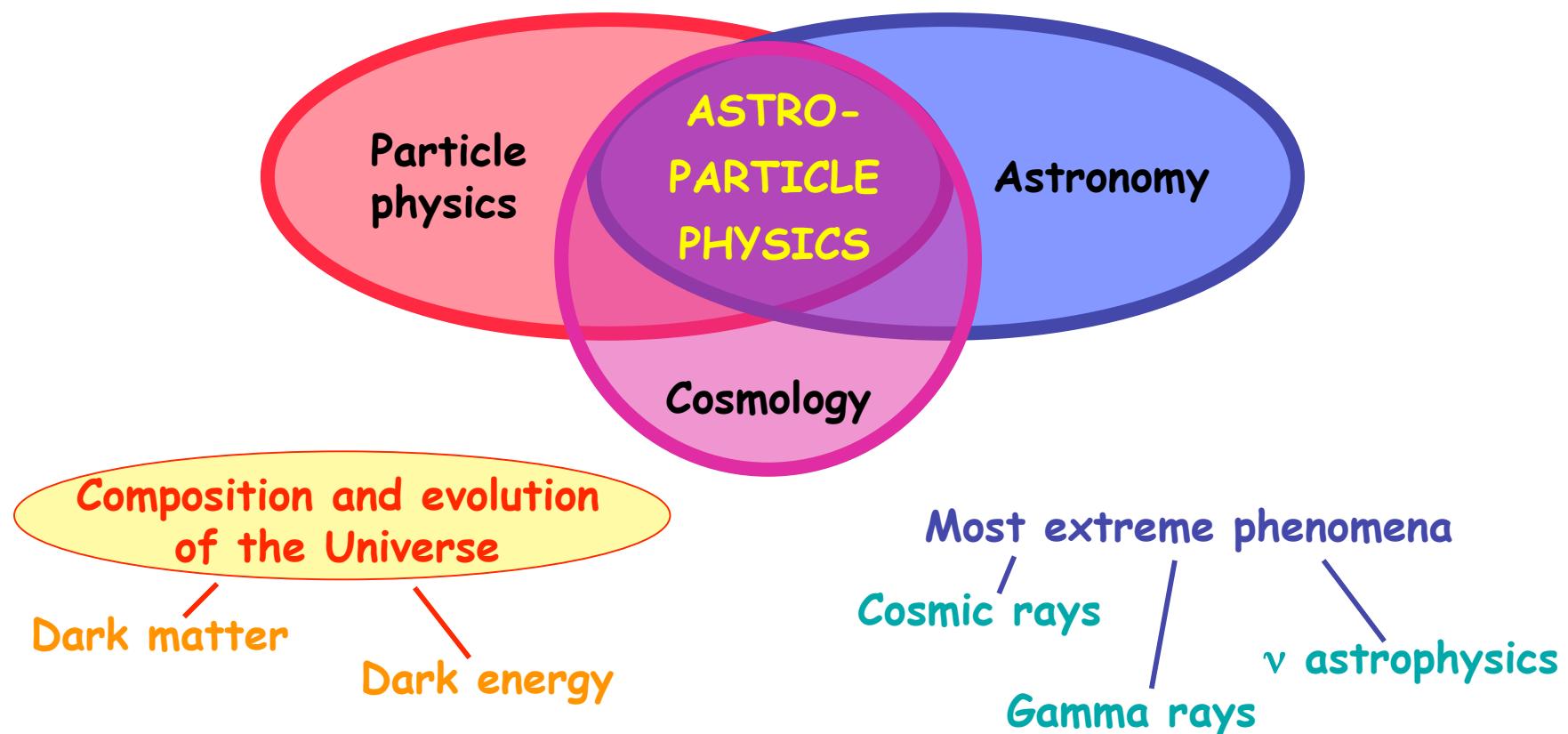
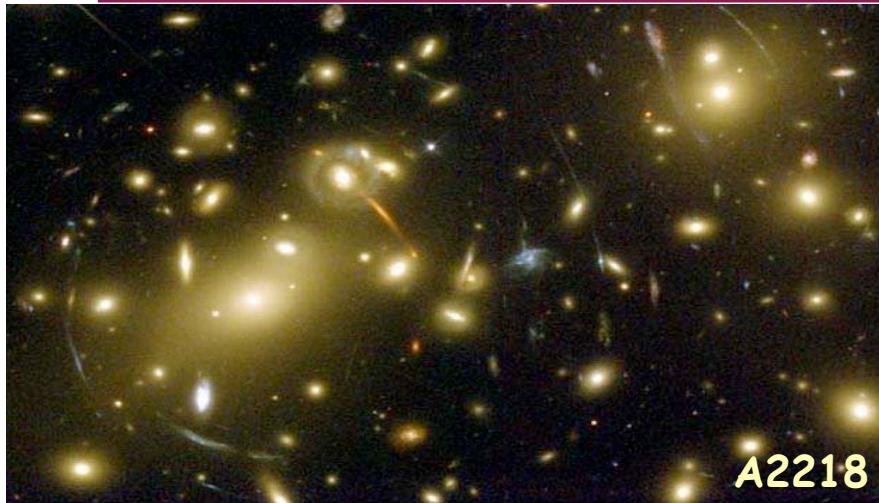


Results from astroparticle physics

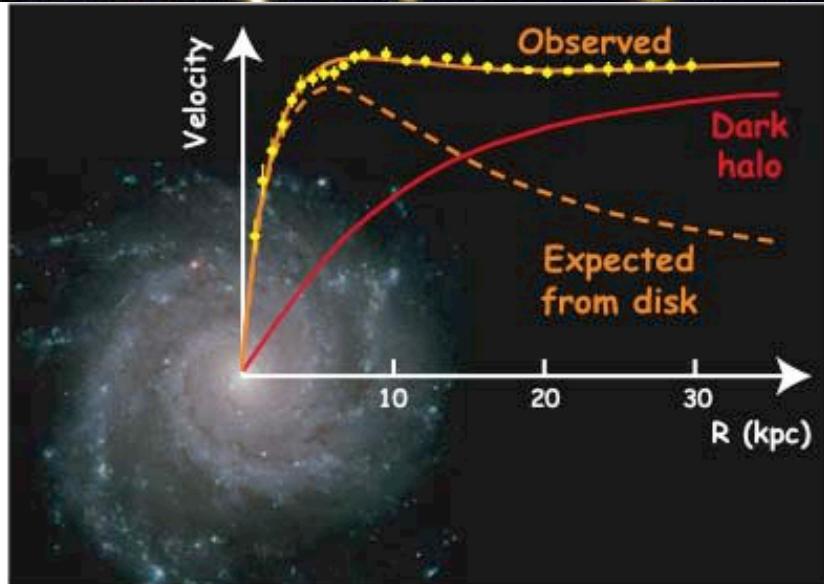
Nathalie Palanque-Delabrouille
CEA-Saclay



Evidence for dark matter



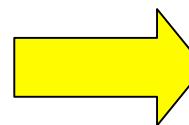
A2218



N. Palanque-Delabrouille

Physics at LHC

General Relativity and
Dark Matter ?



or

MOdified
Newtonian
Dynamics ?

(acceleration $\neq GM/r^2$)
in the weak field regime

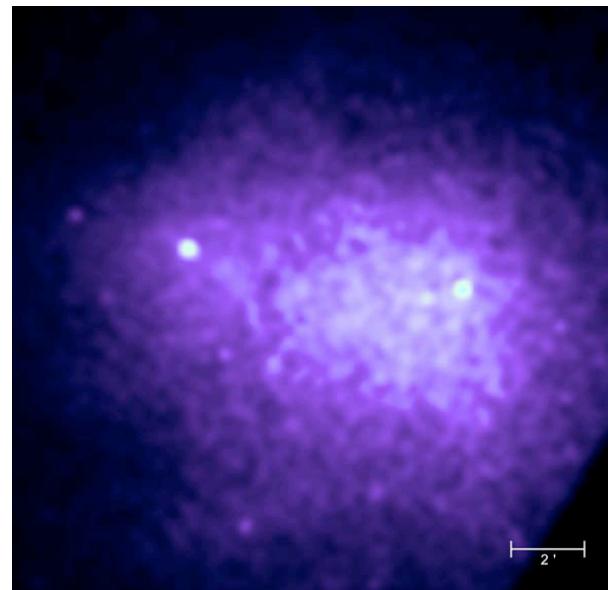
Collision between 2 clusters (1/3)

Coma cluster as seen in
optical (galaxies)



Credit: Kitt Peak

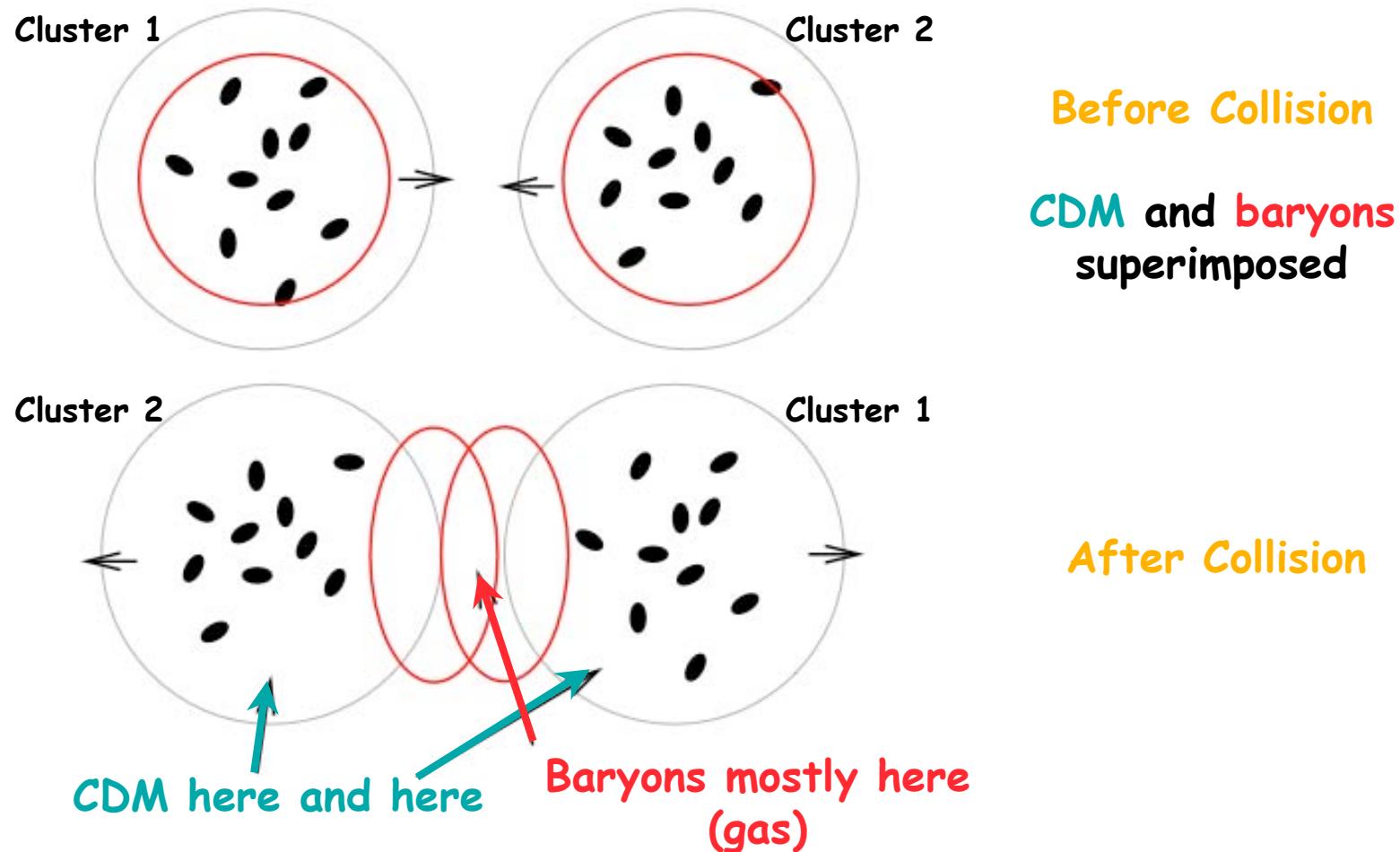
X-ray (gas)



Credit: NASA / CHANDRA

Most of the **baryonic mass** of a cluster
lies in its **gas** (not galaxies)

Collision between 2 clusters (2/3)

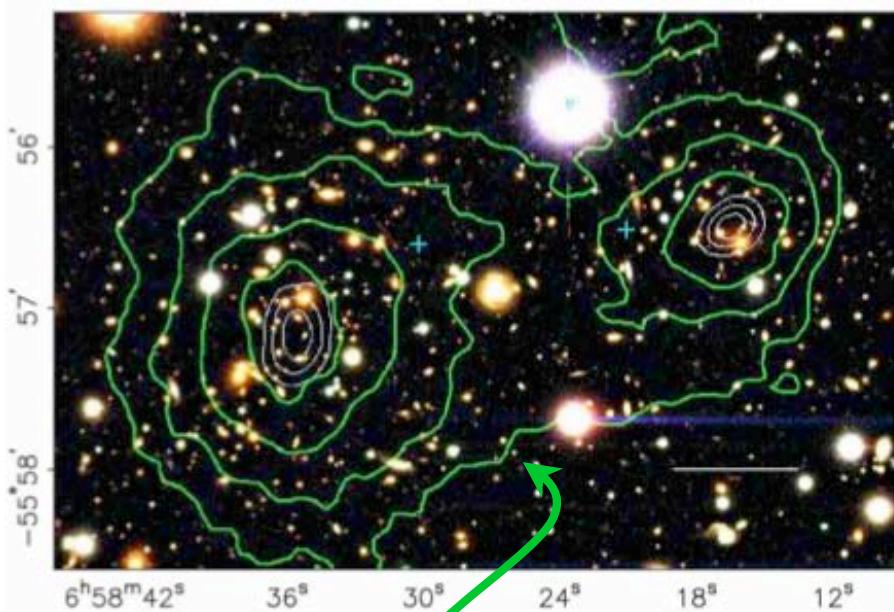


Collision between 2 clusters (3/3)

Collision in 1E0657-558 = bullet cluster

D. Clowe et al., astro-ph/0608407, AJ 648 (2006) L109-113

Weak lensing \Rightarrow Mass not centered on gas
 \Rightarrow Requires Dark Matter
(unless MOND + ~ 3 eV neutrinos)

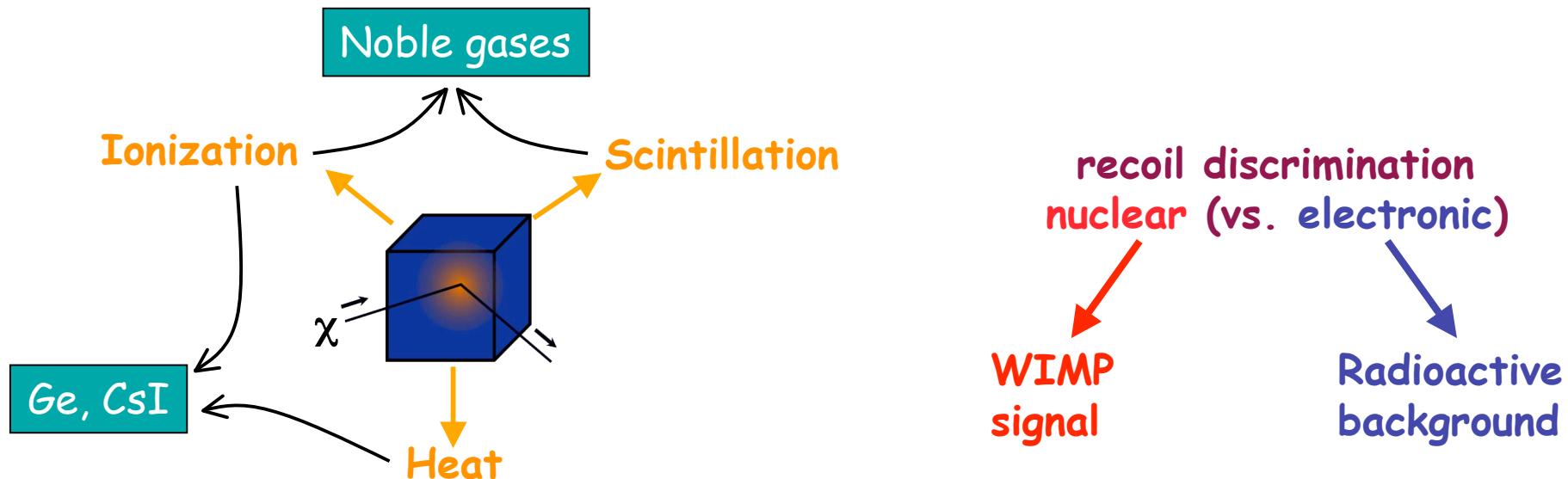


WIMPS as Cold Dark Matter

LSP (neutralino) natural candidate in SUSY theories

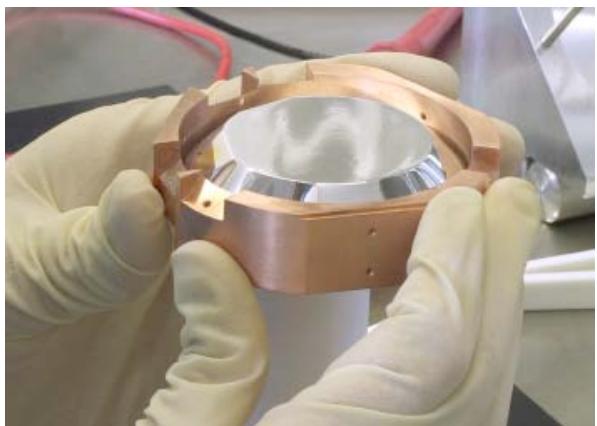
Stable relic from big bang

$$\Omega_\chi \propto 1 / \langle \sigma_A v \rangle$$
$$\sigma_A \sim \sigma_{\text{weak}} \Rightarrow \Omega_\chi \sim 25\%$$



Heat + ionization

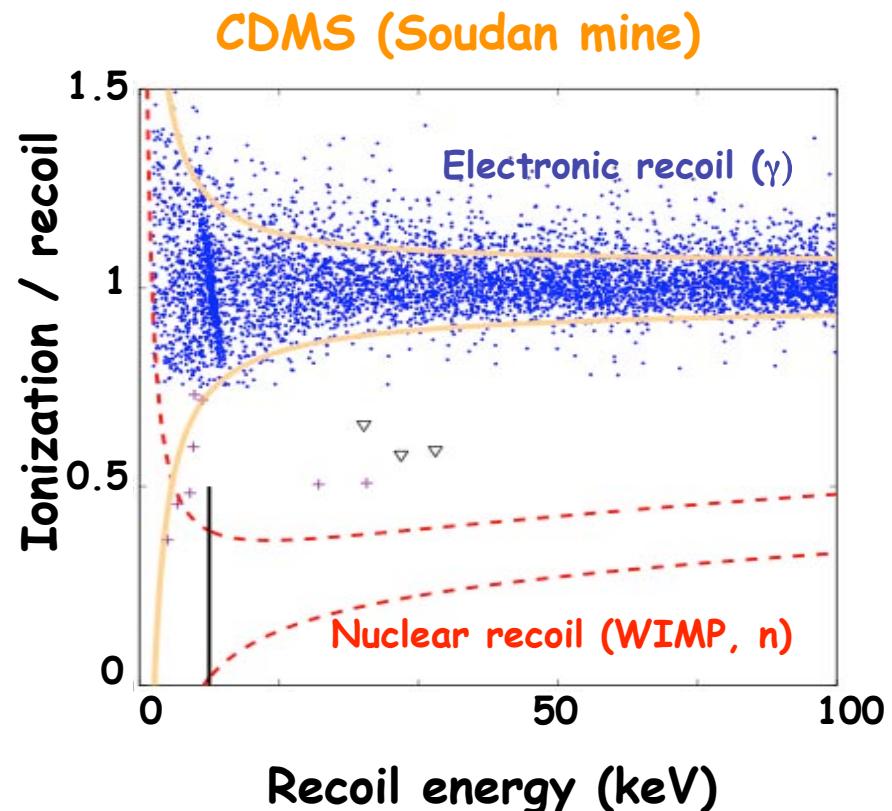
Edelweiss / CDMS



300g Ge bolometer

background free analysis

$S/N \propto \text{time}$



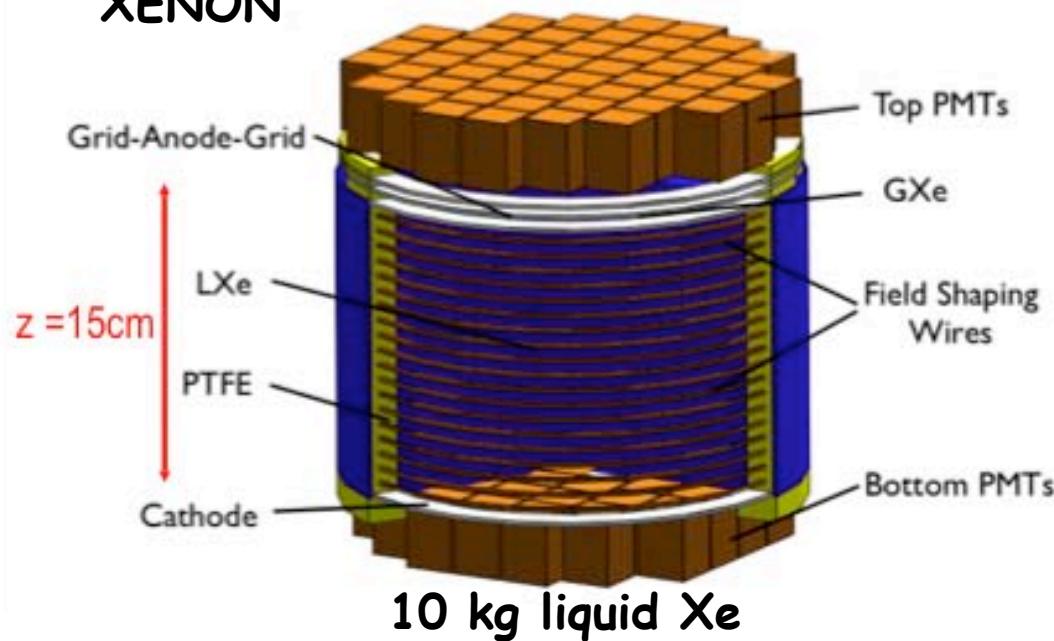
CDMS: Akerib et al.,
Phys Rev Lett. 96, 011302 (2006)

Noble gases (Xe, Ar)

scintillation + ionization

Liquid detectors, easily **extendable** to larger masses
Good **sensitivity** to low-mass WIMPs
The way to go?

XENON

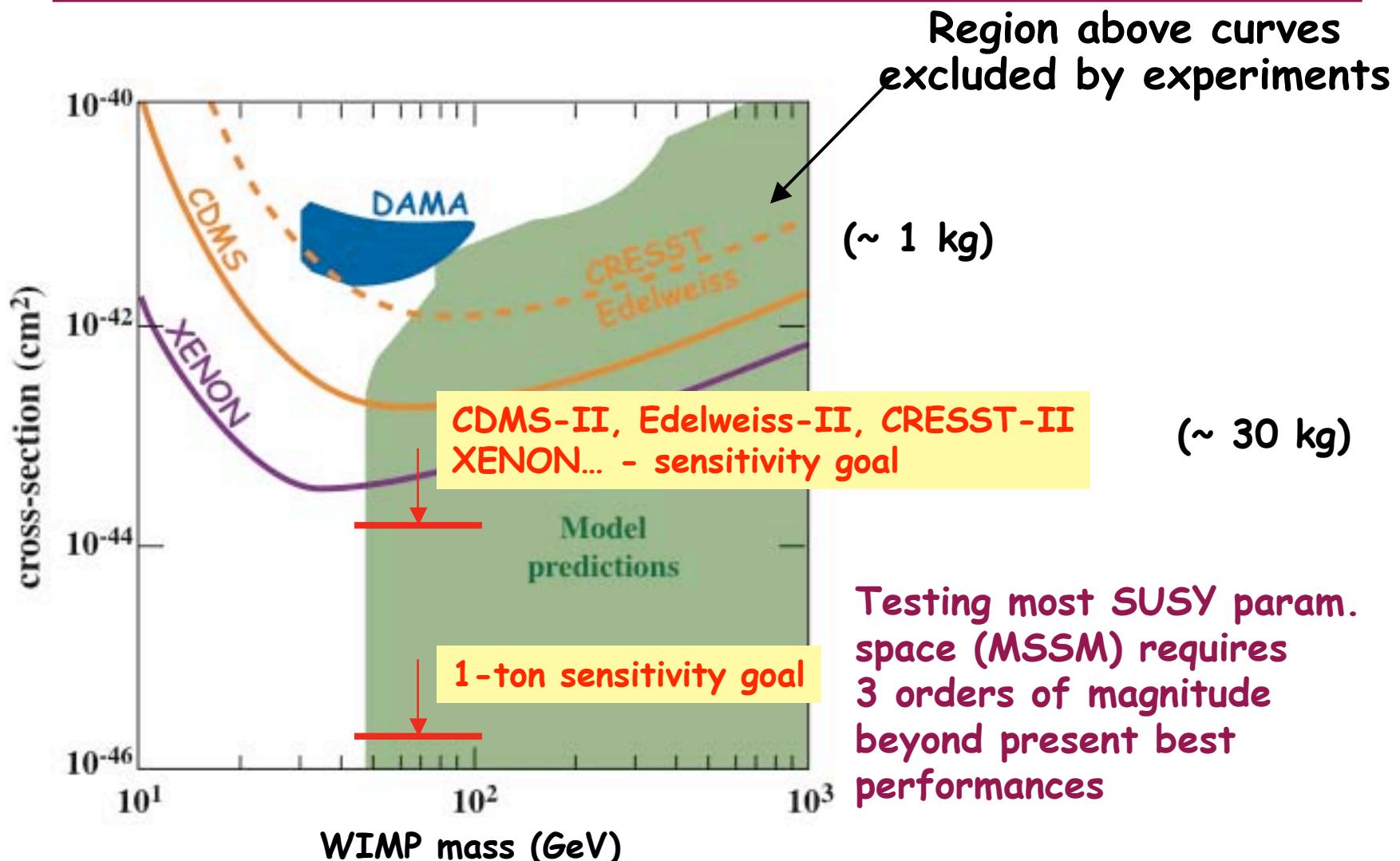


Remaining background
(despite a fiducial volume
of $\sim 50\%$ of total)



$$S/N \propto \sqrt{\text{time}}$$

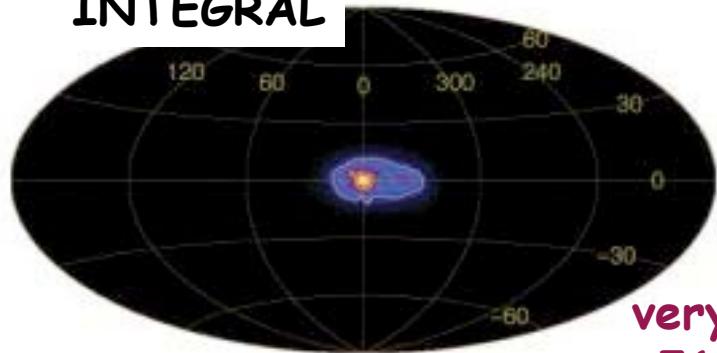
Overview on direct detection



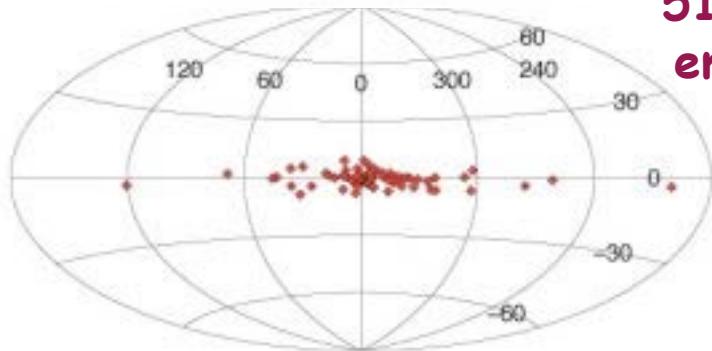
Indirect searches for WIMPS

(WIMP annihilations)

INTEGRAL



very strong
511 keV
emission



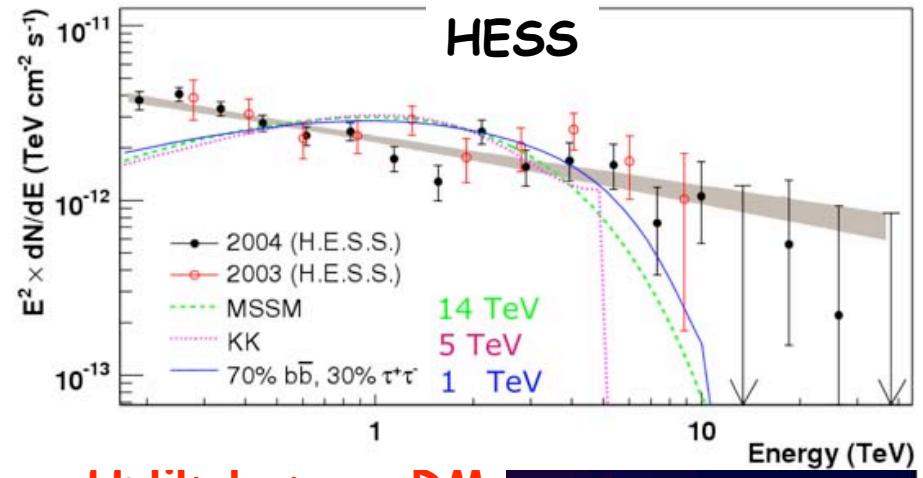
Light (~100MeV) DM particle?
Asymmetry correlated with
distribution of X-Ray binaries
(50-70% of signal)

Weidenspointner et al. Nature 451 (2008) 159

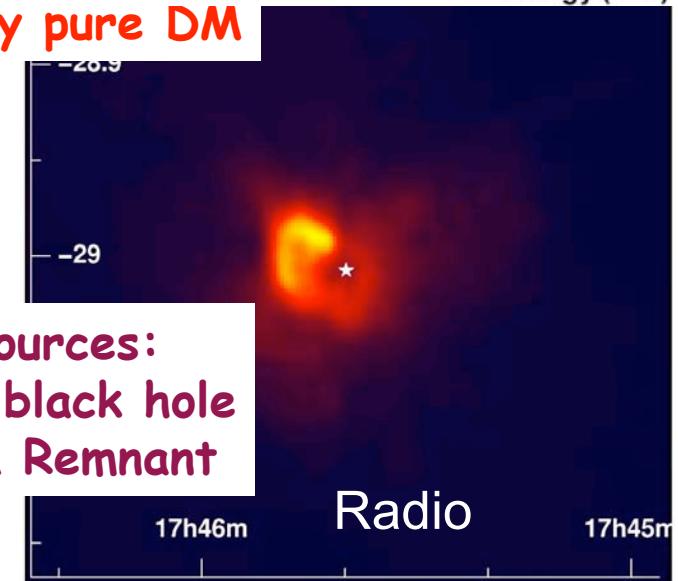
N. Palanque-Delabrouille

Physics at LHC

HESS



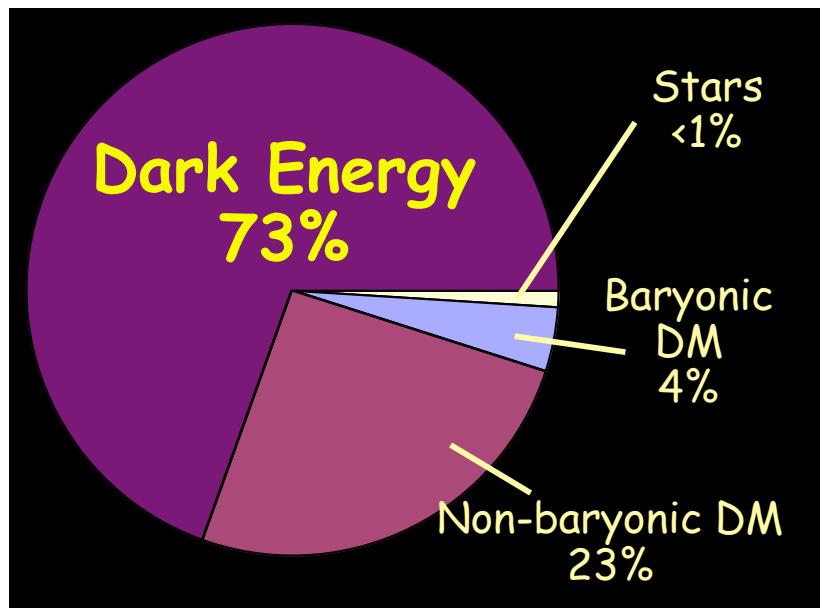
→ Unlikely pure DM



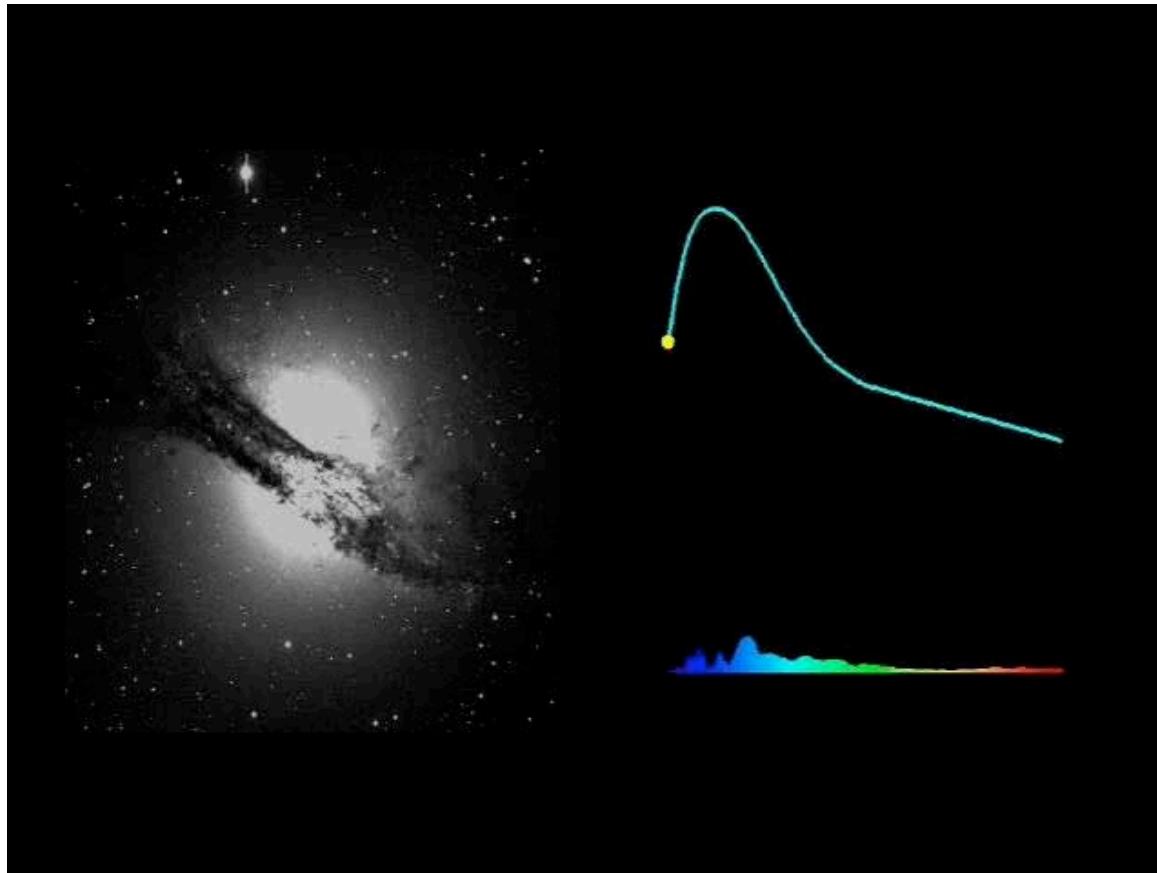
Possible sources:
3 $10^6 M_\odot$ black hole
Supernova Remnant

Aharonian et al. PRL 97 (2006) 221102

Dark energy



Study of type Ia supernovae



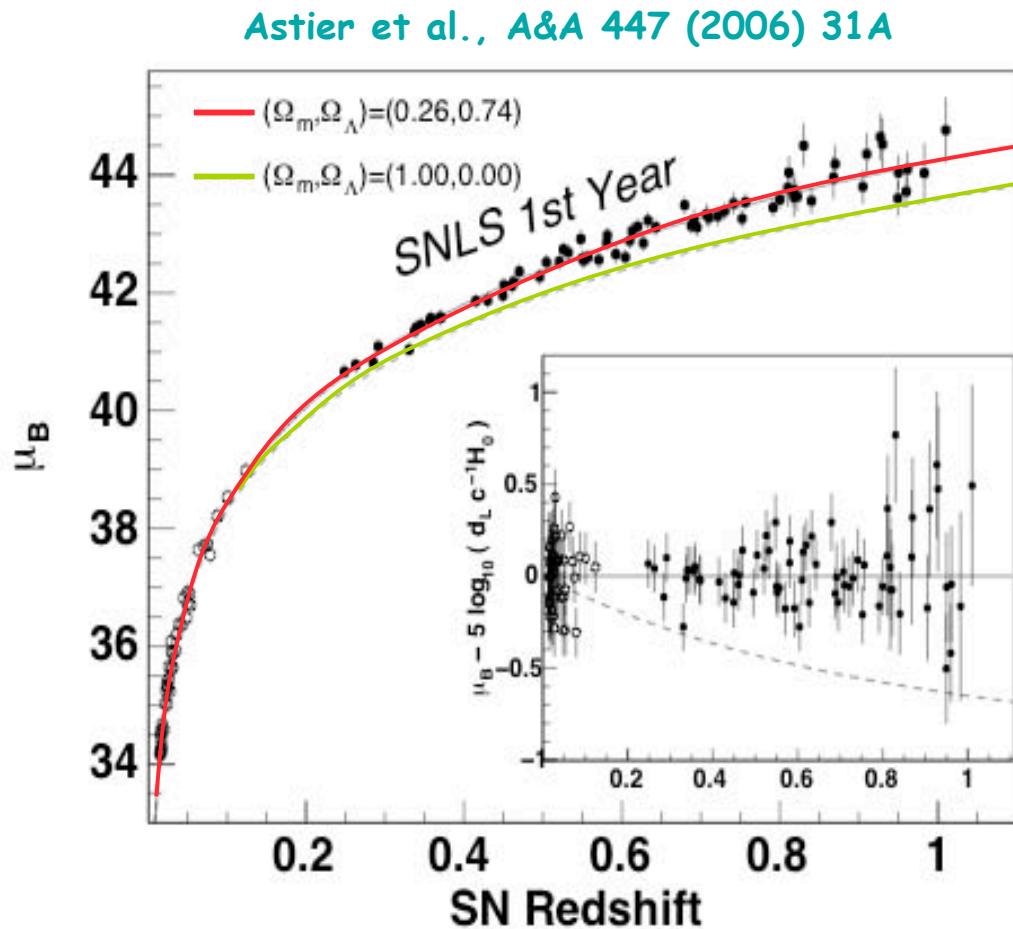
Photometry

- light-curve
- max flux
- distance

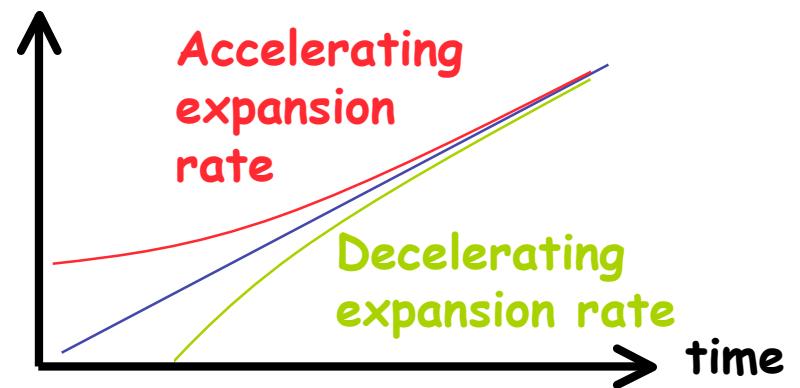
Spectrum

- SNIa
- redshift z

SNLS 2006



Size of universe



$$1 + z = \frac{\text{size}_{\text{today}}}{\text{size}_{\text{emission}}}$$

flat Λ CDM:

$$\Omega_M = 0.263 \pm 0.042 \pm 0.032$$

$$\rightarrow \Omega_\Lambda = 0.74$$

Equation of state of DE

Time evolution of dark energy density ρ_{de} determined by w

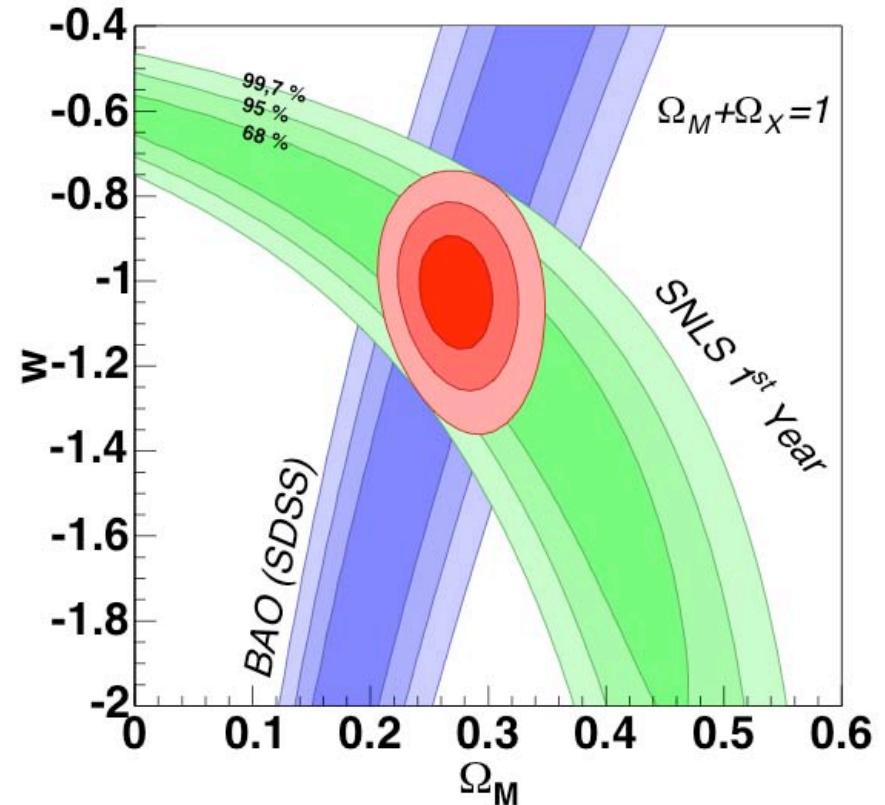
$$w = \frac{p_{de}}{\rho_{de}}$$

$$\frac{1}{\rho_{de}} \frac{d\rho_{de}}{dt} = -3H(1+w)$$

- $w = -1$ cosmological constant
- $w = 0$ matter
- $w = 1/3$ relativistic matter, radiation

No evidence so far for $w \neq -1$
(and no serious theory)

Astier et al., A&A 447 (2006) 31A



$$w = -1.02 \pm 0.10$$

Standard ruler

Standard candles : supernovae

- evolution (variation of flux) and impact on cosmology?
- dust?

Standard rulers

- almost no systematics !

Sound horizon at recombination

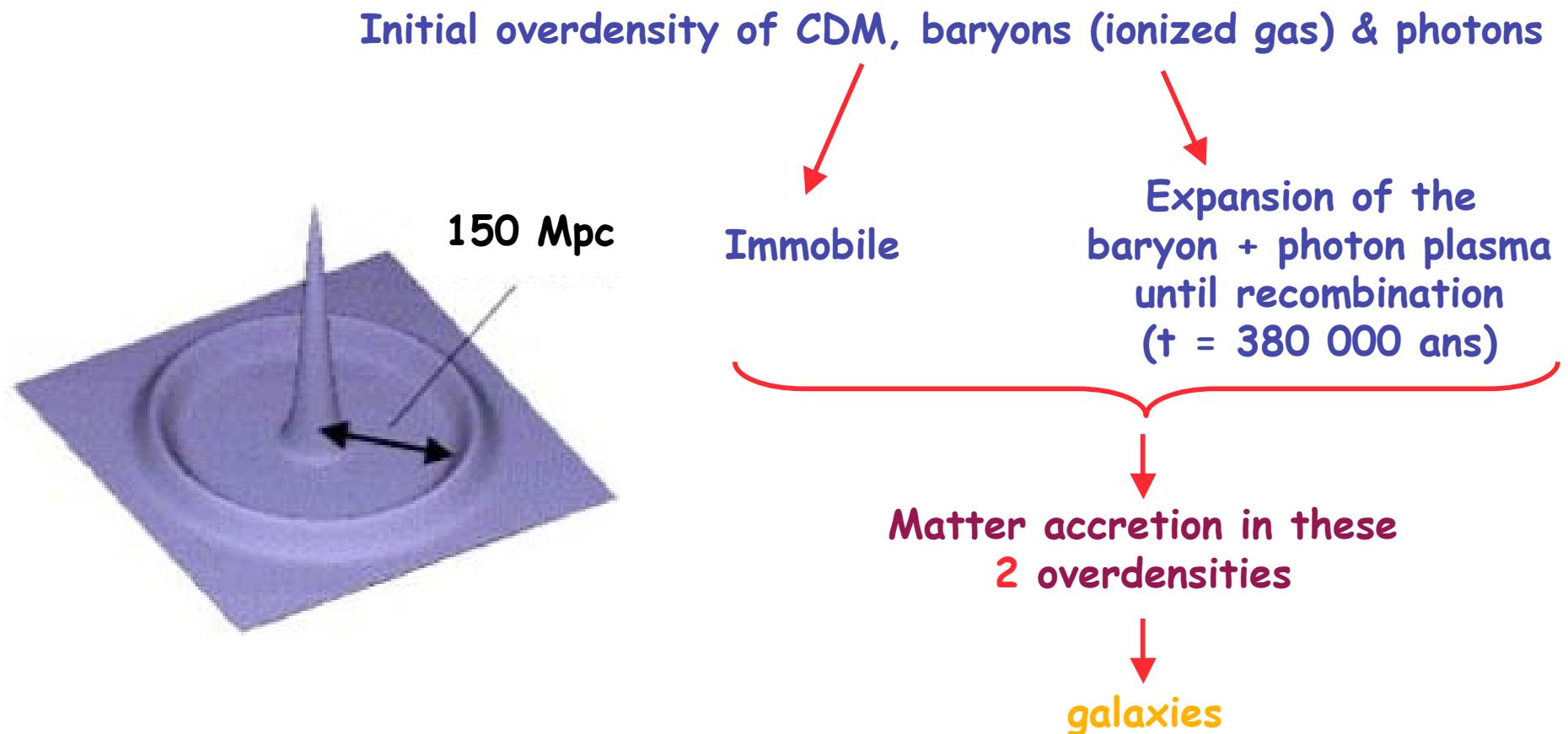
Photon distribution
(CMB)

Galaxy distribution
(BAO)

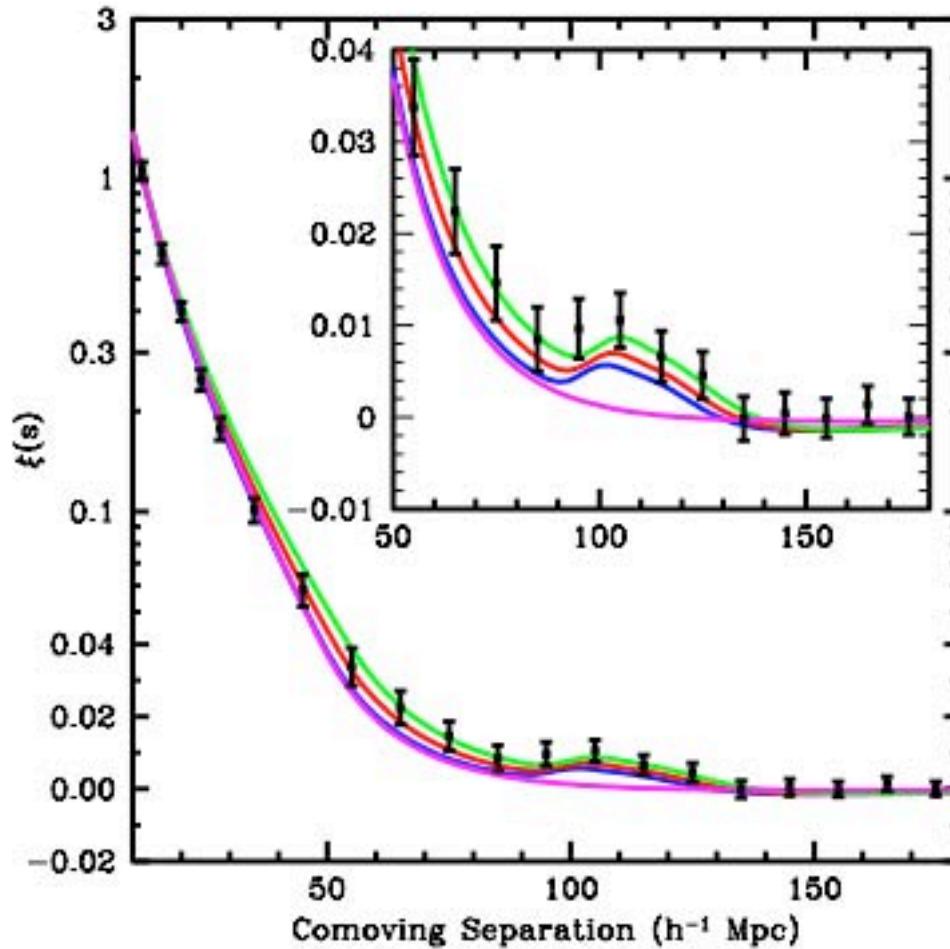


Matter (galaxy) distribution

Spherical baryon-photon sound wave propagation until recombination



Sloan Digital Sky Survey



Position of acoustic peak :

$$s \approx c_s t(z = 1100) (1 + z)$$

$$\propto \frac{1}{H(z = 1100)}$$

$$\boxed{\propto \frac{1}{\sqrt{\Omega_M}}}$$

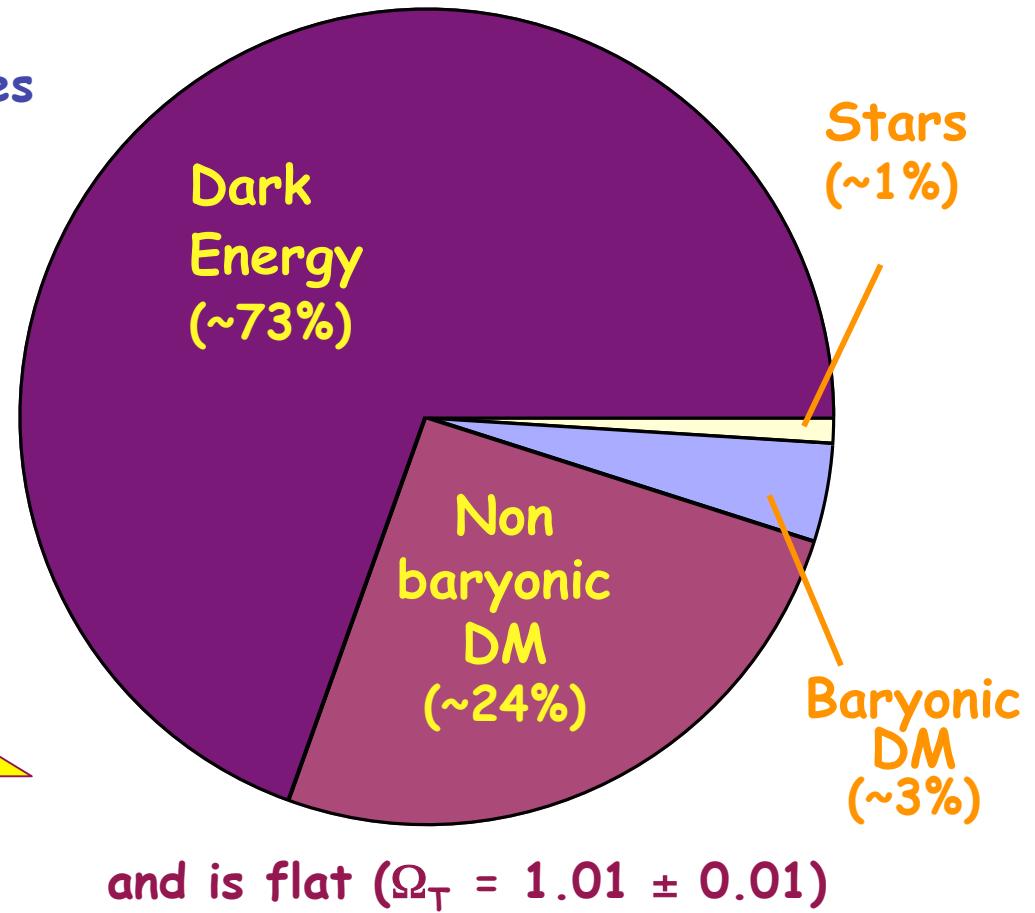
SDSS ($z \sim 0.3$)
Eisenstein et al, Ap.J. 633 (2005) 560
 $\Omega_{cdm} + \Omega_b = 0.273 \pm 0.025$
 $+ 0.123(1+w) + 0.137(1-\Omega_T)$

Concordance model

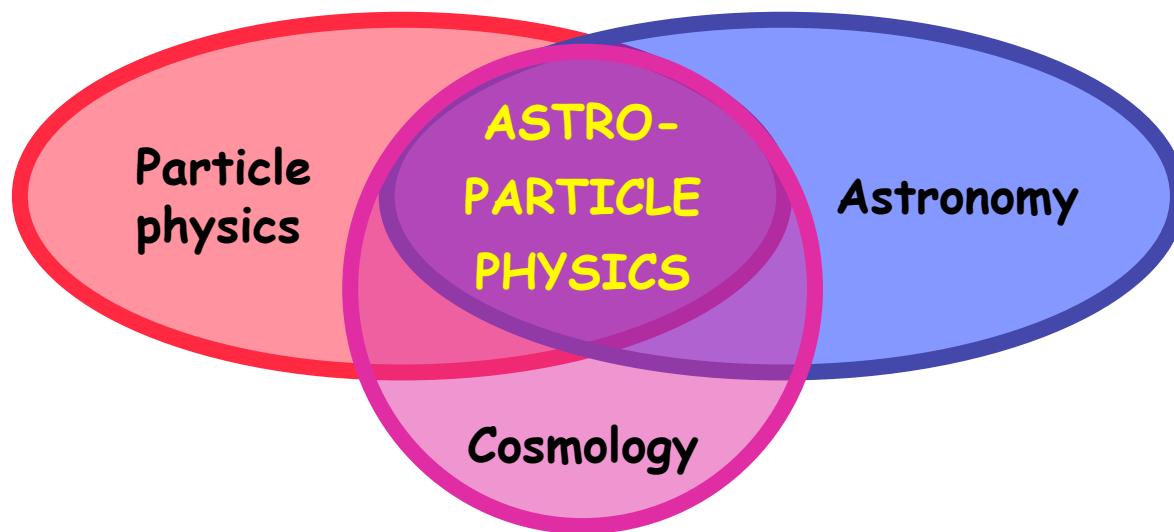
Evidence from

- Microwave background anisotropies (WMAP)
- Type Ia Supernovae (SNLS)
- Galaxy distribution (SDSS)

imply the Universe **behaves**
as though it consists of



Results from astroparticle physics



Composition and evolution
of the Universe

Dark matter

Dark energy

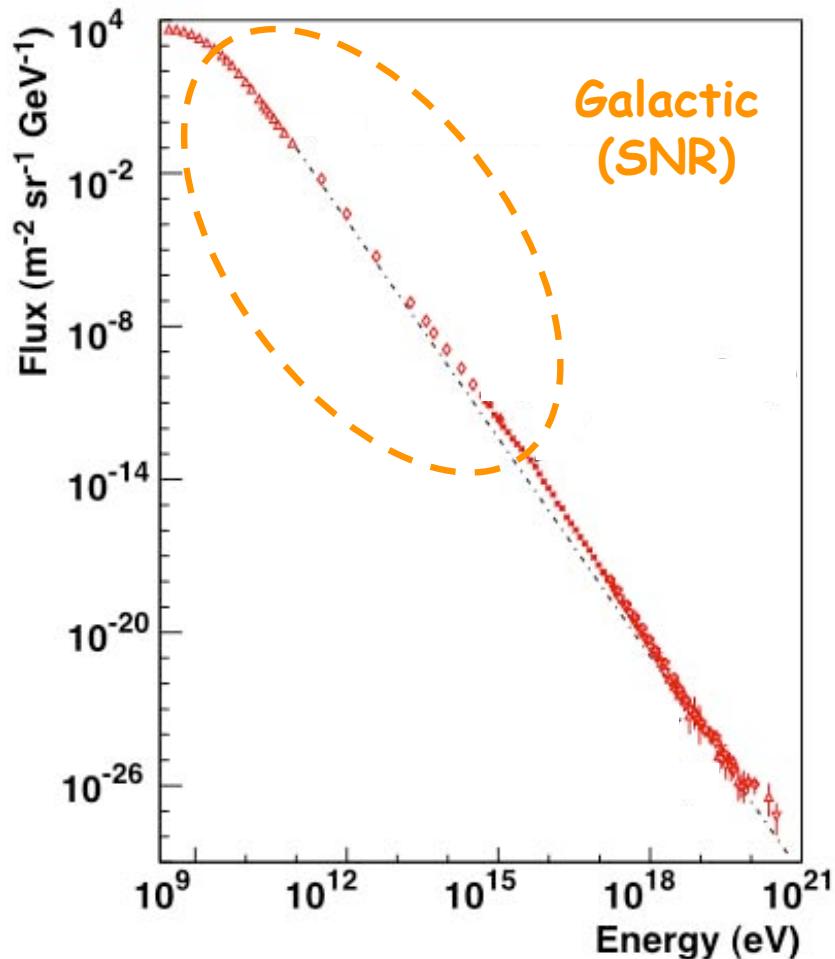
Most extreme phenomena

Cosmic rays

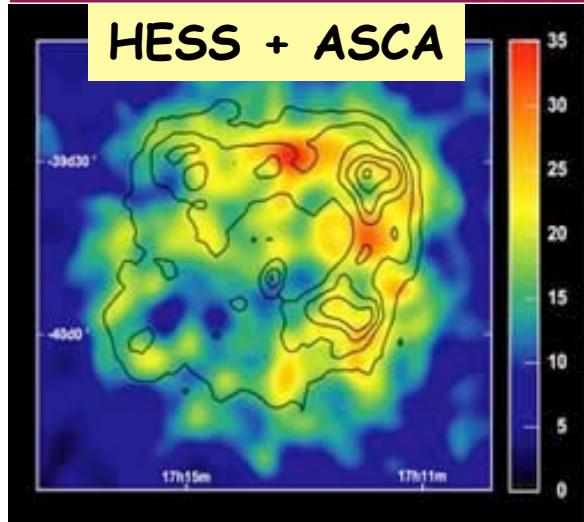
Gamma rays

ν astrophysics

Structure in CR spectrum



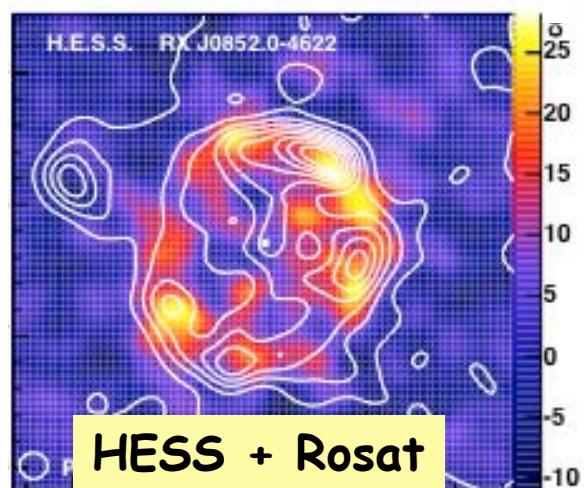
HESS : first confirmation



F. Aharonian et al., 2004 Nature 432, 75



HESS : gamma-ray color map
($E \sim 1$ TeV)

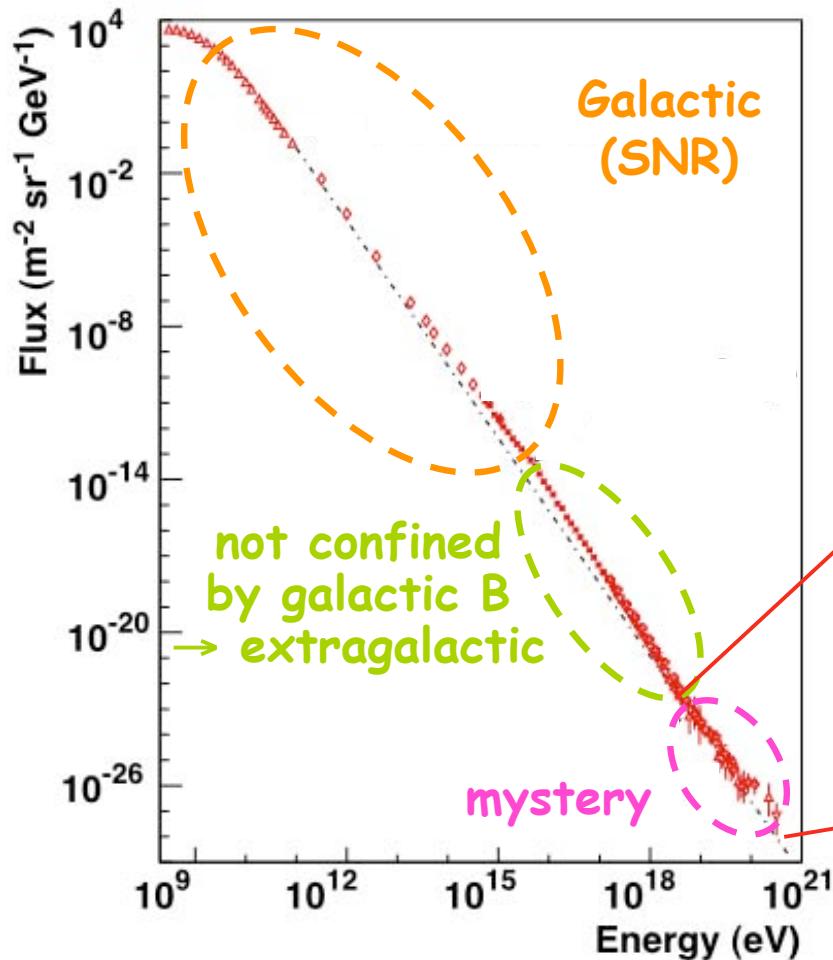


F. Aharonian et al., 2005 A&A 437, L7

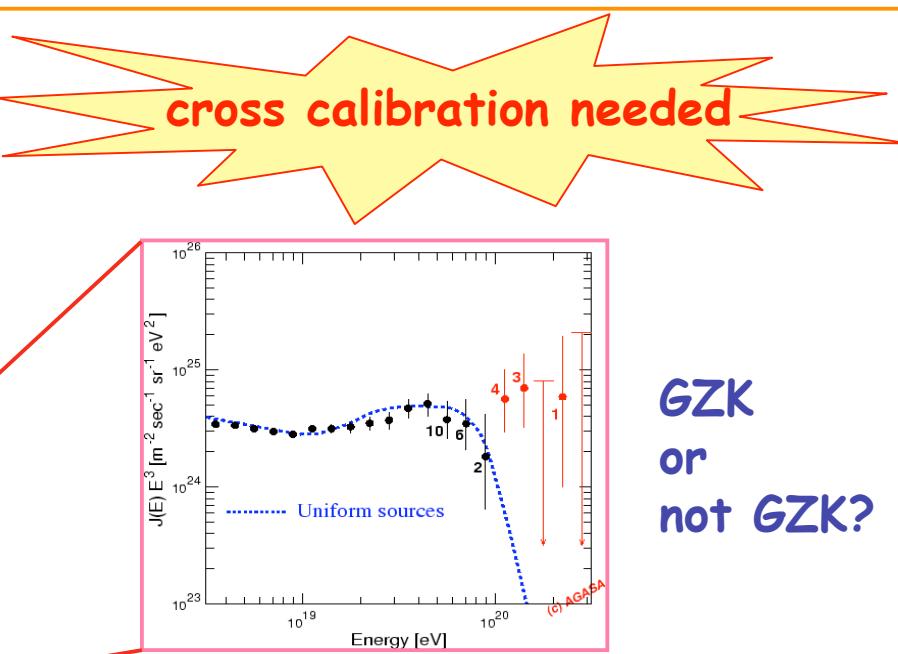
ASCA / ROSAT : X-ray contours
($E \sim 1$ keV)

Excellent overlap →
confirmation of SN remnants
as multi TeV particle accelerators

Structure in CR spectrum



AGASA: 17 events above 6×10^{19} eV
HiRes : 2 events (~ 20 expected)



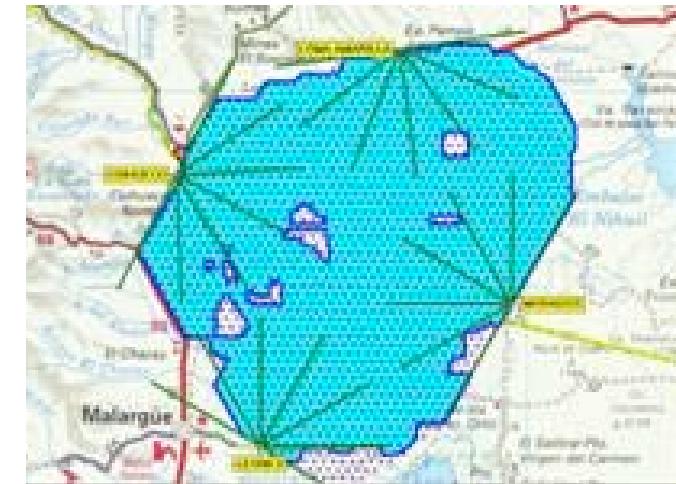
$$E_{\max} = 3.2 \times 10^{20} \text{ eV} = 50 \text{ J}$$

AUGER

Air fluorescence + ground arrays
2 sites (Argentina, USA):
1600 ground detectors
+ 4 air fluorescence telescopes
Over 3000 km²



N. Palanque-Delabrouille



Auger South

- Nearly completed
- $\sim 1.000.000$ events recorded
- $E_{\max} = 1.8 \cdot 10^{20}$ eV

Auger North?

- improved statistics (local supercluster)
- test of isotropy

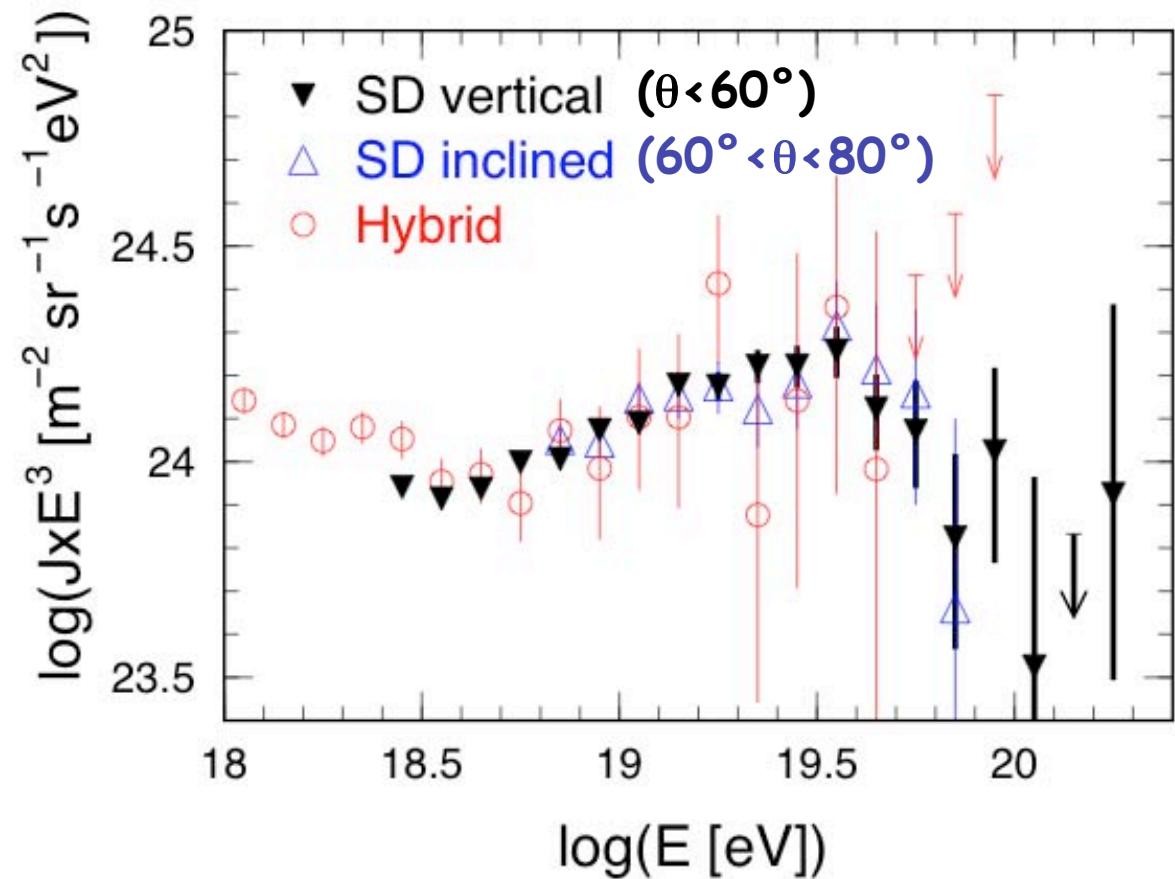
AUGER - spectrum

UHE end of spectrum

3 samples

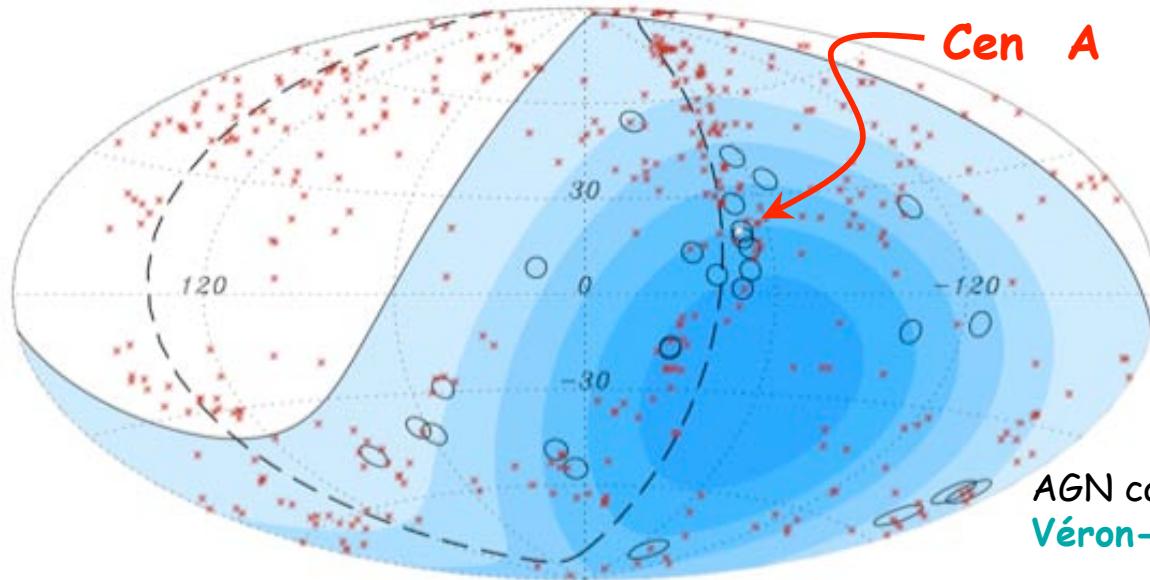
All agree with
presence of
GZK cut-off

(flat spectrum
above $4 \cdot 10^{19}$
excluded at 6σ)



Abraham et al., arXiv:0806.4302v1 [astro-ph]

AUGER - origin of UHECR



Good angular resolution ($< 1^\circ$)
⇒ Study of anisotropies

- Events $E > 57$ EeV
- ✗ AGNs $d < 71$ Mpc

AGN catalog:
Véron-Céty and Véron, A&A 2006, 455 773

	Number $E > 57$ EeV	Number correlated within 3°	Expected if isotropy
Total sample	27	20	5.6
Excluding galactic plane	21	19	5.0

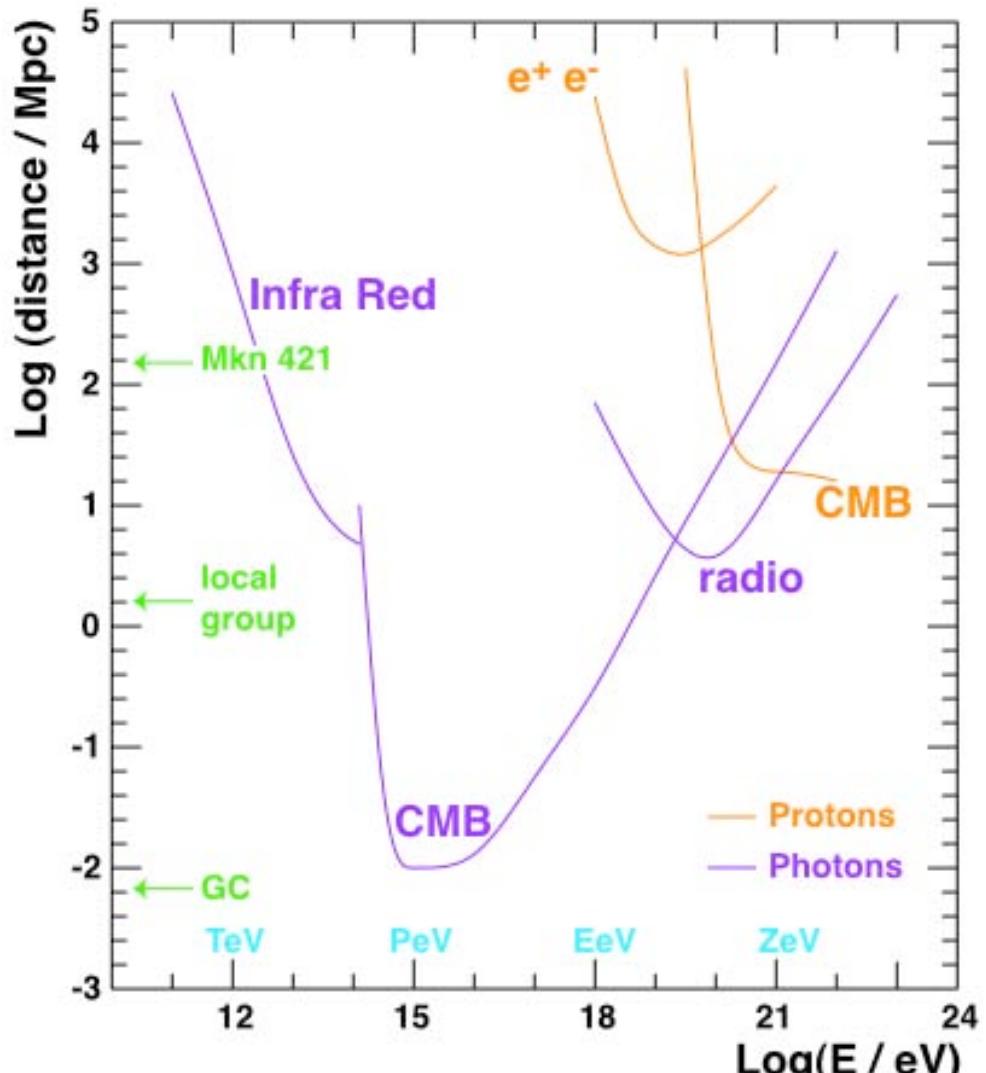
First evidence for a
correlation of UHECR
with astronomical sources

Abraham et al., arXiv:0712.2843v2 [astro-ph]

N. Palanque-Delabrouille

Physics at LHC

Which probe?



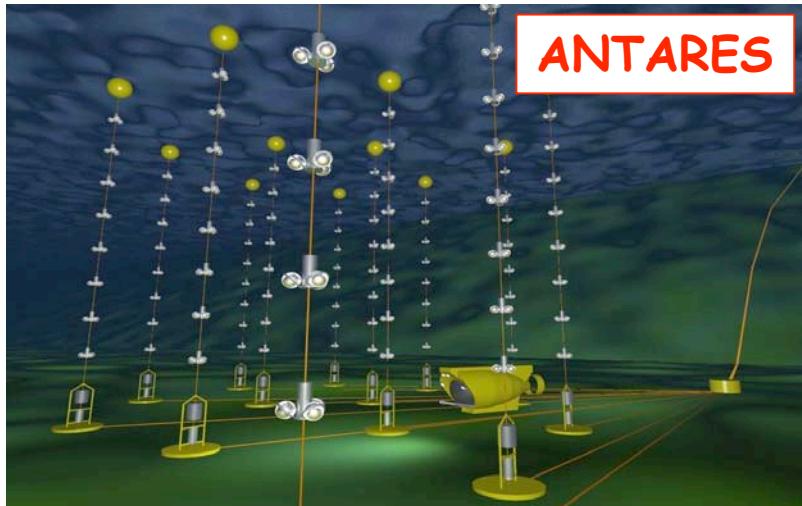
Photons: absorbed (GZK)

Protons: absorbed (GZK)
& deviated ($E < 10^{18} \text{ eV}$)

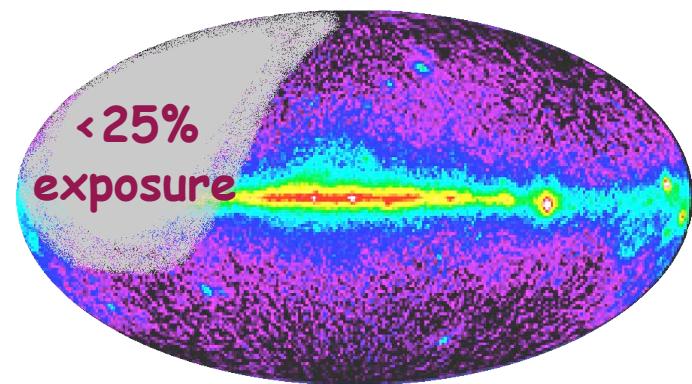
Neutrons: $\tau \sim 15 \text{ mn}$
 $d_{\max} = 10 \text{ kpc}$ ($E = 10^{18} \text{ eV}$)

Neutrinos
no charge,
“no” interaction
with matter
nor radiation

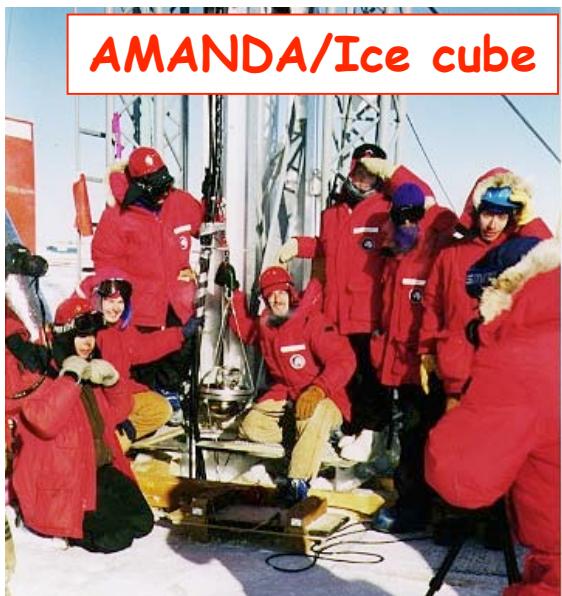
Neutrino telescopes



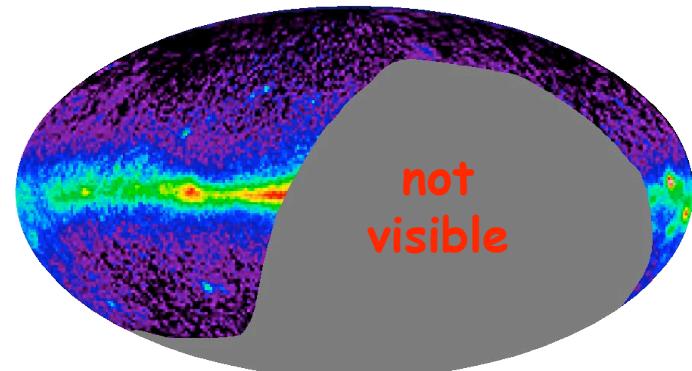
Better
angular
resolution
($\sim 0.2^\circ$)
12 lines



ANTARES/AMANDA
 0.6π sr overlap



Better
sensitivity
(less absorption)
40 lines



Conclusions

Complementarity of probes...

Cosmic rays

Charged (\Rightarrow do not point except at UHE)

GZK cutoff confirmed

First correlation with possible source at UHE

Gamma rays

Confirmation of SN remnants as
TeV particle accelerators

Neutrinos

Northern (ANTARES) and southern (Ice cube) taking data
No astrophysical detections yet... Keep tuned

...and of particle physics, cosmology and astrophysics

Dark matter

Still trying to detect it ...

Dark energy

Cosmological constant still best bet