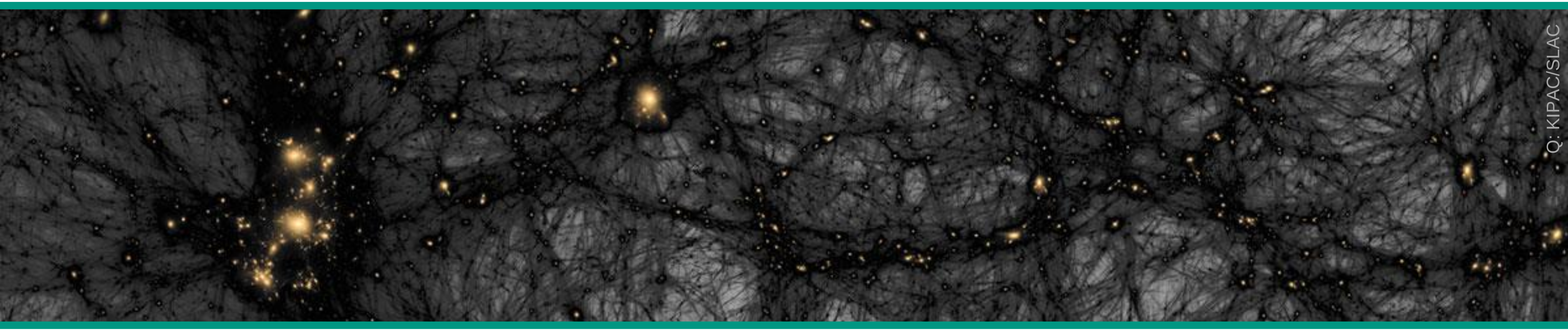
Astroparticle physics I – Dark Matter

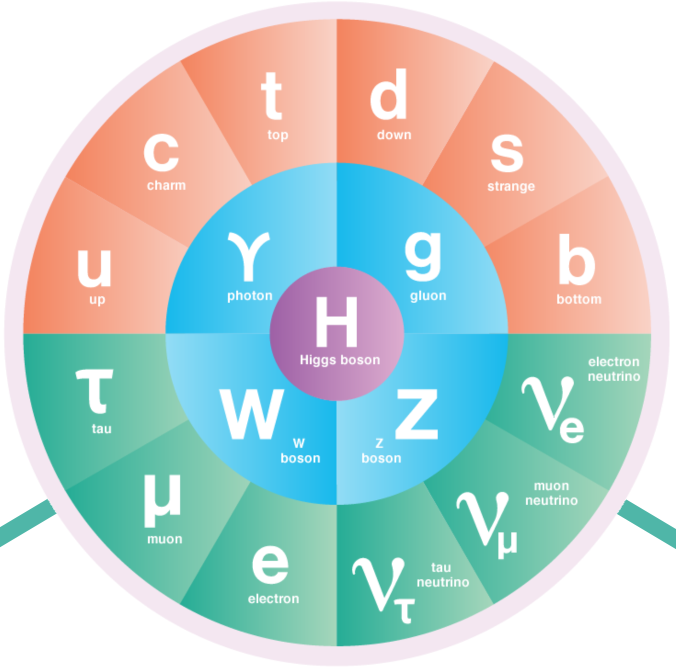
WS22/23 Lecture 1 Oct. 26, 2022



Astro **P**article **P**hysics – a first overview

- **What are our topics?**

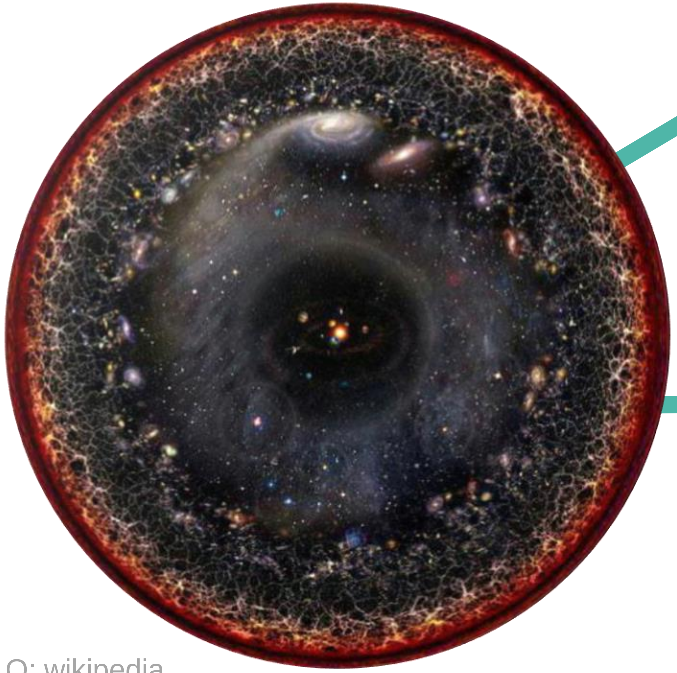
particle



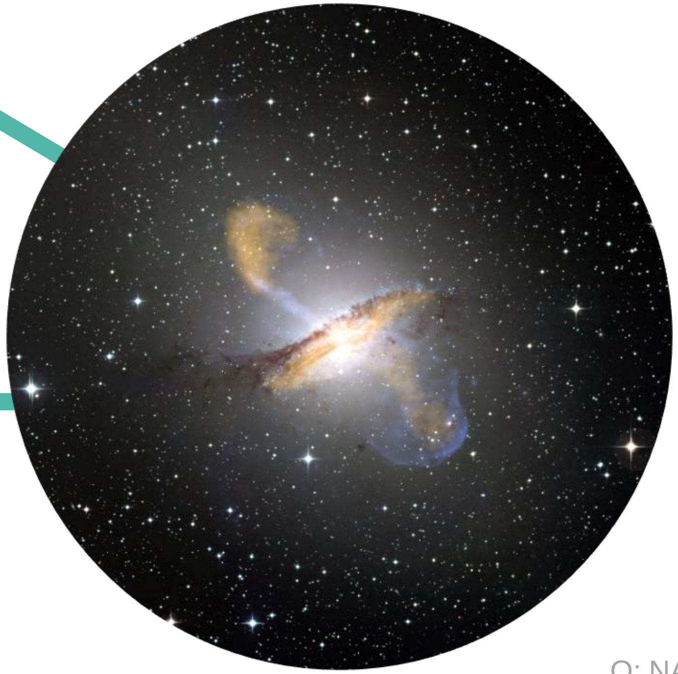
physics

Q: Symmetry Magazine

cosmo-
logy



interconnections



astro-
physics

Q: wikipedia

Q: NASA

Astro **P**article **P**hysics – a first overview

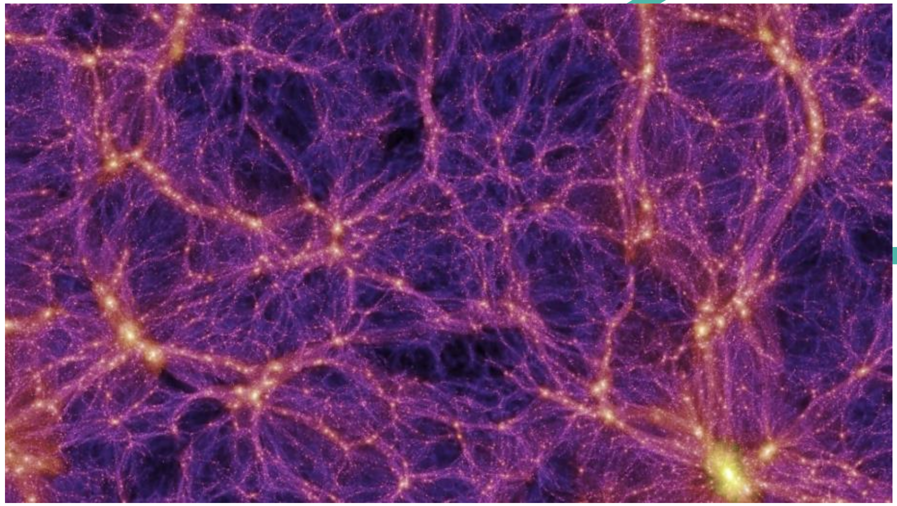
Karlsruhe Institute of Technology

- **example:**
  Dark Matter (DM)

Q: Symmetry Magazine

DM candidates in particle physics

DM in cosmo-logy



Q: MPG

Q: wikipedia

DM in astro-physics

Astro Particle Physics – the explosive birth event

- **neutrinos: information on processes during a core-collapse supernova**

SN1987a – February ´87

Q: NASA/HST, nobelprize, TIME, SuW

AstroParticlePhysics – the central motivation

- APP: deciphering the Code of the Universe

AstroParticlePhysics – the central motivation

Karlsruhe Institute of Technology

- **APP: deciphering the Code of the Universe – here at KIT**

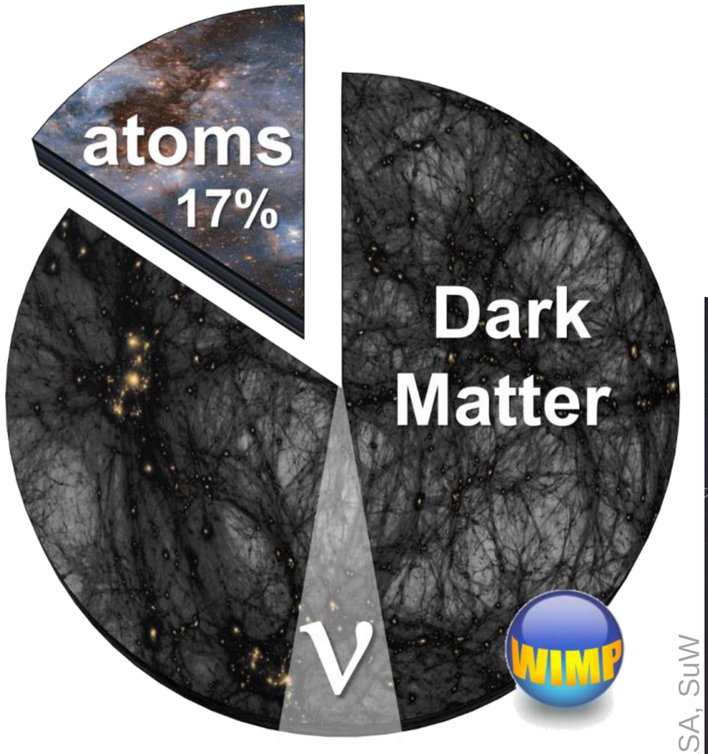
KATRIN
Einstein-Telescope
GridKa

hands-on
TRAINING

Auger
IceCube
XENON-nT

AstroParticlePhysics – the central motivation

- neutrinos & neutralinos: from the Big Bang & the universe



neutrinos

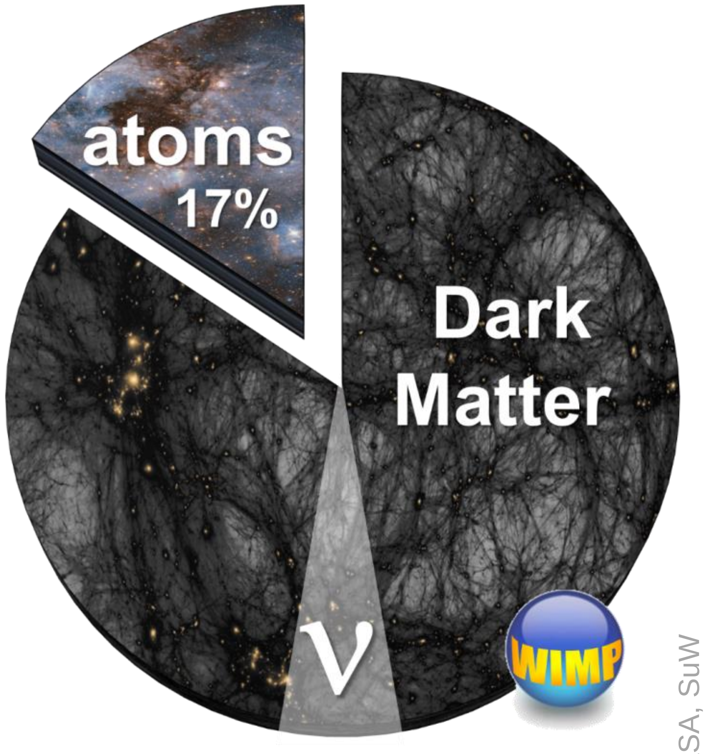
- massive **neutrinos** as
  Hot Dark Matter - HDM
- massive **neutralinos** as
  Cold Dark Matter - CDM

Q: NASA, SuW

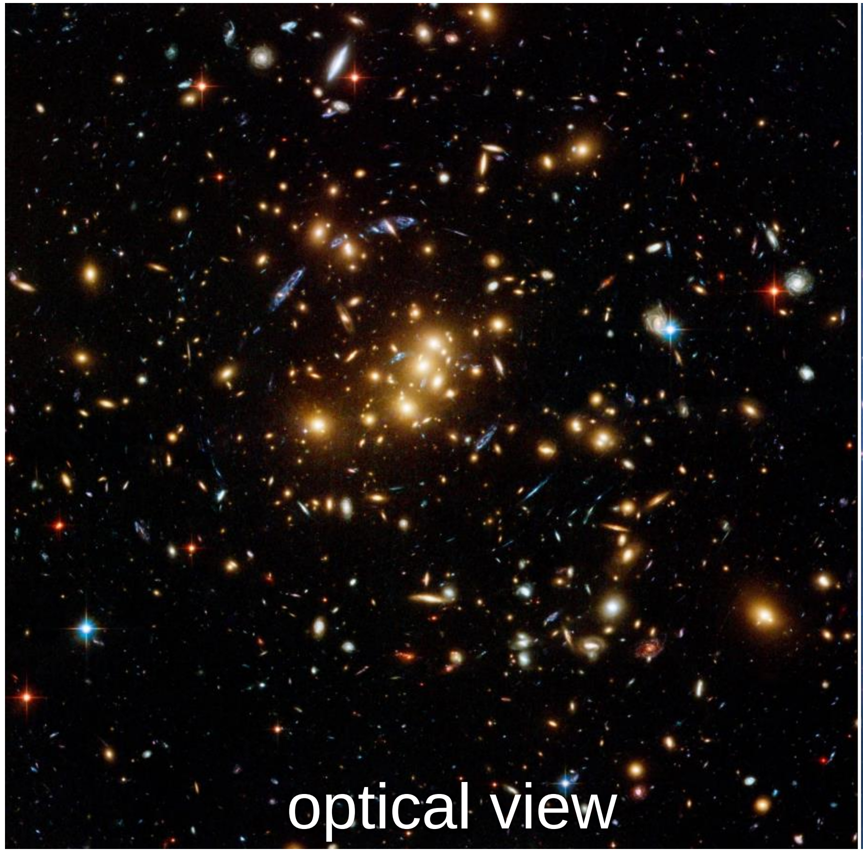
Astro Particle Physics & Cosmology: perfect match

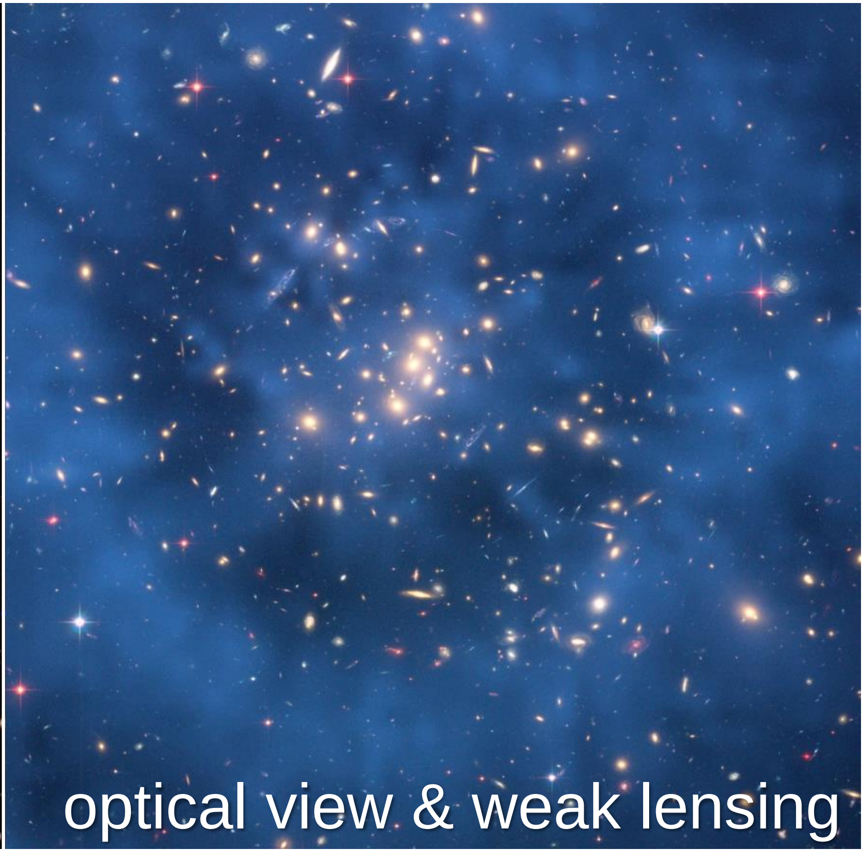
- **Dark Matter: maps by gravitational lenses, see ´Introduction to Cosmology´**

Cosmology lectures: Tuesdays 11:30-13:00. kl. HS. A



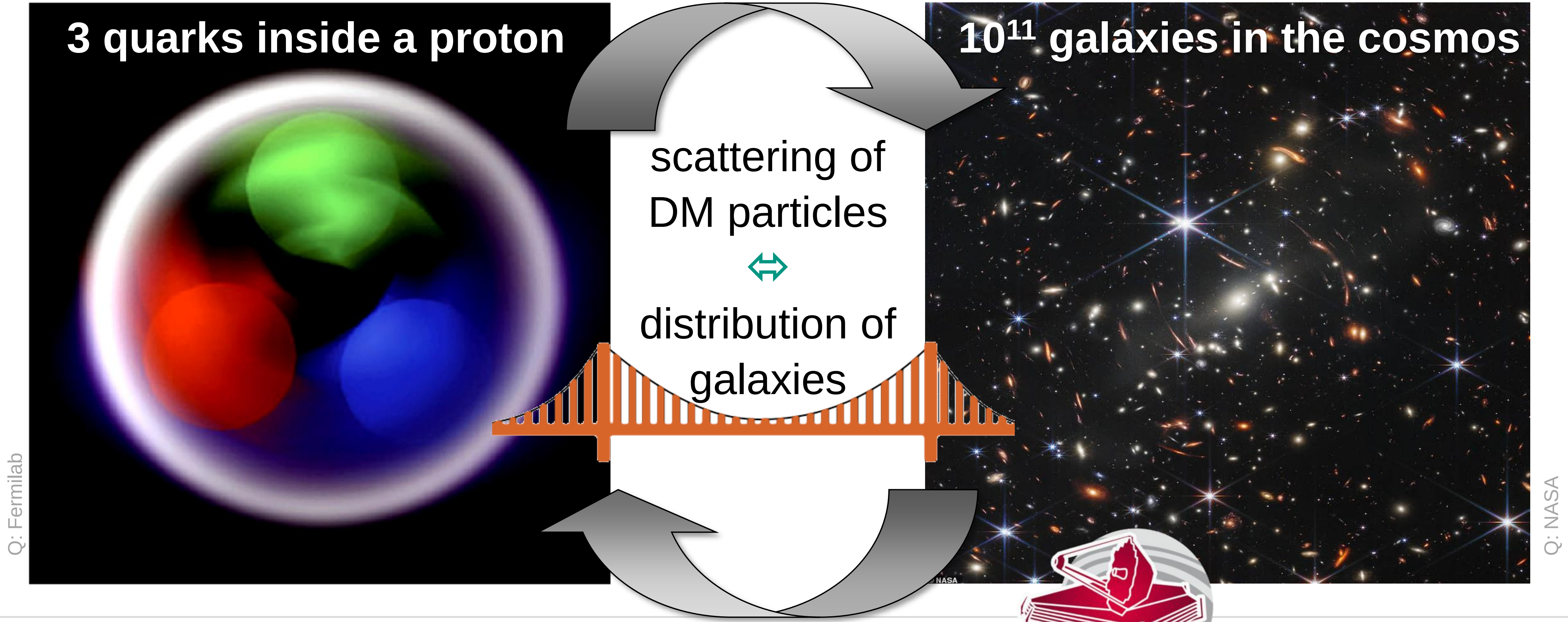
Q: NASA, SuW





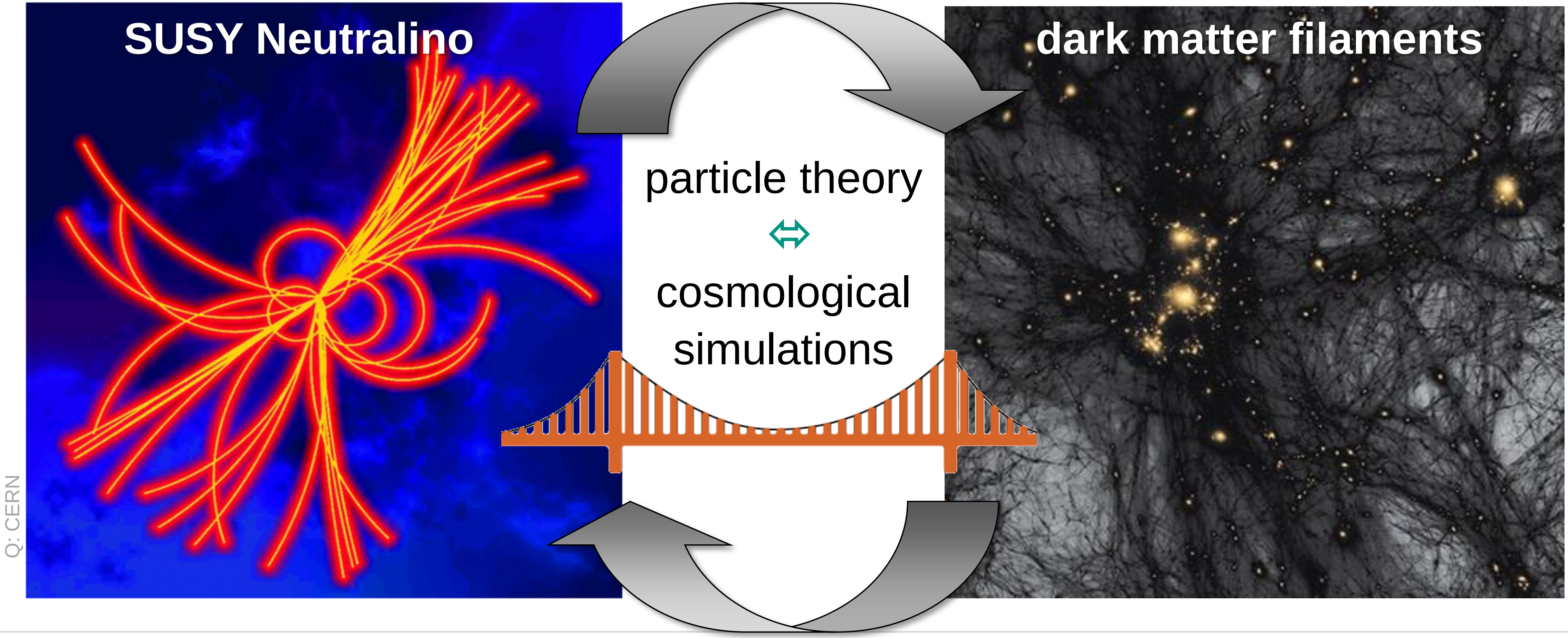
Astro Particle Physics – cross connections #1

- …from the **quark level** to the entire **cosmos**…



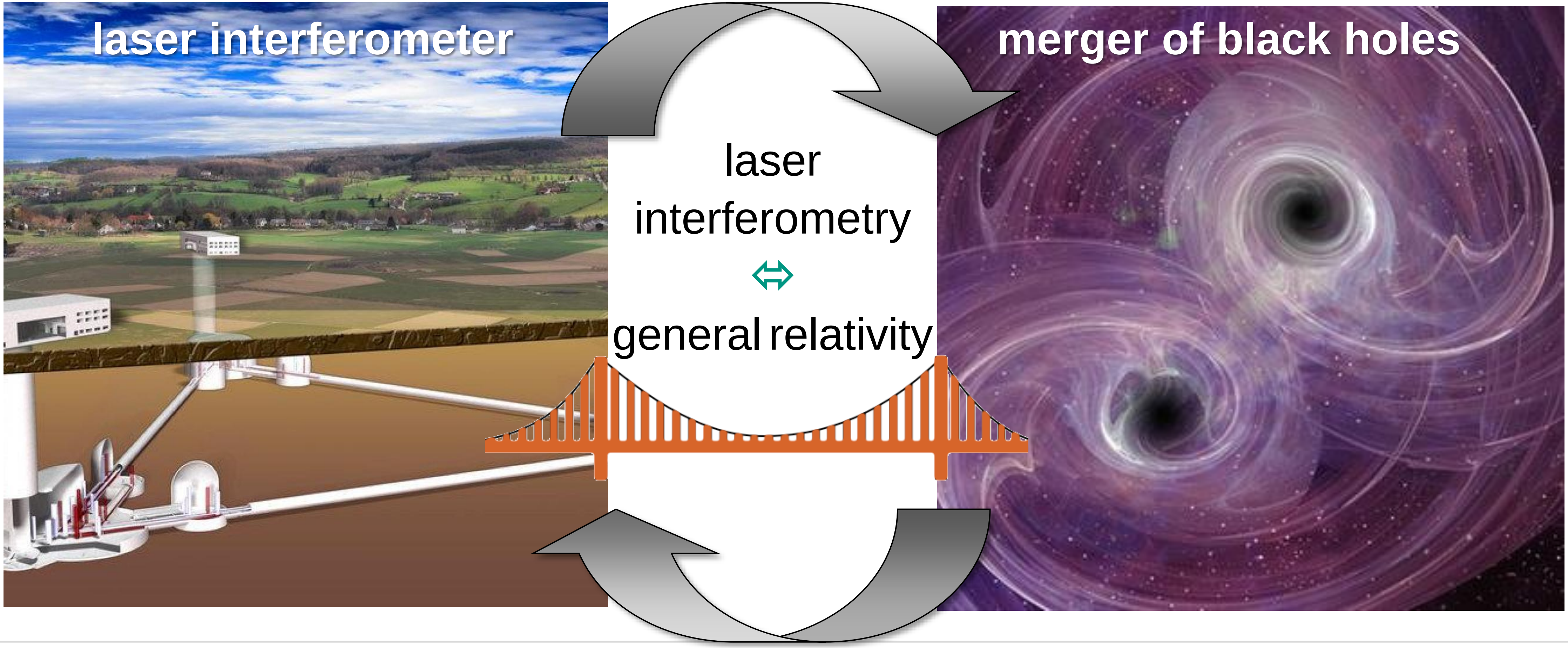
Astro Particle Physics – cross connections #2

- …from **neutralinos** to **dark matter** in the cosmos…



Astro Particle Physics – cross connections #3

- …from gravitational waves to black holes & strong gravity (GR*)



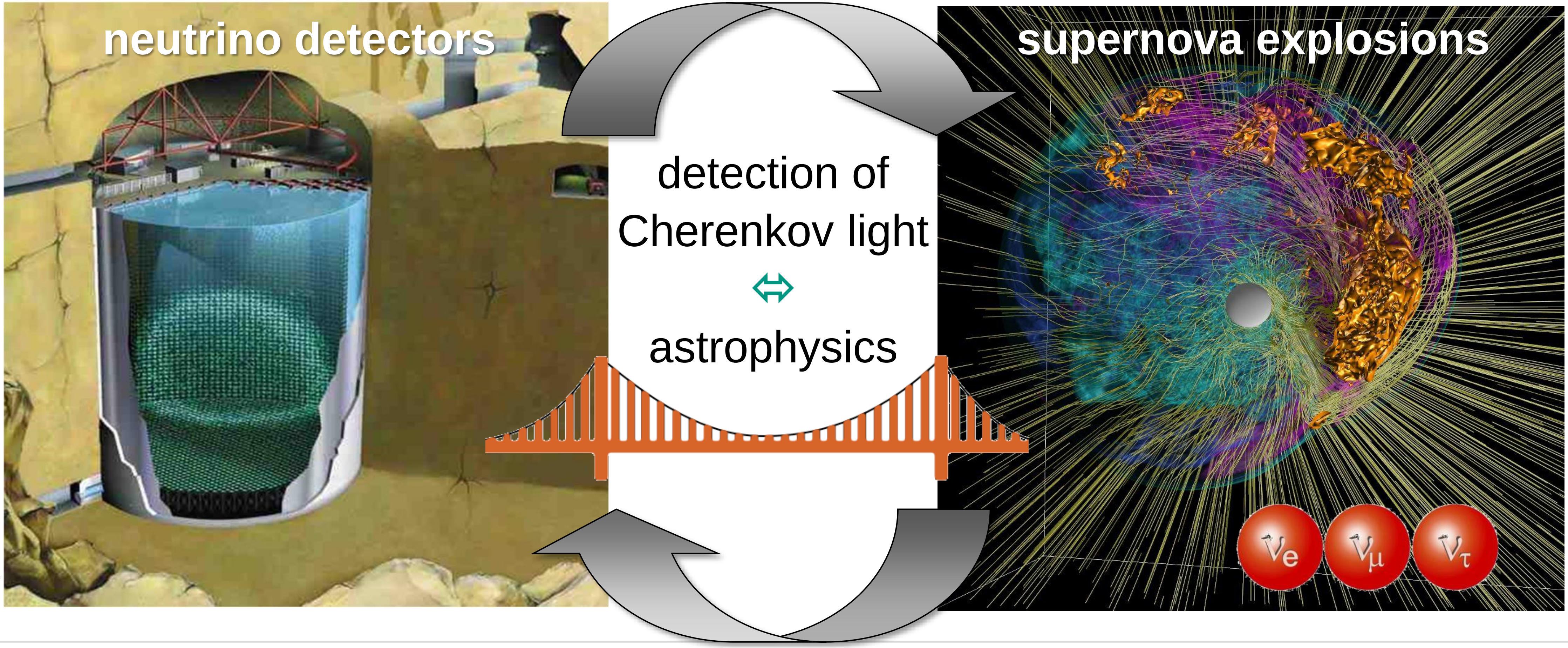
Q: NIKHEF, ET

Q: visuals unlimited

*General Relativity

AstroParticlePhysics – cross connections #4

- …from **neutrino detectors** to **core-collapse supernovae**

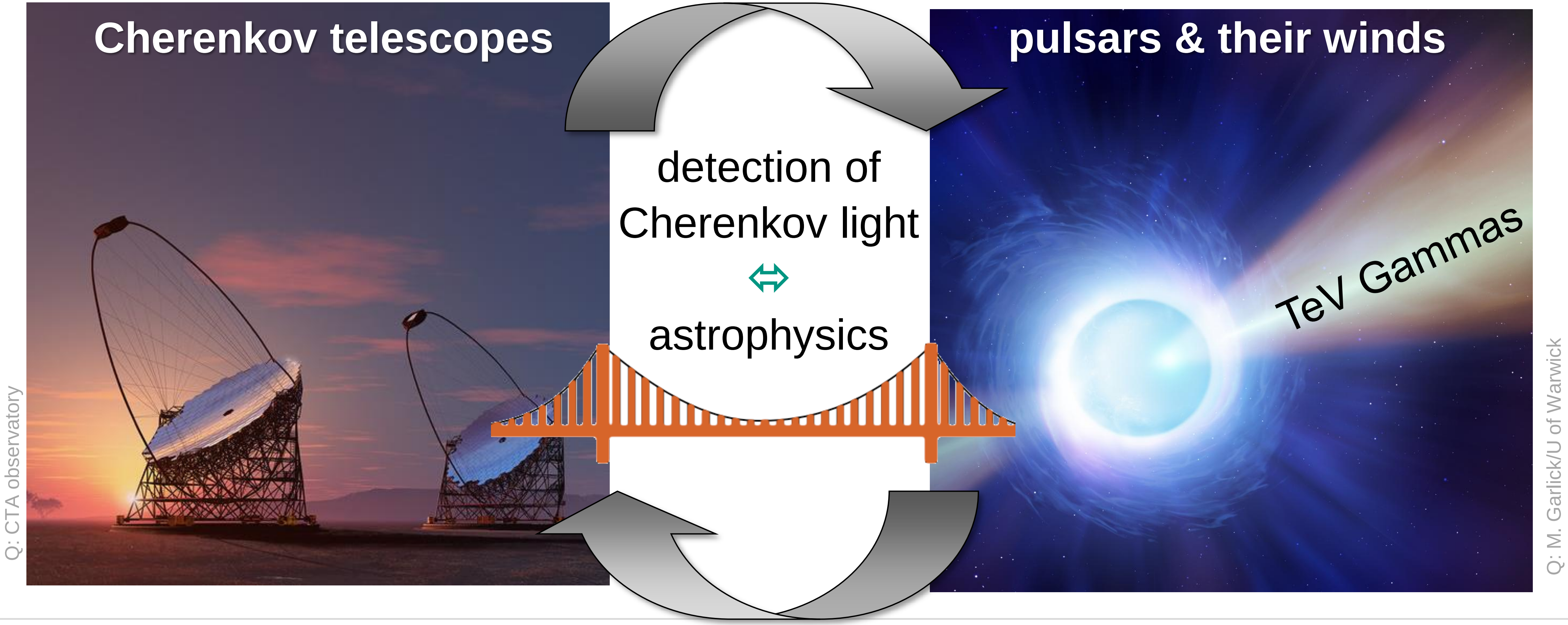


Q: scientific american

Q: ORNL

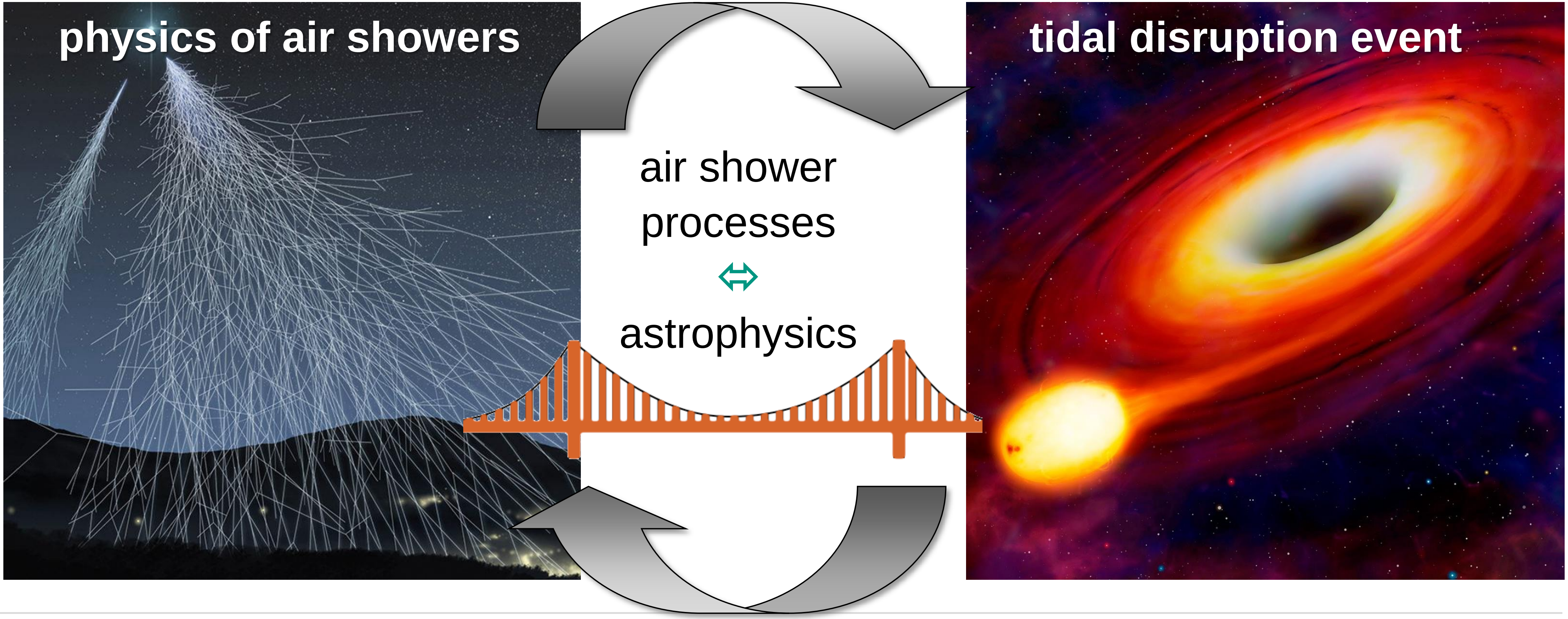
AstroParticlePhysics – cross connections #5

- …from **TeV-Cherenkov telescopes** to **pulsar wind nebulae**



AstroParticlePhysics – cross connections #6

- …from **air shower arrays** to **cosmic super accelerators**



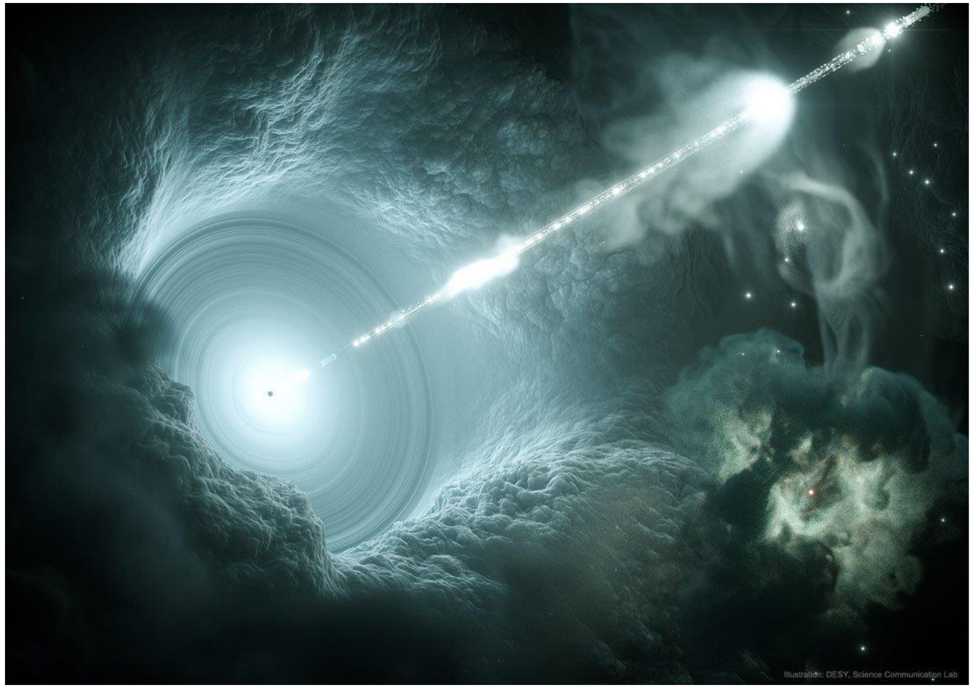
Q: Welt der Physik

UHECR = Ultra-high Energy Cosmic Ray

Astro Particle Physics – recent breakthroughs

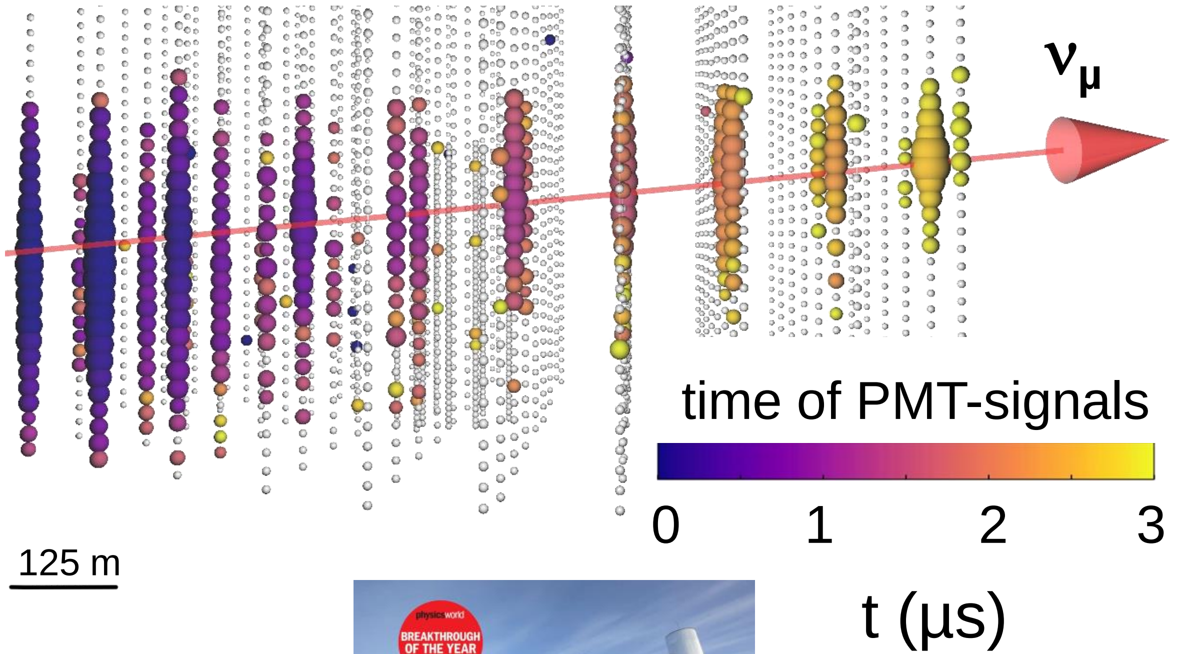
- **…from ultra-high energy neutrinos to blazars…**

´Texas source´: TXS 0506+056
an active supermassive black hole



Blazars as sources for UHE* ν´s

Sept. 22, 2017: IceCube observes
an event with E = 290 TeV



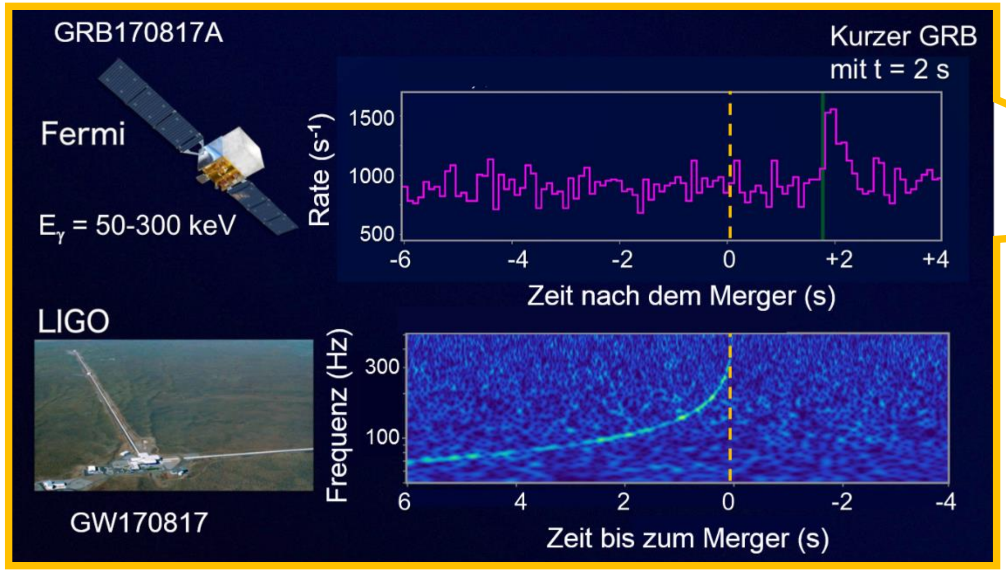
Q: DESY

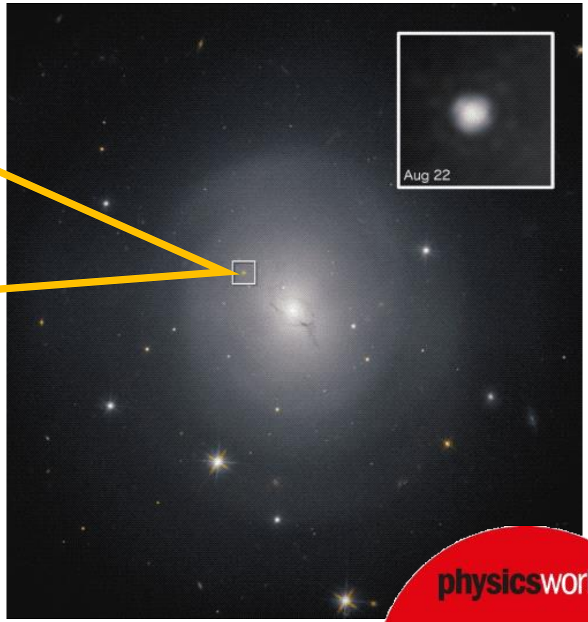
*UHE = ultra-high energy

AstroParticlePhysics – recent breakthroughs

- …from **gravitational waves** to **GRB*s**…

merger process of two neutron stars observed *live*





Q: HST, Fermi, Ligo

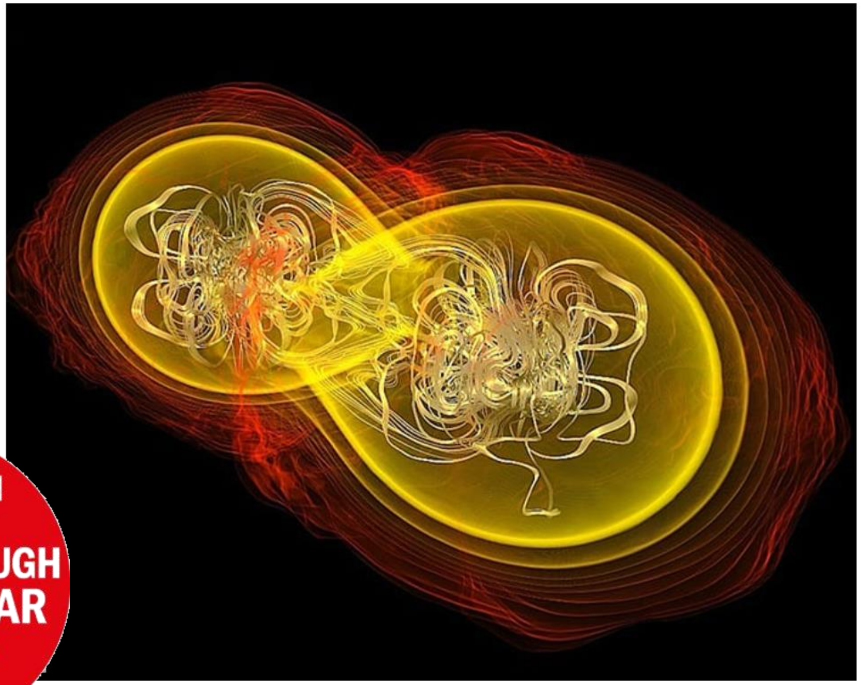
news on the origin of *heavy elements*

ASTRONOMY AND SPACE | NEWS

First multimessenger observation of a neutron-star merger is Physics World 2017 Breakthrough of the Year

11 Dec 2017 Hamish Johnston

The ***Physics World*** 2017 Breakthrough of the Year goes to the international team of astronomers and astrophysicists that ushered in a new era of astronomy by making the first ever multimessenger observation involving gravitational waves. Nine other achievements are highly commended and cover topics ranging from topological physics to Egyptology and more.



…hrouded in mystery: artist's impression of merging neutron stars

Q: physics world

*GRB = Gamma Ray Burst

Astro **P**article **P**hysics – a very recent observation

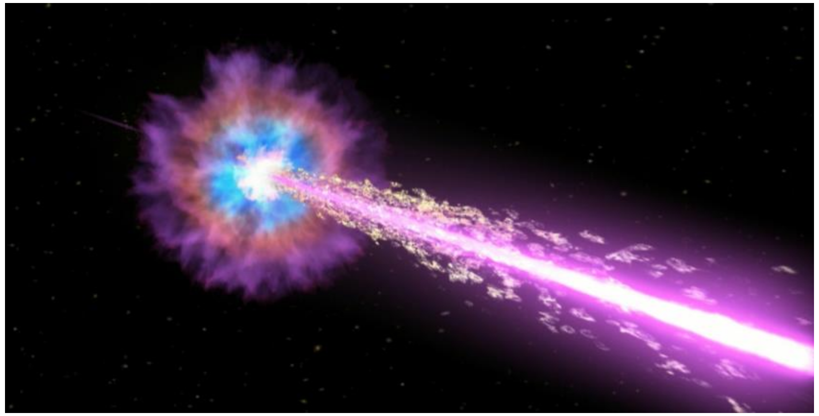
- **…a unique record GRB occured only ~ two weeks (October 9, 2022) ago…**

  - collapse of a massive star to a black hole

generation of a very long burst (~10 h) of gamma rays with peak energies up to 14 TeV

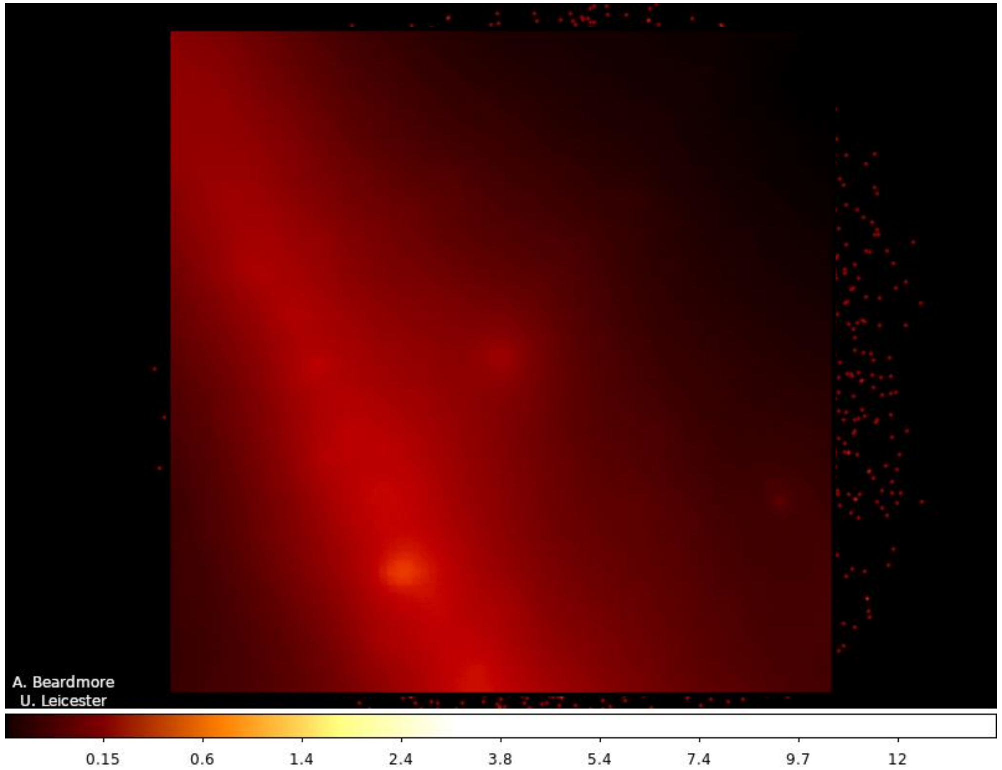
HOT TOPIC

GRB occured at a distance d = 2 Gpc
here: light reflection at dust grains in between



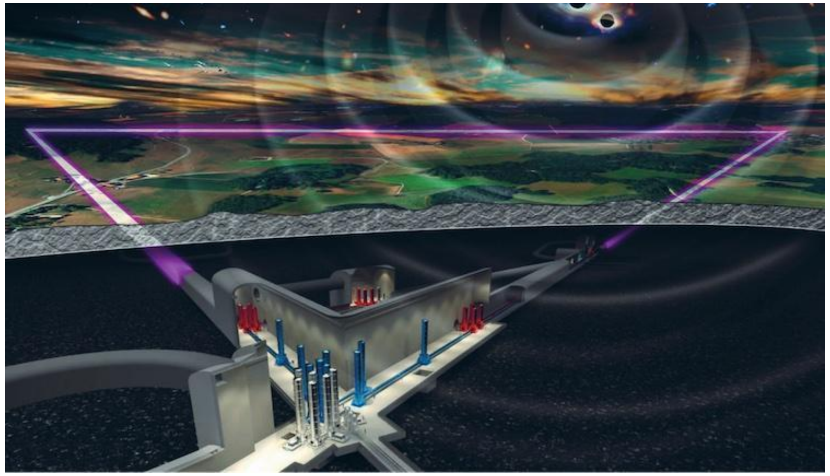
OCTOBER 15, 2022

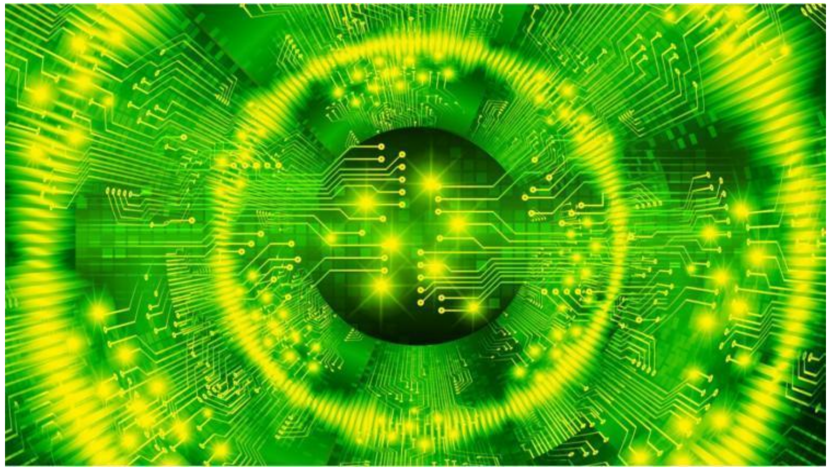
Record-breaking gamma-ray burst possibly most powerful explosion ever recorded



Astro Particle Physics – future breakthroughs

- **DZA – Deutsches Zentrum für Astrophysik: a new centre in the Lausitz**

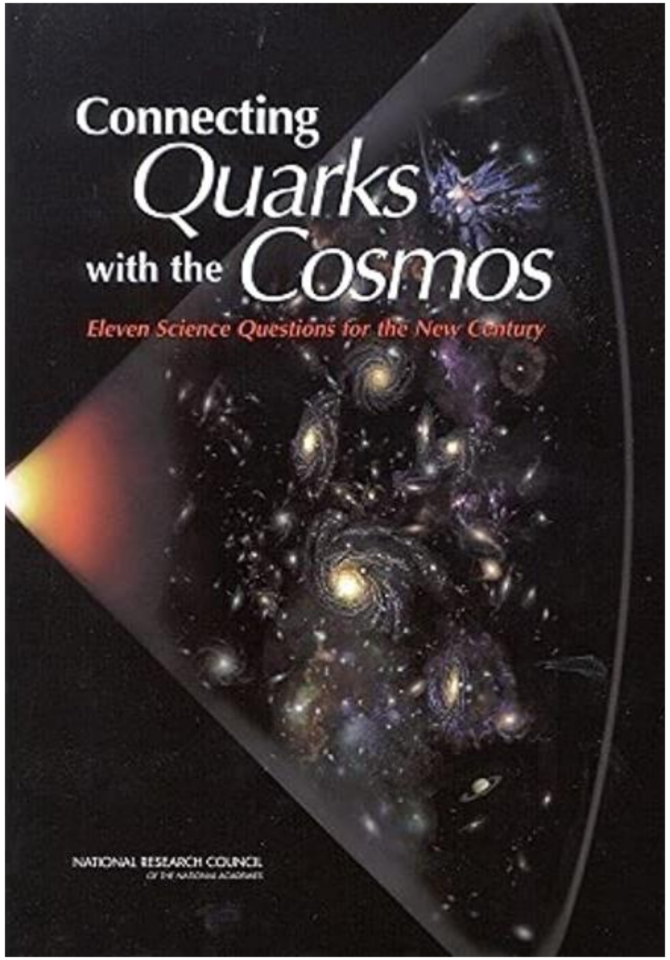


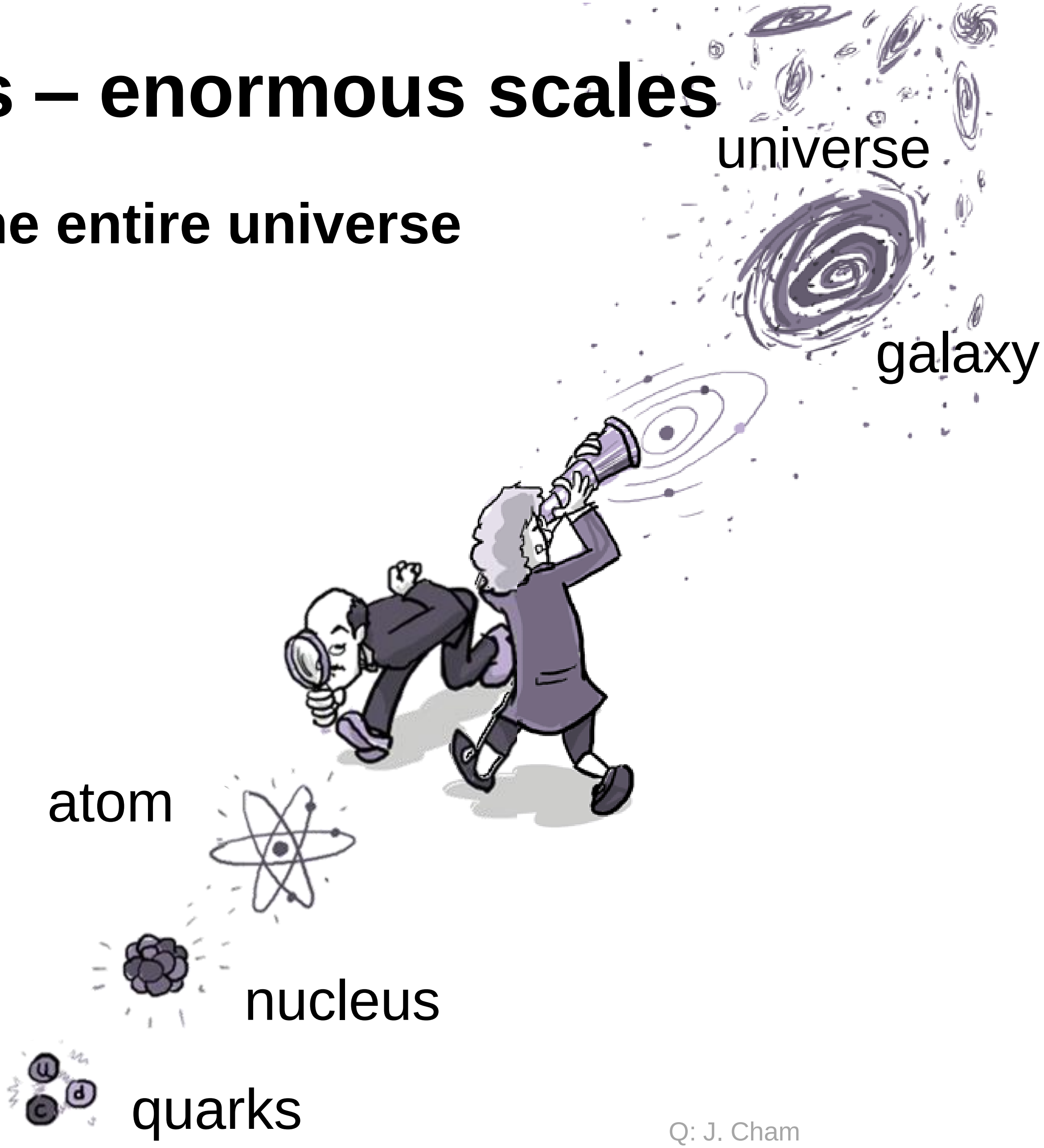


- bundling the activities of German astroparticle physics

Astro Particle Physics – enormous scales

- from the quark scale to the entire universe





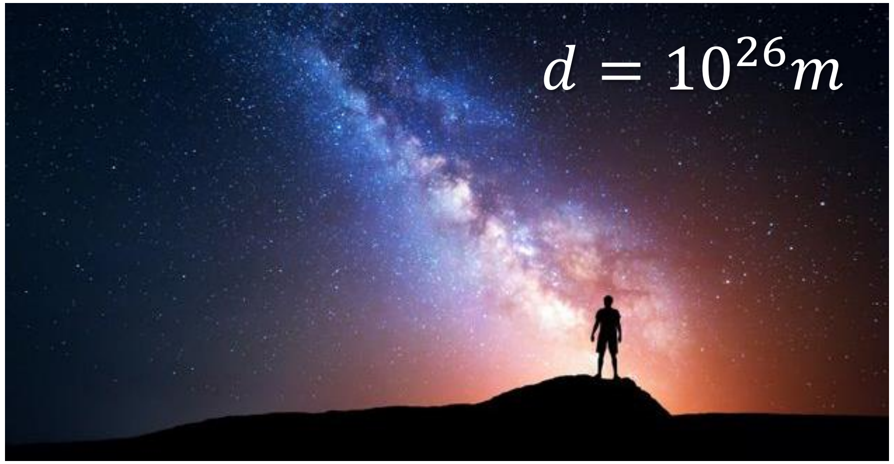
10^{26} m

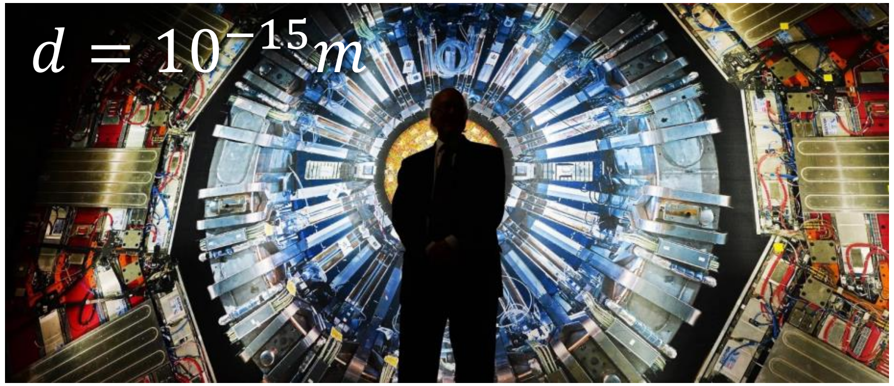
10^{-15} m

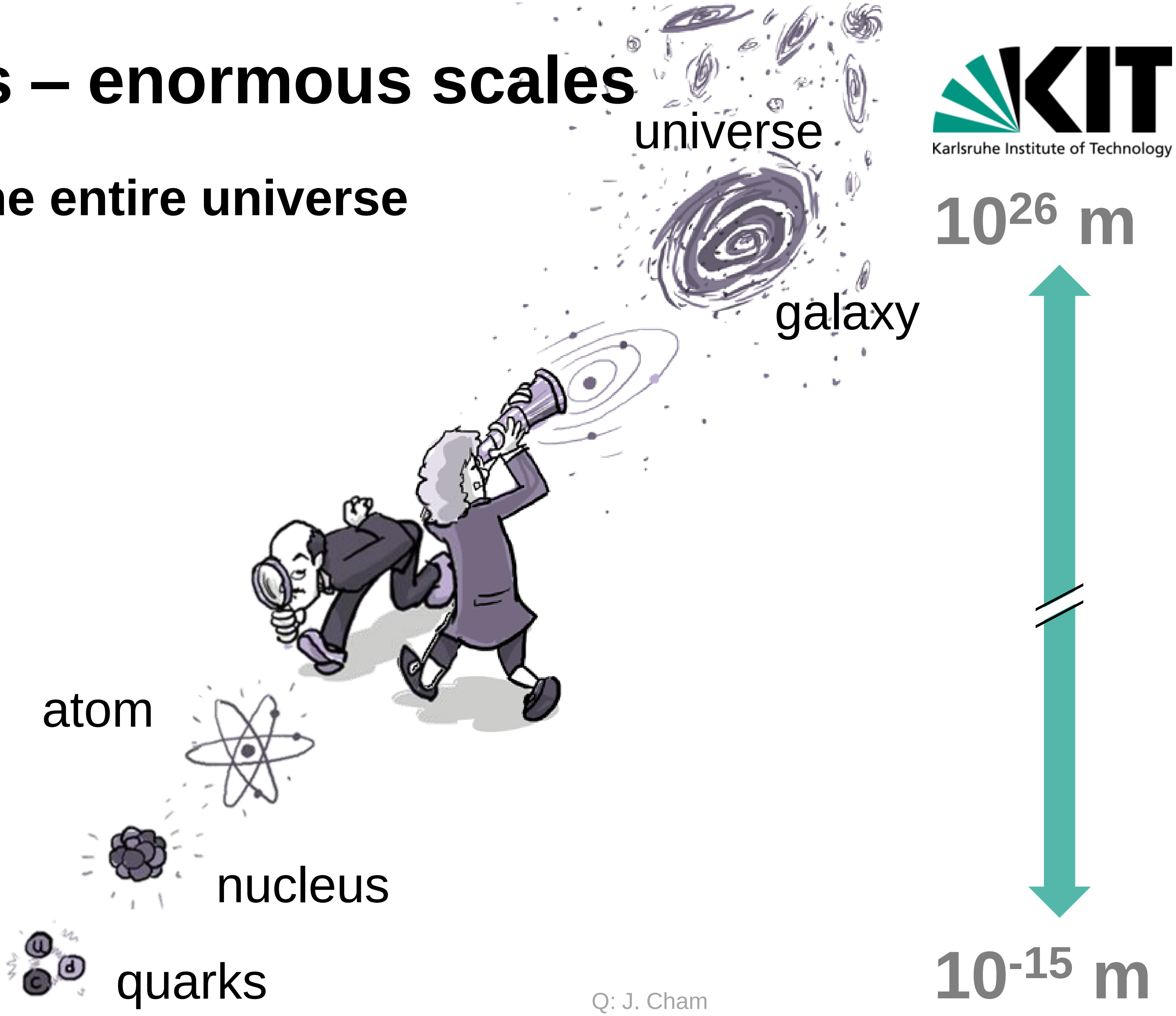
Q: J. Cham

Astro Particle Physics – enormous scales

- from the quark scale to the entire universe



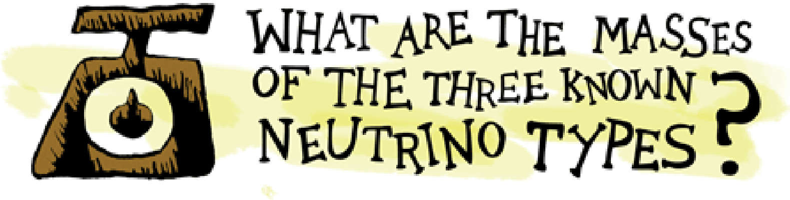


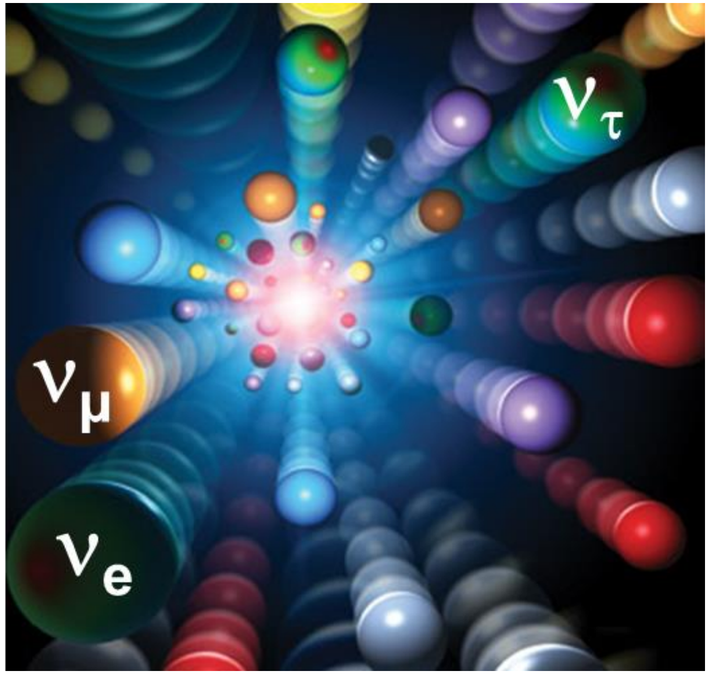


AstroParticlePhysics – open questions

- **what is the nature of neutrinos?**

- we can find out by **observing their role** in the cosmos!





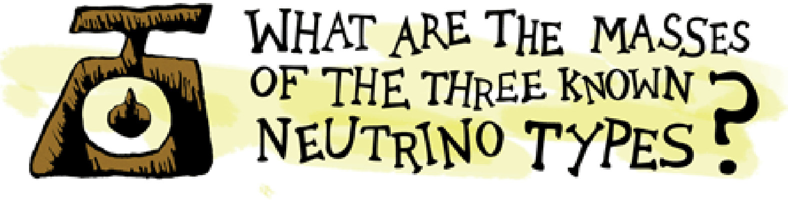
- using our knowledge of cosmic evolution / galaxy formation

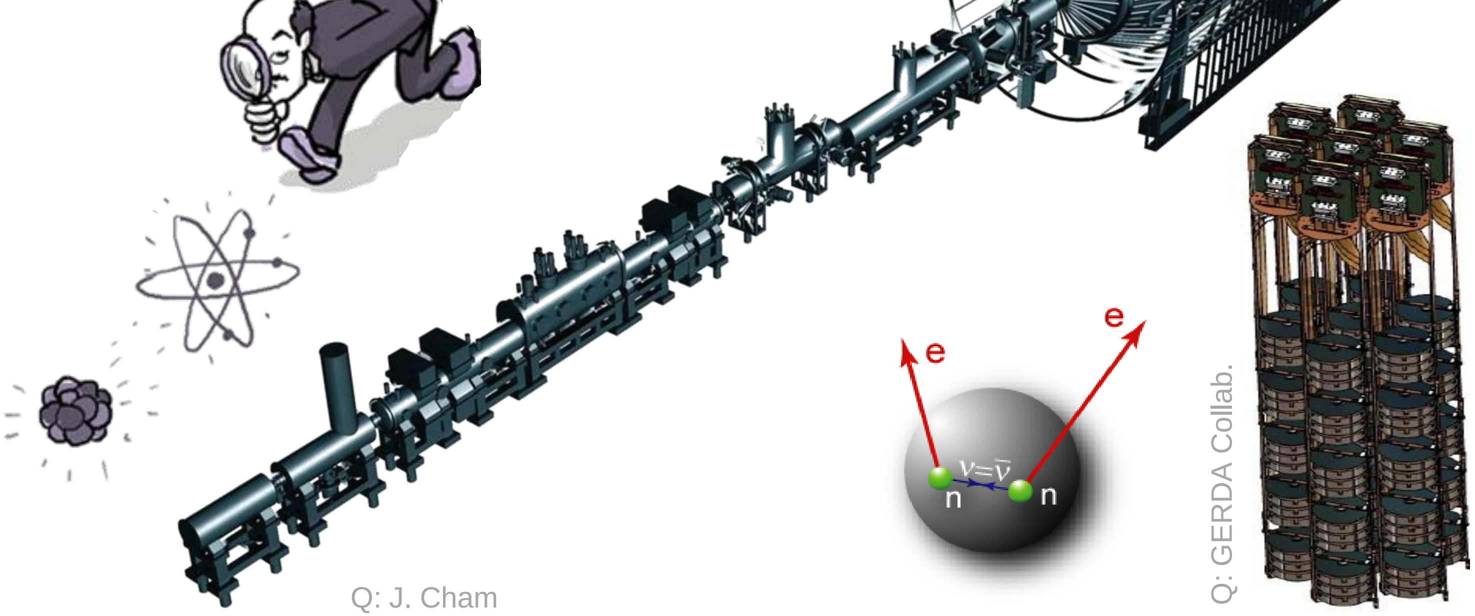
Q: J. Cham

AstroParticlePhysics – open questions

- **what is the nature of neutrinos?**

- we can find out by doing **experiments** in the lab!





Q: J. Cham

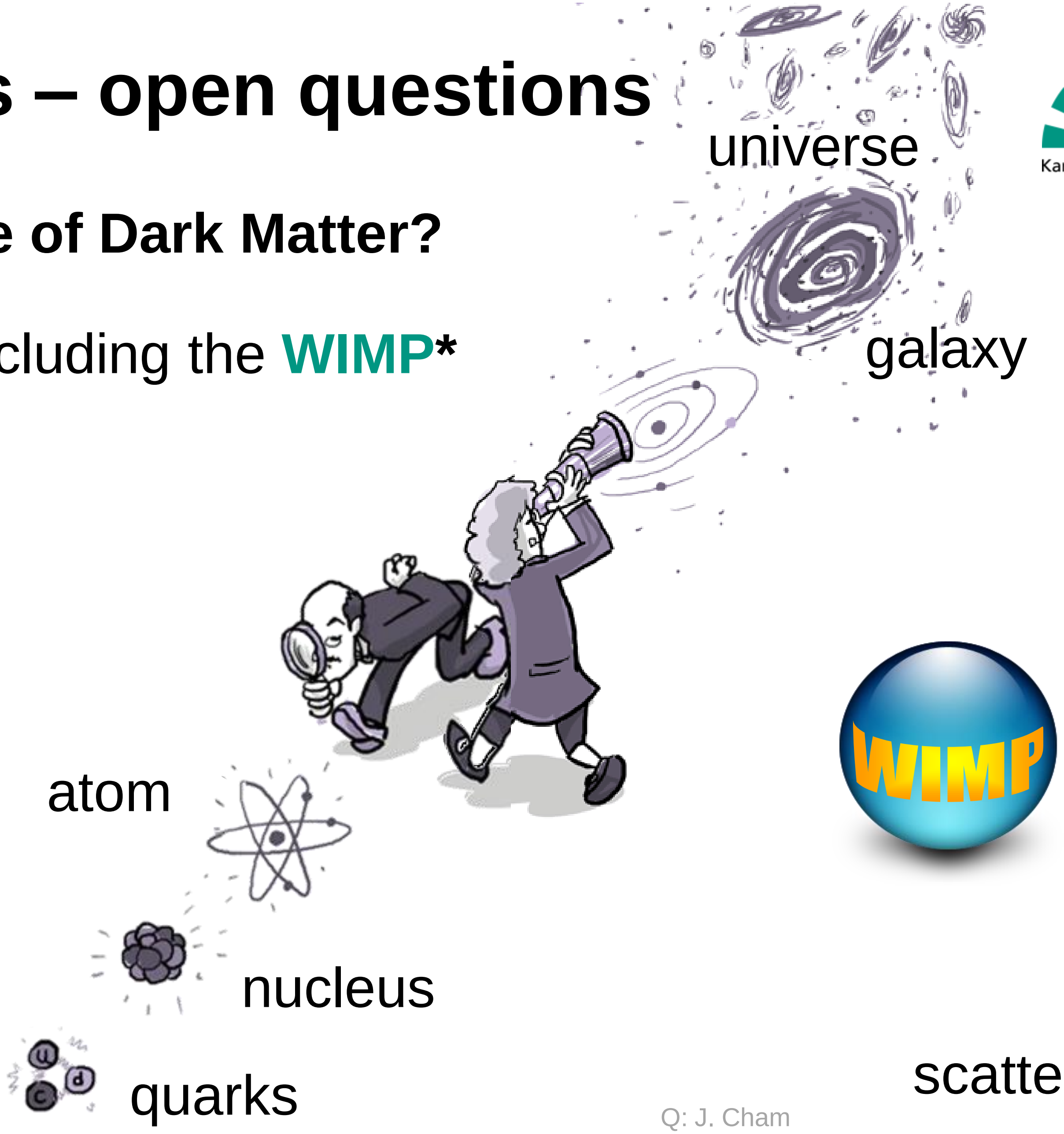
Q: GERDA Collab.

- using our knowledge of ß-decay theory

Astro Particle Physics – open questions

- **what is the particle nature of Dark Matter?**

- there are many candidates, including the **WIMP***



*

dark halo

scattering process

- how can we detect them?

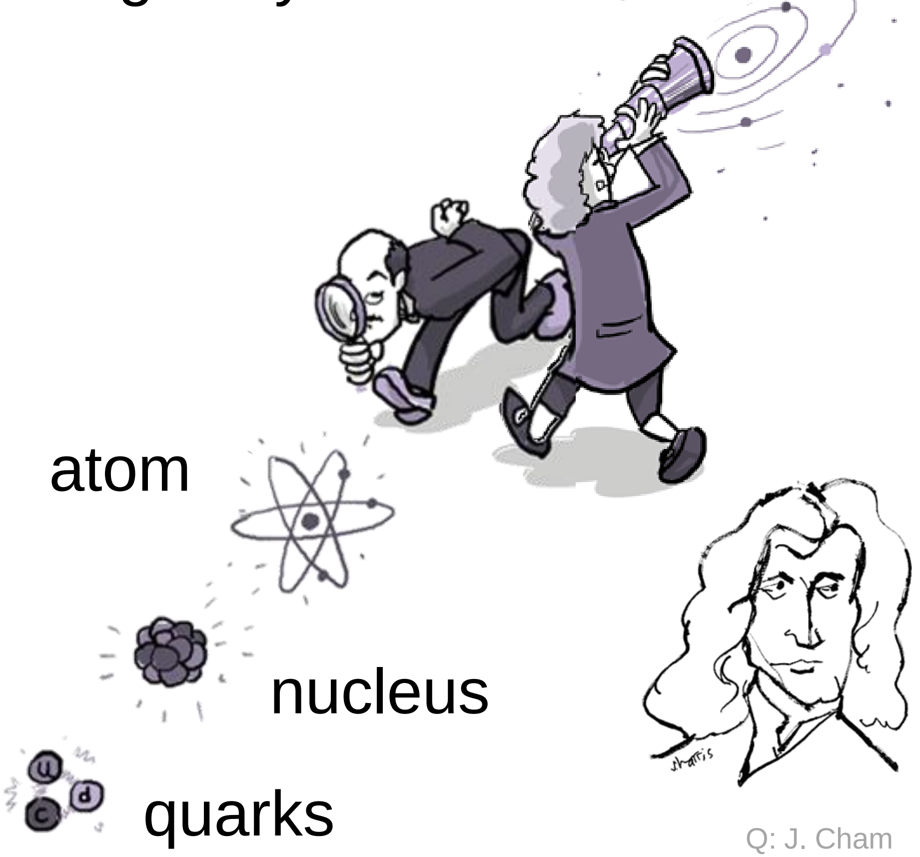
- how to measure their mass?

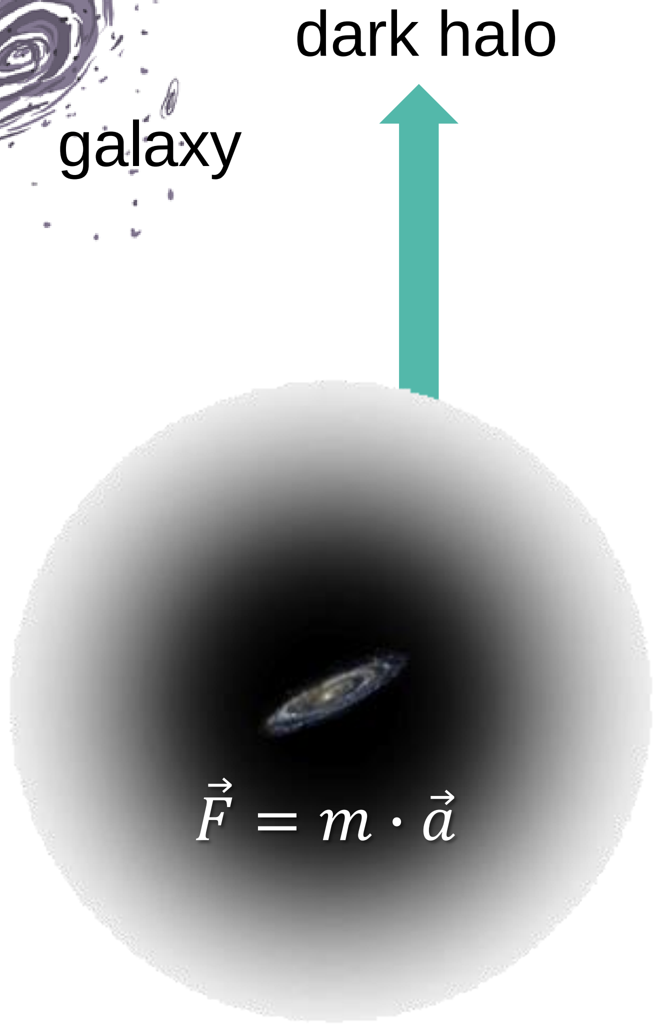
* **W**eakly **I**nteracting **M**assive **P**article

AstroParticlePhysics – open questions

- **Are we certain Dark Matter exists?**

- yes, we are! To modify Newtonian gravity does **not** work





- Dark matter halos surround all galaxies, plus other evidences

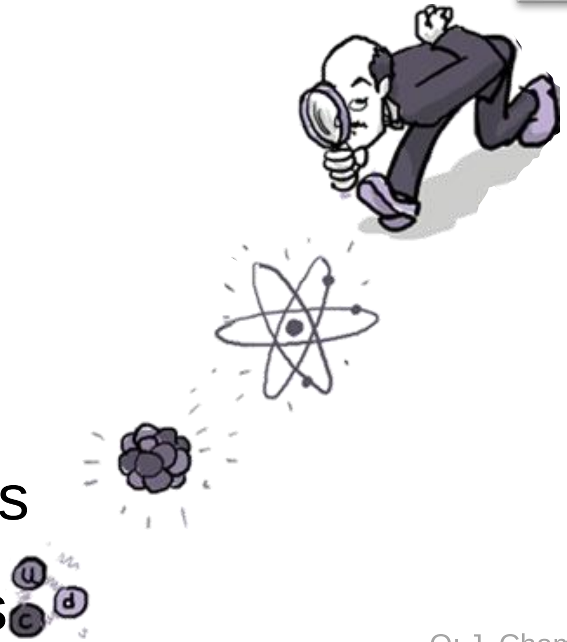
Q: J. Cham

Astro **P**article **P**hysics – open questions

- **what is the particle nature of Dark Matter?**

- we can find out via **detecting it here on Earth**!

Q: CRESST



- using novel advanced detectors

- background reduction methods

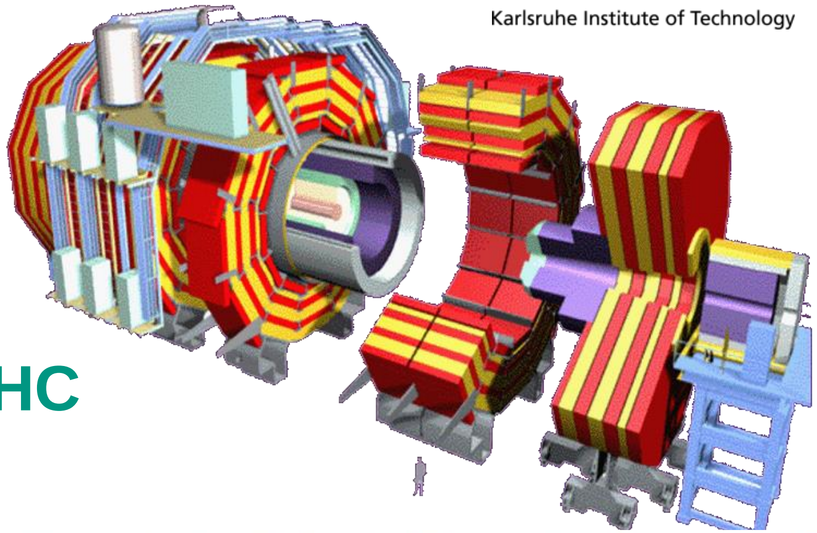
Q: J. Cham

Q: XENON/DARWIN

AstroParticlePhysics – open questions

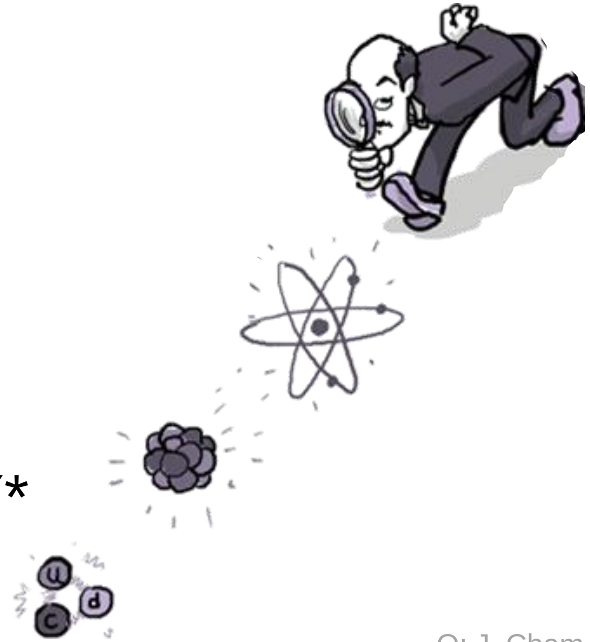
- **what is the particle nature of Dark Matter?**

- we can find out by **producing it** via an accelerator!



Q: CMS

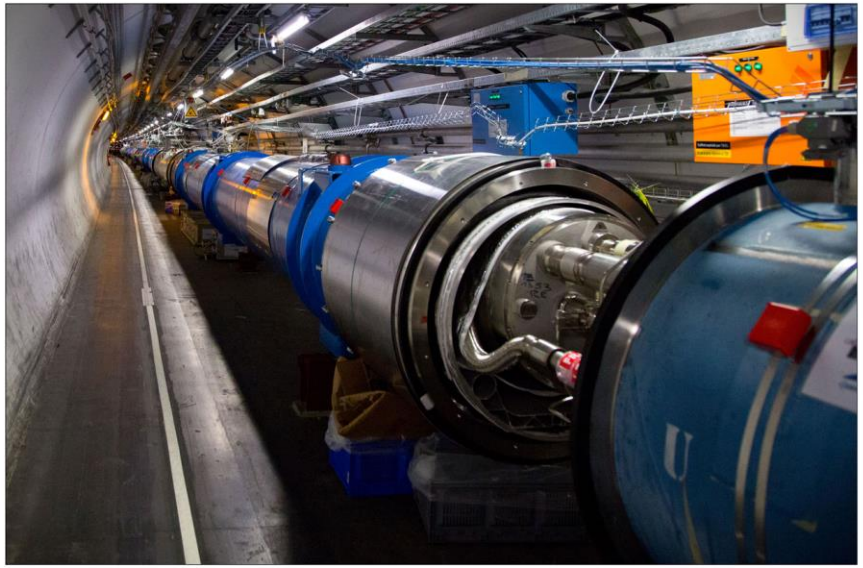
LHC



- using our knowledge of SUSY*

- using our knowledge of LHC

Q: J. Cham, CERN



*Super-Symmetry

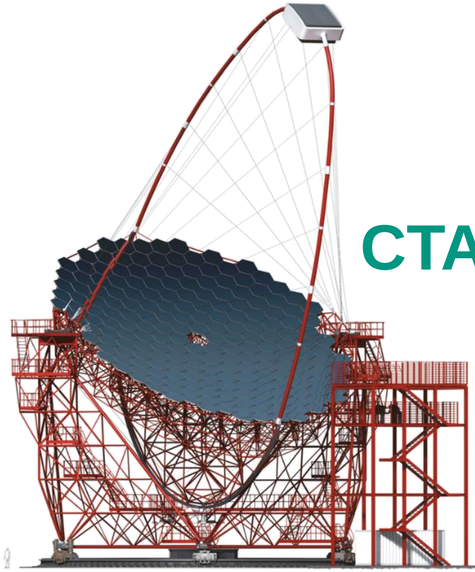
AstroParticlePhysics – open questions

universe

galaxy

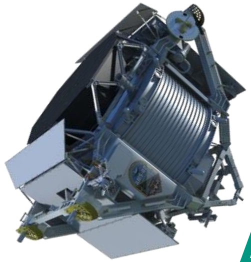
- what is the particle nature of Dark Matter?

- we can find out by **observing its decay** in the cosmos!

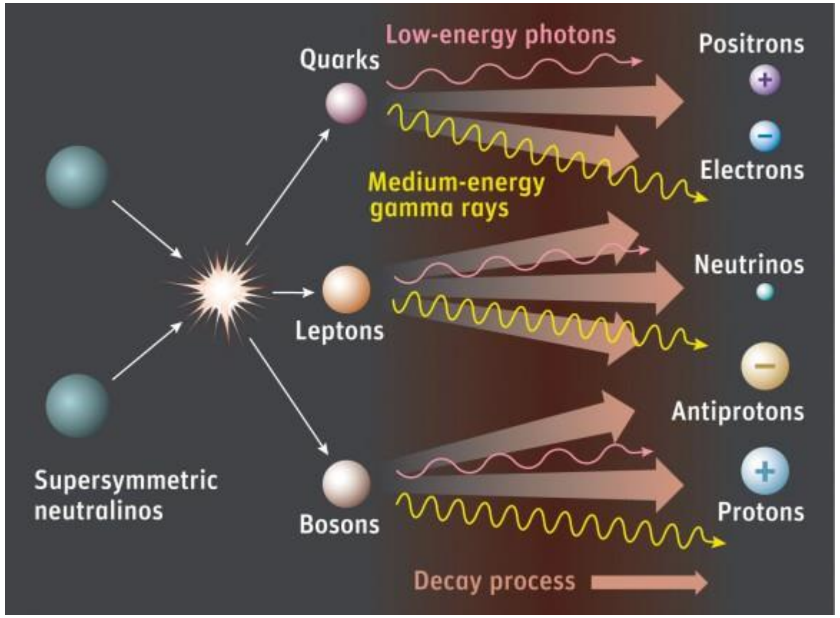


Q: CTA

CTA*



AMS**



- using our knowledge of theory (SUSY)

- using our knowledge of cosmic accelerators

Q: J. Cham

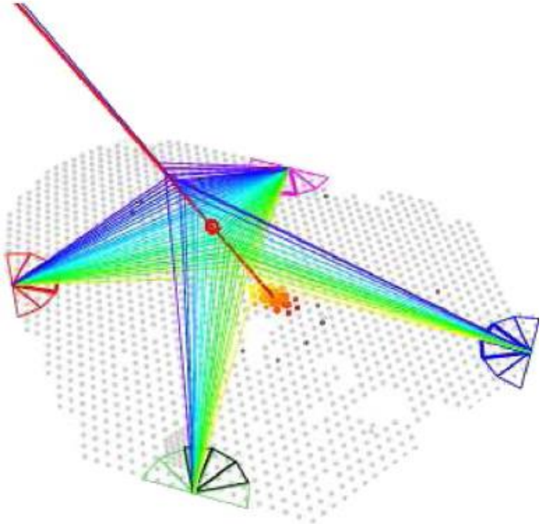
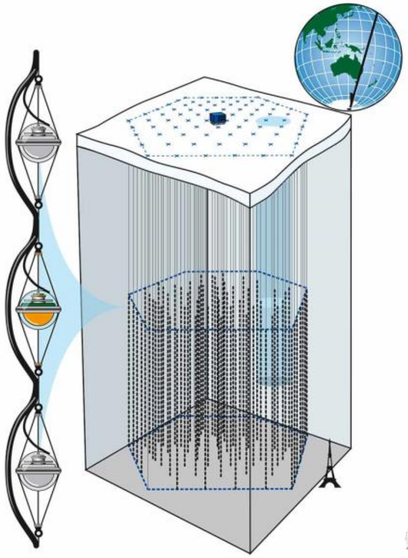
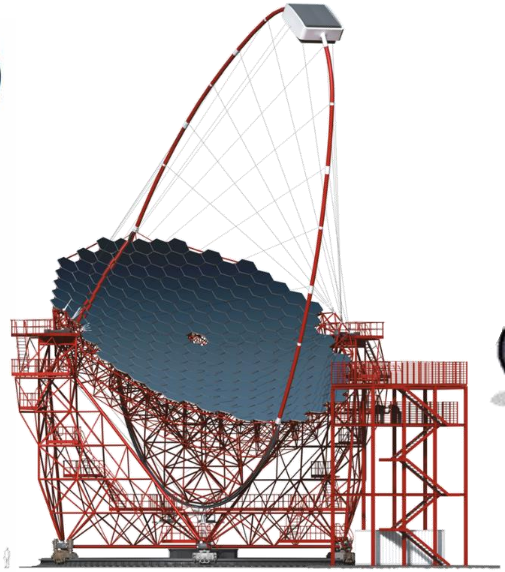
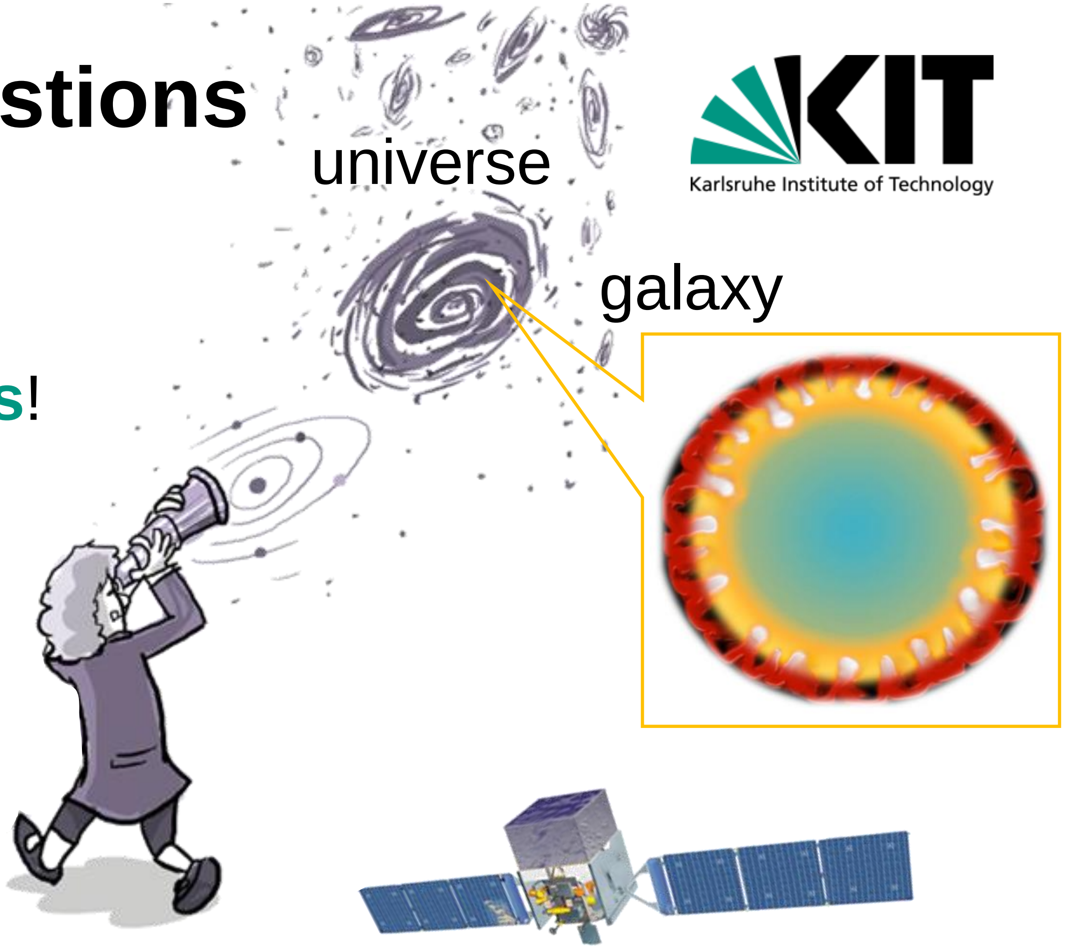
* **C**herenkov **T**elescope **A**rray

** **A**lpha **M**agnetic **S**pectrometer

AstroParticlePhysics – open questions

- **what is the nature of cosmic rays?**

- we can find out by **using different messengers**!

- combing our knowledge of each messenger: gammas, neutrinos, protons & nuclei

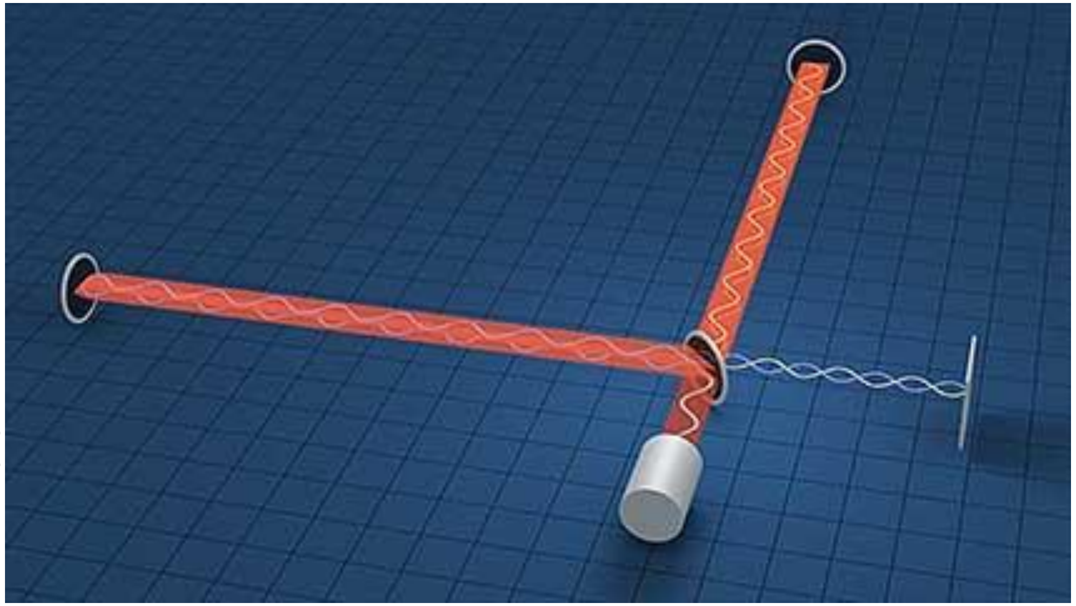
- using our knowledge of magnetic fields

Q: J. Cham

AstroParticlePhysics – open questions

■ what is the nature of gravitational waves

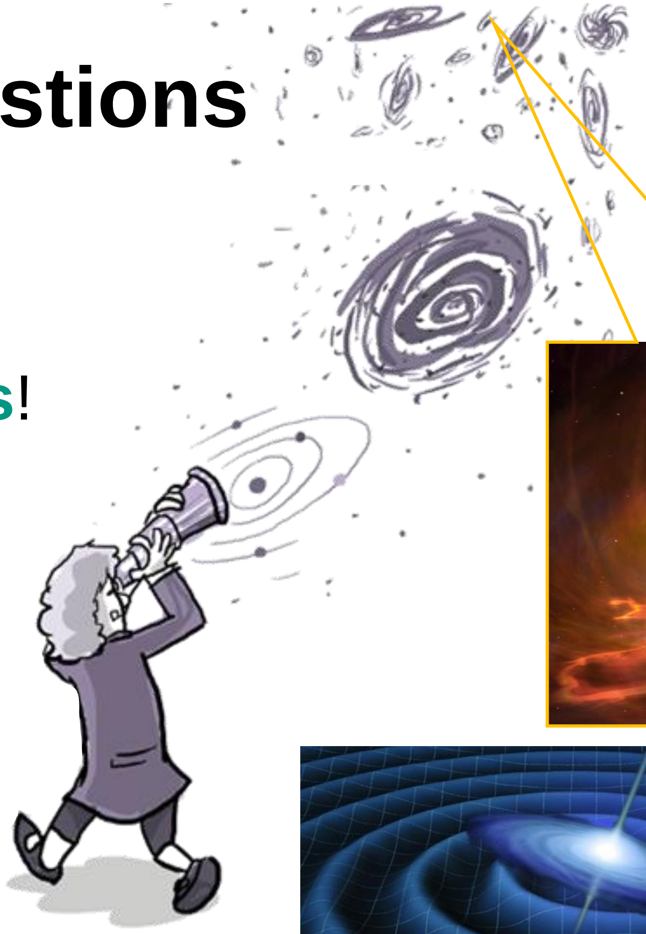
- we can find out by **using laser interferometers**!



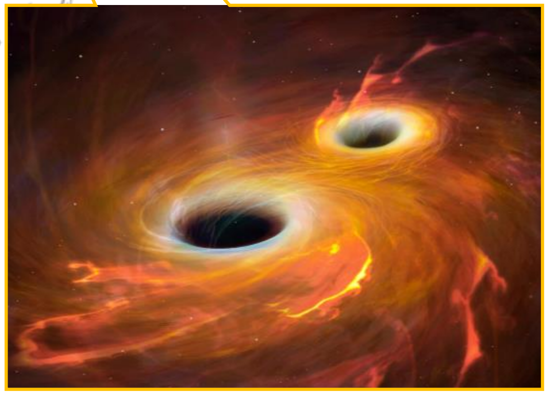
Q: APS physics

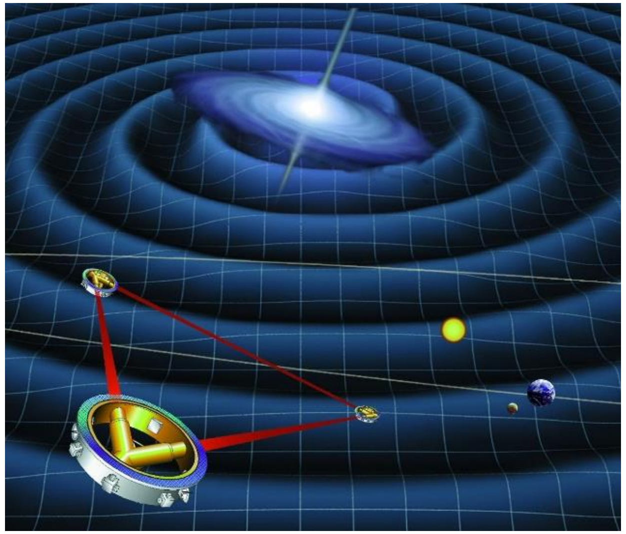
- using our knowledge of general relativity

- combining data from surface of earth & in space



Q: J. Cham

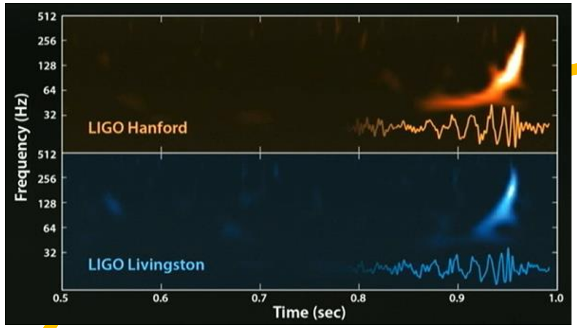




Q: NASA/LISA

AstroParticlePhysics – skills

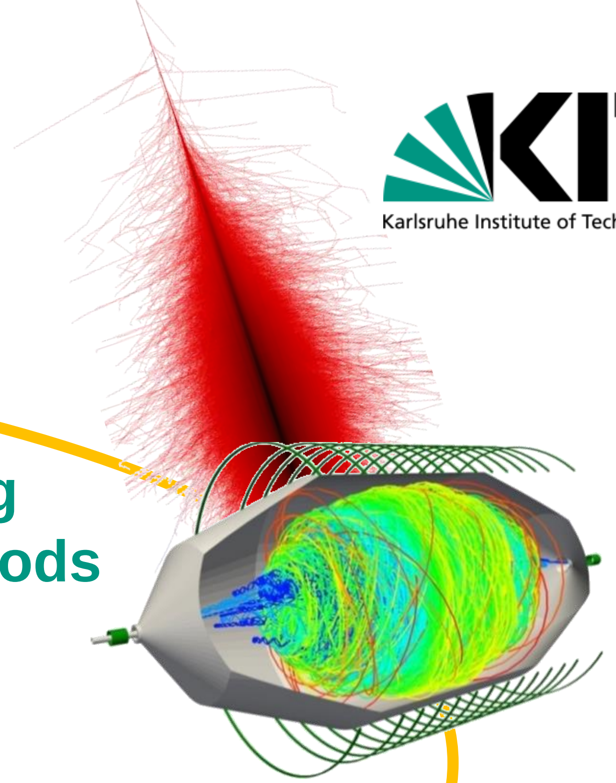
- what skills do I learn in this lecture series?



Q: LIGO

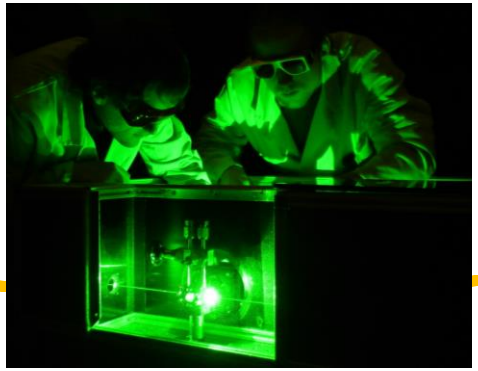
HOT TOPIC

hands-on
TRAINING

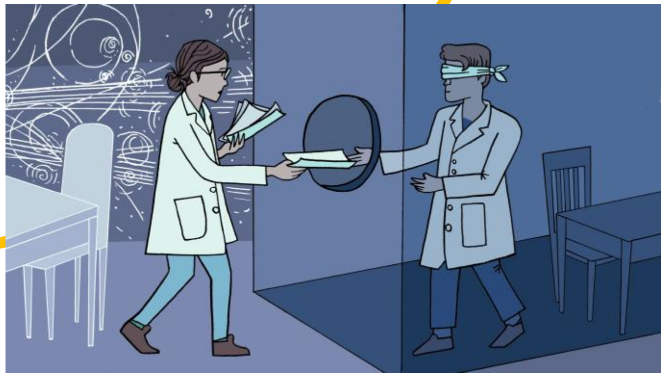


leading
MC-methods

modern detectors



advanced technologies



analysis techniques

Astro Particle Physics – skills

Karlsruhe Institute of Technology

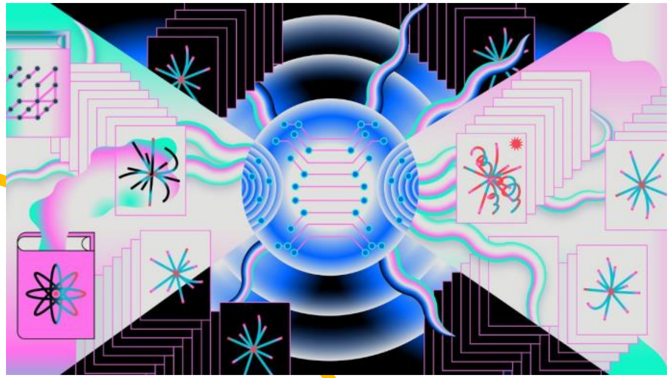
- what skills do I learn in this lecture series?

arXiv

HOT TOPIC

hands-on
TRAINING

modern electronics



Q: symmetry magazine (2)

Q: wikipedia

modern astrophysics

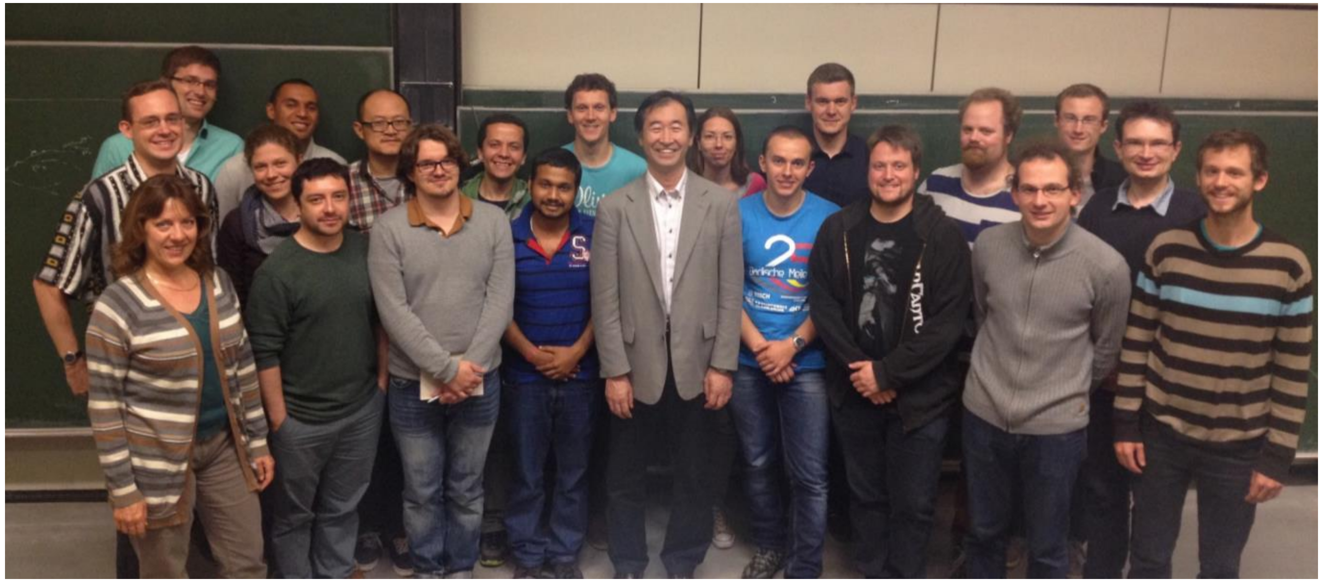
latest particle theory models

Astro Particle Physics – science network

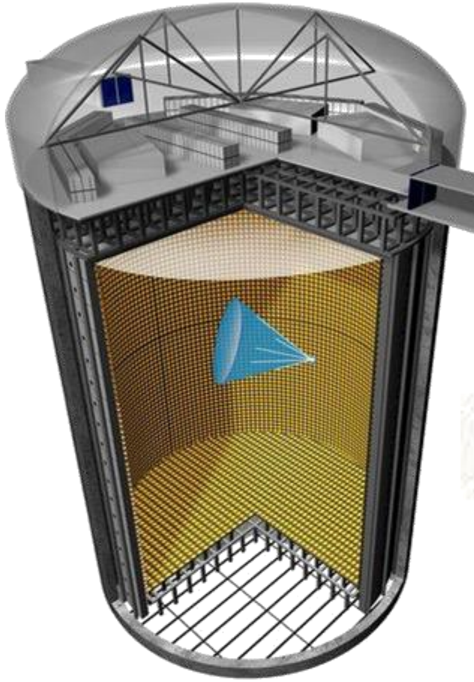
Karlsruhe Institute of Technology

- **What conncetions does APP provide? Meet and greet… a Nobel Laureate**

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald "for the discovery of neutrino oscillations, which shows that neutrinos have mass."



July 10, 2014 – Takaaki Kajita @ kl. HS A



Nobelprize.org
The Official Web Site of the Nobel Prize

Takaaki Kajita

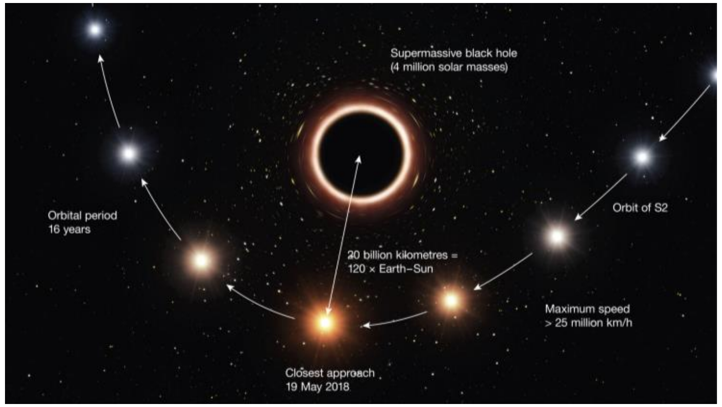
Astro Particle Physics – science network

- **What conncetions does APP provide? Meet and greet… a Nobel Laureate**

The Nobel Prize in Physics 2020 was divided, the other half jointly to Reinhard Genzel and Andrea Ghez "for the discovery of a supermassive compact object at the centre of our galaxy"

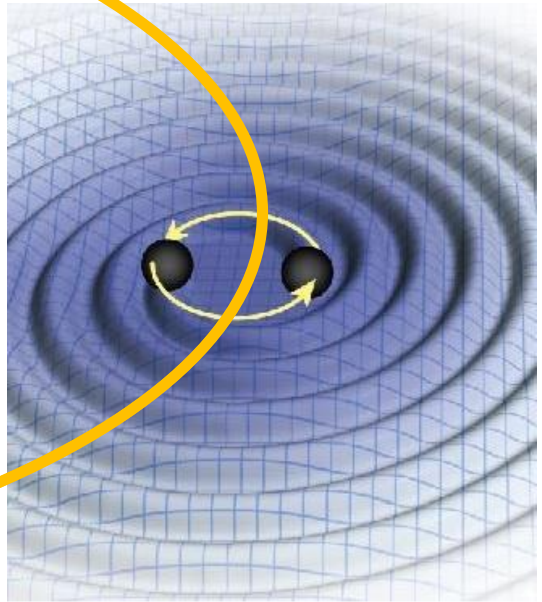
October 4/5, 2022 – R. Genzel @ KIT / KATRIN

Nobelprize.org
The Official Web Site of the Nobel Prize



Reinhard Genzel

- and the winner is…



Einstein's waves win Nobel Prize in physics

By Paul Rincon and Jonathan Amos
BBC Science News

Nobel Prize in Physics 2017

© Nobel Media. Ill. N. Elmehed
Rainer Weiss

The Nobel Prize in Physics 2017 was divided, one half awarded to Rainer Weiss, the other half jointly to Barry C. Barish and Kip S. Thorne *"for decisive contributions to the LIGO detector and the observation of gravitational waves"*.

Nobelprize.org
The Official Web Site of the Nobel Prize

© Nobel Media. Ill. N. Elmehed
Barry C. Barish

© Nobel Media. Ill. N. Elmehed
Kip S. Thorne

Q: BBC

AstroParticlePhysics – topic events (2021 ed.)

- what was new in this lecture series? Interruption of TeV-gamma views…

Q: MAGIC

direct view from MAGIC to volcanic eruption at the Cumbre Vieja (Santa Cruz de Tenerife)

Astro Particle Physics – topic events (2022 ed.)

Karlsruhe Institute of Technology

- what is new this semester in this lecture series?

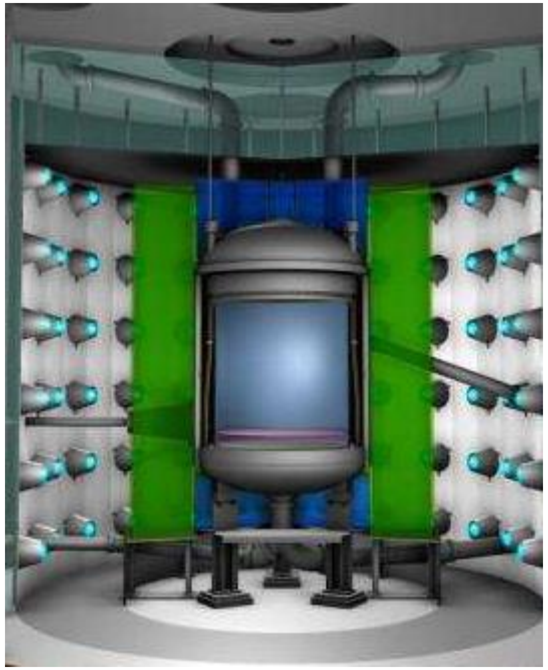
arXiv:2207.03764v2 [hep-ex] 18 Jul 2022

First Dark Matter Search Results from the LUX-ZEPLIN (LZ) Experiment

J. Aalbers,[1,2] D.S. Akerib,[1,2] C.W. Akerlof,[3] A.K. Al Musalhi,[4] F. Alder,[5] A. Alqahtani,[6] S.K. Alsum,[7] C.S. Amarasinghe,[3] A. Ames,[1,2] T.J. Anderson,[1,2] N. Angelides,[5,8] H.M. Araújo,[8] J.E. Armstrong,[9] M. Arthurs,[3] S. Azadi,[10] A.J. Bailey,[8] A. Baker,[8] J. Balajthy,[11] S. Balashov,[12] J. Bang,[6] J.W. Bargemann,[10] M.J. Barry,[13] J. Barthel,[14] D. Bauer,[8] A. Baxter,[15] K. Beattie,[13] J. Belle,[16] P. Beltrame,[5,17] J. Bensinger,[18] T. Benson,[7] E.P. Bernard,[13,19] A. Bhatti,[9] A. Biekert,[13,19] T.P. Biesiadzinski,[1,2] H.J. Birch,[3,15] B. Birrittella,[7] G.M. Blockinger,[20] K.E. Boast,[4] B. Boxer,[11,15] R. Bramante,[1,2] C.A.J. Brew,[12] P. Brás,[21] J.H. Buckley,[22] V.V. Bugaev,[22] S. Burdin,[15] J.K. Busenitz,[23] M. Buuck,[1,2] R. Cabrita,[21] C. Carels,[4] D.L. Carlsmith,[7] B. Carlson,[14] M.C. Carmona-Benitez,[24] M. Cascella,[5] C. Chan,[6] A. Chawla,[25] H. Chen,[13] J.J. Cherwinka,[7] N.I. Chott,[26] A. Cole,[13] J. Coleman,[13] M.V. Converse,[27] A. Cottle,[4,16] G. Cox,[14,24] W.W. Craddock,[1] O. Creaner,[13] D. Curran,[14] A. Currie,[8] J.E. Cutter,[11] C.E. Dahl,[16,28] A. David,[5] J. Davis,[14] T.J.R. Davison,[17] J. Delgaudio,[14] S. Dey,[4] L. de Viveiros,[24] A. Dobi,[13] J.E.Y. Dobson,[5] E. Druszkiewicz,[27] A. Dushkin,[18] T.K. Edberg,[9] W.R. Edwards,[13] M.M. Elnimr,[23] W.T. Emmet,[29] S.R. Eriksen,[30] C.H. Faham,[13] A. Fan,[1,2,*] S. Fayer,[8] N.M. Fearon,[4] S. Fiorucci,[13] H. Flaecher,[30] P. Ford,[12] V.B. Francis,[12] E.D. Fraser,[15] T. Fruth,[4,5] R.J. Gaitskell,[6] N.J. Gantos,[13] D. Garcia,[6] A. Geffre,[14] V.M. Gehman,[13] J. Genovesi,[26] C. Ghag,[5] R. Gibbons,[13,19] E. Gibson,[4] M.G.D. Gilchriese,[13] S. Gokhale,[31] B. Gomber,[7] J. Green,[4] A. Greenall,[15] S. Greenwood,[8] M.G.D.van der Grinten,[12] C.B. Gwilliam,[15] C.R. Hall,[9] S. Hans,[31] K. Hanzel,[13] A. Harrison,[26] E. Hartigan-O'Connor,[6] S.J. Haselschwardt,[13] S.A. Hertel,[32] G. Heuermann,[3] C. Hjemfelt,[26] M.D. Hoff,[13] E. Holtom,[12] J.Y-K. Hor,[23] M. Horn,[14] D.Q. Huang,[3,6] D. Hunt,[4] C.M. Ignarra,[1,2] R.G. Jacobsen,[13,19] O. Jahangir,[5] R.S. James,[5] S.N. Jeffery,[12] W. Ji,[1,2] J. Johnson,[11] A.C. Kaboth,[12,25,†] A.C. Kamaha,[20,33] K. Kamdin,[13,19] V. Kasey,[8] K. Kazkaz,[34] J. Keefner,[14] D. Khaitan,[27] M. Khaleeq,[8] A. Khazov,[12] I. Khurana,[5] Y.D. Kim,[35] C.D. Kocher,[6] D. Kodroff,[24] L. Korley,[3,18] E.V. Korolkova,[36] J. Kras,[7] H. Kraus,[4] S. Kravitz,[13] H.J. Krebs,[1] L. Kreczko,[30] B. Krikler,[30] V.A. Kudryavtsev,[36] S. Kyre,[10] B. Landerud,[7] E.A. Leason,[17] C. Lee,[1,2] J. Lee,[35] D.S. Leonard,[35] R. Leonard,[26] K.T. Lesko,[13] C. Levy,[20] J. Li,[35] F.-T. Liao,[4] J. Liao,[6] J. Lin,[4,13,19] A. Lindote,[21] R. Linehan,[1,2] W.H. Lippincott,[10,16] R. Liu,[6] X. Liu,[17] Y. Liu,[7] C. Loniewski,[27] M.I. Lopes,[21] E. Lopez Asamar,[21] B. López Paredes,[8] W. Lorenzon,[3] D. Lucero,[14] S. Luitz,[1] J.M. Lyle,[6] P.A. Majewski,[12] J. Makkinje,[6] D.C. Malling,[6] A. Manalaysay,[11,13] L. Manenti,[5] R.L. Mannino,[7] N. Marangou,[8] M.F. Marzioni,[17] C. Maupin,[14] M.E. McCarthy,[27] C.T. McConnell,[13] D.N. McKinsey,[13,19] J. McLaughlin,[28] Y. Meng,[23] J. Migneault,[6] E.H. Miller,[1,2,26] E. Mizrachi,[9,34] J.A. Mock,[13,20] A. Monte,[10,16] M.E. Monzani,[1,2,37] J.A. Morad,[11] J.D. Morales Mendoza,[1,2] E. Morrison,[26] B.J. Mount,[38] M. Murdy,[32] A.St.J. Murphy,[17] D. Naim,[11] A. Naylor,[36] C. Nedlik,[32] C. Nehrkorn,[10] H.N. Nelson,[10] F. Neves,[21] A. Nguyen,[17] J.A. Nikoleyczik,[7] A. Nilima,[17] J. O'Dell,[12] F.G. O'Neill,[1] K. O'Sullivan,[13,19] I. Olcina,[13,19] M.A. Olevitch,[22] K.C. Oliver-Mallory,[8,13,19] J. Orpwood,[36] D. Pagenkopf,[10] S. Pal,[21] K.J. Palladino,[4,7] J. Palmer,[25] M. Pangilinan,[6] N. Parveen,[20] S.J. Patton,[13] E.K. Pease,[13] B. Penning,[3,18] C. Pereira,[21] G. Pereira,[21] E. Perry,[5] T. Pershing,[34] I.B. Peterson,[13] A. Piepke,[23] J. Podczerwinski,[7] D. Porzio,[21,‡] S. Powell,[15] R.M. Preece,[12] K. Pushkin,[3] Y. Qie,[27] B.N. Ratcliff,[1] J. Reichenbacher,[26] L. Reichhart,[5] C.A. Rhyne,[6] A. Richards,[8] Q. Riffard,[13,19] G.R.C. Rischbieter,[20] J.P. Rodrigues,[21] A. Rodriguez,[38] H.J. Rose,[15] R. Rosero,[31] P. Rossiter,[36] T. Rushton,[36] G. Rutherford,[6] D. Rynders,[14] J.S. Saba,[13] D. Santone,[25] A.B.M.R. Sazzad,[23] R.W. Schnee,[26] P.R. Scovell,[4,12] D. Seymour,[6] S. Shaw,[10] T. Shutt,[1,2] J.J. Silk,[9] C. Silva,[21] G. Sinev,[26] K. Skarpaas,[1] W. Skulski,[27] R. Smith,[13,19] M. Solmaz,[10] V.N. Solovov,[21] P. Sorensen,[13] J. Soria,[13,19] I. Stancu,[23] M.R. Stark,[26] A. Stevens,[4,5,8] T.M. Stiegler,[39] K. Stifter,[1,2,16] R. Studley,[18] B. Suerfu,[13,19] T.J. Sumner,[8] P. Sutcliffe,[15] N. Swanson,[6] M. Szydagis,[20] M. Tan,[4] D.J. Taylor,[14] R. Taylor,[8] W.C. Taylor,[6] D.J. Temples,[28] B.P. Tennyson,[29] P.A. Terman,[39] K.J. Thomas,[13] D.R. Tiedt,[9,14,26] M. Timalsina,[26] W.H. To,[1,2] A. Tomás,[8] Z. Tong,[8] D.R. Tovey,[36] J. Tranter,[36] M. Trask,[10] M. Tripathi,[11] D.R. Tronstad,[26] C.E. Tull,[13] W. Turner,[15] L. Tvrznikova,[19,29,34] U. Utku,[5] J. Va'vra,[1] A. Vacheret,[8] A.C. Vaitkus,[6] J.R. Verbus,[6] E. Voirin,[16] W.L. Waldron,[13] A. Wang,[1,2] B. Wang,[23] J.J. Wang,[23] W. Wang,[7,32] Y. Wang,[13,19] J.R. Watson,[13,19] R.C. Webb,[39] A. White,[6] D.T. White,[10] J.T. White,[39,‡] R.G. White,[1,2] T.J. Whitis,[1,10] M. Williams,[3,18] W.J. Wisniewski,[1] M.S. Witherell,[13,19] F.L.H. Wolfs,[27] J.D. Wolfs,[27] S. Woodford,[15] D. Woodward,[24,§] S.D. Worm,[12] C.J. Wright,[30] Q. Xia,[13] X. Xiang,[6,31] Q. Xiao,[7] J. Xu,[34] M. Yeh,[31] J. Yin,[27] I. Young,[16] P. Zarzhitsky,[23] A. Zuckerman,[6] and E.A. Zweig[33]

(The LUX-ZEPLIN (LZ) Collaboration)

New results on WIMP Dark Matter

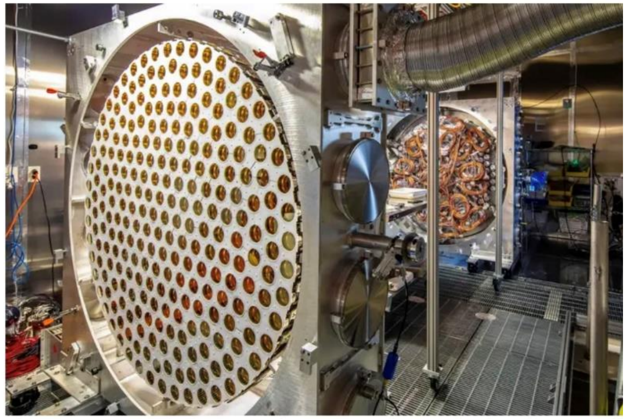


World's most sensitive dark matter detector tested for the first time

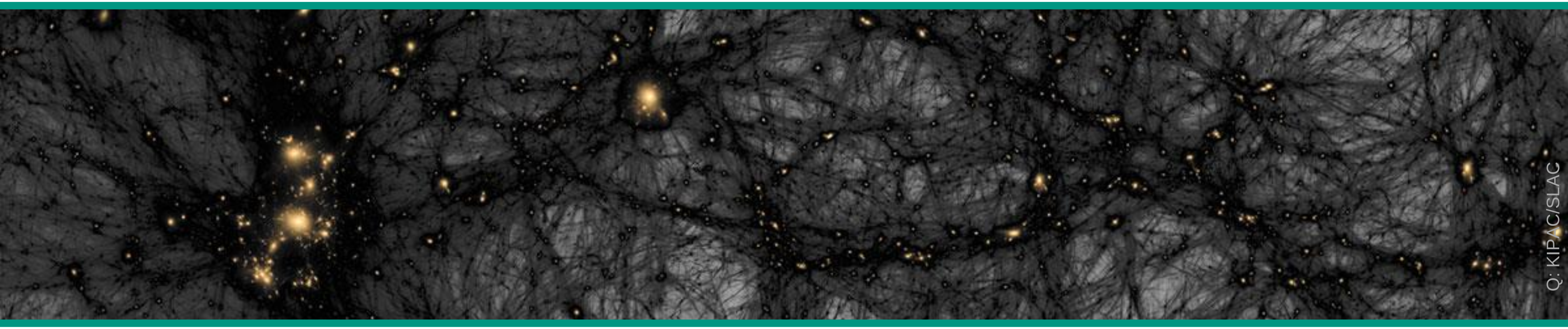
A brief test has proven that the new LUX-ZEPLIN dark matter detector is the most sensitive ever. It may be our best bet for finally finding dark matter particles

PHYSICS 7 July 2022

By Leah Crane



The LUX-ZEPLIN dark matter detector at the Sanford Undergroun Research Facility in South Dakota is the most sensitive ever



OUTLINE

Astroparticle Physics – 1: Outline

1. Introduction

1.1 **Particle Radiation from the Laboratory**

1.2 **Particle Radiation from the Universe**

2. Experimental Methods

2.1 **Multi-Messenger Methods**

2.1.1 Air Shower Experiments
2.1.2 Gamma Telescopes
2.1.3 Neutrino Telescopes

Astroparticle Physics – 1: Outline

Astroparticle Physics – 1: Outline

4. Dark Matter

4.1 Introduction

3.2 **DM Candidates**

3.3 **WIMP search at the LHC**

3.4 **indirect WIMP detection methods**

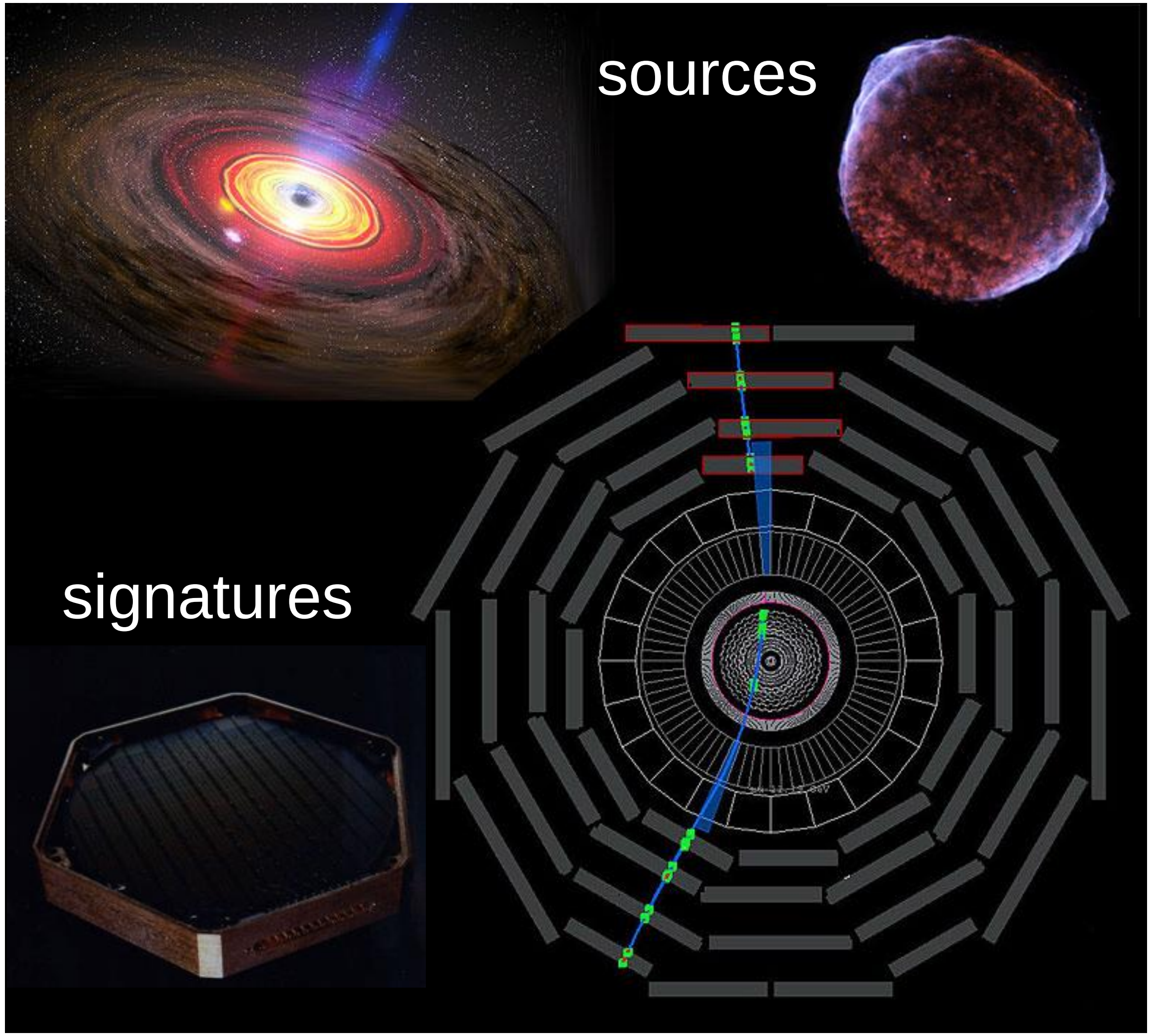
3.4.1 Gammas and positrons

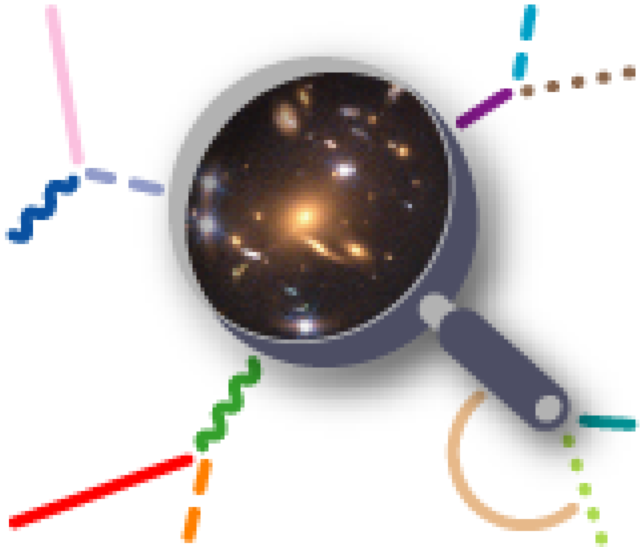
3.4.2 Neutrinos

Astroparticle Physics – 1: Outline

1. INTRODUCTION

- **Particle radiation from the Laboratory and from the Universe**



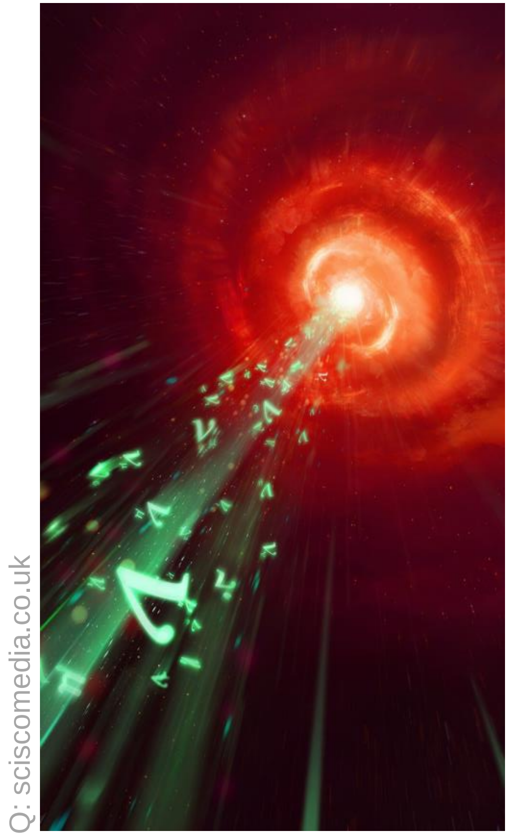


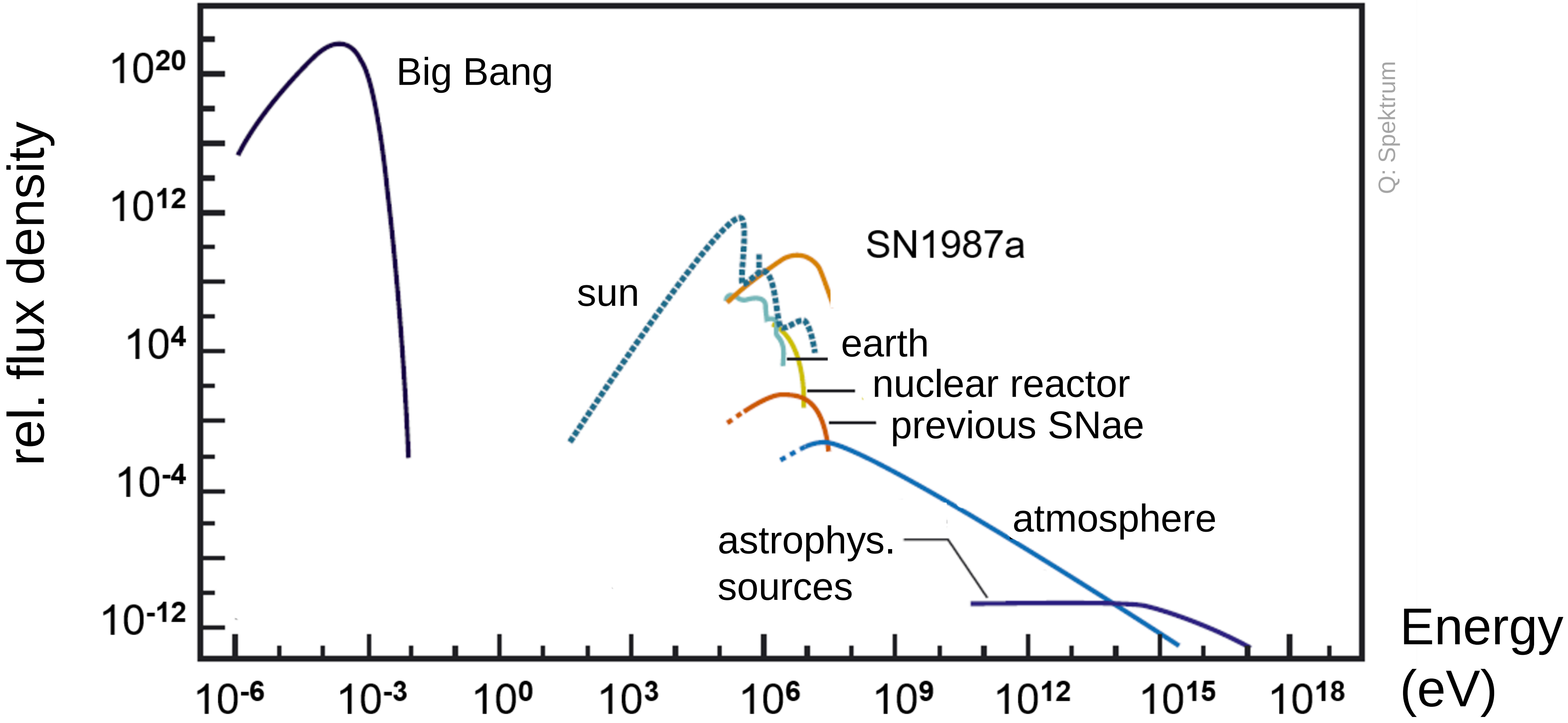
detection methods

Q: NASA, CMS, CDMS

Example: neutrinos from the earth & beyond

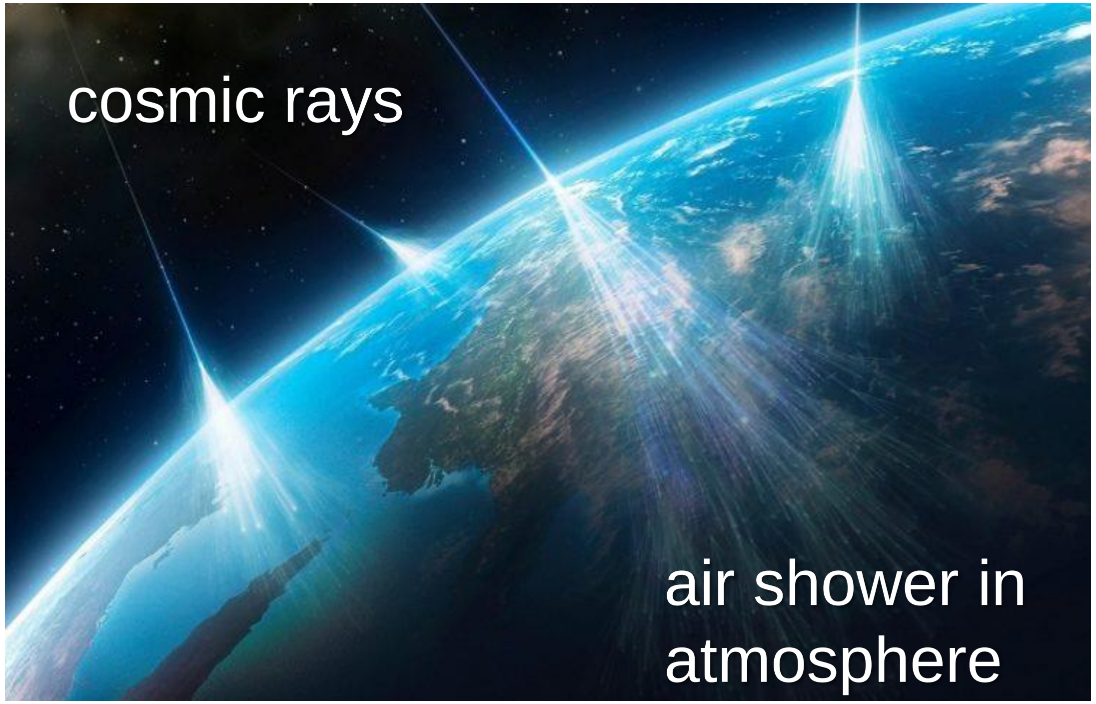
- extremely broad energy region, many sources



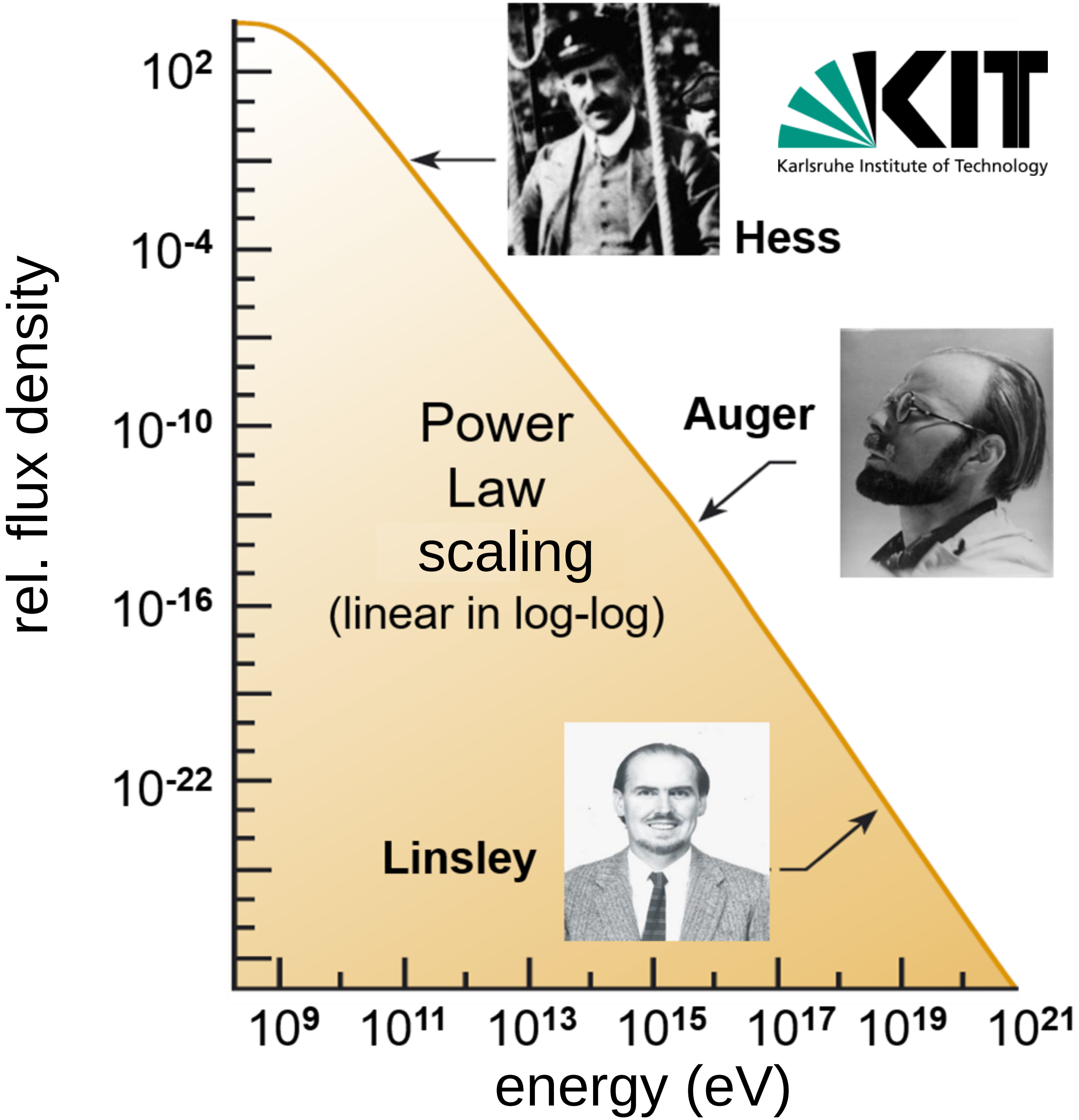


Example: cosmic rays

- extremely broad energy region, many sources

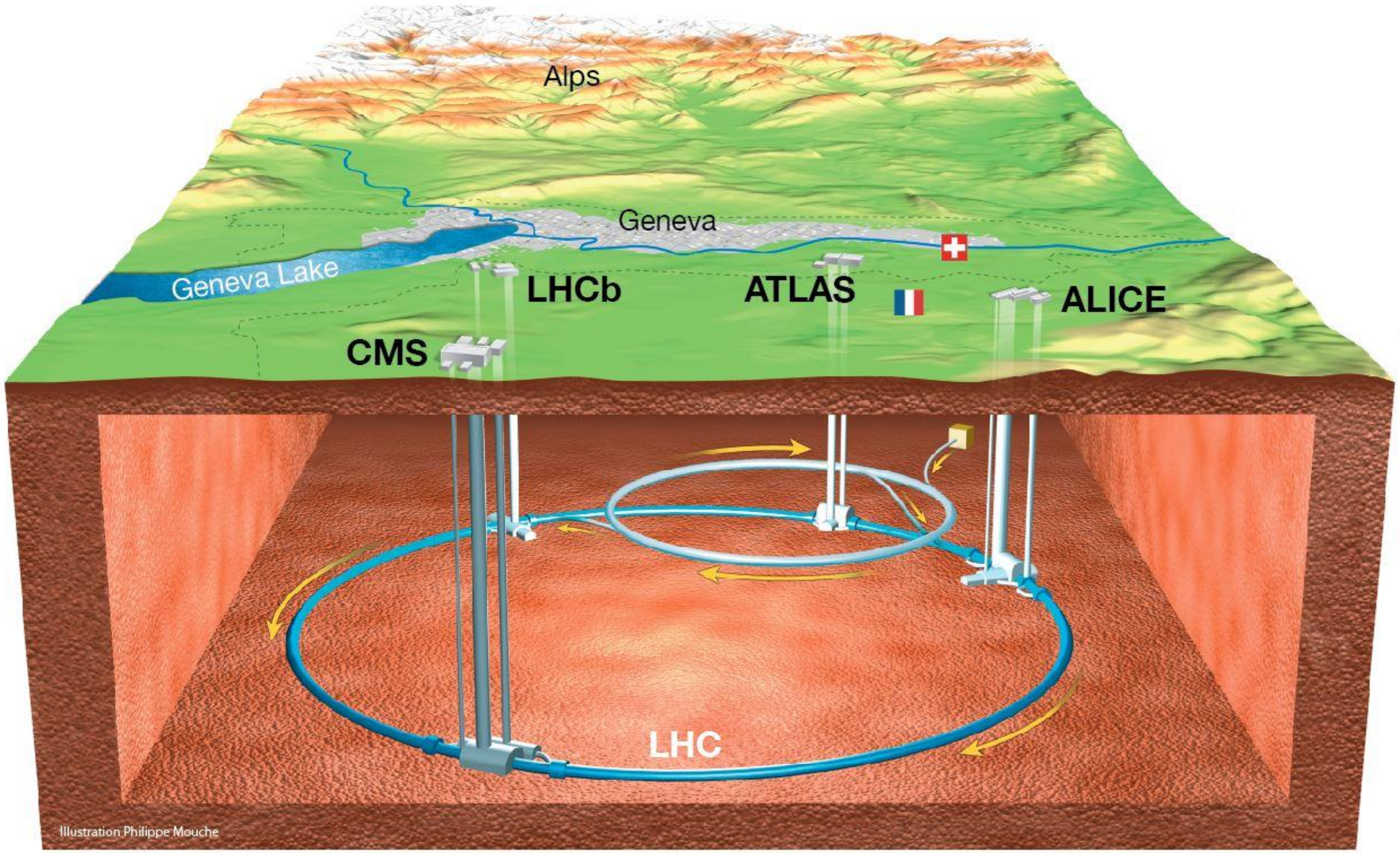


Q: electroverse.net

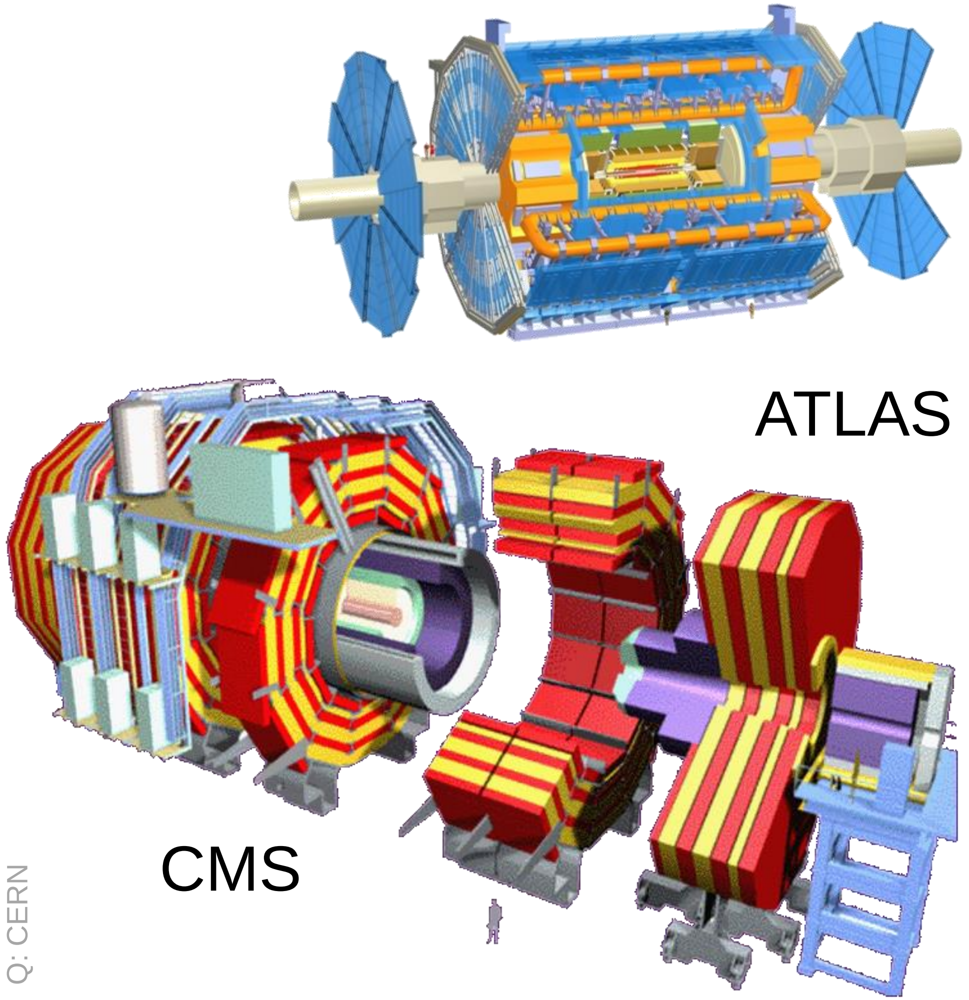


1.1 particle radiation from the laboratory

- **accelerators at TeV-scale: Search for SUSY***



Q: CERN

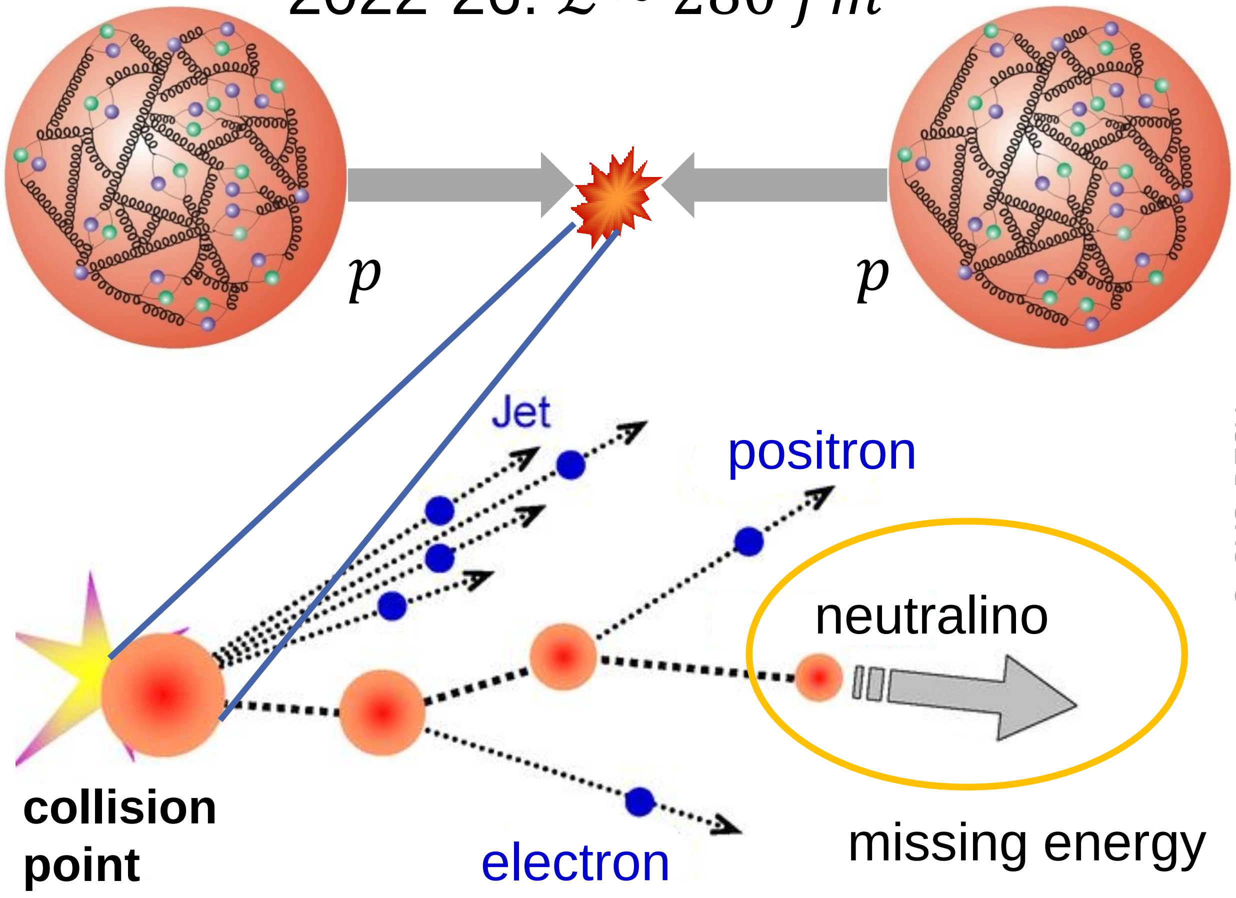


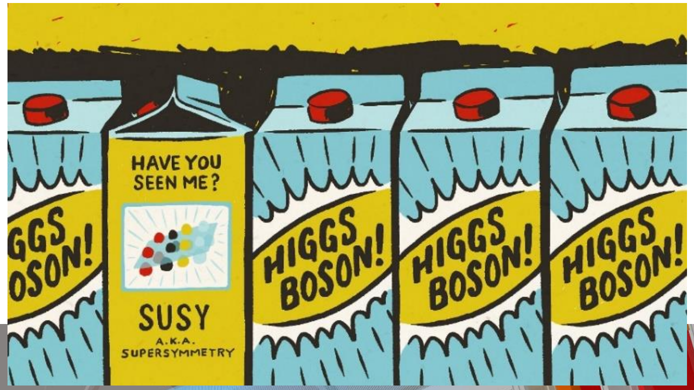
*SUSY = SUper SYmmetry

Accelerator-based SUSY-searches at LHC

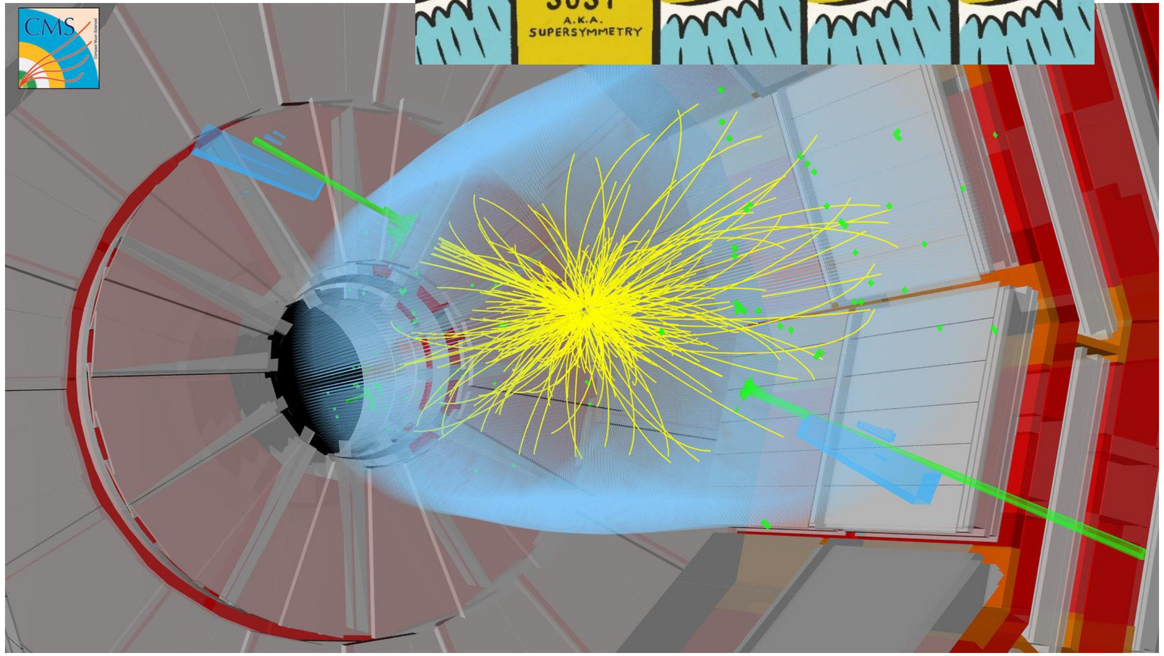
- **Run 3: proton-proton collisions at $\sqrt{s} = 13.6$ TeV**

2022-26: $\mathcal{L} \sim 280\ fm^{-1}$





Q: symmetry magazine



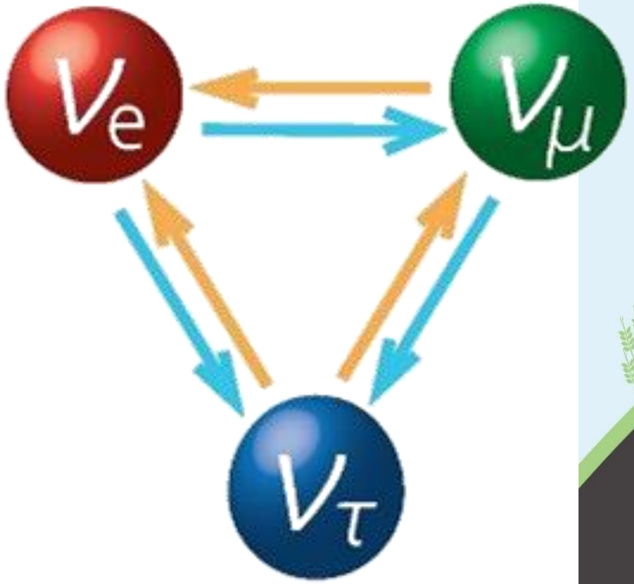
Q: CMS, DESY

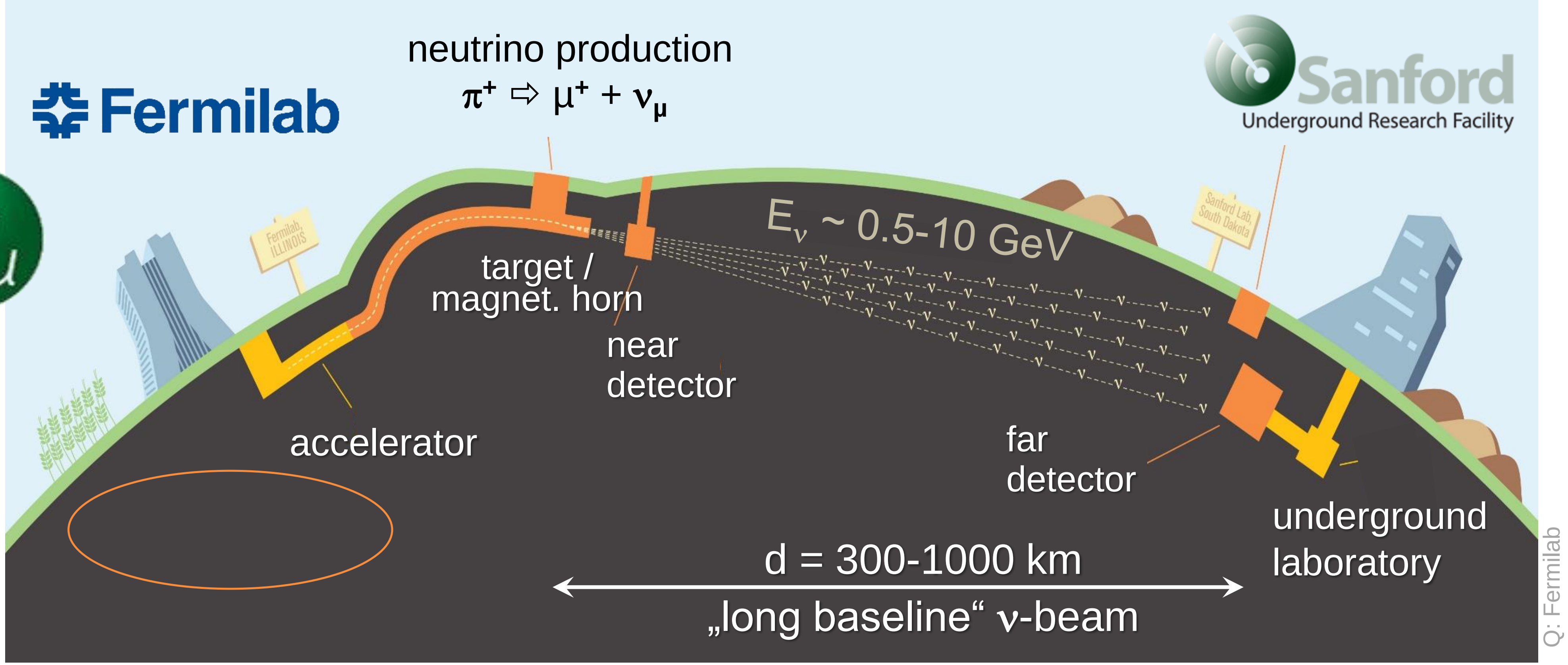
missing transversal energy/momentum

Accelerator-based neutrino oscillation studies

- **long-baseline (LBL) neutrino beams at the GeV-scale: mixing properties, CP**

set-up of an LBL-ν-experiment



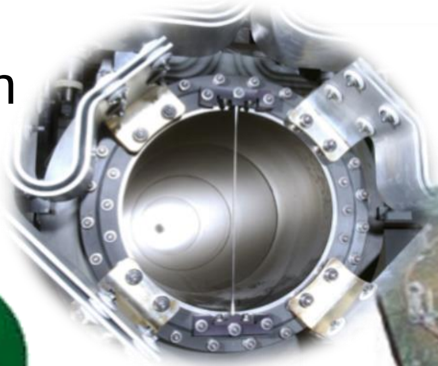


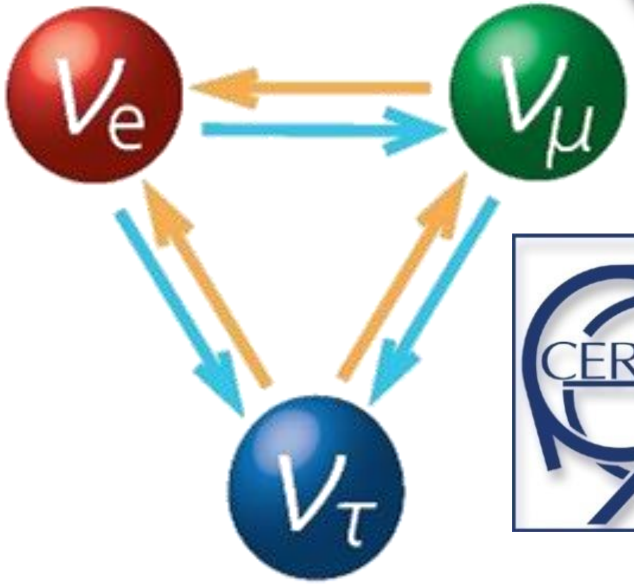
Accelerator-based neutrino oscillation studies

Karlsruhe Institute of Technology

- example: the CERN – Gran Sasso LBL-neutrino-beam

magnetic horn

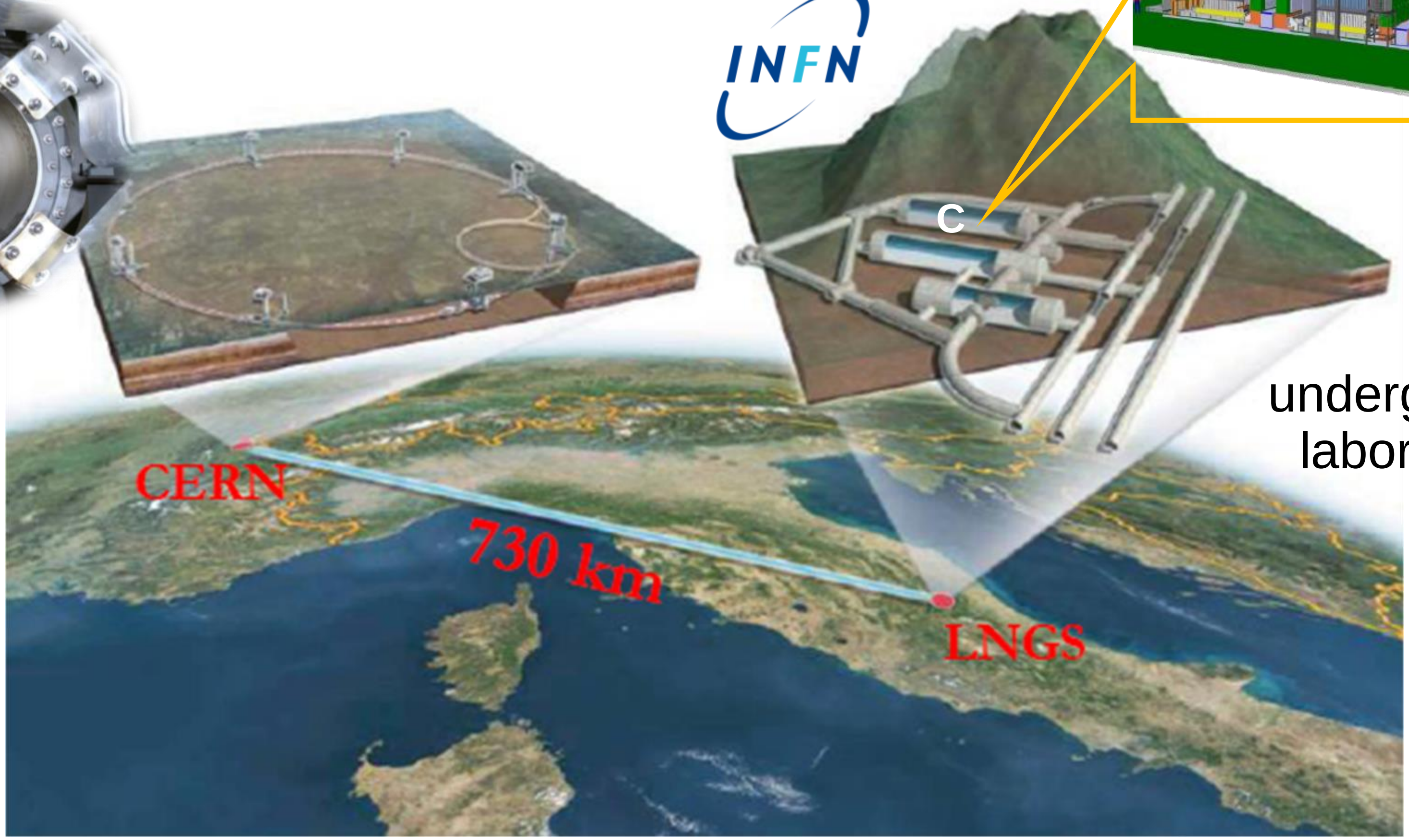




CERN CNGS

Laboratori Nazionali del Gran Sasso

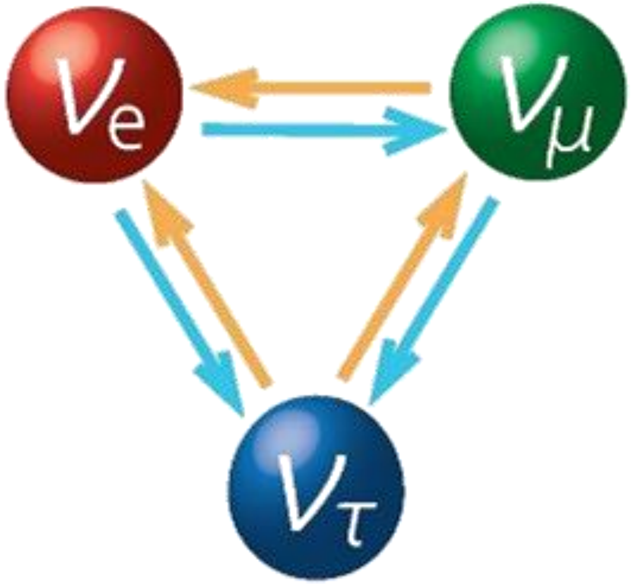
INFN

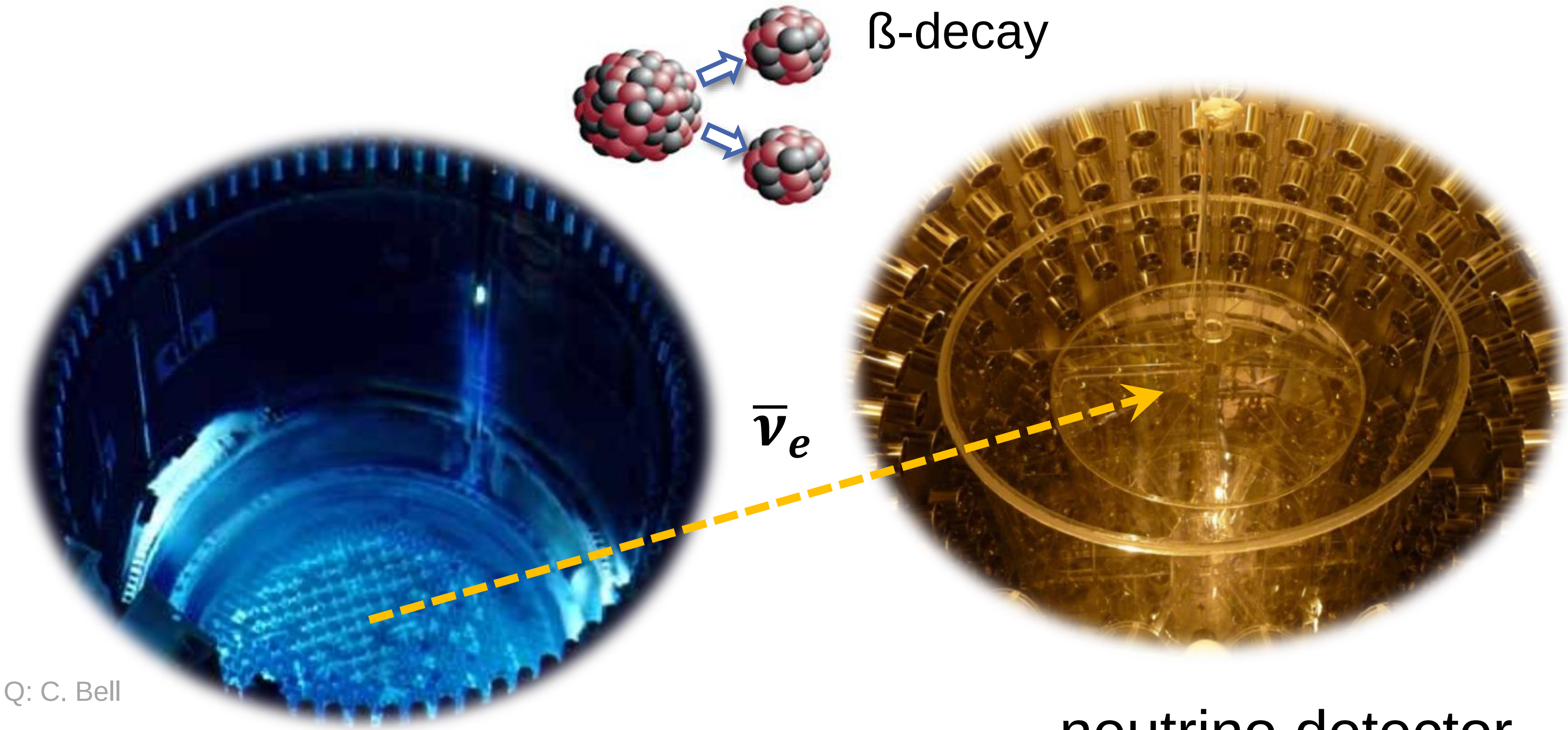


underground laboratory

reactor-based neutrino oscillation studies

- **long-baseline neutrino beams at the MeV-scale: mixing properties, CP**





Q: C. Bell

nuclear reactor

neutrino detector

Q: Double Chooz

reactor-based neutrino oscillation studies

- example: the Daya Bay neutrino-oscillation experiment in China

Q: Daya Bay