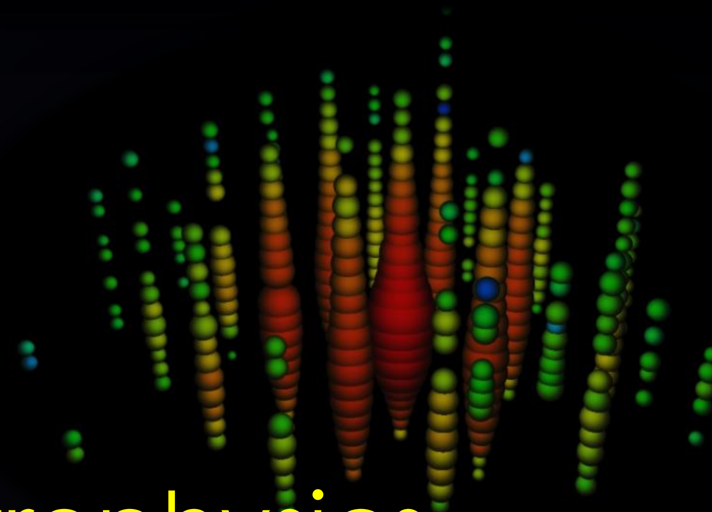
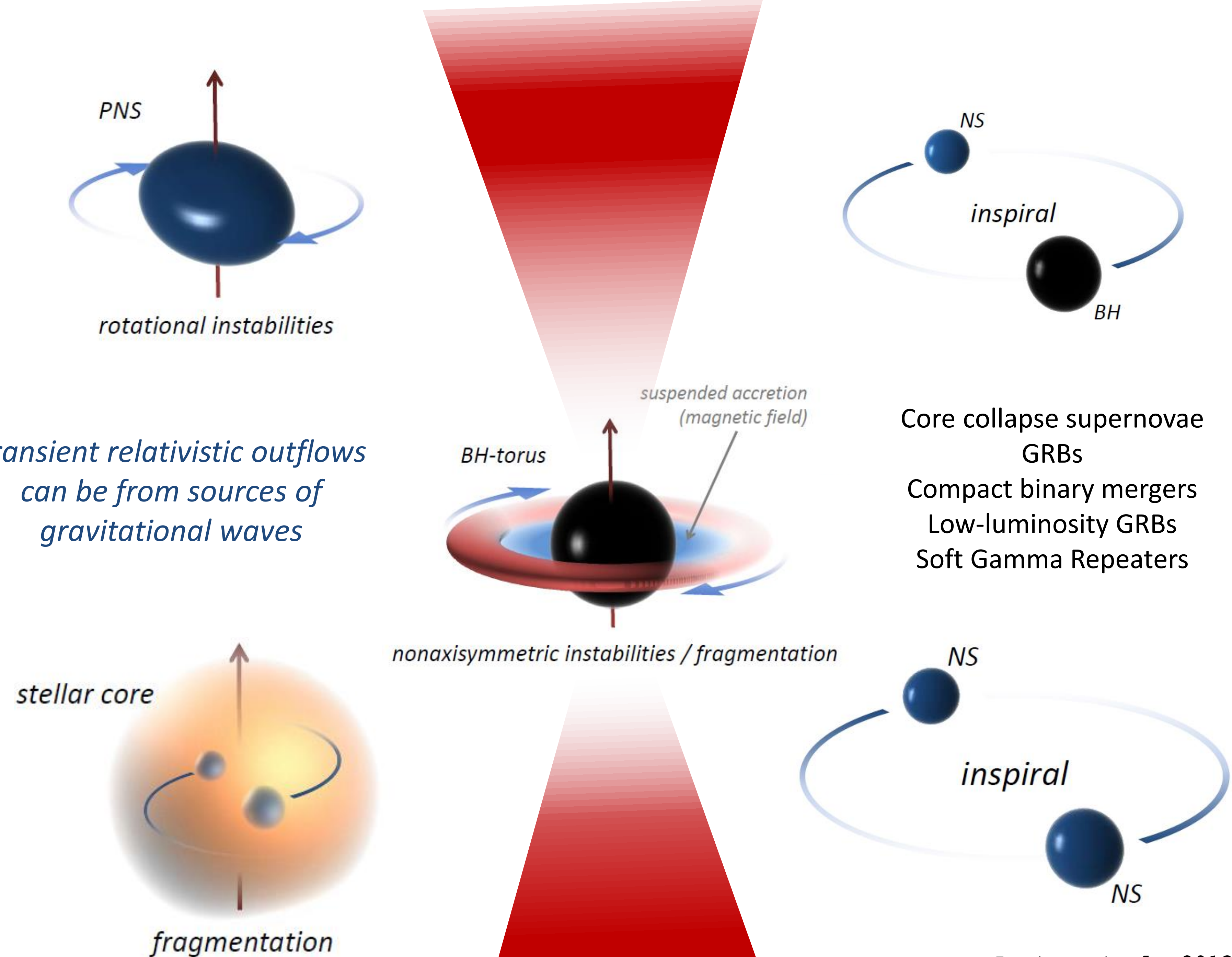
Multi-Messenger Astrophysics with Gravitational Waves and High energy neutrinos



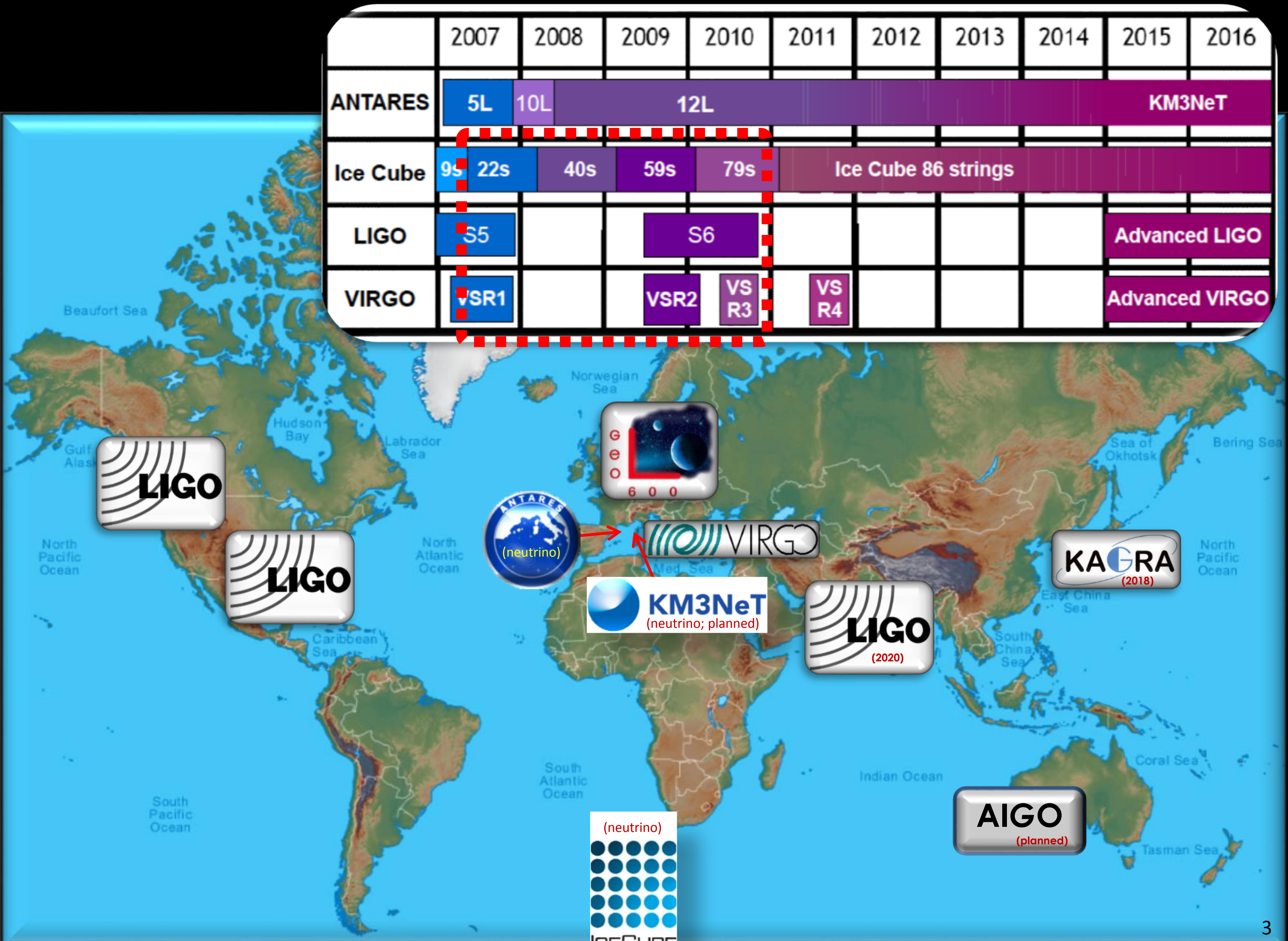
Imre Bartos
Columbia University



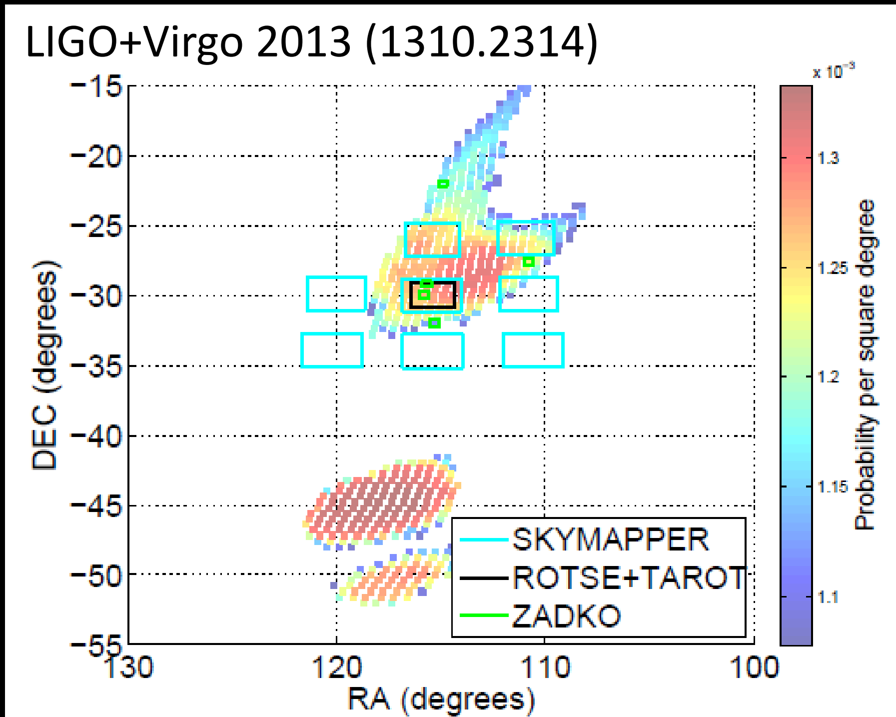
Transient relativistic outflows can be from sources of gravitational waves

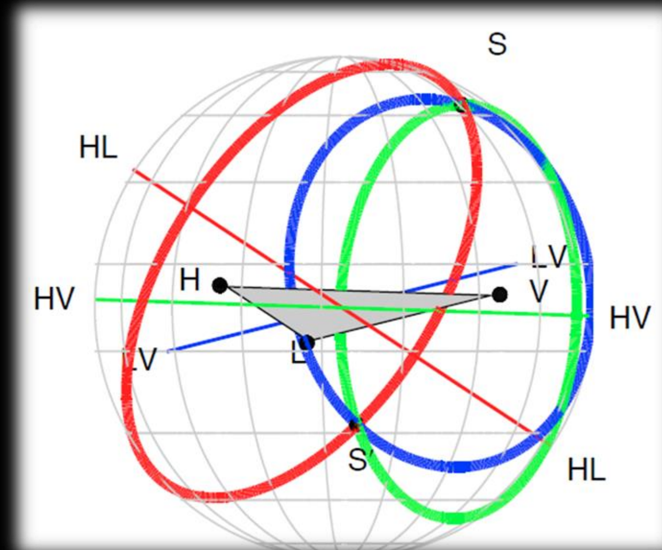
Core collapse supernovae
GRBs
Compact binary mergers
Low-luminosity GRBs
Soft Gamma Repeaters

Bartos et al. 2013


2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
ANTARES
5L
10L
12L
KM3NeT
Ice Cube
9s
22s
40s
59s
79s
Ice Cube 86 strings
LIGO
S5
S6
Advanced LIGO
VIRGO
VSR1
VSR2
VS R3
VS R4
Advanced VIRGO
LIGO
LIGO
GEO 600
ANTARES
(neutrino)
VIRGO
KM3NeT
(neutrino; planned)
LIGO
(2020)
KAGRA
(2018)
AIGO
(planned)
(neutrino)
ICECUBE

Gravitational wave follow-up will be challenging



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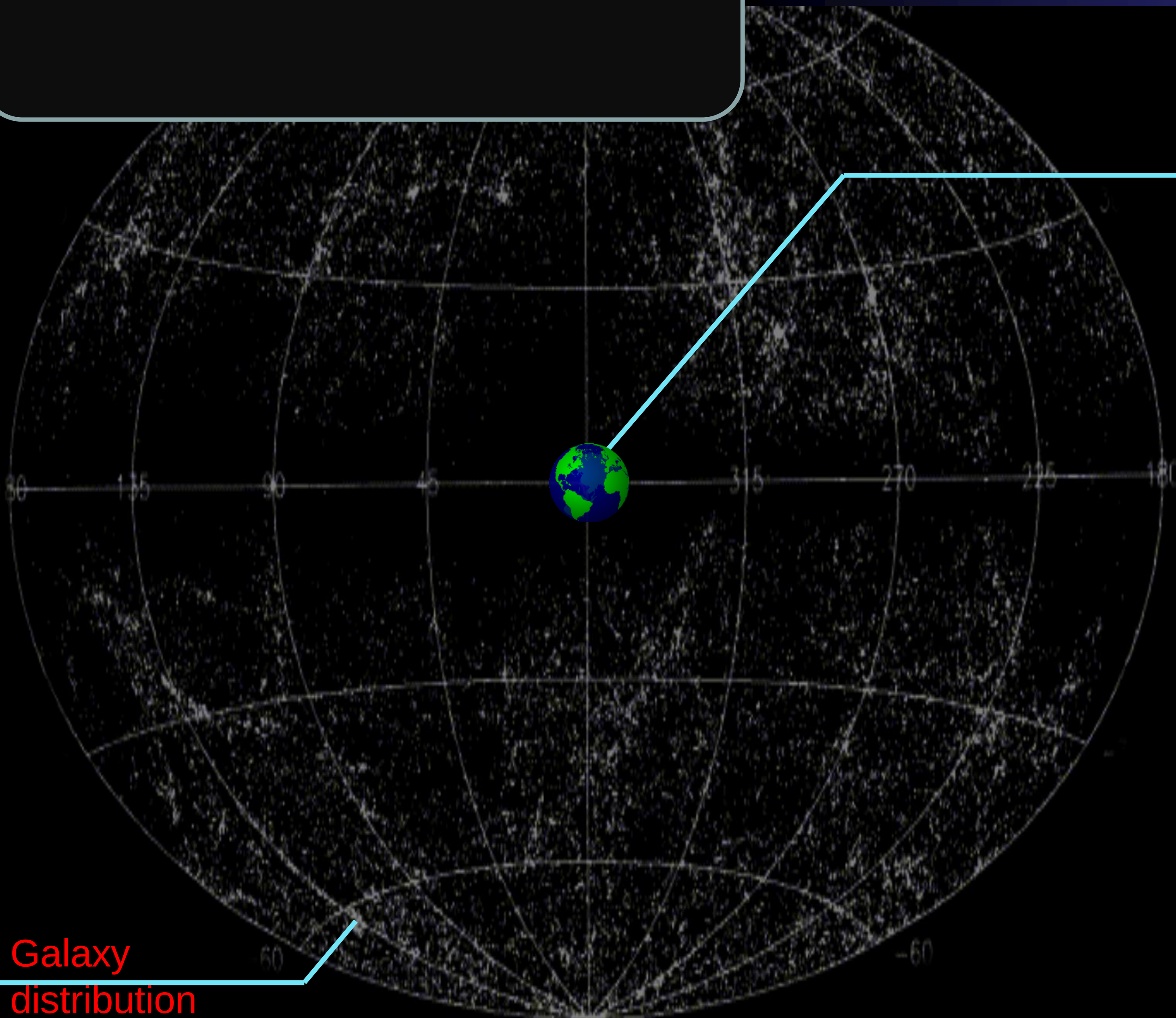
High-energy neutrinos can be game-changers.

GW+ν

Galaxy distribution can be used to narrow sky coverage

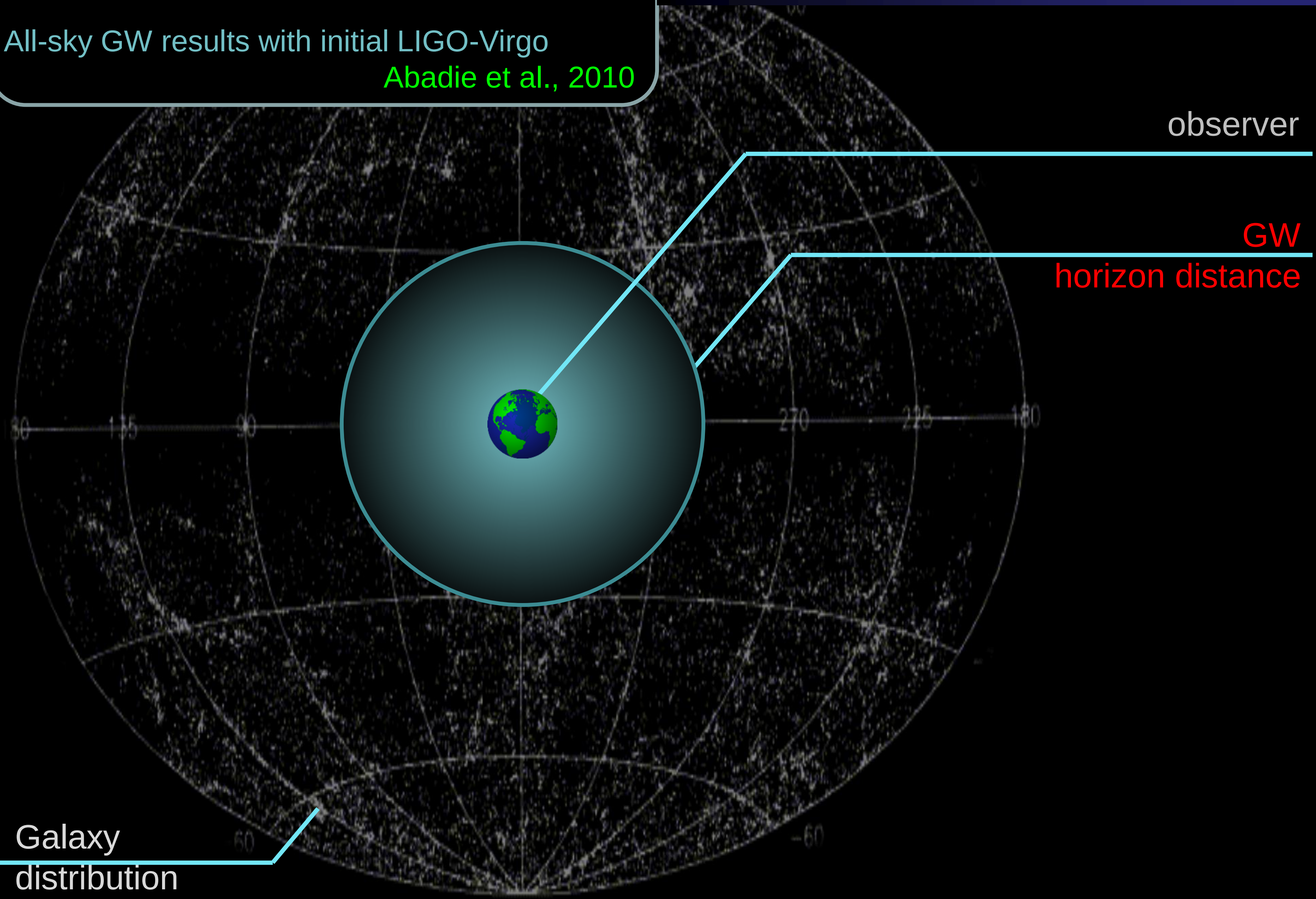


GW+ν

Gravitational waves

All-sky GW results with initial LIGO-Virgo

Abadie et al., 2010

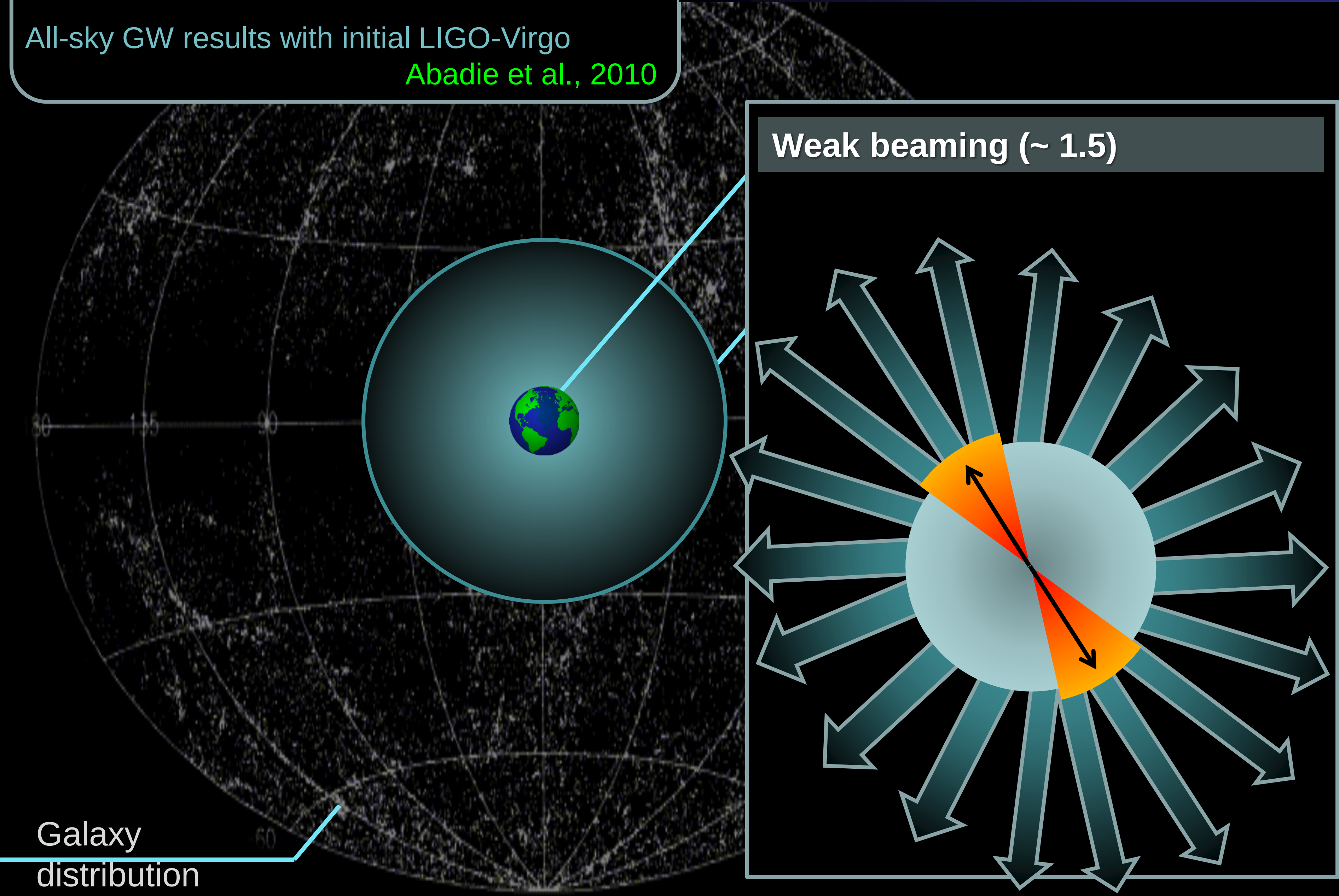


GW+*ν*

Gravitational waves

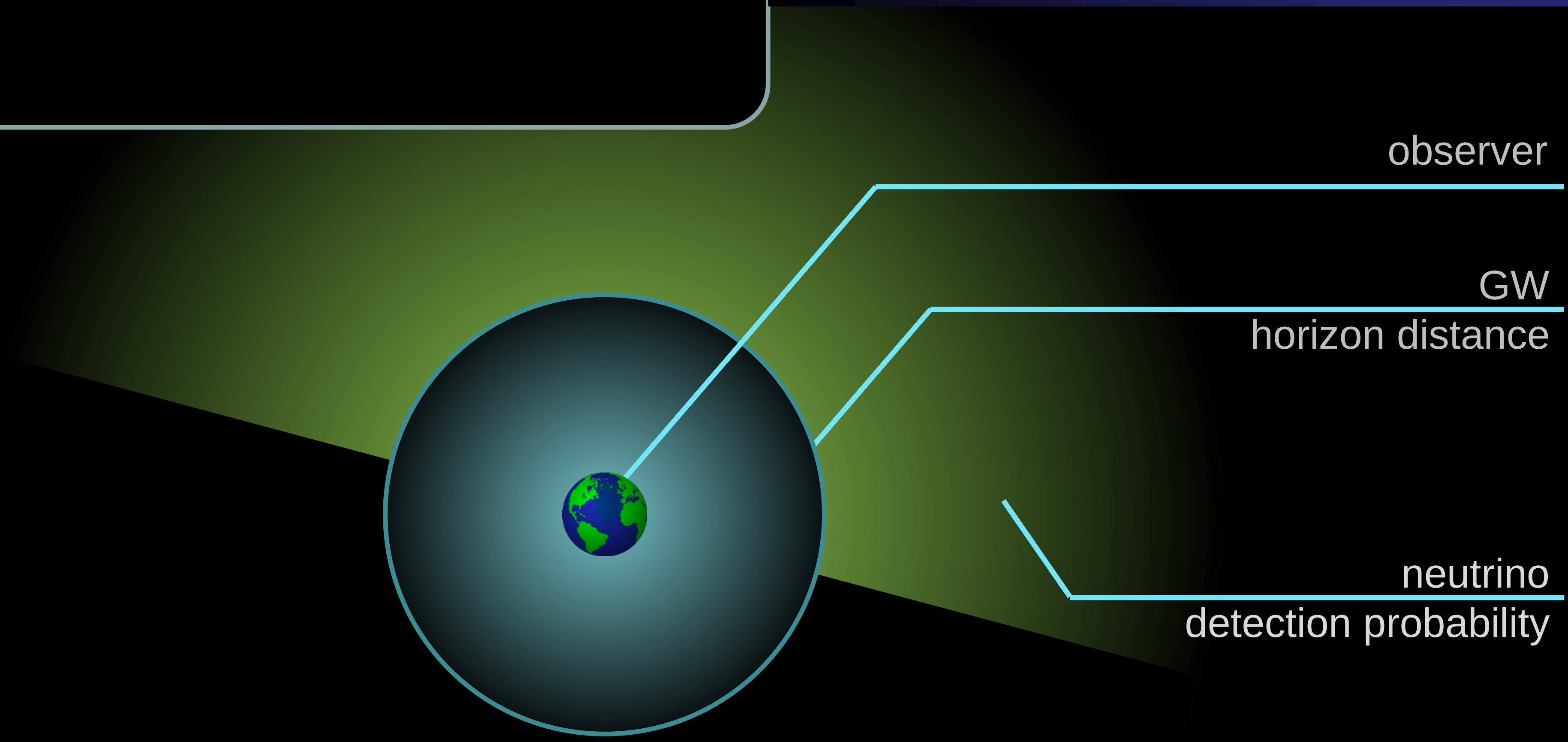
All-sky GW results with initial LIGO-Virgo

Abadie et al., 2010



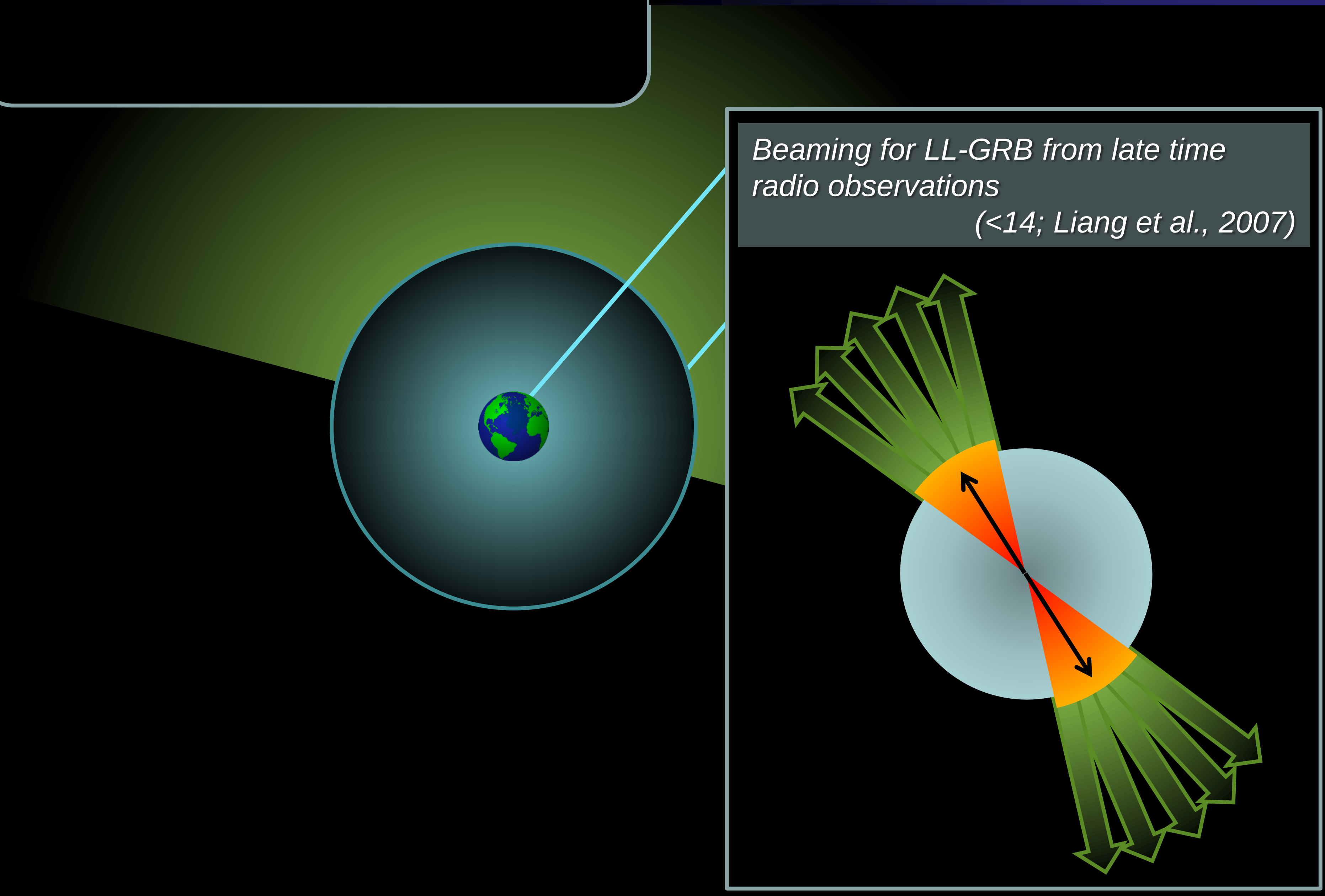
GW+ν

High-energy neutrino



GW+ν

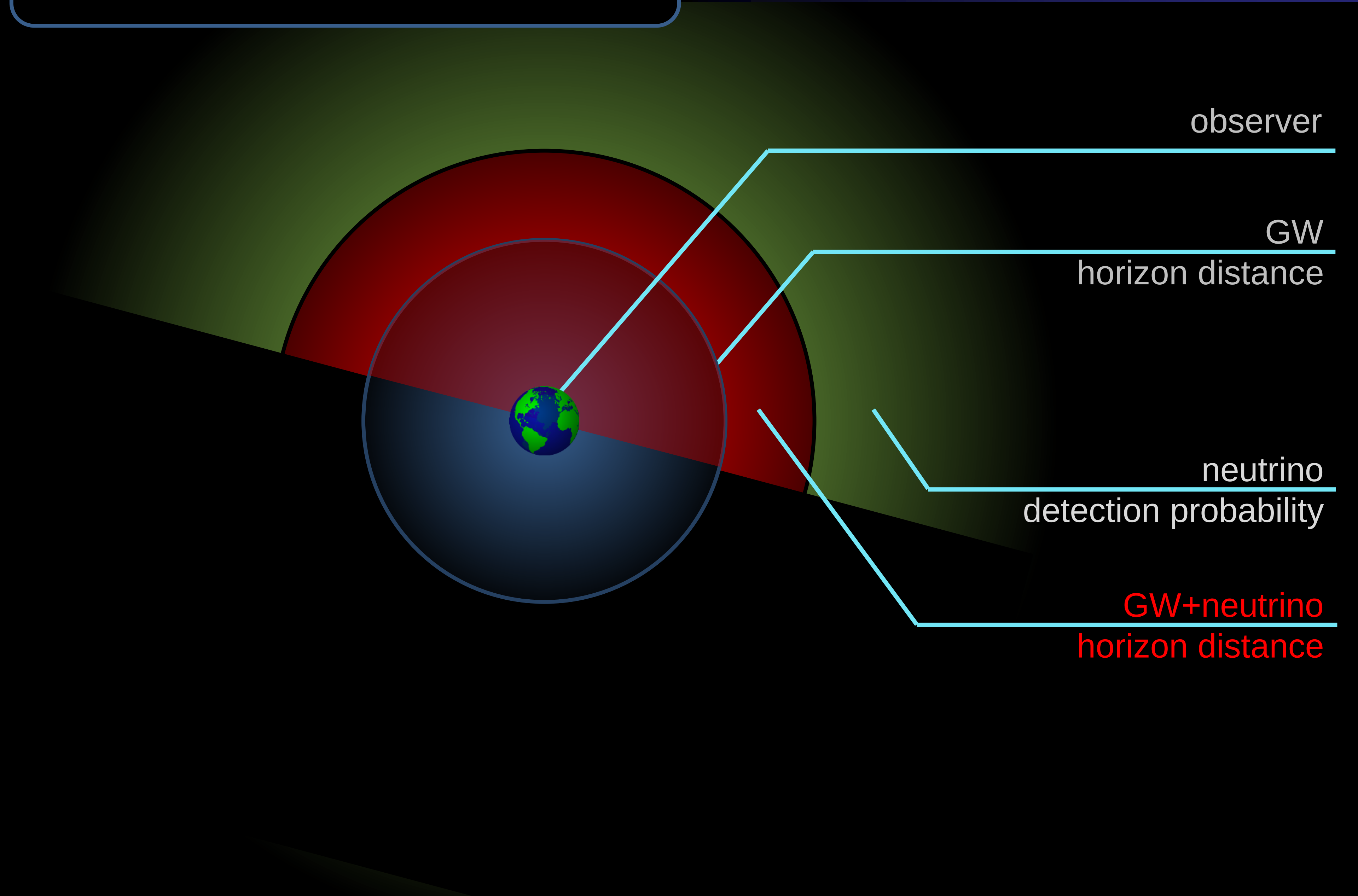
High-energy neutrino



MULTIMESSENGER

GW + high energy neutrino

GW coincident with ≥ 1 neutrino



MULTIMESSENGER

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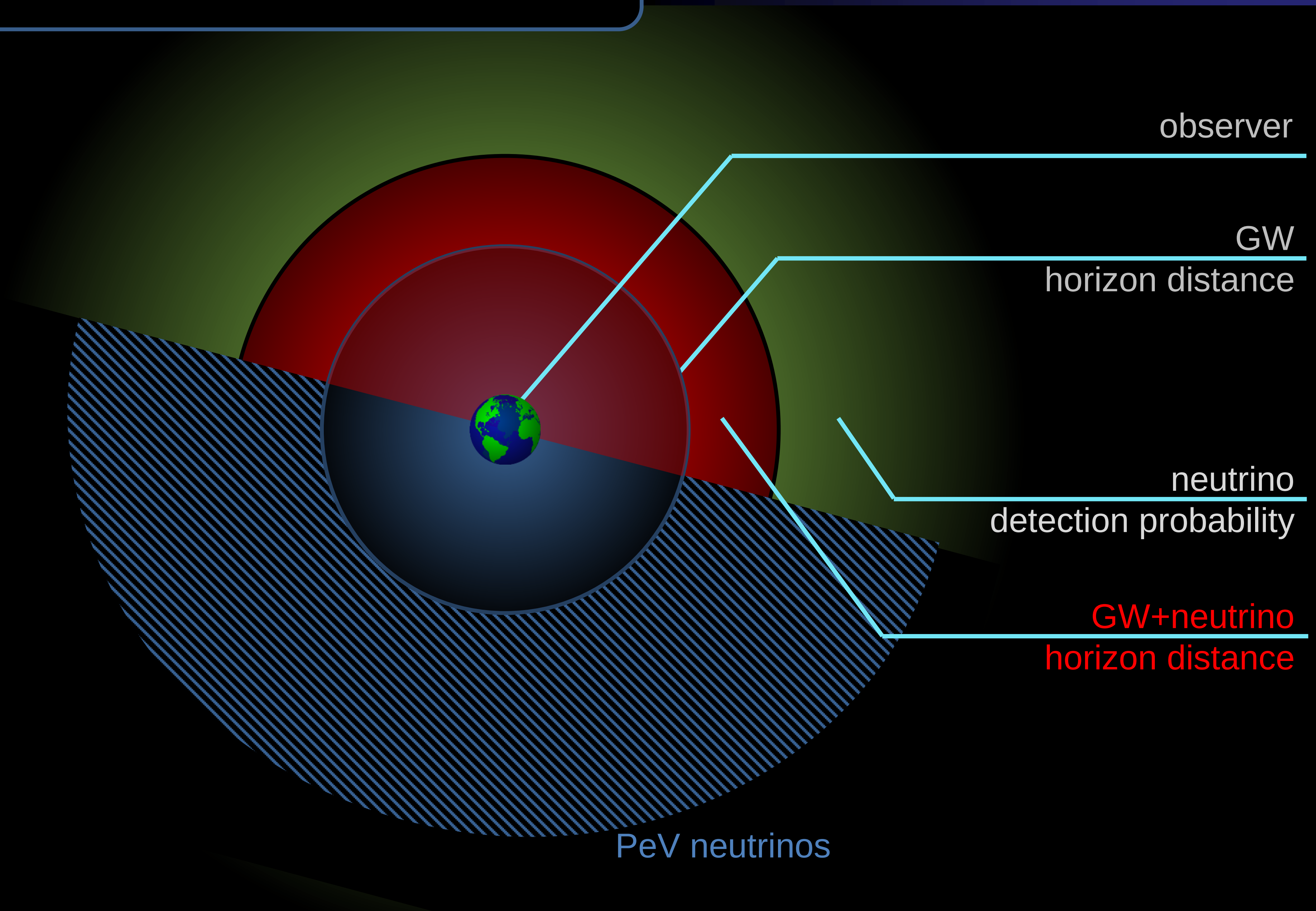
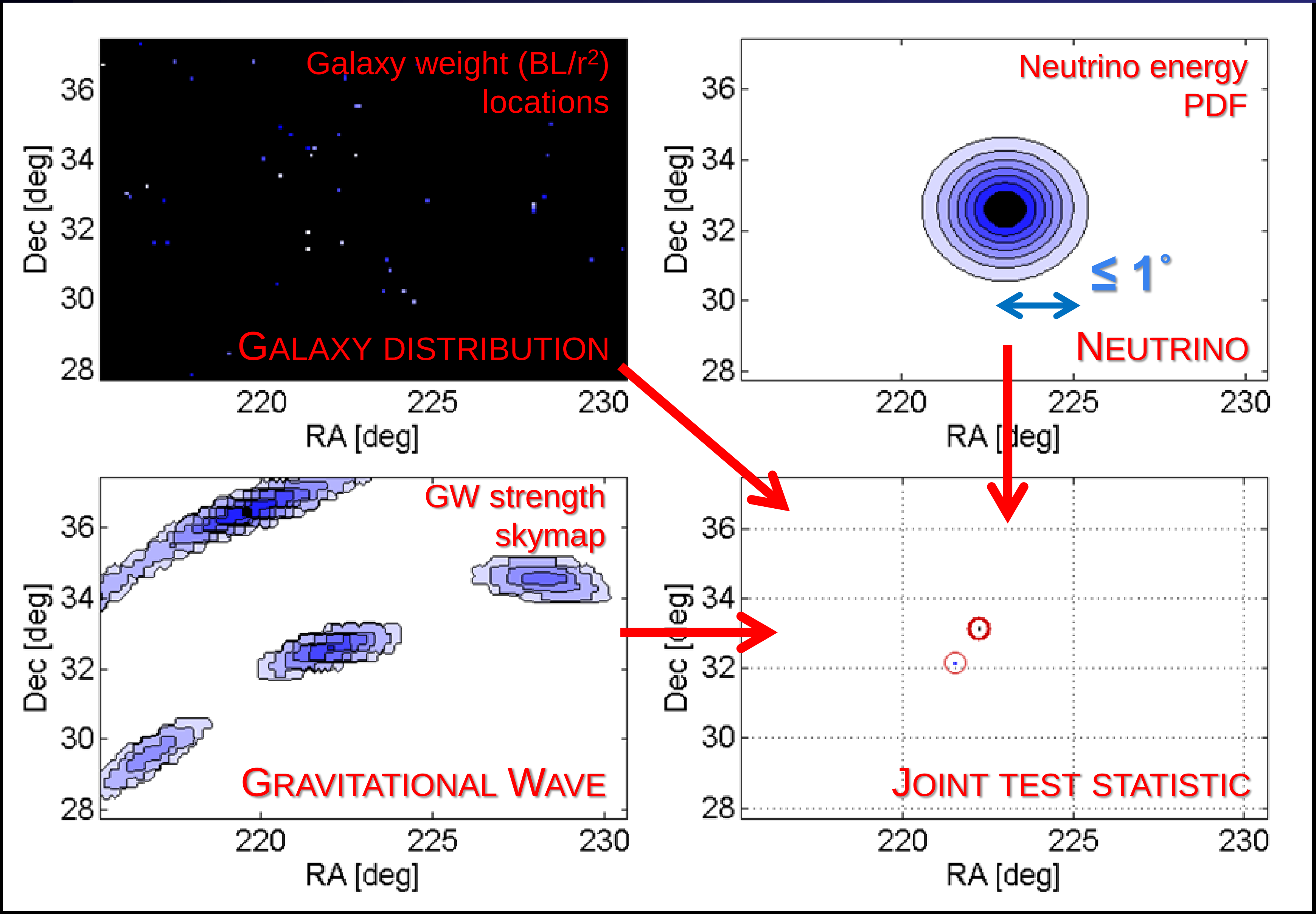
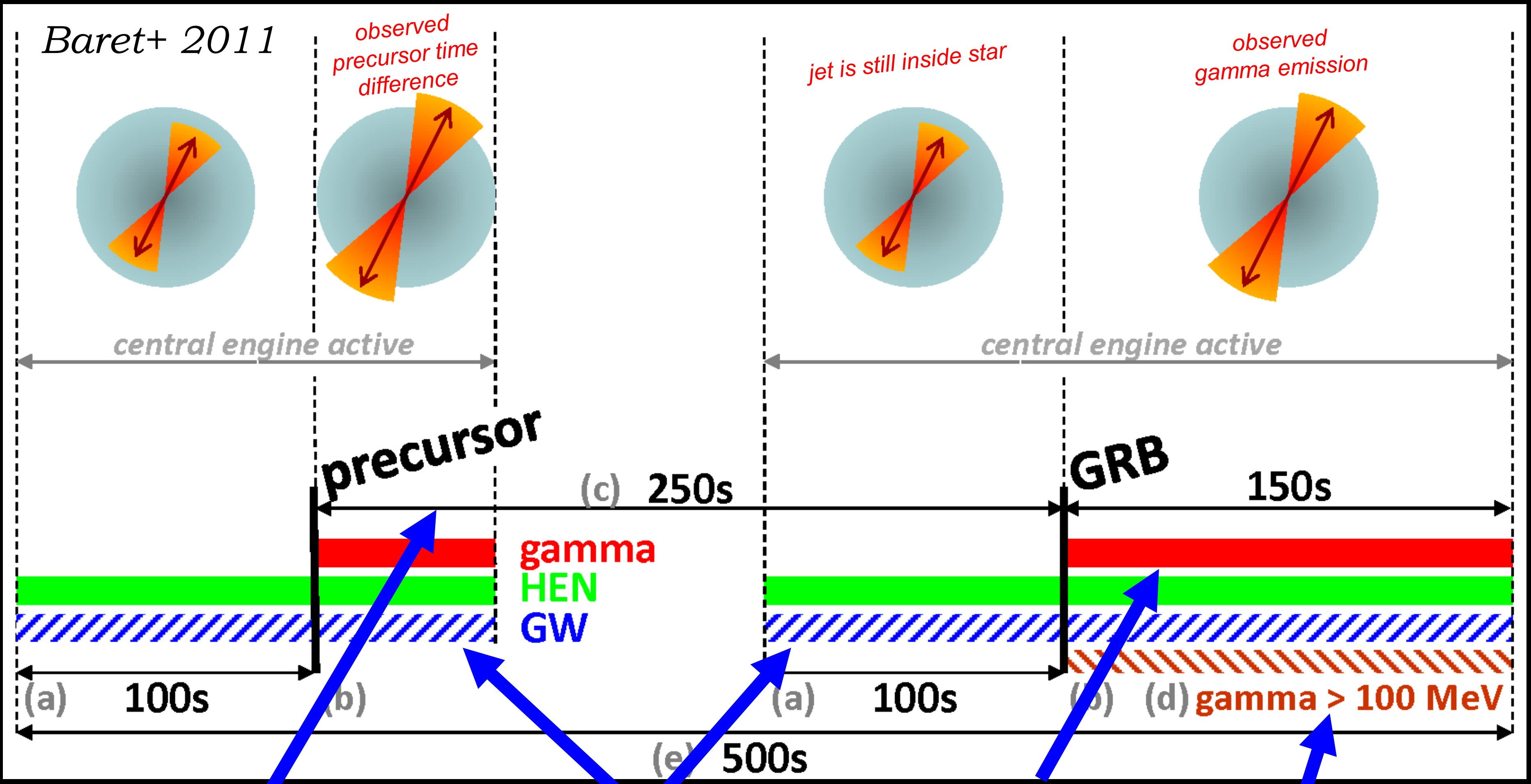


Joint Analysis: The Ingredients



Baret et al. PRD 2012

Coincidence Time Window



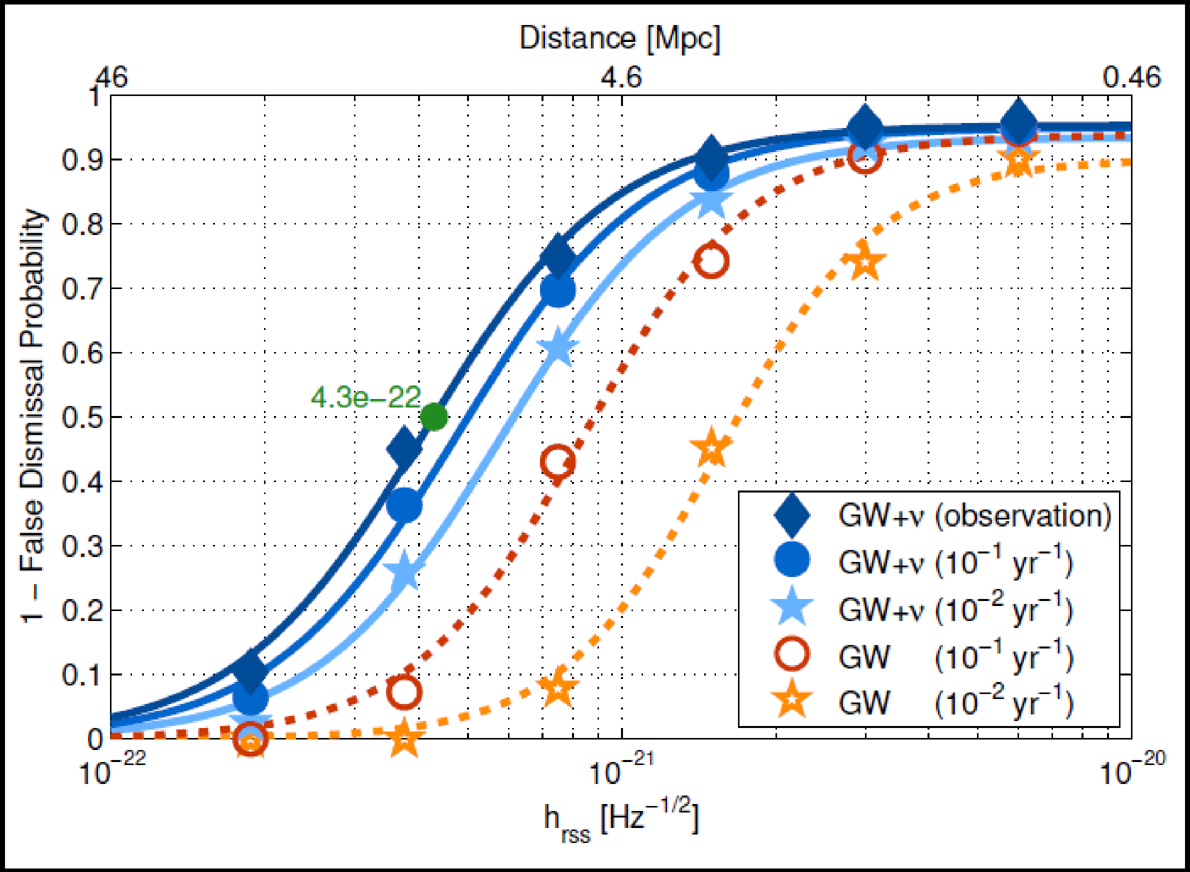
BATSE precursors (374)
Burlon et al., 2008

Ott, 2009 ++

BATSE GRBs (~1200)
> 100 MeV photons from Fermi

Coincidence time window: 500s

Sensitivity



IceCube+LIGO+Virgo PRD 2014

Increased sensitivity for joint search

Especially useful for high-significance detection

Results with initial detectors (aLIGO-Virgo will be 10x better --- >100 Mpc)

Next steps

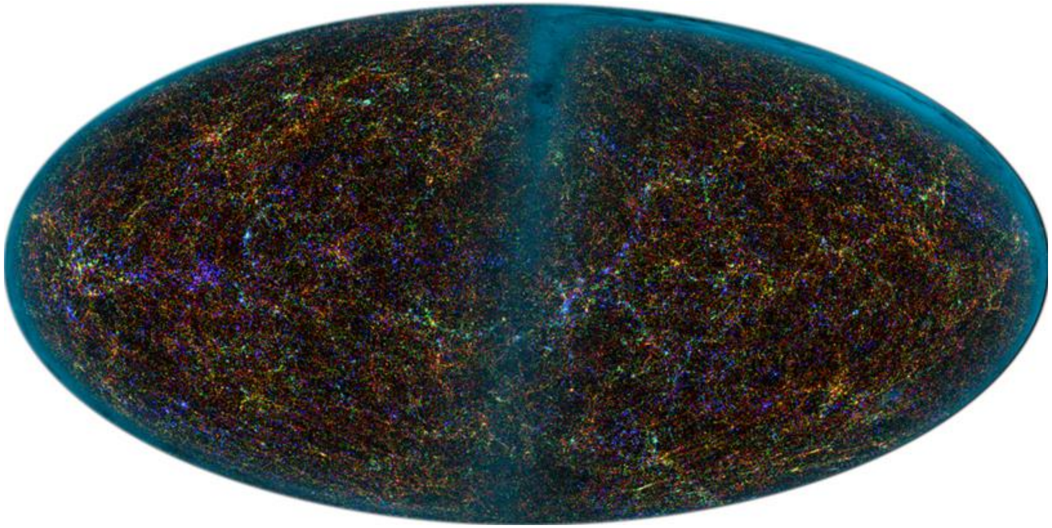
- ✓ Advanced LIGO will start observation this summer
- ✓ IceCube is operational
- ✓ Real-time analysis – electromagnetic follow-up
- ✓ Galaxy information – catalogs
- ✓ Source model

Galaxy catalogs

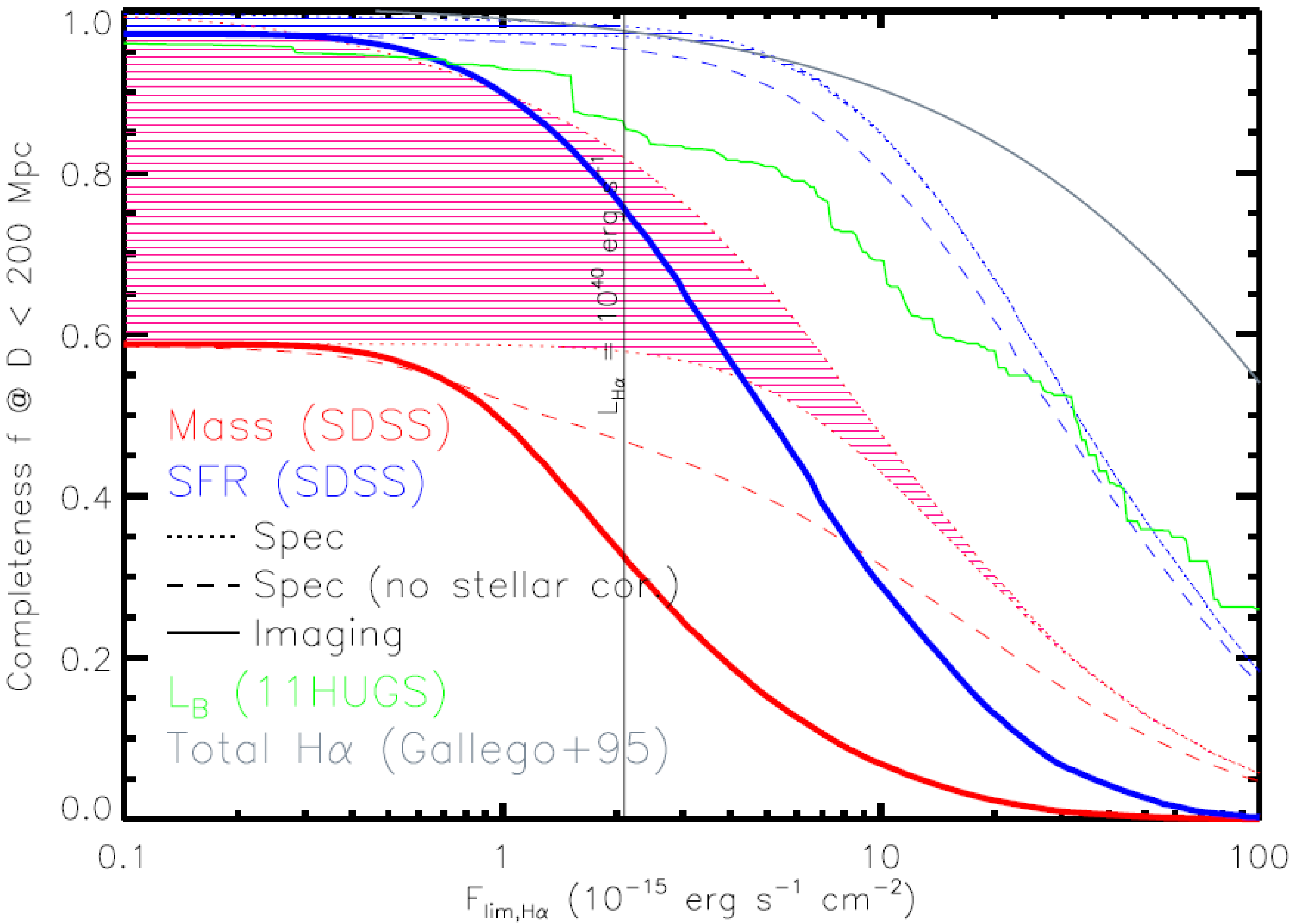
- How will we detect?
  - Gamma < hour
  - Optical/NIR emission up to 1-2 weeks after event (kilonovae)
  - Radio > year
- What are the difficulties?
  - Large sky area
  - Foreground events
- How will a galaxy catalog help?
  - Can point in right directions
  - Decreases foreground by a factor of a 1000 (<200 Mpc).

Galaxy catalogs – not complete!

- We typically need star-formation rate
  (binary mergers – Star formation rate + galaxy stellar mass)
- GWGC is only complete out to ~40 Mpc.
- 60% complete out to 100 Mpc.
- This will not be enough. It will be hard to make more complete maps out to the required distance of 200-500 Mpc.



How can we make a complete catalog?



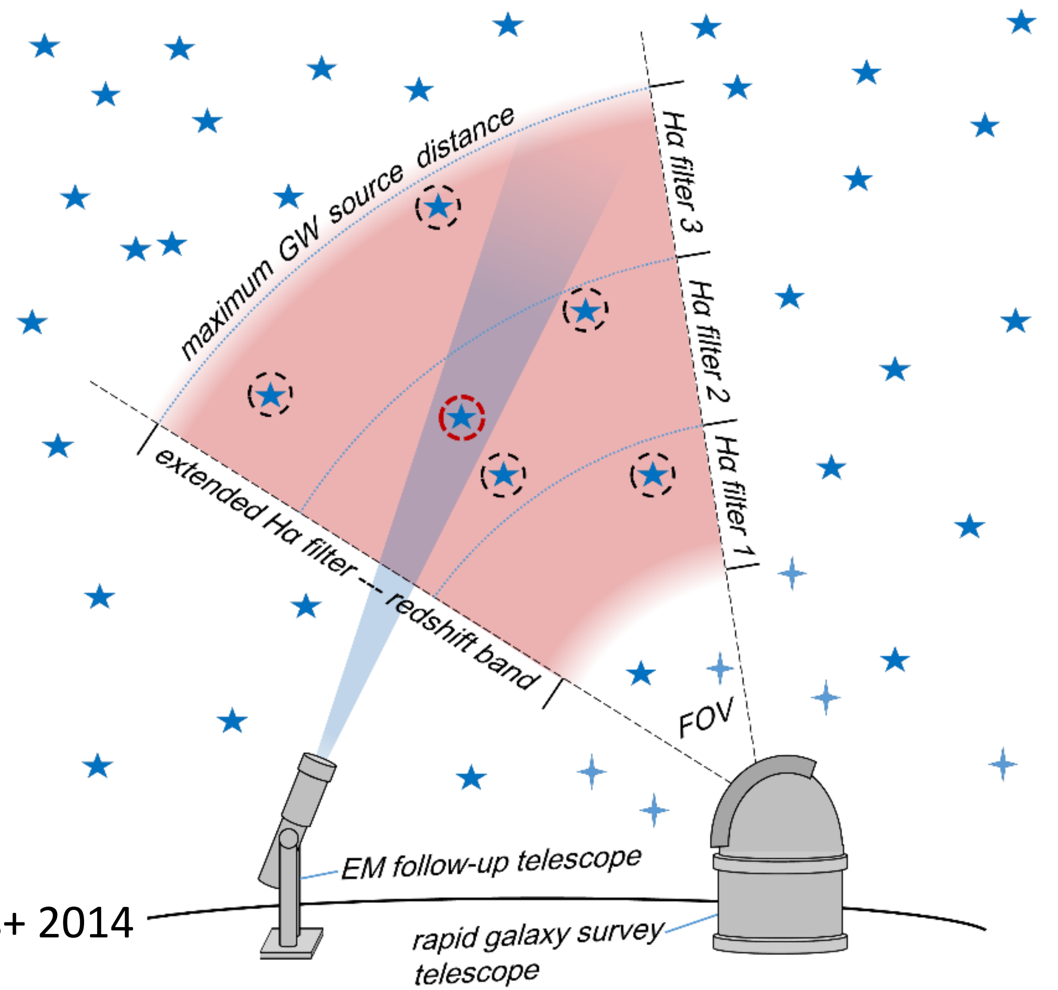
Metzger+ ApJ 2013

Catalog on the fly

- Can we make a catalog in the right time frame, distance range and sky area?

  ✓ 1 week
  ✓ 200-500 Mpc
  ✓ 100 deg^2

- Extended H-alpha survey (R-band comparison)
  - We only want to find galaxies within horizon distance
  - We don't necessarily need more info than this as long as catalog is complete



Bartos+ 2014

- Meter class telescopes work.

- Don't need very high completeness (Hanna+ 2014)

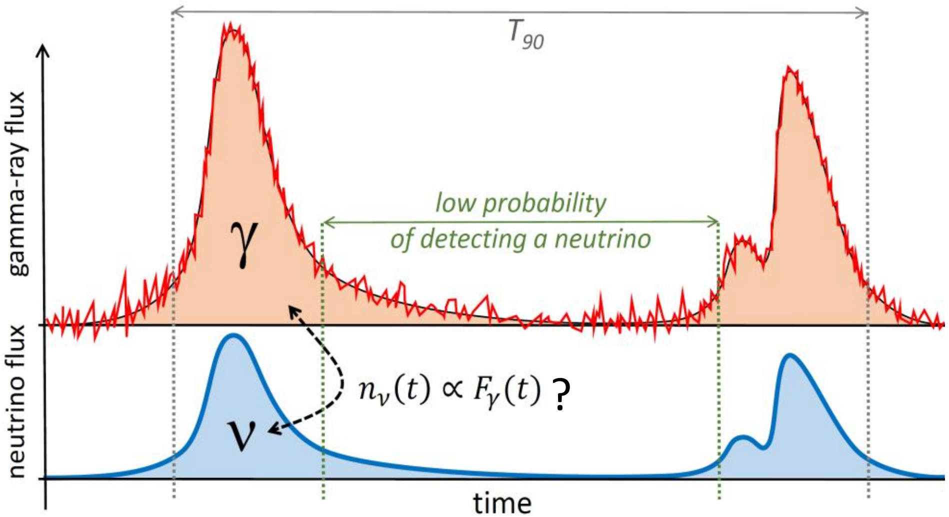
Neutrino – gamma-ray correlation

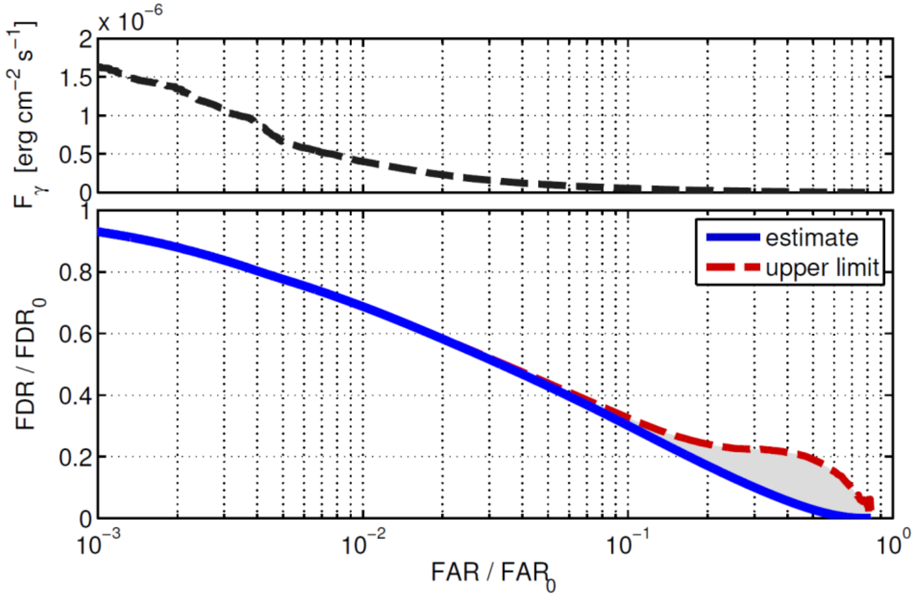
Gamma-ray --- neutrino emission mechanism is connected → temporal correlation
Hummer et al. PRL 2012 --- GRB fluence & neutrino fluence linearly correlated (117 GRBs)

Using temporal correlation can decrease False Alarm Rate by x100

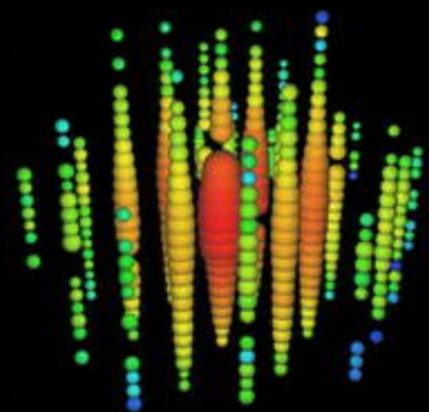
Discovery potential for GRBs = 1 TeV neutrino
~ few GeV neutrino

More comprehensive emission model can help even more.





Bartos & Marka PRD(R) 2014



Summary

- GW+neutrino analyses will begin this summer
- Real-time multimessenger opportunities
- Joint observations: GW+neutrino+EM
- Galaxy catalogs (on the fly?)