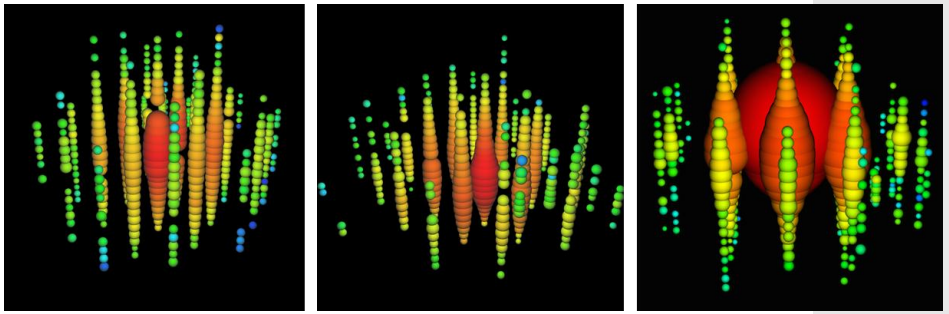
RUB

RUHR-UNIVERSITÄT BOCHUM

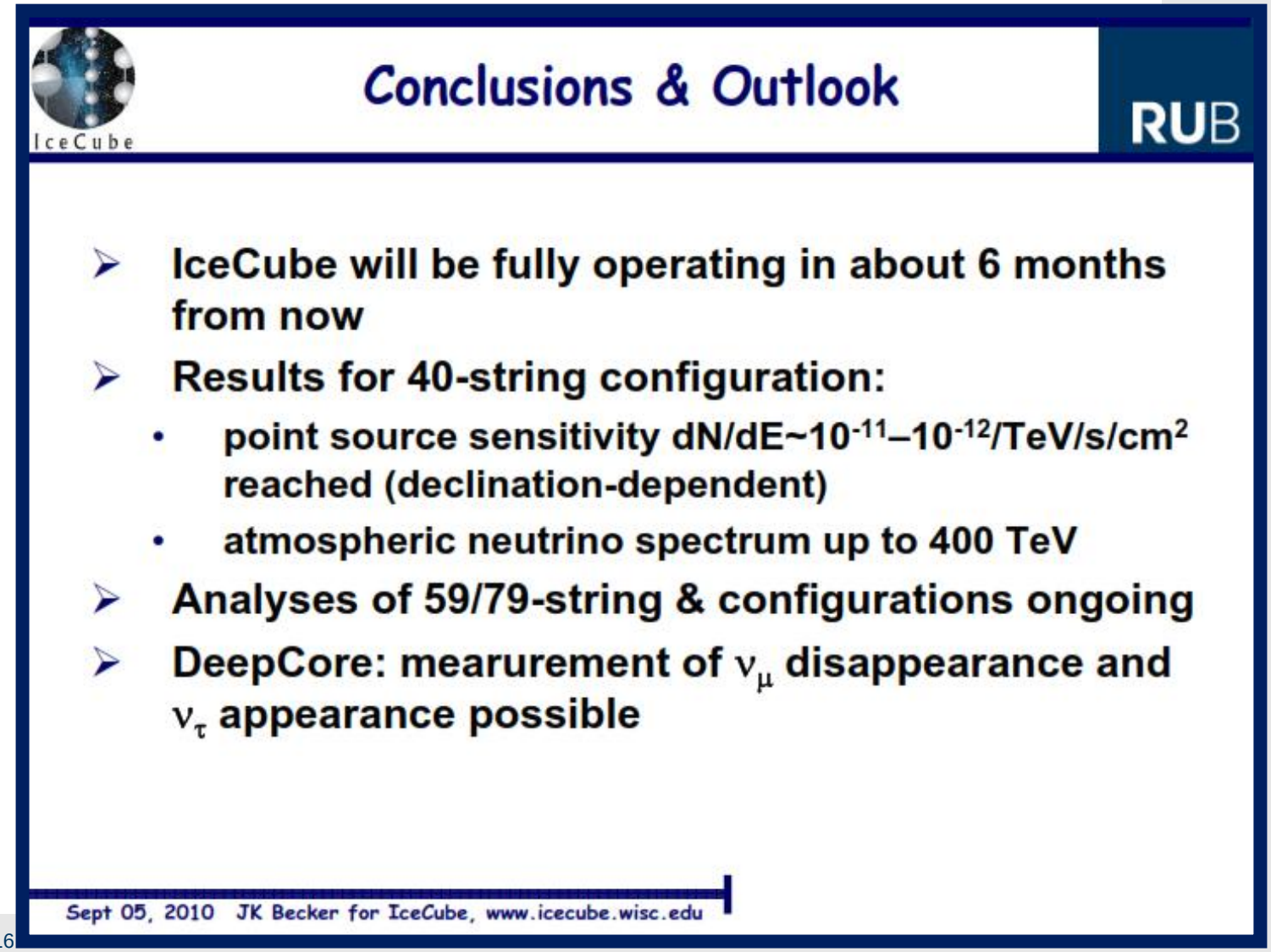
On the (extra)galactic origin(s) of the IceCube astrophysical neutrino signal

Julia Tjus (born: Becker)

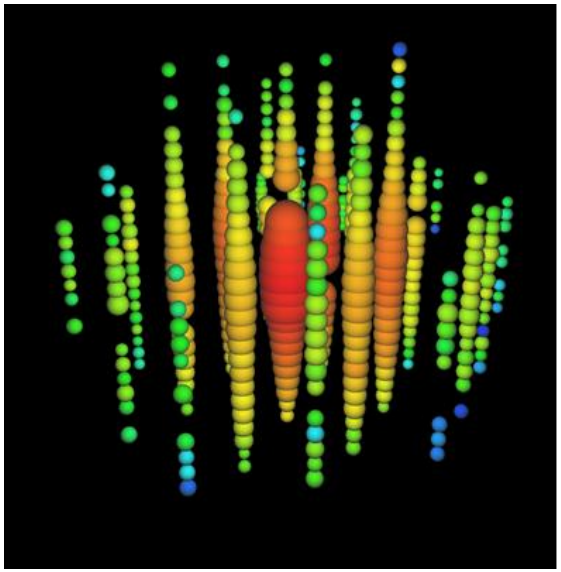
FAKULTÄT FÜR PHYSIK & ASTRONOMIE
Theoretische Physik IV: Plasma-Astroparticle Physics



NOW 2010:

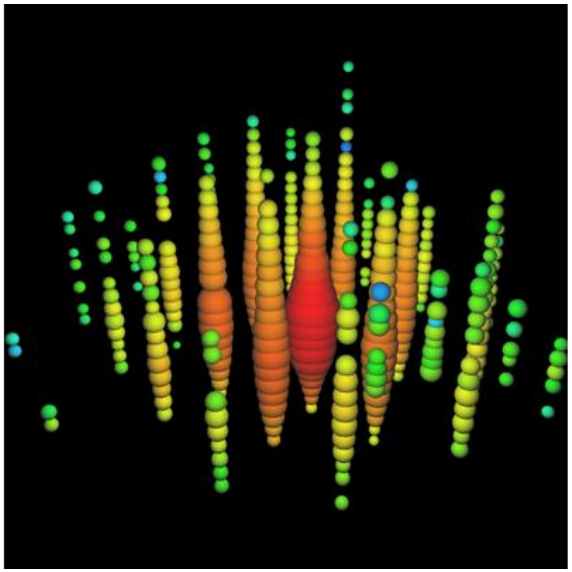

IceCube
Conclusions & Outlook
RUB
IceCube will be fully operating in about 6 months from now
Results for 40-string configuration:
point source sensitivity dN/dE~10-11–10-12/TeV/s/cm2 reached (declination-dependent)
atmospheric neutrino spectrum up to 400 TeV
Analyses of 59/79-string & configurations ongoing
DeepCore: mearurement of νμ disappearance and ντ appearance possible
Sept 05, 2010 JK Becker for IceCube, www.icecube.wisc.edu

The Big Three:



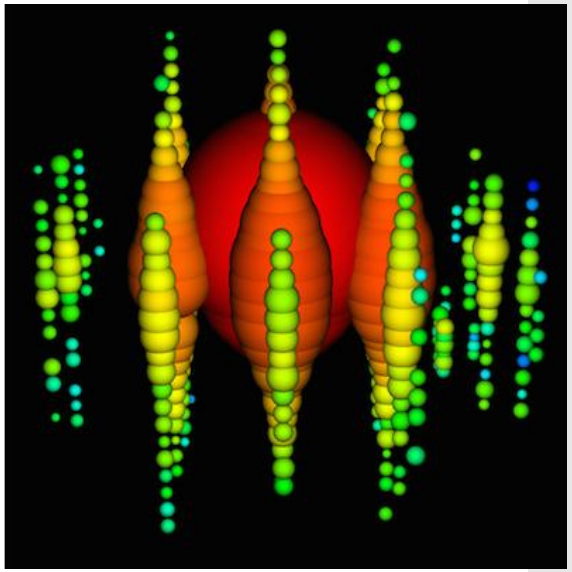
Bert, 1 PeV

August 2010



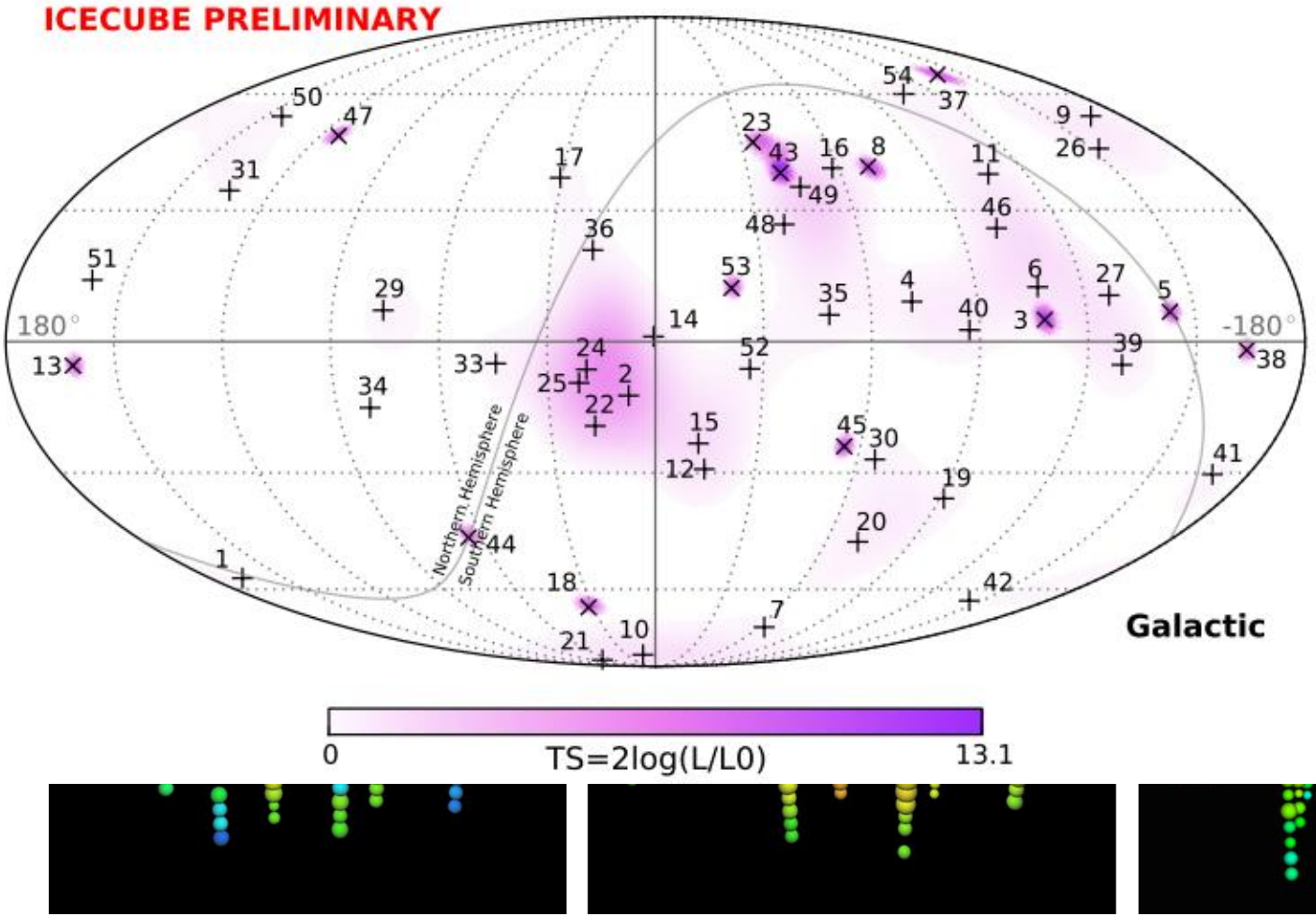
Ernie, 1.1 PeV

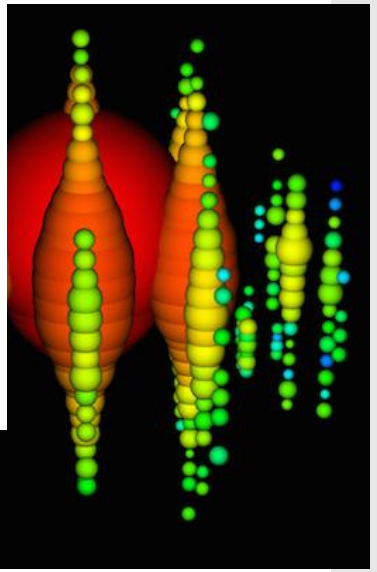
Januar 2012



Big Bird, 2.2 PeV

Dec 2012





Bert, 1 PeV

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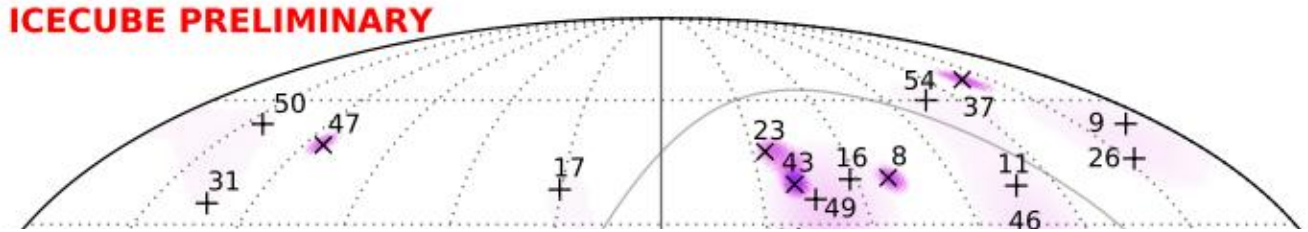
ICECUBE PRELIMINARY
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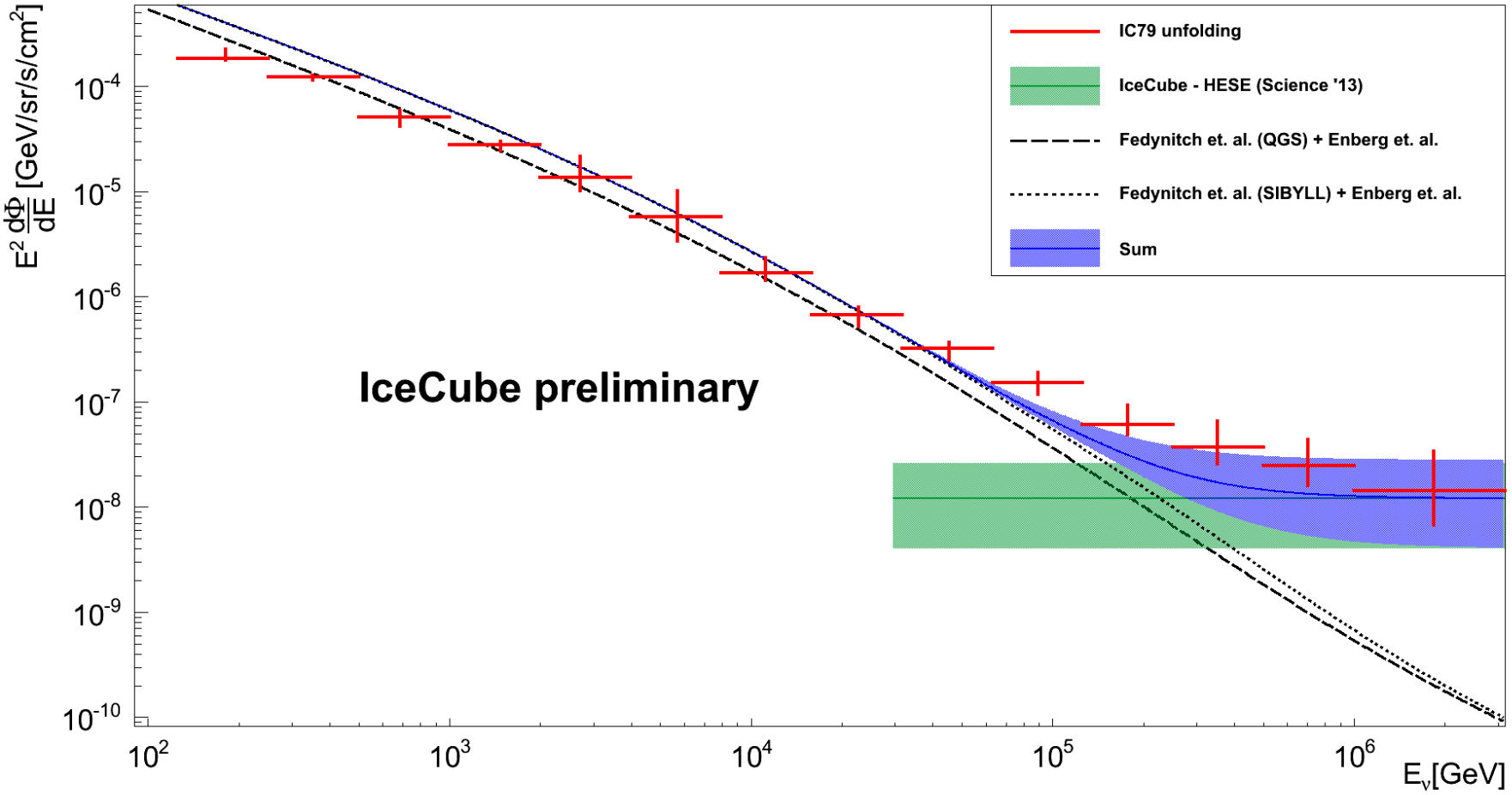
RUB


IC79 unfolding
IceCube - HESE (Science '13)
Fedynitch et. al. (QGS) + Enberg et. al.
Fedynitch et. al. (SIBYLL) + Enberg et. al.
Sum
IceCube preliminary
$E^2 \frac{d\Phi}{dE}$ [GeV/sr/s/cm^2]
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^2
10^3
10^4
10^5
10^6
E_ν[GeV]

Contents

- (Very) (short) summary of IceCube results
- Galactic origin (SNR?): pros, cons and conclusions
- Extragalactic origin: active galaxies as PeV candidates
- Future tests

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- **(Very) (short) summary of IceCube results**
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WANTED

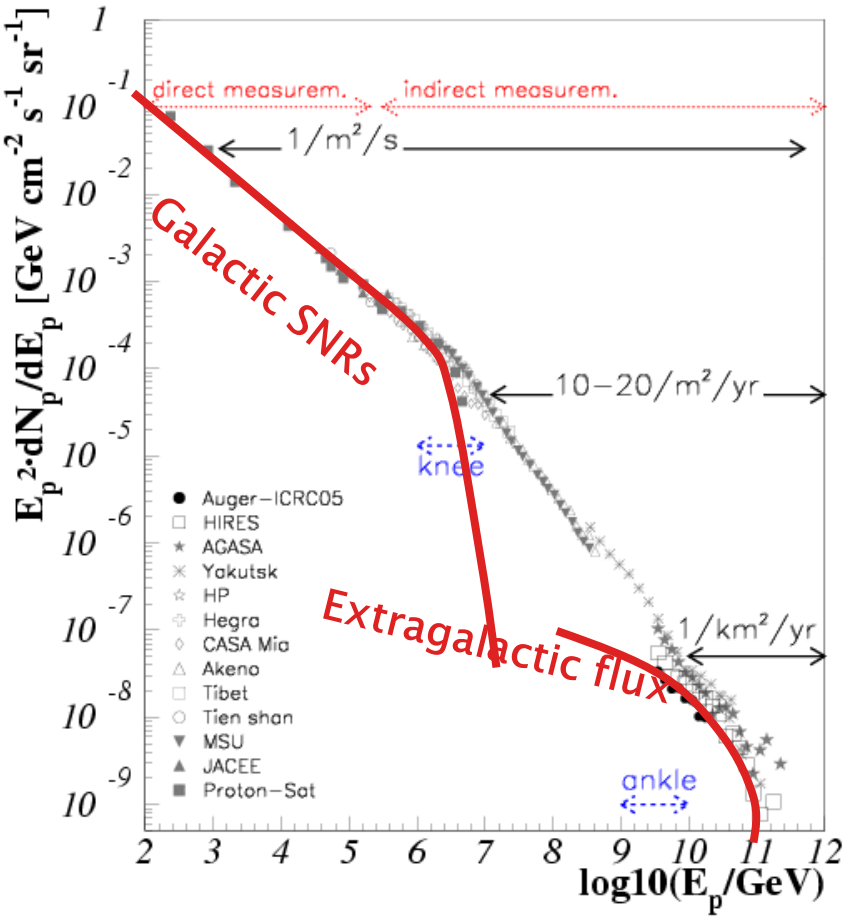
sources with such conditions

- **Astrophysical signal of strength:**
  $E^2 * dN_\nu/dE_\nu \sim 10^{-8}$ GeV s^{-1} cm^{-2} sr^{-1}
- **Spectral behavior:**
  - *Broken power-law/single power-law?*
  - *No clear evidence for a cutoff*
- **Spatial Clustering?:** So far isotropic distribution
- **Temporal Clustering?:** search for flares/gamma-ray bursts did not give a significant clustering result (yet)

REWARD

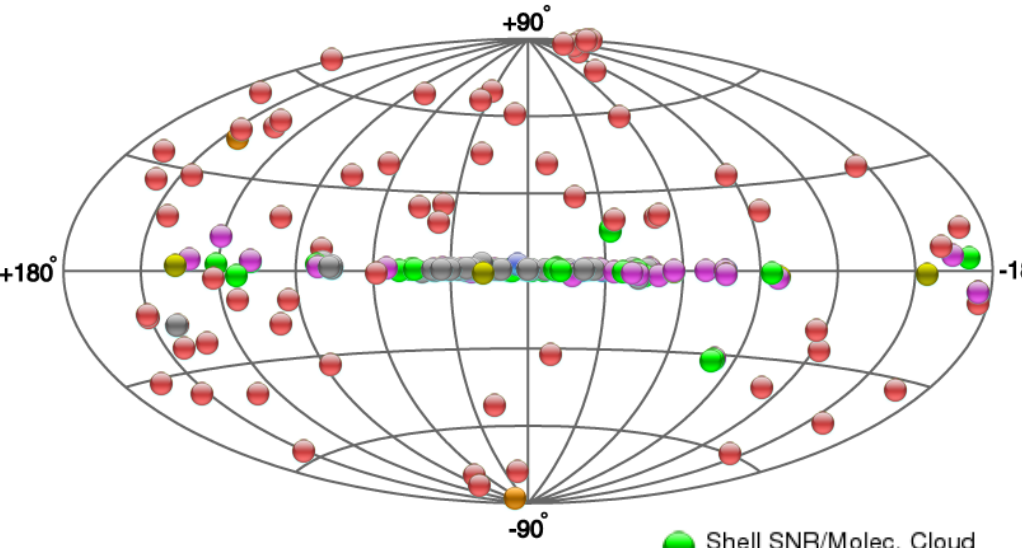
Clues from other messengers

Cosmic rays
(modified by diffusion/transport)



Clues from other messengers

Gamma-rays
(hadronic – π0 & leptonic – IC/brems)



Cosmic rays
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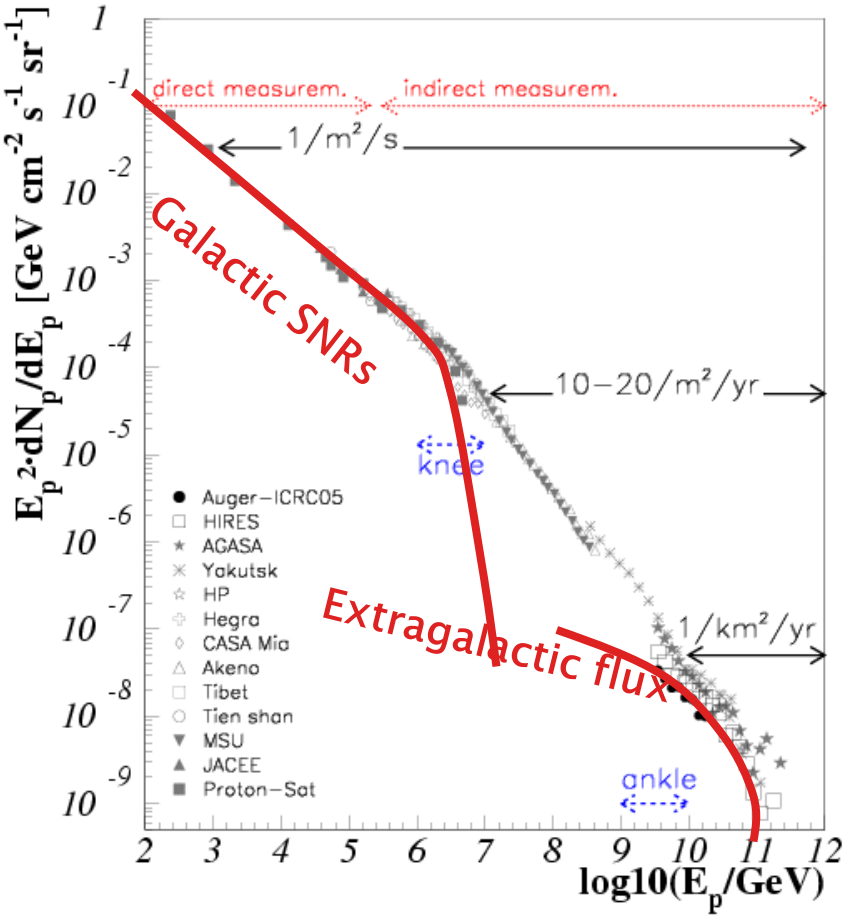

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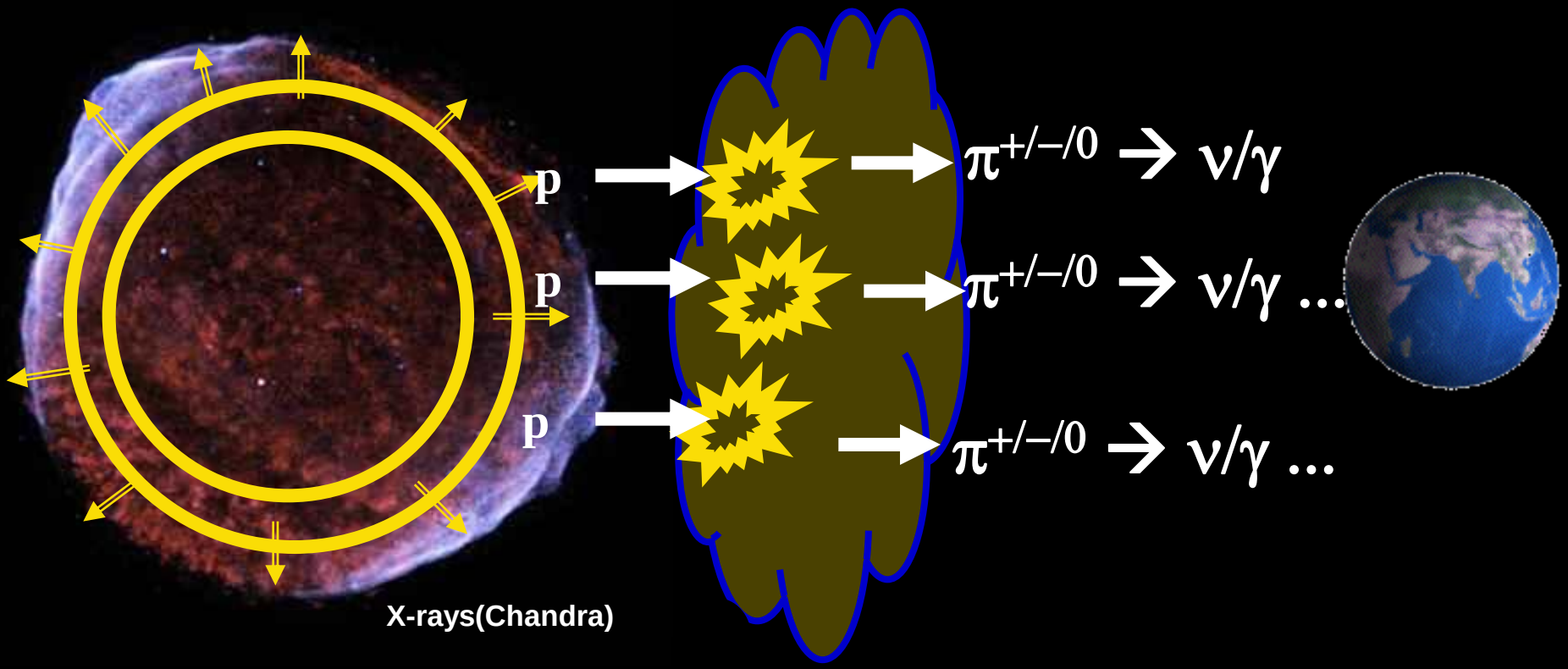
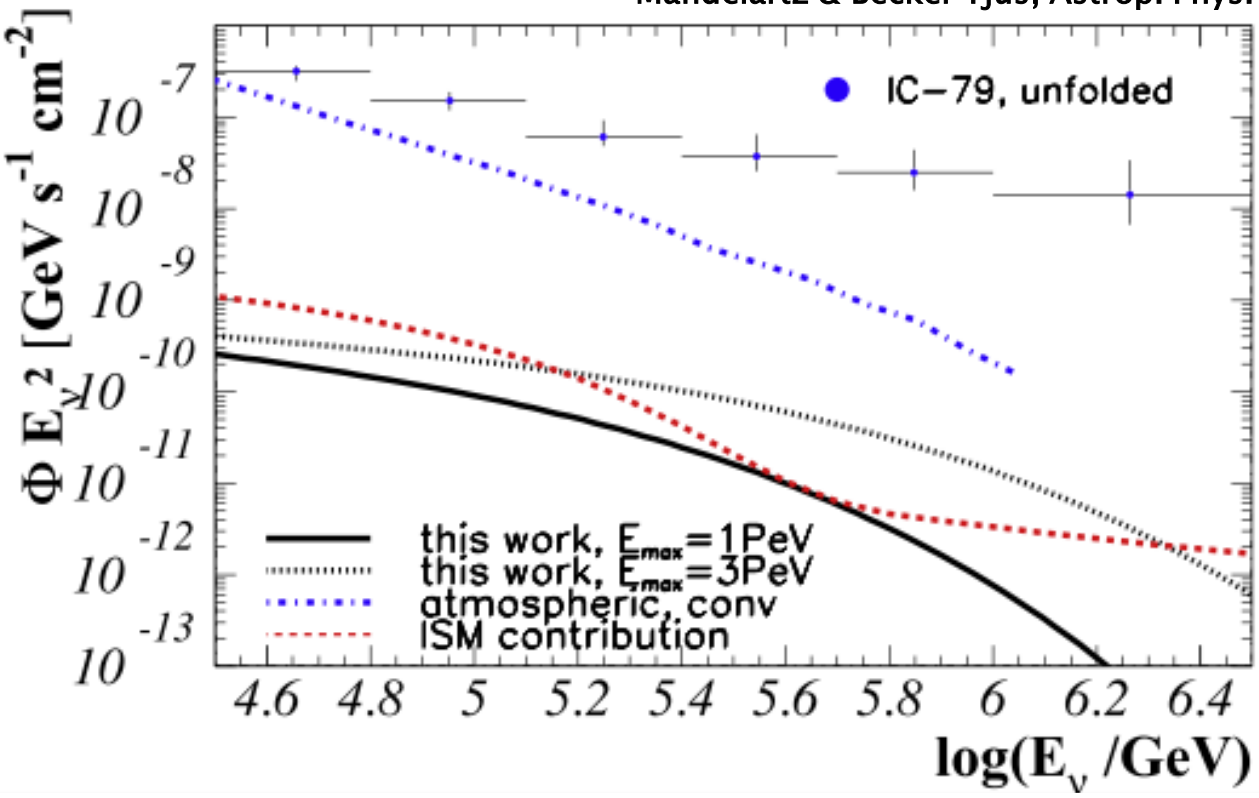
SNRs as high-energy neutrino sources



- Galactic contribution to diffuse signal:
  - look at all SNRs in the Galaxy
  - Extended regions with neutrino production after transport (e.g. Cygnus, Galactic Center, Diffuse CRs in ISM)

Diffuse flux from SNRs in Milky Way

Mandelartz & Becker Tjus, Astrop. Phys. (2015)

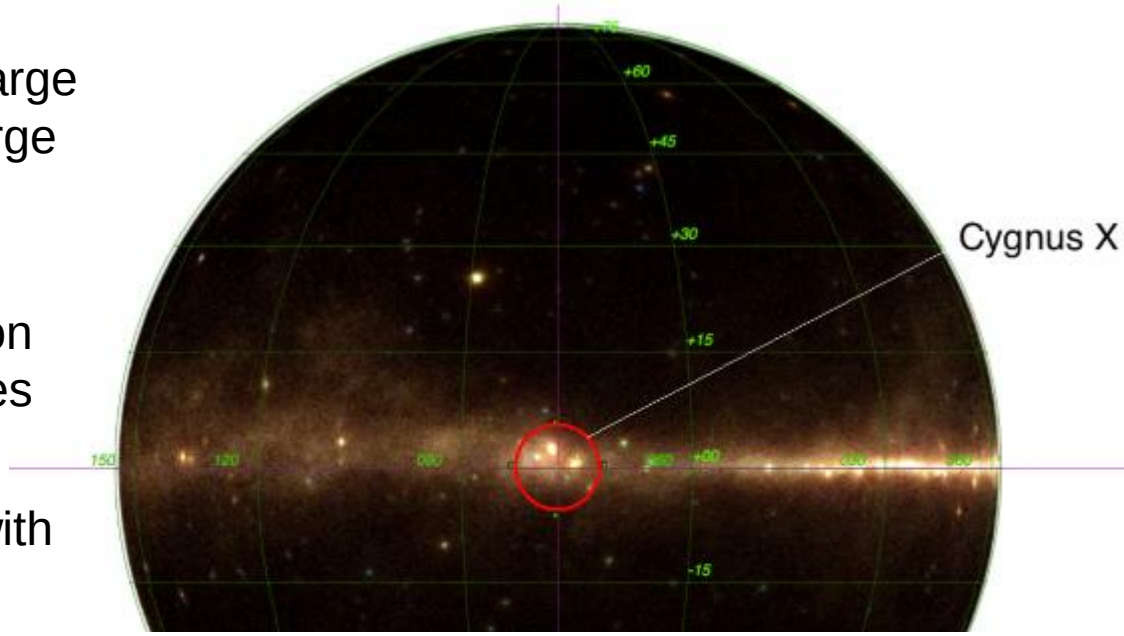


➔SNR unresolved flux can dominate over truely diffuse signal
➔Only a small fraction of all signal events can come from the Milky Way
➔(even if you count all photons in the MW, you end up with only ~2events per year, see Neronov et al)

Gündüz, Eichmann, JBT et al (in prep)

The Cygnus region: extended neutrino emission?

- ➔ Starforming region (δ ~40°): large number of SNRs/PWN/… and large amount of matter (= good target)
- Northern hemisphere: good region for IceCube point source searches
- Modeling: cosmic ray transport with diffusion and advection:

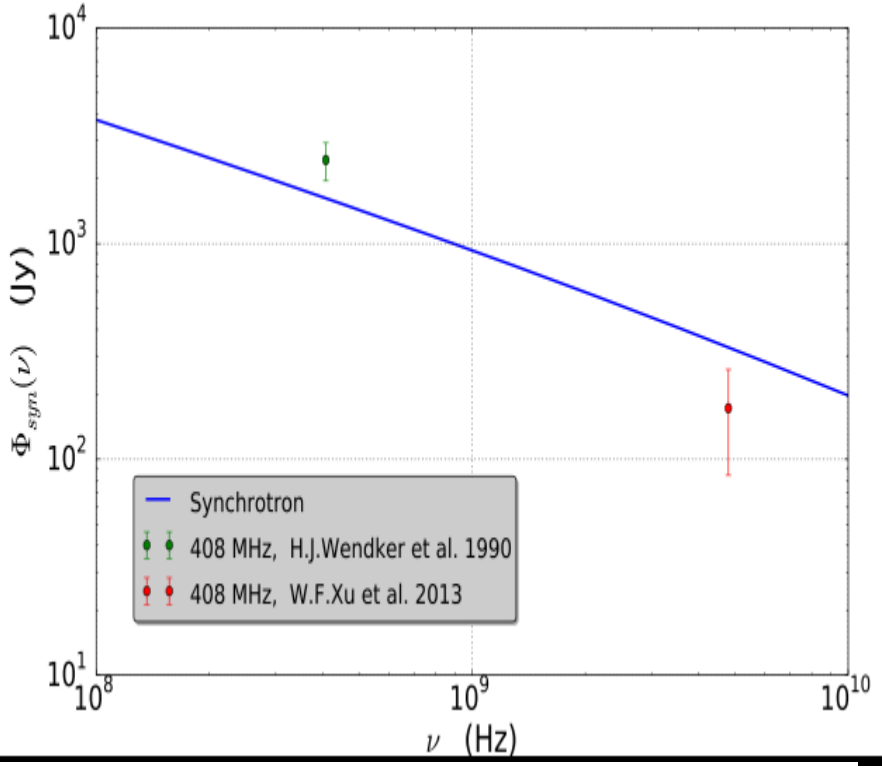


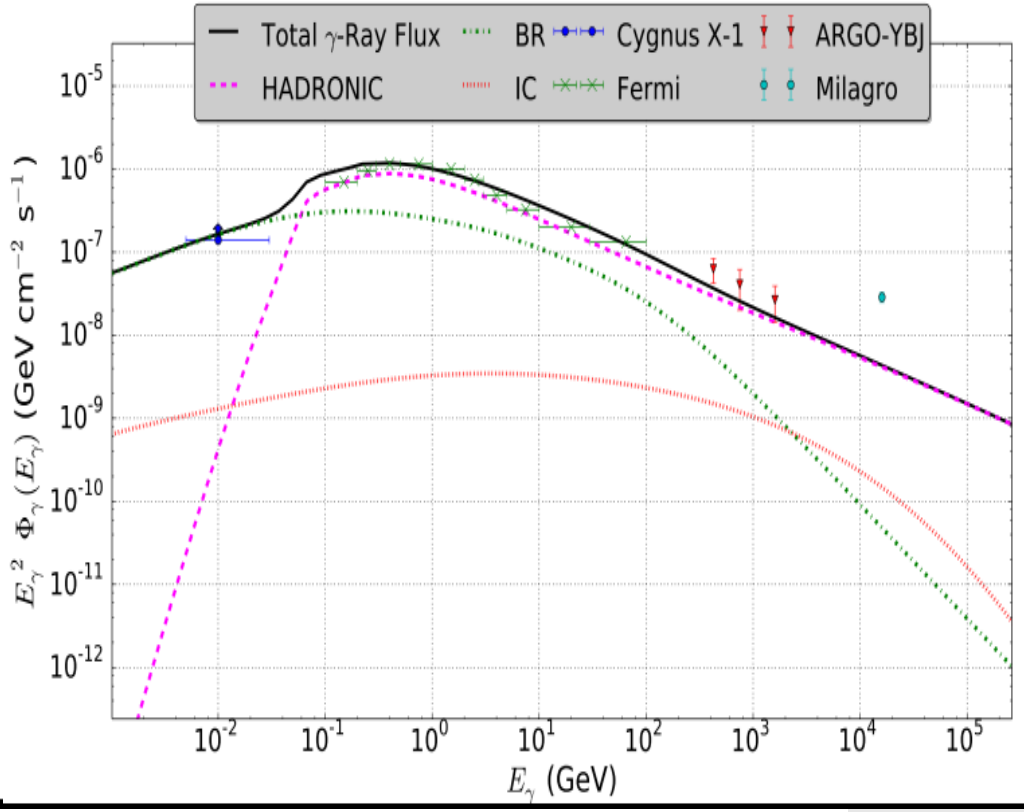
$$\underbrace{\frac{\partial n(\mathbf{x},\mathbf{v},t)}{\partial t}}_{\text{Storage}} - \underbrace{\nabla_{\mathbf{v}}(F(\mathbf{v})\, n(\mathbf{x},\mathbf{v},t))}_{\text{Continuous Loss}} + \underbrace{\nabla(\mathbf{v}\, n(\mathbf{x},\mathbf{v},t))}_{\text{Advection}} + \underbrace{\nabla(D\,\nabla n(\mathbf{x},\mathbf{v},t))}_{\text{Diffusion}} = \underbrace{q(\mathbf{x},\mathbf{v},t)}_{\text{Generation}}$$

Fermi color map,
150°–300° horizontal plane

Gündüz, Eichmann, JBT et al (in prep)

Cygnus: fit to gamma-data
➔ best fit including local diffusion

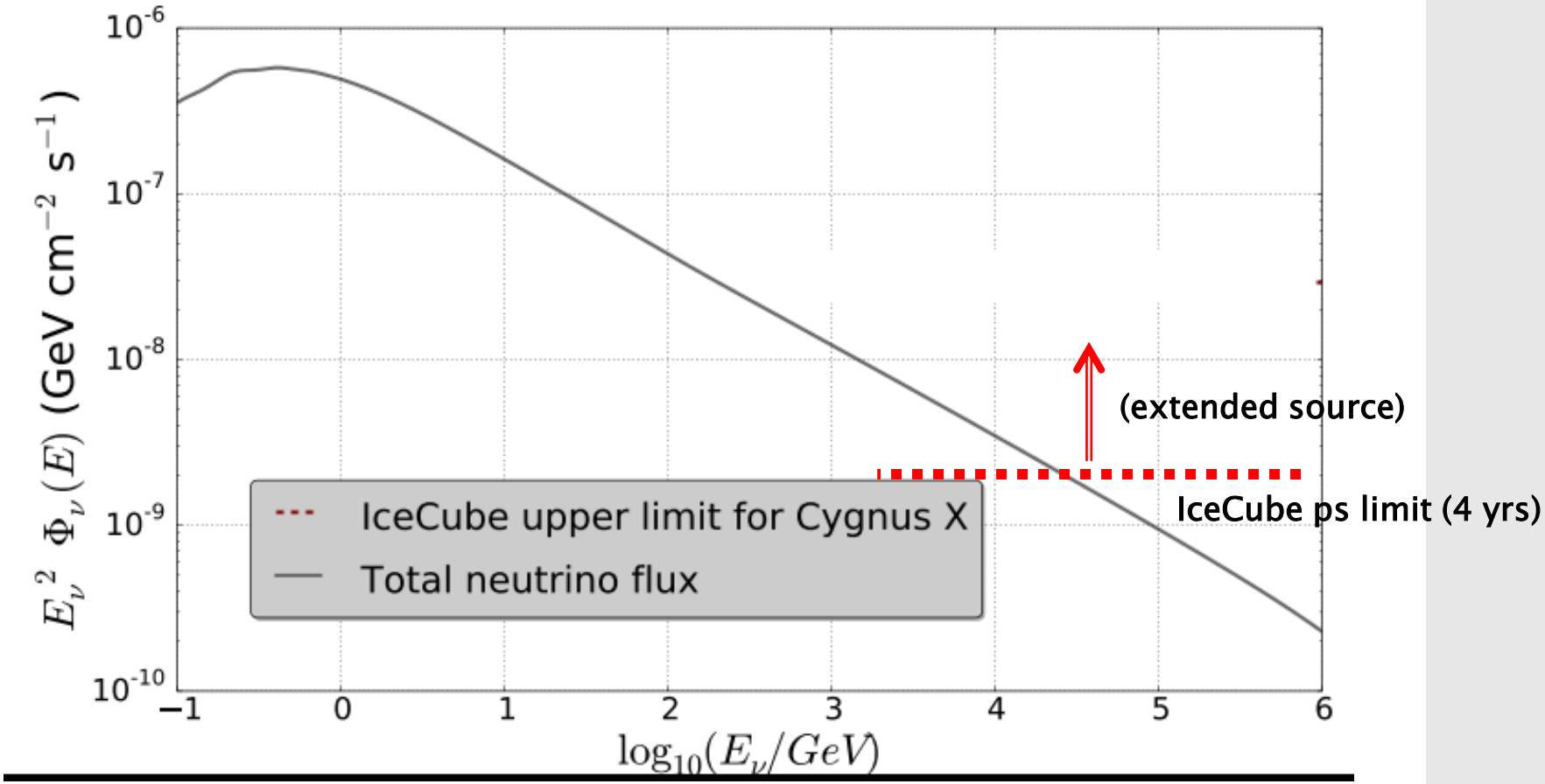




➔Synchrotron, Inverse Compton, Bremsstrahlung, π^0
➔Fit on radio (408/4800MHz), MeV (COMPTEL), GeV-TeV (Fermi, ARGO) data
➔COMPTEL data + radio fix bremsstrahlung: MILAGRO data difficult to explain in MWL picture

Gündüz, Eichmann, JBT et al (in prep)

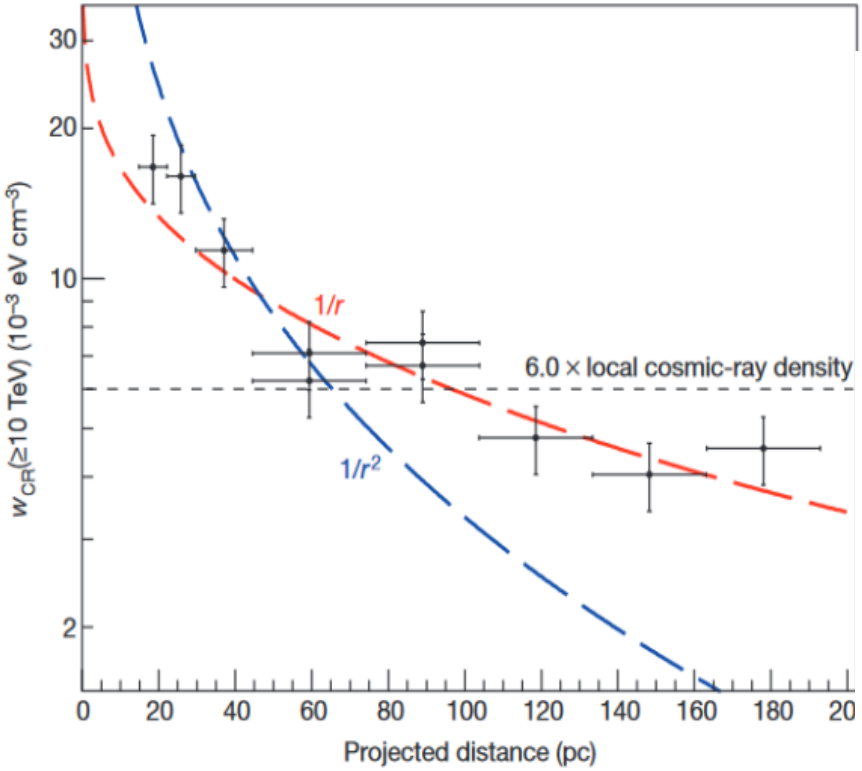
Cygnus: Expected neutrino flux

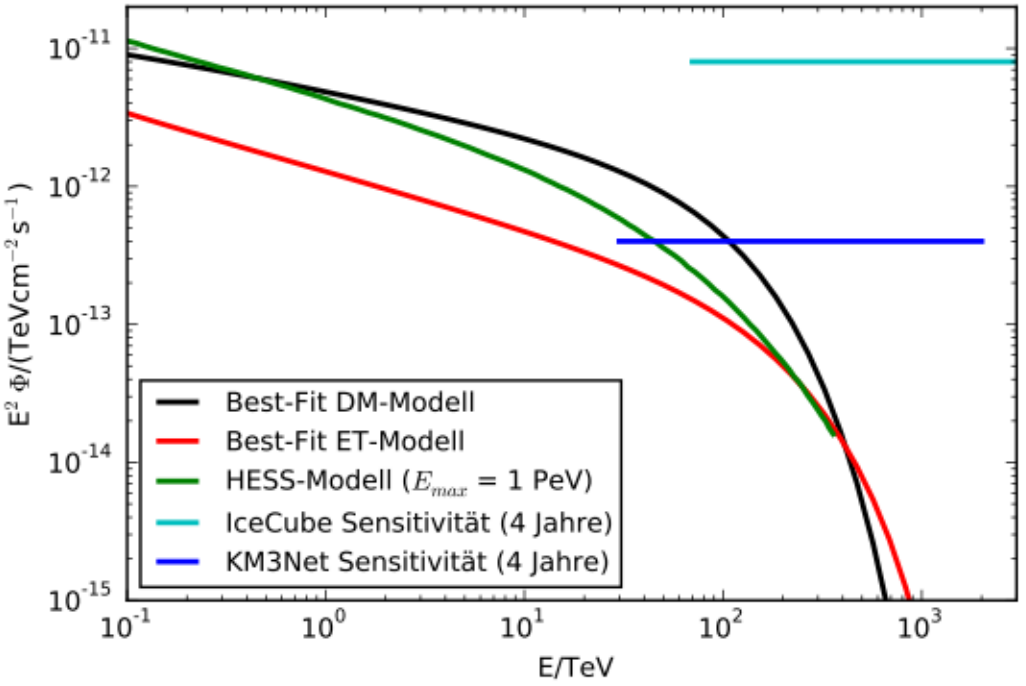


➔Gamma-ray signal likely dominated by leptonic processes
➔MILAGRO data point difficult to fit → too high flux? → HAWC…
➔Steep neutrino flux too low now, but interesting in the next years (Gen2/KM3NeT)

Galactic Center: future target (KM3NeT/IceCube-Gen2)

$$0 = \frac{\partial}{\partial\gamma}(|\dot{\gamma}|_p\, n_p) - \frac{n_p}{\tau_p^{diff}(\gamma)} - \frac{n_p}{\tau_p^{adv}} + q_p(\gamma).$$



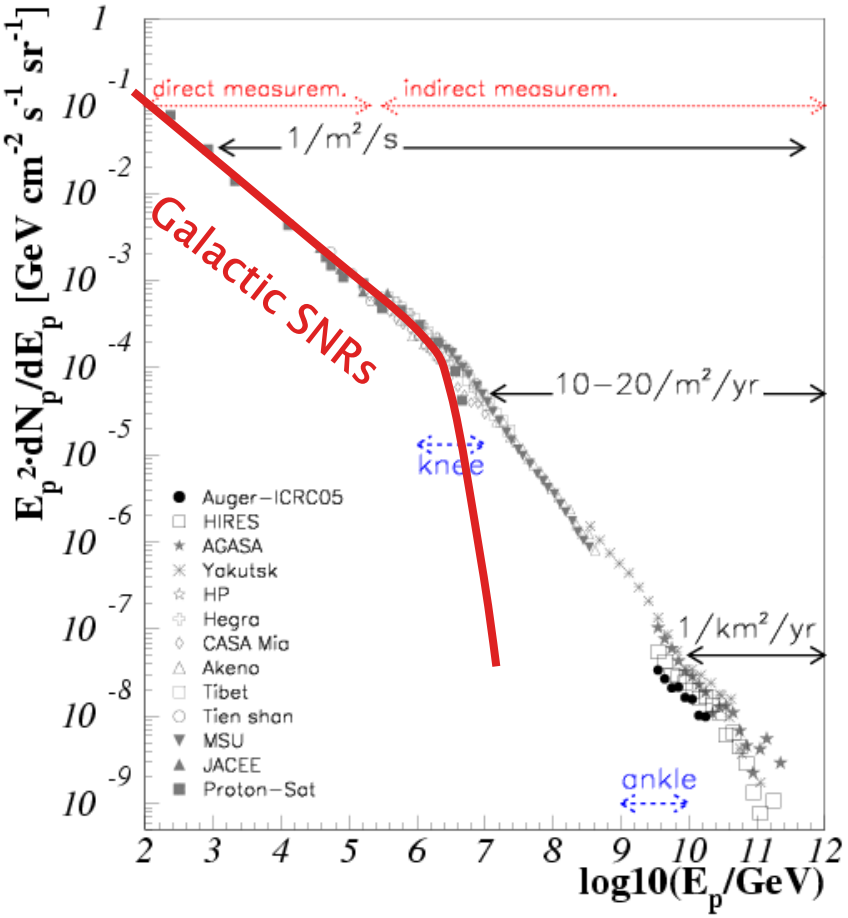


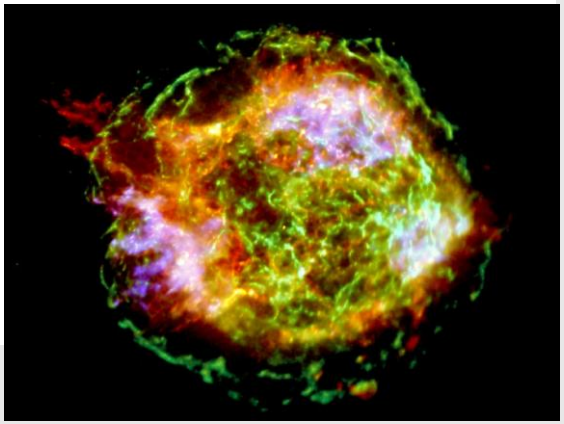
H.E.S.S. Coll, Nature, March 2016

Tim Höhne, Bachelor's thesis, RU Bochum, Germany

Galactic origin?
Supernova remnants

- **Astrophysical signal of strength:** $E^2 * dN_\nu/dE_\nu \sim 10^{-8}$ GeV s^{-1} cm^{-2} sr^{-1}
  - **too high for Galactic sources!**
- **Spectral behavior:**
  - **cutoff @ PeV-energies**
  - **expected**
- **Spatial Clustering?: So far isotropic distribution**
  - **Clustering in Galactic plain expected**
  - **Halo emission? [Taylor, Gabici & Aharonian 2014]**
- **Temporal Clustering?:** no
  - **not expected**





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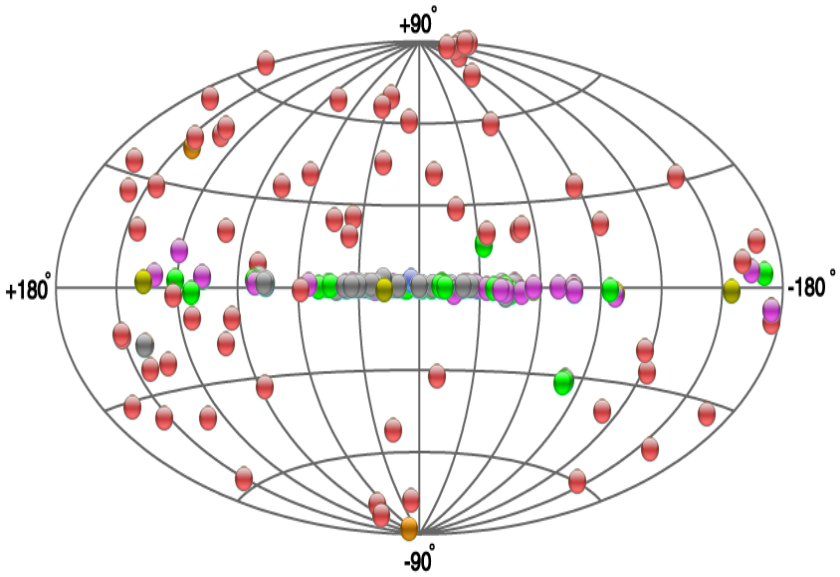
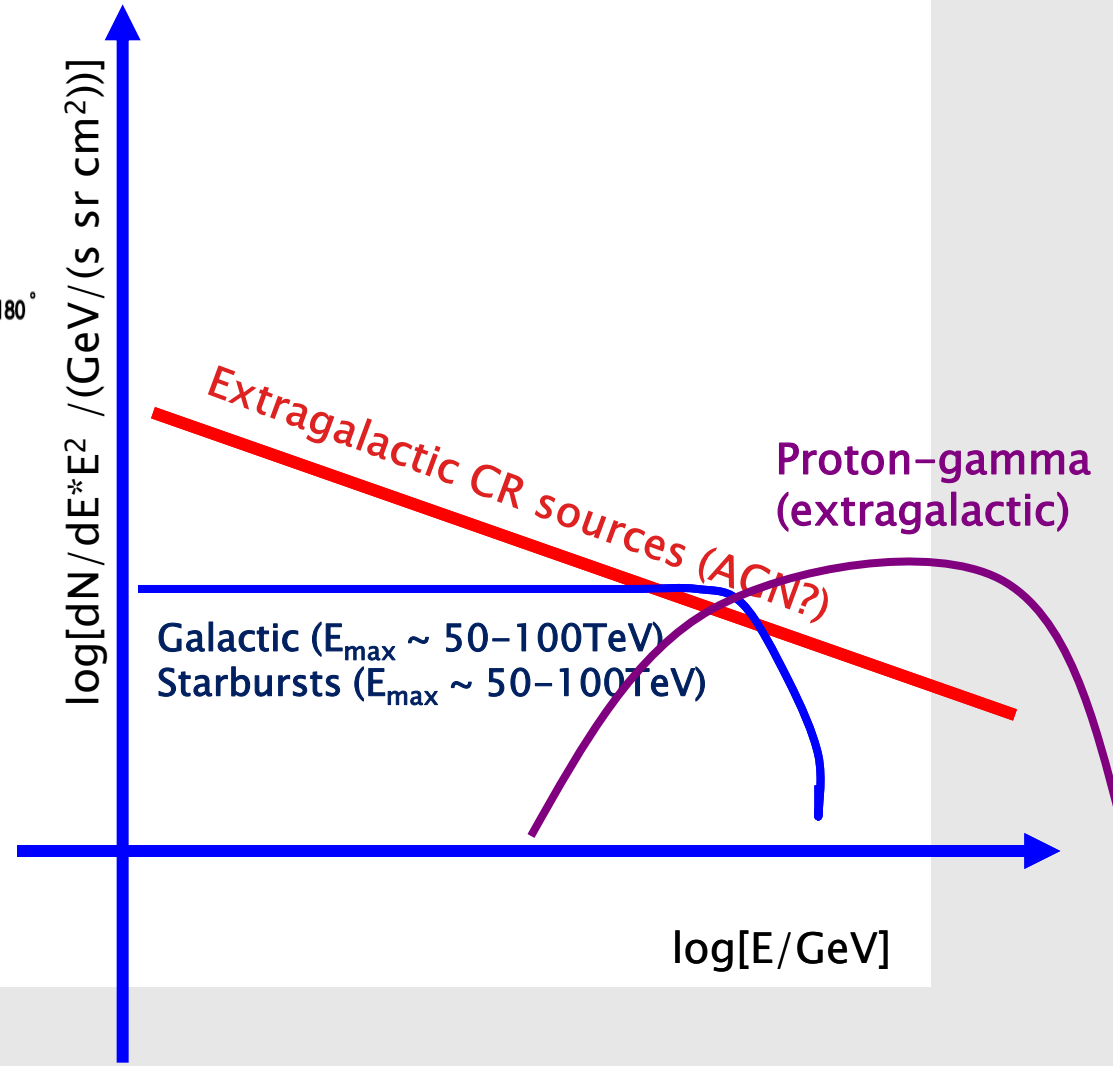
Neutrino flux and extragalactic sources: GRBs, AGN, starbursts



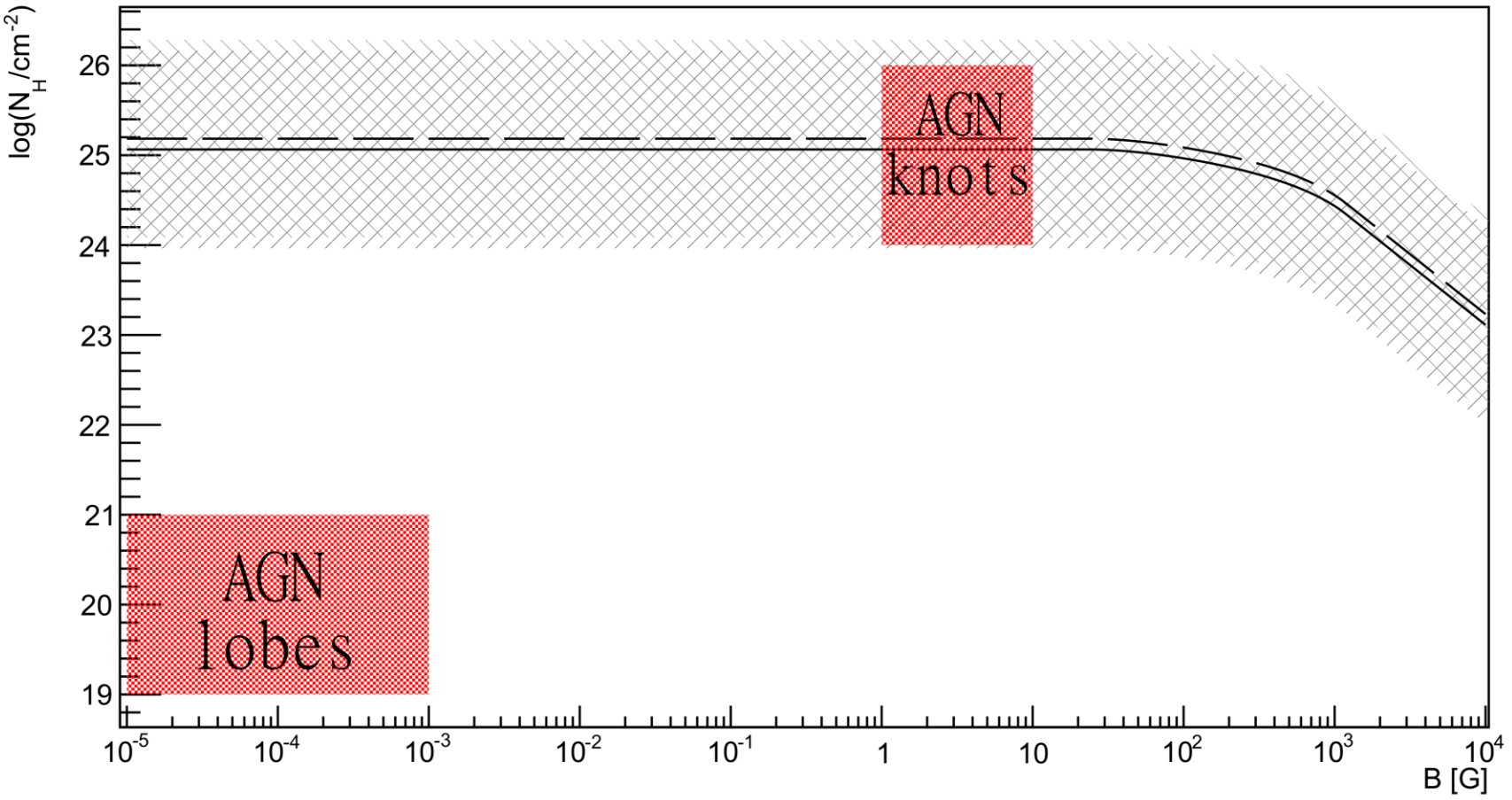
Source Types

- PWN
- Binary XRB PSR Gamma BIN
- HBL IBL FRI FSRQ Blazar LBL AGN (unknown type)
- Shell SNR/Molec. Cloud Composite SNR Superbubble
- Starburst
- DARK UNID Other
- uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR



FR-Galaxies

allowed Parameter space VS observed properties



Becker Tjus, Eichmann, Halzen, Saba, PRD (2014), arXiv:1406.0506

JBT (in prep)

Detection of point sources?
Back-of-the-envelop

- Comparison:
  - Point source sensivitiy: $\Phi_\nu \sim 2 \cdot 10^{-12} \cdot \left(\frac{t}{4yr} \right)^{-0.5}$ TeV cm^{-2} s^{-1}
  - Diffuse signal $\Phi^{DS} \sim 10^{-11}$ TeV cm^{-2} s^{-1} sr^{-1}

JBT (in prep)

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Back-of-the-envelop

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  - Diffuse signal $\Phi^{DS} \sim 10^{-11}$ TeV cm^{-2} s^{-1} sr^{-1}
  - Strongest point source‘s contribution to diffuse signal:

$$\Phi_{\nu,\mathrm{ps}}^{\mathrm{strongest}} = \eta_{\mathrm{theo}} \cdot \Phi^{\mathrm{DS}}$$

  - Theoretical factor η_{theo} depends on electromagnetic luminosity of the strongest source, the luminosity function of the source class and the relation between average source parameters and the one for the strongest source

Example FR-I galaxies:
Emission from core, i.e. close to AGN

→Strongest point source: M87 (core emission ~ a few Jy at 22GHz);
→ Calculation and comparison of diffuse and point source signal:

Assuming correlation with radio emission following JBT, Eichmann, Halzen, PRD 2014

→ η_{theo} ~0,09 →

Sensitivity improvement by a factor of ~ 3 with respect to 4yrs

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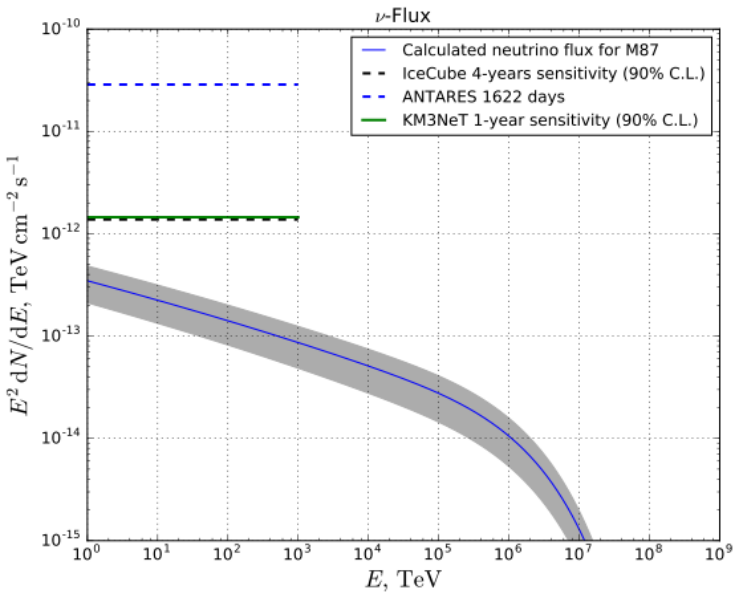
Sensitivity improvement by a factor of ~ 3 with respect to 4yrs

THIS IS JUST BACK-OF-THE ENVELOPE!

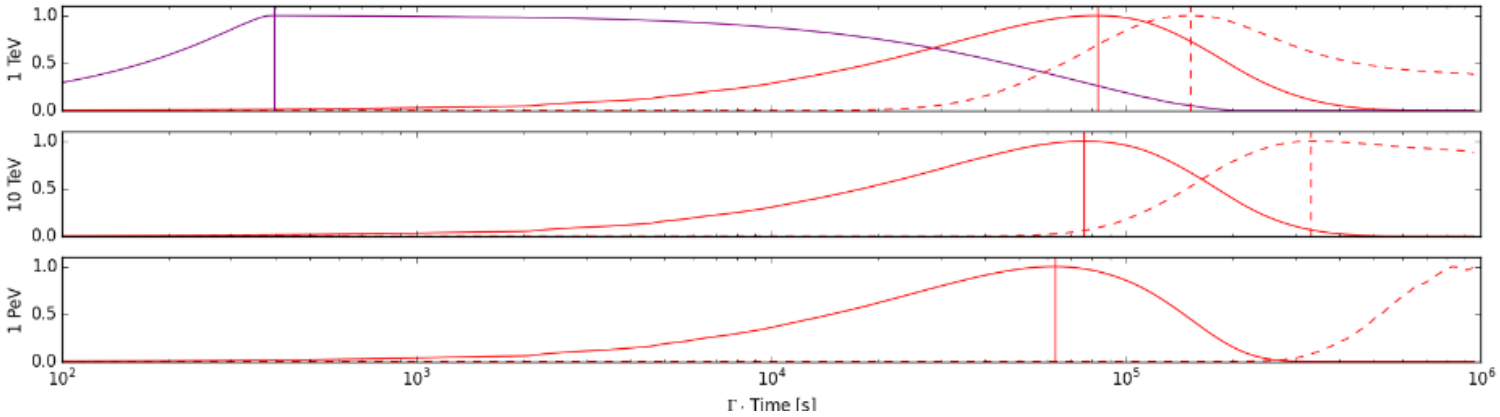
More information available from gamma-ray data: possibility to determine source properties of M87 with respect to average properties of diffuse signal sample ➔



Future: correlation of MWL signatures for flares in MWL campaigns (KM3NeT/IceCube-Gen2)

IC+Bremsstrahlung
IC+Bremsstrahlung w/Accel.
Proton-Proton
Proton-Proton w/Accel.

$$\frac{\partial f_a}{\partial t} = \nabla \cdot (D \nabla f_a) + \frac{1}{p^2}\frac{\partial}{\partial p}\left(D_p p^2 \frac{\partial f_a}{\partial p} + \dot{p}_a f_a \right) + S_a \delta(t)$$

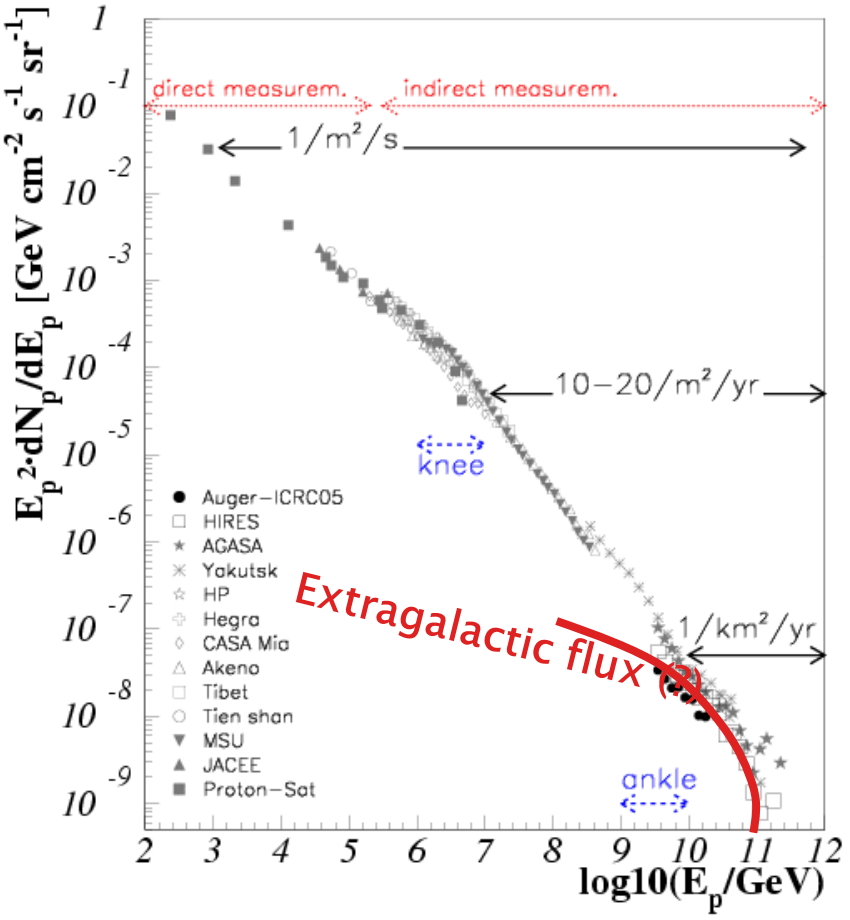


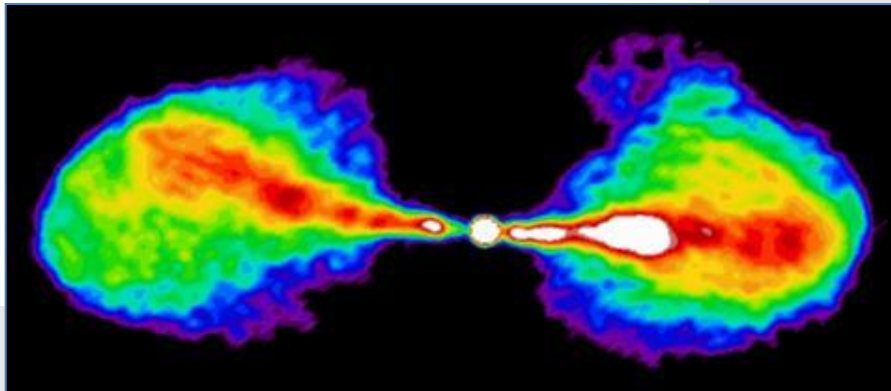
Leptonic and hadronic gamma-ray emission happen at different times with respect to the neutrino flare – long-term potential for MWL modeling to investigate hadronic emission scenario and ratio of electrons to protons in extragalactic sources

Mandelartz & JBT (in prep)

Extragalactic origin?
Active Galactic Nuclei

- **Astrophysical signal of strength:** $E^2 * dN_\nu/dE_\nu \sim 10^{-8}$ GeV s^{-1} cm^{-2} sr^{-1}
  - yes: for certain sub classes
- **Spectral behavior:**
  - **$E^{-2.3}$:**
  - yes: to be compatible with observed flux of UHECRs, it needs to be $E^{-2.3}$ or steeper
- **Spatial Clustering?: So far isotropic distribution**
  - would expect isotropic distribution from AGN source class
- **Temporal Clustering?:** no
  - not necessarily



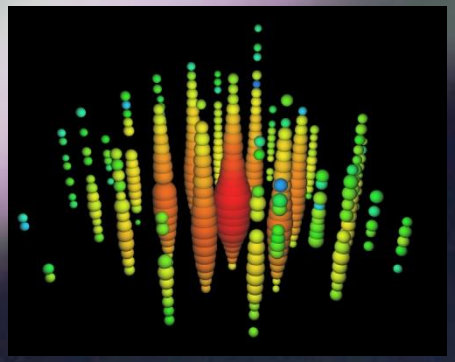


Summary and Outlook

- Galactic sources:
  - cannot make up the entire signal (too few gamma-rays)
  - are interesting point (and extended) sources for future detectors KM3NeT and IceCube-Gen2

Summary and Outlook

- Galactic sources:
  - cannot make up the entire signal (too few gamma-rays)
  - are interesting point (and extended) sources for future detectors KM3NeT and IceCube-Gen2
- Extragalactic sources:
  - GRB expectation ~factor 3 lower than signal strength to begin with: not expected as (dominant) sources
  - Dedicated GRB searches: strong limit on neutrino fluxes
  - AGN good candidates:
    - FR-I → low intensity of nearest sources, but exist in large numbers: good candidates for diffuse flux;
    - blazars? – gamma-ray spectra often look quite leptonic (e.g. Mkn501, Mkn421)
    - Other radio galaxies, Seyferts, … ?
  - Starbursts: maximum energy should be below 1PeV: difficult to discuss them as sources of the highest energy eventss



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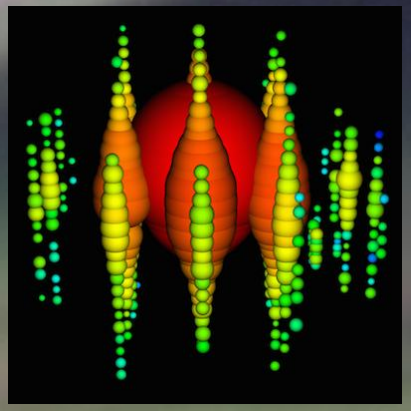

Ready for your questions