

# IceCube-Gen2 Neutrino Observatory

A Window to the Extreme Universe

Marek Kowalski

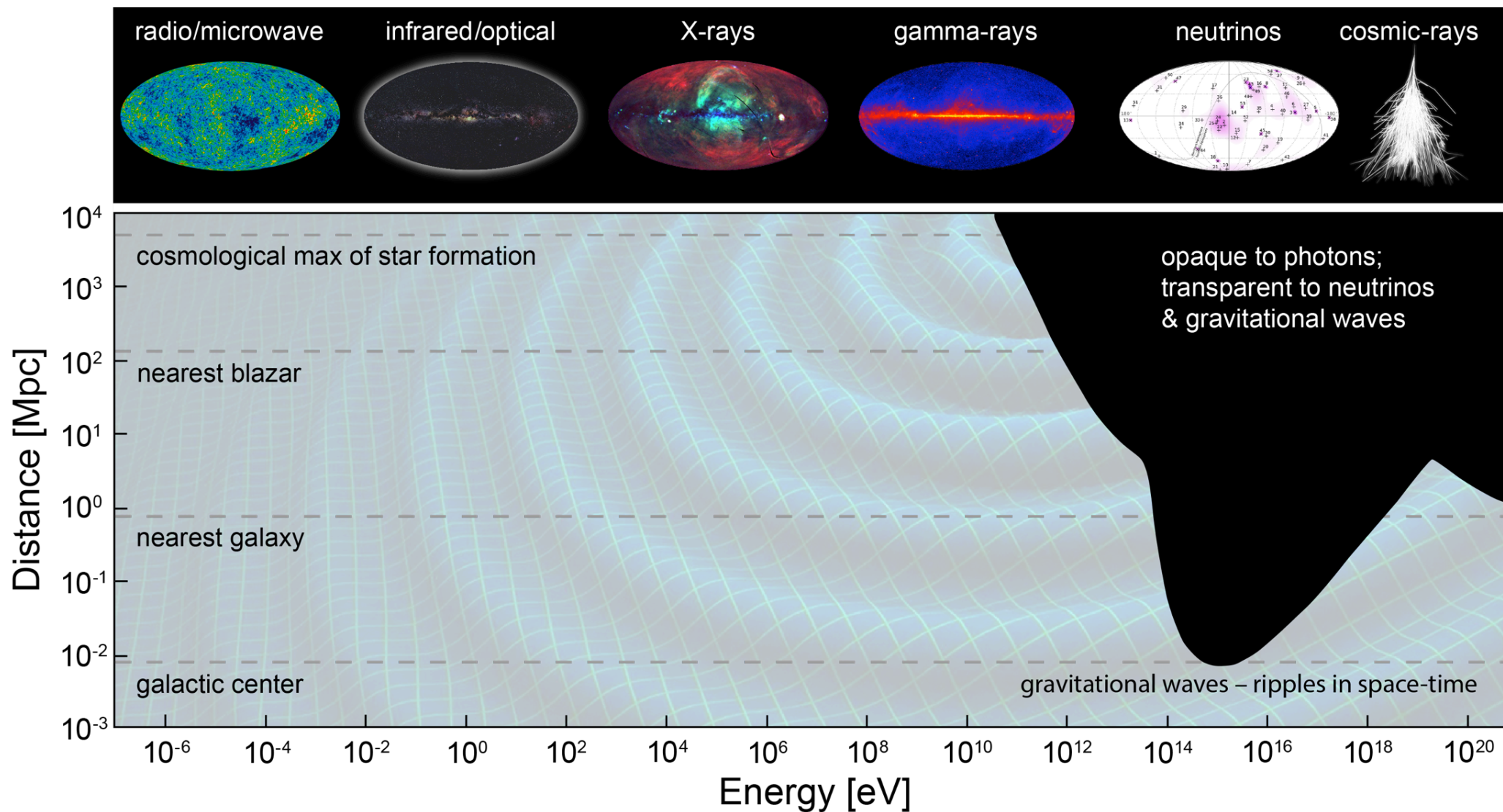
KAT strategy meeting, Bad Honnef, 3.12.2020

South Pole 2009



# The energy frontier in astronomy

Universe opaque to photons for  $\frac{1}{4}$  of the spectrum





# 10 yrs of IceCube - a first view on the PeV Universe

## Some highlights

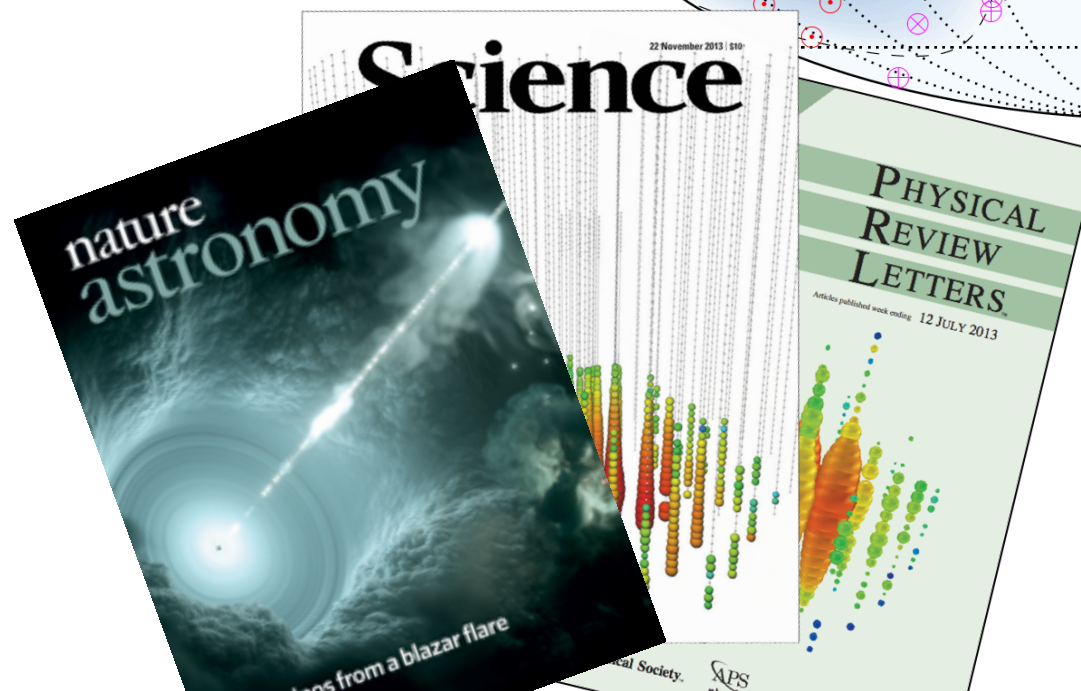
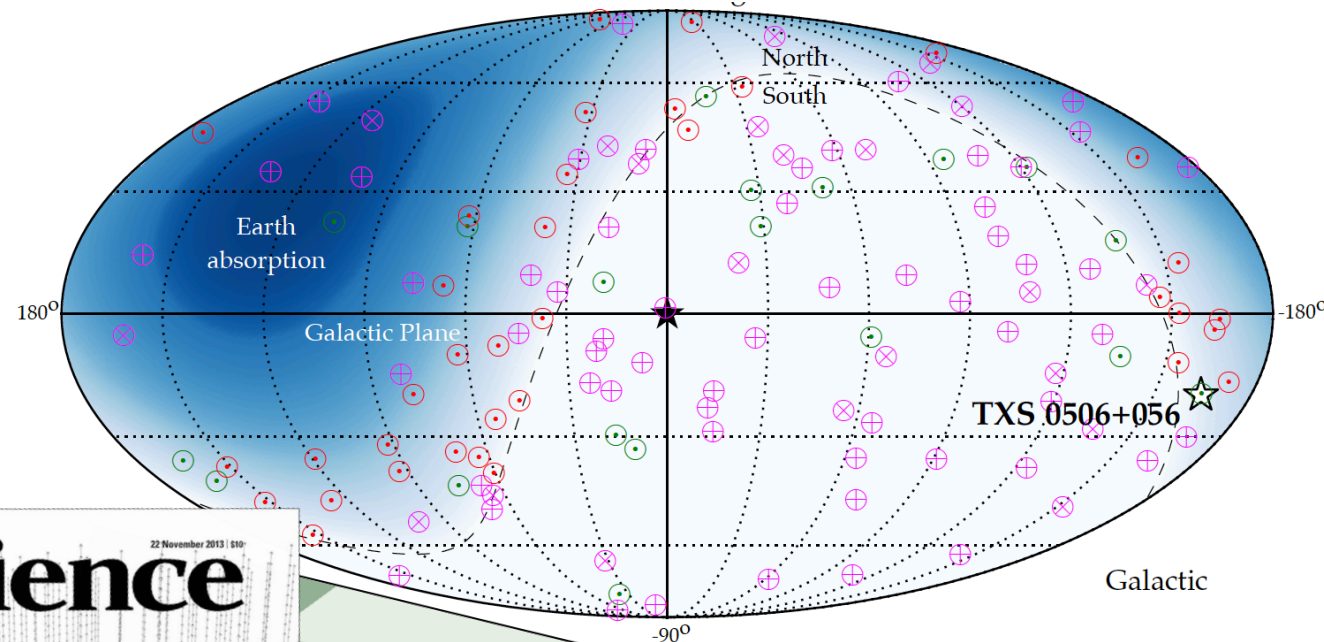
2013: Discovery of cosmic PeV neutrino flux

2018: Evidence for Blazars as neutrino sources

2020: Observation of first tau neutrino ([2011.03561](#))

& Glashow resonance interaction ( $\bar{\nu}_e$  @ 6.4 PeV)

Sky map of cosmic neutrinos



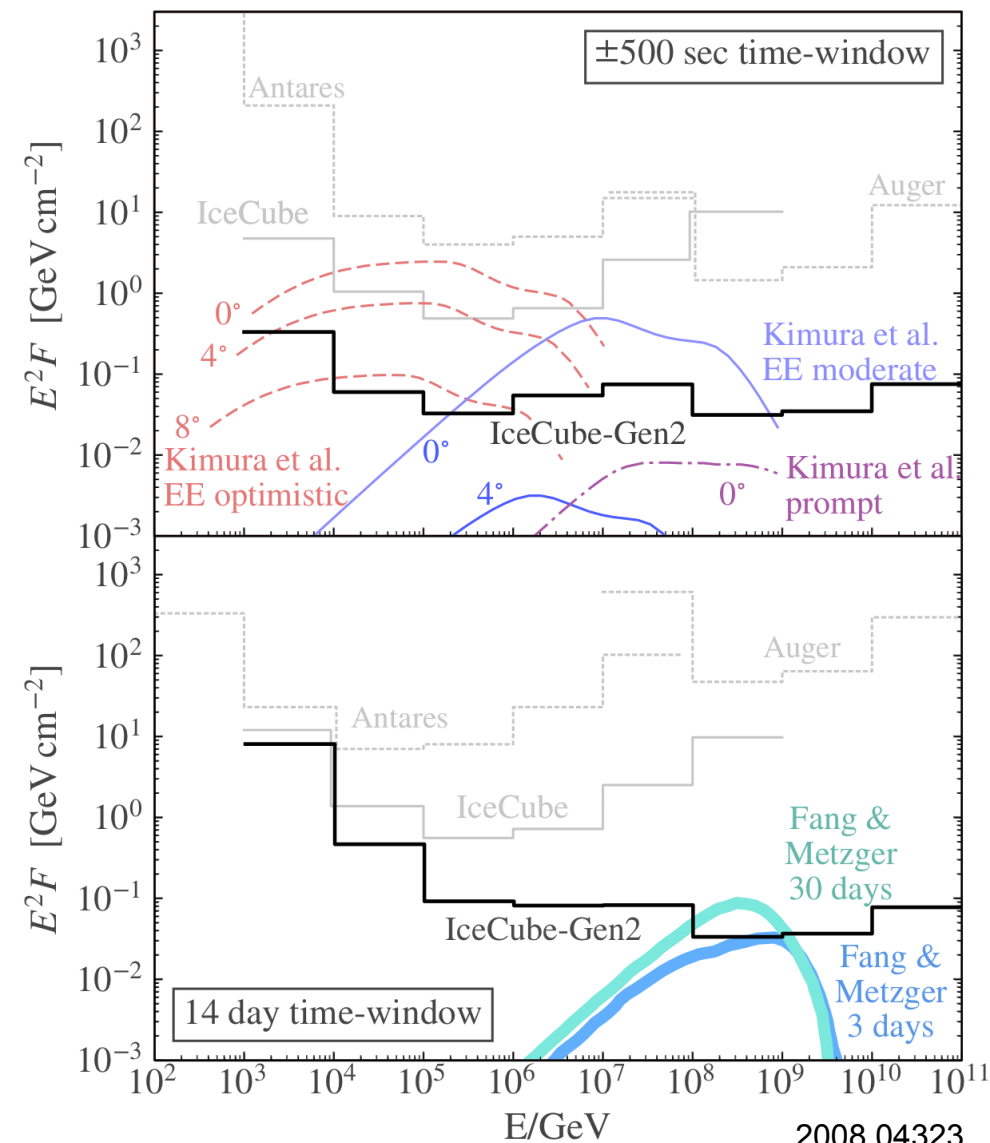
# Scientific objectives for IceCube-Gen2

## Questions emerging after 10 years of IceCube operations

1. Resolving the high-energy sky from TeV to EeV energies
2. Understanding cosmic particle acceleration through multimessenger observations
3. Revealing the sources and propagation of the highest energy particles in the universe
4. Probing fundamental physics with high-energy neutrinos, e.g. cosmic flavor physics



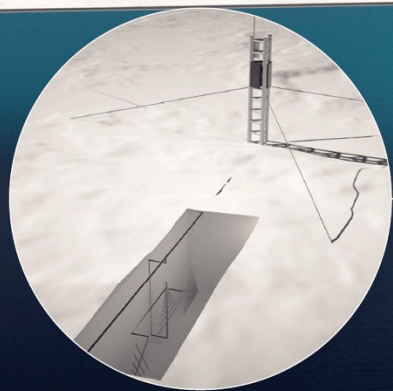
Example: neutrinos from Kilonovae / GW sources



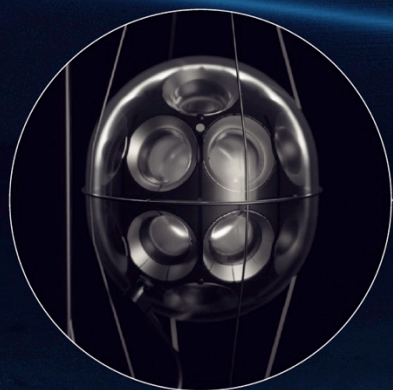


# ICECUBE

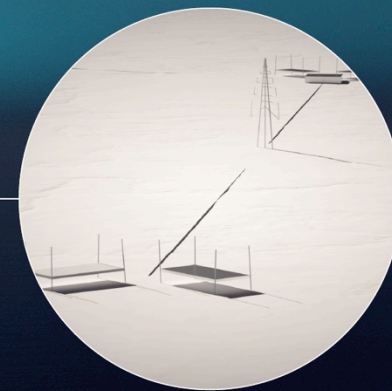
## GEN2



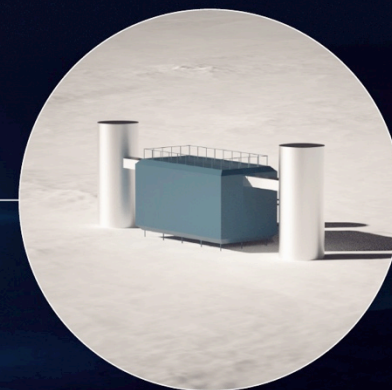
**Radio Array** | Station



**Optical Array** | Sensor



**Surface Array** | Station

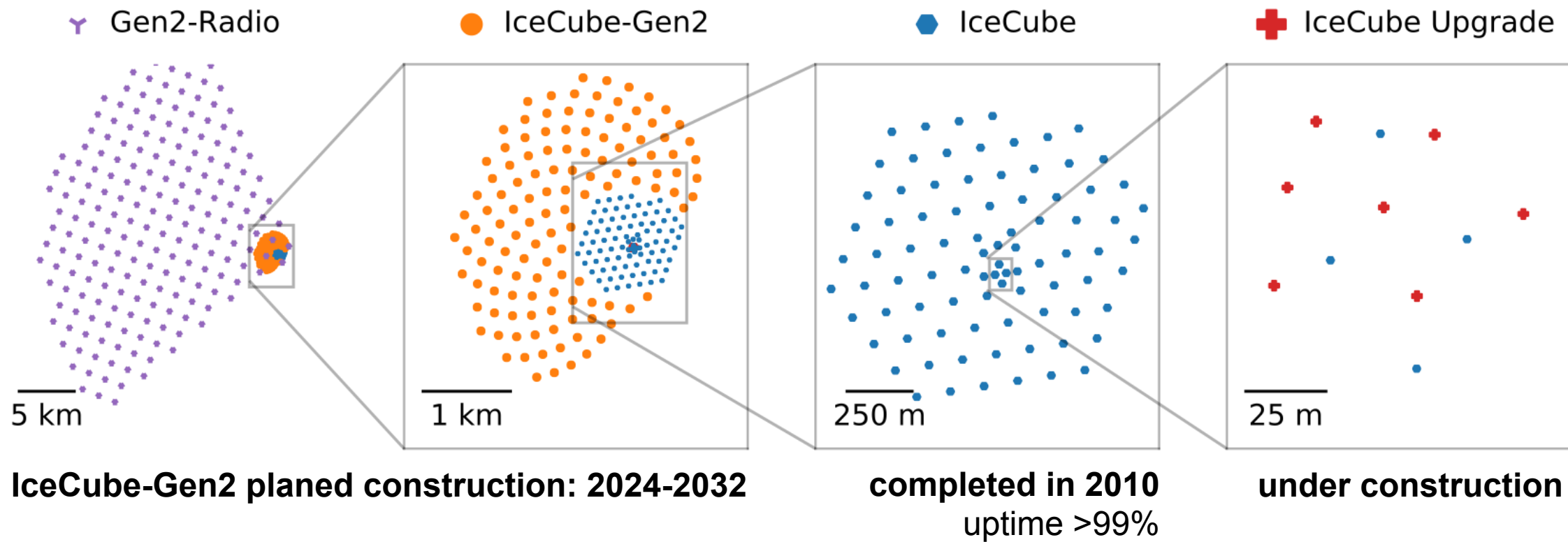


**IceCube** | Laboratory




# The IceCube Gen2 facility at the South Pole

Wide-band observatory: Optimizing scales for leading sensitivity from  $10^9$  to  $10^{20}$  eV



[Gen2 white paper: 2008.04323](#)

 **AUSTRALIA**  
University of Adelaide

 **BELGIUM**  
Université libre de Bruxelles  
Universiteit Gent  
Vrije Universiteit Brussel

 **CANADA**  
Queen's University  
University of Alberta–Edmonton

 **DENMARK**  
University of Copenhagen

 **GERMANY**  
Deutsches Elektronen-Synchrotron  
ECAP, Universität Erlangen-Nürnberg  
Humboldt-Universität zu Berlin  
Karlsruhe Institute of Technology  
Ruhr-Universität Bochum  
RWTH Aachen University  
Technische Universität Dortmund  
Technische Universität München  
Universität Mainz  
Universität Wuppertal  
Westfälische Wilhelms-Universität  
Münster

 **JAPAN**  
Chiba University  
University of Tokyo

 **NEW ZEALAND**  
University of Canterbury

 **REPUBLIC OF KOREA**  
Sungkyunkwan University

 **SWEDEN**  
Stockholms universitet  
Uppsala universitet

 **SWITZERLAND**  
Université de Genève

 **TAIWAN**  
National Taiwan University

 **UNITED KINGDOM**  
King's College London  
University of Oxford  
University of Manchester  
Queen Mary University of London

 **UNITED STATES**  
California Polytechnical State University  
Clark Atlanta University  
Columbia University  
Drexel University  
Georgia Institute of Technology  
Lawrence Berkeley National Lab  
Loyola University Chicago

Marquette University  
Massachusetts Institute of Technology  
Mercer University  
Michigan State University  
Ohio State University  
Pennsylvania State University  
South Dakota School of Mines and  
Technology  
Southern University  
and A&M College  
Stony Brook University  
University of Alabama  
University of Alaska Anchorage  
University of California, Berkeley  
University of California, Irvine  
University of California, Los Angeles  
University of Chicago

University of Delaware  
University of Kansas  
University of Maryland  
University of Notre Dame du Lac  
University of Rochester  
University of Texas at Arlington  
University of Wisconsin–Madison  
University of Wisconsin–River Falls  
Yale University

# THE ICECUBE-GEN2 COLLABORATION

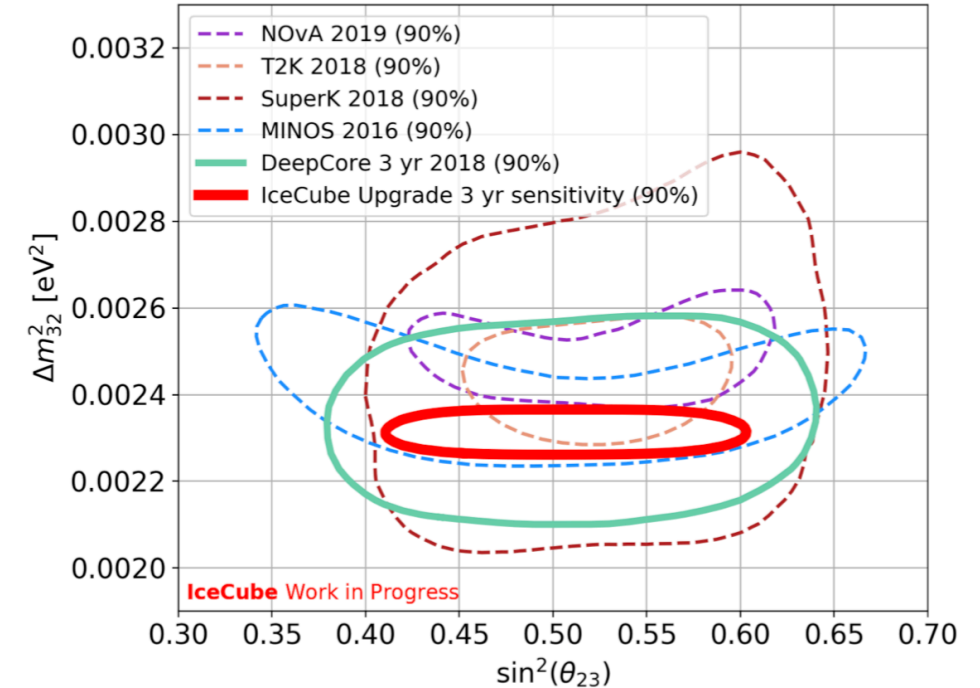


# Developments towards IceCube-Gen2

## IceCube Upgrade / IceCube Gen2-Phase I



- Unprecedented sensitivity to atmospheric neutrino mixing parameters and neutrino mass ordering
- Detailed calibration of ice properties
- Essential R&D for IceCube-Gen2
- Fully funded. Total costs ~40 MEuro, German contribution ~25% (funded by BMBF/Helmholtz)
- Sensor work package lead by Germany
- Essential contributions to calibration devices (POCAM, Acoustic Module)
- Construction ongoing, until recently on track to deploy in 2022/23, but due to Covid we are now forced to re-baseline to 2023/24.



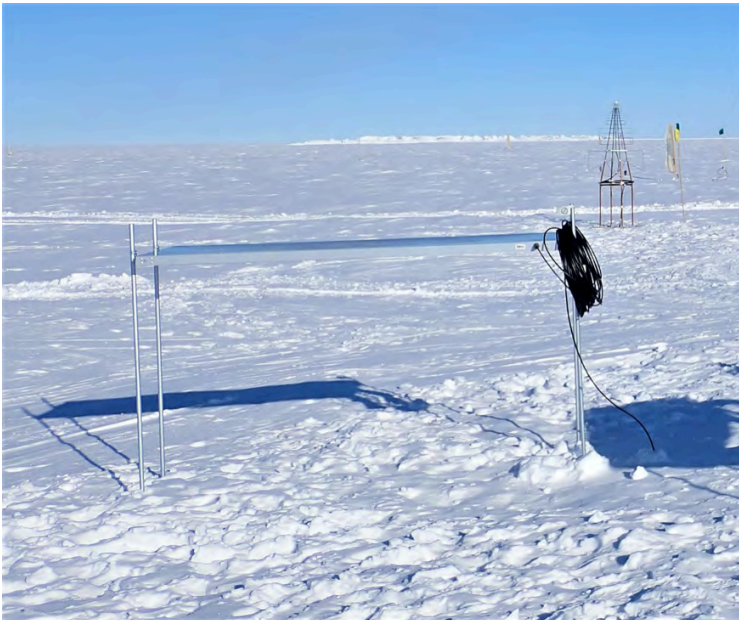
mDOM: -400 of 700 Upgrade sensors are mDOMs, developed and produced in Germany

# Developments towards IceCube-Gen2

## IceTop enhancement and RNO-G

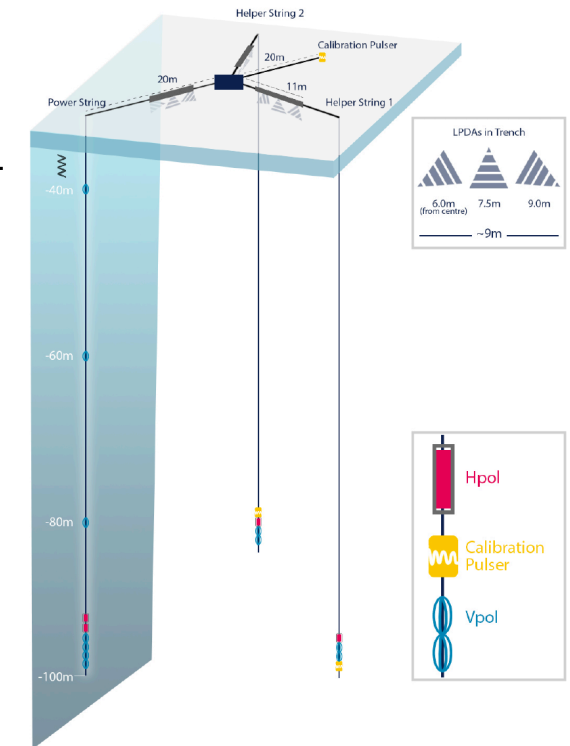


- Enhancement of IceTop (surface array of IceCube), through scintillators and radio surface antennas, under German leadership
- Unique cosmic ray science and vetoing
- Baseline technology for Gen2



- RNO-G, to be located at Summit Station, Greenland, co-leadership from Germany
- Array of radio sensors to measure neutrinos above 10 PeV, baseline technology for Gen2
- Funded, deployment: 2021-2023

Radio station:  
(2010.12279)

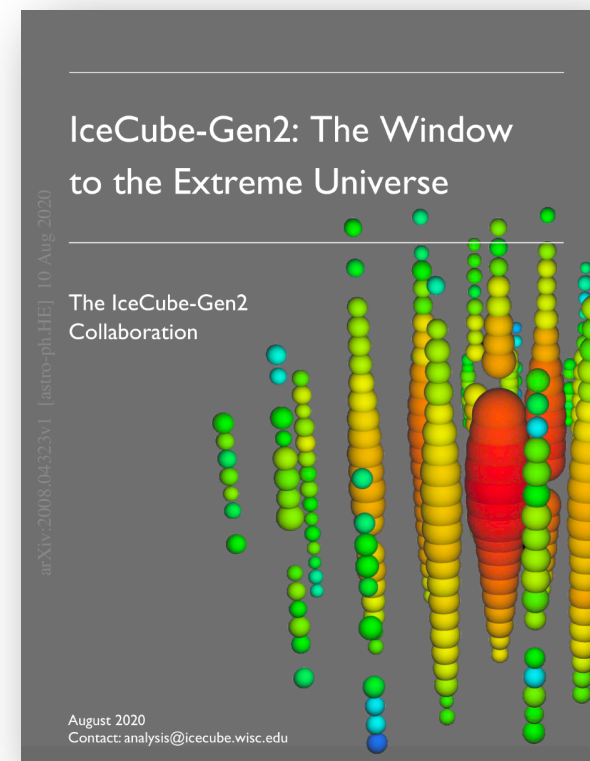


# Developments towards IceCube-Gen2

## Status

- CDR phase completed and published along scientific goals in our White Paper
- PDR to be completed fall 2021
- Project office assembled (incl. project director, project engineer, ...)
- DESY and KIT submitted joint proposal for Helmholtz Forschungsinfrastruktur
- German groups leading surface and radio effort
- Community workshops scheduled for next semester:
  - Polar science (18-20.1.2021)
  - Gen2 science (Spring 2021)

## Extended Gen2 White Paper: 2008.04323



>30 related contributions to  
Snowmass 2021, Astro2020  
Decadal Survey



Snowmass2021 - Letter of Interest

*IceCube-Gen2: the next generation wide band neutrino observatory*

### Thematic Areas

- ☒ (IF2) Instru
- ☒ (IF10) Instr
- ☒ (UF01) Und
- ☒ (UF03) Und
- ☒ (NF1) Neut
- ☒ (NF4) Neut
- ☒ (NF10) Neu
- ☒ (CF7) Cosm

Snowmass2021 - Letter of Interest

Monitoring Galactic core-collapse supernova neutrinos with IceCube and IceCube-Gen2

NF Topical Groups: (check all that apply ☐ ☒)

Snowmass2021 - Letter of Interest

*Highest Energy Galactic Cosmic Rays*

### Thematic Areas: (check all that apply ☐ ☒)

- ☐ (CF1) Dark Matter: Particle Like
- ☐ (CF2) Dark Matter: Wavelike
- ☐ (CF3) Dark Matter: Cosmic Probes
- ☐ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
- ☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Phase and Beyond
- ☒ (CF6) I
- ☒ (CF7) C
- ☒ (EF06)

Snowmass2021 - Letter of Interest

*Letter of Interest on Dark Matter Physics with the IceCube Neutrino Observatory*

Contact:  
Andreas F.  
Authors:  
(RU Boch  
Irksutsk, R  
nois (U W

Topical Groups: (check all that apply ☐ ☒)  
☒ (NF1) Neutrino oscillations

Snowmass2021 - Letter of Interest

*IceCube-Gen2: The Window to the Extreme Universe*

### Thematic Areas:

- ☒ (NF1) Neutrino oscillations
- ☒ (NF2) Sterile neutrinos
- ☒ (NF3) Beyond the Standard Model
- ☒ (NF4) Neutrinos from natural sources
- ☒ (NF5) Neutrino properties
- ☒ (NF6) Neutrino cross sections
- ☒ (NF8/TF11) Theory of neutrino physics
- ☒ (NF10) Neutrino detectors
- ☒ (CF7) Cosmic Probes of Fundamental Physics

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Marek Kowalski (DESY) marek.kowalski@desy.de

Authors: IceCube-Gen2 Collaboration

### Abstract:

The discovery of cosmic neutrinos, announced by IceCube in 2013, has opened a new window to the high energy Universe. The observations made to date have already brought us one step closer to answering key questions, such as: what are the sources in the PeV sky and how do they drive particle acceleration; where are cosmic rays of extreme energies produced and on which paths do they propagate through the universe; and are there signatures of new physics at TeV-EeV energies? IceCube-Gen2, a next generation neutrino observatory, is designed to address these questions. In conjunction with continued progress in multi-messenger astrophysics, IceCube-Gen2 promises to elevate the cosmic neutrino field from the discovery realm to the precision era and to a survey of the sources in the neutrino sky. IceCube-



# Instrumentation and Operation costs

	IceCube (\$M)	IceCube Gen2 (\$M)
Optical/surface array	112	152
Radio array	-	26
<b>Total instrumentation</b>	<b>112</b>	<b>178</b>
Project, implementation, polar support, data systems	166	169
<b>Total</b>	<b>278</b>	<b>347</b>

Expected contributions to instrumentation based on number of collaborators: **GER fraction 25% or ~40 MEuro**

Annual **operation cost** estimated at 9 MEuro, similar to IceCube.  
GER fraction: 400kEuro p.a. common fund and ~1.5 MEuro equivalent in-kind services (computing, software, etc)

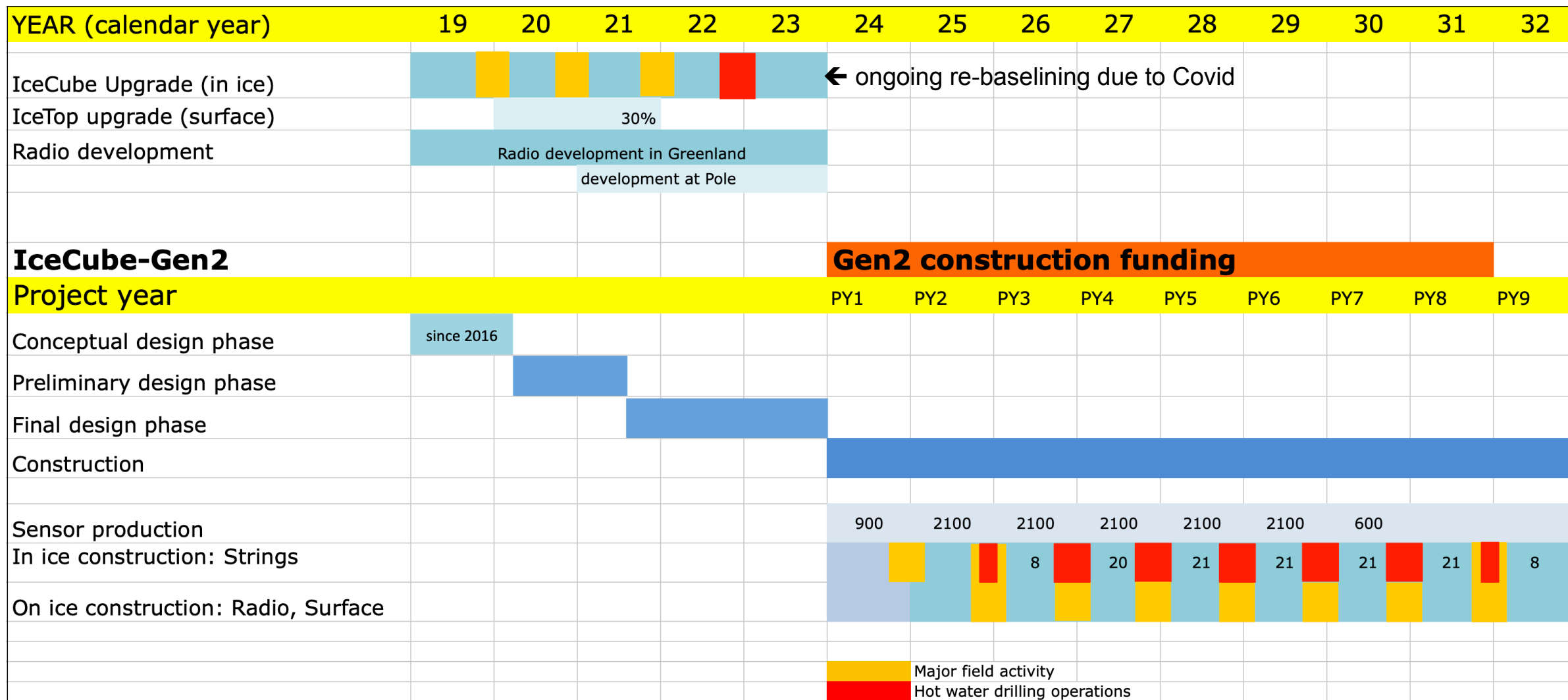


**Gen2 DOM (baseline):**  
represents 2/3 of the instr. costs; to be produced in large quantities in GER

**Right:** Alternative concepts also being developed by German groups



# Timeline



# Summary

- IceCube, completing construction 10 years ago, delivered several breakthroughs in neutrino astronomy and pushed the boundaries in cosmic ray science as well as neutrino physics
- German groups deeply engaged in preparing next generation technology, with several funded projects underway (IceCube-Upgrade, IceTop extension, RNO-G)
- IceCube-Gen2 designed and optimized to harvest the enormous scientific opportunities, e.g. a uniquely sensitive neutrino observatory, ranging from GeV to beyond EeV in energy
- Getting ready to start IceCube-Gen2 construction soon!

