GALACTIC COSMIC RAYS

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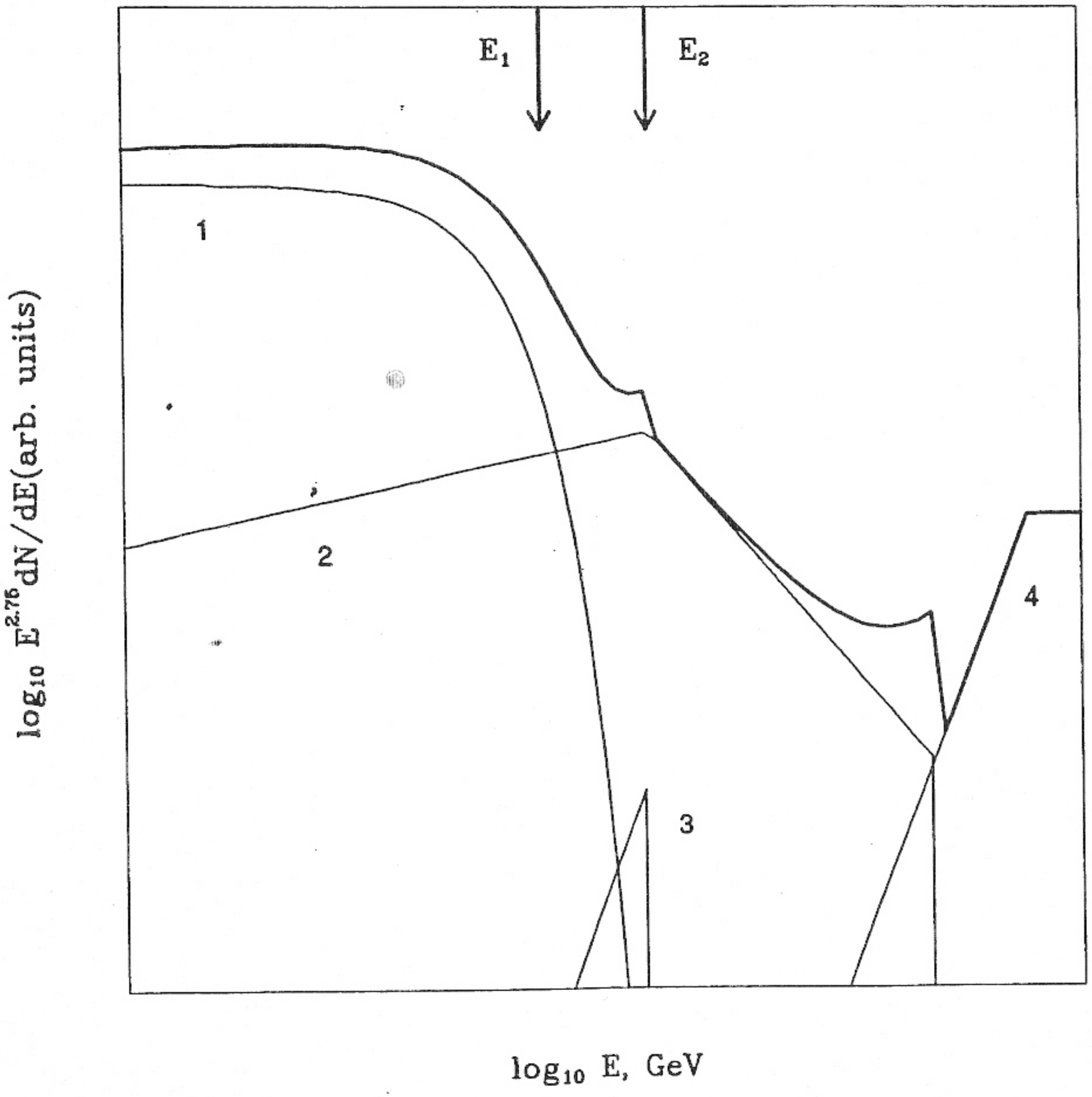
Galactic Cosmic Rays: Two competing concepts

- ISM-SN: Acceleration to knee
- Reason for knee limit of SNR acceleration
- Then stochastic acceleration to ankle
- Injection from dust or suprathermal particles in ISM
- Propagation with Kolmogorov and reacceleration in ISM
- Wind-SN: Acceleration to ankle
- Reason for knee diminishing of acceleration efficiency, drift component weakened
- Abundances from wind material
- Propagation with excited turbulence in wind-shells, and outside with Kolmogorov

BIERMANN



FROM
STANEV,
BIERMANN,
GAISSER
1993
PAPER CR IV
ASTRON. & ASTROPH.

1: SEDOV-EXPLOS.
2: WIND-EXPLOS.
3. POLAR CAP OF WIND-EXPLOS
4: RADIO GALAXIES

Spectrum and knee

- Gain: Lorentz Transformation: kicks on each side
- Adiabatic losses: system expands while particle goes back and forth
- Injection history: modified from density gradient, steepening in wind
- Drift gains: Curvature scale visible to particle depends on particle momentum
- Match acceleration near pole with acceleration near equator:

  $E_{knee} \simeq Z\, e\, B(r)\, r\, (\frac{v_{sh}}{c})2$
- Requires for wind-SN: Most massive stars are similar to each other in explosion
- Implies: Magneto-rotational mechanism of Bisnovatyi-Kogan 1970 to 2005: Supernovae, Hypernovae, GRBs

KARDASHEV 1964

Propagation

- Electrons observed $E^{-10/3}$
- Loss dominated: Synchrotron, Inverse Compton
- Injection $E^{-7/3}$
- Average nuclei observed $E^{-8/3}$
- Kolmogorov spectrum in ISM on all scales tested
- Diffusive losses: $\tau_L \sim E^{-1/3}$
- Source for nuclei then injection: $E^{-7/3}$
- Test electrons at lower energy (below about 10 GeV): nonthermal radio spectra consistent with $E^{-8/3}$

Abundances

- ISM-SN: Selection seen in energetic particles (SOHO data), so maybe many stars similar to Sun, dMe stars...
- Then acceleration out of this population of energetic particles
- Sufficient flux?
- ISM-SN: Start with dust particles, dust charged
- Predicts broad γ-ray lines, not yet seen
- Explains abundances, but not all isotopes
- Wind-SN: ISM, RSG winds + WR winds
- Explains abundances, isotopes; requires 10^{52} ergs in explosion (hypernova for the most massive stars);
  tests not all done

Injection and storage IV

- Relativistic diffusion:
  $I(k) \sim k^{-13/9}$
  $\tau \sim p^{-5/9}$
  Grammage: $\tau n v \sim p^{-5/9}$
- Minimum: Maximum momentum
  Grammage: $L/cnc \sim const(p)$
- This is now for WR star shells and environments, and reproduces the data.
- Similar, but simpler arguments can be made for RSG shells and environments.
- Corresponding arguments for the ISM.

differential Fe v_p ablation!

Gamma ray spectrum

- Adding then the emission components for
- ISM interaction
- RSG environment interaction
- WR environment interaction
- Bremsstrahlung
- We obtain the spectra as shown

S. CASANOVA

Interaction III

- γ-ray spectrum of Galaxy:
- corresponding to a CR spectrum $E^{-7/3}$ in inner Galaxy (from RSG wind shells), and to
- $E^{-8/3}$ in outer Galaxy (from average ISM)
- Spatially more patchy than just matter distribution: Source + matter
- Sum of various IC and Bremsstrahlung components
- MILAGRO: steep spectrum seen, HESS, flat spectrum seen, $E^{-2.29 \pm 0.07}$ MAGIC, ...
- KASKADE and KASKADE GRANDE tests, match oblique showers at many energies, for muon and electron components

Magnetic fields

- Fits to data (Cas A etc) by Völk et al. give magnetic fields much stronger than the ISM value x 4
- Three possibilities:
- 1) Upstream stellar wind : factor x4 might fit
- 2) Instability enhances magnetic field to a few percent of ram pressure (Bell 2004, 2005; Blasi et al. 2005) due to pre-existing cosmic rays
- Electric sheet currents driven by shear flow in shock - would also help to explain large scale symmetry of Galactic magnetic field (ongoing work with A. Kandus)

Critical tests

- ISM-SN: smooth proton spectrum from GeV to TeV to PeV
- Wind-SN: protons have steps down from transition from ISM to RSG to WR stars as sources high energies A. Meli
- ISM-SN: TeV emission of Galaxy should correspond to average CR spectrum
- Wind-SN: TeV emission more patchy than just matter distribution, very many extended patches of high emission, and flatter spectrum corresponding to injection $E^{-7/3}$
- ISM-SN: Abundance selection from ISM and dust formation, or suprathermal particles in dMe stars
- Wind-SN: Abundance from wind material in RSG and WR stars

Challenge for ISM-SN versus Wind-SNe

- High energies.. Highly oblique shocks accelerate faster [illegible]

- Isotopic precise abundances: has looked like WR stars for some time

- Spallation at young age of Galaxy: No other way to explain the very old star abundances in the light elements Li, Be, B (Reeves 2005)

- Anti-protons and positrons:
  Strong & Moskalenko cannot fit the γ-ray spectrum, nor the positron and anti-proton spectrum; the wind model can (work with E.-S. Seo and R. Sina)

- Neutrino spectrum of inner Galaxy: We are waiting

Thesis

- Cosmic rays out of interstellar medium (most H)
  and winds of massive stars (He, C, O, ...)
- Most of the heavy elements from very massive stars
- Knee from physics in the winds of stars
- Interaction near the sources
- Maximum particle energy $3\,10^{18}$ eV, then Fe
- Prediction and tests:
- Gamma ray spectrum of the inner and outer Galaxy
- Neutrinos from the inner Galaxy