



The Dark Side of the Universe

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The mysteries of the Universe

- how was born ? Big Bang of course . Nice words, not an explanation !
- why it looks like the same wherever we look at ? Inflation of course. Not much knowledge on it.
- what is made of ? We only know 4% of it.
- how will it end ? If it will end !

because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know.

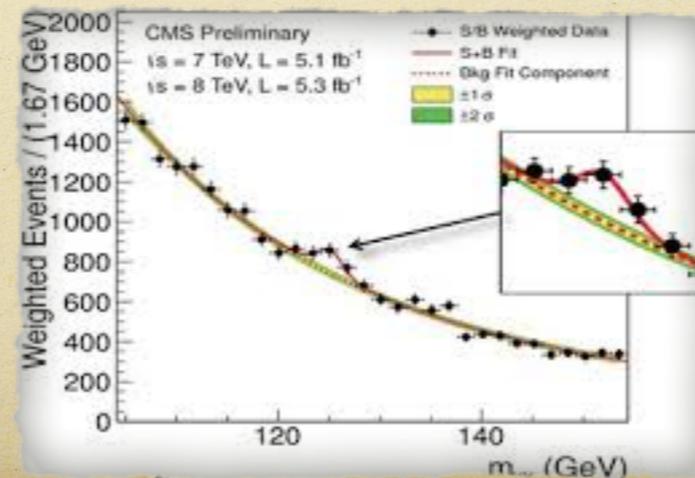
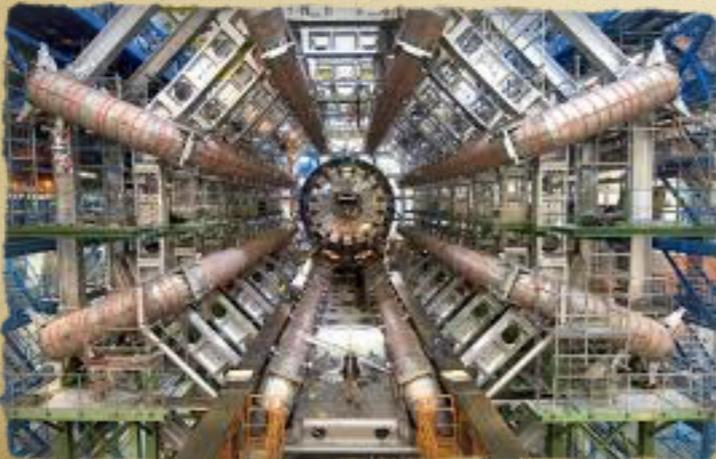
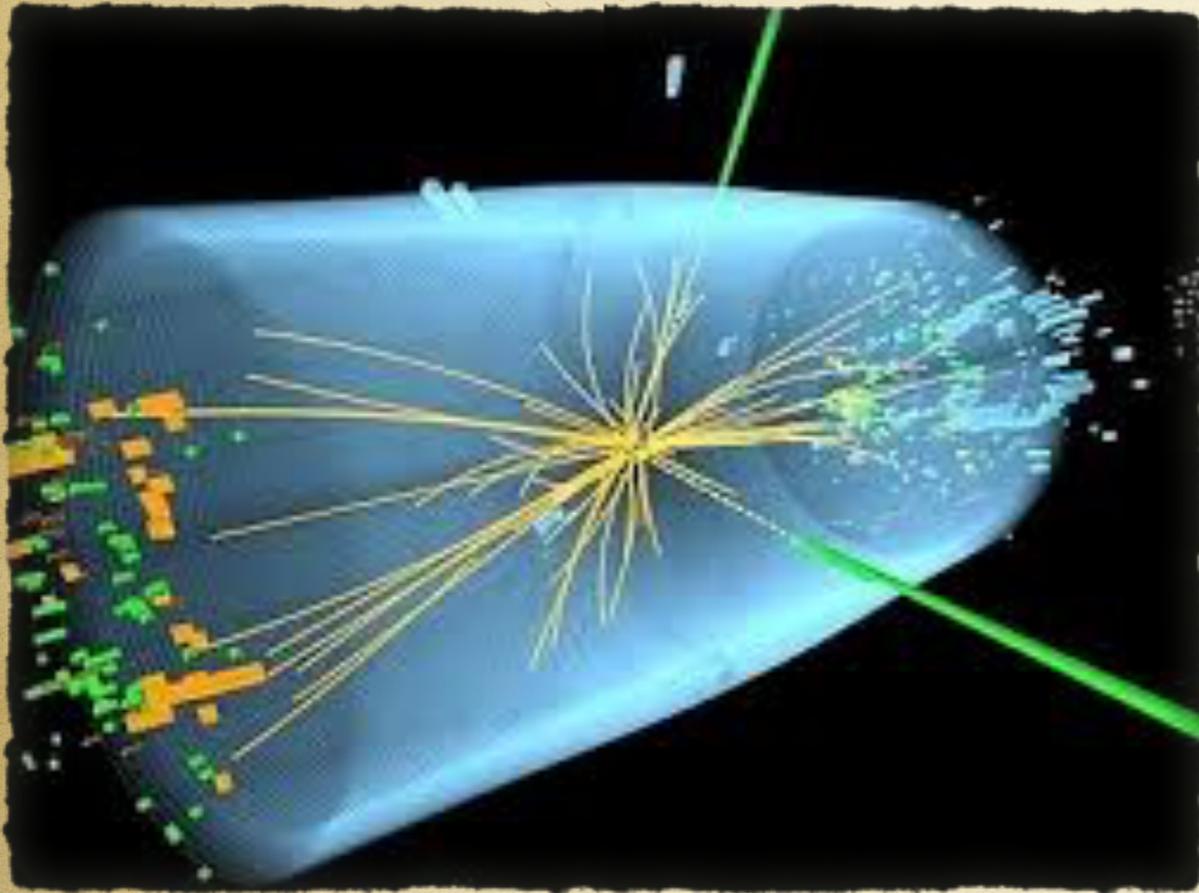
D. Rumsfeld

what we know and what we
know that we don't know

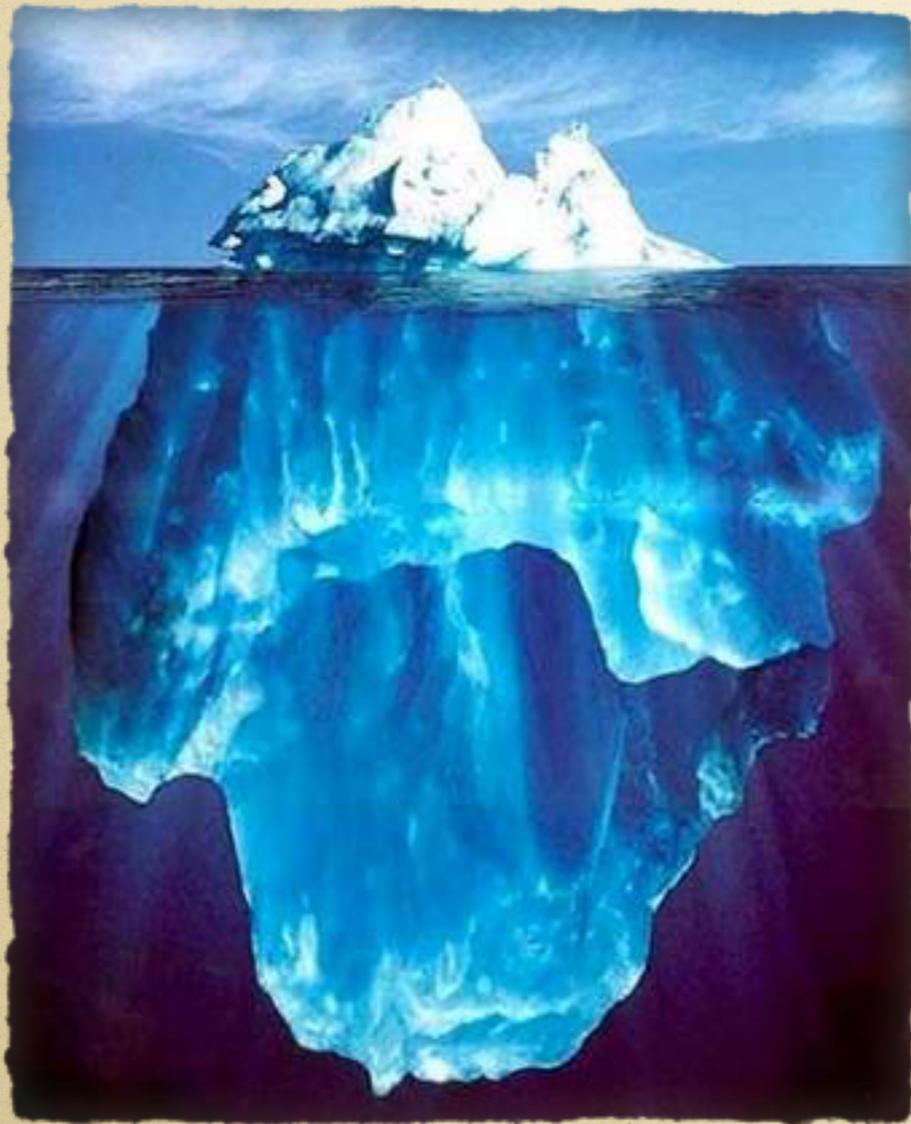
- We know the matter we are done (the Standard Model)
- we know that there is a lot of Dark Matter
- we believe (!?) in the existence of Dark Energy

Completion arrived with

Higgs



The (in)famous 4%



our world

the Dark Universe

The matter we do not see



and were not enough there
is another Dark problem



The Dark Side of the Force

what is it ?

- I do not know, we do not know
- useless to pronounce obscure words about it
- I will only try to show you what evidence we have for it !

starting from a
fundamental question



**EXPAND
FOREVER**



**EXPAND
AND STOP**



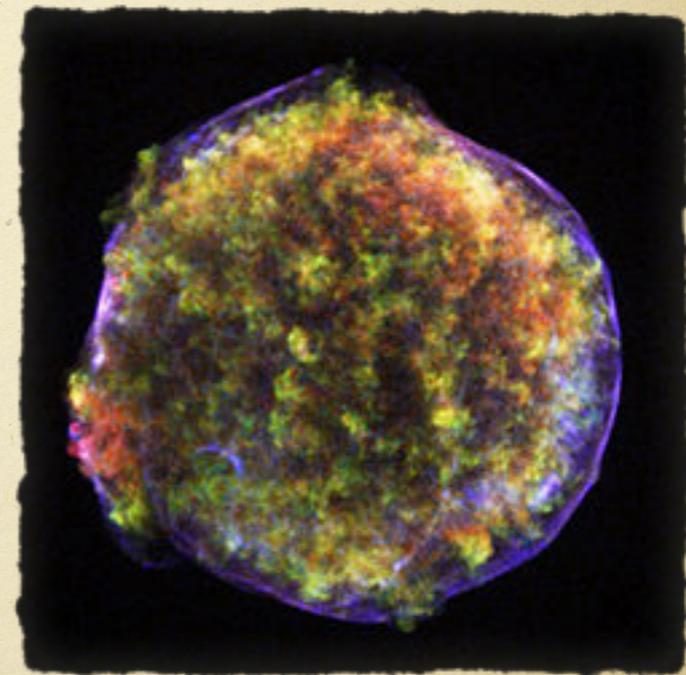
**EXPAND
THEN
COLLAPSE**

how can we know it ?



We need a lamp that makes the same light and we can place at different distances from us : a standard candle

Supernovae (Ia) are standard candles

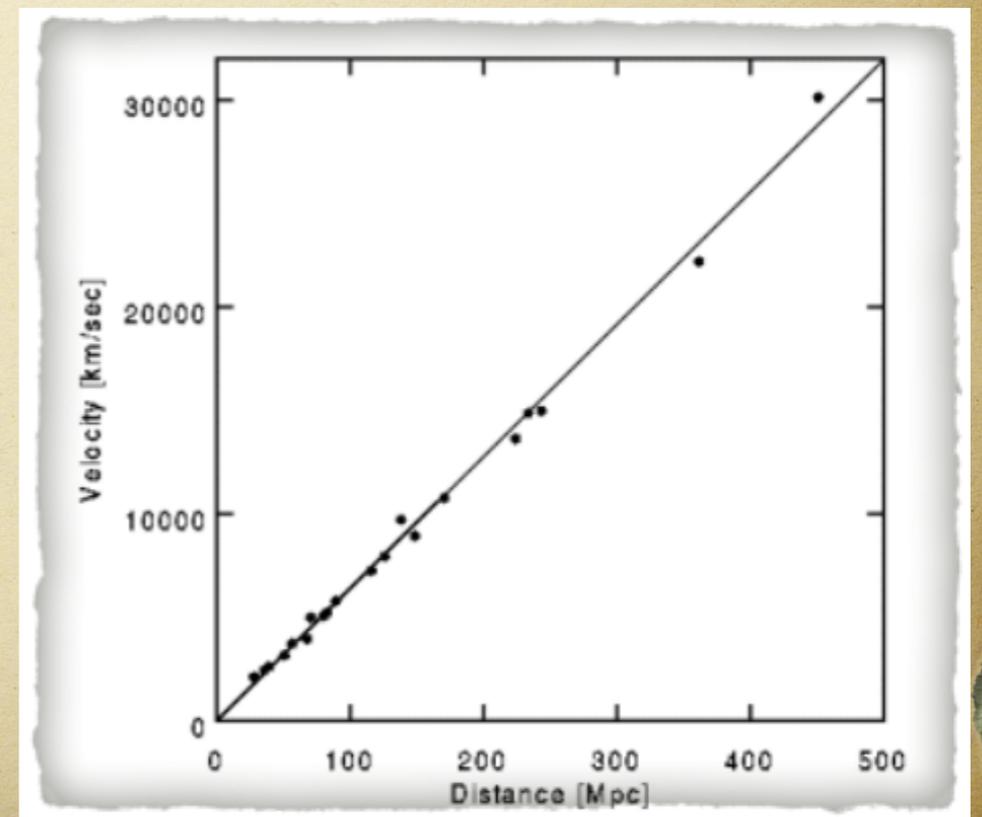


Born by the explosion of a white dwarf

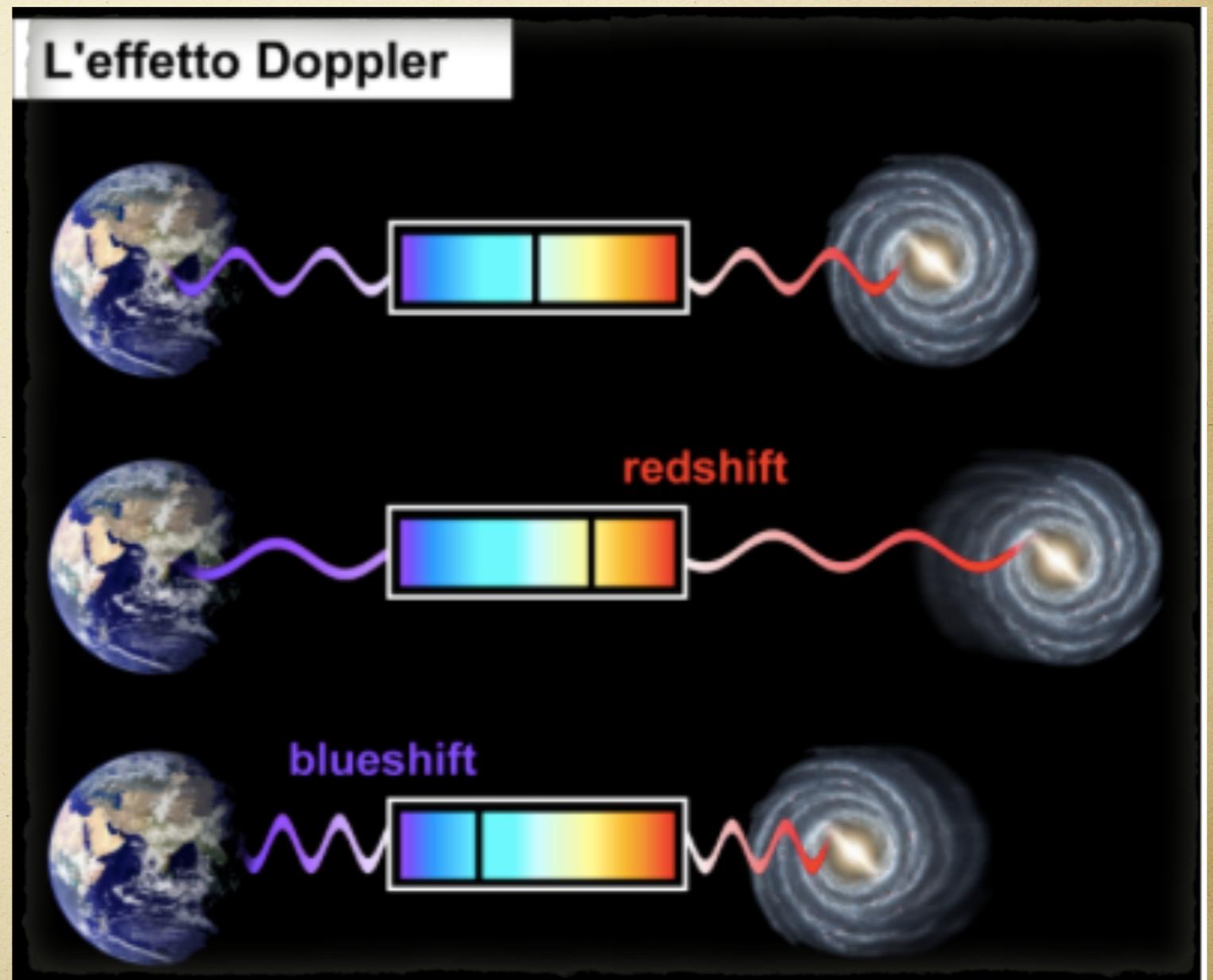
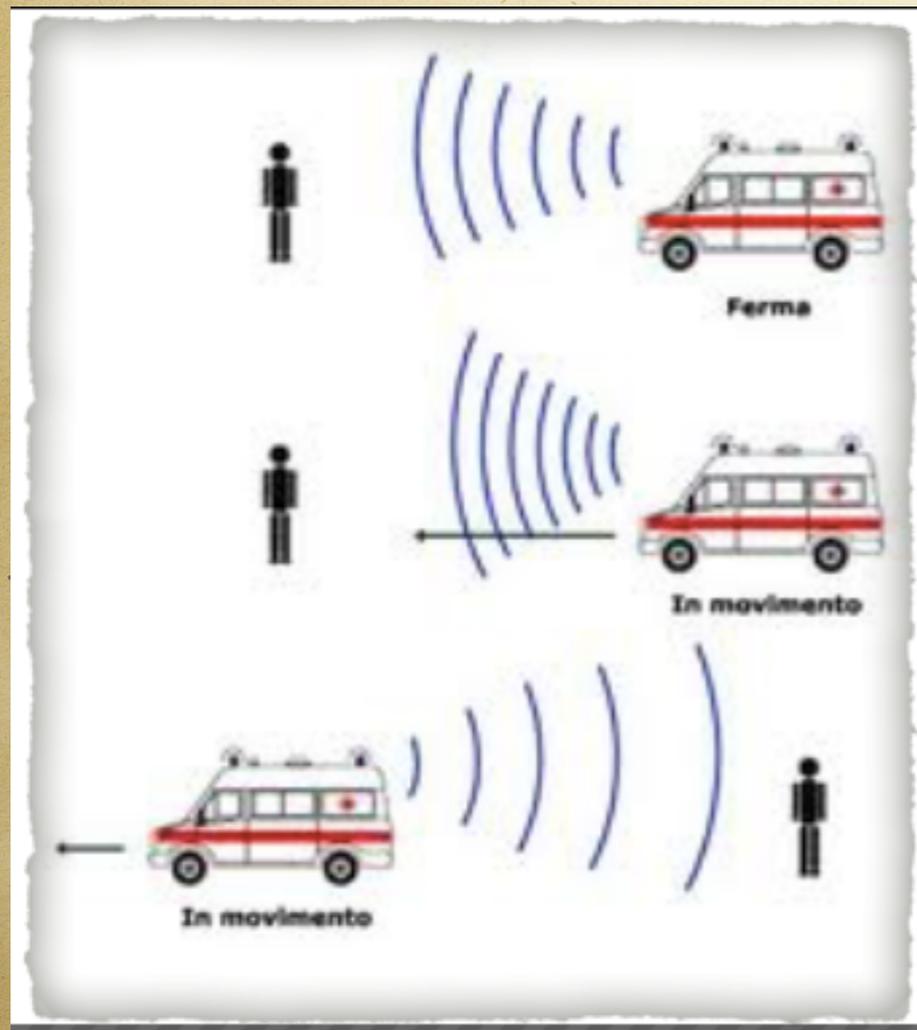
then we can proceed

- we know from the amount of light we receive how far the the source is
- then we use the Hubble law

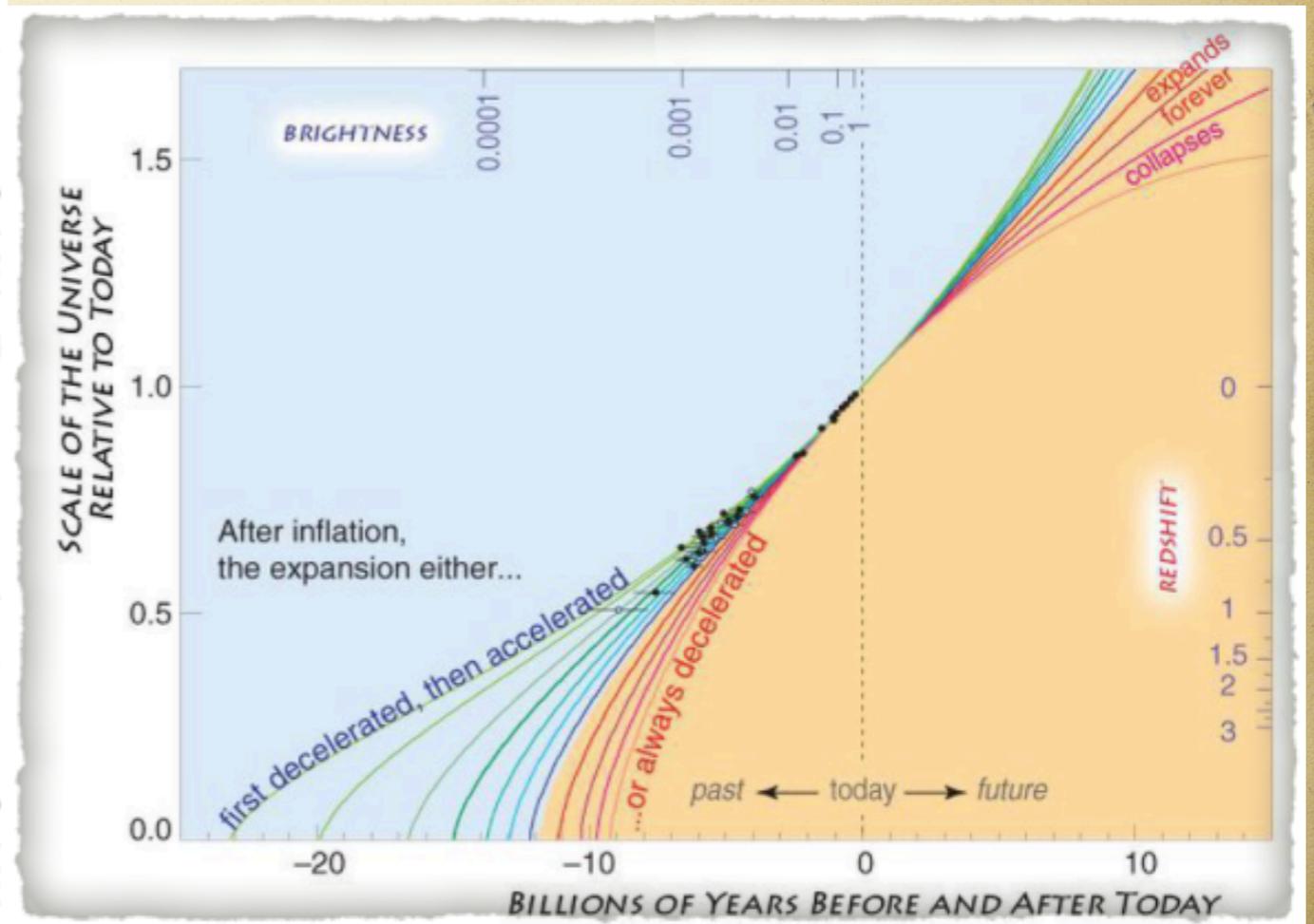
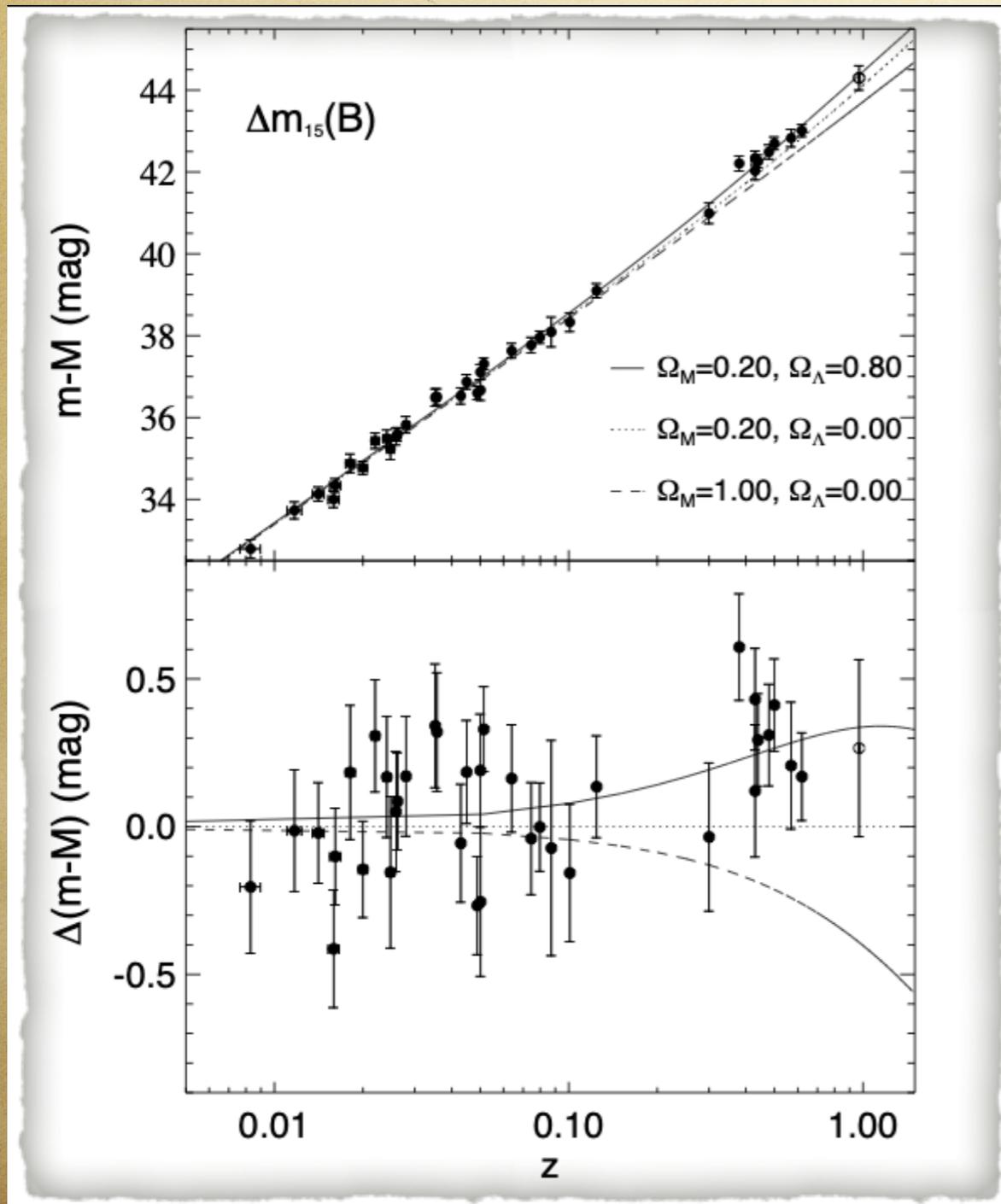
the farther they are
the faster
they recede from us



let me remind you the Doppler effect

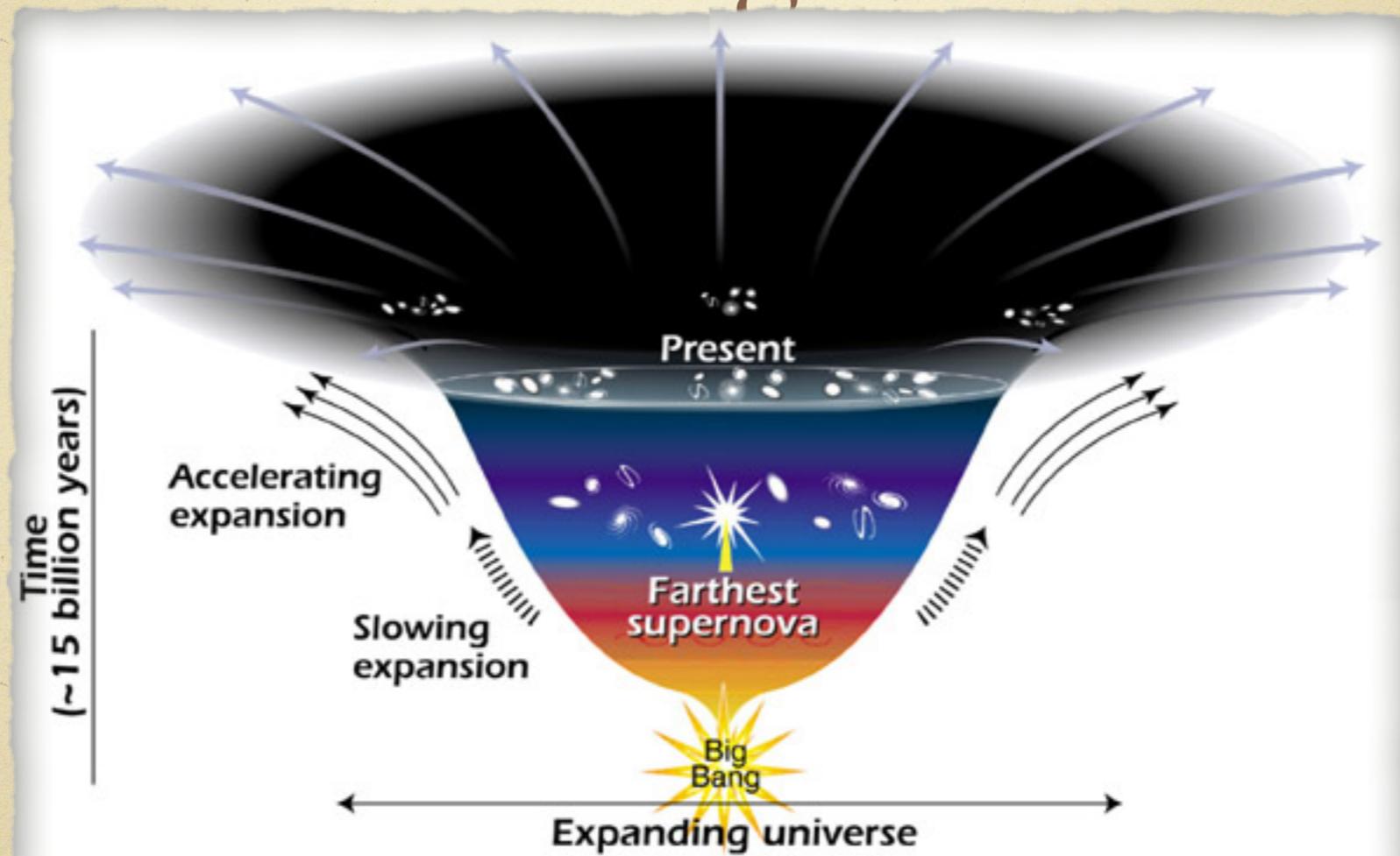


The first evidence (1998)



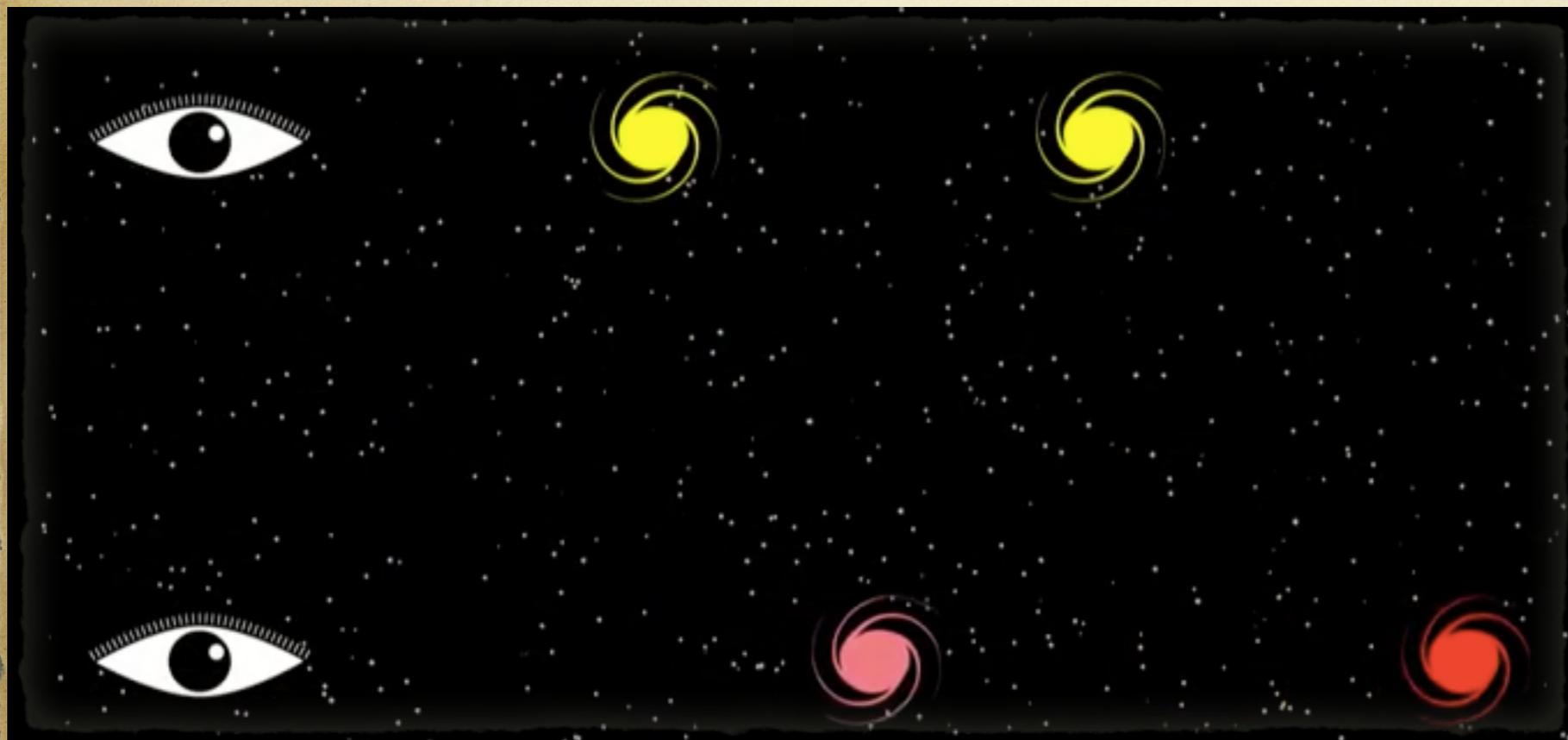
and the prediction

Peculiar...we are in the right place at the right moment



This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

the Hydrogen lines do not lie



and they say that:

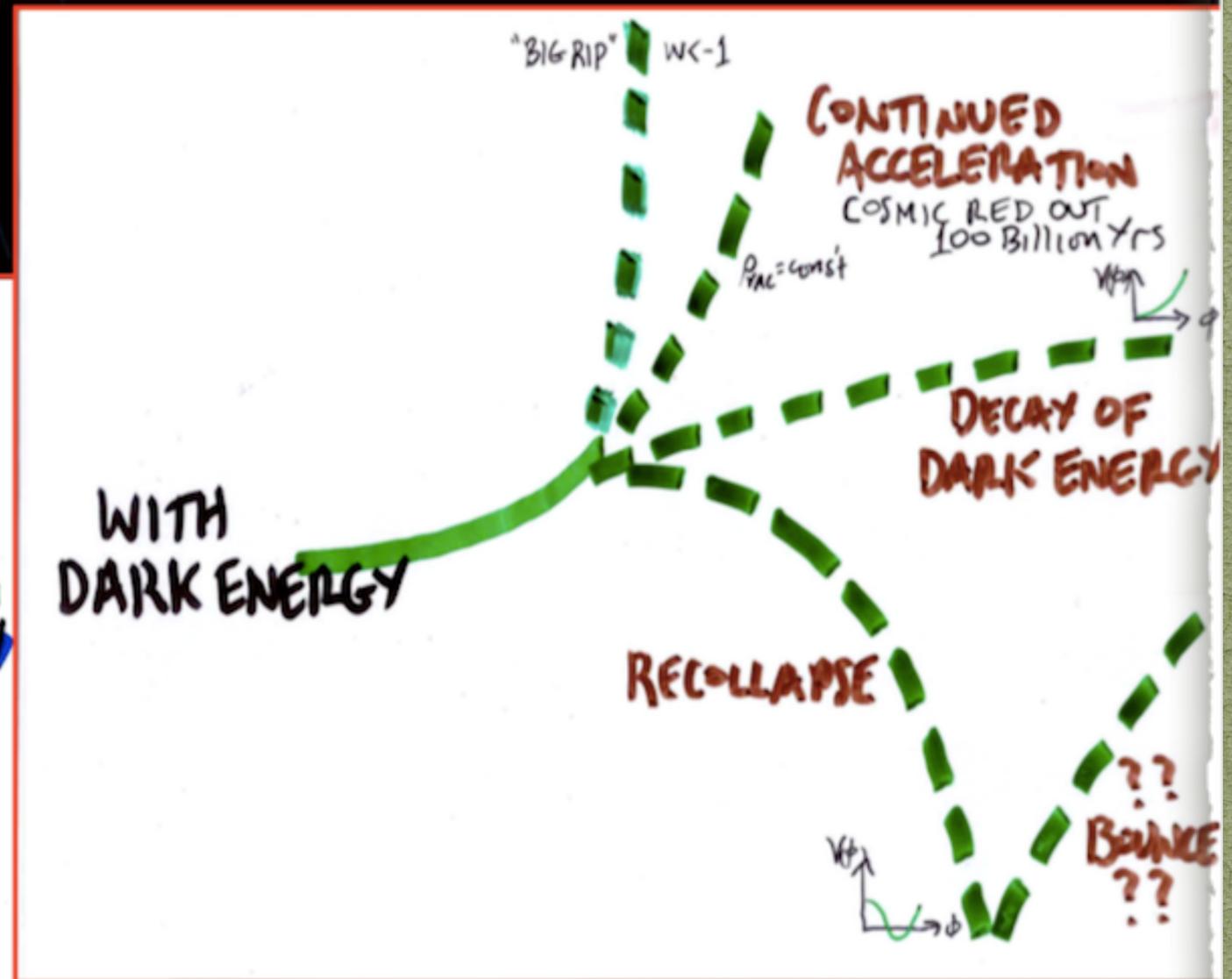
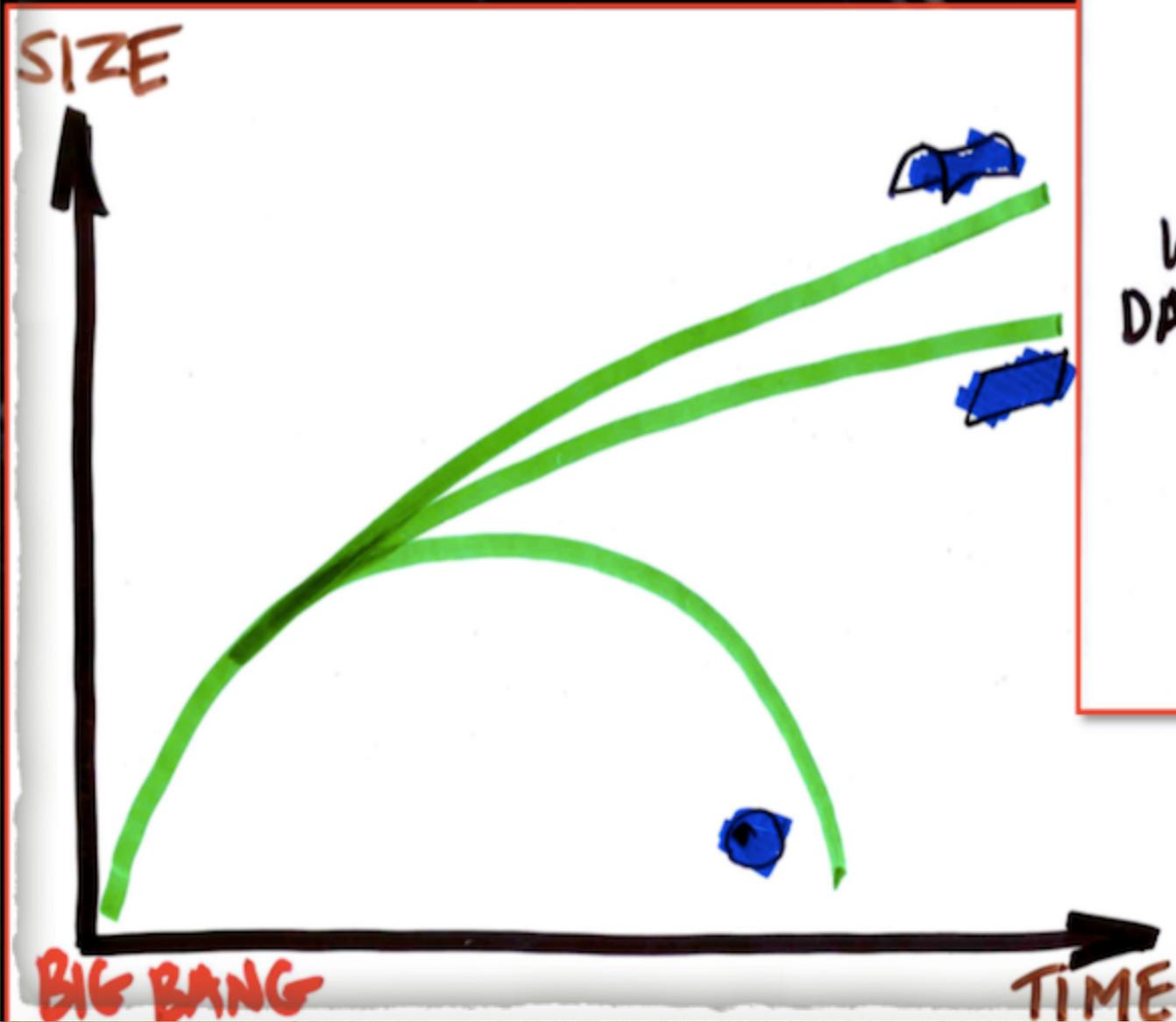
the sources are
farther than the
amount of light
would tell !

hummm ?

- the Universe expands at higher speed than we thought
- worse , its expansion accelerates
- why so ? well...it is a sort of anti-gravityeasy to say but they are just words....words....words...
- we could not find a better words then Dark Energy

it is not irrelevant though

In the Presence of Dark Energy, a Flat Universe Can Expand Forever, Re-collapse, or Even Experience a Big Rip!



Cannot Understand Our Cosmic Destiny Until We Understand What Dark Energy Is!

just to let you think !



DON'T LET THE BRIGHT
LIGHTS FOOL YOU

THE DARK SIDE

CONTROLS THE UNIVERSE

OUR UNIVERSE

STARS: 0.5%

DARK MATTER: 33%

DARK ENERGY: 66%

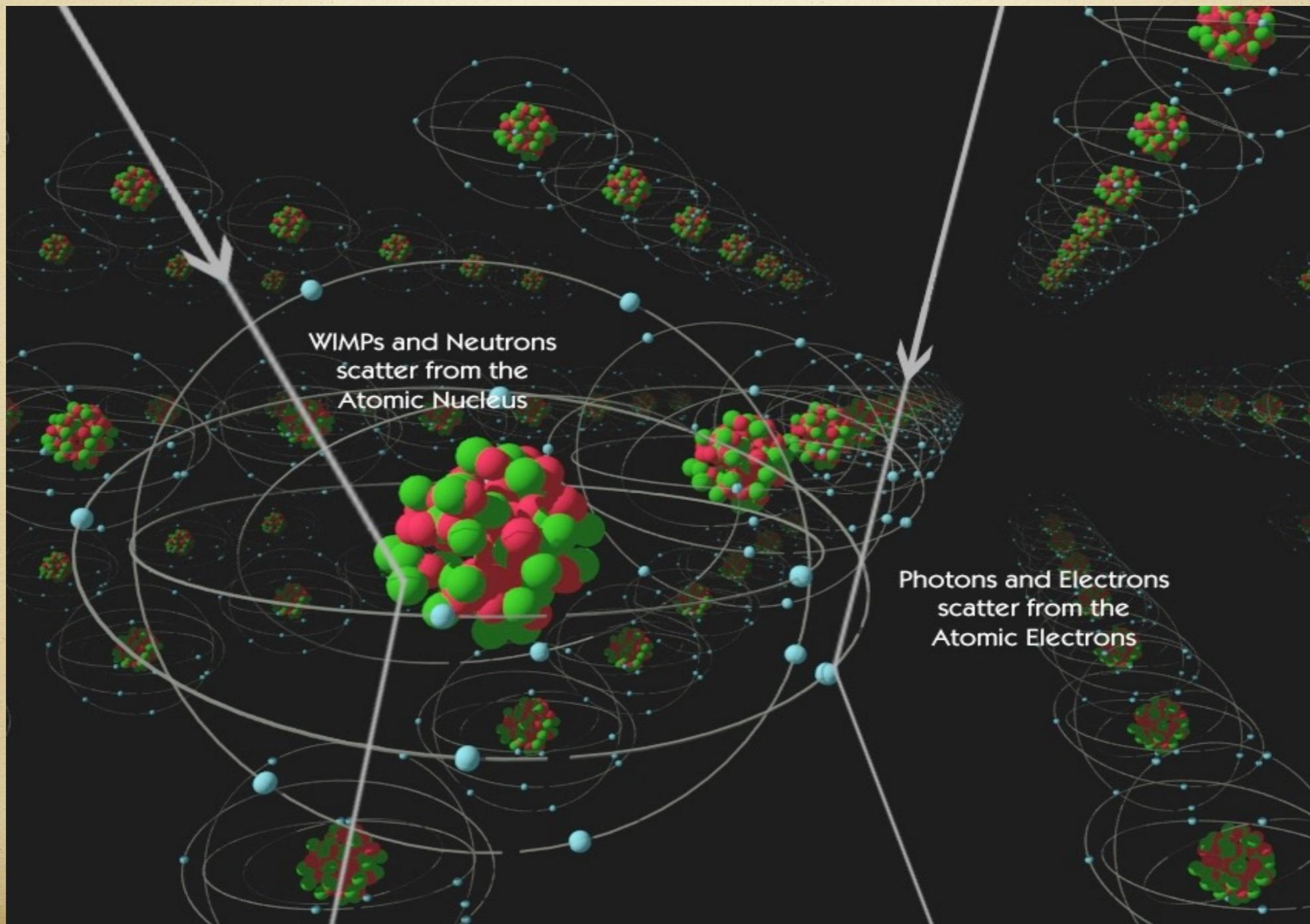
DARK MATTER HOLDS IT TOGETHER

DARK ENERGY DETERMINES HIS DESTINY

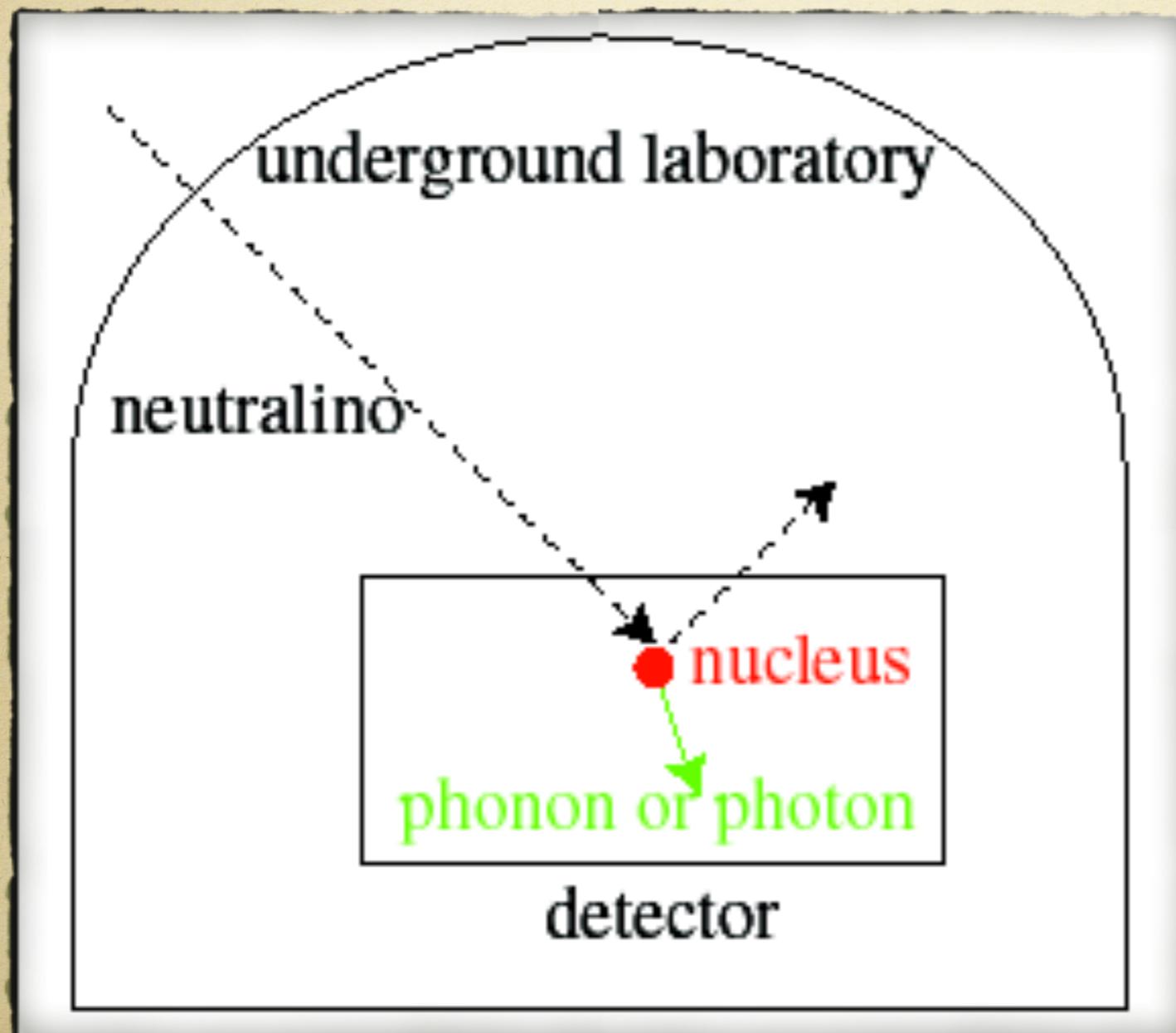
How to (perhaps) find Dark Matter



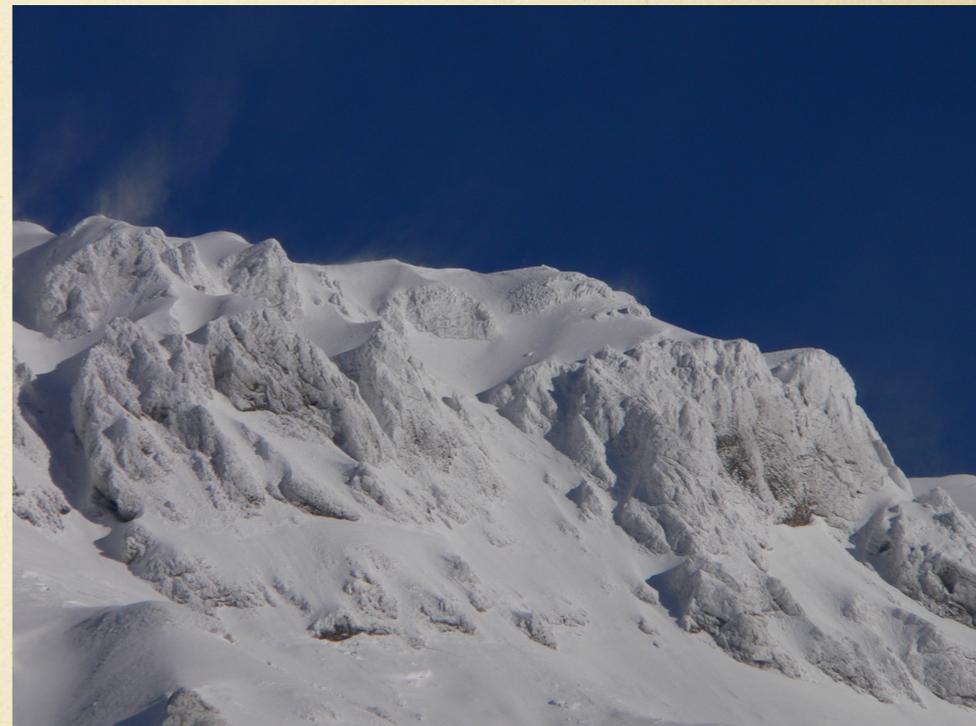
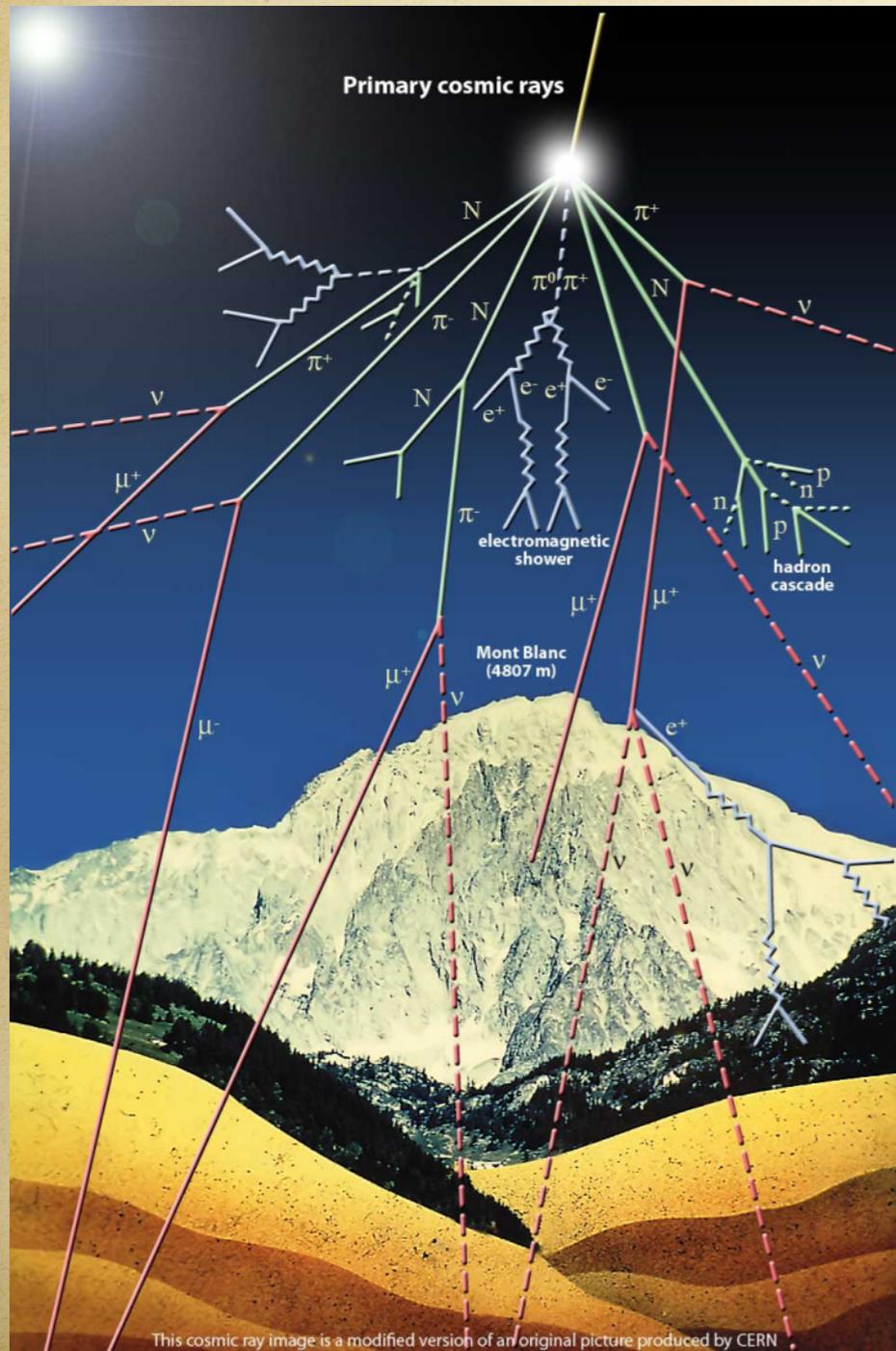
if it is made by particles, they will hit nuclei
(even if seldom!)



one chance is to go far from any
cosmic-ray induced noise
in the 'cosmic silence'



One great place is Laboratori Nazionali del Gran Sasso



3 experimental halls ~100 x 20 m² (h 20 m)

Muon Flux

$3.0 \cdot 10^{-4} \mu \text{m}^{-2} \text{s}^{-1}$

a 100 milion time reduction



Neutron Flux

$2.92 \cdot 10^{-6} \text{ n cm}^{-2} \text{ s}^{-1}$ (0-1 keV)

$0.86 \cdot 10^{-6} \text{ n cm}^{-2} \text{ s}^{-1}$ (> 1 keV)



Depth: 1400 m

Surface: 17800 m²

Volume: 180000 m³

Ventilation: 1 Lab vol/3 h

Electric power: 1300 kW

Access: horizontal

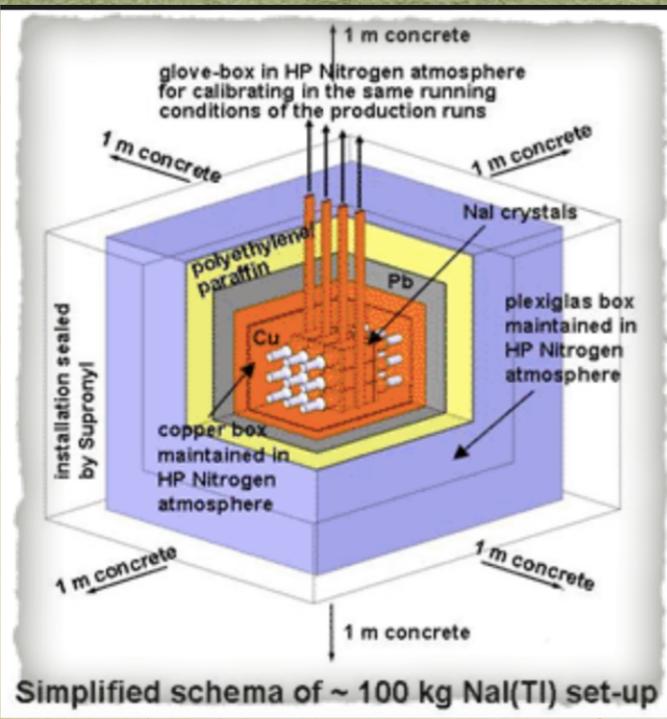
what are we really looking at and under
which hypothesis

- Dark Matter has to be a halo permeating the entire galaxy
- it has to be made of elementary particles although of unknown nature that interacts weakly (very weakly ! otherwise we would have seen them) so that we name them WIMP's (weakly interacting massive particles)

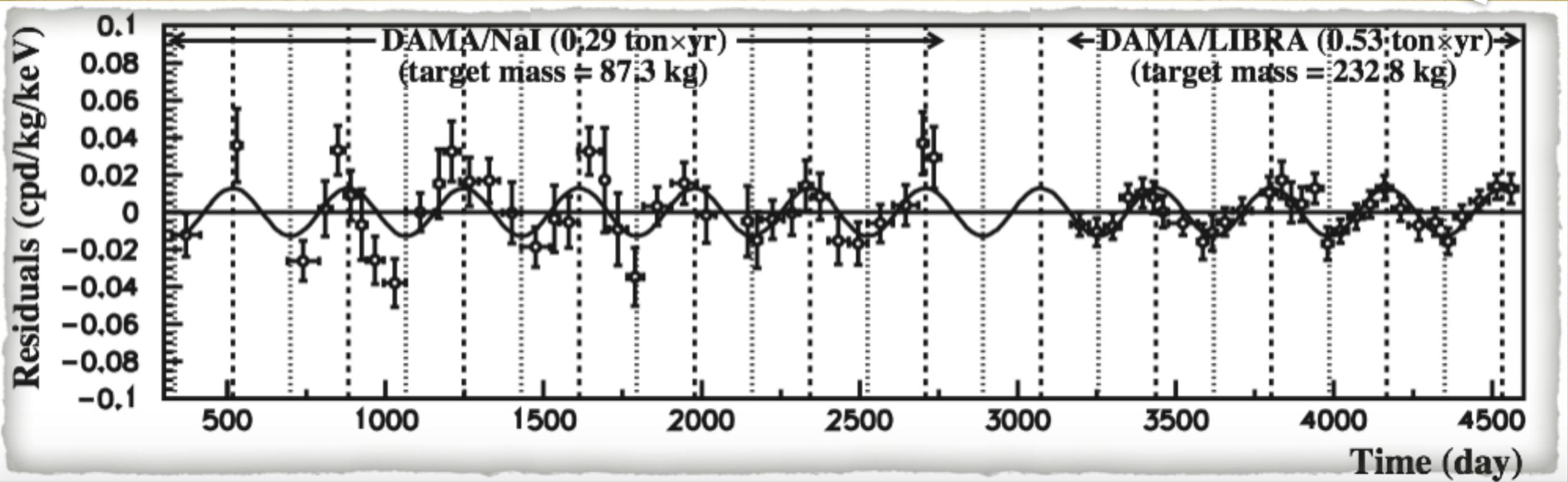
it could go like this



well....



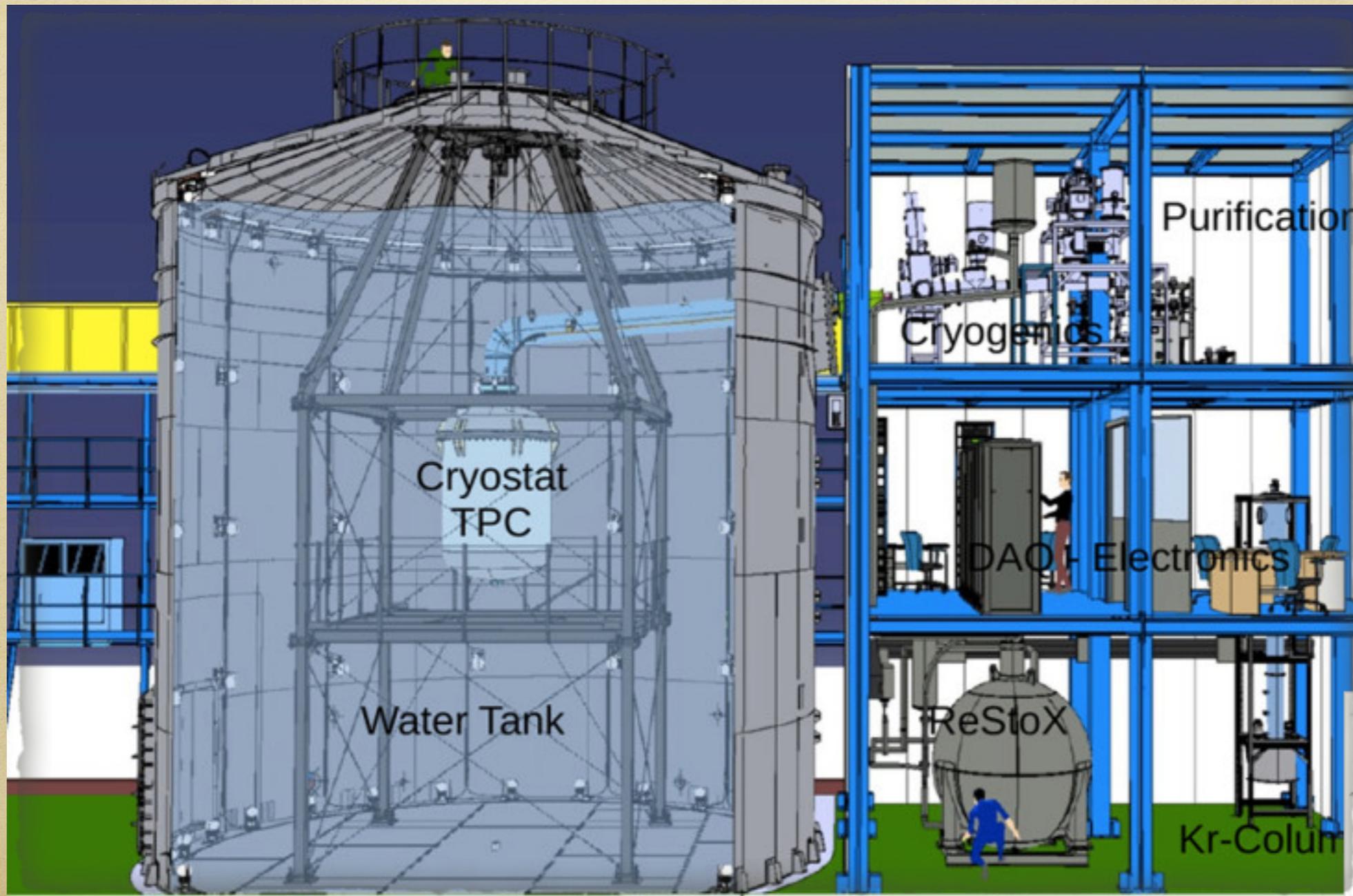
the DAMA/LIBRA results at LNGS looks very much like what we expect.....



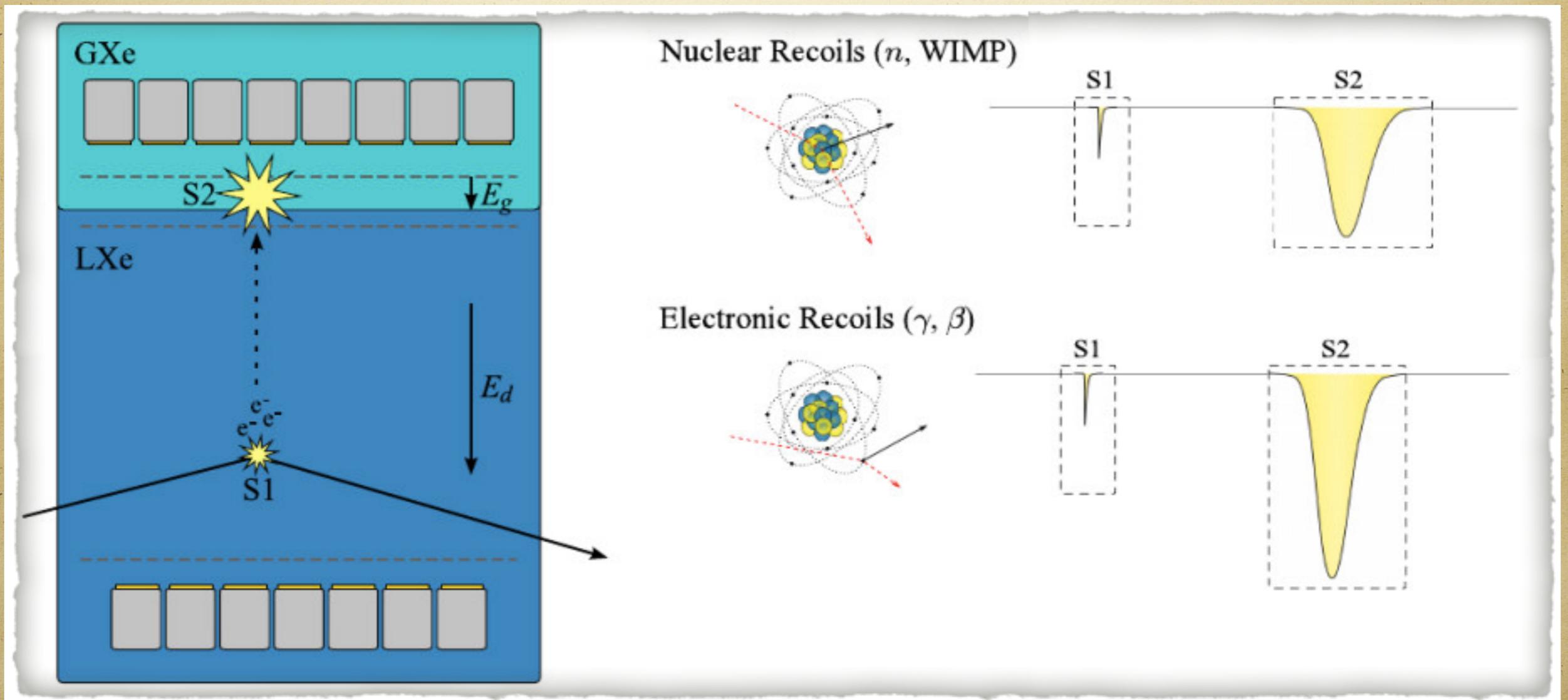
then? game over?

- unfortunately not (or not yet)
- first of all we need a confirmation from an independent experiment
- and then looking only at a time variation does not allow to draw a conclusion on the origin of it (DM particles do not show their ID)
- so ..what next ?
- Let's see !

at LNGS the best results
are from XENON

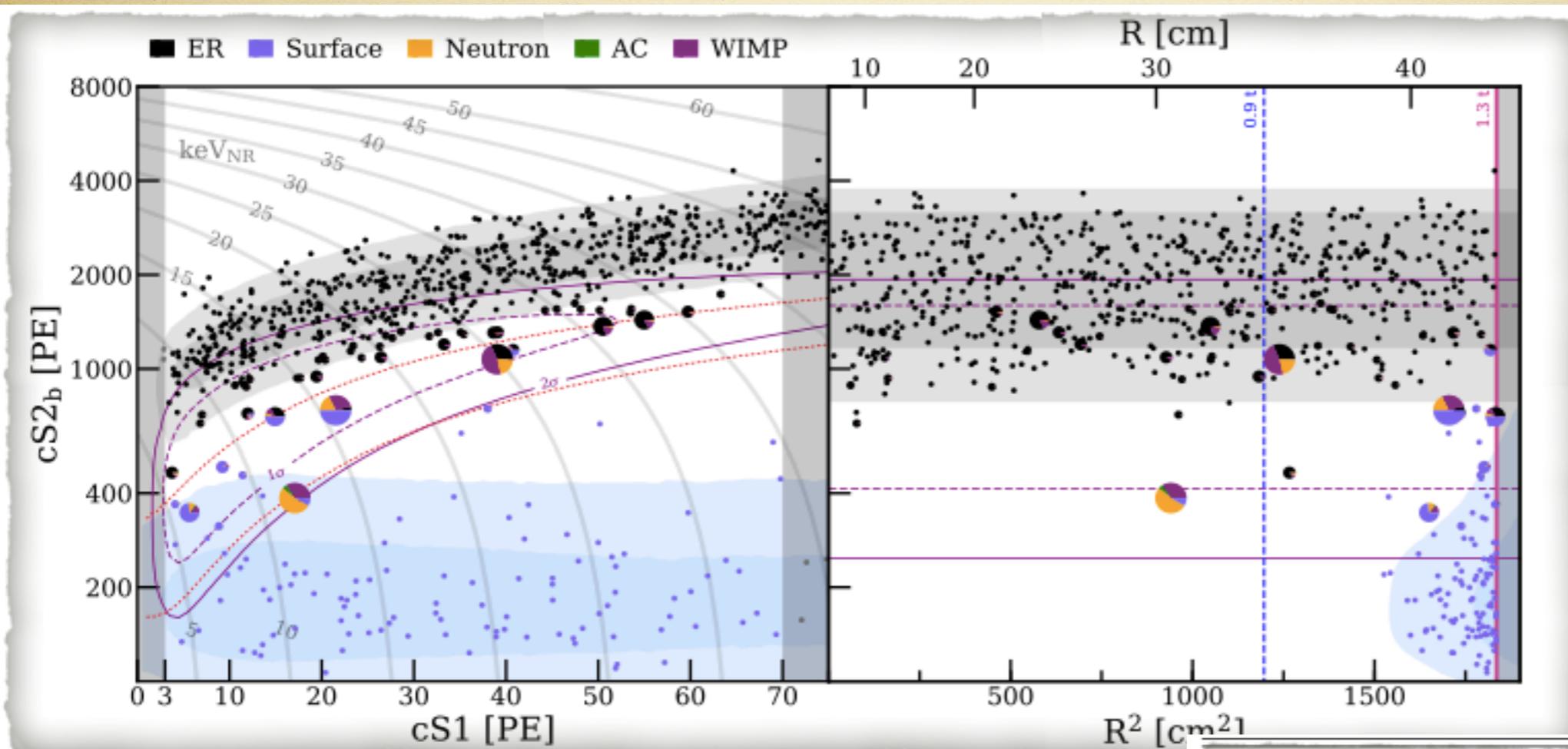


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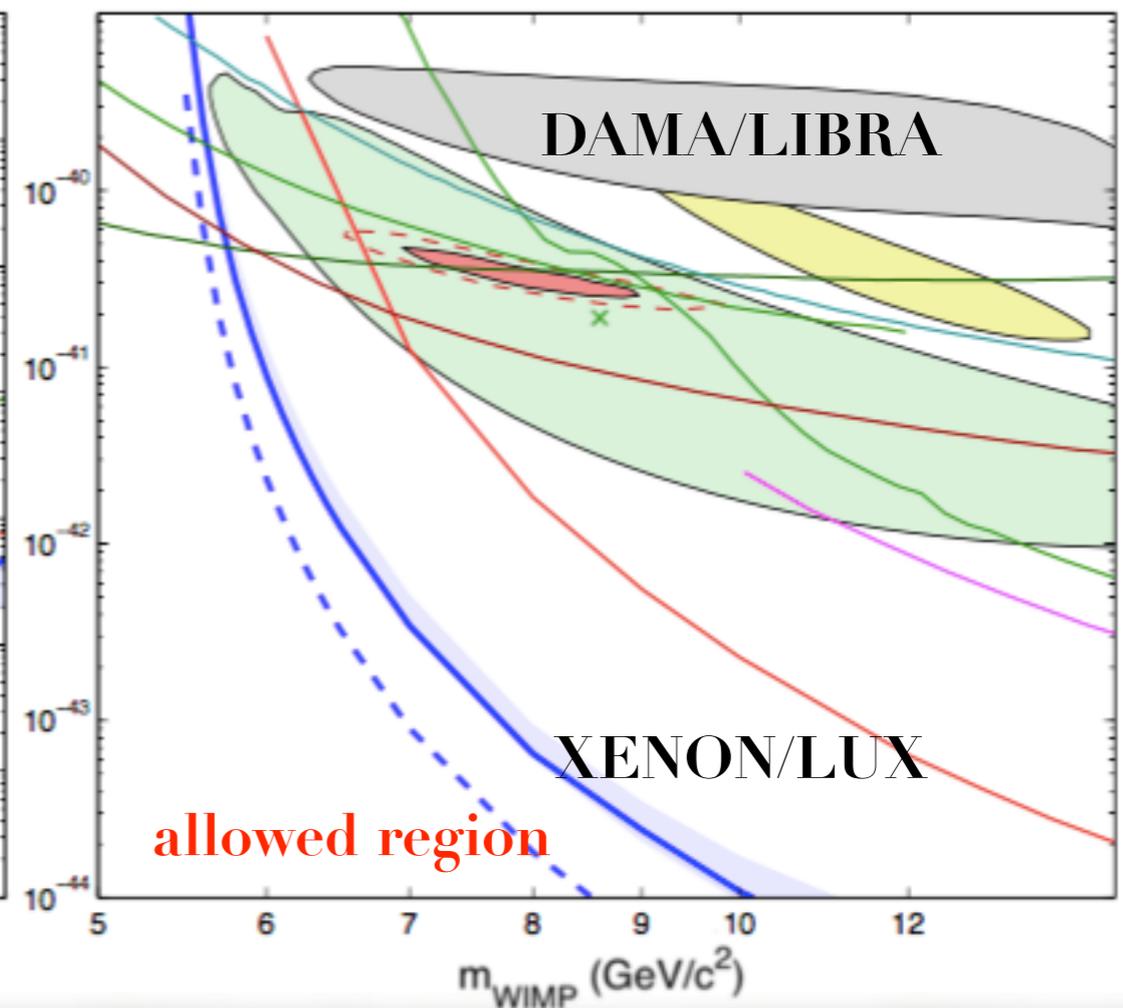
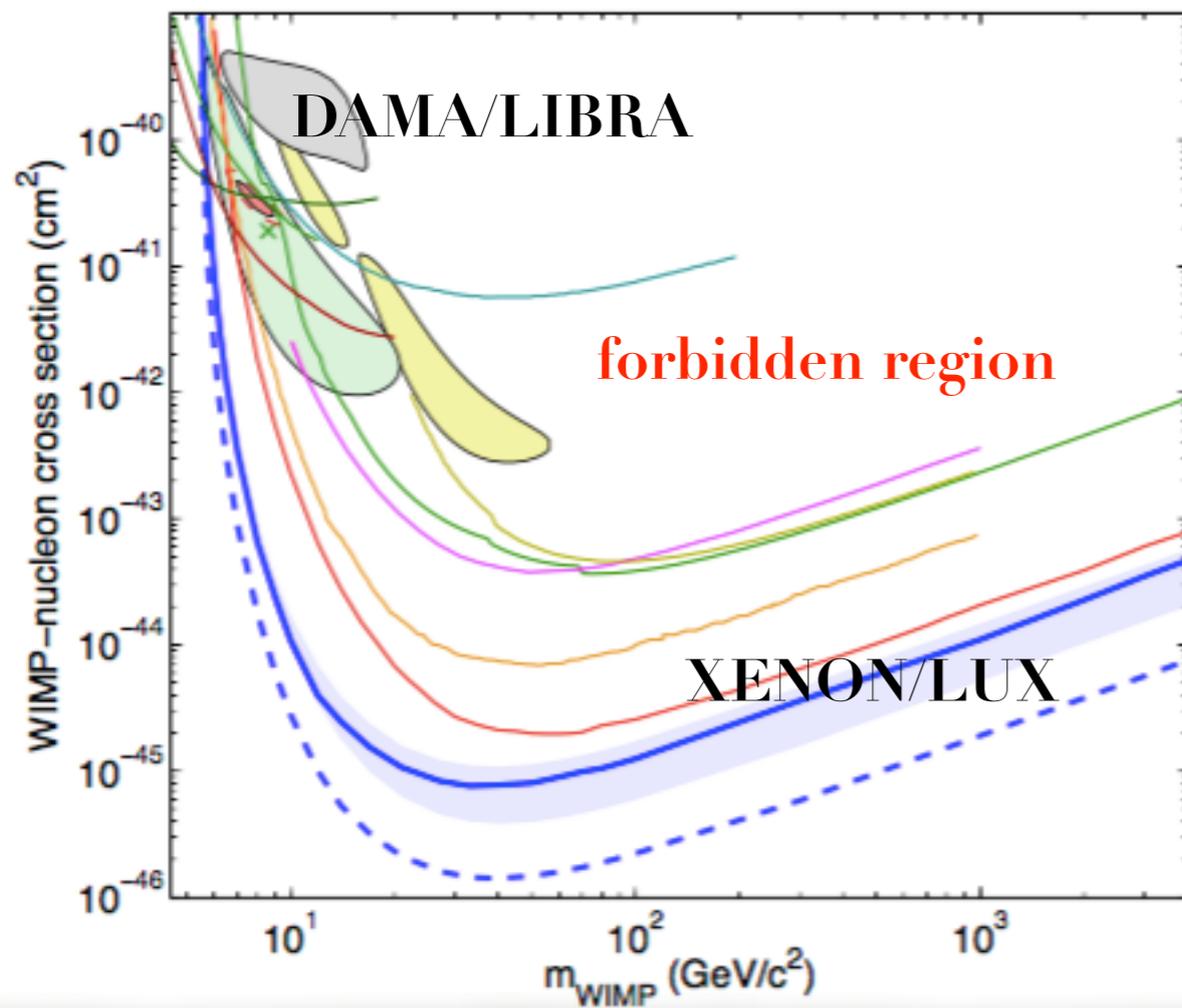
permettono di distinguere il tipo di urto

XENON-1Ton a LNGS



Mass	1.3 t	1.3 t	0.9 t	0.65 t
(cS1, cS2 _b)	Full	Reference	Reference	Reference
ER	627±18	1.62±0.30	1.12±0.21	0.60±0.13
neutron	1.43±0.66	0.77±0.35	0.41±0.19	0.14±0.07
CEνNS	0.05±0.01	0.03±0.01	0.02	0.01
AC	0.47 ^{+0.27} _{-0.00}	0.10 ^{+0.06} _{-0.00}	0.06 ^{+0.03} _{-0.00}	0.04 ^{+0.02} _{-0.00}
Surface	106±8	4.84±0.40	0.02	0.01
Total BG	735±20	7.36±0.61	1.62±0.28	0.80±0.14
WIMP _{best-fit}	3.56	1.70	1.16	0.83
Data	739	14	2	2

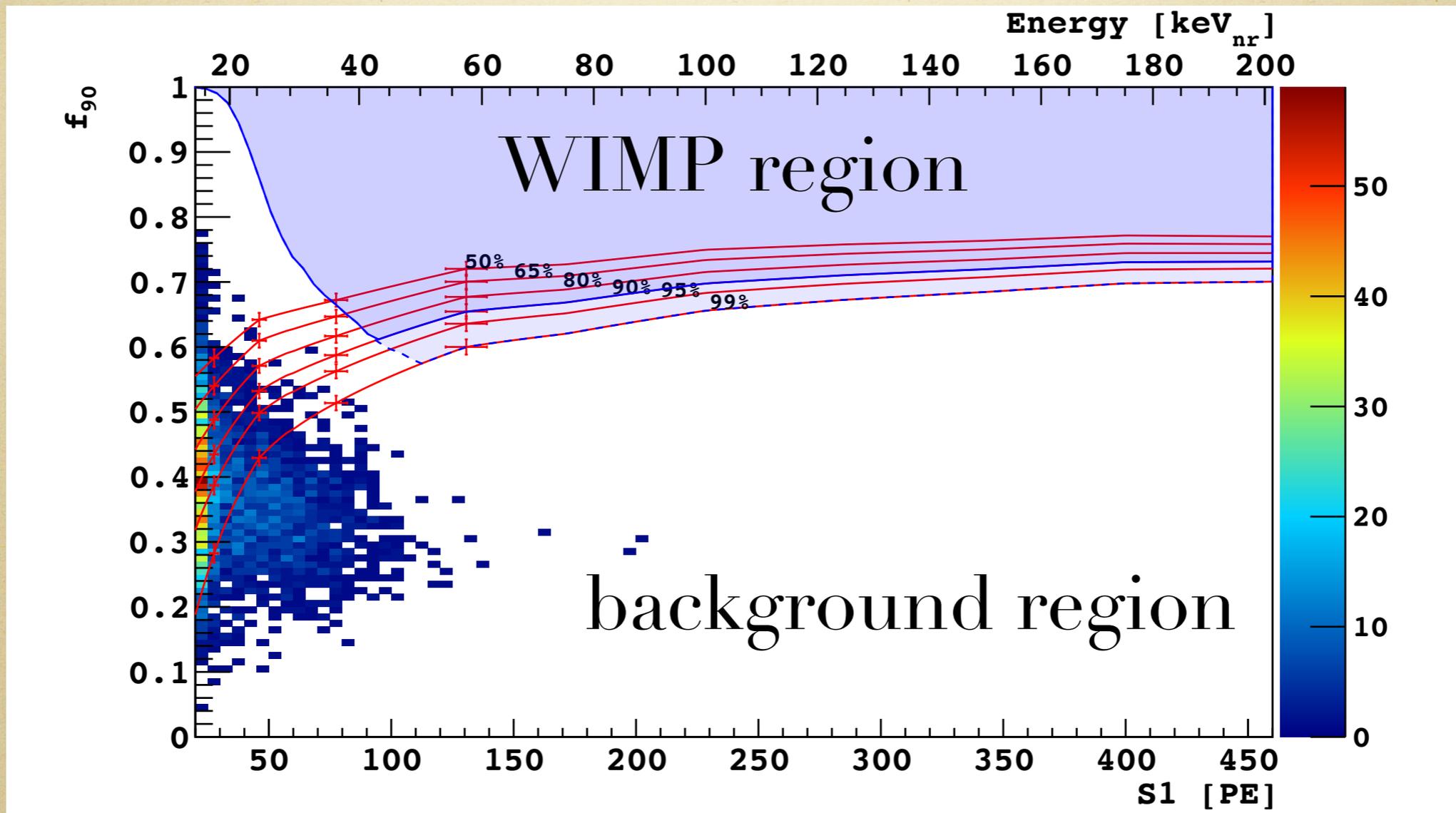
overall where are we ?
(in confusion !)



the limits of noble liquid detectors

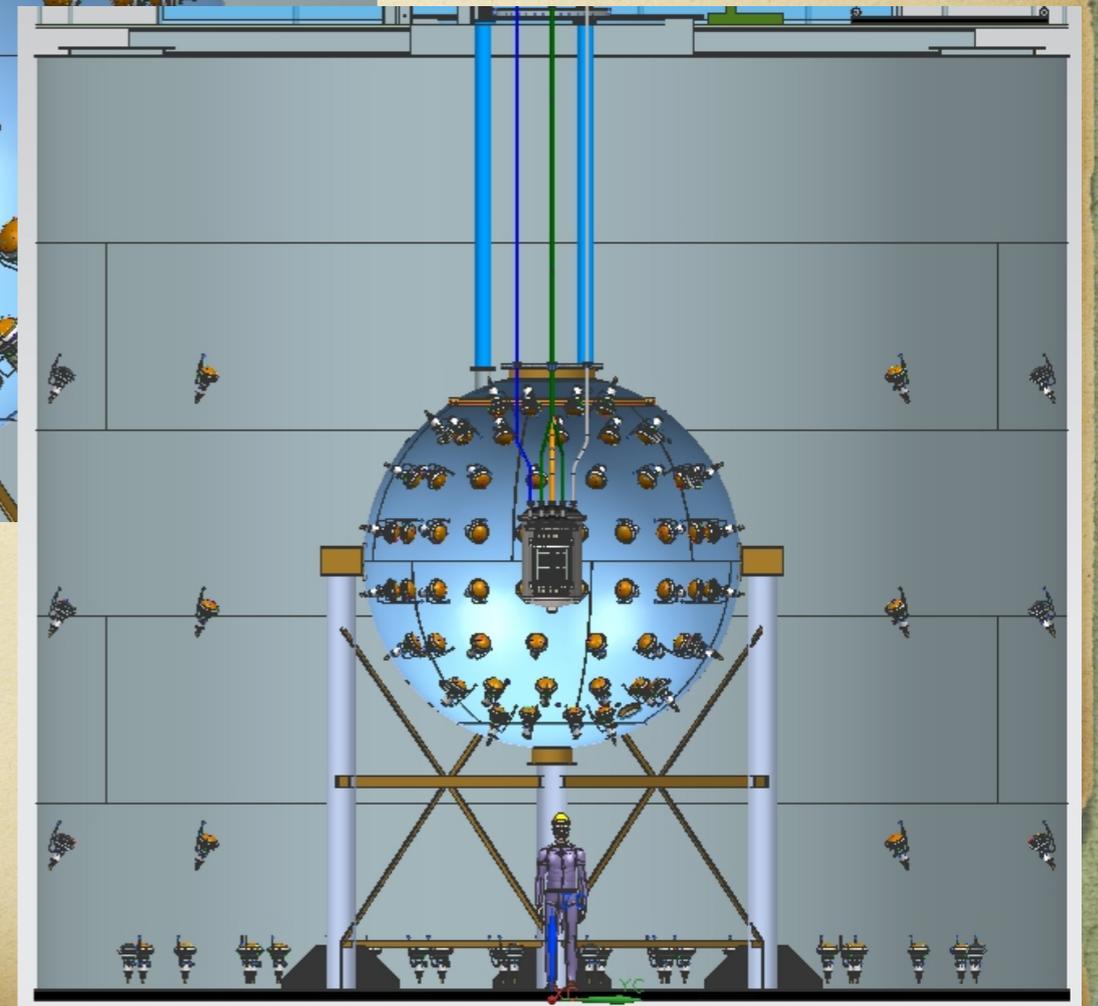
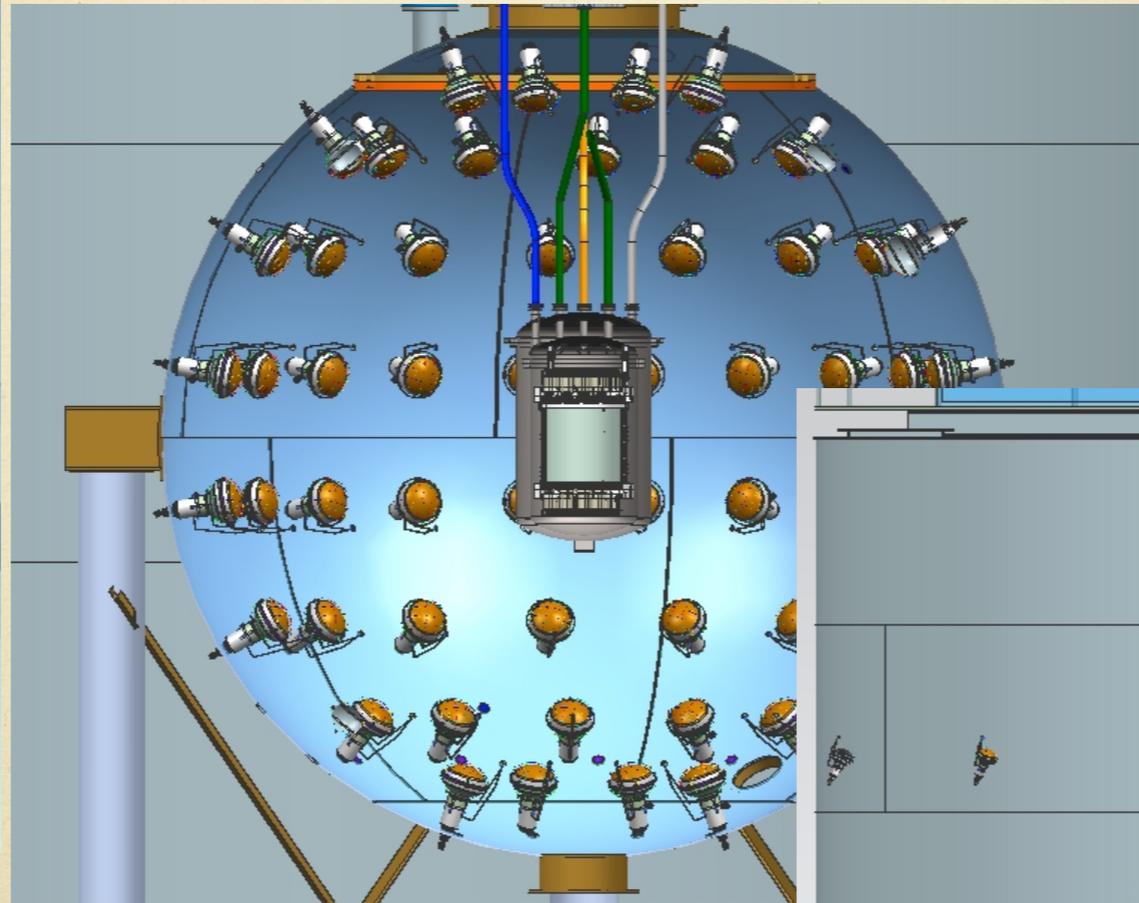
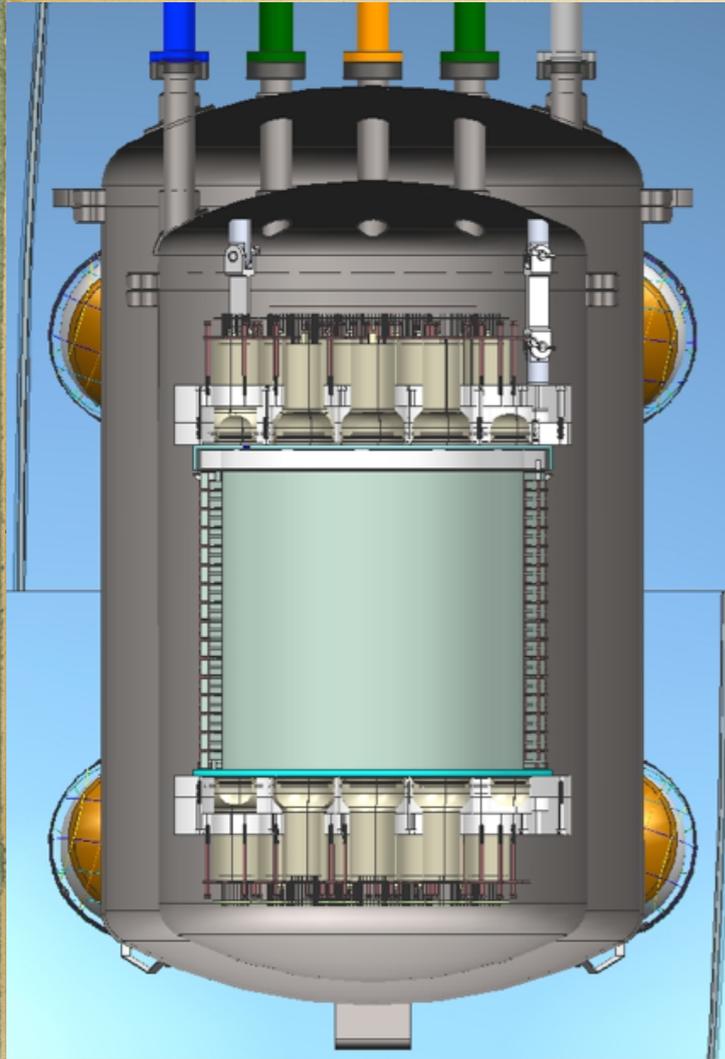
- this kind of detectors so far have had insufficient mass for being able to observe the summer-winter modulation
- they have a sensibly higher threshold than DAMA/LIBRA, so that much less events are expected to make things more difficult
- they count event in a region where electromagnetic induce events are excluded (signals coming from electrons)
- however in the 'electromagnetic free region' still you might have a neutron collision that mimics a WIMP
- this fact reduces even more the region where to search

the Holy Graal Zero Background



A new project at LNGS: Dark Side

Dark Side@LNGS



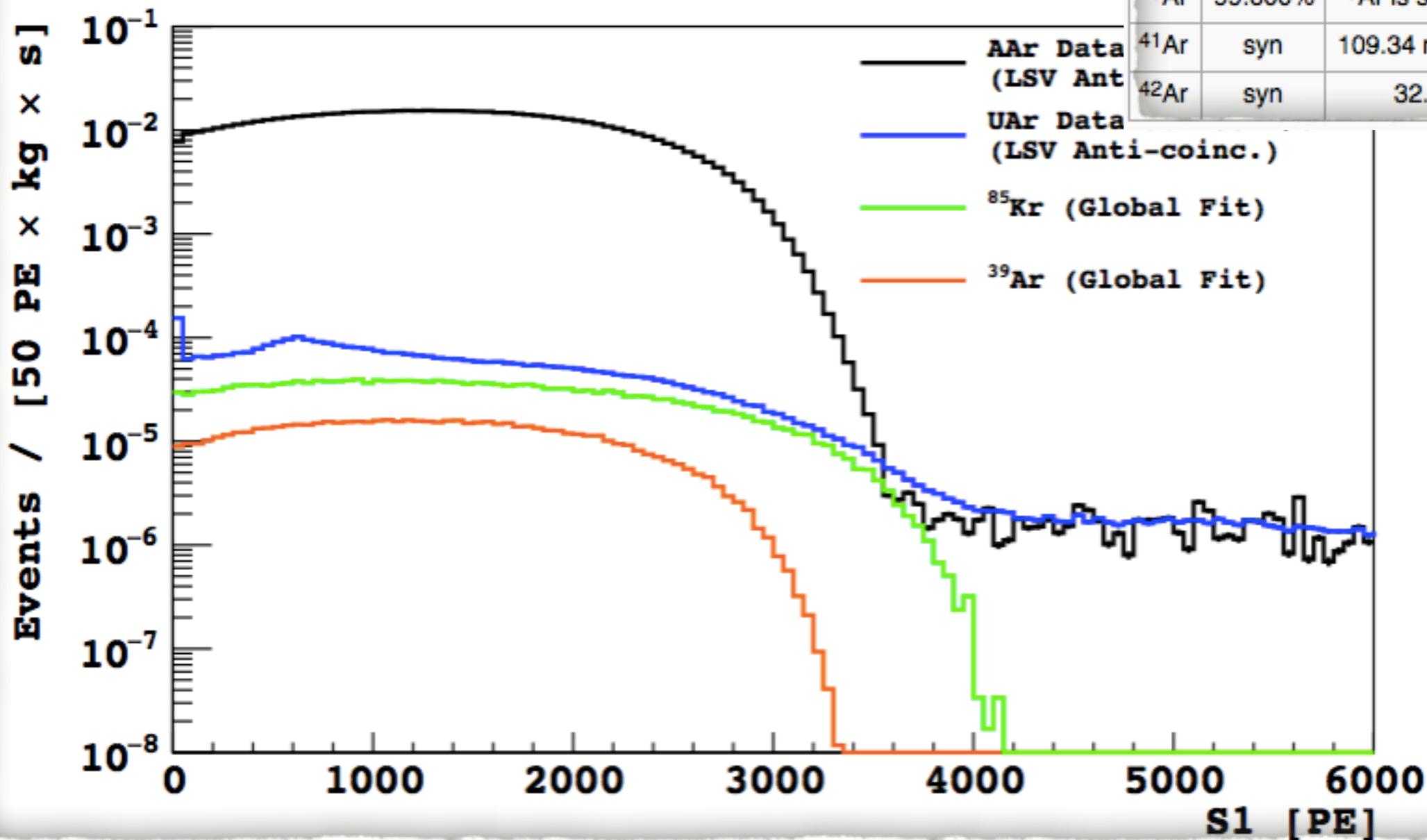
Dark Side

- based on Argon
- possibly allowing a big volume (20 Tons) keeping Zero Background

the key is in getting rid of

^{39}Ar

iso	NA	half-life	DM	DE (MeV)	DP
^{36}Ar	0.337%	-	($\beta^+\beta^+$)	0.4335	^{36}S
^{37}Ar	syn	35 d	ϵ	0.813	^{37}Cl
^{38}Ar	0.063%	^{38}Ar is stable with 20 neutrons			
^{39}Ar	trace	269 y	β^-	0.565	^{39}K
^{40}Ar	99.600%	^{40}Ar is stable with 22 neutrons			
^{41}Ar	syn	109.34 min	β^-	2.49	^{41}K
^{42}Ar	syn	32.9 y	β^-	0.600	^{42}K



How to ?

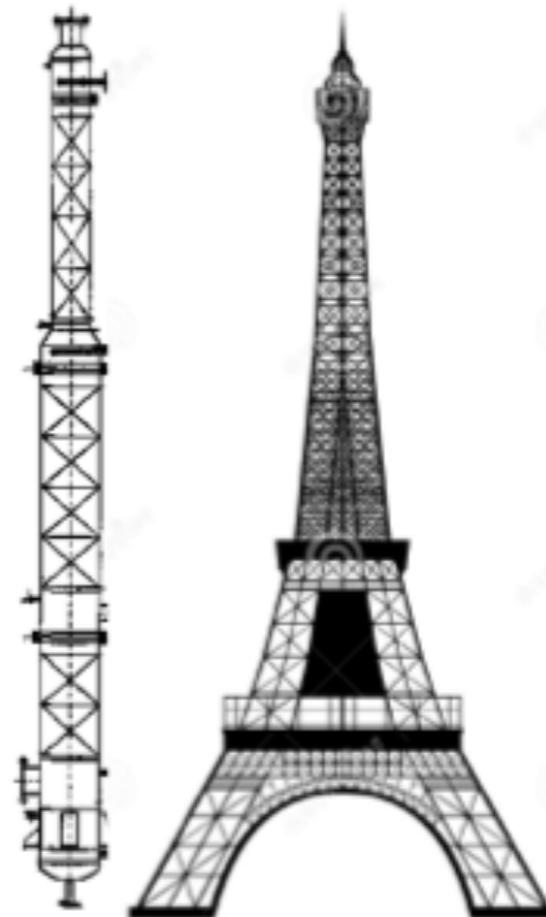
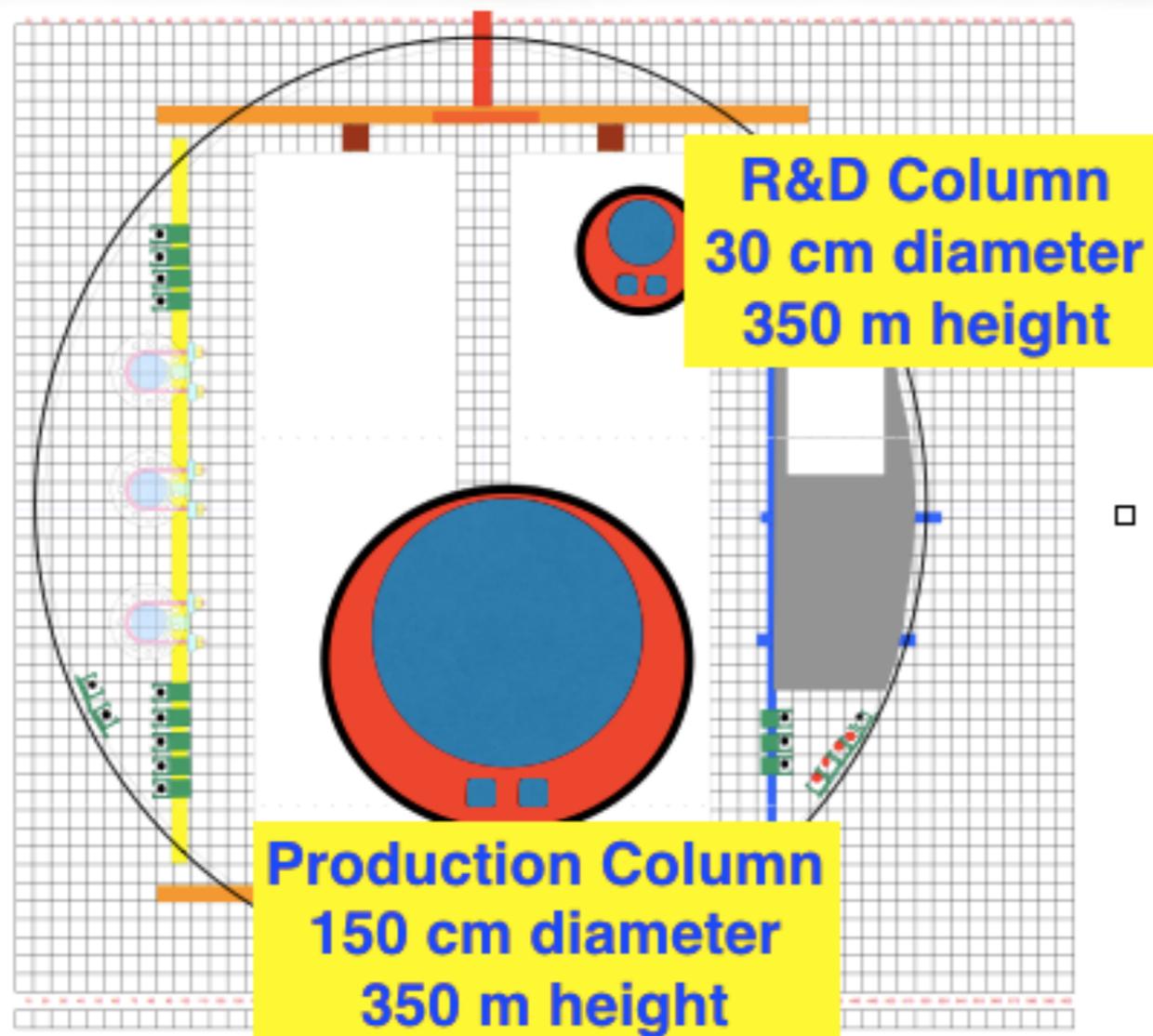
- It is produced (the ^{39}Ar) in the cosmic-ray interaction in the atmosphere
- if we find a mine where to pump it out we are already at a good point...
- we have set up a project called Urania in Colorado (Princeton-INFN) to extract Argon 300 poorer in ^{39}Ar**we want to do better !**

Aria@Sulcis



By using the shaft of a closed coal mine in Sardinia

separation by cryogenic distillation



It relies on different vapour tensions for the different isotopes of the same element

Thousands of equilibrium states are needed

Once done will be used for other applications

- lighter isotopes are even easier
- ^{18}O (H_2^{18}O for ^{18}F in cyclotrons \rightarrow PET)
- ^{13}C (breath test, NMR)
- ^{15}N (agriculture, NMR, reactors of new generation)

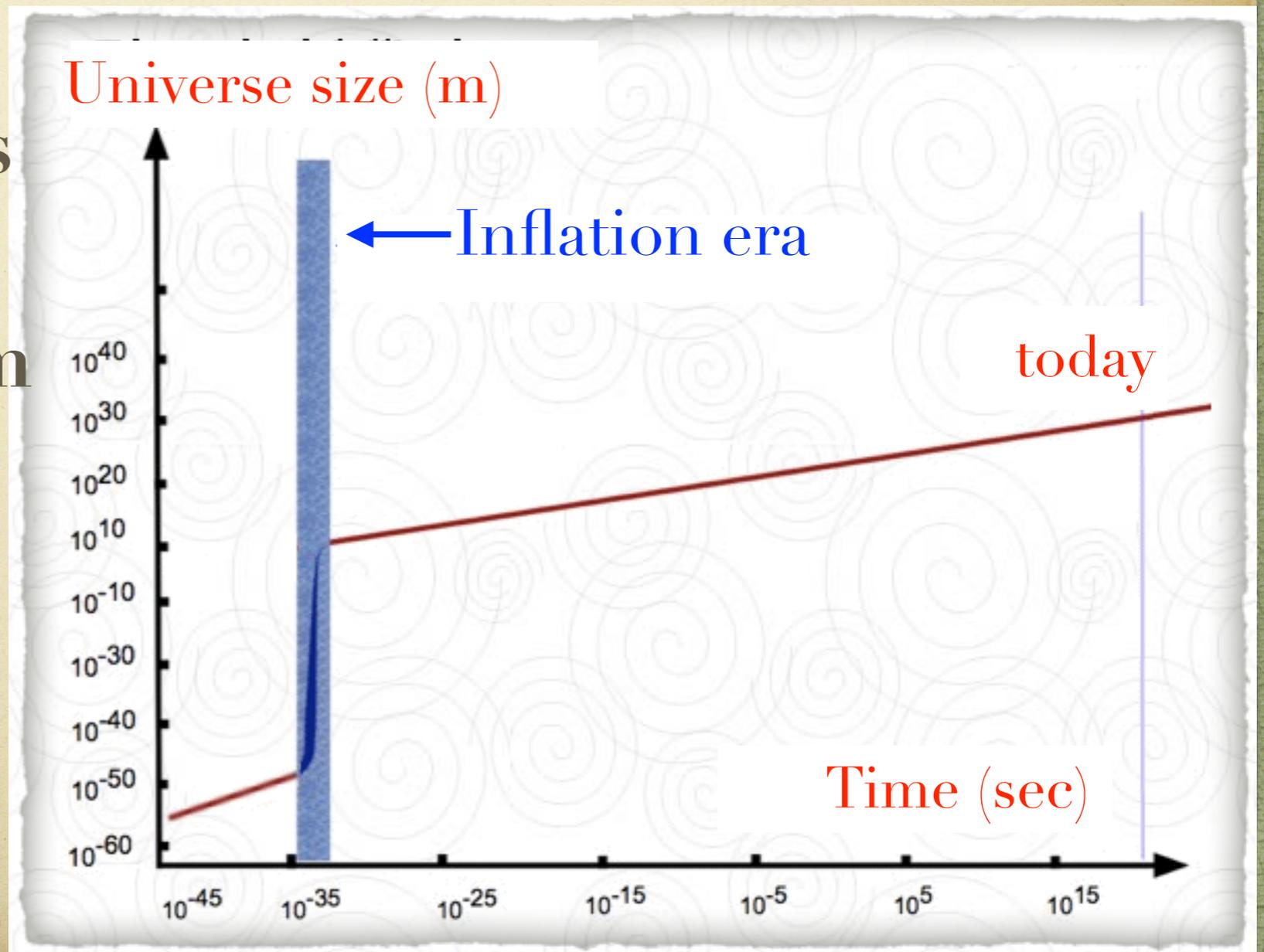
the fundamental research

has a social impact even
when it looks for ghosts !

back to the other Dark Problem

➤ a kind of Dark Energy appeared once in the Universe (the Inflation !)

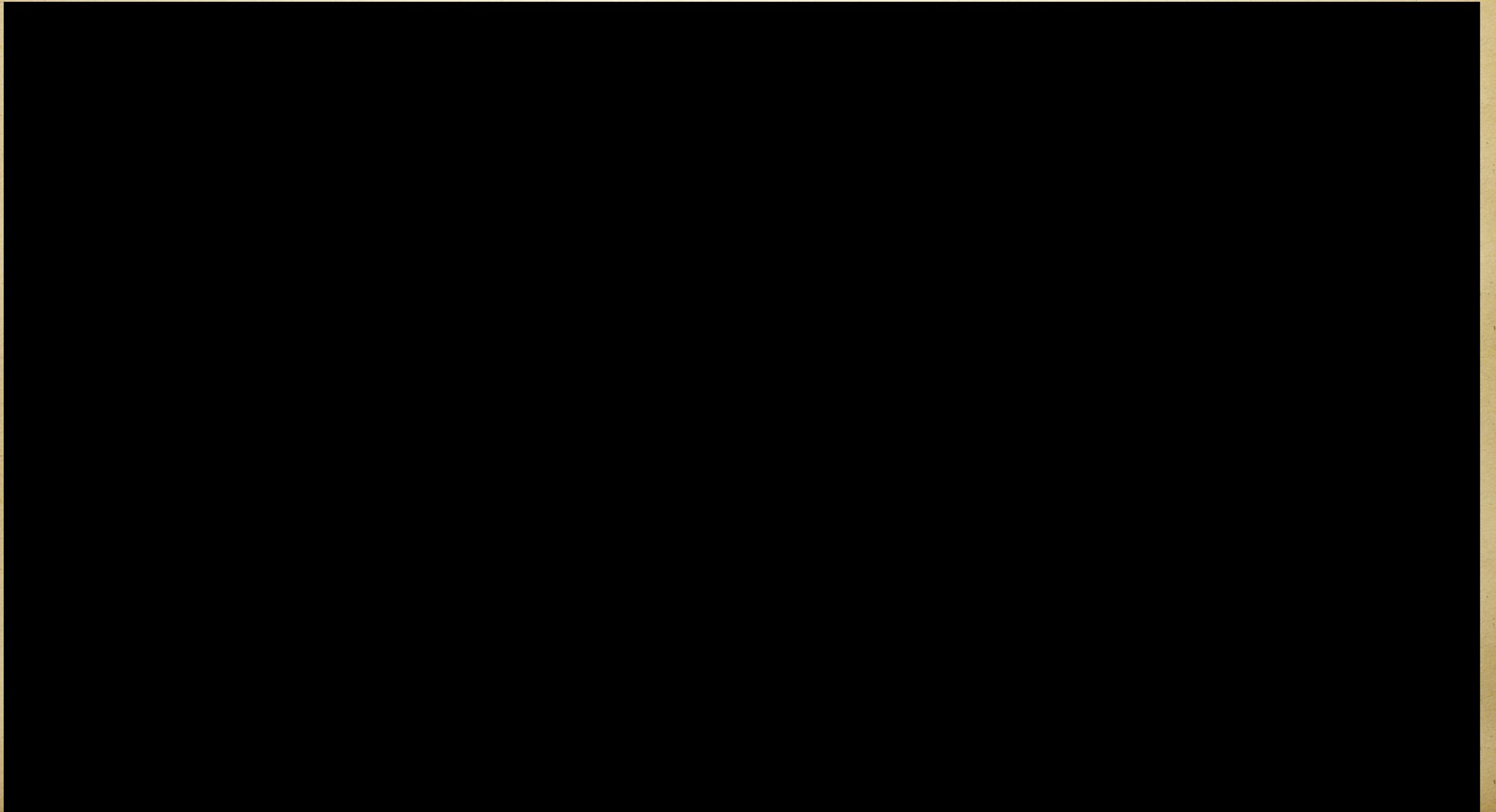
understanding this phenomenon that arises from Vacuum is fundamental to predict the future of the Universe itself



Einstein might have been right even when he thought to be wrong

- Albert Einstein writes General Relativity (100 years ago) $R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$
- He thinks that gravity will eventually bring the Universe to a collapse while he much prefers a sort of static Universe
- In order to prevent the collapse he introduce an arbitrary parameter (not forbidden) (he names it the Cosmological Constant) $G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$
- Hubble and LeMaitre discover that Universe is actually expanding !
- Einstein declares the CosCon the worse blunder of its career
- Not so, it has come back ! It was there ! However since the Universe was already expanding it makes the expansion accelerating.

at face value the fate of the
Universe looks like this



do not despair

Conclusion

...here have been revealed, with regard to this new and excellent science, of which my work is only the beginning, roads and tools of which other brains, more acute than mine, will explore the most remote corners.

GALILEO GALILEI