Old and News from Astroparticle Physics

Franco Giovannelli

INAF-Istituto di Astrofisica e Planetologia Spaziali, Roma

NEW e-mail: franco.giovannelli@iaps.inaf.it

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Outline of the talk

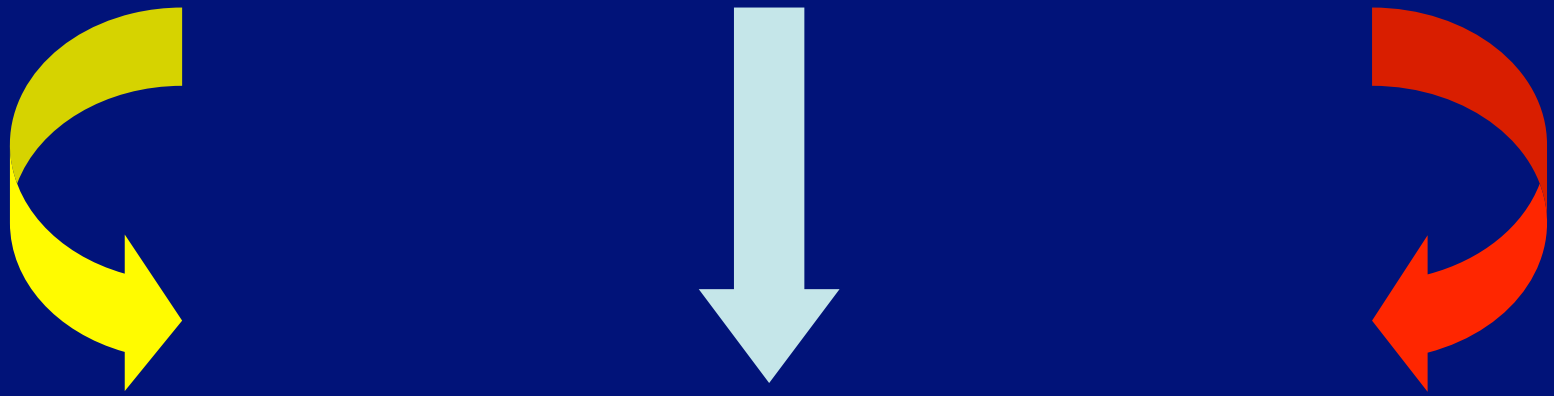
- Introduction
  - Photonic Astrophysics
  - Particle Astrophysics
  - Neutrino Astrophysics
- Important steps in our knowledge
- News
- Conclusions

The Three Tools Necessary

Photonic Astrophysics

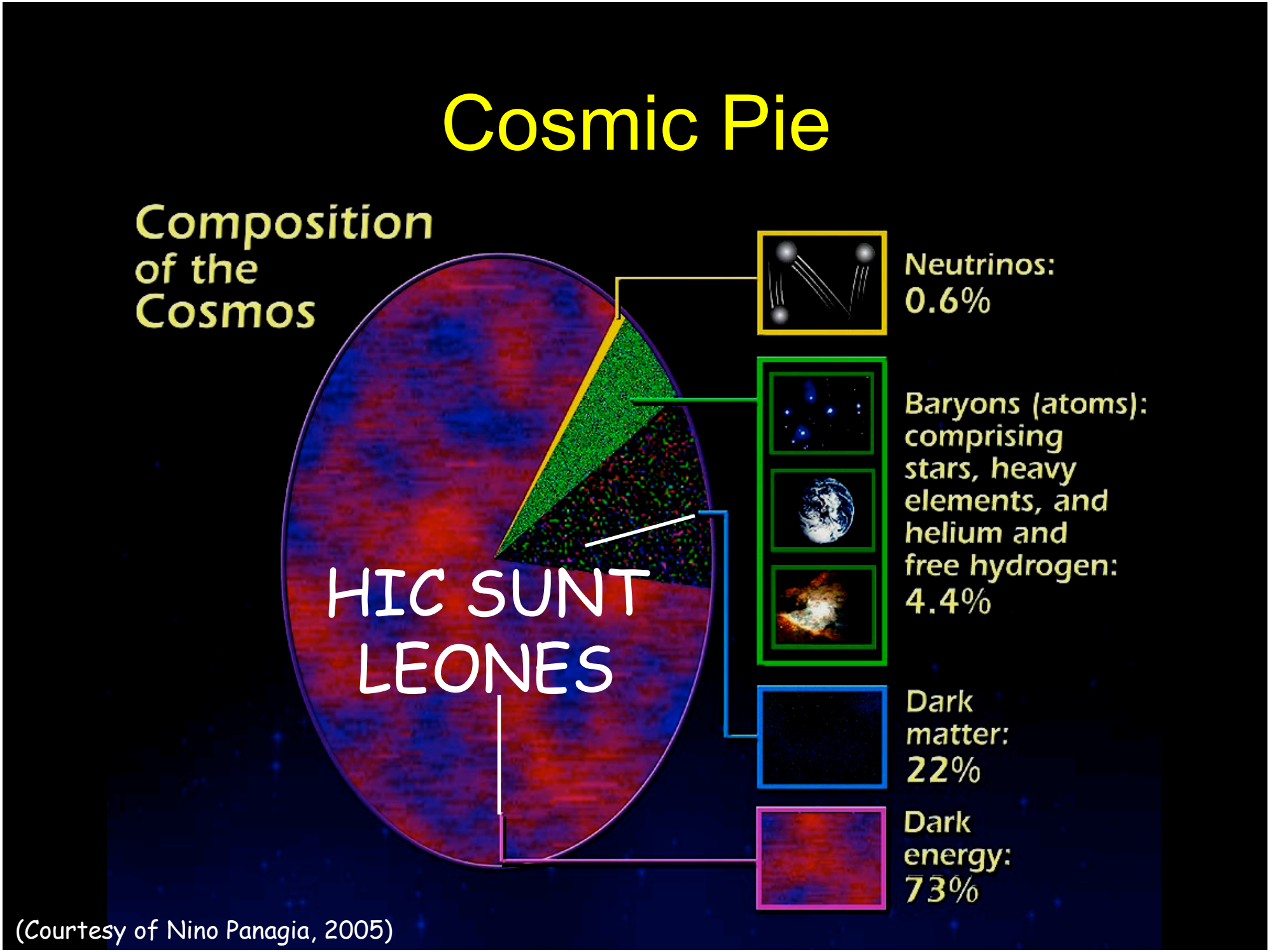
Neutrino Astrophysics

Particle Astrophysics



Astroparticle Physics

Cosmic Pie



(Courtesy of Nino Panagia, 2005)

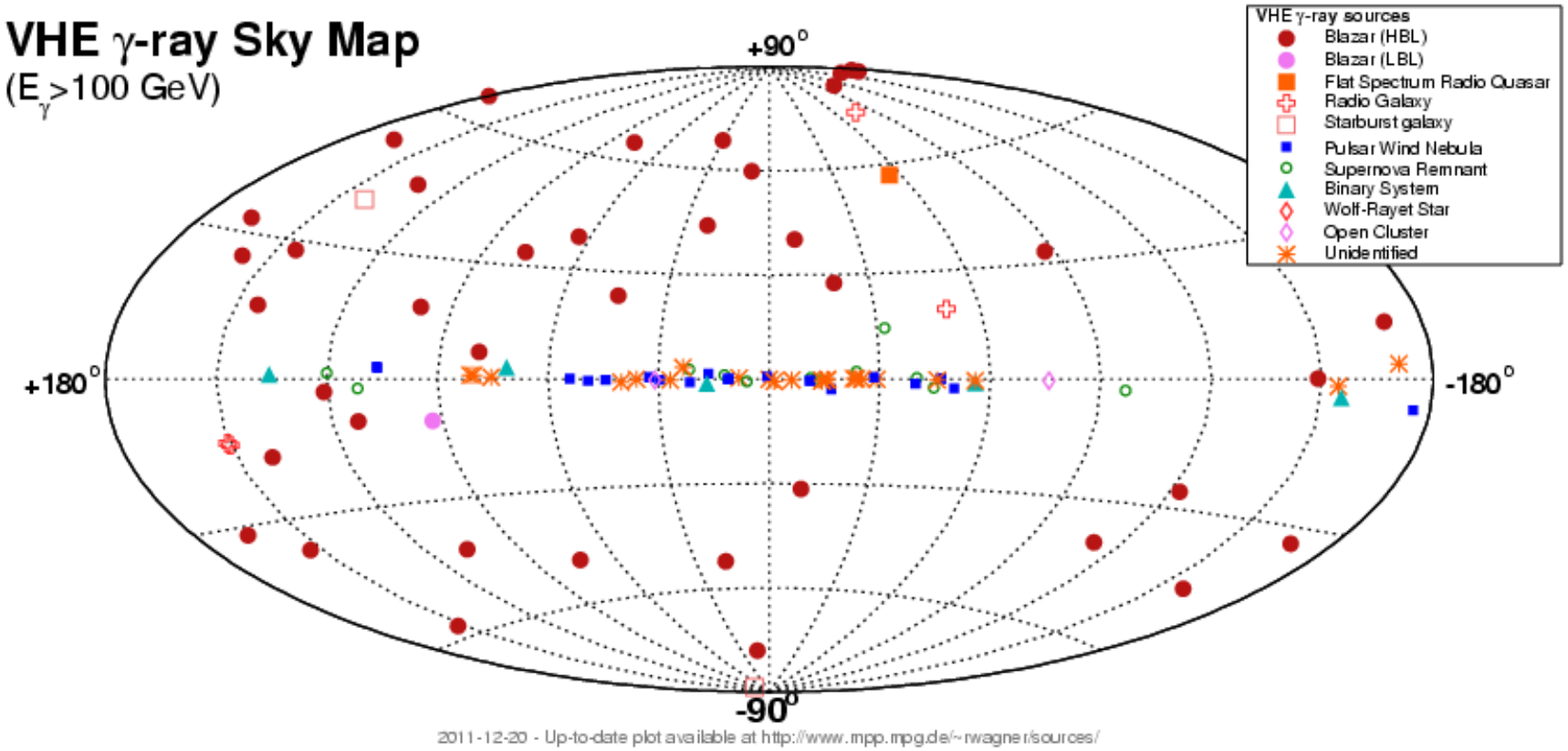
Multifrequency Observations
(possibly Simultaneous)

are Fundamental
in
Photonic Astrophysics
&
Particle Astrophysics

….The Universe manifests
not only through
electromagnetic radiation
but also through
astroparticles
including neutrinos

VHE γ-Ray Astronomy

http://www.mppmu.mpg.de/~rwagner/sources/
(see also http://tevcat.uchicago.edu/)



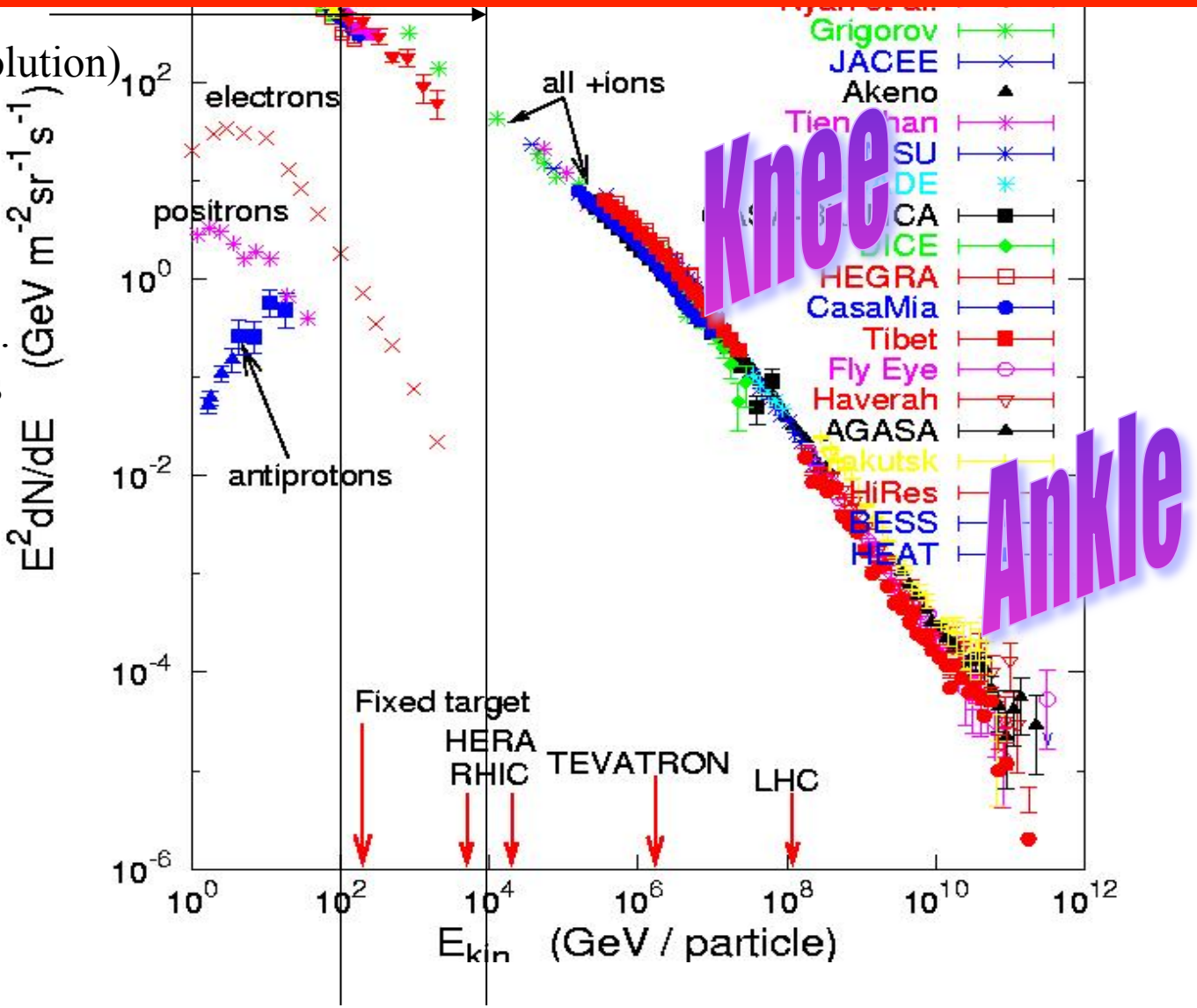
All the identified source classes also exhibit emission in the radio and/or X-ray regime

46 61 107

Cosmic Ray Multifrequency Measurements

Calorimeters
(less good resolution)

Air-shower arrays
on the ground to overcome low flux.
Don't see primaries directly.



Gaisser, 2005

LHC Investigation Fields

- Dark Energy
- Dark Matter
- Extra Dimensions
- Higgs
- Supersymmetry

LHC is the vessel sailing the Dark Energy and Dark Matter unknown oceans

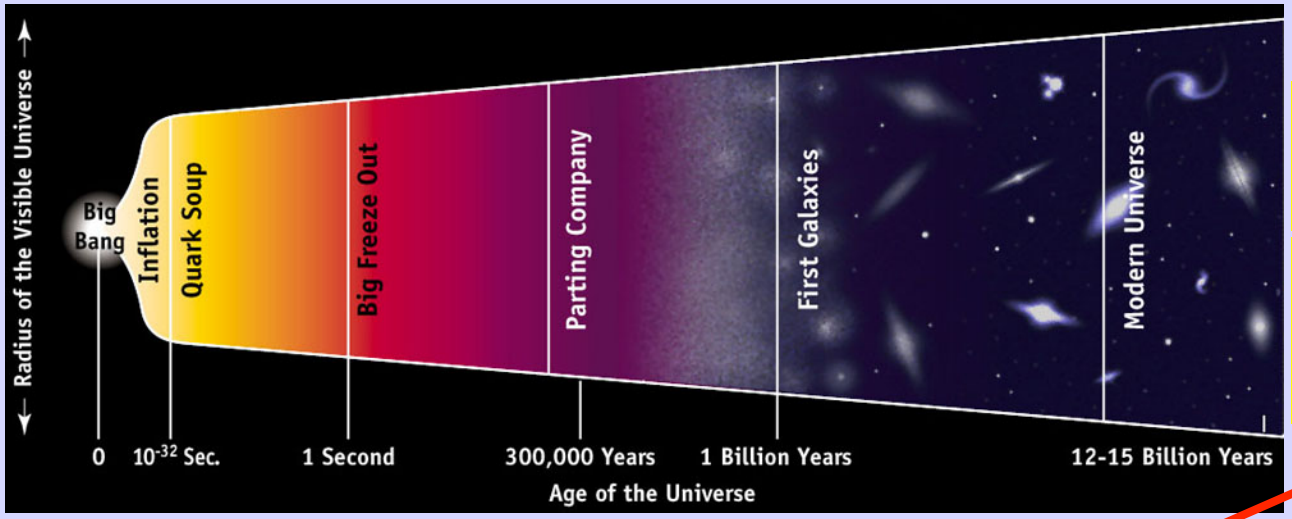
LHC is a complementary tool for HE observatories looking directly to the Universe

- LHC is probably the highest and ultimately active-physics technological wonder, difficult to be outdated because of dimensions and costs.
- Probably in the next decades it will be cheaper to develop more sensitive passive-physics ground-based experiments, and even if space-based or Moon-based.

Some of the most important steps on our Knowledge of the physics of the Universe

(biased by my knowledge and feelings)

BIG BANG theory has been proved

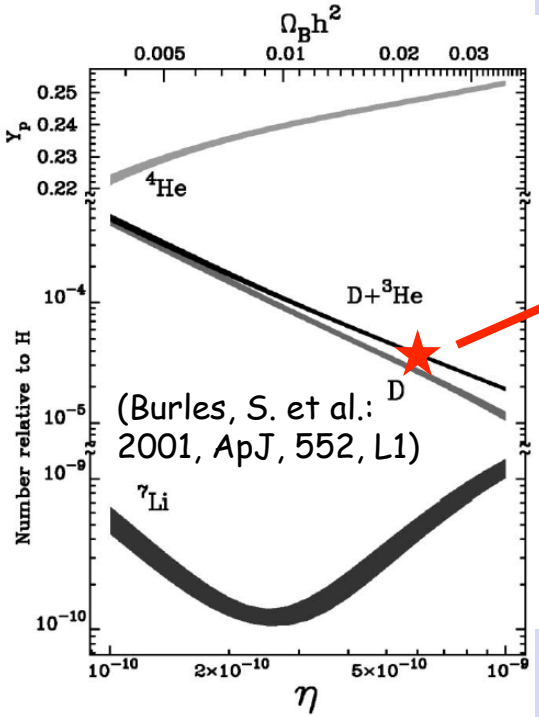


$\Omega_B h^2 = 0.023/0.020$

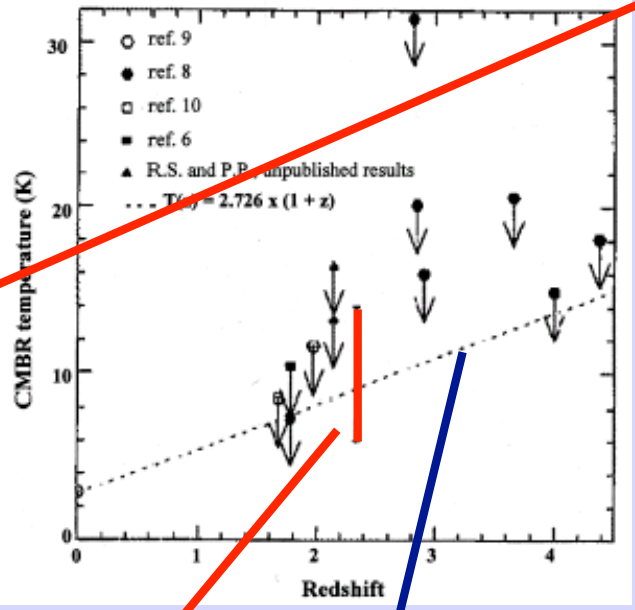
(Netterfield etal.: 2002, ApJ, 571, 604)

$\Omega_B h^2 = 0.021$

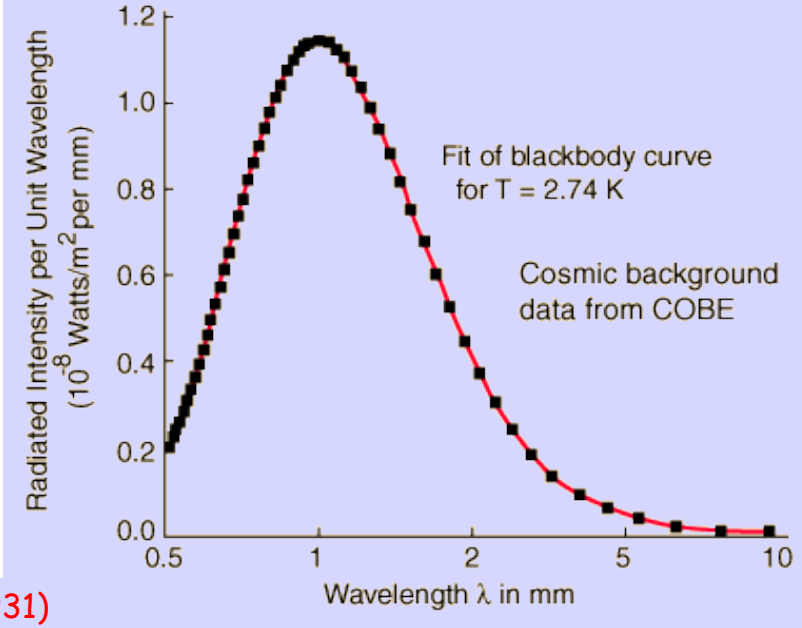
(de Bernardis etal.: 2000, Nature, 404, 955)
(de Bernardis etal.: 2001, AIPC, 555. 85)



(Burles, S. et al.: 2001, ApJ, 552, L1)



(Srianand, R. et al.: 2000, Nature, 408, 931)

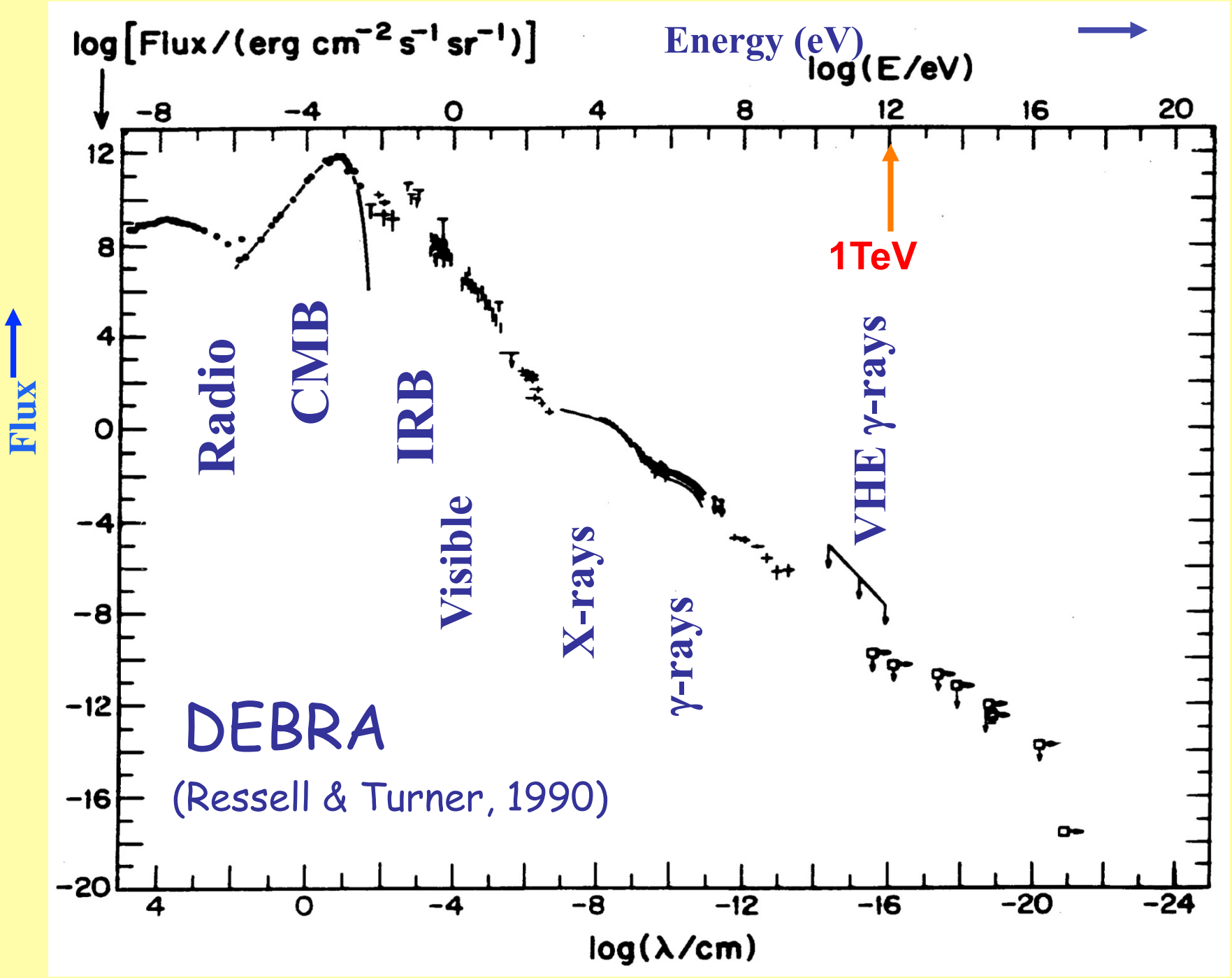


$T_{CMBR}(z=0) = 2.726 \pm 0.010$ K

$6.0\ K < T_{CMBR}(z=2.34) < 14.0\ K$

$T_{CMBR}(z=2.34) = 9.1\ K$

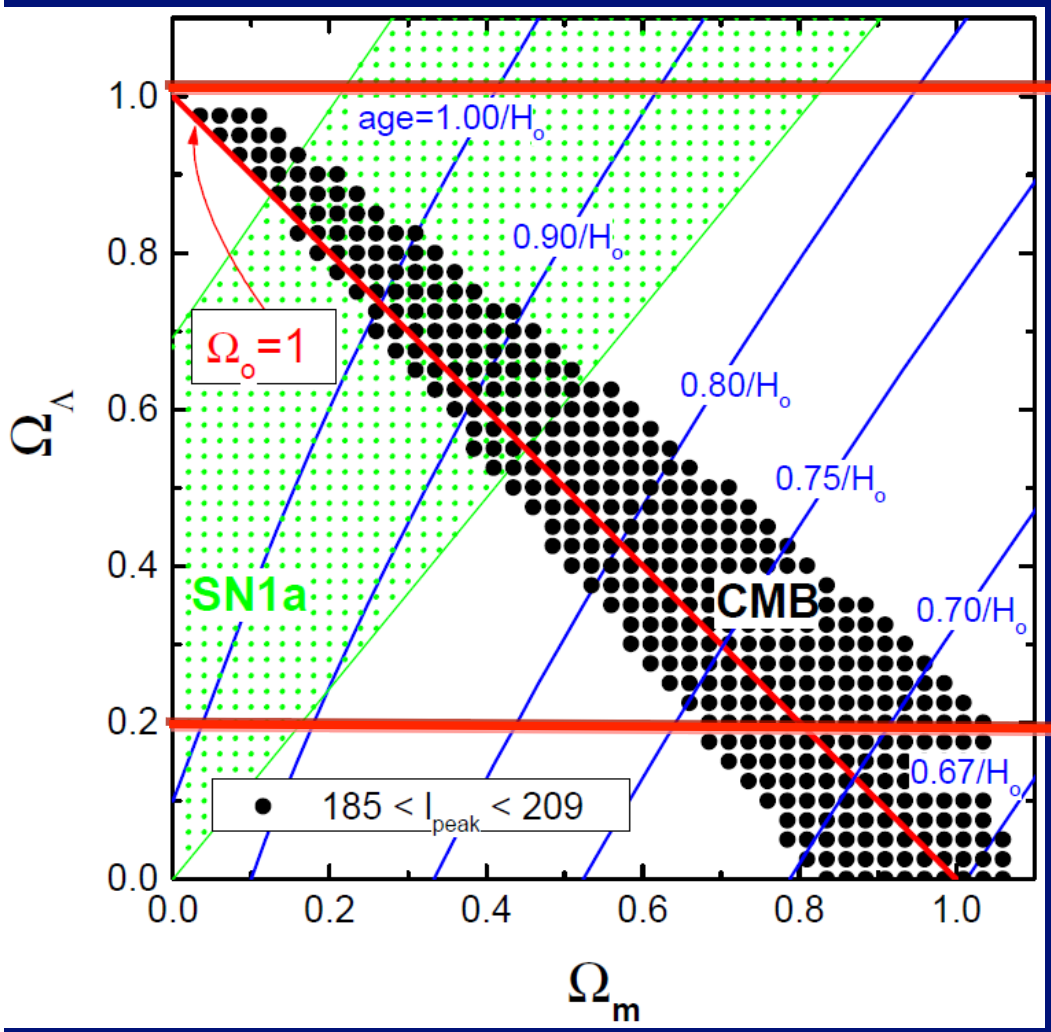
$T_{CMBR} = T_{CMBR}(0)\ (1 + z)$

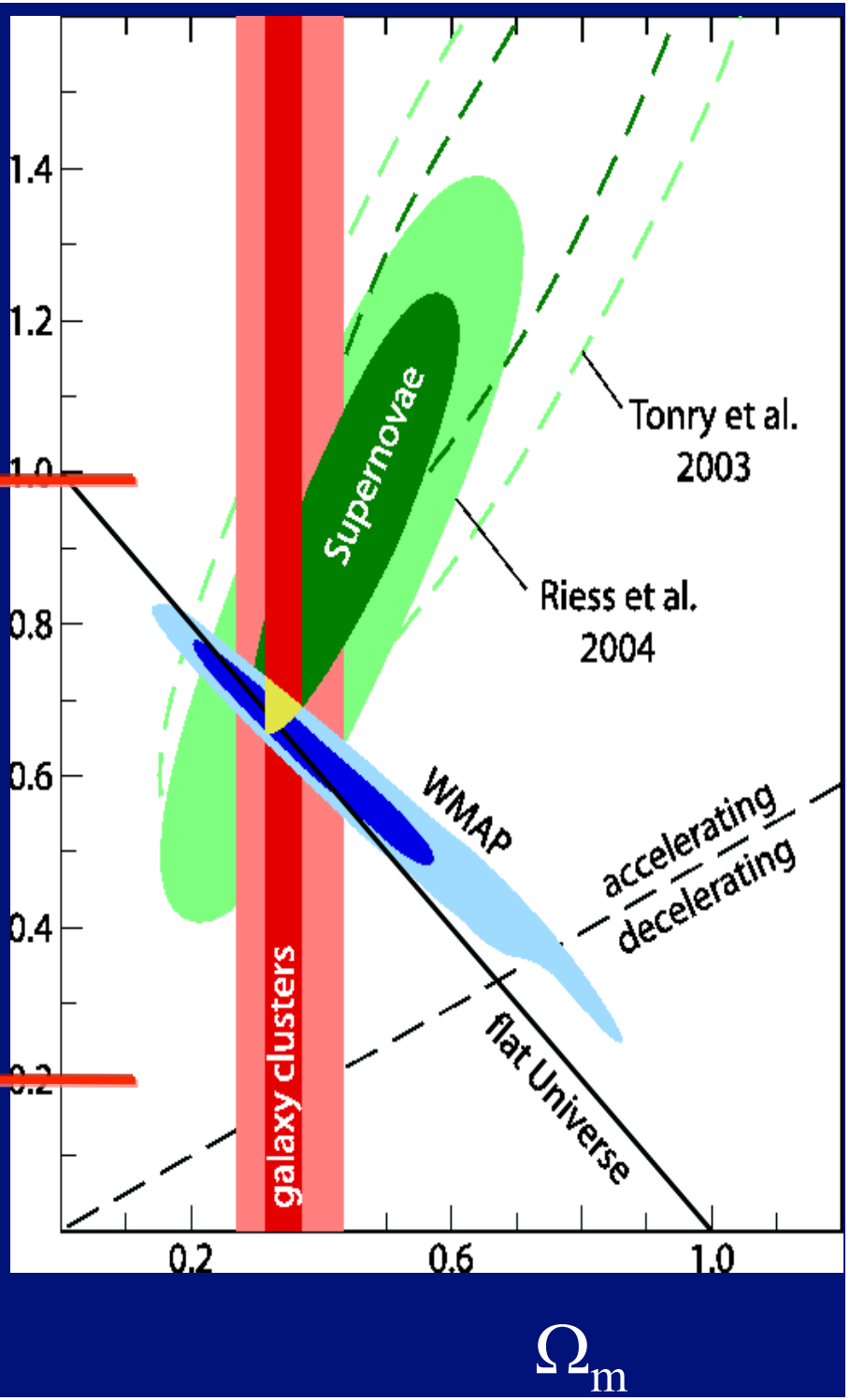

log[Flux/(erg cm^{-2} s^{-1} sr^{-1})]
Energy (eV)
log(E/eV)
-8
-4
0
4
8
12
16
20
1TeV
Flux
Radio
CMB
IRB
Visible
X-rays
γ-rays
VHE γ-rays
DEBRA
(Ressell & Turner, 1990)
12
8
4
0
-4
-8
-12
-16
-20
4
0
-4
-8
-12
-16
-20
-24
log(λ/cm)

The Universe is flat

Schuecker et al. 2003, 2004
REFLEX cosmological constraints
(ESO-PR June 2004)

(de Bernardis etal.:
2000, Nature, 404, 955)





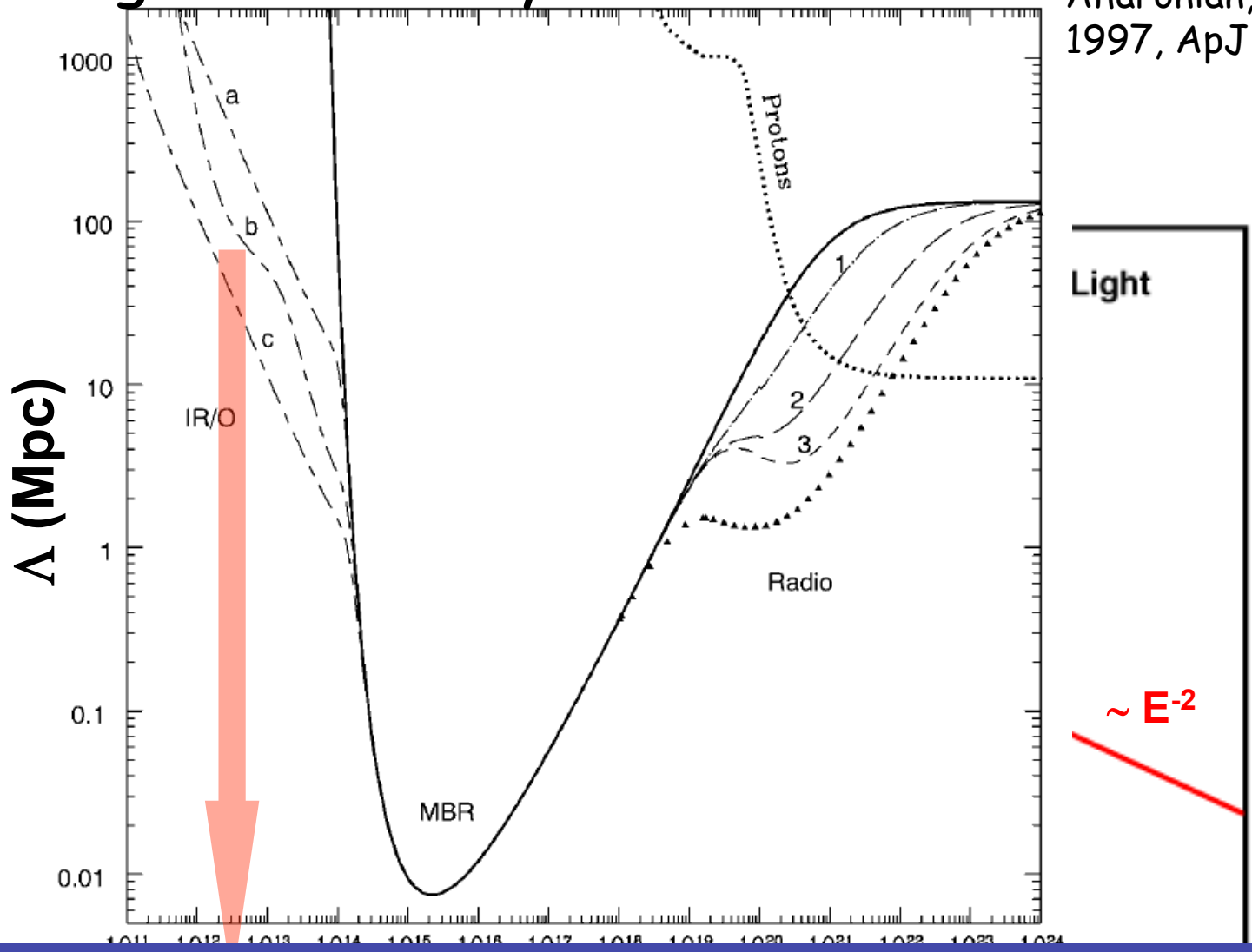
Absorption of γ-ray in the Universe

Extragalactic Background Light (EBL)

$$\gamma' + \gamma_{BKGD} \longrightarrow e^+ + e^-$$

Neglecting evolutionary effects

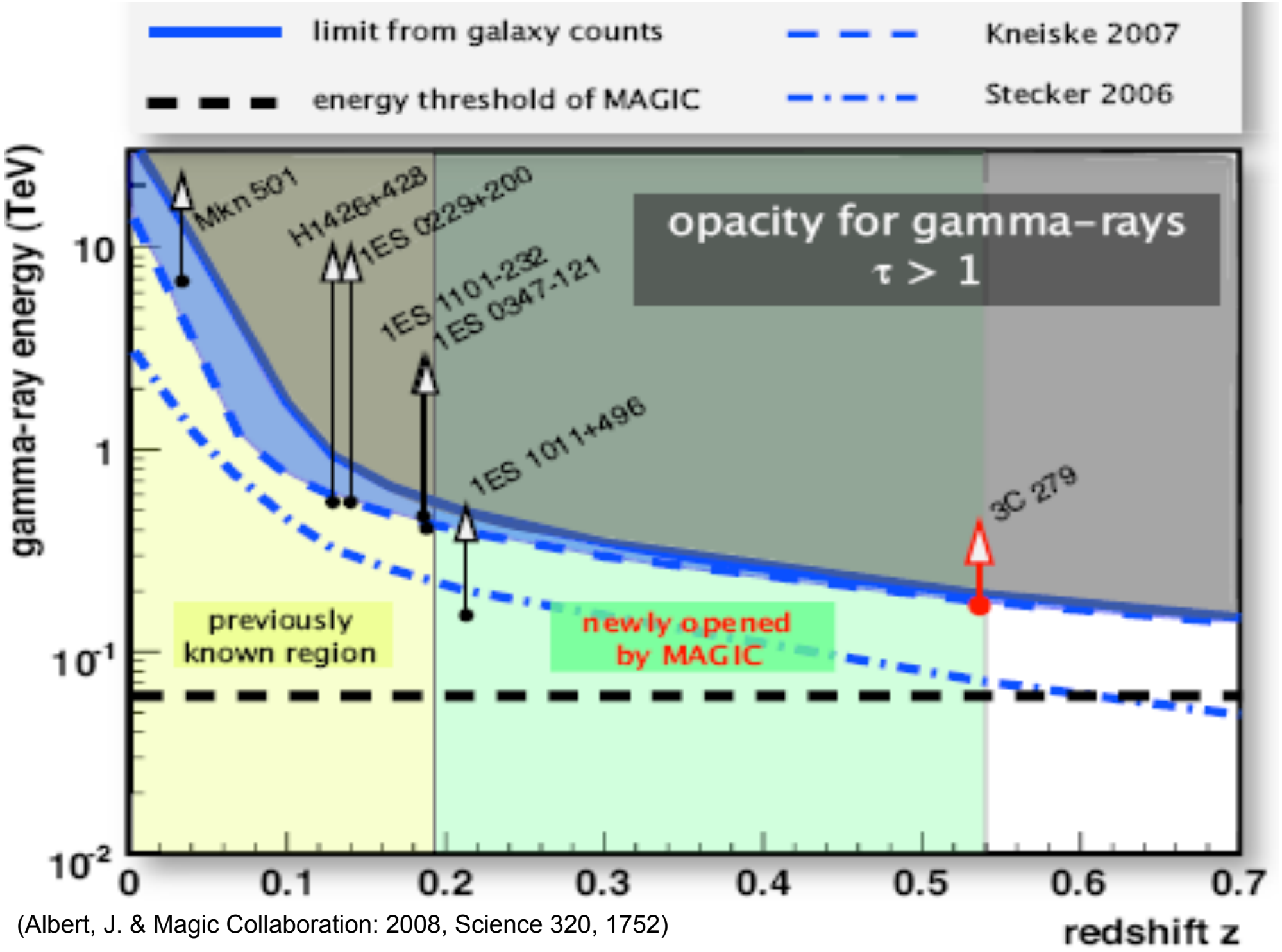
(Coppi, P.S. & Aharonian, F.A.: 1997, ApJ 487, L9)



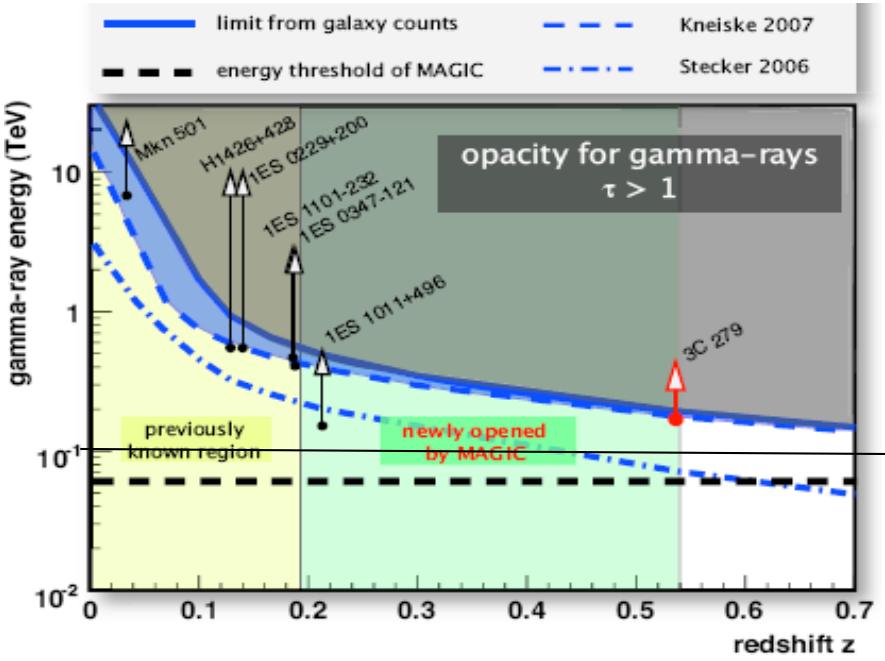
For γ-rays energies above a few TeV,
the distance they can propagate ≤ 100 Mpc

Most of the VHE Universe seems not visible to us

(Barbara de Lotto, 2010)



(Albert, J. & Magic Collaboration: 2008, Science 320, 1752)

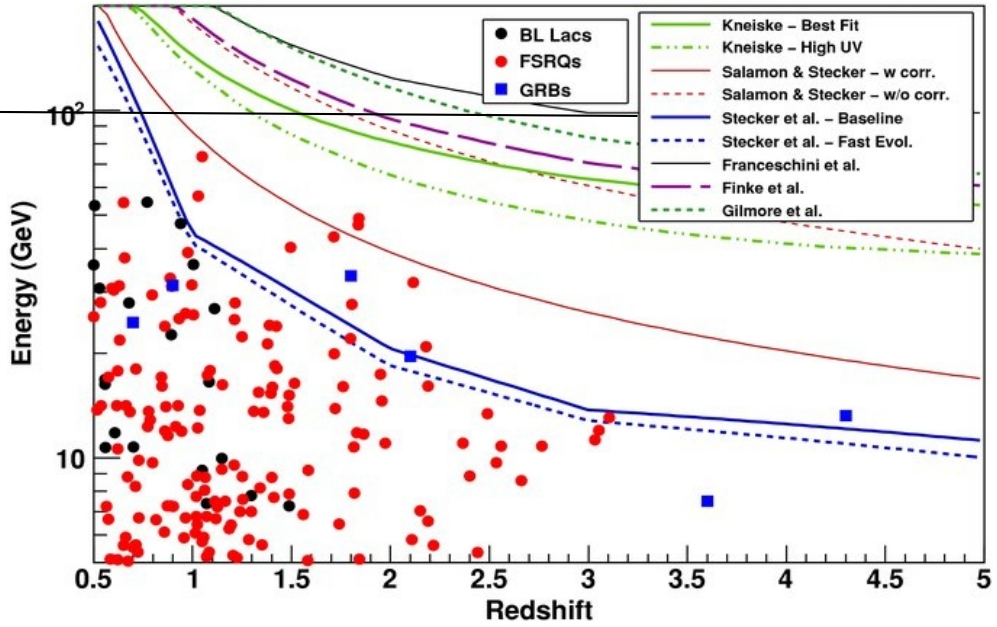


(Albert, J. & Magic Collaboration: 2008, Science 320, 1752)

MAGIC

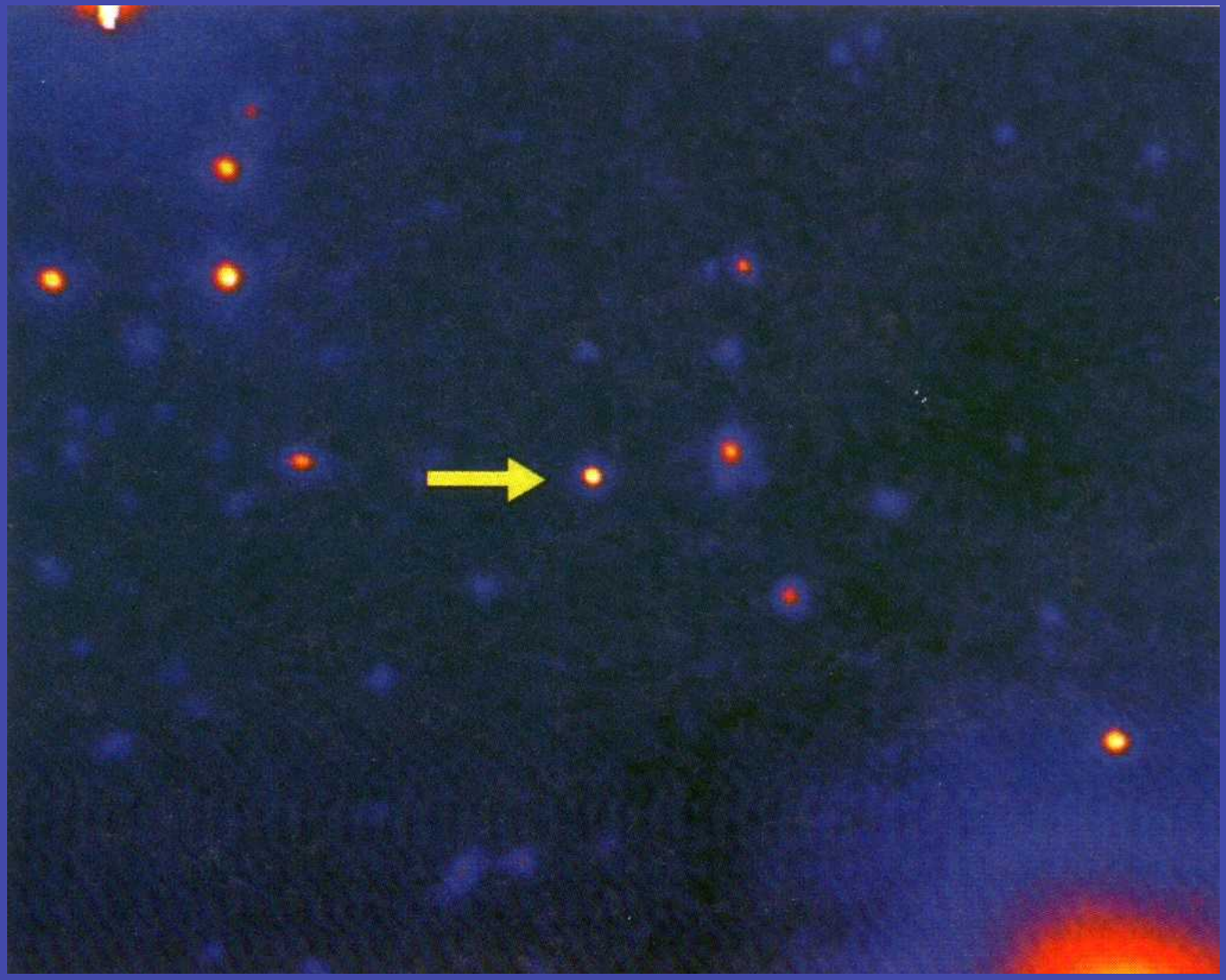
FERMI

(Abdo, A.A. et al.: 2010, ApJ 723, 1082)



opacity for gamma-rays
$\tau = 3$

Every time that the man pointed larger telescopes toward the sky, he looked at farer objects



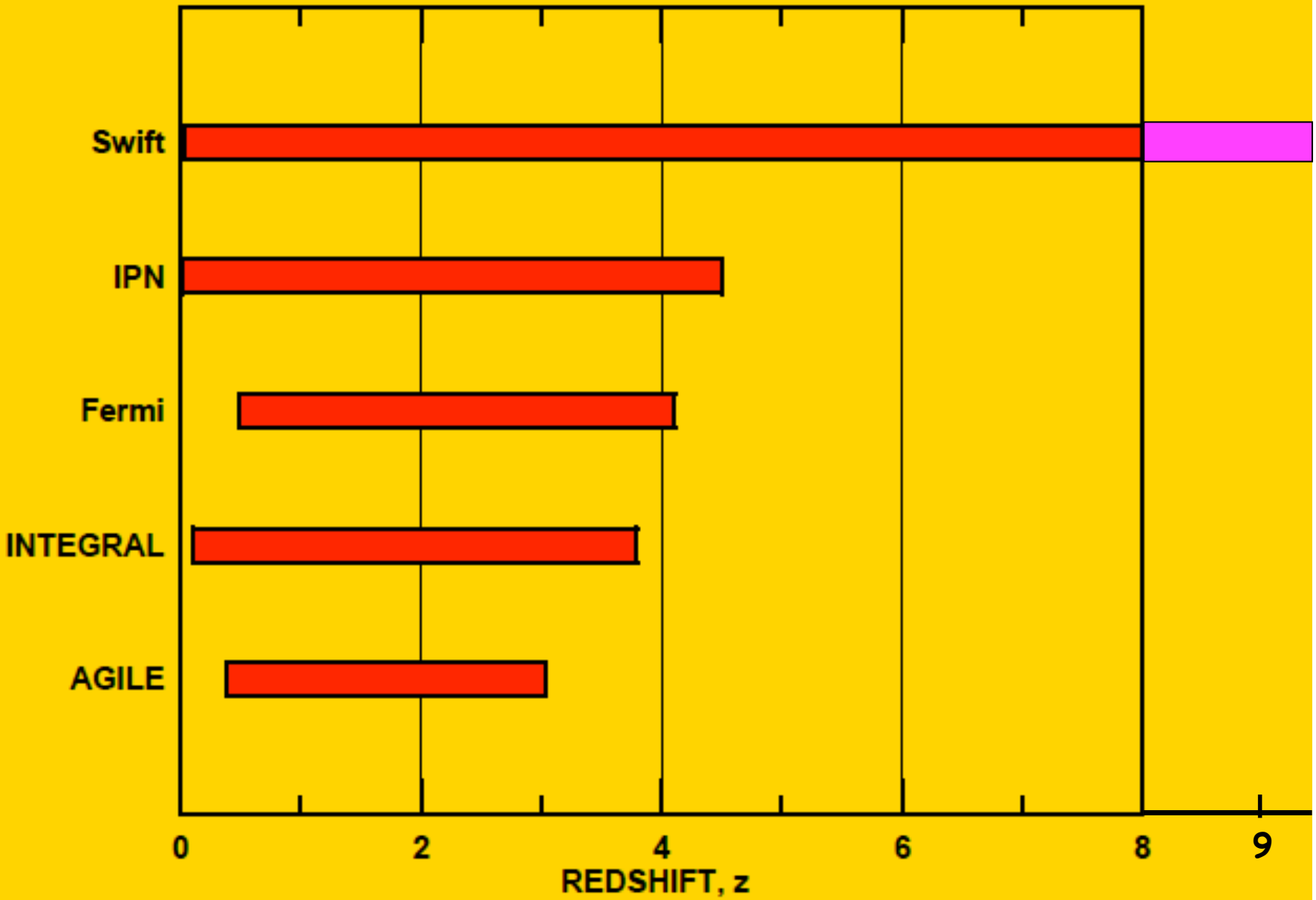
$z = 6.1$

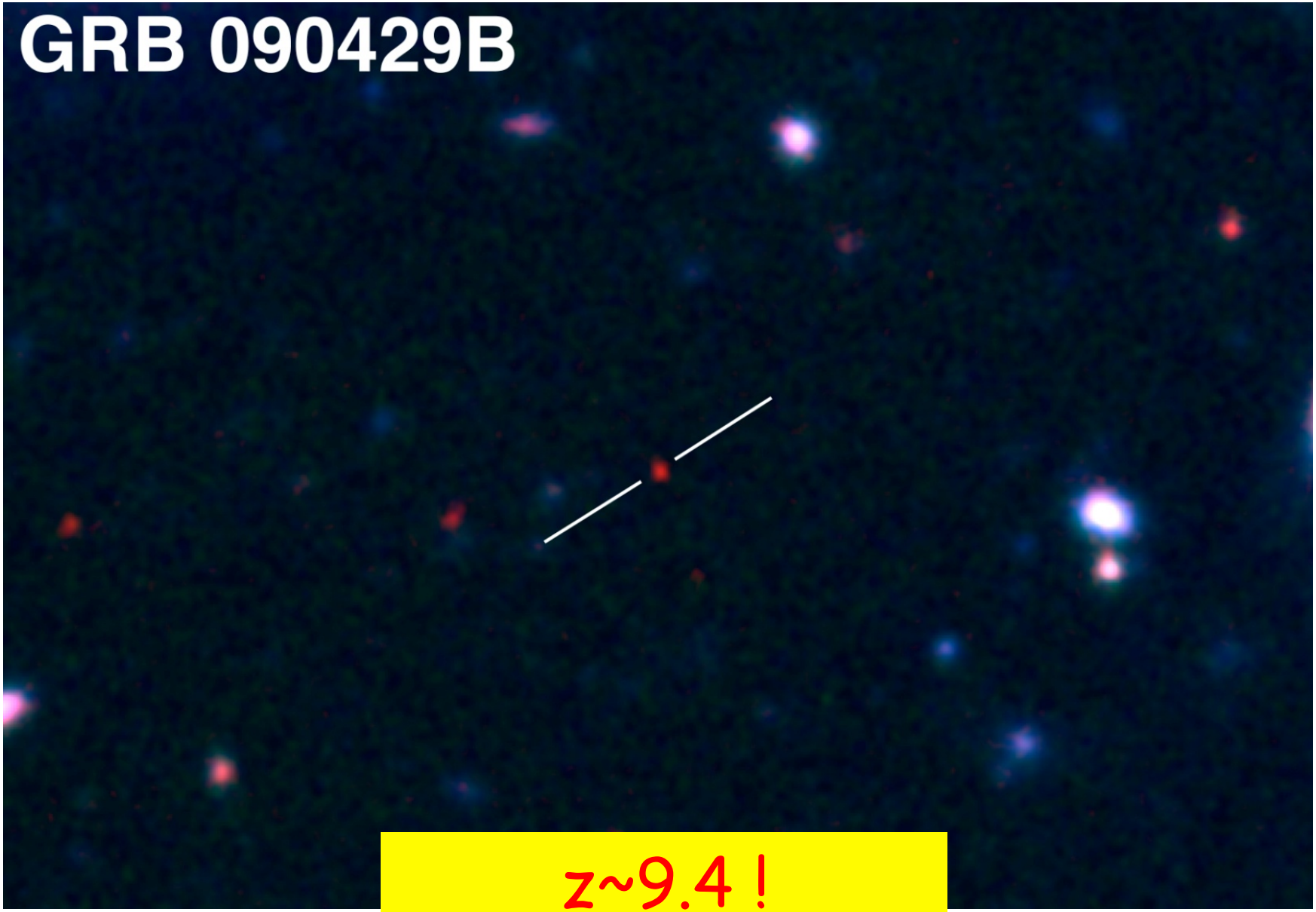
10^9 yr after Big Bang

10 m Keck image of QSO J 1148+5251

Overview: Redshifts Sampled by Various Missions

(Hurley, 2010)



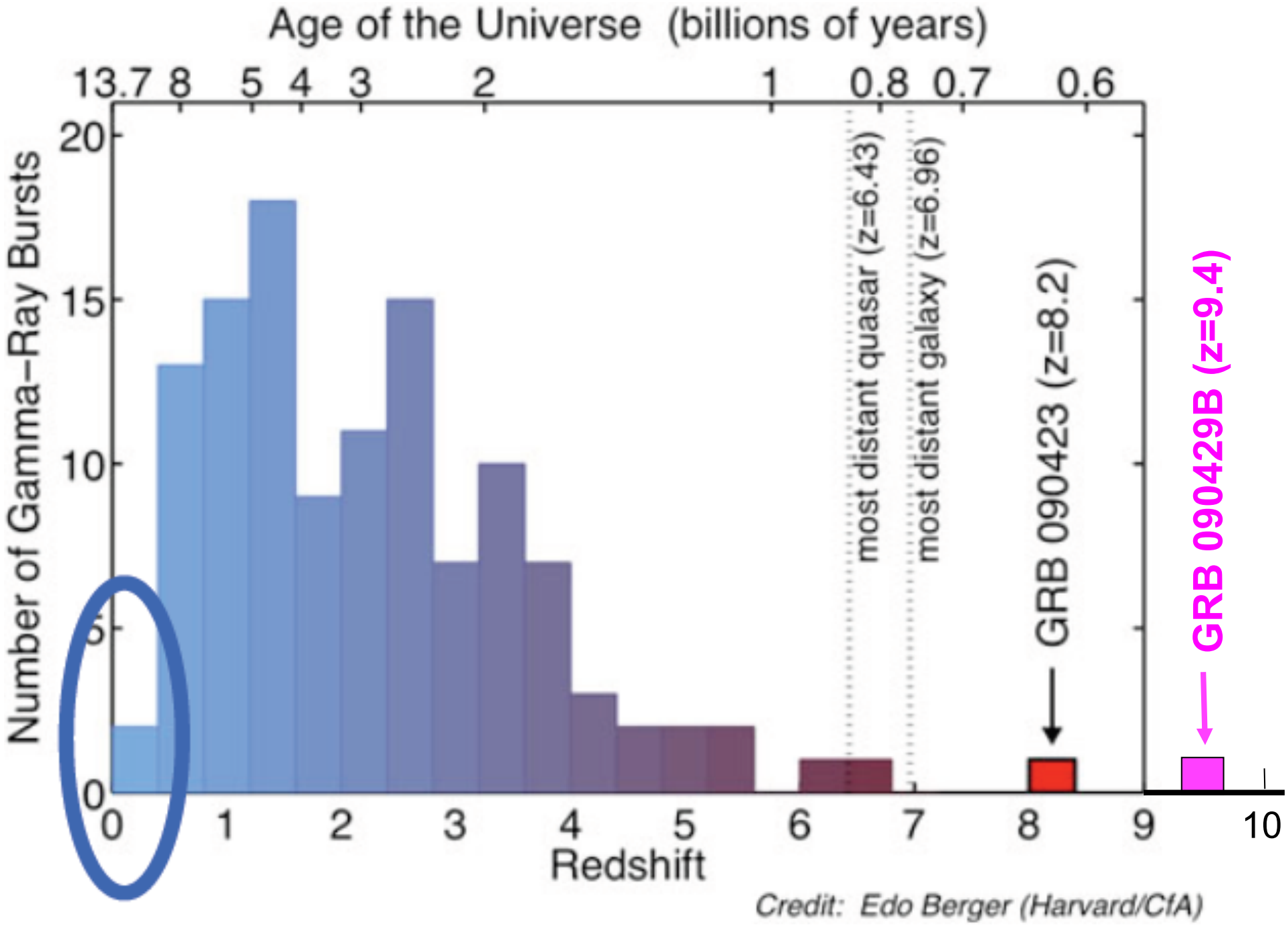


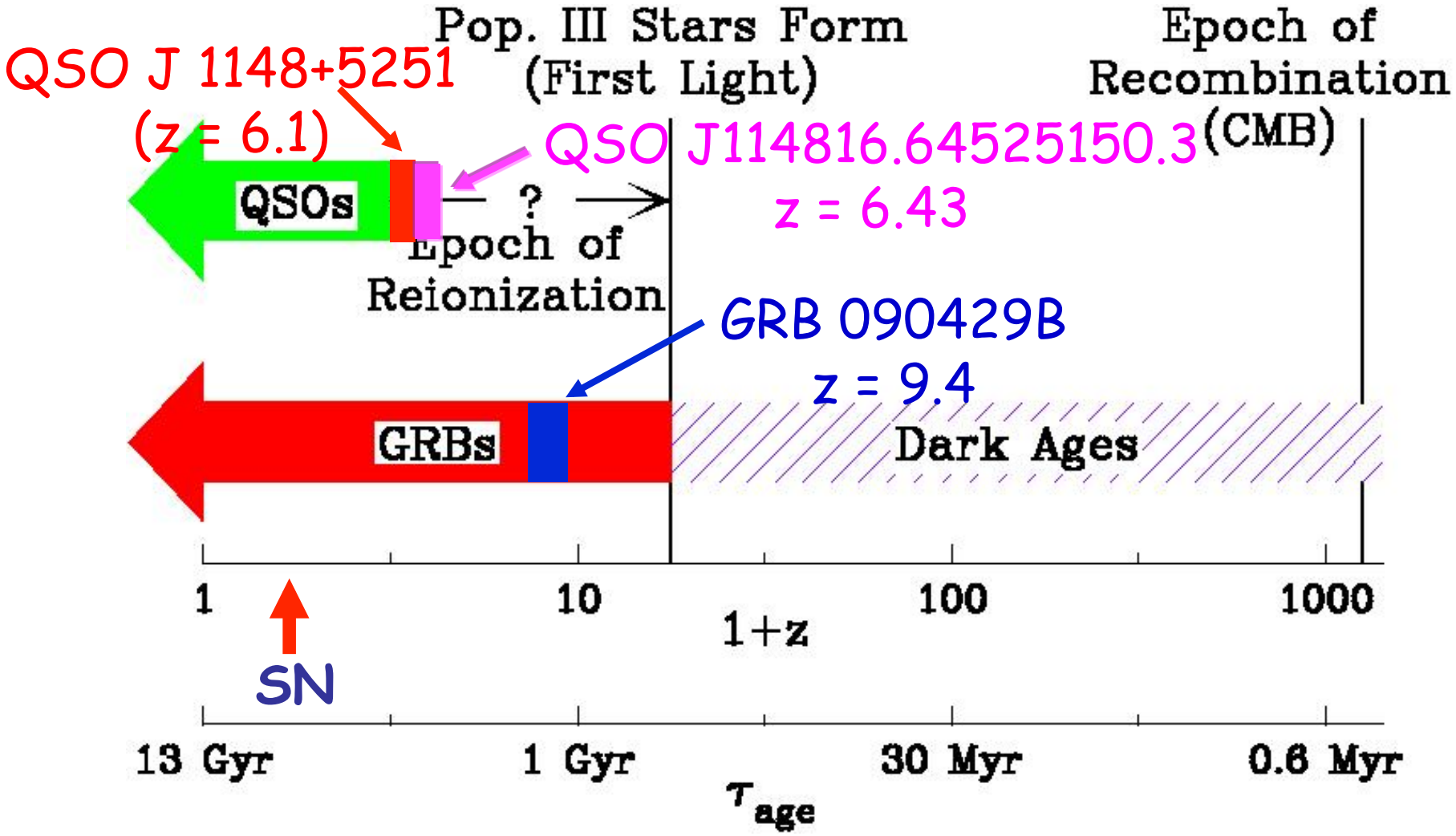
SWIFT
Detection

z~9.4 !

(Cucchiara et al. 2011, ApJ 736, 7

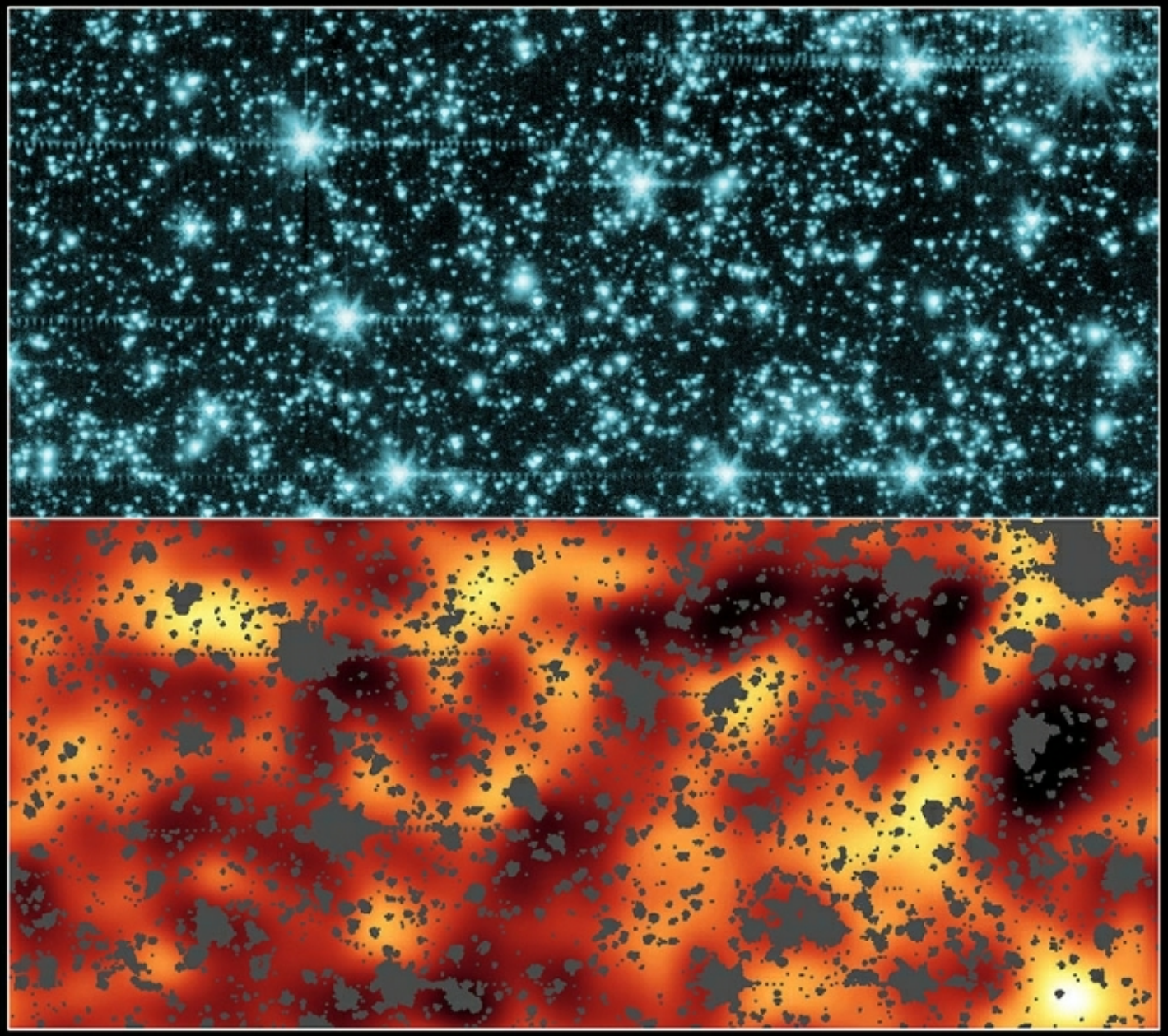
+ press releases of May 25)


Age of the Universe (billions of years)
13.7
8
5
4
3
2
1
0.8
0.7
0.6
Number of Gamma−Ray Bursts
20
15
10
0
0
1
2
3
4
5
6
7
8
9
10
Redshift
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
GRB 090429B (z=9.4)
Credit: Edo Berger (Harvard/CfA)



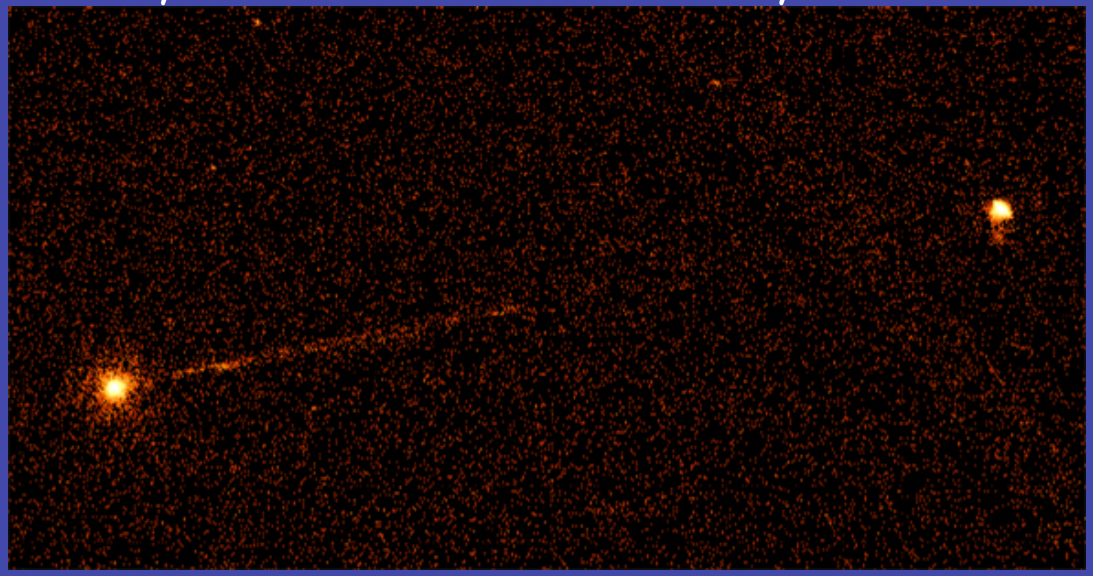
GRBs are believed to be detectable out to very high redshifts up to $z \sim 25$ (the first stars: Lamb & Reichart 2000; Ciardi & Loeb 2000; Bromm & Loeb 2002). SNe Ia are detected only at redshifts of $z \sim 1.7$.

Inhomogeneity in I.R. background suggests the existence of the old Population III stars

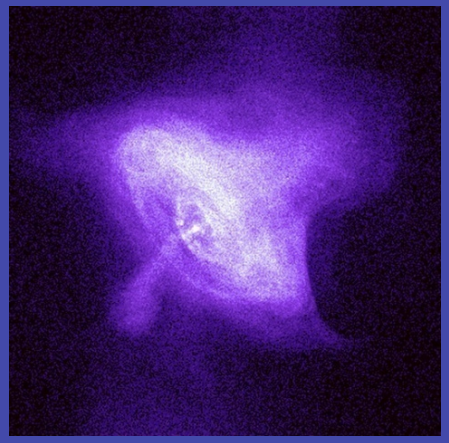


Every object rotating with adequate energy produces a jet

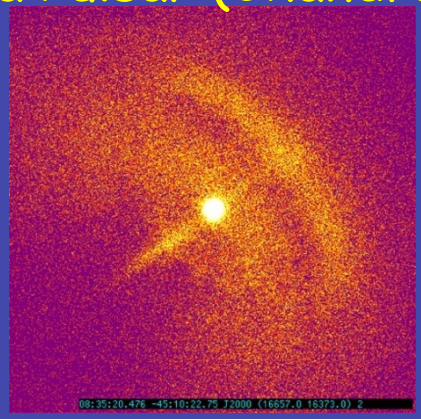
X-Ray Jet in the Radio Galaxy Pictor A



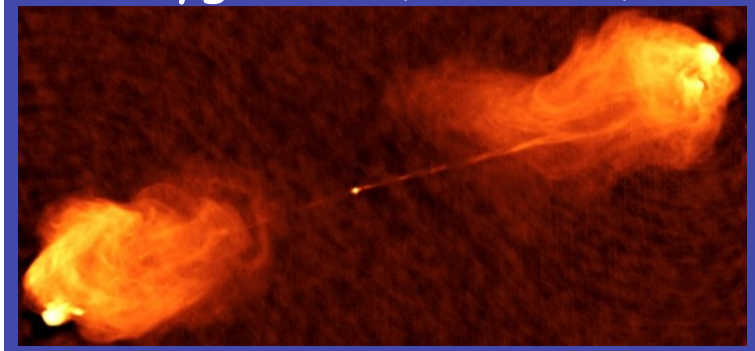
Crab Nebula (Chandra)



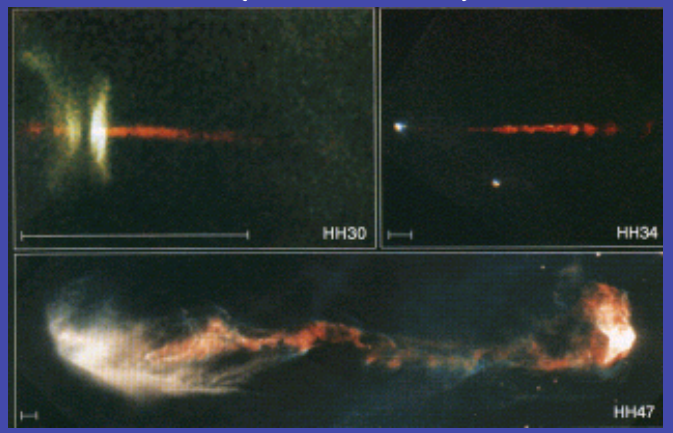
Vela Pulsar (Chandra)



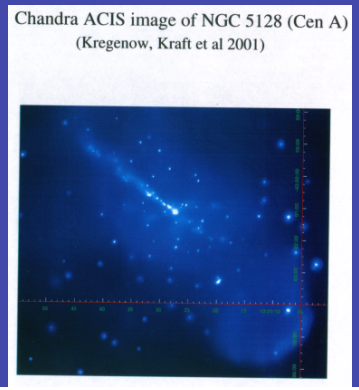
Cygnus A (Chandra)



HH (Chandra)

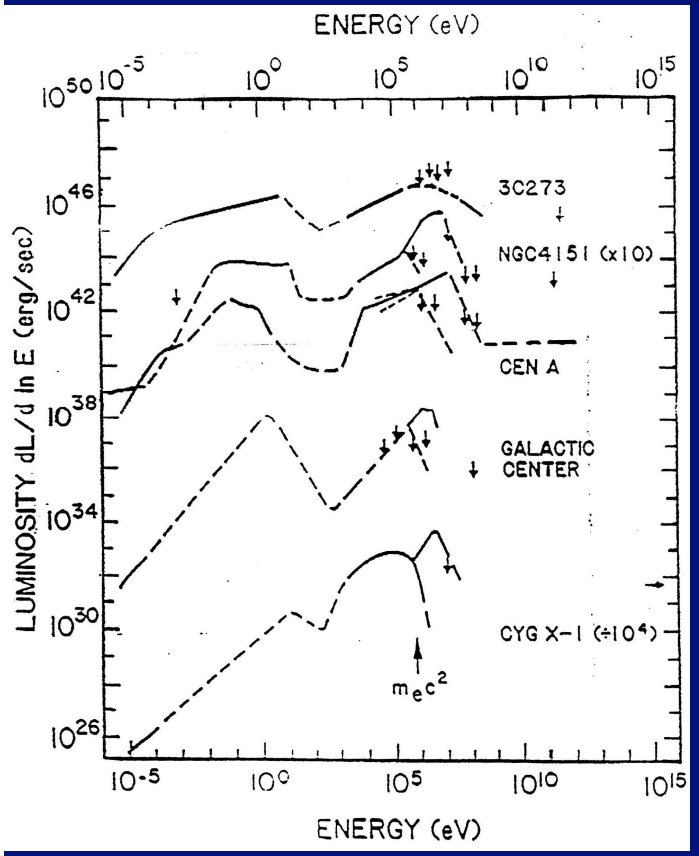


Cen A (Chandra)



In cosmic sources if the energy is produced by the same kind of engine ....
There is ANALOGY among them
independent of the factor scales in masses and dimensions

AGNs & GALACTIC COLLAPSED OBJECTS: UNIFIED SCHEME



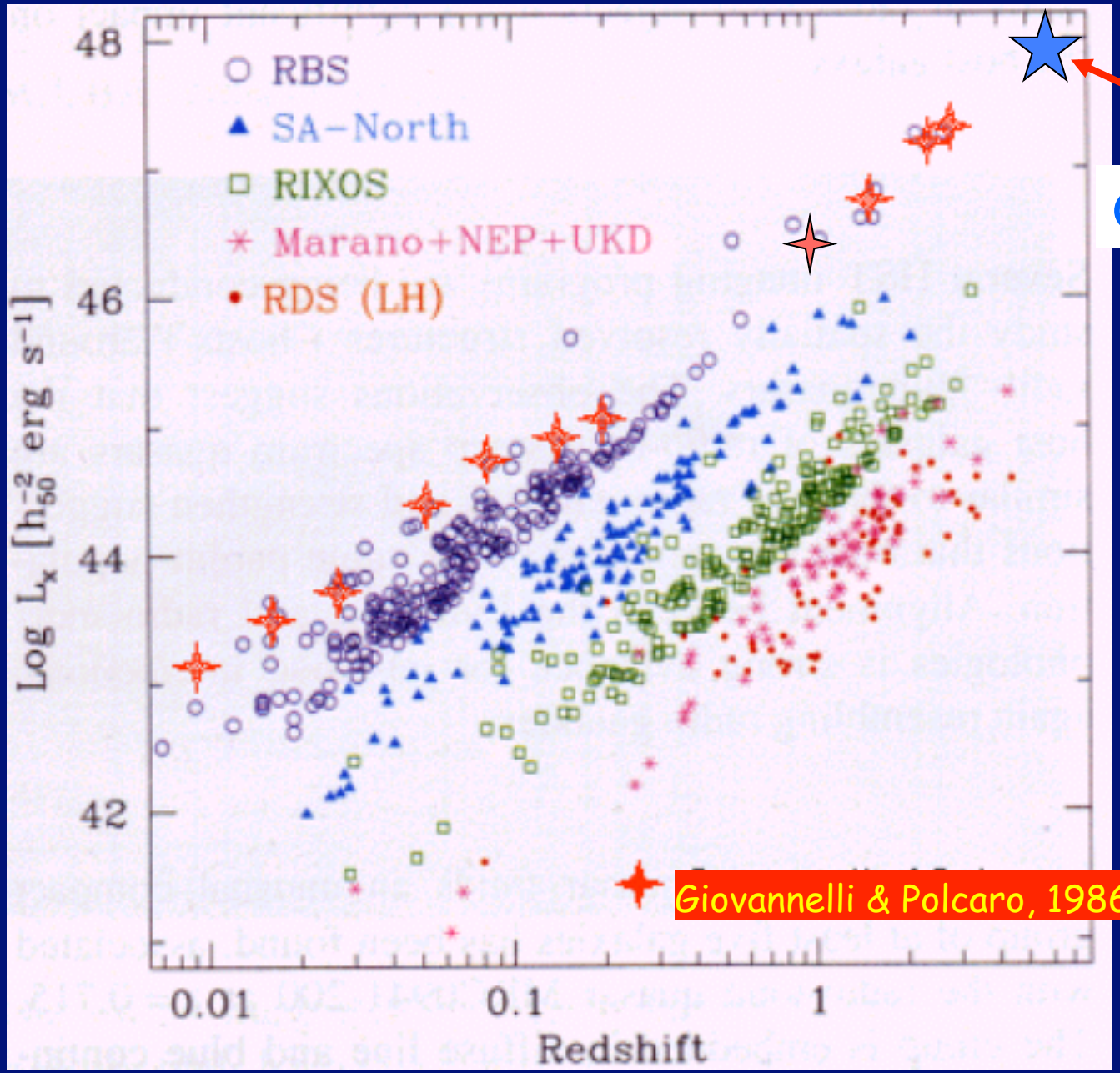
- THE MAIN IDEA (now very popular): ENGINE PRODUCING HIGH ENERGY RADIATION IS OF THE SAME KIND FOR ALL EXTRAGALACTIC EMITTERS (Giovannelli & Polcaro, 1986).
- DIFFERENCES IN MASS AND MASS ACCRETION RATES ⇒ ANALOGY CAN BE EXTENDED UNTIL GALACTIC BLACK HOLES.

- THE EMISSION OF EXTRAGALACTIC X-RAY SOURCES IS:

$$L_{TOT} = L_{NUC} + L_{HGC}$$

L_{NUC} = TOTAL NUCLEAR LUMINOSITY

L_{HGC} = HOST GALAXY COMPONENT (from discrete sources)

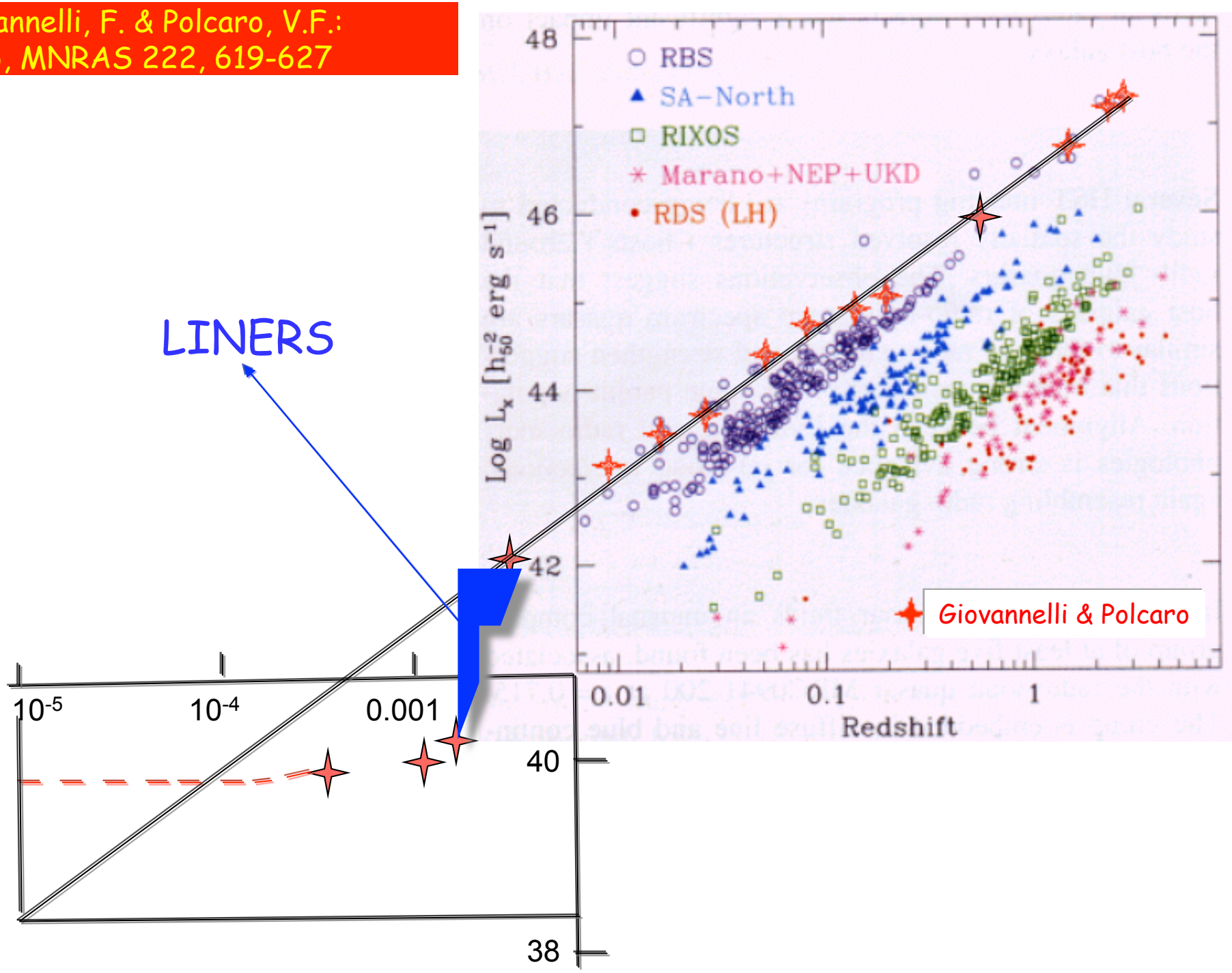


QSO J 1148+5251

Expected (2 KeV)
$L_x \sim 7 \times 10^{47}$ erg s^{-1}

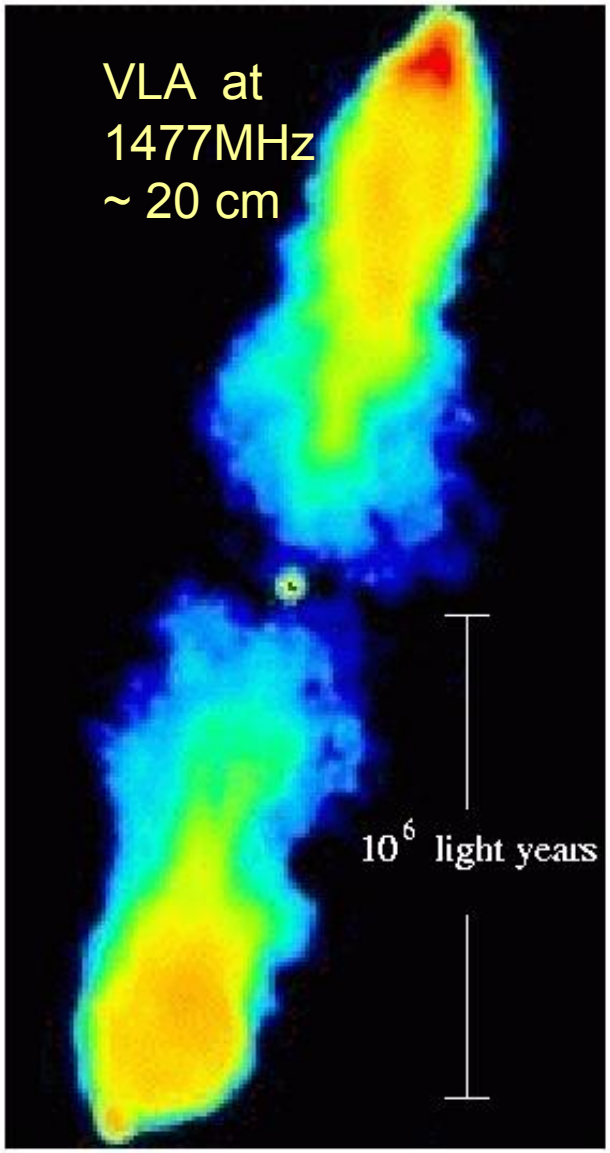
Giovannelli & Polcaro, 1986, MNRAS 222, 619-627

Giovannelli, F. & Polcaro, V.F.:
1986, MNRAS 222, 619-627

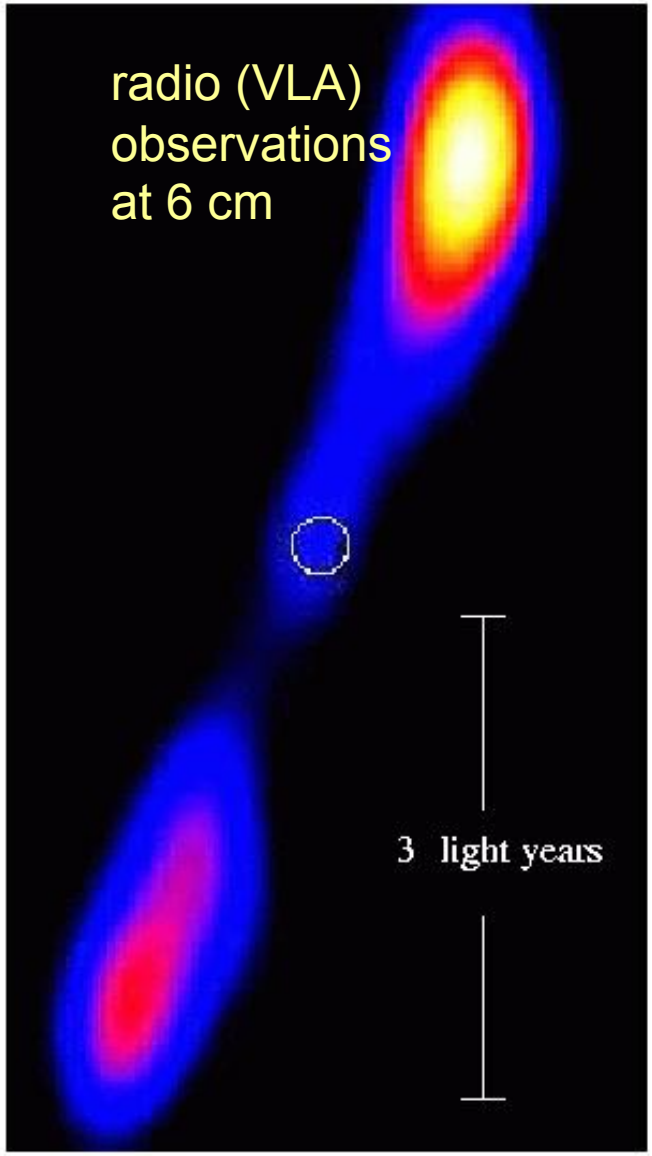


QUASARS → MICROQUASARS

Quasar 3C 223



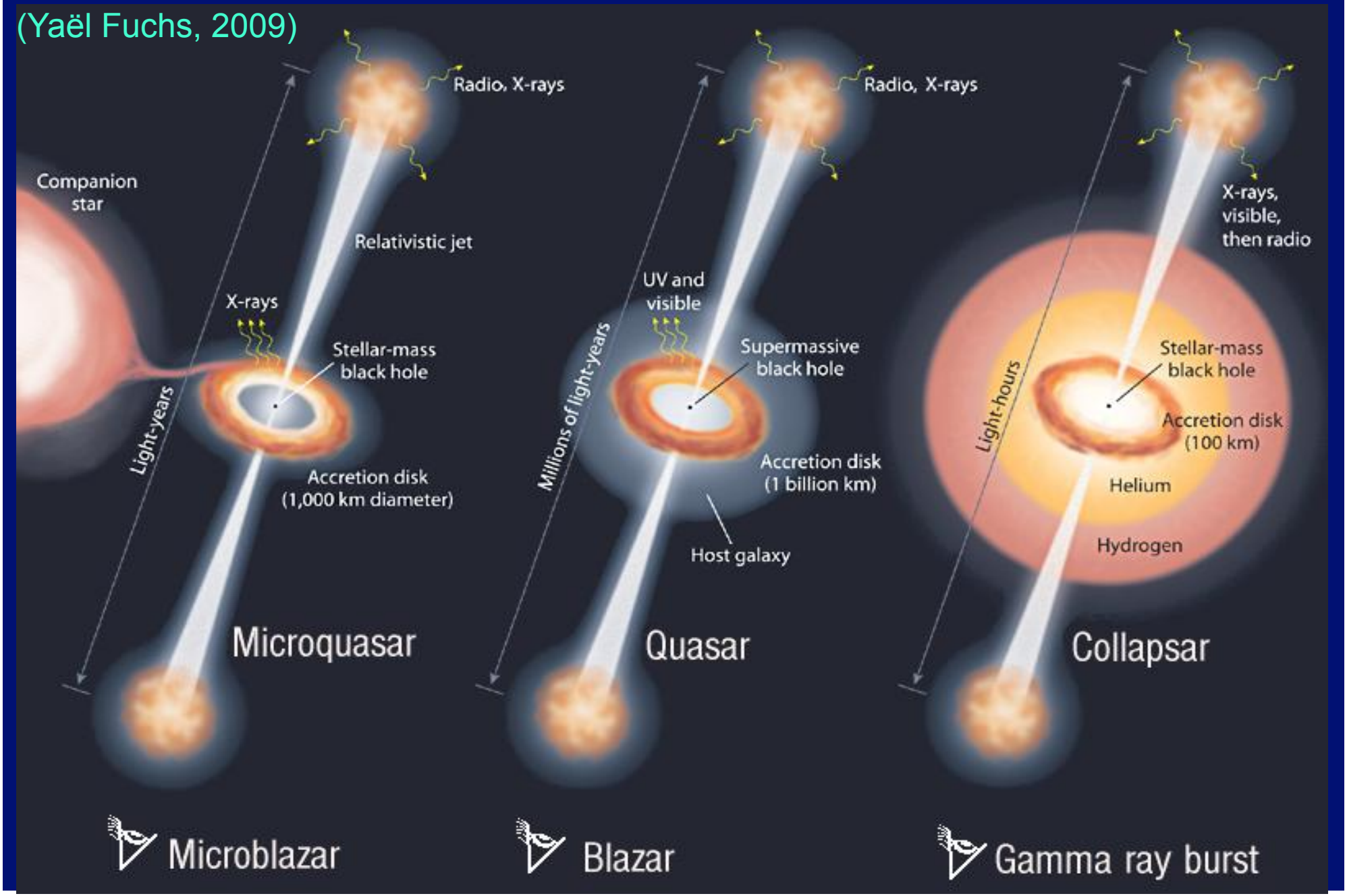
Microquasar 1E1740.7-2942



(Mirabel et al. 1992)

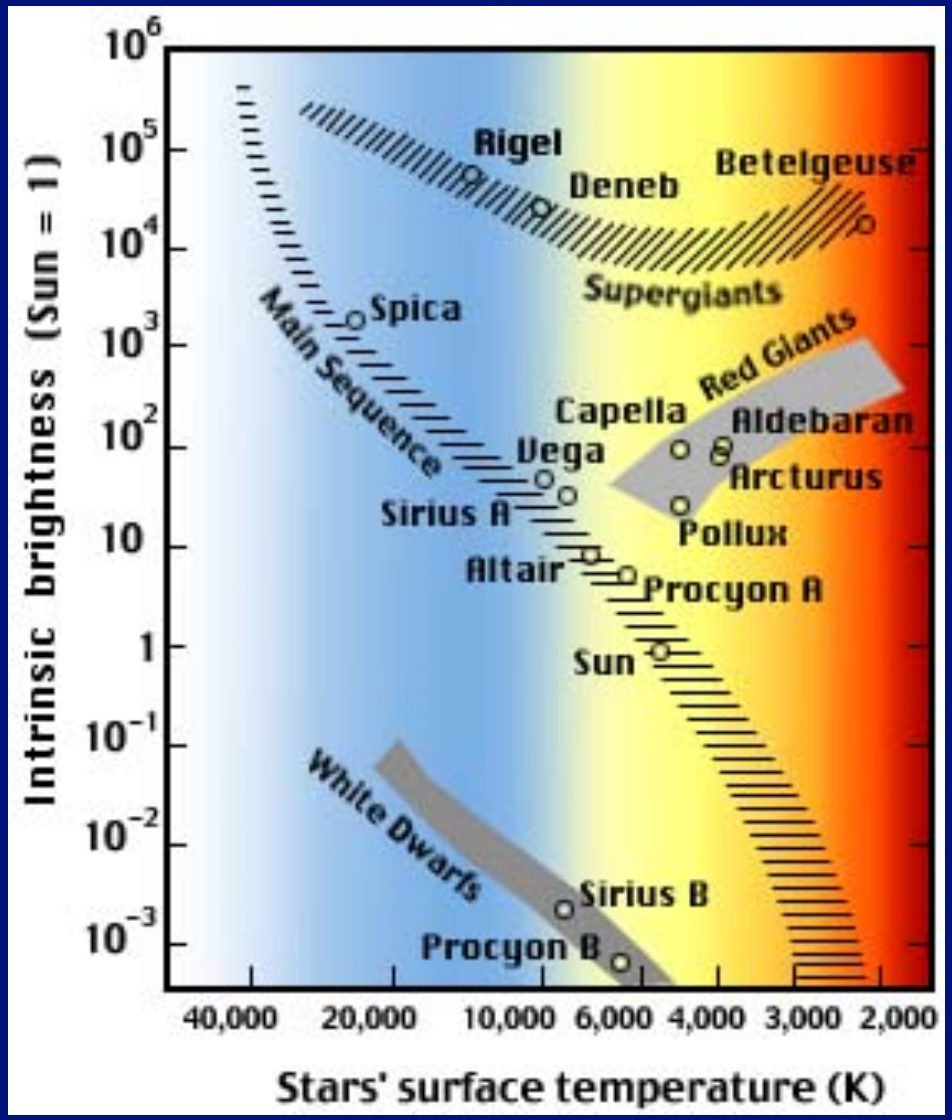
MICROQUASAR / QUASAR / GRB ANALOGY

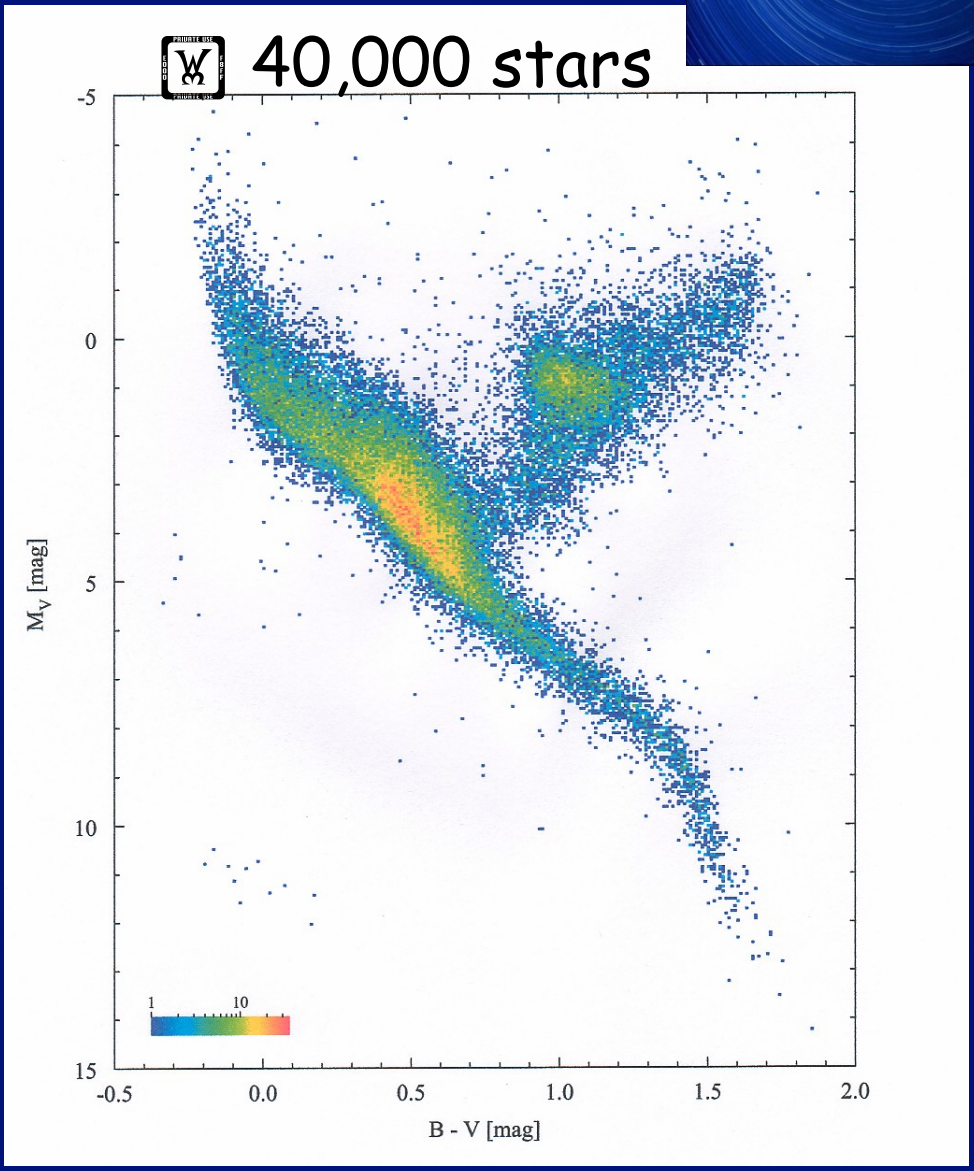
(Yaël Fuchs, 2009)

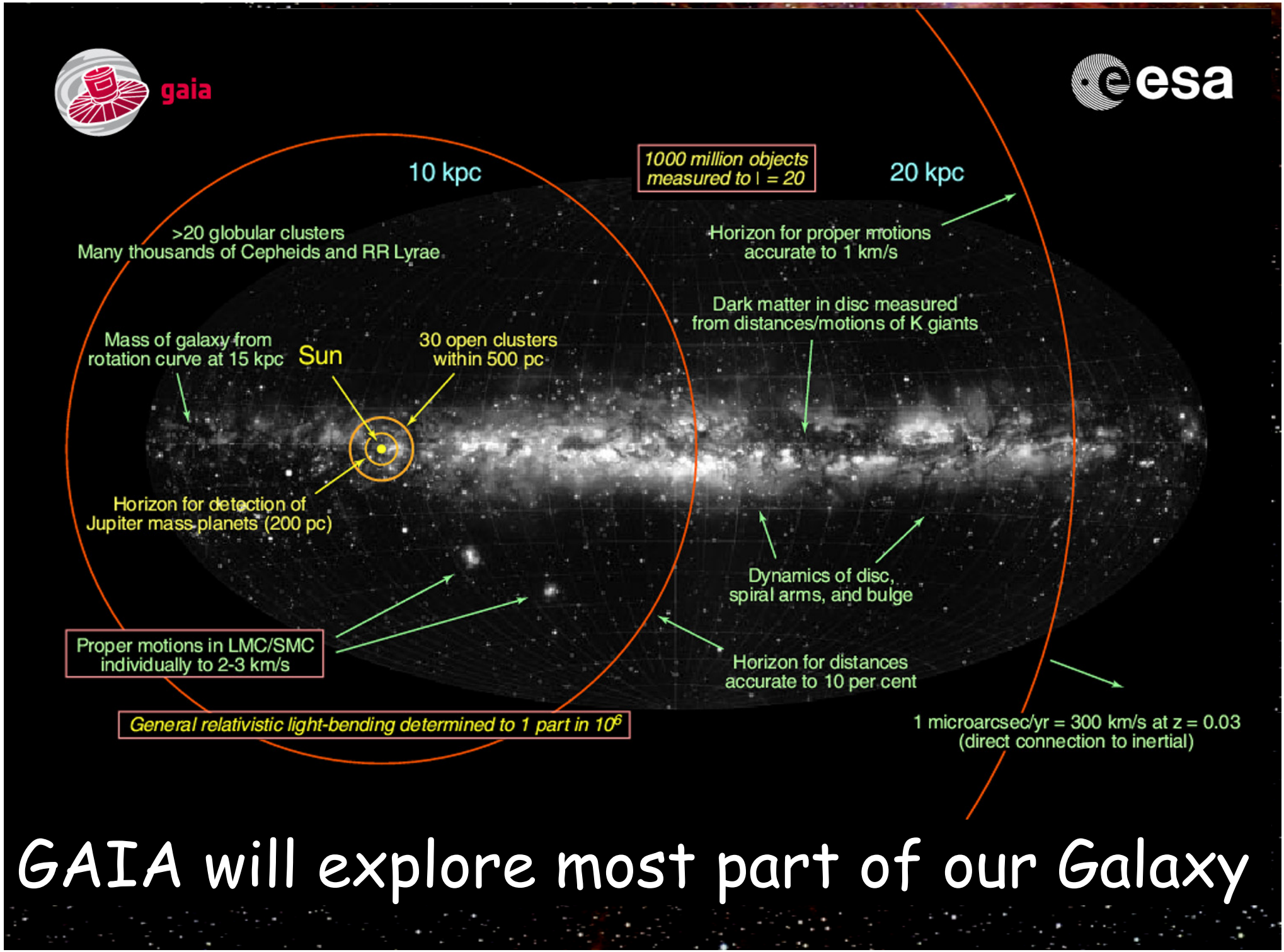


Chronicle of the Galaxy

The first H-R diagram constructed with measured distances (HIPPARCOS)

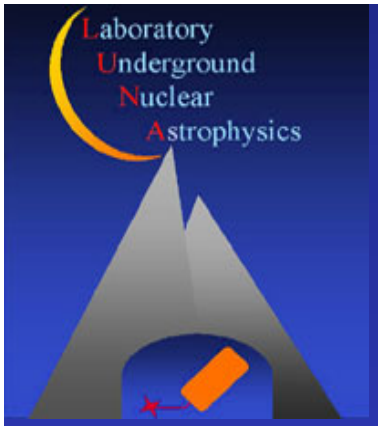




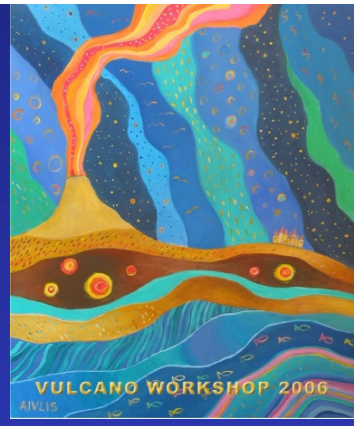


GAIA will explore most part of our Galaxy

Nuclear Astrophysics



Laboratory Underground Nuclear Astrophysics



Measurements of nuclear cross sections of interest in BBN with the LUNA experiment

- BBN and the "Precision Cosmology" Epoch
- The LUNA experiment
- $P(D,\gamma)^3He$
- $^3He(D,p)^4He$ } 50 kV accelerator
- $^3He(^4He,\gamma)^7Be$ In progress!!
- $D(^4He,\gamma)^6Li$ (leading process for the ^6Li production) } 400 kV accelerator

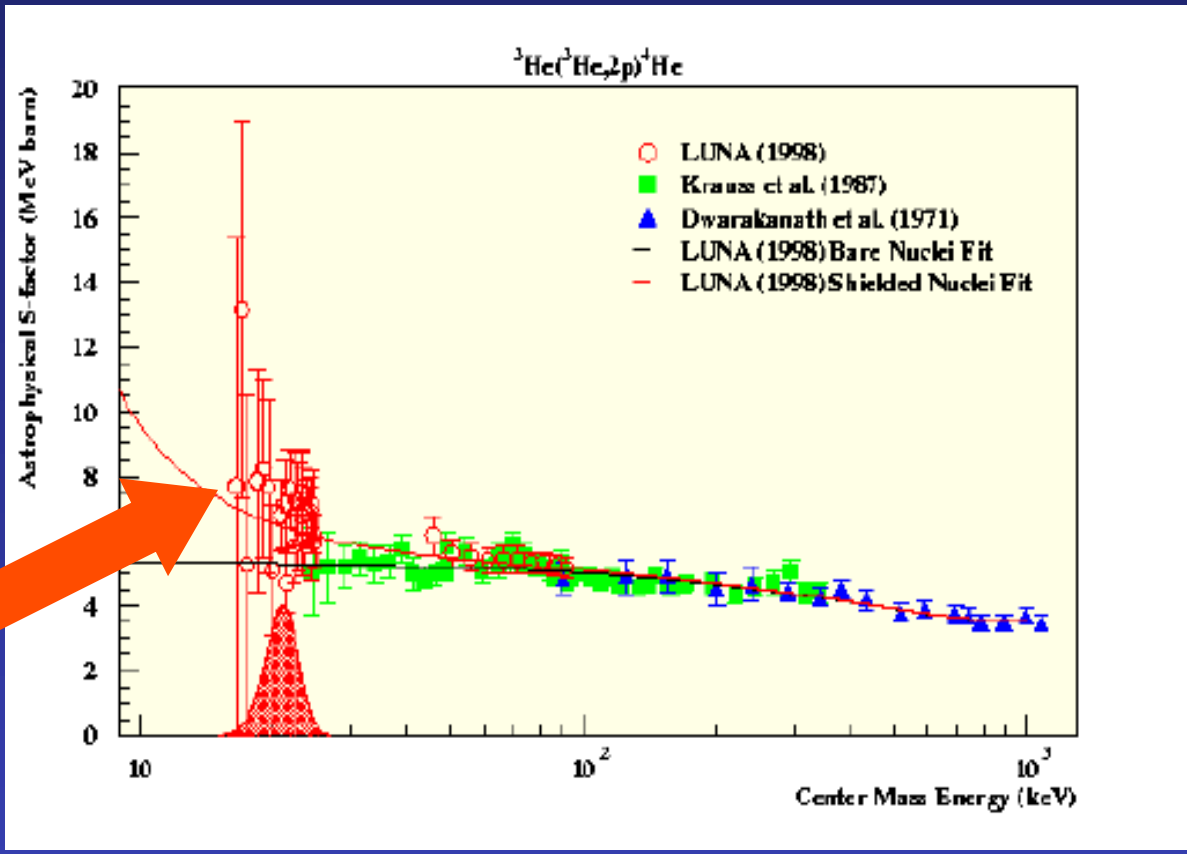
Carlo Gustavino (2006)
For the LUNA collaboration

$^3He(^3He;2p)^4He$

S(0) = 5.32 MeV barn

σ_{min} = 0.02 pb

2 events/month !

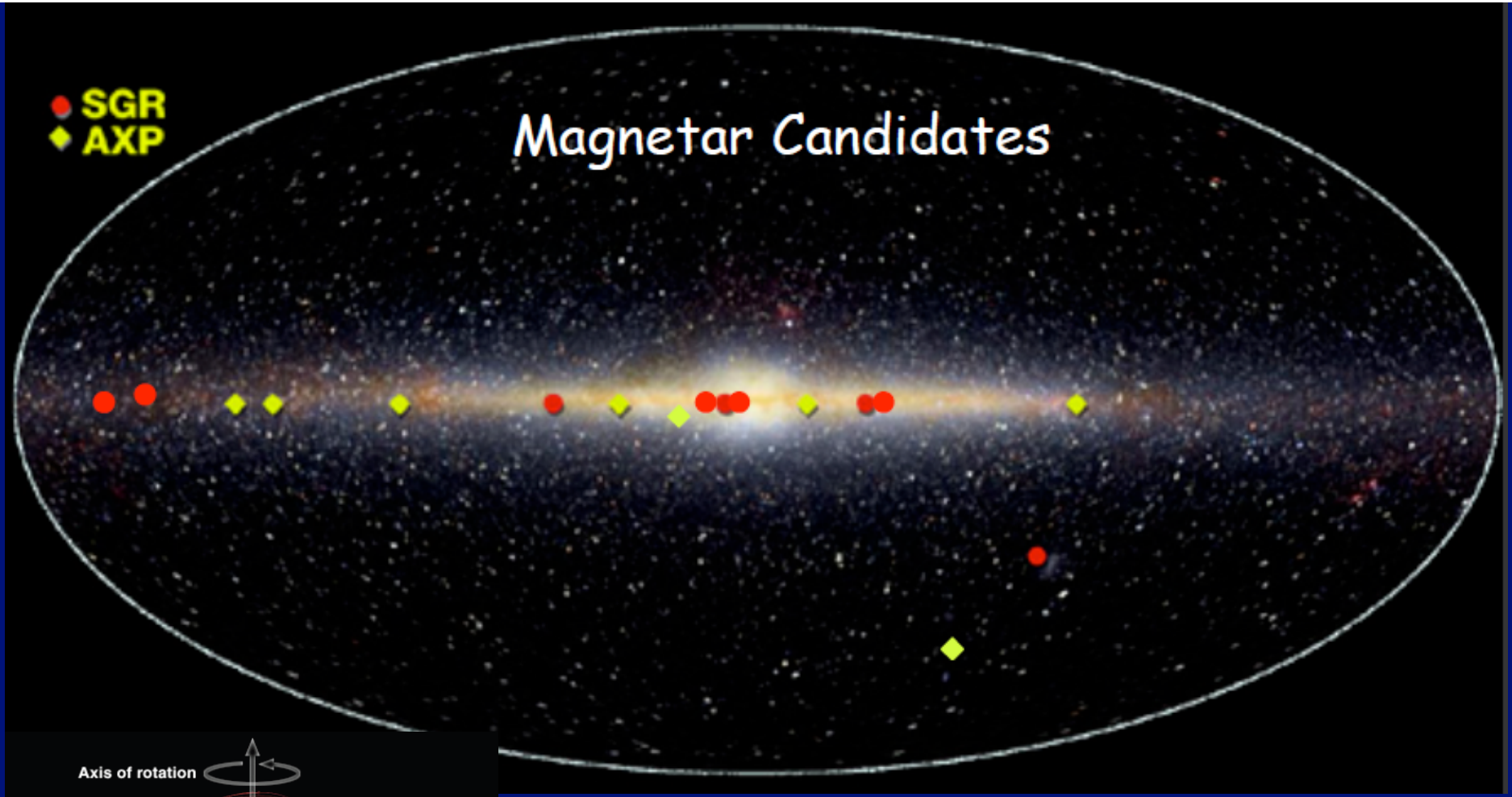


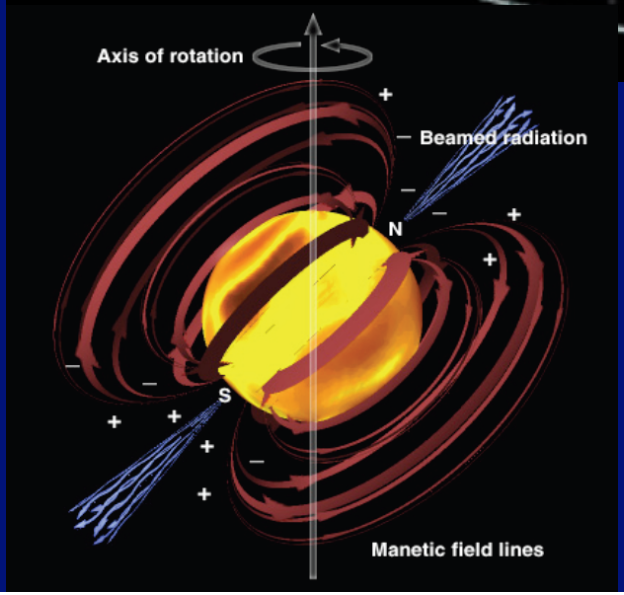
J. Bachall: "Historical breakthrough"

Dear Professors Corvisiero and Rolfs:

I am writing to you about a historic opportunity of which I first became aware at the recent meeting on Solar Fusion Reactions at the Institute of Nuclear Theory, Washington University. At this meeting, I had the opportunity to see for the first time the results of the LUNA measurements of the important $3He - 3He$ reaction in a region that covers a significant part of the Gamow energy peak for solar fusion. This was a thrill that I had never believed possible. These measurements signal the most important advance in nuclear astrophysics in three decades.

If magnetars exist….
And they do exist….
We must accept all the consequences





B 10^{15} Gauss

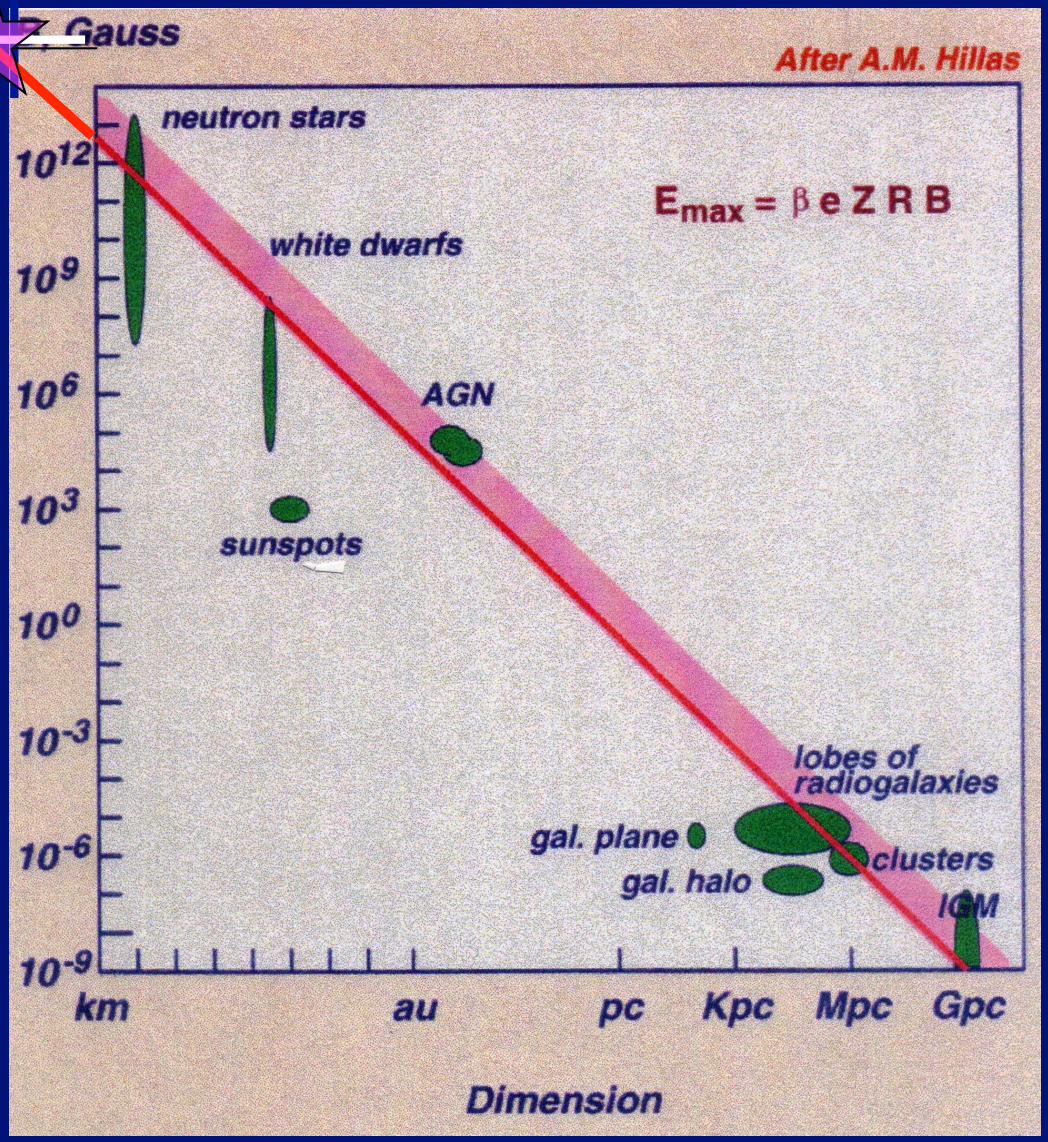
(Von Kienlin, 2010)

10 m: acceleration zone

10^{15} Gauss

Quark Stars ?

Are Black Holes strictly necessary ???

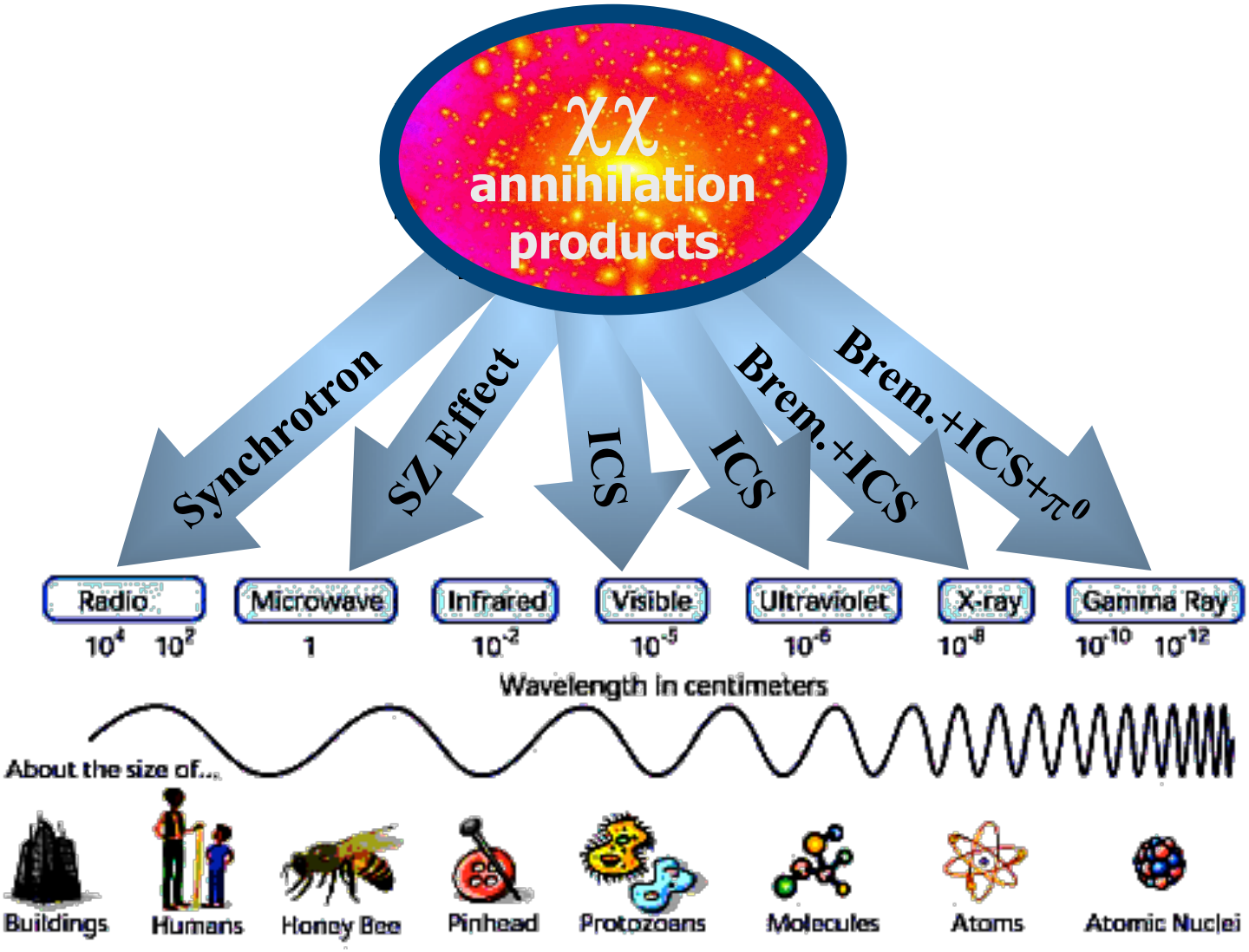


(Giovannelli & Sabau-Graziati, 2007)

(Courtesy of Todor Stanev)

Dark Matter

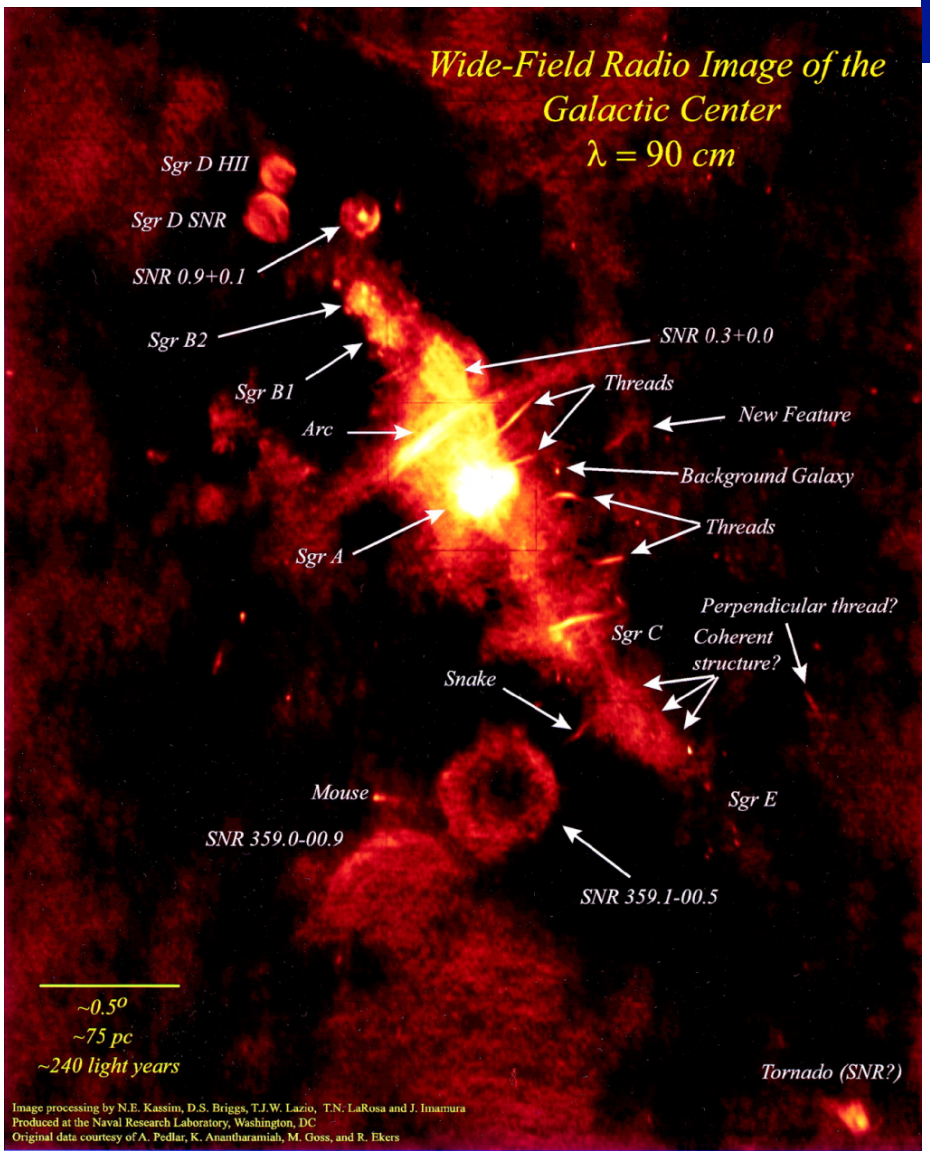
Covering the whole e.m. spectrum



(courtesy of Sergio Colafrancesco, 2006)

Targets for DM search

Highest DM density candidate
Close by
Not extended



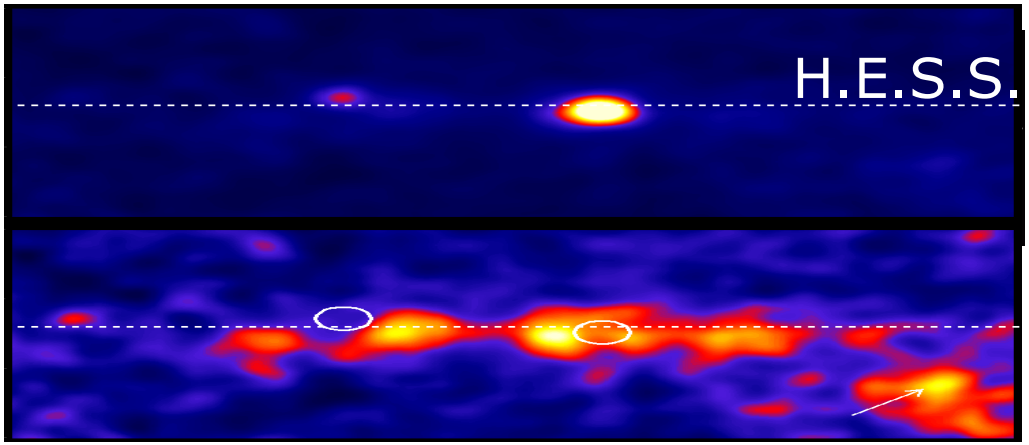
(LaRosa, T.N. et al.: 2000, AJ 119, 207)

Galactic Center

Distance (7.5 kpc) →
GC best candidate for indirect DM searches ?

BUT:

- other γ-ray sources in the FOV, i.e. SNR Sgr A East



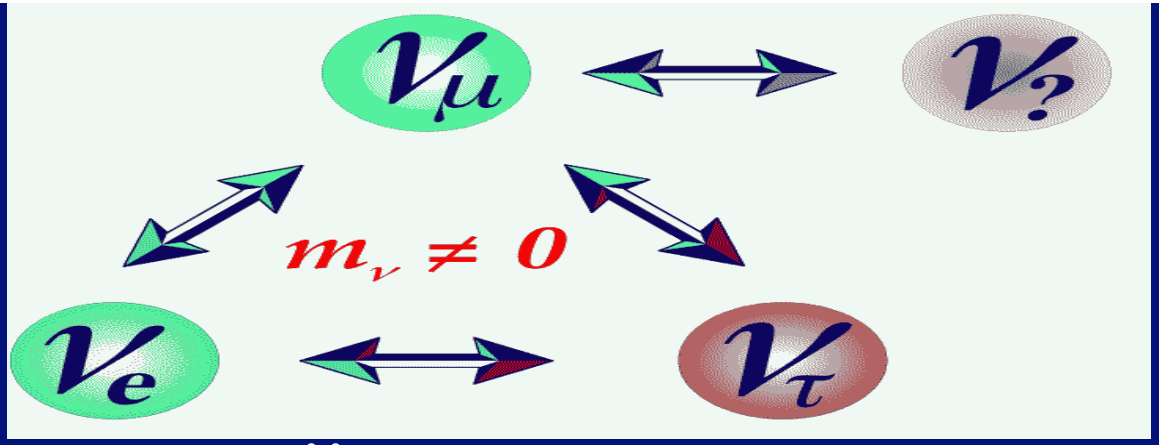
- competing plausible scenarios
- halo core radius: extended vs point-like

Dark Energy

???????

HIC SUNT LEONES

What about neutrinos ?



(Luca Stanco, 2010)

Neutrino oscillations are consistently described by three families ν_1, ν_2, ν_3 with mass values m_1, m_2 and m_3 that are connected to the flavor eigenstates ν_e, ν_μ and ν_τ by a mixing matrix U. The neutrino oscillation probability depends on three mixing angles, θ_{12}, θ_{23}, θ_{13}; two mass differences,

$\Delta m^2_{12} = m^2_2 - m^2_1$, $\Delta m^2_{23} = m^2_3 - m^2_2$,

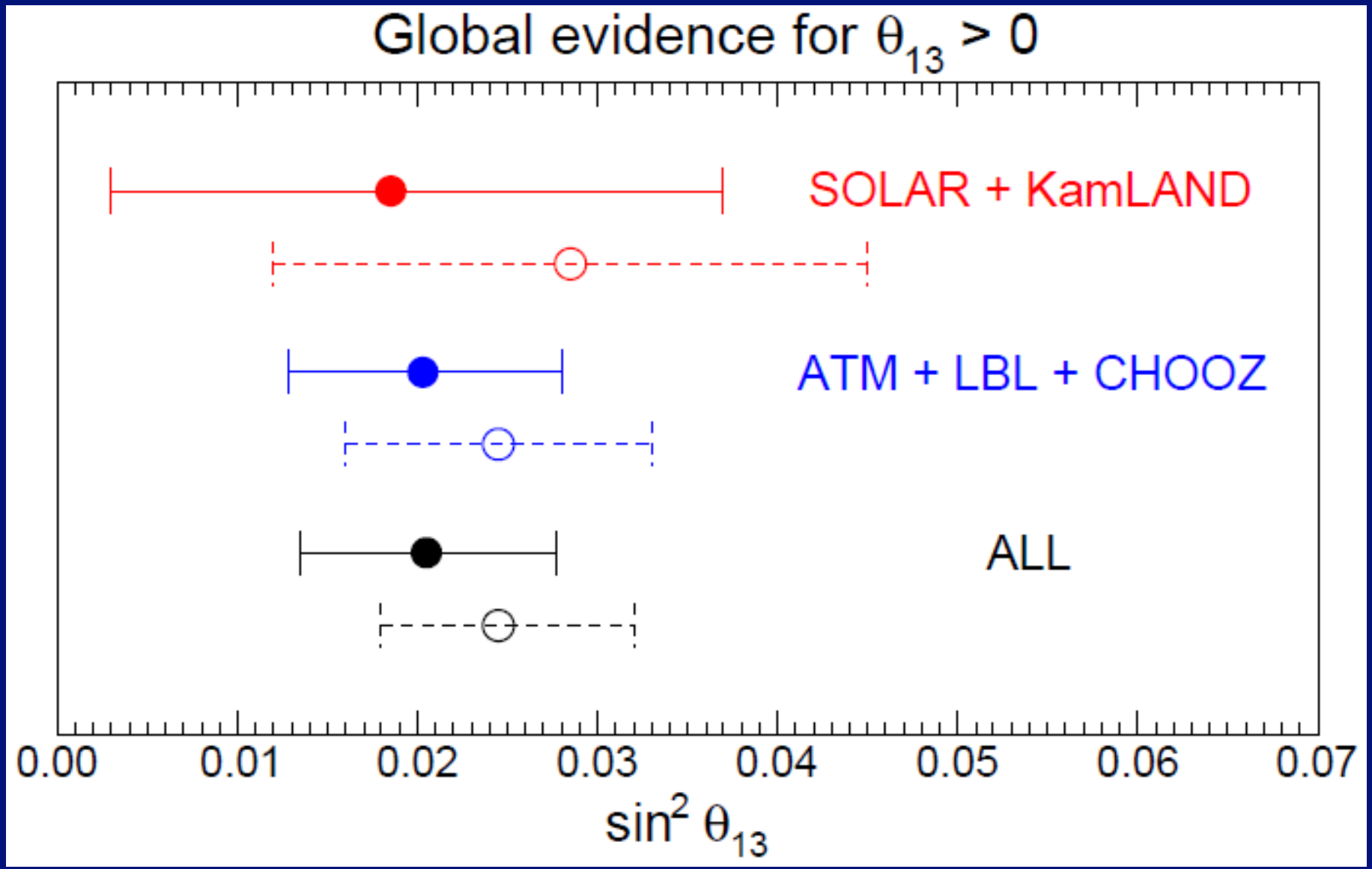
and a CP phase δ_{CP}.

The possibility of measuring CP violation can be fulfilled only if the value of the neutrino mixing parameter θ_{13} is such that $\sin^2(2\theta_{13}) \gtrsim 0.01$.

Osc. type	Neutrinos	Experiments
θ_{12}	ν_e (solar, reactors)	SNO, SK, Borexino, Kamland
θ_{23}	ν_μ (atmospheric,accelerators)	SK, Minos, T2K
θ_{13}	ν_e (reactors)	Daya Bay, Reno, Double Chooz
θ_{14}	ν_e (reactors, radioactive sources)	SBL Reactors, Gallex, Sage. **This Proposal**
θ_{24}	ν_μ (accelerators)	CDHS, MiniBooNE. **This Proposal**

Table XXXVIII. Measurements of the mixing angle as provided by different experiments.

Light Sterile Neutrinos: A White Paper (Abazajian_etal.: 2012, arXiv:1204.5379v1)



(Fogli et al.: 2011, PhRevD 84e3007F)

parameter	best fit	2σ	3σ
$\Delta m^2_{21}\ [10^{-5} eV^2]$	$7.59^{+0.23}_{-0.18}$	7.22–8.03	7.03–8.27
$\lvert\Delta m^2_{31}\rvert\ [10^{-3} eV^2]$	$2.40^{+0.12}_{-0.11}$	2.18–2.64	2.07–2.75
$\sin^2\theta_{12}$	$0.318^{+0.019}_{-0.016}$	0.29–0.36	0.27–0.38
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$	0.39–0.63	0.36–0.67
$\sin^2\theta_{13}$	$0.013^{+0.013}_{-0.009}$	≤ 0.039	≤ 0.053

The evidence for $\sin^2 \theta_{13} \sim$ few % opens the door to CP violation searches in the neutrino sector, with profound implications for our understanding of the matter-antimatter asymmetry in the universe.

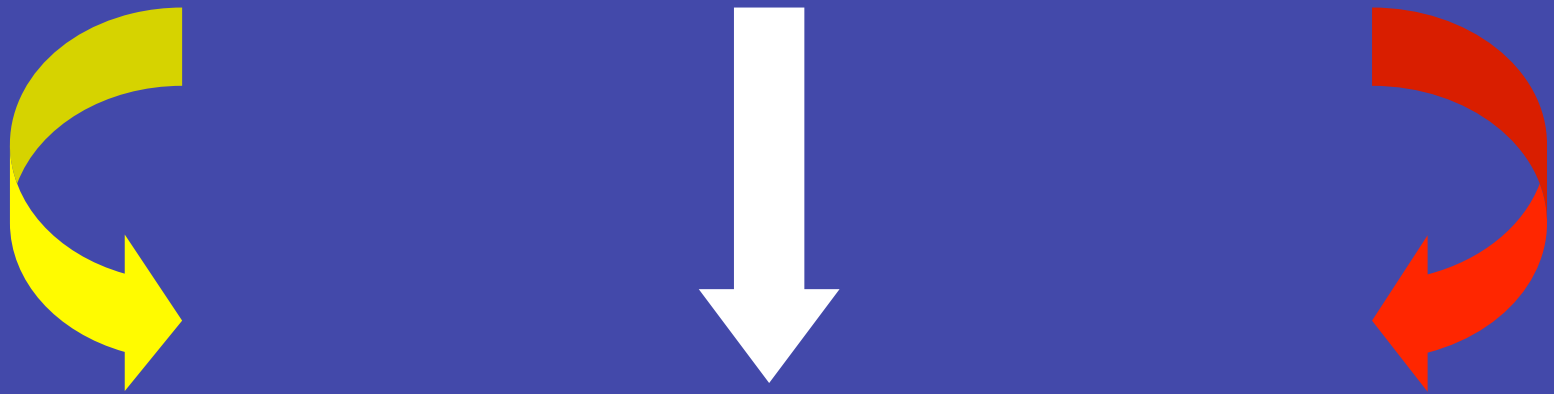
(Mezzetto, M.: 2011, Journal of Physics: Conference Series **335**, 012005)

PROSPECTS and CONCLUSIONS

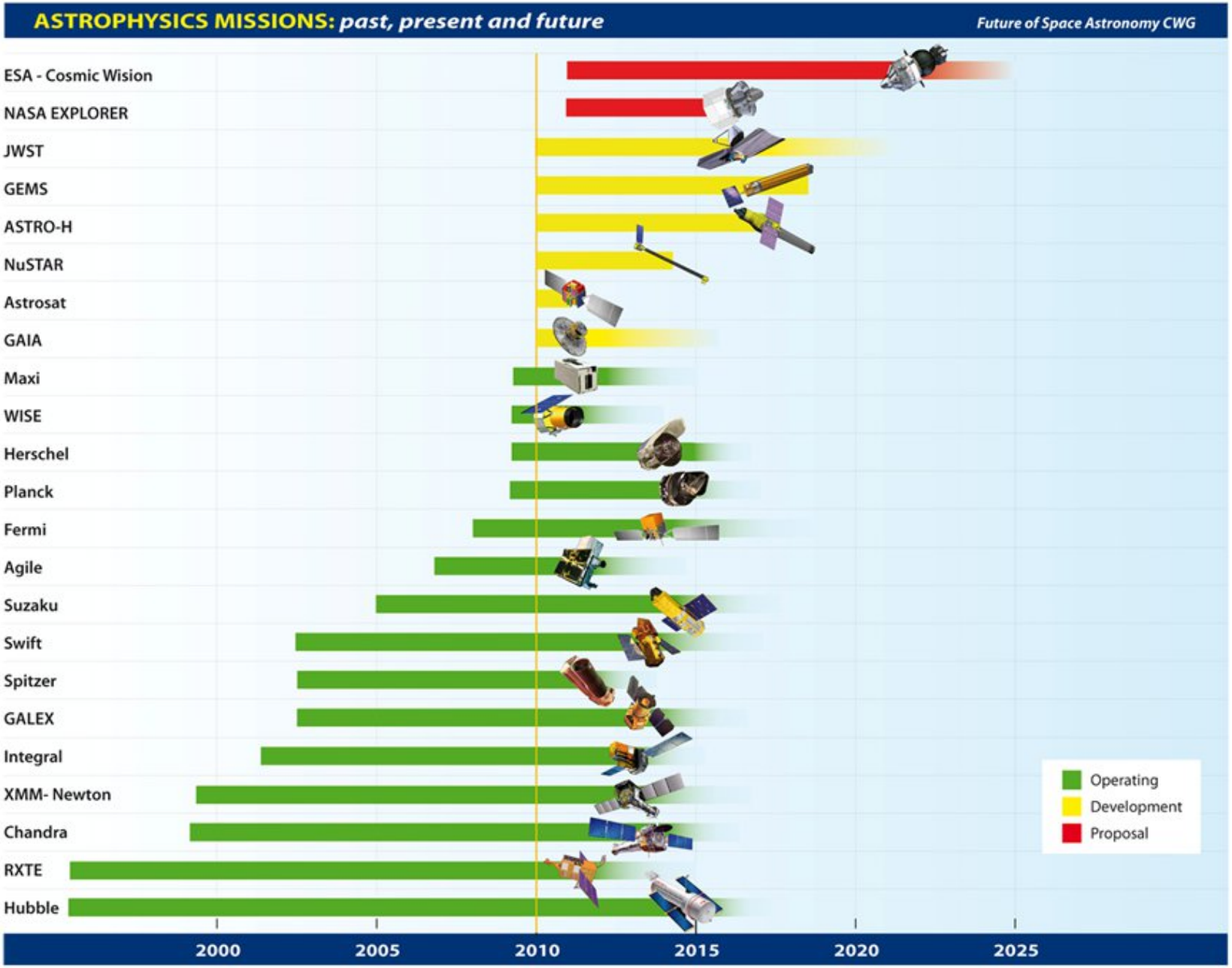
Photonic Astrophysics

Neutrino Astrophysics

Particle Astrophysics

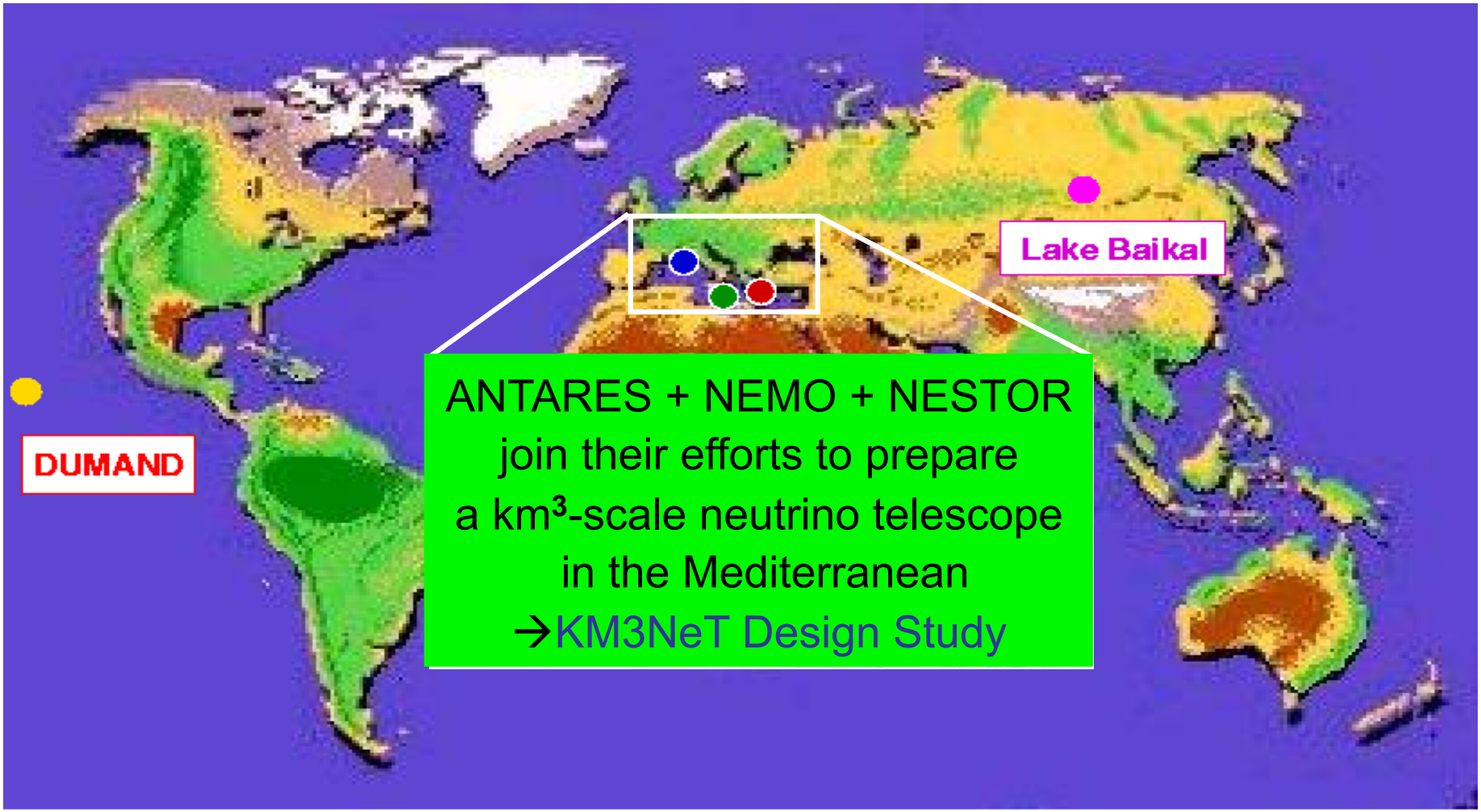


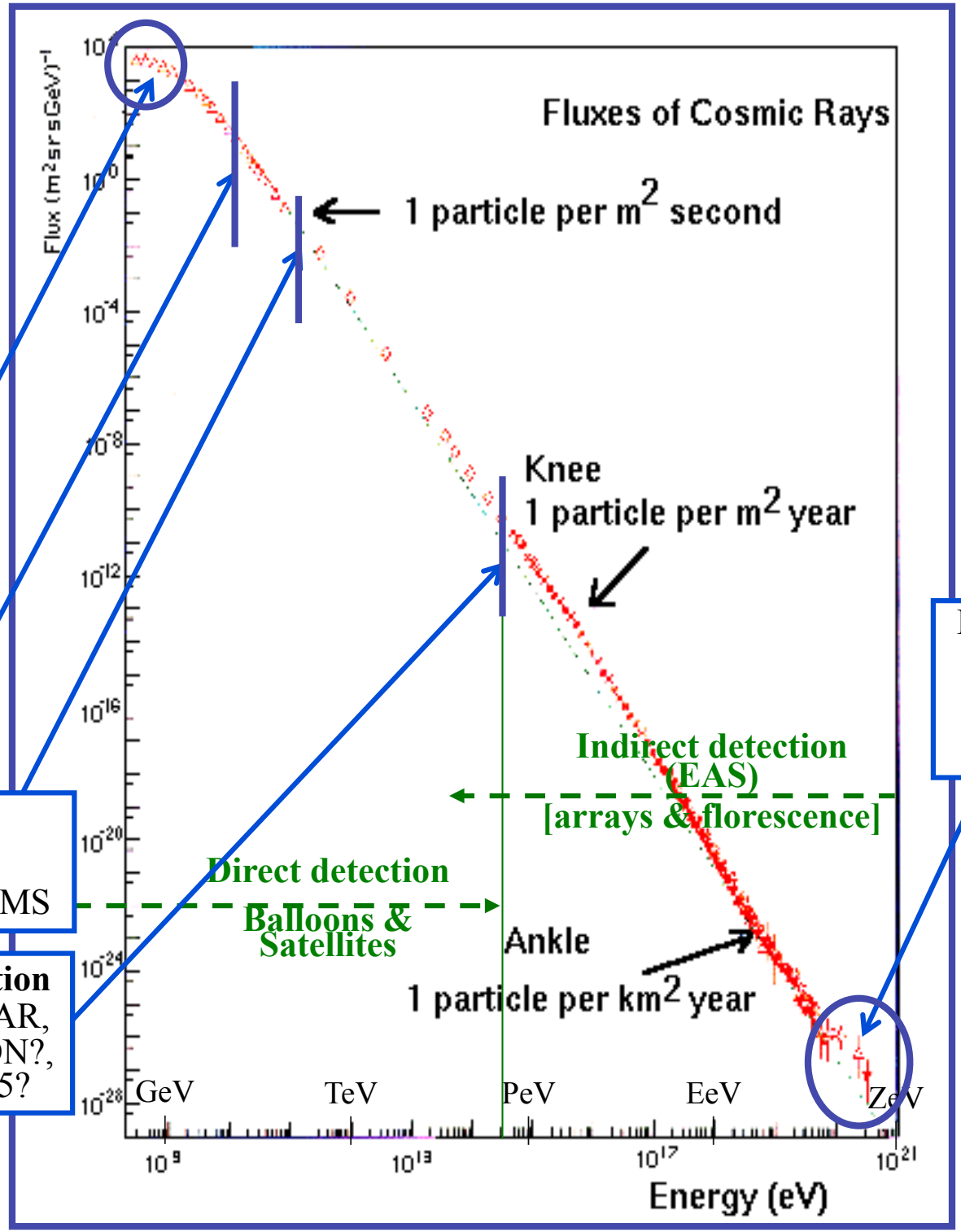
Astroparticle Physics



(Courtesy P. Ubertini, COSPAR Working Group – Report on Future of Space Astronomy, in press)

The Neutrino Telescope Worl Map





High Z
[ENTICE, ECCO]

Light elements and Isotopes
[ACE]

Antiparticles and Antinuclei
[BESS,PAMELA,AMS

Elemental Composition
[CREAM, ATIC, BEAR, ACCESS?, NUCLEON?, INCA?, PROTON-5?

Extreme Energy CR
[AUGER, EUSO, TUS, KLYPVE?, OWL??]

(Spillantini, 2008)

Many Thanks for Your Attention