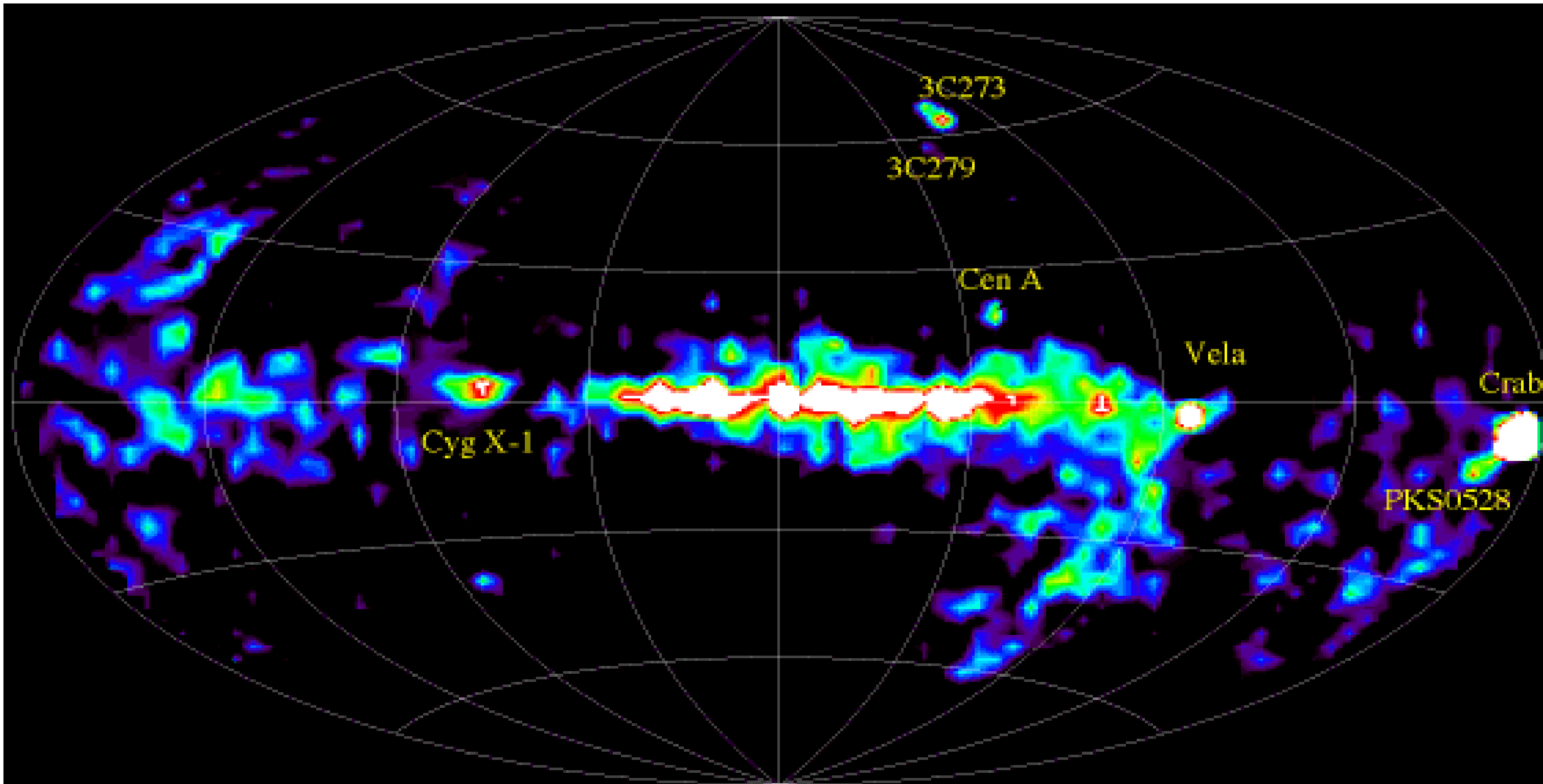
GCRO/COMPTEL (NASA)

1991 - 2000

En. range : 0.75 - 30 MeV

Ang. Res : few deg

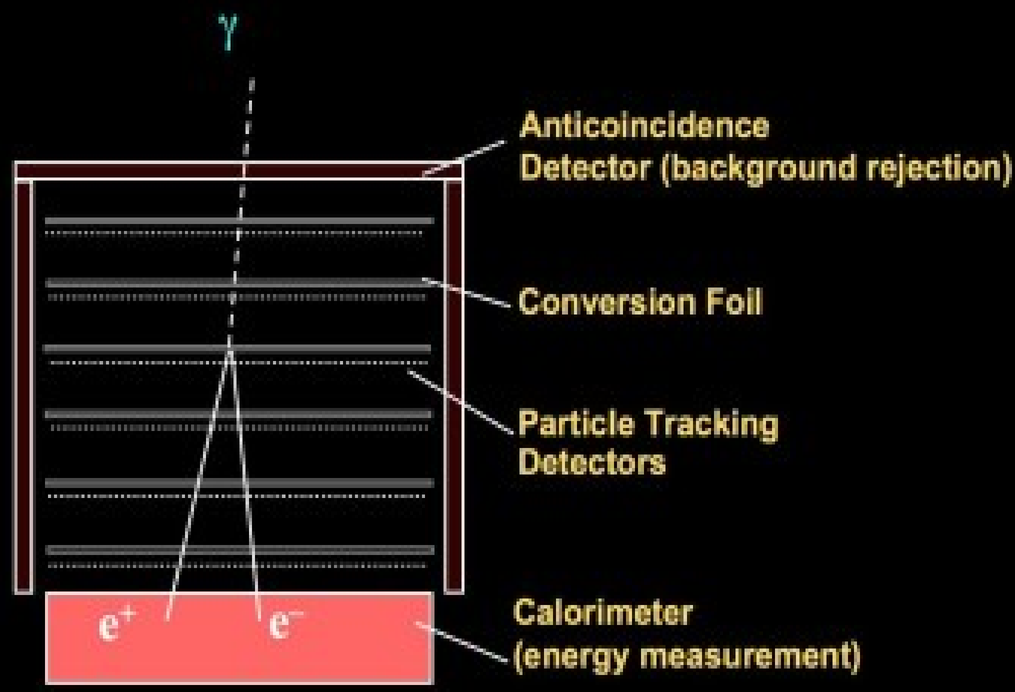
The MeV sky



Pair Production Telescopes

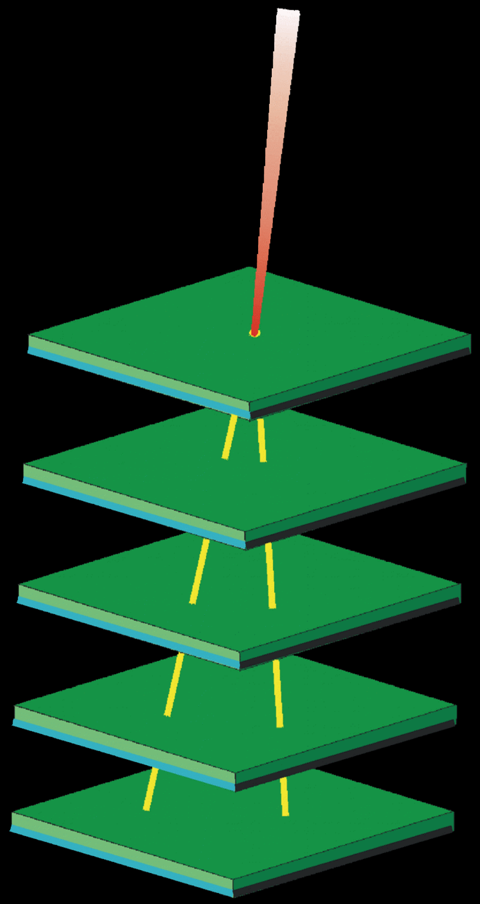
En. range : > 30 MeV

Ang. Res : few deg / E



Detection in pair production telescopes

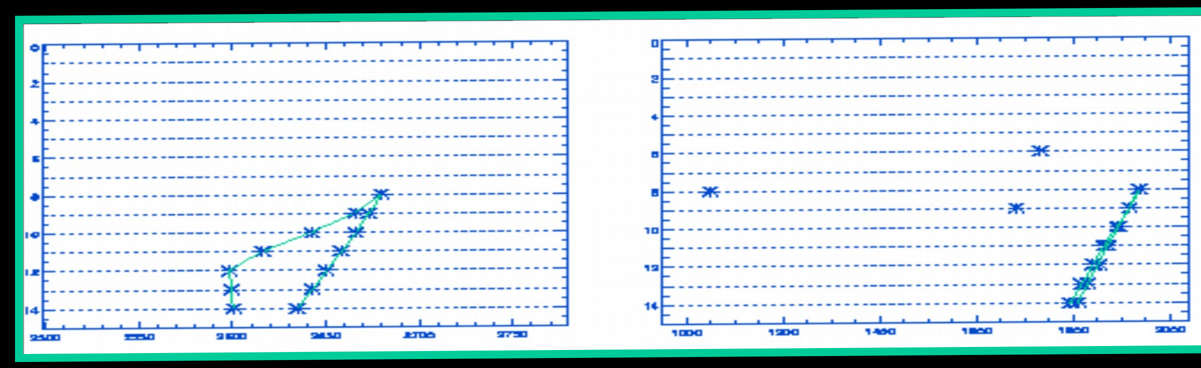
$\gamma \rightarrow e^+e^-$



the pair conserves p and E

but:

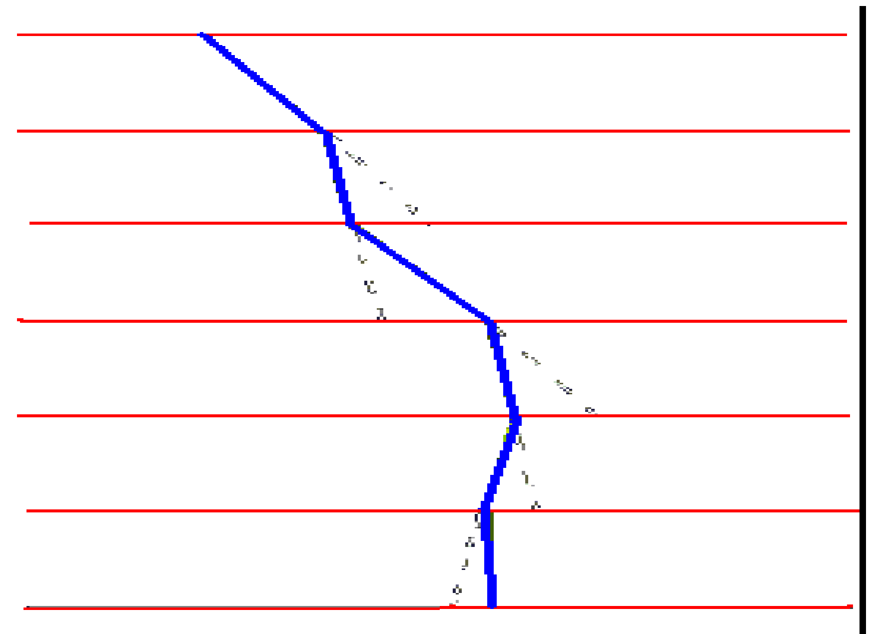
- **Only projection information**
- **Multiple Scattering**
- **Noise hits**

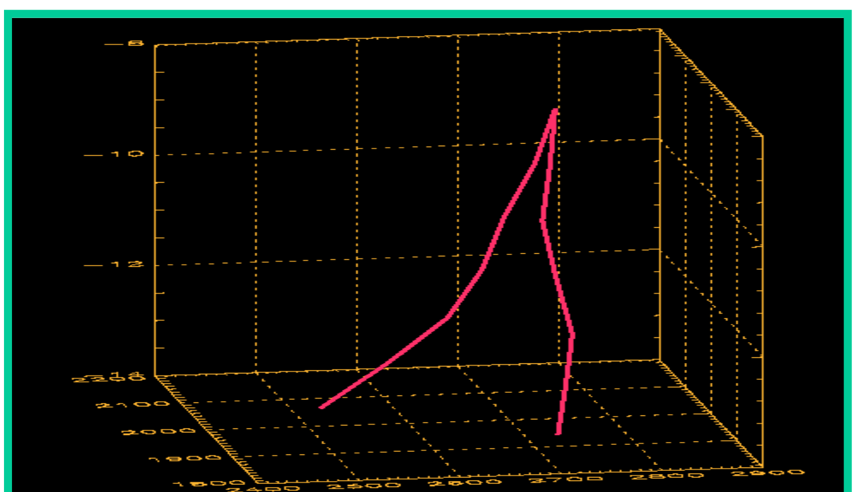


Multiple scattering

Moliere formula :

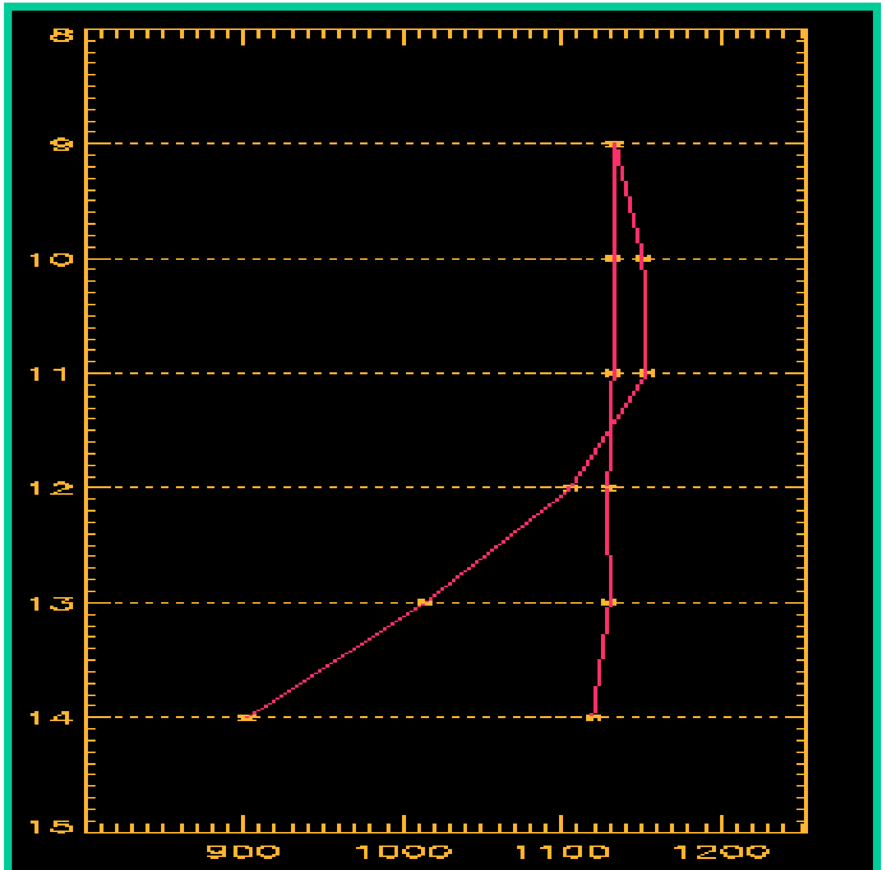
$$\theta_{rms} = \frac{13.6}{E_e[MeV]}\sqrt{\frac{z}{X_0}}\left(1+0.038\ln\frac{z}{X_0}\right)$$

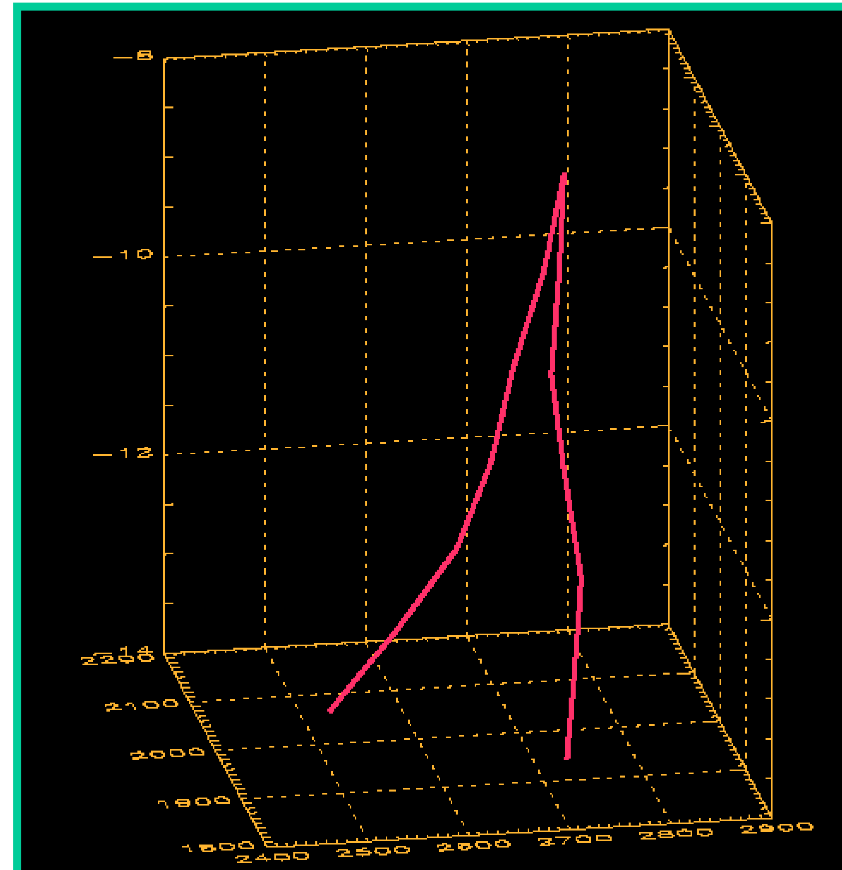




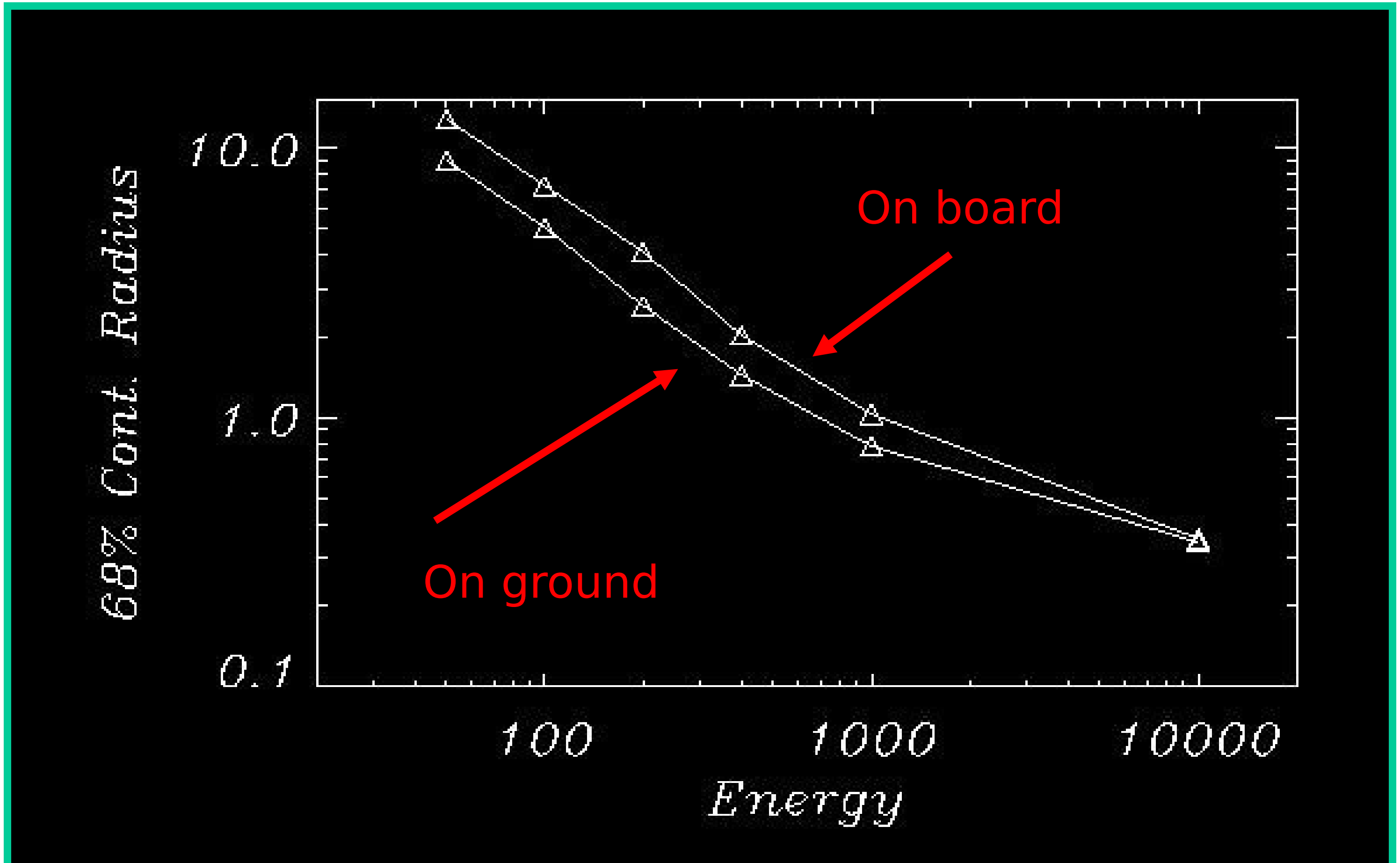
- *Measure of MS angles along the track and crossed thickness*
- *Three-dimensional track reconstruction*
- *Energy loss (bremsstrahlung and ionization)*

Track reconstruction – Kalman F.





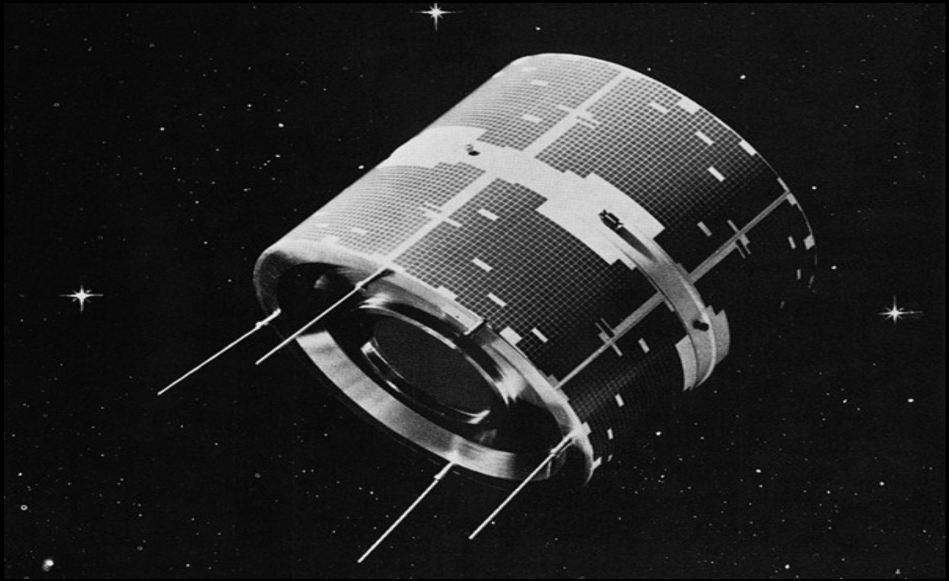
Angular Resolution



Pair Production Telescopes

SAS 2 (NASA)

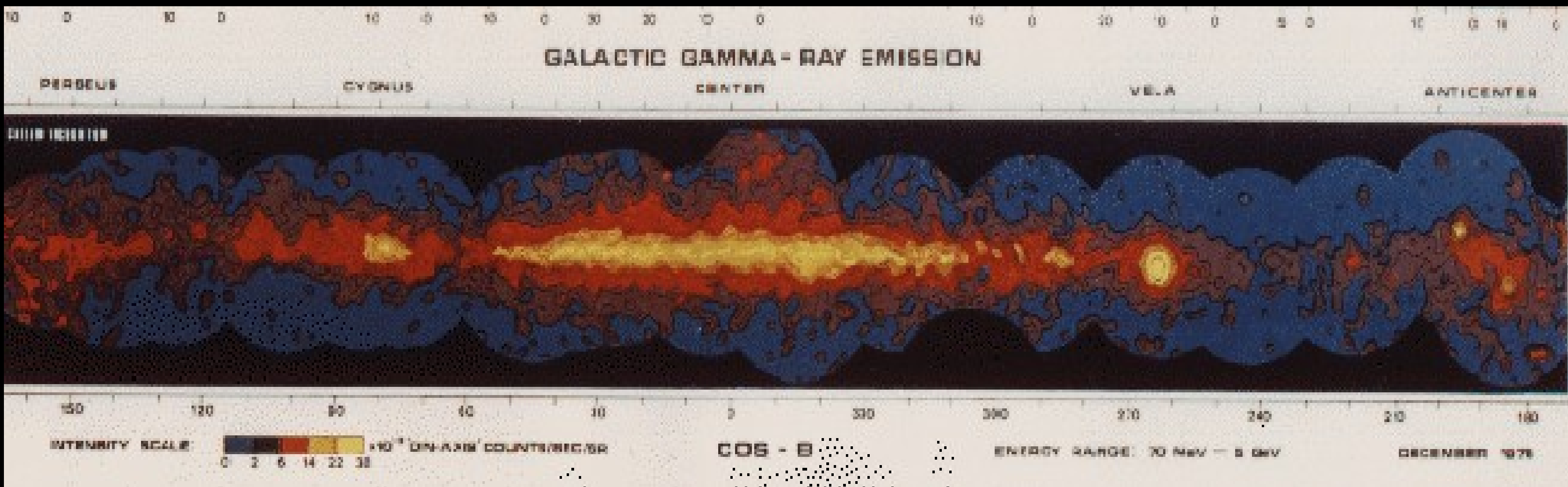
1973 - 1974



COS B (ESA)

1975 - 1982

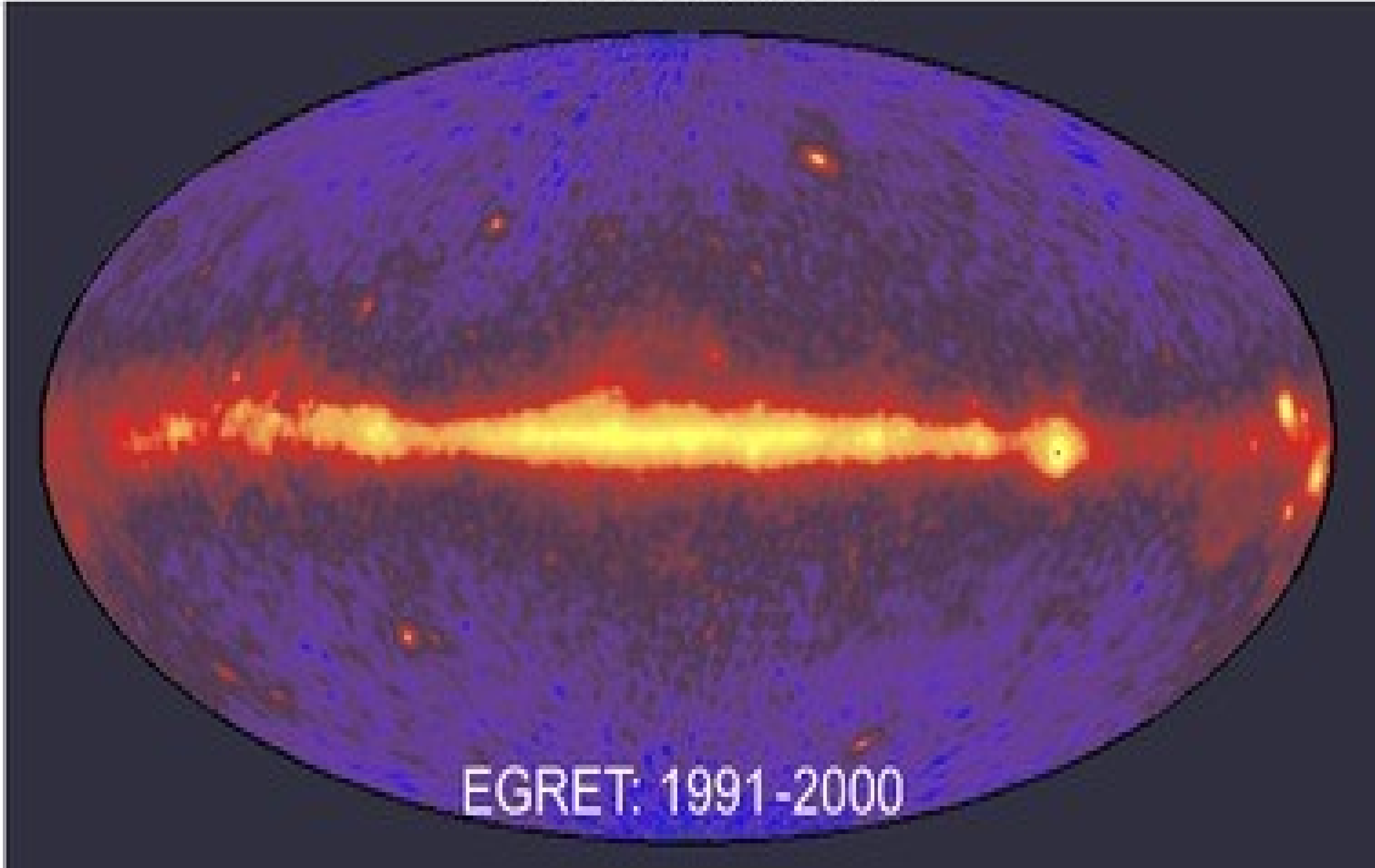
Pair Production Telescopes



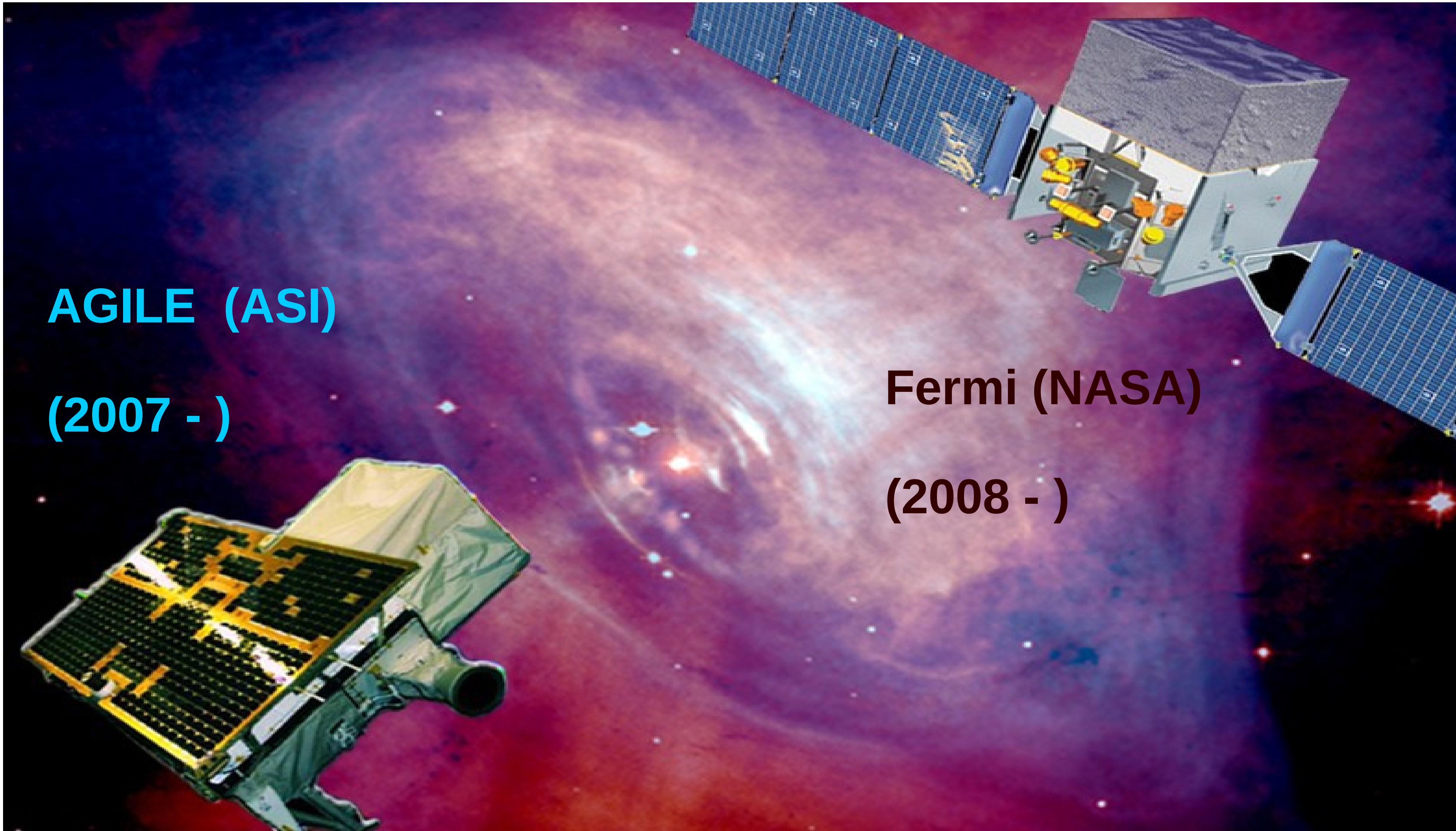
Pair Production Telescopes

GCRO/EGRET (NASA)

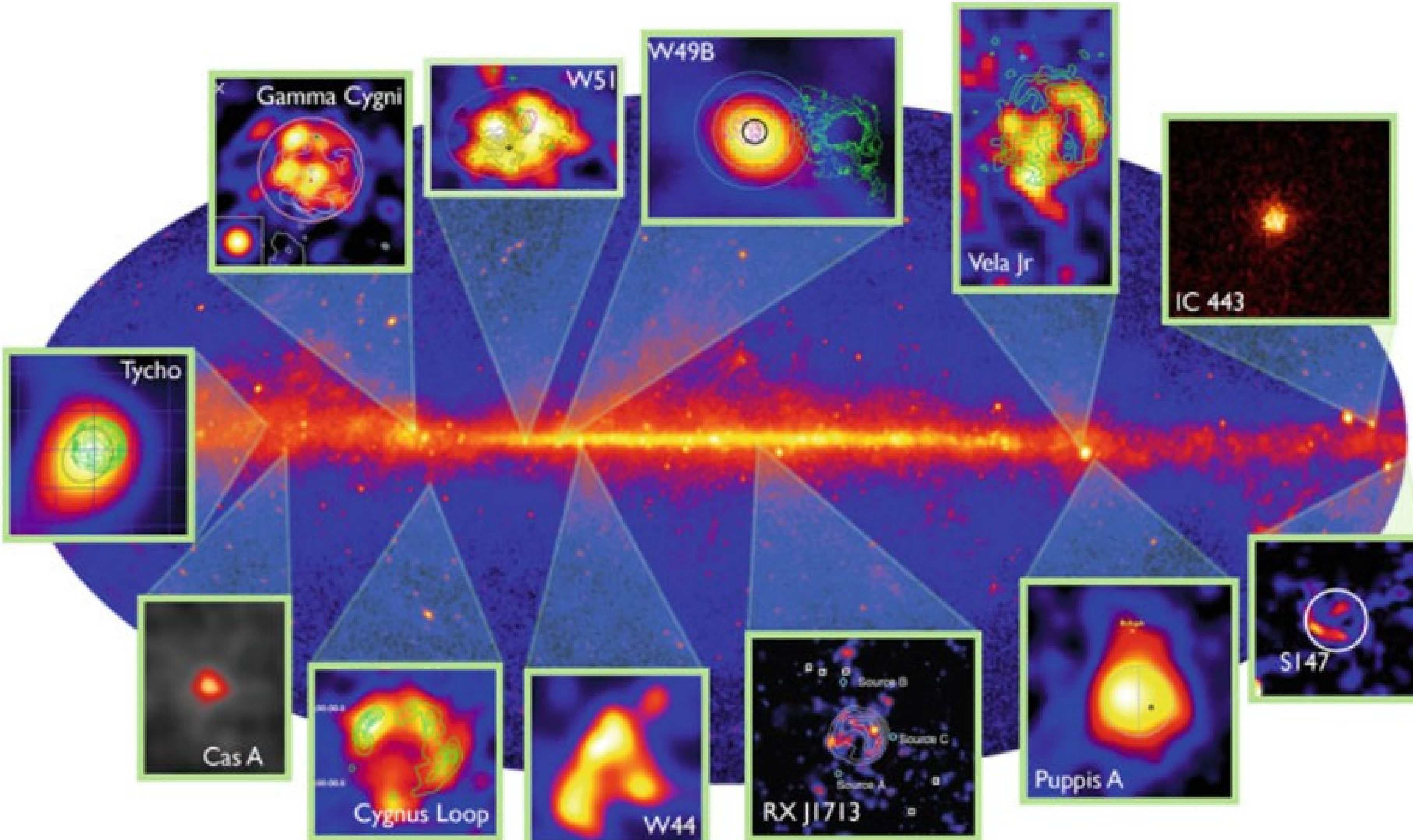
1991 - 2000


EGRET: 1991-2000

Pair Production Telescopes

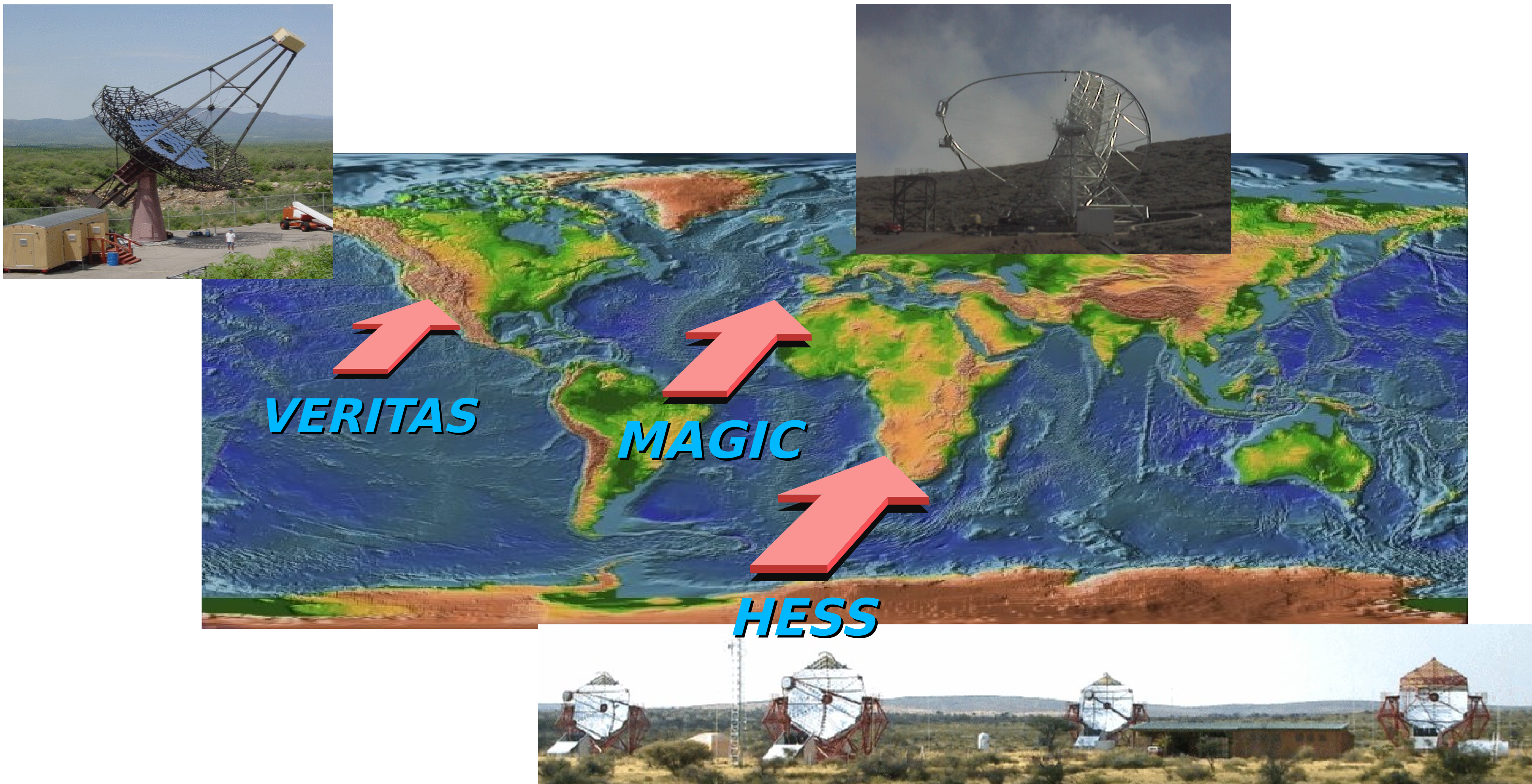


The GeV Sky



Gamma Cygni
W51
W49B
Vela Jr
IC 443
Tycho
Cas A
Cygnus Loop
W44
Source B
Source C
Source A
RX J1713
Puppis A
S147

Existing Cherenkov Telescopes



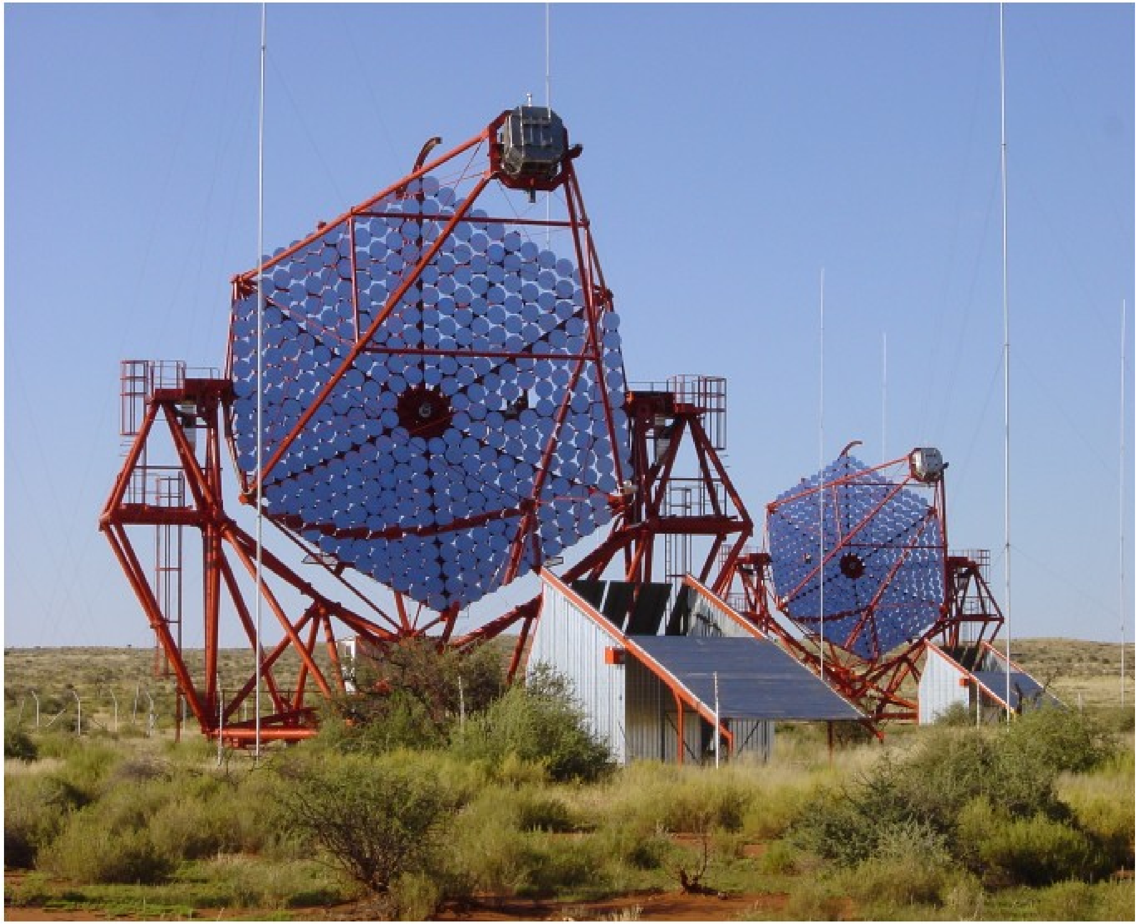
HESS telescope

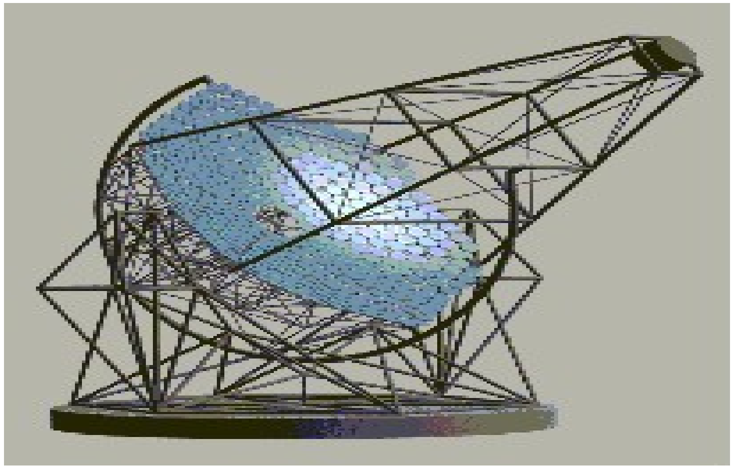
H.E.S.S consists currently of 4 telescopes arranged in a square with 120 m side length and provide multiple stereoscopic view of air showers.

Each telescope consists of a dish with an effective area of 107 m^2 and a camera.

The mirrors collect Cherenkov light from air showers and focus it onto the camera.

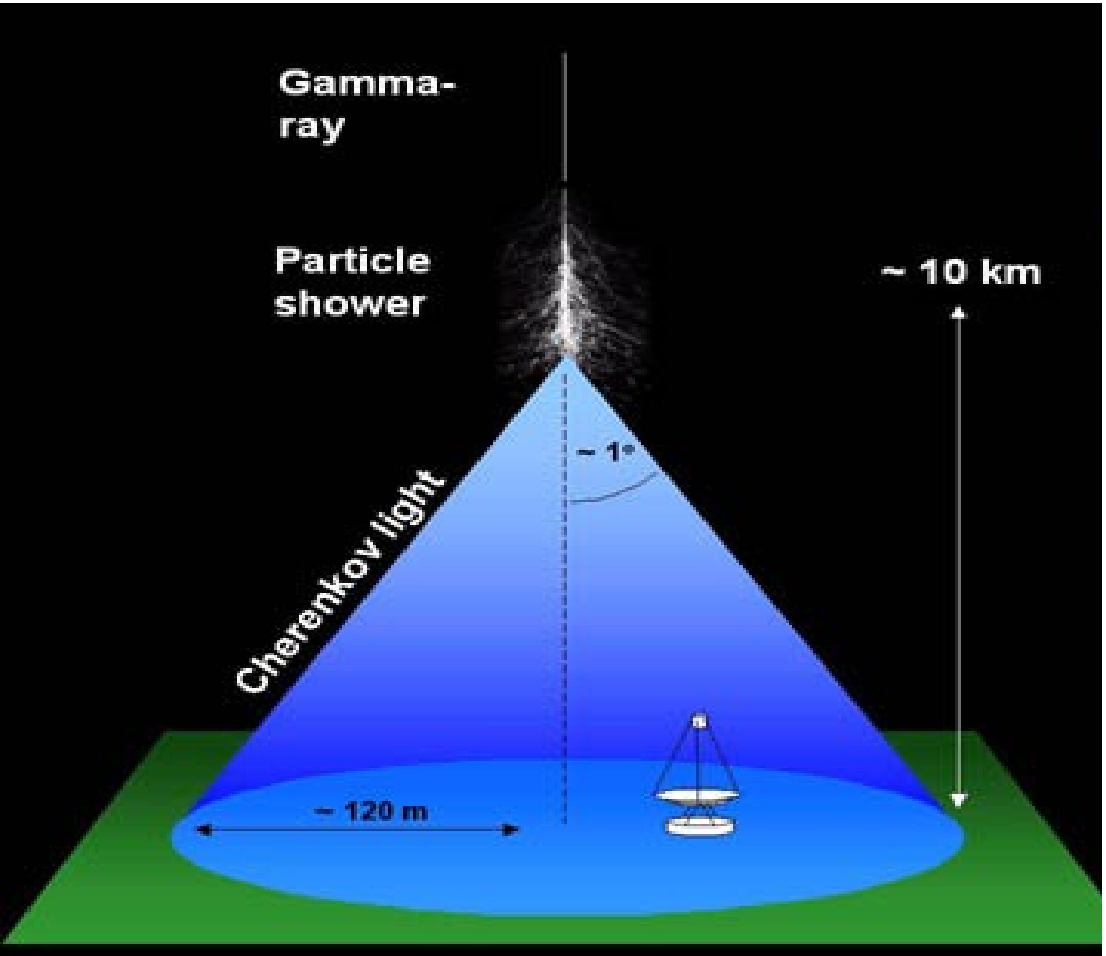
Maximum slewing speed: 100°/ min.

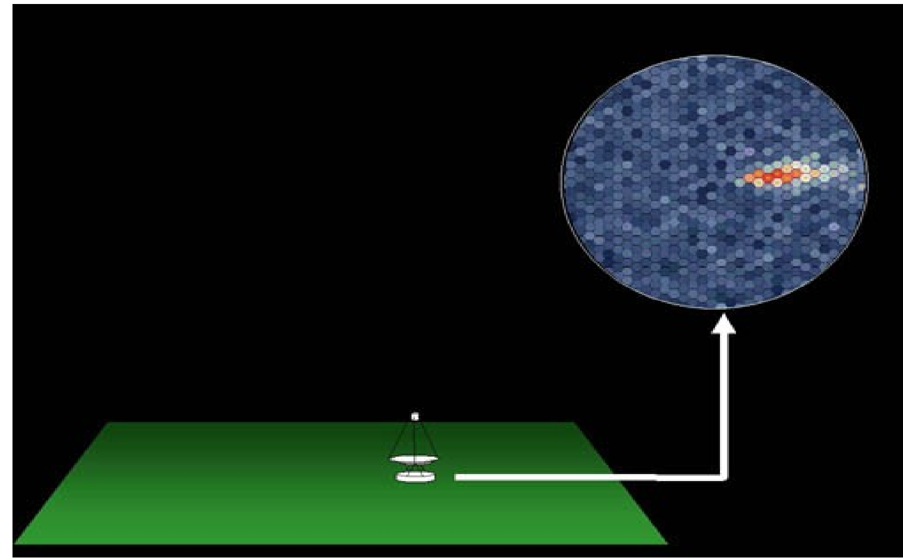




The Davies Cotton telescopes have a focal length of 15 m and a reflectivity of ~80 %.

Air showers with a single telescope

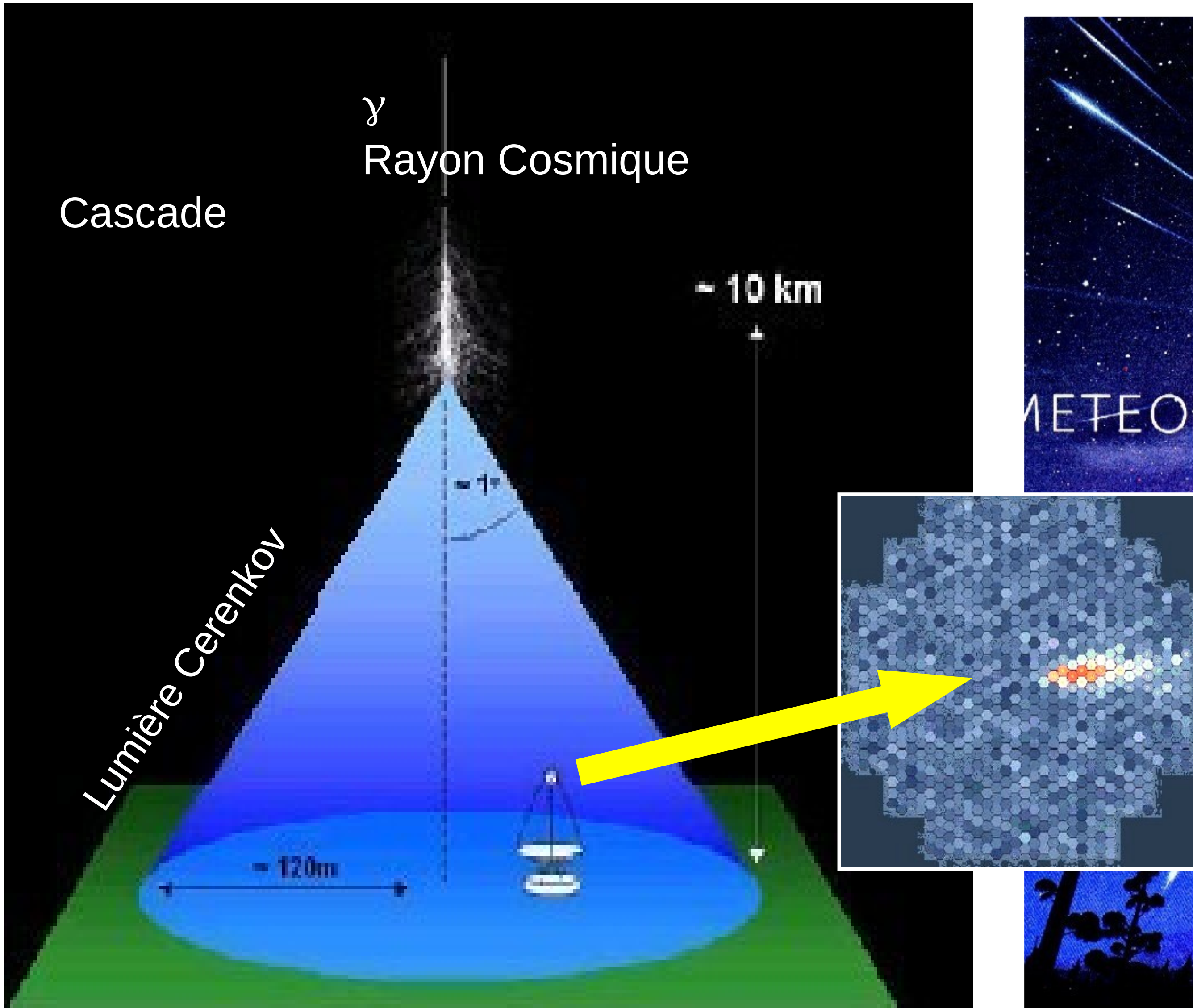




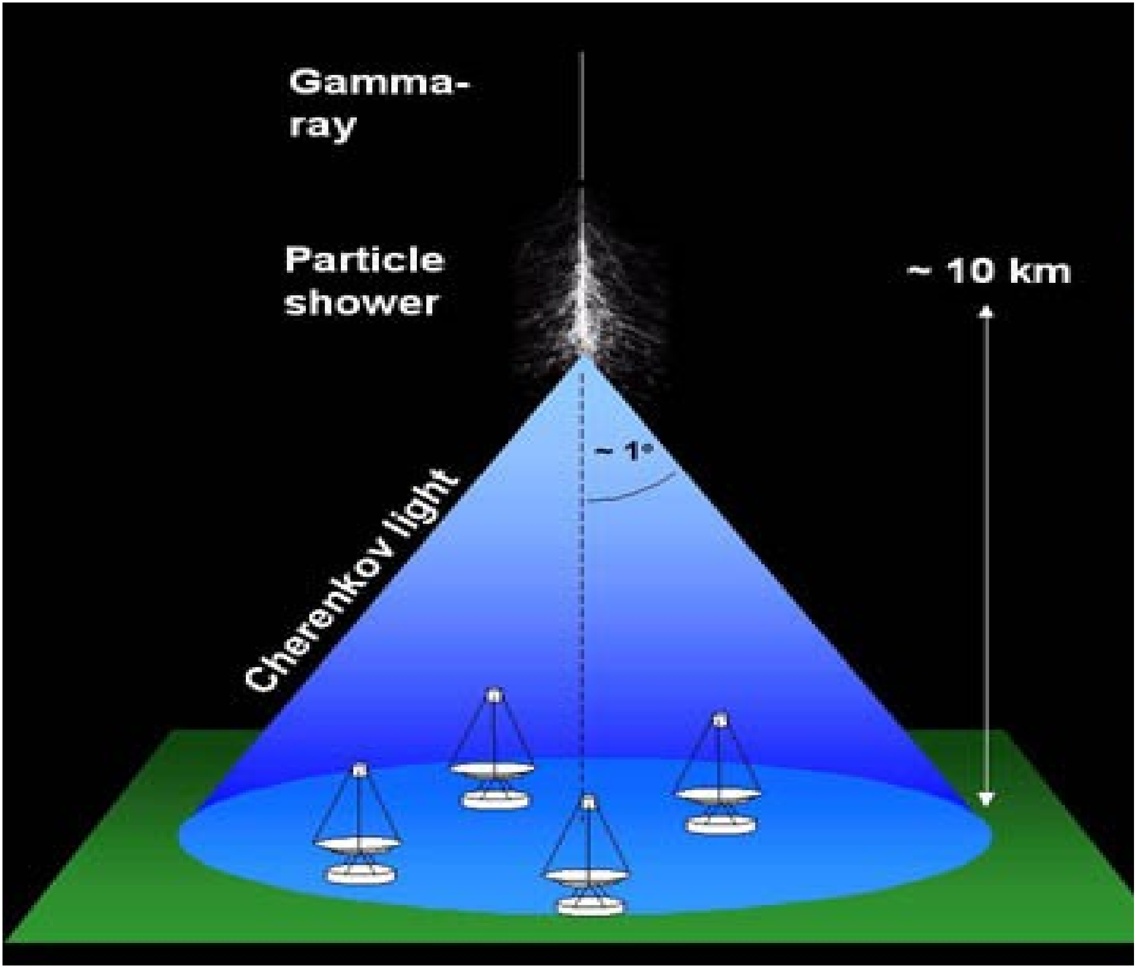
Air showers from gamma rays with E >100 GeV develop at a height of about 10 km. A pool of Cherenkov light from the shower with a radius of ~120 m reaches the ground.

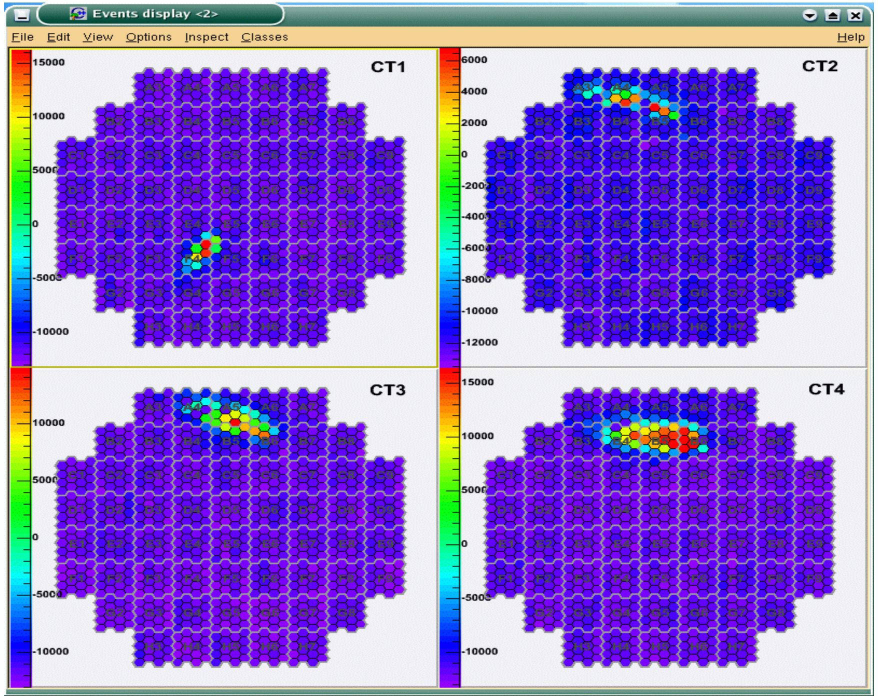
The image of the shower can be seen as a single track with the camera of one telescope.

Air showers with a single telescope



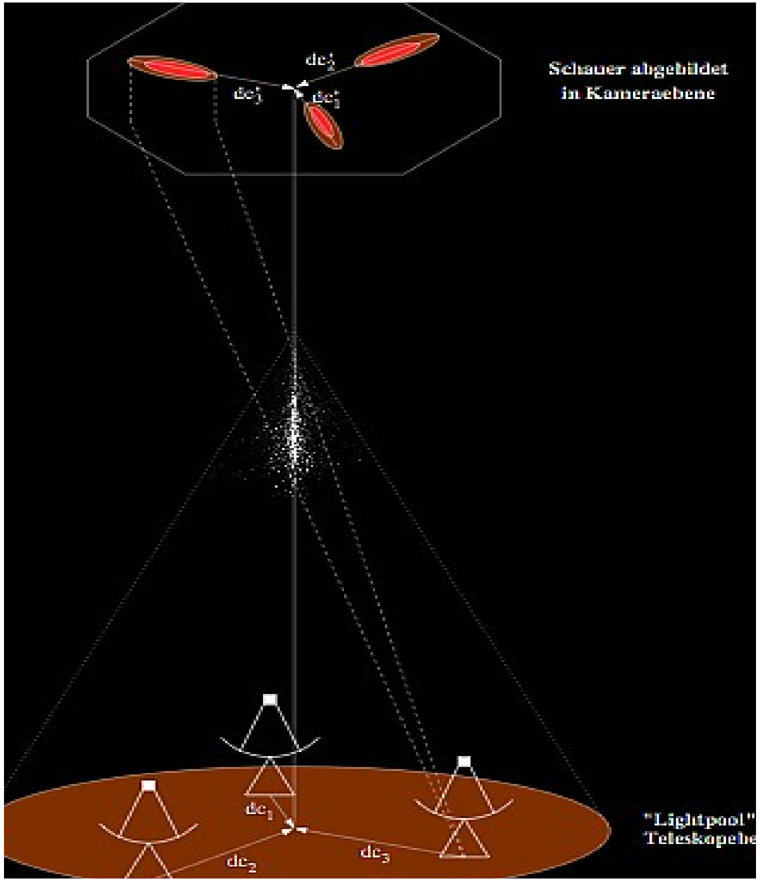
Stereoscopic Observation of an Air Shower





With several telescopes, a stereoscopic (or multiscopic) view of a single shower is possible. This allows to reconstruct the shower geometry and to reject background signals.

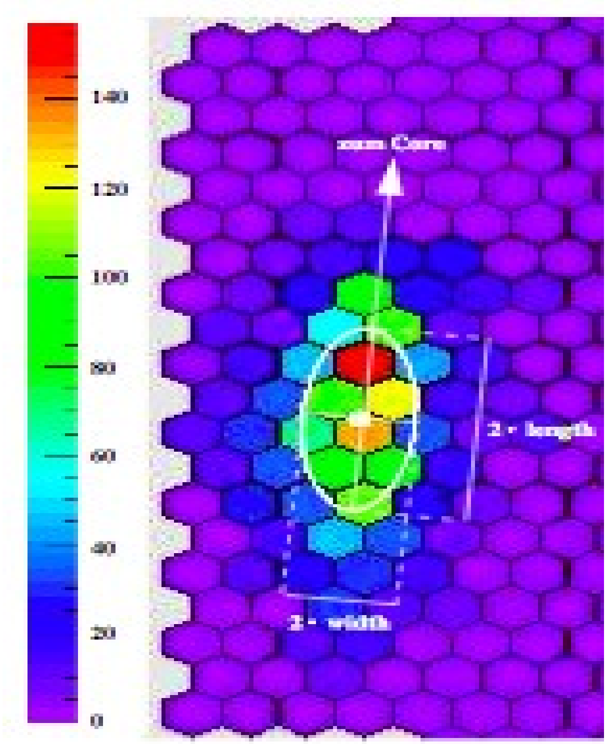
Air Shower Image Projection



(figures taken from the Ph.D. thesis by Oliver Bolz, Ludwigshafen 2004)

The image of the air shower that is projected onto the camera has the form of an ellipse.

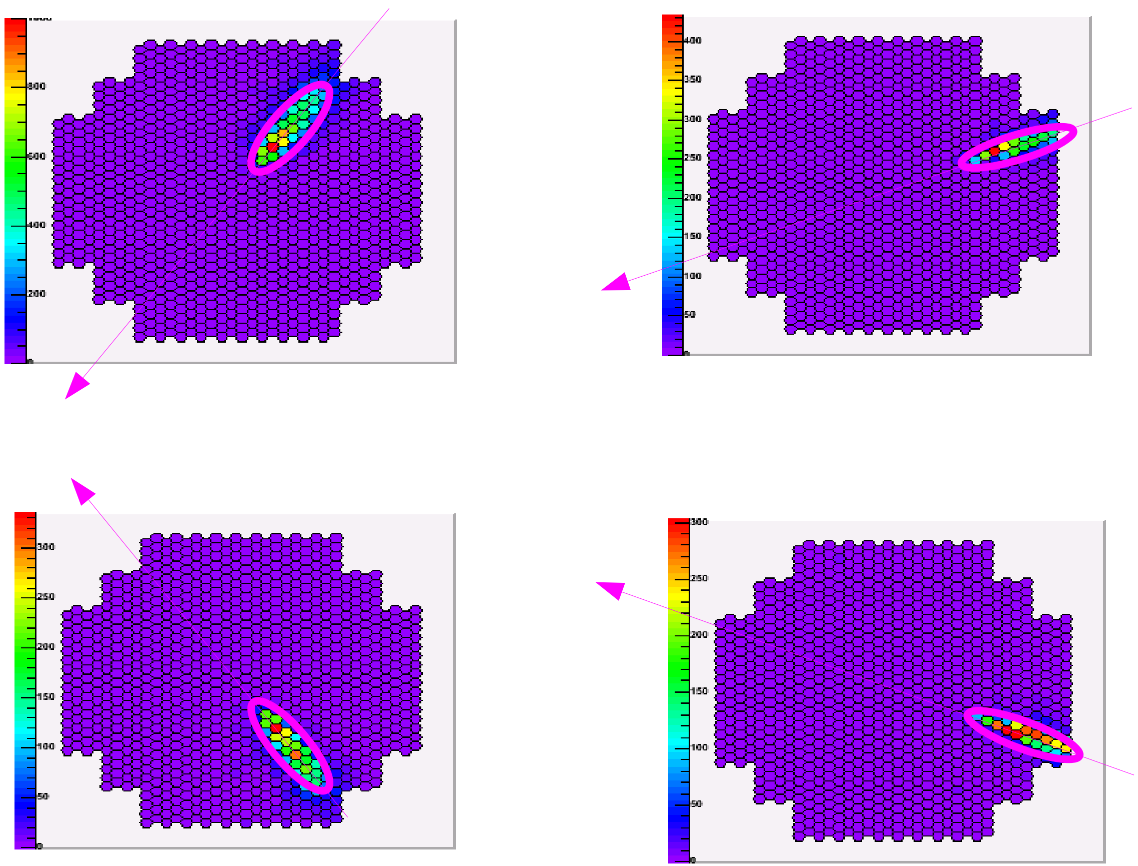
In the reconstruction of the air shower, one fits an elliptical form to the image to extract the "Hillas-parameters" that characterize the air shower. Two important parameters are the width and the length of the ellipse.



One also takes into account the distribution of intensities over the PMTs that are part of the image.

In the image shown here, the red pixel has the largest number of photoelectrons. It indicates the direction of the shower core.

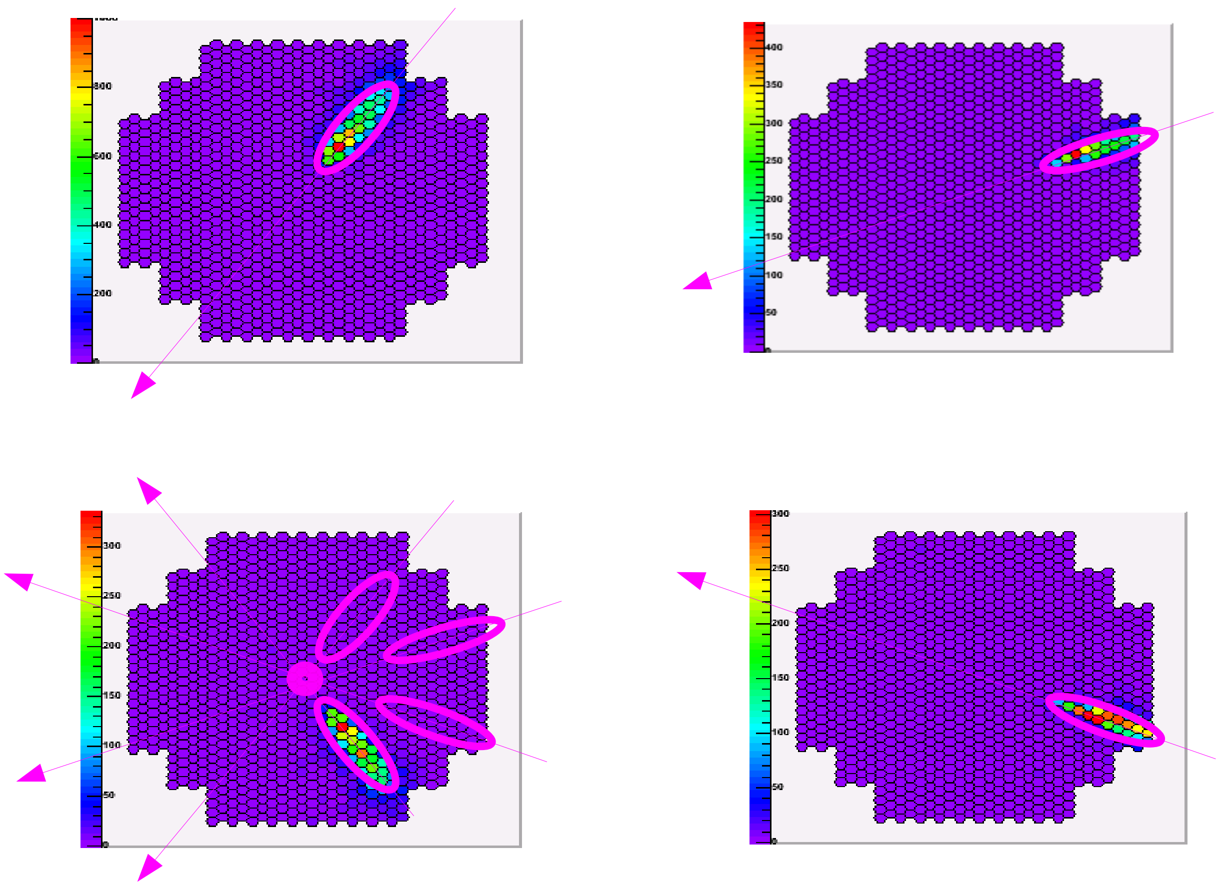
Reconstruction of the Direction of the Air Shower



The stereoscopic observation provides information on the direction of the air shower.

All telescopes point at the same direction in the sky, so we can superpose the images from the air shower seen in different cameras.

Reconstruction of the Direction of the Air Shower

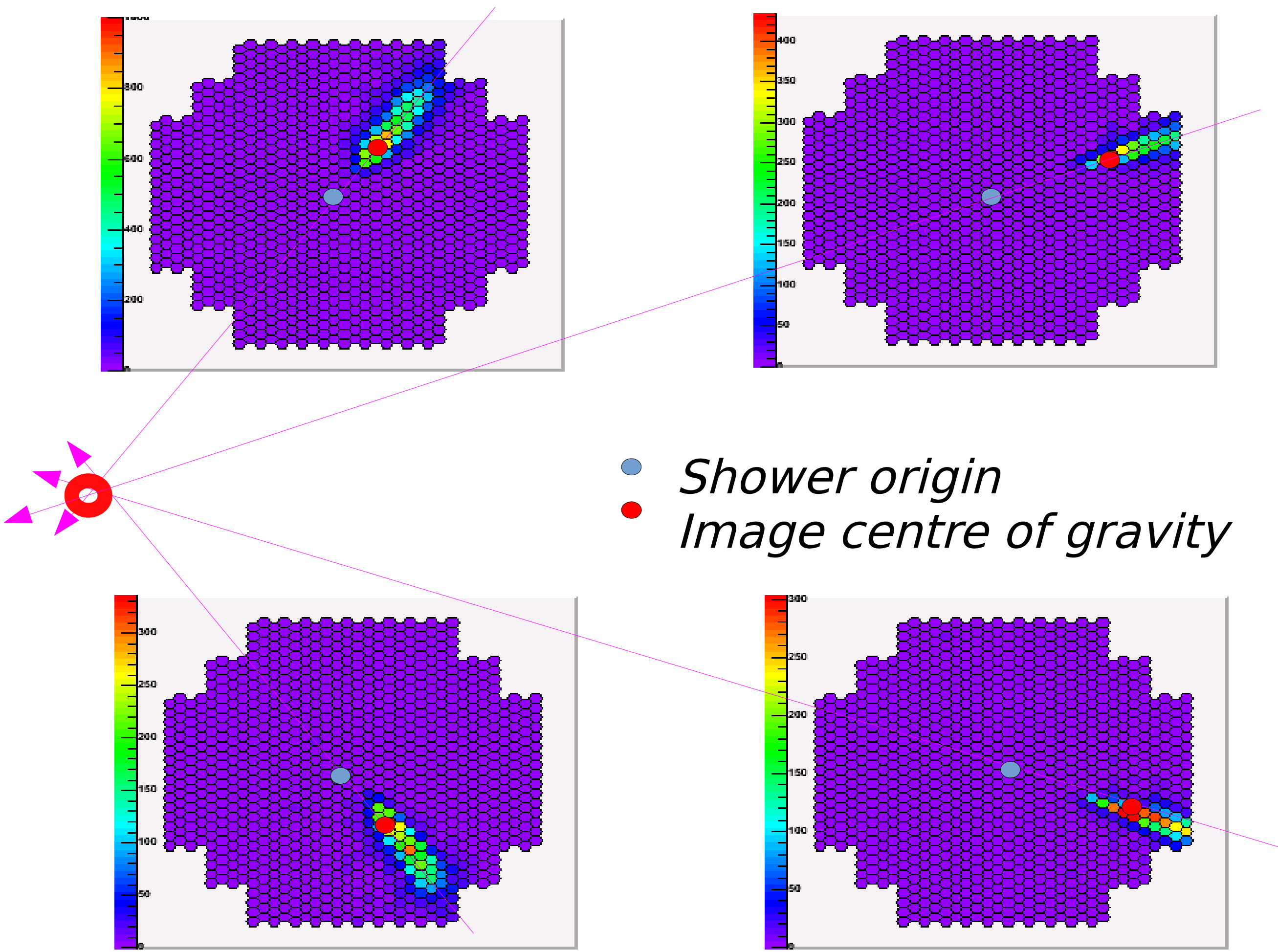


In this case, the air shower came directly from the direction the telescopes are pointing at.

If they are pointing at a known source, one would identify the shower with a photon from that source.

The angular resolution of H.E.S.S. is a few arc minutes.

Reconstruction of the Shower Impact Point



Geometrical determination of the shower impact point on the ground provides a better understanding of the shower geometry.

This is very useful for the energy reconstruction of the event.

Reconstruction of the Shower Energy

The energy of the primary particle, i.e. the γ-ray, is determined from the total recorded signal size, which can be converted into a flux of Cherenkov photons.

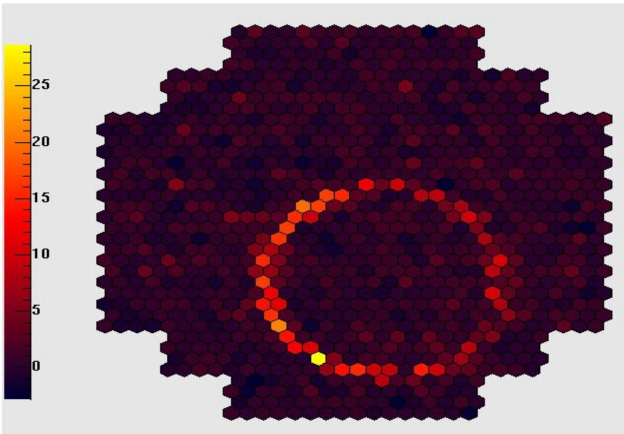
Once the geometry of the air shower – i.e. the inclination of the shower axis and the impact point – has been determined, one compares the recorded signal to lookup tables.

These lookup tables are generated with Monte Carlo simulations of γ-ray induced air showers at different energies and geometries. They contain lateral distributions of Cherenkov photon densities for each simulated shower.

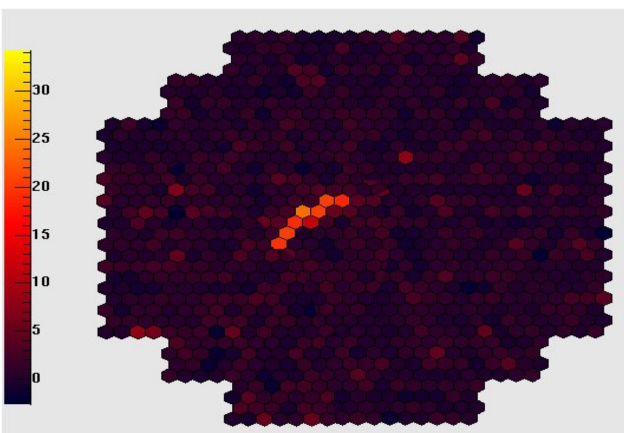
A comparison of the recorded signal size and the simulated photon fluxes provides the energy of the observed shower.

The energy resolution of H.E.S.S. is on the order of 15 %.

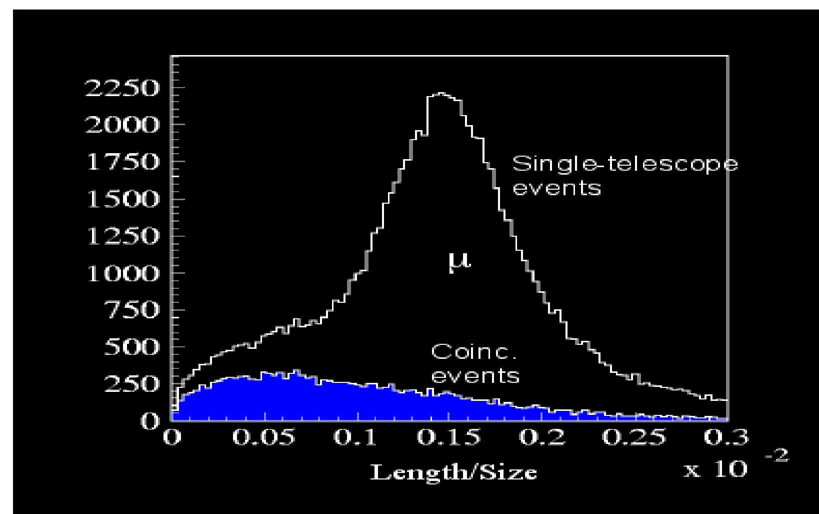
Background - Muons



Muons that hit the telescope leave a ring-shaped Cherenkov light signal and are easily identifiable. Muons that pass the telescope at some (not too large) distance can leave a signature that is not easy to distinguish from the image of an air shower. Due to the large muon flux in the atmosphere, this is a considerable source of background.



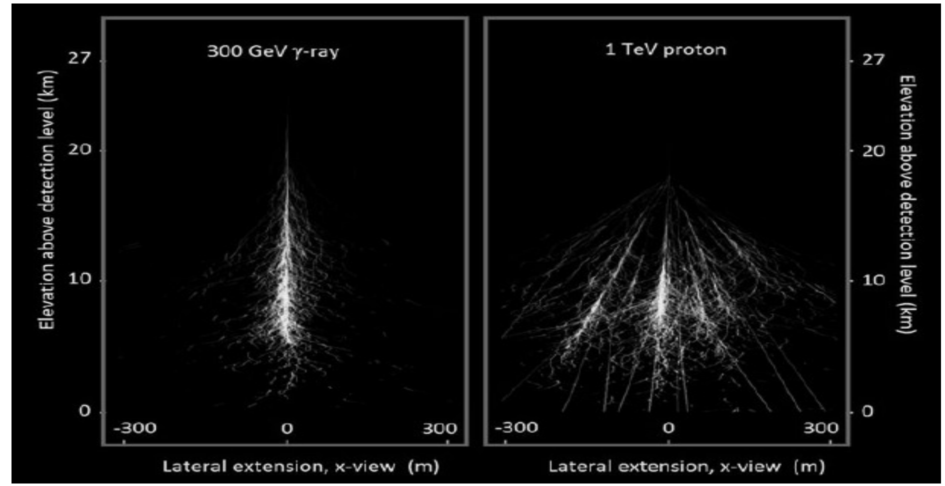
Muons can however be rejected by requiring at least two telescopes to be triggered simultaneously.



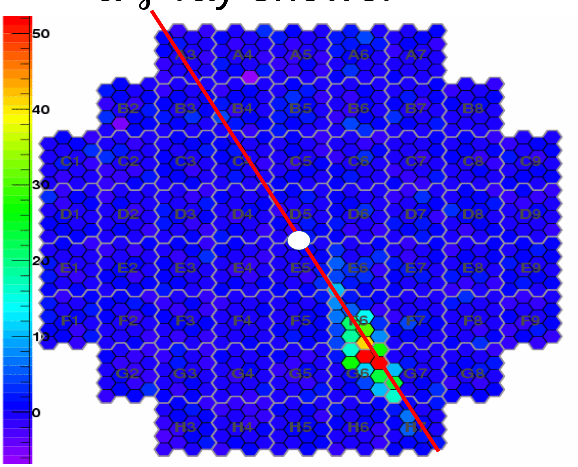
Background – Hadronic Showers

Hadronic showers do not leave a clear track. They look more like a "blob". When fitting an ellipse to the image, the width of the ellipse is usually larger than in the case of a γ-ray shower.

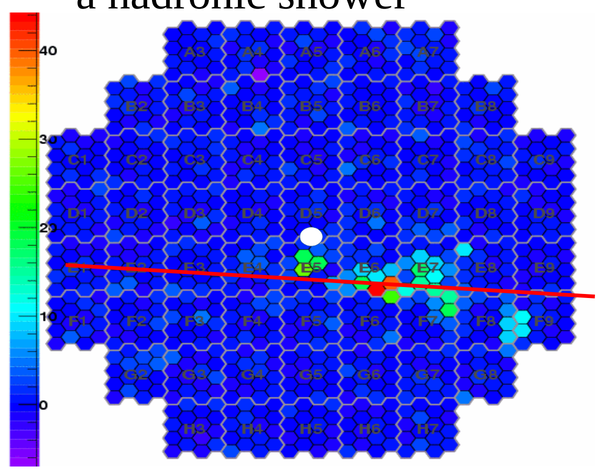
One rejects hadronic showers by applying a cut on the observed width.

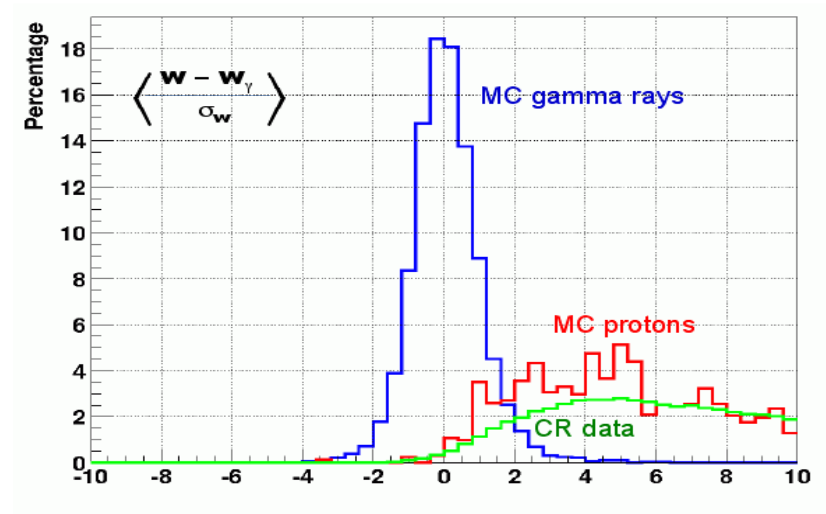


a γ-ray shower

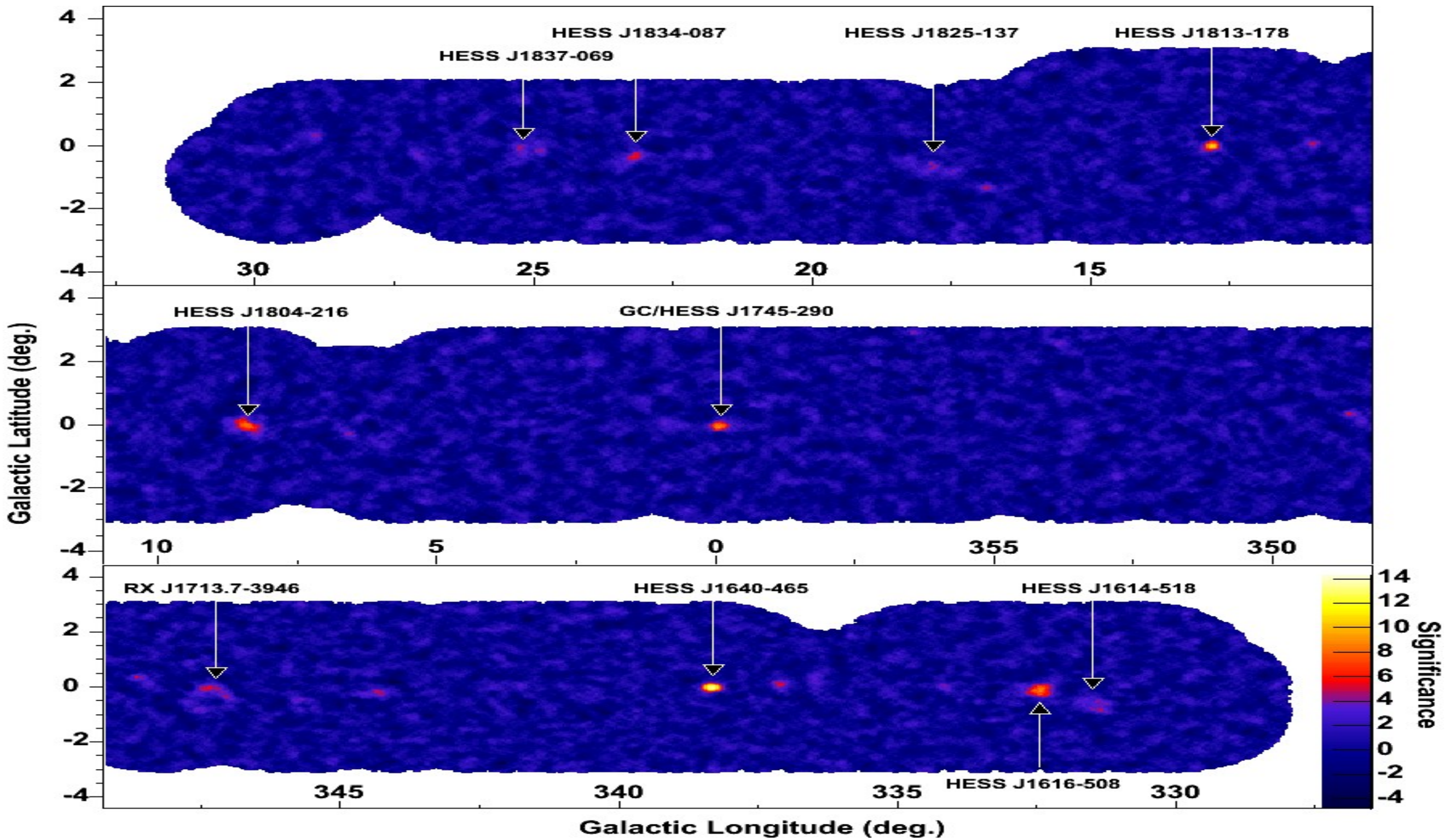


a hadronic shower





Galactic Plane Survey



All sky telescopes – Milagro

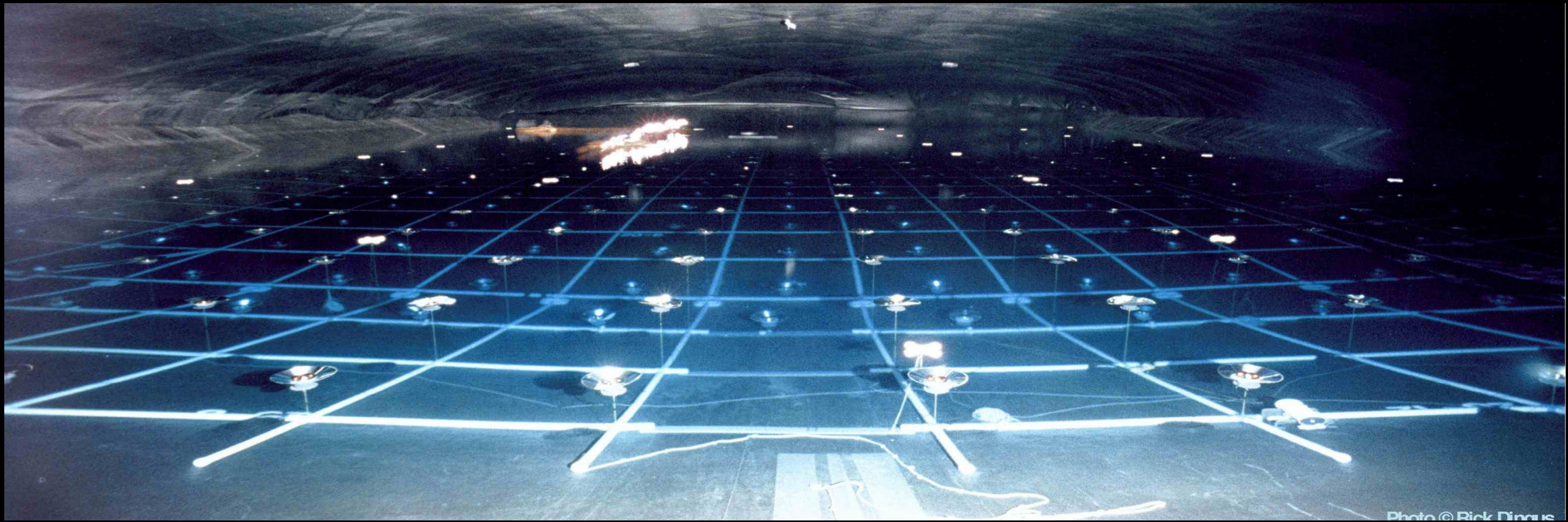
- located near Los Alamos, NM, USA; altitude 2650 m
- a pond of size 80m x 60m x 8 m filled with pure water
- 175 tanks in a larger array
- 2 layers of PMTs (723 in total) observe Cherenkov light from air shower particles
- upper layer: electrons, positrons
  lower layer: muons

All sky telescopes: Milagro

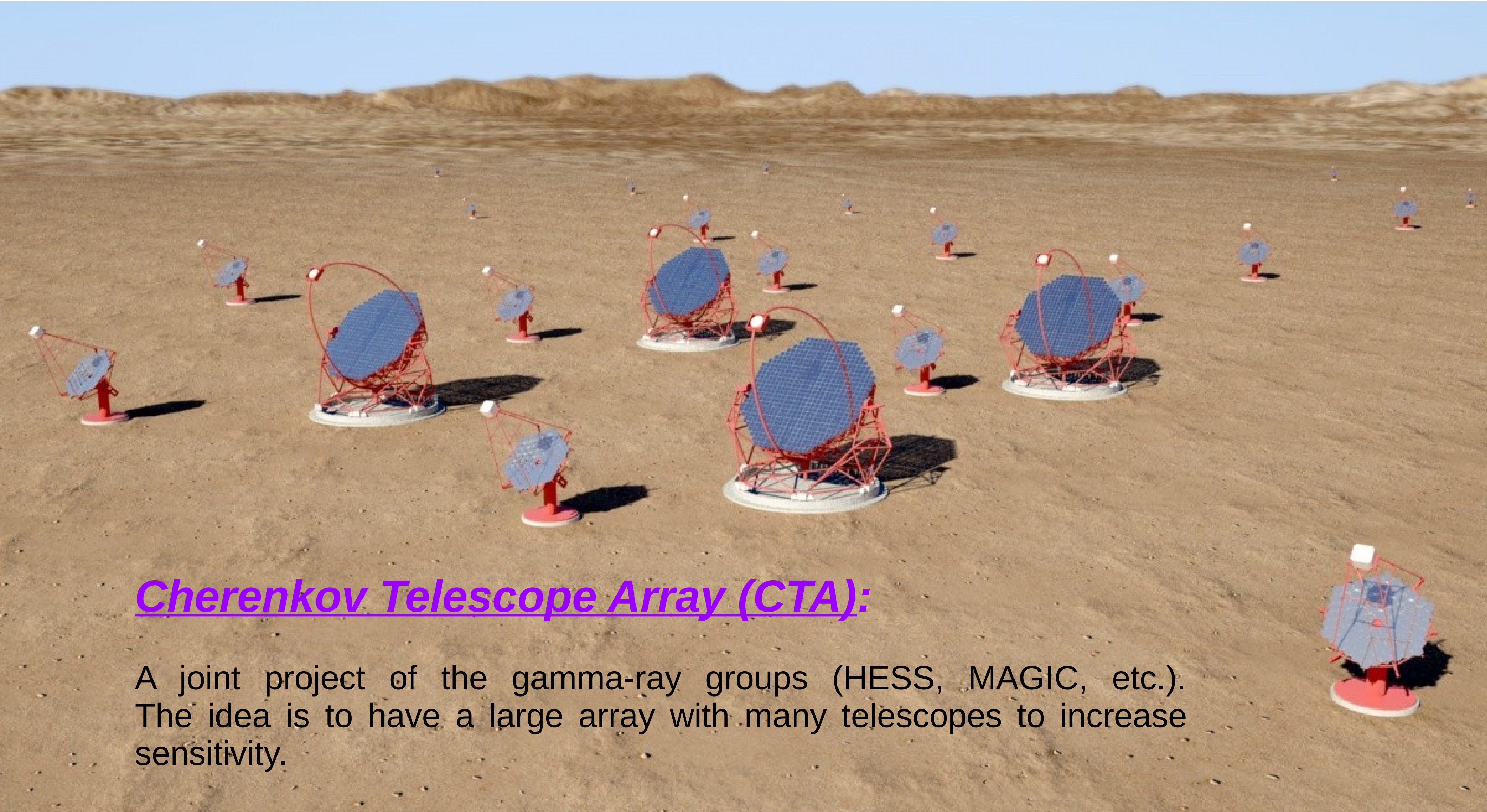
100% duty cycle, very large field of view (~ 1 sr), good sensitivity at TeV energies
=> ideal for all (northern) sky survey of gamma-ray sources

Only 0.8 degree angular resolution, higher energy threshold than IACTs

=> complementary method to IACTs and satellites; similar method used by ARGO (Tibet)



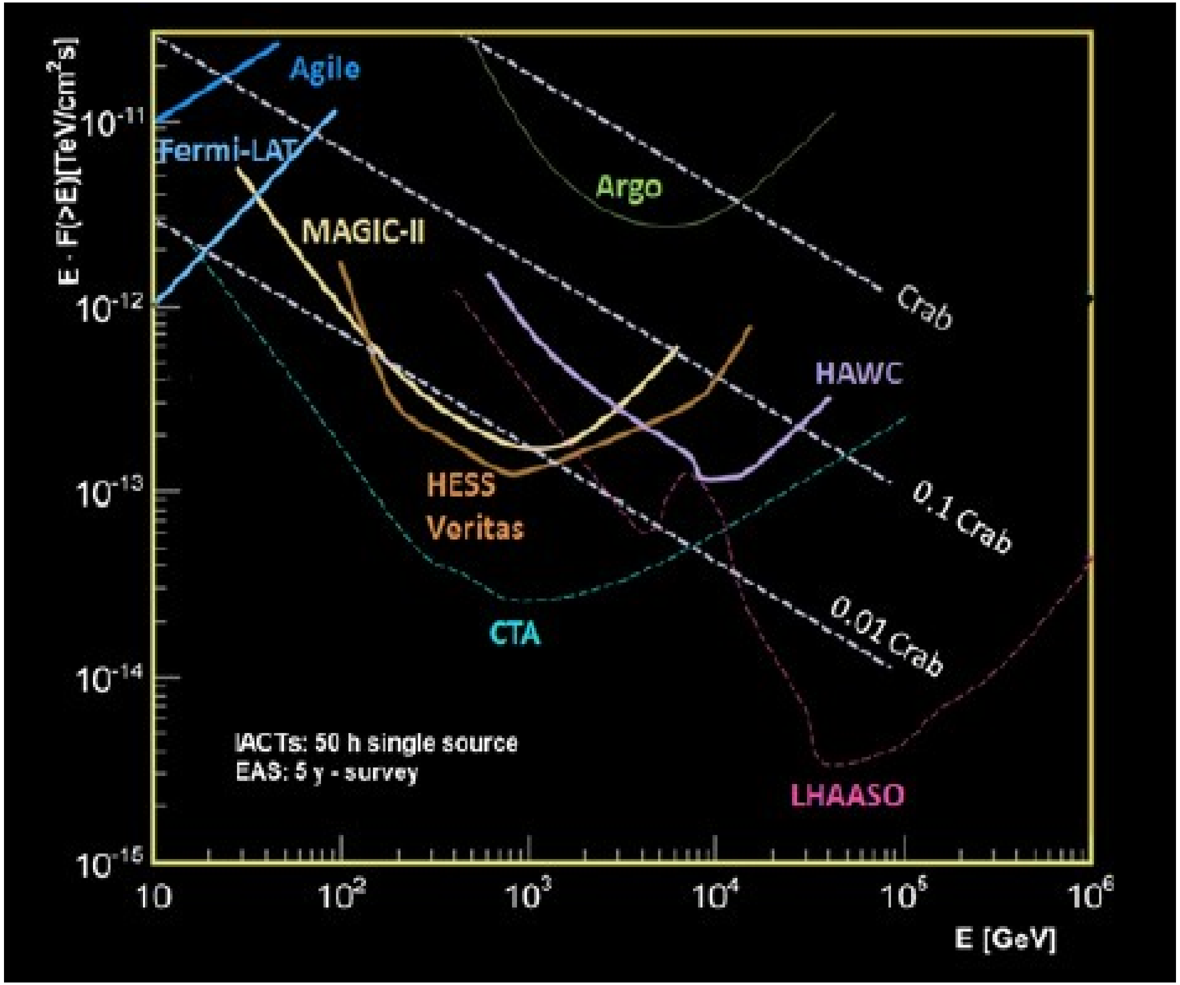
Future Projects



Cherenkov Telescope Array (CTA):

A joint project of the gamma-ray groups (HESS, MAGIC, etc.). The idea is to have a large array with many telescopes to increase sensitivity.

Future Projects

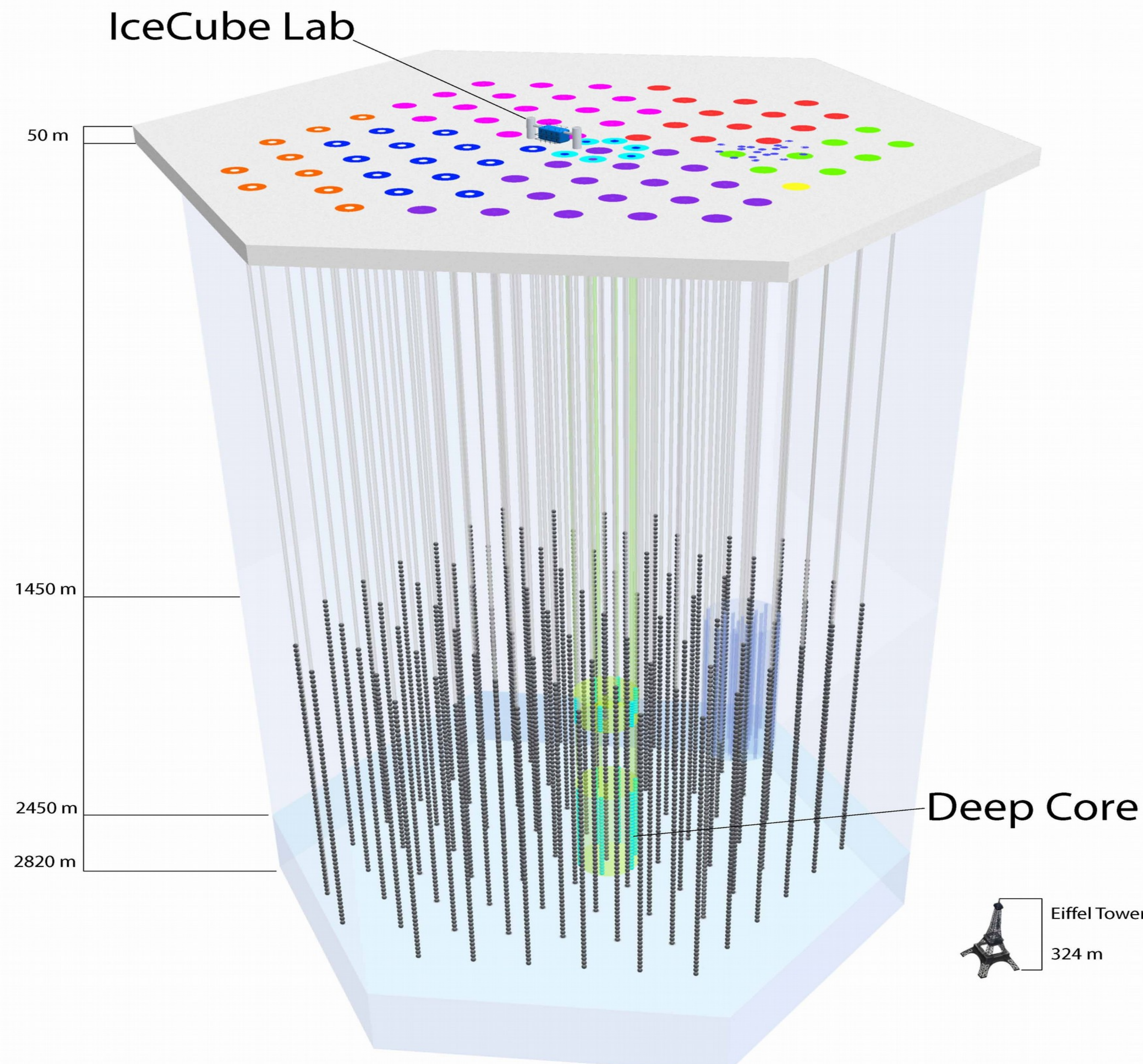


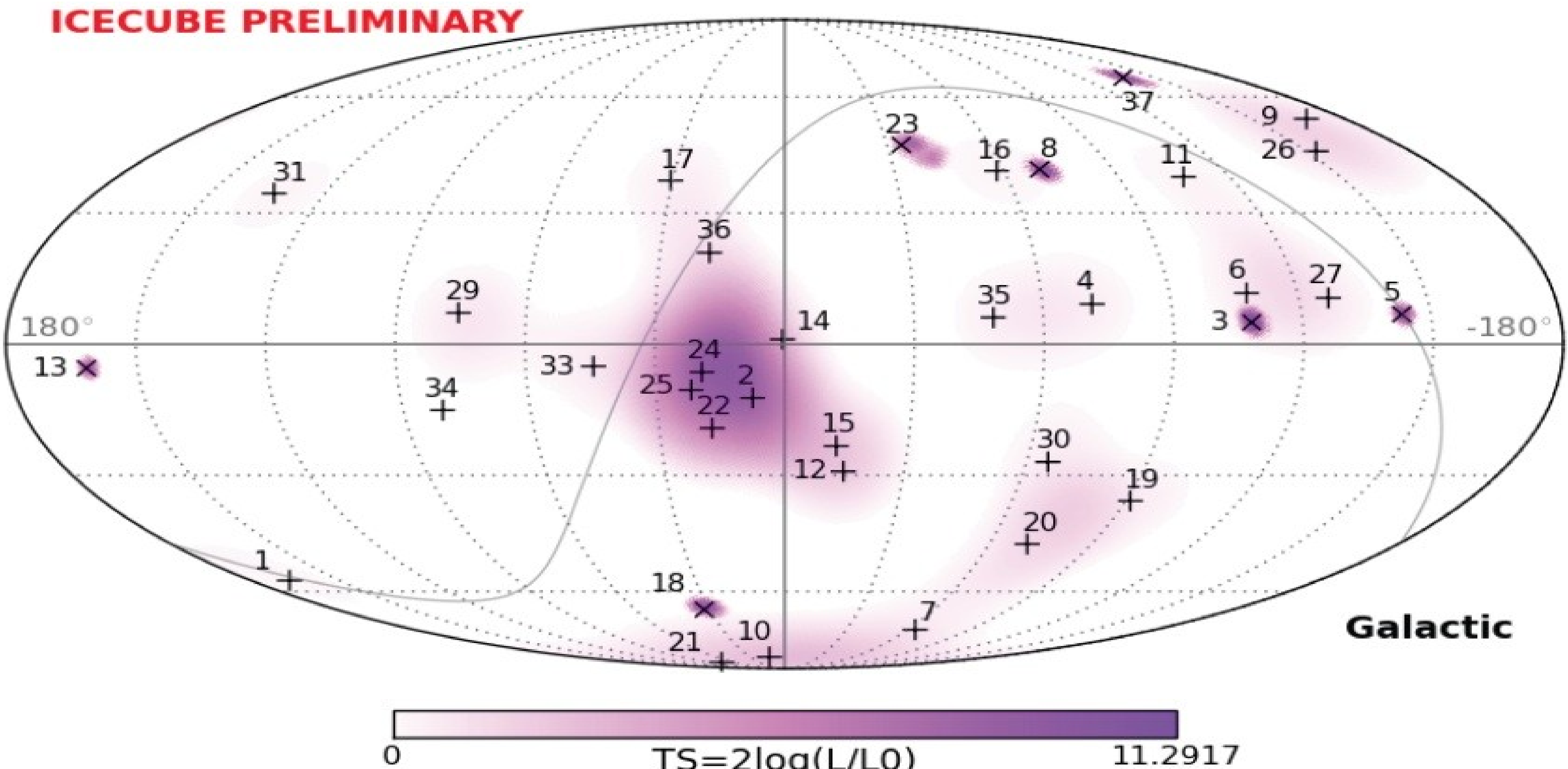
Cherenkov Telescope Array (CTA):

A joint project of the gamma-ray groups (HESS, MAGIC, etc.). The idea is to have a large array with many telescopes to increase sensitivity.

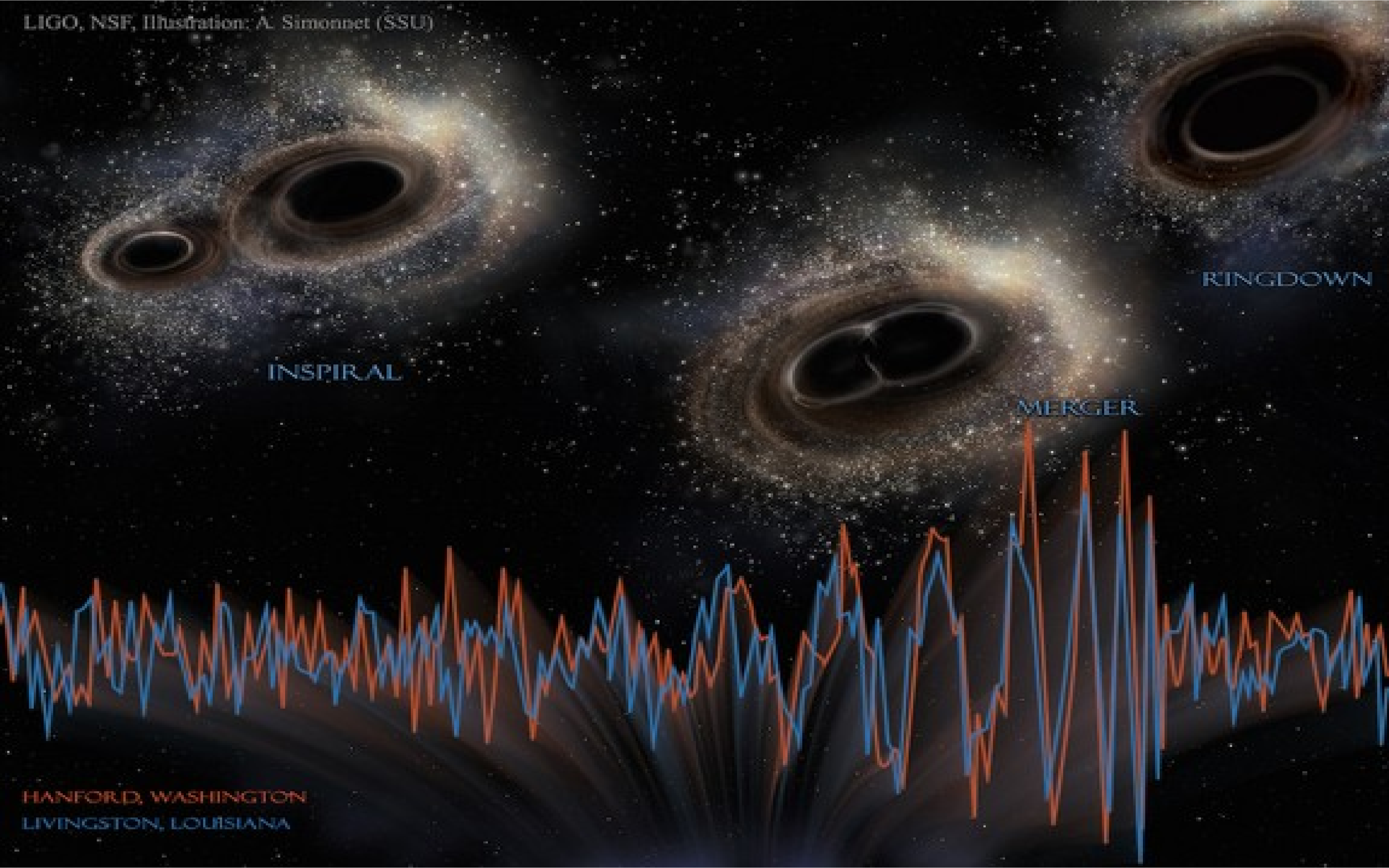
High Altitude Water Cherenkov array (HAWC):

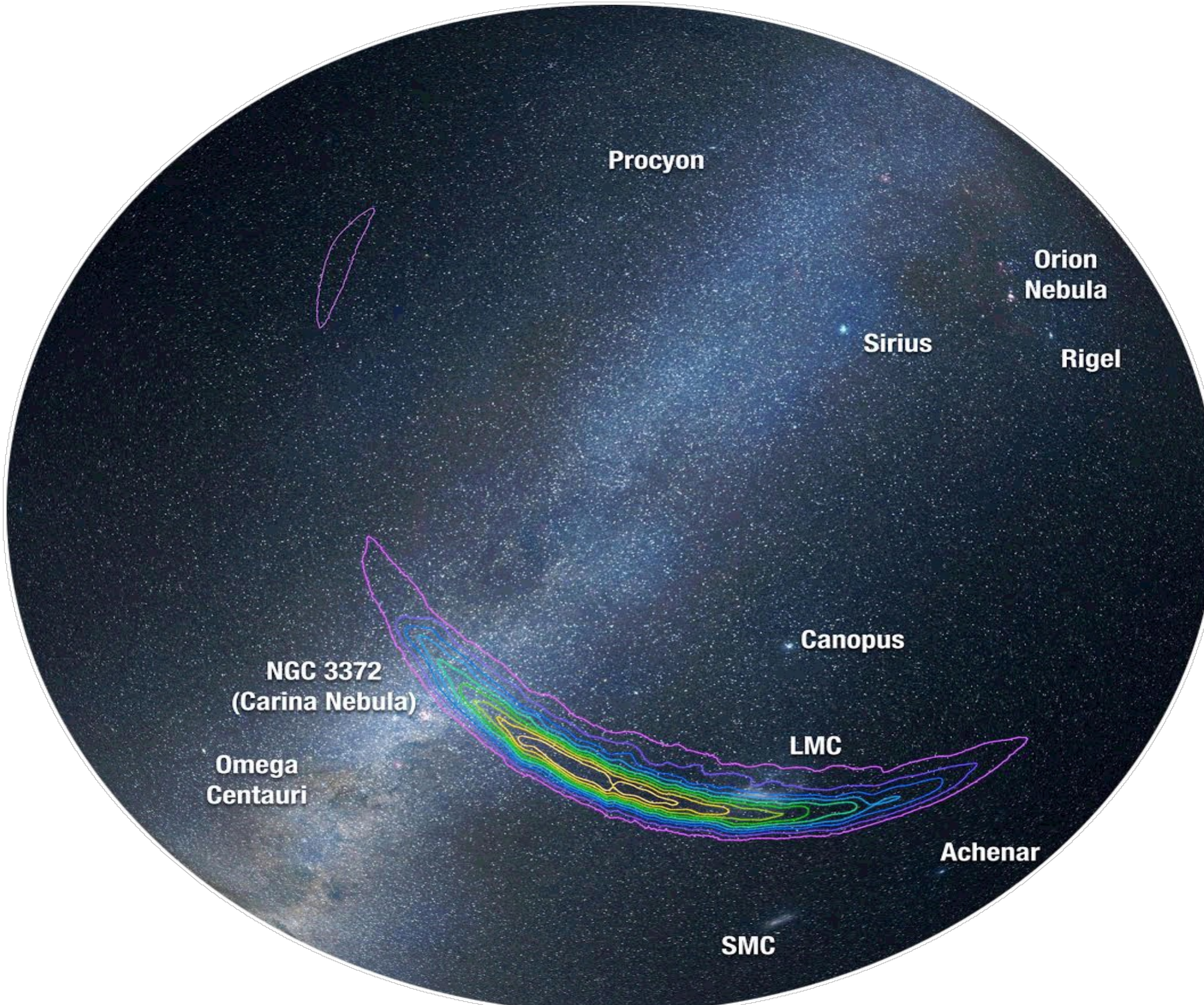
next generation of the Milagro style detectors, larger effective area, higher altitude (lower E threshold)


IceCube Lab
50 m
1450 m
2450 m
2820 m
Deep Core
Eiffel Tower
324 m



ICECUBE PRELIMINARY
180°
-180°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
29
30
31
33
34
35
36
37
Galactic
0
TS=2log(L/L0)
11.2917


LIGO, NSF, Illustration: A. Simonnet (SSU)
INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA


Procyon
Orion
Nebula
Sirius
Rigel
Canopus
NGC 3372
(Carina Nebula)
LMC
Omega
Centauri
Achenar
SMC