Master’s specialisation in Particle and Astrophysics

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www.ru.nl/english/education/masters/particle-and-astrophysics

change perspective

Radboud University

Master's specialisation in Particle and Astrophysics

A physics programme that covers the inner workings of the universe

from the smallest to the largest scale

Focus

Elementary particles and their fundamental interactions, origin and evolution of the universe, and the corresponding underlying mathematical structures

Special emphasis on interdisciplinary topics: astroparticle physics, cosmic rays, dark matter, quantum gravity, confronting theory and experiment

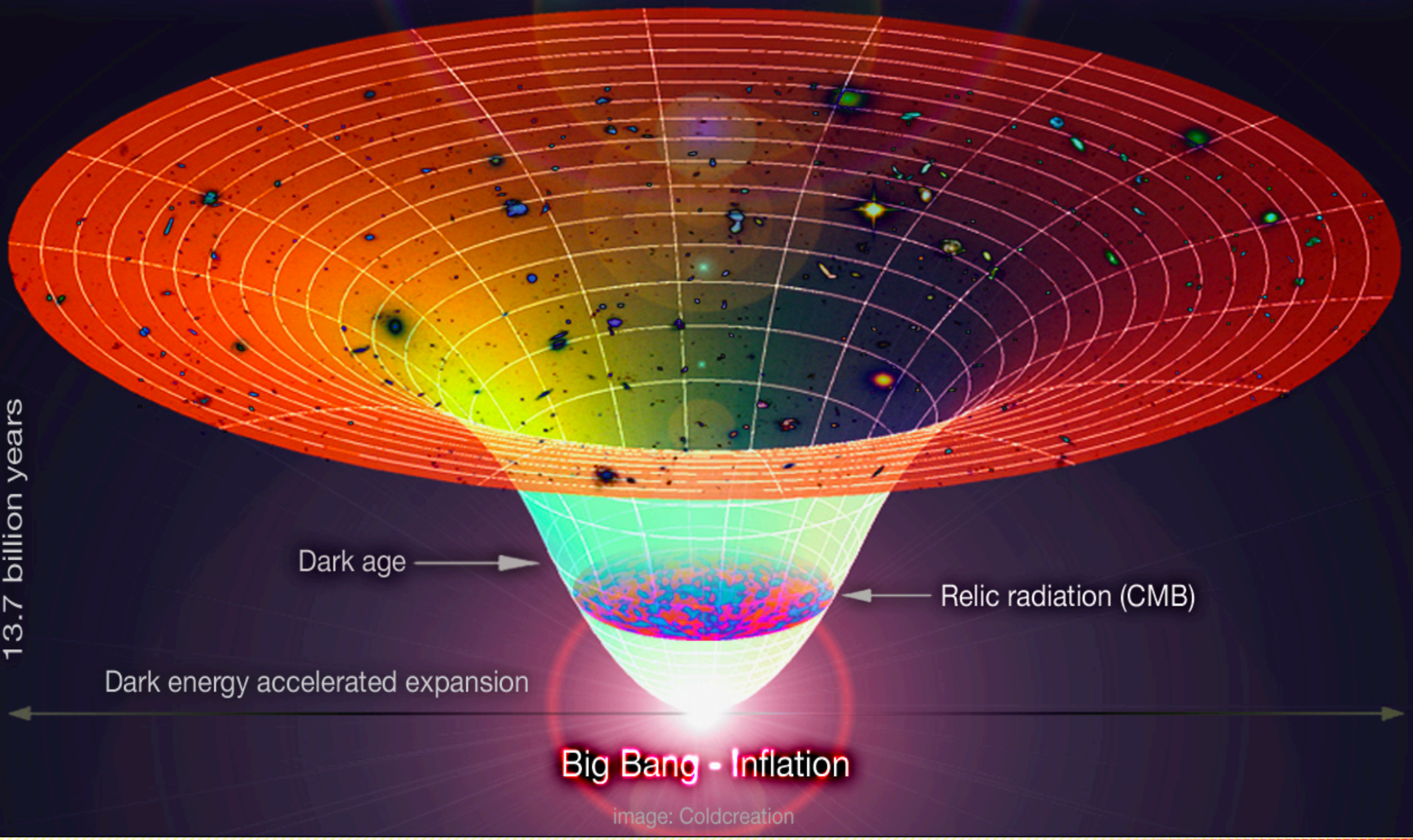
For whom

- good analytical and/or numerical skills
- Interest in fundamental science and fundamental research

This specialisation is part of the Master's programmes in

- Physics and Astronomy
- Science

Accelerated Expansion of the Universe



THE BIG BANG THEORY

Electron

Galaxy

TIME BEGINS		ONE SECOND				PRESENT DAY
Time 10^{-43} sec.	10^{-32} sec.	10^{-6} sec.	3 min.	300,000 yrs.	1 billion yrs.	15 billion yrs.
Temperature	10^{27}°C	10^{13}°C	10^{8}°C	10,000°C	-200°C	-270°C

1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fractiion of a second.

2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles

3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons.

4 Still too hot to form into atoms, charged electrons and protons prevent light from shining: the universe is a superhot fog.

5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and heliium. Light can finally shine.

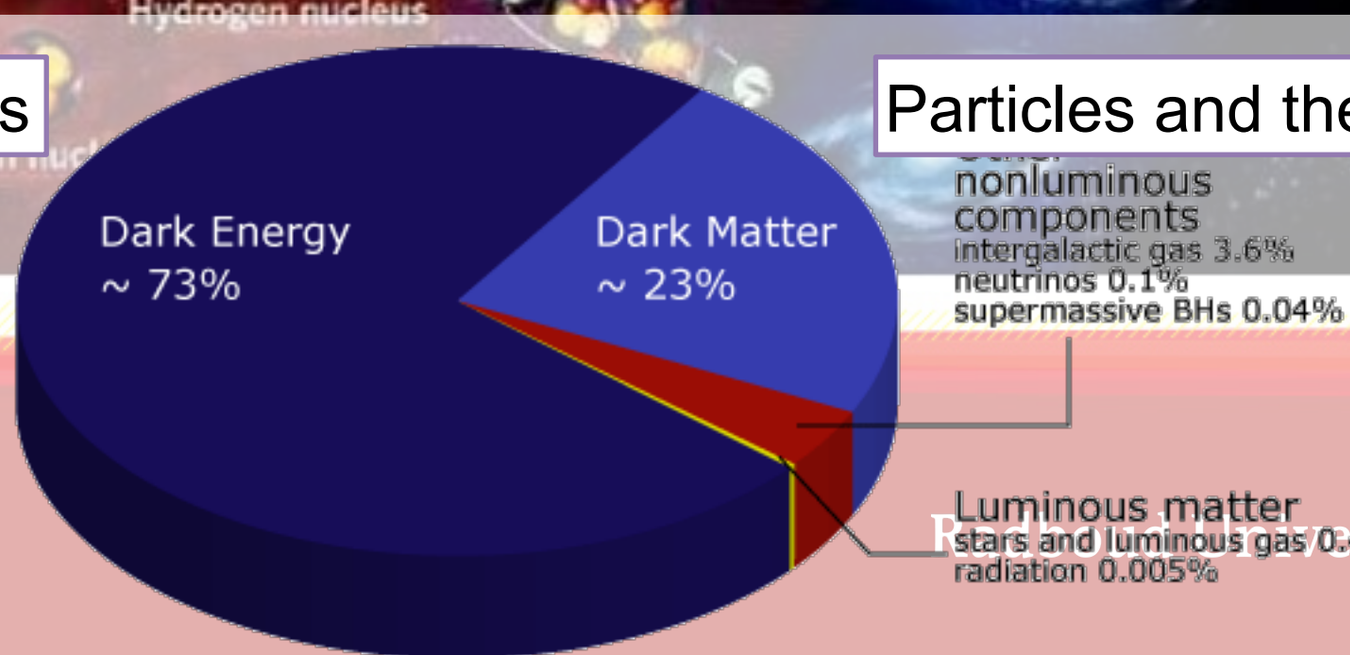
6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars

7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; those will eventually turn into new stars and planets.

➔ 2 mandatory courses in first semester to learn the basic principles:

Gravity and the Cosmos

Particles and the Cosmos



change perspective

Radboud University

IN·DEI·NOMINE·FELICITER

Why study Particle and Astrophysics at Radboud University?

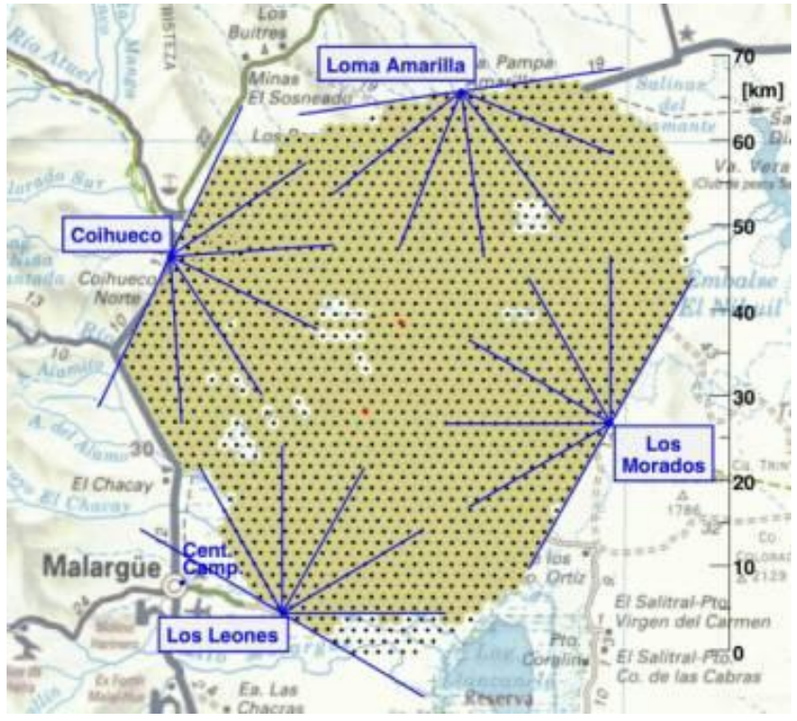
- provides you with a thorough background in high-energy physics, astrophysics or mathematical physics … and the interface between them!
- many interdisciplinary research topics ⇨ ideal for curious students
- flexible programme that allows you to customize
- opportunity to perform theoretical, experimental and/or observational research
- possibility to participate in large-scale research projects
  - Large Hadron Collider (LHC) at CERN in Switzerland (particle physics at highest energies)
  - Pierre Auger Cosmic Ray Observatory in Argentina (highest energetic cosmic rays)
  - European Southern Observatory (ESO) in Chile
  - Event Horizon Telescope (Black Hole radio image)
  - Low-frequency Array for Radio Astronomy (LOFAR) in Western Europe
  - LIGO and VIRGO (Gravitational Waves)

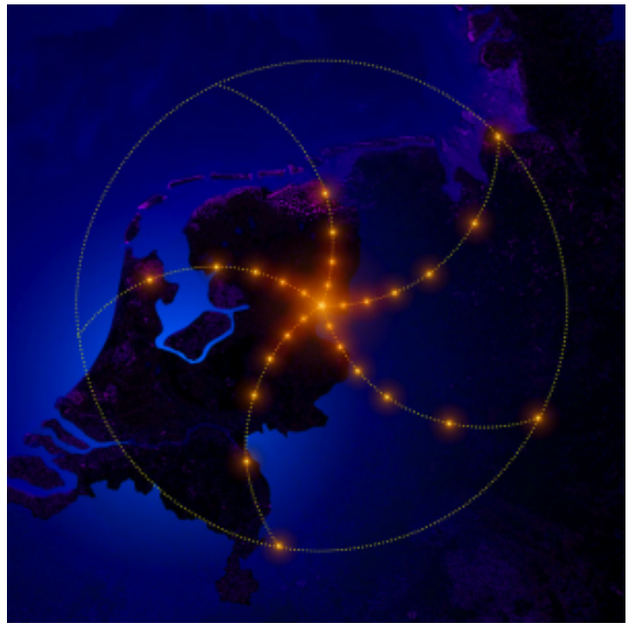
Some of the questions addressed in Particle and Astrophysics

- What is the origin of our universe?
- What is dark matter … and dark energy?
- How to quantize gravity?
- What can gravitational waves teach us?
- What is the origin of mass?
- What is the origin of ultra-high-energy cosmic rays …
- Can we observe a black hole directly?
- Or more simple:

Why is the charge of the electron = charge of the proton ? …

Big Questions …. Big experiments

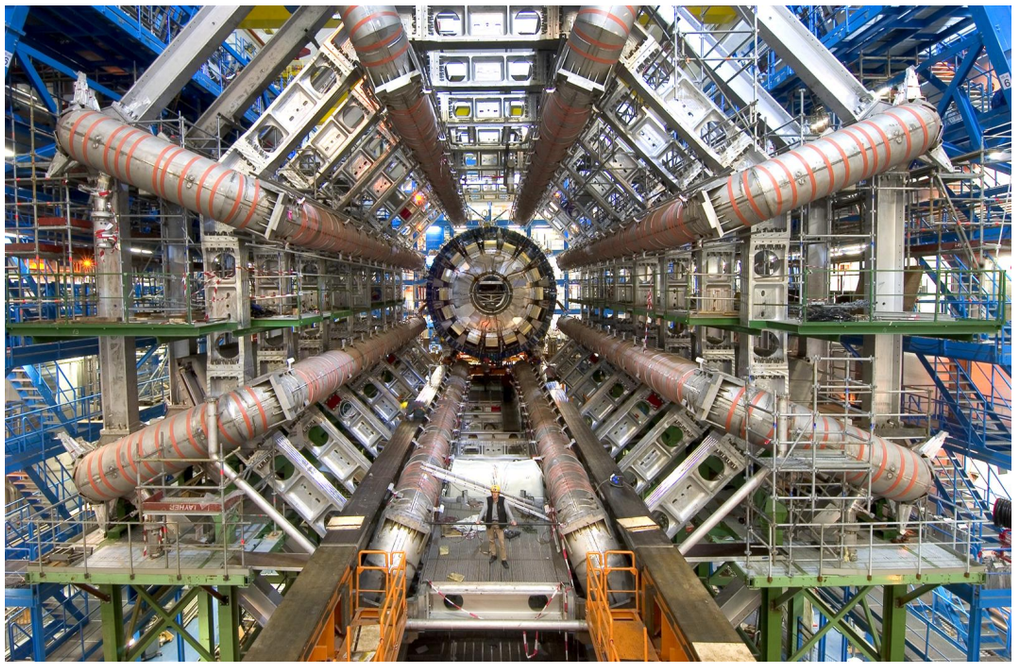




Big experiments

....

Big detectors



Curriculum Particle and Astrophysics

(total load: 2 years, 120 EC)

Master's Physics and Astronomy

Compulsory courses (22 EC)
Specialisation electives (25 EC)
Free electives (13 EC)
Internship (60 EC)

Master's Science

Compulsory courses (15 EC)
Specialisation electives (6 EC)
Free electives (6 EC)
Philosophy elective (3 EC)
Internship 1 (39-54 EC)
Literature thesis (6 EC)
Internship 2 (30-45 EC)

2 years of Master studies: Physics and Astronomy

A. Mandatory courses - Physics and Astronomy, Particle and Astrophysics 18 EC
B. Elective courses - Physics and Astronomy 24 EC
C. Master Thesis Physics and Astronomy 60 EC
D. Professional Preparation 1 EC
E. Philosophy 3 EC
F. Free electives 14 EC

Idea: Year 1 courses , Year 2 Master thesis

Mandatory: Example first semester…

- Semester 1:

Particles and the Cosmos (6 EC), Gravity and the Cosmos (6 EC), Electrodynamics (6 EC)
+ typically 2 courses free choice

Compulsory courses for all students of Particle and Astrophysics

Gravity and the cosmos (6 EC)
The role of gravity in our universe: introduction to general relativity, cosmology, black holes, gravitational waves, quantum gravity, open questions.

Particles and the cosmos (6 EC)
Elementary particles and their mutual interactions + their role in the universe: experimental methods, Standard Model of particle physics, astroparticle physics, dark matter, open questions.

Student Seminar Particle and Astrophysics (3 EC)
Each student gives a seminar on a chosen topic in particle and/or astrophysics.
Aim: developing scientific presenting skills + broadening of research horizon.

Research related to the specialisation Particle and Astrophysics

This specialisation is connected to the

Institute for Mathematics, Astrophysics and Particle Physics (IMAPP)

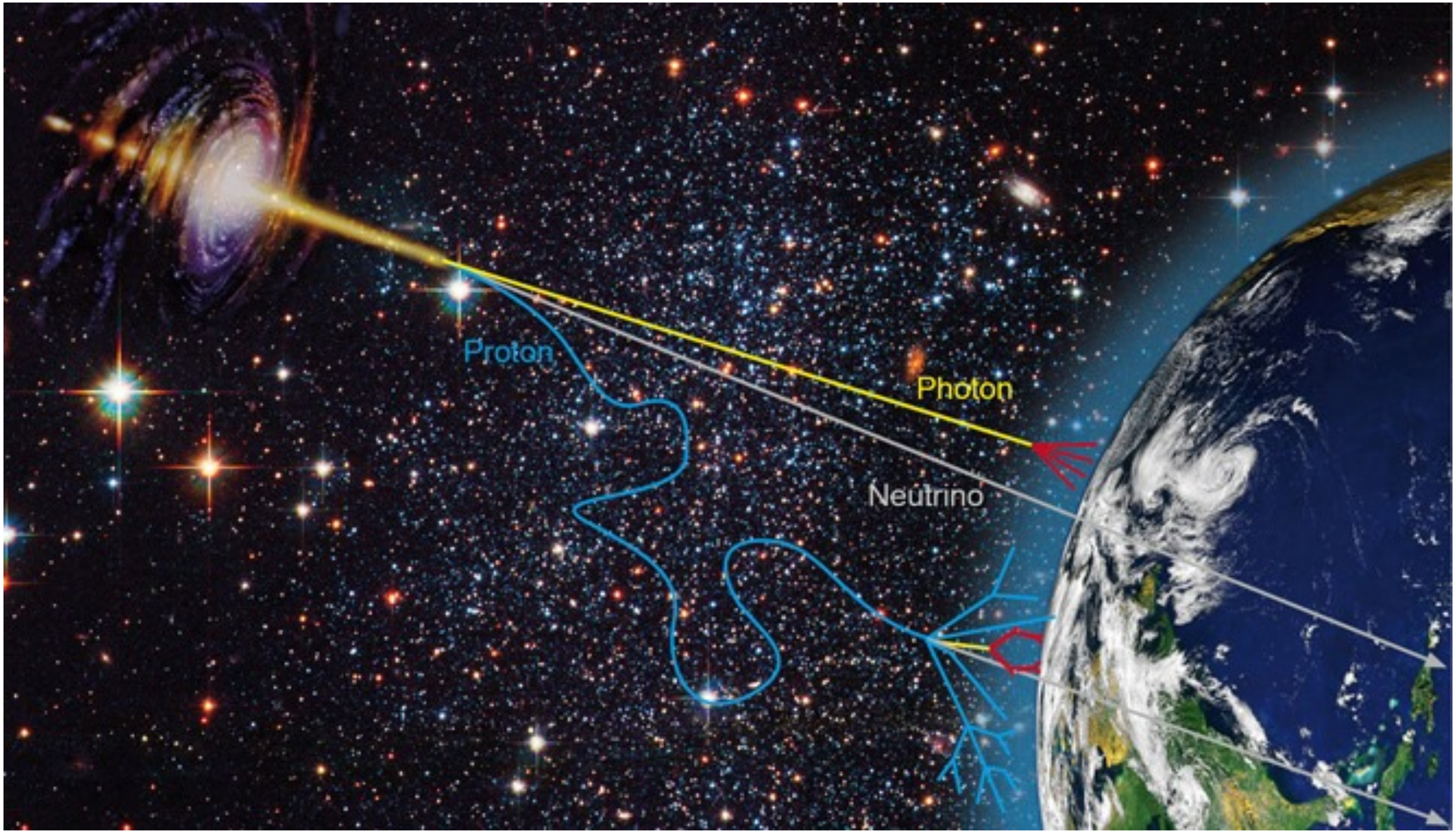
Research topics

- Mathematics: algebra and topology, applied stochastics, mathematical physics
- Astrophysics: radio astronomy, astroparticle physics, black holes, surveys, galactic magnetism, evolution of galaxies, compact binary systems, gravitational waves, instrumentation development
- High-energy Physics: experimental collider physics, cosmic rays, dark matter, theoretical collider physics, quantum gravity

On-site Facilities

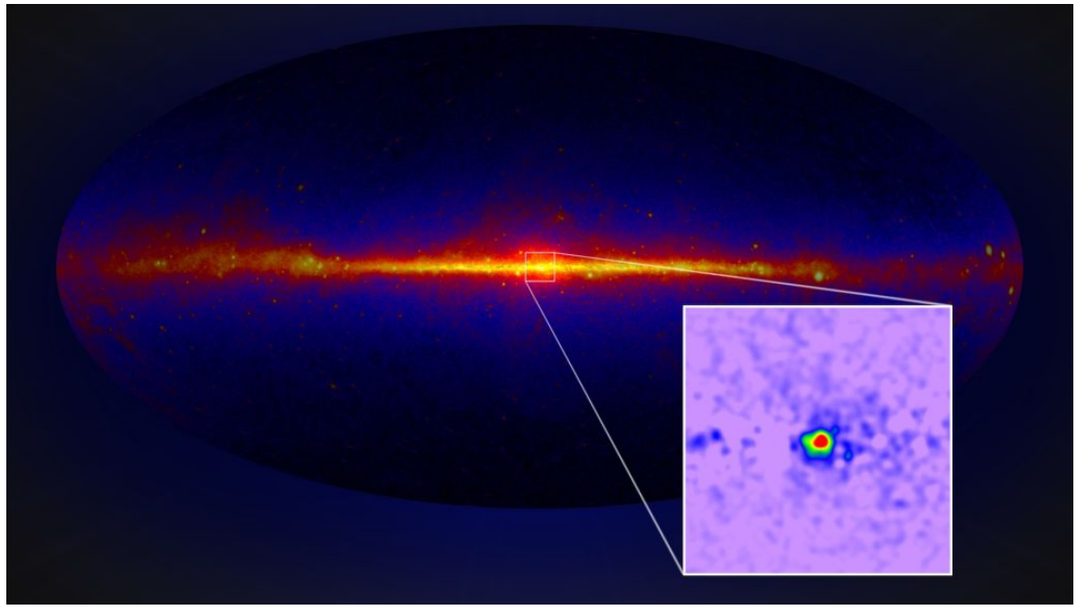
- two optical telescopes
- one radio interferometer
- a LOFAR prototype antenna

The universe as accelerator



The dark side of the universe

Galactic center

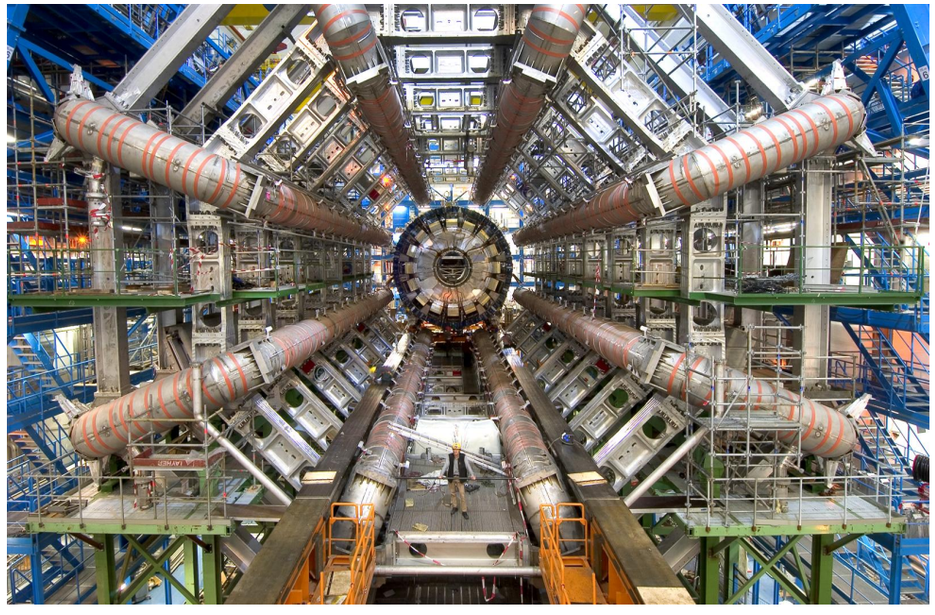


meets

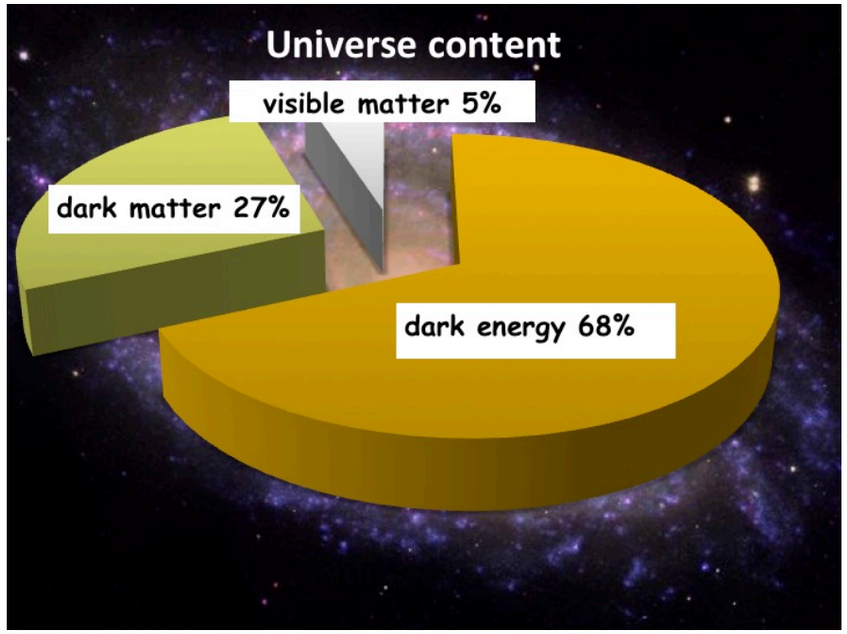
dark

matter

particle accelerator

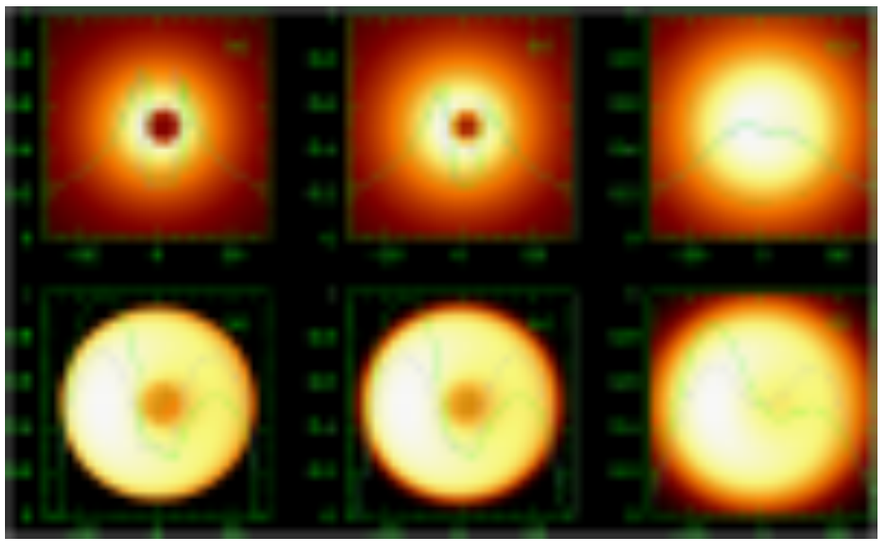


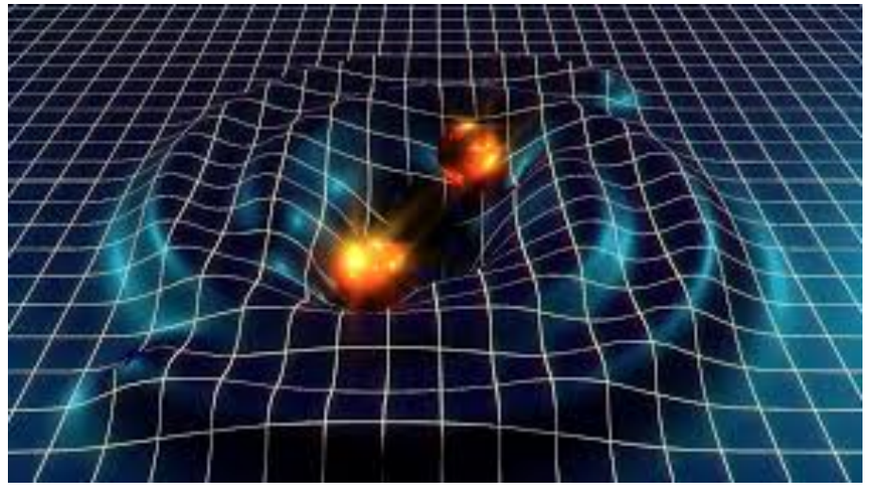
dark energy ???



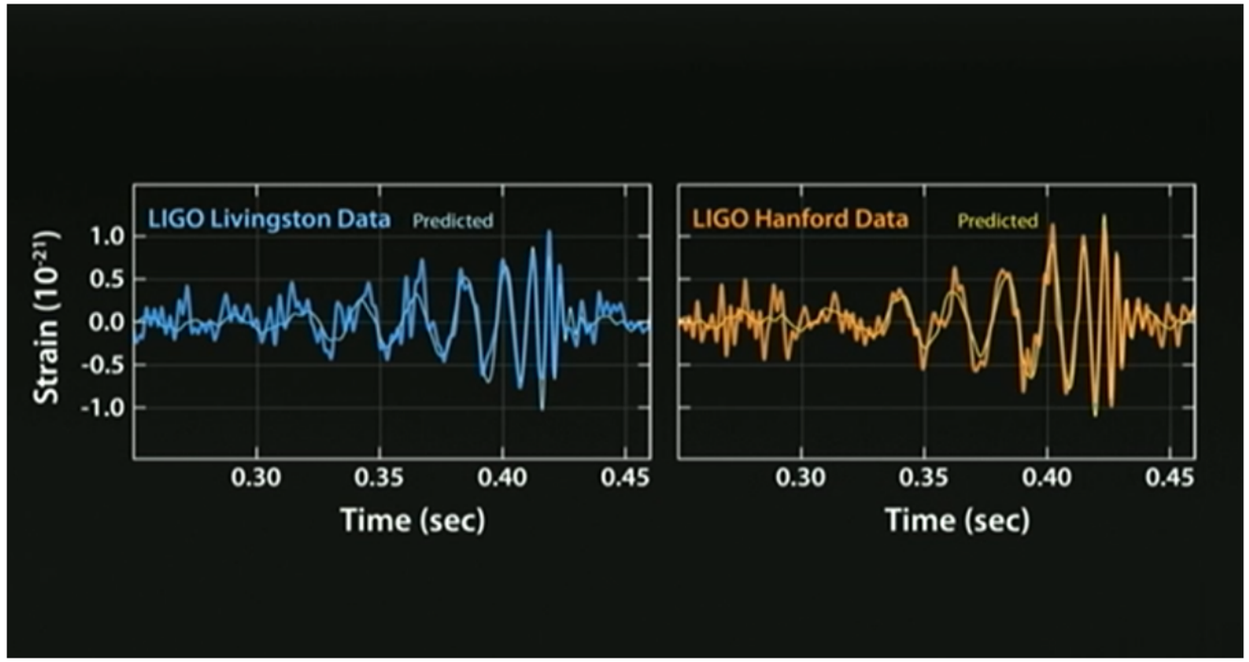
Gravity gone berserk

Event Horizon telescope observing the central black hole



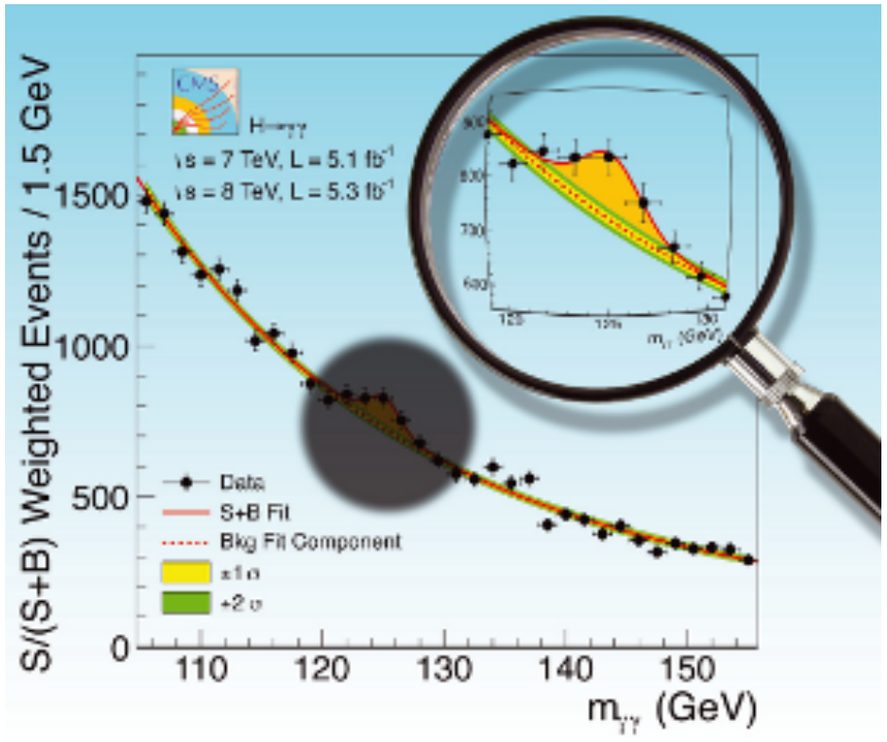


Riding the gravitational waves (2016)

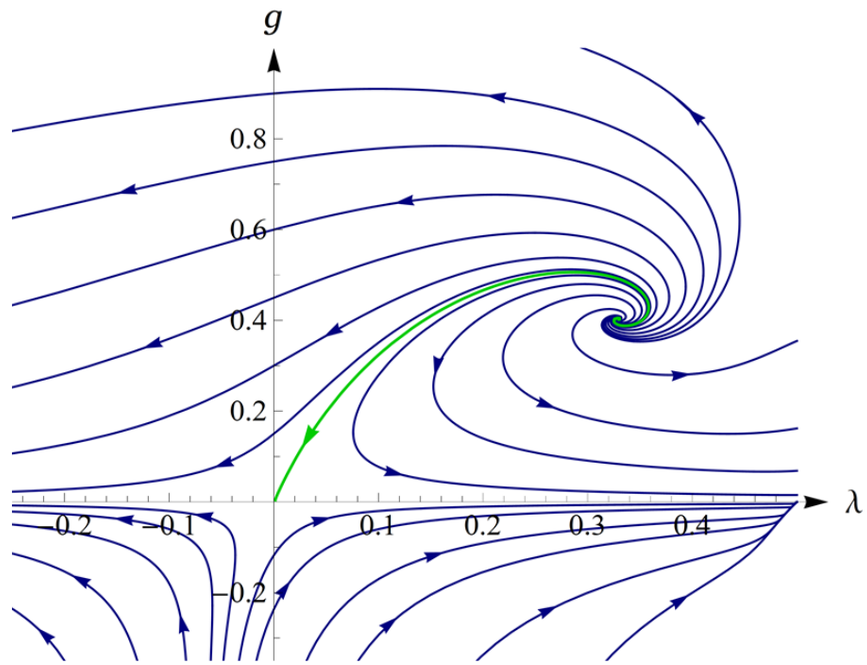


Zooming in on the early universe

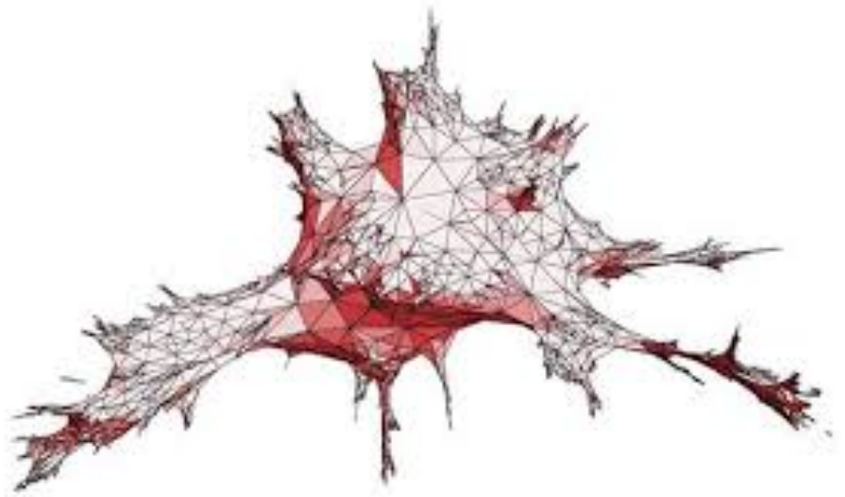
From Higgs© 2012



via

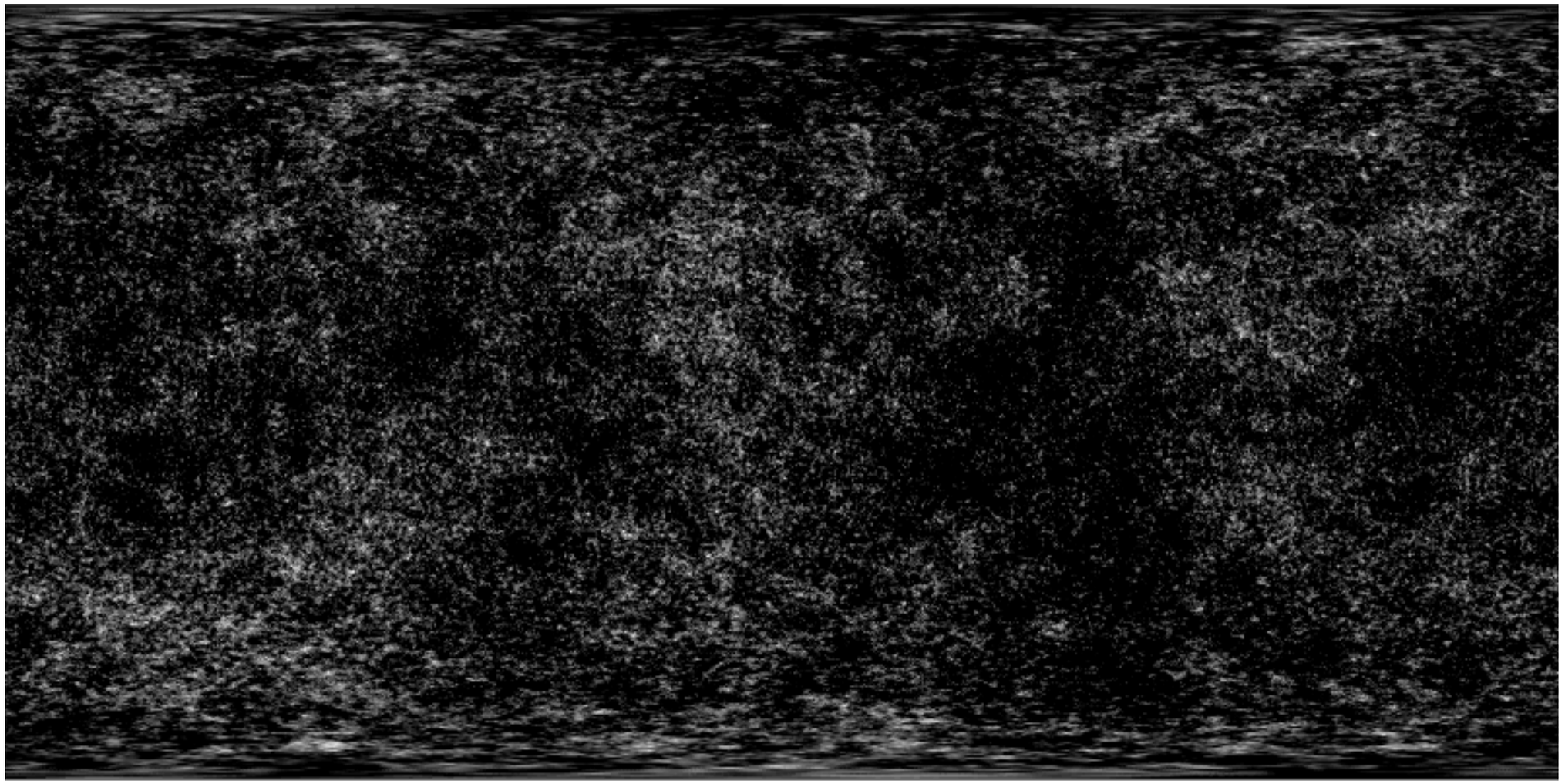


to building your own universe



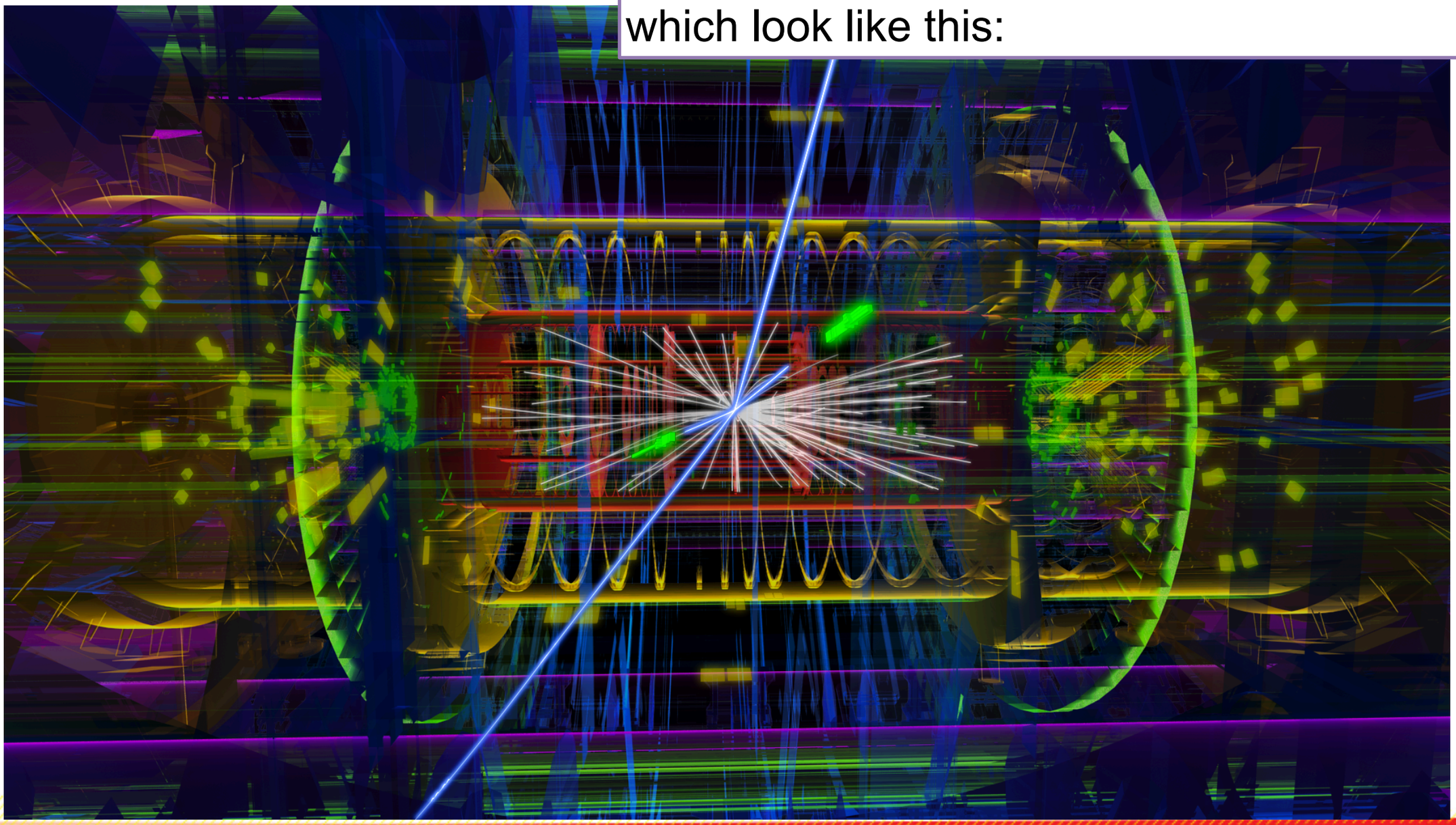
Advanced data analysis – Unraveling Dark Matter with Machine Learning

Trying to bring image analysis to the extreme !

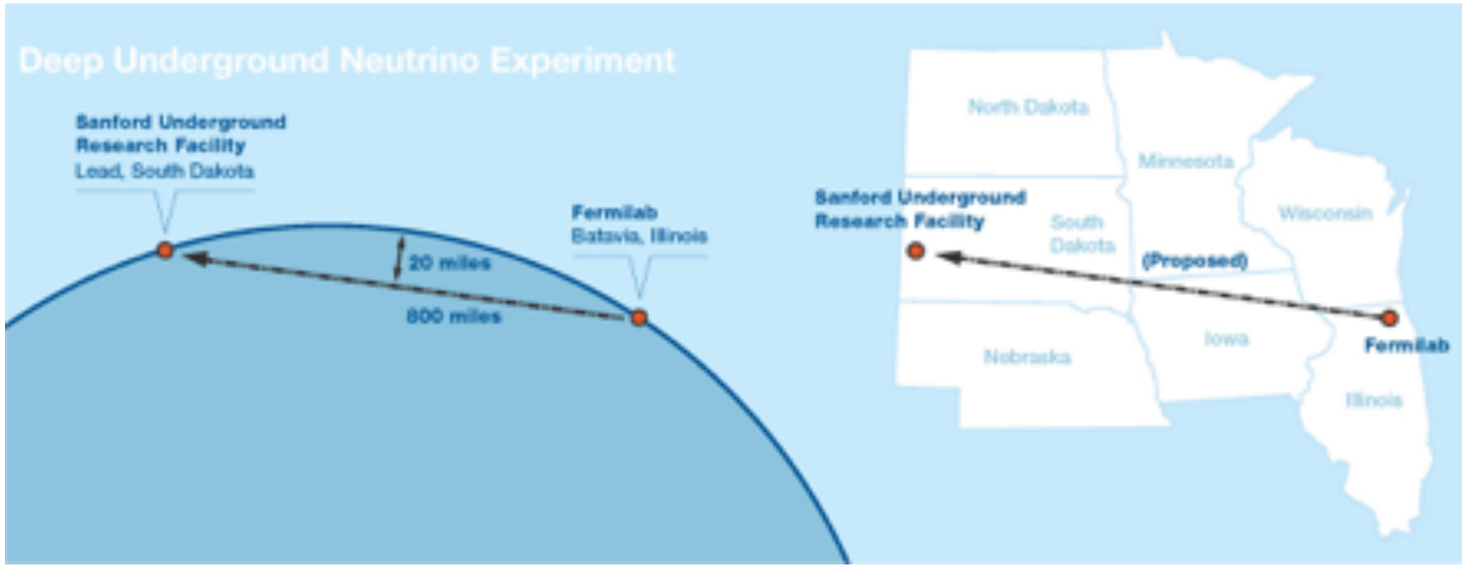


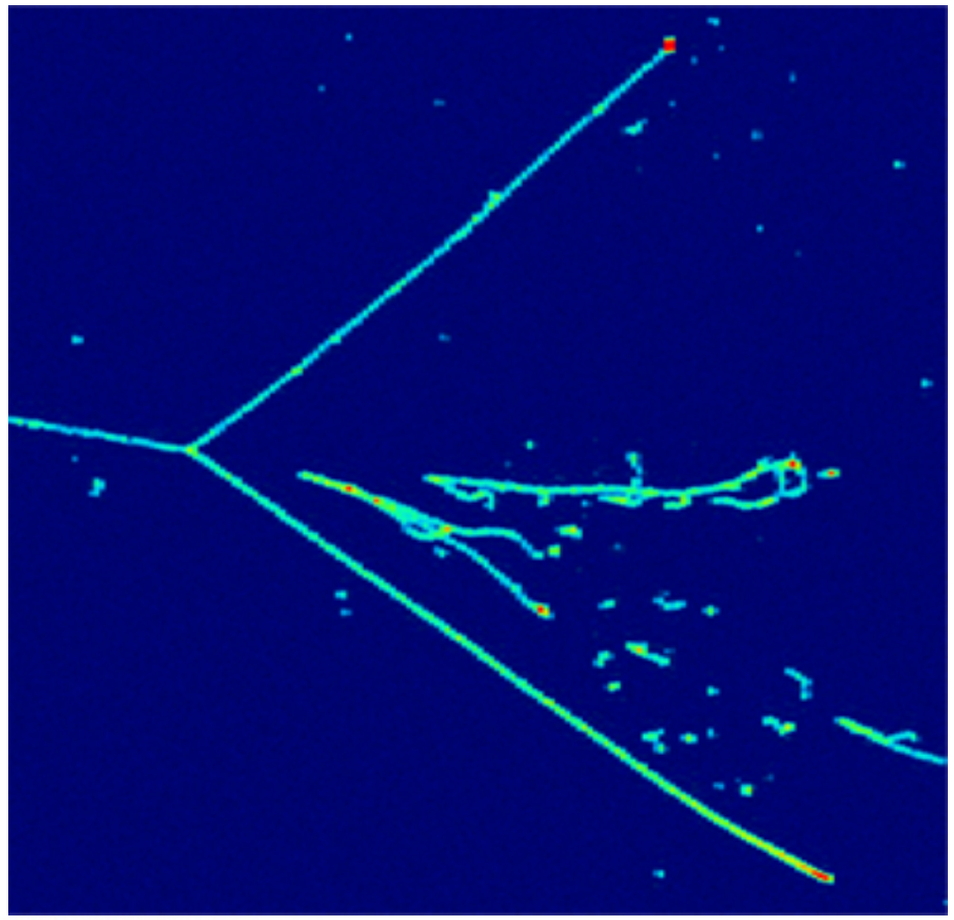
Advanced data analysis – Unraveling Dark Matter with Machine Learning

Finding Dark Matter in 10^10 of LHC events which look like this:



Instrumentation

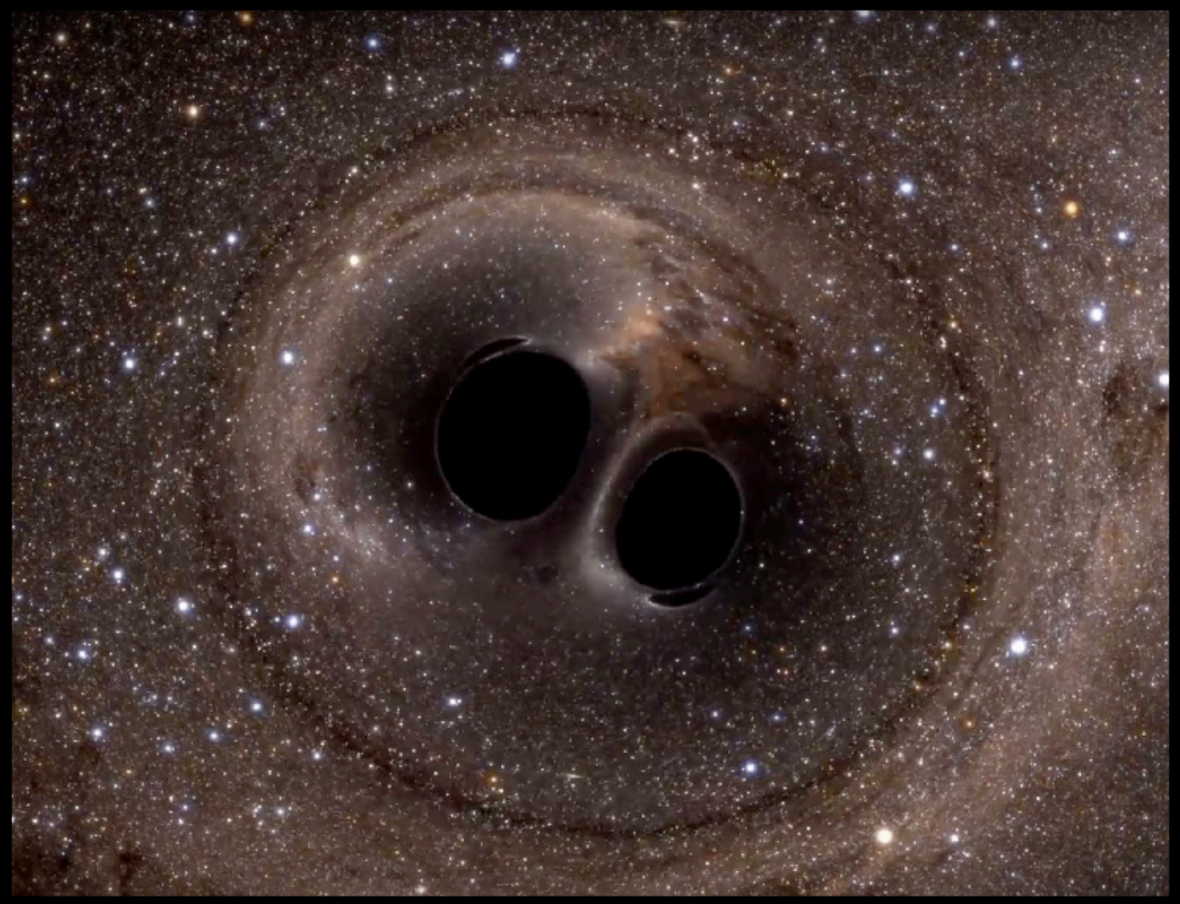




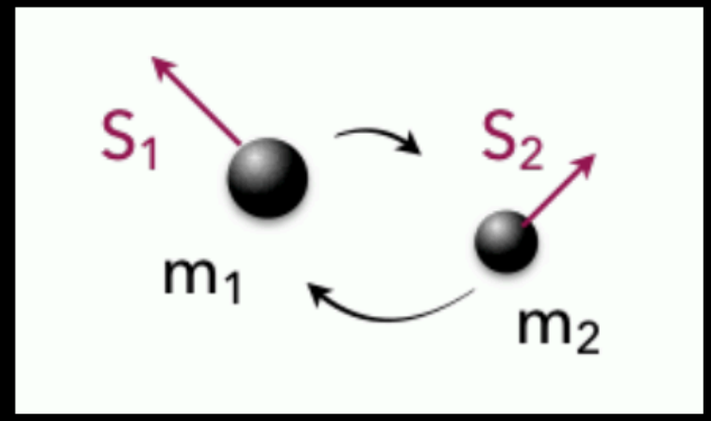
Neutrino oscillations in the Deep Underground Neutrino Experiment DUNE (Fermilab, Chicago): study neutrino (and charged particle) interactions in liquid argon

Gravitational Waves: Exploring the dark side of the universe

Merging black hole binaries



- Binary black holes exist in the universe
- They collide due to the emission of gravitational waves
- They move at almost the speed of light
- There is one merger every ~15 minutes



- ❖ How many?
- ❖ Where do they form?
- ❖ How massive?
- ❖ Do they spin?
- ❖ Are Einstein's predictions correct?
- ❖ …

Binary black holes are dark!
Only gravitational waves can answer those questions!

https://www.youtube.com/watch?v=-7krHb9_d-E

Internships Master's specialisation in particle and astrophysics

Relevant departments at Radboud University and their master coordinators

- Astrophysics (www.astro.ru.nl): Søren Larsen
  S.Larsen@astro.ru.nl
  024-3652806

- High-energy physics (www.ru.nl/highenergyphysics): Sascha Caron
  scaron@cern.ch
  024-3653660

Want to go abroad?

- any of the Max Planck Institutes for Astronomy in Germany
- Institute of Astronomy at KU Leuven
- CERN (Geneva, Switzerland) ← get a first taste as CERN summer student
- many international partners/facilities ← on-site observations possible

Other possibilities

- Radboud Radio Lab (www.radboudradiolab.nl): interface with industry
- Companies (NXP, KPMG, spin-off companies, …)

Admission requirements Particle and Astrophysics

You'll need a Bachelor's diploma in

- Physics and Astronomy
- Science (from Radboud University)
- Physics
- Applied Physics
- … or a closely related discipline

And a fluency in both written and spoken English

- A TOEFL score of >575 (paper based) or >232 (computer based) or >90 (internet based)
- An IELTS score of >6.5
- Cambridge Certificate of Advanced English (CAE) or Certificate of Proficiency in English (CPE) with a mark of C or higher

Native speakers of English and students with a Dutch VWO or Bachelor's diploma don't need to perform an English test.

Career prospects Particle and Astrophysics

You'll be highly appealing to employers in academia and business in view of your

- numerical, statistical, and analytical skills
- abstract way of thinking
- complex problem solving skills

Like some of our alumni you may become

- researcher at a university (all over the world)
- researcher at a research institute (KNMI, ESA, SRON, CERN, …)
- researcher at a company (Shell, NXP, ASML, Philips, Unilever, Akzo Nobel, …)
- teacher (VO, HBO, HO)
- business or government employee (as consultant, manager, ICT expert, …)
- founder of your own spin-off company (Medipix, Amsterdam Scientific Instruments, Omics2Image, Innoseis, ReSnap, Interaqt, …)

Thanks for your attention

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For more information, please contact the relevant student advisors:

Physics and Astronomy
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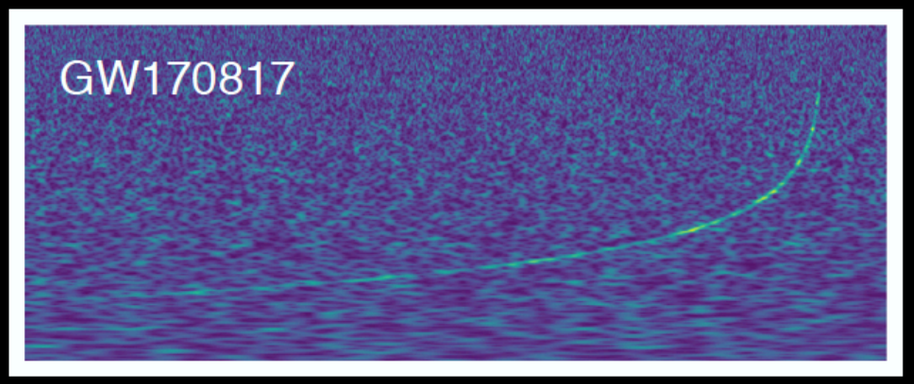
024-3653013

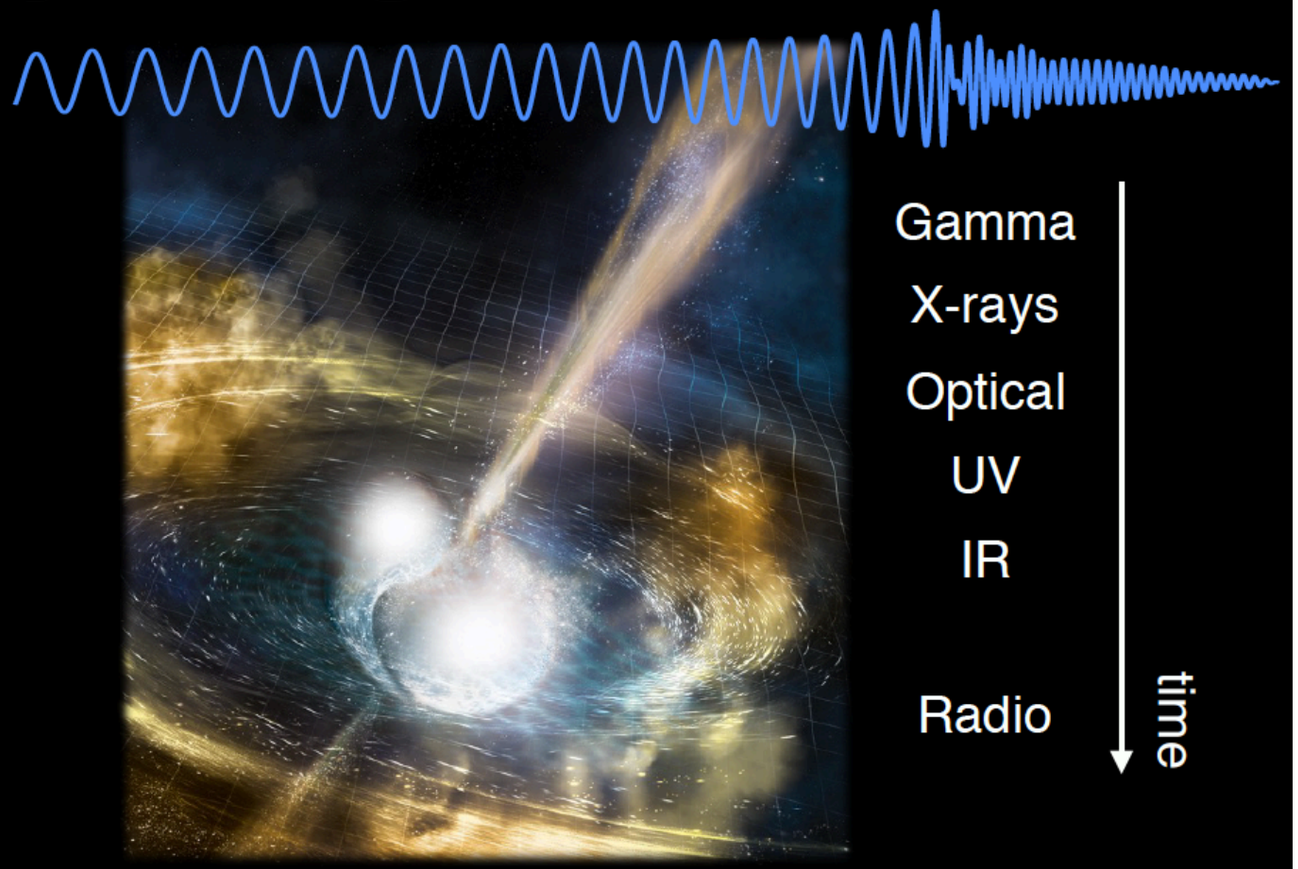
Science
Marjolijn Roeters
science@ru.nl
024-3652029

Gravity & Light

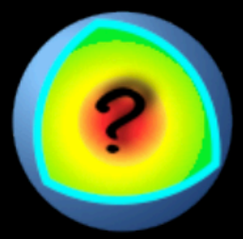
Two colliding neutron stars & their electromagnetic signatures



~100s: The longest chirp yet observed!

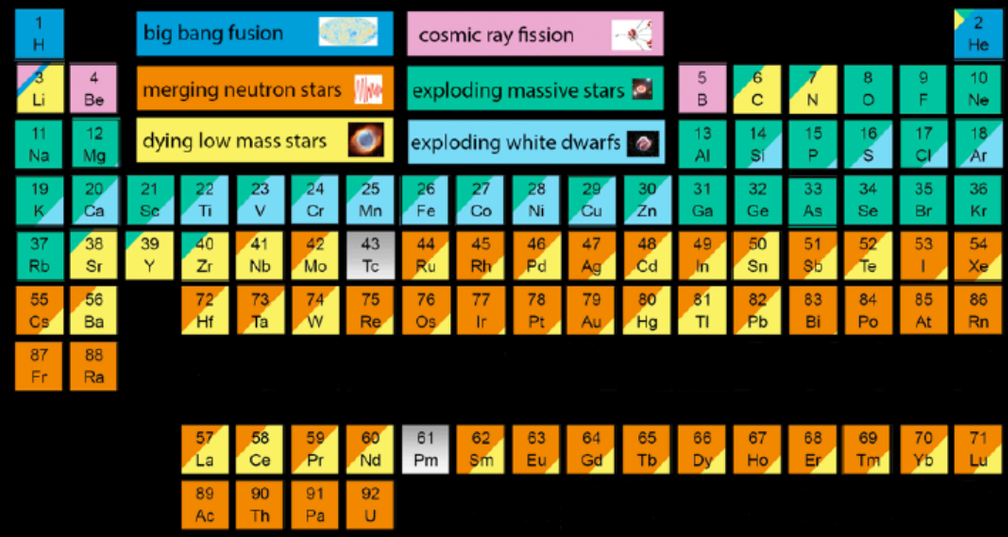


Neutron stars: the densest material objects in the universe



- What are they made of?
- Are they all the same?
- What is their size?
- What is the engine of short gamma ray bursts?
- Where are the heavy elements created?
- …

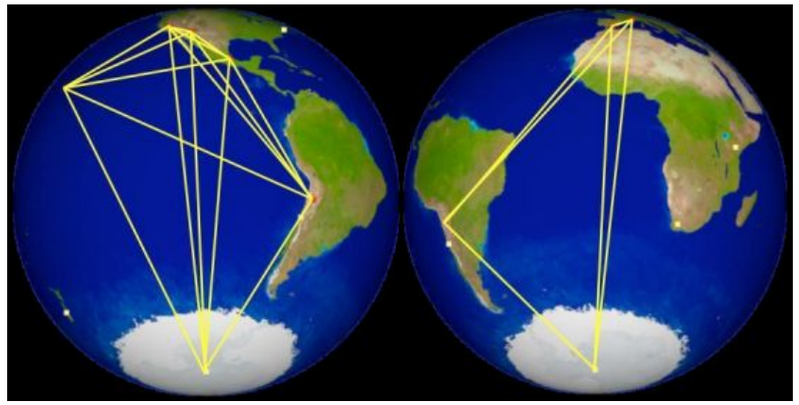
The Origin of the Solar System Elements



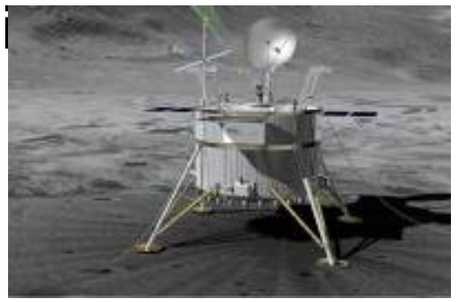
Graphic created by Jennifer Johnson

Astronomical Image Credits: ESA/NASA/AASNova

Flashing some master projects



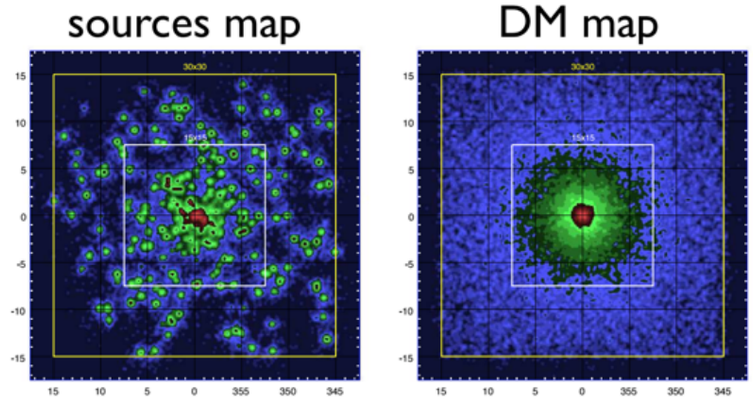
- Improved event horizon telescope: adding a telescope in Nami



- Testing a prototype of a lunar radio antenna
- Develop and test a cosmic-ray detector for a mini satellite

- Discovering magnetic structures in the interstellar medium

Flashing some master projects



- Galactic Center photon excess: millisecond pulsars or dark matter?
- Using machine learning to look for new physics
- Searching for Majorana neutrinos using enriched Calci[illegible]
- Cosmic perturbations from Asymptotic Safety