DAMPE experiment and its latest results

Qiang Yuan (袁强)
(On behalf of the DAMPE collaboration)
Purple Mountain Observatory, CAS

2018-10-11 @ NTU
Outline

• Overview of dark matter indirect detection
• Dark matter particle explorer (DAMPE)
  ➢ DAMPE experiment
  ➢ Status and on-orbit performance
  ➢ Physical results
• Summary
Composition of the Universe

- The universe is made up of 68% dark energy, 27% dark matter and 5% ordinary matter.
- We know little about the Universe!
Detection of (WIMP) dark matter particles

(a) Direct detection

(b) Collider detection

Dark matter

SM particle

SM particle

Dark matter

(c) Indirect detection

Gamma-ray

Electron Positron Neutrino

Proton Antiproton
Underground direct detection

- Nuclear recoil from WIMP-nuclei collision
- Placed in deep underground laboratory to shield cosmic ray backgrounds
Jinping dark matter experiments

Yue, Q. (2016)

CDEX (2018)

PandaX (2017)
Current status

No signal has been successfully found. Stringent limits are placed.
Collider detection

Missing energy events.

No signal of dark matter production has been identified yet in many colliders.
Some ongoing cosmic-ray/gamma-ray experiments

CALET

AMS-02

Fermi

Yangbajing/LHAASO

HESS/MAGIC/VERITAS/CTA
Excess of high energy positron fraction

\[ p + p \rightarrow \pi^\pm + \cdots \rightarrow e^\pm + \cdots \]
Gamma-ray excess from Galactic center

Gordon and Macias (2013)

Calore et al. (2015)

- Generalized NFW$^2$ distribution
- Spectrum peaks at 1-3 GeV
- Consistent with dark matter annihilation with 40 GeV mass and $10^{-26}$ cm$^3$/s cross section
- Millisecond pulsars?

Goodenough & Hooper (2009)
Vitale & Morselli (2009)
Hooper & Goodenough (2011)
Hooper & Linden (2011)
Abazajian & Kaplinghat (2012)
Gordon & Macias (2013)
Huang et al. (2013)
Abazajian et al. (2014)
Daylan et al. (2014)
Zhou et al. (2014) ...
• The standard background model under-predicts cosmic ray antiprotons in 1-10 GeV band, which could be explained by \~50 GeV dark matter annihilation

• Uncertainties of hadronic/nuclear interactions and solar modulation

Cui, QY et al. (2017)
Cuoco et al. (2017)
Summary of dark matter searches

• Collider: Null!

• Direct: Null!

• Indirect:
  1. positron excess
  2. gamma-ray excess
  3. antiproton excess
  Inconclusive!
Summary of dark matter searches

- Collider: Null!
- Direct: Null!
- Indirect:
  1. positron excess
  2. gamma-ray excess
  3. antiproton excess
     Inconclusive!

- Astronomers can not see dark matter, but they discover dark matter
- Physicists can in principle “see” dark matter, but they find nothing yet
Outline

- Overview of dark matter indirect detection
- Dark matter particle explorer (DAMPE)
  - DAMPE experiment
  - Status and on-orbit performance
  - Physical results
- Summary
Dark Matter Particle Explorer: probe the high-energy window with higher energy resolution, higher energy reach, and clearer particle ID

- Dark matter particles
- High energy cosmic rays
- Gamma-ray astronomy
The DAMPE collaboration

- **China**
  - Purple Mountain Observatory, CAS
  - University of Science and Technology of China
  - Institute of High Energy Physics, CAS
  - Institute of Modern Physics, CAS
  - National Space Science Center, CAS

- **Italy**
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento

- **Switzerland**
  - University of Geneva
Launched on Dec. 17, 2015, at JiuQuan satellite launch center

Named as “Wukong”
DAMPE detector

- Charge (dE/dx in PSD, STK and BGO)
- Track (STK and BGO)
- Energy (BGO)
- Particle identity (BGO and NUD)

Chang et al. (2017, Astropart. Phys.)
Beam tests at CERN

• 14days@PS, 29/10-11/11 2014
  – e @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c
  – p @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c
  – π- @ 3GeV/c, 10GeV/c
  – γ @ 0.5-3GeV/c
• 8days@SPS, 12/11-19/11 2014
  – e @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c
  – p @ 400GeV/c (SPS primary beam)
  – γ @ 3-20GeV/c
  – μ @ 150GeV/c,
• 17days@SPS, 16/3-1/4 2015
  – Fragments: 66.67-88.89-166.67GeV/c
  – Argon: 30A- 40A- 75A GeV/c
  – Proton: 30GeV/c, 40GeV/c
• 21days@SPS, 10/6-1/7 2015
  – Primary Proton: 400GeV/c
  – Electrons @ 20, 100, 150 GeV/c
  – γ @ 50, 75, 150 GeV/c
  – μ @ 150 GeV /c
  – π+ @10, 20, 50, 100 GeV/c
• 6days@SPS, 20/11-25/11 2015
  -- Pb 030 AGeV/c (and fragments)
Beam tests of electrons

Chang et al. (2017, Astropart. Phys.)
Beam tests of protons

Test beam and simulation comparison

Chang et al. (2017, Astropart. Phys.)
Outline

• Overview of dark matter indirect detection
• Dark matter particle explorer (DAMPE)
  ➢ DAMPE experiment
  ➢ Status and on-orbit performance
  ➢ Physical results
• Summary
Observation overview

5 full scans of the sky

5M events/day
4.6 billion in total
On-orbit performance

PSD stability: 0.5%

STK stability: 0.7%

BGO stability: 0.5%

NUD stability: 0.9%
Typical DAMPE event

4.7 TeV electron
Typical DAMPE events

Electron

Gamma

Proton
On-orbit performance: energy calibration

Counts

MIPs

On-Orbit Data
MC-Digi Data

H₂ liquid
He gas
Sn
Pb

Deposited Energy (MeV)
Particle identification is crucial

\[ p/\gamma \sim 10^5 \]

\[ p/e \sim 10^3 \]
On-orbit performance: particle identification

0.5-1.0 TeV

- We use the lateral (SumRms) and longitudinal (energy ratio in last layer) developments of the showers to discriminate electrons from protons
- For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV

(Nature 552 (2017) 63-66)
Outline

• Overview of dark matter indirect detection
• Dark matter particle explorer (DAMPE)
  ➢ DAMPE experiment
  ➢ Status and on-orbit performance
  ➢ Physical results
• Summary
Physical results: electron+positron fluxes

530 days of data
2.8 billion events
1.5 million e+e- (>25 GeV)

- Highest precision and lowest background in TeV energy range
- Direct detection of a spectral break at ~1 TeV with 6.6σ confidence level

Ambrosi et al. (2017)
Three-component e⁺e⁻ model

- Primary e⁻ accelerated together with ions (in e.g., supernova remnants)
- Secondary e⁻ and e⁺ from hadronic interaction of cosmic ray nuclei
- Additional e⁻ and e⁺ from extra sources (e.g., pulsars, ...)

![Graph showing electron and positron spectra]
Implication of DAMPE data: improve constraints on model parameters of the 1st and 3rd components

bkg cutoff energy vs. pulsar cutoff

mchi vs. $<\sigma v>$

Yuan et al. (2017)
arXiv:1711.10989
Implication of the spectral break: break of continuous source distributions in space and time

- Cooling time of TeV electrons $\sim$ Myr, effective propagation range $\sim$ kpc
- Assuming a total SN rate of 0.01 per year, the total number of SNRs within the effective volume and cooling time is $O(10)$

Fang et al. (2017)
Yuan & Feng (2018)
Physical results: variable AGNs

- DAMPE detected outbursts of CTA 102 and 3C 454.3
- Consistent with multi-wavelength observations

Yuan et al. (2017; ICRC)
Physical results: pulsars

Lei et al. (2017; ICRC)
Summary

• DAMPE detector is working extremely well since its launch more than 2 years ago
  – The electron + positron spectrum at TeV energies has been precisely measured → as anticipated!
    • A clear spectral break has been directly measured at ~ 1 TeV → crucial to understanding some mysteries in cosmic ray physics!
  – Nuclei measurements are ongoing
  – Photon detection capability is demonstrated but more statistics to profit the excellent energy resolution at high energy is needed

Thanks for your attention!