# $\nu$-astronomy and GRBs

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# High energy $\nu$'s: A new window

MeV $\nu$ detectors:

- Solar & SN1987A $\nu$'s
- Stellar physics (Sun's core, SNe core collapse)
- $\nu$ physics

>0.1 TeV $\nu$ detectors:

- Extend $\nu$ horizon to extra-Galactic scale

  MeV $\nu$ detectors limited to local (Galactic) sources

  [10kt @ 1MeV→1Gton @ TeV , $\sigma_{TeV}/\sigma_{MeV}\sim10^6$ ]
- Study "Cosmic accelerators" [p$\gamma$, pp → $\pi$'s→$\nu$'s]
- $\nu$ physics

# X-Galactic cosmic accelerators

- $>10^{19}$ eV: Extra-Galactic (light?) nuclei

  $j_p(>10^{20}\ \text{eV}) = 1/100\ \text{km}^2\ \text{yr}\ (2\pi\ \text{sr})$

- Open Q's: Primaries? Sources? Acceleration?

  The suspects: GRBs, AGN

- GRB accelerators:

  $e^-$ acceleration → p acceleration to $\sim 10^{21}$eV

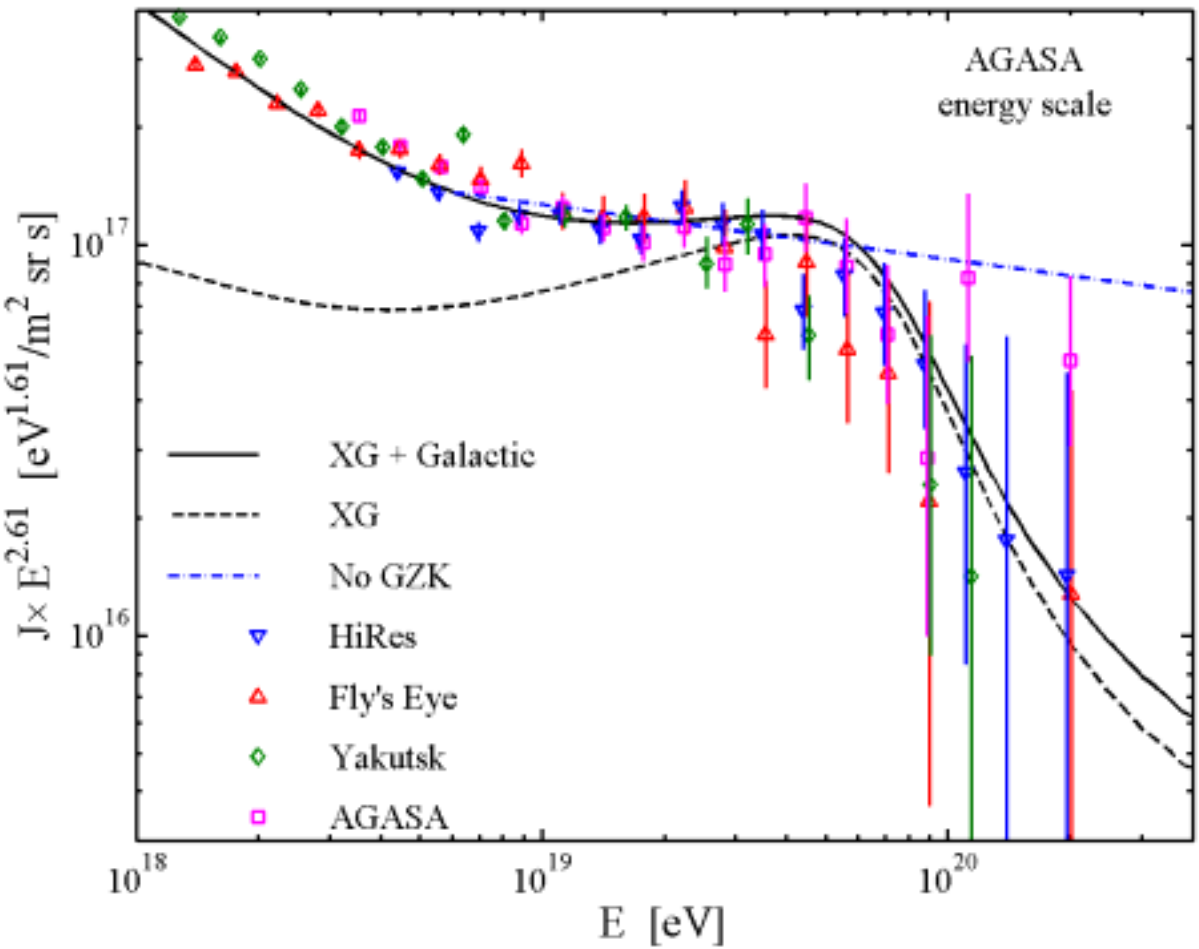
  $(dE/dt\ dV)_{GRB} \sim (dE/dt\ dV)_{XG\text{-}CR}$

[Waxman 95, 04]

# X-Galactic CRs: GZK

- $E_p > 0.6 \times 10^{20}$eV: $p + \gamma_{CMB} \rightarrow N + \pi$

  $\Rightarrow$ $d_{GZK} \sim 50$ Mpc $\ll d_H \sim 4$ Gpc




[Bahcall & Waxman 03]

# The X-Galactic $\nu$ intensity

- $\nu$-production:

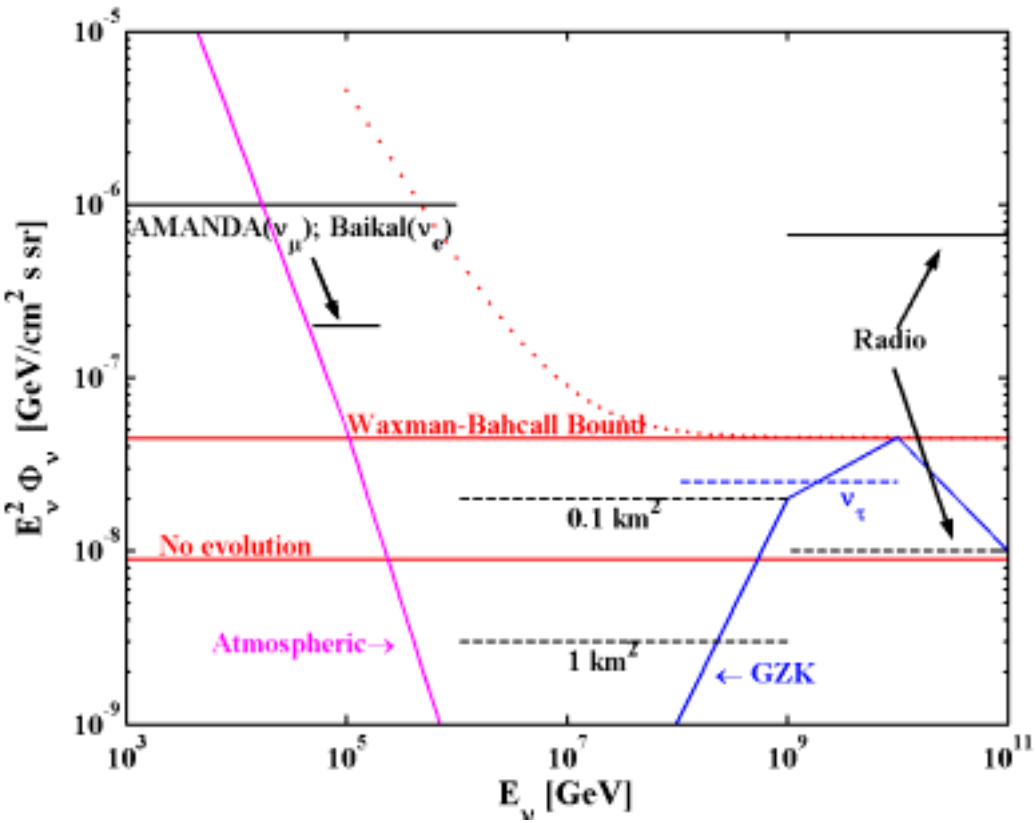
$$p\gamma,\ pp(n) \longrightarrow \pi^{+(-)} \longrightarrow \nu\text{'s}$$

- Cosmic HE $\nu$-background (Waxman-Bahcall bound):

$$\varepsilon_\nu^2 \frac{dj_\nu}{d\varepsilon_\nu} < \frac{1}{4}\ \zeta\ \frac{c/H_0}{d_{\mathrm{GZK}}}\ \varepsilon_p^2 \frac{dj_p}{d\varepsilon_p} \approx 10^{-8}\ \zeta\ \frac{\mathrm{GeV}}{\mathrm{cm}^2 \mathrm{s\ sr}}$$

[Waxman & Bahcall 99;
Bahcall & Waxman 01]

# Experiments




- Optical Cerenkov
  - South Pole

  Amanda: 660 OM, 0.1 km$^2$

  IceCube: +600 OM (05/06)

  4800 OM=1 km$^2$s
  - Mediterranean

  Antares: 1 line,

  75 OM (3/06) → 0.1 km$^2$

  Nestor: (?) → 0.1 km$^2$

  km3Net: R&D → 1 km$^2$

- UHE: Radio

  Rice (Ice)

  ANITA (Balloon)

Air shower

Auger ($\nu_\tau$)

EUSO (?)

# Star bursts

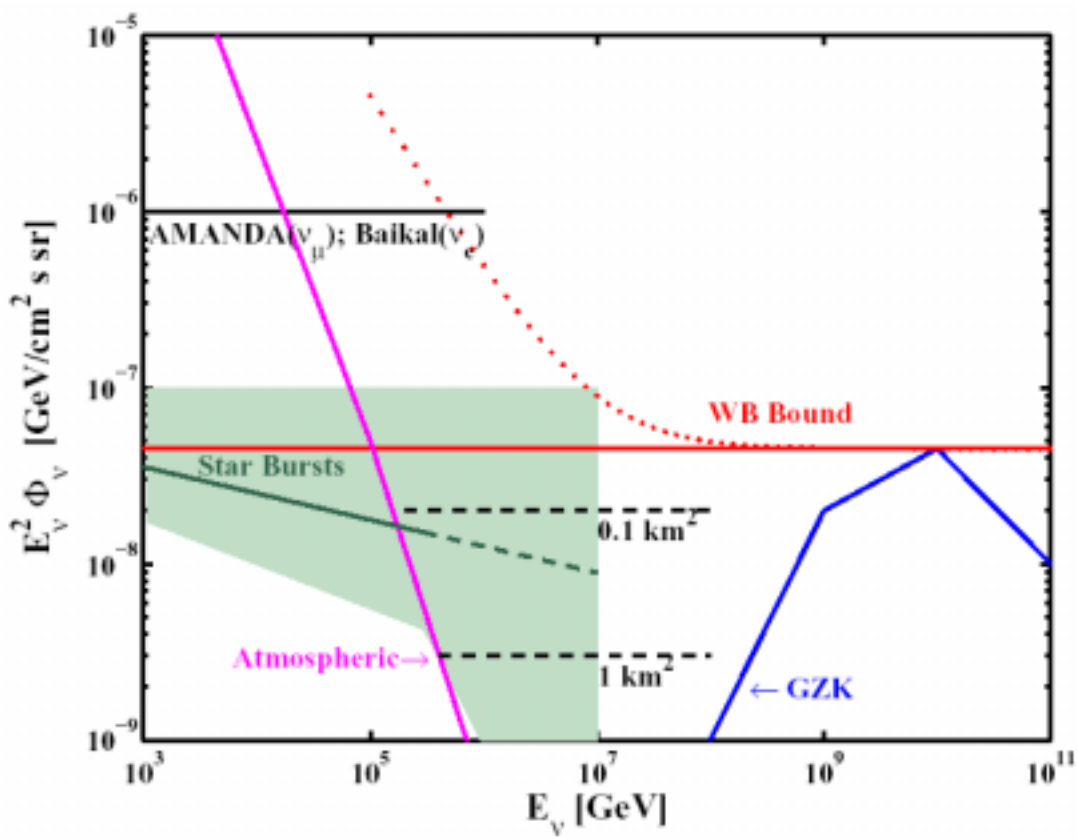
- Star burst [n~$10^3$/cc] : B ~1 mG

  → CR "calorimeters":

[Quataert et al. 06]

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

Synchrotron radio — calibration → $\Phi_\nu$




[Loeb & Waxman 06;
Quataert, Thompson & Waxman 06]

# Generic GRB fireball ν's

- If: Baryonic fireball, internal shocks

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

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

$$f_{p\to\pi} \approx 0.2$$ (Weak dependence on model parameters)

$$\Rightarrow \quad \varepsilon^2\Phi_\nu \approx 0.2\Phi_\nu^{WB} = 10^{-8}\,\frac{\mathrm{GeV}}{\mathrm{cm}^2\,\mathrm{s\ sr}}\ , \quad \varepsilon_\nu \geq 10^{14.5}\ \mathrm{eV}$$

$$J_{\nu\to\mu} \approx 20/\mathrm{km}^2\mathrm{yr}$$

[Waxman & Bahcall 97, 99; Rachen & Meszaros 98; Alvarez-Muniz & F. Halzen 99; Guetta et al. 04; Hooper, Alvarez-Muniz, Halzen & E. Reuveni 04]

- Background free:

$$J^A_{\nu\to\mu} \sim 4\times10^{-3}\left(\frac{\Delta\Theta}{0.5^o}\right)^2\left(\frac{E}{100\mathrm{TeV}}\right)^{-\beta}/\mathrm{km}^2\mathrm{yr}\,; \quad \beta = \begin{cases} 1.7 & E < 100\mathrm{TeV} \\ 2.5 & E > 100\mathrm{TeV} \end{cases}$$

# ν- physics & astro-physics

- γ-ν timing: Violation of Lorentz Inv.
  (Quantum Gravity)

[Waxman & Bahcall 97;
Amelino-Camelia et al. 98;
Colman & Glashow 99;Jacob & Piran 06]

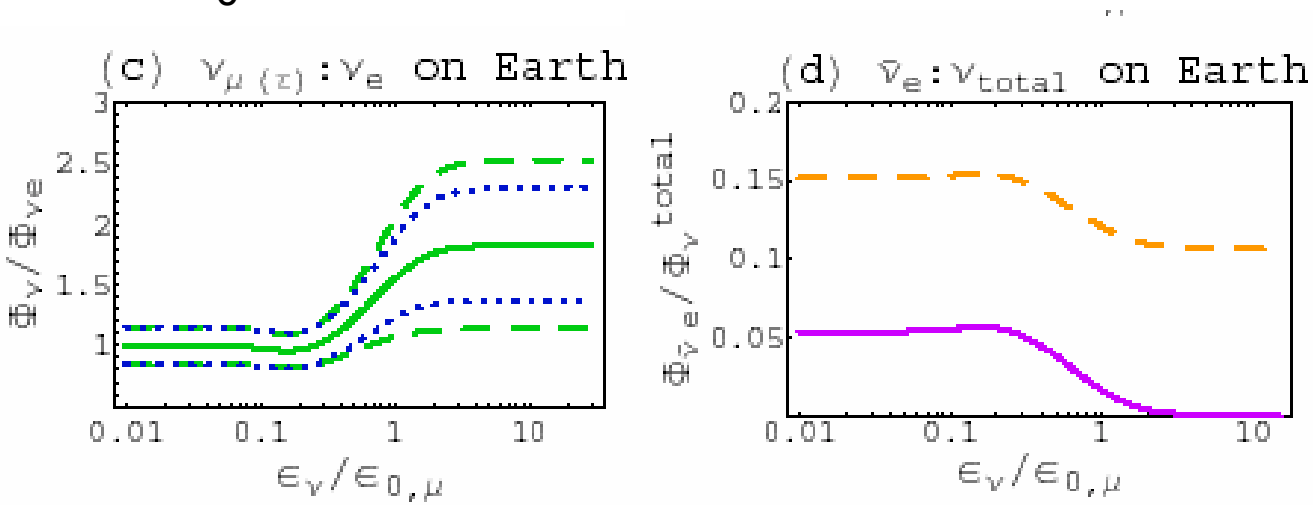
- π decay → $\nu_e:\nu_\mu:\nu_\tau$ = 1:2:0 (Osc.)→ $\nu_e:\nu_\mu:\nu_\tau$ = 1:1:1
  τ appearance experiment

[Waxman & Bahcall 97]

- EM energy loss of μ's (and π's)
  $\nu_e:\nu_\mu:\nu_\tau$ = 1:1:1 (E>$E_0$)→ 1:2:2
  GRBs: $E_0$~$10^{15}$eV

[Rachen & Meszaros 98]

[Kashti & Waxman 05]



# GRBs, $\nu$'s & SWIFT

- Precursor 1-10 TeV $\nu$'s

  "Collapsar" jet

  Failed jets?

  Slow jets in all SN ?

[Meszaros & Waxman 01; Razzaque, Meszaros & Waxman 03]

[Razzaque, Meszaros & Waxman 04; Ando & Beacom 05]

- Late X/UV flares

  If: Late central engine internal shocks ($\Gamma$~10)

  → $\Phi_\nu$(flare) may be ~ $\Phi_\nu$(prompt)

[Murase et al. 06, Gupta & Zhang 06]

- Low L GRBs

  If: Similar $\gamma$-ray mechanism (baryonic fireball…)

  → $\Phi_\nu$(LL-GRB) may be ~ $\Phi_\nu$(HL-GRB)

[Murase & Nagataki 06]

# Outlook

- HE $\nu$ telescopes

  ~1 km$^3$ (=1Gton) 1-1000TeV $\nu$ detectors

  >>1 km$^3$ [radio,...] >>1000TeV $\nu$ detectors

- Some open Q's for $\nu$-astronomy

  * HE CRs: Primaries, Sources, Acceleration

  * Physics of extreme sources- GRBs

    The "engine": Baryonic fireball? Late flares? ...

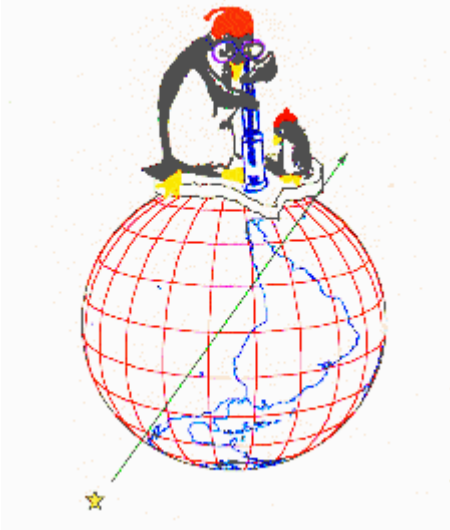
    The progenitor: Collapsar jets? Jets in SNe? ...

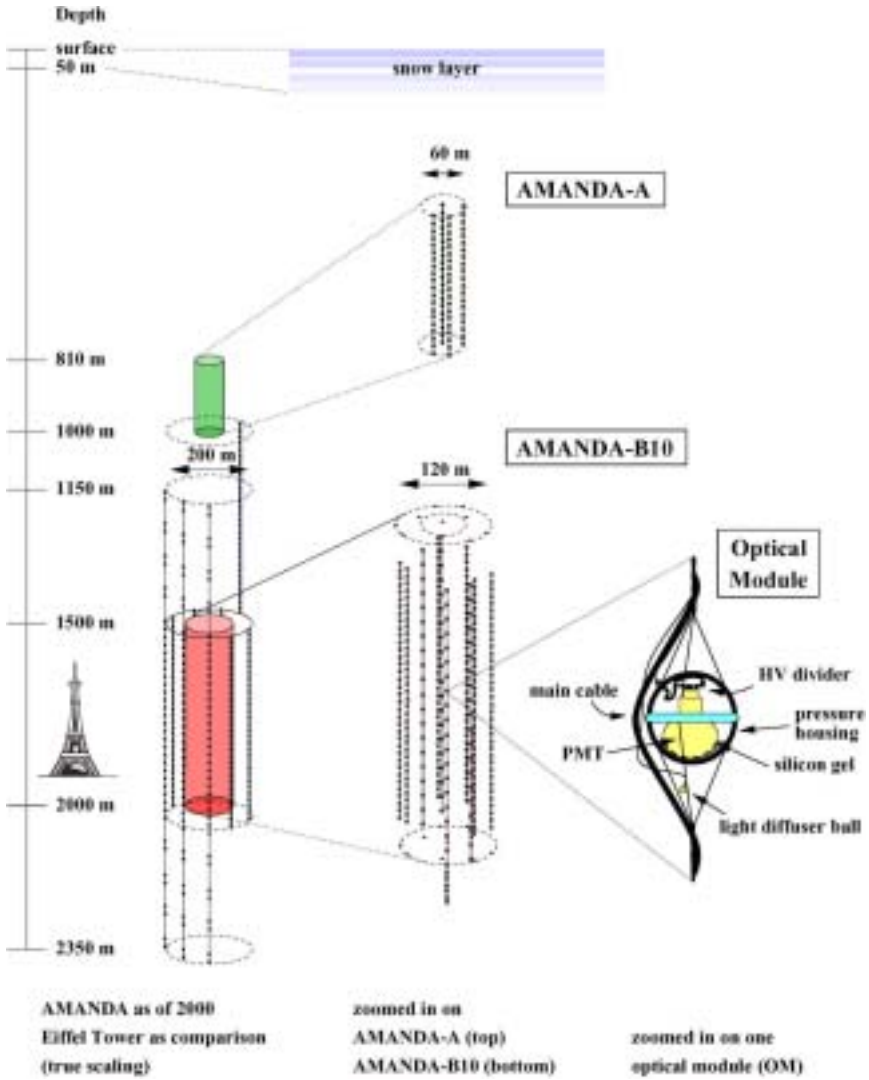
- $\nu$ properties with $\nu$ telescopes

  $\nu_\mu \leftrightarrow \nu_\tau$ → $\tau$ appearance

  GRBs: $\gamma\nu$ Timing → LI to 1:$10^{16}$; WEP to 1:$10^6$

# AMANDA & IceCube

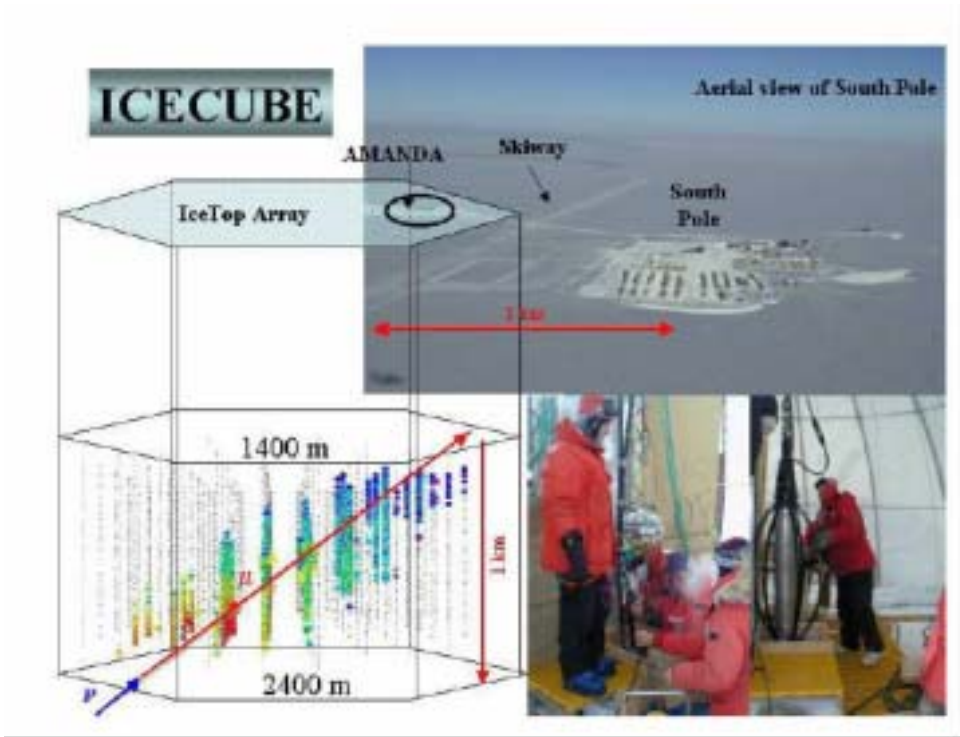





AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

zoomed in on one
optical module (OM)



# The Mediterranean effort

- ANTARES, NESTOR, NEMO → km3net