

Overview of multi-messenger astronomy

*Mapping Highly Energetic Messengers
throughout the Universe*

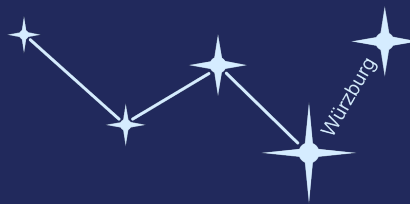
Group Highlights since Past Year

Leonard Pfeiffer

on behalf of Prof. S. Buson, MessMapp Group and Collaborators

Chair for Astronomy, JMU Würzburg · DESY, Zeuthen

FRANCI 2026 · 20 July 2026 · Würzburg



The Group & Collaborators

Website: messmapp.github.io · PI: Prof. Sara Buson

Focus

Multi-messenger & time-domain astrophysics
High-energy gamma-ray transients and variable sources
The physical processes in AGN
The origin of astrophysical neutrinos.

Based at

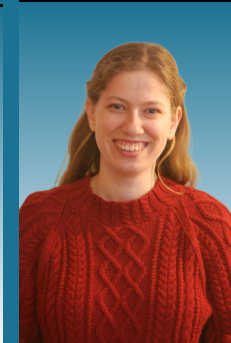
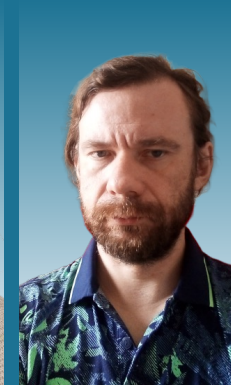
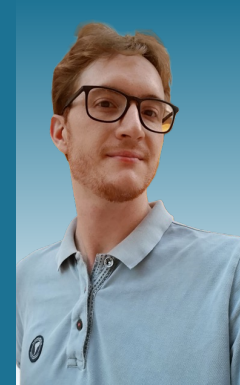
Chair for Astronomy, Julius-Maximilians-Universität Würzburg
& DESY, Zeuthen

Active collaborations

Fermi-LAT · KM3NeT · COSI

Multiwavelength observations of AGN combined with state-of-the-art theoretical modelling and multimessenger facility data.

The Group (2025/2026)



KM3NeT: the UHE Neutrino KM3-230213A

A discovery paper and the companion paper we lead



Nature 638, 376–382 (2025)

Observation of an Ultra-High-Energy Cosmic Neutrino with KM3NeT

A ~ 220 PeV neutrino event, KM3-230213A, the most energetic neutrino ever observed, detected by the ARCA detector in Feb. 2023.

KM3NeT Collaboration

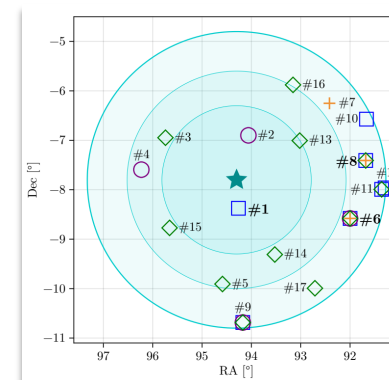
doi.org/10.1038/s41586-024-08543-1



★ Co-LED BY OUR GROUP (Lincetto, Pfeiffer, Plavin et al.) · accepted for publication

Characterising Candidate Blazar Counterparts of the Ultra-High-Energy Event KM3-230213A

- 17 candidate blazars in the 3° localisation region identified & followed up
- Full multiwavelength coverage: radio, optical, X-ray, gamma-ray
- One radio flare coincident with the neutrino arrival
- Rising X-ray flux & a gamma-ray flare found in two other candidates



KM3NeT, MessMapp Group, Fermi-LAT, OVRO 40-m, SVOM

arXiv:2502.08484

SED Modelling of a Candidate Counterpart

Zooming into the closest blazar candidate to KM3-230213A



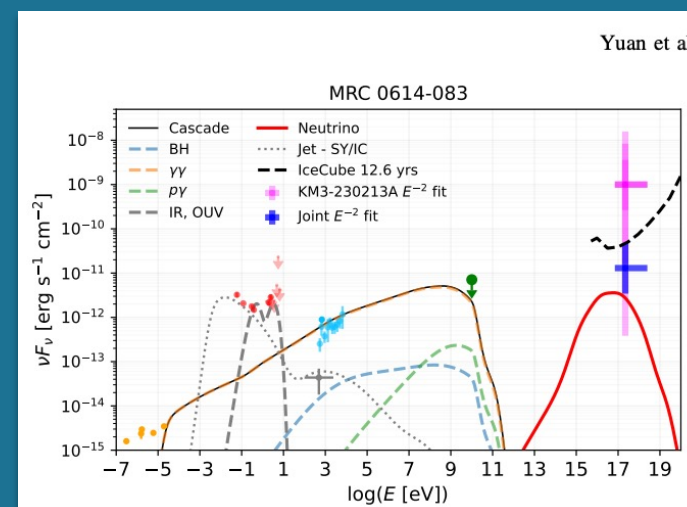
ApJL 998, L1 (2026)

An Accretion Flare Interpretation for the Ultra-High-Energy Neutrino Event KM3-230213A

SED modelling of MRC 0614-083 (the blazar candidate closest to the neutrino localisation and exhibiting variable multiwavelength emission) testing an accretion-flare origin for the event.

Yuan, Pfeiffer, Winter, Sanchez Zaballa, Buson, Testagrossa, Azzollini

iopscience.iop.org/article/10.3847/2041-8213/ae3a73



The model self consistently reproduces the SED shape and the optical-IR-X-ray flux enhancement found in the light curve and predicts a ~ 100 PeV neutrino flux consistent with the KM3Net/IceCube E^{-2} joint fit. Main open issue: Redshift

Modelling neutrino candidate blazars

What's next from the group



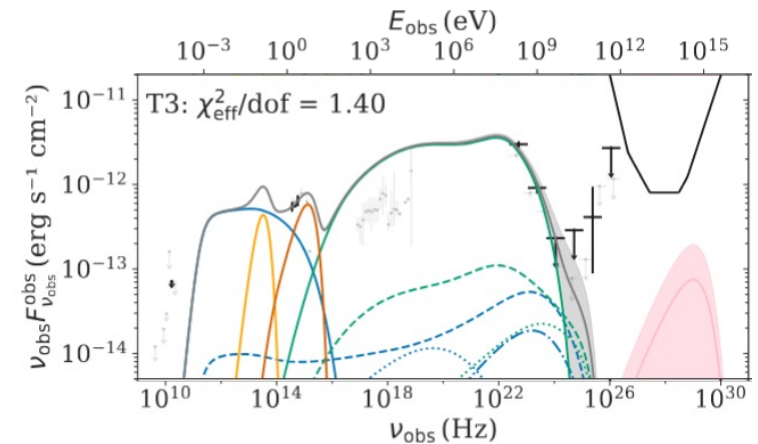
PAPER SUBMITTED

A lepto-hadronic perspective on the properties of the candidate neutrino-emitter blazar 5BZQ J0808+4950

Building on the group's lepto-hadronic modelling framework to identify and characterise sources who are spatially consistent with candidates identified in S. Buson et al 2022&2023. **Led by M. Boughelilba**

Time-dependent lepto-hadronic modelling of a blazar spatially associated with an IceCube neutrino excess and an individual high-energy event (IC110929A).

We show the source's states are driven mainly by changes in particle injection, that predicted X-ray emission correlates more strongly with neutrino output than gamma-rays do, and that the predicted neutrino rate is consistent with the single detected event.



A Single Source Class for the Diffuse Flux?

Theory work with Walter Winter, Damiano F. G. Fiorillo and Sara Buson



Single-source-class interpretation of the diffuse astrophysical neutrino flux

Winter, Fiorillo & Buson · *Phys. Rev. D* 113, 123043 (2026) · [arXiv:2603.15754](#)

Tests whether the diffuse astrophysical neutrino flux can be explained by a single, standard-candle-like source class, using a py interaction channel to naturally reproduce the observed spectral break near 30 TeV.

py channel

dominant neutrino production process

~ 30 TeV break

naturally reproduced by a thermal target spectrum

80–300 eV

preferred target-photon temperature range

Finding: A four-parameter py model fit to IceCube data yields four statistically degenerate scenarios for the origin of the break but current data can't distinguish between them. Future flavor composition and Glashow-resonance measurements (e.g. IceCube-Gen2) should break the degeneracy.

An analysis tool for public neutrino data

What's next from the group

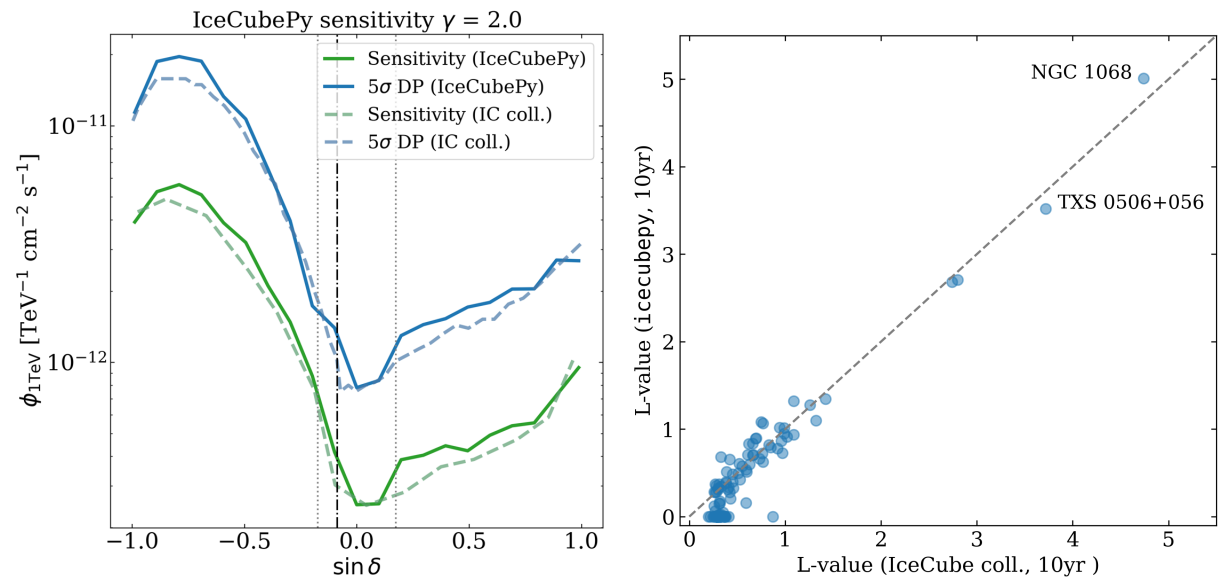


IN PREPARATION

icecube.py: an Open-Source Analysis Framework for IceCube Public Neutrino Data

An open analysis framework that lets the community reproduce IceCube point-source searches on the public 10-year muon-neutrino dataset. **Led by M. Lincetto**

Its sensitivity, discovery potential, and source significances (including the hotspots around NGC 1068 and TXS 0506+056) closely reproduce IceCube's own published results, offering the community a validated, reproducible tool for neutrino astronomy.



ACME: Visits to Centres of Expertise

Building expertise across facilities



APC, Paris

José María Sánchez Zaballa

had the opportunity to discuss **likelihood analysis** codes, the use of GammaPy for **neutrino analysis**, and the use of the instrument response functions of the full **KM3NeT/ARCA230** detector for a benchmark study between different neutrino analysis codes. In addition, I participated in several design sessions for a **pilot study on the X-ray-Neutrino correlation** in AGN. Notably, I successfully carried out the **Integration** of a private **IceCube public data analysis code** (icecubepy) to an online multi-messenger analysis platform (MMODA)

KM3NeT, Marseille

Leonard Pfeiffer

contributed to **KM3NeT**'s real-time multiwavelength follow-up framework by implementing gamma-ray (**Fermi-LAT/FAVA**) and optical (**ZTF, Rubin**) timing modules to help constrain candidate source selection for neutrino alerts; these are already operational, with further components (**TNS search, offline gamma-ray analysis**) under development. This work is expected to feed into upcoming KM3NeT astro-module publications (**GCN neutrino alerts**) and follow-up studies of interesting source associations.

MuMeNTA Workshop

Multi-Messenger and Numerical Techniques in Astrophysics

2023

2024

2025

2026

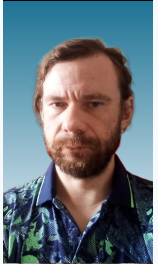
2027



Bringing together the community developing numerical techniques for simulating and analysing multi-messenger (photon / neutrino / cosmic-ray) emission, code comparison, ML applications, and open-source practice. Our group is proud to keep co-organising this now well-established, community-driven meeting. The next one will happen in **Spring 2027!**

A Systematic Catalogue of Fermi-LAT Flares

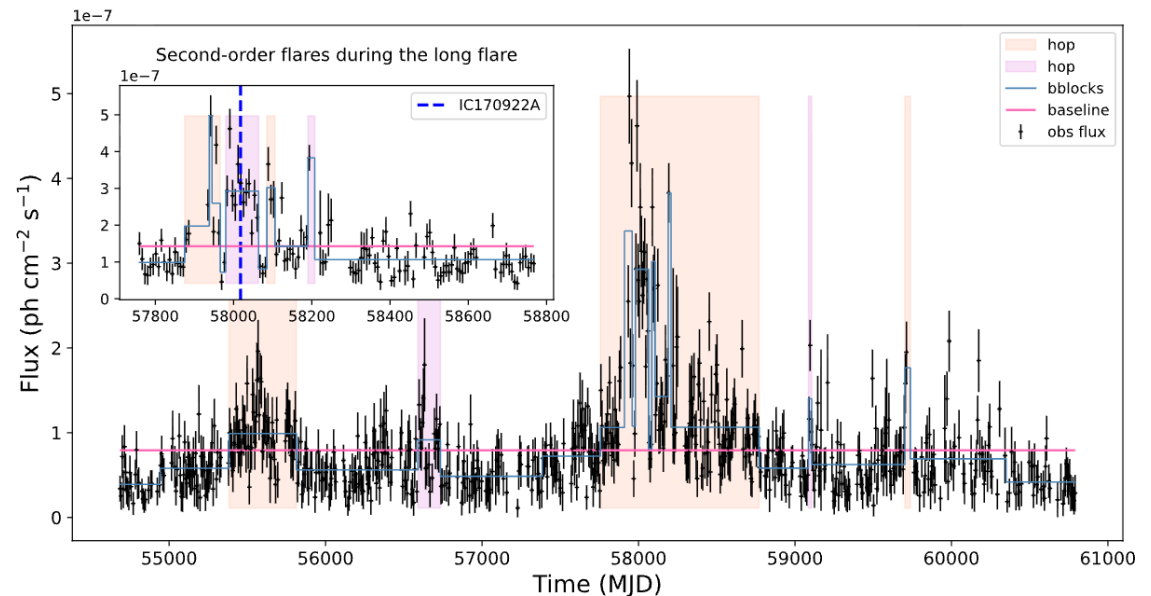
Dmitry Prokhorov (former PostDoc)



SUBMITTED

Signatures of scale-free dynamics in blazar gamma-ray flares

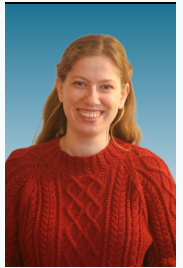
Blazar γ -ray light curves show complex, seemingly random flaring. This paper develops a hierarchical, recursive segmentation method to systematically characterize flares from Fermi-LAT data and test whether their statistics match theoretical expectations. One of the results is that flares emerge as natural, scale-free structures rather than random events.



Outreach:



NETZWERK
TEILCHENWELT



Leading the Würzburg site · teilchenwelt.de

A nationwide outreach network for astro-particle & particle physics, organised by TU Dresden in close collaboration with CERN, DESY, and collaborations like Fermi-LAT and IceCube.

4,000+

students reached per year

150+

supporting scientists

37

universities & facilities

IN WÜRZBURG, EACH YEAR

6–7

school visits

3–4

local events

~300

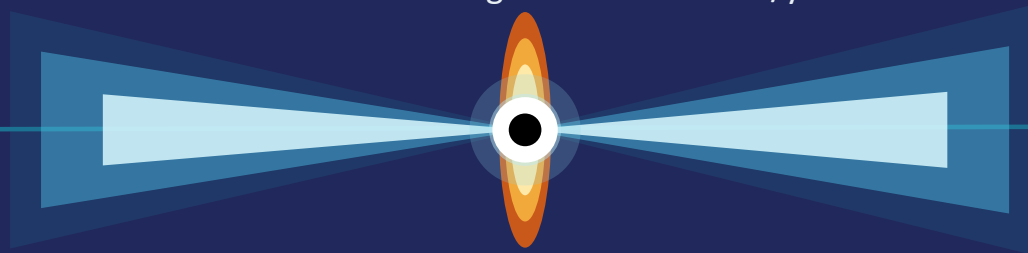
students engaged

One of 37 sites nationwide encouraging students to pursue a career in science.



A busy and productive year

- 3 papers published/accepted on KM3NeT, blazars & the diffuse neutrino flux
- 1 catalogue paper submitted; 3 theory papers, 2 observational papers and 1 framework paper in preparation
- 2 ACME-funded expertise visits (APC Paris & KM3NeT Marseille)
- Co-organising the now-yearly MuMeNTA workshop
- Sara Buson lecturing at the 6th Hel.A.S. Summer School
- Leading outreach for Netzwerk Teilchenwelt in Würzburg for ~300 students/year



Thank you!

messmapp.github.io · sara.buson@uni-wuerzburg.de · leonard.pfeiffer@uni-wuerzburg.de



6th Hel.A.S. Summer School

Sara Buson as invited lecturer

“Multi-messenger Astronomy”

Hellenic Astronomical Society · NKUA, Athens

24–28 August 2026

Training for graduate students and early-career postdocs across gravitational waves, cosmic rays, astrophysical neutrinos, gamma/X-rays, and ML applications.

Confirmed lecturers include Sara Buson (JMU Würzburg / DESY Zeuthen), Matteo Cerruti (APC Paris), Foteini Oikonomou (NTNU) and others.

6th

EDITION

*of a biennial school
for the community*

IN PREPARATION

icecubepy: an Open-Source Analysis Framework for IceCube Public Neutrino Data

