1) Cosmic rays & IceCube neutrinos

2) Multimessenger astronomy & blazars

3) Results & current work
Blazar: FSRQ/BL Lac

$10^{-3}$ pc

Big Blue Bump

Synchrotron

Leptonic (SSC, EC)?

Hadronic?

Fermi/LAT

2FGL

2MASS

WISE

BAT

Planck

UVOT

ATCA

TANAMI

XRT

γ

ν Fν \left[10^{-12}\text{ erg s}^{-1}\text{ cm}^{-2}\right]

Frequency [Hz]

10^{9} \quad 10^{12} \quad 10^{15} \quad 10^{18} \quad 10^{21} \quad 10^{24}
The cosmic ray spectrum after Hillas 2006
Which sources can accelerate particles to Ultra-High Energies and how?

How do we identify the sources of UHECR?
Mücke (2000)
IceCube Preliminary
IceCube Preliminary

Events per 1347 Days

Deposited EM-Equivalent Energy in Detector (TeV)

Detection of high-energy photons is not proof for hadronic processes!

→ Upscattering of Synchrotron photons by relativistic electrons via Inverse Compton
Pion photoproduction and neutrinos

\[
\begin{align*}
F_\nu &= \frac{2}{3} \cdot \frac{3}{4} F_\pi = \frac{1}{2} F_\pi \\
F_\gamma &= \frac{1}{3} F_\pi + \frac{1}{4} \cdot \frac{2}{3} F_\pi = \frac{1}{2} F_\pi
\end{align*}
\]

Mannheim 1993,1995
Mücke 2000
HAS A NEUTRINO BEEN ASSOCIATED WITH A HIGH-ENERGY PHOTON EMITTER?
MAYBE!
Blazars & AGN

★ Cumulative search: no significant counterparts (Glüsenkamp et al. 2016)

★ Contribution from Blazars & Pulsar Wind Nebulae (PWNe; Padovani et al. 2014)?

★ Blazars as a class capable of producing observed neutrino flux (Krauss et al. 2014);
Krauss et al. 2014
<table>
<thead>
<tr>
<th>Source</th>
<th>$F_\gamma$ (erg cm$^{-2}$ s$^{-1}$)</th>
<th>events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0235–618</td>
<td>$(1.0^{+0.5}_{-0.5}) \times 10^{-10}$</td>
<td>$0.19^{+0.04}_{-0.04}$</td>
</tr>
<tr>
<td>0302–623</td>
<td>$(3.4^{+0.7}_{-0.7}) \times 10^{-11}$</td>
<td>$0.06^{+0.01}_{-0.01}$</td>
</tr>
<tr>
<td>0308–611</td>
<td>$(7.5^{+2.9}_{-2.9}) \times 10^{-11}$</td>
<td>$0.14^{+0.05}_{-0.05}$</td>
</tr>
<tr>
<td>1653–329</td>
<td>$(4.5^{+0.5}_{-0.5}) \times 10^{-10}$</td>
<td>$0.86^{+0.10}_{-0.10}$</td>
</tr>
<tr>
<td>1714–336</td>
<td>$(2.4^{+0.5}_{-0.6}) \times 10^{-10}$</td>
<td>$0.46^{+0.10}_{-0.12}$</td>
</tr>
<tr>
<td>1759–396</td>
<td>$(1.2^{+0.3}_{-0.2}) \times 10^{-10}$</td>
<td>$0.23^{+0.50}_{-0.40}$</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1.9 ± 0.4</strong></td>
</tr>
</tbody>
</table>

Krauss et al. 2014
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★ Coincidence of blazar outburst and high-energy neutrino event (Kadler, Krauss et al. 2016)
High-Energy Cosmic Neutrinos

IceCube Collaboration 2013; Aartsen et al. 2014
$F_{100-300\text{MeV}} \left[ 10^{-6} \text{cm}^{-2} \text{s}^{-1} \right]$
$F_{100-300000\text{MeV}} \left[ 10^{-6}\text{cm}^{-2}\text{s}^{-1} \right]$ vs MJD

For a detailed analysis of the data, please refer to the full publication.
Variability as indicator for association!
Conclusions

★ Association not expected for each HE neutrino

★ Connection between high-energy (not LAT!) flux and neutrino flux

★ Blazars & AGN are the most promising candidates

★ Currently extending study to 100 TeV

★ Track events are promising for direct association

★ Further blazar flares promising for ruling out/confirming blazar hypothesis
37 LAT photons

→ Only 1 photon associated with a resolved source, a blazar

(after IceCube Collaboration 2014)
Extragalactic origin consistent with isotropic distribution