

A Global Strategy for The Future of High-Energy Neutrino Astronomy

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In collaboration with:

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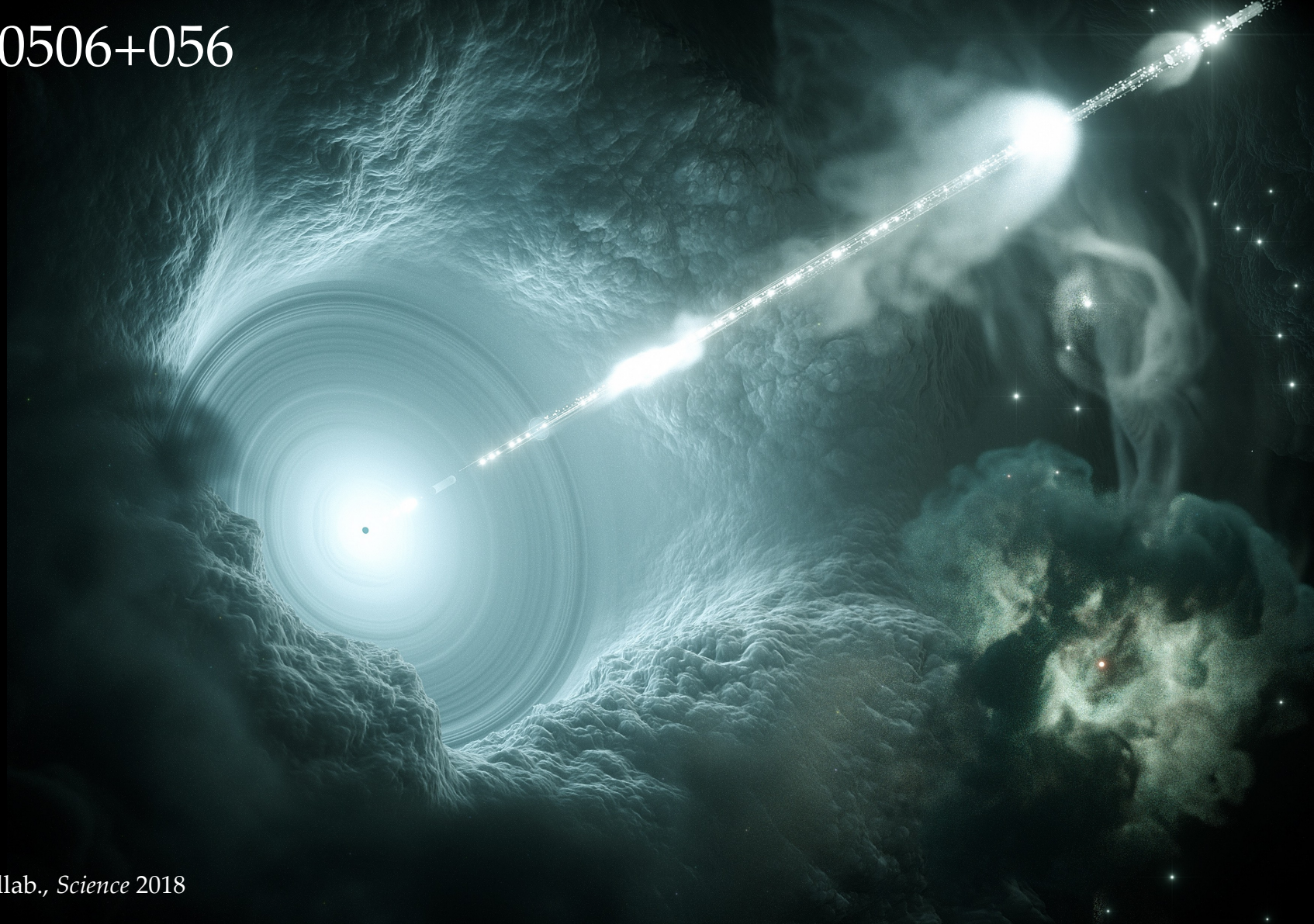
UNIVERSITY OF
COPENHAGEN



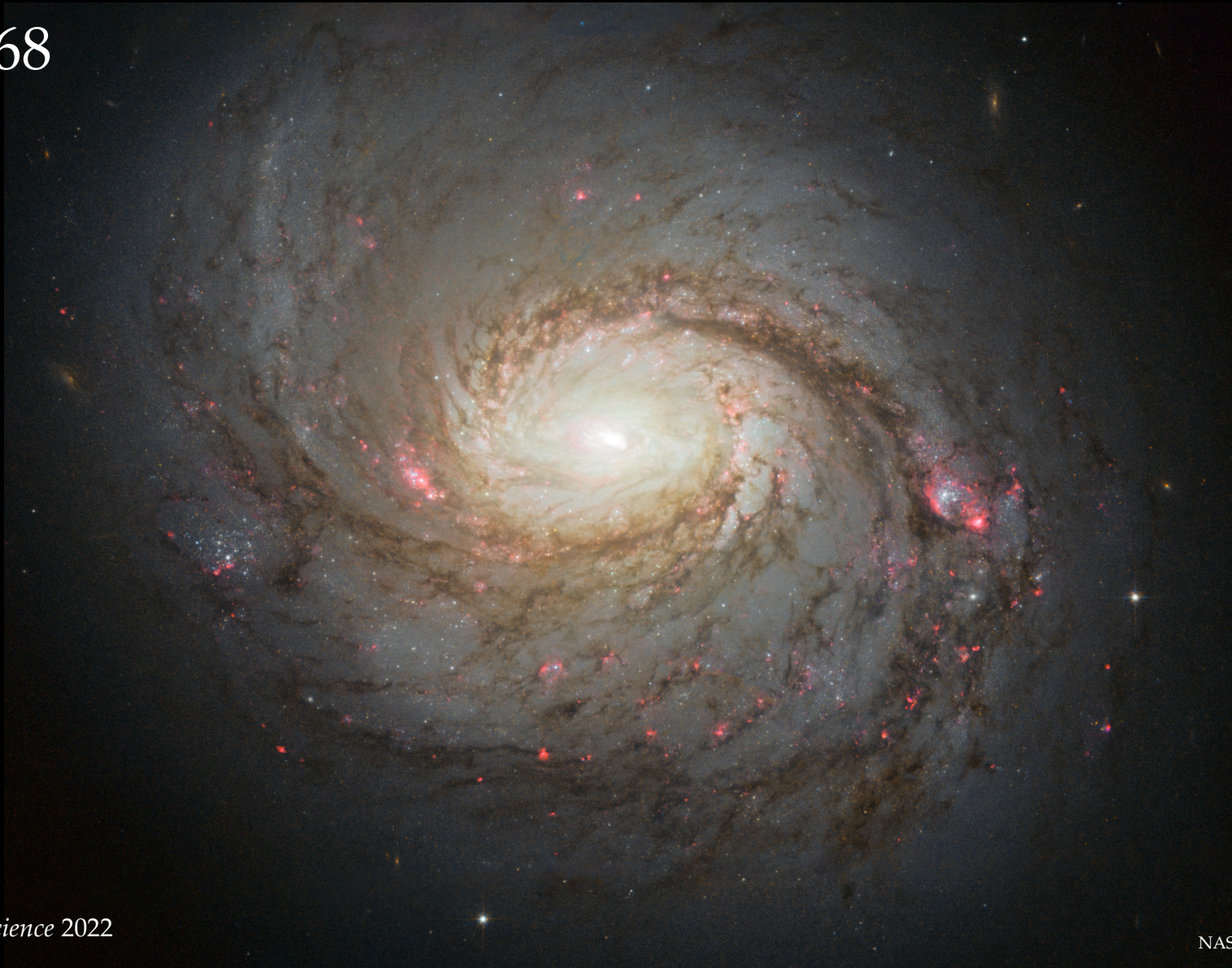
VILLUM FONDEN



TXS 0506+056



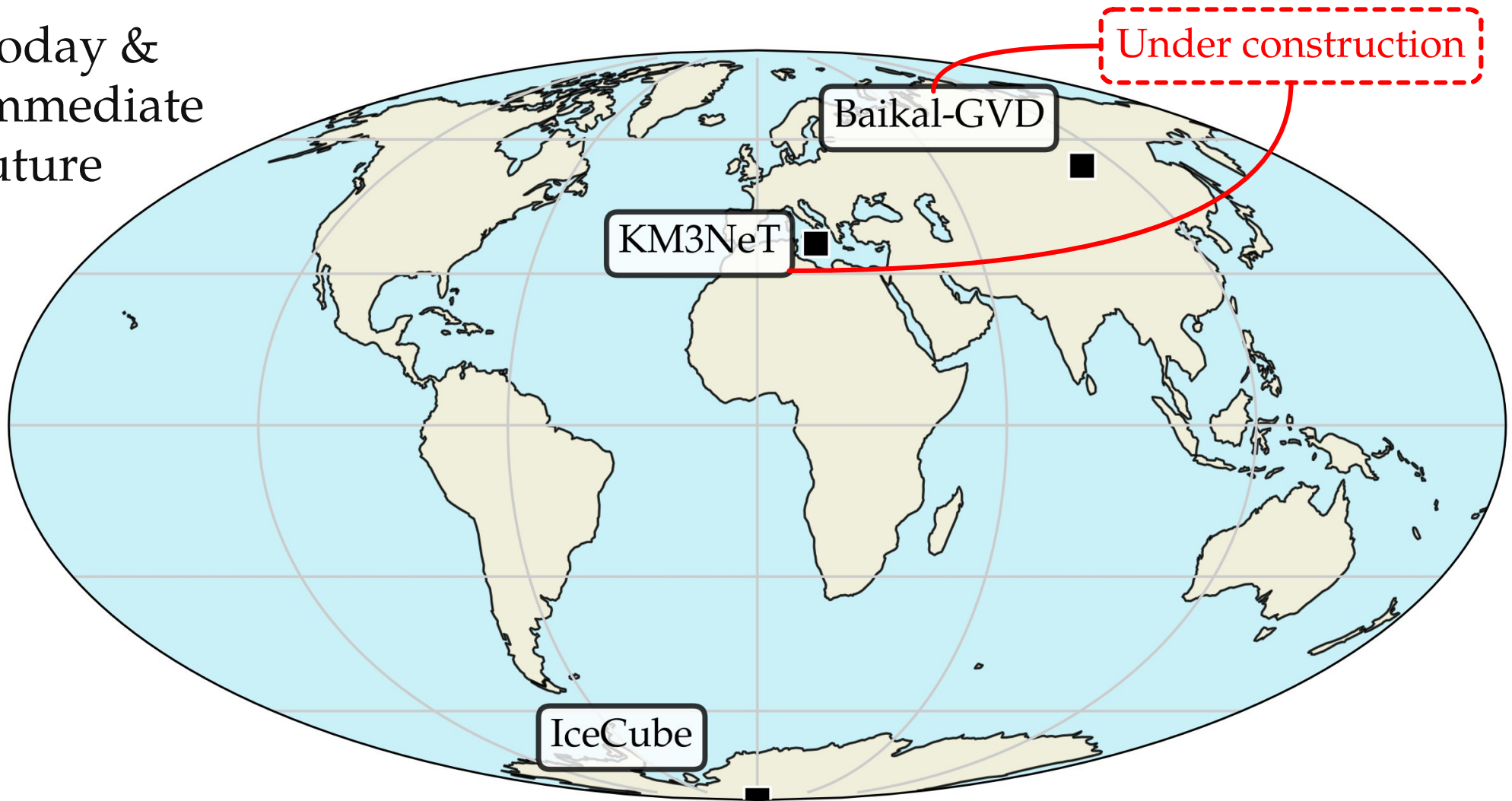
NGC1068



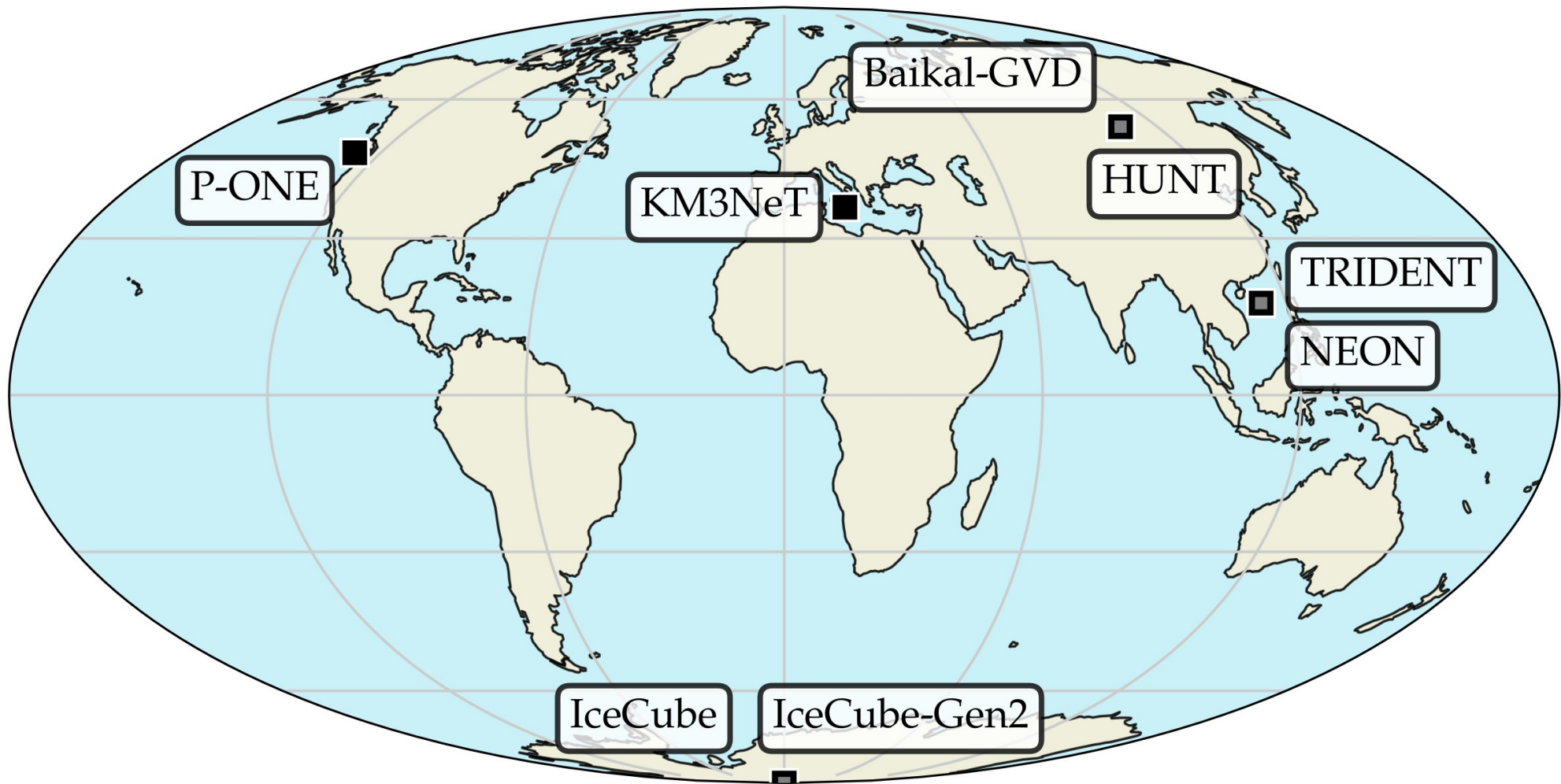
Milky Way



Today &
immediate
future



How do we hasten
the pace of source discovery?



Three simplifications in the results shown today:

- 1 We only use track events
Good pointing accuracy — we will be looking for sources
- 2 Each detector is treated as IceCube-like, repositioned and scaled-up
In reality, DOM spacing, string spacing, medium, *etc.* matter
- 3 Only use TeV–PeV neutrinos
We make forecasts based on known (or presumed) properties of their flux

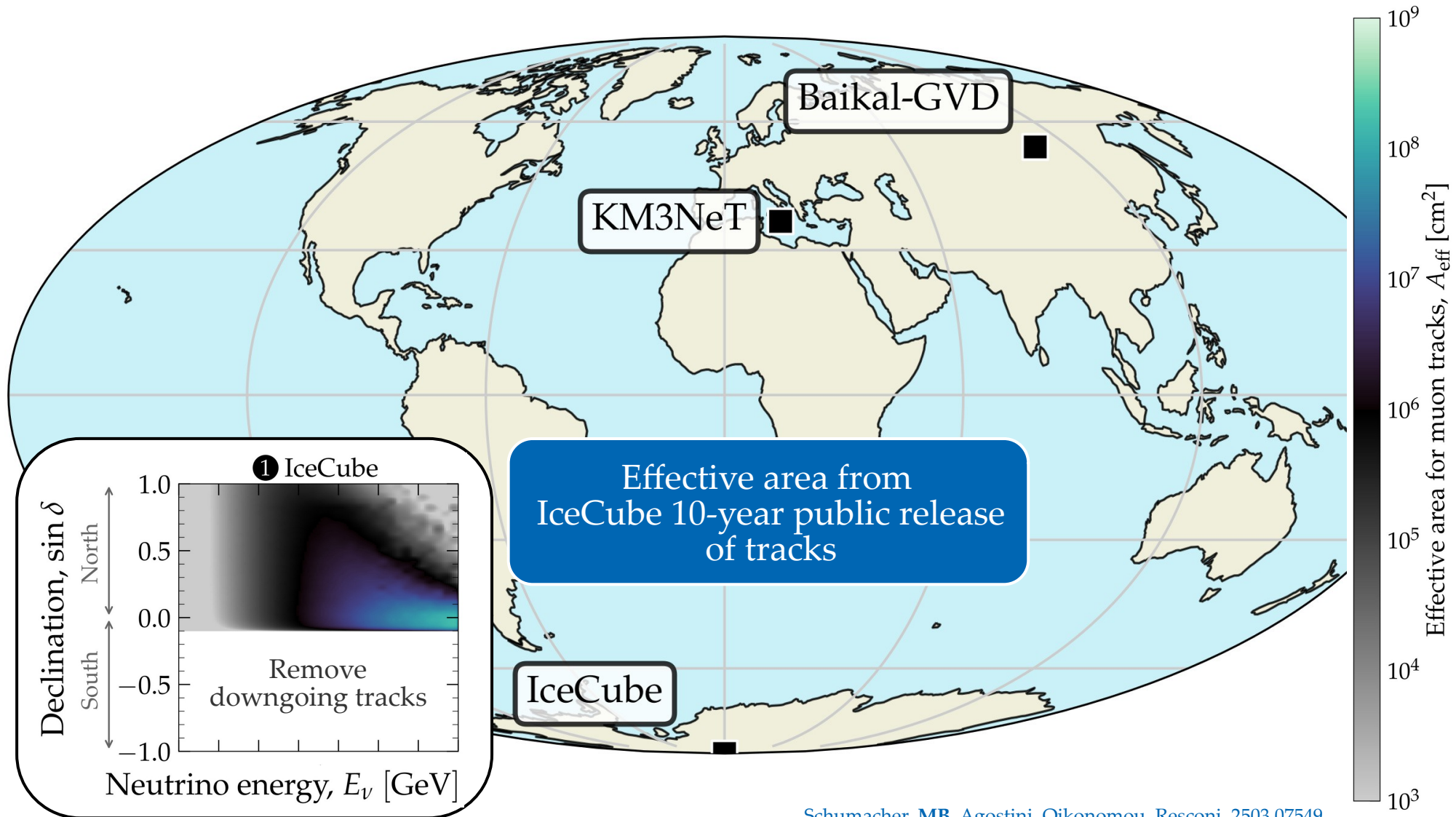
Note: The PLEuM code has flexibility to go beyond these simplifications



github.com/PLEnuM-group/Plenum

Please excuse
the crudity of this model

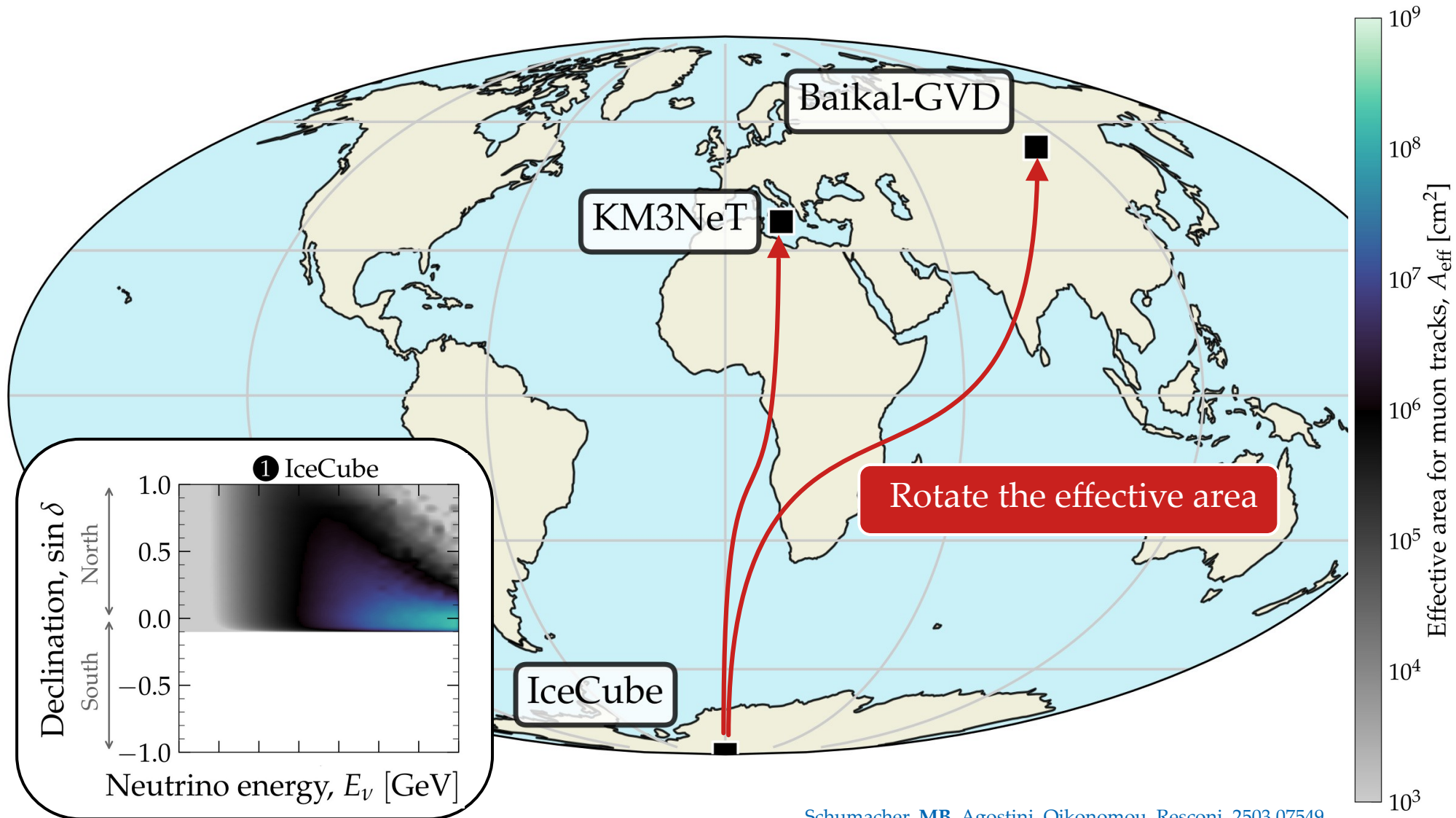


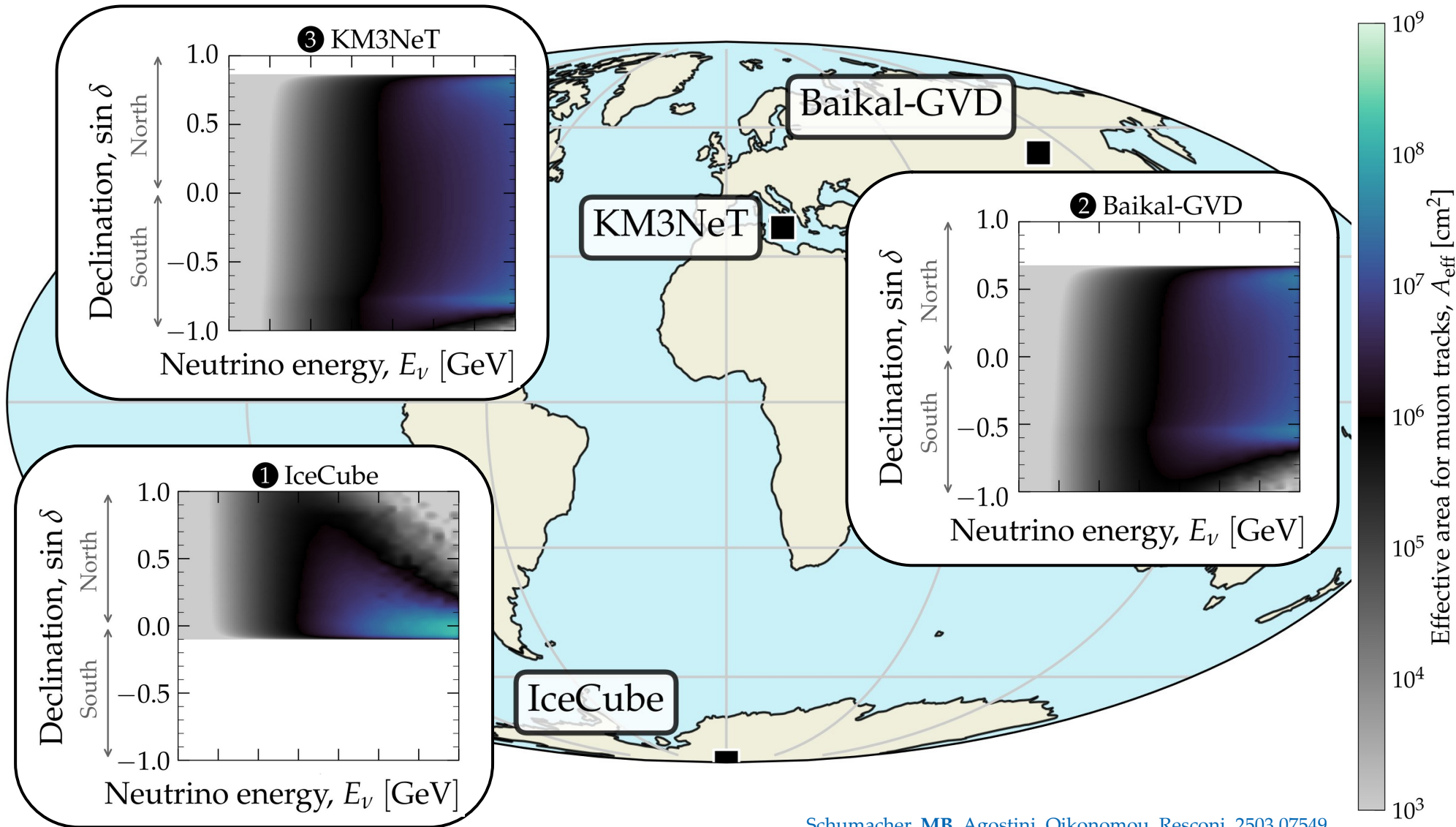


Neutrino telescope	Location	Size relative to IceCube ^a	Start date ^b
Ongoing			
IceCube	South Pole	1	2011
Under construction			
KM3NeT	Mediterranean Sea	1	2025
Baikal-GVD	Lake Baikal	1	2027

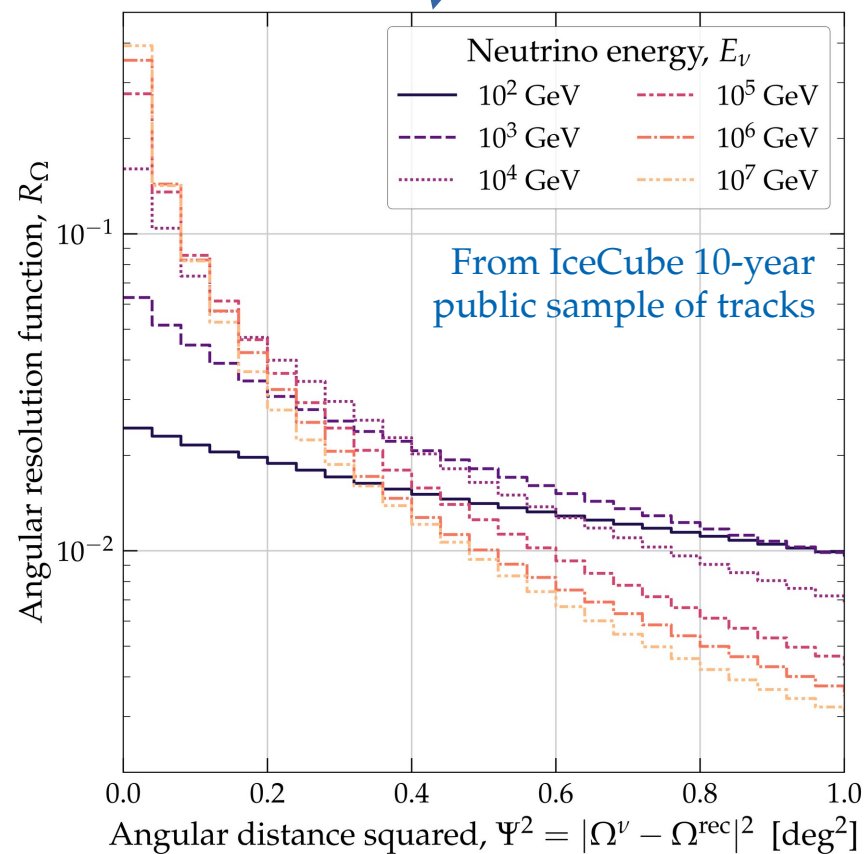
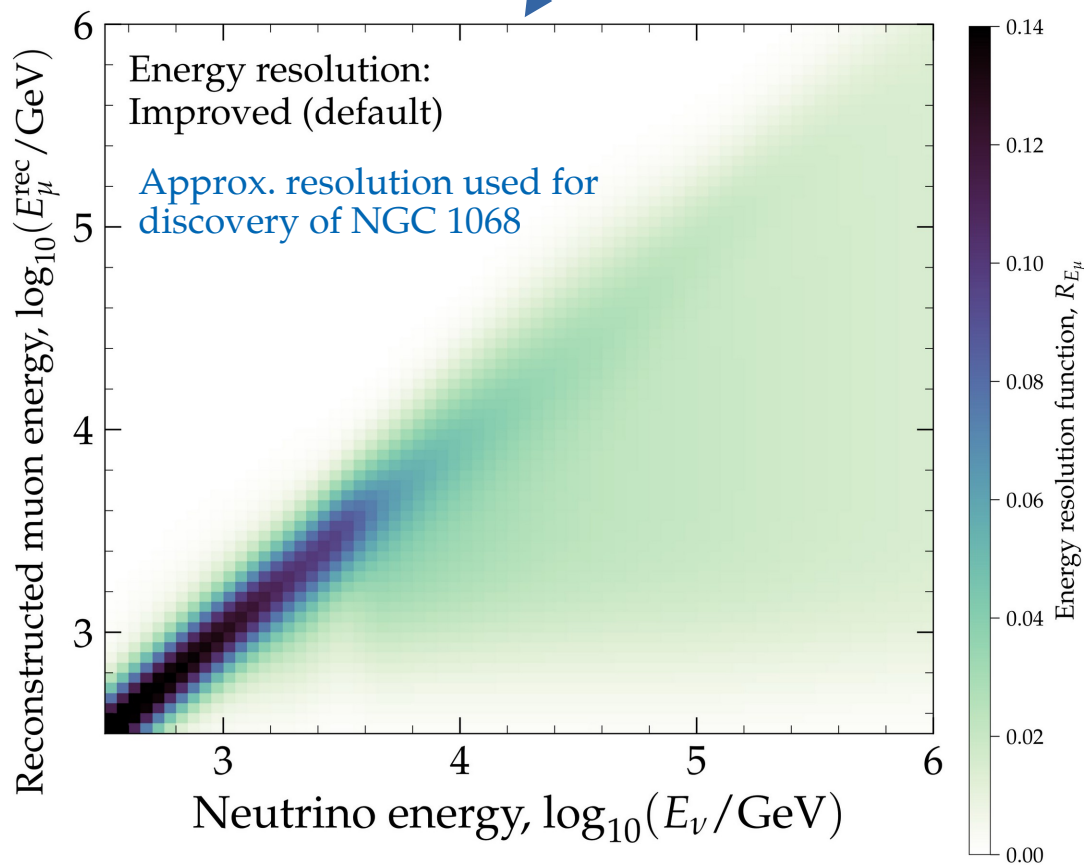
^a Approximate size of the final detector configuration that is used in this paper.

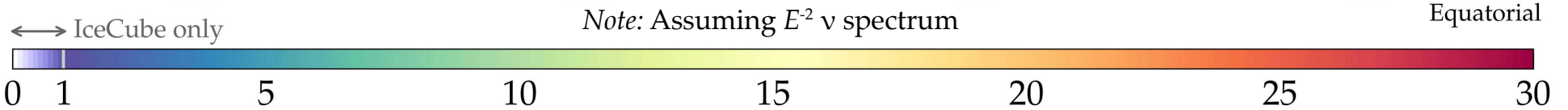
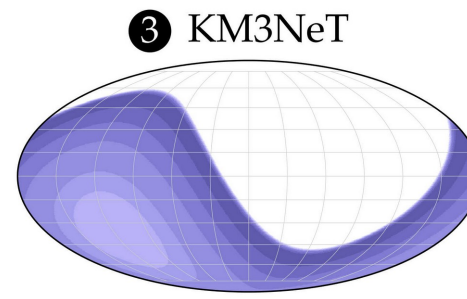
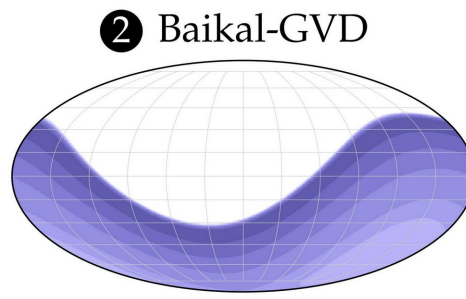
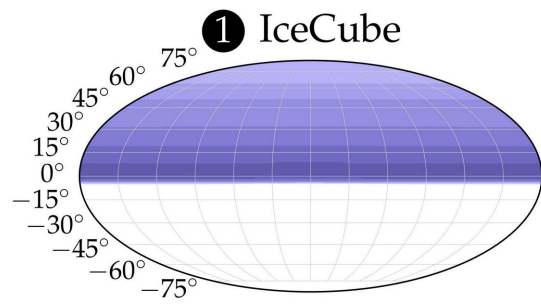
^b Approximate dates when the final configuration of the detector is expected to be completed, used in this analysis but subject to change.

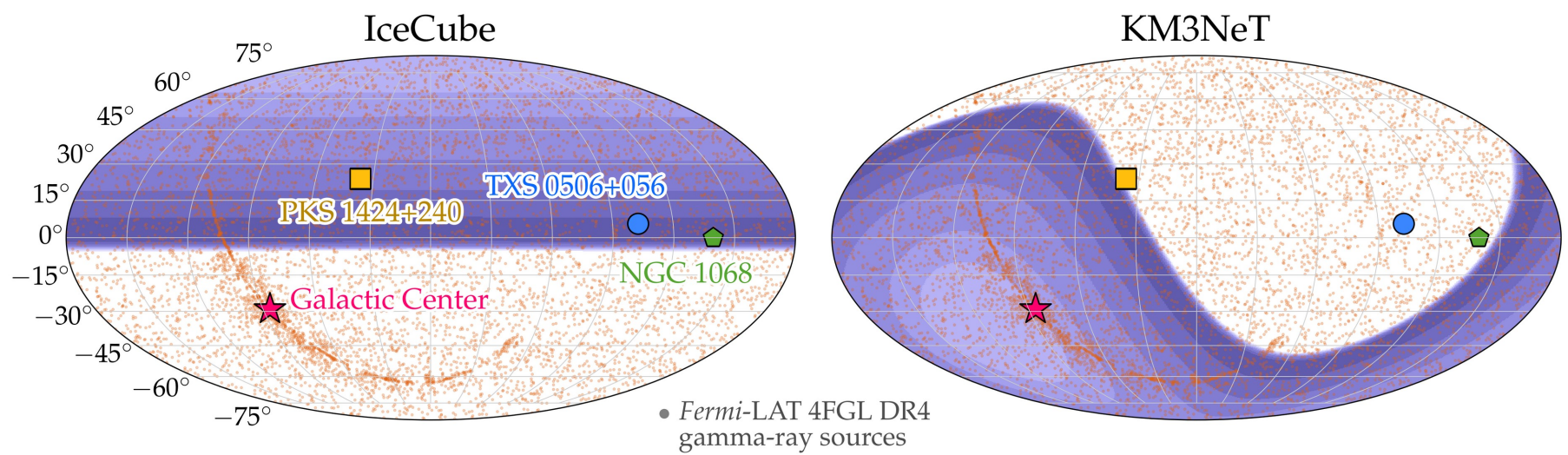




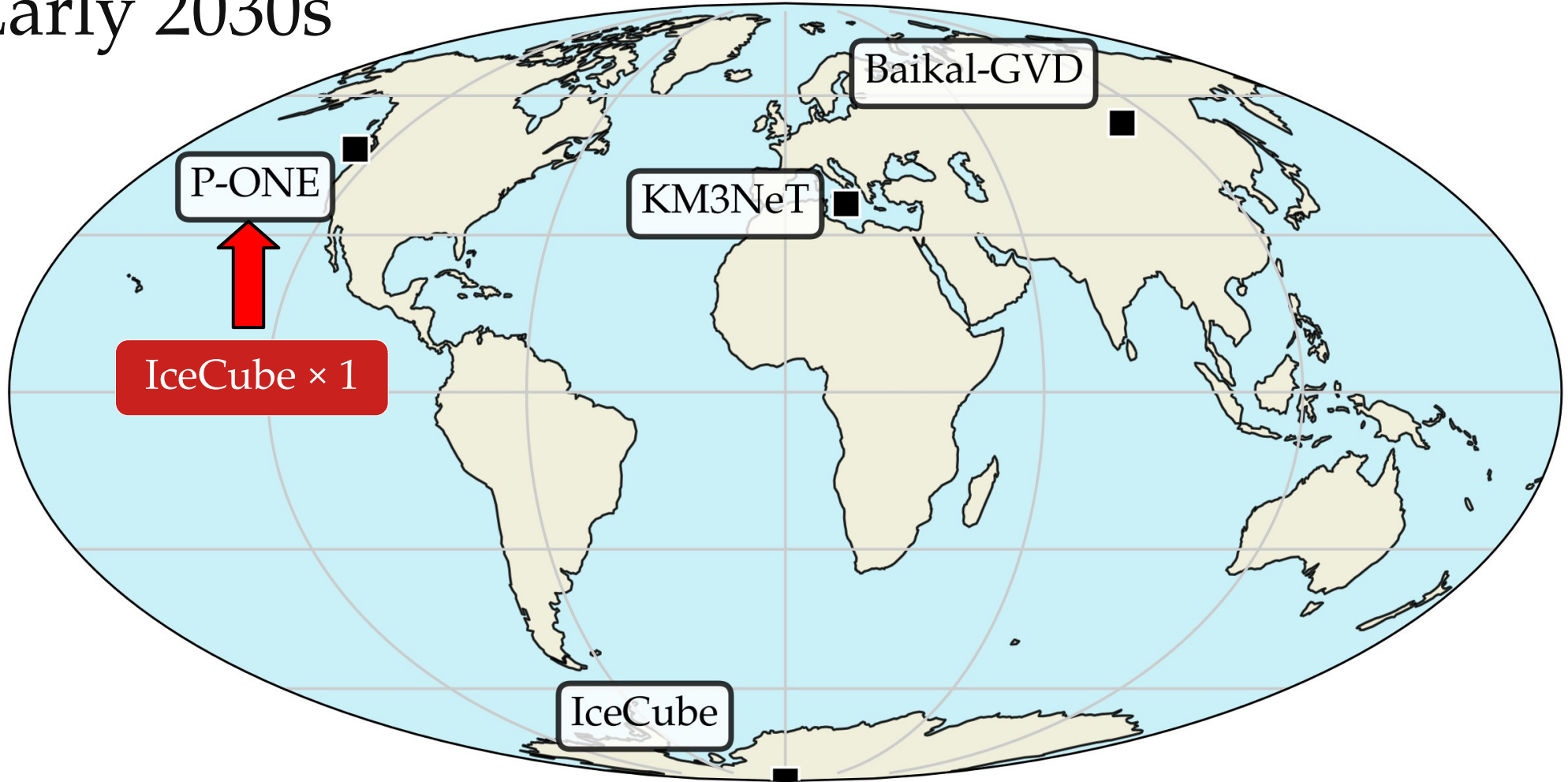
Number of events $\propto$ Neutrino flux $\times$ Effective area $\times$ Energy resolution $\times$ Angular resolution

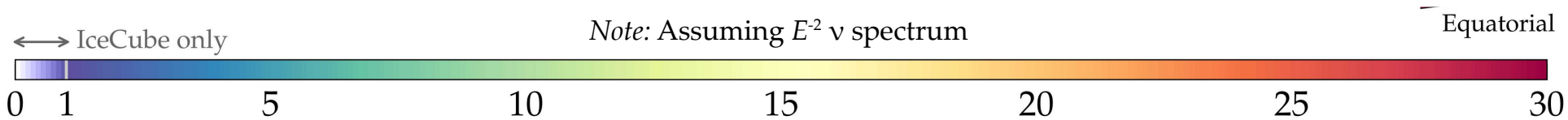
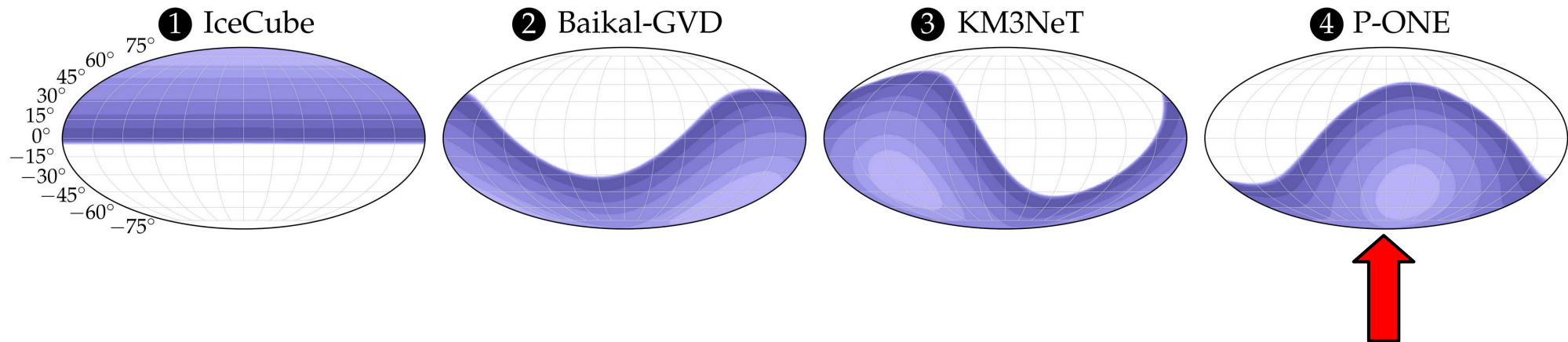




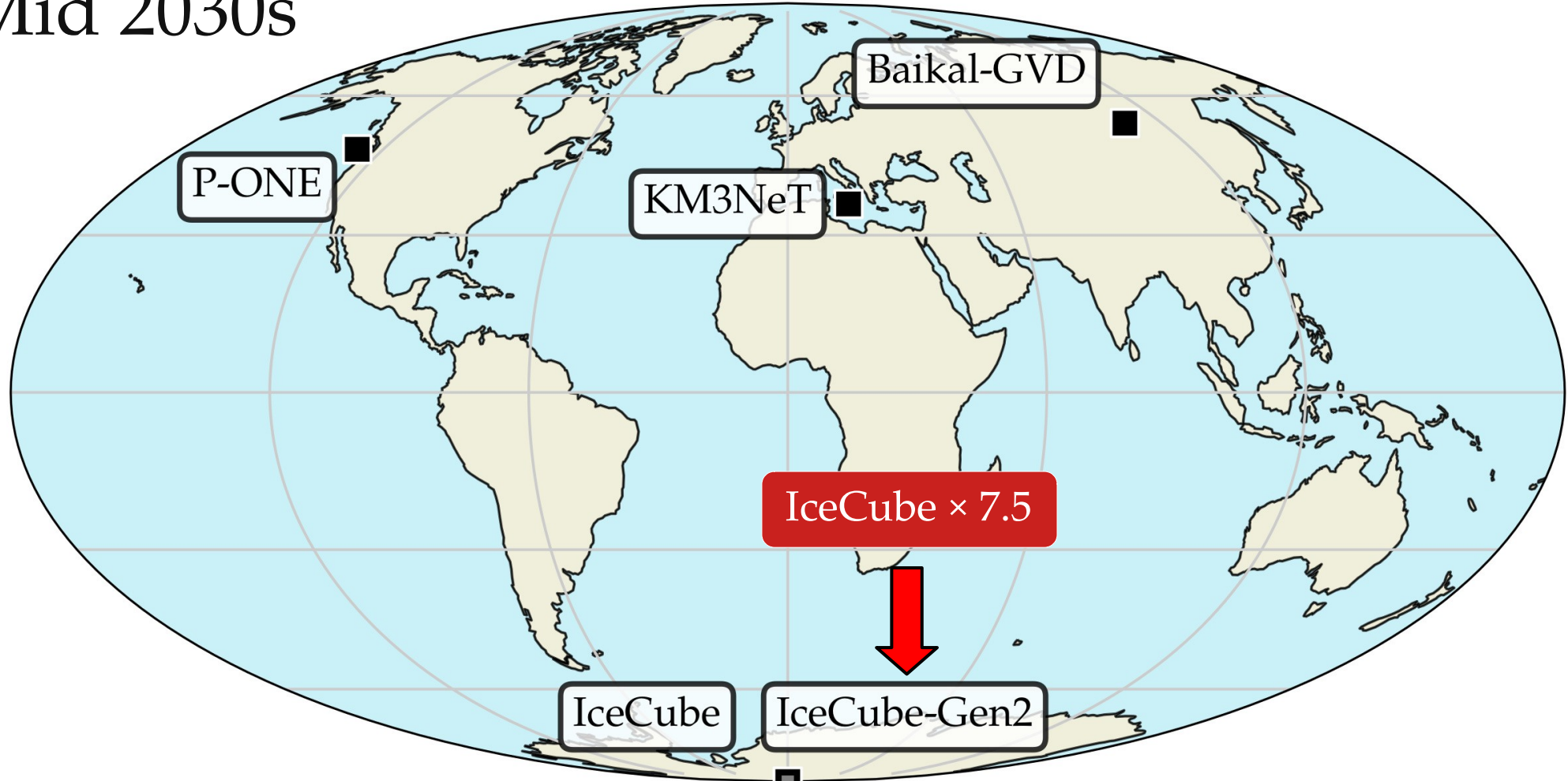


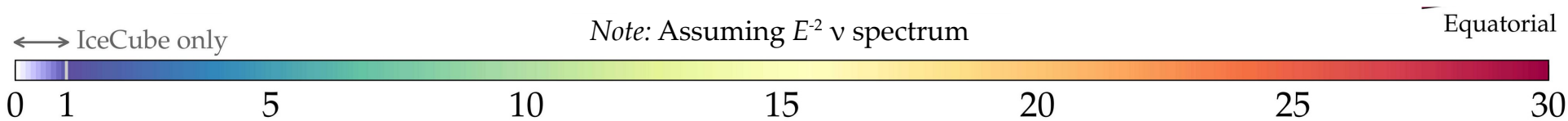
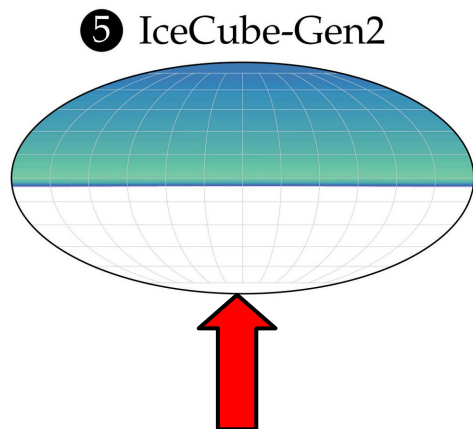
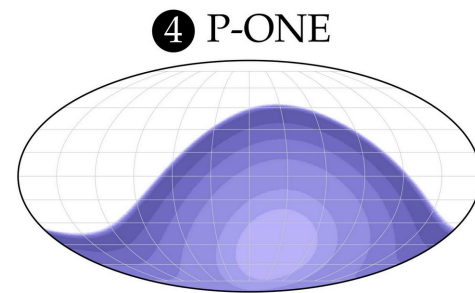
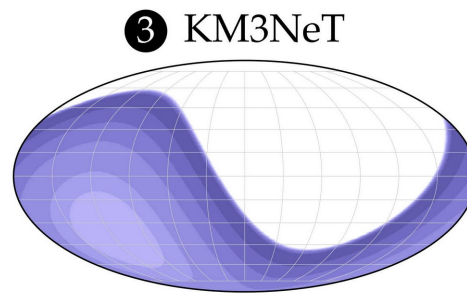
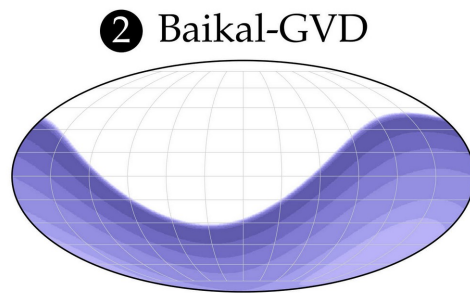
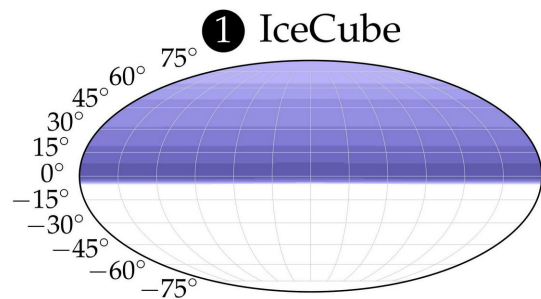
Early 2030s



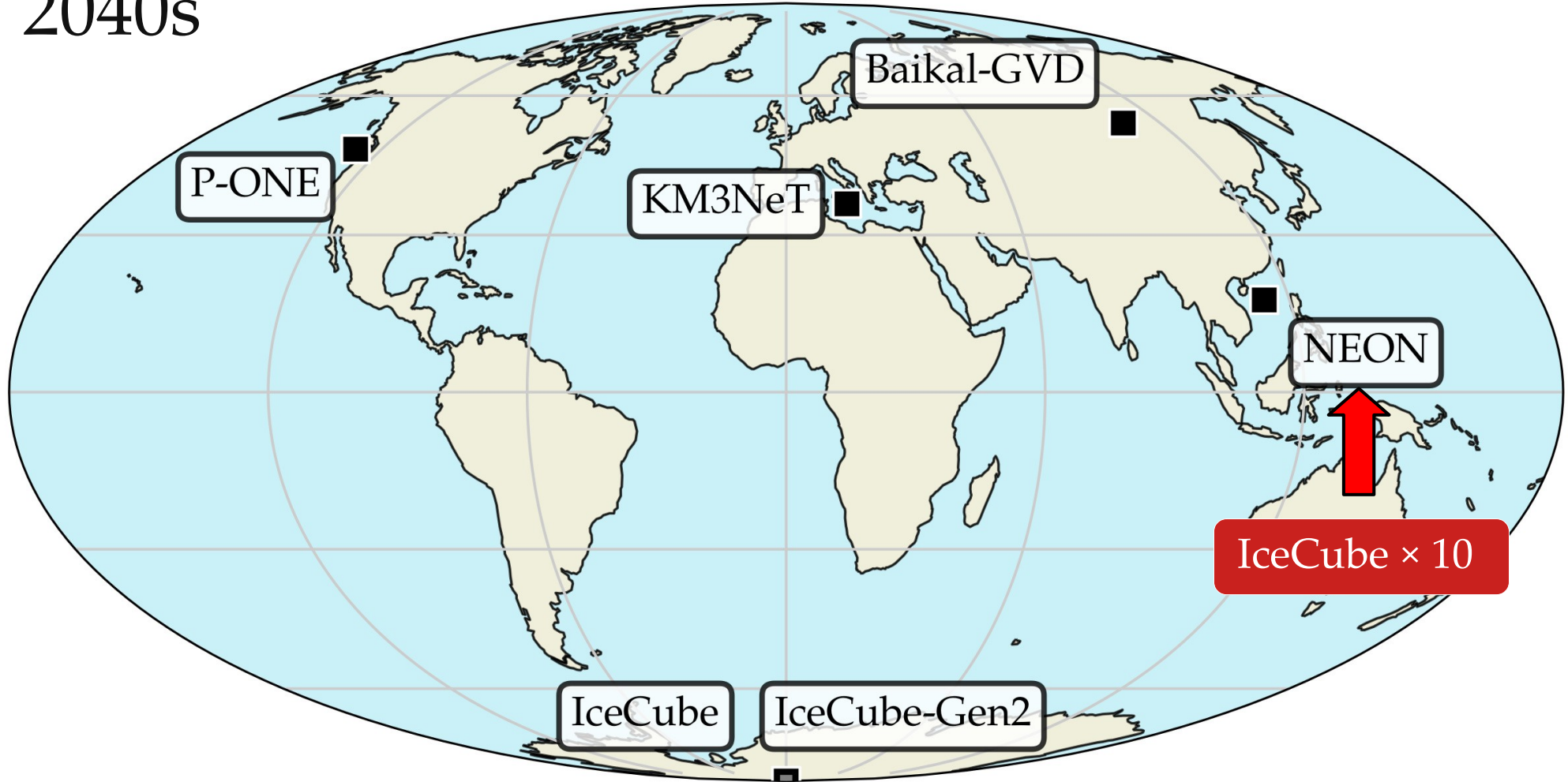


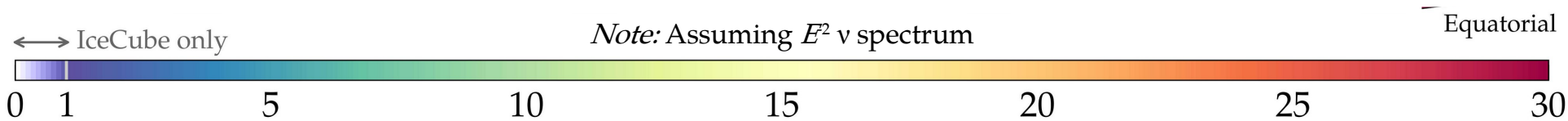
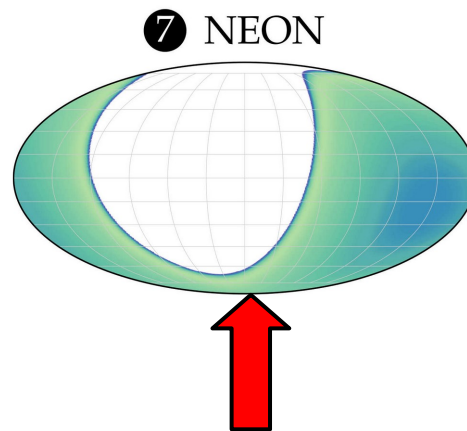
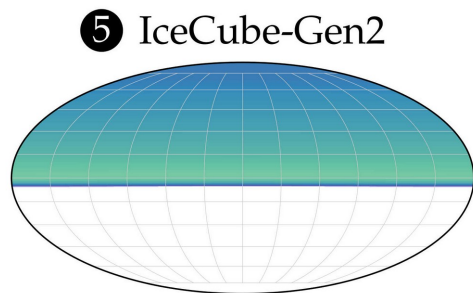
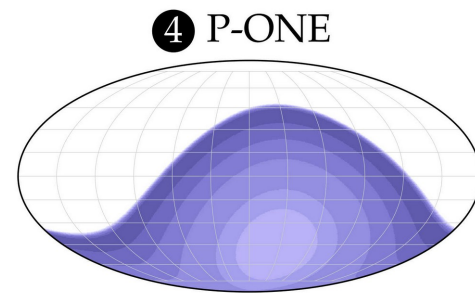
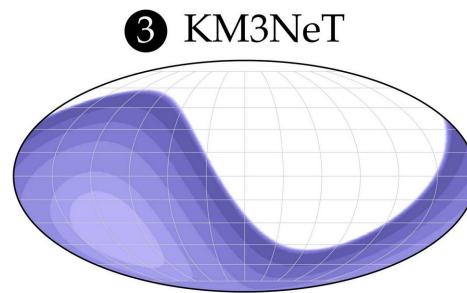
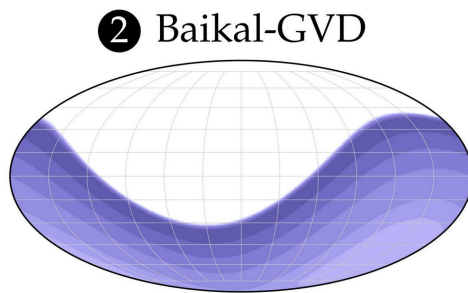
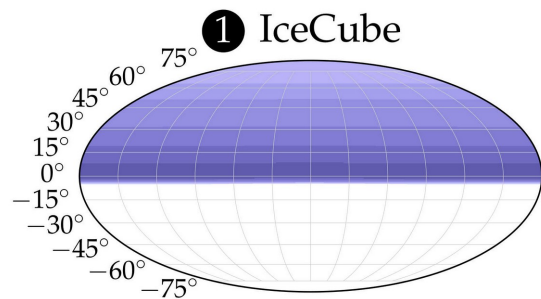
Mid 2030s





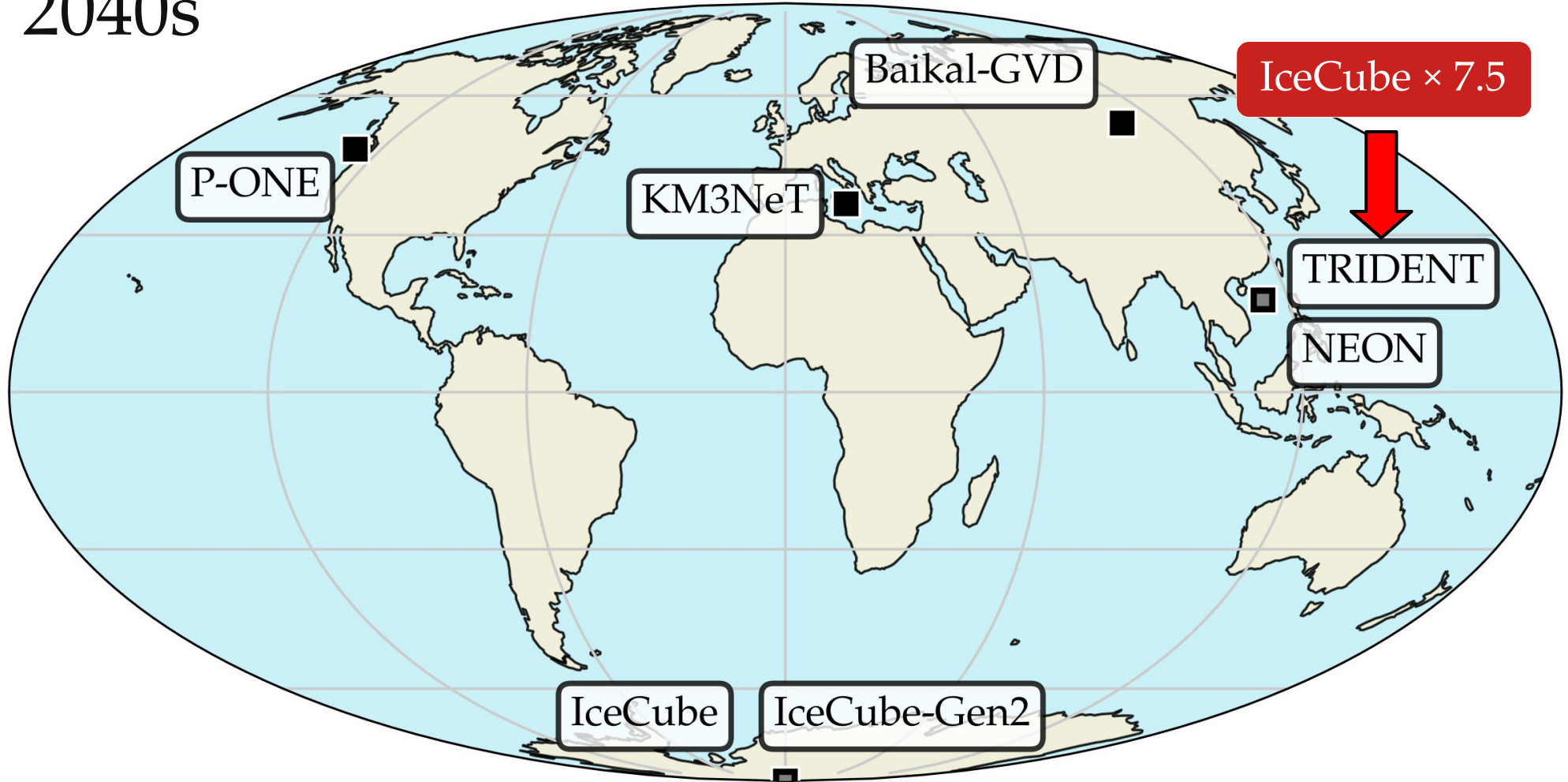
2040s

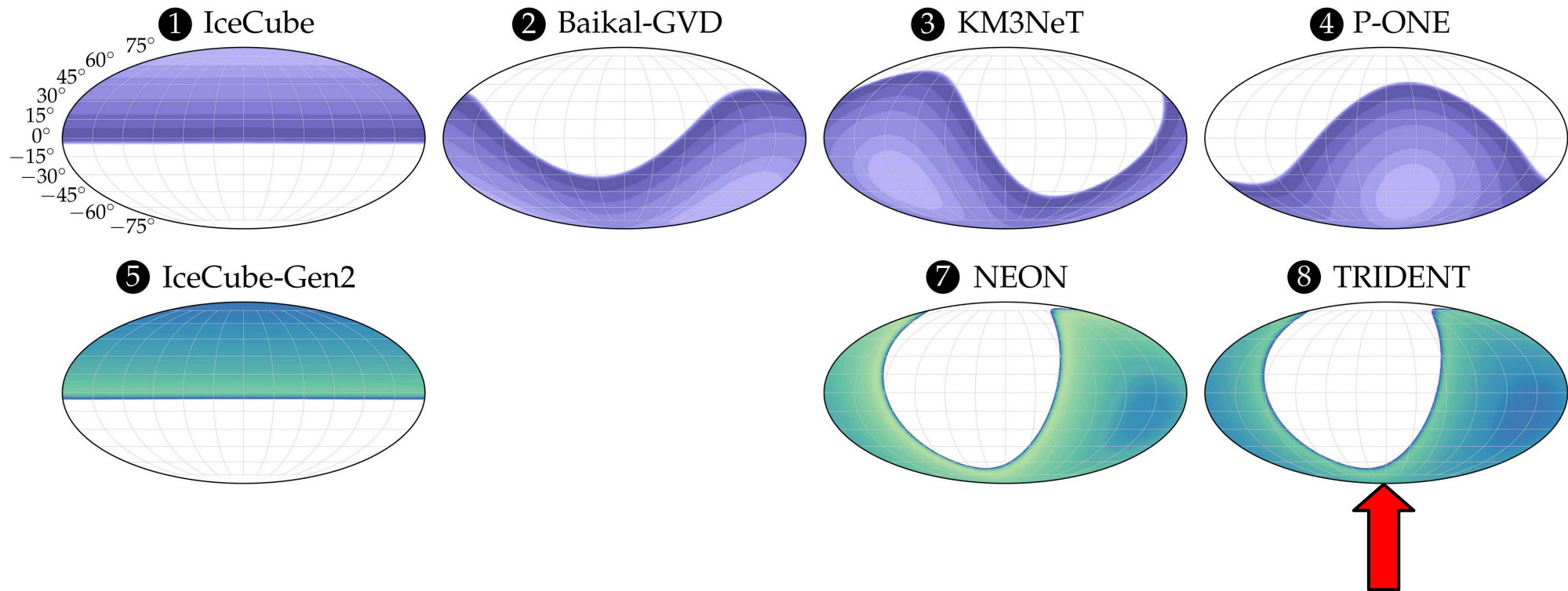




Rate of detected muon tracks relative to IceCube maximum

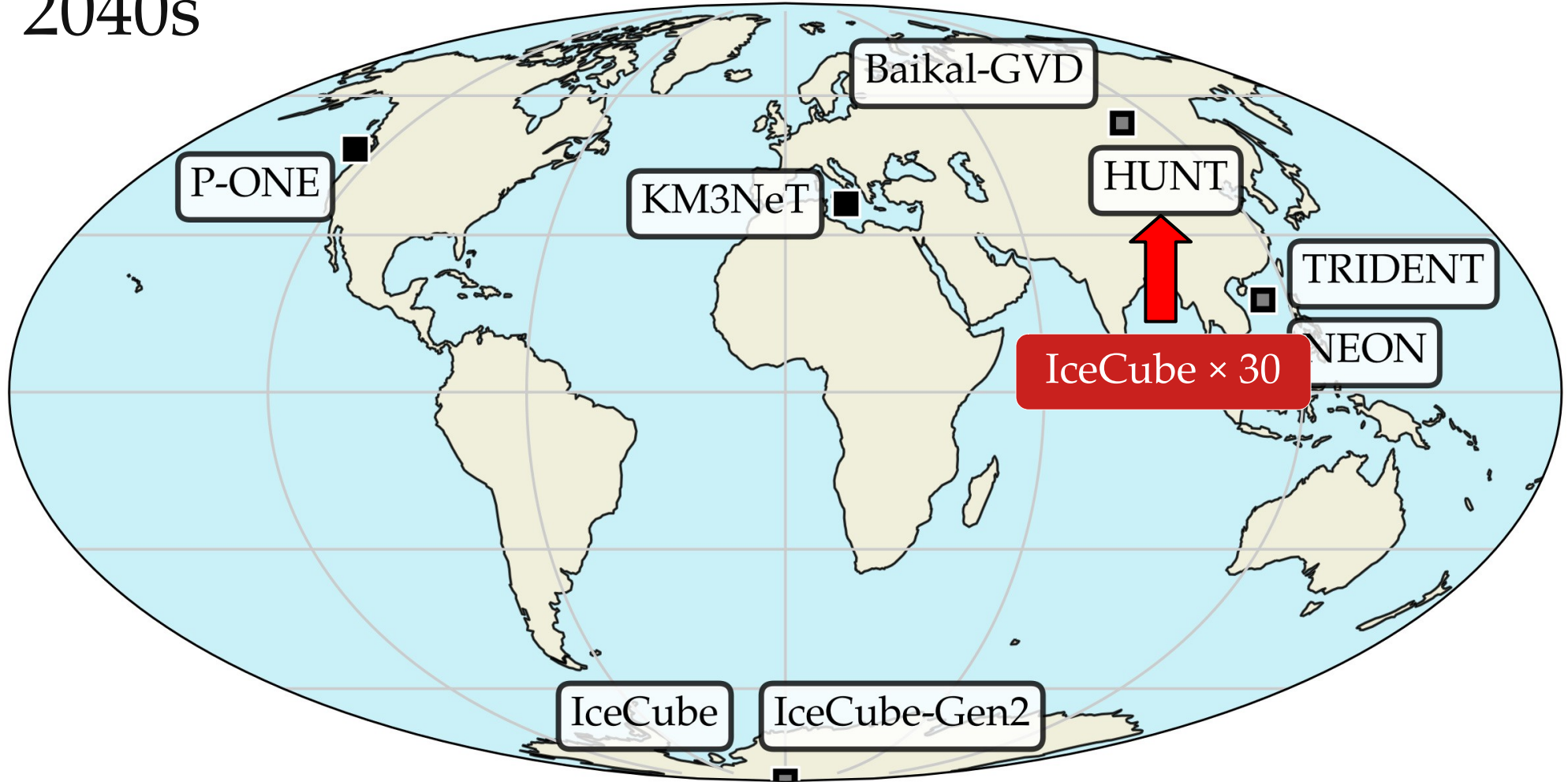
2040s

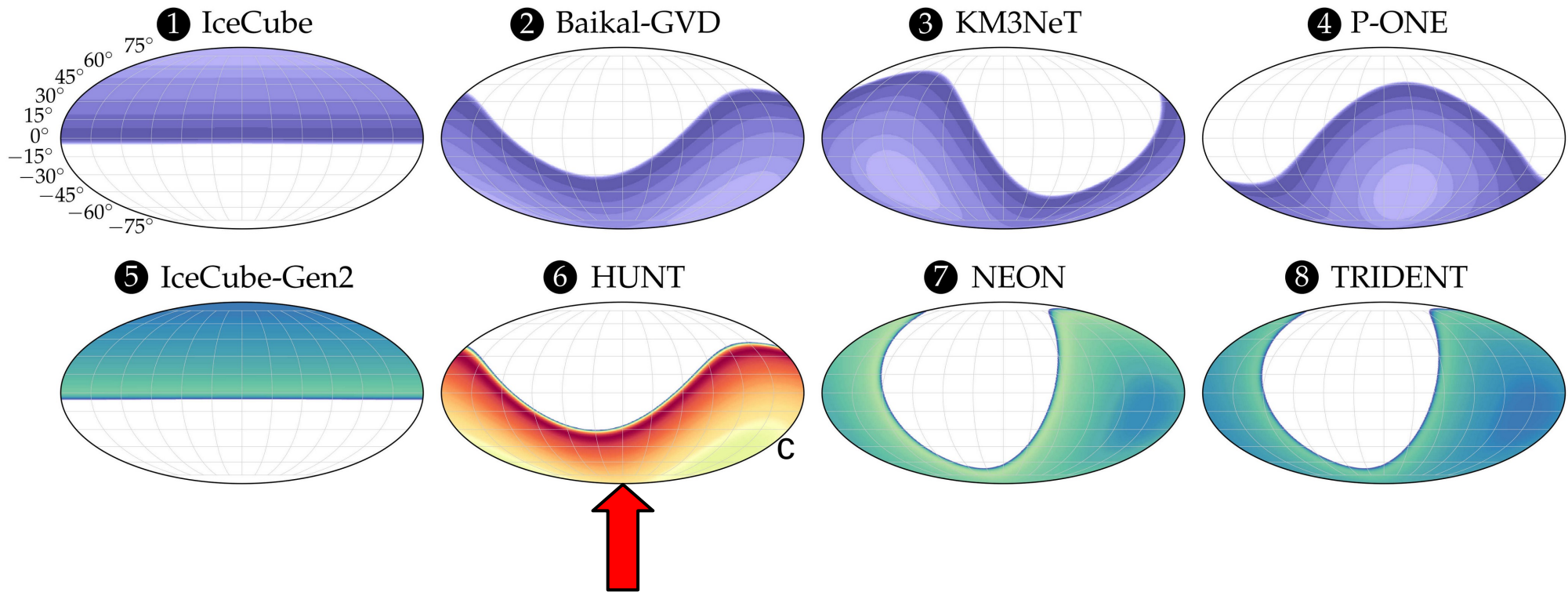




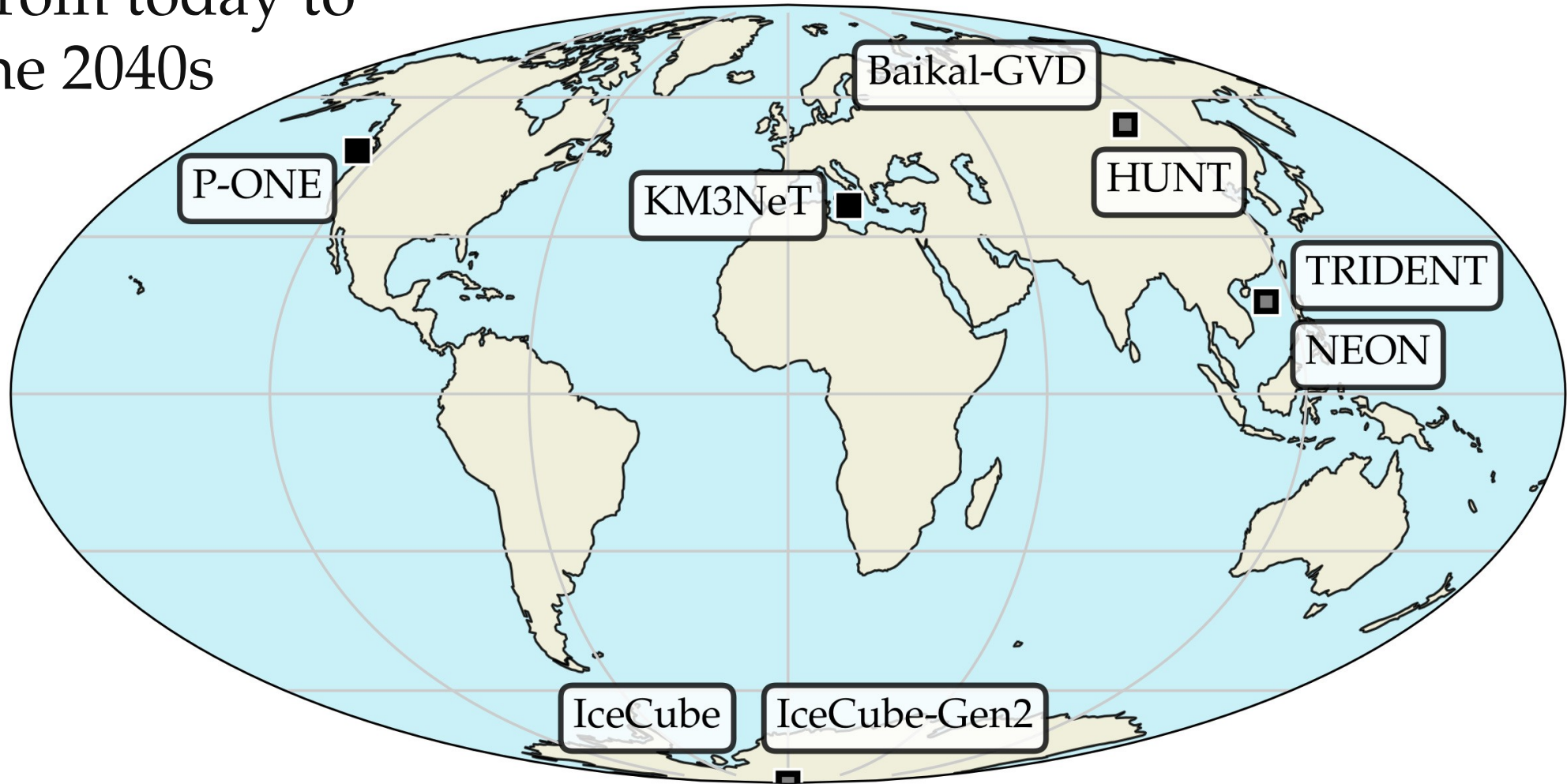
Rate of detected muon tracks relative to IceCube maximum

2040s





From today to
the 2040s

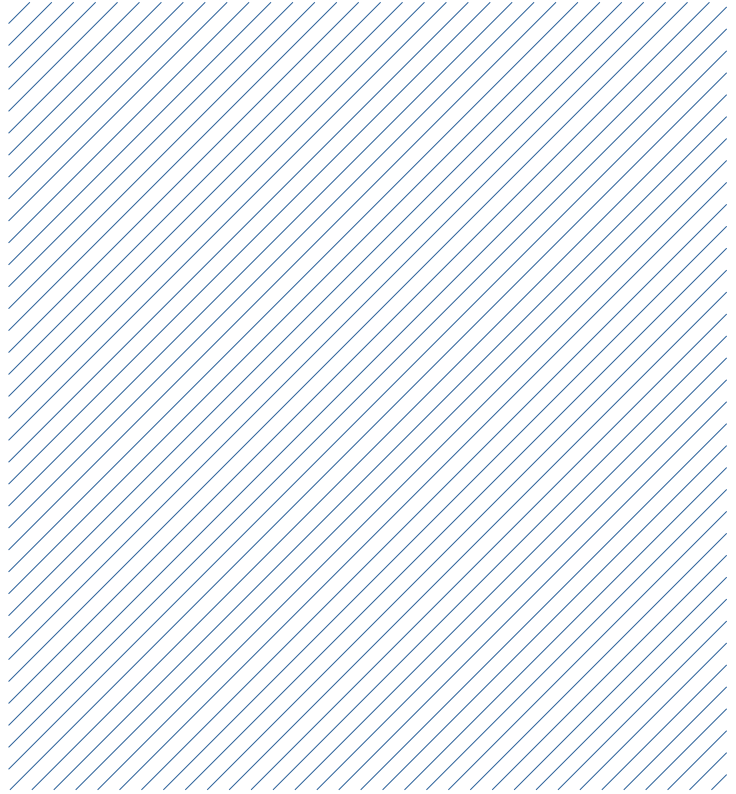


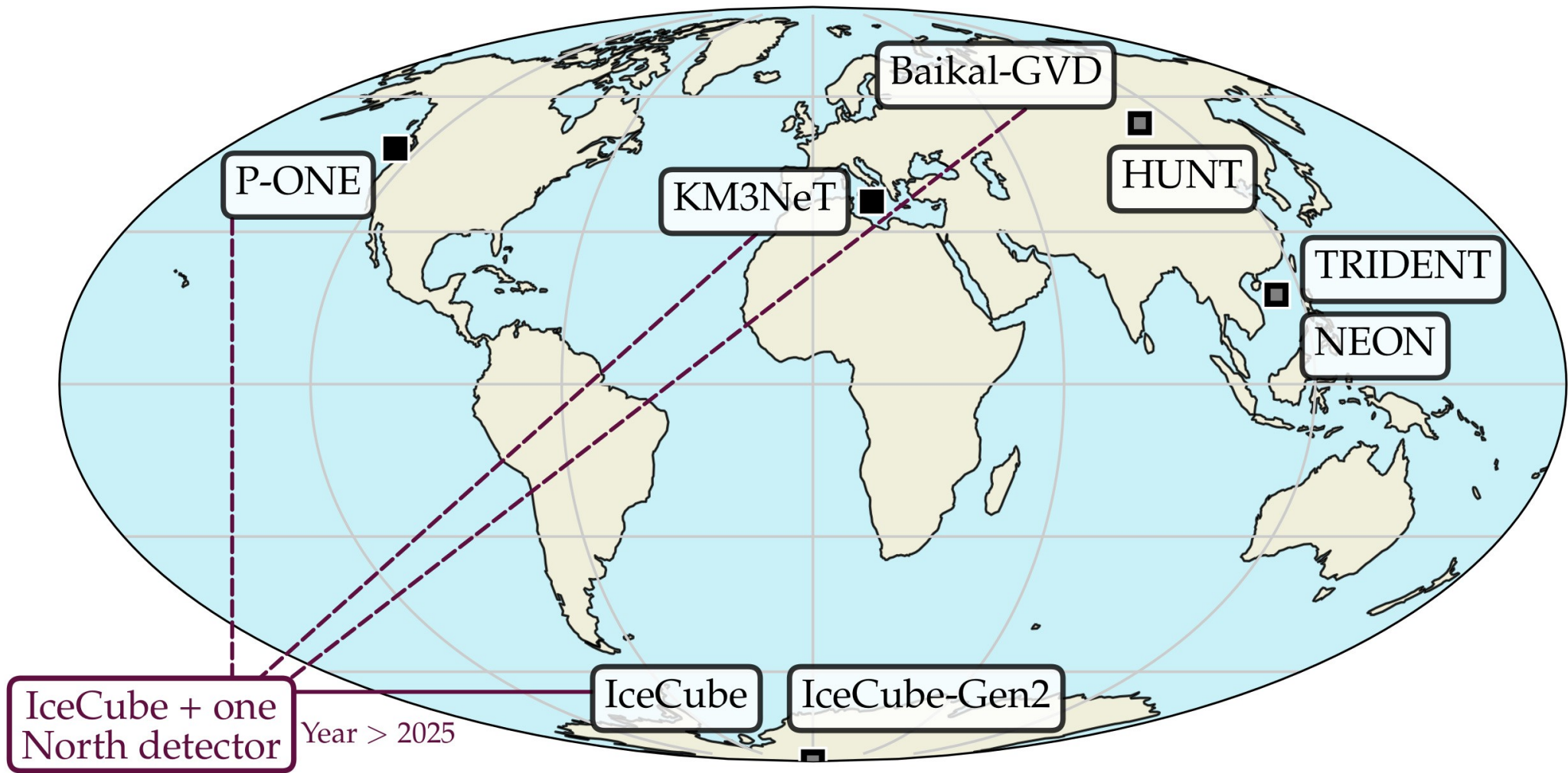
Neutrino telescope	Location	Size relative to IceCube ^a	Start date ^b
Ongoing			
IceCube	South Pole	1	2011
Under construction			
KM3NeT	Mediterranean Sea	1	2025
Baikal-GVD	Lake Baikal	1	2027
Under prototyping, design, planning			
P-ONE	Cascadia Basin	1	2031
IceCube-Gen2	South Pole	7.5	2035
TRIDENT	South China Sea	7.5	2040
NEON	South China Sea	10	2040
HUNT	Lake Baikal ^c	30	2040

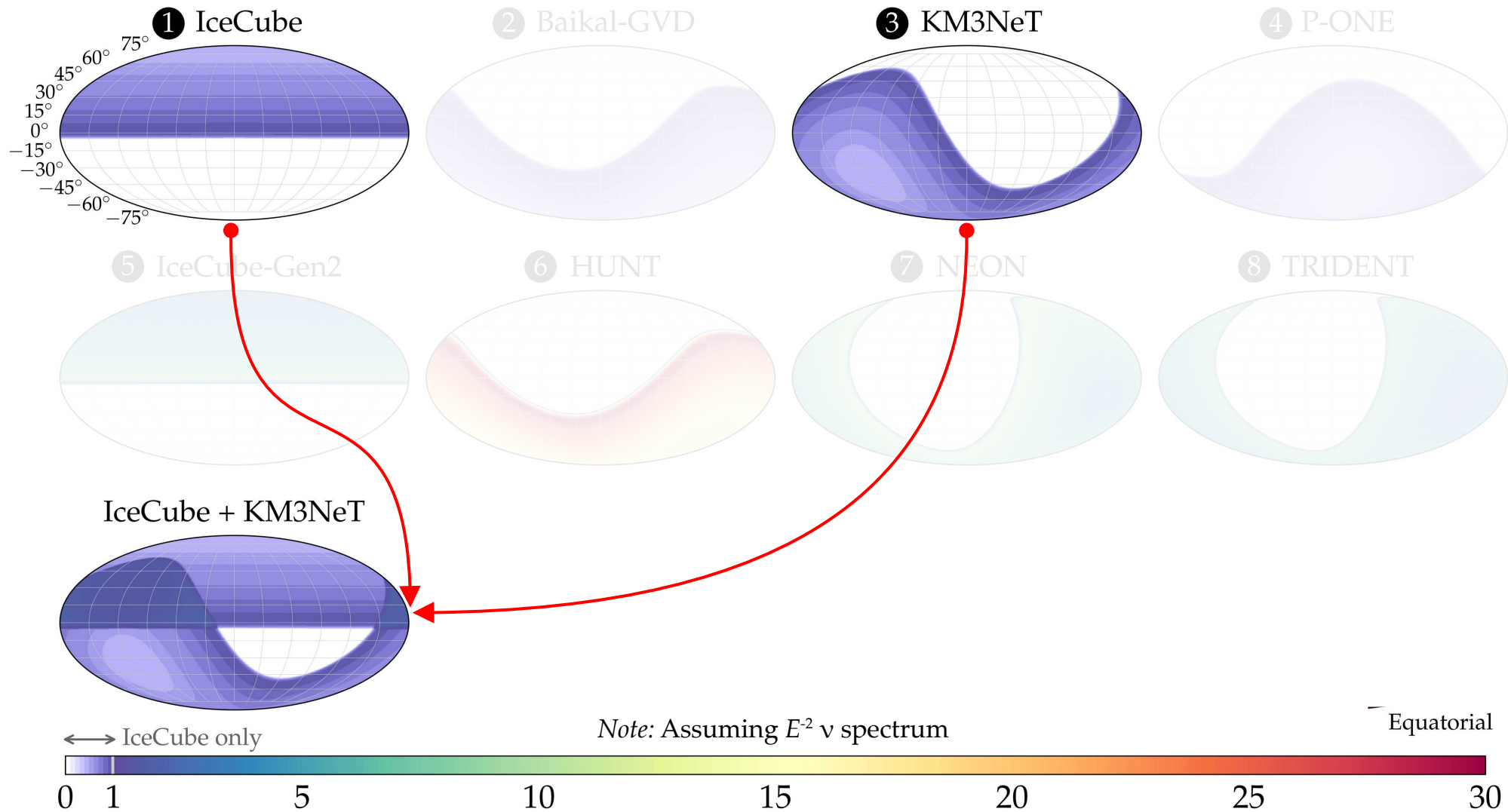
^a Approximate size of the final detector configuration that is used in this paper.

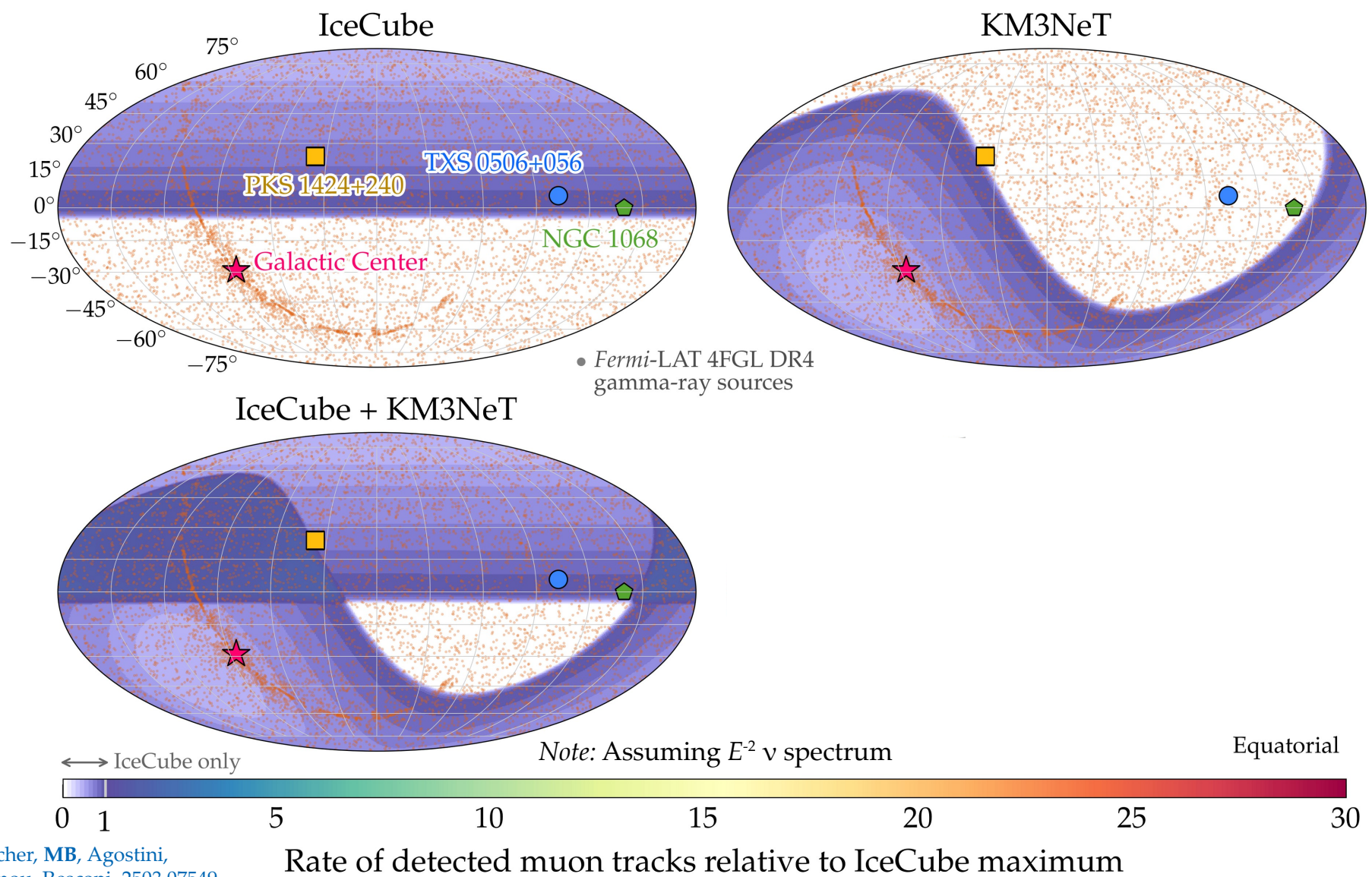
^b Approximate dates when the final configuration of the detector is expected to be completed, used in this analysis but subject to change.

^c Two possible locations have been proposed for HUNT: Lake Baikal and the South China Sea. We use the former in our analysis since NEON and TRIDENT are already planned for the latter.







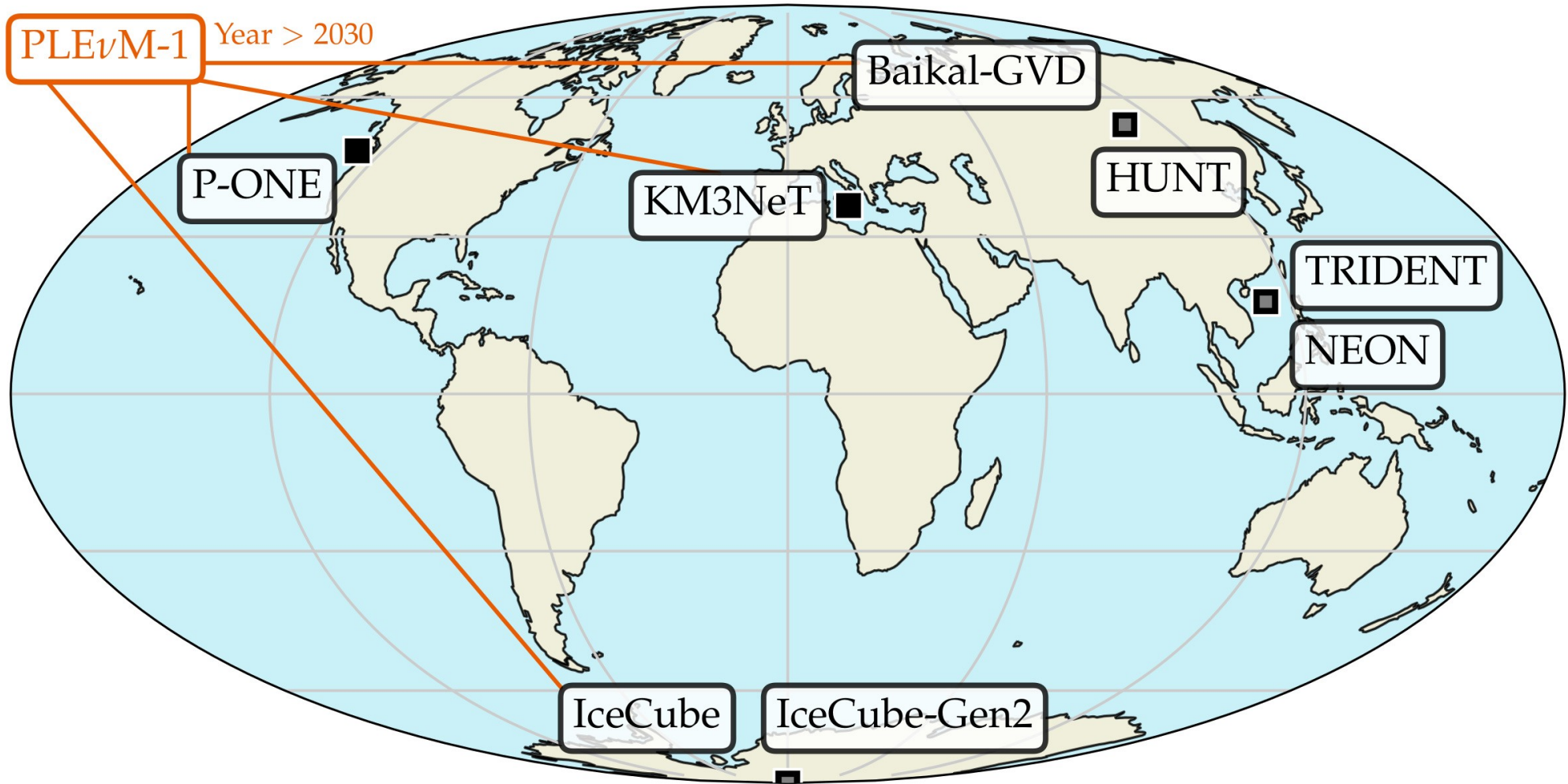


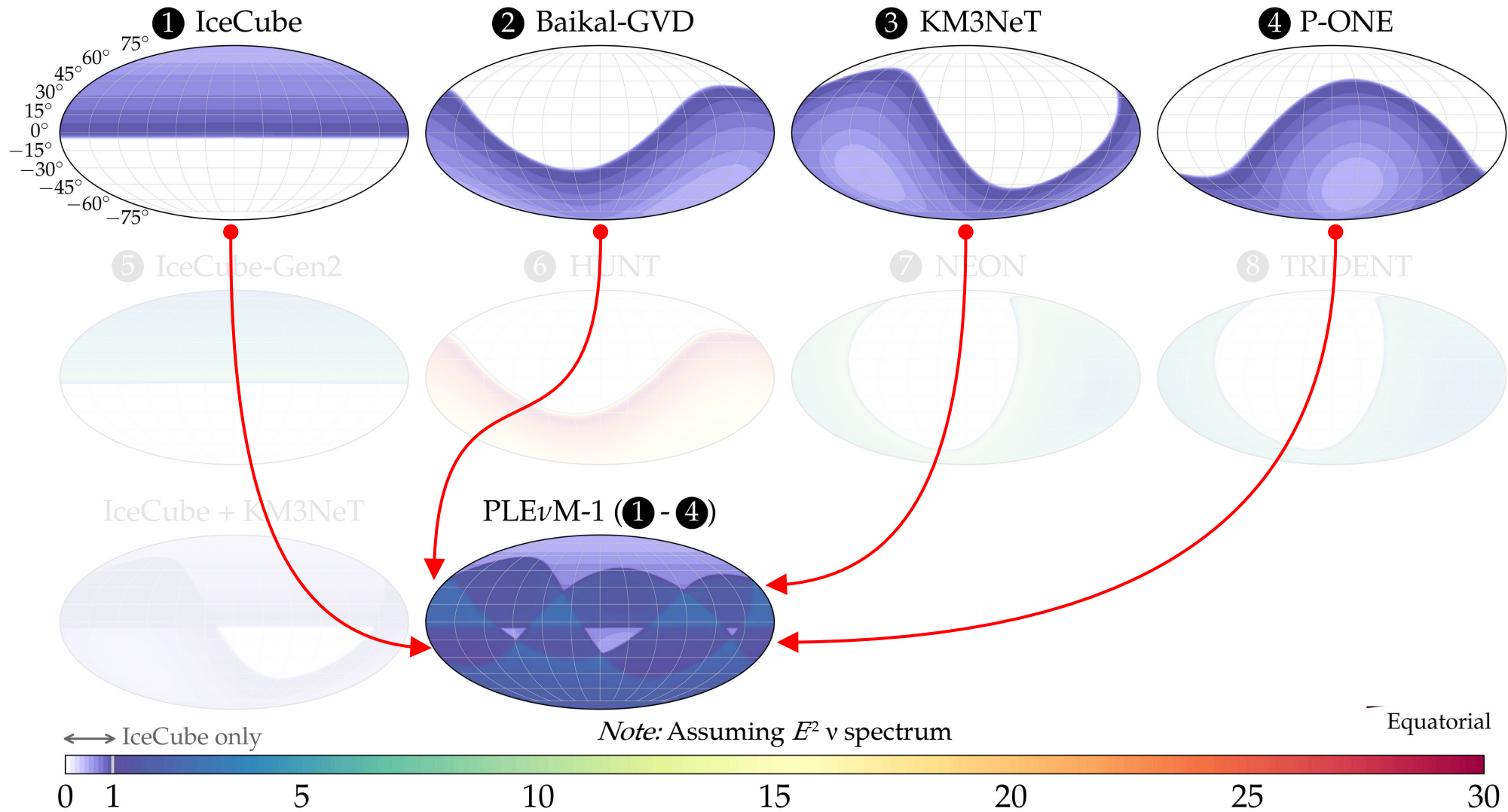
Neutrino telescope	Location	Size relative to IceCube ^a	Start date ^b	Included in PLE ν M		
				PLE ν M-1	PLE ν M-2	PLE ν M-3
Ongoing						
IceCube	South Pole	1	2011	✓		
Under construction						
KM3NeT	Mediterranean Sea	1	2025	✓	✓	✓
Baikal-GVD	Lake Baikal	1	2027	✓	✓	✓
Under prototyping, design, planning						
P-ONE	Cascadia Basin	1	2031	✓	✓	✓
IceCube-Gen2	South Pole	7.5	2035		✓	✓
TRIDENT	South China Sea	7.5	2040			✓
NEON	South China Sea	10	2040			✓
HUNT	Lake Baikal ^c	30	2040			✓

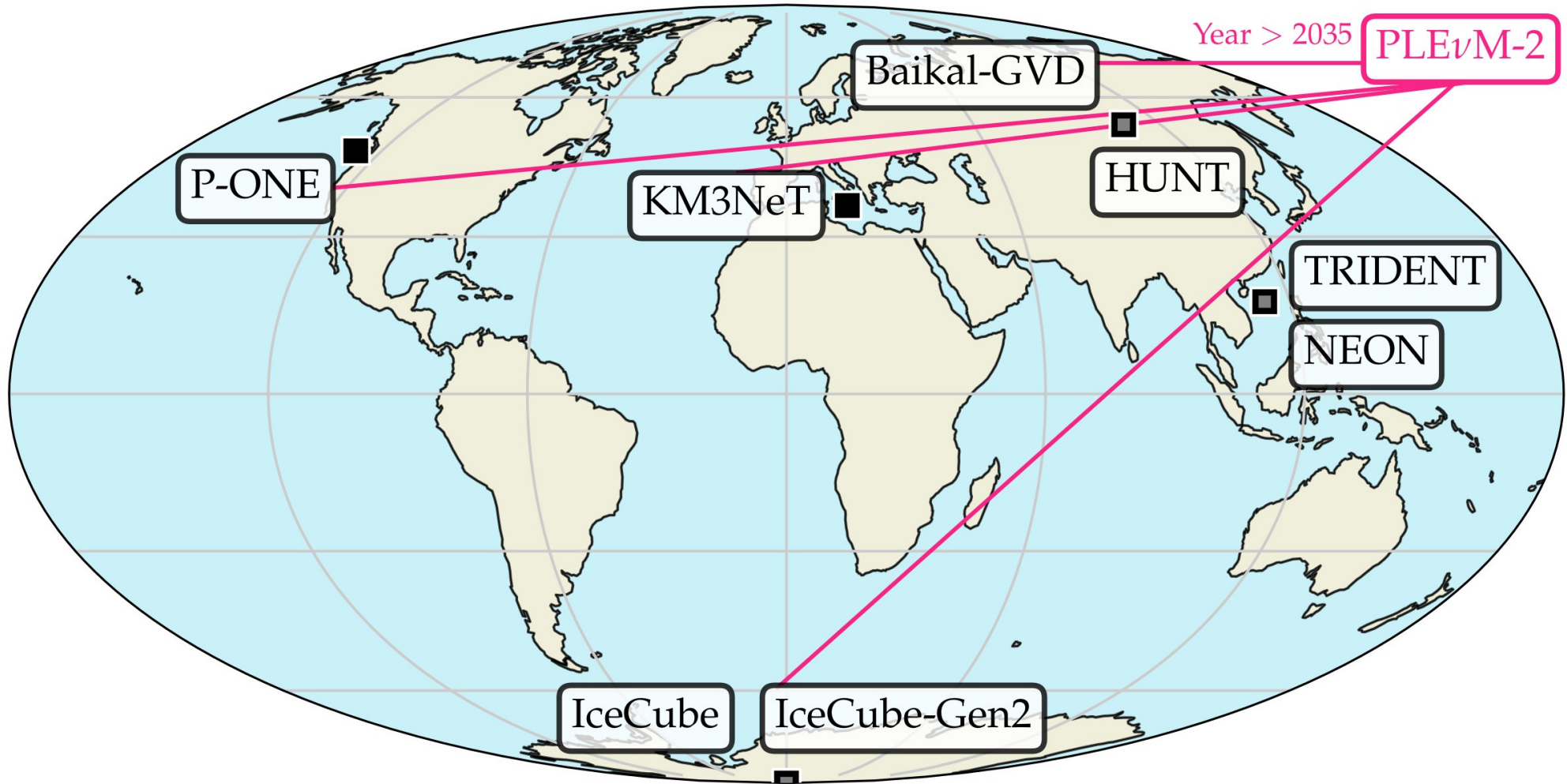
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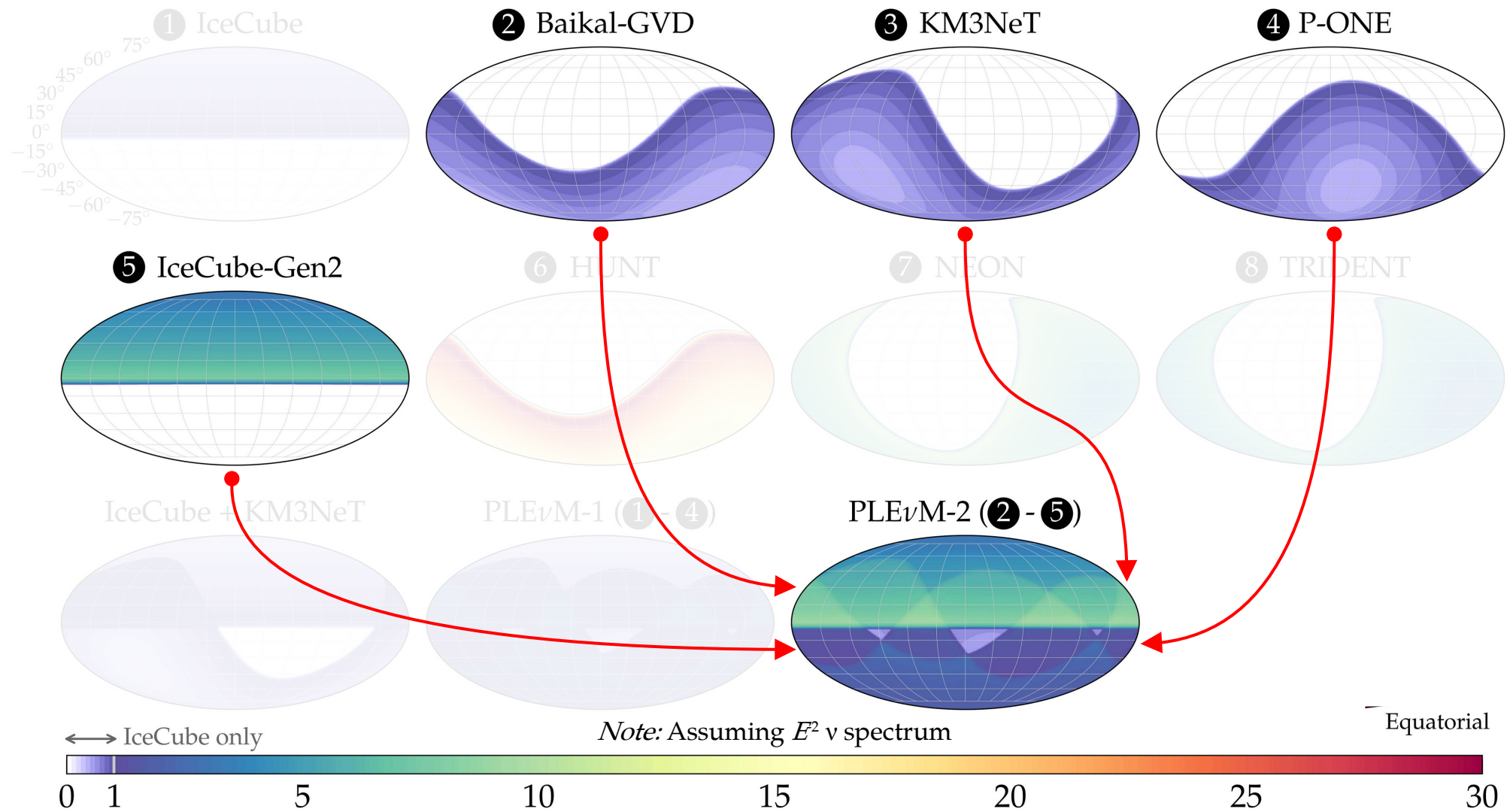
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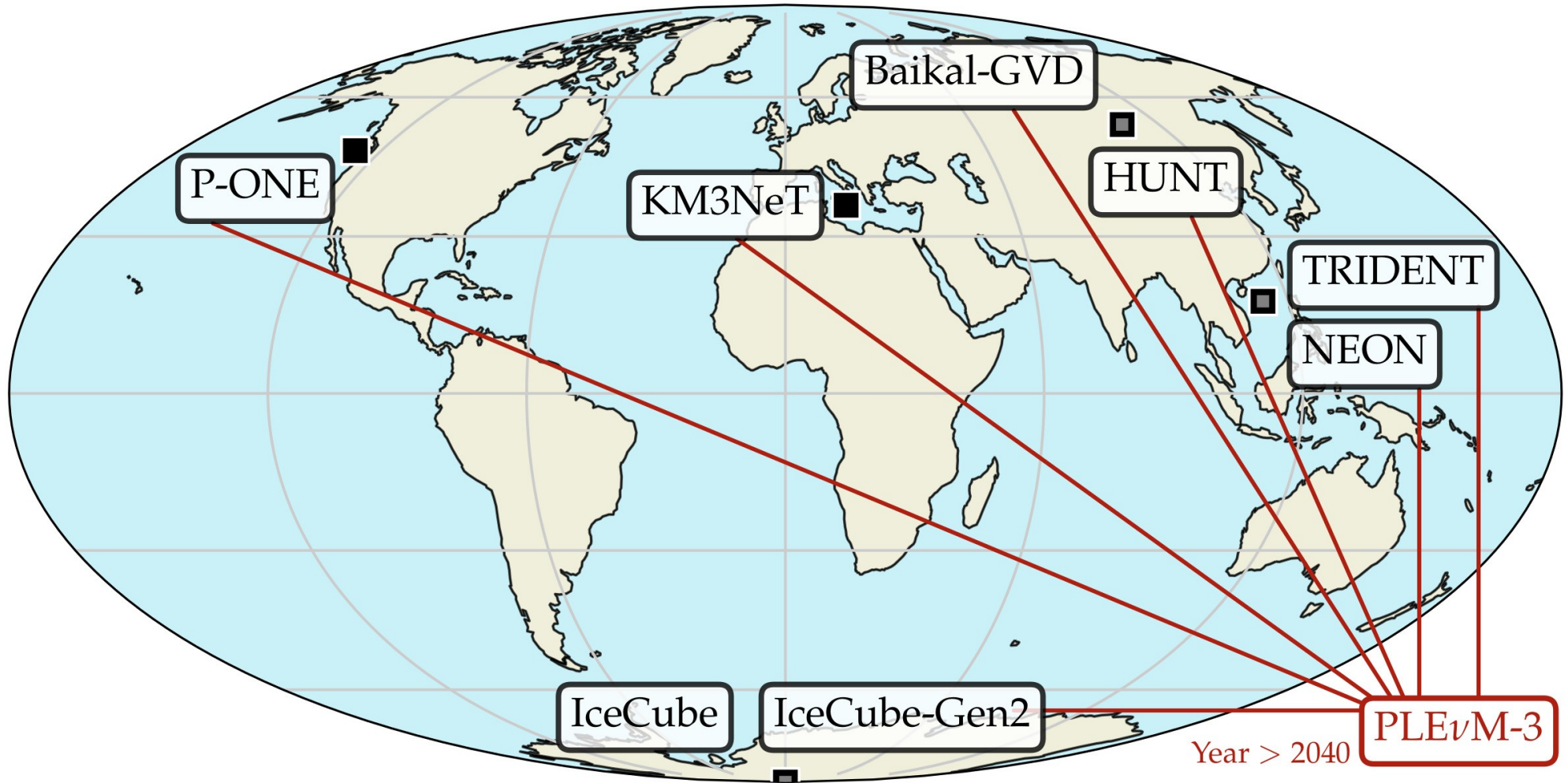
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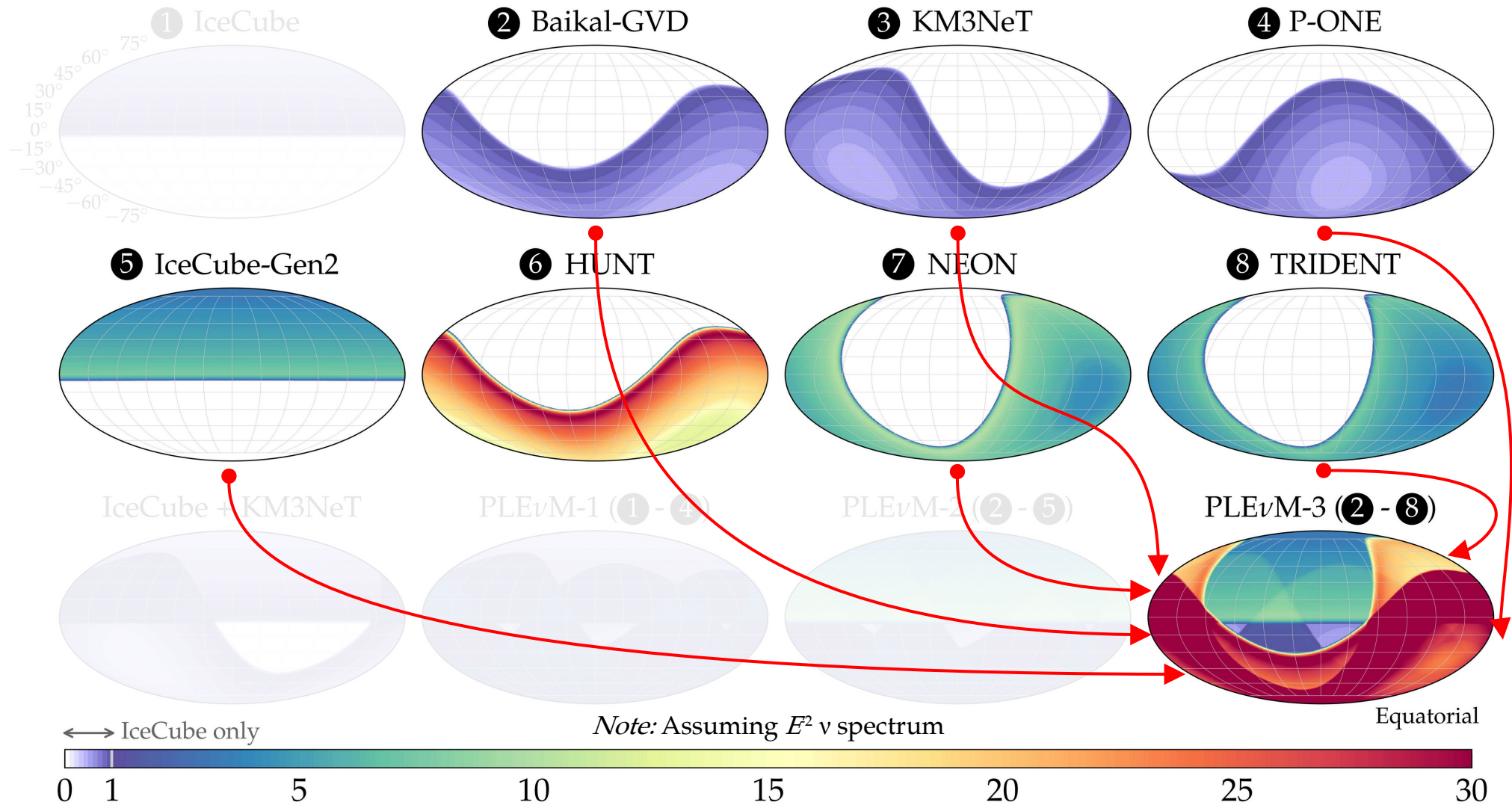




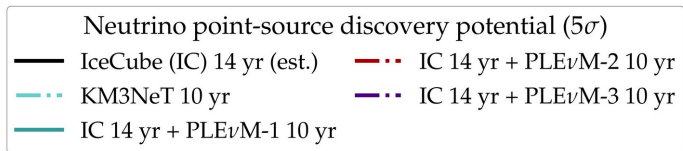








Discovery (5σ) of a steady-state point source



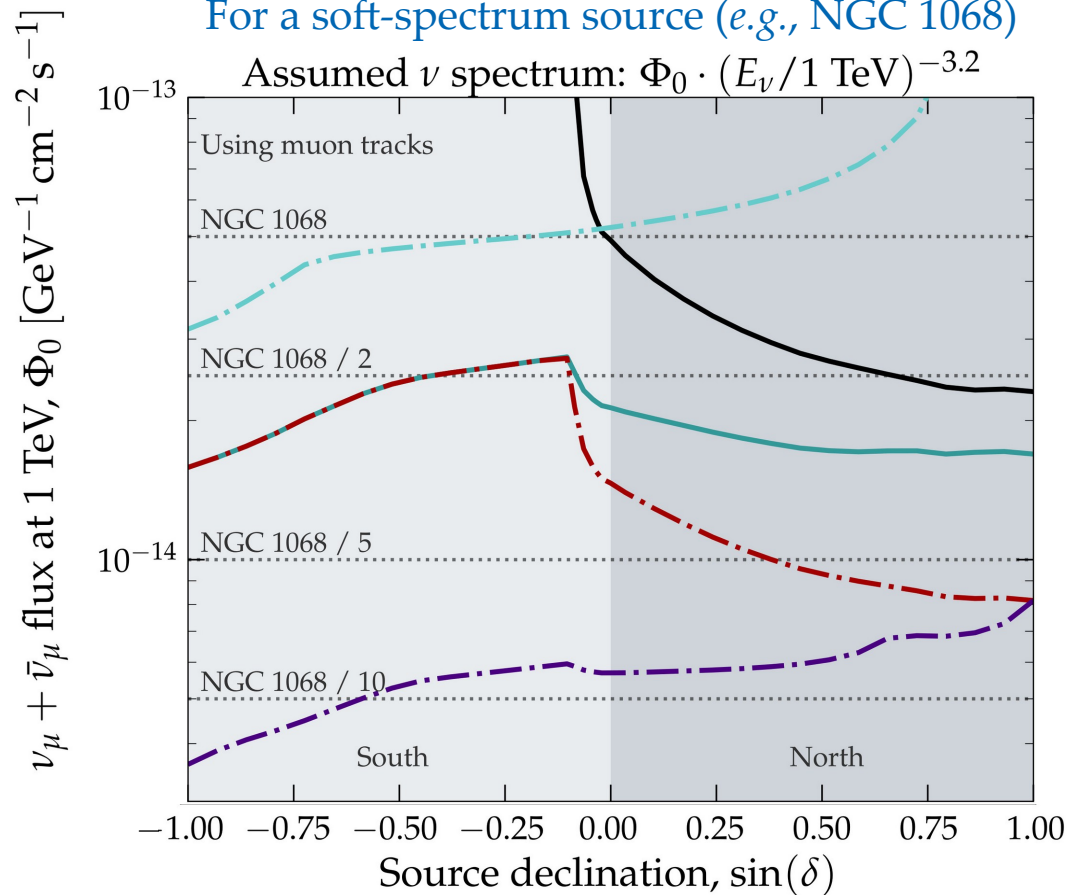
PLE ν M-1: IceCube + Baikal-GVD + KM3NeT + P-ONE

PLE ν M-2: IceCube-Gen2 + Baikal-GVD + KM3NeT + P-ONE

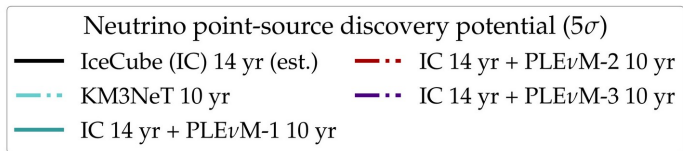
PLE ν M-3: PLE ν M-2 + HUNT + TRIDENT + NEON

For a soft-spectrum source (*e.g.*, NGC 1068)

Assumed ν spectrum: $\Phi_0 \cdot (E_\nu/1 \text{ TeV})^{-3.2}$



Discovery (5σ) of a steady-state point source



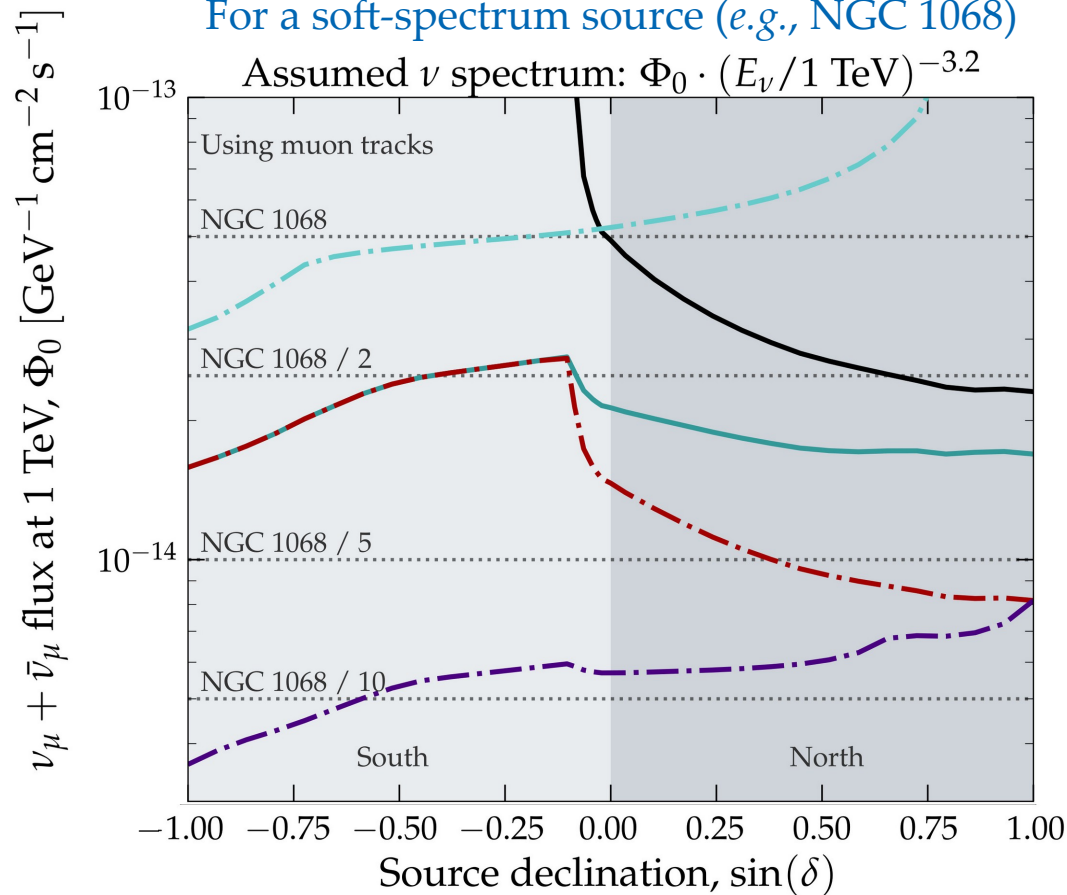
PLE ν M-1: IceCube + Baikal-GVD + KM3NeT + P-ONE

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PLE ν M-3: PLE ν M-2 + HUNT + TRIDENT + NEON

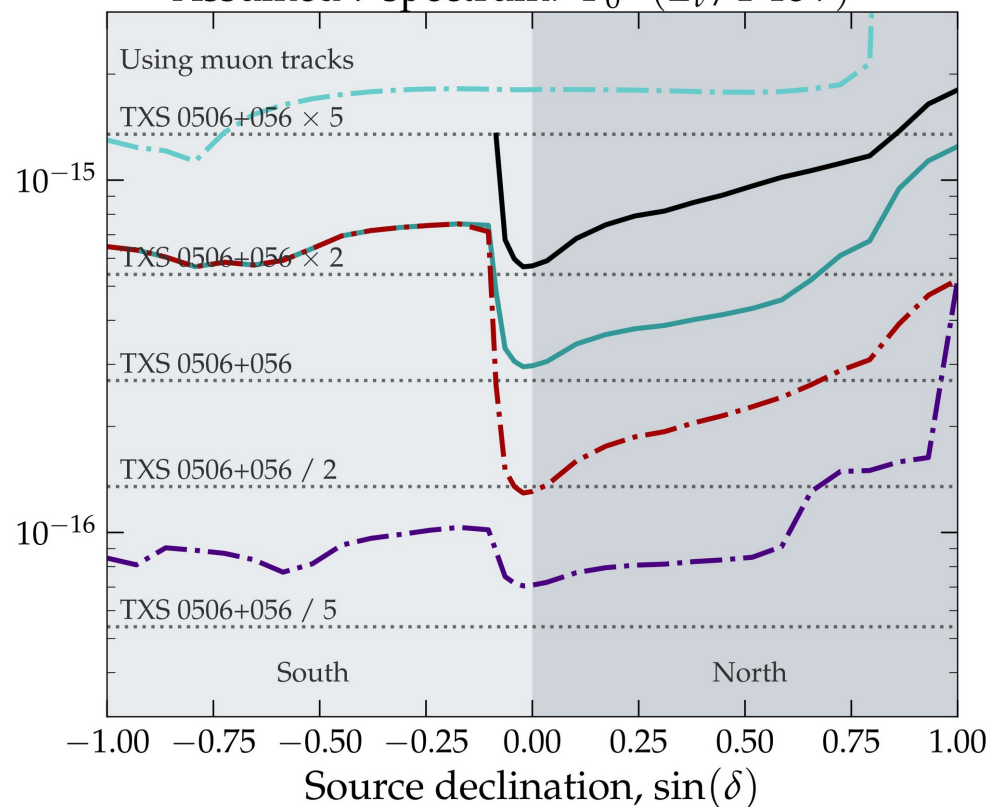
For a soft-spectrum source (*e.g.*, NGC 1068)

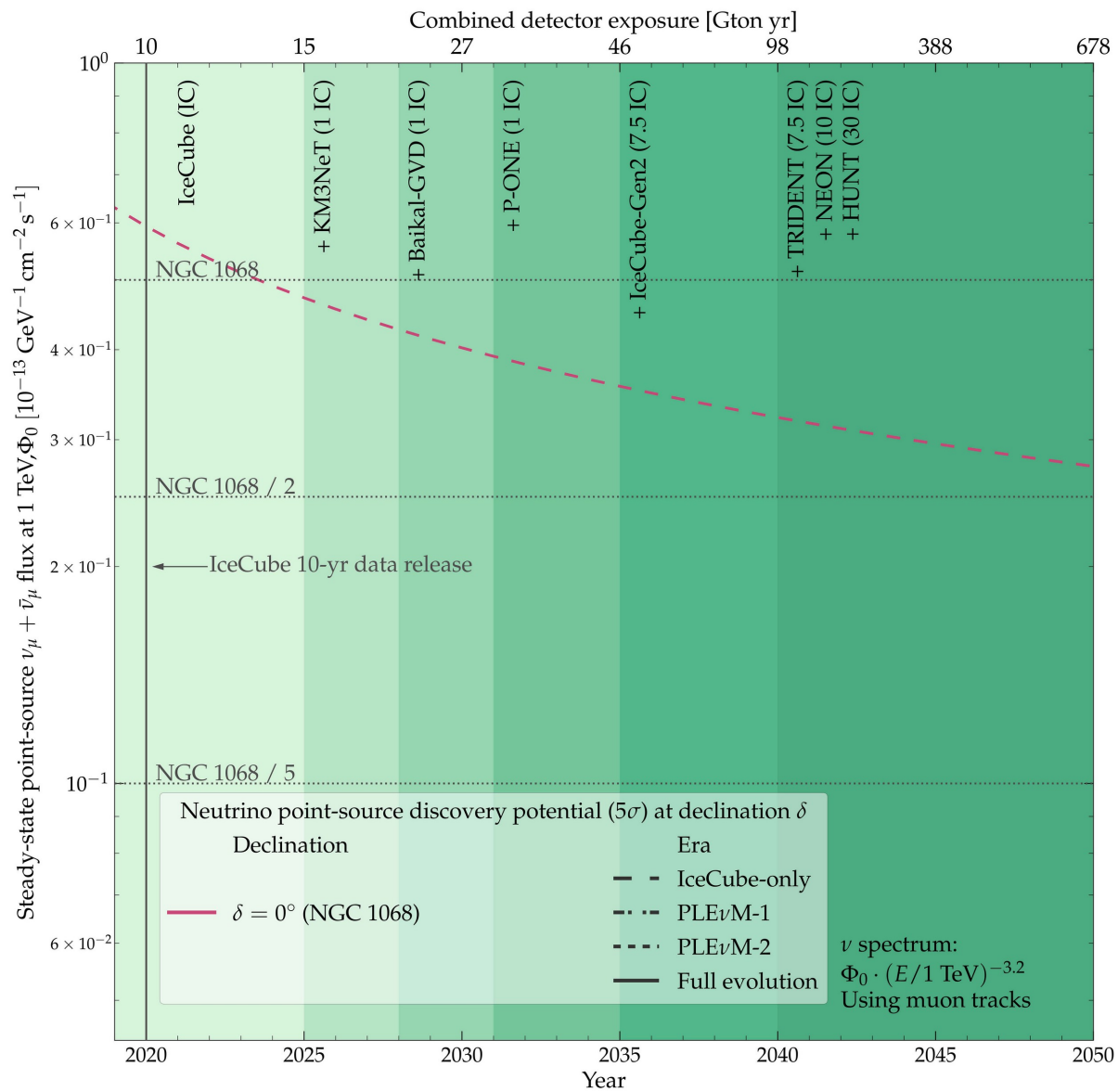
Assumed ν spectrum: $\Phi_0 \cdot (E_\nu/1 \text{ TeV})^{-3.2}$

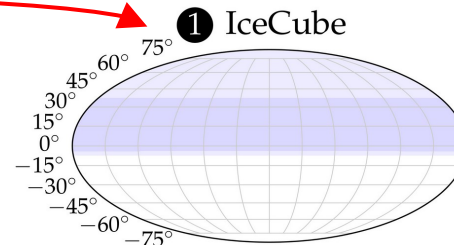
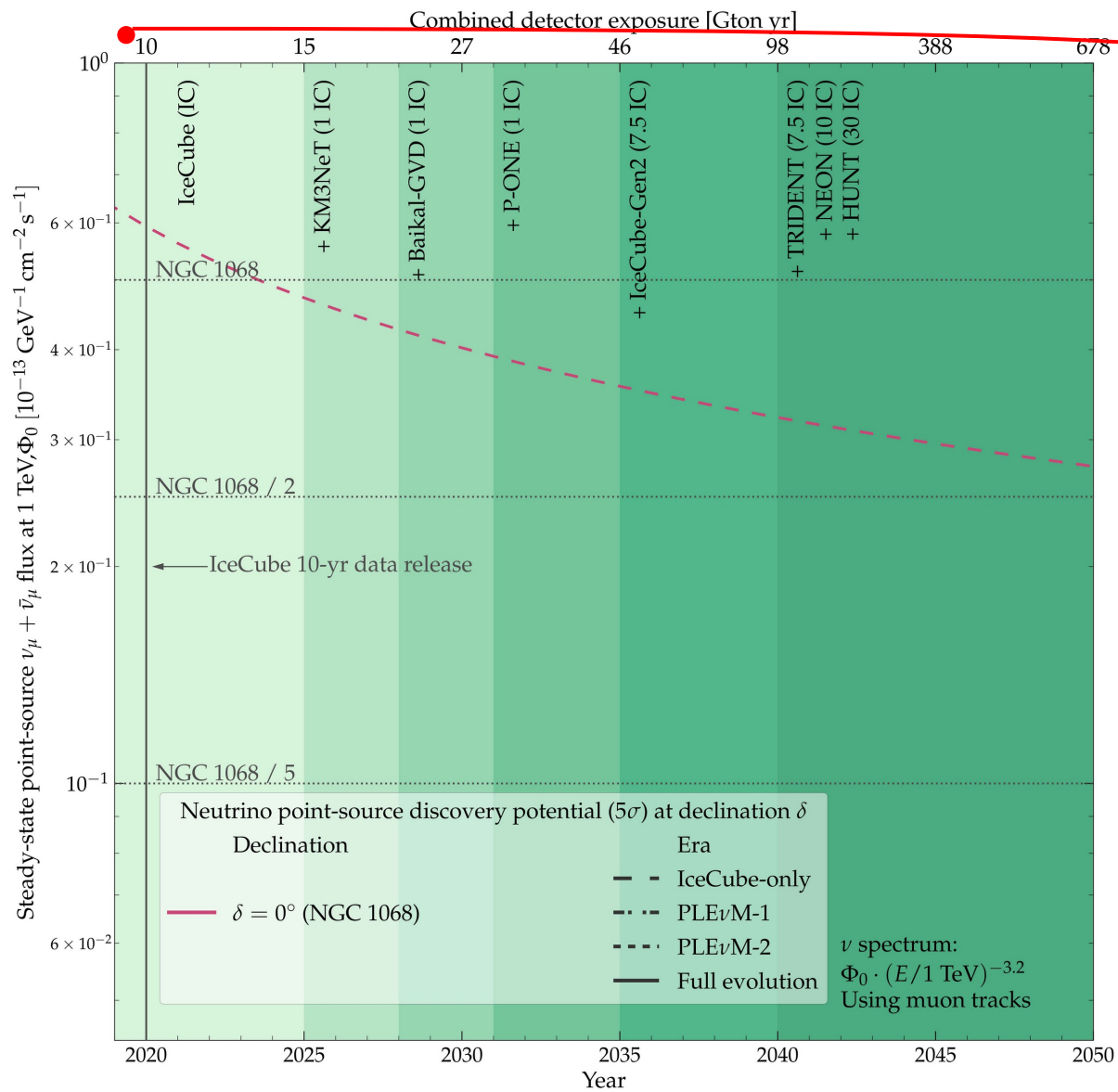


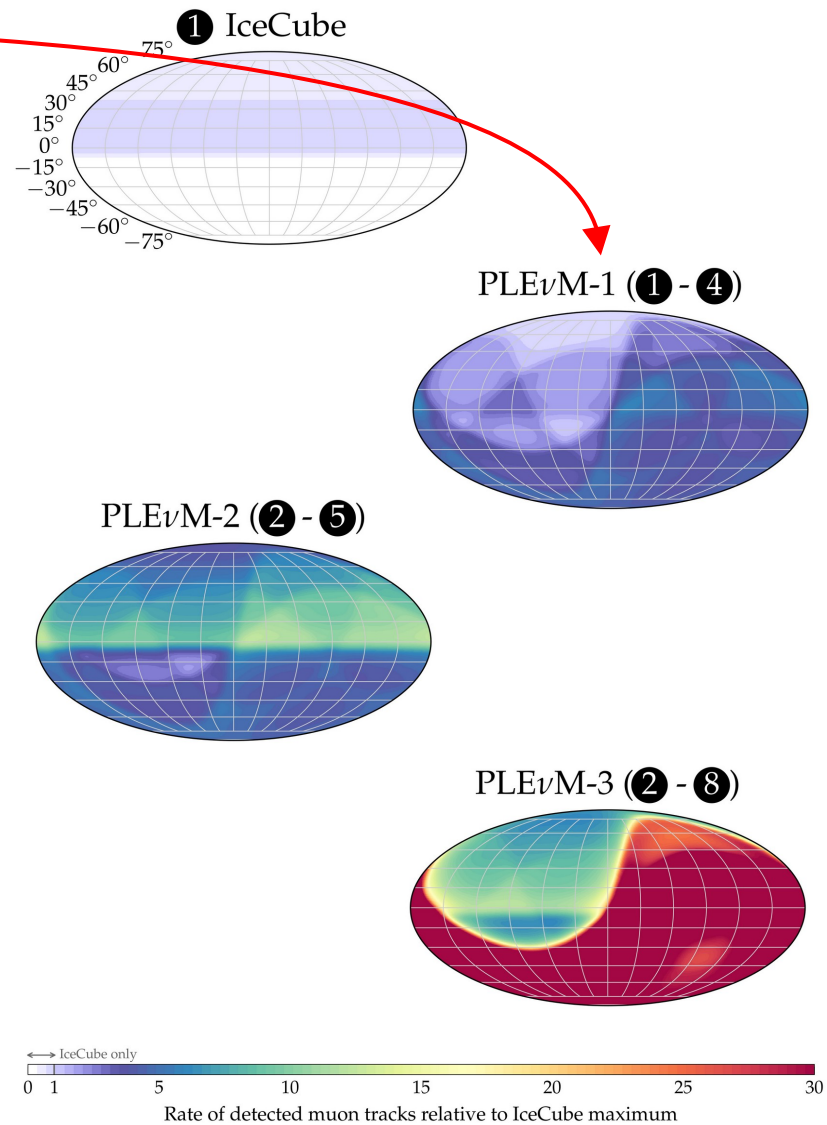
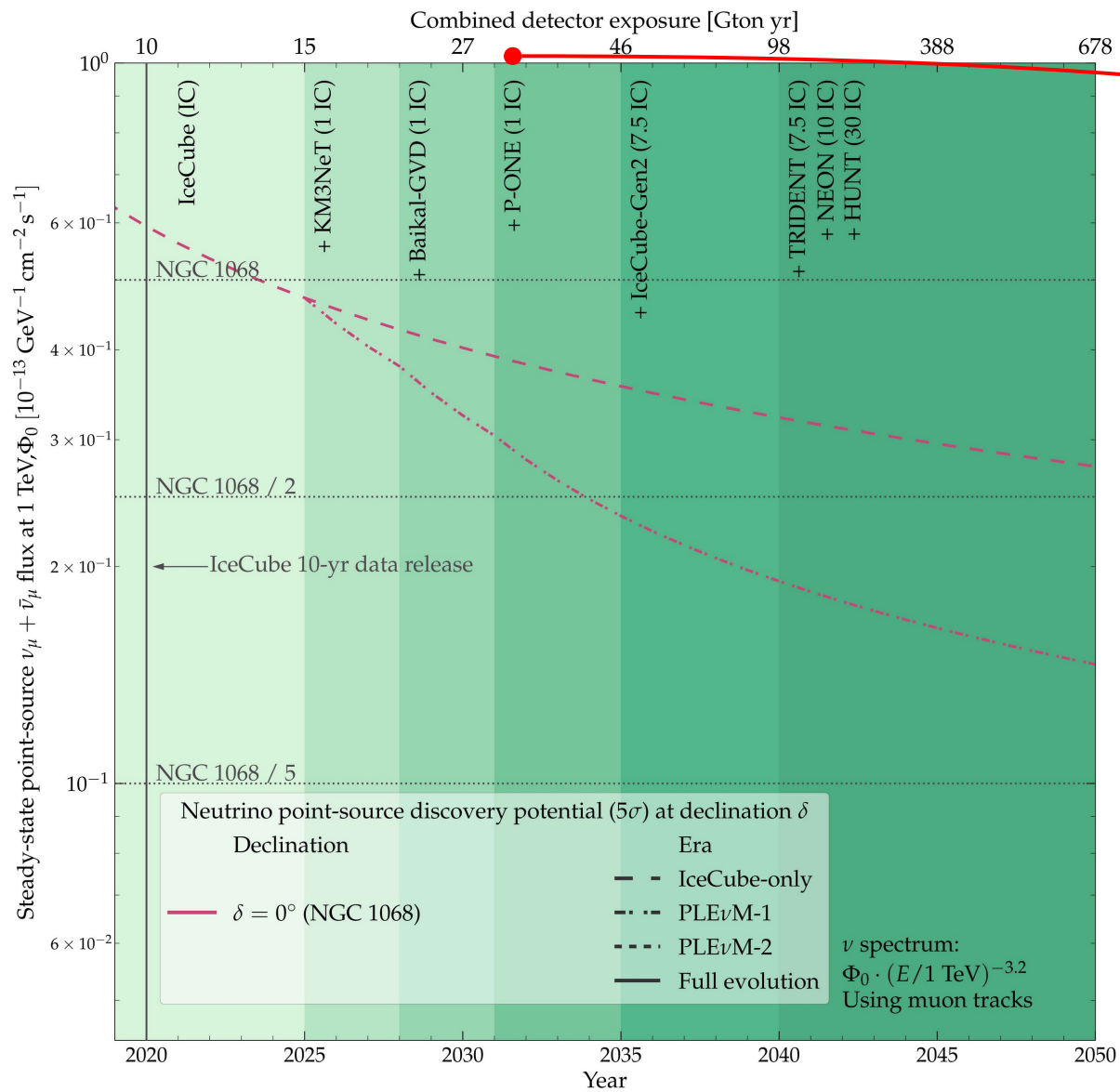
For a hard-spectrum source (*e.g.*, TXS 0506+056)

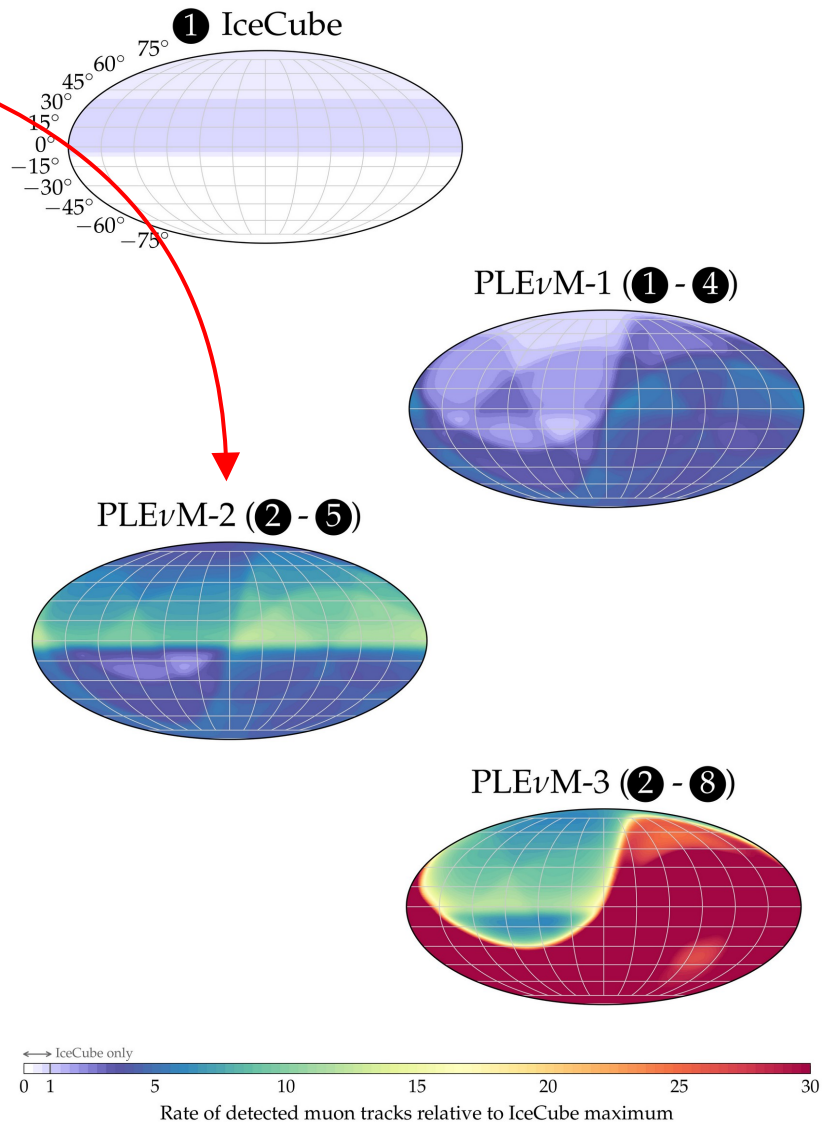
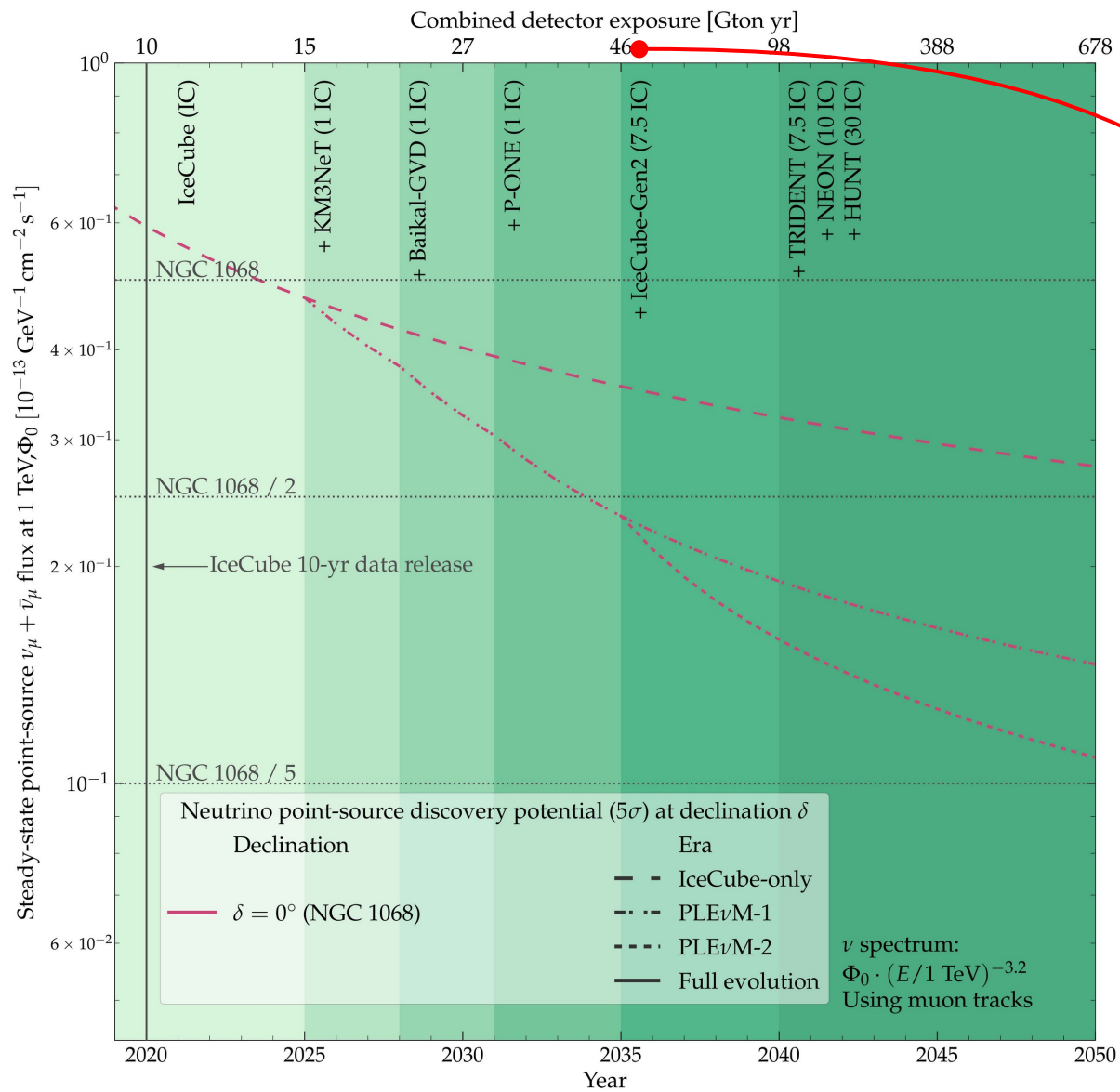
Assumed ν spectrum: $\Phi_0 \cdot (E_\nu/1 \text{ TeV})^{-2}$

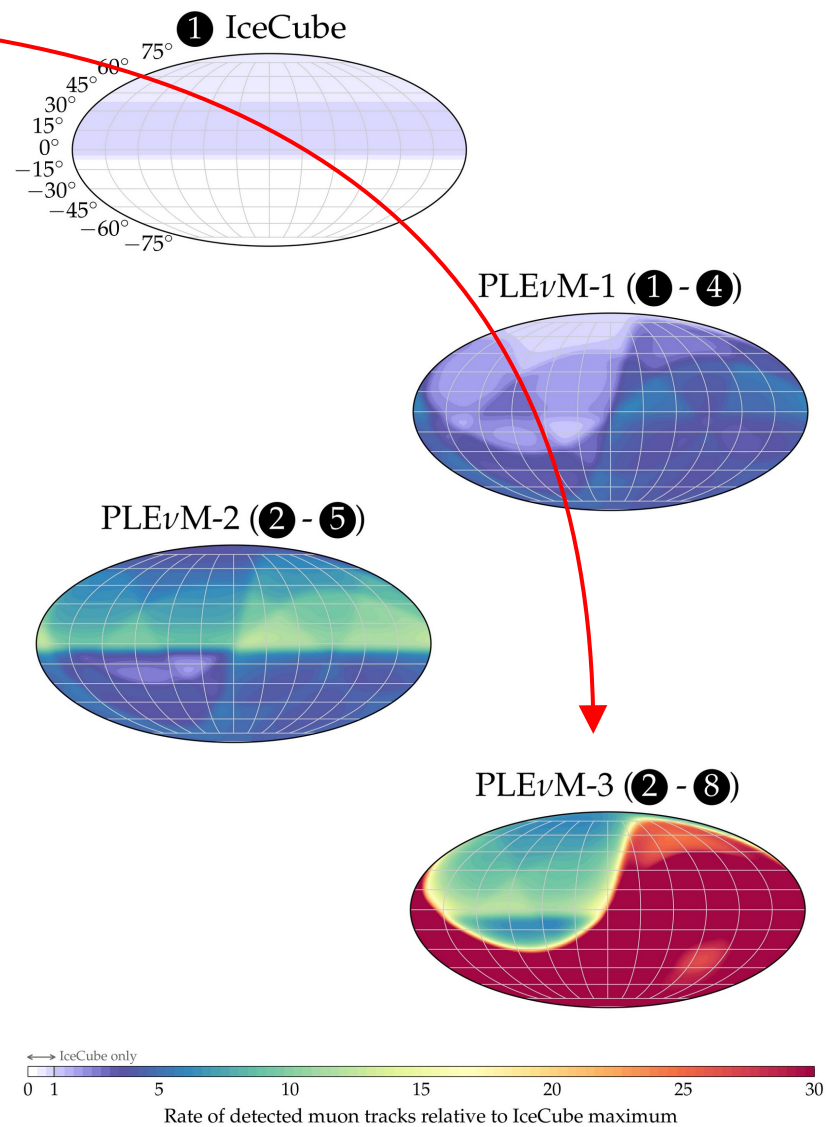
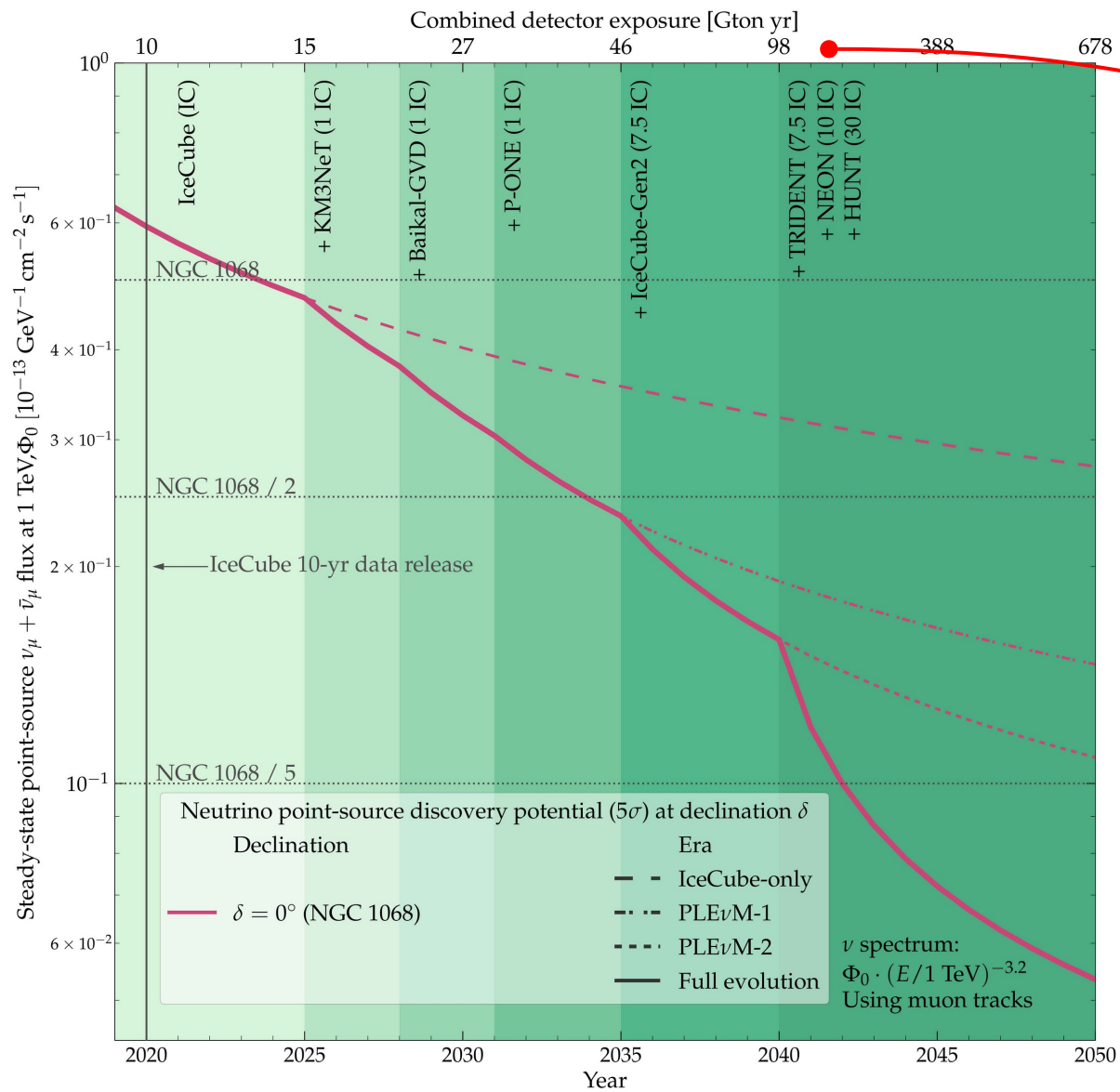


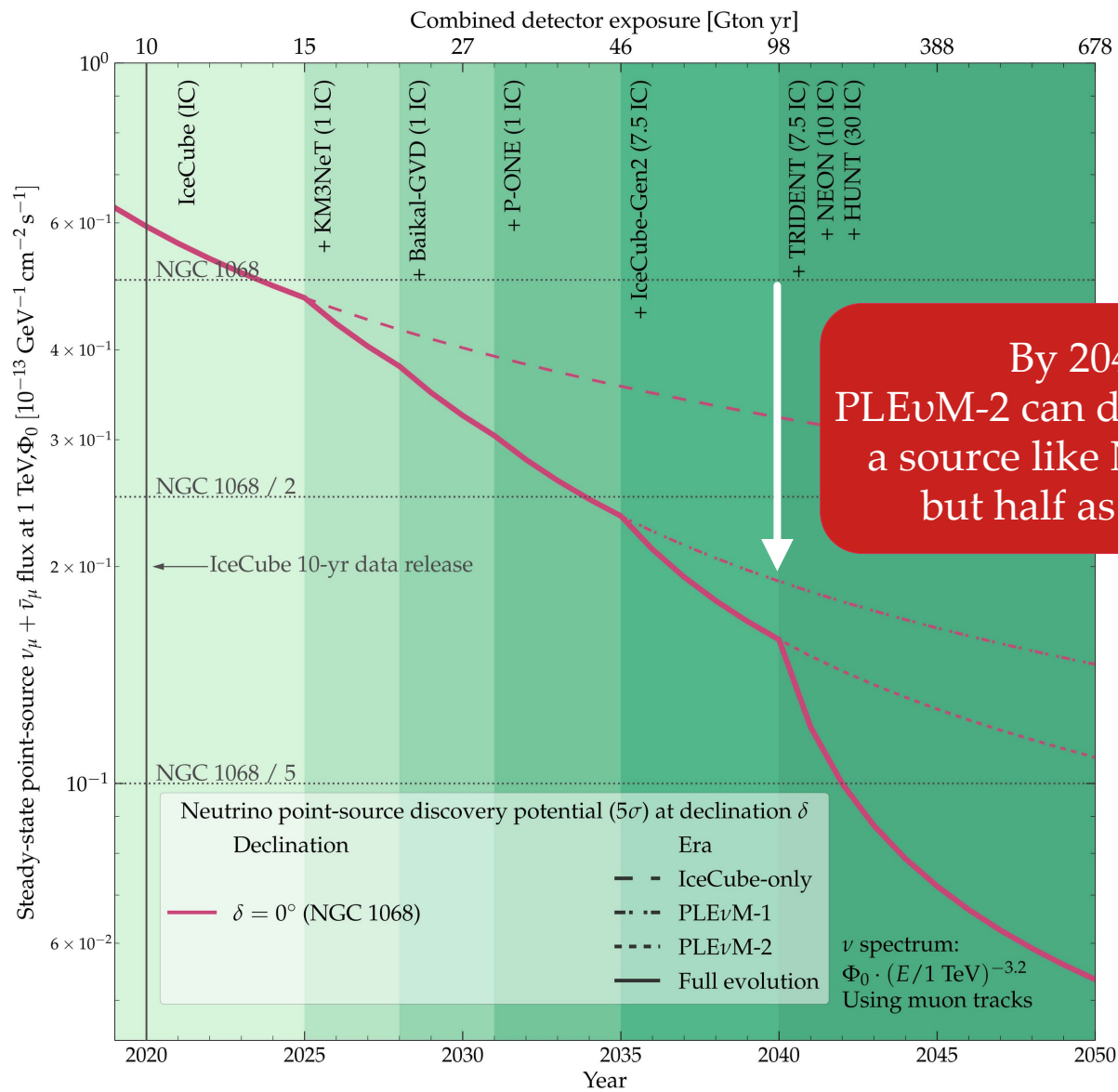


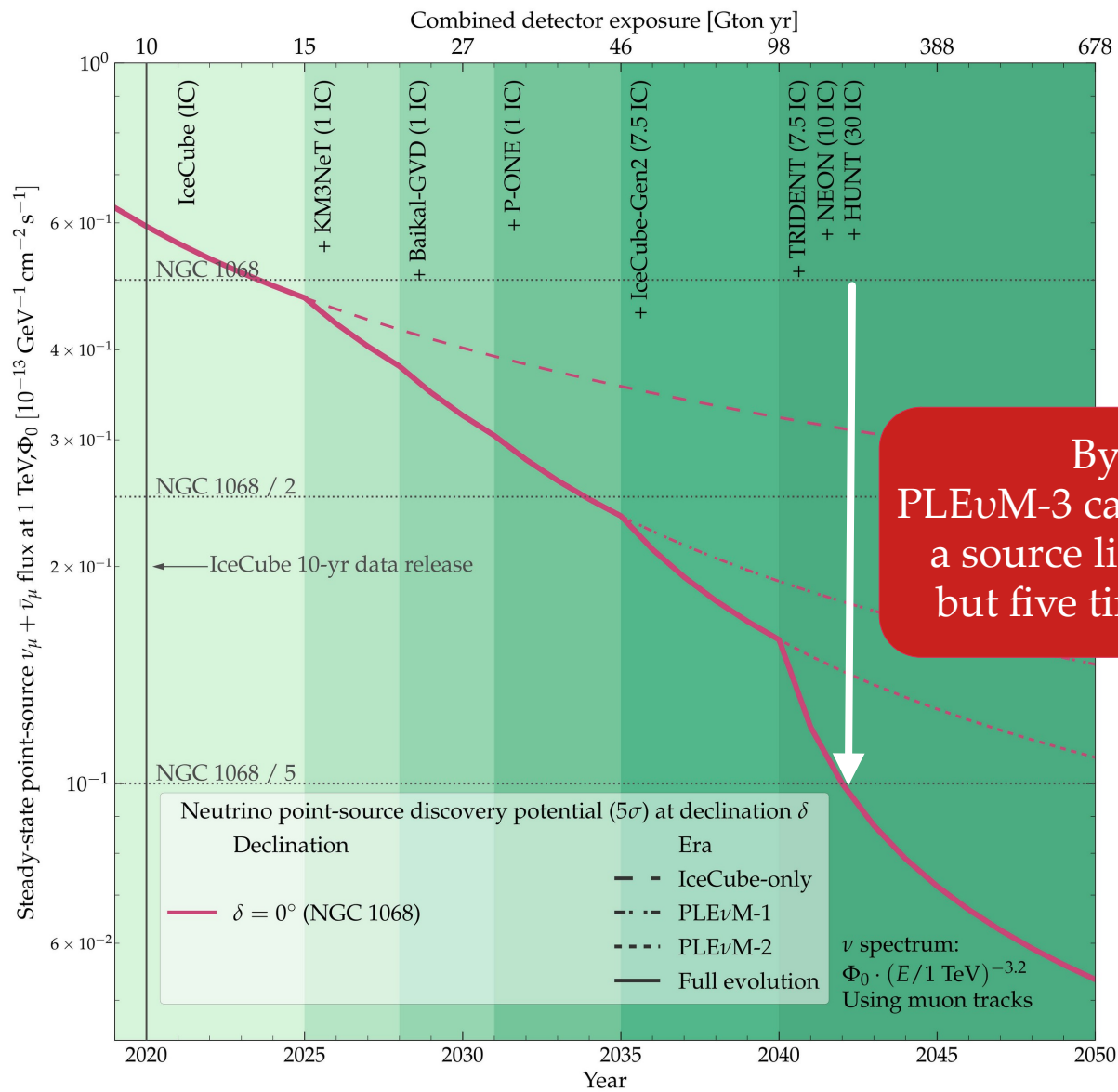


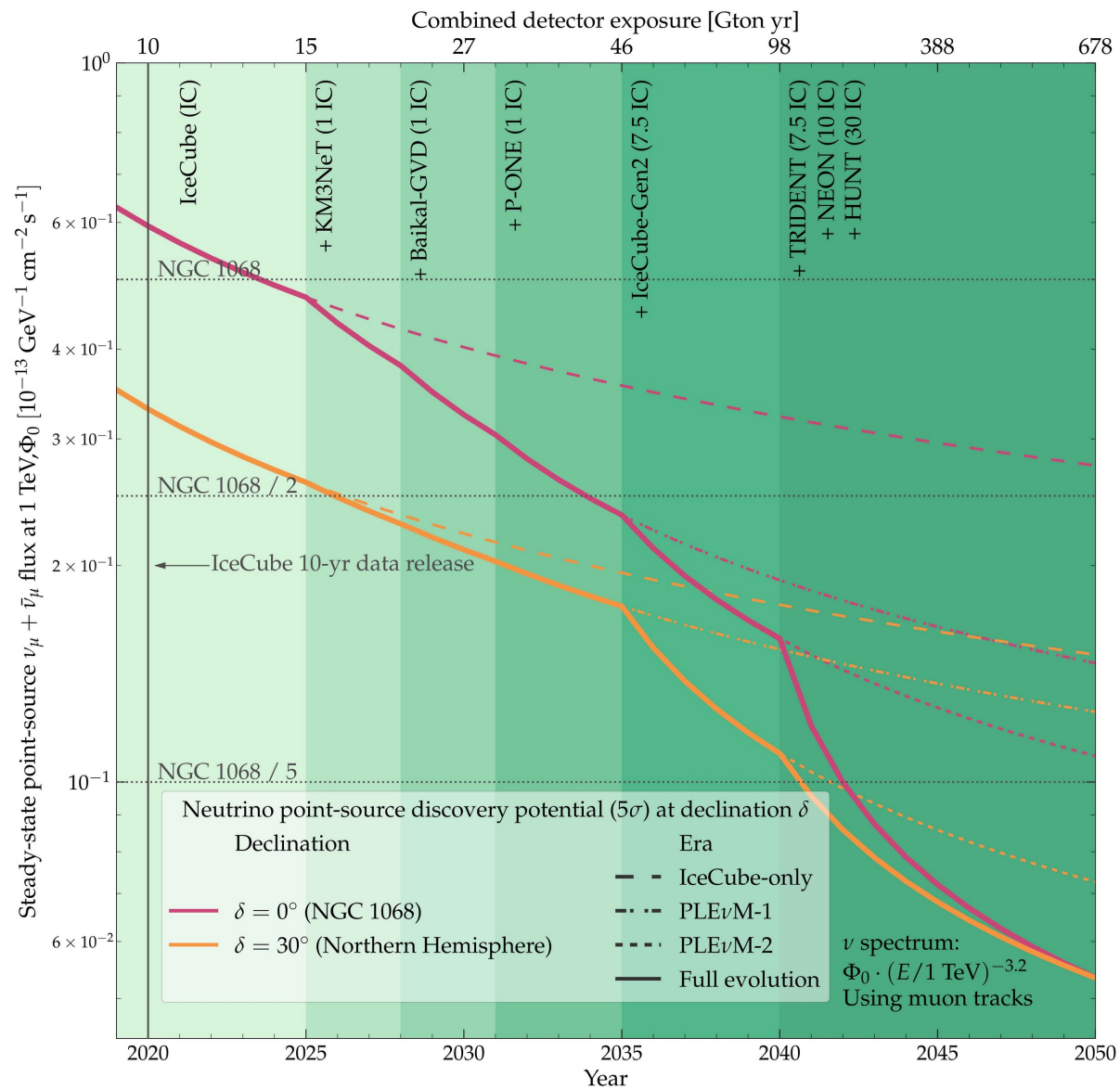


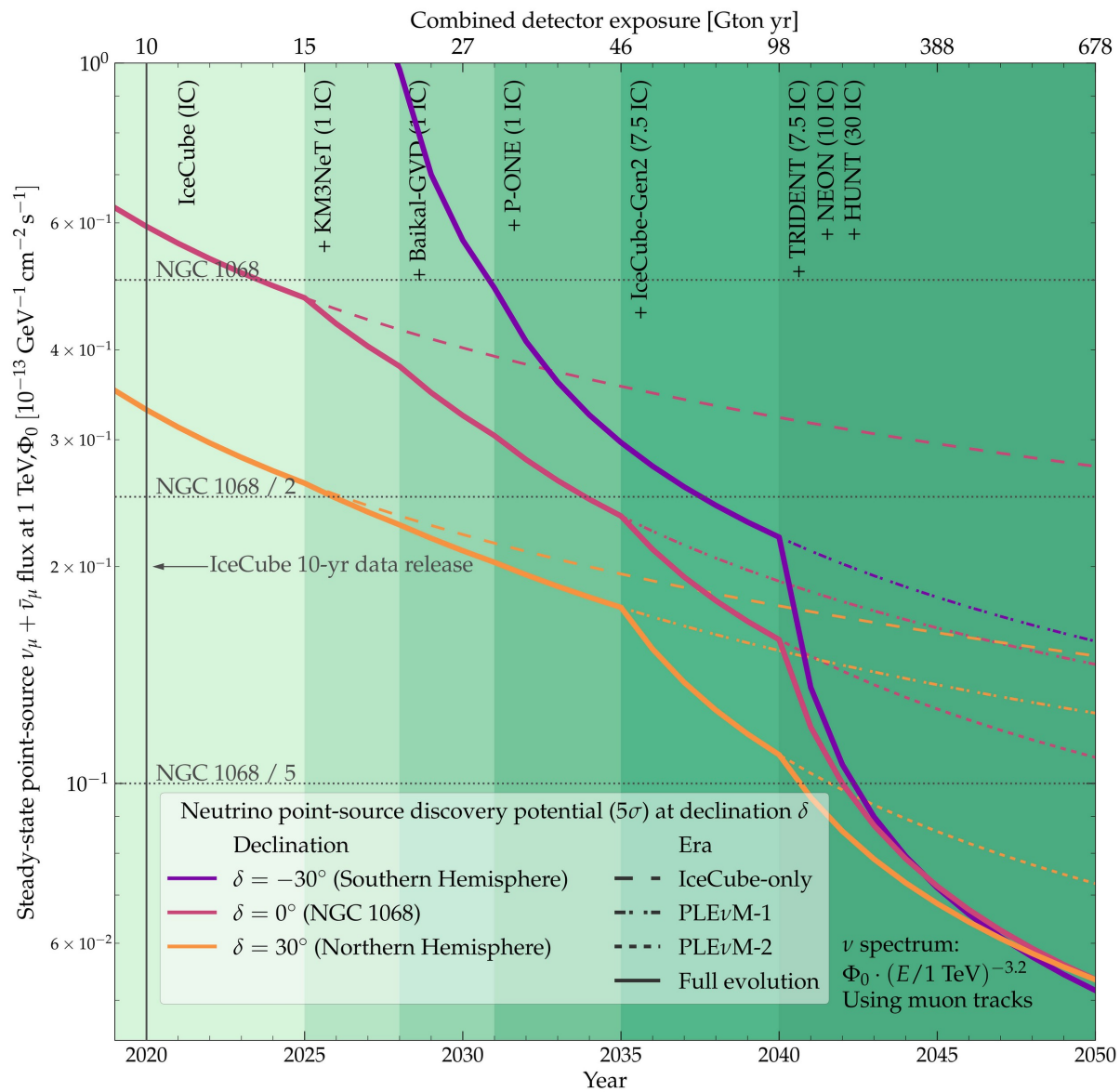


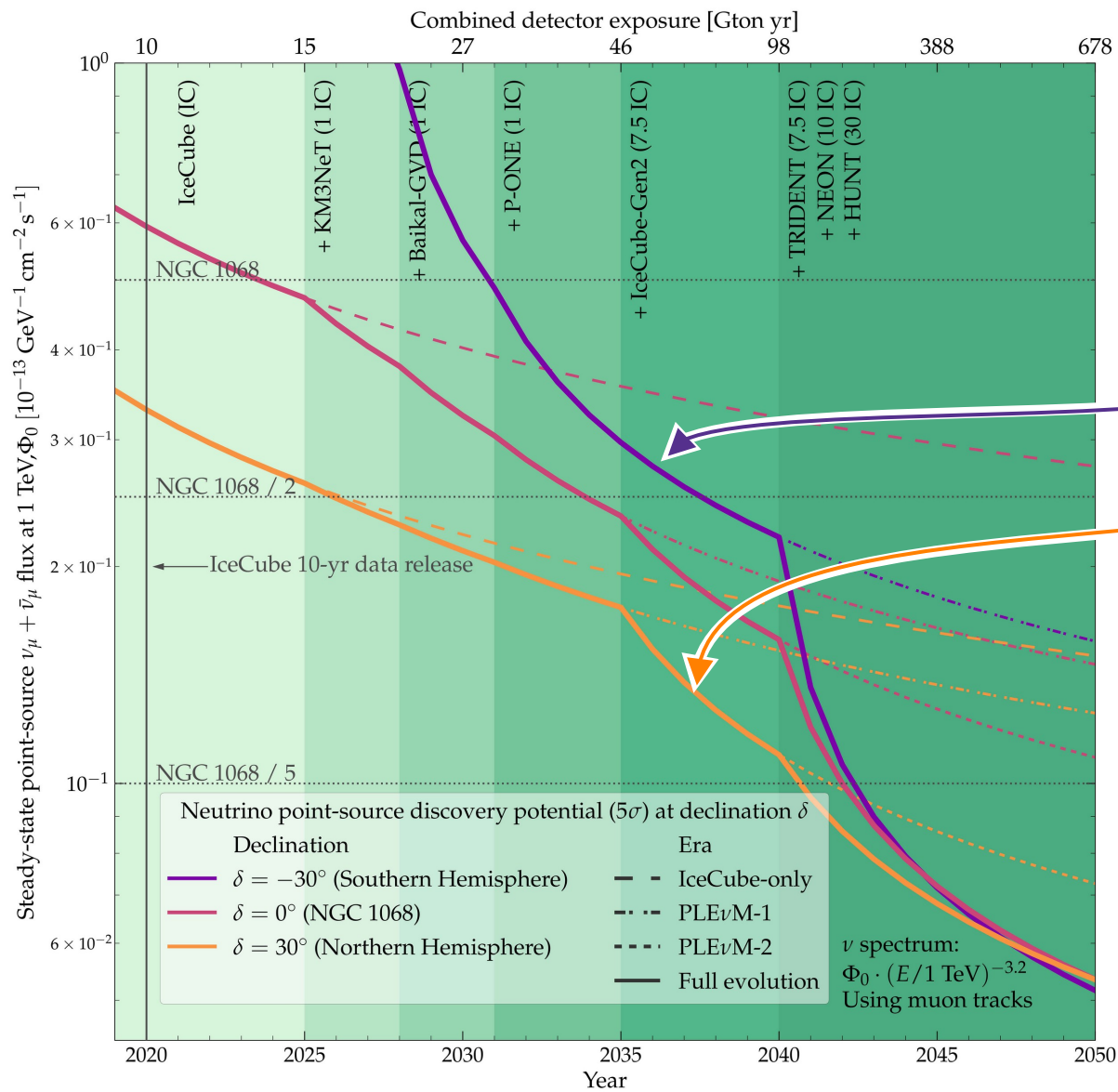


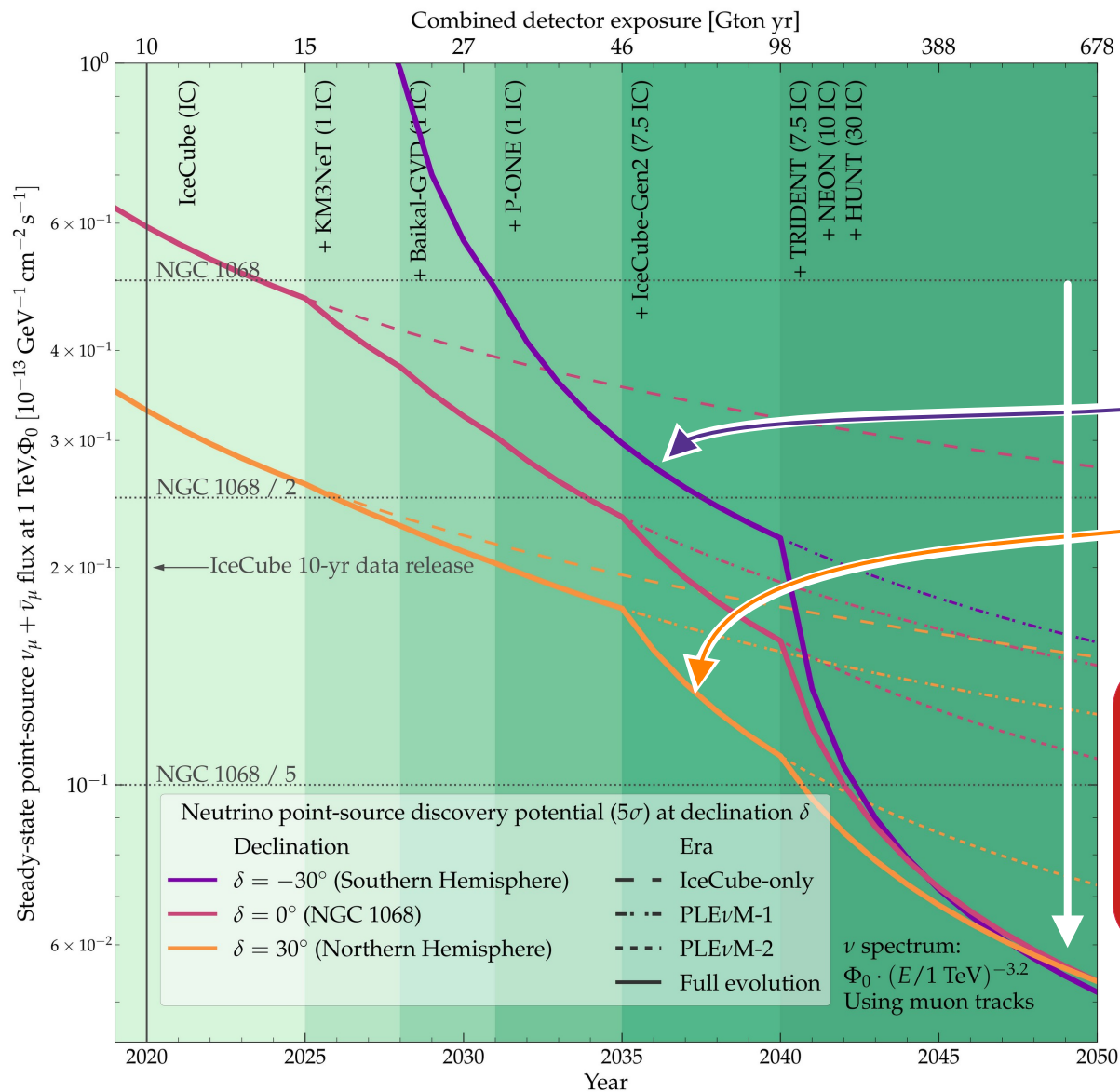






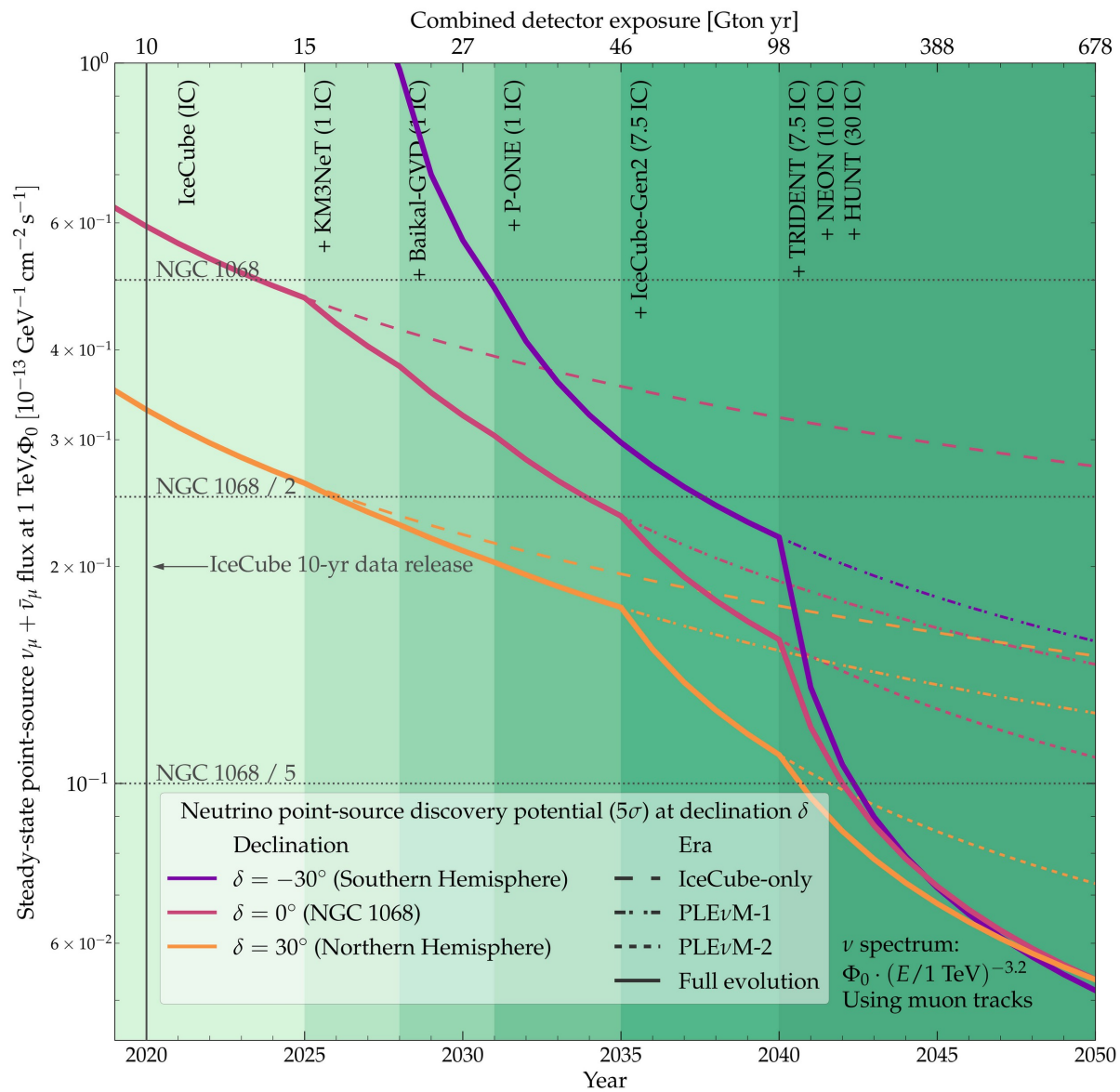


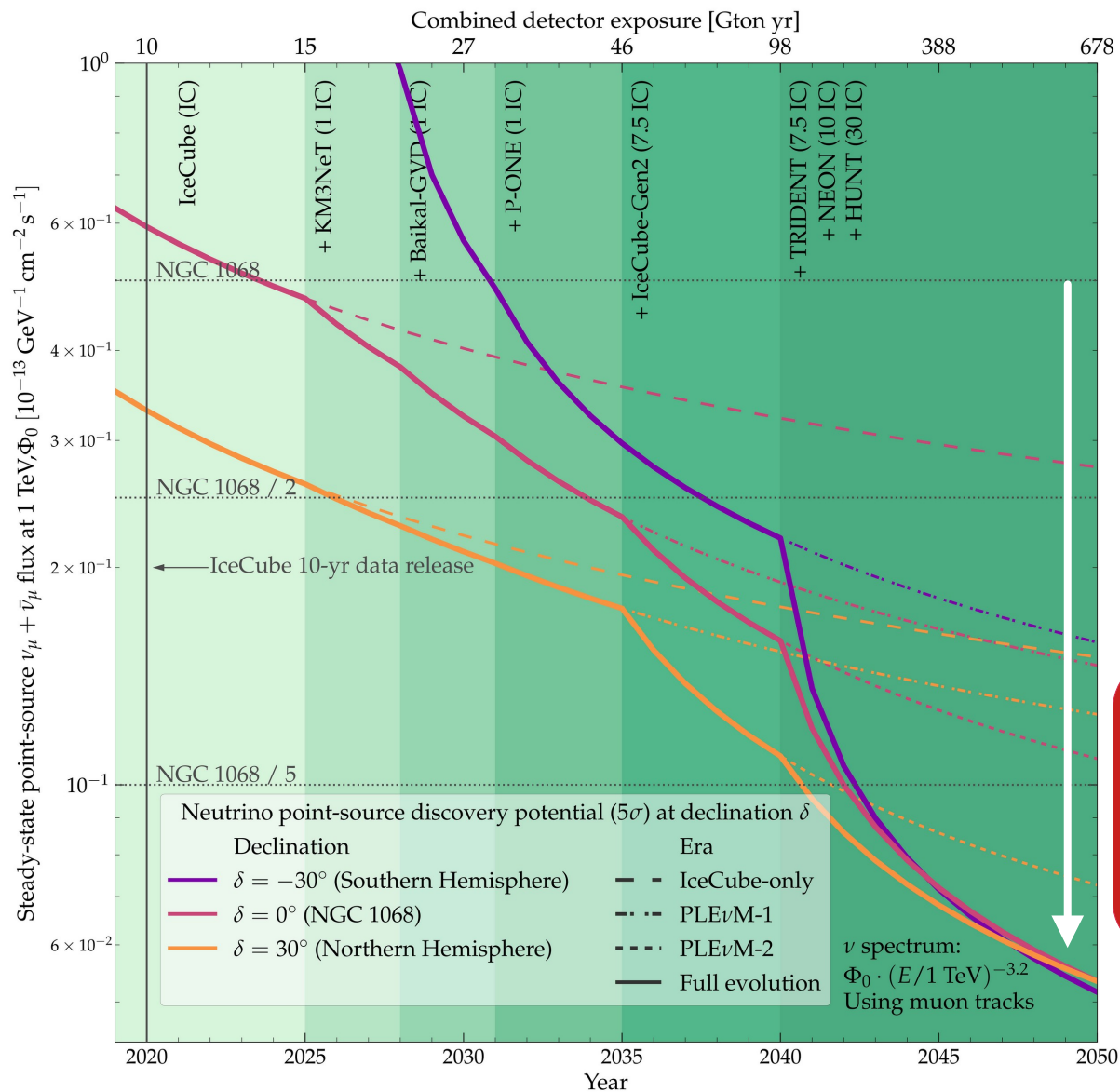




Similar improvement if the source
is in the
Southern or Northern Hemispheres

By 2050:
PLEνM-3 can discover (5σ)
a source like NGC-1068,
ten times dimmer,
anywhere in the sky!





By 2050:
PLEνM-3 can discover (5σ)
a source like NGC-1068,
ten times dimmer,
anywhere in the sky!

How many sources?

Redshift evolution of number density of sources follows star-formation rate

All sources have identical luminosity

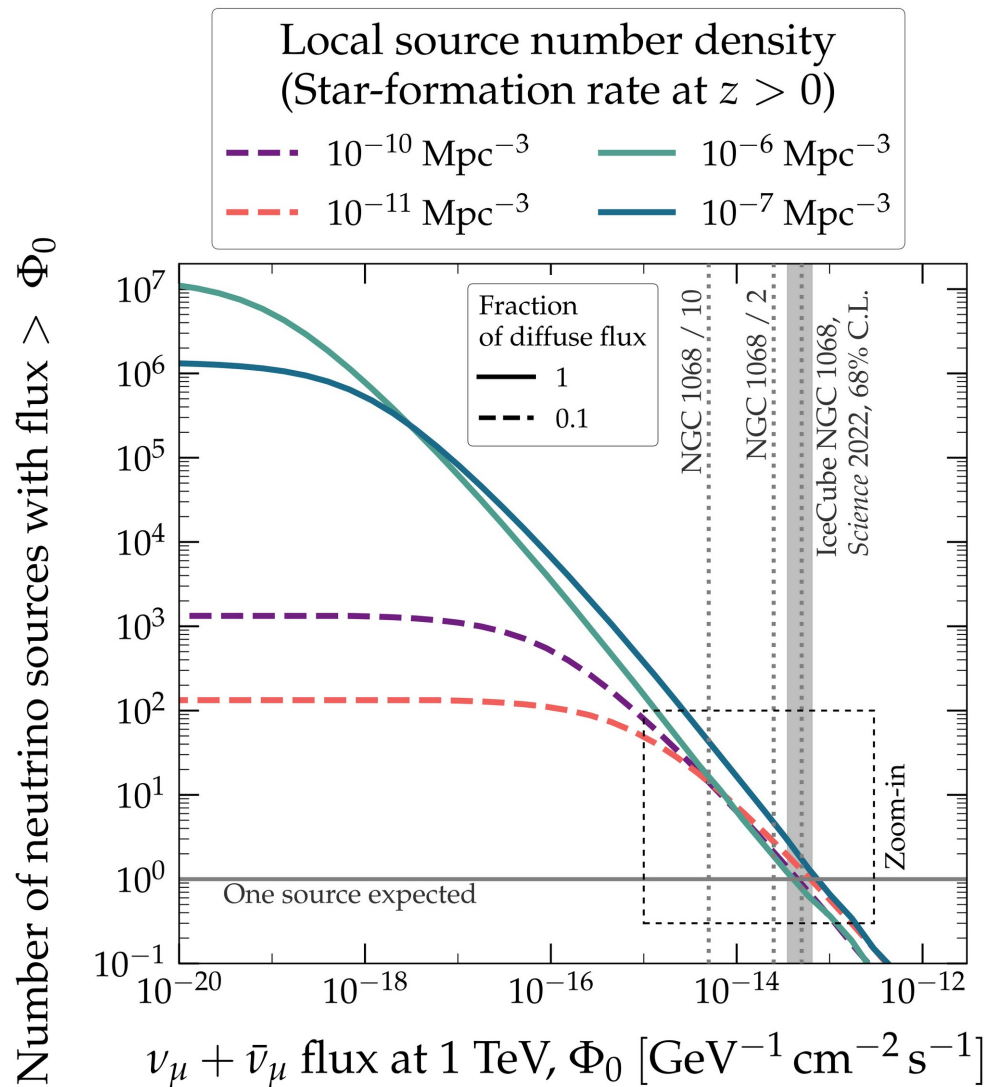
PLEνM-1 can detect sources 40% as bright as NGC 1068

→ 2–6 sources

PLEνM-2 can detect sources 10% as bright as NGC 1068

→ 10–40 sources

Demanding only 3σ evidence raises prospects by 50%



Take-home

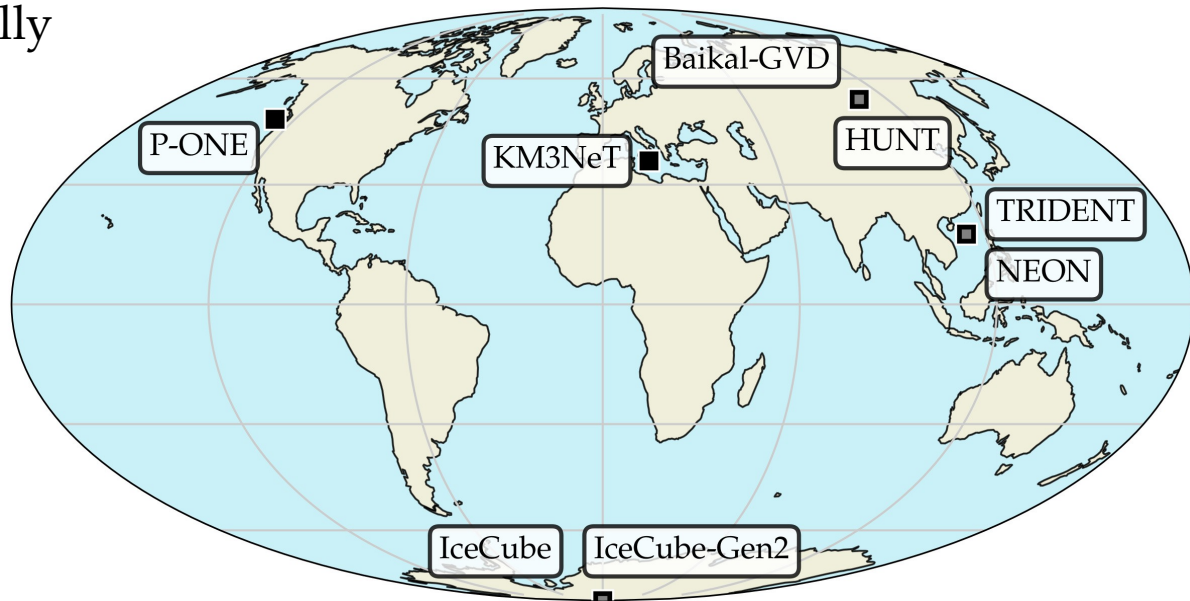
The path to full-fledged neutrino astronomy is (partially) to think globally

A global distributed network of telescopes could realistically discover dim sources anywhere

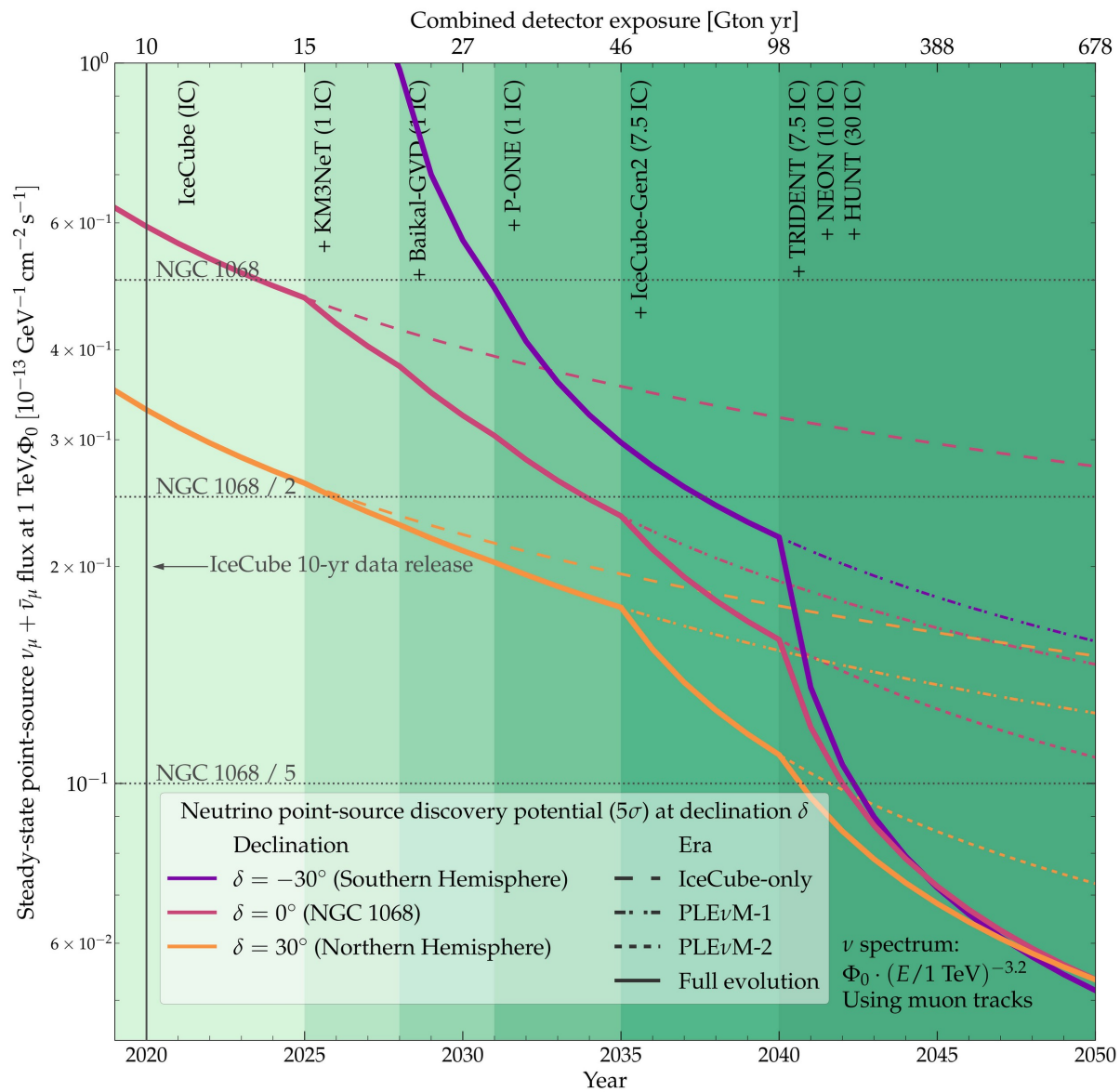
Room for improvement:
use cascades, better reconstruction

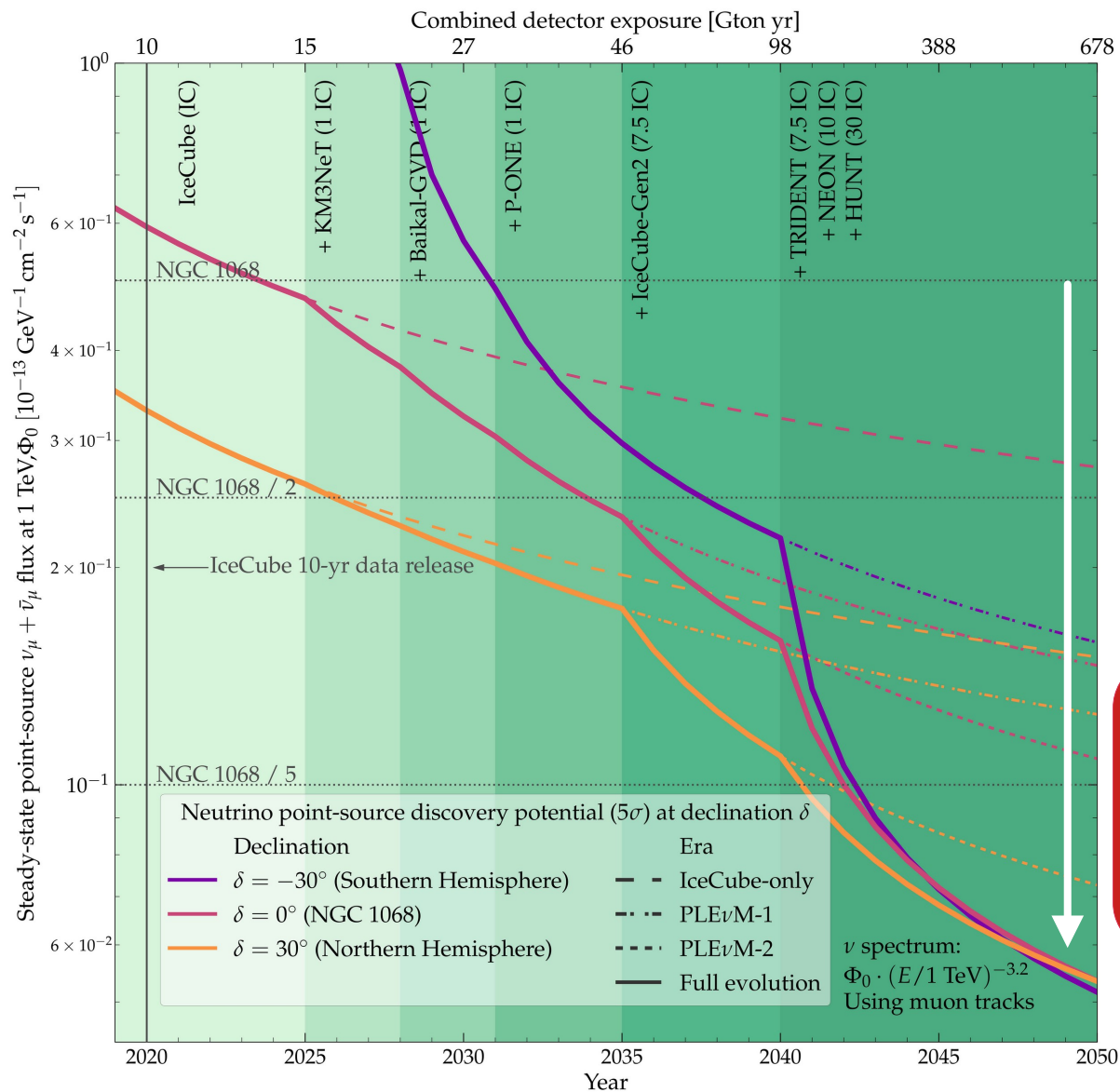
Public PLEuM code:

 github.com/PLEnuM-group/Plenum

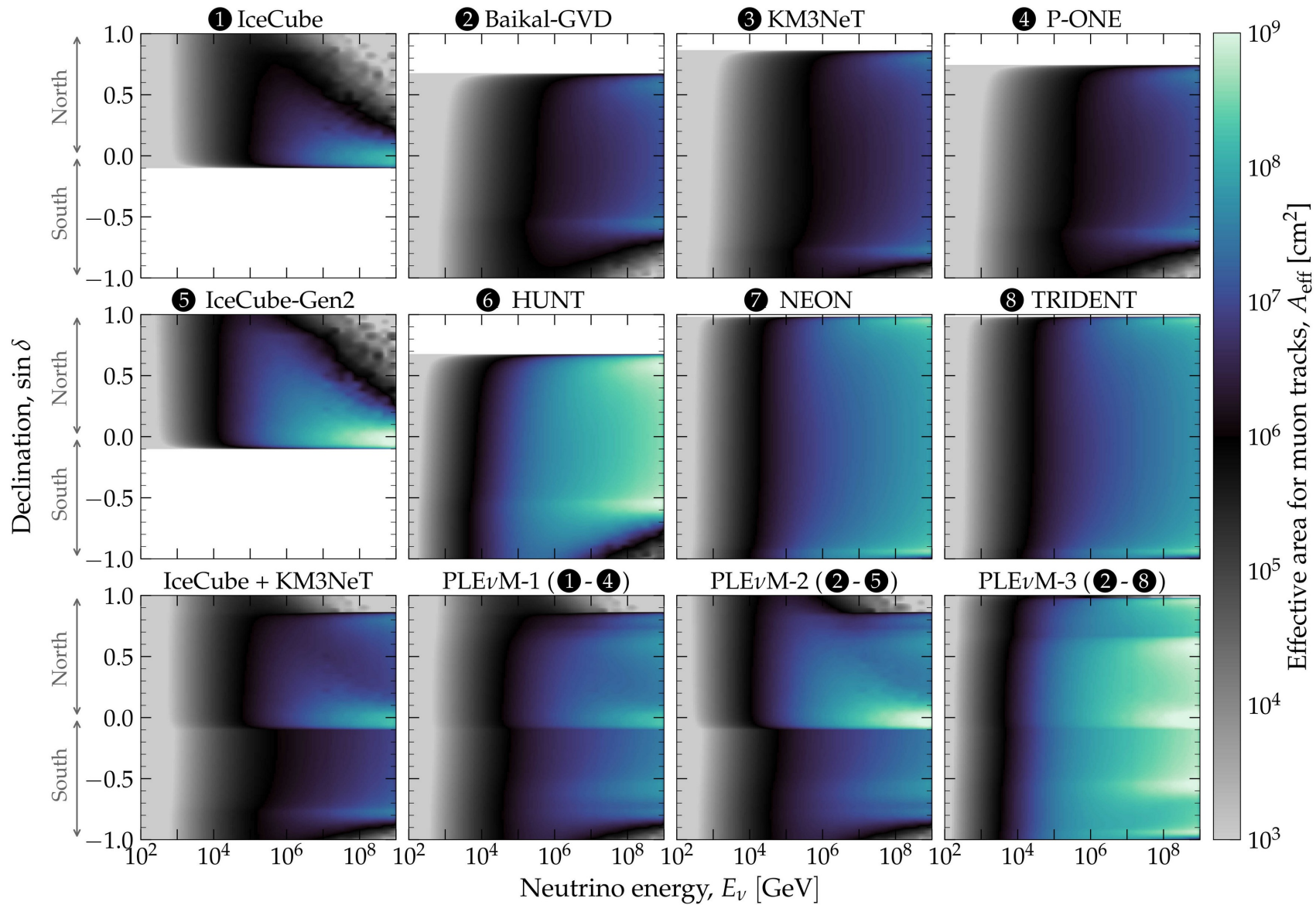


Backup slides



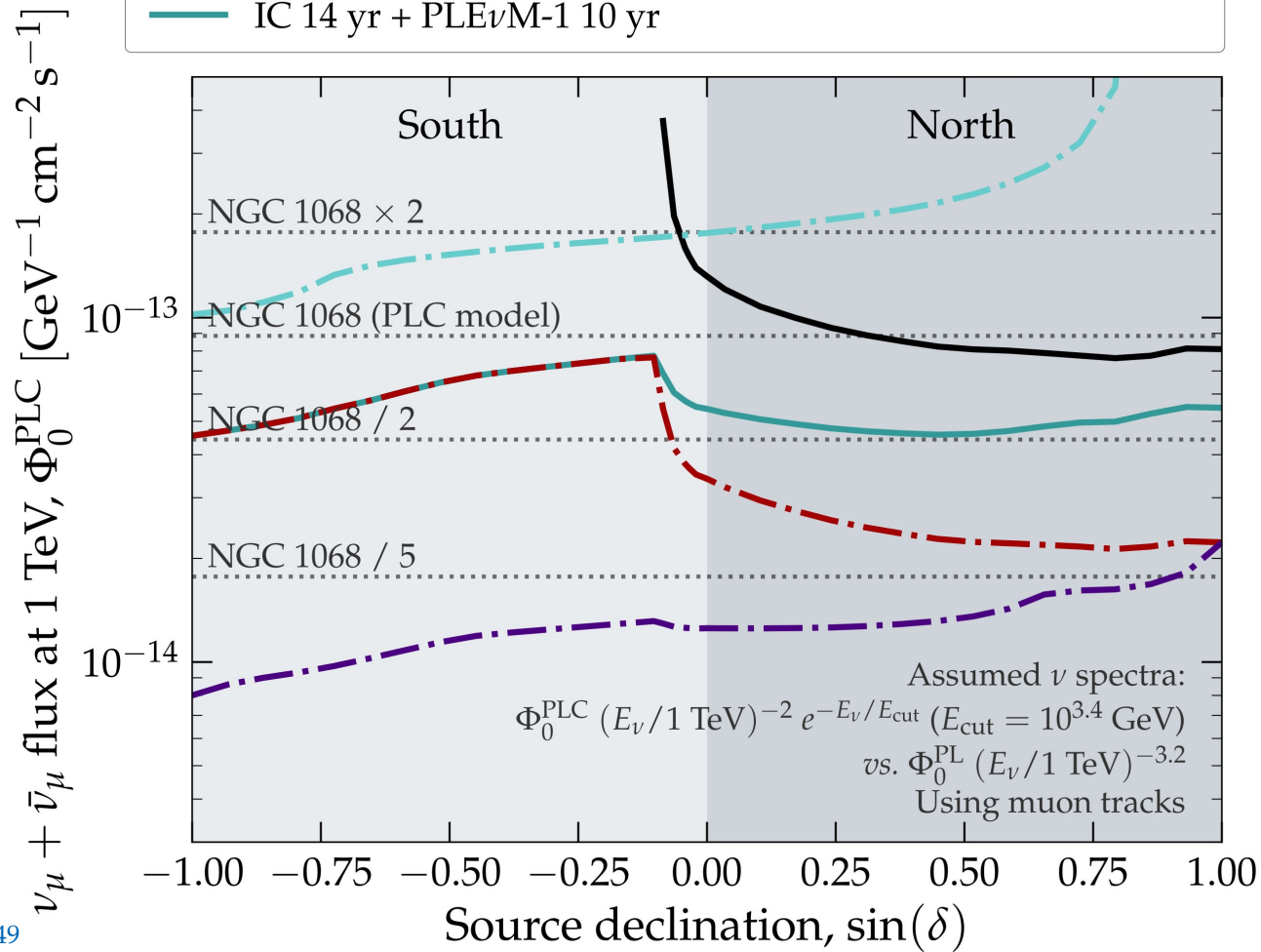


By 2050:
 PLEvM-3 can discover (5σ)
 a source like NGC-1068,
 ten times dimmer,
anywhere in the sky!



Discrimination of power law *vs.* power law with cut-off (3σ)

- IceCube (IC) 14 yr (est.)
- IC 14 yr + PLE ν M-2 10 yr
- · - KM3NeT 10 yr
- · - IC 14 yr + PLE ν M-3 10 yr
- IC 14 yr + PLE ν M-1 10 yr



Discovery of a
hard-spectrum source
(like TXS 0506+056,
but steady-state)

