Search for neutrinos from AGN using a data-driven source selection

Sebastian Schindler

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MMS Annual Meeting 2023

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IceCube
South Pole Neutrino Observatory

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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Naturwissenschaftliche Fakultät

Evidence for neutrino sources

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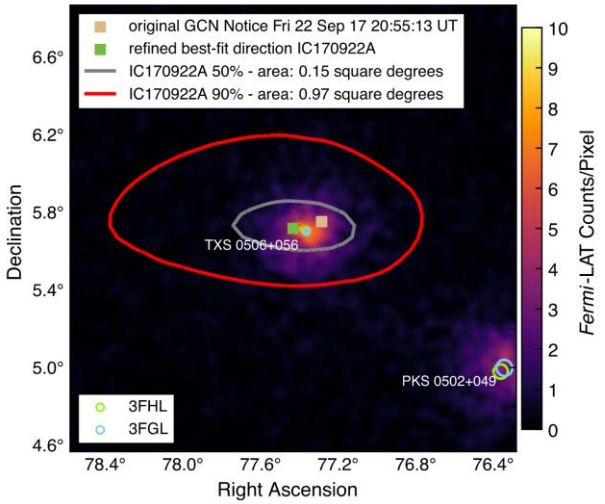
TXS 0506+056

significance: ~ 3 σ

type: ***Blazar***

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*†



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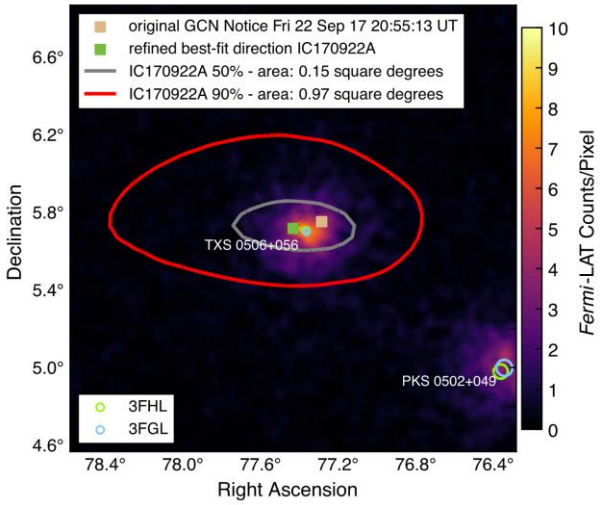
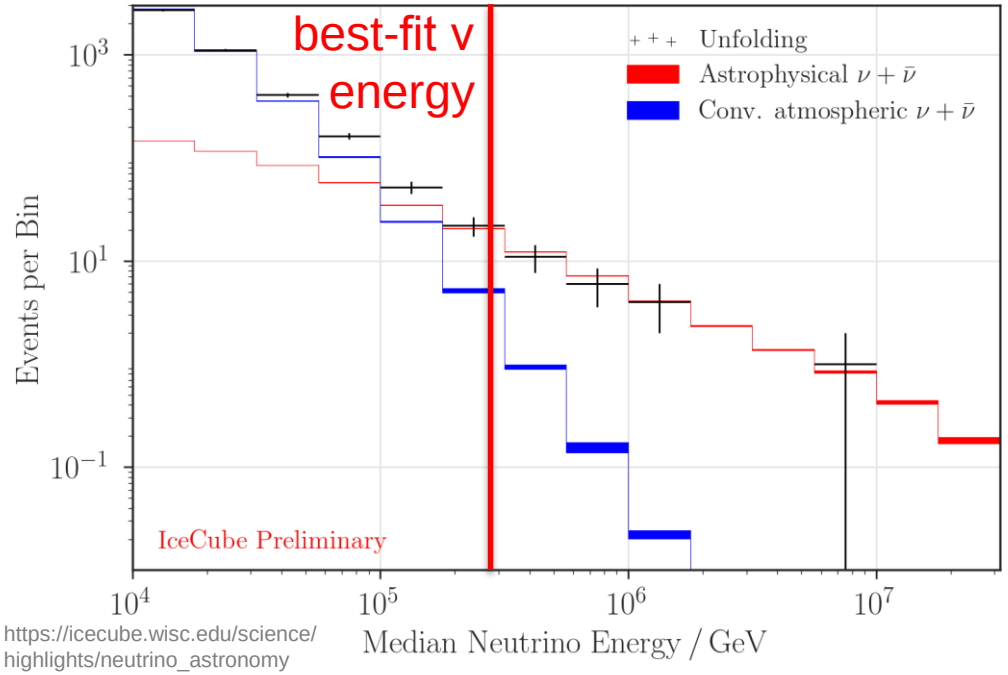
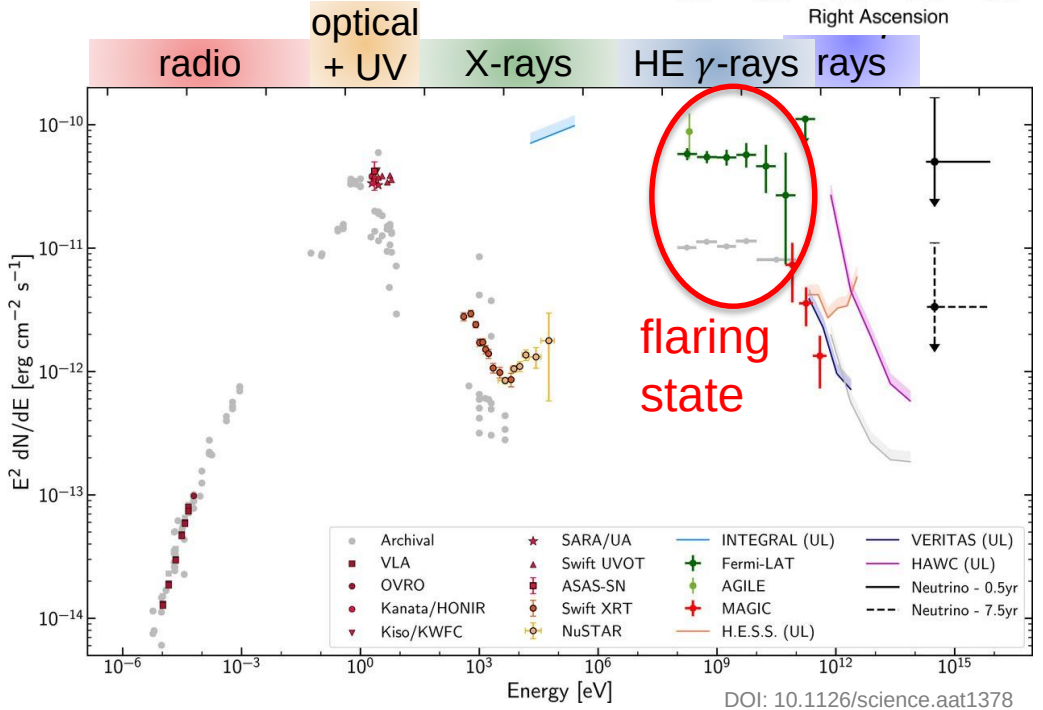




https://icecube.wisc.edu/science/highlights/neutrino_astronomy



DOI: 10.1126/science.aat1378

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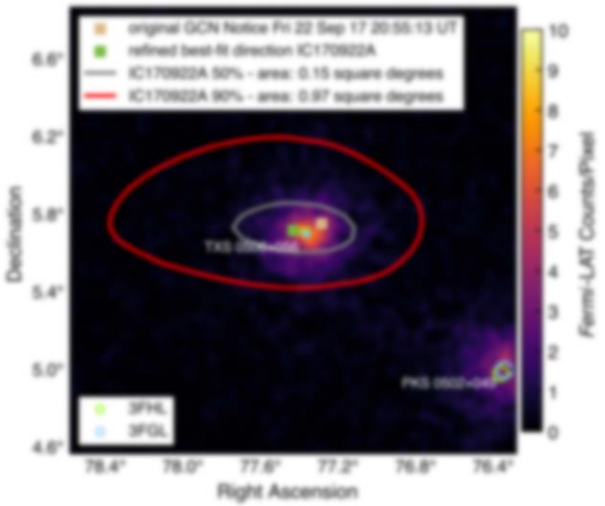


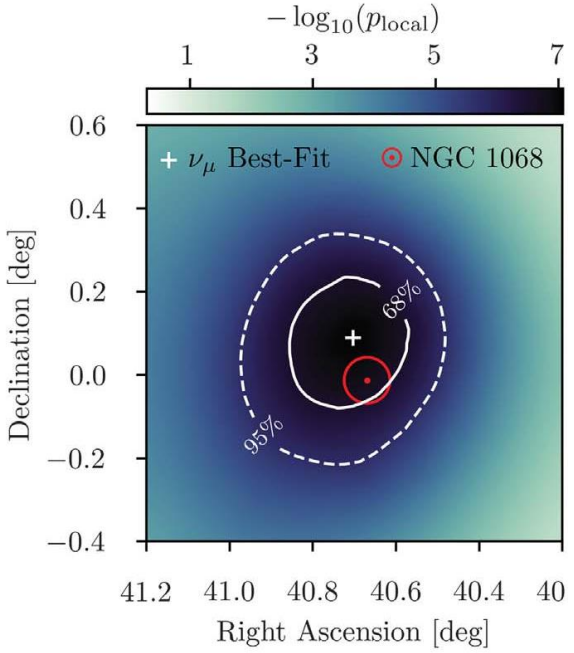
NGC 1068

significance: 4.2 σ

type: ***Seyfert 2 galaxy***

Evidence for neutrino emission from the nearby active galaxy NGC 1068

IceCube Collaboration*†



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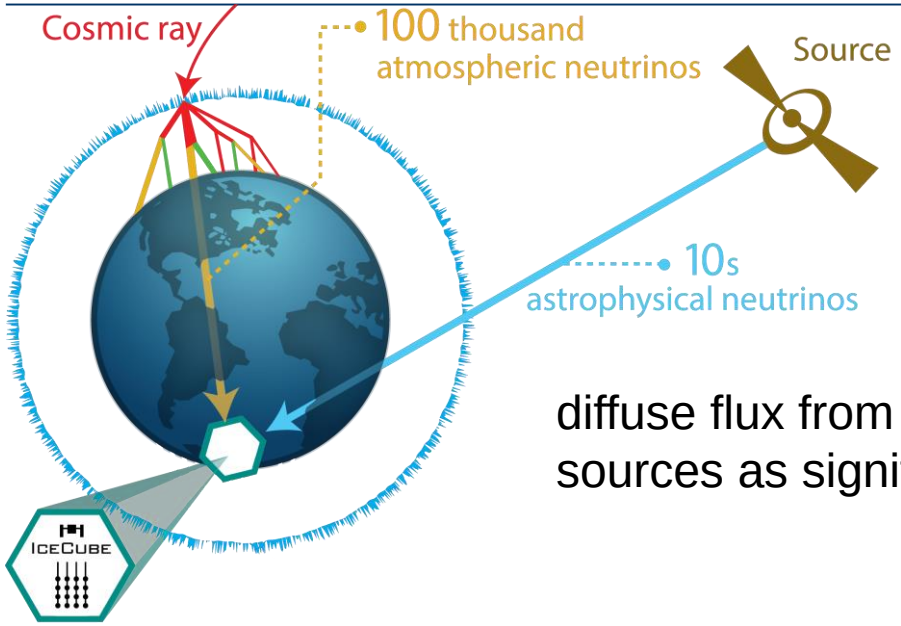

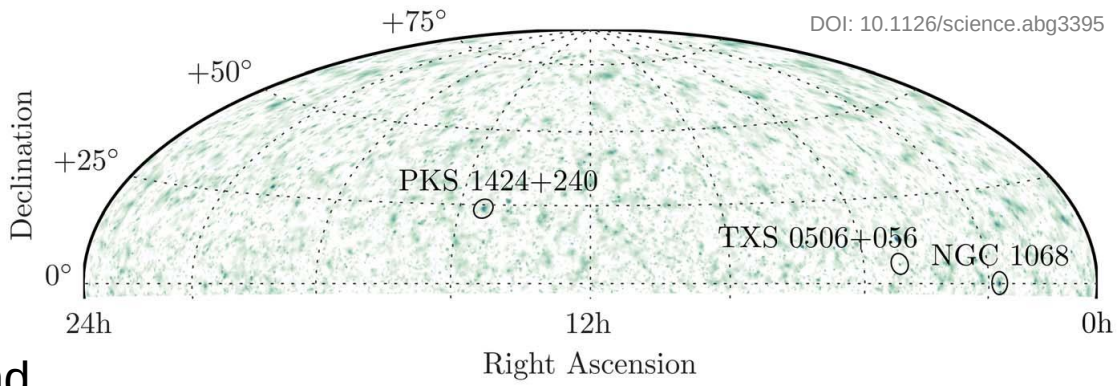

diffuse flux from background,
sources as significant excess

additionally source list search

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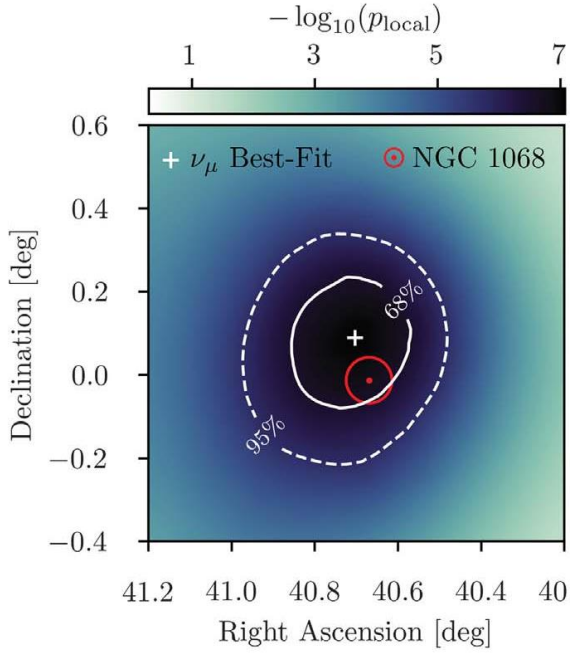

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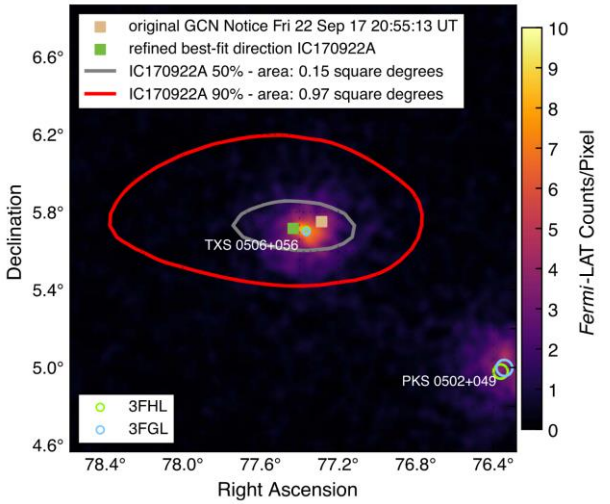

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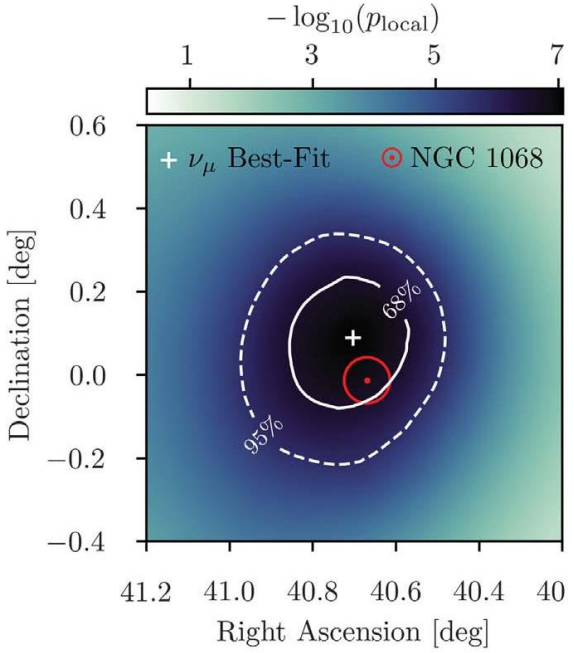

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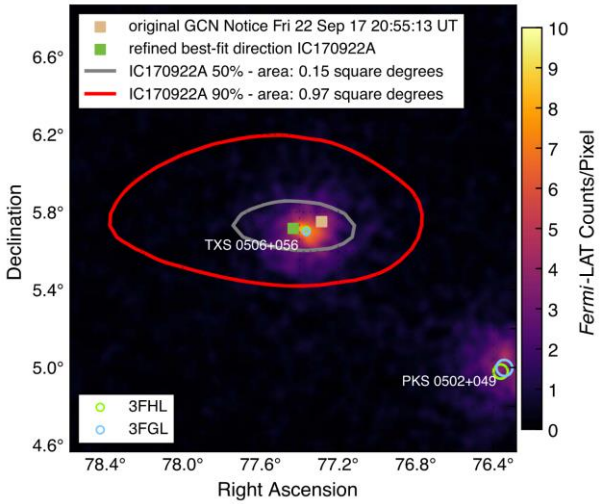

Active Galactic Nuclei

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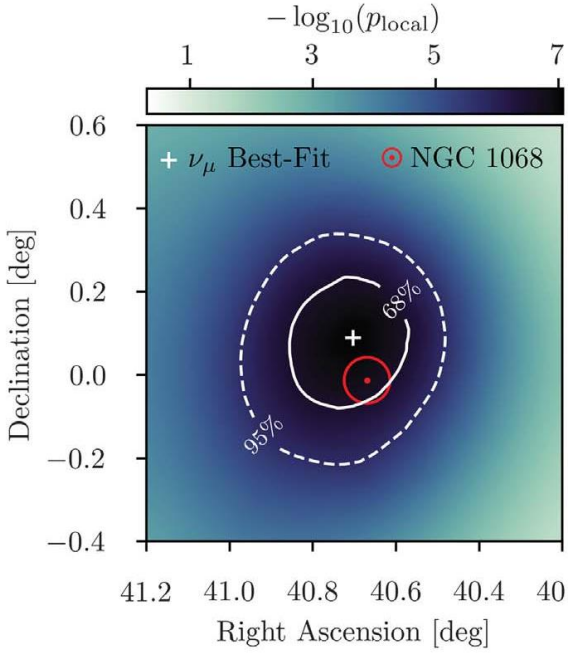
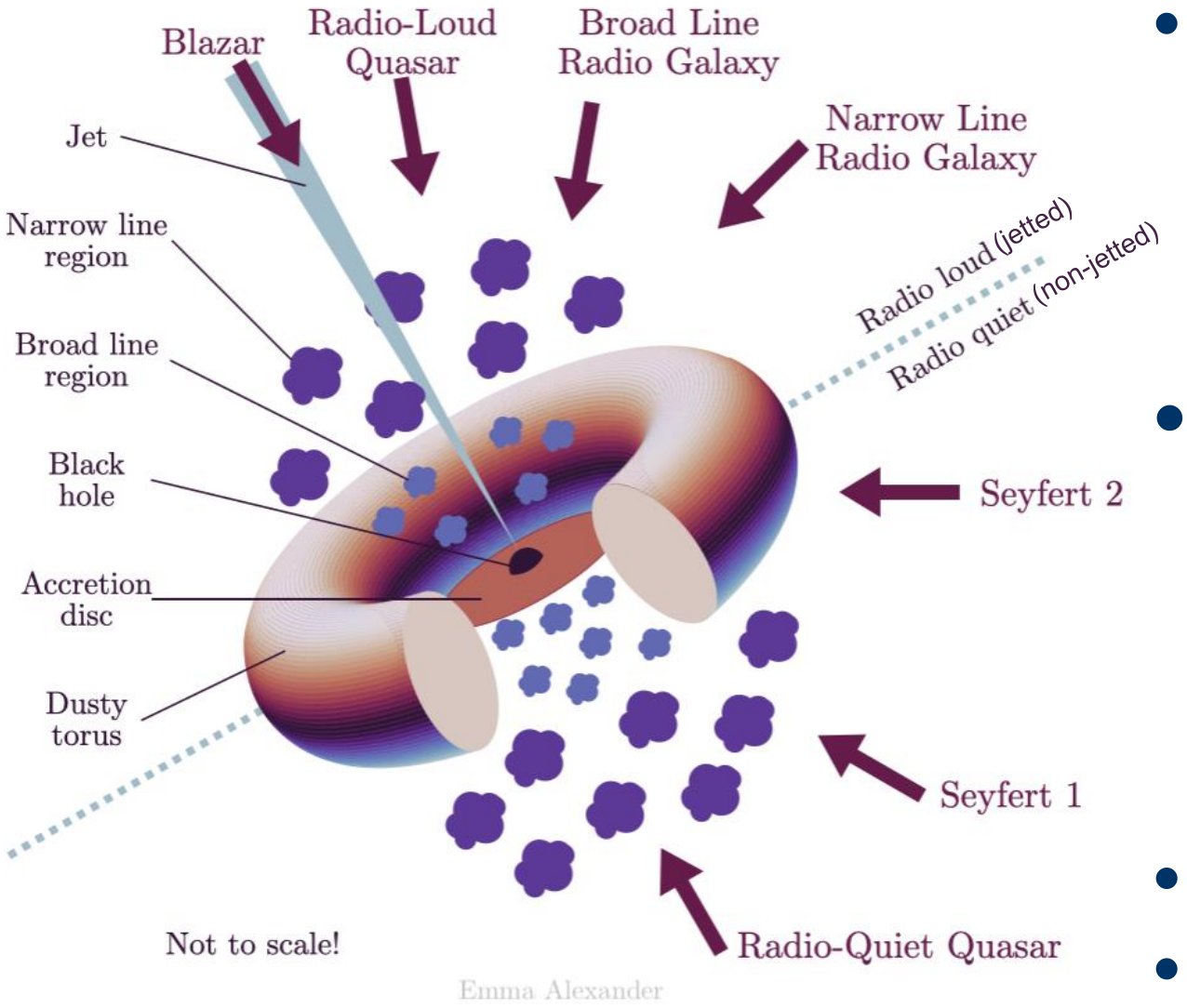


but which type?

→ stacking search using AGN promising

Active Galactic Nuclei



- many observationally diverse extragalactic phenomena
  - small/large radio flux
  - spectral lines different (large/small, broad/narrow)
  - variability yes/no etc. pp. …
- **Unified Model of AGN** (Urry, Padovani 1995) explains distinct observations as effects of orientation to observer
  → one class of objects appearing differently
  - supermassive black hole as power source
  - accretion disk, cold material, dusty torus, jet
- not a perfect model, still under debate
- neutrino emission through several processes

Searching for neutrinos from AGN

this analysis: do **not** want to…

- … test specific physical model for neutrino emission in AGN
- … constrain ourselves to existing AGN classification

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the normal way, e.g.

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historical classification is not optimal…

- created before Unified Model of AGN
- based on specifics of astronomical observations
  e.g. width of certain spectral lines, feature-richness of spectra
- catalogues are made from perspective of astronomers
  → not necessarily optimal for neutrino search!

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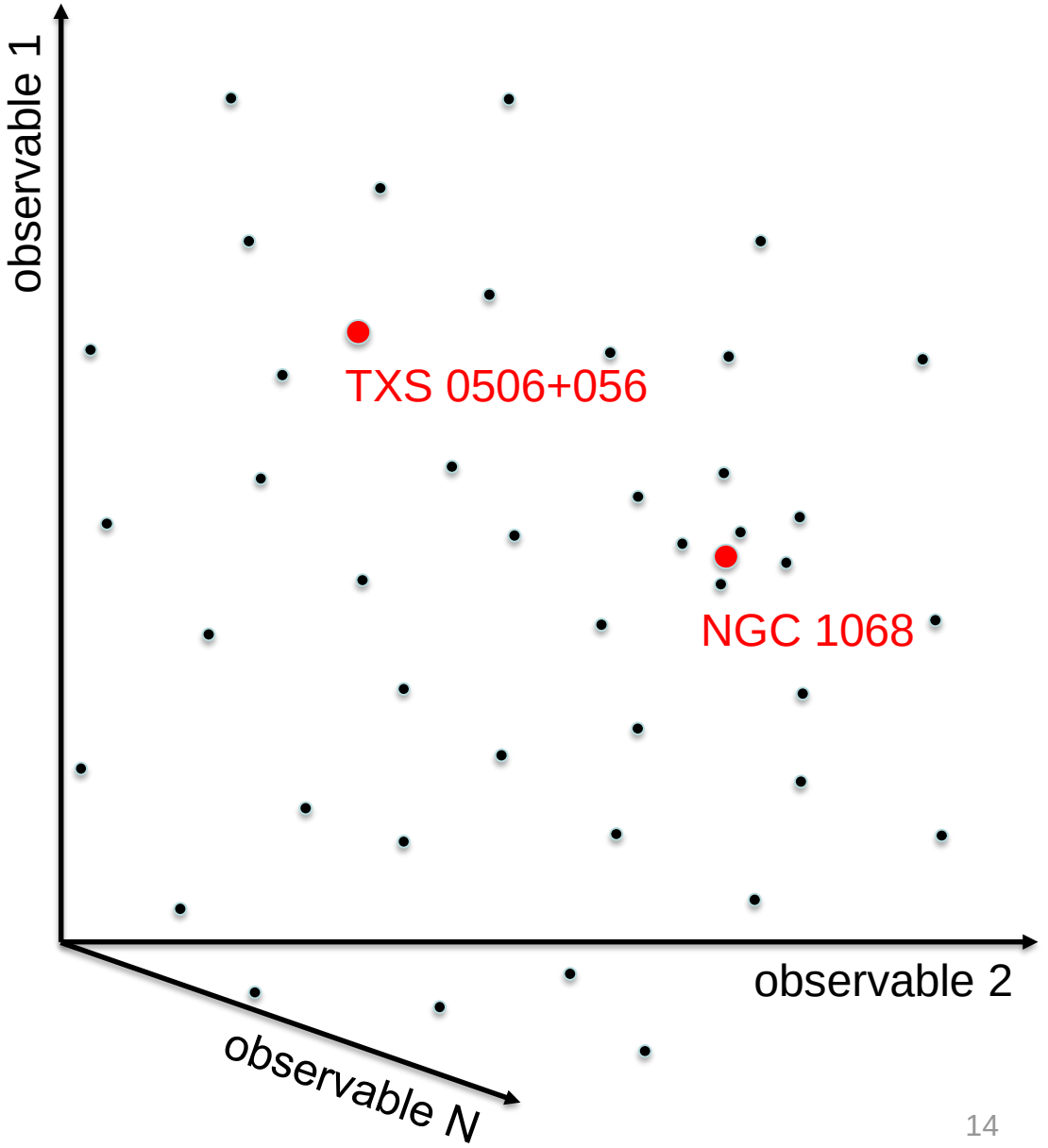
➔ **this analysis:**
- **emission-model-independent search**
- **independently from historical AGN classification scheme**

Phase space of AGN observables

- **many different observable quantities** from AGN:
  - flux in some waveband: radio, x-ray, γ-ray etc.
  - strength, broadness, shape etc.

    of spectral line X, Y, Z etc.
  - polarization etc.



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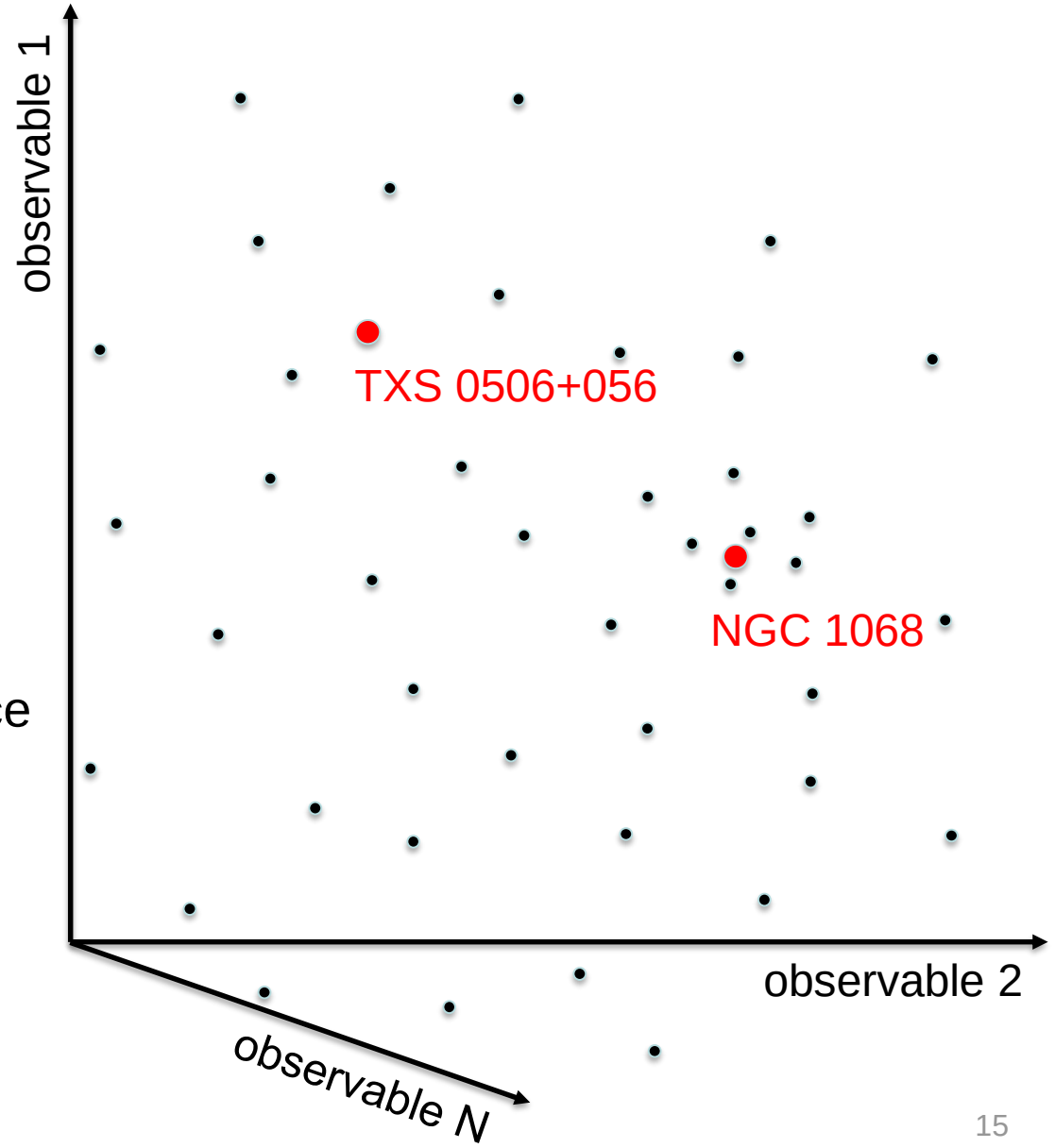
- **each observable is a continuum** (axis in space)
  → many observables span a high-dimensional space
- **populate space** with many observed AGN
  → probably not homogenously distributed



Phase space of AGN observables

distance in phase space

↕

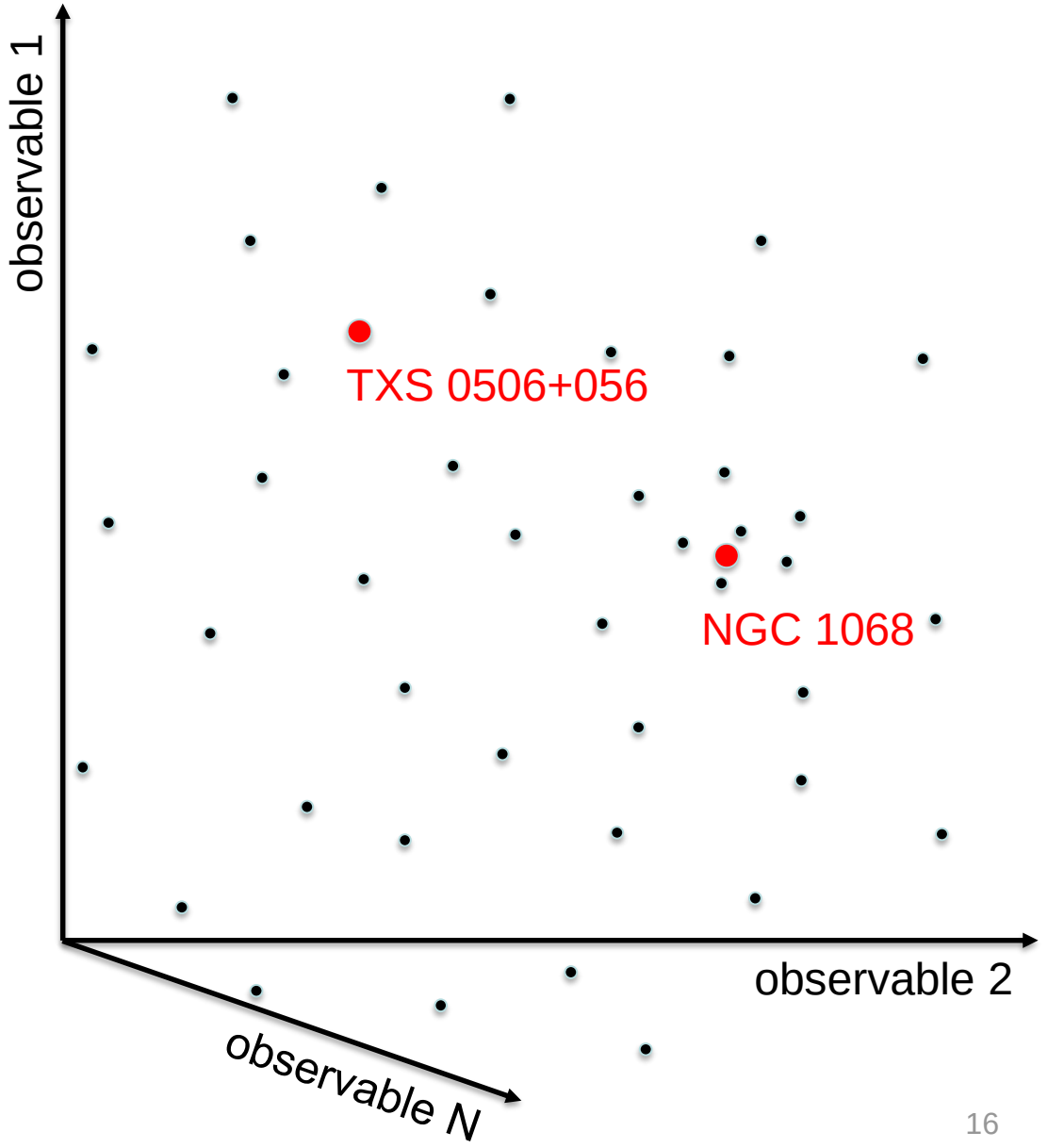
measure for similarity of AGN

clusterings / distinguishable groups

↕

common features,

indication for sub-classes?

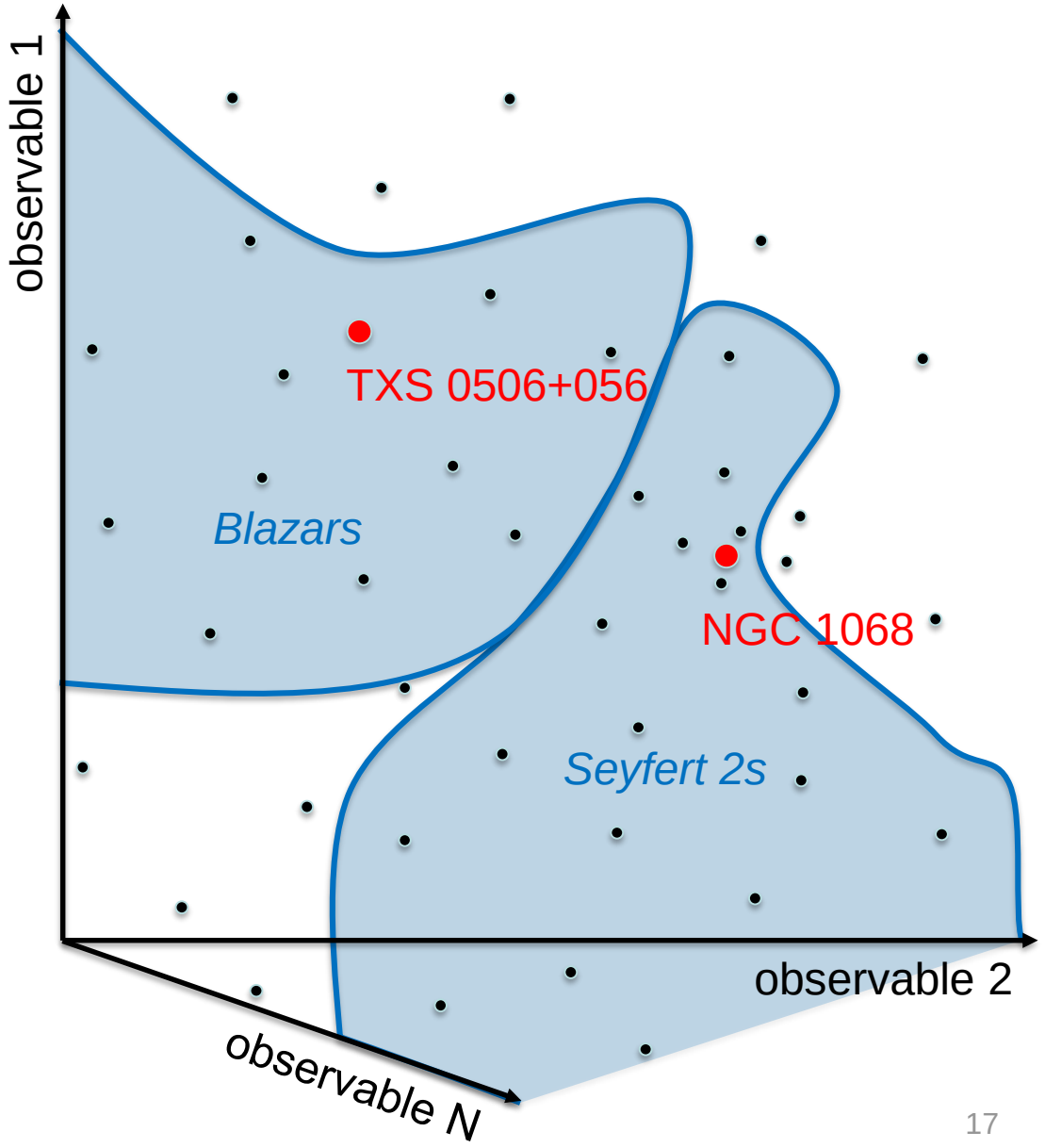


Phase space of AGN observables

expect:

historical classification visible as clusters to some degree

e.g. Blazars should not be completely mixed with other AGN



Phase space of AGN observables

expect:

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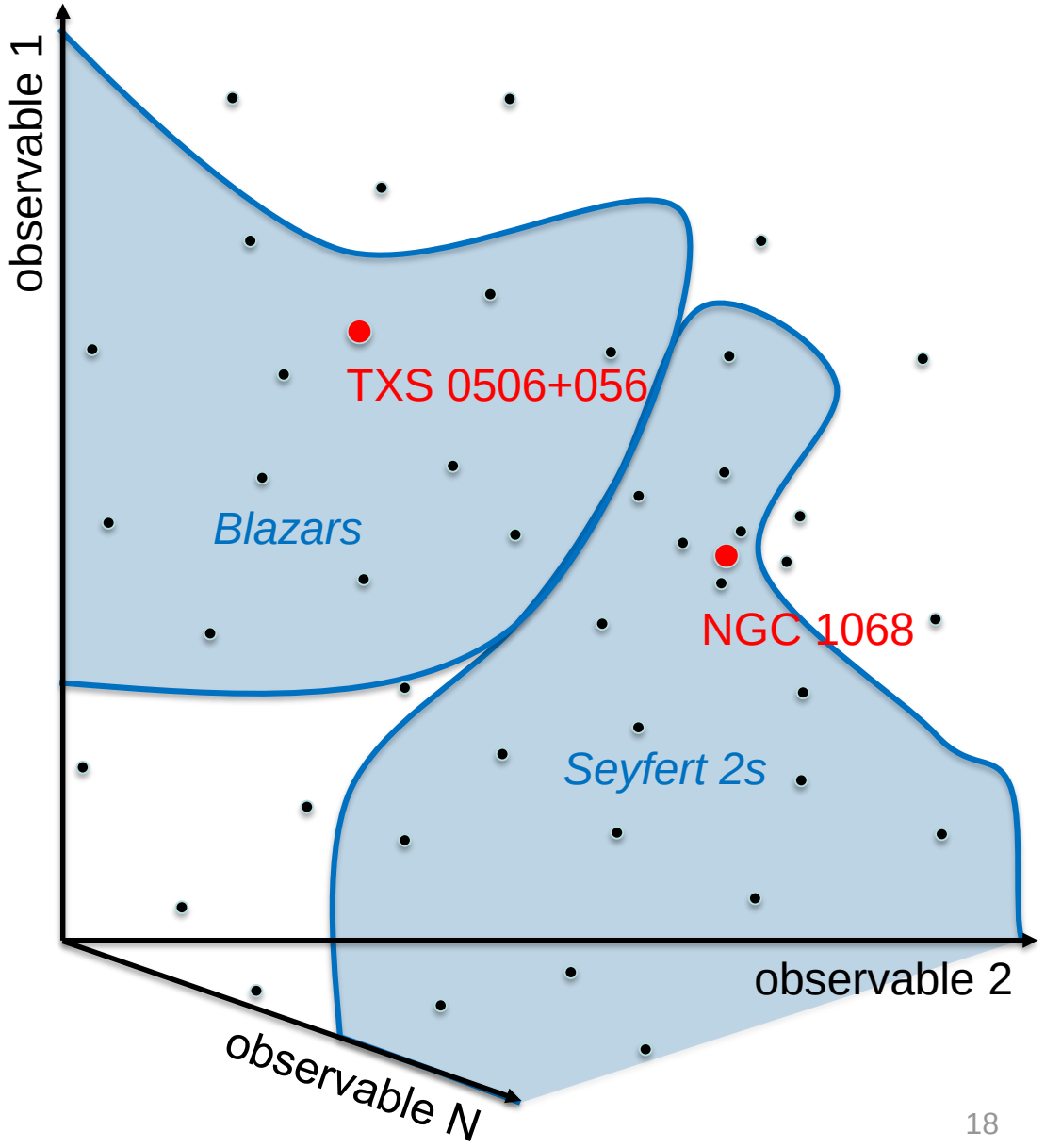
possibly:

not all visible clusters corresponding to historical classification

e.g. some classes more or less separated than others, additional clusters within / across AGN classes



Phase space of AGN observables

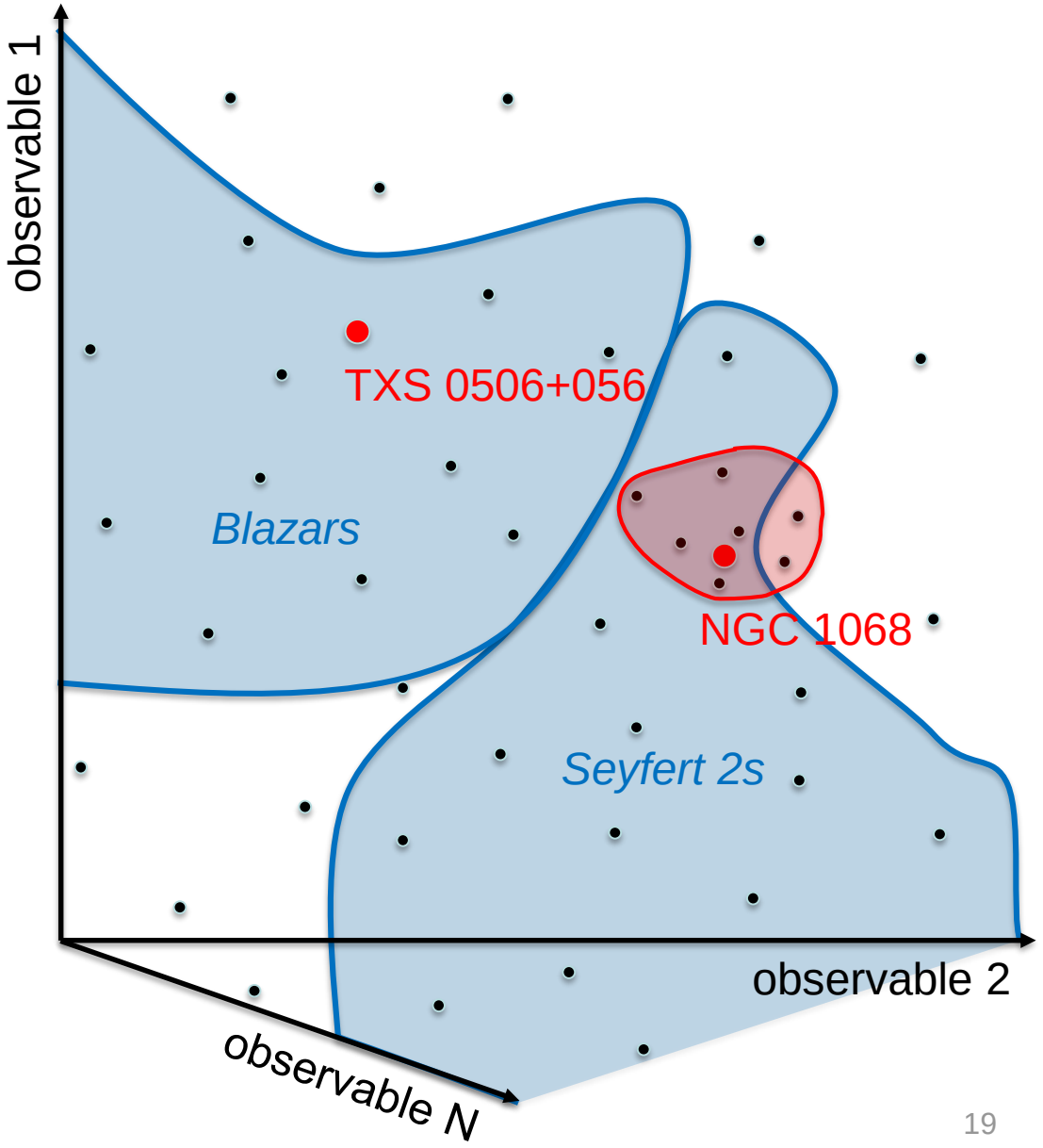
- use **interesting clusters of AGN** as source list for stacking search
- interesting clusters?

  e.g. inclusion of **existing candidate** in cluster

  → *"which smallest cluster includes NGC 1068?"*

➔ stack sources that are **intrinsically similar to existing candidates**

(e.g. TXS 0506+056 & NGC 1068)

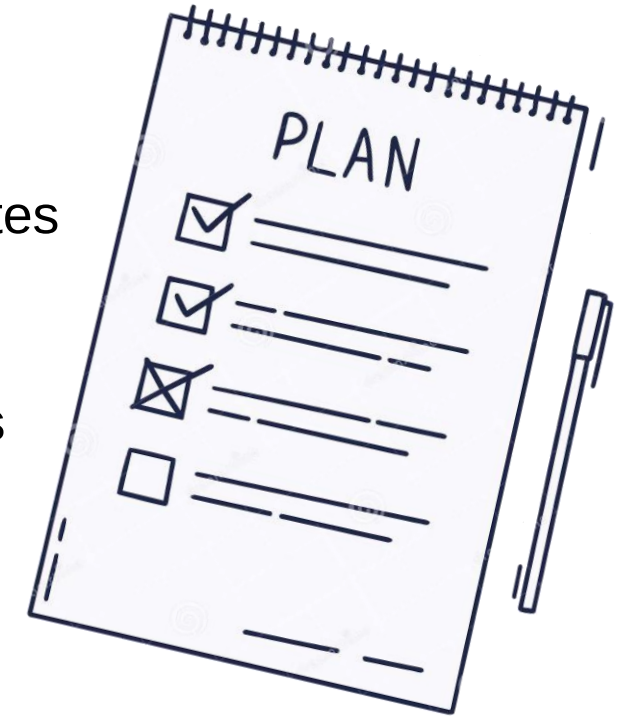


Analysis plan

1. **build extensive catalog** of AGN with many different observables
   a) decide on observables to use (flux in certain waveband, spectral lines etc.)
   b) combine astronomical catalogs
   c) populate phase space

2. **cluster search** in observable space to select AGN closest to candidates
   a) run cluster search algorithm
   b) select interesting clusters based on location of candidate sources

3. perform **stacking analysis** with AGN within selected clusters



First concrete steps

which observables?

- start with simplest observable: **flux in some waveband** (only a few for now)
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- inspired by Federica Bradascio's (DESY Zeuthen) PhD thesis:
  large catalog of AGN in **x-ray, radio & infrared**
- see next slides…

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  large catalog of AGN in **x-ray, radio & infrared**
- see next slides…

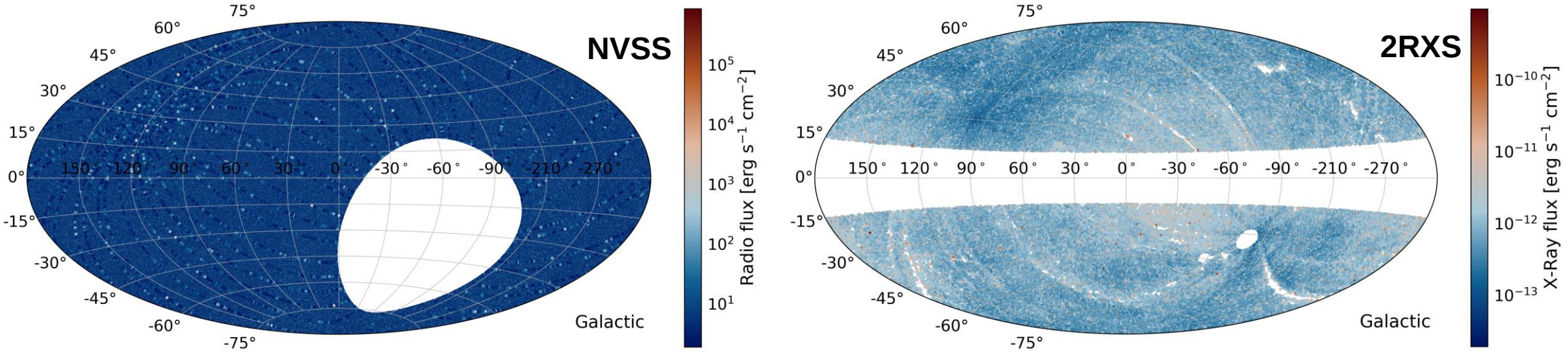
which cluster algorithm?

- scalable to many dimensions, generic enough, exist
- machine learning to handle high dimensionality?
- good starting point: **HDBSCAN** (Hierarchical Density-Based Spatial Clustering of Applications with Noise)
  → state-of-the-art cluster algorithm for explorative data analysis

DOI: 10.1007/978-3-642-37456-2_14
by R. Campello, D. Moulavi, J. Sander

First steps: Catalogs

- radio: **NVSS** (NROA VLA Sky Survey, 1998, 1.4 GHz / 21 cm)
  - $> -40°$ declination, 1.8 million sources
  - radio emission at this wavelength → AGN most of the time
- x-ray: **2RXS** (ROSAT All-sky Survey, 1990, 0.1 – 2.4 keV)
  - all-sky, ~ 100,000 sources



PhD thesis Federica Bradascio

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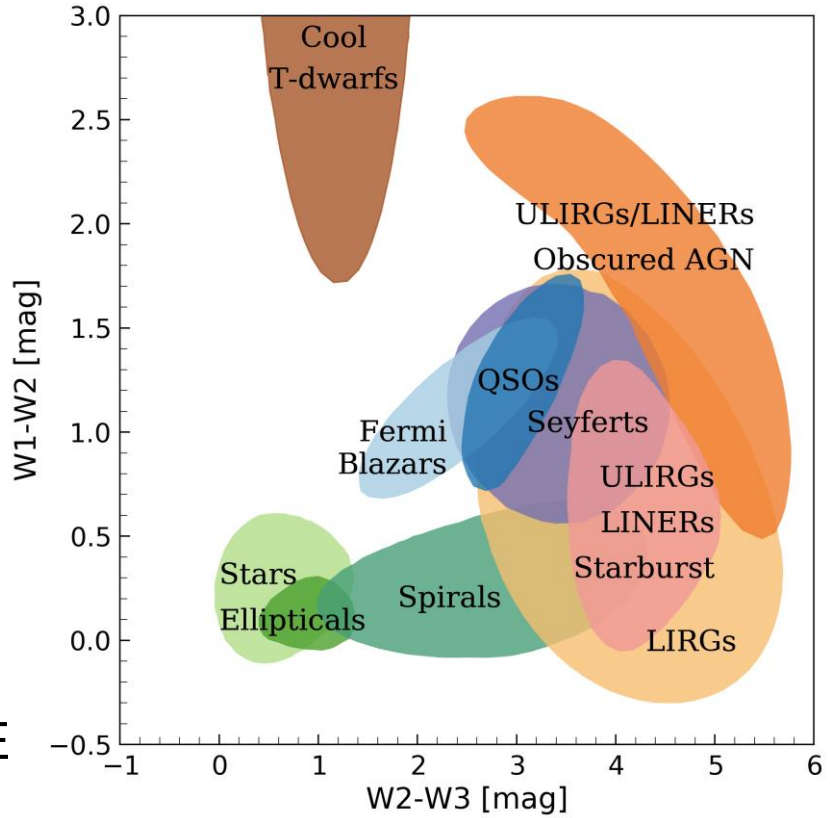
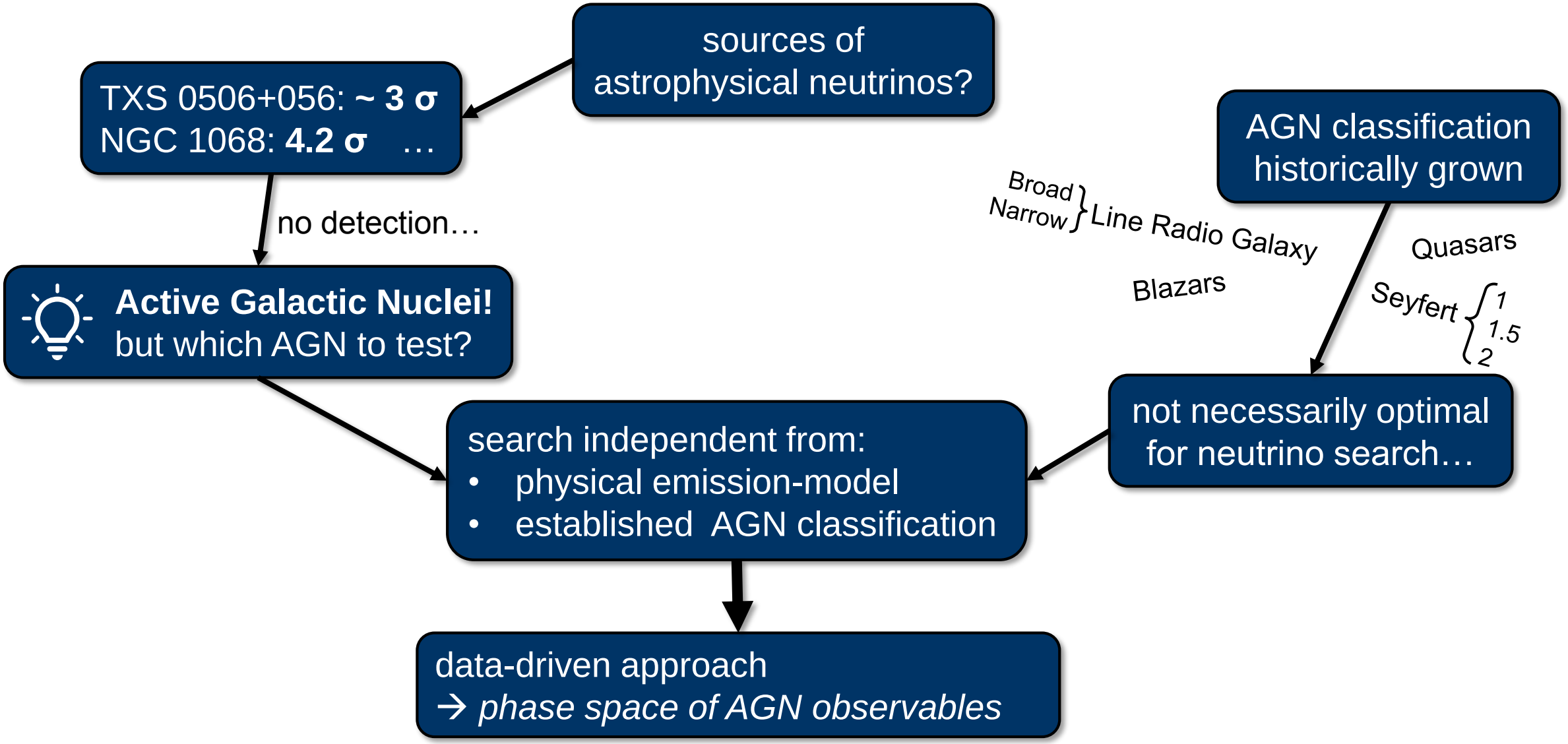
- infrared: **AllWISE** (Wide-field Infrared Survey Explorer, 2010, 4 bands of few μm)
  - all-sky, millions of AGN candidates
  - Salvato et al. 2017: correlated catalog of 2RXS and AllWISE
    - more than just positional cross-matching
  - selection of AGN possible with color cuts (cuts based on differences in IR bands)
  - not all sources are AGN → correlate catalog with radio



Summary


sources of astrophysical neutrinos?
TXS 0506+056: ~ 3 σ
NGC 1068: 4.2 σ …
no detection…
Active Galactic Nuclei!
but which AGN to test?
search independent from:
• physical emission-model
• established AGN classification
data-driven approach
→ phase space of AGN observables
AGN classification historically grown
Broad
Narrow
Line Radio Galaxy
Blazars
Quasars
Seyfert 1 1.5 2
not necessarily optimal for neutrino search…

Thank you for your attention

Questions?

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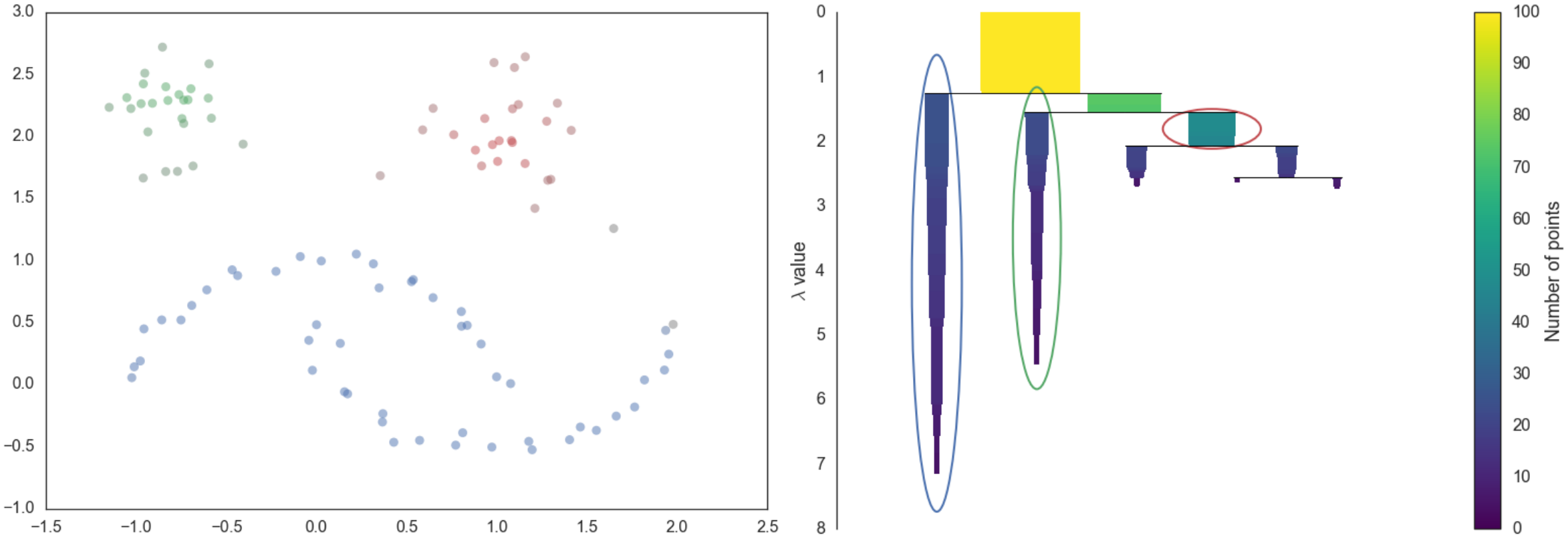
Backup

HDBSCAN cluster algorithm

https://hdbscan.readthedocs.io/

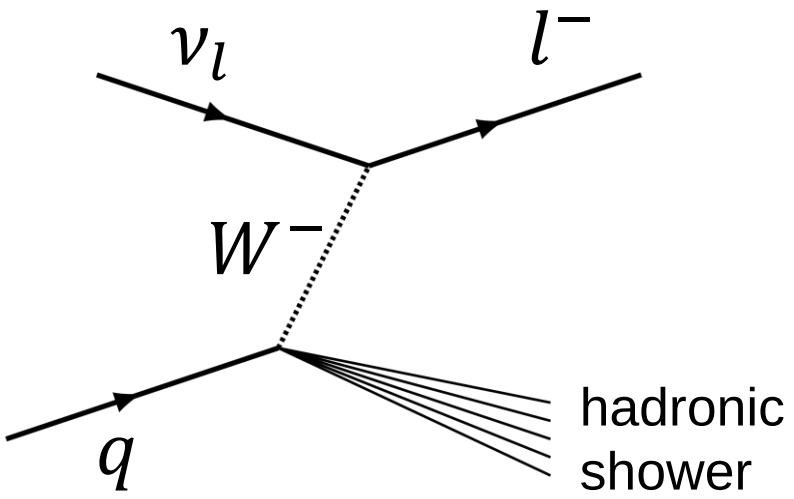


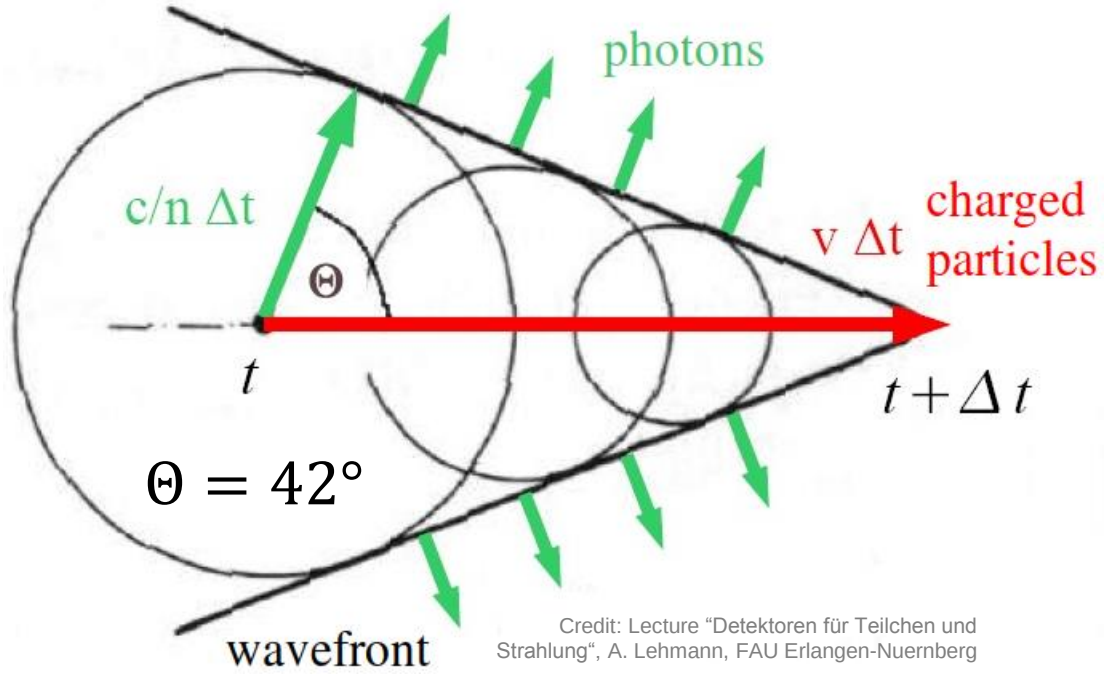
Detection principle

deep inelastic scattering in matter:

$$\nu_l + q \rightarrow l^- + \text{hadr. show.}$$

(anti-neutrinos: $\bar{\nu}_{\bar{l}} + q \rightarrow l^+ + \text{hadr. show.}$)





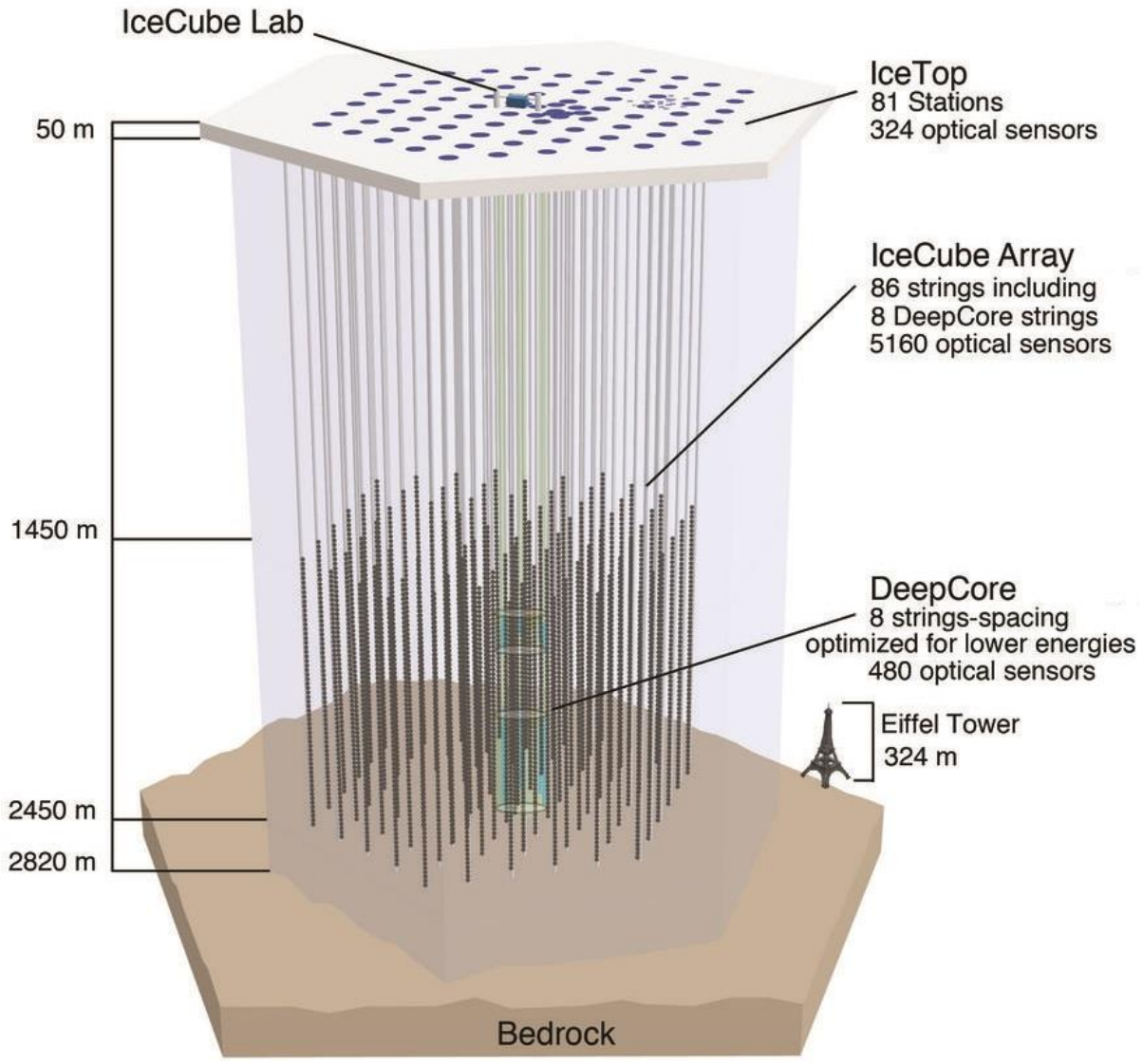
Credit: Lecture "Detektoren für Teilchen und Strahlung", A. Lehmann, FAU Erlangen-Nuernberg

charged particles in water

→ **Cherenkov radiation**:

- polarization of medium: blue light
- $v \approx c > \frac{c}{n}$ (particles overtake light): emission in cone-shaped shock wave

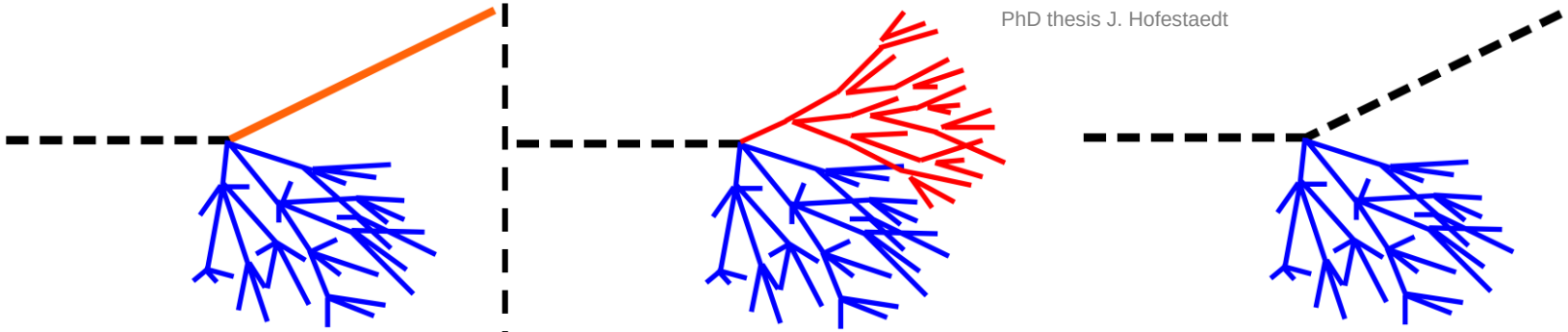
IceCube Neutrino Observatory



- light detection: PMTs in Digital Optical Modules (DOMs)
- coverage of $\approx 1\,\mathrm{km}^3$ of optically clear ice at the south pole
- time-stamping of photon arrival times (resolution $\approx 2\,\mathrm{ns}$)

Event reconstruction

PhD thesis J. Hofestaedt



ν_μ, ν_τ | ν_e, ν_τ | ν_l NC

event signature:

track-like | shower-like

best detector function:

tracker | calorimeter

→ **direction** | → **energy**

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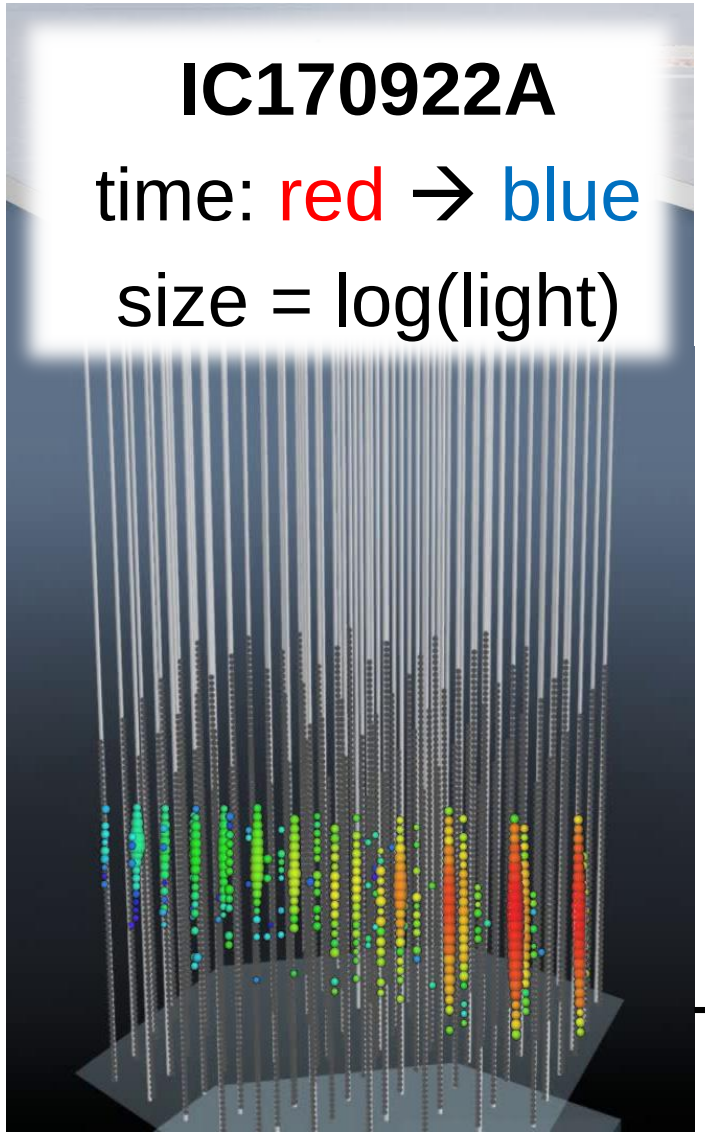

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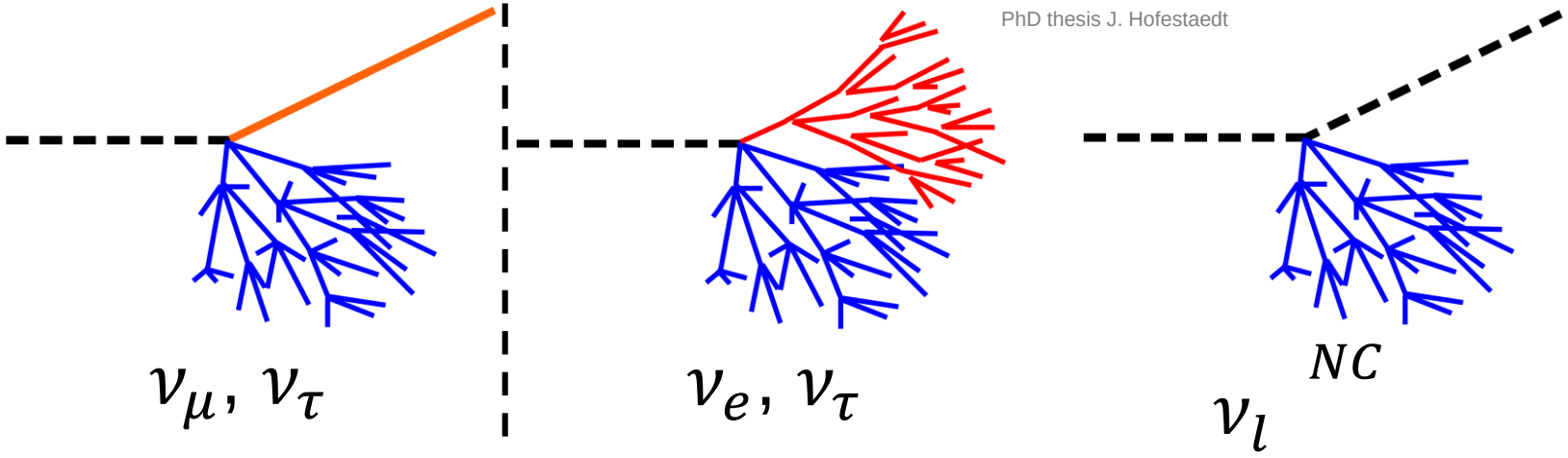

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precise! | high! $E \approx 290\ \mathrm{TeV}$ ($> 183\ \mathrm{TeV}$ 90% CL)