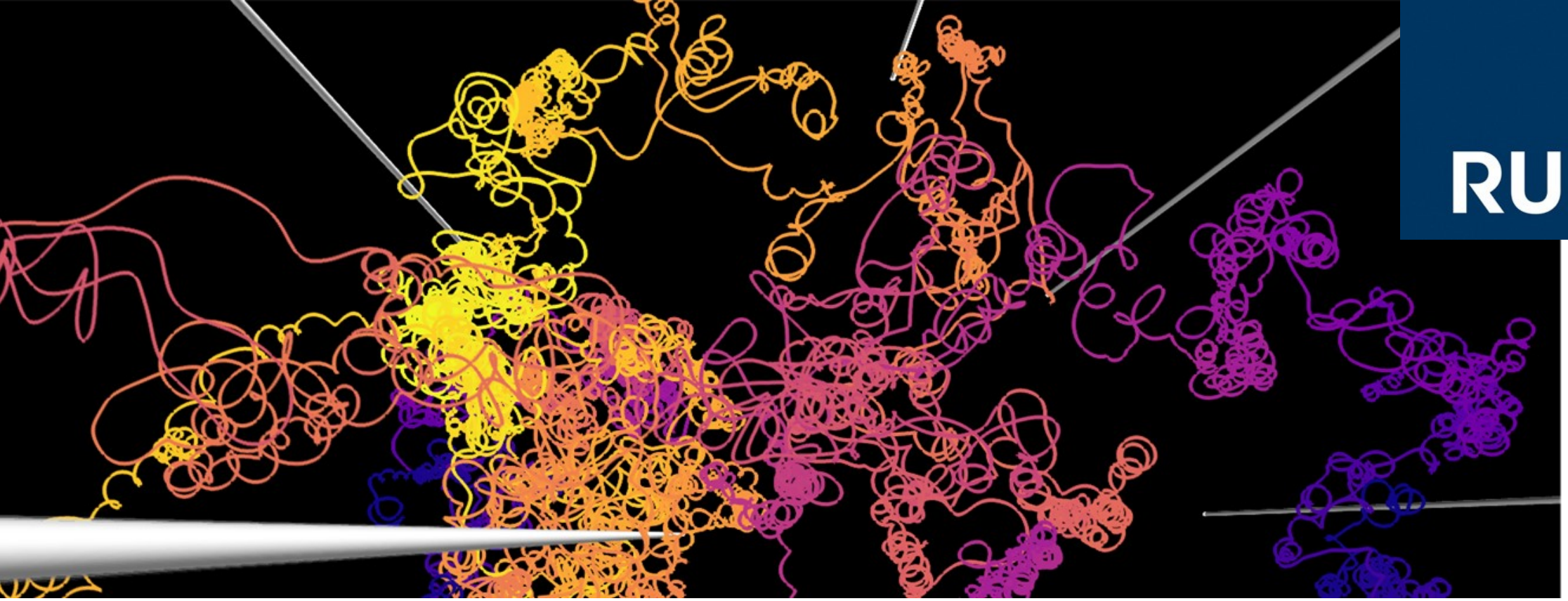


# CRPropa Workshop
# 25.-27. September 2023

Ruhr University Bochum
Julien Dörner, Lukas Merten and Julia Tjus

# How is CR Propagation modelled?

# Not within a single framework, because…

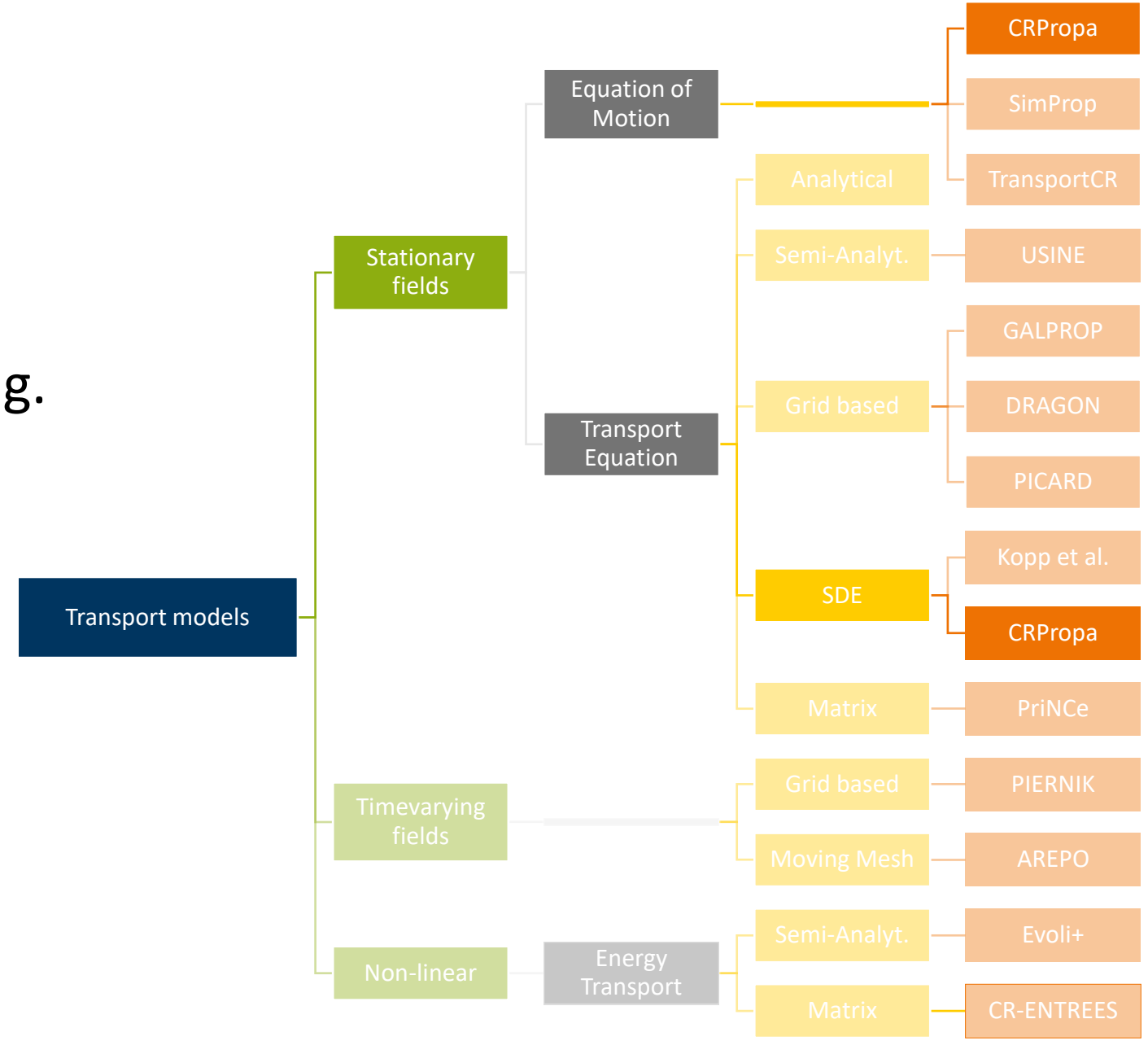
… the problem is too complicated.

Important questions:

- Are observables spatially resolved?
- Is time evolution important?
- Dominated by leptonic processes?
- Do cosmic rays influence their environment?
- What kind of targets are expected?
- Do the targets evolve in space or time?
- Coherent and/or turbulent magnetic fields?
- Is the particle transport ballistic or diffusive?

# A family tree of propagation tools

…and many more are missing.



# CRPropa

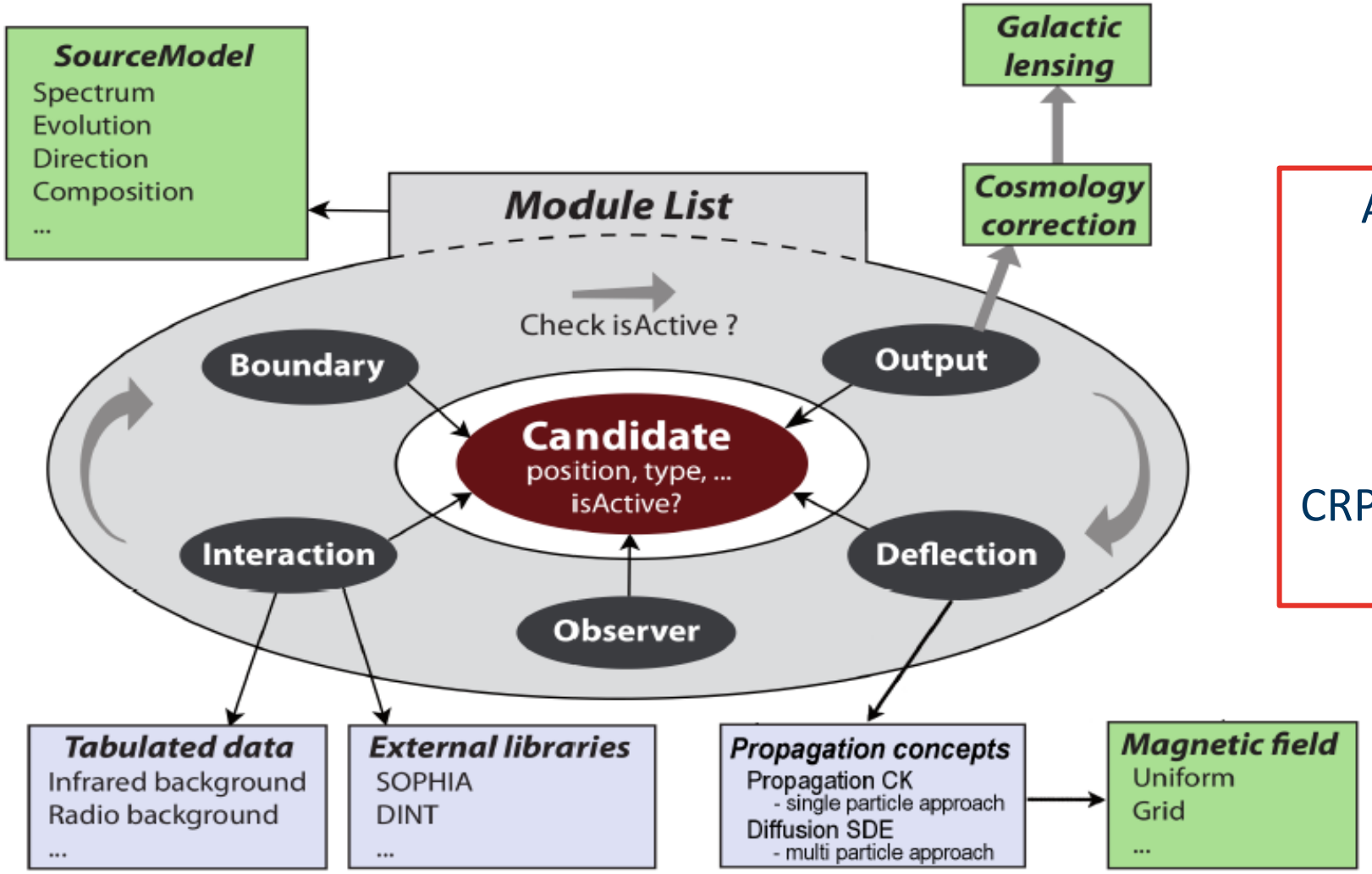
# CRPropa – Cosmic Ray Propagation Framework

- Originally designed for 3D propagation of UHECRs in extra-galactic space
- Extended to lower energies with diffusion approach
- Monte Carlo simulation framework
- Models individual CRs or phase-space elements
- Includes many of the relevant interactions

# CRPropa – A Community Driven Project

- Open source project with contributions from many institutes
  - Hamburg, Nijmegen, Madrid, Abu Dhabi, Aachen, Wuppertal, Bochum, L'Aquila, Bonn, Innsbruck, Paris, Oxford, Brussels, …
- Mainly written in c++ with Python steering
- Works on simple laptops but scales well on computing clusters
- Easy to customize and extend

# Basic Principle – The Candidate

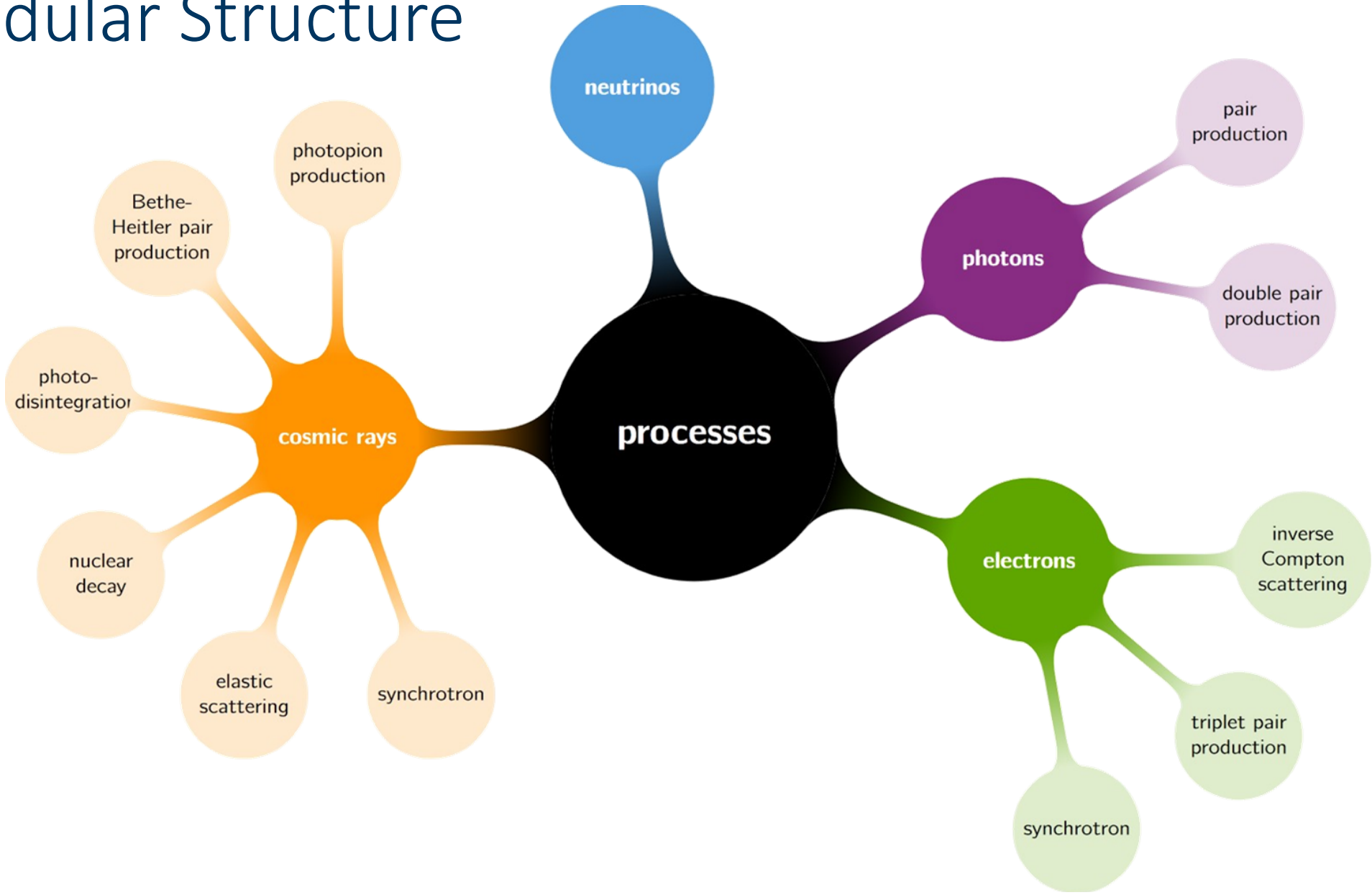



All modules must be designed stateless

→

CRPropa can be parallelized without cross node communication!

# Modular Structure



# How to build a simulation?

- SimplePropagation
- PropagationCK
- PropagationBP
- DiffusionSDE

Deflection

- ElectronPairProduction
- PhotoPionProduction
- PhotoDisintegration
- NuclearDecay

Nuclei-Interacion

- EM(Double/Triple)-PairProduction
- EMInverseCompton-Scattering

EM-Interactions

- Redshift
- SynchrotronRadiation
- AdiabaticCooling

General Interactions

- MaximumTrajectory-Length
- MinimumEnergy
- CubicBoundary
- SphericalBoundary
- …

Boundaries/ Thresholds

- ObserverSmallSphere
- ObserverTracking
- ObserverPoint
- ObserverDetectAll
- ObserverTime-Evolution

Observer

- ShellOutput
- TextOutput
- HDF5Output
- ParticleCollector

Output

- PerformanceModule

Others

# Organisation

# Useful Information

Talks: 30 minutes (incl. Discussion)

- Please upload your presentation to Indico
- Or send them by mail to: lukas.merten@rub.de

Coffee and beverages break including vegan options

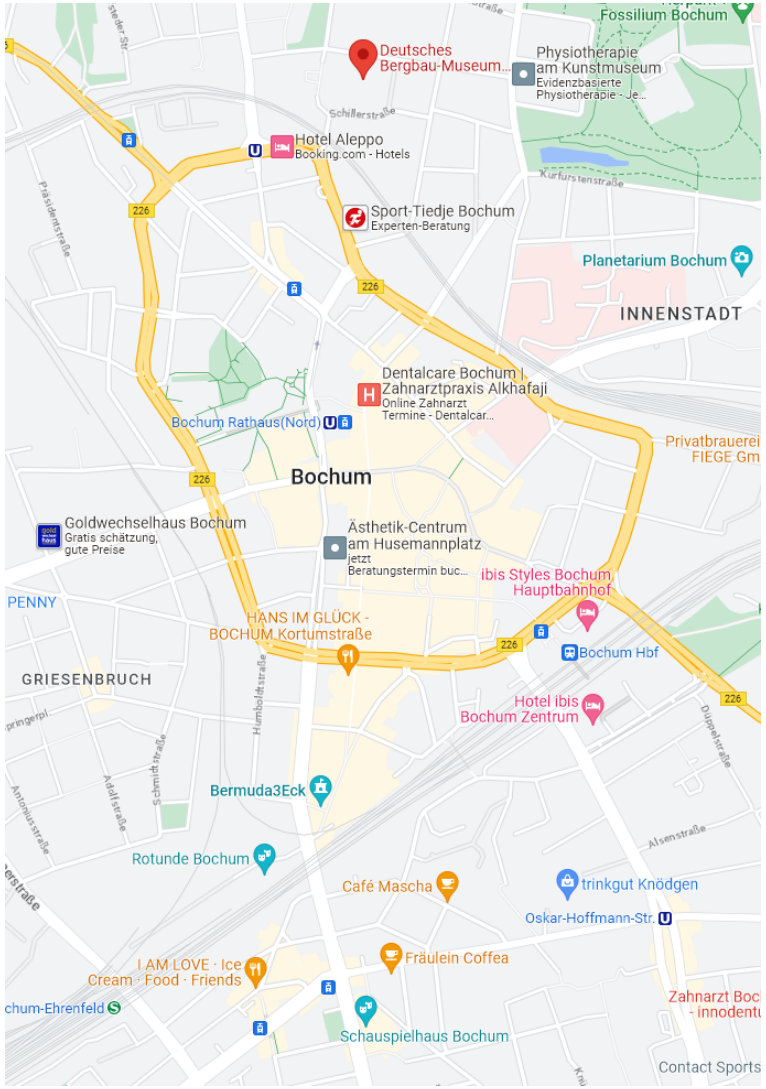
- 10:30 – 11 am
- 3:30 – 4 pm

eduroam or guest account

Conference Dinner: Tuesday 7pm @ Yamas

Contact: lukas.merten@rub.de

# Directions


Fossilium Bochum
Deutsches Bergbau-Museum...
Physiotherapie am Kunstmuseum
Evidenzbasierte Physiotherapie - Je...
Hotel Aleppo
Booking.com - Hotels
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INNENSTADT
Dentalcare Bochum | Zahnarztpraxis Alkhafaji
Online Zahnarzt Termine - Dentalcar...
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Privatbrauerei FIEGE Gm
Bochum
Goldwechselhaus Bochum
Gratis schätzung, gute Preise
Ästhetik-Centrum am Husemannplatz
jetzt Beratungstermin buc...
ibis Styles Bochum Hauptbahnhof
PENNY
HANS IM GLÜCK - BOCHUM Kortumstraße
Bochum Hbf
GRIESENBRUCH
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Café Mascha
trinkgut Knödgen
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I AM LOVE · Ice Cream · Food · Friends
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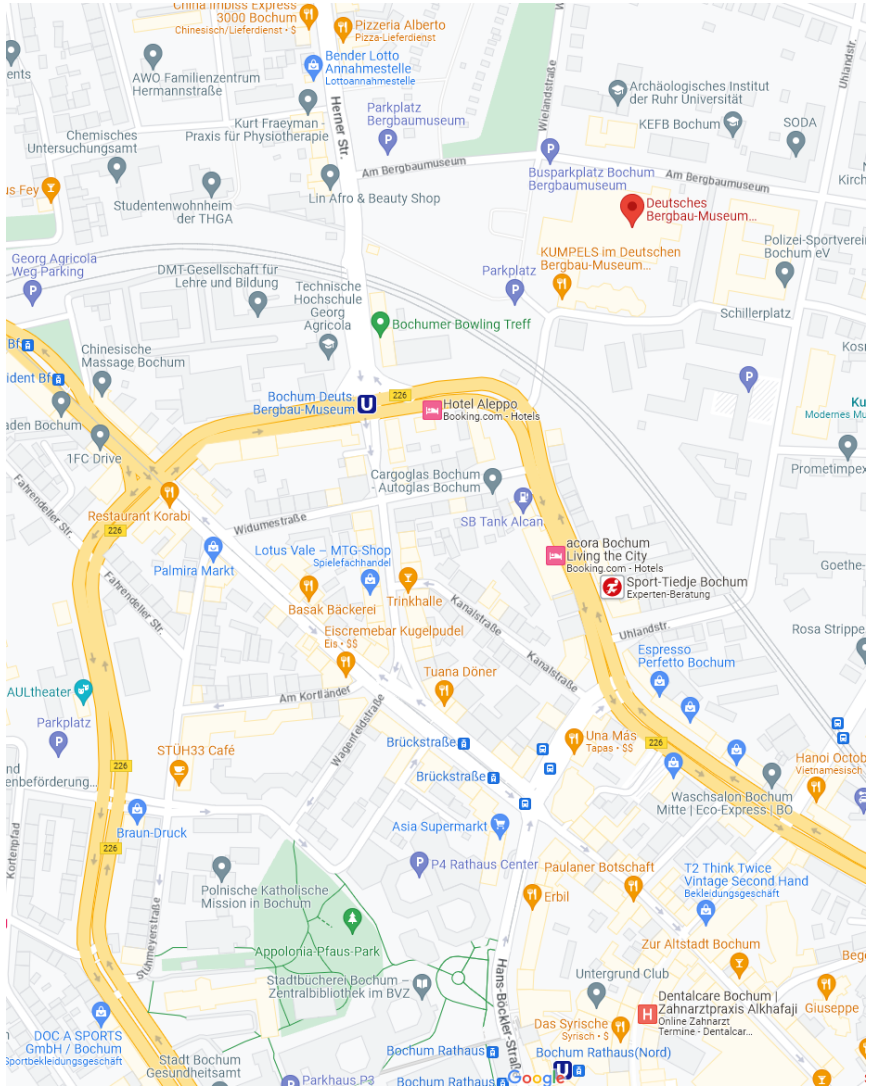
Contact Sports


Pizzeria Alberto
Pizza-Lieferdienst
Bender Lotto Annahmestelle
Lottoannahmestelle
AWO Familienzentrum Hermannstraße
Kurt Fraeyman - Praxis für Physiotherapie
Parkplatz Bergbaumuseum
Archäologisches Institut der Ruhr Universität
KEFB Bochum
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Studentenwohnheim der THGA
Lin Afro & Beauty Shop
Busparkplatz Bochum Bergbaumuseum
Deutsches Bergbau-Museum...
KUMPELS im Deutschen Bergbau-Museum...
Georg Agricola Weg Parking
DMT-Gesellschaft für Lehre und Bildung
Technische Hochschule Georg Agricola
Bochumer Bowling Treff
Chinesische Massage Bochum
Bochum Deutsches Bergbau-Museum
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SB Tank Alcan
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Lotus Vale – MTG Shop
Spielefachhandel
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Experten-Beratung
Basak Bäckerei
Trinkhalle
Eiscremebar Kugelpudel
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Tuana Döner
Parkplatz
STÜH33 Café
Una Más
Tapas · $$
Brückstraße
Waschsalon Bochum Mitte | Eco-Express | BO
Braun-Druck
Asia Supermarkt
P4 Rathaus Center
Paulaner Botschaft
Erbil
T2 Think Twice Vintage Second Hand
Bekleidungsgeschäft
Polnische Katholische Mission in Bochum
Appolonia Pfaus-Park
Zur Altstadt Bochum
Stadtbücherei Bochum – Zentralbibliothek im BVZ
Untergrund Club
Dentalcare Bochum | Zahnarztpraxis Alkhafaji
Online Zahnarzt Termine - Dentalcar...
Giuseppe
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Bochum Rathaus(Nord)
Parkhaus P3
Google

# Schedule

| Time | Monday, September 25th | | Tuesday, September 26th | | Wednesday, September 27th | |
|---|---|---|---|---|---|---|
| | Speaker | Title | Speaker | Title | Speaker | Title |
| 09:00-10:30 | Lukas Merten | Introduction | | | Lukas Merten | Ensemble Averaged Transport with CRPropa |
| | Simone Rossoni | CRPropa simulations or anisotropy studies | Leander Schlegel | Time dependent particle injection to investigate the local source behaviour of flaring AGN | Horst Fichtner | t.b.a. |
| | Janning Meinert | Impact of a ΛCDM extension of UHECR propagation | Athithya Aravinthan | Synchrotron Radiation in CRPropa | Frederic Effenberger | Investigating Charged Particle Transport in Non-Gaussian Magnetic Turbulence Models |
| 10:30-11:00 | **Coffee Break** | | **Coffee Break** | | **Coffee Break** | |
| 11:00-12:30 | Frederik Krieger | Normalizing Flows for Parameter Estimaton of UHECR Sources with Surface Detector Data of the Pierre Auger Observatory | Andrey Saveliev | On numerical Simulations of Intergalactic Electromagnetic Cascades with Lorentz Invariance Violations Using CRPropa | Pedro de la Torre Luque | The Galactic diffuse gamma-ray and neutrino emission at the PeV frontier |
| | Domenik Ehlert | Population studies of UHECR sources | Rafael Alves Batista | Coupling axion-like particles to photons during propagation: the ALPinist plug-in | Sophie Aerdker | Modeling Superdiffusive Particle Transport with CRPropa 3.2 |
| | Pavlo Platko | Combined fit of the UHECRs with jetted AGN | Gaetano Di Marco | Characterisation of gamma-ray propagation in our Galaxy | **Discussion** | |
| 12:30-14:00 | **Lunch Break** | | **Lunch Break** | | **Lunch Break** | |
| 14:00-15:30 | Carmelo Evoli | Towards SimProp-Sirente: the new release of the SimProp Code (online) | Paolo Da Vela | Probing the intergalactic magnetic field through gamma-ray observations | Sebastian Hutschen-reuter | The IMAGINE magnetic field library |
| | **Discussion** | | Alexander Korochkin | Very-high-energy gamma ray propagation with CRPropa, Crbeam, and ELMAG | **Discussion: The future of CRPropa** | |
| 15:30-16:00 | **Coffee Break** | | **Coffee Break** | | **Coffee Break** | |
| 16:00-17:30 | Julien Dörner | Hadronic Interactions in CRPropa | Luis Enrique Espinosa | Influence of plasma instabilities on the propagation and spectrum of extragalactic electromagnetic cascades | **Developer Meeting** | |
| | Leonel Morejon | Simulating UHECR sources with CRPropa using updated interaction modules | Marcel Schroller | Local Source Physics with CRPropa - Extending Test Particle Simulations for Modelling Leptohadronic AGN Jets | | |
| | **Discussion** | | **Discussion** | | | |
| 19:00 | | | **Dinner (YAMAS)** | | | |

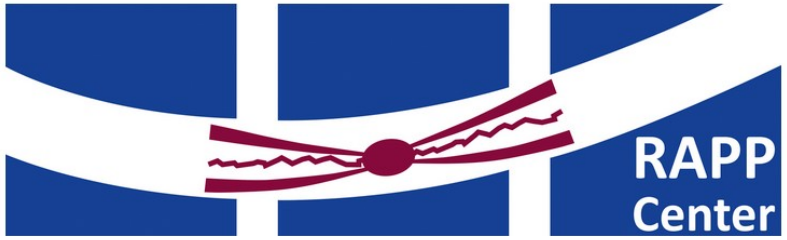
# Support

# Sponsored by


RESEARCH DEPARTMENT
Plasmas with Complex Interactions

Funded by

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

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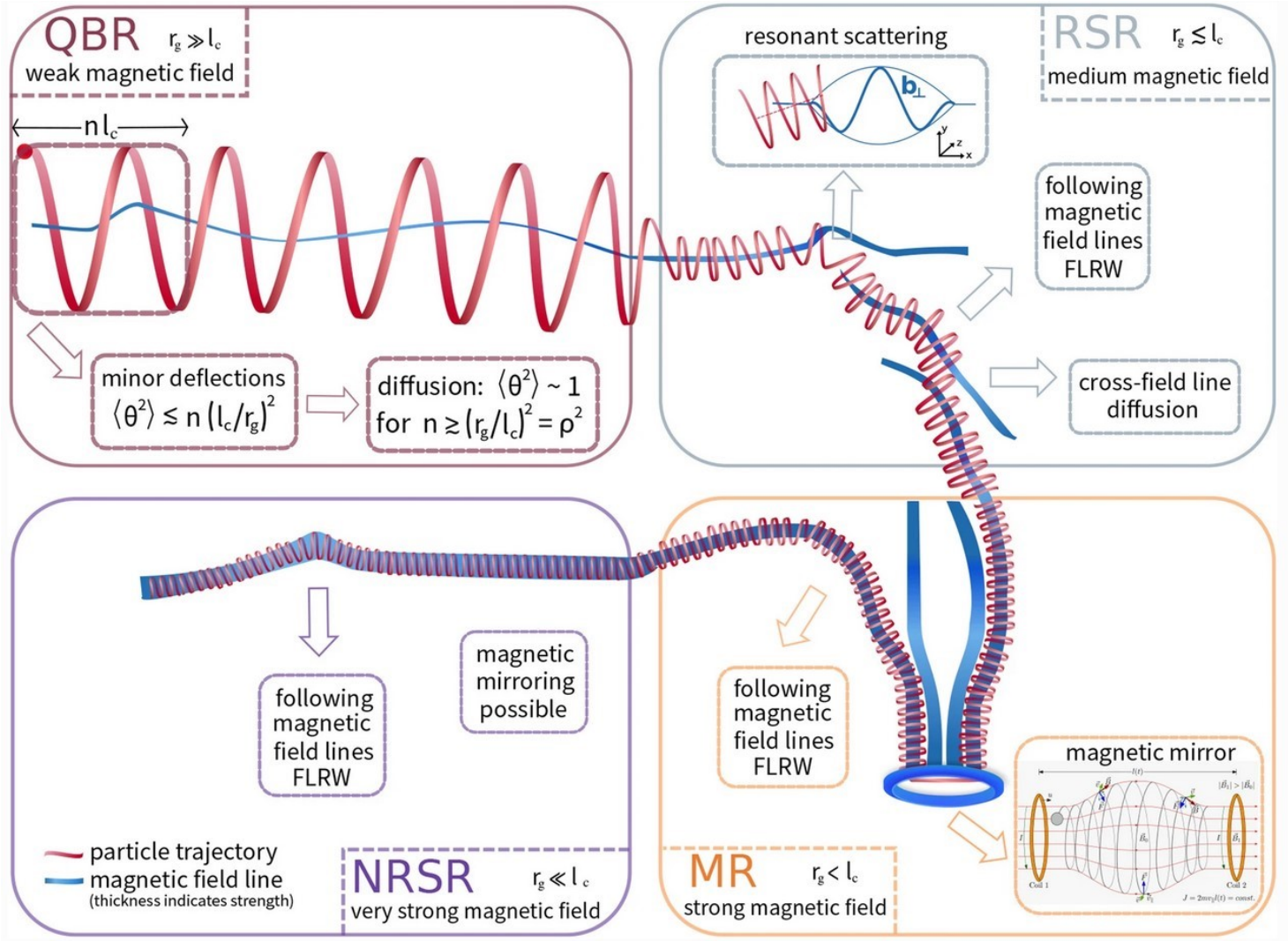
# Backup

# Why do we need Modelling of CR Transport?

# Magnetic Field Deflections



# Magnetic Field Properties

- Can be structured on large scales
  - Direction, ordering
  - Strength
- Turbulent components are often observed
  - Power spectrum
  - Anisotropies
  - Intermittency

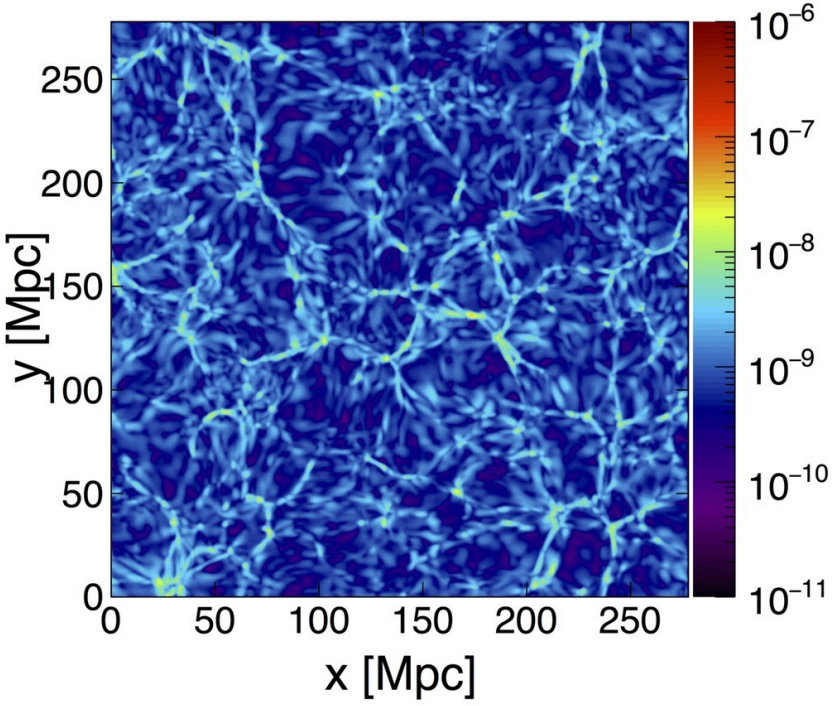
Random deflections → Smearing of sources

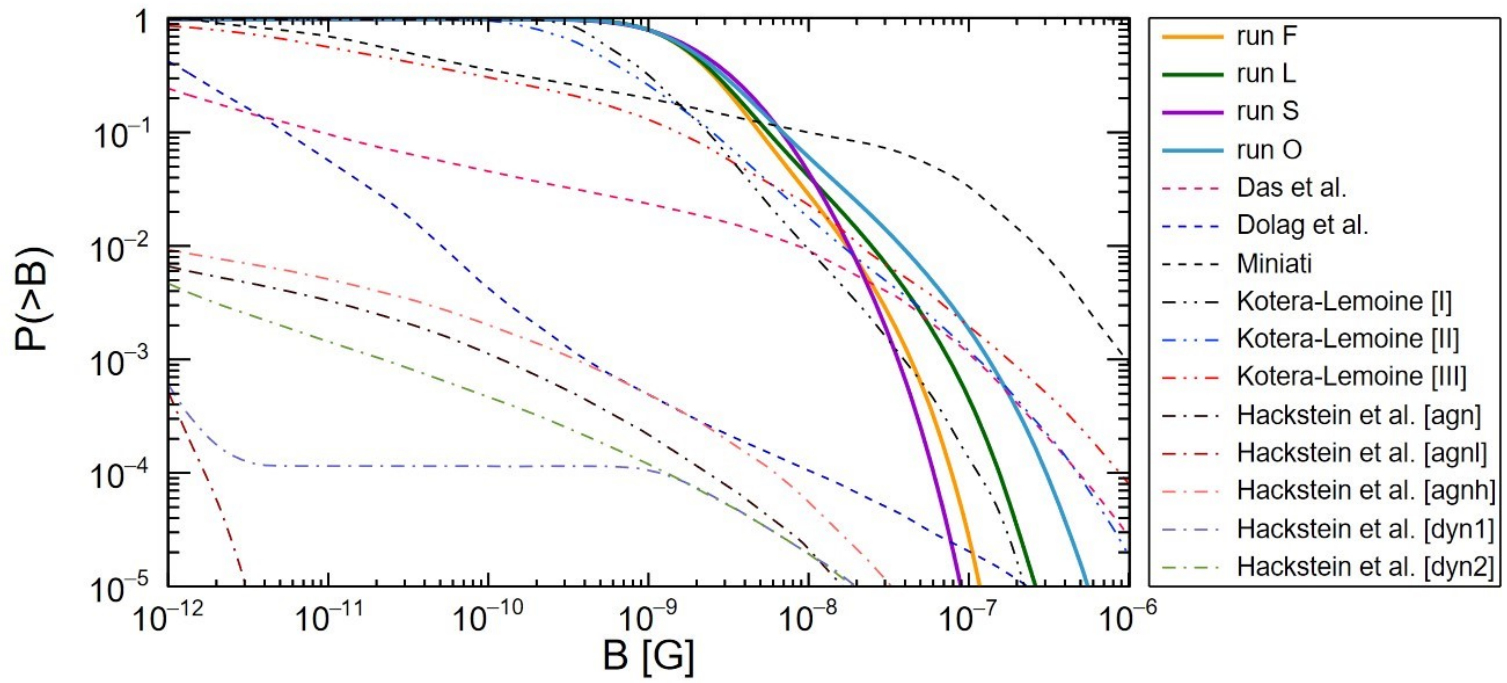
Coherent deflections → Shift of apparent source position

Combination → Magnetic horizon

Alves Batista et al. Phys. Rev. D (2017)

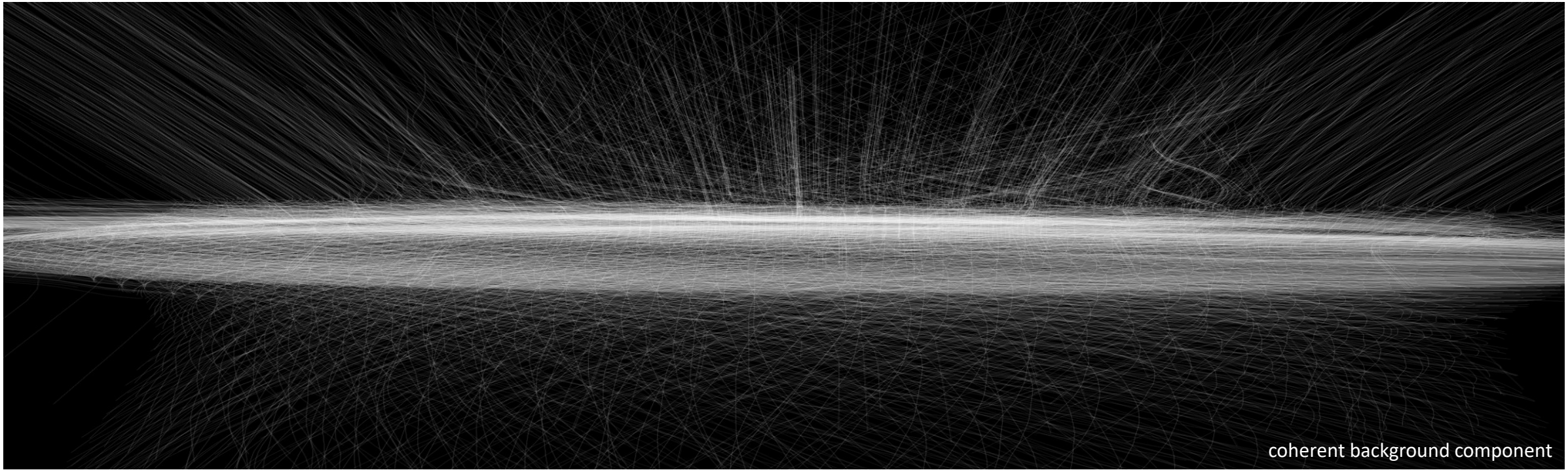
# Extra-Galactic Magnetic Fields



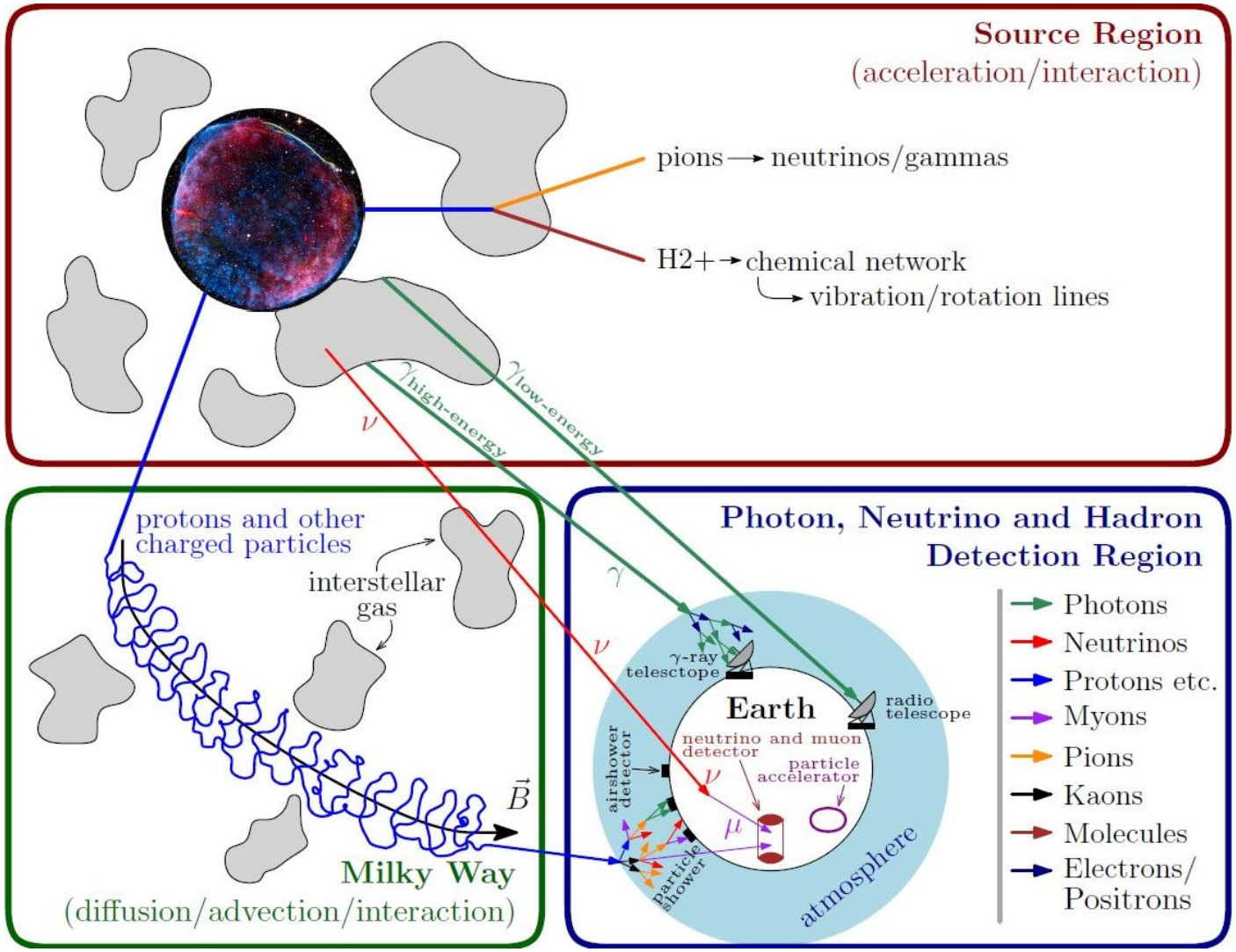
Jansson and Farrar ApJ Letters (2012)

# Galactic Magnetic Field



# Why do we need Modelling of CR Interactions?

# Interactions and Secondaries



# Interactions and Losses

Cosmic Rays are never propagating in a pure vaccum

→Energy losses and production of secondaries

## Possible processes

Synchrotron Radiation, Ionization, Inverse Compton Scattering, (Double, Triple) Pair Production, Photo Meson Production, Photo Disintegration, Spallation, Nuclear Decay, …

## Possible Targets

- Photon Fields (CMB, EBL, Synchrotron photons, Corona, etc.)
- Hadronic Targets (HI/HII, H+, dust, He, etc.)
- Magnetic Fields

# Secondaries

…everything that is produced during the propagation of CRs.

- Photons, Neutrinos, Electrons, Muons, lighter Cosmic Rays, etc.
- Can have complicated energy spectra
- Induce interactions themselves

Provide valuable otherwise inaccessible knowledge about CRs

- Source position ← neutrinos
- Energetics ← gamma rays
- Transport properties ← light cosmic rays (B/C ratio)
- Composition ← Muons