MINISTERIO DE EDUCACIÓN Y CIENCIA
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

# STAR FORMATION AND COSMIC RAYS

**Mercedes Mollá Lorente**

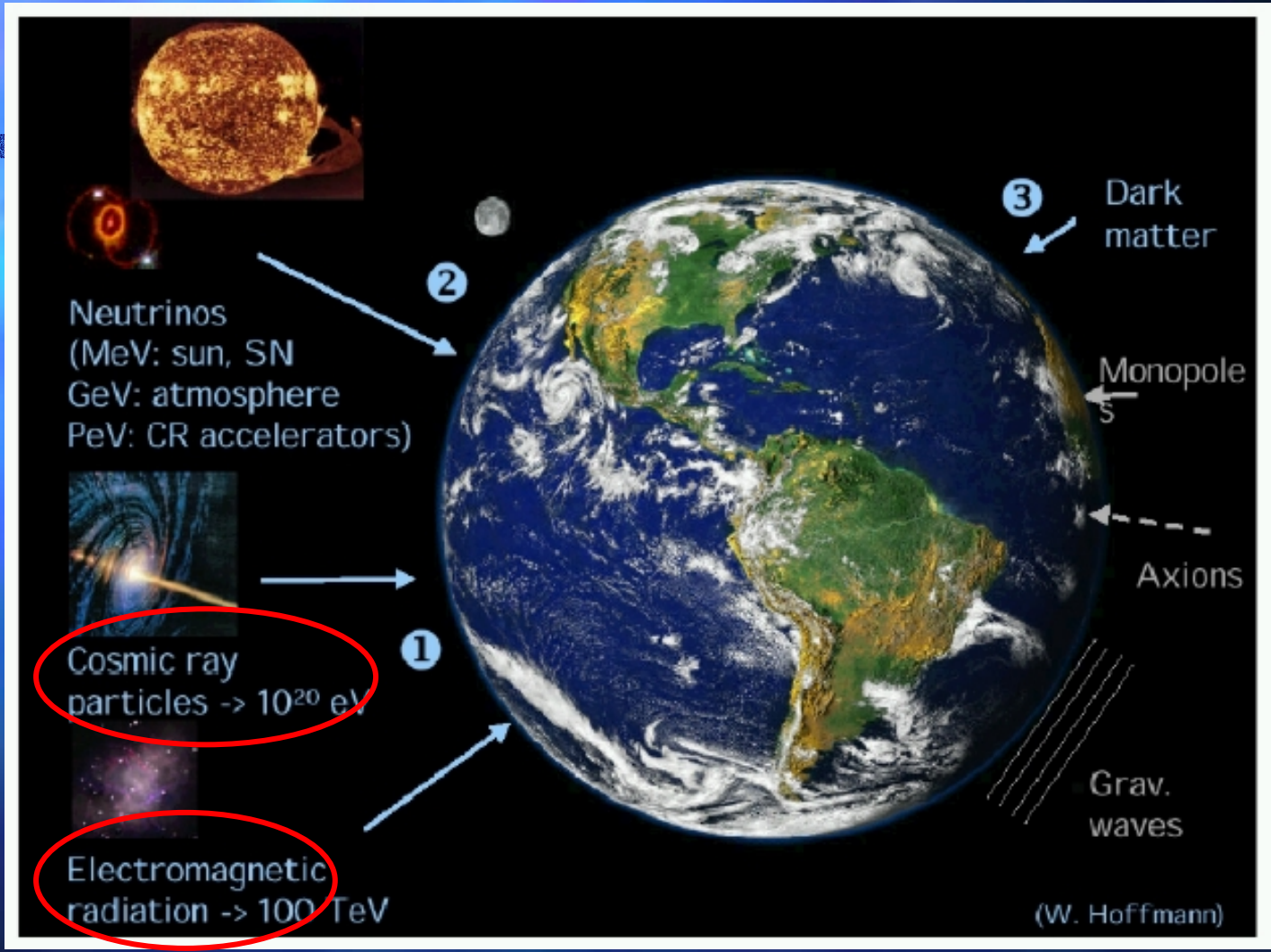
**C.I.E.M.A.T**

**Enero-2006**

**Estallidos de formación estelar en galaxias. Madrid 2006**

**Una aproximación multifrecuencia a la formación estelar en Galaxias**

# How do we obtain information from Universe?

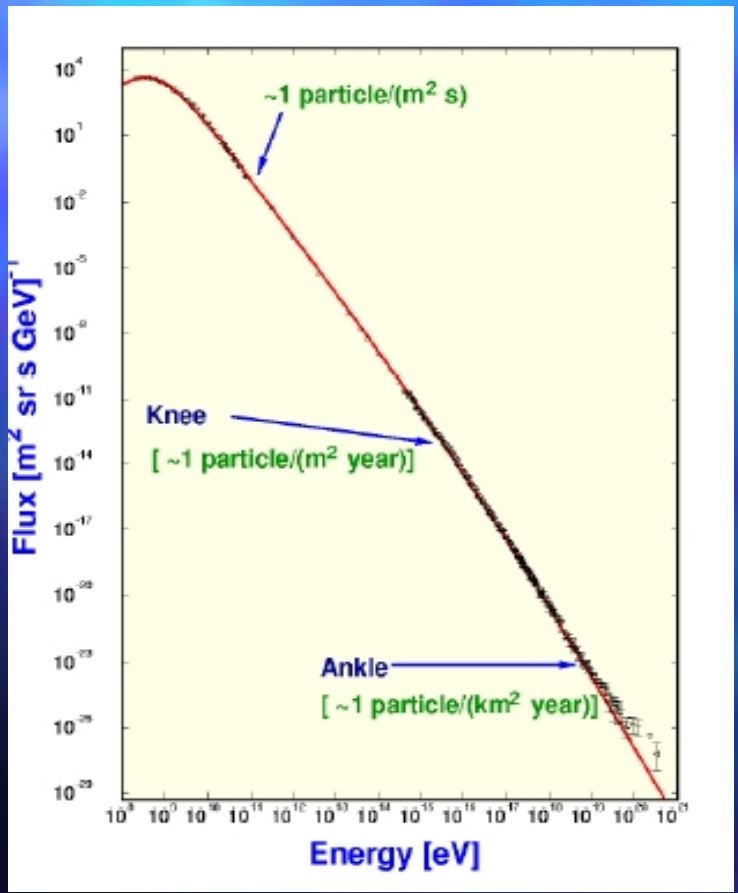



1. **Matter which arrives directly**
2. **Lost of directionality**

# COSMIC RAYS

- Accelerated charged particles arriving in Earth from the Sun, our galaxy and other galaxies
- Mainly protons (90%) and $\alpha$ particles (9%)

$\Phi_p(E)dE=12.5(E+E0)^{-2.6}dE\ cm^{-2}\ s^{-1}$




- The spectra show a power law since some eV up to $10^{20}$ eV with some features called the knee and the ankle
- They move through the interstellar medium (ISM) where they experience scattering, re-acceleration and energy loss due to the irregularities of the ISM and to magnetic fields before reaching the Solar Neighbourhood
- Their origin is very uncertain: Their spectra suggest some electromagnetic processes similar to those from high energy acelerators of particles
- Some particles with E~GeV are ejected by the Sun: it is probable that other stars also eject this type of particles
- The probable mechanims: particles ejected by stars reflected repetively in magnetic clouds of gas. This may occur by interstellar shocks in SN remnants
- Some of these primary accelerated particles impact on the ISM producing secondary particles

# Abundances in cosmic rays

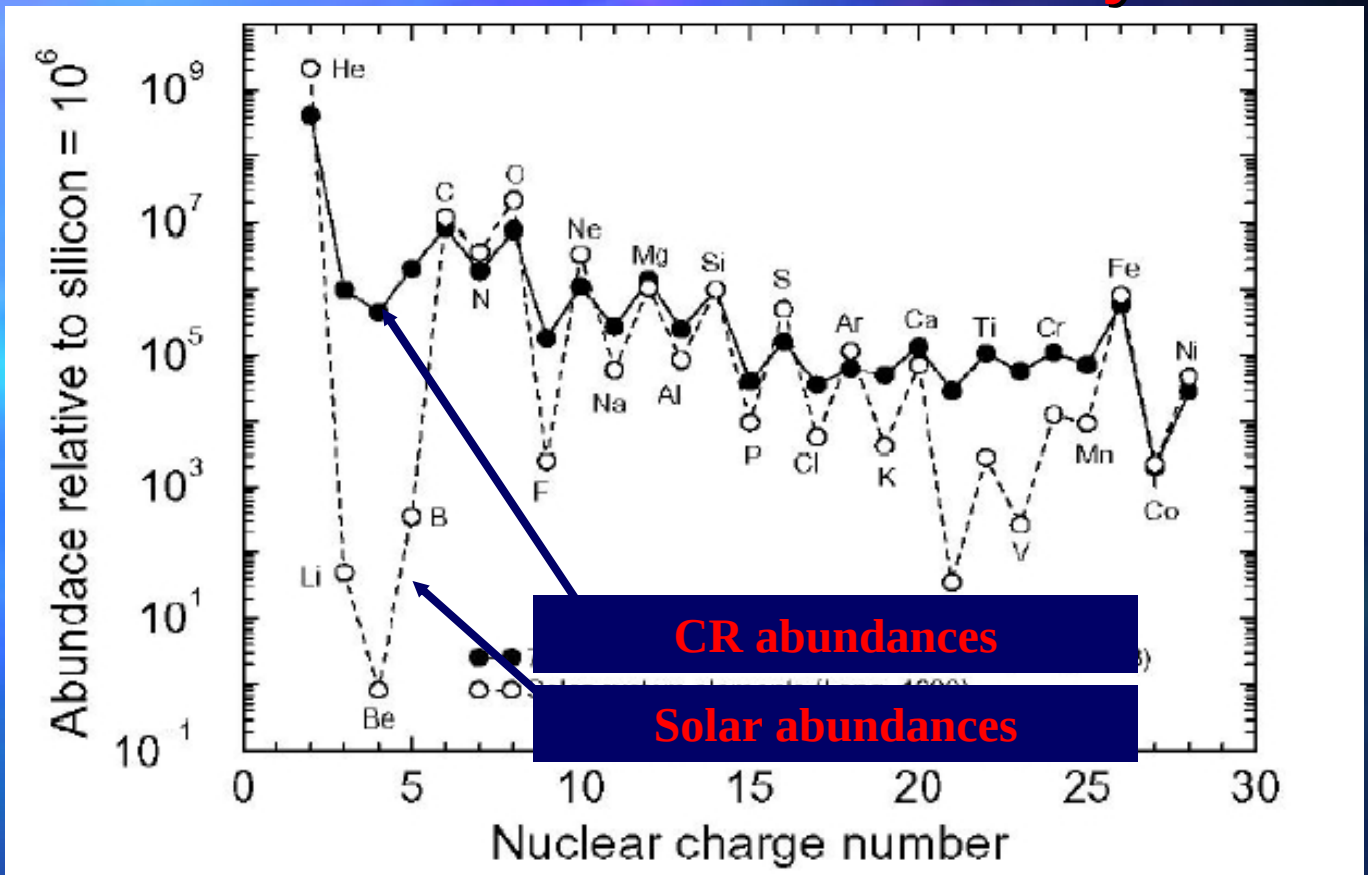
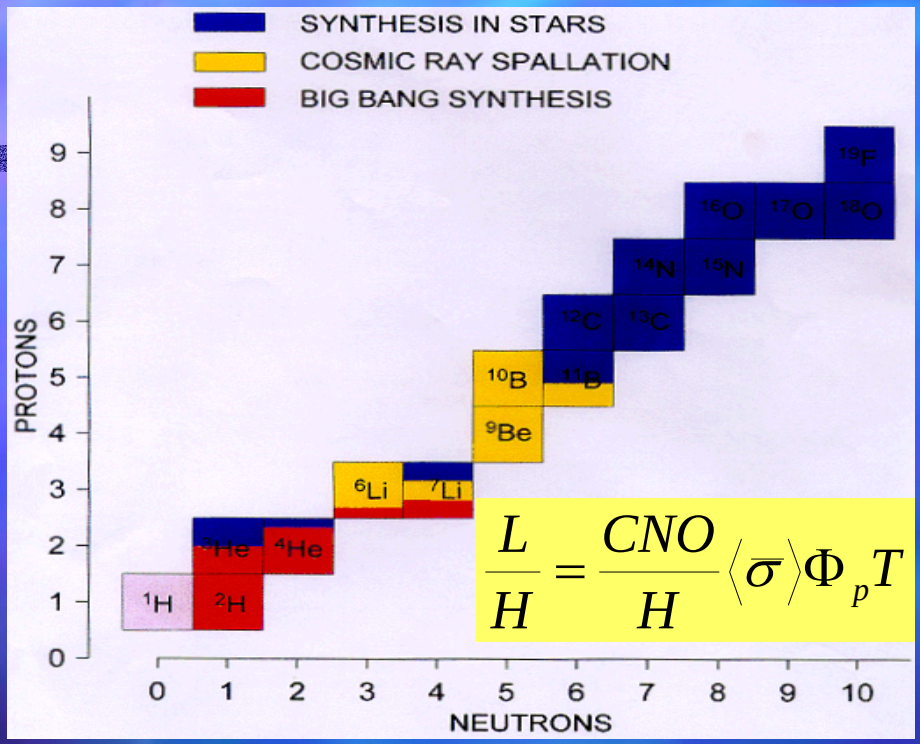



Fig. 2.— The relative elemental abundances of 70-280 Mev/nucleon cosmic rays (closed circles, taken from Tab. 2 by Simpson, 1983) compared to the solar system abundances (open circles, taken from Tab. 38 by Lang, 1980) normalized to Si $= 10^6$.

- The abundances are similar to the solar ones
- They are higher for the light elements
- Isotopical anomalities

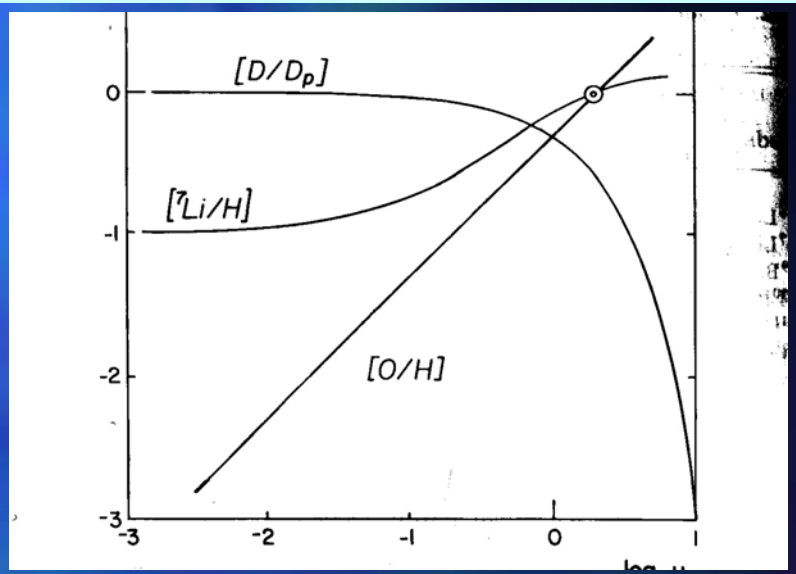
# The elements and nuclei production




$$\frac{L}{H} = \frac{CNO}{H}\langle\sigma\rangle\Phi_p T$$

**The light elements cannot be produced as primordial nuclei (except $^{7}$Li) nor by stellar nucleosynthesis since they are destroyed in the interiors of stars**

**p,α+ CNO ⟶ $^{6,7}$Li,$^{9}$Be,$^{10,11}$B**



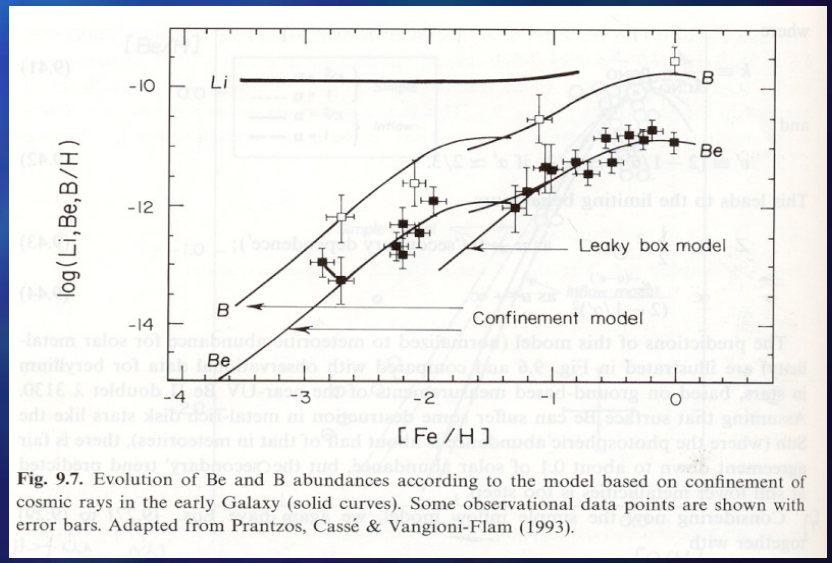
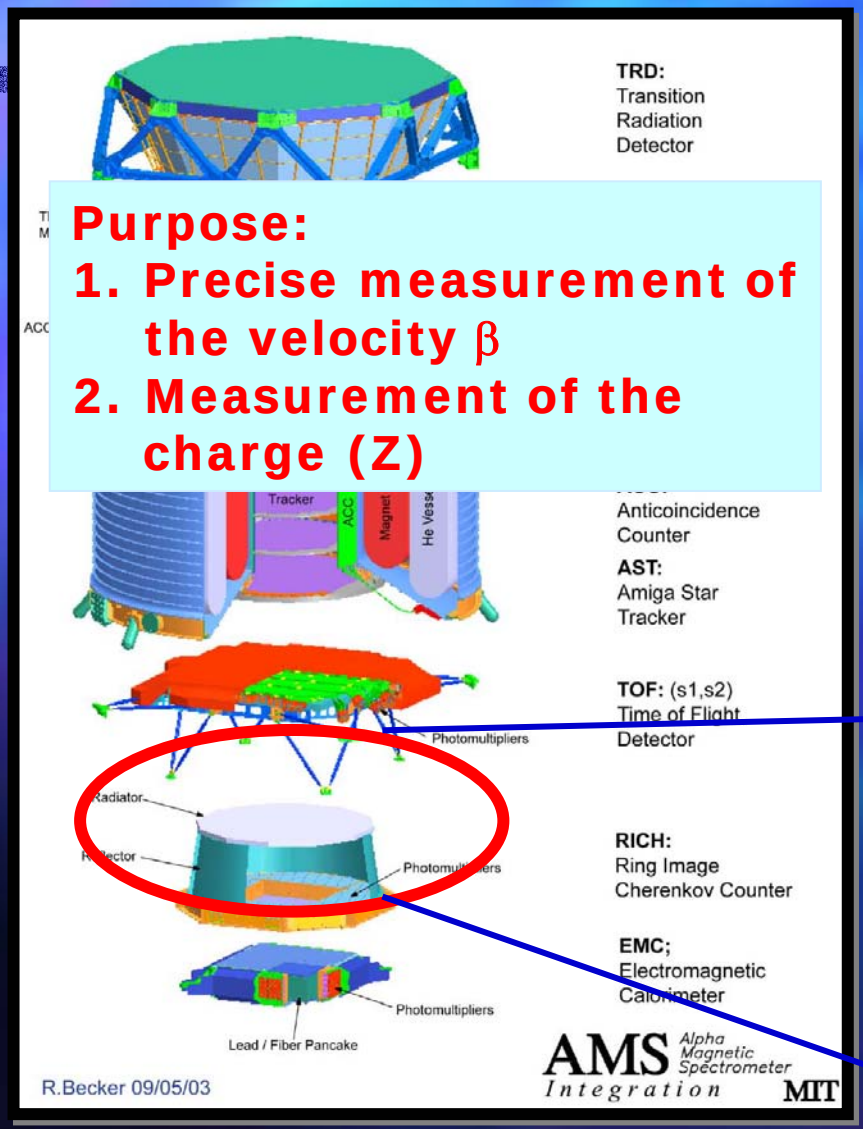




**Fig. 9.7.** Evolution of Be and B abundances according to the model based on confinement of cosmic rays in the early Galaxy (solid curves). Some observational data points are shown with error bars. Adapted from Prantzos, Cassé & Vangioni-Flam (1993).

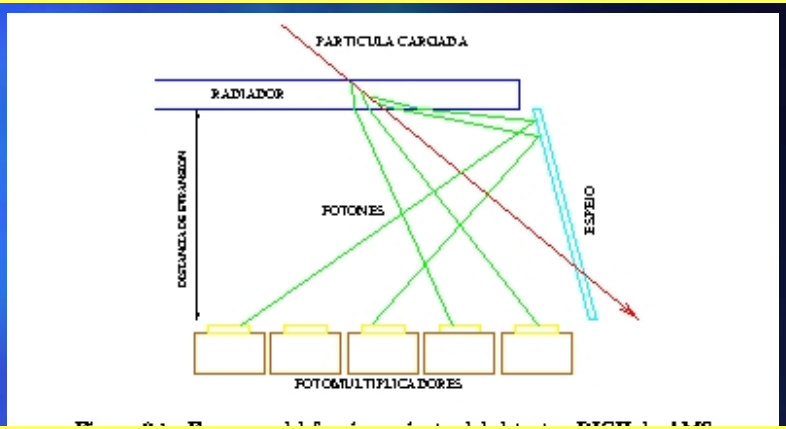
# AMS

## Detection in the space: direct study of measurements



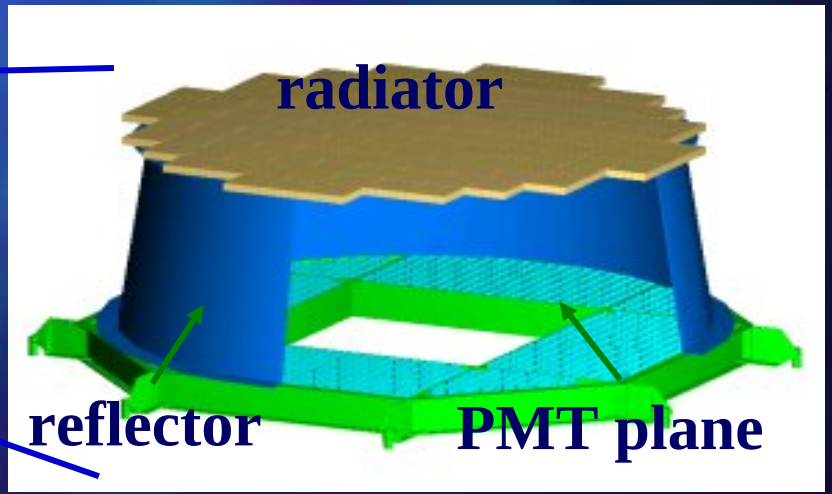

**Purpose:**

1. **Precise measurement of the velocity β**
2. **Measurement of the charge (Z)**

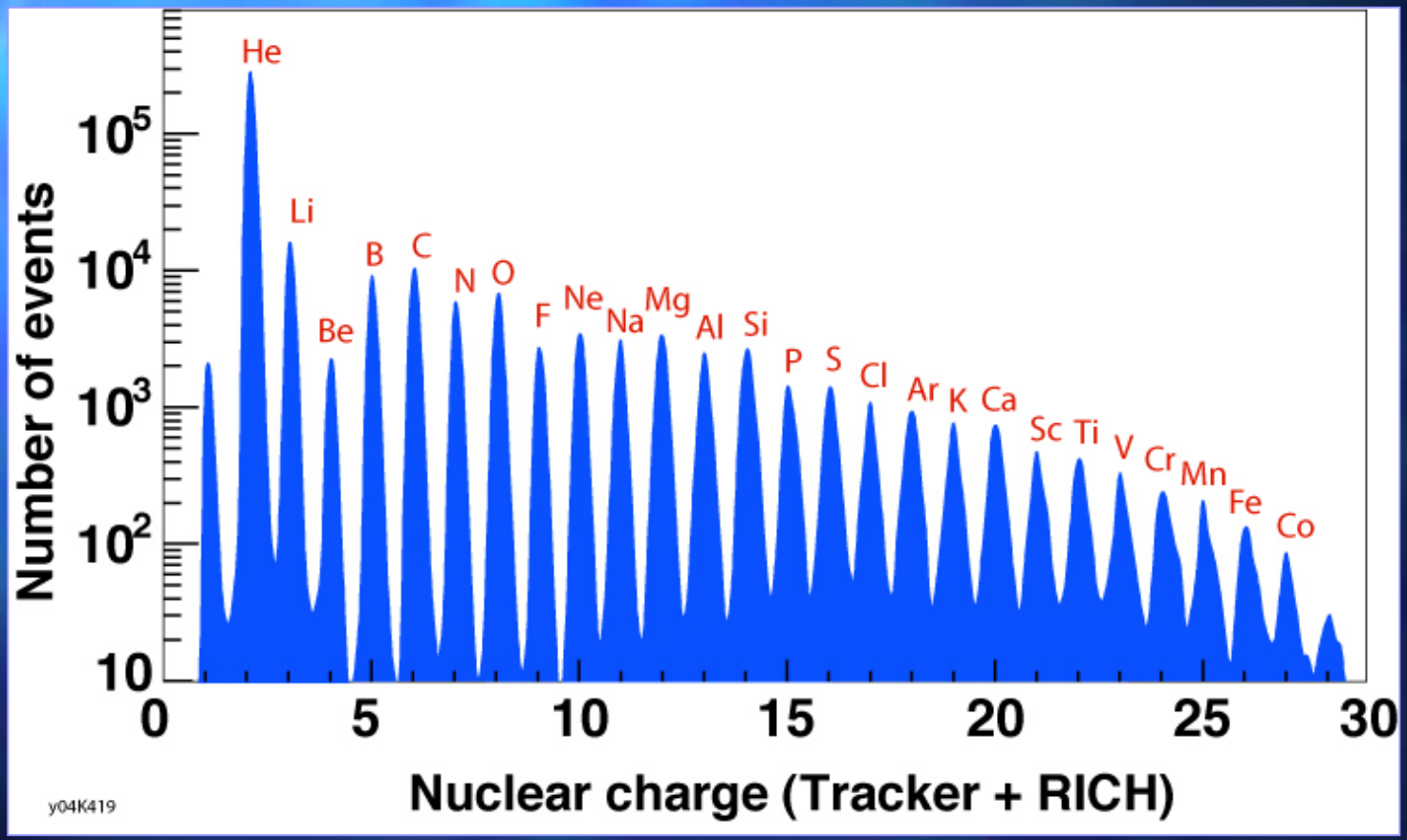



**Cerenkov**

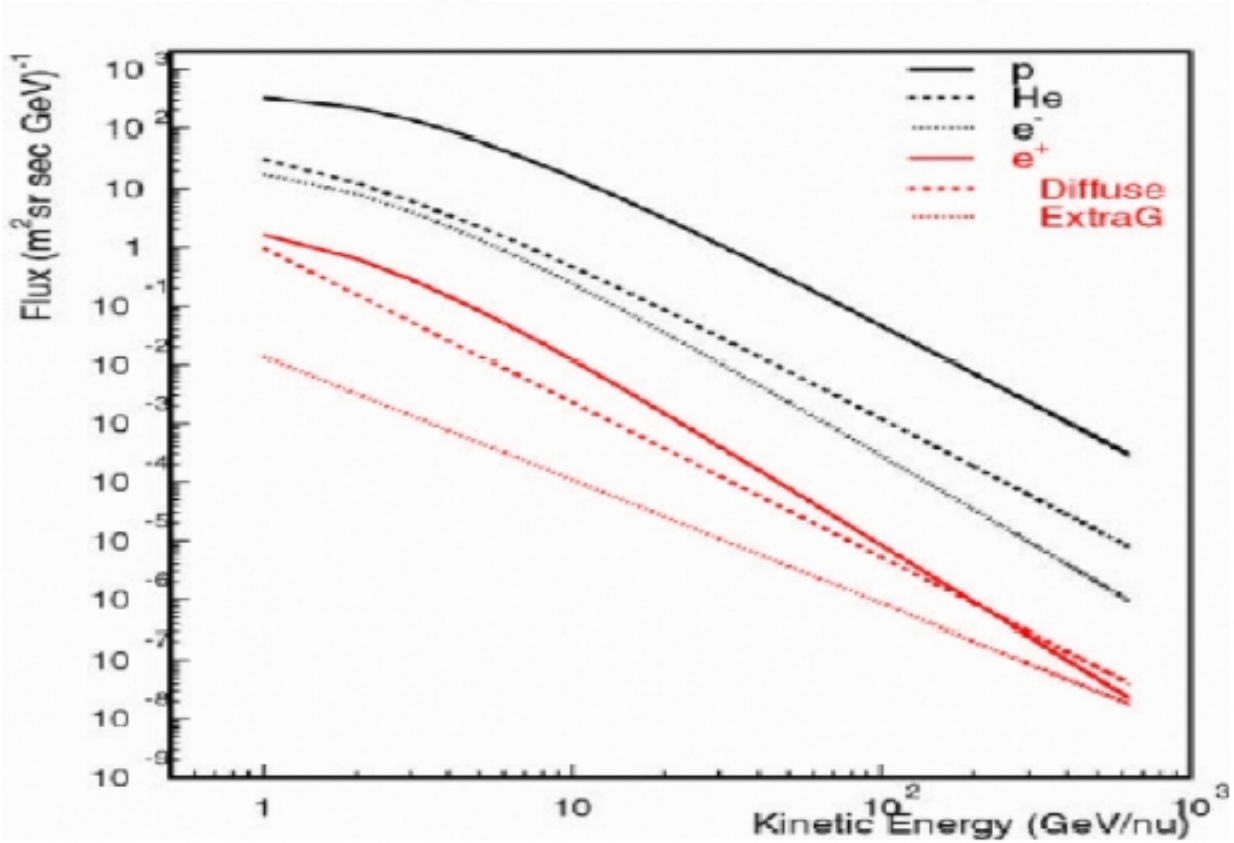
**light emitted in the radiator by relativistic charged particles.**



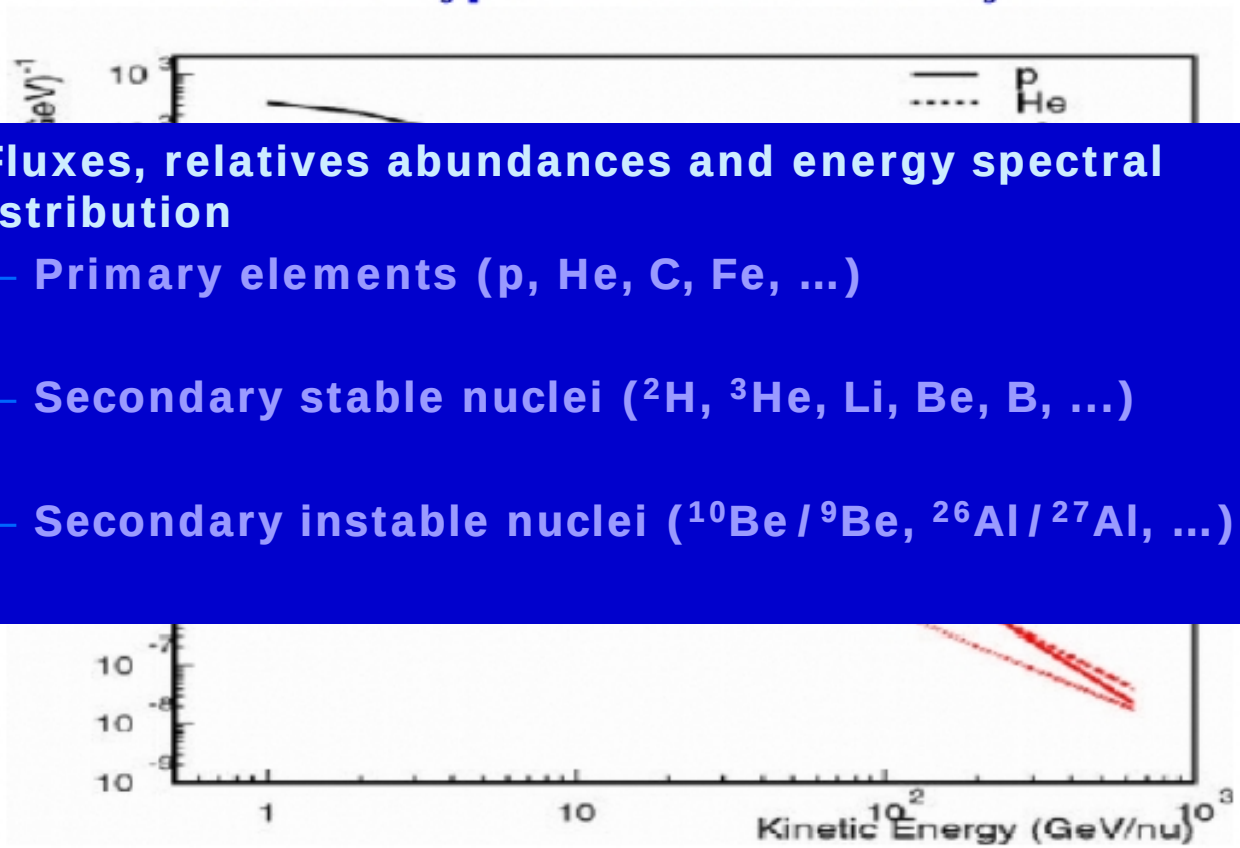
# The RICH detector: expected results



# Particle Types in the Cosmic Rays



# Particle Types in the Cosmic Rays

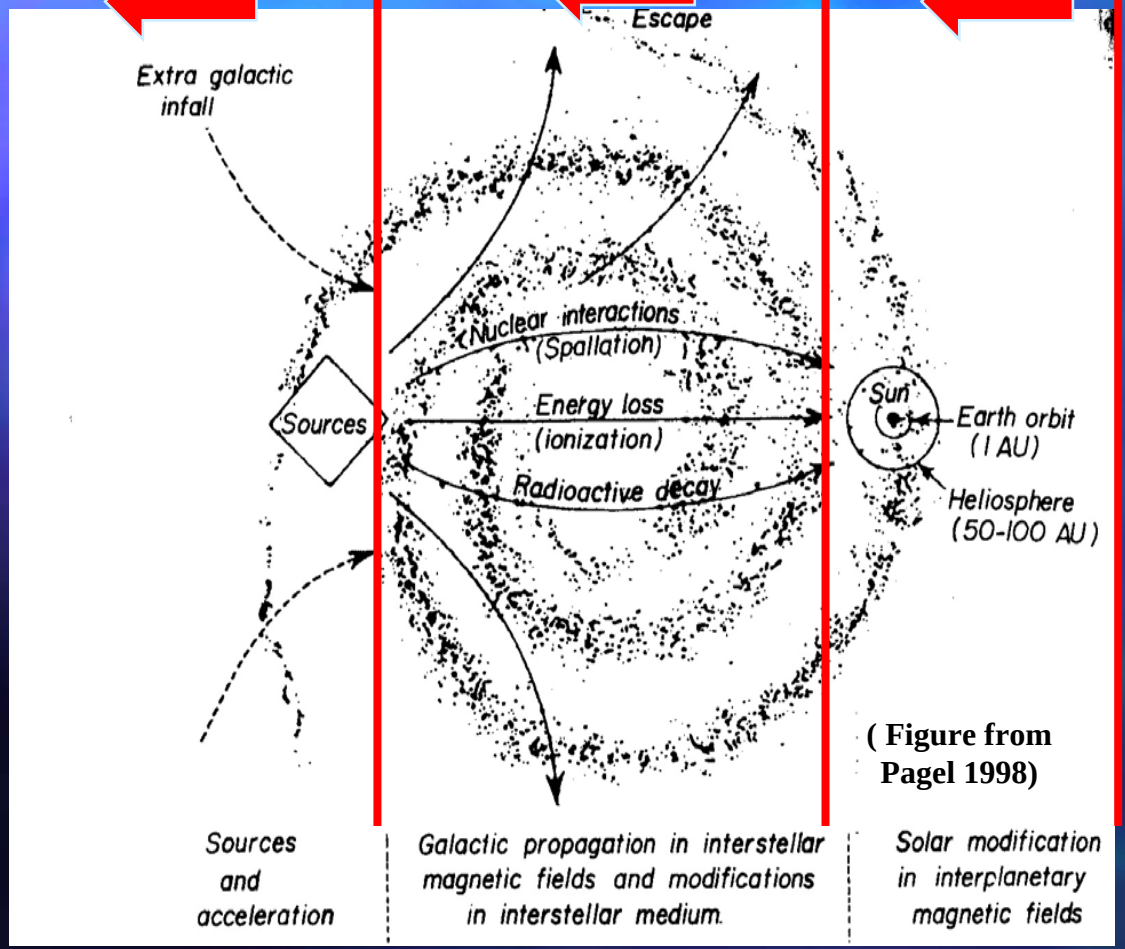



- **Fluxes, relatives abundances and energy spectral distribution**
  - **Primary elements (p, He, C, Fe, …)**
  - **Secondary stable nuclei ($^2$H, $^3$He, Li, Be, B, …)**
  - **Secondary instable nuclei ($^{10}$Be/$^9$Be, $^{26}$Al/$^{27}$Al, …)**

**Origin:**
**From where do the particles proceed? Which kind of acceleration mechanims does work?**

**Propagation**
**Interactions of particles through the Galaxy in the way to The Earth**

**Modulation**
**Effect of the particles interactions with the solar wind (magnetic field of the Sun , heliosfere)**




**( Figure from Pagel 1998)**

## How do the cosmic rays come to the Earth?

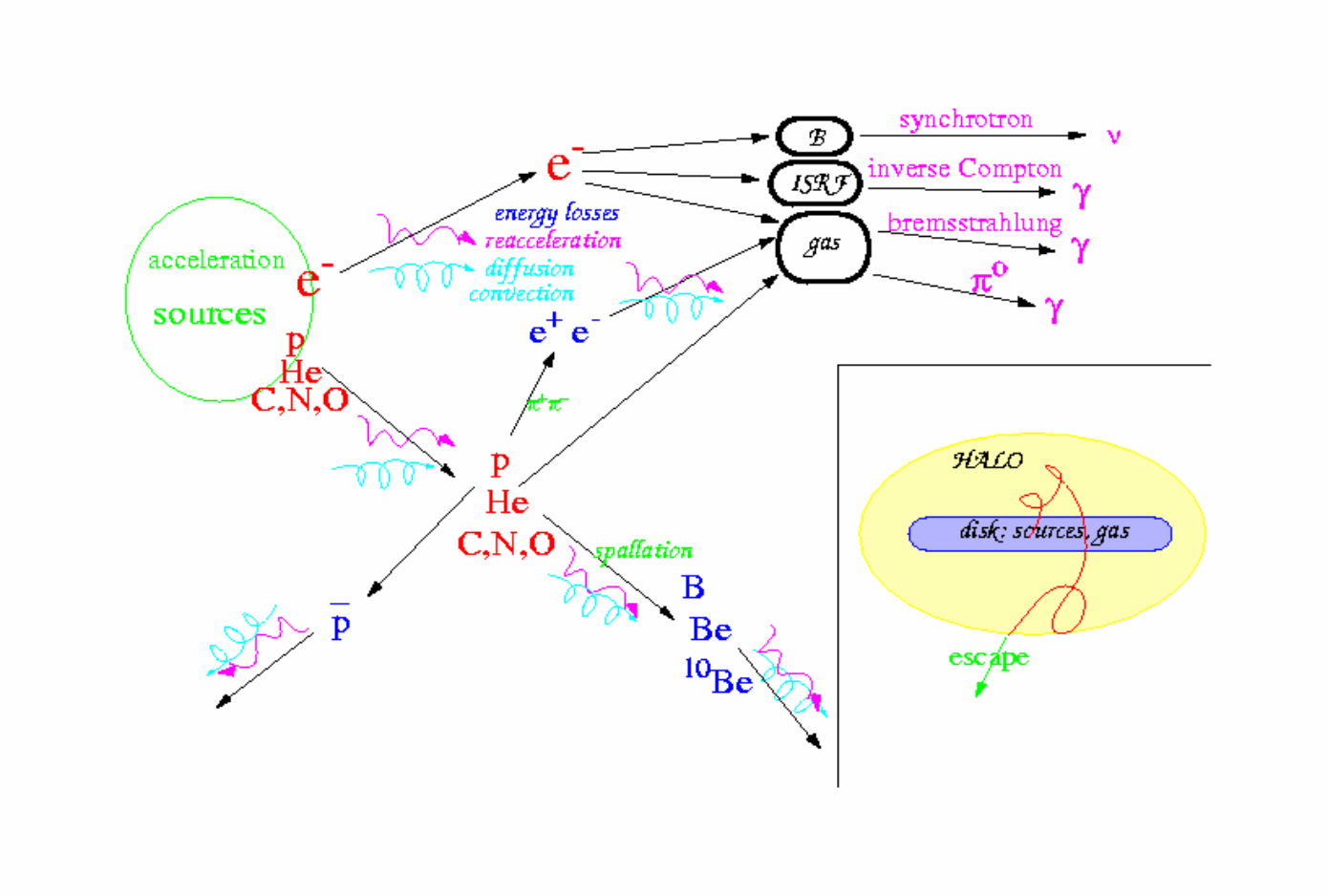
**The high energy cosmic ray nuclei are accelerated particles that move through the interstellar medium (ISM) where they experience scattering, re-acceleration and energy loss due to the irregularities of the ISM and to magnetic fields before reaching the Solar Neighbourhood**

# INFORMATION OBTAINED FROM COSMIC

- **PRIMARY:**
  - **Energy injected and spectrum of Q(E): the precise measurement of the energy spectra for primary elements, mostly H and He, allows the accurate determination of the spectral index : clues about the origin and acceleration process**
  - **Pattern of accelerated nuclei $S(n_i)$ : the precise measurement of the energy spectra for *primary elements* up to Fe will allow to obtain the abundance pattern**

- **SECONDARY NUCLEI:**
  - **Where they form: The precise measurement of the ratio secondary/primary spectra will allow to determine the size of the diffusive region or confinement volume, where cosmic rays move before escape of the galaxy.**
  - **When they form: Some of the new species created are radioactive. Thus, the unstable isotope spectra determination will give information about the time spent by the particles within the confinement region.**

# γ RAY ASTROPHYSICS




- γ diffuse background, both galactic and extragalactic
- dark matter search through χ annihilation
- γ source location

# EGRET

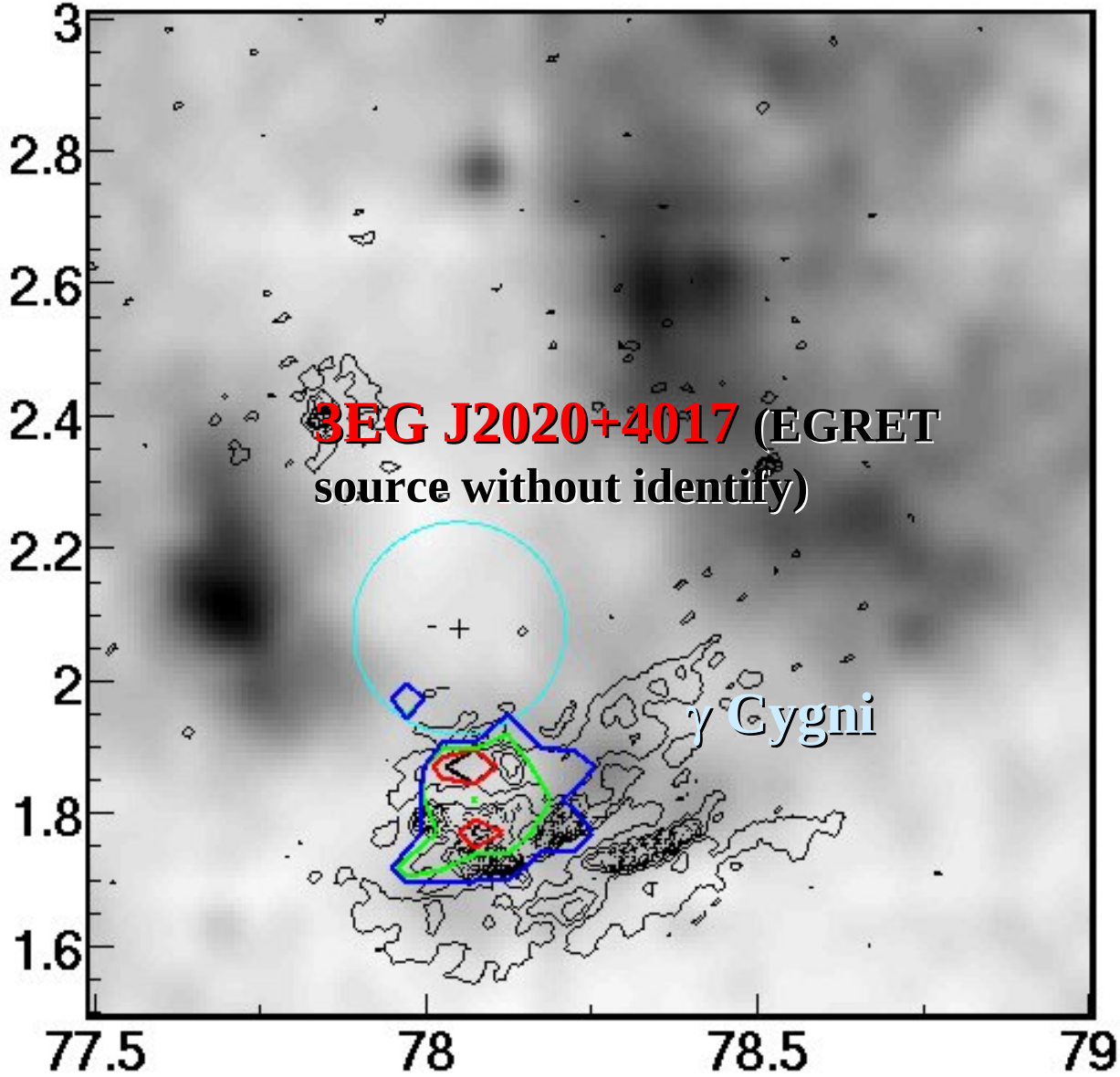
| Name | R.A. (deg) | Decl. (deg) | $l$ | $b$ | $\theta_{95}$ | $F$ | $\Delta F$ | $\gamma$ | Counts | $(TS)^{1/2}$ | VP | ID | Other Name | Note | Reference | $z$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3EG J0617+2238..... | 94.30 | 22.63 | 189.00 | 3.05 | 0.13 | 51.4 | 3.5 | 2.01 | 1075 | 17.4 | P1234 | | 2EG J0618+2234 | @ | 1,15,17 | |
| | | | | | | 33.2 | 6.9 | ±0.06 | 146 | 5.4 | .2+ | | GEV J0617+2237 | C | | |
| | | | | | | 62.3 | 8.5 | | 237 | 8.7 | 1.0 | | IC 443 SNR? | | | |
| 3EG J2020+4017..... | 305.25 | 40.30 | 78.05 | 2.08 | 0.16 | 123.7 | 6.7 | 2.08 | 1974 | 21.0 | P1234 | | 2EG J2020+4026 | @ | 1,15,17,24 | |
| | | | | | | 132.3 | 15.9 | ±0.04 | 398 | 9.5 | 2.0 | | GEV J2020+4023 | C | | |
| | | | | | | 88.8 | 22.1 | | 116 | 4.5 | 7.1 | | γCyg SNR? | | | |

Many interesting sources with 'C' flag

*Notes.*—@, see note in text; E, extended source (applies only to the Large Magellanic Cloud); em, possibly extended source or multiple sources (based on source location maps inconsistent with a single point source or poor fit to the calibrated PSF, from the observation or sum of observations presented in the first entry for the source); C, source confusion may affect flux, significance, or position. (Below-threshold excesses are considered in assigning this symbol, so some weak sources may be designated as confused despite having no other catalog sources nearby, e.g., in Fig. 4.) Sources with no entry (other than @) in this column are consistent with the EGRET PSF for a single source.

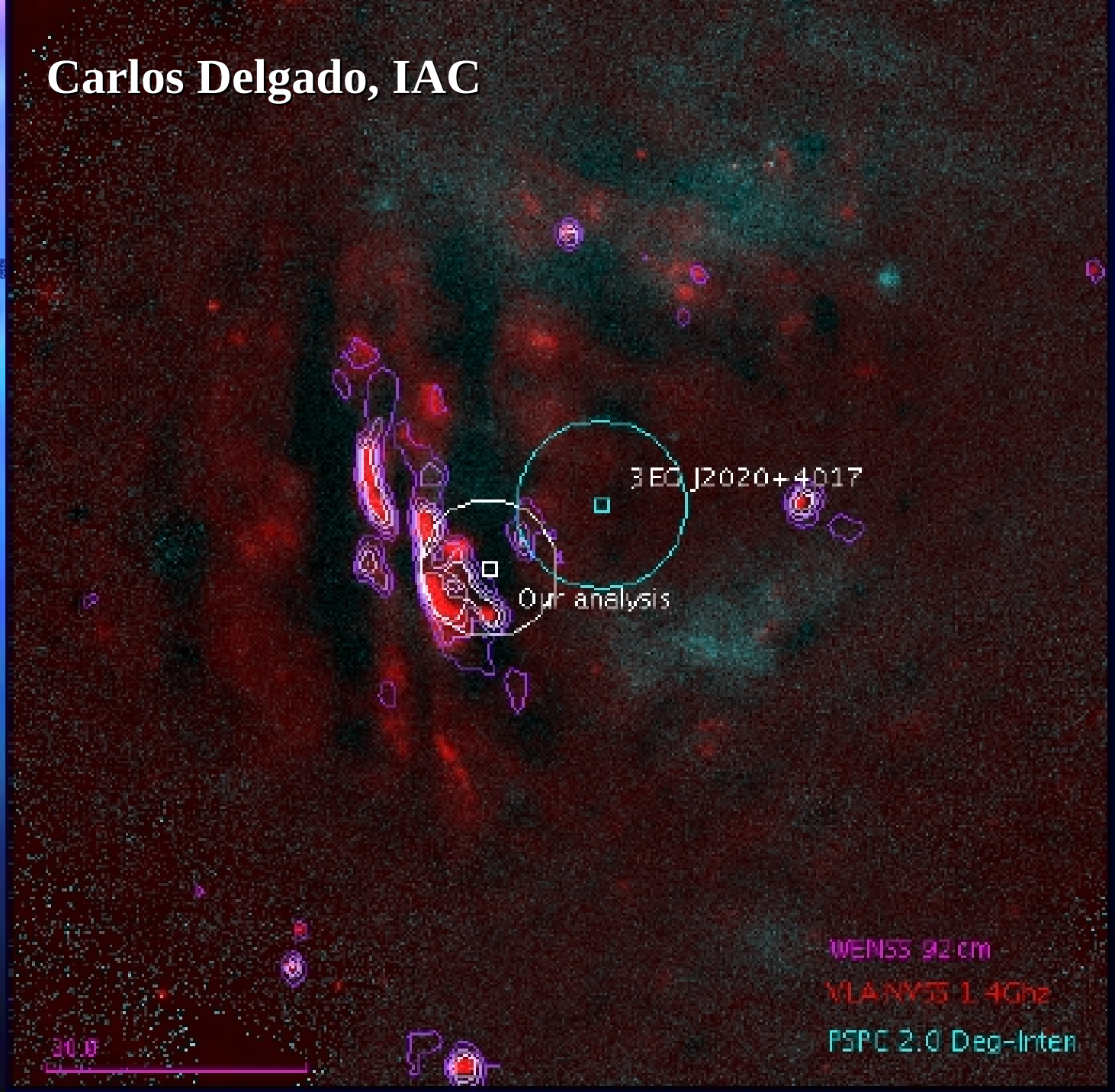
Bayessian analysis

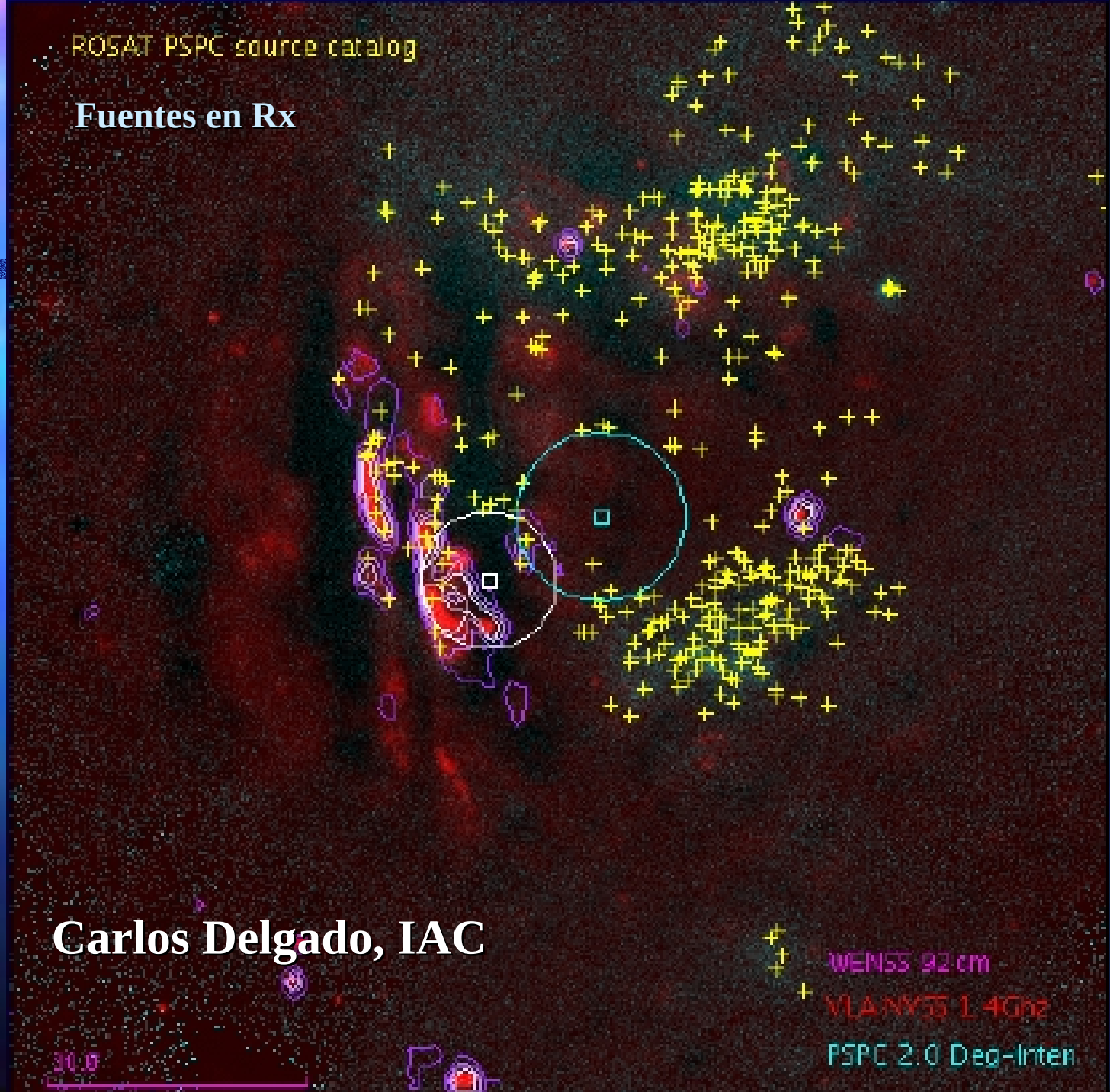
This source is in an active region in X and radio bands

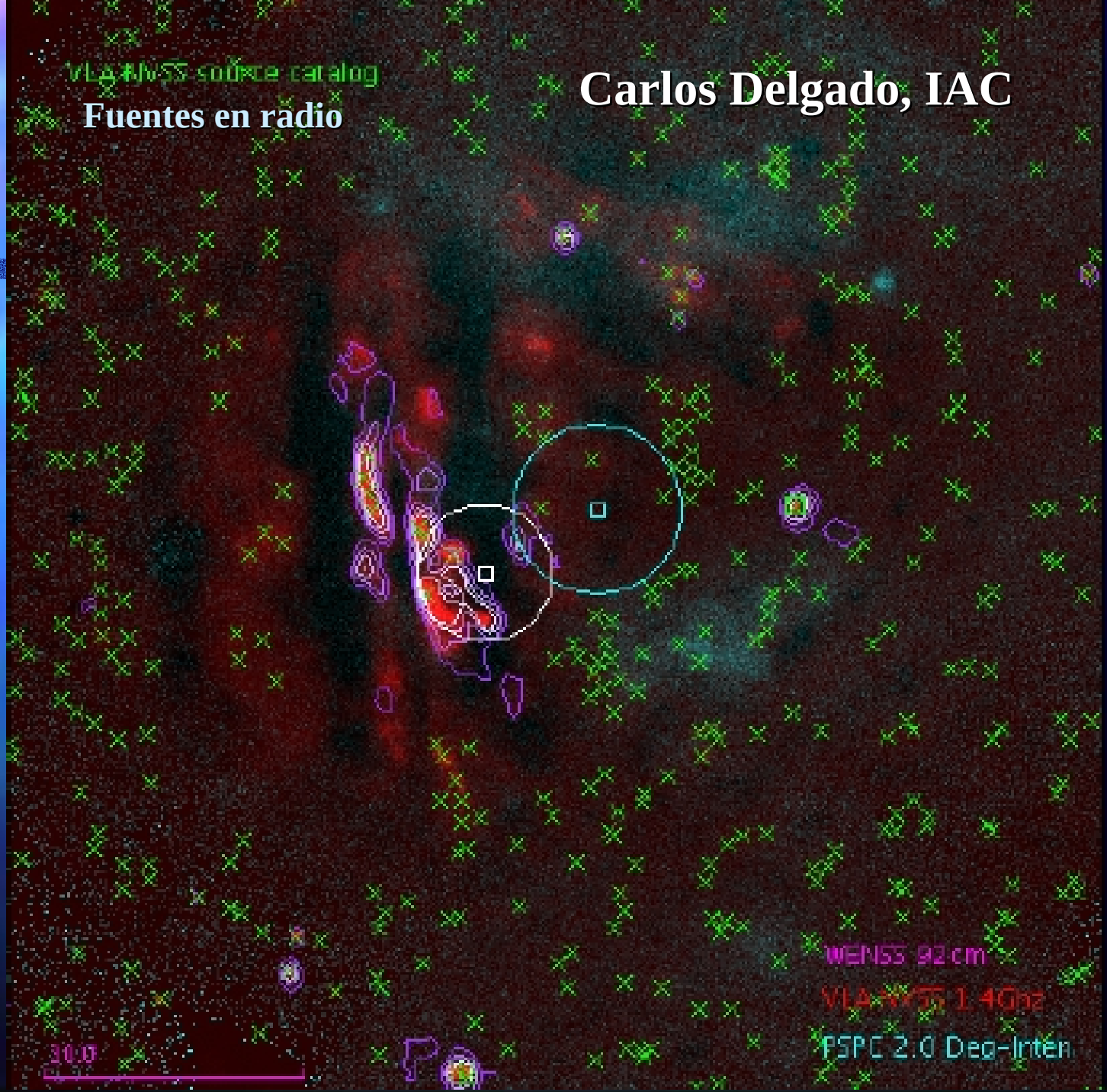



Carlos Delgado, IAC

# Carlos Delgado, IAC




ROSAT PSPC source catalog
Fuentes en Rx
Carlos Delgado, IAC
WENSS 92 cm
VLA NVSS 1.4GHz
PSPC 2.0 Deg-Inten
30.0




# Fuentes en radio

Carlos Delgado, IAC

# Carlos Delgado, IAC

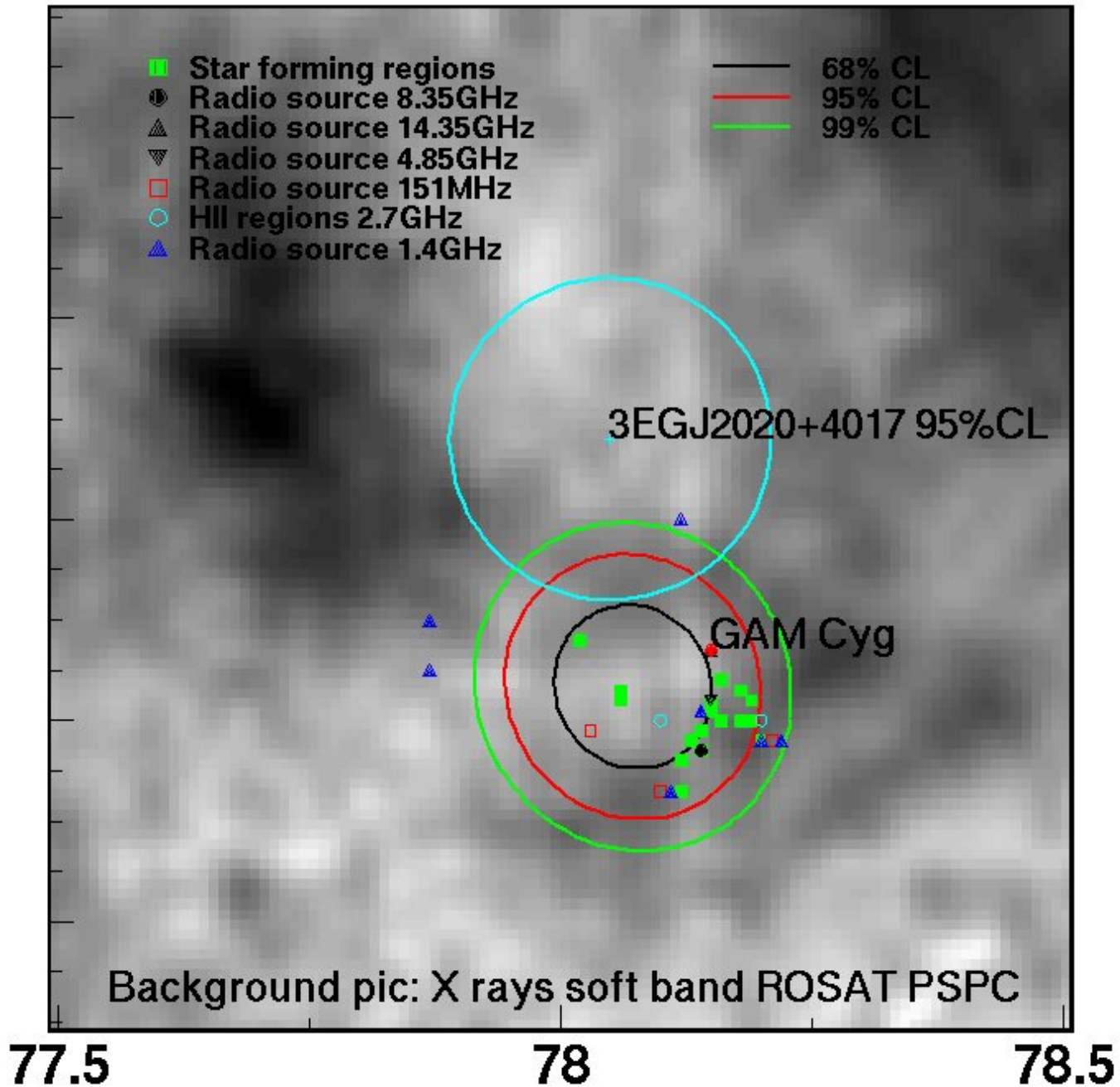
Avedisona star forming regions catalog

## Regiones de formación estelar

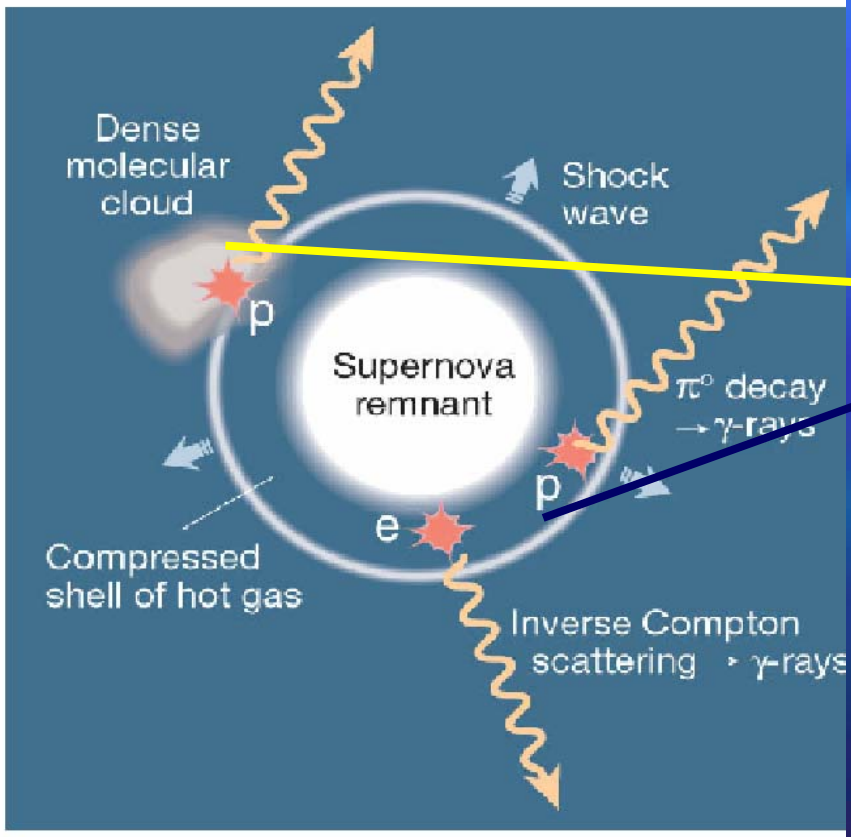


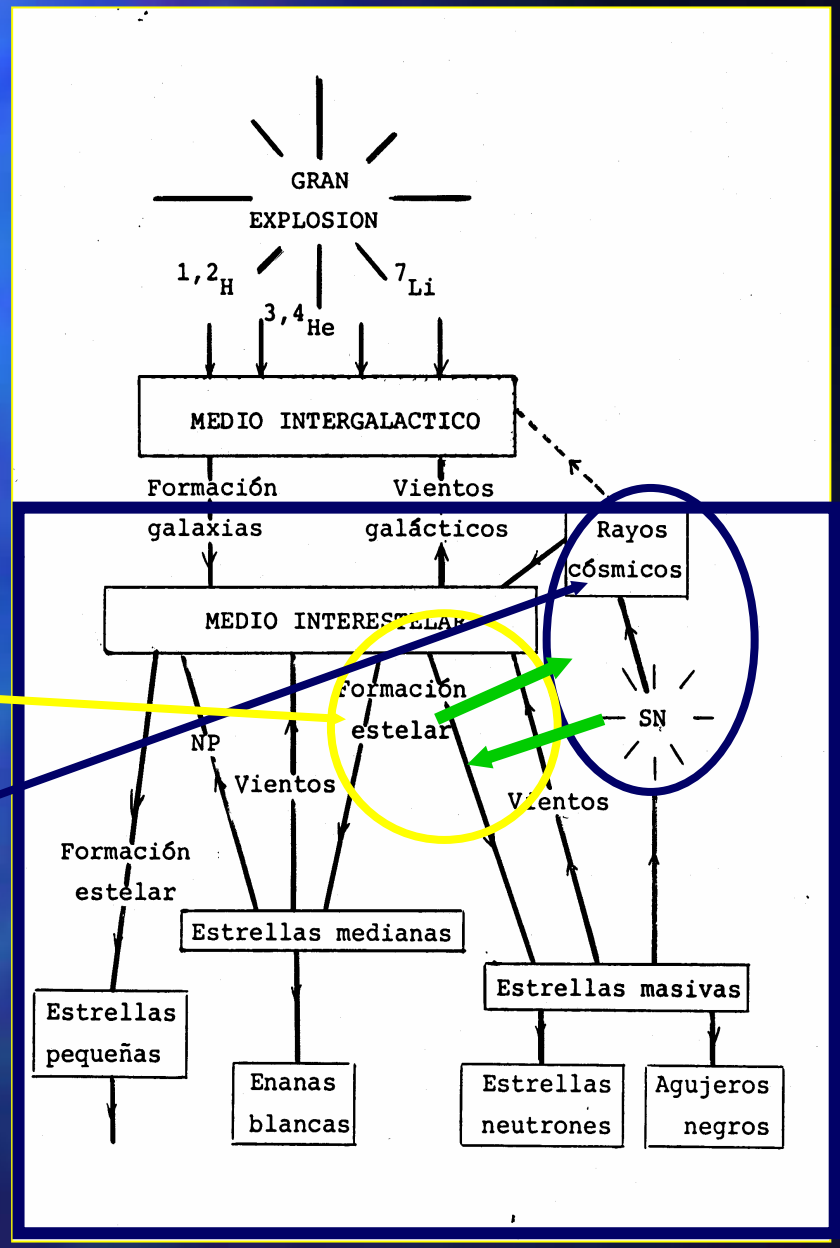
The new location is in the shell of the remnant SN W66 of γ Cygni

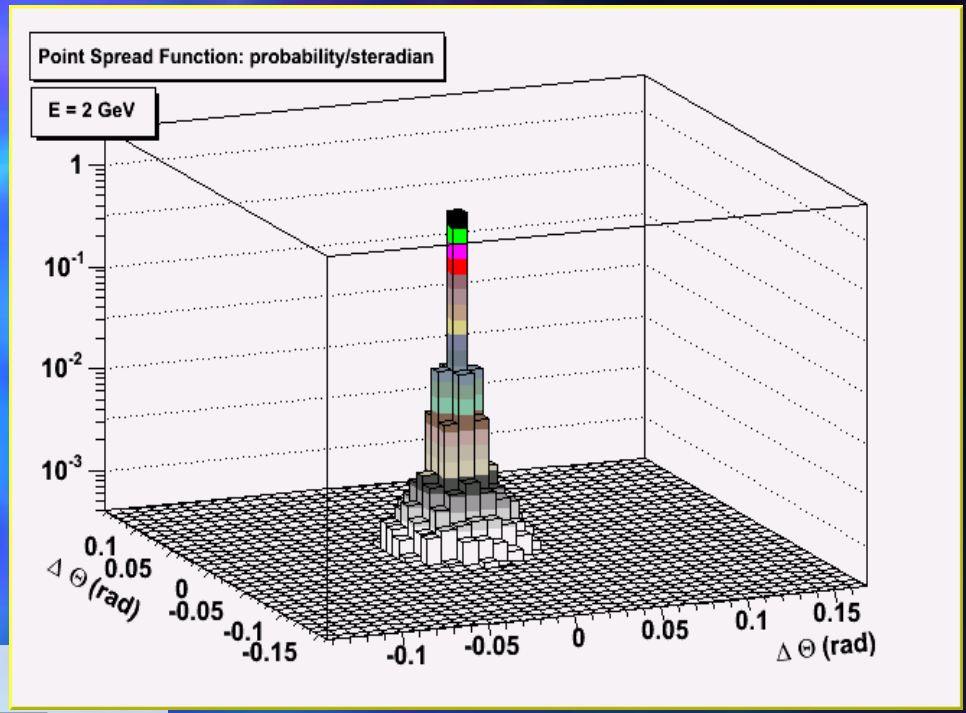
There is star-forming regions around

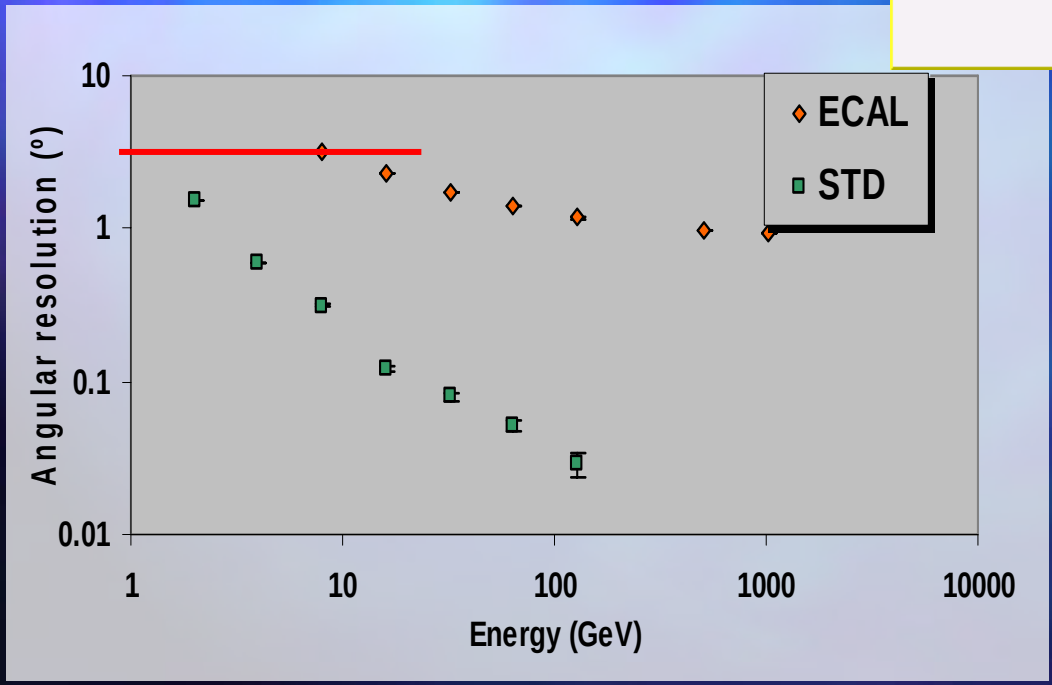


**The SN remnants are close to molecular clouds: star formation sites.**




Point Spread Function: probability/steradian
E = 2 GeV
1
$10^{-1}$
$10^{-2}$
$10^{-3}$
0.1
0.05
0
-0.05
-0.1
-0.15
Δ Θ (rad)
-0.1
-0.05
0
0.05
0.1
0.15
Δ Θ (rad)


10
1
0.1
0.01
Angular resolution (°)
ECAL
STD
1
10
100
1000
10000
Energy (GeV)

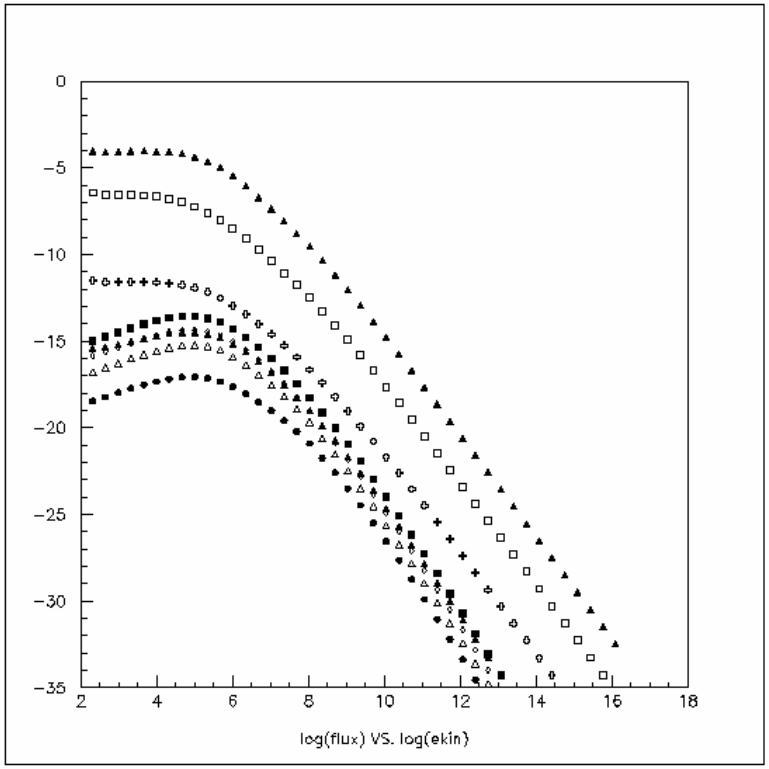
- *…SN progenitors into OB associations, formed on a short timescale from the collapse of a giant molecular cloud (e.g. Blitz, 1993). The explosion of the first SN among such an association is thus to be followed by several tens of others within a few million years, at approximately the same location.*

- *This results in the formation of a `multiple supernova remnant', powered by both the SN explosions and the strong winds of Wolf-Rayet stars in the OB association, which grows as a large bubble of hot, tenuous plasma known as a superbubble (e.g. MacLow & McCray, 1988; Tomisaka 1998; Korpi et al. 1999). Superbubbles (SBs) are commonly observed in X-rays in our and nearby galaxies.*

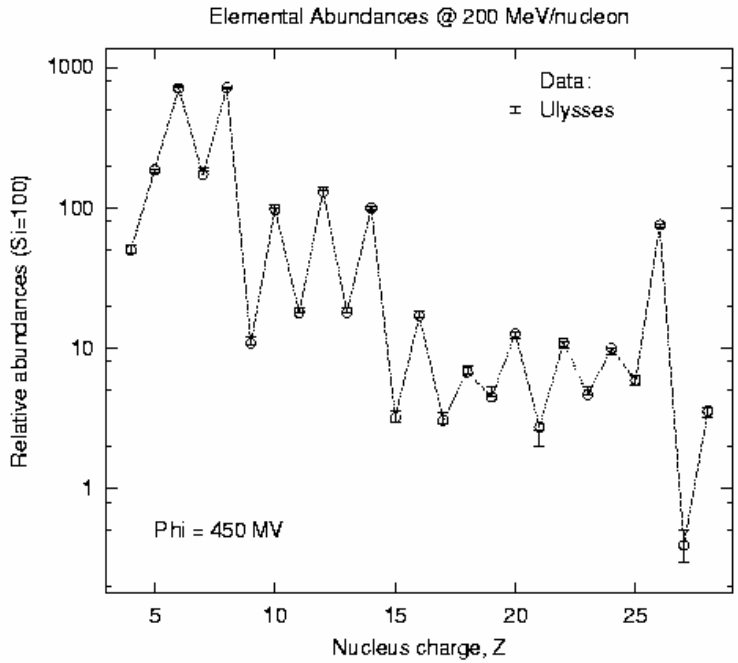
- *The impact of multiple SNe on their environment is large, and if SN explosions are indeed the GCR source of energy, the fact that most SNe occur in groups should incite us to take their collective effect into account when considering cosmic ray acceleration. In particular, it seems natural to expect an intense supersonic turbulence inside the accelerator, due to the interaction of individual SN shocks and strong stellar winds in the SBs. …(Drury, et al)*

# Source:

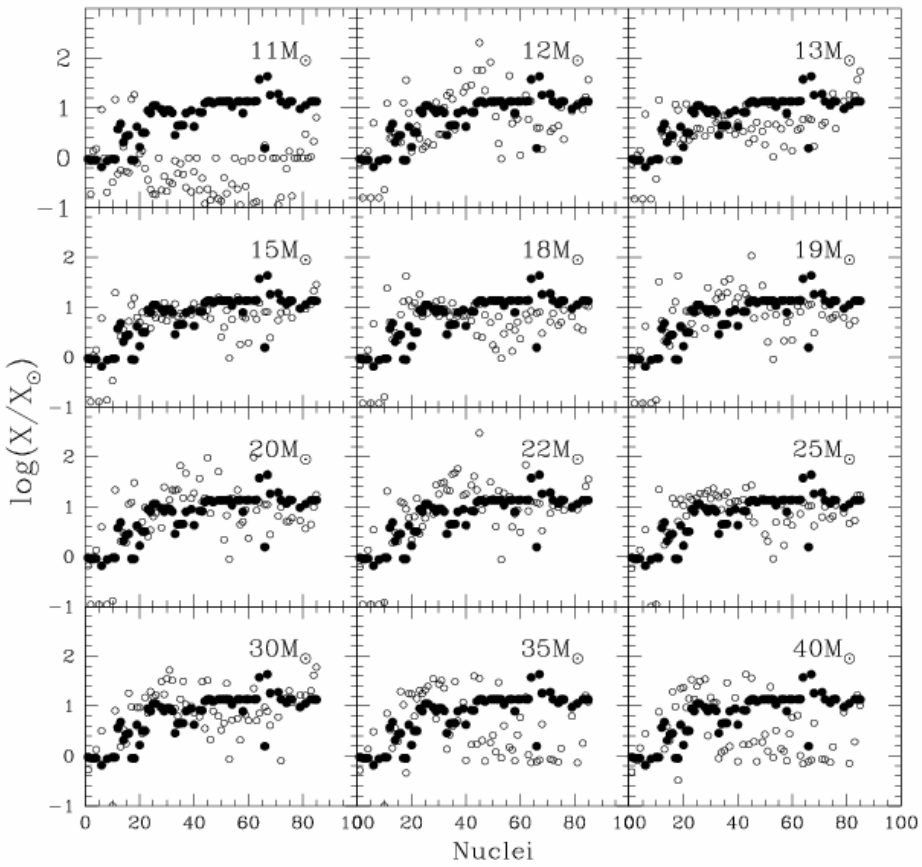
## Obtention of spectra for any nuclei




**The precise measurement of the energy spectra for *primary elements* up to Fe will allow to obtain the abundance pattern. Its comparison with elemental abundances ejected by different mass stars will give clues about the type of source.**



***The most striking difference between the isotopic composition of the Galactic Cosmic Ray Sources (GCRS) and the solar system is the factor 3 enhanced $^{22}Ne/^{20}Ne$ ratio observed in the GCRS, while isotopic ratios involving heavier isotopes like magnesium or silicon have near solar values. Wolf--Rayet (WR) stars appear as a promising source for the $^{22}Ne$ excesses. Indeed, during the WC phase, a particular stage during the WR phase stellar models predict that $^{22}Ne$ is significantly enhanced in the stellar winds.***



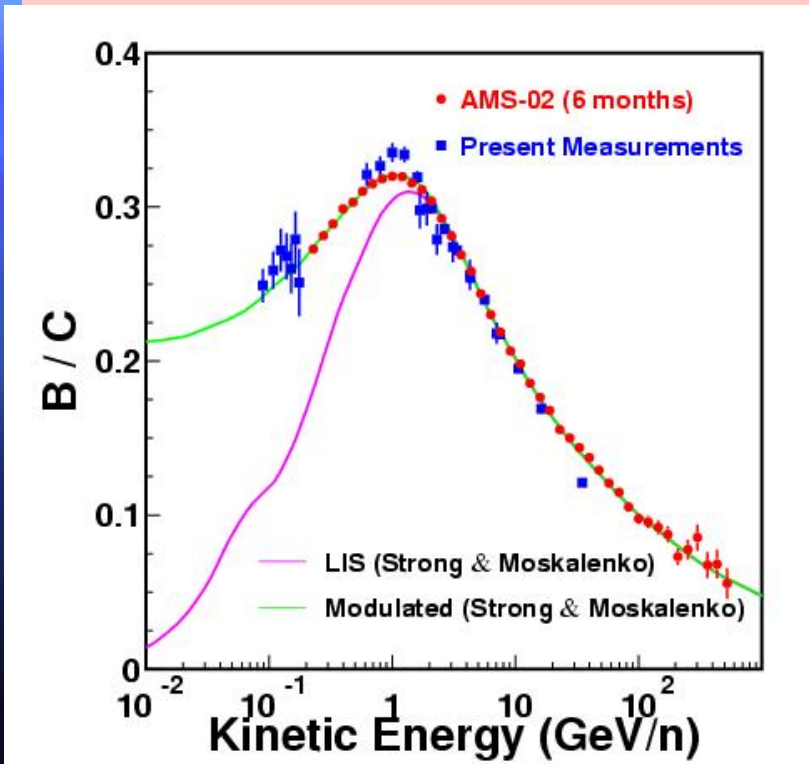
# Núcleos ligeros

**AMS will measure the spectrum up E $\lesssim$1 TeV/n**

**In 3 years will collect**

**$\approx 10^5$ C with E > 100 GeV/n**

**and $\approx 10^4$ B with E > 100 GeV/n**




**The precise measurement of the ratio secondary/primary spectra will allow to determine the quantity of matter traversed and, hence, the size of the diffusive region or confinement volume, where cosmic rays move before escape of the galaxy.**

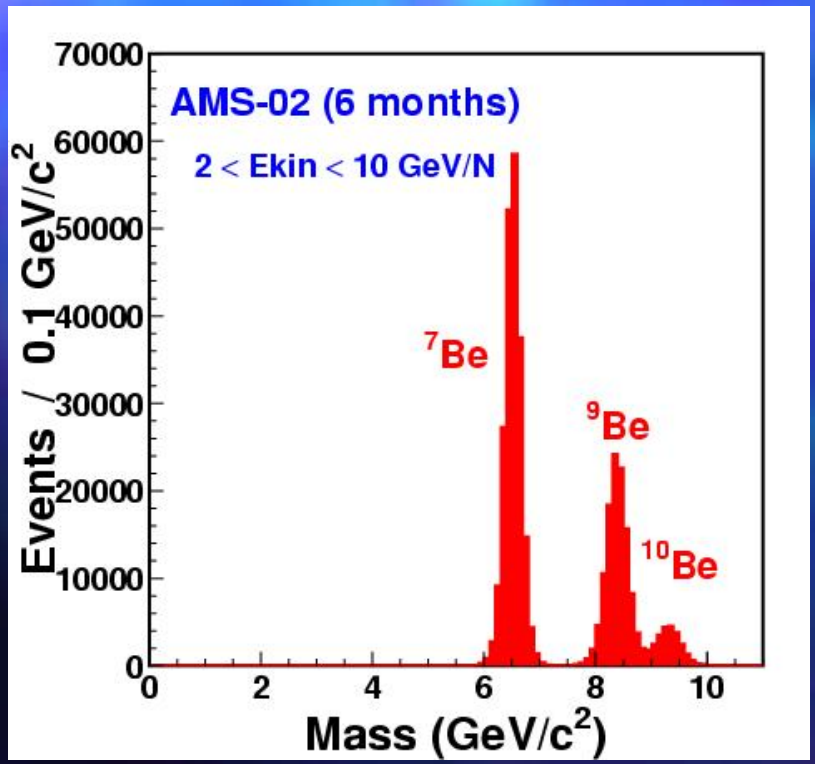
# Light Isotopes

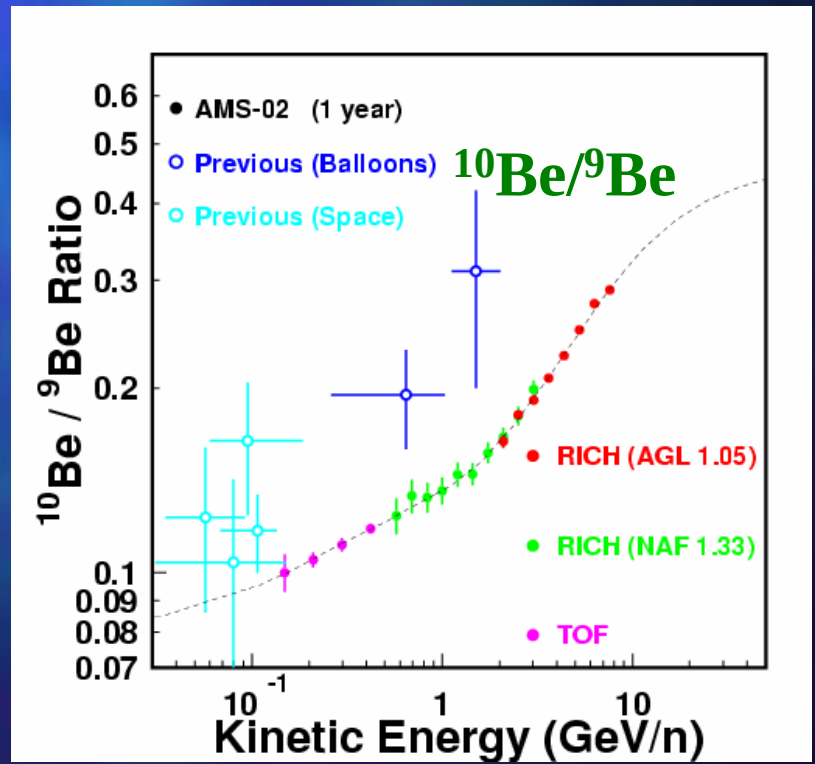
- **Radioactive nuclei ≡ *Cosmic Ray Chronometers***

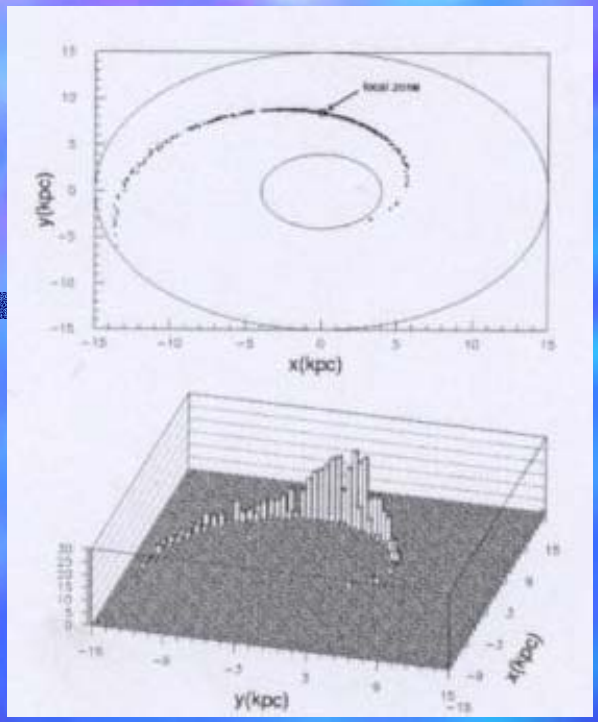
  $^{10}$Be $t_{1/2}$ = 1.51 Myr

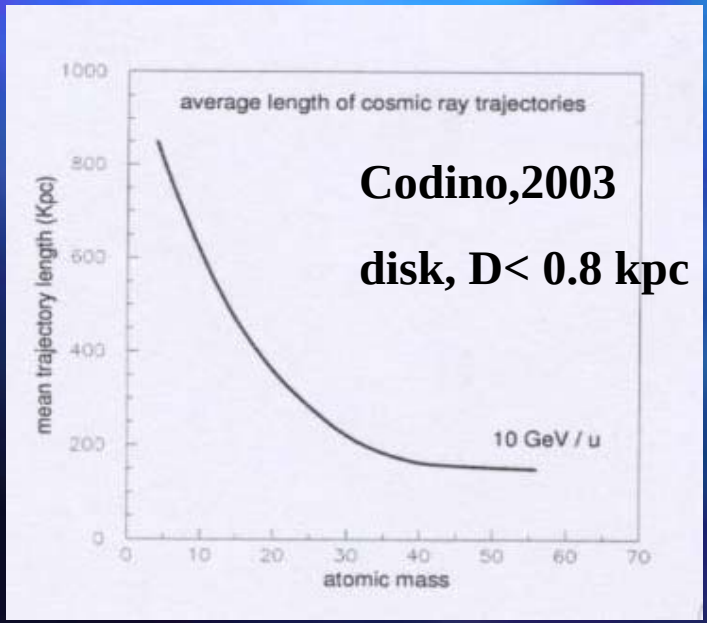
  $^{26}$Al $t_{1/2}$ = 4.08 Myr

- **Some of the new species created are radioactive. Thus, the unstable isotope spectra determination will give information about the time spent by the particles within the confinement region.**



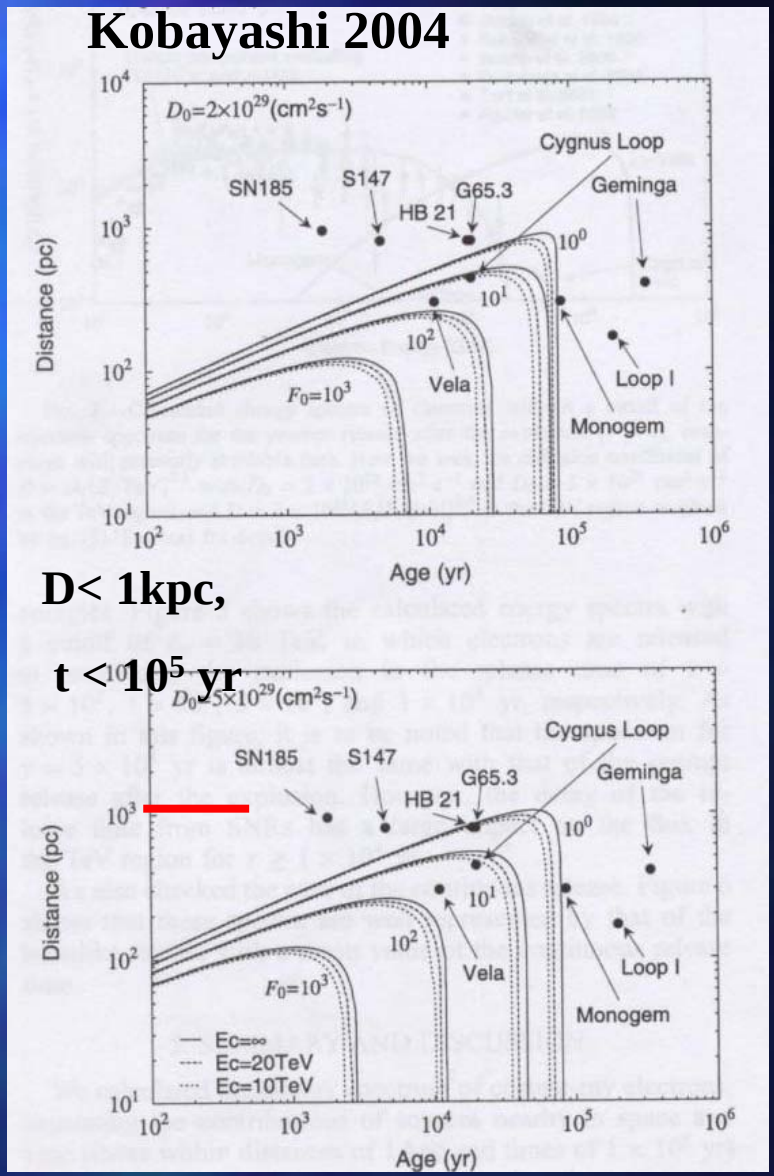



**Codino,2003**

**disk, D< 0.8 kpc**

**Kobayashi 2004**




**D< 1kpc,**

**t <$10^5$ yr**

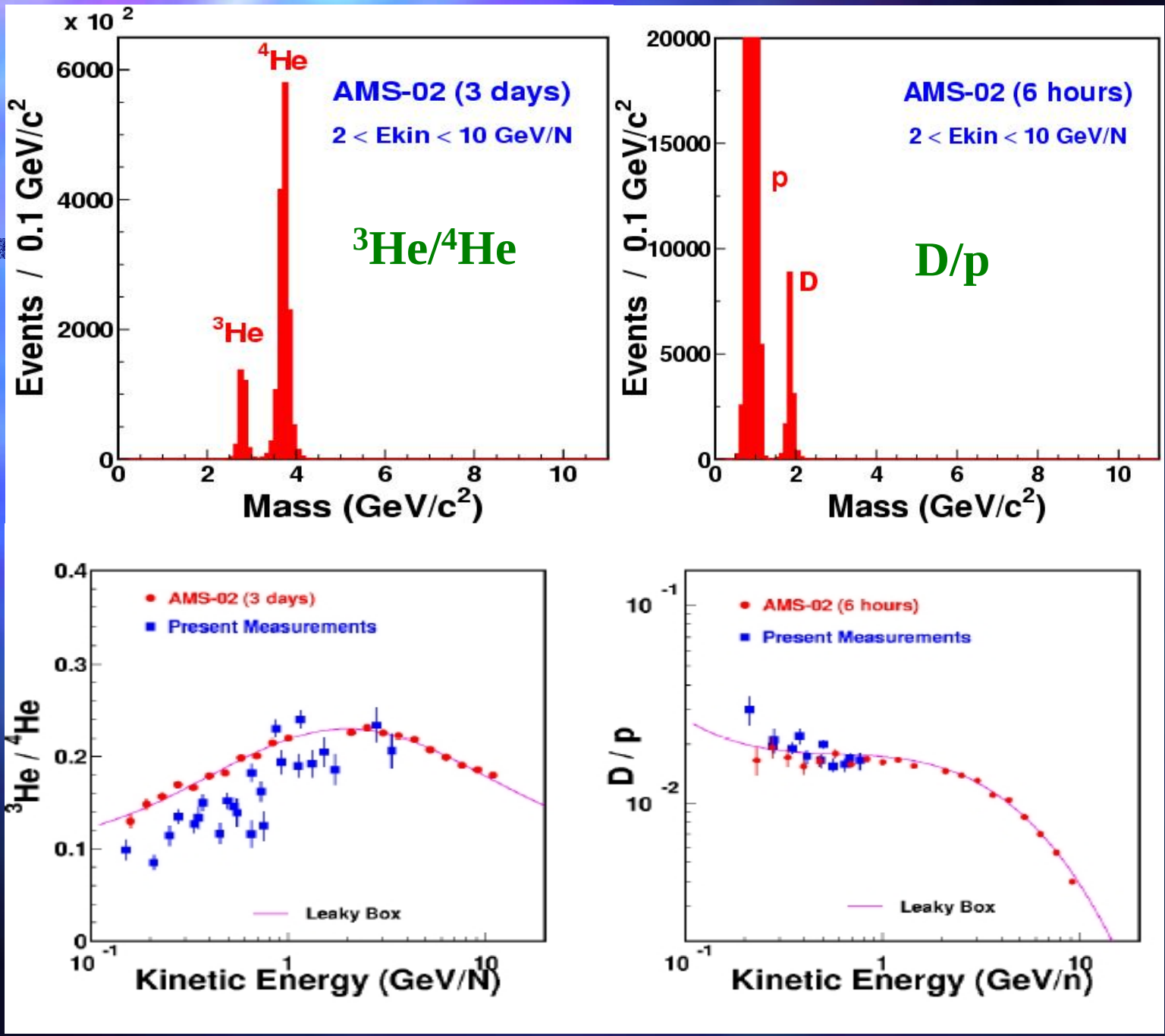
# Summary

## The connection cosmic rays and star formation

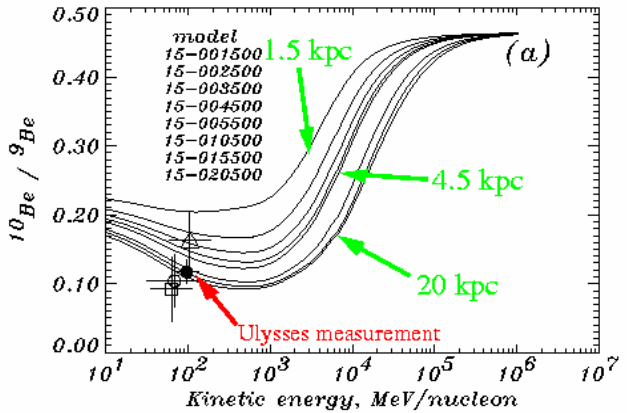
- **Cosmic Rays: Origin, propagation, measurements…**
  - **Measuring the spectra for different isotopes**
  - **To obtain the original spectra (propagation models)**
  - **Relation of these spectra with the sources of cosmic rays**

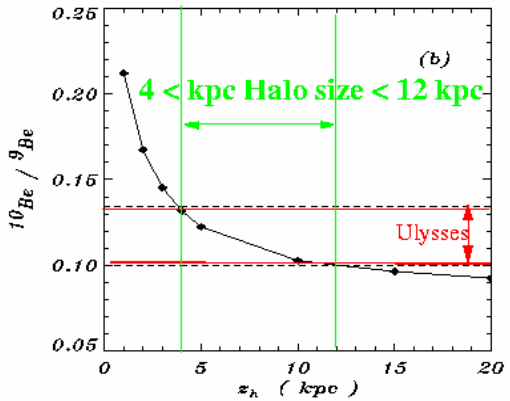
- **Star formation: production of elements**
  - **Stars form and die**
  - **Some elements are ejected to the ISM: abundances. Only elements created by nucleosynthesis.**
  - **Light elements: Li, Be and B**

- **Measurements of abundances in the cosmic rays**
- **Abundances of light elements: how to produce them**
- **Possible cosmic rays sources: relation on star formation**


x 10 2
Events / 0.1 GeV/c2
4He
3He
AMS-02 (3 days)
2 < Ekin < 10 GeV/N
3He/4He
Mass (GeV/c2)
Events / 0.1 GeV/c2
p
D
AMS-02 (6 hours)
2 < Ekin < 10 GeV/N
D/p
Mass (GeV/c2)
3He / 4He
AMS-02 (3 days)
Present Measurements
Leaky Box
Kinetic Energy (GeV/N)
D / p
AMS-02 (6 hours)
Present Measurements
Leaky Box
Kinetic Energy (GeV/n)

$^{10}$Be determination of halo size
for reacceleration model

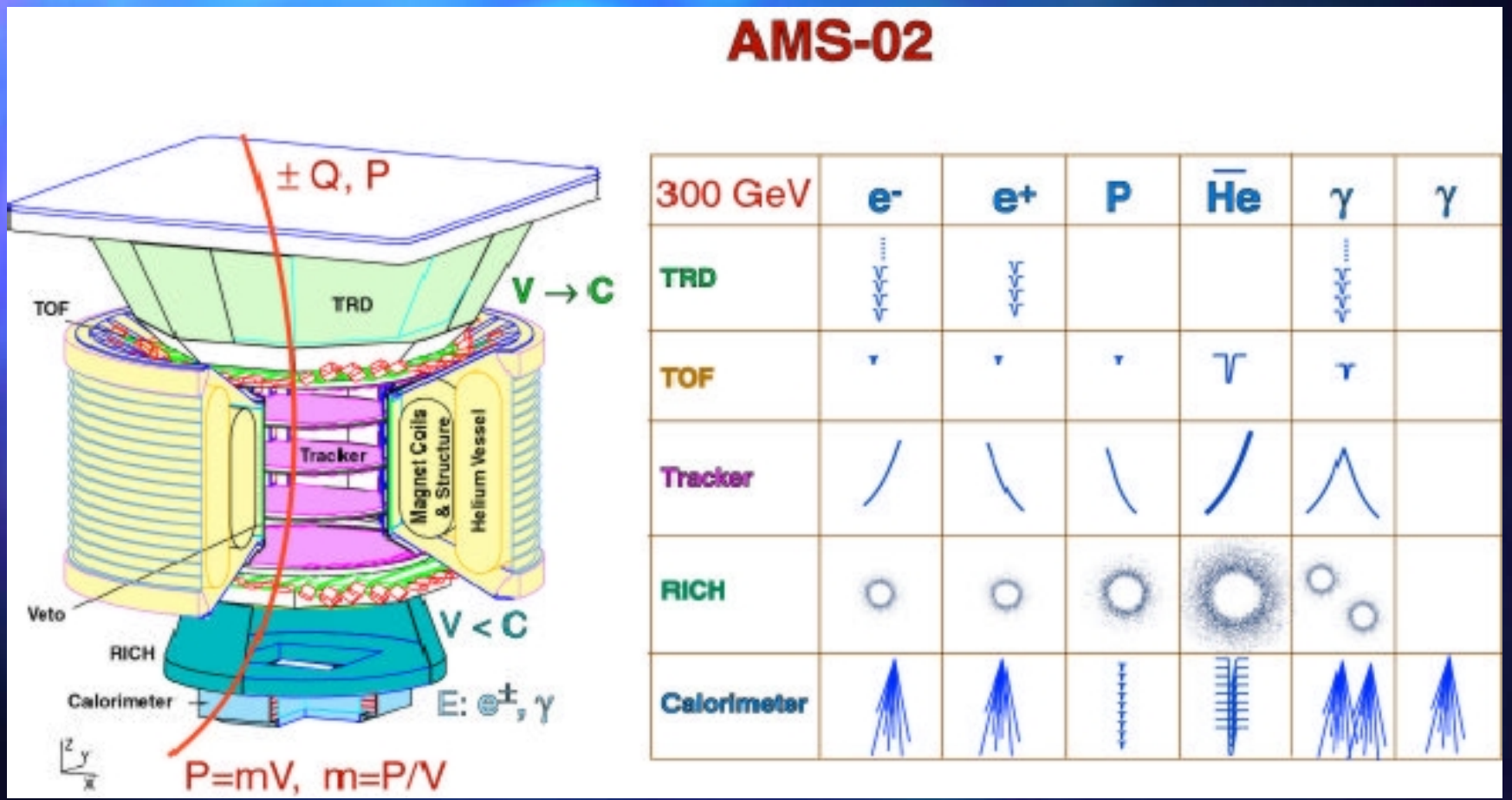



**El tamaño del halo H > 4 kpc**

# AMS detector

Set of sub detectors devoted to the measurement of energy and particle identification: Z, mass,...



# The transport equation

$$\frac{\partial N_i(E)}{\partial t} = \overset{1}{-\frac{N_i}{\gamma\tau_i}} + \overset{2}{Q_i(E)} \overset{3}{-Dif.} + \overset{4}{\frac{\partial}{\partial E}(b_i(E)N_i(E))}$$

$$- \overset{5}{\left[\sigma_{He,i}(E)n_{He} + \sigma_{p,i}(E)n_H\right]v_i N_i(E)}$$

$$+ \overset{6}{\sum_j \int_0^\infty N_j(E')\left[n_{He}\sigma_{He,ji}(e,E') + n_H\sigma_{pji}(E,E')v_j\right]dE'}$$

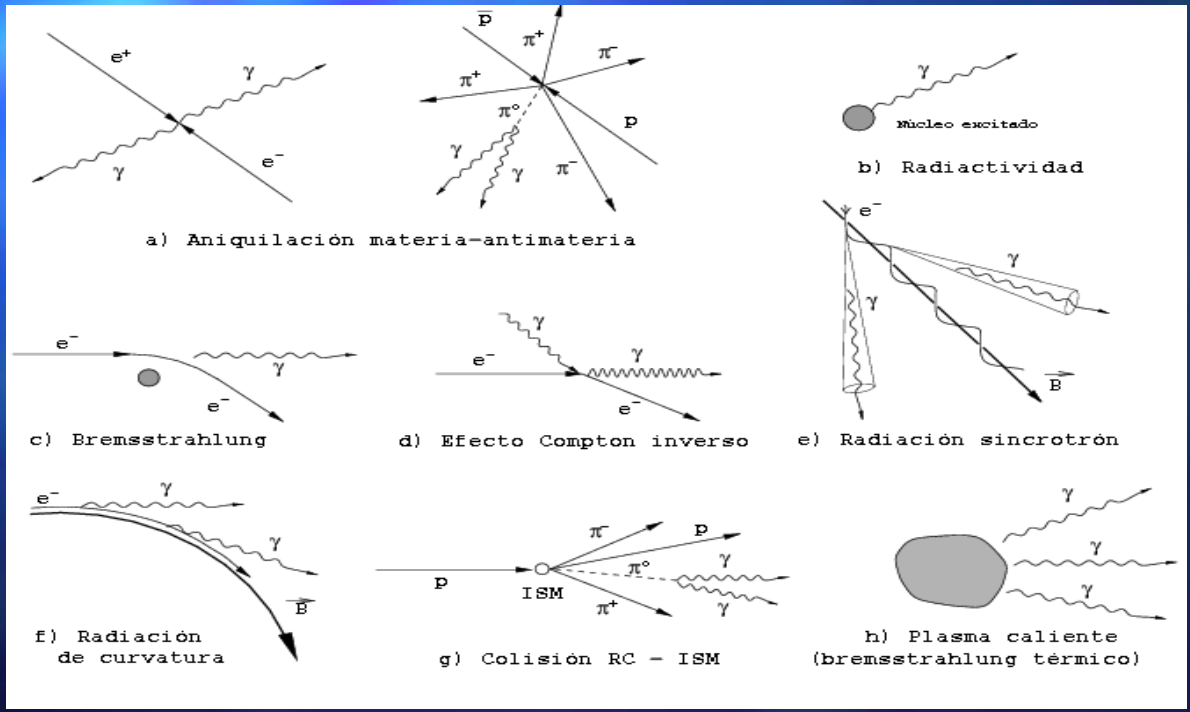
1) Radiactive decay loss
2) Original source of particles
3) Difussion term
4) Ionization loss
5) Destruction by spallation of nuclei
6) Formation of new nuclei by spallation of other more massive ones

**The galprop model solves the transport equation including difussion, convection and reacceleration**

Gamma Rays are not deviated by the magnetic fields. They can be associated to their sources.

Gamma rays from the galactic disk are produced by the decays of neutral pions coming from the interactions of the cosmic rays with the interstellar medium.

It is possible to obtain the cosmic ray density by measuring the diffuse gamma ray from the galactic plane. It is necessary to know the background in order to search for rare events.



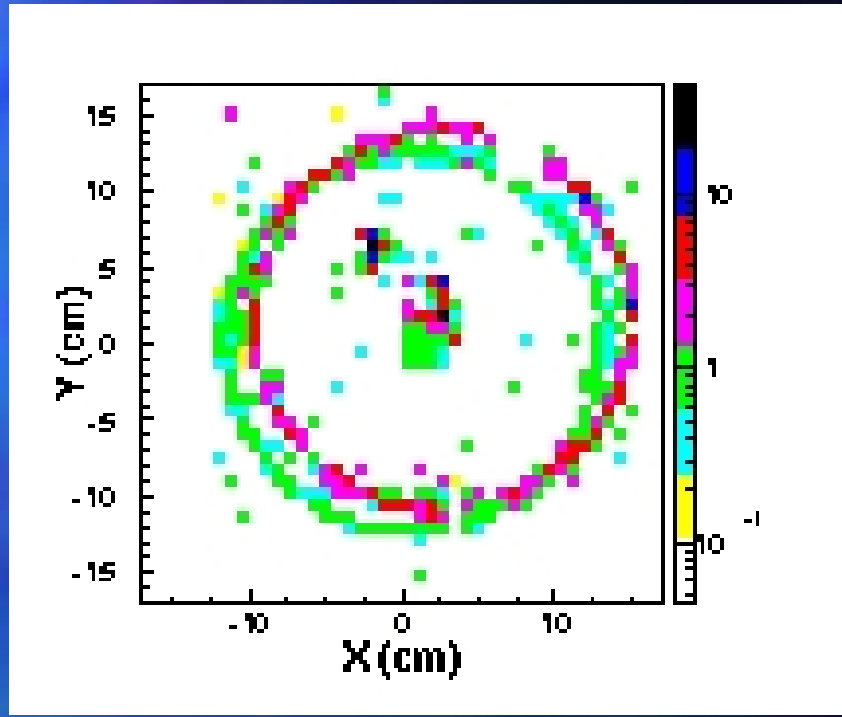
$$\frac{d^2N}{d\lambda dl} = \frac{2\pi\alpha z^2}{\lambda^2}\sin^2\theta_c$$

l= distance in the medium

λ= wavelength

Z= charge of particles

α= fine structure constant




**The spectrum is shifted to short wavelength**

**The number of photons depends on Z**

**The measure of the angle $\theta_c$ is a measurement of the particle velocity β**