

CRPropa 3.2 – astroparticle propagation framework from TeV to ZeV energies.



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CRPropa 3, overview [1]

Open-source simulation framework for:

- Extragalactic propagation
 - Galactic propagation
 - Acceleration
 - of
 - Cosmic rays
 - Electromagnetic (EM) cascades (to GeV energies)
 - Neutrinos
- with energies in the TeV – ZeV range.

It includes:

- All relevant interactions for nuclei
 - All relevant interactions for EM cascades
 - Deflections in magnetic fields
 - Redshift evolution
 - Adiabatic cooling
- and models are provided for the
- Galactic magnetic field (GMF)
 - Extragalactic magnetic field (EGMF)
 - Large-scale structure density field
 - Extragalactic background light (EBL)

Available from:

crpropa.desy.de

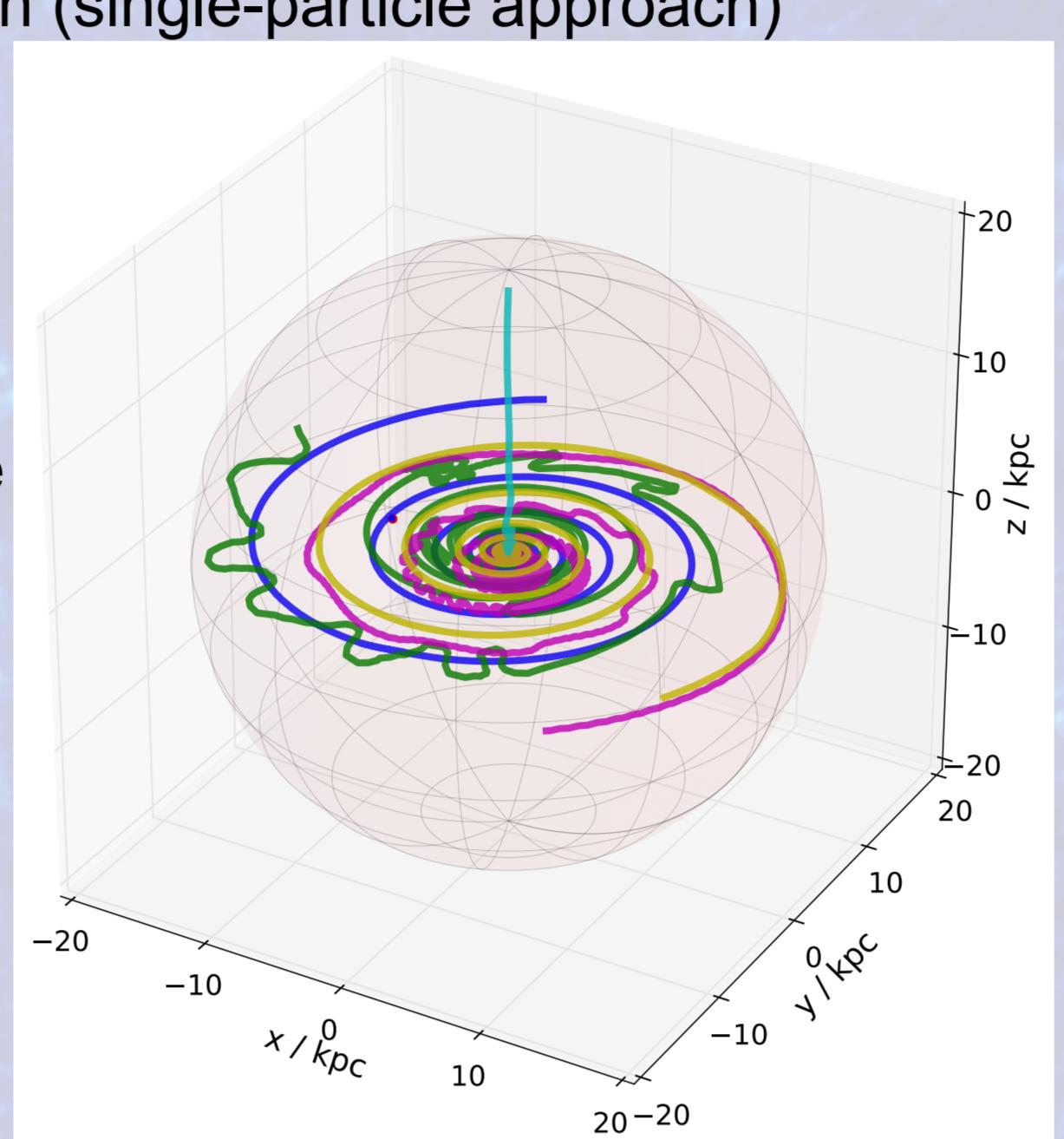
Extragalactic cosmic rays

- 1D, 3D and 4D simulation environments
- Deflections in EGMF
- Energy-loss interactions with CMB and EBL:
 - Pair production
 - Photodisintegration
 - Photomeson production
- Nuclear decay
- Expansion of the universe
- Creation of secondary particles:
 - Secondary nuclei
 - Photons, electrons and positrons
 - Neutrinos
- Deflection in GMF with lensing technique
- New in 3.2 [3]:**
 - Targeting method with learning technique for optimised emission direction

Solve equation of motion (single-particle approach)

Figure:

- 5 protons
- $E = 10^{16}$ eV
- Isotropic emission
- From Galactic centre
- Pshirkov '11 GMF



Galactic cosmic rays

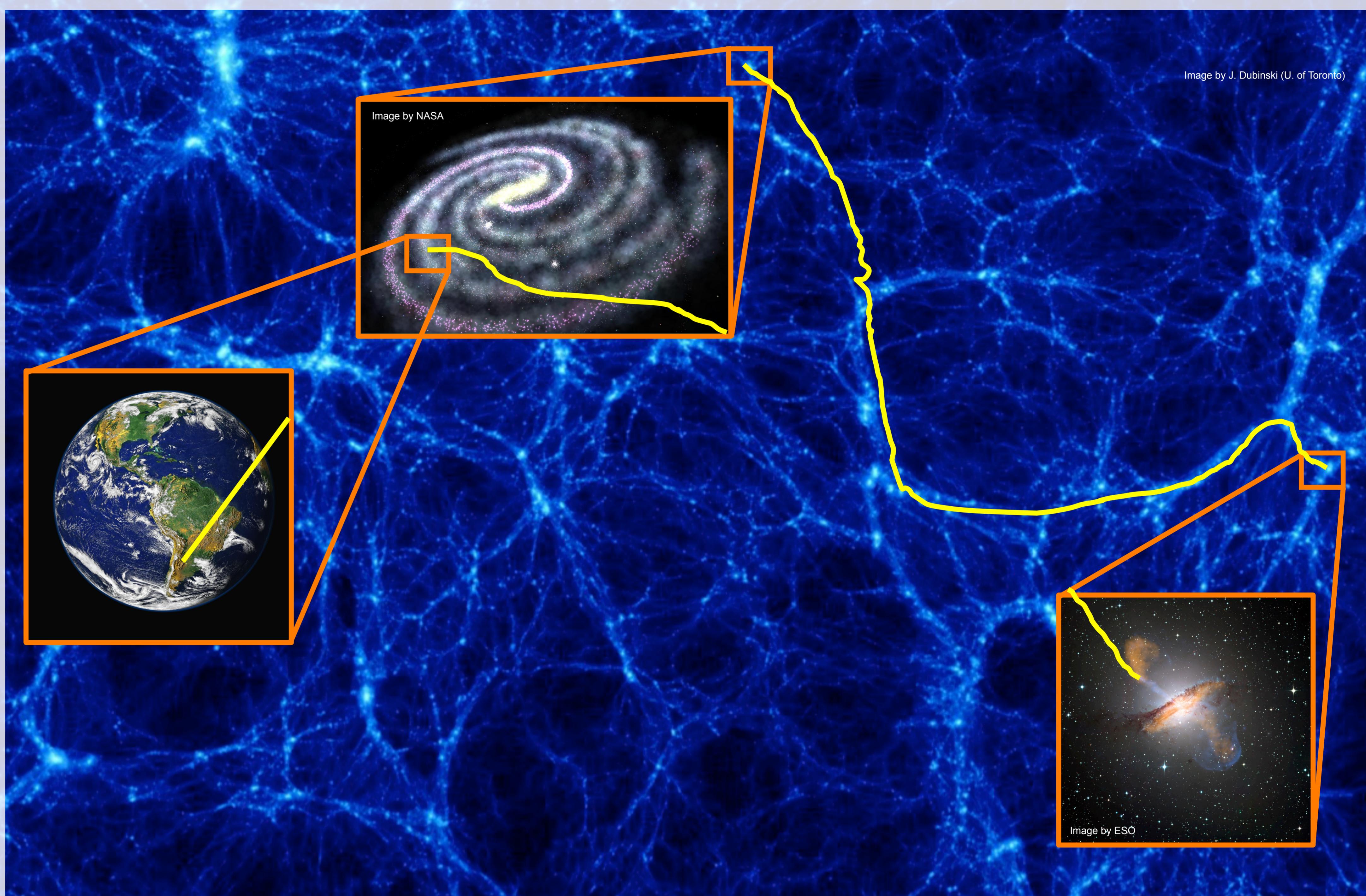
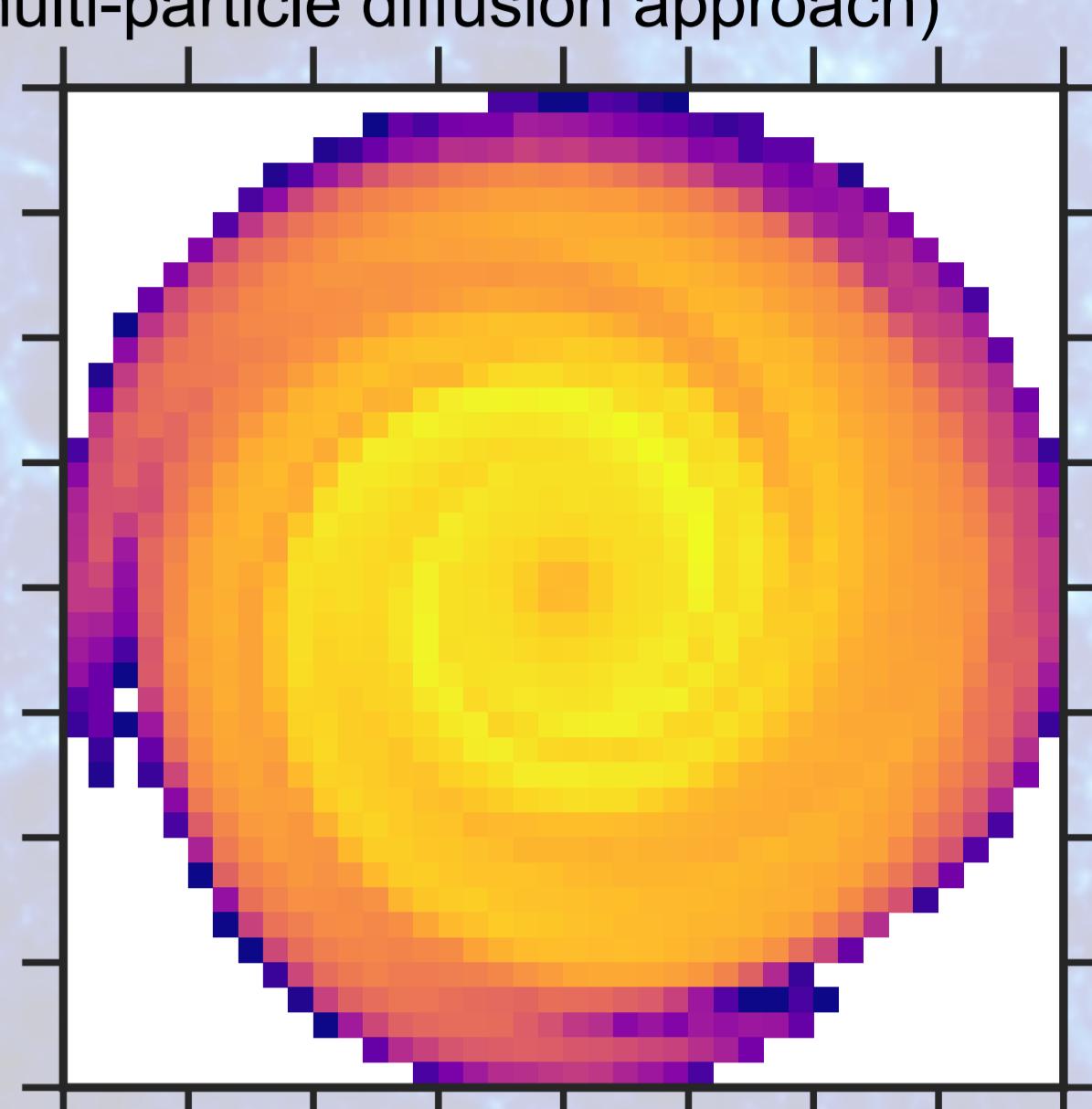
New in 3.2 [2]

Solve transport equation (multi-particle diffusion approach)

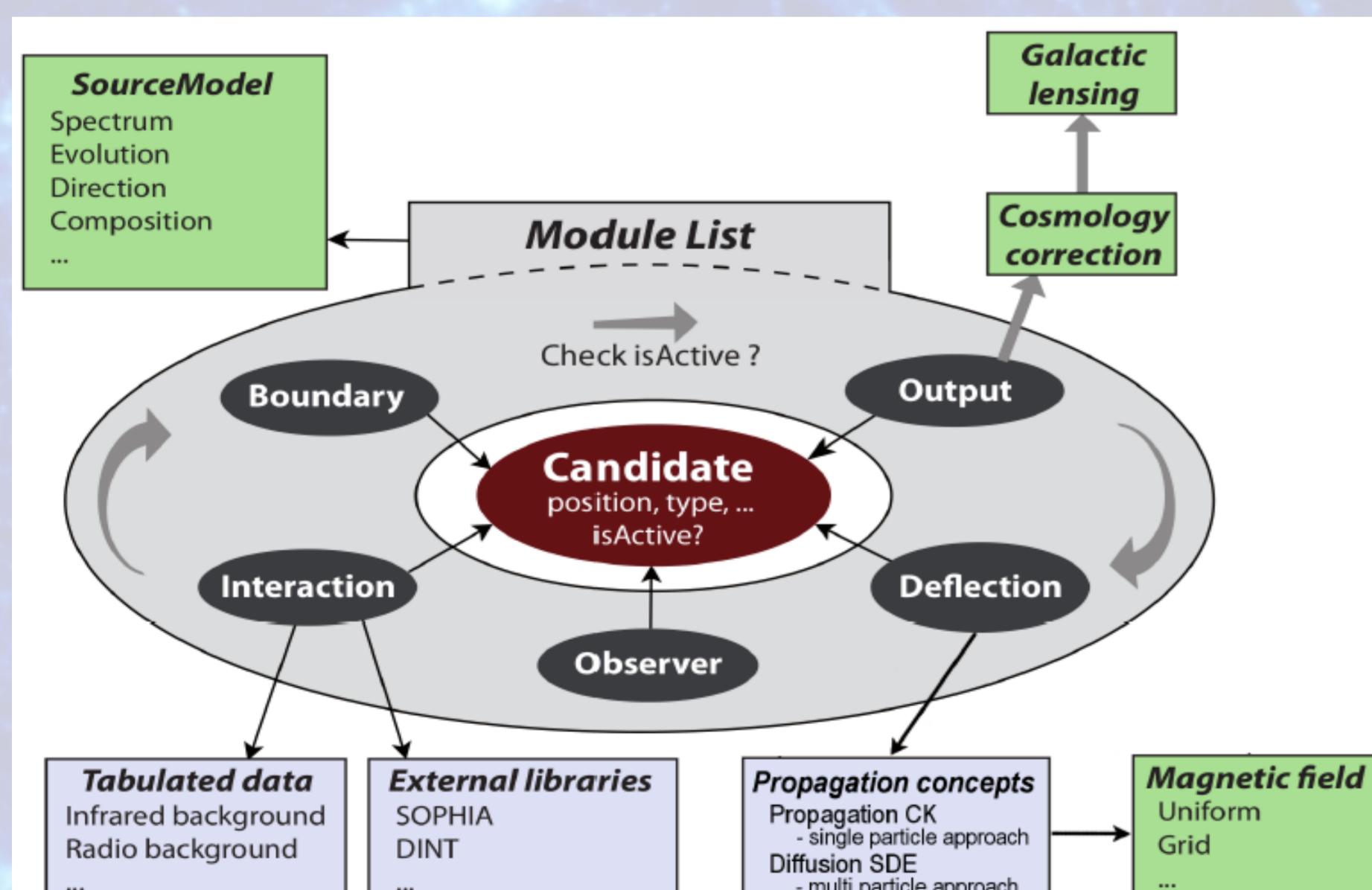
- Anisotropic diffusion
- Advection
- Adiabatic cooling
- Momentum diffusion

Figure:

- Cosmic-ray density
- In Galactic plane
- Homogeneous injection
- Jansson Farrar '12 GMF



Modular structure



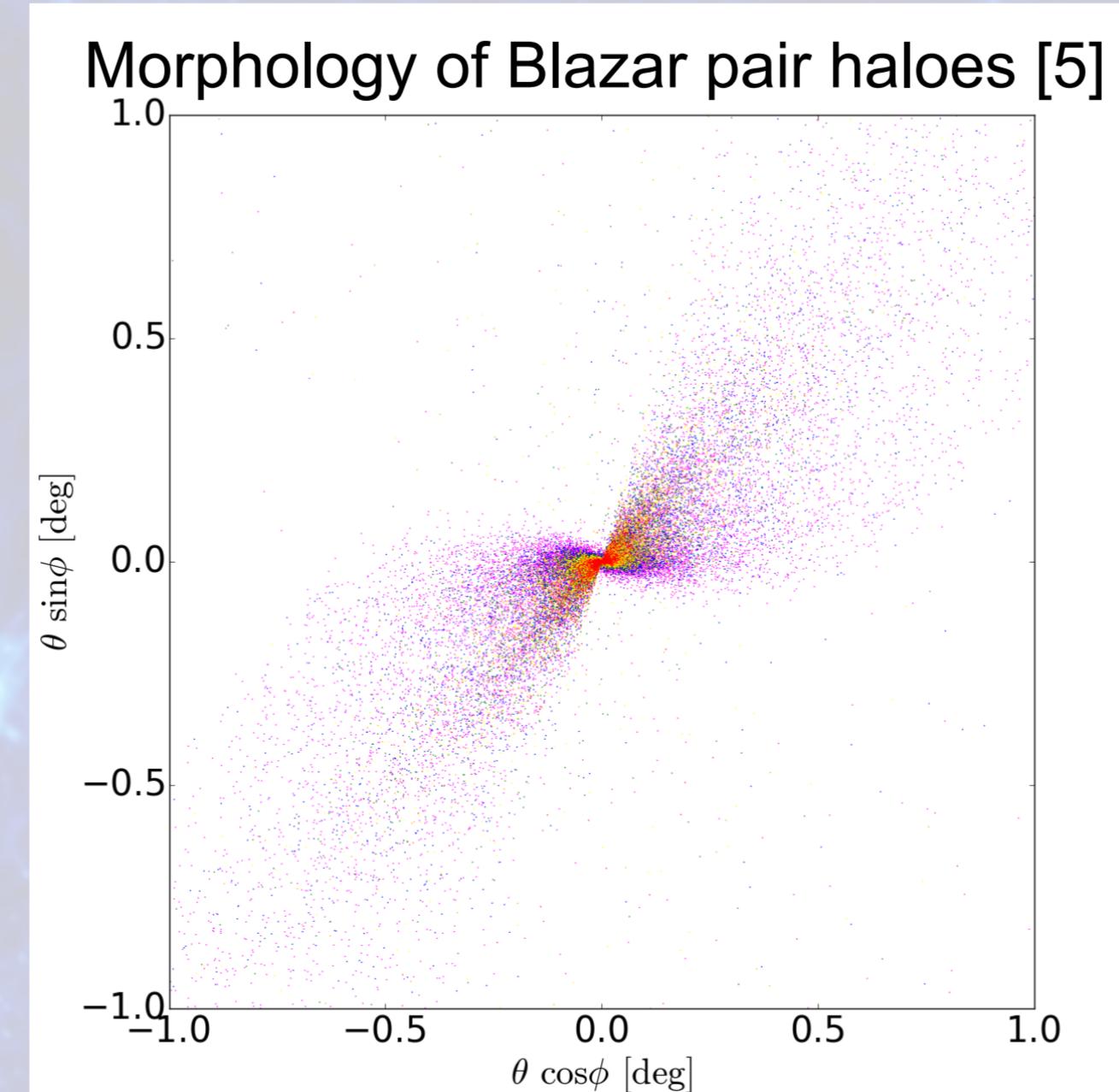
Electromagnetic cascades

Interactions:

- Pair production
- Double pair production
- Triplet pair production
- Inverse Compton scattering

New in 3.2 [4]:

- Additional photon production channels
- Full 3D treatment of EM cascades
- Thinning method for fast simulations

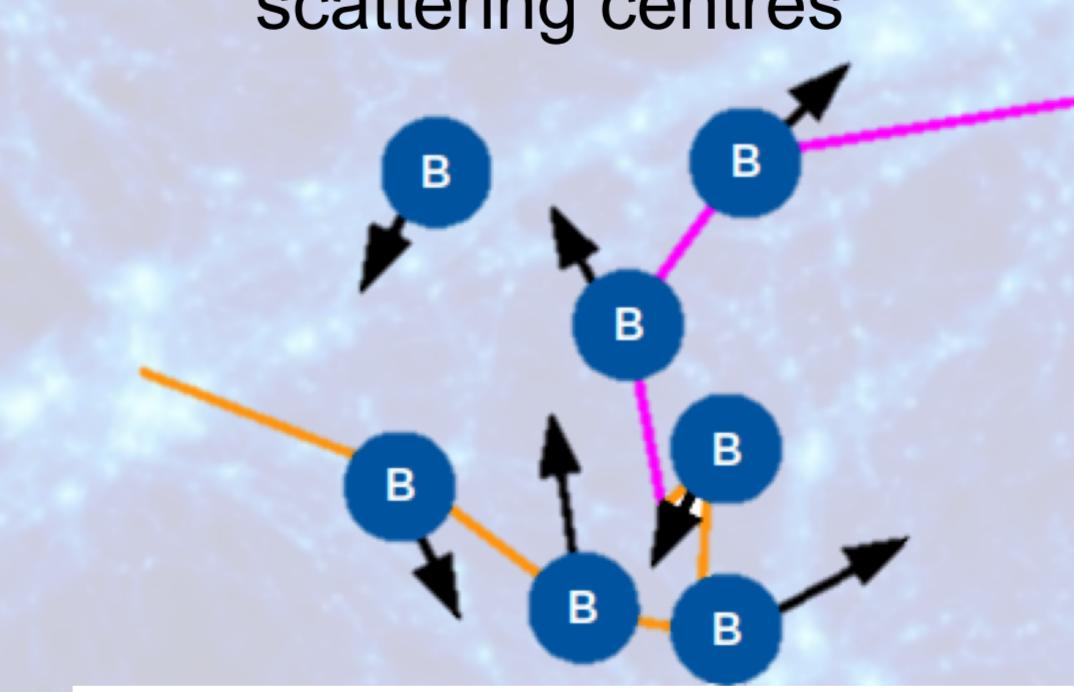


Diffusive Shock Acceleration

New in 3.2 [6]

Second order

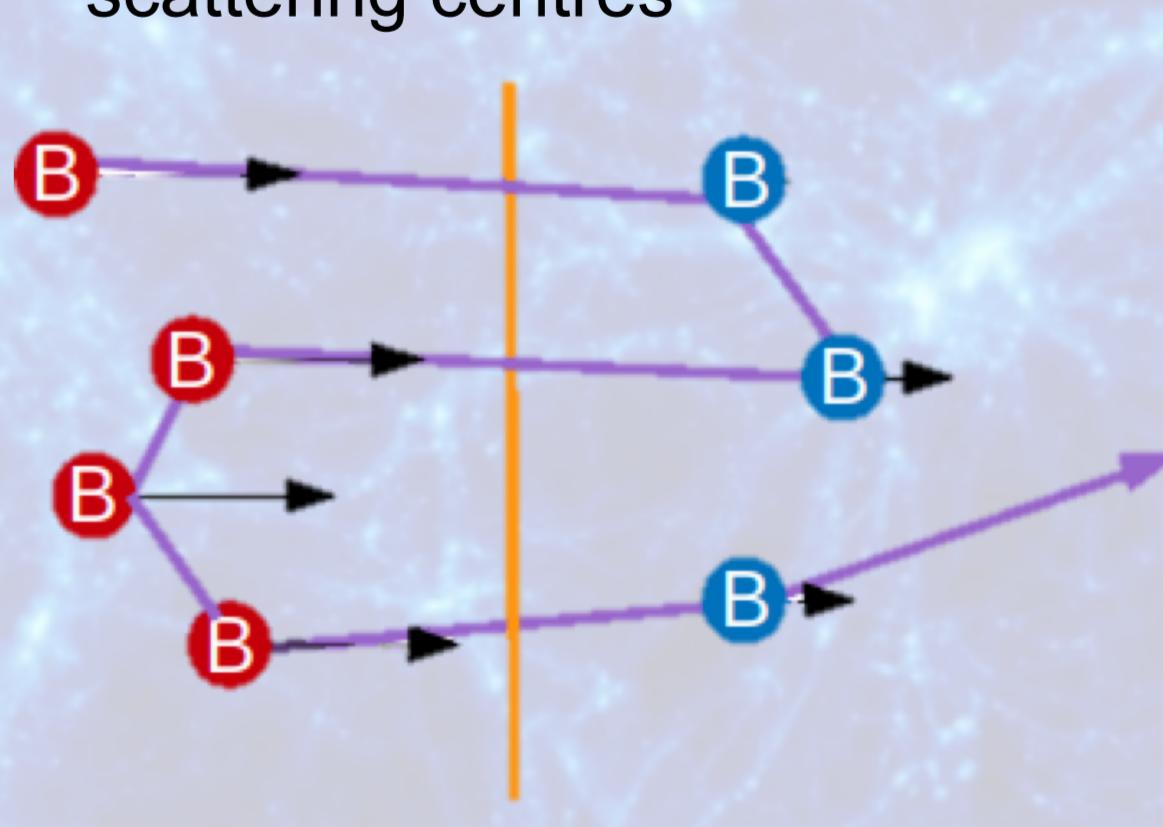
- Acceleration at random scattering centres



New in 3.2 [7]

First order

- Acceleration at directed scattering centres



References

- [1] R. Alves Batista et al., JCAP 1605 (2016) 038
- [2] L. Merten et al., JCAP 1706 (2017) 046
- [3] J. Jasche, A. van Vliet and J. Rachen, in preparation
- [4] C. Heiter et al., Astropart. Phys. 102 (2018) 39
- [5] R. Alves Batista et al., Phys. Rev. D94 (2016) 083005
- [6] T. Winchen and S. Buitink, Astropart. Phys. 102 (2018) 25
- [7] T. Winchen, S. Buitink and J. Rachen, in preparation

