THE HIGH ENERGY ASTROPHYSICS GROUP

Pasquale Blasi

STAFF: *Roberto Aloisio, Elena Amato, Rino Bandiera, Niccolo Bucciantini, Marco Salvati*

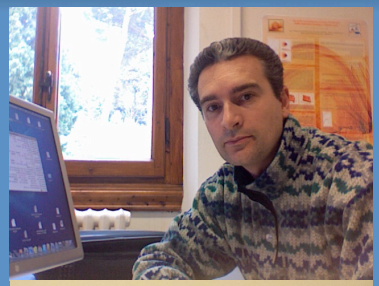
Postdoc: *Giovanni Morlino*

UniFi: *Luca Del Zanna*

Students: *Barbara Olmi*

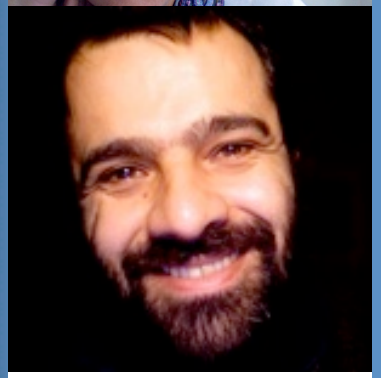
Pasquale Blasi

Luca Del Zanna



Elena Amato

Barbara Olmi



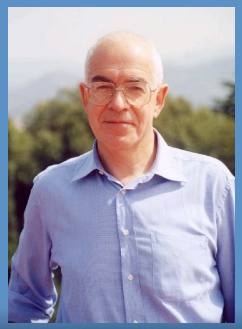
Roberto Aloisio

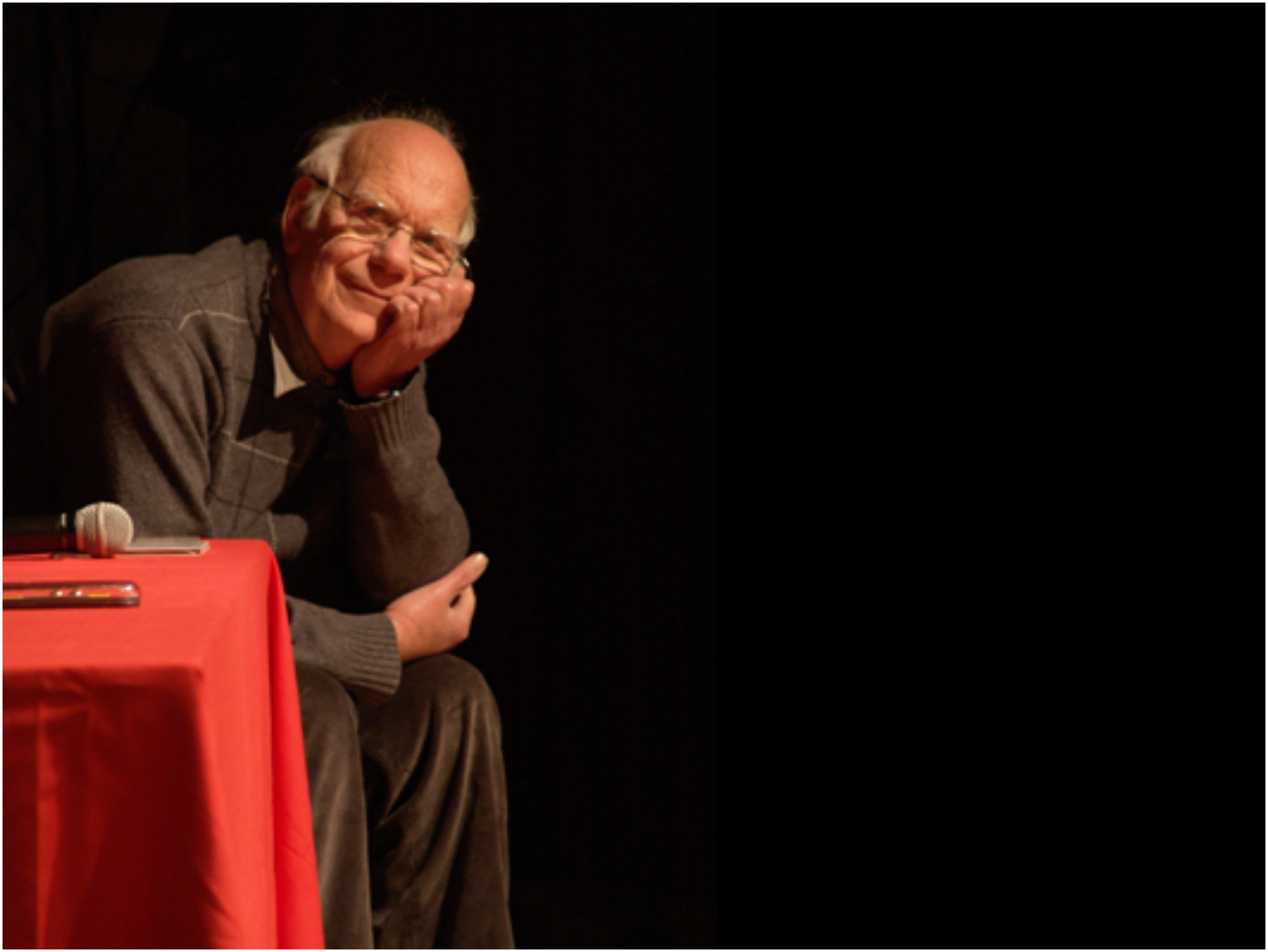
Rino Bandiera

Niccolo Bucciantini

Giovanni Morlino

Marco Salvati





Main Research Topics

NON LINEAR PARTICLE ACCELERATION IN SHOCK WAVES (Amato, Blasi, Morlino)

ORIGIN OF COSMIC RAYS – ACCELERATION IN SNR AND PROPAGATION IN THE GALAXY (Amato, Bandiera, Blasi, Morlino)

PHENOMENOLOGY OF SUPERNOVA REMNANTS (Bandiera)

ORIGIN OF COSMIC POSITRONS (Amato, Blasi)

ORIGIN OF ULTRA HIGH ENERGY COSMIC RAYS (UHECR) AND NEUTRINOS (Aloisio, Blasi)

PARTICLE ACCELERATION IN RELATIVISTIC SHOCKS (Amato, Blasi)

PULSAR WIND NEBULAE (Amato, Bandiera, Bucciantini, Del Zanna)

MAGNETARS (Bucciantini)

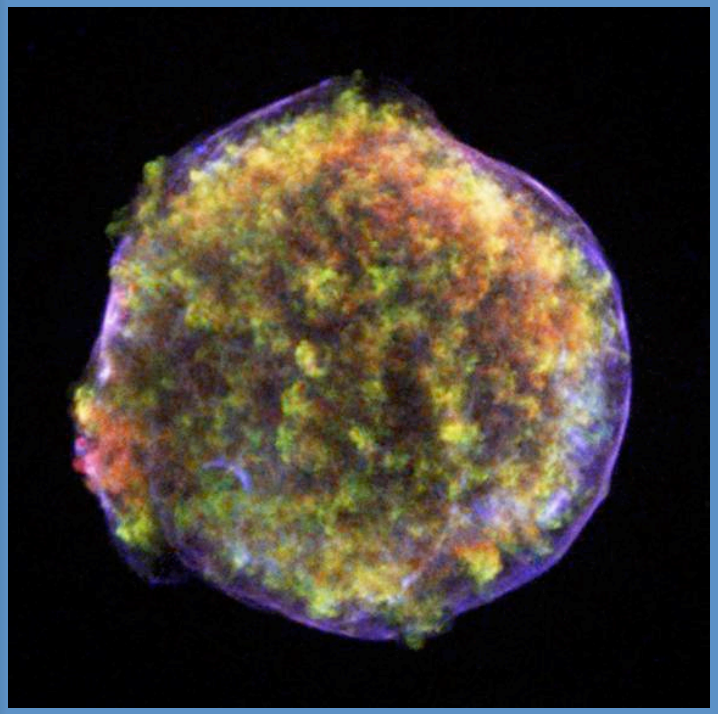
NON-THERMAL PHENOMENA IN CLUSTERS OF GALAXIES (Blasi)

SIGNATURES OF DARK MATTER ANNIHILATION (Aloisio, Blasi)

MAIN RECENT RESULTS

1. DEVELOPMENT OF THE NON LINEAR THEORY OF PARTICLE ACCELERATION AT SHOCK WAVES AND APPLICATION TO SNR
2. PARTICLE ACCELERATION IN PARTIALLY IONIZED MEDIA
3. PULSAR WIND NEBULAE AND THEIR TEMPORAL BEHAVIOUR
4. THE TRANSITION REGION FROM GALACTIC CR TO EXTRAGALACTIC COSMIC RAYS
5. MAGNETARS AS POSSIBLE GAMMA RAY BURSTS PROGENITORS

ORIGIN OF CR IN SNRs



Particles are energized through a process known as diffusive shock acceleration

The observed fluxes could be explained if about 10-20% of the bulk kinetic energy were converted into CRs

SNRs are well known sources of non thermal radiation… this is visible in the form of multifrequency spectra that extend from radio to gamma rays

Problems:

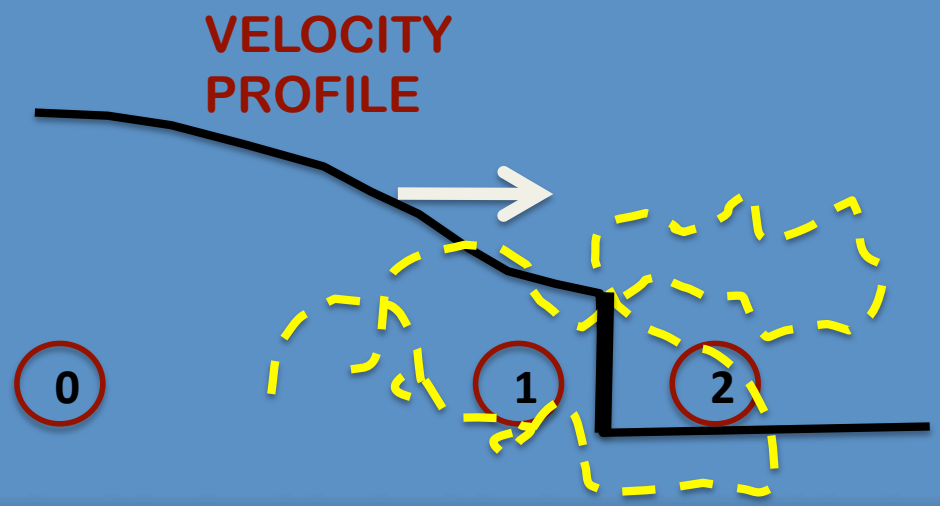
1) **Create a theoretical framework that describes observations and predicts new observables**
2) **Have a theory of the transport to the Earth that is compatible with observed chemicals and anisotropy**

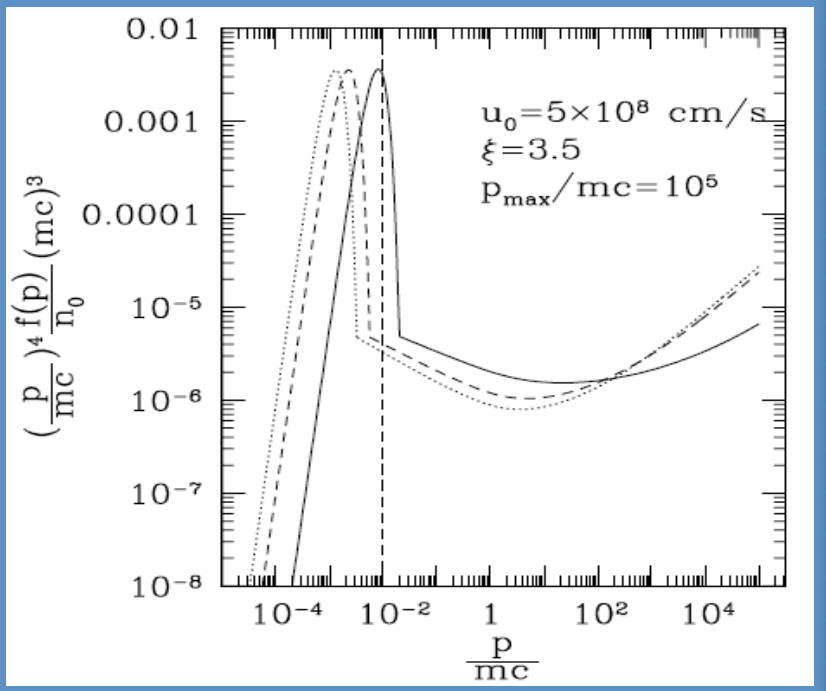
NON LINEAR THEORY

PB 2002, 2004, Amato & PB 2005, 2006, Amato, PB, Caprioli, Morlino …

A theory of particle acceleration that allows one to describe:

1. ***Dynamical reaction of accelerated particles***
2. ***CR-induced B-field and their reaction + CR diffusion***
3. ***Recipe for injection (self-regulation)***





X-ray rims and B-field amplification

TYPICAL THICKNESS OF FILAMENTS: ~ 10^{-2} pc

The synchrotron limited thickness is:

$$\Delta x \approx \sqrt{D(E_{max})\tau_{loss}(E_{max})} \approx 0.04\ B_{100}^{-3/2}\ \mathrm{pc}$$

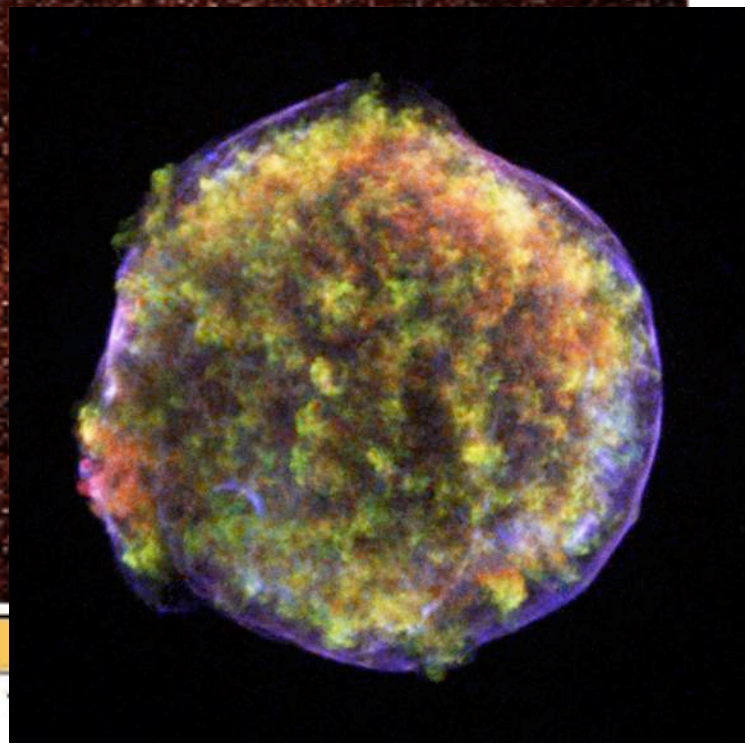
$$B \approx 100\ \mu\mathrm{Gauss}$$

$$E_{max} \approx 10\ B_{100}^{-1/2}\ u_8\ \mathrm{TeV}$$

$$\nu_{max} \approx 0.2\ u_8^2\ \mathrm{keV}$$

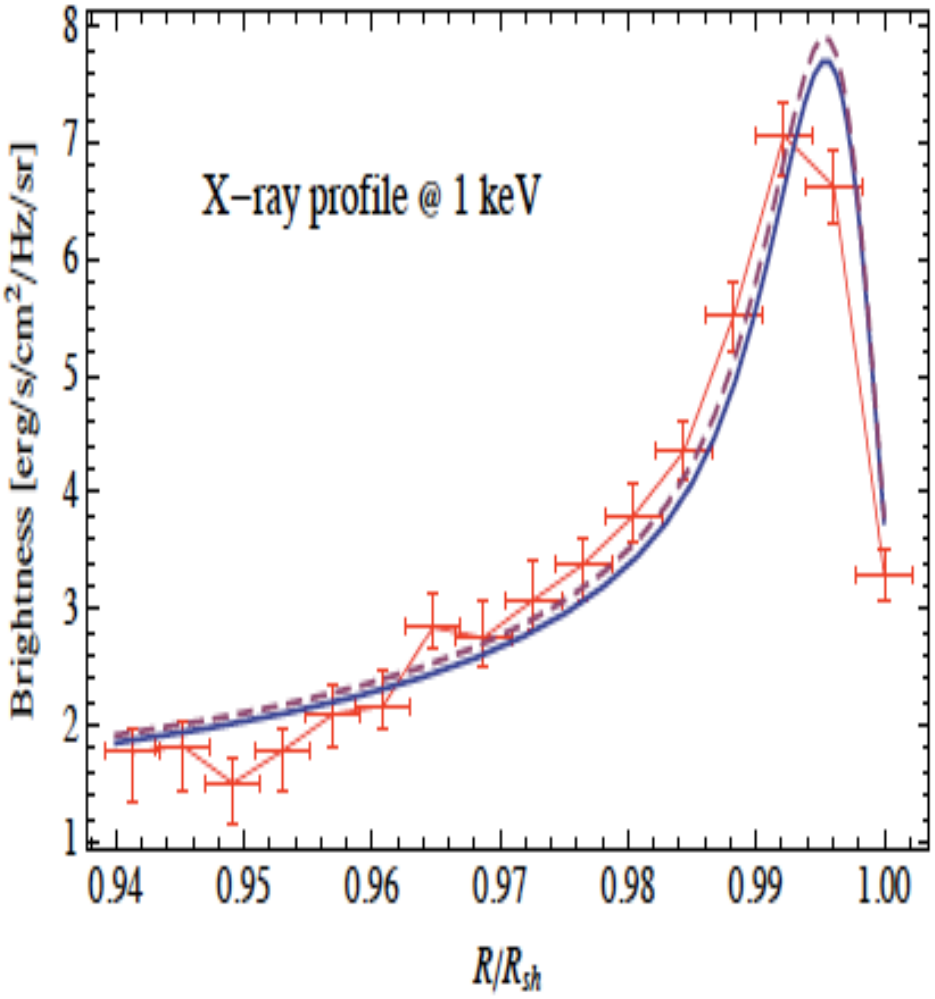
In some cases the strong fields are confirmed by time variability of X-rays

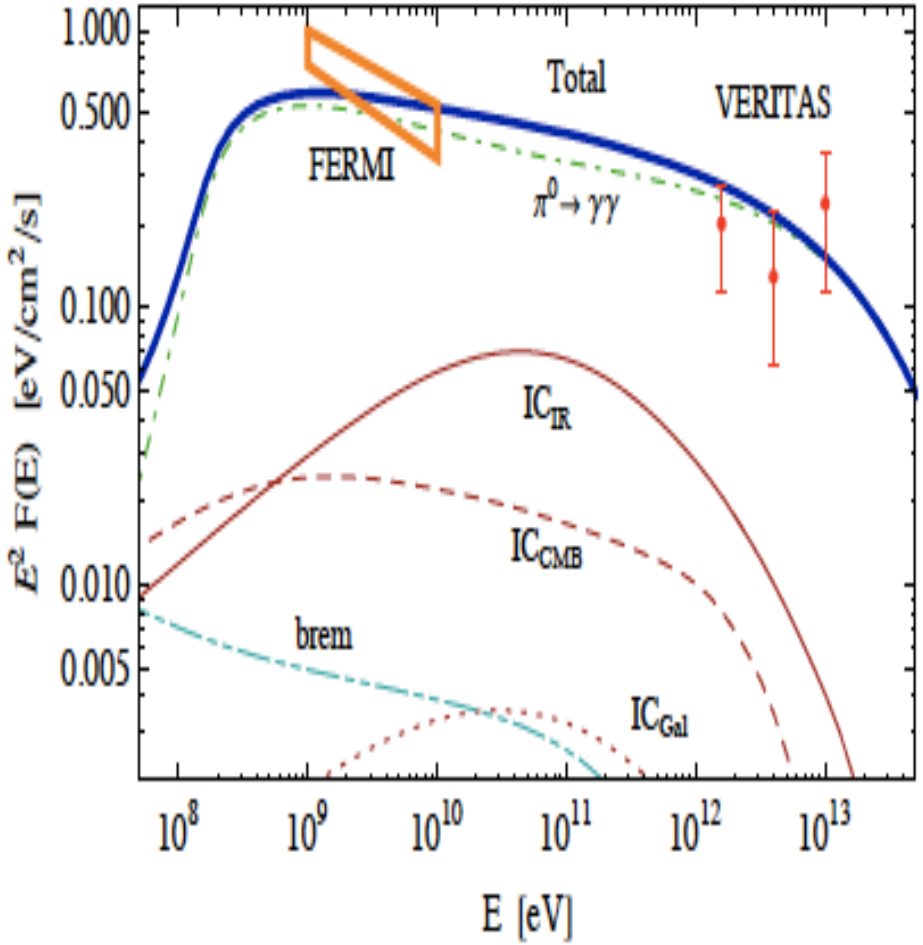
Uchiyama & Aharonian, 2007



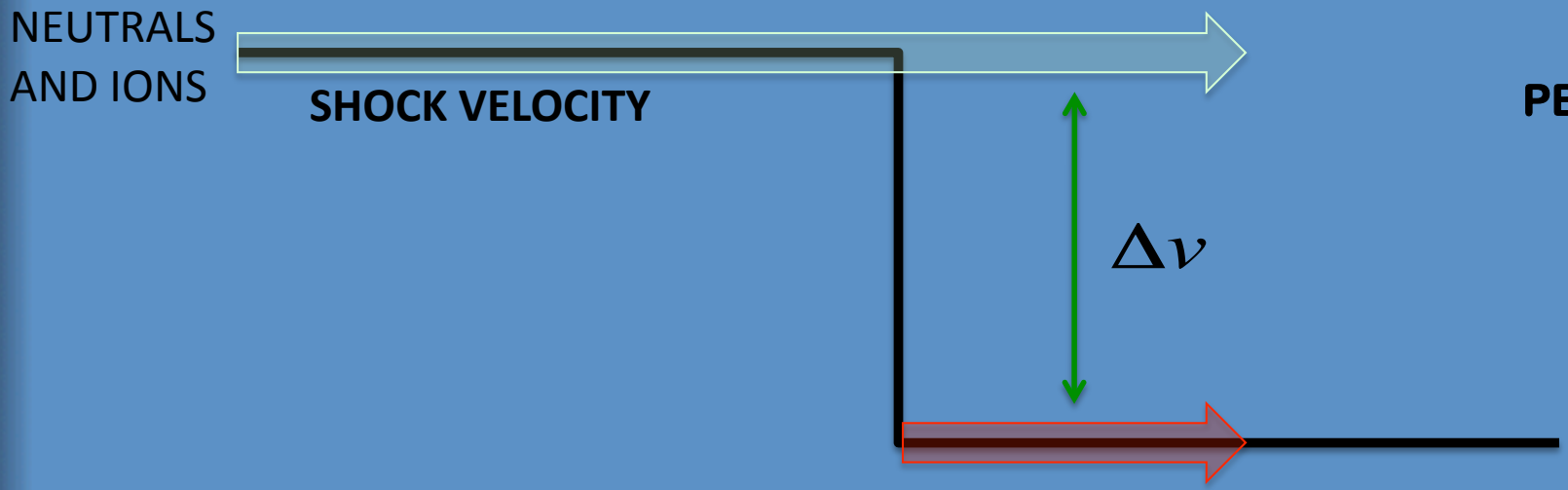
The case of Tycho

Morlino&Caprioli 2011

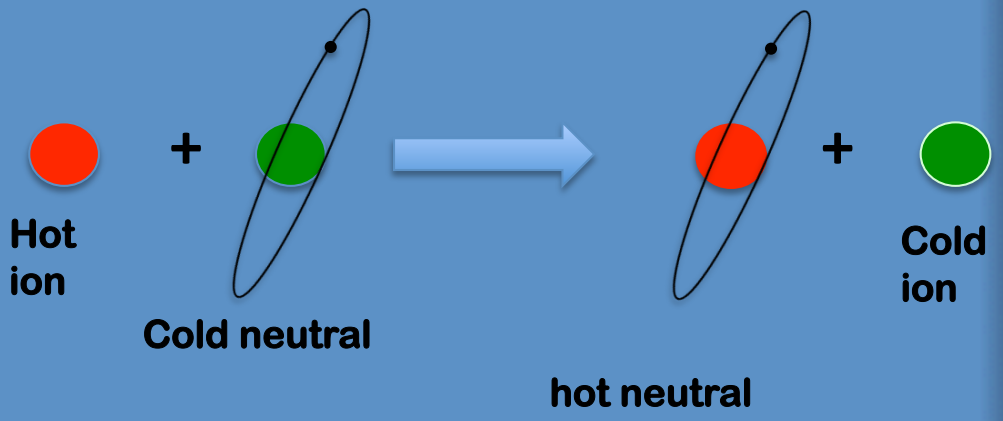




HOW TO NAIL DOWN CRs USING BALMER LINES

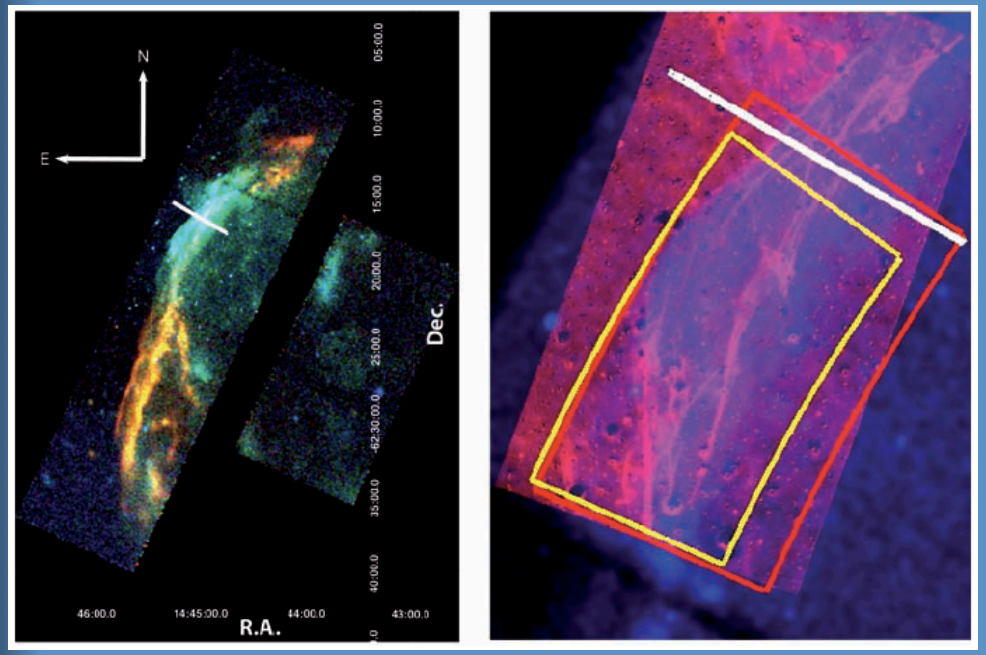


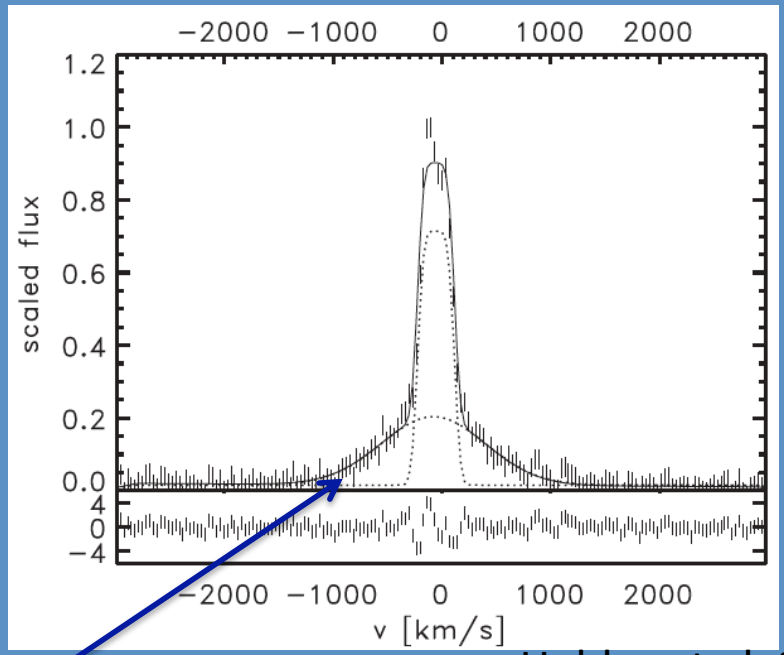
CHARGE EXCHANGE → BROAD BALMER LINE (NEUTRALS THAT MADE CHARGE EXCHANGE) REFLECTING THE TEMPERATURE OF IONS…



BUT THE LATTER AFFECTED BY EFFICIENT CR ACCELERATION

BROAD BALMER LINES NARROWER THAN FOR UNMODIFIED SHOCKS





Helder et al. 2009

$$W_{broad} = \sqrt{8 \ln 2 \frac{kT_2}{m}} \approx 1.02\ v_{sh}$$

$$W_{broad} = 1100 \pm 63\,km/s \rightarrow T_2 = 2.3 \pm 0.3\,keV$$

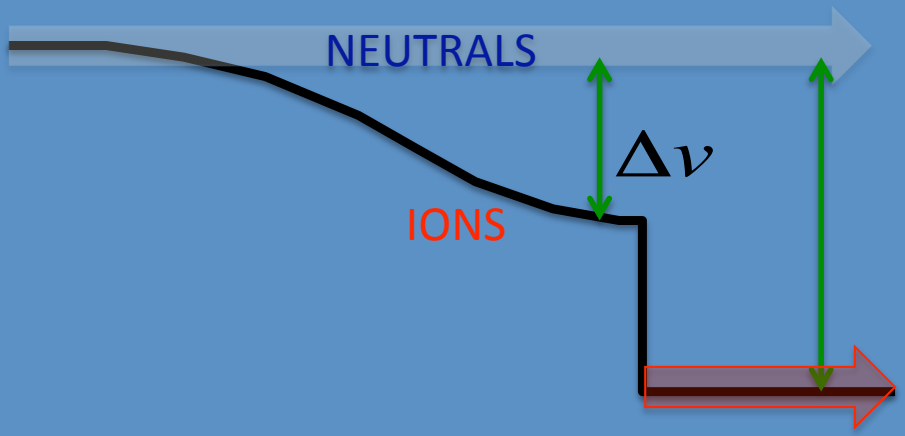
Shock speed from proper motion

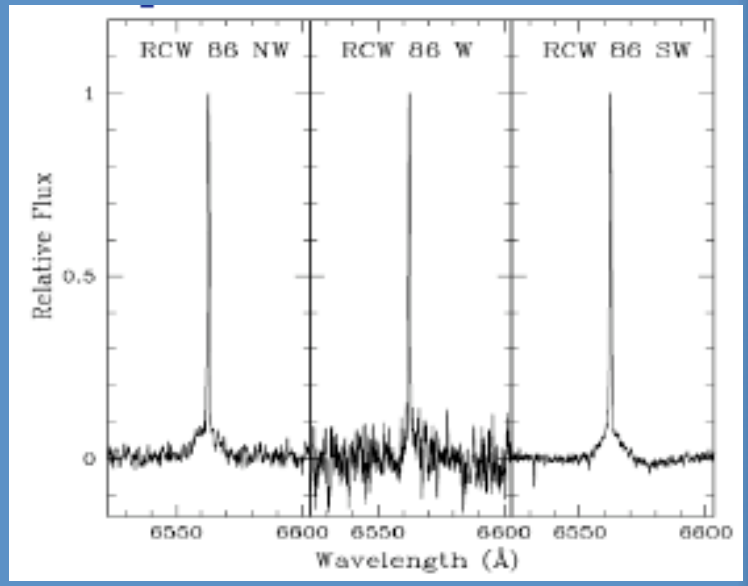
$$v_{shock} = 6000 \pm 2800\,km/s \left(\frac{d}{2.5 \pm .5\,kpc}\right) \left(\frac{\dot{\theta}_{obs}}{0.5 \pm .2''\,yr^{-1}}\right) \rightarrow T_2 = \begin{array}{l} 20-150\,keV\,(no\ equilibration) \\ 12-90\,keV\,(equilibration) \end{array}$$

INFERRED EFFICIENCY of CR ACCELERATION 50-60% !!! (BUT model dependent)

NARROW BALMER LINES BROADER THAN FOR UNMODIFIED SHOCKS

Sollerman et al. 2003





CHARGE EXCHANGE OCCURS NOW IN THE CR INDUCED PRECURSOR

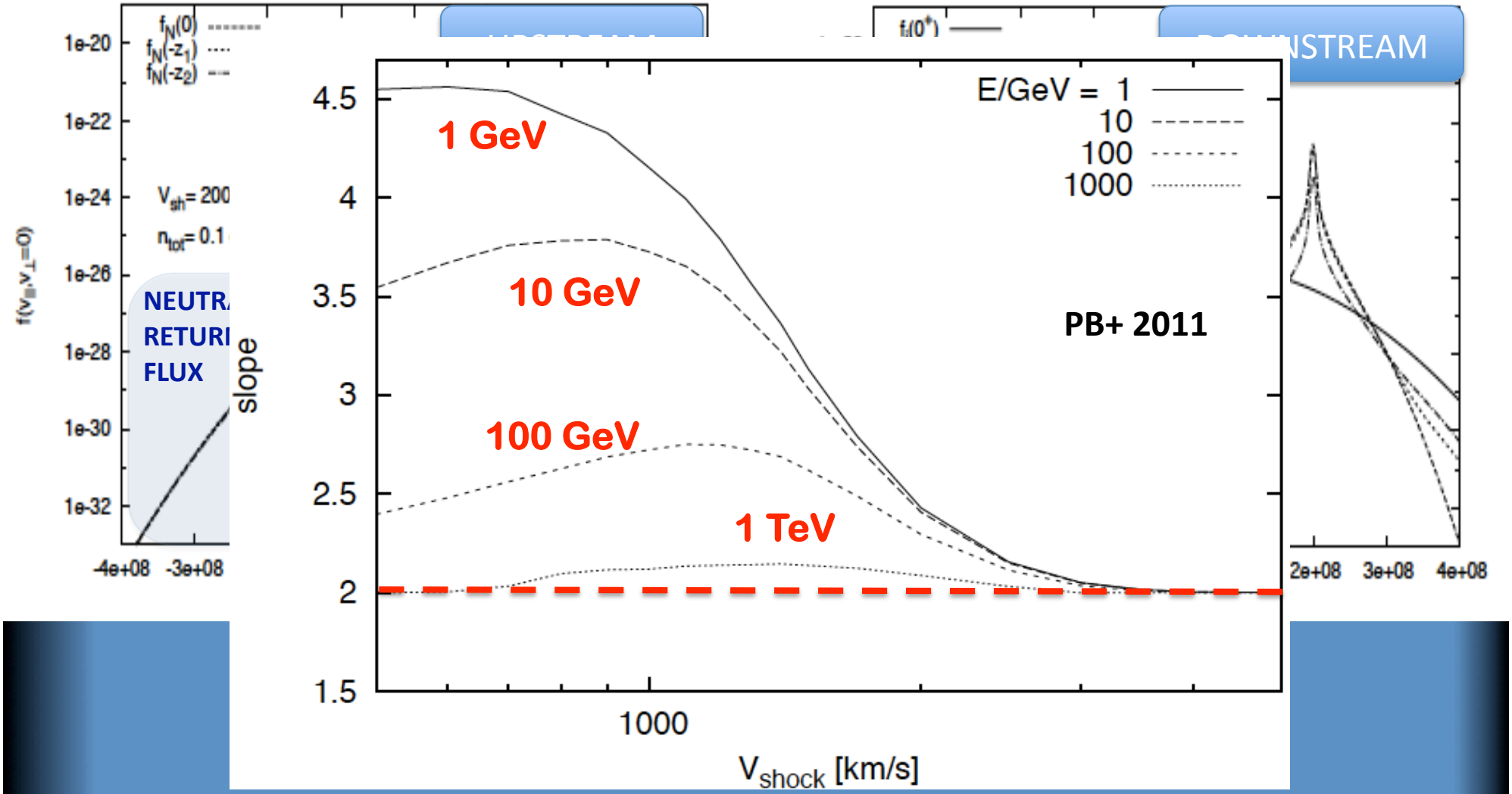
$$W_{broad} = \sqrt{8 \ln 2 \frac{kT_0}{m}} \approx 21 \text{ km/s} \left(\frac{T_0}{10^4 K} \right)^{1/2}$$

$$W_n \sim 30-50\, km/s \rightarrow T \sim 2-6\, 10^4 K$$

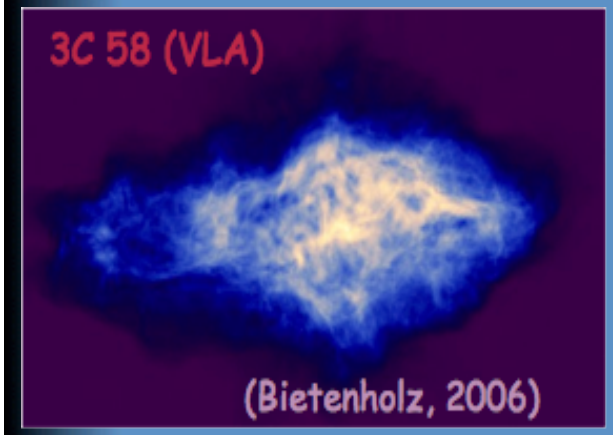
NARROW BALMER LINE BROADER THAN FOR AN UNMODIFIED SHOCK

Discovery of the neutral return flux

PB+2011

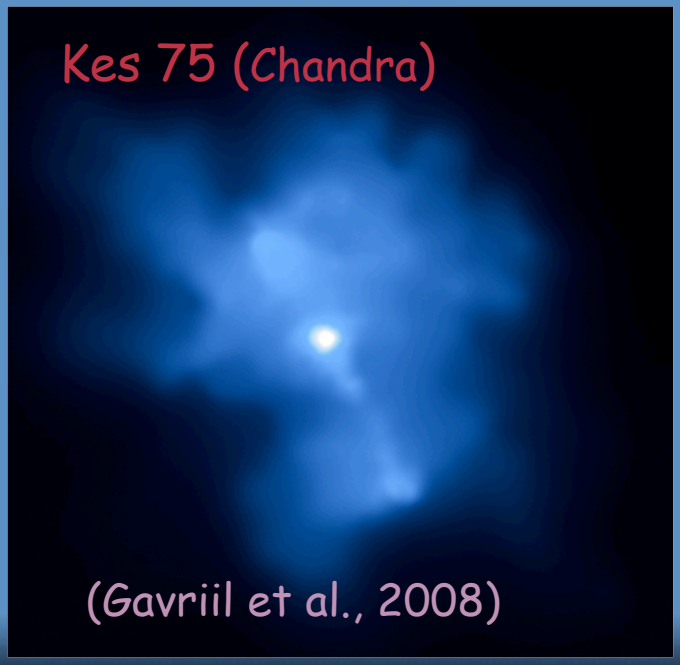


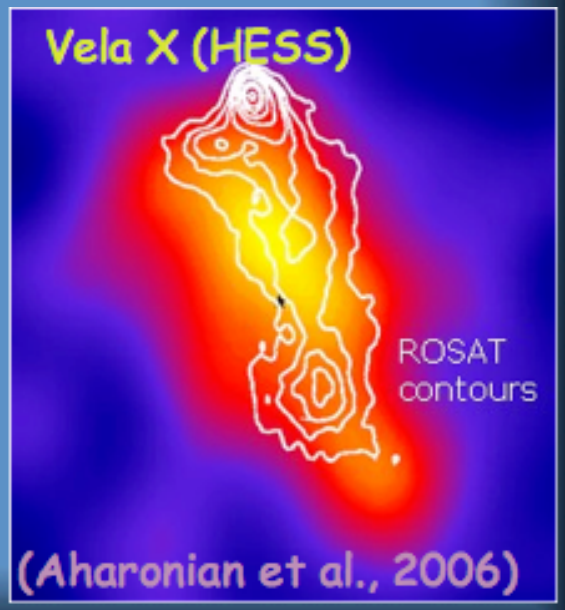
Pulsar Wind Nebulae



Plerions:

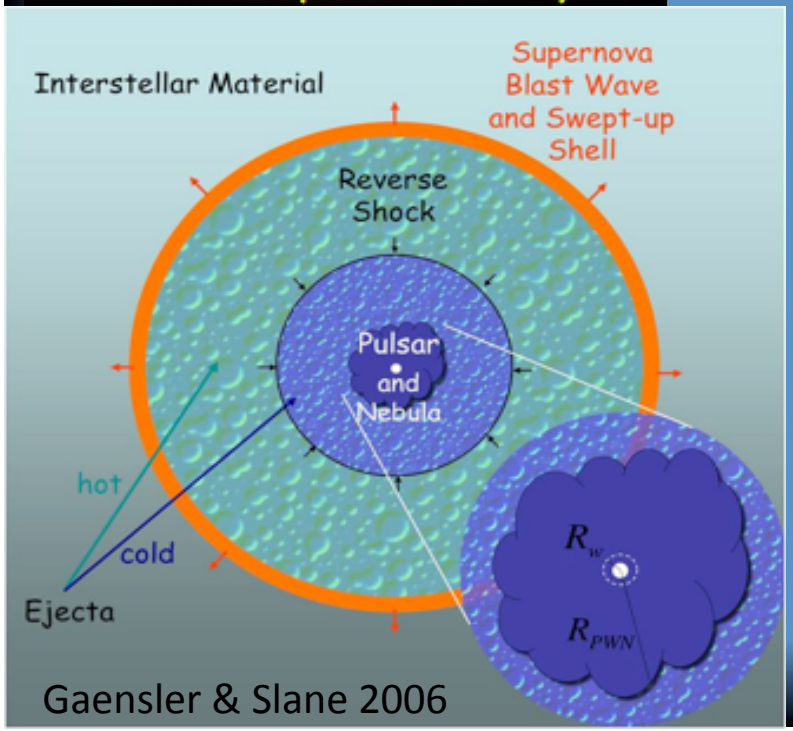
- ✓Supernova Remnants with a center filled morphology
- ✓Flat radio spectrum (α_R<0.5)
- ✓Very broad non-thermal emission spectrum (from radio to multi-TeV γ-rays)



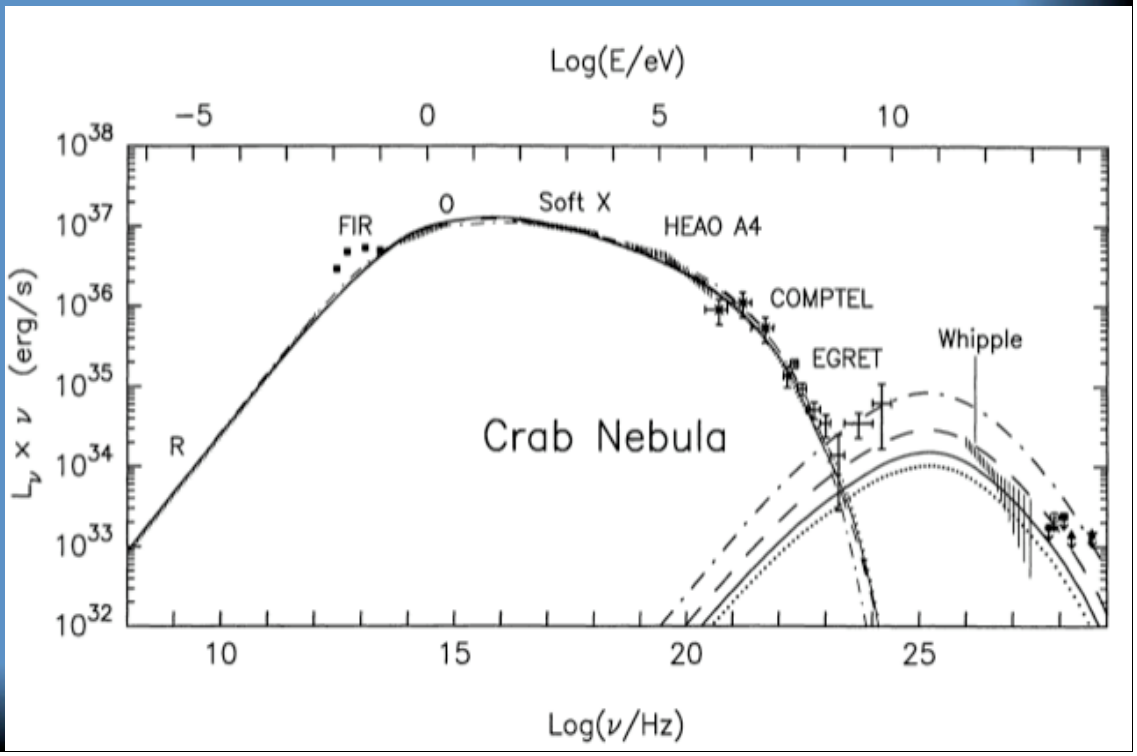


The Crab Nebula

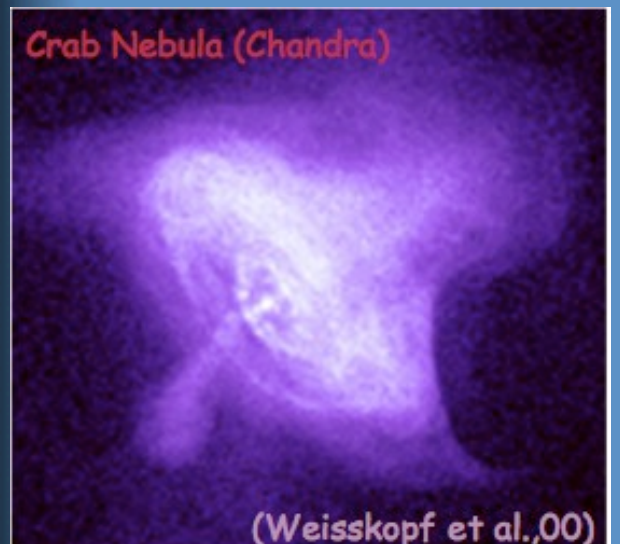
Primary emission mechanism: synchrotron radiation by relativistic particles in an *intense* (>few x 100 B_{ISM}) *ordered* (high degree of polarization, in radio, optical and even γ-rays, Dean et al 08) magnetic field

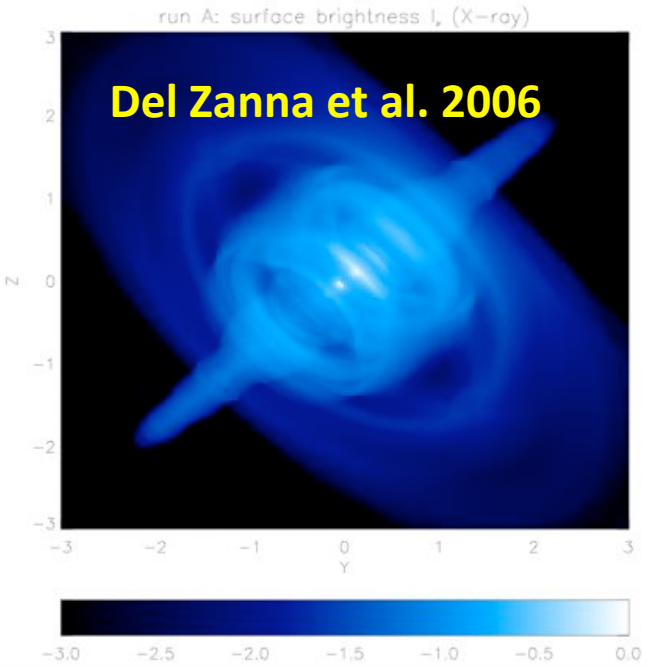


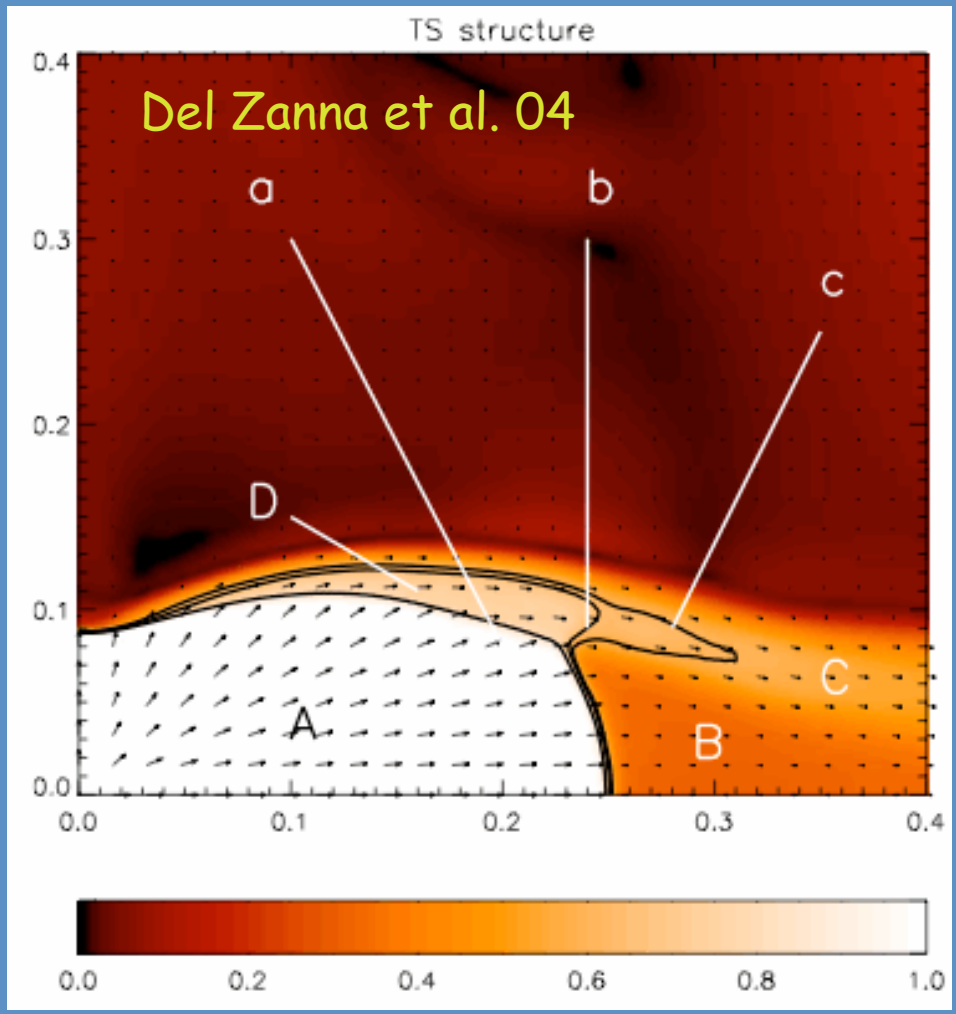
Gaensler & Slane 2006



A more realistic structure of the termination shocks

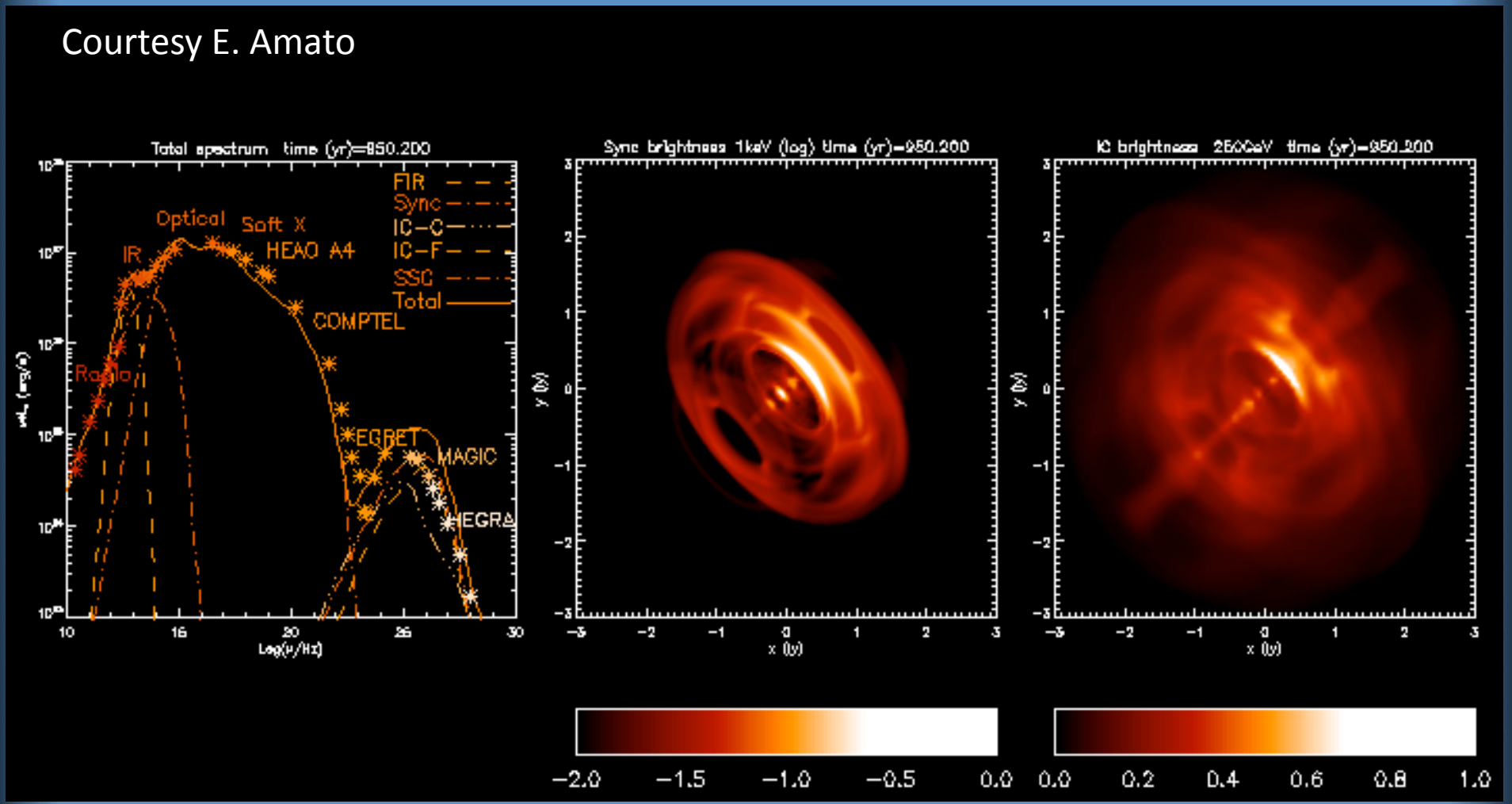






Variability in MHD models

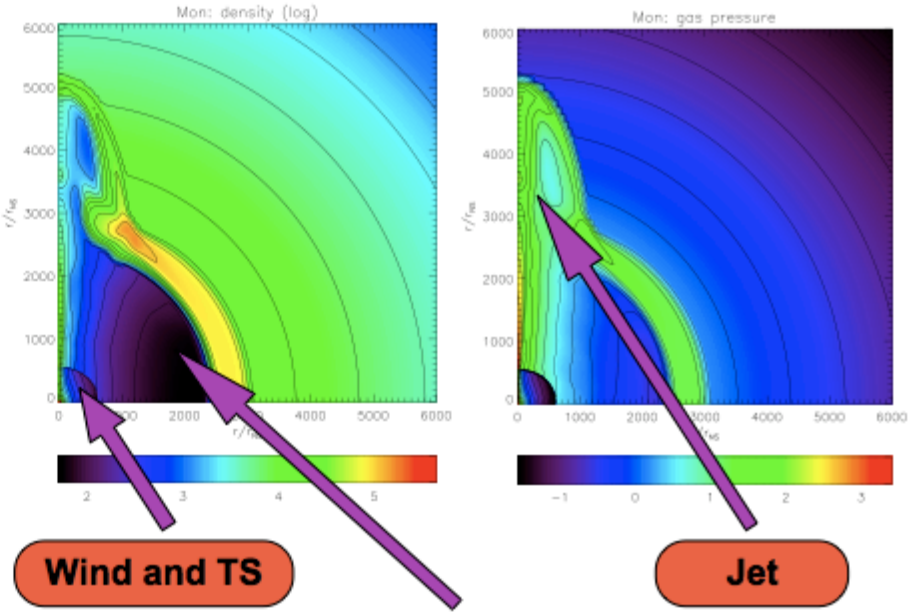
Courtesy E. Amato

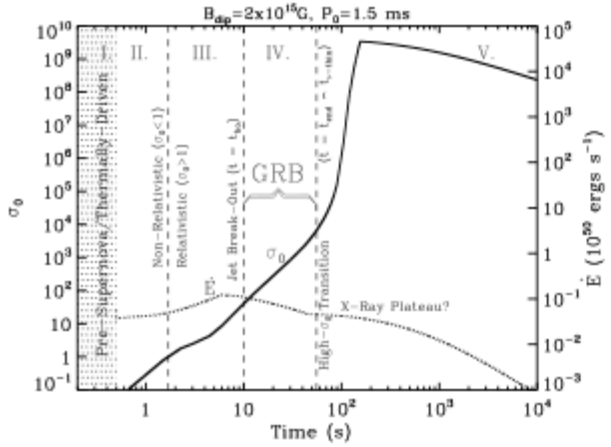


Millisecond Magnetar Model for GRBs

Why: Alternative to accretion on a BH. More compatible with SN connection. Naturally explain Late Activity. Stronger observational predictions.

Results: Simulations show that magnetar outflows can lead to the formation of GRB jets. Correct timing (100 sec). Correct energetics (10^{51} erg). Correct collimation (10 deg)

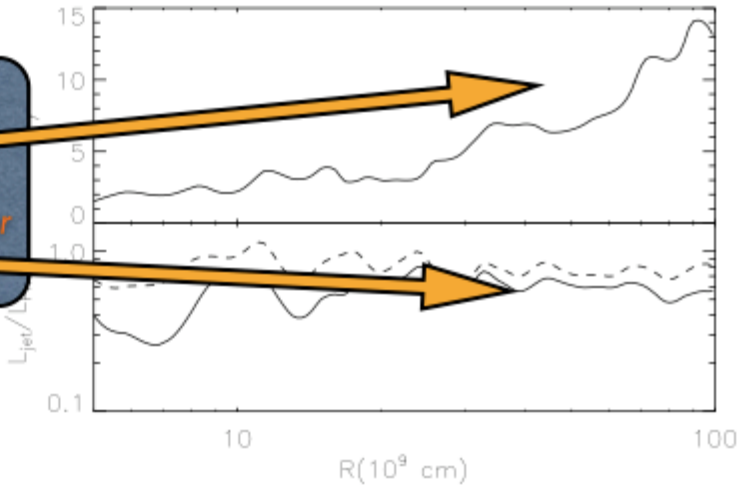




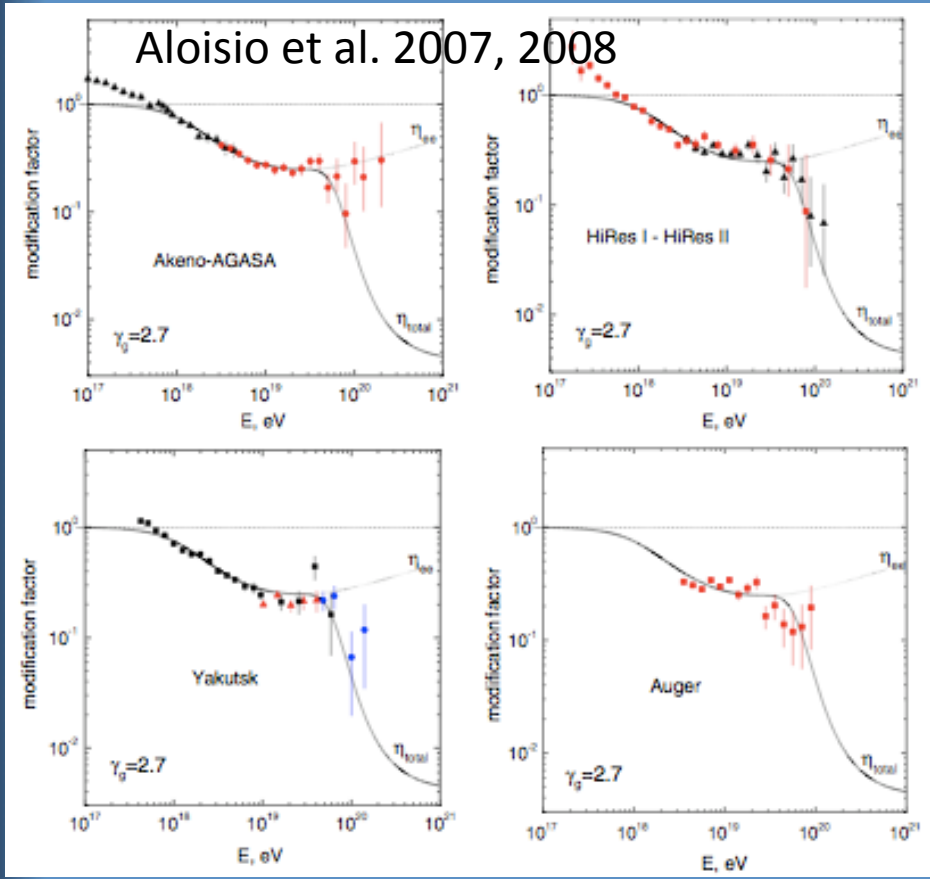
Evolution of a Magnetar outflow

Magnetar Jet efficiently accelerates.

Jet carries most of magnetar Energy



ULTRA HIGH ENERGY COSMIC RAYS



1. TRANSITION FROM GALACTIC TO EXTRAGALACTIC CRs
2. INVESTIGATION OF THE SO-CALLED DIP MODEL (THE TRANSITION TAKES PLACE AT 10^{18} eV)
3. THE EXTRAGALACTIC SPECTRUM IS CHARACTERIZED BY A DIP FEATURE ASSOCIATED WITH THE BETHE-HEITLER PAIR PRODUCTION PROCESS
4. THE GALACTIC SPECTRUM IS NOT REQUIRED TO EXTEND TO THE ANKLE

RA HAS GIVEN A CRUCIAL CONTRIBUTION TO THE INVESTIGATION OF THE TRANSPORT OF HEAVY NUCLEI ON COSMOLOGICAL DISTANCES, IN ORDER TO INTERPRET RECENT DATA ON SPECTRA AND CHEMICAL COMPOSITION (Aloisio et al. 2011, 2012)

NUMBERS

In the last ten years only, circa 150 refereed papers with about 4000 citations (ONLY THEORY PAPERS)

The total H-factor of the Group is H=45

FUNDING –
Mainly through PRIN MIUR, PRIN INAF, ASI plus FFO

Currently active:
PRIN INAF 2010-2012
ASTRI/CTA 2010-2012

Applying for:
ERC-ADVANCED GRANT, PRIN MIUR, FIRB

NUMBERS

THE RESULTS OF OUR RESEARCH HAVE BEEN PRESENTED IN ABOUT 10-15 INVITED REVIEW TALKS PER YEAR (more than 100 total in the last 10 years) + countless contributed TALKS

The Group provides considerable scientific support to:

The Pierre Auger Collaboration (PB)
Fermi-LAT (PB)
Cherenkov Telescope Array (CTA) (EA, RB, PB, GM)
MAGIC (MS)

Past Students (10 yrs): S. Gabici, D. De Marco, C. Ferrigno, G. Morlino, D. Caprioli + G. Vannoni (laurea)