Cosmic Ray Introduction

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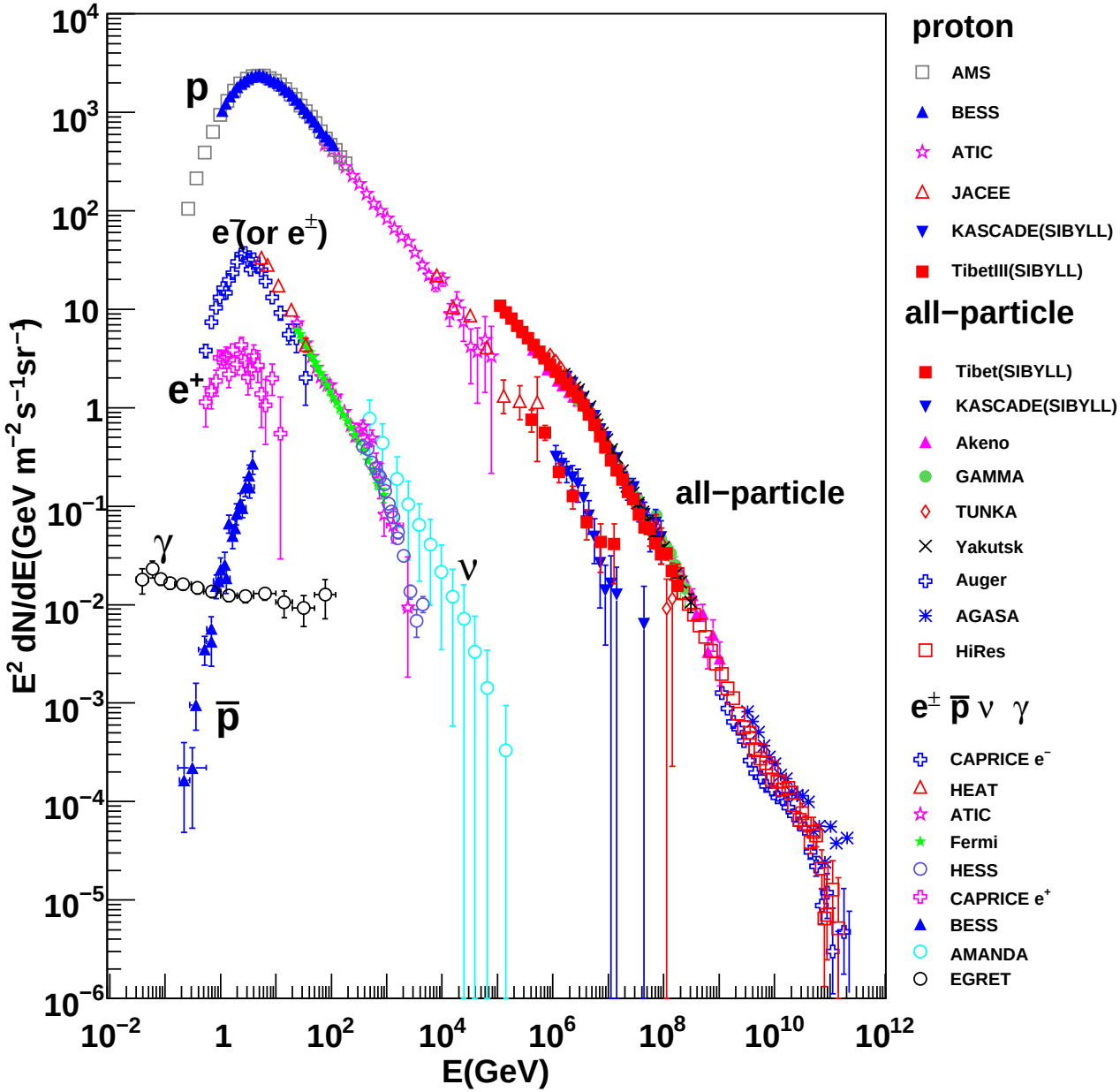
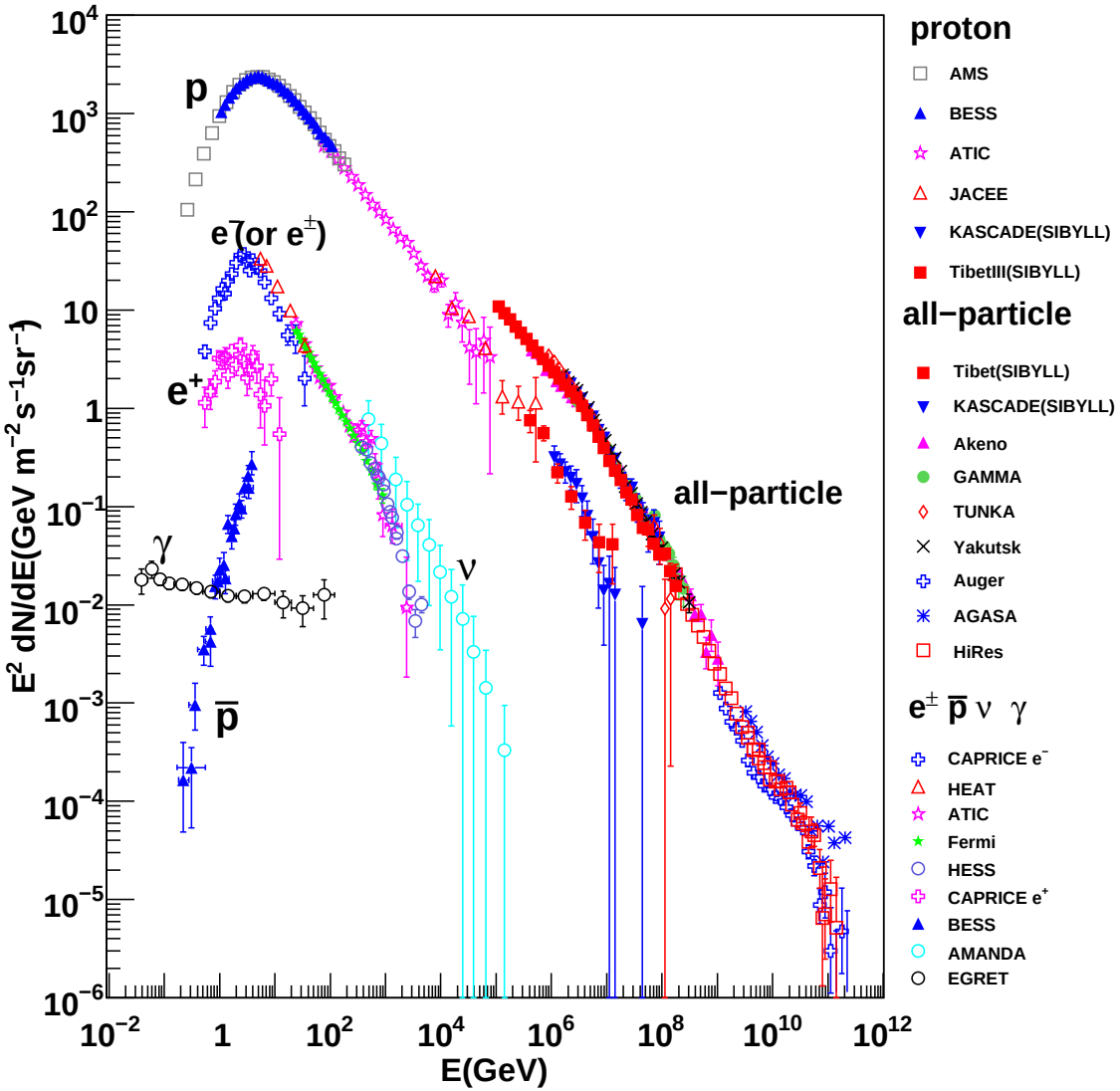

p
e⁻(or e±)
e+
γ
ν
p̄
all−particle
E² dN/dE(GeV m⁻² s⁻¹ sr⁻¹)
E(GeV)
proton
AMS
BESS
ATIC
JACEE
KASCADE(SIBYLL)
TibetIII(SIBYLL)
all−particle
Tibet(SIBYLL)
KASCADE(SIBYLL)
Akeno
GAMMA
TUNKA
Yakutsk
Auger
AGASA
HiRes
e± p̄ ν γ
CAPRICE e⁻
HEAT
ATIC
Fermi
HESS
CAPRICE e+
BESS
AMANDA
EGRET

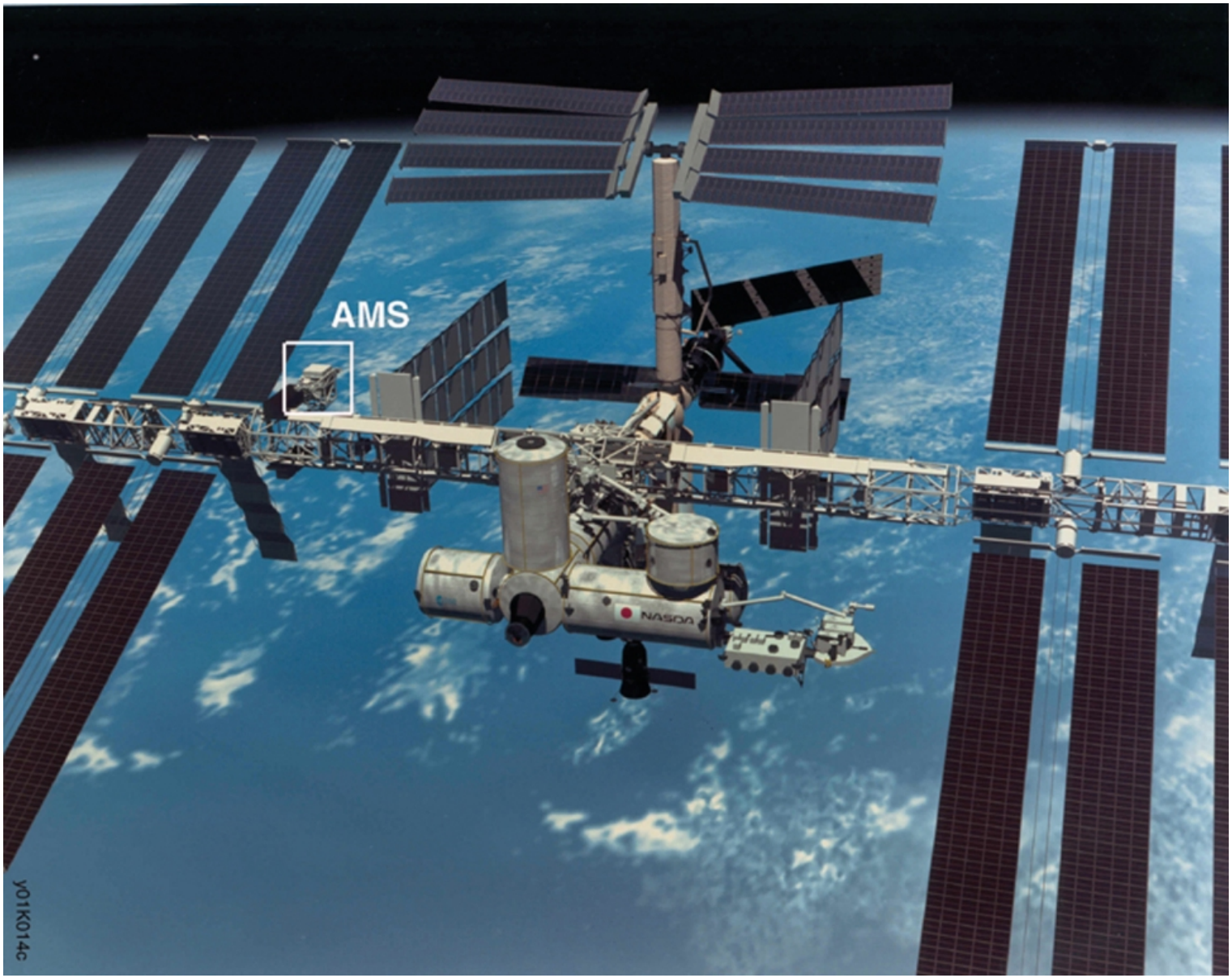


- Flux at 100 GeV:
  $\sim$ 1 particle/m^2/sec
- Flux at 10^6 GeV ("knee"):
  $\sim$ 1 particle/m^2/year
- Flux at 10^{10} GeV ("ankle"):
  $\sim$ 1 particle/km^2/year
- At 10^{11} GeV: endpoint
  ("GZK cutoff", see later)

Tools for studying cosmic rays

- Space-based experiments
  - PAMELA, AMS-02, Fermi, ...
  - $E \lesssim 10^3$ GeV
  - Clean measurement, long observation times

AMS-02 (Alpha Magnetic Spectrometer)



Tools for studying cosmic rays

- Space-based experiments
  - PAMELA, AMS-02, Fermi, ...
  - $E \lesssim 10^3$ GeV
  - Clean measurement, long observation times
- Balloon experiments
  - $E \lesssim 10^6$ GeV
  - Only short observation periods
  - Atmospheric distortions
- Imaging Air Čerenkov Telescopes
  - HESS, MAGIC, VERITAS, ...
  - 10 GeV $\lesssim E \lesssim 10^6$ GeV

H.E.S.S. (High Energy Stereoscopic System)

Tools for studying cosmic rays

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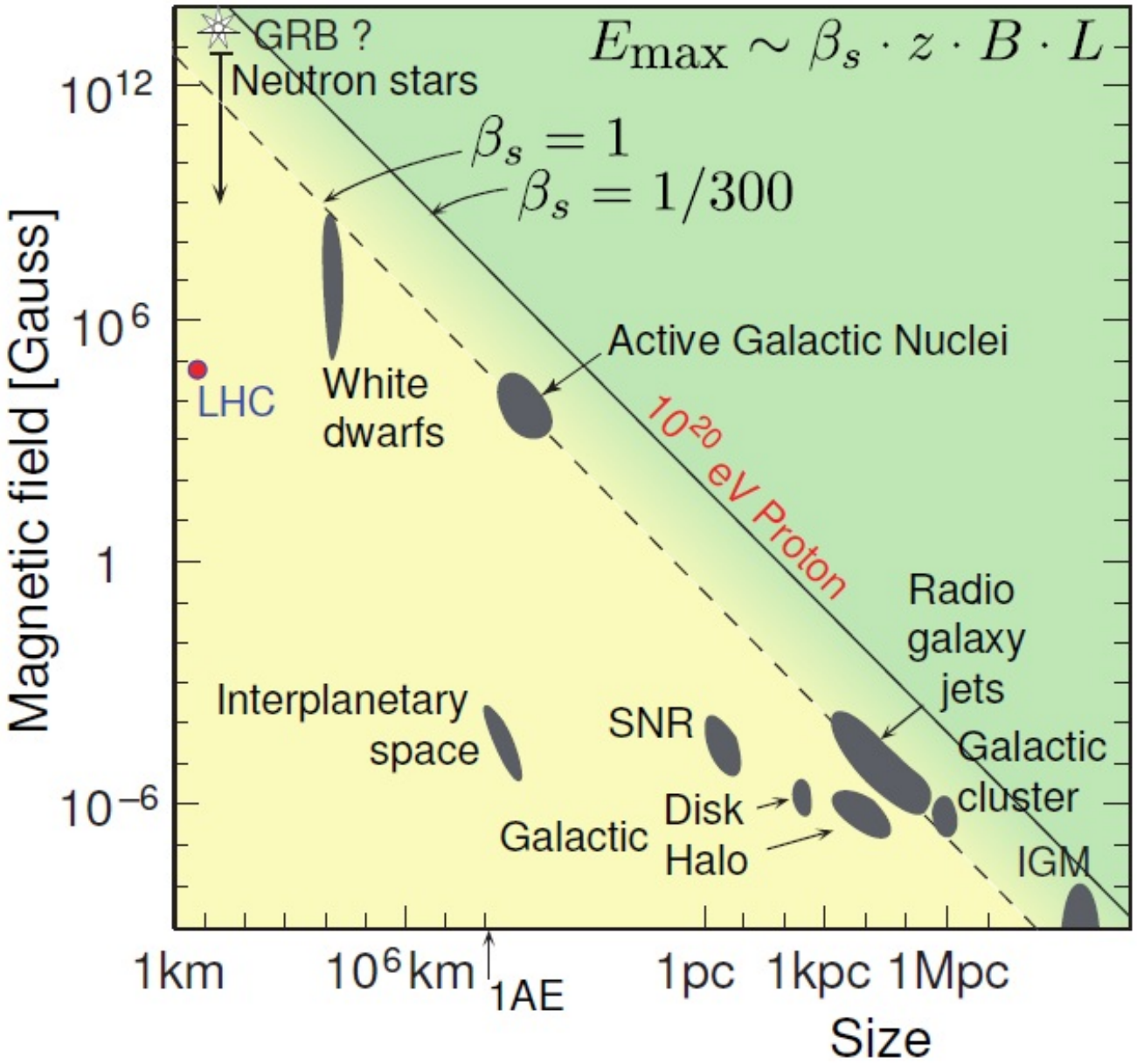
- Imaging Air Čerenkov Telescopes
  - HESS, MAGIC, VERITAS, ...
  - $10 \text{ GeV} \lesssim E \lesssim 10^6$ GeV
- Air shower detectors
  - Pierre Auger observatory, ...
  - $10^5 \text{ GeV} \lesssim E \lesssim 10^{12}$ GeV

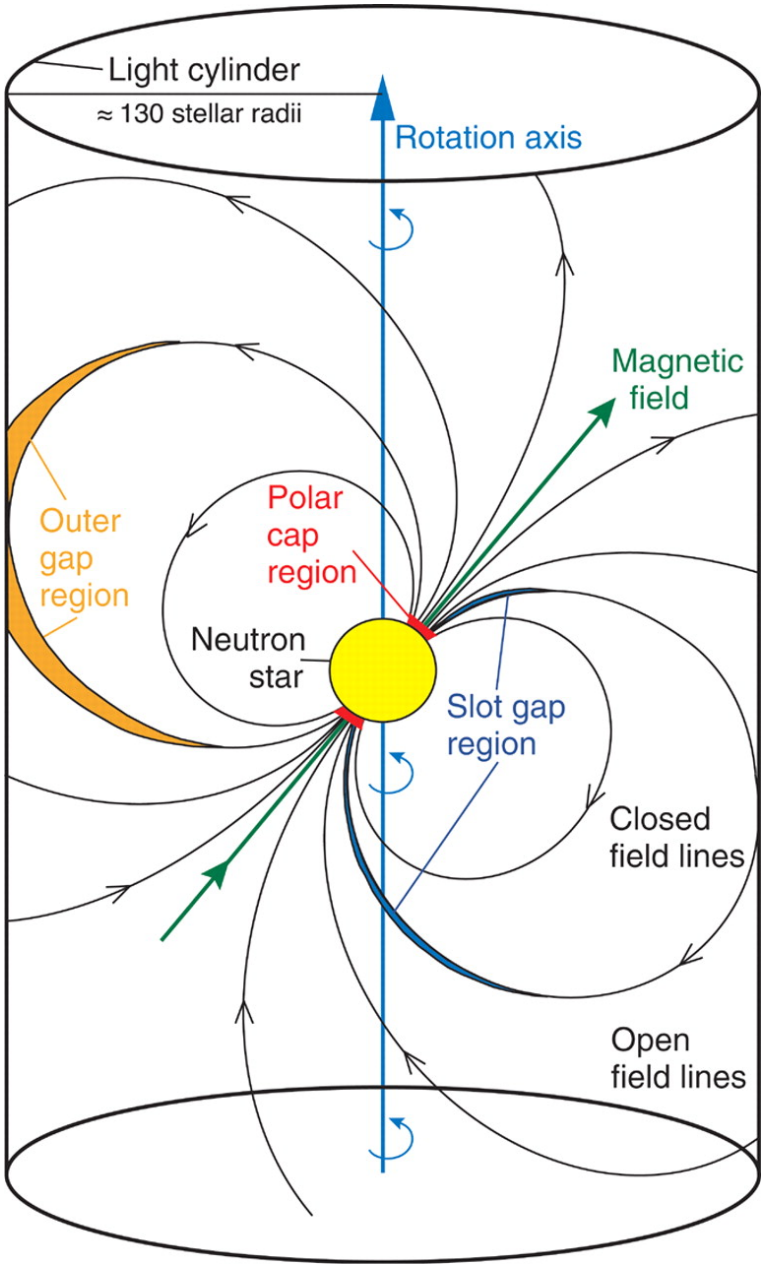
Pierre Auger Observatory

Pierre Auger Observatory

Hillas Plot


$E_{max} \sim \beta_s \cdot z \cdot B \cdot L$
GRB ?
Neutron stars
$\beta_s = 1$
$\beta_s = 1/300$
Active Galactic Nuclei
White dwarfs
LHC
10^{20} eV Proton
Radio galaxy jets
Galactic cluster
IGM
Interplanetary space
SNR
Disk
Halo
Galactic
Magnetic field [Gauss]
10^{12}
10^{6}
1
10^{-6}
1km
10^6km
1AE
1pc
1kpc
1Mpc
Size

Pulsars


Light cylinder
≈ 130 stellar radii
Rotation axis
Magnetic field
Outer gap region
Polar cap region
Neutron star
Slot gap region
Closed field lines
Open field lines