PTOLEMY

# How to unravel the youngest Universe: Introduction to the PTOLEMY project

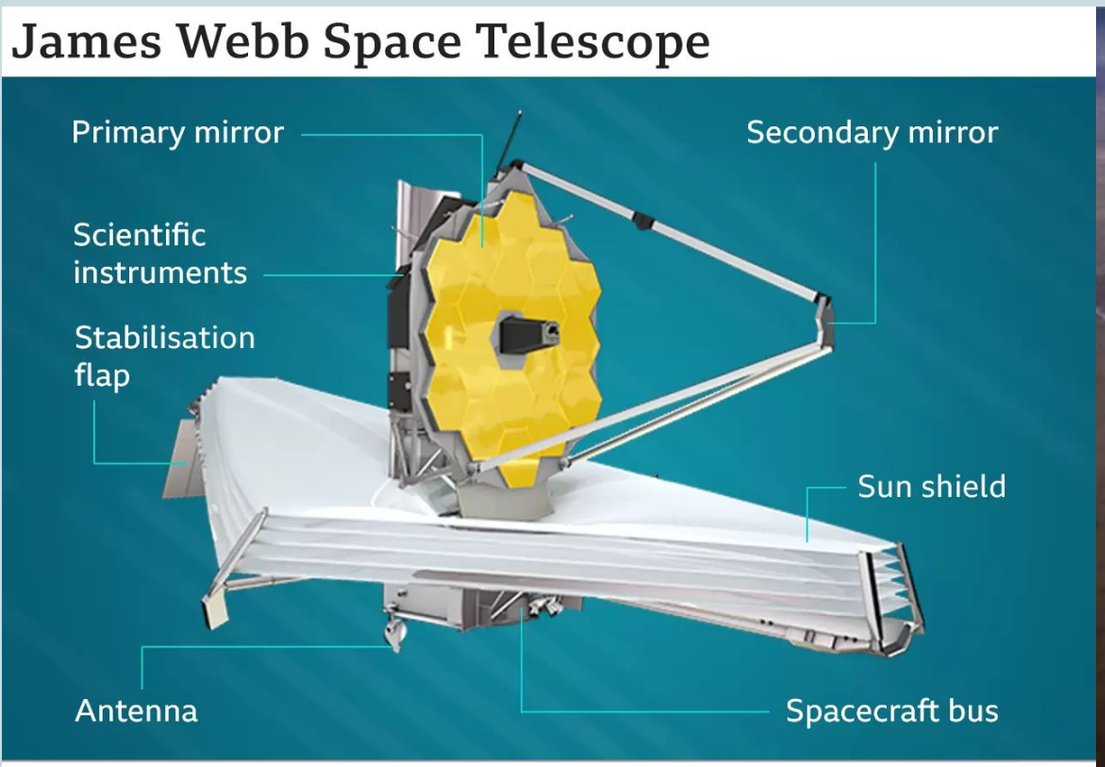
Chris Tully (Princeton University)

4 December 2024

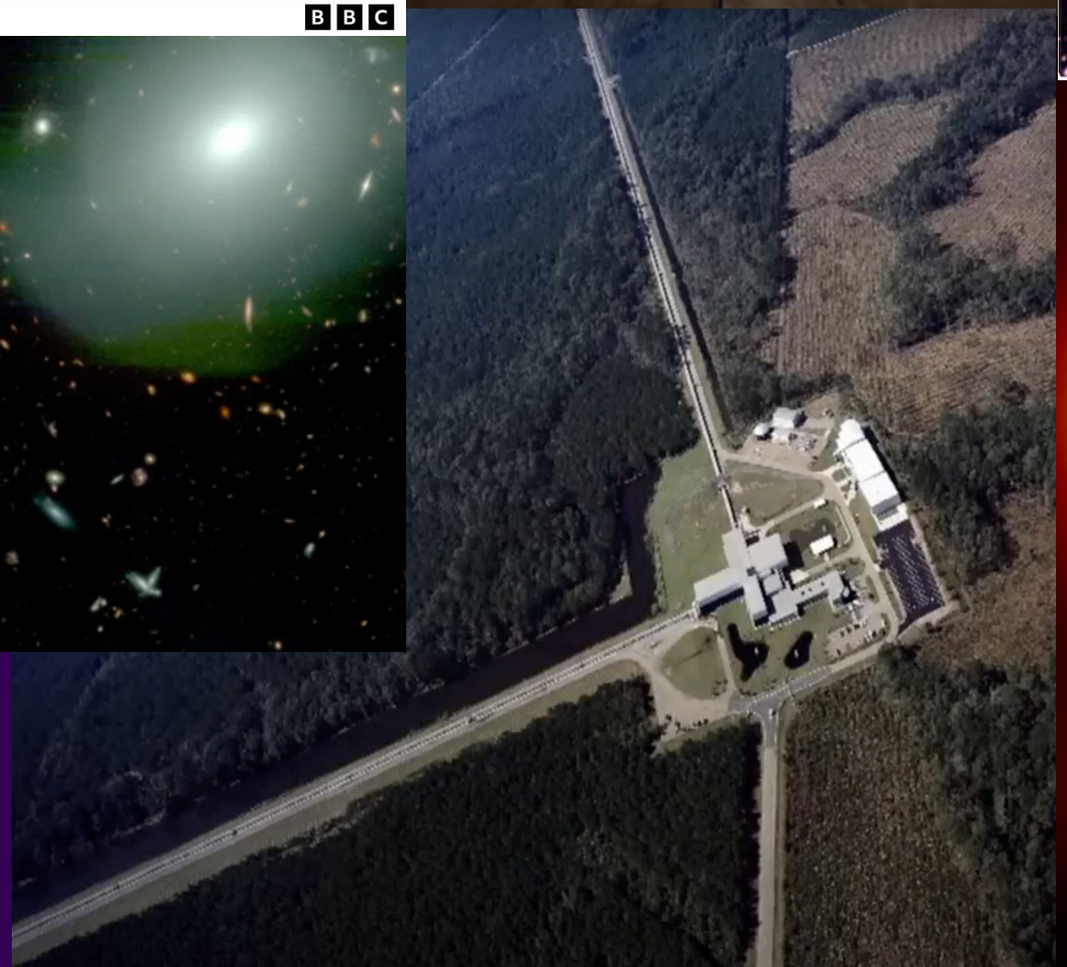
Genoa, Italy

Research supported by John Templeton Foundation

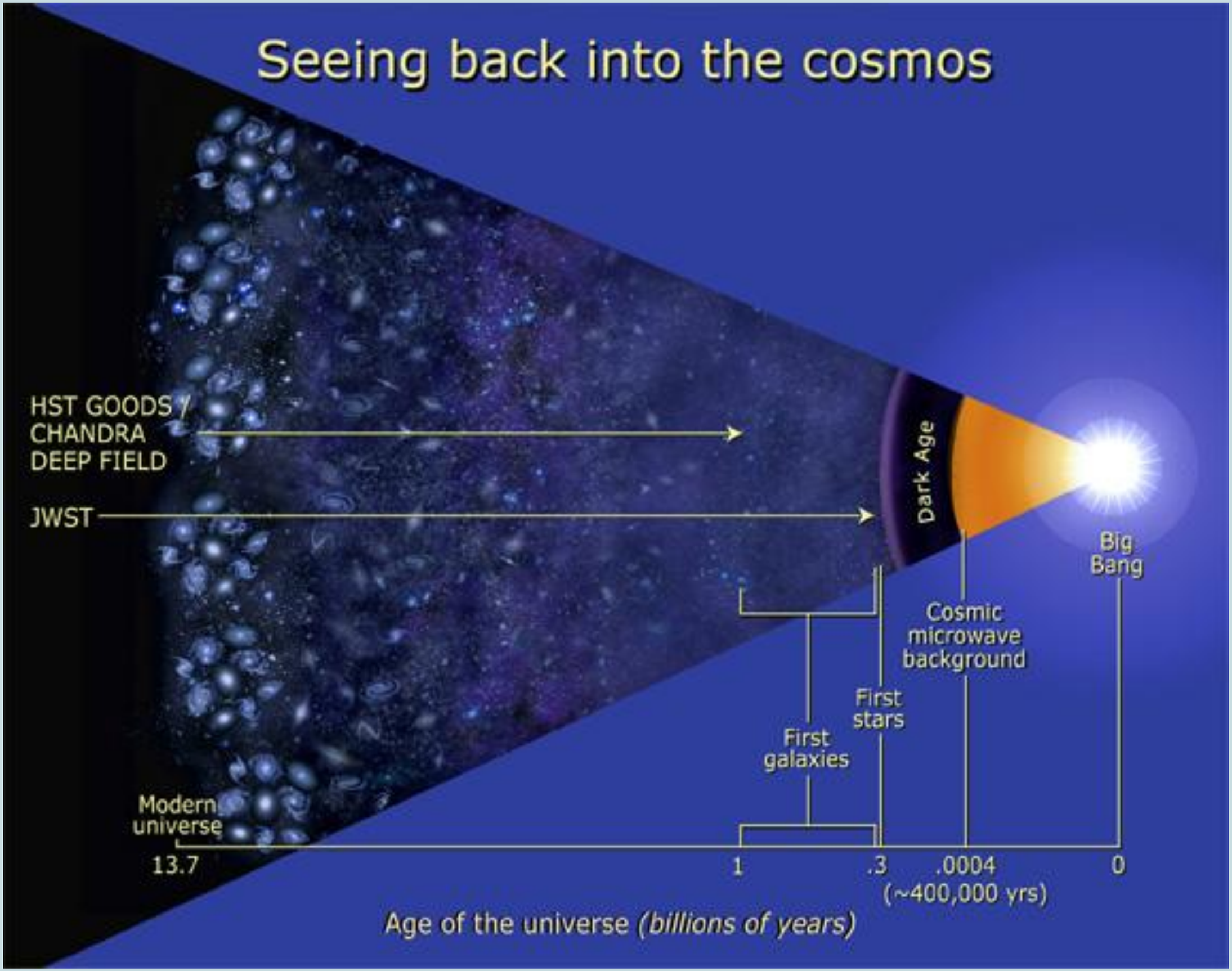
# ERA OF AMAZING NEW TELESCOPES

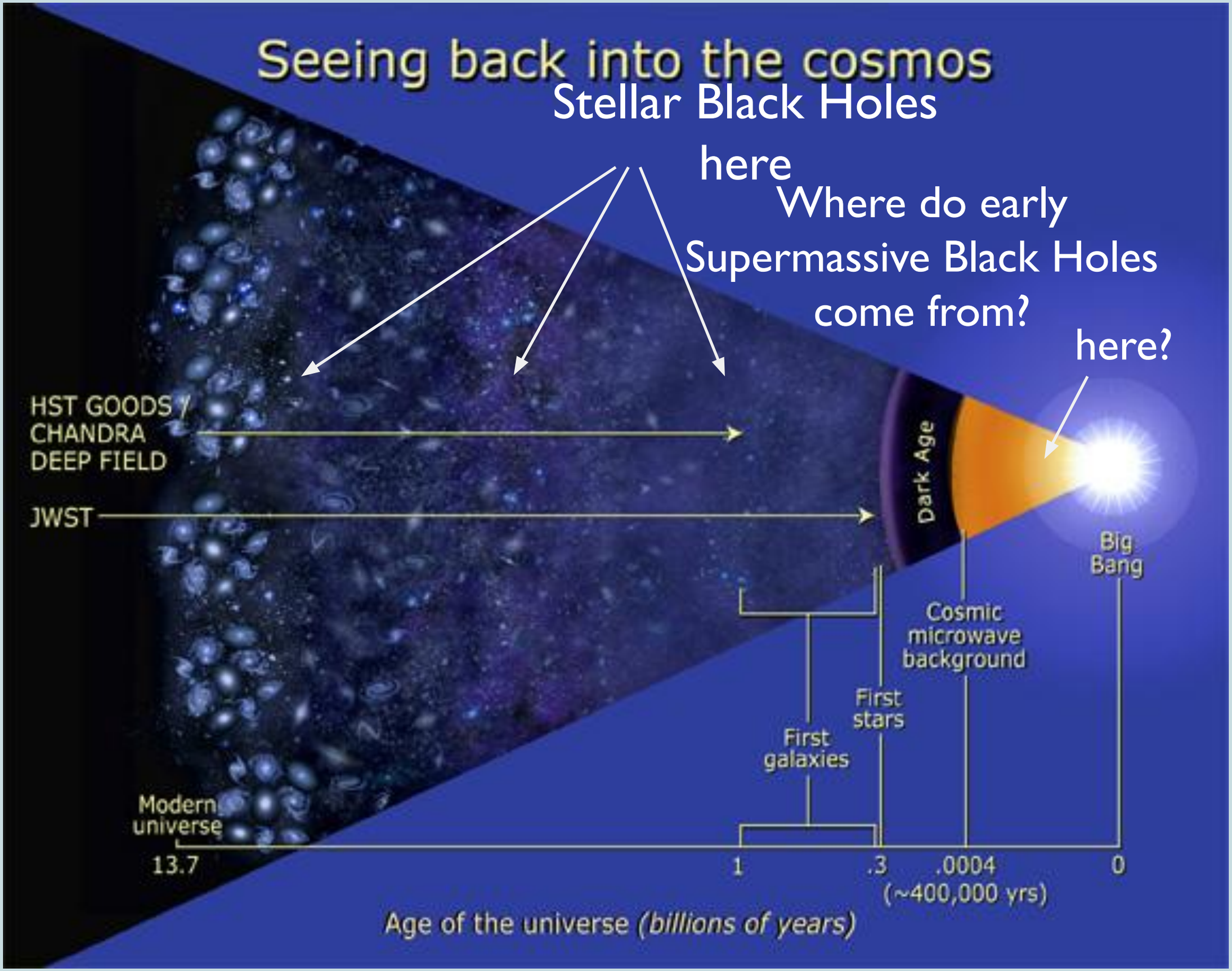



https://www.space.com/james-webb-space-telescope-ancient-black-hole-quasar



Event Horizon Telescope
Supermassive Black Hole
at Center of Milky Way Galaxy


Seeing back into the cosmos
HST GOODS / CHANDRA DEEP FIELD
JWST
Dark Age
Big Bang
Cosmic microwave background
First stars
First galaxies
Modern universe
13.7
1
.3
.0004
(~400,000 yrs)
0
Age of the universe (billions of years)


Seeing back into the cosmos
Stellar Black Holes here
Where do early Supermassive Black Holes come from?
here?
HST GOODS / CHANDRA DEEP FIELD
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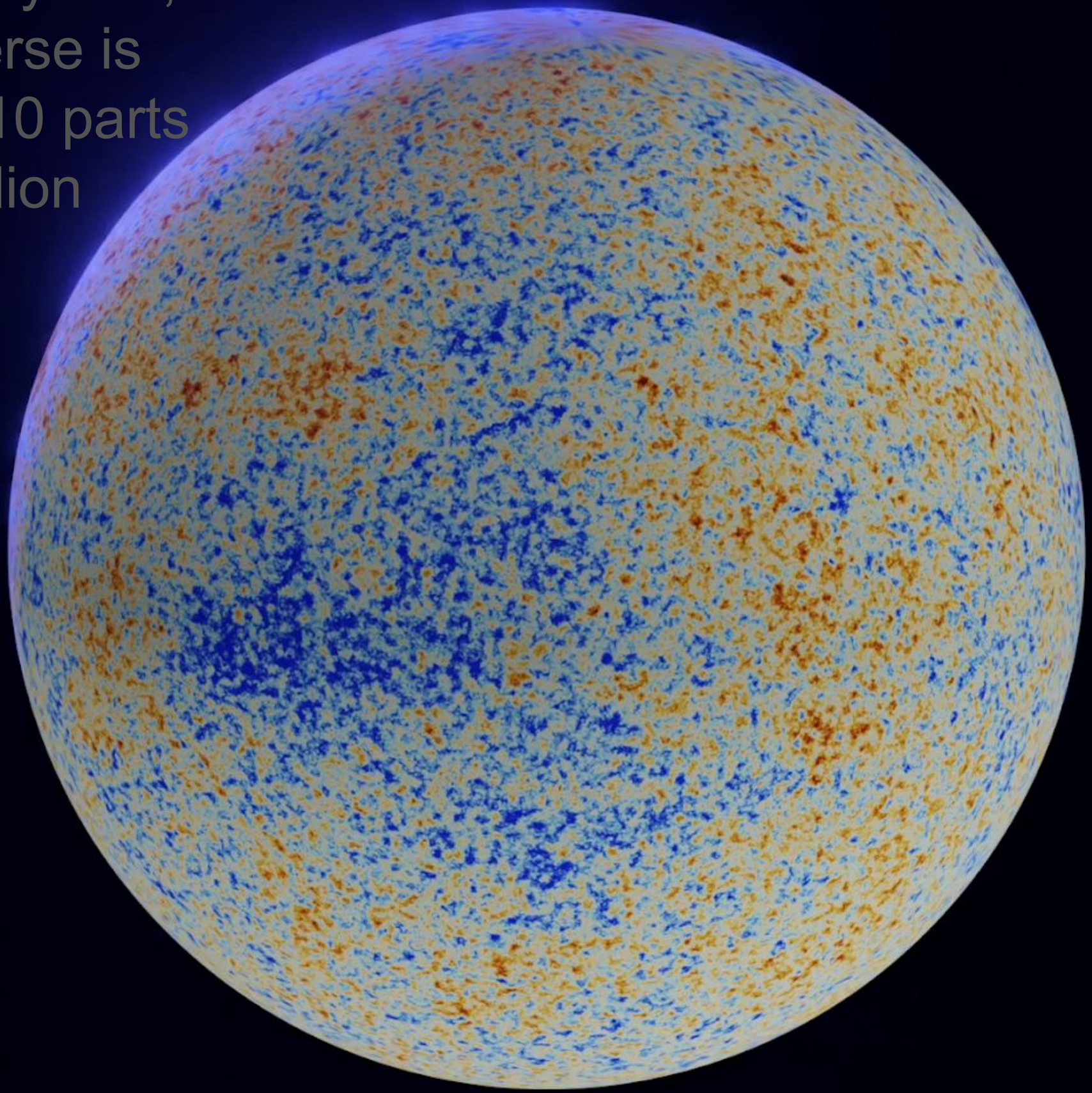
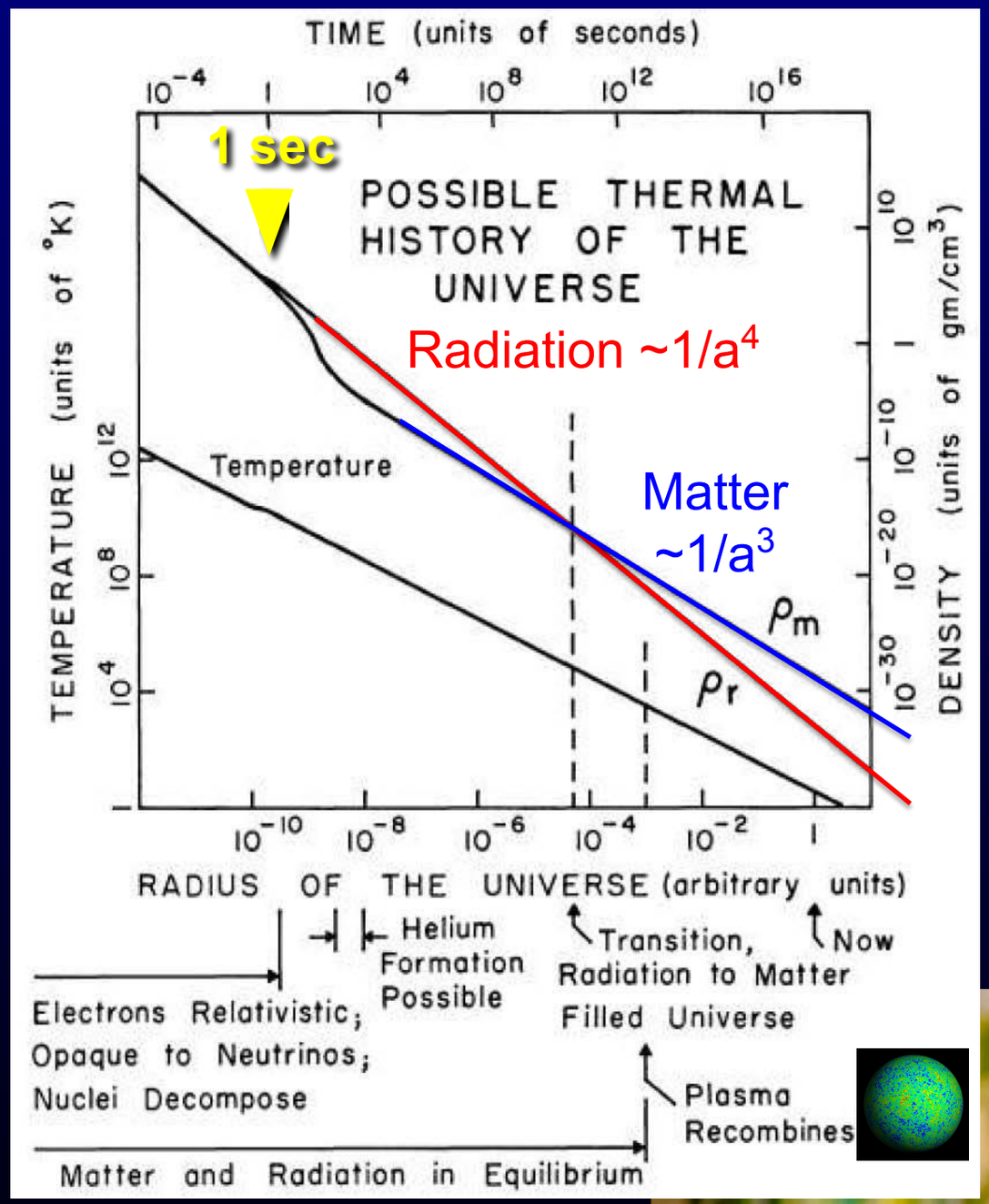
Age of the universe (billions of years)

At 330,000 years, the Universe is smooth to 10 parts per million



# Cosmic Neutrino Background




Number density:

$n_\nu = 112/cm^3$

Temperature:

$T_\nu \sim 1.95K$

Time of decoupling:

$t_\nu \sim 1$ second

~50% of the Total Energy Density of the Universe @ 1 sec

neutron/proton ratio @start of nucleosynthesis

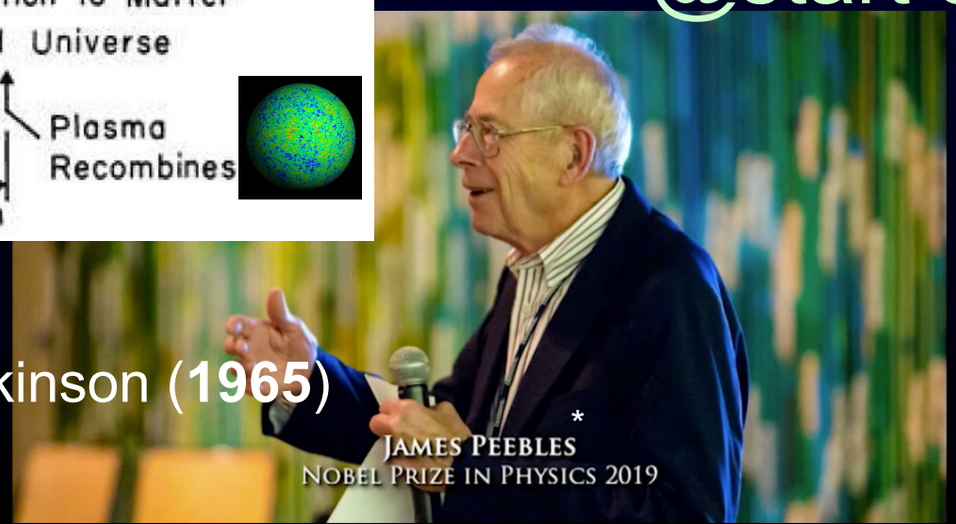
 $^4He$

$^2H$

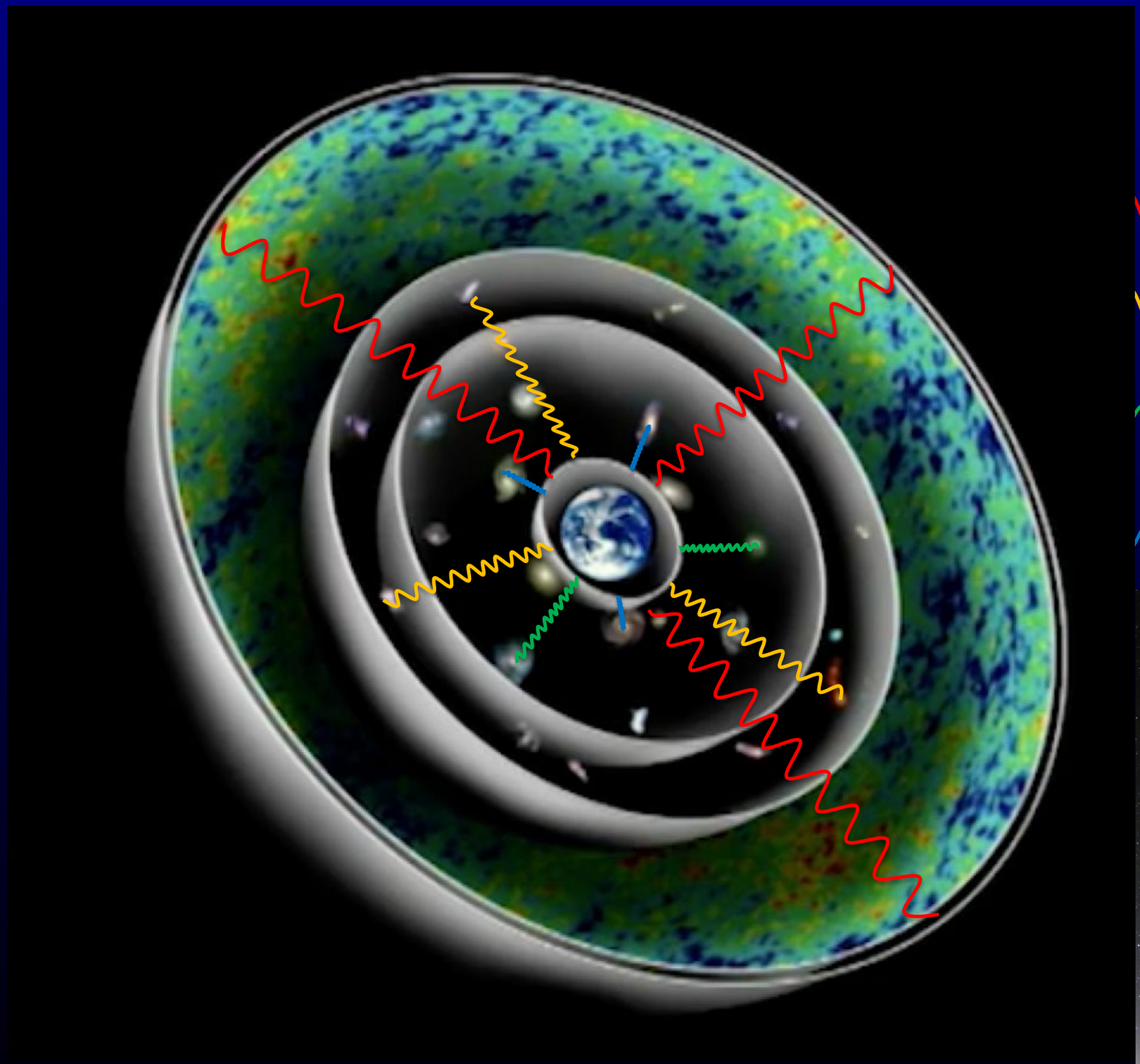
($^3H$

e)

Dicke, Peebles*, Roll, Wilkinson (**1965**)



# Looking Back in Time with Photons



Emission Time

-13.8x$10^9$ years

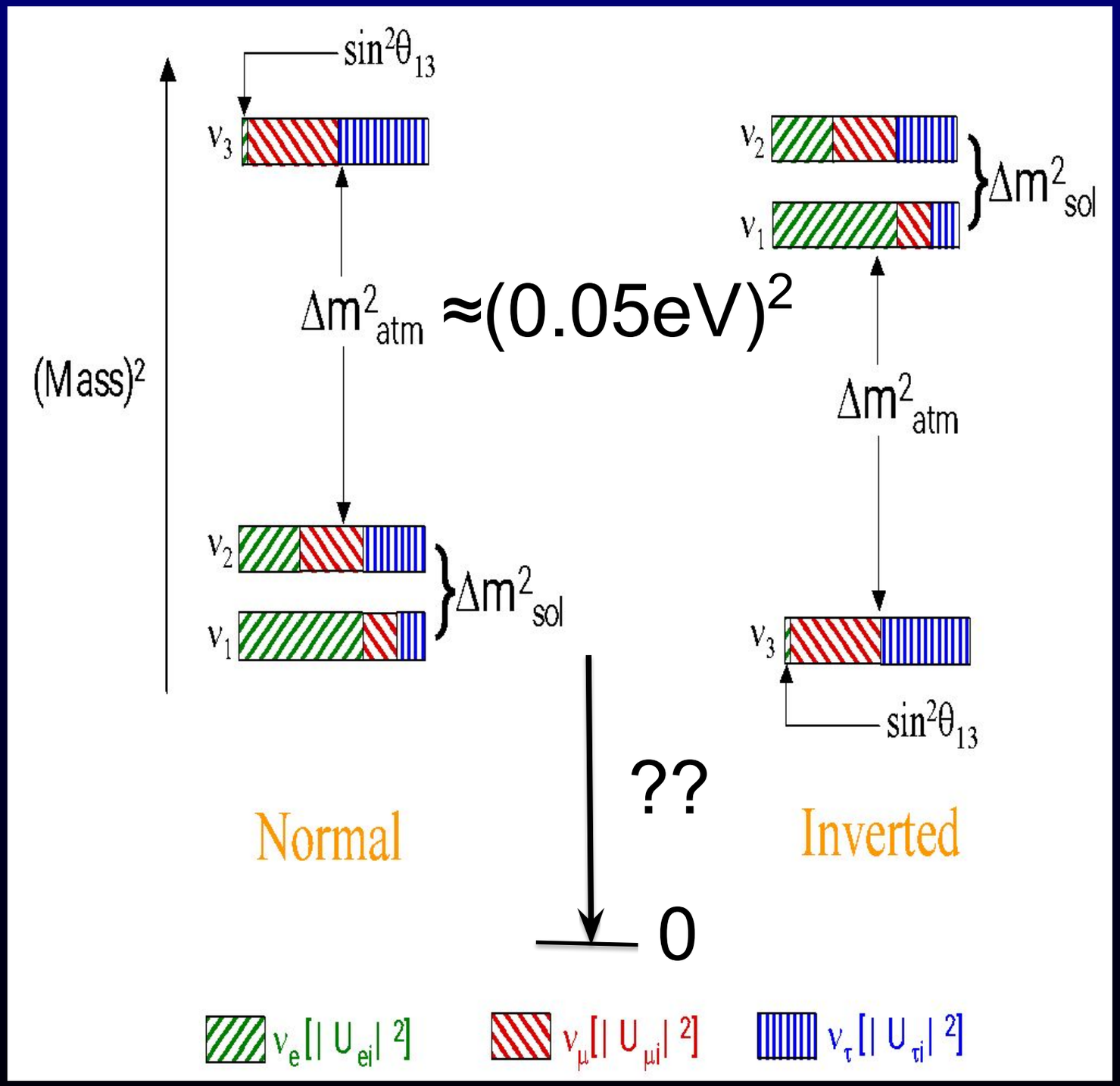
-4x$10^9$ years

-200x$10^6$ years

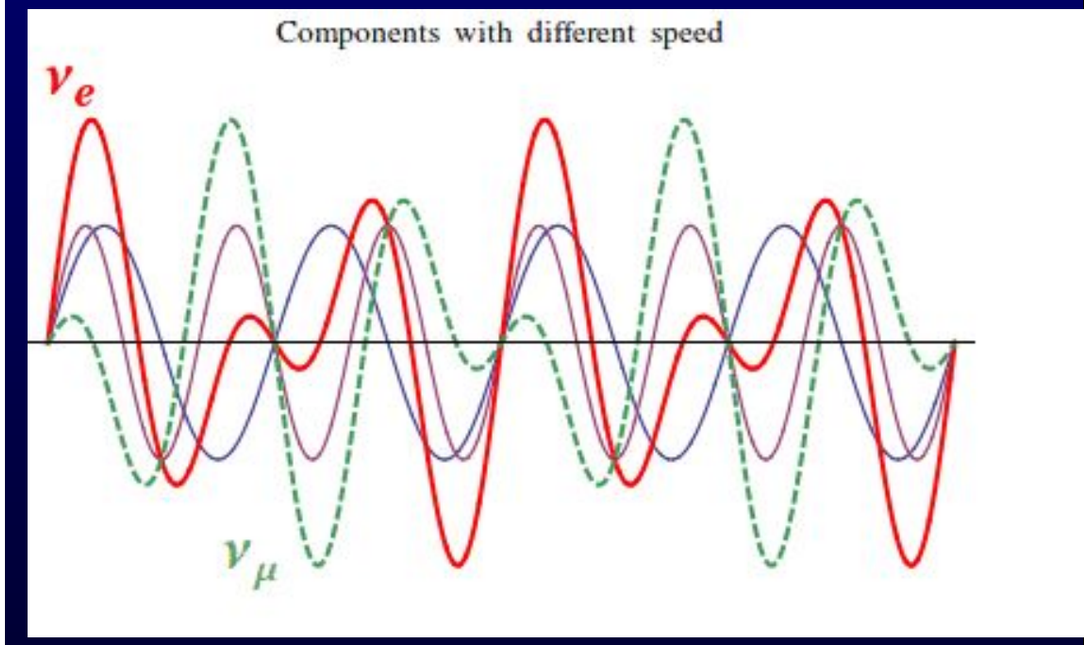
-2x$10^6$ years

All of this light arrives at the same time (t=0)

# Neutrino Masses from Oscillations




Theory developed by
Bruno Pontecorvo




3 mass eigenstates
X
3 flavors
(electron, muon, tau)

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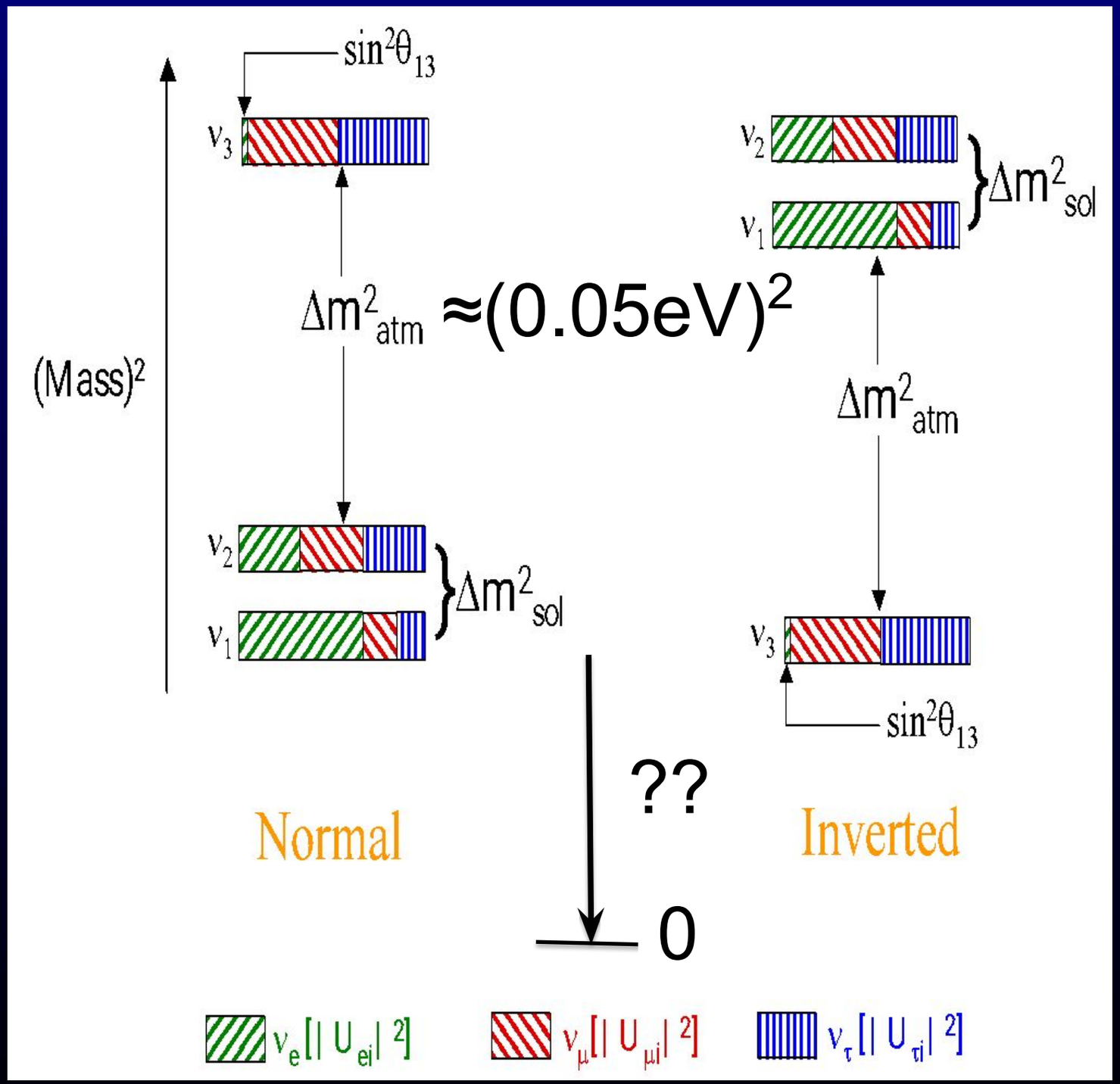


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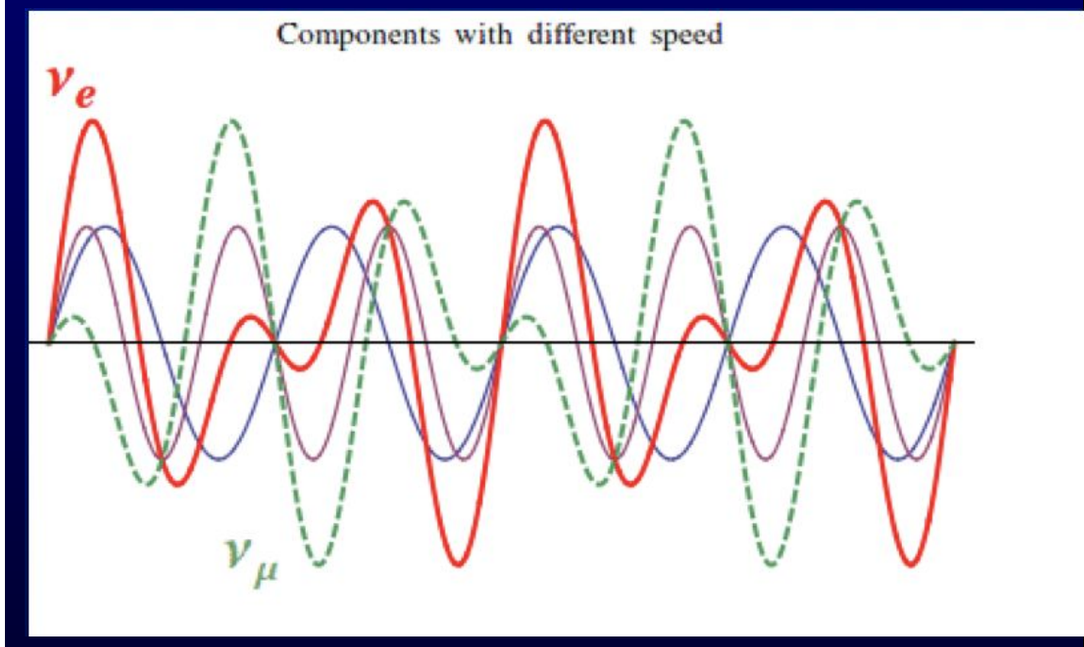


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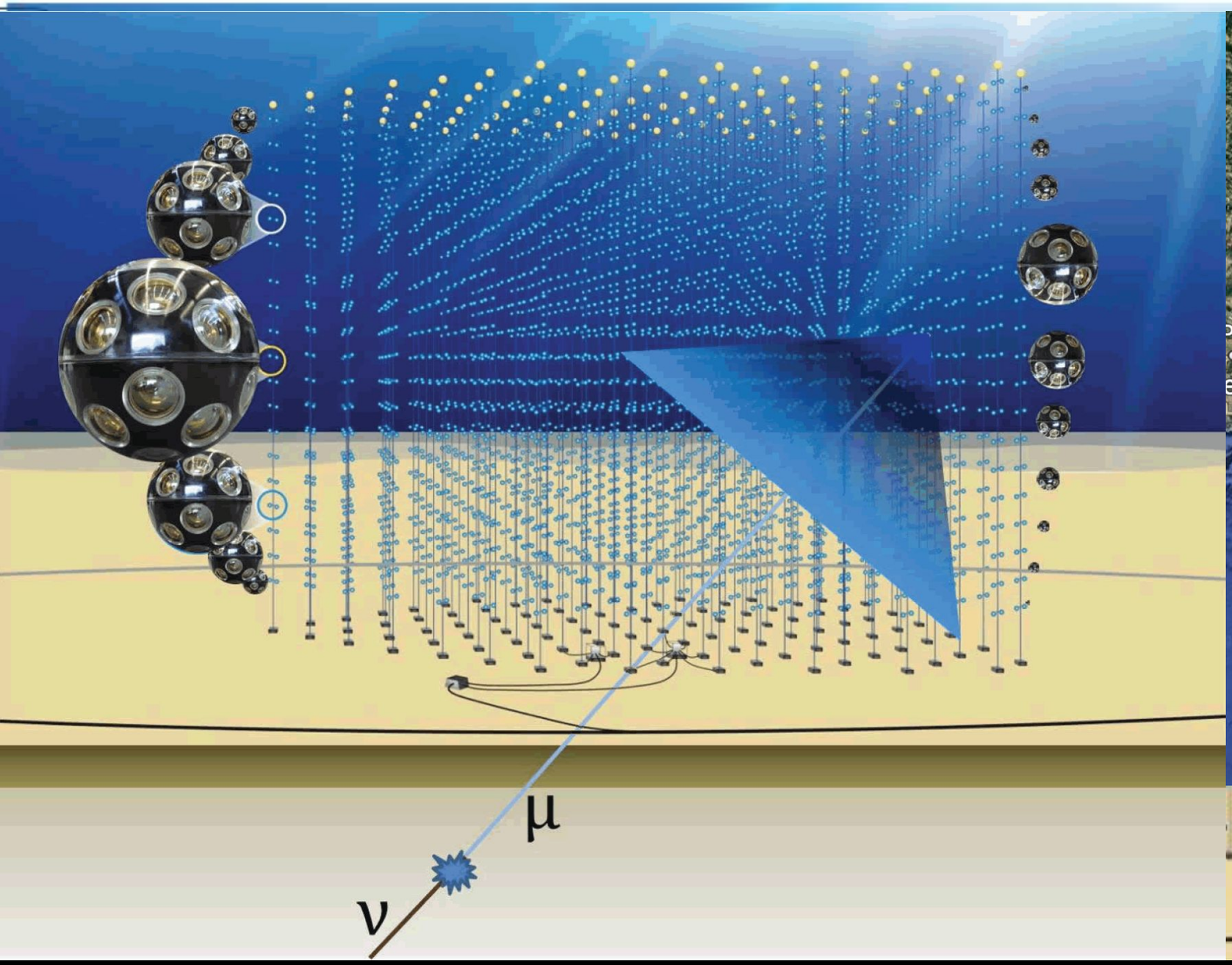
# Neutrino Mass Oscillation Observatory

**KM3NeT/ORCA** (**O**scillation **R**esearch with **C**osmics in the **A**byss)
determination of the neutrino mass hierarchy
($E_\nu$ ~ MeV - GeV) low energy neutrinos
Depth – 2500 m – offshore Toulon (France)

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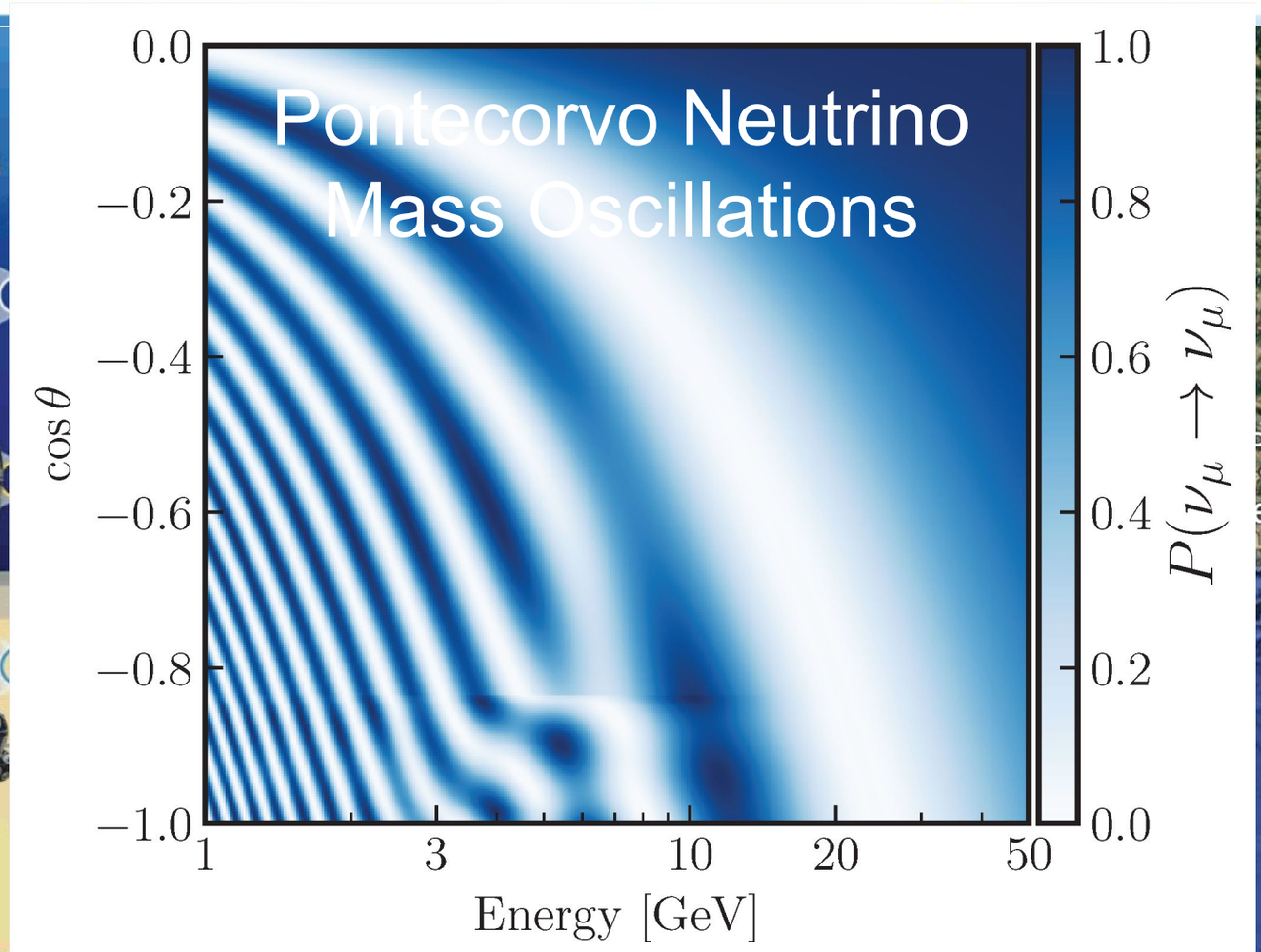
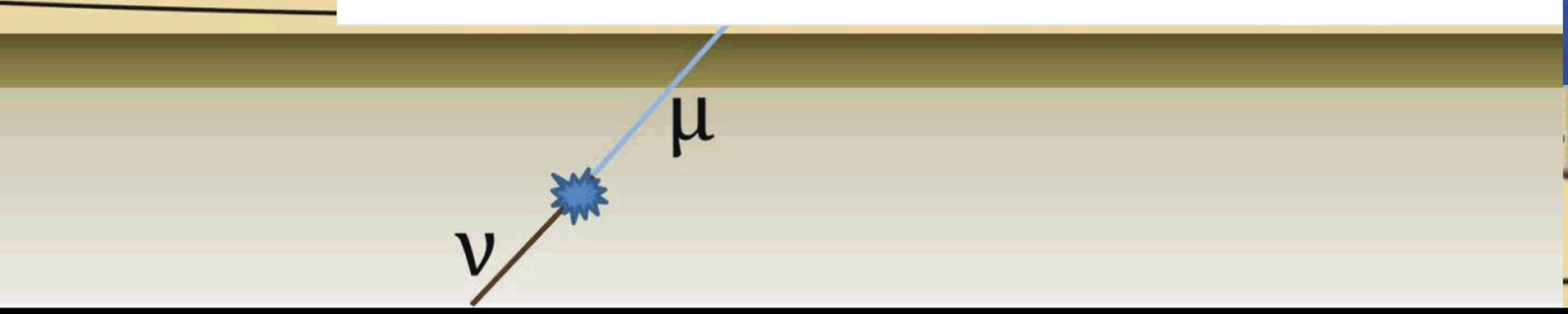
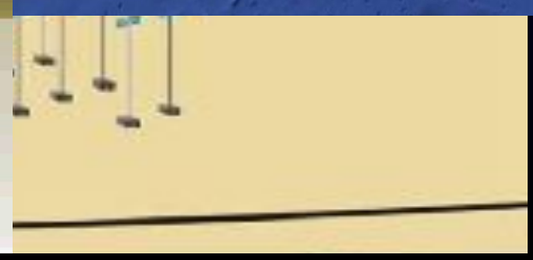
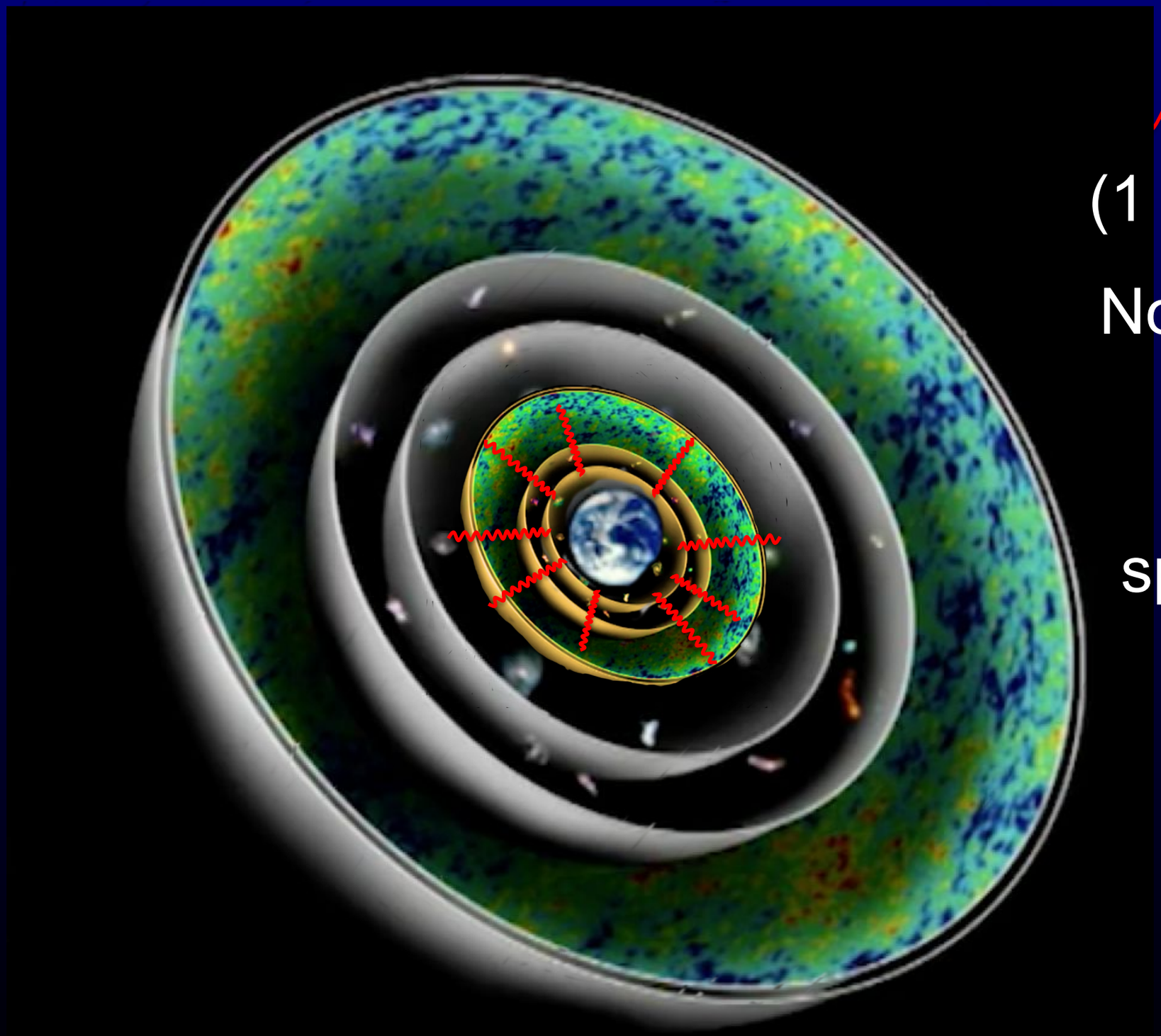






# Massive Neutrino Timeline



Emission Time

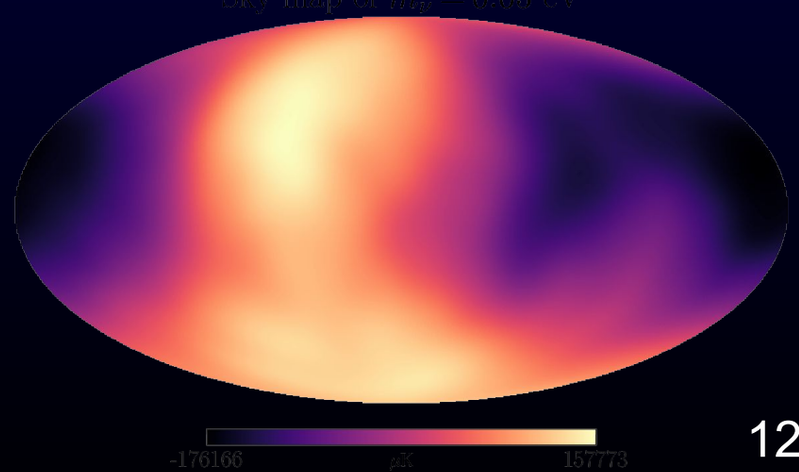
~~~ -13.8x$10^9$ years

(1 second after Big Bang)

No comparable flux from other sources

Starting radius more spread out due to mass

Neutrino Sky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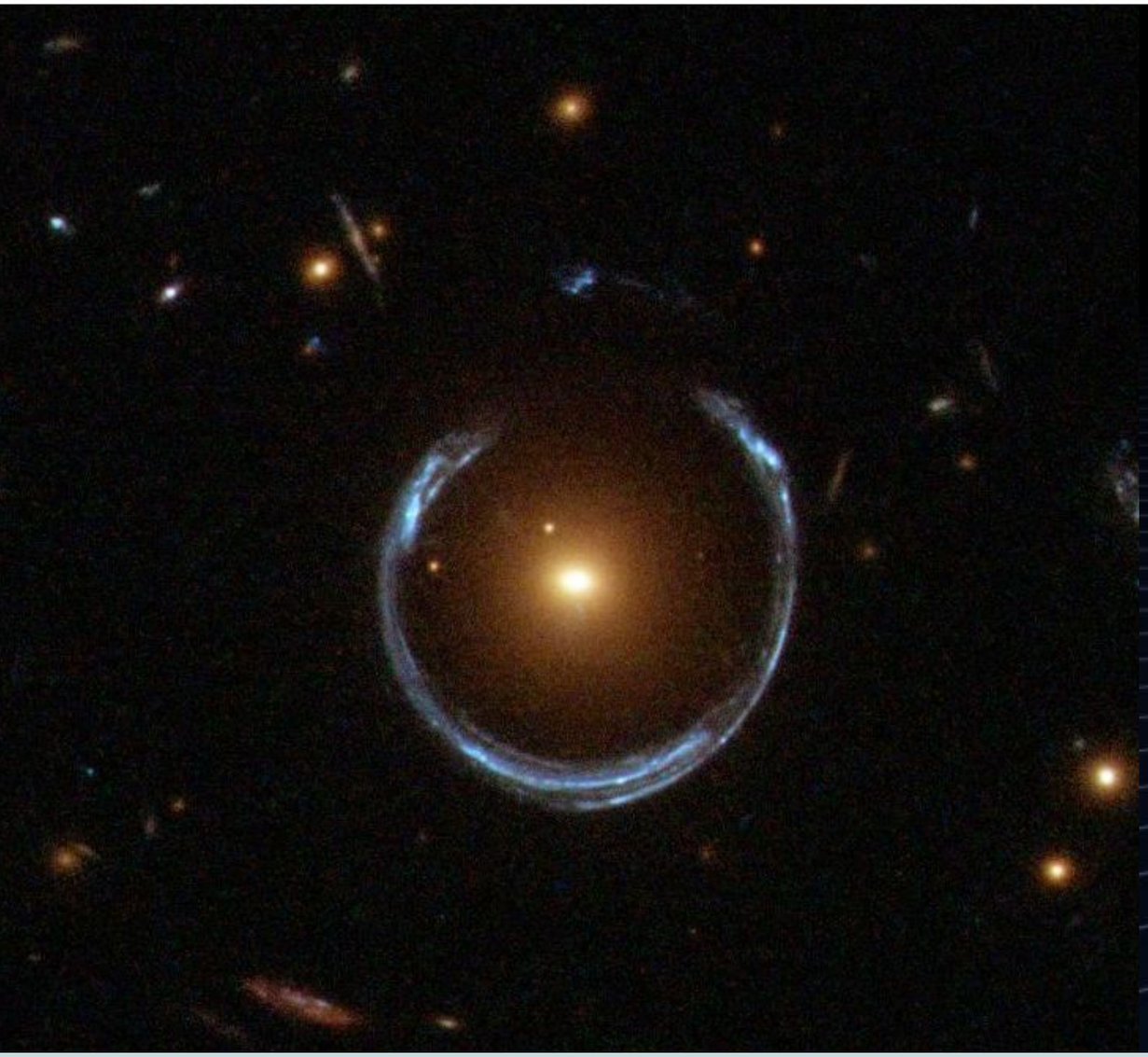
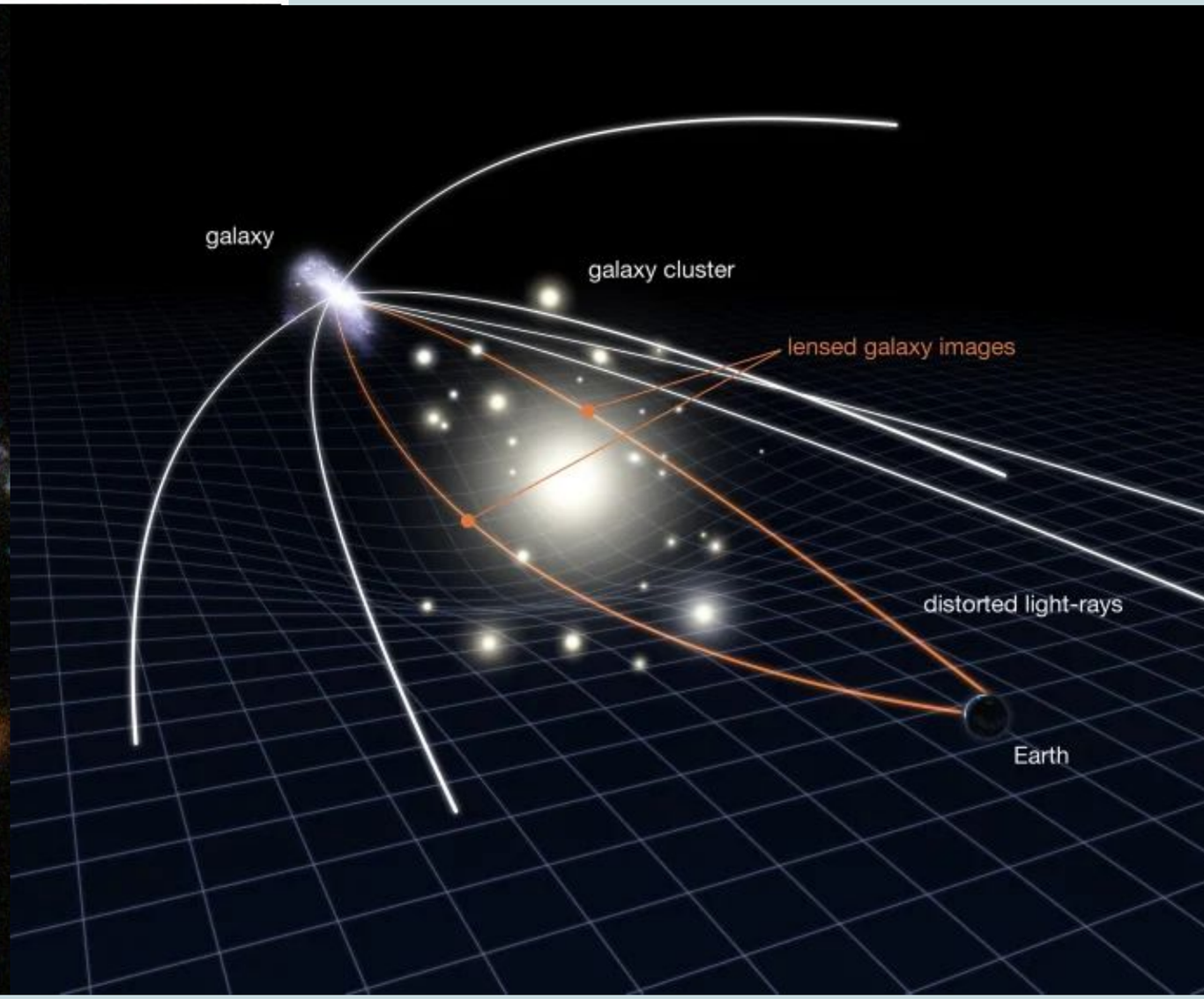
# Einstein rings

Predicted by Einstein in 1936

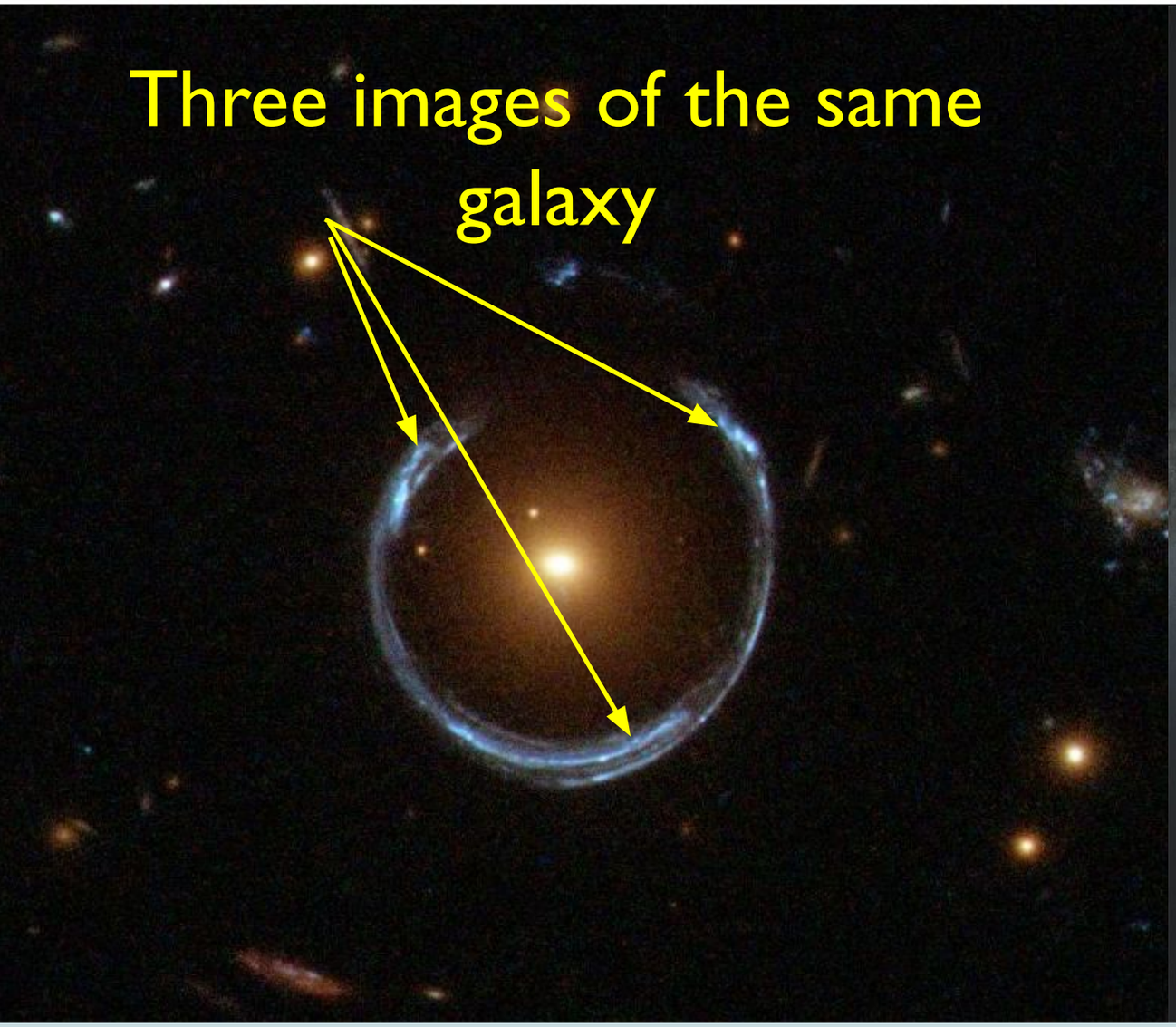


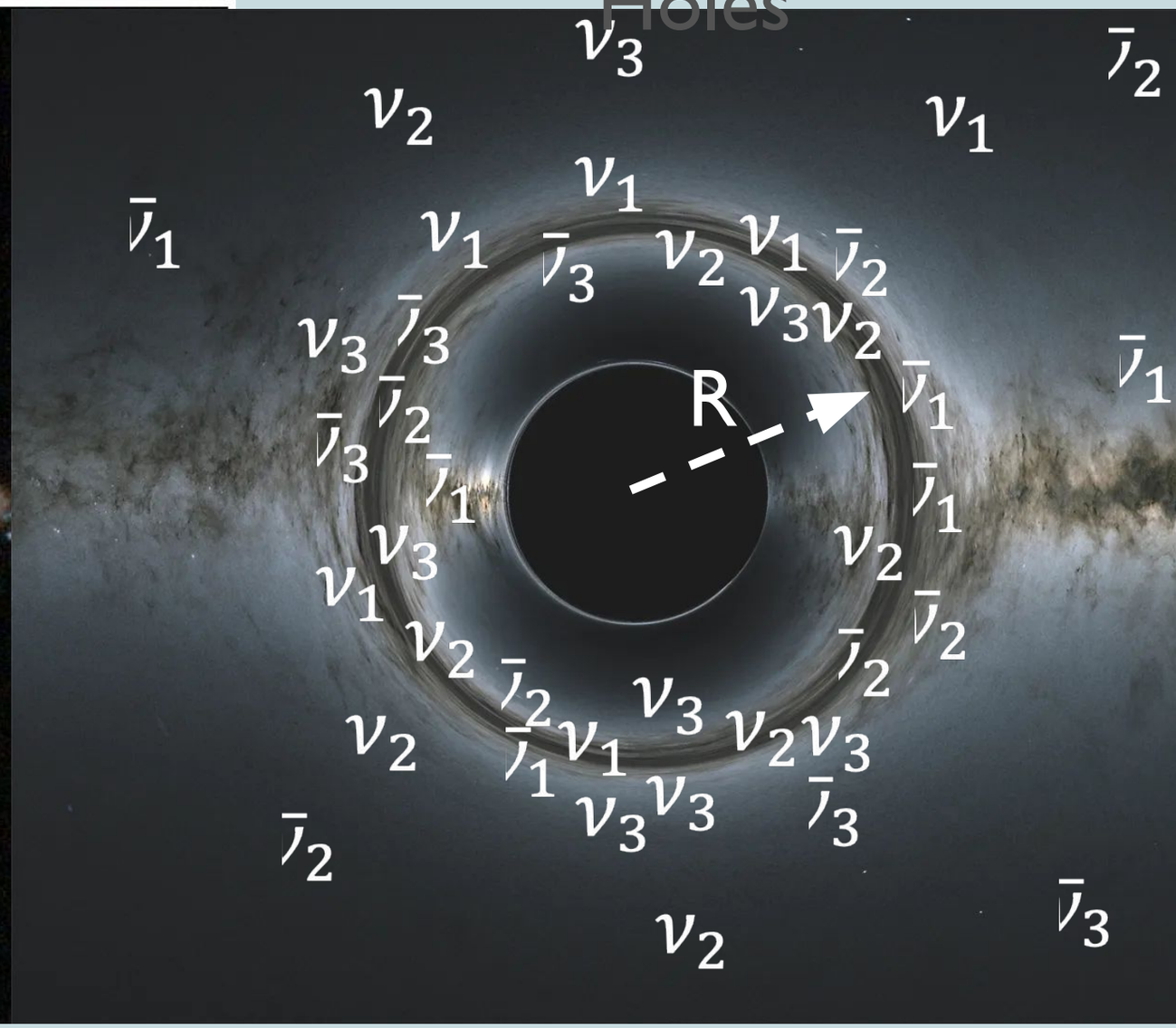


# Neutrino Rings? from Primordial Black Holes

**Einstein rings**

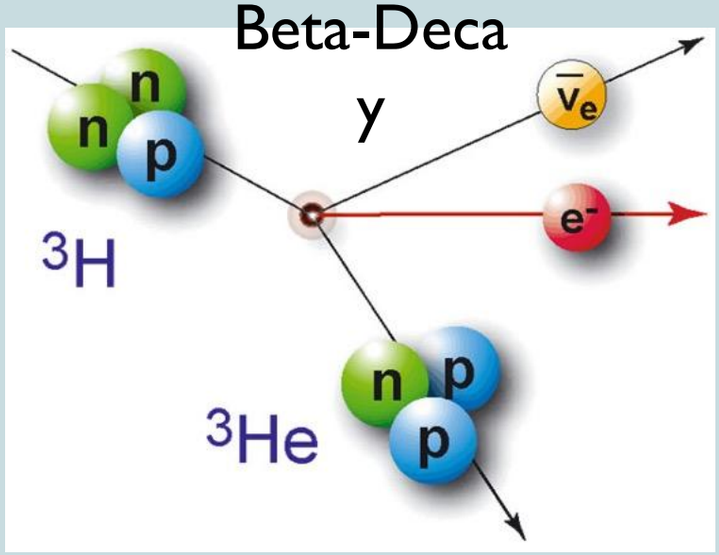
Predicted by Einstein in 1936

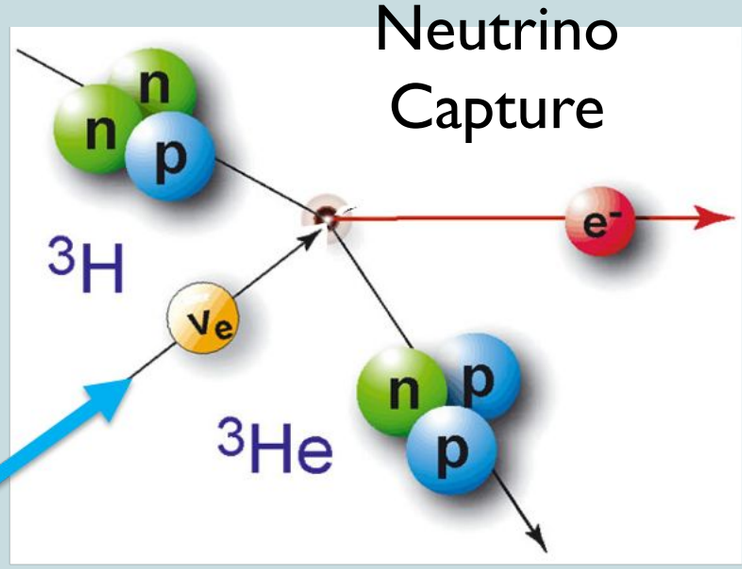


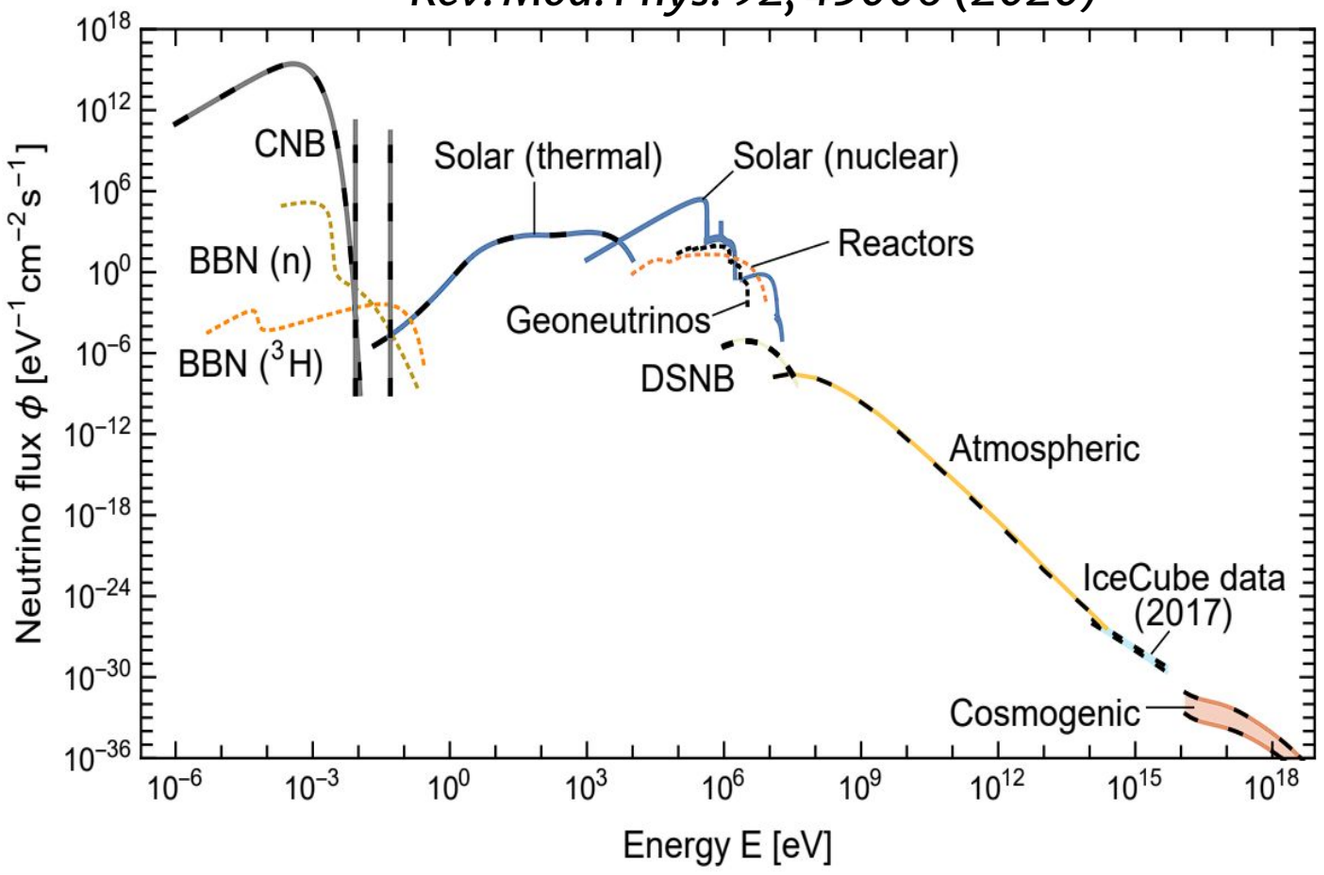
# PTOLEMY - RELIC NEUTRINO DETECTION

## PonTecorvo Observatory for Light Early-universe Massive-neutrino Yield

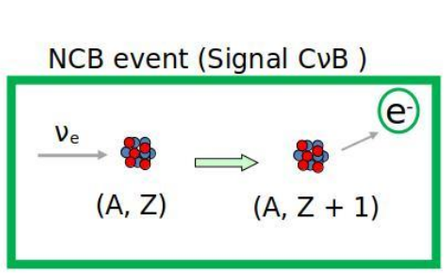


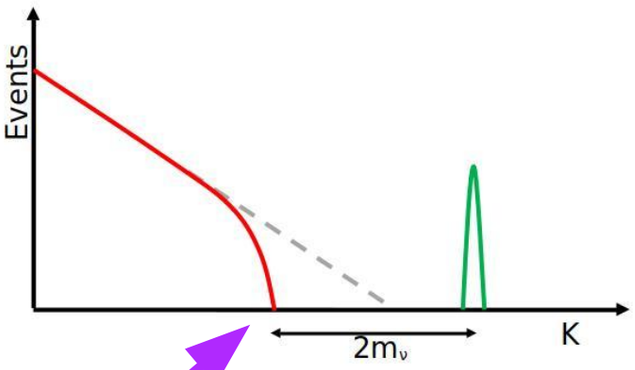




*Rev. Mod. Phys. 92, 45006 (2020)*




## Signature of CνB




## Neutrino Mass Effect on Endpoint Predicted by Enrico Fermi

# IDEA OF ENRICO FERMI

**90 year anniversary!**

Fermi, E. Versuch einer Theorie der β-Strahlen. I. *Z. Phys.* **88**, 161–177 (**1934**). https://doi.org/10.1007/BF01351864

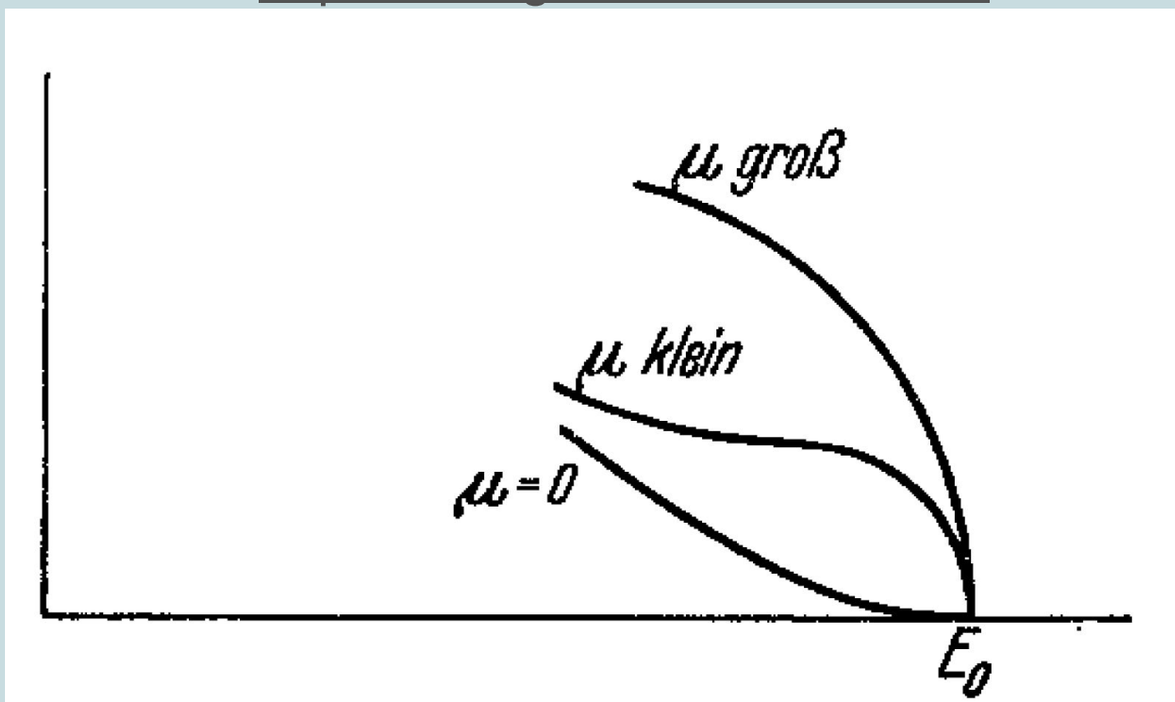
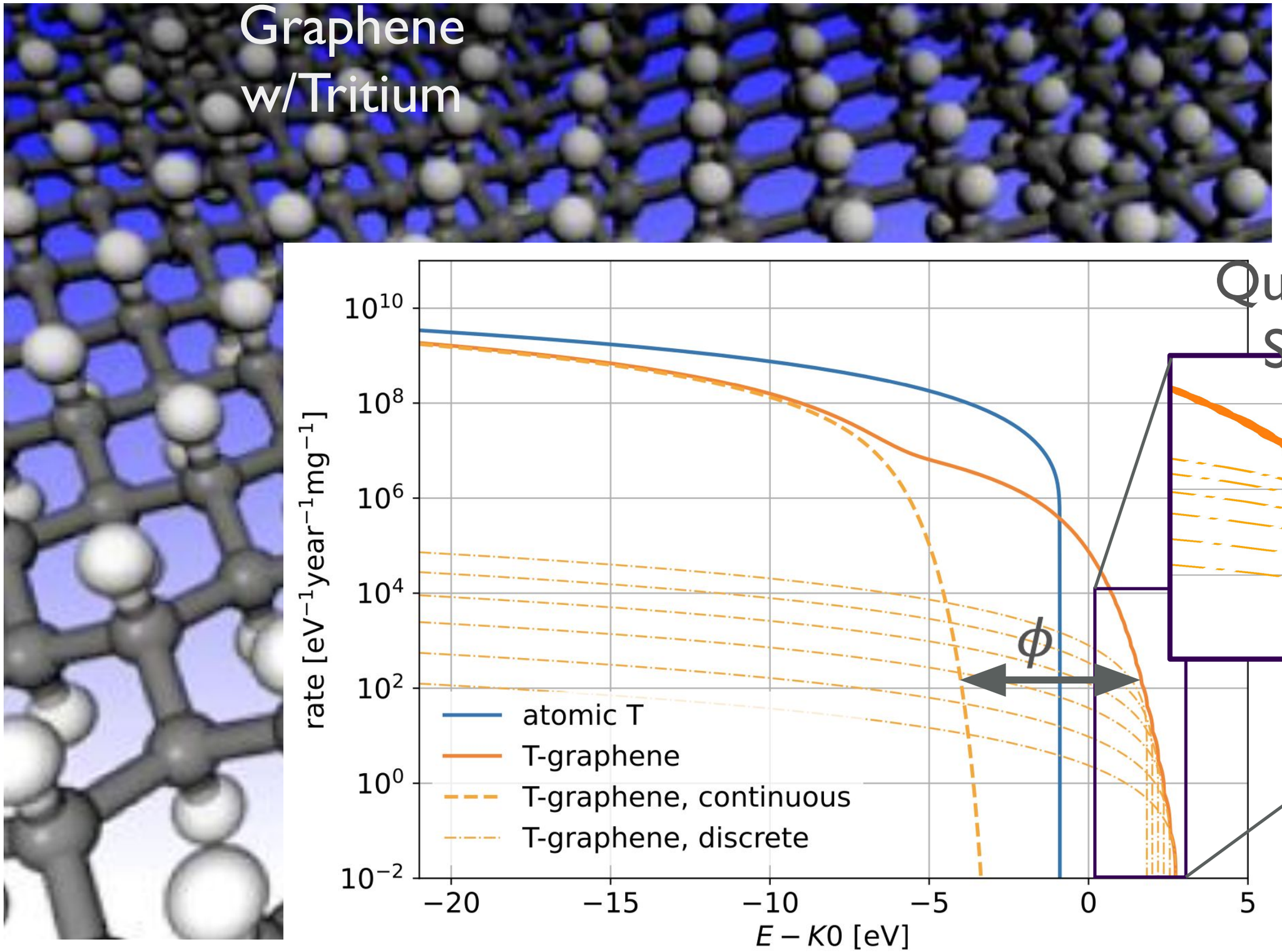



Fig. 1.

The neutrino masses are so tiny, their effects are smaller than atomic transitions in normal materials.
(There is a reason that there are no units on this plot.)

# PTOLEMY: 2D MATERIAL - GRAPHENE




Other graphene structures also under study



$\phi \equiv$ "Atomic" work function

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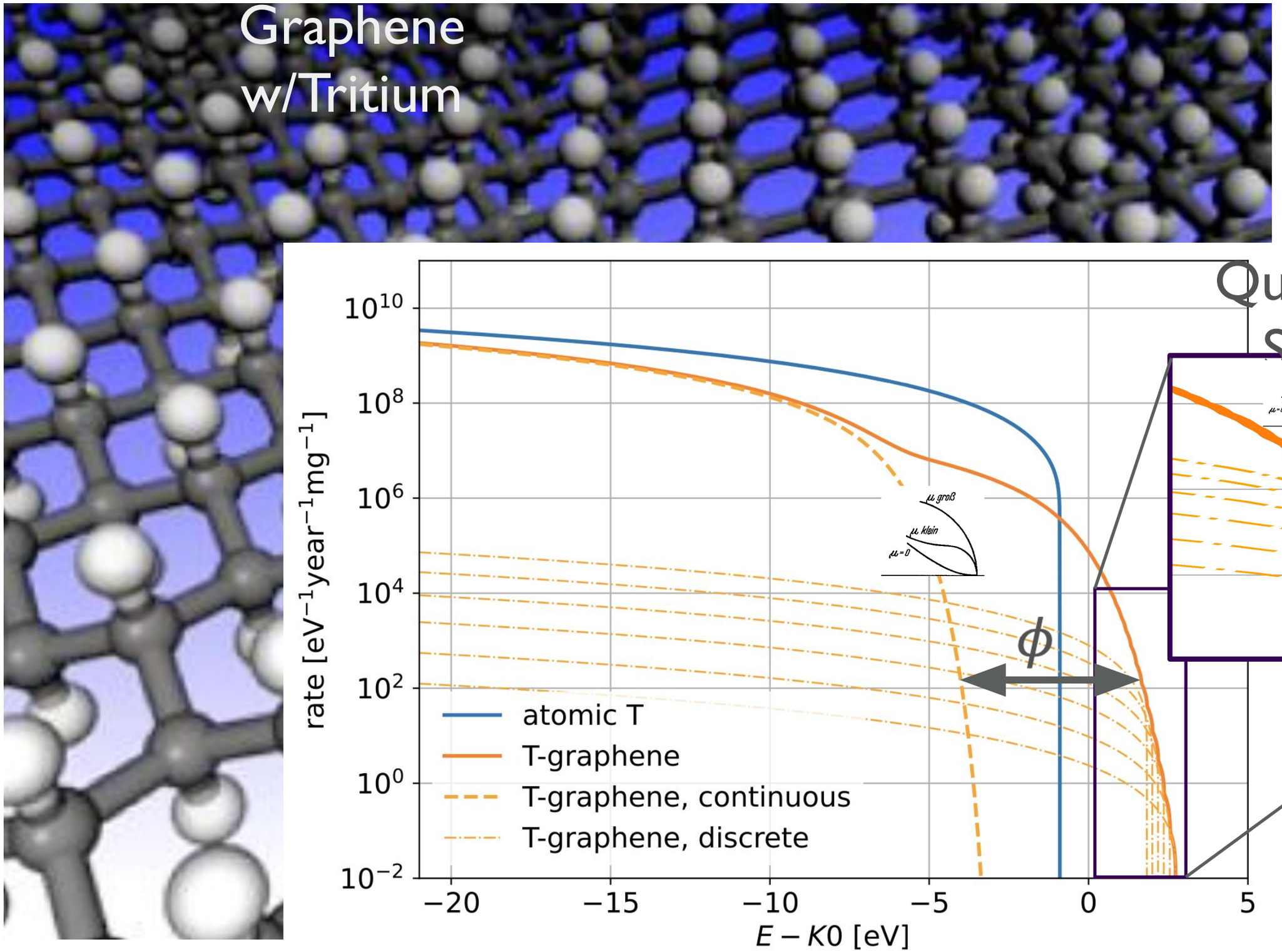


Other graphene structures also under study

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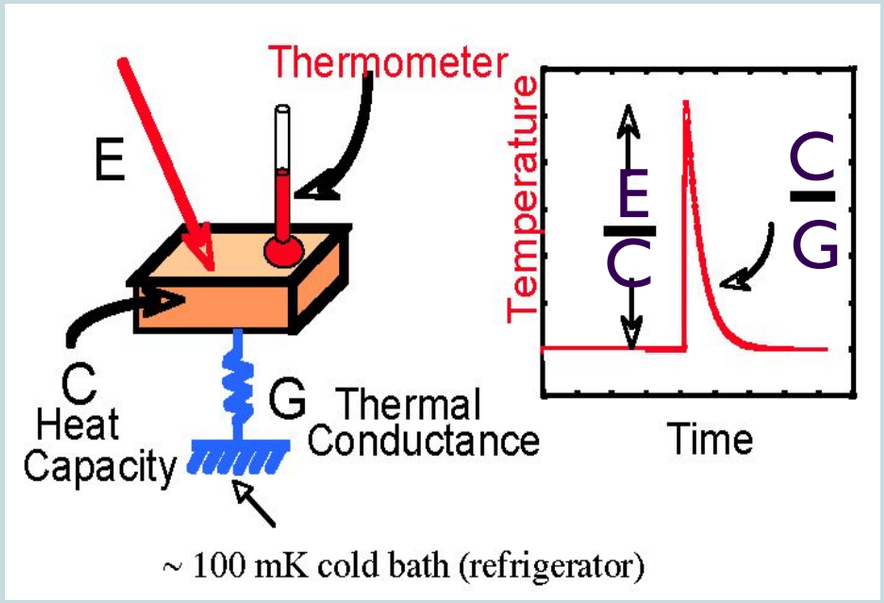
# MICRO-CALORIMETER



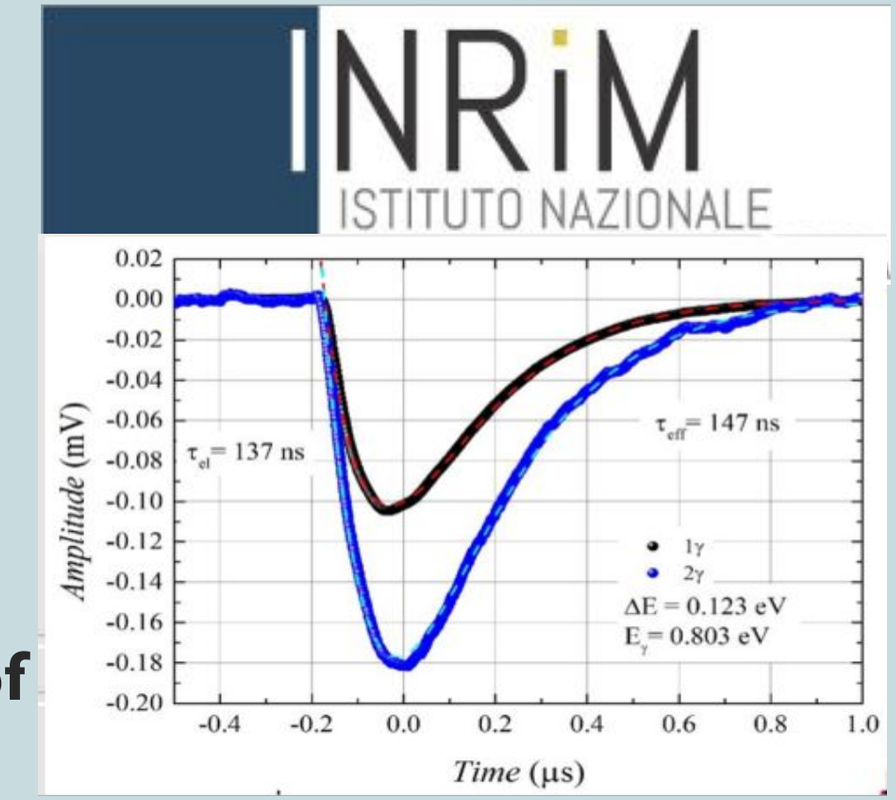

**Design Goal (PTOLEMY):** $\Delta E_{FWHM}$ = 0.05 eV @ 10 eV

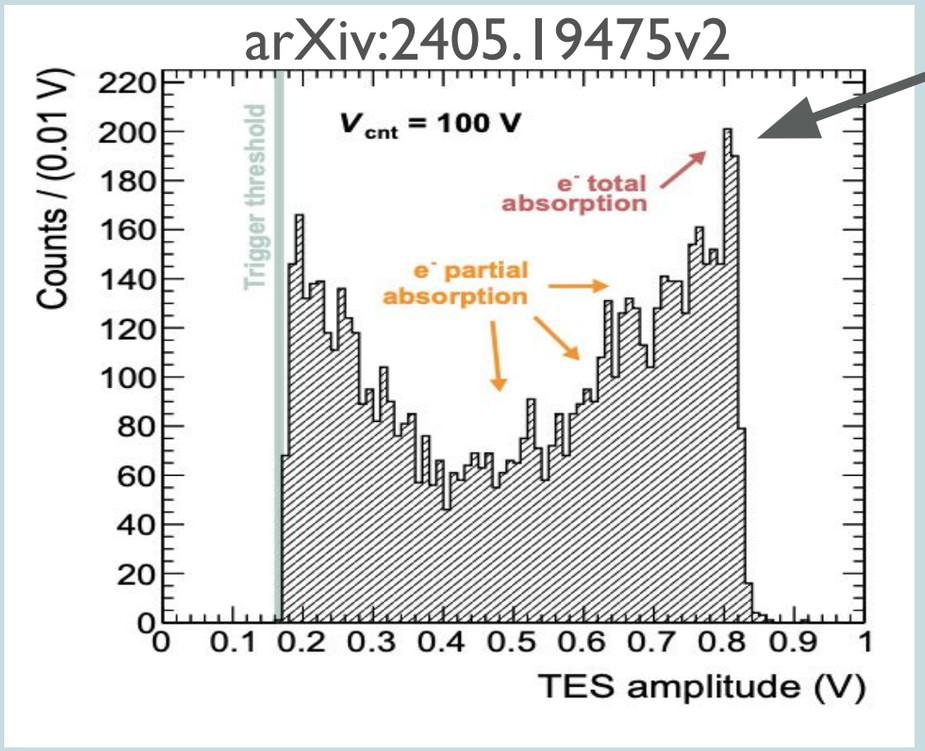
**translates to** $\Delta E \propto E^{\alpha}$ $(\alpha \leq 1/3)$

$\Delta E_{FWHM}$ = 0.022 eV @ 0.8 eV

**Based on the expertise of the INRiM an important results have been achieved on electron measurement with TES.**

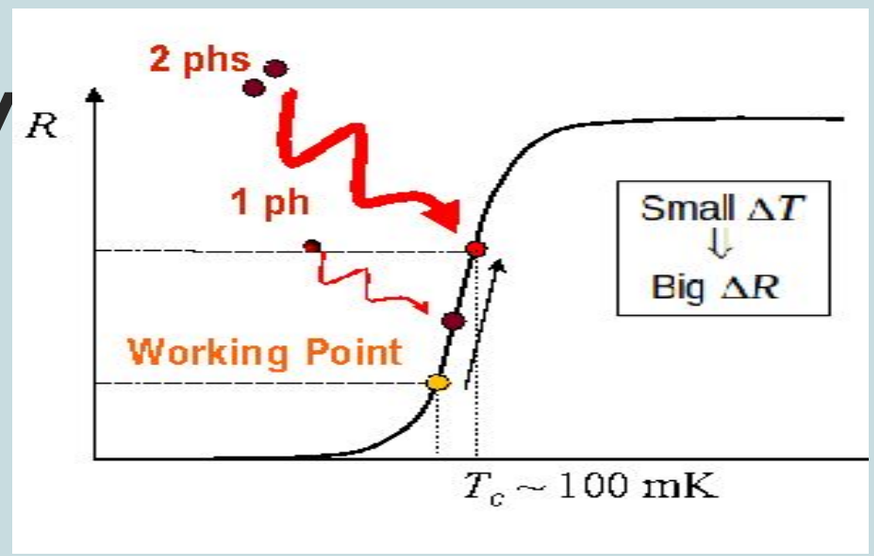
**Key elements of the measurements: performing TES and new e-source based on nanostructures**



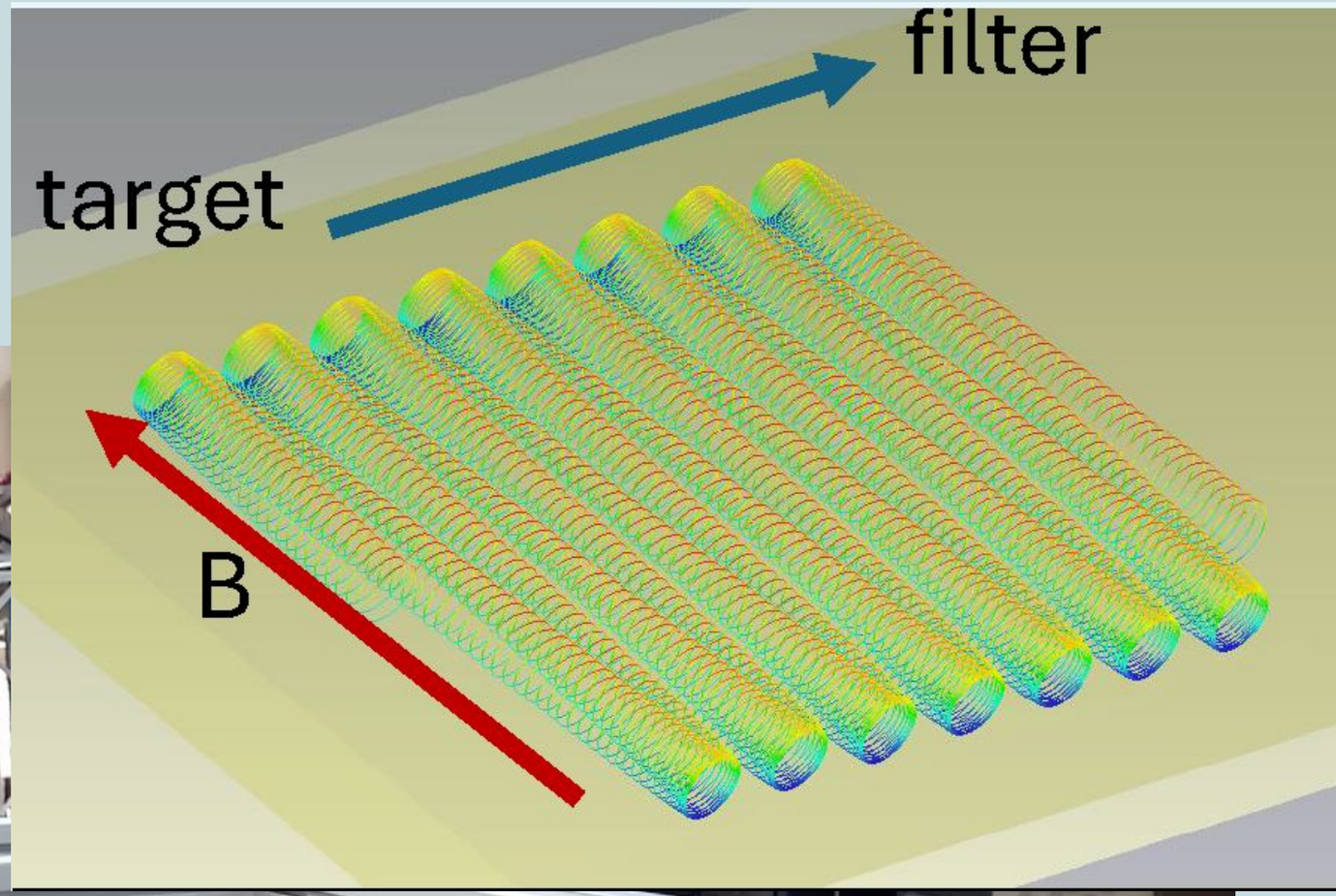

**First measurement of electrons at 100 V with resolution of ~1-1.5 eV**

Best in the World!

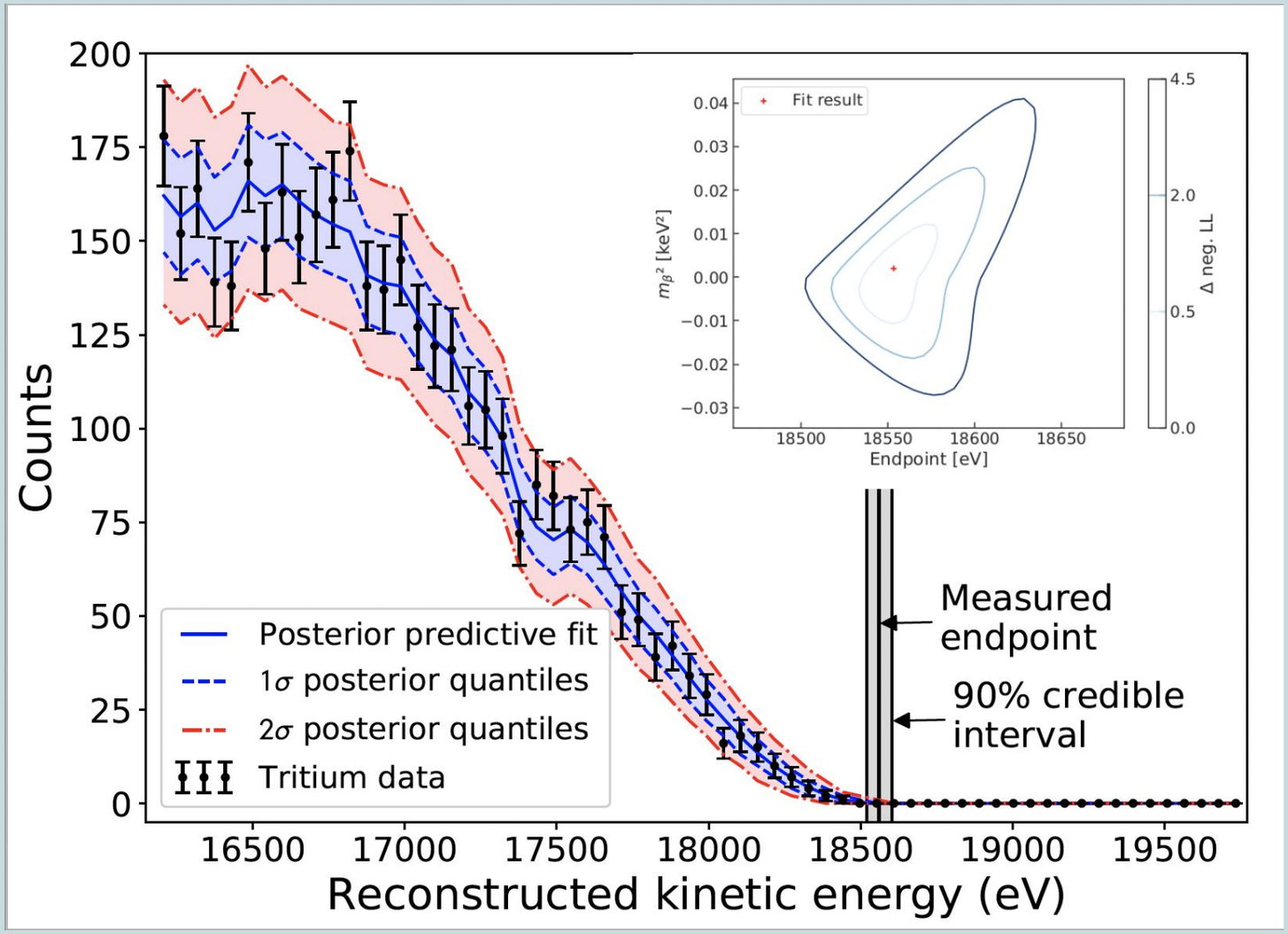


# RF MEASUREMENTS
# NON-DESTRUCTIVE ELECTRON TAG

Can we detect the (semi-relativistic) electron on its way to the micro-calorimeter?



# RECENT PROJECT 8 TRITIUM RF MEASUREMENT




https://arxiv.org/abs/2203.07349

RF measurement background levels extremely low.

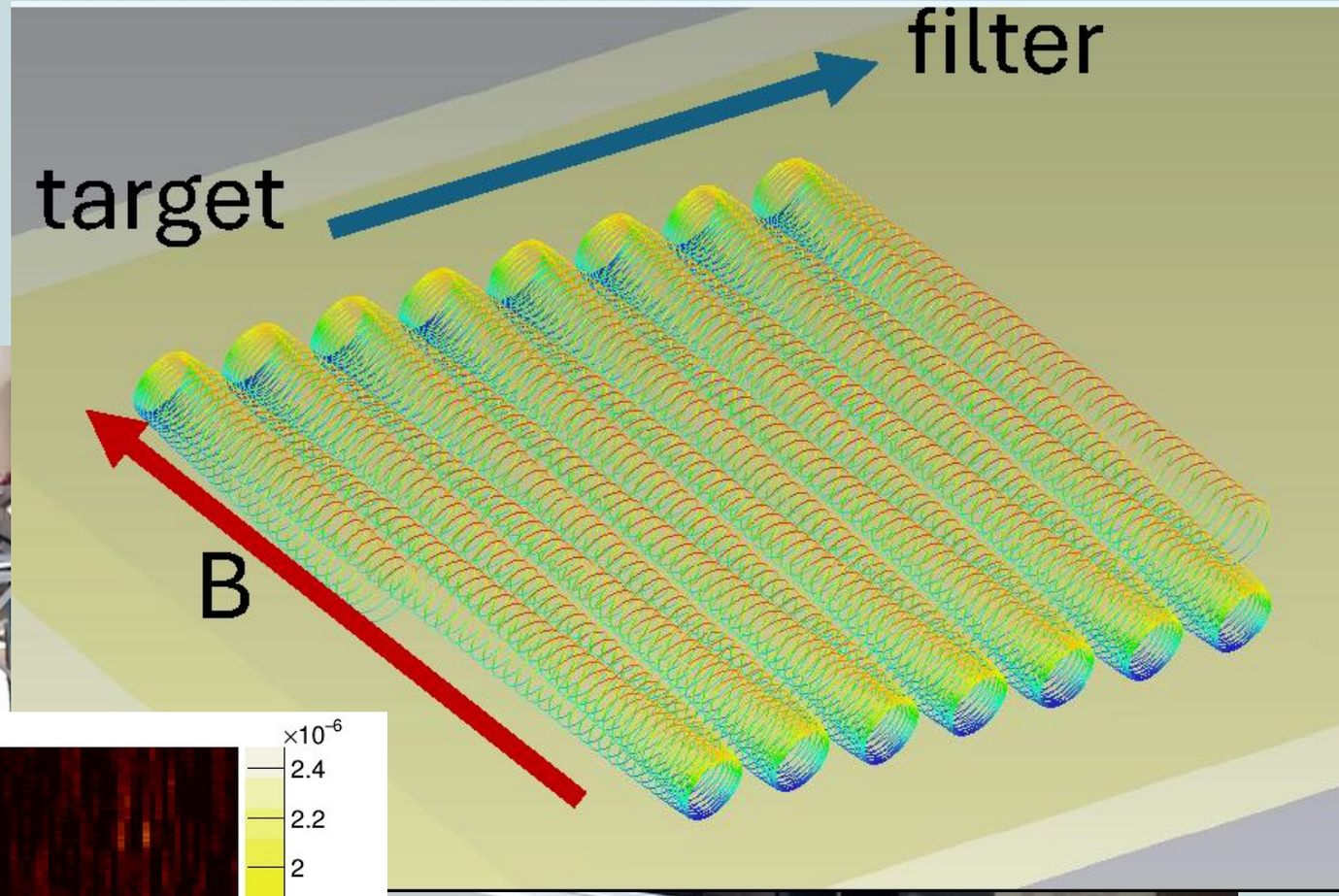
No events observed above endpoint,
Setting upper limit on background rate

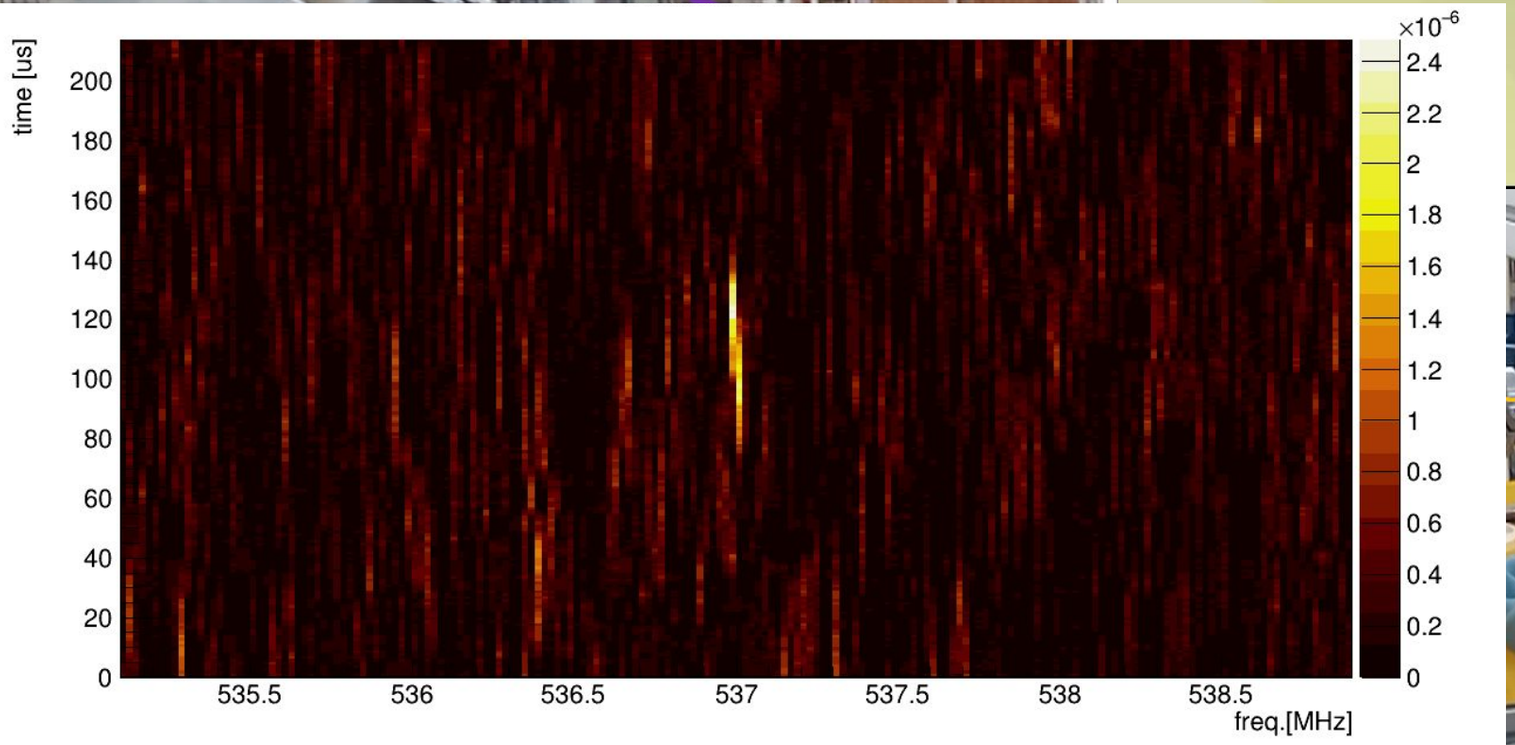
< $3 \times 10^{-10}$ /eV/s (90% CL)

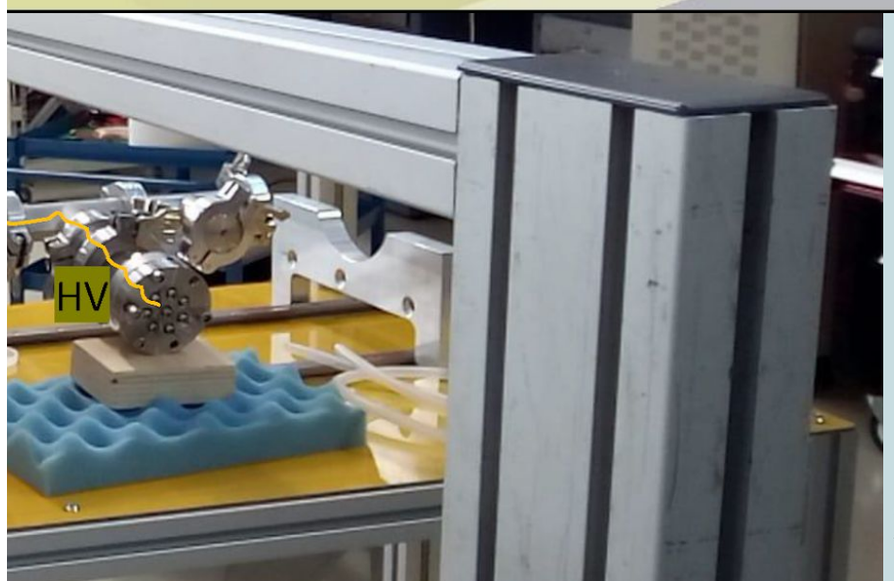
**Background Rate < 1 event per eV in 100 years!**

# ACHIEVED!! RF MEASUREMENTS NON-DESTRUCTIVE ELECTRON TAG

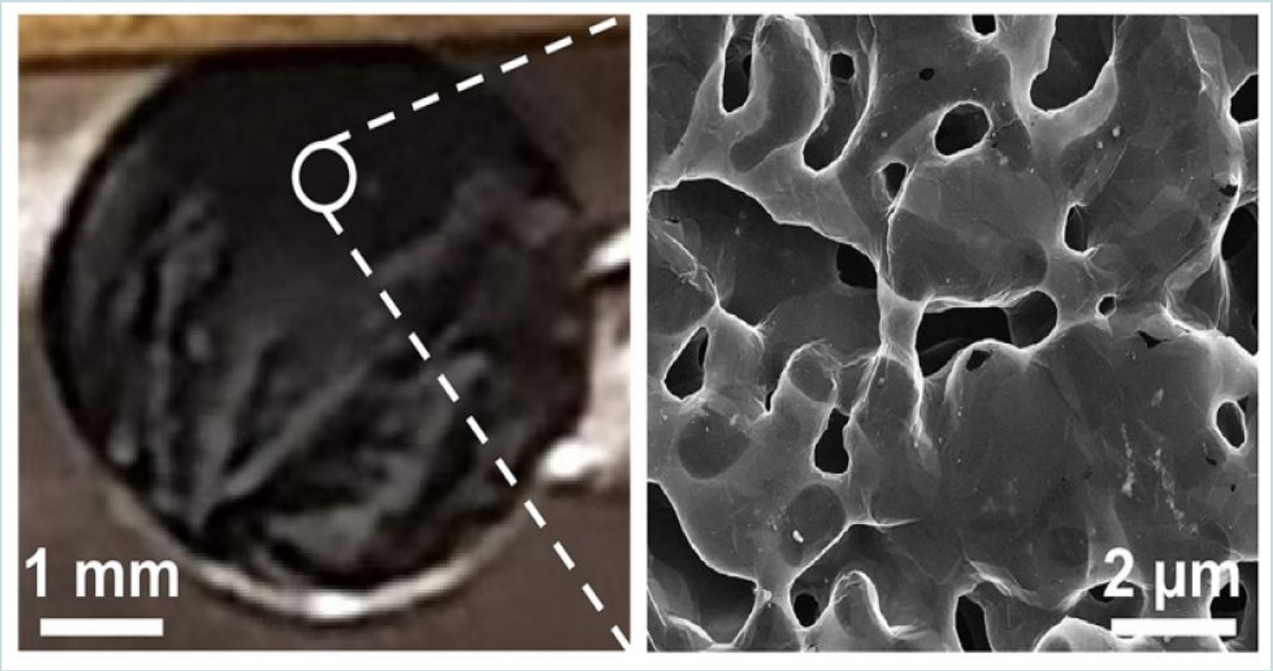
Can we detect the (semi-relativistic) electron on its way to the micro-calorimeter?

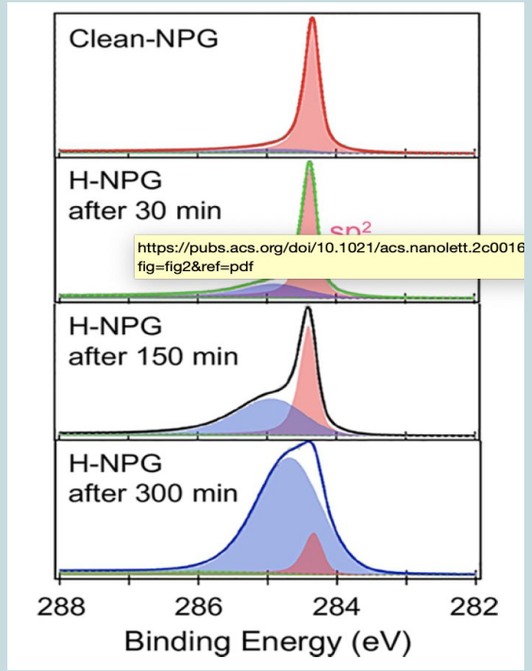


# TARGET FABRICATION

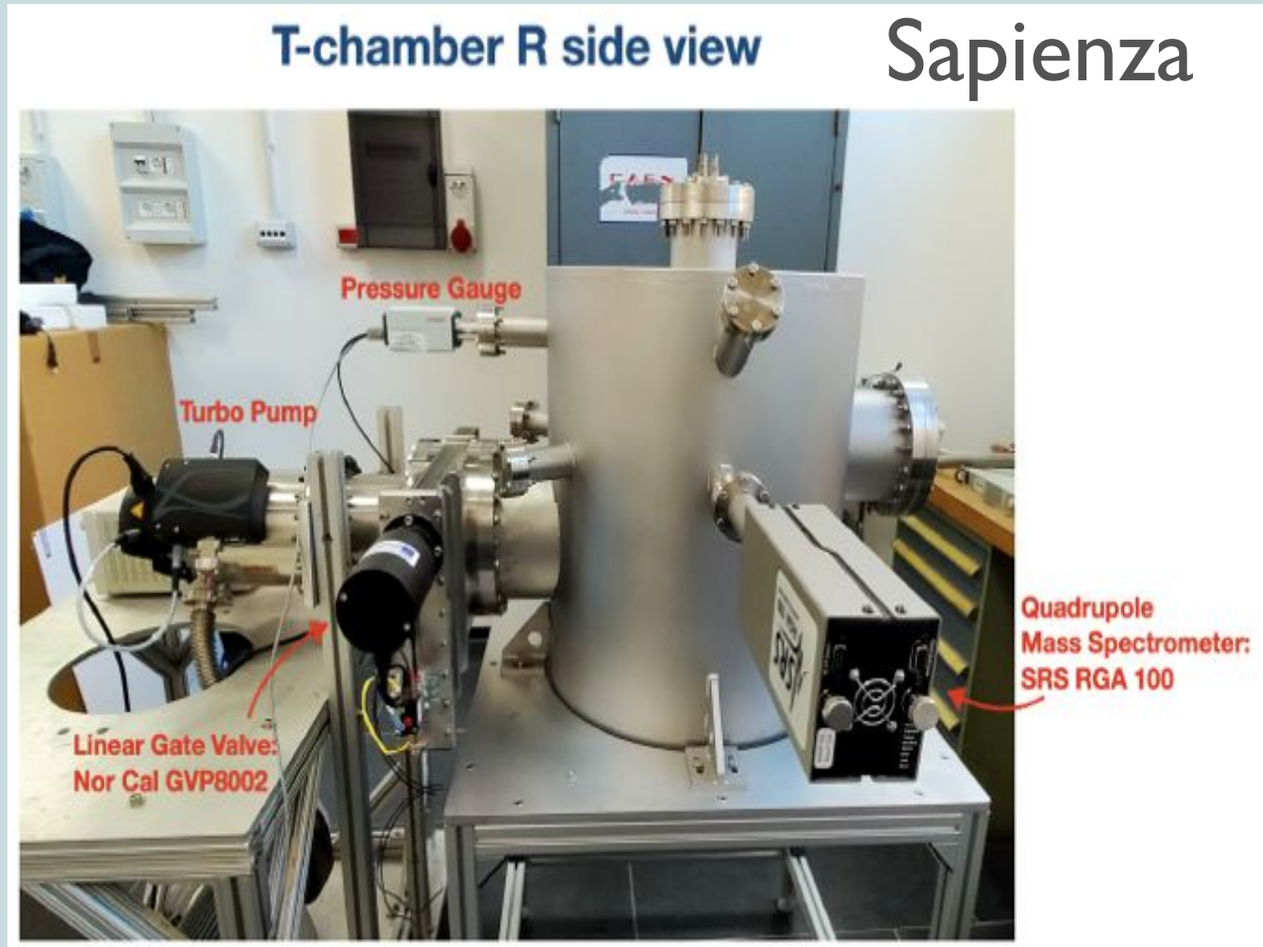



Best in the World!

*Hydrogenation of nano-porous graphene (left and center) showing over 90% coverage per carbon atom through the increase of $sp^3$ bonding (blue on right)*

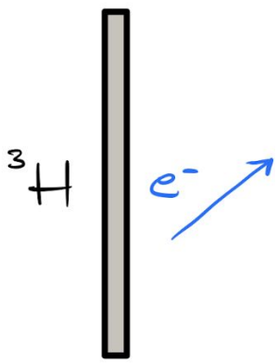
*DOI: 10.1021/acs.nanolett.2c00162*



# PTOLEMY: THE IDEA

JINST 17 (2022) 05, P05021

- A new electromagnetic filter idea based on RF detection and dynamic E setting




By A. Esposito

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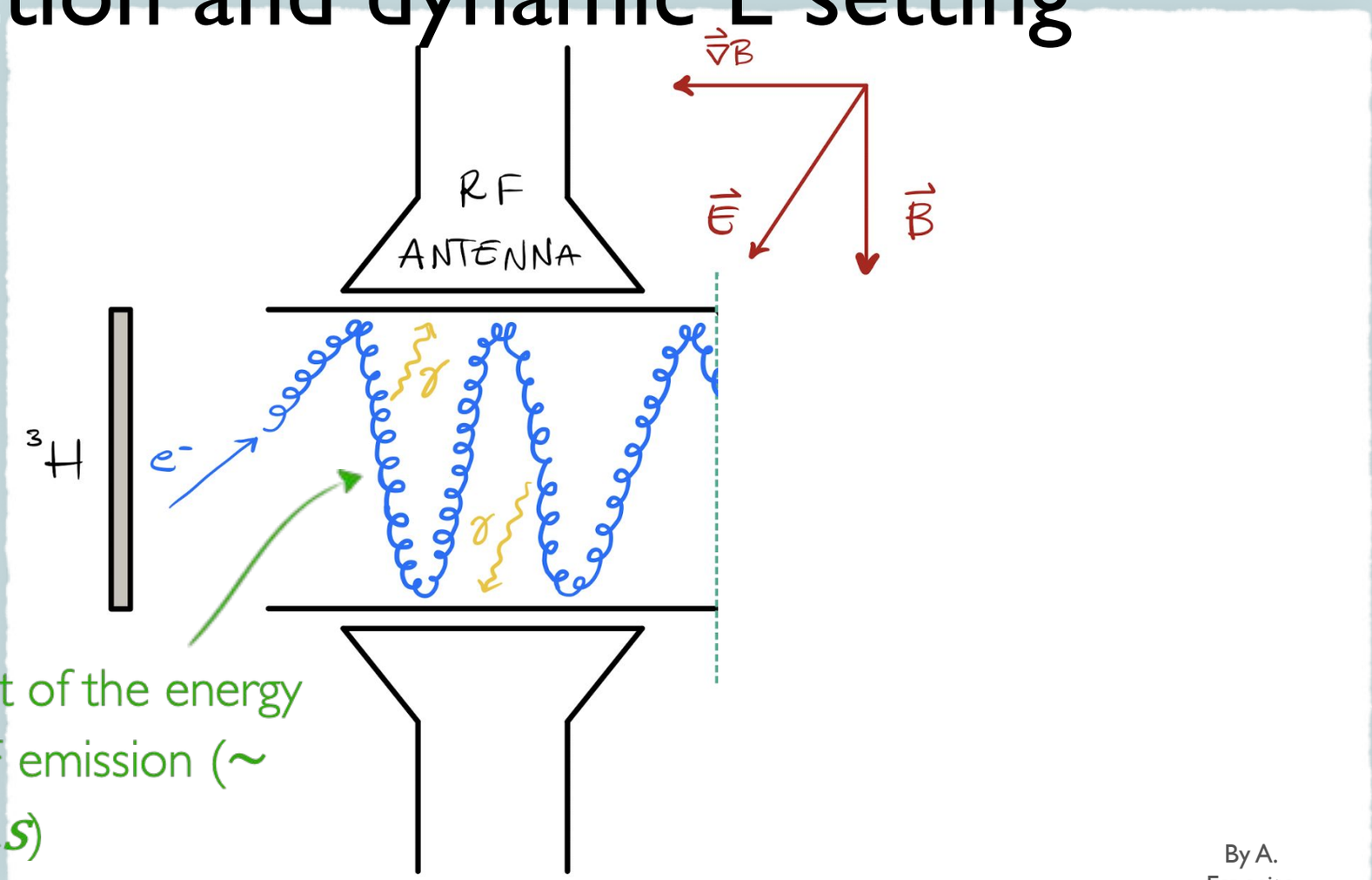


first measurement of the energy via cyclotron RF emission ($\sim 10\mu s$)

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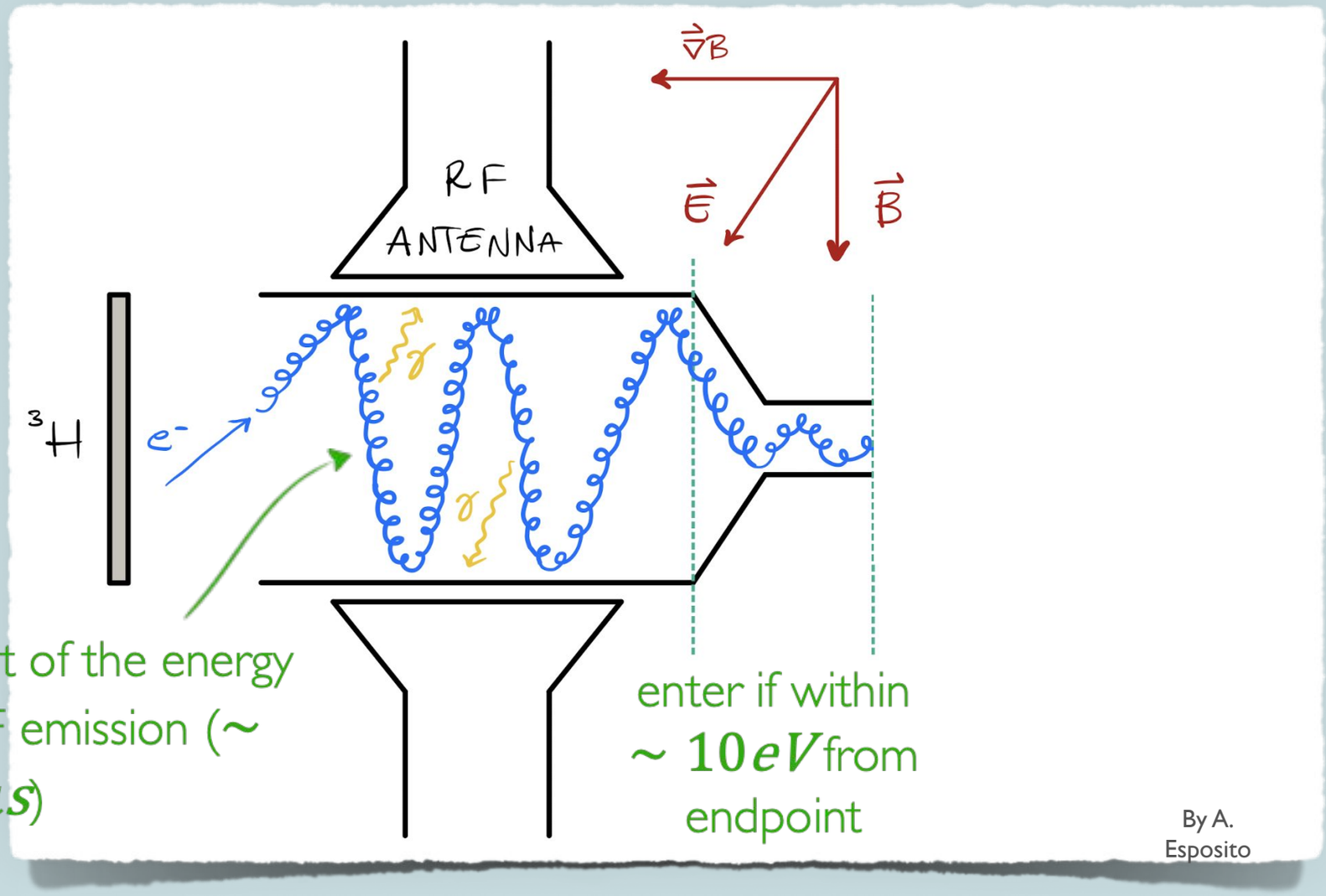

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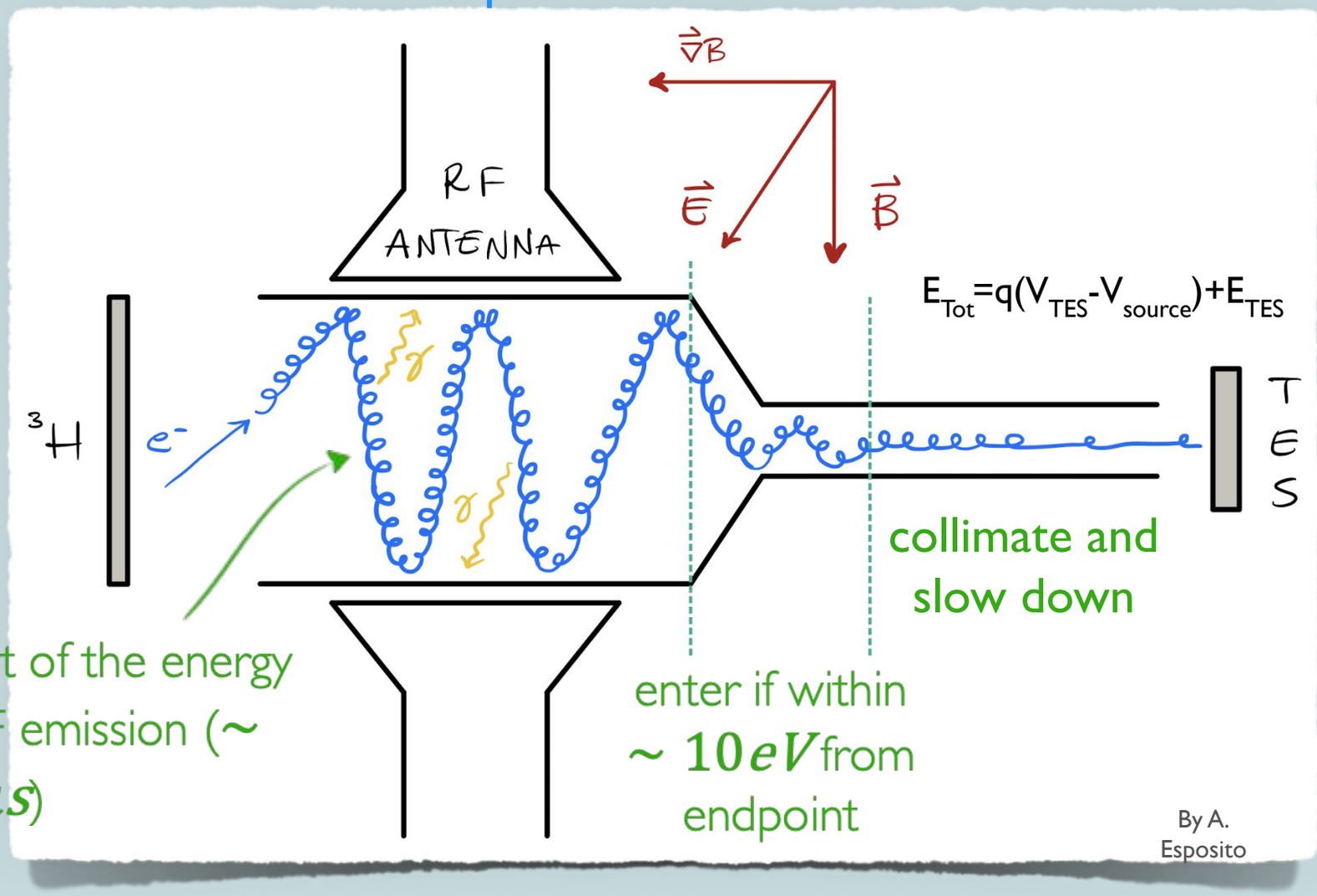
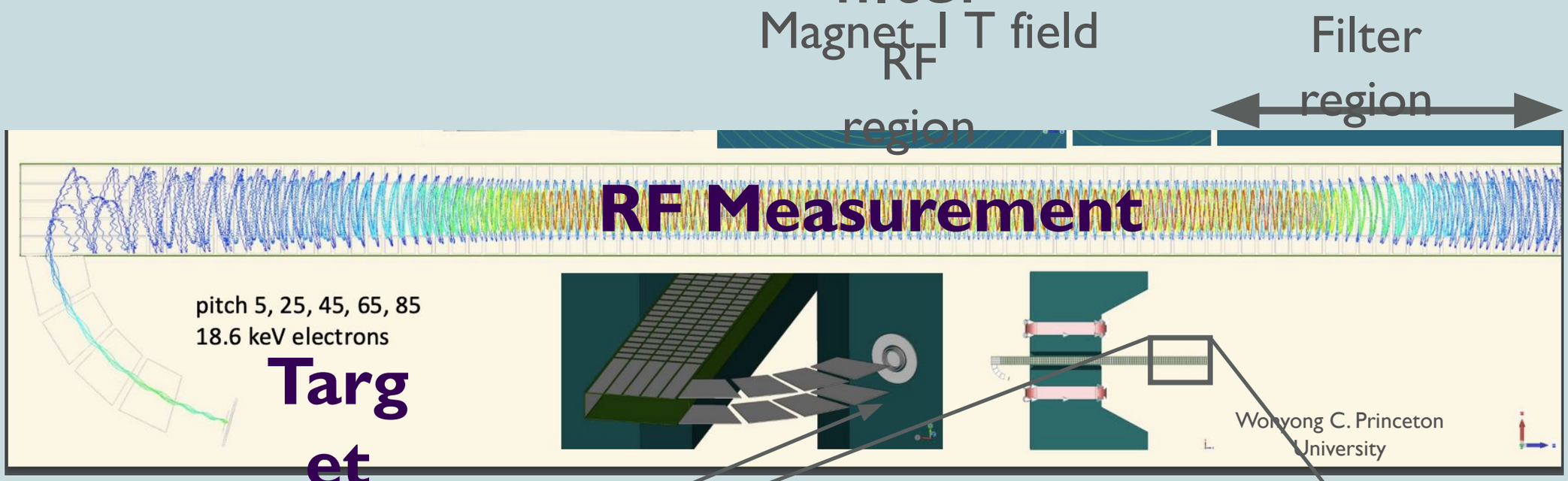
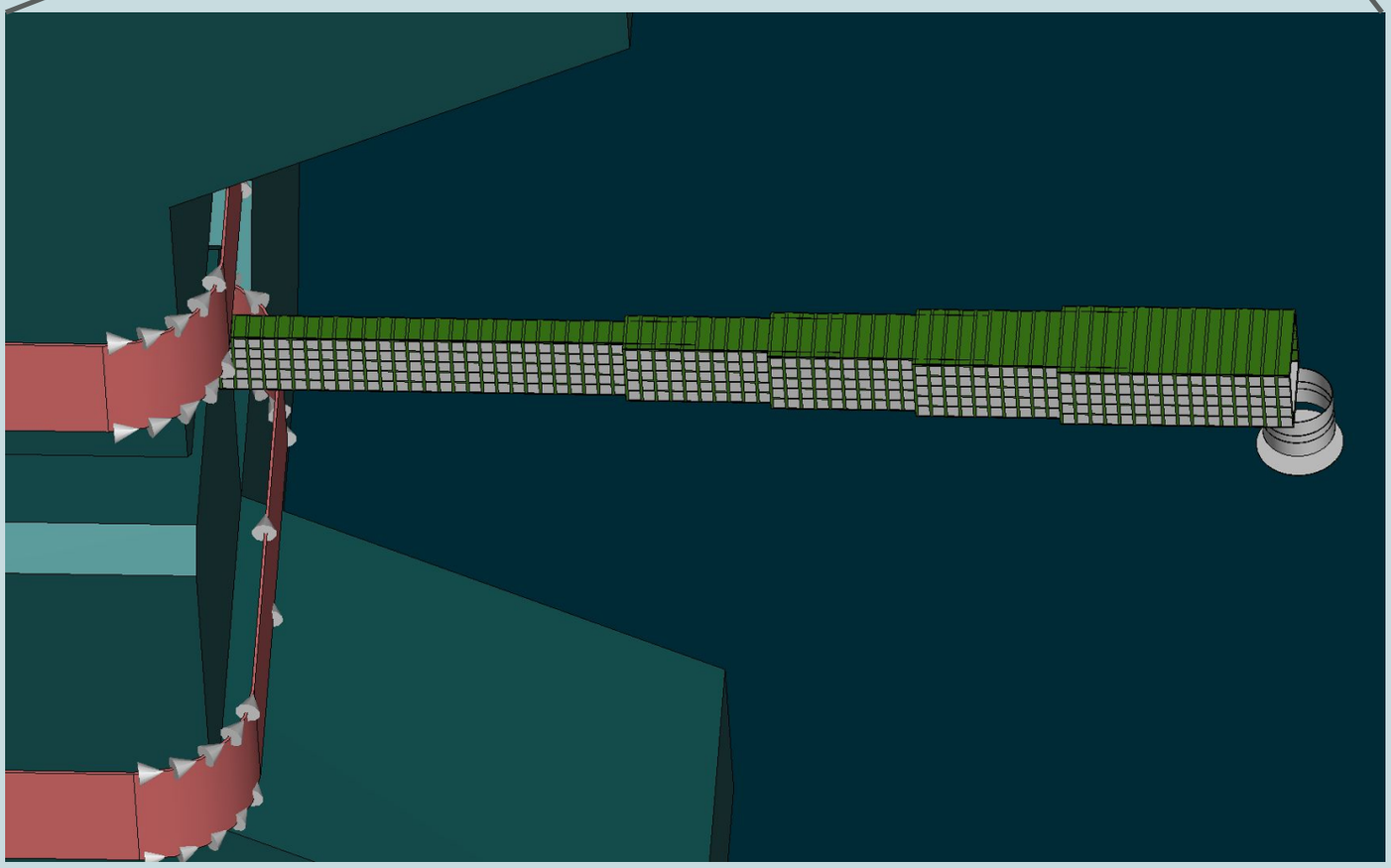



first measurement of the energy via cyclotron RF emission (~ $10\mu s$)

# Detailed simulation of the PTOLEMY filter




Geometry relying on modularity approach to increase instrumented target mass

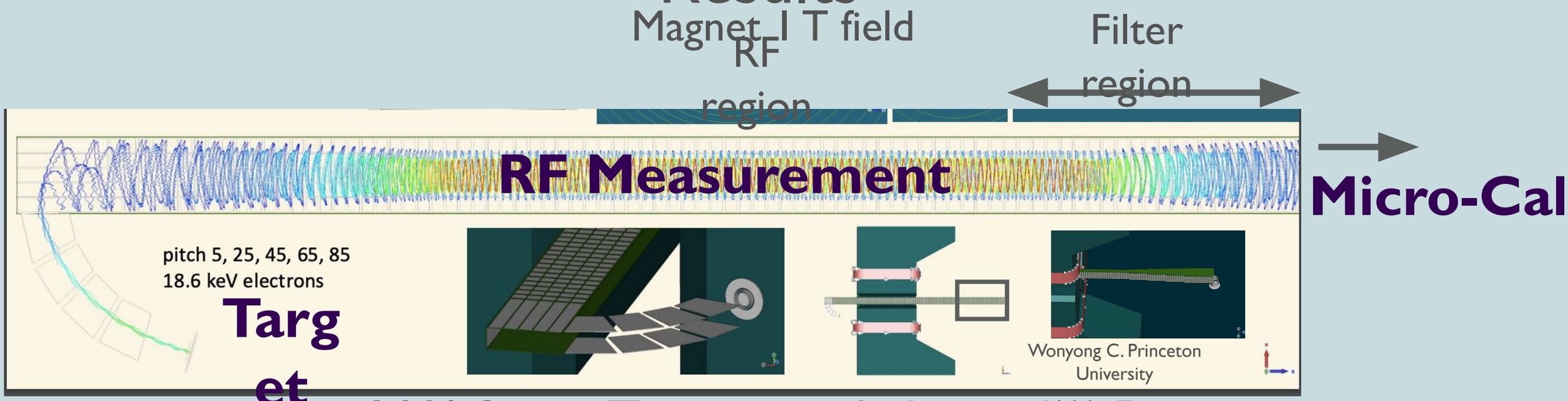


Micro-calorimeter region with focusing system to match beam and calorimeter array

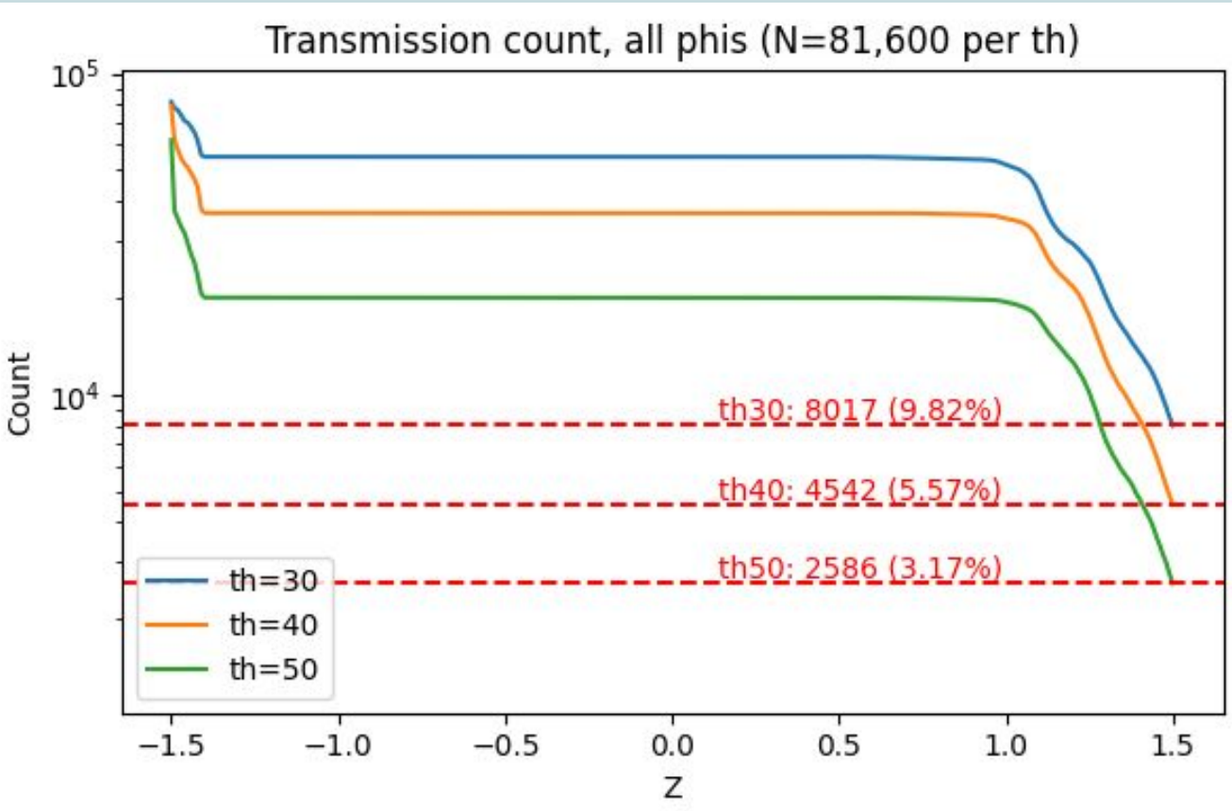
Zero B Field FOCUSING with Einzel lens (90 degress)

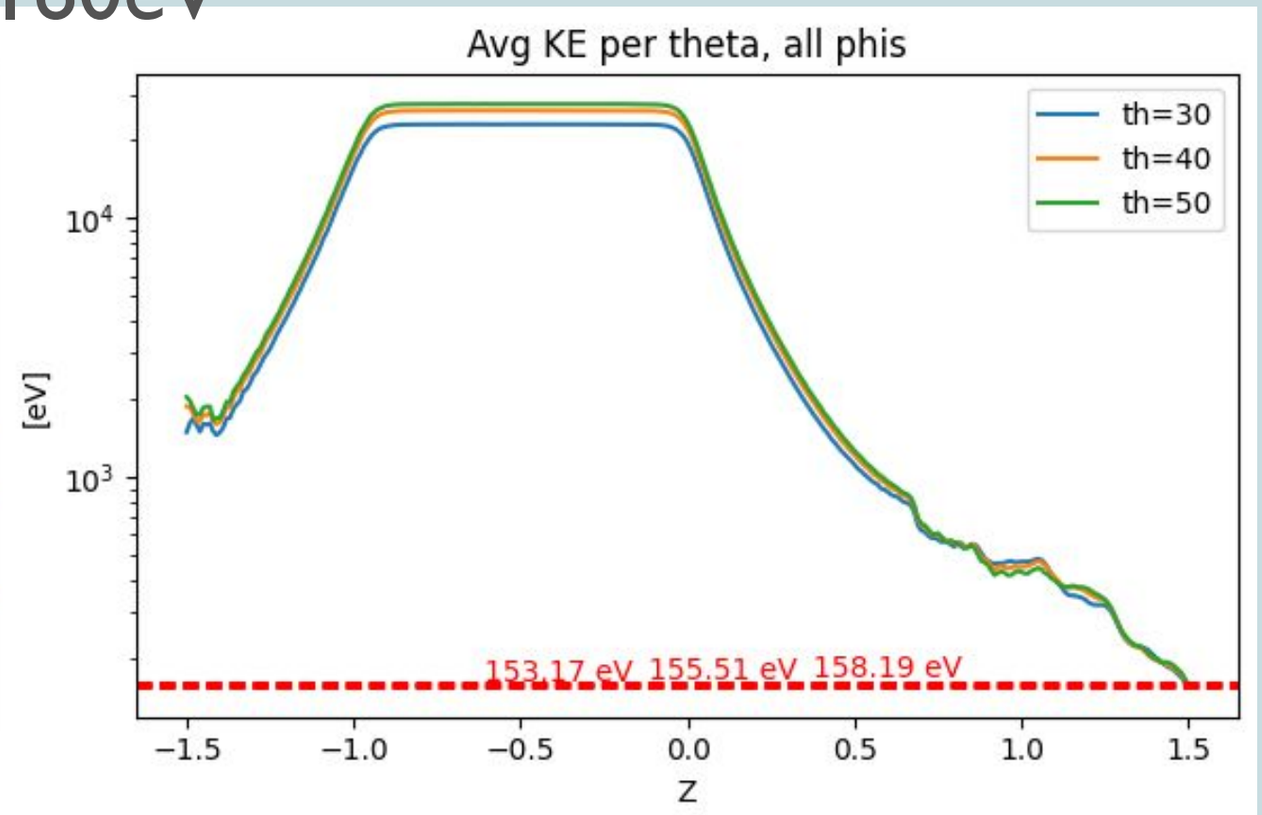
**Microcalorimeter**

# End-to-End Drift Collimation and Transmission Results




10% Static Transport Achieved!!! Down to 160eV



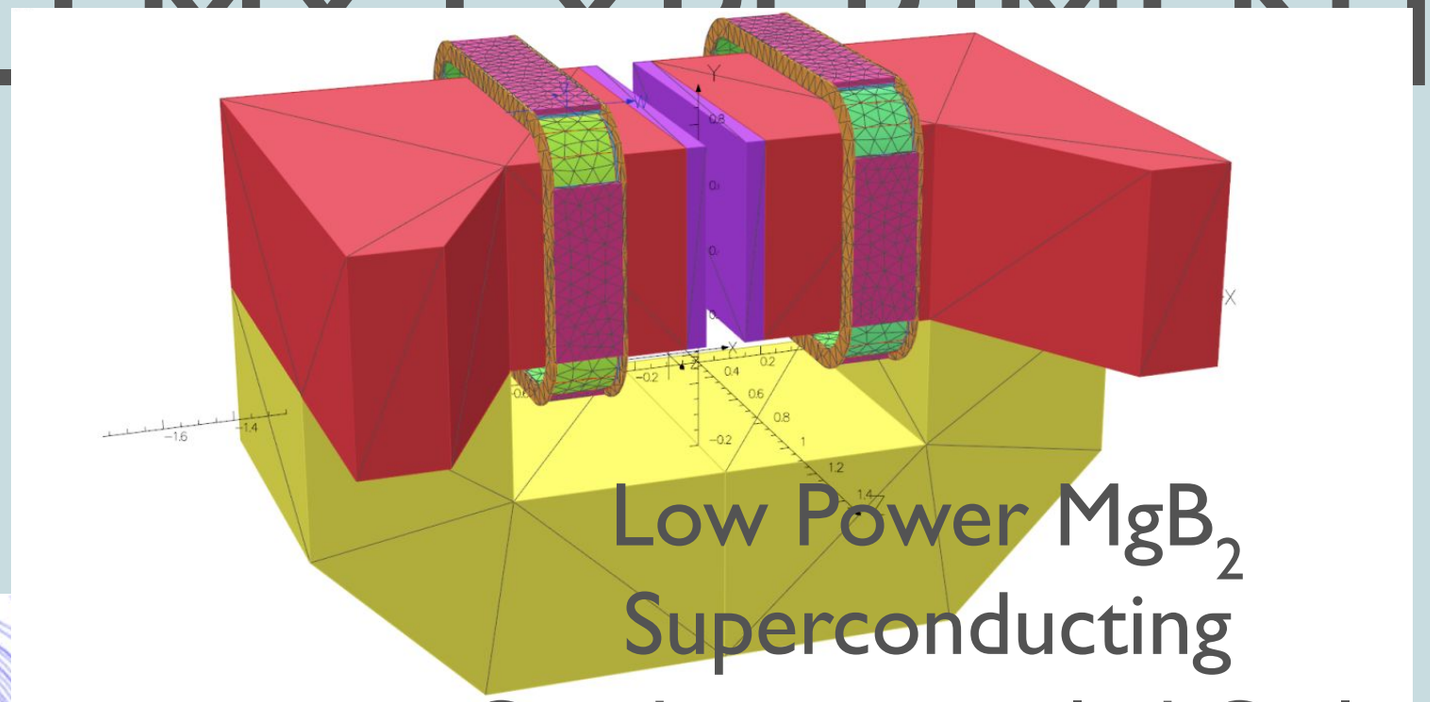



# INSTALLED AT THE LNGS

# KEY ELEMENT TO REALIZE THE PTOLEMY EXPERIMENT

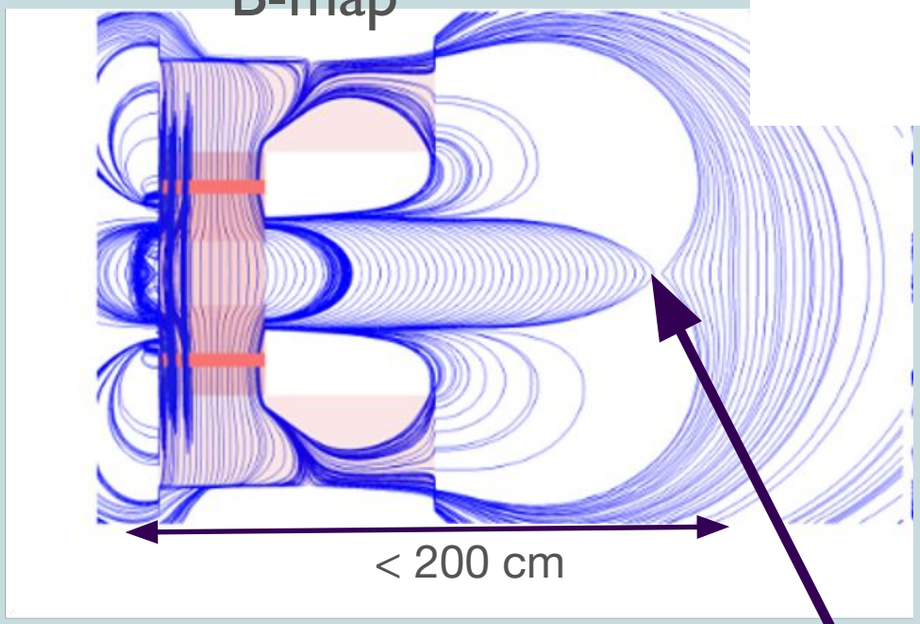
**Construction ASG/Suprasys consortium of a 6G dipole with special attention to the fringe field**

**Tour on Friday!!**



Low Power $MgB_2$ Superconducting Conduction-cooled Coils

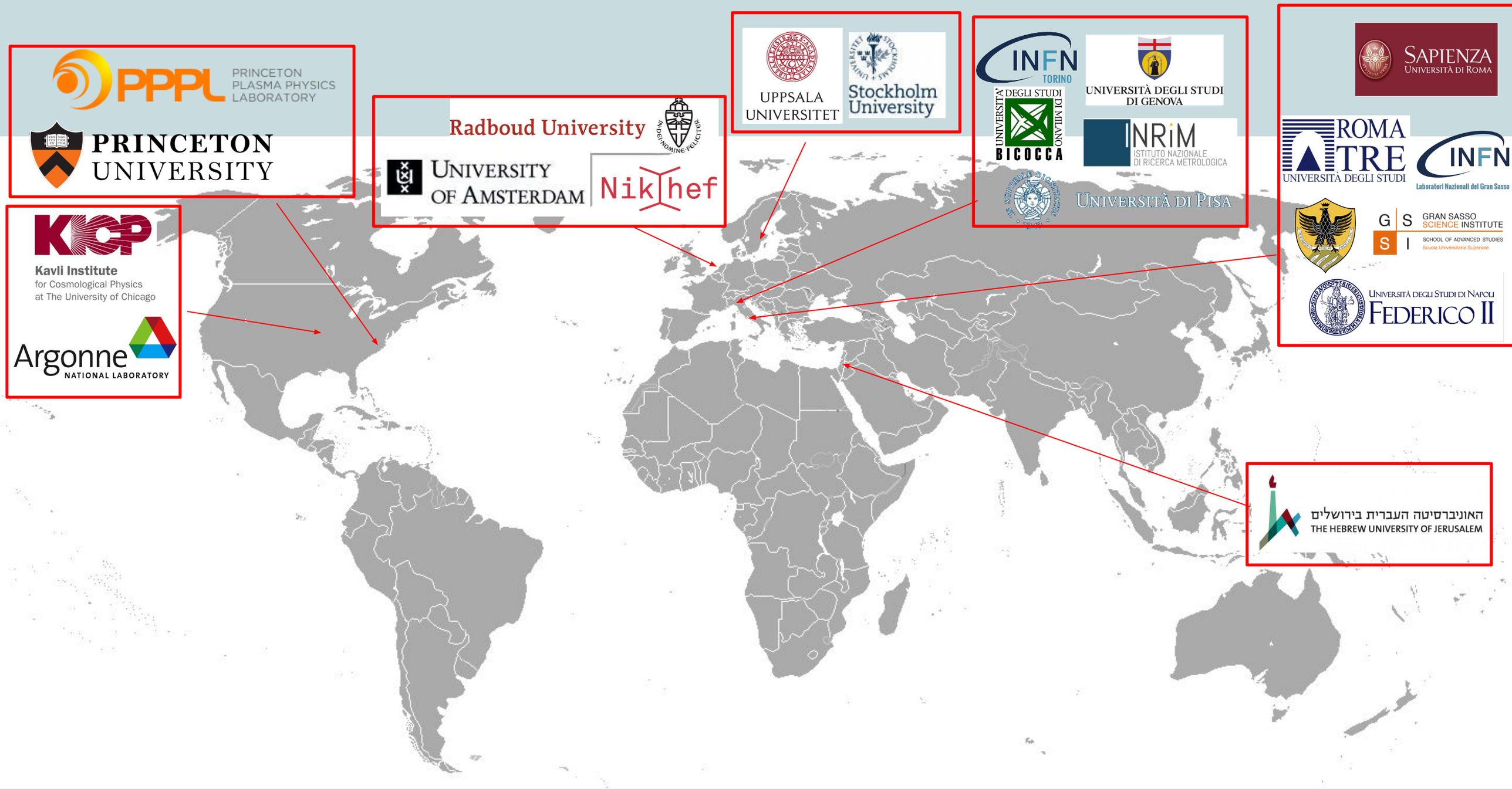
Simulated B-map





Zero B field saddle point key feature of the field map

# The PTOLEMY Collaboration



# The PTOLEMY Collaboration

14 May 2024, Pollica, Italy

# CONCLUSION

- PTOLEMY's goal is to eventually detect the cosmic neutrino background
- The detector prototype will be ready at LNGS by the next year
- Prototype baseline option is: T embedded on graphene; New concept EM filter; electron energy resolution measured in several steps (MCP/SDD). Ultimately operating TES with sub-eV energy resolution.