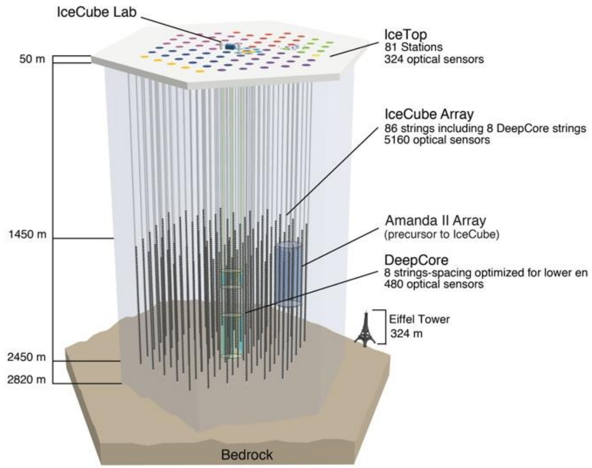
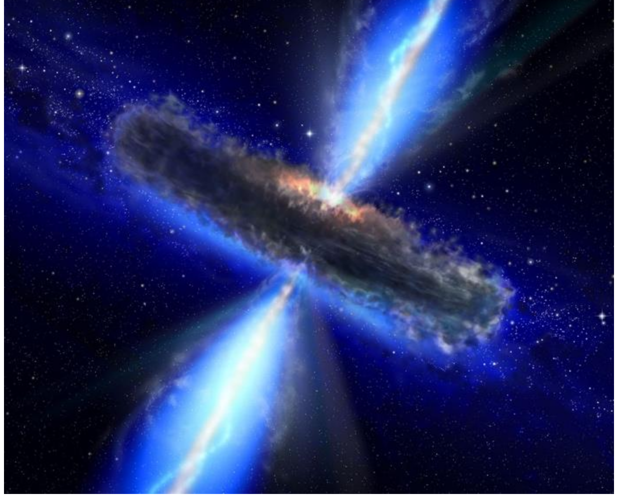
 

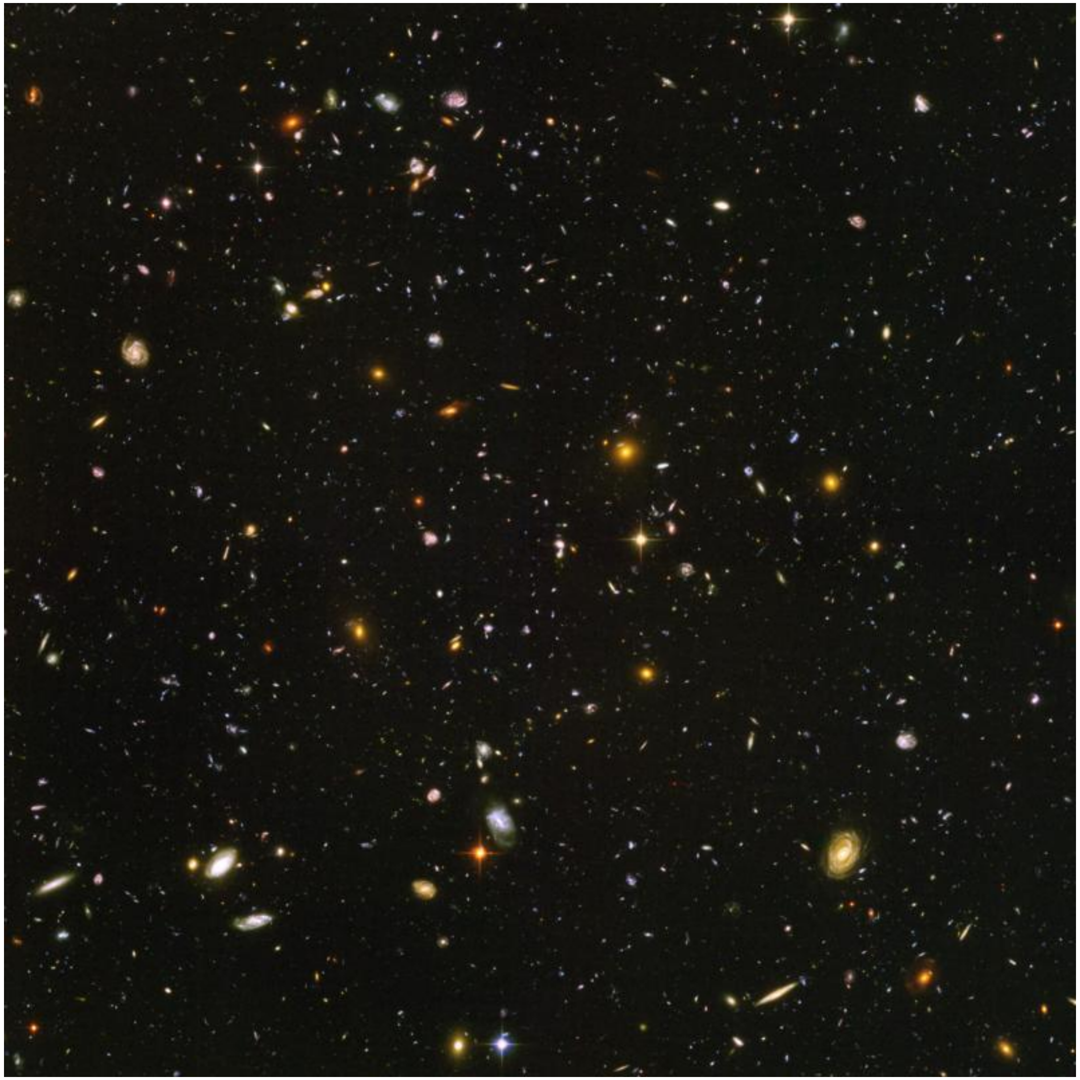


Multi-messenger emission from AGN

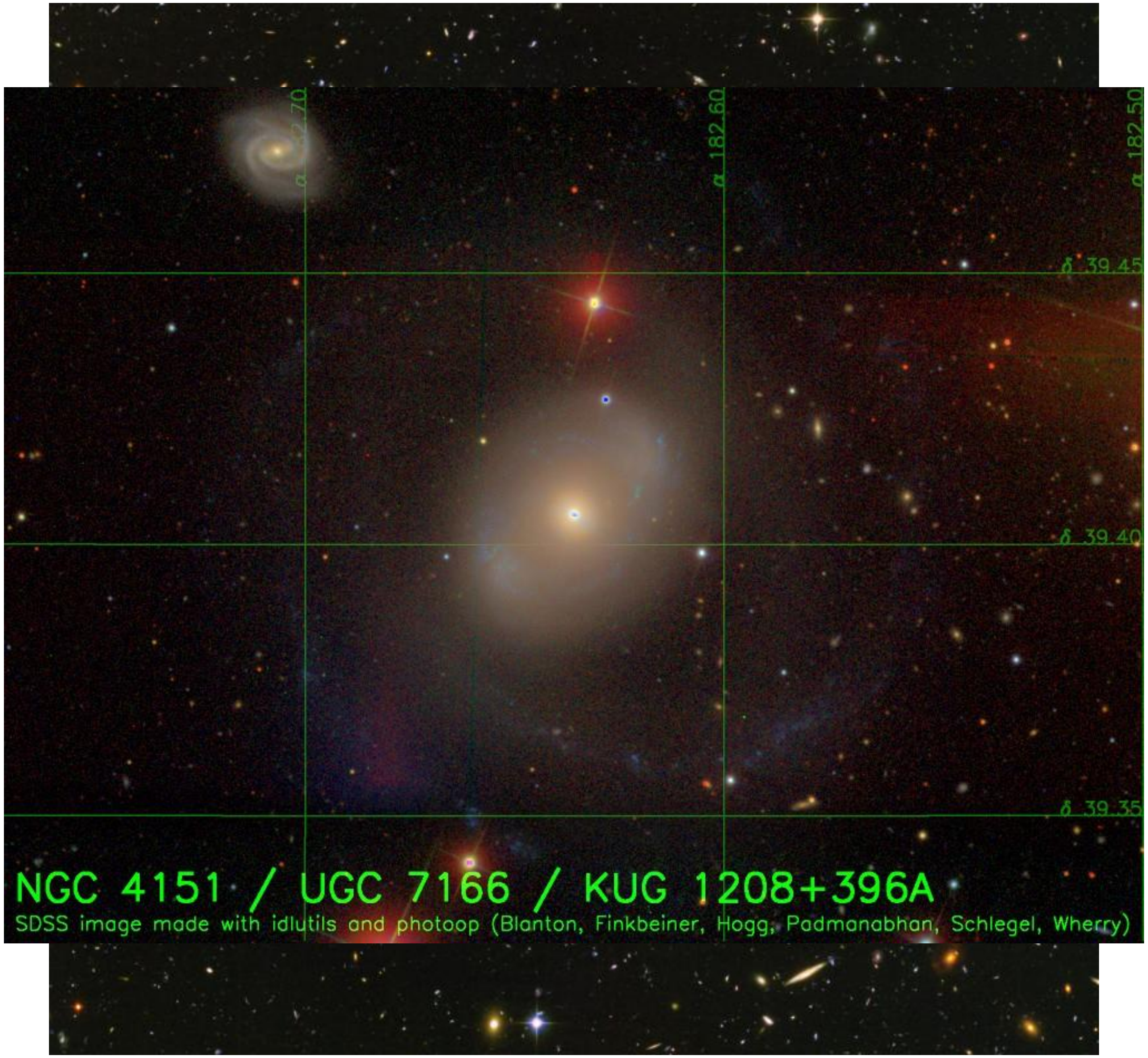
Paolo Padovani, European Southern Observatory, Garching bei München, Germany

- A broad look at AGN
- The TXS 0506+056 blazar – IceCube neutrino *2017* association
- The NGC 1068 Seyfert – IceCube neutrino *2022* association
- Which, if any, AGN are neutrino emitters (and why)?
- Open issues and the near future

What are AGN?

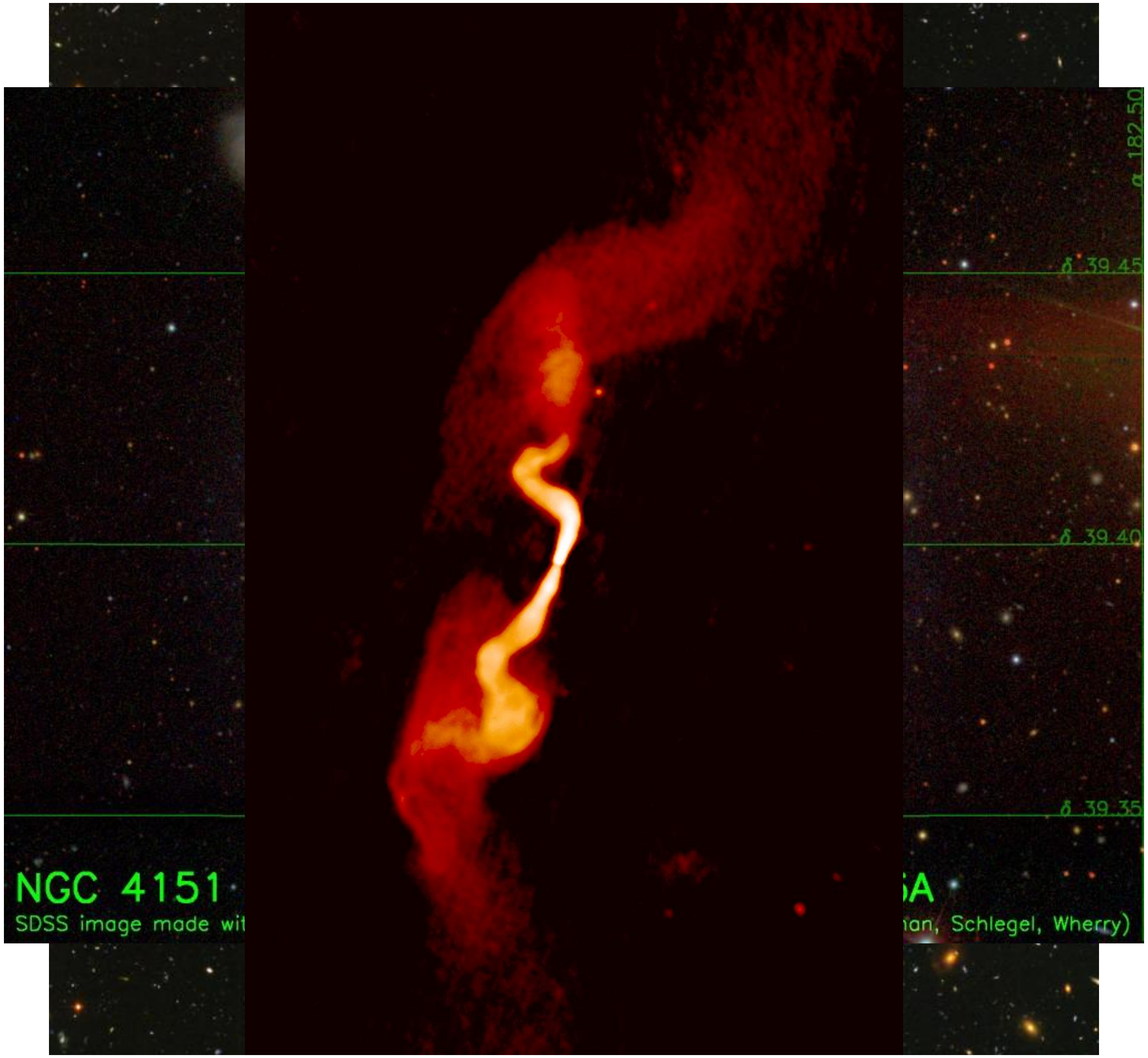


What are AGN?



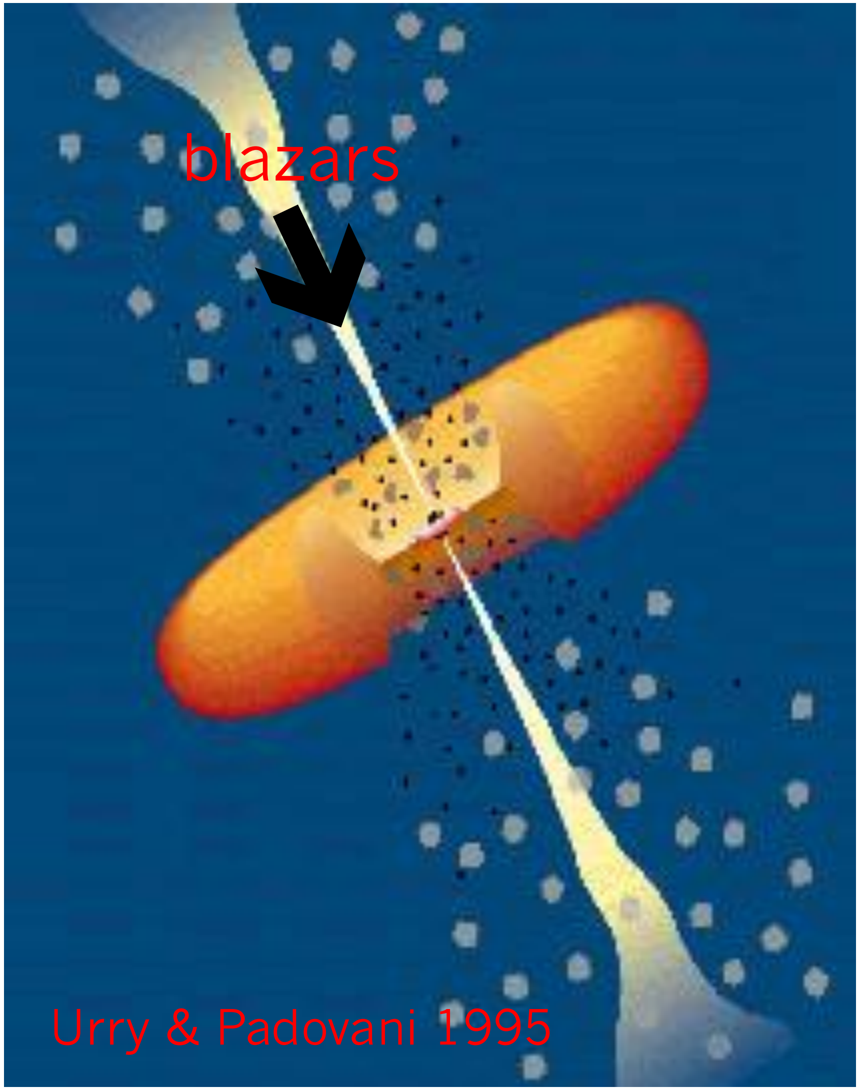
NGC 4151 / UGC 7166 / KUG 1208+396A
SDSS image made with idlutils and photoop (Blanton, Finkbeiner, Hogg, Padmanabhan, Schlegel, Wherry)

What are AGN?



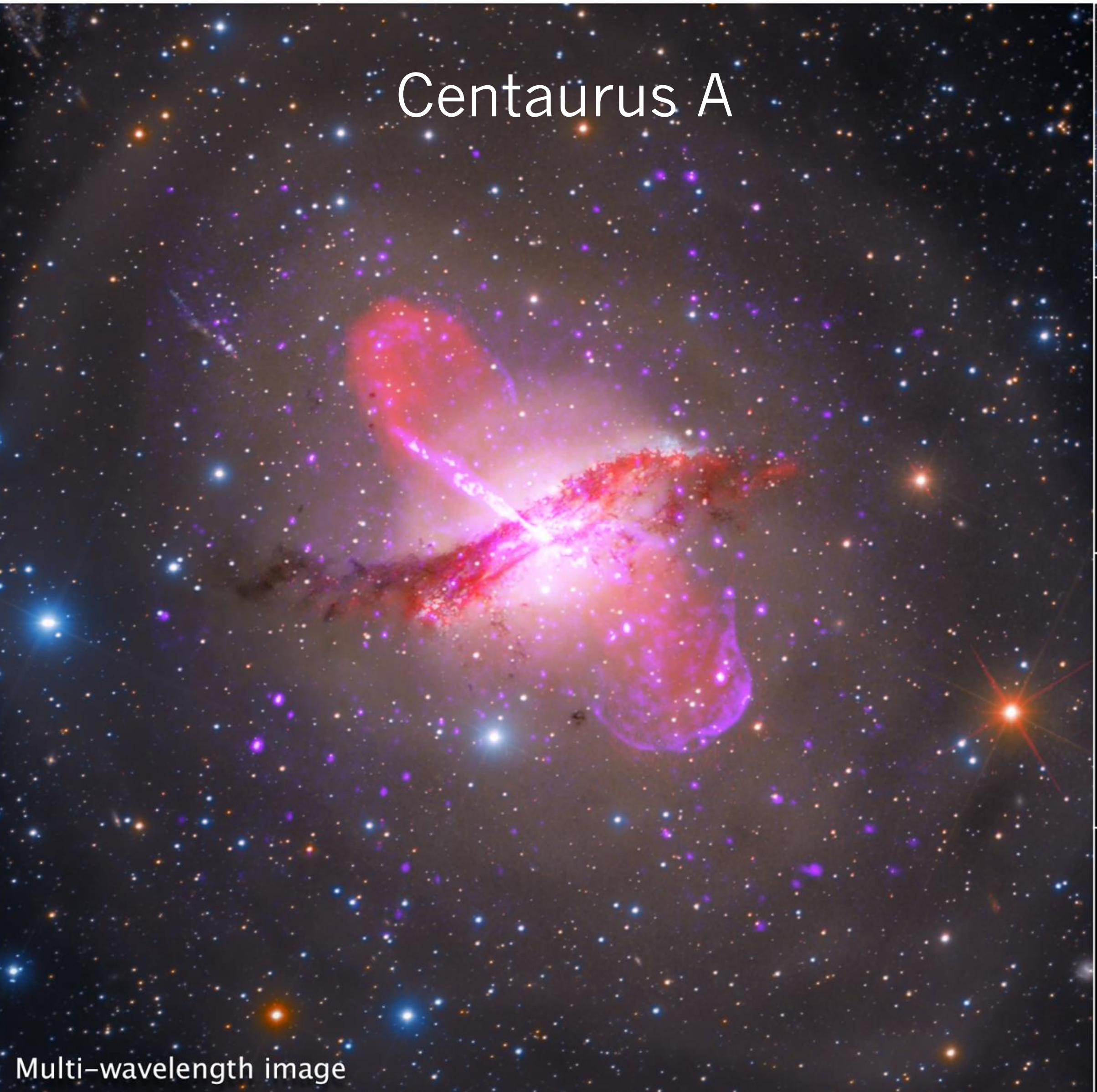
δ 39.45
δ 39.40
δ 39.35
NGC 4151
SDSS image made wit
an, Schlegel, Wherry)

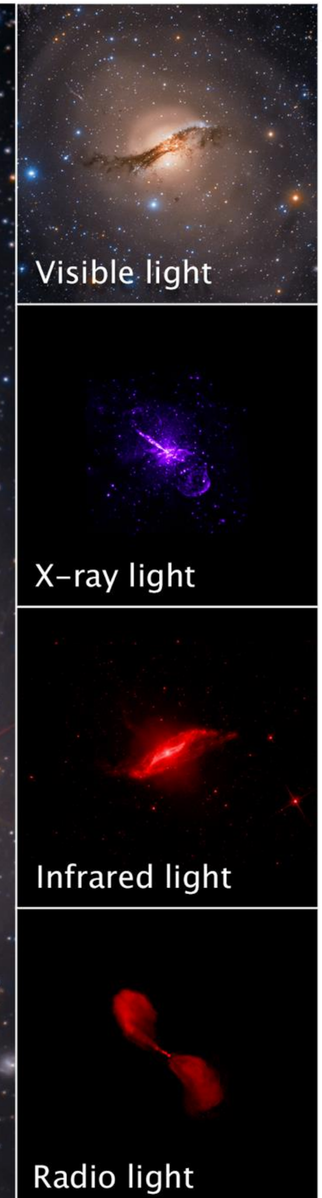
What are AGN?

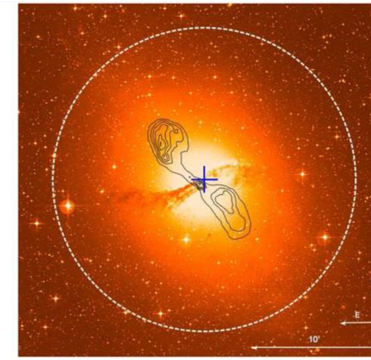


Less than 1 galaxy out of 100,000 is a blazar!

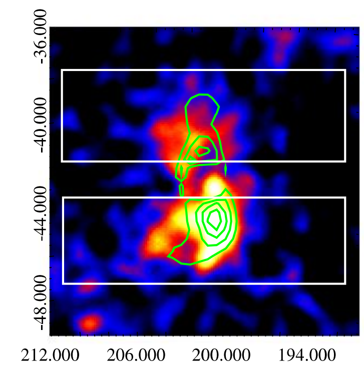
Why multi-wavelength?





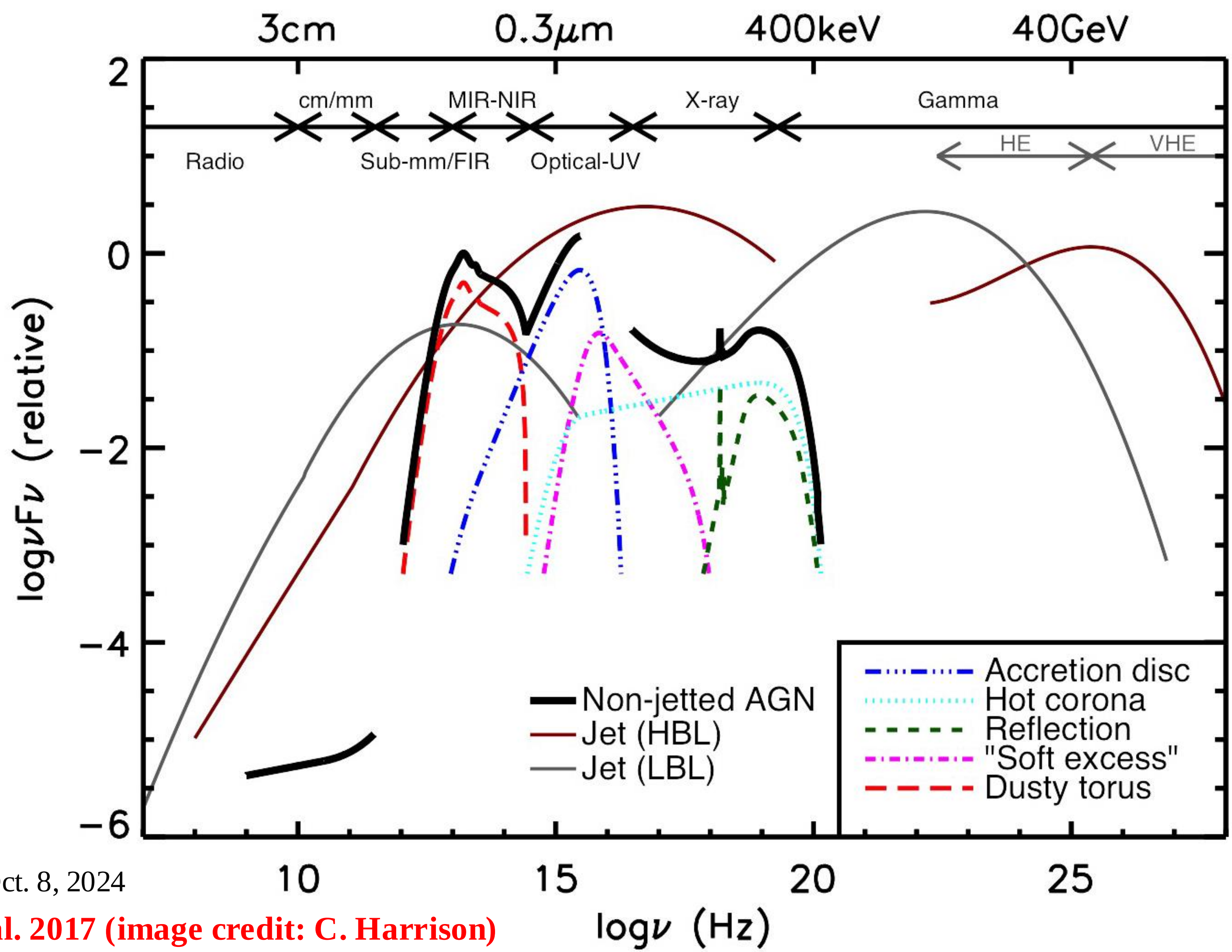


Aharonian et al. (2009),
E > 0.1 TeV [H.E.S.S.]
(**nucleus**)



Yang et al. (2012),
E < 3 GeV [*Fermi*]
(**lobes**)

The AGN Spectral Energy Distribution

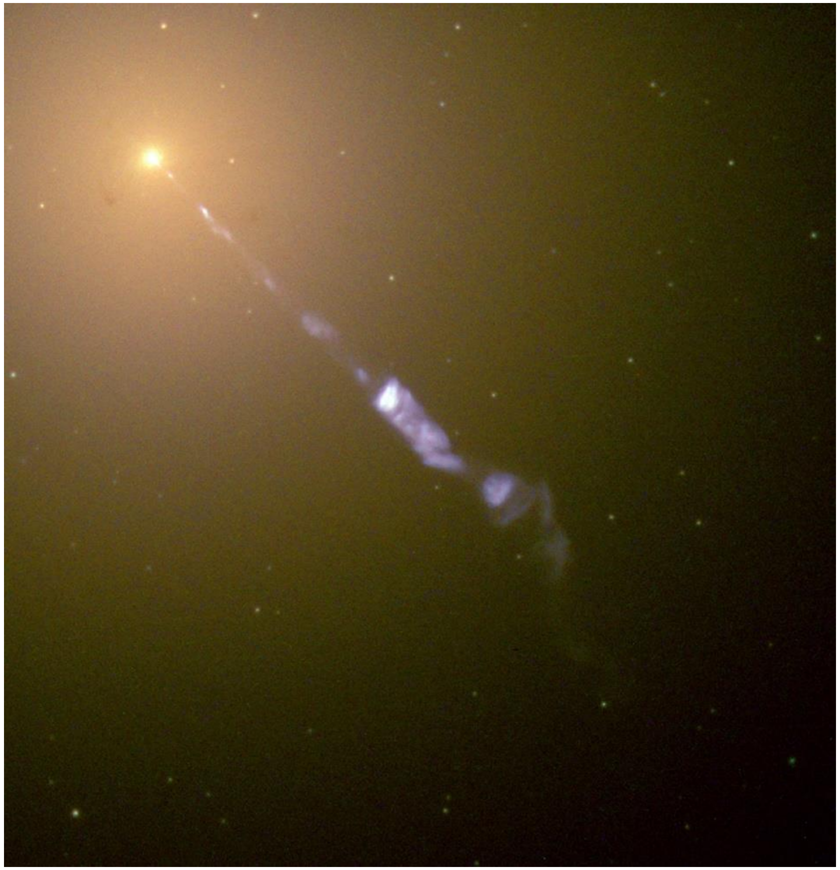


Oct. 8, 2024

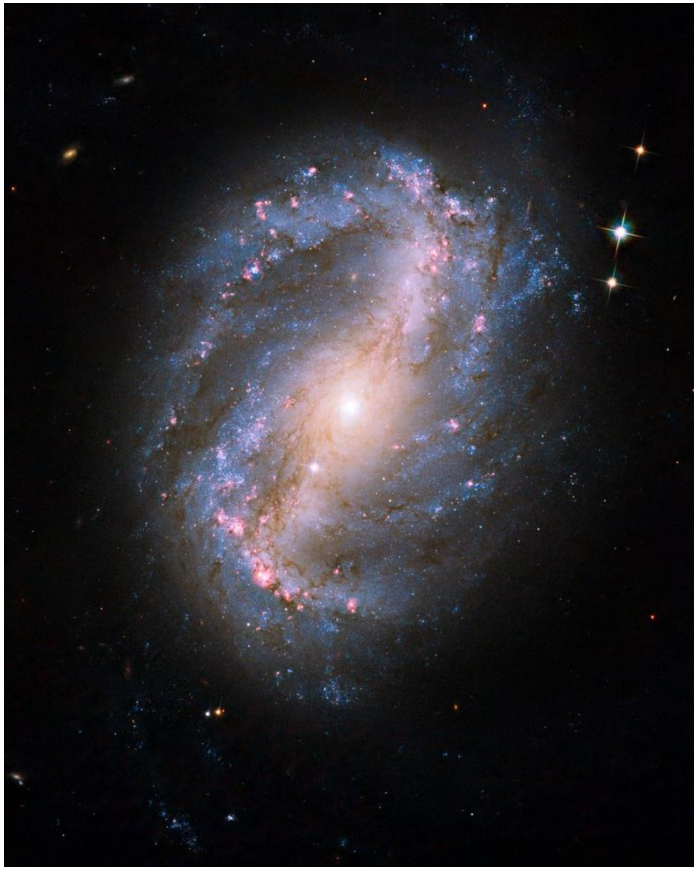
PP et al. 2017 (image credit: C. Harrison)

Jetted vs. non-jetted AGN

M87



NGC 4051



Jetted and non-jetted AGN

PUBLISHED: 24 JULY 2017 | VOLUME: 1 | ARTICLE NUMBER: 0194

comment

On the two main classes of active galactic nuclei

Paolo Padovani

Active galactic nuclei (AGNs) are empirically divided into 'radio-loud' and 'radio-quiet'. These 50-year-old labels are obsolete, misleading and wrong. I argue that AGNs should be classified as 'jetted' and 'non-jetted' based on a physical difference — the presence (or lack) of strong relativistic jets.

It is widely accepted that AGNs are powered by supermassive black holes. And it is (almost) equally widely accepted that there are two main classes of AGNs: the radio-loud (RL) and the radio-quiet (RQ). These classifications go all the way back to the work of Sandage[1], who realized soon after the discovery of the first quasar — 3C 273, a very strong radio source — that there were many similar sources in the sky that were however undetected by the radio telescopes of the time. It was later understood that these quasars were only radio-faint, but the name radio-quiet stuck. Indeed, for the same optical power, the radio powers of RQ quasars are a few orders of magnitude smaller than those of their RL counterparts. This is, in fact, how RQ quasars are characterized: relatively low radio-to-optical flux density ratios (radio loudness, $R \lesssim 10$) and low radio powers ($P_{1.4GHz} \lesssim 10^{24}$ W Hz^{-1} locally[2]). We know now that RQ AGNs are the norm, not the exception, as they make up the large majority (>90%) of the AGN population[3]. We also know that, despite what the odd labels might suggest, the differences between the two classes are not restricted to the radio band; far from it. And they are not simply taxonomic either, as the two classes represent intrinsically different objects. Most RL AGNs emit a large fraction of their energy non-thermally over the whole electromagnetic spectrum. In contrast, the multiwavelength emission of RQ AGNs is dominated by thermal emission, directly or indirectly related to the accretion disk around the supermassive black hole.

The most striking difference is in the hard X-ray to gamma-ray band: while many (likely all, but see below) RL sources emit all the way up to GeV (2.4×10^{23} Hz) and sometimes TeV (2.4×10^{26} Hz) energies, nearby (RQ) bright Seyfert galaxies have a sharp cut-off at energies $\lesssim$1 MeV (ref. [4]). This cut-off has to apply to the whole RQ AGN population in order to not violate the constraint provided by the X-ray background above these energies[5]. Moreover, no RQ AGN has ever been detected in gamma-rays[6] with the exception of NGC 1068 and NGC 4945, two Seyfert 2 galaxies in which the gamma-ray emission is thought to be related to their starburst component[7]. This means that, while RQ AGNs are actually not radio-quiet, they are gamma-ray-quiet.

Due to what are the differences between the two classes? One simple thing: the presence (or absence) of a strong relativistic jet. The relative (and absolute) strength of the radio emission in the two classes is just a consequence of this fundamental physical difference. Hence the need for the new and better names, jetted and non-jetted AGNs[2]. This is illustrated in Fig. 1, which compares the spectral energy distributions (SEDs) of typical non-jetted AGNs with those of two jetted ones, a BL Lac and a flat-spectrum radio quasar (FSRQ). Both of these belong to the blazar class, which

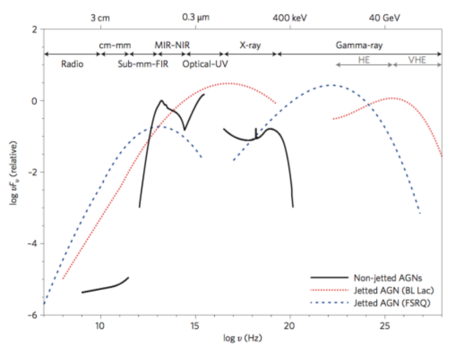


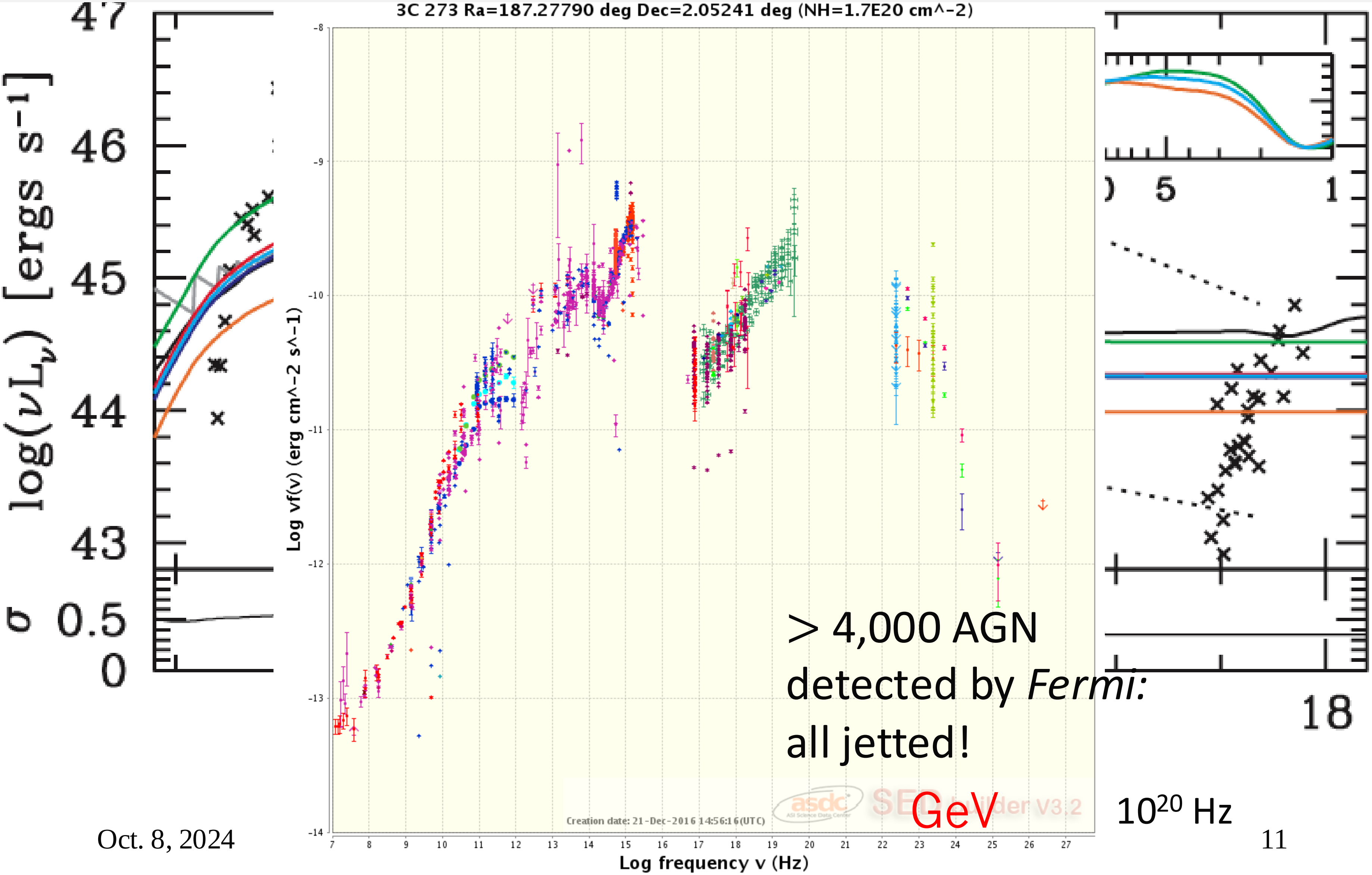
Figure 1 | A schematic representation of the SEDs of AGNs. The black solid curve represents the typical SED of non-jetted AGNs, while the dotted red and dashed blue lines refer to two jetted AGNs, a BL Lac (based on the SED of Mrk 421) and a flat-spectrum radio quasar (based on the SED of 3C 454.3), respectively. The plot is adapted from ref. 17 and Padovani *et al.*, manuscript in preparation. ν, frequency; F_ν, flux; FIR, far-infrared; MIR, mid-infrared; NIR, near-infrared; HE, high energy; VHE, very-high energy. Image credit: C. M. Harrison.

NATURE ASTRONOMY 1, 0194 (2017) | DOI: 10.1038/s41550-017-0194 | www.nature.com/natureastronomy 1

The jetted – non-jetted AGN dichotomy

- Two main classes:
  - ✓ jetted AGN emit a *large fraction* of their energy non-thermally and in association with powerful relativistic jets
  - ✓ the multi-wavelength emission of non-jetted AGN is *dominated* by thermal emission, directly or indirectly related to the accretion disk
- Strongest argument comes from hard X-rays–γ-rays

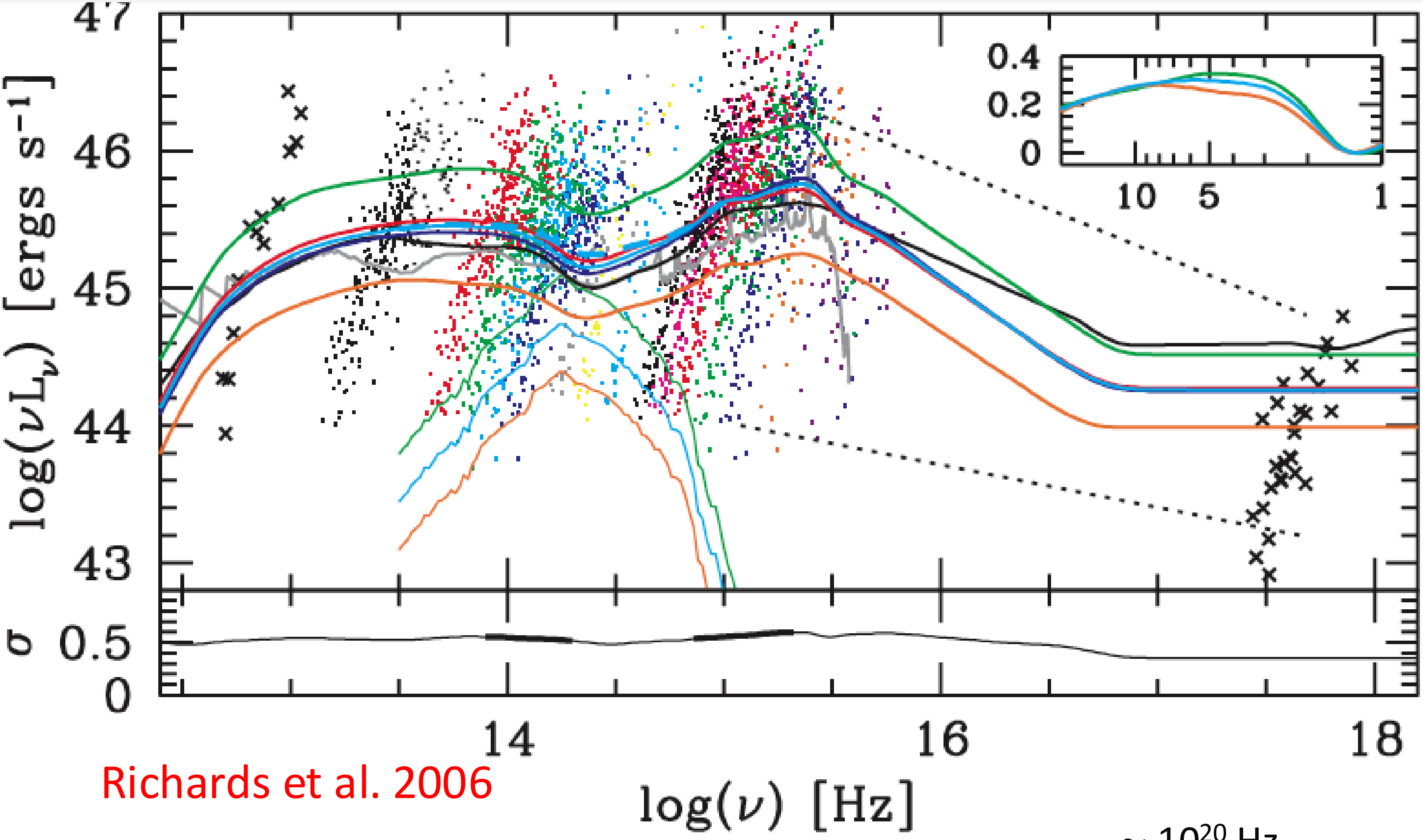
The jetted – non-jetted AGN dichotomy



> 4,000 AGN detected by *Fermi:* all jetted!

10^{20} Hz

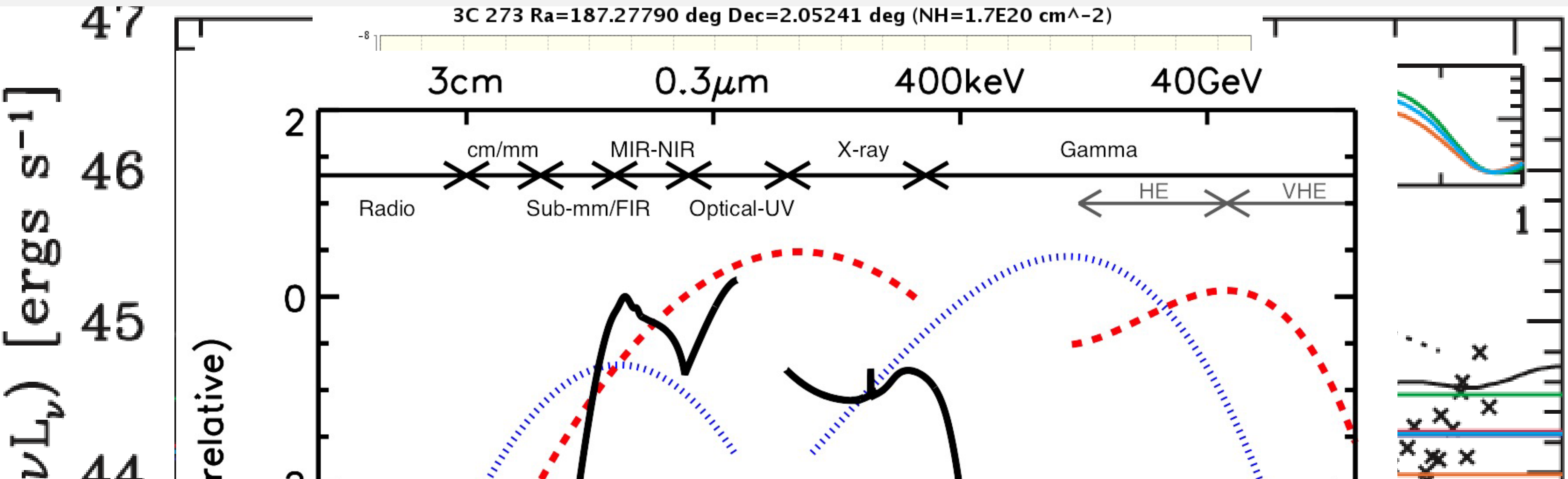
The jetted – non-jetted AGN dichotomy



Richards et al. 2006

~ 10^{20} Hz

The jetted – non-jetted AGN dichotomy

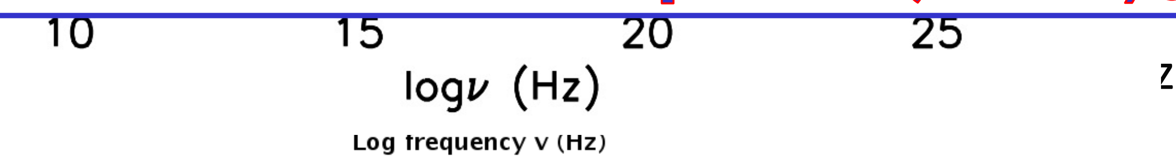


Jetted AGN: strong, relativistic jets!

Non-jetted AGN: <u>might</u> have small, weak, slow jets!

>4,000 AGN

Jetted AGN are the exception (< 10%)



Neutrinos in a nutshell

- Italian for "little neutral one"
- Tiny mass: < 0.45 eV/c^2 (KATRIN Collaboration 2024), < 1/1,000,000 m_e (= 9 10^{-28} g)*
- Electrically neutral, weakly interacting elementary subatomic particle
- Three types: electron (ν_e), muon (ν_μ), and tau (ν_τ)
  - ✓ ~ 340 cosmic neutrinos/cm^3 in the Universe [E ~ 0.0002 eV]
  - ✓ ~ 10^{11} solar neutrinos/cm^2/s on Earth → ~ 10^{14} s^{-1} through our bodies [E $\lesssim$ 1 MeV]
- Probably the second most common particle in the Universe (dark matter?)

*1 eV = 2.42 x 10^{14} Hz

Neutrinos in a nutshell

- Italian for ”little neutral one”
- Tiny m 24), <
  1/1,00
- Electr
  subat
- Three
  ✓ [E ~
  ✓ ~ 10^{14}
- Proba
  Unive

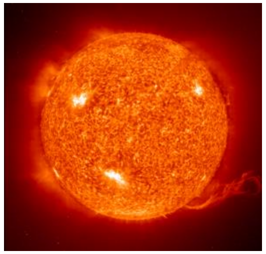
*1 eV = 2.42 x 10^{14} Hz

Neutrino Astronomy

- Only **two** astronomical neutrino sources known (until very recently):

✓ the Sun: $4p \rightarrow {}^4He + 2e^+ + 2\nu_e + Energy$

$E_{\nu e} \approx 1$ MeV*

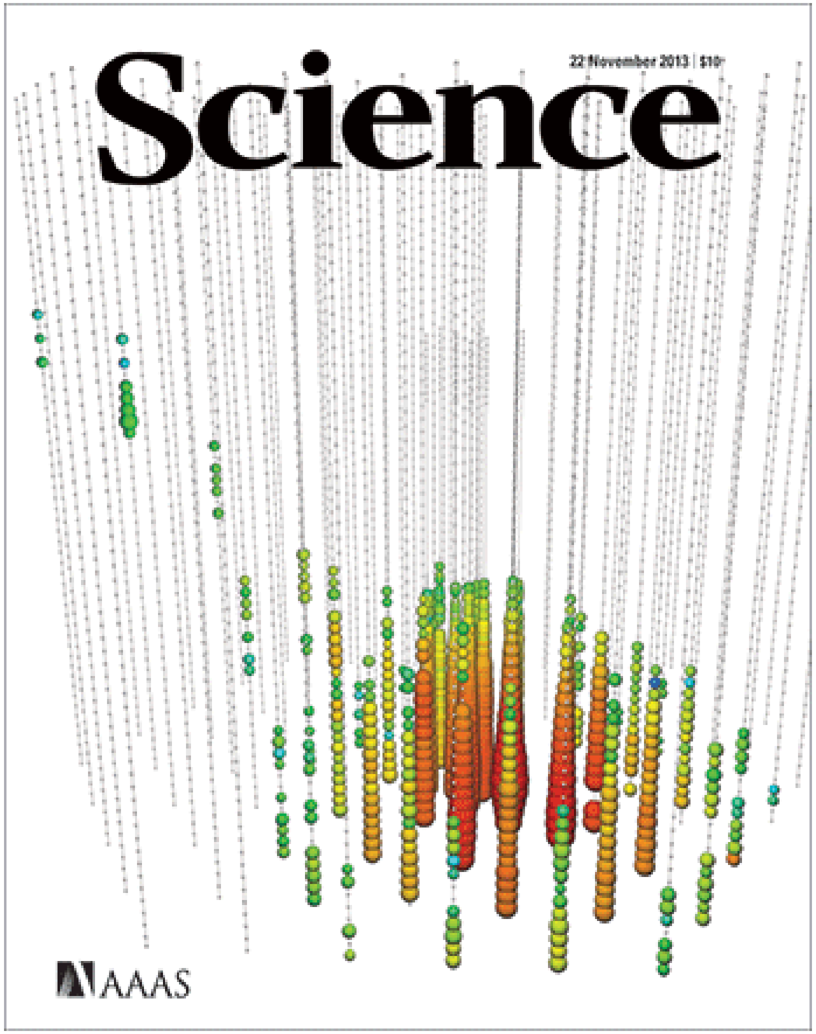


✓ SN 1987a: $e + p \rightarrow n + \nu_e$

$E_{\nu e} \approx 20$ MeV

*1 eV = 2.42 x 10^{14} Hz → 1 MeV = 2.42 x 10^{20} Hz

IceCube (2013)



Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube Detector

IceCube Collaboration*

Introduction: Neutrino observations are a unique probe of the universe's highest-energy phenomena: Neutrinos are able to escape from dense astrophysical environments that photons cannot and are unambiguous tracers of cosmic ray acceleration. As protons and nuclei are accelerated, they interact with gas and background light near the source to produce subatomic particles such as charged pions and kaons, which then decay, emitting neutrinos. We report on results of an all-sky search for these neutrinos at energies above 30 TeV in the cubic kilometer Antarctic IceCube observatory between May 2010 and May 2012.

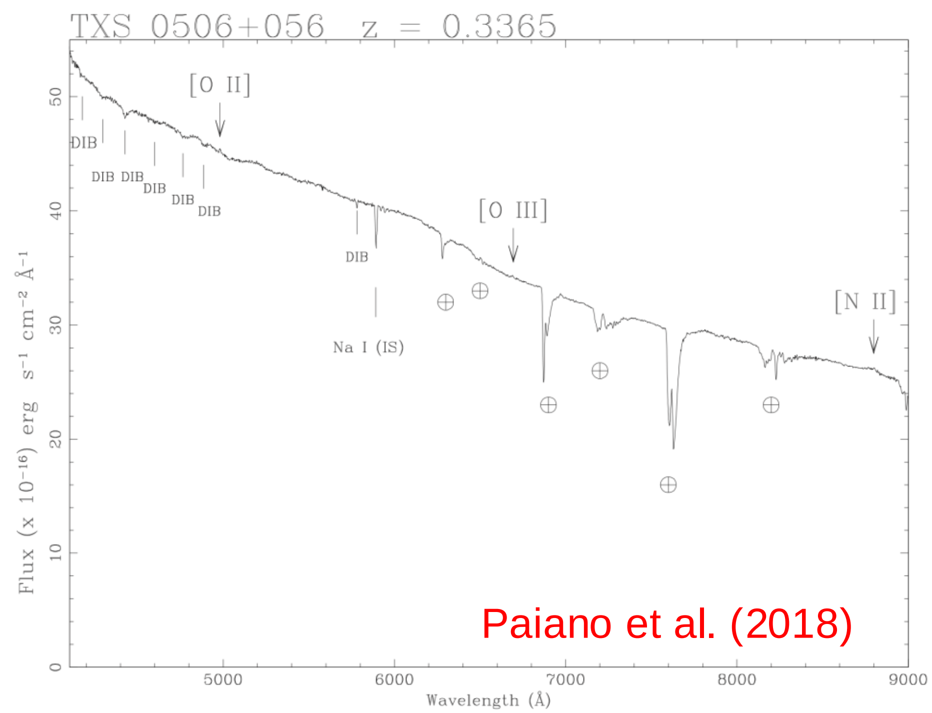
Methods: We have isolated a sample of neutrinos by rejecting background muons from cosmic ray showers in the atmosphere, selecting only those neutrino candidates that are first observed in the detector interior rather than on the detector boundary. This search is primarily sensitive to neutrinos from all directions above 60 TeV, at which the lower-energy background atmospheric neutrinos become rare, with some sensitivity down to energies of 30 TeV. Penetrating muon backgrounds were evaluated using an in-data control sample, with atmospheric neutrino predictions based on theoretical modeling and extrapolation from previous lower-energy measurements.

Results: We observed 28 neutrino candidate events (two previously reported), substantially more than the $10.6^{+5.0}_{-3.6}$ expected from atmospheric backgrounds, and ranging in energy from 30 to 1200 TeV. With the current level of statistics, we did not observe significant clustering of these events in time or space, preventing the identification of their sources at this time.

1 TeV = 10^{12} eV

The first (extragalactic) neutrino source

TXS 0506+056, a blazar (a BL Lac) at z = 0.3365; p−value (post-trial) ~ 3 − 3.5σ

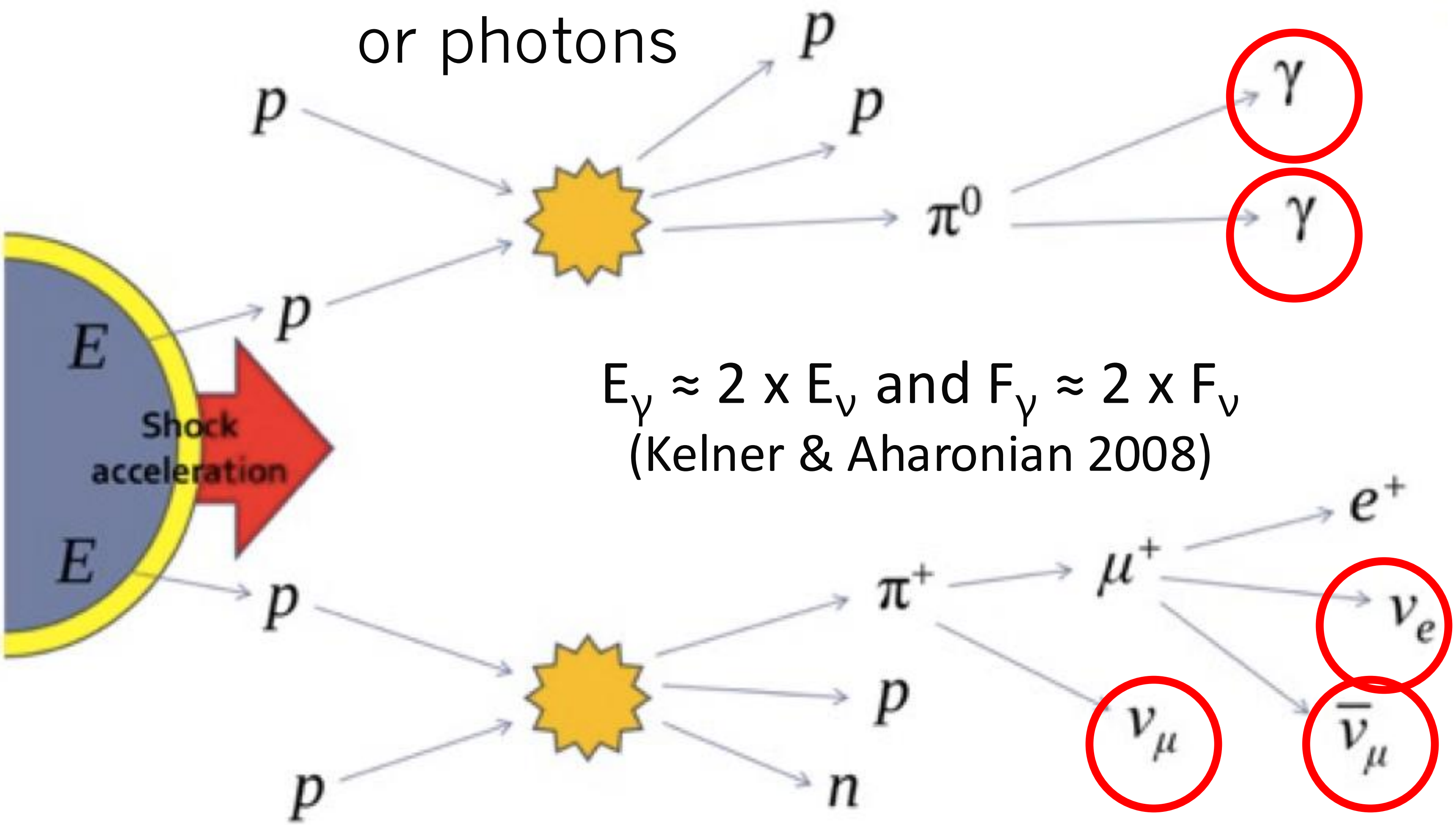


E ~ 290 TeV (2017: 1 ν) and ~ 20 TeV (2014-15:~13 ν)

1 PeV = 10^{15} eV

High-energy neutrino physics

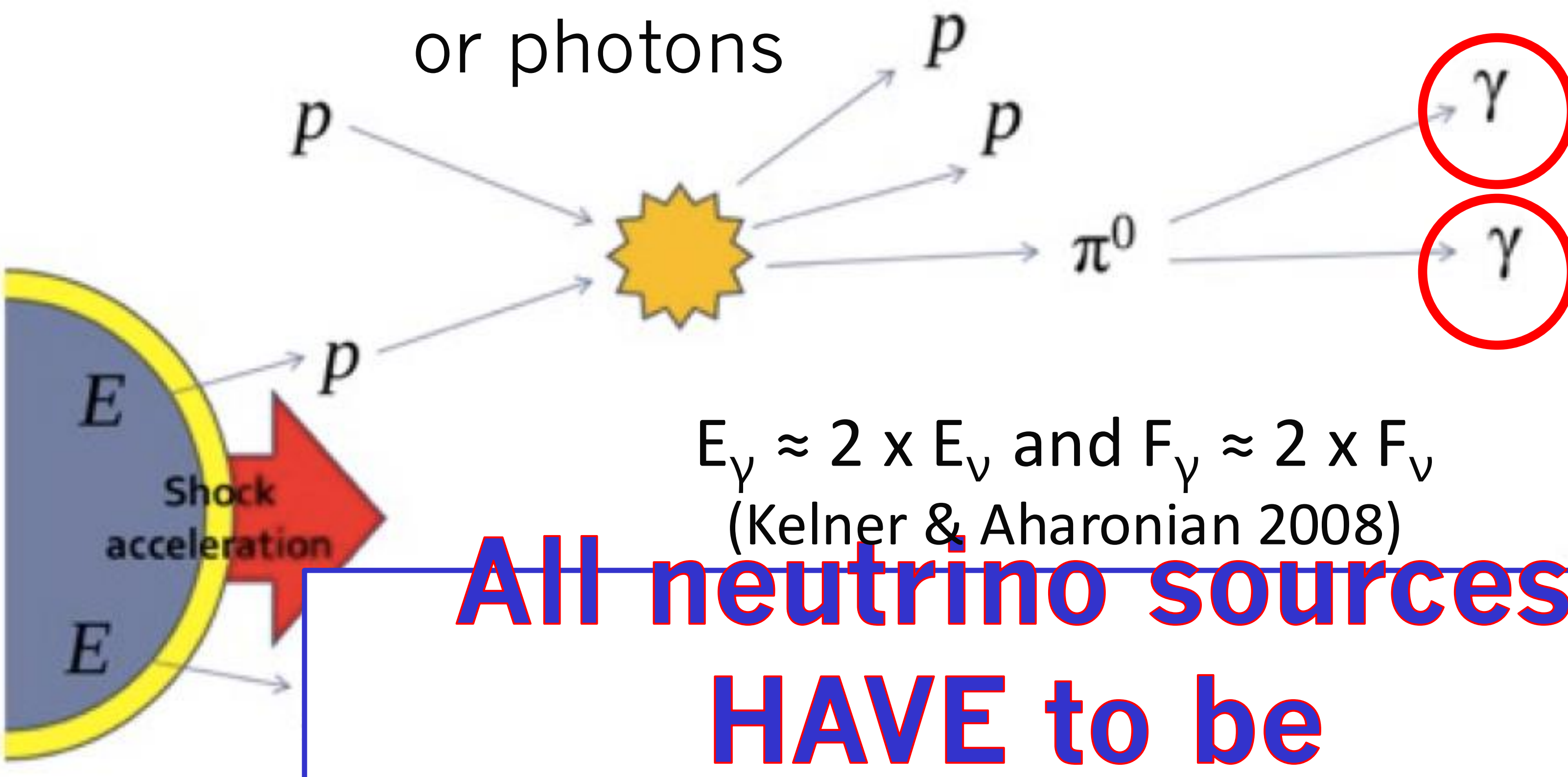
or photons



$E_\gamma \approx 2 \times E_\nu$ and $F_\gamma \approx 2 \times F_\nu$
(Kelner & Aharonian 2008)

High-energy neutrino physics

or photons



$E_\gamma \approx 2 \times E_\nu$ and $F_\gamma \approx 2 \times F_\nu$
(Kelner & Aharonian 2008)

All neutrino sources HAVE to be (intrinsically) γ-ray sources!

NGC 1068 and IceCube

RESEARCH

NEUTRINO ASTROPHYSICS

Evidence for neutrino emission from the nearby active galaxy NGC 1068

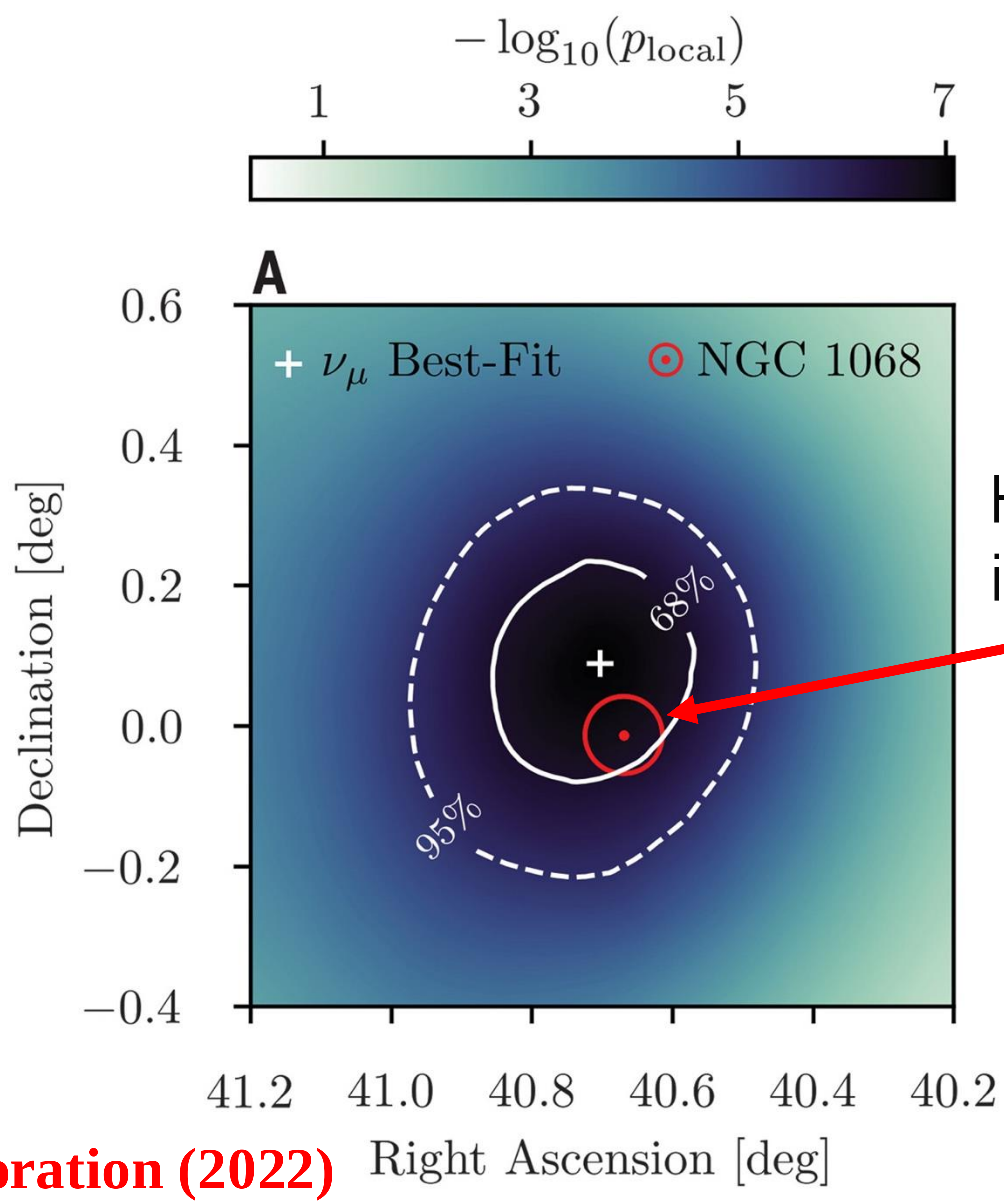
IceCube Collaboration*†

$E_{\nu} \sim 1.5 - 15$ TeV

A supermassive black hole, obscured by cosmic dust, powers the nearby active galaxy NGC 1068. Neutrinos, which rarely interact with matter, could provide information on the galaxy's active core. We searched for neutrino emission from astrophysical objects using data recorded with the IceCube neutrino detector between 2011 and 2020. The positions of 110 known gamma-ray sources were individually searched for neutrino detections above atmospheric and cosmic backgrounds. We found that NGC 1068 has an excess of 79^{+22}_{-20} neutrinos at tera–electron volt energies, with a global significance of 4.2σ, which we interpret as associated with the active galaxy. The flux of high-energy neutrinos that we measured from NGC 1068 is more than an order of magnitude higher than the upper limit on emissions of tera–electron volt gamma rays from this source.

IceCube Collaboration (2022)

Neutrino emission location



Host galaxy in the optical

IceCube Collaboration (2022)

Neutrino source in NGC 1068

nature astronomy

Review article https://do

High-energy neutrinos from the vicinity of the supermassive black hole in NGC 1068

Received: 1 December 2023

Accepted: 15 July 2024

Published online: 18 September 2024

Check for updates

P. Padovani[1], E. Resconi[2], M. Ajello[3], C. Bellenghi[2], S. Bianchi[4], P. Blasi[5,6], K.-Y. Huang[7], S. Gabici[8], V. Gámez Rosas[9], H. Niederhausen[10], E. Peretti[8,11], B. Eichmann[12], D. Guetta[13], A. Lamastra[14] & T. Shimizu[15]

We present a comprehensive multi-messenger study of NGC 1068, the prototype Seyfert II galaxy associated with high-energy neutrinos following a detection by the IceCube Neutrino Observatory. Various aspects of the source, including its nuclear activity, jet, outflow and starburst region, are analysed in detail using a multi-wavelength approach and relevant luminosities are derived. We then explore its γ-ray and neutrino emissions and investigate the potential mechanisms underlying these phenomena and their relations with the different astrophysical components to try to understand which is responsible for the IceCube neutrinos. By first using simple order-of-magnitude arguments and then applying specific theoretical models, we infer that only the region close to the accretion disk around the supermassive black hole has the right density of both the X-ray photons needed to provide the targets for protons to sustain neutrino production and the optical/infrared photons required to absorb the associated, but unobserved, γ-rays. We conclude by highlighting ongoing efforts to constrain a possible broad connection between neutrinos and active galactic nuclei, as well as future synergies between astronomical and neutrino facilities.

PP et al., Nature Astronomy, 2024 (arXiv:2405.20146)

Neutrino source in NGC 1068

nature astronomy

Review article https://do

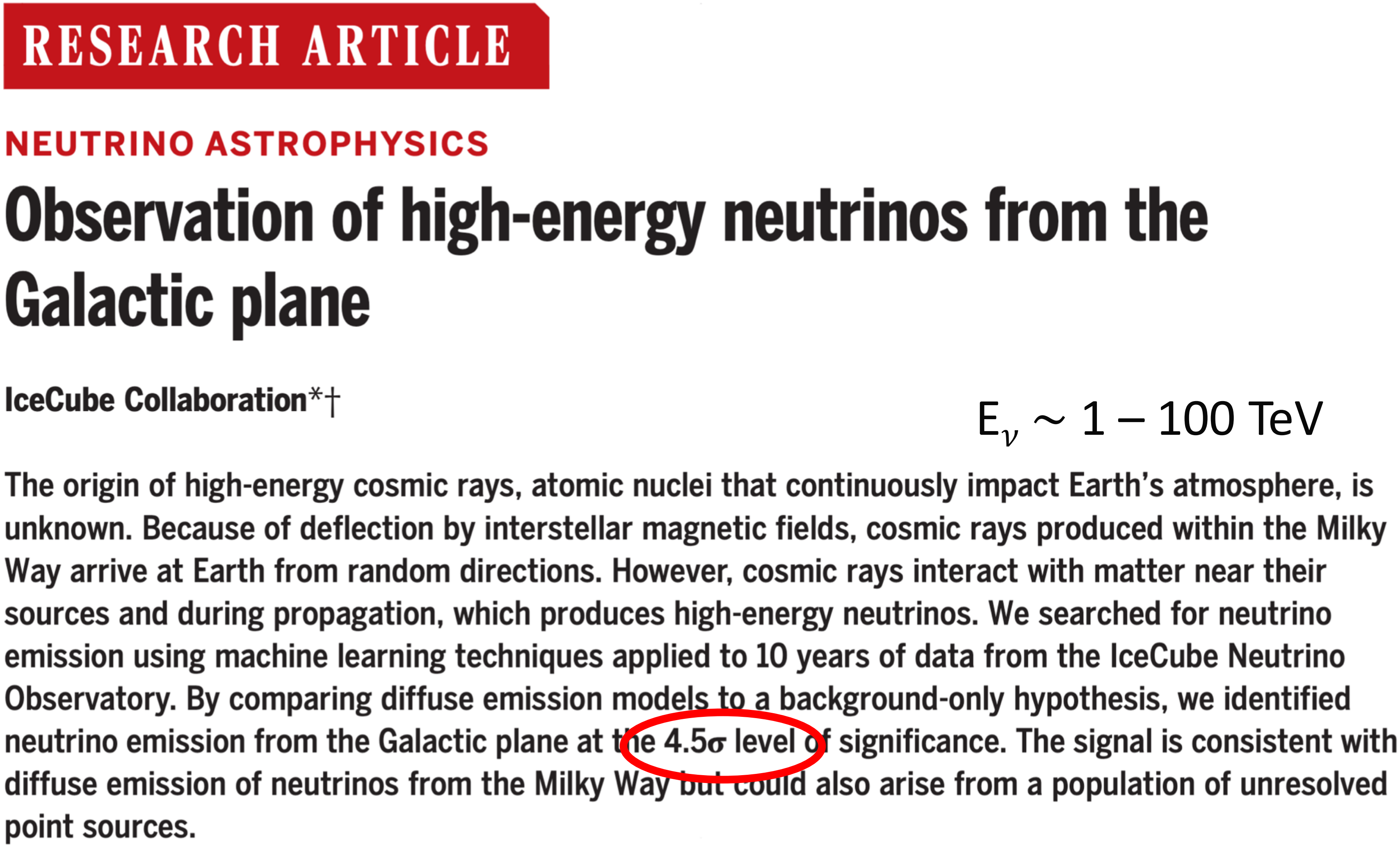
High-energy neutrinos from the vicinity of the supermassive black hole in NGC 1068

Neutrinos are providing striking (and unique) evidence for non-thermal emission in the core of non-jetted AGN!

using simple order-of-magnitude arguments and then applying specific theoretical models, we infer that only the region close to the accretion disk around the supermassive black hole has the right density of both the X-ray photons needed to provide the targets for protons to sustain neutrino production and the optical/infrared photons required to absorb the associated, but unobserved, γ-rays. We conclude by highlighting ongoing efforts to constrain a possible broad connection between neutrinos and active galactic nuclei, as well as future synergies between astronomical and neutrino facilities.

PP et al., Nature Astronomy, 2024 (arXiv:2405.20146)

The Galactic Plane and IceCube


RESEARCH ARTICLE

NEUTRINO ASTROPHYSICS

Observation of high-energy neutrinos from the Galactic plane

IceCube Collaboration*†

The origin of high-energy cosmic rays, atomic nuclei that continuously impact Earth's atmosphere, is unknown. Because of deflection by interstellar magnetic fields, cosmic rays produced within the Milky Way arrive at Earth from random directions. However, cosmic rays interact with matter near their sources and during propagation, which produces high-energy neutrinos. We searched for neutrino emission using machine learning techniques applied to 10 years of data from the IceCube Neutrino Observatory. By comparing diffuse emission models to a background-only hypothesis, we identified neutrino emission from the Galactic plane at the 4.5σ level of significance. The signal is consistent with diffuse emission of neutrinos from the Milky Way but could also arise from a population of unresolved point sources.

$E_\nu \sim 1 - 100$ TeV

IceCube Collaboration (2023)

Obvious questions

- Why TXS 0506+056? What about other blazars?
- Why NGC 1068? What about other non-jetted AGN?

Status of blazar detections after TXS 05056+056. 1. IceCube results

- 3.3σ* combined excess in the northern sky due to NGC 1068 and three blazars: TXS 0506+056, PKS 1424+240, and GB6 J1542+6129 (Aartsen et al. 2020)

- 3.0σ cumulative time-dependent excess in the northern sky due to NGC 1068, M87, and two blazars: TXS 0506+056, and GB6 J1542+6129 (Abbasi et al. 2021)

* all p-values are post-trial

Status of blazar detections after TXS 05056+056. 2. IceCube results

THE ASTROPHYSICAL JOURNAL, 954:75 (11pp), 2023 September 1 https://doi.org/10.3847/1538-4357/acdfcb

Search for Correlations of High-energy Neutrinos Detected in IceCube with Radio-bright AGN and Gamma-Ray Emission from Blazars

R. Abbasi[1], M. Ackermann[2], J. Adams[3], S. K. Agarwalla[4,65], J. A. Aguilar[5], M. Ahlers[6], J. M. Alameddine[7], N. M. Amin[8], K. Andeen[9], G. Anton[10], C. Argüelles[11], Y. Ashida[4], S. Athanasiadou[2], S. N. Axani[8], X. Bai[12],

Abstract

The IceCube Neutrino Observatory sends realtime neutrino alerts with a high probability of being astrophysical in origin. We present a new method to correlate these events and possible candidate sources using 2089 blazars from the Fermi-LAT 4LAC-DR2 catalog and with 3413 active galactic nuclei (AGNs) from the Radio Fundamental Catalog. No statistically significant neutrino emission was found in any of the catalog searches. The result suggests that a small fraction, <1%, of the studied AGNs emit neutrinos that pass the alert criteria, and is compatible with prior evidence for neutrino emission presented by IceCube and other authors from sources such as TXS 0506 + 056 and PKS 1502 + 106. We also present cross-checks to other analyses that claim a significant correlation using similar data samples.

Unified Astronomy Thesaurus concepts: Neutrino astronomy (1100); Gamma-ray sources (633); Radio active galactic nuclei (2134)

Status of blazar detections after TXS 05056+056. 3. other results

- 3.2σ correlation excess for 47 γ-ray **blazars** [intermediate- and high-peaked sources (IBLs and HBLs): $\nu_{peak,synch} > 10^{14}$ Hz] (Giommi et al. 2020)
- 2.9σ correlation excess for strong very-long-baseline interferometry (VLBI)-selected AGN; four brightest associations are all **blazars** [low-peaked sources (LBLs: $\nu_{peak,synch} < 10^{14}$ Hz)] (Plavin et al. 2020)
- 3.0σ correlation excess for strong VLBI-selected AGN, different IceCube sample (Plavin et al. 2021; plus Plavin et al. 2023).

Both ruled out by the IceCube collaboration (Abbasi et al. 2023)

Status of blazar detections after TXS 05056+056. 4. other results

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **519,** 1396–1408 (2023) https://doi.org/10.1093/mnras/stac3607
Advance Access publication 2022 December 9

A multimessenger study of the blazar PKS 0735+178: a new major neutrino source candidate

N. Sahakyan,[1,2,3★] P. Giommi,[4,5,6] P. Padovani,[7,8] M. Petropoulou,[9] D. Bégué,[10] B. Boccardi[11] and S. Gasparyan[1]

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[2] *ICRANet, Piazza della Repubblica, 10 65122 Pescara, Italy*
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Based on the above, PKS 0735+178 should be considered one of the best very high-energy neutrino source candidates detected so far.

KM3NeT neutrino telescopes while it was flaring in the γ-ray, X-ray, ultraviolet, and optical bands. We present a detailed study of this peculiar blazar to investigate the temporal and spectral changes in the multiwavelength emission when the neutrino events were observed. The analysis of *Swift-XRT* snapshots reveal a flux variability of more than a factor 2 in about 5×10^3 s during the observation on 2021 December 17. In the γ-ray band, the source was in its historical highest flux level at the time of the arrival of the neutrinos. The observational comparison between PKS 0735+178 and other neutrino source candidates, such as TXS 0506+056, PKS 1424+240, and GB6 J1542+6129, shows that all these sources share similar spectral energy distributions, very high radio and γ-ray powers, and parsec scale jet properties. Moreover, we present strong supporting evidence for PKS 0735+178 to be, like all the others, a masquerading BL Lac. We perform comprehensive modelling of the multiwavelength emission from PKS 0735+178 within one-zone lepto-hadronic models considering both internal and external photon fields and estimate the expected accompanying neutrino flux. The most optimistic scenario invokes a jet with luminosity close to the Eddington value and the interactions of $\sim$ PeV protons with an external UV photon field. This scenario predicts $\sim$0.067 muon and anti-muon neutrinos over the observed 3-week flare. Our results are consistent with the detection of one very high-energy neutrino like IceCube-211208A.

Status of blazar detections after TXS 05056+056. 5. other results

- 4.6σ post-trial correlation excess between the Roma-BZCAT Multifrequency Catalogue of Blazars with a neutrino map of the *southern sky* covering 7 years of IceCube observations (Buson et al. 2022a,b)

Status of blazar detections after TXS 05056+056. 5. other results

- $\underline{4.6\sigma}$ post-trial correlation excess between the Roma-BZCAT Multifrequency Catalogue of Blazars with a neutrino map of the sc … son et

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Correlating High-energy IceCube Neutrinos with 5BZCAT Blazars and RFC Sources

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Abstract

We investigate the possibility that blazars in the Roma-BZCAT Multifrequency Catalogue of Blazars (5BZCAT) are sources of the high-energy astrophysical neutrinos detected by the IceCube Neutrino Observatory, as recently suggested by Buson et al. Although we can reproduce their $\sim 4.5\sigma$ result, which applies to 7 yr of neutrino data in the southern sky, we find no significant correlation with 5BZCAT sources when extending the search to the northern sky, where IceCube is most sensitive to astrophysical signals. To further test this scenario, we use a larger sample consisting of 10 yr of neutrino data recently released by the IceCube Collaboration, this time finding no significant correlation in neither the southern nor the northern sky. These results suggest that the strong correlation reported by Buson et al. using 5BZCAT could be due to a statistical fluctuation and possibly the spatial and flux nonuniformities in the blazar sample. We perform some additional correlation tests using the more uniform, flux-limited, and blazar-dominated Radio Fundamental Catalogue and find a $\sim 3.2\sigma$ equivalent *p*-value when correlating it with the 7 yr southern neutrino sky. However, this correlation disappears completely when extending the analysis to the northern sky and when analyzing 10 yr of all-sky neutrino data. Our findings support a scenario where the contribution of the whole blazar class to the IceCube signal is relevant but not dominant, in agreement with most previous studies.

Status of blazar detections after TXS 05056+056. 6. take home message

- Blazars keep popping up
- However, strong hints that only somewhat rare blazar sub-classes are involved (our group)
- Consistent with overall result that blazars can explain only < a few % of the IceCube signal (IceCube collaboration 2017, 2019, 2023 [dependent on the assumed power-law spectrum] + our group)

What about other Seyferts?

DRAFT VERSION JUNE 12, 2024
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arXiv:2406.06684

Search for neutrino emission from hard X-ray AGN with IceCube

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J.M. ALAMEDDINE ,[23] N. M. AMIN,[44] K. ANDEEN ,[42] C. ARGÜELLES ,[14] Y. ASHIDA,[53] S. ATHANASIADOU,[65]

(Dated: June 12, 2024)

Submitted to ApJL

ABSTRACT

Active Galactic Nuclei (AGN) are promising candidate sources of high-energy astrophysical neutrinos since they provide environments rich in matter and photon targets where cosmic ray interactions may lead to the production of gamma rays and neutrinos. We searched for high-energy neutrino emission from AGN using the *Swift*-BAT Spectroscopic Survey (BASS) catalog of hard X-ray sources and 12 years of IceCube muon track data. First, upon performing a stacked search, no significant emission was found. Second, we searched for neutrinos from a list of 43 candidate sources and found an excess from the direction of two sources, Seyfert galaxies NGC 1068 and NGC 4151. We observed NGC 1068 at flux $\phi_{\nu_\mu+\bar{\nu}_\mu} = 4.02^{+1.58}_{-1.52} \times 10^{-11}$ TeV^{-1} cm^{-2} s^{-1} normalized at 1 TeV, with power-law spectral index, $\gamma = 3.10^{+0.26}_{-0.22}$, consistent with previous IceCube results. The observation of a neutrino excess from the direction of NGC 4151 is at a post-trial significance of 2.9σ. If interpreted as an astrophysical signal, the excess observed from NGC 4151 corresponds to a flux $\phi_{\nu_\mu+\bar{\nu}_\mu} = 1.51^{+0.99}_{-0.81} \times 10^{-11}$ TeV^{-1} cm^{-2} s^{-1} normalized at 1 TeV and $\gamma = 2.83^{+0.35}_{-0.28}$.

What about other Seyferts?

Draft version June 13, 2024
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arXiv:2406.07601

IceCube Search for Neutrino Emission from X-ray Bright Seyfert Galaxies

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Submitted to ApJ Letters

ABSTRACT

The recent IceCube detection of TeV neutrino emission from the nearby active galaxy NGC 1068 suggests that active galactic nuclei (AGN) could make a sizable contribution to the diffuse flux of astrophysical neutrinos. The absence of TeV γ-rays from NGC 1068 indicates neutrino production in the vicinity of the supermassive black hole, where the high radiation density leads to γ-ray attenuation. Therefore, any potential neutrino emission from similar sources is not expected to correlate with high-energy γ-rays. Disk-corona models predict neutrino emission from Seyfert galaxies to correlate with keV X-rays, as they are tracers of coronal activity. Using through-going track events from the Northern Sky recorded by IceCube between 2011 and 2021, we report results from a search for individual and aggregated neutrino signals from 27 additional Seyfert galaxies that are contained in the BAT AGN Spectroscopic Survey (BASS). Besides the generic single power-law, we evaluate the spectra predicted by the disk-corona model. Assuming all sources to be intrinsically similar to NGC 1068, our findings constrain the collective neutrino emission from X-ray bright Seyfert galaxies in the Northern Hemisphere, but, at the same time, show excesses of neutrinos that could be associated with the objects NGC 4151 and CGCG 420-015. These excesses result in a 2.7σ significance with respect to background expectations.

Neutrinos from non-jetted AGN

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Astronomy & Astrophysics

LETTER TO THE EDITOR

The neutrino background from non-jetted active galactic nuclei

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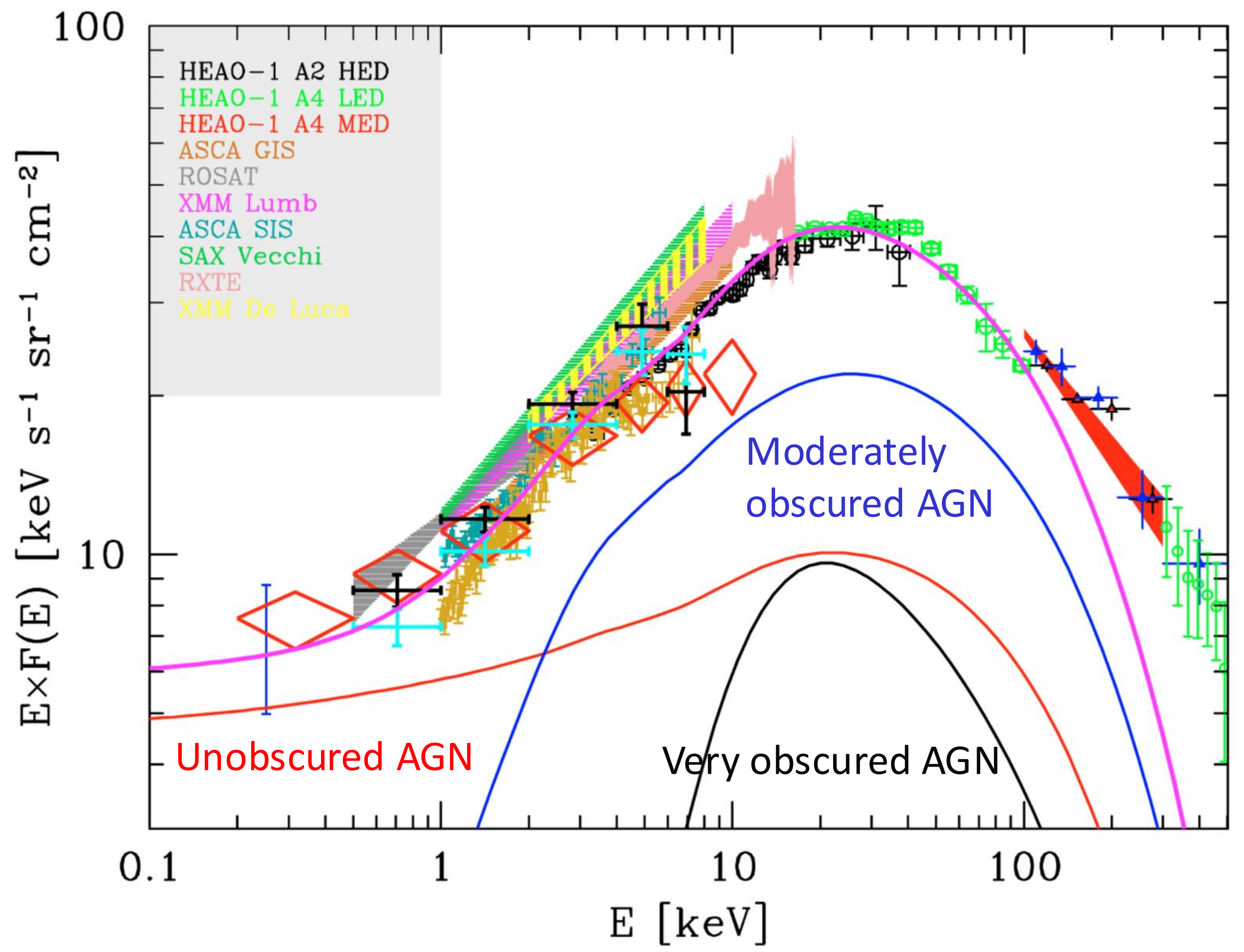
ABSTRACT

Aims. We calculate the contribution to the neutrino background from the non-jetted active galactic nuclei (AGN) population following the recent IceCube association of TeV neutrinos with NGC 1068.
Methods. We exploited our robust knowledge of the AGN X-ray luminosity function and evolution and converted it to the neutrino band by using NGC 1068 as a benchmark, together with a theoretically motivated neutrino spectrum.
Results. The resulting neutrino background up to redshift 5 does not violate either the IceCube diffuse flux or the upper bounds for non-jetted AGN, although barely so. This is consistent with a scenario in which the latter class makes a substantial contribution mostly below 1 PeV, while jetted AGN, that is, blazars, dominate above this energy, in intriguing agreement with the dip in the neutrino data at ~300 TeV. More and better IceCube data on Seyfert galaxies will allow us to constrain the fraction of neutrino emitters among non-jetted AGN.

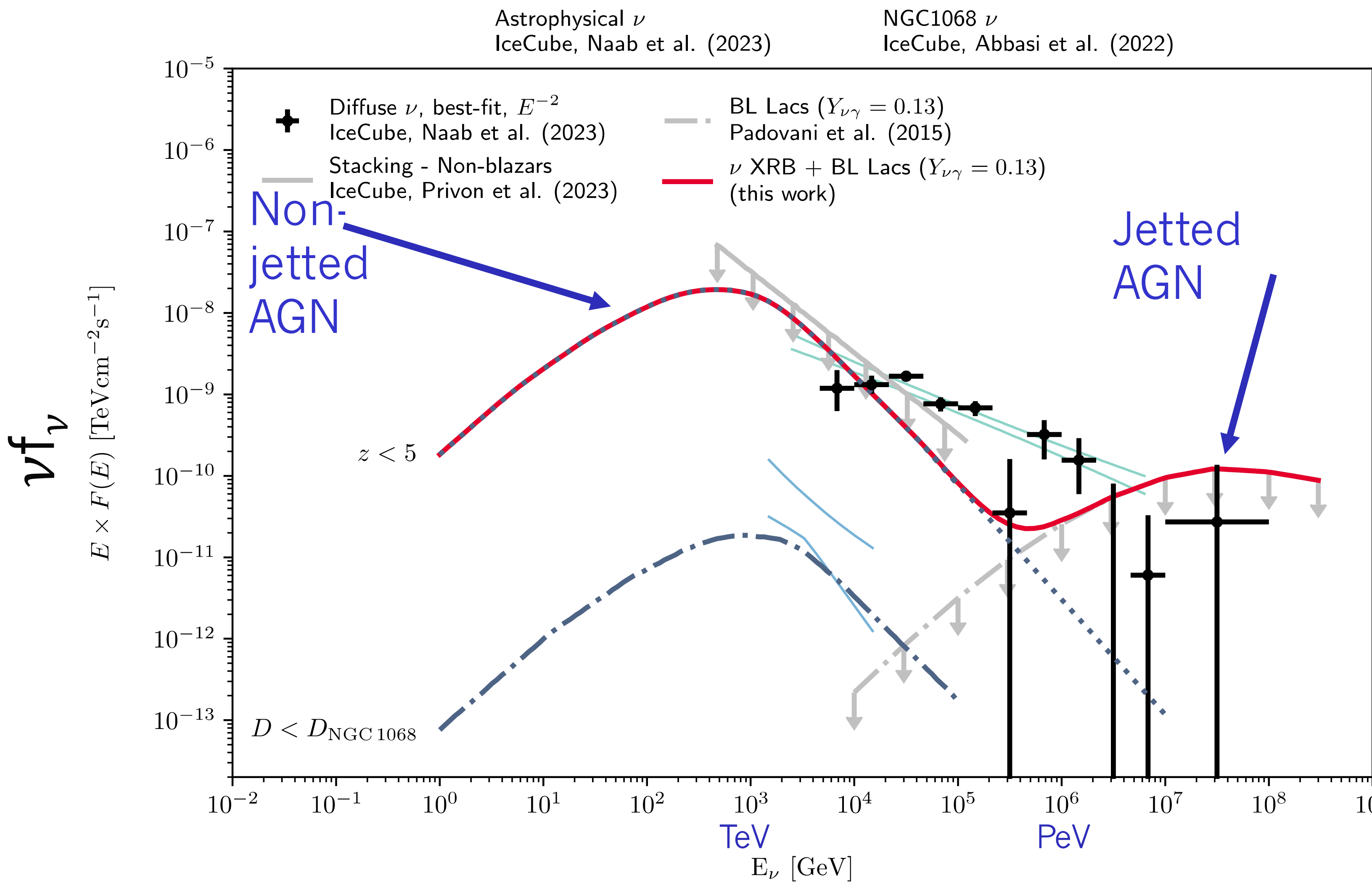
Key words. neutrinos – radiation mechanisms: non-thermal – galaxies: Seyfert

Population synthesis of the X-ray background



Gilli, Comastri, & Hasinger (2007)

Neutrinos from non-jetted AGN



More Seyferts?

- IceCube fluxes and spectral slopes and typical X-ray data for NGC 4151 and CGCG 420-015 give neutrino/X-ray flux ratios ~ **10* and 60 times higher** than for NGC 1068

- *Clearly, more and better IceCube data are of paramount importance, both on the source and population side, to make progress on this issue.*

*updated from ~ 6 in PP et al., 2024, A&A Letters based on arXiv:2406.06684

More Seyferts?

- IceCube fluxes and spectral slopes and typical X-ray data for NGC 4151 and CGCG 420-015 give neutrino/X-ray flux ratios ~ **10***

Based on the latest (2.7 – 2.9 σ) IceCube results, only ~ 2 – 10 % of non-jetted AGN might be neutrino emitters

- *and population side, to make progress on this issue.*

*updated from ~ 6 in PP et al., 2024, A&A Letters based on arXiv:2406.06684

Conclusions. 1.

- Different bands give us very different perspectives on the physics and different AGN types

- We are witnessing the birth of extragalactic Neutrino Astronomy

PHYSICAL REVIEW LETTERS

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EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

Riccardo Giacconi, Herbert Gursky, and Frank R. Paolini
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and

Bruno B. Rossi
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received October 12, 1962)

Data from an Aerobee rocket carrying a payload consisting of three large area Geiger counters have revealed a considerable flux of radiation in the night sky that has been identified as consisting of soft x rays.

The entrance aperture of each Geiger counter consisted of seven individual mica windows comprising 20 cm^2 of area placed into one face of the counter. Two of the counters had windows of about 0.2-mil mica, and one counter had windows of 1.0-mil mica. The sensitivity of these detectors for x rays was between 2 and 8 Å, falling sharply at the extremes due to the transmission of the filling gas and the opacity of the windows, respectively. The mica was coated with lampblack to prevent ultraviolet light transmission. The counter was placed in a well formed by an anticoincidence scintillation counter designed to reduce the cosmic-ray background. The experiment was intended to study fluorescence x rays produced on the lunar surface by x rays from the sun and to explore the night sky for other possible sources. On the basis of the known flux of solar x rays, we had estimated a flux from the moon of about 0.1 to 1 photon cm^{-2} sec^{-1} in the region of sensitivity of the counter.

The rocket launching took place at the White Sands Missile Range, New Mexico, at 2359 MST on June 18, 1962. The moon was one day past full and was in the sky about 20° east of south and 35° above the horizon. The rocket reached a maximum altitude of 225 km and was above 80

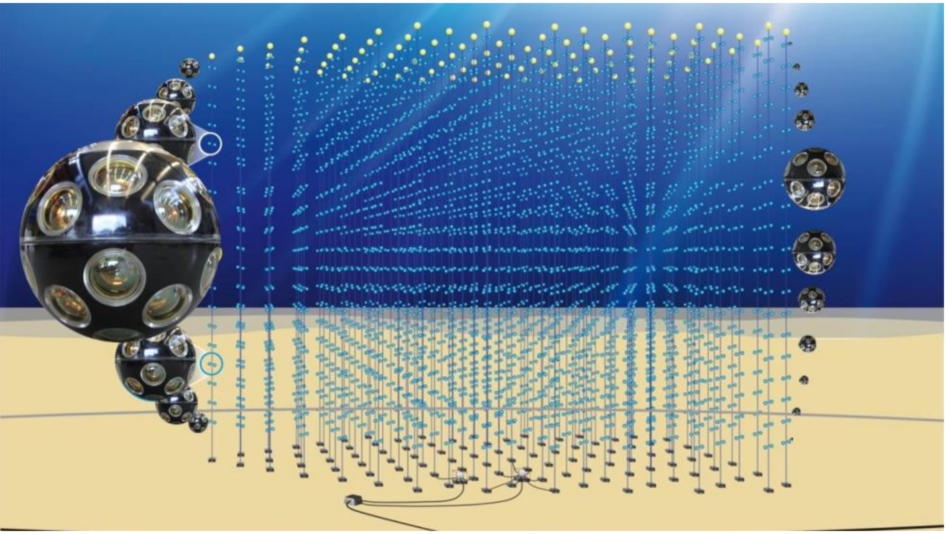
Conclusions. 1.

- Different bands give us very different perspectives on the physics and different AGN types
- We are witnessing the birth of extragalactic Neutrino Astronomy
- At present ≈ 3σ IceCube associations with blazars
- But only a small blazar sub-class is likely contributing to the IceCube signal

Conclusions. 2.

- 4.2σ association with NGC 1068; more Seyferts coming up – plus 4.5σ with the Galactic Plane
- Seyferts could produce low-E ($\lesssim$ PeV) neutrinos while blazars could produce the high-E ones
- Protons with E ~ 40 – 400 TeV!

The future of neutrino Astronomy



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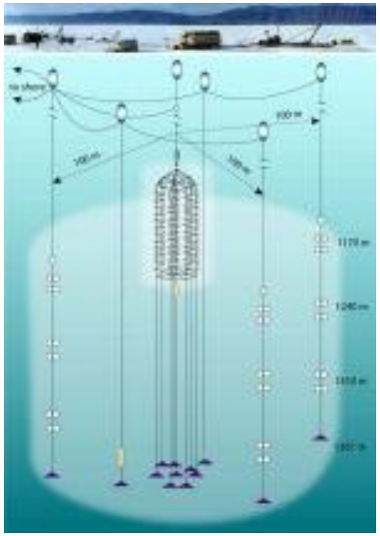

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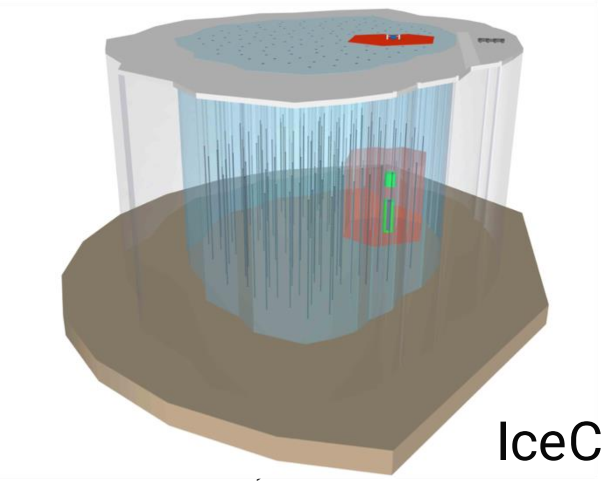
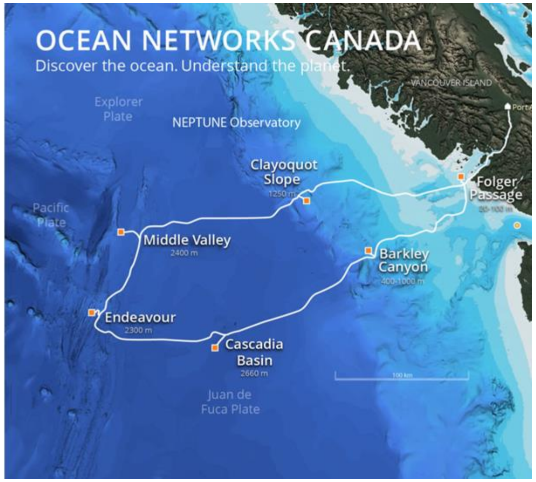


IceCube-Gen2



Pacific Ocean Neutrino Experiment