# Lecture 2 - Jan 29 2013

# The Next 2-3 Lectures

- Today we are continuing the intro to the field and will discuss a bit of the history of the field, (see heasarc.gsfc.nasa.gov/docs/heasarc/headates/heahistory.html)
- atmospheric transmission (Melia's book sec 1.3) , the objects of high energy astrophysics (e.g. neutron stars, black holes, clusters of galaxies ) from a very broad perspective ( Rosswog and Bruggen ch 5.1 and Melia sec

Physical Processes-**Melia ch 5 and Rosswog and Bruggen ch 3**

**Black body radiation**
**Synchrotron Radiation**
**Compton Scattering**
**Line emission and absorption**
**Absorption (not in the recommended texts)**

Please read Melia chapter 1 for a broad introduction to the field

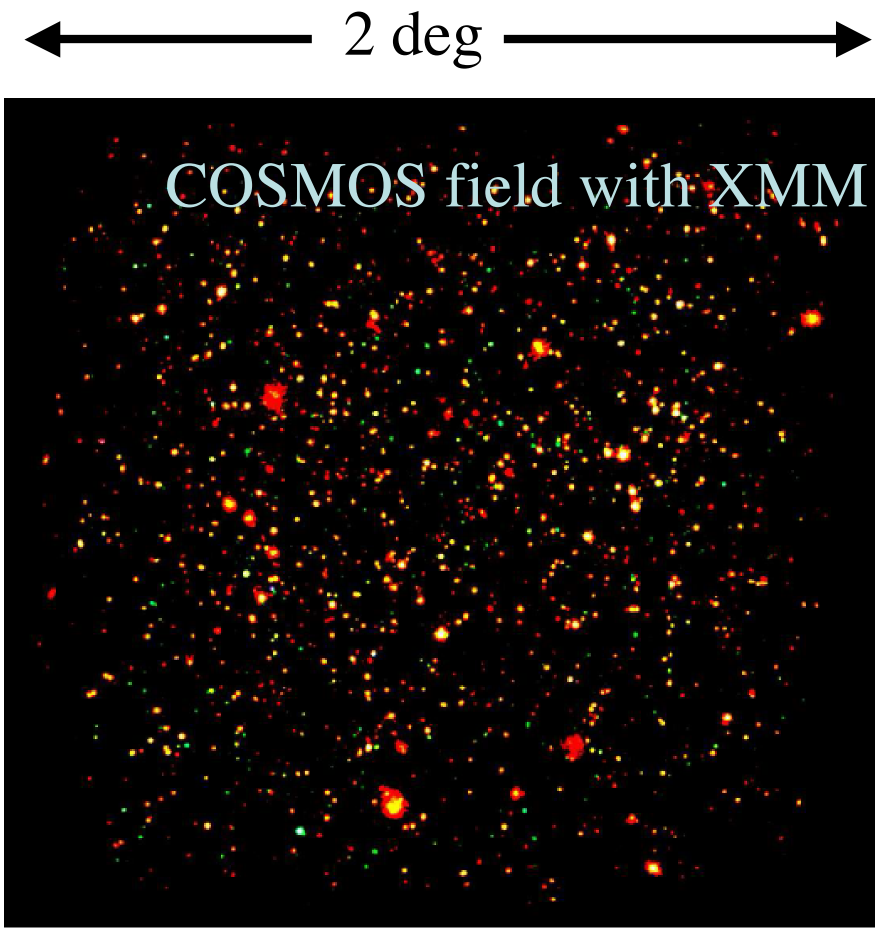
A very nice teaching resource is Joern Wilm's website http://pulsar.sternwarte.uni-erlangen.de/wilms/teach/index.html

# X-ray Astronomy

- From its start in 1962 sensitivity has increased by $10^7$

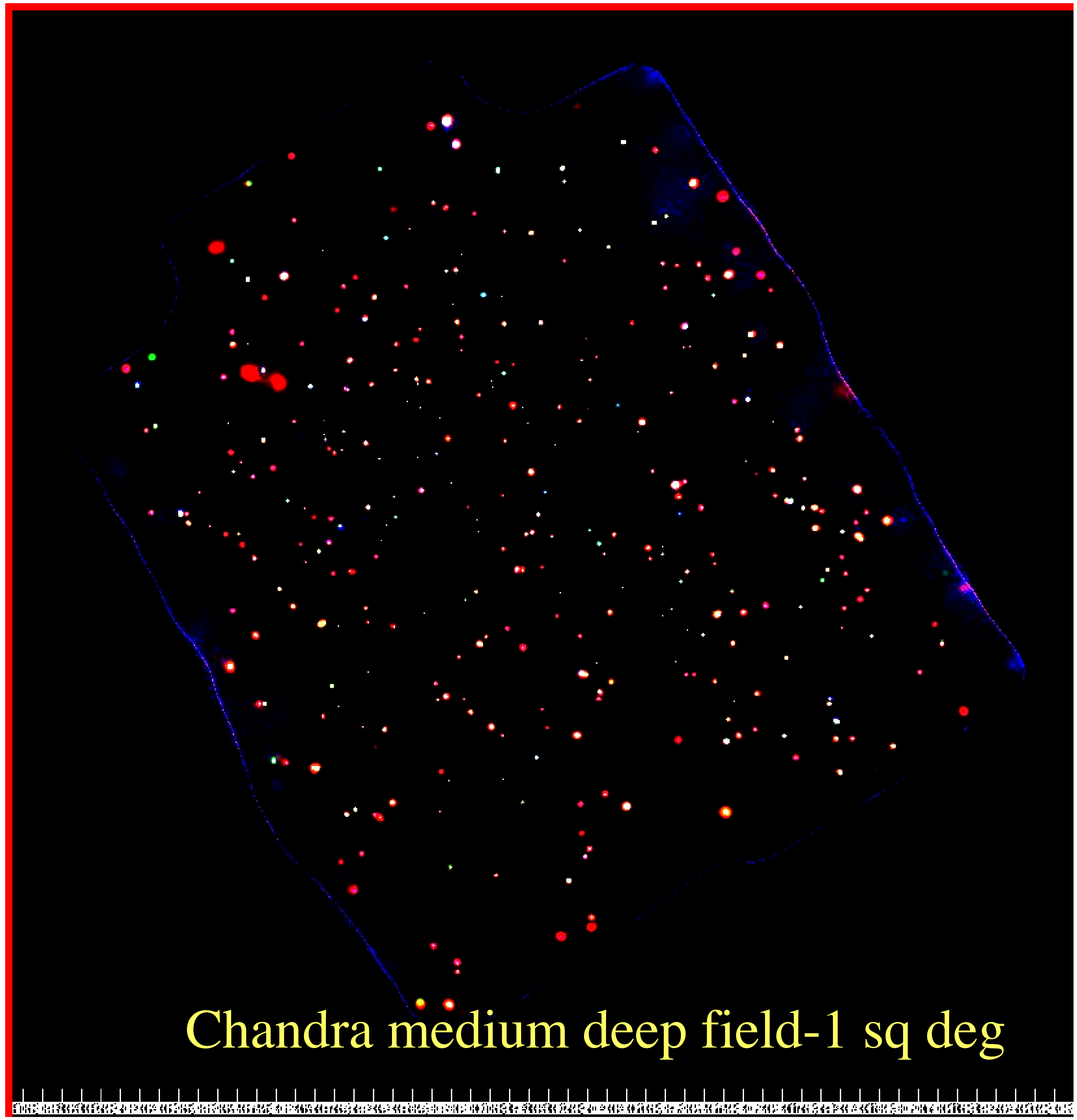
(~$5x10^{-17}$ $ergscm^2sec$ in the 0.5-2 keV band)

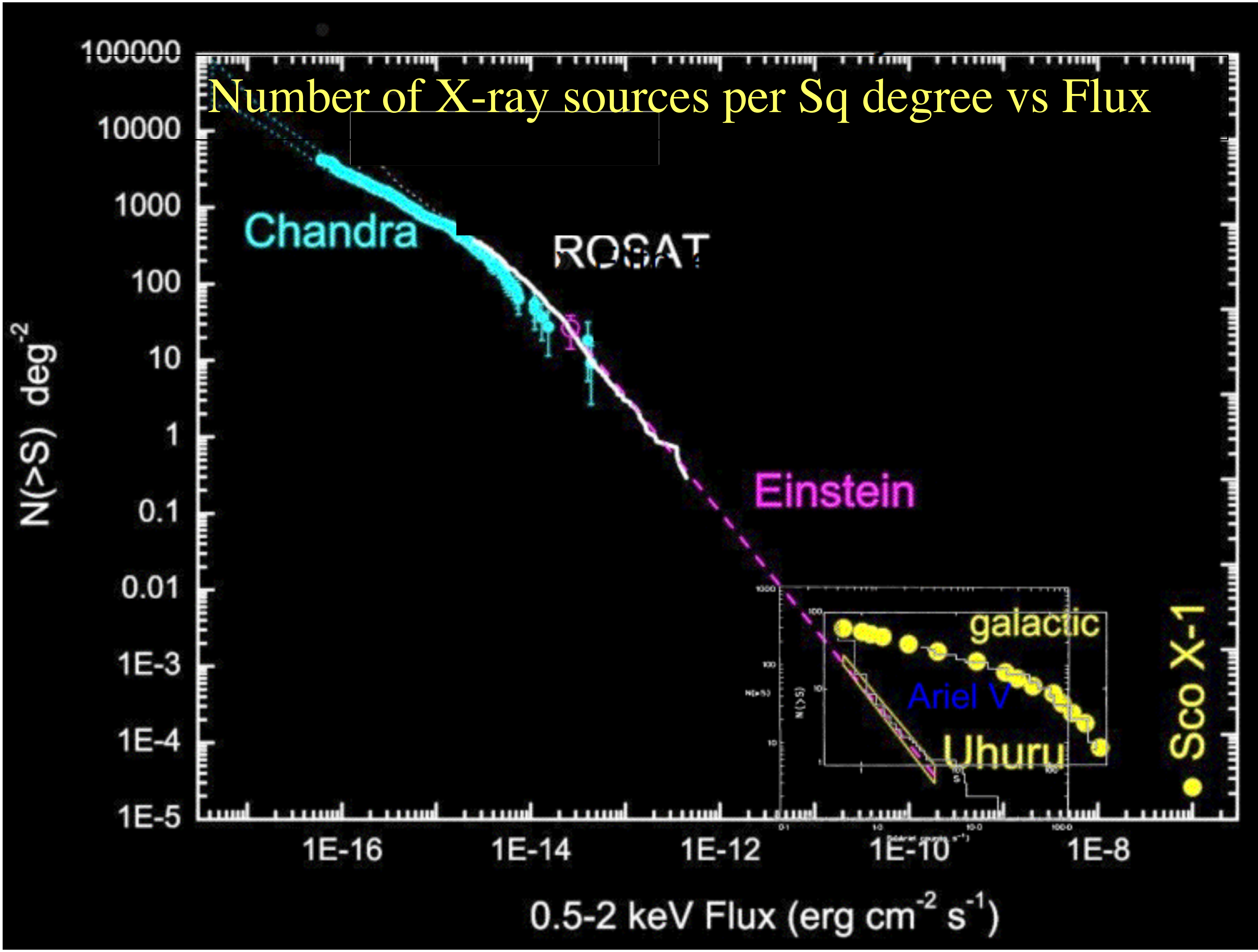
  - angular resolution by $10^5$ (0.5")
  - spectral resolution by $10^4$ ($E/\Delta E$~1000)
- There are now >300,000 known x-ray sources (in 1977~1000 sources, in 1969~25)
- At the faintest levels probed by Chandra there are >2000 x-ray sources/$deg^2$ (e.g. $10^8$ all sky)
- Despite these spectacular advances x-ray astronomy is photon limited (the largest x-ray telescopes have collecting areas of 3000 $cm^2$ compared to $10^6$ $cm^2$ for the largest optical telescopes- cosmology with a 12" telescope !)




# Nature of Faint X-ray Sources

- Most of the faint x-ray sources are active galaxies (AGN, quasars, Seyfert galaxies)
- At a median redshift of 0.7 ($D_L$=4260 Mpc = $1.312 \times 10^{28}$ cm)
- median x-ray luminosity $10^{43.5}$ergs/sec =$8 \times 10^{9}$ $L_{sun}$
- The red 'blobs' are clusters of



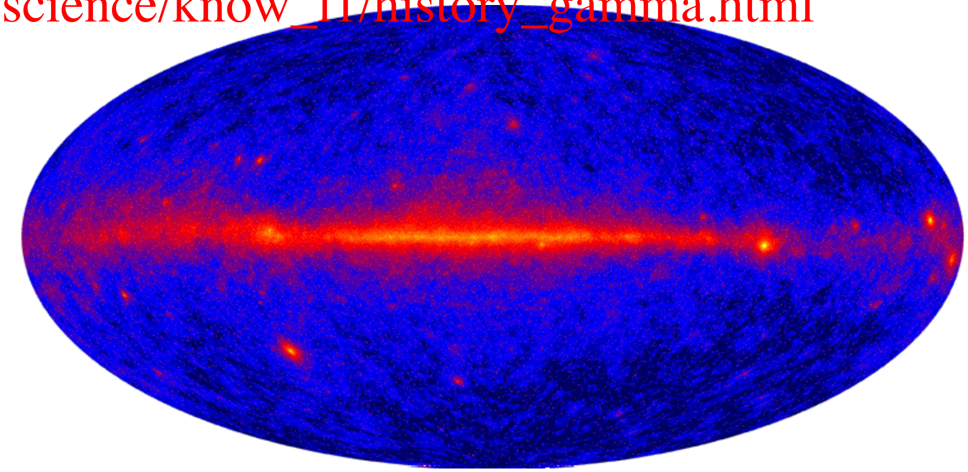


Number of X-ray sources per Sq degree vs Flux
N(>S) deg-2
0.5-2 keV Flux (erg cm-2 s-1)
Chandra
ROSAT
Einstein
galactic
Ariel V
Uhuru
Sco X-1

High Energy Astrophysics is 'New'- see
heasarc.gsfc.nasa.gov/docs/heasarc/headates/heahistory.html
http://imagine.gsfc.nasa.gov/docs/science/know_l1/history_gamma.html

γ-Rays gamma rays are emitted by the nucleus or from other particle decays or annihilation events.

- 1958 a burst of gamma rays from a solar flare
- 1962 diffuse γ-ray background at ( 0.1 to 3 MeV) - Ranger 3, which flew by the moon.
- 1967 The 1st cosmic γ-Ray Burst (GRB)* via the Vela 4a,b satellites. This discovery was not made public for several years due to military classification.
- 1970 γ-ray emission from the Galactic Center
- 1971 pulsed high-energy γ-ray emission from the Crab Pulsar above 50 MeV



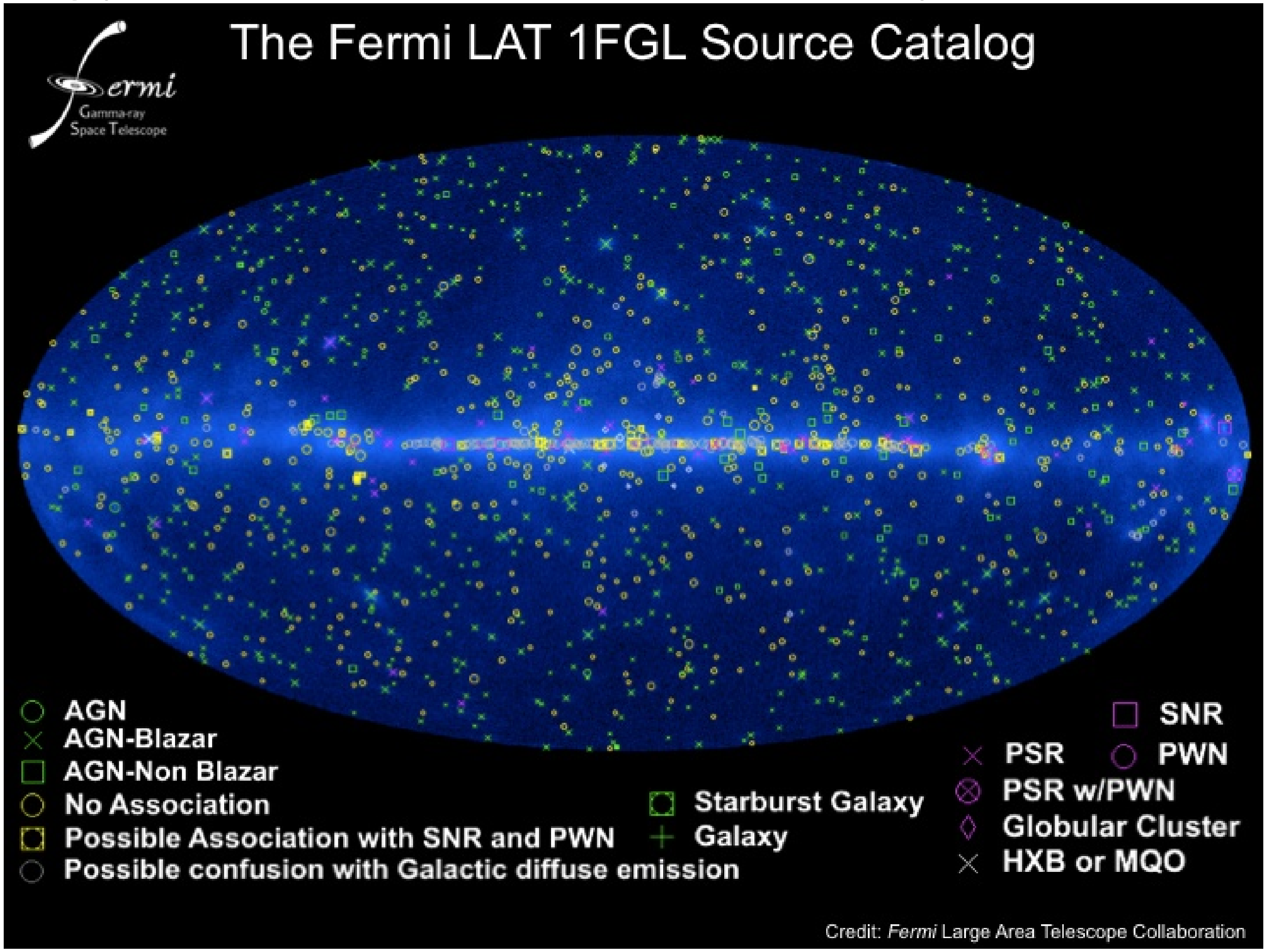
γ-Ray Sky with Fermi
Detected >1000 sources in first year of operation (most are blazars and pulsars)

Other γ-Ray sources include
Supernova remnants
Unusual binary stars

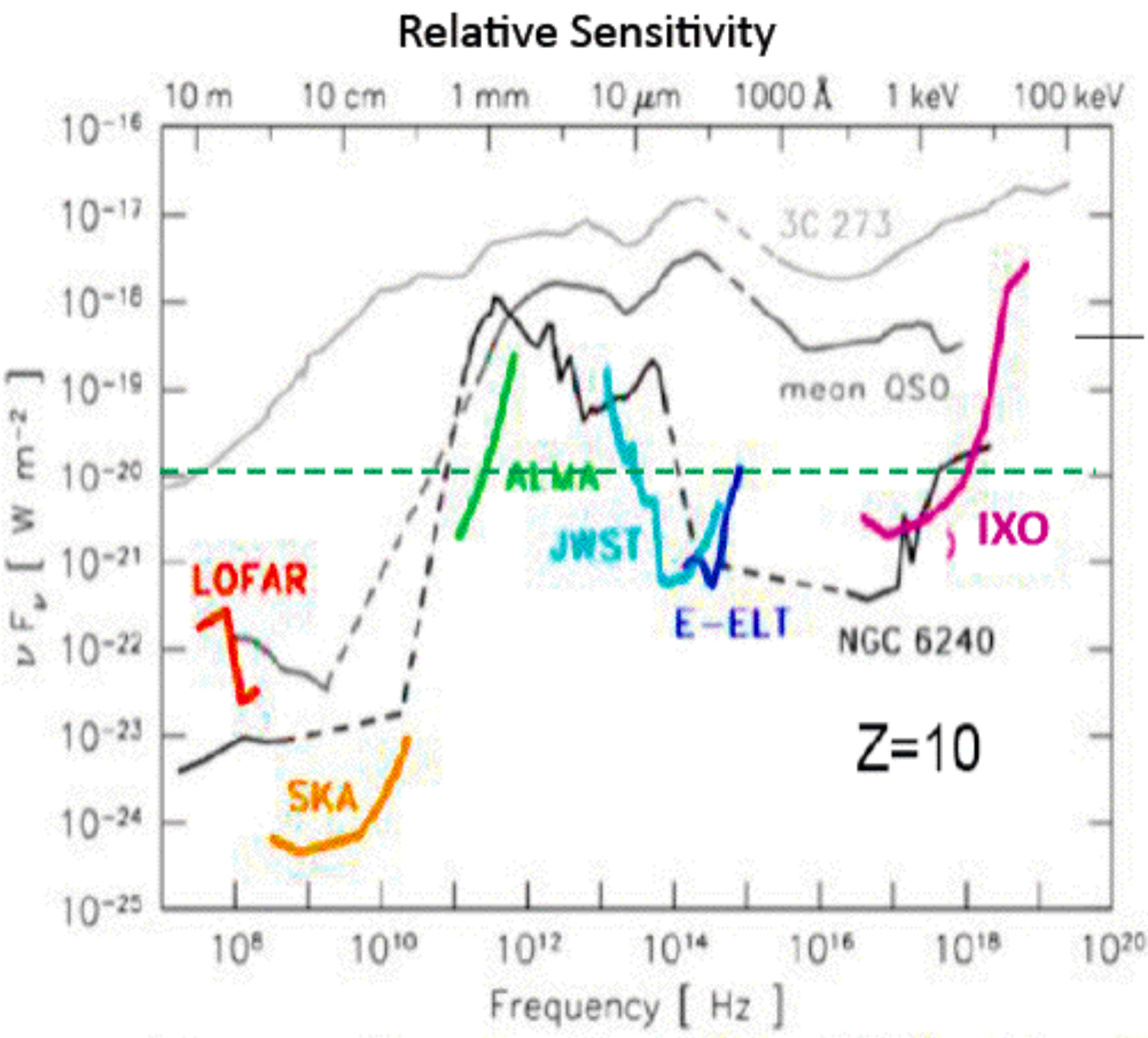
***Notice the introduction of vast amounts of jargon***

# Fermi High Energy (>100 MeV) Gamma-ray Sources

- Many classes
- Blazars
- Pulsars
- Supernova remnants
- Starburst galaxies
- Binaries



# Relative Sensitivity Astronomical Observatories



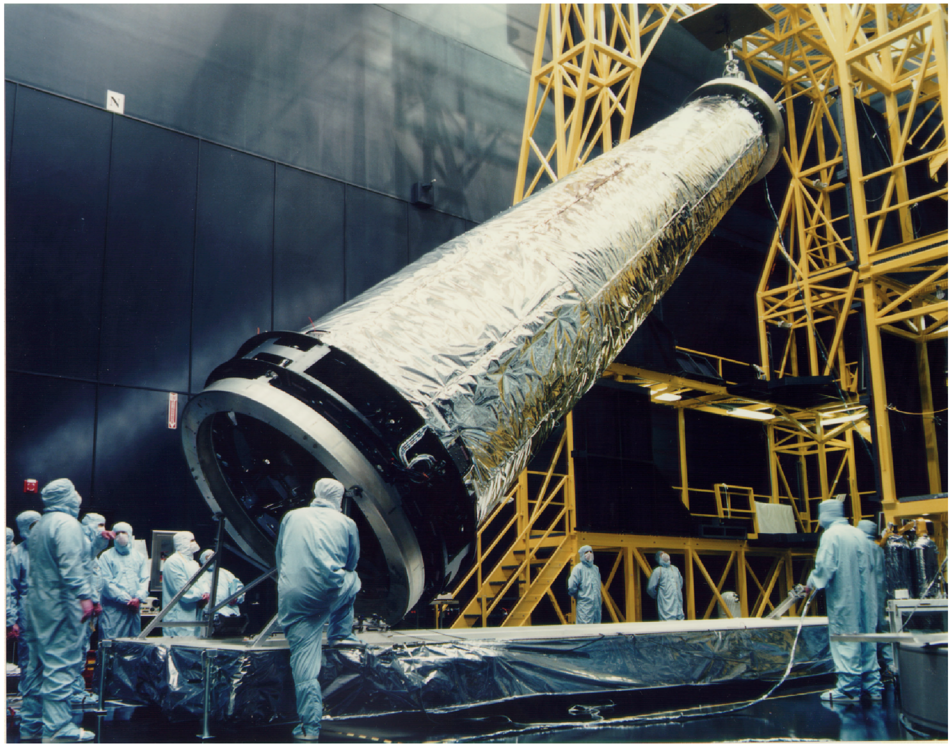

- For multi-wavelength study of the faintest known **x-ray** sources one needs the <u>largest</u> optical and IR telescopes

# Space Based High Energy

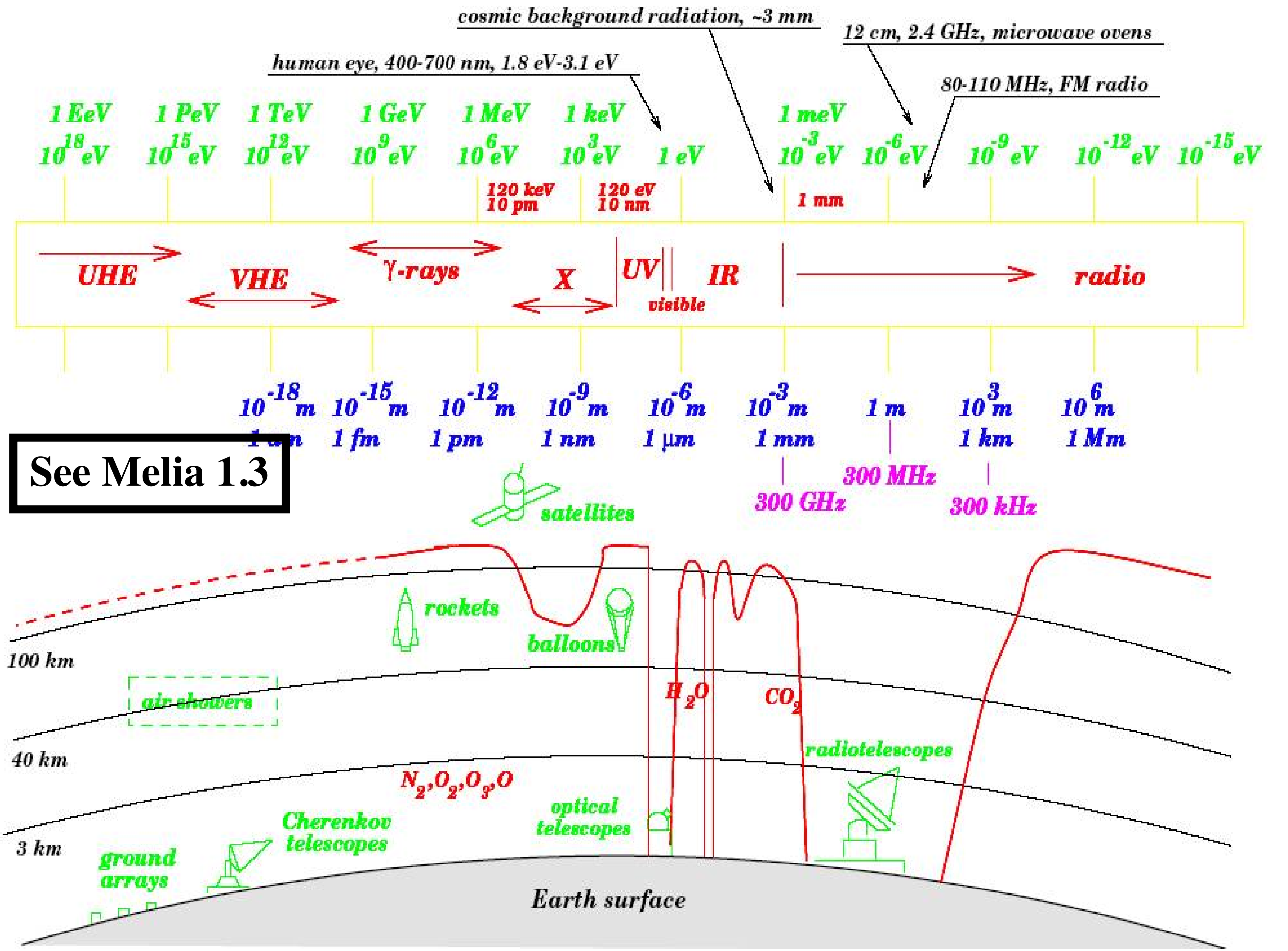
- The atmosphere is opaque (at ground level) to all wavelengths from γ-rays (TeVs) to ultra-violet($10^{13}$-10 eV;1eV=$1.6\times10^{-12}$ ergs/$cm^2$/sec)**
- Thus to detect 'high energy' photons need to go to space*
- Space missions are expensive and take a lot of time

*its possible to detect TeV photons indirectly from the ground

** I will use CGS rather than MKS- it is traditional in astrophysics- I will also often use eV, keV etc for energy and flux in photons/$cm^2$/sec/energy bin

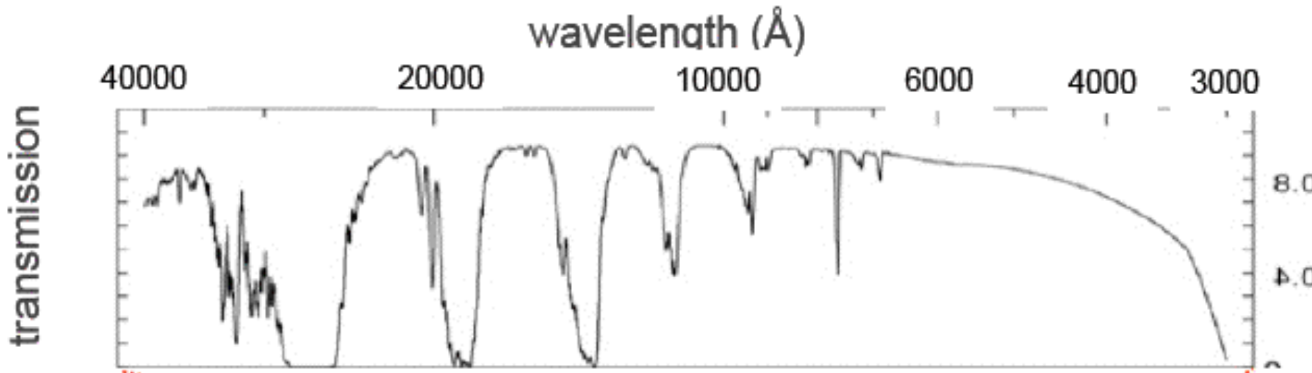


Chandra Optical Bench


cosmic background radiation, ~3 mm
12 cm, 2.4 GHz, microwave ovens
human eye, 400-700 nm, 1.8 eV-3.1 eV
80-110 MHz, FM radio
1 EeV
1 PeV
1 TeV
1 GeV
1 MeV
1 keV
1 meV
$10^{18}$ eV
$10^{15}$ eV
$10^{12}$ eV
$10^{9}$ eV
$10^{6}$ eV
$10^{3}$ eV
1 eV
$10^{-3}$ eV
$10^{-6}$ eV
$10^{-9}$ eV
$10^{-12}$ eV
$10^{-15}$ eV
120 keV 10 pm
120 eV 10 nm
1 mm
UHE
VHE
γ-rays
X
UV
IR
visible
radio
$10^{-18}$ m
$10^{-15}$ m
$10^{-12}$ m
$10^{-9}$ m
$10^{-6}$ m
$10^{-3}$ m
1 m
$10^{3}$ m
$10^{6}$ m
1 am
1 fm
1 pm
1 nm
1 μm
1 mm
1 km
1 Mm
300 MHz
300 GHz
300 kHz
satellites
rockets
balloons
100 km
air showers
$H_2O$
$CO_2$
40 km
radiotelescopes
$N_2$,$O_2$,$O_3$,O
optical telescopes
Cherenkov telescopes
3 km
ground arrays
Earth surface

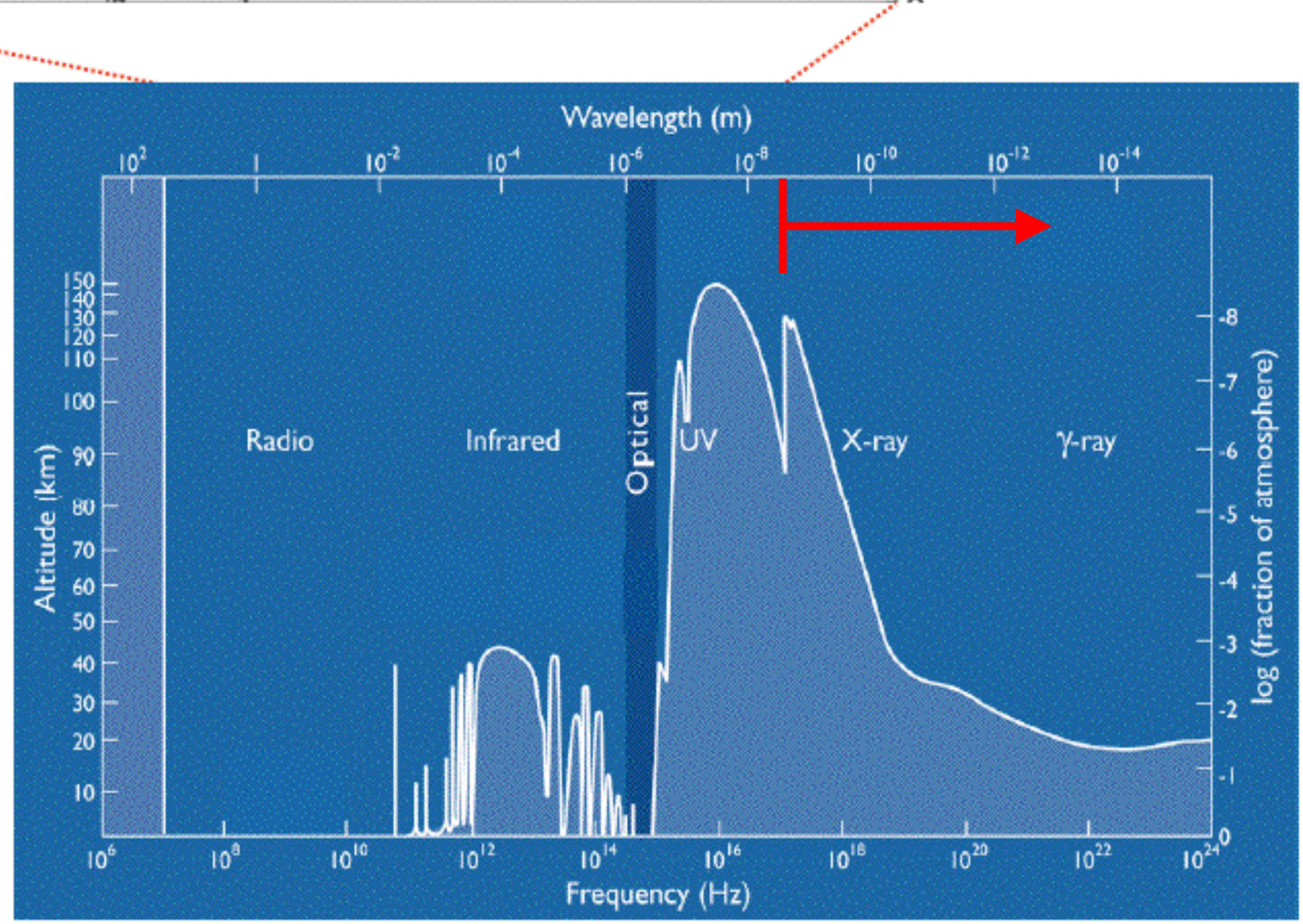
**See Melia 1.3**

# Atmospheric transmission



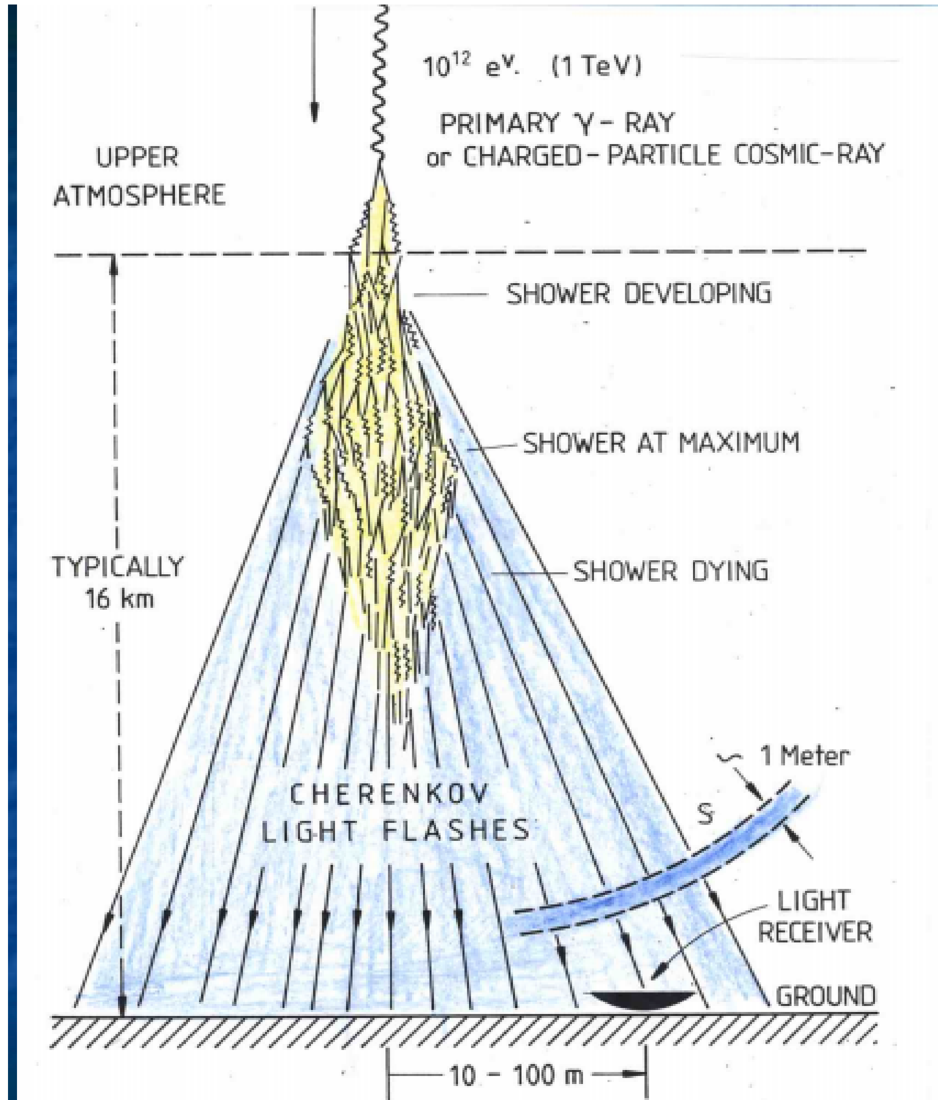

optical-near IR

Why go into space?
High Energy Photons get absorbed in earths atmosphere- graph shows atmospheric height at which 1/2 of photons absorbed



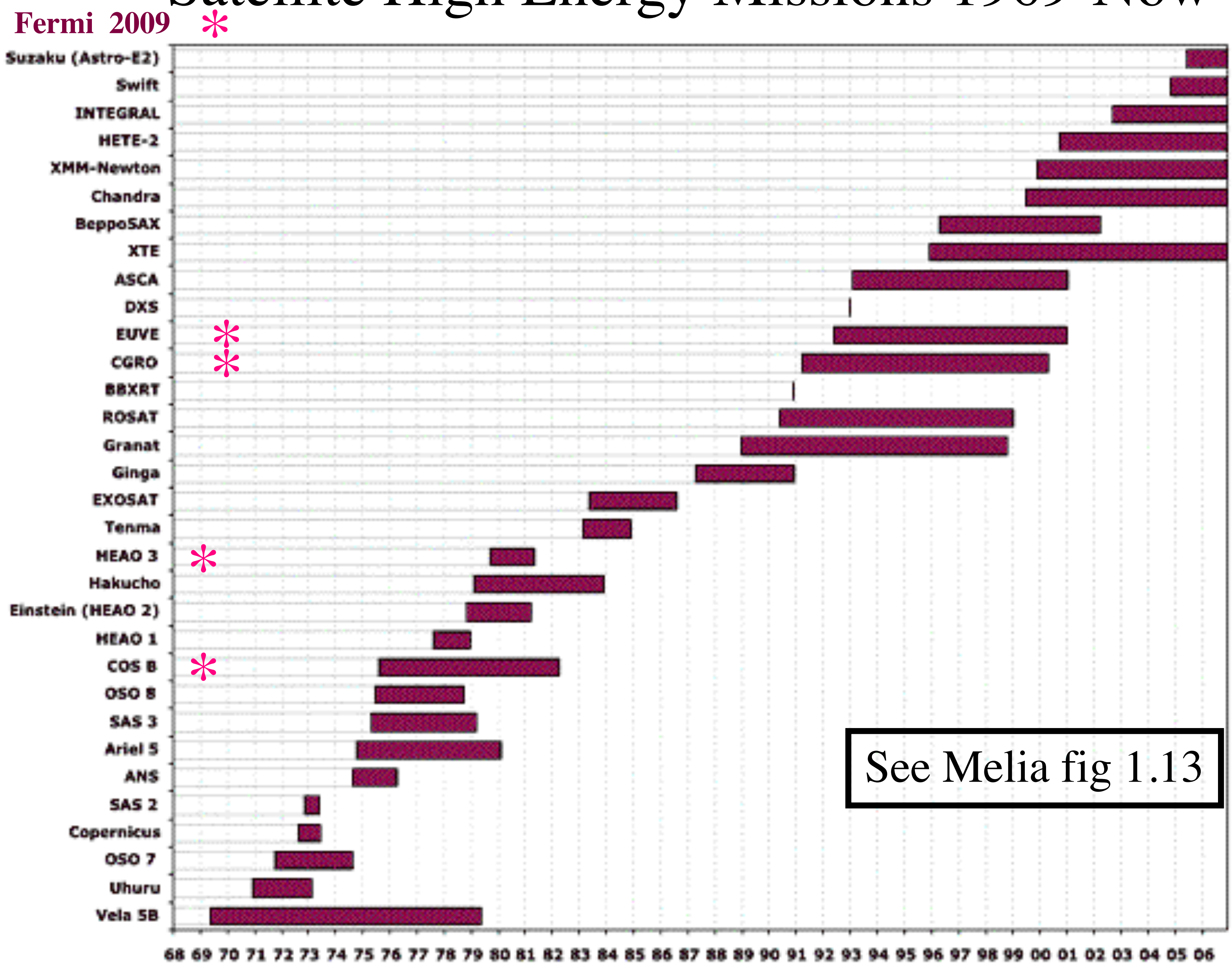
# Very High Energy Cosmic Rays and TeV Astronomy

- Very high energy photons and cosmic rays interact in the atmosphere but produce observable effects from the ground

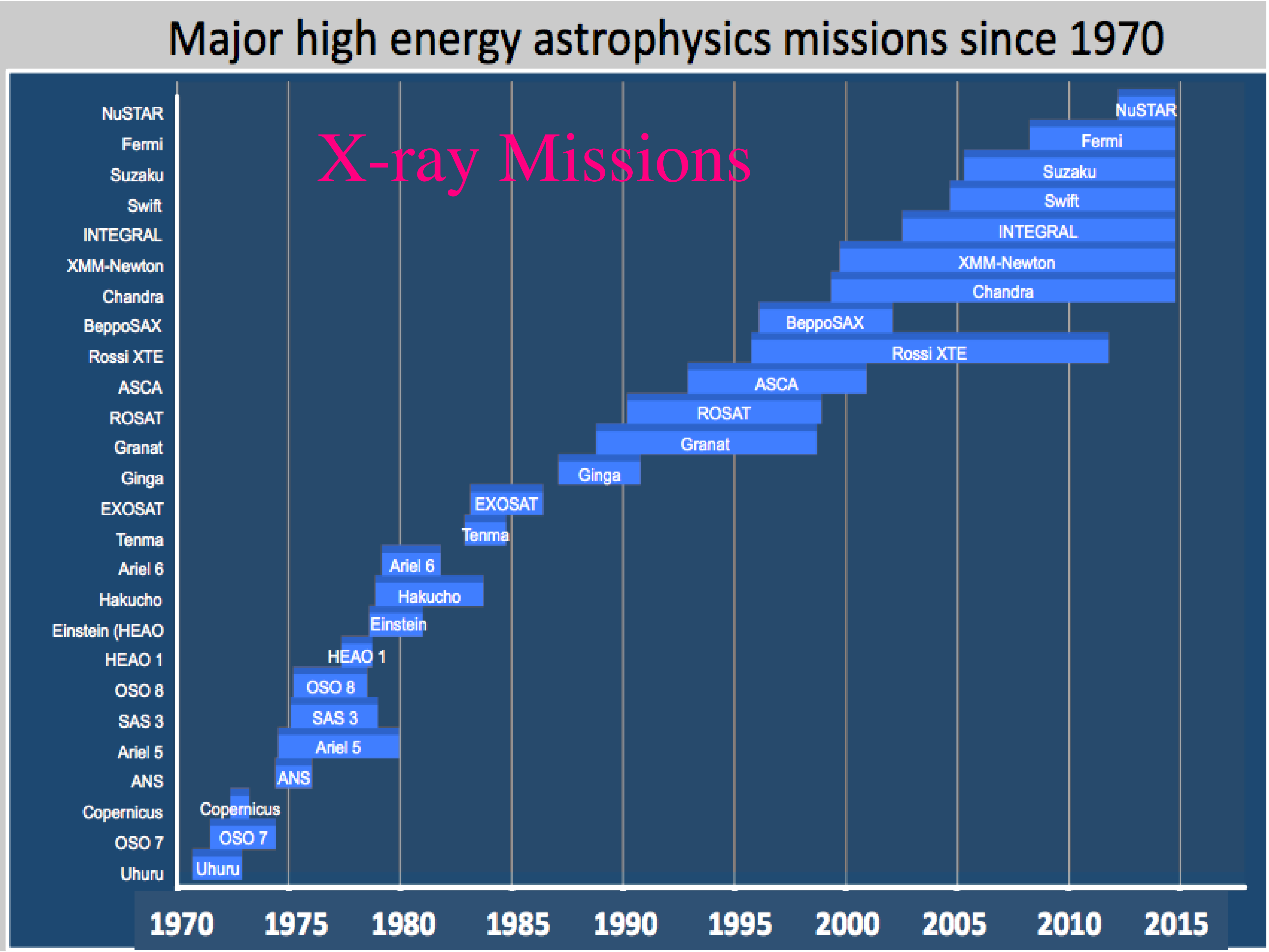



Weekes 2007

# Satellite High Energy Missions 1969-Now




See Melia fig 1.13



Major high energy astrophysics missions since 1970
X-ray Missions
NuSTAR
Fermi
Suzaku
Swift
INTEGRAL
XMM-Newton
Chandra
BeppoSAX
Rossi XTE
ASCA
ROSAT
Granat
Ginga
EXOSAT
Tenma
Ariel 6
Hakucho
Einstein (HEAO
HEAO 1
OSO 8
SAS 3
Ariel 5
ANS
Copernicus
OSO 7
Uhuru
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

# The Objects of High Energy Astrophysics-Neutron Stars

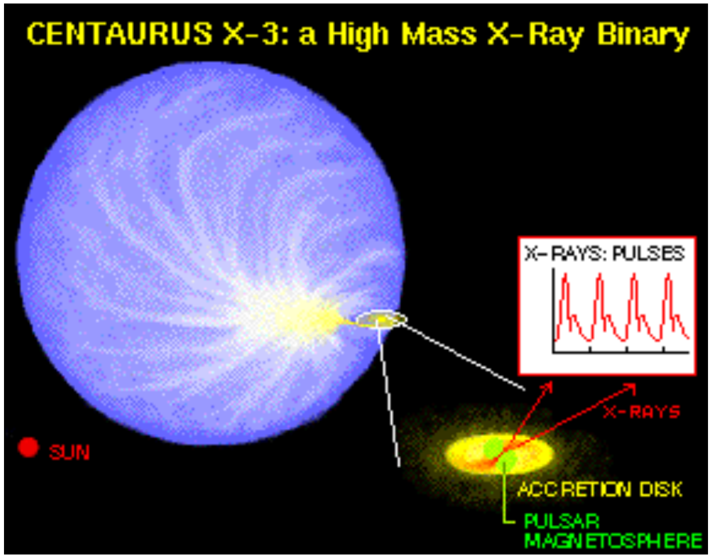
R+B pg 161 sec 5.1

- 1934, Baade and Zwicky proposed the existence of the neutron star 2 years after Chadwick's* discovery of the neutron ! - they proposed that the neutron star is formed in a supernova

- 1967, Shklovsky explained the X-ray and optical observations of Scorpius X-1 (the first non-solar) x-ray source as radiation coming from a neutron star **via accretion.**

- 1967, Jocelyn Bell and Antony Hewish** discovered regular radio pulses from the Crab-radiation from an isolated, rotating neutron star. The energy source of the pulsar is the rotational energy of the neutron star.

- 1971, Giacconi*** et al discovered 4.8 sec pulsations in an X-ray source in the constellation Centarus, Cen X-3: Emission from a rotating hot neutron star. The energy source is the same as in Sco X-1




*Nobel laureate in physics awarded for his discovery of the neutron.

** Nobel laureate in physics 1974

***Nobel laureate in physics 2002

# History: Baade and Zwicky

Walter Baade

"With all reserve, we advance the view that a *supernova* represents the transition of an ordinary star into a *neutron star* consisting mainly of neutrons…

*Baade & Zwicky (1934)*

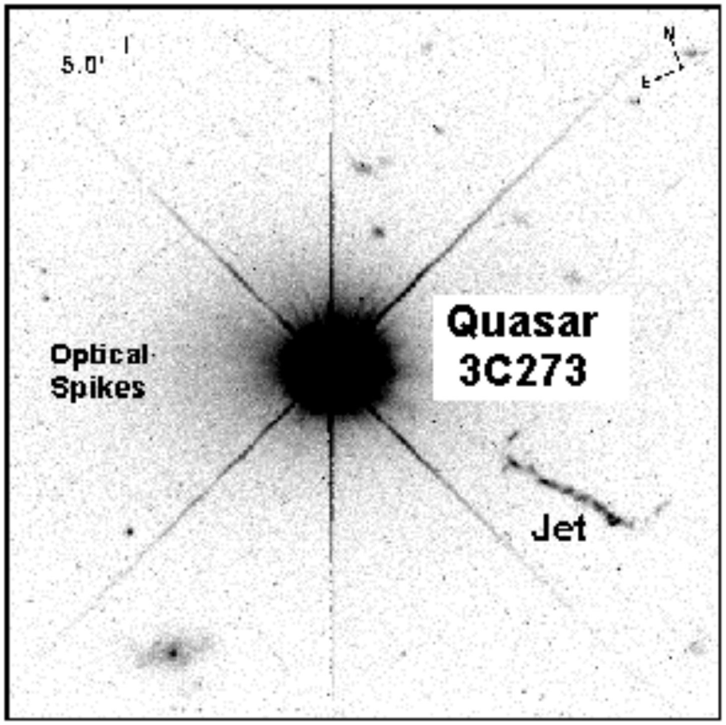
Just 2 yrs after the discovery of the neutron!

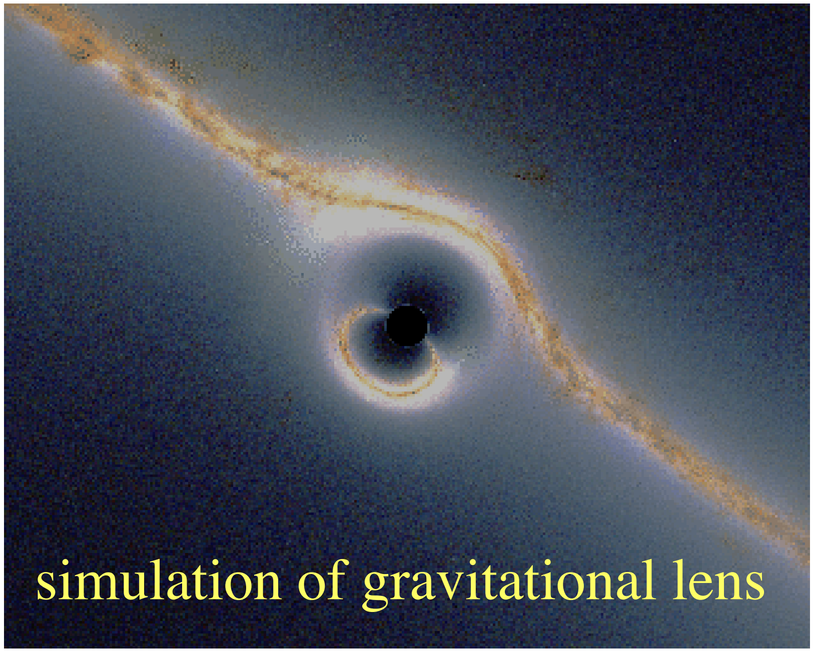

Fritz Zwicky

# Black Holes Melia ch 10.1

- 1963 Schmidt identified the first quasar, showing that these starlike objects exhibit ordinary hydrogen lines, but at redshifts far greater than those observed in stars.
- Quasars were shown to be powerful x-ray sources in the mid-1970s
- Quasars are accreting supermassive ($M>10^6 M_{sun}$ black holes (*)- how do we know this??
- The first accreting 'stellar mass' black hole Cyg X-1 was identified in 1972 as an x-ray source
- About 20 BHs in the Milky Way are known (100's more in nearby galaxies)
- $\sim 10^8$ AGN

* $M_{sun=}$ $2 \times 10^{33}$ gm





simulation of gravitational lens

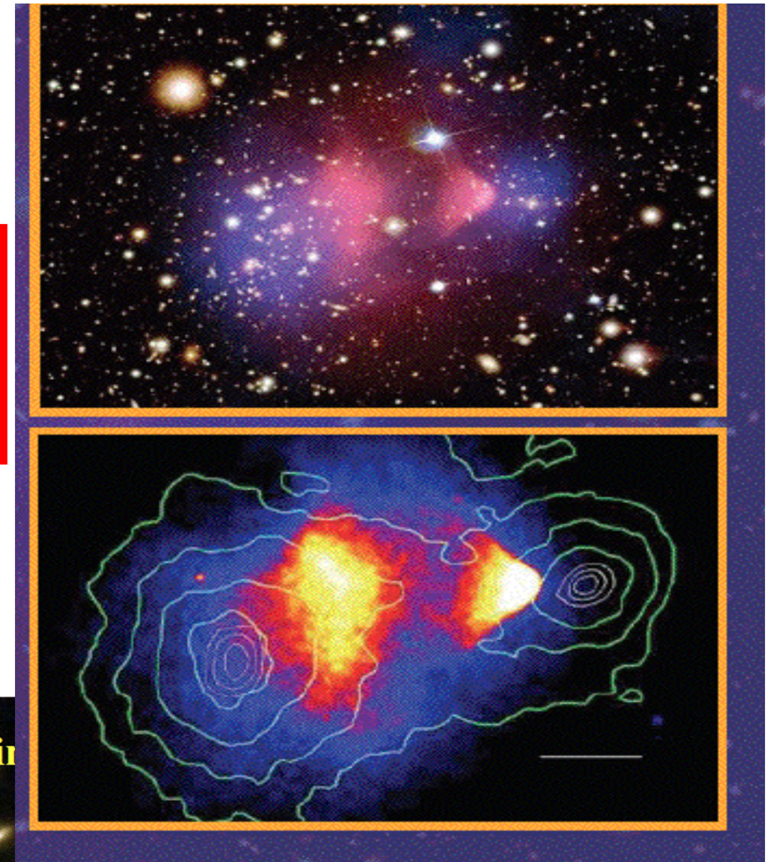
# Clusters of Galaxies

Most massive and largest objects in the universe- $M>10^{14}M_{\odot}$ $R\sim3.08\times10^{24}$ cm= 1 Mpc

Most of the baryons* in clusters are in the hot x-ray emitting gas- most of the mass is **dark matter**

Can act as a gravitational lens**- revealing the amount of and distribution of **dark matter*****.

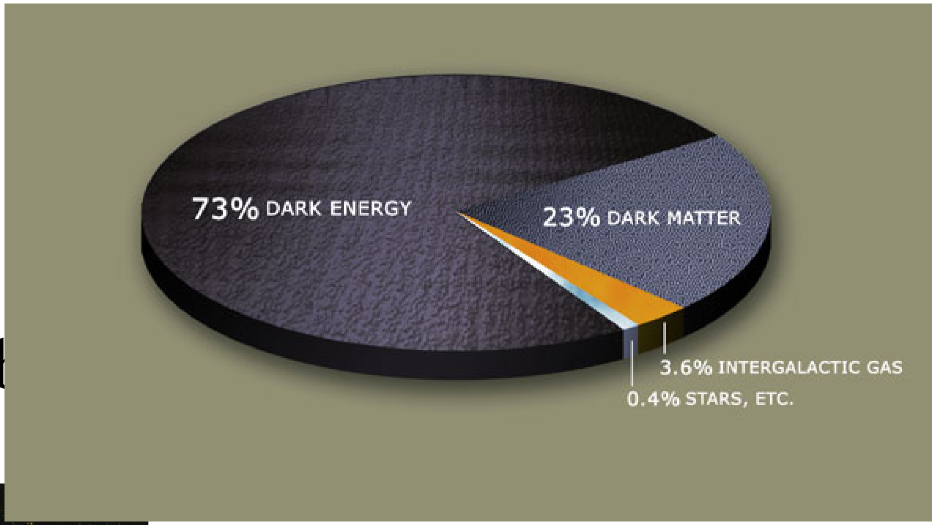
**the bending of light by strong gravity can act as a lens



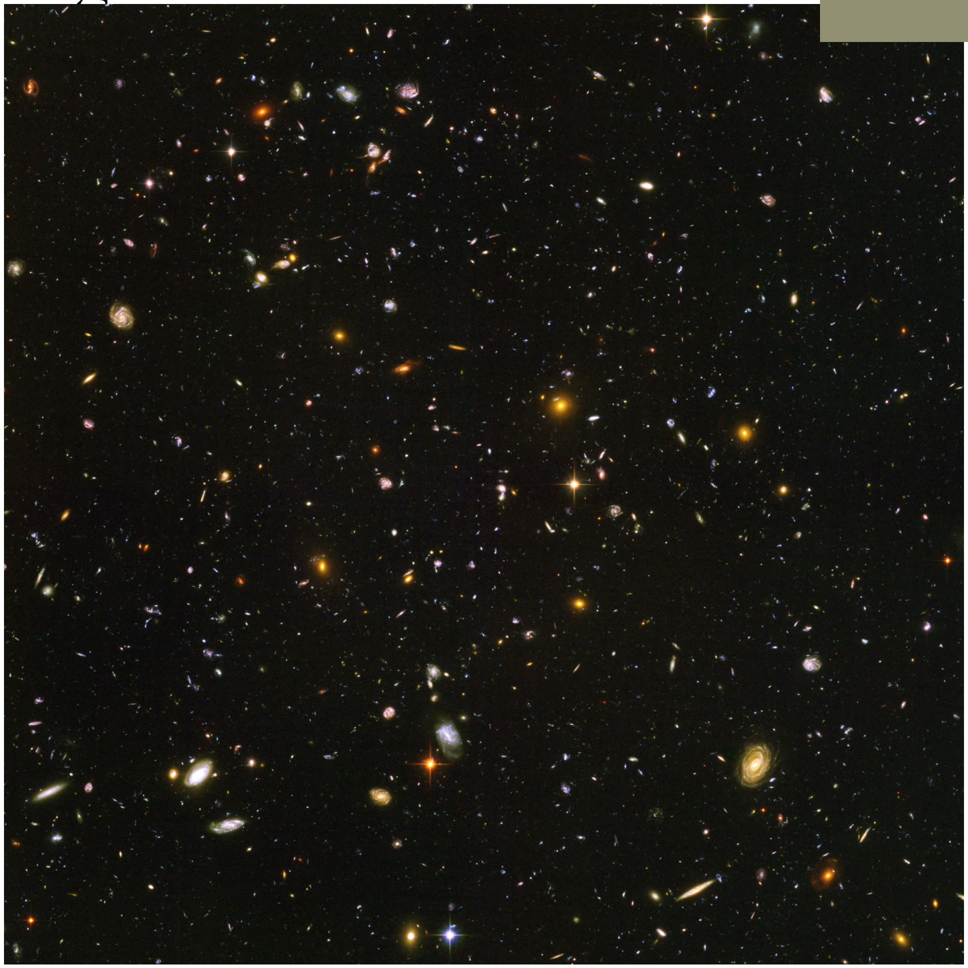

*Baryon- neutrons protons, nuclei of atoms

# Dark Matter

- 'Dark' matter is material that interacts via gravity but does not emit or absorb light




Dark matter has 6x mass of baryons averaged over the entire universe.

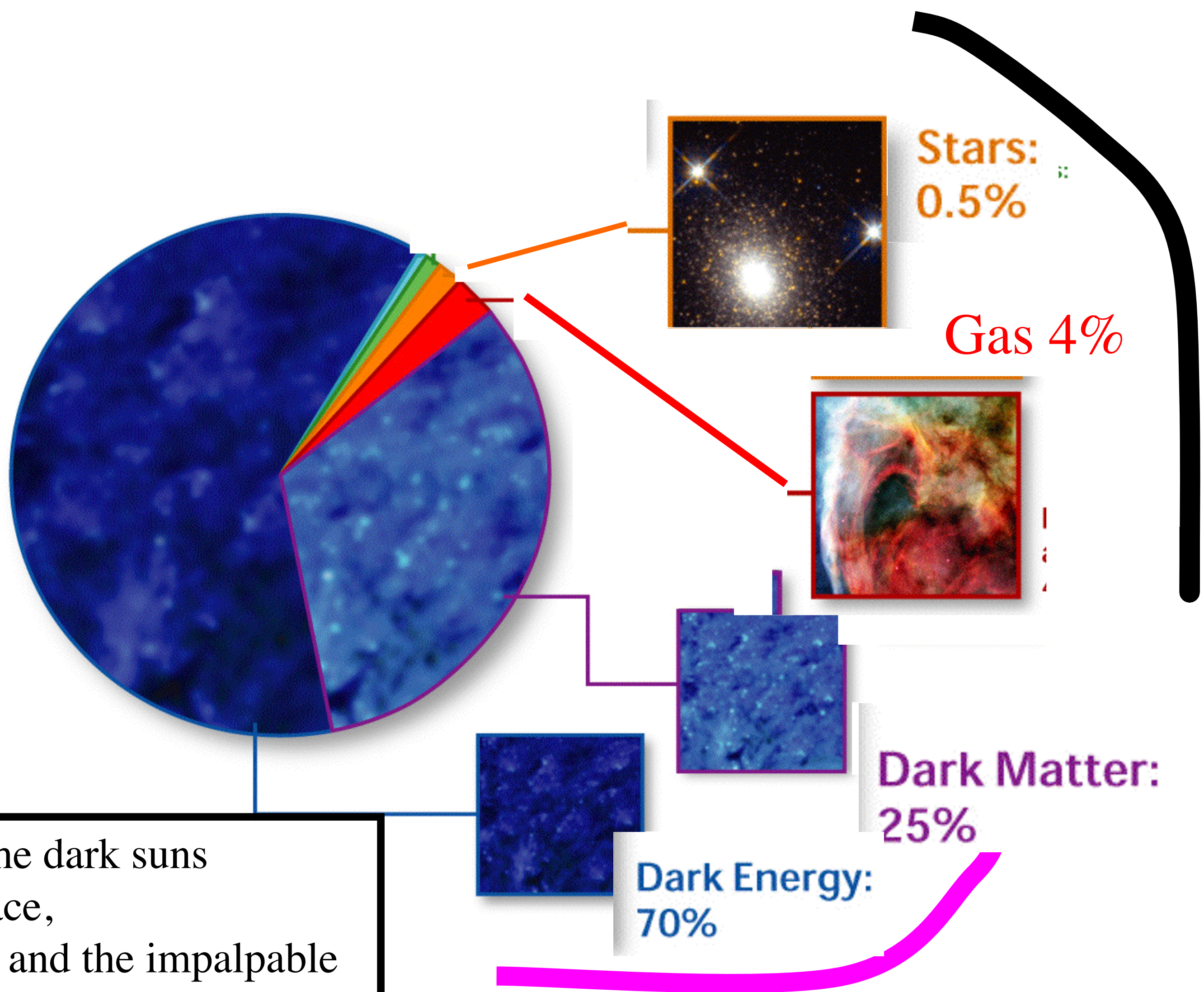


Hubble deep field

# Dark Matter

- The biggest indication that we do not understand the universe very well
- **95% of the universe consists of stuff that is not understood and can't be 'seen'**
- **The name 'Dark Matter' conveys what we don't know**

Stuff we understand




Stuff we **don't** understand

> The bright suns I see and the dark suns
> I cannot see are in their place,
> The palpable is in its place and the impalpable
> is in its place
> **Walt Whitman Leaves of Grass**

# Physical Processes Over View – More Equations Later

## Melia ch 5 and Rosswog and Bruggen ch 3

- How are 'high energy' photons produced
  - Continuum

Thermal emission processes

Blackbody radiation
Bremsstrahlung

Non-thermal processes

Synchrotron radiation

Inverse Compton emission

Non-thermal bremms

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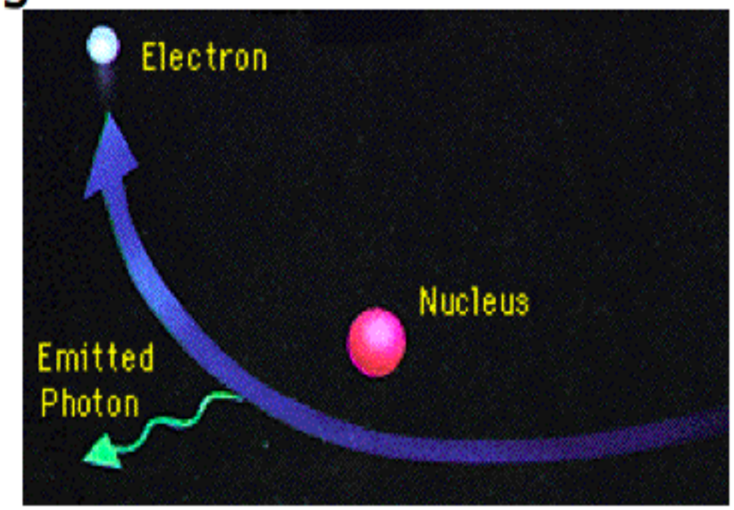
In "thermal" processes the electrons are in a Maxwell-Boltzman distribution- the system has a 'temperature'

In non-thermal the electron distribution is often a power law-no temperature

## BREMSSTRAHLUNG

- "Braking radiation"




**Examples: clusters of galaxies, supernova remnants, stellar coronae**

**Electromagnetic radiation is produced by the acceleration of charged particles (mostly electrons)**