A ghost (particle) story
Blazar accretion and jets

Fe Krauss
Felicia.Krauss@psu.edu
fe@fekrauss.com

Overview

Introduction

How powerful is black hole particle acceleration (in jets)?

- IceCube-190331A
- IceCube-200615A
- Cascades
- PKS 2005−489

Overview

Introduction

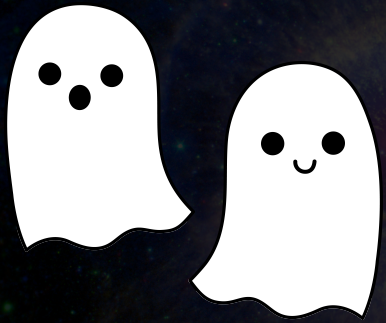
How powerful is black hole particle acceleration (in jets)?

How does accretion work in AGN?

A GHOST (PARTICLE) STORY
BLAZAR ACCRETION AND JETS

FE KRAUSS
FELICIA.KRAUSS@PSU.EDU
FE@FEKRAUSS.COM

There's something strange in the neighborhood...



- PARTICLE

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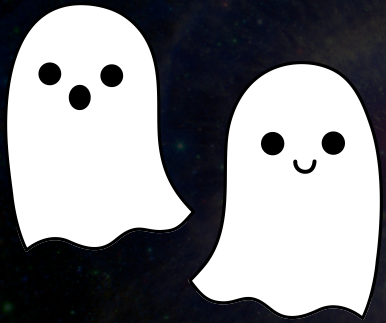

- PARTICLE

Neutrinos

	Neutrinos	Ghosts
Moves through objects	✓	✓

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https://ghostbusters.fandom.com/wiki/CDI_System

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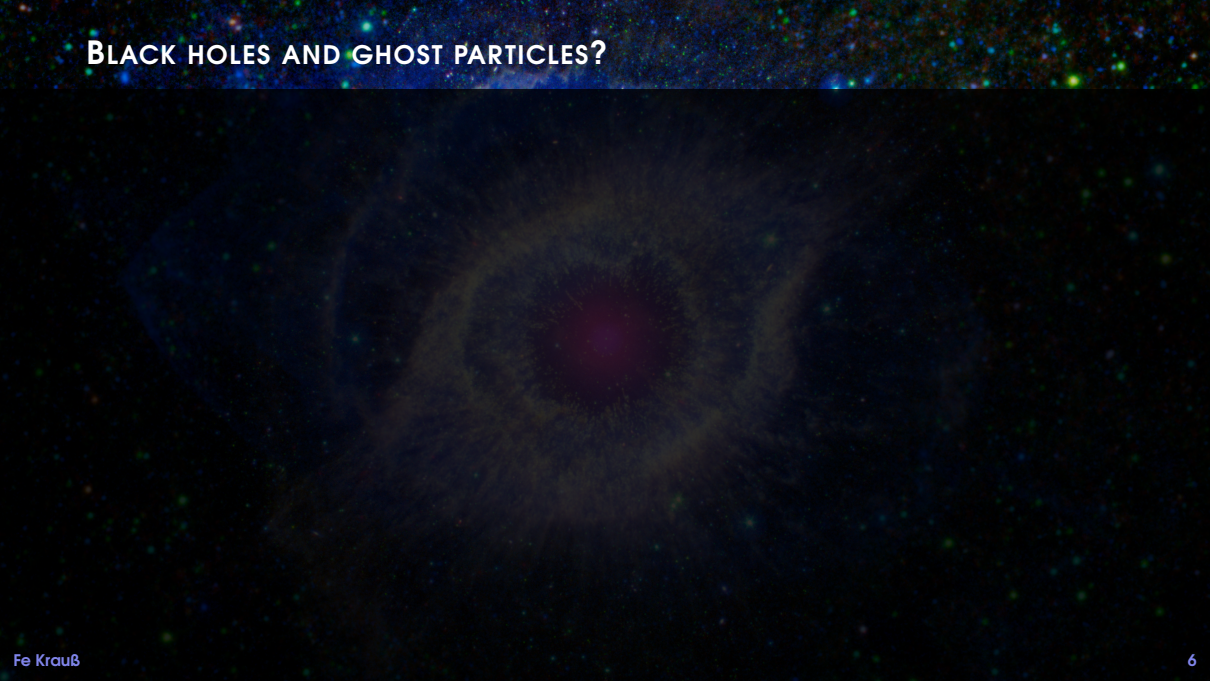
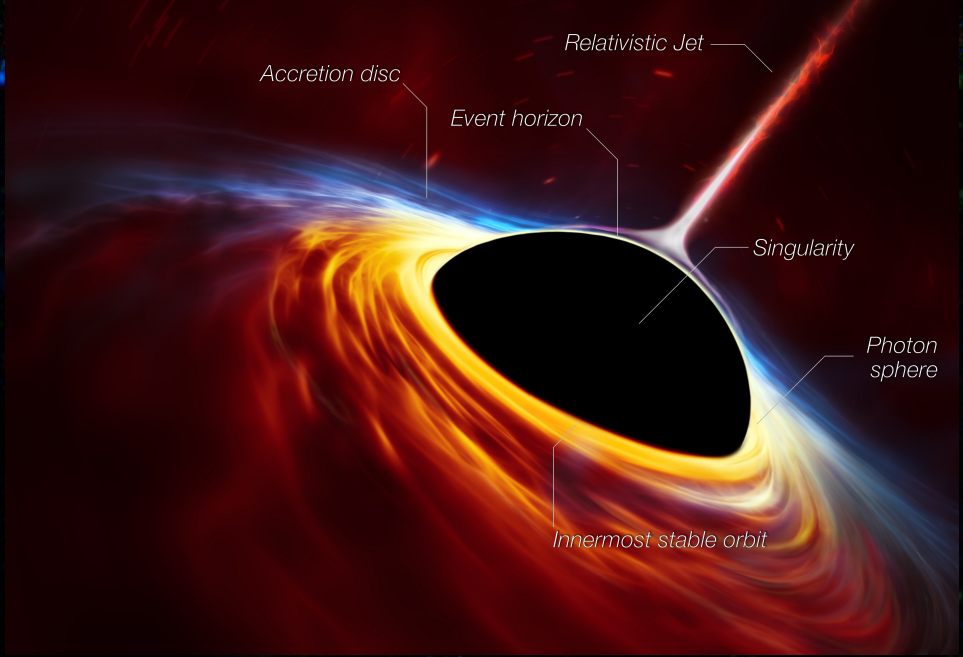
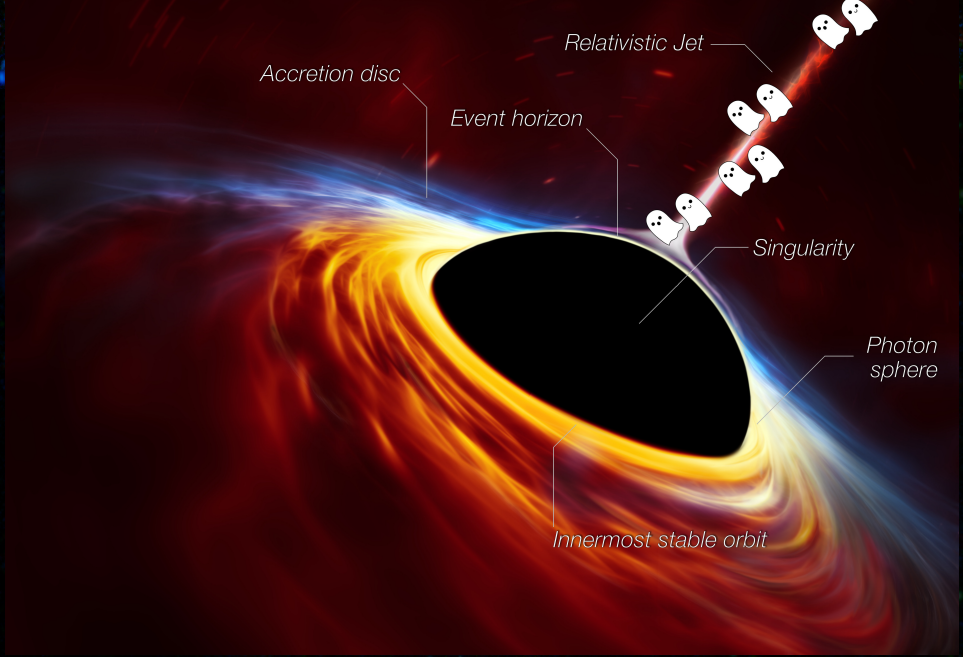
Very lightweight	✓	✓
Different types	✓	✓
Spirit	✗	✓
Seen in the Antarctic	✓	?

https://oceanwide-expeditions.com/blog/seven-frightfully-fun-polar-ghost-stories

Black holes and ghost particles?




Relativistic Jet
Accretion disc
Event horizon
Singularity
Photon sphere
Innermost stable orbit


Relativistic Jet
Accretion disc
Event horizon
Singularity
Photon sphere
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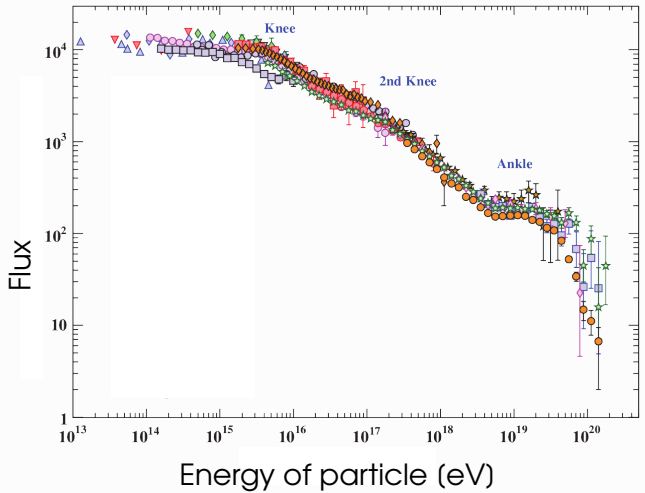
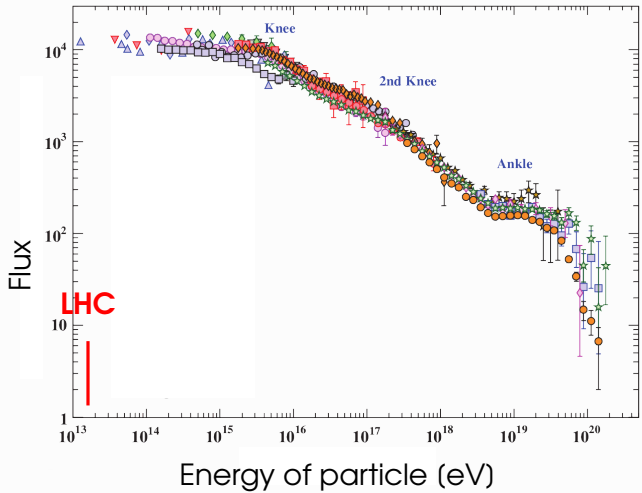
Mannheim et al. (1993, 1995)

Cosmic Rays



Tanabashi et al. (2018)

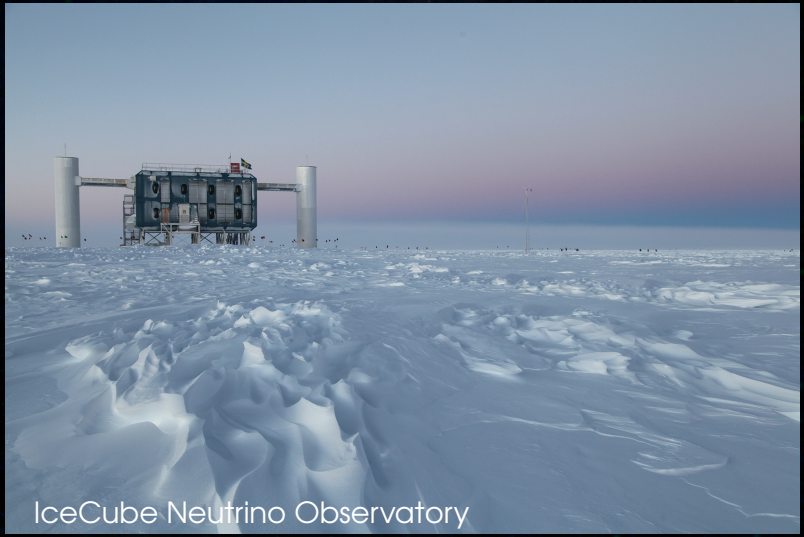
Cosmic Rays



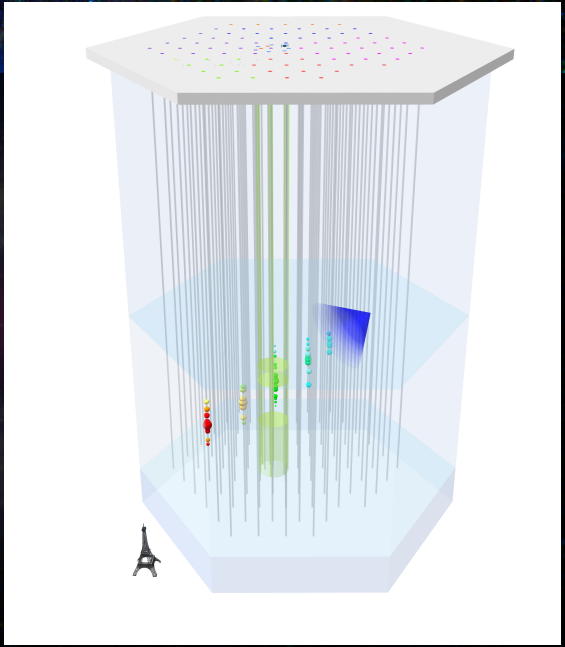
Tanabashi et al. (2018)

Who you gonna call?

Who you gonna call?



Ghost(-particle) busters!



1.75 miles = 2.8 km depth

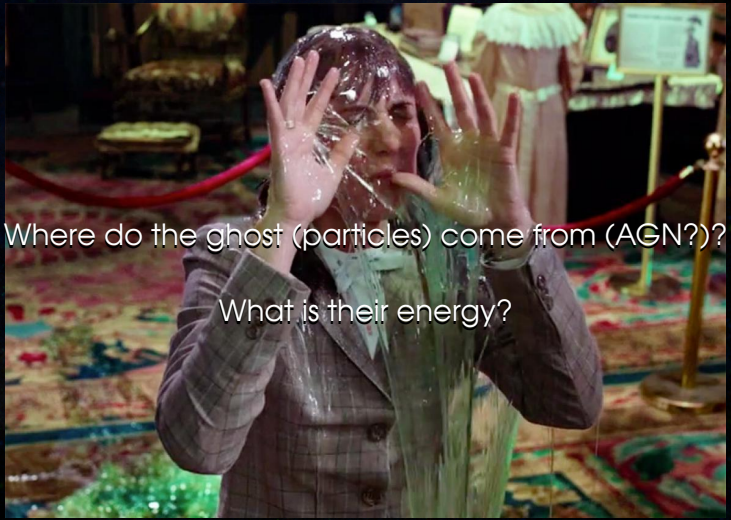
GHOST(-PARTICLE) BUSTERS!

Ectoplasm

Cherenkov light

©Sony Pictures

GHOST(-PARTICLE) BUSTERS!



©Sony Pictures

SUPERMASSIVE BLACK HOLES & PARTICLE ACCELERATION

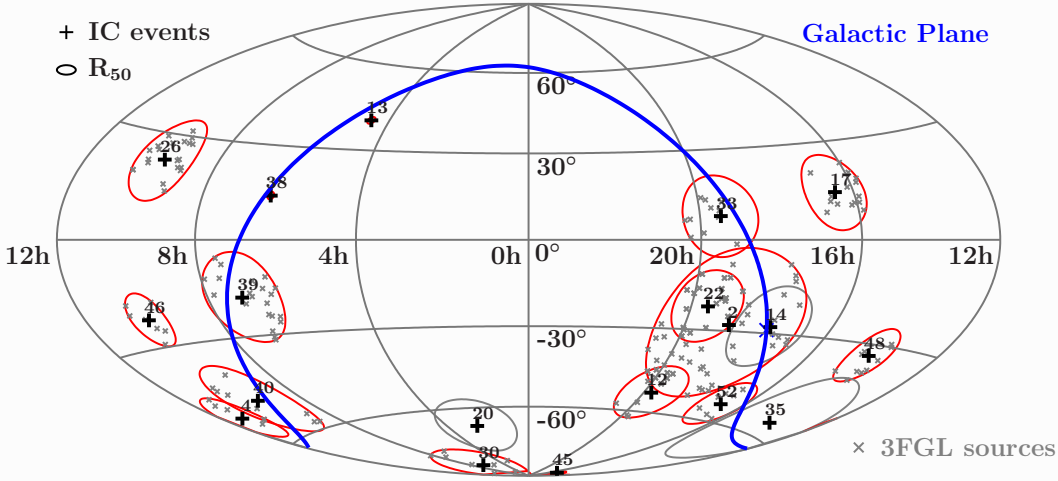
How powerful is black hole particle acceleration?

How powerful is black hole particle acceleration?

How do jets affect galaxy evolution and cluster dynamics?

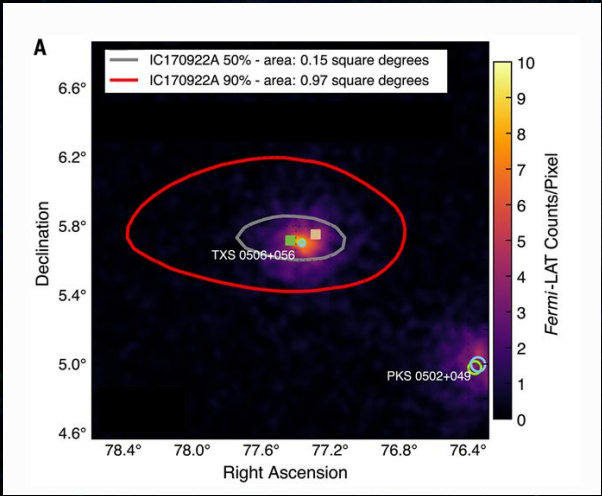
Identify neutrino counterparts: IceCube-190331A

IceCube events



(Krauß et al. 2018, A&A 620, A174)

TXS 0506+056 & IceCube170922A



(IceCube Collaboration, Fermi-LAT Collaboration et al. 2018, Science 361, eaaat 1378)

TXS 0506+056 & IceCube 170922A

One of the first blazar-neutrino connections

Low "signalness" of $\sim$50%

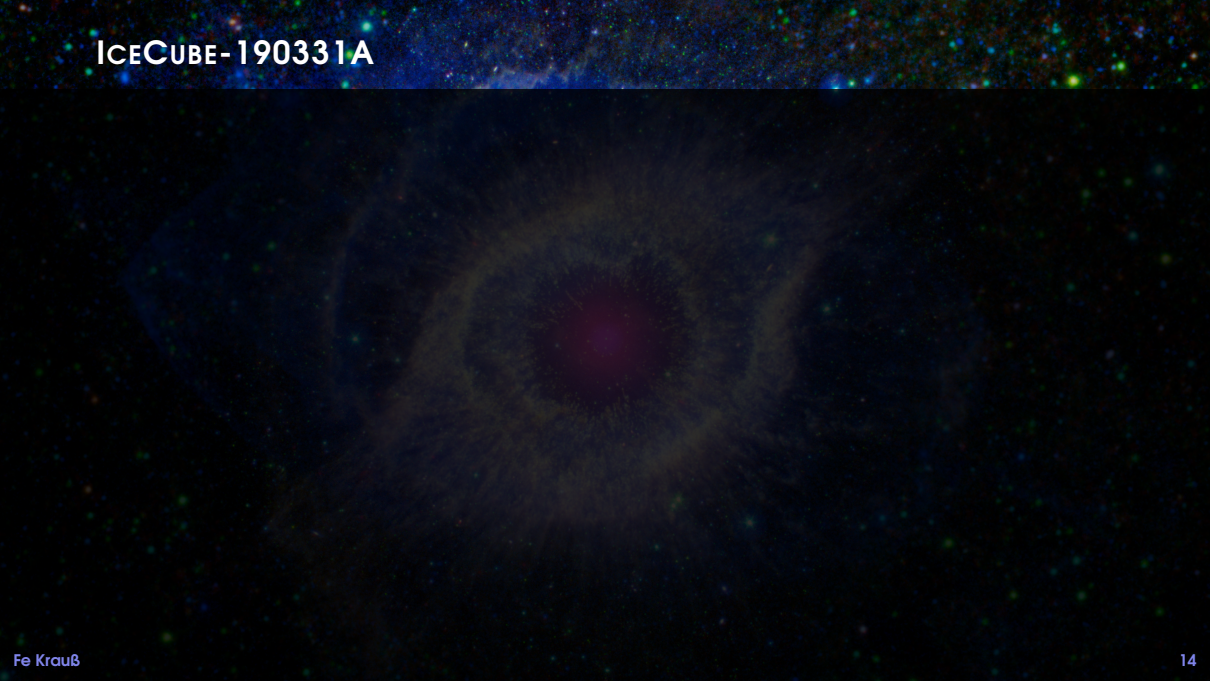
TXS 0506+056 & IceCube 170922A

One of the first blazar-neutrino connections

Low "signalness" of $\sim$50%

Do all AGN accelerate protons and produce neutrinos?
At which energies?

IceCube-190331A



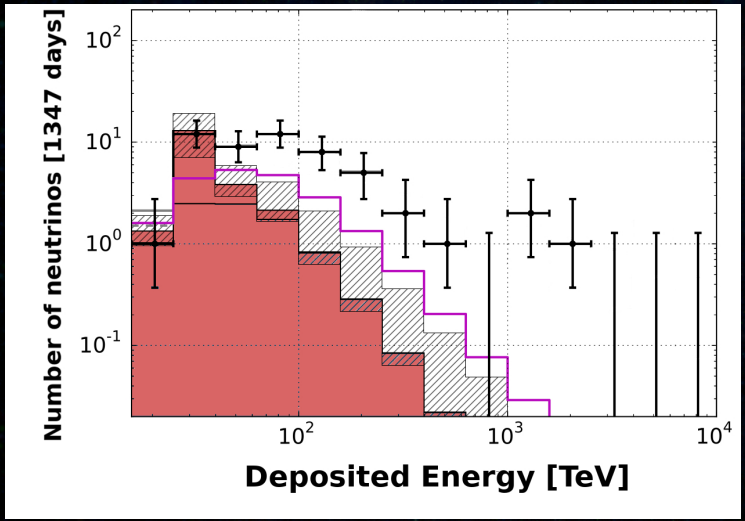
IceCube-190331A

ν_μ with E "several PeV"

$r_{90} \sim 0.^\circ 3$

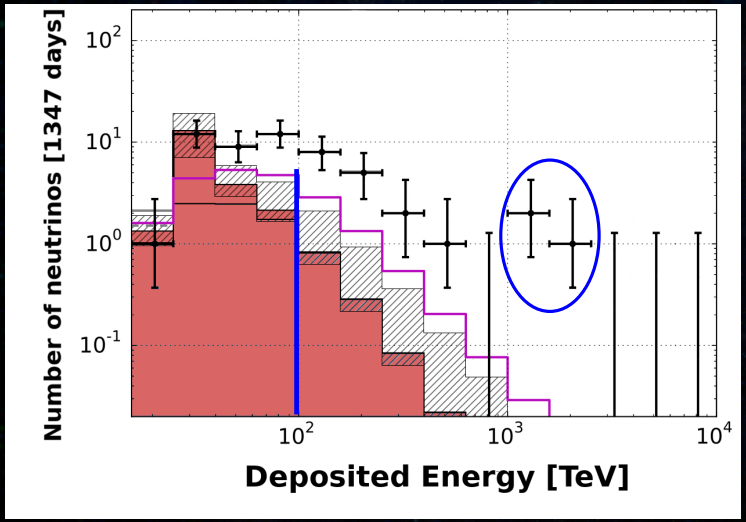
signalness: unpublished, but likely $p_{\text{astro}} \gtrsim 95\%$

IceCube190331A



IceCube Collaboration (2013, 2013, 2014, 2015)

IceCube190331A



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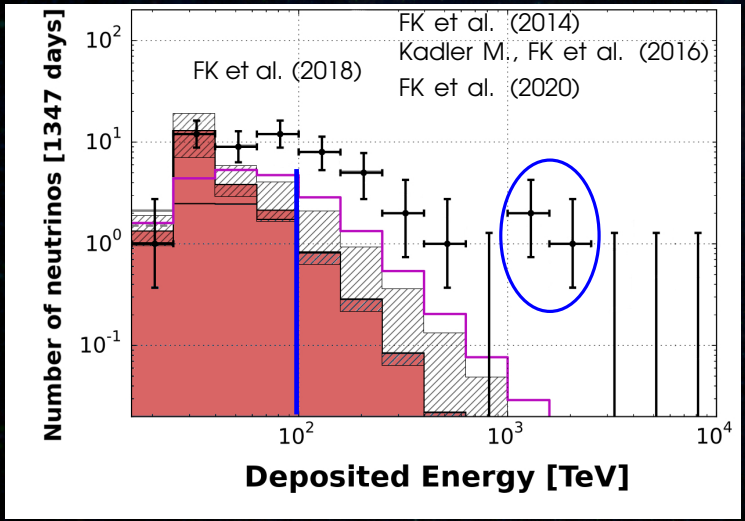
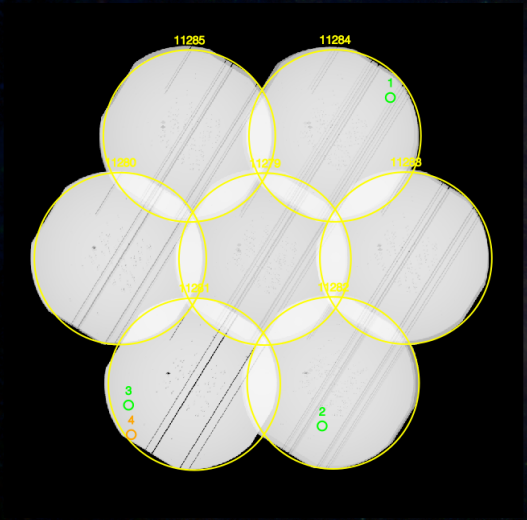


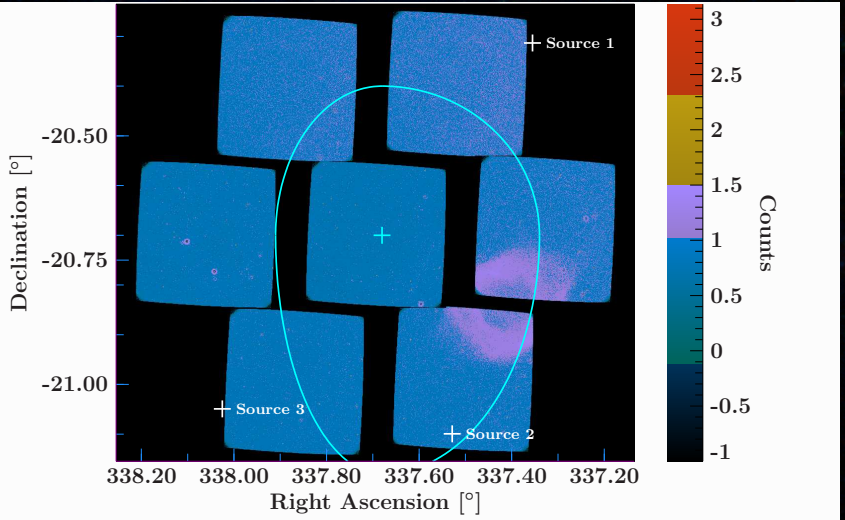
IceCube Collaboration (2013, 2013, 2014, 2015)

IceCube190331A: AMON follow-up



FK et al. (2020)

IceCube190331A: AMON follow-up



FK et al. (2020)

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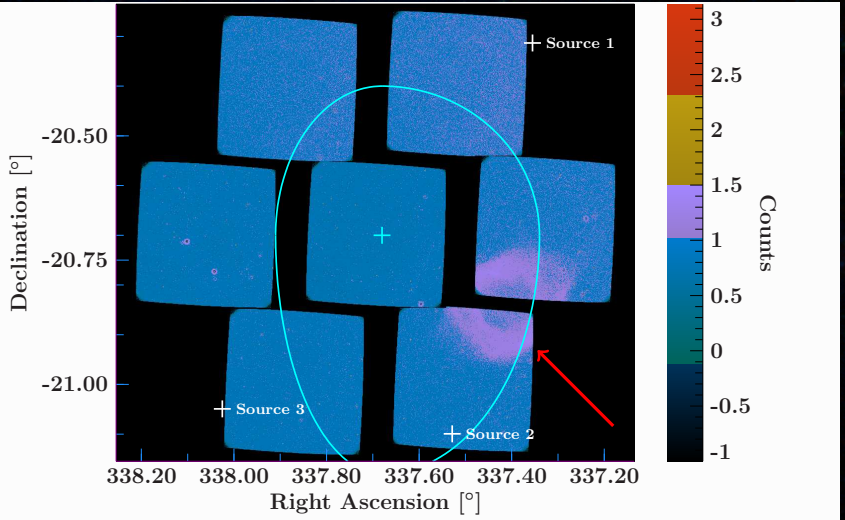
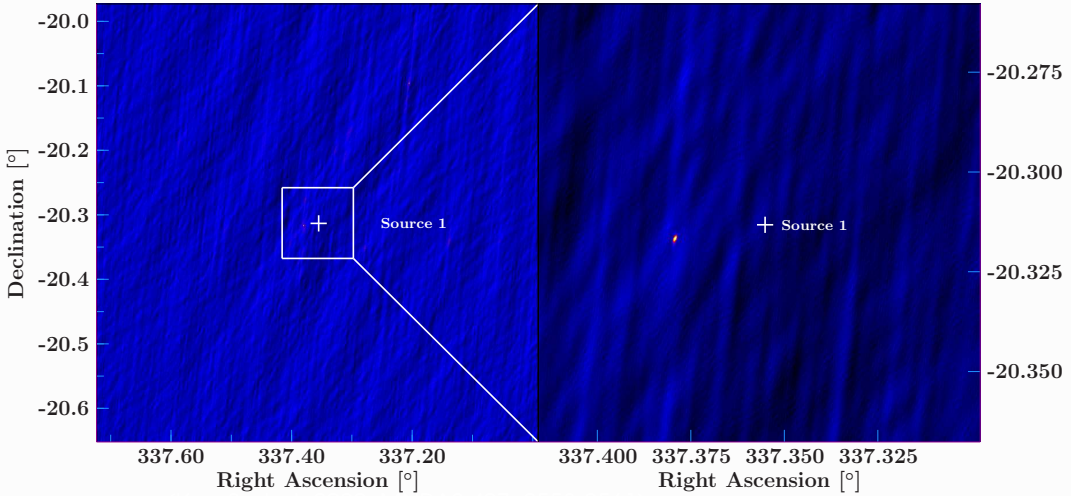


FK et al. (2020)

ATCA FOLLOW-UP



ATCA AND *Fermi*/LAT FOLLOW-UP

No γ-ray counterpart

No radio bright counterpart

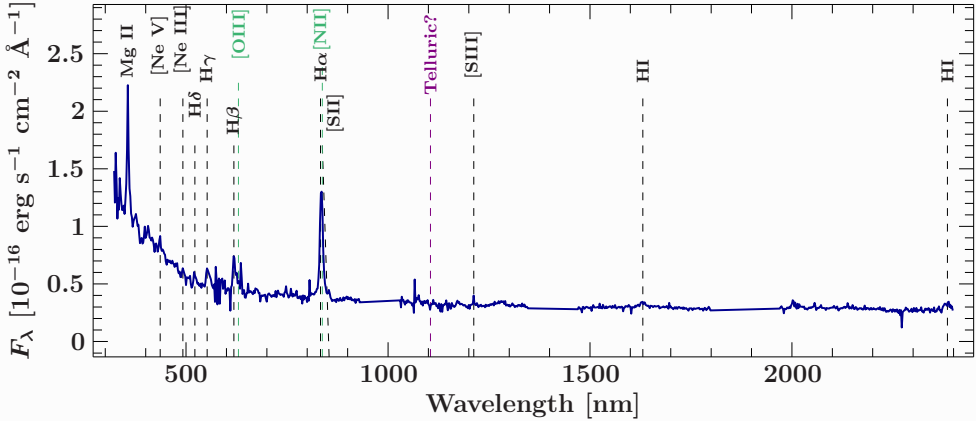
ATCA AND *Fermi*/LAT FOLLOW-UP

No γ-ray counterpart

No radio bright counterpart

$\rightarrow$ Radio-quiet AGN as dominant source counterparts?

VLT/X-Shooter follow-up



(Krauß et al. 2020, MNRAS 497, 2553-2561)

Conclusions IceCube-190331A

- IceCube-190331A: no obvious counterpart
- X-ray/multiwavelength follow-up of neutrino track events
- Possible radio-quiet contribution to IceCube neutrinos

Identify neutrino counterparts: IceCube-200615A

IceCube-200615A

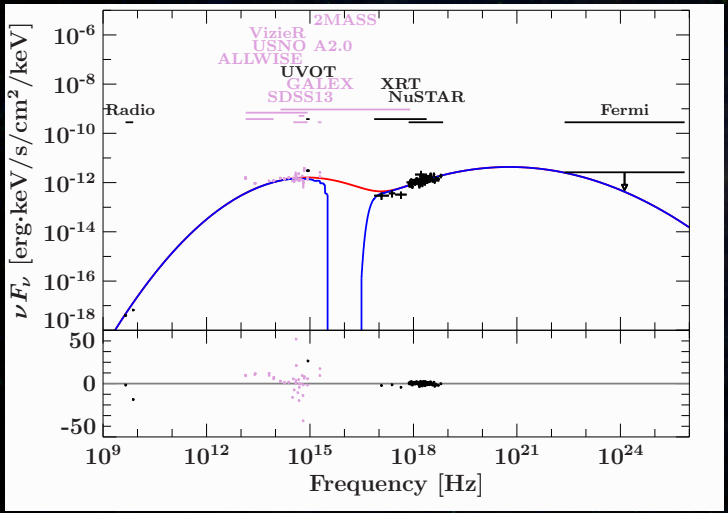
ν_μ with $E = 496\,\mathrm{TeV}$

$r_{90} \sim 1.^\circ 2$

signalness: 82.8%

Ongoing project with undergraduate (BSc) student Grant Temple.

IceCube-200615A



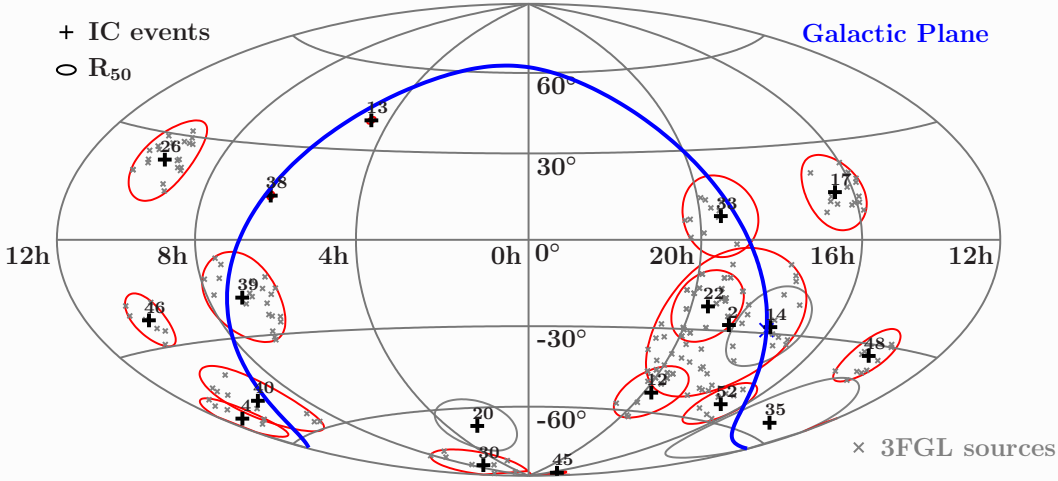
SED: Grant Temple, preliminary result.

one of the fastest *NuSTAR* follow-ups

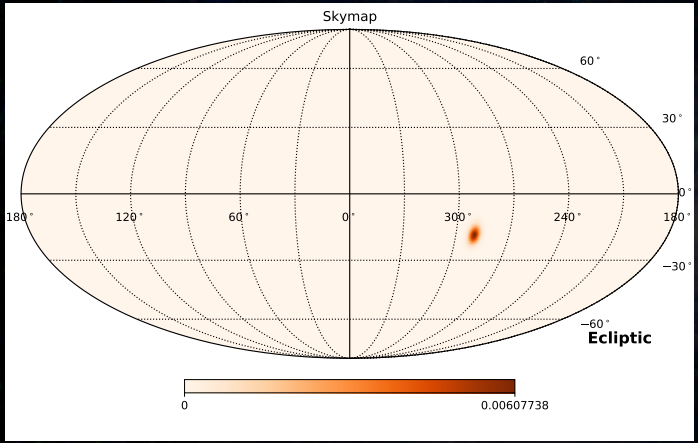
VLA follow-up

Temple, FK et al., in prep.

Cascades


+ IC events
R50
Galactic Plane
60°
30°
0°
-30°
-60°
12h
8h
4h
0h
20h
16h
12h
× 3FGL sources

Cascades



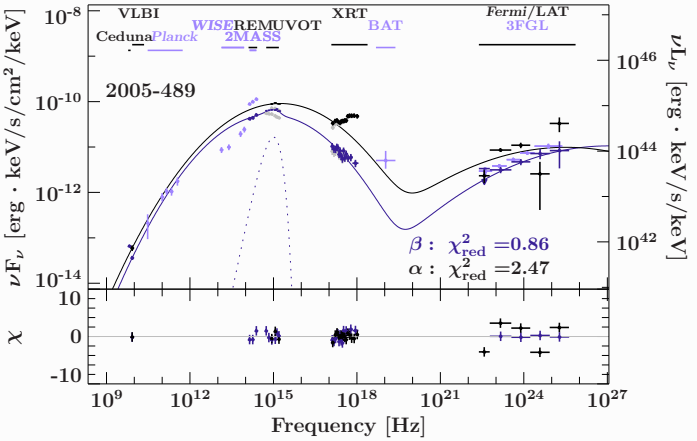
Re-analysis of Cascade events by Timothée Gregoire (PSU): machine learning (DNN)

https://arxiv.org/pdf/2101.11589.pdf

Nicholas Craft: Follow-up of two neutrino events

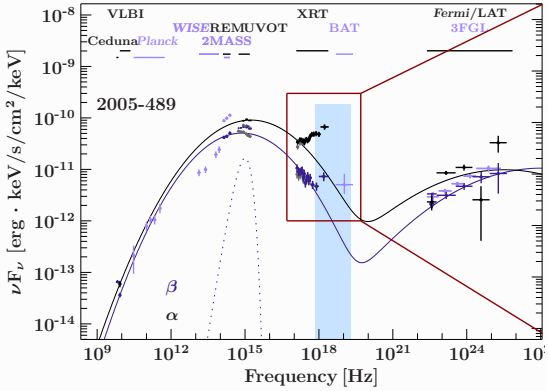
Understanding jet physics
PKS 2005−489

The peculiar SED of PKS 2005−489



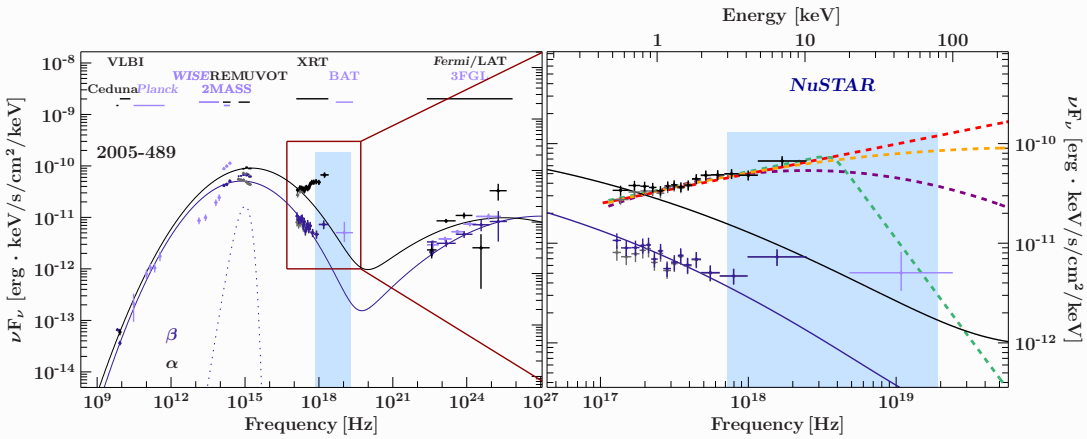
FK et al. (2016)

The peculiar SED of PKS 2005−489



FK et al. (2016)

The peculiar SED of PKS 2005−489



FK et al. (2016)

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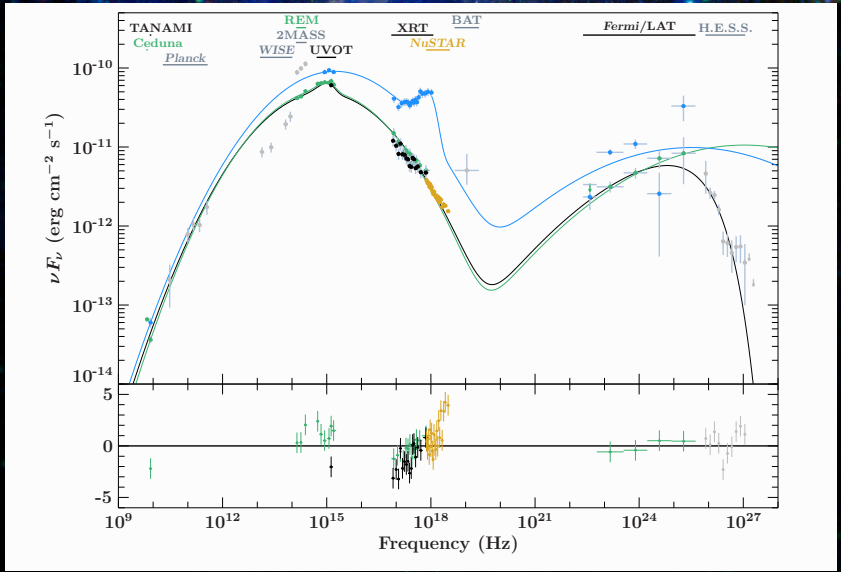
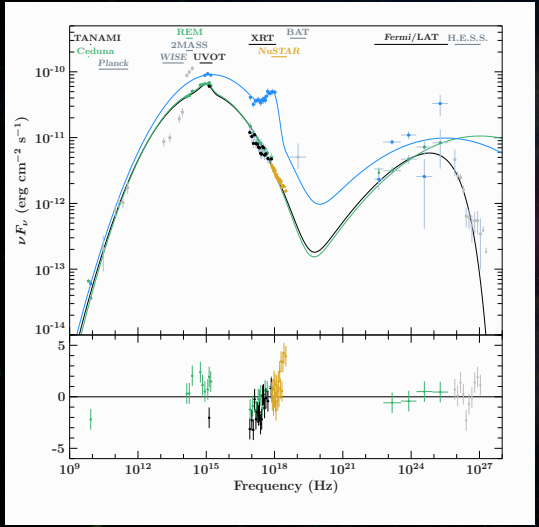


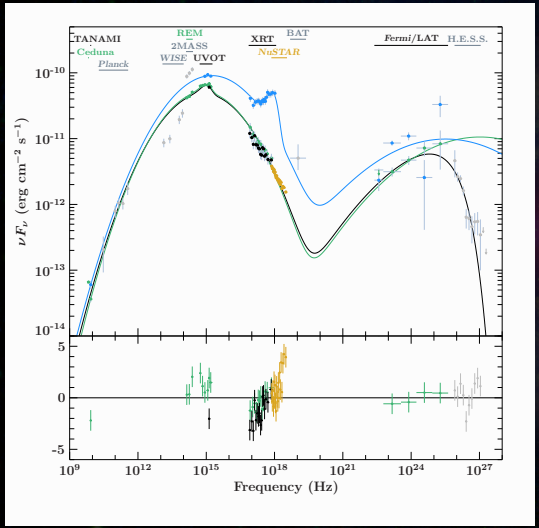
The peculiar SED of PKS 2005−489



preliminary SED: Owen Chase

Chase, FK et al., in prep.

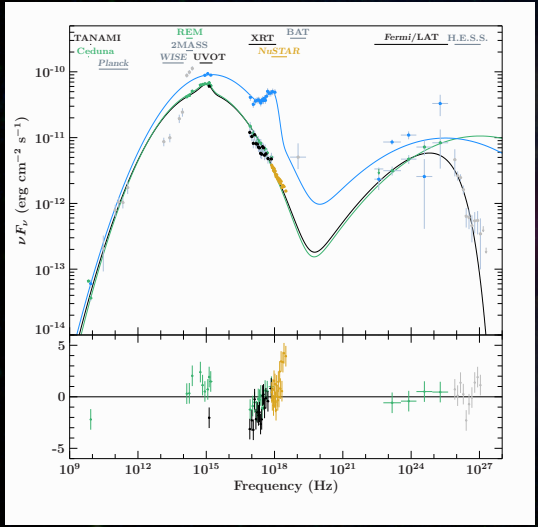
The peculiar SED of PKS 2005−489



Unusual SED in high state

Additional component?
Hadronic component?
Detector problem?

The peculiar SED of PKS 2005−489



Unusual SED in high state

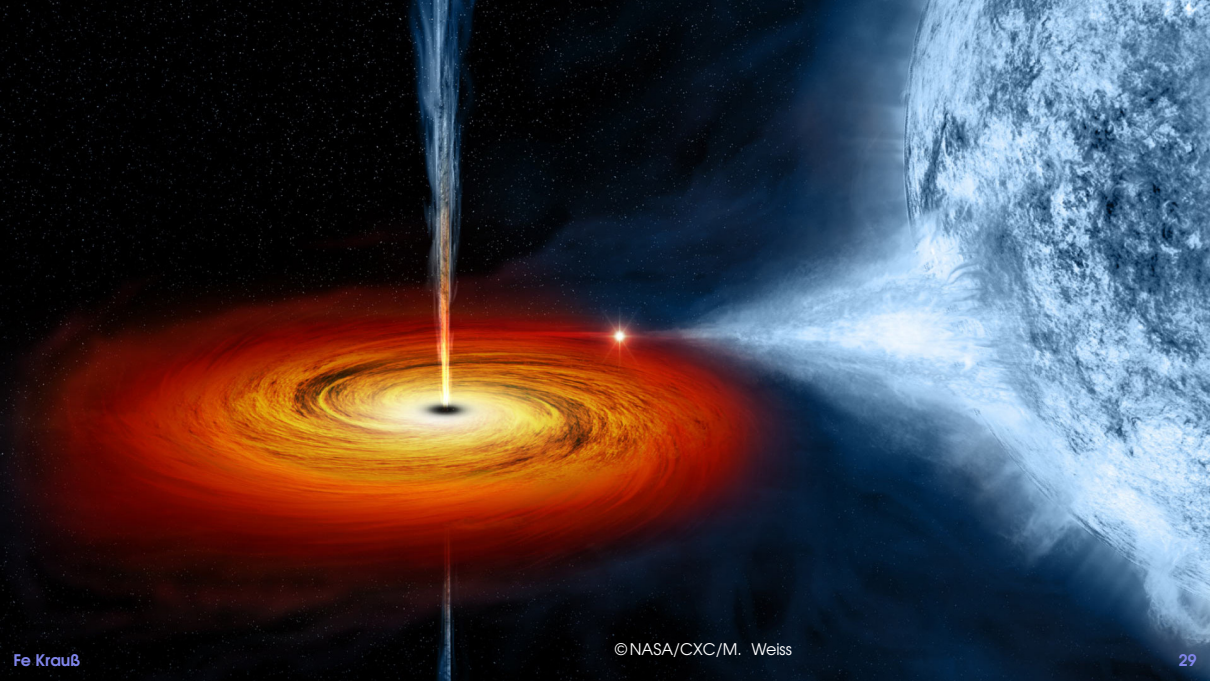
Additional component?
Hadronic component?
Detector problem?

→ Need X-ray observation in high state

Particle acceleration near supermassive black holes

Particle acceleration near supermassive black holes

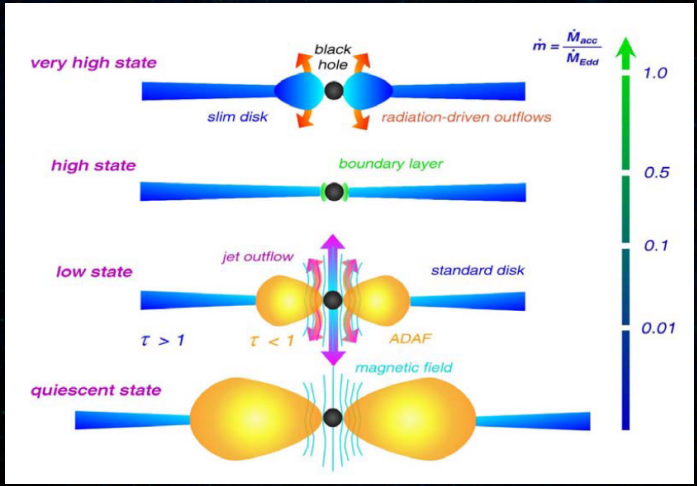
Accretion disk

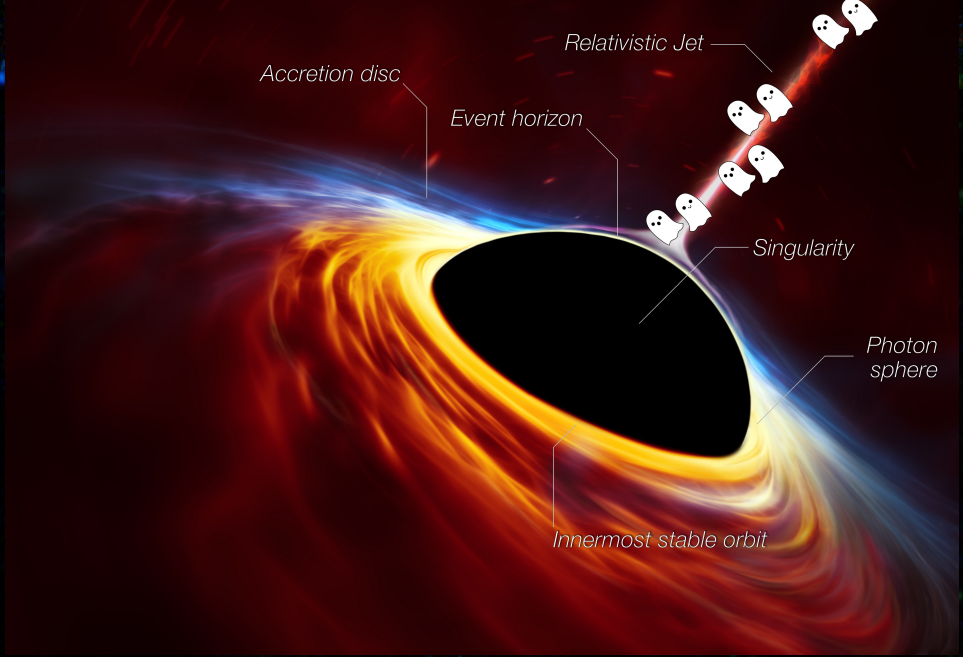


©NASA/CXC/M. Weiss

What are accretion disks

Disks vs $\dot{M}$




Relativistic Jet
Accretion disc
Event horizon
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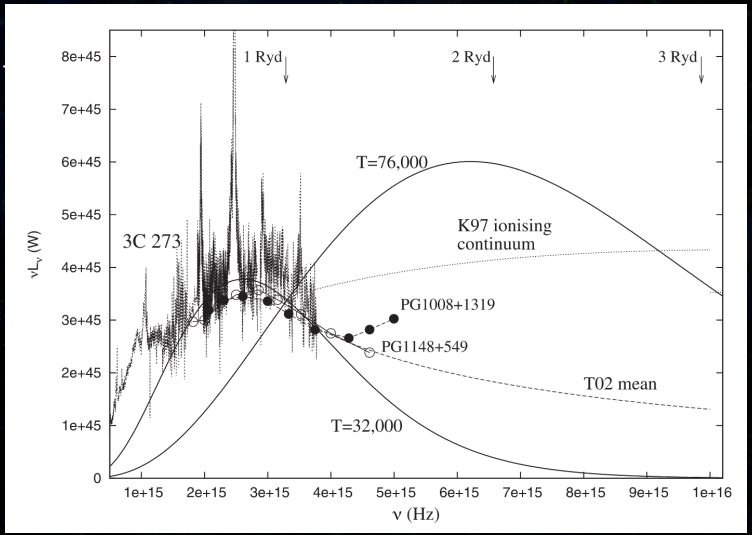
Temperature problem

QUASAR DISKS



Temperature problem

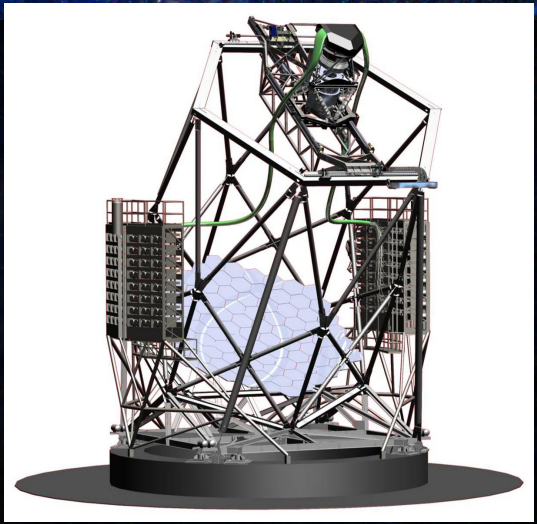
Clouds at 30 R_S: reprocessed emission (UV variability)

inhomogeneous structure at different radii

Lawrence (2012)

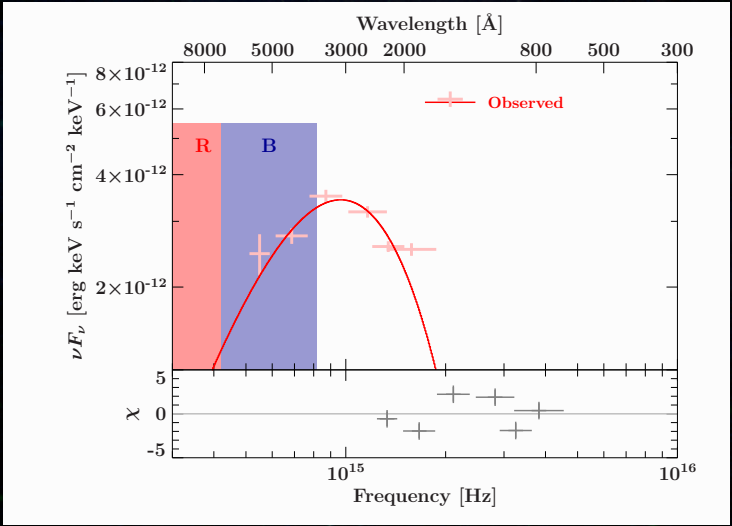
Hobby-Eberly Telescope (McDonald Observatory)
10 m
Main mirror is at 55° angle.

HET/VIRUS: Visible Integral-field Replicable Unit Spectrographs



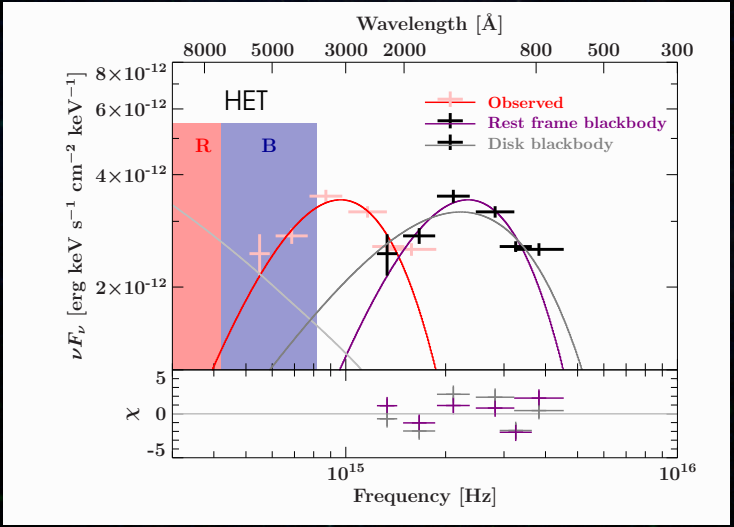
150 identical fiber fed optical spectrographs

HET EXPECTATION

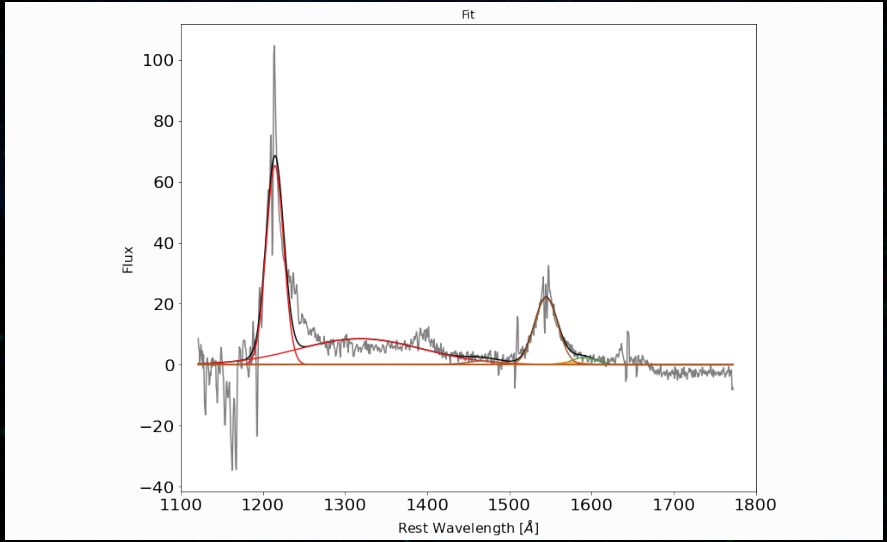


FK et al. (2016)

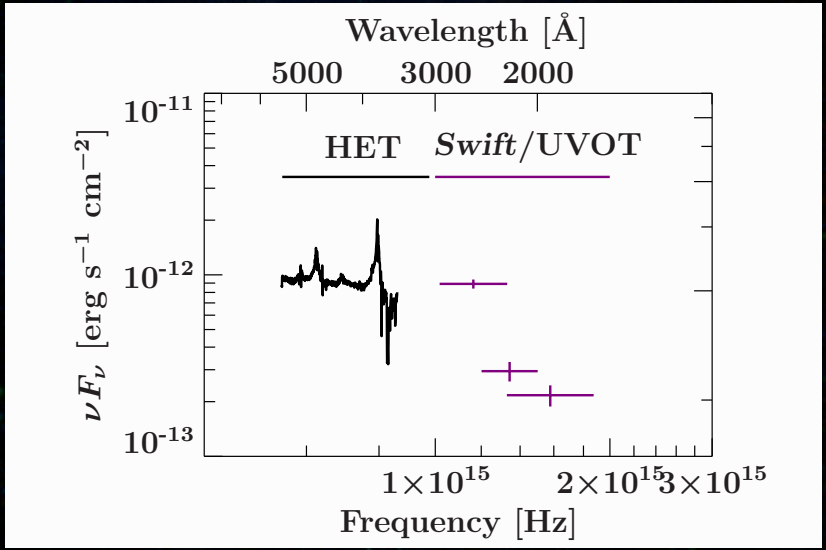
HET EXPECTATION



HET Preliminary fit



Simultaneous HET/VIRUS + *Swift*/UVOT



HET Preliminary fit

No spectral curvature

Additional data for 4 sources with simultaneous UVOT data

M_{BH} from C IV

FK, Eracleous M., Fox D. et al. in prep.

Conclusions accretion disk

Swift/UVOT data not sufficient in describing optical shape?

High quality optical spectrum constrains redshift, M_{BH}, continuum curvature

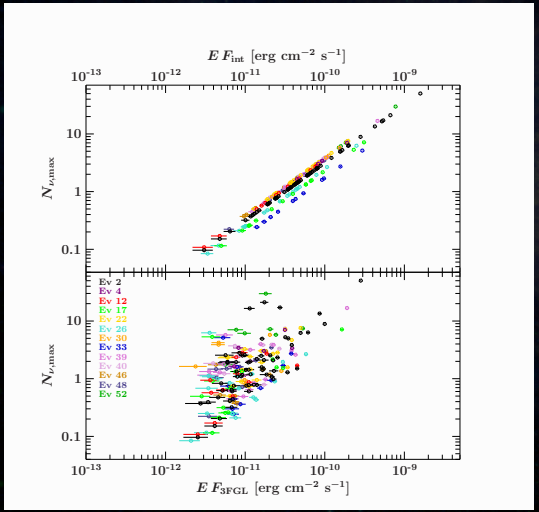
Conclusions

Jetted/non-jetted AGN as neutrino counterparts?

Getting closer to finding cosmic ray sources

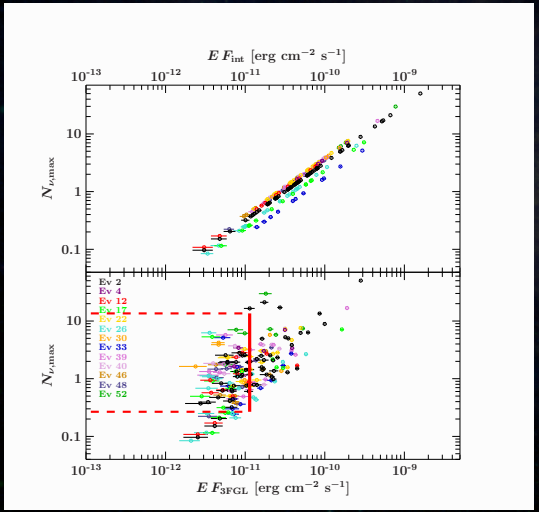
Better understanding of jet physics

Correlation with γ-ray flux



FK et al. (2018)

Correlation with γ-ray flux



FK et al. (2018)

Neutrino numbers

$N_{\nu,\mathrm{max,all}} = 493$
$N_{\nu,\mathrm{spec,all}} = 97$
$N_{\nu,\mathrm{f,all}} = 24.13$

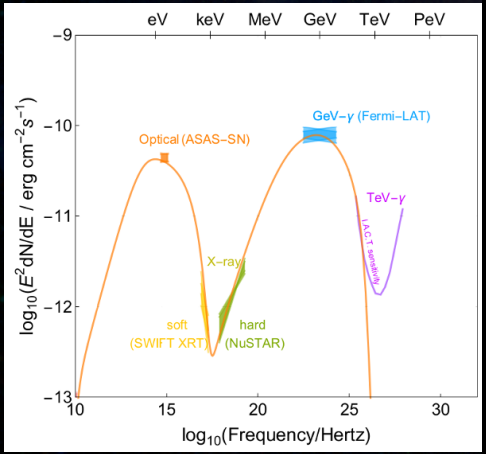
6 cosmic events (/16): 25% of emission hadronic

Highest expected # neutrino: PKS 1830−211: 2.7
Only 2 sources above 1 ν

FK et al. (2018)

X-RAY OBSERVATIONS & HADRONICNESS

Leptonic modeling



(Gao et al. 2019, Nature Astronomy 3, p.88-92)

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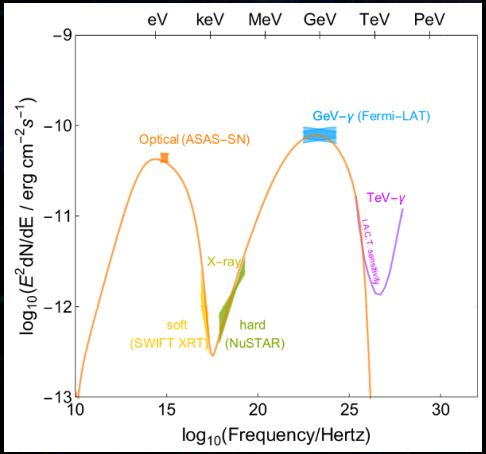

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\+ explains data well

– cannot explain neutrino

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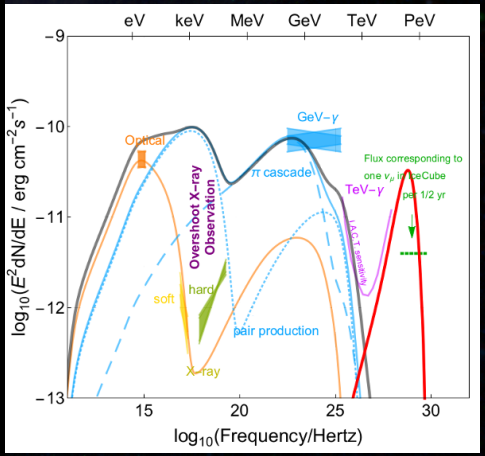
Hadronic modeling



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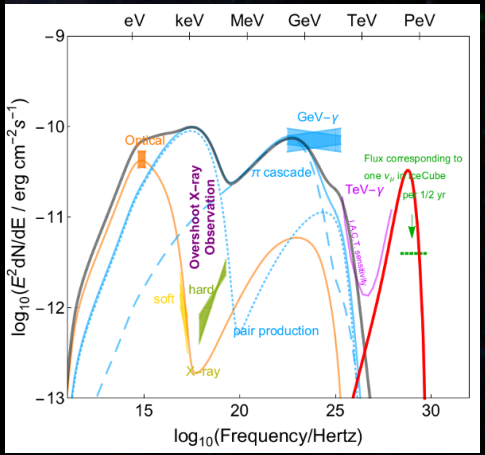

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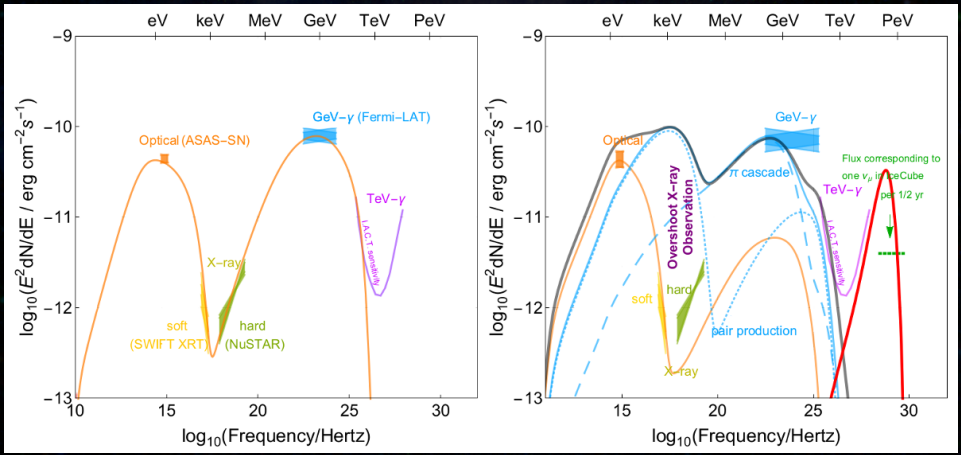

X-RAYS CONSTRAIN HADRONIC CONTRIBUTION & NEUTRINO FLUX!