RUB

RUHR-UNIVERSITÄT BOCHUM

The interplay of magnetic fields and cosmic rays

...and what we can learn from it

Julia Tjus

FAKULTÄT FÜR PHYSIK & ASTRONOMIE
Theoretische Physik IV

The observed cosmic ray spectrum

- -9 < log(E/GeV) < 6: Supernova Remnants, …

- 6 < log(E/GeV) < 9.3: Leaky Box; Galactic sources; pulsars, X-ray binaries, SNRs w/ winds …

- log(E/GeV) > 9.3: extragalactic
→ AGN, GRBs, Clusters, ...

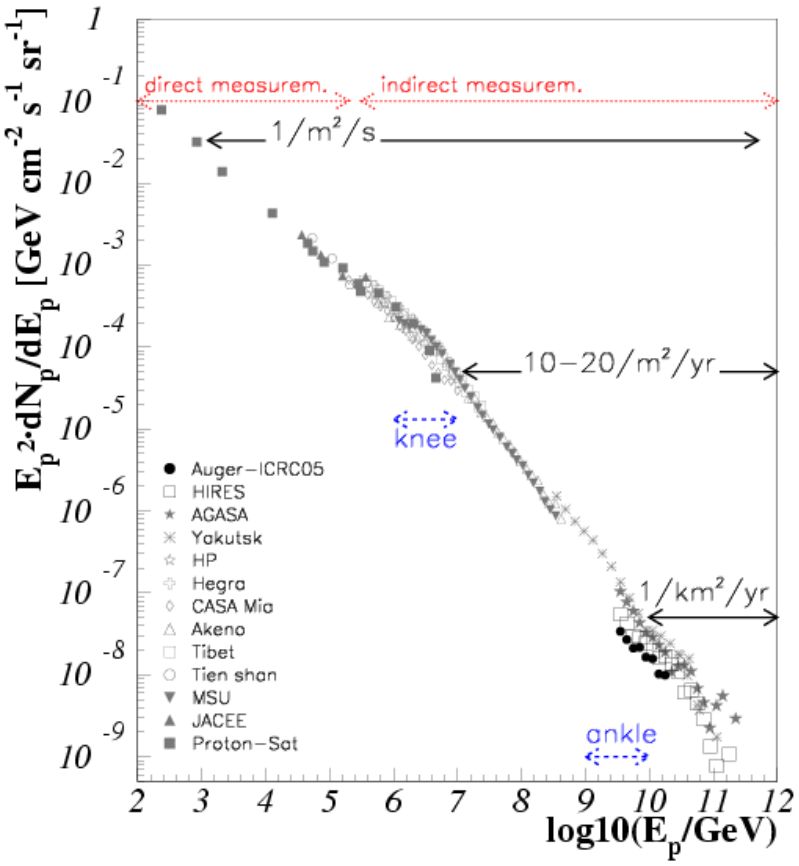
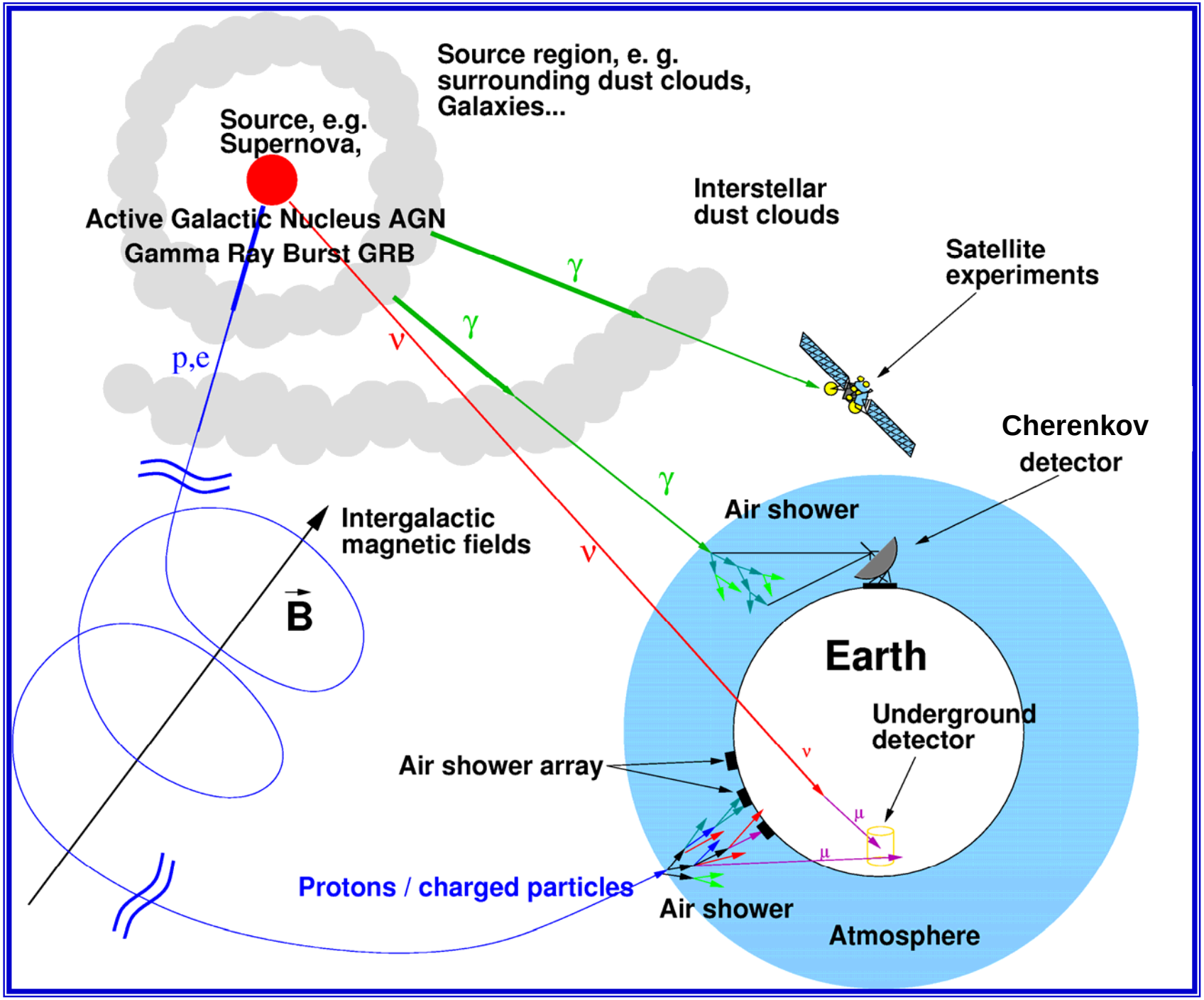
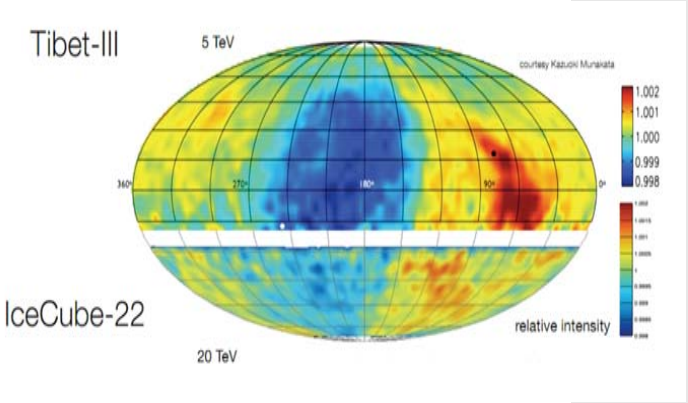


Figure: Becker (2008)

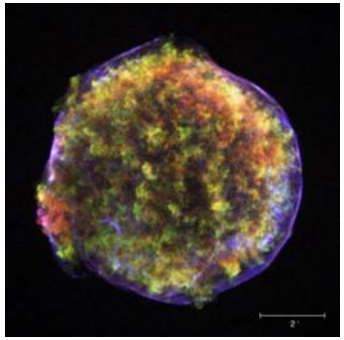

Source region, e. g.
surrounding dust clouds,
Galaxies...
Source, e.g.
Supernova,
Active Galactic Nucleus AGN
Gamma Ray Burst GRB
Interstellar
dust clouds
Satellite
experiments
γ
γ
γ
ν
p,e
Cherenkov
detector
Air shower
Intergalactic
magnetic fields
B
ν
Earth
Underground
detector
Air shower array
ν
μ
μ
Protons / charged particles
Air shower
Atmosphere

Contents

- Cosmic ray anisotropy @ TeV energies

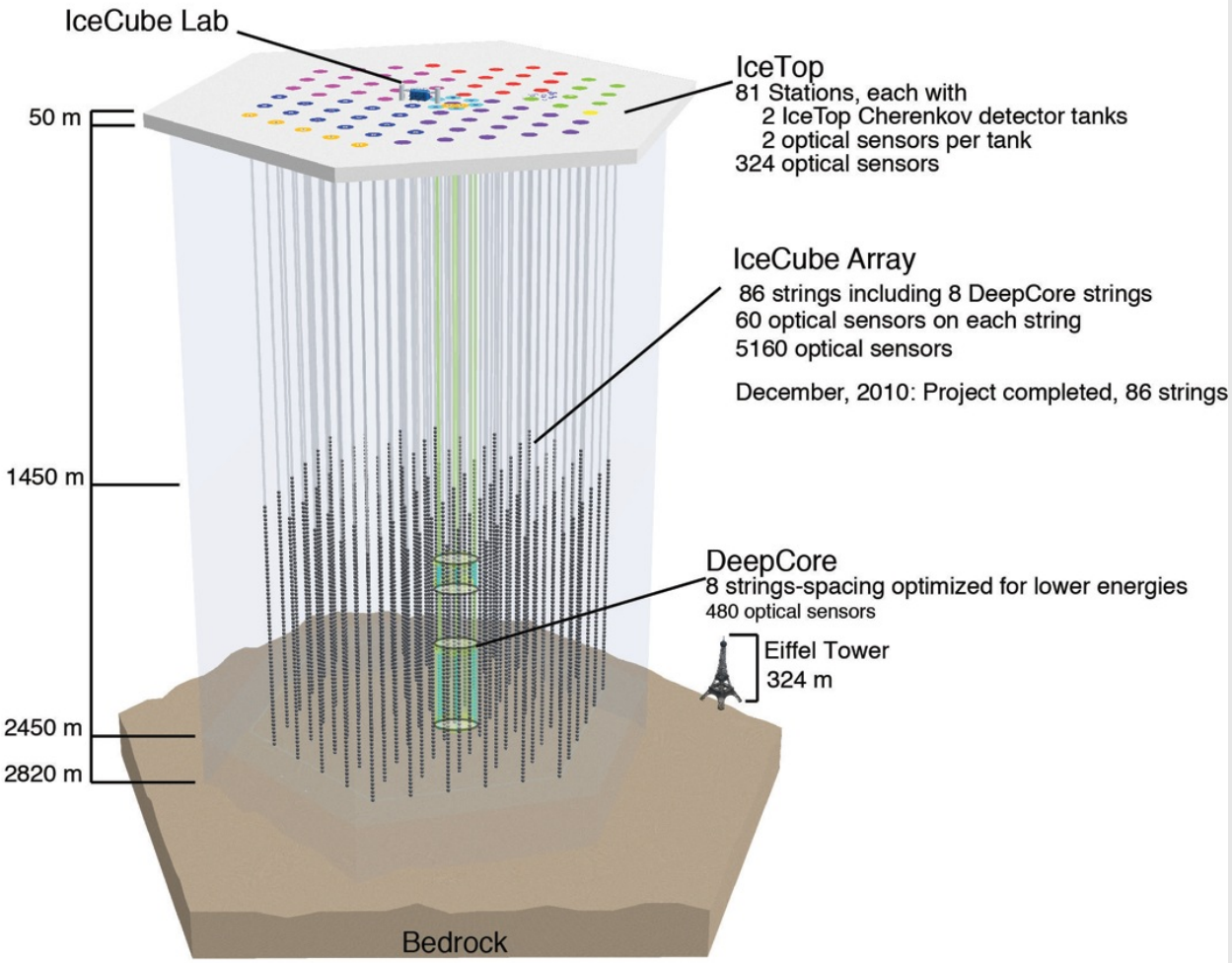


- Supernova remnants

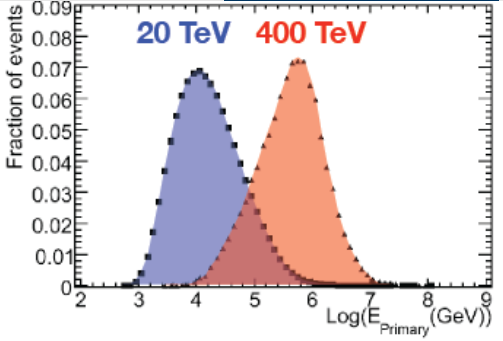


- Starburst Galaxies

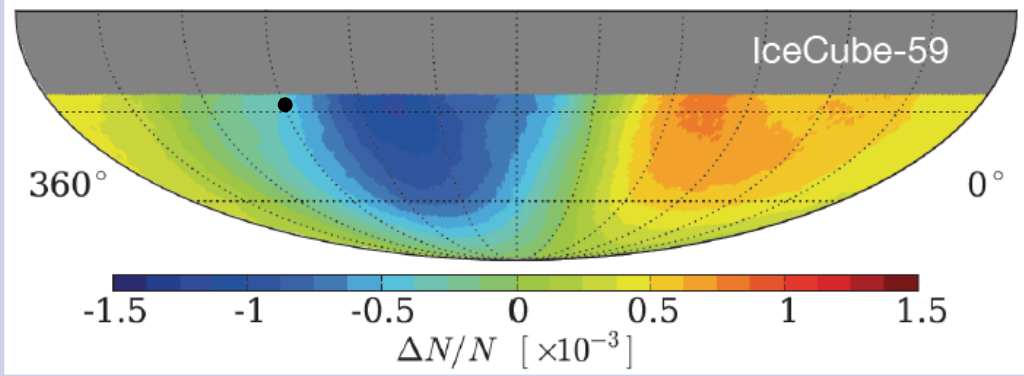
IceCube measurements → cosmic ray induced muons → cosmic ray distribution > TeV energies



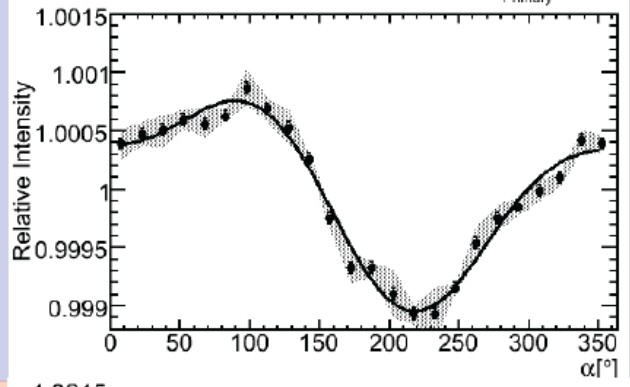
cosmic ray anisotropy

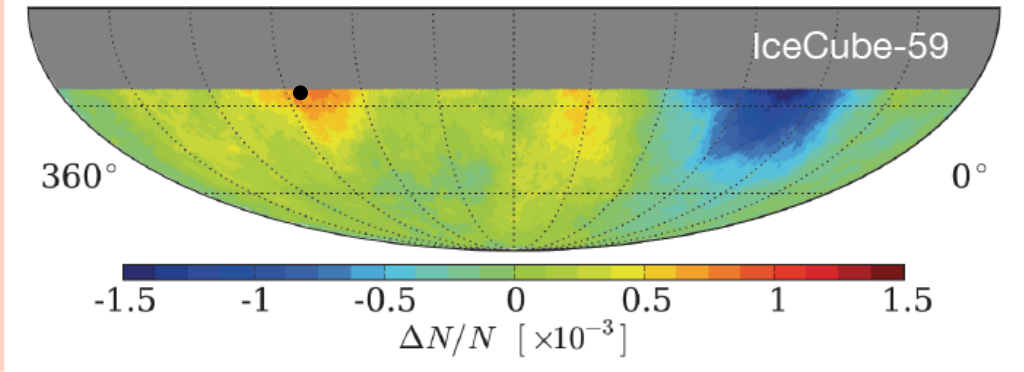


relative intensity equatorial coordinates

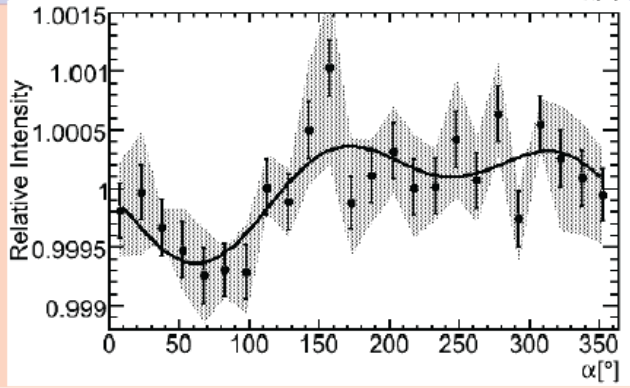


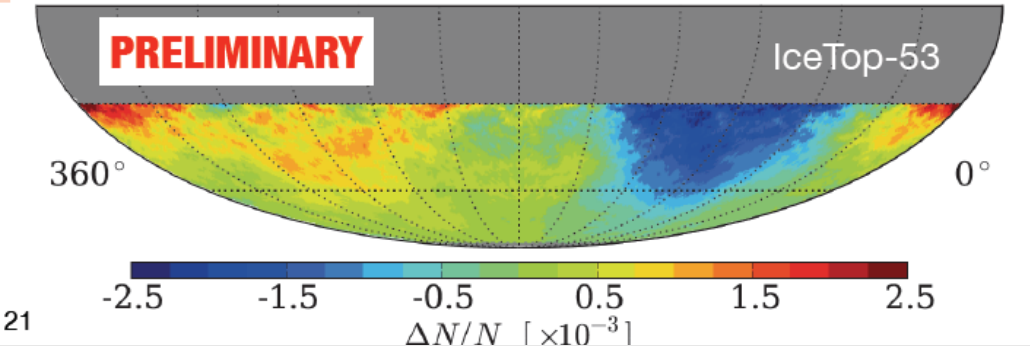
20 TeV





400 TeV





640 TeV

Abbasi et al., ApJ, **746**, 33, 2012

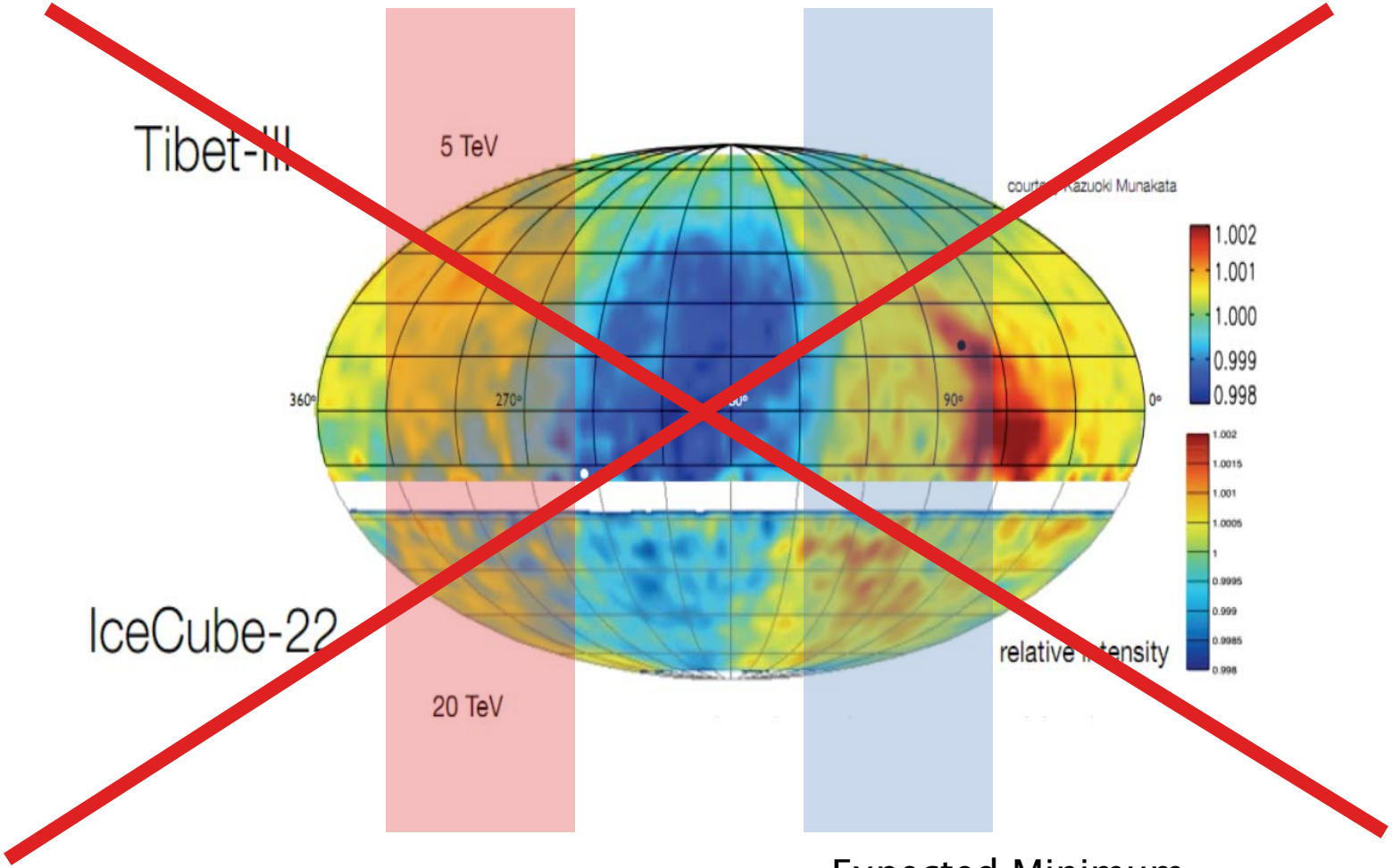
Santander et al., arXiv:1205.3969

Desiati (for IceCube), Vulcano 2012

Large-scale anisotropy
Three possibilities

- Compton-Getting effect: motion of the solar system through the cosmic ray rest frame
- Anisotropic distributions of cosmic ray sources
- Anisotropic structure of magnetic fields

Testing the Compton-Getting hypothesis



Expected Maximum

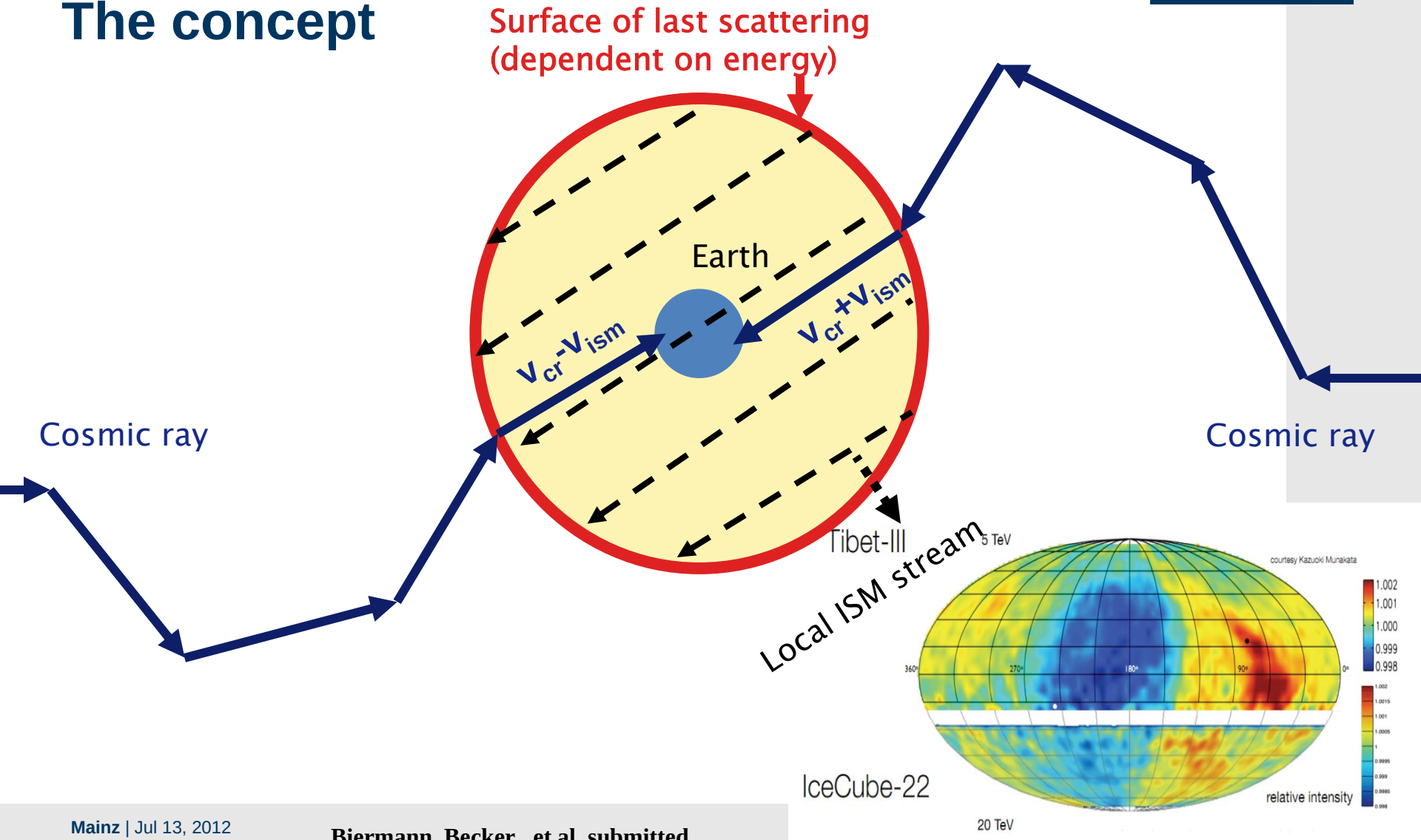
Expected Minimum

Compton Getting - revised

- Compton Getting assumption:
  - **Sun co-rotating in Galaxy & cosmic rays not**
- **Not realistic:** cosmic rays produced by SNRs → also co-rotating!
- **Relevant velocity:** local ISM velocity at scales of no scattering →

Biermann, Becker Tjus, et al, submitted

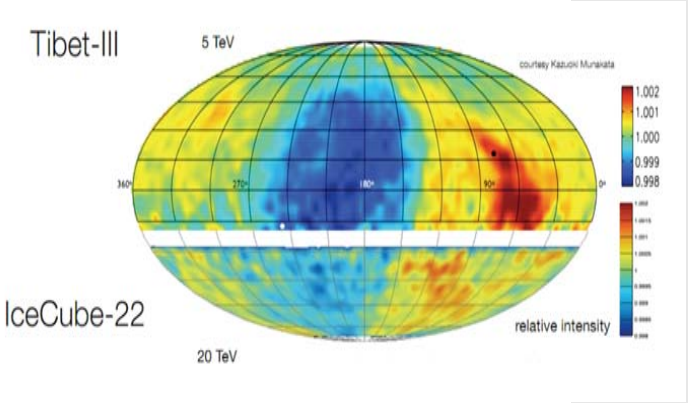
The concept



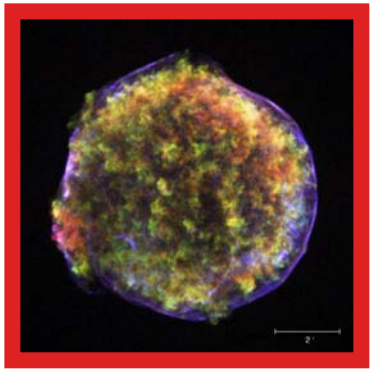
Biermann, Becker, et al, submitted

Contents

- Cosmic ray anisotropy @ TeV energies



- Supernova remnants

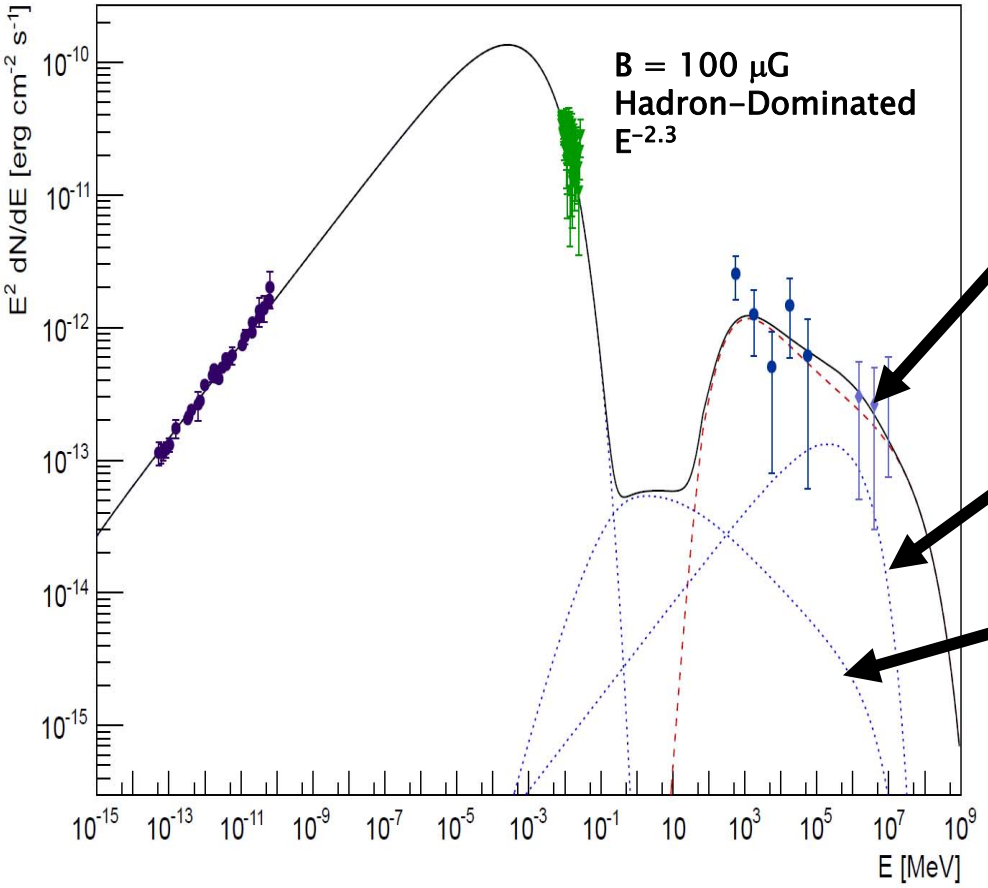


- Starburst Galaxies

SNRs: available information from observations

- **Radio observations → non-thermal electrons**
- **Gamma-ray radiation → hadrons/leptons**
  - π^0-decays, IC, brems
- **Molecular ions: lines**
  - Cosmic ray ionization
  - *Difficulty:* CR spectrum at low energies not known

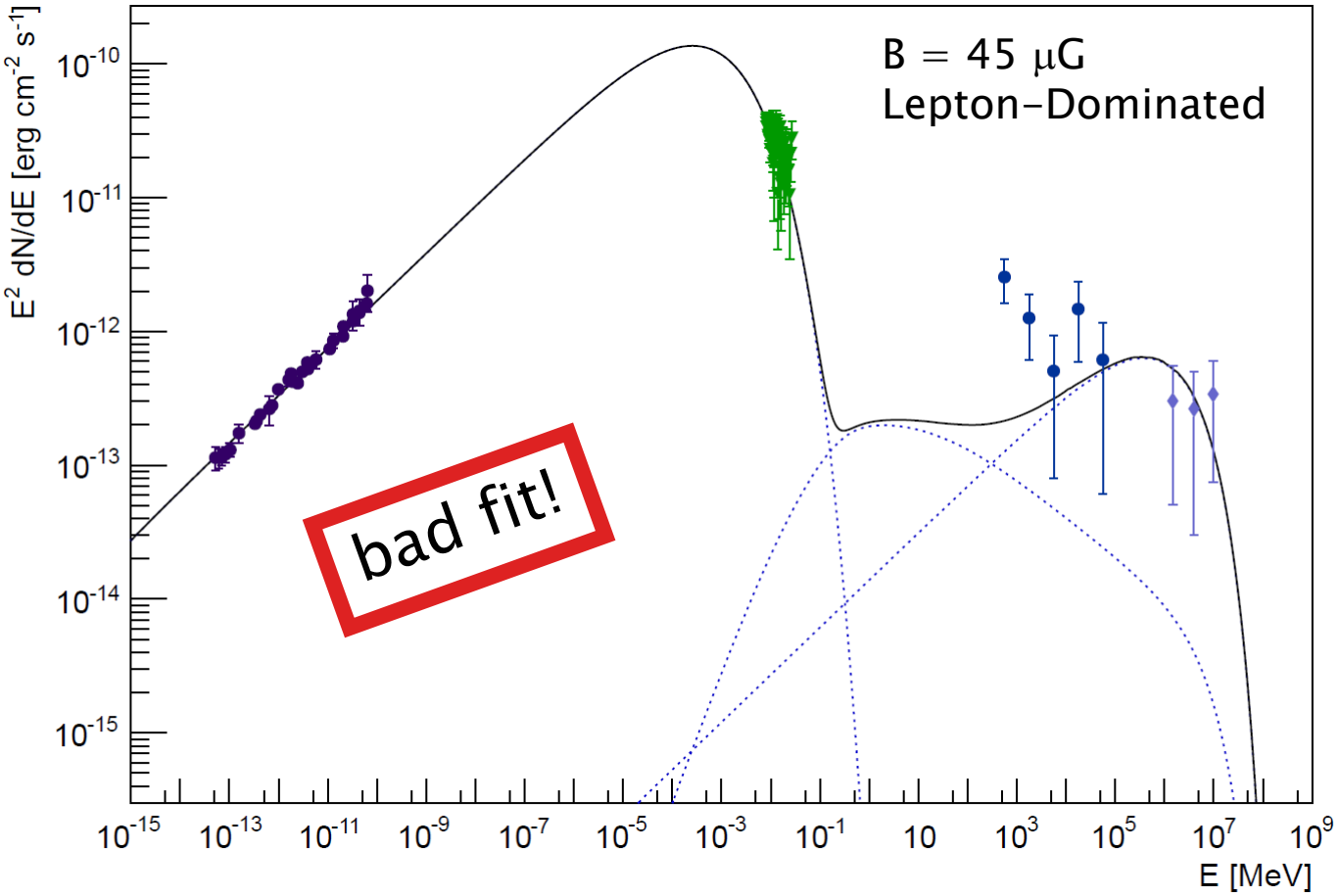
Gamma-ray example:
Tycho



Emission @ GeV/TeV:

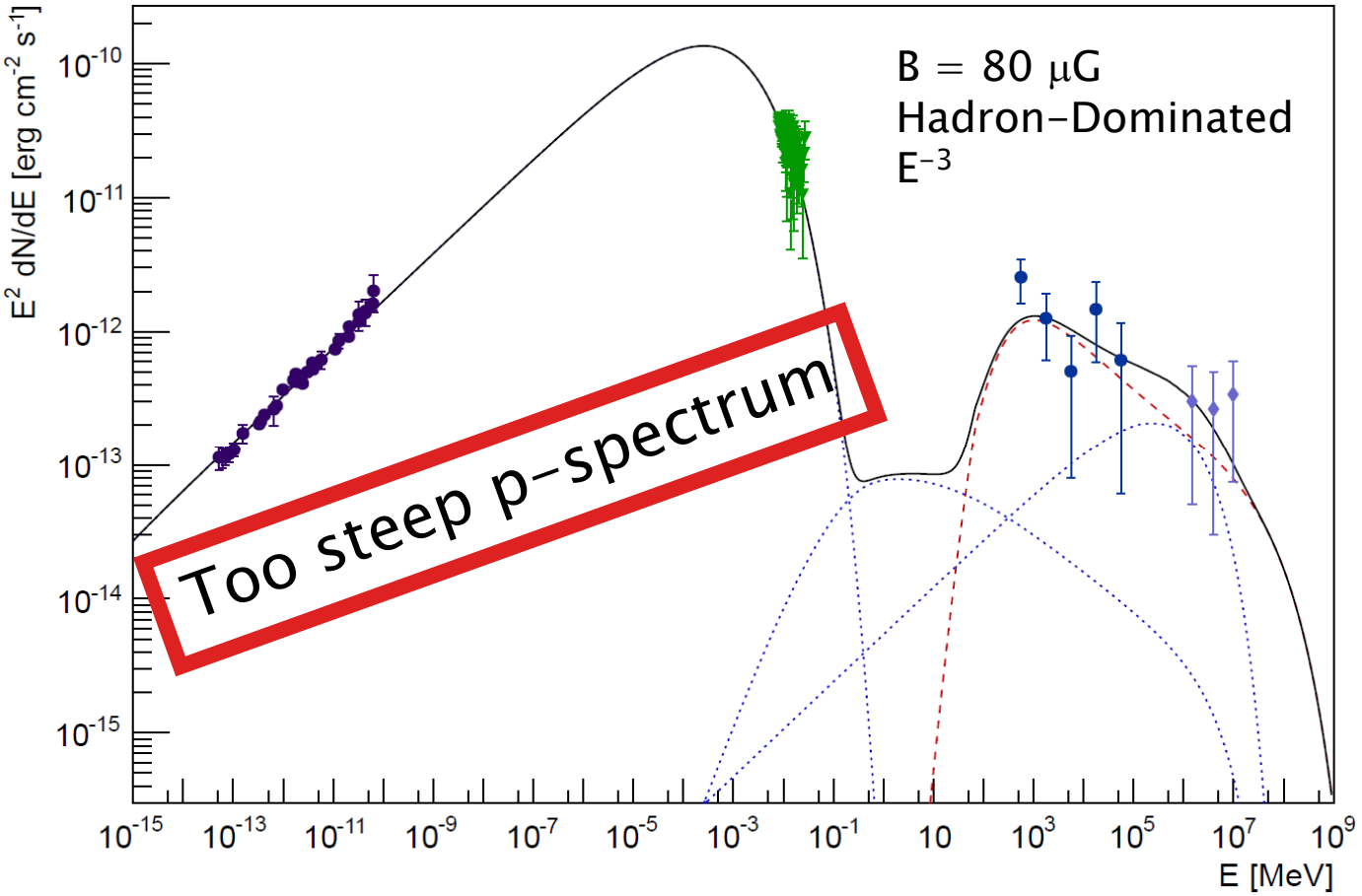
- Hadronic interactions (n; p):
  - pp → π → γ/ν
- Inverse Compton (B-field; e-):
  - eγ → e'γ'
- Bremsstrahlung (B-field; n; e-):
  - ep → e' p γ

Hadronic VS Leptonic emissions



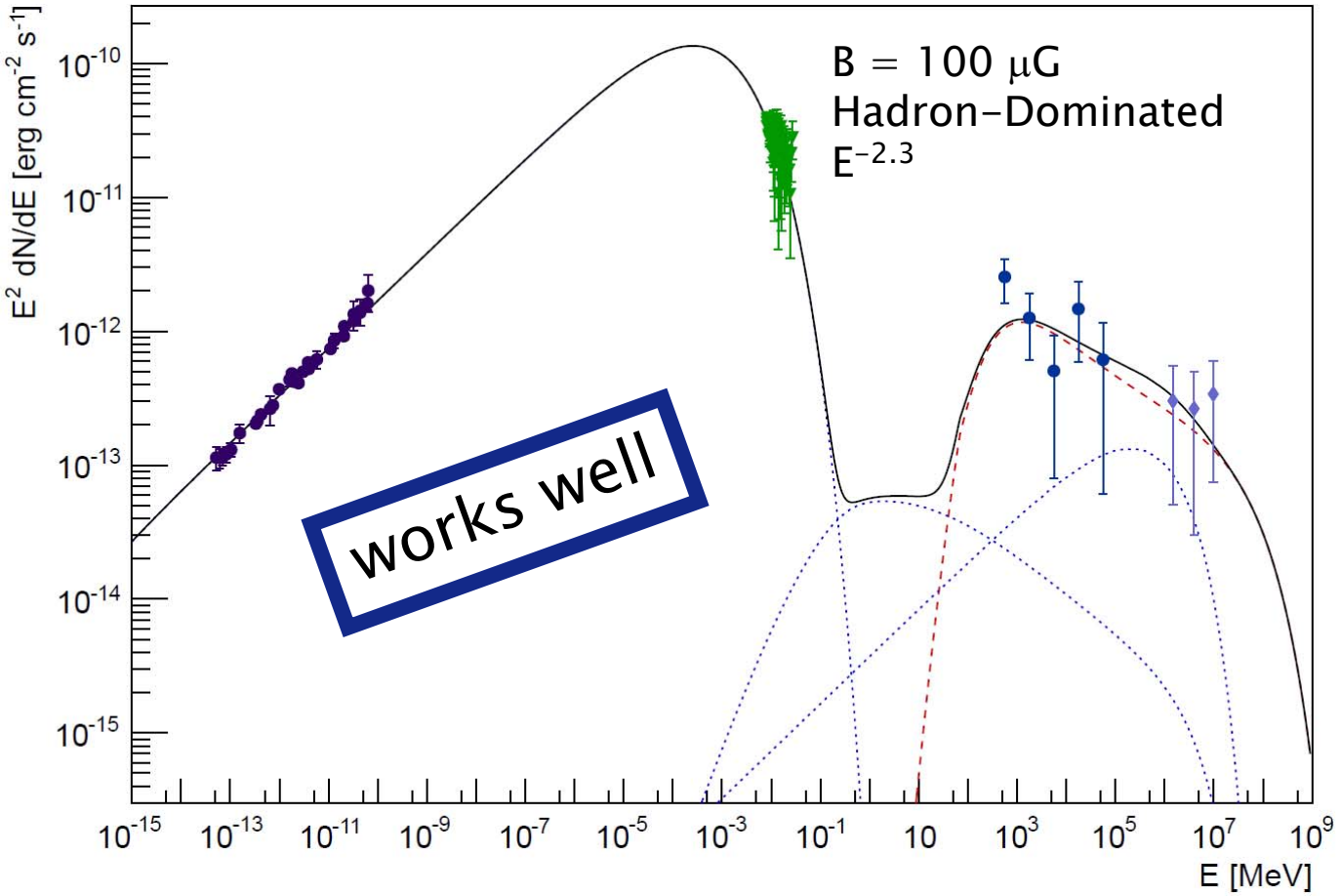
Mandelartz, Becker Tjus, et al, in prep

Hadronic VS Leptonic emissions



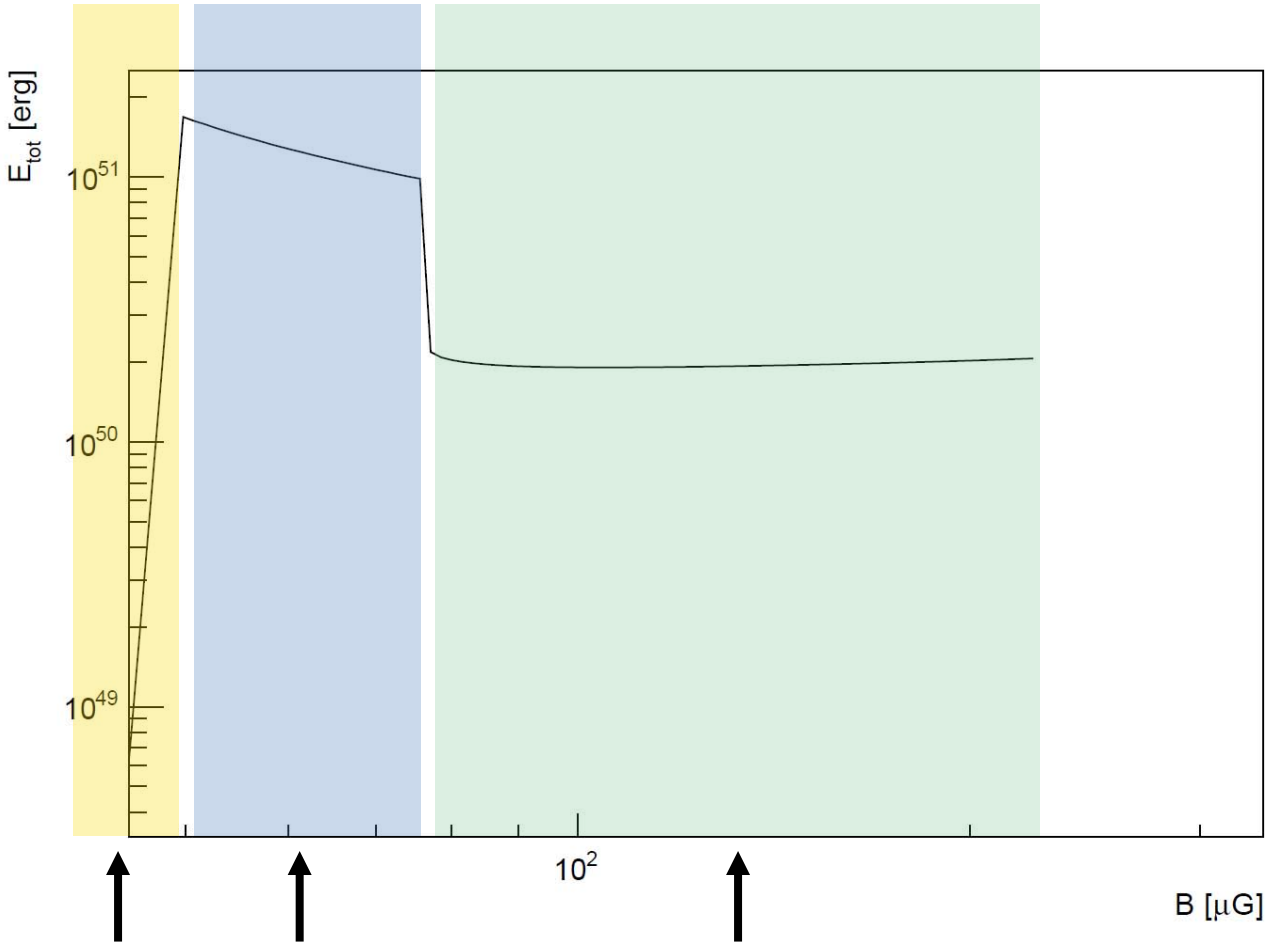
Mandelartz, Becker Tjus, et al, in prep

Hadronic VS Leptonic emissions



Mandelartz, Becker Tjus, et al, in prep

Tycho: total required energy



Lepton-dominance

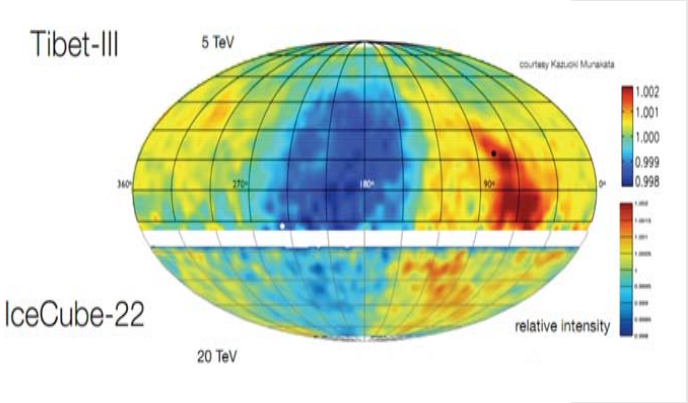
Hadron-dominance, $\sim E^{-3}$

Hadron-dominance, $\sim E^{-2.3}$

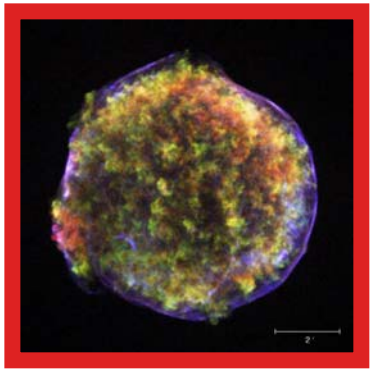
Mandelartz, Becker Tjus, et al, in prep

Contents

- Cosmic ray anisotropy @ TeV energies

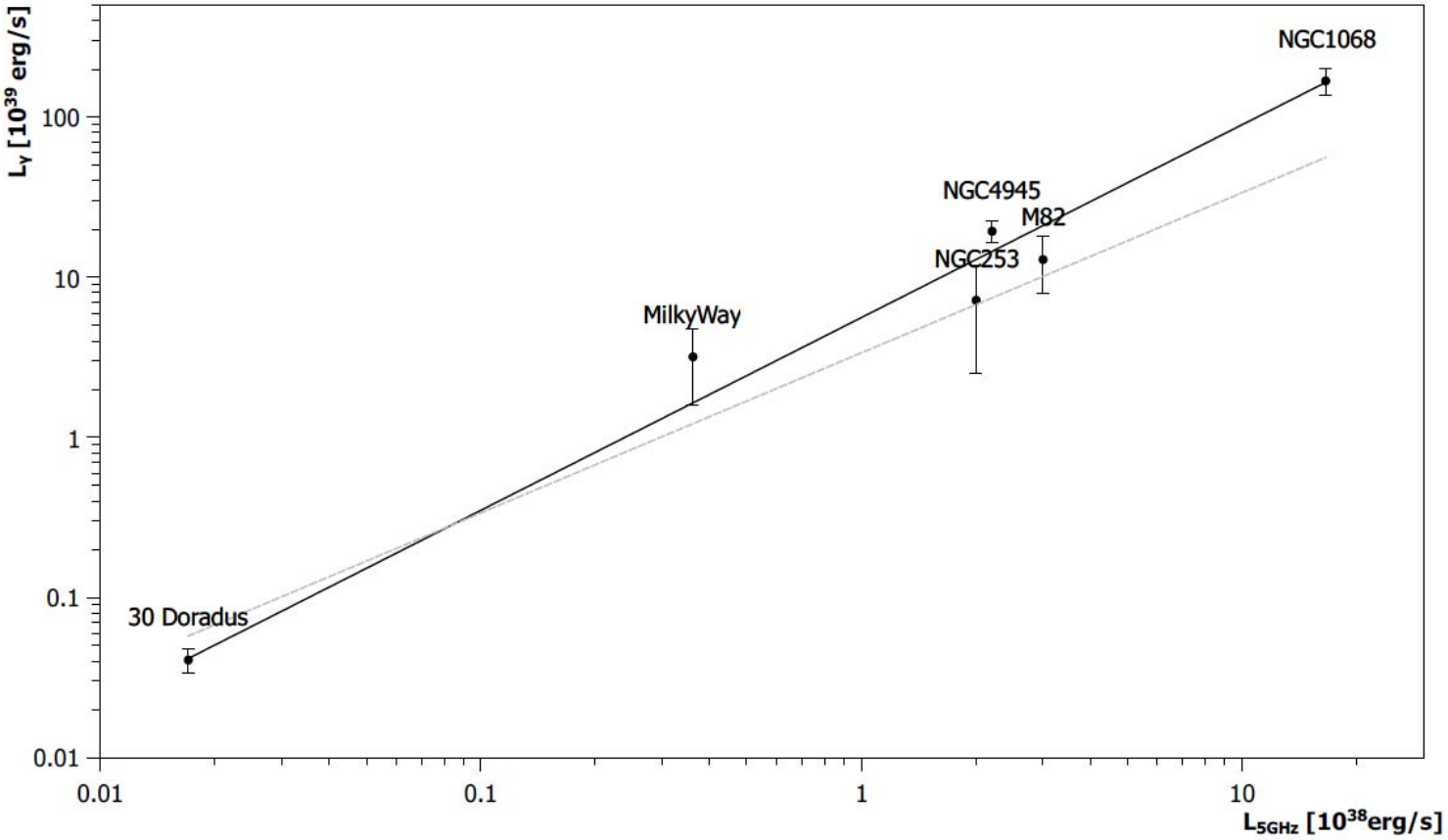


- Supernova remnants



- Starburst Galaxies

Radio - GeV correlation?



Theoretical origin if electrons and protons have the same origin

Becker, Schuppan, Schöneberg, Vulcano 2011 & ms in prep

High-energy signal (hadronic)

$$L_\gamma = V N_{SNR} \int_{E_{\min}}^{E_{\max}} E_\gamma \Phi_\gamma(E_\gamma) dE_\gamma$$

$$\Phi_\gamma = c \cdot n_H \cdot \int_0^1 \sigma_{inel}\left(\frac{E_\gamma}{x}\right) \cdot \lambda_p \cdot F_\gamma\left(x, \frac{E_\gamma}{x}\right) \frac{dx}{x}$$

Target density

Cross section

Primary flux

Distribution function

$$x = \frac{E_\gamma}{E_p}$$

Radio signature (electron-synchrotron)

$$L_\nu = V N_{SNR} a_e \frac{1}{6} \beta^2 m_e^2 c^4 \left(\frac{\sigma_T B}{e}\right) \left(\frac{\nu}{\nu_G}\right)^\delta$$

Emission Volume

SNR number/galaxy

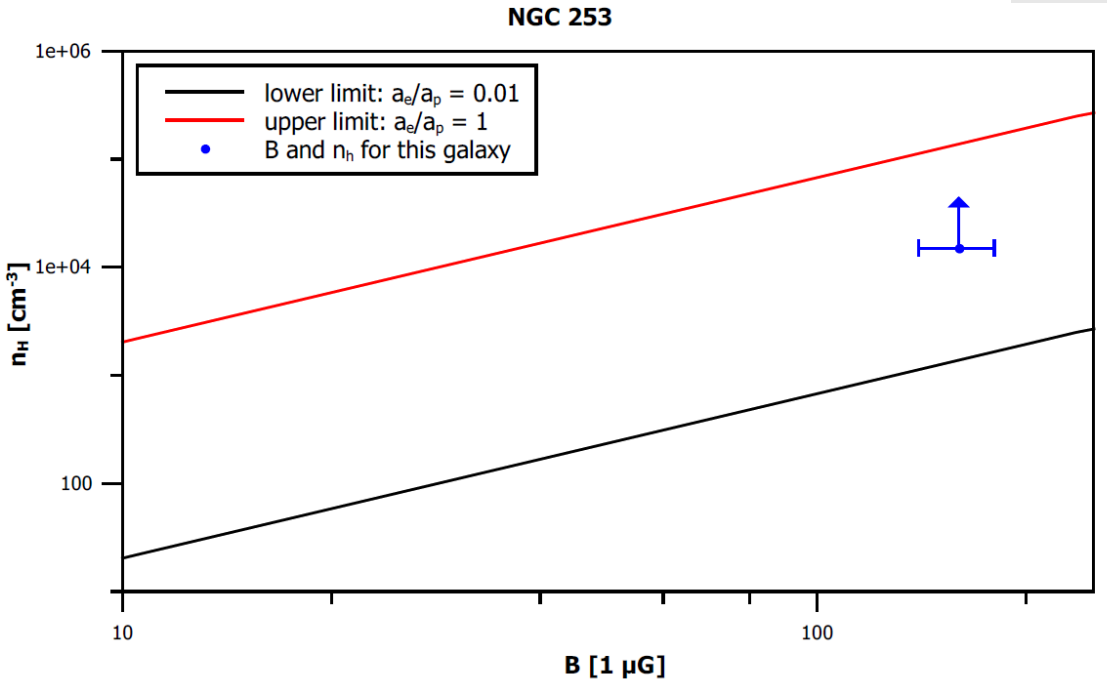
e-Spectrum normalization:
$dN/dE = a_e * E^{-p}$

$(1-p)/2$

$$\nu_G = \frac{eB}{2\pi m_e c}$$

Constraining the magnetic field using gamma-ray data?

- Available information:
  - Radio/Gamma-data
- Parameters:
  - B
  - n
  - a_e/a_p
- ➔ B can be determined where density is known and assuming a constant ratio a_e/a_p



Schöneberg, Becker Tjus, et al, in prep

Discussions ongoing with RJ Dettmar, B Adebahr et al

Cosmic rays and magnetic fields:
what we can learn from them...

- **Anisotropy** @ TeV (hadronic) cosmic ray energies
  - Needs to be investigated → magnetic field effect/source distribution/local plasma

- **SNR-SED** from radio up to TeV → information about
  - Magnetic field strength
  - Electron & Hadron Spectra

- **Starburst Galaxies**
  - Radio-Gamma correlation might help to estimate magnetic field