



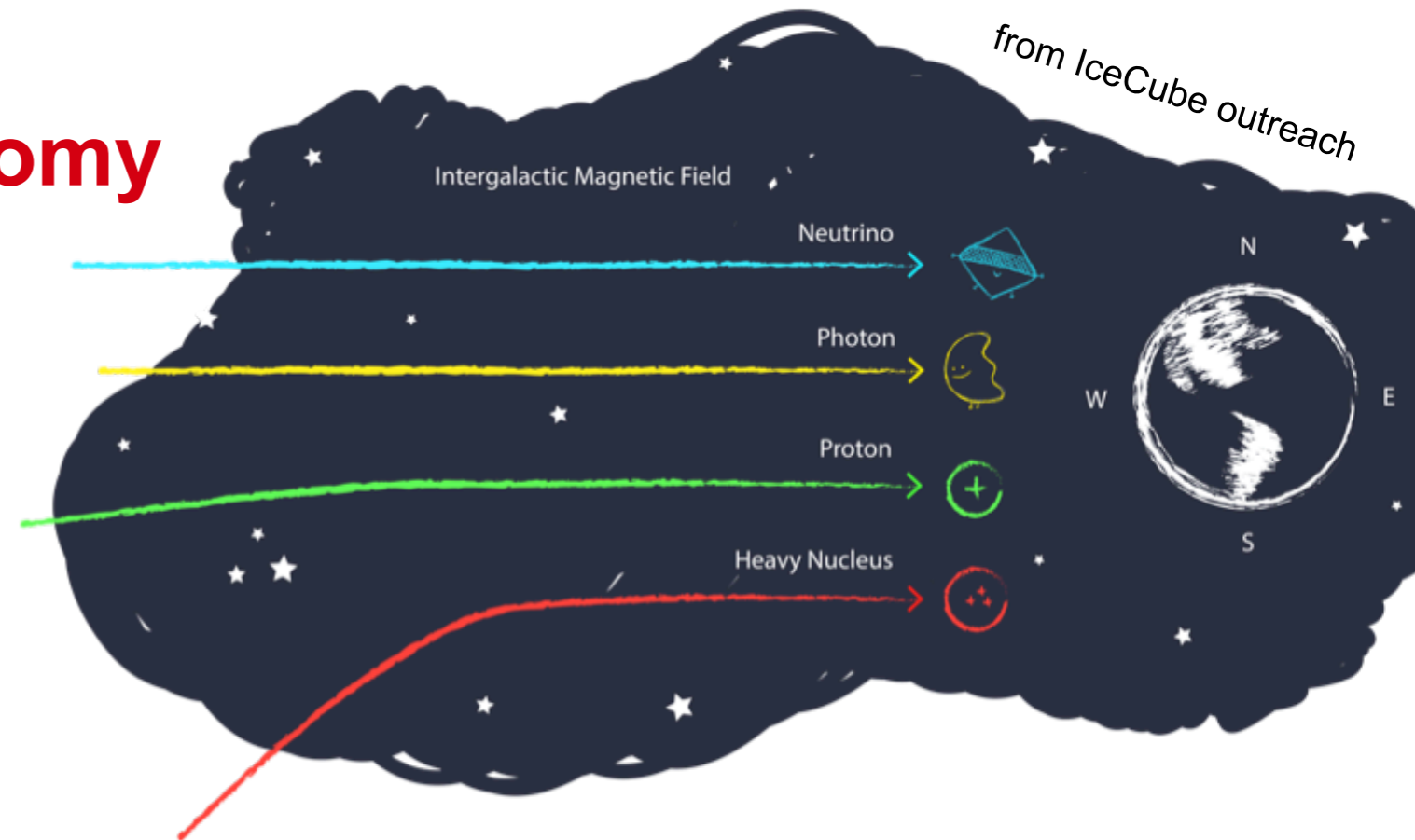
Multi-messenger follow-ups with IACTs

Clemens Hoischen - Potsdam University
14th Rencontres du Vietnam . Quy Nhon

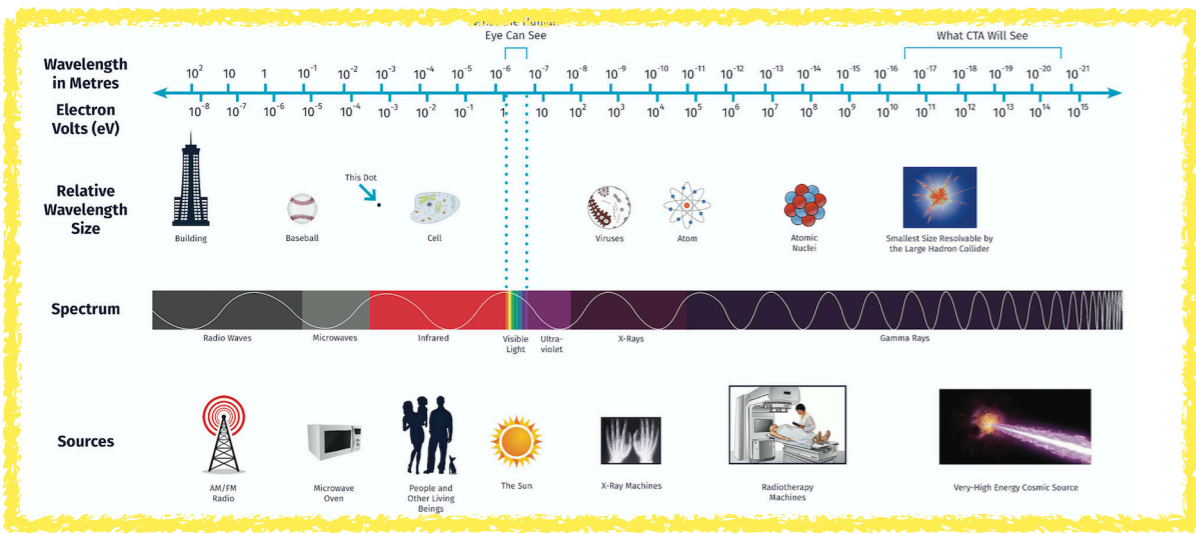


Universität Potsdam

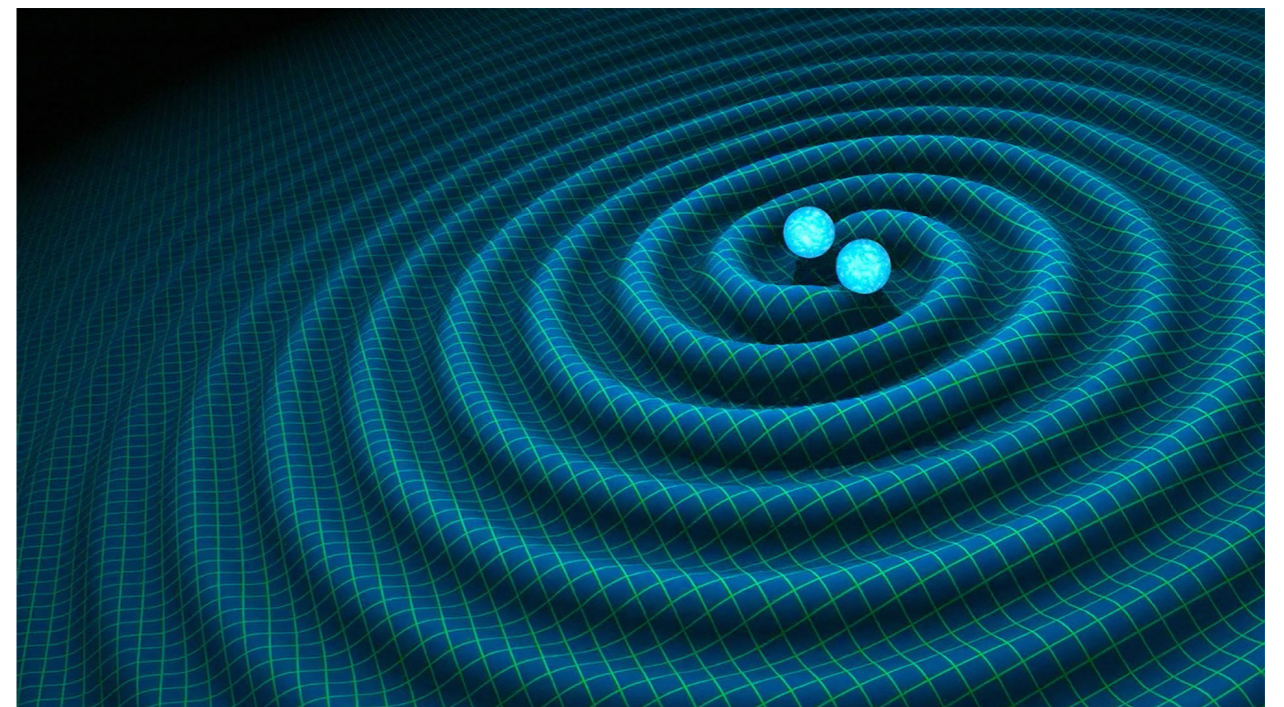
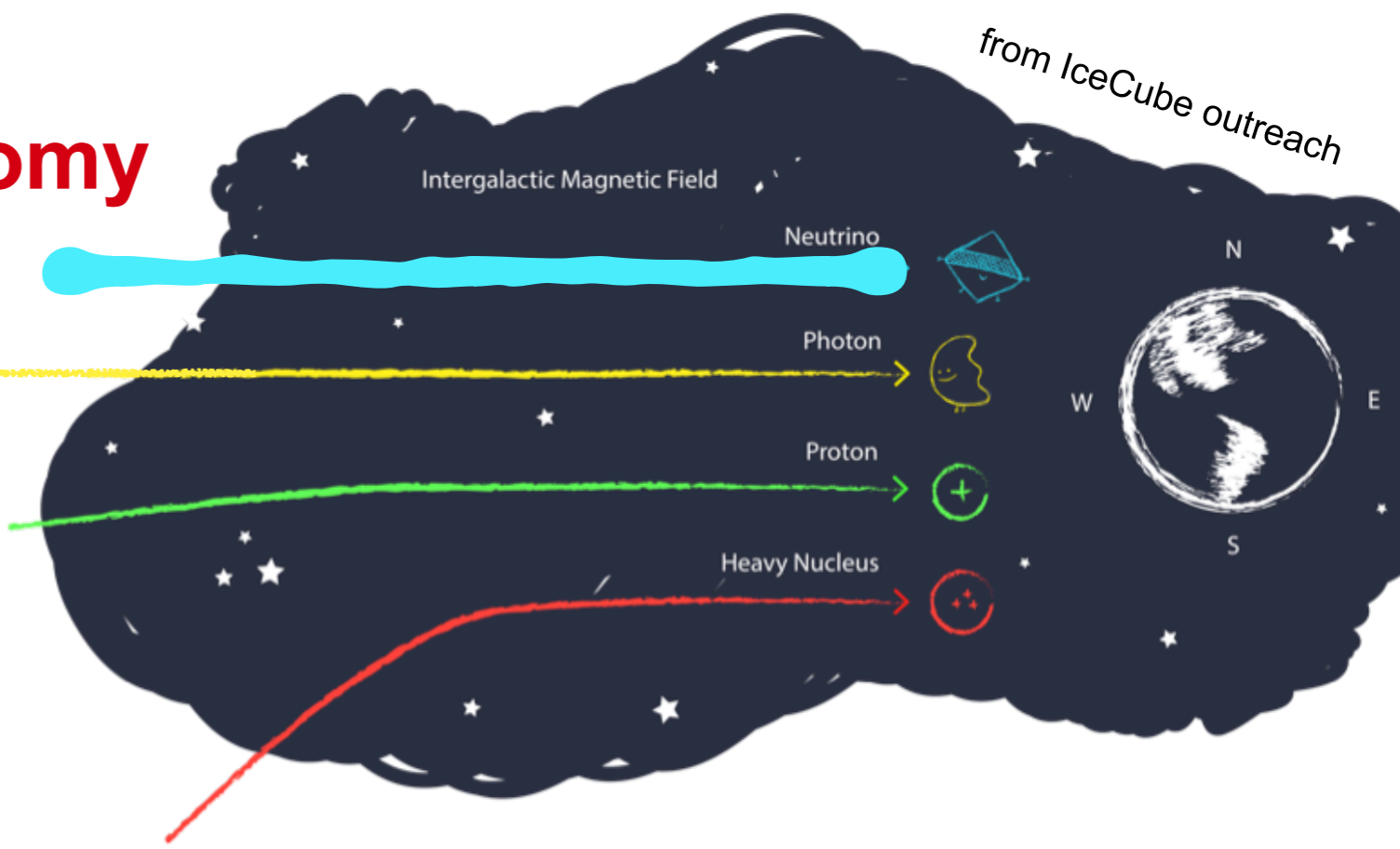
Multi-messenger astronomy



Multi-messenger astronomy



from CTA outreach



Early examples of multi-messenger astronomy

- Solar flares and cosmic rays
~ 1950

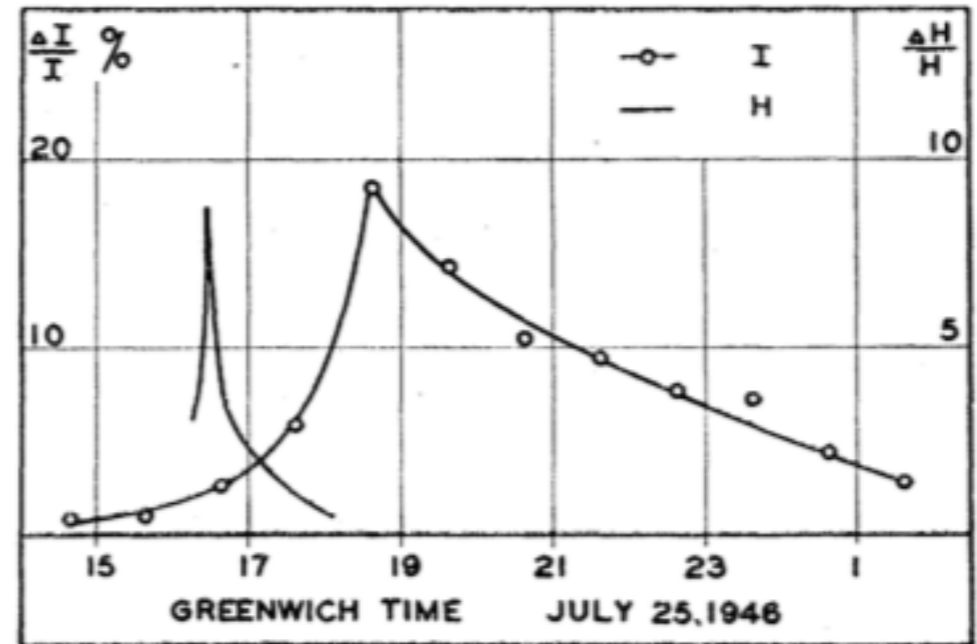
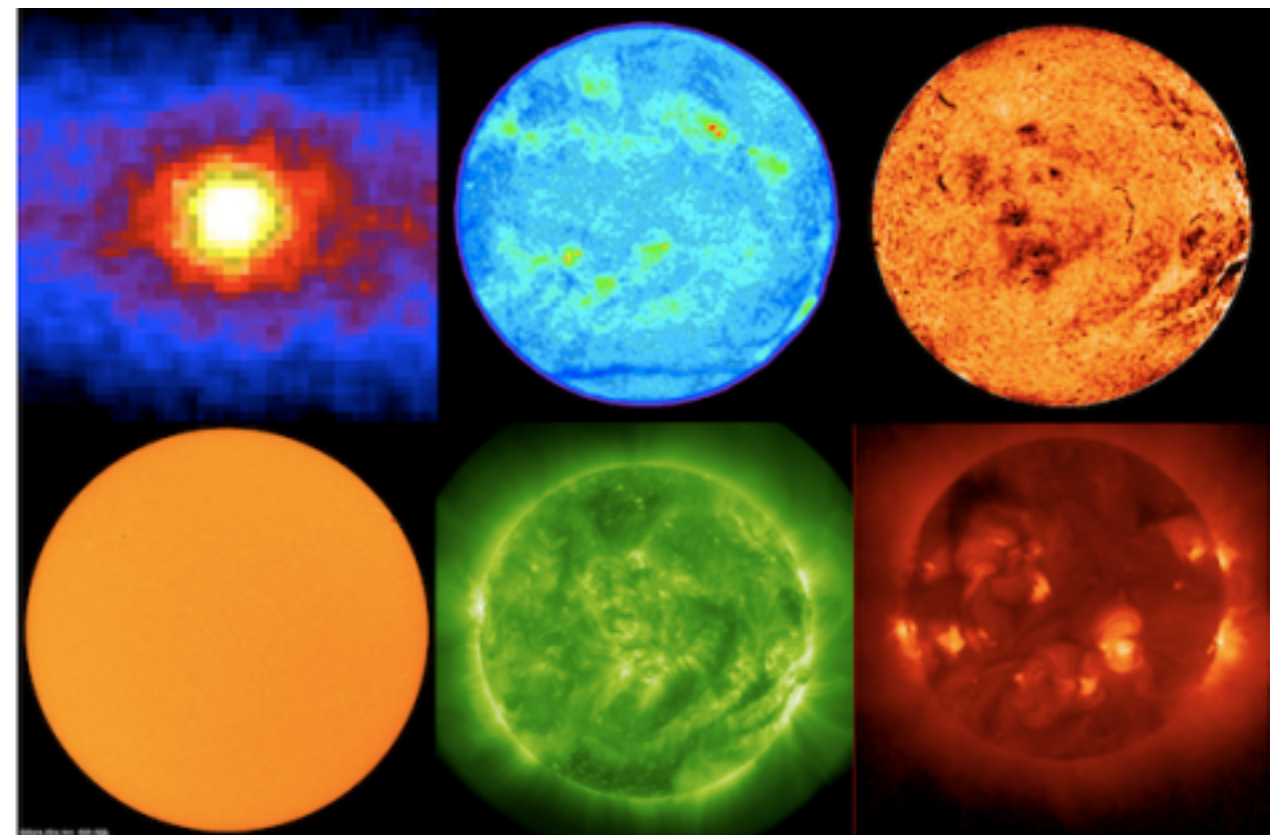


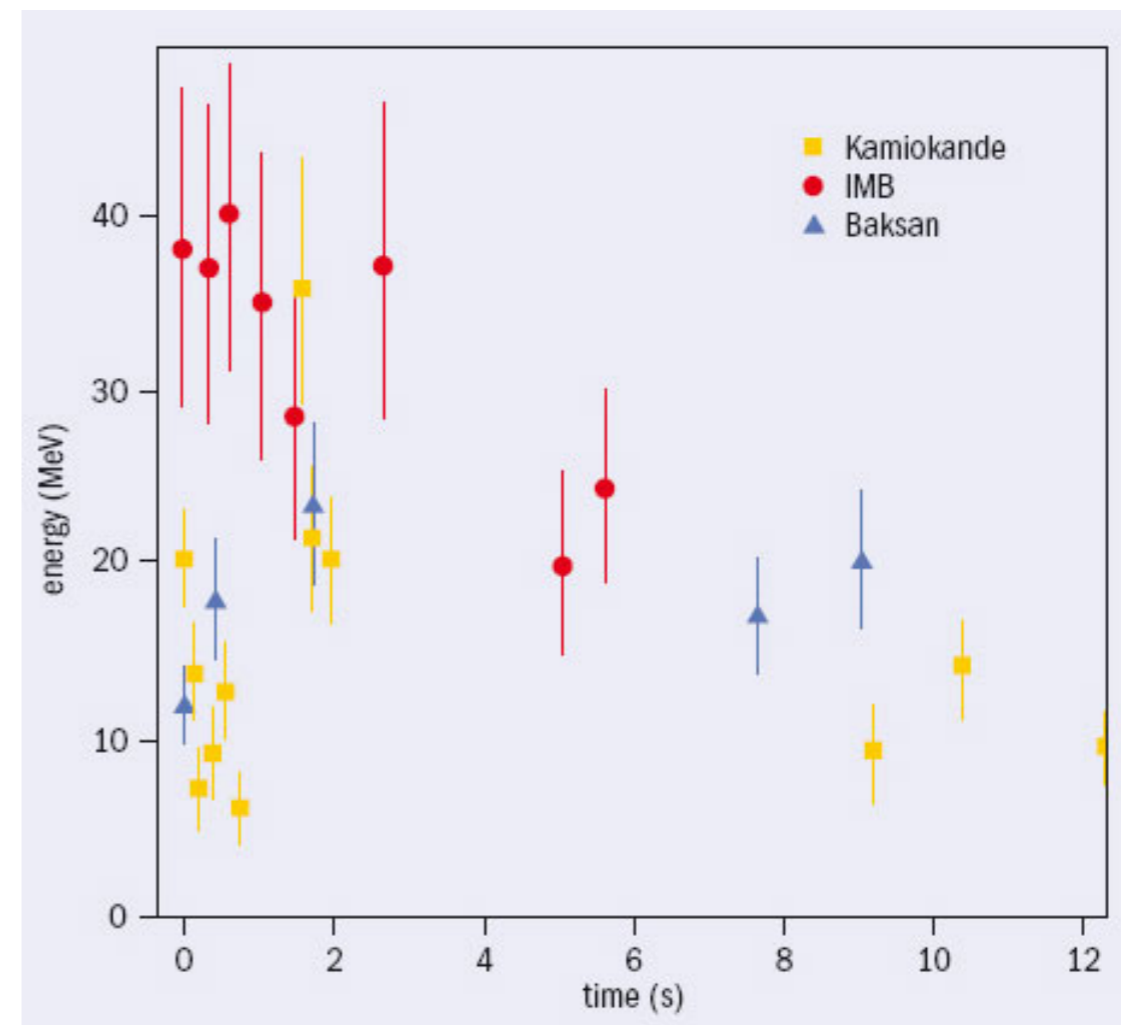
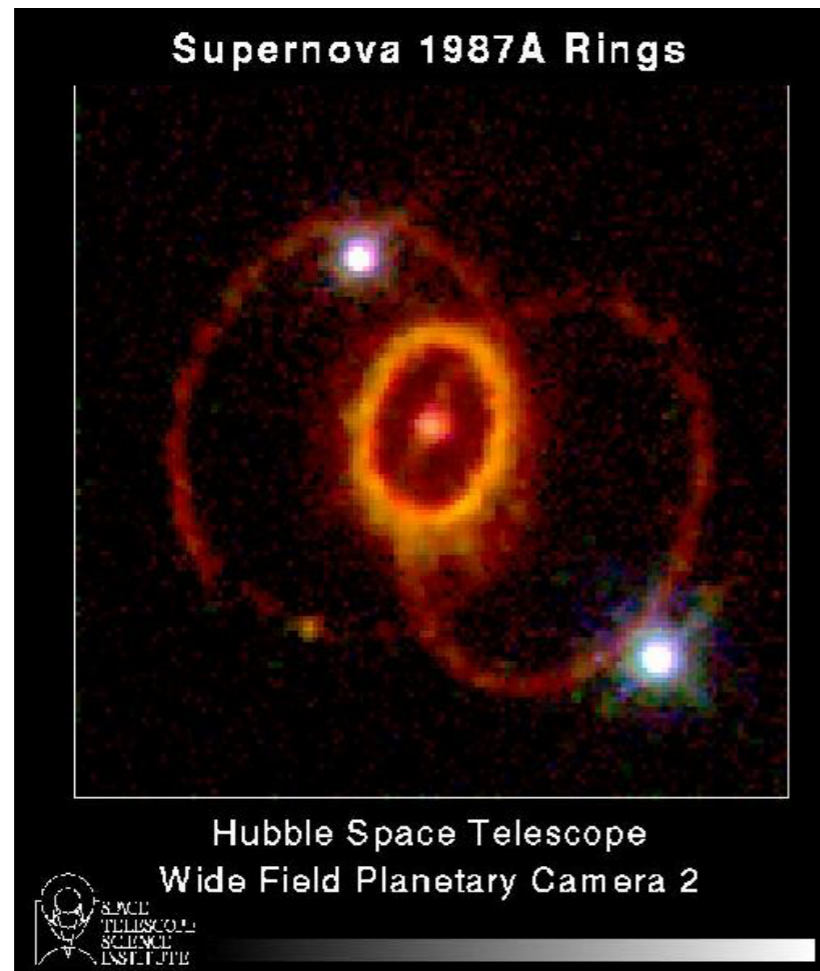
FIG. 1. Curves of (I) hourly readings of the percent increase of the cosmic-ray intensity above its pre-flare average; (H) the relative increase in the width of the H_{α} line above its normal value (Ellison⁶).

- Neutrinos from the sun
~ 1970



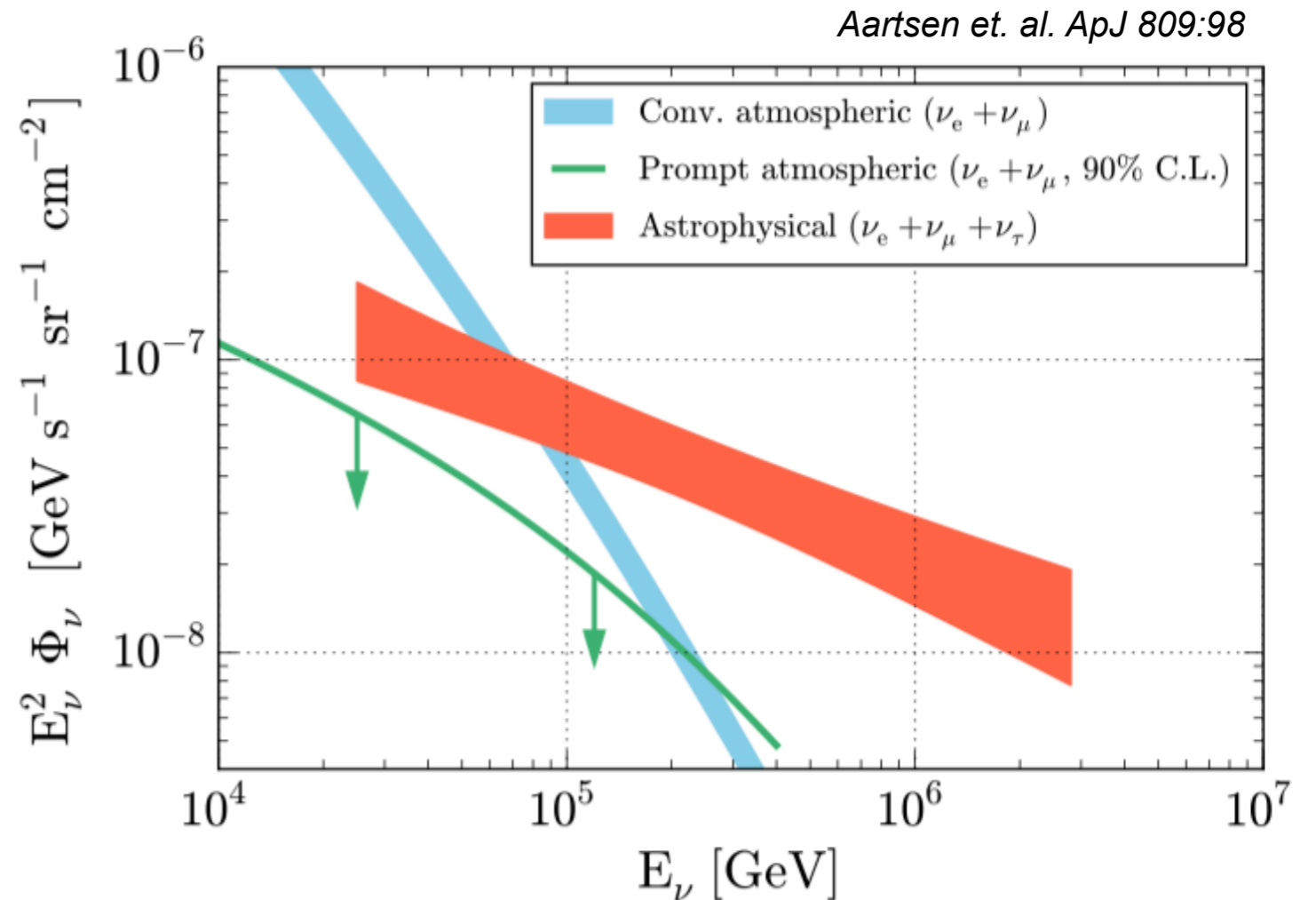
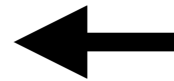
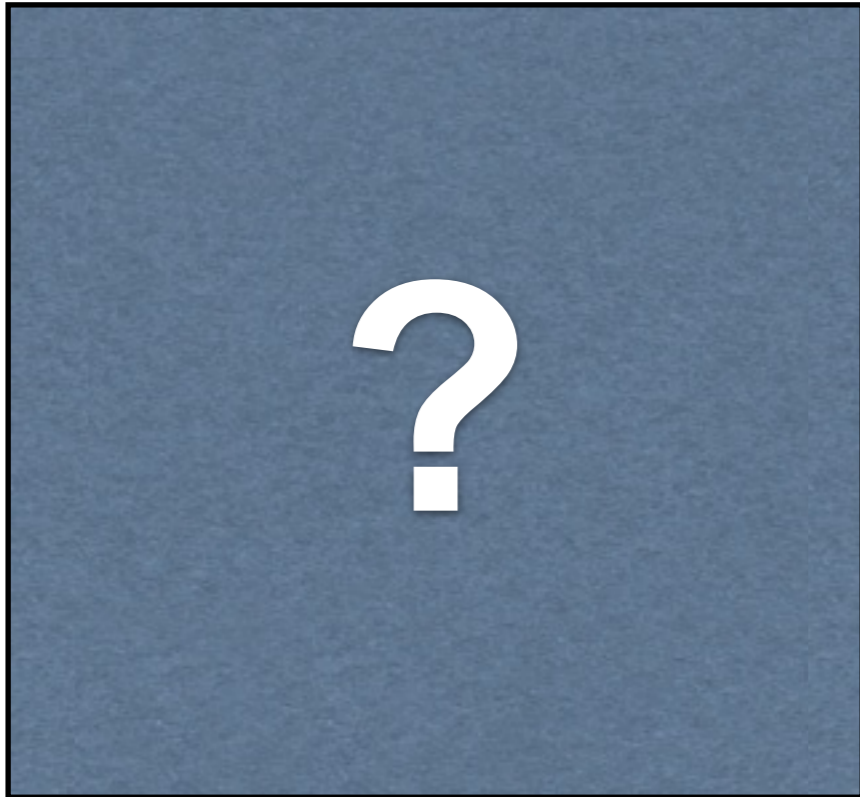
Multi-messenger observation

Searching for neutrino counterparts



Supernova detected clearly
Neutrinos perfectly consistent with expectations

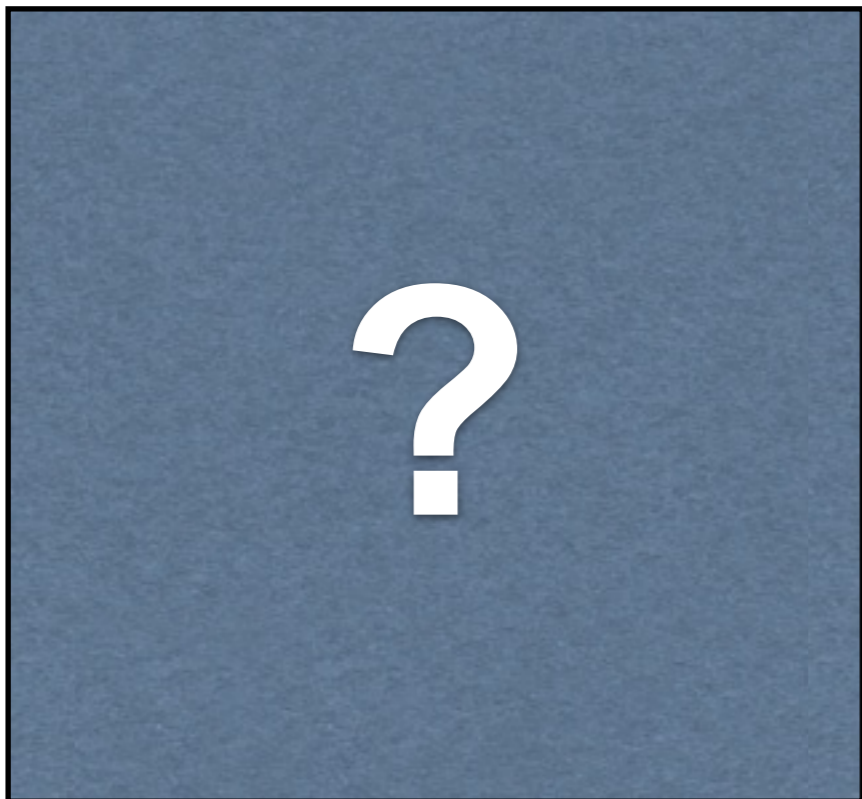
Multi-messenger observation Searching for neutrino counterparts



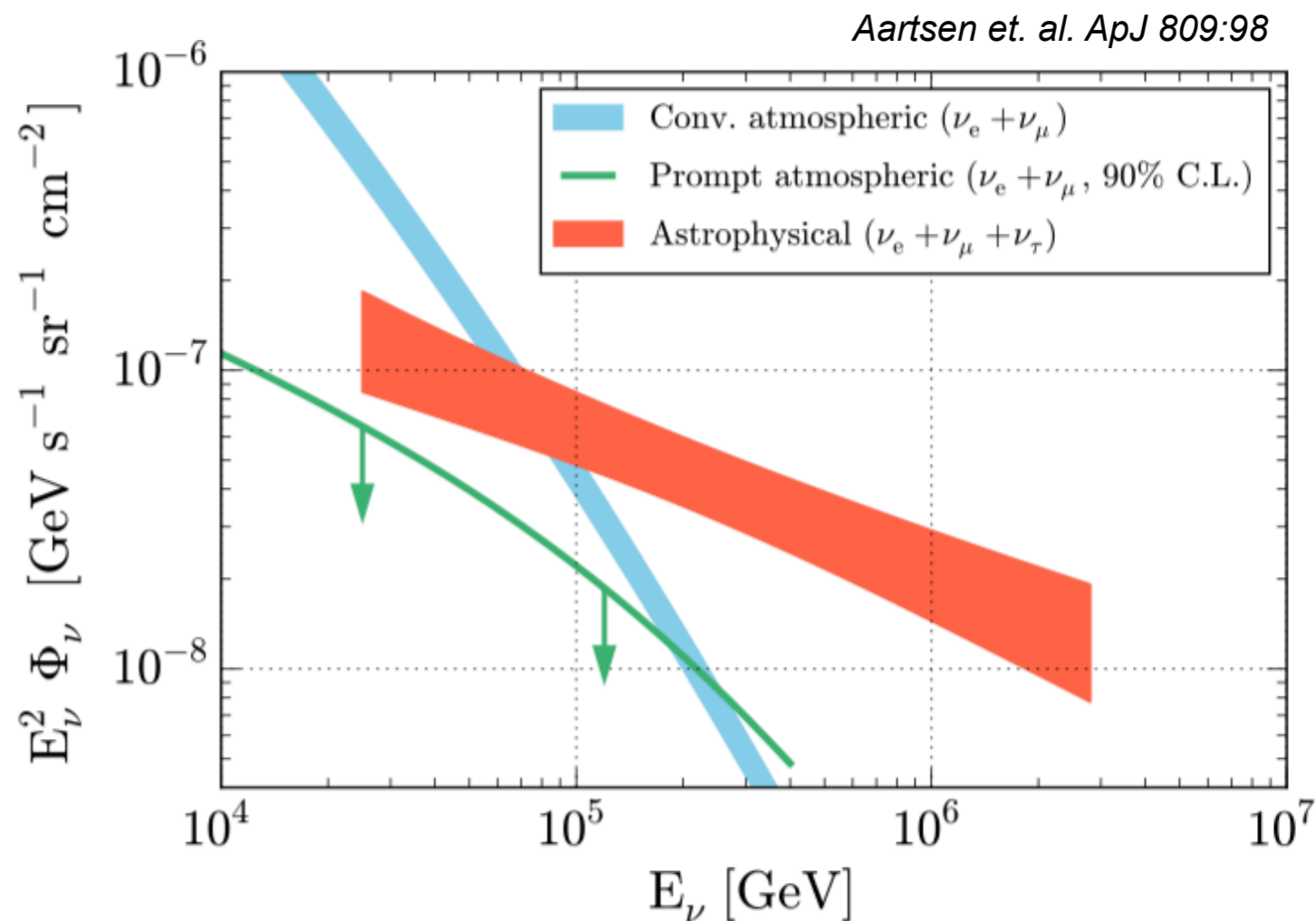
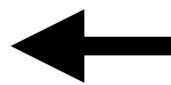
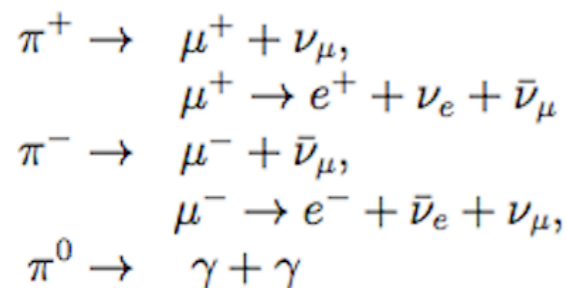
Astrophysical flux detected.

Not clear where they are coming from. Links to the mystery of the sources of CRs

Multi-messenger observation Searching for neutrino counterparts



$$p + p/\gamma \rightarrow p/n + \pi^\pm + \pi^0 + K^\pm + \dots$$



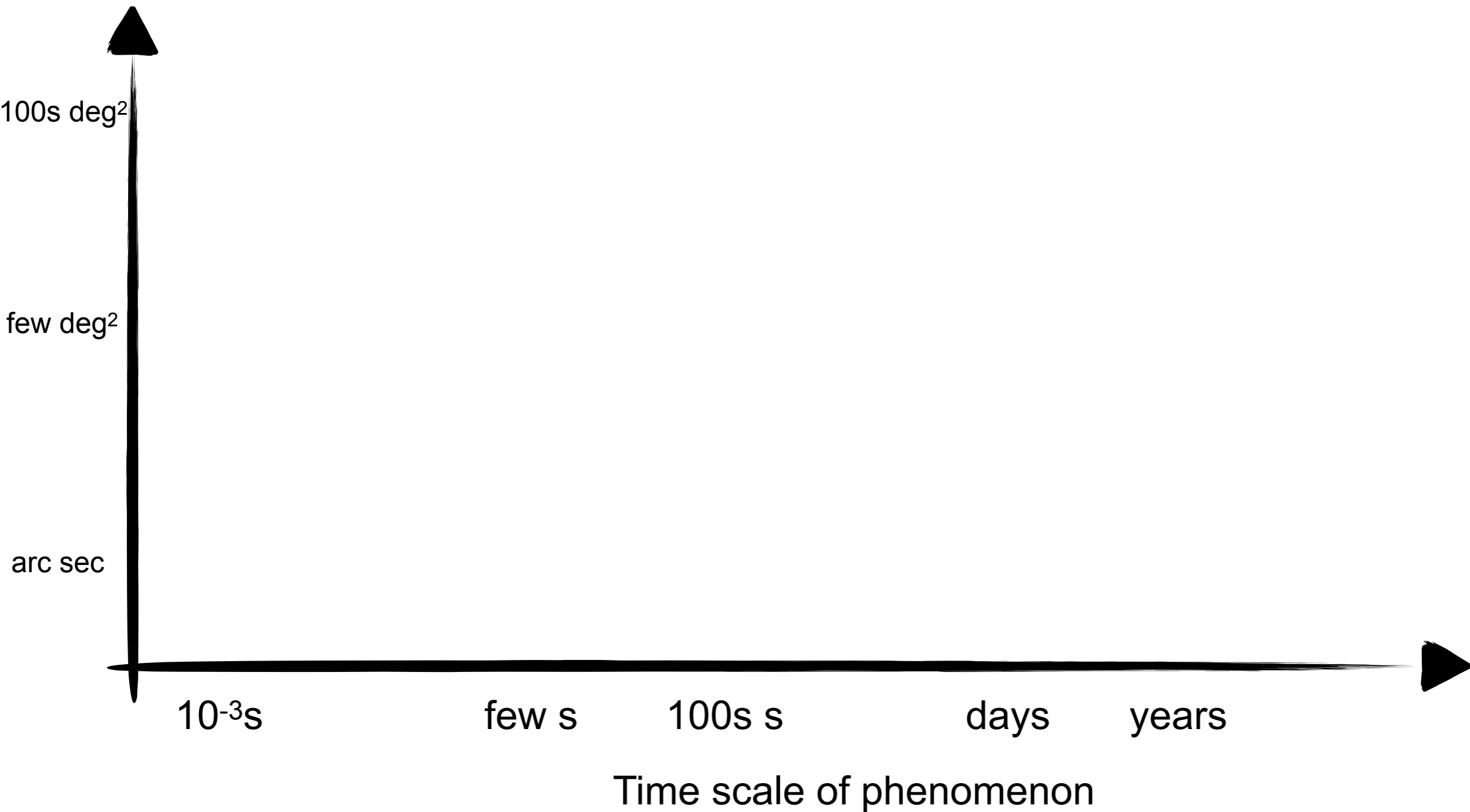
Gamma rays are natural counterparts to high energy neutrinos in hadronic cosmic ray acceleration scenarios

Key parameters of IACTs

- Energy threshold ~ 50 GeV
- Field of view \sim few deg in diameter
- Response time ~ 30 s to a few min
- localisations ~ 0.01 deg

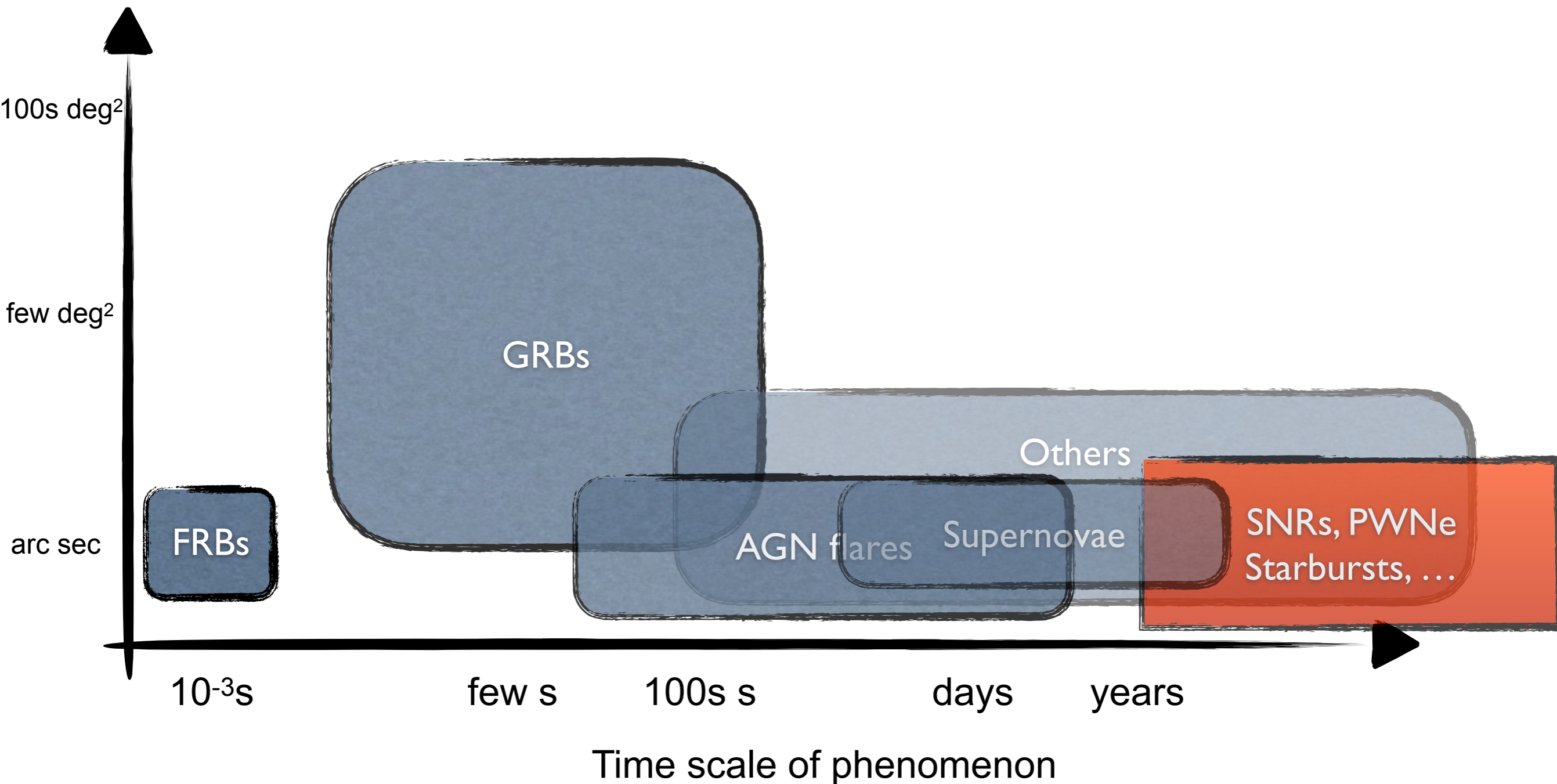
Phase space for MM targets

Localisation
precision



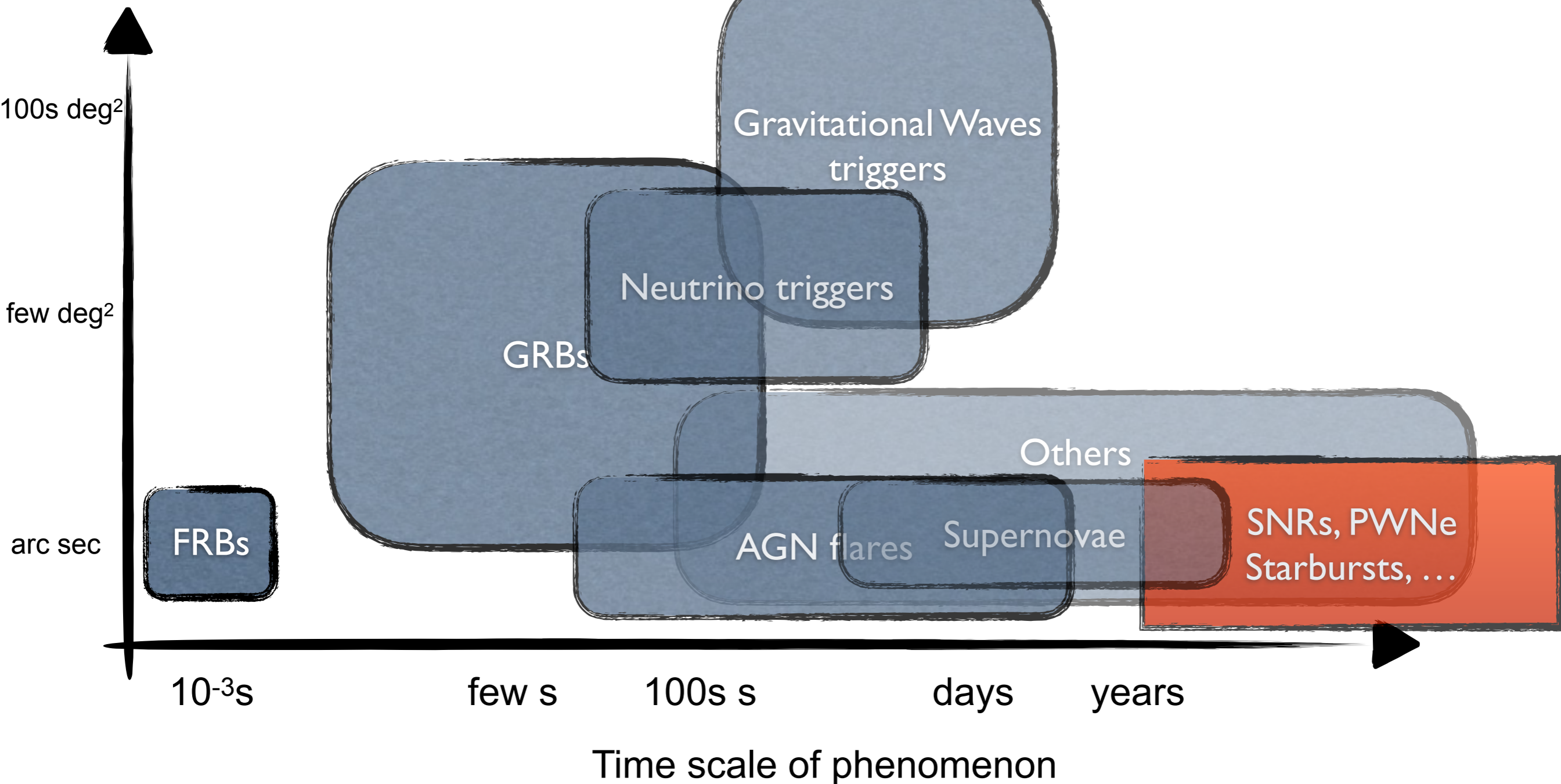
Phase space for MM targets

Localisation
precision

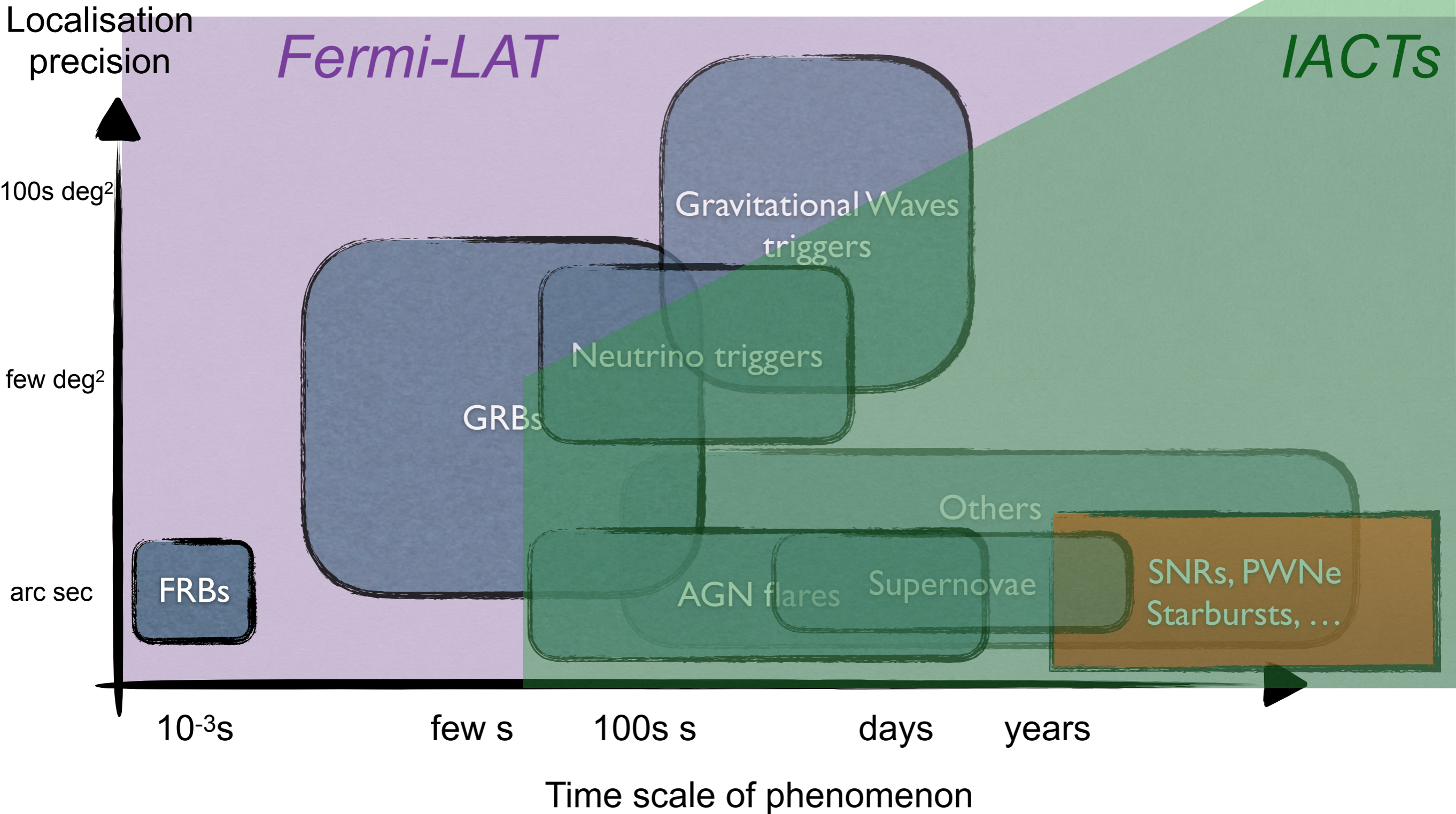


Phase space for MM targets

Localisation
precision

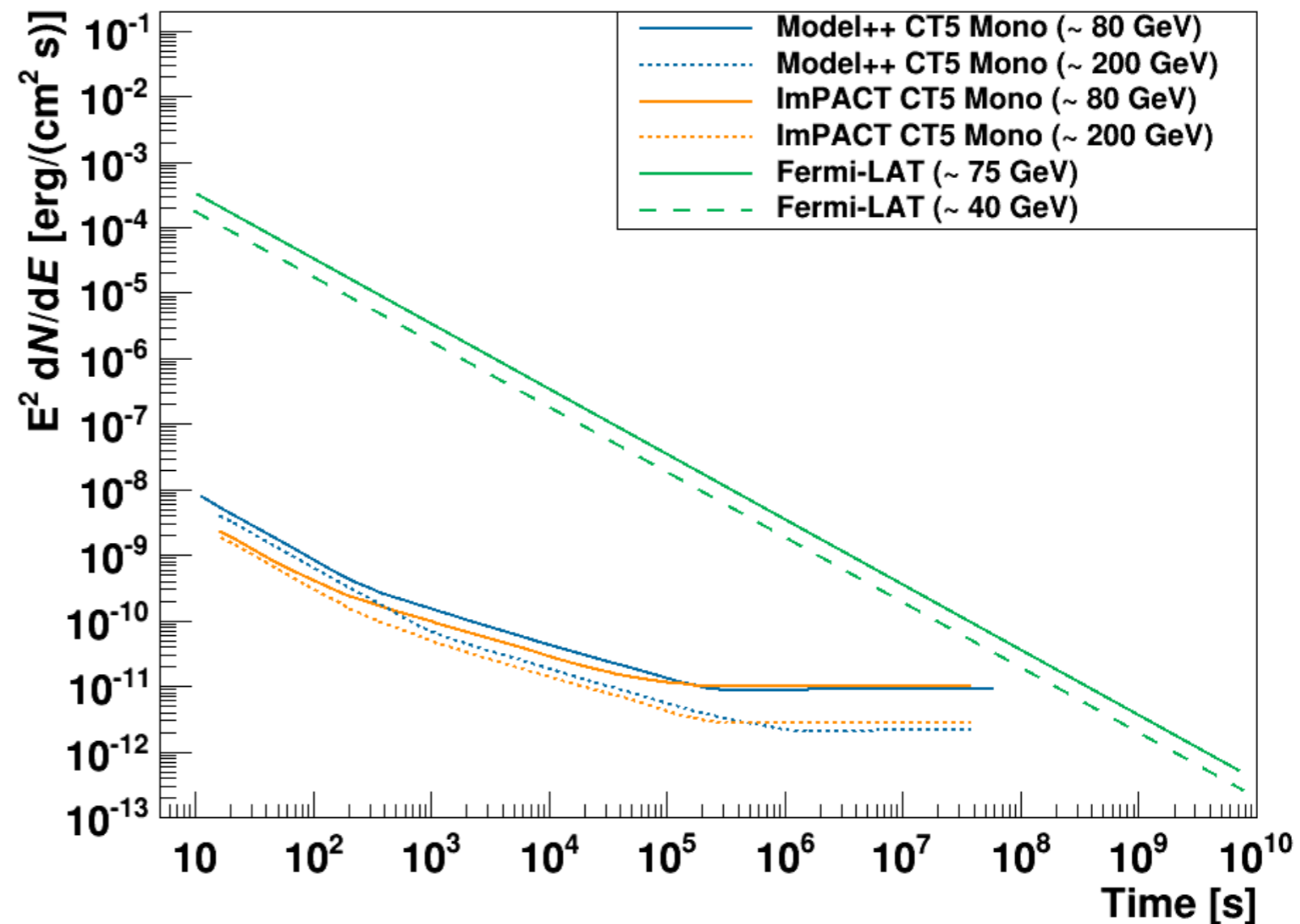


Phase space for MM targets



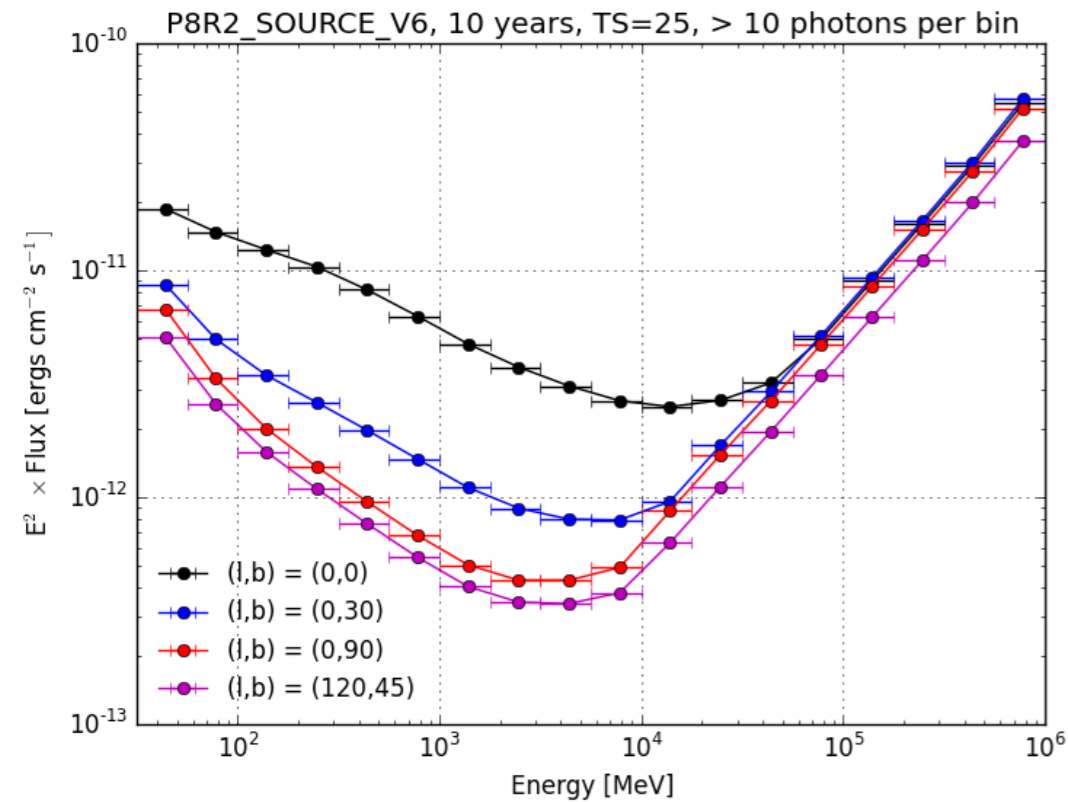
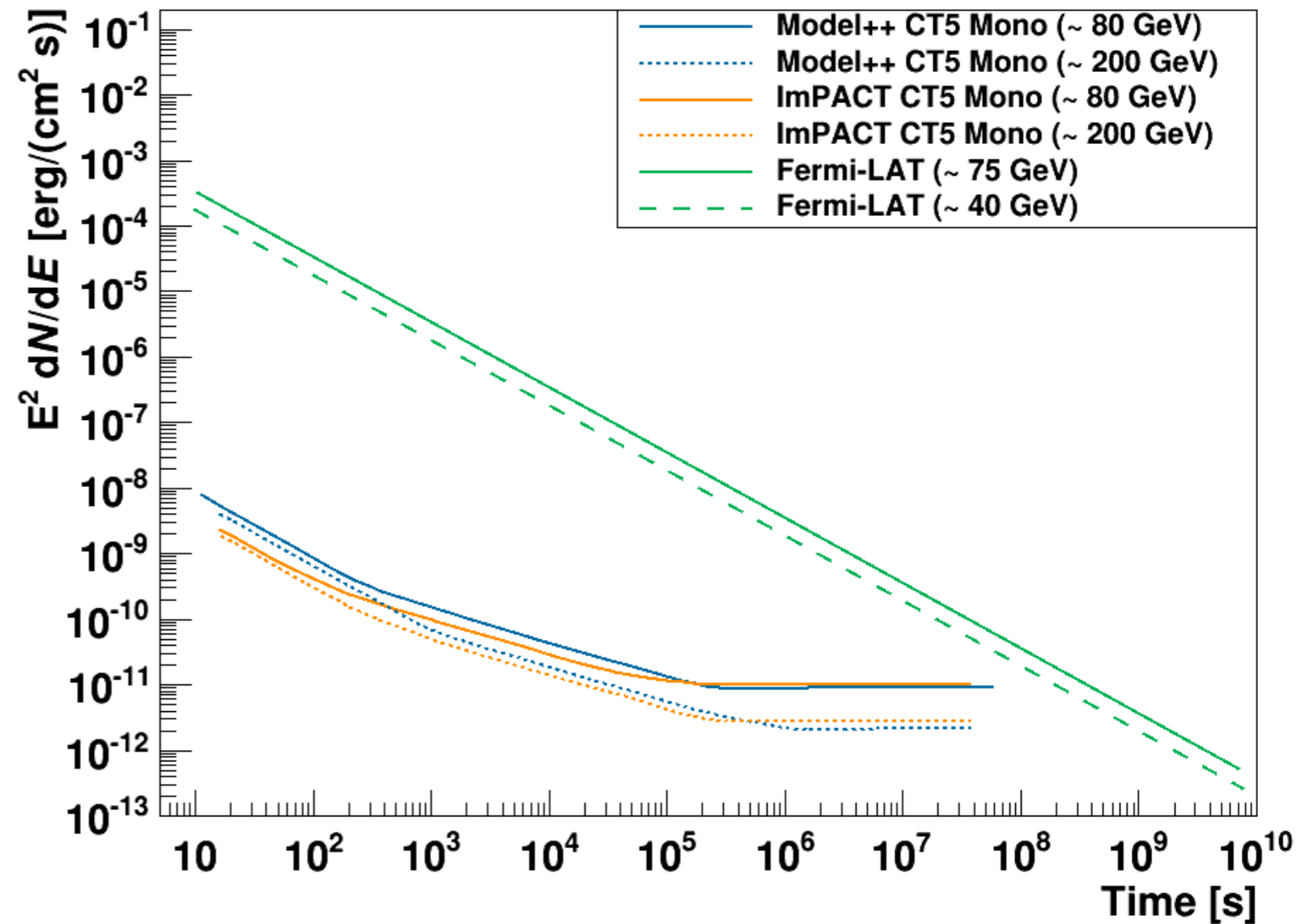
Key parameters of IACTs

- Energy threshold ~ 50 GeV
- Field of view \sim few deg in diameter
- Response time ~ 20 s to a few min
- localisations ~ 0.01 deg
- **Sensitivity**



Key parameters of IACTs

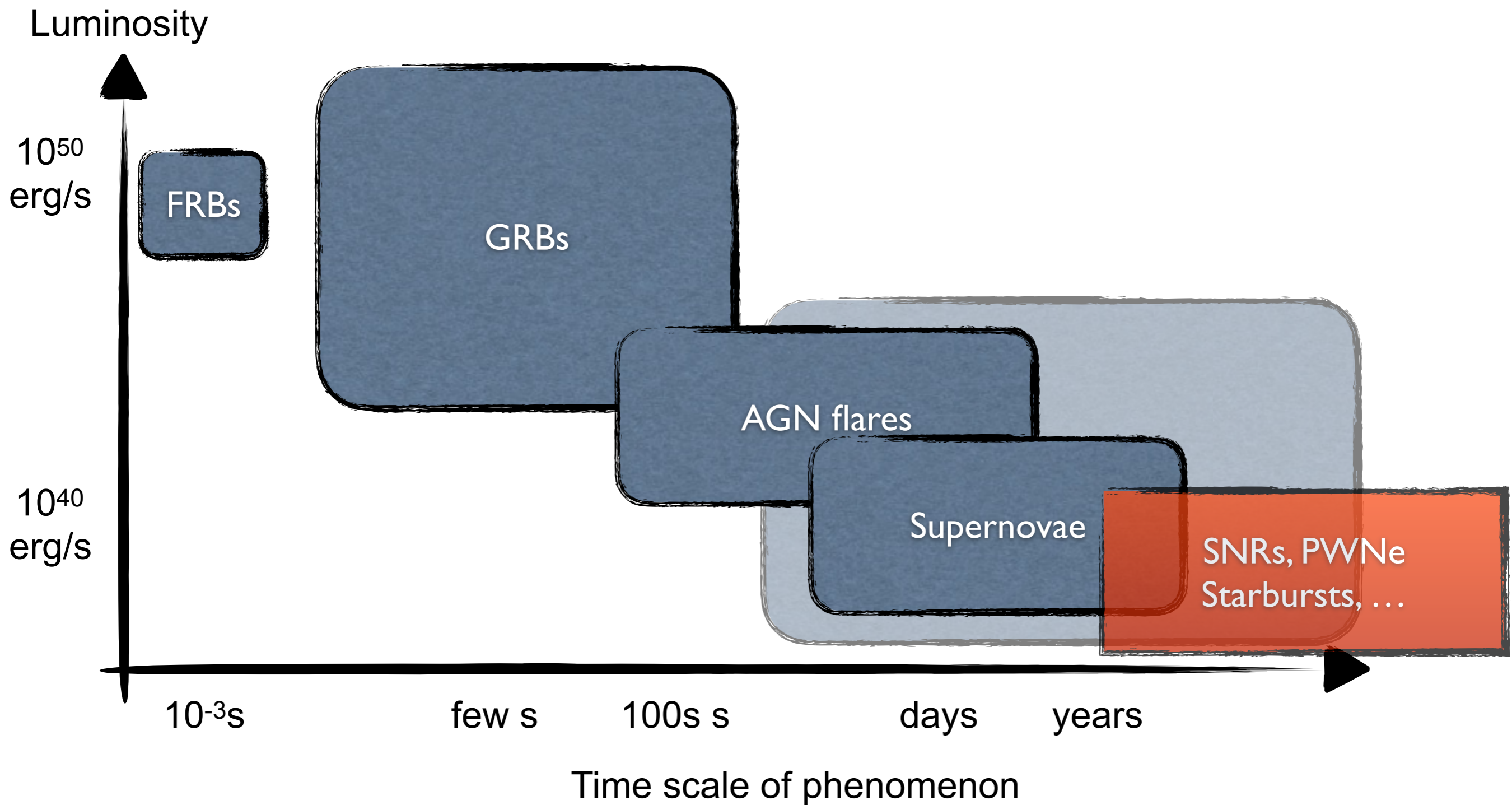
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Phase space for MM targets

Neutrino triggers

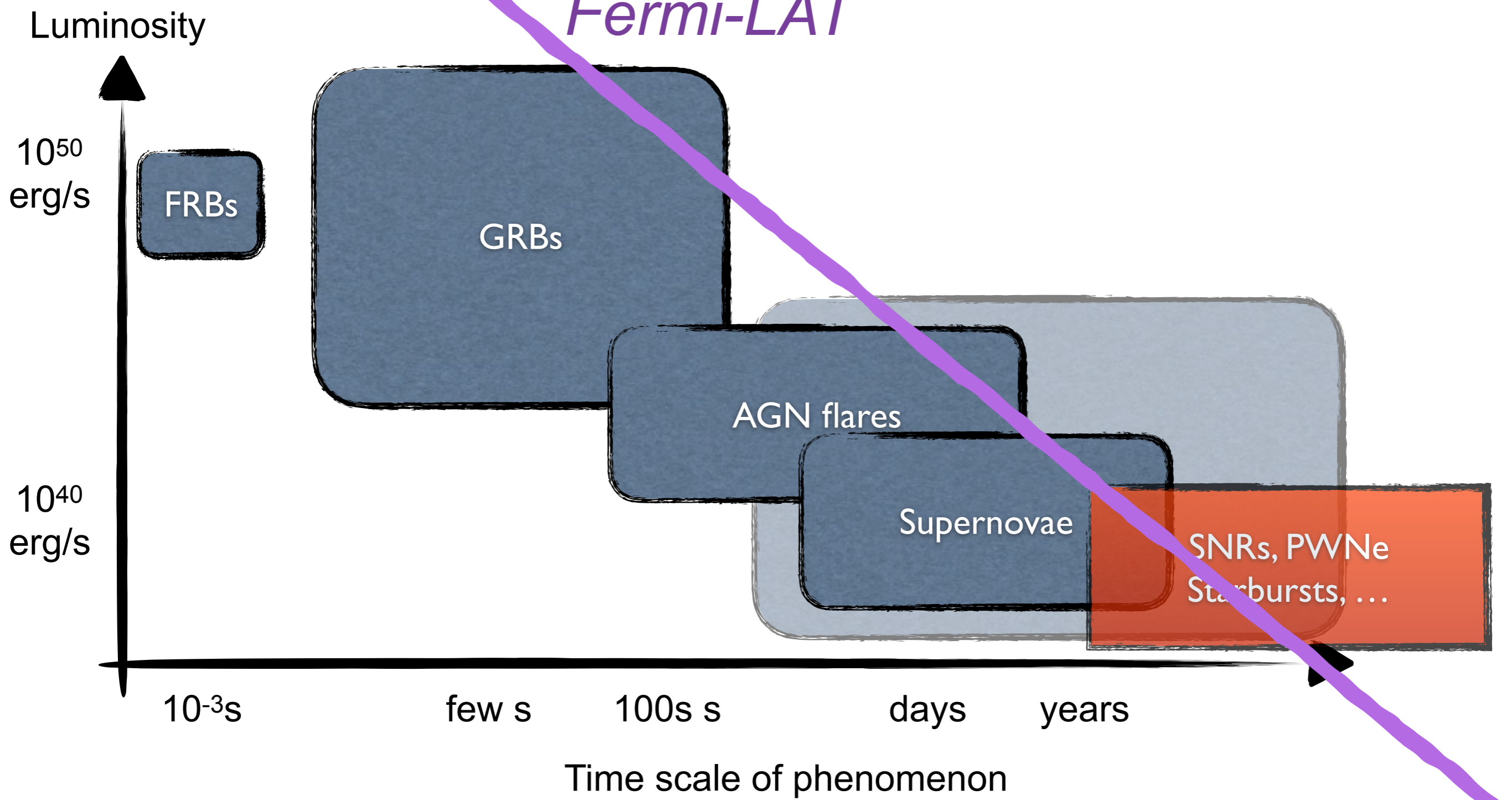
Gravitational Waves triggers



Phase space for MM targets

Neutrino triggers

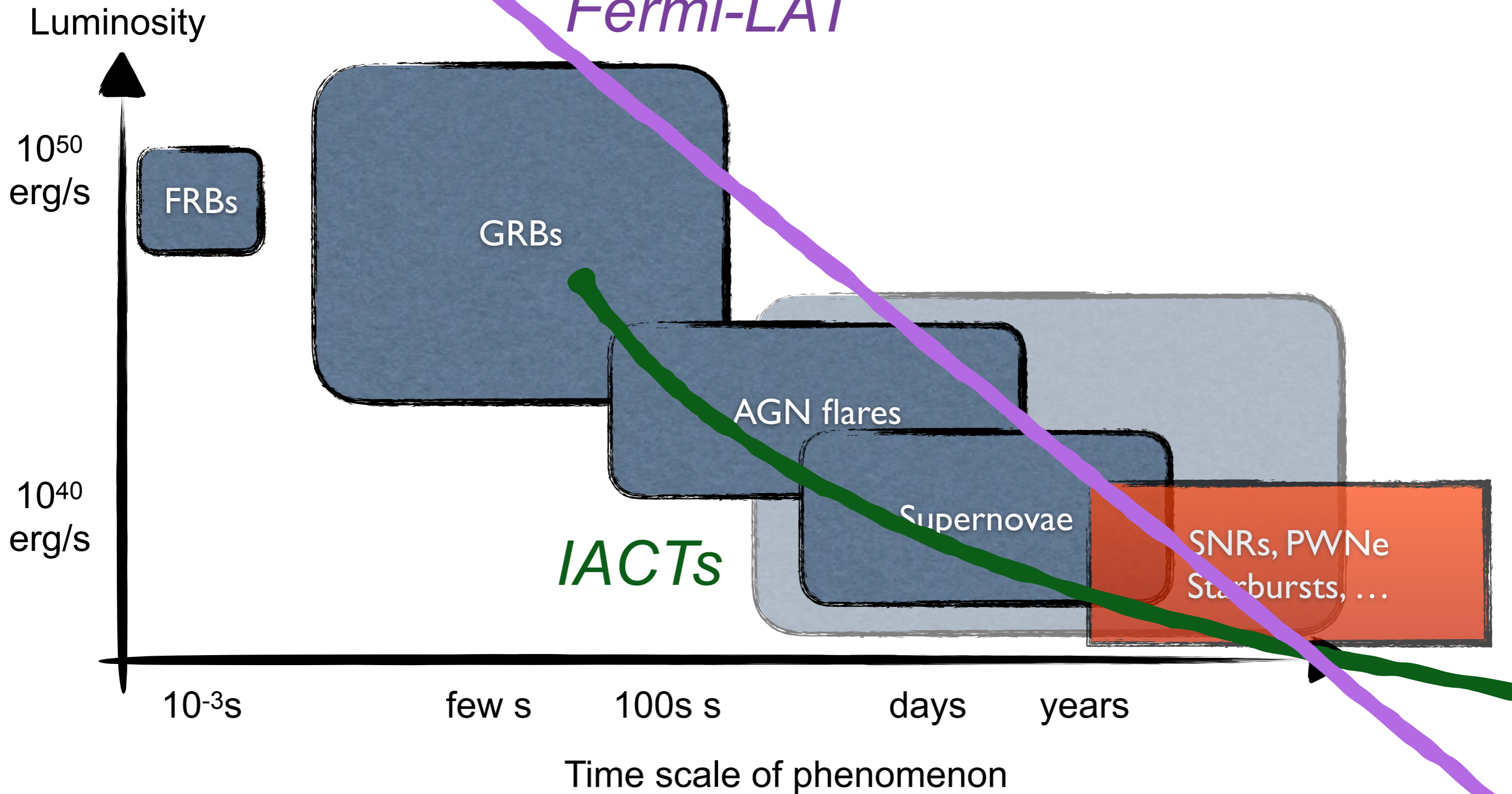
Gravitational Waves triggers



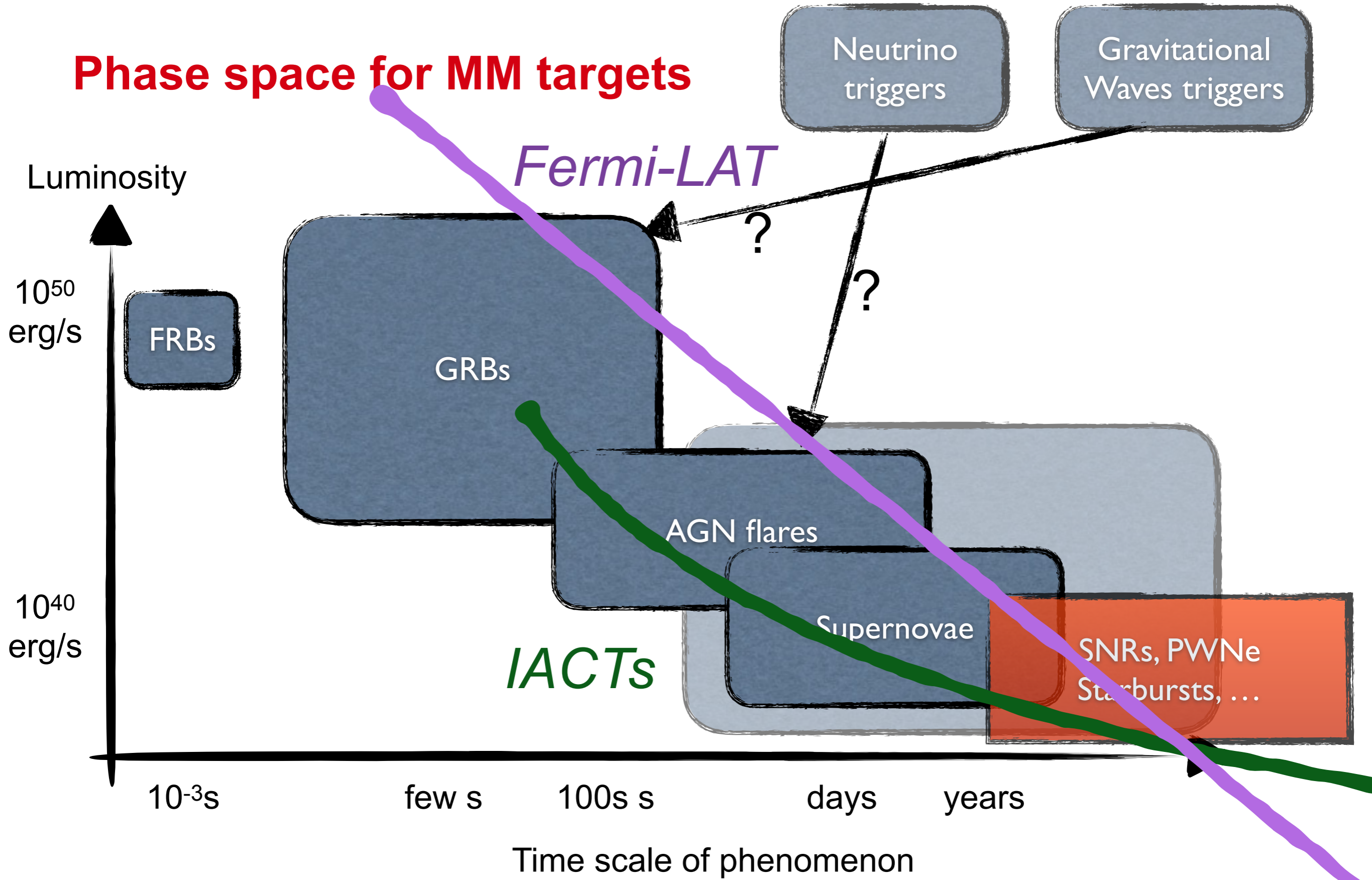
Phase space for MM targets

Neutrino triggers

Gravitational Waves triggers

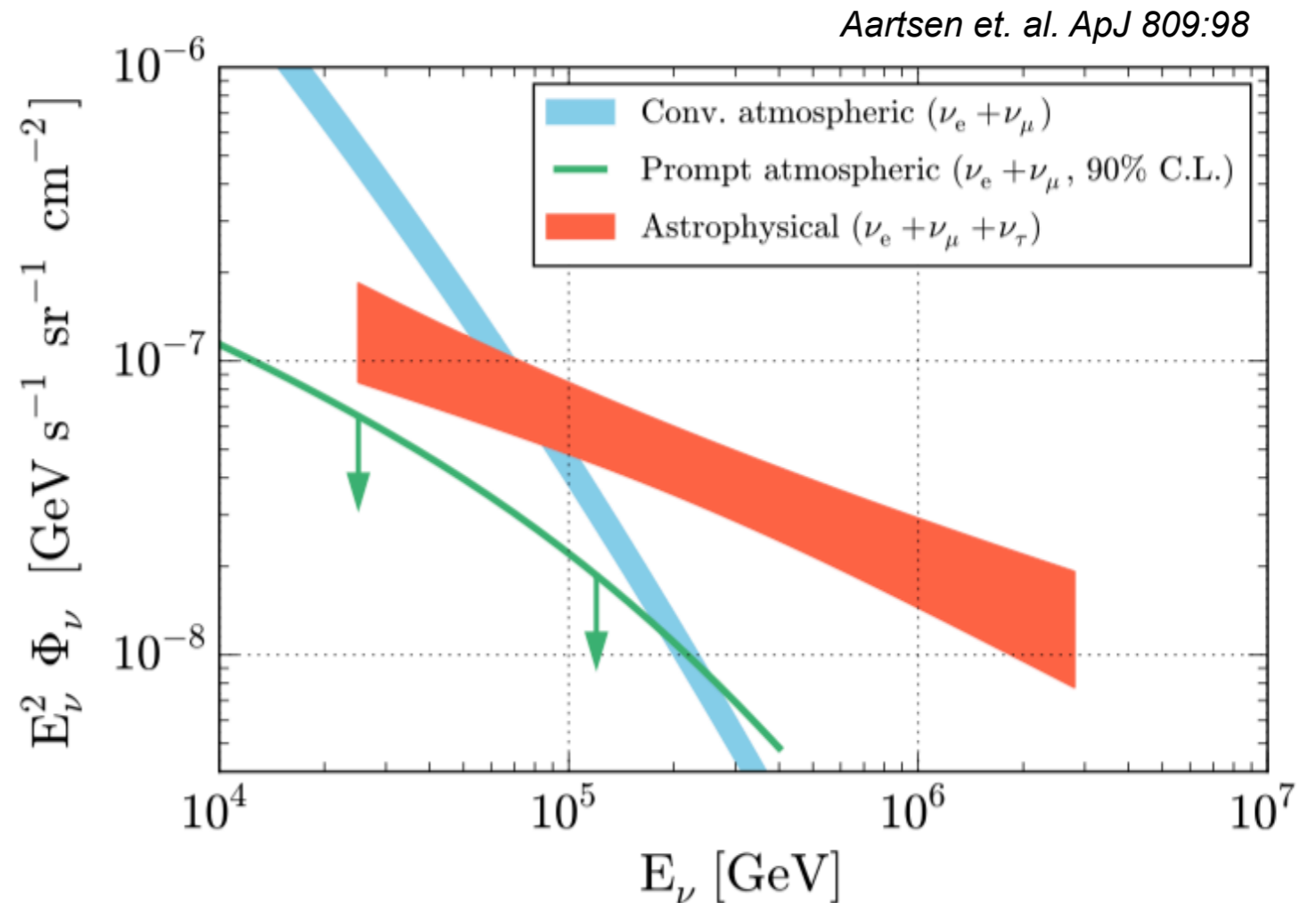
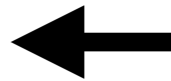
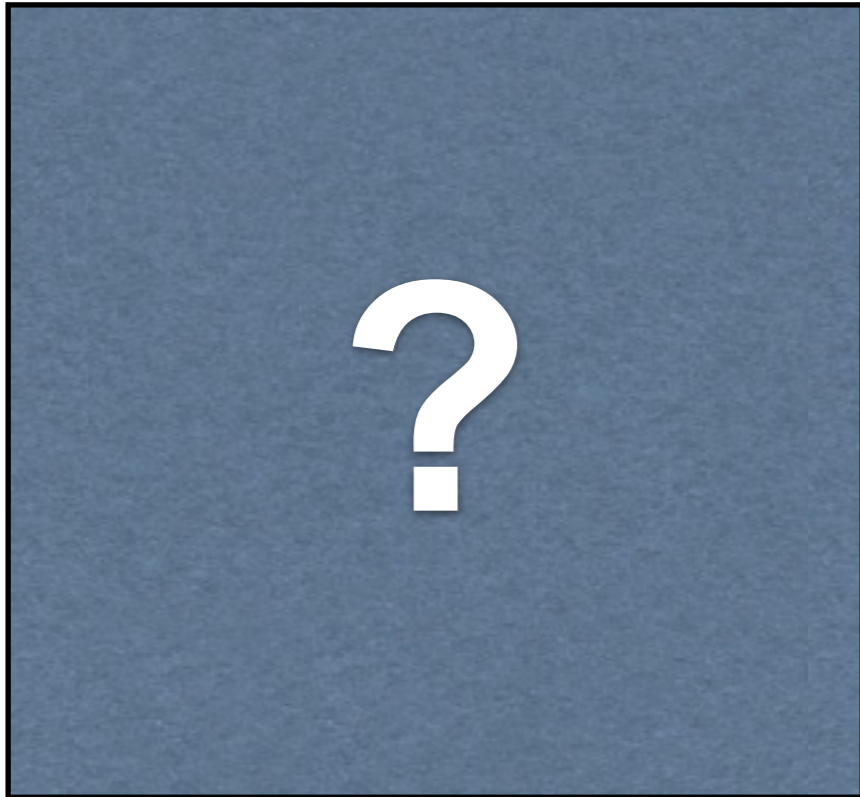


Phase space for MM targets



Multi-messenger observation

Searching for neutrino counterparts



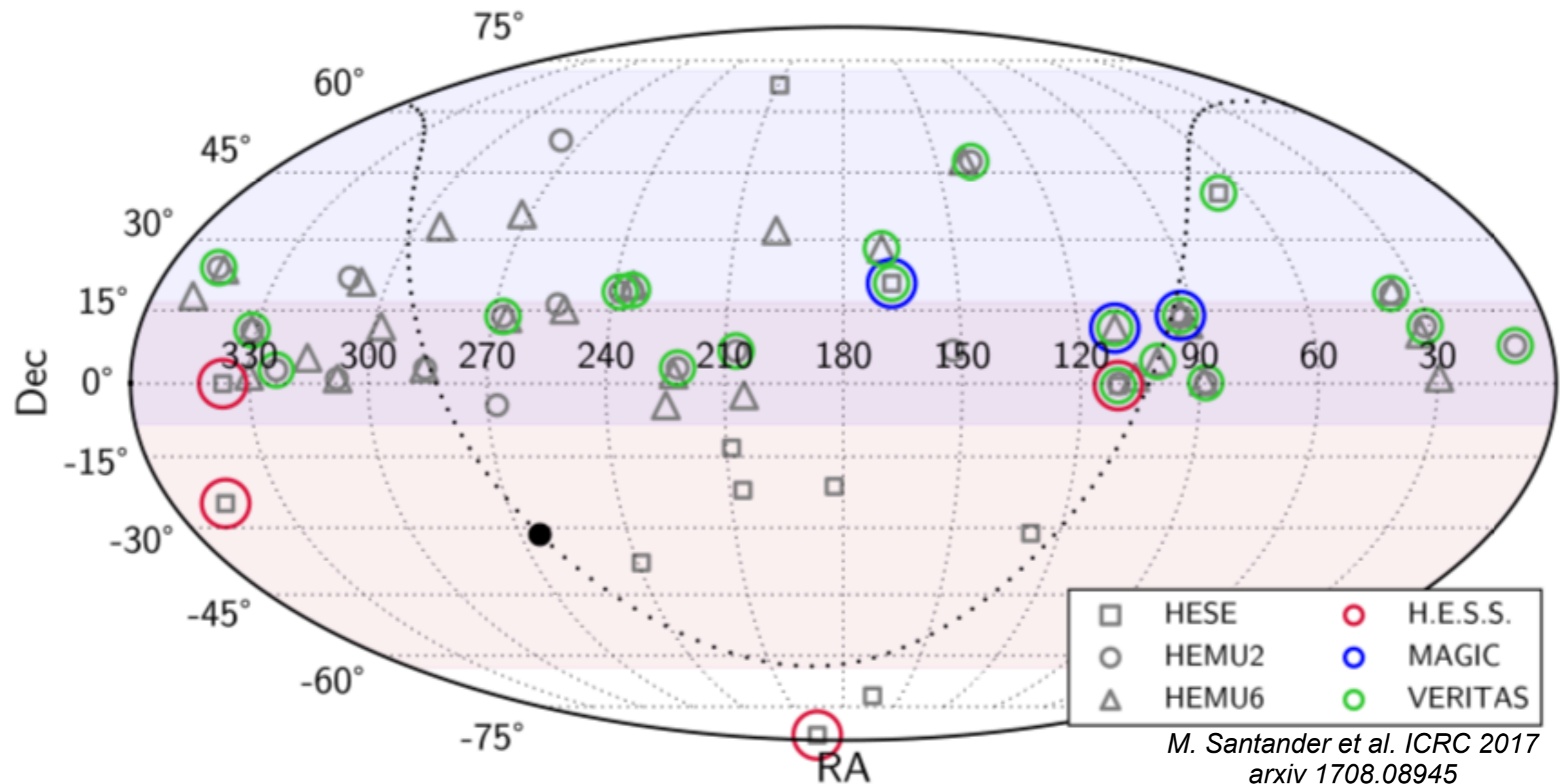
Astrophysical flux detected. Perfectly consistent to see them.

Not clear where they are coming from. Links to the mystery of the sources of CRs

Multi-messenger observation with IACTs

Searching for stable neutrino counterparts

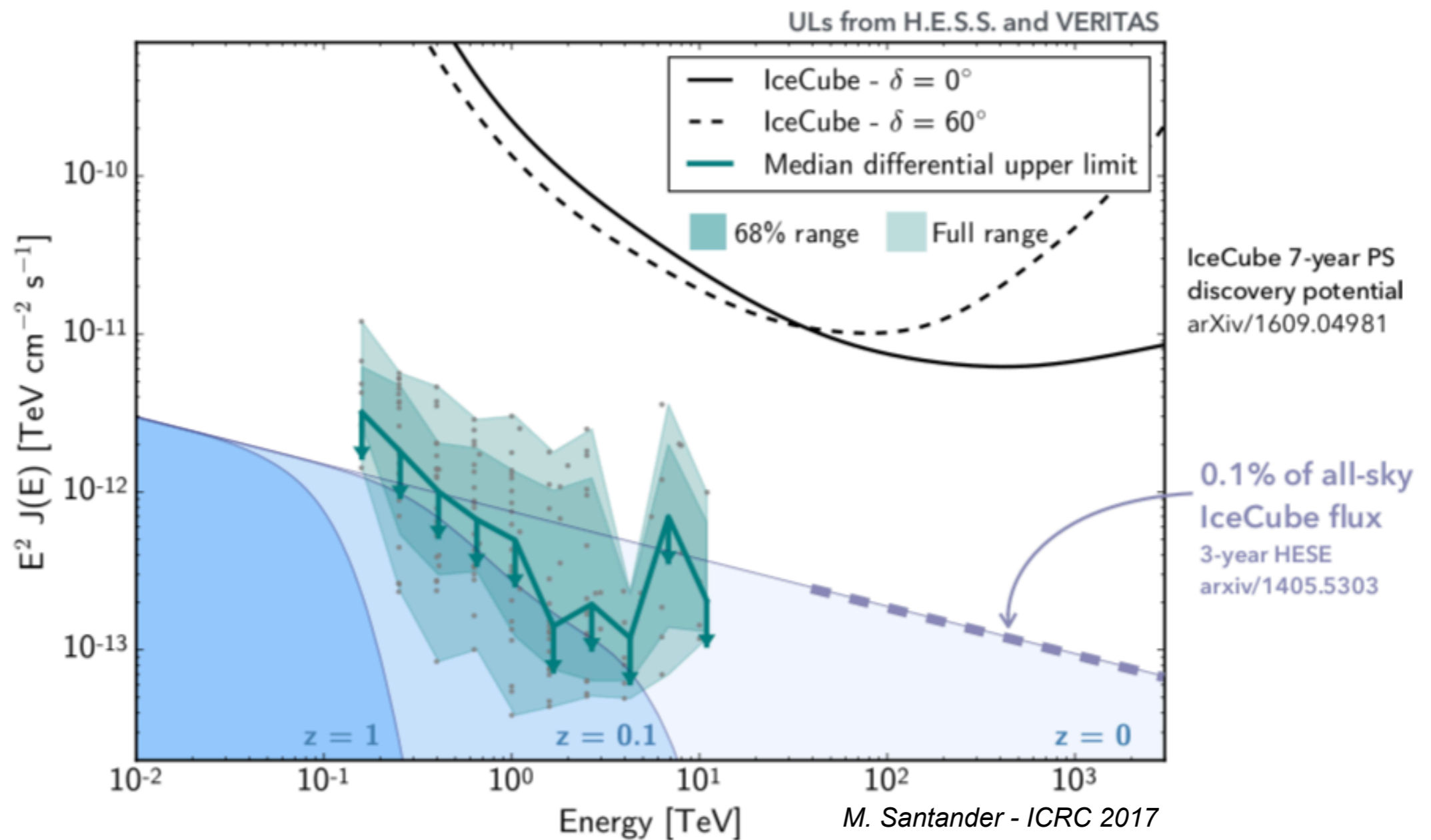
- Collective effort to search for neutrino counterparts



Multi-messenger observation with IACTs

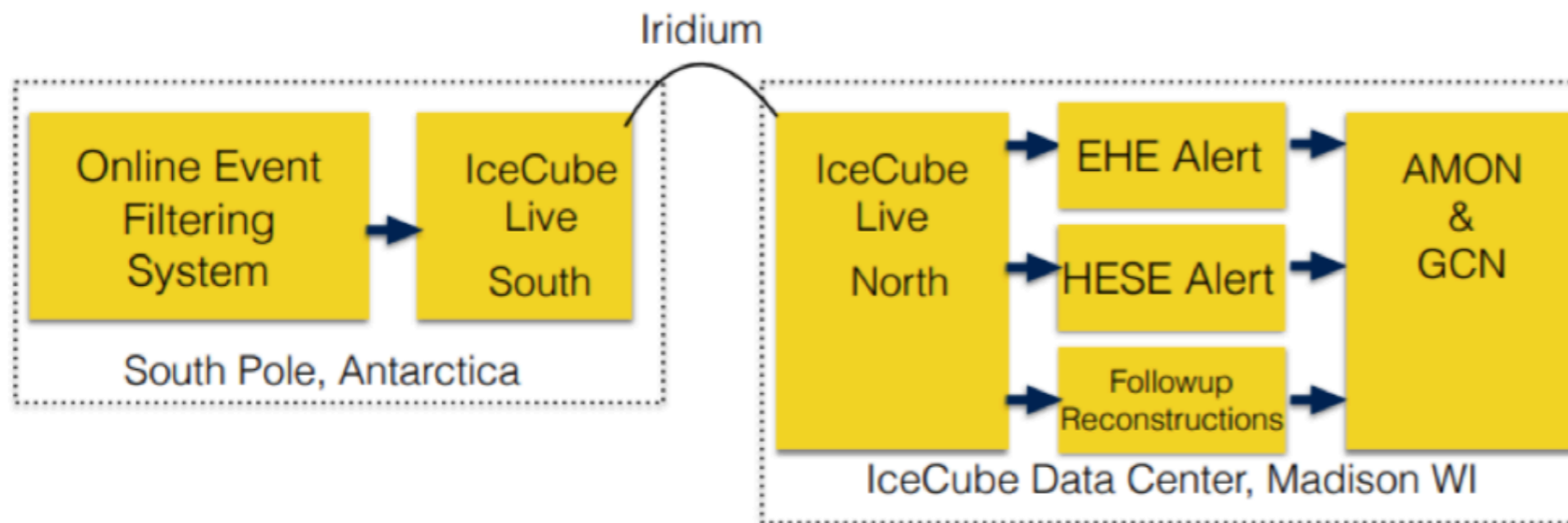
Searching for stable neutrino counterparts

- Collective effort to search for neutrino counterparts

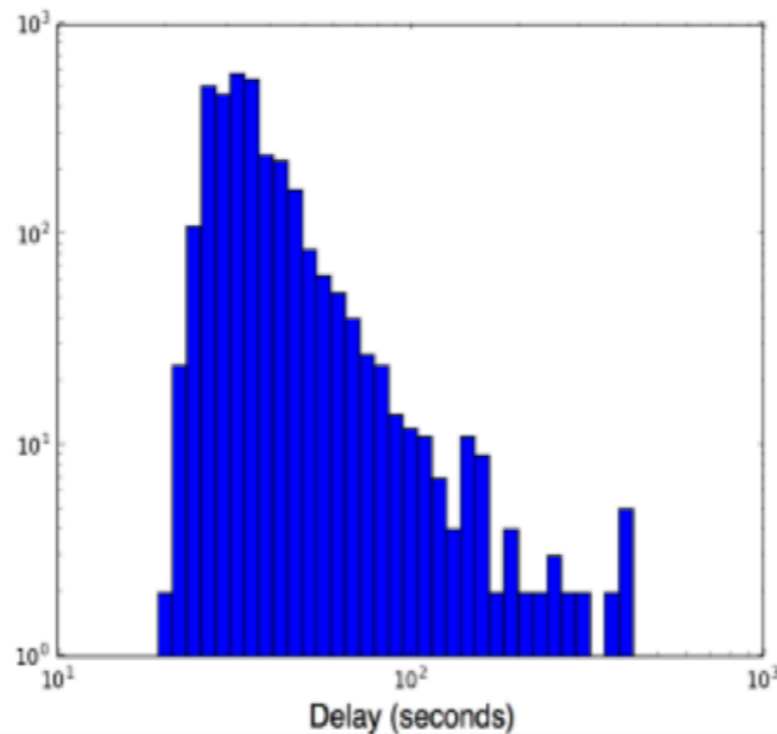


Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts



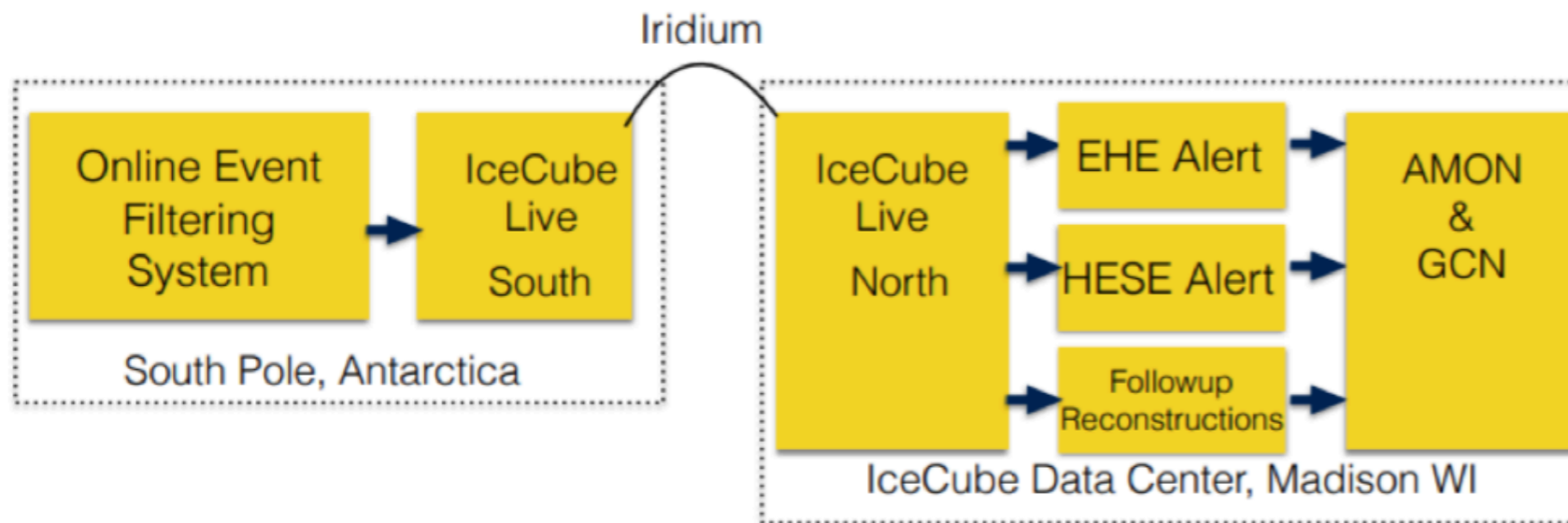
Median alert latency: 33 seconds



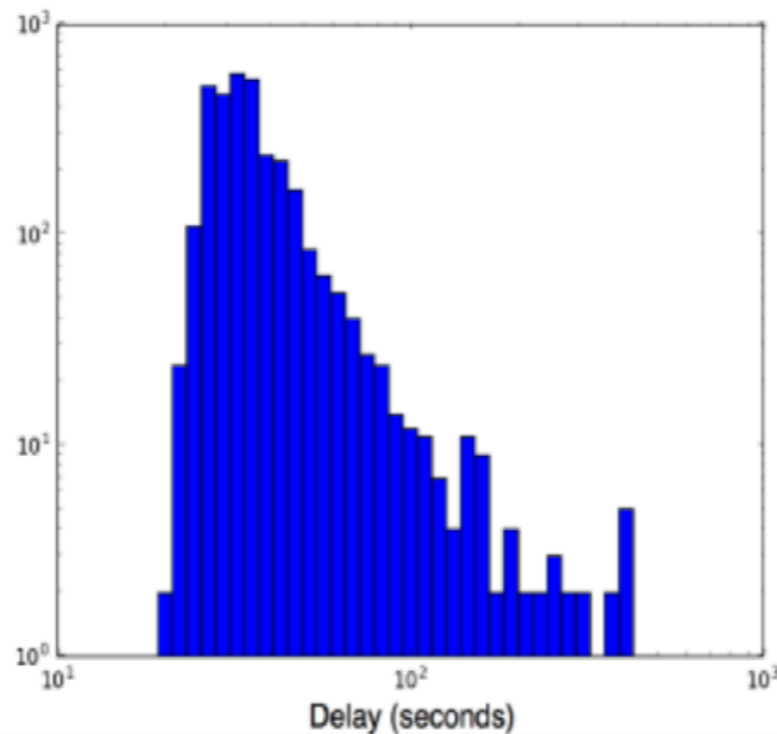
from Aya Ishihara, Chiba Multi-messenger workshop 2018

Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts



Median alert latency: 33 seconds



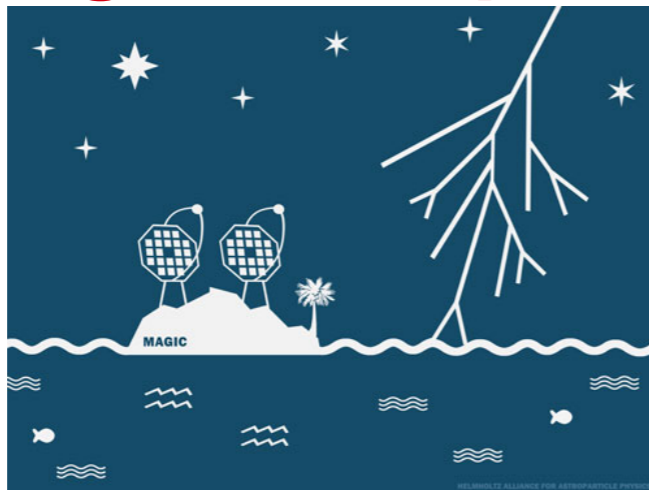
In the order of 0.5 alerts / month

- IACT duty cycle
- No access to the entire sky every night
- Current IACTs are nicely spread out
- Few chances to observe with low latency

from Aya Ishihara, Chiba Multi-messenger workshop 2018

Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts



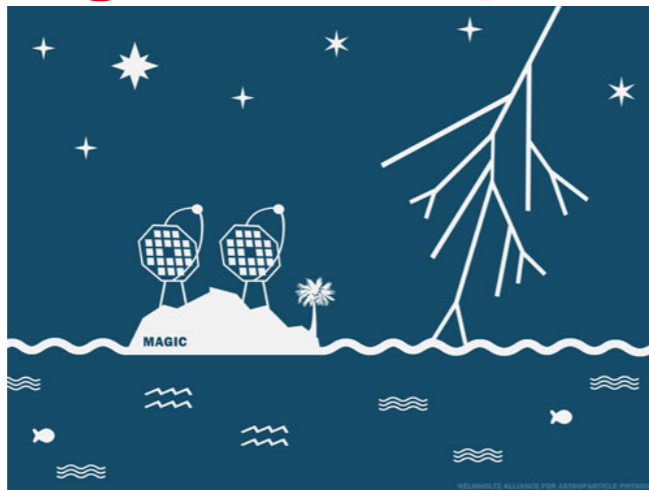
IceCube-	160427A	160731A	170321A	170922A
<i>From IceCube:</i>				
Right Ascension [deg]	240.57	214.54	98.33	77.43
Declination [deg]	9.34	-0.33	-14.48	5.72
Median angular resolution [deg]	0.60	0.33	0.33	0.25
Deposited energy [TeV]	~140	<100	>120	>23
<i>MAGIC data taking:</i>				
Zenith angle range [deg]	18 - 26	45-65	45-60	22-52
Effective observation time [h]	1.85	1.3	1.0	12.9

IceCube Alert ID	UTC Date	Obs delay [hr]	Exposure [hr]	VERITAS publication
IceCube-160427A	27 April 2016	0.05	3.15	(98)
IceCube-161103A	3 November 2016	0.06	1.5	-
IceCube-170321A	21 March 2017	19.3	0.5	-
IceCube-170922A	22 September 2017	12.2	5.5	(59)

Date	Alert identifier	Delay of observations	Duration of observations
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Nov 3, 2016	IceCube-161103A	12h	2h
Sep 22, 2017	IceCube-170922A	4h	3h 14m

Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts



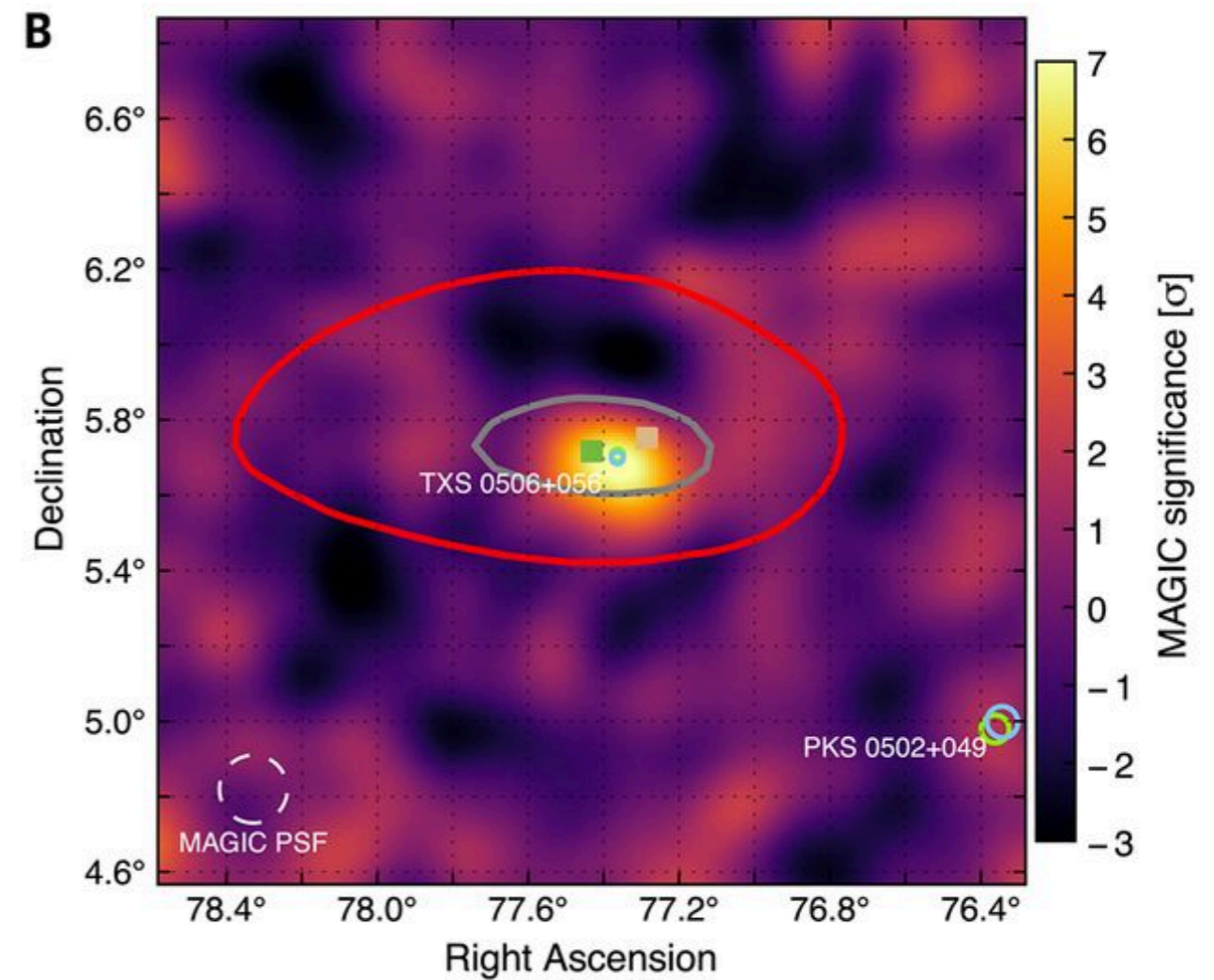
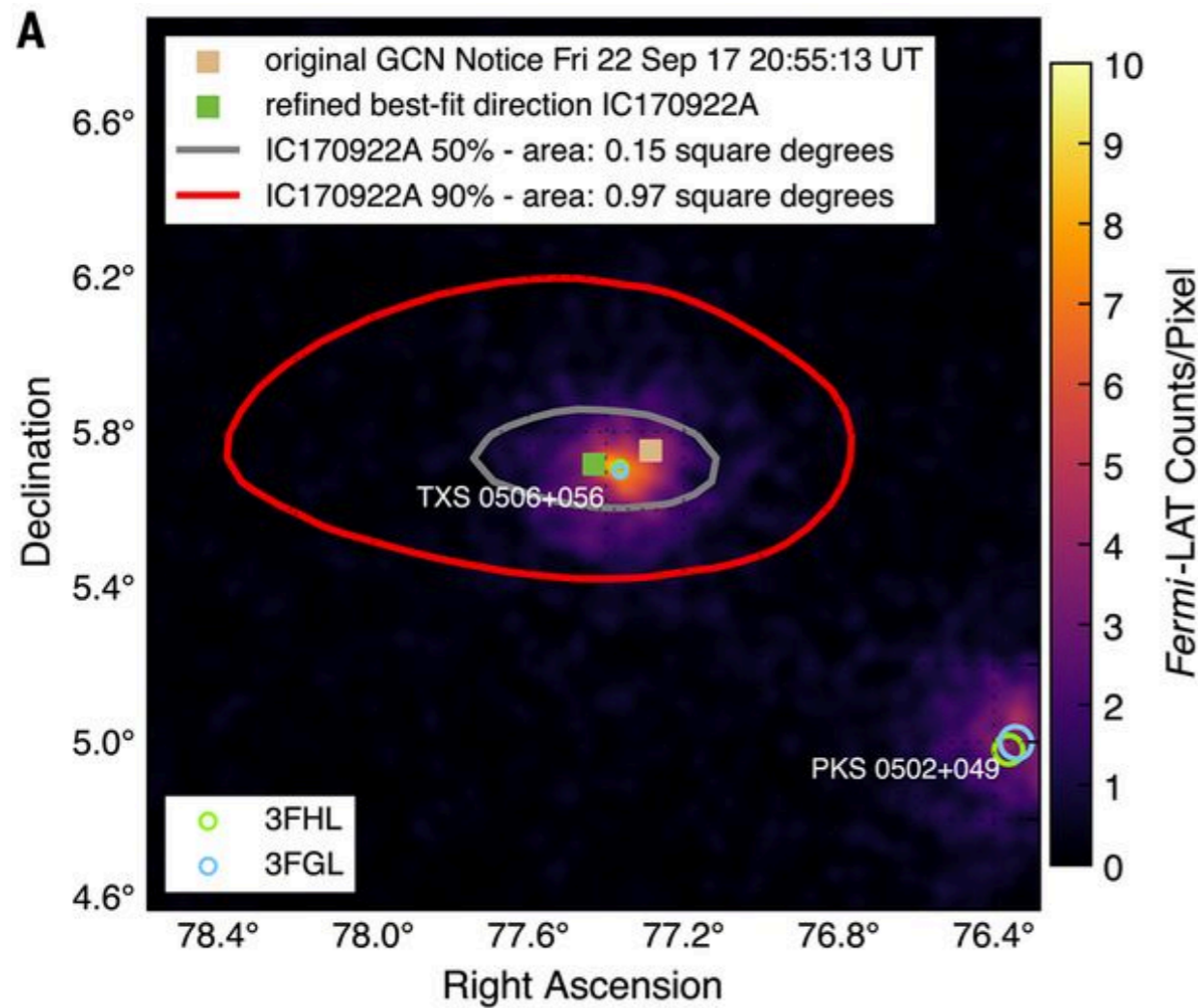
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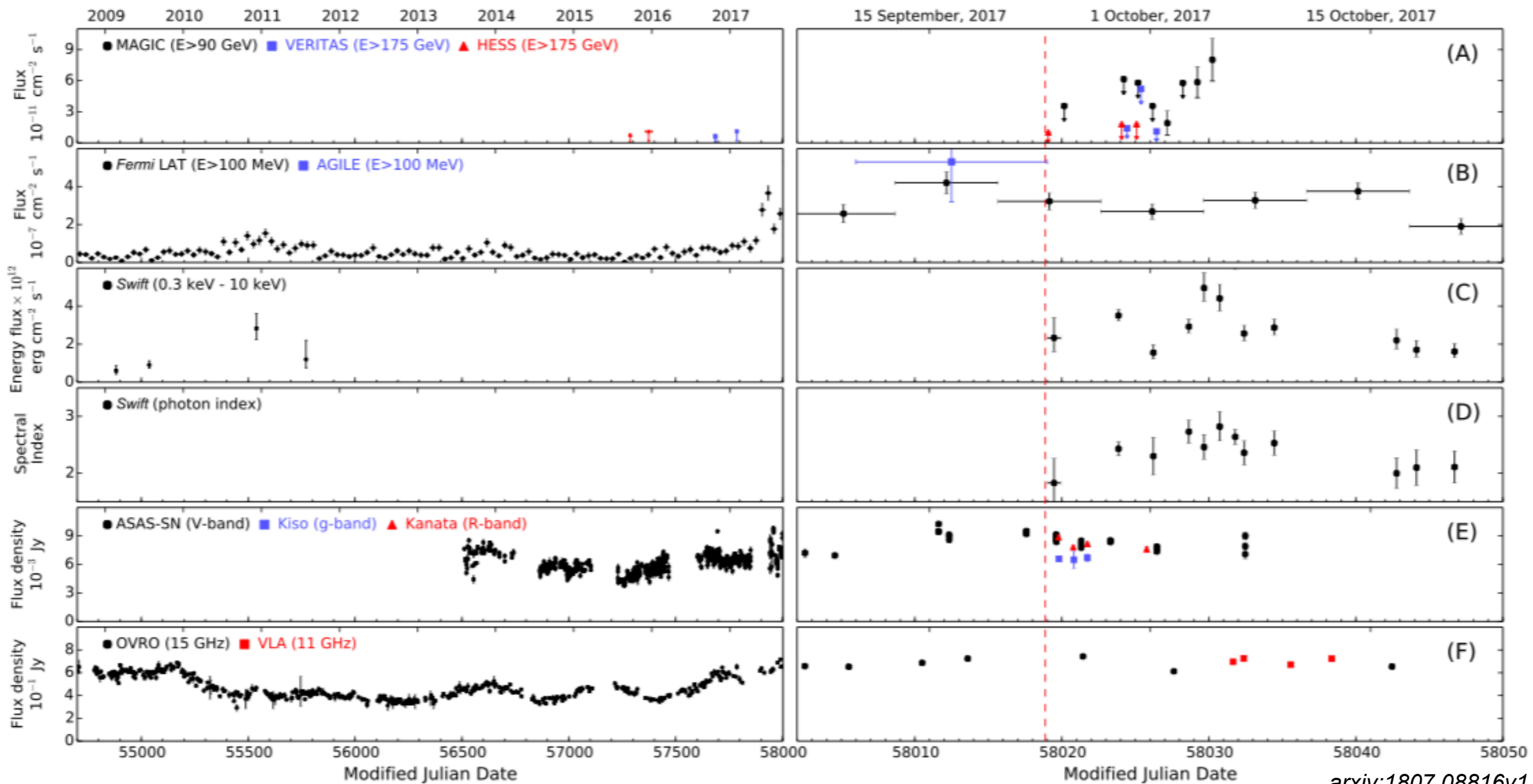
Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts



Multi-messenger observation with IACTs

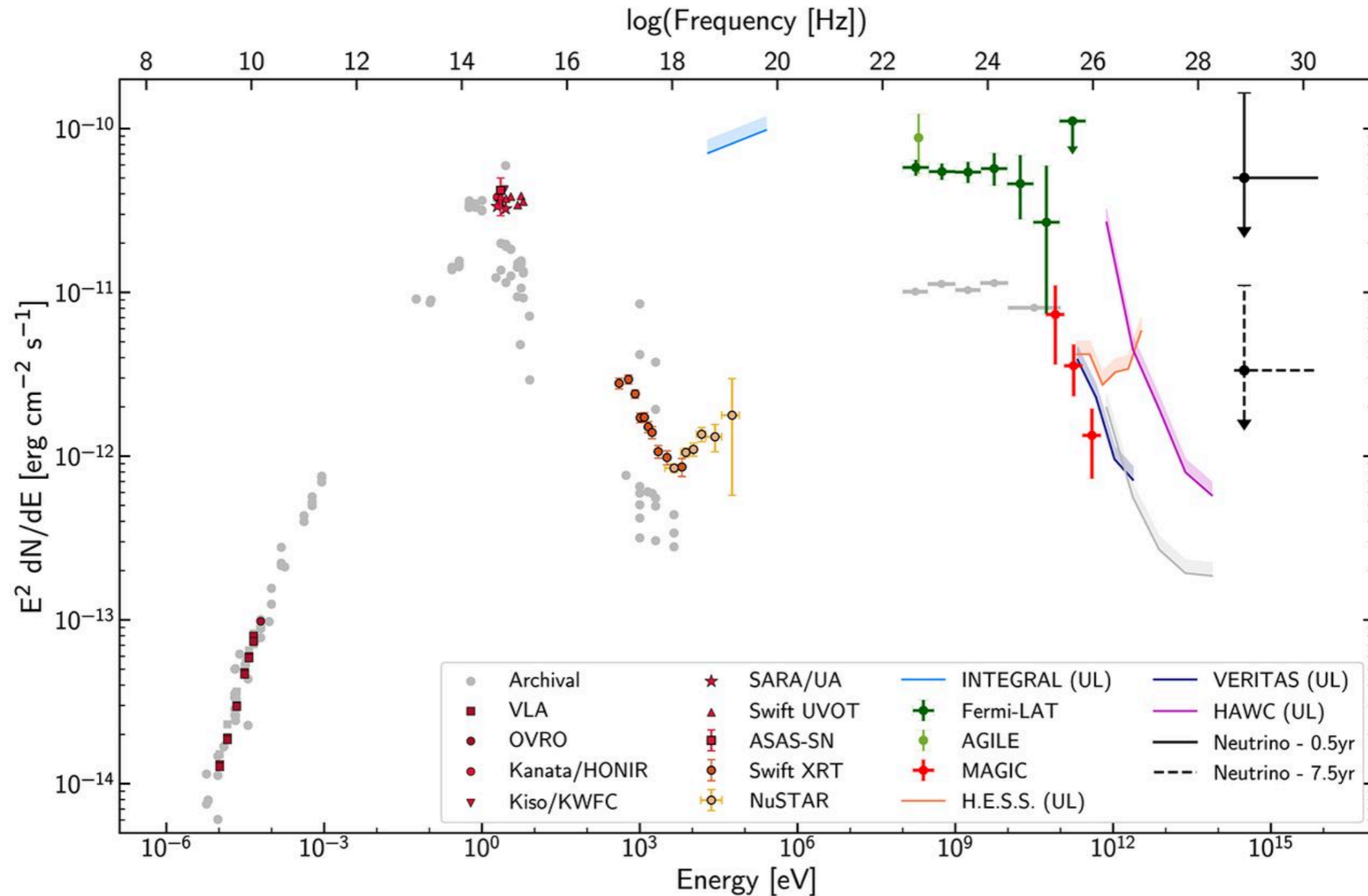
Searching for temporally varying neutrino counterparts



arxiv:1807.08816v1

Multi-messenger observation with IACTs

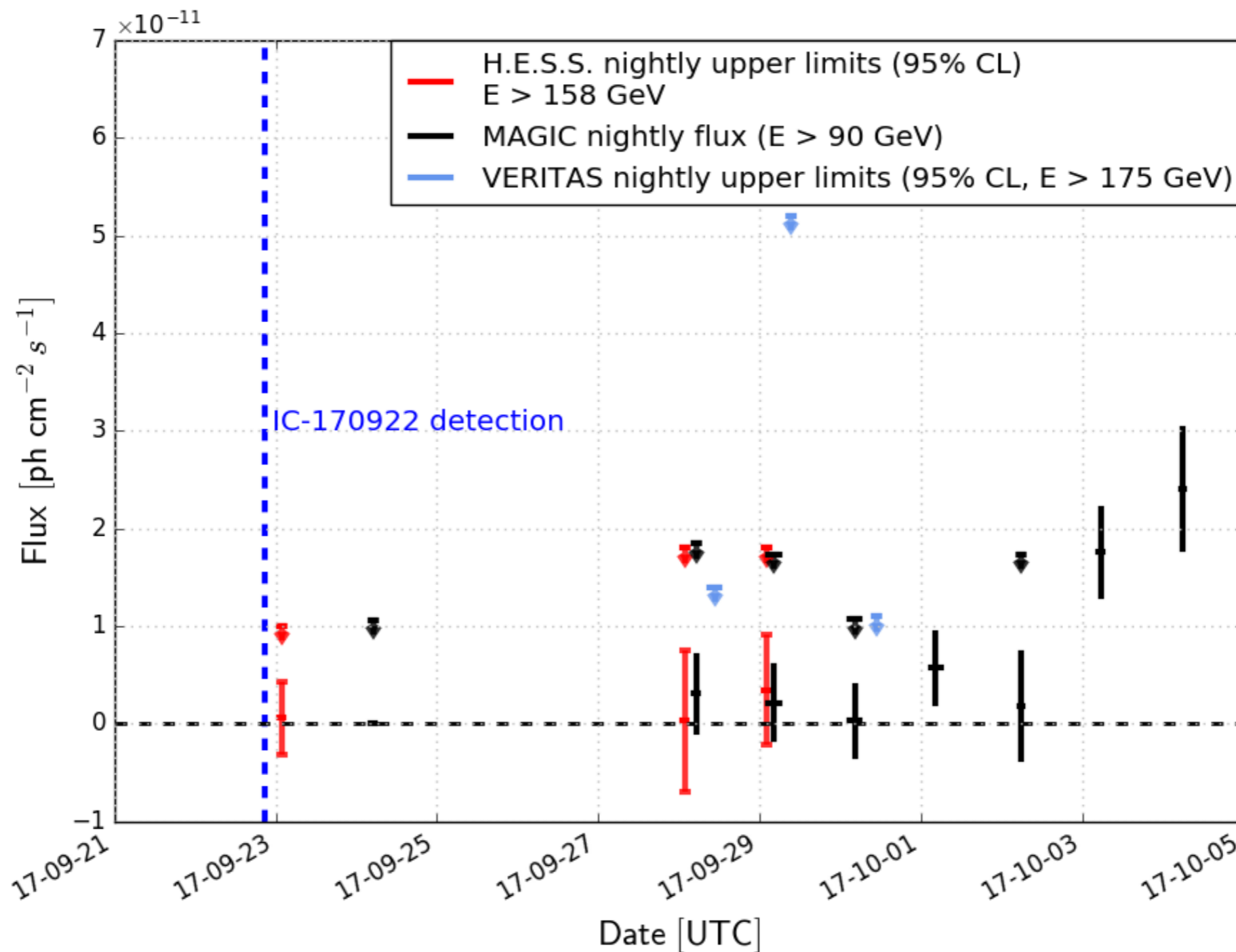
Searching for temporally varying neutrino counterparts



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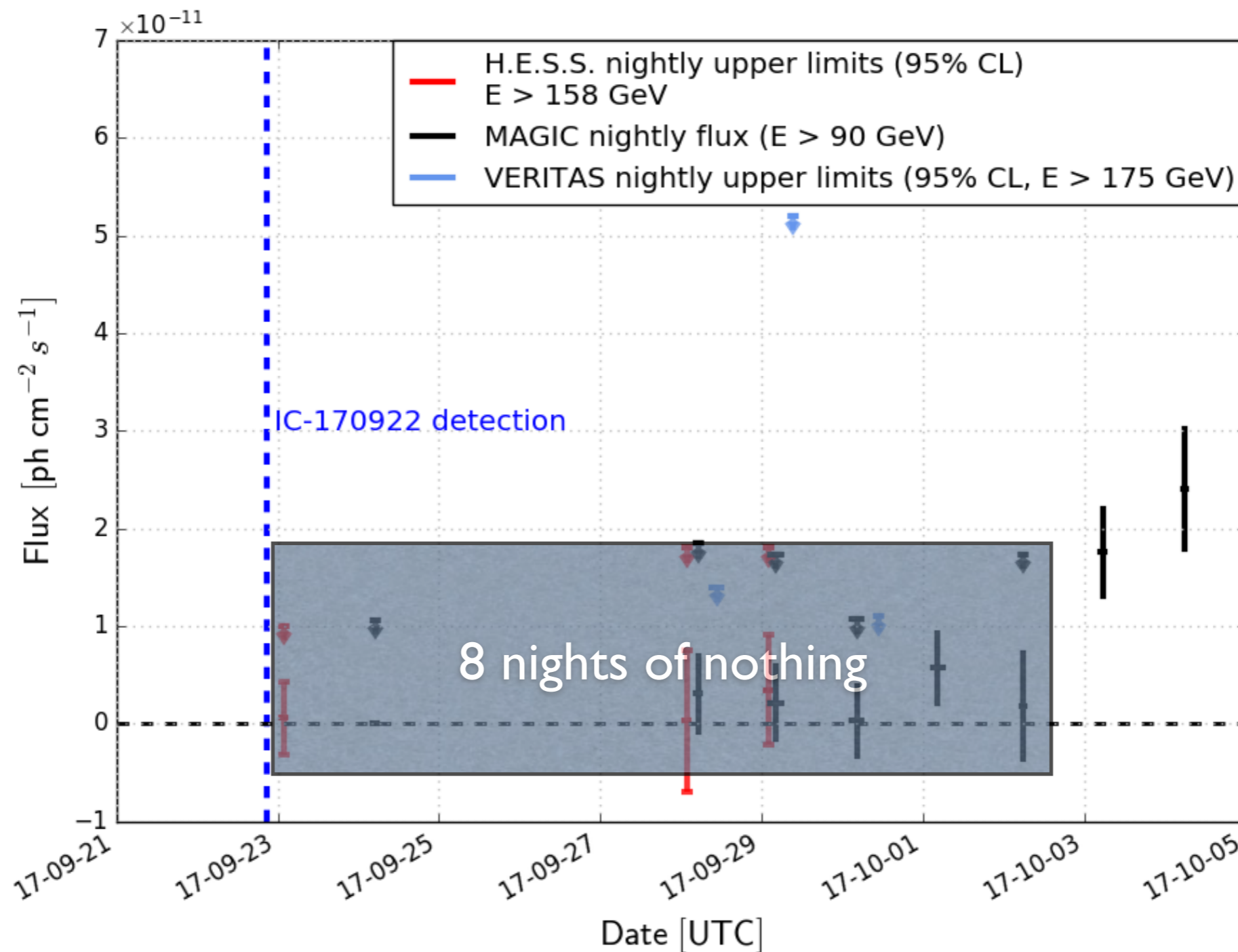
Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts



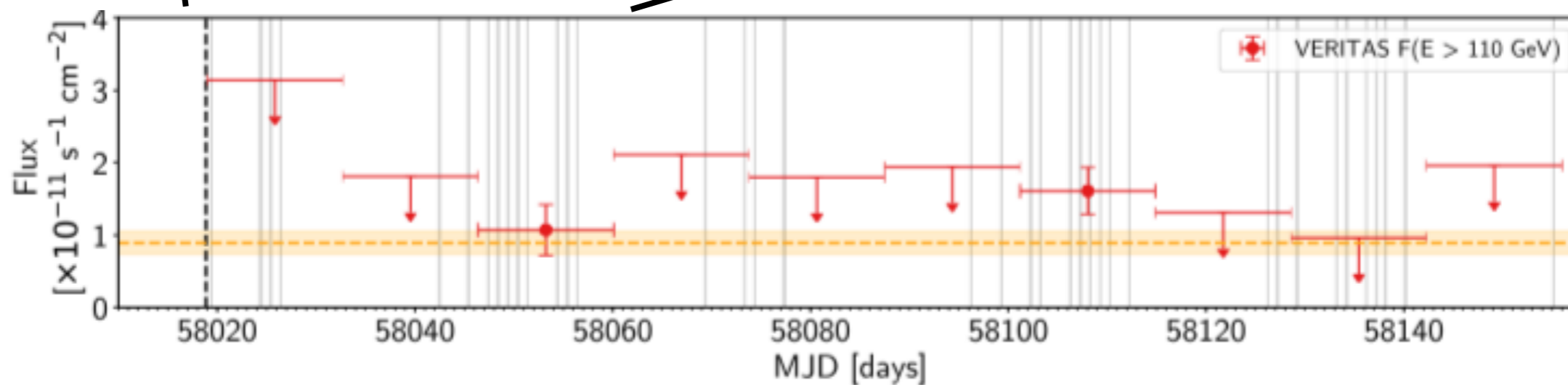
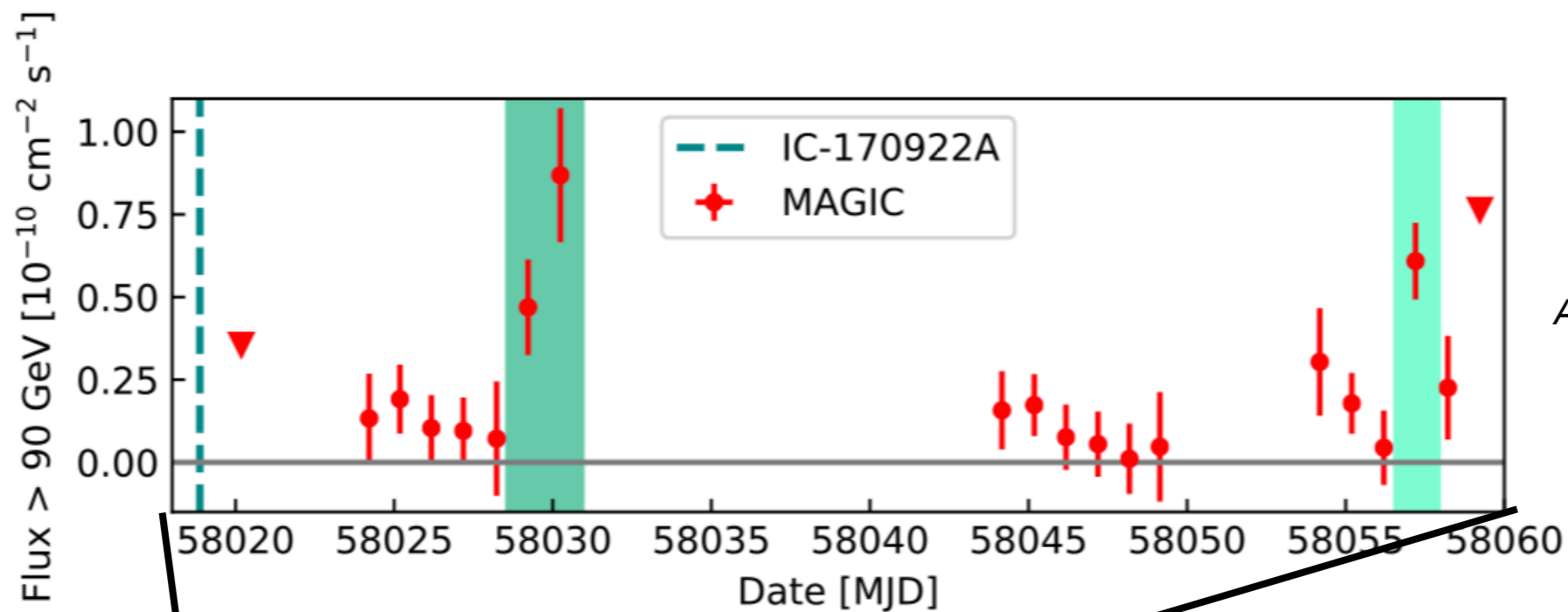
Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts



Multi-messenger observation with IACTs

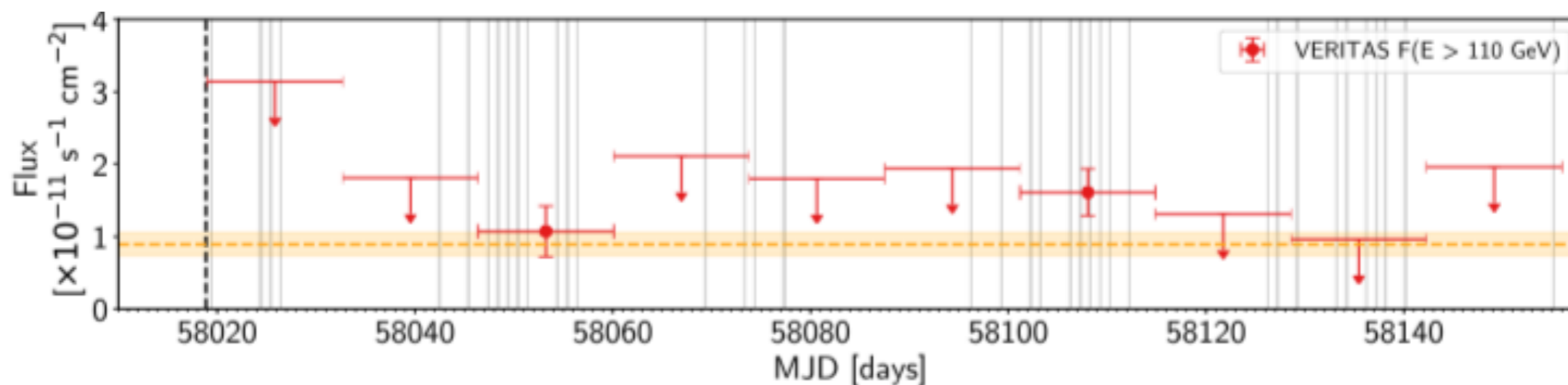
Searching for temporally varying neutrino counterparts



Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts

- TXS is fluctuating just at the edge of detectability above ~ 100 GeV on timescales of \sim day
- Continuous high state at ~ 1 GeV for months
- One Neutrino ...

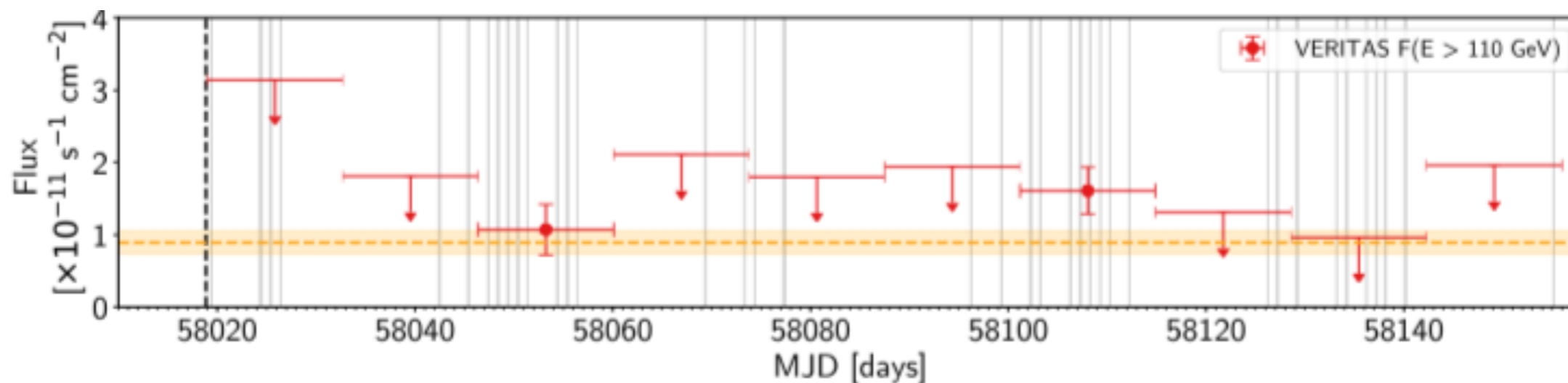


arxiv:1807.04607

Multi-messenger observation with IACTs

Searching for temporally varying neutrino counterparts

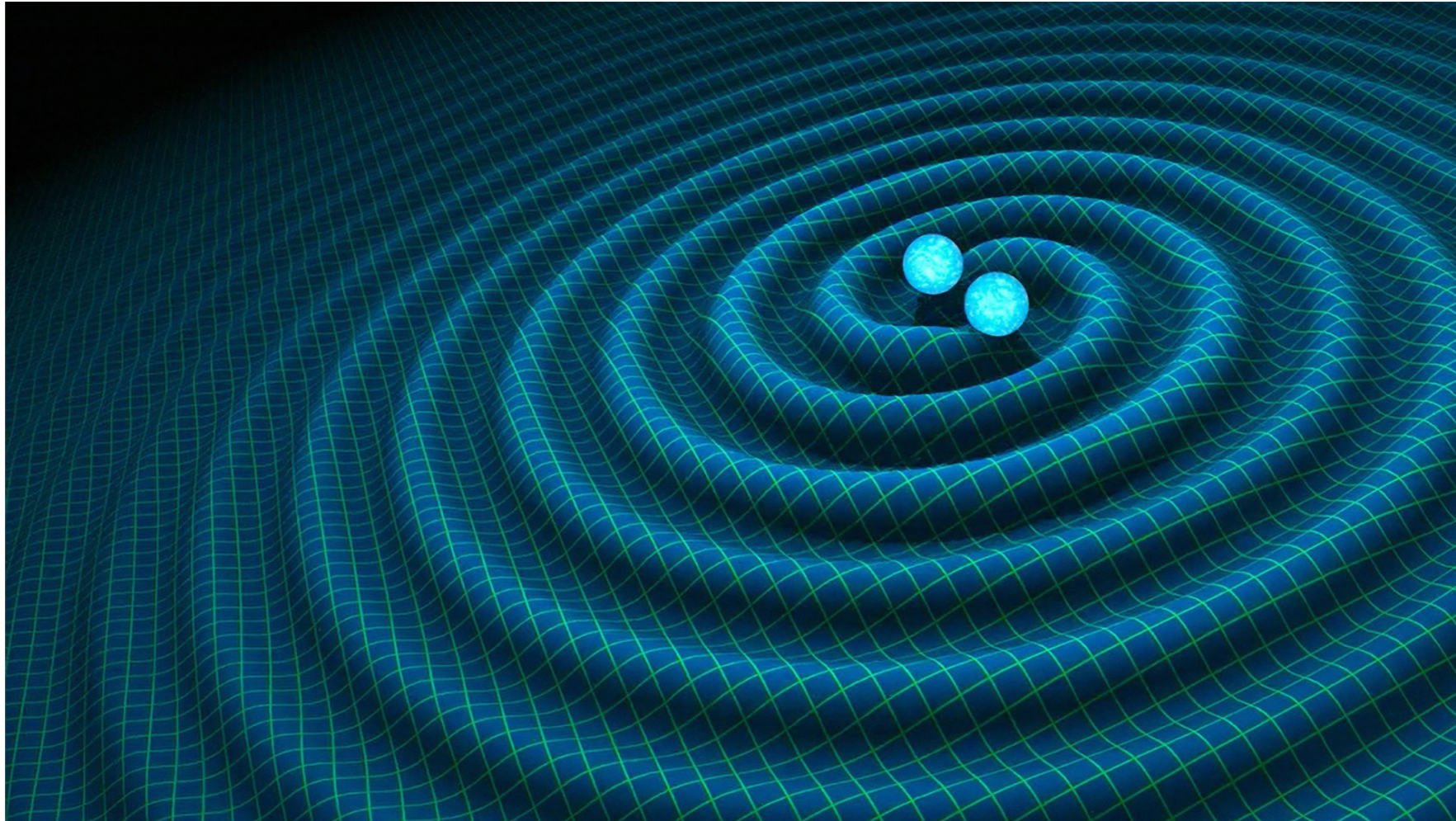
- TXS is fluctuating just at the edge of detectability above ~ 100 GeV on timescales of \sim day
 - Continuous high state at ~ 1 GeV for months
 - One Neutrino ... and zenith angle in IceCube is of astrophysical origin. This probability, the so-called signalness of the event (14), was reported to be 56.5% (17). Although IceCube can robustly identify
- > More IACT follow-up of Neutrinos needed.
- > Optimised monitoring needed.



arxiv:1807.04607

Multi-messenger observation with IACTs

Gravitational Wave counterparts at TeV energies?



Multi-messenger observation with IACTs

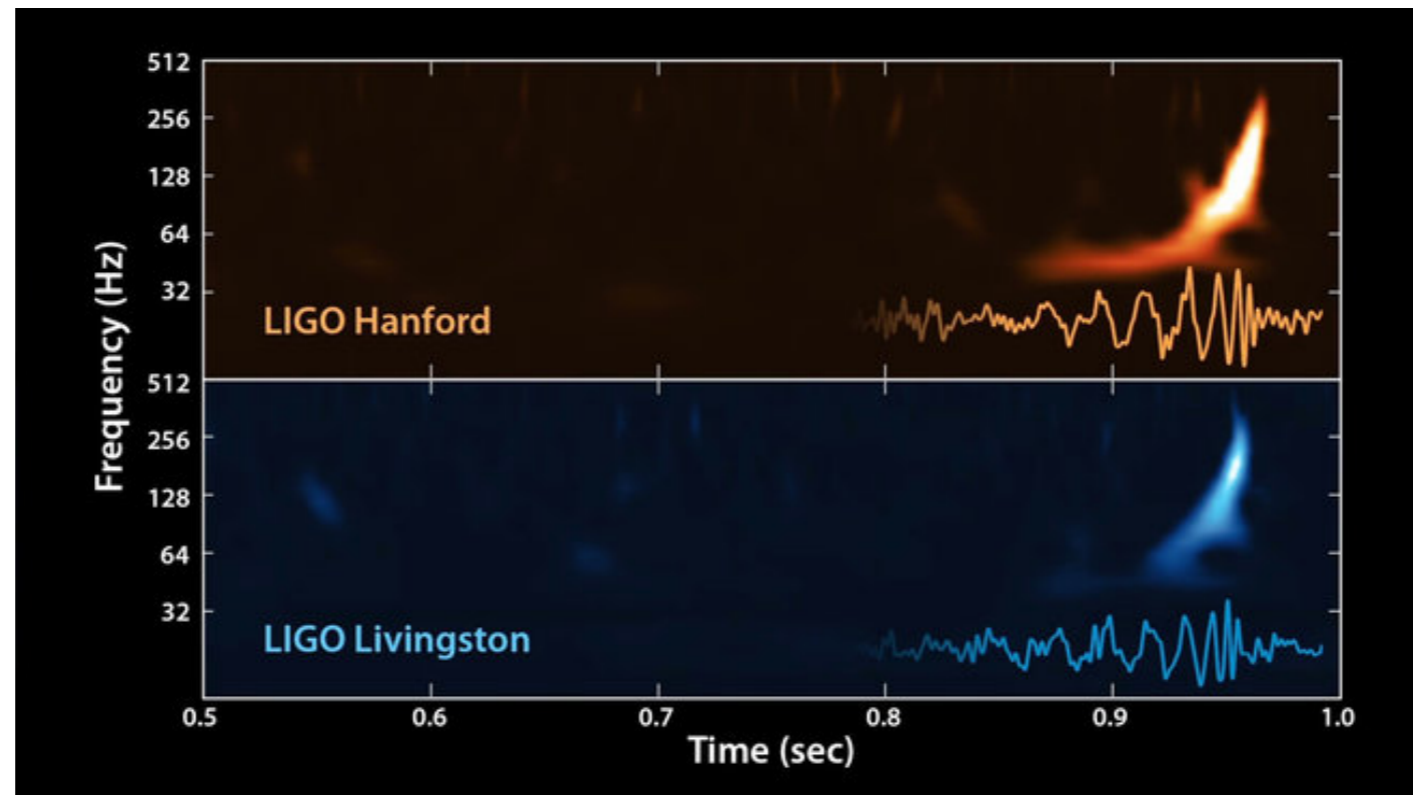
Gravitational Wave counterparts at TeV energies?

- (Indirectly) Ongoing since 20 years
- Searching for high-energy emission from GRBs
- GRBs predicted to originate from NS-NS mergers
- NS-NS mergers predicted to generate Gravitational Waves

Multi-messenger observation with IACTs

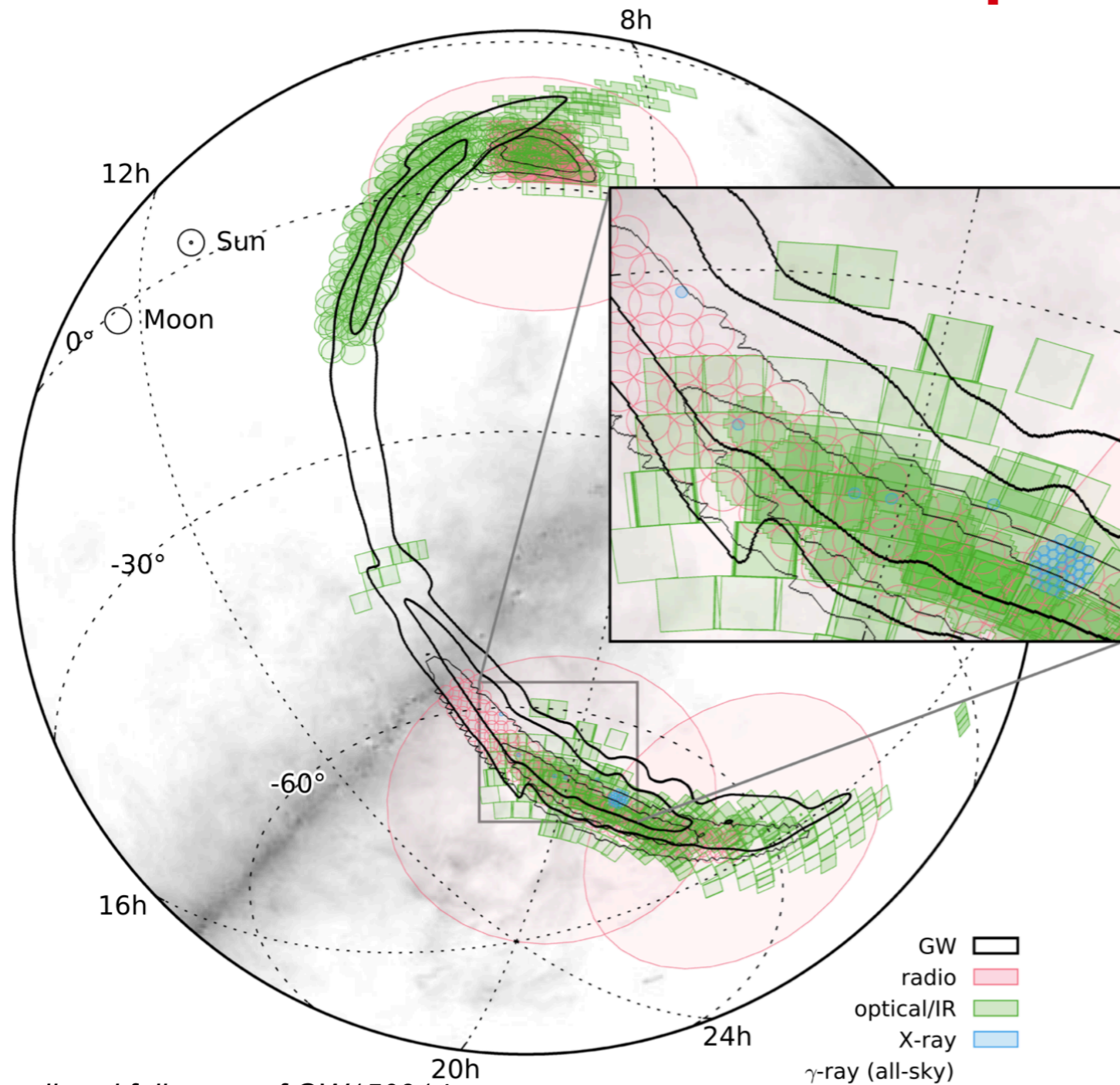
Gravitational Wave counterparts at TeV energies?

- (Indirectly) Ongoing since 20 years
- Searching for high-energy emission from GRBs
- GRBs predicted to originate from NS-NS mergers
- NS-NS mergers predicted to generate Gravitational Waves
- **Gravitational Waves are actually detectible now**



Multi-messenger observation with IACTs

Gravitational Wave counterparts at TeV energies?



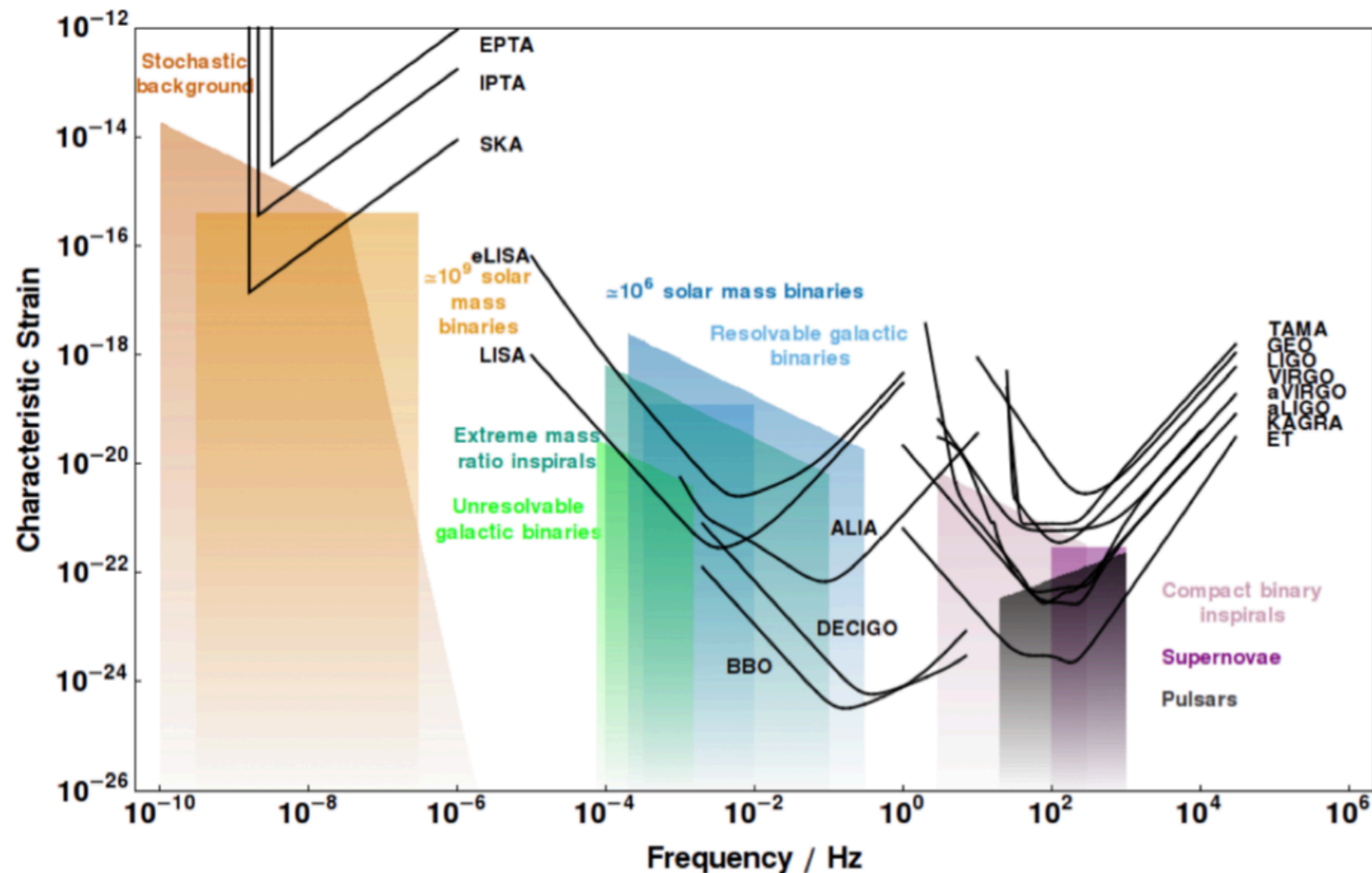
IACT limitations:

- FoV too small to cover significant fractions of localisation uncertainty

Broadband follow-up of GW150914
The Astrophysical Journal Letters, 826:L13 (8pp), 2016 July 20

Multi-messenger observation with IACTs

Gravitational Wave counterparts at TeV energies?



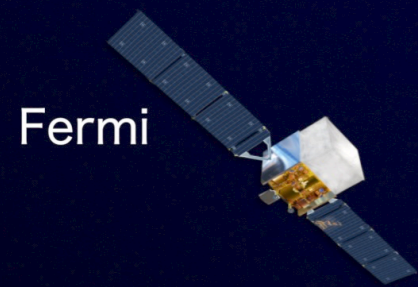
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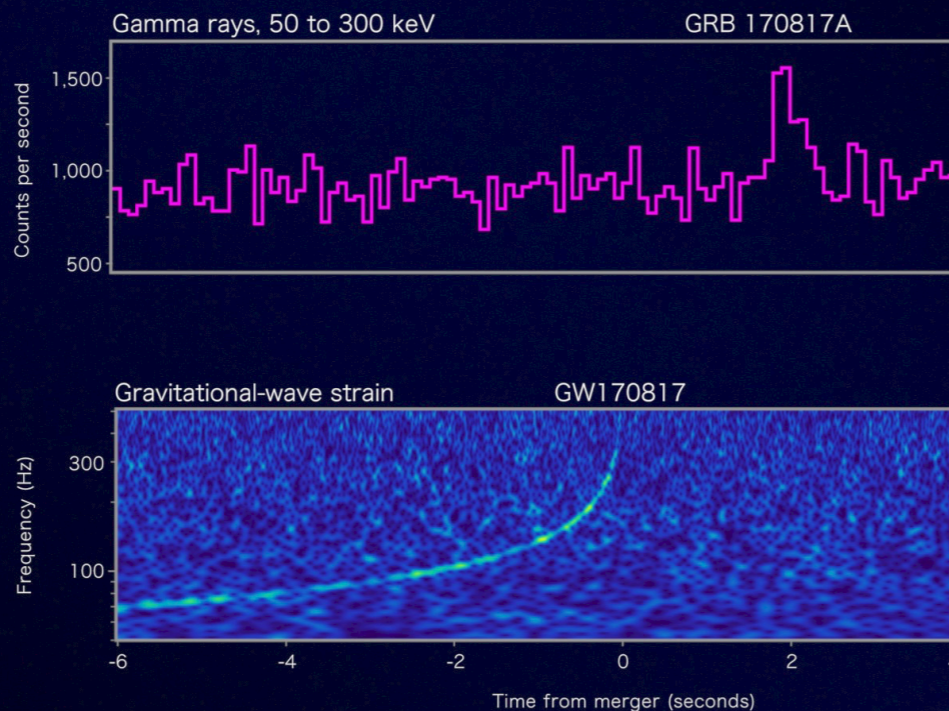
Multi-messenger observation with IACTs

Gravitational Wave counterparts at TeV energies?

GW/GRB 170817



from NASA



IACT limitations:

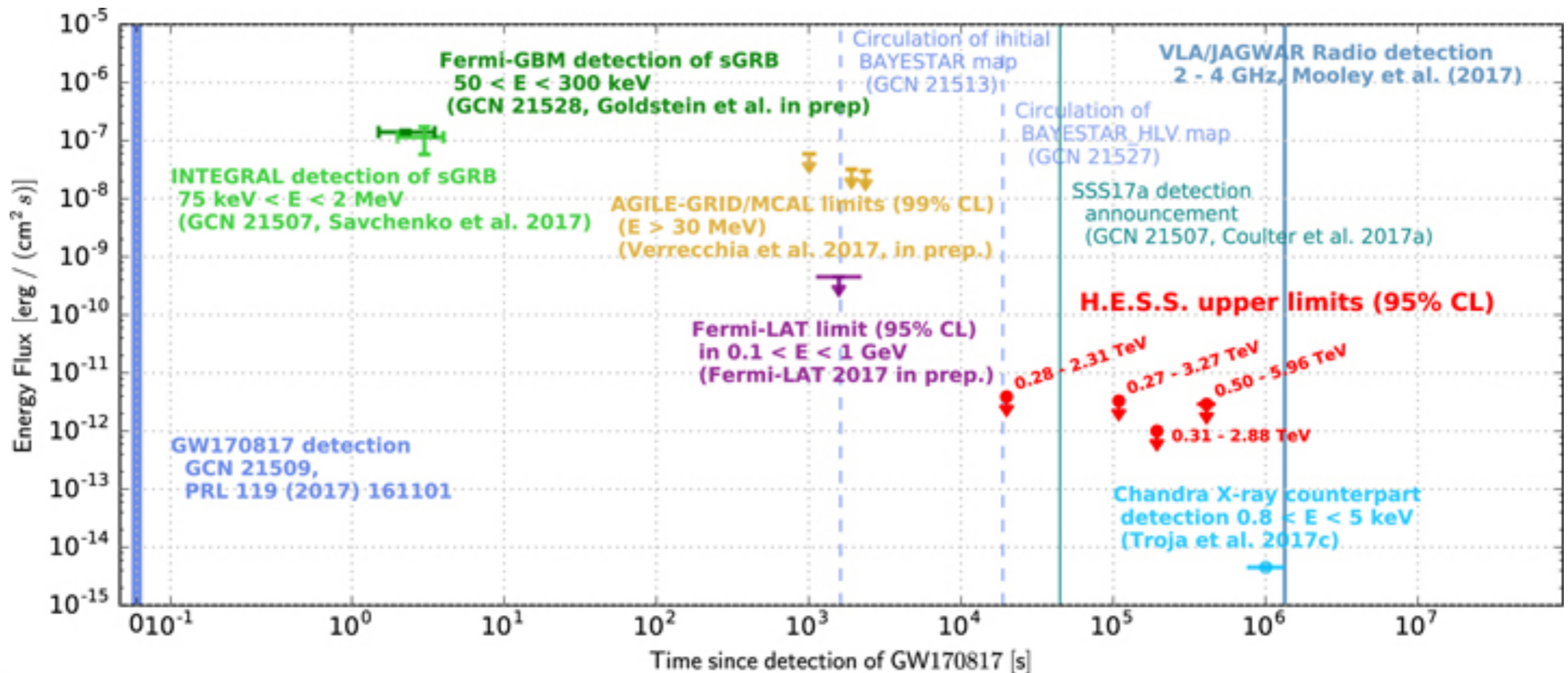
- FoV too small to cover significant fractions of localisation uncertainty
- BH-BH mergers are not expected to emit any radiation other than gravitational
- NS-NS mergers are also in range now

Multi-messenger observation with IACTs

Gravitational Wave counterparts at TeV energies?

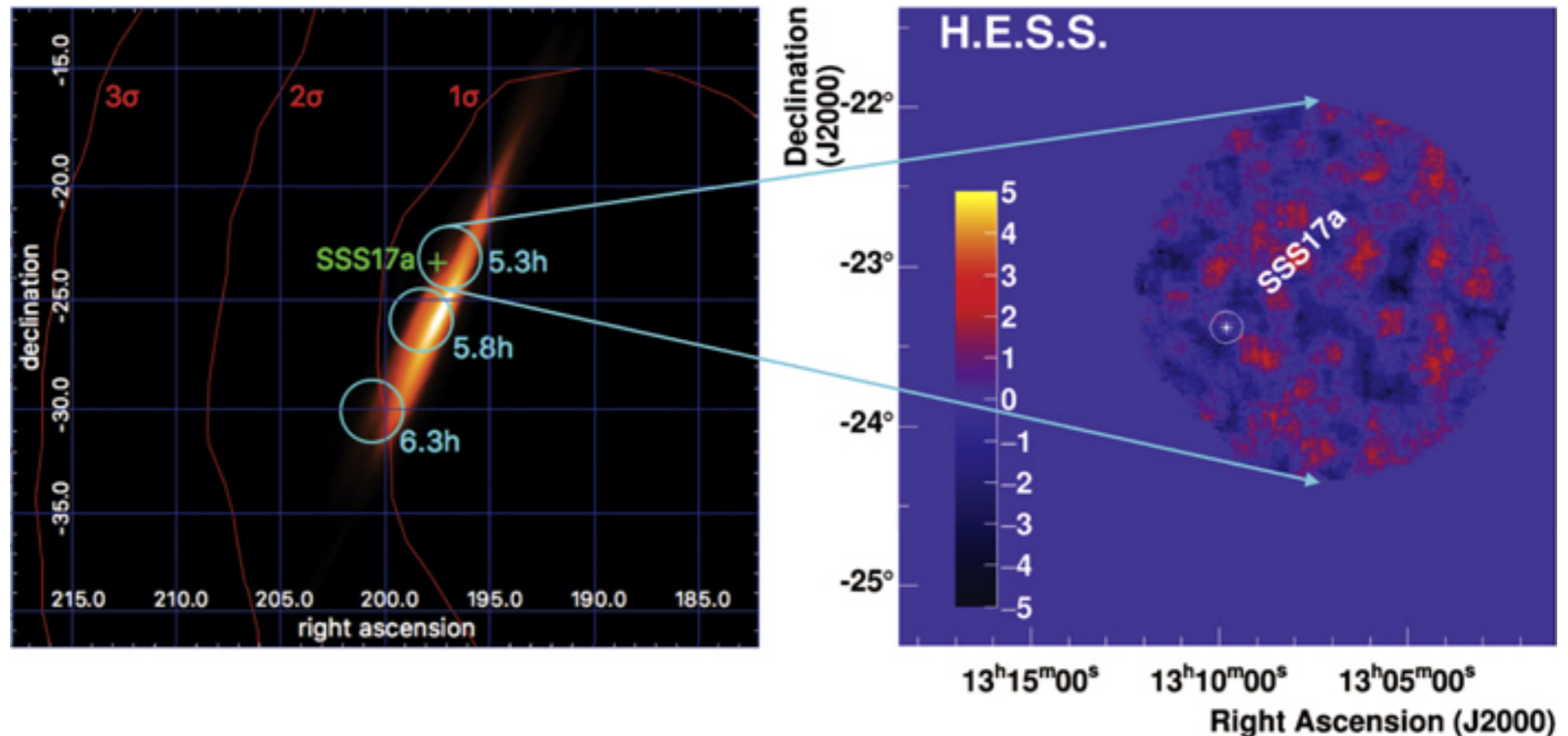
H.E.S.S. still tried...

and observed the counterpart location as first ground based pointed observatory.
only 5 minutes after the three-detector localisation was circulated.



Multi-messenger observation with IACTs

Gravitational Wave counterparts at TeV energies?

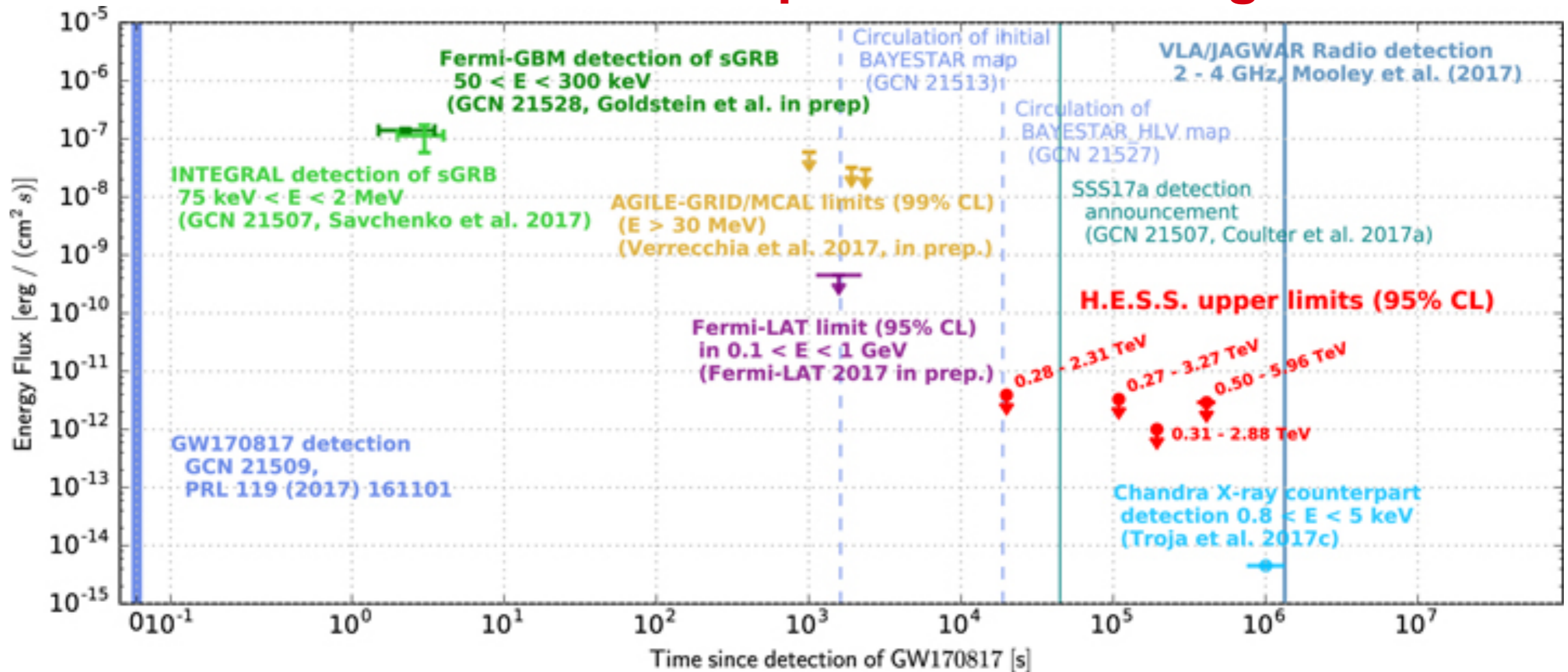


Optimised follow-up strategy:

- Combined galaxy catalog + localisation uncertainty
- Automated
(see arXiv:1705.10138 for details on the schedule calculation)

Multi-messenger observation with IACTs

Gravitational Wave counterparts at TeV energies?



Another take away message:

- No GW detection in this case = no follow-up what so ever!
 - Just another weak and poorly localised Fermi-GBM GRB.
- Now: closest GRB ever! GRB with most intensive follow-up!

Multi-messenger observation with IACTs Prospects for the coming years

Multi-messenger studies with IACTs are heavily driven by observations:

- Taking risks and perform exploratory observations
 - Probe the rich transient (optical) sky (ASASSN, ZTF)
 - Get prepared for the radio transient sky (see MeerKATs THUNDERKAT program)
 - Learn about Multi-messenger source candidates even without Neutrinos and GWs
- Collaboration between IACTs
 - Exploit having 3 running sites:
 - Distribute monitoring of Neutrino candidate sky regions if possible
 - Optimise GW follow-up scans

