Point Source Searches by IceCube: Recent Results and Progress

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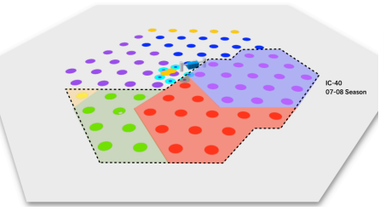
Stockholm University

VLVvT 2011 Erlangen

2011 October

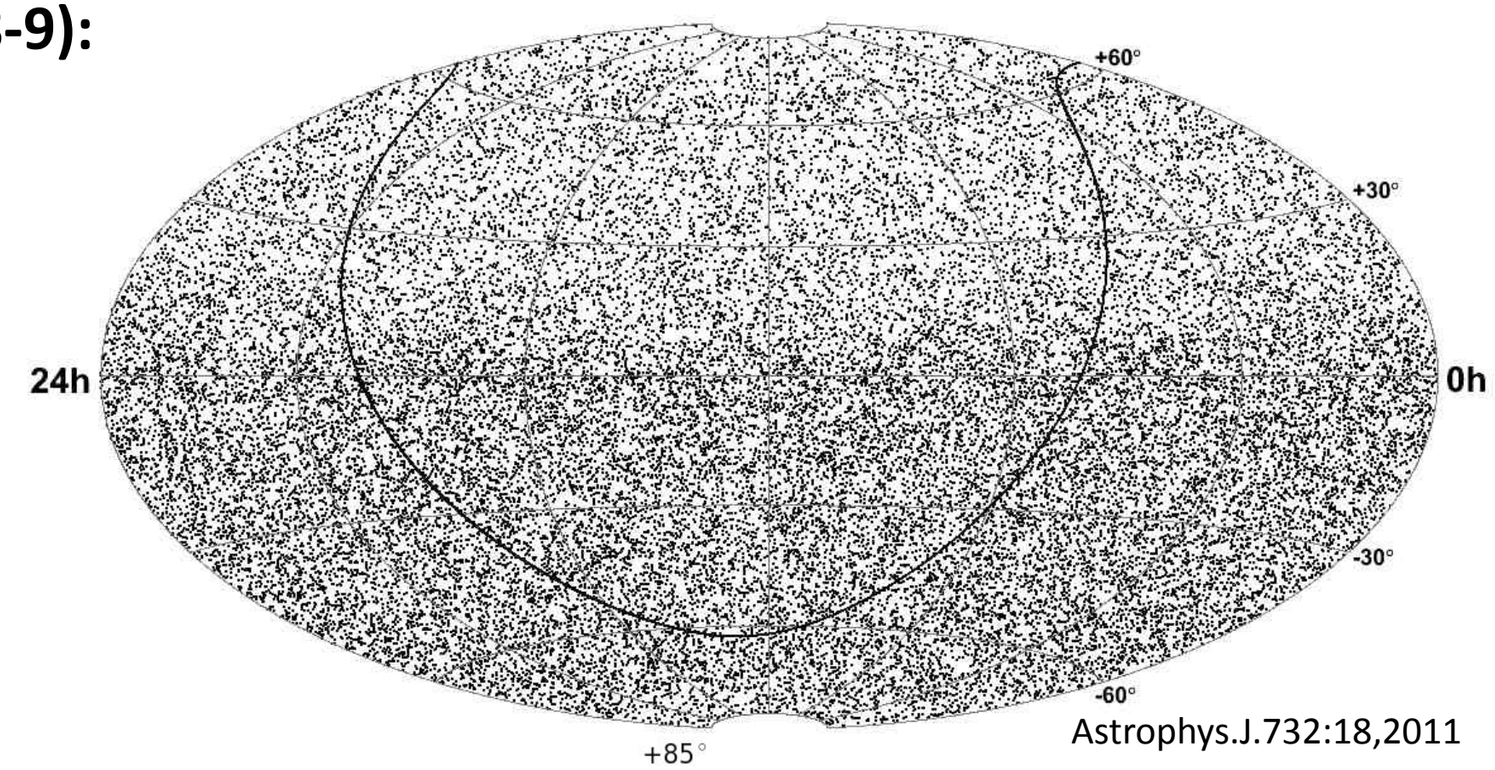
Photo: Freija Descamps

IceCube 40 + IceCube 59-string Point Source Search



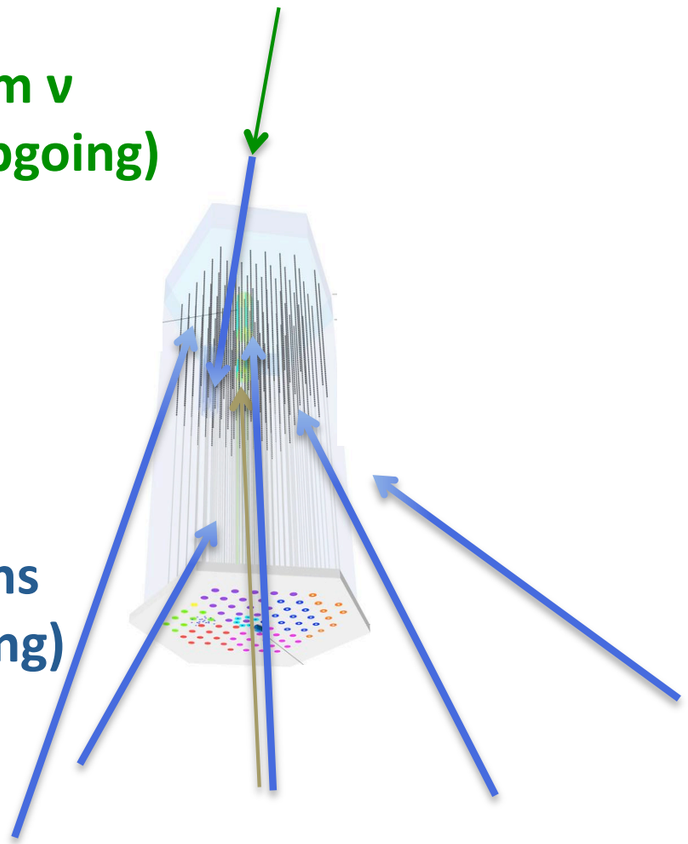
375 days livetime

IceCube 40 strings (2008-9):



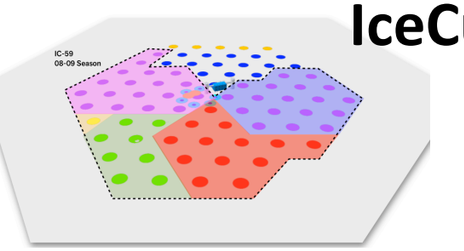
Astrophys.J.732:18,2011

Atm ν (upgoing)

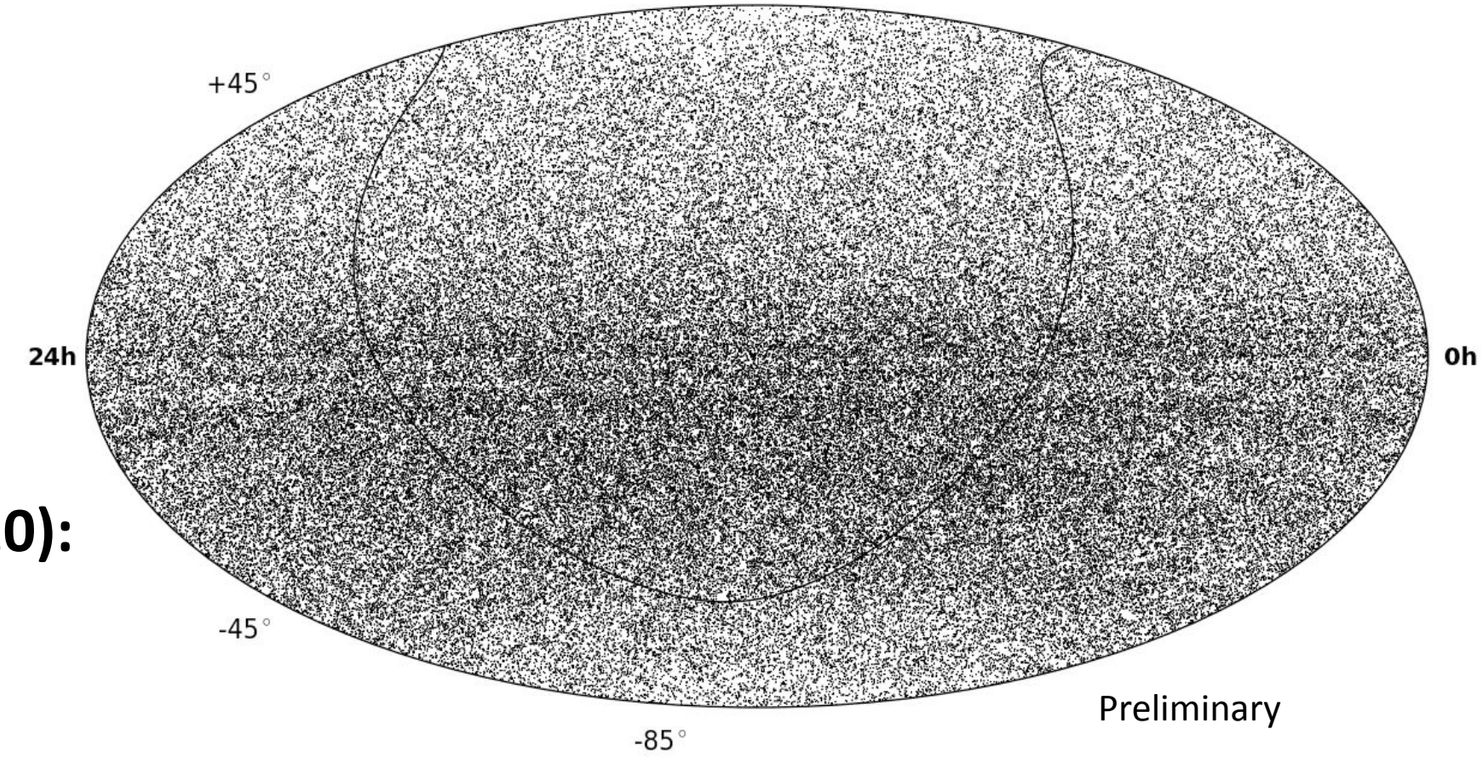


Atm muons (downgoing)

IceCube 59 strings (2009-10):



348 days livetime

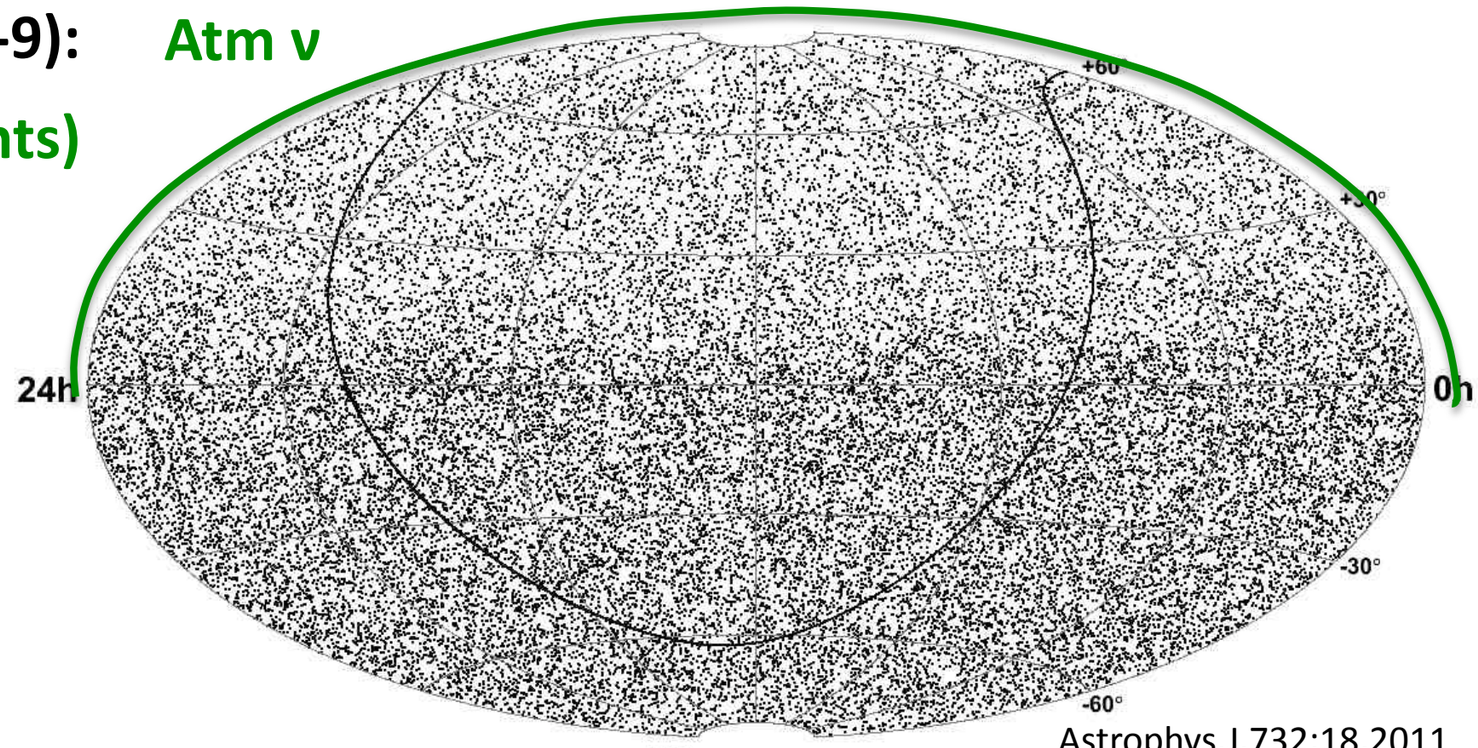


Preliminary

IceCube 40 + IceCube 59-string Point Source Search

IceCube 40 strings (2008-9):

14,121 upgoing (ν candidate events)



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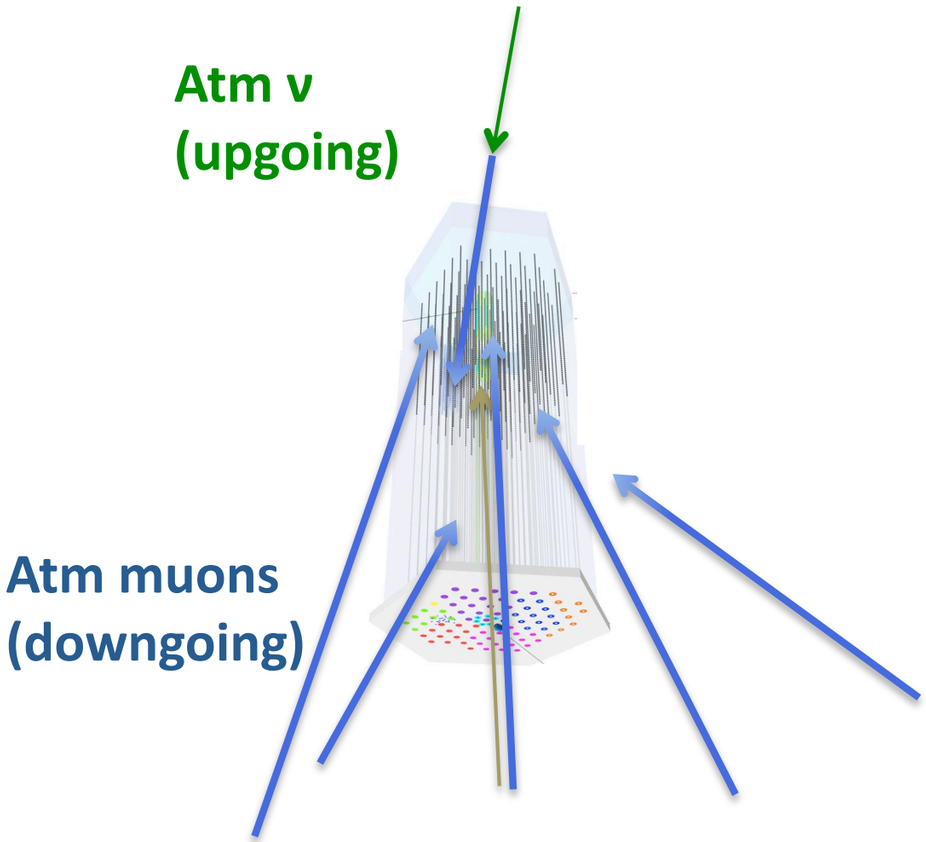
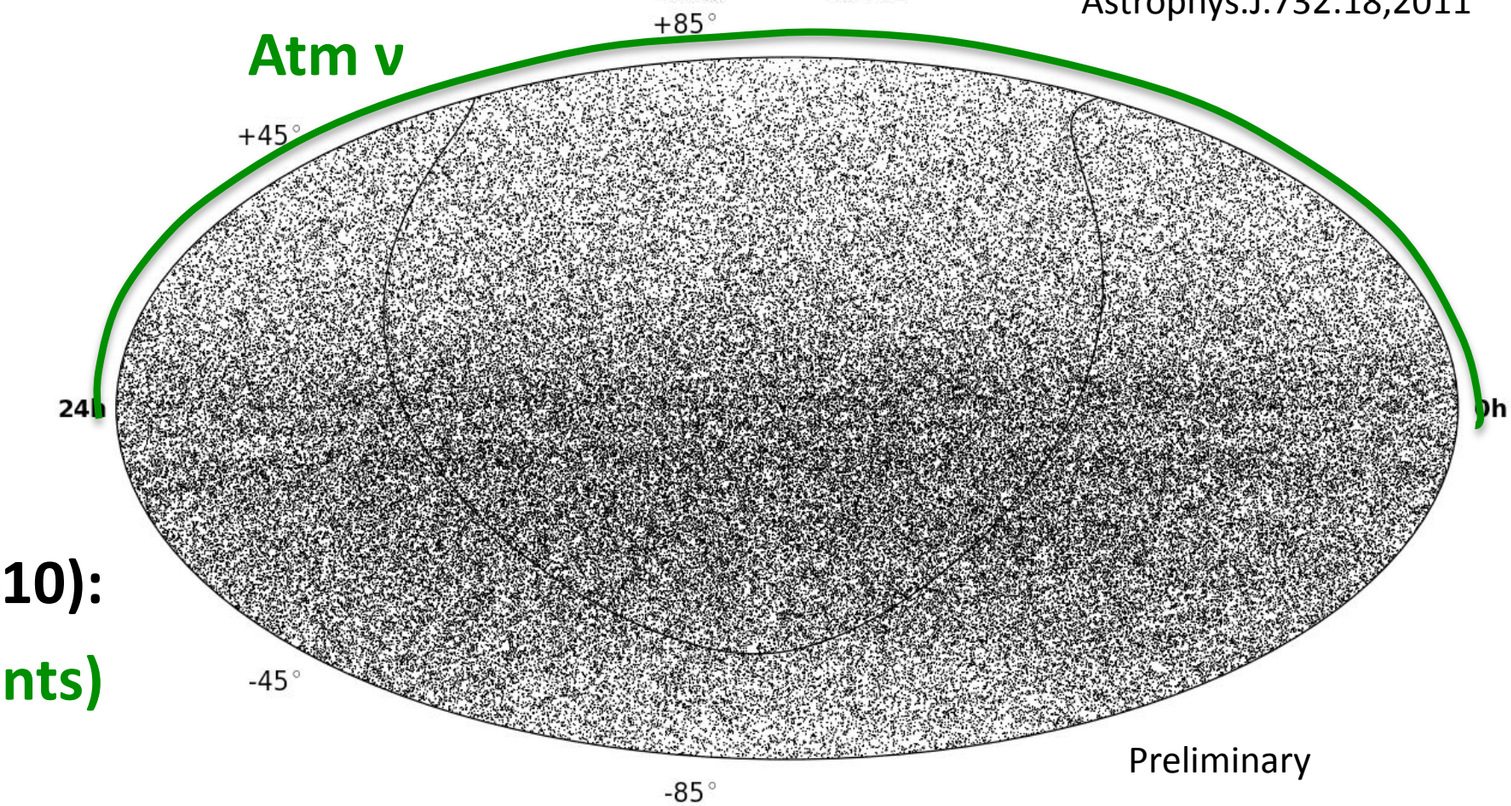


IceCube 59 strings (2009-10):

43,339 upgoing (ν candidate events)



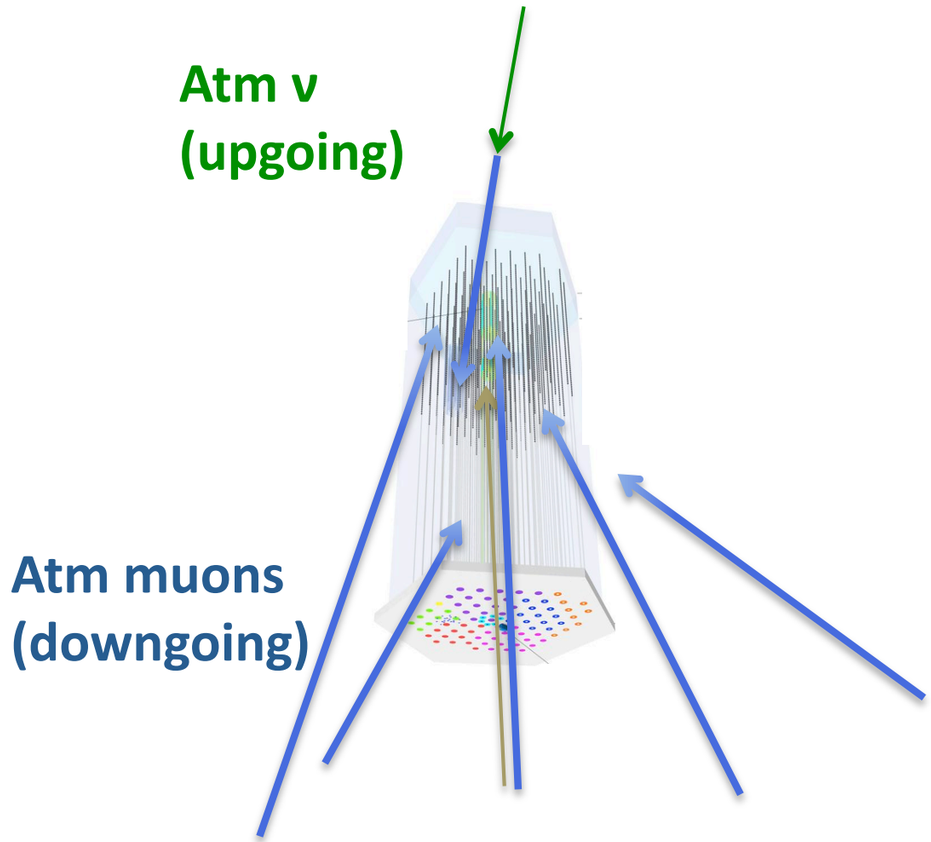
Preliminary

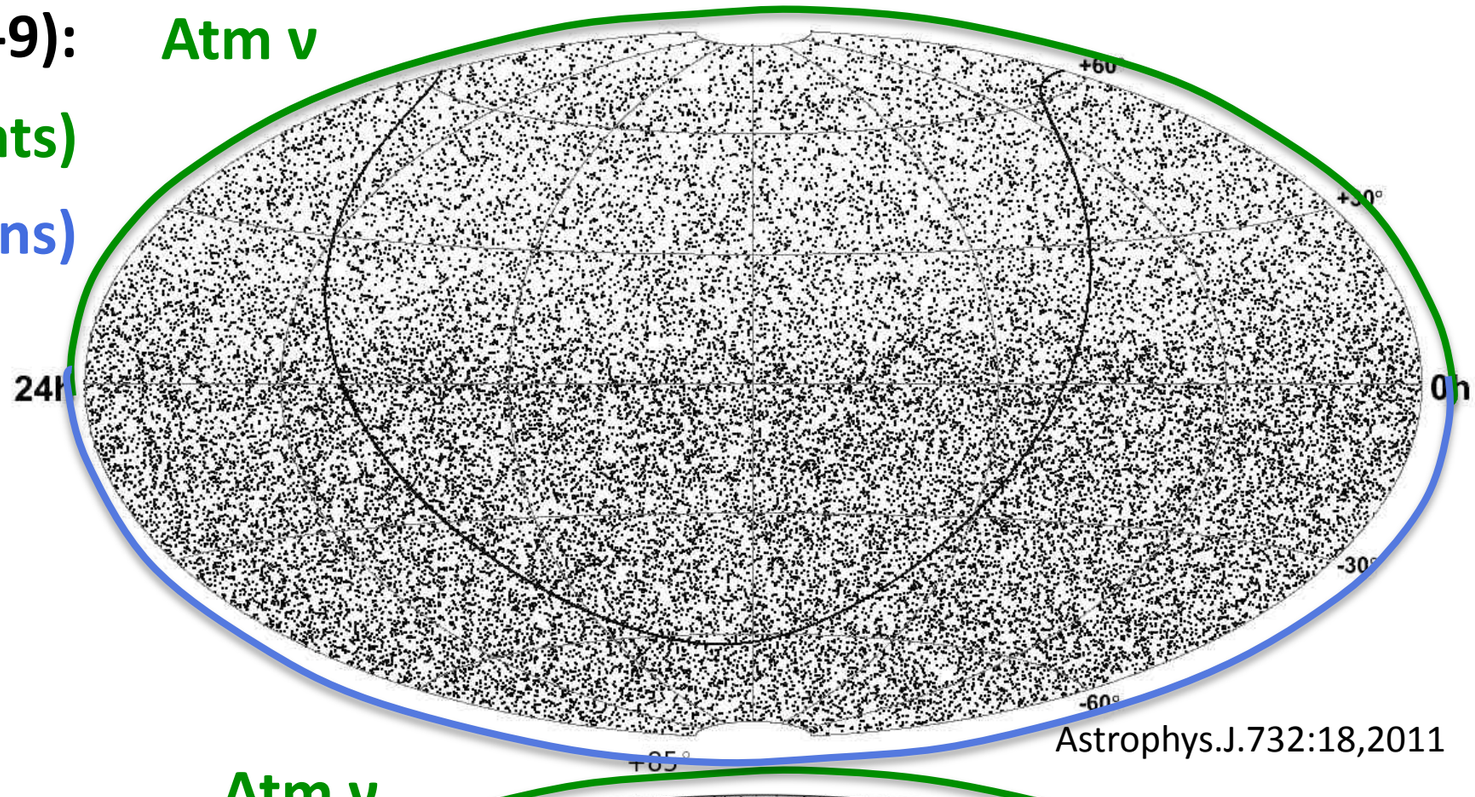
IceCube 40 + IceCube 59-string Point Source Search

IceCube 40 strings (2008-9):

14,121 upgoing (ν candidate events)

22,779 downgoing (HE CR muons)





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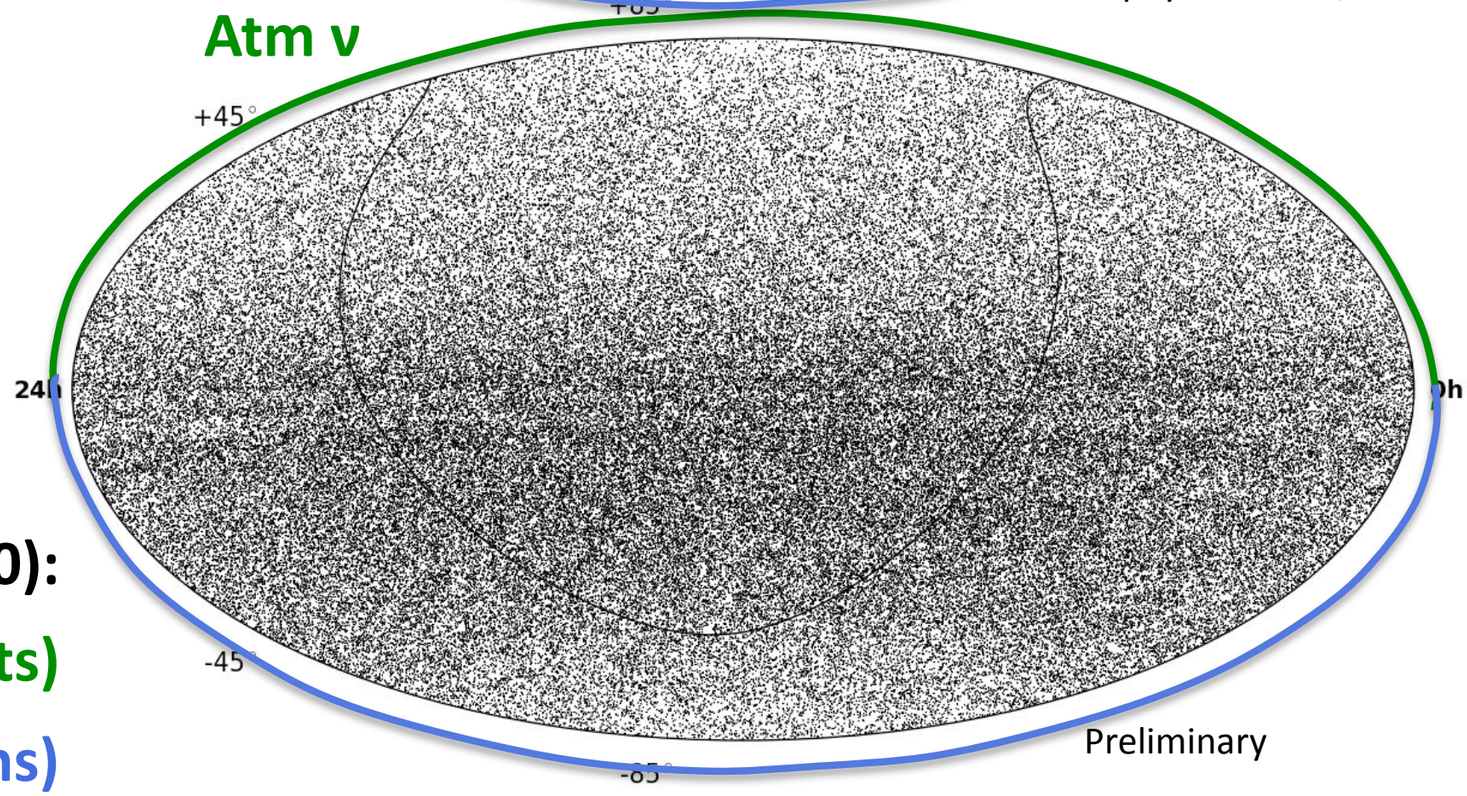

IceCube 59 strings (2009-10):

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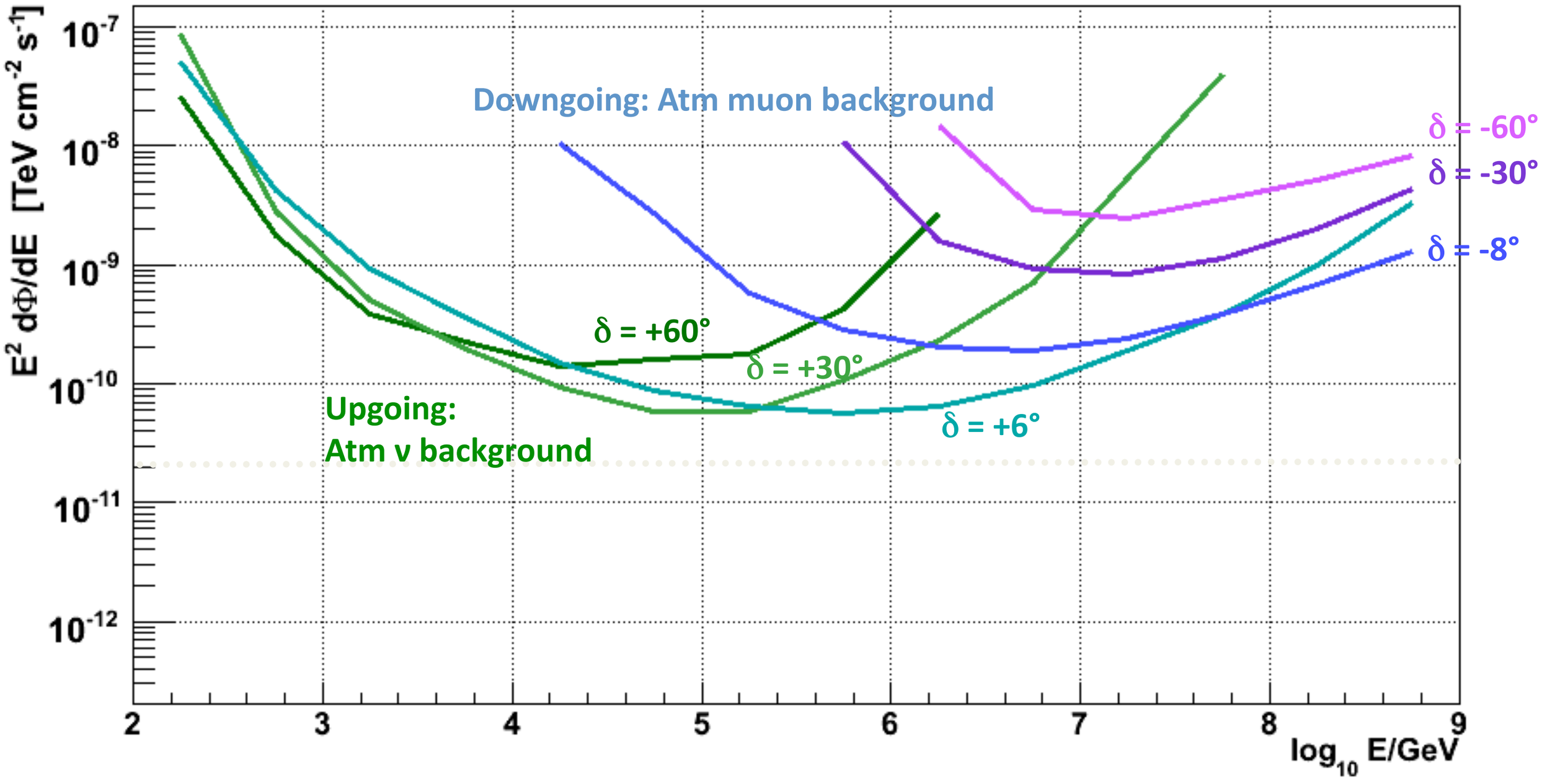
64,230 downgoing (HE CR muons)

Preliminary

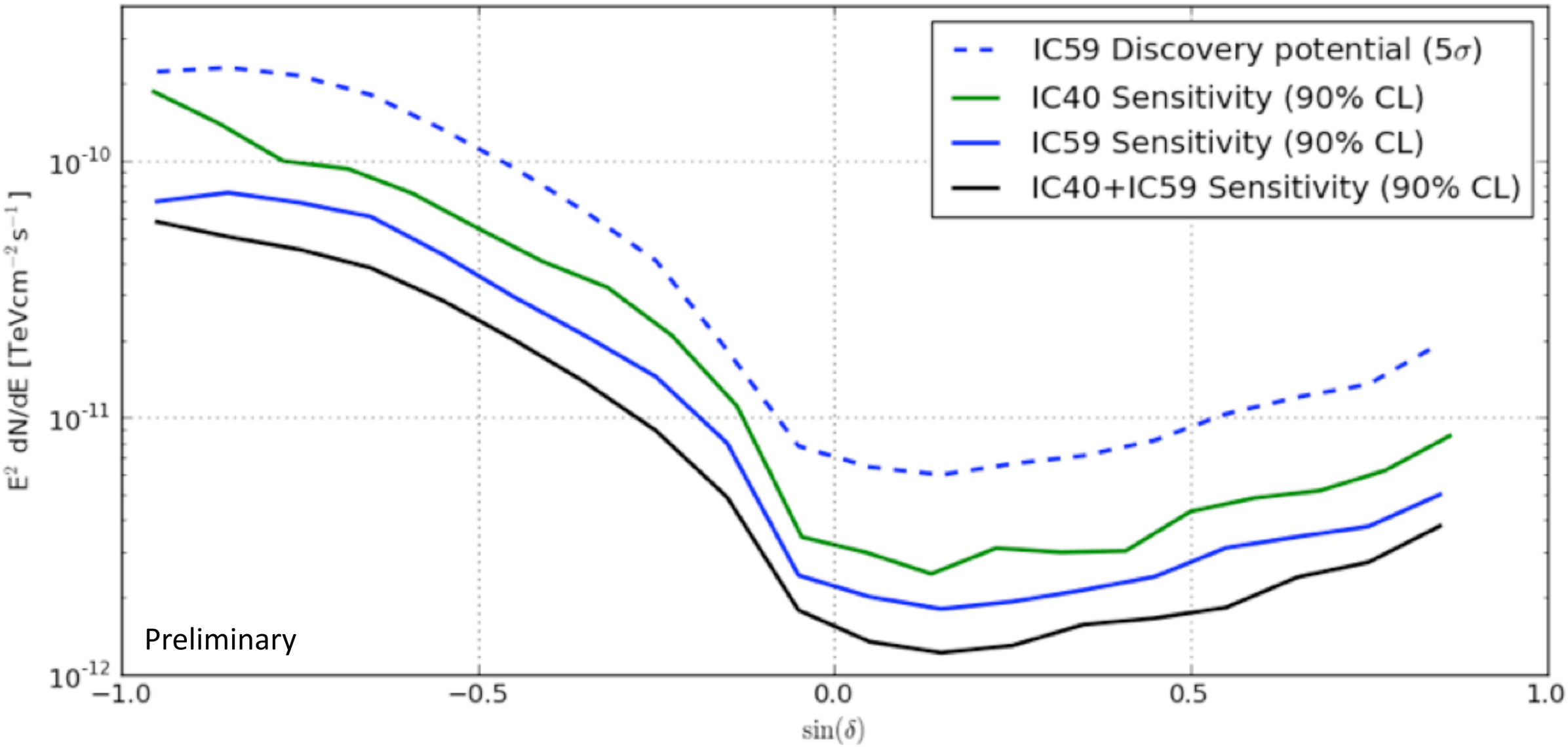
Differential Sensitivity Dependence on Direction



IC40 Differential 5σ Discovery Potentials

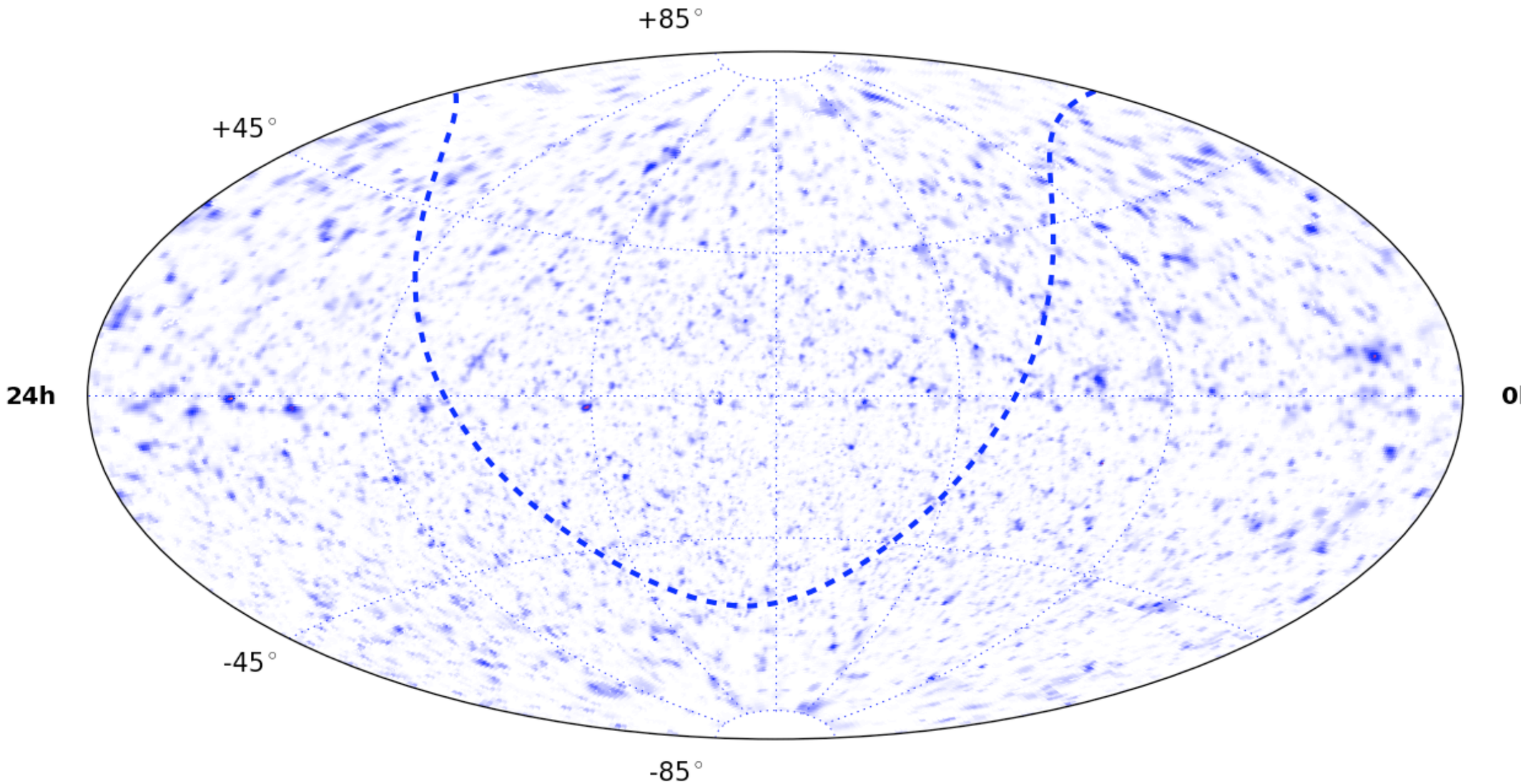
(for E^{-2} signal injected in 1/2 decades of energy)

IceCube 40 + IceCube 59 E^{-2} Sensitivity



J. A. Aguilar et al., ICRC 2011

Results: Joint IC40+IC59 Point Source Skymap



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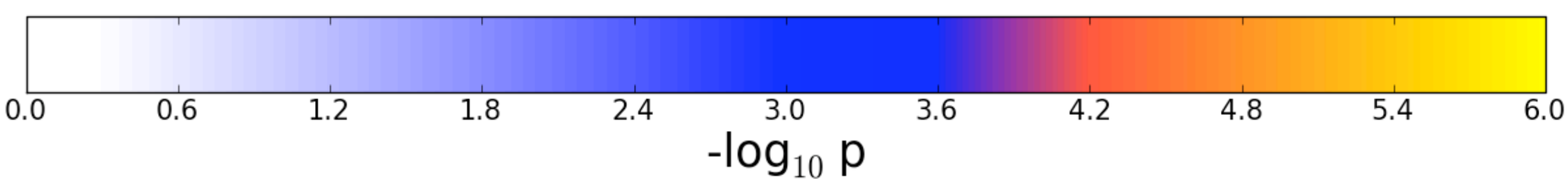

J. A. Aguilar et al., ICRC 2011

Results: Joint IC40+IC59 Point Source Skymap

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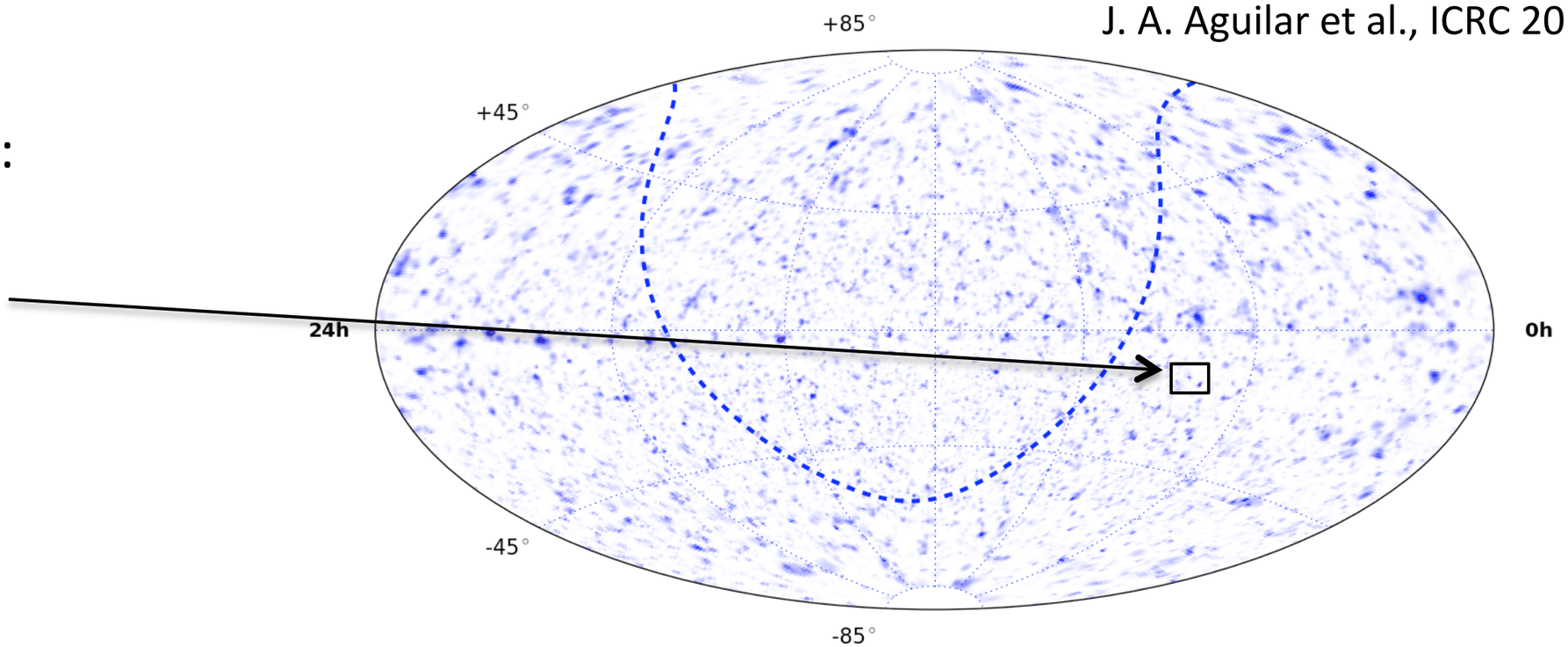
Most significant spot:
r.a. = 75.45°
dec. = -18.15°
n_s = 18.3
γ = -3.9
$-\log_{10}$ p-value = 4.65



$$\mathcal{S}_i = \frac{1}{2\pi\sigma_i^2} e^{-|\vec{x}_i - \vec{x}_s|^2/2\sigma_i^2} \cdot P(E_i|\gamma)$$

$$\mathcal{L}(n_s, \gamma) = \prod_{i=1}^{N} \left(\frac{n_s}{N} \mathcal{S}_i(\gamma) + (1 - \frac{n_s}{N}) \mathcal{B}_i \right)$$

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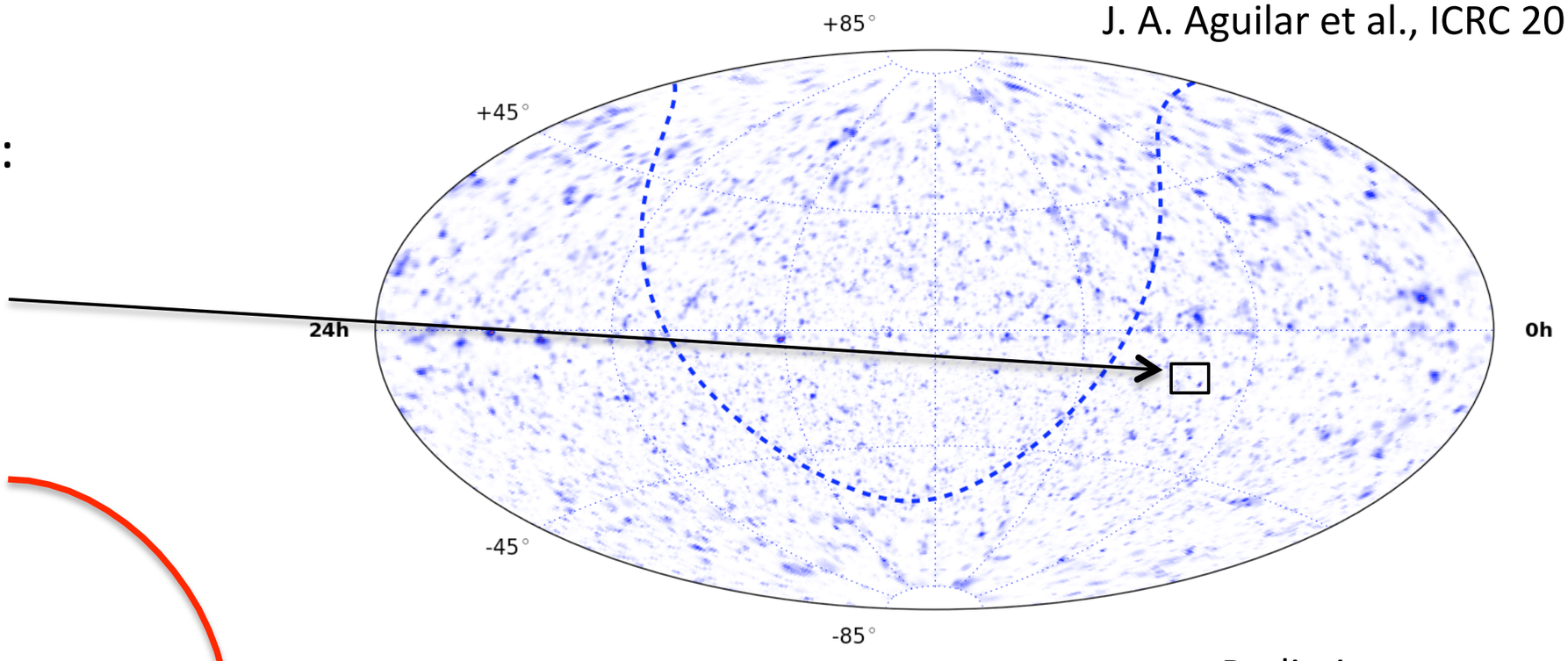

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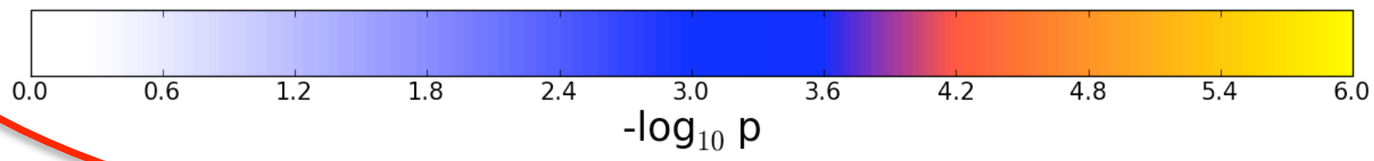

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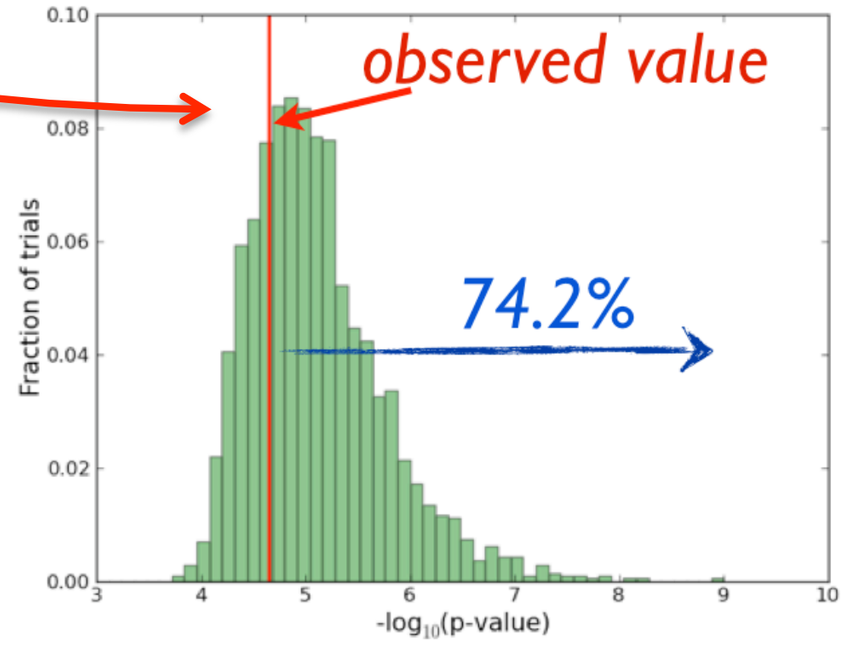
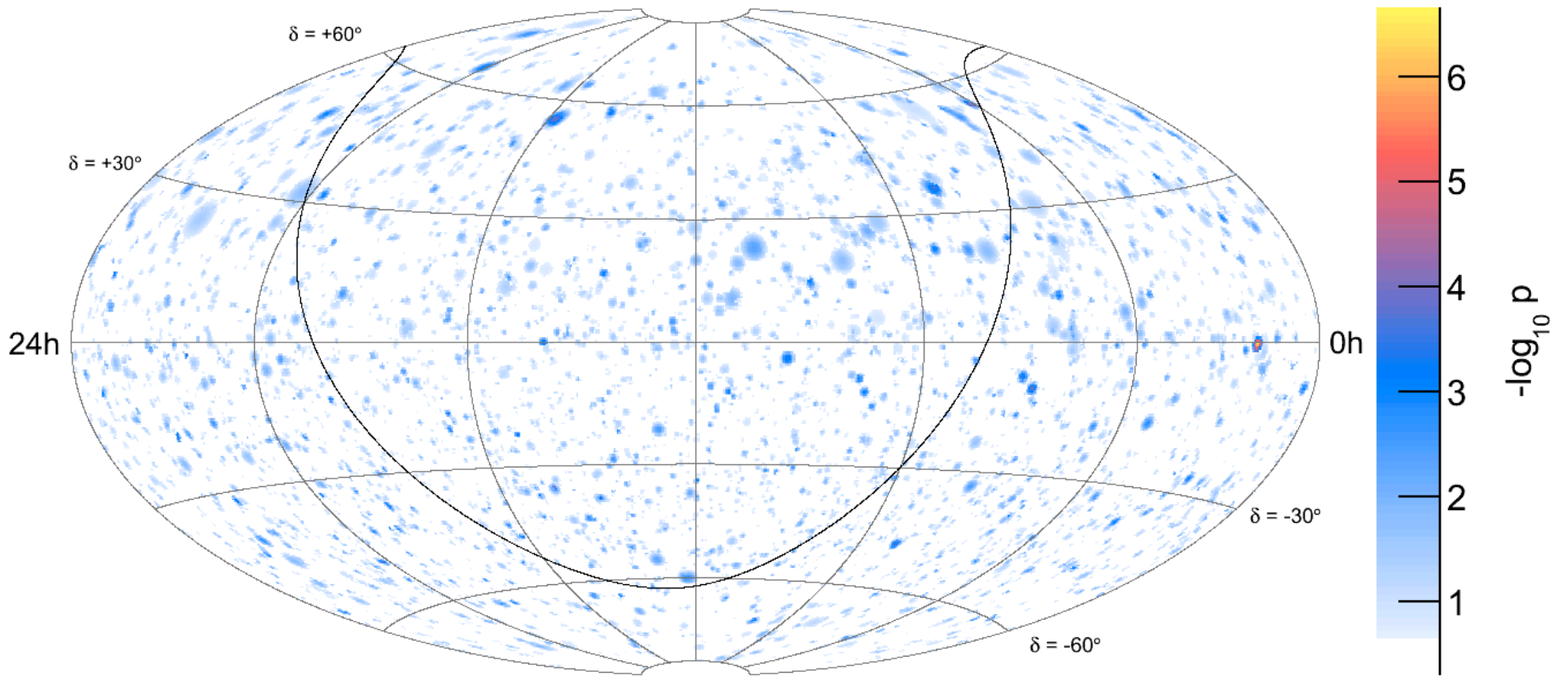


Time-Dependent All-Sky Search (IceCube-59)

M Baker et al., ICRC 2011



Preliminary

$$\mathcal{S}_i = \frac{1}{2\pi\sigma_i^2} e^{-|\vec{x}_i - \vec{x}_\mathrm{s}|^2/2\sigma_i^2} \cdot P(E_i|\gamma) \cdot \frac{1}{\sqrt{2\pi}\sigma_\mathrm{T}} e^{-(t_i - T_0)^2/2\sigma_\mathrm{T}^2}$$

$$\mathcal{L}(n_s, \gamma, \sigma_\mathrm{T}, T_0) = \prod_{i=1}^{N} \left(\frac{n_s}{N} \mathcal{S}_i(\gamma, \sigma_\mathrm{T}, T_0) + (1 - \frac{n_s}{N}) \mathcal{B}_i \right)$$

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Most significant spot:

r.a. = 21.35°

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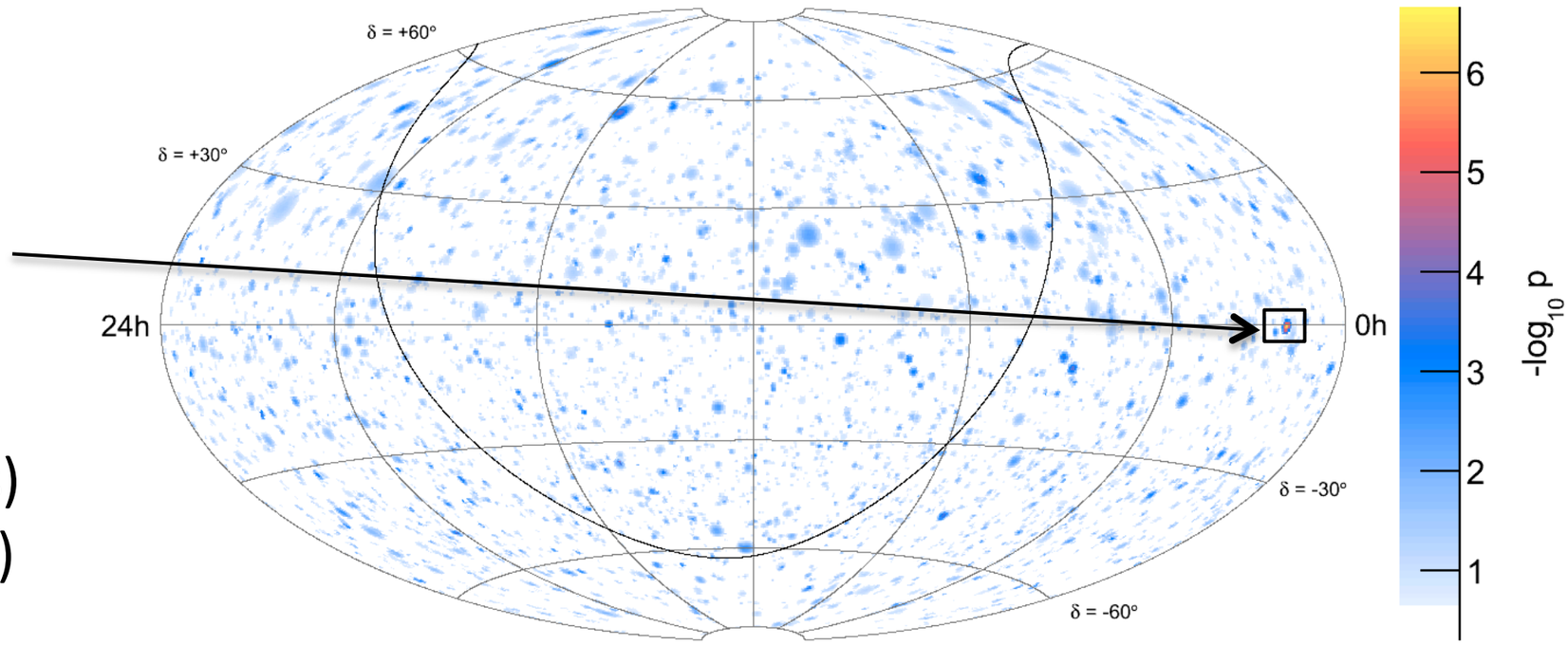
n_s = 14.5

γ = -3.9

σ_T = 5.5 days (FWHM 13 days)

T_0 = 55259 MJD (2010 Mar. 4)

$-\log_{10}$ p-value = 6.69



Preliminary

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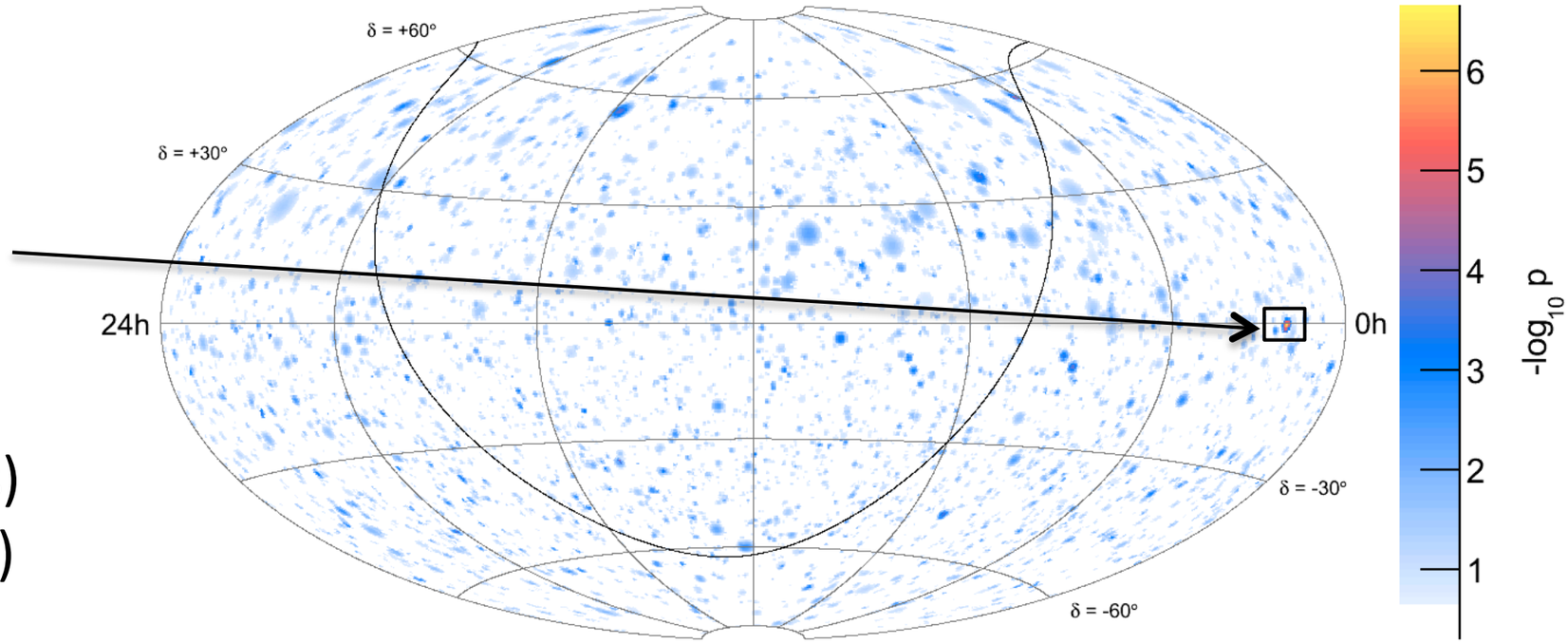

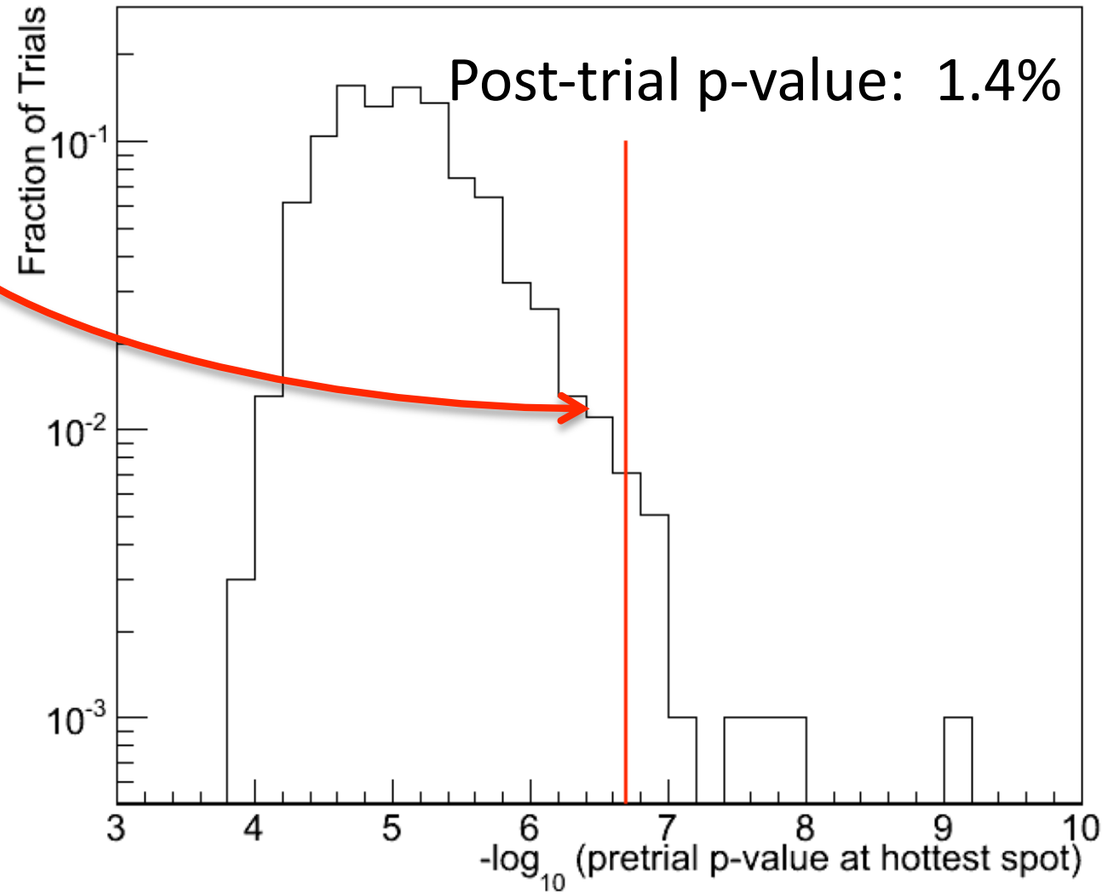

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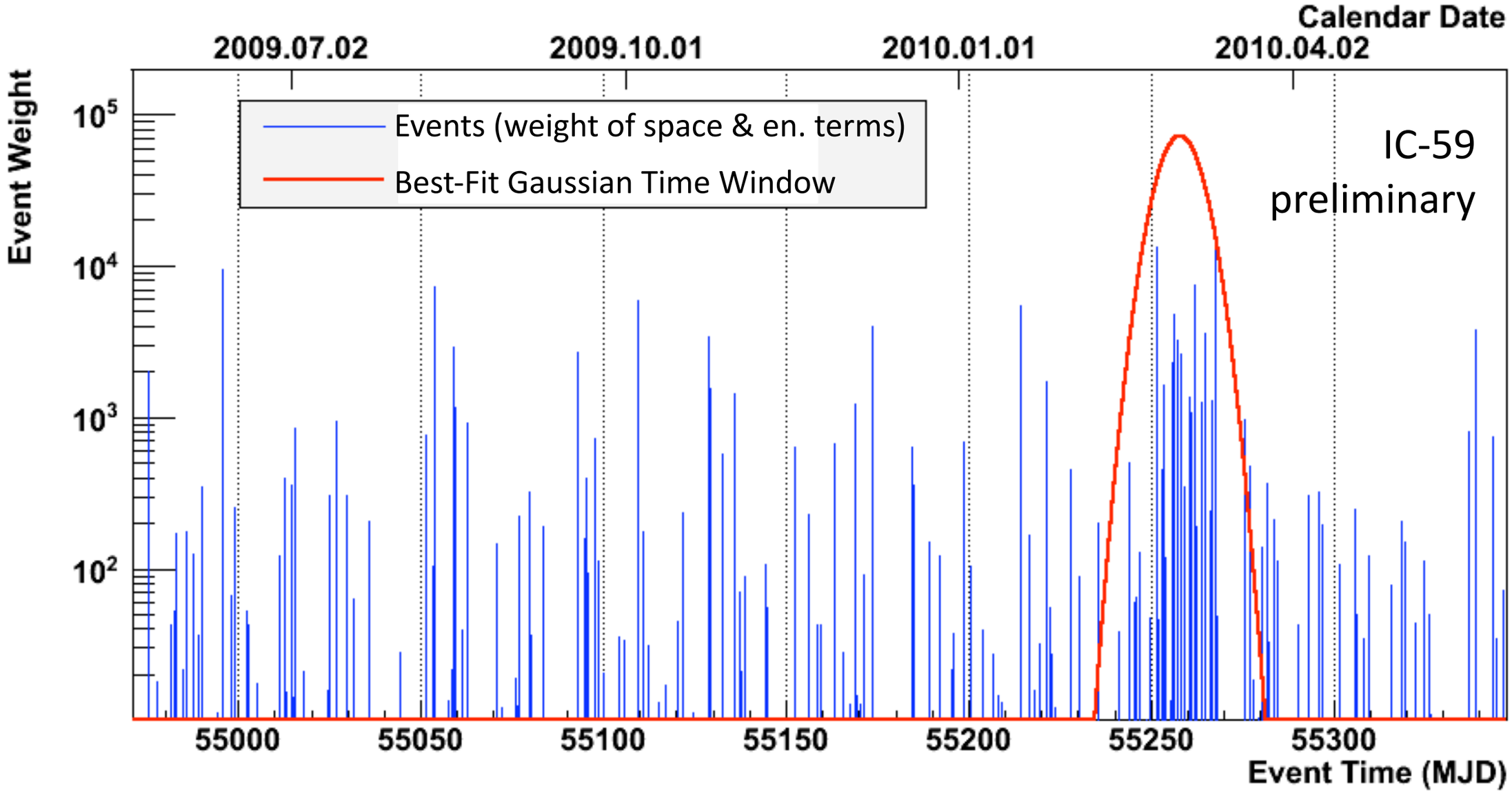
M Baker et al., ICRC 2011



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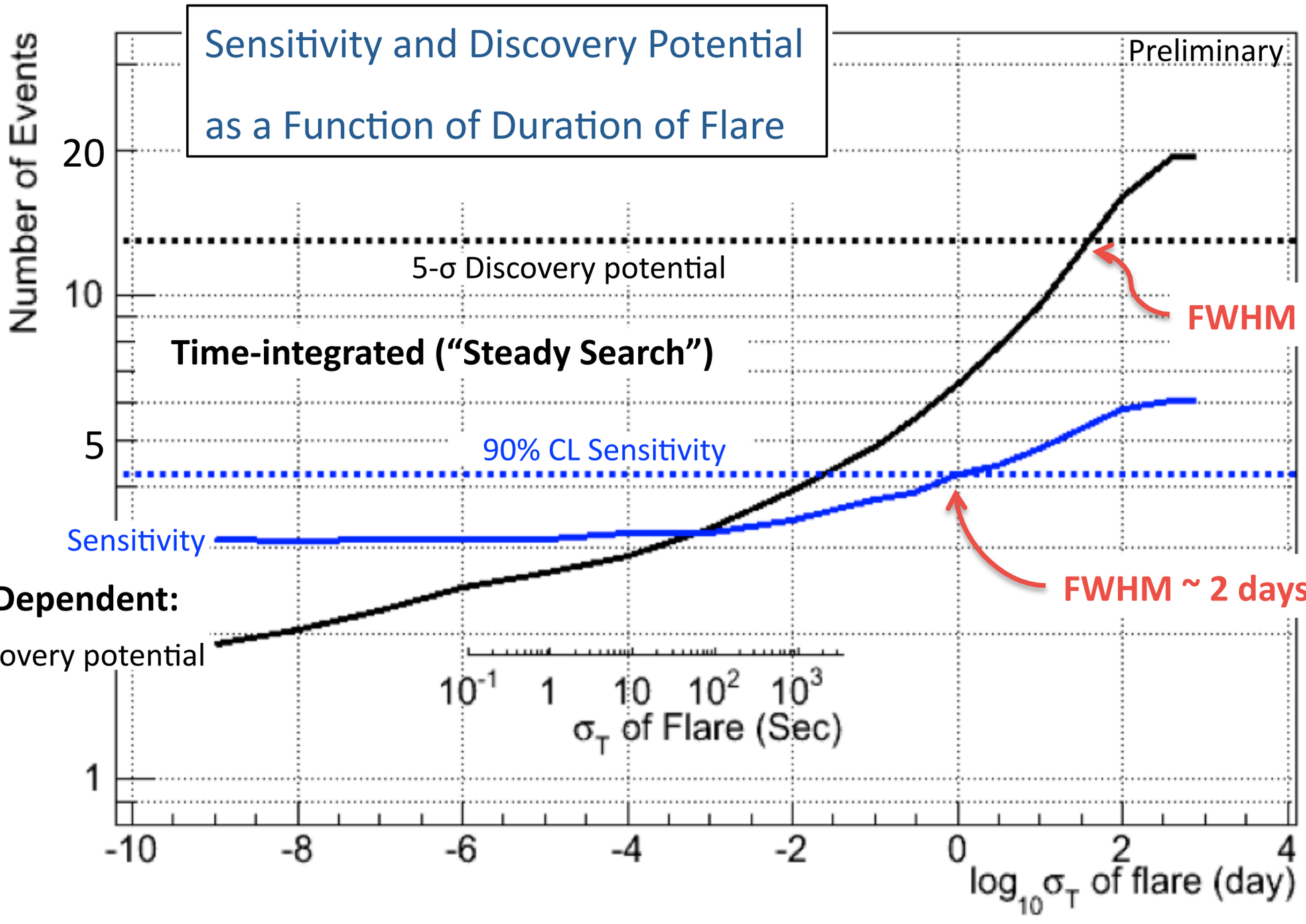
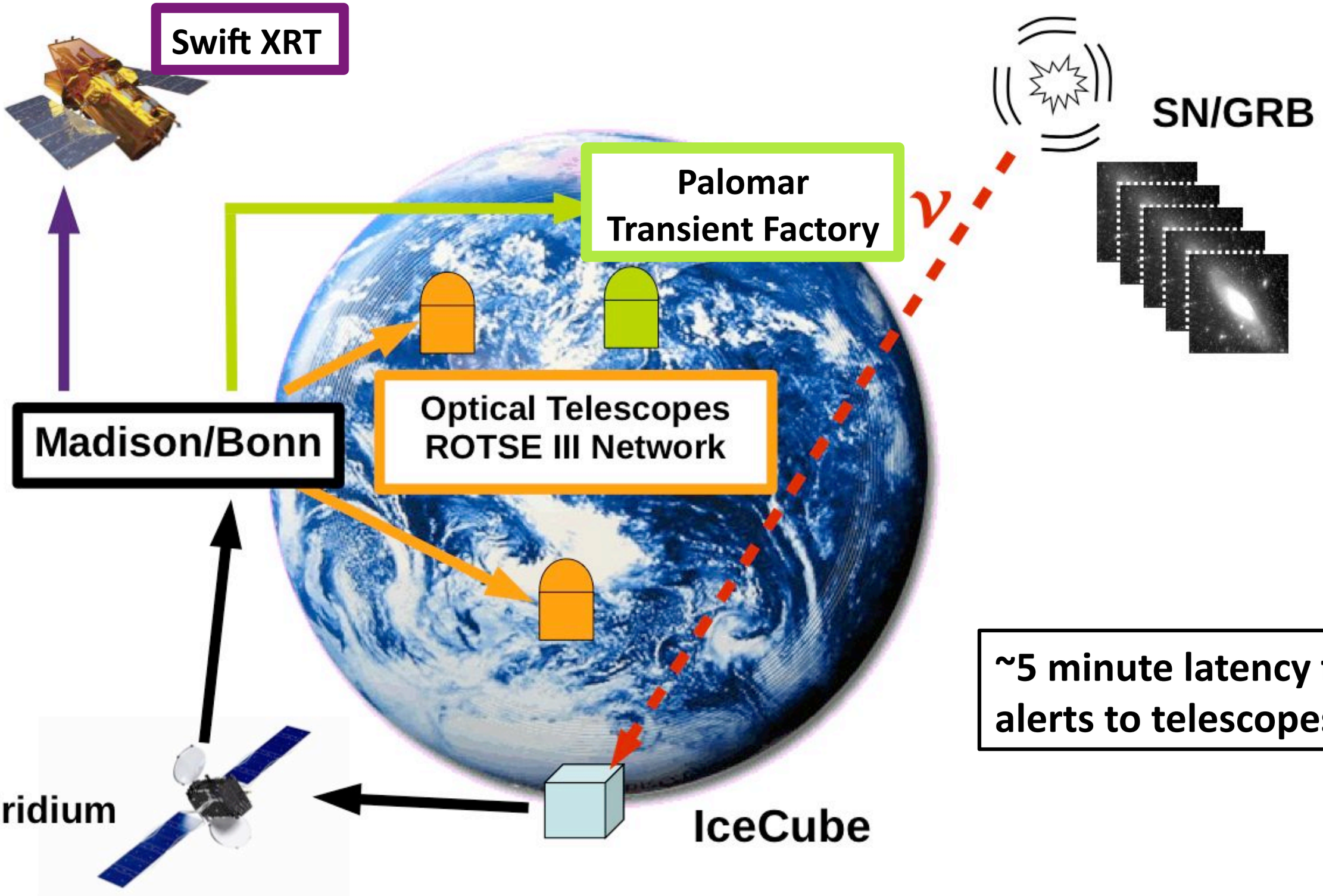


IceCube Optical and X-Ray Follow-Up Programs



~5 minute latency for alerts to telescopes

IceCube Optical Follow-Up Program

Reduce Background - by **6 orders of magnitude** at South Pole:

~ **2 kHz detector trigger level** (cosmic ray muons)

Use fast online reconstructions and event selections

~ 2 mHz (atmospheric neutrinos)

Generate Alerts – select **Multiplets:**

Two (or more) events arriving:

- within **100 seconds,** and
- with angular separation of **< 4°**

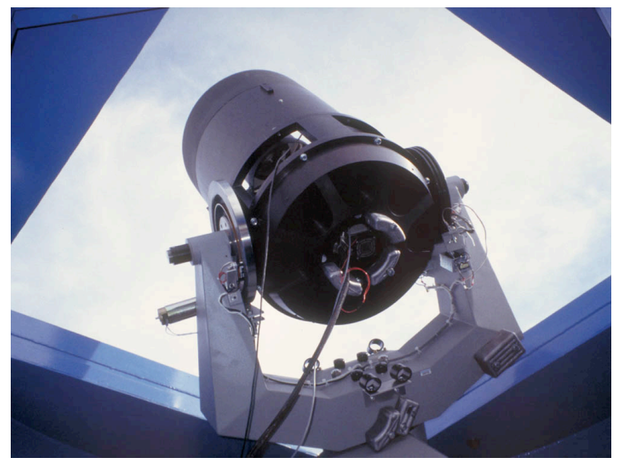
Rate of multiplets due to atm. bkg. **~ 25 per year**

or, with **tighter cuts** for < 25 per year

Current IceCube Burst Follow-Up Programs

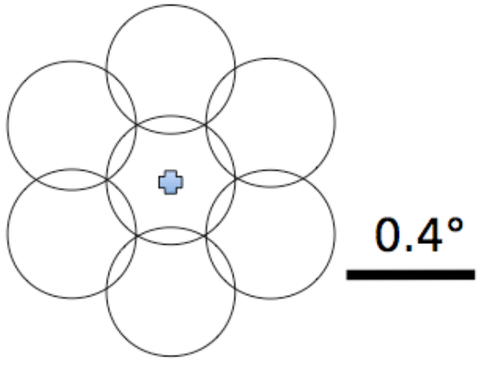
Telescope	Approx. Alert Rate	IceCube Triggered since
ROTSE	**30 alerts / yr**	**Dec. 2008**
Palomar Transient Factory	**10 alerts / yr**	**Jul. 2010**
Swift XRT	**7 alerts / yr**	**Feb. 2011**

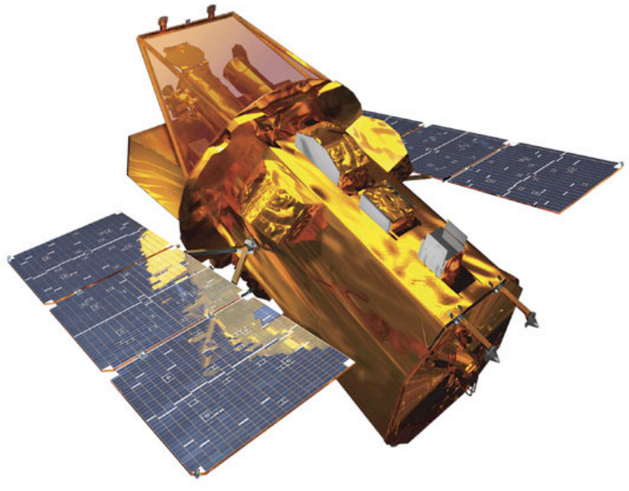
FoV: 1.85° x 1.85°
Limiting Magnitude: 18.5



FoV: 3.5° x 2.3°
Limiting Magnitude: 20.6

Tiled observations to match IceCube PSF





IceCube Optical Follow-Up Program

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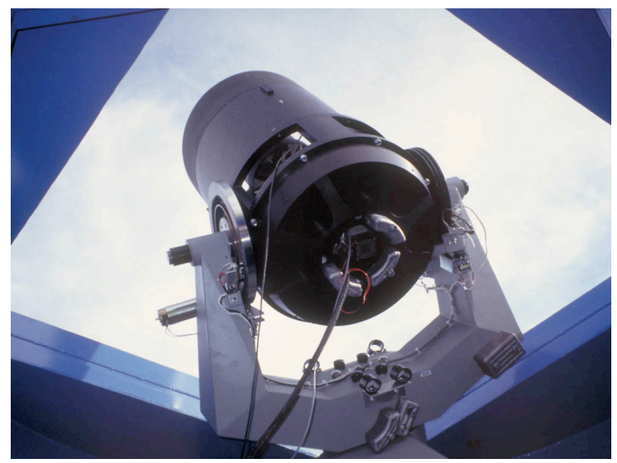


2008 Dec. 16 – 2009 Dec. 31 (IceCube 40- and 59-string configurations)

31 IceCube alerts forwarded to ROTSE

-5 too close to sun

-7 too close to galactic plane

-2 good data not collectable

= 17 good optical follow-ups

When ROTSE receives alert: Prompt observation – thirty 60 sec exposures

Follow-up observations – each night, next 14-24 nights

Analysis: Image subtraction to find optical SN counterpart

IceCube Optical Follow-Up Program

Telescope	Approx. Alert Rate	IceCube Triggered since
ROTSE	**30 alerts / yr**	**Dec. 2008**

FoV: 1.85° x 1.85°

Limiting Magnitude: 18.5

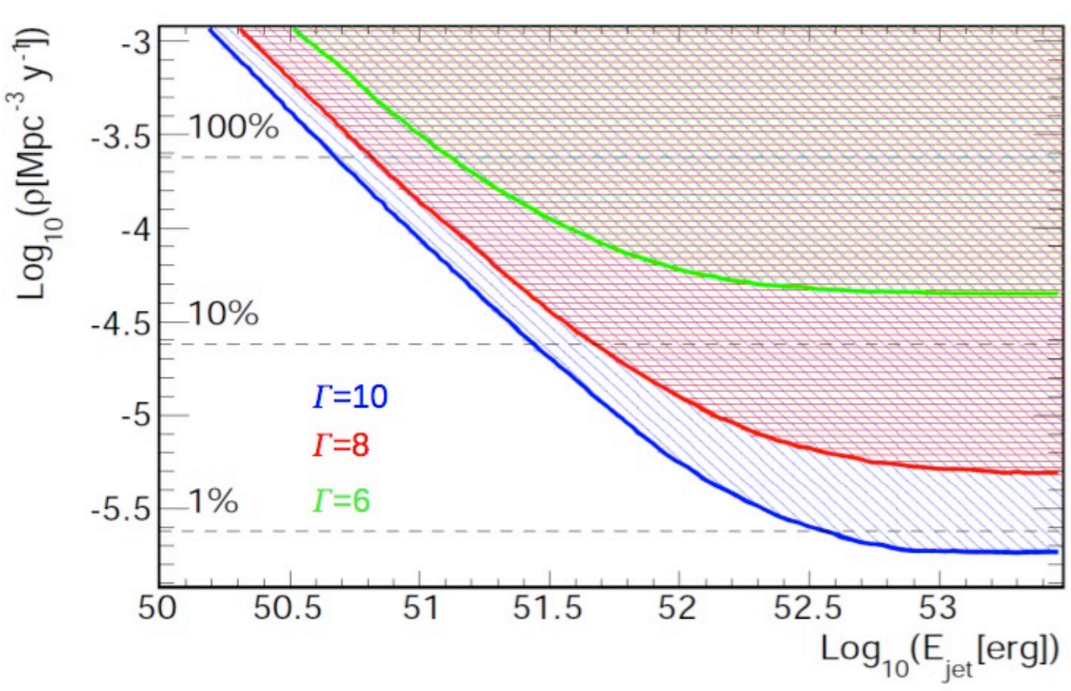
No optical counterpart observed.

First limits on hadronic jet production in core-collapse SNe jet derived.

A. Franckowiak et al., ICRC 2011

Limit on core collapse supernova (CCSN) jet model (90% confidence level) depending on:

- jet energy E_{jet}
- Lorentz boost factor Γ
- rate of CCSN with jets ρ



Preliminary

Stringent limits for higher boost factors in soft jet model:

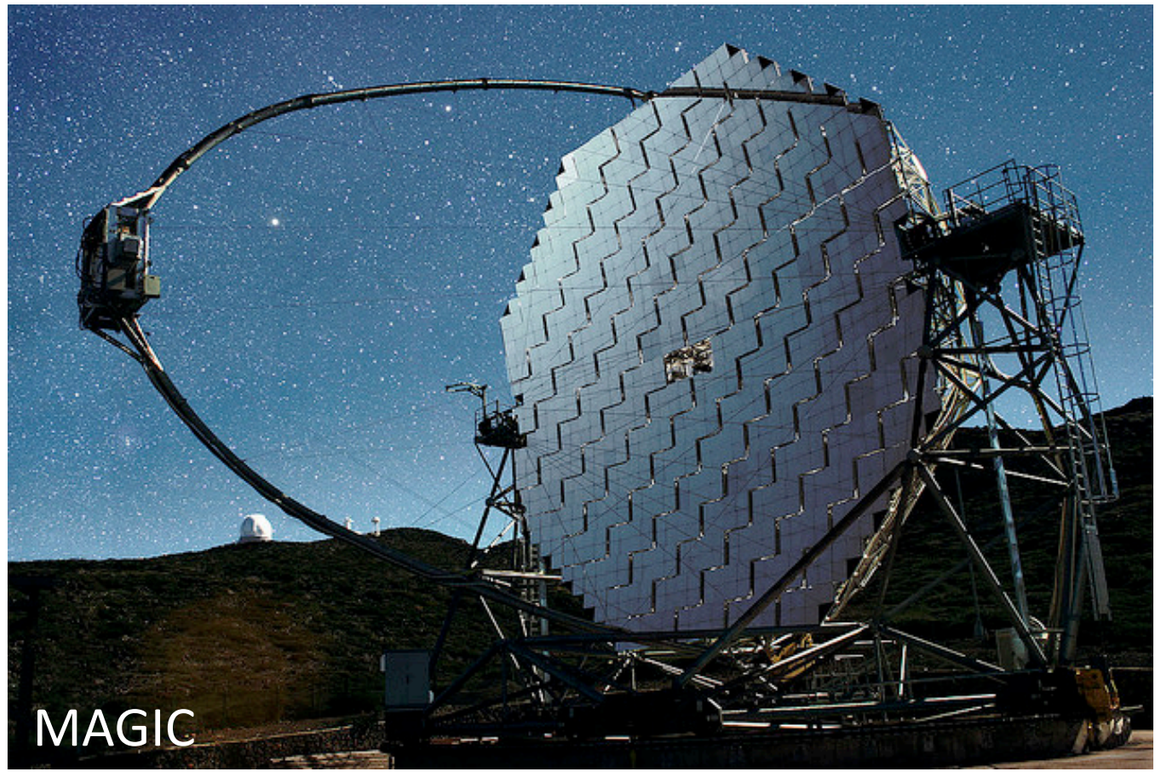
< 7.8% of all SNe have a jet with Γ=10 and a typical jet energy of $E = 3 \cdot 10^{51}$ erg.

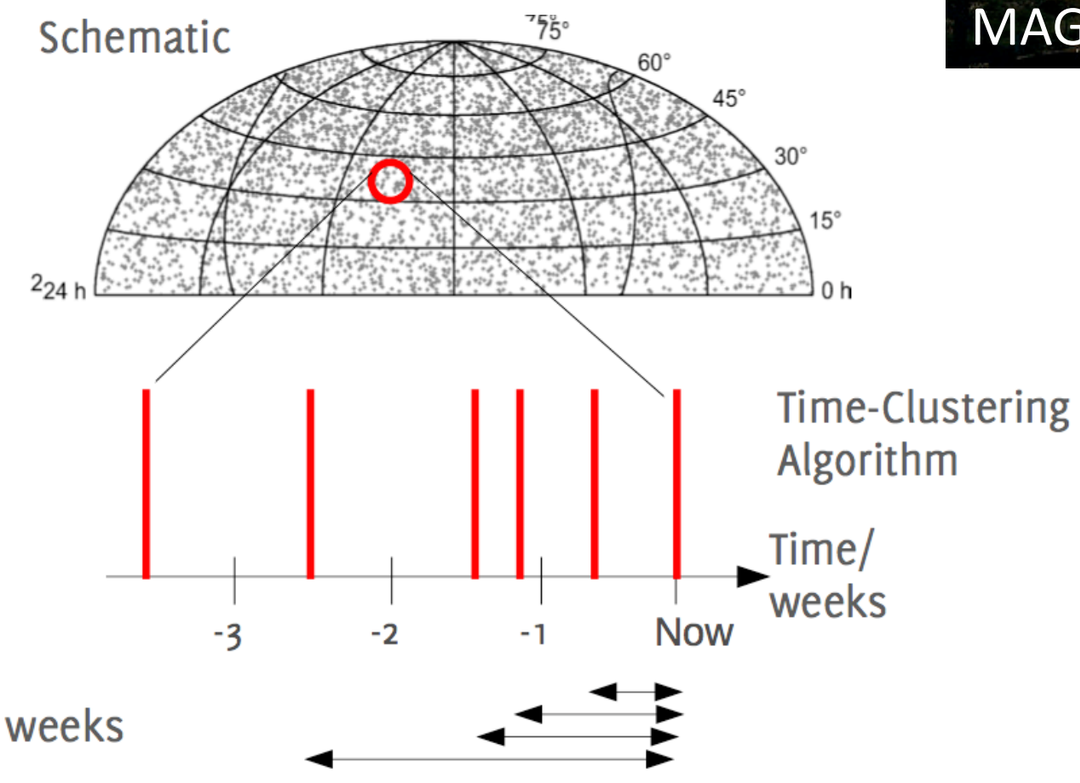
Neutrino-Triggered Target of Opportunity Program

Same online stream as Optical Follow-Up,
But:

- monitors **specific list of variable sources**
- evaluates on **sliding scale, up to 3-weeks** (typical of e.g. AGN flares)
- send ~ one to few alerts per year

Operating with MAGIC, VERITAS since summer 2011





R. Franke, E. Bernardini et al., ICRC 2011

Summary

Time-Integrated Searches:

IceCube 40 + 59 + 79 + 86(1 year) + 86(2 year) +86(3 year) ….

Reaching sensitivity comparable to photon flux of bright galactic TeV sources.

Begin to probe beneath this level for TeV neutrino detections.

Photo: Freija Descamps

Summary

Time-Integrated Searches:

- IceCube 40 + 59 + 79 + 86(1 year) + 86(2 year) +86(3 year) ….
- Reaching sensitivity comparable to photon flux of bright galactic TeV sources.
- Begin to probe beneath this level for TeV neutrino detections.

Time-Dependent Searches:

- Stand-alone: IceCube all-sky Untriggered Search
- ν-alerts to other telescopes: Optical / Gamma / X-Ray Follow Ups
- other telescopes -> ν searches:
  - Stacking (accumulate with time): GRB searches
  - One-Time: AGN flares / Crab flare analysis

Photo: Freija Descamps

Summary

With completed detector, many analyses can move to real or near-real time

Steady searches are starting to scratch the surface of TeV neutrino astronomy

High energy sky is highly variable; discovery can happen overnight, at any time

Patience Required!