# High energy neutrino sources: Challenges & Prospects

Eli Waxman
Weizmann Institute

# High energy n's: A new window

MeV n detectors:

- Solar & SN1987A n's
- Stellar physics (Sun's core, SNe core collapse)
- n physics

>0.1 TeV n detectors:

- Extend n horizon to extra-Galactic scale

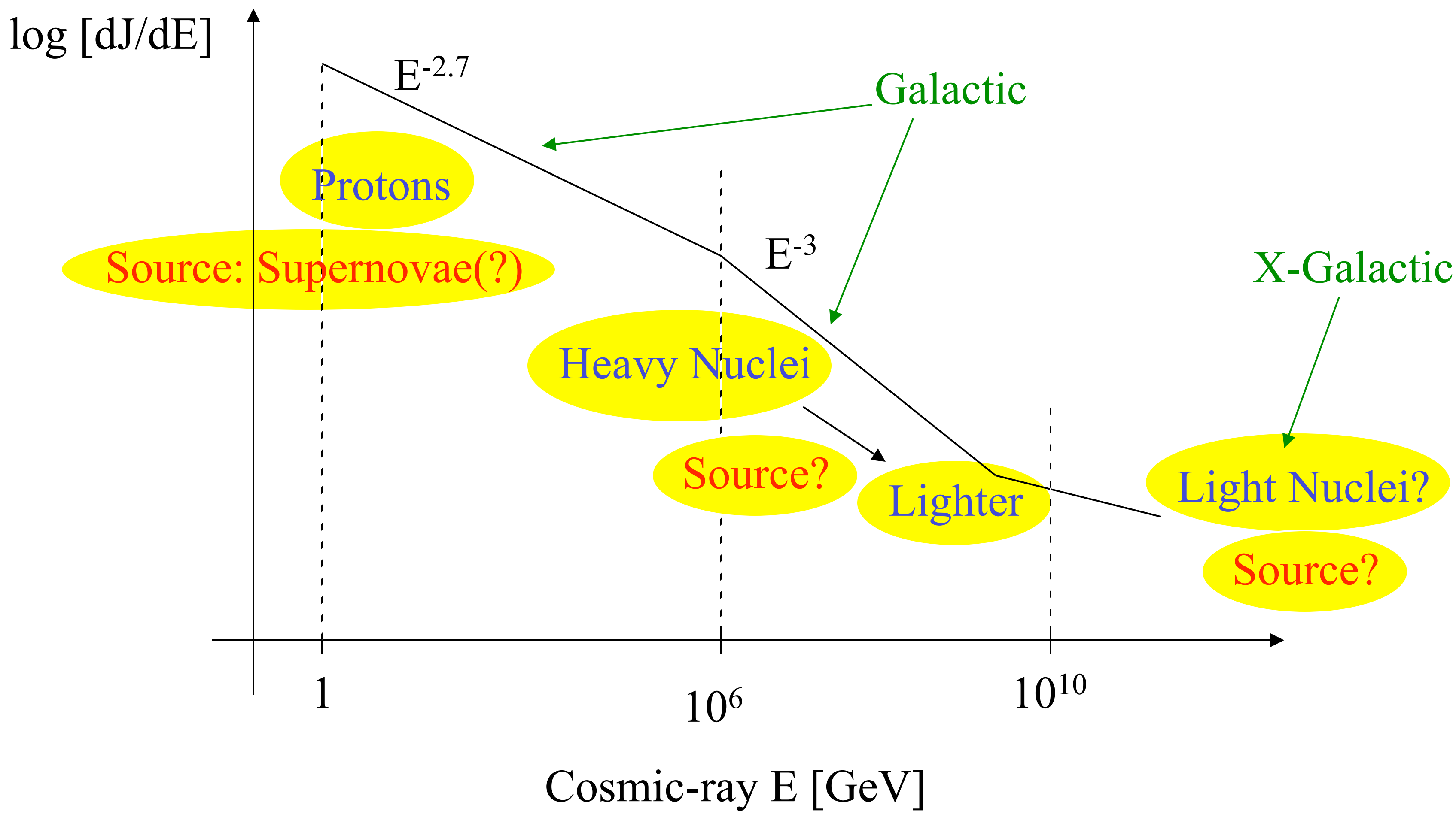
  MeV n detectors limited to local (Galactic) sources

  [10kt @ 1MeV→1Gton @ TeV , $s_{TeV}/s_{MeV}$~$10^6$ ]
- Study "Cosmic accelerators" [pg, pp → p's → n's]
- n physics

Cosmic accelerator:

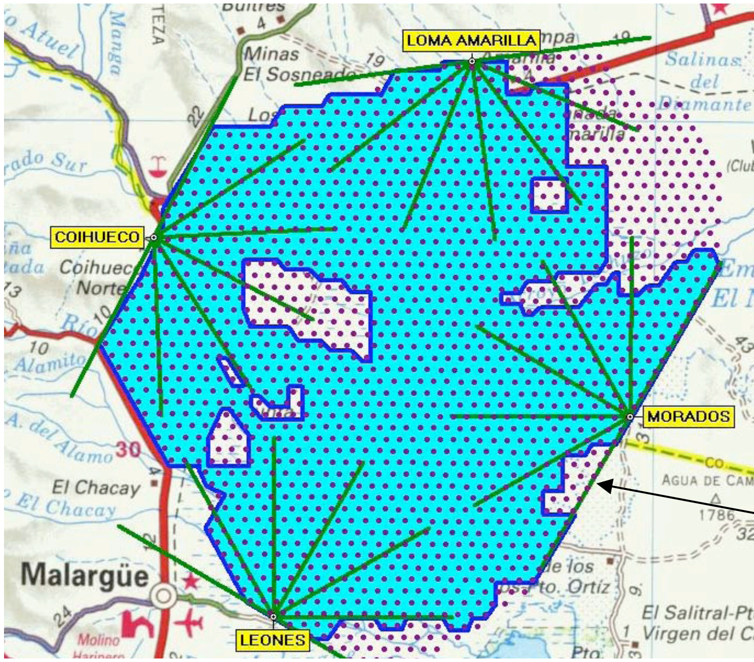
- Open questions → Prime scientific motivation
- Observed properties → Detector characteristics

# Cosmic accelerators




[Blandford & Eichler, Phys. Rep. 87;
Axford, ApJS 94;
Nagano & Watson, Rev. Mod. Phys. 00]

# UHE, $>10^{10}$GeV, CRs

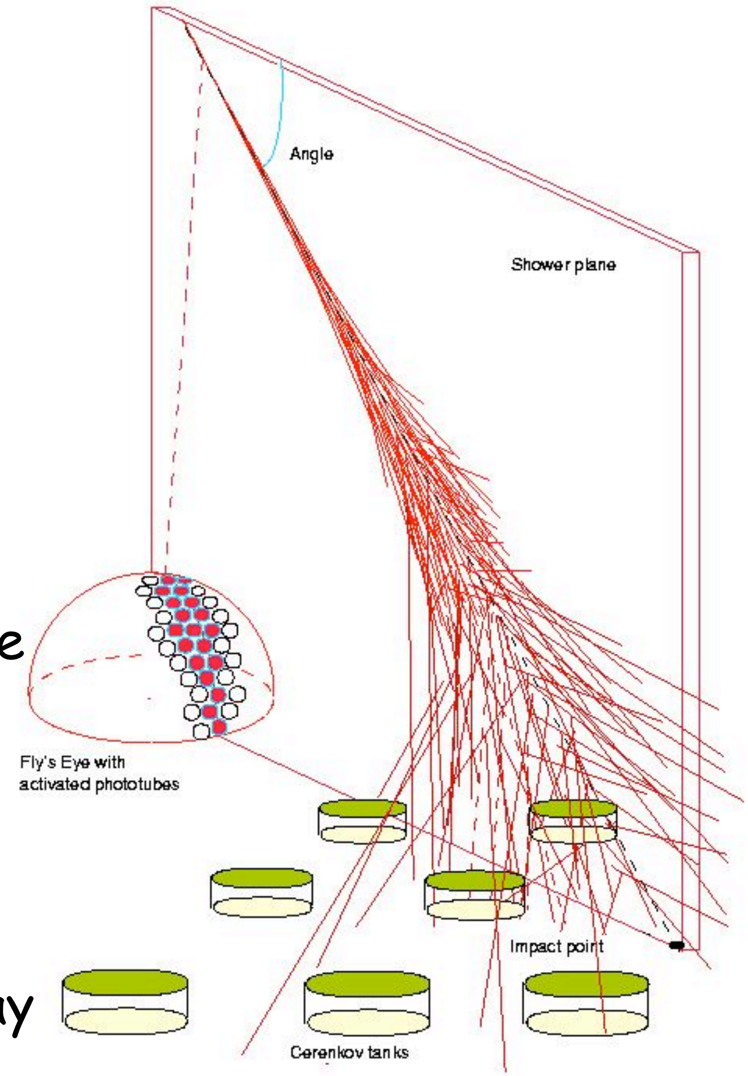



$J(>10^{11}\mathrm{GeV}) \sim 1$ / 100 km$^2$ year 2p sr

Auger:
3000 km$^2$

Fluorescence detector

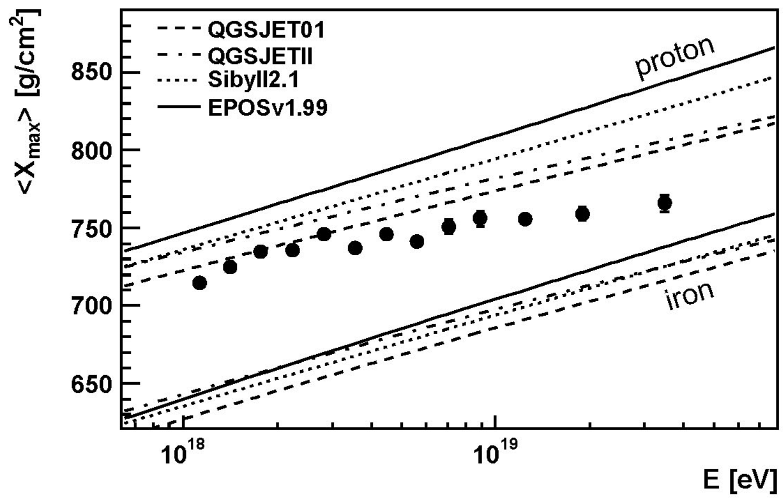
Ground array

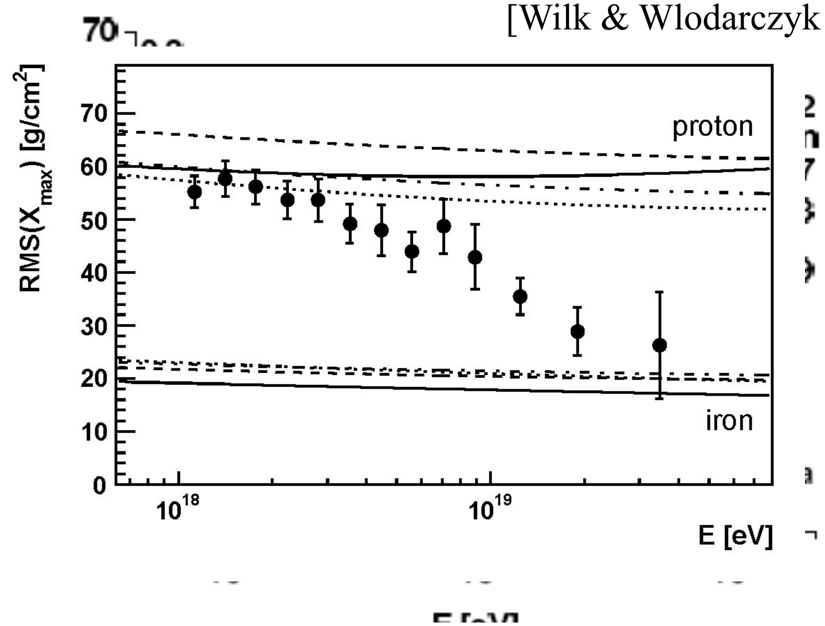


# Composition

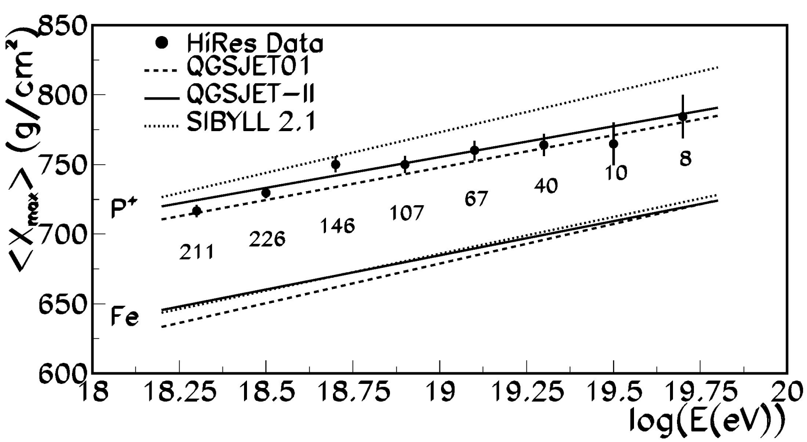
Auger 2010

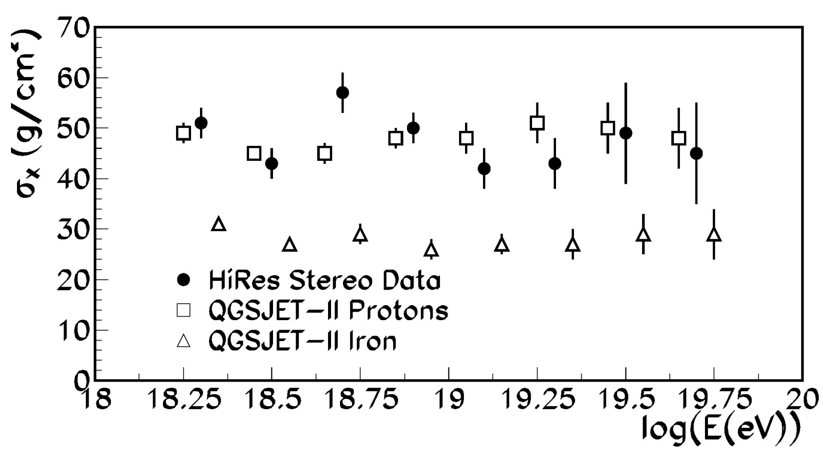
[Wilk & Wlodarczyk 10]



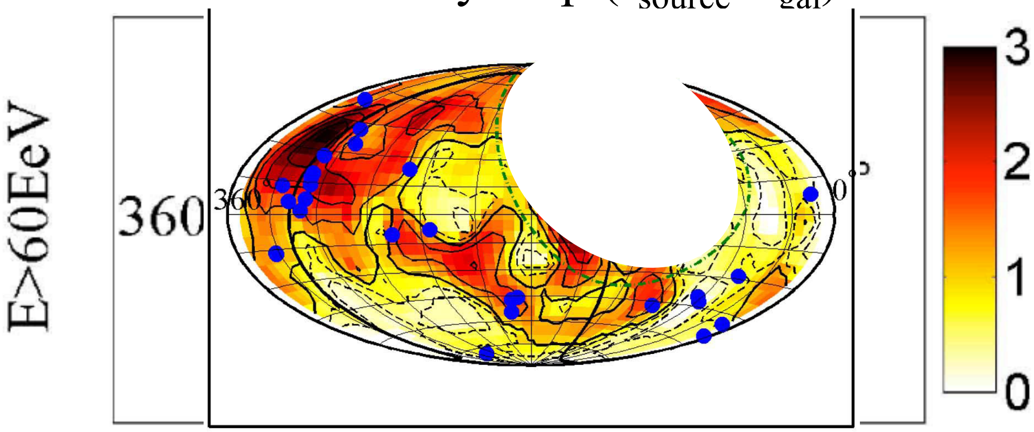

HiRes 2010



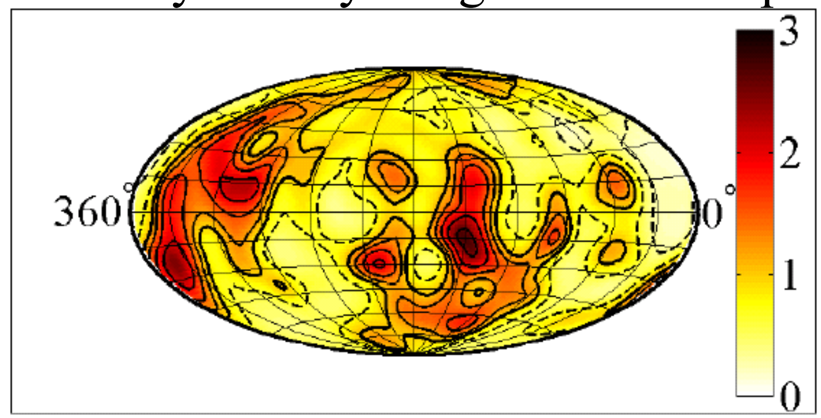
# Anisotropy

Biased ($r_{source}$~$r_{gal}$ for $r_{gal}$>$\bar{r}_{gal}$)
CR intensity map ($r_{source}$~$r_{gal}$)




[Kashti & EW 08]

Galaxy density integrated to 75Mpc




[EW, Fisher & Piran 97]

- Cross-correlation signal:
  Anisotropy @ 98% CL; Consistent with LSS
  Repeater absence → $N_s$>$N^2$ → n>$10^{-4}$/$Mpc^3$
- Larger (27->69) sample: Aniso. @ 98.5% CL [Foteini et al. 11]

- Correlation with AGN?
  - Signal gone
  - Even if there = LSS

[Auger coll. 08]

# Composition-Anisotropy connection

- Plausible assumptions:

  Acceleration of Z(>>1) to E ~ Acceleration of p to E/Z

  $J_p(E/Z) \geq J_Z(E/Z)$

+ Note: p(E/Z) propagation = Z(E) propagation

→ Anisotropy of Z at $10^{19.7}$eV implies

  Stronger aniso. signal (due to p) at $(10^{19.7}/Z)$ eV

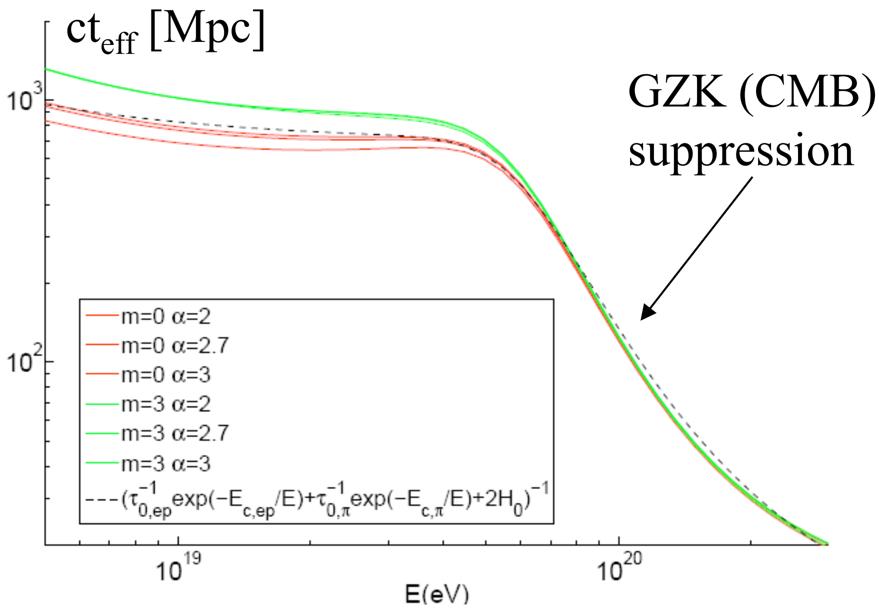
! Not observed! → No high Z at $10^{19.7}$eV.

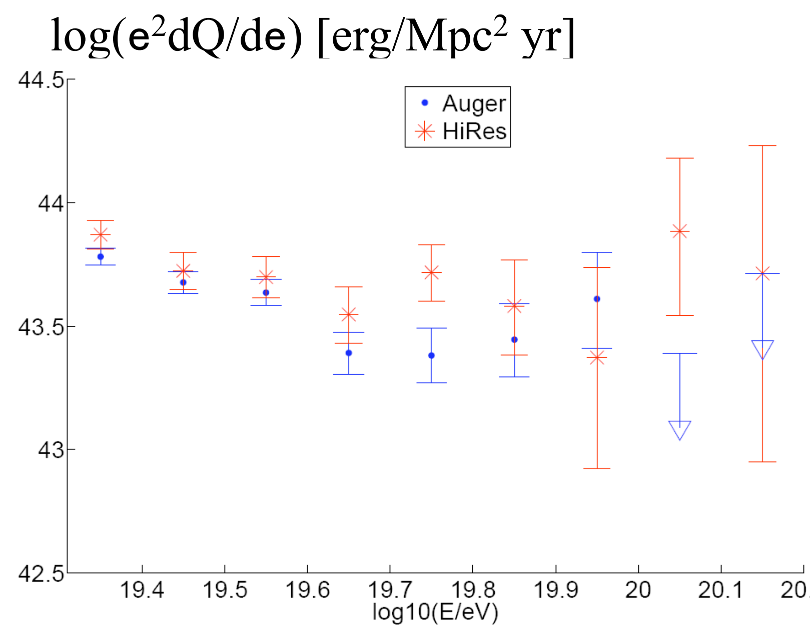
[Lemoine & EW 09]

# Flux & Spectrum

- $e^2(dN/de)_{Observed}=e^2(dQ/de)\ t_{eff.}$ $(t_{eff.}: p + g_{CMB} \rightarrow N + p)$

  Assume: p, $dQ/de \sim (1+z)^m e^{-a}$




[Katz & EW 09]

- $>10^{19.3}$eV: consistent with
  protons, $e^2(dQ/de) = 0.5(+-0.2) \times 10^{44}$ erg/Mpc$^3$ yr + GZK

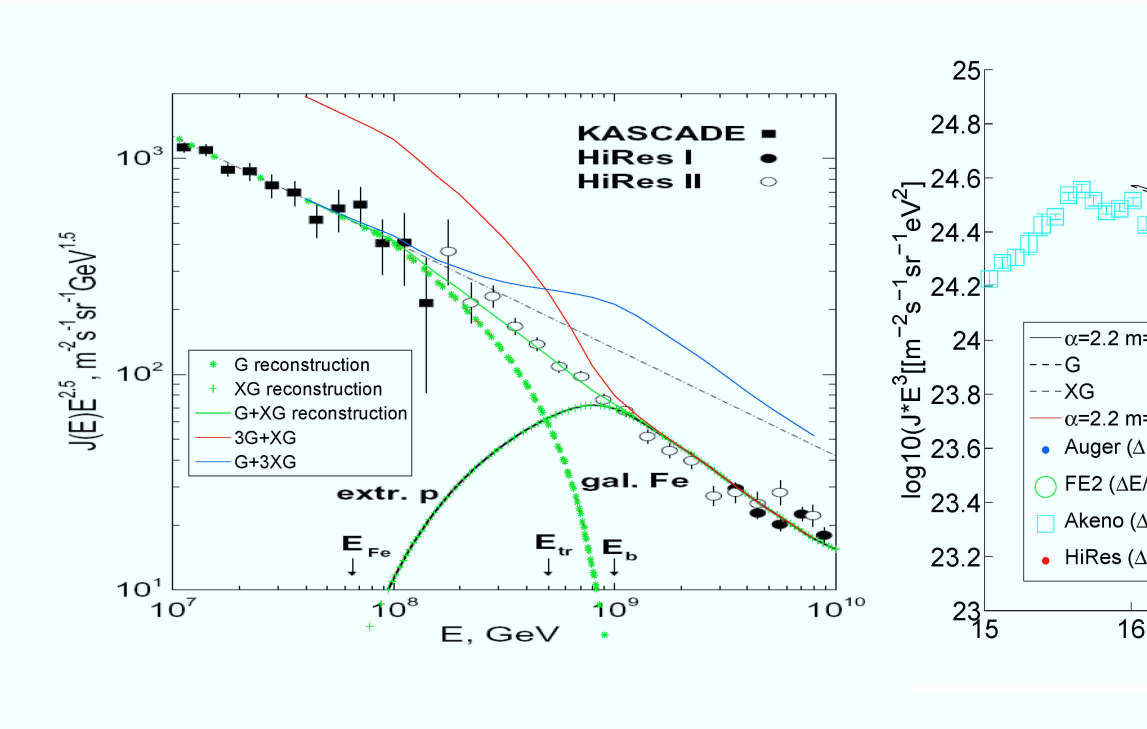
[EW 1995; Bahcall & EW 03]

- $e^2(dQ/de)$ ~Const.: Consistent with shock acceleration

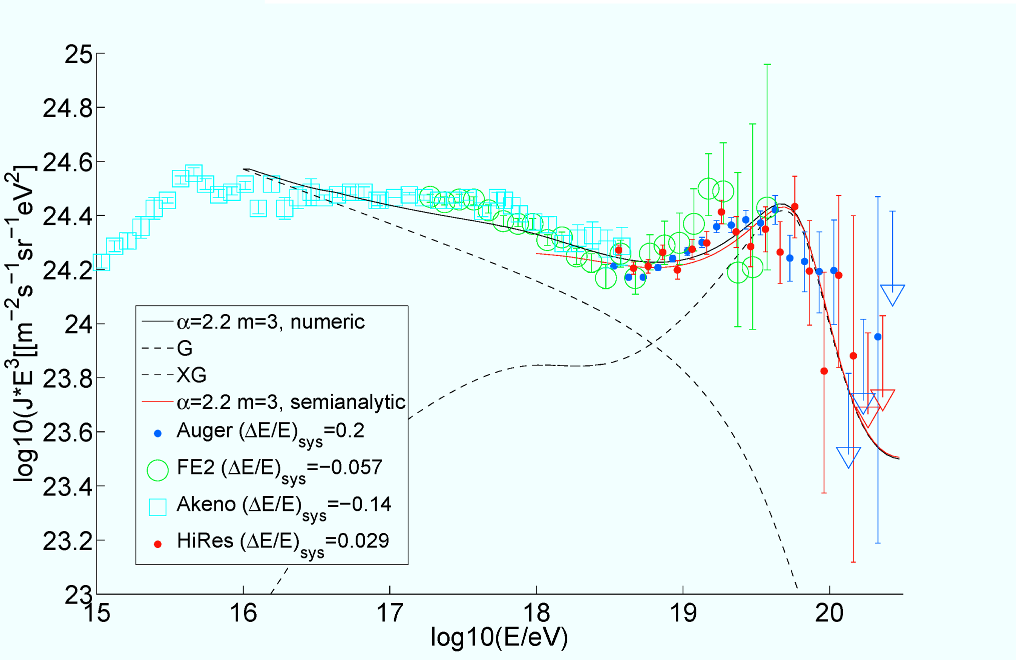
[Reviews: Blandford & Eichler 87; EW 06

cf. Lemoine & Revenu 06]

# G-XG Transition at ~$10^{18}$eV?




@ $10^{18}$eV: Fine tuning

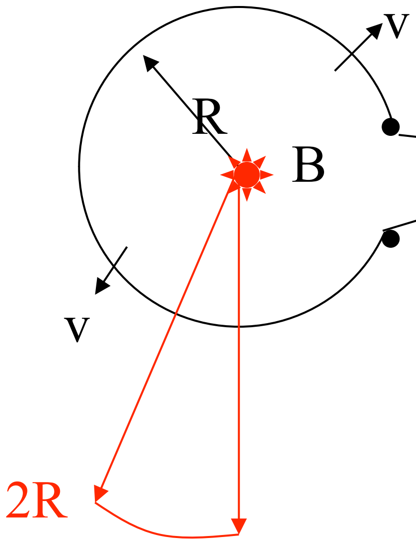



Inconsistent spectrum

Cutoff @ $10^{19}$eV

[Katz & EW 09]

# The $10^{20}$eV challenge




/ =R/G

($dt_{RF}$=R/Gc)

$$V = \frac{1}{c}\dot{\Phi} \sim \frac{1}{c}\frac{BR^2}{R/\mathrm{v}} = \frac{\mathrm{v}}{\mathrm{c}}BR \quad \Rightarrow \quad \varepsilon_p < \frac{\mathrm{v}}{\mathrm{c}}eBR \;\; / \; G$$

$$L > 4\pi R^2 G^2 \frac{B^2}{8\pi}\mathrm{v} > \frac{1}{2\mathrm{v}/c}\left(\frac{\varepsilon_p}{e}\right)^2 c \;\; G^2$$

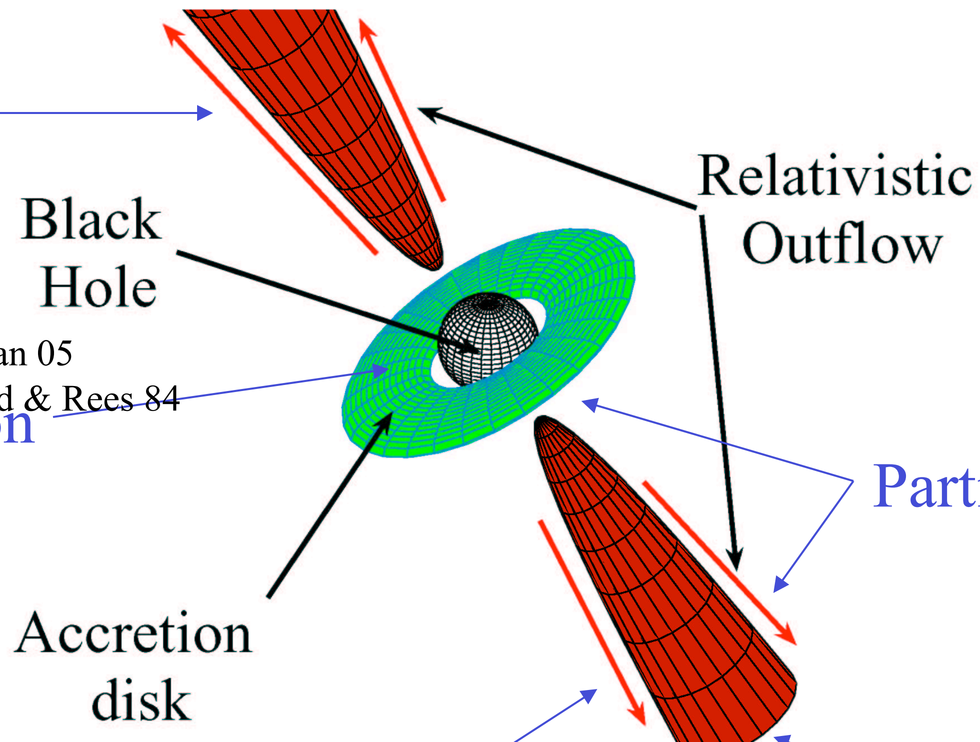
$$L > \frac{\Gamma^2}{\mathrm{v}/c}\left(\frac{\varepsilon_p}{10^{20}\,\mathrm{eV}}\right)^2 \times 10^{46}\ \mathrm{erg/s}$$

$$= \frac{\Gamma^2}{\beta}\varepsilon_{p,20}^2 \times 10^{12}\ \mathrm{L_{sun}}$$

[EW 95, 04,
Norman et al. 95]

# Source physics challenges

- GRB: $10^{19} L_{Sun}$, $M_{BH} \sim 1 M_{sun}$, $\dot{M} \sim 1 M_{sun}/s$, $G \sim 10^{2.5}$
- AGN: $10^{14} L_{Sun}$, $M_{BH} \sim 10^{9} M_{sun}$, $\dot{M} \sim 1 M_{sun}/yr$, $G \sim 10^{1}$
- MQ: $10^{5} L_{Sun}$, $M_{BH} \sim 1 M_{sun}$, $\dot{M} \sim 10^{-8} M_{sun}/yr$, $G \sim 10^{0.5}$




[Reviws:
GRBs Kouveliotou 94; Piran 05
AGN Begelman, Blandford & Rees 84
MQ HE:
Aharonian et al 2005;
Khangulyan et al 2007]

# What do we know about $>10^{19}$eV CRs?

- $J(>10^{11}\text{GeV})\sim 1$ / 100 km$^2$ year 2p sr
- Most likely X-Galactic ($R_L=e/eB=40e_{p,20}$kpc)
- (An)isotropy: 2s, consistent with LSS
- Composition?

  HiRes- p, Auger- becoming heavier(?), Anisotropy suggests p

- Production rate & spectrum:

  protons, $e^2(dQ/de)\sim 0.5(+-)0.2\times 10^{44}$ erg/Mpc$^3$ yr + GZK
- No "repeaters": $N_{source}>N_{CR}^2 \rightarrow n(@\ 10^{19.7}\text{eV}) > 10^{-4}/\text{Mpc}^3$

- Acceleration (expanding flow):

  Confinement→ $L>L_B>10^{12}\ (G^2/b)\ (e/Z\ 10^{20}\text{eV})^2\ L_{sun}$

  Synch. losses→ $G > 10^{2.5}\ (L_{52})^{1/10}\ (dt/10\text{ms})^{-1/5}$

!! No $L>10^{12}\ L_{sun}$ at $d<d_{GZK}$ → Transient Sources

# UHECR sources: Suspects

- Constraints: - $L > 10^{12} (G^2/b) L_{sun}$ , $G > 10^{2.5} (L_{52})^{1/10} (dt/10ms)^{-1/5}$
  - $e^2(dQ/de) \sim 10^{43.7}$ erg/Mpc$^3$ yr
  - $d(10^{20}eV) < d_{GZK} \sim 100$Mpc

  !! No $L > 10^{12} L_{sun}$ at $d < d_{GZK}$ → Transient Sources

- Gamma-ray Bursts (GRBs)

  $L_g \sim 10^{19} L_{Sun} > 10^{12} (G^2/b) L_{sun} = 10^{17} (G/10^{2.5})^2 L_{sun}$ [EW 95, Vietri 95, Milgrom & Usov 95]

  $G \sim 10^{2.5} (L_{52})^{1/10} (dt/10ms)^{-1/5}$

  $e^2(dQ/de)_g \sim 10^{53}$erg$*10^{-9.5}$/Mpc$^3$ yr = $10^{43.5}$ erg/Mpc$^3$ yr

  Transient: $DT_g \sim 10$s << $DT_{pg} \sim 10^5$ yr [EW 95]

- Active Galactic Nuclei (AGN, Steady):

  $G \sim 10^1$ → $L > 10^{14} L_{Sun}$ = few brightest [Blandford 76; Lovelace 76]

  !! Non at $d < d_{GZK}$ → Invoke:

  * "Hidden" (proton only) AGN [Boldt & Loewenstein 00]

  * $L \sim 10^{14} L_{Sun}$ , Dt~1month flares [Farrar & Gruzinov 08]

  If $e^-$ accelerated: X/g observations → rare $L > 10^{17} L_{sun}$ [EW & Loeb 09]

# A comment on production rates

- "$Q_{g,MeV,GRB} \sim 10^{-2} Q_{UHECR}$"

[e.g. Wick et al. 04 ; Berezinsky 08; Eichler et al 2010]

- Discrepancy due mainly to
  Assuming UHECRs X-Galactic above $\sim 10^{18}$eV
  (instead of $\sim 10^{19}$eV)

# HEn: UHECR bound

- p + g → N + p

  $p^0 \rightarrow 2g$ ;  $p^+ \rightarrow e^+ + n_e + n_m + \bar{n}_m$

→ Identify UHECR sources

  Study BH accretion/acceleration physics

- For all known sources, $t_{gp}$<1:

$$\varepsilon_\nu^2 \frac{dj_\nu}{d\varepsilon_\nu} \le \Phi_{\rm WB} \equiv 10^{-8}\,\zeta \left( \frac{\varepsilon^2 dQ/d\varepsilon}{10^{44}\,{\rm erg/Mpc^3 yr}} \right) \frac{\rm GeV}{\rm cm^2 s\ sr}$$

$$\zeta = 1, 5 \quad \text{for} \quad f(z) = 1, (1+z)^3$$

[EW & Bahcall 99; Bahcall & EW 01]

- If X-G p's: $$\varepsilon_\nu^2 \frac{dj_\nu}{d\varepsilon_\nu}(10^{19}\,{\rm eV}) = \Phi_{\rm WB}$$

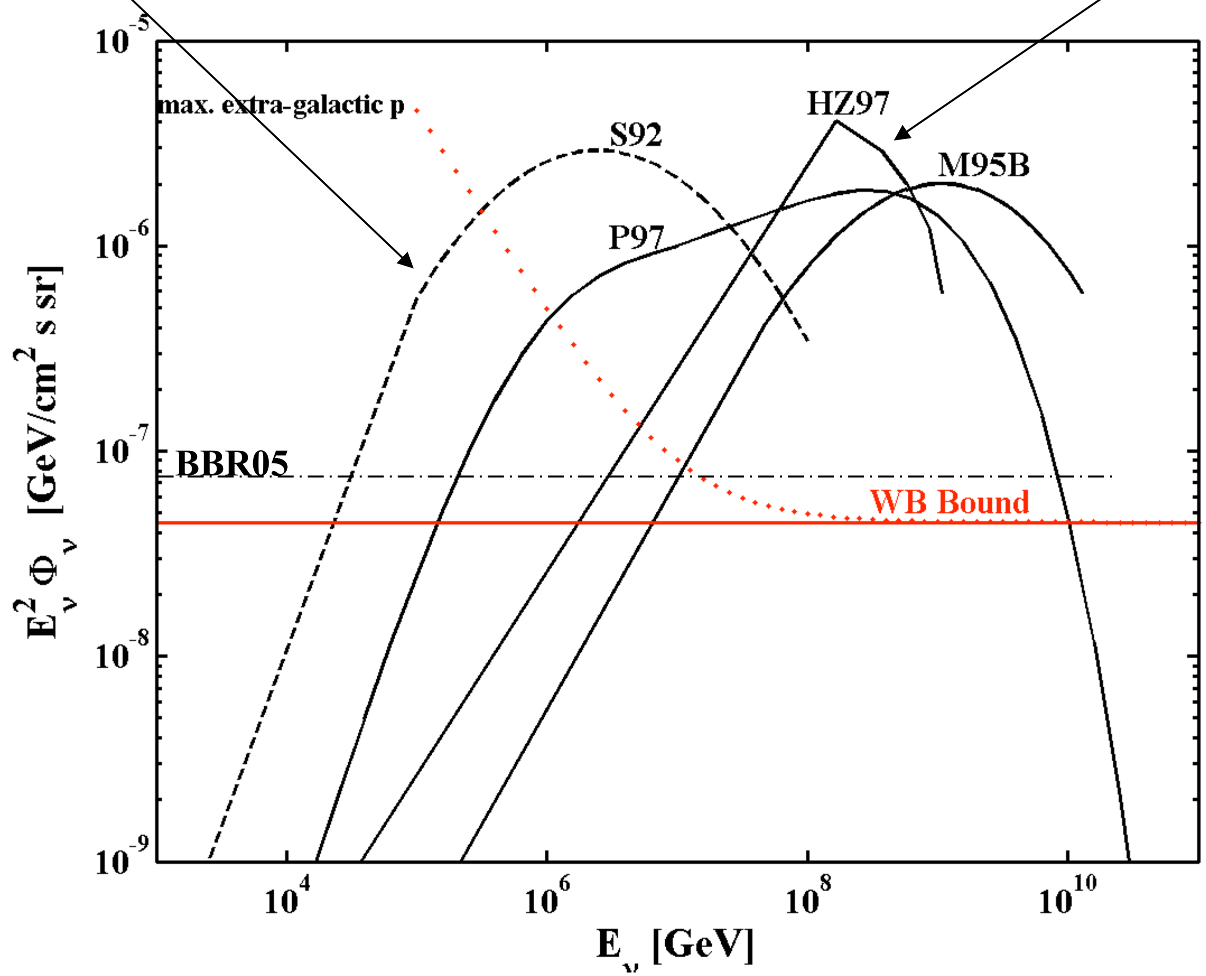
[Berezinsky & Zatsepin 69]

→ Identify primaries, determine f(z)

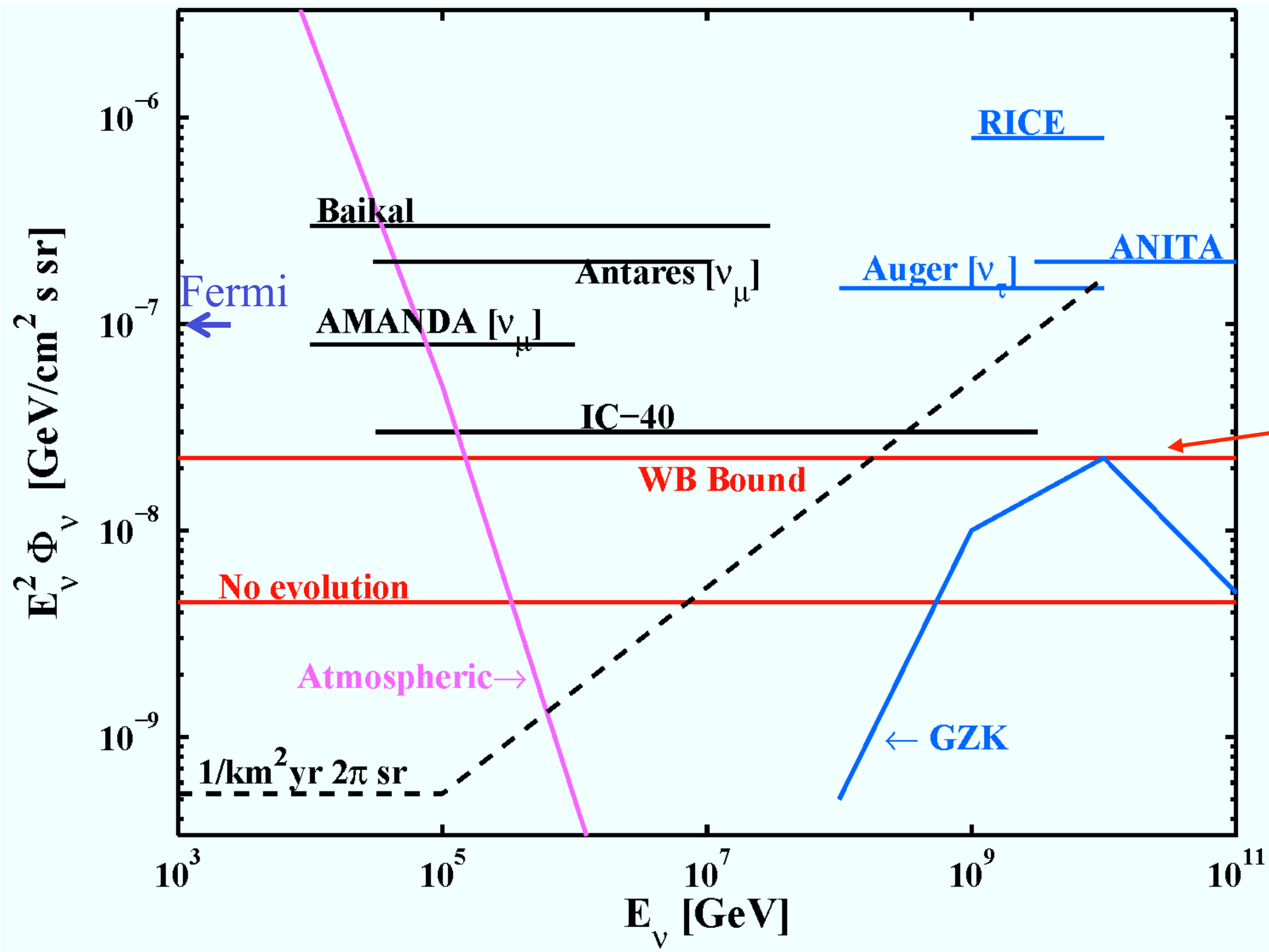
# Bound implications: I. AGN n models

“Hidden” (n only) sources

Violating UHECR bound



# Bound implications: II. n experiments




2 flavors,

$$\frac{\varepsilon^2 dQ/d\varepsilon}{10^{44}\,\mathrm{erg/Mpc^3 yr}} = 0.5$$

No "hidden" sources!

# Will IC detect steady sources?

- $1 \times 6 \times 10^{19}$ eV /3000 km$^2$ = $2 \times 10^4$ TeV/km$^2$

  $\times P_{nm}(1\text{TeV}) \sim 10^{-6}$ → 0.02 m/km$^2$

  No repeaters → $<10^{-3}$ m/km$^2$

→ Steady source detection Unlikely

(unless $L_n > 100\ L_{CR}$,

i.e. "Hidden sources" which do not exist)

# Transient sources: GRB ν's

- If: Baryonic jet

$$(\varepsilon_p/\Gamma)(\varepsilon_\gamma/\Gamma) \geq 0.3\ \mathrm{GeV}^2$$

$$\varepsilon_\gamma = 1\ \mathrm{MeV},\ \Gamma = 10^{2.5} \Rightarrow \quad \varepsilon_p \geq 10^{16}\ \mathrm{eV},\ \ \varepsilon_\nu \geq 10^{14.5}\ \mathrm{eV}$$

$$f_{p\to\pi} \approx 0.2$$

$$\Rightarrow \quad \varepsilon^2\Phi_\nu \approx 0.2\Phi_\nu^{WB} \quad , \quad \varepsilon_\nu \geq 10^{14.5}\ \mathrm{eV}$$

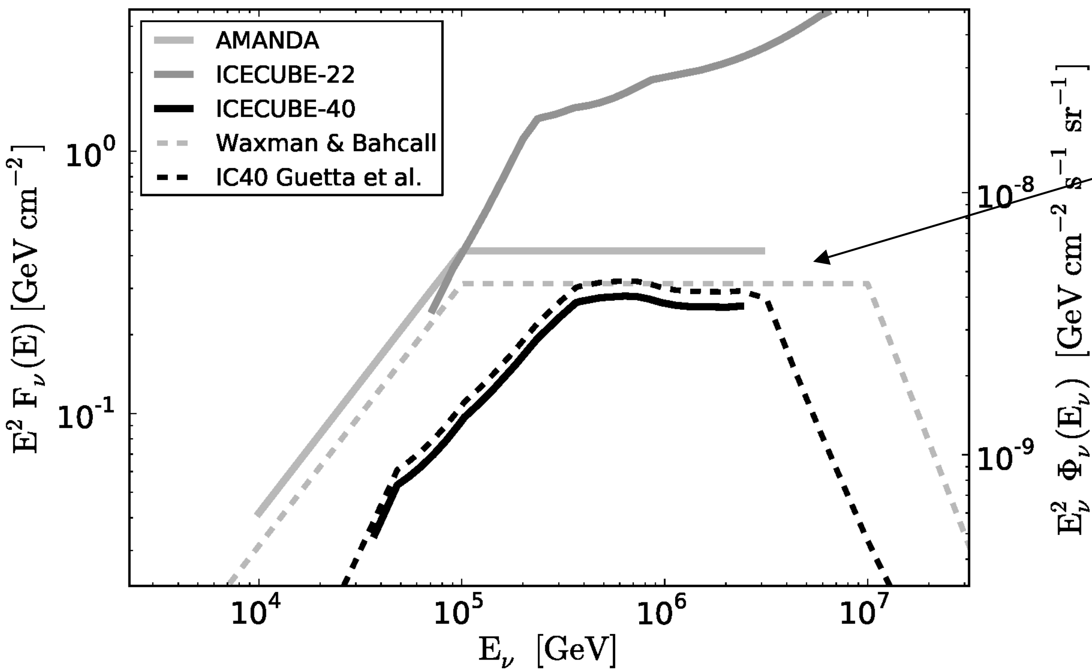
$$J_{\nu\to\mu} \approx 10\left(\frac{\zeta}{5}\right)\left(\frac{f_\pi}{0.2}\right)\left(\frac{\varepsilon^2 dQ/d\varepsilon}{0.5\times 10^{44}\,\mathrm{erg/Mpc^3yr}}\right)/\,\mathrm{km^2yr}, \quad \sim 1\nu\ /100\ \mathrm{GRB}$$

[EW & Bahcall 97, 99; Rachen & Meszaros 98; Guetta et al. 01; Murase & Nagataki 06]

- Background free:

$$J^A_{\nu\to\mu} \sim 10^{-10}\left(\frac{\Delta\Theta}{0.5^o}\right)^2\left(\frac{E}{100\mathrm{TeV}}\right)^{-\beta}/\,\mathrm{km^2s}\,; \qquad \beta = \begin{cases} 1.7 & E < 100\mathrm{TeV} \\ 2.5 & E > 100\mathrm{TeV} \end{cases}$$

# GRB n's: IC40 constraints




$$\frac{\varepsilon^2 dQ/d\varepsilon}{10^{44}\,\mathrm{erg/Mpc^3 yr}} = 1$$

- No n's for 117 GRBs (~1 expected, at 90%CL <2)
- IC is achieving relevant sensitivity

# What will we learn?

- Detection: highly informative
  - Identify CR source
  - Strong support: Baryonic jets, p acceleration,
    dissipation by collisionless shocks
  - Fundamental/n physics

- Non-detection: ambiguous
  - 10/$km^2$yr is an order of mag. (proportional to z x dQ/dE x $f_p$)
  - Significant non-detection (<<10/$km^2$yr, <<1n/100GRB)

    Poynting jet (no p)

    or

    Dissipation mechanism (eg no p acceleration to relevant E)

    or

    Radiation mechanism (→$f_p$<<0.2)

# n- physics & astro-physics

- p decay → $n_e:n_m:n_t$ = 1:2:0 (Osc.)→ $n_e:n_m:n_t$ = 1:1:1
  t appearance experiment [EW & Bahcall 97]

- GRBs: n-g timing (10s over Hubble distance)
  LI to $1:10^{16}$; WEP to $1:10^{6}$
  [EW & Bahcall 97; Amelino-Camelia,et al.98; Coleman &.Glashow 99; Jacob & Piran 07]

- EM energy loss of m's (and p's)
  $n_e:n_m:n_t$ = 1:1:1 ($E>E_0$)→ 1:2:2
  GRBs: $E_0 \sim 10^{15}$eV
  [Rachen & Meszaros 98; Kashti & EW 05]

- Optimistic (very): Combining $E<E_0$, $E>E_0$ flavor measurements may constrain flavor mixing
  [CPV, $\mathrm{Sin}Q_{13}$ Cosd]
  [Blum, Nir & EW 05; Winter 10]

# Non-UHE X-Galactic sources

- Starbursts
- SNe

# Starburst Galaxies

$$pp \to pn\pi^+, \quad \pi^+ \to \mu^+ + \nu_\mu \to e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$$

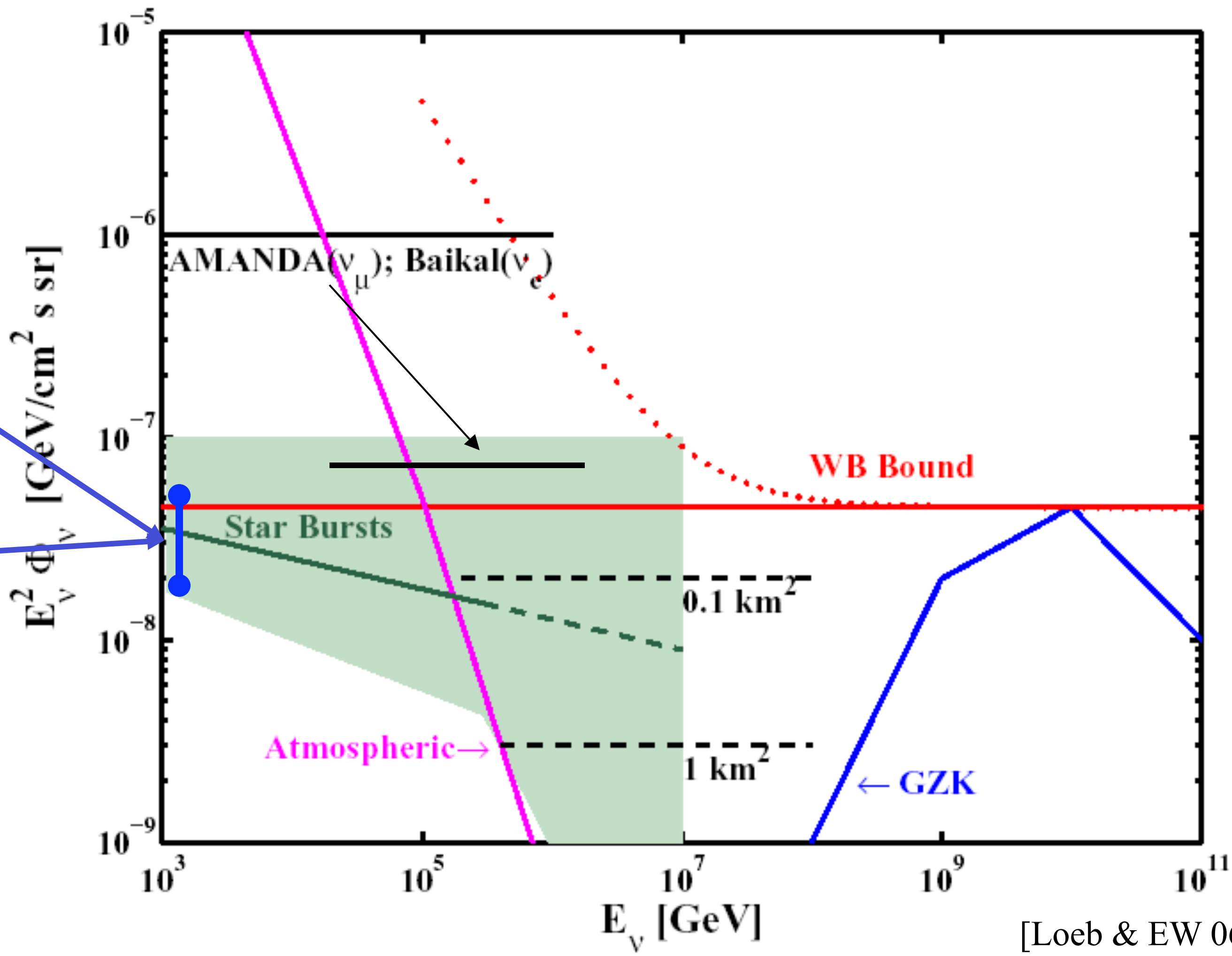
Synchrotron radio (~1GeV) → calibration → $F_\nu$

$\pi^0 \to \gamma\gamma$, $F_\nu \sim F_\gamma$

M82, NGC253:
TeV
Hess, VERITAS 09

10GeV
Fermi 09→
dN/dE~1/E$^p$, p<~2.2

[Lacki et al. 11]




[Loeb & EW 06]

# (multi-)TeV SN n's

- Radiation-to-collisionless mediated shocks
  Jet driven SNe
  → p acceleration & dense target → n's

[ - Razzaque et al. 04; Ando & Beacom 05;
- Gaisser and T. Stanev 87; Murase et al. 09;
- Wang et al. 2007; Murase et al. 08;
- EW & Loeb 01; Murase et al. 10]

- Rare SNe may have efficient $E_k$->n conversion
  Example: $10^{50}$erg in 1TeV n @ 100Mpc → 0.5m/km$^2$
  Bgnd (1TeV) ~ 0.03/km$^2$day
  → Challenging if rare (<1:10)

# A comment on Galactic-CRs

# Galactic CR sources: SNRs?

- Motivation for SNRs as sources:
  - * $L_{G,CR} \sim 10^{-1.5} L_{G,SN}$
  - * Max e~$10^{15}$eV
  - * $e^-$ acceleration to $10^{15}$eV from X emission

[Blandford & Eichler, Phys. Rep. 87; Axford, ApJS 94]

[e.g. Koyama et al. 95]

- TeV photons from SNRs (RXJ1713.7-3946, RXJ0852.0-4622)
  - * Claim: pp→p origin, Confirms CR ion production

[e.g. Aharonian et al. 04—, Berezhko & Volk 06]

- pp→p origin in contradiction with radio, thermal-X (non detection of thermal X→ n<~0.1/cm³):

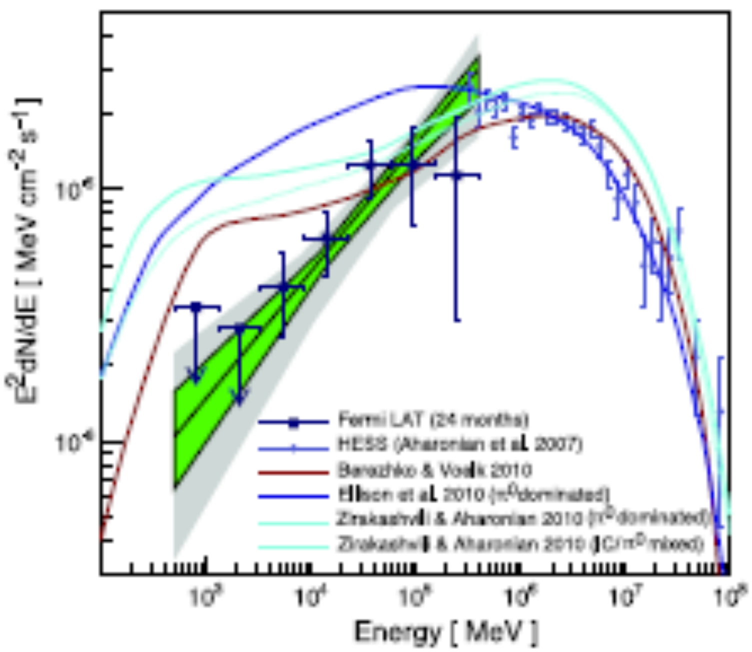
$$(\nu L_\nu)_{pp} / (\nu L_\nu)_{Therm.Berm.} < 10^{-2}$$

TeV consistent with $e^-$ IC

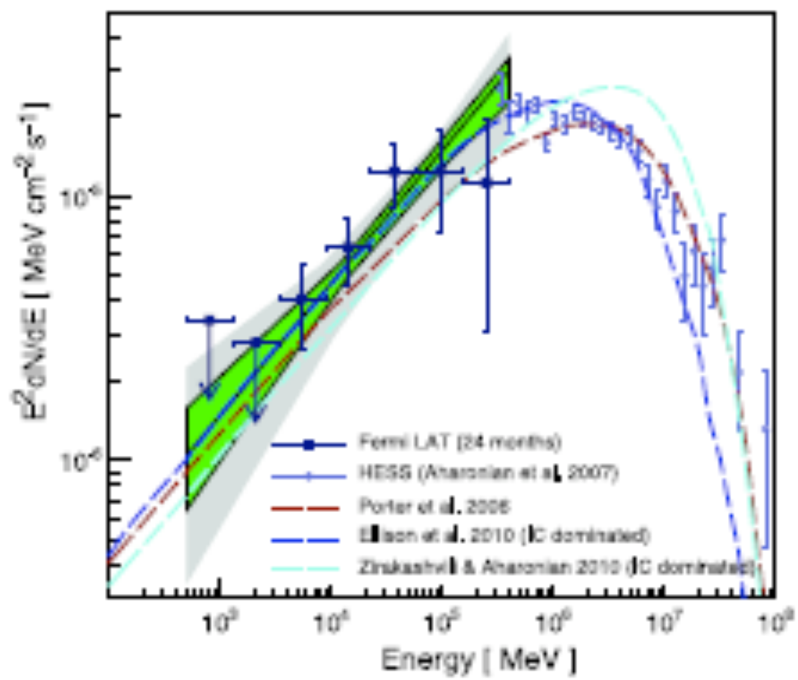
[Katz & EW 08]

# FERMI RXJ1713.7-3946

## Hadronic models




## Leptonic models




[Abdo et al. 11]

# Summary

- IceCube's sensitivity meets minimum requirements for detection of XG sources (IceCube is becoming dangerous)
- 1st conclusion: No hidden sources
- Transients are the prime targets
- XG n detection rate limited (<~10/yr)
- Detection of a handful of n's may resolve outstanding puzzles:
  - Identify UHECR (& G-CR) sources
  - Resolve open "cosmic-accelerator" physics Q's
    (related to BH-jet systems, particle acc., rad. mechanisms)
  - Constrain n physics, LI, WEP
  - The unexpected?
- Coordinated wide field EM transient monitoring crucial
  - Enhance n detection sensitivity
  - Identify sources, Physics output
- Time to go for >>1km scale detectors

# Back up slides

# GRB proton/electron acceleration

## Electrons

- MeV g's:

$$L_\gamma \approx 10^{51 \to 52}\ \mathrm{erg/s}$$

(In the first equation, the 51 is struck through and replaced by 52.)

- $t_{gg}$<1:

$$\Gamma > 10^{2.5}$$

- e⁻ (g) spectrum:

$$dn_e / d\varepsilon_e \propto \varepsilon_e^{-2}$$

- e⁻ (g) energy production

$$\varepsilon_e^2 \frac{d\dot{n}_e}{d\varepsilon_e} \sim \frac{10}{\mathrm{Gpc^3 yr}} \times 10^{52}\,\mathrm{erg} = 10^{44} \frac{\mathrm{erg}}{\mathrm{Mpc^3 yr}}$$

$$\cong \frac{0.5}{\mathrm{Gpc^3 yr}} \times 10^{53.5}\,\mathrm{erg} = 10^{44} \frac{\mathrm{erg}}{\mathrm{Mpc^3 yr}}$$

[EW 95, 04]

## Protons

- Acceleration/expansion:

$$L > 10^{50.5}\ \varepsilon_{p,20}^2 \left(\Gamma / 10^{2.5}\right)^2 \mathrm{erg/s}$$

- Synchrotron losses:

$$\Gamma > 10^2\ \varepsilon_{p,20}^{3/4} \left(\Delta t / 10\mathrm{ms}\right)^{-1/4}$$

- Proton spectrum:

$$dn_p / d\varepsilon_p \propto \varepsilon_p^{-2}$$

- p energy production:

$$\varepsilon_p^2 \frac{d\dot{n}_p}{d\varepsilon_p} \geq \varepsilon_e^2 \frac{d\dot{n}_e}{d\varepsilon_e} \approx 10^{44} \frac{\mathrm{erg}}{\mathrm{Mpc^3 yr}}$$

Afterglow, $R_{GRB}$~SFR

# The GRB "GZK sphere"

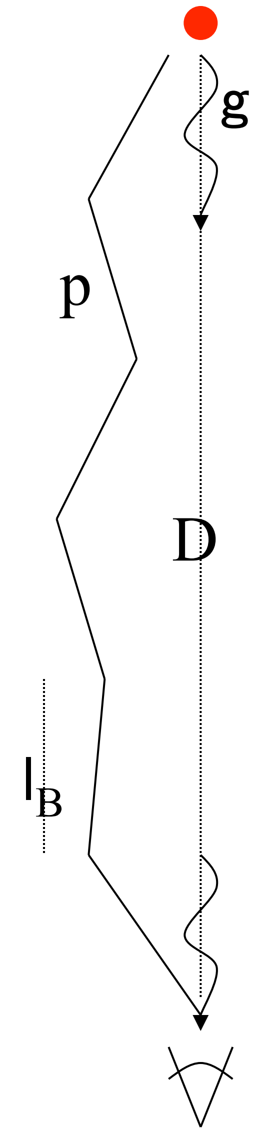
- LSS filaments:
  D~1Mpc, $f_V$~0.1, n~$10^{-6}$cm$^{-3}$, T~0.1keV
  $e_B$=($B^2$/8p)/nT~0.01 (B~0.01mG), $l_B$~10kpc

$$\Theta \approx 0.3^0 \frac{(d/100\mathrm{Mpc})^{1/2}}{\varepsilon_p/10^{20}\mathrm{eV}} D(f_V \lambda_B \varepsilon_B)^{1/2}$$

$$\tau_{Spread} \sim \tau_{Delay} \sim \Theta^2 \frac{d}{c} \sim 10^5 \mathrm{yr} \left( \frac{d/100\mathrm{Mpc}}{\varepsilon_p/10^{20}\mathrm{eV}} \right)^2 D^2 (f_V \lambda_B \varepsilon_B)$$

$$R_{GRB} \sim 0.5/\mathrm{Gpc}^3\mathrm{yr}$$

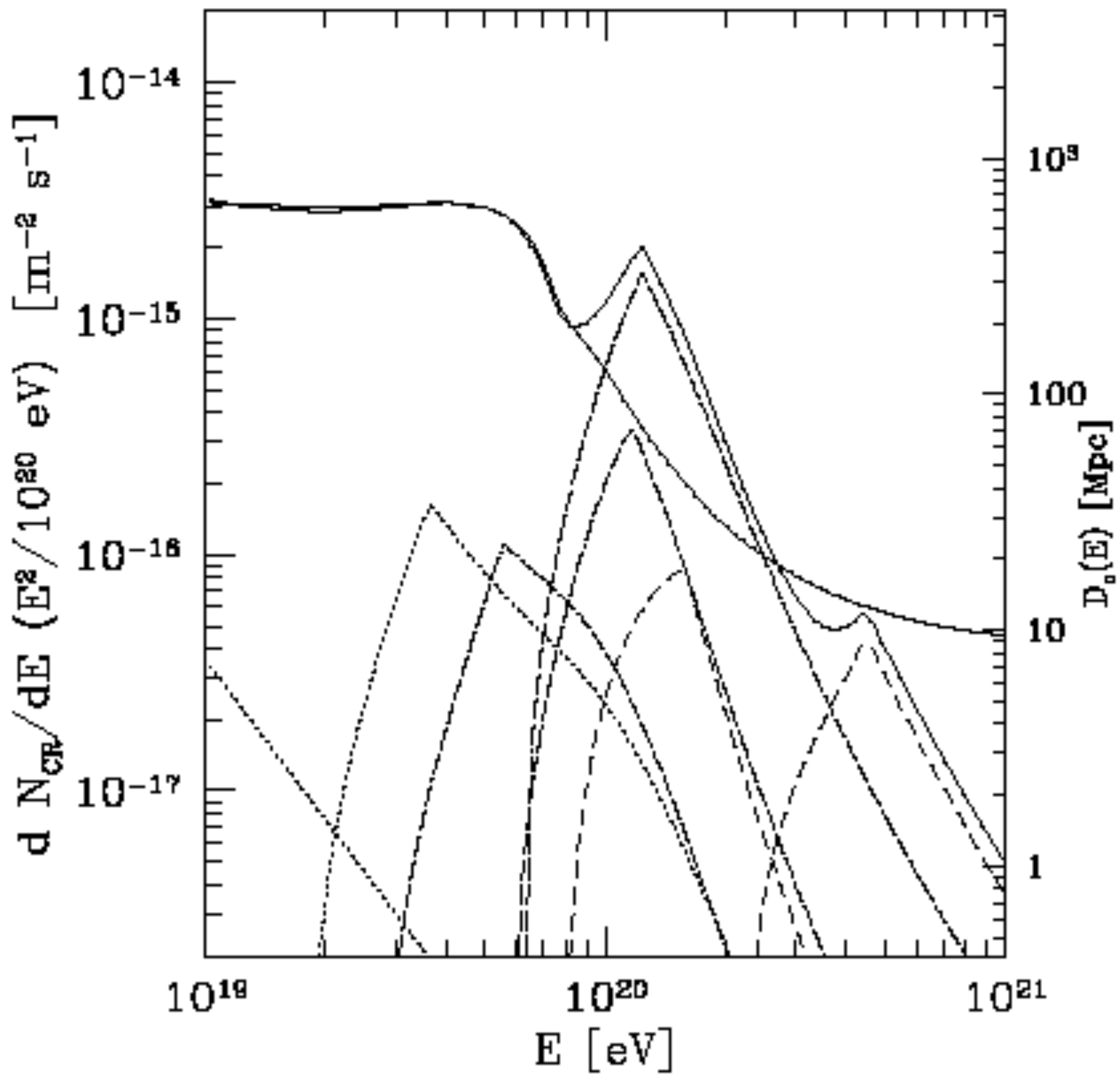
$$\Rightarrow N_{GRBs}(>10^{20}\mathrm{eV}) \sim 10^2\ D^2 (f_V \lambda_B \varepsilon_B)$$




- Prediction: $N_{GRBs}(>3\times10^{20}\mathrm{eV}) \sim \mathrm{few}$

[EW 95; Miralda-Escude & EW 96, EW 04]

# GRB Model Predictions




[Miralda-Escude & EW 96]

# GRBs & UHECRs: Predictions

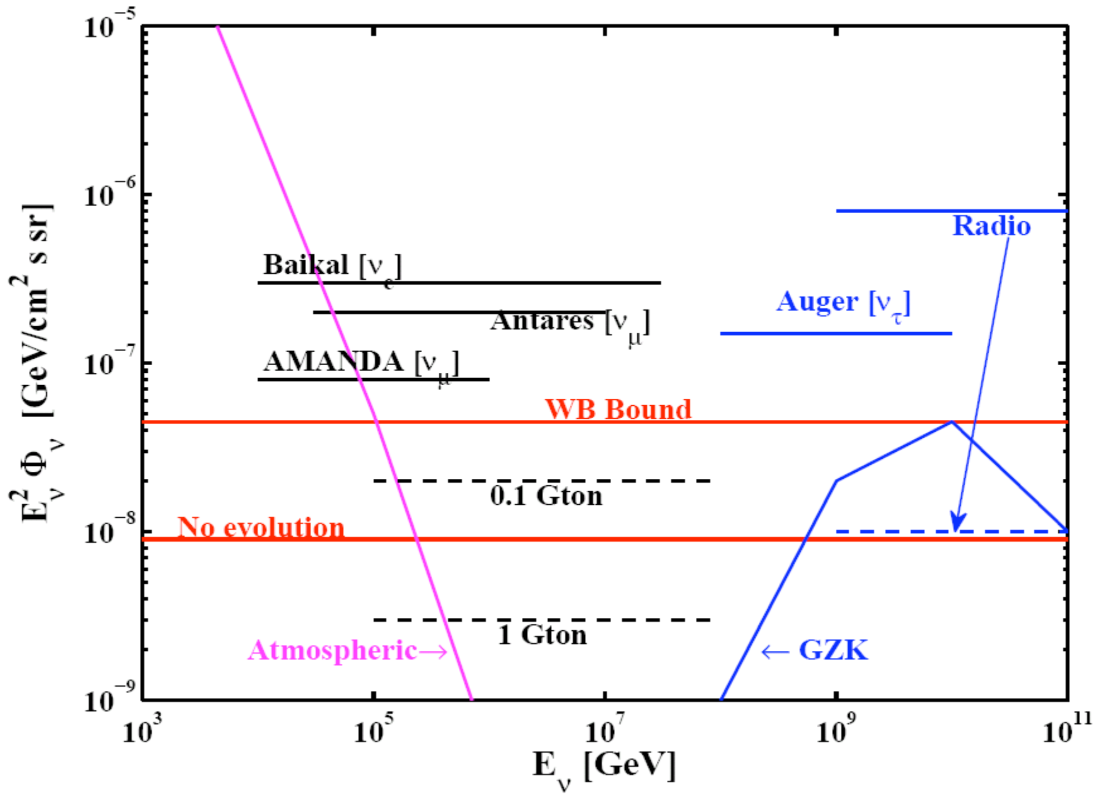
- CR experiments:
  - Few narrow spectrum sources above $3\times10^{20}$eV

    [Miralda-Escude & EW 96]
  - Difficult to check, even with Auger

- HE n experiments
  ~10 (100TeV events)/Gton/yr
  Accessible to IceCube, Km3Net

  [EW & Bahcall 97, 99; Rachen & Meszaros 98; Guetta et al. 01; Murase & Nagataki 06]

# HE n experiments




Optical Cerenkov

- South Pole

Amanda: 660 OM, 0.05 km$^3$

IceCube: +660/yr OM
(05/06…)
4800 OM=1 km$^3$s

- Mediterranean

Antares: 10 lines (Nov 07),
750 OM → 0.05 km$^3$

Nestor: (?) → 0.1 km$^3$

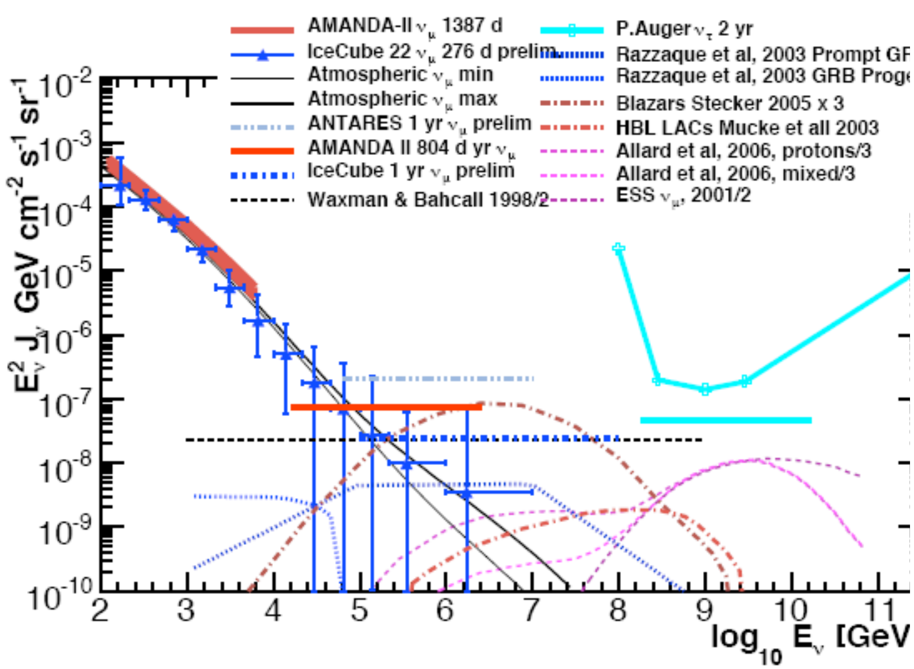
km3Net: R&D → 1 km$^3$

---

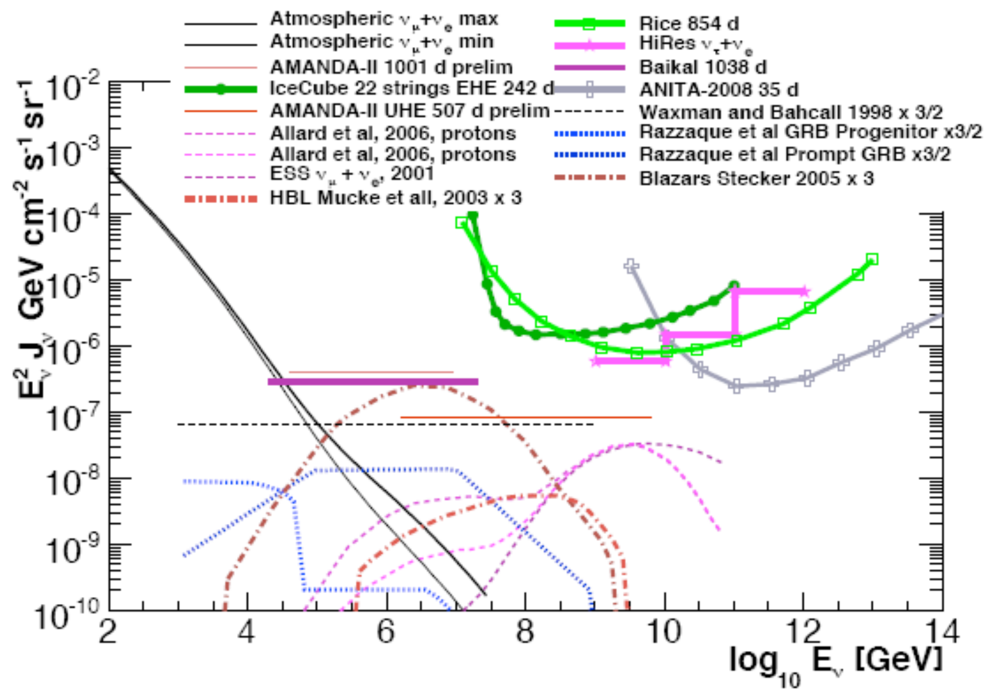
•UHE:

| Radio | Air shower |
|---|---|
| Aura, Ariana (in Ice) | Auger $(n_t)$ |
| ANITA (Balloon) | EUSO (?) |

LOFAR




Single flavor



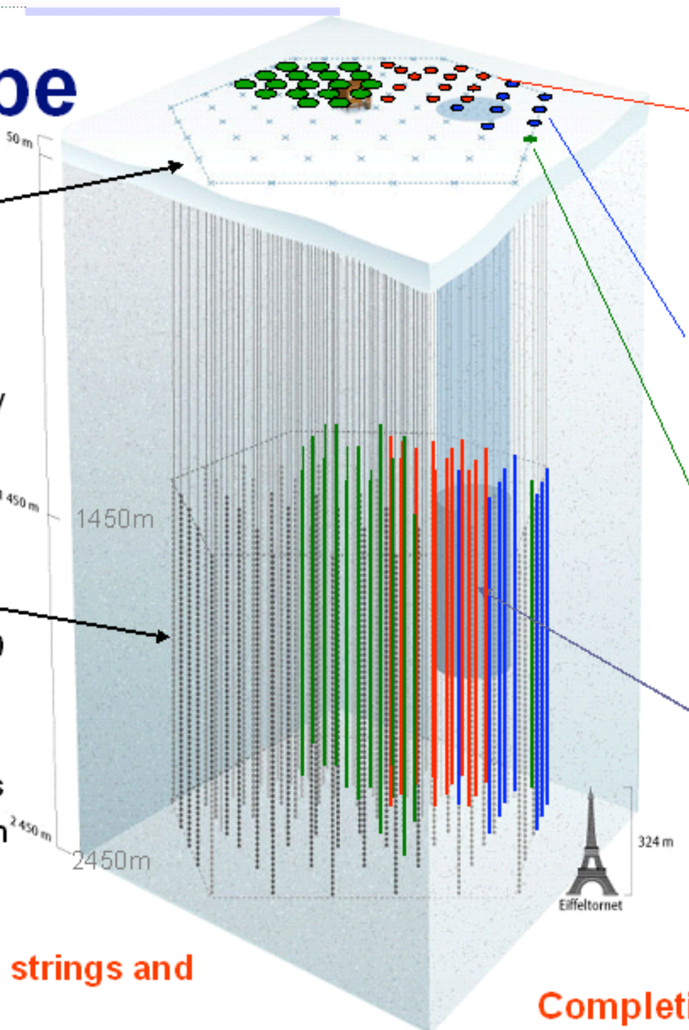

Multi flavor

[Anchordoqui & Montaruli 09]

# AMANDA & IceCube

Depth
surface

## IceCube




**IceTop**
Air shower detector
80 pairs of ice
Cherenkov tanks
Threshold ~ 300 TeV

**InIce**

Goal of 80 strings of 60
optical modules each

17 m between modules
125 m string separation

2006-2007:
13 strings deployed

**2007-2008**
**18 strings deployed**

2005-2006: 8 strings

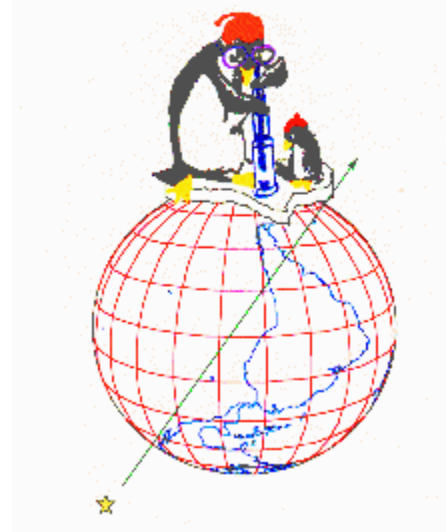
2004-2005 : 1 string

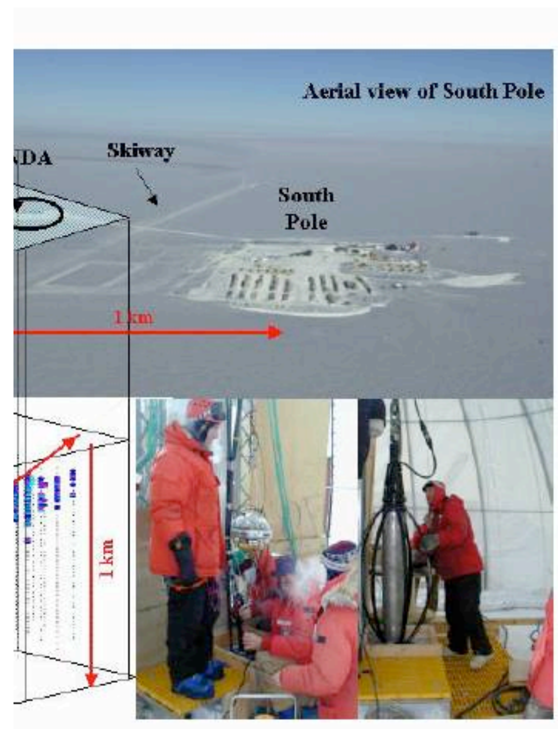
AMANDA-II
19 strings
677 modules

Current configuration:
40 strings,
40 IceTop stations
plus AMANDA

**2008/09: add 18 strings and tank stations**

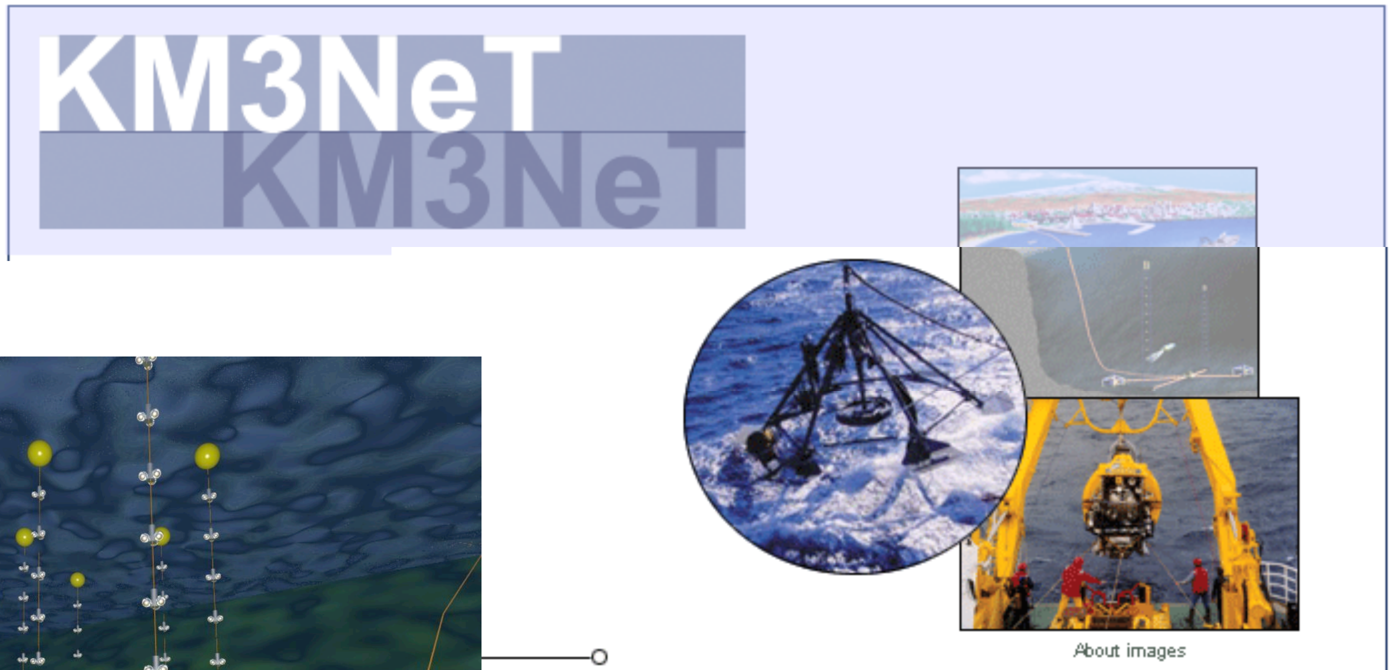
**Completion by 2011.**

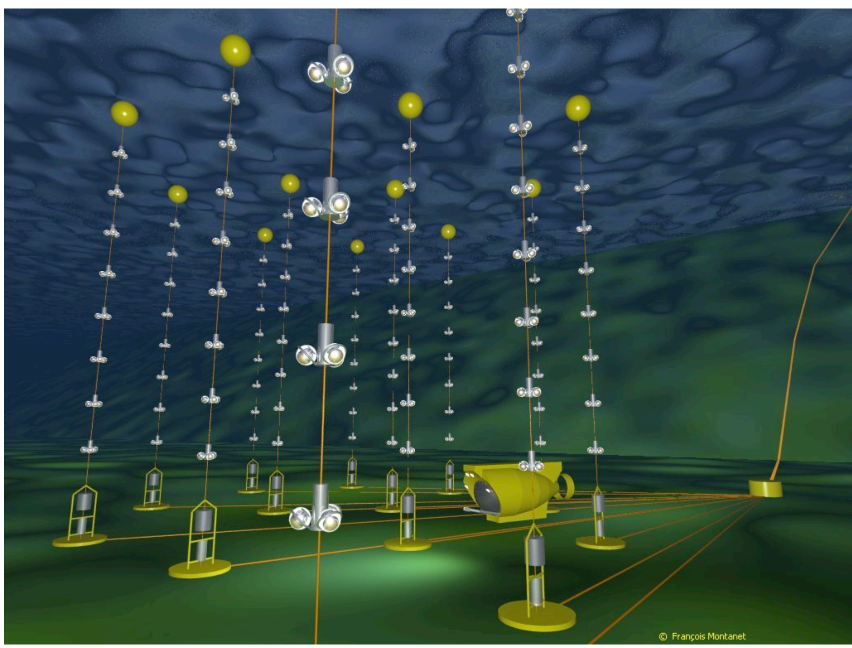




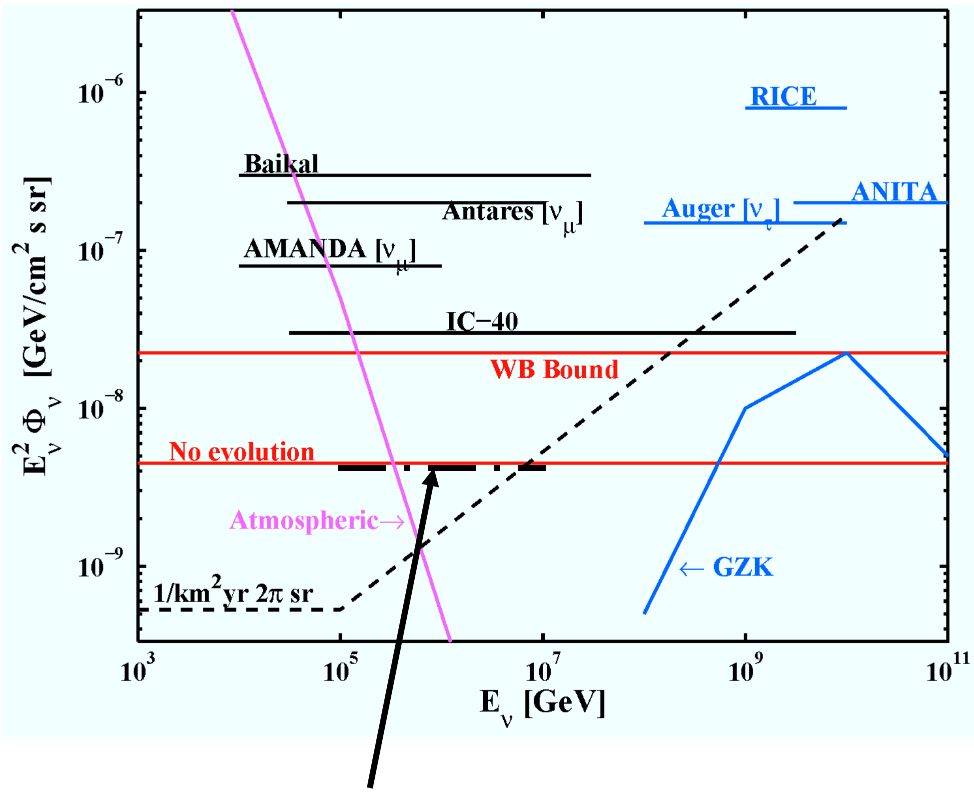
# The Mediterranean effort

- ANTARES (NESTOR, NEMO) → KM3NeT

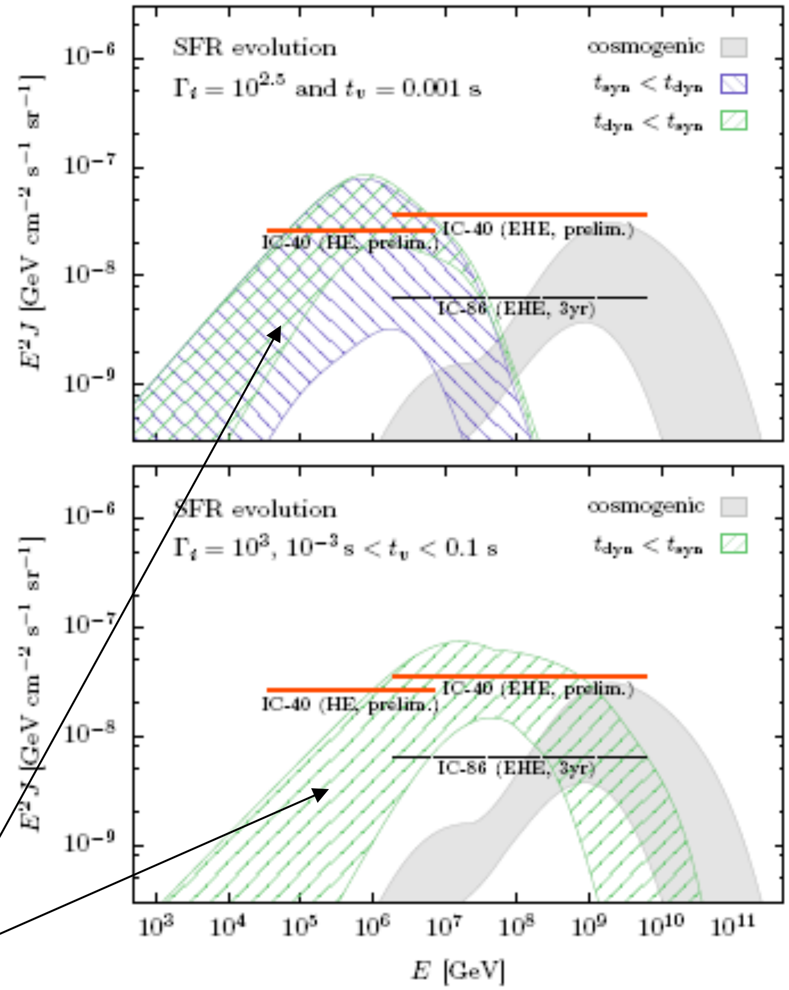


# GRB n's: IC constraints- diffuse




GRB n's [WB97]



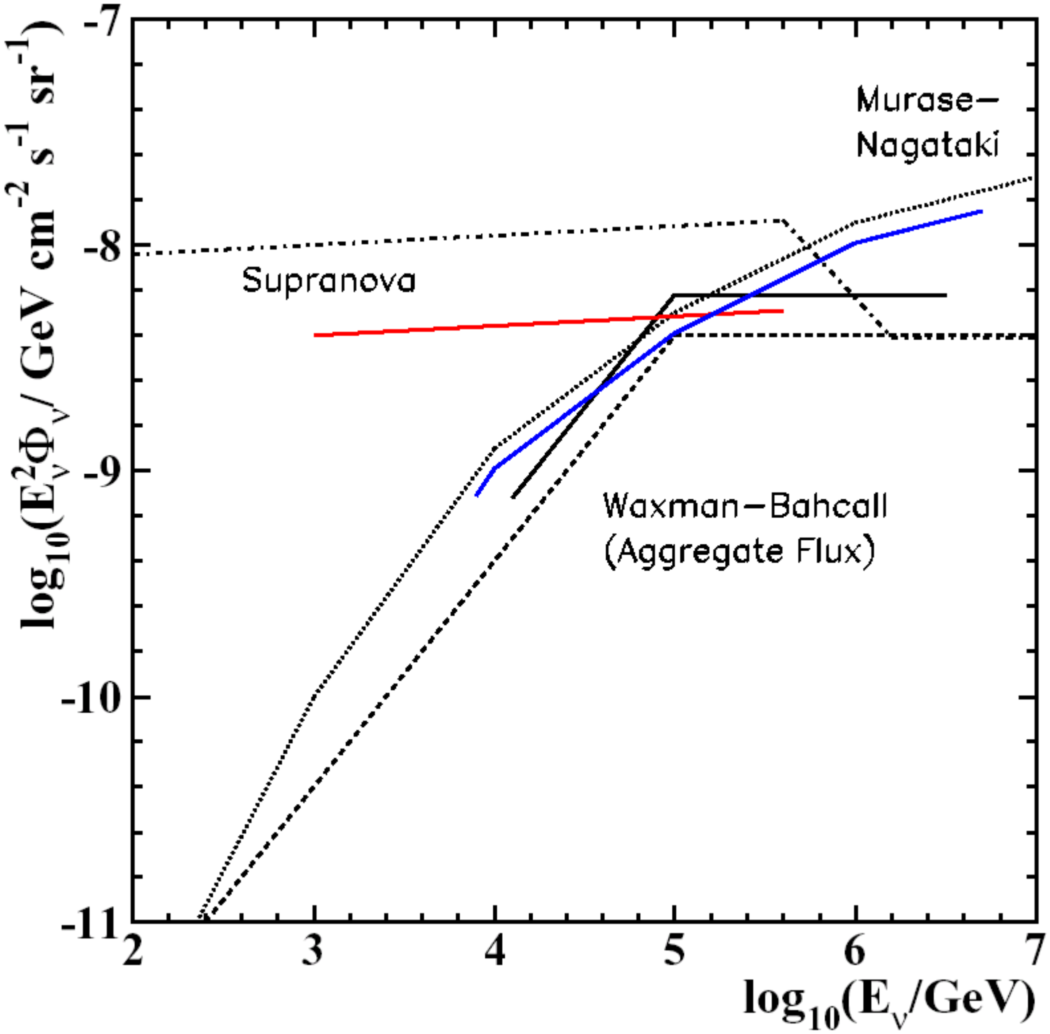

GRB n's [Ahlers et al 11]:

$E^2 dN/dE \sim 1/E^{0.3}$ & G-XG transition < $4\times10^{18}$eV

→ $L_{CR}(10^6 GeV) > 30\ L_{UHECR}$ (Back to "hidden" sources)

# The current limit

[Achterberg et al. 08 (The IceCube collaboration)]



# GRB G & $f_{pp}$

$$\Gamma = 300\left(L_{\gamma,52}\frac{\varepsilon_\gamma/\tau_{\gamma\gamma}(\varepsilon_\gamma)}{100\text{MeV}}\frac{10\text{ms}}{\Delta t}\right)^{1/6}, \qquad \varepsilon^{synch.}_{\gamma,b} \approx 1\varepsilon_e^{3/2}\varepsilon_b^{1/2}\frac{L^{1/2}_{\gamma,52}}{(\Gamma/300)^2(\Delta t/10\text{ms})}\text{MeV}$$

- Prompt ~1MeV synch → $f_{pp}$ ~ $t_{gg}$(100MeV)~1

  $t_{gg}$(100MeV)~1 G~300 ⟷

  Prompt GeV photons

  → $t_{gg}$(100MeV)<<1, G>>300, no n's ??

[Abdo et al. 09; Greiner et al. 09; Dermer 10]

Is $t_{gg}$(100MeV)<<1?

- Challenge to prompt MeV sync production

- 95% of LGRB not detected by LAT

  For bright GRBs, non detection implies:

  F(>100MeV)/F(1MeV) < 0.1 → $t_{gg}$(100MeV)>~1 ?

[Guetta et al. 10]

# GRB G's

- Caution in inferring $G_{min}$:
  - No exponential cutoff at $t_{gg}>1$, rather $nf_n \sim 1/n$
  - GeV & MeV emission likely originate from different radii (HE delay), $n(t_{gg}=1) \sim R$

- Internal collisions at $R_0$ → "residual" coll. @ $R >> R_0$

  $E(R) \sim 1/R^q$ with $q<2/3$ [Li & EW 08]

  $nf_n \sim 1/n^q$ for $n>n(t_{gg}=1, R=R_0)$ [Li 10]

  May account for:

  prompt optical (avoid self-abs.)

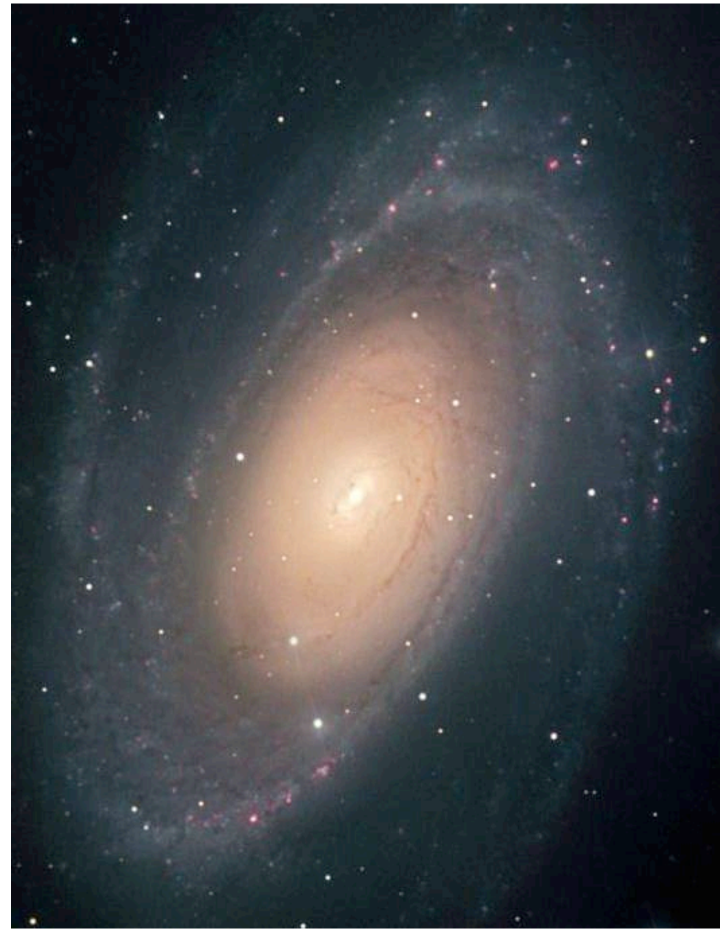
  prompt GeV (avoid pair prod.)

  GRB080916c HE delays → G~300 [Li 10]

M82

Mark Westmoquette (University College London),
Jay Gallagher (University of Wisconsin-Madison),
Linda Smith (University College London),
WIYN//NSF, NASA/ESA

M81



Robert Gendler

# Star bursts: A lower bound?

- Star burst galaxies:
  - Star Formation Rate
    $\sim 10^3 M_{sun}/yr \gg 1\ M_{sun}/yr$ "normal" (MW)
  - Density $\sim 10^3/cc \gg 1/cc$ "normal"
  - B ~1 mG >> 1mG "normal"

- Most stars formed in (z>1.5) star bursts

- High density + B:

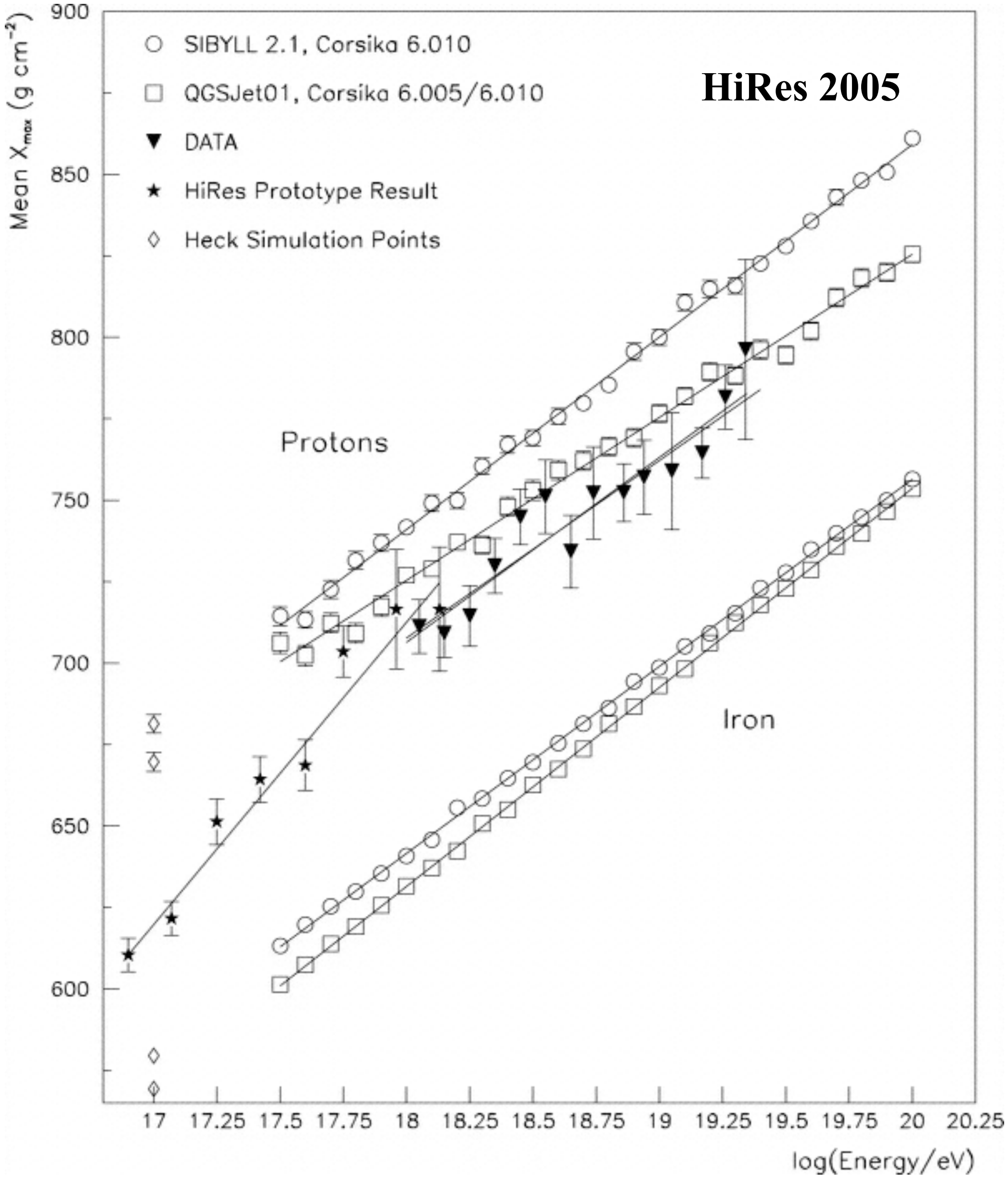
  CR $e^-$'s lose all energy to synchrotron radiation

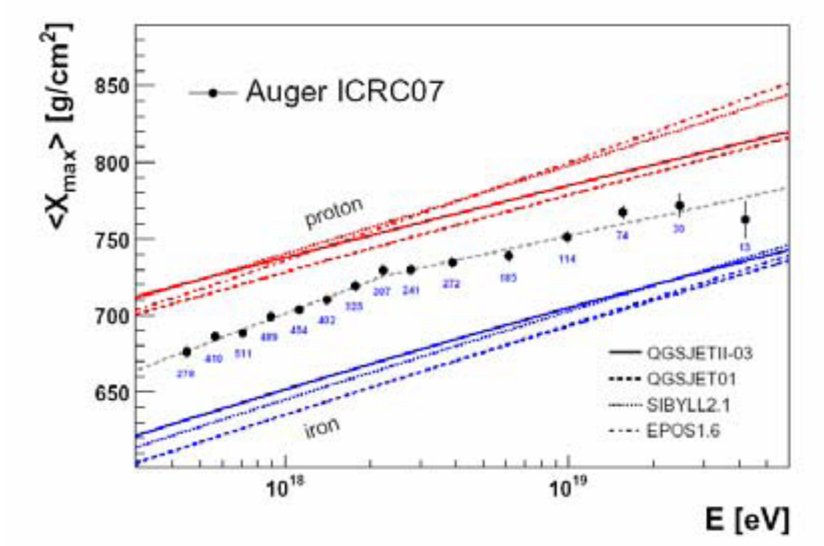
  [Quataert et al. 06]

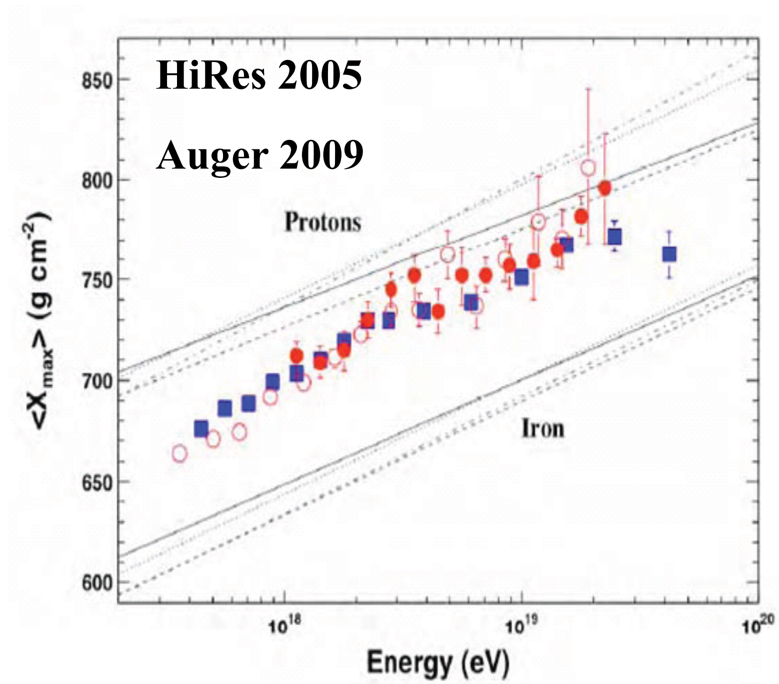
  CR p's lose all energy to p production

  [Loeb & EW 06]

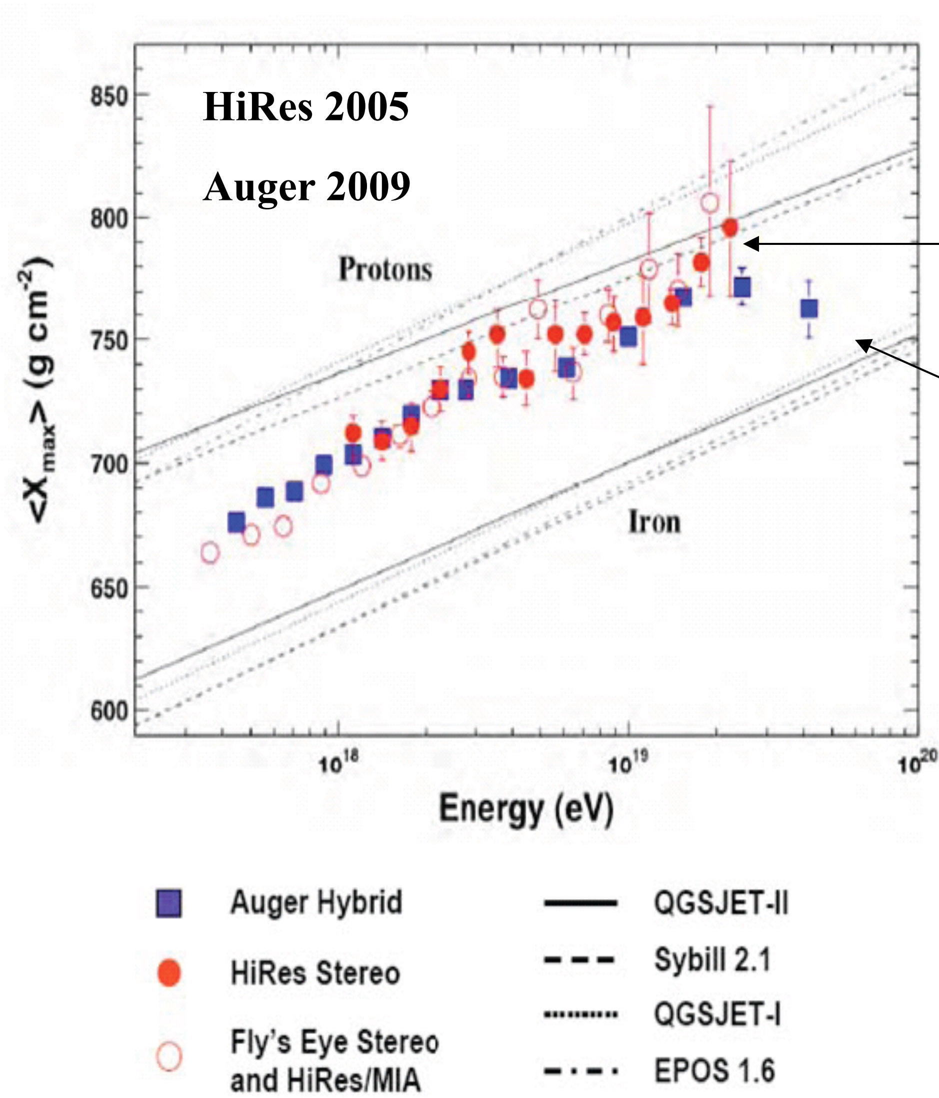
# Composition clues



# Composition clues




**Protons**

**Heavier at highest E?**

**Or: modified s extrapolation?**

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Astronomy & Astrophysics

# A catalogue of quasars and active nuclei: 12th edition★

M.-P. Véron-Cetty and P. Véron

Observatoire de Haute Provence, CNRS, 04870 Saint-Michel l'Observatoire, France
e-mail: [mira.veron;philippe.veron]@oamp.fr

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ABSTRACT

*Aims.* This catalogue is aimed at presenting a compilation of all known AGN in a compact and convenient form and we hope that it will be useful to all workers in this field.
*Methods.* Like the eleventh edition, it includes position and redshift as well as photometry ($U$, $B$, $V$) and 6 cm flux densities when

and, when available, 20 and 6 cm flux densities.

This catalogue should not be used for any statistical analysis as it is not complete in any sense, except that it is, we hope, a complete survey of the literature.

et al. It contained 202 objects. The number of known quasars has since steadily increased until the year 2000 (see Table 1). The release of both the 2dF catalogue (Croom et al. 2001, 2003) and the first part (Abazajian et al. 2003) of the "Sloan Digital Sky Survey" (Fan et al. 1999) has dramatically increased the number of known quasars justifying the 10th and 11th editions of the present catalogue. The recent release of the last three installments of the SDSS (Abazajian et al. 2004, 2005; Adelman-McCarthy et al. 2006) which has again almost doubled the number of known quasars, made a new edition timely.

This edition contains quasars with measured redshift known to us prior to January 1st, 2006; as in the preceding editions, we do not give any information about absorption lines or X-ray properties. But we give the absolute magnitude[1] for each object and, when available, 20 and 6 cm flux densities.

This catalogue should not be used for any statistical analysis as it is not complete in any sense, except that it is, we hope, a complete survey of the literature.

| QSO | BL Lac | Seyfert 1 | reference |
|---|---|---|---|
| 202 | | | De Veny et al. (1971) |
| 2251 | | 190 | Véron-Cetty & Véron (1984) |
| 2835 | 73 | 236 | Véron-Cetty & Véron (1985) |
| 3473 | 84 | 258 | Véron-Cetty & Véron (1987) |
| 4169 | 117 | 358 | Véron-Cetty & Véron (1989) |
| 6225 | 162 | 575 | Véron-Cetty & Véron (1991) |
| 7383 | 171 | 695 | Véron-Cetty & Véron (1993) |
| 8609 | 220 | 888 | Véron-Cetty & Véron (1996a) |
| 11 358 | 357 | 1111 | Véron-Cetty & Véron (1998) |
| 13 214 | 462 | 1711 | Véron-Cetty & Véron (2000a) |
| 23 760 | 608 | 2765 | Véron-Cetty & Véron (2001) |
| 48 921 | 876 | 11 777 | Véron-Cetty & Véron (2003) |
| 85 221 | 1122 | 9628 | Present edition |

In Table_BL, we list all confirmed, probable or possible BL Lac objects with or without a measured redshift, without consideration of their absolute magnitude. As better spectra are becoming available, broad emission lines have been detected in a