PERSPECTIVES of

HIGH ENERGY NEUTRINO ASTRONOMY

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Vulcano
27 may 2006

High Energy Neutrino Astrophysics will **CERTAINLY** become an essential field in a New Multi-Messenger Astrophysics

What is under discussion is how long and difficult this road will be.

How Significant will be the results obtained with the Km3 Telescopes discussed in this Conference

PREDICTIONS
about what we will see looking out of
a "NEW WINDOW"
to observe the universe around us
are "dangerous"

Surprising results are:

possible

... indeed likely

... and in fact very desired

by all interested in the field

As a “WARNING”
for the audience

.....

and for myself

.....

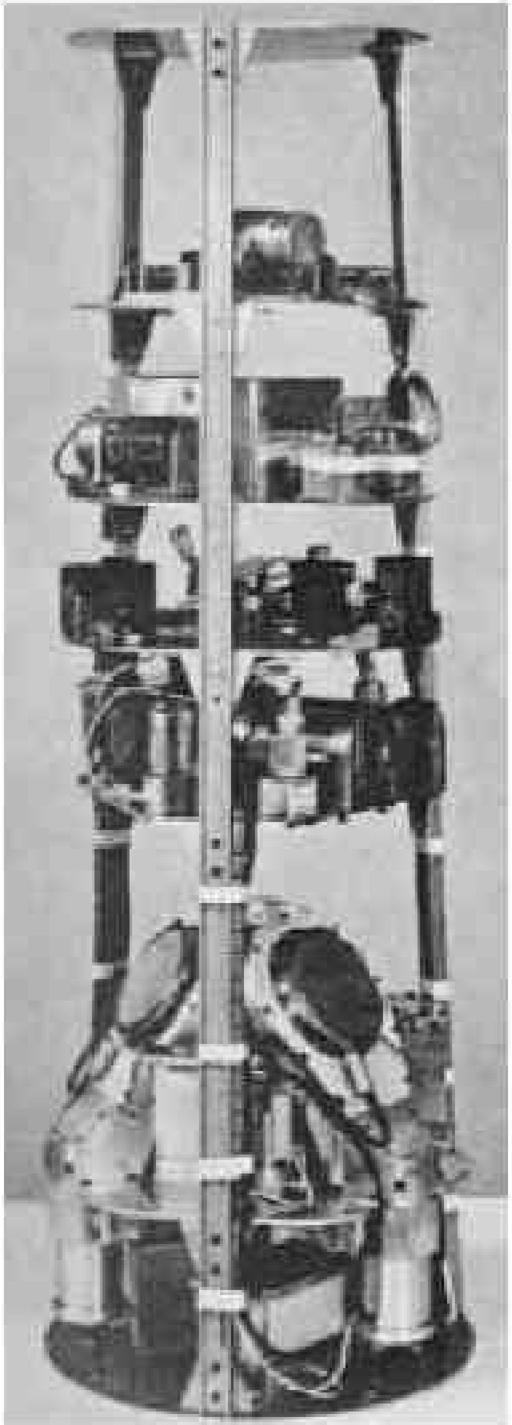
One example from
the History of Science :

The birth of X-ray Astronomy

June 12th 1962

BIRTH OF X-RAY ASTRONOMY

June 12 1962



PHYSICAL REVIEW LETTERS

VOLUME 9 DECEMBER 1, 1962 NUMBER 11

EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

Riccardo Giacconi, Herbert Gursky, and Frank R. Paolini
American Science and Engineering, Inc., Cambridge, Massachusetts

and

Bruno B. Rossi
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received October 12, 1962)

Figure 1. The payload of the June 12, 1962, AS&E rocket. From X-ray Astronomy (Eds. R. Giacconi and H. Gursky), 1974, Riedel, Dordrecht, p9.

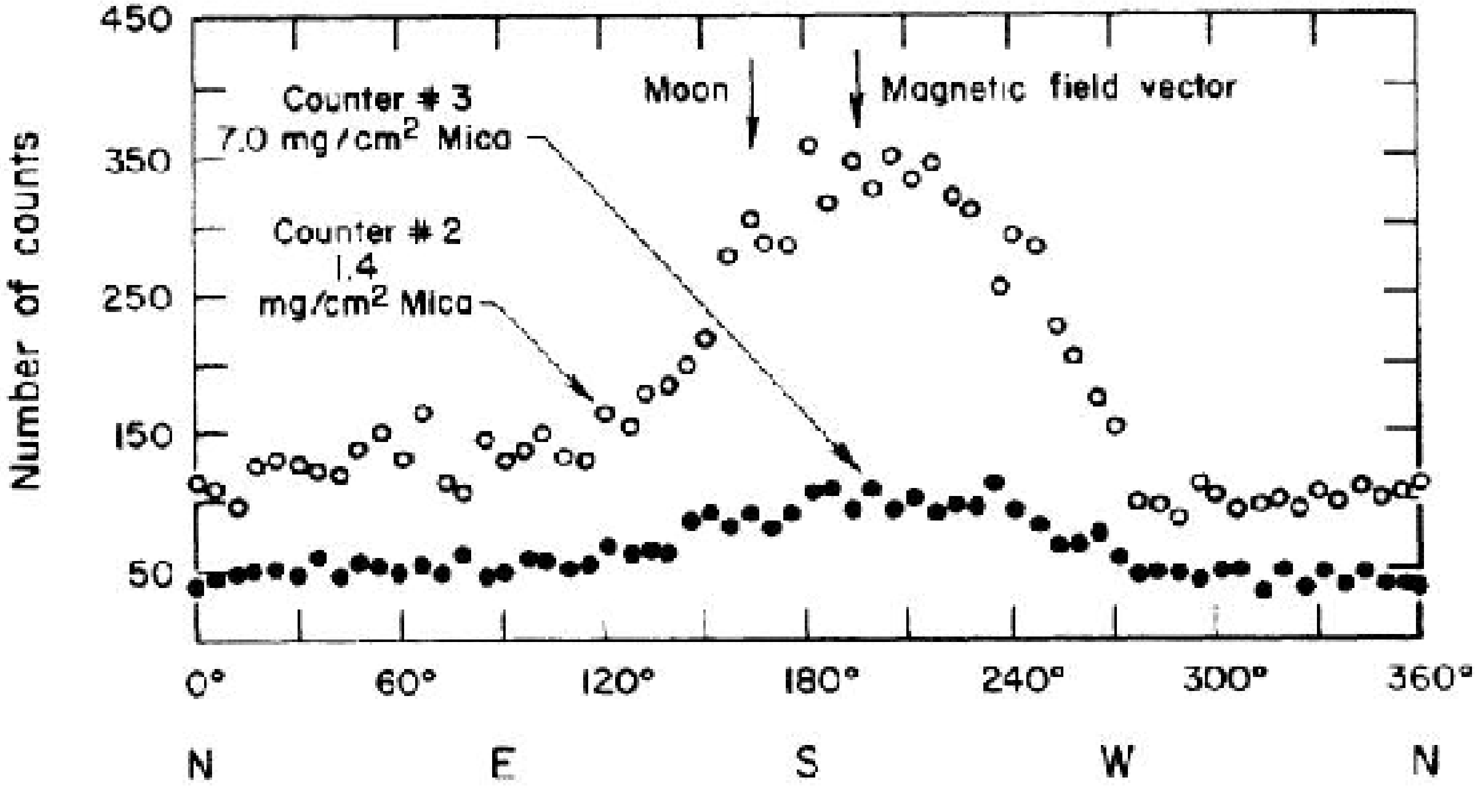


FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.

ONE GALACTIC SOURCE **SCO-X1**

Evidence for diffuse EXTRA-GALACTIC (isotropic) FLUX

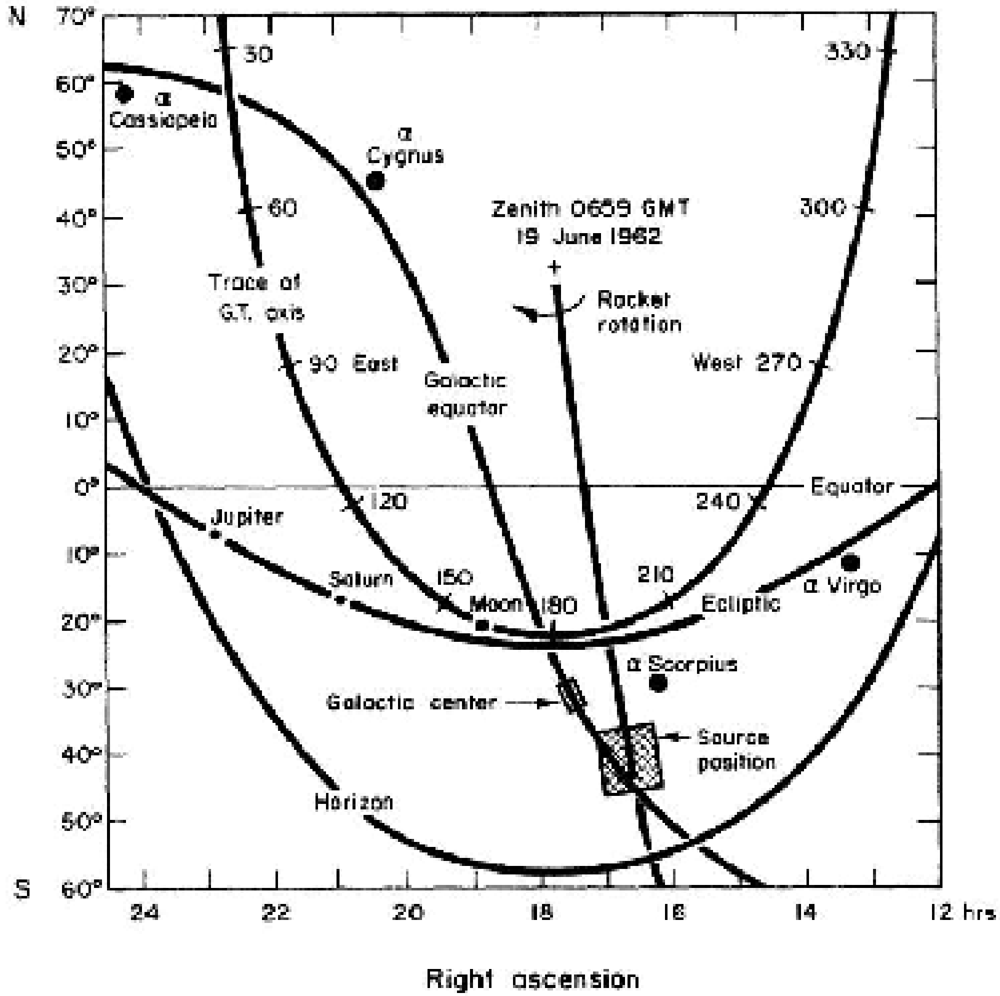


FIG. 2. Chart showing the portion of sky explored by the counters.

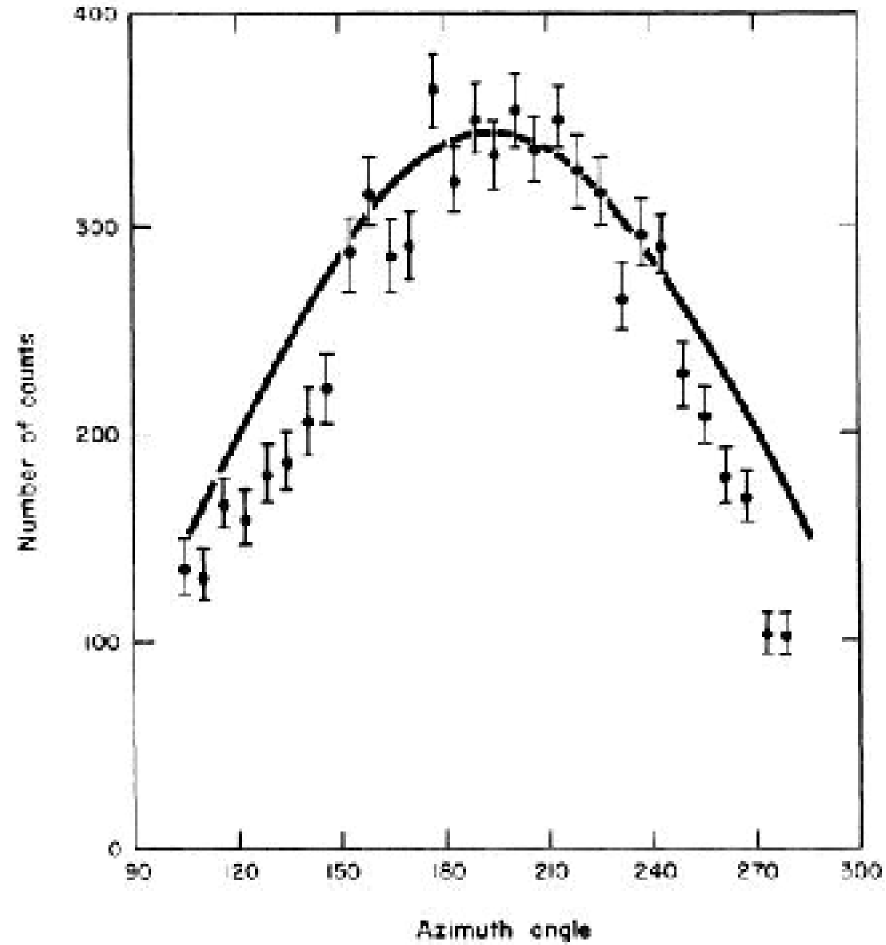


FIG. 4. Comparison of experimental results with the computed angular dependence for a unidirectional beam of electrons exhibiting exponential absorption in the counter window.

PREDICTION (1960)

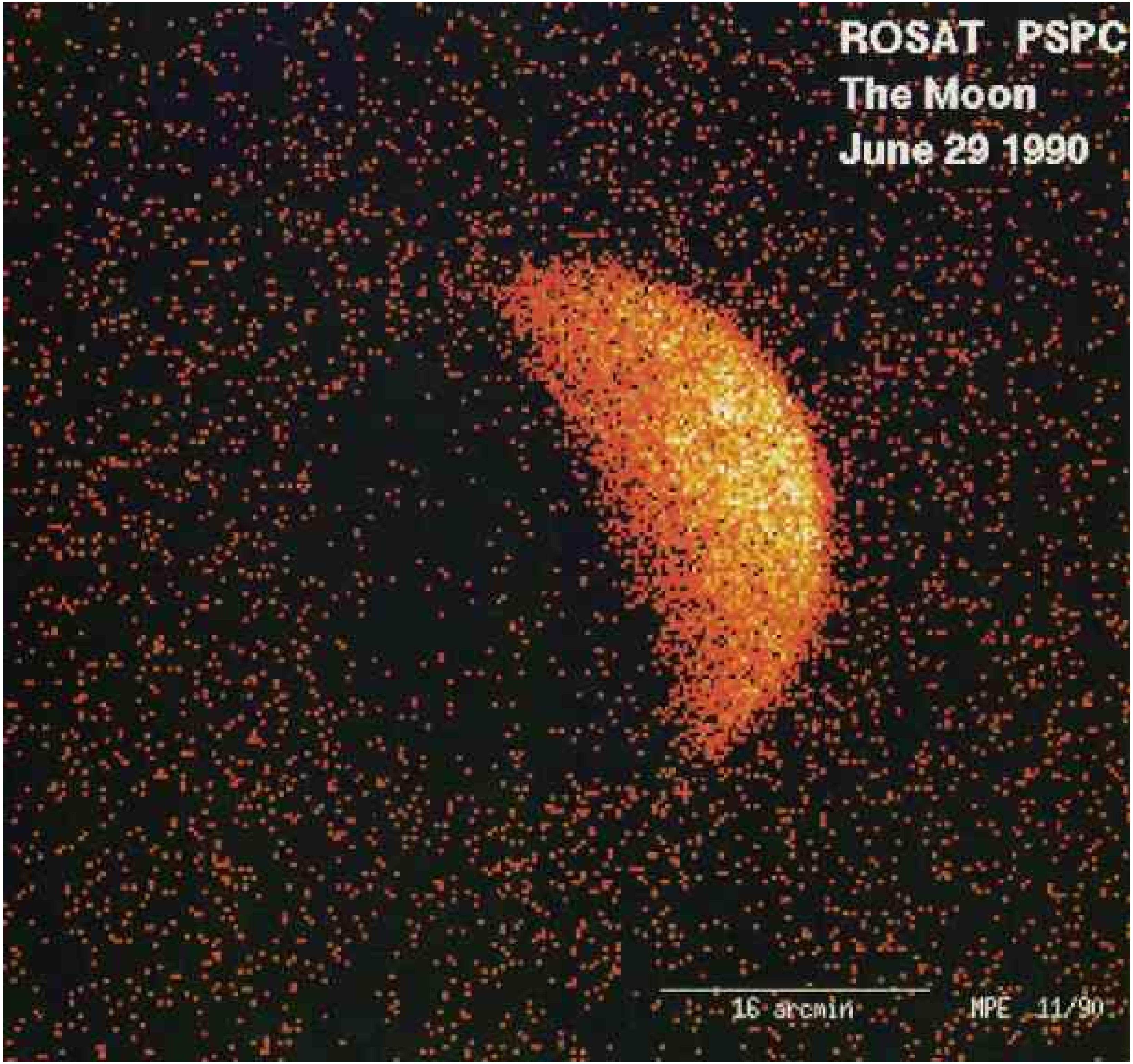
Brightest Source the MOON

Giacconi, Clark, Rossi (1960)			
Source	*Maximum Wavelength*	*Mechanism for Emission*	*Estimated Flux*
Sun	< 20 Å	Coronal emission	~ 10^6 cm^{-2} s^{-1}
Sun at 8 light years	< 20 Å	Coronal emission	2.5 x 10^{-4} cm^{-2} s^{-1}
Sirius if $L_X \sim L_{OPT}$	< 20 Å	? No convective zone	0.25 cm^{-2} s^{-1}
Flare stars	< 20 Å	Sunlike flare?	?
Peculiar A stars	< 20 Å	B ~ 10^4 Gauss Large B Particle acceleration	?
Crab nebula	< 25 Å	Synchrotron $E_E \geq 10^{13}$ eV in B ~ 10^{-4} Gauss Lifetimes?	?
Moon	< 23 Å	Fluorescence	0.4 cm^{-2} s^{-1}
Moon	~ 20 Å	Impact from solar wind Electrons φ_E = 0–10^{13} cm^{-2} s^{-1}	0–1.6 x 10^3 cm^{-2} s^{-1}

SKY

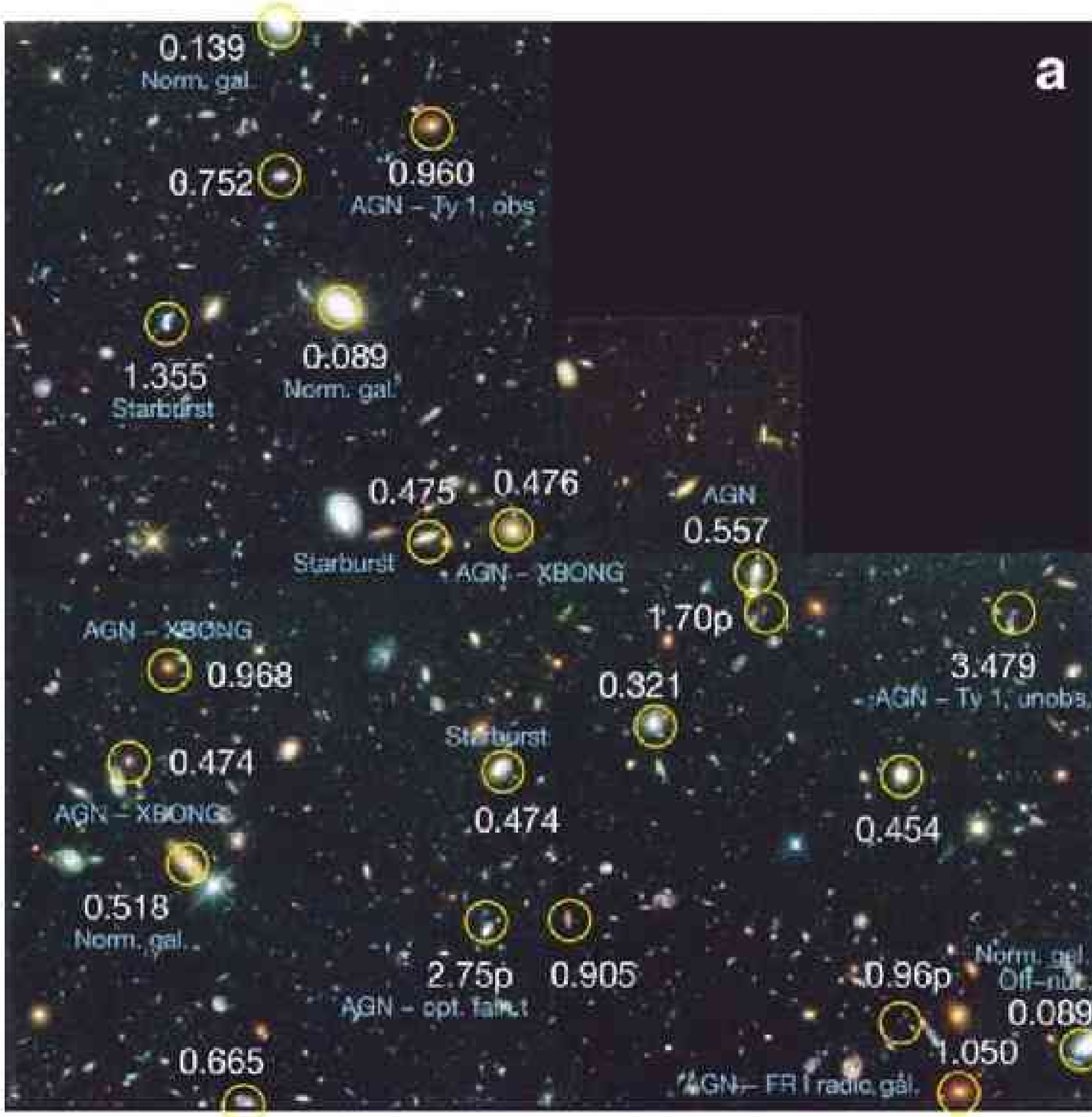
MUCH BRIGHTER than the MOON

7000 sources/$(^o)^2$

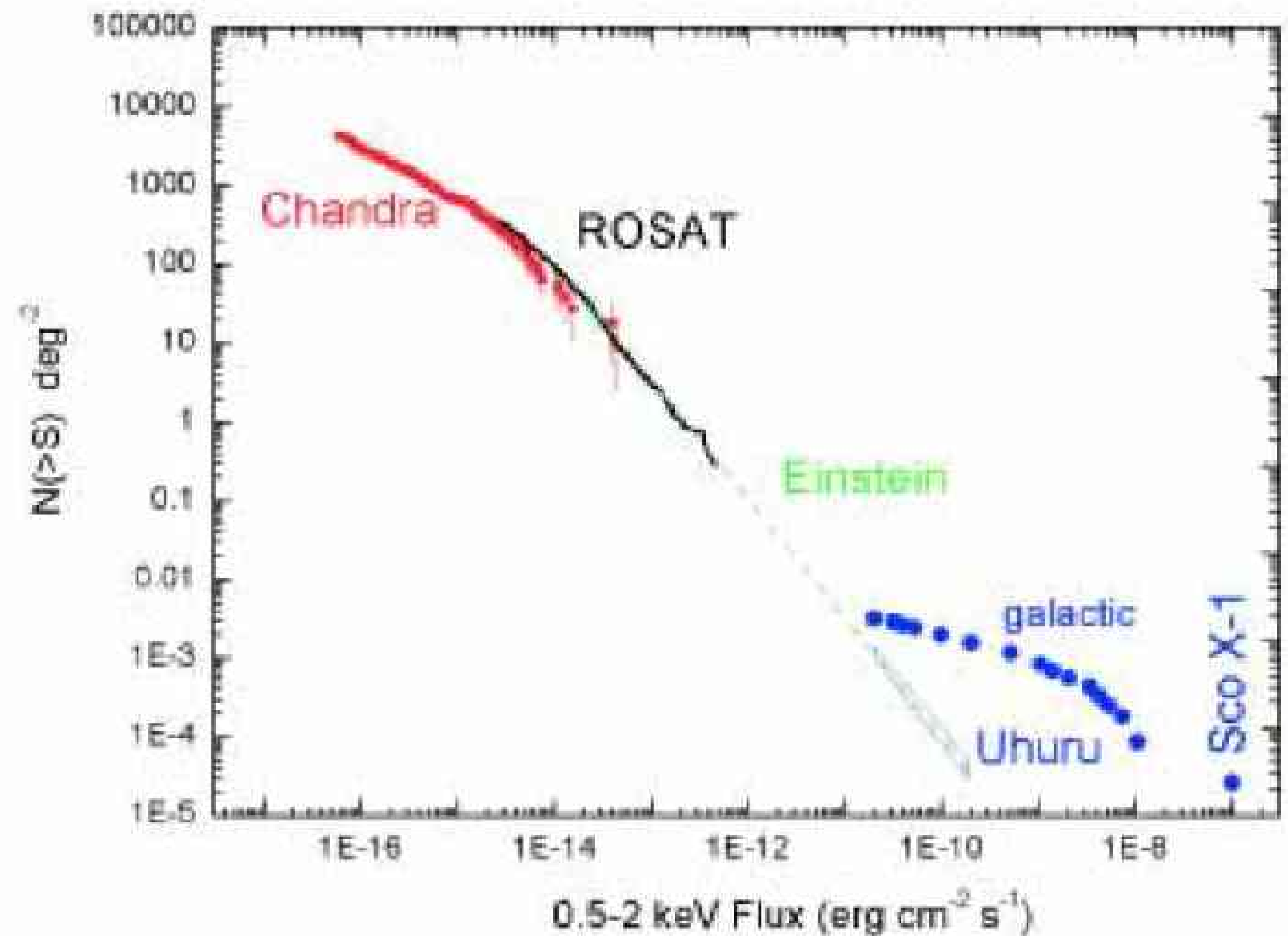


CHANDRA

Deep Field North



The X-ray SKY


Chandra
ROSAT
Einstein
galactic
Uhuru
Sco X-1
N(>S) deg^{-2}
0.5-2 keV Flux (erg cm^{-2} s^{-1})
100000
10000
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-16
1E-14
1E-12
1E-10
1E-8

A second Interesting history:

TeV Gamma Ray Astronomy

“ at the DOOR OF PARADISE ”

Long History

…. 30 years of efforts before
the first source (the CRAB Nebula)
1988 Richard Lamb , Vulcano

Neutrino Telescopes are

“Discovery Instruments”

the significance of their results
will be verified only a Posteriori.

But we do have some important guidance
from the results of Gamma Astronomy
(and Cosmic Ray Physics)

Extraordinary progress in recent years
in High Energy Astrophysics.
mostly in Gamma Astronomy (GeV and TeV)

Identification of several classes of
Astrophysical Accelerators

- SNR
- μQuasars
- GRB
- AGN

Important Guidance for the estimation
of the Properties (Luminosity, Spectrum, ...)
of High Energy Neutrino Sources.

Components of the Neutrino Flux

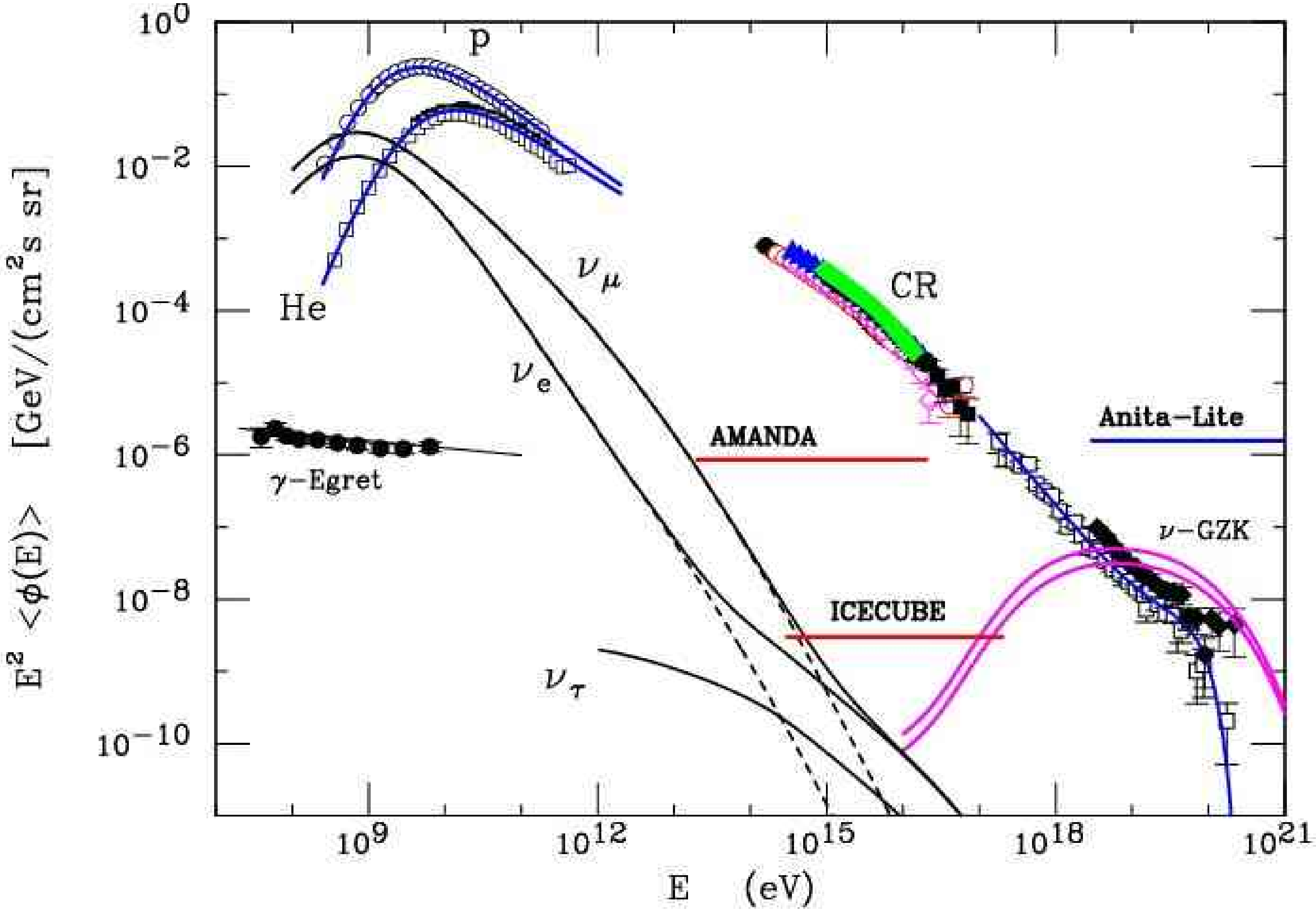
$$\phi_{\nu_\alpha}(E,\Omega) = \phi_{\rm atm}^{\rm standard}(E,\Omega) + \phi_{\rm atm}^{\rm prompt}(E,\Omega)$$

$$+ \phi_{\rm Galactic}(E,\Omega) + \phi_{\rm Extra~Gal}(E,\Omega)$$

$$+ \sum_{\rm Galactic} \phi_j(E)\,\delta[\Omega-\Omega_j]$$

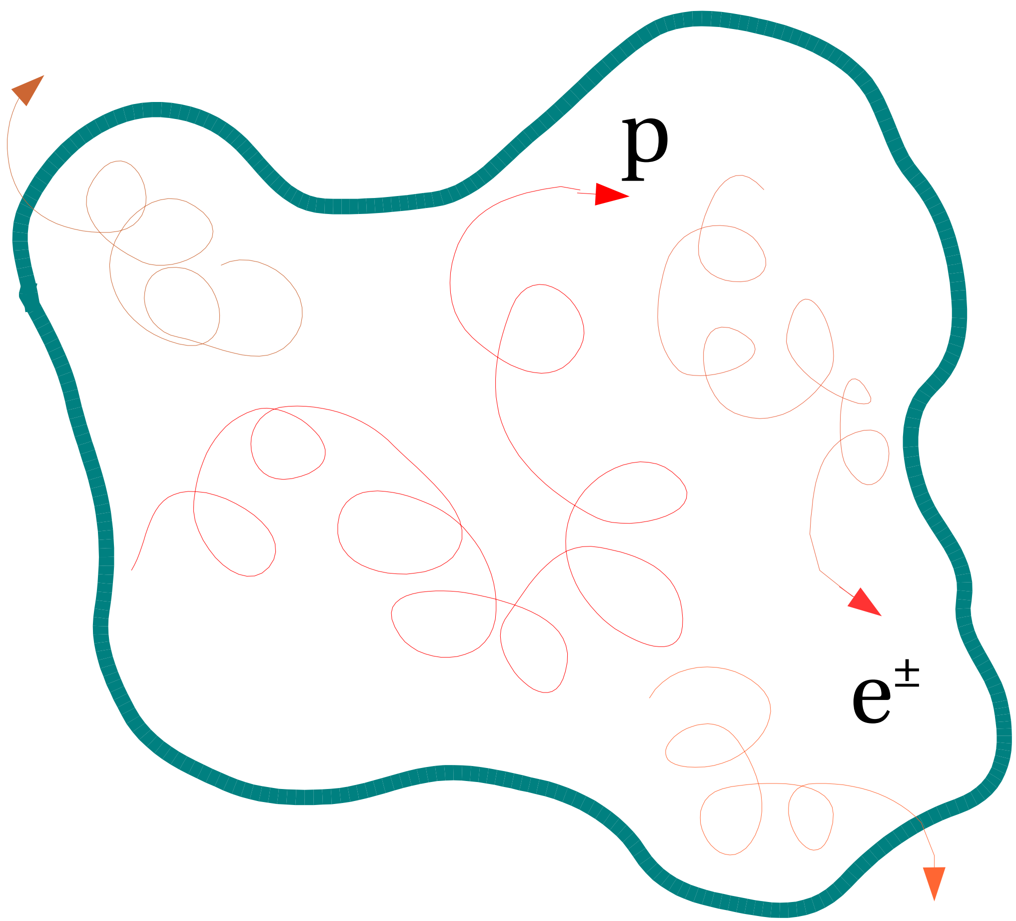
$$+ \sum_{\rm Extra~Gal} \phi_k(E)\,\delta[\Omega-\Omega_k]$$

$$\sum_k \phi_k(E)\,\delta[\Omega-\Omega_k] \Longrightarrow \phi_{\rm Diffuse}(E)$$



p
He
ν_μ
ν_e
ν_τ
γ-Egret
CR
AMANDA
ICECUBE
Anita-Lite
ν-GZK
$E^2 \langle\phi(E)\rangle$ [GeV/(cm^{2}s sr)]
E (eV)
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^9
10^{12}
10^{15}
10^{18}
10^{21}

“ASTROPHYSICAL” NEUTRINOS



Astrophysical Object containing:

Populations of relativistic protons, Nuclei electrons/positrons

Emission of:

γ rays

Neutrinos

Cosmic Rays

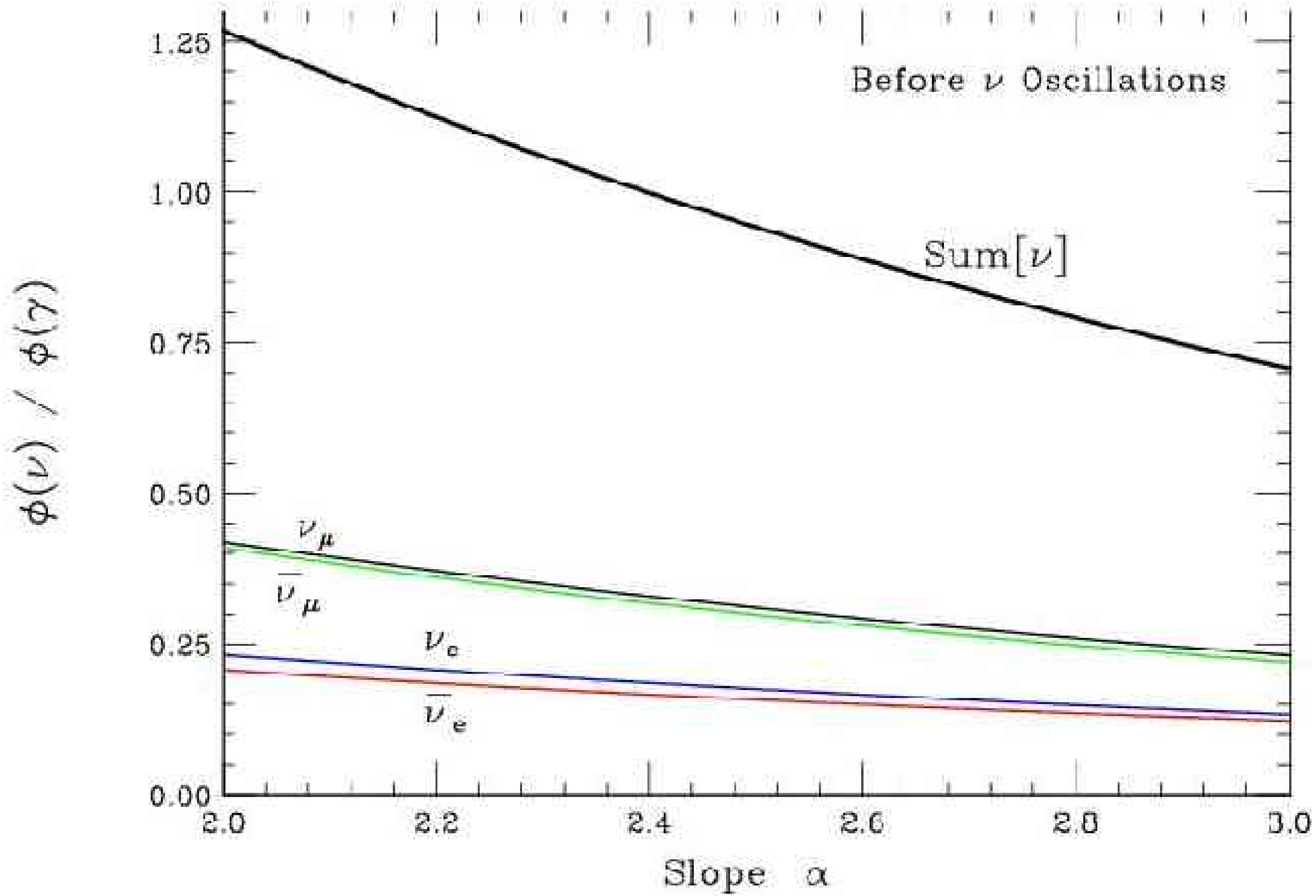
Relation between

PHOTONS and NEUTRINOS

- Assuming HADRONIC production for the photons:
- In the absence of photon absorption

One Photon $\simeq$ One Neutrino

Ratio Neutrino-Photon $\phi(\nu) \ / \ \phi(\gamma)$



$$\{\nu_e, \overline{\nu}_e, \nu_\mu, \overline{\nu}_\mu, \nu_\tau, \overline{\nu}_\tau\} \ \simeq \ \{1+\epsilon, 1-\epsilon, 2, 2, 0, 0\}$$

Effect of Neutrino Oscillations

$$\langle P(\nu_\alpha \to \nu_\beta)\rangle = \langle P(\overline{\nu}_\alpha \to \overline{\nu}_\beta)\rangle = \sum_j |U_{\alpha j}|^2 \, |U_{\beta j}|^2$$
$$\simeq \begin{pmatrix} 0.6 & 0.2 & 0.2 \\ 0.2 & 0.4 & 0.4 \\ 0.2 & 0.4 & 0.4 \end{pmatrix} \qquad (1)$$

Before Oscillations

$$\{\nu_e, \overline{\nu}_e, \nu_\mu, \overline{\nu}_\mu, \nu_\tau, \overline{\nu}_\tau\} \simeq \{1+\epsilon, 1-\epsilon, 2, 2, 0, 0\}$$

After Oscillations

$$\{\nu_e + \overline{\nu}_e, \nu_\mu + \overline{\nu}_\mu, \nu_\tau + \overline{\nu}_\tau\} = \{1, 1, 1\}$$

HESS

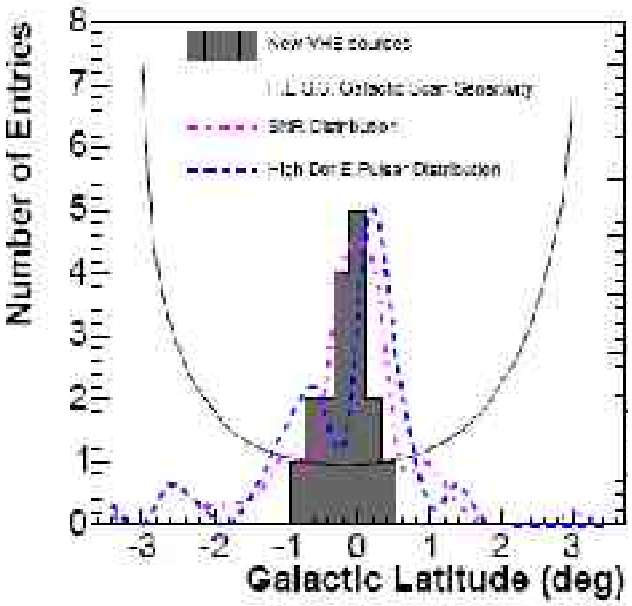
Science
March - 2005

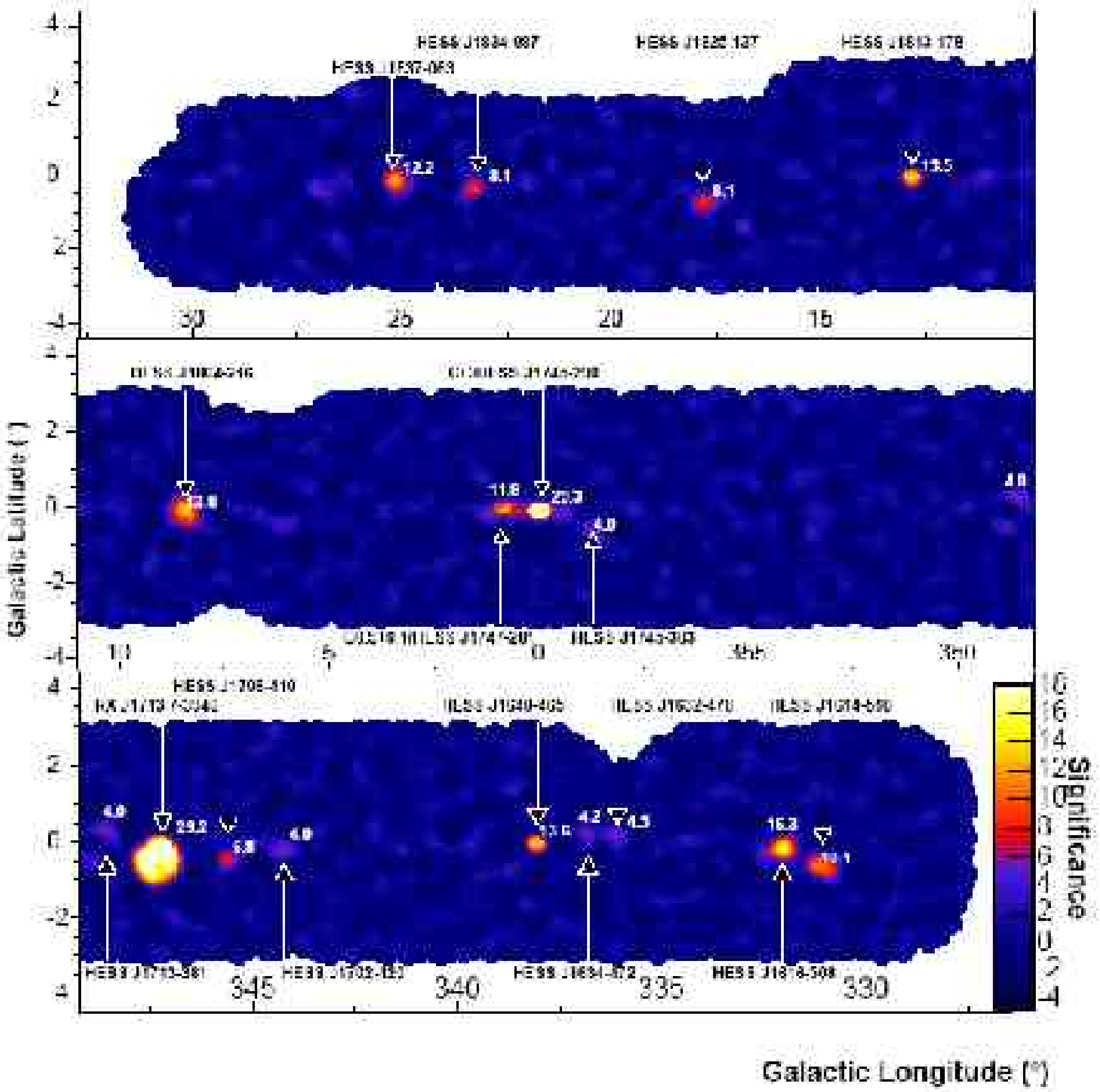
“SCAN”

of the

Galactic Plane

15 New Sources
+ 3 Known





Source Counts

Source Type*	2003	2005
Pulsar Wind Nebula (e.g. Crab, MSH 15-52 ...)	1	6
Supernova Remnants (e.g. Cas-A, RXJ 1713 ...)	2	6
Binary Pulsar (B1259-63)	0	1
Micro-quasar (LS 5039)	0	1
Diffuse (Cygnus region)	0	1
AGN (e.g. Mkn 421, PKS 2155 ...)	7	11
Unidentified	2	6
TOTAL	**12**	**32**

* Includes likely associations of HESS unid sources.

GALACTIC TEV SOURCES

Source	Type	Slope Γ	Φ(0.2 TeV)	Φ(1 TeV)	d (Kpc)	P(1–10 TeV)
			(10^{-12} cm^{-2} s^{-1})			10^{34} erg s^{-1}
CRAB Nebula	PWN	2.49	231.	21.	2	3.4
LS 5039	μQuasar	2.12	6.5	1.1	2.9	0.4
PSR B1259-63	PWN (binary)	2.44	30.	3.0	1.5	0.3
RXJ 1713.7-3946	SNR	2.19	99.	14.6	1	0.6
GC (Sgr A*)	SMBH	2.21	14	2.0	8.5	6.2
MSH 15-52 (PSR B1509-58)	PWN	2.27	35.	4.5	5.2	5.1
G0.9+0.1	SNR	2.40	5.7	0.6	8.5	1.7
HESS J1614-518	–	–	9.	0.95	–	–
HESS J1616-508 (PSR J1617-5055)	PWN	–	17.	1.8	6.1	2.7
HESS J1640-465 (G338.3-0.0)	SNR	–	19.	2.0	6	0.3
HESS J1804-2 (G8.7-0.1 / W30)	PWN	–	16.	1.7	6	2.5
HESS J1813-178 (G12.02 02)	SNR	–	12.	1.3	6.6	2.3
HESS J1825-137 (PSR J1826-1334)	PWN	–	9.	0.9	3.9	5.5
HESS J1834-087 (G23.3-0.3 / W41)	SNR		13.	1.4	4.8	1.3
HESS J1837-069 (G25.5+0.0 ?)	SNR	–	9.	0.9	–	–

TeV Galactic Sources
Measured by HESS, MAGIC

Have FLUX:

Flux (E_γ > 1 TeV) = 0.11 - 2.1

UNIT : $10^{-11}\ (\mathrm{cm}^2\ \mathrm{s})^{-1}$

Two Brightest sources in the TeV sky:
2 young SNR
RX 1713.7-3946
Vela Junior

VERY POSITIVE

The HESS scan of the central part of the Milky Way has determined the "scale" (typical Power) of the High Energy Photon Sources

Several (all) of these sources are candidates as Neutrino Sources.

Less POSITIVE ....

The Sources (assuming no gamma absorption) are weak for the KM3 telescopes.

Sensitivity to Point Sources in a Neutrino Telescope

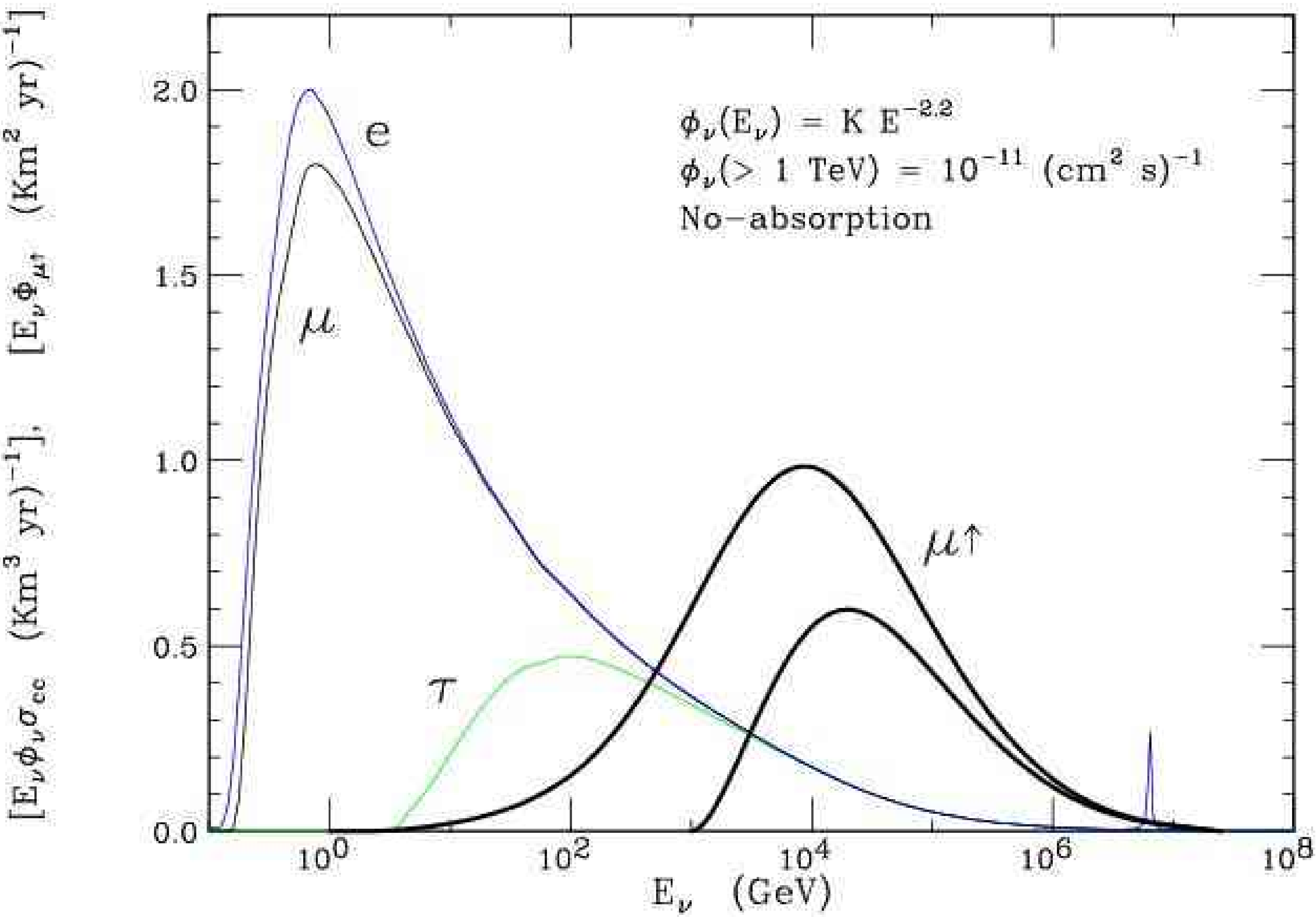
Determine the minimum luminosity of a neutrino source to be detectable

Normalization:

Neutrino Flux $E_\nu > 1$ TeV $= 10^{-11}\ (\mathrm{cm}^2\ \mathrm{s})^{-1}$

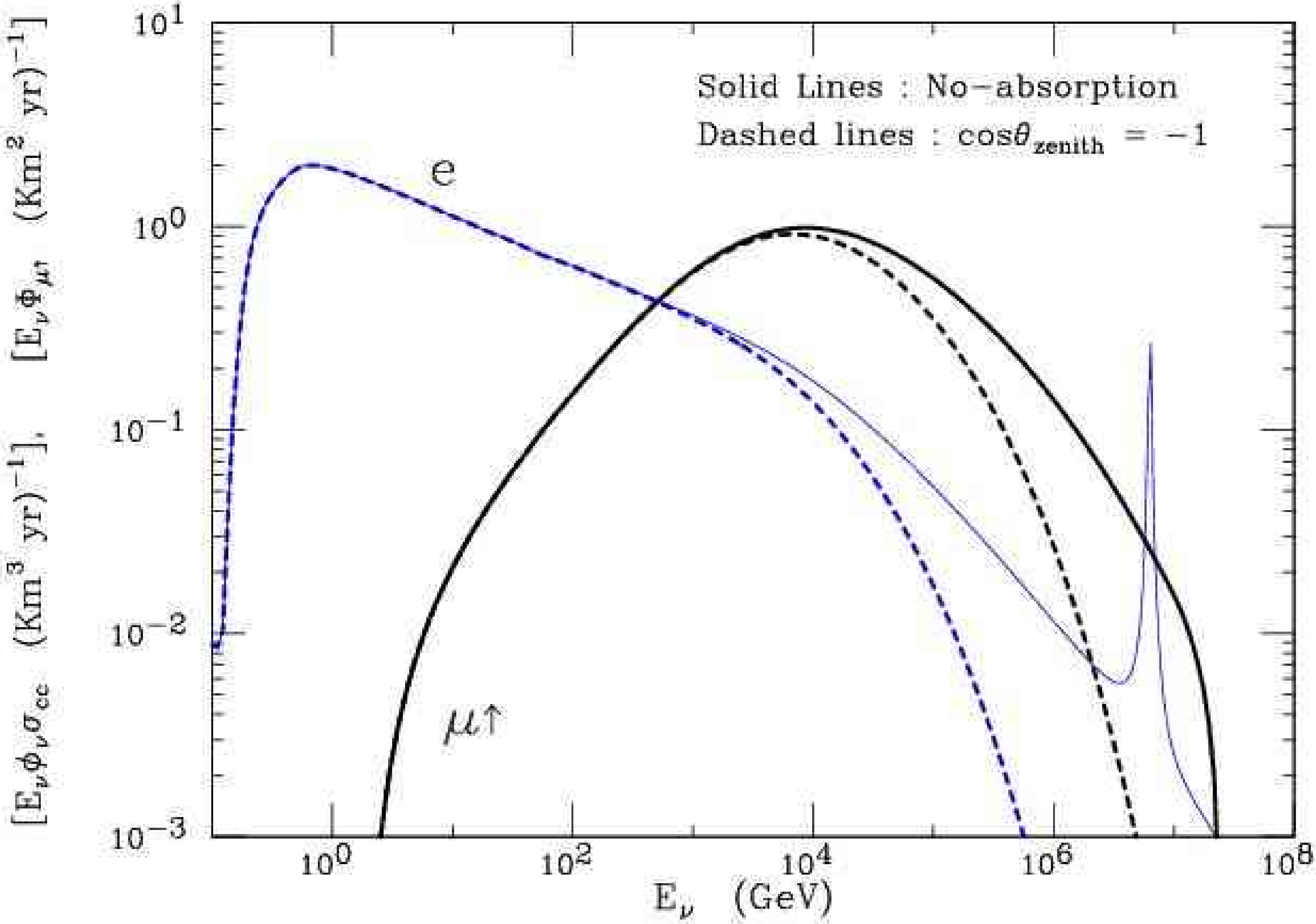
Shape

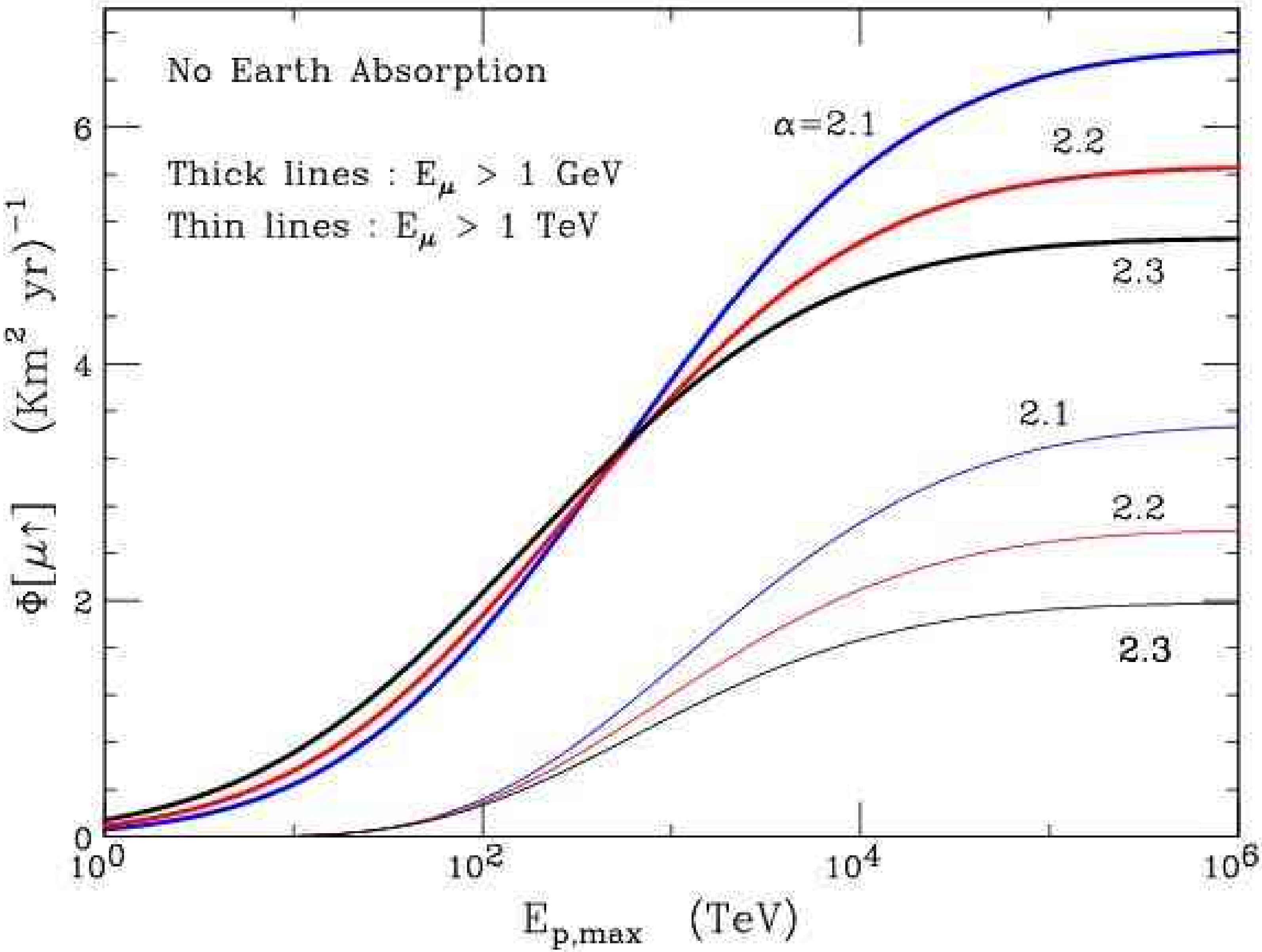
Power Law : $\alpha = 2.2$



$$\Phi_{\mu\uparrow} \simeq 5.6 \quad \left[\frac{\phi_\nu(\geq 1\ \text{TeV})}{10^{-11}\ (\text{cm}^2\,\text{s})^{-1}}\right]\ (\text{Km}^2\ \text{yr})^{-1}$$

Effect of Neutrino Absorption in the Earth





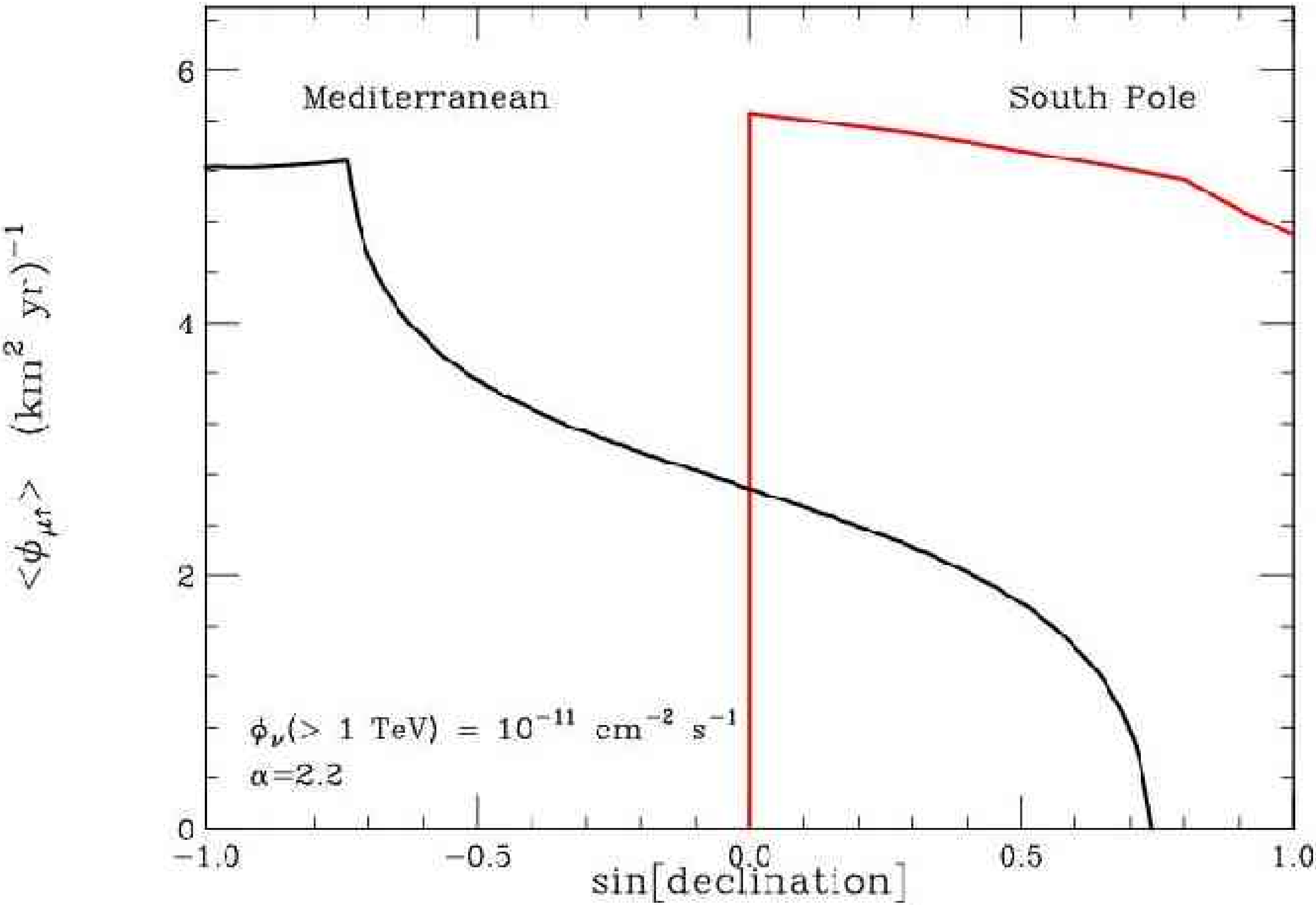
No Earth Absorption
Thick lines : E_μ > 1 GeV
Thin lines : E_μ > 1 TeV
α=2.1
2.2
2.3
2.1
2.2
2.3
$\Phi[\mu\uparrow]$ $(\mathrm{Km}^2\ \mathrm{yr})^{-1}$
$E_{p,max}$ (TeV)
0
2
4
6
10^0
10^2
10^4
10^6

Event Rate
of neutrino-induced Muons

under the Assumption

Flux (Neutrinos) = Flux (photons)

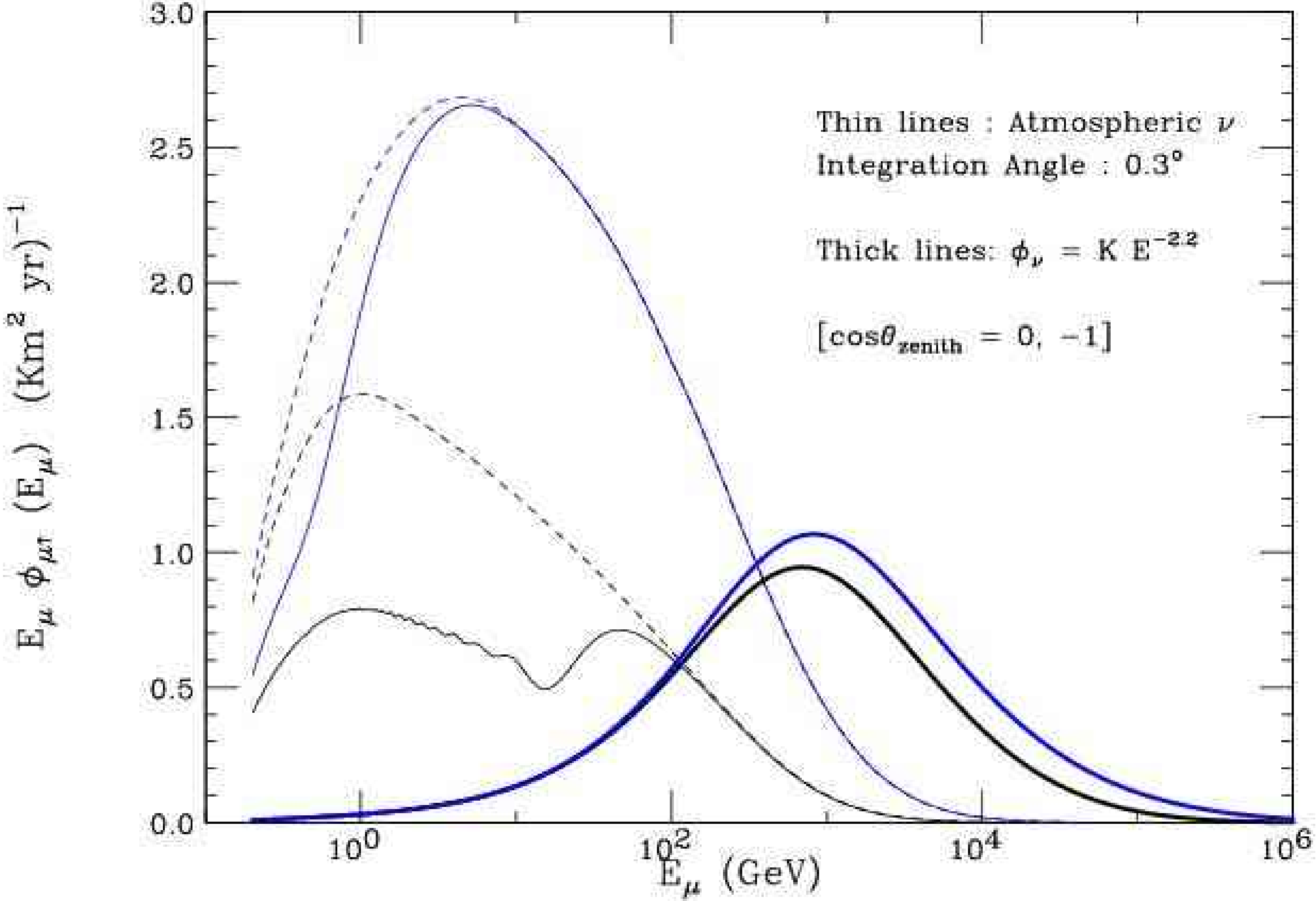
FEW EVENTS PER YEAR
for the STRONGEST HESS SOURCES



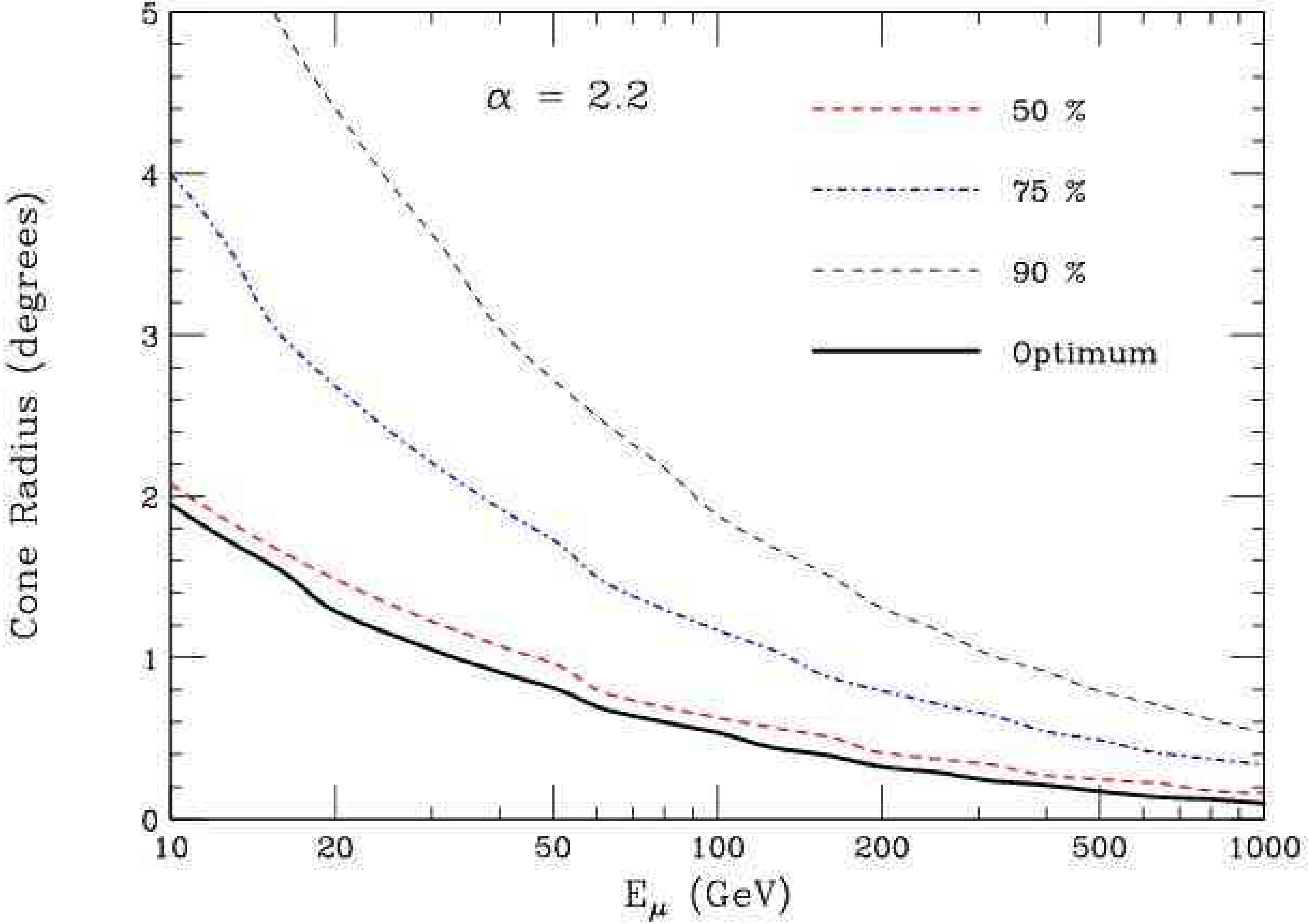
Mediterranean
South Pole
$\phi_\nu(> 1 \text{ TeV}) = 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$
α=2.2
$<\phi_{\mu\uparrow}> \quad (\text{km}^2 \text{ yr})^{-1}$
sin[declination]
0
2
4
6
−1.0
−0.5
0.0
0.5
1.0

BACKGROUND

Atmospheric Neutrinos



Angular Distribution of the Neutrino – induced Muons



Control of the Background below 1/year is Possible but is a very difficult Problem:

- Source of Intrinsic small Size
  Quasi-Point Like Source
- High Energy cut
  $E_\mu > 1$ TeV
- Very good Energy Resolution
  (Fraction of a degree)

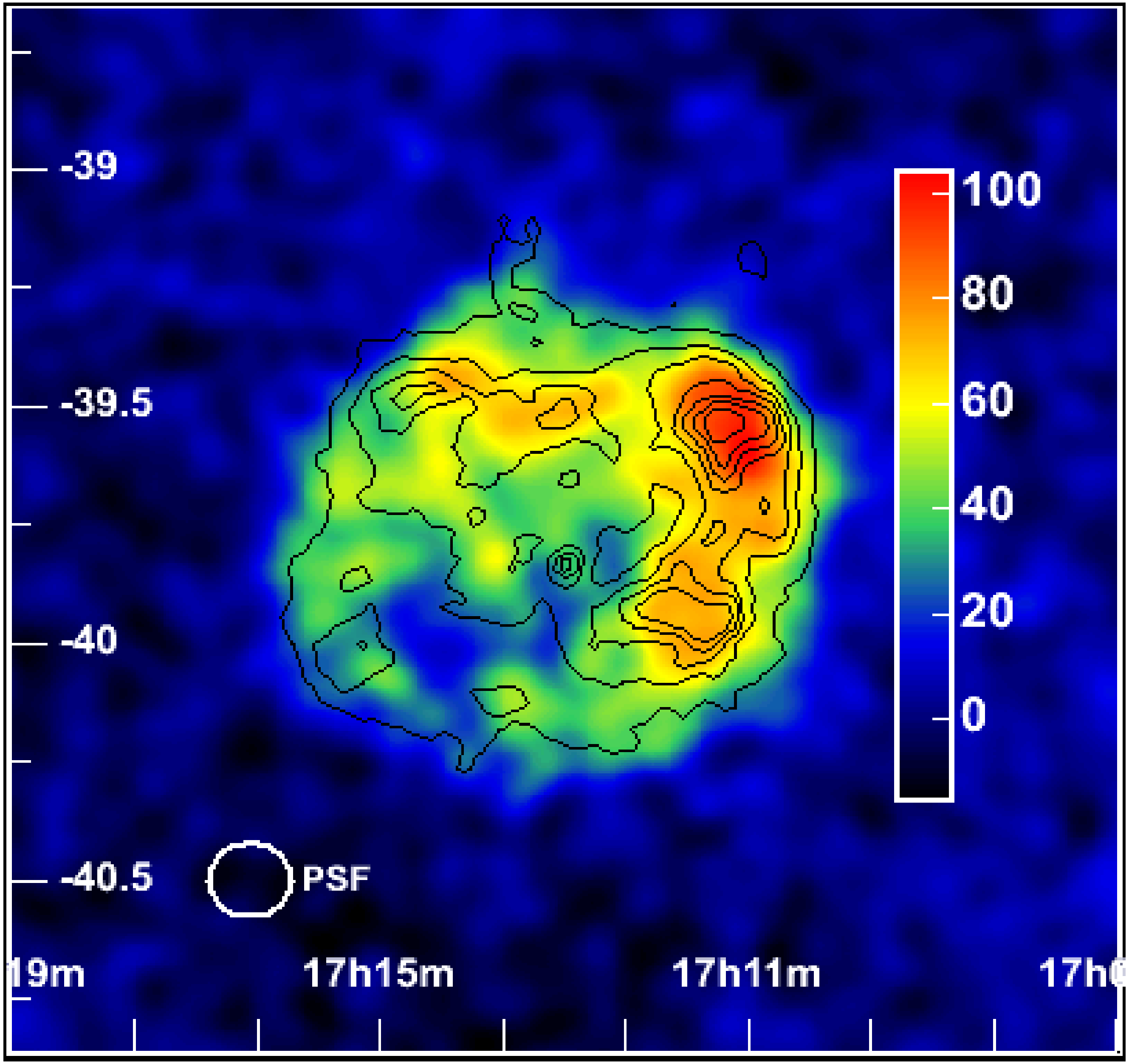
If this is achieved

Sensitivity is SIGNAL Limited

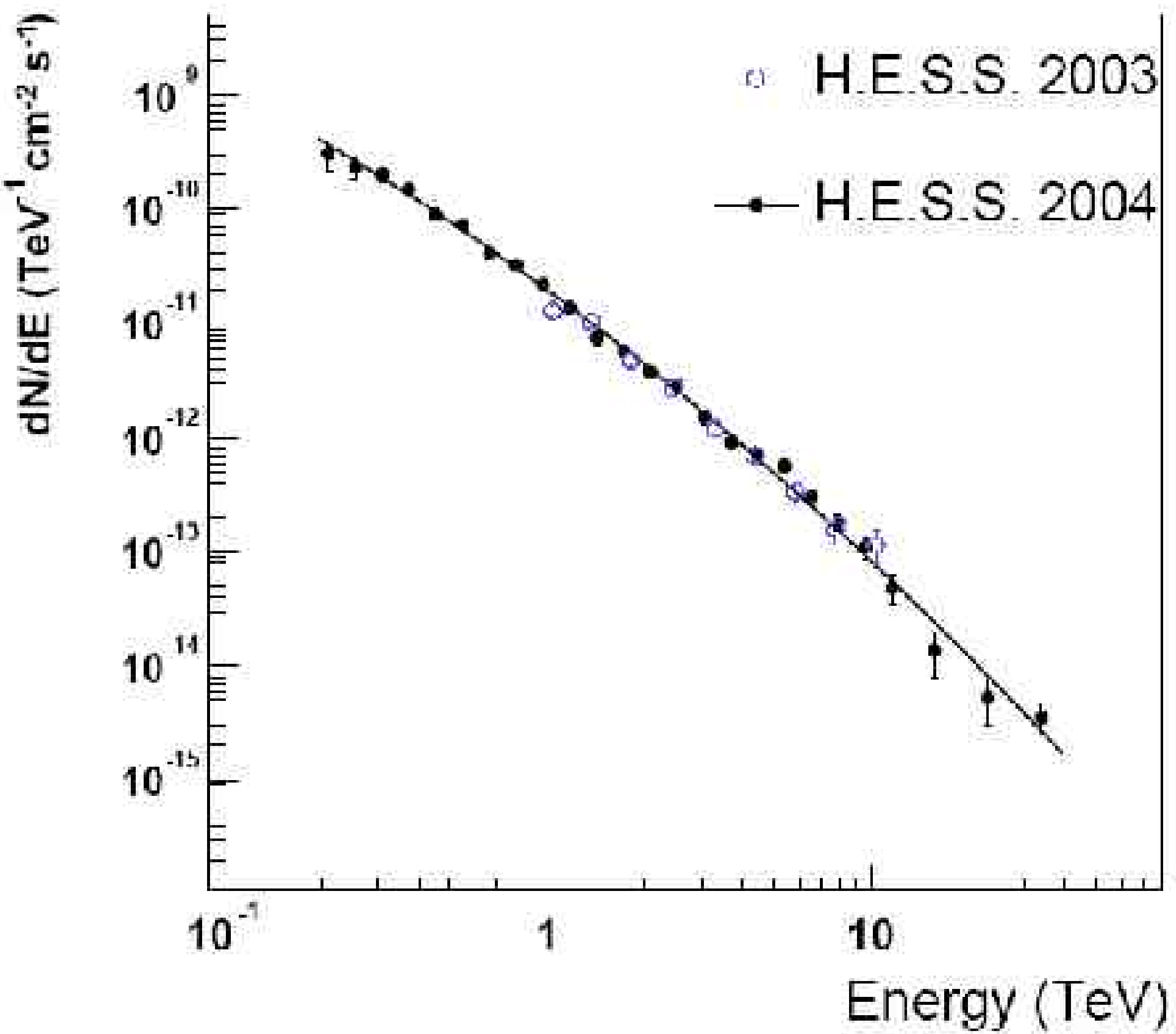
Brightest TeV Sources could be Detectable

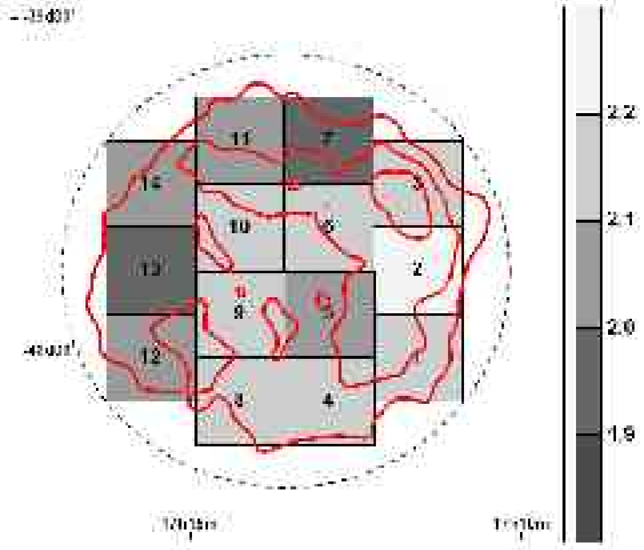
GALACTIC NEUTRINOS

SuperNova Remnants: RX1713.7-3946



SuperNova RX1713.7-3946



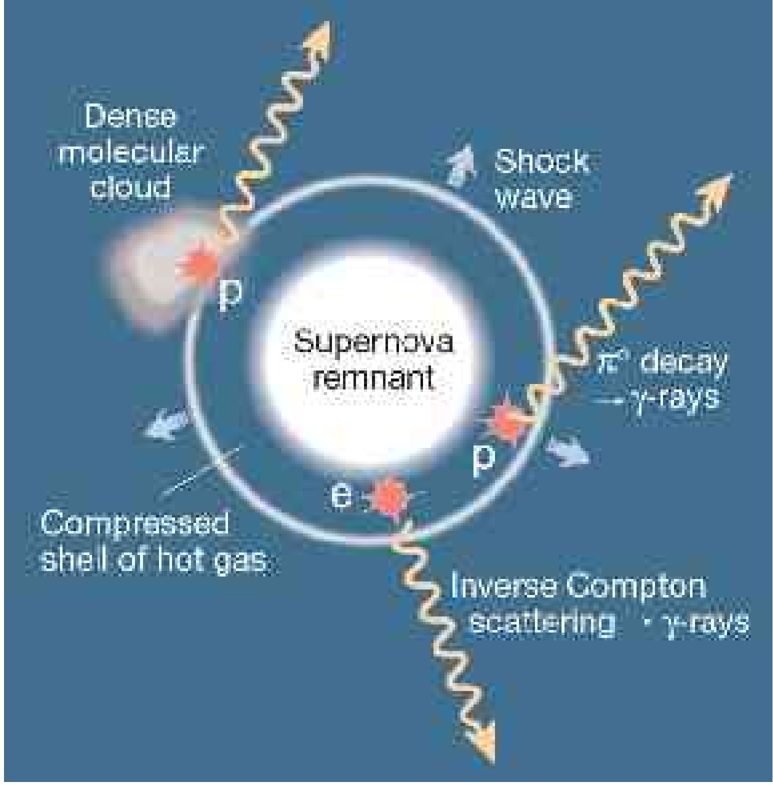


Most natural
(perhaps not unique)
interpretation:

Hadronic Cosmic Rays
accelerated by the
SN blast wave interacting
with the interstellar
medium

Photon Production

$$p + \text{gas} \rightarrow \pi^{\circ} + \ldots \rightarrow \gamma\,\gamma + \ldots$$



Gas density

$$\phi_\gamma(E_\gamma) = \frac{1}{4\pi d^2} \int dE_0\, N_p(E_0)\, \sigma_{\rm in}(E_0)\, (\beta c)\, \langle n \rangle\, \frac{dN_{p\to\gamma}}{dE_\gamma}(E_\gamma;\, E_0)$$

Proton Population inside the SN remnant

$$[\text{Total Energy}]_{\text{protons}} = \int \mathrm{d}E_0 \; E_0 \; N(E_0) \simeq \frac{10^{49}\ \text{erg}}{\langle n \rangle}$$

$$\langle n \rangle \simeq \text{few} \times 10^2\ \text{cm}^{-3}$$

$$E_{\text{kin}}(\text{SN}) = \frac{1}{2}\, M_{\text{ejected}}\, v^2 \simeq 10^{51}\ \text{erg}$$

$$E(\text{CR}) \simeq 0.01\ E_{\text{kin}} \simeq 10^{49}\ \text{erg}$$

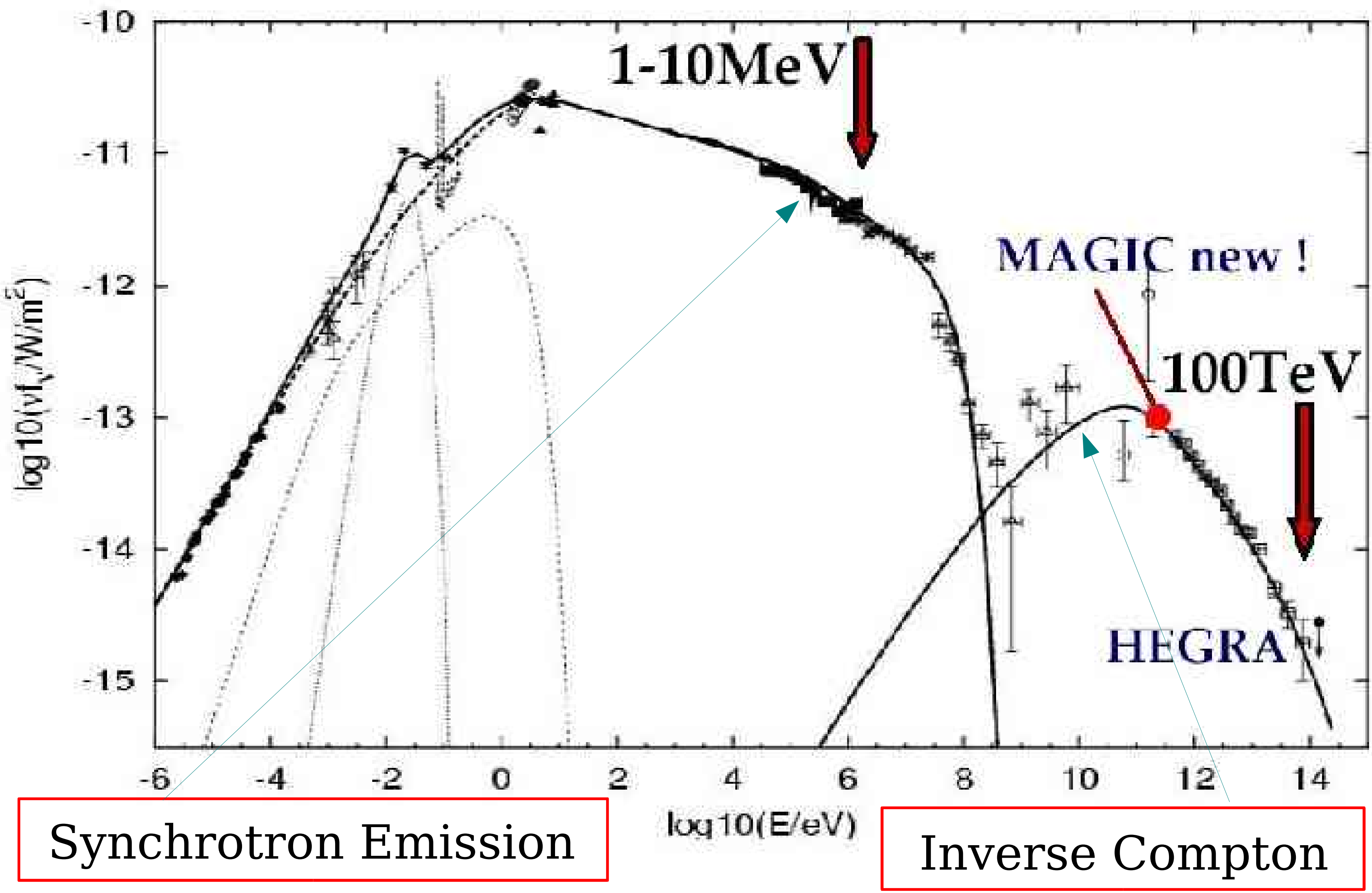
$$(\text{Power Galaxy})_{\text{CR}} = \frac{E(\text{CR})}{\tau_{SN}} \simeq \frac{10^{49}\ \text{erg}}{30\ \text{years}} \simeq 10^{40}\ \text{erg s}^{-1} \simeq 2.6 \times 10^{6}\ L_{\odot}$$

PULSAR WIND NEBULAE

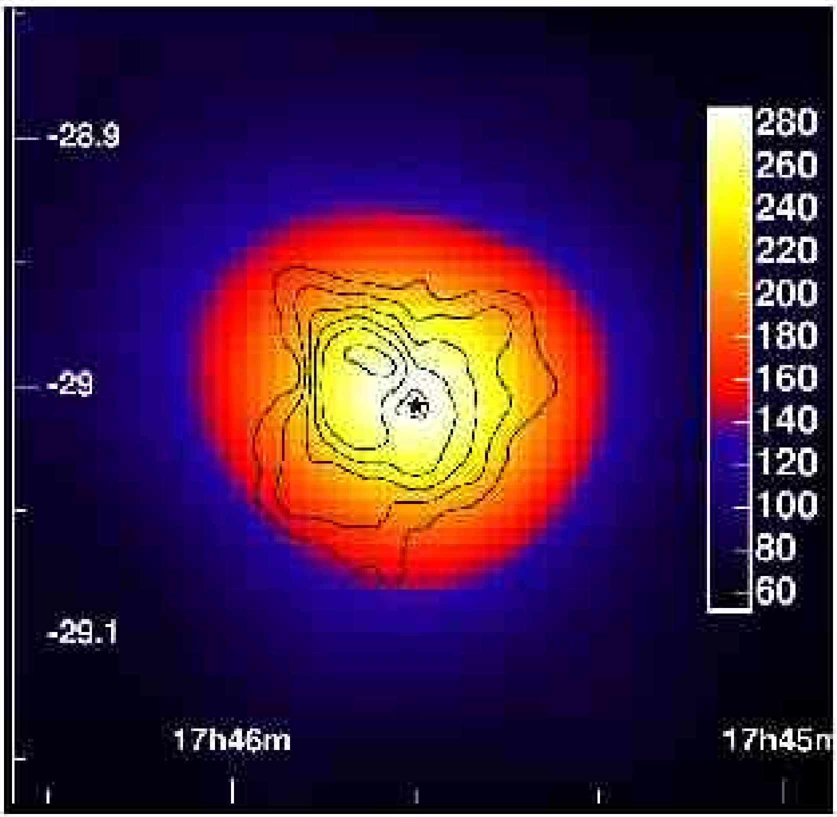
Electromagnetic Fields
Near the Surface of
the Neutron Star
are strong enough to pull
charged particles out of the
neutron star
(or generate pairs of e+e-)
Creating a "Pulsar Wind"

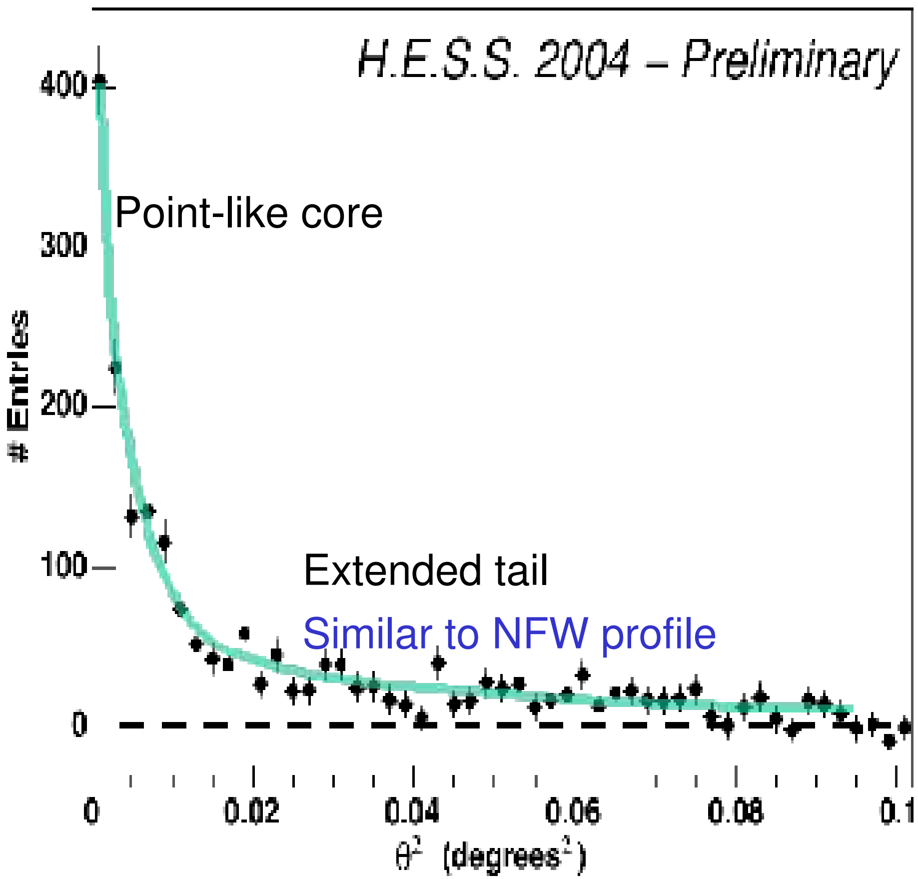
The pulsar wind creates
shocks near the neutron star
that accelerates
electrons and positrons
to relativistic energies

CRAB NEBULA
(Self Synchrotron Compton)



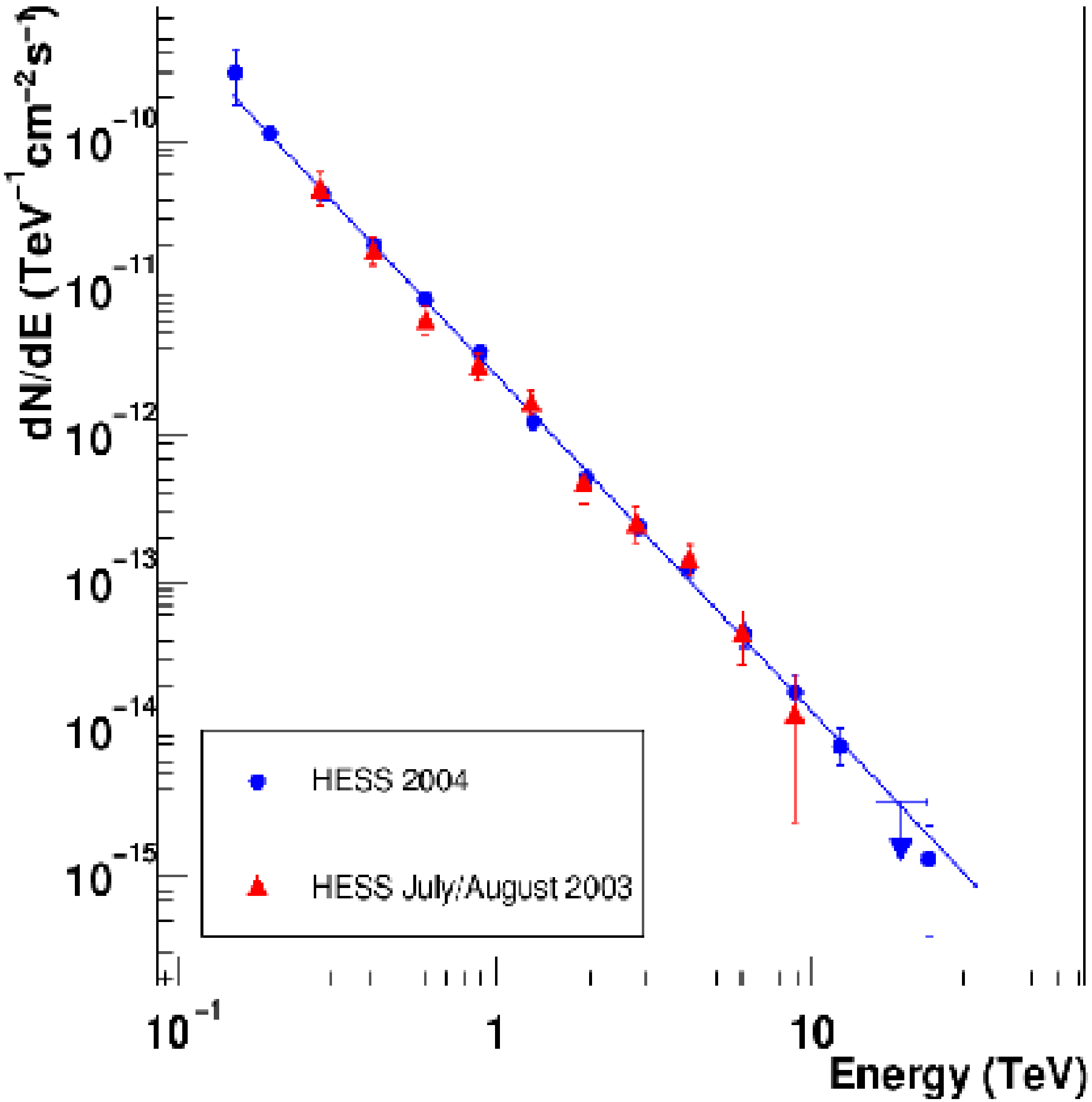
GALACTIC CENTER





Colors: H.E.S.S.
Contours: Radio

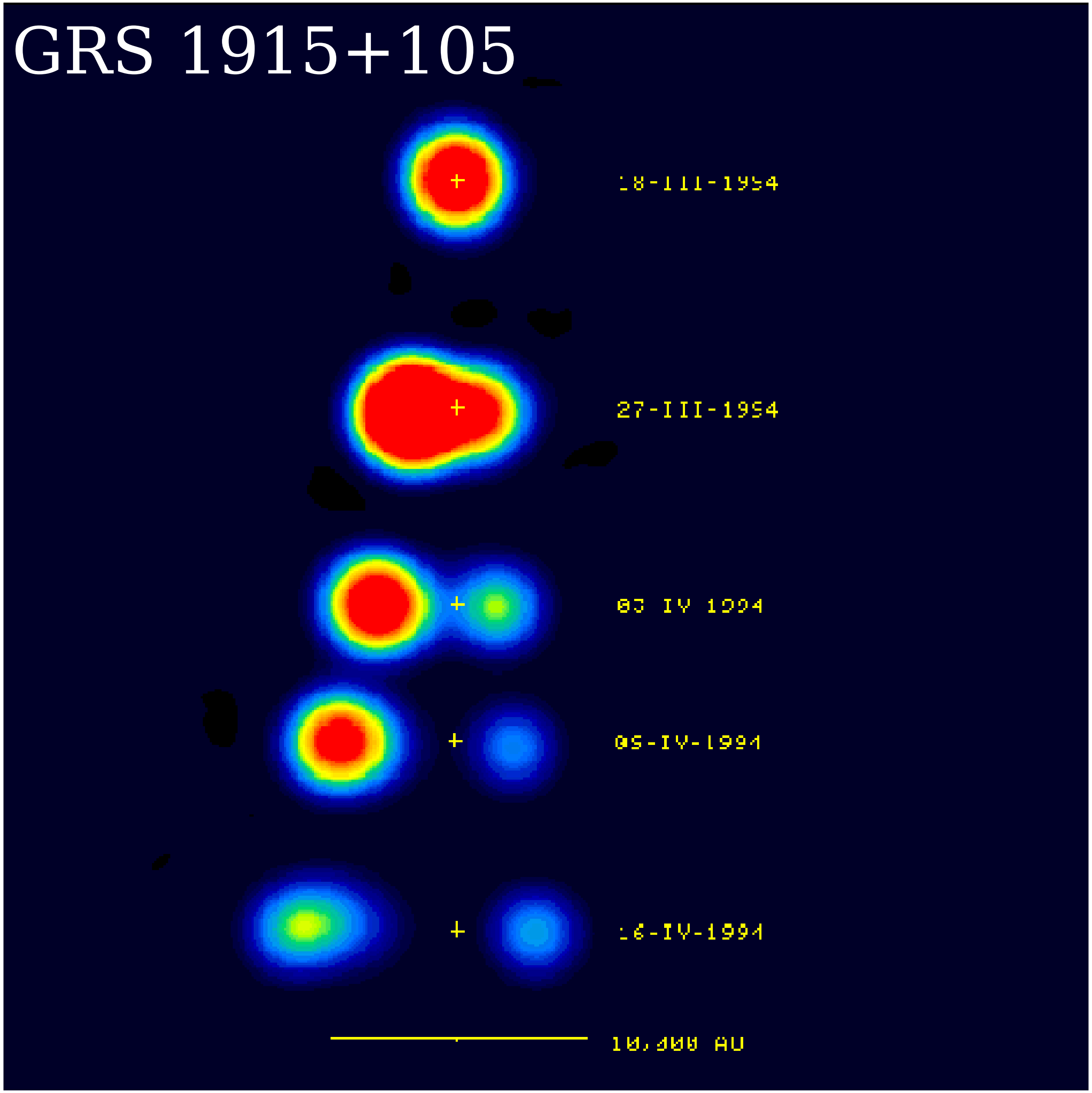
Angular distribution



Power law index 2.3

No significant
Variability
in 40 hourse
of observations
distributed in 2 years

MICROQUASARS

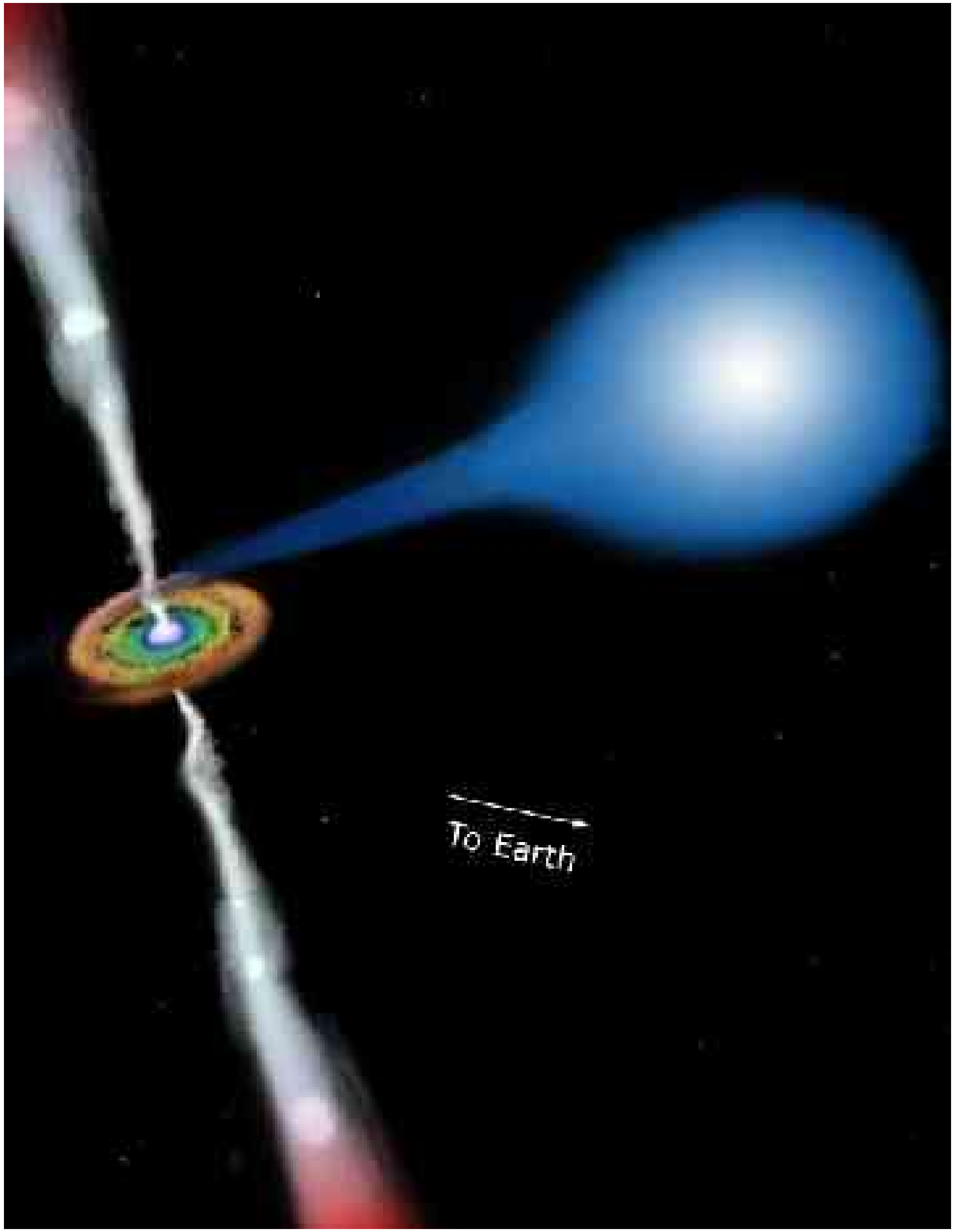


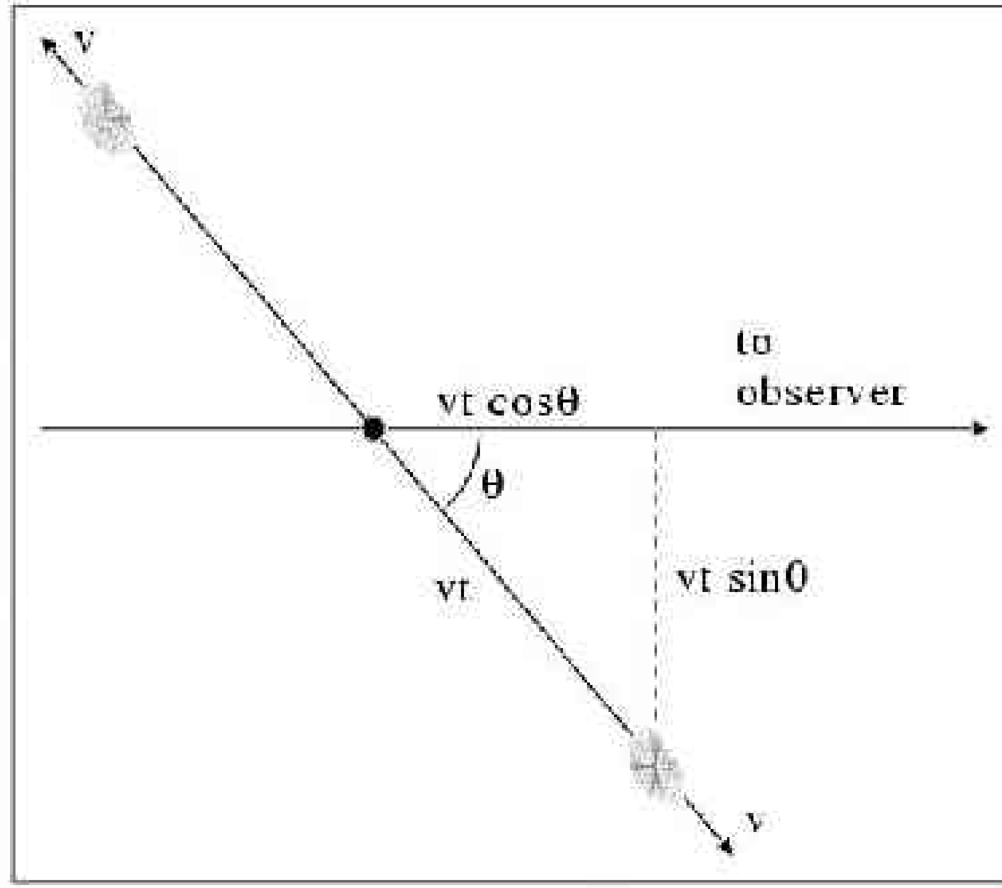
Galactic binary system with one stellar mass black hole

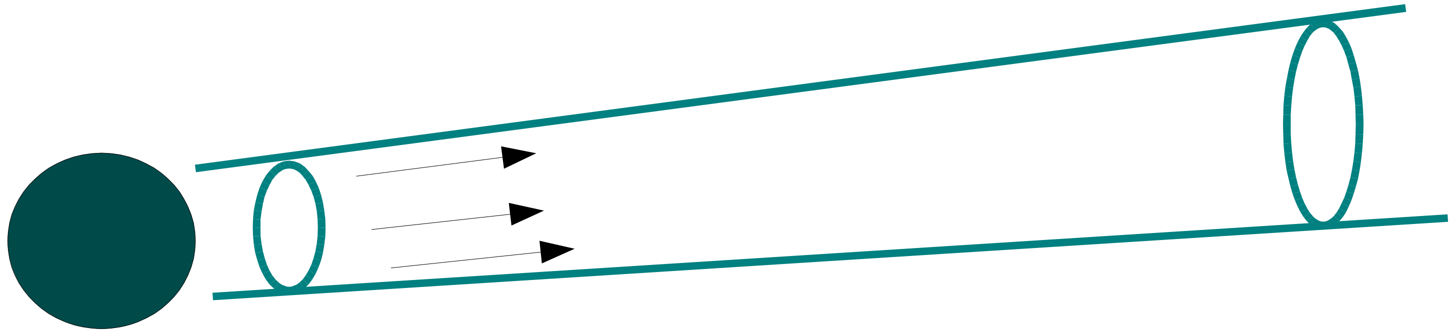
Symmetric emission of Plasma "blobs"

Detection in Radio (VLBI)

Geometry of the emission of the two jets







$$L_{\rm jet} = \left(\pi R^2\right) \; \left(\rho^* \; \Gamma\right) \; c\,\beta$$

$$\rho = \rho_B + \rho_e^{\rm rel} + \rho_p^{\rm rel} + \rho_{\rm cold-plasma}$$

$$L_{\rm jet} = L_B + L_e^{\rm rel} + L_p^{\rm rel} + L_{\rm cold-plasma}$$

Two components certainly exist
because of the observation of the RADIO SIGNAL:

Relativistic Electrons

Magnetic Field

$$n_e(E_e) = K_e \; E_e^{-p}$$

$$\mathcal{D} = \frac{1}{\Gamma\,(1 - \beta\,\cos\theta)}$$

Radio emission

$$S_\nu \equiv \frac{dL_{\rm syn}}{d\nu} = \frac{K_e\,V}{4\pi\,d^2} \;\; \mathcal{D}^{3+\left(\frac{p-1}{2}\right)} \; C(p) \;\; B^{\frac{p+1}{2}} \;\; \nu^{-\frac{p-1}{2}}$$

$$\rho = \rho_B + \rho_e^{\rm rel} \quad = \quad \frac{B^2}{8\pi} + a\ B^{-\frac{p+1}{2}}$$

Minimization

$$B = \overline{B} = \left(\frac{1+p}{4}\right)^{\frac{2}{p+5}} \left(\frac{8\,\pi}{a}\right)^{\frac{2}{p+5}}$$

$$\rho_{\rm min} = \frac{\overline{B}^2}{8\pi}\left(1 + \frac{4}{1+p}\right)$$

$$L_{jet} \gg L_{\rm syn}$$

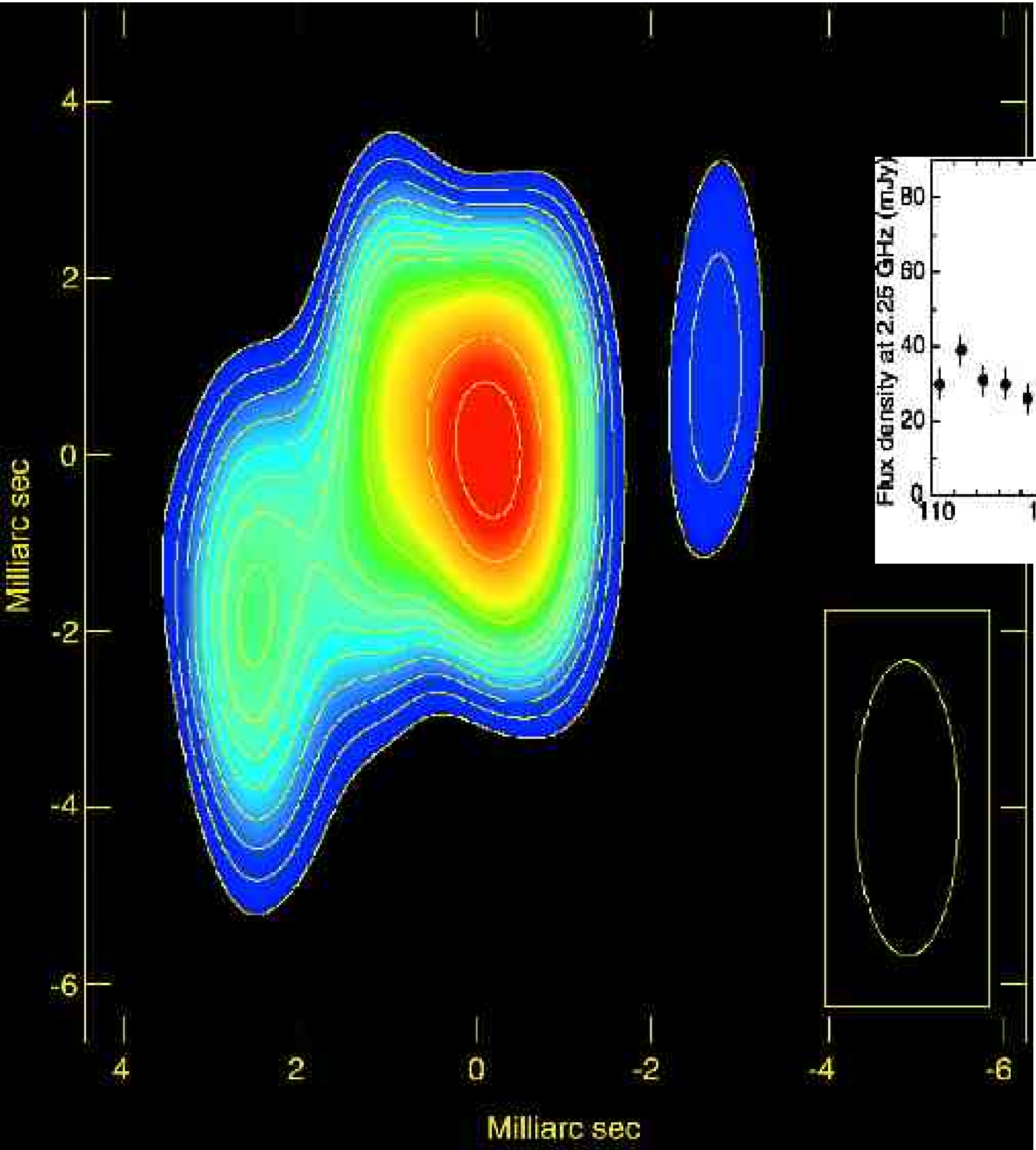
$$L_p^{\rm rel} \gtrsim L_e^{\rm rel}$$

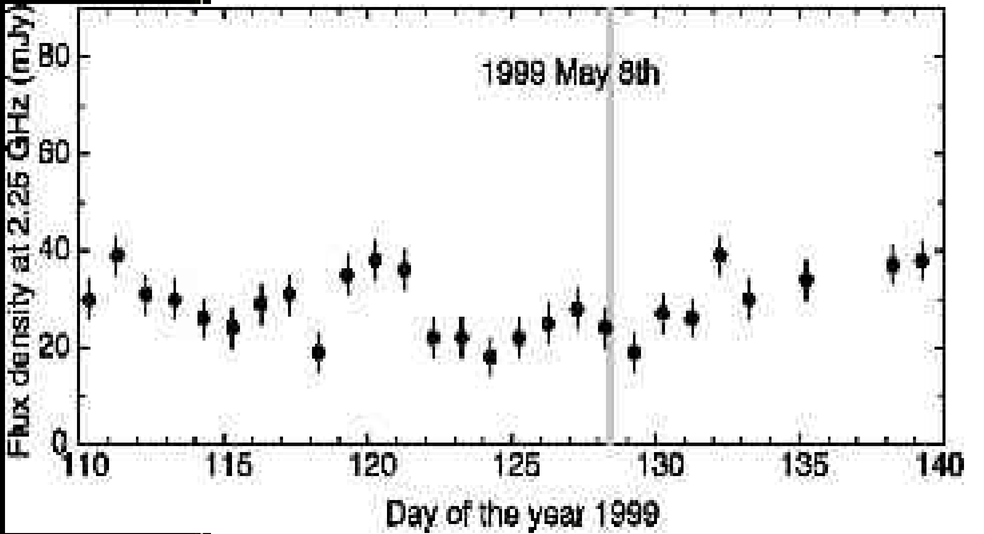
$$L_\nu \simeq f\ L_p^{\rm rel} \simeq 0.25\ L_p^{\rm rel}$$

$$L_\nu \sim L_\gamma^{\rm unabsorbed}$$

Dissipation of the power in relativistic ELECTRONS :
Inverse Compton Scattering on ambient photons.
Dissipation of the power in relativistic PROTONS:
interactions with the cold plasma inside the jet.
$\Longrightarrow$ Significant Production of neutrinos

LS 5039



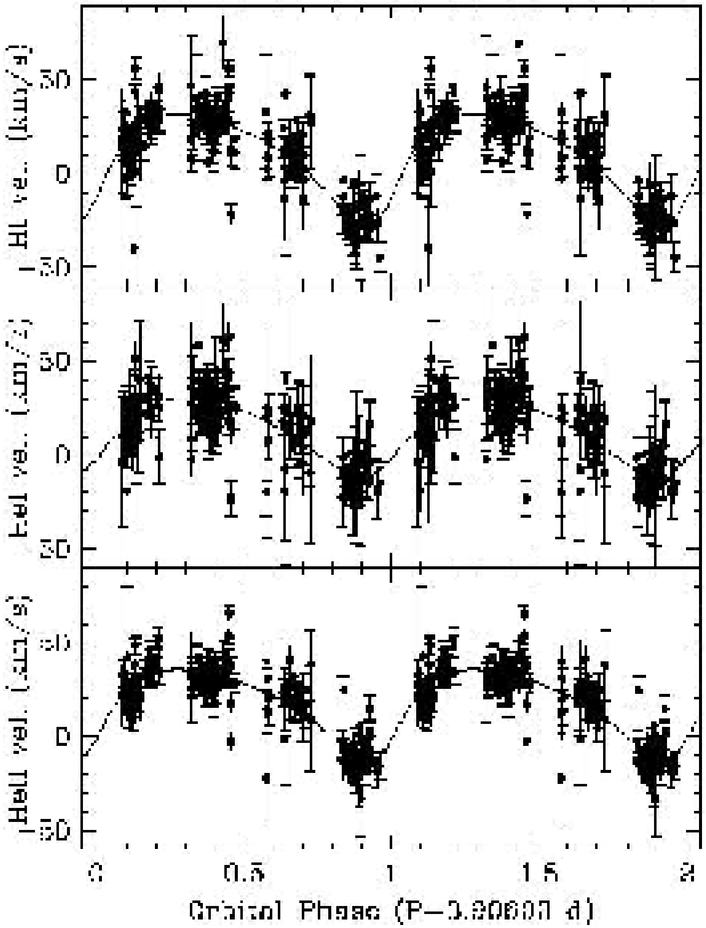


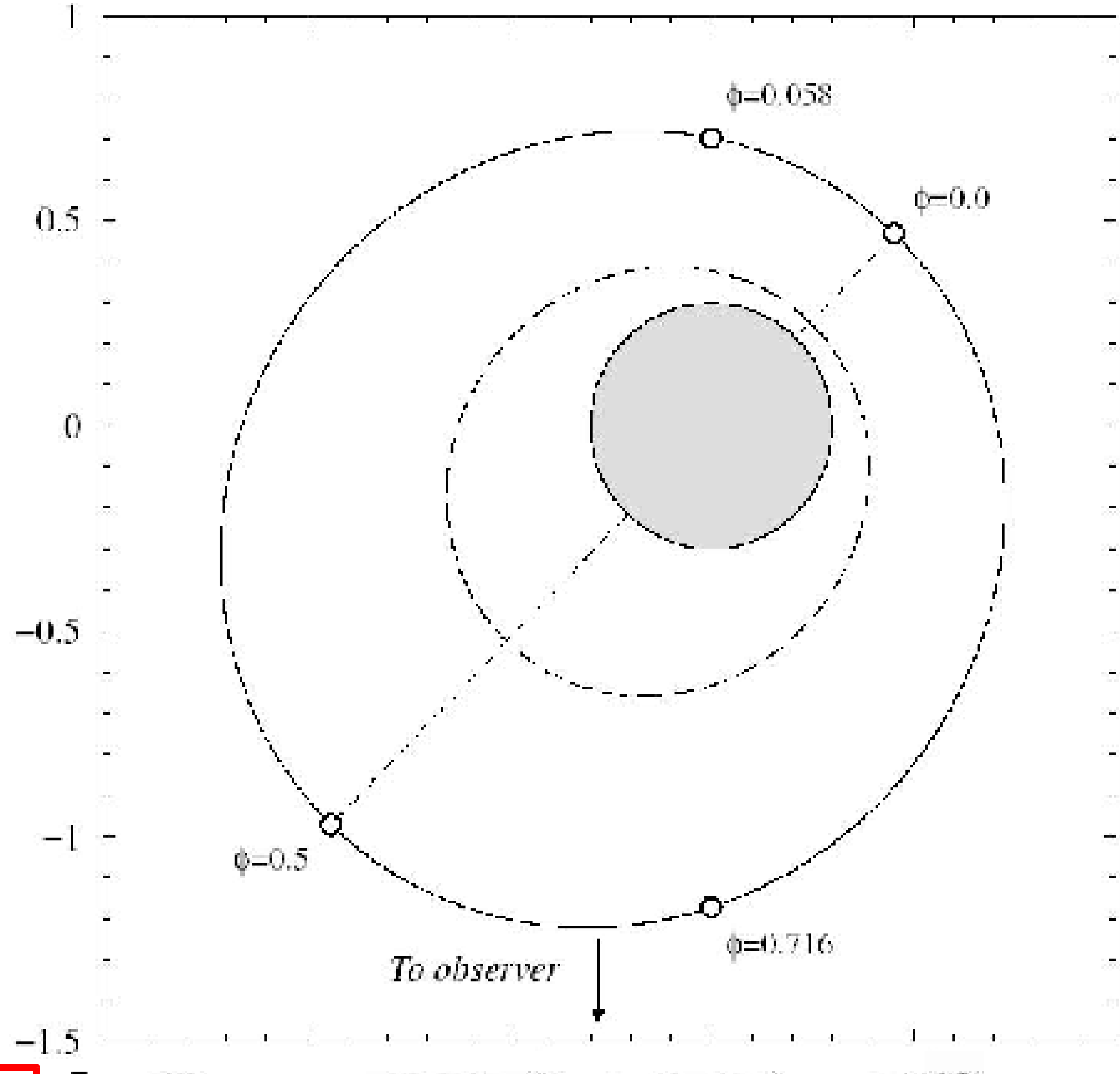
$\beta \simeq 0.4$

$\theta \simeq 68^\circ$

$\Gamma \simeq 1.09$

$\mathcal{D} \simeq 1.08$





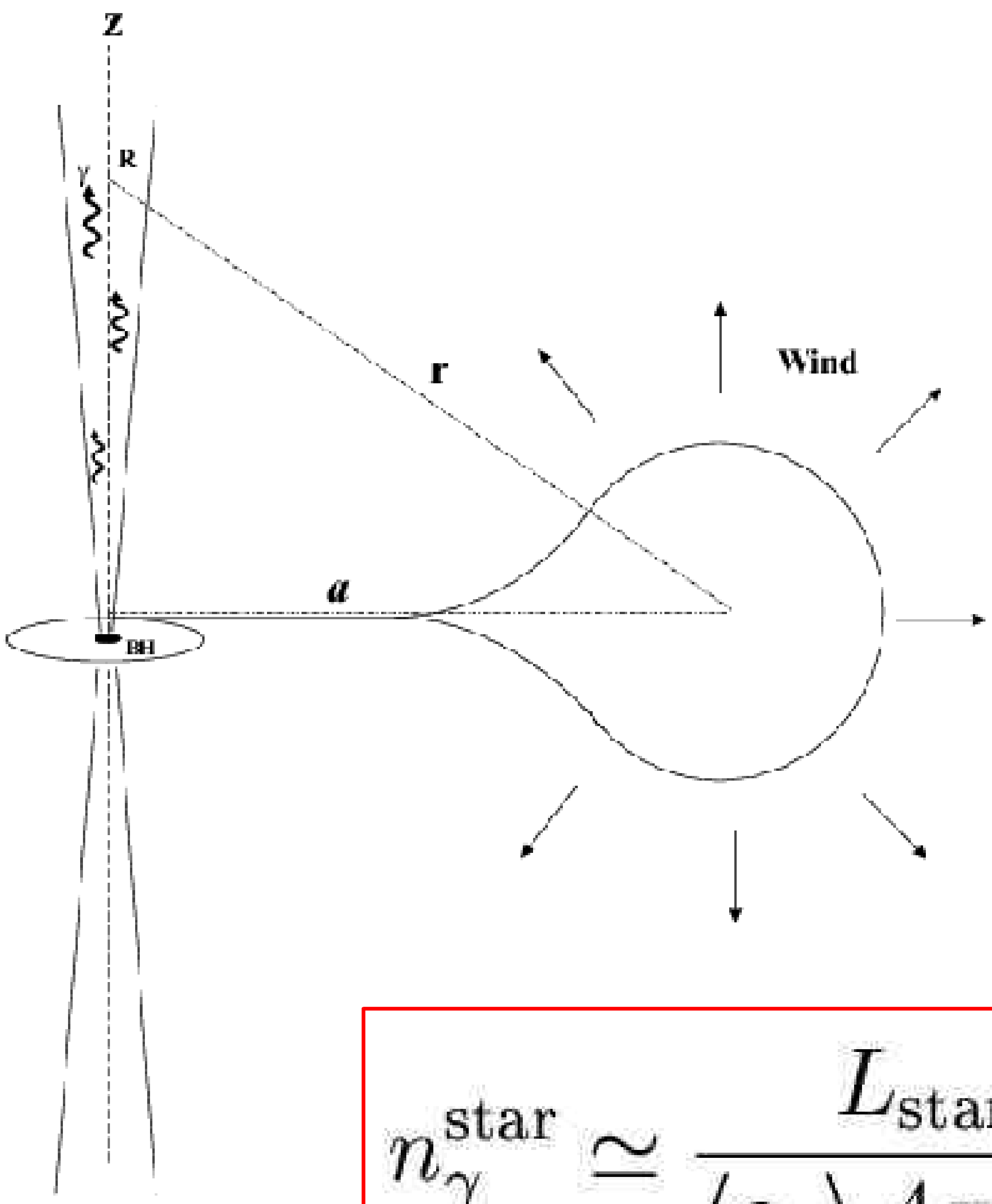
$$M_\bullet = 3.7^{+1.3}_{-1.0}\ M_\odot$$

$$M_{\rm companion} = 22.9^{+3.4}_{-2.9}\ M_\odot$$

$$R_{\rm orbit} = 2.16\ (1 \pm 0.35) \times 10^{12}\ \mathrm{cm}$$

$$P_{\rm orbit} = 3.90603 \pm 0.00017\ \mathrm{days}$$

$$i = 24.9^\circ \pm 2.8^\circ$$



ABSORPTION

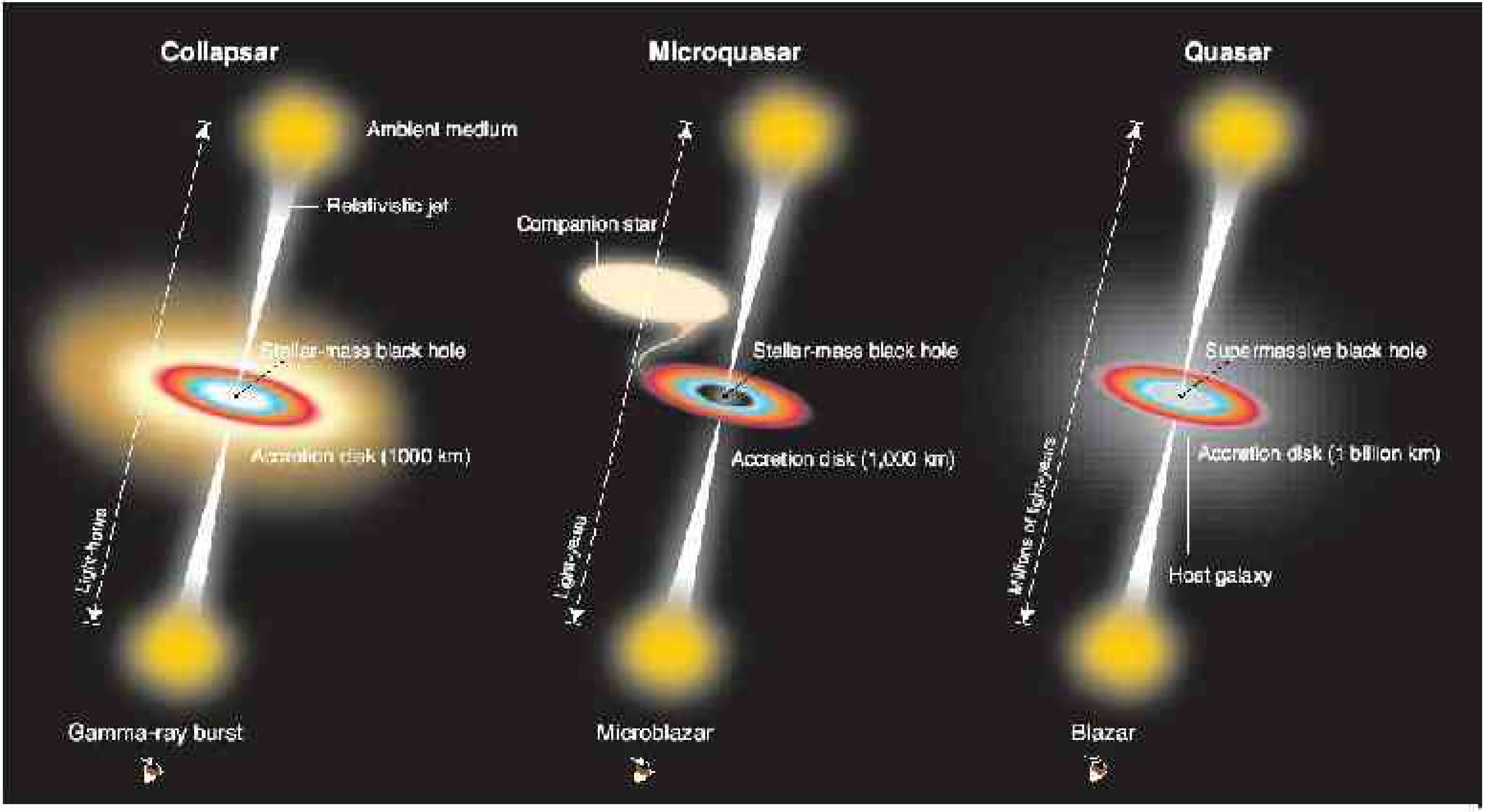
$$\gamma\gamma \rightarrow e^+ e^-$$

$$E_\gamma \, \langle \varepsilon_\gamma \rangle \gtrsim 2\, m_e^2$$

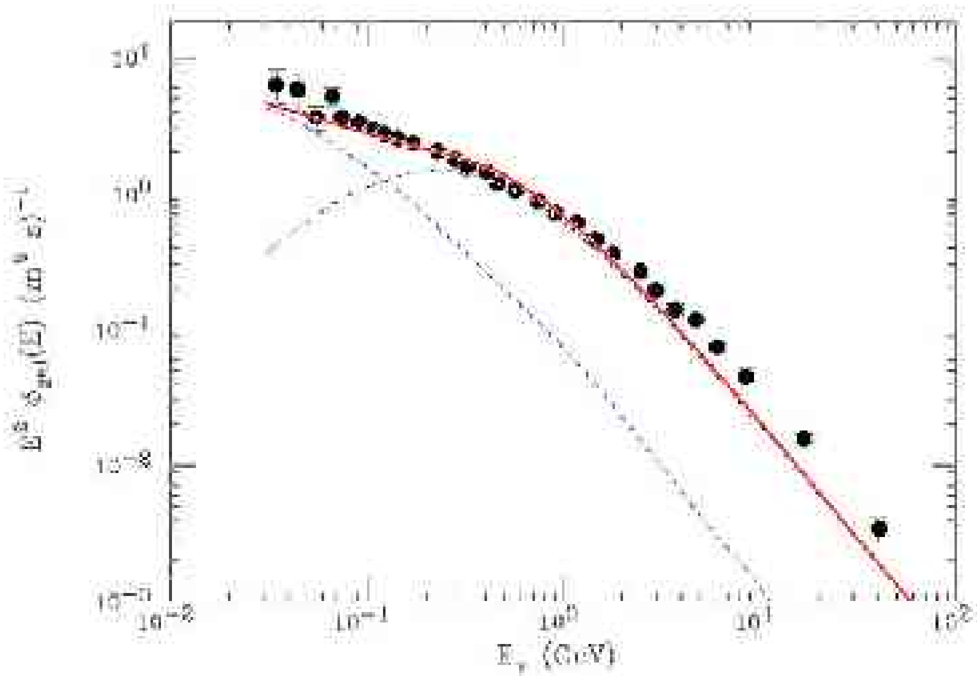
$$E_\gamma \gtrsim \frac{2\, m_e^2}{\langle \varepsilon_\gamma \rangle} \sim 50\ GeV$$

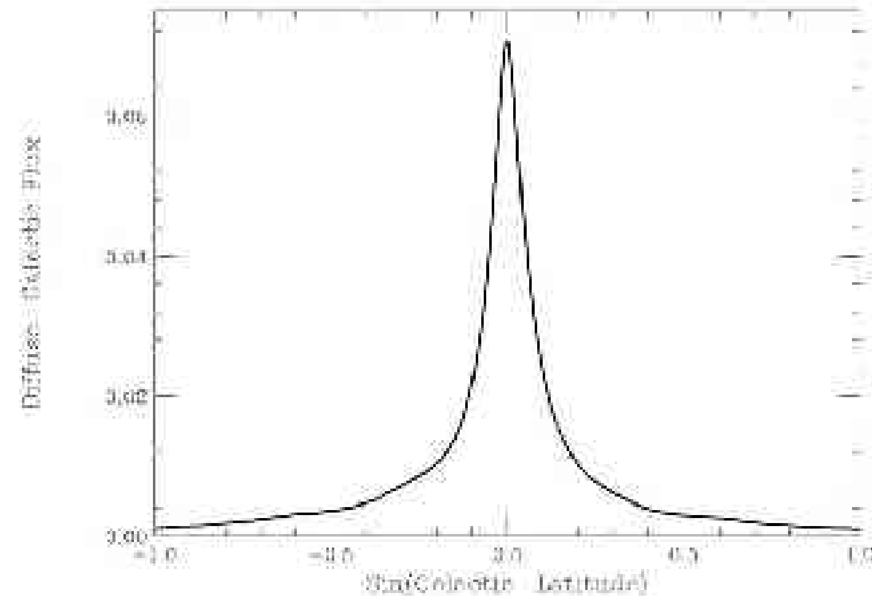
$$n_\gamma^{\rm star} \simeq \frac{L_{\rm star}}{\langle \varepsilon_\gamma \rangle \; 4\pi\, d^2\, c} \simeq \frac{5 \times 10^{14}}{d_{12}^2}\ {\rm cm}^{-3}$$

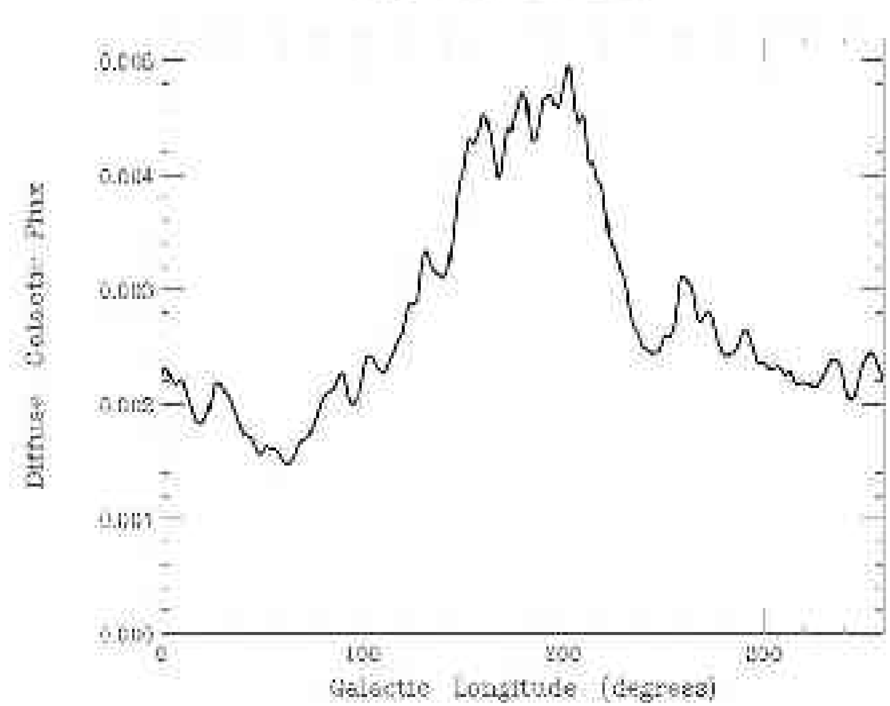
JETs in ASTROPHYSICS



GALACTIC DIFFUSE NEUTRINOS







EXTRA-GALACTIC NEUTRINOS

EXTRA-GALACTIC NEUTRINOS

UNRESOLVED FLUX

Sum of all High Energy
Neutrino Sources.

Proportional to the
Average Power Density of the
Neutrino Sources in the Universe

Flux → Particle density

$$n(E) = \frac{4\pi}{c}\ \phi(E)$$

Energy density

$$\rho(E) = n(E)\ E = \frac{4\pi}{c}\ \phi(E)\ E$$

$$\rho_\nu = \int_0^{t_0} dt \, \frac{\mathcal{L}(t)}{[1+z(t)]} = \int_0^{\infty} dz \left| \frac{dt}{dz} \right| \frac{\mathcal{L}(z)}{(1+z)}$$

$$= \int_0^{\infty} dz \, \frac{\mathcal{L}(z)}{H(z)\,(1+z)^2} = \frac{\mathcal{L}_0}{H_0}\,\xi$$

$$\xi = \int_0^{\infty} dz \left[\frac{H_0}{H(z)}\right] \left[\frac{\mathcal{L}(z)}{\mathcal{L}_0}\right] (1+z)^{-2}$$

POWER INJECTION IN THE UNIVERSE

$$\mathcal{L}_0 = \text{Power Density at Present Epoch}$$

$$(\mathcal{L}_0\,\xi) \equiv \langle \mathcal{L} \rangle = \text{“Average'' Power Density}$$

$$\xi = \int_0^\infty dz\, \frac{G(z)}{\mathcal{H}(z)\,(1+z)^2}$$

$$[\Omega_{\rm m} = 1,\ \Omega_\Lambda = 0]$$

$$\xi_{[\text{No evolution}]} = \frac{2}{5} = 0.4$$

$$[\Omega_{\rm m} = 0.3,\ \Omega_\Lambda = 0.7]$$

$$\xi_{[\text{No evolution}]} = 0.53$$

$$\xi(\text{SFR}) \simeq 3.0$$

$$\xi(\text{AGN}) \simeq 2.2$$

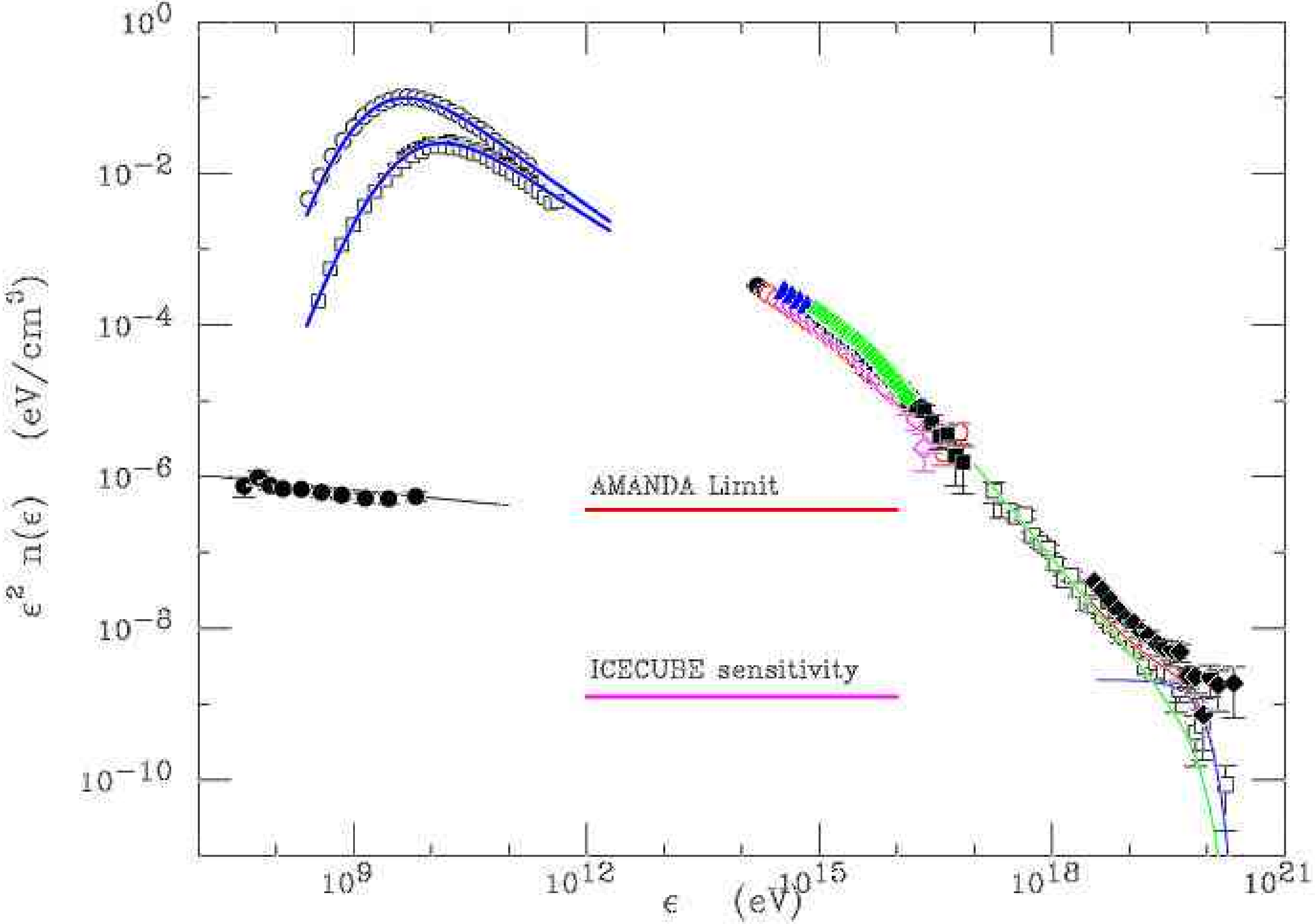
Neutrinos Injected with a Power Law of slope α

$$\rho_\nu(E_{\rm min}) = \frac{\mathcal{L}_0(E_{\rm min})}{H_0}\,\xi_\alpha$$

$$\xi_\alpha = \int_0^\infty dz\,\left[\frac{H_0}{H(z)}\right]\,\left[\frac{\mathcal{L}(z)}{\mathcal{L}_0}\right]\,(1+z)^{-\alpha}$$

$$k_\alpha \simeq (\alpha-2)/[1-(E_{\rm min}/E_{\rm max})^{\alpha-2}]^{-1}$$

$$\phi_\nu(E) = K_\nu\,E^{-\alpha} = \left(\frac{\mathcal{L}_0(E_{\rm min})\,E_{\rm min}^{\alpha-2}\,\xi_\alpha\,k_\alpha}{4\pi\,H_0}\right)\,E^{-\alpha}$$



10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
$\epsilon^2\, n(\epsilon)\quad (\mathrm{eV/cm^3})$
AMANDA Limit
ICECUBE sensitivity
10^{9}
10^{12}
10^{15}
10^{18}
10^{21}
$\epsilon\quad (\mathrm{eV})$

$\alpha = 2$

$$K_\nu \simeq 3.7 \times 10^{-11} \left[\frac{(\mathcal{L}_0\, \xi)_{\rm decade}}{L_\odot/{\rm Mpc}^3} \right] \frac{\rm GeV}{\rm cm\ s\ sr}$$

Current Limit on the diffuse ν flux :

$$(\mathcal{L}_0 \xi) \lesssim 2.4 \times 10^4 \ (L_\odot\ {\rm Mpc}^{-3})\ {\rm decade}^{-1}$$

Km^3 Detector Sensitivity

$$(\mathcal{L}_0\, \xi) \gtrsim 80$$

Sources of Power in the Universe

- STARS
- DEATH of STARS
  - SuperNovae
  - GRB's (long duration)
- Coalescing Compact Objects
- Active Galactic Nuclei

STELLAR POWER

B–band optical luminosity
Peebles & Fukugita
"The cosmic energy inventory,"
Astrophys.J. 616, 643 (2004).

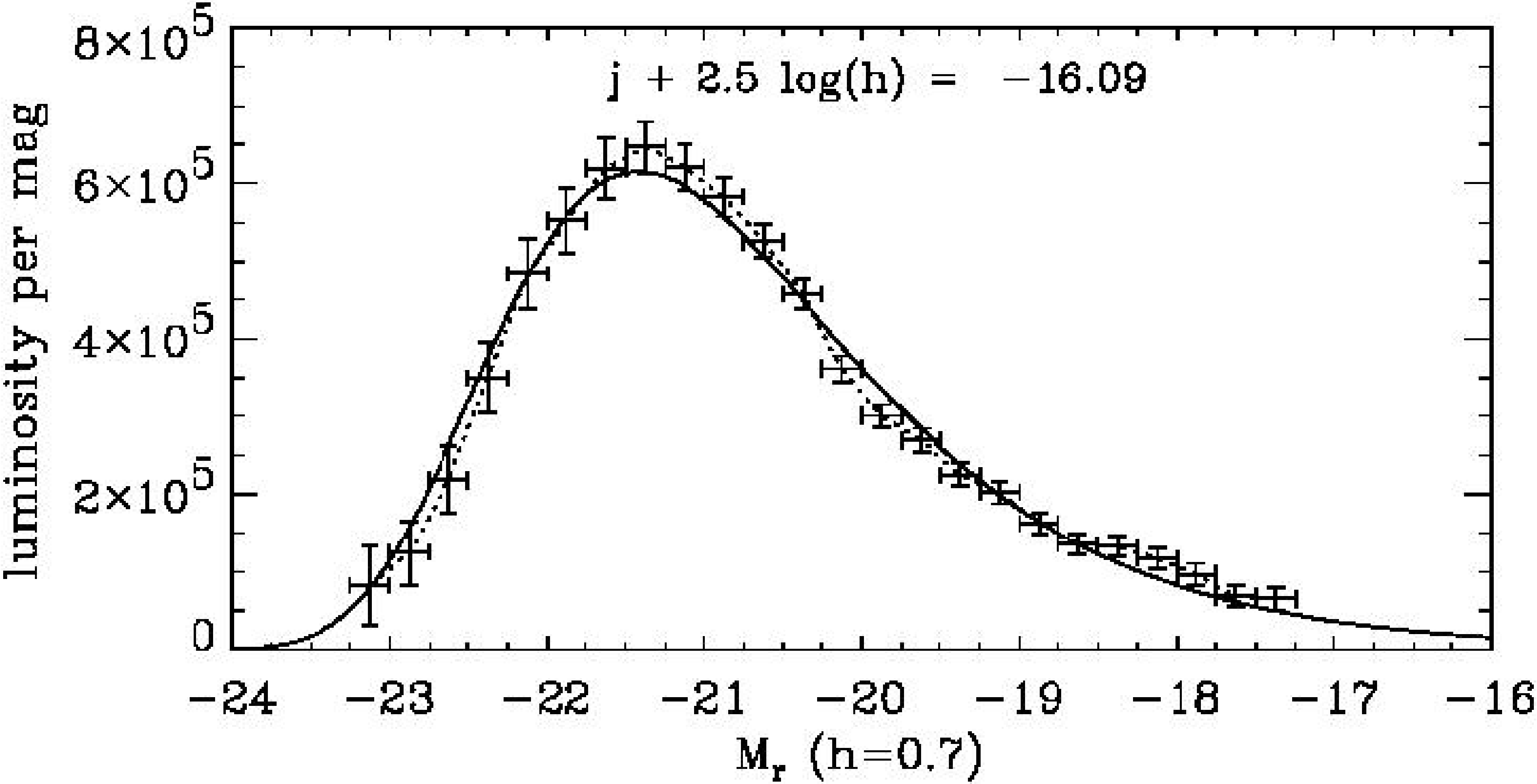
$$(\mathcal{L}\,\xi)_B^{\rm star} \simeq 5.6 \times 10^8 \;\left(\frac{L_\odot}{\rm Mpc^3}\right)$$

Hauser & Dwek,
"The Cosmic Infrared Background:
Measurements and Implications"
Ann.Rev.Astr.Astrophys. 39, 249 (2001).

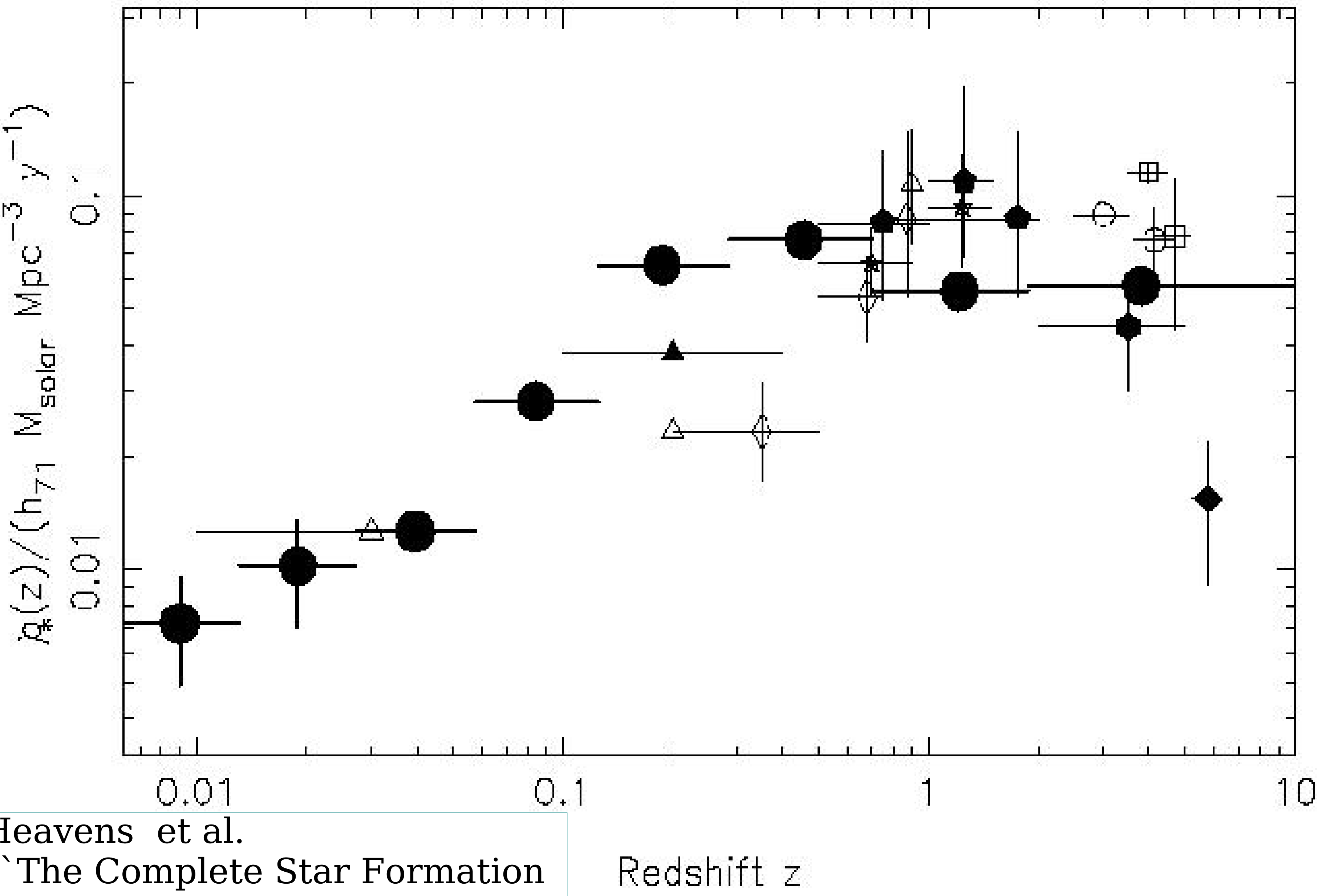
$$\langle \mathcal{L}^{\rm bol}_{\rm star} \rangle = (0.36 \div 1.23) \times 10^9 \;\frac{L_\odot}{\rm Mpc^3}$$

SDSS

Z [0.015, 0.080]

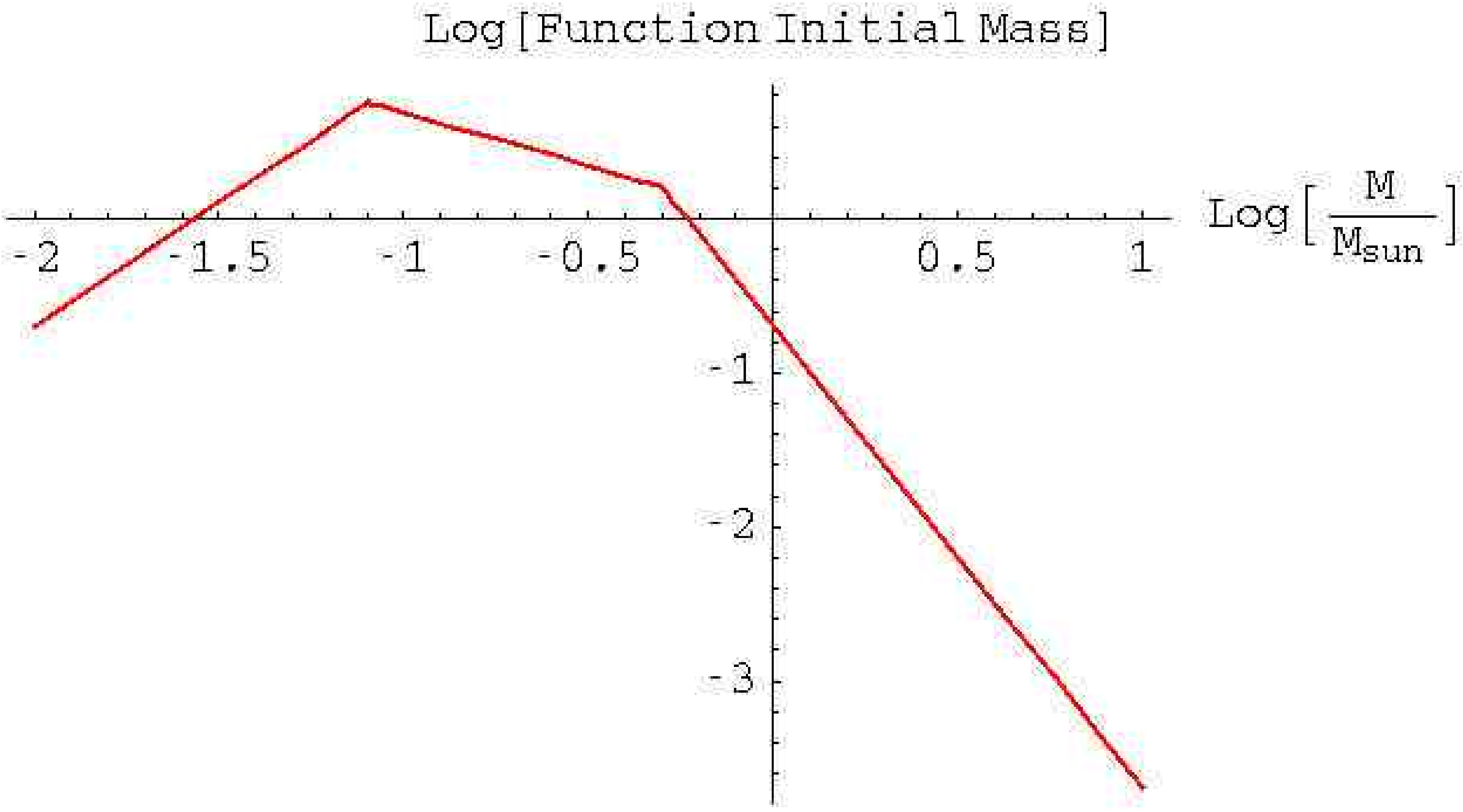


COSMIC HISTORY OF the STAR FORMATION



Heavens et al.
``The Complete Star Formation
History of the Universe,''
Nature 428, 625 (2004)

INITIAL MASS FUNCTION $\psi = \int dM \ M \ \frac{dN_{\rm star}}{dM}$

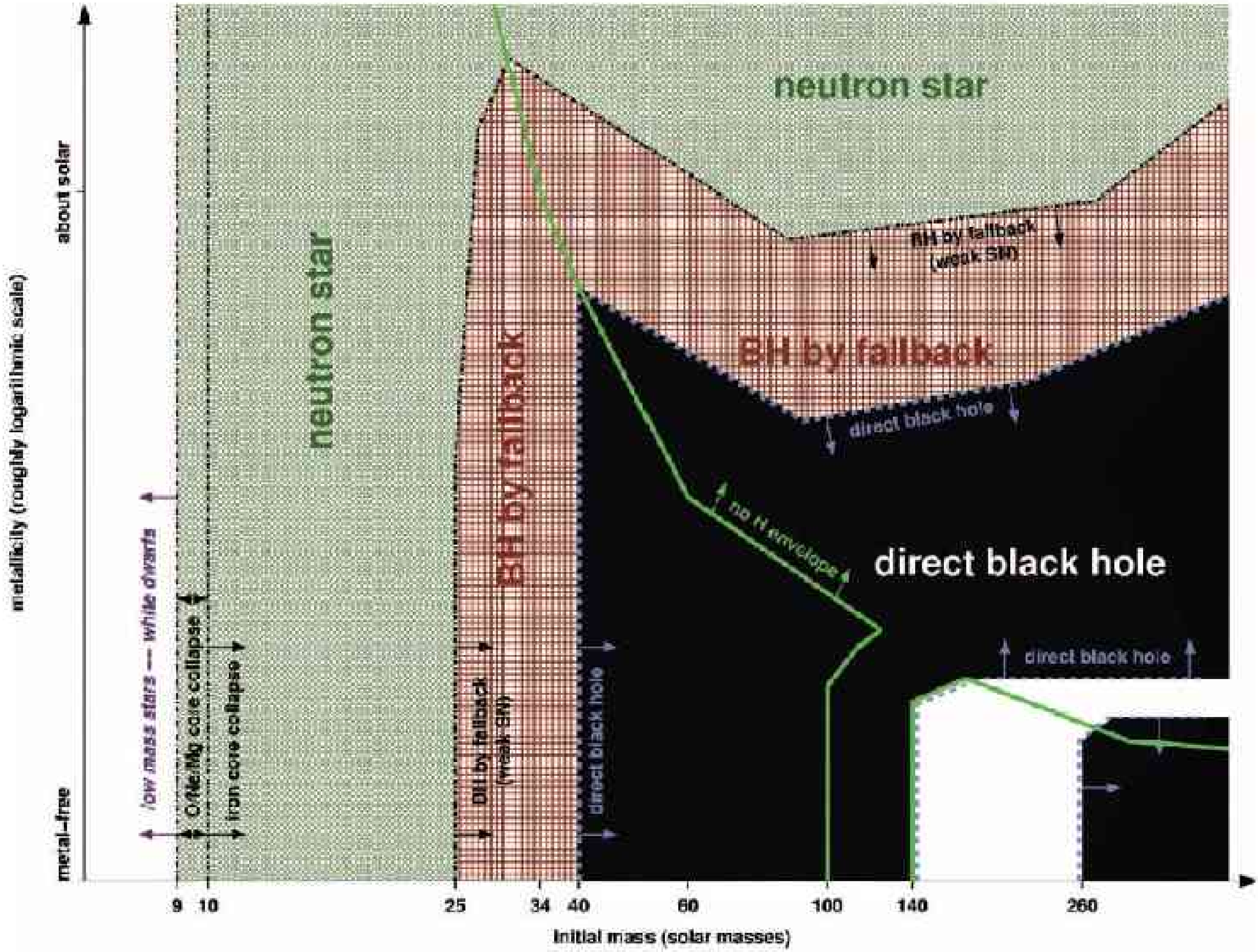


Total mass gone into the Star Formation
in history of the universe:

$$\rho_{\rm star} \simeq 5.9 \times 10^8 \ \left(\frac{M_\odot}{\rm Mpc^3}\right)$$

$$\Omega_{\rm star} = 0.0043 \simeq 0.09 \ \Omega_{\rm baryon}$$

Estimate of the SN Rate:
All stars with $M > 8 \ M_\odot$
end their evolution with gravitational core–collapse.



neutron star
neutron star
BH by fallback
BH by fallback
BH by fallback (weak SN)
direct black hole
direct black hole
direct black hole
direct black hole
no H envelope
BH by fallback (weak SN)
low mass stars — white dwarfs
O/Ne/Mg core collapse
iron core collapse
metallicity (roughly logarithmic scale)
about solar
metal-free
9
10
25
34
40
60
100
140
260
initial mass (solar masses)

$$R_{\rm SN} = \psi(0) \frac{\int_8^{100} dM \frac{dN}{dM}}{\int_{0.08}^{100} dM \ M \ \frac{dN}{dM}}$$

$$\simeq 7.9^{+2.4}_{-3.9} \times 10^{-4} \ ({\rm Mpc}^3 \ {\rm yr}^{-1})$$

$$R_{\rm SN}^{\rm observed} \simeq 7.6^{+6.4}_{-2.0} \times 10^{-4} \ ({\rm Mpc}^3 \ {\rm yr}^{-1})$$

$$\langle E_{\rm kin} \rangle_{SN} \simeq 1.6 \times 10^{51} \ {\rm erg}$$

$$(\mathcal{L} \ \xi)_{\rm SN,kin} \simeq 4.2 \times 10^6 \left(\frac{L_\odot}{{\rm Mpc}^3} \right)$$

POWERING THE GALACTIC COSMIC RAYS

$$L_{\rm cr}(\text{Milky Way}) \simeq \frac{\rho_{\rm cr}\, V_{\rm conf}}{T_{\rm conf}}$$

$$\simeq 2 \times 10^{41} \left(\frac{\rm erg}{\rm s}\right)$$

Power Provided by the conversion with an efficiency of order 15-20 % of the Kinetic Energy of SuperNovae.

It is Natural to Expect that the Production of Cosmic Rays is a Universal Process, correlated with Star Formation and Death (and therefore to Optical Light)

$$L_B(\text{Milky Way}) \simeq 4.6 \times 10^{10}\ L_\odot$$

$$\mathcal{L}_B \simeq 1.9 \times 10^8 \ \left(\frac{L_\odot}{\text{Mpc}^3}\right)$$

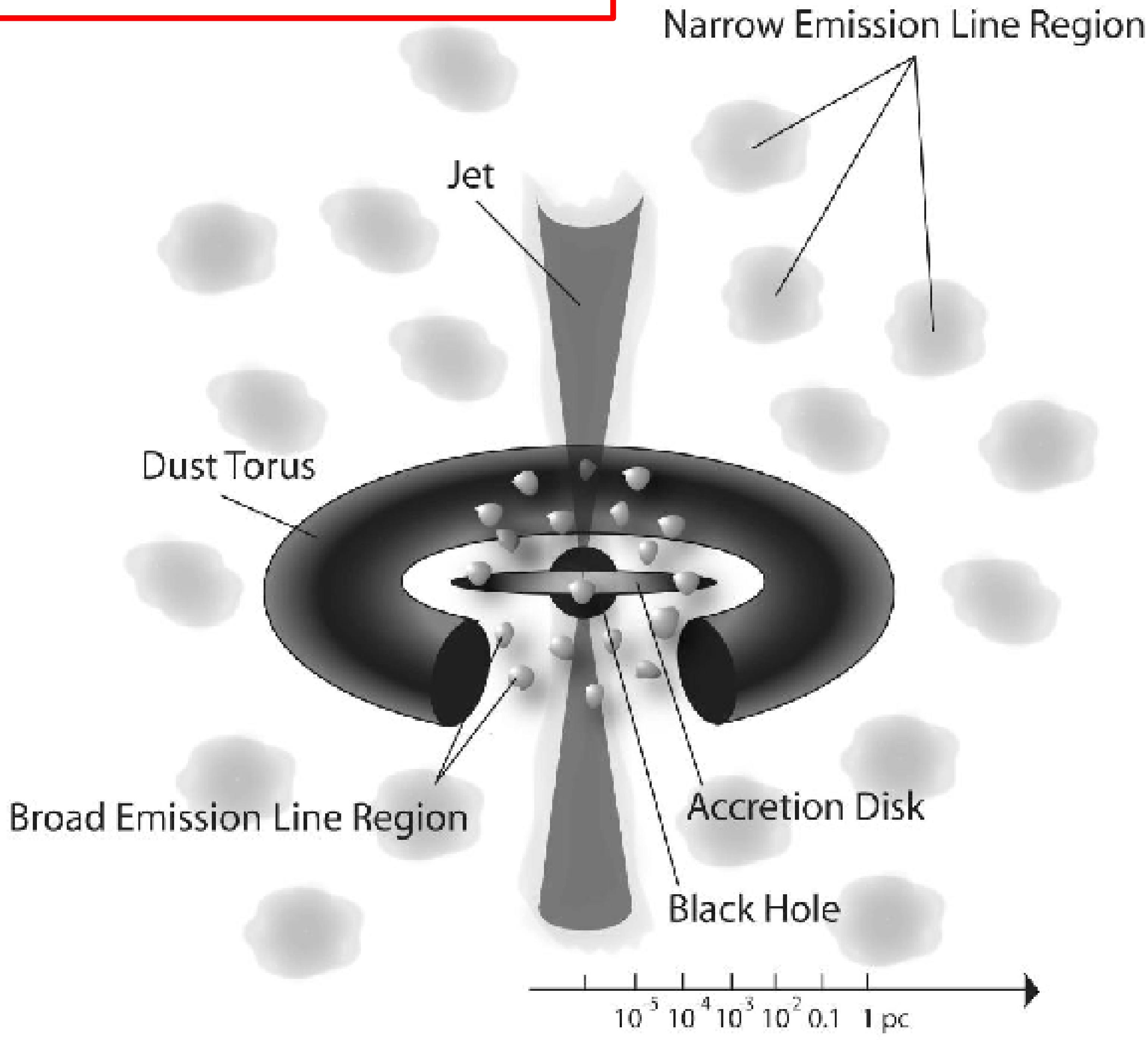
$$\mathcal{L}_{\rm cr} \simeq \mathcal{L}_B \ \frac{L_{\rm cr}(\text{MW})}{L_B(\text{MW})} = 2.3 \times 10^5 \ \left(\frac{L_\odot}{\text{Mpc}^3}\right)$$

Good Matching between
the power needed to have "Universal Cosmic Ray Production:
and the Power available in SN explosions.

$$(\mathcal{L}\,\xi)_{\rm cr} \simeq 2.2 \times 10^5 \left(\frac{L_\odot}{\rm Mpc^3}\right)$$

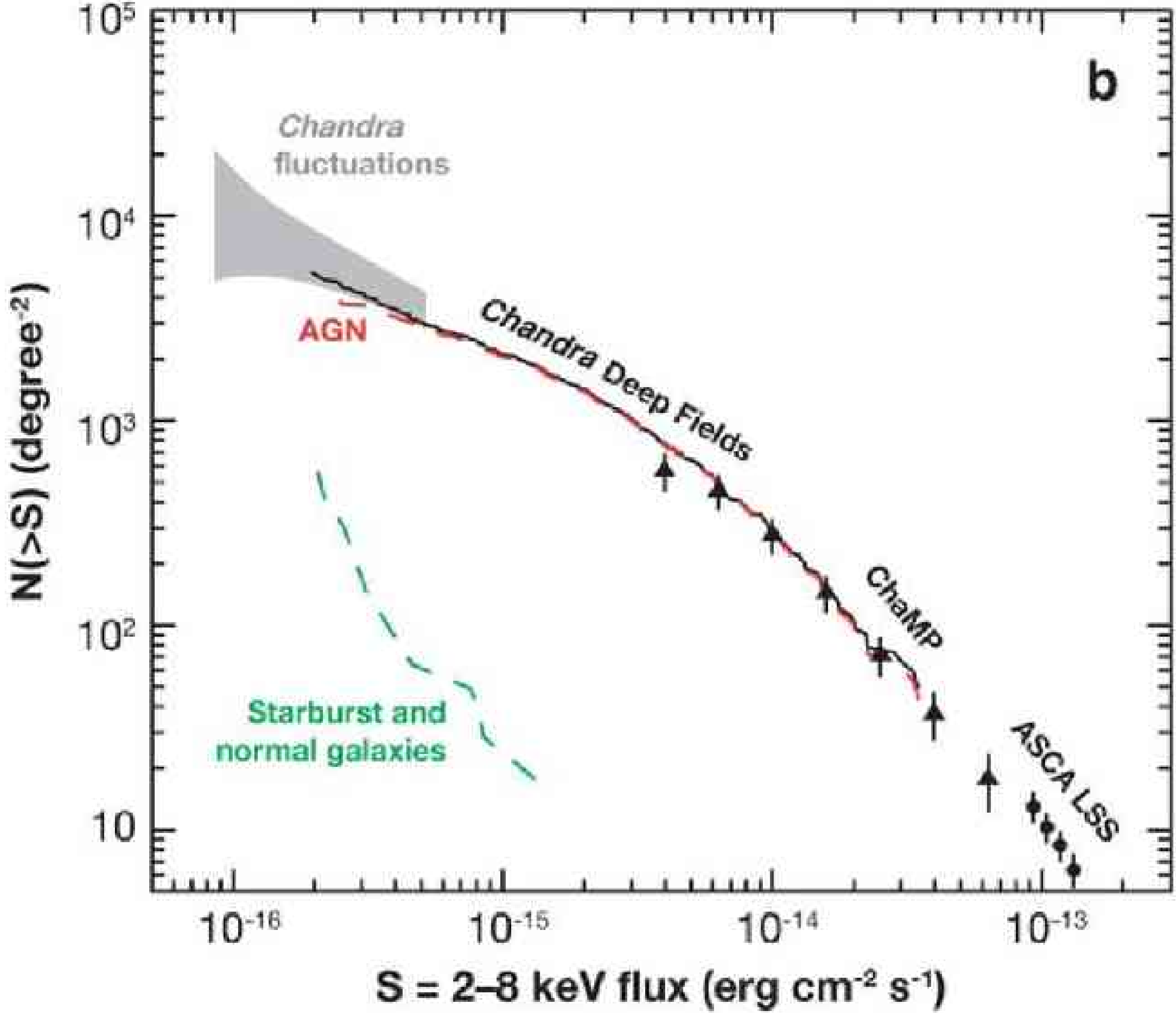
$$(\mathcal{L}\,\xi)_{\rm SN,kin} \simeq 4.2 \times 10^6 \left(\frac{L_\odot}{\rm Mpc^3}\right)$$

ACTIVE GALACTIC NUCLEI

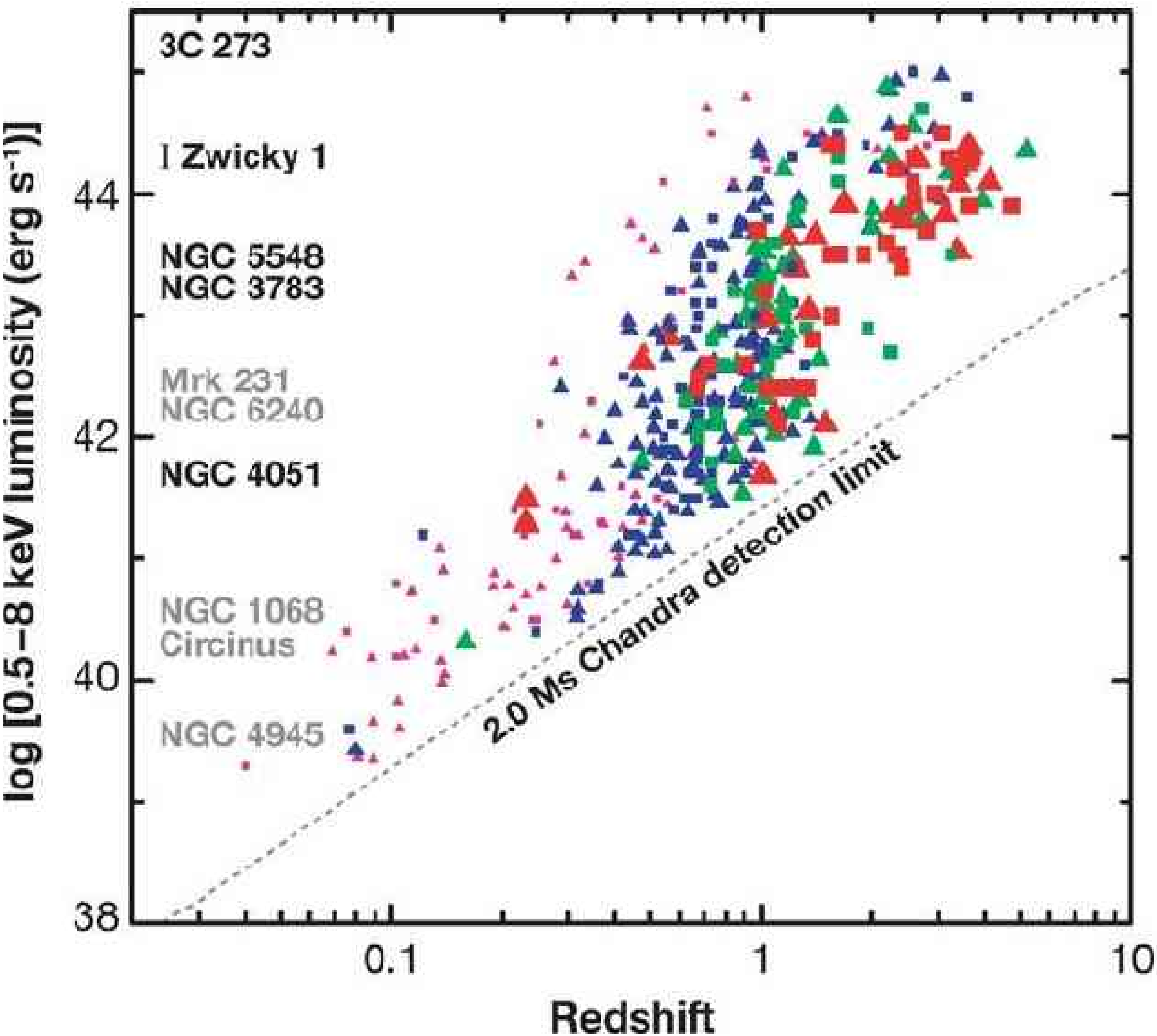


AGN
Fueled by
ACCRETION POWER

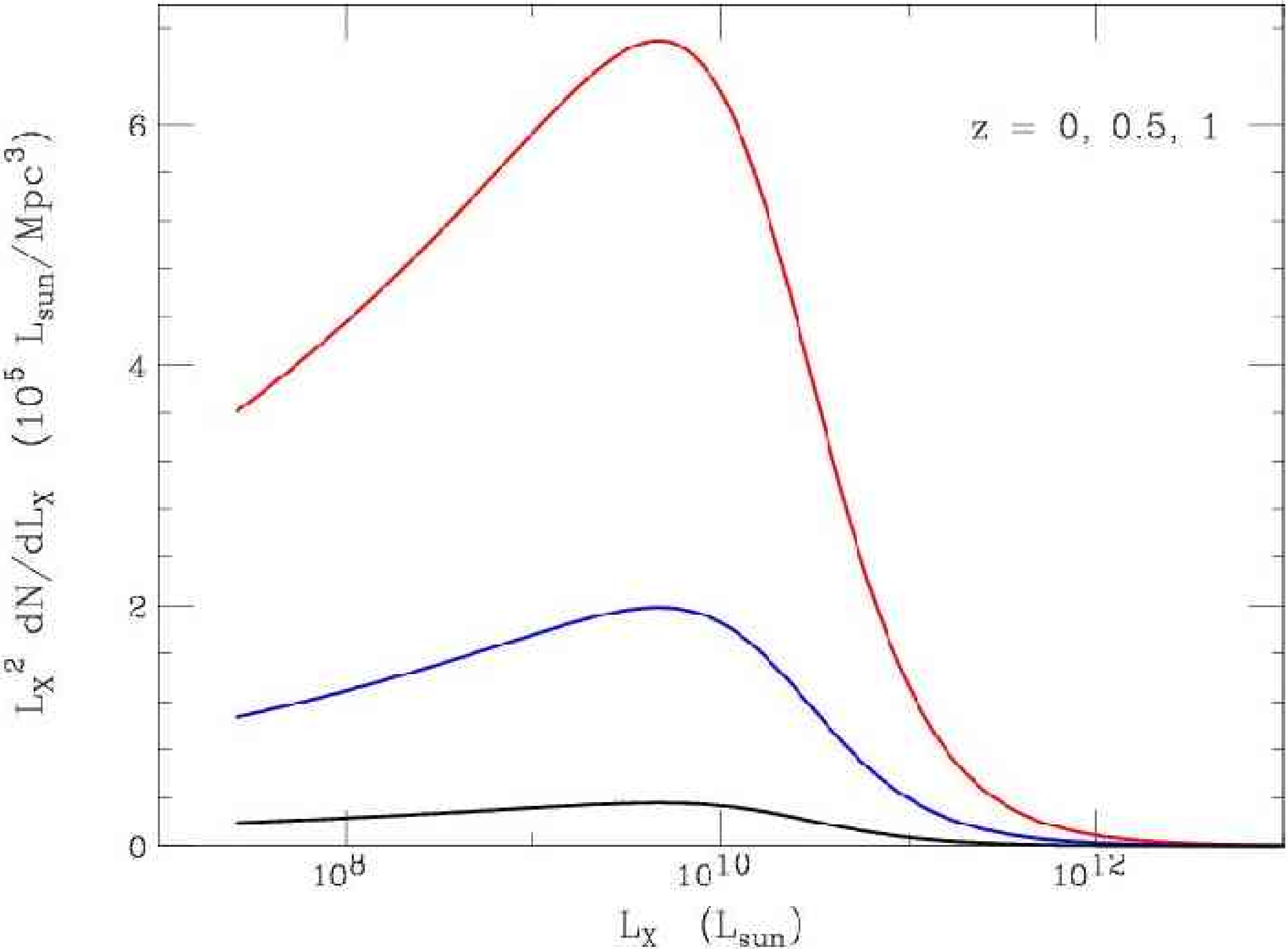
What is the
ENERGY OUTPUT
of the ensemble of AGN ?



b
Chandra fluctuations
AGN
Chandra Deep Fields
ChaMP
ASCA LSS
Starburst and normal galaxies
N(>S) (degree⁻²)
S = 2–8 keV flux (erg cm⁻² s⁻¹)


3C 273
I Zwicky 1
NGC 5548
NGC 3783
Mrk 231
NGC 6240
NGC 4051
NGC 1068
Circinus
NGC 4945
2.0 Ms Chandra detection limit
log [0.5–8 keV luminosity (erg s-1)]
44
42
40
38
0.1
1
10
Redshift

Y. Ueda *et al.*, "Cosmological Evolution of the Hard X-Ray AGN Luminosity Function: Formation History of Supermassive Black Holes", Prog.Th.Phys.Supp **155**, 209 (2004)



$$(\mathcal{L}\,\xi)_{\mathrm{AGN},X} \;\sim\; 6.4\times10^{5}\,\left(\frac{L_\odot}{\mathrm{Mpc}^3}\right)$$

$$(\mathcal{L}\,\xi)_{\mathrm{AGN,bol}} \;\simeq\; 2\times10^{7}\,\left(\frac{L_\odot}{\mathrm{Mpc}^3}\right)$$

$$(\mathcal{L}\,\xi)_{\mathrm{Blazars},\gamma} \;\simeq\; 1\text{--}4\times10^{4}\,\left(\frac{L_\odot}{\mathrm{Mpc}^3}\right)$$

Relation between AGN Power and the SUPER MASSIVE BLACK HOLES MASS

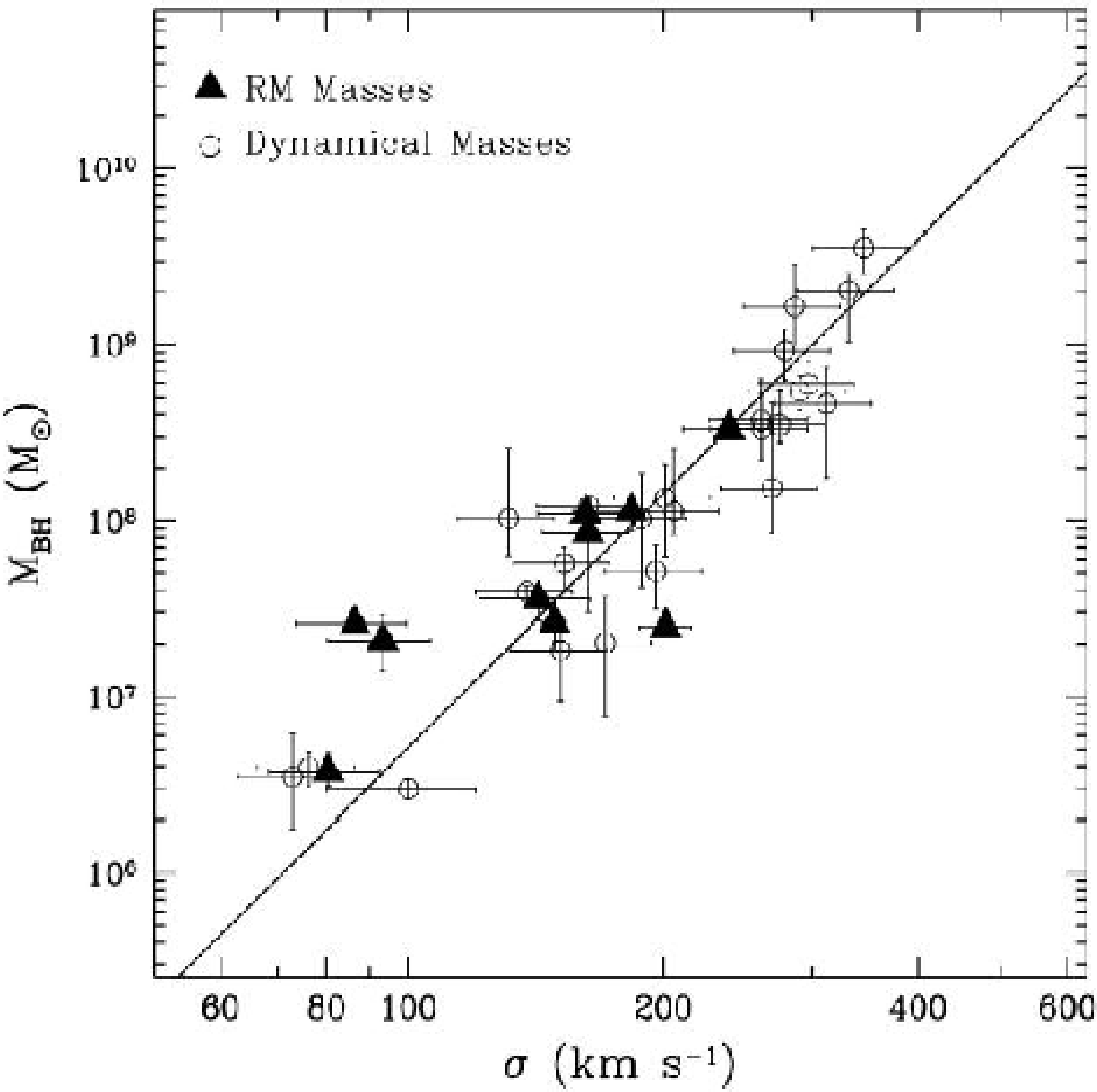
Mass m falling into a Black Hole of mass $M_\bullet$

Energy $\varepsilon\, M$ is radiated away in different forms

The Black Hole is increased by an amount: $M_\bullet \to M_\bullet + (1-\varepsilon)\, m$

$$M_\bullet = \frac{(1-\varepsilon)}{\varepsilon}\; E_{\rm radiated}$$

$$\varepsilon = \frac{E_{\rm radiated}}{m} \simeq \frac{G\, M_\bullet}{r} \simeq \frac{G\, M_\bullet}{f\, R_S} = \frac{G\, M_\bullet}{f\;2\, G\, M} = \frac{1}{2\, f} \simeq 0.1$$



Correlation between Mass

Velocity Dispersion

$$\frac{M_{\bullet}}{10^8 \mathrm{M}_{\odot}} = (1.66 \pm 0.24) \left(\frac{\sigma}{200 \ \mathrm{km \ s^{-1}}} \right)^{4.86 \pm 0.43}$$

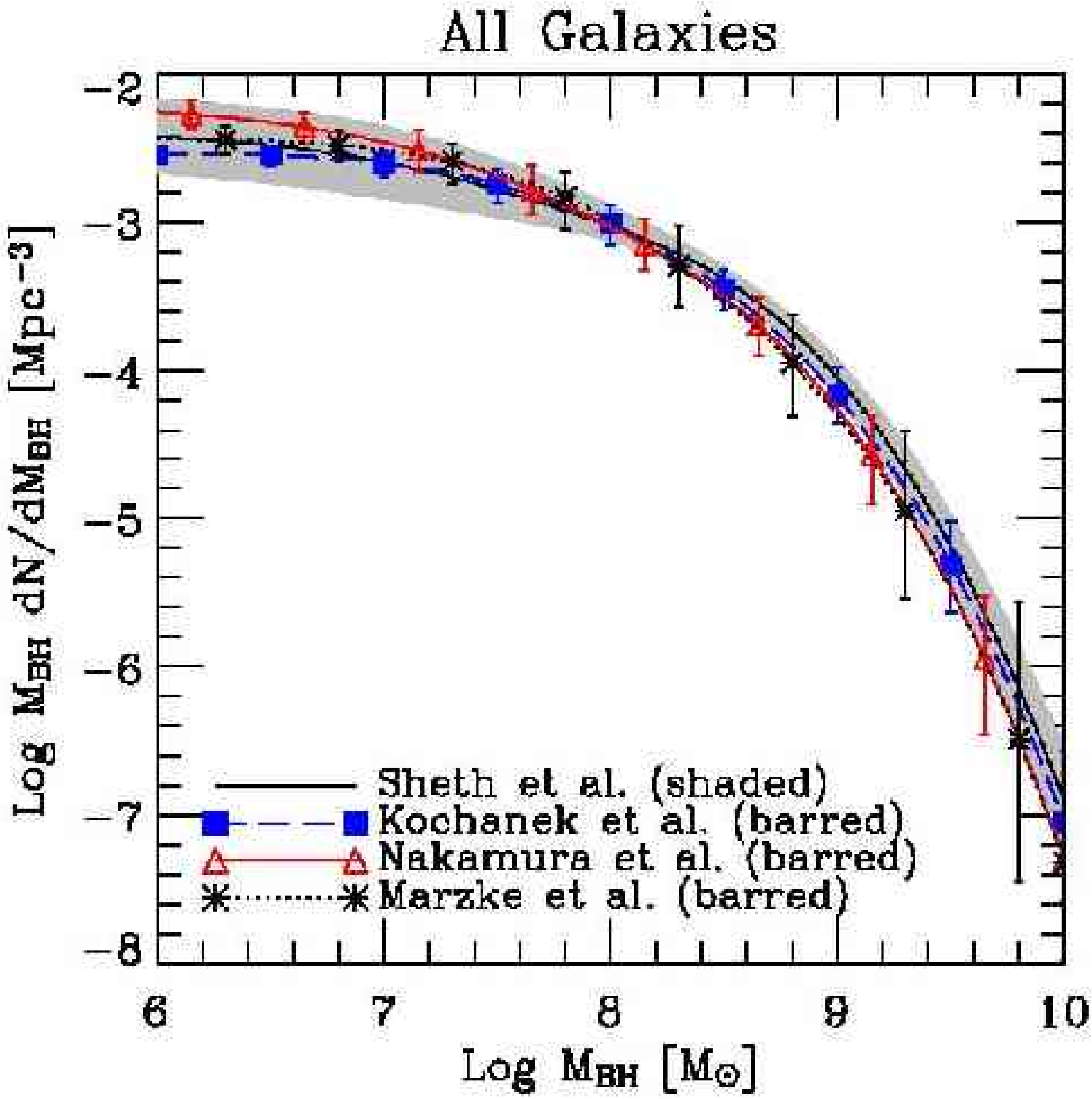
ESTIMATES of the

TOTAL MASS

in

SUPER MASSIVE BLACK HOLES

$\rho_\bullet$ ($M_\odot Mpc^{-3}$)	Reference
Local Quiescent Galaxies ($z < 0.025$)	
$2.3^{+4.0}_{-1.5} \times 10^5$	Wyithe & Loeb (2003)
$2.4 \pm 0.8 \times 10^5$	Aller & Richstone (2002)
$\sim 2.5 \times 10^5$	Yu & Tremaine (2002)
$2.8 \pm 0.4 \times 10^5$	McLure & Dunlop (2004)
$4.2 \pm 1.0 \times 10^5$	Shankar et al. (2004)
$\sim 4.5 \times 10^5$	Ferrarese (2002a)
$4.6^{+1.9}_{-1.4} \times 10^5$	Marconi et al. (2004)
$\sim 5 \times 10^5$	Merritt & Ferrarese (2001a)
$\sim 5.8 \times 10^5$	Yu & Tremaine (2002)
QSOs Optical Counts ($0.3 < z < 5.0$)	
$\sim 1.4 \times 10^5$	Shankar et al. (2004)
$\sim 2 \times 10^5$	Fabian (2003)
$\sim 2.1 \times 10^5$	Yu & Tremaine (2004)
$\sim 2.2 \times 10^5$	Marconi et al. (2004)
$2 - 4 \times 10^5$	Ferrarese (2002a)
AGN X-ray Counts ($z(peak) \sim 0.7$)	
$\sim 2 \times 10^5$	Fabian (2003)
$\sim 4.1 \times 10^5$	Shankar et al. (2004)
$4.7 - 10.6 \times 10^5$	Marconi et al. (2004)



Marconi et al.
MNRAS 304, L7
(2003)

Comparing
L(AGN, bolometric)

to
M(SMBH)

Good consistency

Efficiency ~ 0.10

$$\rho(\mathrm{BH}) = 4.6(+1.9;-1.4)\ [10^5\ M_\odot\ \mathrm{Mpc}^{-3}]$$

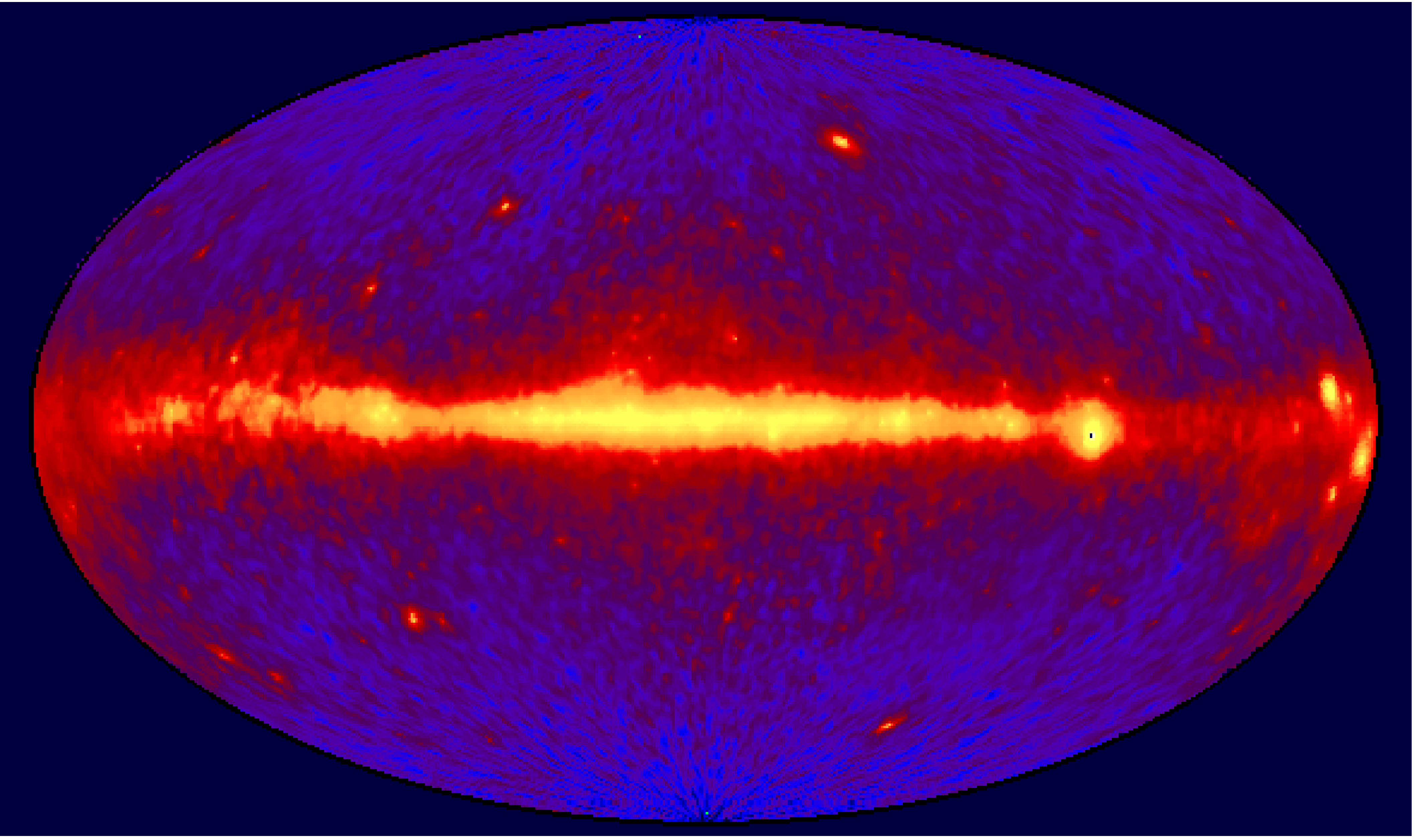
Indicators of Neutrino Source:

- GAMMA RAYS
- COSMIC RAYS

Compton Gamma Ray Observatory

1991-2000

EGRET all Sky Map



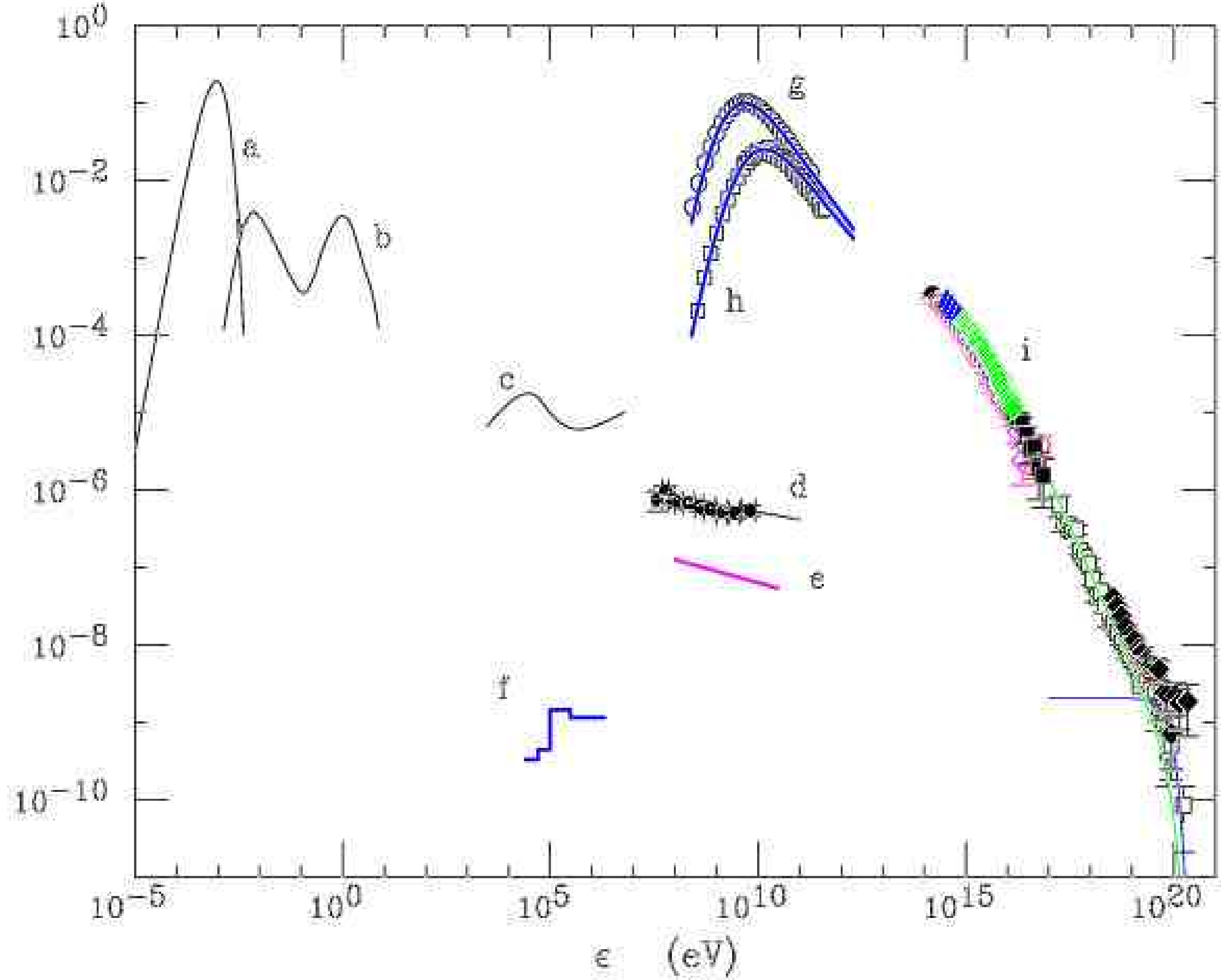
EGRET EXTRAGALACTIC FLUX

$$\Phi_\gamma^{\rm Egret}(\geq E_\gamma) \simeq (1.42 \times 10^{-6}) \left(\frac{E_\gamma}{\rm GeV}\right)^{-1.1} \ {\rm cm}^2\,{\rm s}^{-1}\,{\rm sr}^{-1}$$

$$\rho_\gamma^{\rm Egret}[E_{\rm min},\ 10\,E_{\rm min}] \simeq (1.35 \times 10^{-6}) \left(\frac{E_\gamma}{\rm GeV}\right)^{-0.1} \left(\frac{\rm eV}{{\rm cm}^2}\right)$$

$$(\mathcal{L}\,\xi)_\gamma\,[E_{\rm min},\ 10\,E_{\rm min}] \ \simeq \ 1.44 \times 10^{38} \left(\frac{E_\gamma}{\rm GeV}\right)^{-0.1} \left(\frac{\rm erg}{{\rm s\ Mpc}^3}\right)$$

$$\simeq \ 3.7 \times 10^{4} \left(\frac{E_\gamma}{\rm GeV}\right)^{-0.1} \left(\frac{L_\odot}{{\rm Mpc}^3}\right)$$



10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
$\epsilon^2\ n(\epsilon)\quad (eV/cm^3)$
a
b
c
d
e
f
g
h
i
10^{-5}
10^0
10^5
10^{10}
10^{15}
10^{20}
$\epsilon\quad (eV)$

WHAT IS (ARE) THE SOURCE(S) OF THE EGRET

DIFFUSE EXTRAGALACTIC GAMMA RAY FLUX ?

Can UNRESOLVED BLAZARS account for the diffuse Flux ?

Estimate the Possible Contribution of BLAZARS to the EGRET Extragalactic Background

$$n(L,z) \equiv \frac{dN_{\rm sources}}{dL}(L;\ z)$$

Number density of sources

$$q(E_\gamma, L) = \frac{L}{\log[E_{\rm max}/E_{\rm min}]}\, E^{-2}$$

Model of the emission for a source of luminosity L

$$\frac{dN_\gamma}{dE_\gamma}(E_\gamma;\ L, z) = \frac{(1+z)^2}{4\pi\, d_L^2(z)}\, q[E(1+z);\ L]$$

Source of Luminosity L at redshift z

Total FLUX

$$\phi_{\rm total} = \int dz\, V(z) \int dL\, n(L,z)\, \frac{dN_\gamma}{dE_\gamma}(E_\gamma;\ L,z)$$

Resolved Sources : above a minimum flux

$$\Phi_\gamma \geq \Phi_{\rm min}$$

Distribution
of the observed properties
of the sources
Redshift, Luminosity

Estimates of the Blazar constribution to the diffuse Gamma Ray flux vary:

Stecker & Salamon (Ap.J. 464, 600 (1996) :

Blazars contribution can account for the extragalactic diffuse flux.

Chiang & Mukherjee (Ap.J 496, 752 (1998):

Blazars = 0.25 Extragalactic diffuse flux

The Most common explanations for the Blazar Gamma Radiation is via LEPTONIC (SSC) Models Associated Neutrino Flux not well determined

Exciting Possibility:
Additional (unknown) source of High Energy Photons

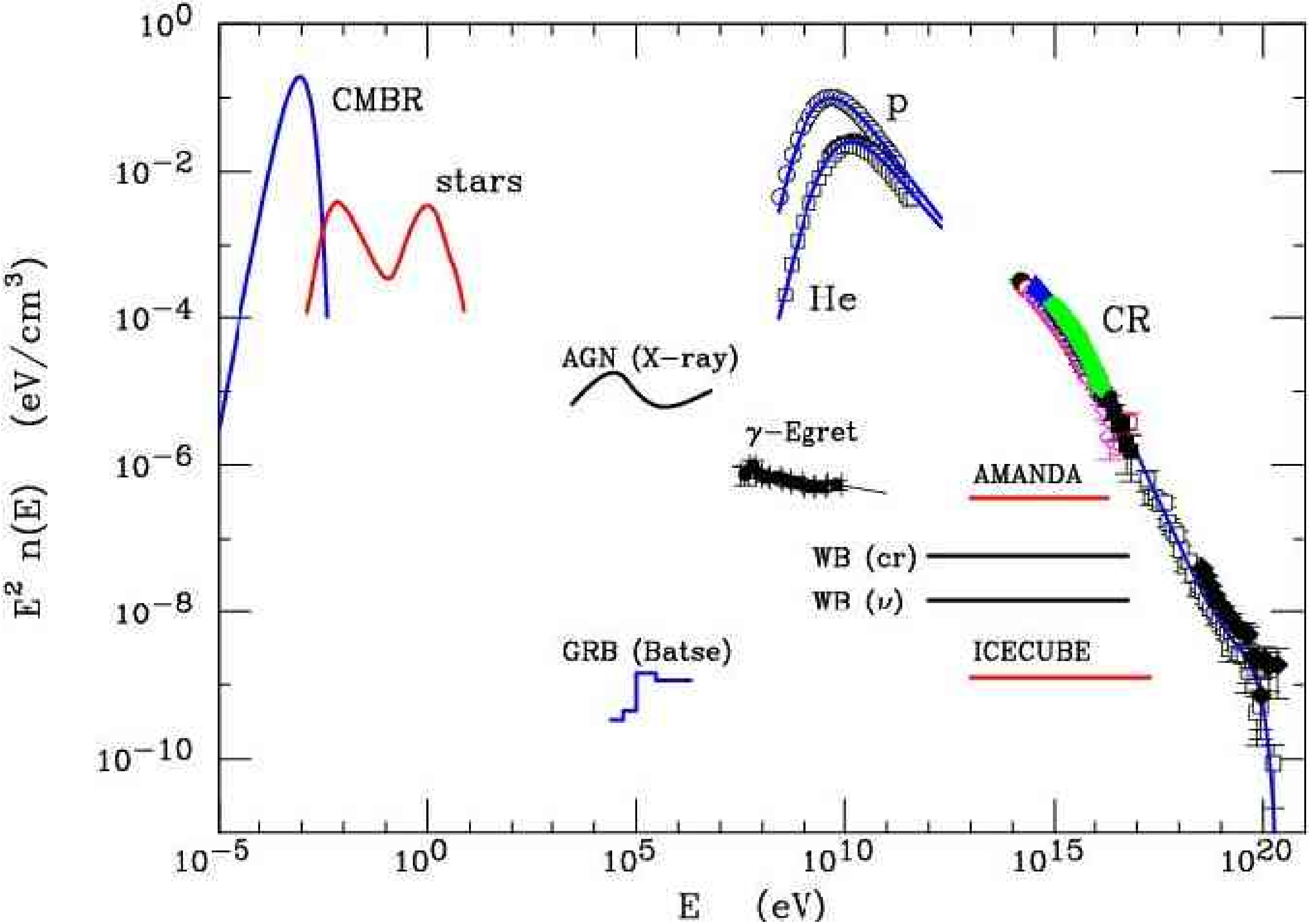
WAXMAN-BAHCALL BOUND

$$Q_{\rm cr}(E,z) \propto E^{-2}$$

$$Q_0 = 10^{44} \left(\frac{\rm erg}{\rm Mpc^3\ yr}\right) = 3.2 \times 10^{36} \left(\frac{\rm erg}{\rm s\ Mpc^3\ s}\right) = 0.82 \times 10^3 \left(\frac{L_\odot}{\rm Mpc^3}\right)$$

$$K_{\rm cr} = \left(\frac{c}{4\,\pi}\right) \frac{Q_0\ \xi_{\rm cr}}{H_0} \qquad\qquad K_\nu \simeq K_{\rm cr}\ f \simeq \frac{K_{\rm cr}}{4}$$

$$\langle \mathcal{L}_\nu^{\rm dec} \rangle_{WB-{\rm bound}} \leq (4.7 \times 10^2)\ \xi\ \left(\frac{L_\odot}{\rm Mpc^3}\right)$$



CMBR
stars
p
He
CR
AGN (X-ray)
γ-Egret
AMANDA
WB (cr)
WB (ν)
GRB (Batse)
ICECUBE
E² n(E) (eV/cm³)
E (eV)

Summary of POWER SOURCES

$$\langle \mathcal{L}\,\xi \rangle_B^{\rm star} \simeq 5.6 \times 10^8 \left(\frac{L_\odot}{\rm Mpc^3} \right)$$

$$(\mathcal{L}\,\xi)_{\rm SN,kin} \simeq 4.2 \times 10^6 \left(\frac{L_\odot}{\rm Mpc^3} \right)$$

$$(\mathcal{L}\,\xi)_{\rm AGN,bol} \simeq 2 \times 10^7 \left(\frac{L_\odot}{\rm Mpc^3} \right)$$

$$(\mathcal{L}\,\xi)_{{\rm AGN},X} \sim 6.4 \times 10^5 \left(\frac{L_\odot}{\rm Mpc^3} \right)$$

$$(\mathcal{L}\,\xi)_{{\rm Blazars},\gamma} \simeq 1\text{--}4 \times 10^4 \left(\frac{L_\odot}{\rm Mpc^3} \right)$$

Significant Power
is available

AMANDA,
ANTARES,
BAIKAL
are
STARTING TO
PROBE INTERESTING
ASTROPHYSICAL
TERRITORY

“EGRET LEVEL”
VERY IMPORTANT !

The potential of the planned km3 neutrino telescopes
to “open the new window” of neutrino Astronomy
are reasonably good.

Probably only few sources will be resolved
with signals of few events/year.
The detection of point sources is not
fully guaranteed.

Most likely sources
are SNR, microQuasars, the Galactic Center.
AGN and GRB's

A diffuse extragalactic Flux is likely to be seen.

Even in the most optimistic case the new telescopes
will just “scratch the surface” of high energy neutrino
Science, and the question of developing higher
sensitivity detectors is very important.

High Energy Neutrino Astronomy

will “SOON” become a Reality

The Km^3 detectors have a very Exciting Potential

- Cosmological Neutrinos
- Geophysical Neutrinos
- Solar Neutrinos
- SuperNova Neutrinos
  (SuperNova Relic Neutrinos)
- Atmospheric Neutrinos
- Astrophysical Neutrinos
- GZK Neutrinos
- Exotic Physics Neutrinos
  (Top-Down Models)
- Dark Matter Annihilation Neutrinos
  (from the Sun or the Center of the Earth)

NEUTRINO
PHYSICS
is a
VERY RICH FIELD