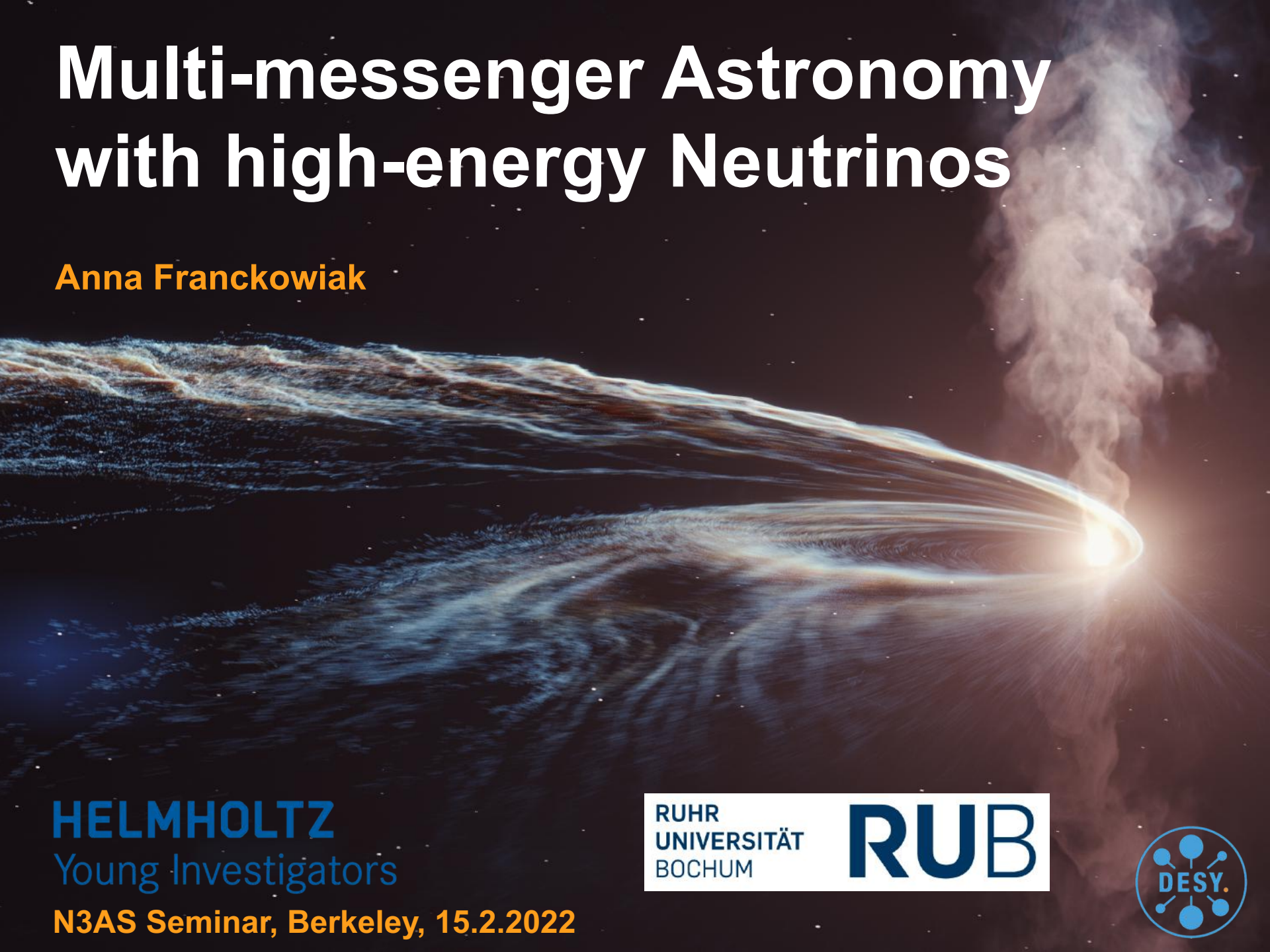
Multi-messenger Astronomy with high-energy Neutrinos

Anna Franckowiak

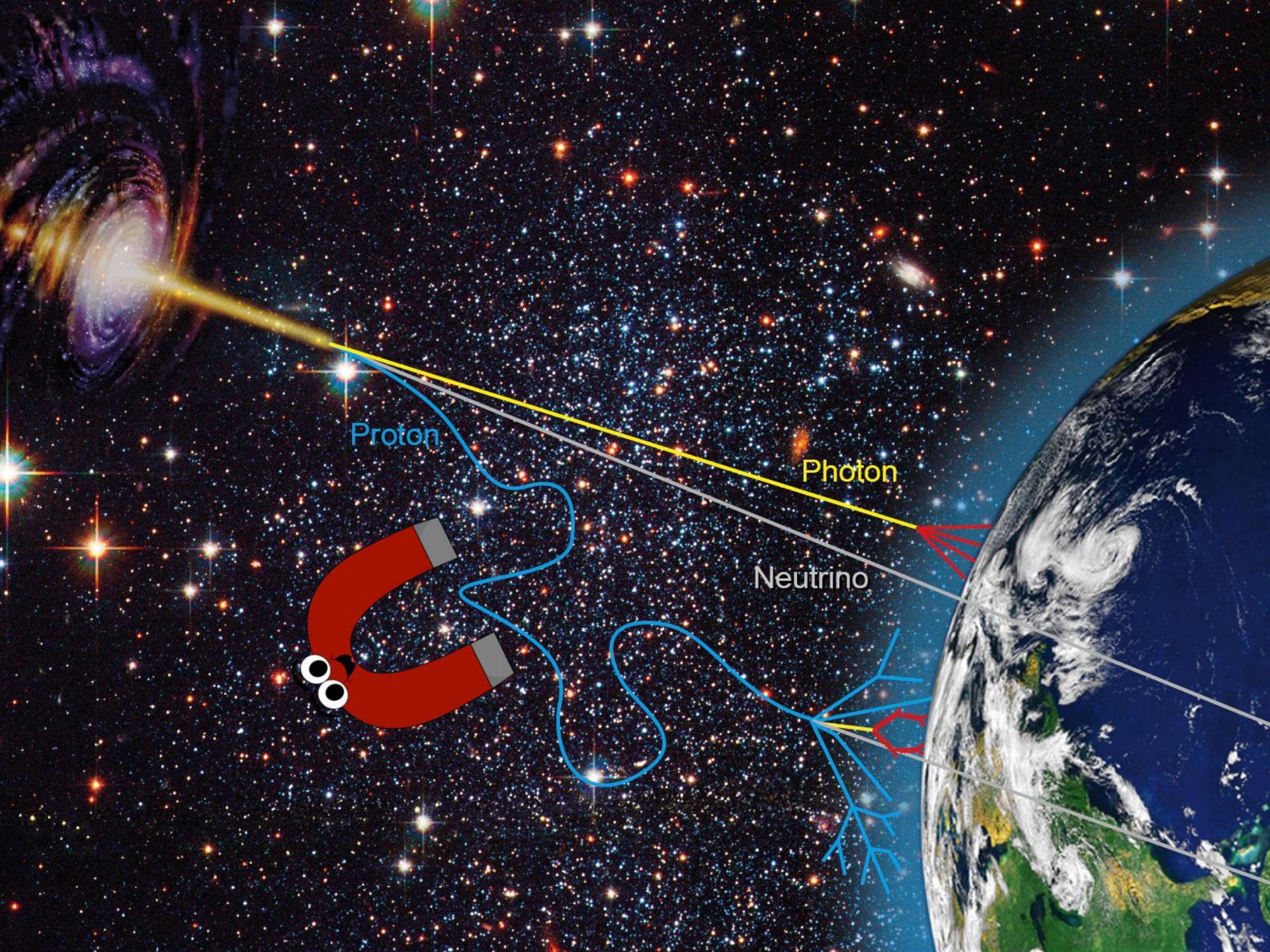


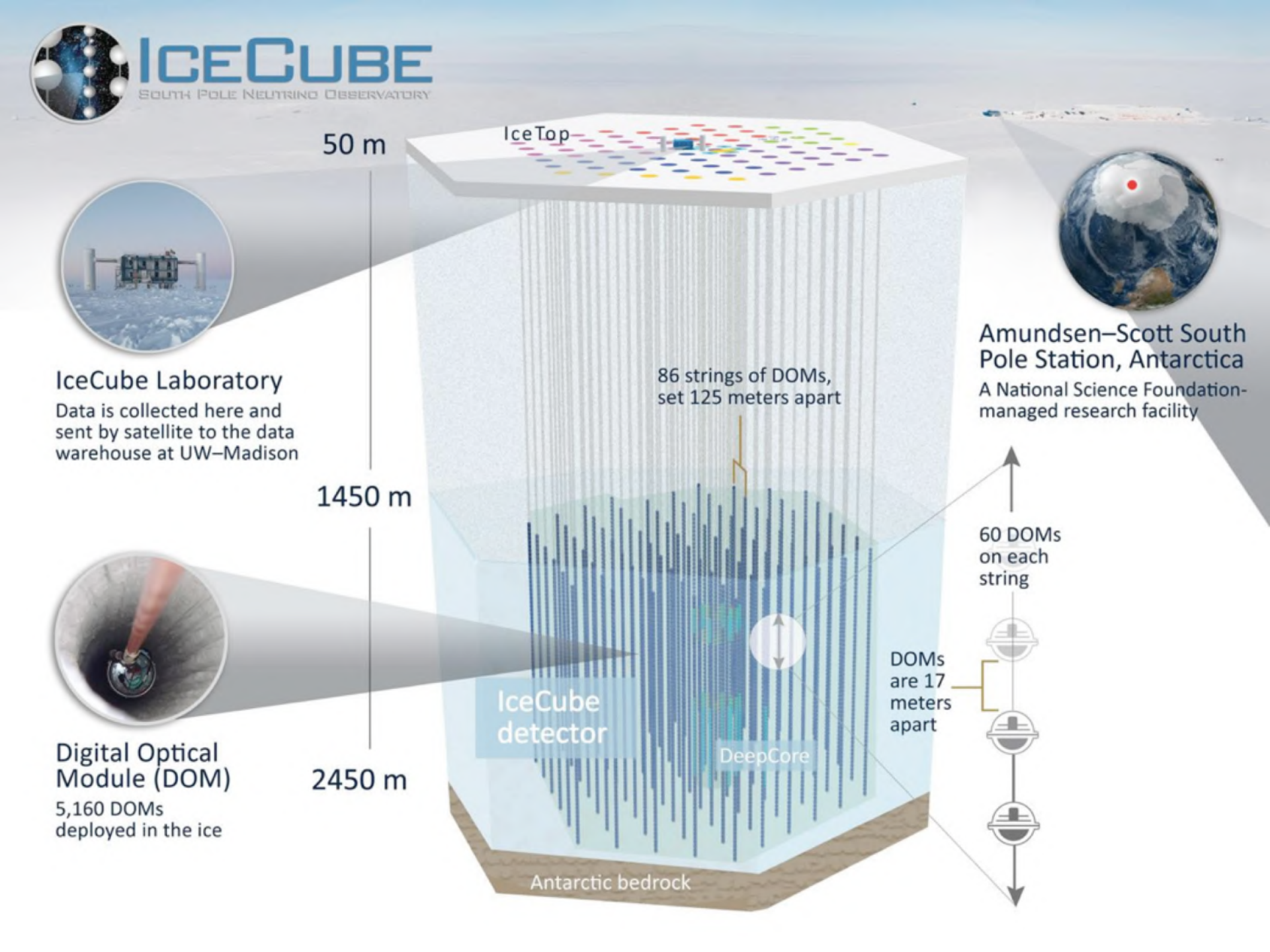
HELMHOLTZ
Young Investigators

RUHR UNIVERSITÄT BOCHUM RUB

DESY.

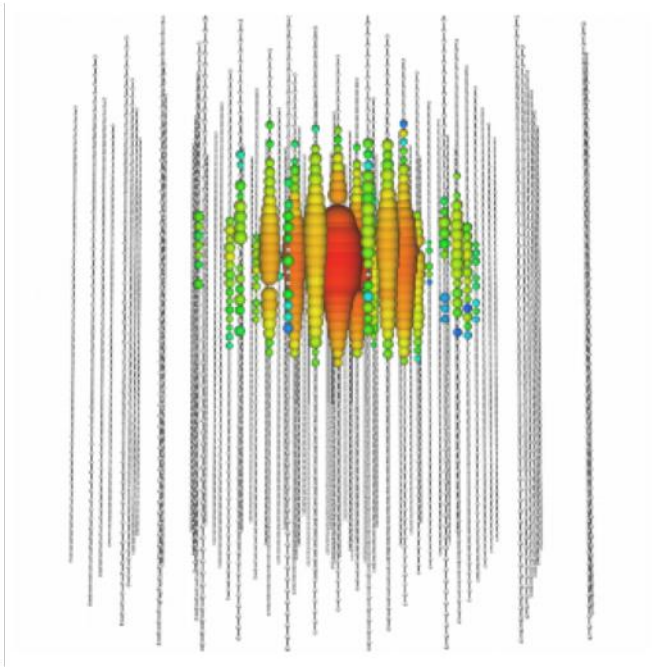
N3AS Seminar, Berkeley, 15.2.2022


Proton
Photon
Neutrino

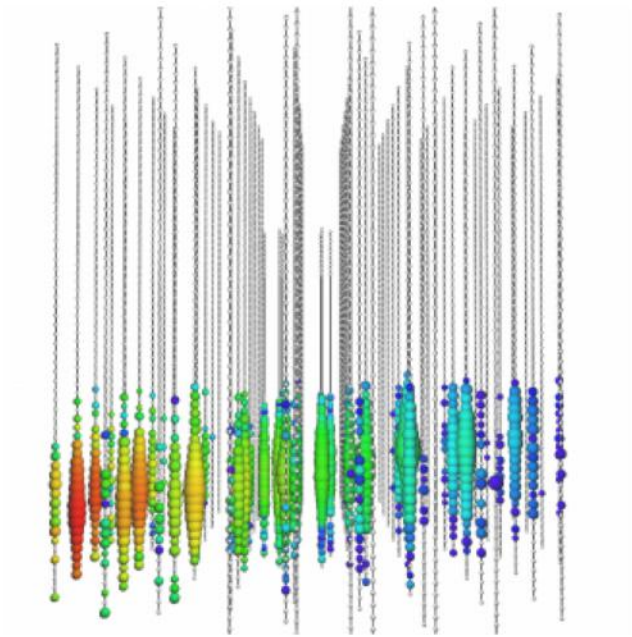

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
1450 m
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
2450 m
Antarctic bedrock

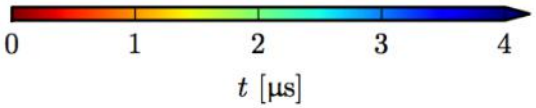
Event Signatures

“shower“ events: neutrinos interacting inside the detector



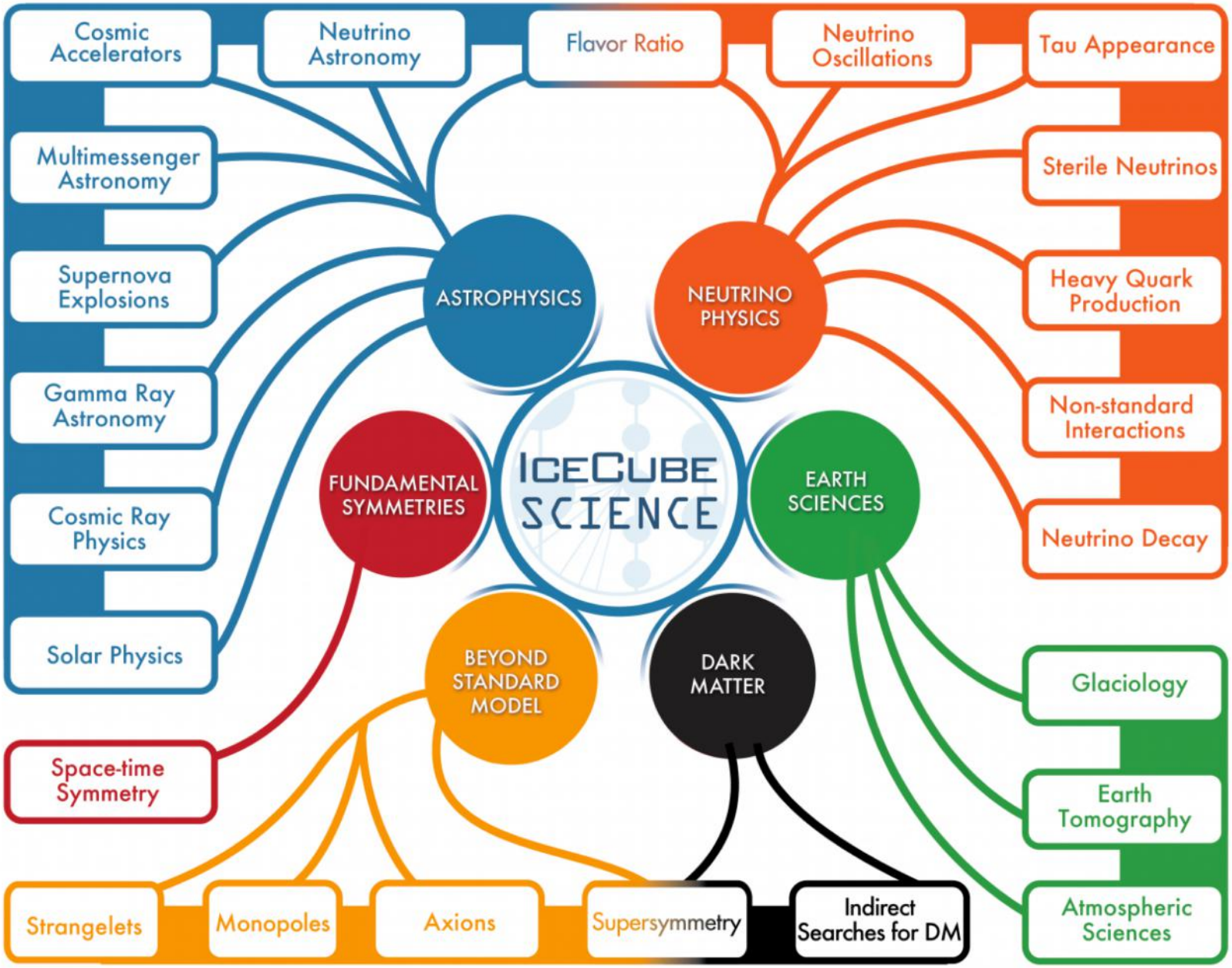
“track“ events: muon neutrinos filtered by the Earth



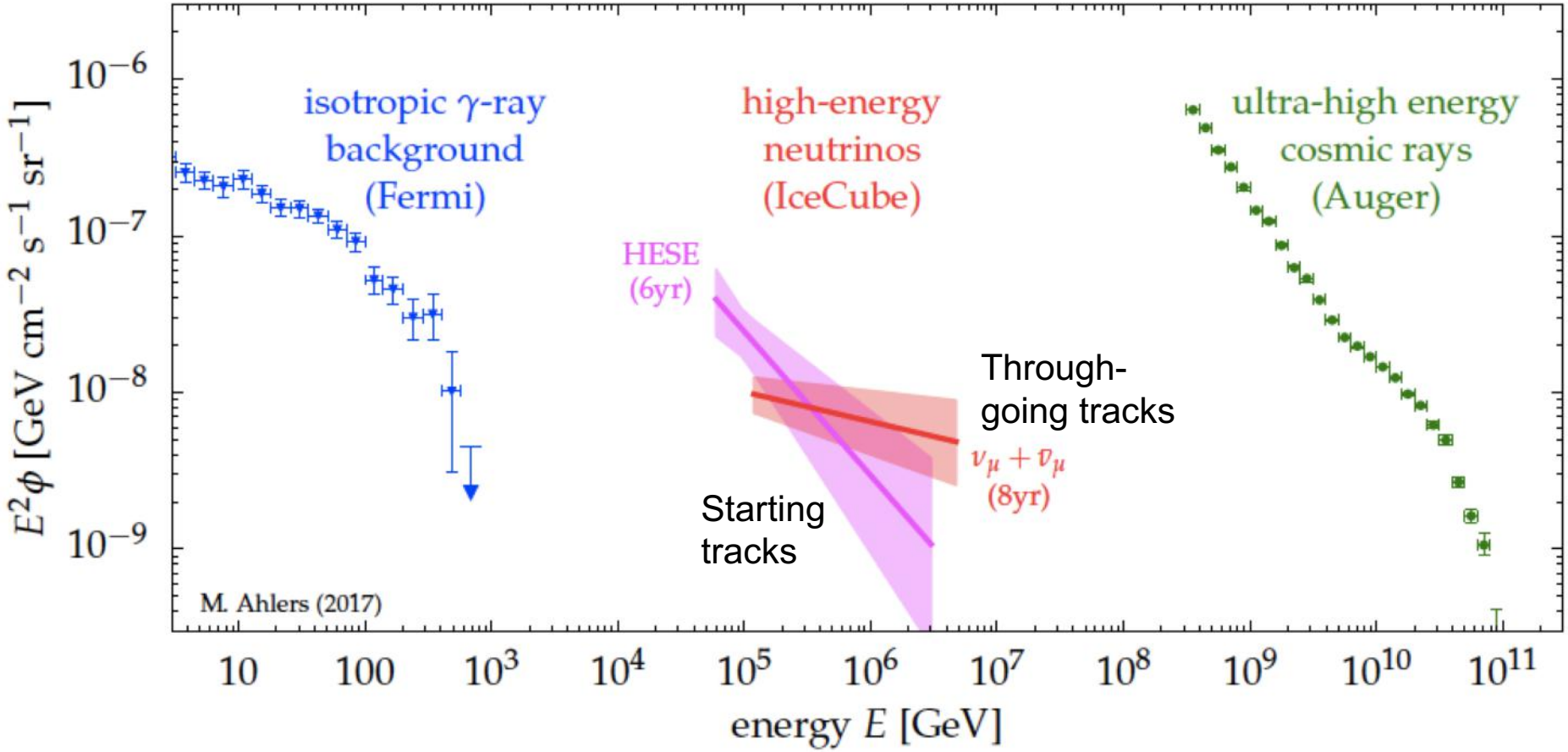


total energy measurement to 10%, all flavors, all sky

astronomy: angular resolution superior (0.2º~0.4º)


ICECUBE SCIENCE
ASTROPHYSICS
Cosmic Accelerators
Neutrino Astronomy
Multimessenger Astronomy
Supernova Explosions
Gamma Ray Astronomy
Cosmic Ray Physics
Solar Physics
NEUTRINO PHYSICS
Flavor Ratio
Neutrino Oscillations
Tau Appearance
Sterile Neutrinos
Heavy Quark Production
Non-standard Interactions
Neutrino Decay
FUNDAMENTAL SYMMETRIES
Space-time Symmetry
EARTH SCIENCES
Glaciology
Earth Tomography
Atmospheric Sciences
BEYOND STANDARD MODEL
Strangelets
Monopoles
Axions
Supersymmetry
DARK MATTER
Indirect Searches for DM

Multi-messenger Diffuse Flux

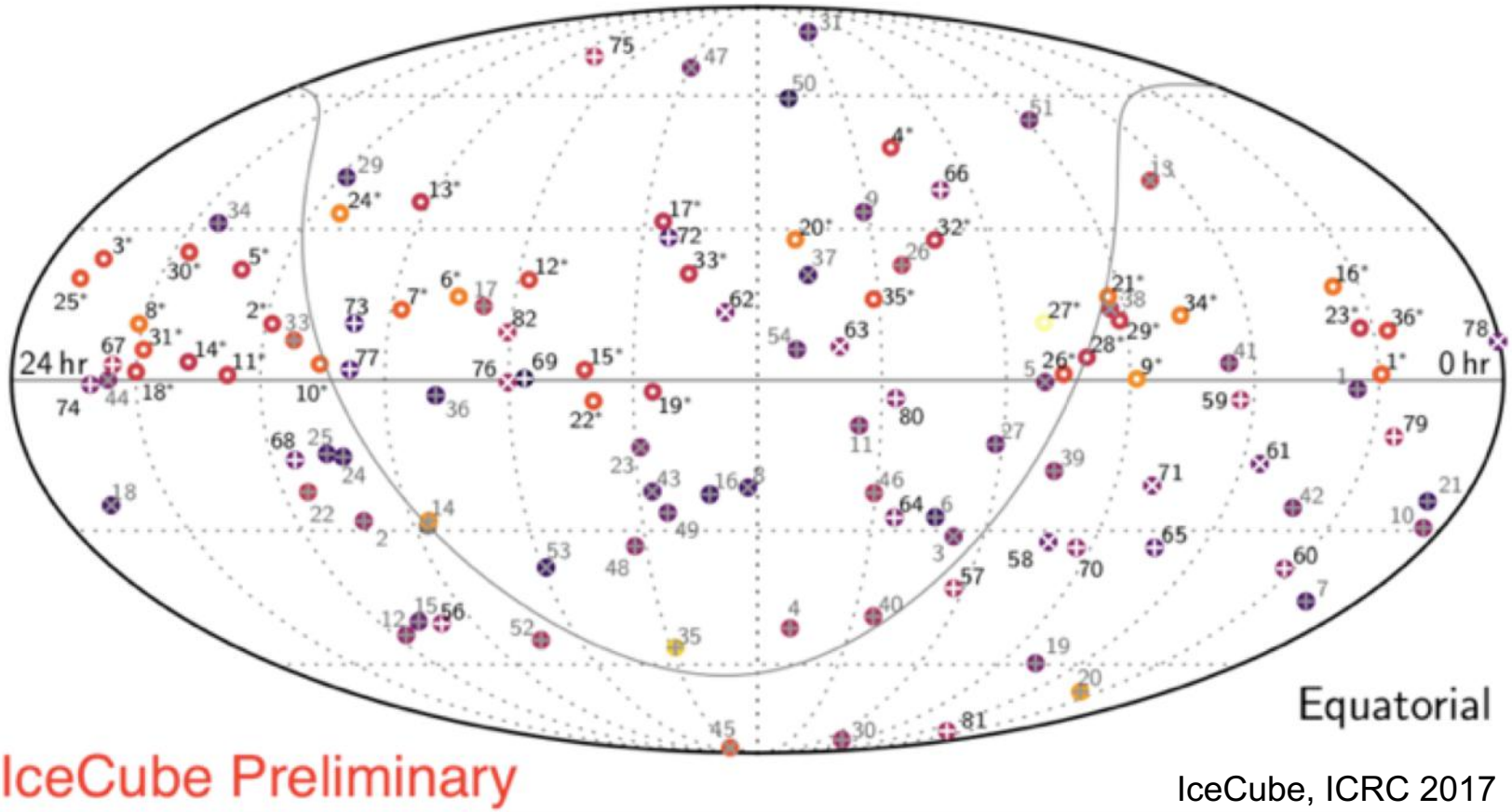


Similar energies in gamma rays, neutrinos & cosmic rays injected into our Universe!

Where to the neutrinos come from?

Where do the Neutrinos come from?

Sky map of likely cosmic neutrinos > 30 TeV (2010 - 2016)



IceCube, ICRC 2017

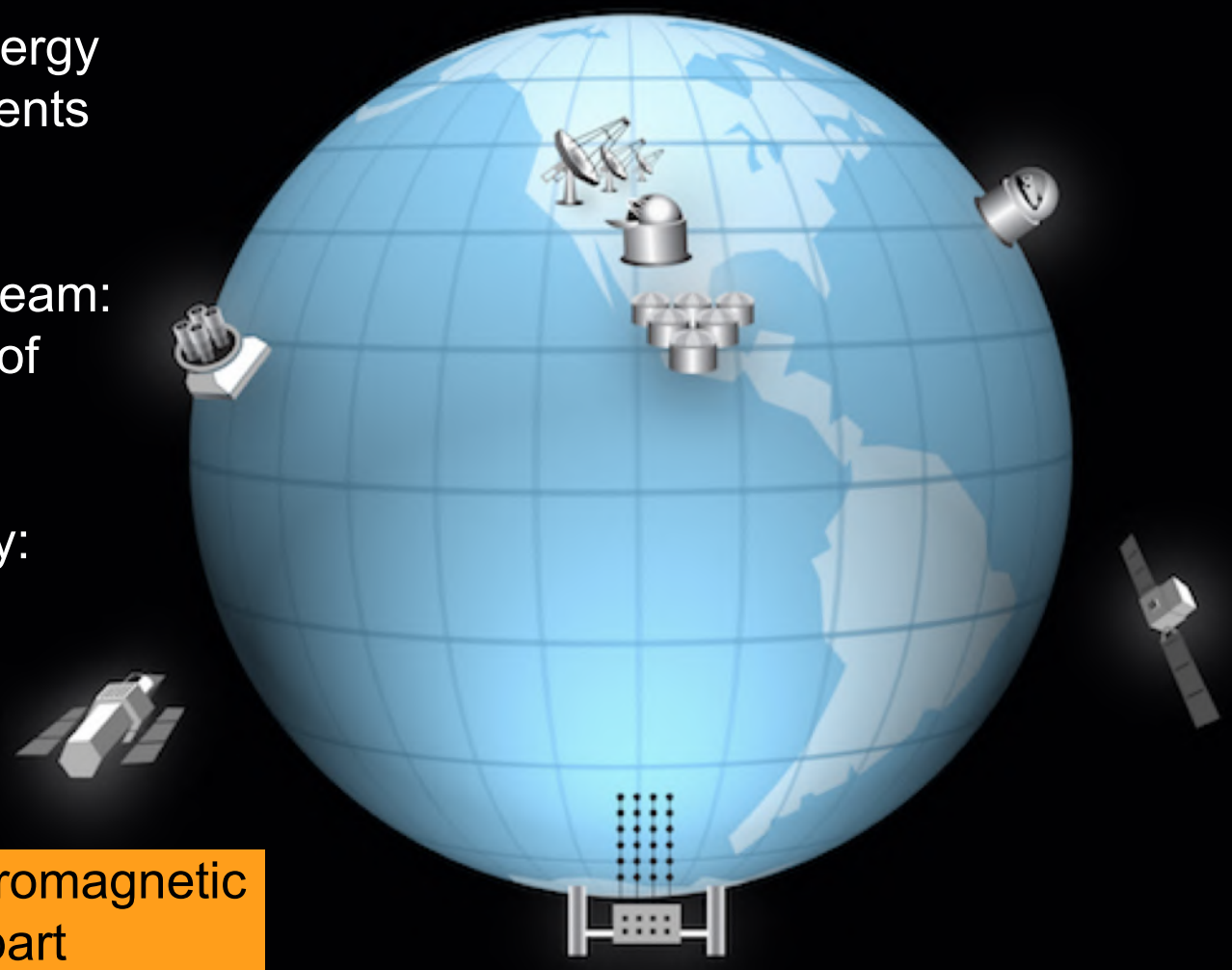
Compatible with an isotropic distribution

→ extragalactic origin of cosmic neutrinos

IceCube Target of Opportunity Program

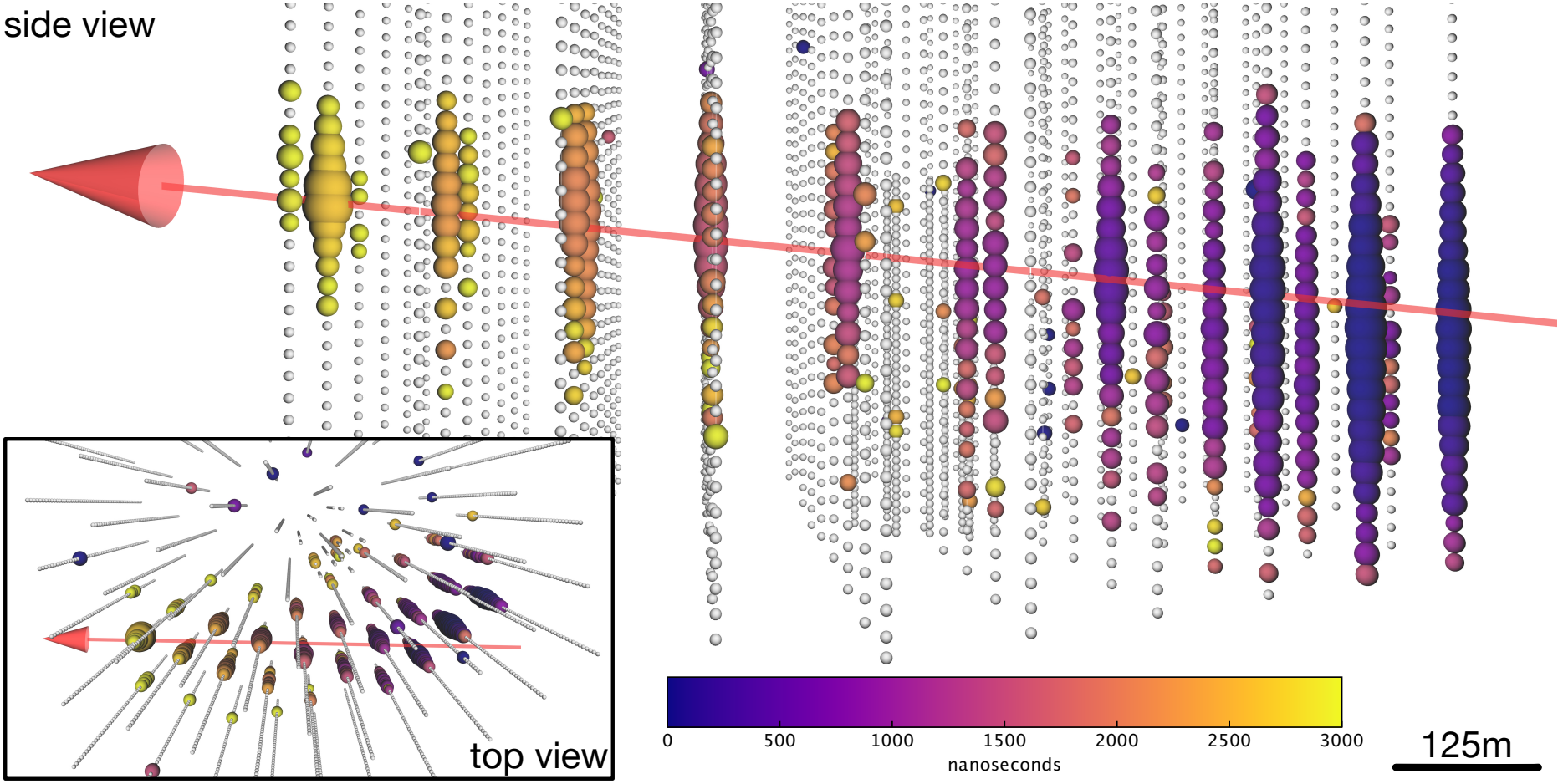
Public alerts since April 2016

- Single high-energy muon track events (> ~100TeV)
- “Gold” alert stream: 10 / yr, ~5 / yr of cosmic origin
- Median latency: 30 sec



Goal: Find electromagnetic counterpart

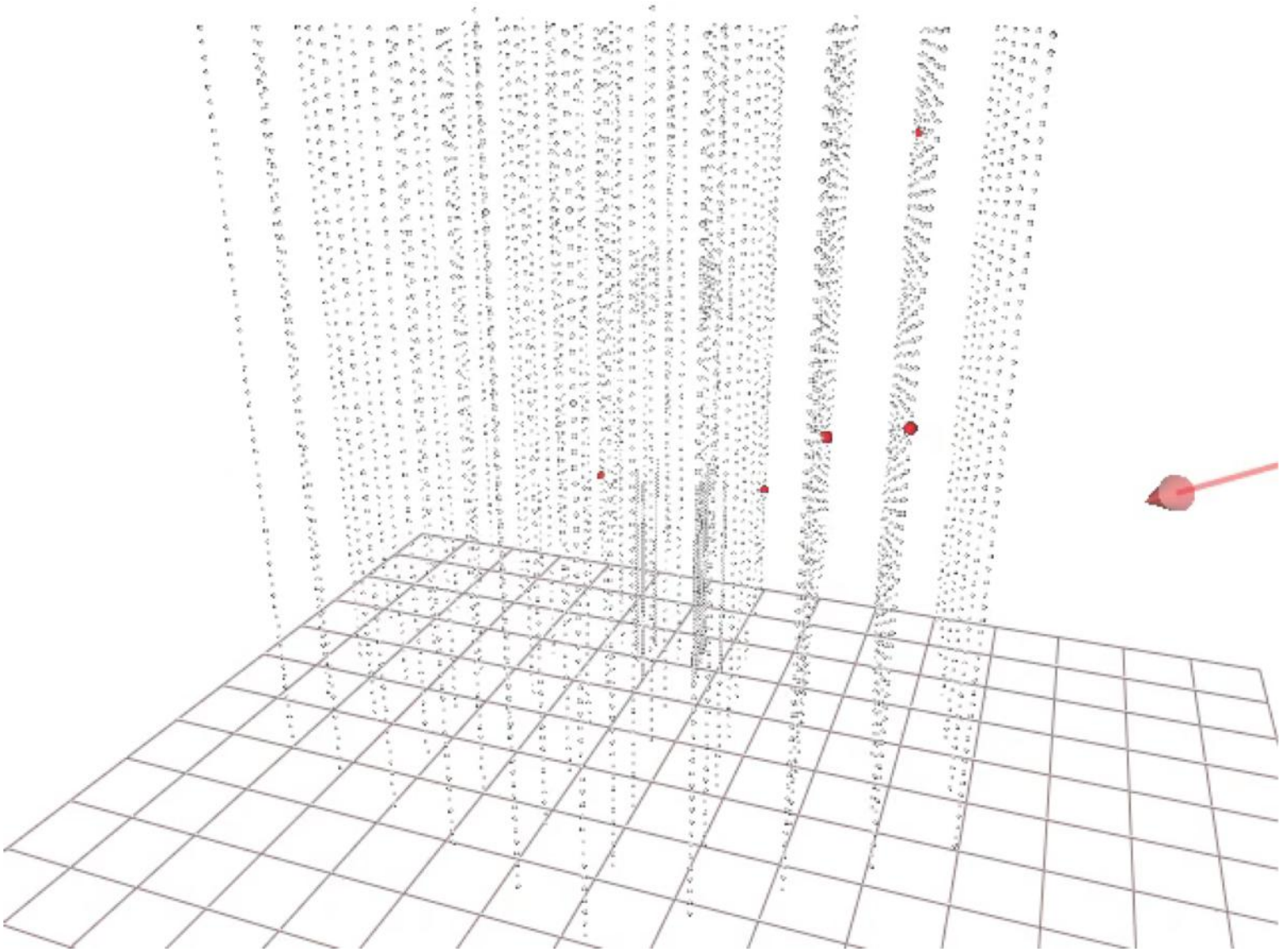
IC-170922A – a 290 TeV Neutrino



Signalness: 56.5%

IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, Kiso, Liverpool, Subaru, Swift, VERITAS, VLA, Science 2018

IC-170922A – a 290 TeV Neutrino

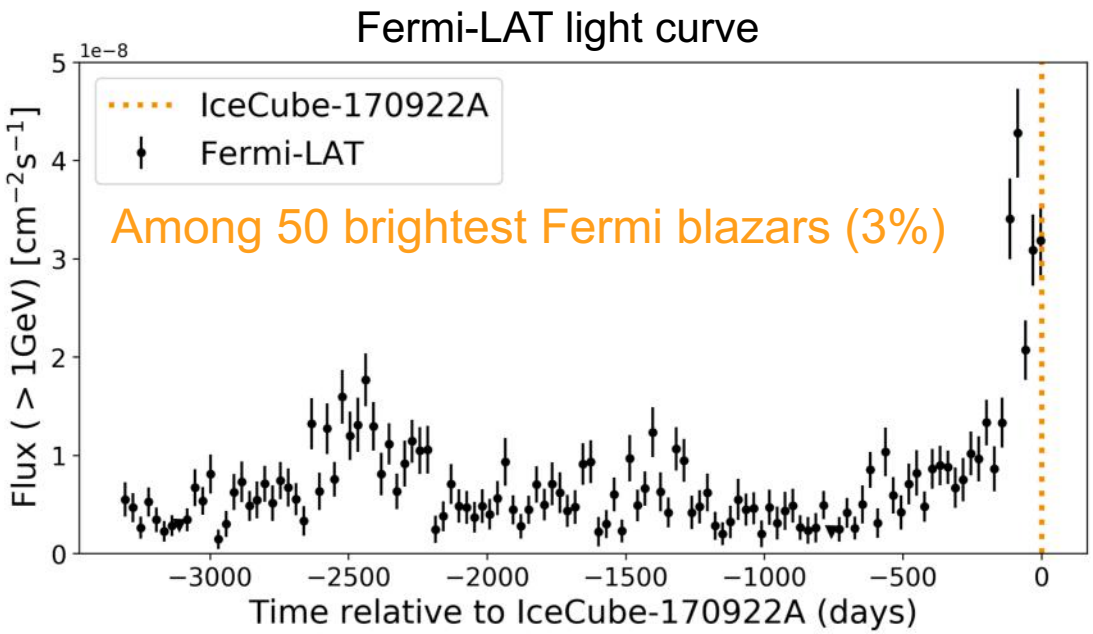


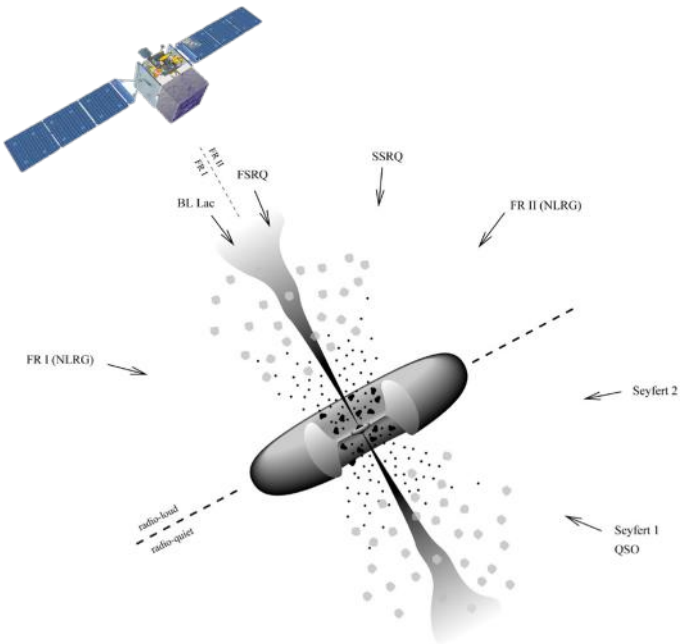
IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, Kiso, Liverpool, Subaru, Swift, VERITAS, VLA, Science 2018

Fermi-LAT finds Flaring Source

Fermi-LAT Coll., ApJ 846, 2017, Video credits: Matteo Giomi, Fermi-LAT Collaboration

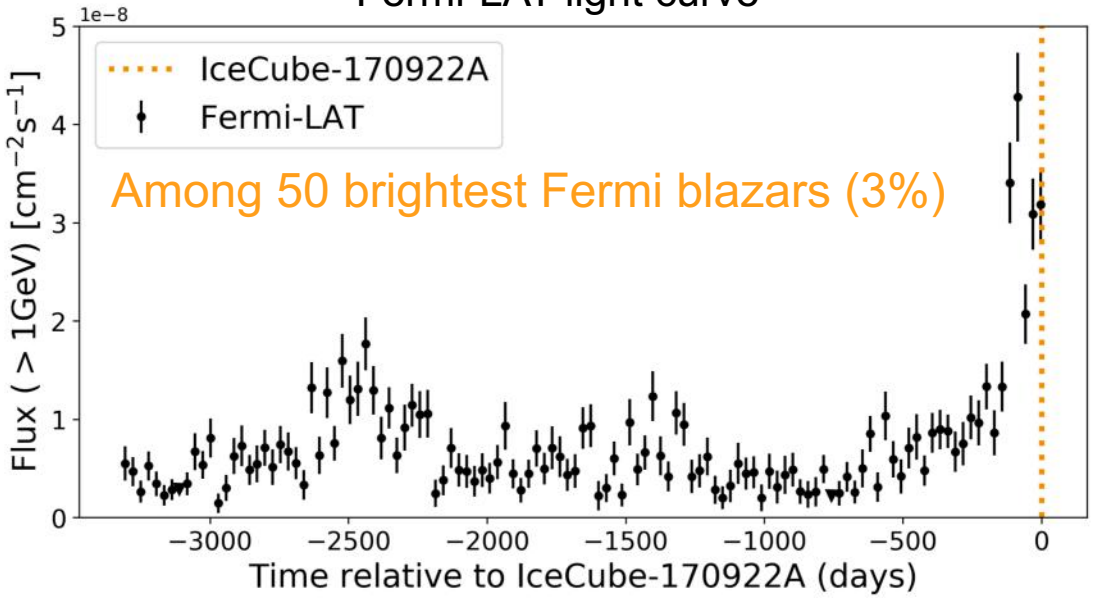
Fermi-LAT finds Flaring Blazar, TXS 0506+056



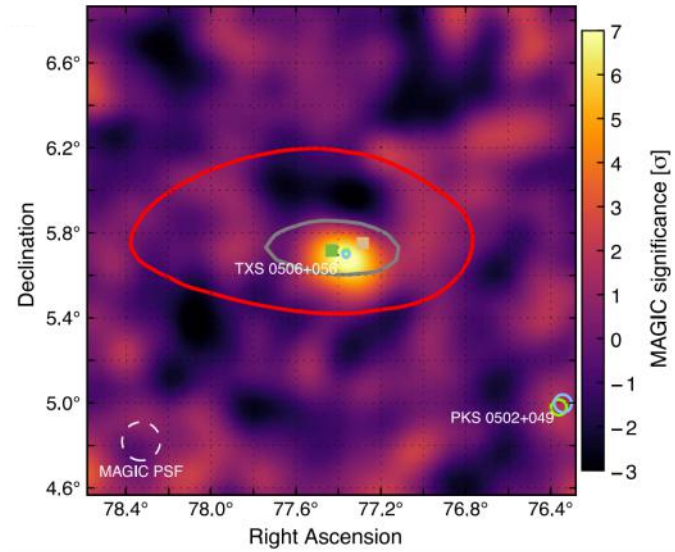


Fermi-LAT finds Flaring Blazar, TXS 0506+056

Fermi-LAT light curve

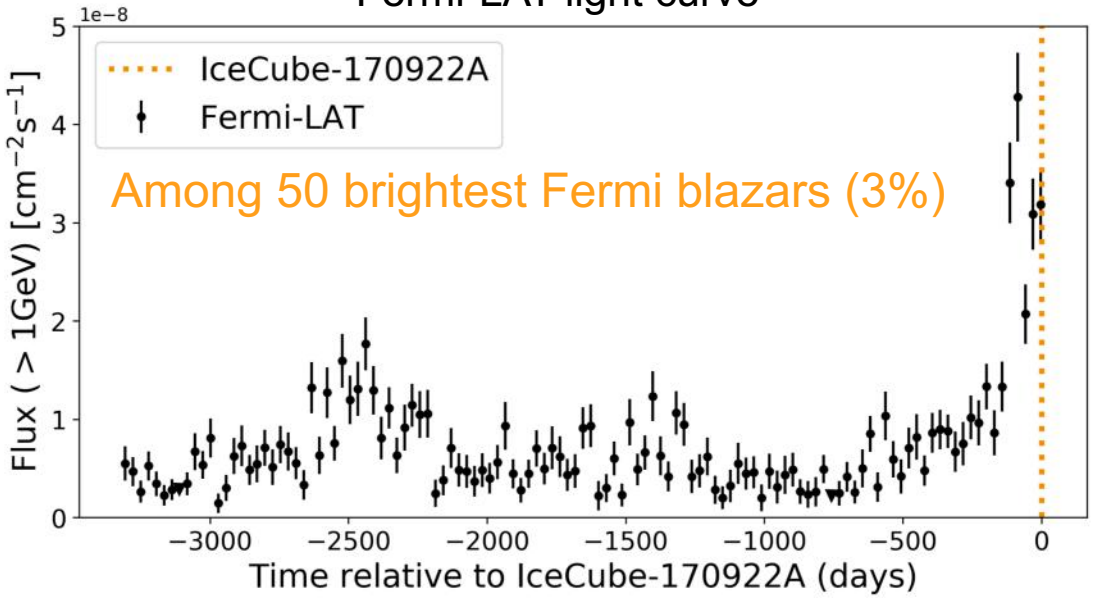


MAGIC Significance map

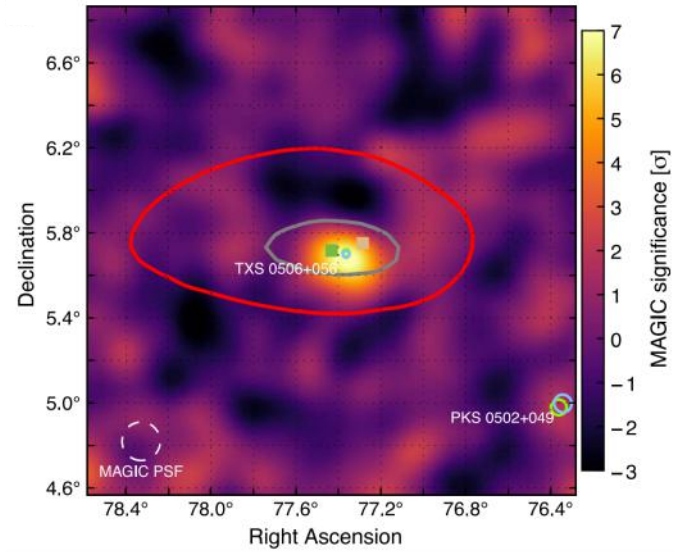


Fermi-LAT finds Flaring Blazar, TXS 0506+056

Fermi-LAT light curve



MAGIC Significance map

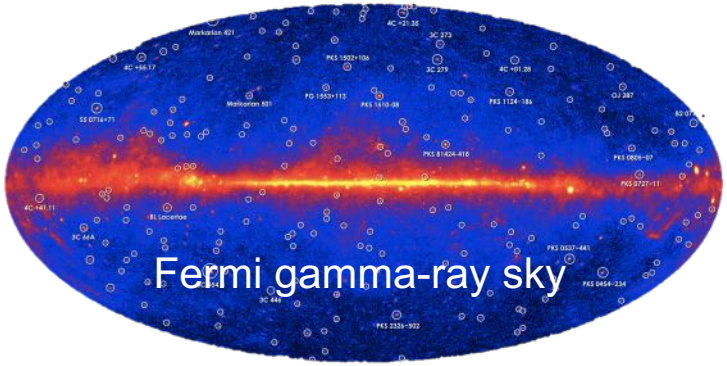


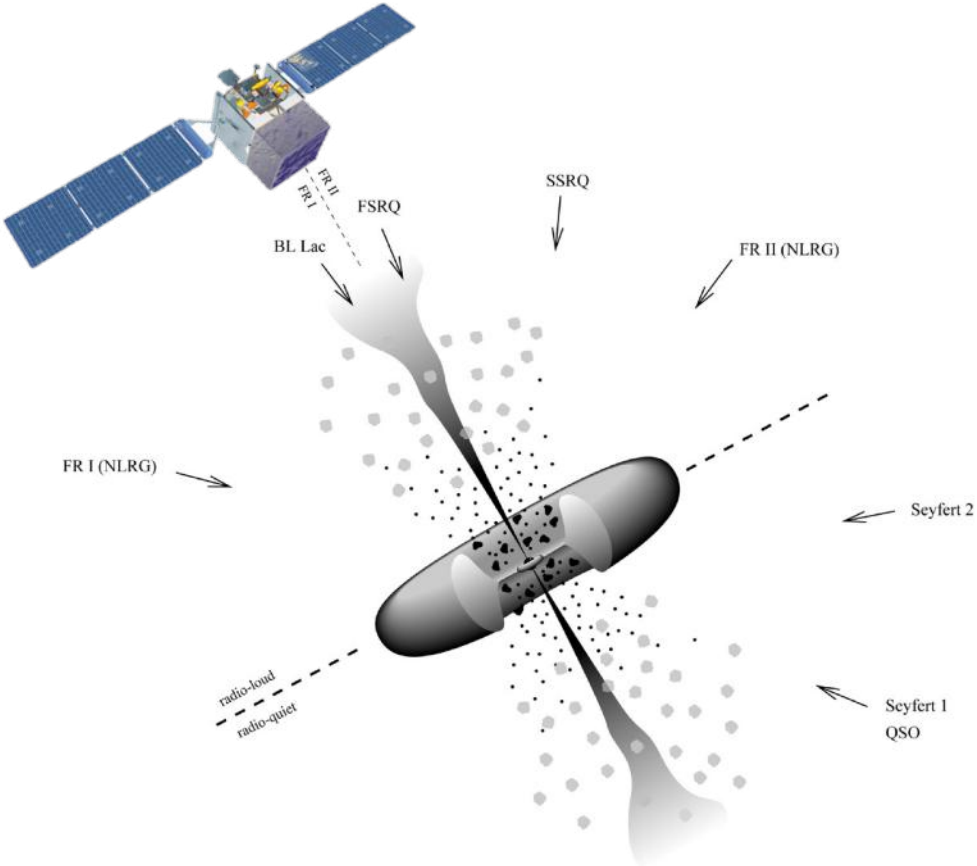
3 sigma significance including trials
> 6 PeV protons accelerated in the source

Do gamma-ray blazars produce all diffuse neutrinos?

Fermi Blazars

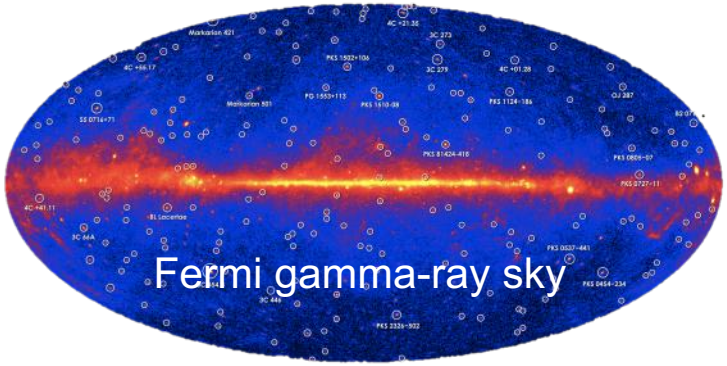
Gamma rays tell us **where** to look for neutrinos

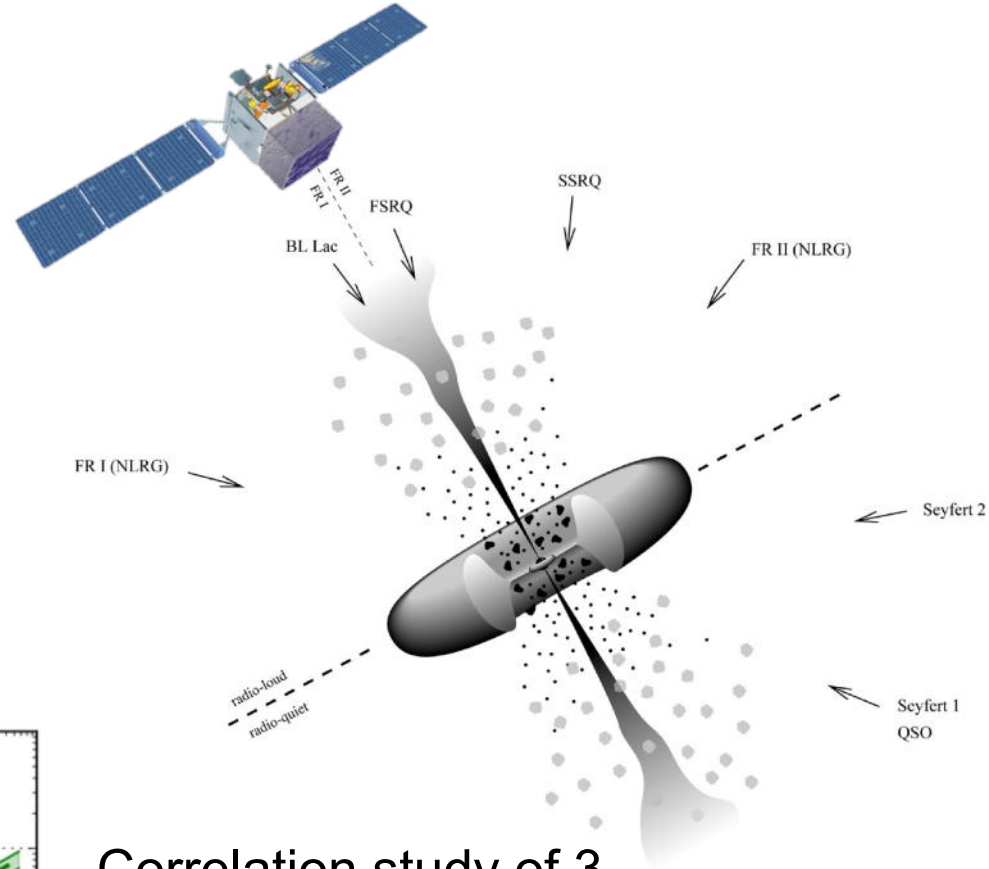


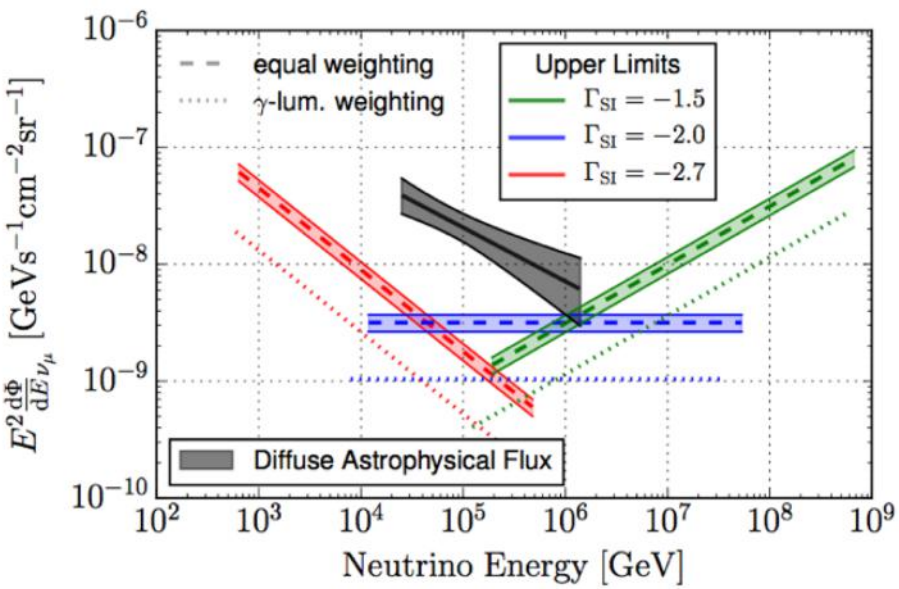


Fermi Blazars

Gamma rays tell us **where** to look for neutrinos







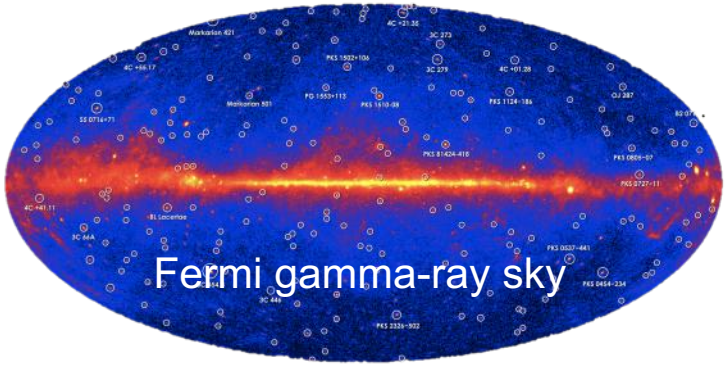
Correlation study of 3 years of IceCube data and 862 ***Fermi*-LAT blazars**

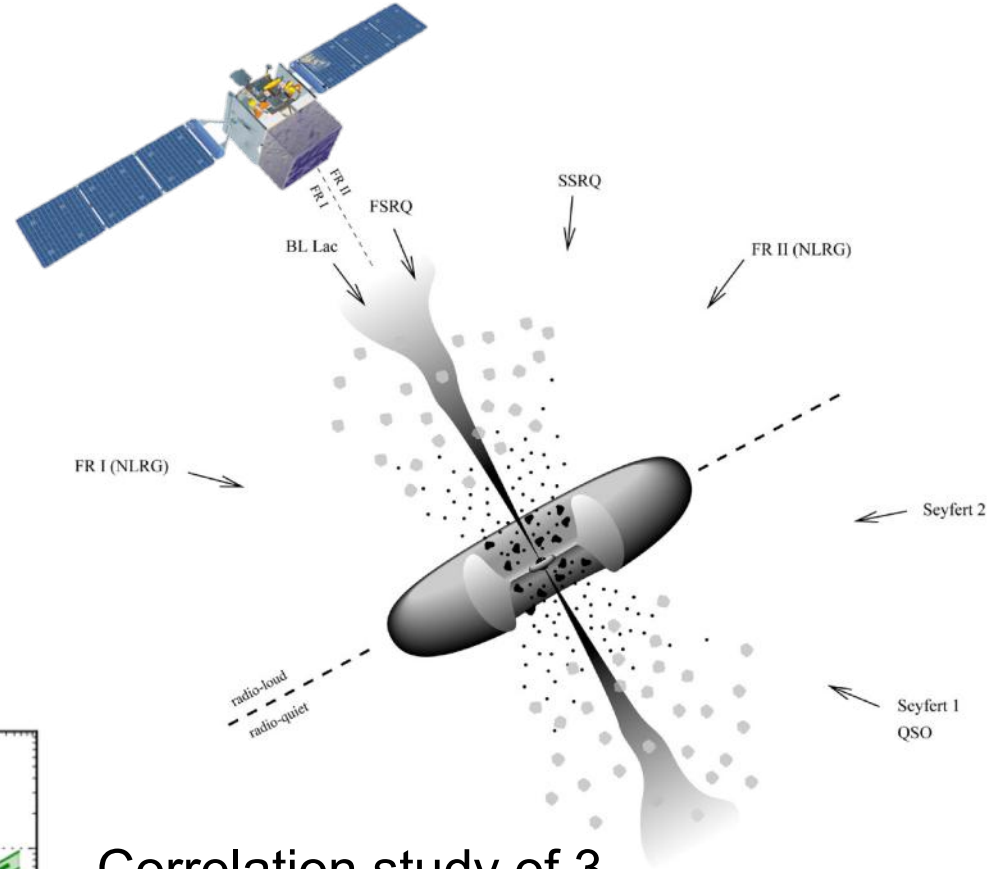
***Fermi*-LAT blazars** can only be responsible for a **small fraction** of the observed ν's.

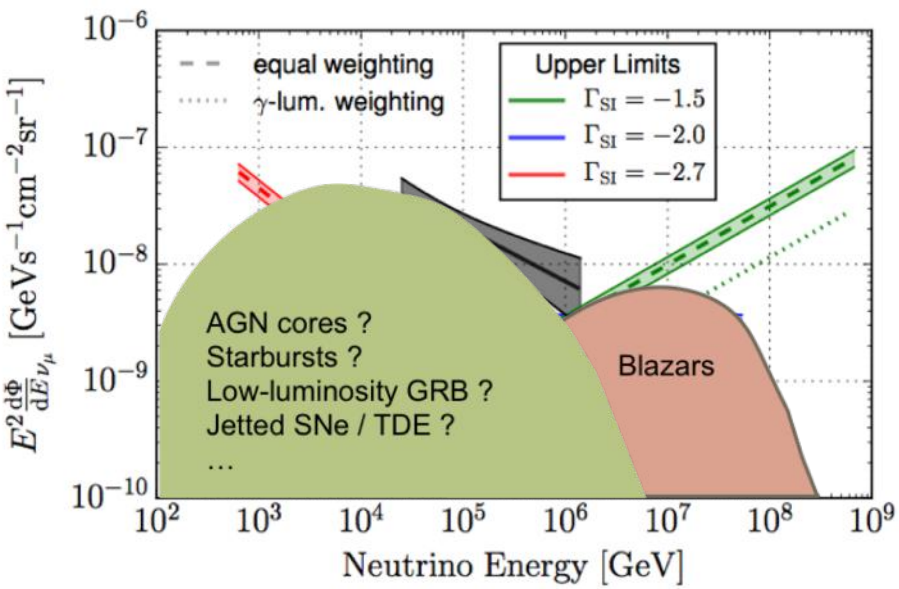
IceCube Coll. ApJ 835 (2017)

Fermi Blazars

Gamma rays tell us **where** to look for neutrinos







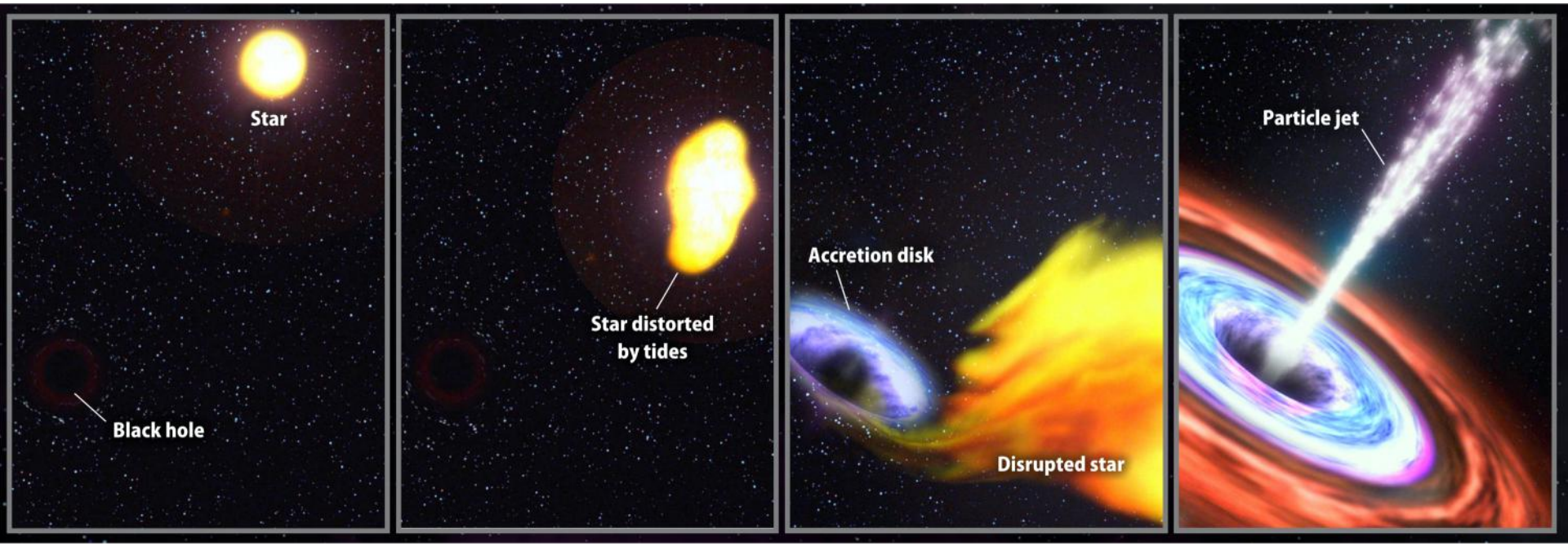
Correlation study of 3 years of IceCube data and 862 ***Fermi*-LAT blazars**

Multiple Populations?

IceCube Coll. ApJ 835 (2017)

Other possible sources?

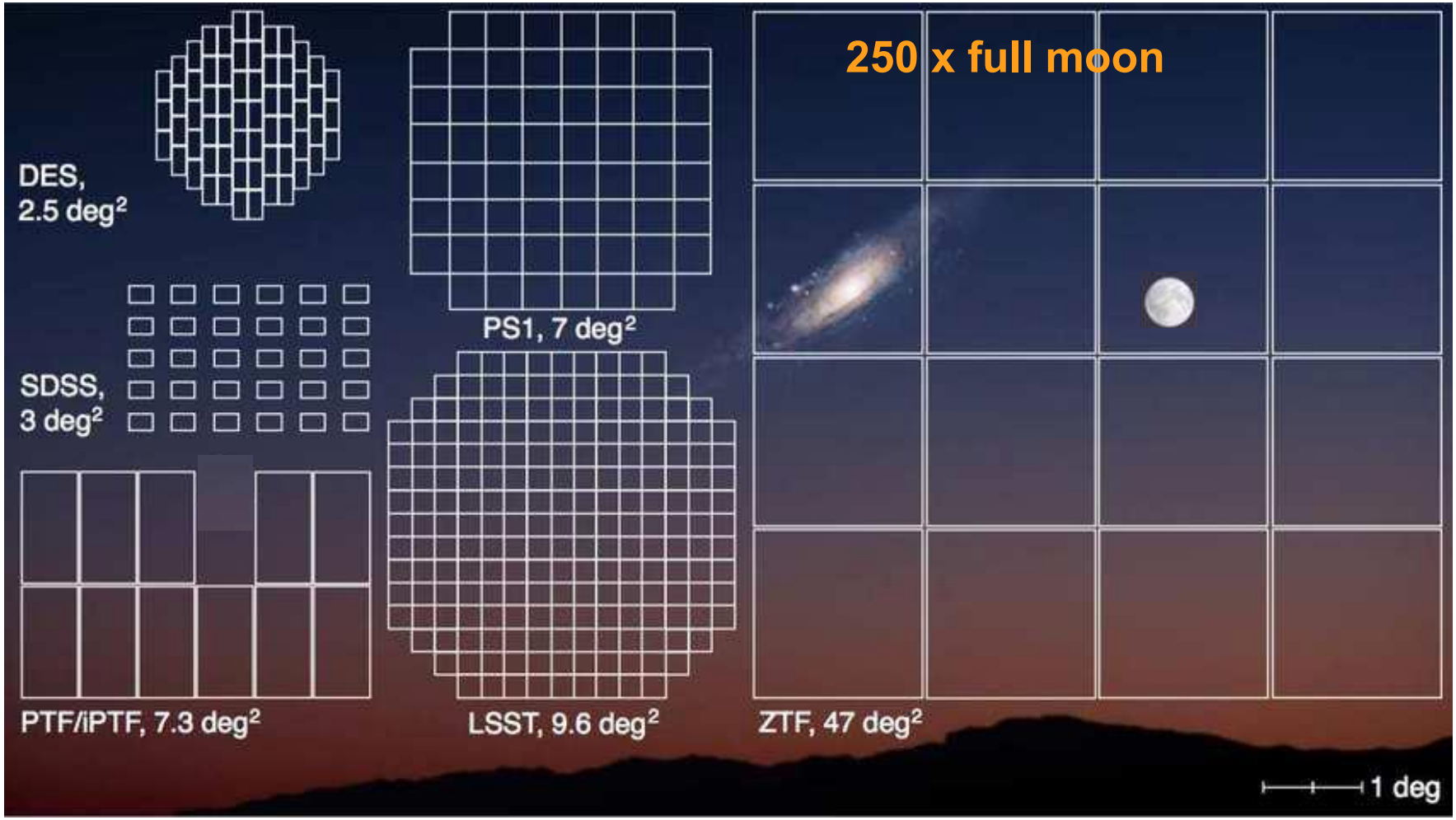
Tidal Disruption Events



~50 TDEs identified, 3 jetted TDEs

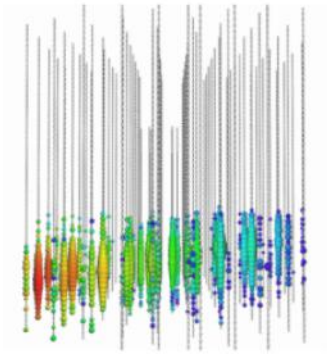
The Zwicky Transient Facility (ZTF)

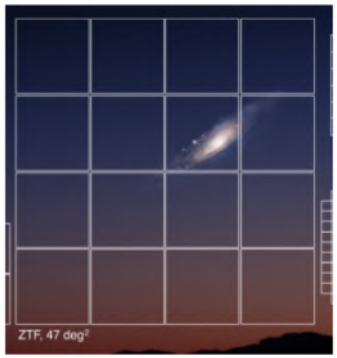
The Zwicky Transient Facility (ZTF) – giant field of view



ZTF Follow-up Pipeline

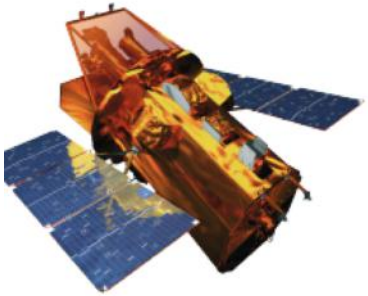
Reject stars, planets, artifacts, asteroids





1. high-energy neutrino alert arrives
2. Observe with ZTF
3. Follow-up with AMPEL

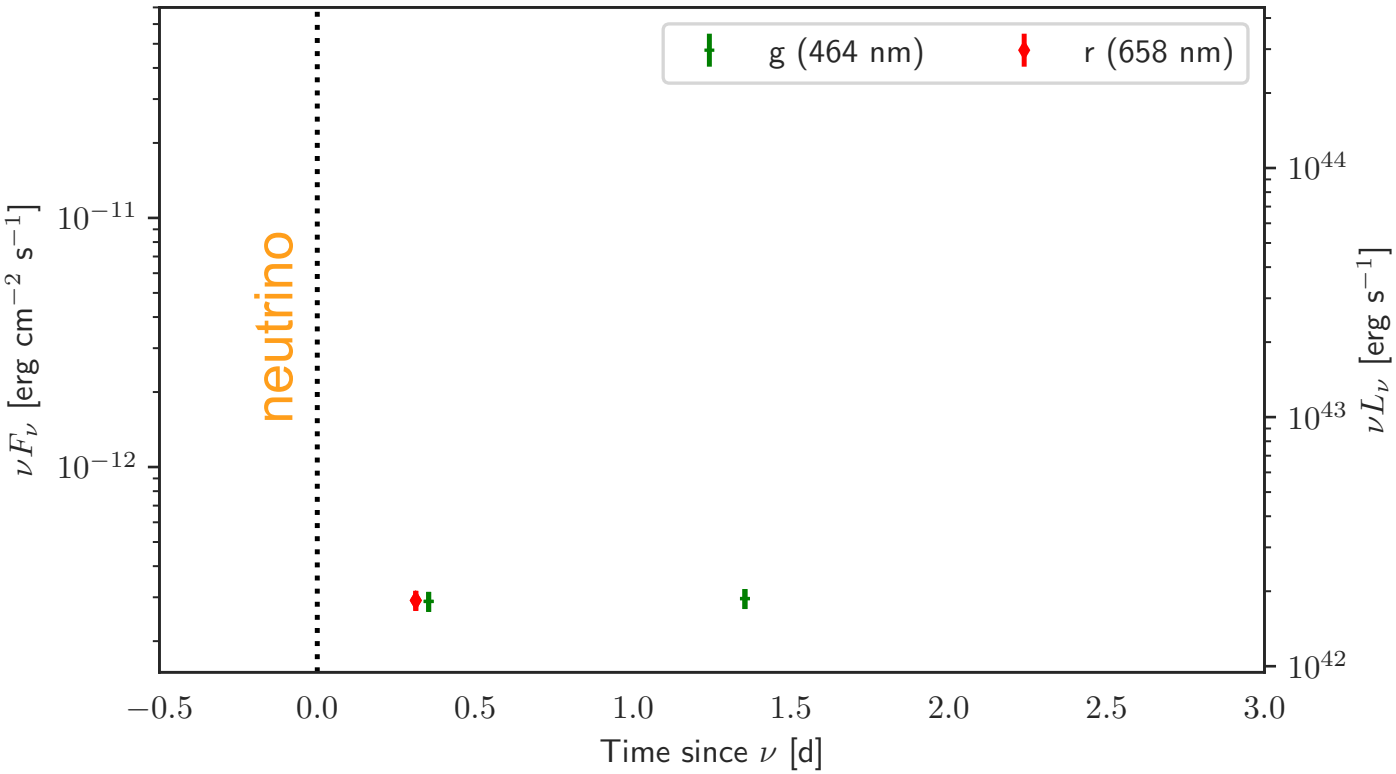
Nordin et al., A&A 631, A147 (2019)

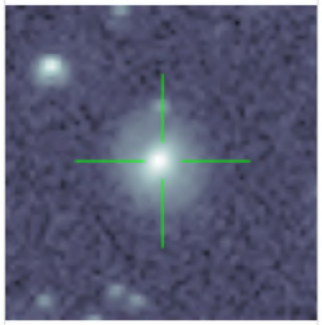


Reject unrelated transients (e.g. Type Ia Supernovae)

4. Trigger further follow-up observations

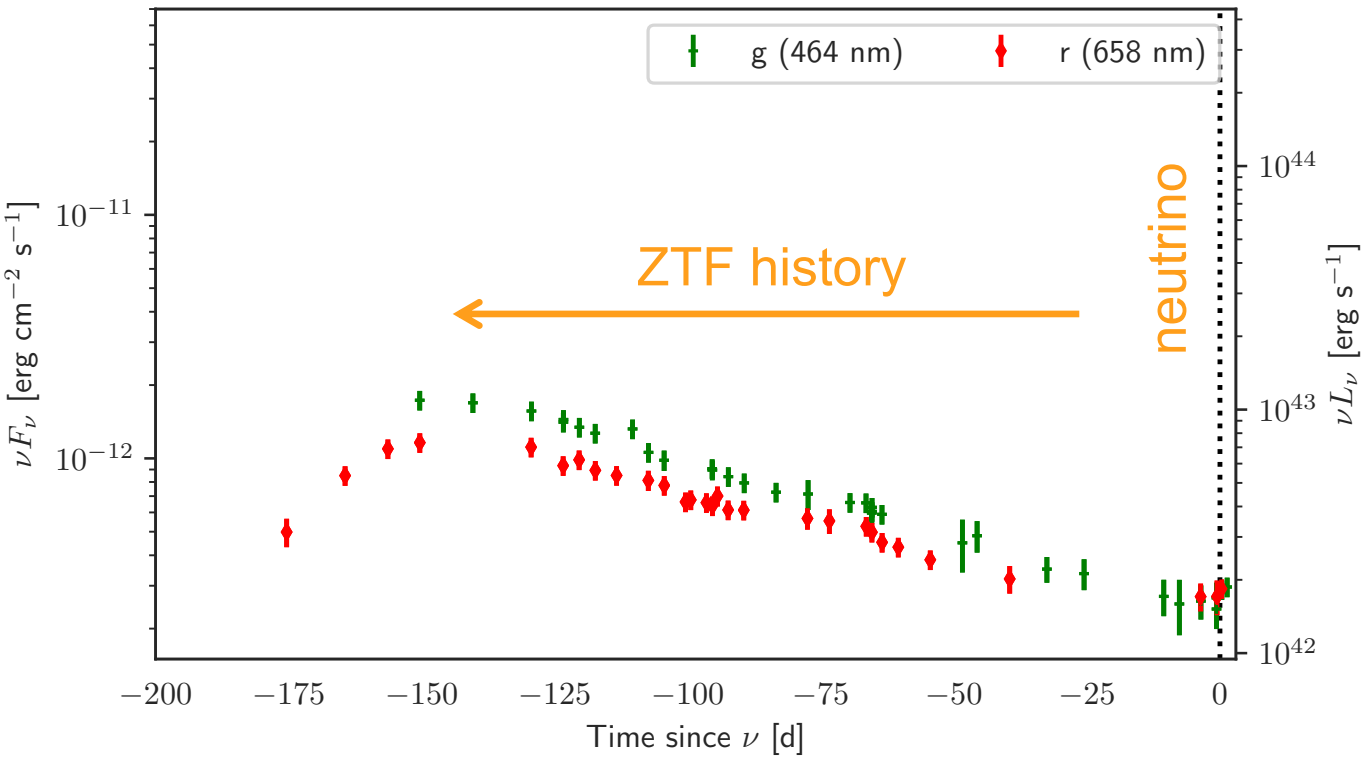
Neutrino IC191001A (200 TeV)

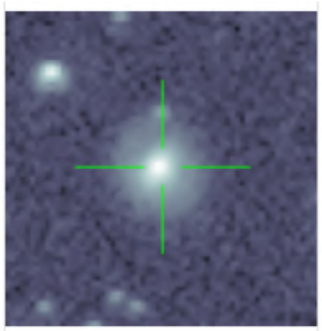




R. Stein et al., Nature Astronomy 2021

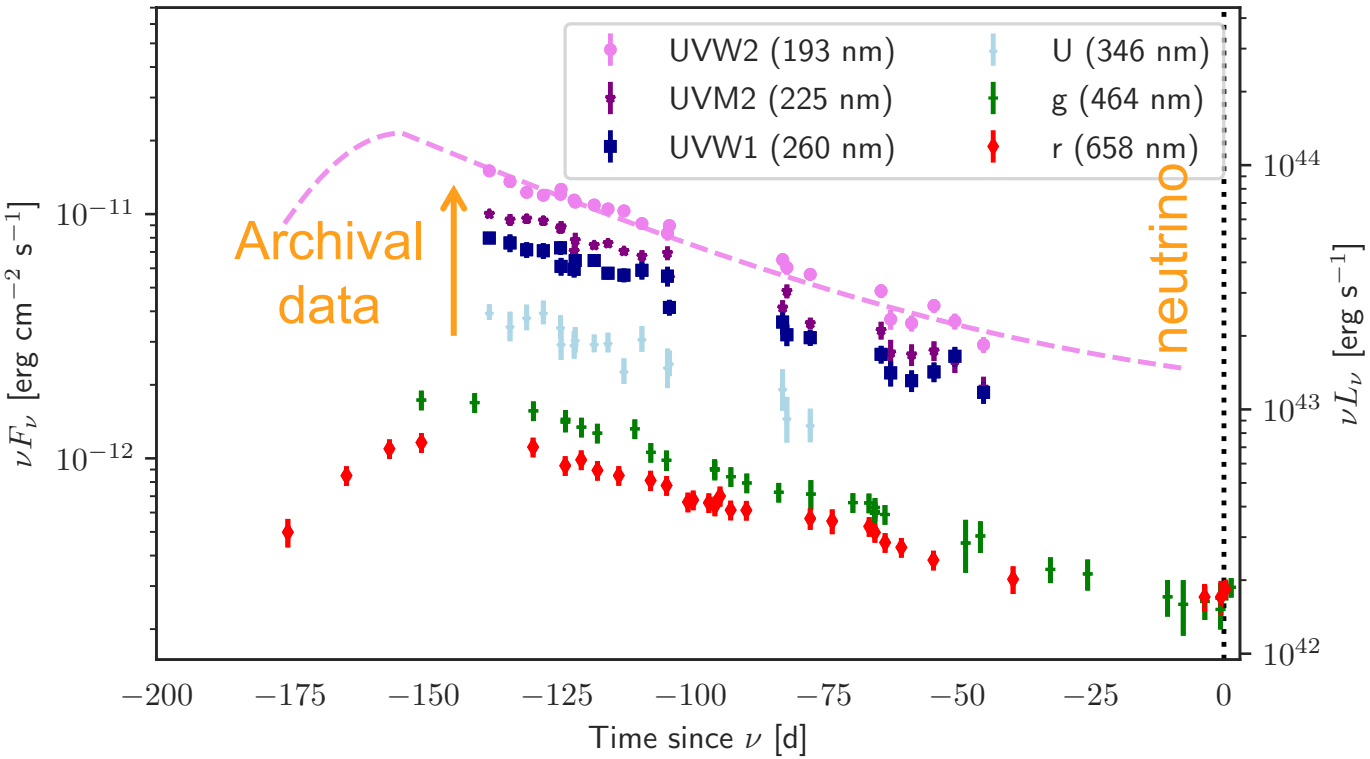
Neutrino IC191001A (200 TeV)

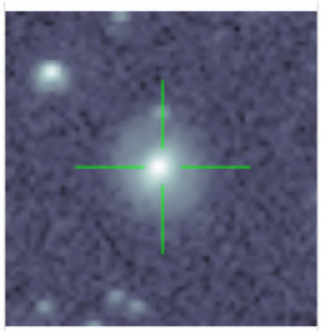




R. Stein et al., Nature Astronomy 2021

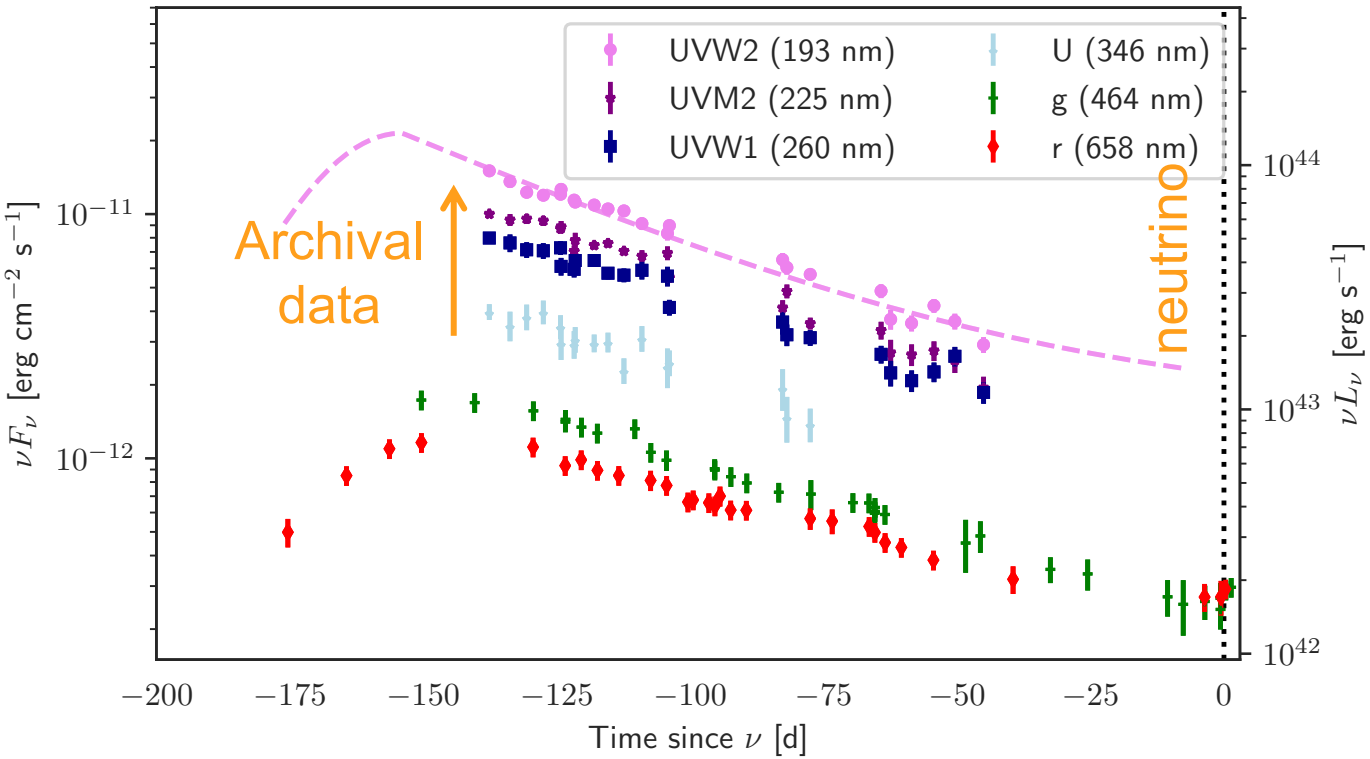
Neutrino IC191001A (200 TeV)

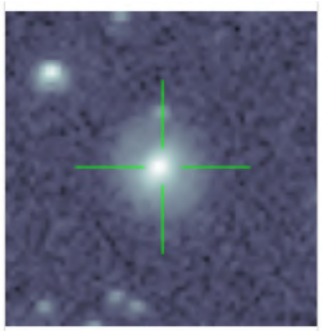




R. Stein et al., Nature Astronomy 2021

Neutrino IC191001A (200 TeV) coincident with Tidal Disruption Event AT2019dsg

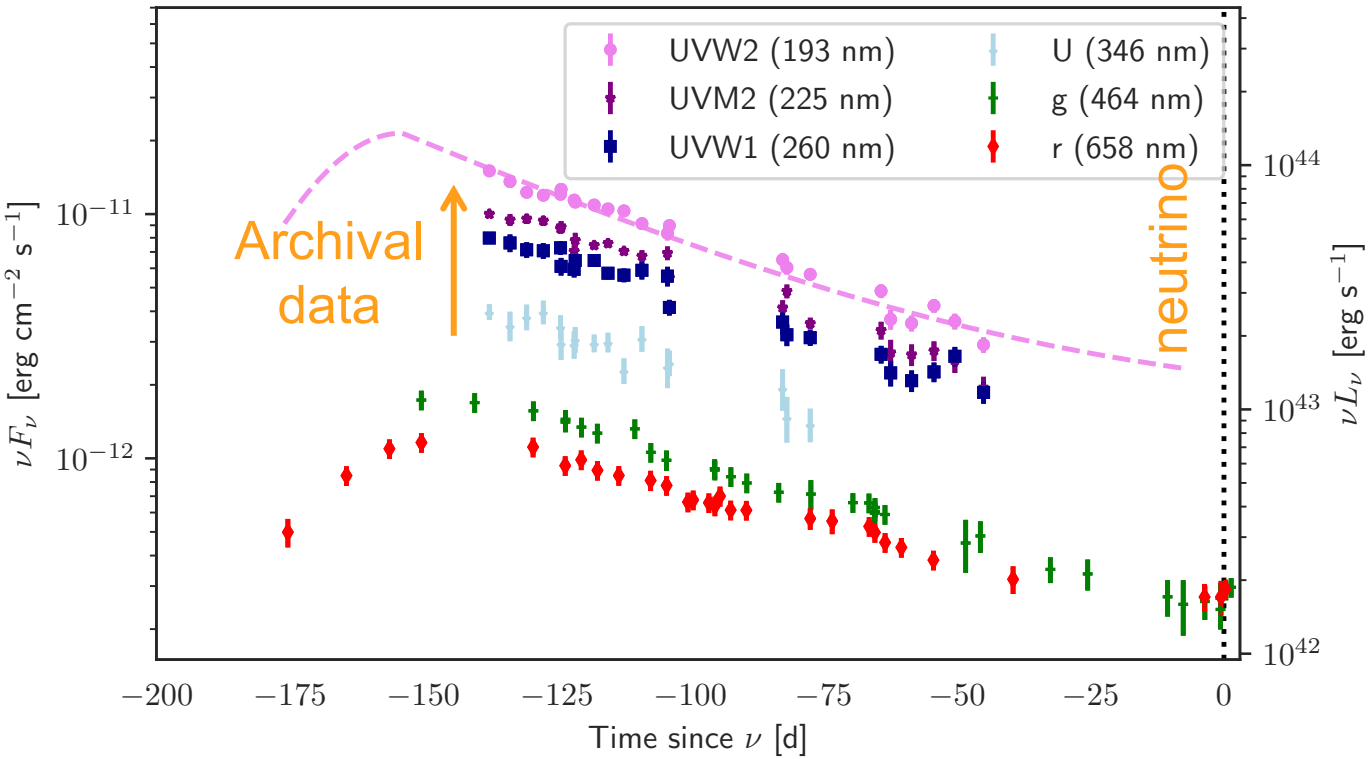


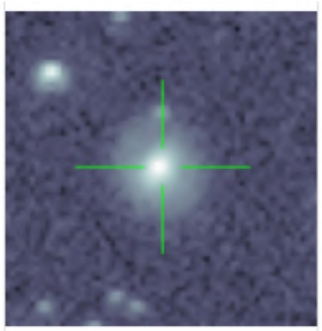


Distance: z = 0.05 (d=230Mpc)

Neutrino IC191001A (200 TeV) coincident with Tidal Disruption Event AT2019dsg

aka as “Bran Stark”



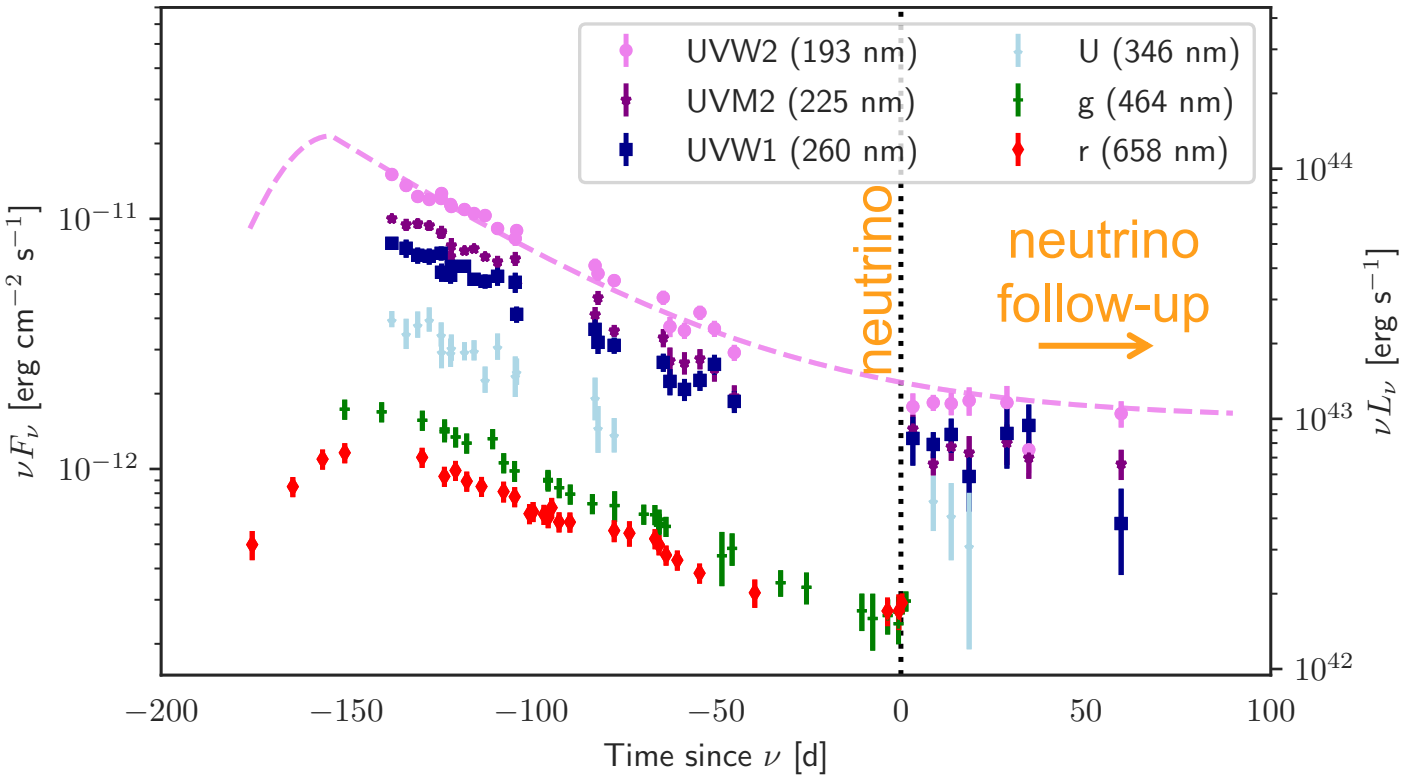


Distance: z = 0.05 (d=230Mpc)

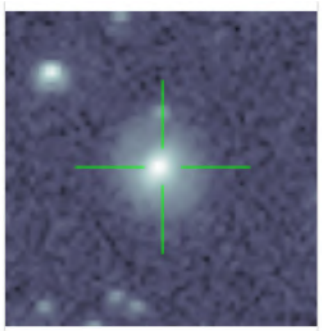
RUB R. Stein et al., Nature Astronomy 2021

Neutrino IC191001A (200 TeV) coincident with Tidal Disruption Event AT2019dsg

aka as “Bran Stark”



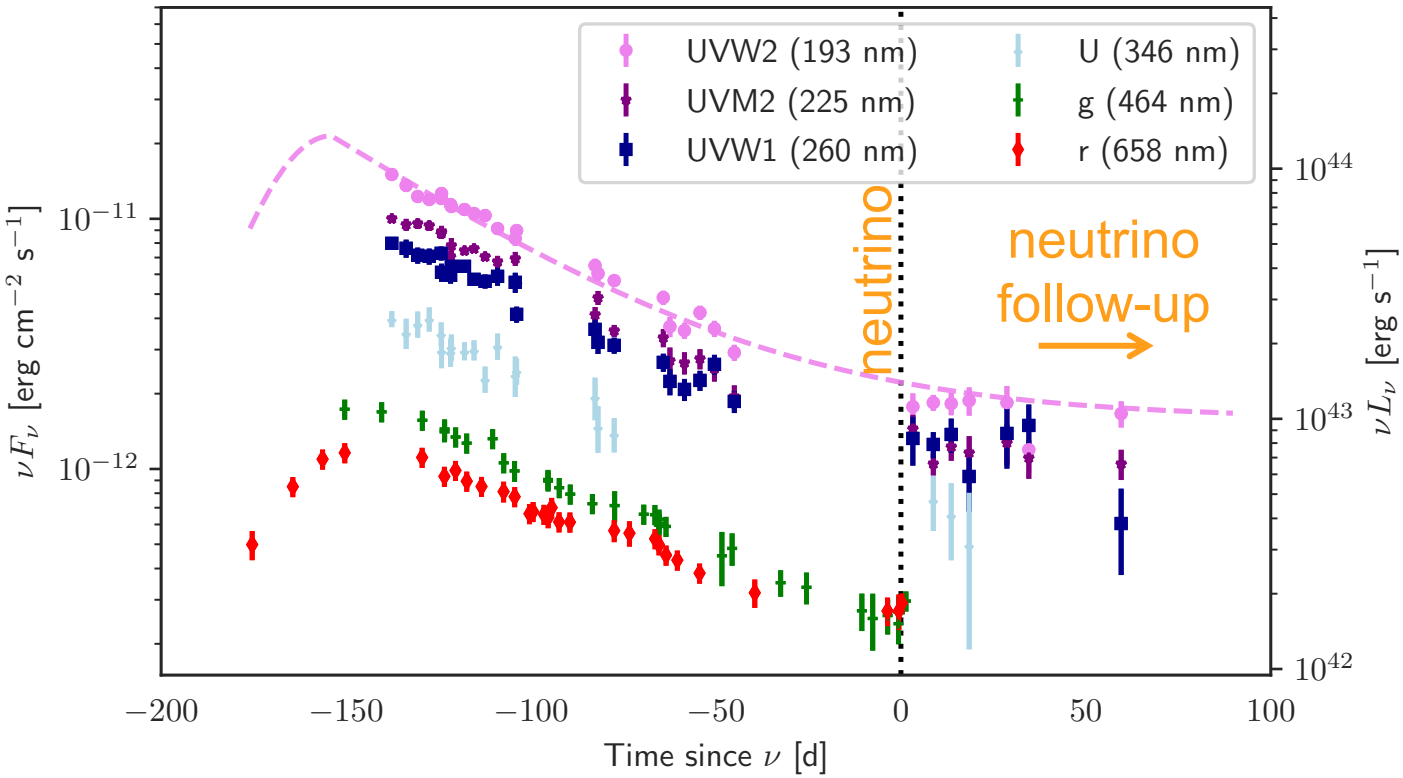
Distance: z = 0.05 (d=230Mpc)

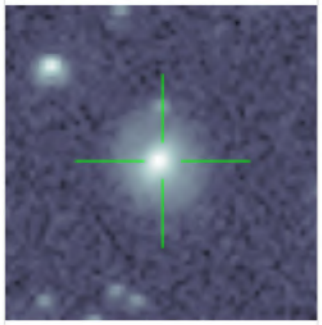


R. Stein et al., Nature Astronomy 2021

Neutrino IC191001A (200 TeV) coincident with Tidal Disruption Event AT2019dsg

aka as “Bran Stark”



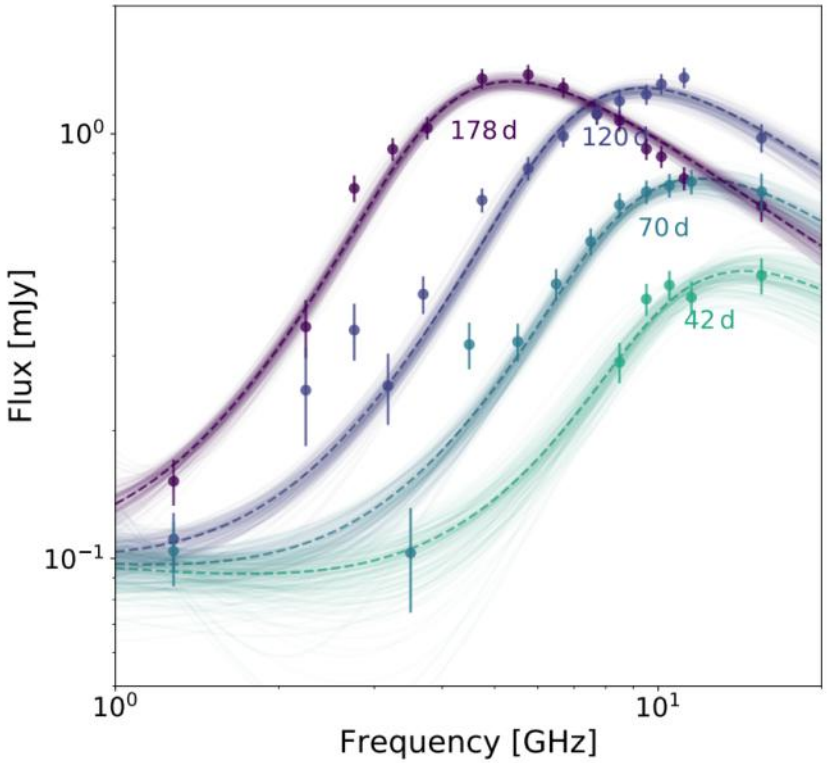


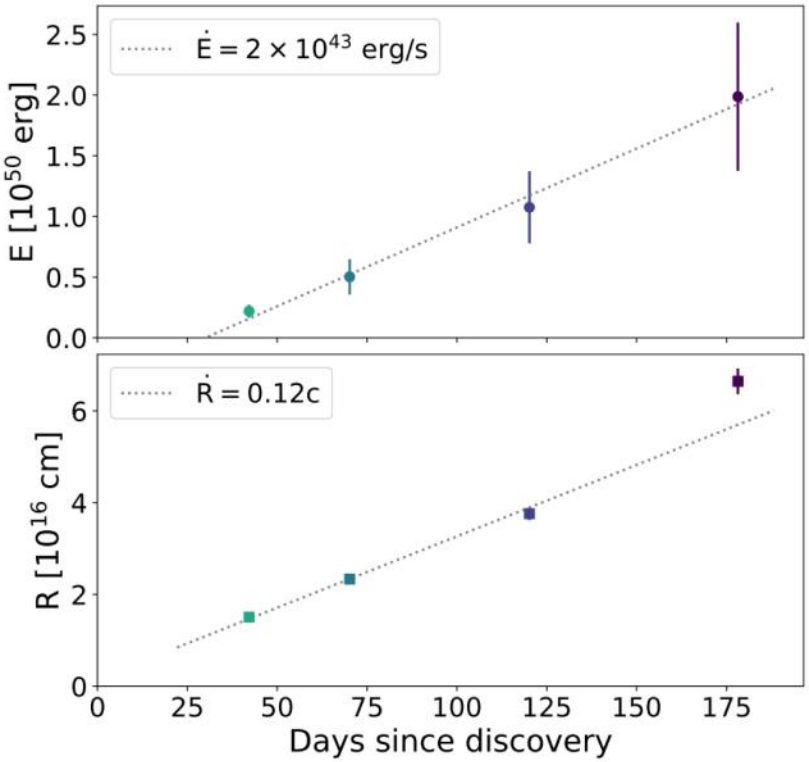
Distance: z = 0.05 (d=230Mpc)

Chance coincidence: 0.2% to find a TDE that bright (including trials)

R. Stein et al., Nature Astronomy 2021

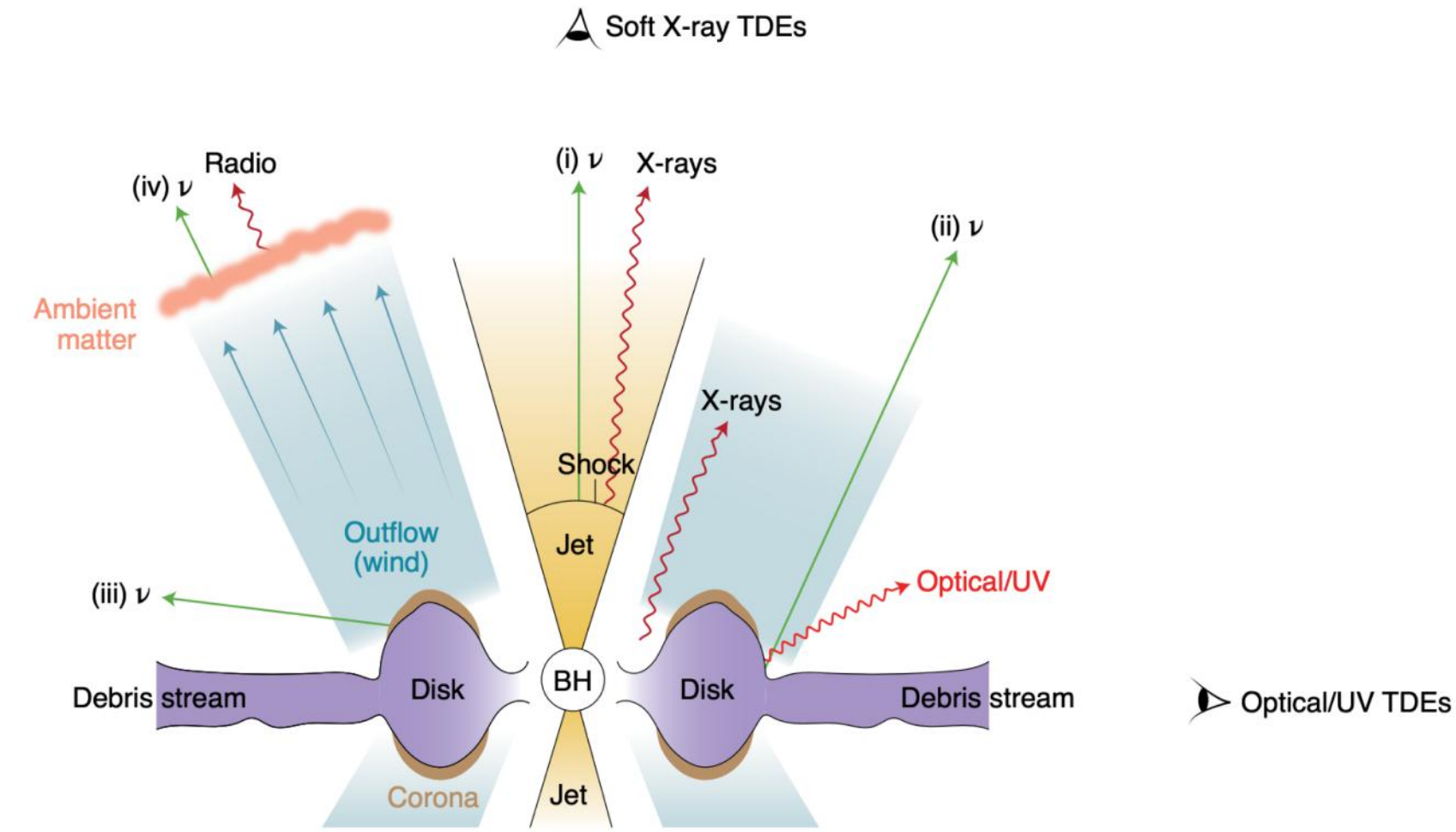
Radio Data reveal long-lasting activity of central engine





R. Stein et al., Nature Astronomy 2021

Various Neutrino Production Scenarios

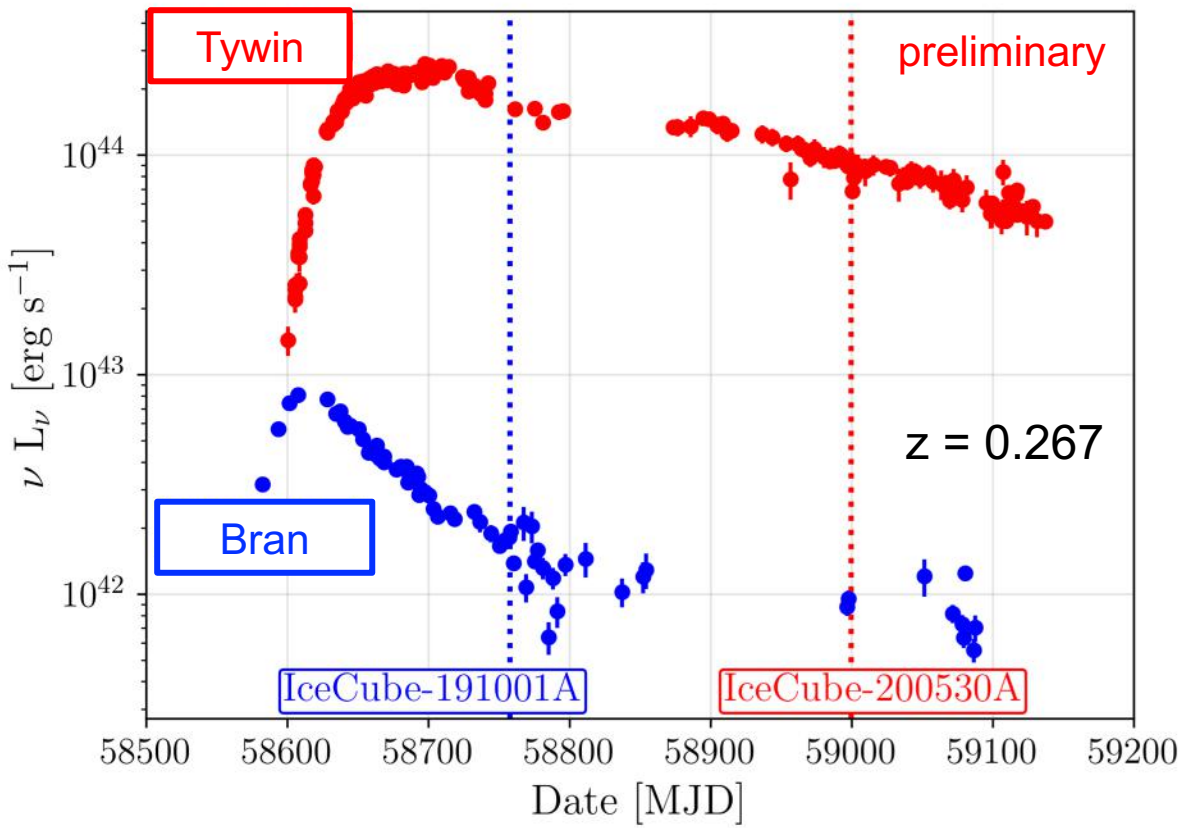


Hayasaki, Nature Astronomy 2021

Second interesting source! AT2019fdr / “Tywin” coincident with IC200530A

Extreme flare in a narrow-line Seyfert 1 galaxy, classified as likely TDE

Optical lightcurve of Tywin compared to Bran Stark



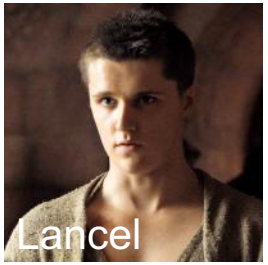
$$p = 3.44 \times 10^{-4}\ (3.4\,\sigma)$$

Are TDEs emerging as new source class?

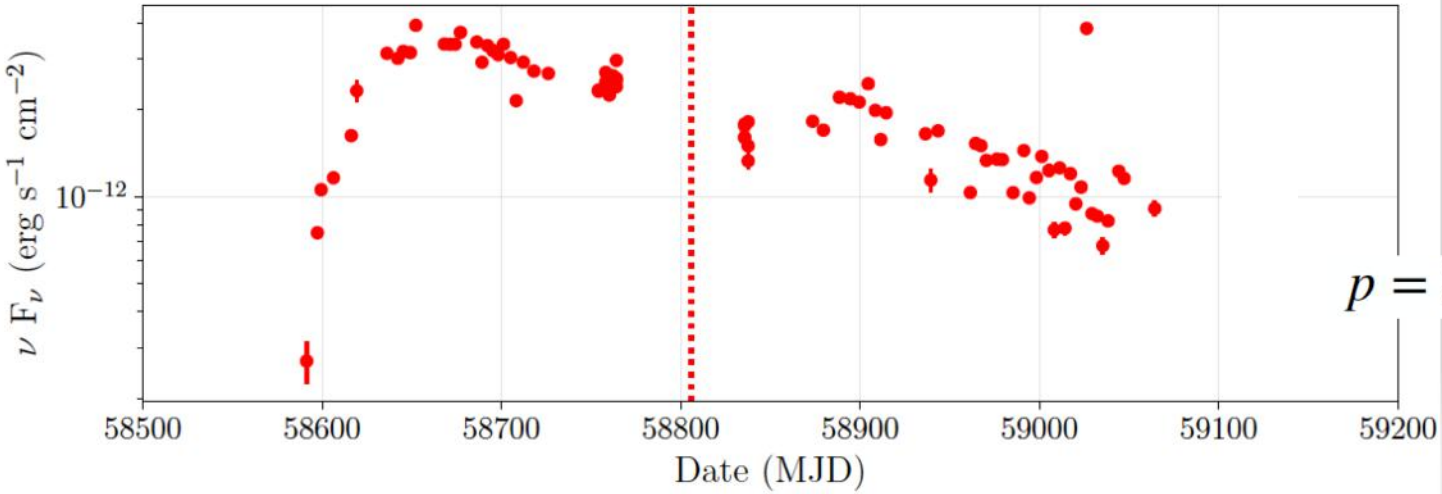
S. Reusch et al. arXiv:2111.09390

Extend search to sample of accretion flares with strong dust echos

Systematic search for coincidence between IceCube public alerts and optical flares that show post-peak neoWISE infrared flares



→ Third coincidence: **AT2019aalc (Lancel)**



$p = 2 \times 10^{-4}$ $(3.7\,\sigma)$

Unified population of accretion flares as new neutrino source class?

S. Van Velzen et al. arXiv:2111.09391

Efficient Acceleration at Eddington Limit?

- These three associated events could produce a significant part of the IceCube high-energy neutrino flux:

  $19^{+22}_{-12}\%$ (90%CL)
- **But:** “Normal” AGN outshine TDEs by two orders of magnitude – why are we not dominated by those?!
- All sources are close to the Eddington limit

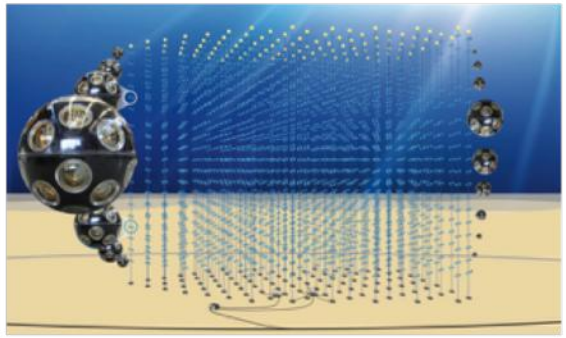
→ **Very efficient neutrino production in TDEs?**

S. Van Velzen et al. arXiv:2111.09391

Next Generation Neutrino Telescopes

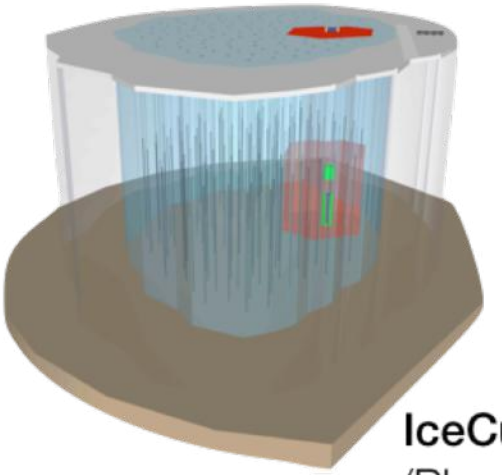
Today's neutrino telescopes

Neutrino sources on the southern sky



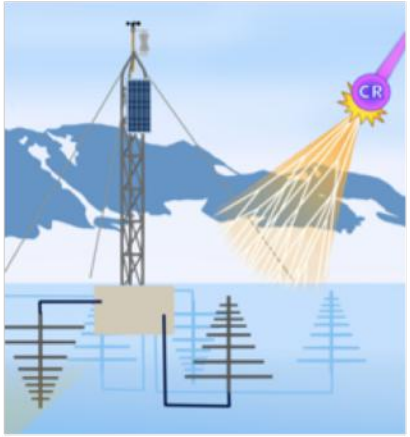
KM3NeT / Baikal-GVD
(construction started)

5x better sensitivity in the TeV-PeV energy range



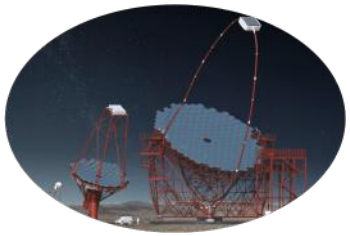
IceCube-Gen2
(Phase 1 started)

Neutrinos bei EeV Energien



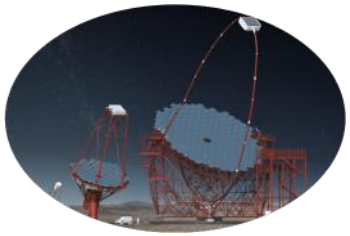
ARA/ARIANNA, RNO, Gen2-Radio
(proposals in)

Summary



unique messengers from the high-energy Universe

Summary



Neutrinos can reveal the sources of high-energy cosmic rays

Summary

Sources still unknown → Electro-magnetic counterparts are crucial to identify the sources.
First compelling candidates found!