High energy neutrino emission from a global accretion flow around a SMBH based on a GRMHD simulation model

Tomohisa KAWASHIMA

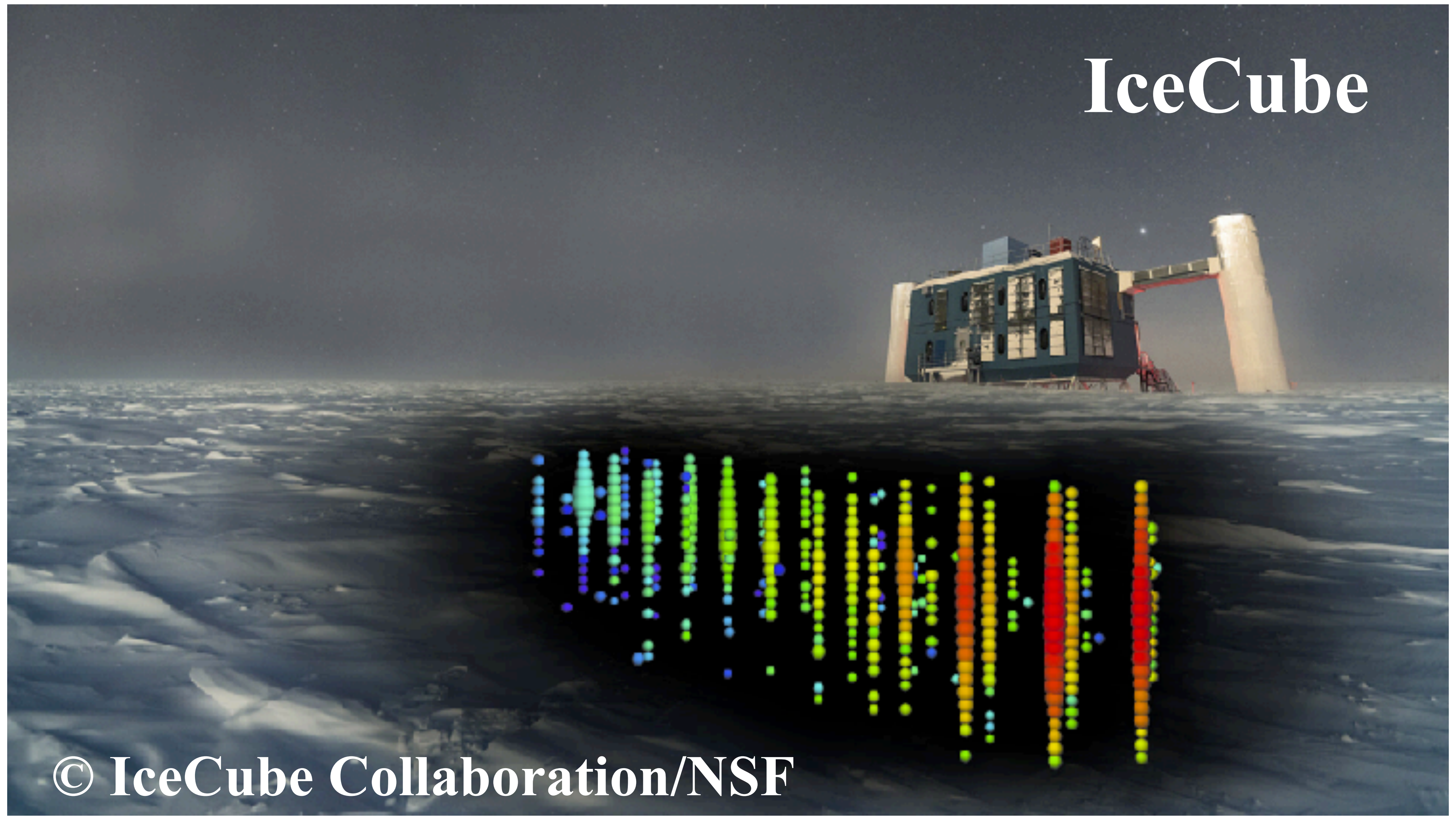
collaboration w/ Katsuaki ASANO

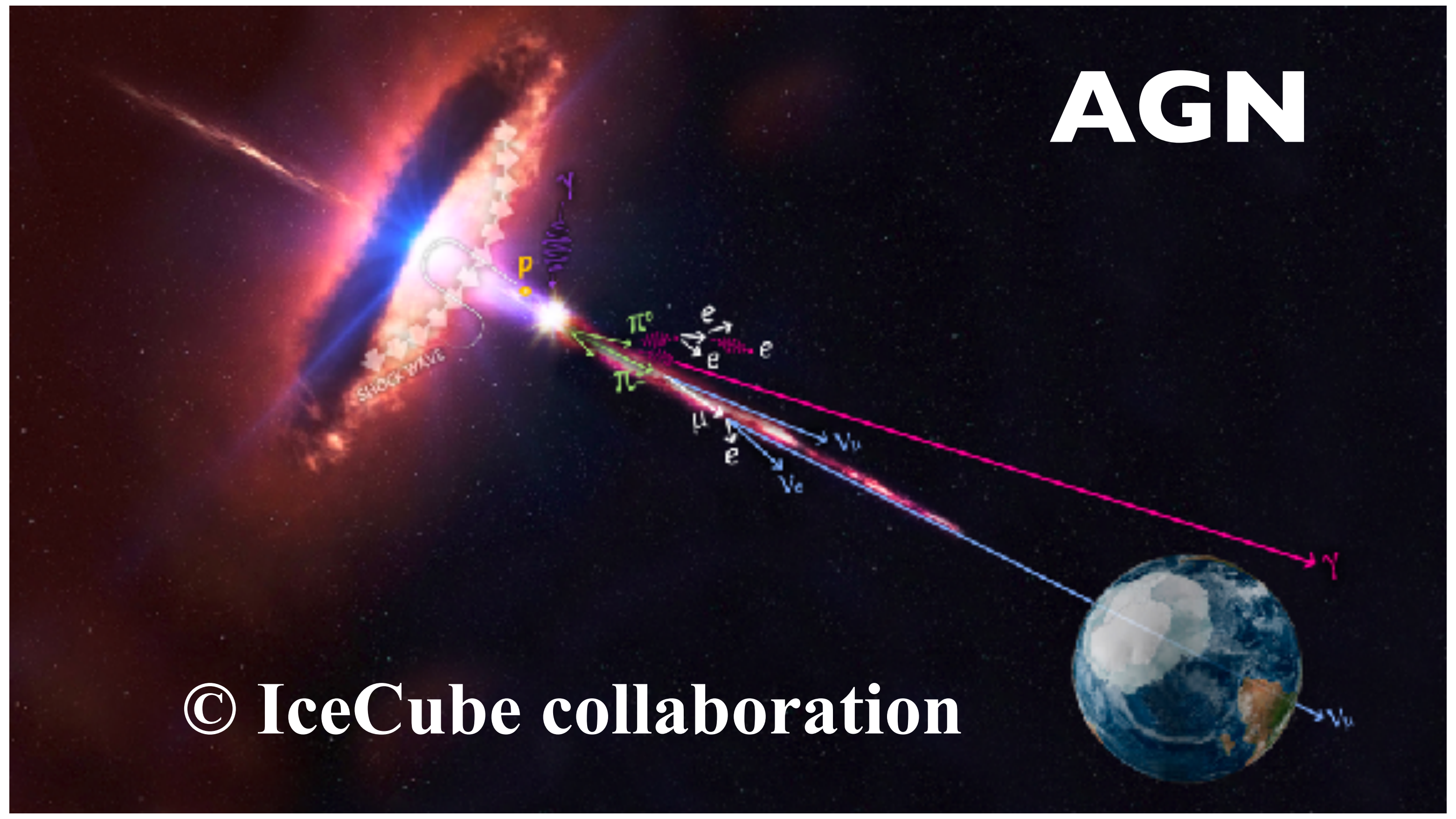
(ICRR, U. of Tokyo)

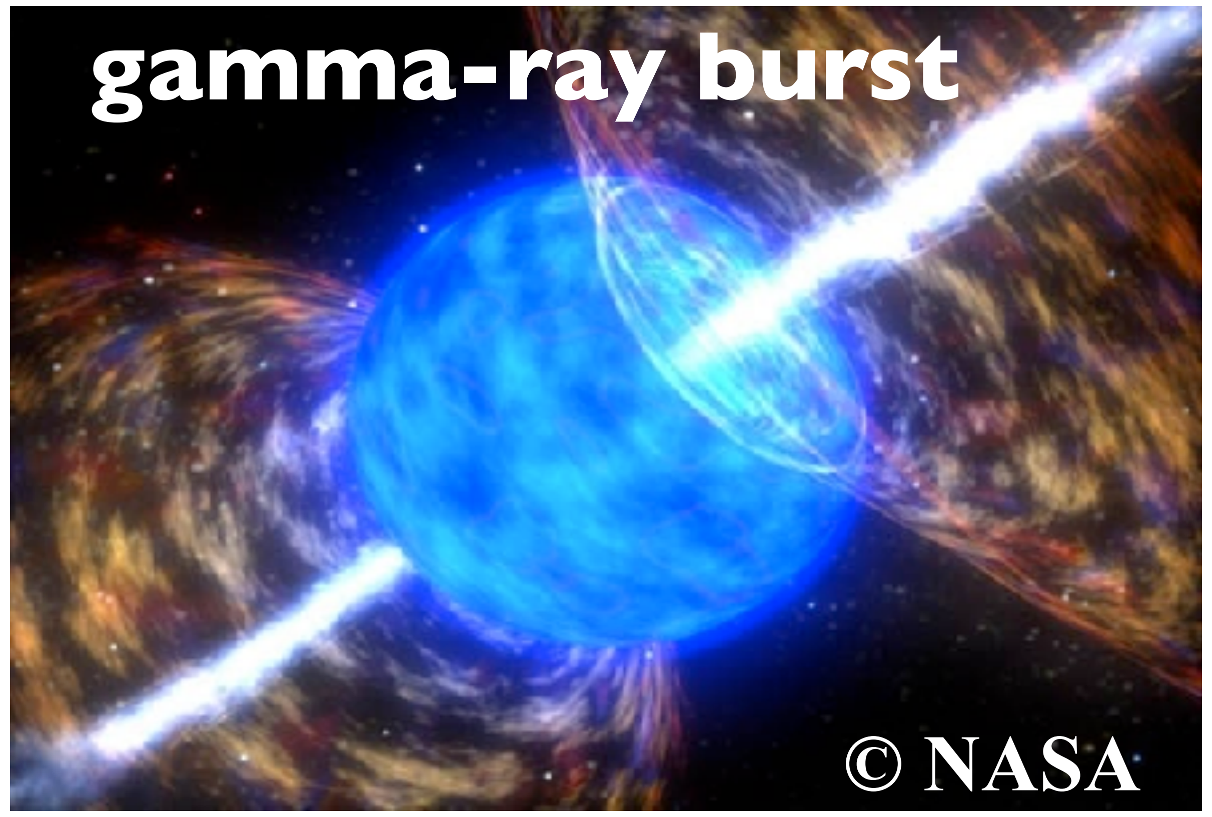
Importance of High Energy (HE) Neutrino

- HE neutrinos are crucial messenger to explore the origin of cosmic-ray accelerations.

- IceCube has detected astrophysical neutrinos, but has not yet fully constraint the neutrino sources.
  - ✓Active Galactic Nuclei (AGN)
  - ✓Galaxy Clusters
  - ✓Starburst Galaxies
  - ✓Low Luminosity Gamma-Ray Bursts







IceCube Neutrino Spectral Energy Distribution (SED)

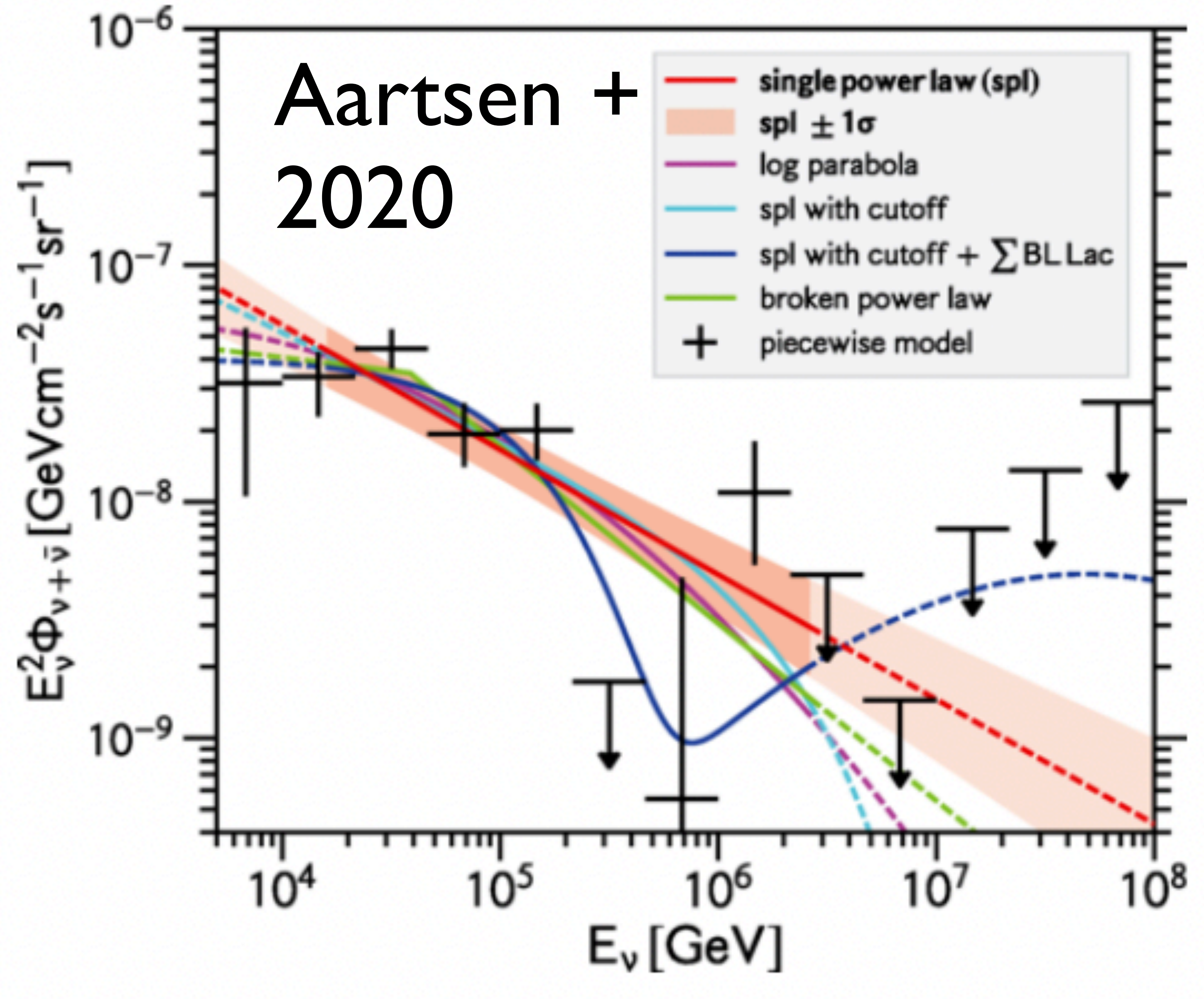
- Diffuse neutrino: moderately flat SEDs (e.g., Aartsen + 2020)
- A neutrino hotspot NGC 1068 detected by a decadal survey: steep(power law index ~3) SED (Aartsen + 2020, IcuCube Collaboration 2022)

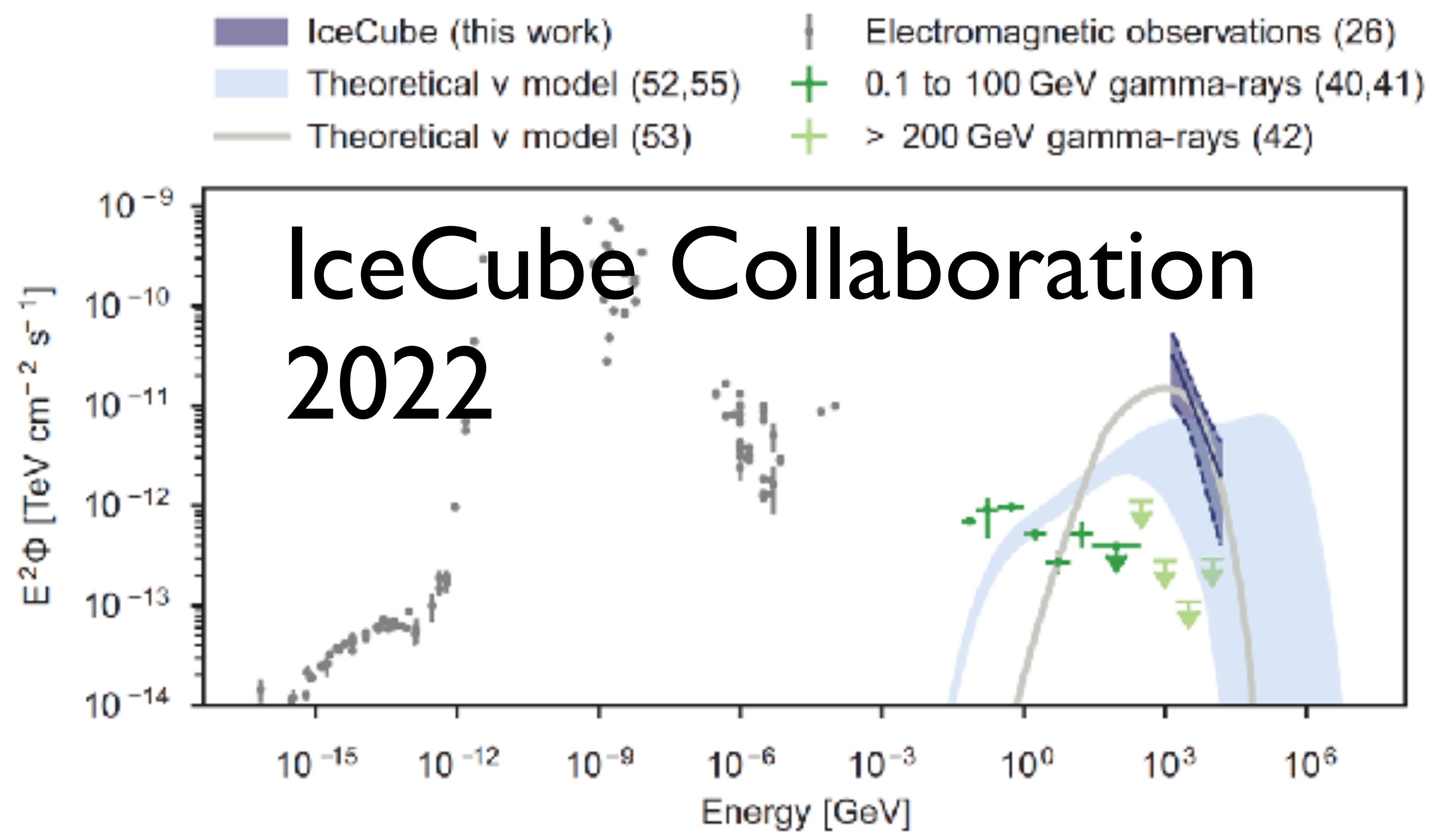
  → Variety of neutrino SED may exist
- Models for neutrino emission in AGNs

  ✓(Radiatively Inefficient) Accretion Flows (e.g., Kimura + 2015)

  ✓Disk-Corona (Inoue Y. + 2020, Murase + 2020, Kimura + 2022)

  ✓Disk-Wind (Inoue S. 2022)



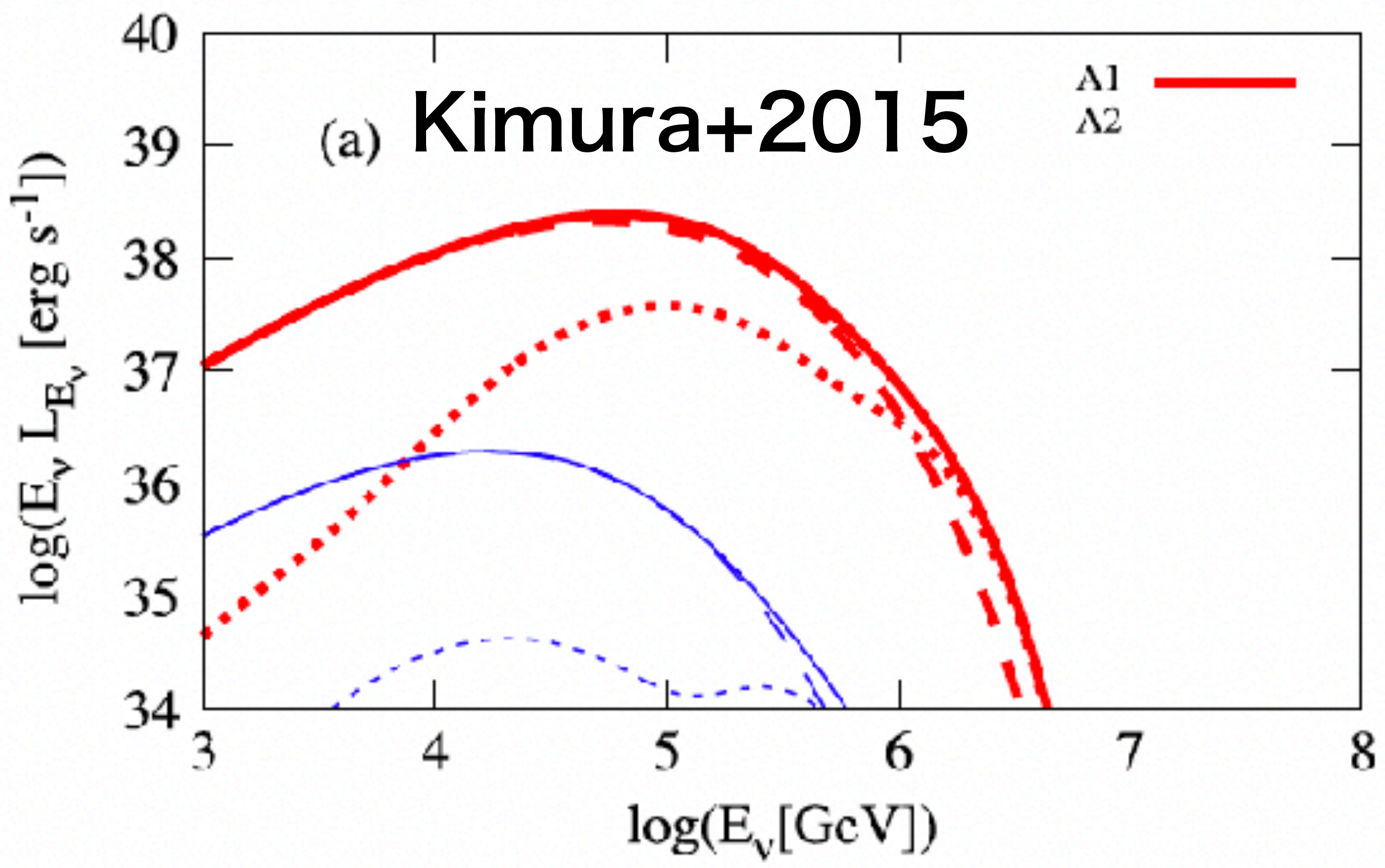


We consider an accretion flow model, in this work.

Cosmic Ray (CR) Acceleration Model in Accretion Flow

- Magnetic Reconnection (e.g., Hoshino + 2013 PIC sim.)
- Turbulence in kinetic scale based on a single-zone approximation (e.g., Kimura + 2015).

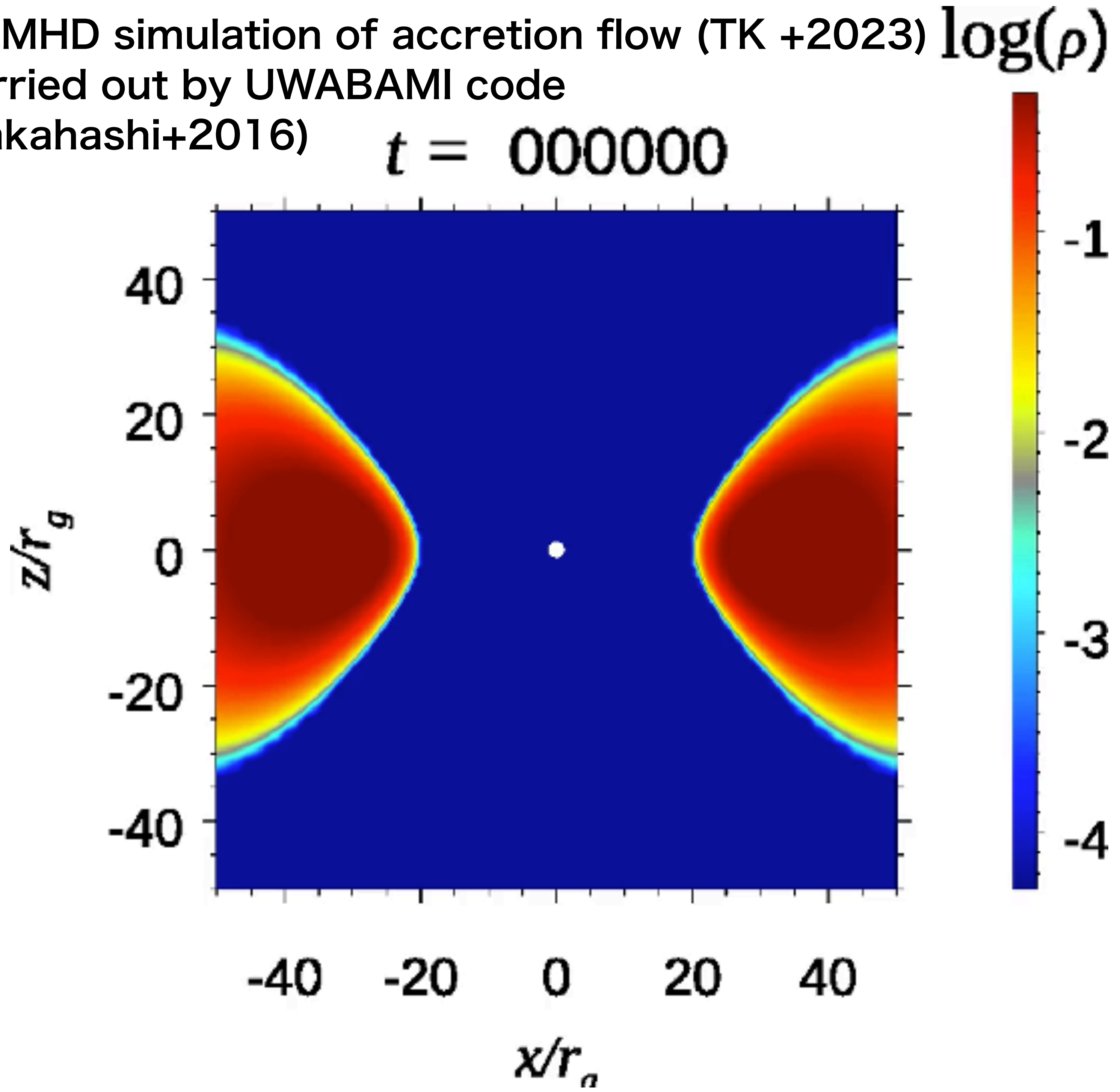
Q: What is the global effect of the accretion flows on the neutrino SEDs?



Purpose of this work：

Studying the global effect of accretion flow on HE neutrino SEDs considering CR acceleration via kinetic scale turbulences and neutrino emission via pp collisions.
← 3D genelal relativistic MHD (GRMHD) simulations of accretion flows + CR acceleration & neutrino emission computation [a new code ν-RAIKOU (ν-来光) code]

GRMHD simulation of accretion flow (TK +2023) carried out by UWABAMI code (Takahashi+2016)



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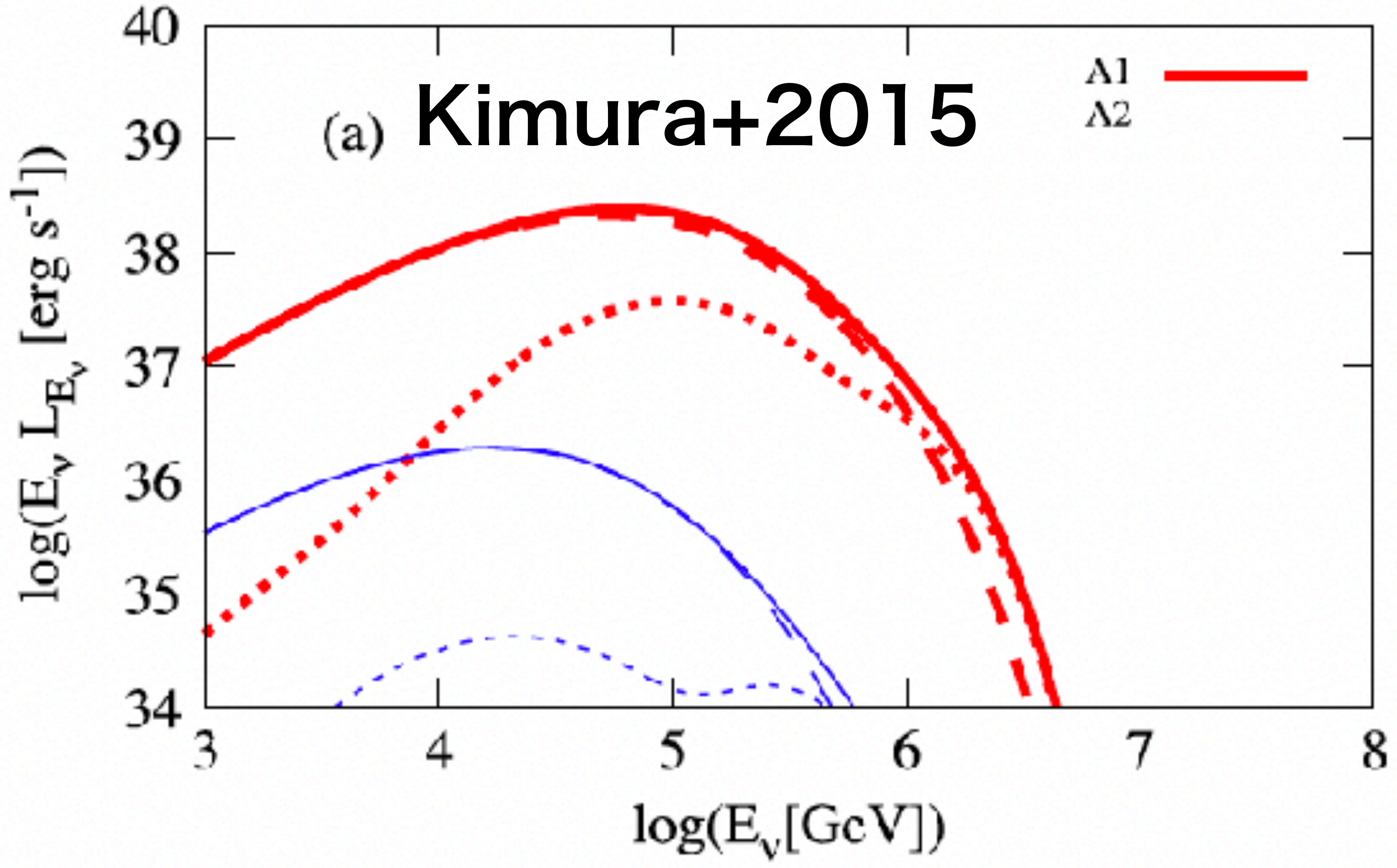

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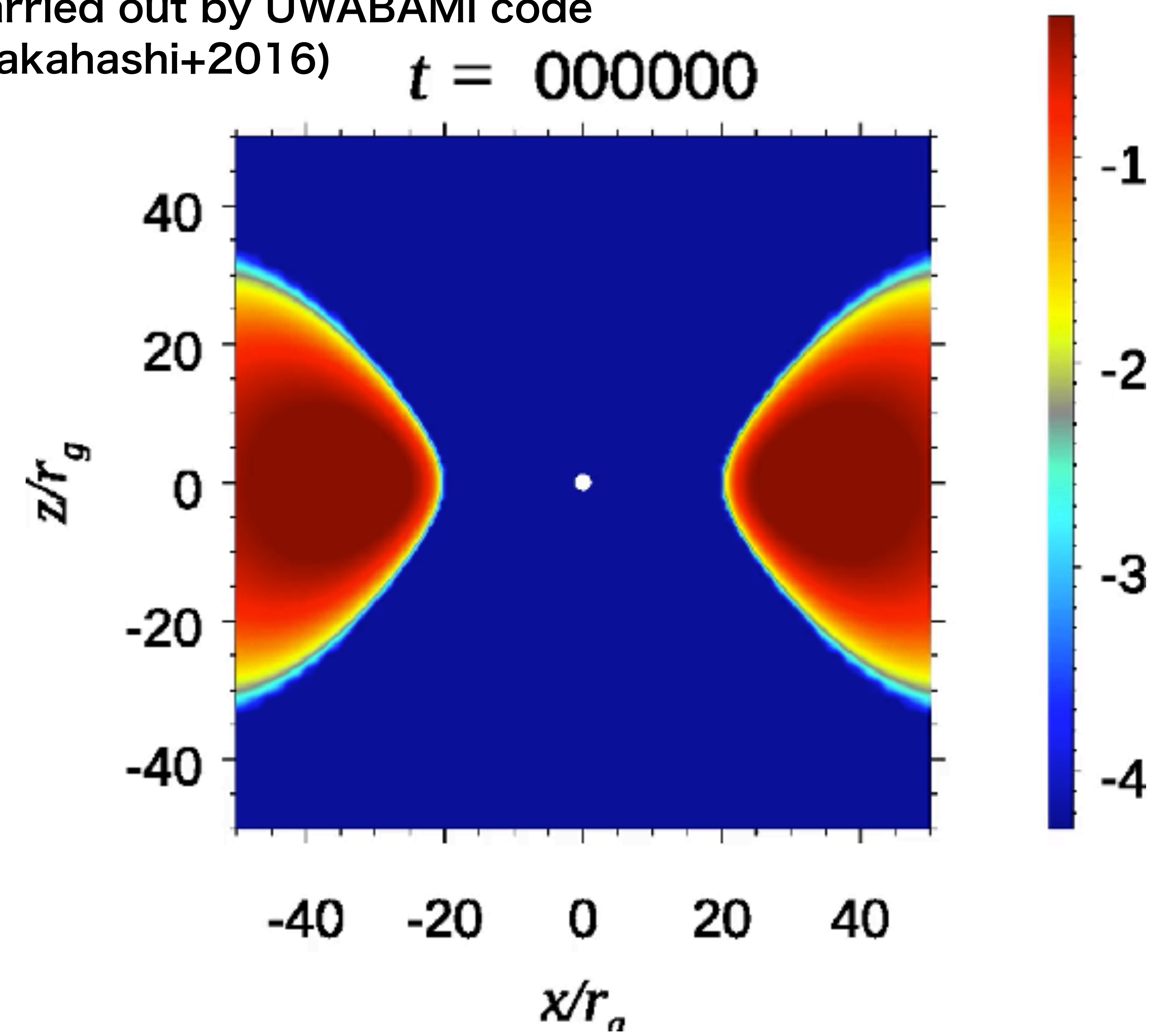
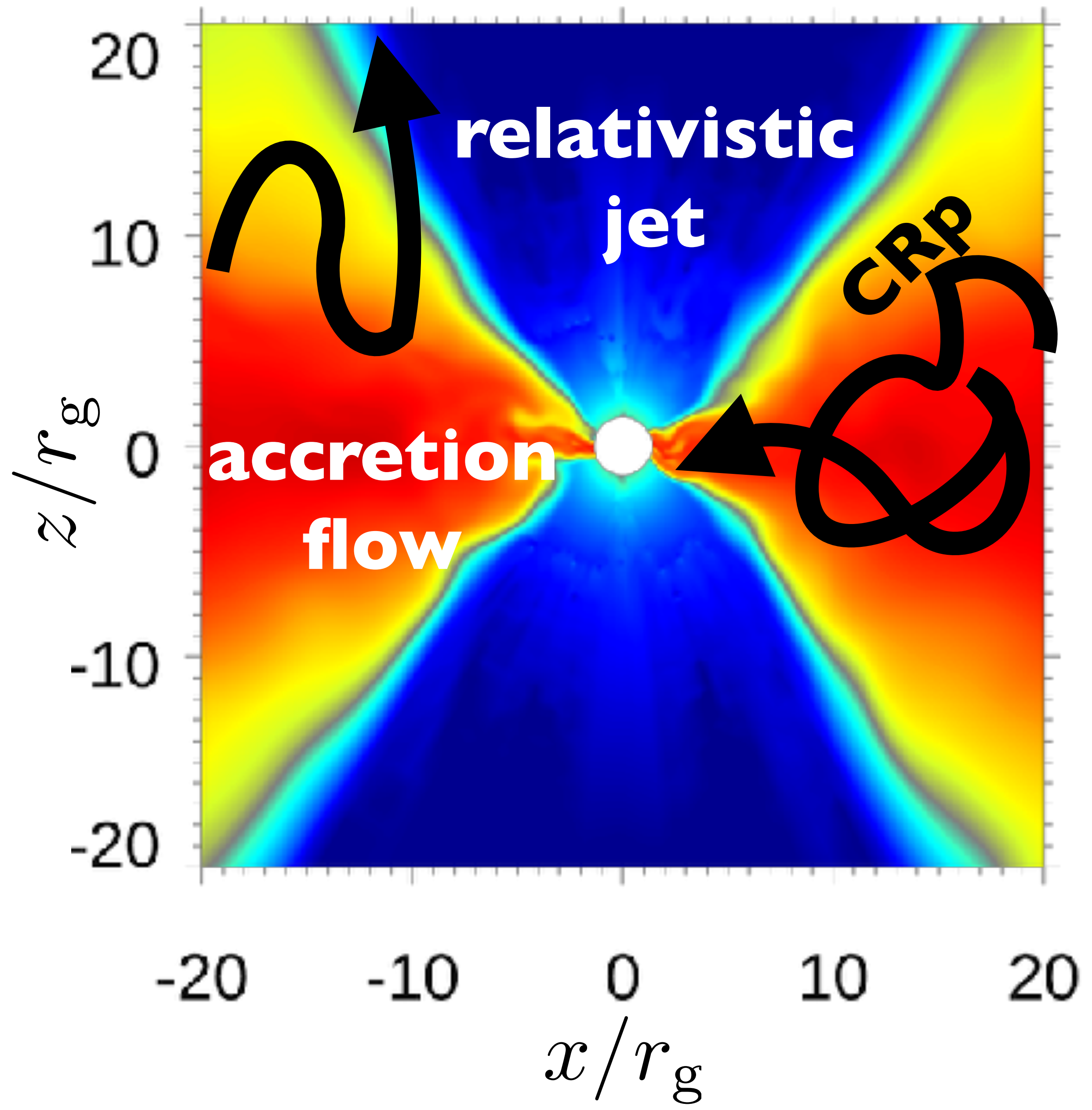


Method



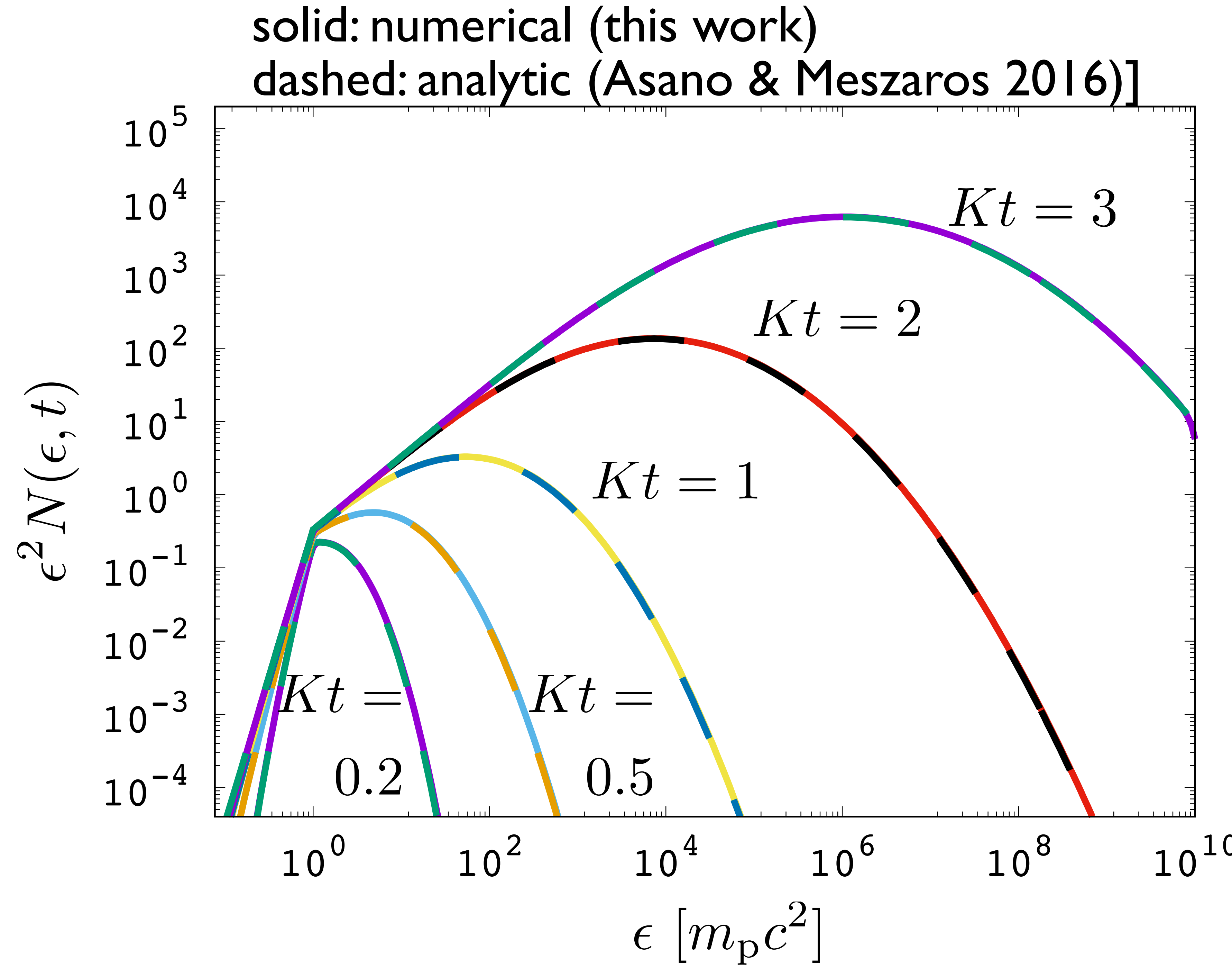
(1) Trajectory of tracer particles of CRp based on 3D GRMHD data

- Assumption: CRps moves aling the streamlines.

  # we are interested in acceleration upto ~PeV (gyro radii < mesh size)
- GRMHD dataset of semi-MAD (moderately magnetized state) (TK+2023) simulated using GR(R)MHD code UWABAMI (Takahashi + 2016).

(2) Computation of SED of CRp

- Fokker-Planck Eqs. are solved at each point of tracer particle in the fluid-rest frame.
- Diffusion and Injection terms in the energy space is solved using Green func.(Becker+2006) with the hard sphere approximation ($D(\varepsilon) = K\varepsilon^2$).
- Compression/expansions effects are also included.

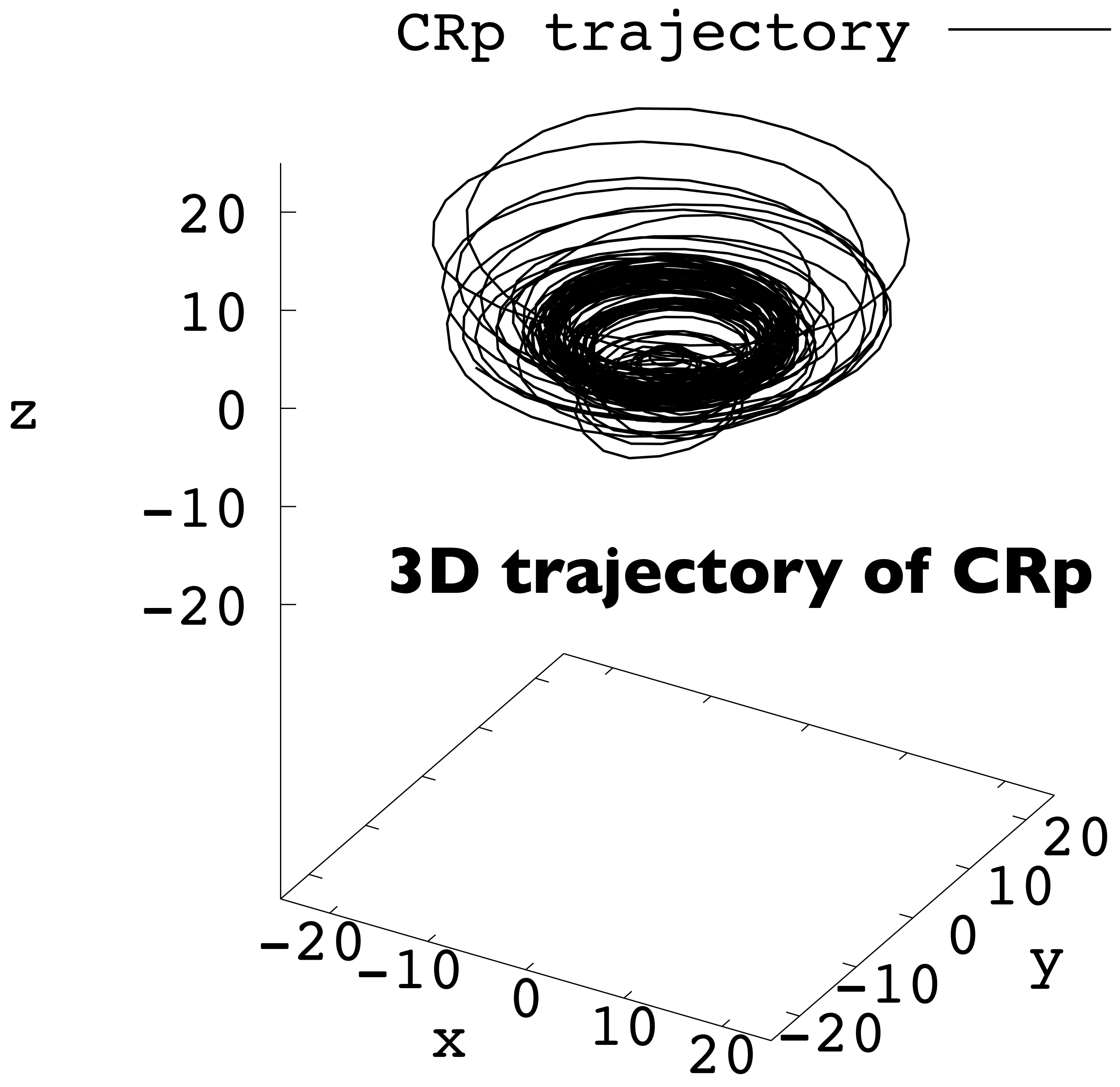


(3) Neutrino SED

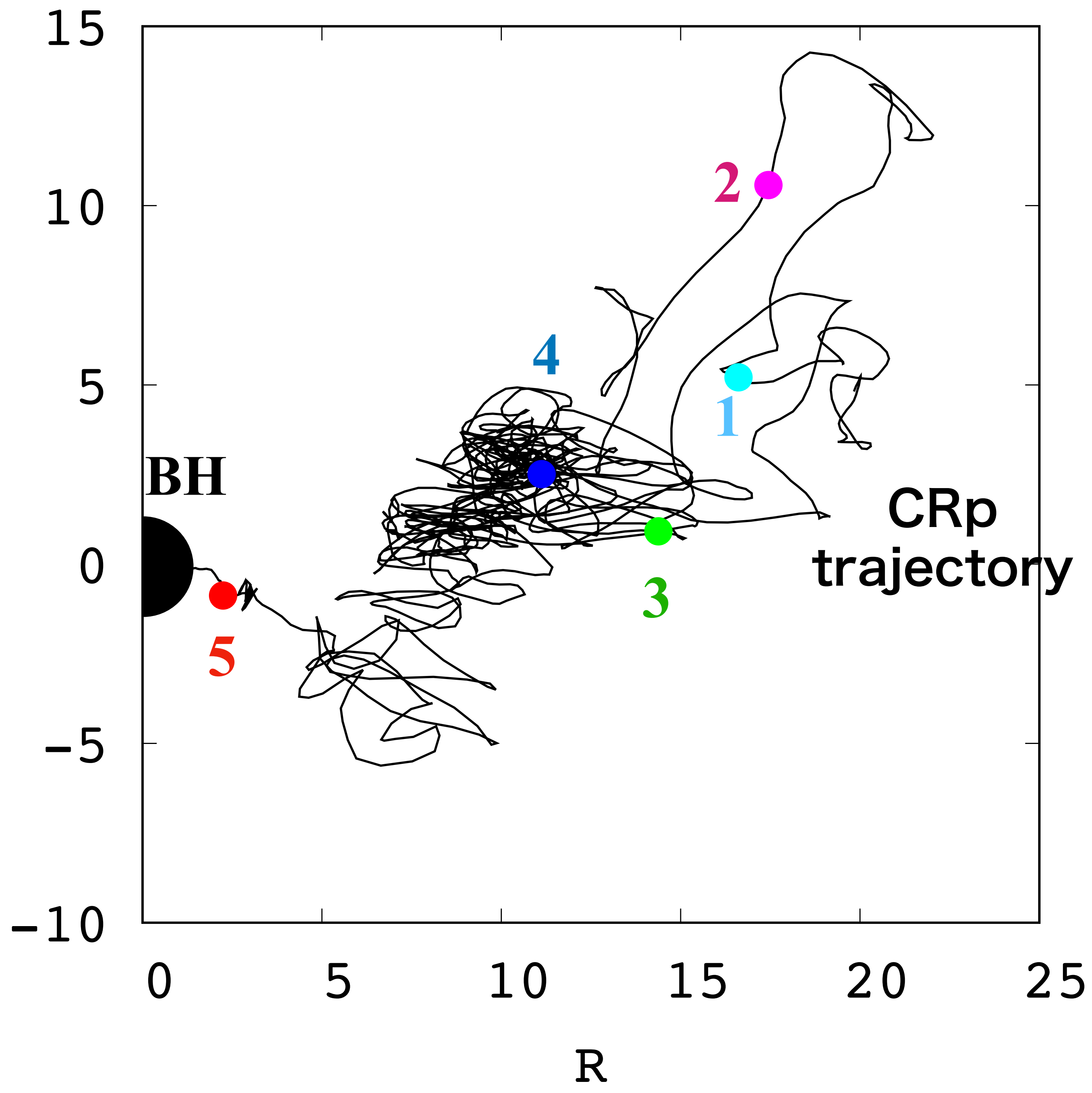
- pp collisions of tracer particle of CRps with thermal protons of GRMHD simulation data.
- Gravitational redshift

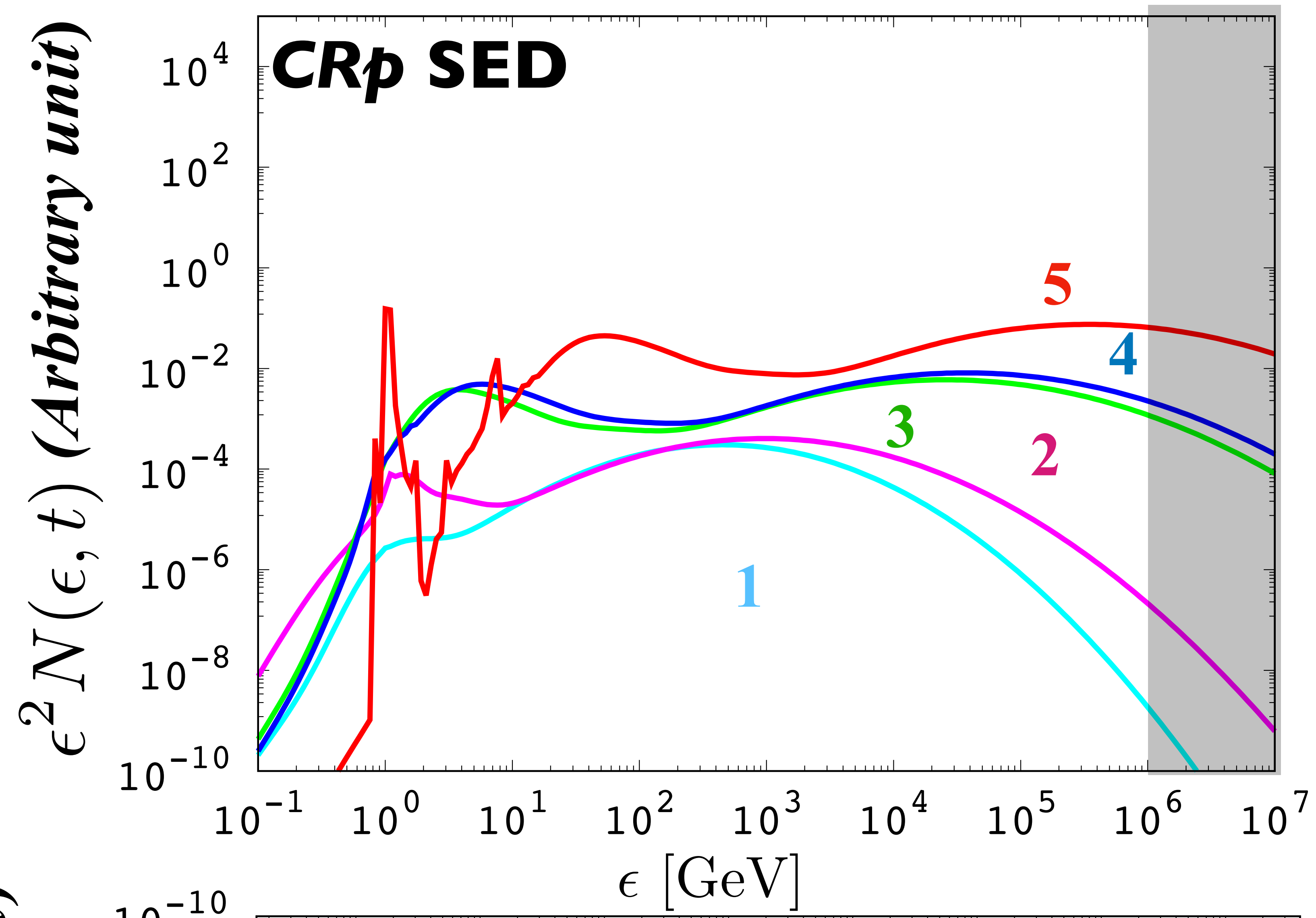
Results (overview)

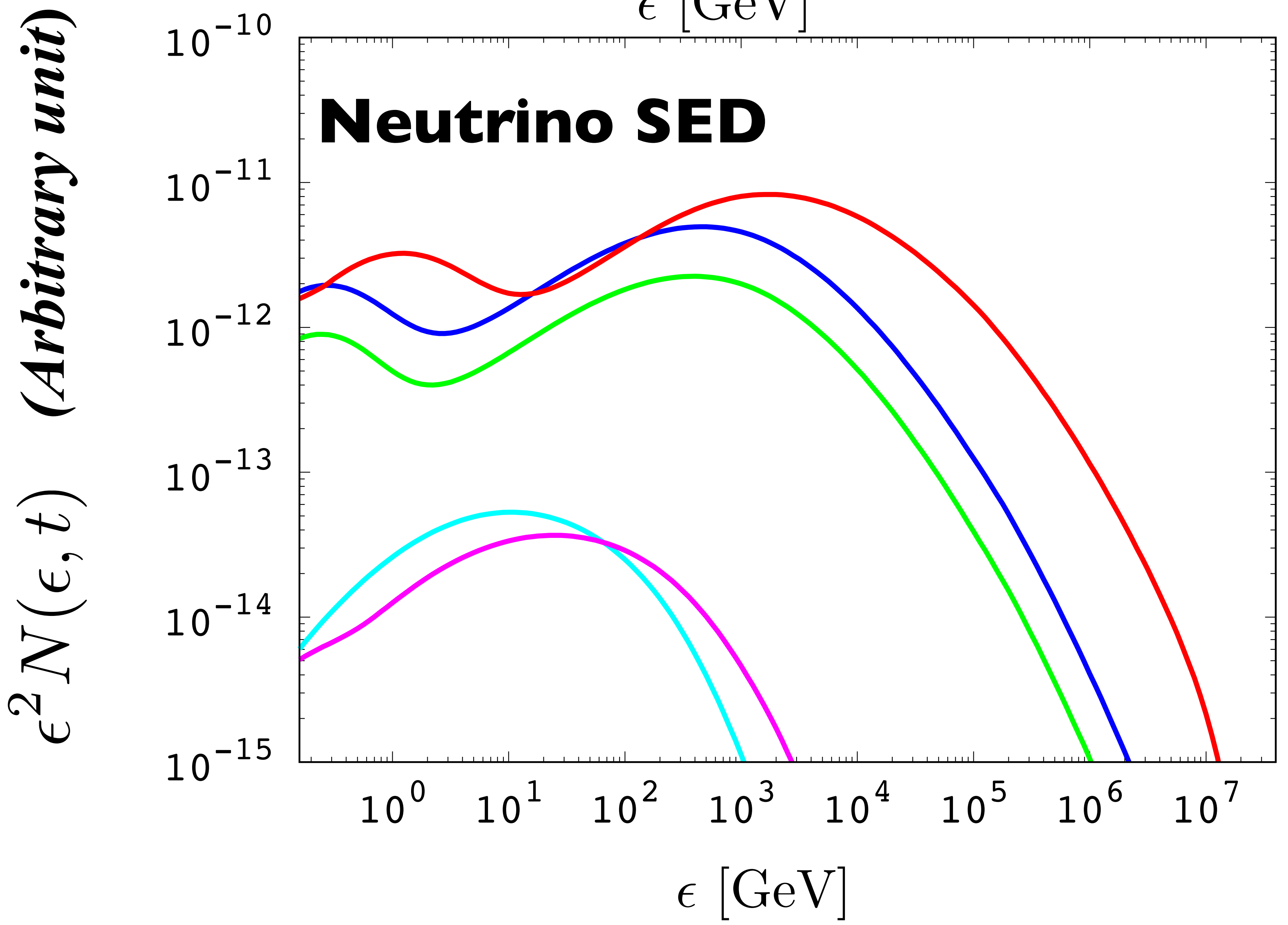
- Computations of CRp trajectory + CRp SEDs + Neutrino SEDs using time-dependent GRMHD data



Project onto poloidal plane



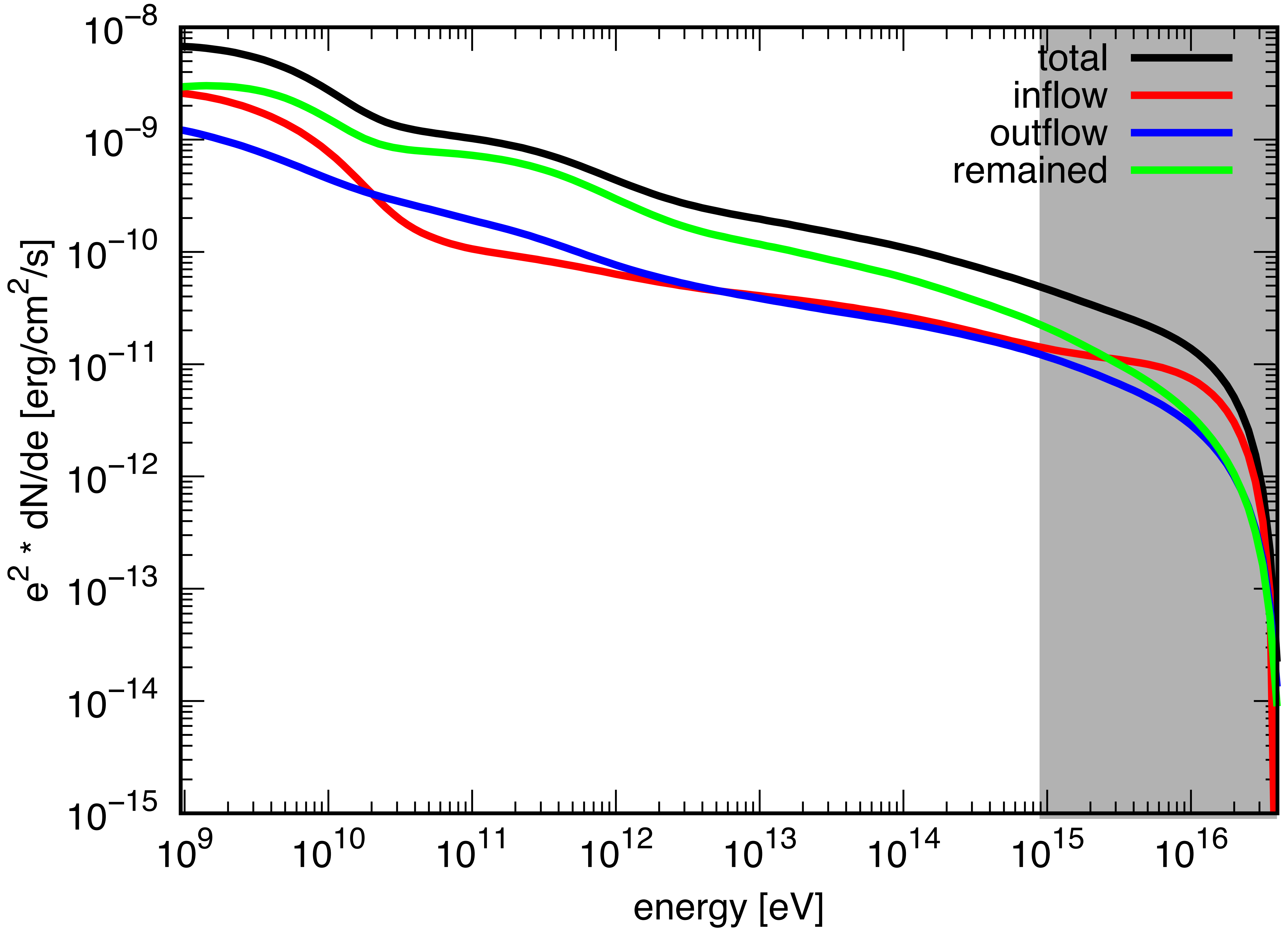




Averaging neutrino SEDs of ~20,000 CRp

Time-Averaged Neutrino SEDs

- **SEDs <u>flatter</u> than single-zone models appear (This will be consistent with diffuse neutrino)**
- Neutrino SEDs decomposed into origin of CRps in inflow, outflow, others (remaining)
- Neutrinos originated from inflow CRp ~ those from (eventual) outflow CRp.



$t_{\rm acc} = v/\dot{v}$ $\quad K = 4\eta/t_{\rm acc}(U_{\rm th}/U_{\rm CR})$ $\quad \eta = 3\times10^{-4}$

$t_{\rm inj} = B/\dot{B}$ $\quad \dot{n}_{\rm inj} = f_{\rm inj}/(\beta t_{\rm inj})$ $\quad f_{\rm inj} = 1.5\times10^{-3}$

Trajectries, SEDs, and Acc. Timescale of CRp

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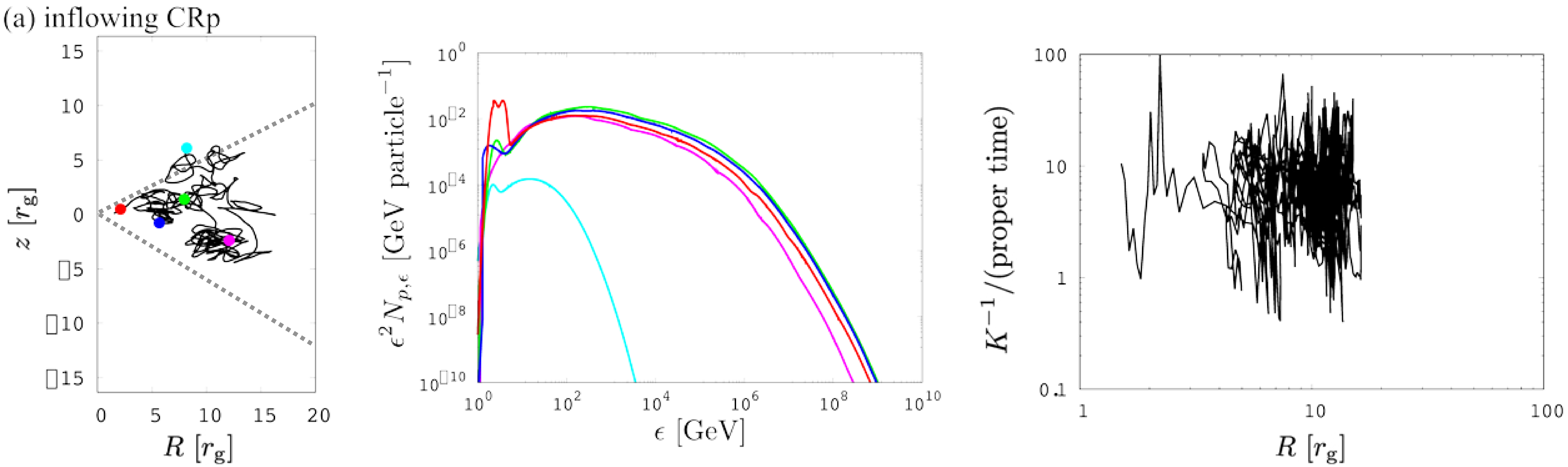
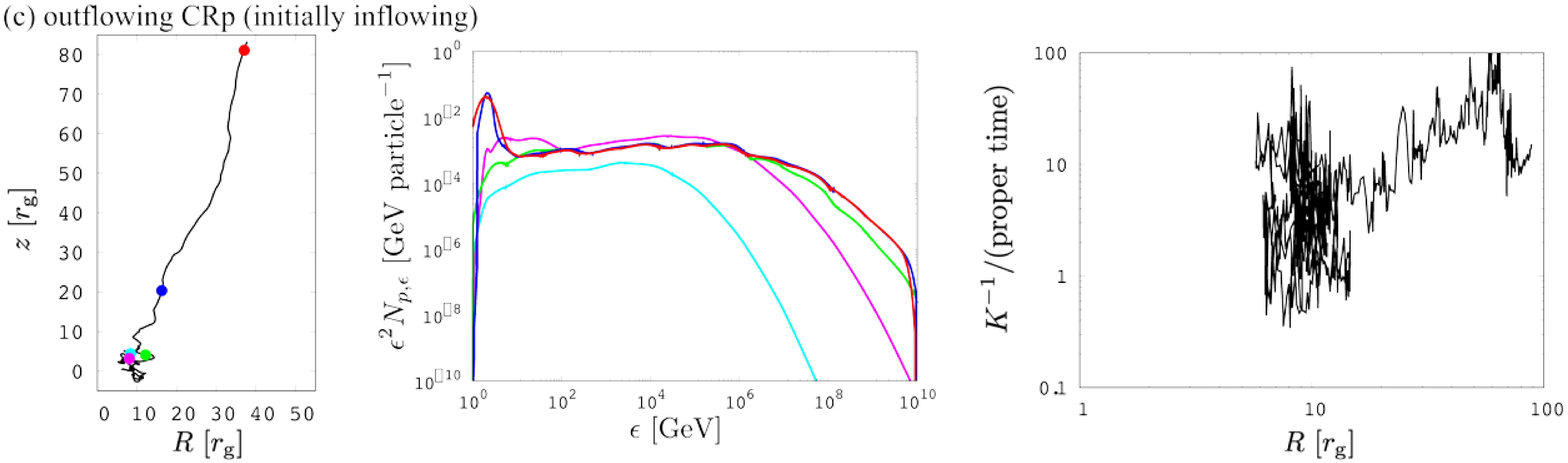
inflow



outflow



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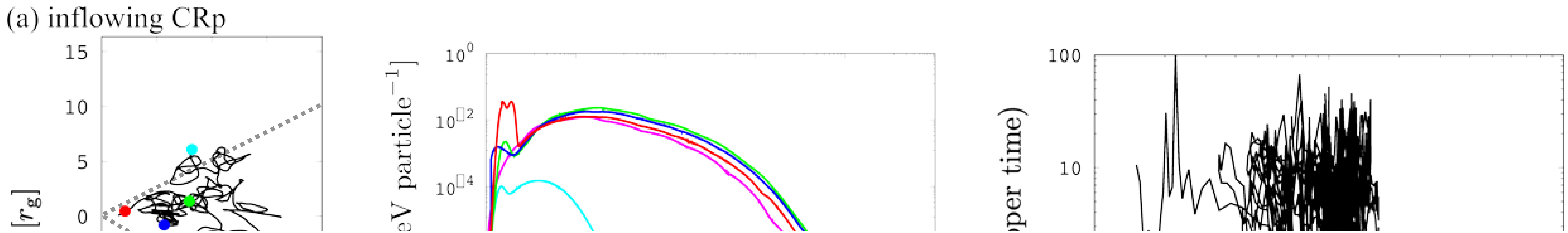
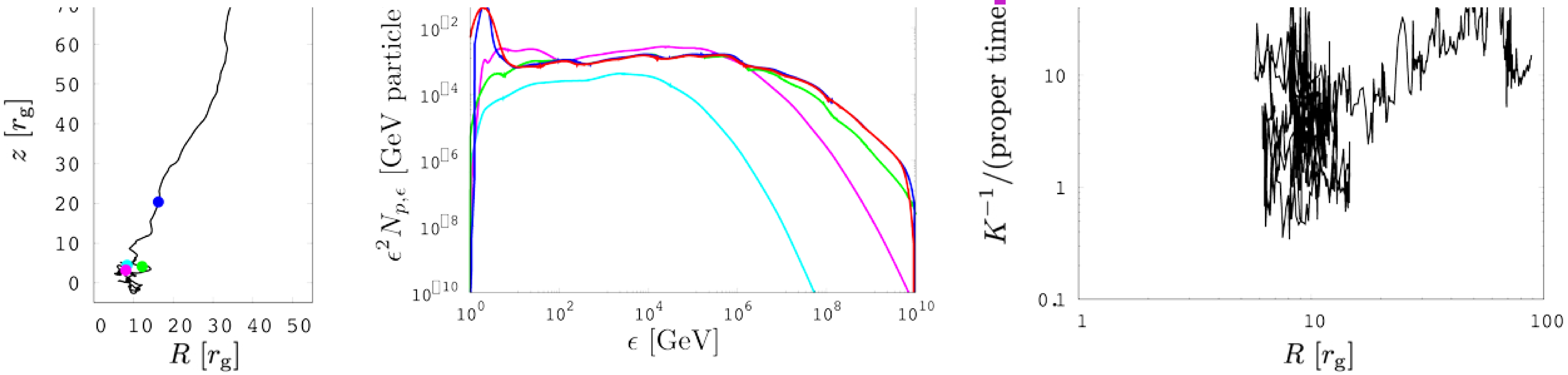


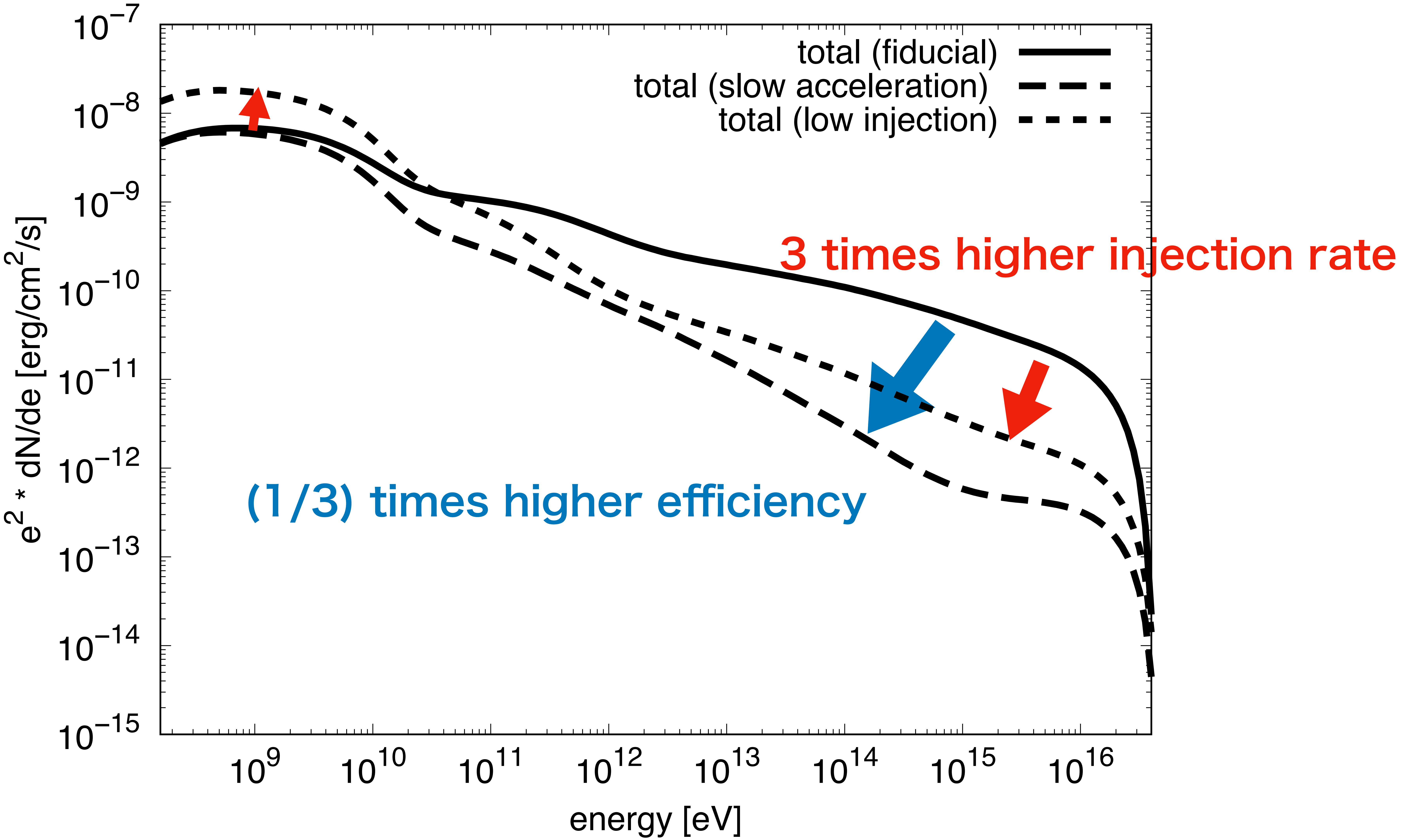
Various SEDs of CRp depending on the trajectories

- **<u>Superposition of resulting neutrino can form flat SEDs</u>**
- **<u>Neutrino originated from (eventually) outflowed CRp can contribute total SEDs comparable to inflowed CRp.</u>**

outflow



Dependence of acceleration efficiency



- Lower the efficiency of the acceleration, lower SEDs can be obtained.
- Higher injection rate → softer SEDs

  ∵ more injected particles result in less efficient acceleration due to the energetics.

Summary

- CRp acceleration & Neutrino emission of global accretion flows based on 3D GRMHD simulation data.
- Due to the global effect (superposition of various injection of accelaration of CRp) → flatter SEDs (consistent with diffuse neutrino SEDs)
- Comparable neutrino originated from inflows and outflows.
- p-γ processes will be incorporated in near future.