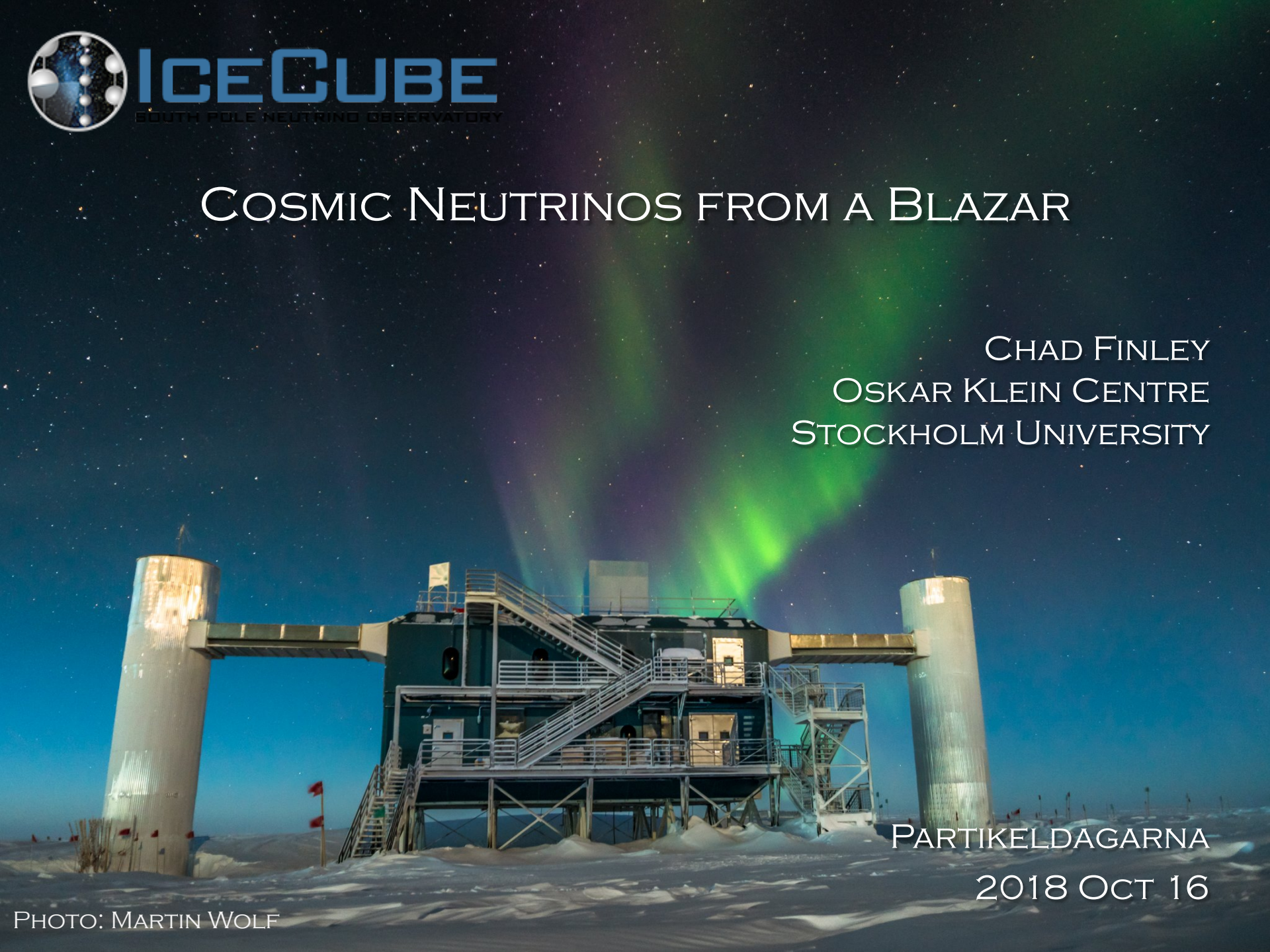


Cosmic Neutrinos from a Blazar

Chad Finley
Oskar Klein Centre
Stockholm University

Partikeldagarna
2018 Oct 16

Photo: Martin Wolf

First Evidence of a high-energy Neutrino Point Source

Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert

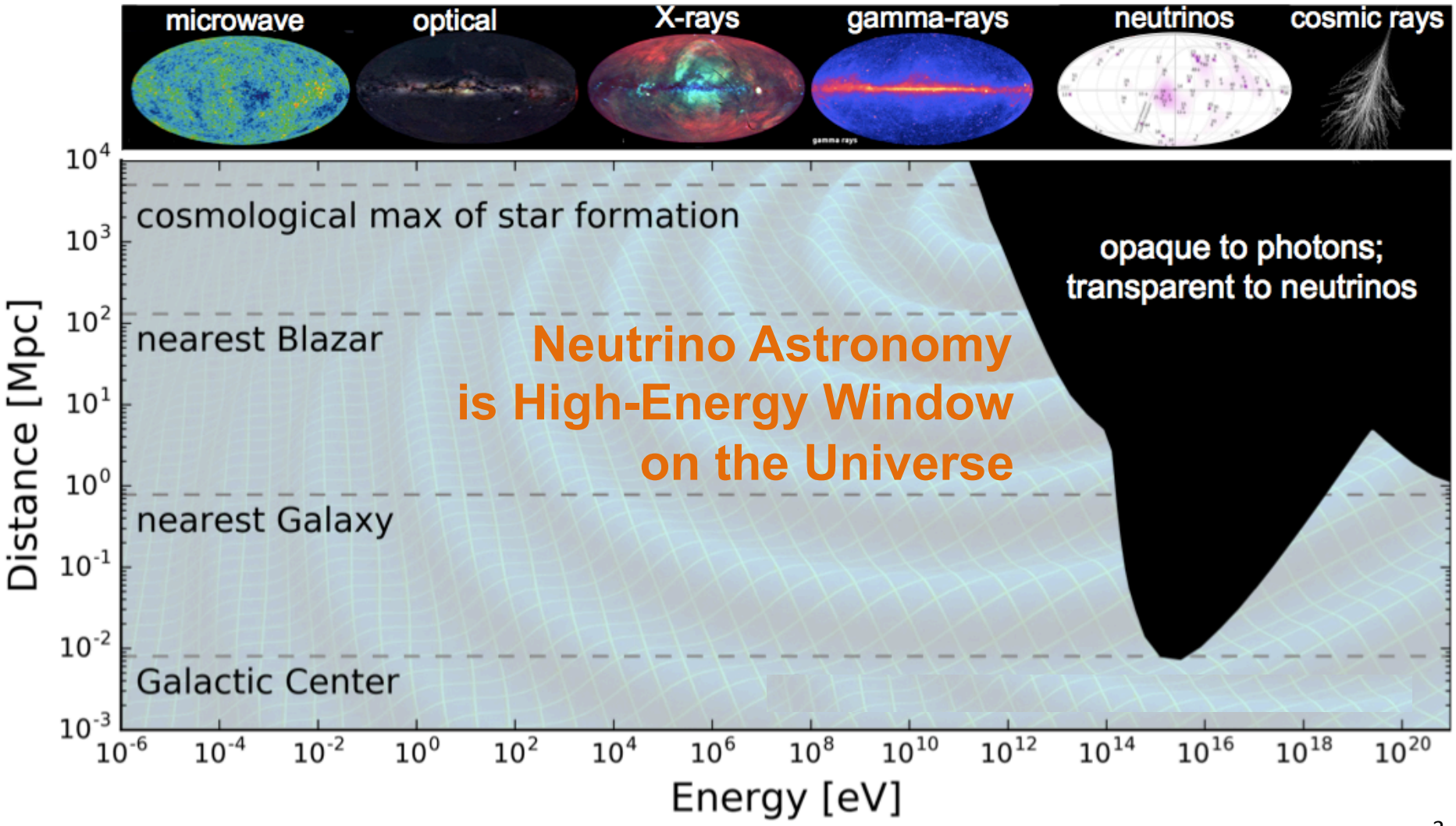
IceCube Collaboration*†

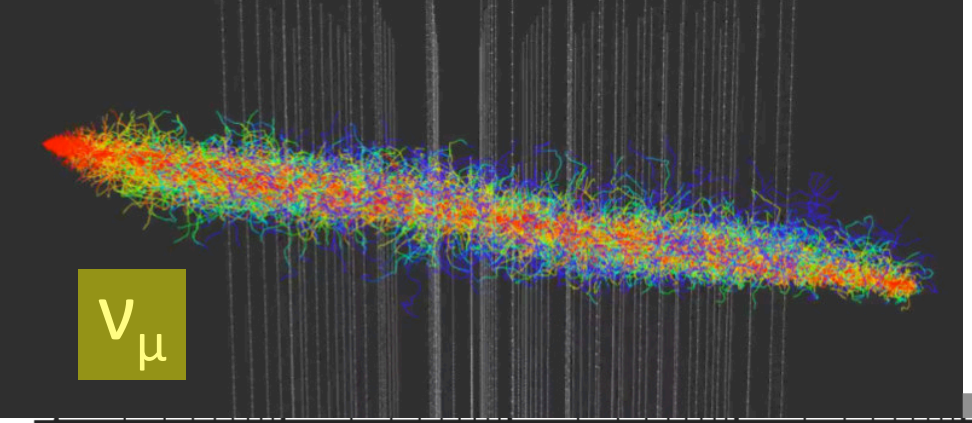
July 2018

Why should neutrino sources exist?

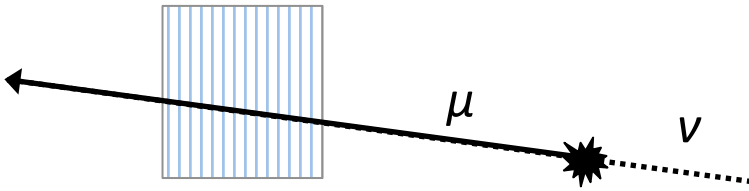
Cosmic rays (protons, nuclei) --- up to 10^{20} eV -- exist. Sources unknown.

Neutrinos expected from sources: $p + \gamma$ or $p + p \rightarrow \pi^{\pm}, \pi^{0}$, decay $\rightarrow \nu, \gamma$





measured $E_{muon} < E_{neutrino}$



ApJ 833(2016)1,3
2012-2015 sample

Background Atmospheric Neutrinos
~ 70 000 neutrinos / year

$E^{-2.1}$ astrophysical
neutrino flux
(~ 100 neutrinos / year)

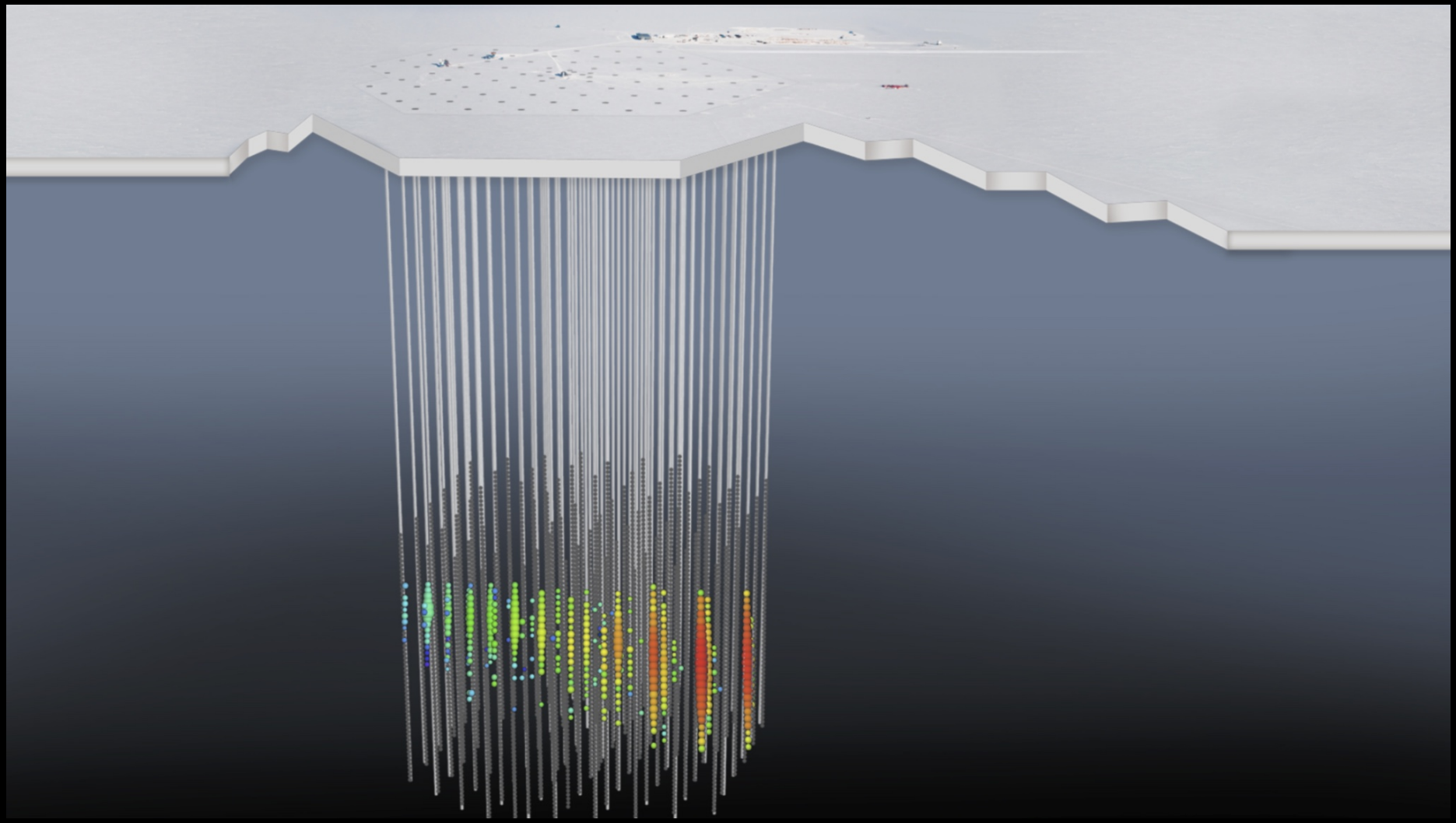
10^3 10^4 10^5 10^6 10^7

Muon Energy Proxy/GeV

Above 100 TeV, an all-sky astro-physical neutrino flux is observed in multiple channels at > 5σ.

Here is how it appears in the muon-neutrino channel.

2017 September 22



Realtime Public Alert Program:

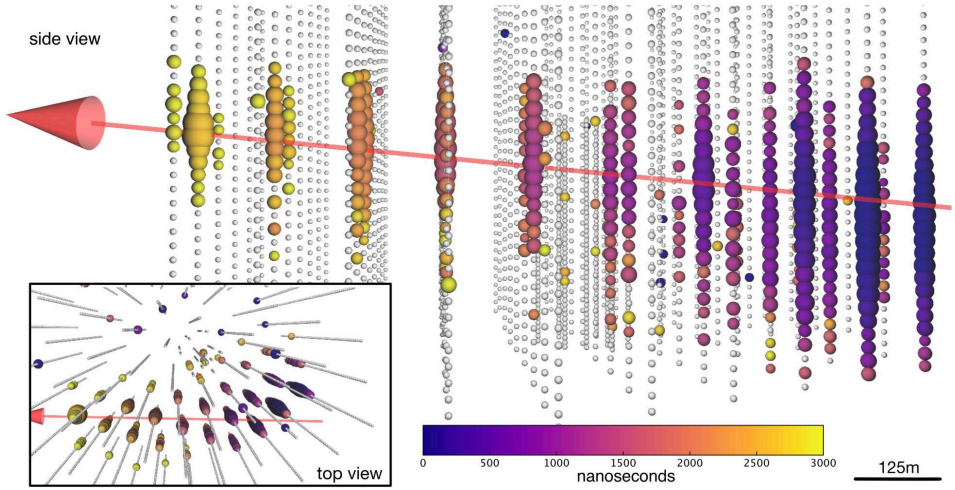
- Began in April 2016
- 4-8 alerts per year
- Transmitted via GCN
  (Gamma-ray Coord. Network)
- Typical latency till public alert:
  < 1 min

```
TITLE:   GCN CIRCULAR
NUMBER:  21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy
neutrino candidate event
DATE:    17/09/23 01:09:26 GMT
FROM:    Erik Blaufuss at U. Maryland/IceCube
<blaufuss@icecube.umd.edu>

Claudio Kopper (University of Alberta) and Erik Blaufuss
(University of  Maryland) report on behalf of the IceCube
Collaboration (http://icecube.wisc.edu/).

On 22 Sep, 2017 IceCube detected a track-like, very-high-energy
event with a high probability of being of astrophysical origin.
The event was identified by the  Extremely High Energy (EHE)
track event selection. The IceCube detector was in a normal
operating state. EHE events typically have a neutrino
interaction vertex that is outside the detector, produce a muon
```

IceCube-170922A:

Energy: 290 TeV (>180 TeV, 90% CL)

RA: 77.43° (-0.65°/+0.95° 90% CL)
Dec: 5.72° (-0.30°/+0.50° 90% CL)



Alert event IceCube-170922A

Date: 22 Sept 2017

IceCube-170922A

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Date: 28 Sept 2017

Fermi-LAT gamma-ray observations

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC), Daniel Kocevski (NASA/MSFC) on behalf of the Fermi-LAT collaboration*
on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Neutrino coincident with a **blazar** (with the name TXS 0506+056) while it is in a state of **enhanced gamma-ray emission**

Alert event IceCube-170922A

Date: 22 Sept 2017

IceCube-170922A

TITLE: GCN CIRCULAR
NUMBER: 21916
SUBJECT: IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
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on 28 Sep 2017; 10:10 UT
Credential Certification: David J. Thompson (David.J.Thompson@nasa.gov)

Subjects: Gamma Ray, Neutrinos, AGN

Date: 4 Oct 2017

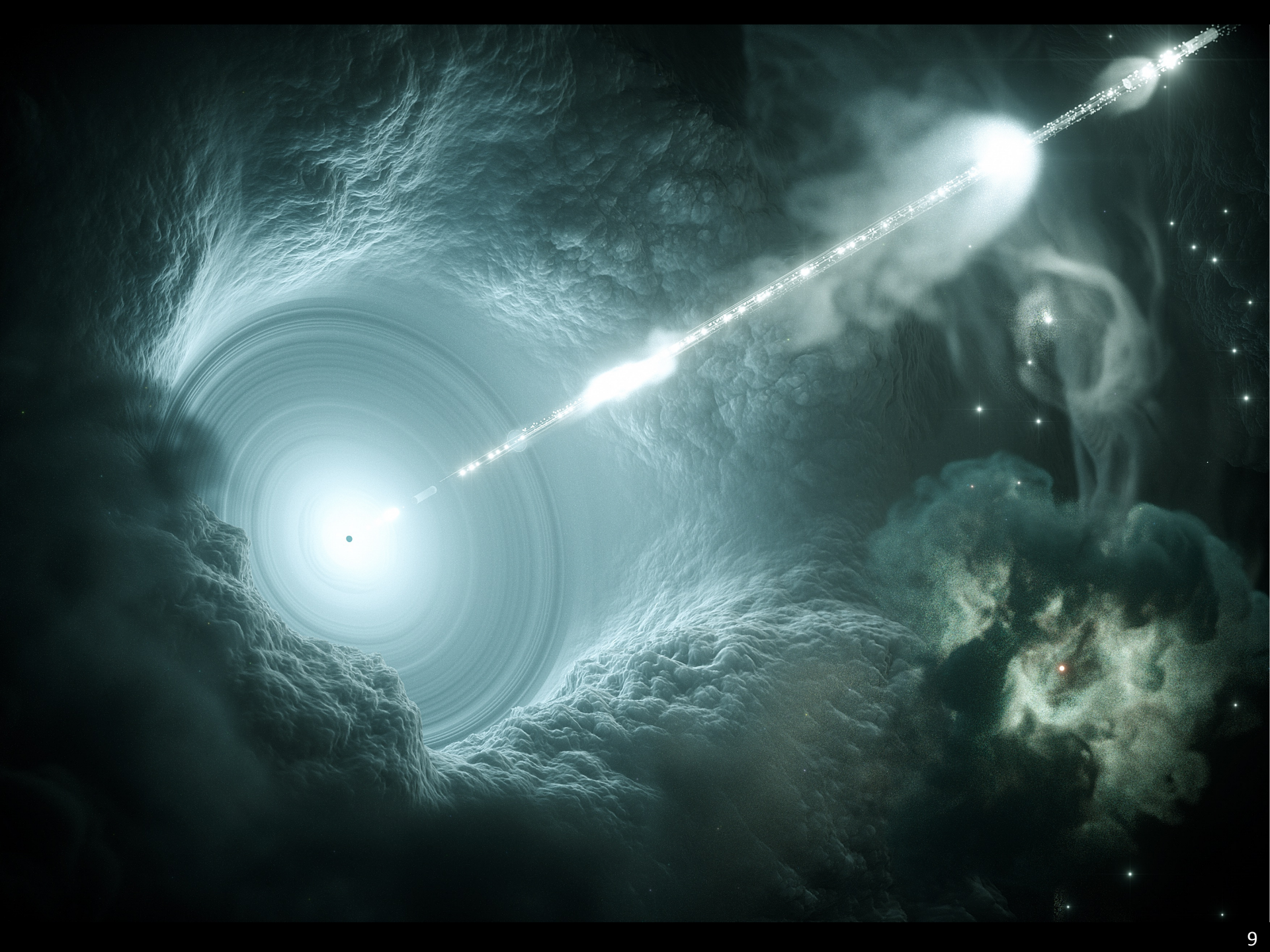
MAGIC VHE gamma-ray observations

Detection of > 400 GeV gamma rays from the blazar

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

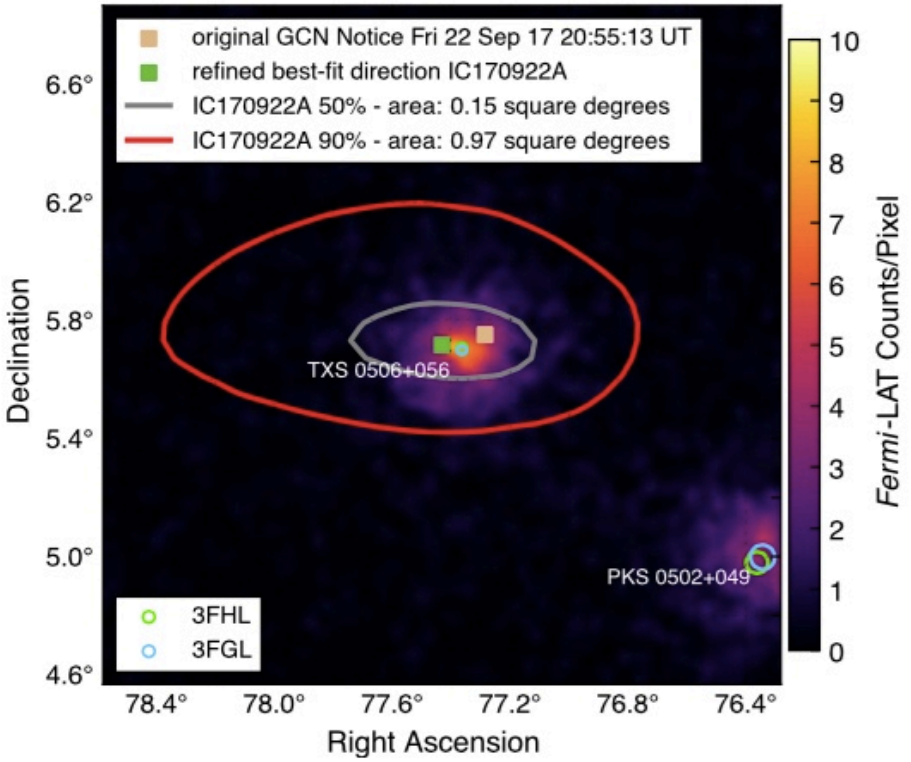
ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

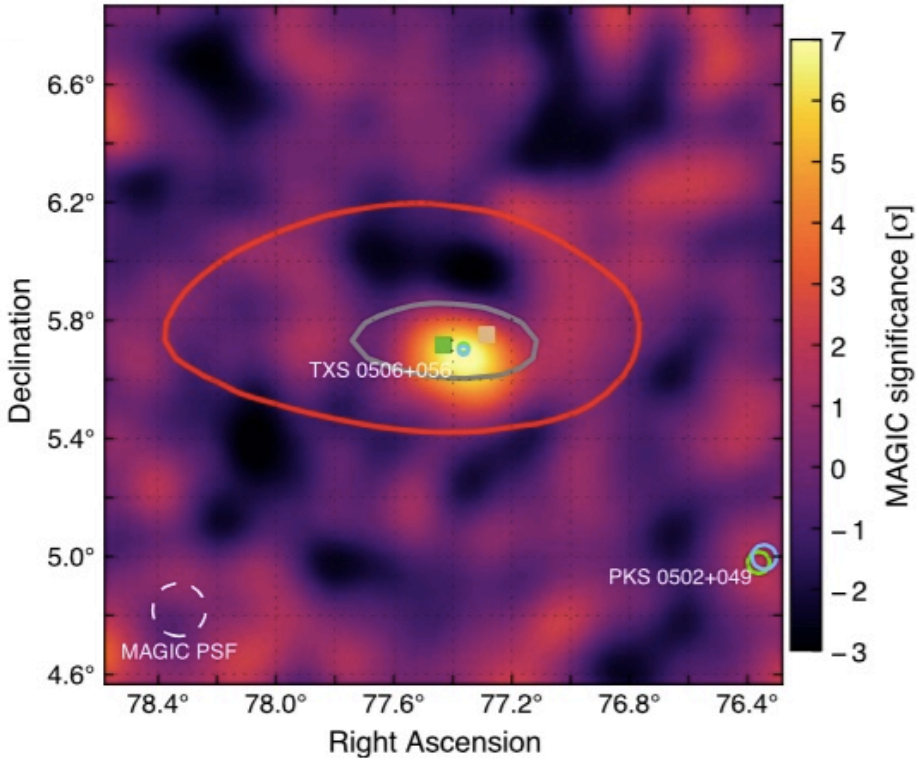


Fermi-LAT , MAGIC observations of IceCube-170922A location

IceCube + Fermi-LAT



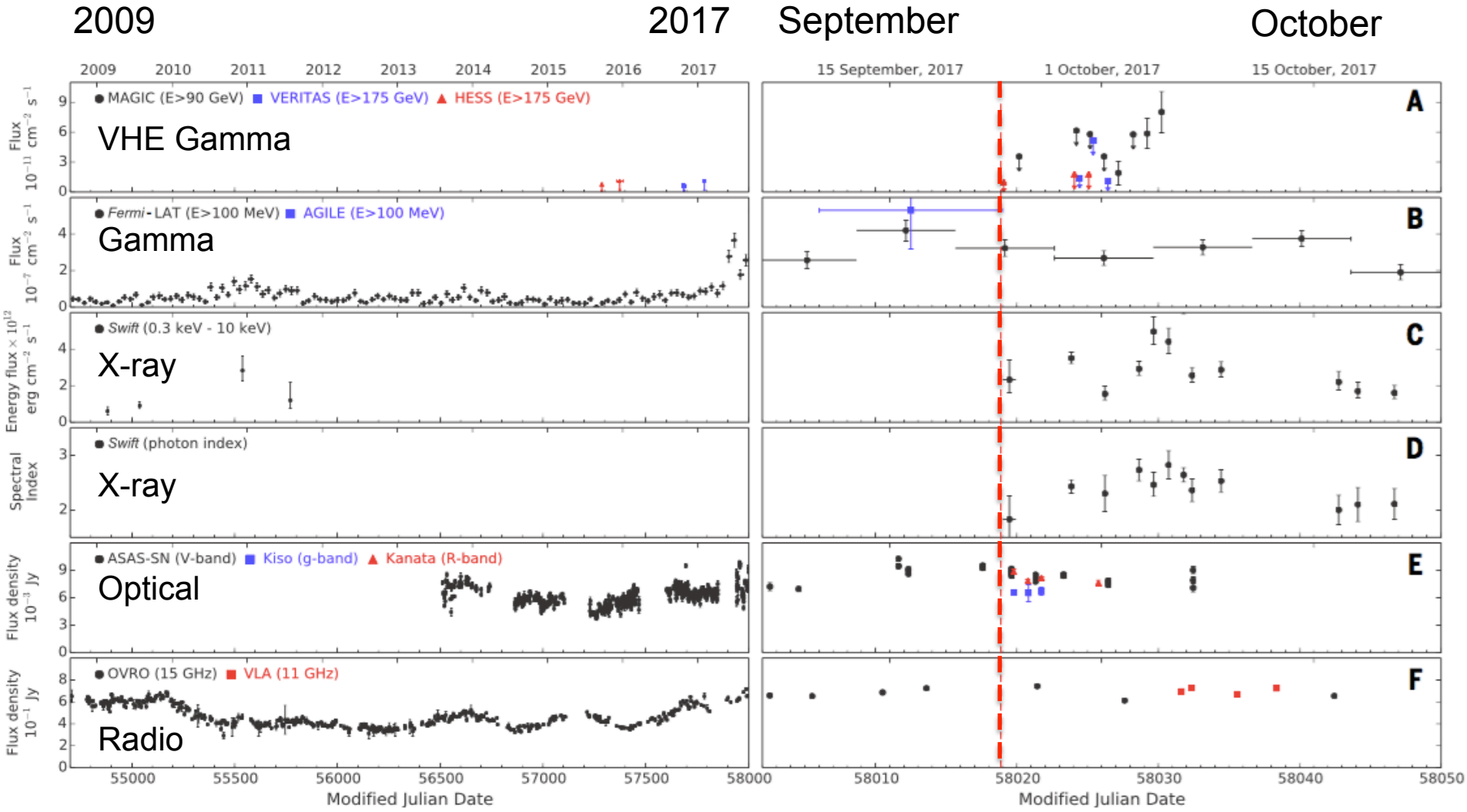
IceCube + MAGIC



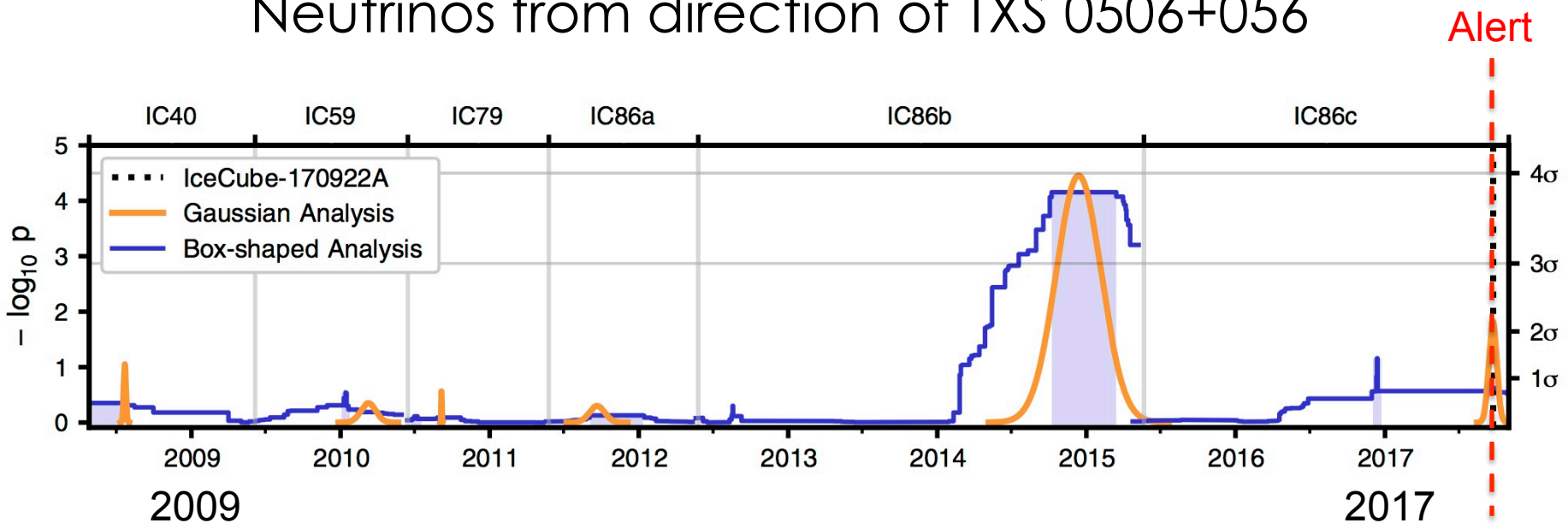
Significance of correlation of IceCube alert event with flaring blazar:

seen by Fermi: ~ 3 sigma, seen by MAGIC above 400 GeV: > 3 sigma

Time-dependent multi-wavelength observations of TXS 0506+056 before and after IceCube-170922A



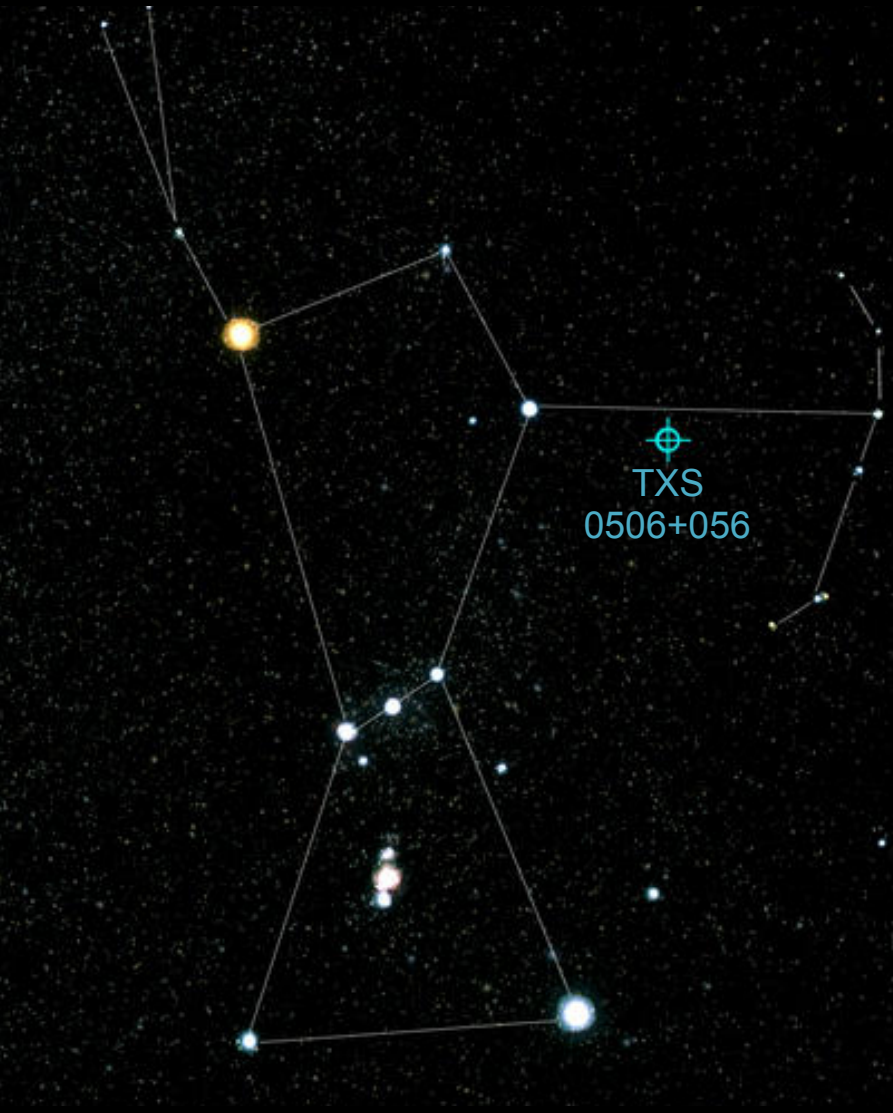
Neutrinos from direction of TXS 0506+056



Time-dependent analysis: self-clustering of events in time at TXS location

Cluster of ~13 event excess during 5-month window 2014-2015

Happens 2 times out of 10 000 by chance, 3.5 sigma



Blazars were one of earliest sources to be predicted as nu sources

Combination of independent pieces of evidence =>

Likely identification of a blazar as first source of high-energy neutrinos

But, not clear yet how all pieces of evidence fit together

Isolated example, or blazars dominant source of HE cosmic rays? UHE cosmic rays? *Not yet known…*

Data will now start to drive models