# The Theory Group

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A few slides about the working framework…

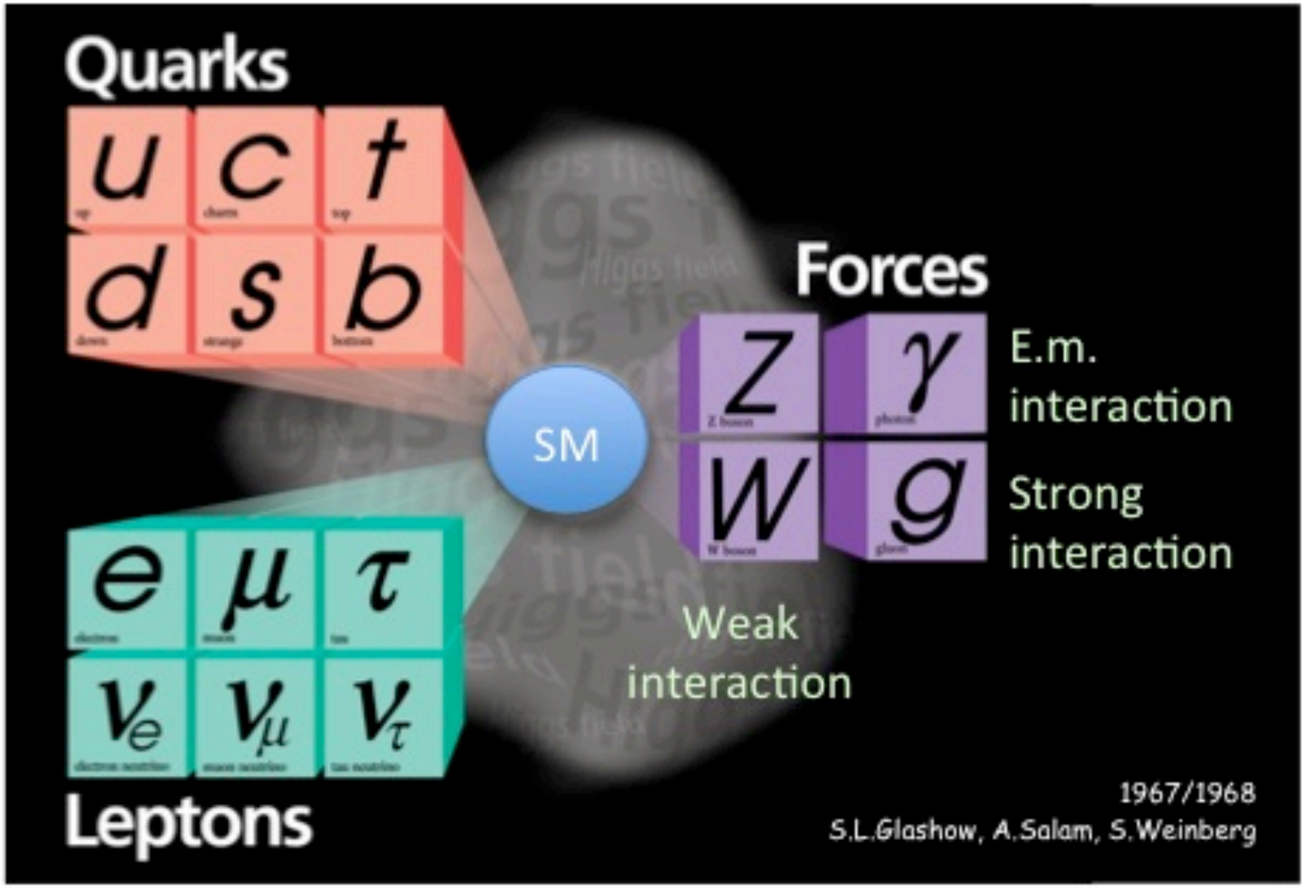
# The Standard Model

Q = +2/3

Q = -1/3

Q = -1

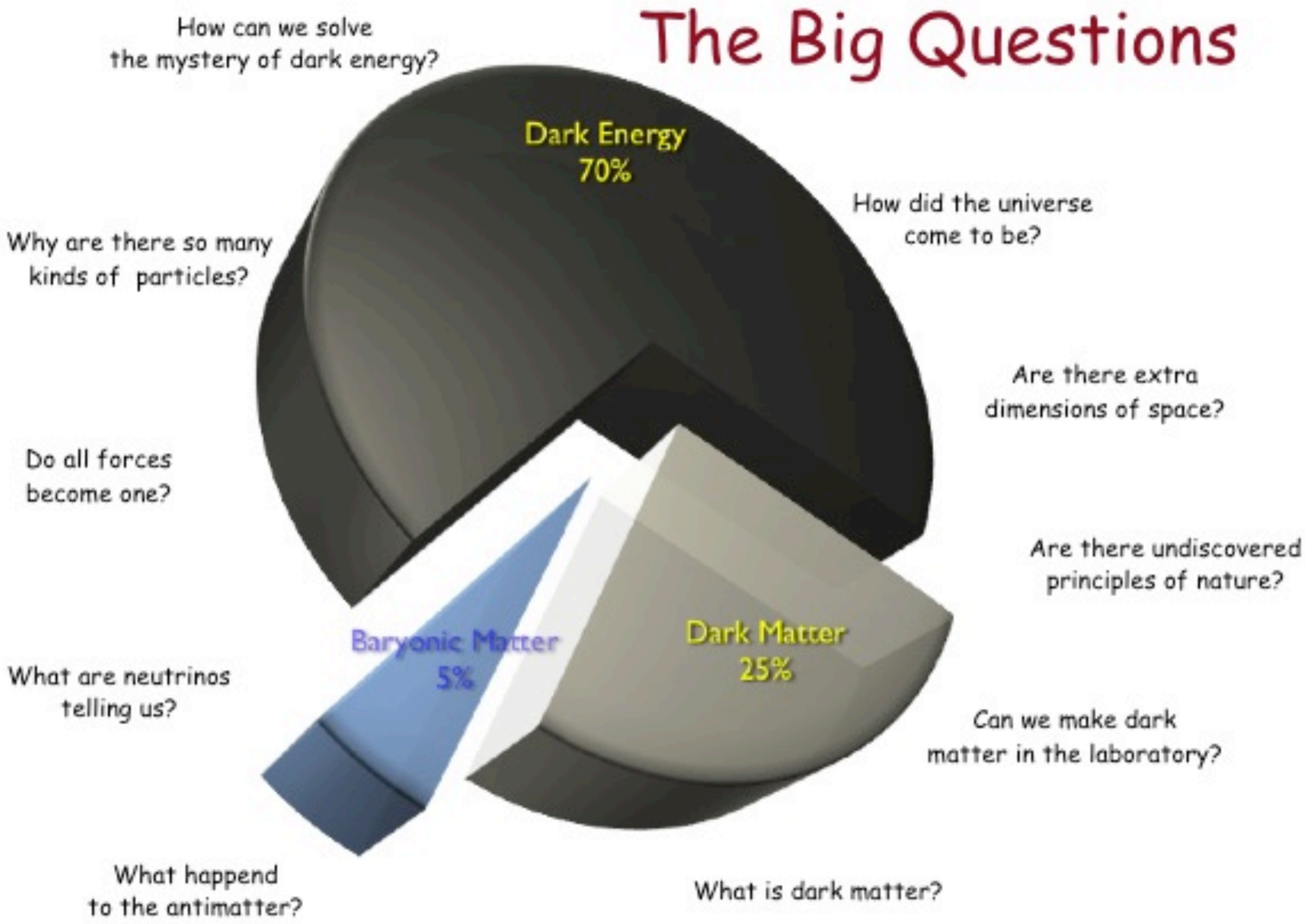
Q = 0




Gravitational Interaction

Note that: Only states (qqq – Baryons) or ($q\bar{q}$ - Mesons) are observed in Nature;   e.g. p=(uud), n=(ddu)

# The ΛCDM cosmological Model



The **theory group** tries to answer some of these questions…

# Instutions & People

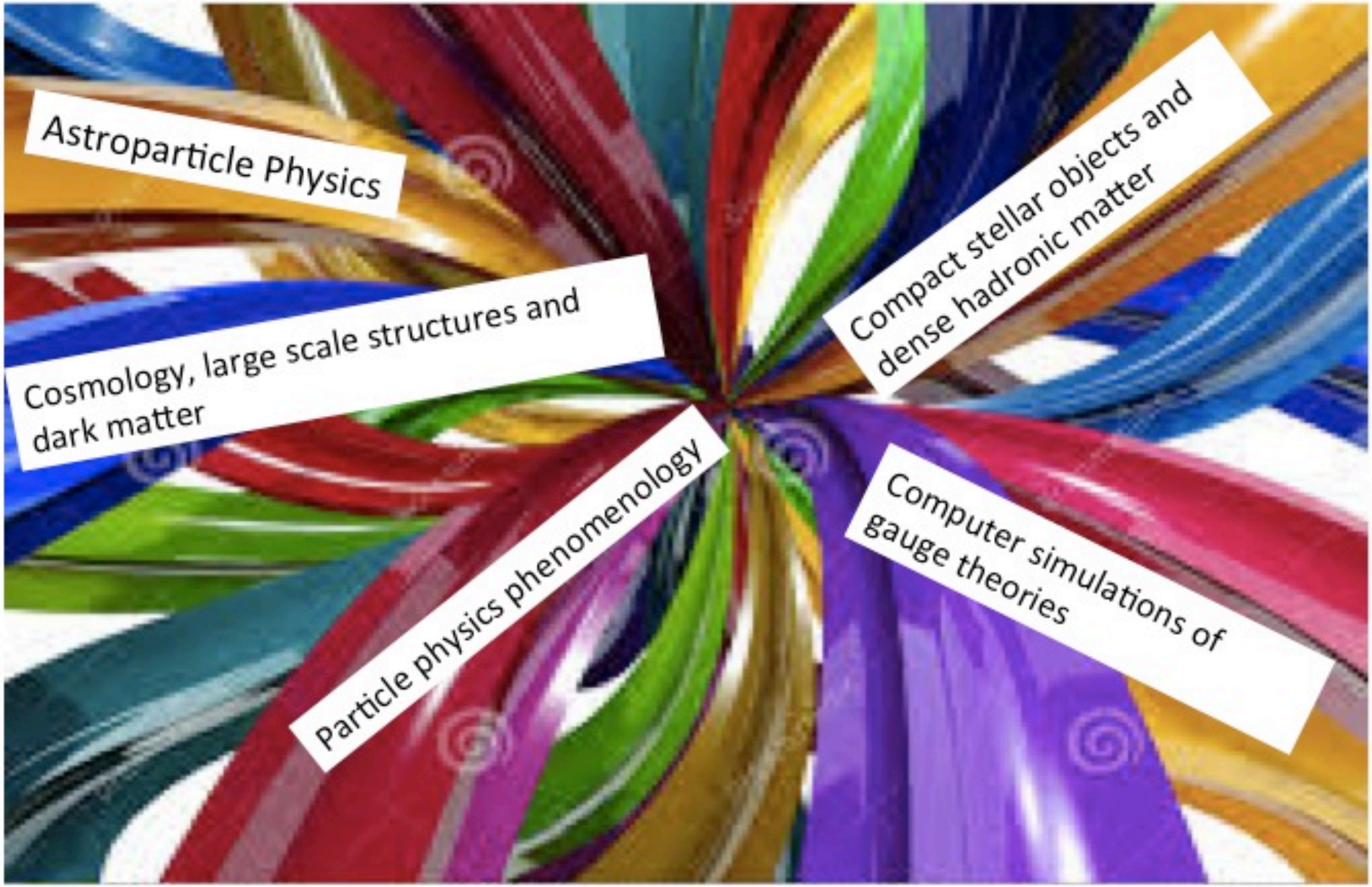
Gran Sasso National Laboratory

University of L'Aquila

Gran Sasso Science Institute

A. Addazi, R.Aloisio, L.Ambrogi, Z. Berezhiani, V. Berezinsky, R. Biondi, D. Boncioli, P. Blasi, A. Breccione, M. D'Angelo, G. Di Carlo, G. Di Panfilo, D. Ejlli, A. Esmaili, P. Giammaria, A. Mammarella, **M. Mannarelli**, G. Pagliaroli, A. Palladino, A. Parisi, L. Pilo, S. Recchia, G. Senjanovic, V. Tello, F. Tonelli, F.L. Villante, F. Vissani

# Research Topics



The different research lines are connected among each others.
I will give few examples in the following …

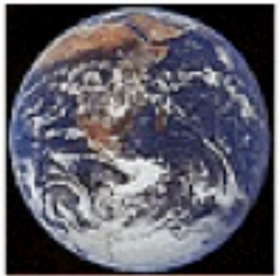
# Neutrino astronomy

- Neutrinos are abundant in the Universe. They are produced through weak interactions by:
  - Radioactive decays
  - Nuclear reactions
  - High energy hadronic collisions
  - Thermal processes (high densities and high temperatures)

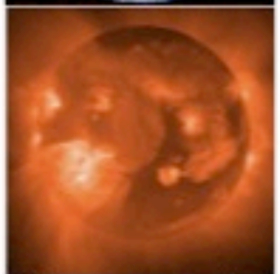
ν from reactors

ν from accelerators

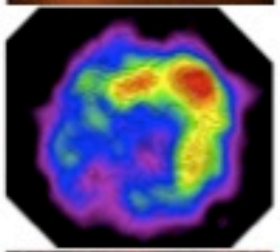
CERN to Gran Sasso Neutrino Beam



ν from the Earth



ν from stars



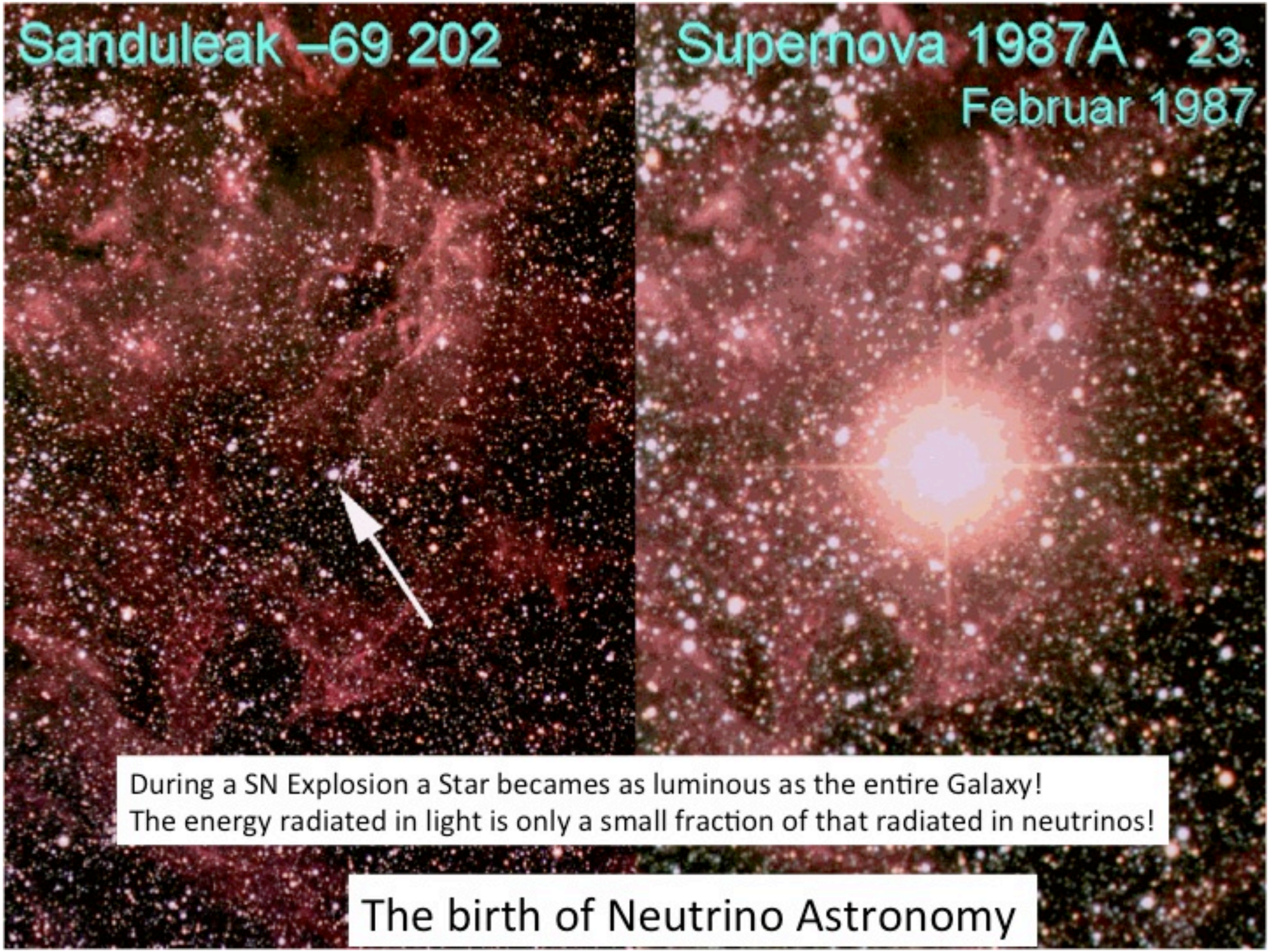
ν from the atmosphere, ν from SN remnants, ...

ν from supernovae, primordial ν ...

# We can learn a lot from neutrinos …

- Neutrinos have a unique role in astrophysics and cosmology because of their peculiar properties:

| | |
|---|---|
| Light and weakly interacting | allow to see deeper and earlier than photons<br>Unique probe for:<br>•stellar interiors (solar, stellar and SN neutrinos)<br>•earth interior (geo-neutrinos)<br>•star formation rates (SN relic neutrinos)<br>•early universe (cosmic neutrinos)<br>•cosmic ray acceleration (SNRs neutrinos)<br><br>Very effective cooling/energy transfer mechanism<br>•SN explosions?<br>•…… |
| Non vanishing masses | Different cosmological behaviour with respect to g<br>Relevant contribution to Dark Matter<br>Influence structure formation in the Universe<br>…… |




During a SN Explosion a Star becames as luminous as the entire Galaxy!
The energy radiated in light is only a small fraction of that radiated in neutrinos!

# The birth of Neutrino Astronomy

# Core-Collapse Supernovae

Progenitor Star

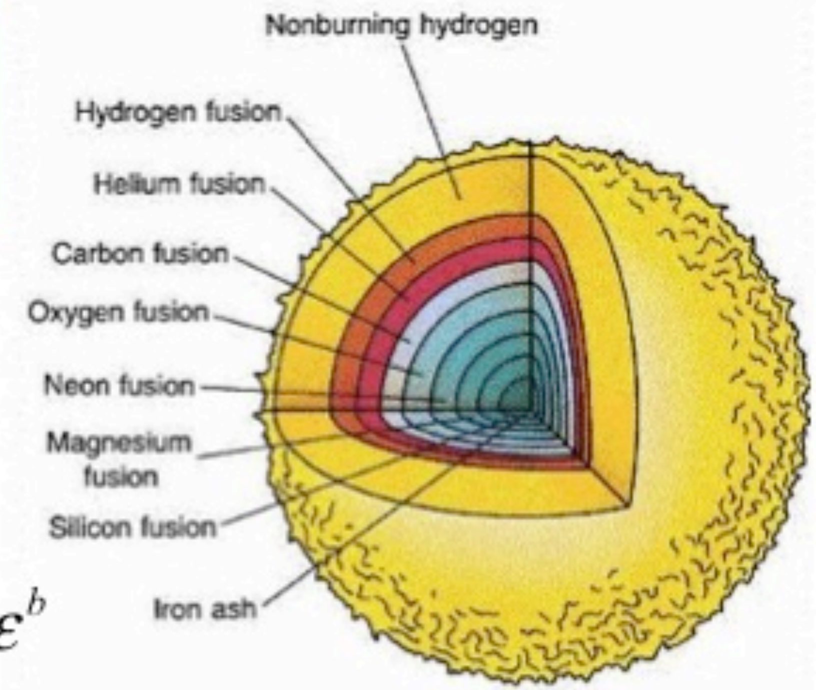
$M_{star} > 8M_{\odot}$

$R_{Star} \sim 200R_{\odot}$

Neutron Star

$M_{NS} \sim 1.4M_{\odot}$

$R_{NS} \sim 15km$




$$\varepsilon_{NS}^{b} \cong \frac{3}{5}\frac{GM^2}{R} = (1-5)\cdot 10^{53}\,erg$$

Neutrinos ➡ $\varepsilon_{\nu} \approx 99\% \cdot \varepsilon^{b}$

Kinetic Energy of the gas ➡ $\varepsilon_{kin} \approx 1\% \cdot \varepsilon^{b}$

Photons ➡ $\varepsilon_{\gamma} \sim 0.01\% \cdot \varepsilon^{b}$

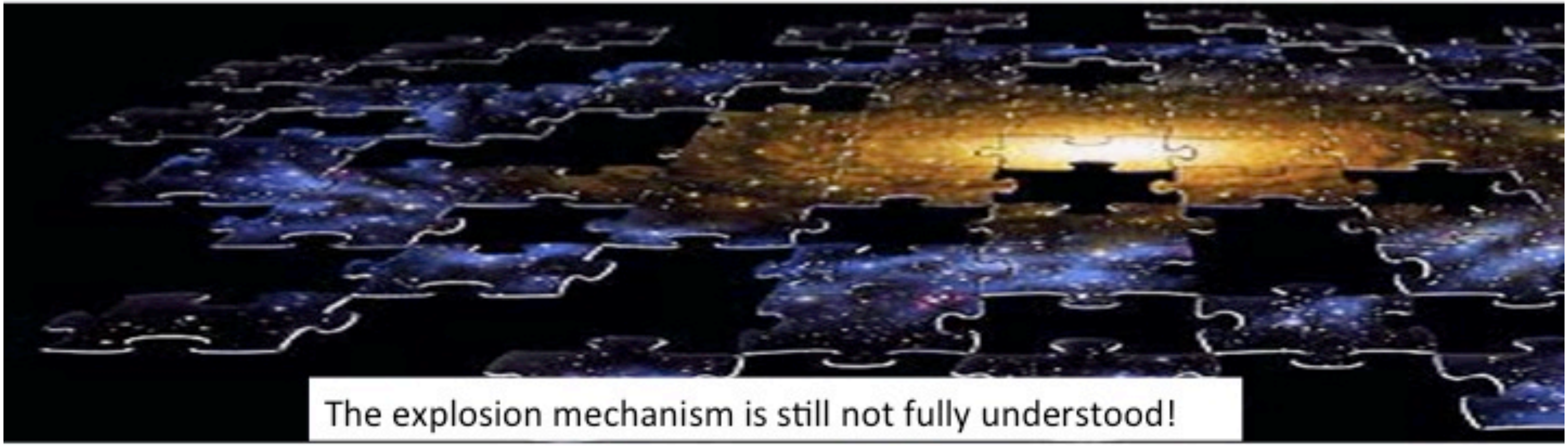
Gravitational Waves ➡ $\varepsilon_{GW} \leq 0.0001\% \cdot \varepsilon^{b}$

$R_{\odot} = 6.955 \cdot 10^{6}\,km$

$M_{\odot} \cong 2 \cdot 10^{30}\,kg$

$G = 6.67 \cdot 10^{-11} m^3 kg^{-1} s^{-2}$

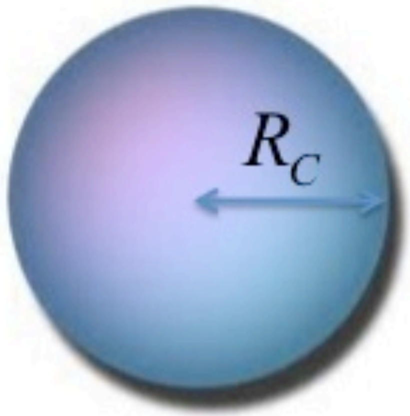
# The Supernova puzzle




# Astrophysics vs Nuclear Matter

SN1987A is the only SN observed in Neutrinos till now (30 events)
Next Galactic SN will be observed with high confidence(1000 events)

COMPACT OBJECT




$\delta R_c = 7\%$

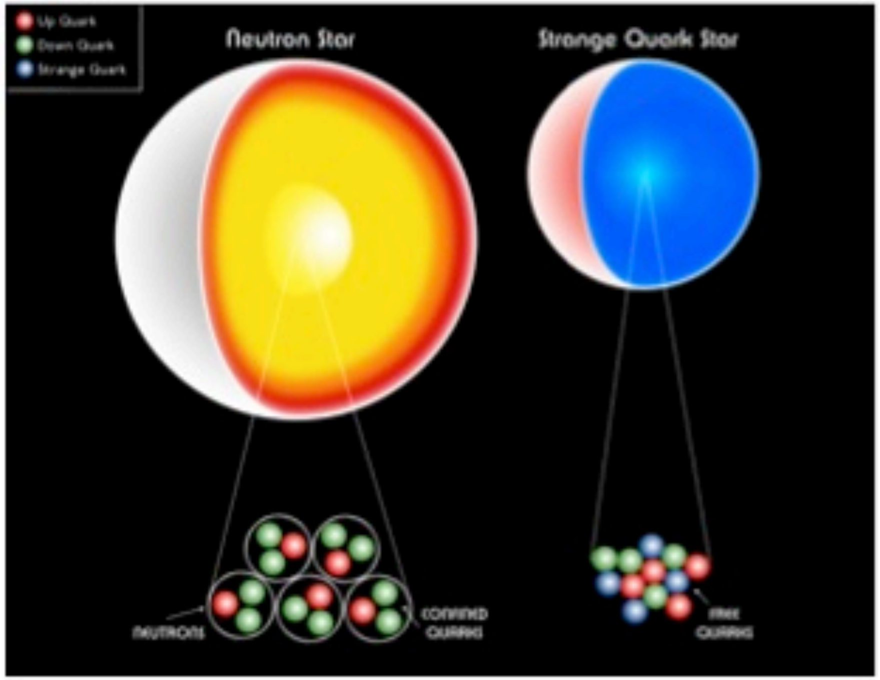
$\delta T_c = 2\%$

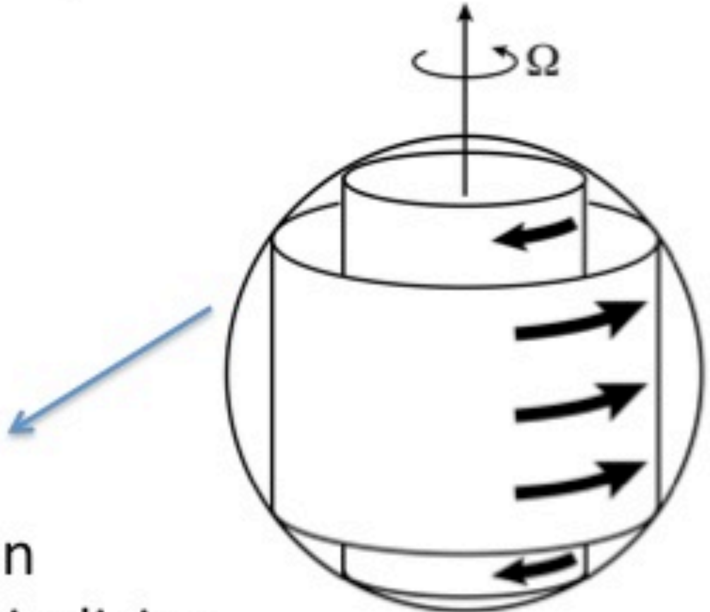
Neutrinos can probe the properties of this Compact Star.

The Astrophysical context is the only
One that allows us to investigate the
States of the matter in the extreme regime
Of very high density and very low temperature!

# From Compact stellar objects to the fundamental state of matter

Looking for… proofs of the existence of strange matter



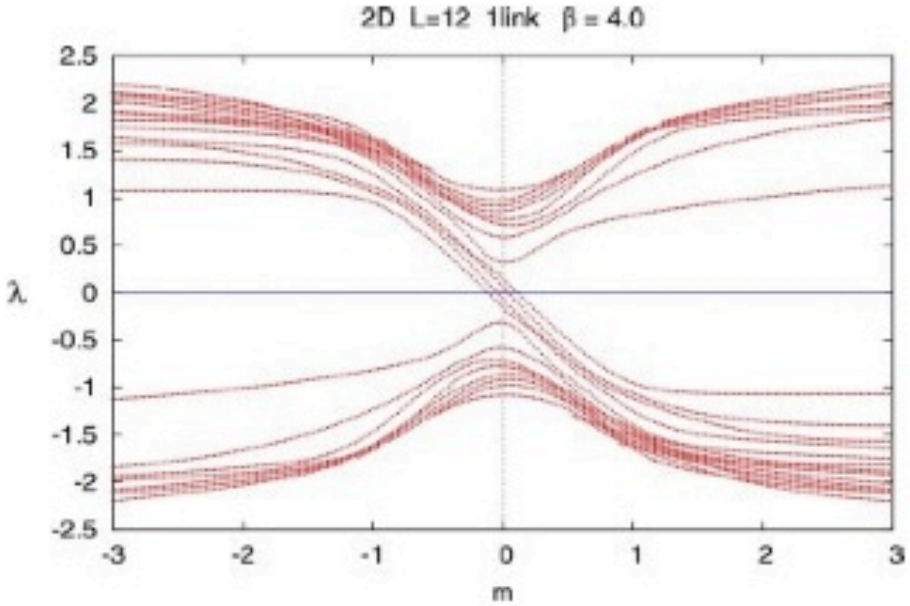

Prediction

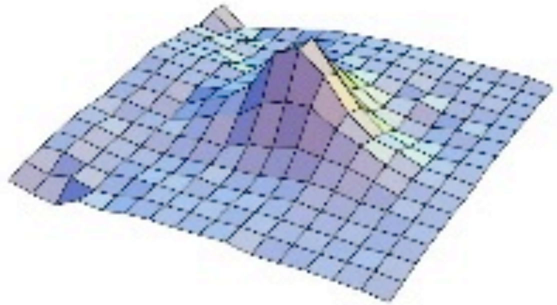
- No periodicity
- Radio Frequency Band
- High Emitted Power
- Short Duration

Non-perturbative aspects of Lattice Gauge Theories:
QCD at finite density and topological structures.

Coordinator: Giuseppe Di Carlo
in collaboration with V. Azcoiti, E. Follana and E. Royo
( Zaragoza University )

Developing numerical methods for the study of QCD vacuum in extreme conditions



Numerical test of
a new definition of
topological charge
on the lattice.

V. Azcoiti, G. Di Carlo, E. Follana, A. Vaquero, Phys.Lett. B744 (2015) 303

# The (possible) link between SNe and Cosmic Rays

Crab Nebula

The gas ejected from a SN continues to expand. Part of the kinetic energy of the explosion can be used to accelerate charged particles (e, p and nuclei) up to TeV energy.

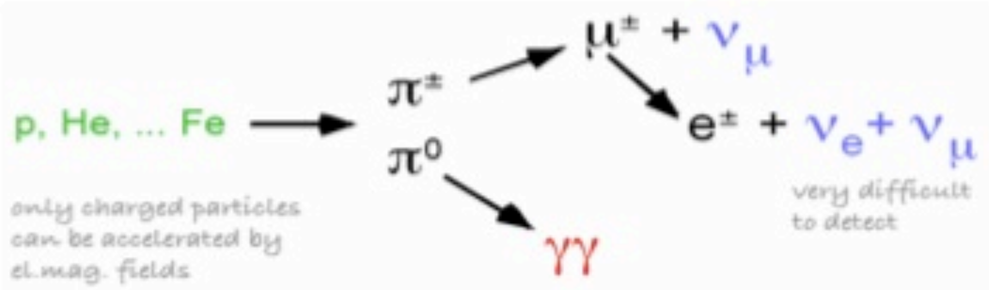
The 10% of the kinetic energy is enough to explain the galactic component of the Cosmic Rays **(Still unknown!).**

Supernova Remnant

$T \approx 1000$ years
$R \approx 10$ ly
$M \approx 5\ M_o$
$V \approx 1000$ km/s
Strong Magnetic Fields

# The link between Cosmic Rays, High Energy Neutrinos and Photons

*The effect of collision between very high energy particles*

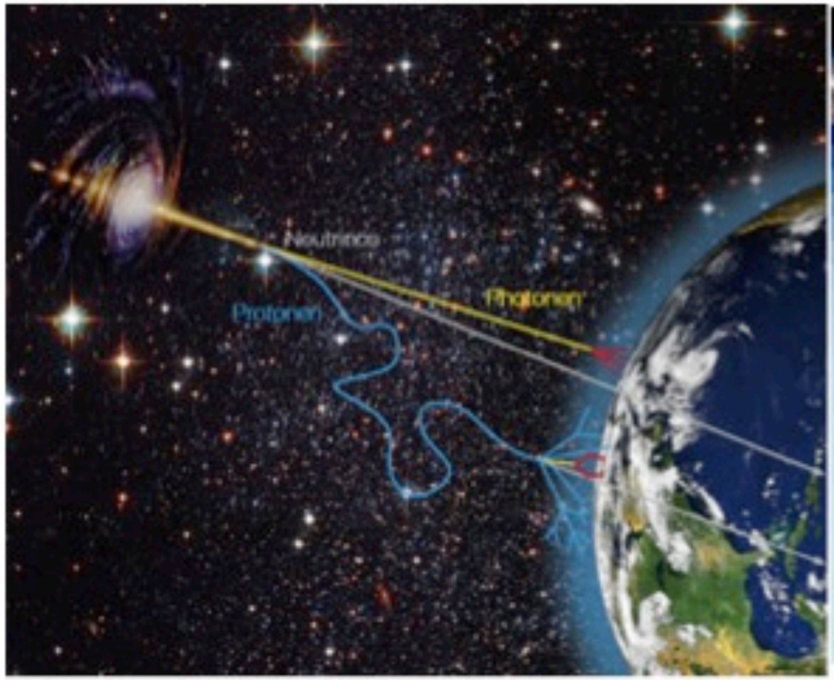


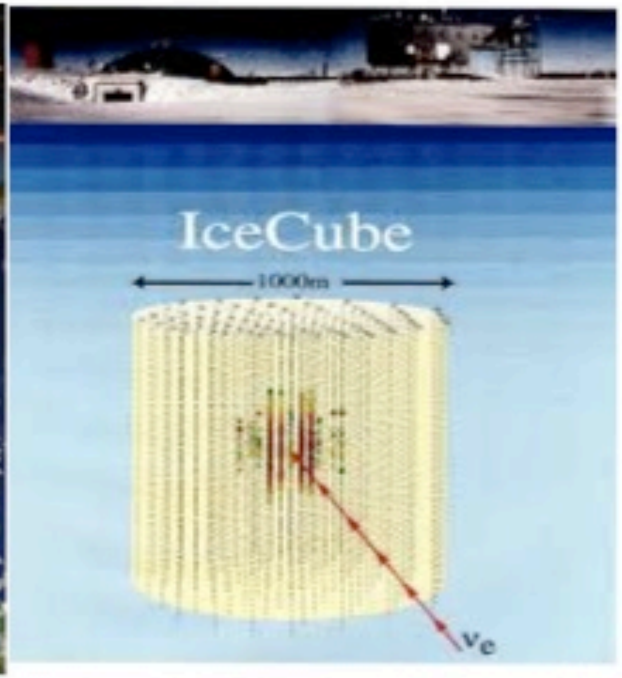

The same mechanism used to produce neutrinos in accelerators (e.g. CERN) can produce TeV Neutrinos and TeV Photons.

Capturing these High Energy Neutrinos we can probe the Cosmic Rays production mechanism.

# A new era for Neutrinos Astronomy

Very high energy neutrinos are captured by IceCube detector

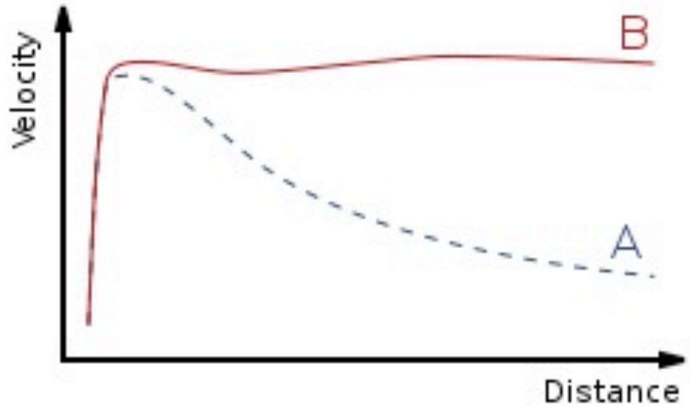



The events observed by IceCube are compatible with an astrophysical source or are background neutrinos produced in our atmosphere?

# Dark Matter

The existence of DM is inferred e.g. from the rotation curve of Galaxies




$$v(r)^2 = G\,M(r) / r$$

A: predicted from visible matter
B: observed

The DM can be also "seen" from the gravitational deflection of light.
Blue: DM distribution (from light deflection)
Red: Gas distribution (from X ray emission)

# The WIMP miracle

WIMP = Weakly Interacting Massive Particle
A new massive particle with weak scales interactions is expected to be produced approximately in the right amount in the early Universe

But .... This is not a strict rule and it is not valid for any DM candidate

# Cosmic coincidencies?

Any model for DM and DE should explain why:

- Dark Energy ≈ Dark Matter (i.e. the Universe started to accelerate NOW)
- Dark Matter ≈ Ordinary Matter

# Alternative explanations to cosmological observations

## Could gravity be different than expected?
## (gravity is not tested on very small and very large scales)

• Dark Energy models based on Massive Gravity
Massive Gravity → general relativity with a massive graviton
(m ~$H_0$, Hubble scale today)
graviton mediates gravitational interactions

• Post Newtonian Tests of alternatives theory of gravity:
Deflection of light by the sun, Mercury's periastron, time delay ....

• Generation and propagation of gravitational waves in massive gravity

• Higgs mechanism for gravity: is GR gauge theory alike ?


FINALLY IT'S OVER
THANK YOU FOR YOUR ATTENTION


thank you
danke
謝謝
ngiyabonga
teşekkür ederim
спасибо
dank je
gracias
tapadh leat
bedankt
hvala
mochchakkeram
dziękuję
go raibh maith agat
obrigado
sukriya
kop khun krap
grazie
arigato
takk
dakujem
мерси
terima kasih
merci