My experience in research: Thoughts and lessons

Mauricio Bustamante

Niels Bohr Institute, University of Copenhagen

UNIVERSITY OF COPENHAGEN

VILLUM FONDEN

ASDF PUCP
January 15, 2021

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LIVE zoom

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ASDF
Asociación de Física

WEBINAR:

Peruanos en ciencias:
Investigación y divulgación

Fecha y Hora: 15 de Enero de 1 a 3 pm

Expositores Invitados:

PhD. Mauricio Bustamante

Profesor Asistente en el Instituto Niels Bohr de la Universidad de Copenhagen. Experto en Física de Particulas y Altas Energías.

Aldo Bartra

Comunicador y divulgador científico reconocido por canales como "Robot de Platón" o "Robot de Colón" en la plataforma YouTube.

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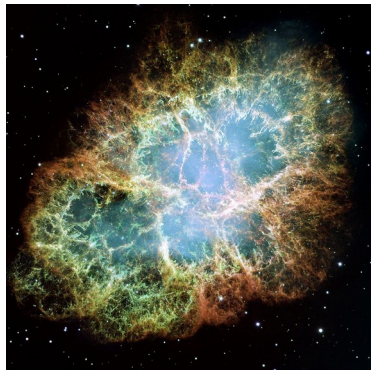

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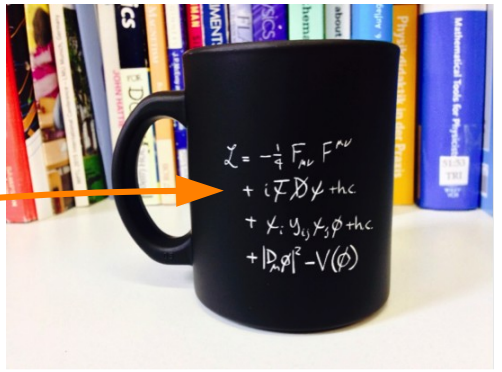

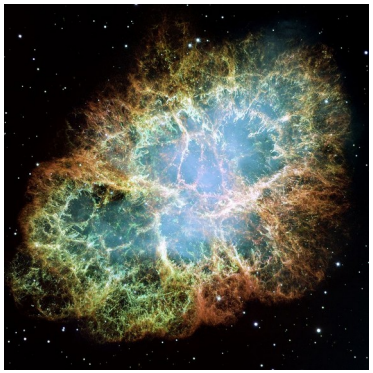

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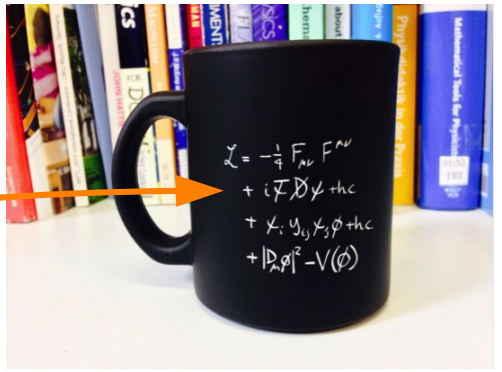

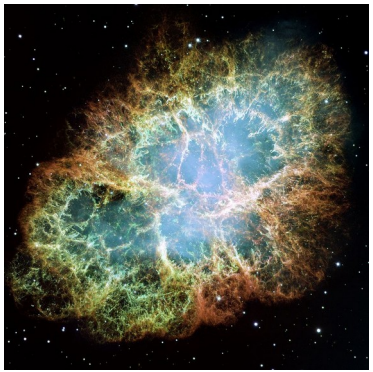

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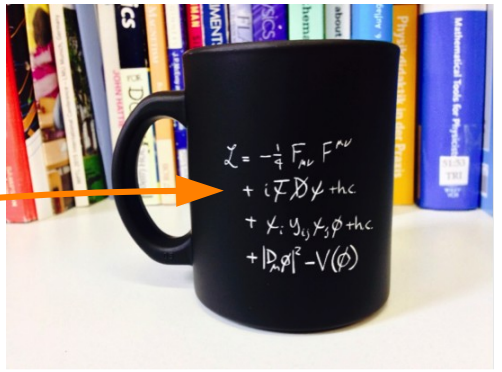

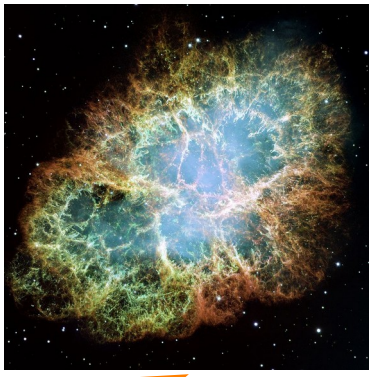

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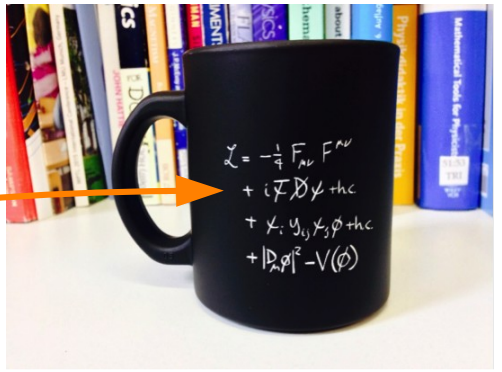

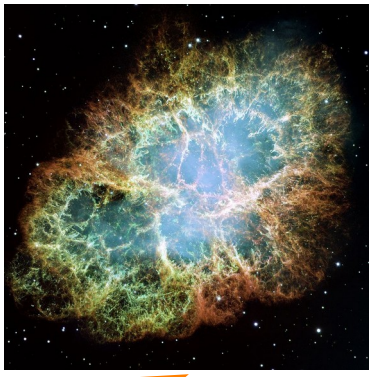

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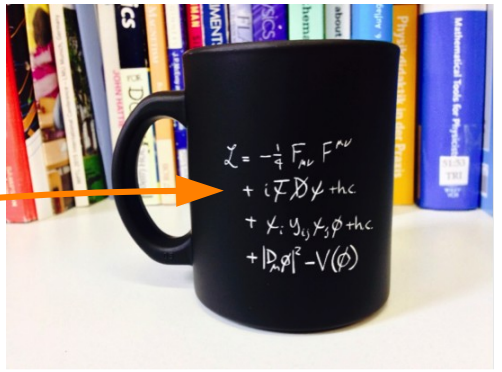

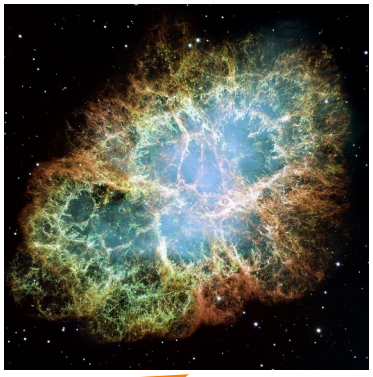

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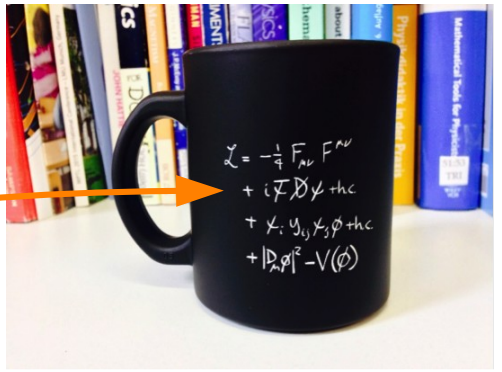

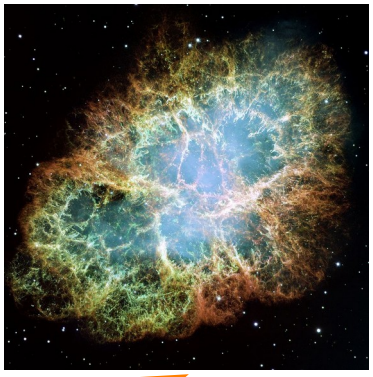

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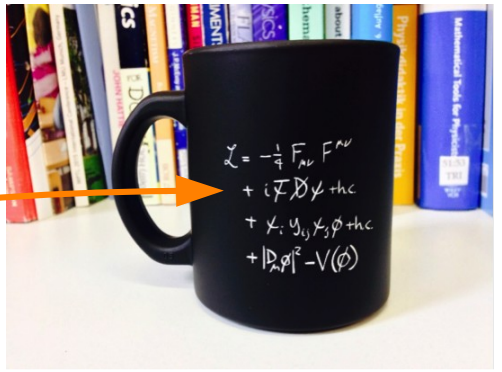

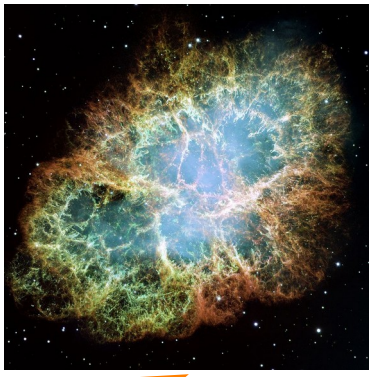

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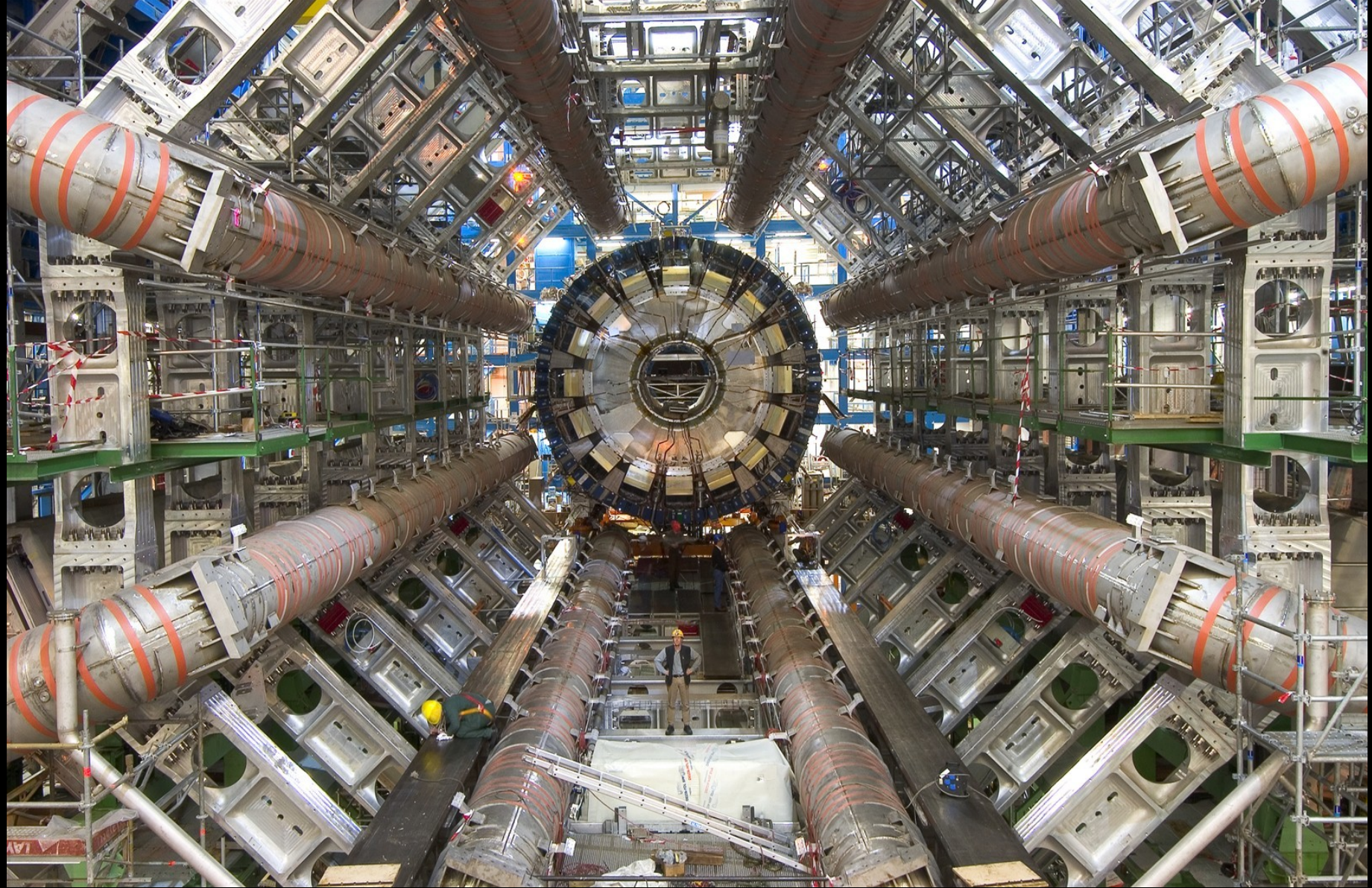
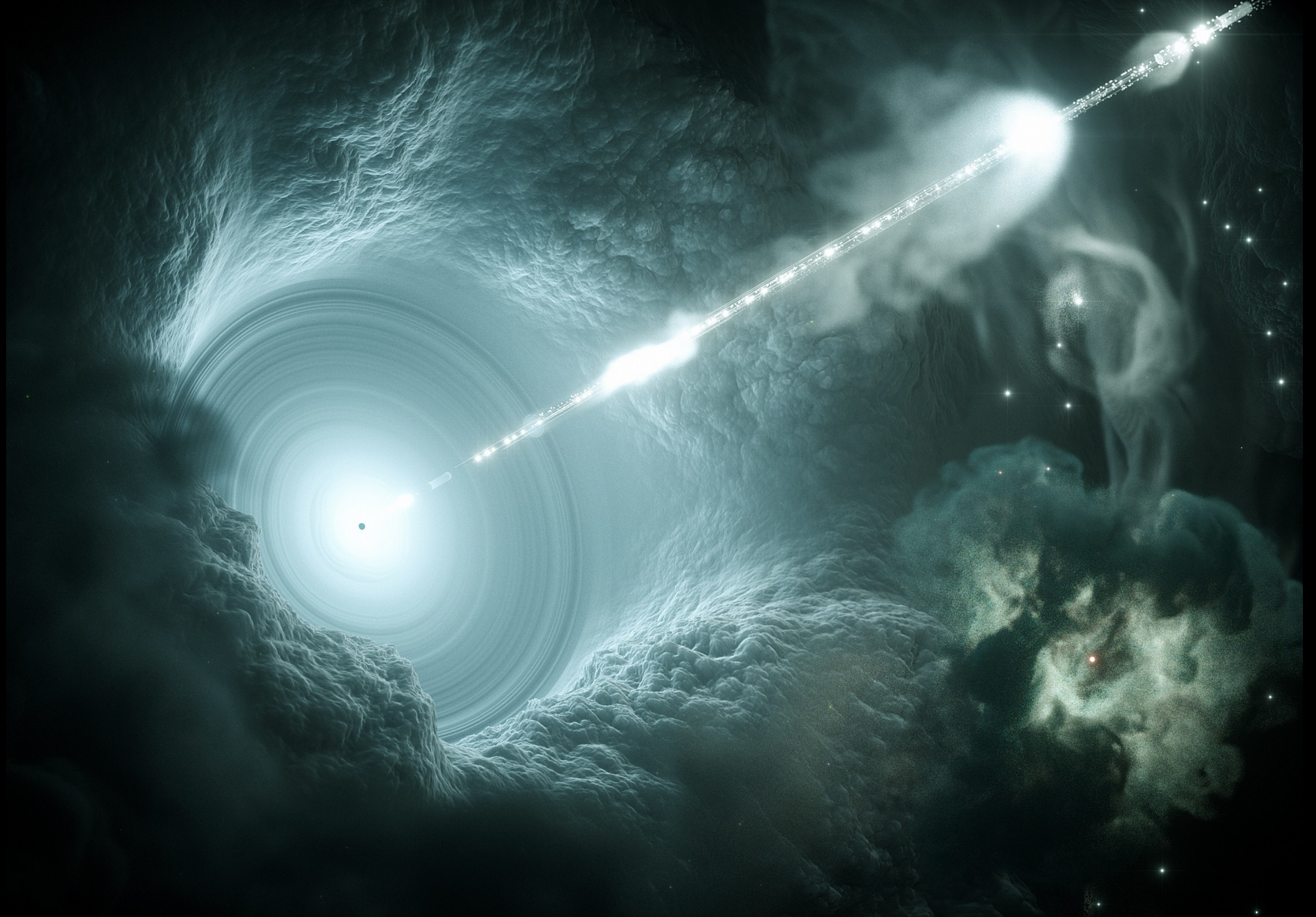


ATLAS



DESY

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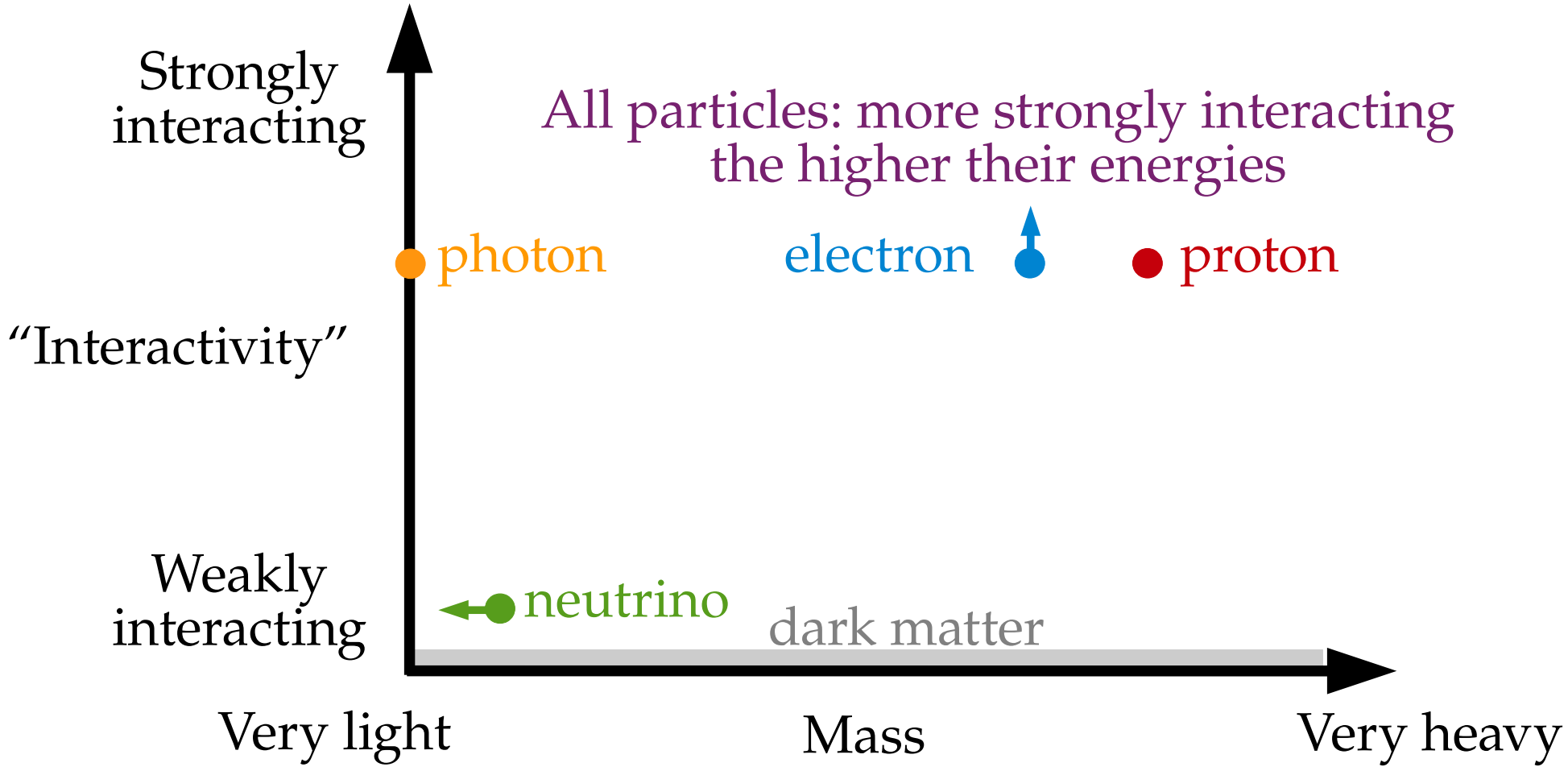
Neutrinos are *very* light and *very* anti-social



Neutrinos are quintessential quantum particles

There are three types, or *flavors*, of neutrinos:

electron neutrino ν_e

muon neutrino ν_μ

tau neutrino ν_τ

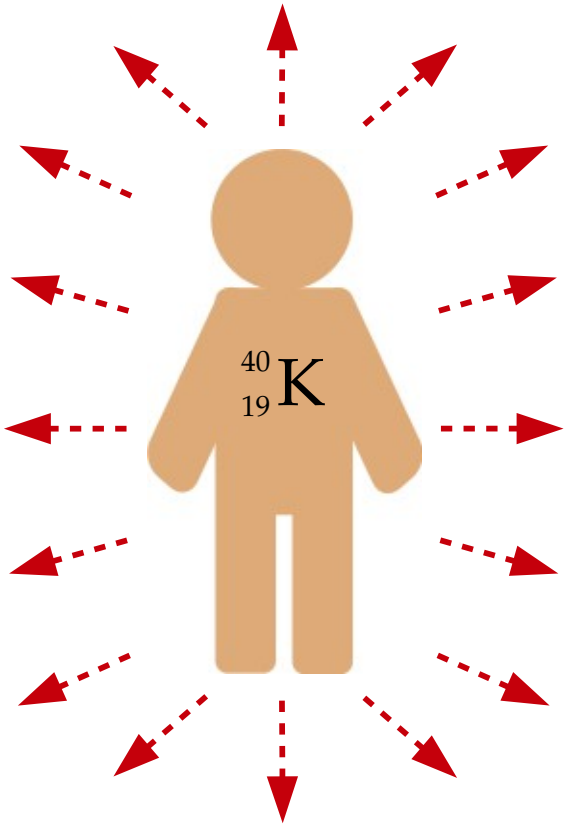
A neutrino is created with *one* definite flavor, *e.g.*,

But may be detected with a different flavor, with some probability

We use quantum mechanics to compute probabilities over *macroscopic* distances!

Neutrinos are everywhere: even *you* make them!

Some of the potassium in bananas is radioactive



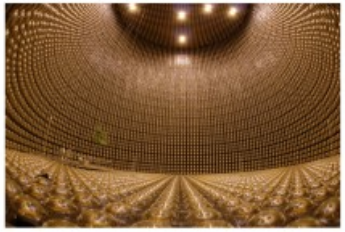
Potassium-40 has a half-life of ~ 1 billion years:

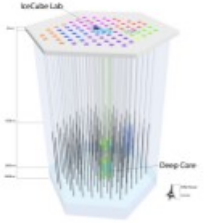
$$e^- + {}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} + \nu_e$$

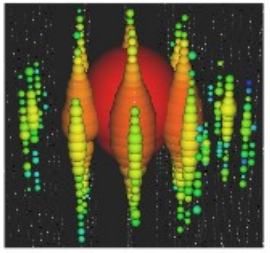
$${}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} + e^+ + \nu_e + \gamma$$

$${}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{20}\mathrm{Ca} + e^- + \bar{\nu}_e$$

4000+ neutrinos emitted each second by a 70-kg person







2013+

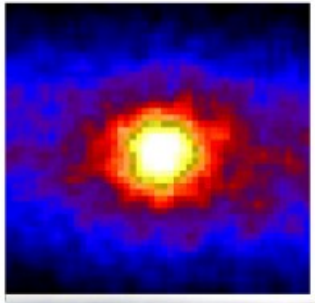
atmospheric

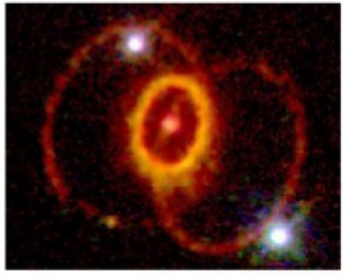
extragalactic

10^6 10^9 10^{12} 10^{15} 10^{18} 10^{21} E [eV]

solar reactor

supernova accelerator





10^{12} eV →

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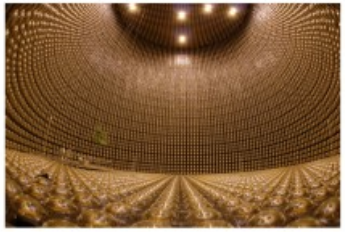

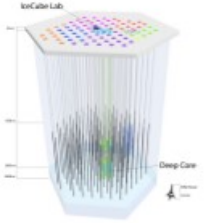

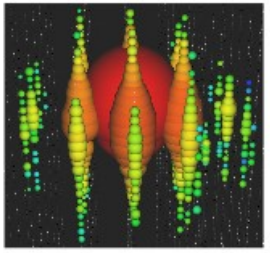

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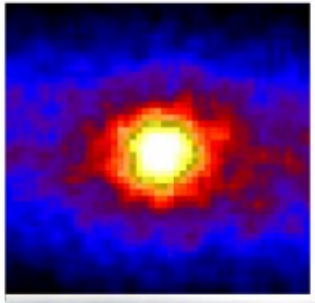

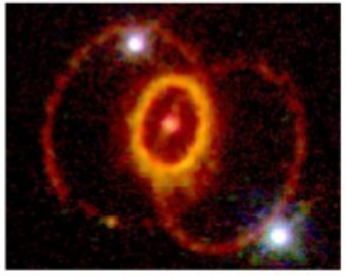

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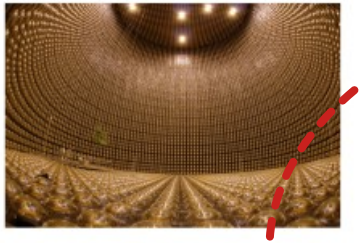

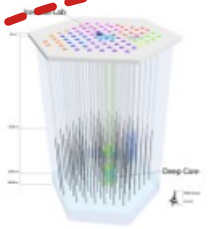

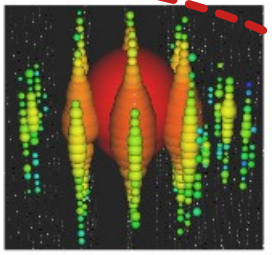

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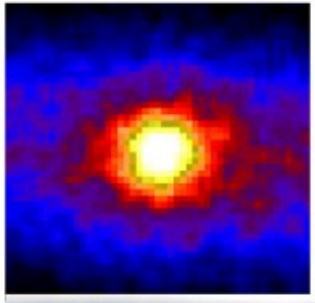

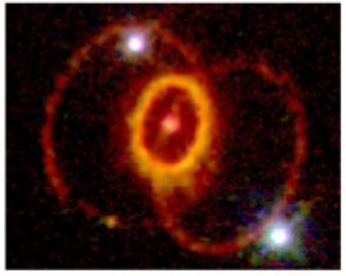

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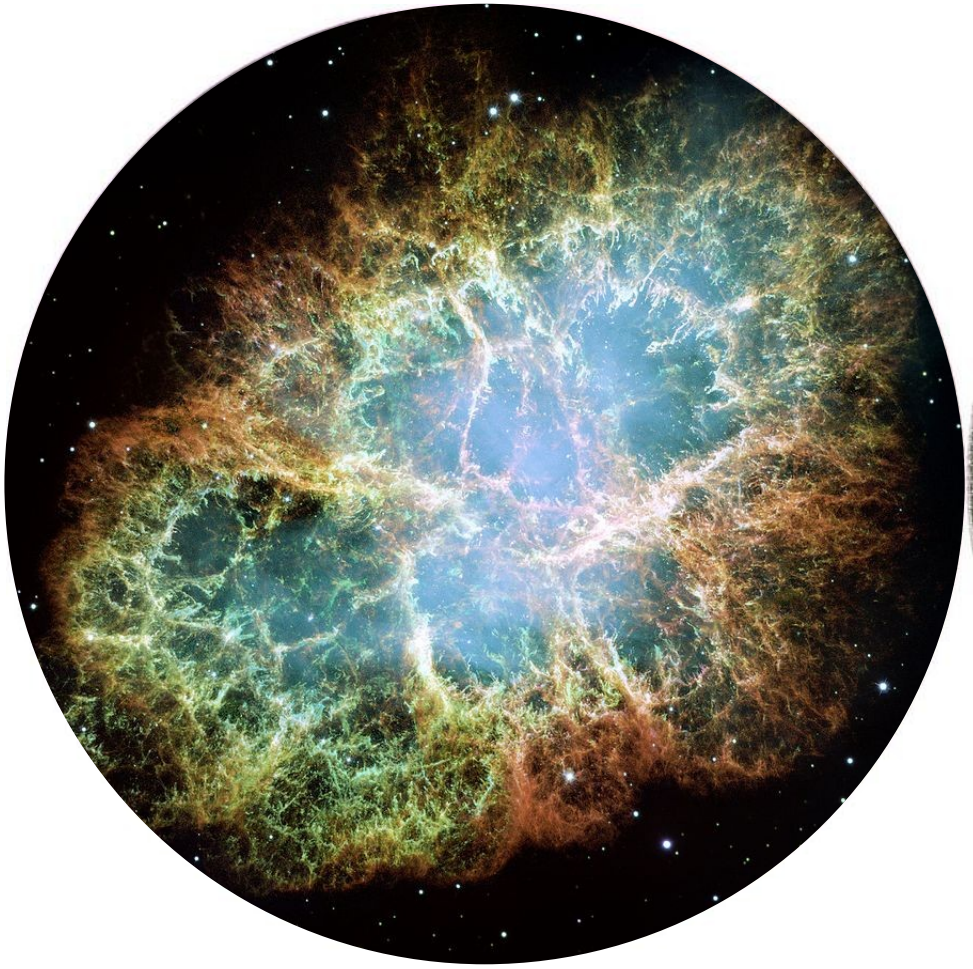

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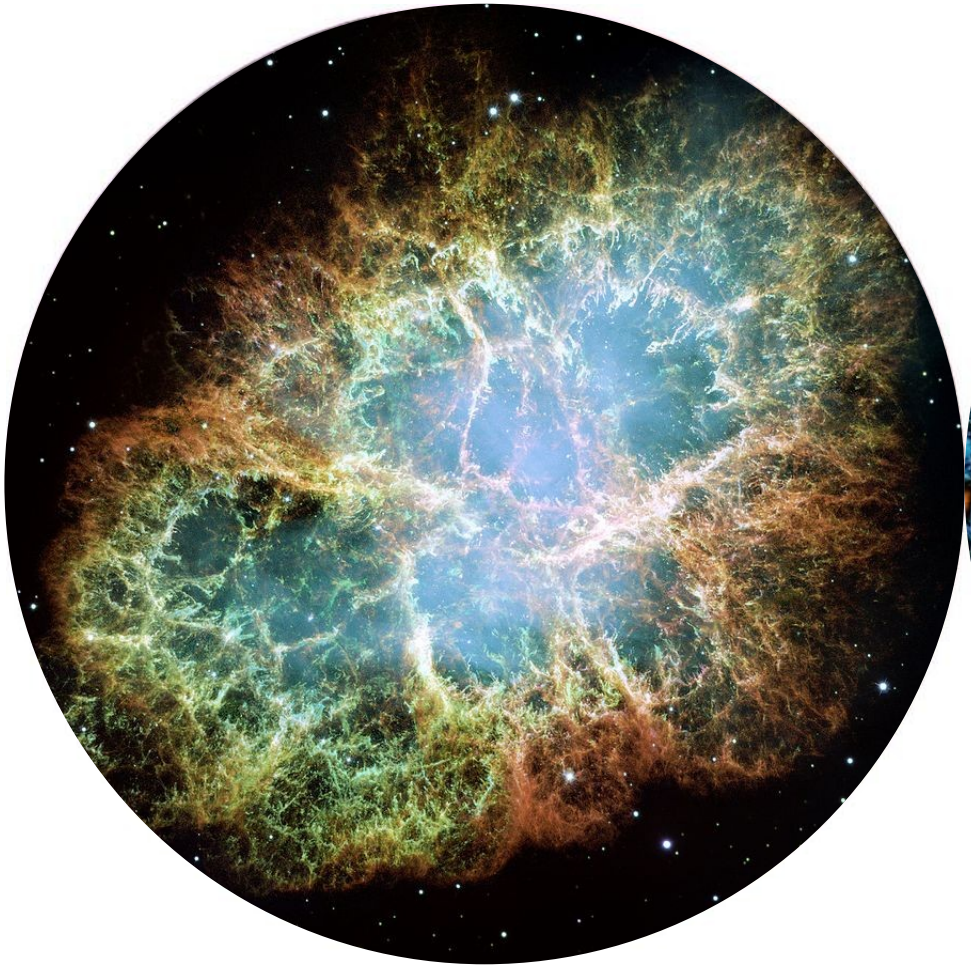

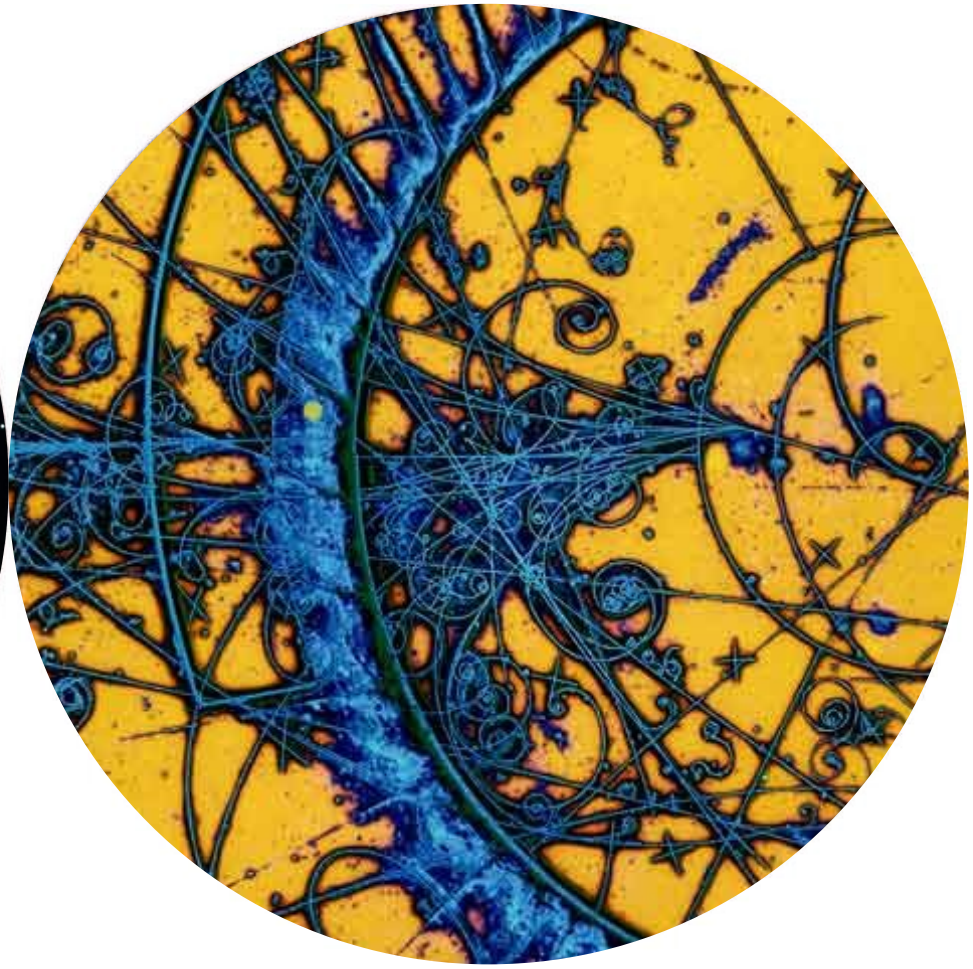

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- Meet future mentors
- Learn the state of the art
- Be exposed to other styles

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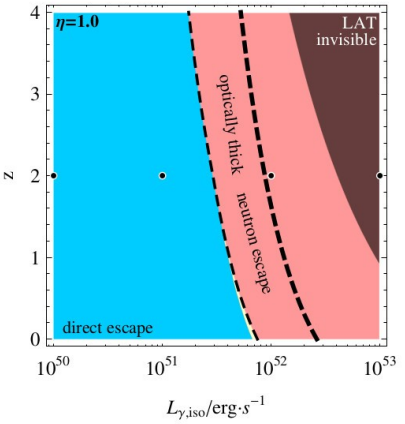
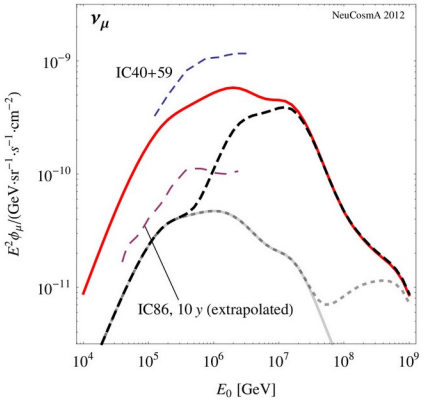
- Meet future colleagues
- Meet future mentors
- Learn the state of the art
- Be exposed to other styles

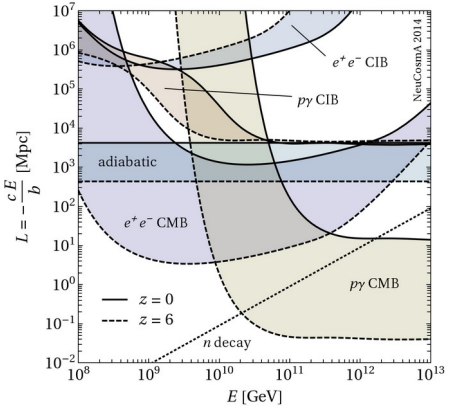
- Started the PUCP Physics colloquia in 2010

PhD years

- 2012-2014: U. Würzburg + DESY (Germany)
- Had a young, motivated PI as supervisor
- Main work on modeling high-energy particle production in extreme astrophysical sources
- Some work on testing new particle physics
- Carried over the research experience from PUCP
- Finished before 3 years
- Started looking for postdocs well in advance



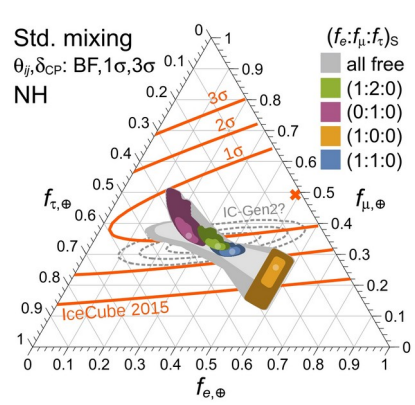


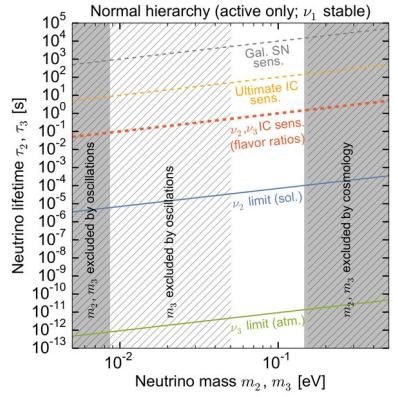


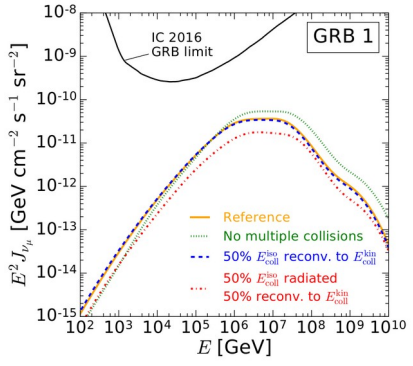
Postdoc years: becoming an independent researcher

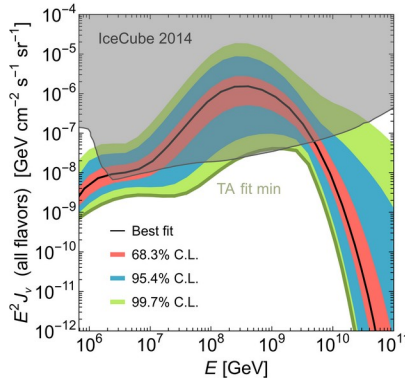
Postdoc #1 (2014-2017):

- Center for Cosmology and Astroparticle Physics (CCAPP), Ohio State U., USA
- Continued work on high-energy neutrino astrophysics
- Progressively transitioned to more particle physics
- Starting working close to experimental collaborations
- Started refereeing papers – helps improve one's writing
- Gave lots of talks (~40 significant ones)!









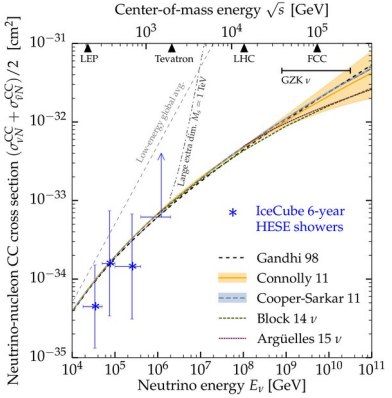
Starting building my own researcher identity: an experimentally minded theoretical perspective

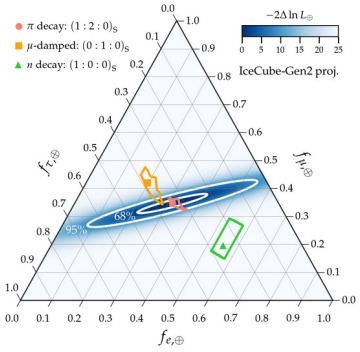
Postdoc years: becoming an independent researcher

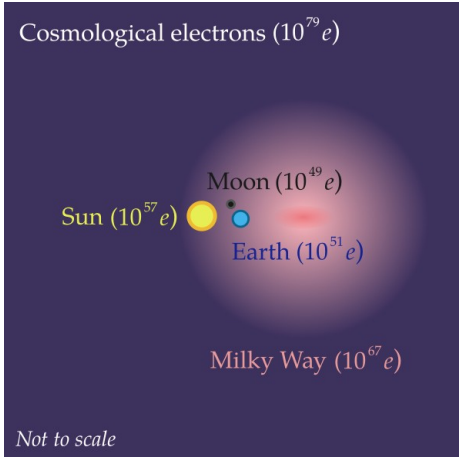
Postdoc #2 (2017-2020):

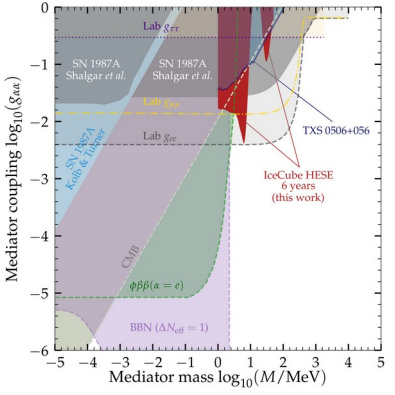
- Niels Bohr Institute, U. of Copenhagen, Denmark
- Main focus firmly on particle physics with high-energy astrophysical neutrinos
- Built up publication portfolio

  + international collaboration network
- Gave lots more talks!
- Refined my writing style









Ready to make the jump to a faculty position

Working with experimental collaborations

- I'm a theorist, but I work in close proximity to experimental collaborations

Theorist

Experimentalist

Working with experimental collaborations

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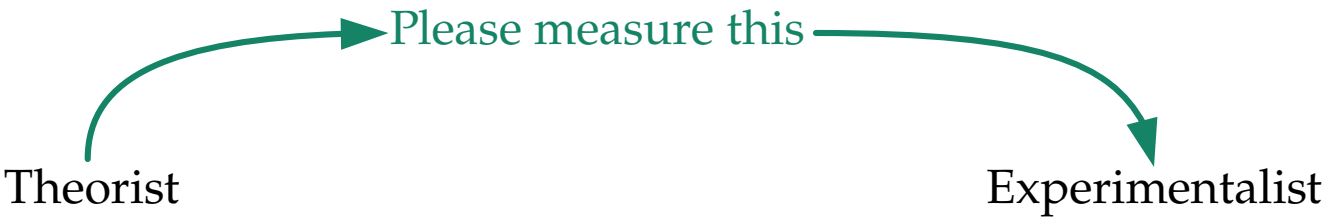

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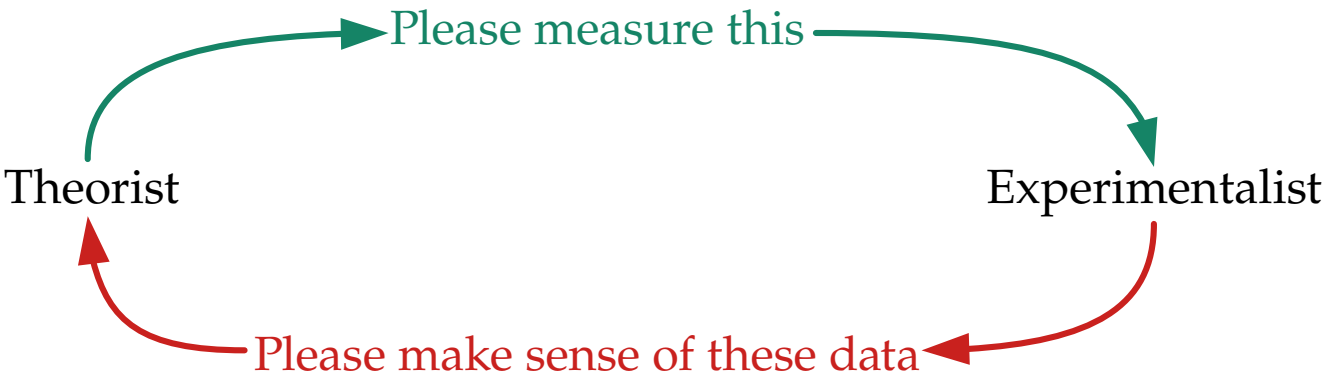

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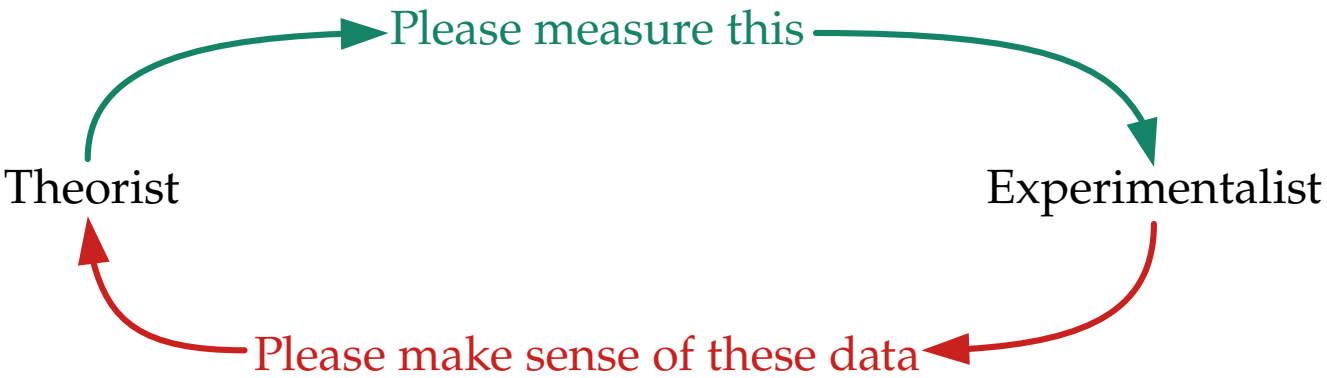
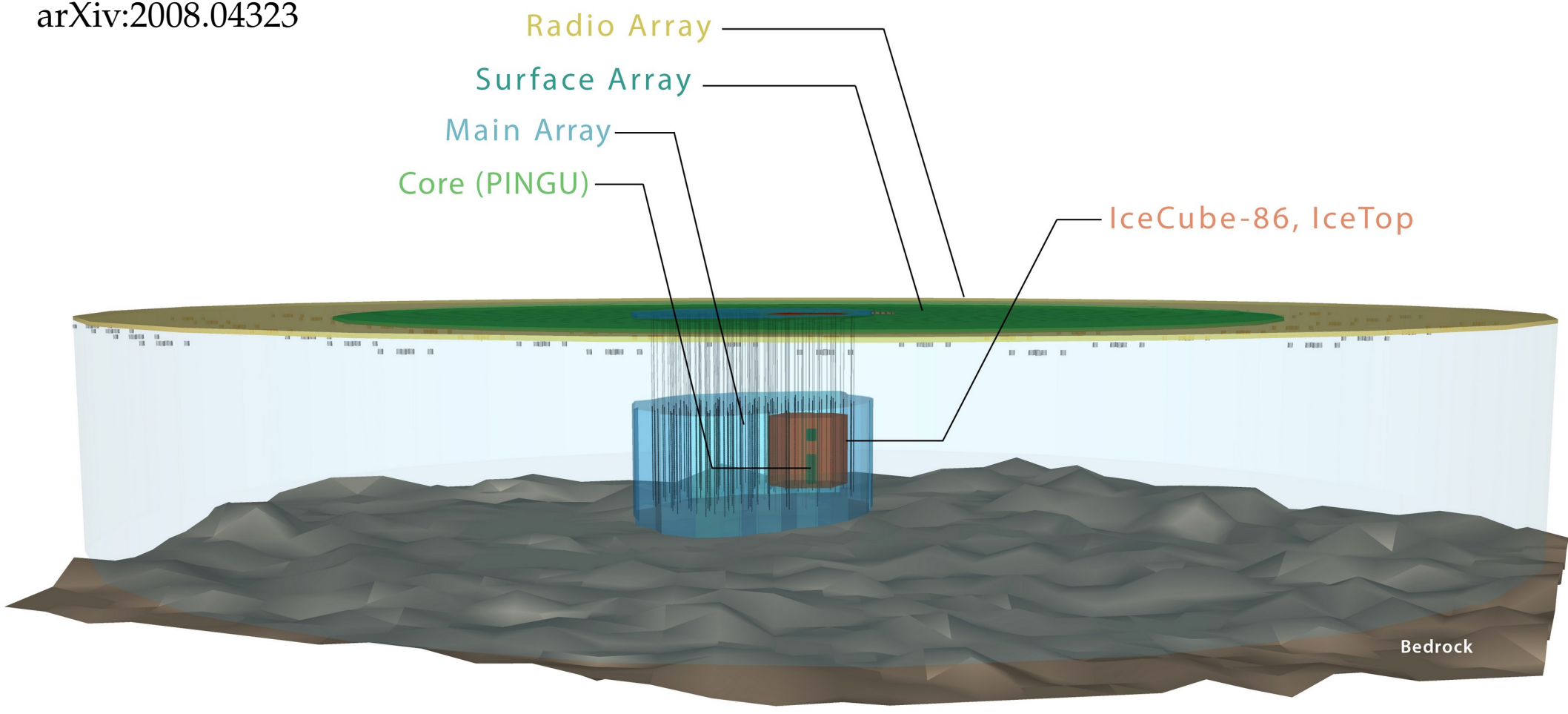
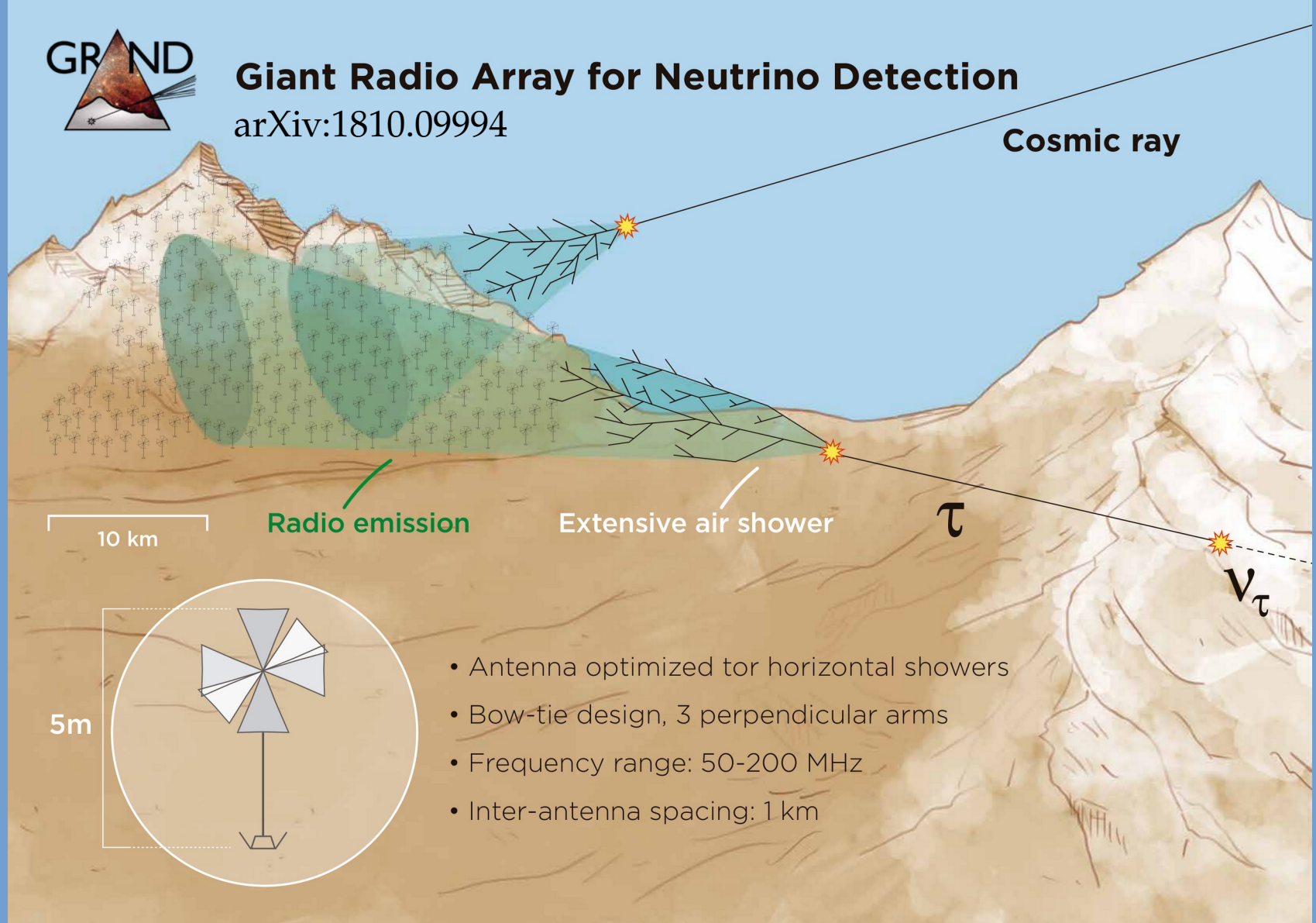


- Plan the next generation of large-scale neutrino telescopes for the coming 10–20 years

IceCube-Gen2

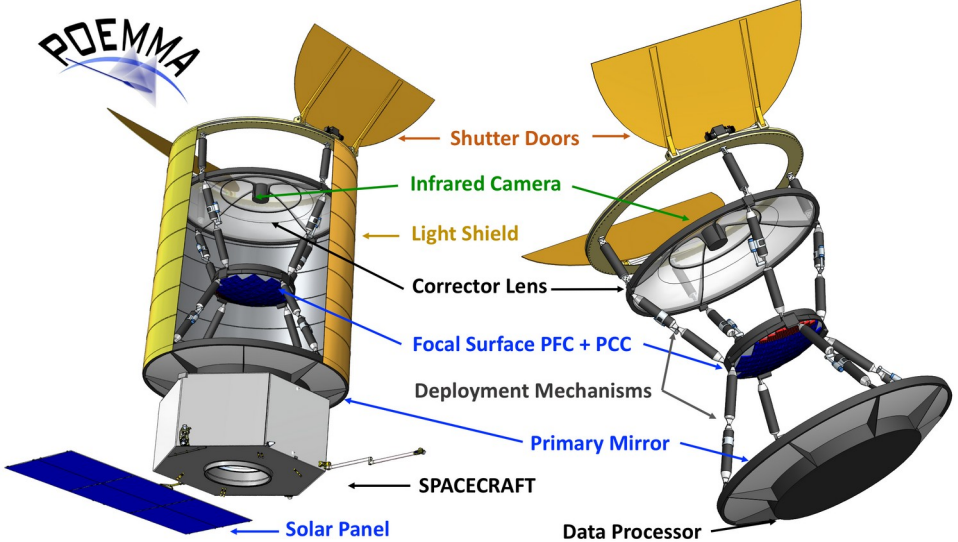
arXiv:2008.04323




GRAND
Giant Radio Array for Neutrino Detection
arXiv:1810.09994
Cosmic ray
10 km
Radio emission
Extensive air shower
τ
ν_τ
5m
• Antenna optimized tor horizontal showers
• Bow-tie design, 3 perpendicular arms
• Frequency range: 50-200 MHz
• Inter-antenna spacing: 1 km

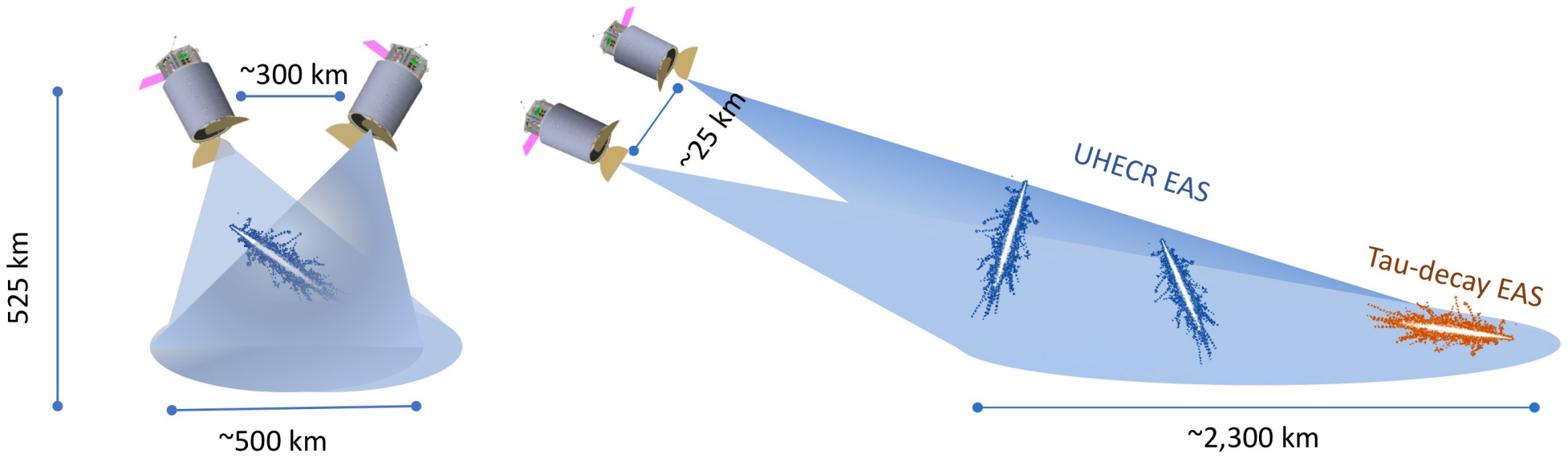
POEMMA:
Probe of Extreme Multi-Messenger Astrophysics

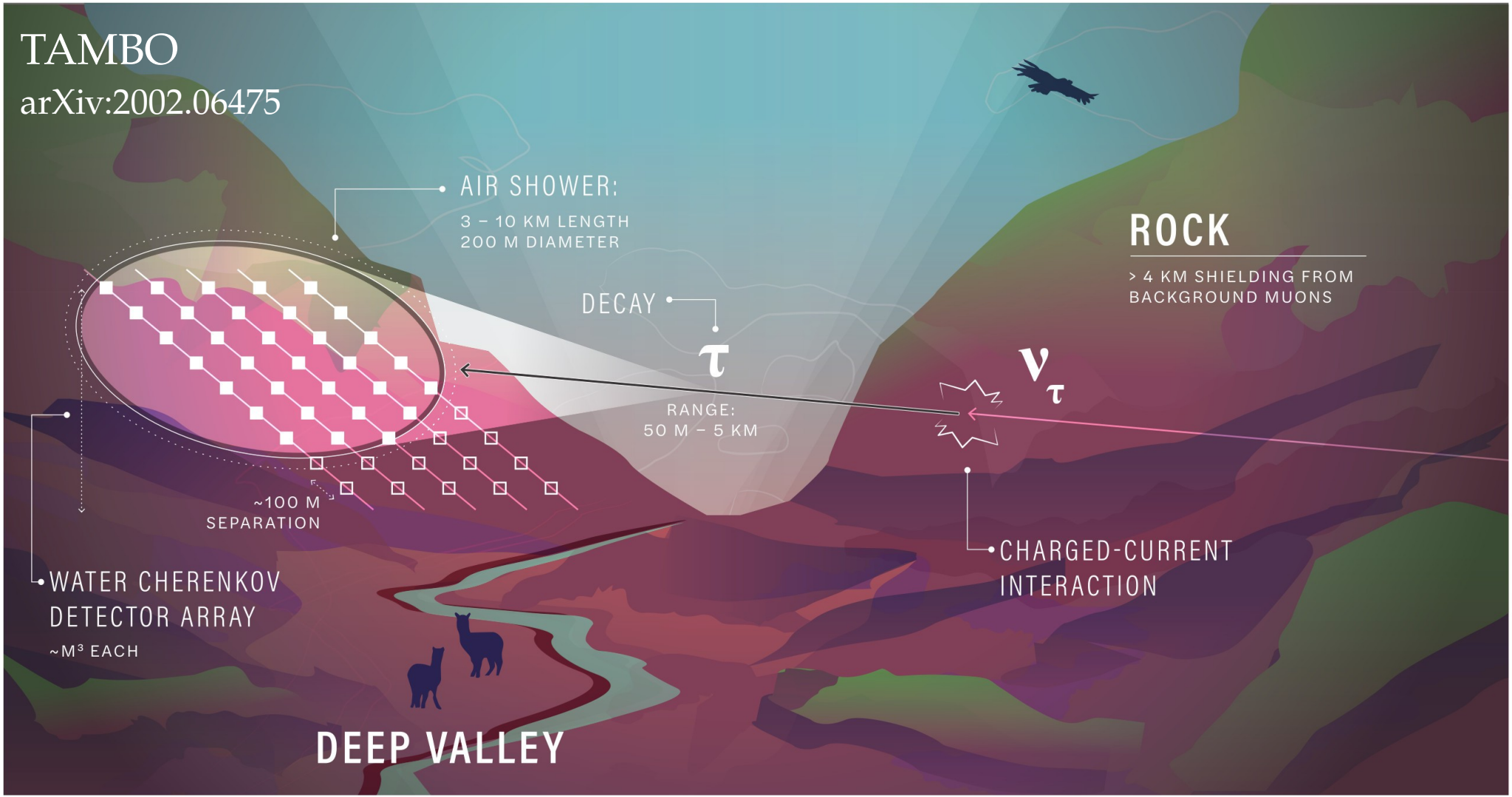
arXiv:2012.07945



POEMMA-Stereo

POEMMA-Limb





TAU AIR-SHOWER MOUNTAIN-BASED OBSERVATORY (TAMBO) · COLCA VALLEY, PERU

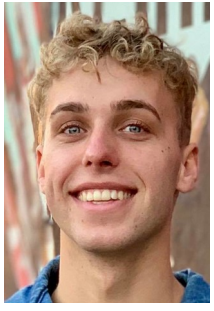
Today: Faculty position

- Assistant Professor, Niels Bohr Institute, U. of Copenhagen, Denmark
- Starting research grant from the Danish Villum Fonden (~1.5M USD)
- Building my own research group (students + postdocs)
- My time is divided between my students, my own research, and grant applications
- Key skill: Time management (Too many things to do, too little time!)
- Working with students is a rewarding time investment

Students: undergraduate

2018: Siqiao Mu (Caltech)
Unitarity bounds of astrophysical neutrinos
PRD 98, 123023 (2018)

2020: Niels Gustav Nortvig Willesen
Unitarity bounds of astrophysical neutrinos
arXiv:2009.01253



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Decay of high-energy cosmic neutrinos

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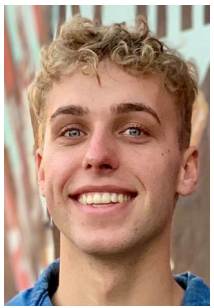

2021: Jonathan Balthazar
Decay of high-energy cosmic neutrinos

- Main goal: first direct exposure to research
- Very well-defined project
- ~4 months to develop project
- Topics closely linked to content courses

Students: MSc

2019–2020: Charlotte Rosenstrøm
Bounds on secret neutrino interactions from High-energy astrophysical neutrinos
PRD 12, 123024 (2020)

2020–2021: Kjartan Másson
Secret interactions of ultra-high-energy neutrinos

2021-2022: Marie Hansen
Interactions between high-energy cosmic neutrinos and axions

Students: MSc

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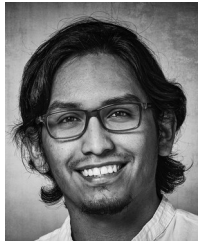
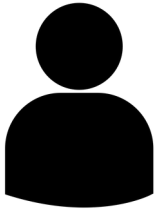
2021-2022: Marie Hansen
Interactions between high-energy cosmic neutrinos and axions

- Main goal: first full project led by the student
- Well-defined goal, but steps and solutions defined (in part) by the student
- ~1 year to develop project
- Topics that require going firmly beyond courses
- Should result in a paper

Students: PhD

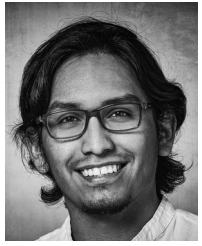


2020–2023: Víctor Valera
Pushing neutrino physics to the cosmic frontiers
Undergad: UNI
MSc: ICTP Trieste



2022-2024: ??
High-energy neutrino physics

Students: PhD



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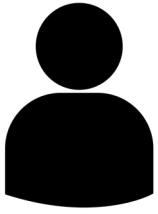

2022-2024: ??
High-energy neutrino physics

- Main goal: perform original, state-of-the-art research
- Well-defined general plan, but freedom to explore
- 3 years to develop project
- Several papers associated
- Prepare to pursue a career in academia if desired

Take-aways

Take-aways

- Doing research is a craft: always improved, never perfected

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Lascaux, 15000 BC

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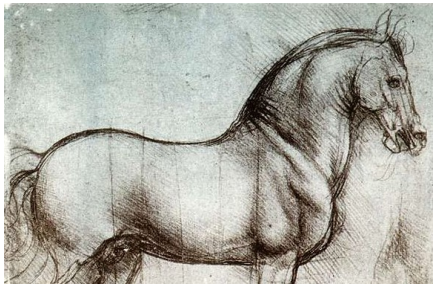

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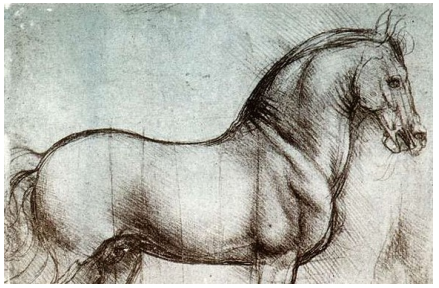

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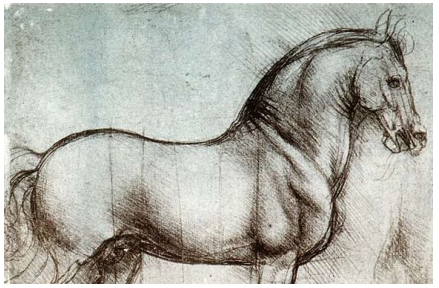

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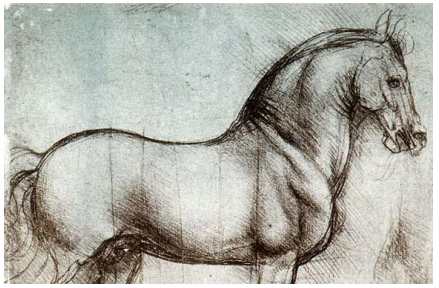
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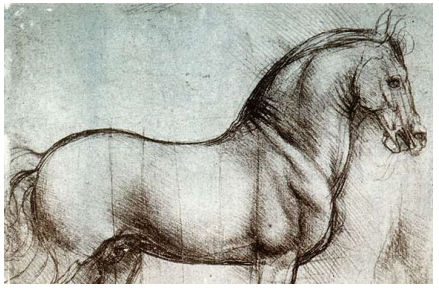
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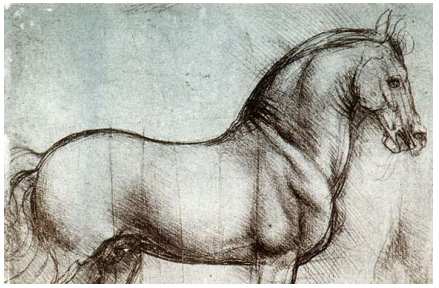
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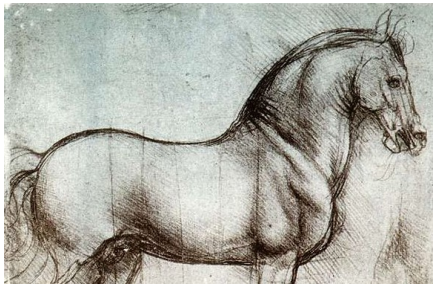
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Have a solid basis → Do research

Learn what you need when you need it

Take-aways

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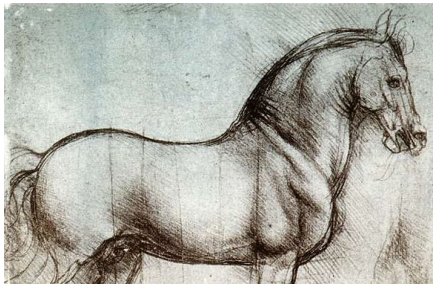
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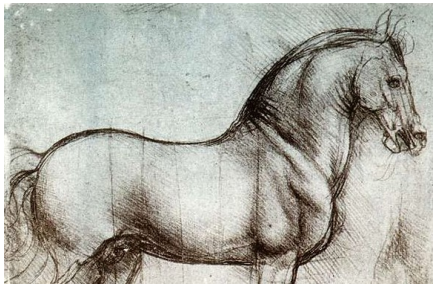
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What interests you? What is your competitive advantage? What do people associate you with?

Why do we do research in science?

Science is the best method that we have to learn about the world while keeping ourselves honest

Why do we do research in science?

Science is the best method that we have to learn about the world while keeping ourselves honest

As a species

As individual

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As individual

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As individual

- Curiosity
- To test out abilities

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As a species

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- Long-term growth of a country
- Combat pseudoscience

As individual

- Curiosity
- To test out abilities
- Altruism

Why do we do research in science?

Science is the best method that we have to learn about the world while keeping ourselves honest

As a species

- Curiosity
- Long-term growth of a country
- Combat pseudoscience

As individual

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More specialized
Degree of specialization
Less specialized
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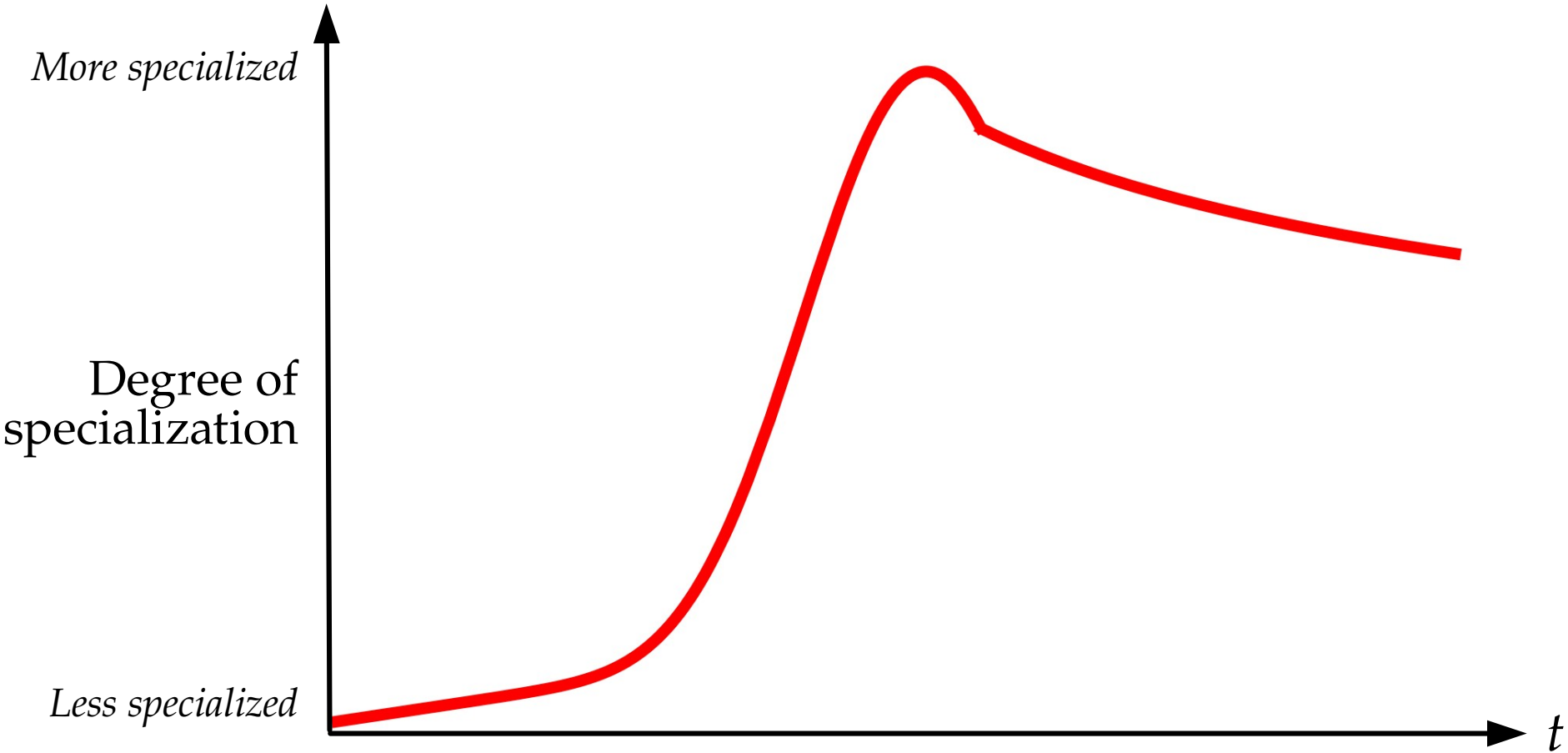
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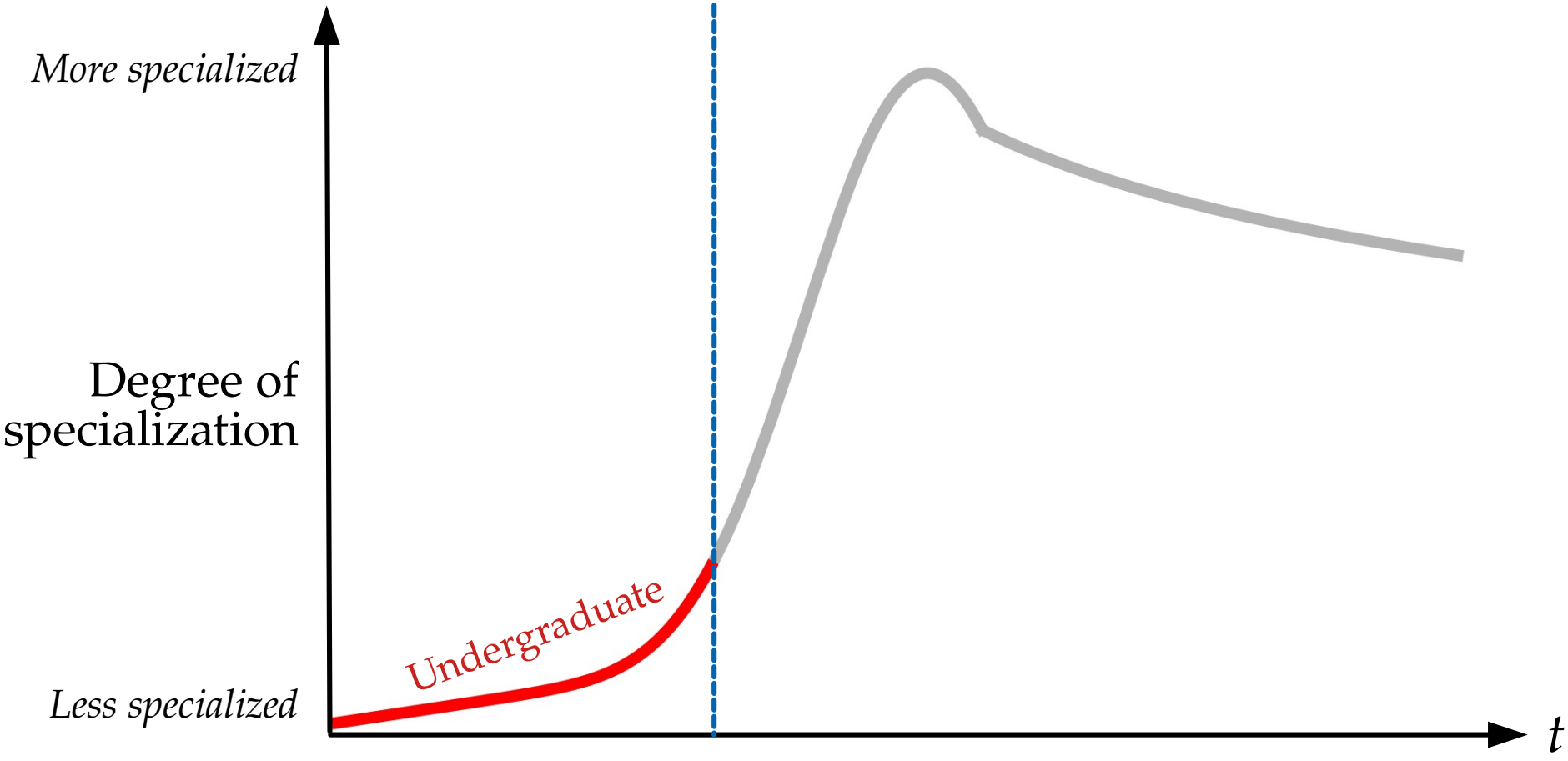
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Degree of specialization
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Undergraduate
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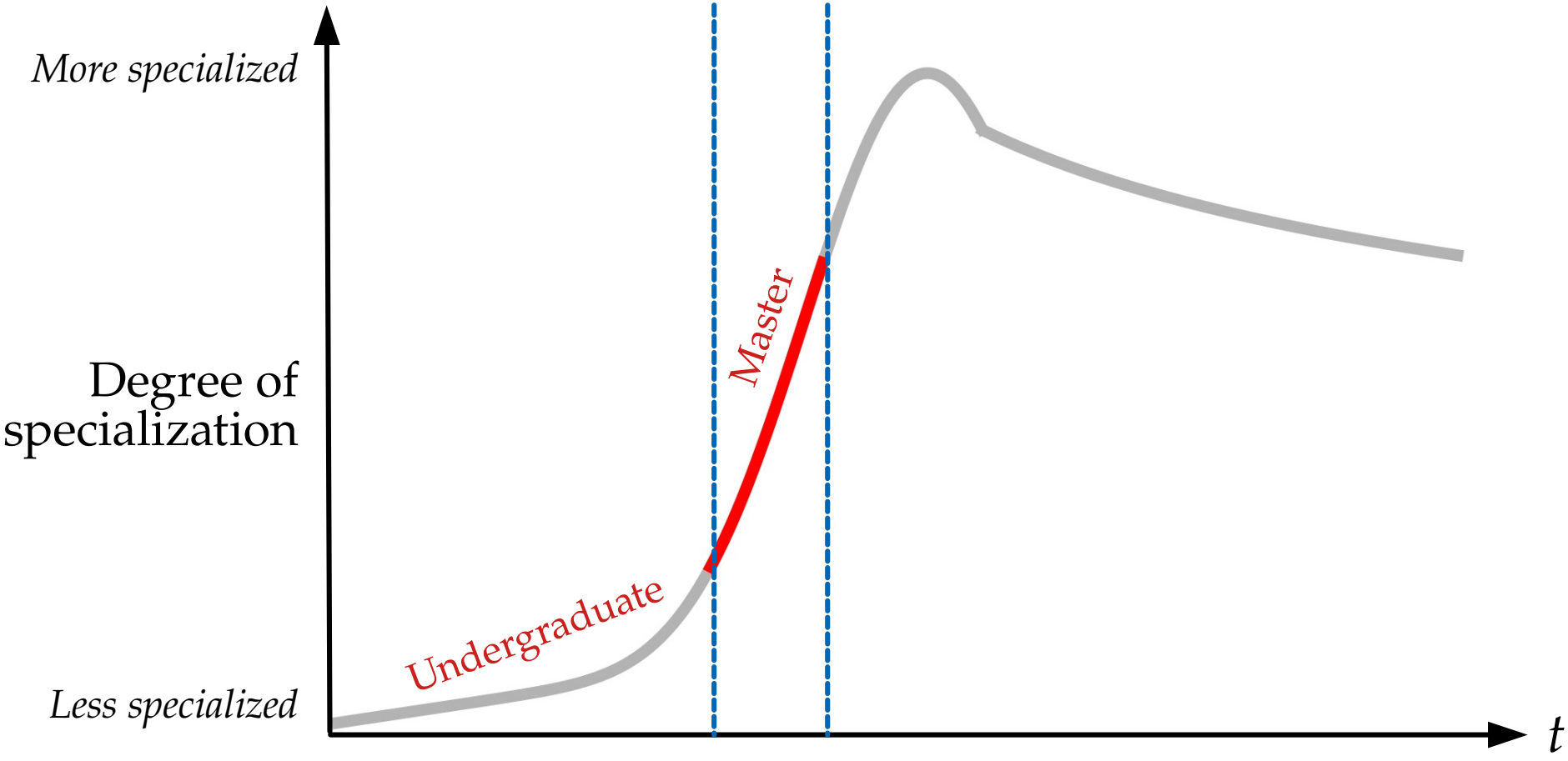
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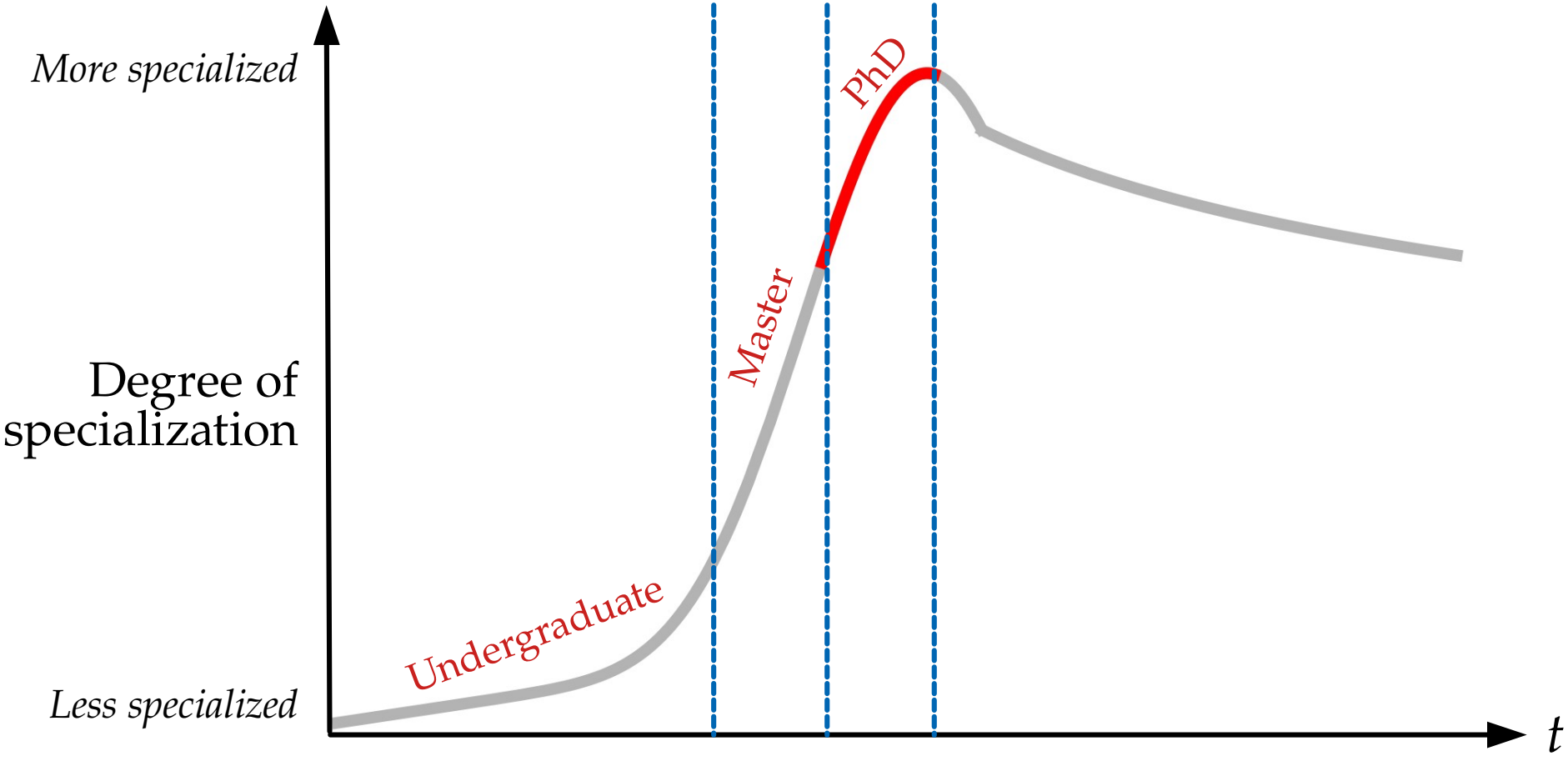
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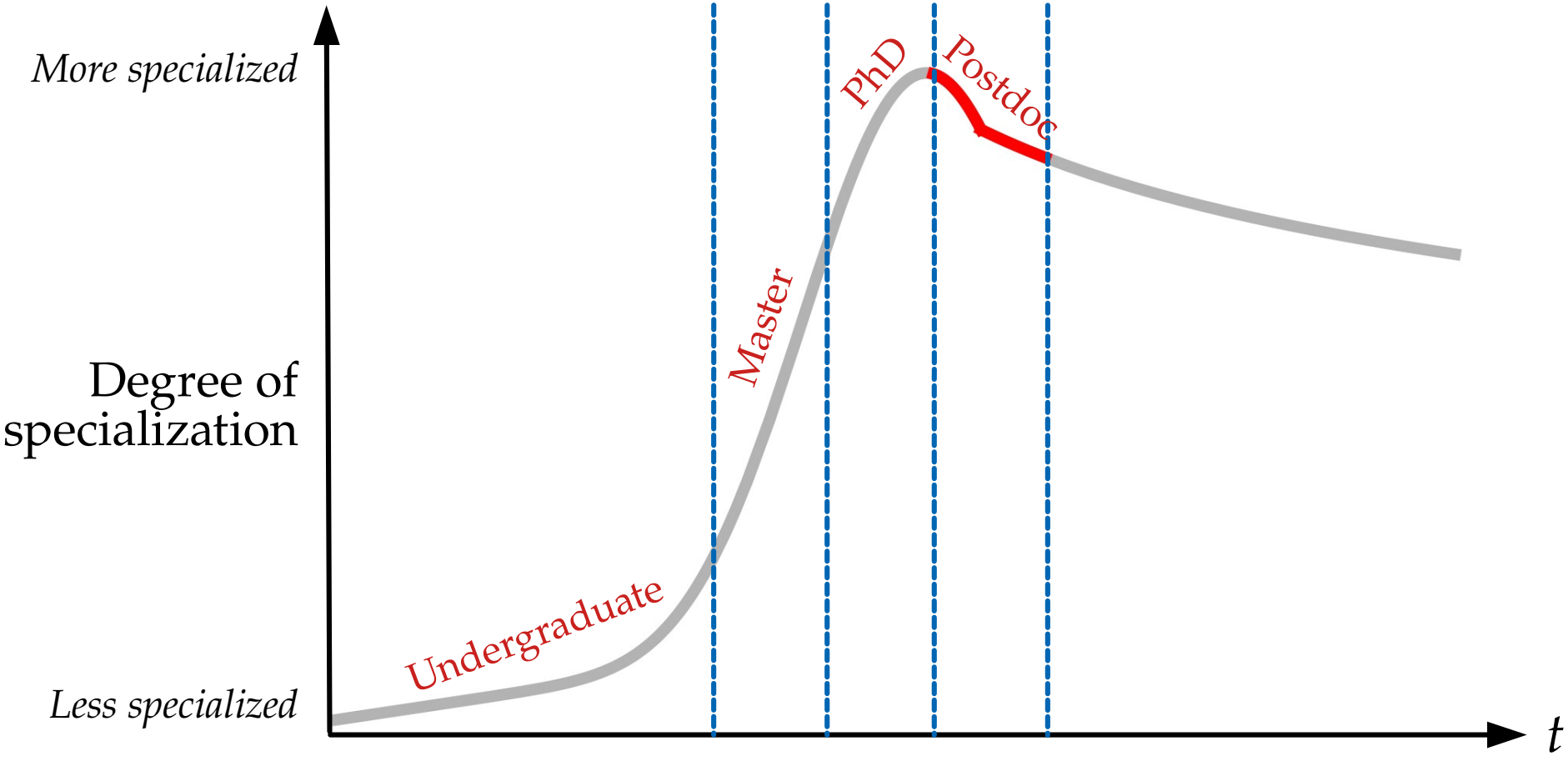
More specialized
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Master
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Postdoc
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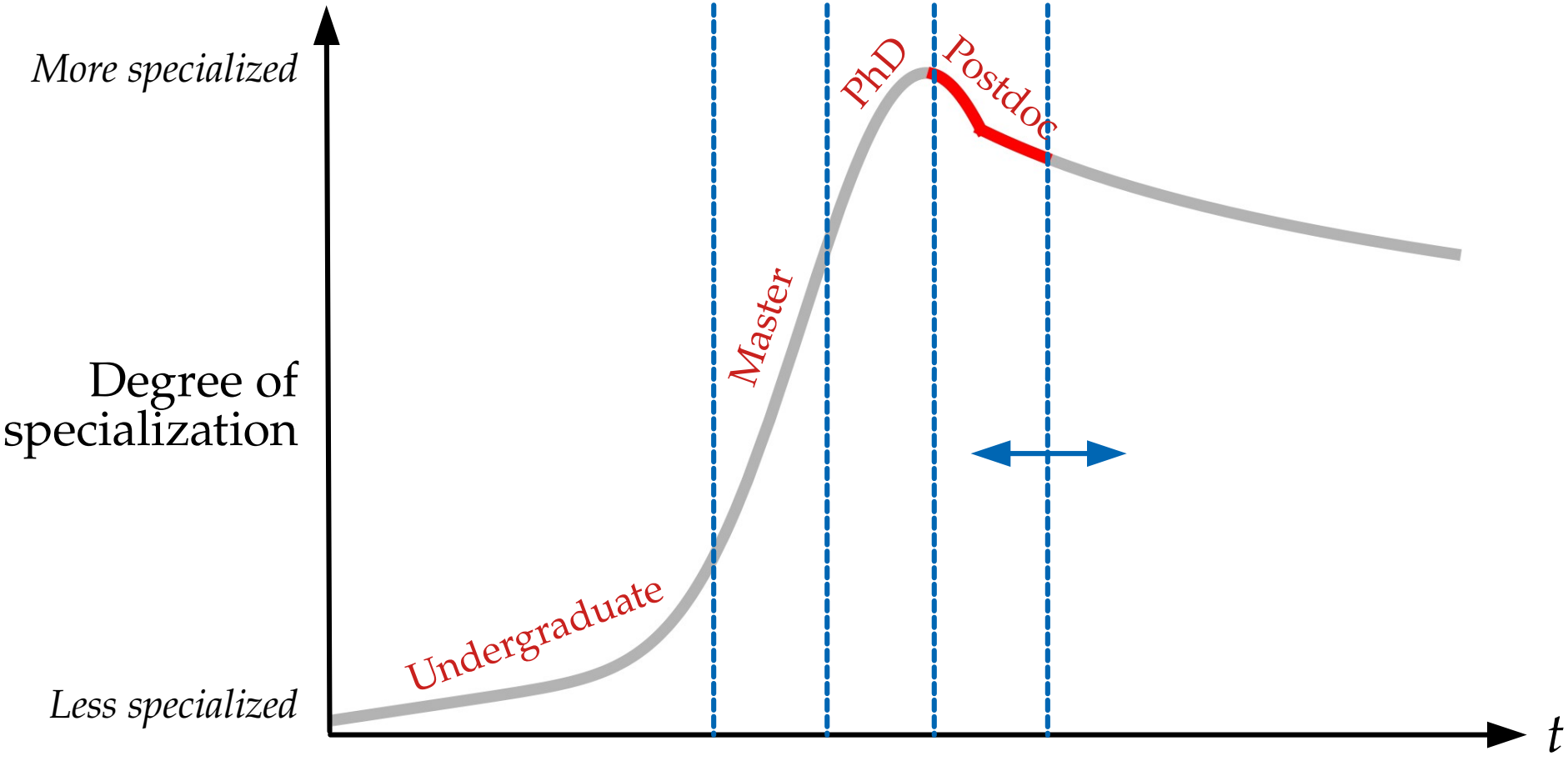
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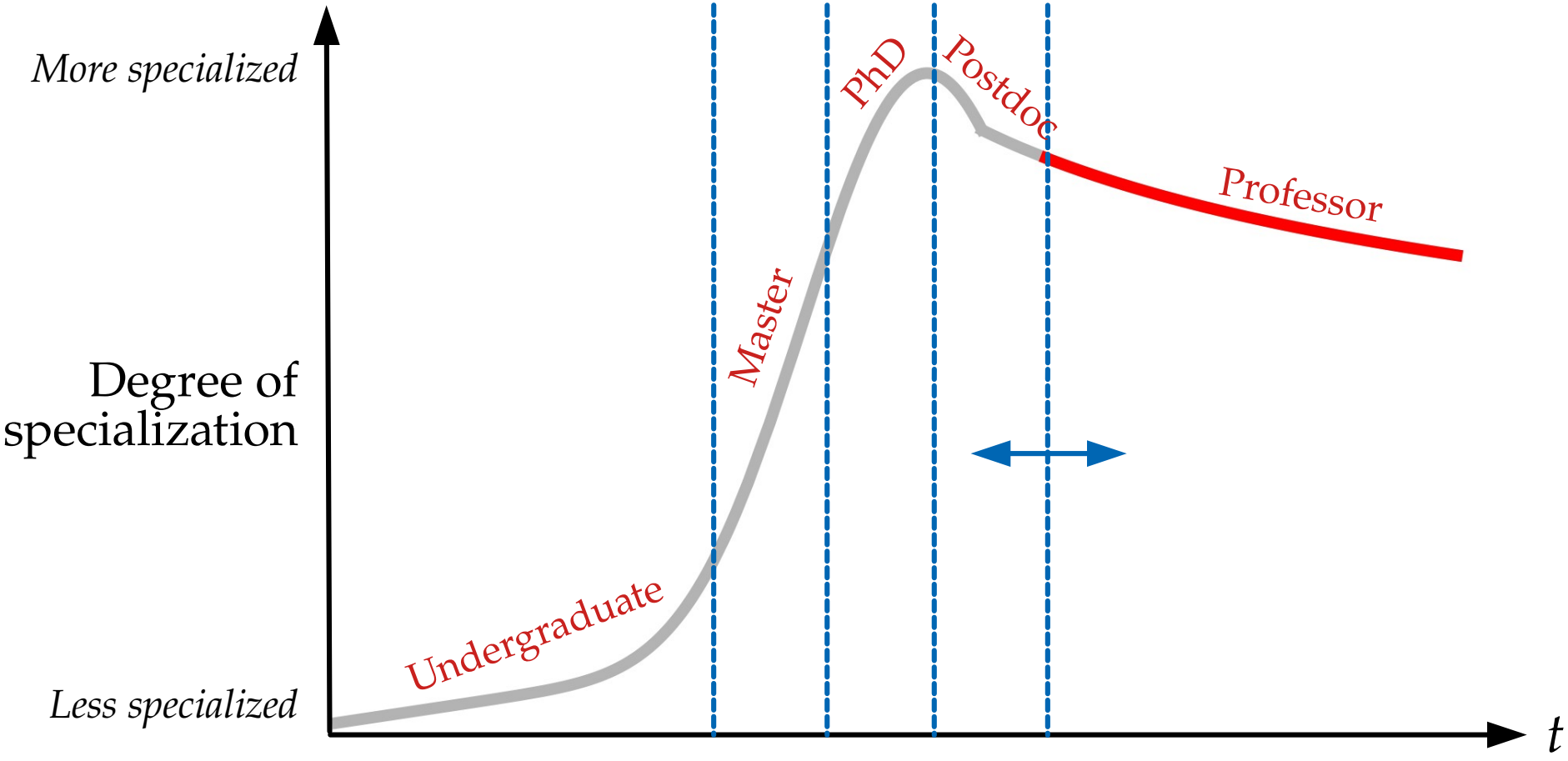
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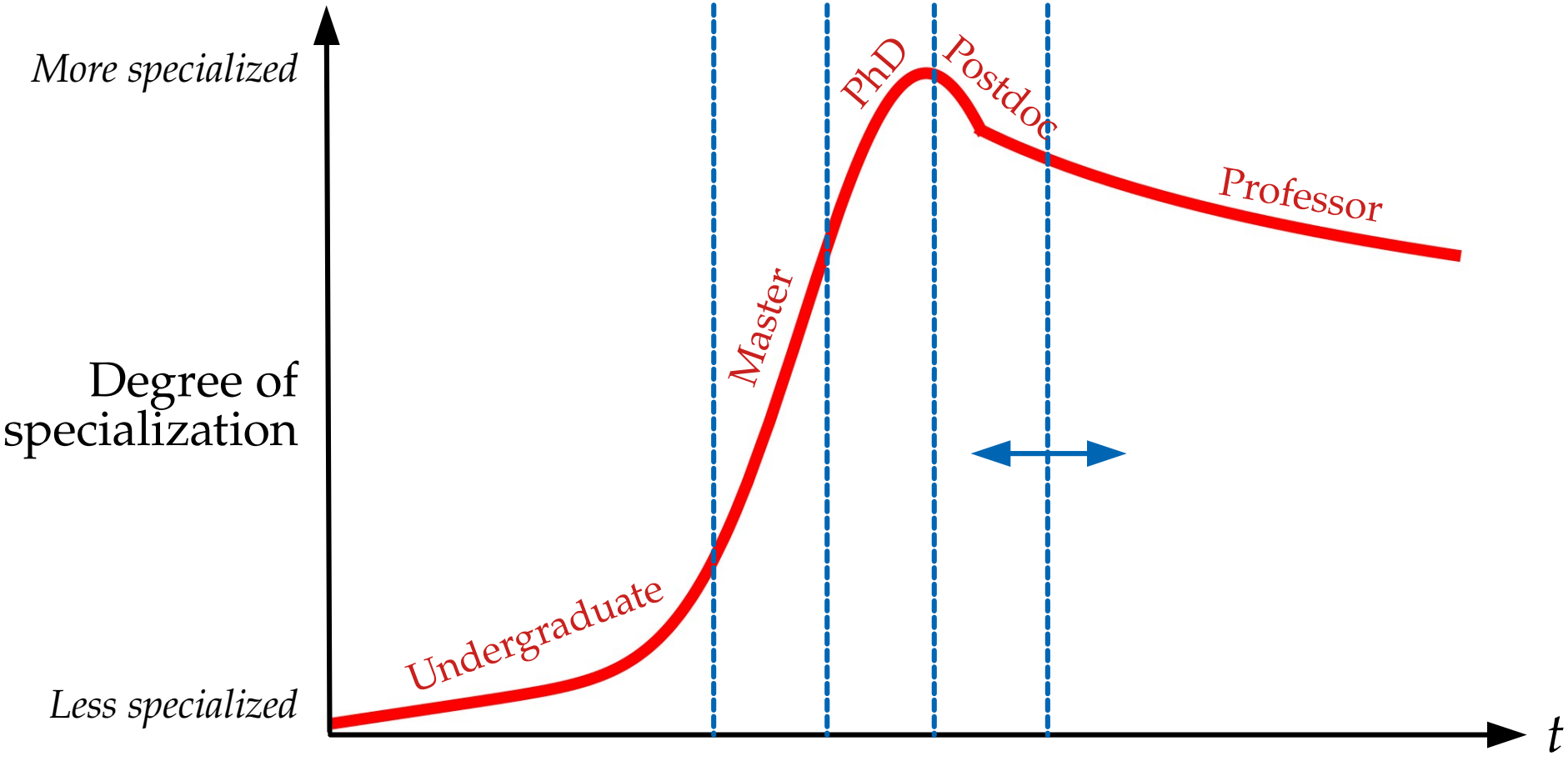
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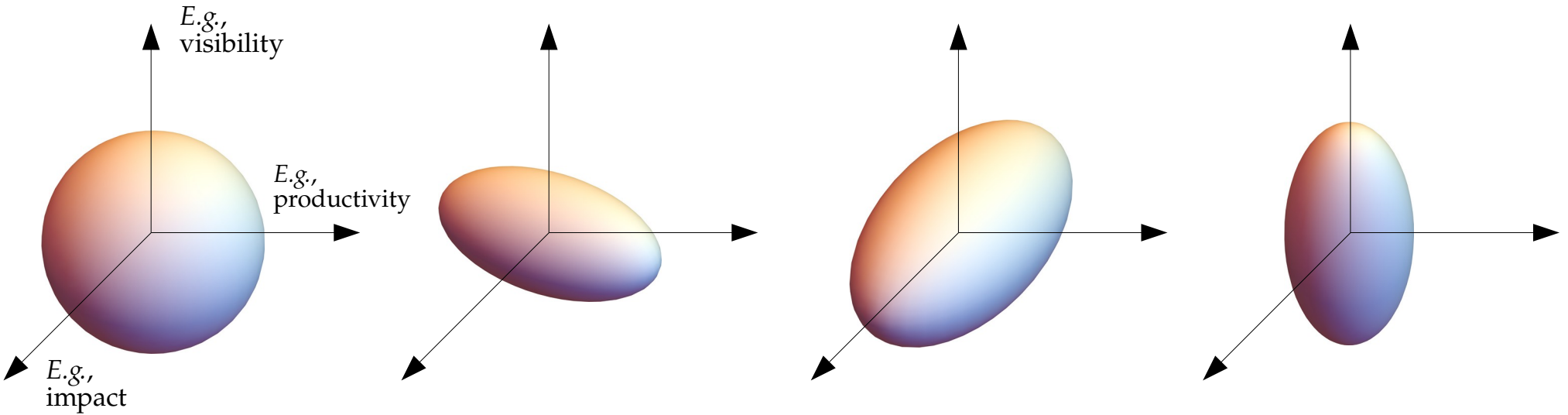
Academic success is a multidimensional function



$$\left(\frac{x}{a}\right)^2 + \left(\frac{y}{b}\right)^2 + \left(\frac{z}{c}\right)^2 = 1$$

Success: $V = \frac{4}{3}\pi abc$

If any of *a*, *b*, or *c* are zero, *V* is zero

Soft skills are crucial!

Most important: Make good science

Second most important: Communicate it effectively!

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  Explain the core of your work in the span of a minute

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Universe's Worth of Electrons to Probe Long-Range Interactions of High-Energy Astrophysical Neutrinos

Mauricio Bustamante and Sanjib Kumar Agarwalla

Phys. Rev. Lett. **122**, 061103 – Published 12 February 2019

Physics See Synopsis: Neutrino Probes of Long-Range Interactions

26

More

Deutsches Elektronen-Synchrotron DESY
A Research Centre of the Helmholtz Association

2015/04/10

Back

Gamma-ray bursts as cosmic particle accelerators

Study provides new insights into the universe's most powerful explosions

This approach can not only explain the observed strong variations in the light curves of gamma-ray bursts. A consequence of this model is also that neutrinos, cosmic rays and gamma-rays must be produced in completely different regions of the jets. This can explain, why the expected flux of neutrinos could not be found. "We expect that the next generation of neutrino telescopes, such as IceCube-Gen-2, will be sensitive to this minimal flux that we're predicting", says Bustamante. In contrast to earlier models, this estimate is more robust and does only weakly depend on the characteristics of individual gamma-ray bursts.

CERNCOURIER | Reporting on international high-energy physics

NEUTRINOS | NEWS

The case of the disappearing neutrinos

15 January 2018

In an additional analysis of six years of IceCube data, Amy Connolly and Mauricio Bustamante of Ohio State University employ an alternative approach which uses 58 IceCube-contained events (in which the neutrino interaction took place within the detector) to measure the neutrino cross-section. Although these events mostly have well-measured energies, their neutrino zenith angles are less well known and they are also much less numerous, limiting the statistical precision.

EurekAlert! | AAAS

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NEWS RELEASE 28-OCT-2019

Giant neutrino telescope to open window to ultra-high-energy universe

SCIENCE CHINA PRESS

Media Contact
Mauricio Bustamante
mbustamante@nbi.ku.dk

http://www.scichina.com/

PHYSICS

Astronomers Propose Huge New Telescope System to Understand the Most Energetic Particles Ever Detected

GIZMODO

Ryan F. Mandelbaum
10/29/18 4:20PM • Filed to: GRAND

14.3K 24 5

"Blazars could maybe make neutrinos in a wide energy range, or maybe it could be something else making these higher-energy neutrinos," Mauricio Bustamante, editor of the experiment's white paper and a postdoc at the Niels Bohr Institute in Copenhagen, told Gizmodo. "We hope it's as interesting as possible."

MIT Technology Review

Sustainable Energy

How Neutrino Beams Could Reveal Cavities Inside Earth

Geophysicists want to use neutrinos to 'x-ray' the Earth, a technique that could reveal undiscovered oil fields. But how practical is such a scheme?

by Emerging Technology from the arXiv Feb 1, 2012

SCIENTIFIC AMERICAN

PHYSICS

Bizarre Particles Keep Flying out of Antarctica's Ice, and They Might Shatter Modern Physics

"It was clear from the start that if the ANITA anomalous events are due to particles that had propagated through thousands of kilometers of Earth, then those particles were very likely not SM particles," said Mauricio Bustamante, an astrophysicist at the Niels Bohr Institute at the University of Copenhagen, who was not an author on the new paper.

Science outreach

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We dedicate this book
To our fellow citizens
Who, for love of truth,
Take from their own wants
By taxes and gifts,
And now and then send forth
One of themselves
As dedicated servant,
To forward the search
Into the mysteries and marvelous simplicities
Of this strange and beautiful Universe,
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- Down the path: consider a TEDx event

Funding opportunities in Peru

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PRONABEC (www.pronabec.gob.pe)

- Beca 18: For senior high-school students (passed)
- Beca Mujeres en Ciencia: For female senior high-school students (passed)
- Beca Inclusión: For people with disabilities (deadline: 15/02/2021)
- Crédito Talento: Credit with comfortable payback times (deadline: 18/03/2021)
- Crédito Continuidad de Estudios: For students affected by COVID-19 (passed)
- Beca Presidente: MSc and PhD abroad, annual (passed)

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PUCP

- Programa de Apoyo a la Iniciación en la Investigación (PAIN): For undergraduate students
  investigacion.pucp.edu.pe/convocatoria/programa-apoyo-iniciacion-en-investigacion-pain
- Programa de Apoyo a la Investigación para Estudiantes de Posgrado (PAIP): For grad students
  investigacion.pucp.edu.pe/convocatoria/programa-apoyo-investigacion-para-estudiantes-de-posgrado-paip
- Beca Huiracocha: For PhD students
  posgrado.pucp.edu.pe/beca-fondo/beca-huiracocha

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- Beca Huiracocha: For PhD students
  posgrado.pucp.edu.pe/beca-fondo/beca-huiracocha

Full list of undergraduate scholarships (State, private): www.pucp.edu.pe/pregrado/becas

Ten tips for beginner researchers 1/2

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5. Start reading scientific articles early (undergrad)
   - Different from reading a non-scientific text
   - Key skill: single out main results quickly

Ten tips for beginner researchers 2/2

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   - Python or Python + C
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10. Be mindful of your mental health
    As important as items 1–9

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  Start thinking about this in your penultimate undergrad year
- Are the undergrad and grad programs competitive internationally?
  Yes! You get a solid foundation to continue your academic career
- Do I need to choose early in my undergrad between theory and experiment?
  Not at all. Yo can explore both to find what you prefer to do in your grad studies.
- As a physicist, do I have job opportunities in the industry?

FAQ

- When can I start to do research?
  Towards the end of your undergraduate years
- How do I start to do research?
  Talk to your professors, get to know the research groups in your department
- When should I start thinking about graduate studies?
  Start thinking about this in your penultimate undergrad year
- Are the undergrad and grad programs competitive internationally?
  Yes! You get a solid foundation to continue your academic career
- Do I need to choose early in my undergrad between theory and experiment?
  Not at all. Yo can explore both to find what you prefer to do in your grad studies.
- As a physicist, do I have job opportunities in the industry?
  Yes! In finance (banks, stock market), software development, consulting, design of new materials, etc.

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Feel free to contact me at mbustamante@nbi.ku.dk