Astroparticle physics in Slovenia

Samo Stanič

RECFA visit to Slovenia, Ljubljana, April 5th 2019

Center for astrophysics and cosmology at the University of Nova Gorica

Main research activities:

- **Studies of ultra-high energy cosmic rays** (Pierre Auger Collaboration)
- **Dark matter studies** (Fermi LAT, CTA)
- **Studies of high-energy astrophysical transients** (Gaia, LSST, others)

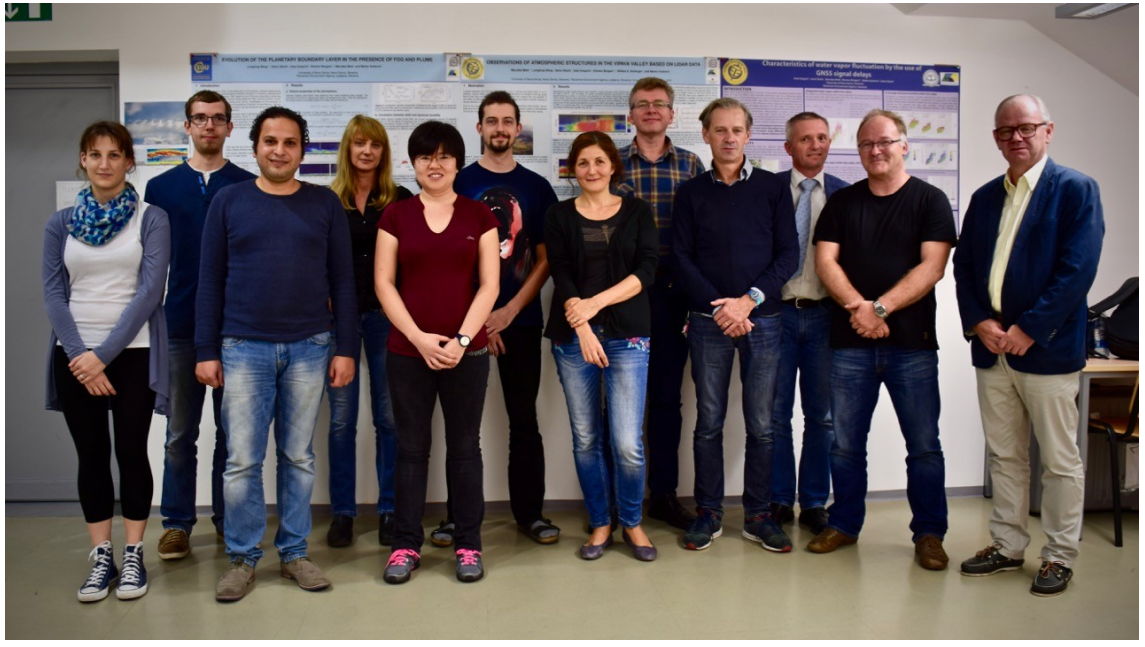
Center for astrophysics and cosmology

Research team
7 senior researchers
1 postdoc
7 PhD students

Funding
- Stable long-term funding of core activities provided by Slovenian Research Agency
- Additional funding from 3 national and 2 EU research projects

Awards
- Apple of inspiration presidential award to T. Petrushevska and G. Zaharijas in 2019

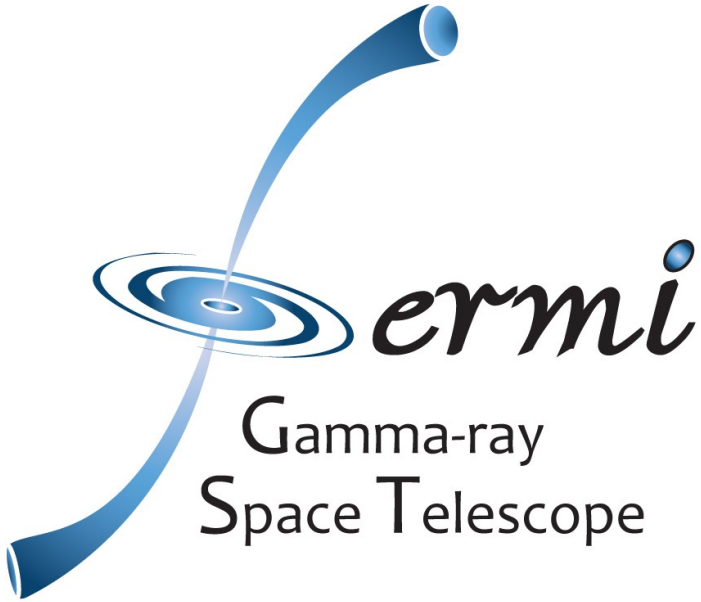
Collaborations
- Pierre Auger
- CTA
- LSST
- Fermi LAT
- Liverpool
- Gaia
- ...

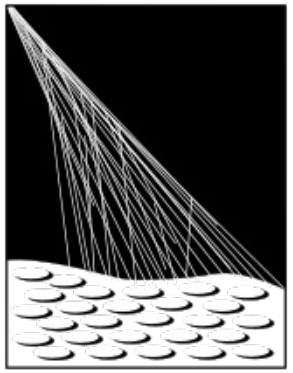


Education

Study of Physics and Astrophysics at UNG

- research excellence oriented program for physics and astrophysics at all levels
- possibility to pursue research in international research collaborations and observatories





PIERRE
AUGER
OBSERVATORY

LIVERPOOL
JOHN MOORES
UNIVERSITY

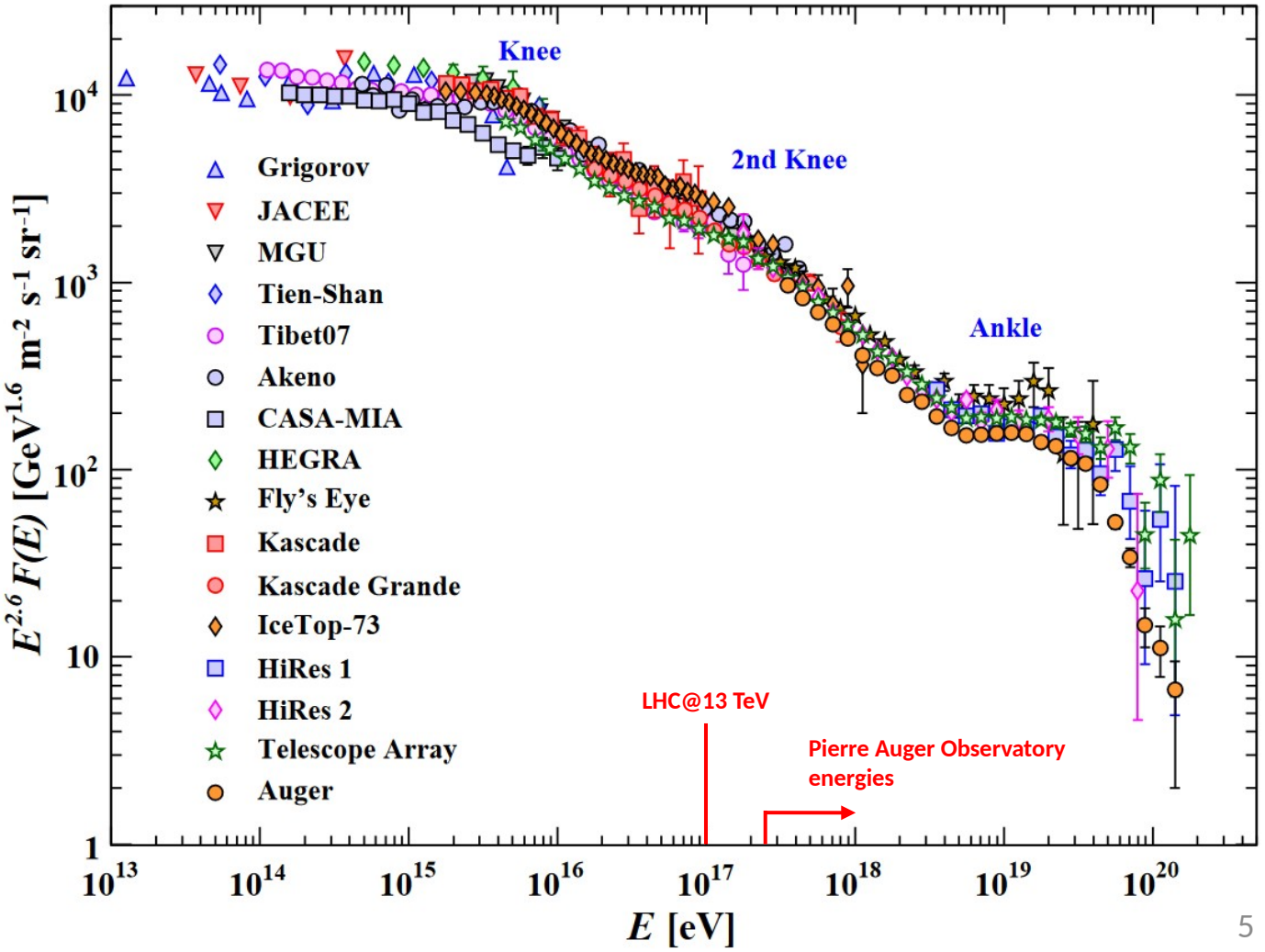
gaia

Studies of ultra-high energy cosmic rays

- Cosmic rays (CR): Charged particles arriving to Earth from extraterrestrial sources
- Ultra-high energy cosmic rays (UHECR): CR with energies above 10^{18} eV
- Energy spectrum features:
  - Knees – Exhaustion of galactic sources of CR
  - Ankle – Domination of extragalactic sources or GZK effect
  - GZK effect – Abrupt drop at the highest energies, scattering of protons and neutrons on cosmic microwave background (CMB) photons

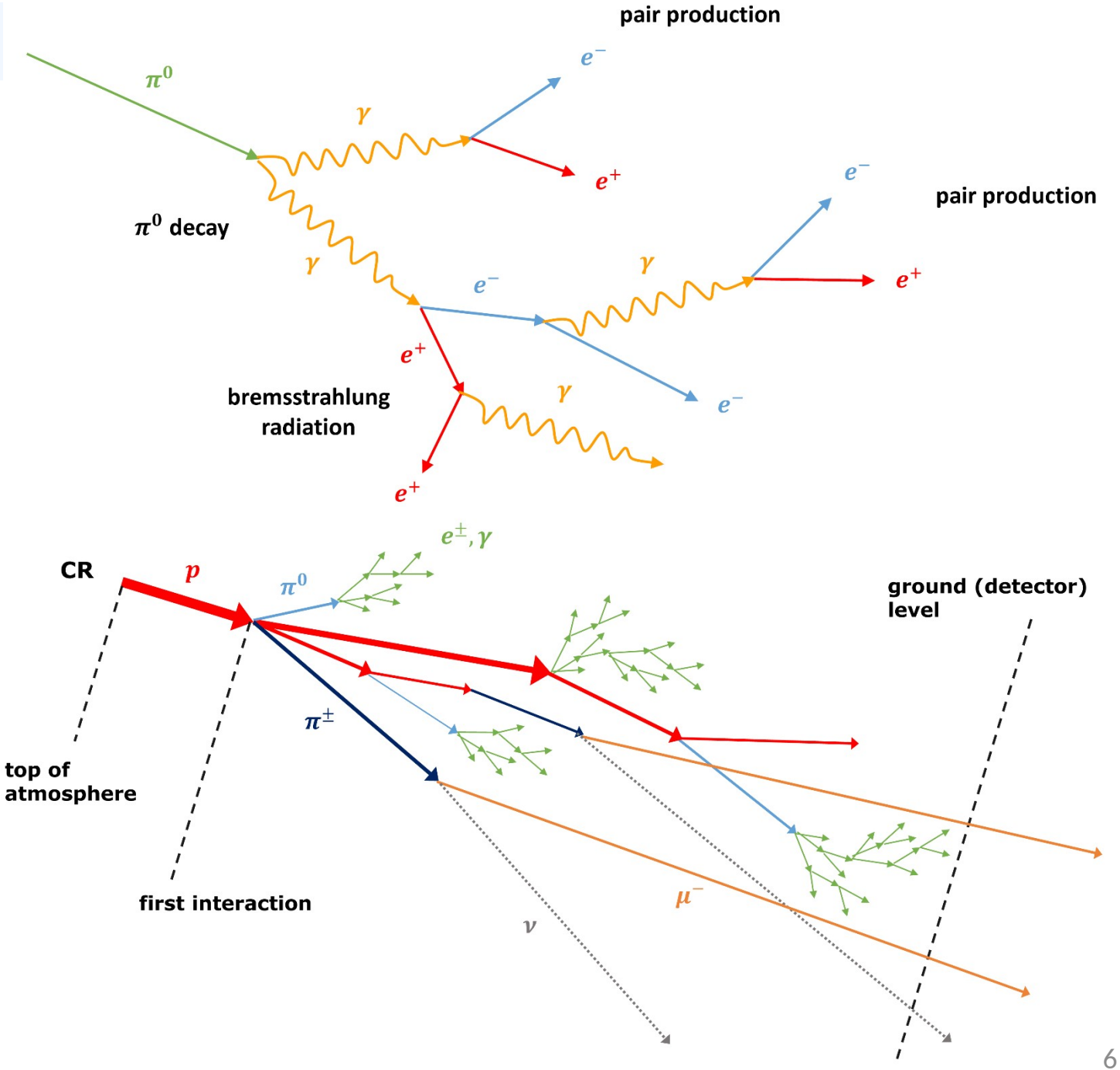
$$p + \gamma_{CMB} \longrightarrow n + \pi^{+}$$

$$n + \gamma_{CMB} \longrightarrow p + \pi^{-}$$



Extensive air showers

- Extensive air shower (EAS): Cascade of secondary particles after interaction of UHECR and atmospheric nuclei
- Main EAS parts:
  - Electromagnetic part (electrons, positrons, photons)
  - Hadronic part (hadrons and mesons)
  - Weakly interacting shower remnants (muons and neutrinos)



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  - Electromagnetic part (electrons, positrons, photons)
  - Hadronic part (hadrons and mesons)
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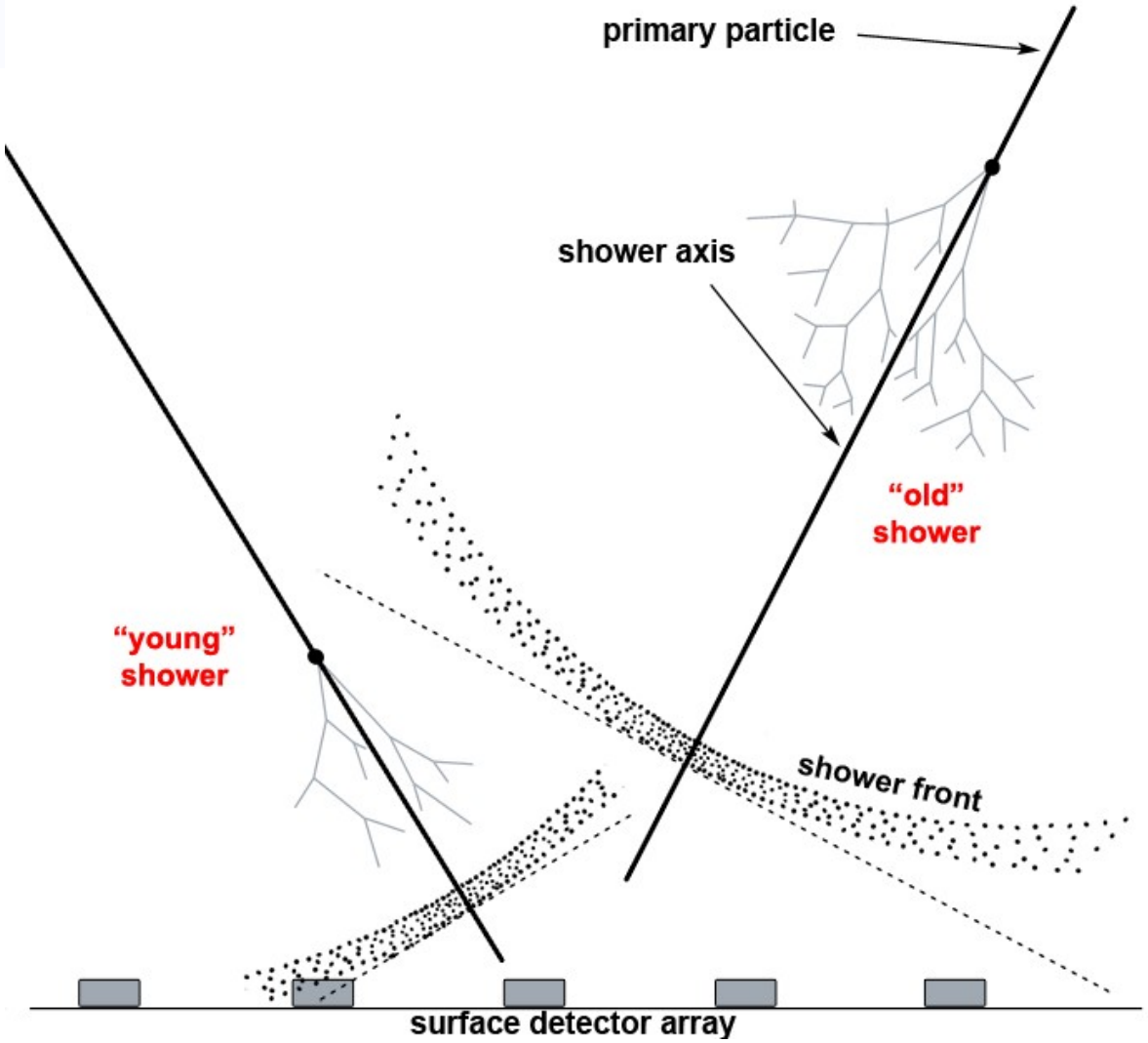
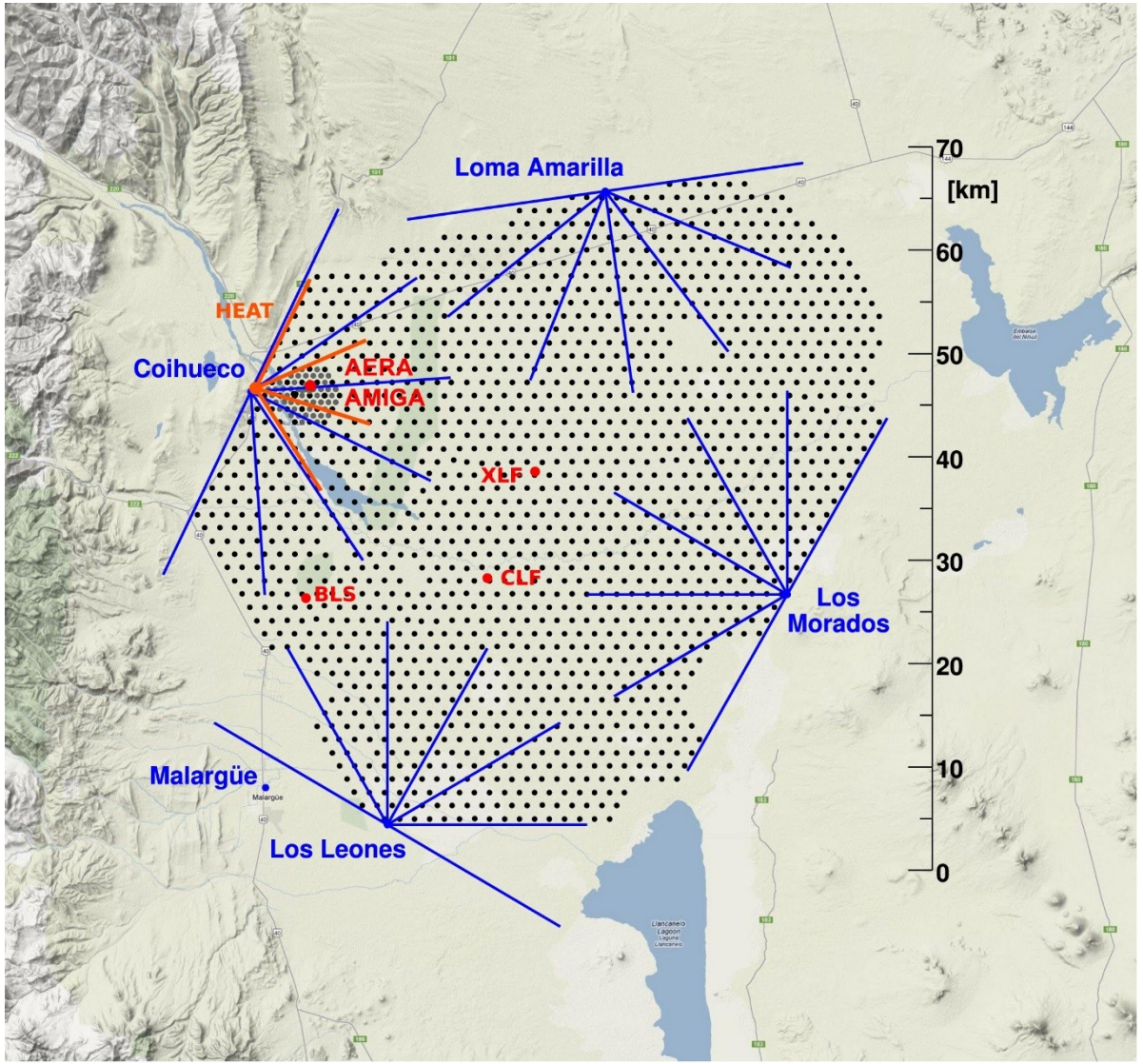
- Primary particle determines the evolution of the EAS:
  - EAS develops higher in the atmosphere for heavier particles (larger interaction cross section)
  - EAS develops lower in the atmosphere for lighter and weakly interacting particles



Pierre Auger Observatory

- The largest observatory for UHECR in the Pampa Amarilla, Argentina
- Consists of a hybrid detection system:
  - Surface detector (SD):
    1600 water Cherenkov stations, area of 3000 km^2, 1.5 km grid separation
  - Fluorescence detector (FD):
    24 fluorescence telescopes, 4 detector buildings, each building has a lidar weather monitoring system
- Low energy extensions for SD and FD reduce energy threshold from 10^{18} eV to $10^{17.2}$ eV
- AugerPrime upgrade (separation of EM and muonic shower parts)



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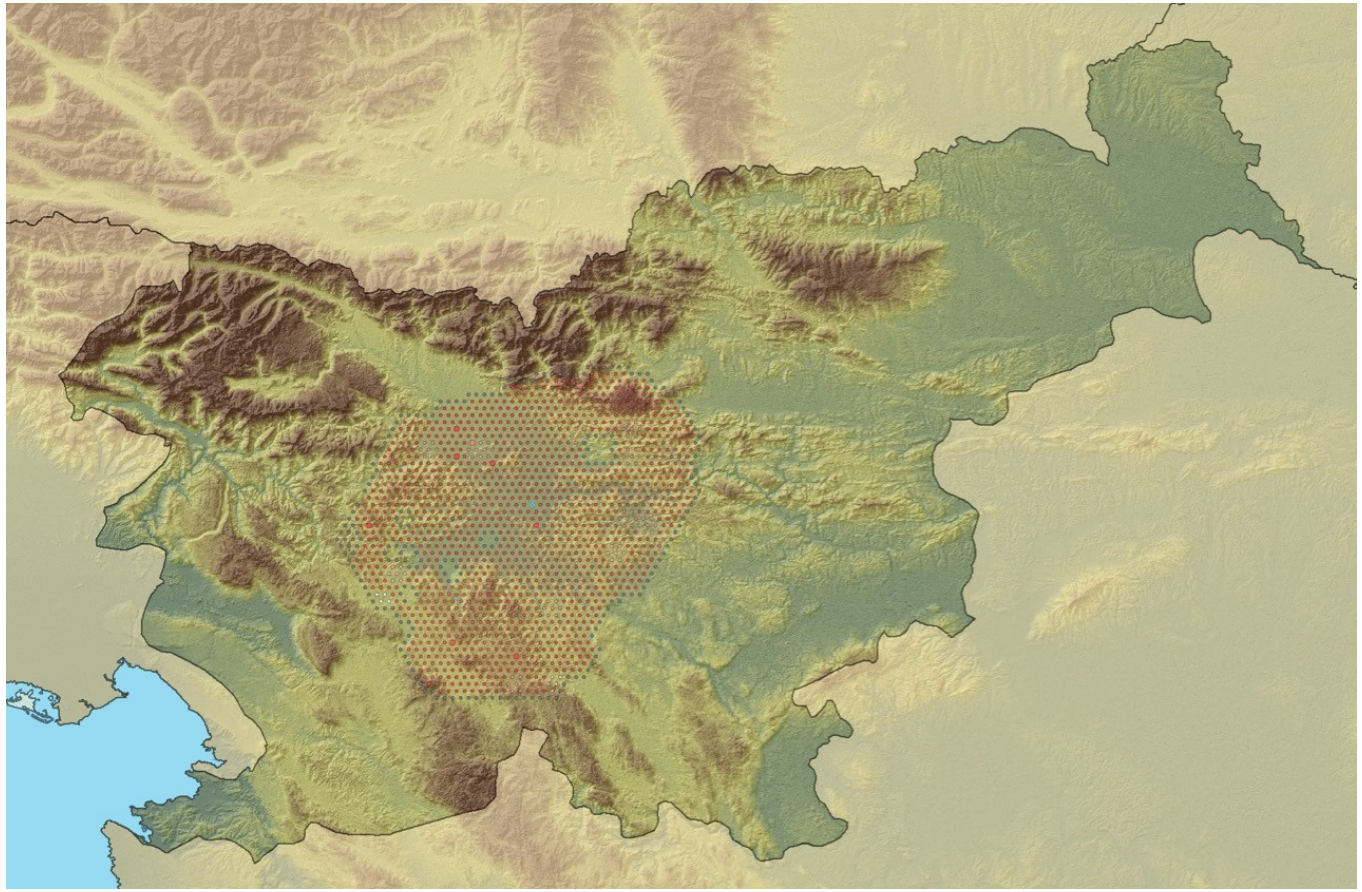
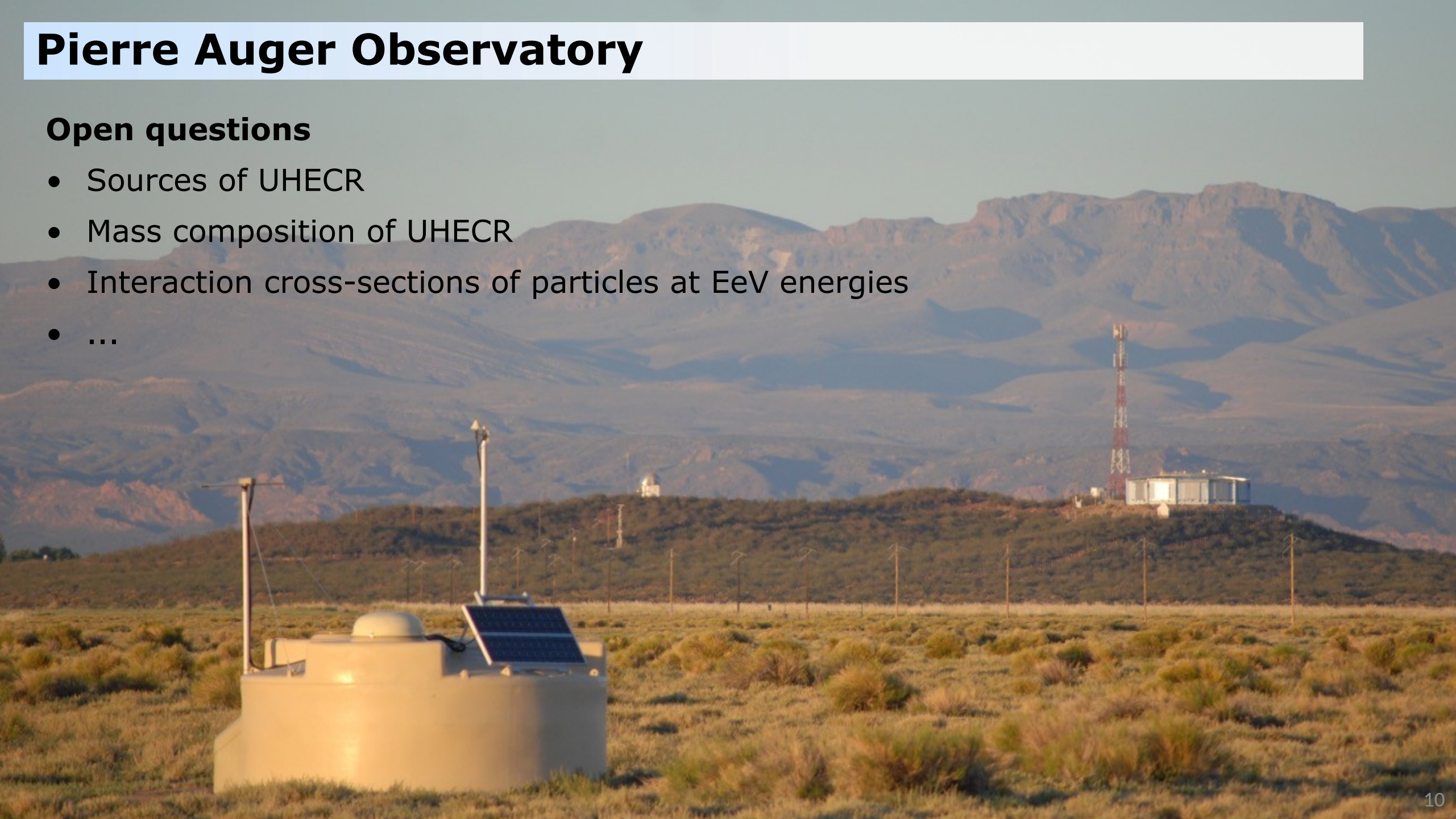


Pierre Auger Observatory

Open questions

- Sources of UHECR
- Mass composition of UHECR
- Interaction cross-sections of particles at EeV energies
- ...



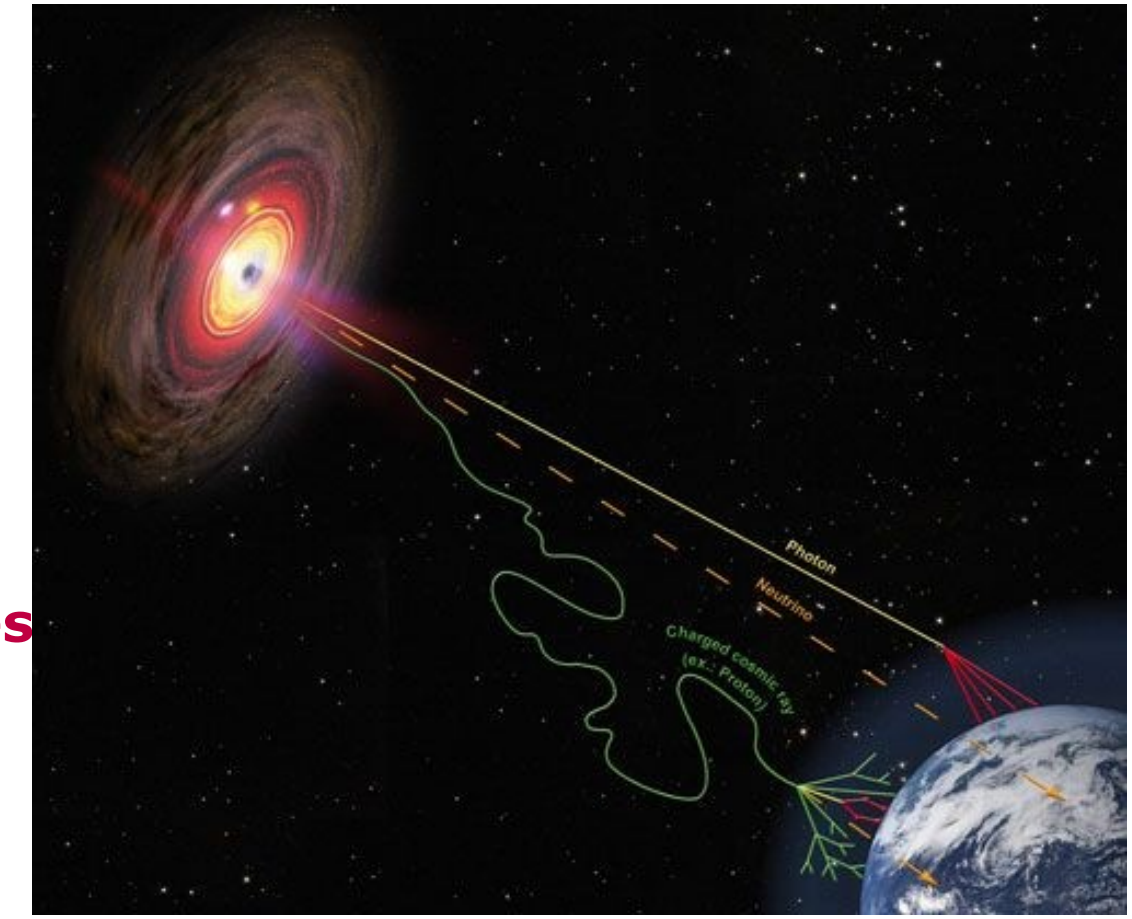
Mass composition of UHECR

- Mass composition studies: Determine mass and charge of UHECR
- Motivations for performing mass composition studies:
  - **Discrimination between hadronic interaction models**
  - **Backtracking of light UHECR with**
  - **Energies > 10^{19} eV to their sources**

$$\Delta\alpha = \frac{Zec}{E}\int_0^L B(x)\sin(\varphi(x))\,dx$$

  - **Acceleration processes that produce UHECR**
  - **Cosmic magnetic field strength**
  - **Identifying energy spectrum features**
- Main drawback: Mass composition highly dependent on hadronic interaction models (extrapolated cross-sections)

(Research topic at CAC)

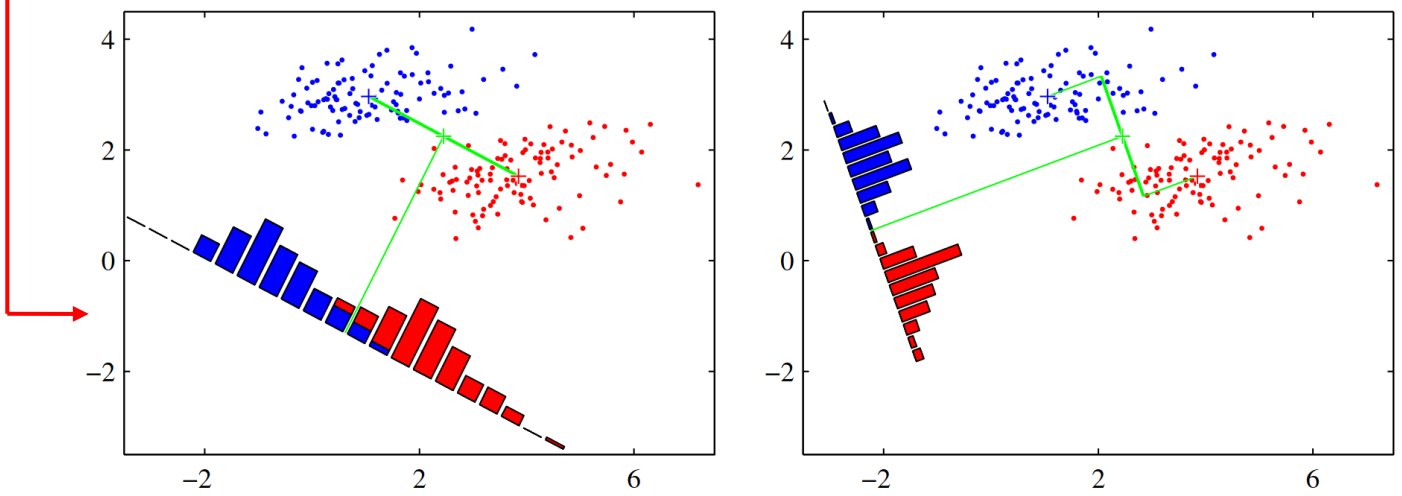


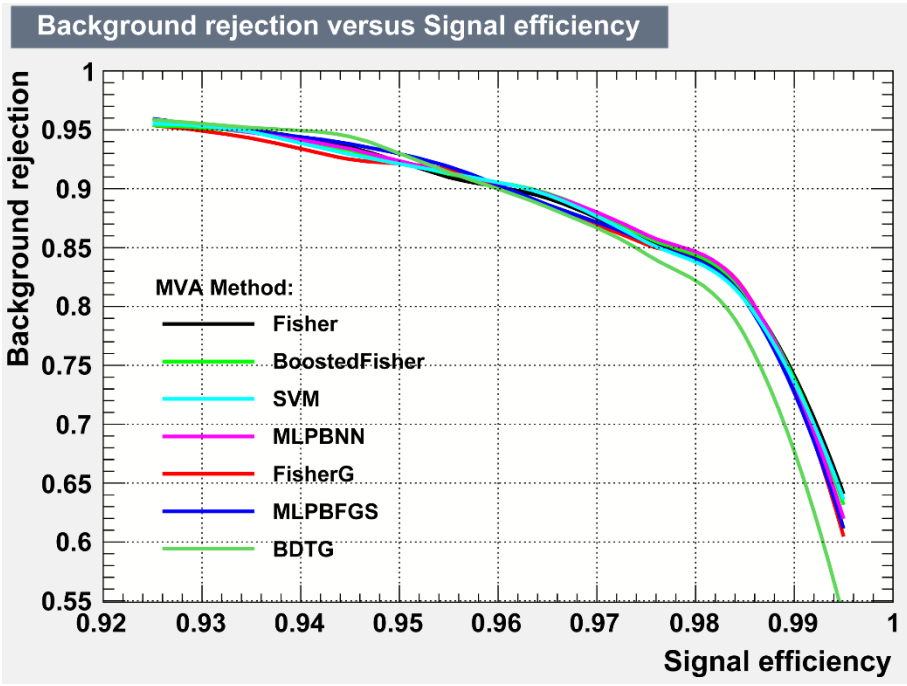
https://steemit.com/science/@shehzad/understanding-cosmic-rays-in-a-simple-way

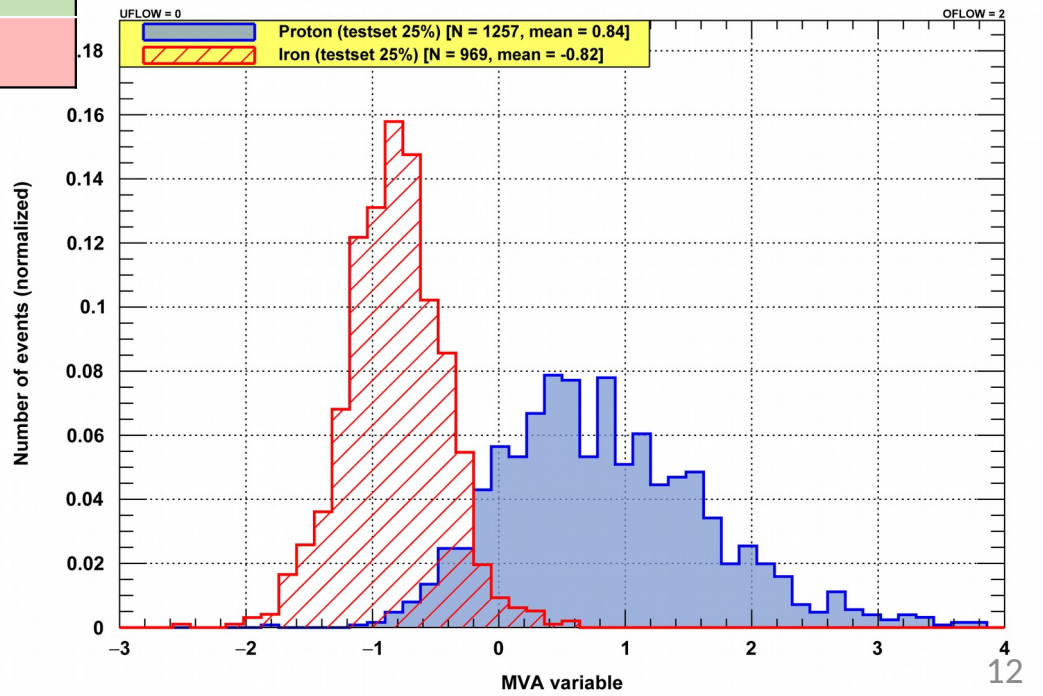
Multivariate analysis

- Combine mass composition sensitive variables to gain optimal separation between different elements
- MVA methods determine the separation strength

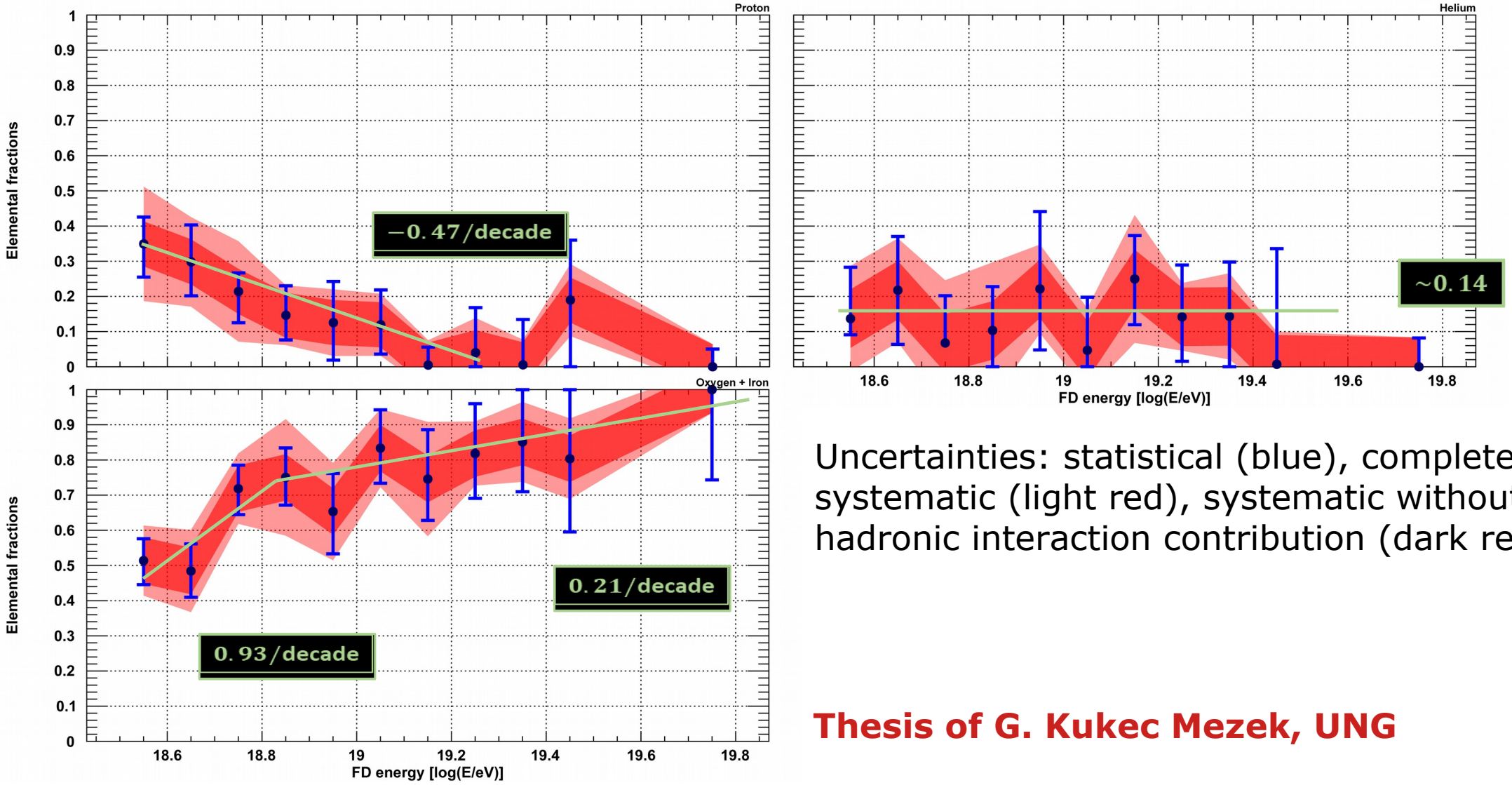
MVA method	No or linear correlations	Non-linear correlations	Training speed
Boosted decision trees (BDT)	Fair	Good	Fast
Multi-layer perceptrons (ANN)	Good	Good	Slow
Fisher linear discriminants	Good	Bad	Fast
Support vector machines (SVM)	Fair	Good	Slow







MVA mass compostion results (preliminary)

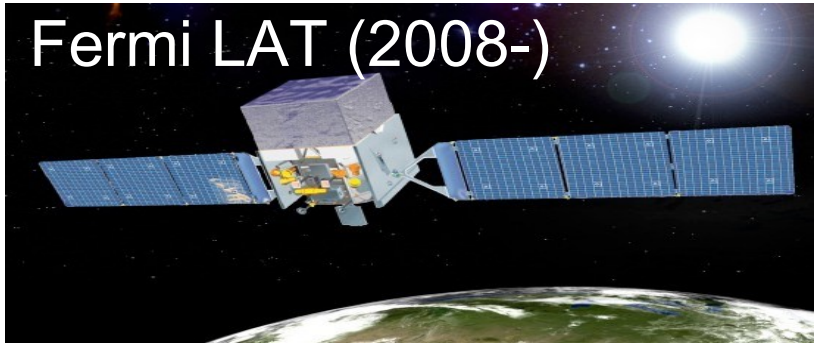


Uncertainties: statistical (blue), complete systematic (light red), systematic without hadronic interaction contribution (dark red)

Thesis of G. Kukec Mezek, UNG

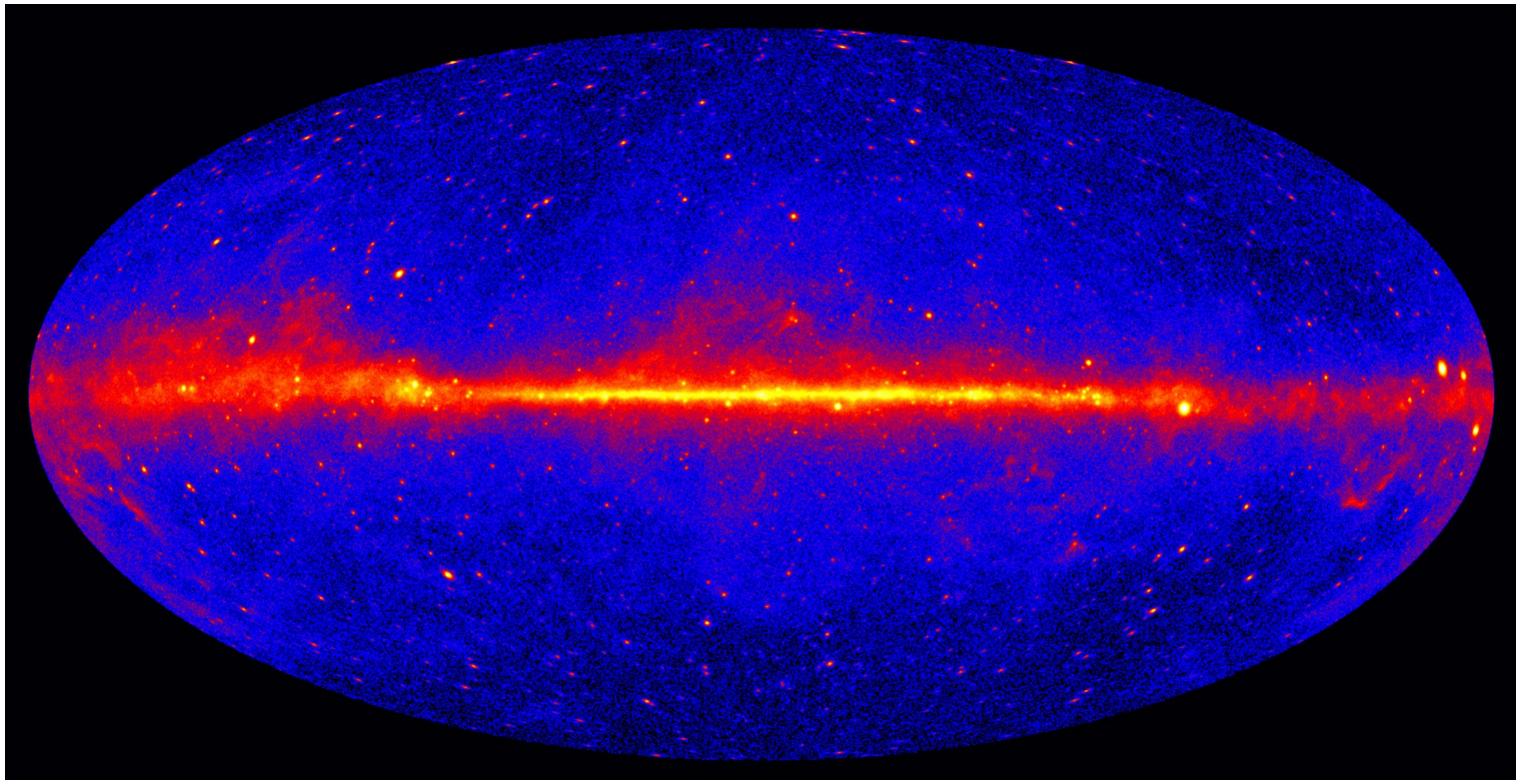
Gamma rays as a probe of dark matter particle properties

About 85% of the matter in the universe may be made up of hypothetical form of matter called **Dark Matter**



- If dark matter particles interact even weakly with standard particles, their signals could be observed, particular from regions with high dark matter density (e.g., the **centre of our galaxy**)

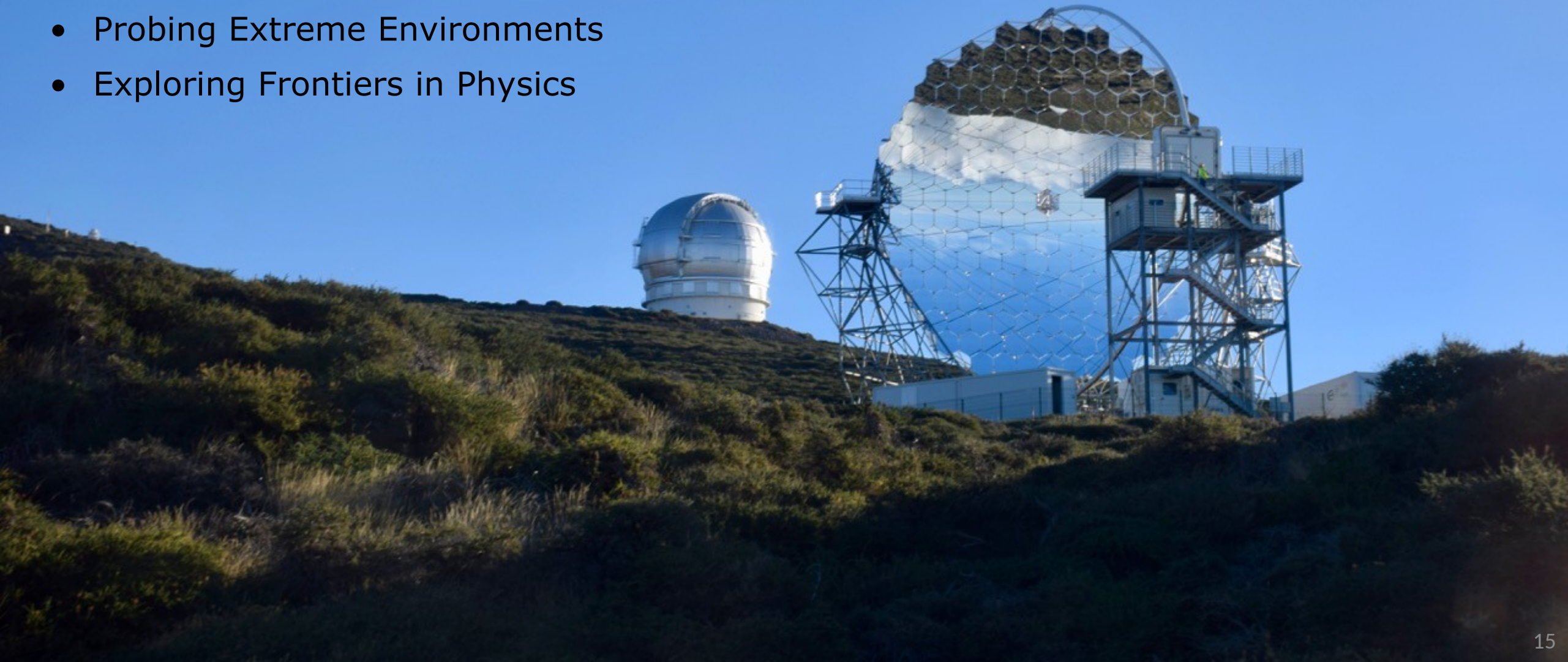
- pairs of dark matter particles could annihilate to produce **gamma rays**



Cherenkov Telescope Array

Next Generation Gamma-Ray Astronomy

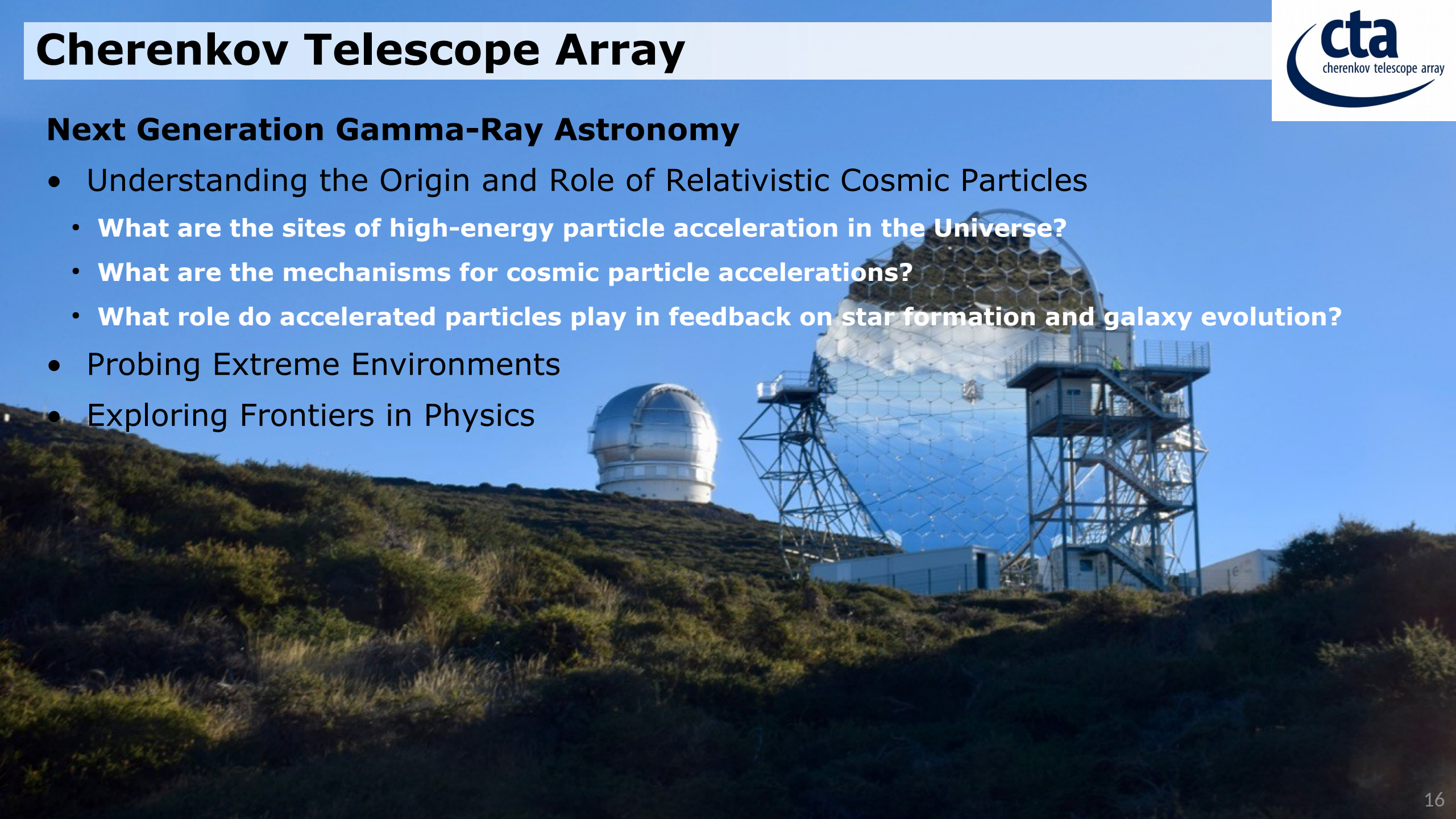
- Understanding the Origin and Role of Relativistic Cosmic Particles
- Probing Extreme Environments
- Exploring Frontiers in Physics



Cherenkov Telescope Array

Next Generation Gamma-Ray Astronomy

- Understanding the Origin and Role of Relativistic Cosmic Particles
  - **What are the sites of high-energy particle acceleration in the Universe?**
  - **What are the mechanisms for cosmic particle accelerations?**
  - **What role do accelerated particles play in feedback on star formation and galaxy evolution?**
- Probing Extreme Environments
- Exploring Frontiers in Physics



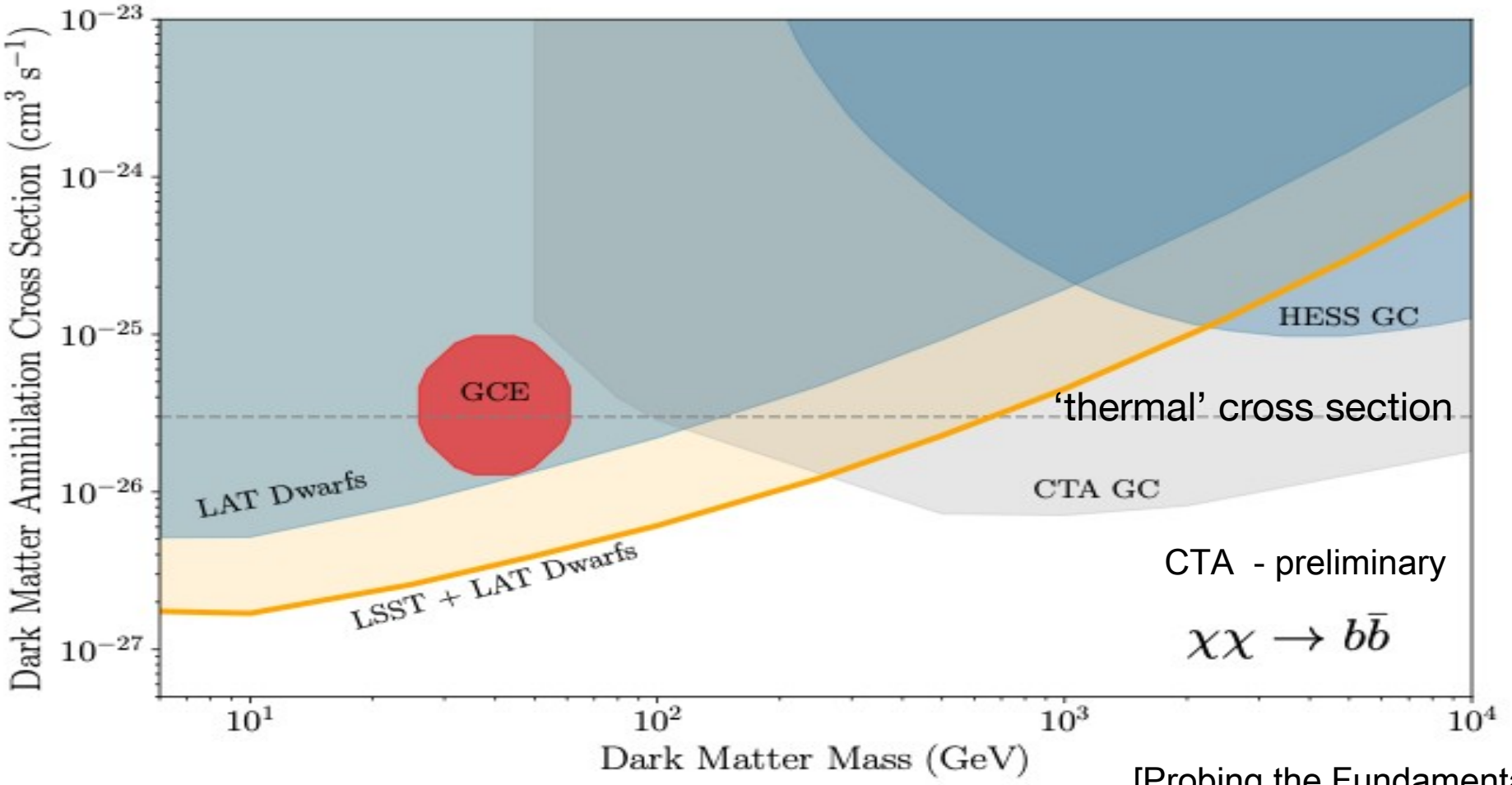
Cherenkov Telescope Array

Next Generation Gamma-Ray Astronomy

- Understanding the Origin and Role of Relativistic Cosmic Particles
- Probing Extreme Environments
- Exploring Frontiers in Physics
  - **What is the nature of dark matter? How is it distributed?**

Gamma-rays are one of the most powerful probes

Fermi LAT + CTA (+ complementary probes (LSST, Euclid, +…))
will test vanilla thermal DM over the whole range 10 GeV - ~>10 TeV

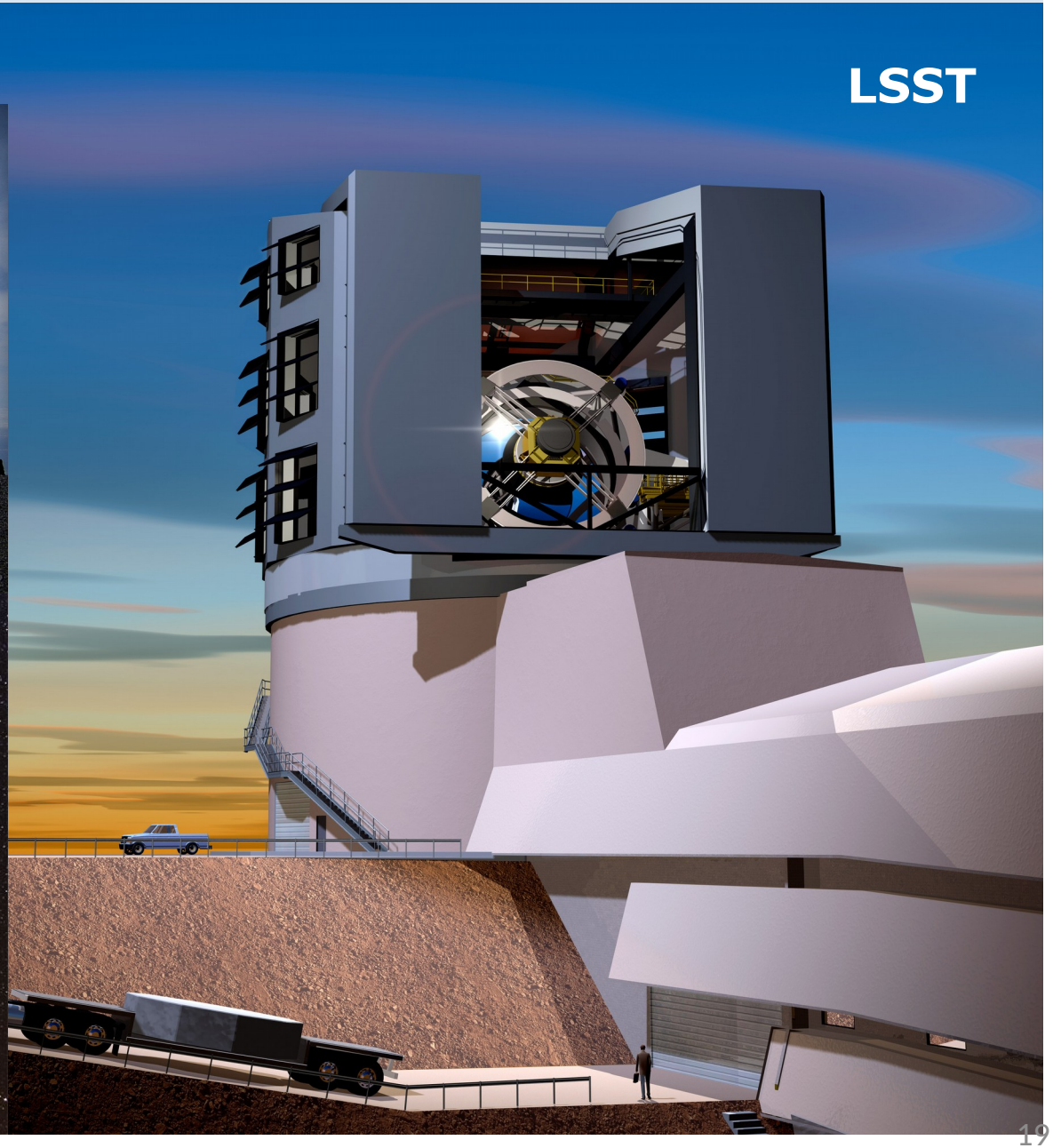


CTA reach: Thesis of C. Eckner, UNG

[Probing the Fundamental Nature of Dark Matter with the LSST, Drlica-Wagner+ (**+ GZ, CE from CAC**), 2019]

High-Energy Astrophysical Transients

Sky surveys and follow up observations of transients by:



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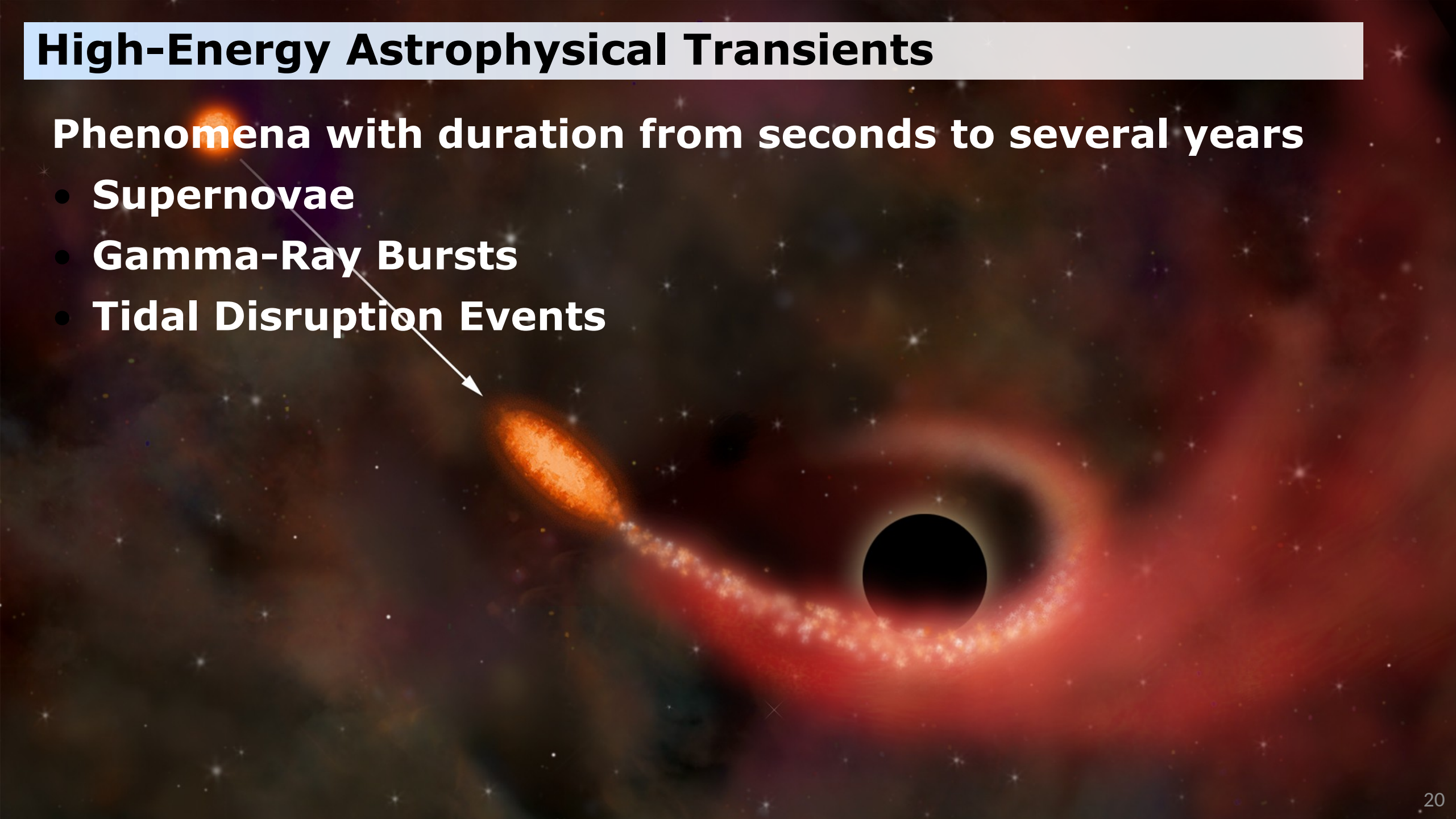


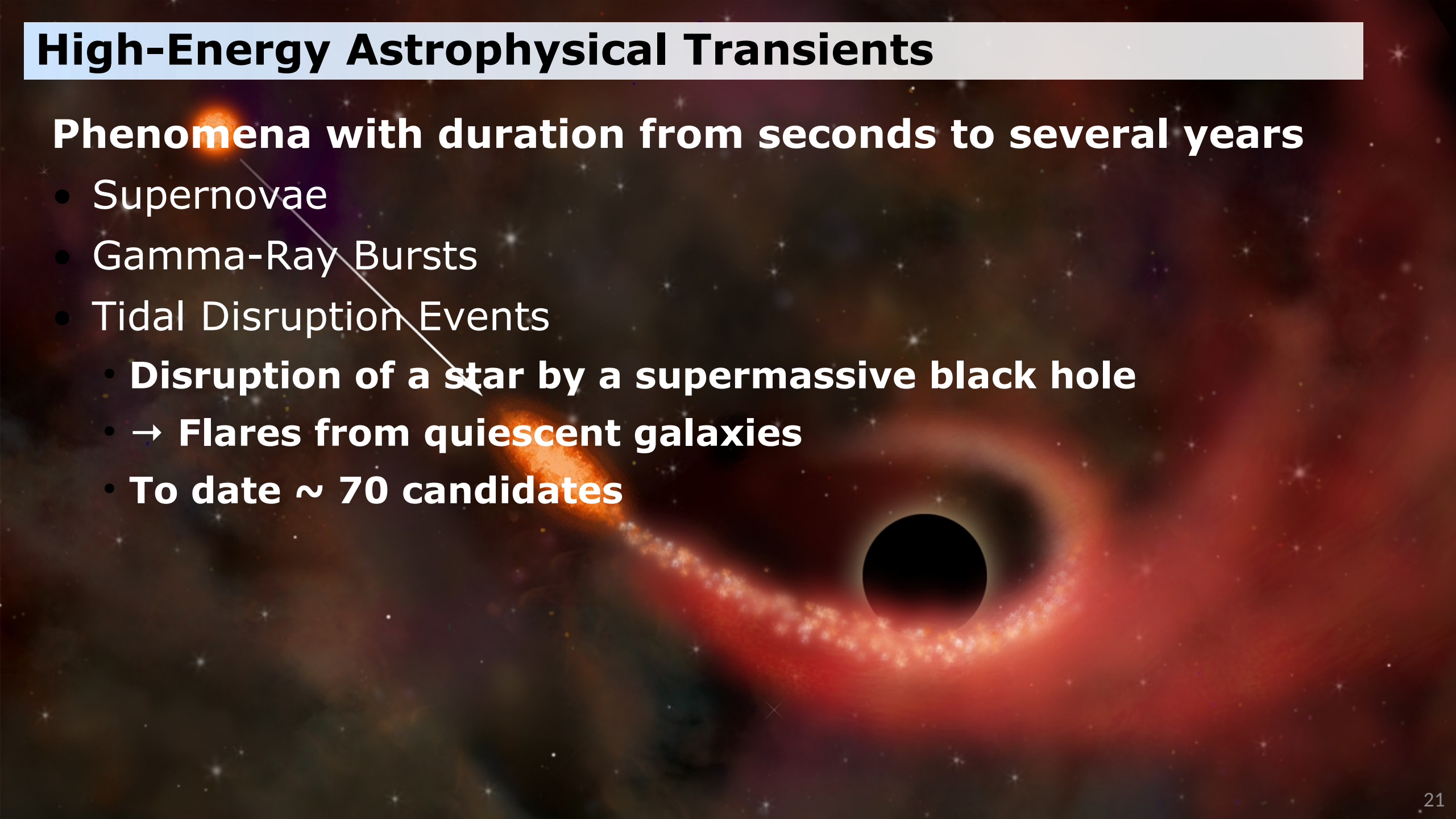
Phenomena with duration from seconds to several years

- **Supernovae**
- **Gamma-Ray Bursts**
- **Tidal Disruption Events**

High-Energy Astrophysical Transients

Phenomena with duration from seconds to several years

- Supernovae
- Gamma-Ray Bursts
- Tidal Disruption Events
  - **Disruption of a star by a supermassive black hole**
  - **→ Flares from quiescent galaxies**
  - **To date ~ 70 candidates**

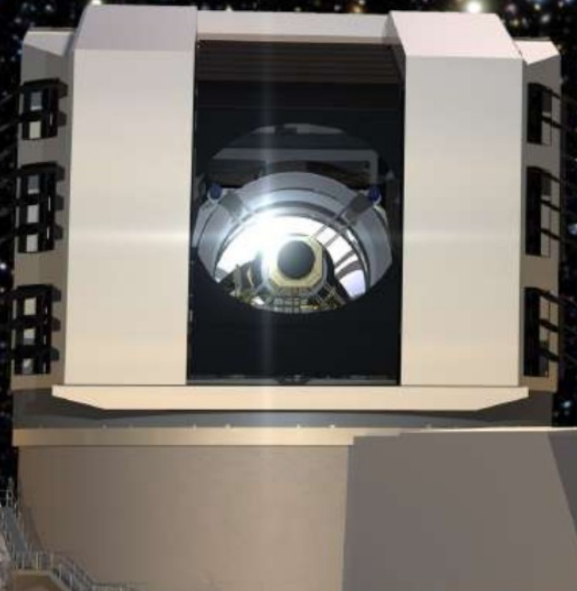


Large Synoptic Survey Telescope (LSST) will be great for transient astronomy

On the ground (Chile)

8.4 m telescope with large FOV camera

First light 2021



TDEs with LSST

Katja Bricman

Center for Astrophysics and Cosmology
University of Nova Gorica

Gaia Science Alerts Workshop, Vipava, October 9th, 2018

+ TDE Simulations by A. Clerici, UNG