The ORIGINS Cluster of Excellence

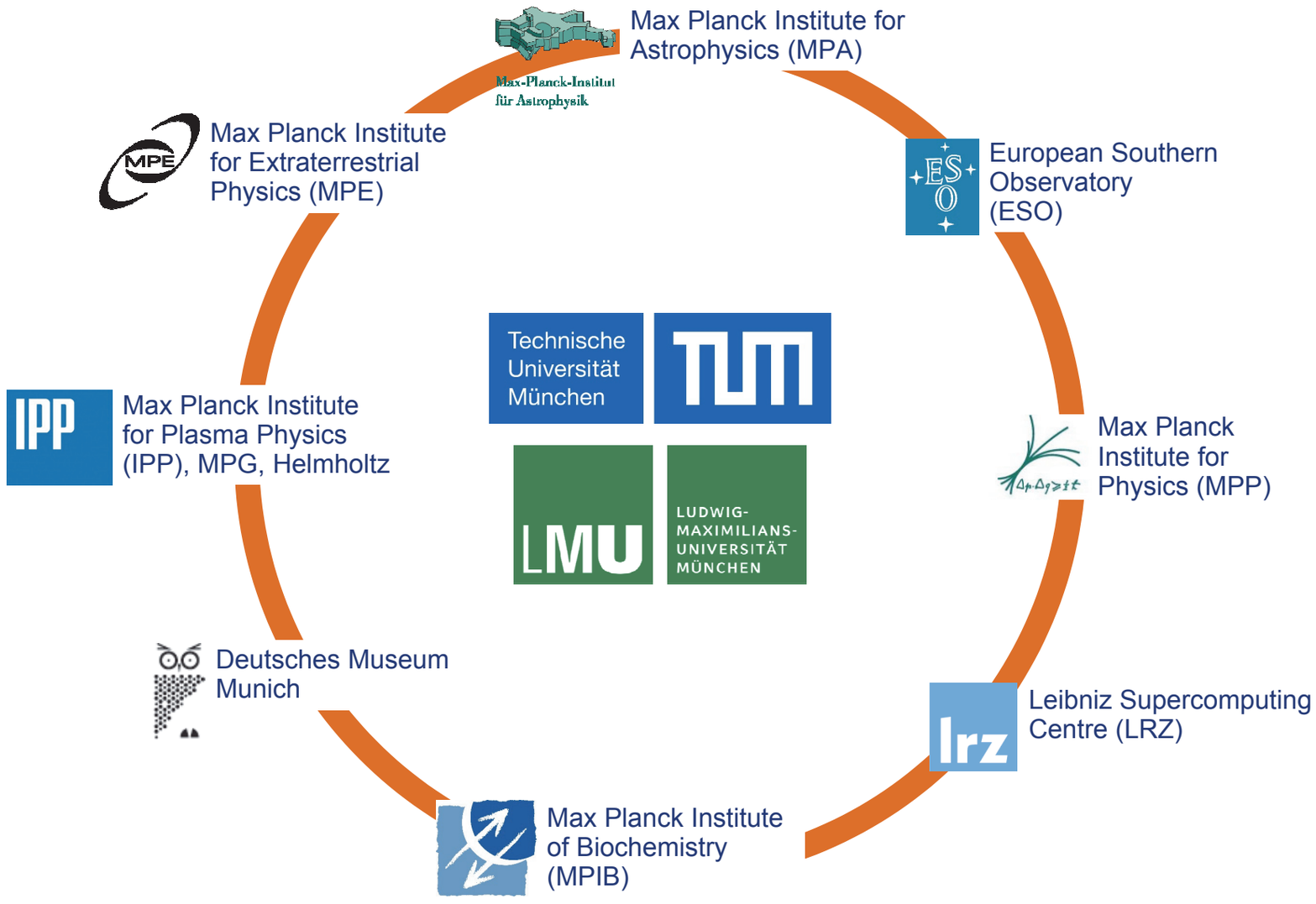
– Torsten Dahms –
Excellence Cluster Universe - TUM

KHuK Jahrestagung 2018
December 7th, 2018

Technische Universität München

From the Origin of the Universe to the First Building Blocks of Life

From the Origin of the Universe to the First Building Blocks of Life



Origins Motivation and Basis

What is the structure of the Universe?

How did it form and evolve?

How did life emerge?

Are we alone in the Universe?

Origins Motivation and Basis

What is the structure of the Universe?

How did it form and evolve?

How did life emerge?

Are we alone in the Universe?

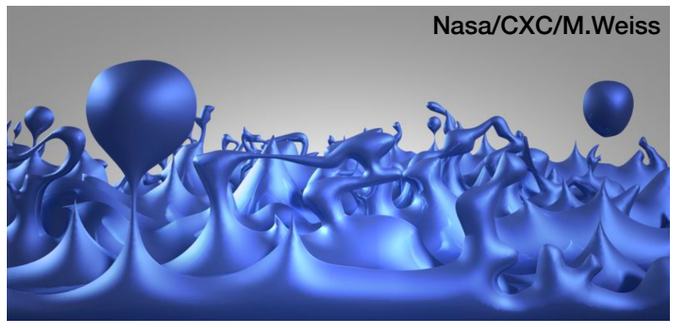
Conjecture:

The Universe and life unfolded from initial conditions laid out in the Big Bang

Hierarchy of Scales

UNIVERSE Cluster

Planck Scale



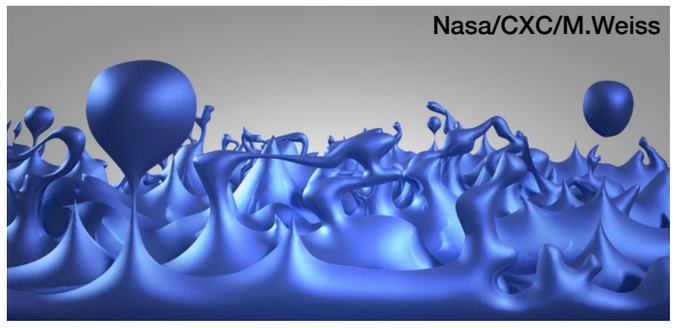
$10^{-35}\,\mathrm{m}$

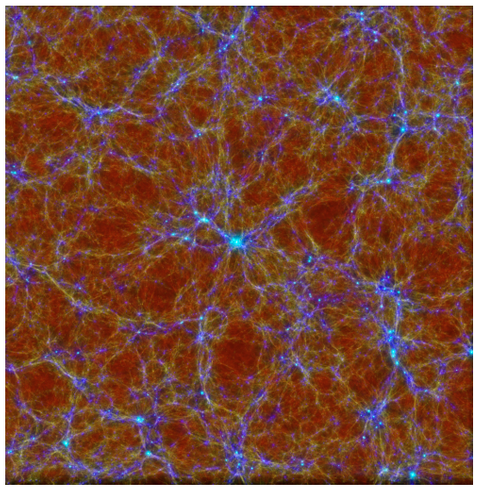
Hierarchy of Scales

UNIVERSE Cluster

Planck Scale

Hubble Scale





$10^{-35}\,\mathrm{m}$ ⟵ ⟶ $10^{24}\,\mathrm{m}$

Intimate coupling of scales

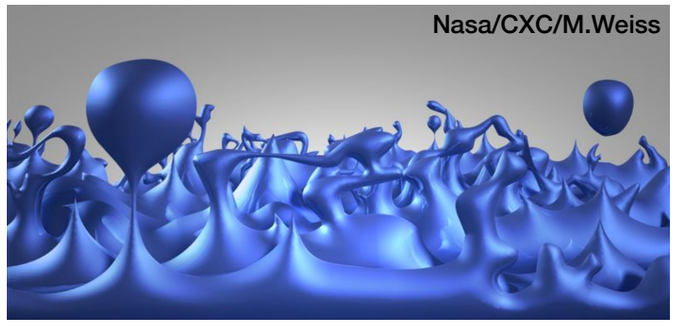
Hierarchy of Scales

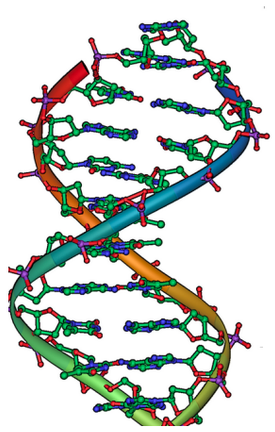
ORIGINS Cluster

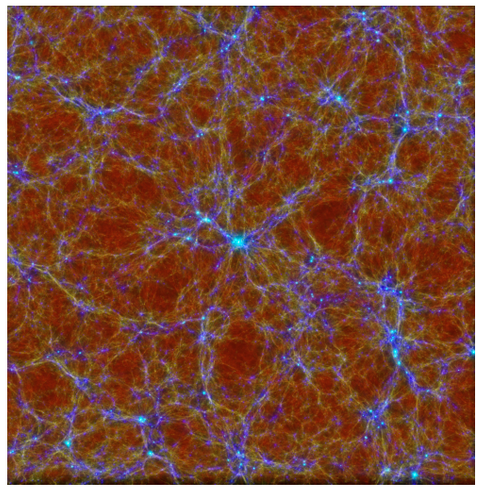
Planck Scale

Origin of Life

Hubble Scale



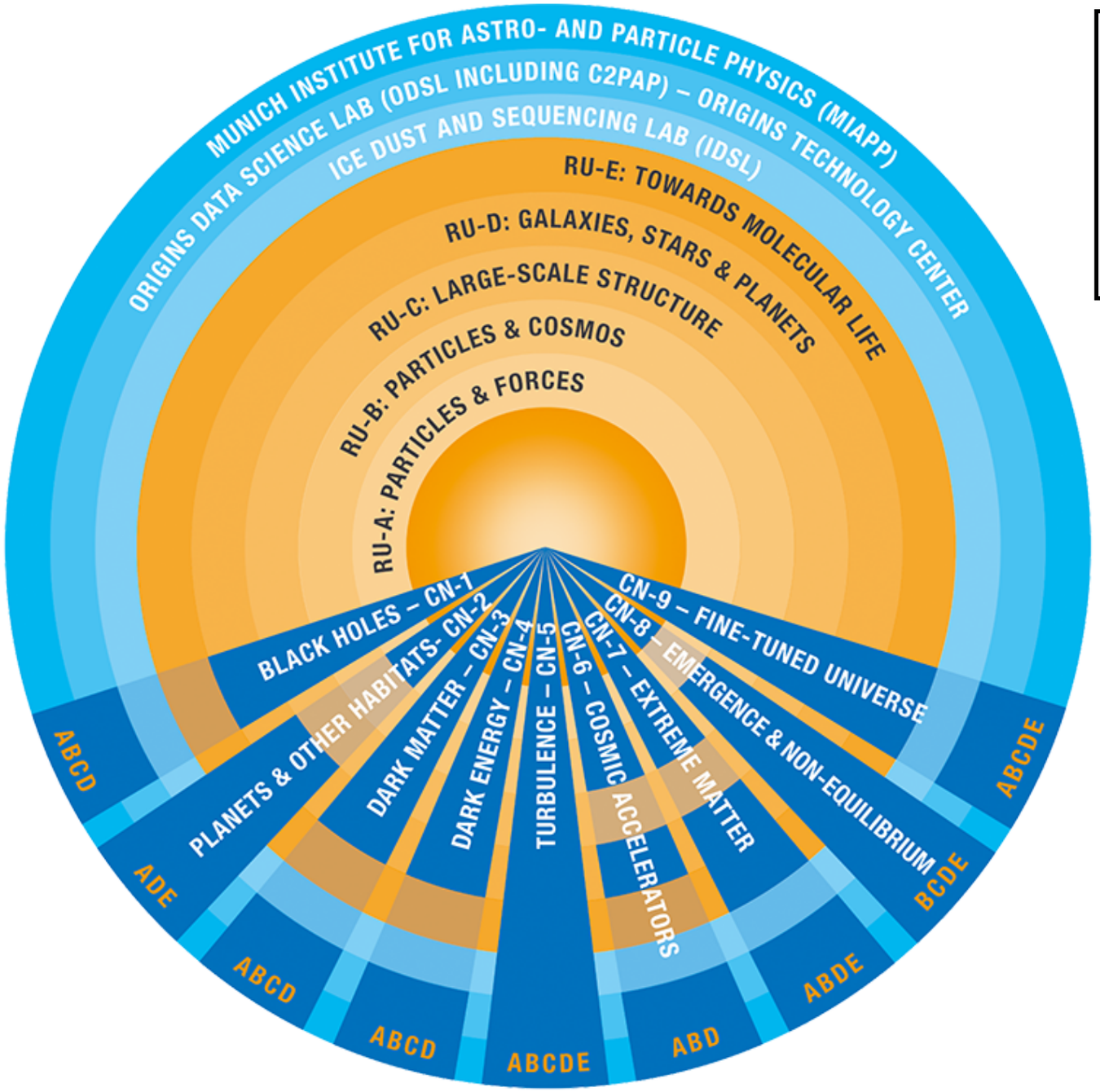




$10^{-35}\,\mathrm{m}$ ⟷ $10^{-9}\,\mathrm{m}$ ⟷ $10^{24}\,\mathrm{m}$

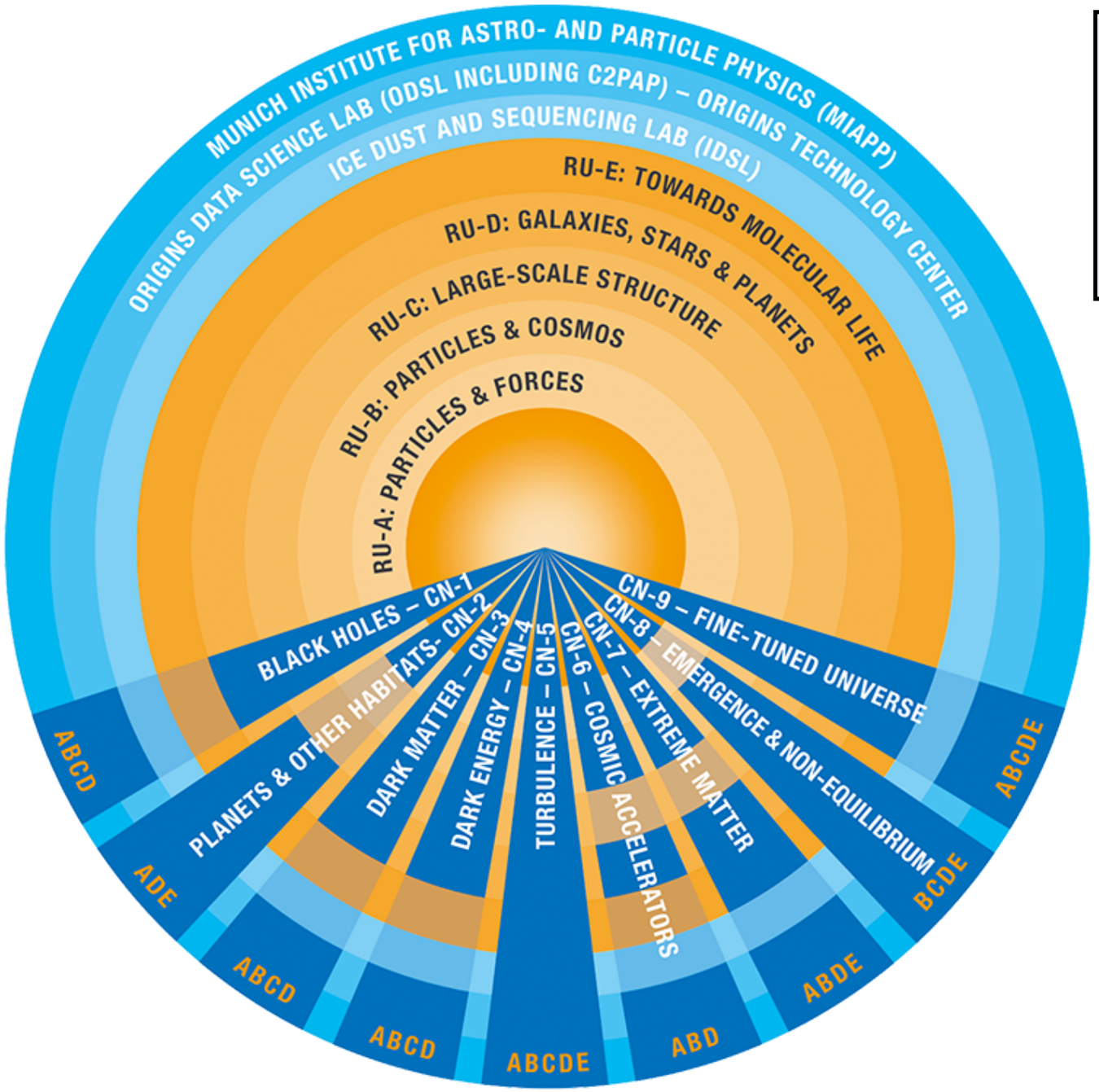
Intimate coupling of scales

Origins Research Structure: 5 Research Units



- **Backbone** of ORIGINS
- **Fundamental nodes** with focused research
- **Subareas** joined by researchers from different communities
- **Milestones**

Origins Research Structure: 5 Research Units



- **Backbone** of ORIGINS
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- **Milestones**

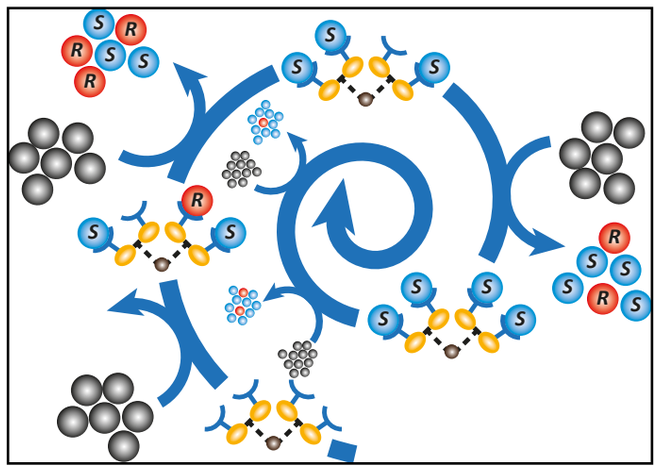
RUs are strongly interlinked by the hierarchy

Origins Research Units

RU-E

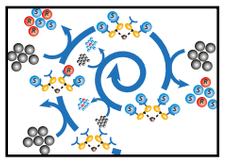
Emergence of molecular life
Information and replication

Complex organic molecules



Design lab experiment of molecular information replication

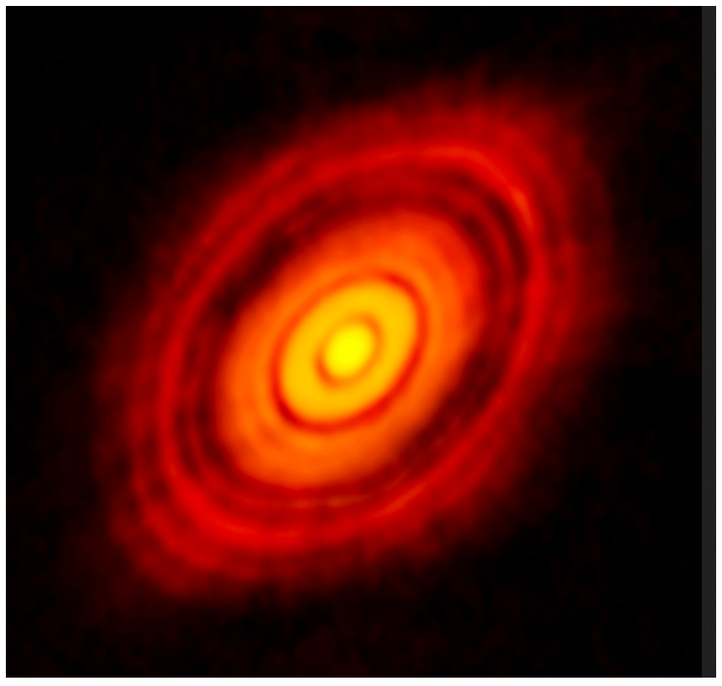
Origins Research Units



RU-D
Formation of stars and planets
Galactic nucleosynthesis

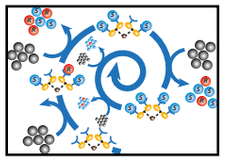
RU-E
Emergence of molecular life
Information and replication

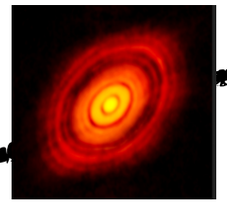
ALMA: Planet-forming disk



Diversity of planet-forming environments,
best suited for life to emerge

Origins Research Units





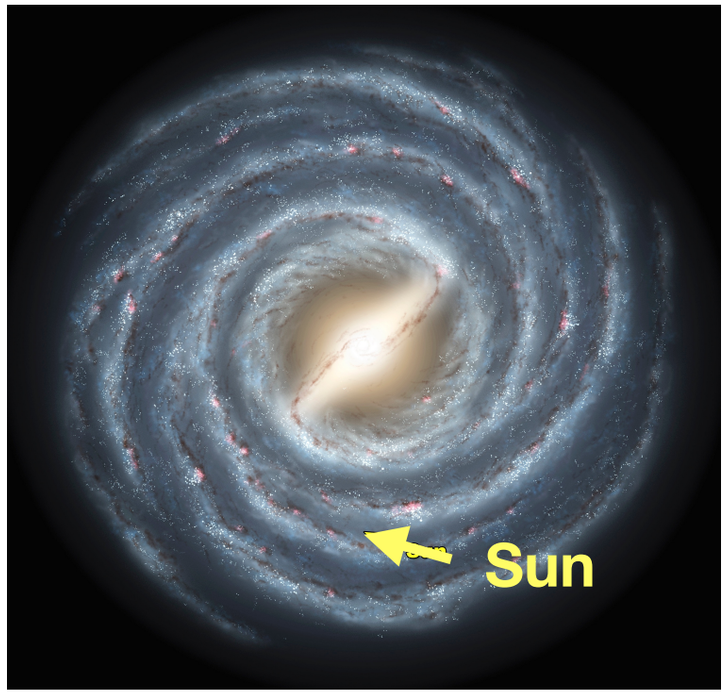
RU-D

Formation of stars and planets
Galactic nucleosynthesis

RU-E

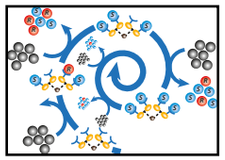
Emergence of molecular life
Information and replication

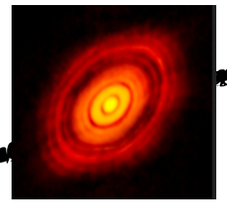
GAIA: Milky Way



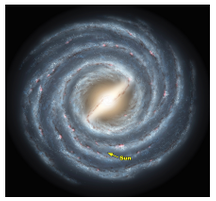
Specify cosmic nuclear enrichment and the formation of the Sun

Origins Research Units



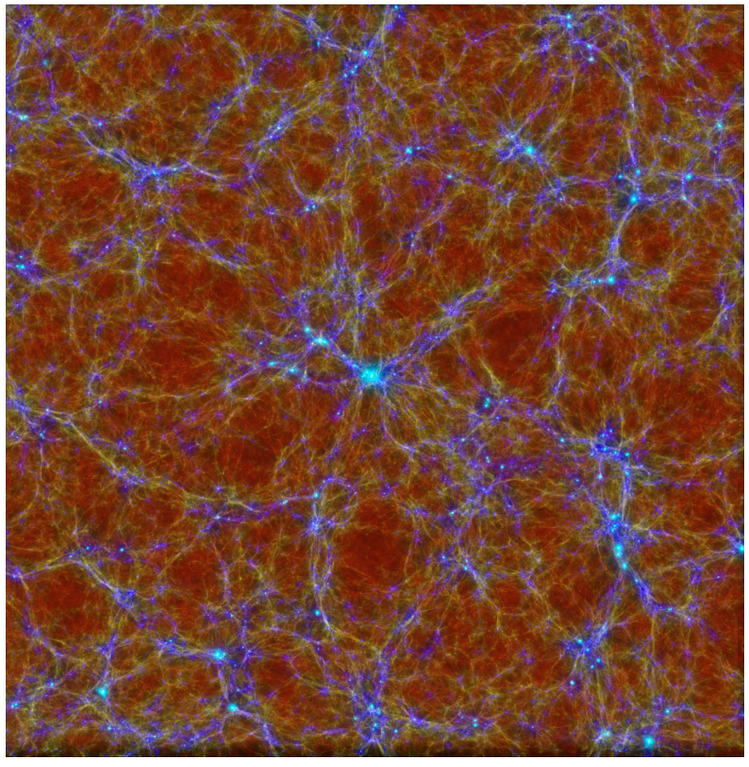


RU-D
Formation of stars and planets
Galactic nucleosynthesis



RU-E
Emergence of molecular life
Information and replication

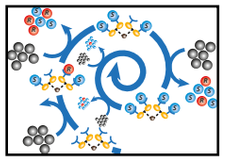
Magneticum simulation

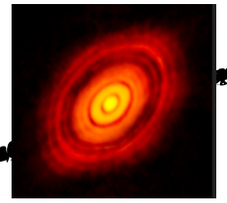


RU-C
The cosmic web
Cosmological parameters

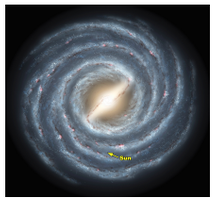
Precise determination of cosmological models and cosmic acceleration

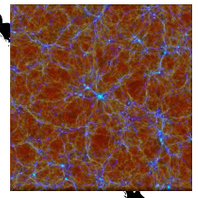
Origins Research Units





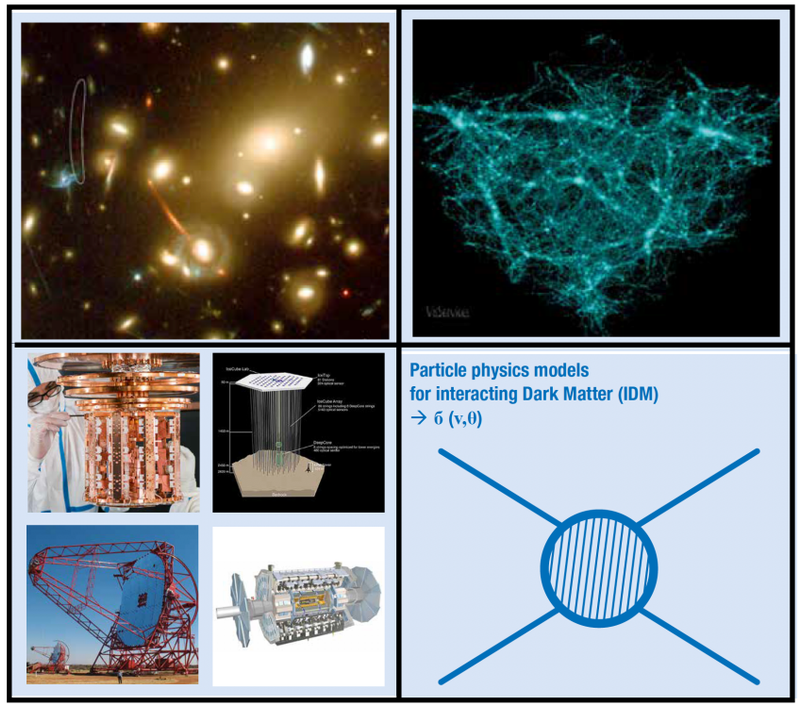
RU-D
Formation of stars and planets
Galactic nucleosynthesis





RU-E
Emergence of molecular life
Information and replication

Dark Matter data center

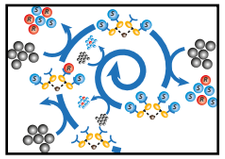


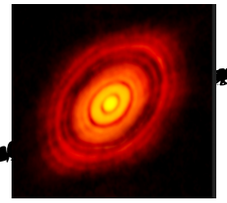
RU-C
The cosmic web
Cosmological parameters

Uncover the mystery of Dark Matter

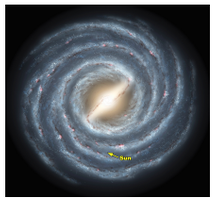
RU-B
Elementary particles and the hidden cosmos

Origins Research Units

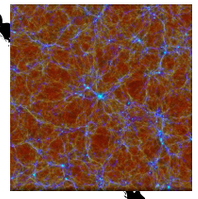




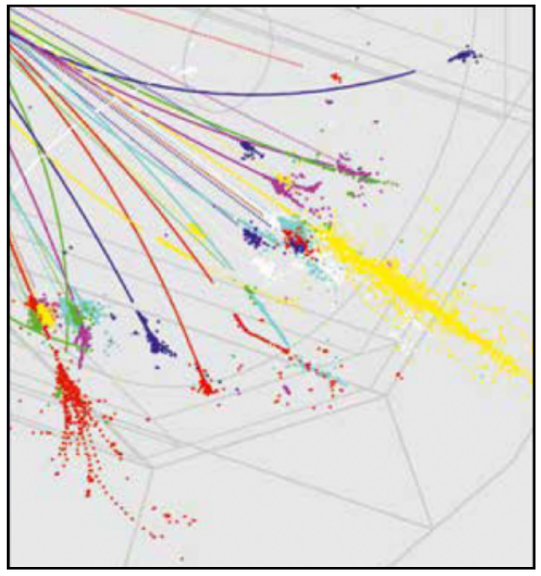
RU-D
Formation of stars and planets
Galactic nucleosynthesis



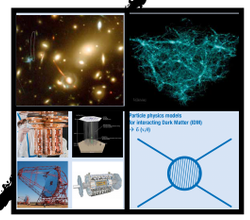
RU-E
Emergence of molecular life
Information and replication



Fundamental particles
and forces

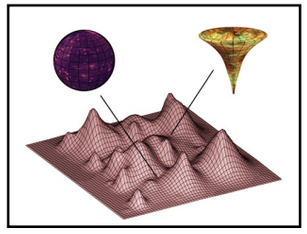


Search for new physics
beyond the Standard Model



RU-C
The cosmic web
Cosmological parameters

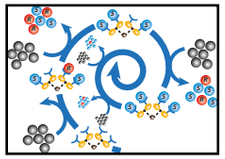
RU-A
New physics: TeV—GeV scale
Planck Scale: spacetime

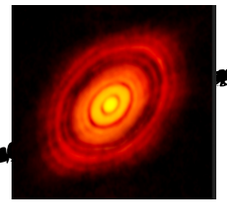


Origin of
spacetime

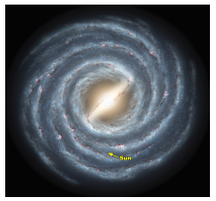
RU-B
Elementary particles and the
hidden cosmos

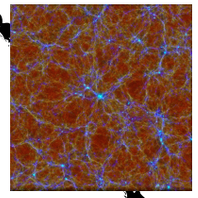
Origins Research Units





RU-D
Formation of stars and planets
Galactic nucleosynthesis



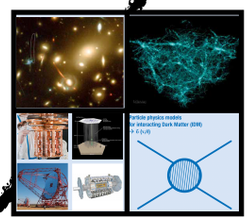


RU-E
Emergence of molecular life
Information and replication

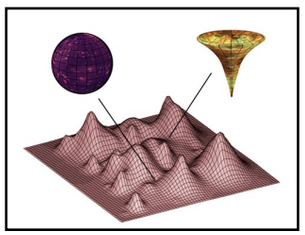
Fine-tuned Universe

Is life inevitable?

RU-C
The cosmic web
Cosmological parameters



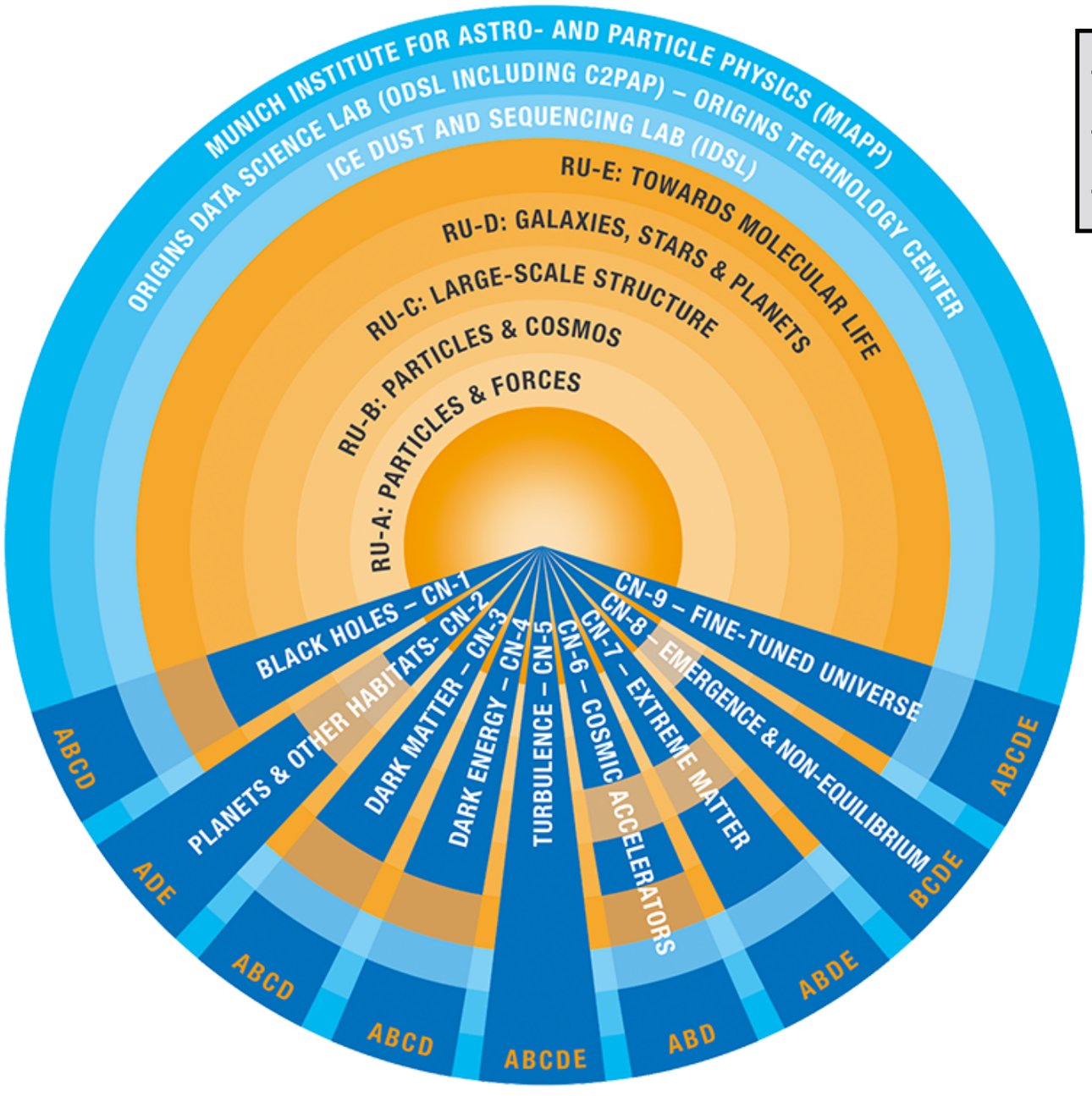
RU-A
New physics: TeV—GeV scale
Planck Scale: spacetime



Origin of spacetime

RU-B
Elementary particles and the hidden cosmos

The Interconnected Universe

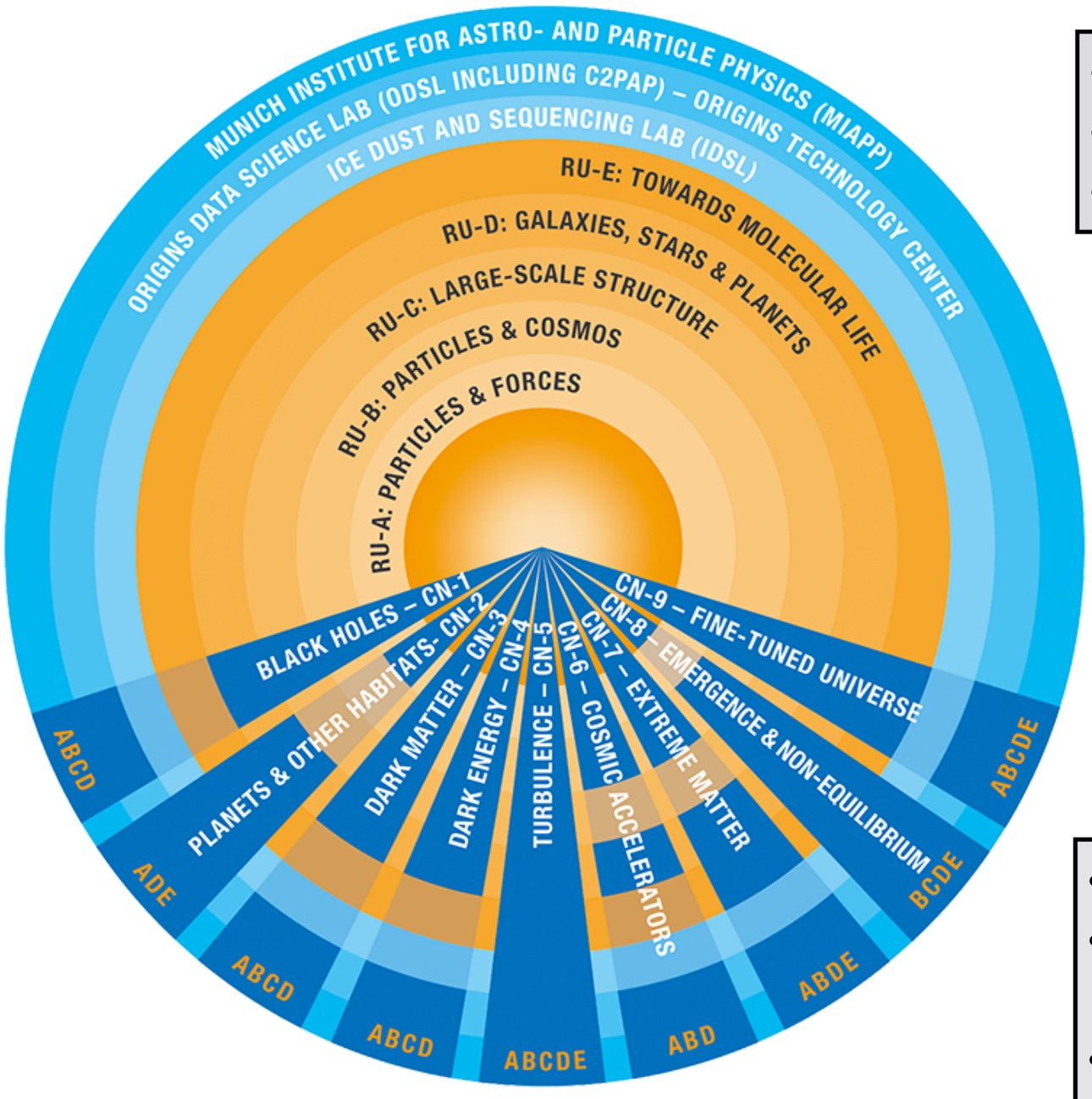


Understanding the Universe requires

- Addressing complex interlinked processes
- Collaborations beyond single disciplines
- Out-of-the-box thinking

The Interconnected Universe

At present 9 connectors



Understanding the Universe requires

- Addressing complex interlinked processes
- Collaborations beyond single disciplines
- Out-of-the-box thinking

The Interconnected Universe

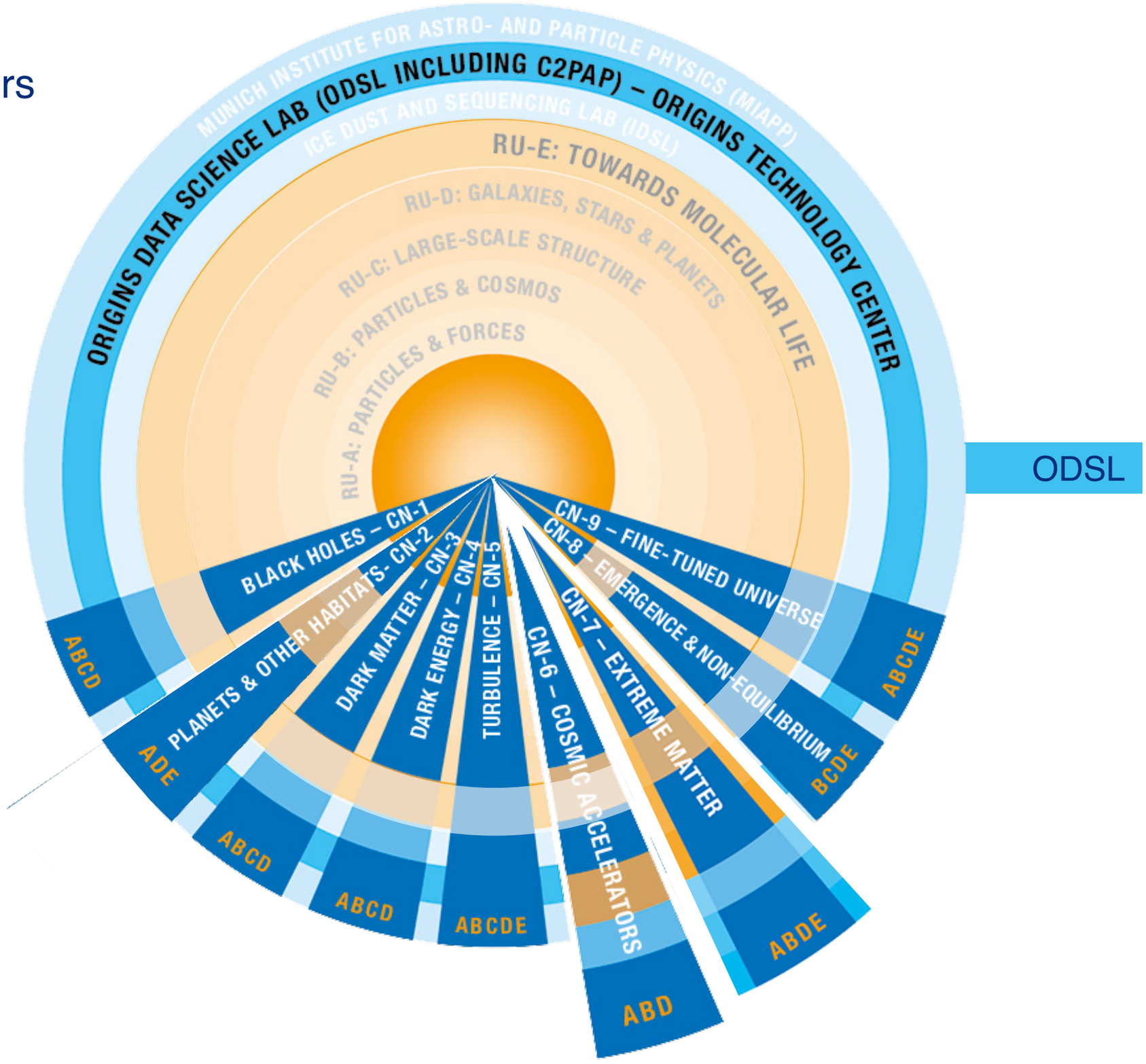
- Contains strictly interdisciplinary connectors
- Addresses overarching scientific questions

+

- Triggers new technologies and concepts
- Trains a new generation of scientists

On What Follows

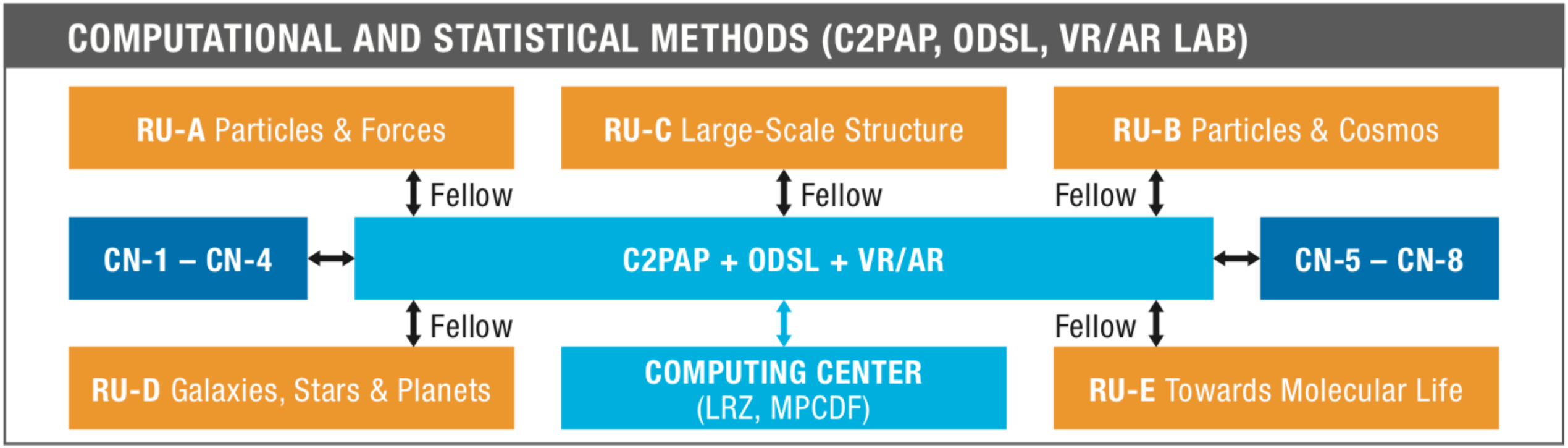
Details of ODSL
and
Two Connectors



ODSL

Origins Data Science Laboratory (ODSL)

A resource for all cluster scientists and a source of innovative developments in data science



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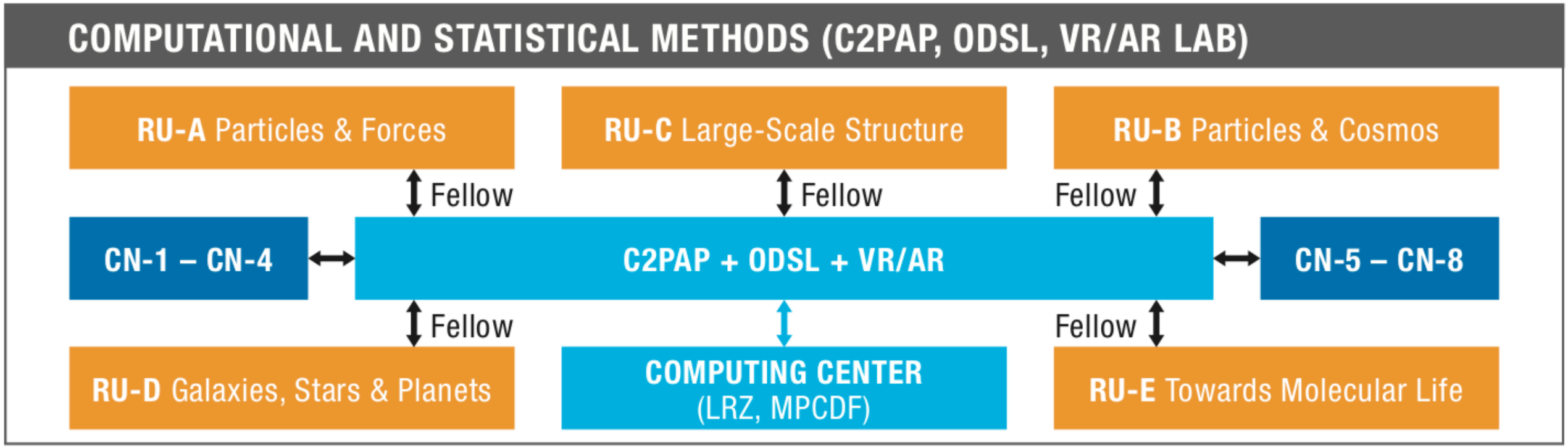
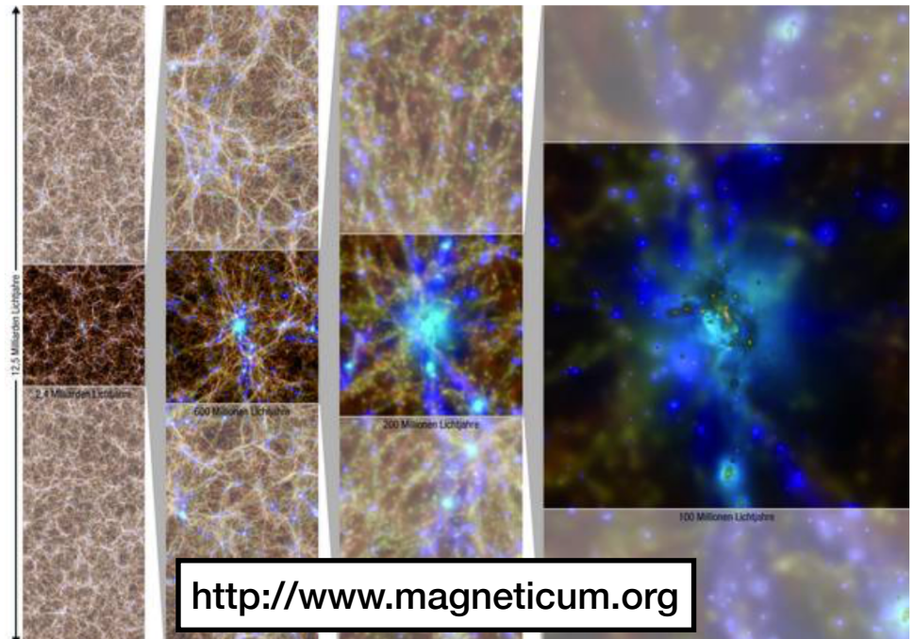
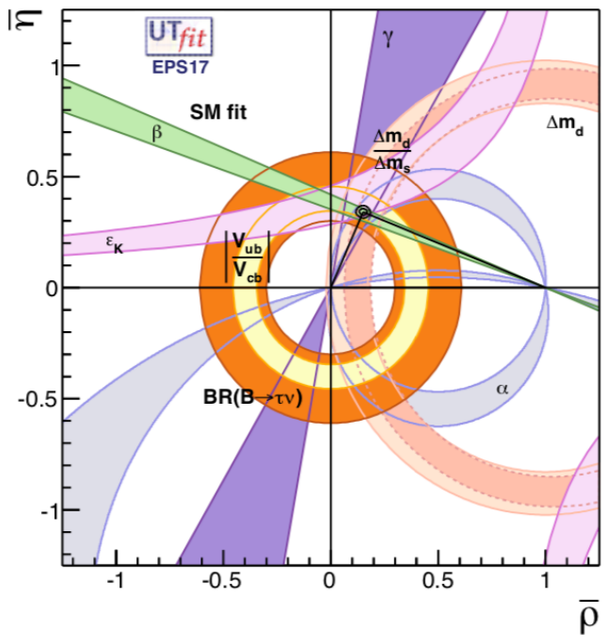


A significant extension of the successful C2PAP from the Excellence Cluster Universe

Cosmological simulation: record $2 \cdot 10^{11}$ elements, area of 12.5 billion light years



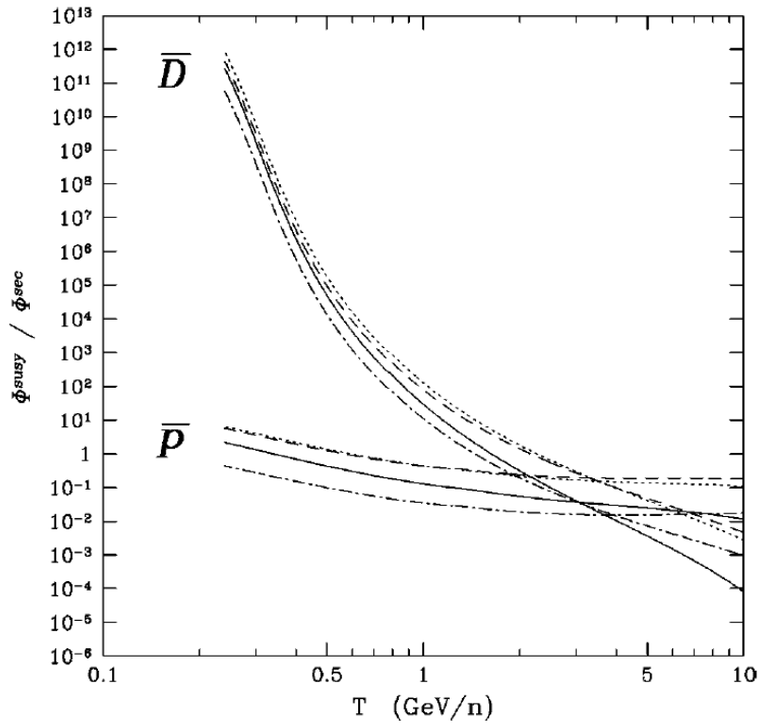
global analysis of SM parameters (CKM)

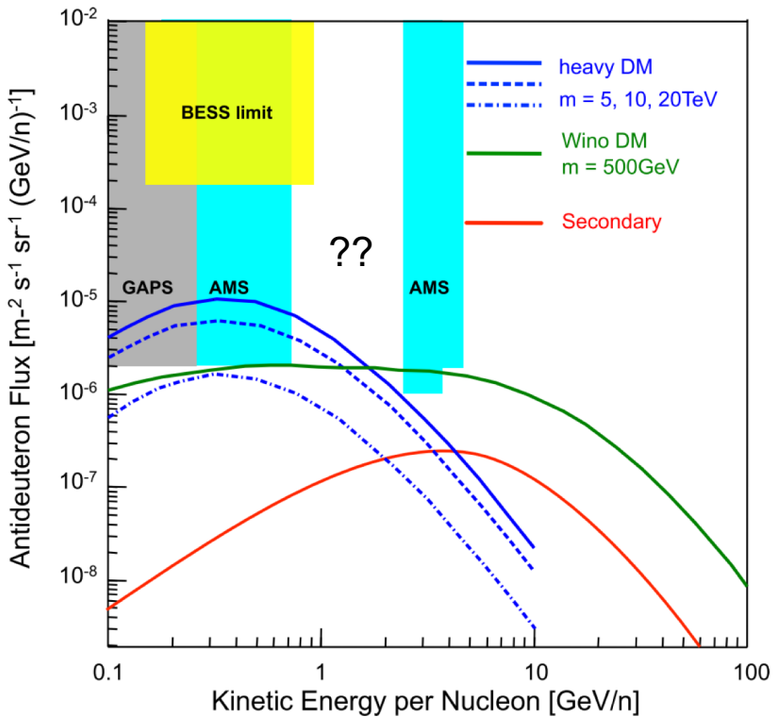


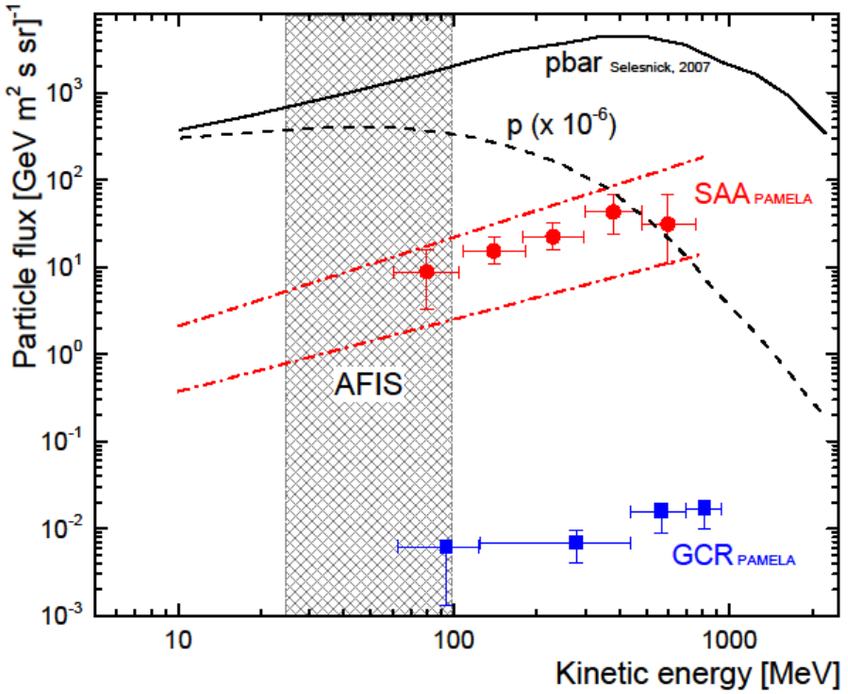
Bayesian Analysis Toolkit

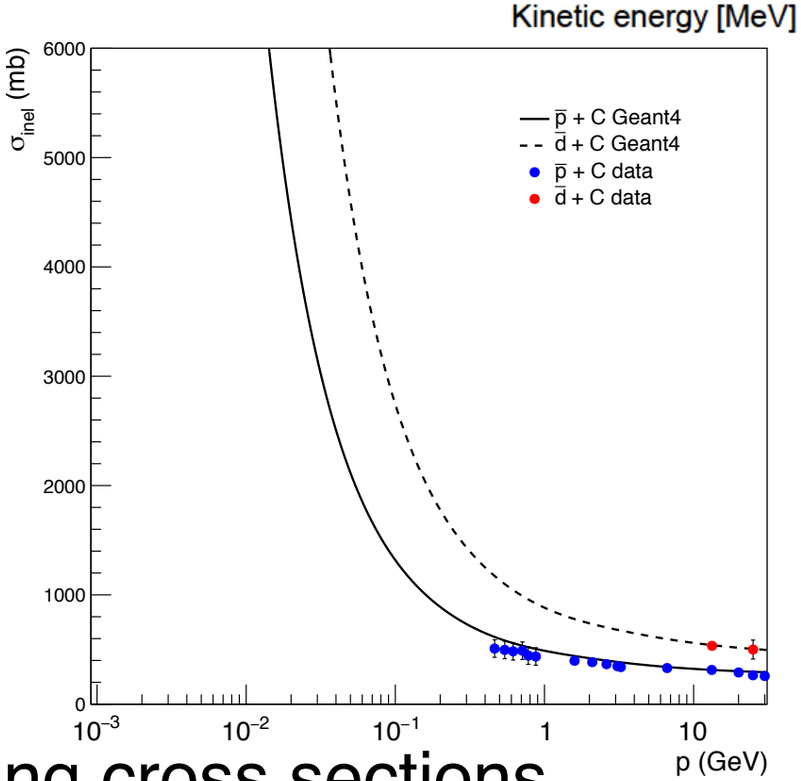
Origins Laboratory for Rapid Space Missions

- **Develop experiments for cube sats and balloon missions**
- Indirect dark matter detection via antiprotons or antideuterons
  - Big advantage of antideuteron: negligible production in SM processes





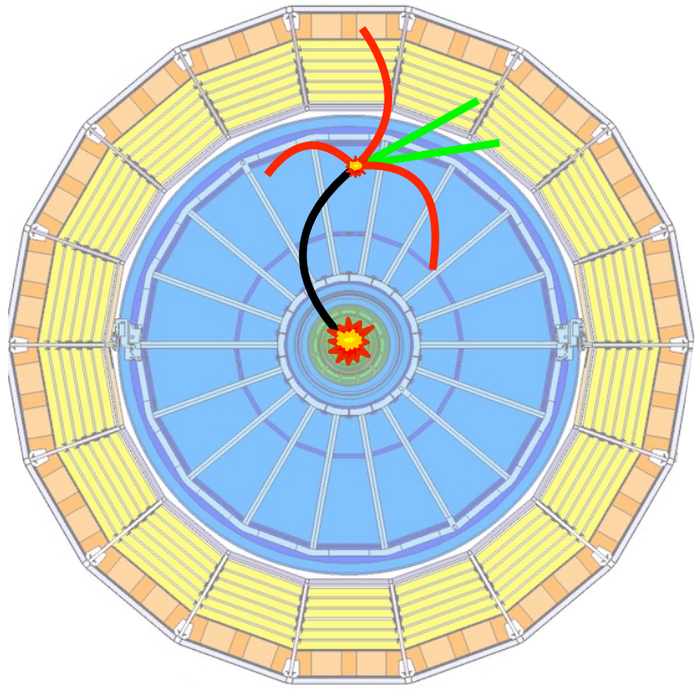


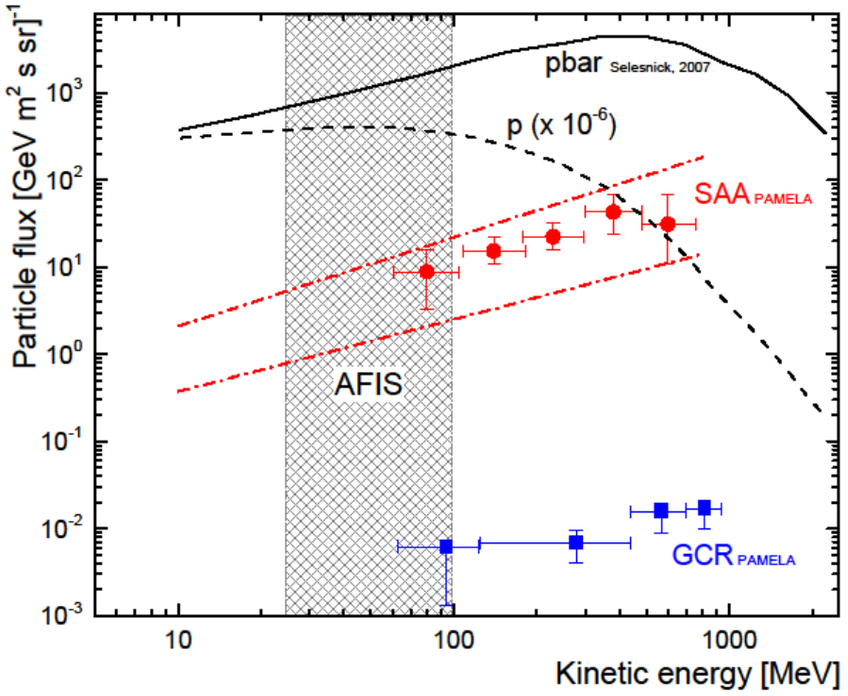


- Unknown low-energy antimatter inelastic scattering cross sections
  → crucial input to determine flux

Origins Laboratory for Rapid Space Missions

- **Develop experiments for cube sats and balloon missions**
- Indirect dark matter detection via antiprotons or antideuterons
  - Big advantage of Antideuteron: negligible production in SM processes





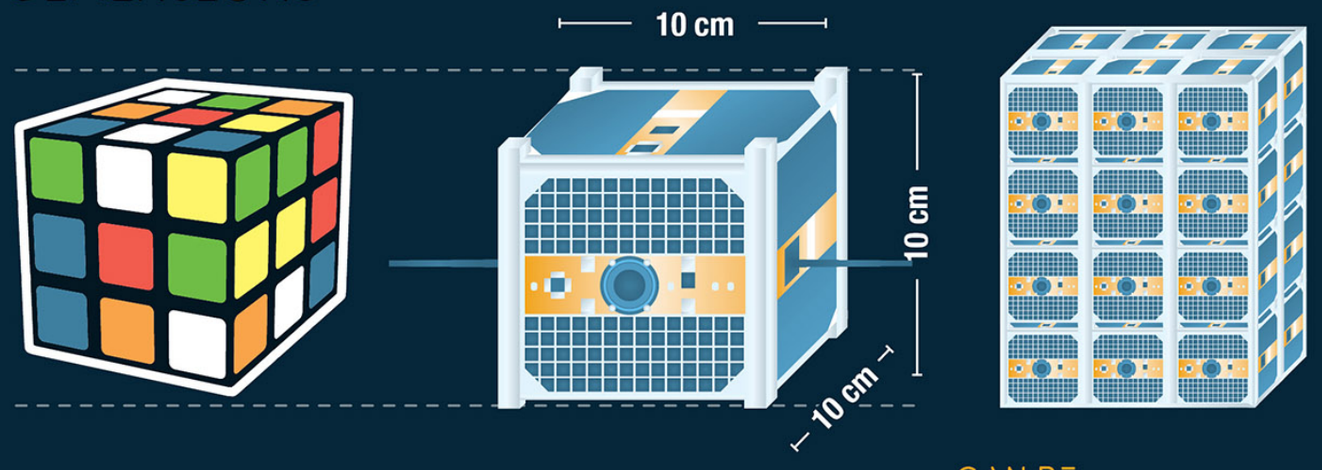
- Unknown low-energy antimatter inelastic scattering cross sections
  → crucial input to determine flux
- Idea: Measure antimatter annihilation in detector material of ALICE

CUBESAT

IT'S HIP TO BE SQUARE!

A **CUBESAT** is a **MINIATURE CUBE-SHAPED SATELLITE.**

DIMENSIONS



USED ALONE (1 unit) --- OR --- CAN BE STACKED Maximum of 24 units

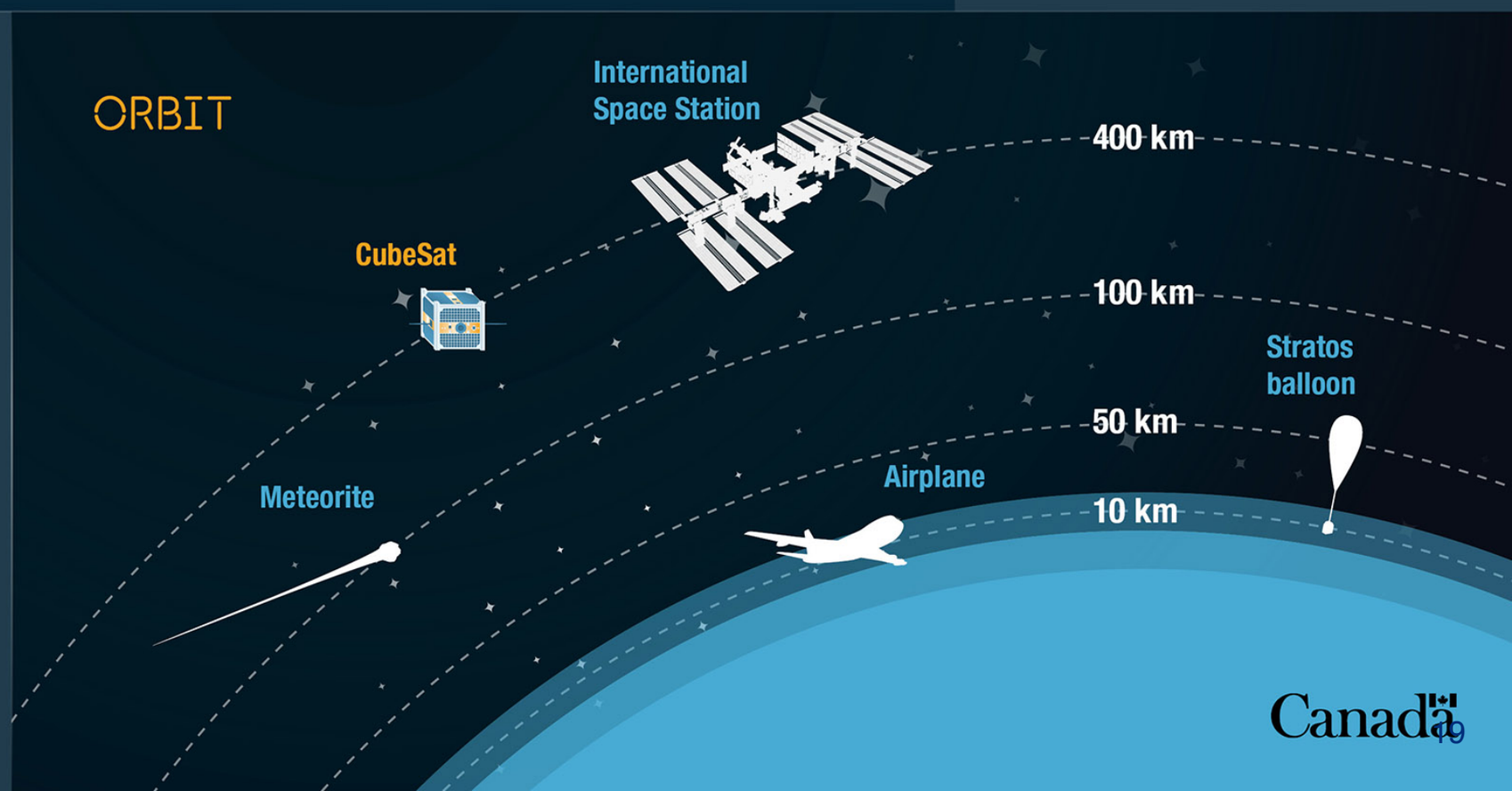
ADVANTAGES

- **BUILT RAPIDLY** (within 24 months)
- **SIMPLE TECHNOLOGY** purchased off-the-shelf
- **SIMPLE TO DESIGN**
- **NO SPACE DEBRIS** they burn up in the atmosphere upon reentry
- **LOW COST**

4 TYPES OF MISSIONS

- **Technology demonstration**
- **Scientific research**
- **Educational project**
- **Commercial**

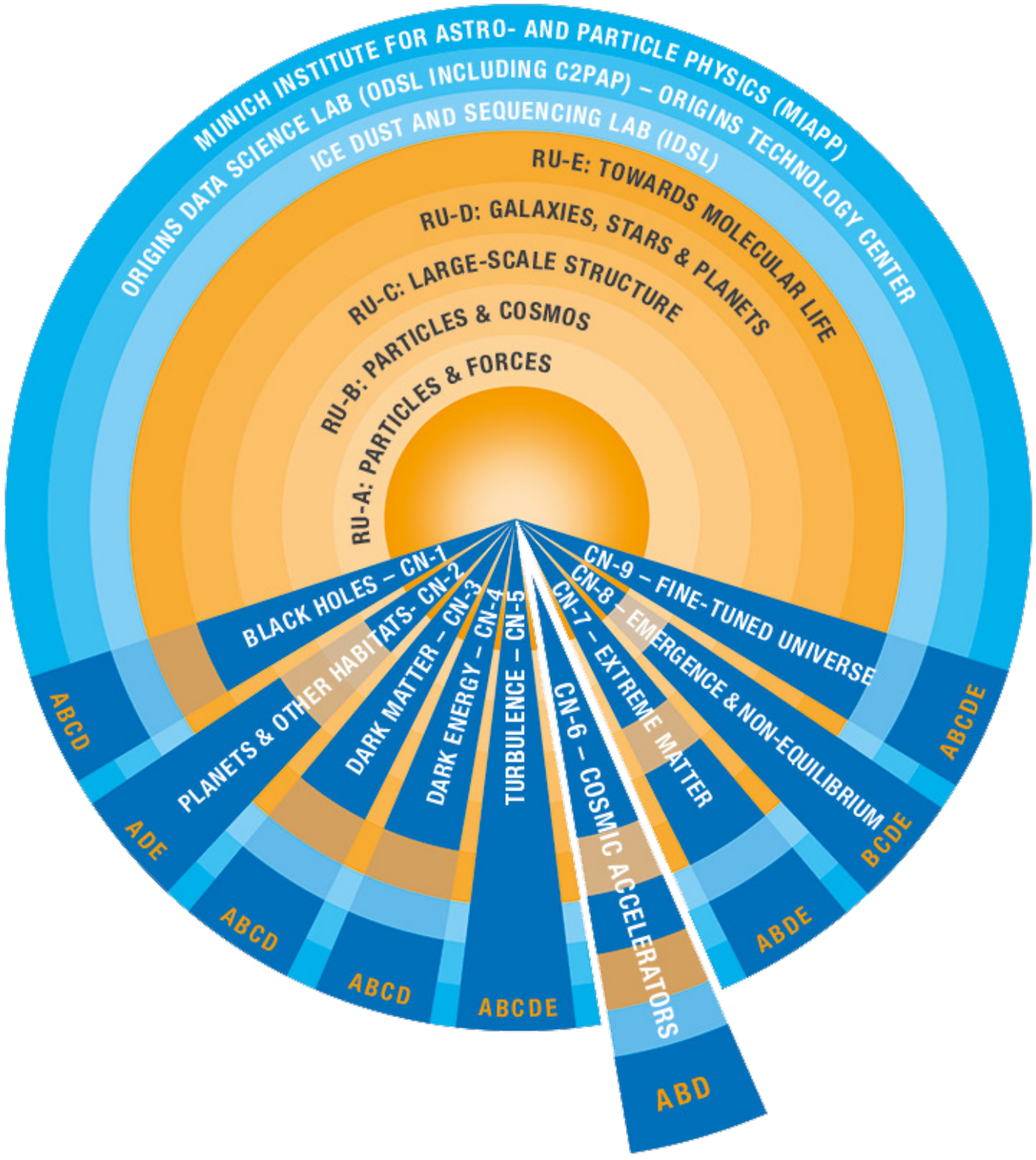
ORBIT



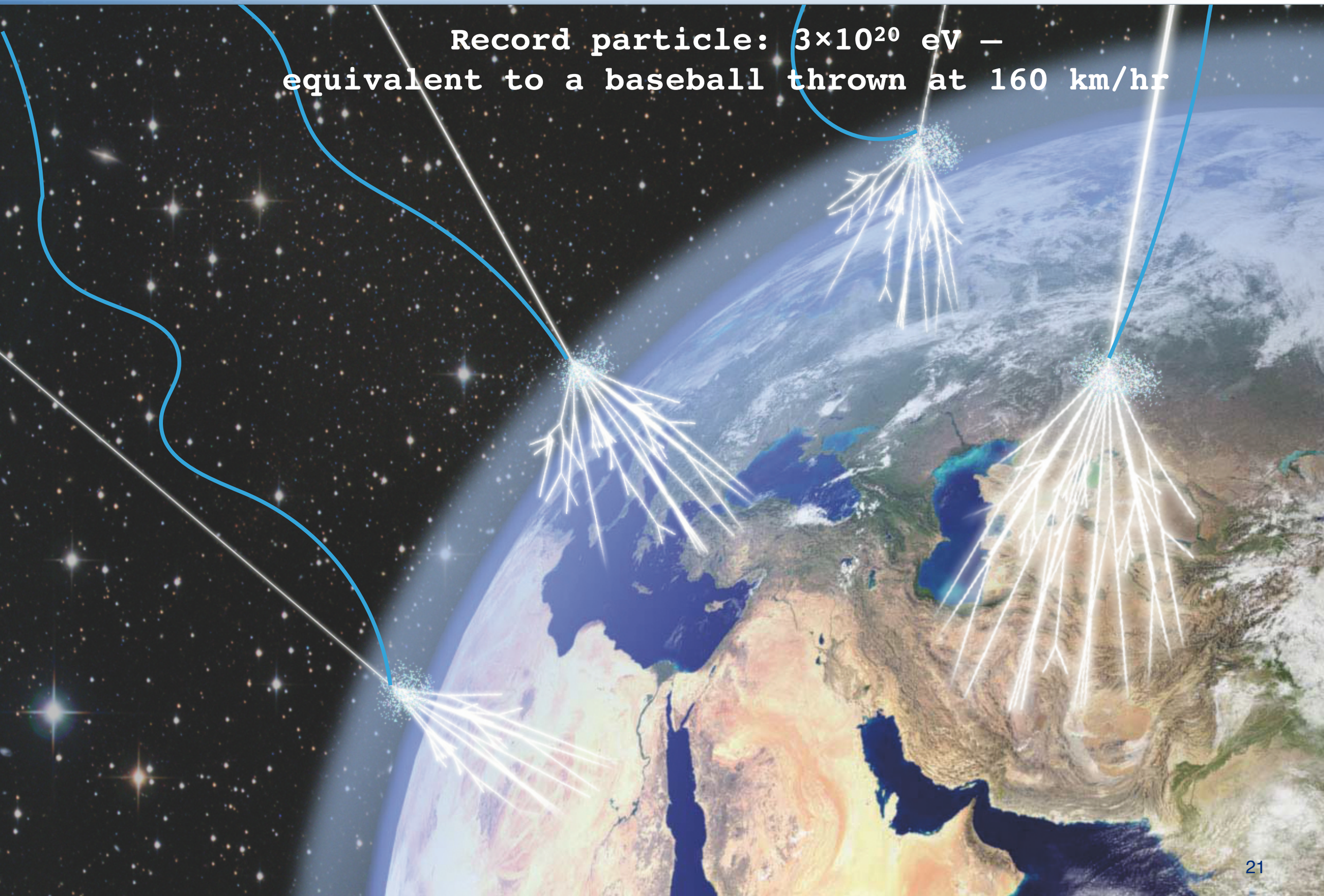
Canadian Space Agency | Agence spatiale canadienne

Canada

Connector 6: Cosmic Accelerators — 100-Year Old Puzzle

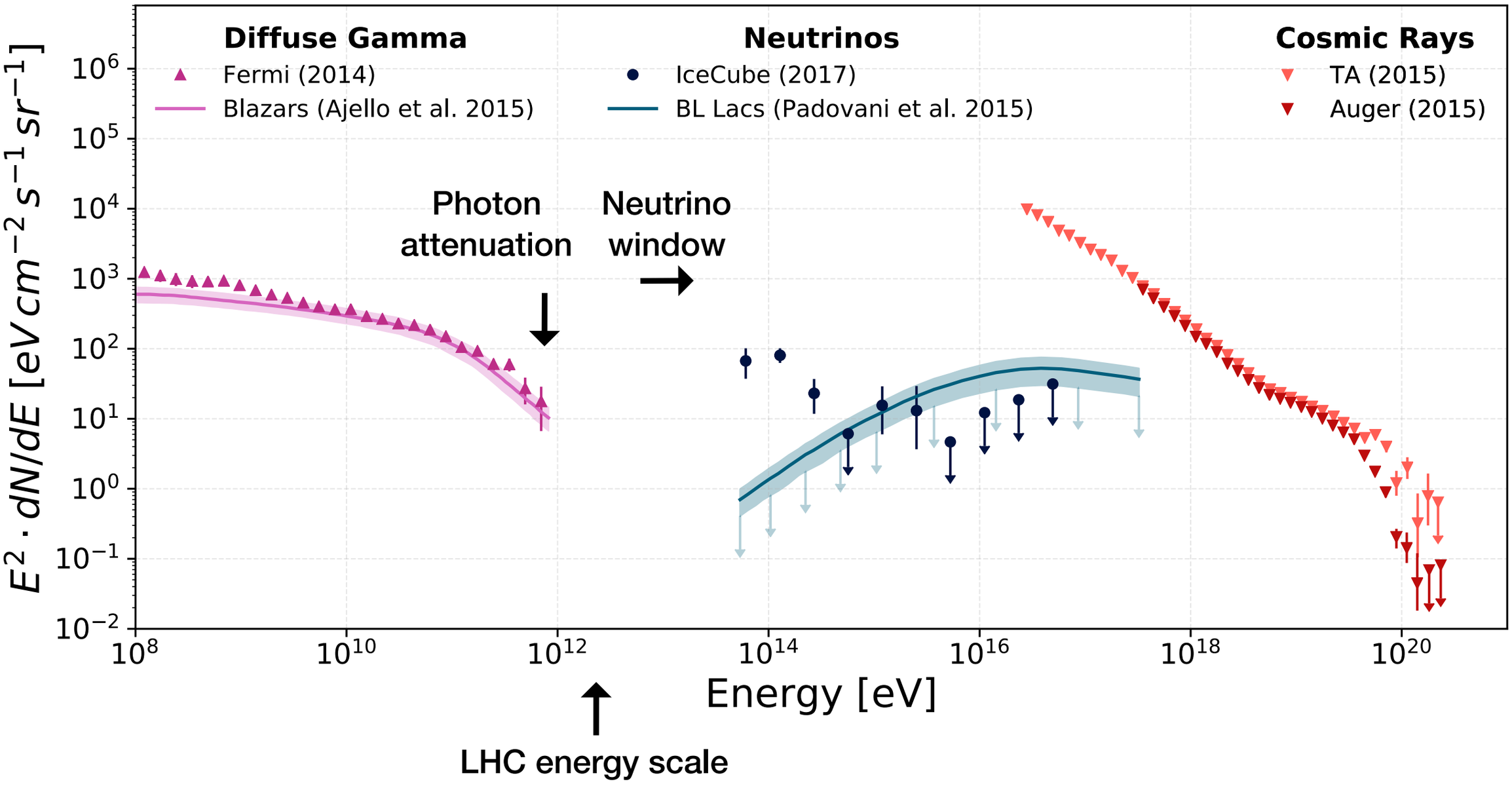


Connector 6: Cosmic Accelerators — 100-Year Old Puzzle



Connector 6: Multi-Messenger Astronomy

Blazars (Active Galactic Nuclei with jet pointing towards us)
populate the gamma-ray sky.
Are they also sources of cosmic particles?



CN-6.1: Multi-Messenger; *Resconi-TUM, Paneque-MPP, Padovani-ESO*

Find and Characterize Cosmic Sources

Improve Knowledge on Sources

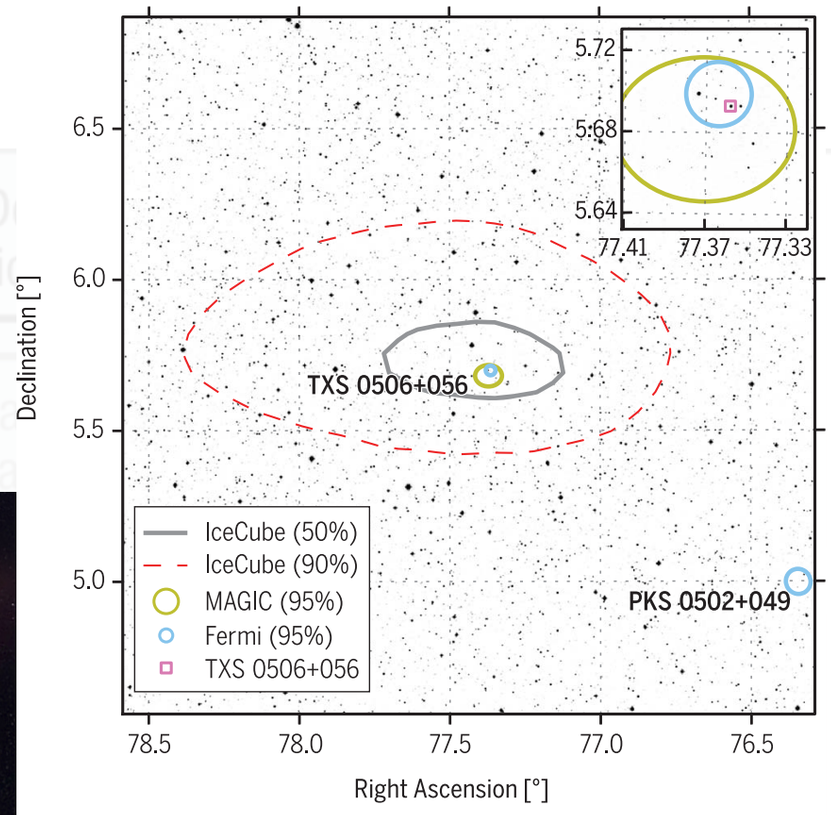
CN-6.2
Theoretical Model for Multi-Messenger Emission in Sources

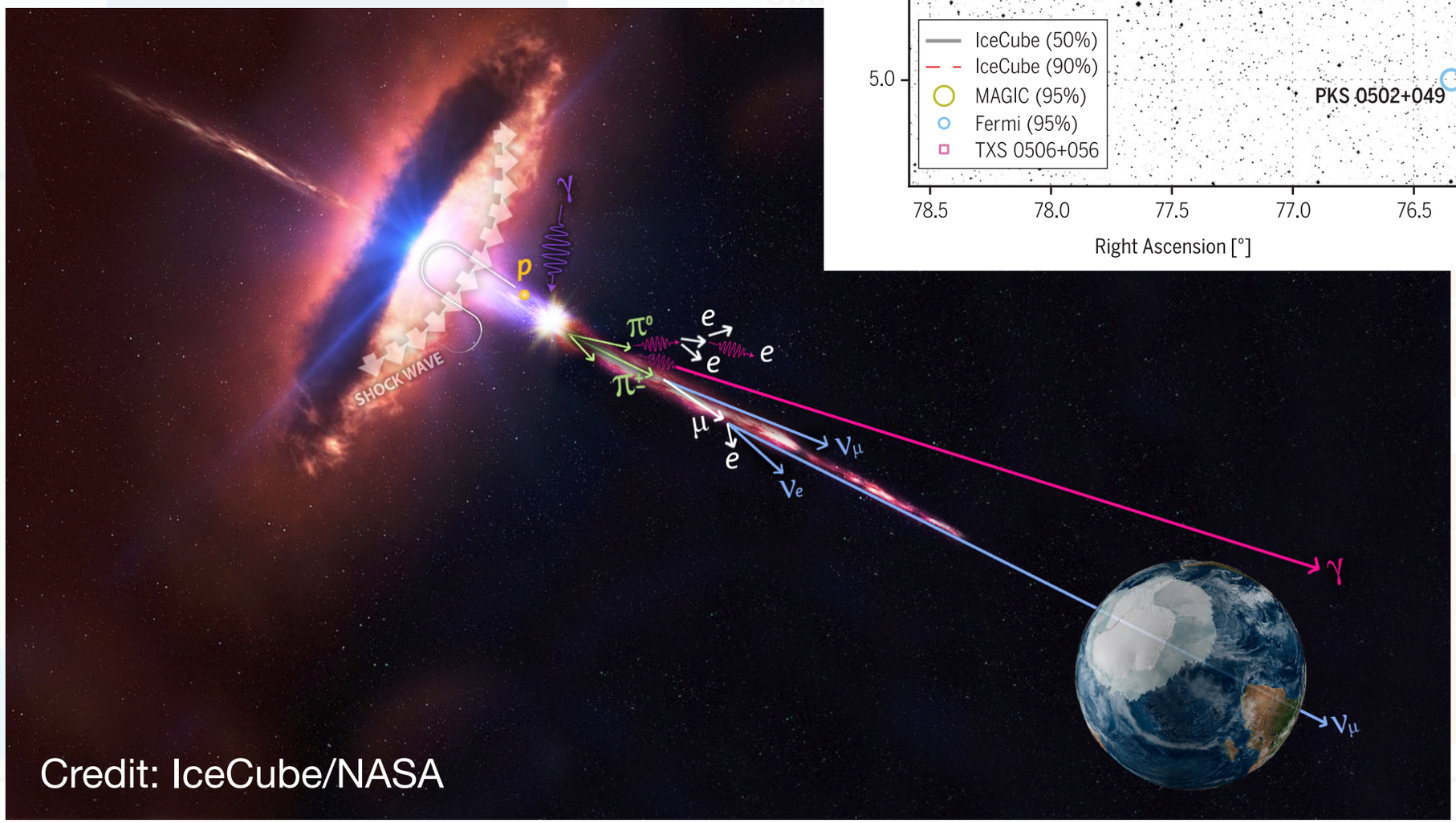
Limita… Spa…

CN-6.1
Multi-Messenger Astronomy

Improve Strategy of Observations and Instrumentation

INSTRUMENTS
(e.g. Fermi, MAGIC and IceCube)





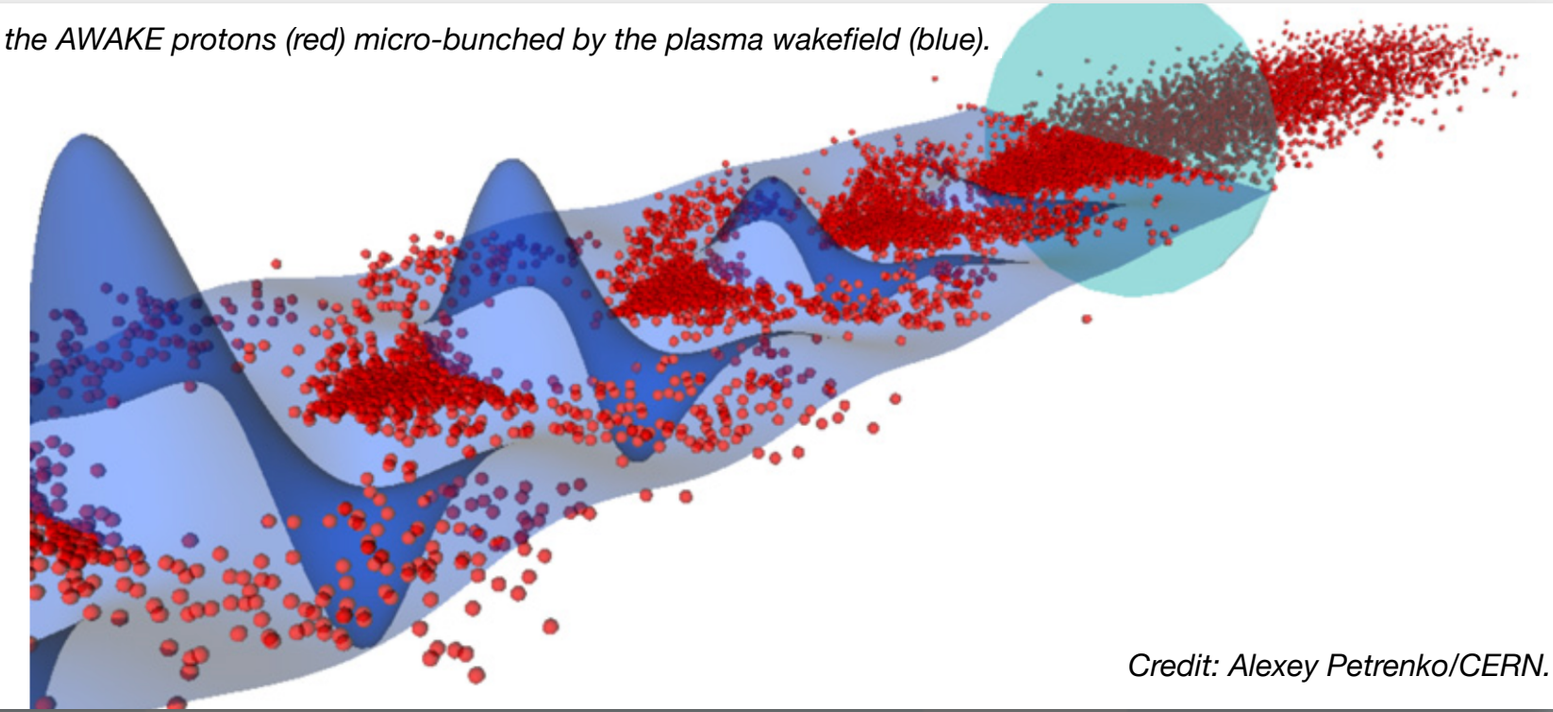
Credit: IceCube/NASA

IceCube et al. Science 361 (2018) 146

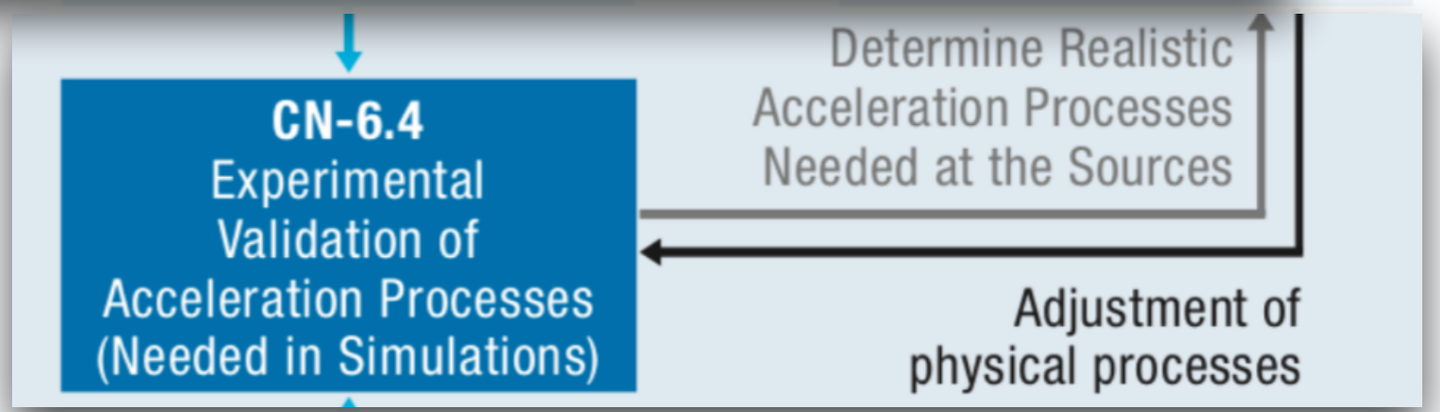
CN-6.4: Acceleration Mechanisms Validation: *Caldwell-MPP, Muggli-MPP*

AWAKE (CERN) = *proof-of-principle plasma wakefield accelerator experiment*

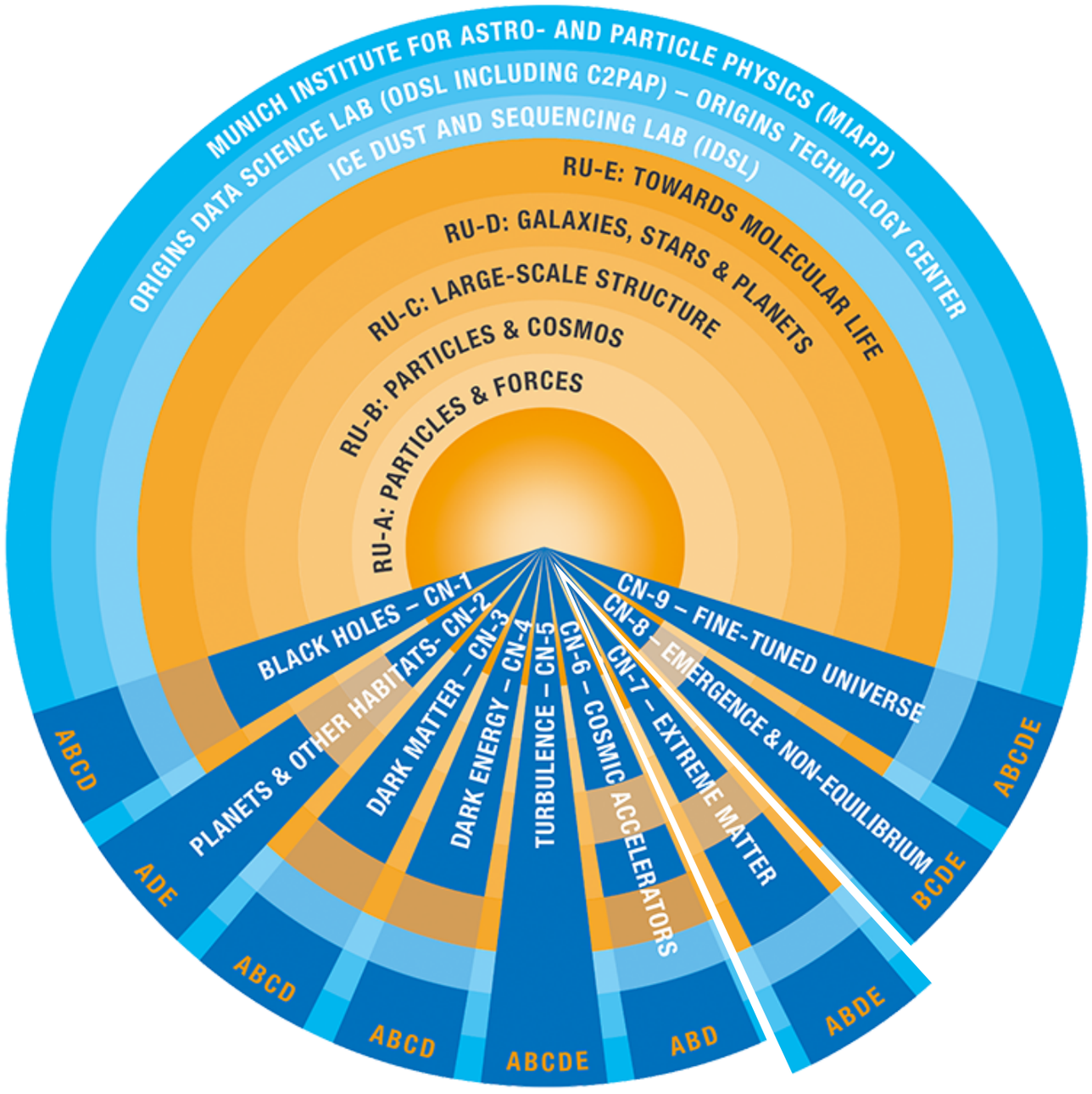
Artists impression of the AWAKE protons (red) micro-bunched by the plasma wakefield (blue).



Credit: Alexey Petrenko/CERN.

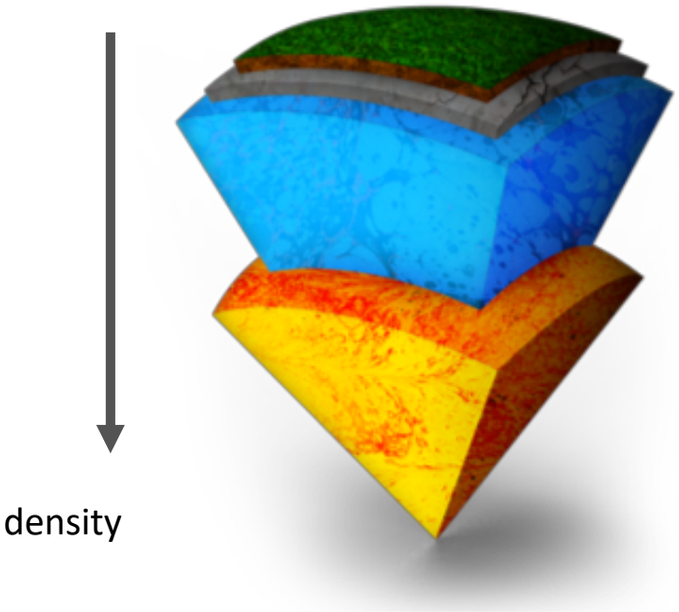


CN-7: Extreme Matter: *Brambilla-TUM, Fabbietti-TUM, Janka-MPA*



CN-7.1: Equation of state of Neutron Star Matter

What is inside a neutron star?

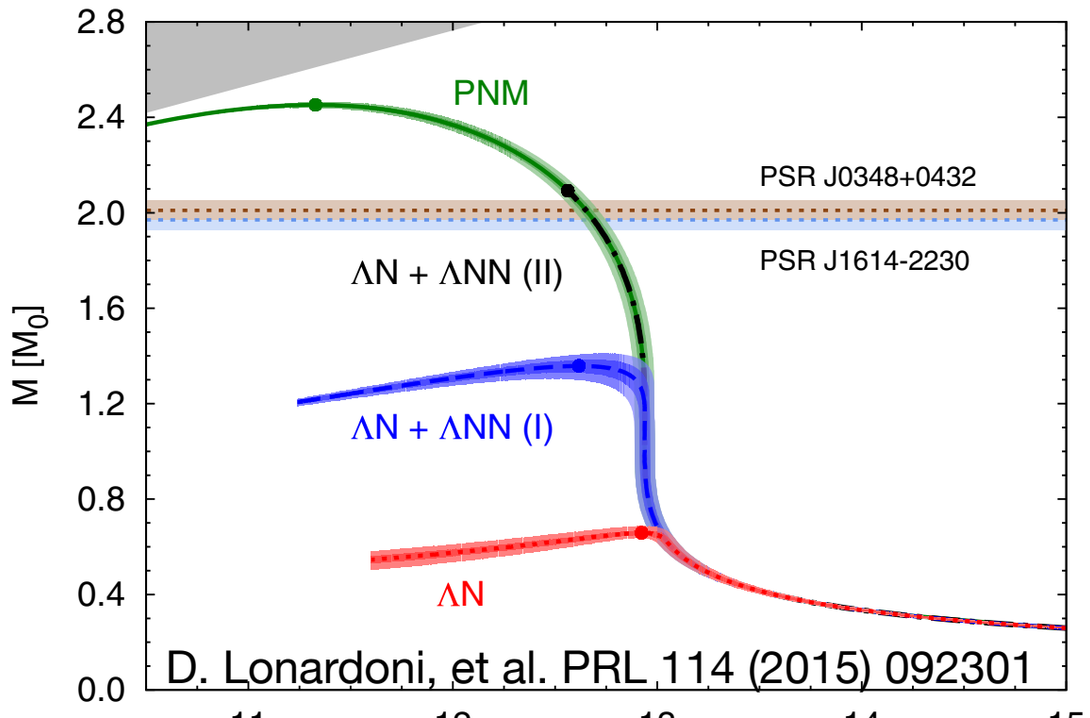


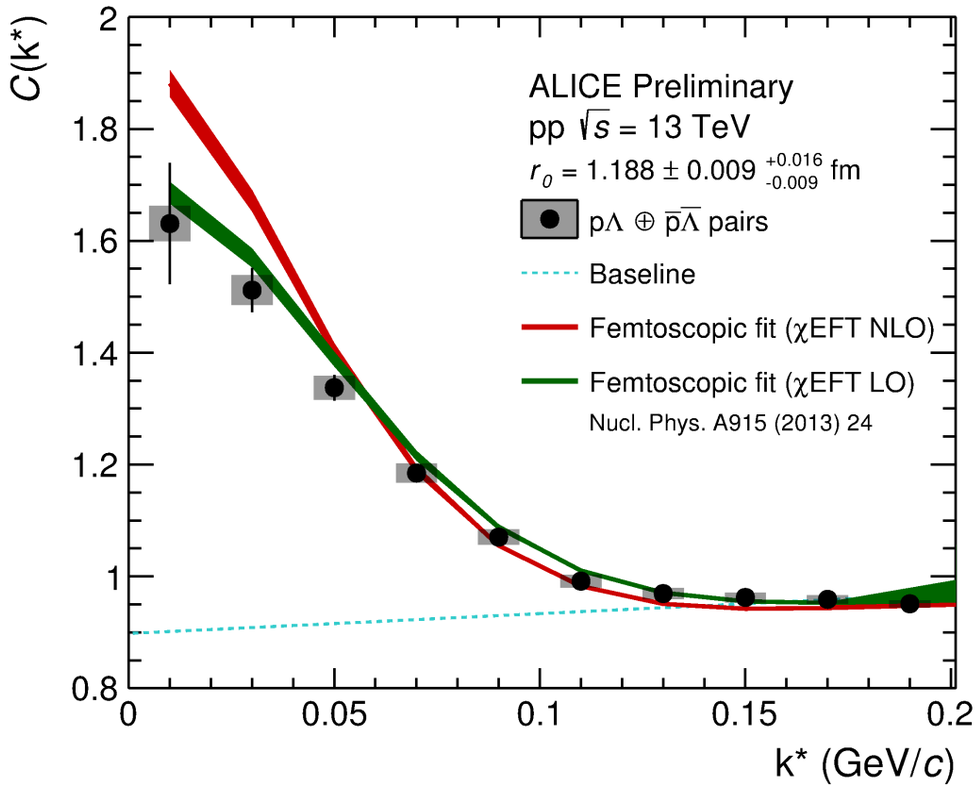
Outer Crust:
Ions, electrons Gas, Neutrons

Inner Core: ??
Neutrons ?? Protons ??
Hyperons ??
Quark Matter ??

EOS depends on particle interactions
→ study strange–nucleon and hyperon–nucleon interactions using femtoscopic methods in pp collisions in ALICE

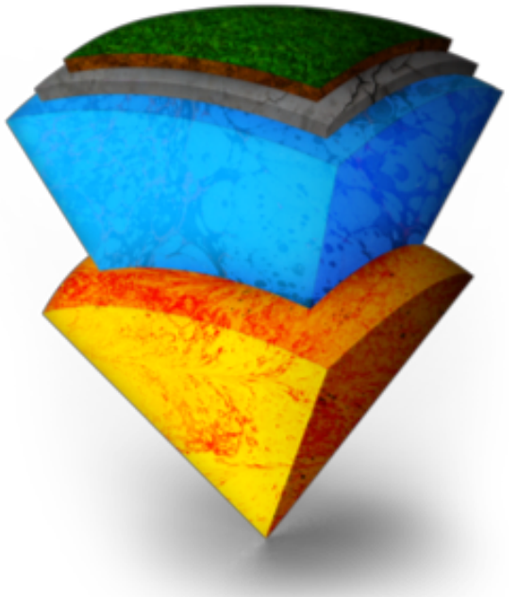
Radius-mass relation strongly depends on EOS





CN-7.1: Equation of state of Neutron Star Matter

What is inside a neutron star?



density

Outer Crust:
Ions, electrons Gas, Neutrons

Inner Core: ??
Neutrons ?? Protons ??
Hyperons ??
Quark Matter ??

EOS depends on particle interactions
→ study strange–nucleon and hyperon–nucleon interactions using femtoscopic methods in pp collisions in ALICE

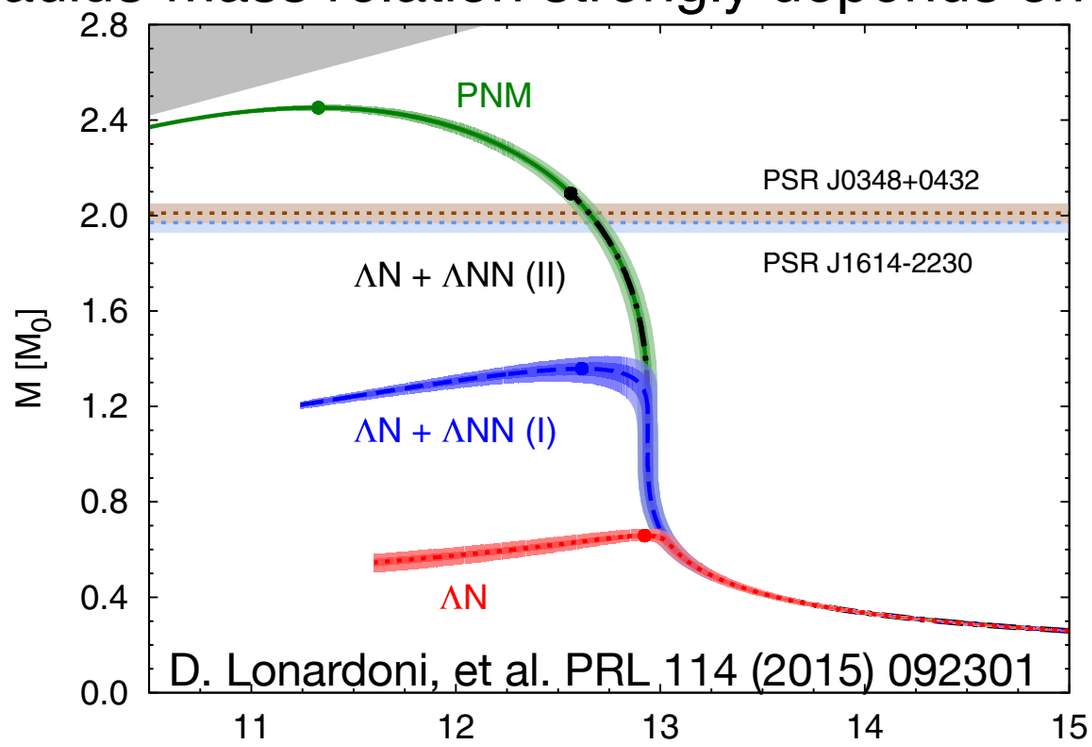
connect

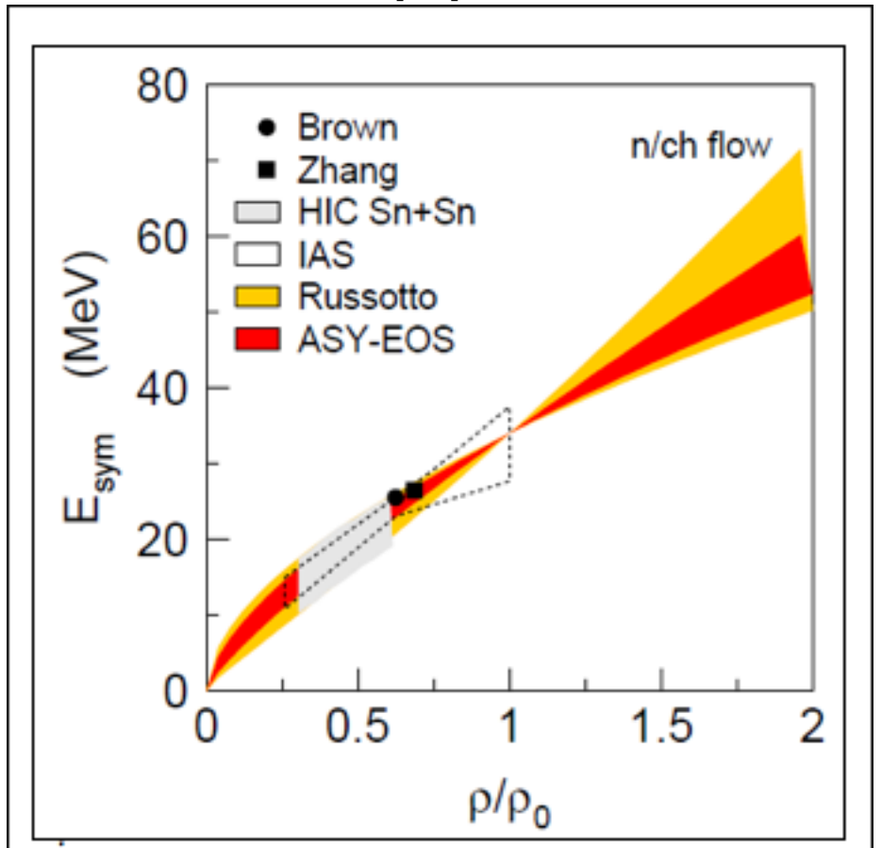
+boundary conditions from Super Novae

Neutron stars: extreme isospin asymmetry
→ large effects from symmetry energy

Study in few-GeV heavy-ion reactions with HADES and R3B based on measured charged pion and kaon ratios

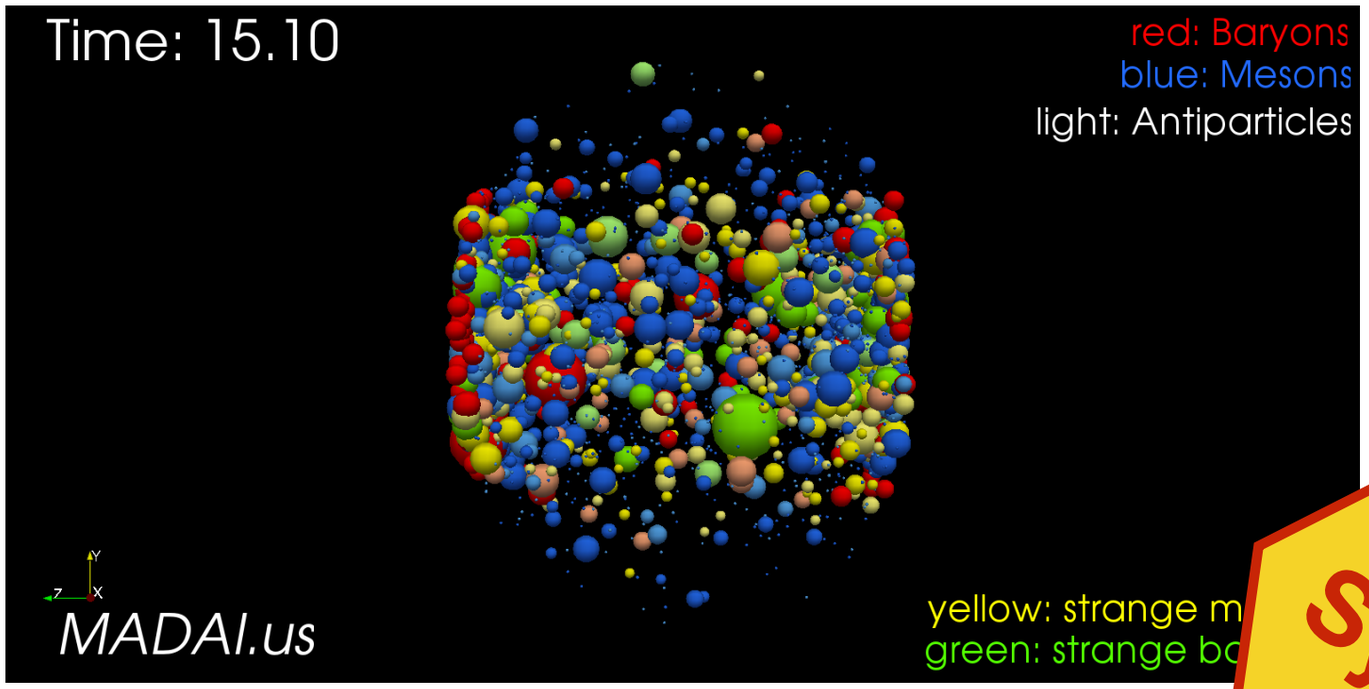
Radius-mass relation strongly depends on EOS





Horrowitz et al. JPhG 41 (2014)
Brown: arXiv:1308.3664
Zhang: PLB 726 (2013)

CN-7.4: Monte Carlo Applications and Development Center

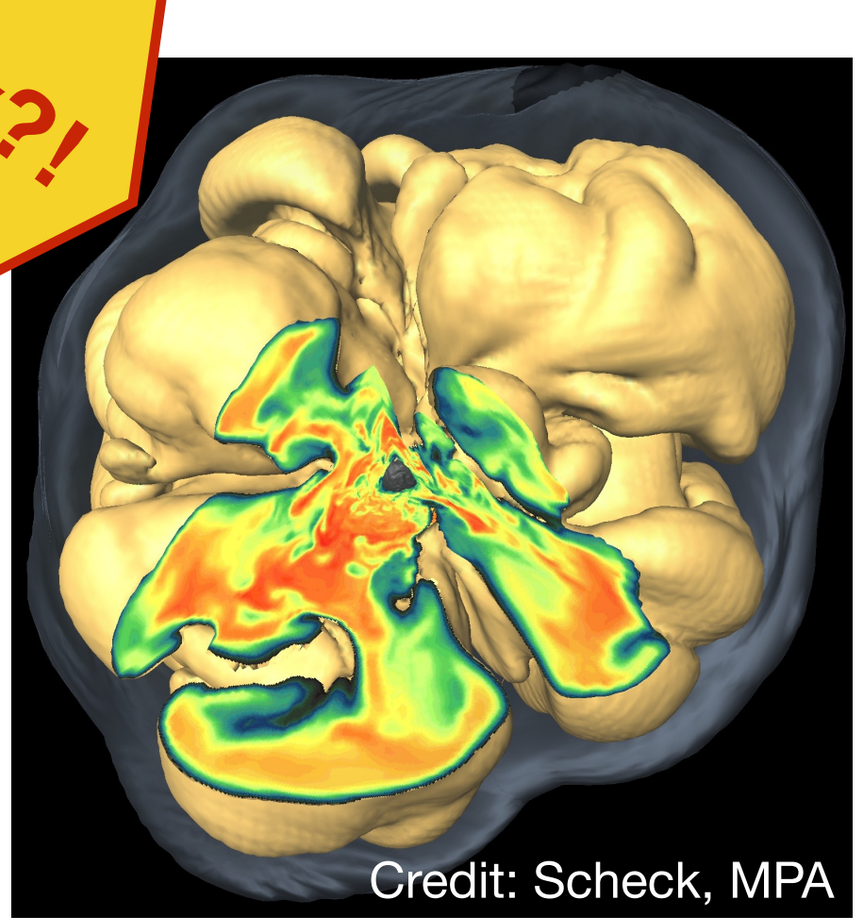


Synergy?!

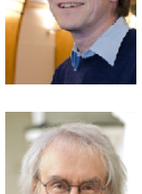
Bring Monte Carlo methods

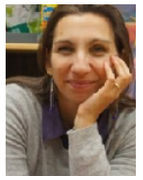
from transport simulations of heavy ion collisions (e.g. UrQMD)

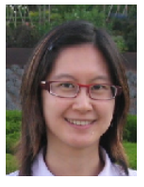
to simulations of Super Novae explosions

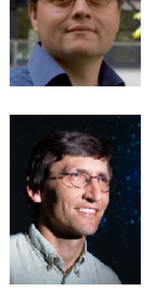
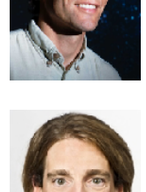


Origins Excellence Cluster



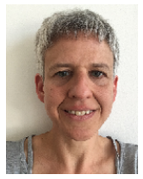




Particle physics

Beneke

Brambilla

Brunner

Dvali (MPP)

Fabbietti

Fierlinger

Lüst (MPP)

Paul

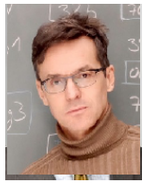
Schaile

Weiler

Astro-particle physics

Caldwell MPP

Ibarra

Resconi (MPP)

Schönert (MPP)

Astro-physics

Burkert (MPE)

Ercolano

Janka MPA

Komatsu MPA

Mohr (MPE)

Weller (MPE)

25 PIs
85 AIs

Astro-biophysics

Braun

Caselli MPE

Frey

Gerland

Trapp