# Um "POEMMA": detector de partículas cósmicas ultra energéticas


Angela V. Olinto

THE UNIVERSITY OF CHICAGO



# Probe Of Extreme Multi-Messenger Astrophysics

## (Sonda da Astrofísica de Multi-Mensageiros Extremos )


POEMMA
NASA
Probe Of Extreme Multi-Messenger Astrophysics
(Sonda da Astrofísica de Multi-Mensageiros Extremos )
Para descrobrir a origem dos
Neutrinos e Raios-Cósmicos Ultra-Energéticos

Multi-Mensageiros?

Raios-Cósmicos?
Neutrinos?

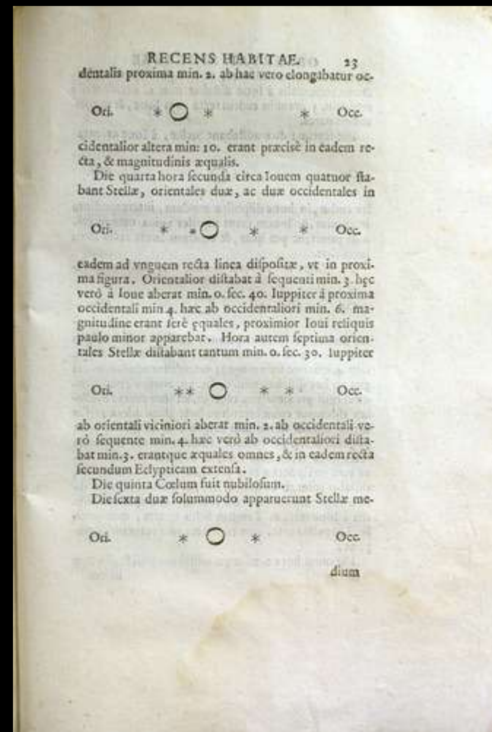
Ultra-Energéticos?

Física em casa - Neutrinos: o que são e para que servem?
André de Gouvêa
Neutrinos: O Que São e Para Que Servem?
André de Gouvêa
Northwestern University
ICTP SAIFR
Física Em Casa
30/07/2020
Andre de Gou...
FÍSICA EM CASA
outreach.ictp-saifr.org
Quintas-feiras 19h · pelo canal SAIFR Divulga!
Física em casa - Aceleradores Cósmicos de Partículas: Buracos Negros e Jatos Supersônicos
Aceleradores Cósmicos de Partículas: Buracos Negros e Jatos Supersônicos
ElisaBete de Gouveia Dal Pino
IAG - Universidade de São Paulo
Elisabete de G...
Física em Casa, 16 de julho, 2020
USP
zoom
Física em casa - Astronomia das ondas gravitacionais
Riccardo Stur...
Astronomia de ondas gravitacionais
Riccardo Sturani
Instituto Internacional de Física - UFRN - Natal
riccardo@iip.ufrn.br
Física em casa - 4 Junho 2020
zoom


Via Láctea
Nuvens de Magalhães
Cometa McNaught
Miloslav Druckmuller (Brno University of Technology)
January 28, 2007, Nahuel Huapi 2014 m, Patagonia, Argentina

Galileo mostra ao Doge de Veneza o poder do telescope (fresco de Giuseppe Bertini)

**Sidereus Nuncius** 1610
Mensageiro Sideral ou Estrelado



RECENS HABITAE. 23

dentalis proxima min. 2. ab hac vero elongabatur oc-

Ori. Occ.

cidentalior altera min: 10. erant præciſè in eadem recta, & magnitudinis æqualis.

Die quarta hora ſecunda circa Iouem quatuor ſtabant Stellæ, orientales duæ, ac duæ occidentales in

Ori. Occ.

eadem ad vnguem recta linea diſpoſitæ, vt in proxima figura. Orientalior diſtabat à ſequenti min. 3. hęc verò à Ioue aberat min. 0. ſec. 40. Iuppiter à proxima occidentali min 4. hæc ab occidentaliori min. 6. magnitudine erant ferè ęquales, proximior Ioui reliquis paulo minor apparebat. Hora autem ſeptima orientales Stellæ diſtabant tantum min. 0. ſec. 30. Iuppiter

Ori. Occ.

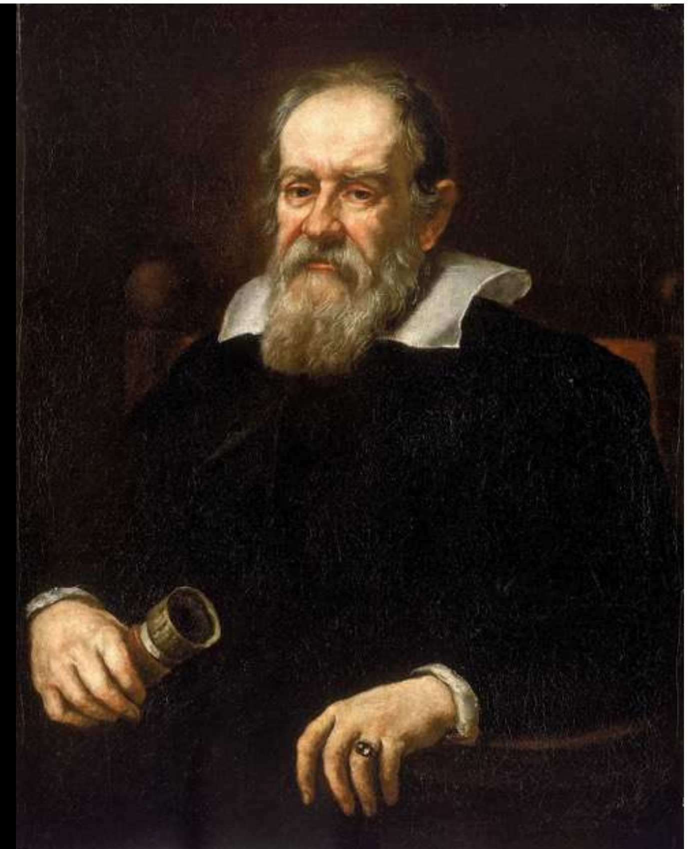
ab orientali viciniori aberat min. 2. ab occidentali verò ſequente min. 4. hæc verò ab occidentaliori diſtabat min. 3. erantque æquales omnes, & in eadem recta ſecundum Eclypticam extenſa.

Die quinta Cœlum fuit nubiloſum.

Die ſexta duæ ſolummodo apparuerunt Stellæ me-

Ori. Occ.

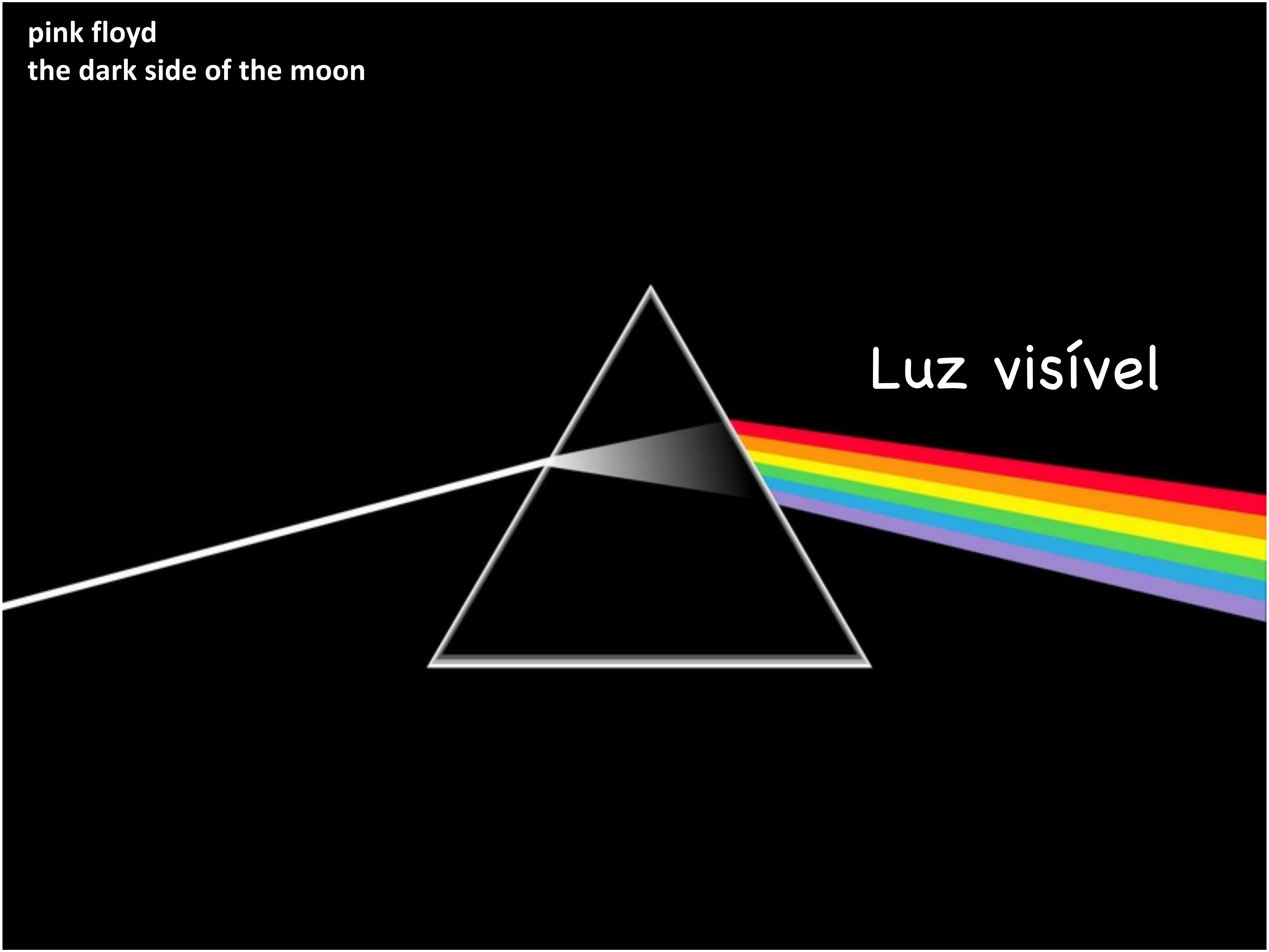
dium



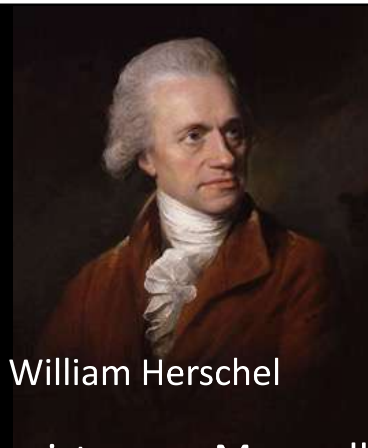
**Galileo Galilei 1609** constrói telescópio começa **astronomia observacional** (ondas ópticas ou visíveis).

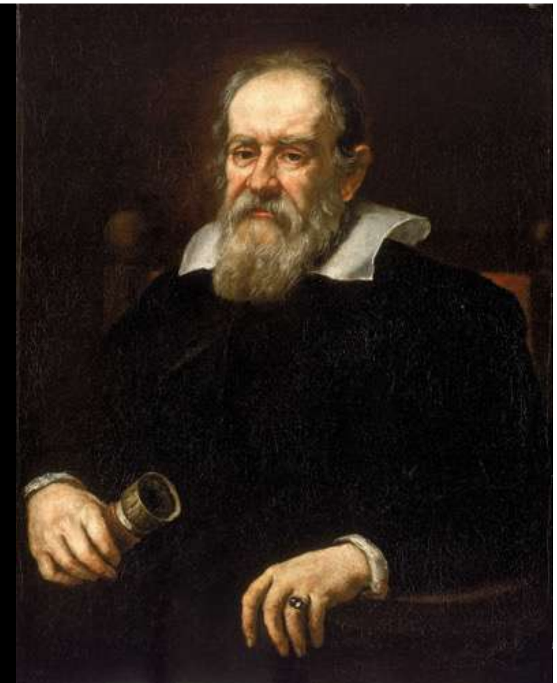

Fases de Venus


4 satélites de Jupiter (luas de Galileo): Europa, Ganímedes, Io e Calisto


pink floyd
the dark side of the moon
Luz visível

1800 William Herschel da **luz infra-vermelha** do Sol. 1830-60 inicio da astronomia infra-vermelha.


William Herschel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1887 Heinrich Hertz  produz **ondas de rádio** previstas por Maxwell


James Clerk Maxwell


Heinrich Rudolf Hertz

1931 Karl Jansky descobriu ondas de radio emitidas pela Via Láctea.


Karl G. Jansky

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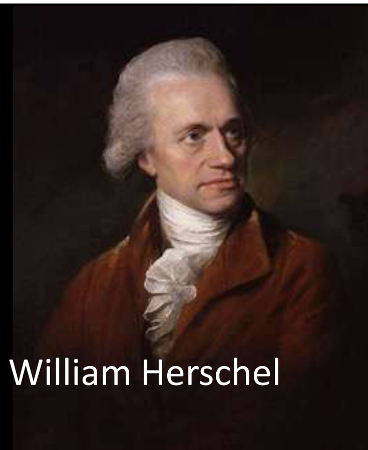
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James Clerk Maxwell


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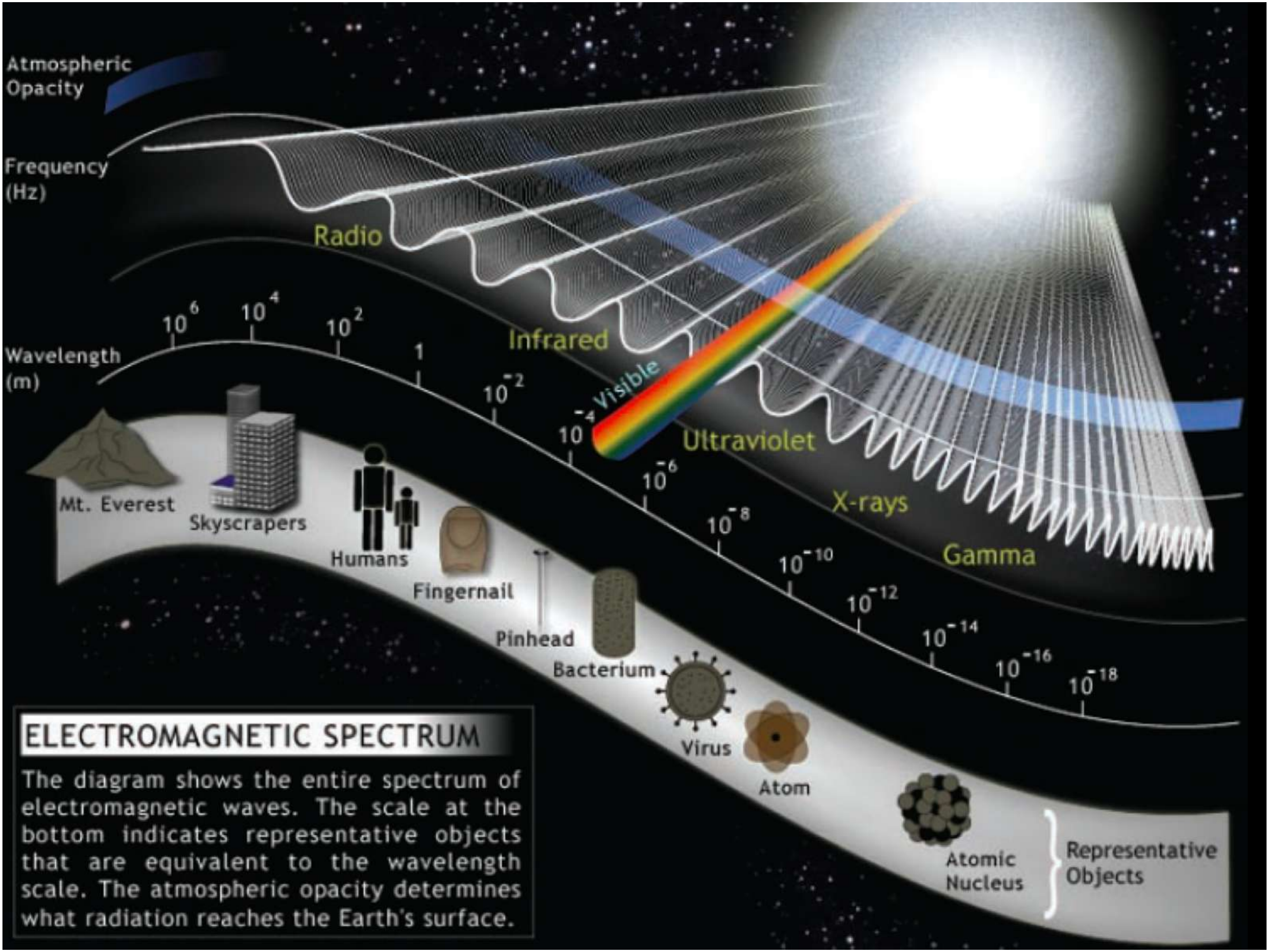
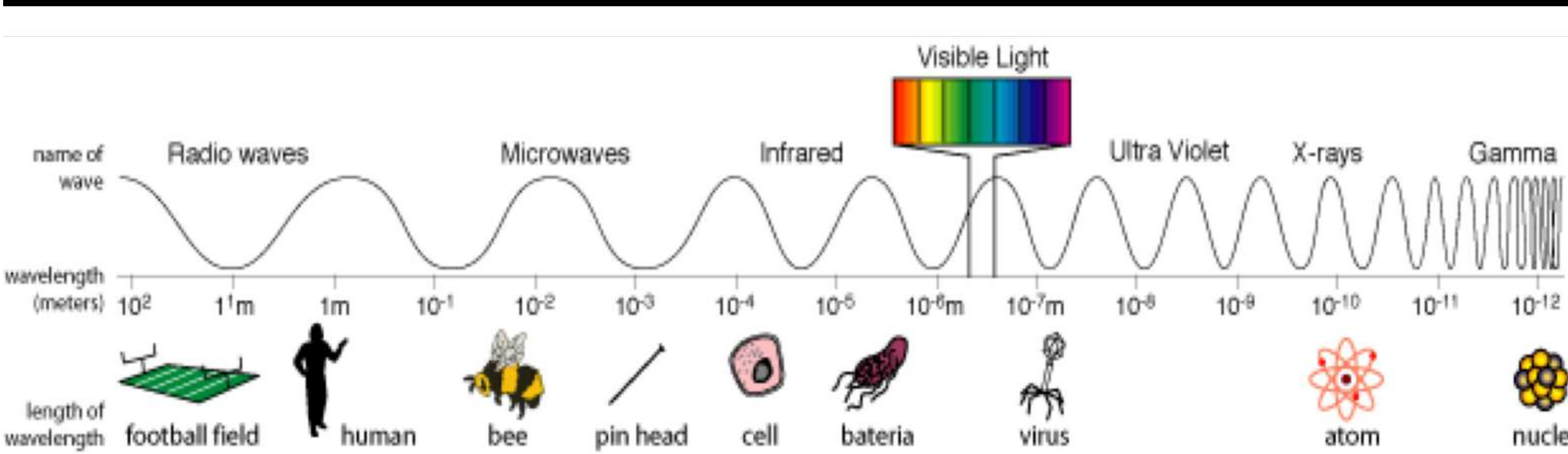

Atmospheric Opacity
Frequency (Hz)
Wavelength (m)
Radio
Infrared
Visible
Ultraviolet
X-rays
Gamma
$10^{6}$ $10^{4}$ $10^{2}$ 1 $10^{-2}$ $10^{-4}$ $10^{-6}$ $10^{-8}$ $10^{-10}$ $10^{-12}$ $10^{-14}$ $10^{-16}$ $10^{-18}$
Mt. Everest
Skyscrapers
Humans
Fingernail
Pinhead
Bacterium
Virus
Atom
Atomic Nucleus
Representative Objects
ELECTROMAGNETIC SPECTRUM
The diagram shows the entire spectrum of electromagnetic waves. The scale at the bottom indicates representative objects that are equivalent to the wavelength scale. The atmospheric opacity determines what radiation reaches the Earth's surface.

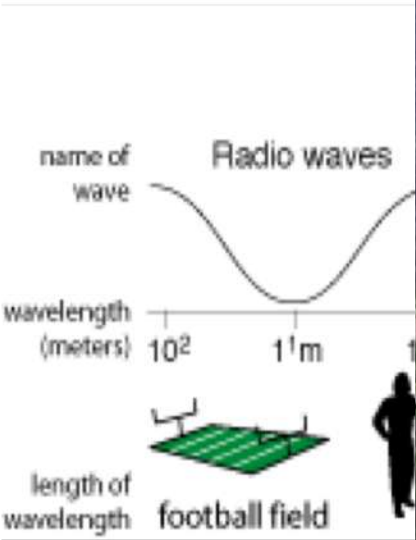
# Espectro Eletromagnético ou "Luz"

15 ordens de grandeza
equivalente a 5 "pianos"




Astronomia Multi-Frequência ou Multi-Wavelength (comprimento de onda)

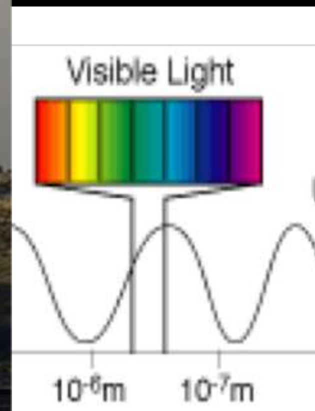
# Telescópios de Rádio





# Telescópios Ópticos

Gran Telescópio Canarias (GTC)



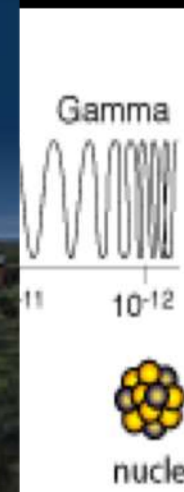

HUBBLE space Telescope

Magellan  Telescopes – Las Campanas (Chile)

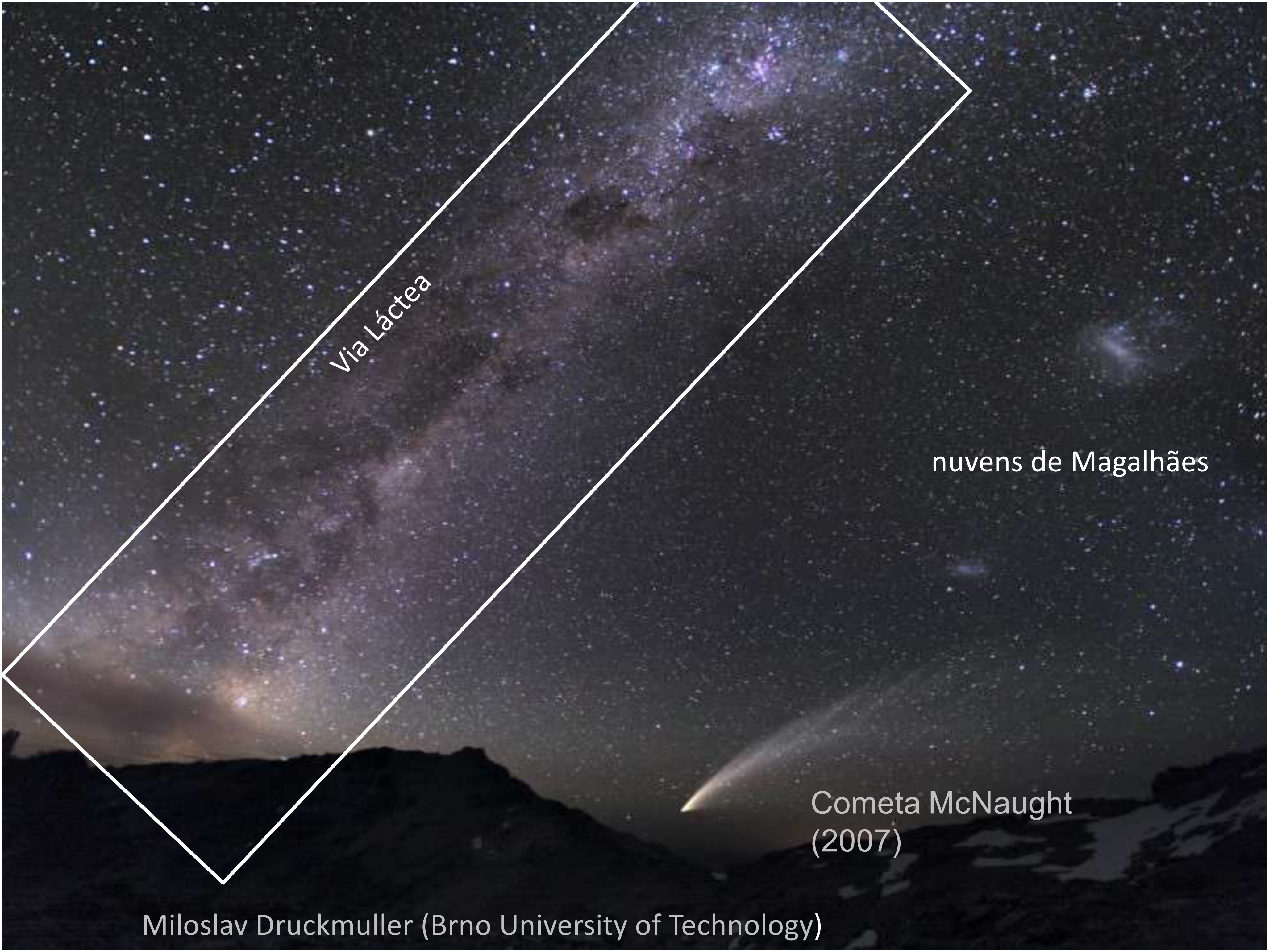
Keck Telescopes – Mauna Kea (Hawaii)

# Telescópios de Raios Gamma



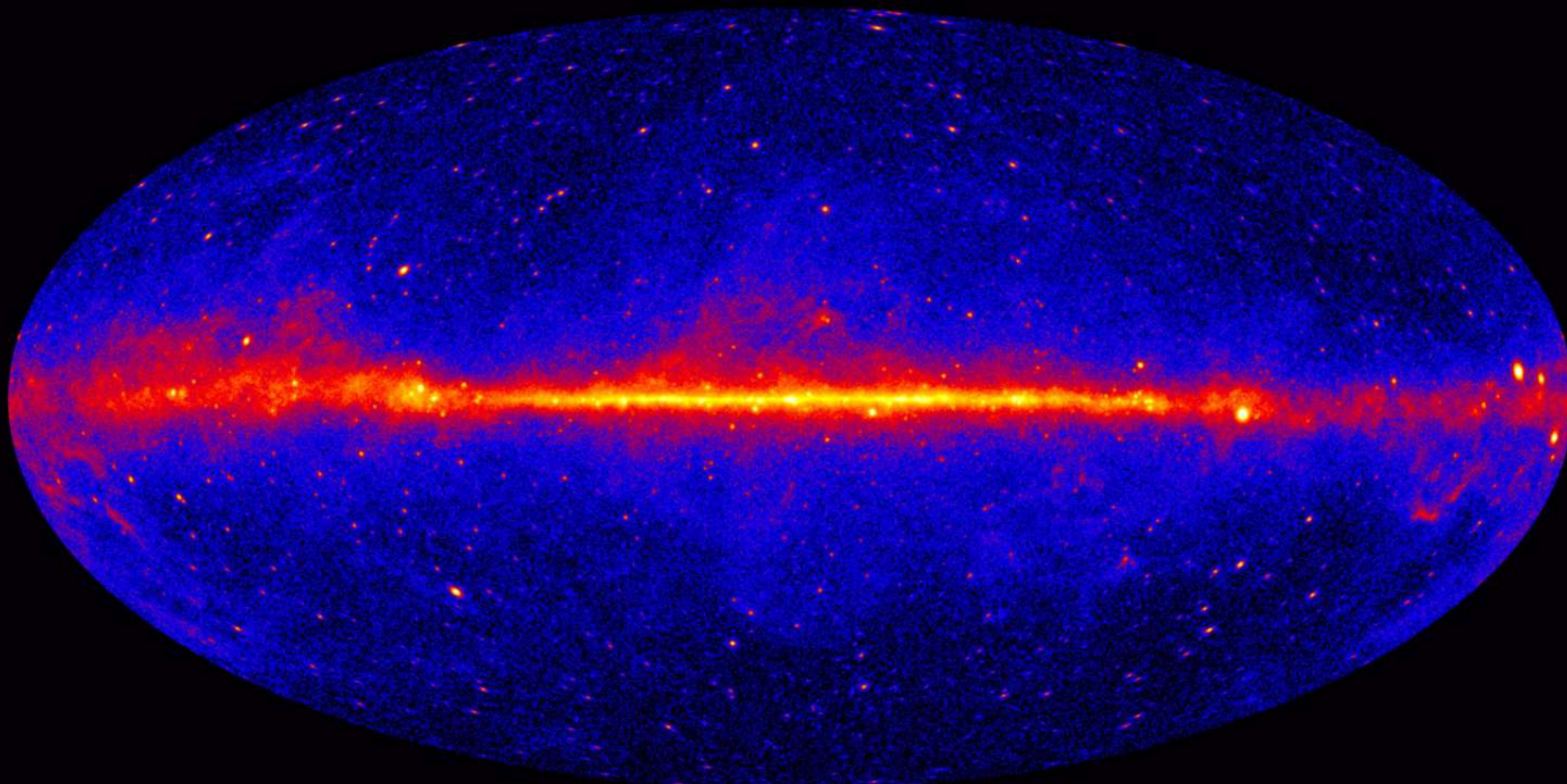




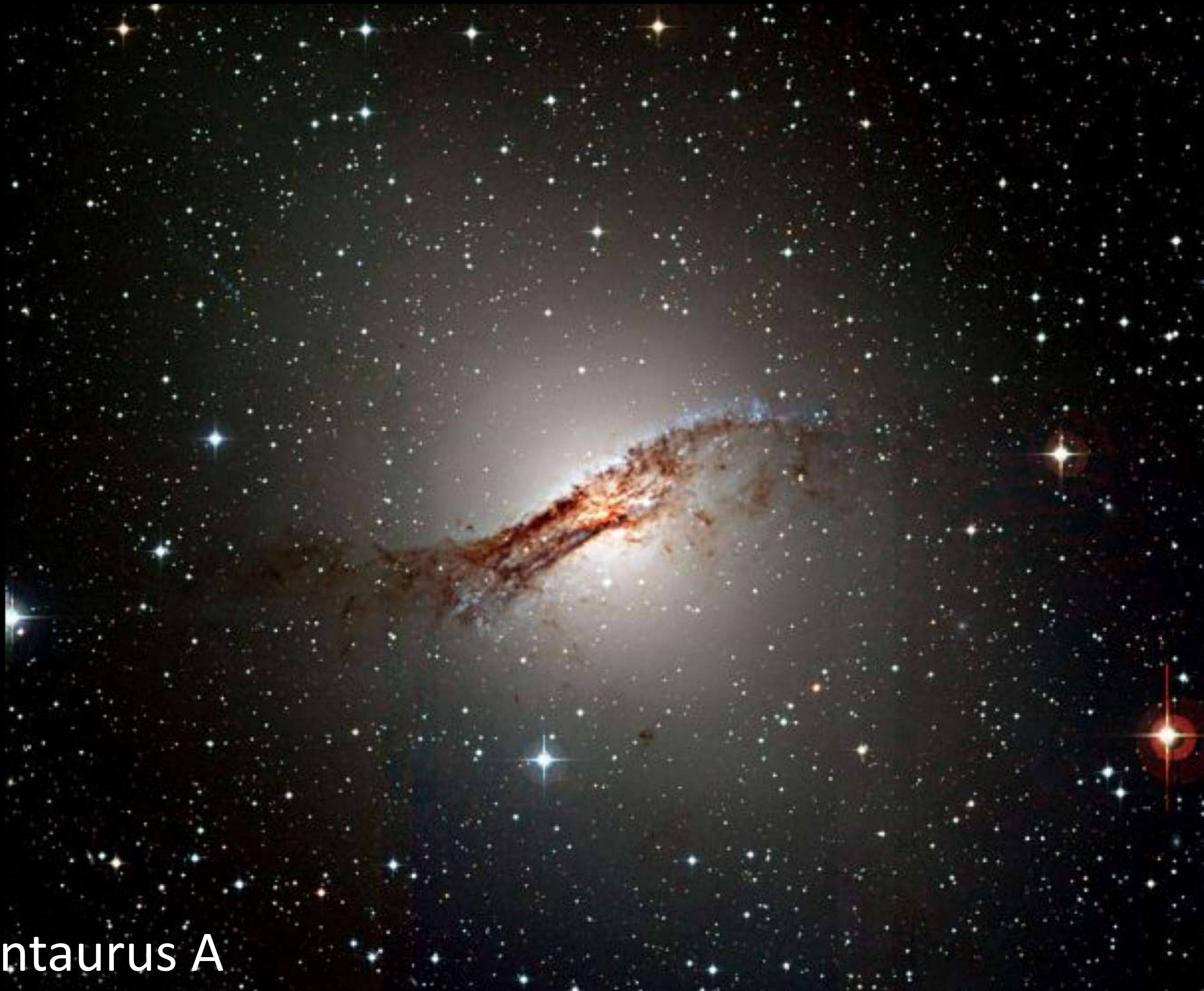

Via Láctea
nuvens de Magalhães
Cometa McNaught
(2007)
Miloslav Druckmuller (Brno University of Technology)

Via Láctea
vista em Luz Visível

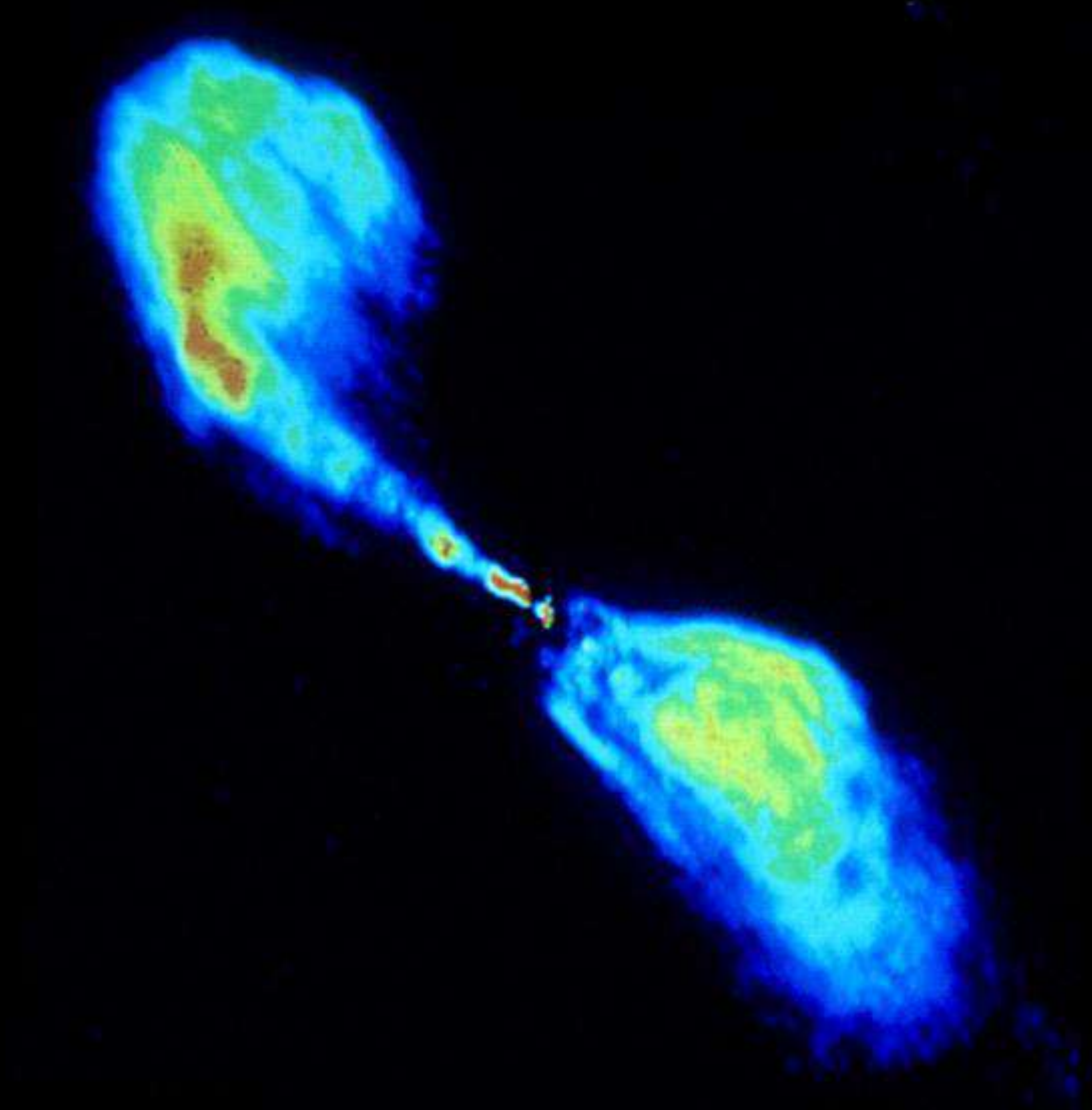
Infra-vermelho

Via Láctea em
Raios Gamma

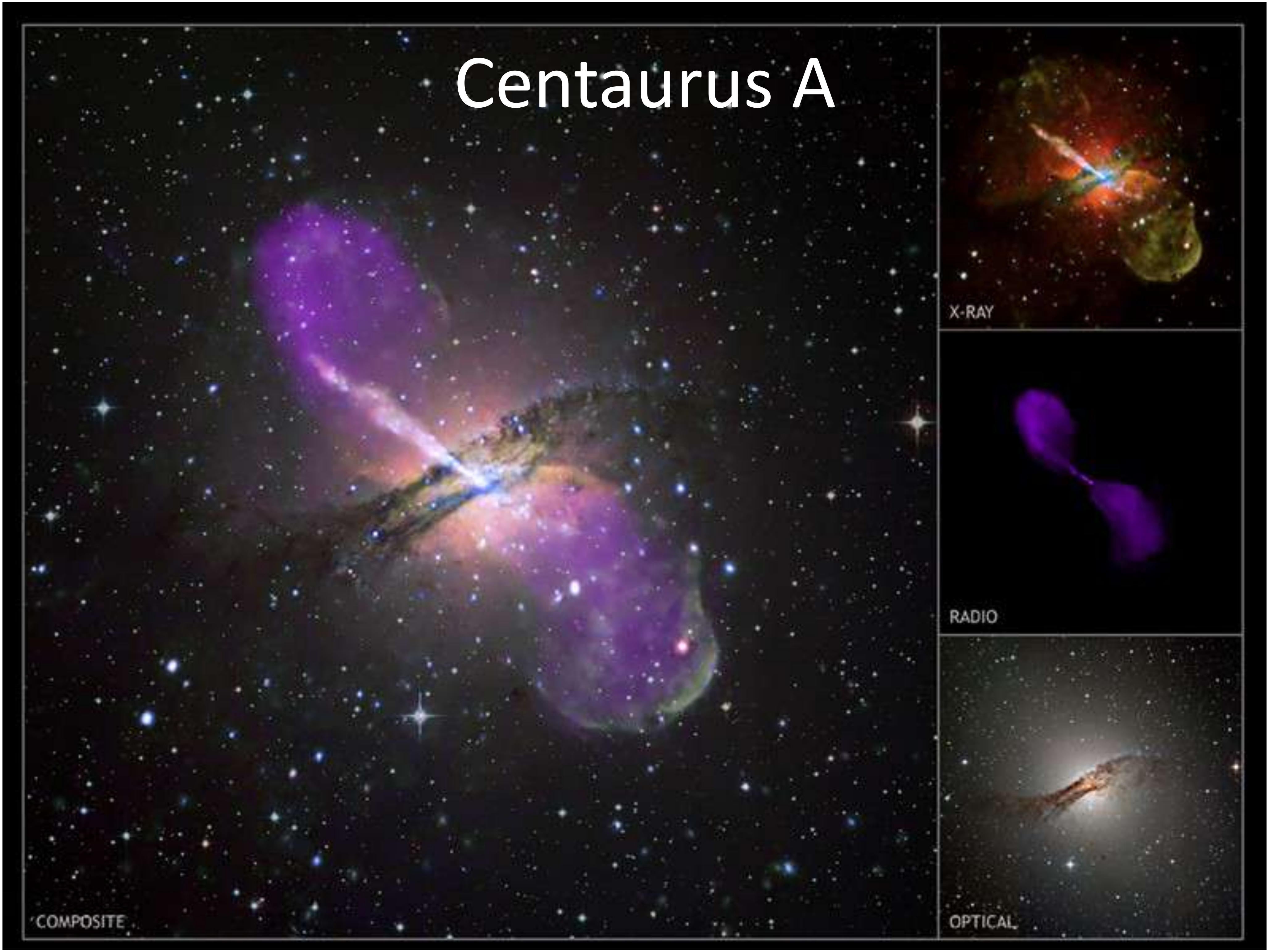


Centaurus A

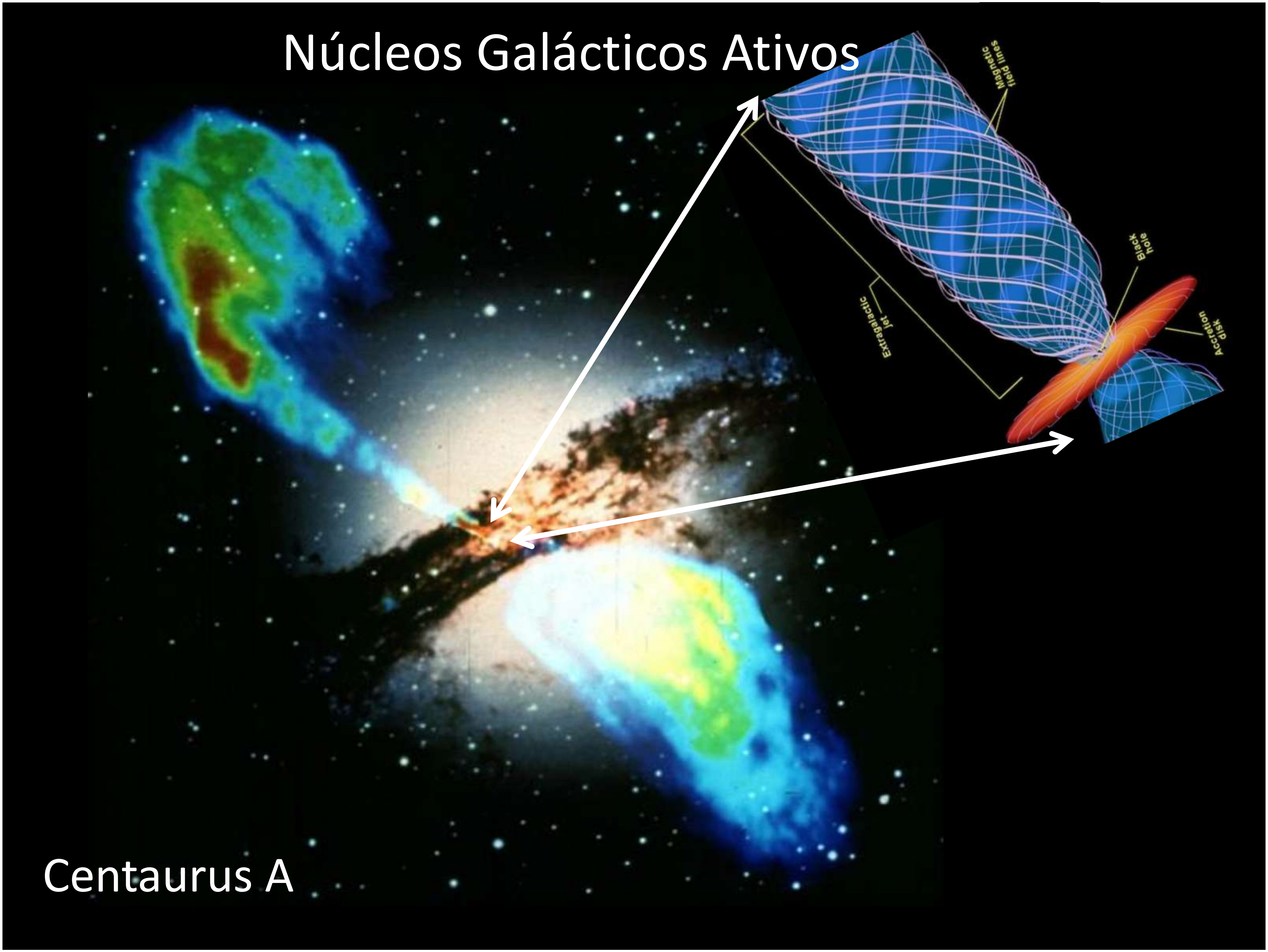


Centaurus A em ondas de Rádio

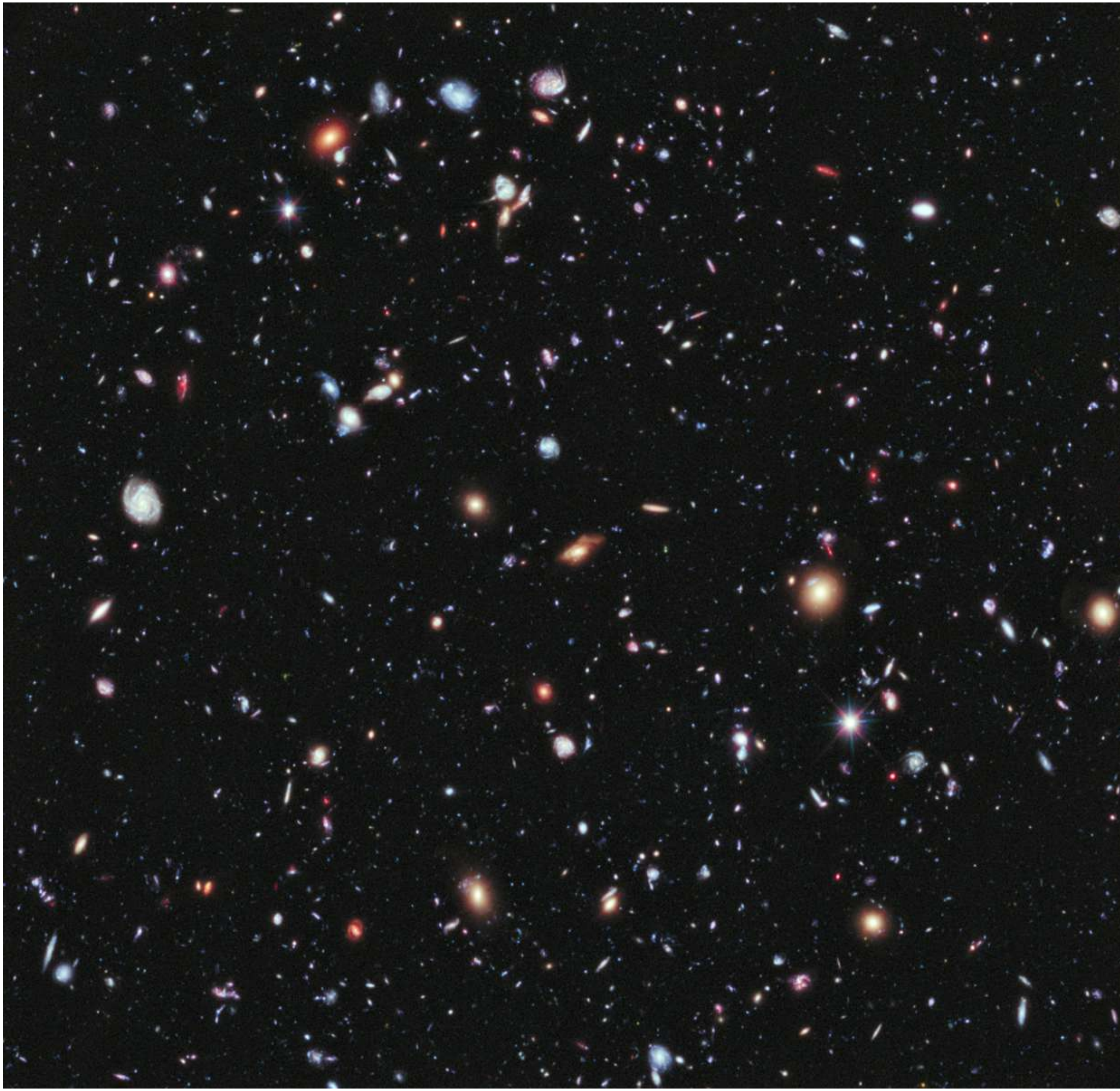
# Centaurus A



# Núcleos Galácticos Ativos

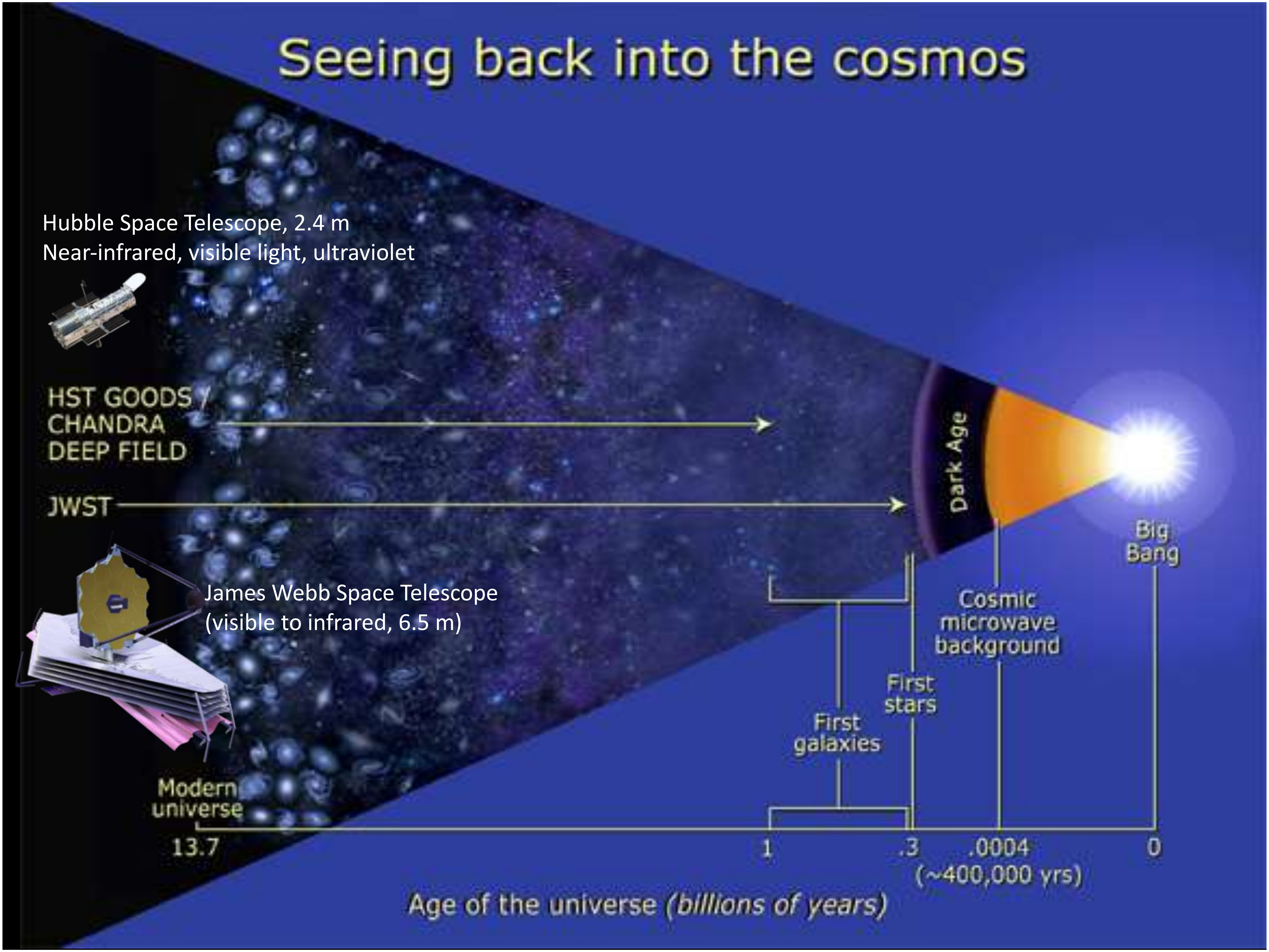



Centaurus A



Hubble eXtreme Deep Field, 2 x 2.3 $arcmin^2$
5,500 galáxias

Observable Universe
~2 Trilhões galáxias


Seeing back into the cosmos
Hubble Space Telescope, 2.4 m
Near-infrared, visible light, ultraviolet
HST GOODS /
CHANDRA
DEEP FIELD
JWST
James Webb Space Telescope
(visible to infrared, 6.5 m)
Dark Age
Big
Bang
Cosmic
microwave
background
First
stars
First
galaxies
Modern
universe
13.7
1
.3
.0004
(~400,000 yrs)
0
Age of the universe (billions of years)

# Imagem do Universo com 380,000 anos!

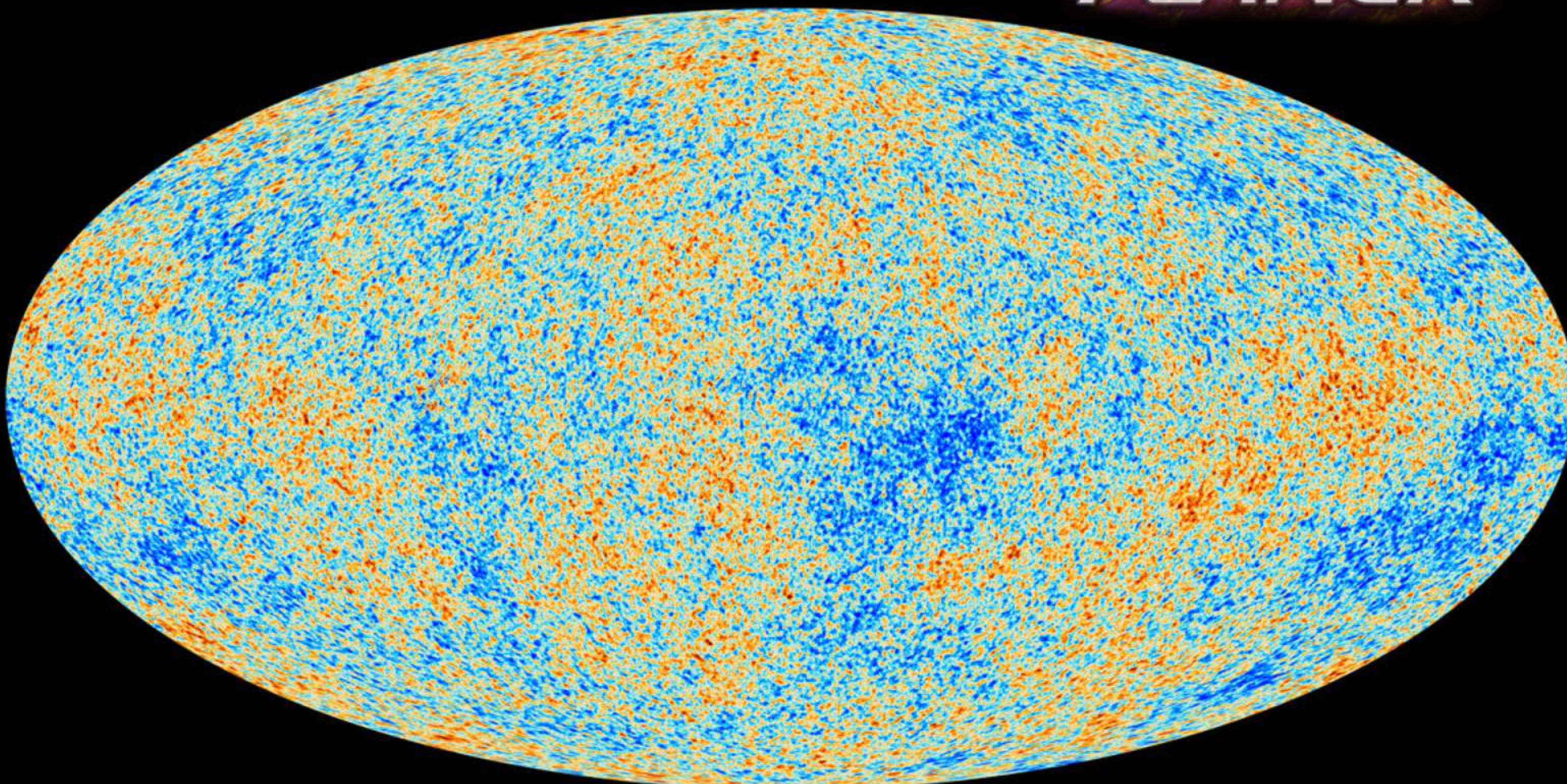
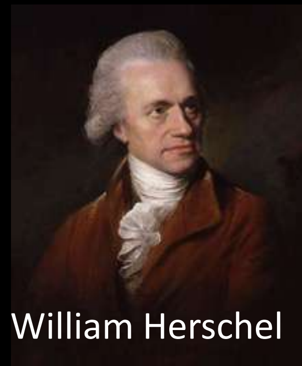



Imagem em Micro-ondas

1800 William Herschel da **luz infra-vermelha**



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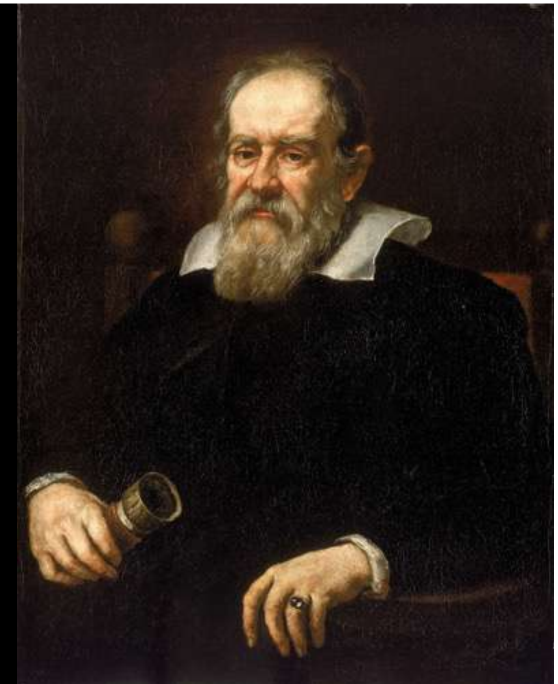


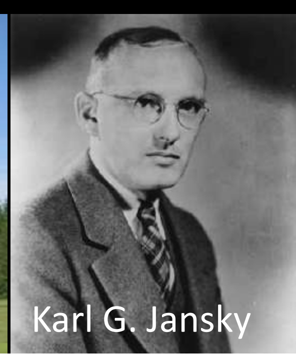
Galileo Galilei 1609 constrói telescópio começa astronomia (ondas ópticas ou visíveis).

1912 Victor Hess descobriu que raios ionizantes são raios cósmicos

núcleos atômicos
primeiros mensageiros distantes
não electromagnéticos

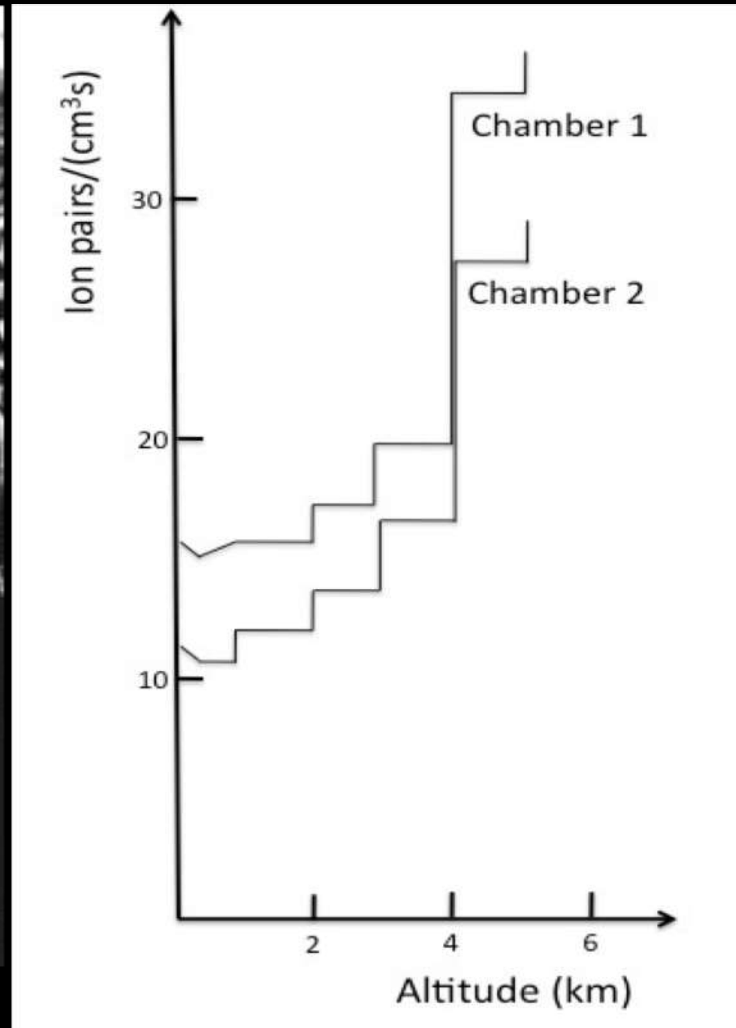
Victor Franz Hess

1931 Karl Jansky descobriu ondas de radio emitidas pela Via Láctea.



Karl G. Jansky

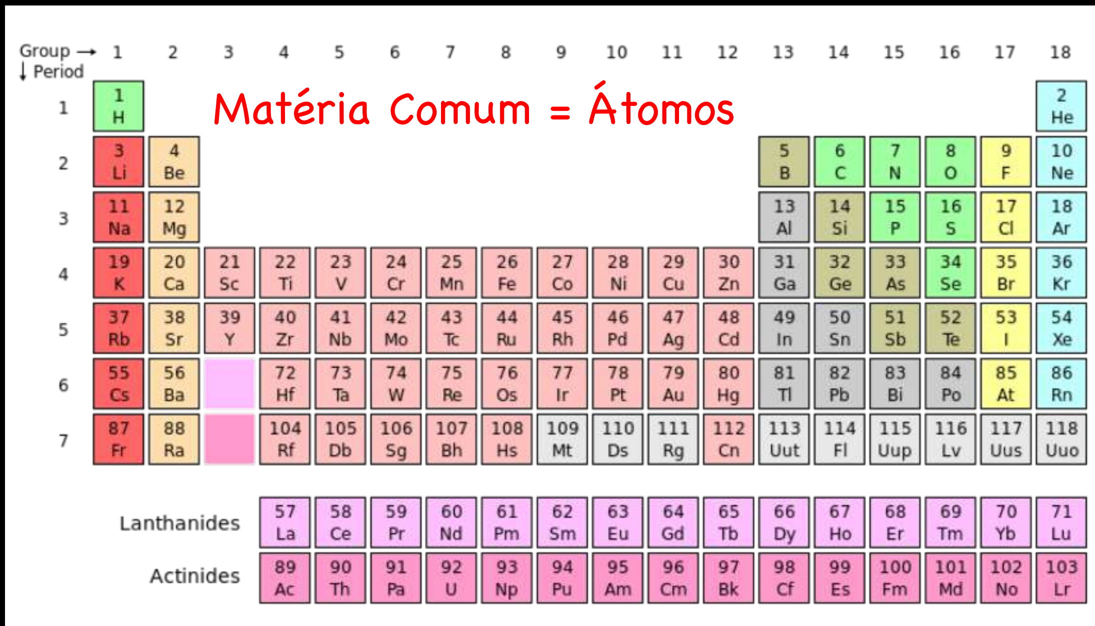
# 1912 Descoberta dos Ráios Cósmicos

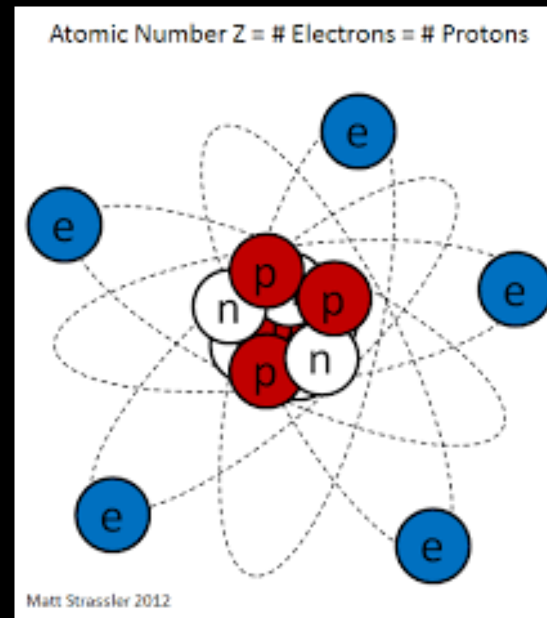


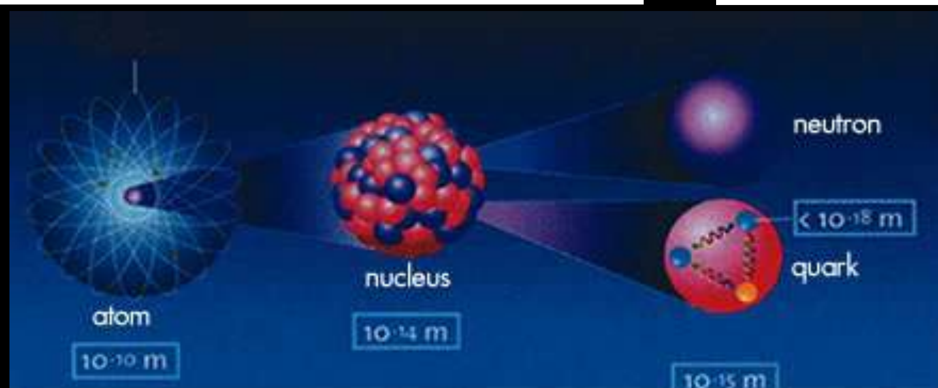

Victor Hess
mostra que radiação ionizante vem de fora da Terra

# Raios Cósmicos

núcleos atômicos, relatívisticos (altamente energéticos):



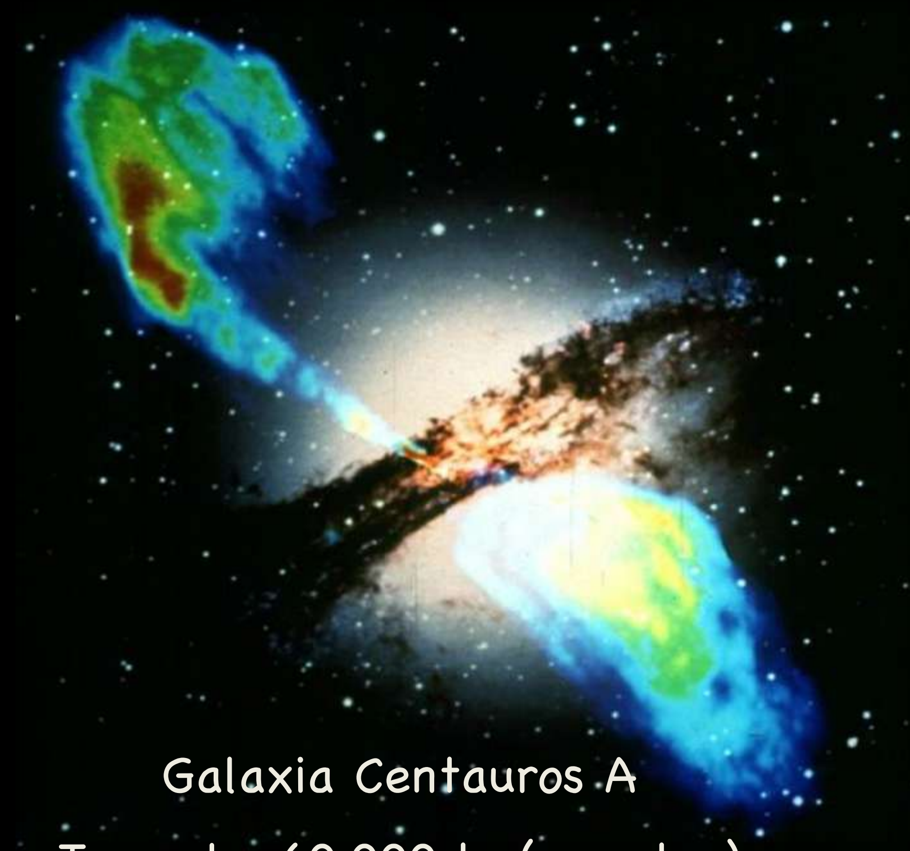

Raios cósmicos = núcleos atômicos, relativísticos (altamente energéticos):
Hidrogenio (protons), He, C, O, Fe, …

# Raios Cósmicos

núcleos atômicos, relatívisticos (altamente energéticos):
Acelerados em regiões extremas do Universo – aonde?

Supernova e Pulsar do Caranguejo

Tamanho 11 ly (anos luz)
Distancia 6,5 kly

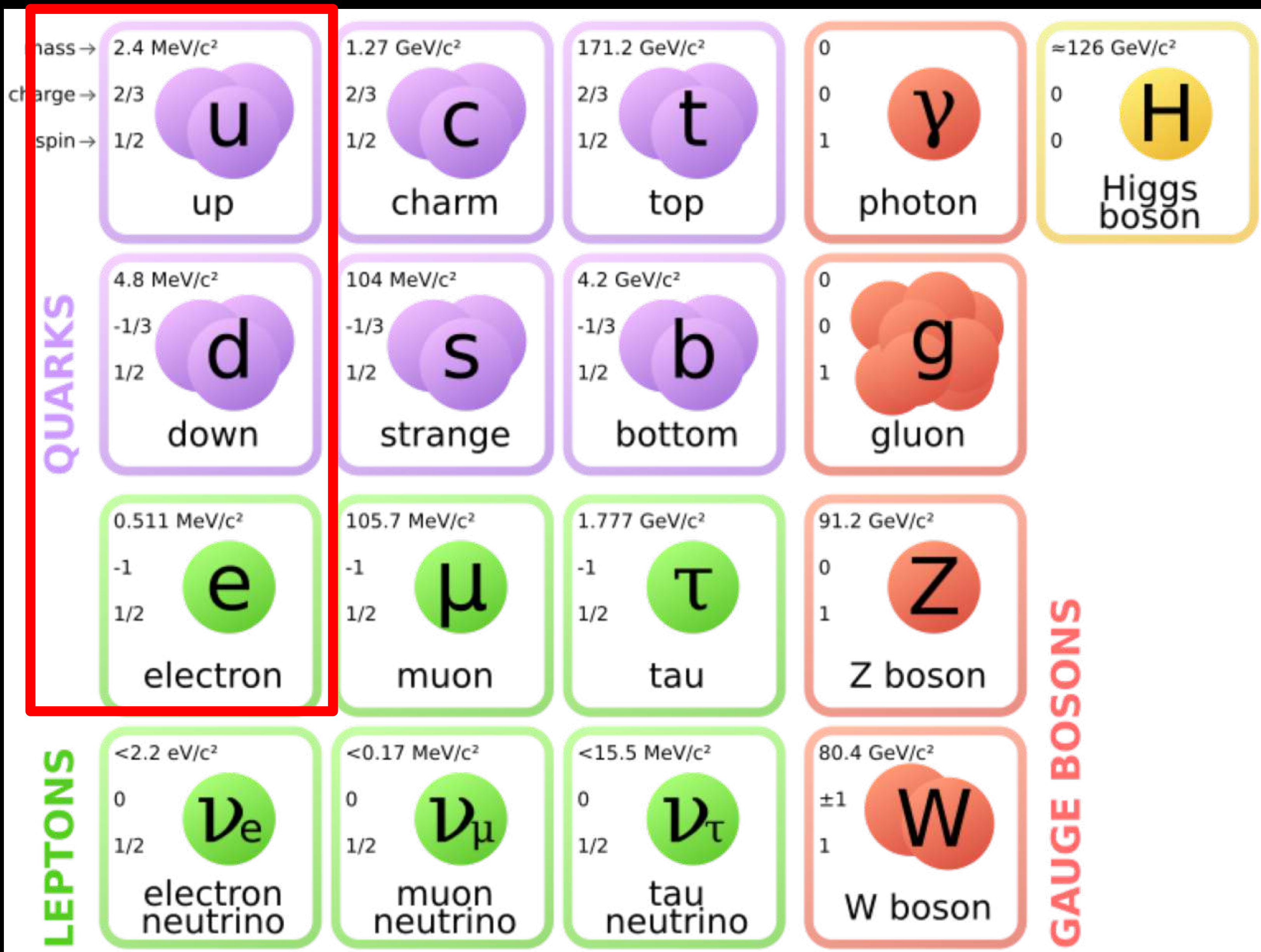


Galaxia Centauros A

Tamanho 60,000 ly (anos luz)
Distancia 10 Mly

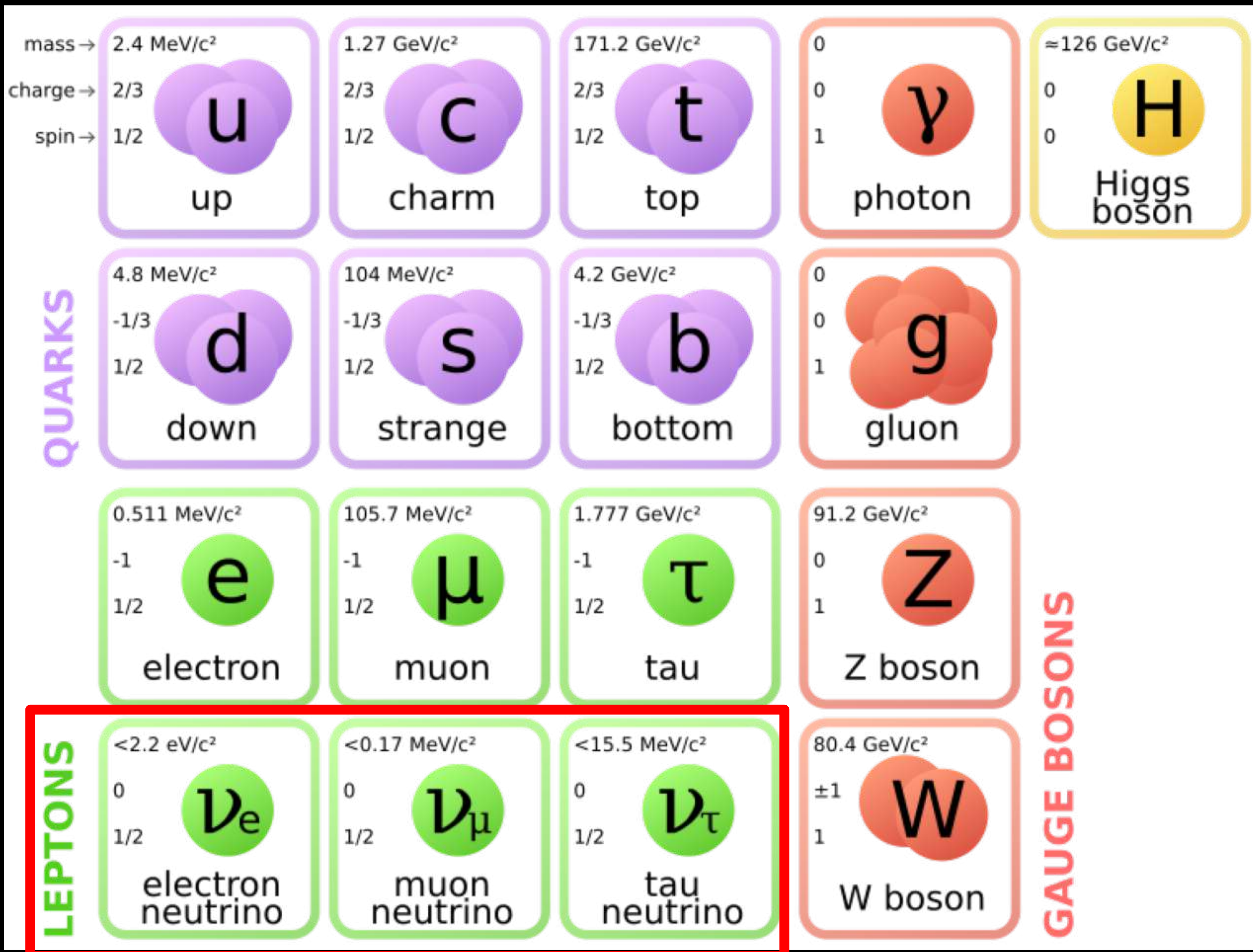
Possivelmente em Explosões Estelares (Supernova), Choques interestelares,
Choques intergalácticos, Jatos de Buracos Negros Supermassivos, …

# Matéria Comum = Quarks e Leptons

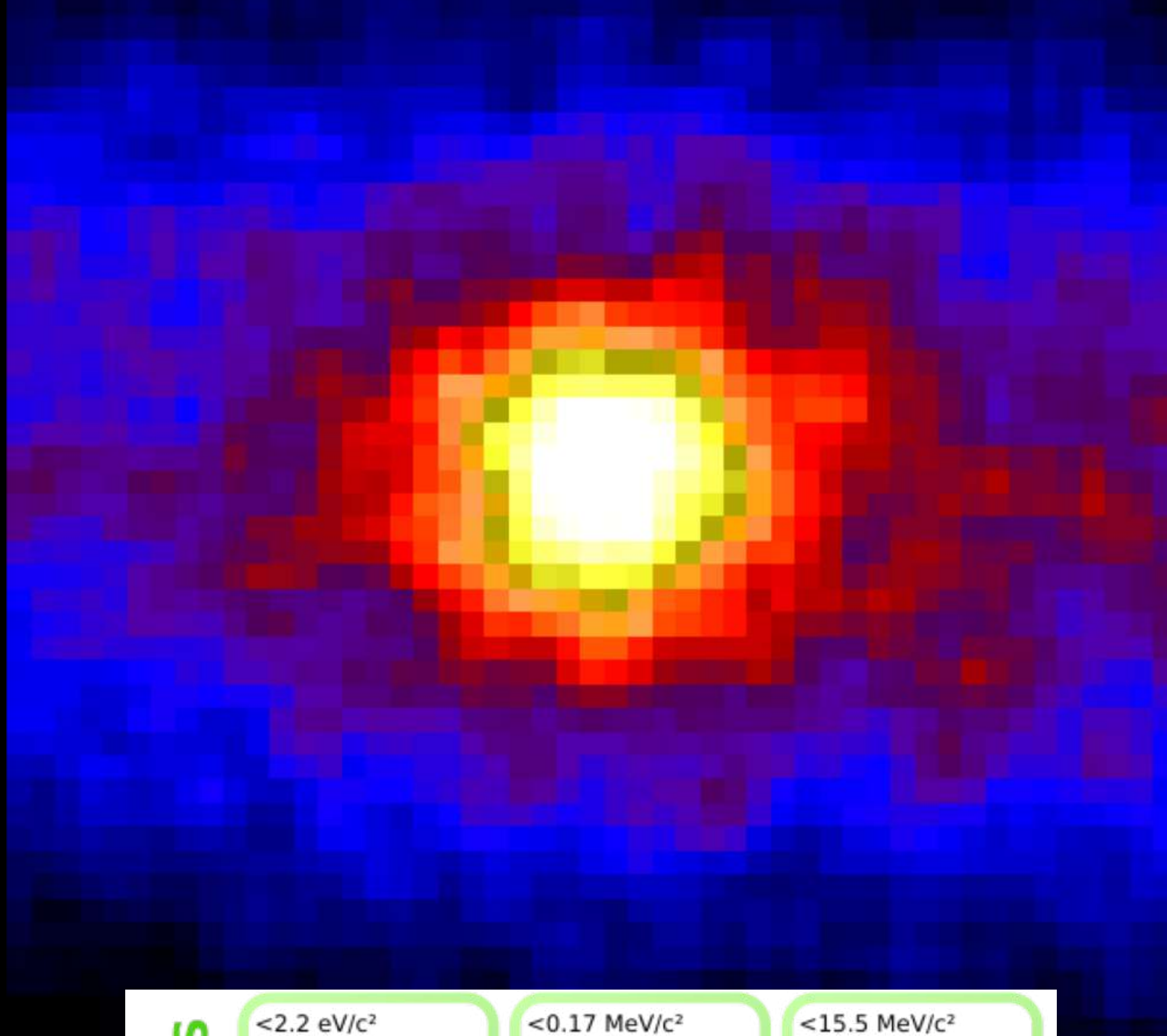


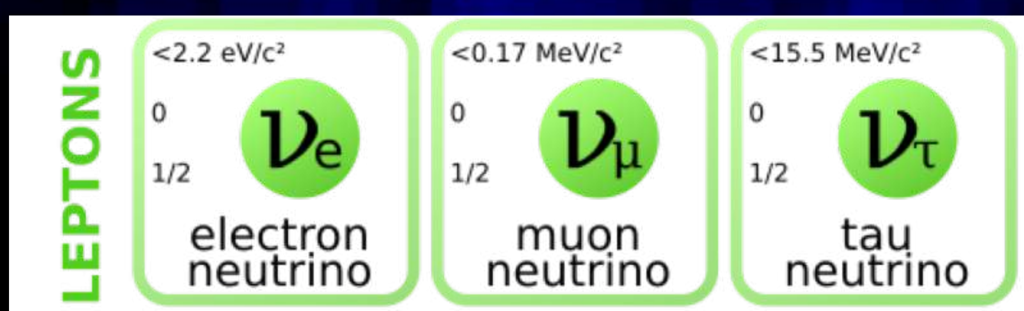
# Neutrinos

"uns 100 bilhões atravessam o seu polegar a cada segundo!"
A. de Gouveia (Fisica em Casa)



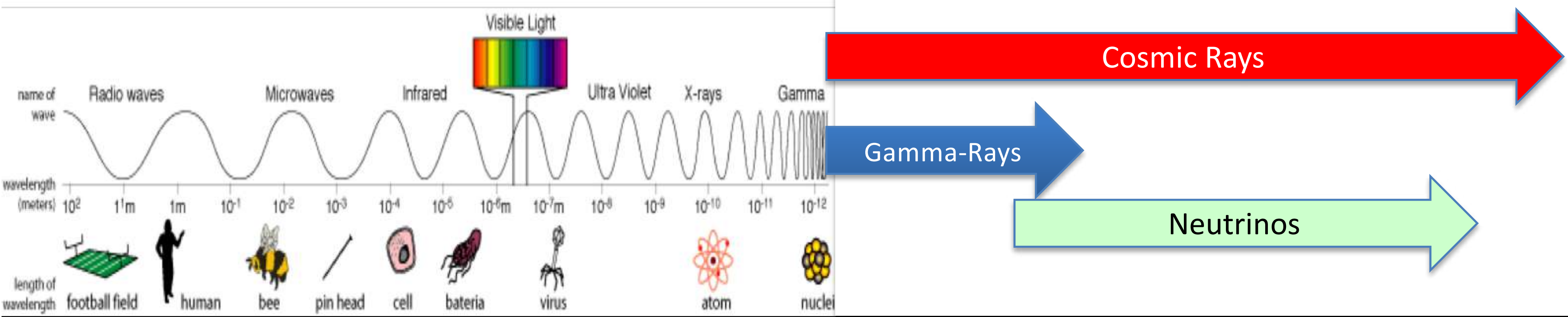
# O Sol em “Luz de Neutrinos”





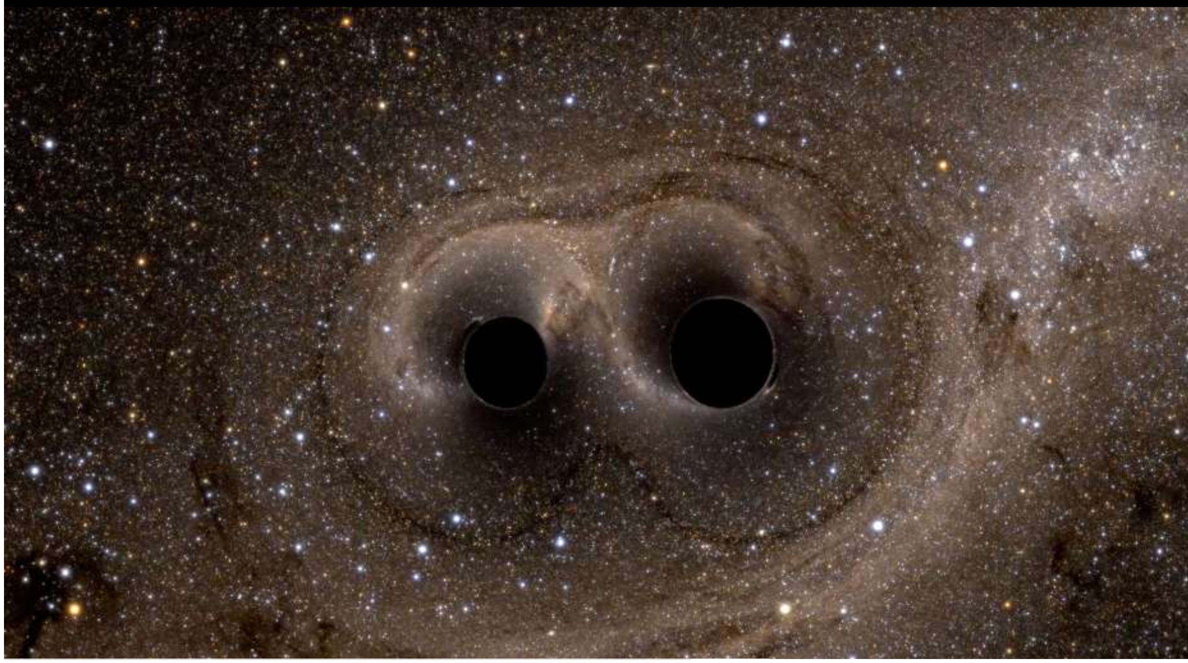
# Partículas Cósmicas

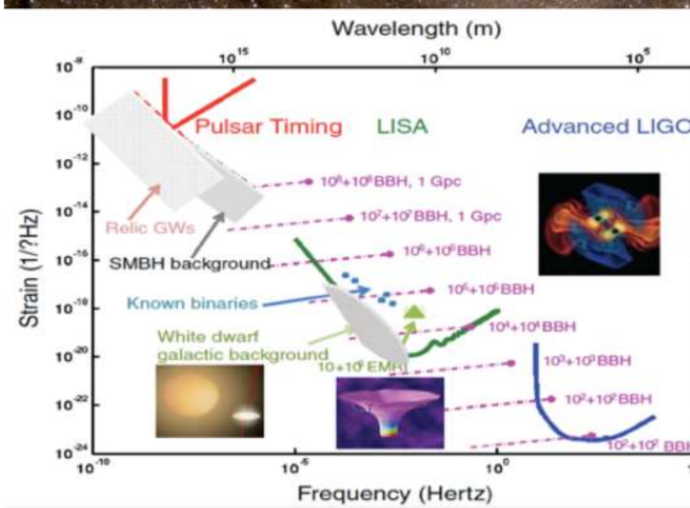
~ dobram o alcance da Astrofísica em energia

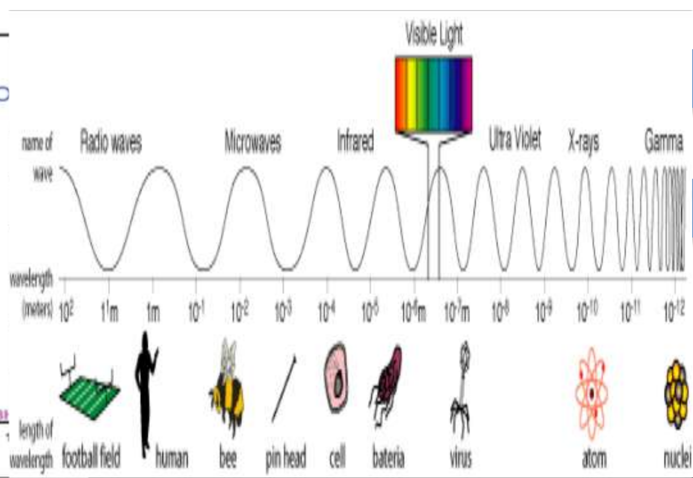


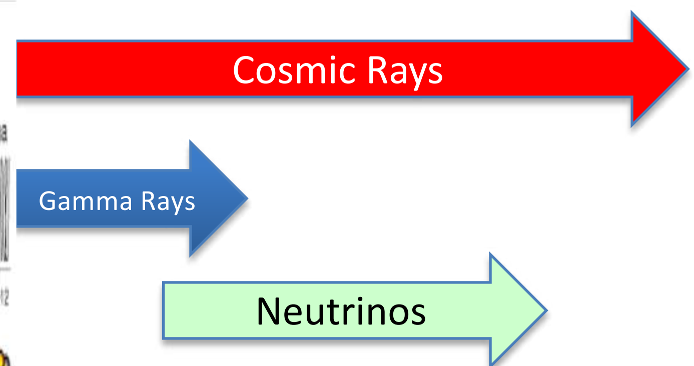
# Multi-Mensageiros

~ triplicam o alcance de energia da Astrofísica : 40 ordens de grandeza






Ondas Gravitacionais

Fótons ou Ondas Eletromagnéticas

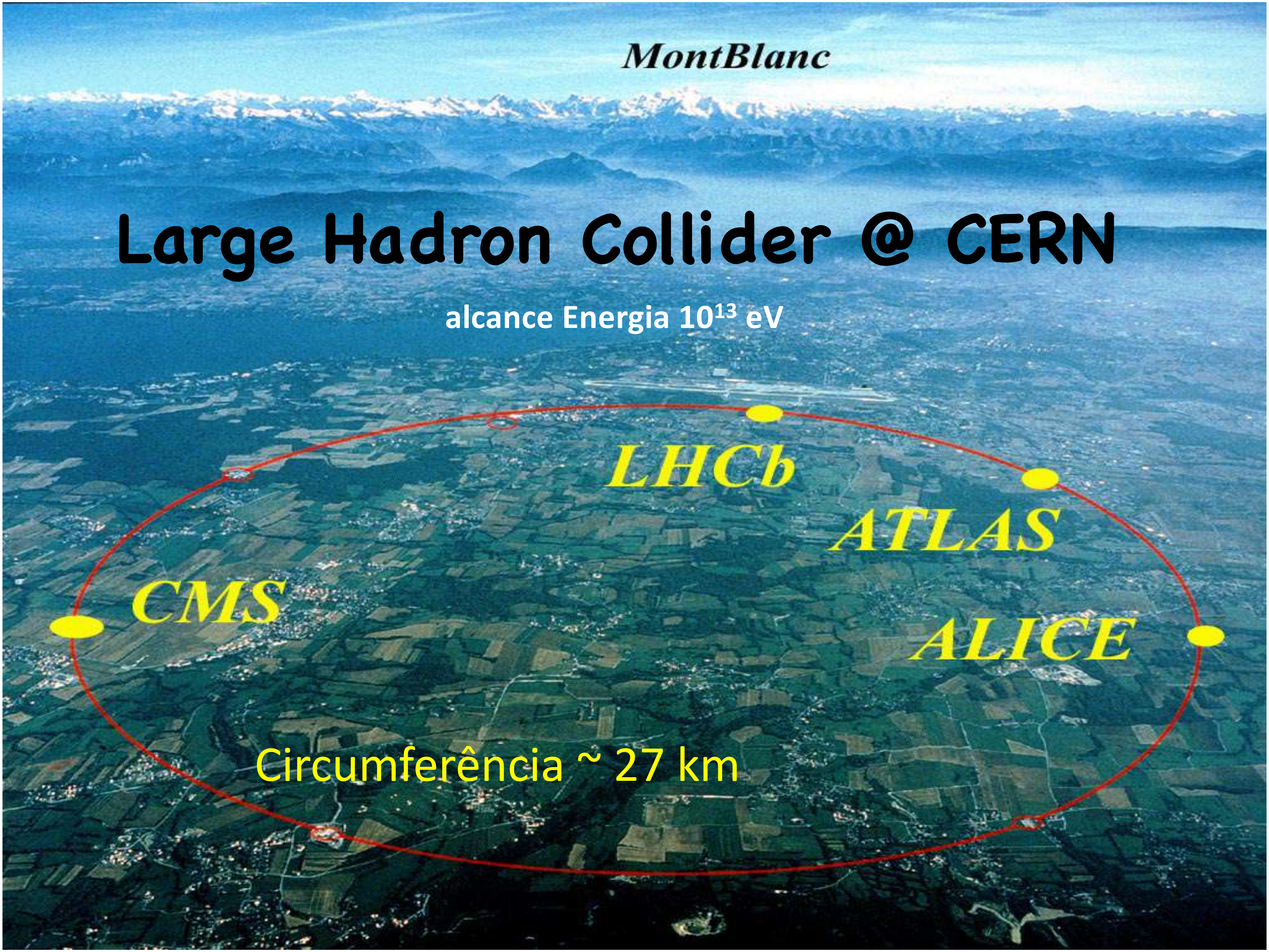
Partículas Cósmicas

Multi-Mensageiros

Raios-Cósmicos

Neutrinos

Ultra-Energéticos

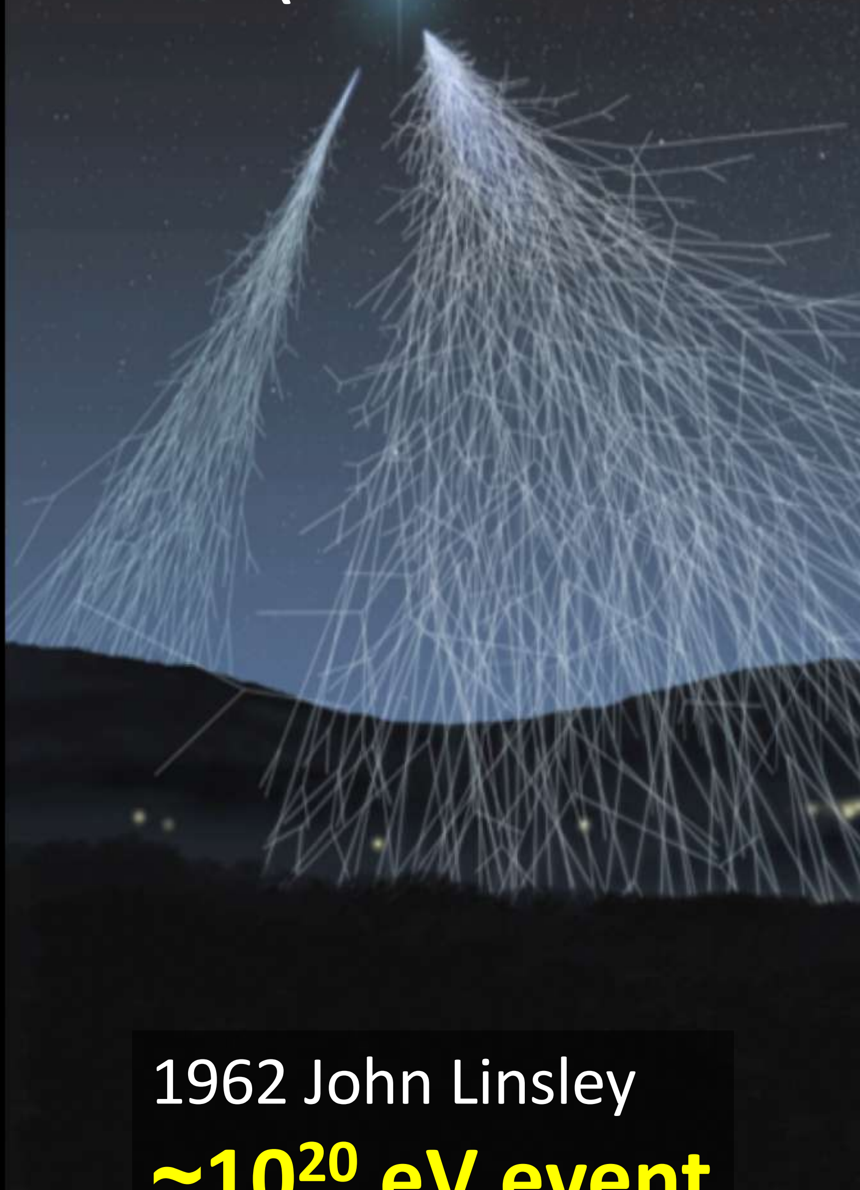

MontBlanc
Large Hadron Collider @ CERN
alcance Energia $10^{13}$ eV
LHCb
ATLAS
CMS
ALICE
Circumferência ~ 27 km

# Extensive Air Showers
# (Chuveiros de ar extensivos)

1937: Pierre Auger

Raios Cósmicos ~ $10^{15}$ eV

# Ultra High Energy Cosmic Rays (Raios Cósmicos Ultra-Energéticos)



1962 John Linsley

**~$10^{20}$ eV event**


Raios Cósmicos Ultra Energéticos:
$10^{20}$ eV
10,000,000 x Energia LHC
Quais são as fontes?

# Observatórios mais importantes de Raios Cósmicos Ultra-Energéticos

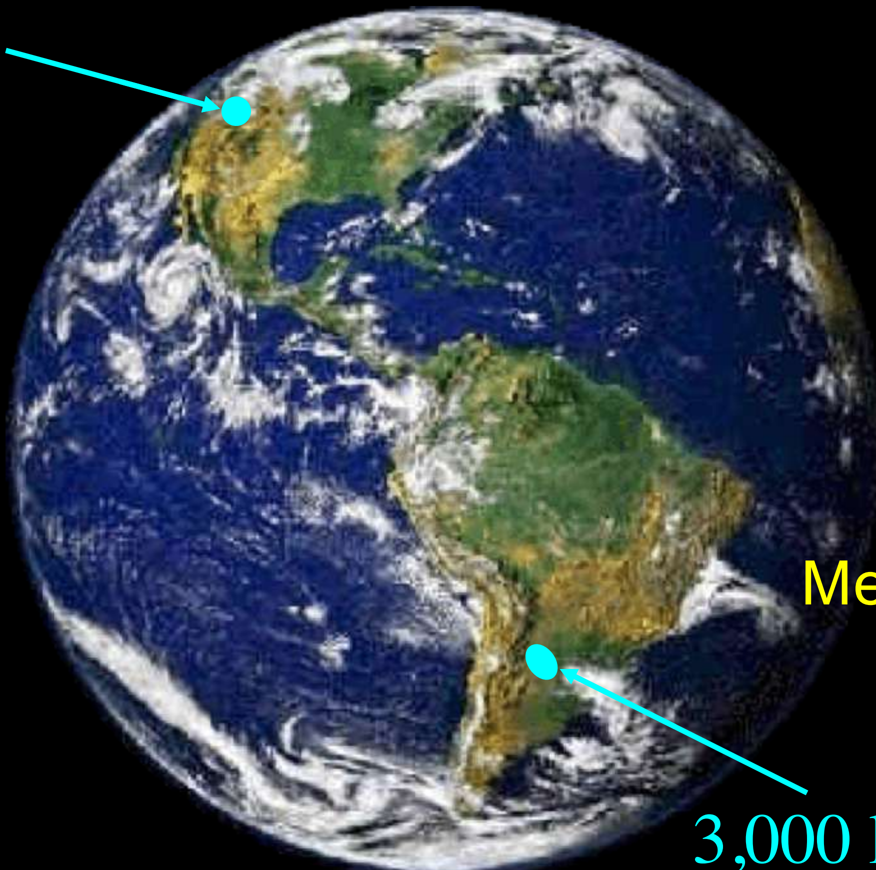
Telescope Array

Utah, USA

(5 country collaboration)

700 km$^2$ array

3 fluorescence telescopes



Pierre Auger Observatory

Mendoza, Argentina

(19 country collaboration)

3,000 km$^2$ array

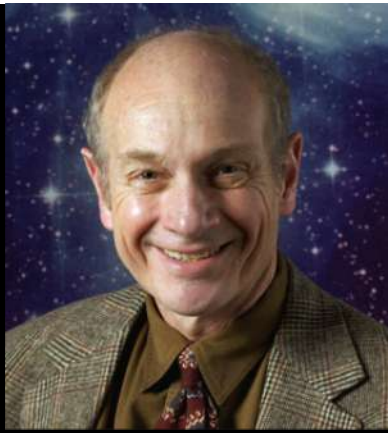
4 fluorescence telescopes

# Pierre Auger Observatory

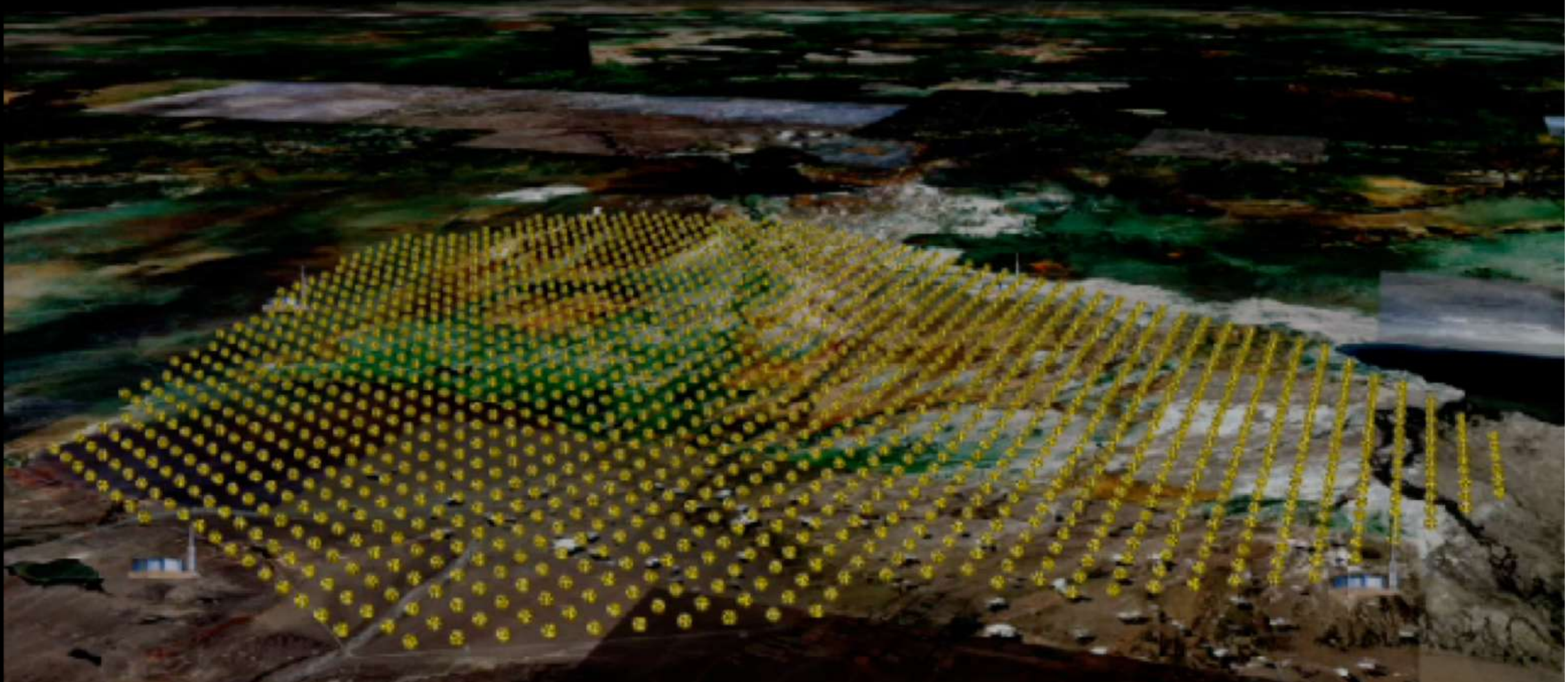
PIERRE AUGER OBSERVATORY

**3,000 km² water Cherenkov detectors array**

**4 fluorescence Telescopes, Malargue, Argentina**

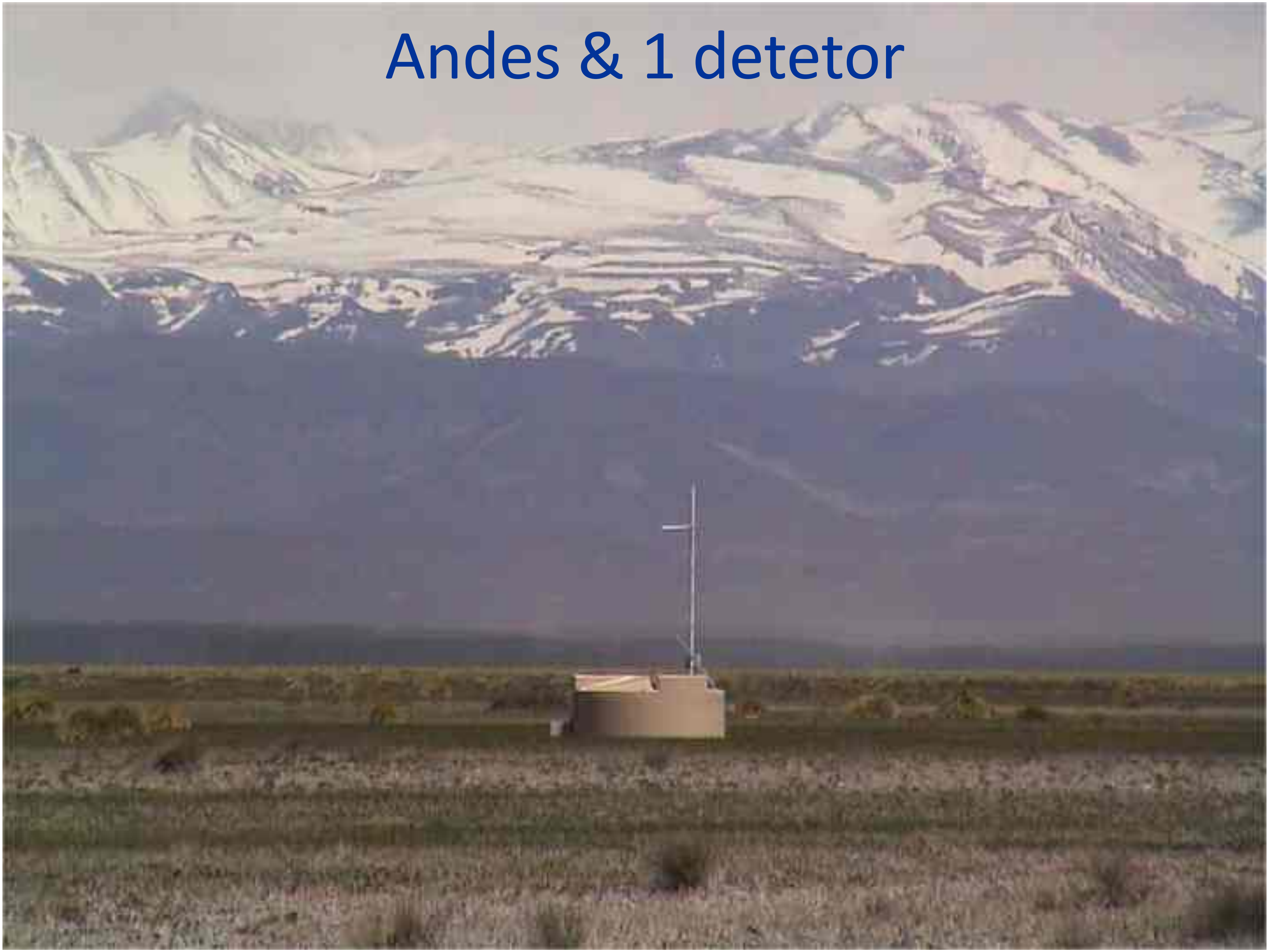


James W. Cronin
1931-2016



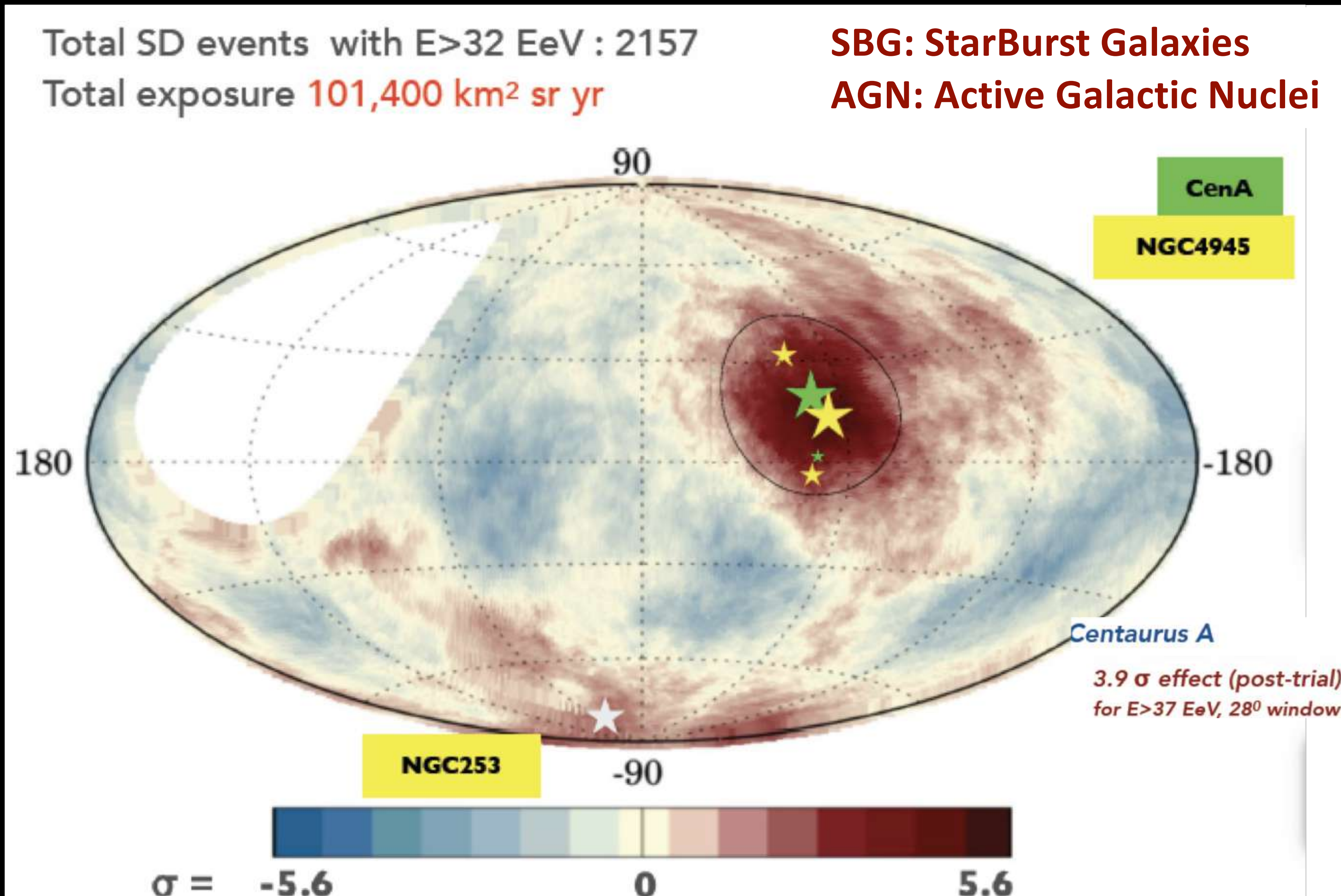
**~ 500 Scientists, 19 Countries**

# Andes & 1 detetor



# 4  telescópios ultravioleta de fluorescência

# Sugestão das Anisotropias > 4 x $10^{19}$ eV

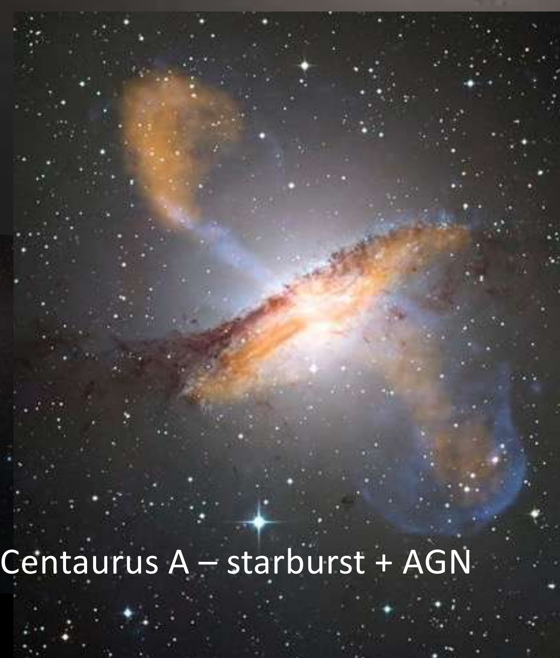


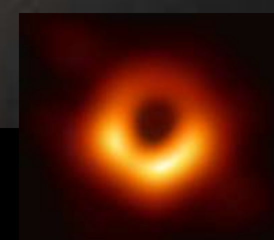
# Galáxias Starbursts ou Núcleos Galácticos Ativos?
# Starbursts Galaxies or Active Galactic Nuclei?


M82 – Starburst Galaxy


M87- AGN


Sculptor Galaxy NGC 253


Centaurus A – starburst + AGN


Event Horizon Telescope
Image of M87

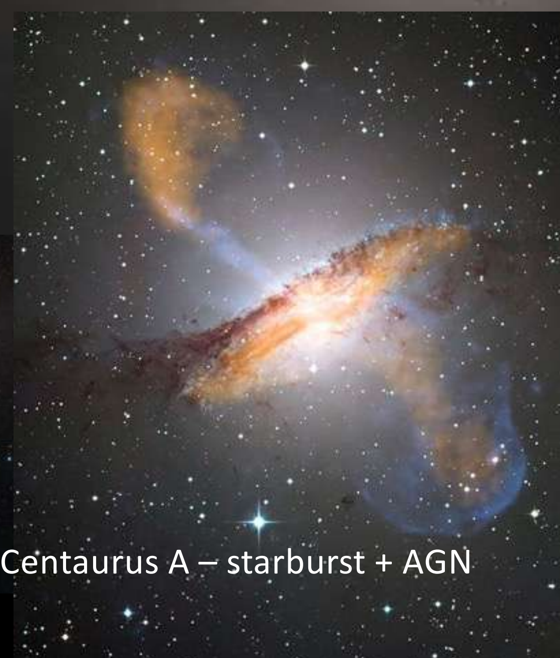
Galáxias Starbursts ou Núcleos Galácticos Ativos?
Starbursts Galaxies or Active Galactic Nuclei?

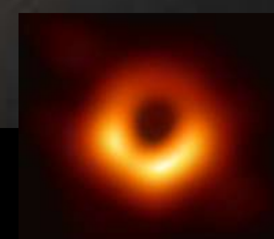

M82 – Starburst Galaxy


M87- AGN

Quais são as fontes?

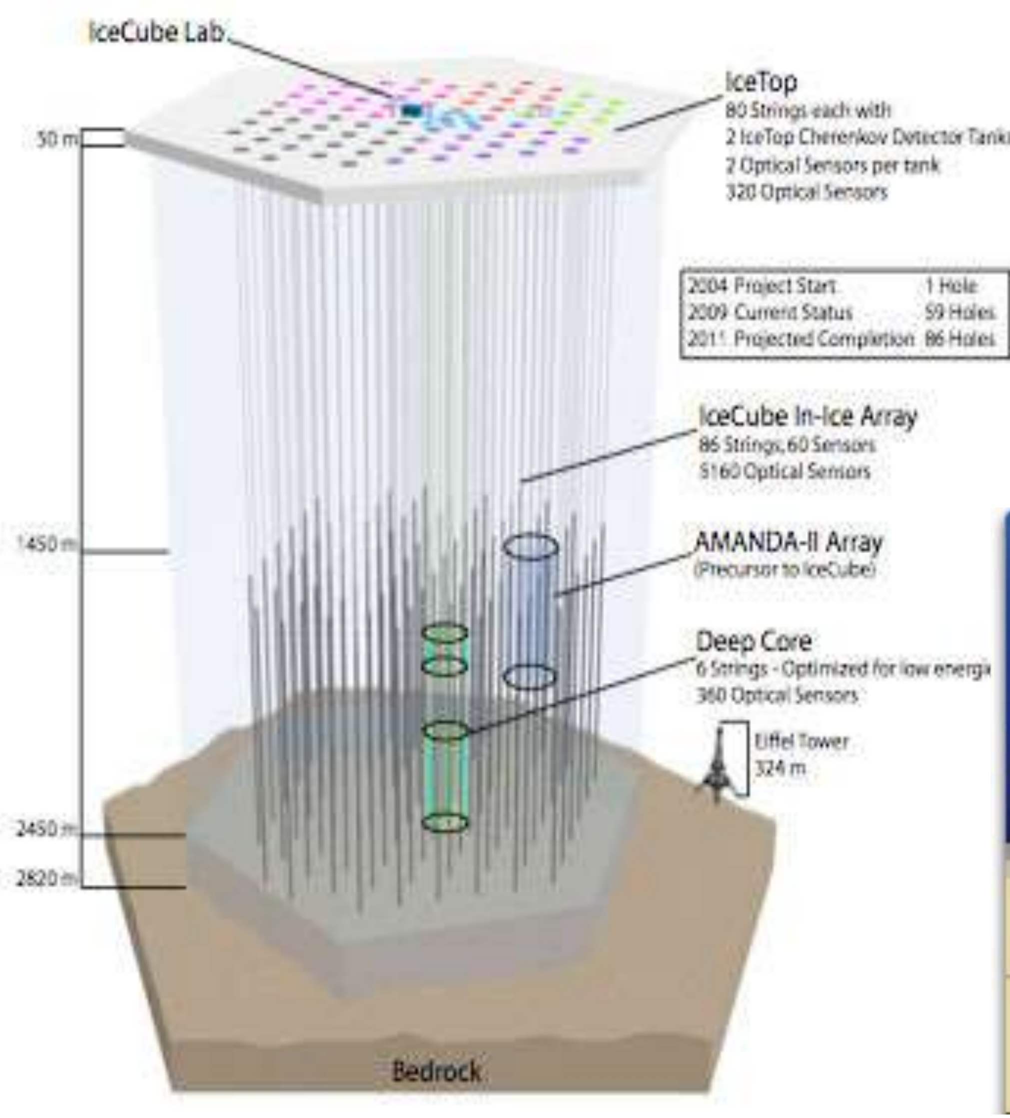

Sculptor Galaxy NGC 253


Centaurus A – starburst + AGN


Event Horizon Telescope
Image of M87

# Telescópios de Neutrinos

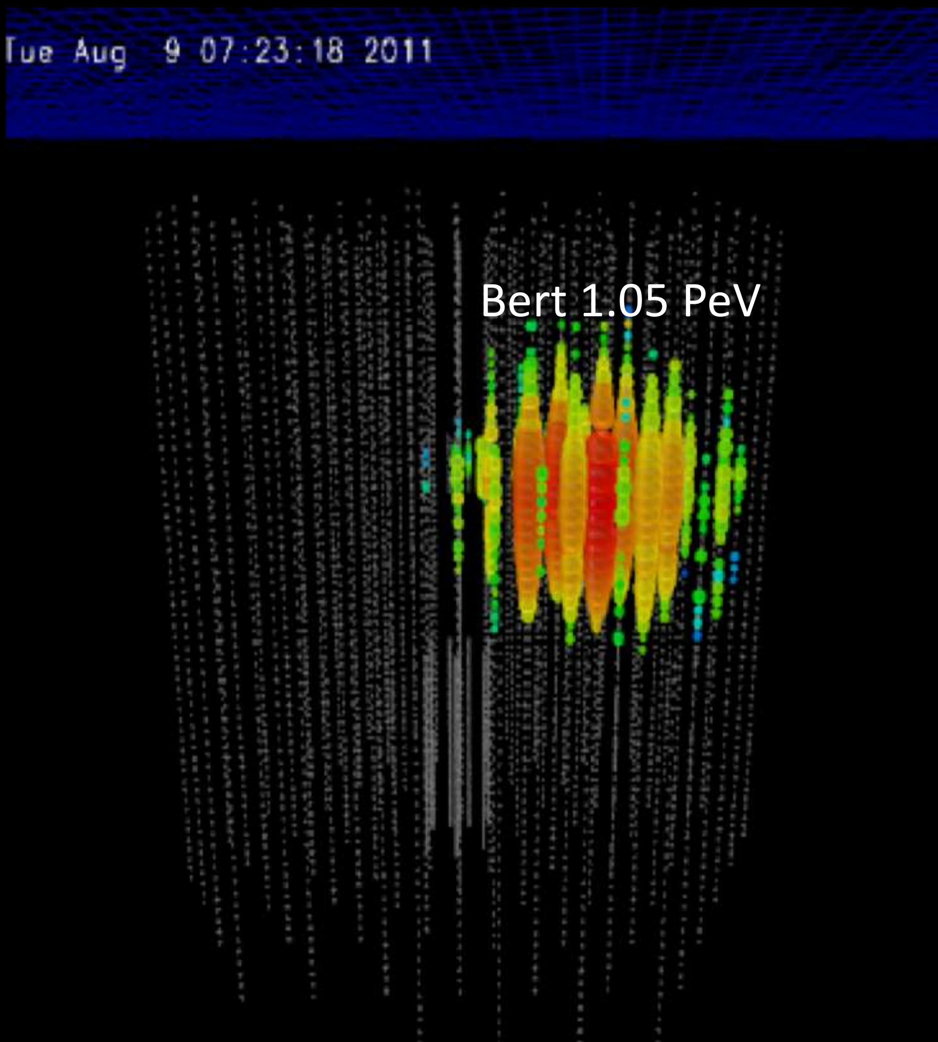
**IceCube – no Polo Sul**

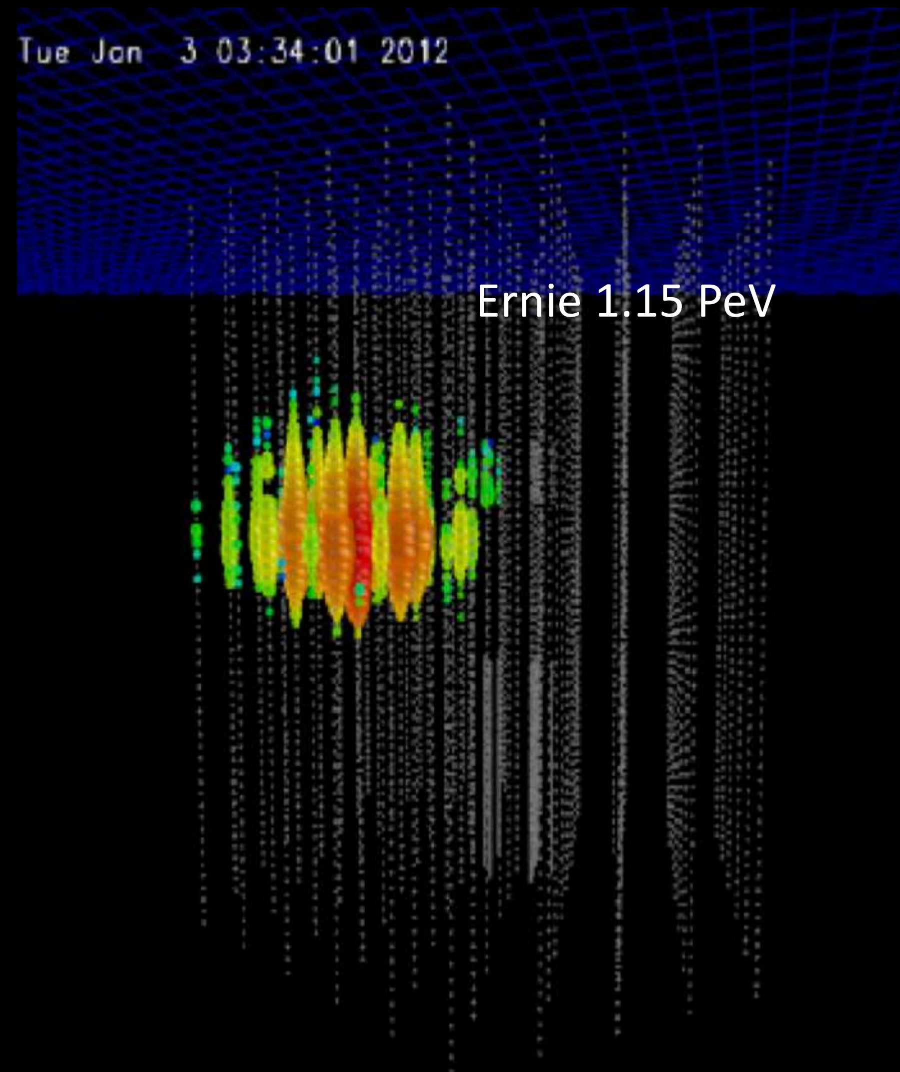



**ANITA – vôos na Antártica**

# Início da Astronomia de Neutrinos

PeV ($10^{15}$ eV)neutrinos first observed by **IceCube** (Apr'13)

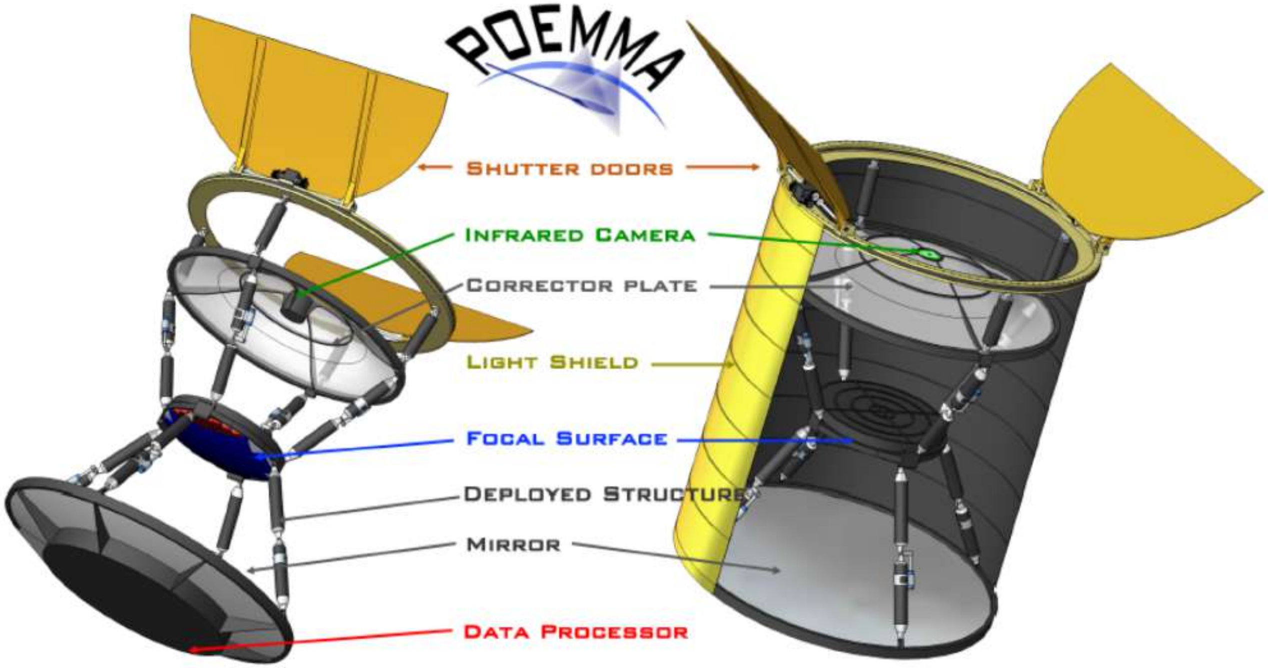


# POEMMA Design at NASA GSFC

**IDL (Instrument Design Lab) Jul 31-Aug 4, 2017**

**MDL (Mission Design Lab) Oct 30-Nov 3, 2017**



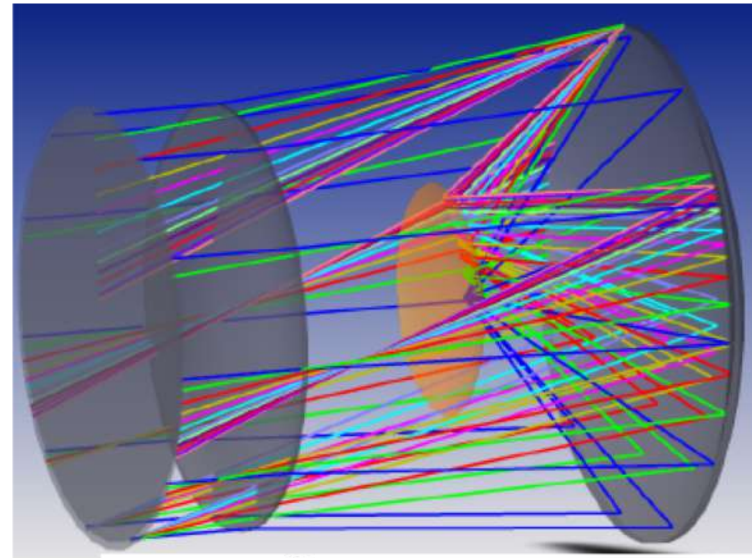
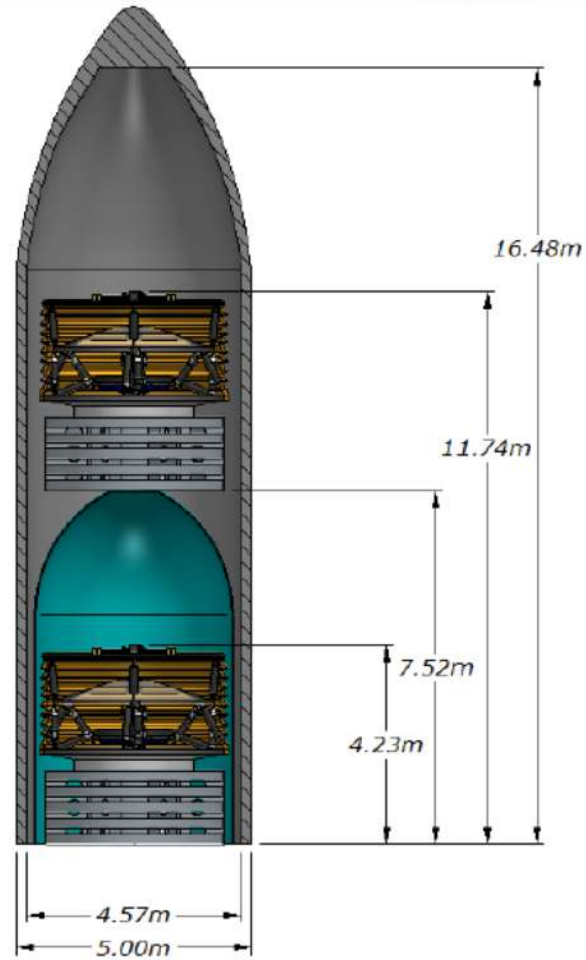
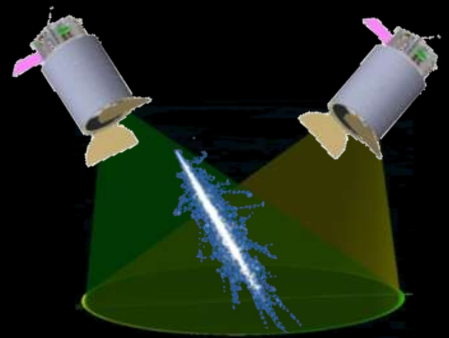



TABLE I: POEMMA Specifications:

| Photometer | Components | | Spacecraft | |
|---|---|---|---|---|
| Optics | Schmidt | 45° full FoV | Slew rate | 90° in 8 min |
| | Primary Mirror | 4 m diam. | Pointing Res. | 0.1° |
| | Corrector Lens | 3.3 m diam. | Pointing Know. | 0.01° |
| | Focal Surface | 1.6 m diam. | Clock synch. | 10 nsec |
| | Pixel Size | $3 \times 3$ mm$^2$ | Data Storage | 7 days |
| | Pixel FoV | 0.084° | Communication | S-band |
| PFC | MAPMT (1$\mu$s) | 126,720 pixels | Wet Mass | 3,450 kg |
| PCC | SiPM (20 ns) | 15,360 pixels | Total Power | 880 W |
| Photometer | (One) | | Mission | (2 Observatories) |
| | Mass | 1,550 kg | Lifetime | 3 year (5 year goal) |
| | Power | 590 W | Orbit | 525 km, 28.5° Inc |
| | Data | < 1 GB/day | Orbit Period | 95 min |
| | | | Observatory Sep. | ~25 - 1000+ km |

Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories

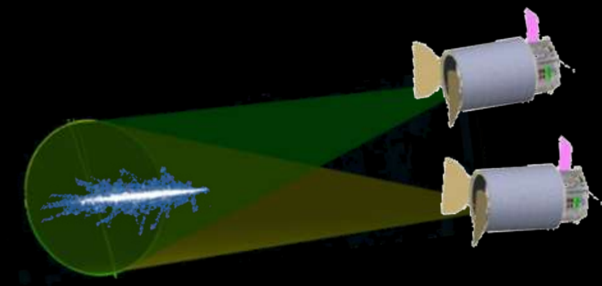




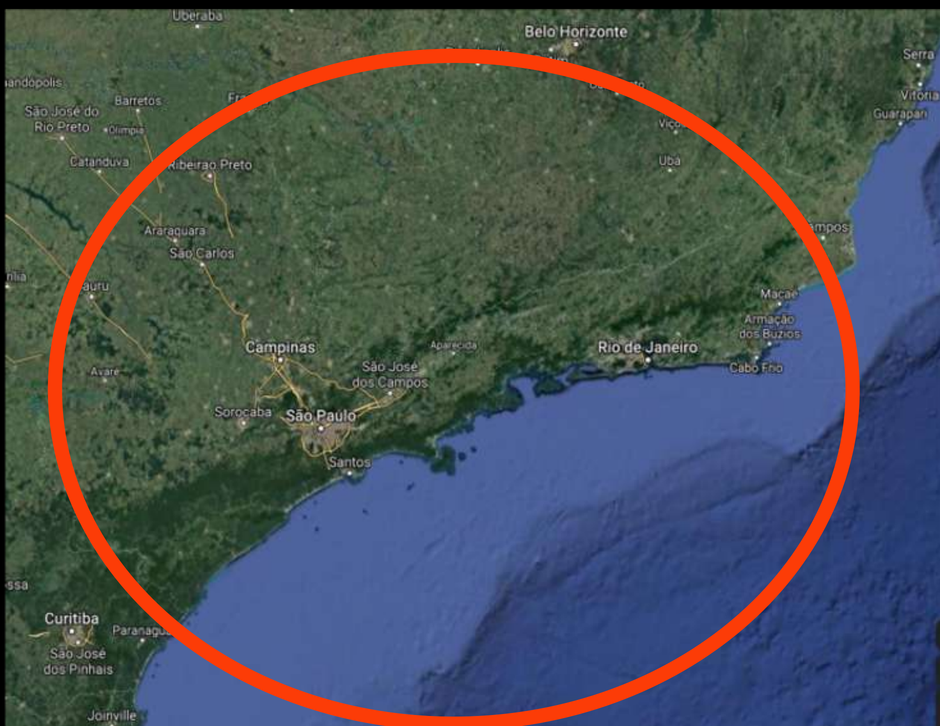
**Nadir for UHECR:**

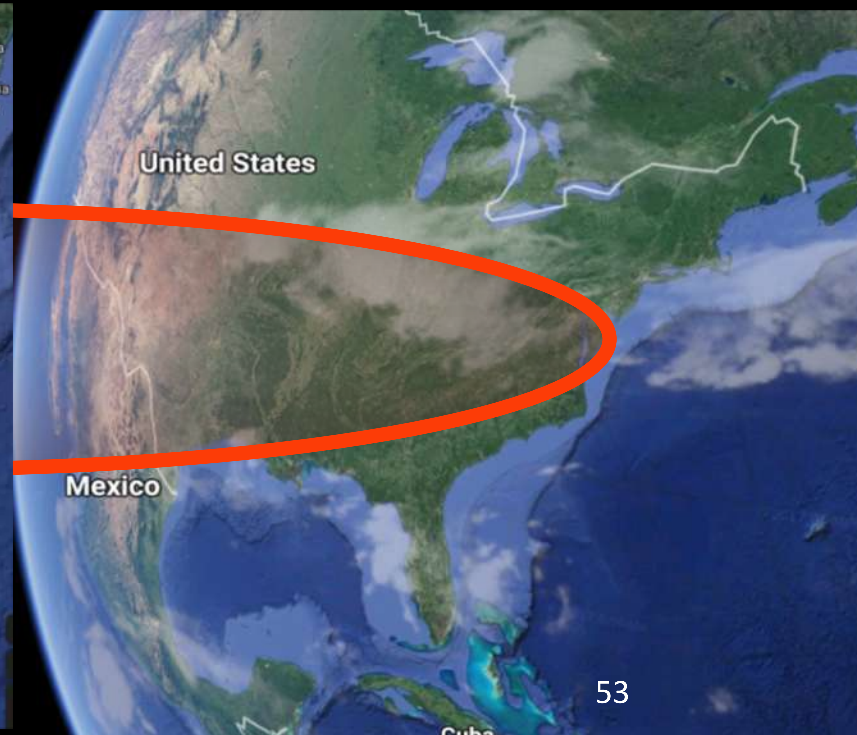
**Radius 200-400 km**

**Observing Modes**

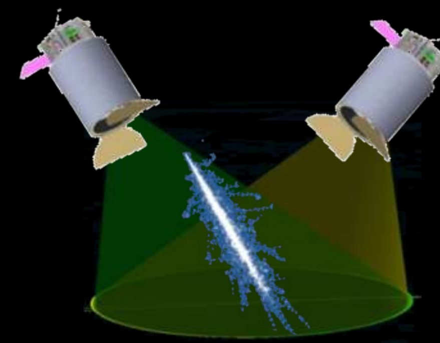


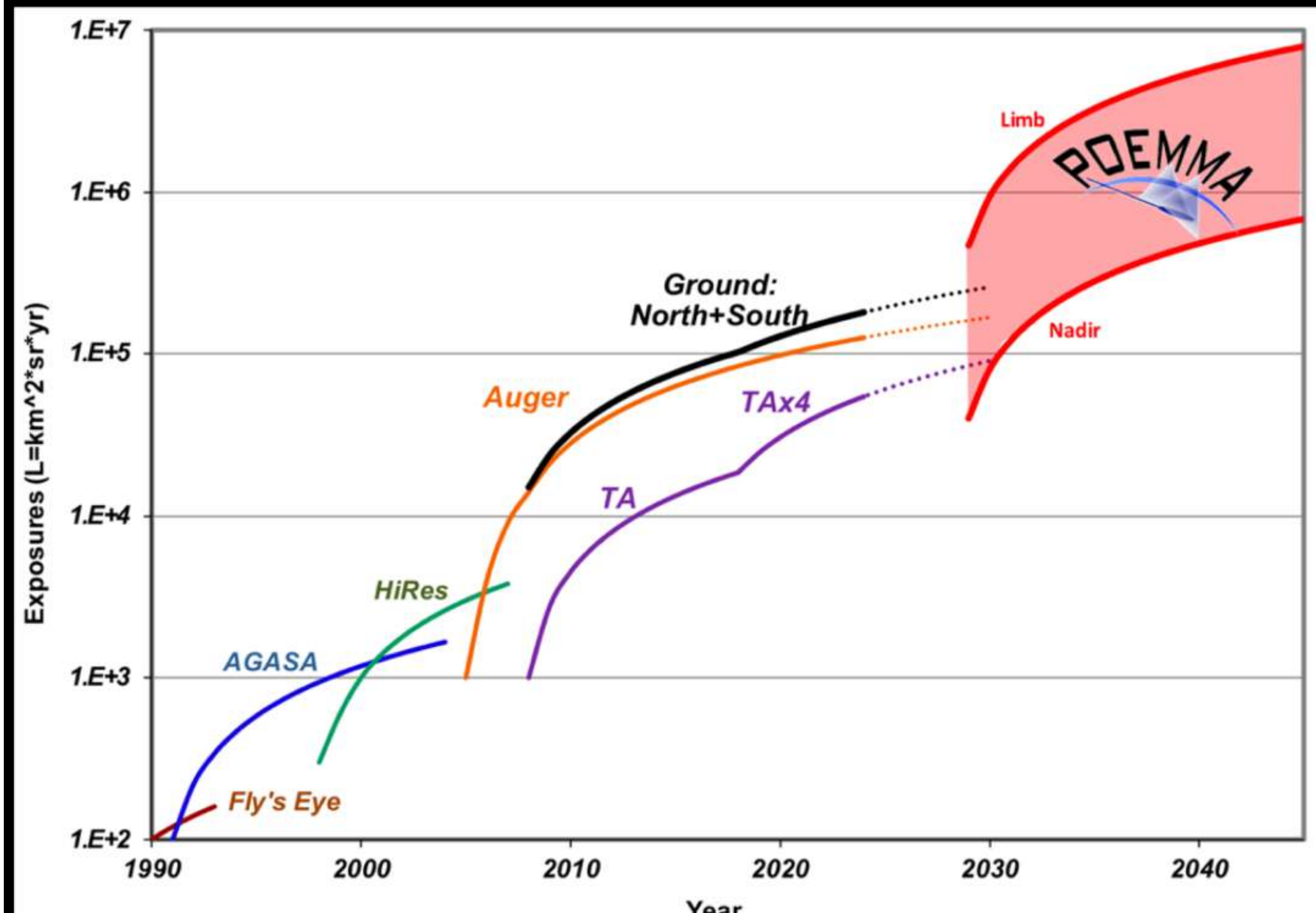
**Limb for Neutrinos & UHECRs**
**Radius 2.6-3.7 $10^3$ km**



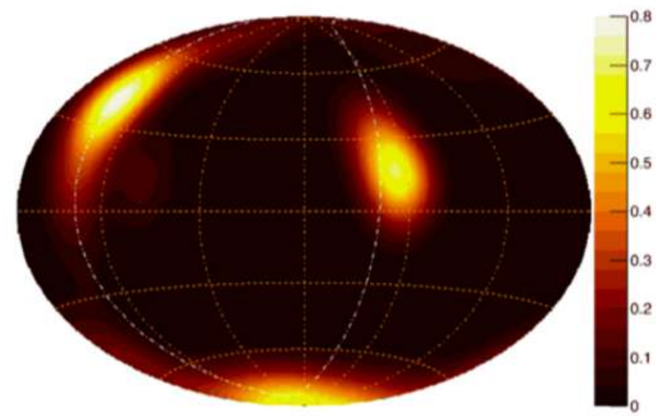



# POEMMA
# UHECR Exposure

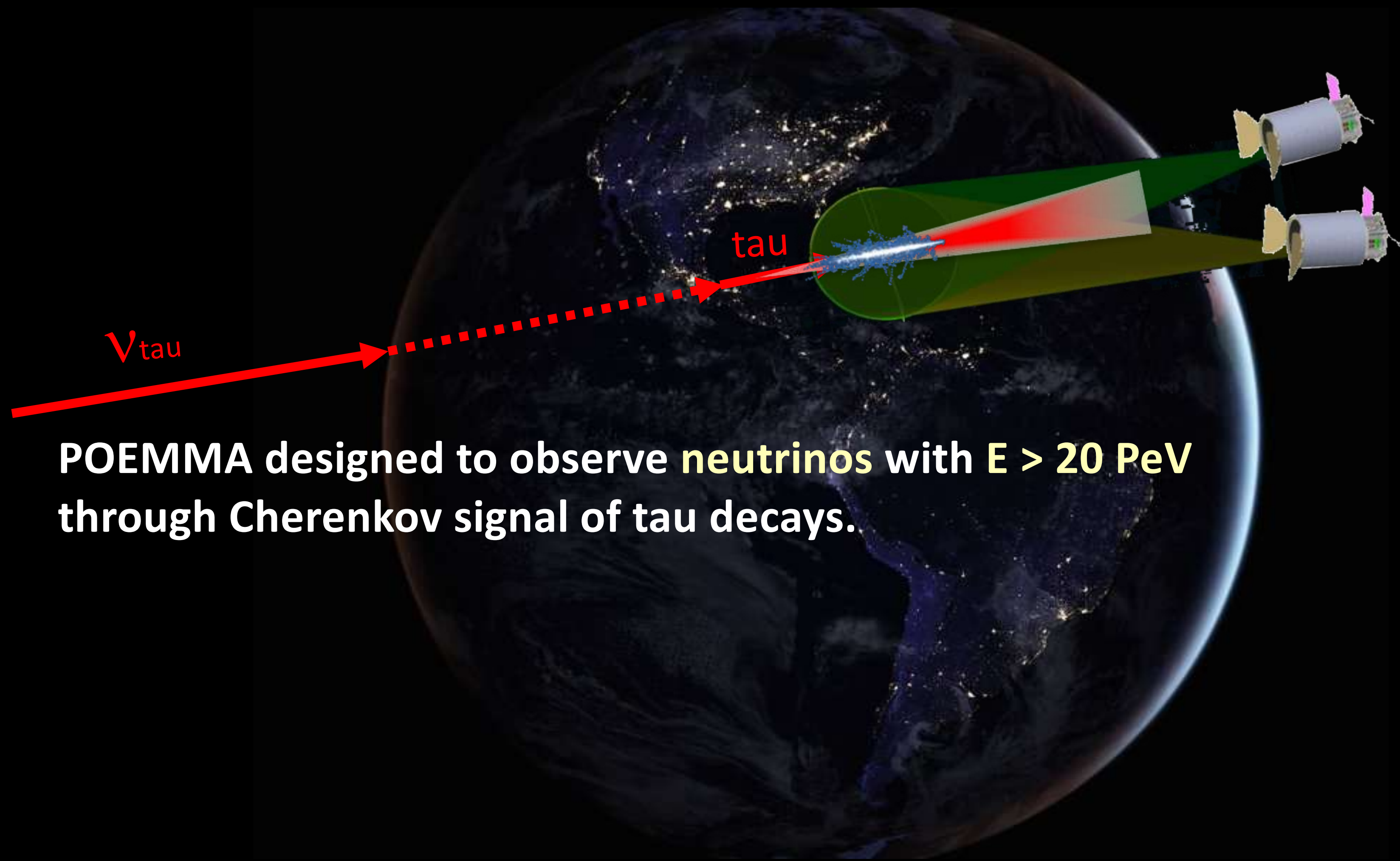





nearby Starburst Galaxies Fermi-LAT

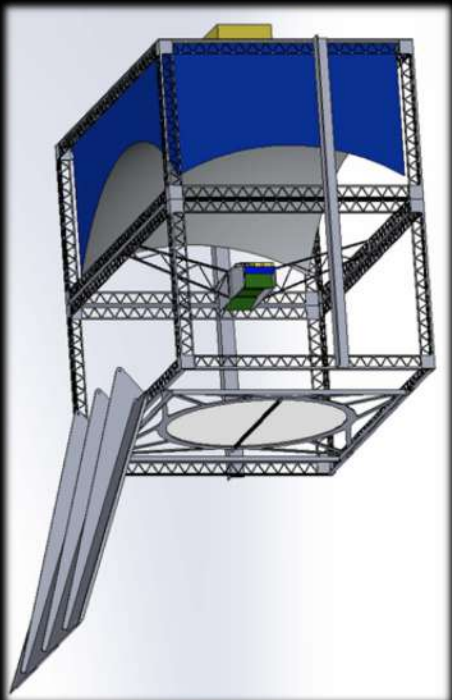


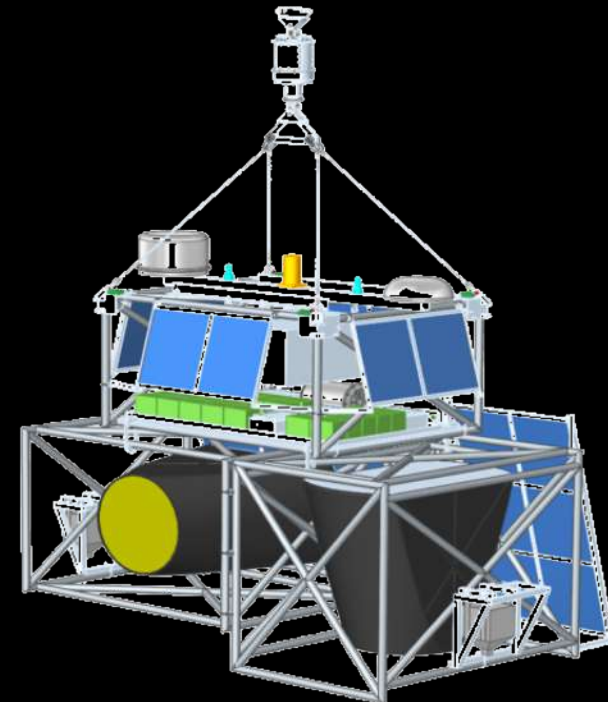
# POEMMA Neutrinos

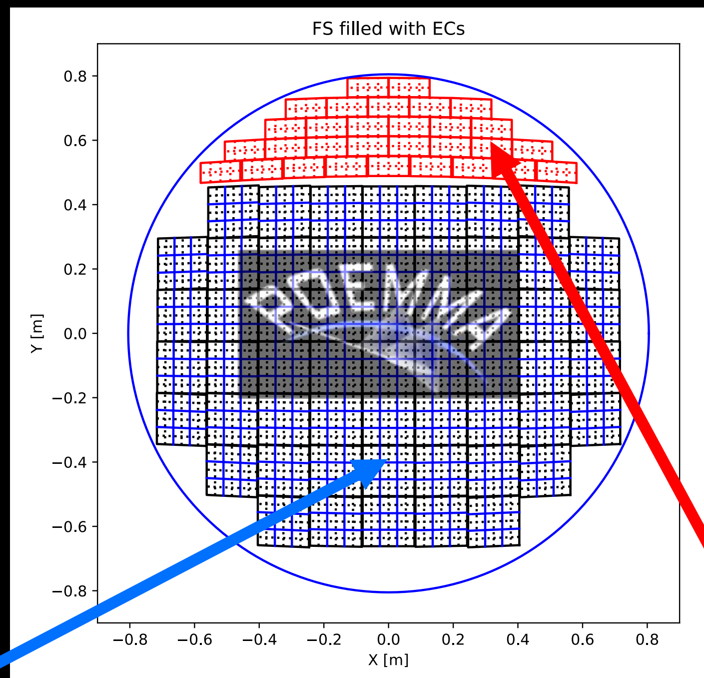


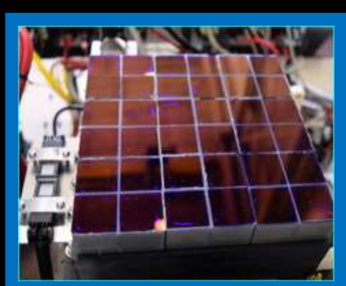

**POEMMA designed to observe neutrinos with E > 20 PeV through Cherenkov signal of tau decays.**

# EUSO-SPB2



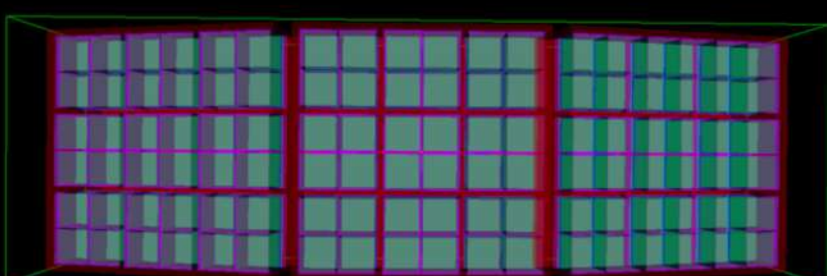


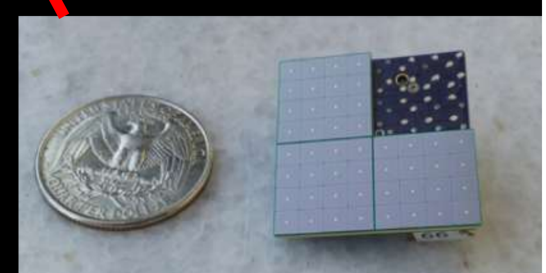


Fluorescence Camera
MAPMTs; 1/microsecond
1.000.000 fotos por segundo

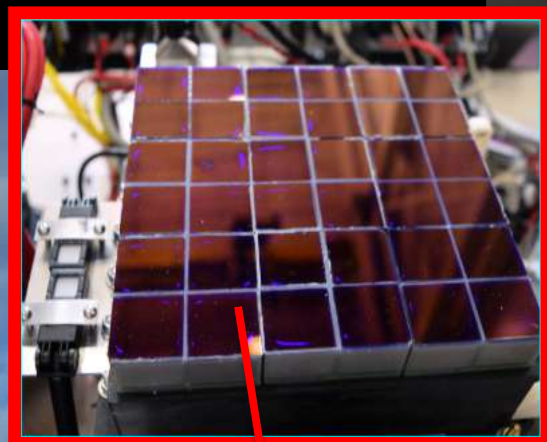
Cherenkov camera
SiPMs
1/10 nanosecos
100 Milhoes fotos/segundo

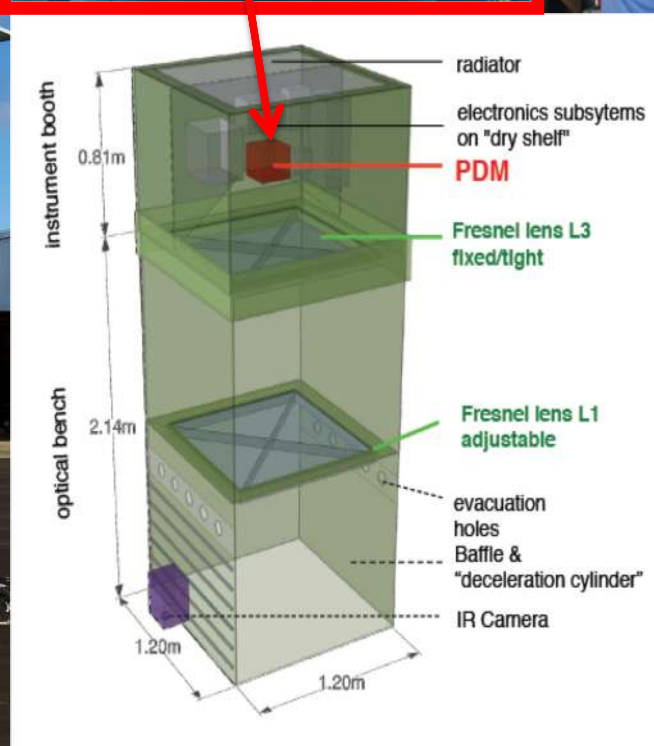




# EUSO-SPB 1

## Extreme Universe Space Observatory on a Super Pressure Balloon






Ultrafast Camera:
Photo-Detector Module (PDM)
(3x3 ECs = 36 MAPMTS ; 2,304 pixels)


EUSO-SPB
launch,
April 24,
2017
23:51 UTC

# WANAKA 2017 Campaign

## Super Pressure Balloon (SPB) EUSO mission

| 2015 | 2016 | 2017 |
| --- | --- | --- |
| NASA Engineering Flight | COSI | EUSO-SPB |

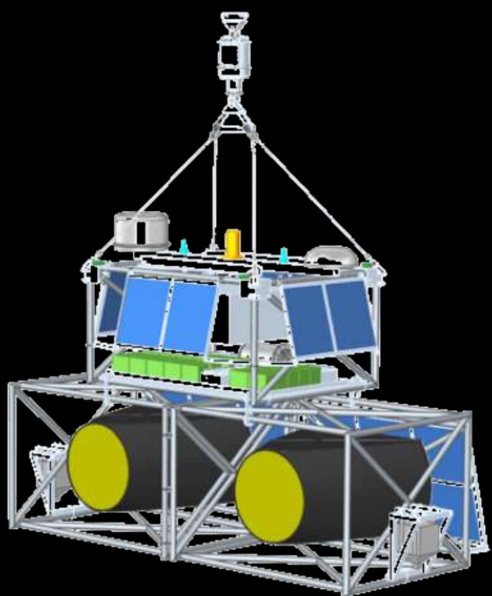
| 32 d 5 h | 46 d 20 h | 12 d 4 h |
| --- | --- | --- |

# Mini-EUSO na Estação Espacial Internacional (ISS) em 2020


https://www.youtube.com/watch?v=lXedBGVHc4o&t=62s

# Sondas Espacias de
# Partículas Cósmicas Ultra-Energéticas

EUSO-SPB2



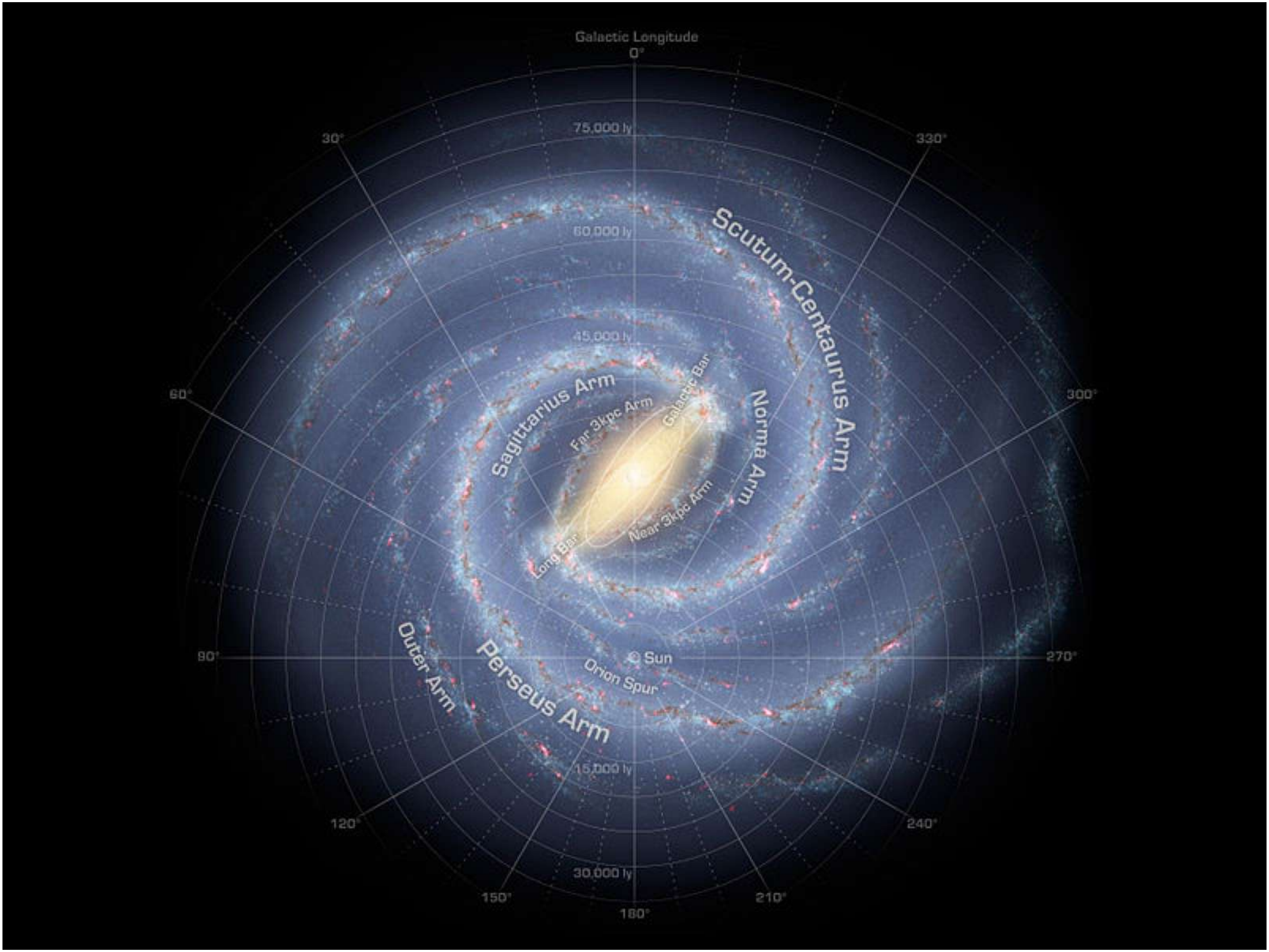

## Atmosfera Terrestre como
## Observatório de Partículas

# POEMMA

## UHECR and Neutrino Observations

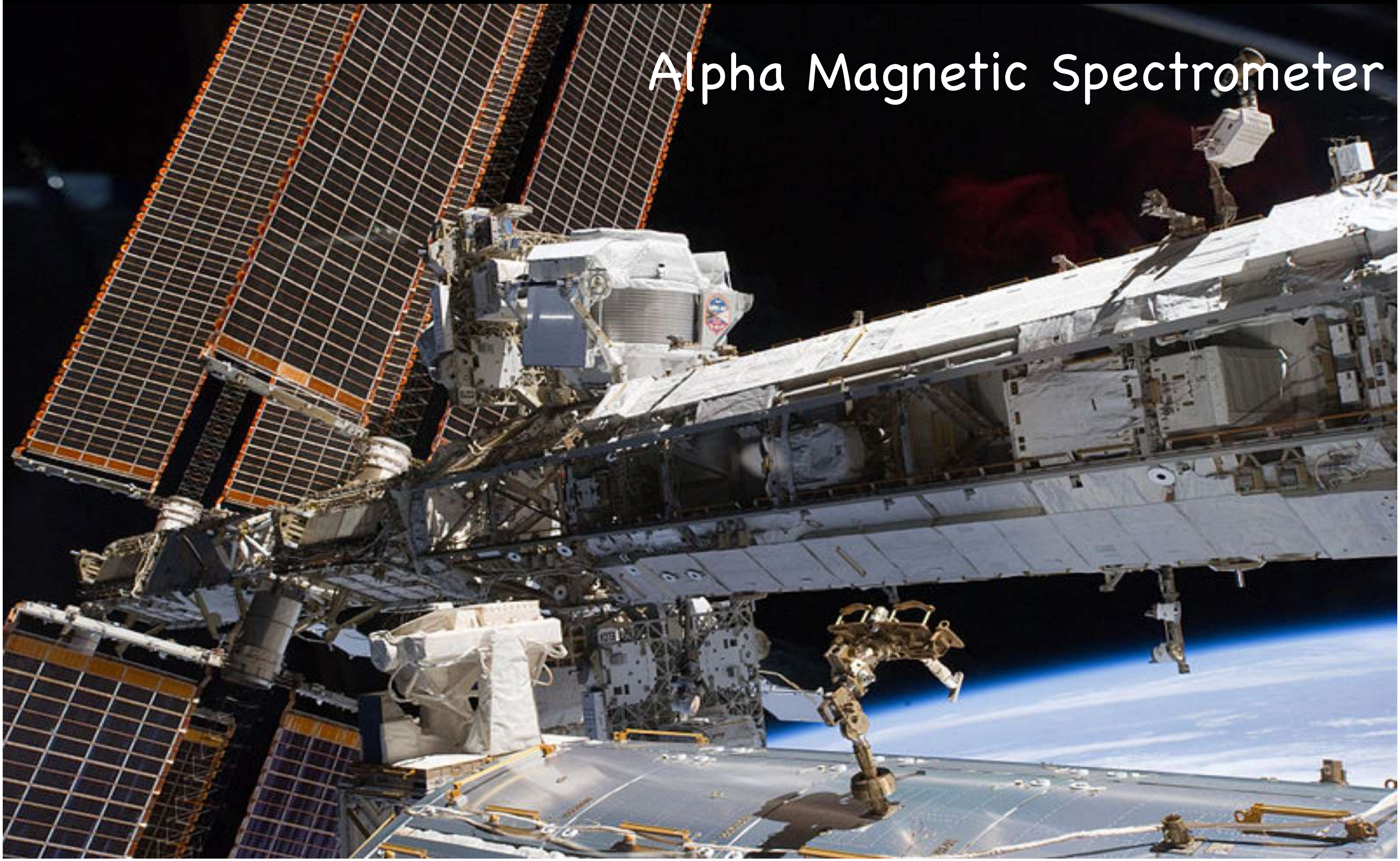
# EUSO-SPB1 Launch from Wanaka, NZ
April 24, 2017

[redacted]



Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
180°
210°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
Outer Arm
Perseus Arm
Sun
Orion Spur

# Laboratórios Espaciais

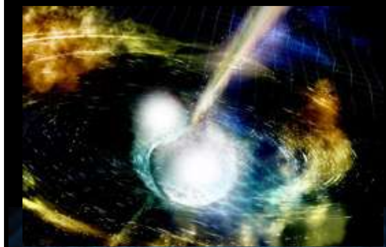


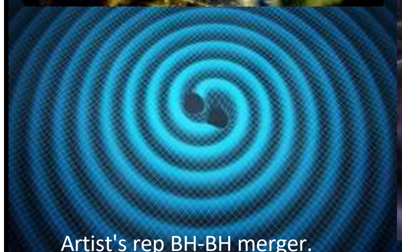
# POEMMA
# Neutrino TOO
(Targets of Opportunity)
Venters et al 2019

**Transient Events**
**few to 100 Million neutrinos/event**

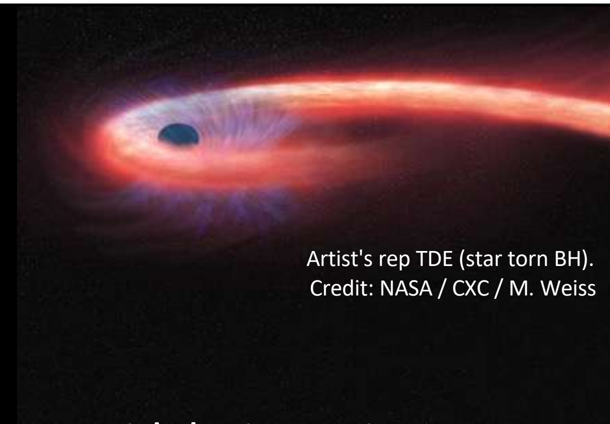
**10 neutrinos up to 120 Mpc!**

**arXiv:1906.07209**


Artist's rep NS-NS merger.
Credit: Credit: NSF/LIGO/
SSU/A. Simonnet.

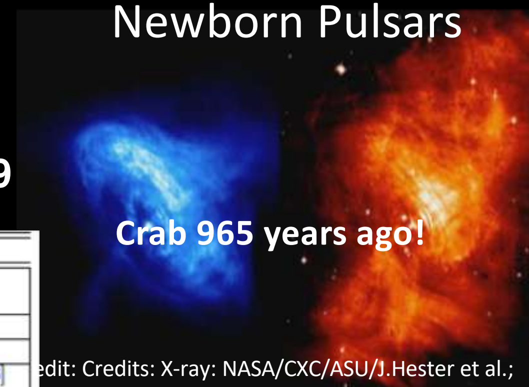

Artist's rep BH-BH merger.
Credit: NASA / JPL/
Swinburne Astron.Prods


Artist's rep WD-WD merger
Credit: Ars Technica

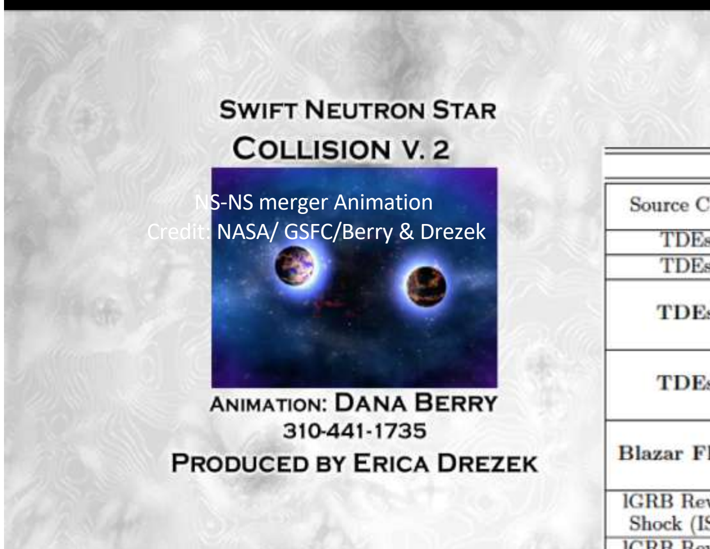

Artist's rep TDE (star torn BH).
Credit: NASA / CXC / M. Weiss

Tidal Disruption Events

Newborn Pulsars



Credit: Credits: X-ray: NASA/CXC/ASU/J.Hester et al.;
Optical: NASA/HST/ASU/J.Hester et al.



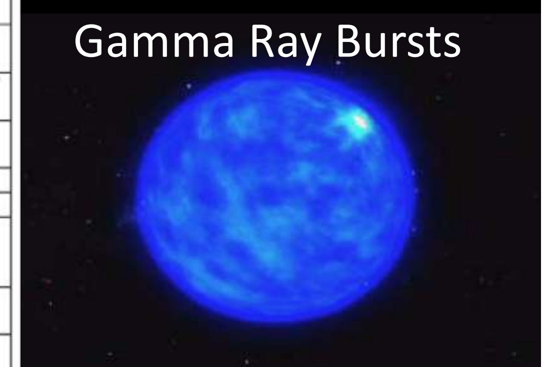
NS-NS merger Animation
Credit: NASA/ GSFC/Berry & Drezek

Binary
Coalescence

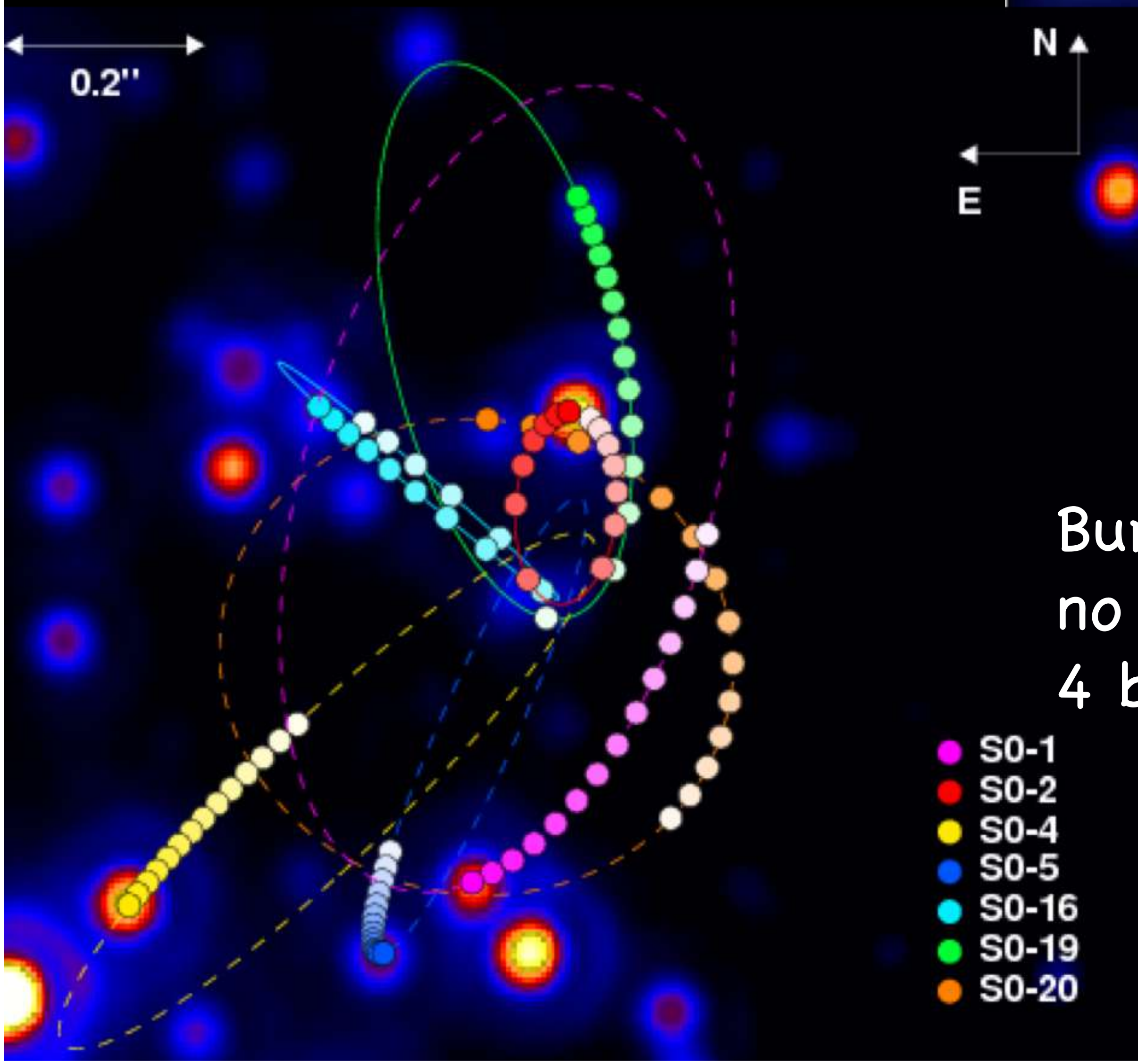
Long Bursts

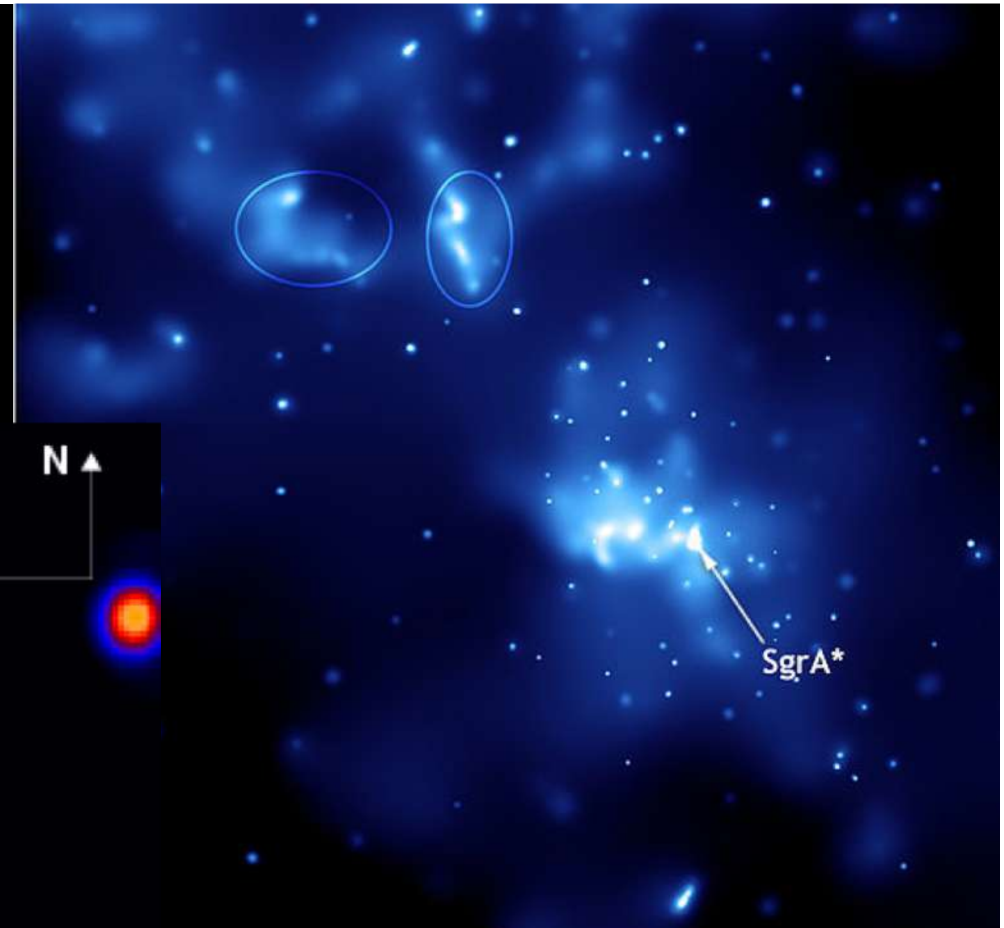
| Source Class | No. of $\nu$'s at GC | No. of $\nu$'s at 3 Mpc | Largest Distance for 1.0 $\nu$ per event | Model Reference |
|---|---|---|---|---|
| TDEs | $1.12 \times 10^5$ | 0.77 | 2.64 Mpc | Dai and Fang [17] average |
| TDEs | $5.62 \times 10^5$ | 3.88 | 5.91 Mpc | Dai and Fang [17] bright |
| **TDEs** | $\mathbf{2.23 \times 10^8}$ | $\mathbf{1.44 \times 10^3}$ | **115.20 Mpc** | **Lunardini and Winter [18] $M_{\mathrm{SMBH}} = 5 \times 10^6 M_\odot$ Lumi Scaling Case** |
| **TDEs** | **NA*** | $\mathbf{1.07 \times 10^3}$ | **100.03 Mpc** | **Lunardini and Winter [18] $M_{\mathrm{SMBH}} = 1 \times 10^5 M_\odot$ Strong Scaling Case** |
| **Blazar Flares** | **NA*** | $\mathbf{1.91 \times 10^2}$ | **42.96 Mpc** | **RFGBW [19] – FSRQ proton-dominated advective escape model** |
| lGRB Reverse Shock (ISM) | $9.88 \times 10^4$ | 0.69 | 2.49 Mpc | Murase [15] |
| lGRB Reverse Shock (wind) | $2.05 \times 10^7$ | 143.75 | 37.36 Mpc | Murase [15] |
| BH-BH merger | $6.94 \times 10^6$ | 47.84 | 20.75 Mpc | Kotera and Silk [20] – $t_{\mathrm{dur}} \sim 10^4$ s |
| **BH-BH merger** | $\mathbf{3.48 \times 10^9}$ | $\mathbf{2.4 \times 10^4}$ | **477.8 Mpc** | **Kotera and Silk [20] – $t_{\mathrm{dur}} \sim 10^{6.7}$ s** |
| **NS-NS merger** | $\mathbf{3.58 \times 10^6}$ | **24.75** | **12.76 Mpc** | **Fang and Metzger [21]** |
| WD-WD merger | 20.06 | 0 | 33.46 kpc | XMMD [22] |
| Newly-born Crab-like pulsars (p) | $1.56 \times 10^2$ | $1.07 \times 10^{-3}$ | 98.27 kpc | Fang [23] |
| Newly-born magnetars (p) | $2.1 \times 10^4$ | 0.13 | 1.1 Mpc | Fang [23] |
| Newly-born magnetars (Fe) | $4.07 \times 10^4$ | 0.26 | 1.53 Mpc | Fang [23] |

Blazar Flares
Gamma Ray Bursts



# Sargitarius A*




Buraco Negro Supermassivo
no centro da nossa Galaxia
4 bilhões de Massas Solares