-Training session-
How to read a plot
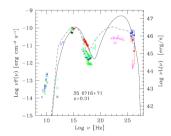
Each experiment gives a contribute in a particular range of the
cosmic (or gamma!) rays spectrum.
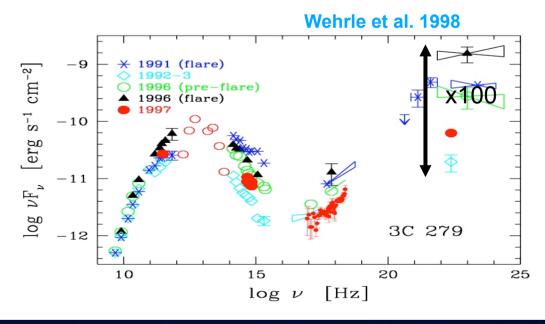

But what is a spectrum?

And, above all, how many ways are there to show
it in a graph??

How to deal with astrophysical graphs?

Let's concentrate on the axes, on the order of magnitude,
on the logarithmic scales,
and so on, in order to get more used with these kind of plots.

...starting by the definition of Energy in eV...

GeV?? TeV?? eV??

> "A single atom is such a small thing that to talk about its energy in Joules would be inconvenient. But instead of taking a definite unit in the same system, like 10–20 J, [physicists] have unfortunately chosen, arbitrarily, a funny unit called an electronvolt (eV) … I am sorry that we do that, but that's the way it is for the physicists."
>
> —Richard Feynman

- **1 eV = 1.6×10^{-19} Joules**

(➜ energy meeded to move an electron under a potential of 1 Volt)

- **10^{20} eV**: **UHECR** - the highest energy cosmic ray ever observed. Like the kinetic energy of a tennis ball!
- **14 TeV** (14 10^{12} eV): **LHC** - energy of protons before collision in LHC.
- **100 GeV**: **MAGIC!**
- **200 MeV**: **NUCLEAR FISSION** - total energy released in nuclear fission of one U-235 atom (on average; depends on the precise break up); this is 82 terajoules per kilogram, or 20,000 tonnes of TNT equivalent per kilogram.
- **17.6 MeV**: **SOLAR FUSION** - total energy released in fusion of deuterium and tritium to form helium-4.
- **13.6 eV**: **HYDROGEN IONIZATION** – in general molecular bond energies are ~eV per molecule.
- **1/40 eV**: **THERMAL TEMPERATURE** - a single molecule in the air has an average kinetic energy 3/80 eV.
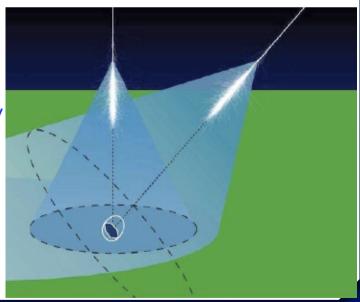
What is a gamma(or cosmic) flux?

$$\phi = \frac{N_\gamma}{A_{eff} \cdot T}$$

In our case it is the number of photons **N** we detect in a certain time **T**, in an area called **$A_{eff.}$**

Which units??

What is our **Effective Area**?
It's a **surface** such that a primary gamma falling (by extrapolating its direction) within it, can be detected by the telescope.
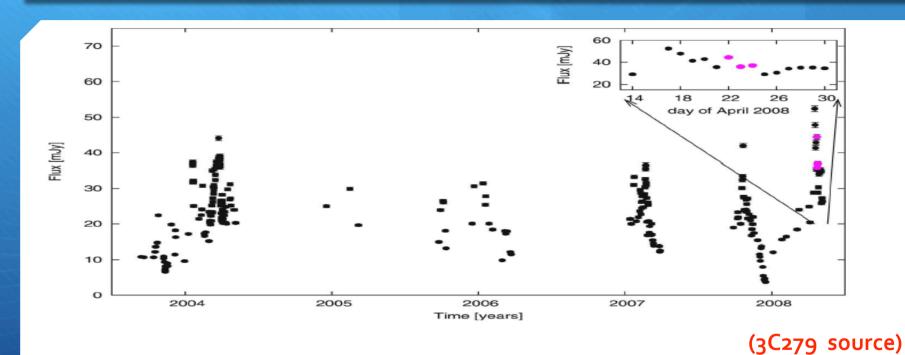
Different flux definitions

Let's discuss together: what do you think could be the difference between these kind of flux definition?
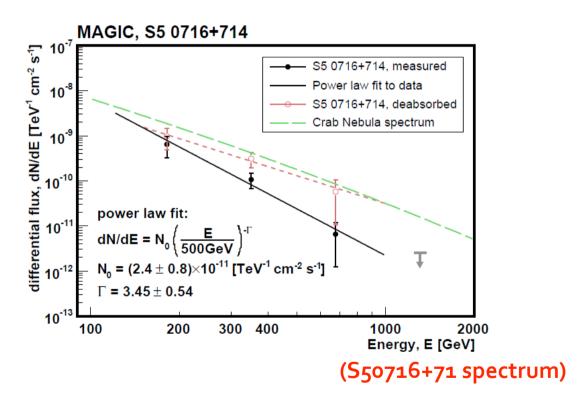
$$\phi = \frac{dN_\gamma}{dA_{eff} \cdot dt}$$

$$\phi_{\text{int } egr} = \phi_{E > E_0} = \int_{E_0}^{\infty} \phi_{diff}(E)$$

$$\phi_{diff}(E) = \frac{d\phi}{dE}$$

Let's try to interprete these plots

(3C279 source)

Tell me the information you miss or need and
try to interprete this and the following plots.

Let's learn how to read a flux plot

MAGIC, S5 0716+714

Legend:
- S5 0716+714, measured
- Power law fit to data
- S5 0716+714, deabsorbed
- Crab Nebula spectrum

power law fit:

$$dN/dE = N_0 \left(\frac{E}{500\,GeV} \right)^{-\Gamma}$$

$N_0 = (2.4 \pm 0.8) \times 10^{-11}$ [$TeV^{-1}\ cm^{-2}\ s^{-1}$]

$\Gamma = 3.45 \pm 0.54$

Axis labels: differential flux, dN/dE [$TeV^{-1}\ cm^{-2}\ s^{-1}$] ; Energy, E [GeV]
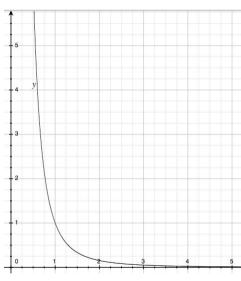
(S50716+71 spectrum)

Which kind of flux is here shown?? What does it means?
Can you interprete a logarithmic scale??
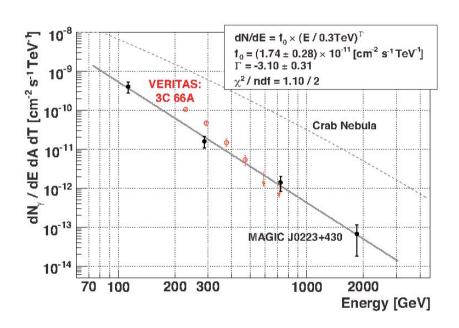What about the error bars? Are they constant?

Power law

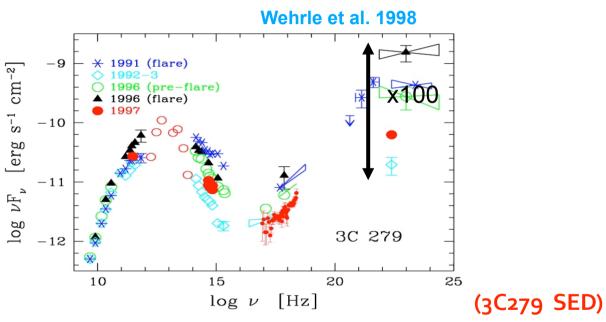What's the difference between a **power law** and an **exponential law**?

$$A \cdot E^{-\alpha}$$

$$A \cdot e^{-\alpha E}$$

Remember that: $\quad E^{-\alpha} = e^{-\alpha \ln(E)}$

Let's learn how to read a flux plot

Why are there two series of points (MAGIC and VERITAS)?
What about the CrabNebula line?

Let's learn how to read a flux plot

Wehrle et al. 1998

(3C279 SED)
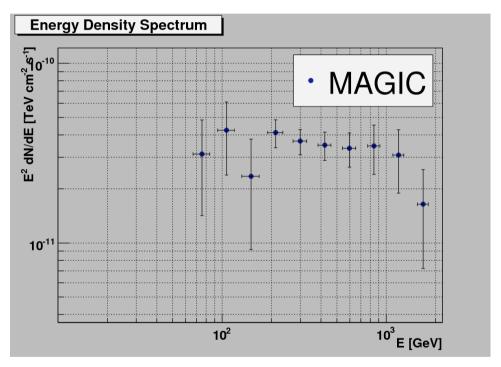
This plot is a SED (Spectral Energy Distribution).
How could you interprete it?
Why are there many points of different colors?
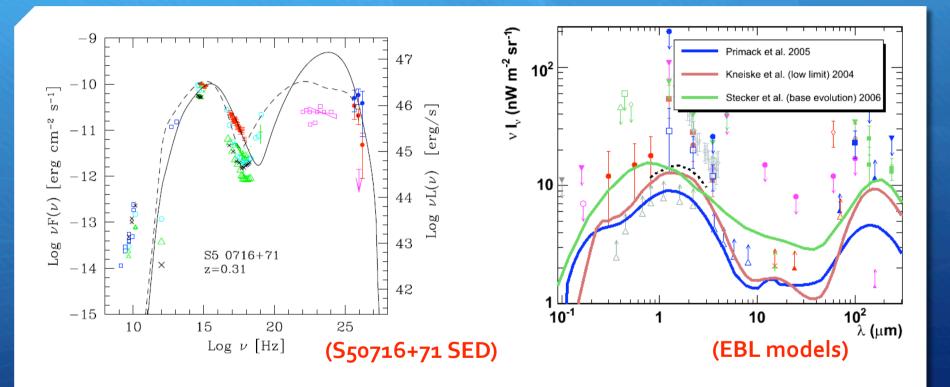Why the errors change?
What about the different years in the legend?
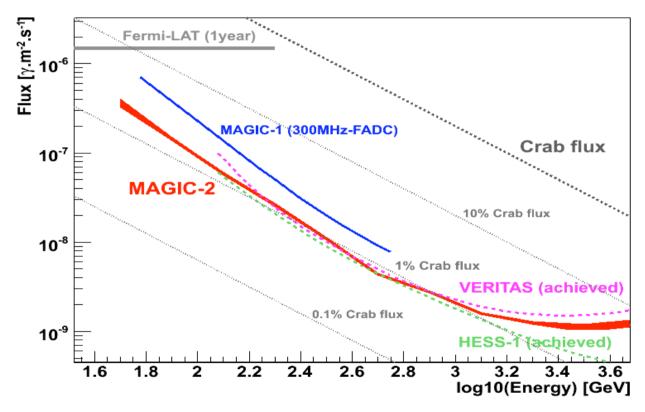Where have finished the GeV units?

Let's learn how to read a flux plot

(Crab E²dN/dE spectrum)

Let's assume this plot quite flat.
What does it mean for the spectrum of this source?

Let's learn how to read a flux plot

(S50716+71 SED)

(EBL models)

What does it mean νF(ν) and/or νI(ν)??
What's the relation between the x axis in these two cases?
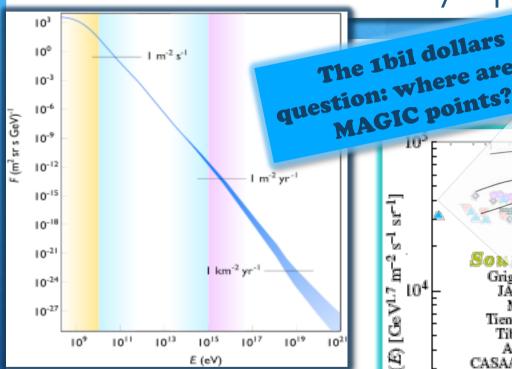
Let's learn how to read a flux plot

This plot is called Sensitivity plot.
If I tell you the flux is y-axis is a minimum flux, what would you guess?

And now …

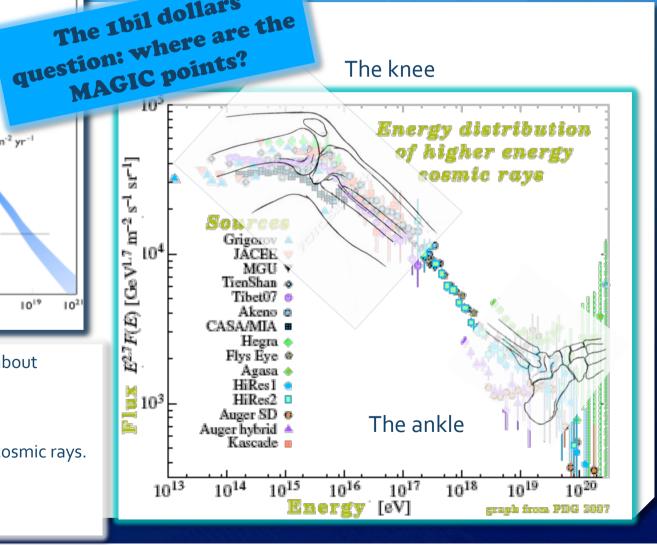Let's come back to our Cosmic-rays spectrum

Now you can understand the cosmic rays spectrum!

The 1bil dollars question: where are the MAGIC points?

The knee

The flux of **10¹¹ eV** cosmic rays is about
1 cosmic ray/m²/second.

This diminishes to about
1 cosmic ray/m²/year for **10¹⁶ eV** cosmic rays.

At **10¹⁹ eV** the flux is only
1 cosmic ray/km2/year.

The ankle

L'immagine è stata elaborata dai nostri psicologi per studiare il vostro livello di stress.
Guardate i due delfini che saltano fuori dall'acqua. I due delfini sono identici.
I ricercatori sono giunti alla conclusione che una persona è a un livello di stress troppo elevato se trova che i due delfini sono differenti. Il livello di stress e' proporzionale al numero di differenze trovate. Se vedete molte differenze tra i due delfini, siete pregati di smettere di ascoltarmi e di fare immediatamente qualcosa di piacevole.

Io qualche idea, in un'isola cosi', ce l'avrei..!!