SEARCH FOR NEUTRINO COUNTERPARTS TO GRAVITATIONAL WAVE EVENTS WITH ANTARES

Alexis Coleiro
on behalf of the ANTARES collaboration

GEMMA workshop | Lecce, June 7th 2018

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- ***Multi-messenger program of ANTARES***
- ***Search for neutrino counterpart to GW events***

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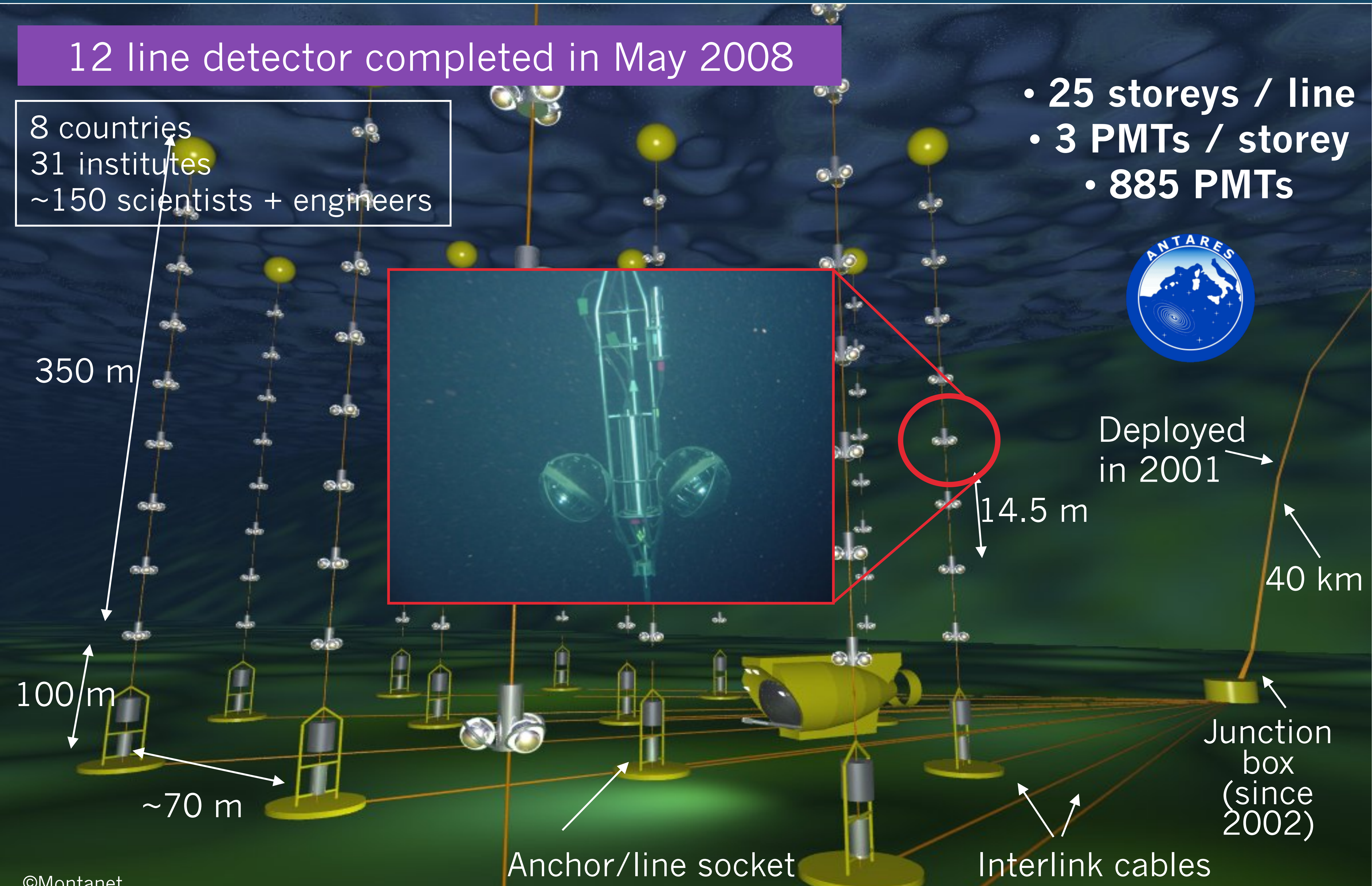
THE ANTARES NEUTRINO TELESCOPE

12 line detector completed in May 2008

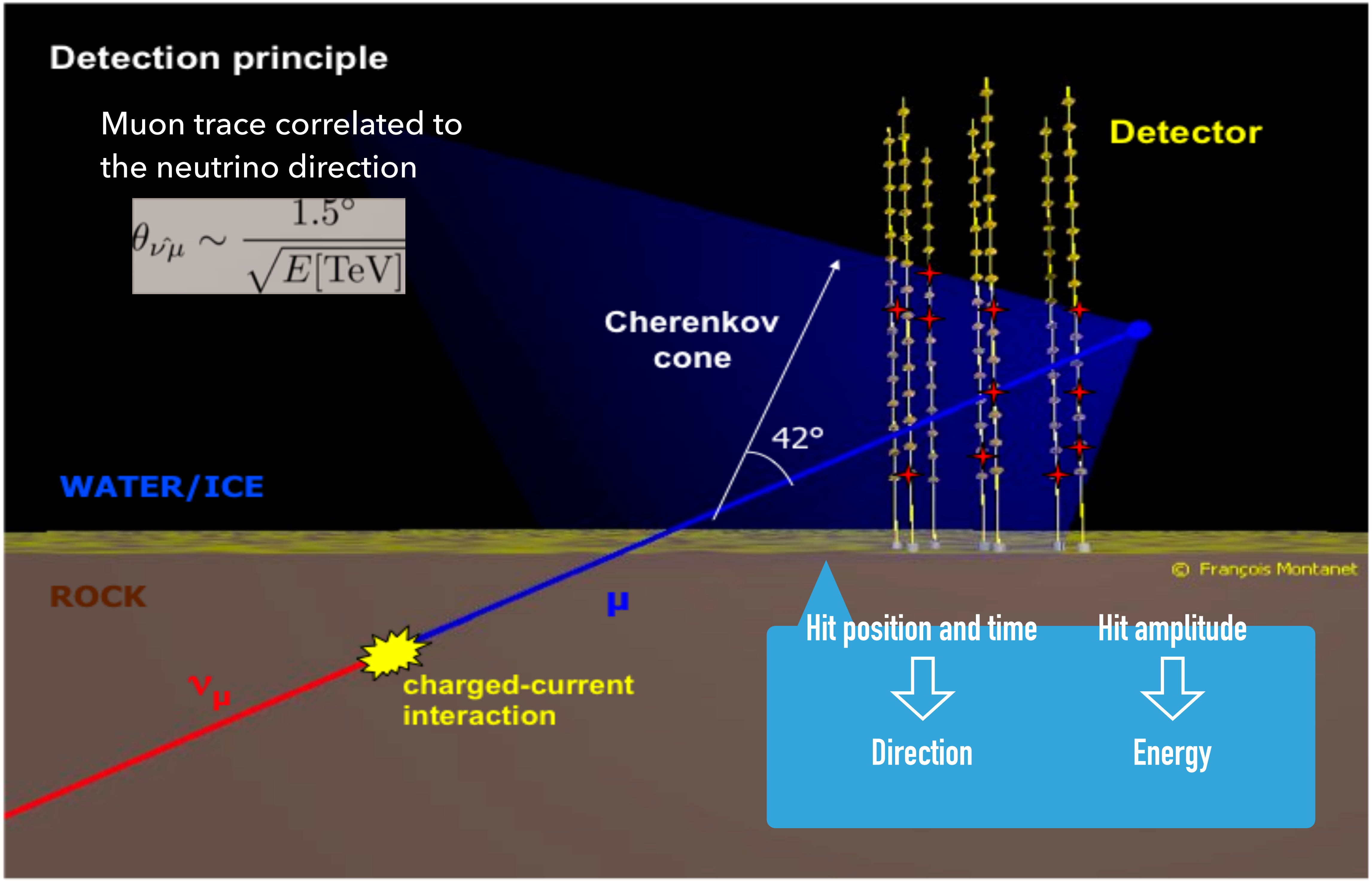
8 countries
31 institutes
~150 scientists + engineers

- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

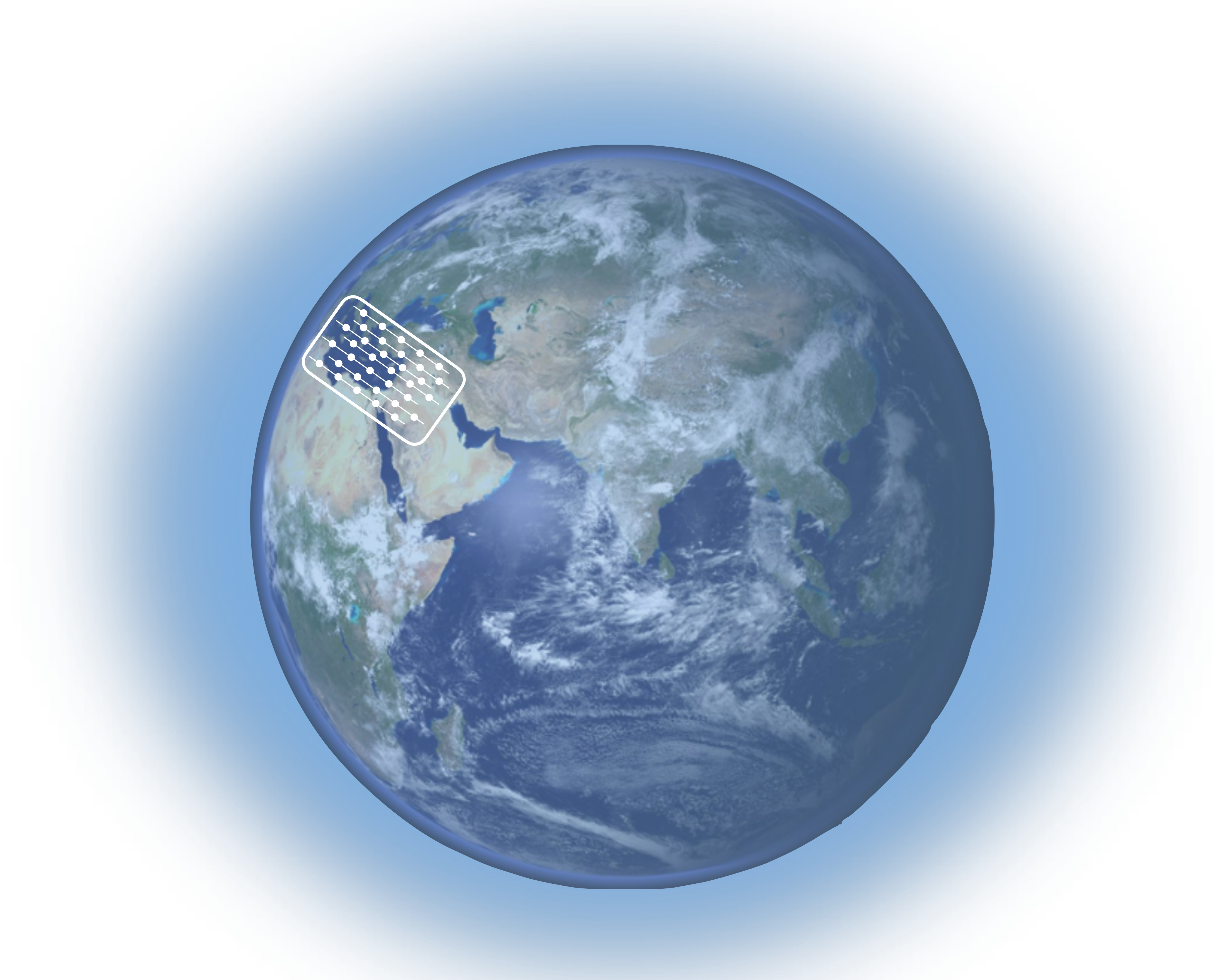


THE ANTARES NEUTRINO TELESCOPE

- Different ways to detect high-energy ν
- One way particularly useful in astronomy:
  observation of muons produced in CC interaction of ν_μ



THE ANTARES NEUTRINO TELESCOPE



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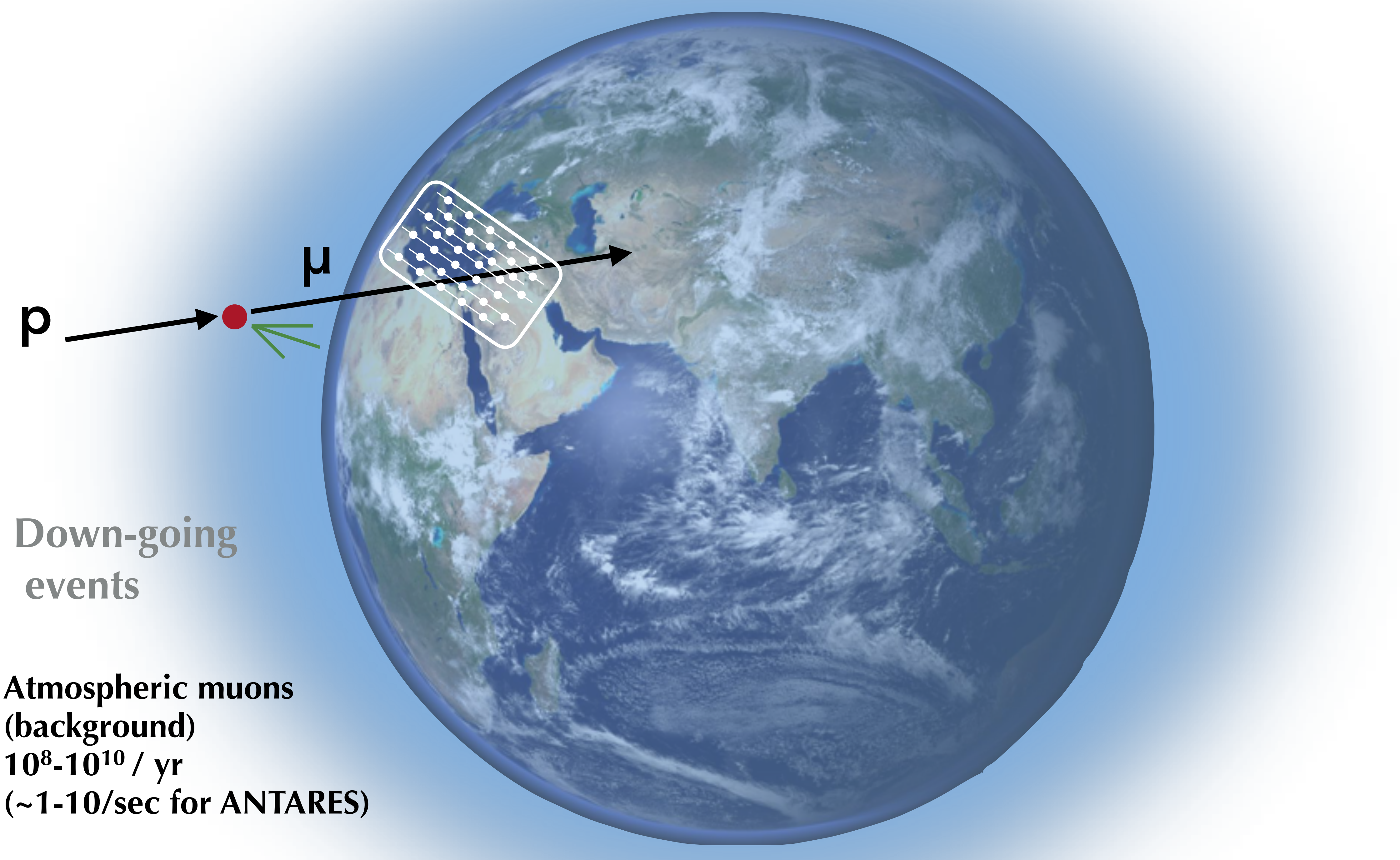
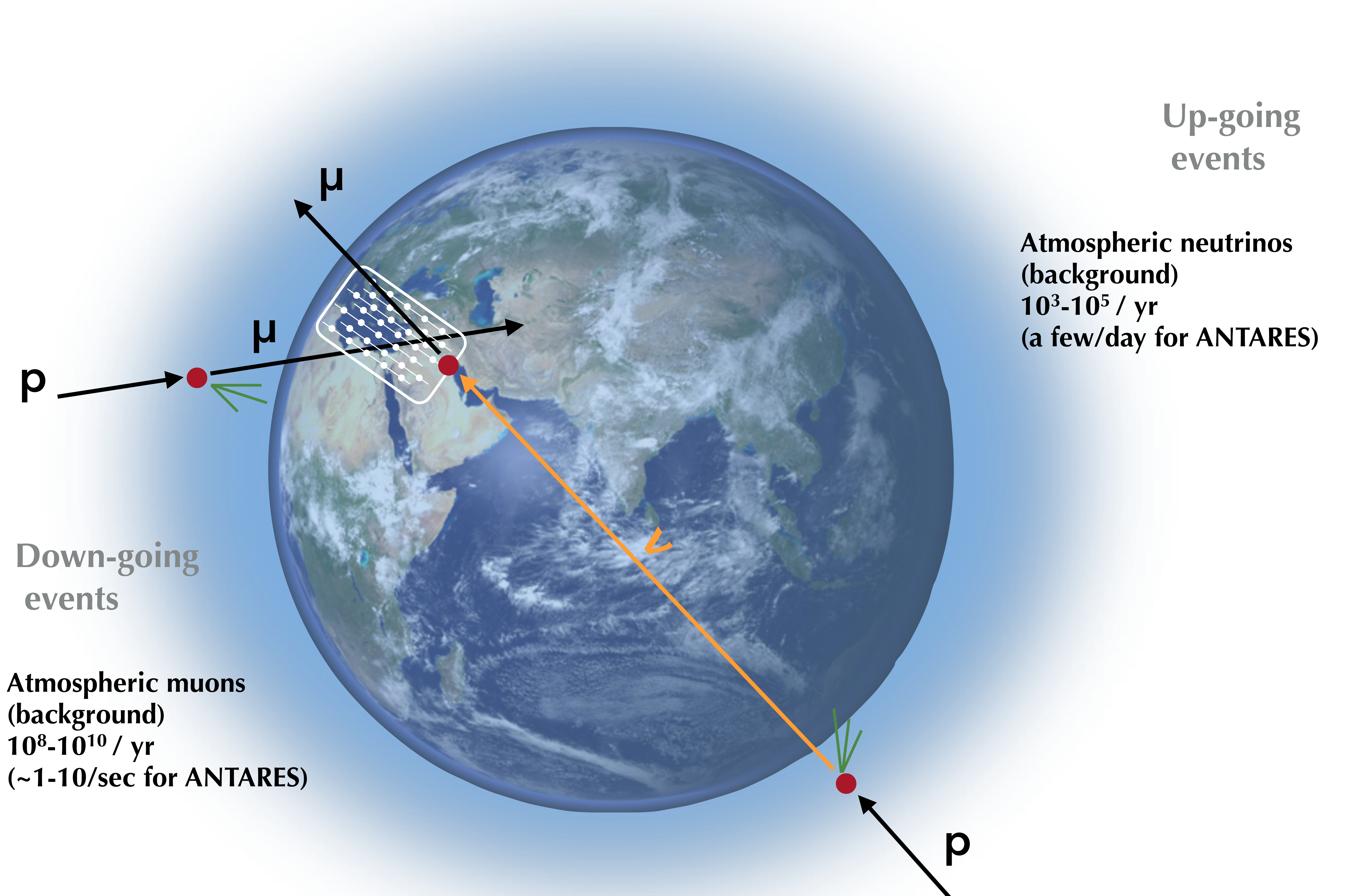


Down-going events

Atmospheric muons (background)
10^8-10^{10} / yr
(~1-10/sec for ANTARES)

THE ANTARES NEUTRINO TELESCOPE



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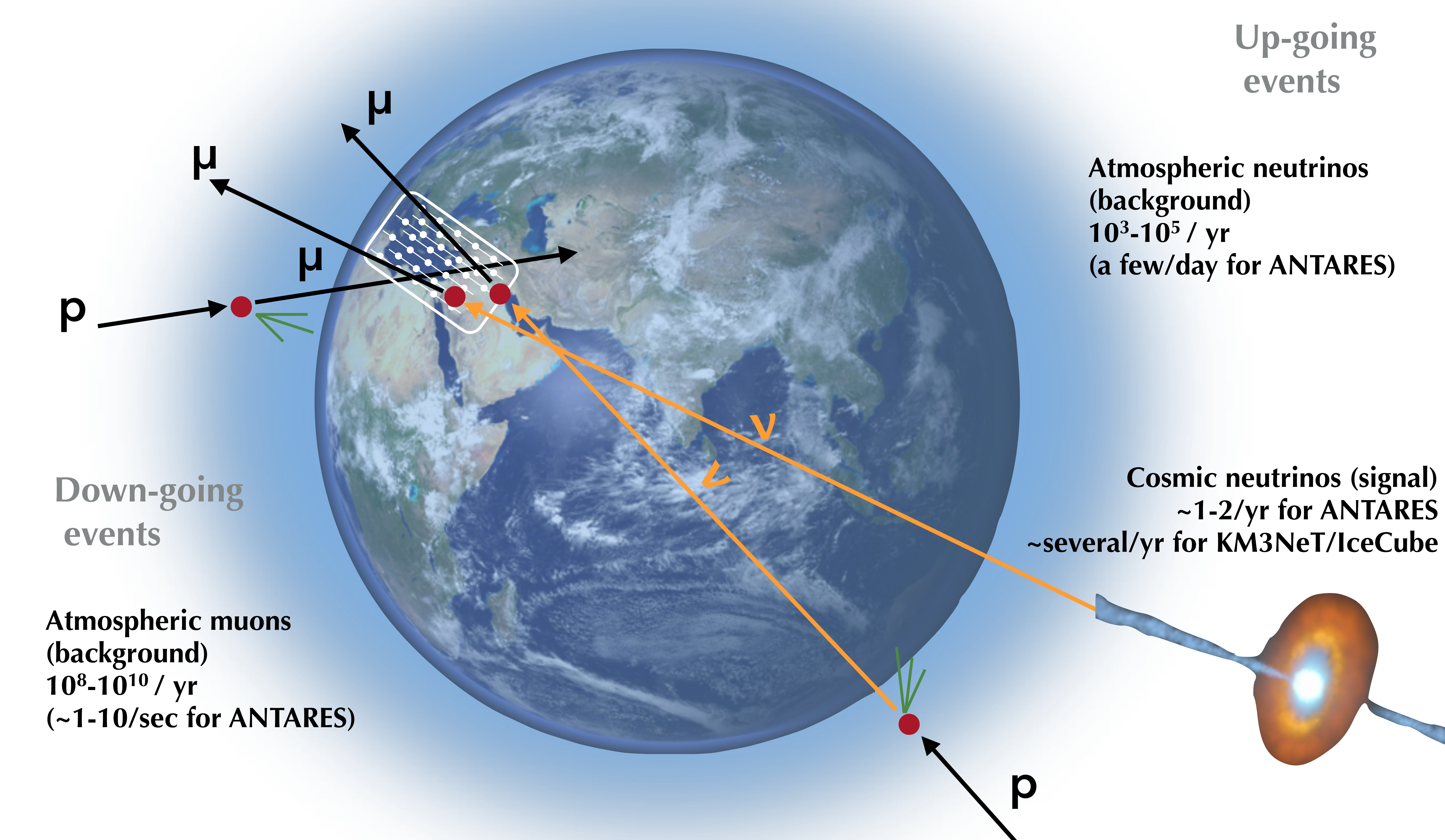
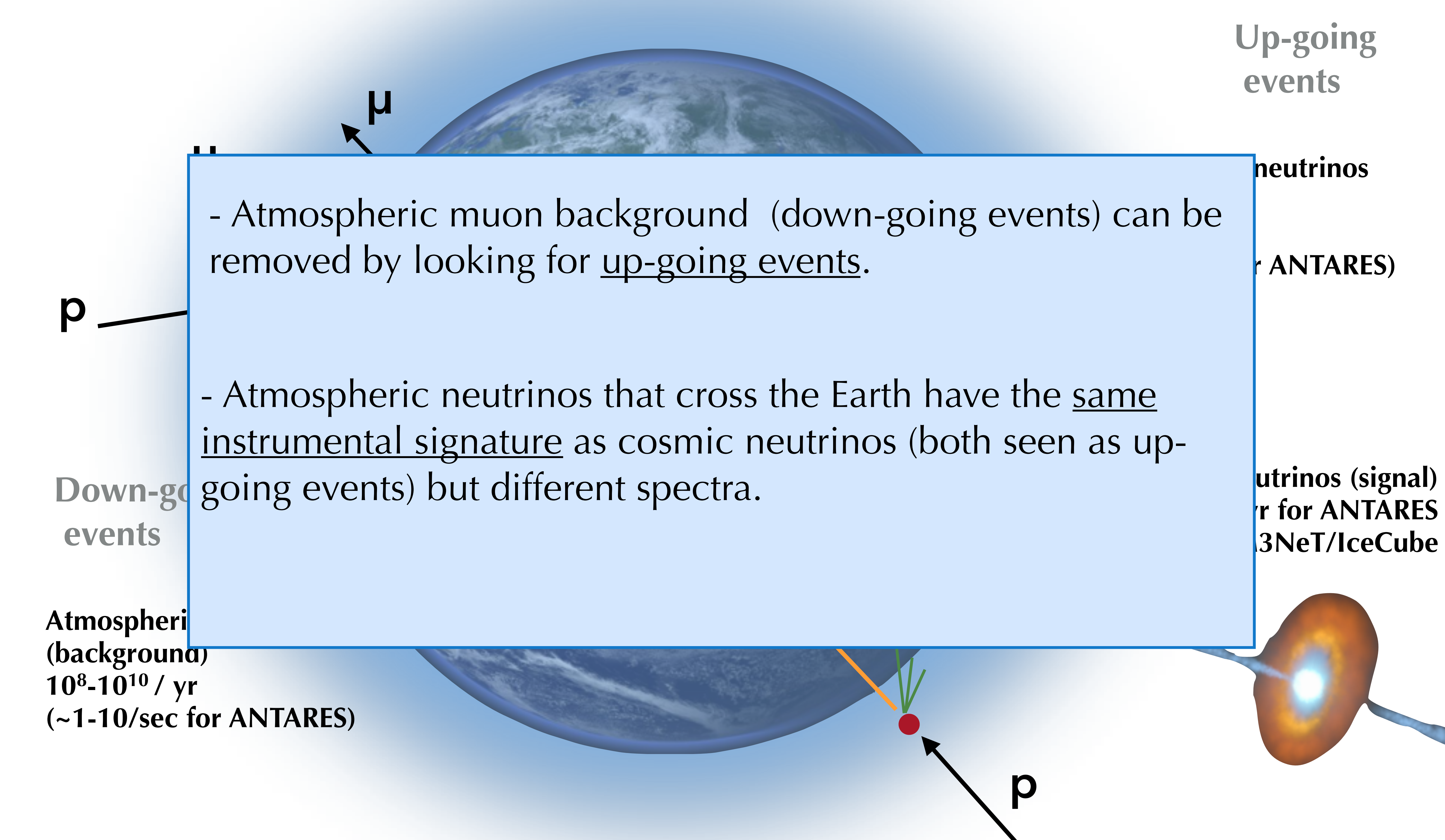


THE ANTARES NEUTRINO TELESCOPE



- Atmospheric muon background (down-going events) can be removed by looking for <u>up-going events</u>.

- Atmospheric neutrinos that cross the Earth have the <u>same instrumental signature</u> as cosmic neutrinos (both seen as up-going events) but different spectra.

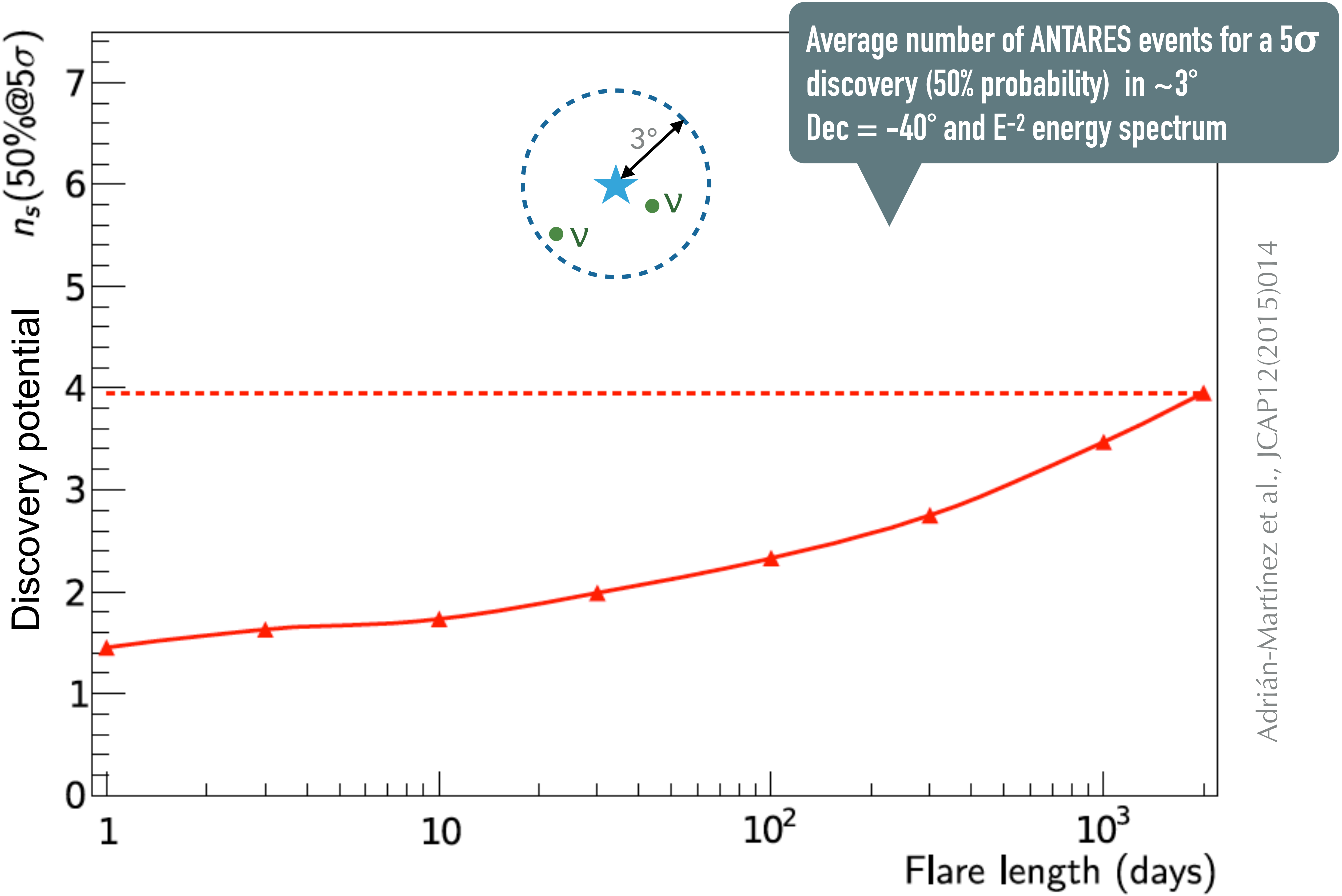
MULTI-MESSENGER PROGRAM OF ANTARES

Neutrino telescopes suitable to look for transient sources: continuously monitoring 2π sr (at least)

Multi-messenger studies of transient & variable sources:

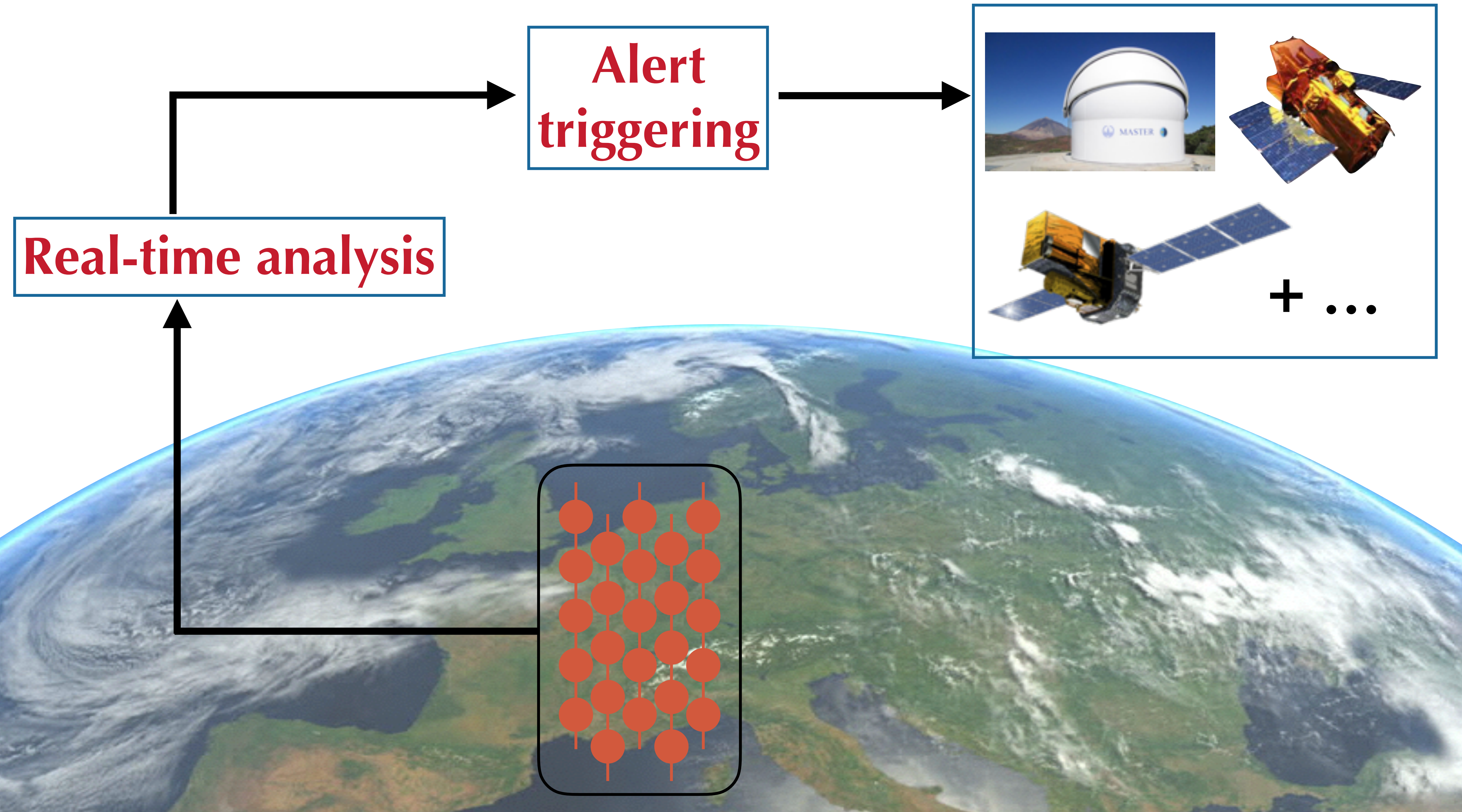
- ➤ increase the sensitivity + discovery potential (reduce the background)
- ➤ increase the statistical significance (requiring joint detection)

MULTI-MESSENGER PROGRAM OF ANTARES



MULTI-MESSENGER PROGRAM OF ANTARES

Two approaches



MULTI-MESSENGER PROGRAM OF ANTARES

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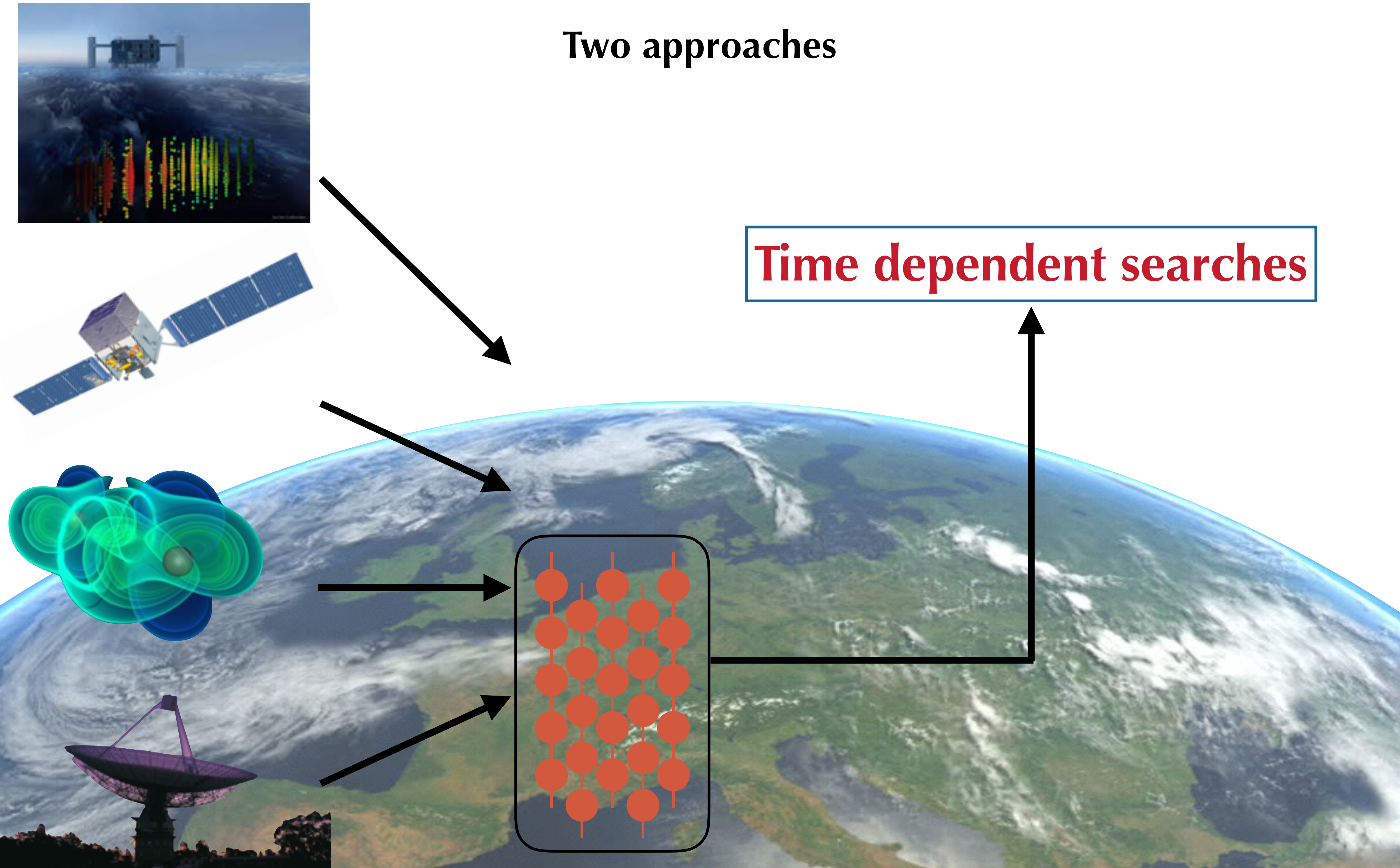
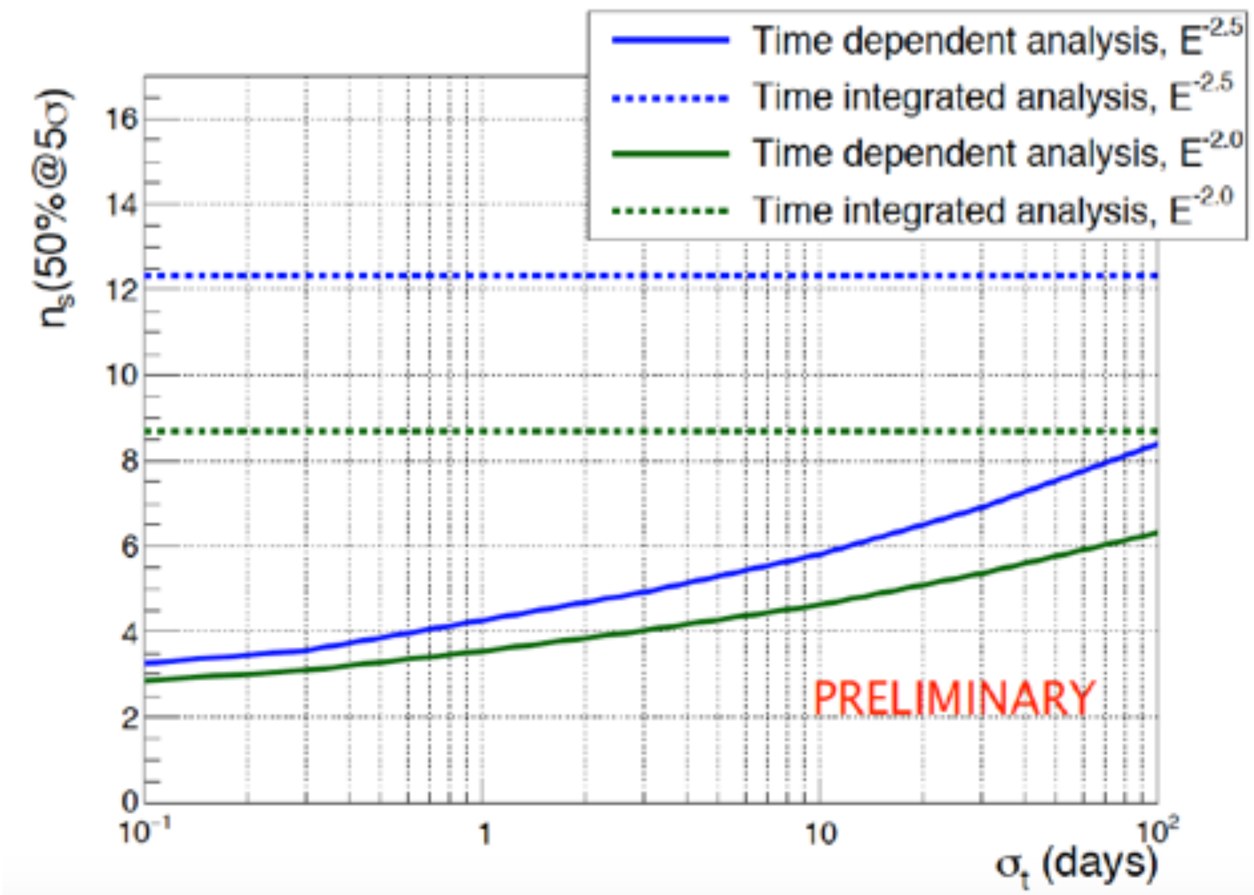
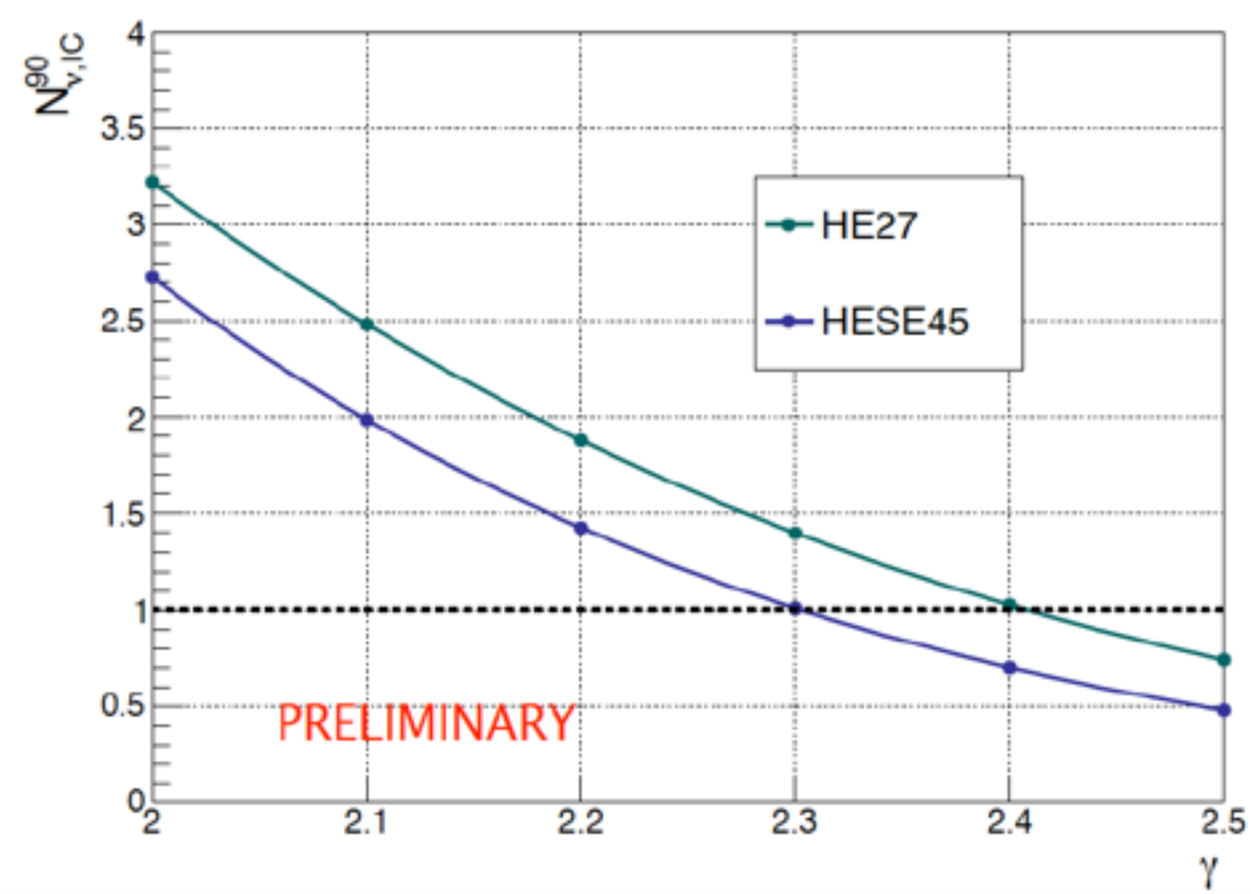


TIME CORRELATIONS WITH ICECUBE EVENTS

- Search for time correlations with IceCube HESE and high-energy ν_μ tracks
- Test transient origin of IceCube events
- No significant correlation (largest excess: 89% p-value post-trial)
- Limits on the fluence w.r.t. flare duration
- Constraint on the spectral index of the neutrino spectrum (assuming ~sec. transient emission

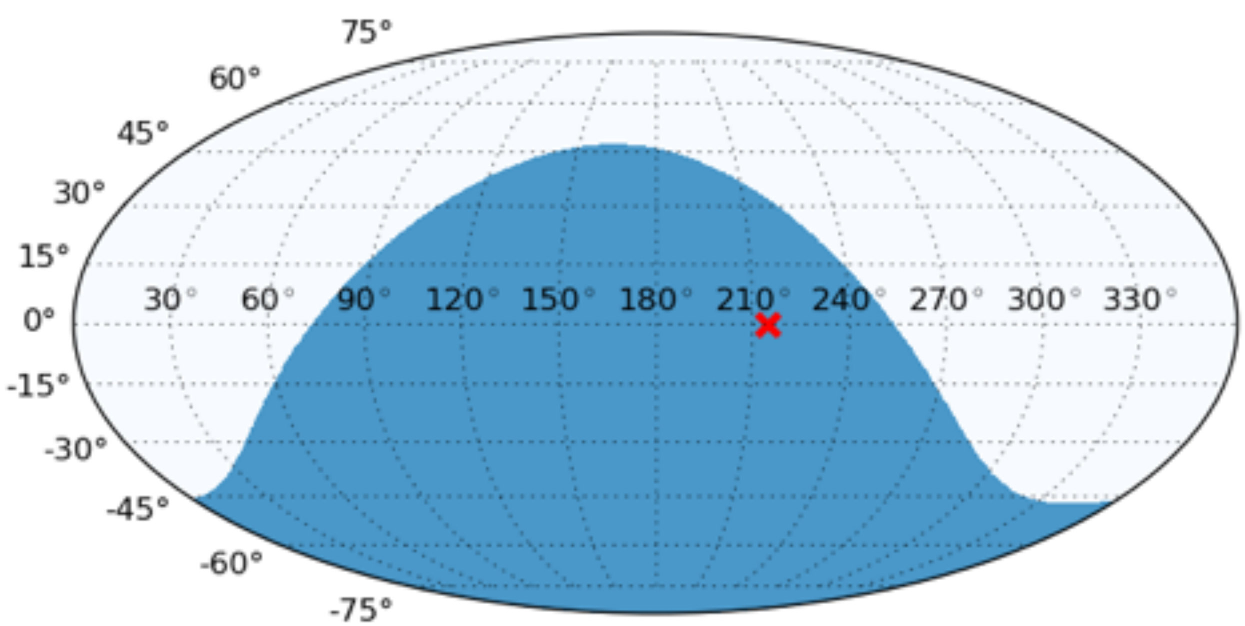




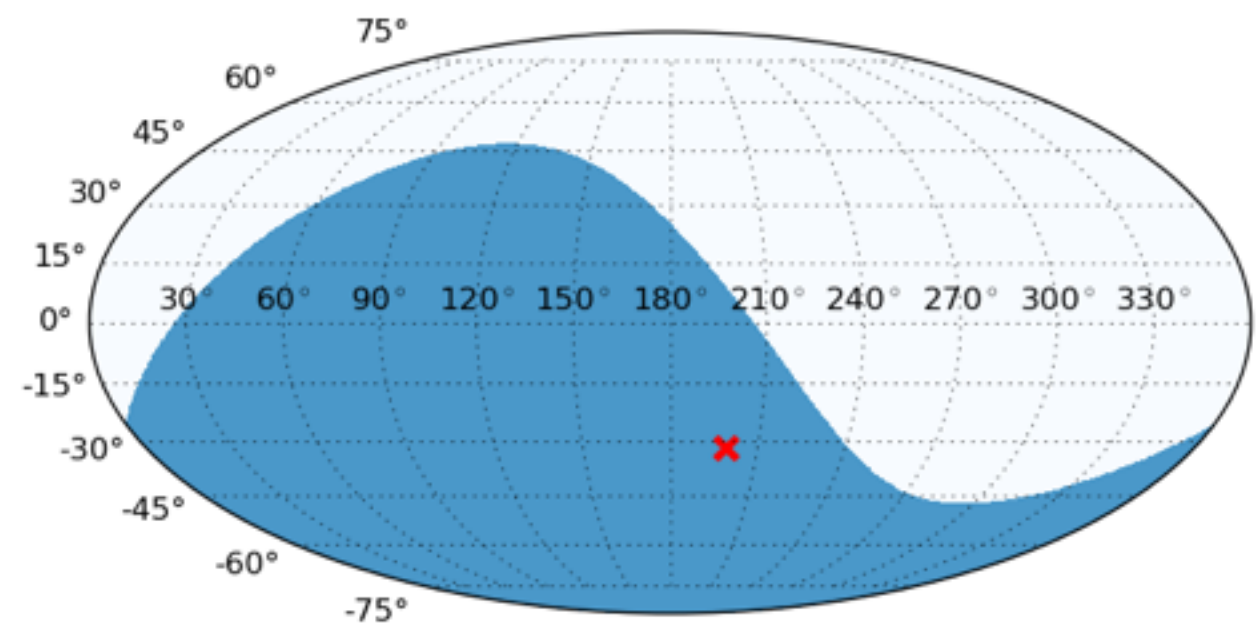
SEARCH FOR COUNTERPARTS TO ICECUBE ALERTS

IceCube High Energy Starting Events and Extremely High Energy (>1 PeV) events.

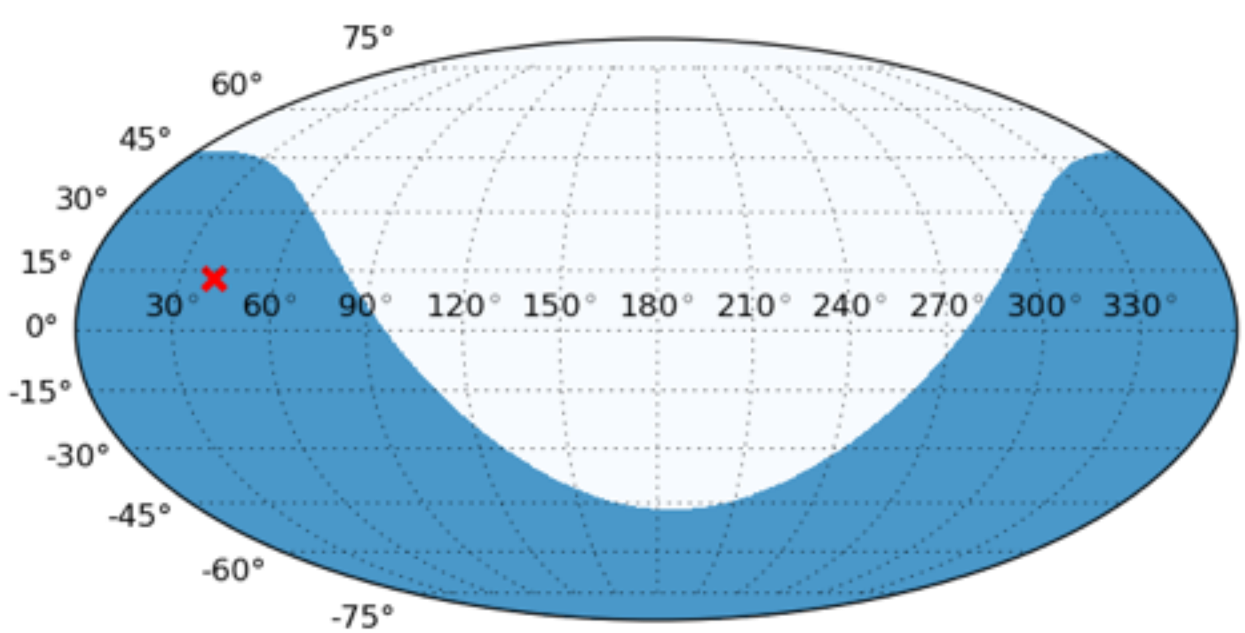
IC160731



IC160814



IC161103



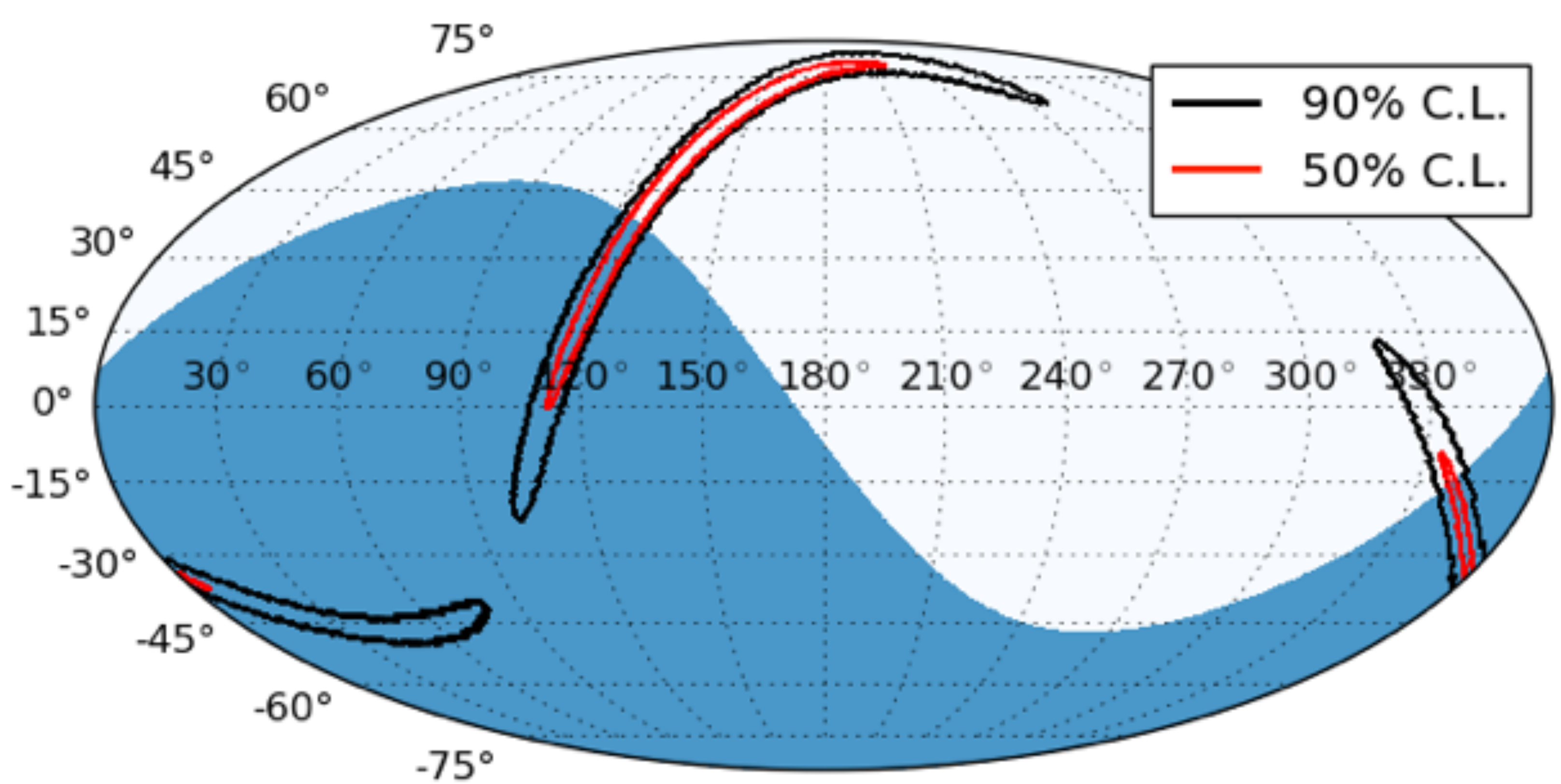
No ANTARES event found in coincidence (ROI=2°, ±500s; ±1h)

⇒ U.L. on the radiant neutrino fluence for E^{-2} and $E^{-2.5}$ spectra:

~15 GeV/cm^2 in [2.8 TeV, 3.3 PeV] for E^{-2}
~30 GeV/cm^2 in [0.4 TeV, 280 TeV] for $E^{-2.5}$

GRAVITATIONAL WAVE FOLLOW-UPS

- Online searches for every GW alert during O2: result communicated to LIGO/Virgo partners
- « Offline » optimized search (jointly with IceCube & Auger) for:
  - GW150914 *(Adrian-Martinez et al., PRD 93, 12, 2016)*
  - GW151226 + LVT151012 *(Adrían-Martinez et al., PRD 96, 2, 2017)*
  - GW170104 *(Albert et al., EPJC 93, 77, 2017)*



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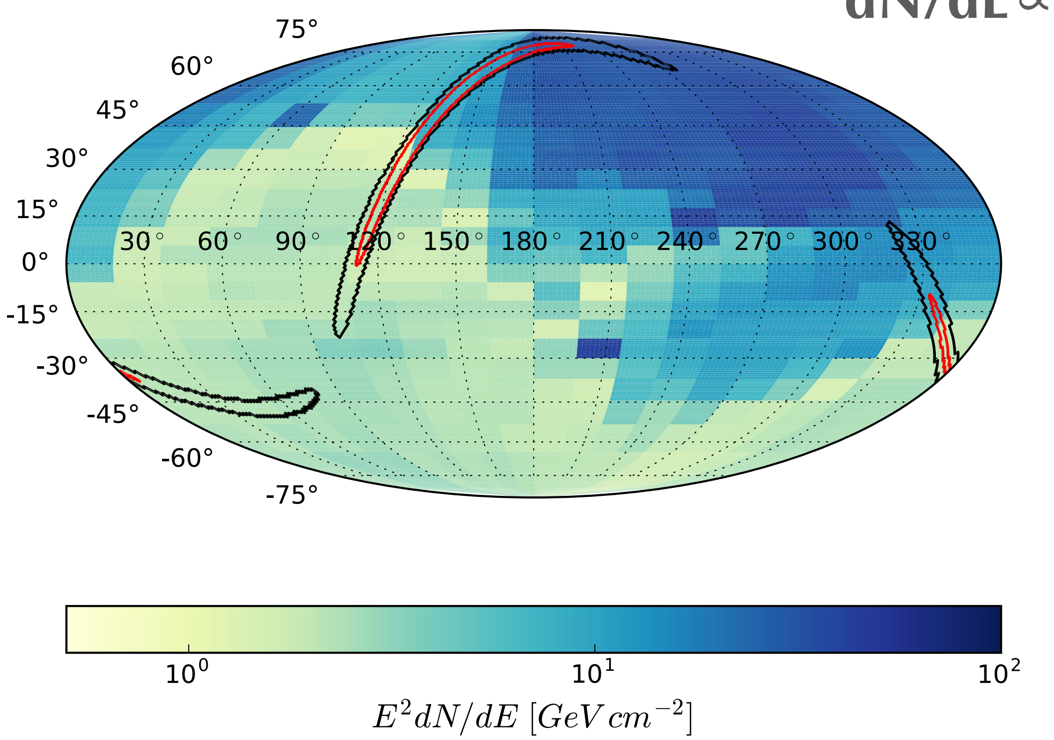
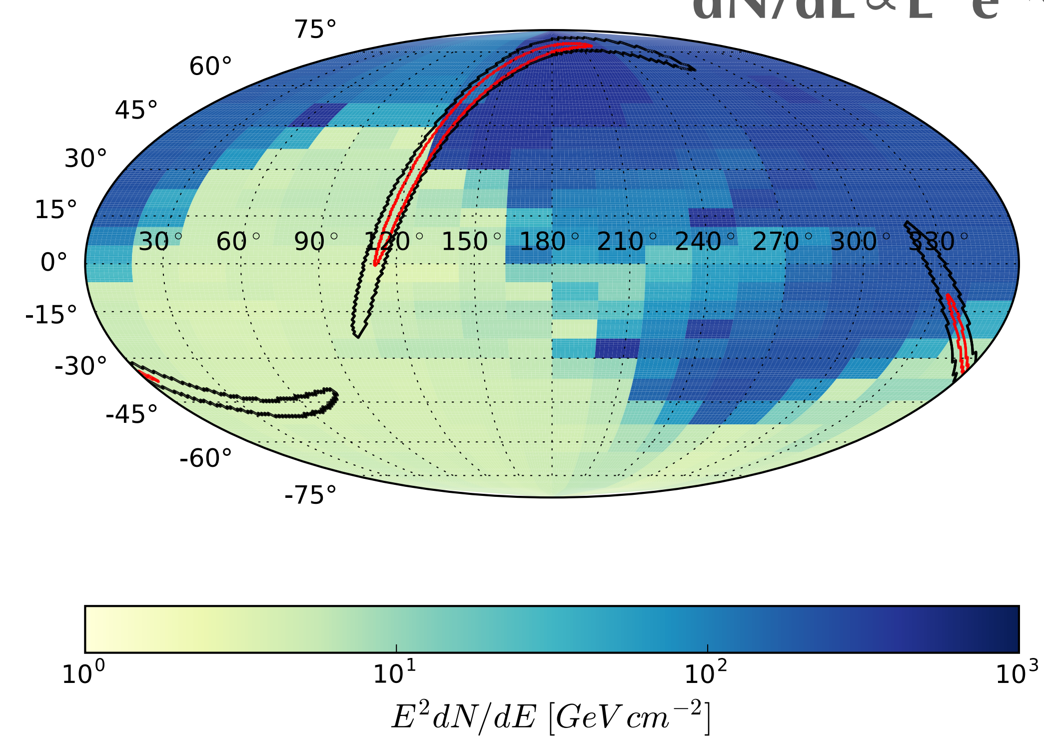
$dN/dE \propto E^{-2}$



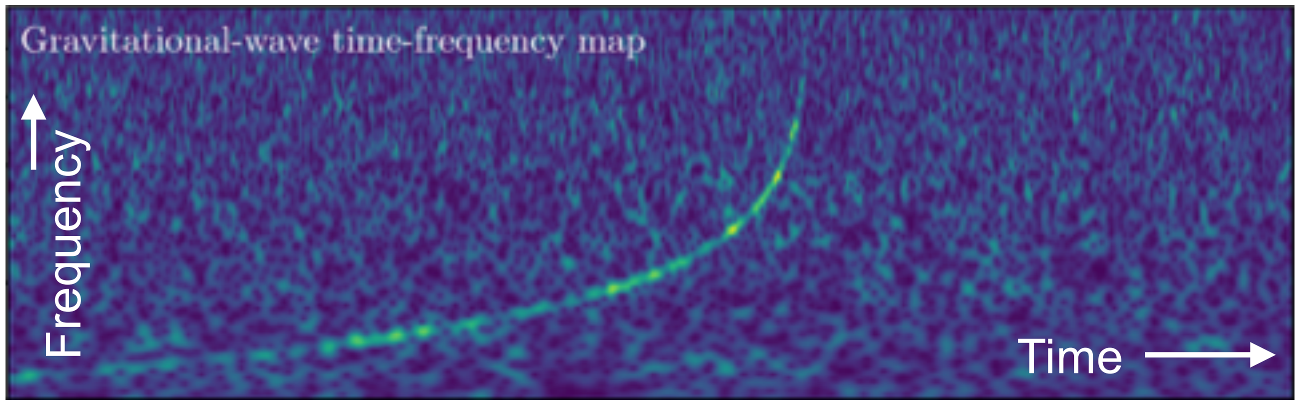
$dN/dE \propto E^{-2} e^{-\sqrt{(E/100\ TeV)}}$



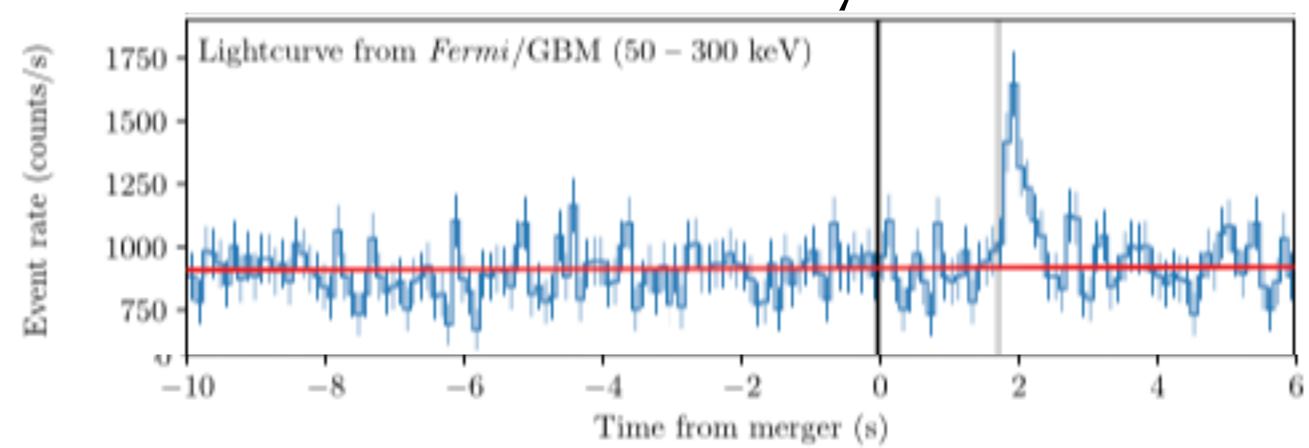
- First analysis above ANTARES horizon (feasible for transients)
- $E_{iso} < 4\ 10^{54}$ erg ($4\ 10^{53}$ at δ=-17°)

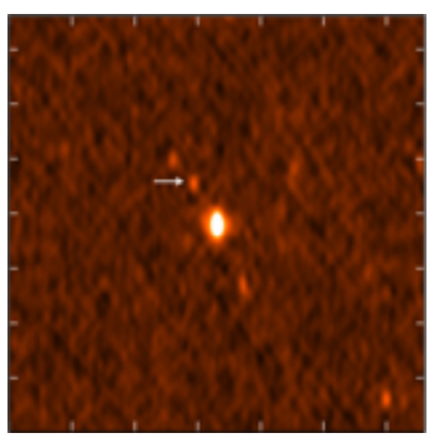
GW170817

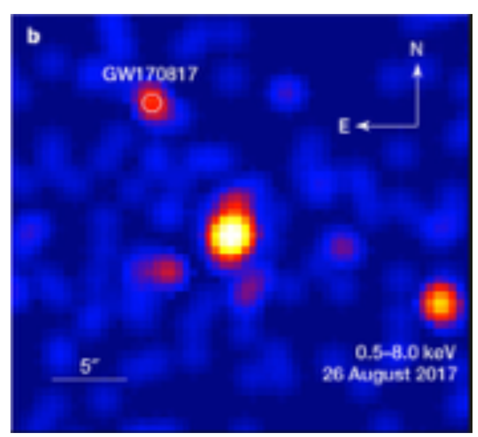
Gravitational waves



Gamma-ray







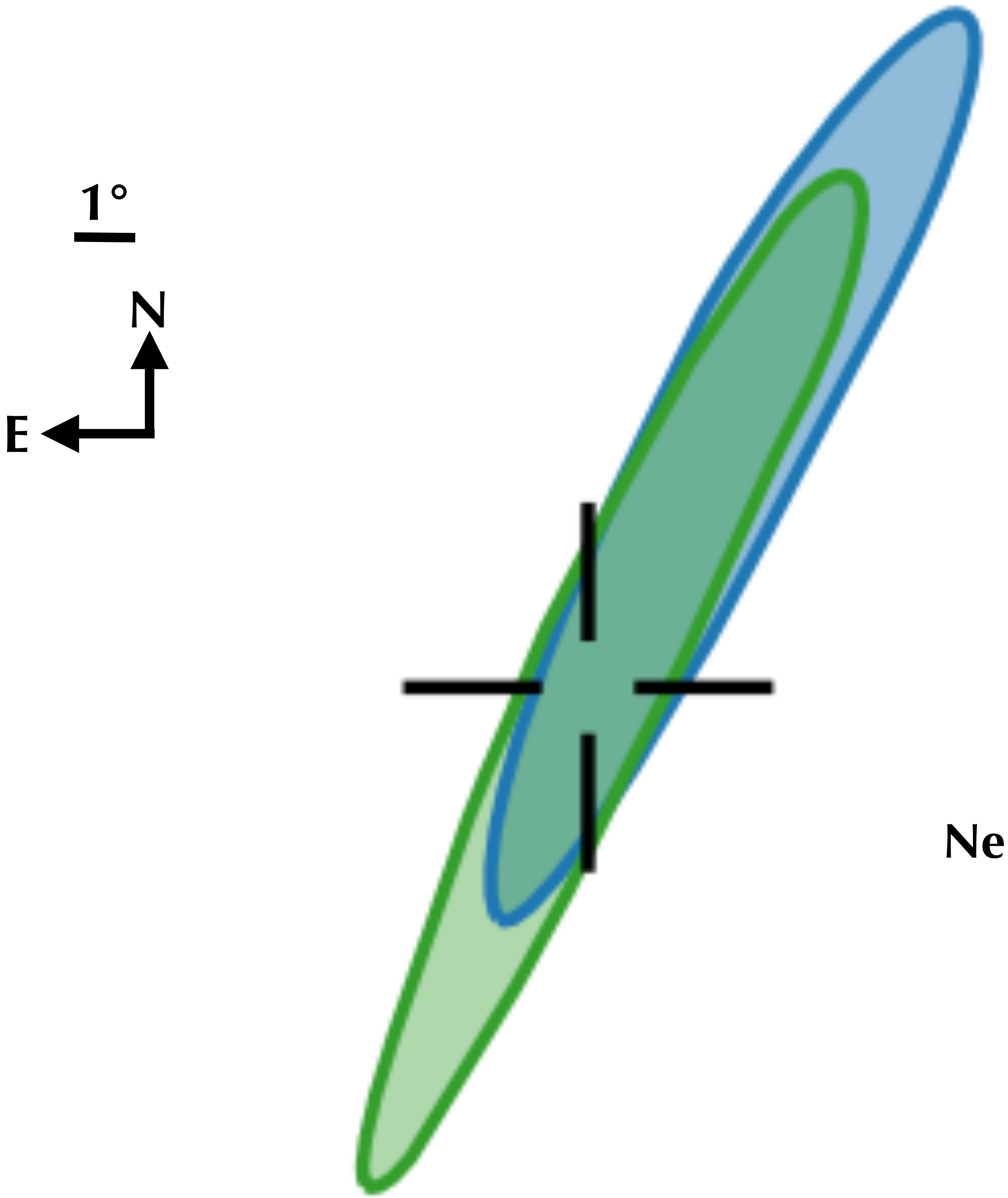
Optical Radio X-rays

ν ?

Expected if:

- ejection process with hadronic component;
- Cosmic-ray acceleration related to magnetar

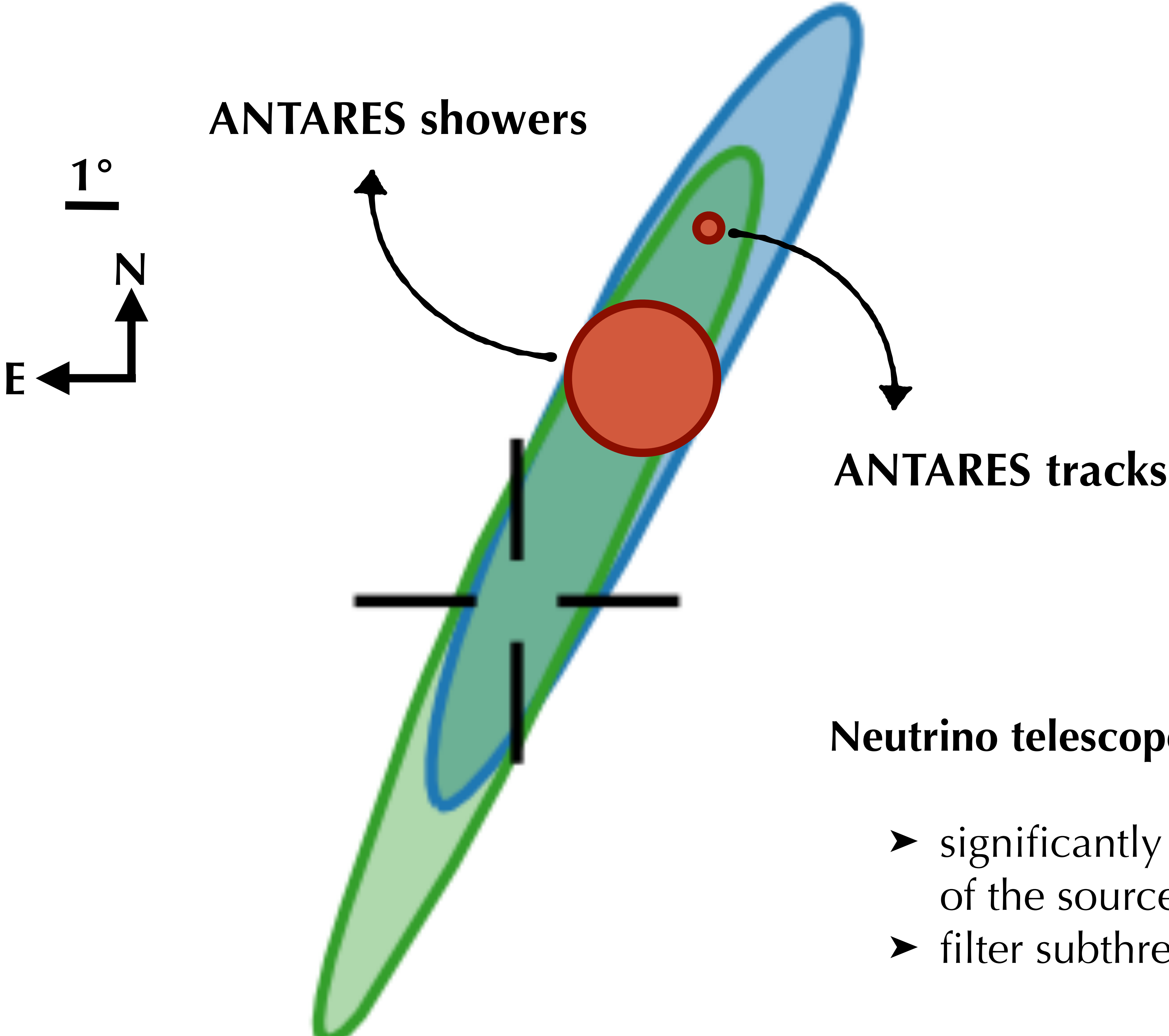
WHY LOOKING FOR NEUTRINOS IN « REAL TIME » ?



Neutrino telescopes can:

- significantly constrain the location of the source
- filter subthreshold events

WHY LOOKING FOR NEUTRINOS IN « REAL TIME » ?

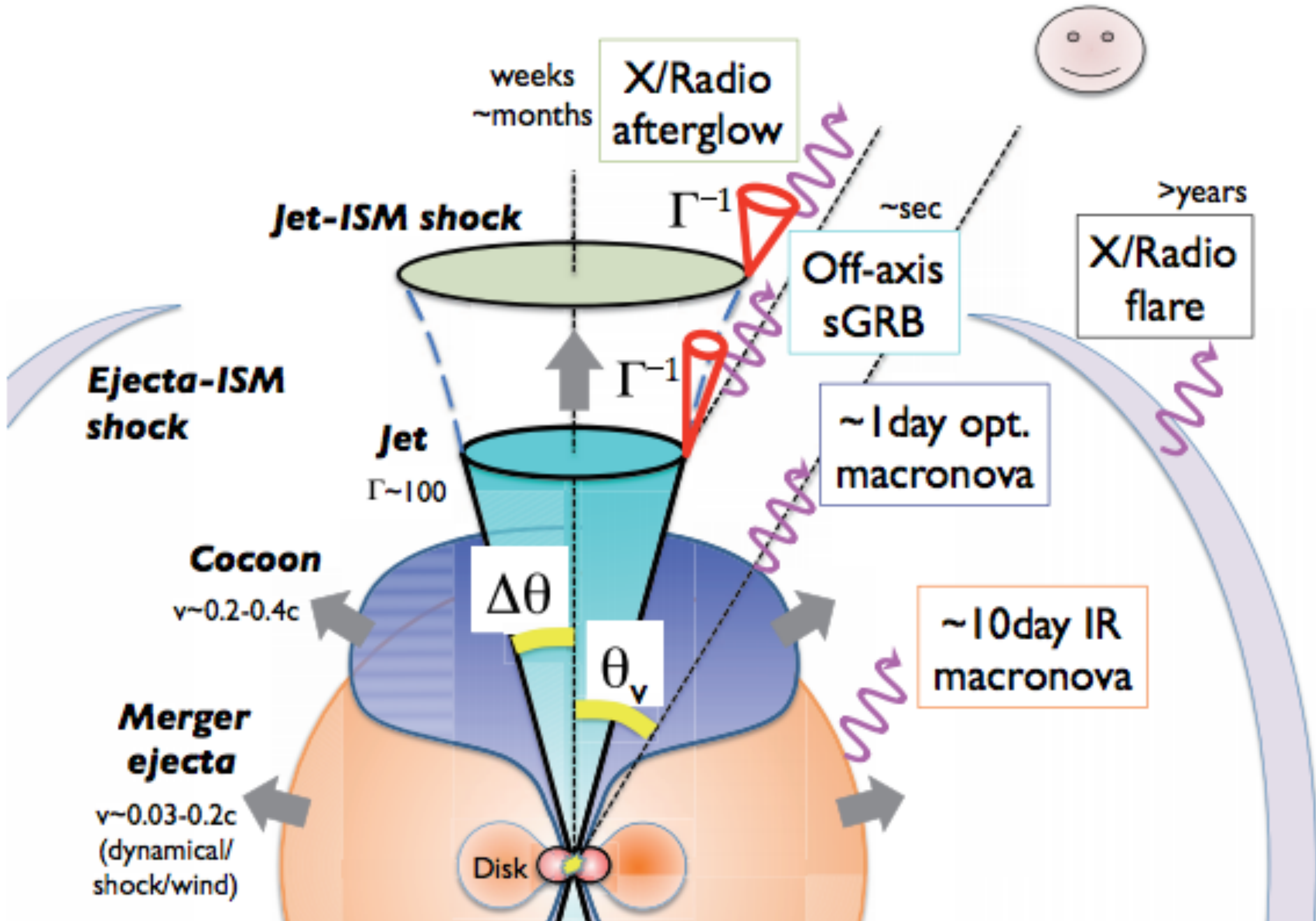


Neutrino telescopes can:

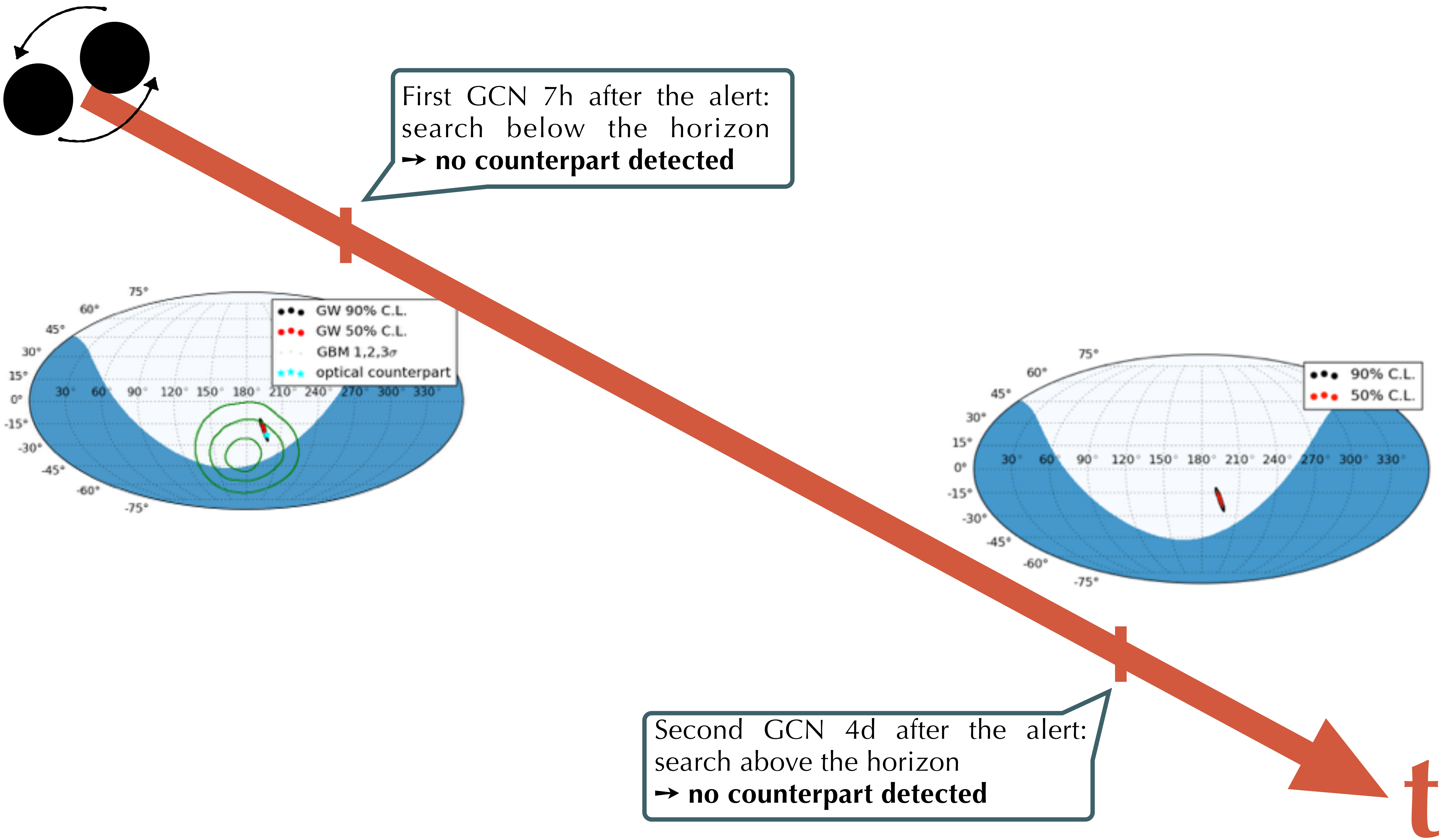
- significantly constrain the location of the source
- filter subthreshold events

WHY LOOKING FOR NEUTRINOS ?

- Could constrain the structure of the relativistic outflow:
  - Presence of a cocoon ?
  - Chocked jet ?



ONLINE ANALYSIS



NEUTRINO DETECTORS

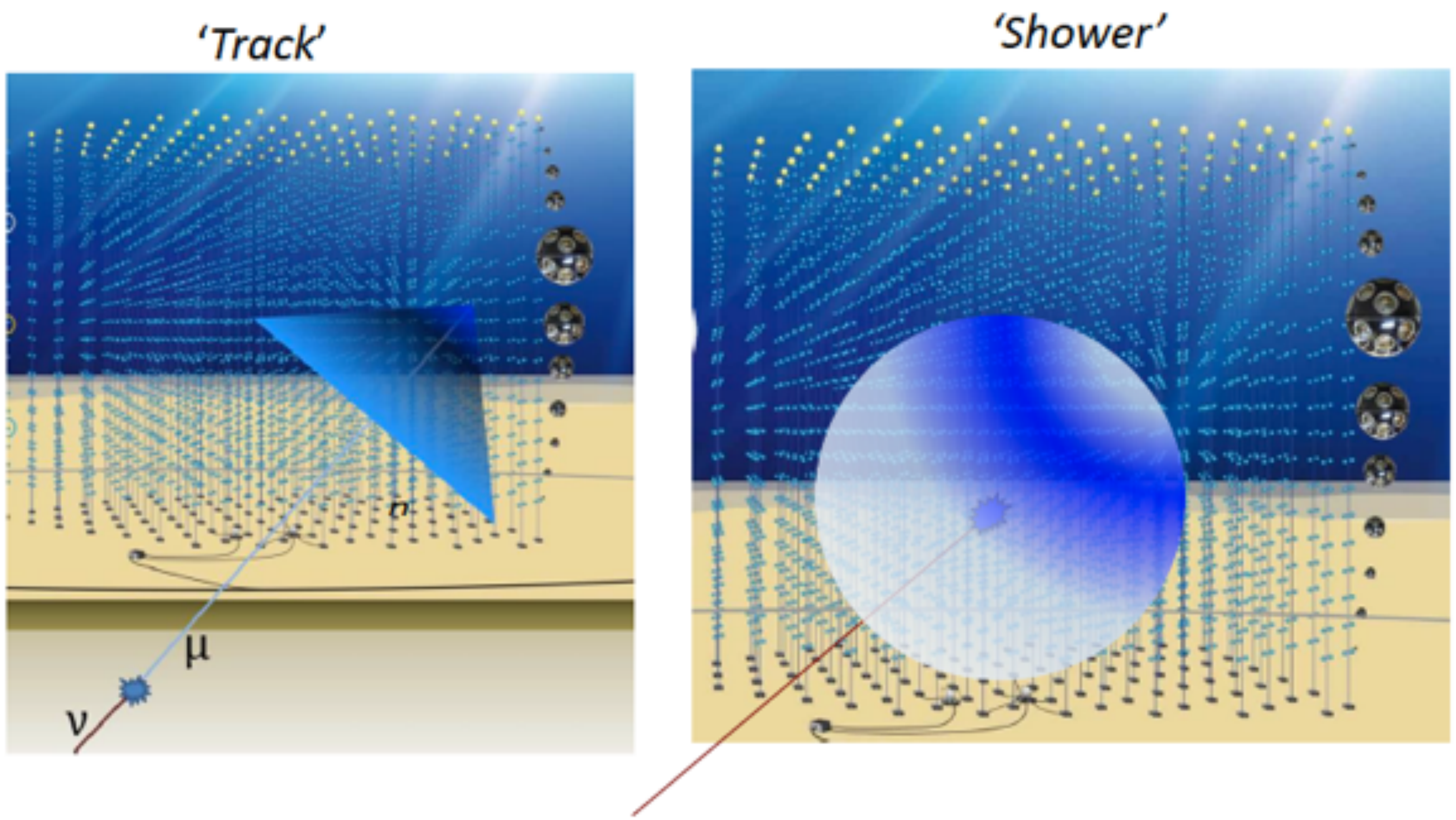
Albert et al. (ANTARES, Auger, IceCube & LIGO/Virgo), ApJL, 850, 2 (2017)

OFFLINE ANALYSIS

- Following the identification of the counterpart (host galaxy): refined and extended search
- Joint work with Auger and IceCube
- Search over ±500 s and +14 days

ANTARES:

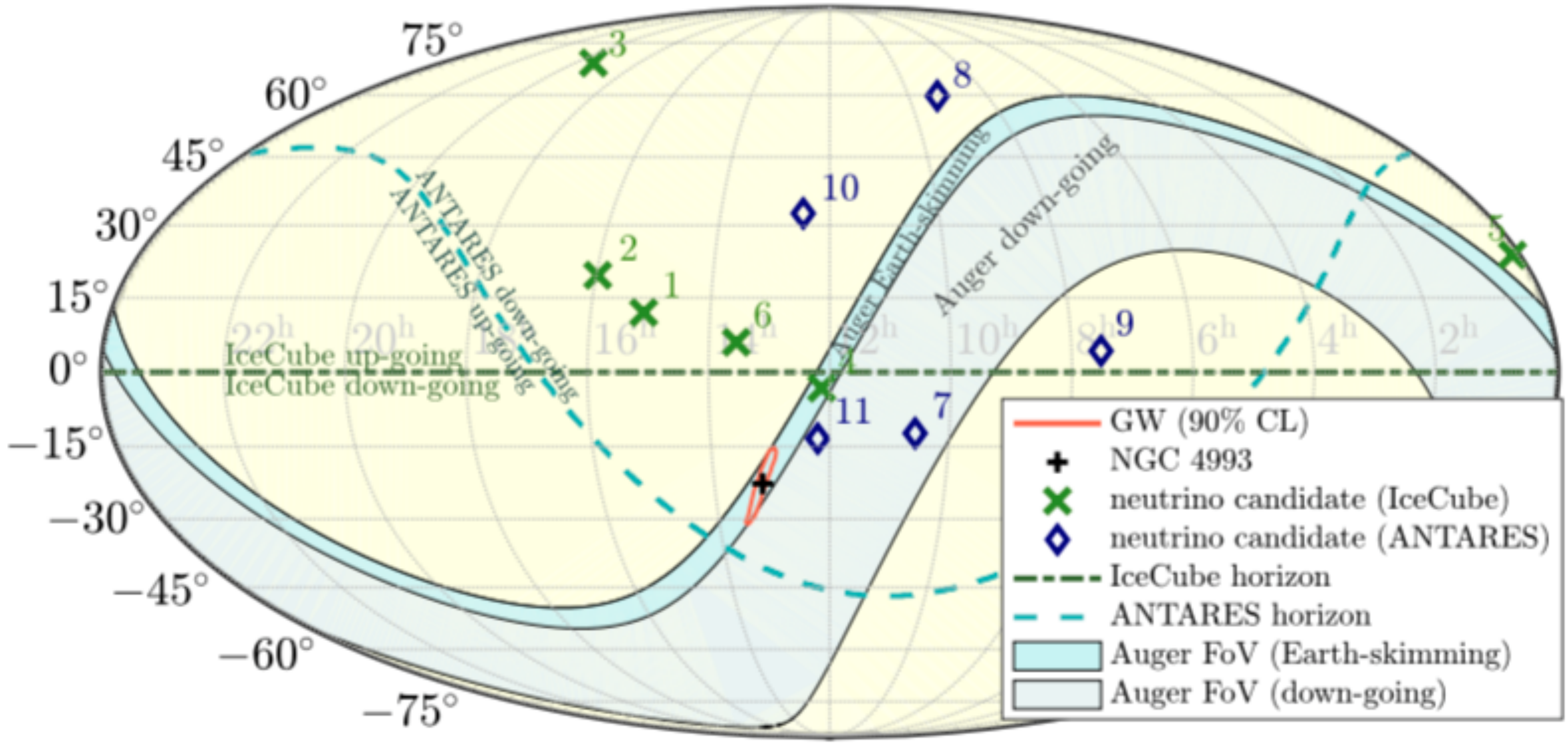
- Dedicated calibrations (positioning, timing and efficiency)
- Track + shower events (all flavors)



- **Optimized analysis for a 3σ discovery over ±500 s**

RESULTS

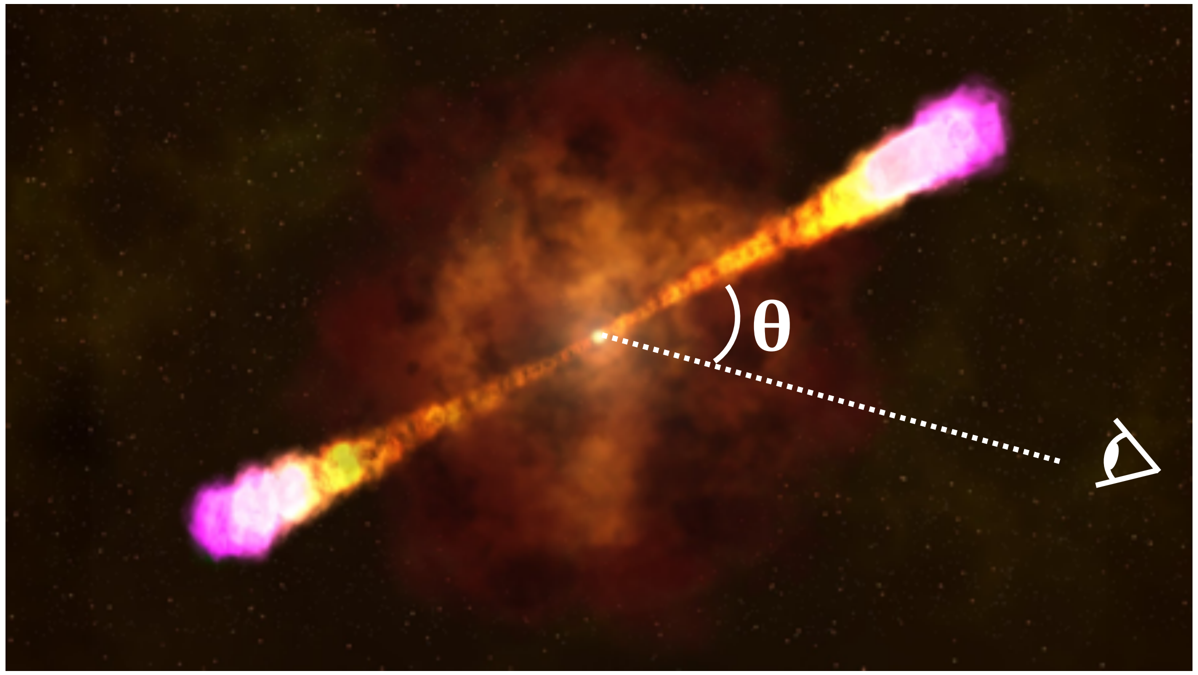
- Over ±500 s around the merger:



Albert et al., ApJL, 850, 2 (2017)

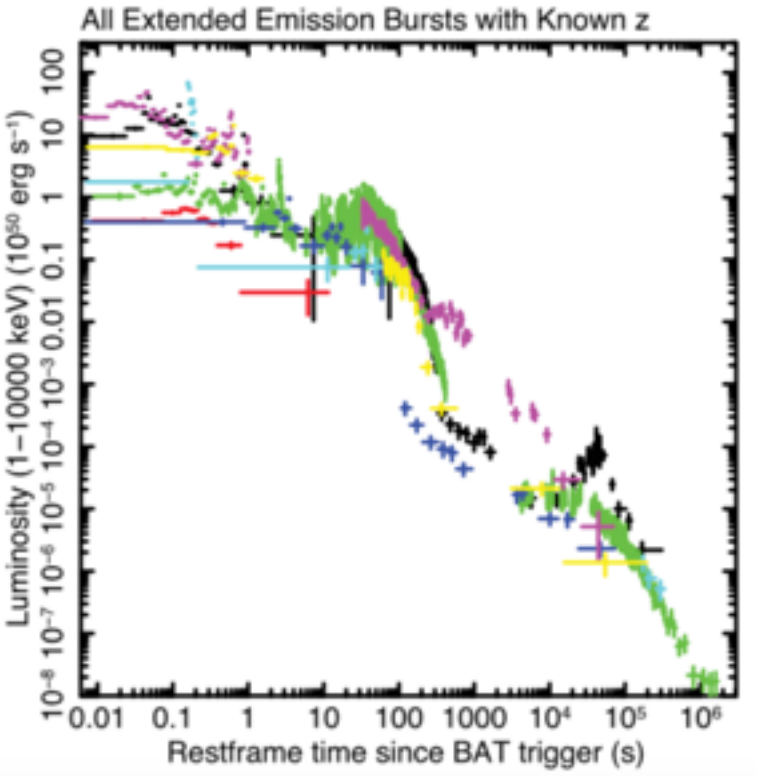
- No counterpart over +14 days

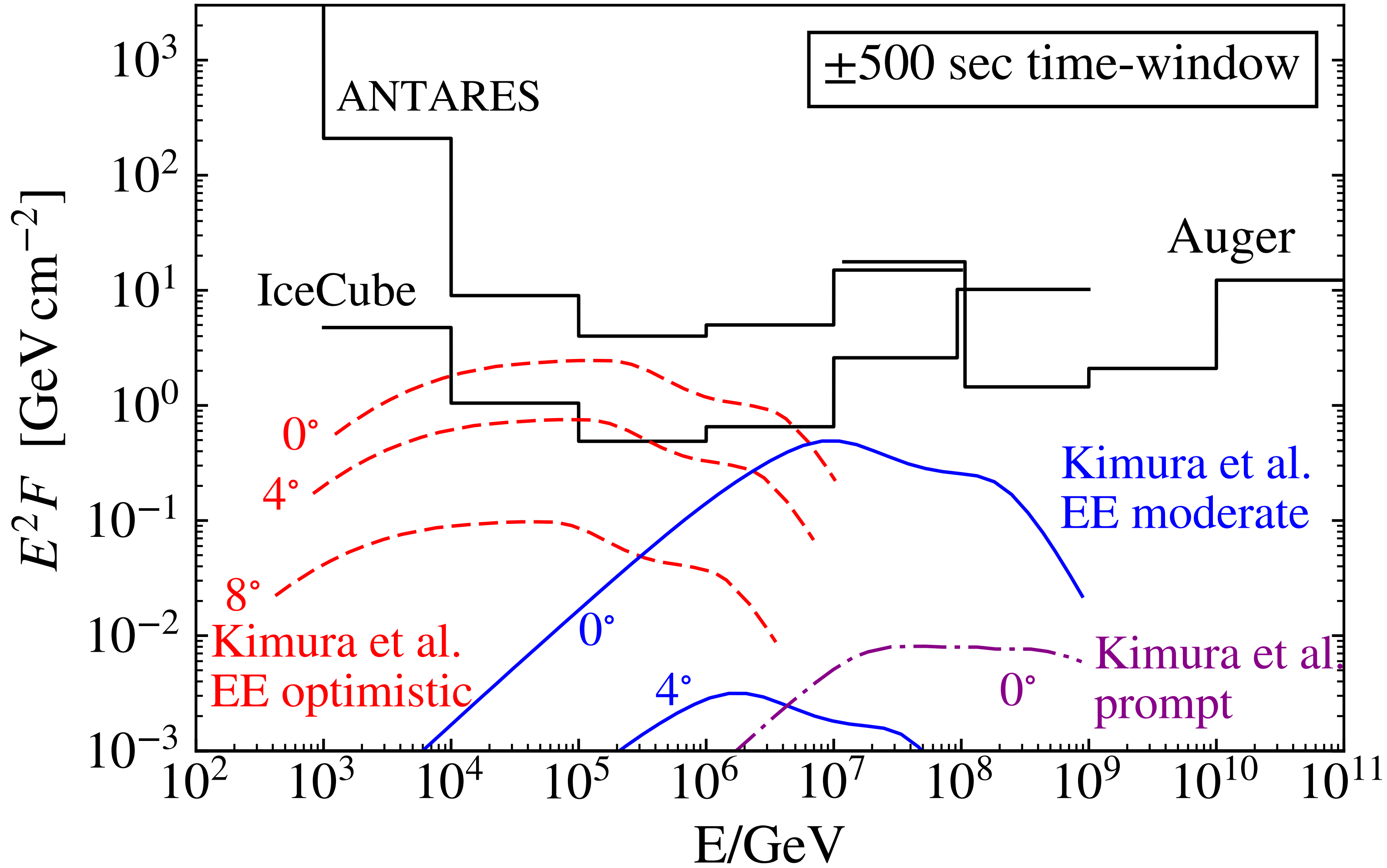
CONSTRAINTS ON THE SOURCE



- Neutrino emission related to the prompt/extended high-energy emission
- Extended emission of GRB: lower **Γ** → higher meson production efficiency
- Assuming relativistic jet viewed off-axis

- Rebrightening in the light curve after the initial emission spike





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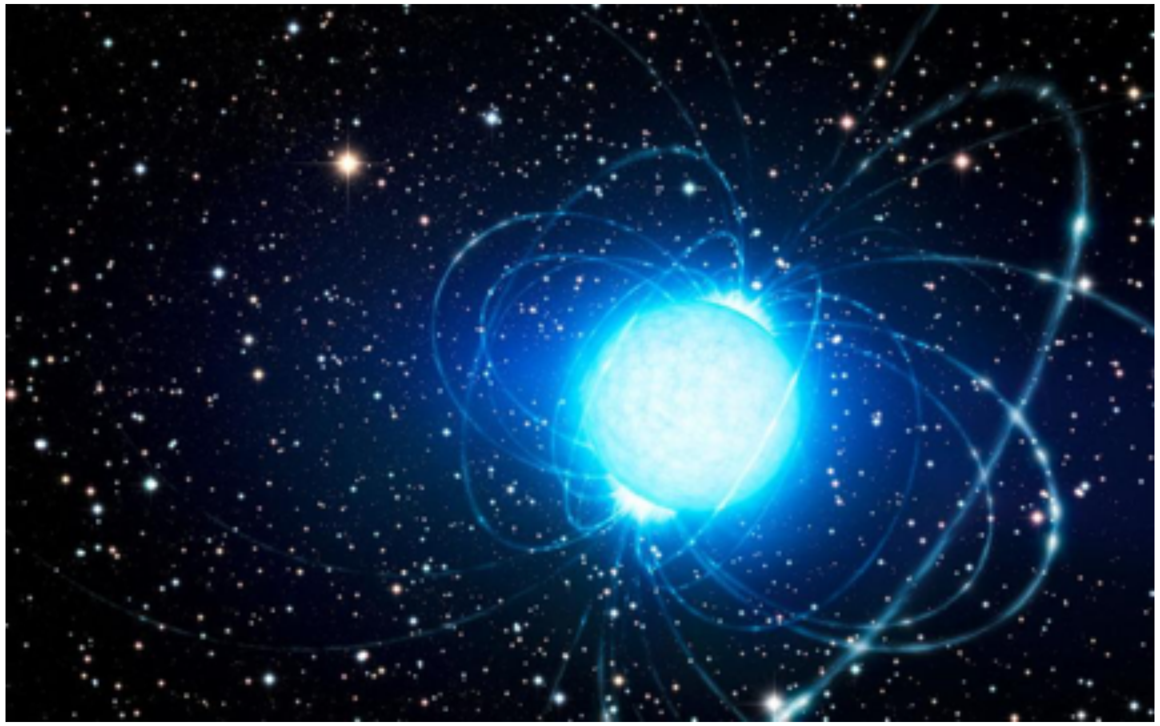
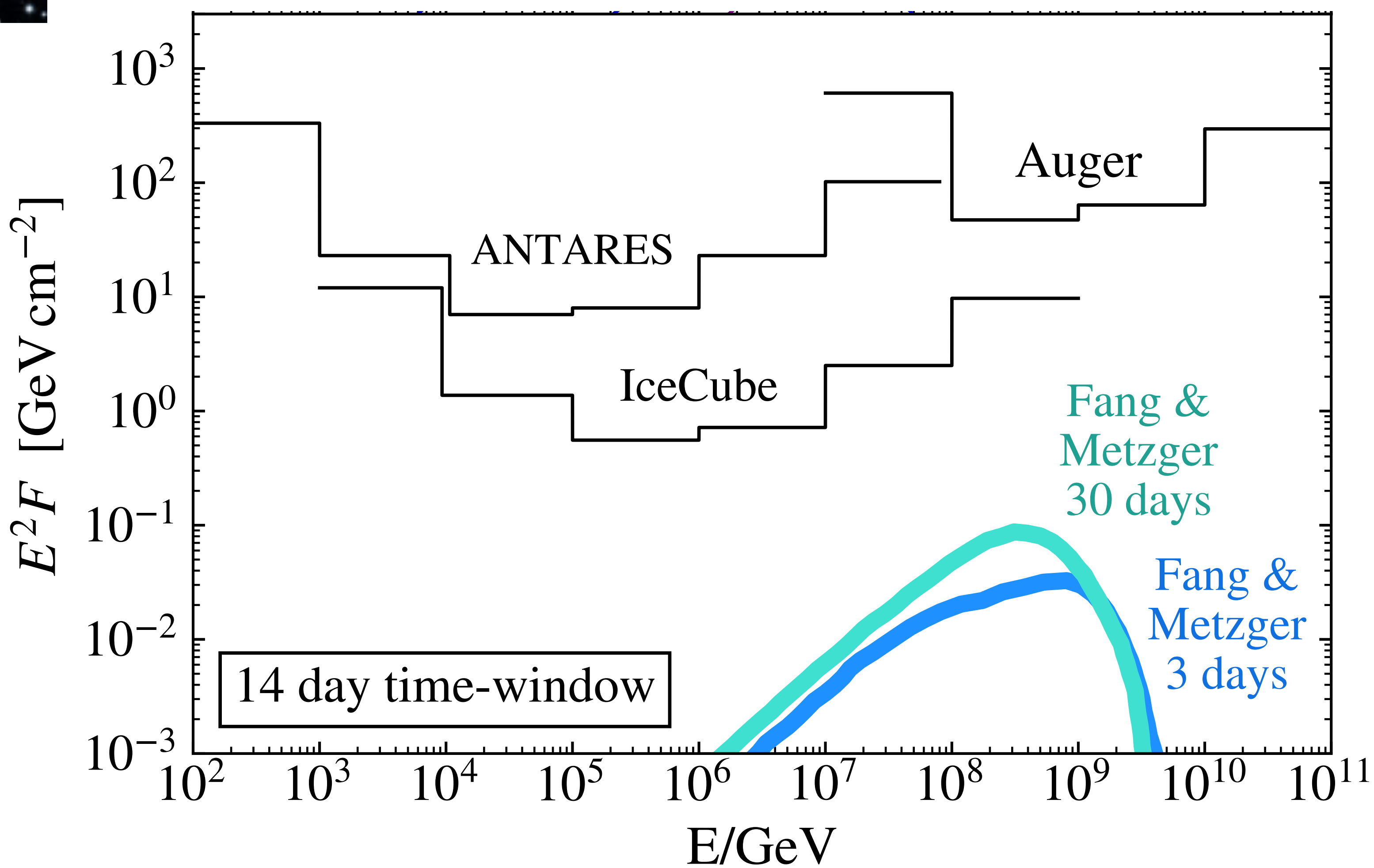


- Neutrino emission related to ejecta material from the merger over several days
- Assumes formation of a magnetar ➝ powers relativistic wind

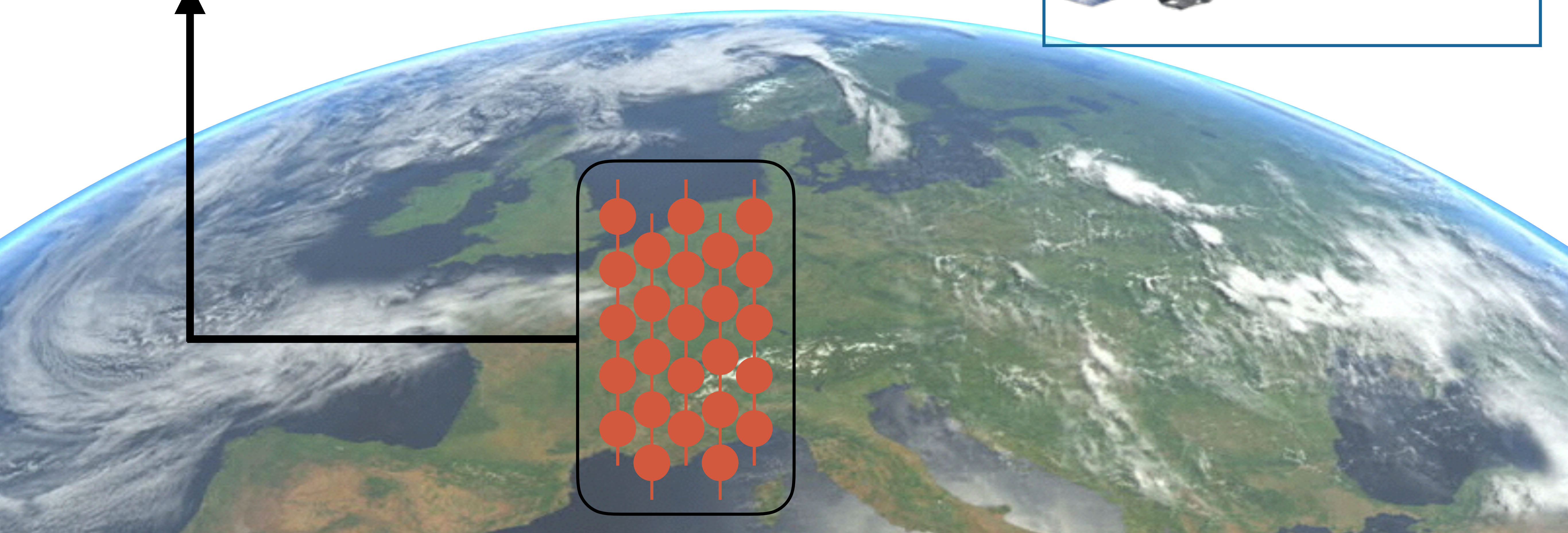


MULTI-MESSENGER PROGRAM OF ANTARES

Two approaches

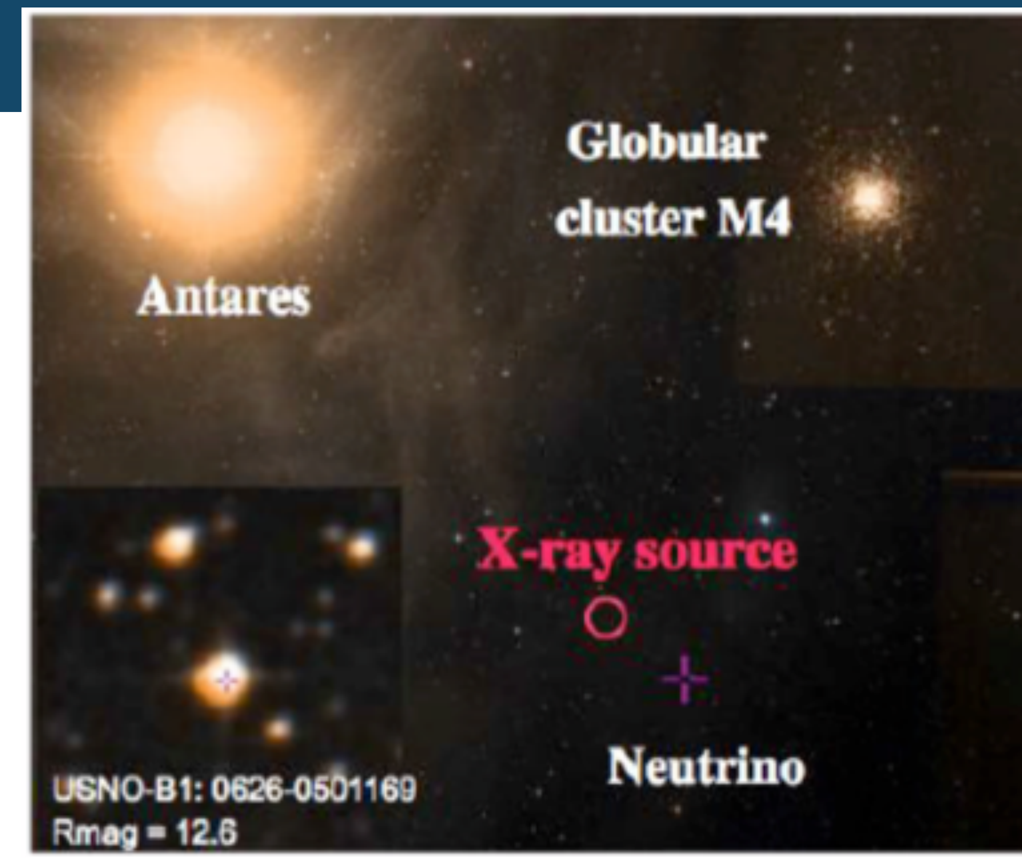
Alert triggering

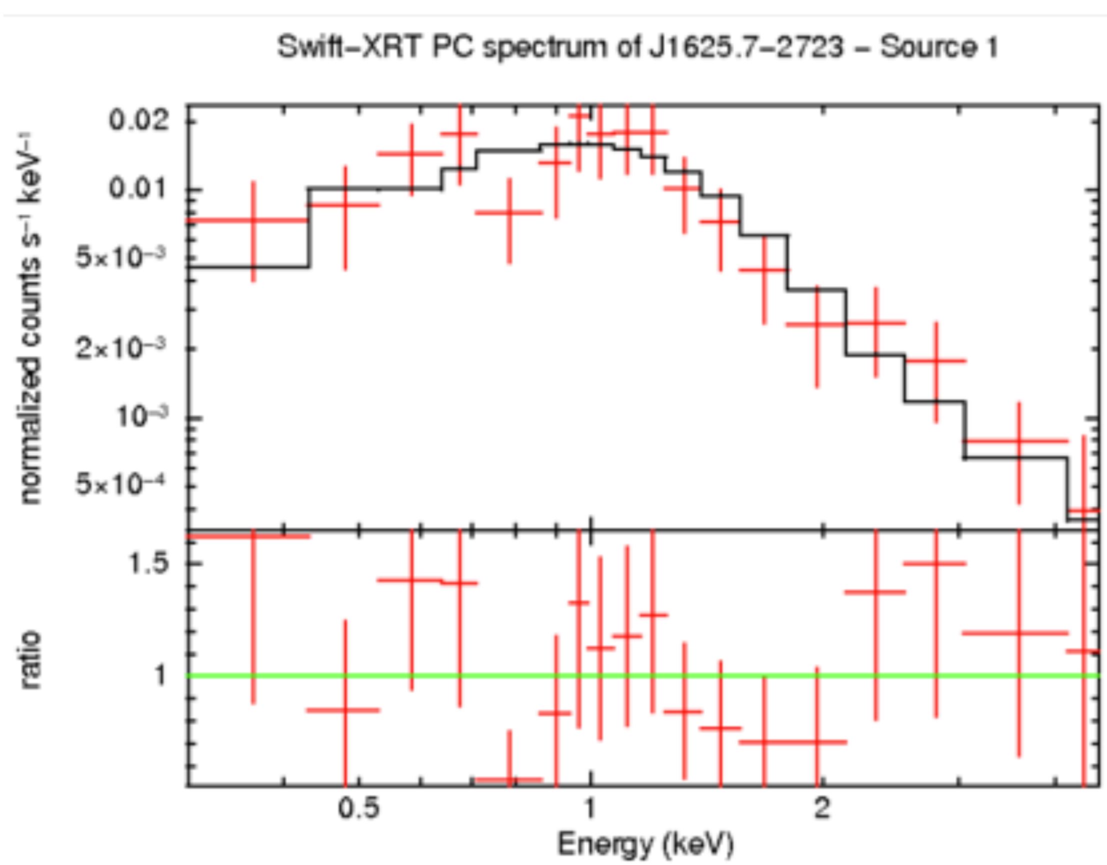
Real-time analysis

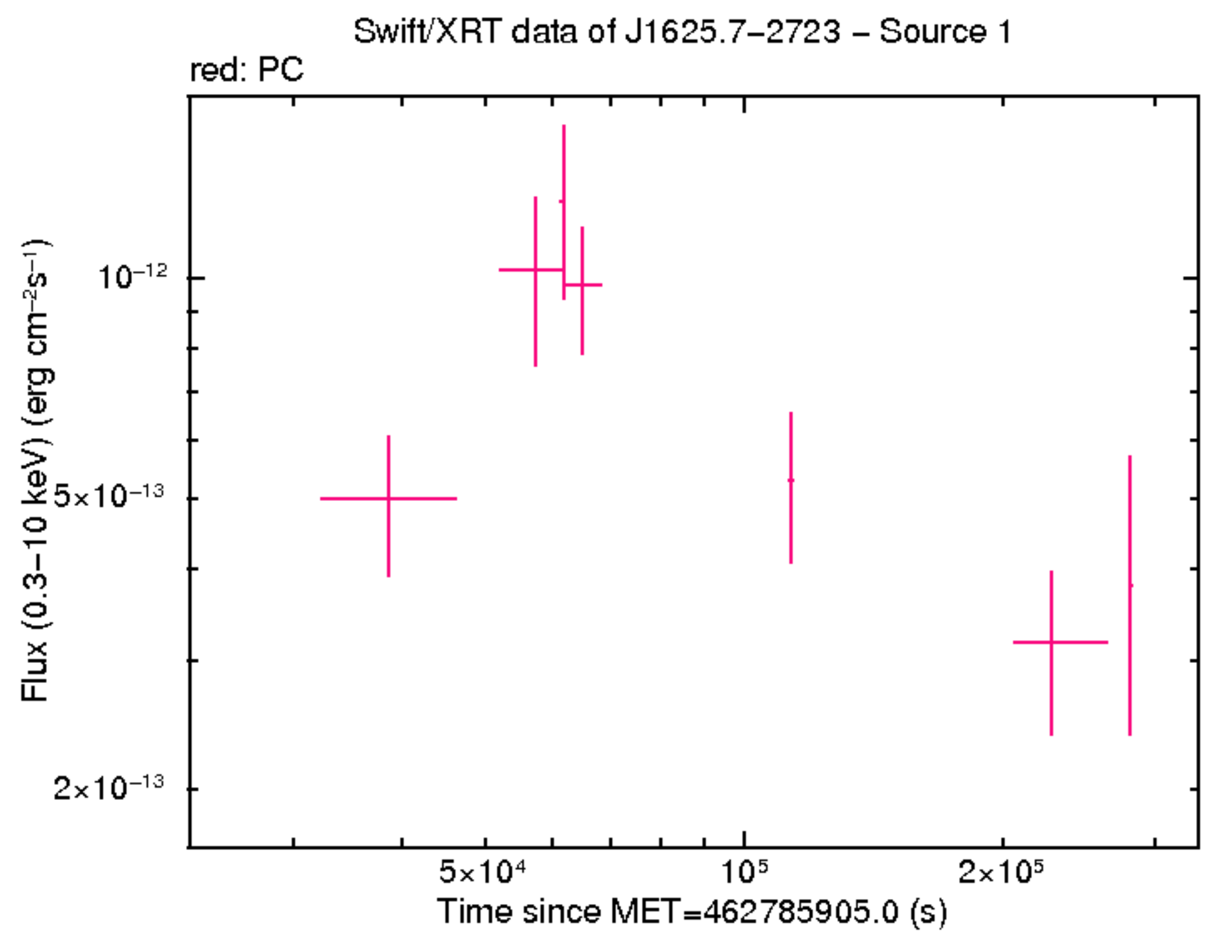


ANTARES ALERTS: 150901A

- E ~50-100 TeV
- Error box=18′
- Sent in 10s to Swift and Master
- Swift obs: +9h
- Master obs: +10h

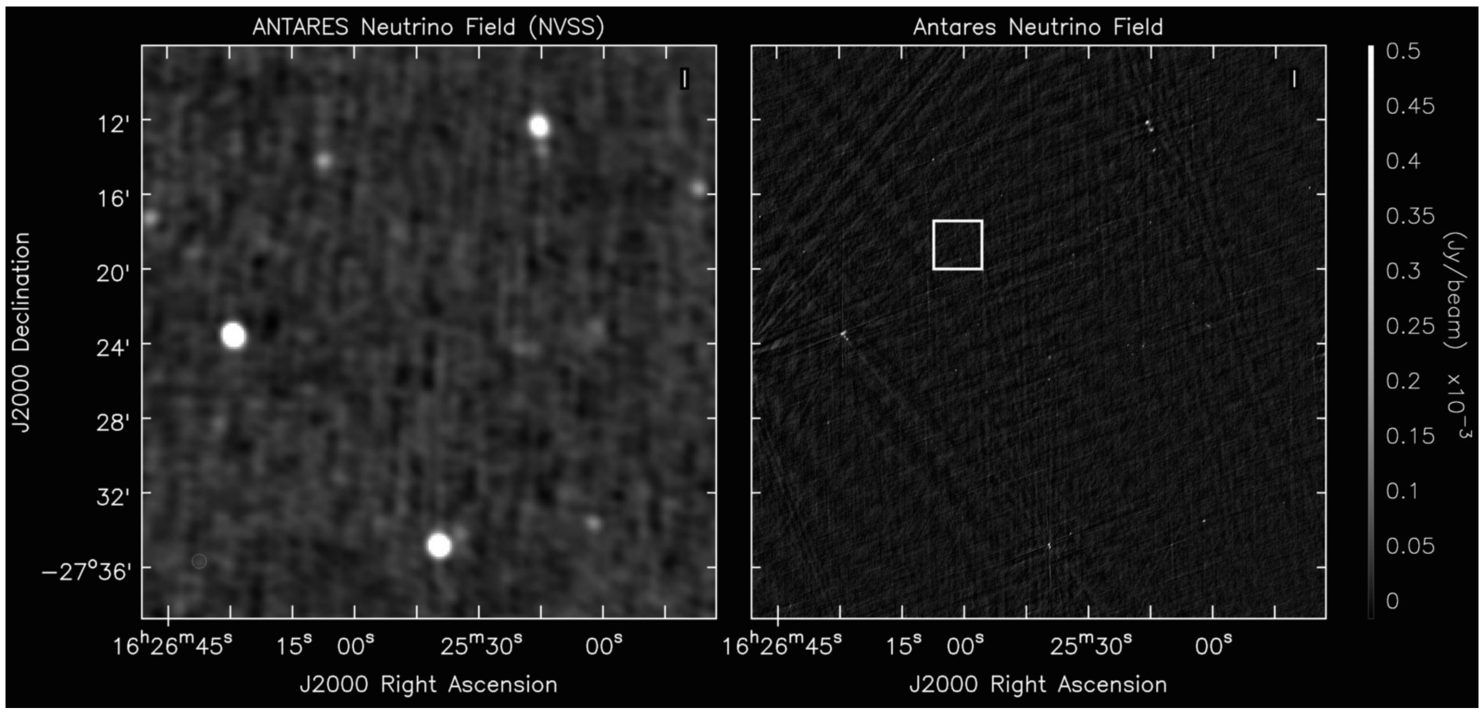


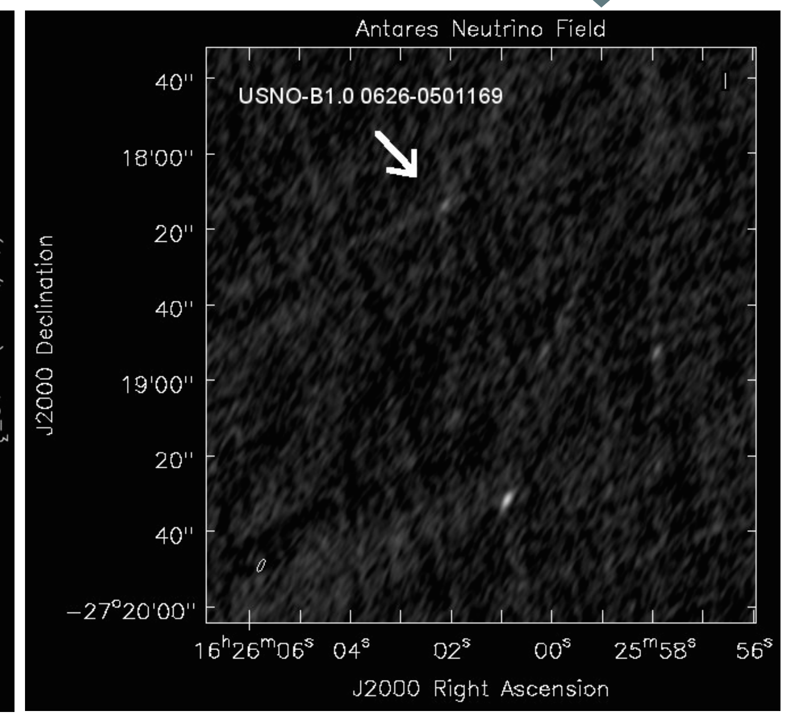


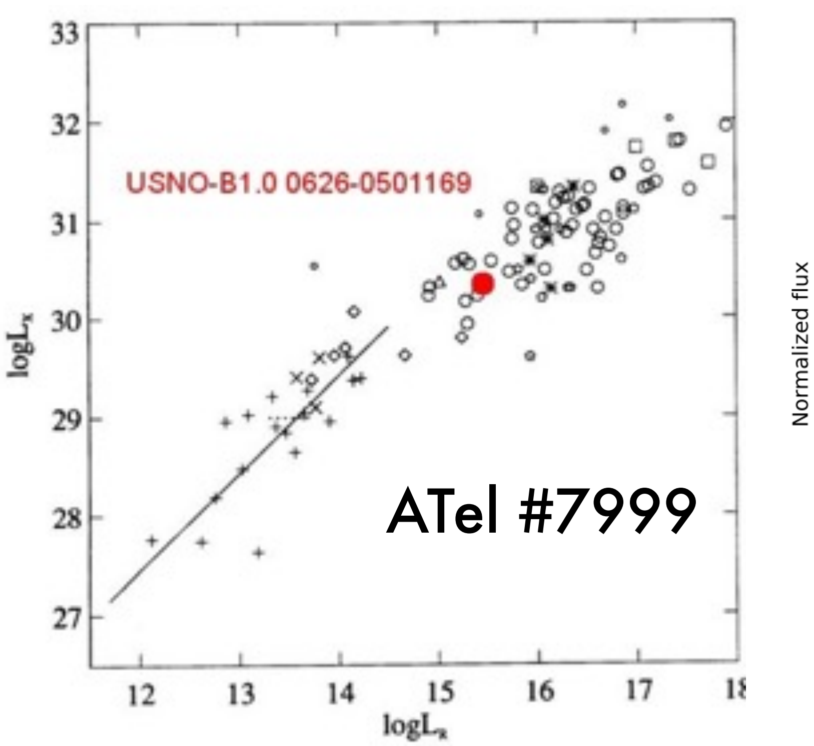


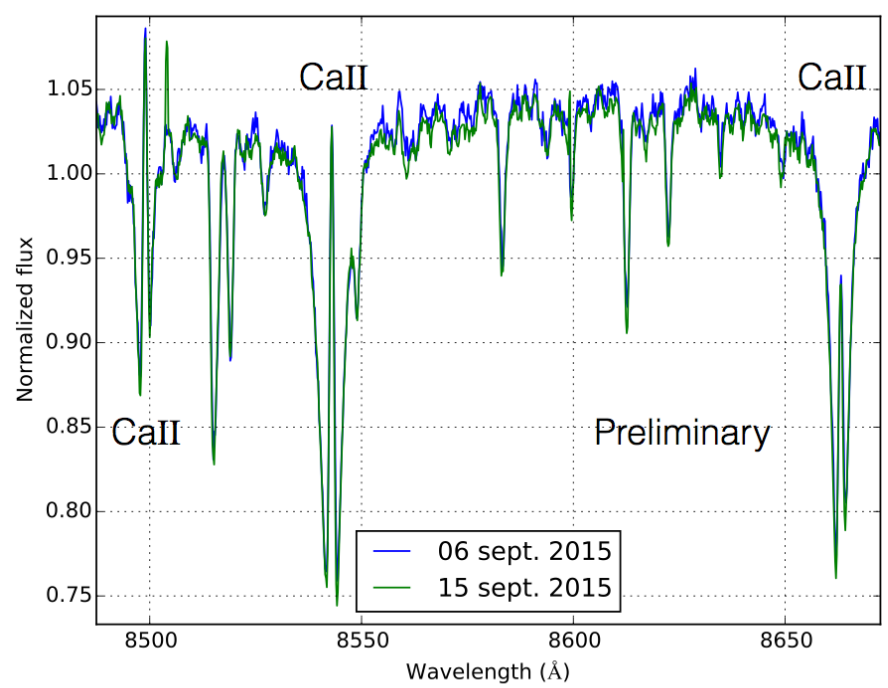
ANTARES ALERTS: 150901A

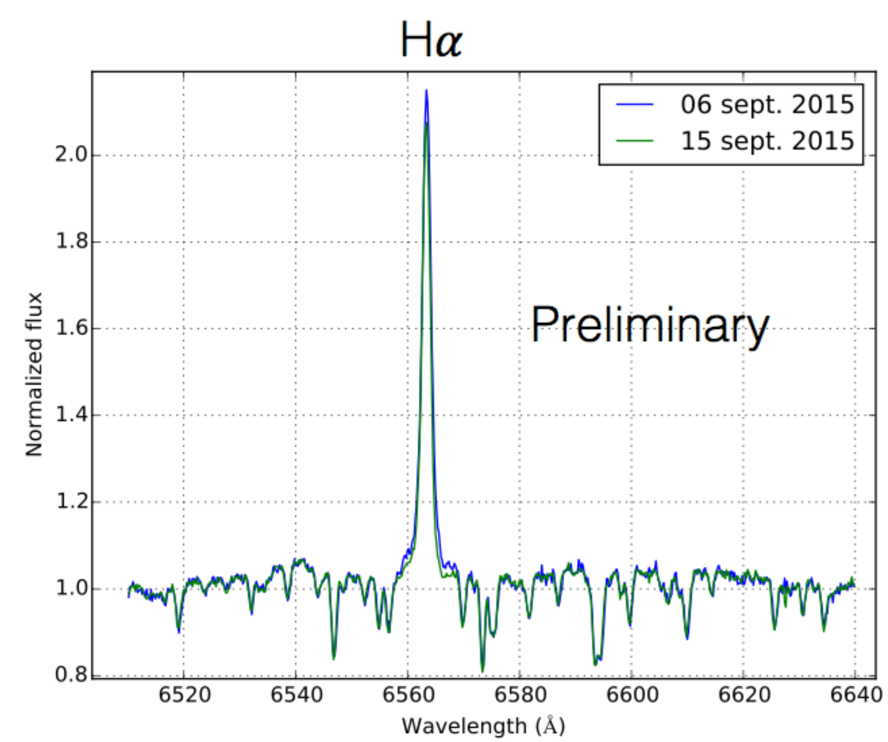
An active X-ray star





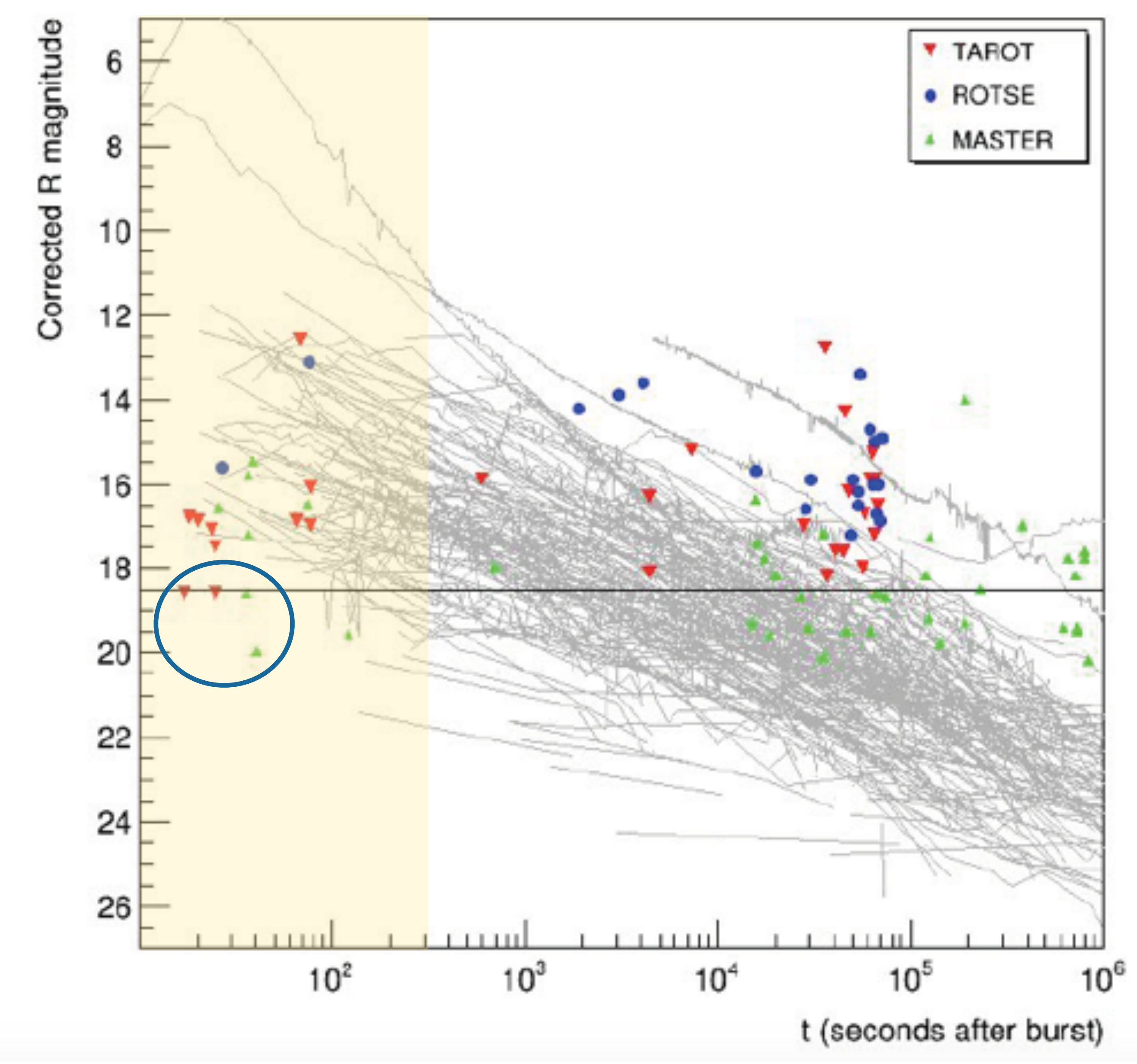






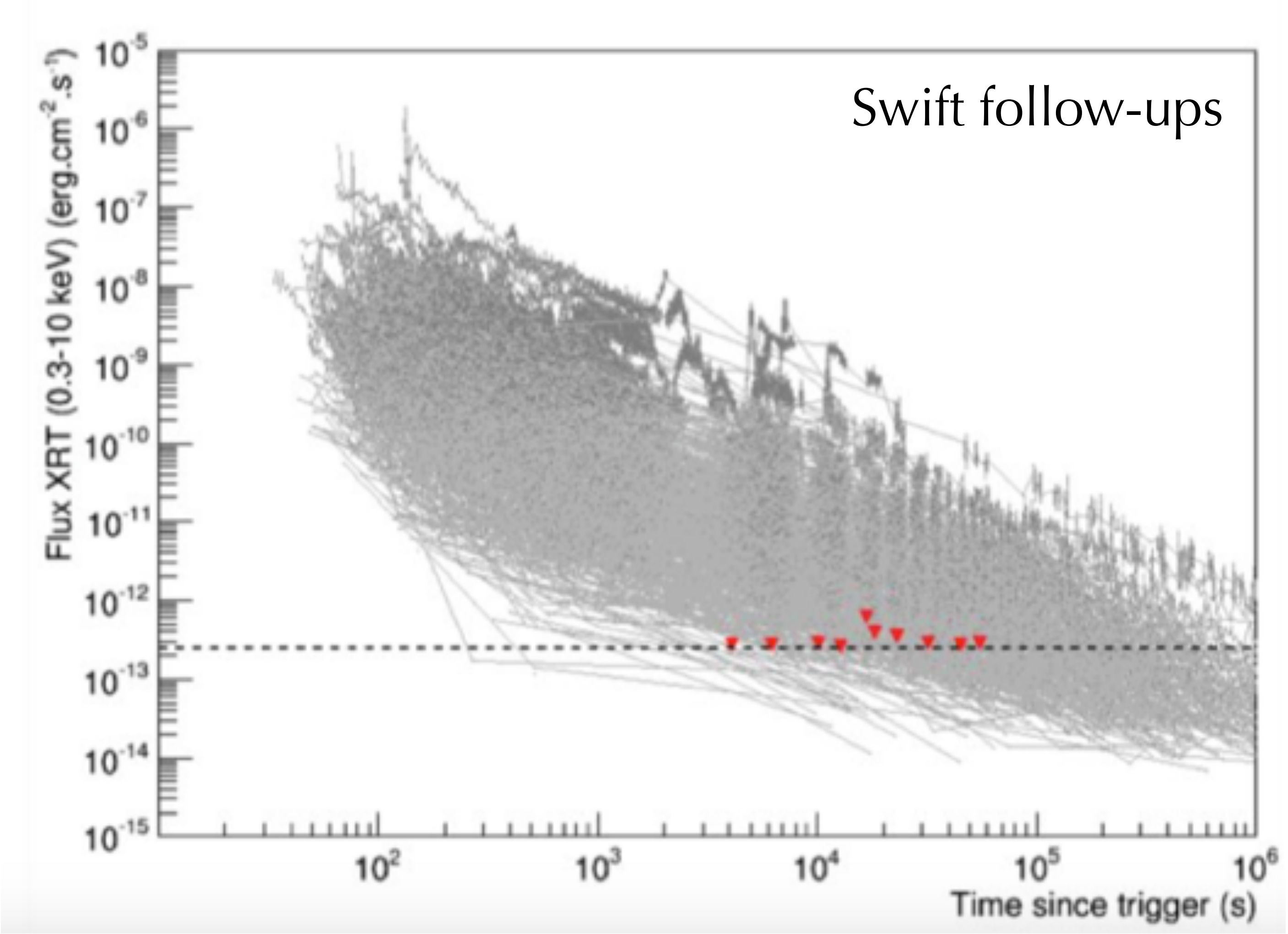
TATOO & GAMMA-RAY BURSTS

- 104 alerts with early (<24h) optical follow-up analyzed (01/2010 - 07/2017)
- 24 follow-ups with delay <1min (best: 17s)
- no transient candidate associated to neutrinos
- Constraints on origin of individual neutrinos
- GRB origin unlikely



TATOO & GAMMA-RAY BURSTS

- 14 X-ray follow-ups (06/2013 - 08/2017)
- delay of 5-6 h on average
- no transient candidate associated to neutrinos
- Constraints on origin of individual neutrinos
- GRB origin unlikely



PERSPECTIVES & CONCLUSIONS

- Multi-messenger astronomy era ! Gravitational waves + neutrino diffuse flux
- Further constrain physical processes at play in high-energy sources
- Increases discovery potential of neutrino telescopes (by observing the same source with different probes)
- Refines the efficiency of the detection, (taking advantage of relaxed cuts in time-dependent analysis)
- Need of wide field-of-view multi-wavelength facilities !