Gravitational Waves & Multimessenger Astrophysics

high-energy neutrinos & electromagnetic counterparts

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Outline

Why?.............

- Multimessenger science prospects
  - Sources of interest

How?.............

- Observation & strategies
  - Low latency searches with GWs
  - GW+ν search
  - Observatory networks: AMON
  - GW+ν observational constraints

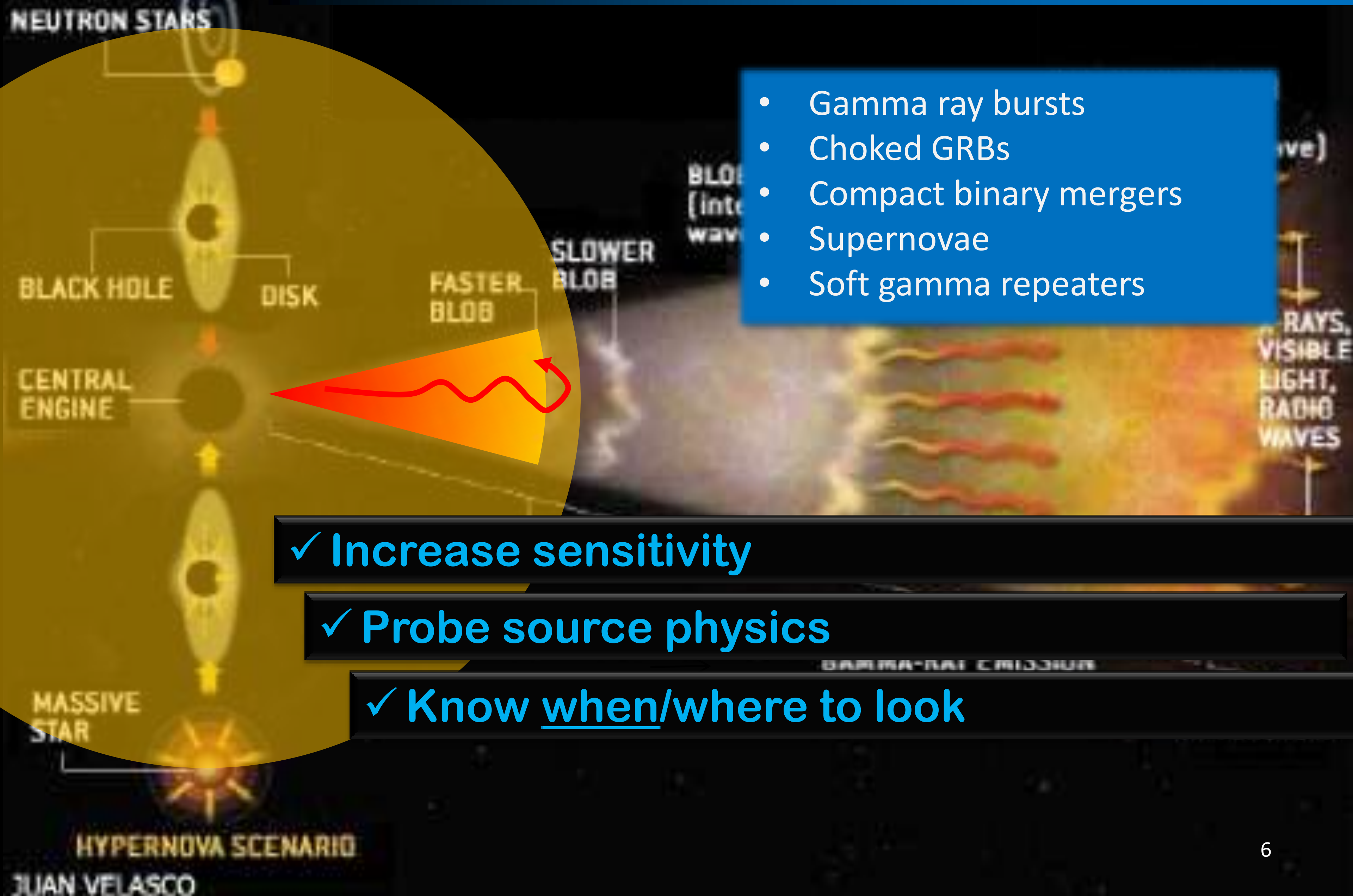
What?............

- ...can we learn from measurements?
  - Collisional heating
  - Probing the jet structure with ν's

Multimessenger Science Prospects

Multimessenger Science prospects

- Gamma ray bursts
- Choked GRBs
- Compact binary mergers
- Supernovae
- Soft gamma repeaters

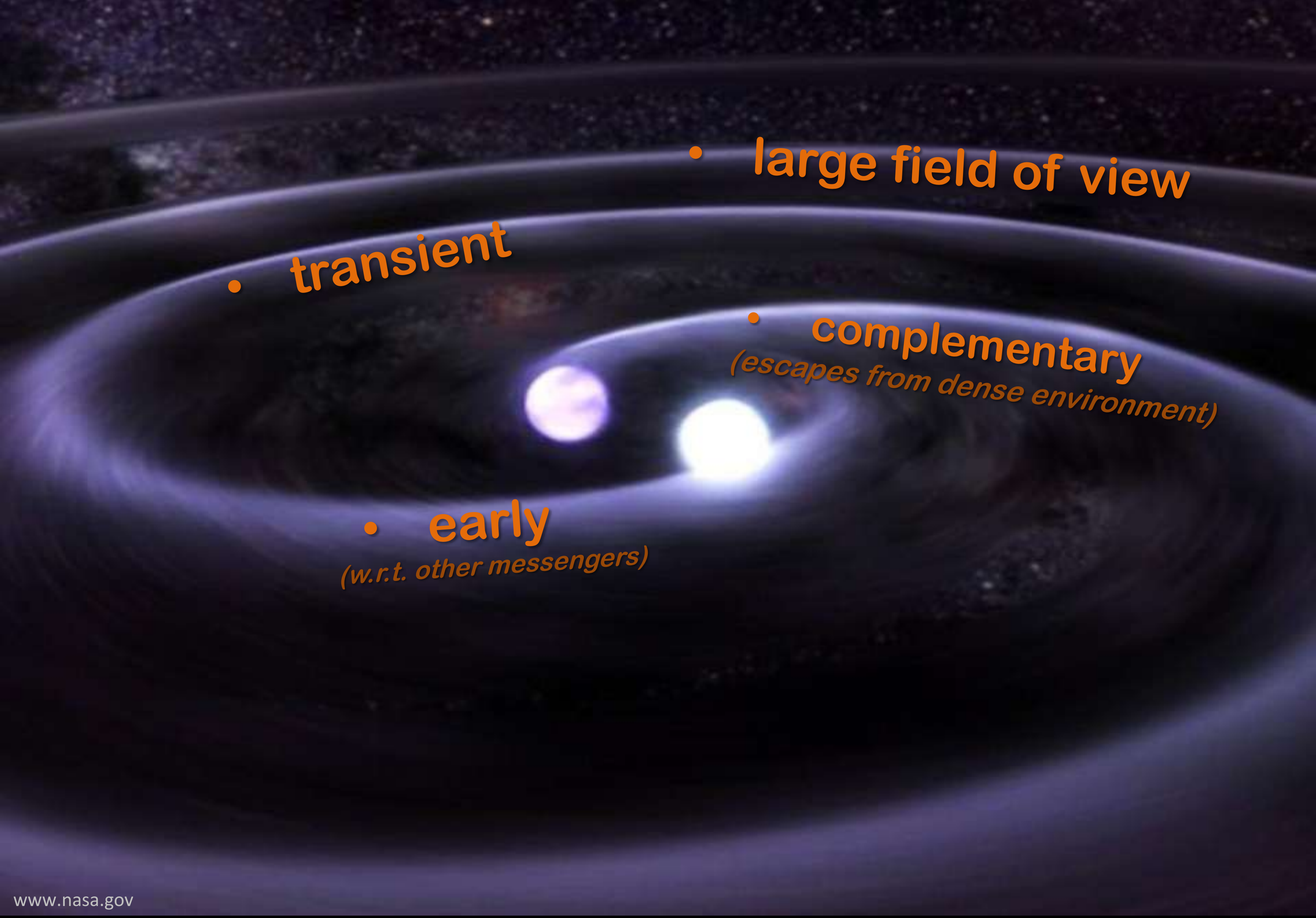


✓ Increase sensitivity

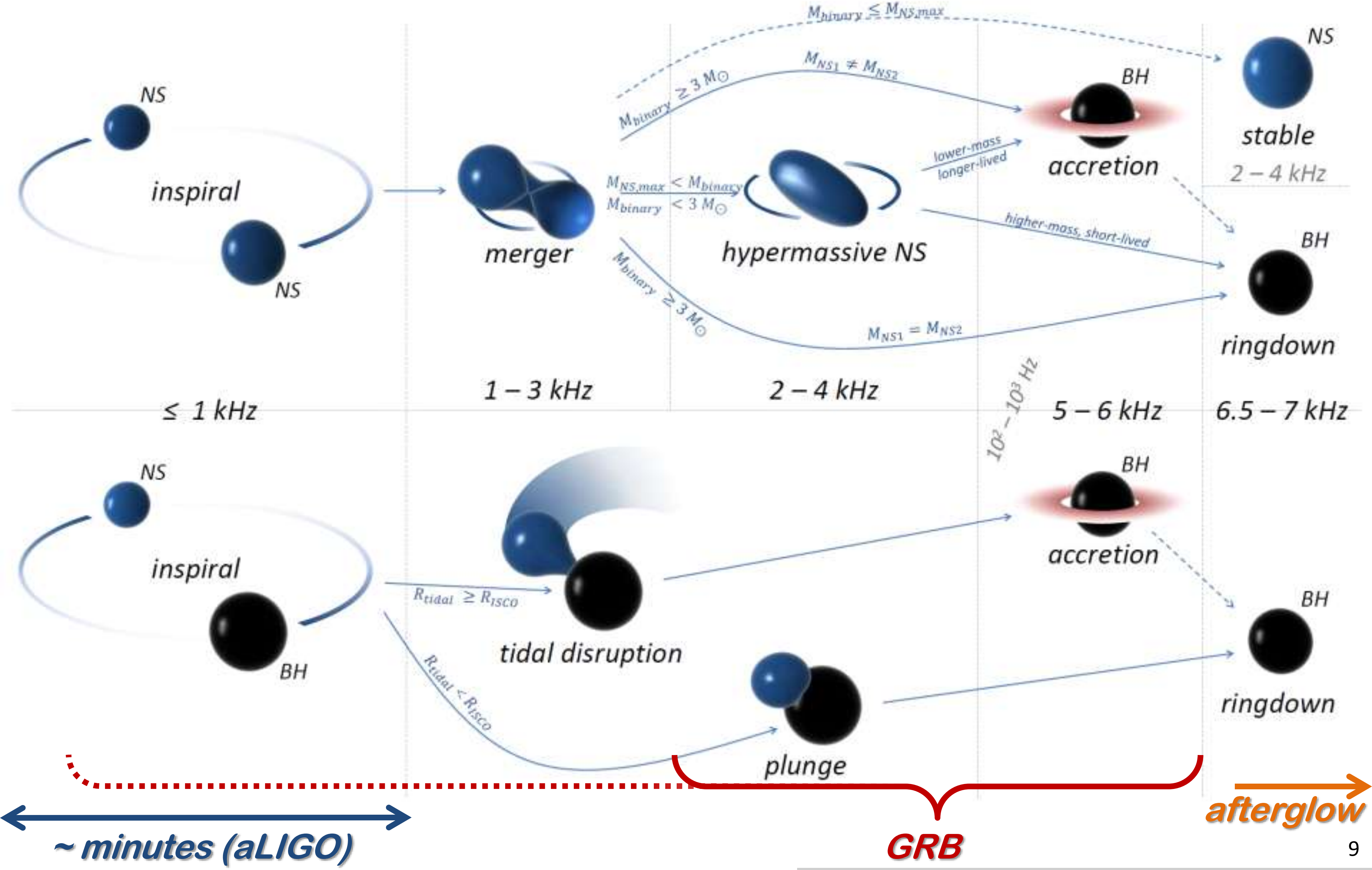
✓ Probe source physics

✓ Know <u>when</u>/where to look

GRAVITATIONAL WAVES FOR REALTIME ASTROPHYSICS

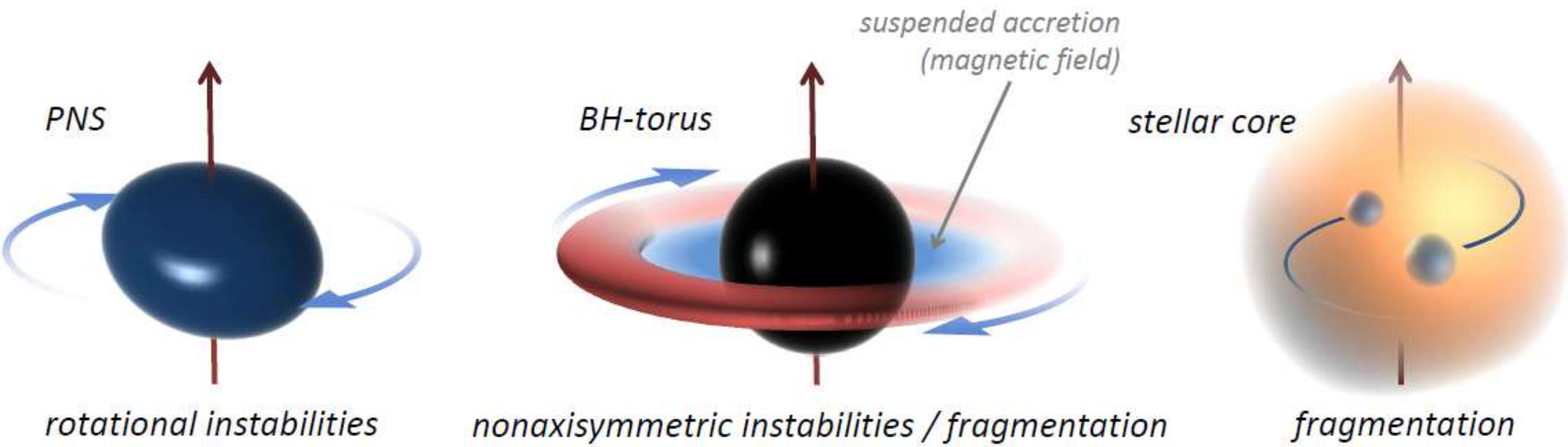


GRAVITATIONAL WAVES – COMPACT BINARIES



Topical review: Bartos et al. 2012

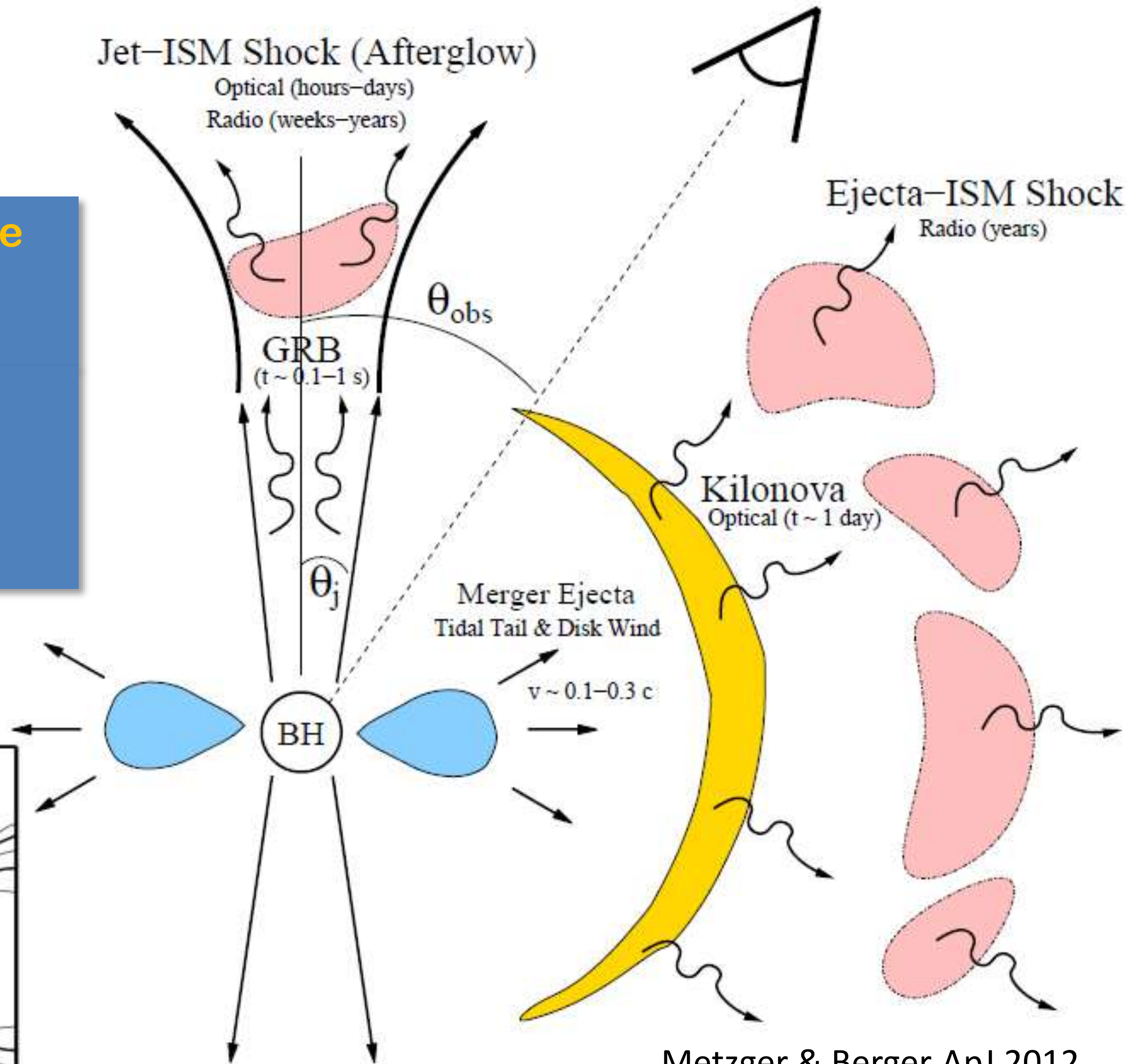
GRAVITATIONAL WAVES – CORE COLLAPSE



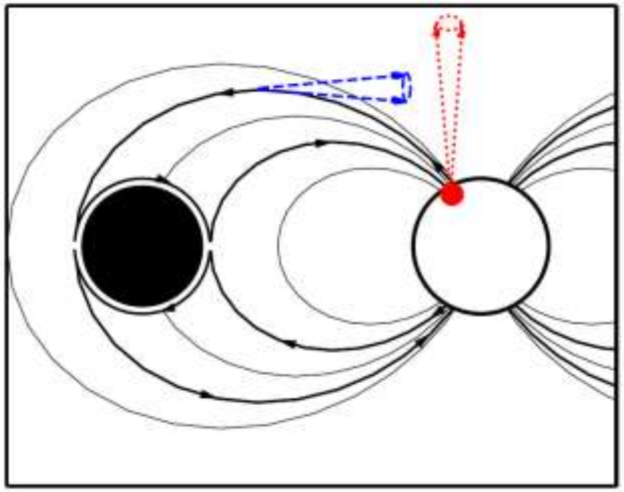
Topical review: Bartos et al. 2012

Gamma ray bursts are highly beamed

Renewed interest in alternative, off-axis electromagnetic counterparts



Metzger & Berger ApJ 2012

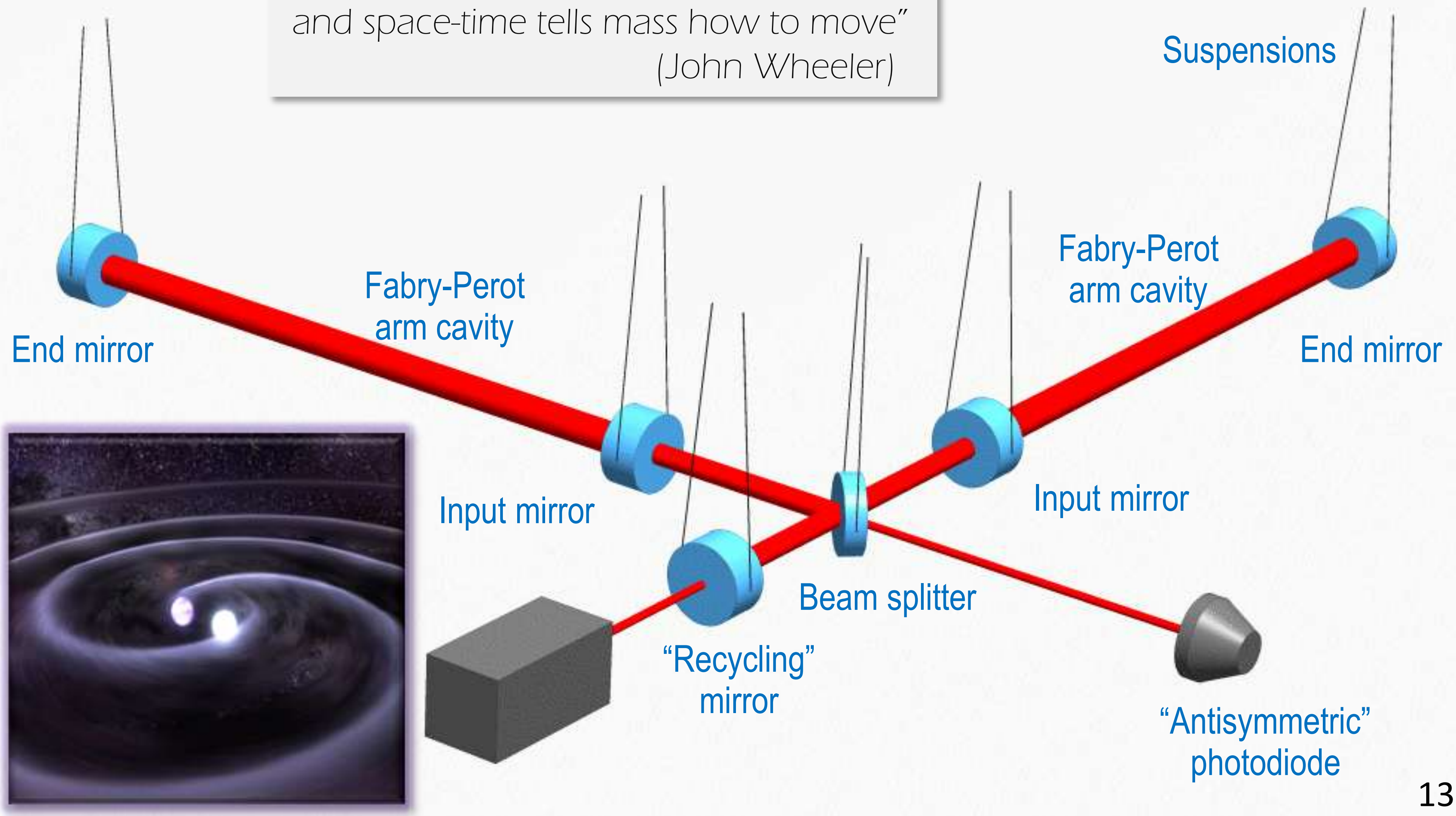


McWilliams & Levin ApJ 2012

Observation & Strategies

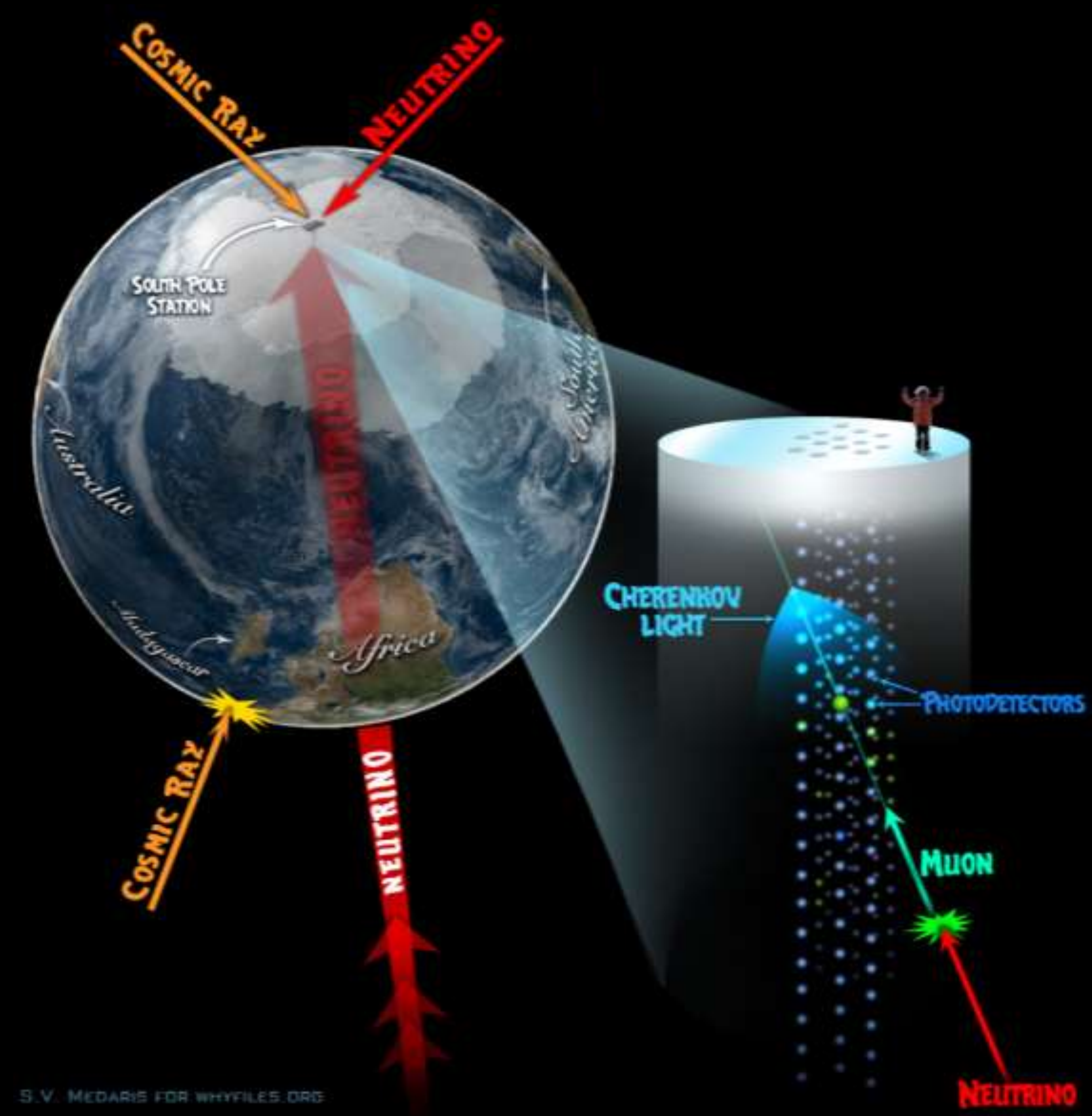
Gravitational wave detection

> "Mass tells space-time how to curve,
> and space-time tells mass how to move"
> (John Wheeler)



High-energy neutrino detection

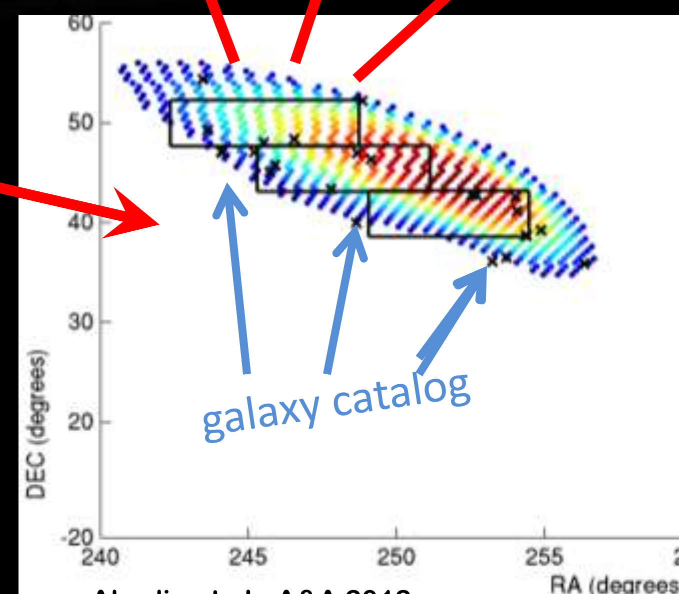
Credit: ESO/A. Roquette



GRAVITATIONAL WAVE DETECTORS

ELECTROMAGNETIC FOLLOW-UP

Analyze GW data, select candidates



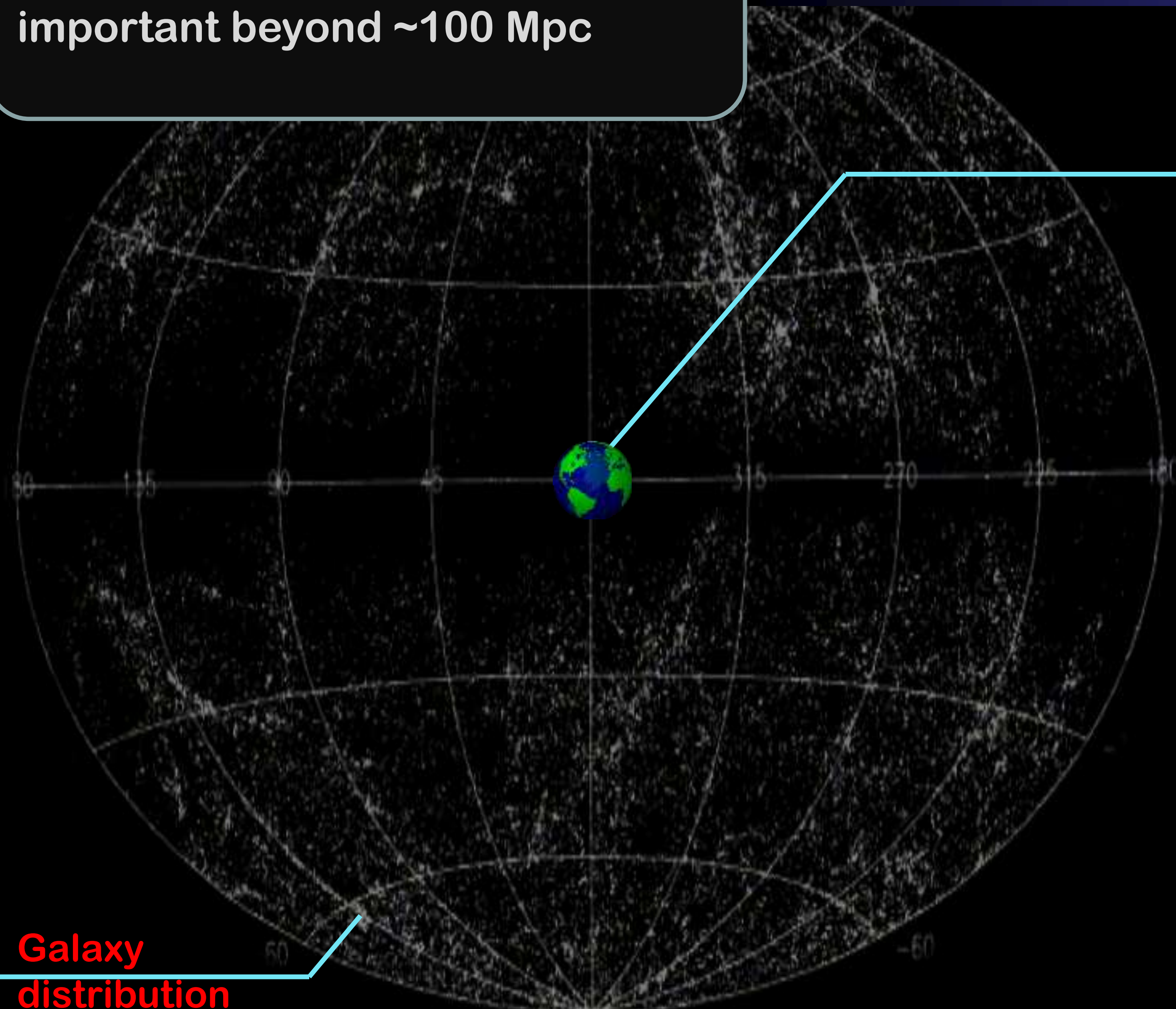
see: **Abadie et al., A&A 2012**

- Latency: O(30min) → O(min)
- Sky area: O(10-40deg^2)

[e.g. see Kanner et al. 2012, Fairhurst 2011]

GW+ν

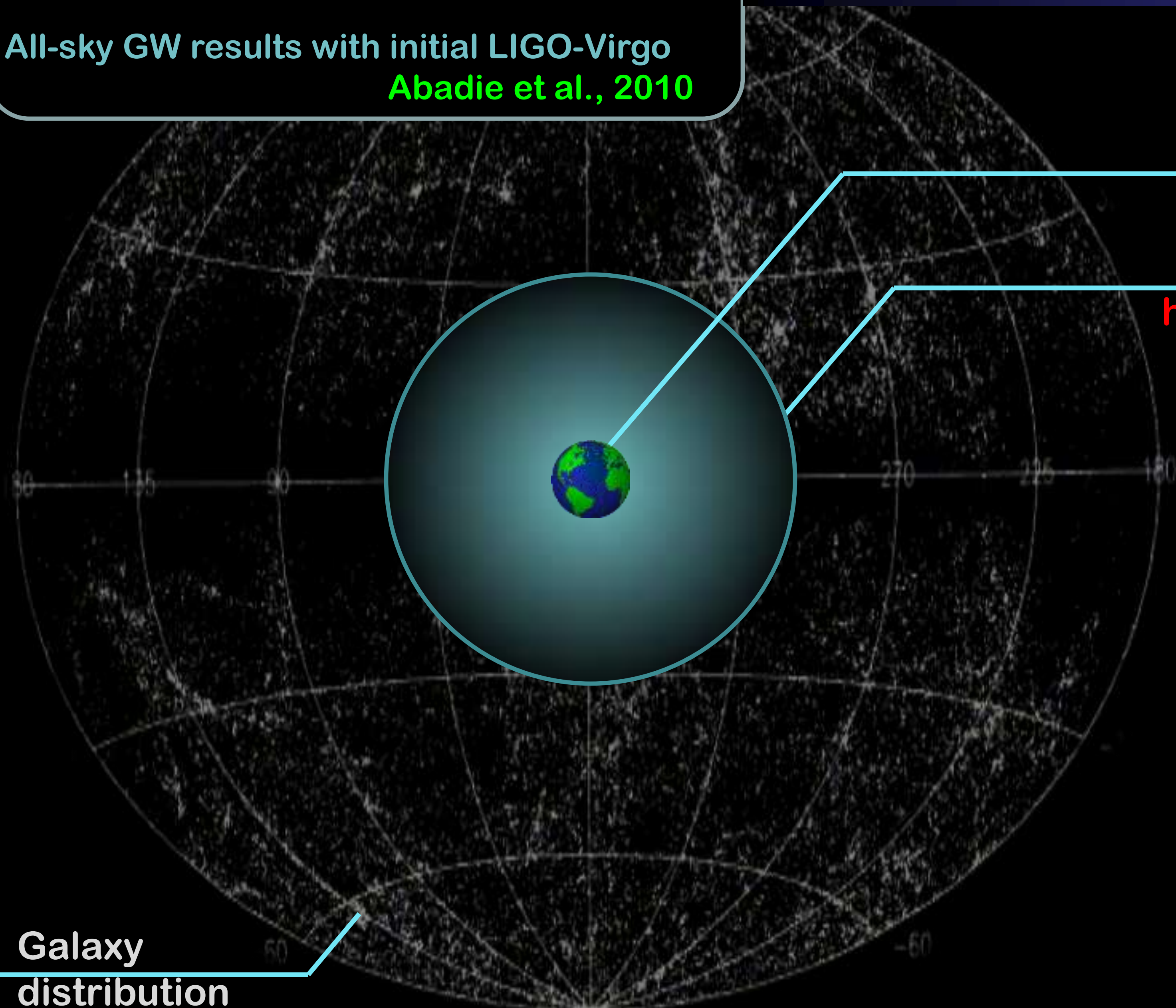
Galaxy distribution can be used to narrow sky coverage – less important beyond ~100 Mpc



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
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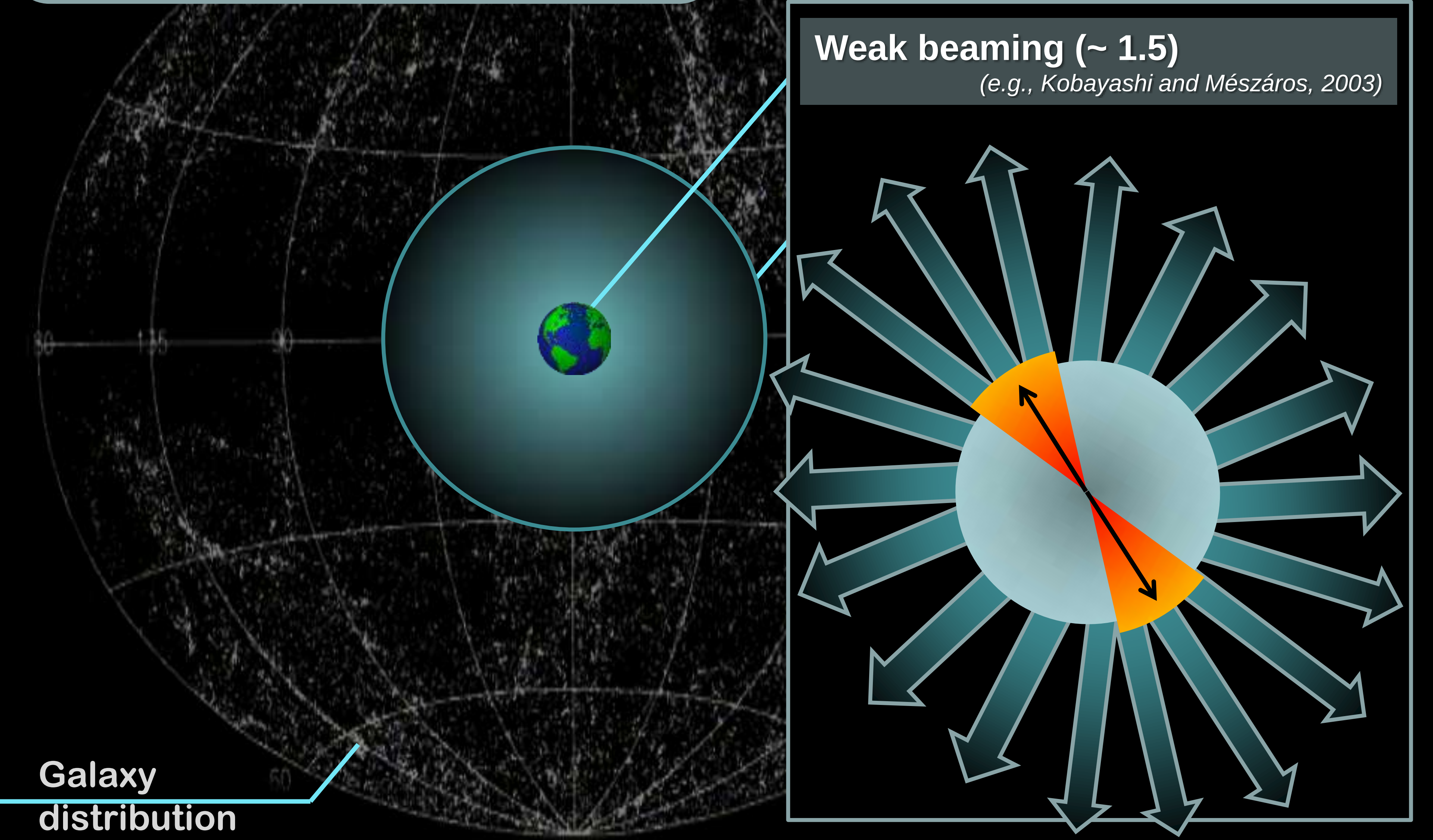
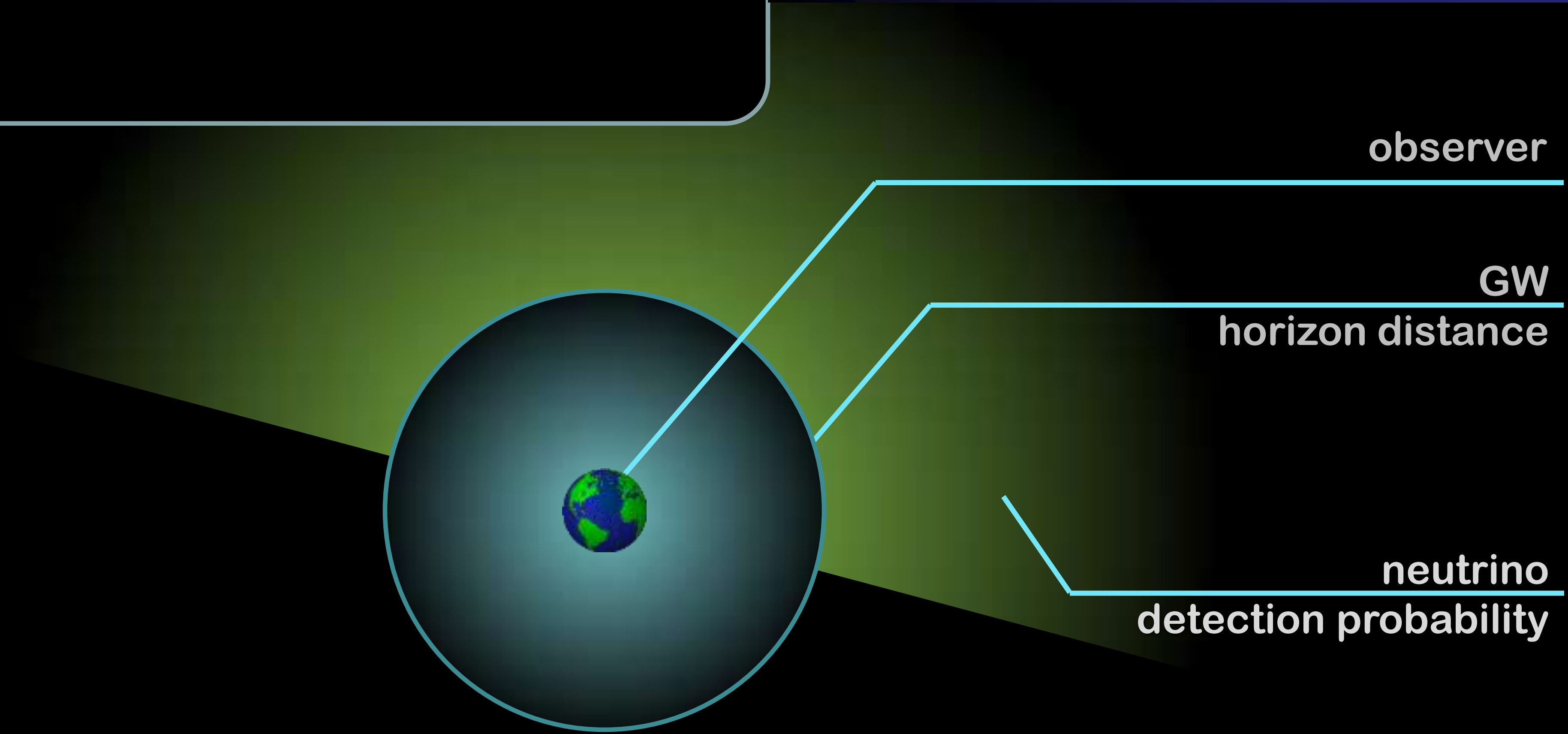


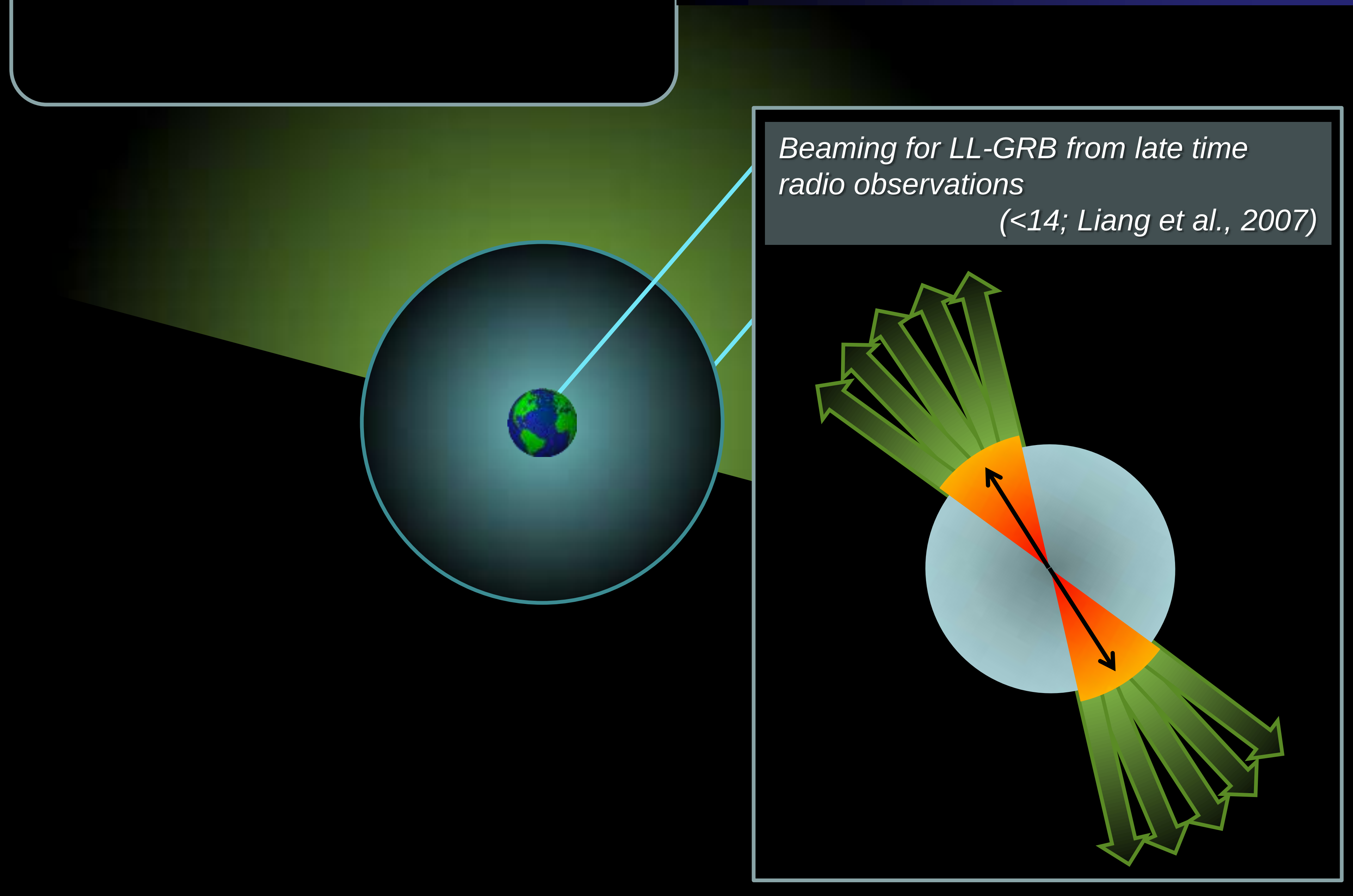
High-energy neutrino

GW+ν



High-energy neutrino

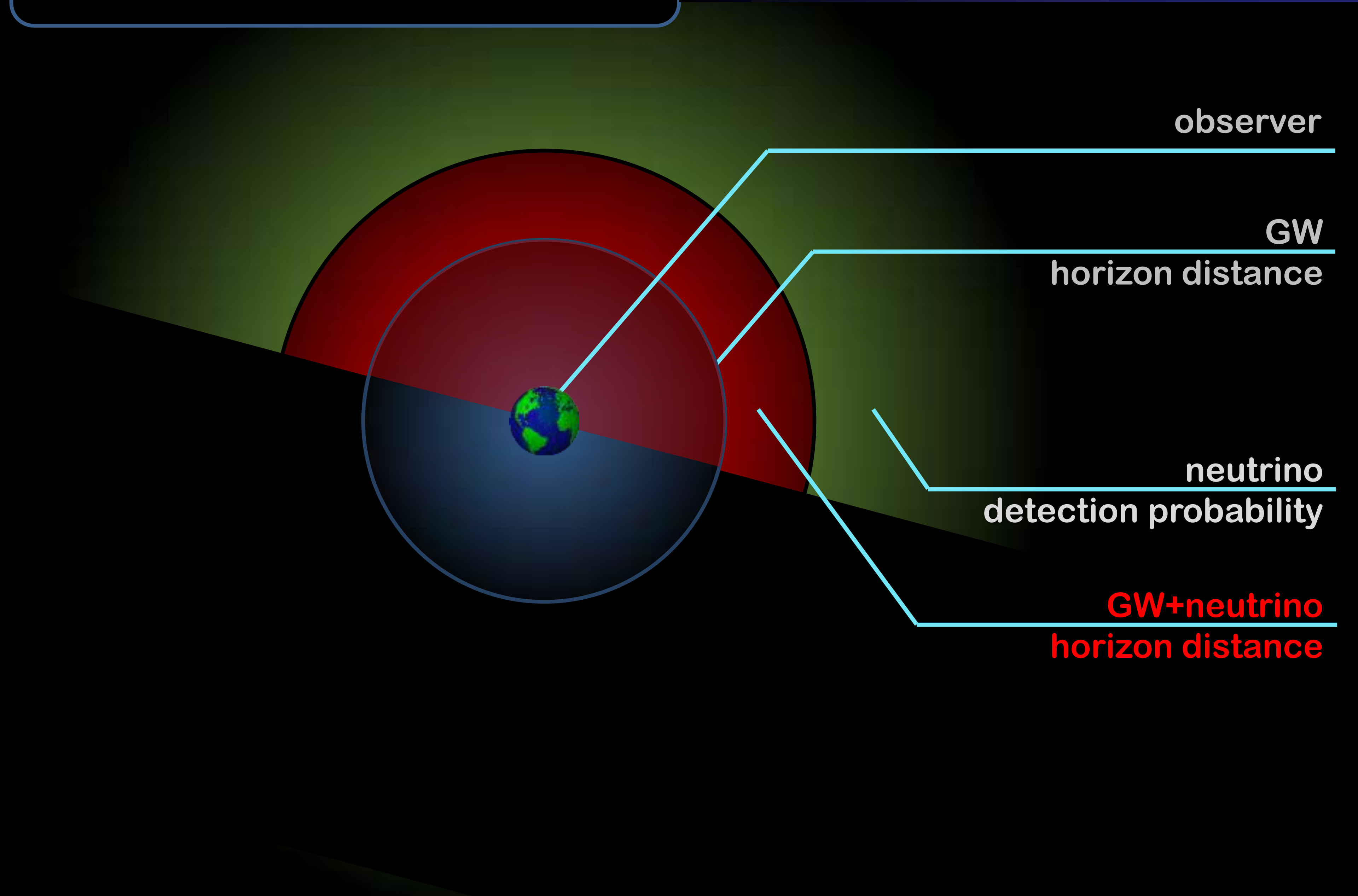
GW+ν



Beaming for LL-GRB from late time radio observations (<14; Liang et al., 2007)

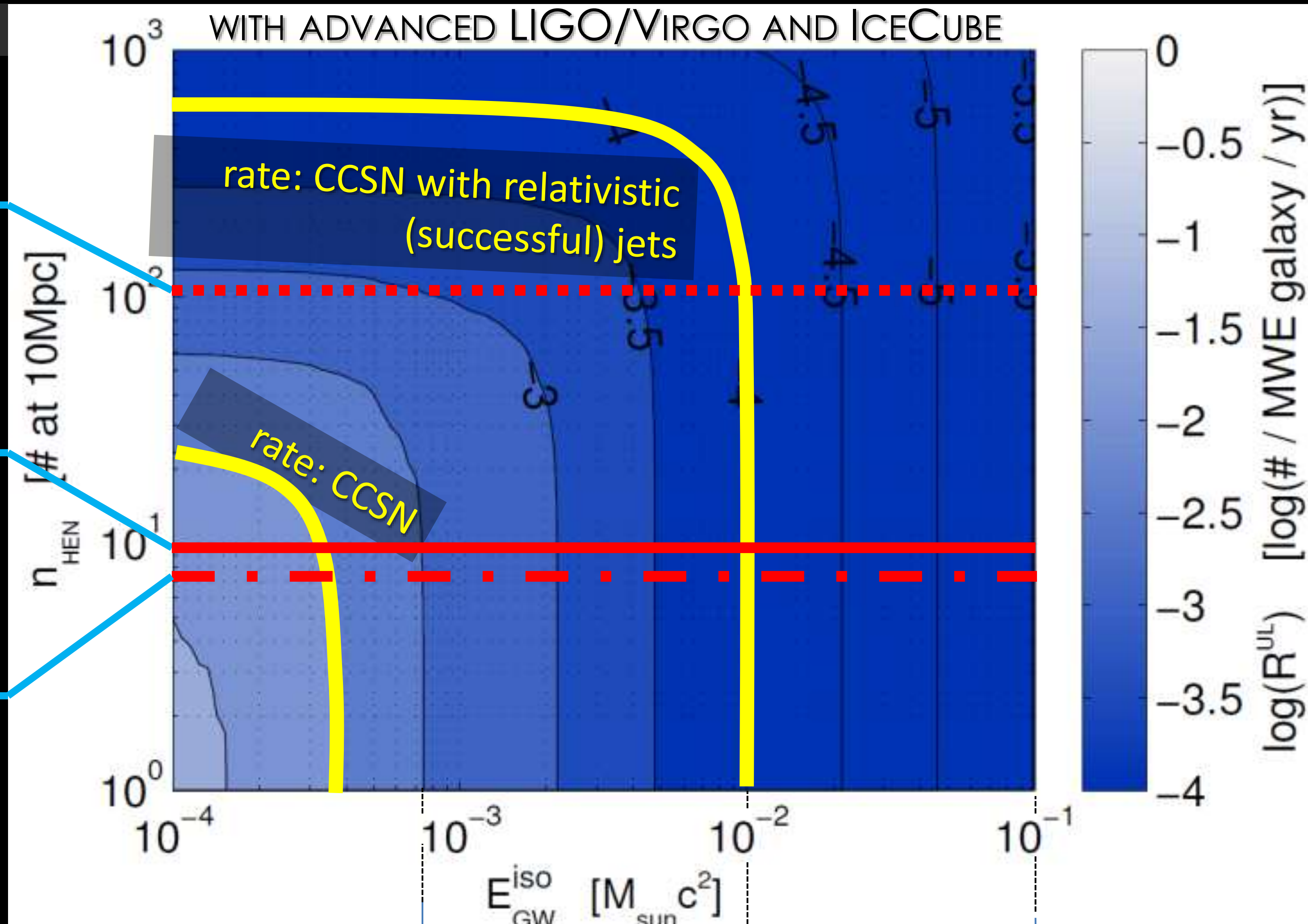
MULTIMESSENGER

GW + high energy neutrino
GW coincident with ≥ 1 neutrino



PROJECTED OBSERVATIONAL CONSTRAINTS

Bartos et al. PRL 2011



Waxman-Bahcall

Guetta et al., 2004

mildly relativistic jets in CCSNe

Ando & Beacom, 2005

reverse shocks

Horiuchi & Ando, 2008

fragmentation of collapsar accretion disks

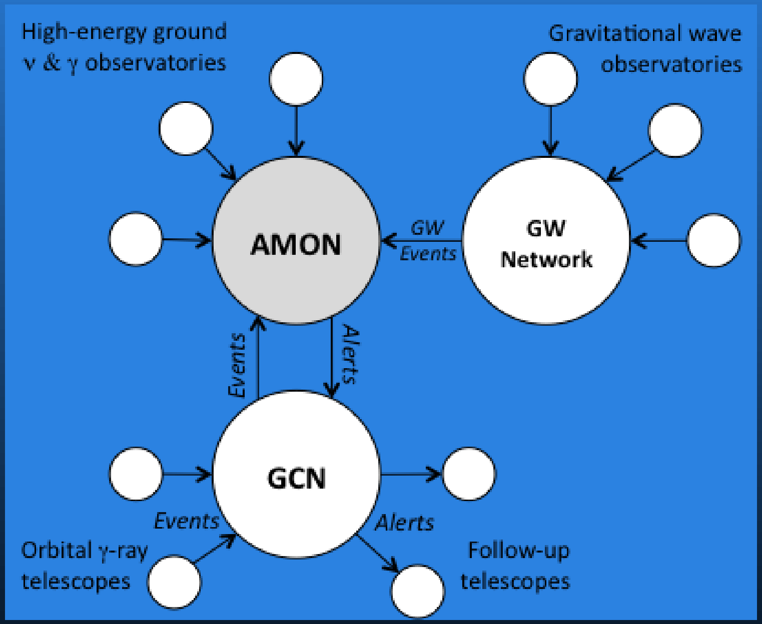
suspended accretion

compact binary mergers

Davies et al., 2002

van Putten et al., 2004

Schutz, 1989

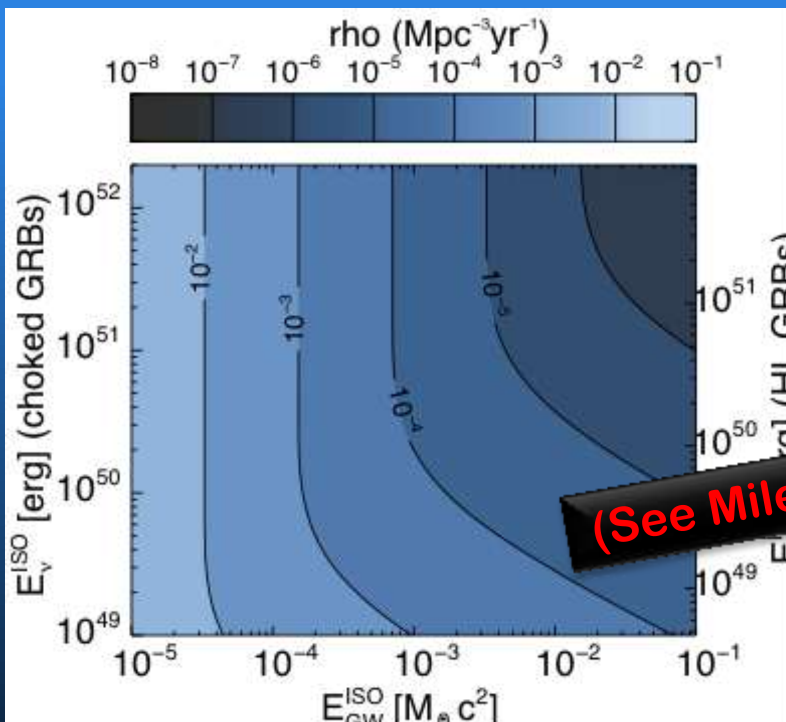


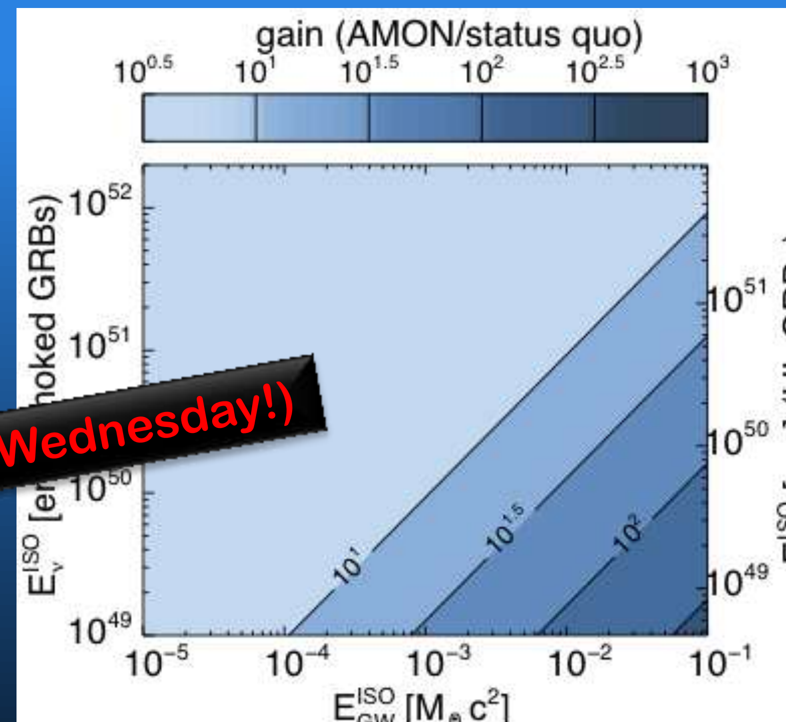
- AMON is a *consortium* of observatories and shared cyber infrastructure
- AMON will enable:
  - Collaborative archival searches
  - Realtime identification of multimessenger coincidences
  - Alerting of follow-up observatories
- Systems are being designed to keep data ownership and control with the collaborations

Smith et al. 2012

AMON

Astrophysical Multimessenger Observatory Network





(See Miles' talk on Wednesday!)

Best limits for a realtime search come from using sub-threshold trigger events (e.g. single n)

Gains of up to ~100 when compared to pairing separate above-threshold GW and n alerts

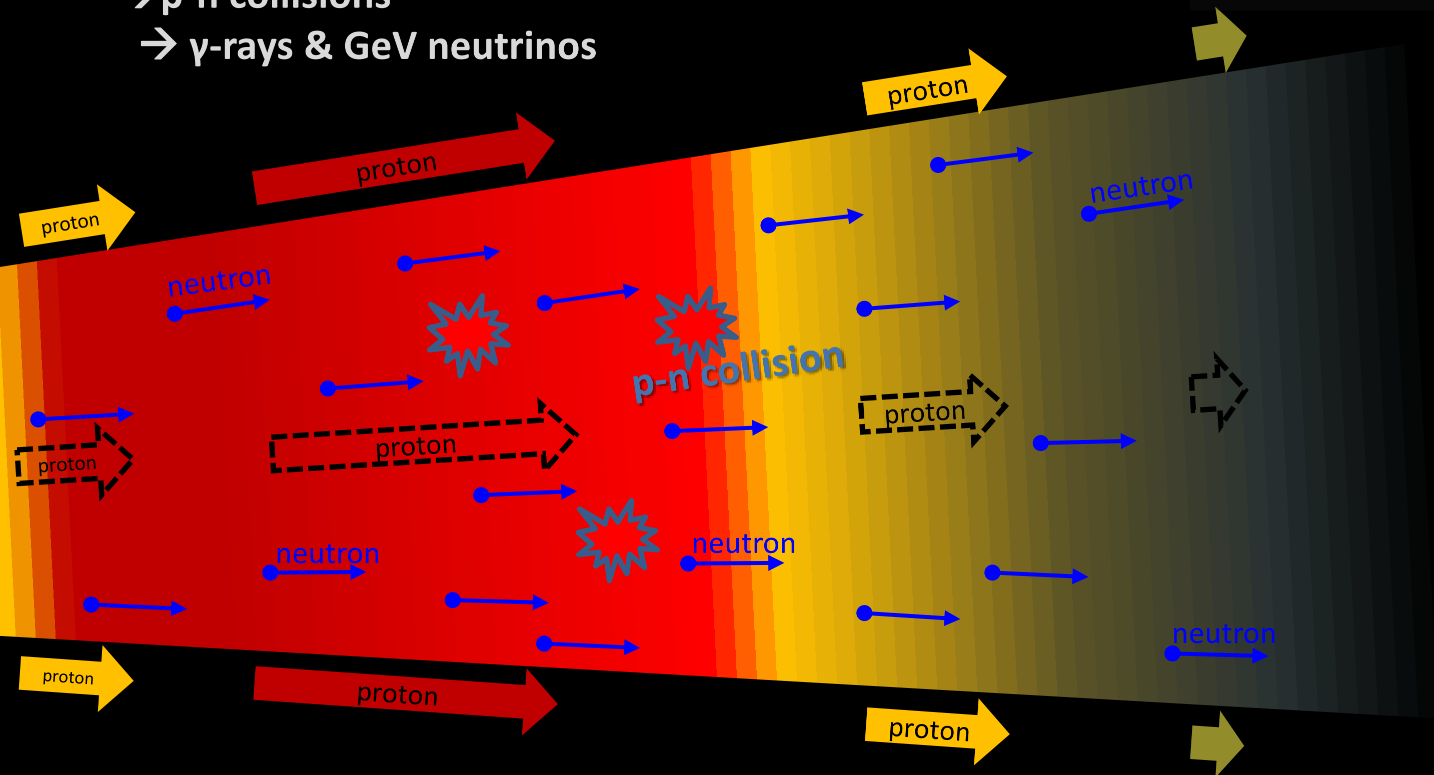
Smith et al. 2012

What can Multimessenger detections tell us about astrophysical phenomena?

Collisional Heating

Derishev et al. ApJ 1999
Bahcall & Mészáros PRL 2000
Mészáros & Rees ApJ 2000

p-n two-fluid compound state
→p-n collisions
→ γ-rays & GeV neutrinos



$f_\nu \sim 1/2$

$1-f_\nu$ → γ photons → Band-type spectrum

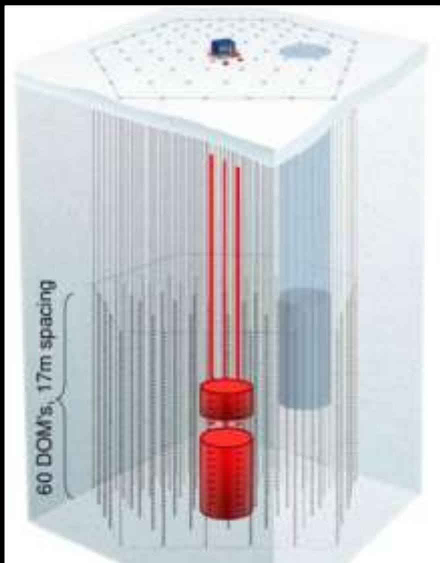
f_ν → GeV neutrinos: $\varepsilon_\nu \sim 0.1\,\Gamma$ GeV

Beloborodov MNRAS 2010

DETECTION PROSPECTS: ICECUBE-DEEPCORE

Bartos et al. 2013

http://www.physics.wisc.edu/groups/neutrino-experimental/



IceCube-DeepCore

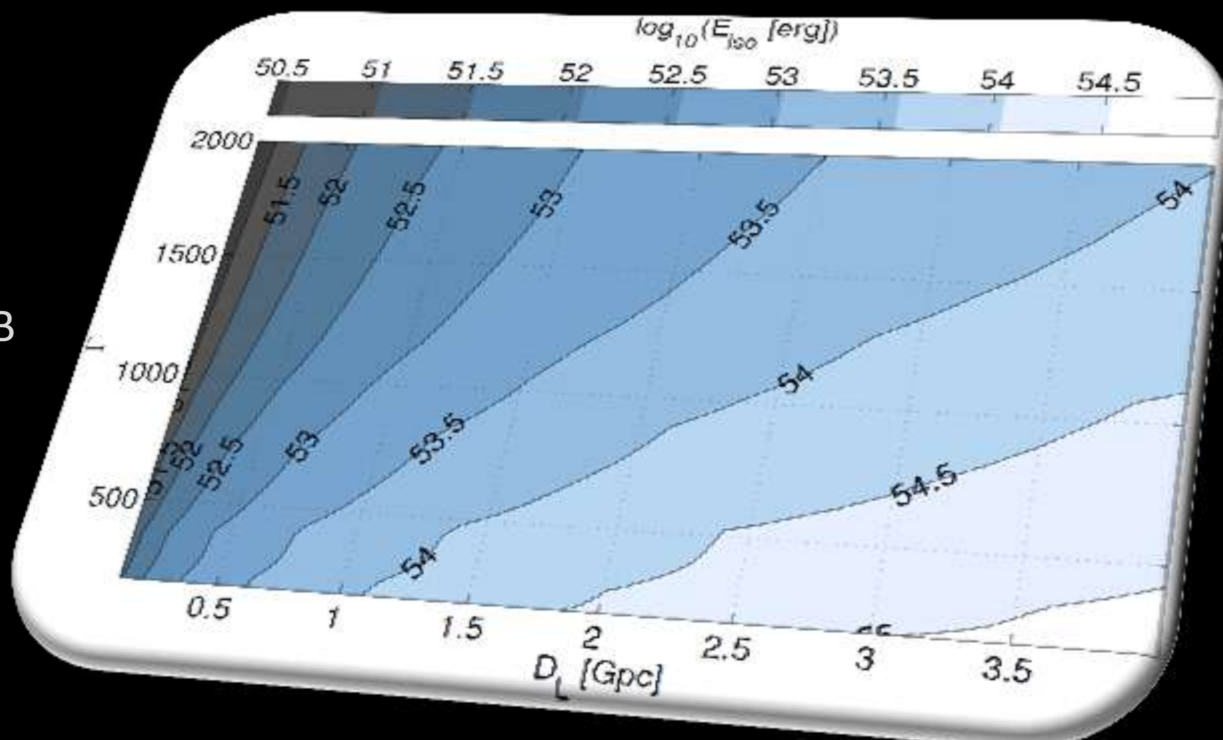
Sensitivity: 10-100 GeV
(+IceCube: >100 GeV)

→ GRB: $100 < \Gamma < 1000$ ✓

Low background: ~10^{-4} per GRB

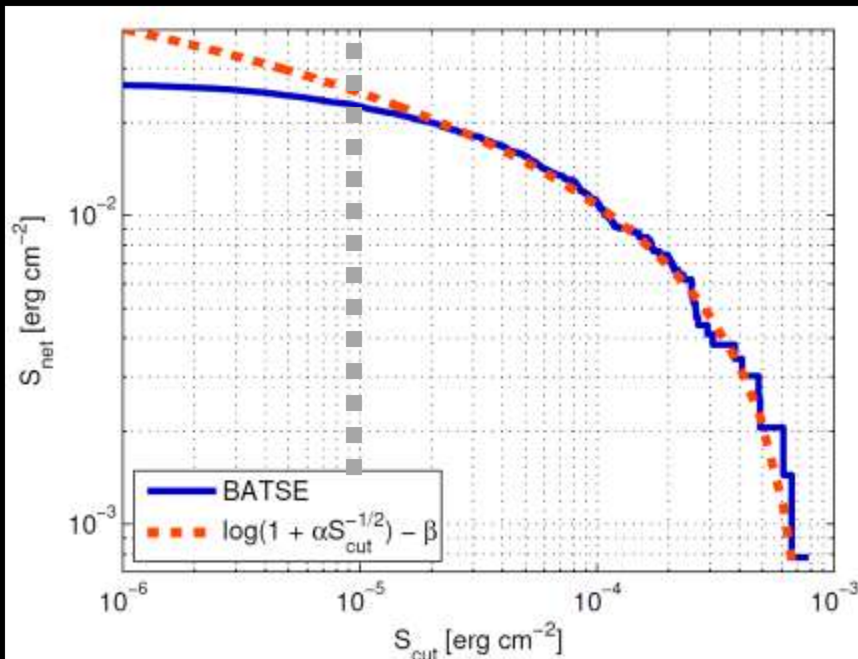
→ 1 neutrino is already interesting!

Most GRBs produce $\langle n \rangle \ll 1$ neutrino

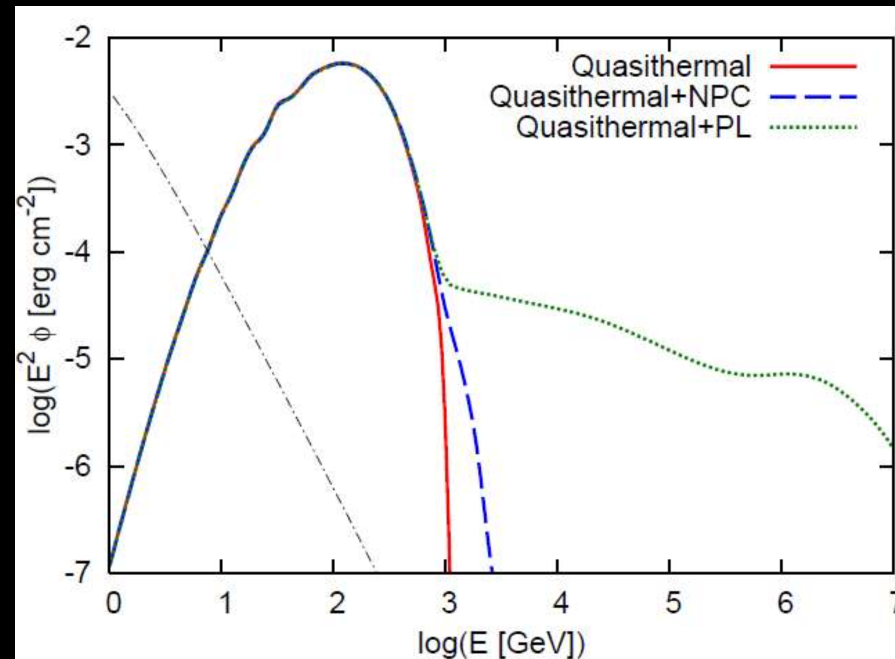


E_{iso} that would result in $\langle n \rangle$=1 detected neutrino

DETECTION PROSPECTS: ICECUBE-DEEPCORE 2



Bartos et al. 2013



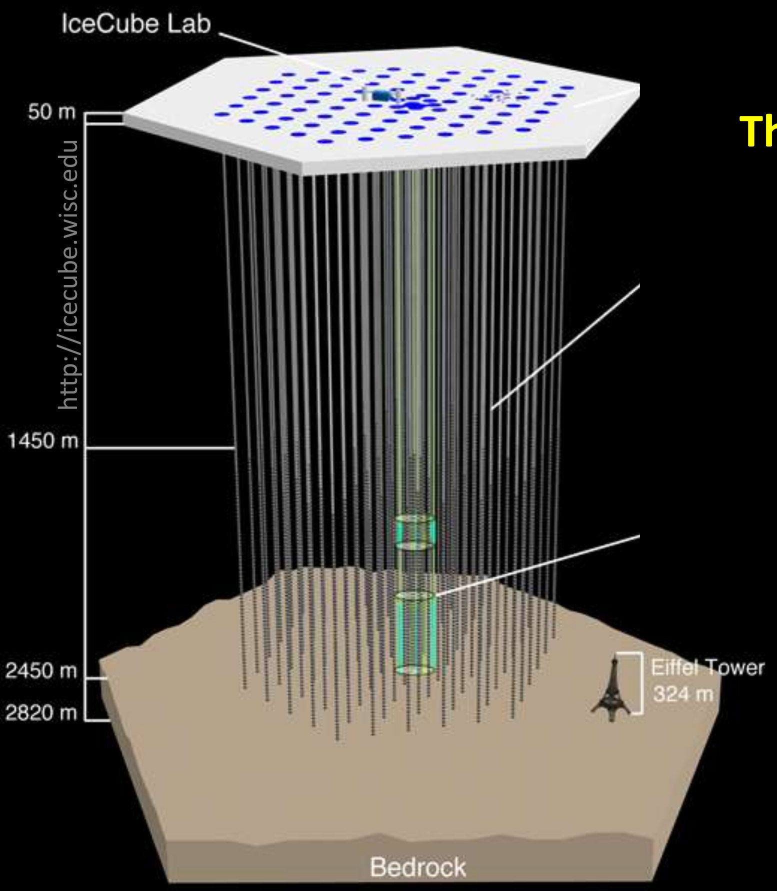
Murase et al. 2013

(see Kohta's talk tomorrow)

Focus on the brightest sources
- don't lose much
- reduced background

Energy distribution
- background rejection
- probe emission properties
- tune flux estimate

DEEPCORE: SCIENCE PROSPECTS



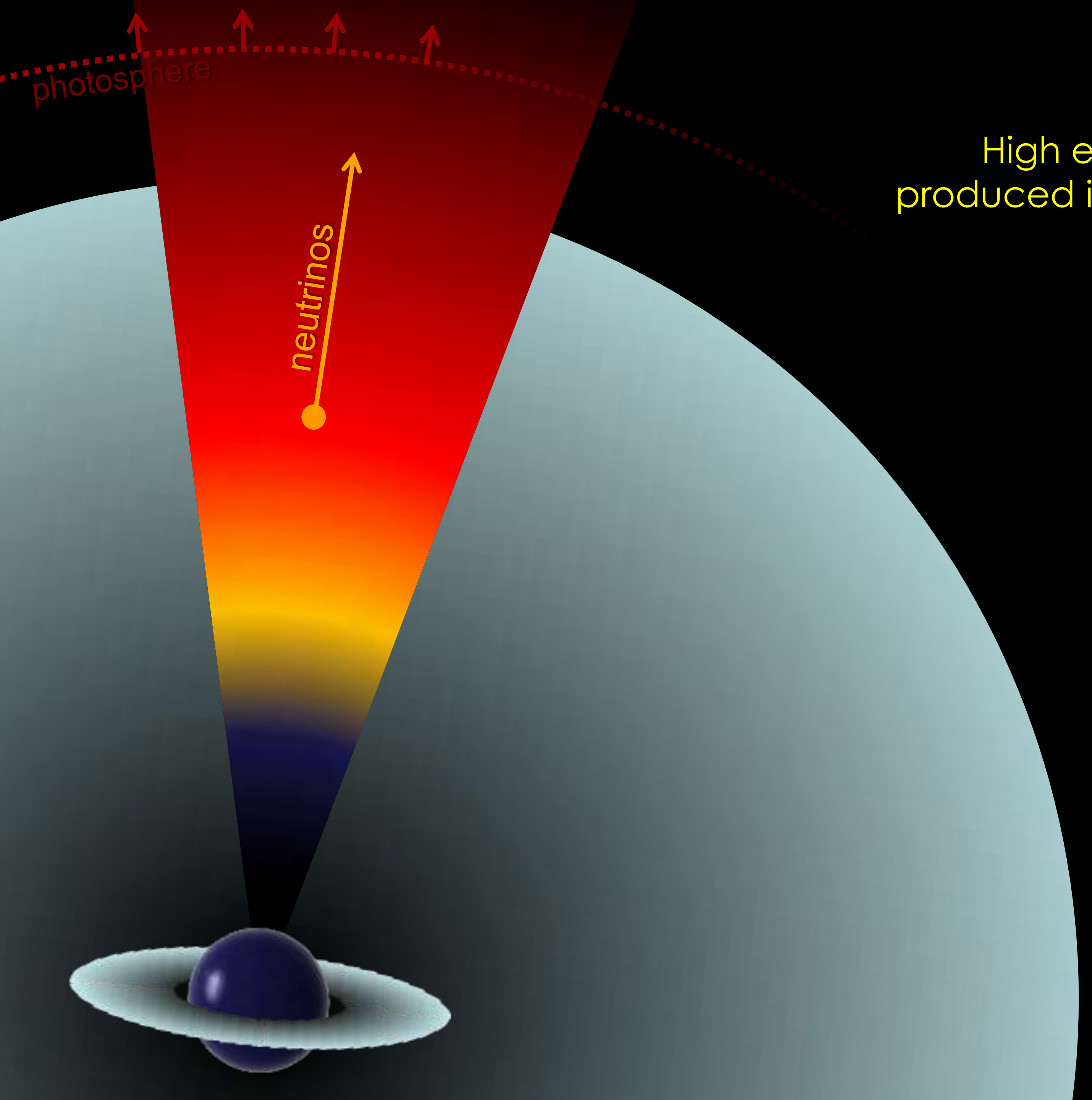
Bartos et al. 2013

The detection of GeV neutrinos from GRBs would:

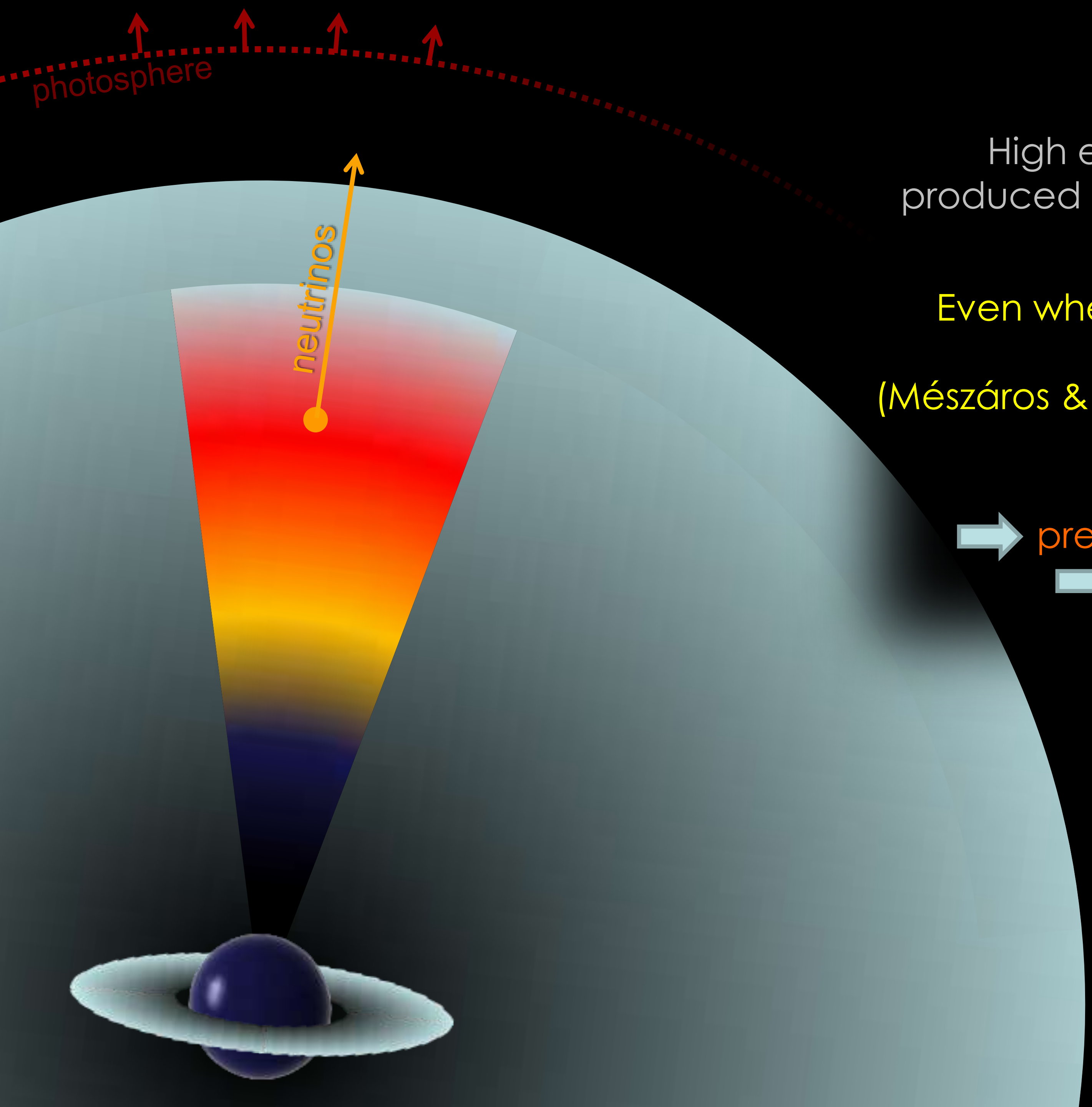
- **Confirm collisional heating of GRBs**
- **Lorentz factor: alternative measurement**
- **Gamma-production efficiency (f_γ)**
- **…**

Interesting scientific objective for IceCube-DeepCore and for planning future upgrades

http://en.minghui.org/emh/articles/2003/3/30/33976p.html



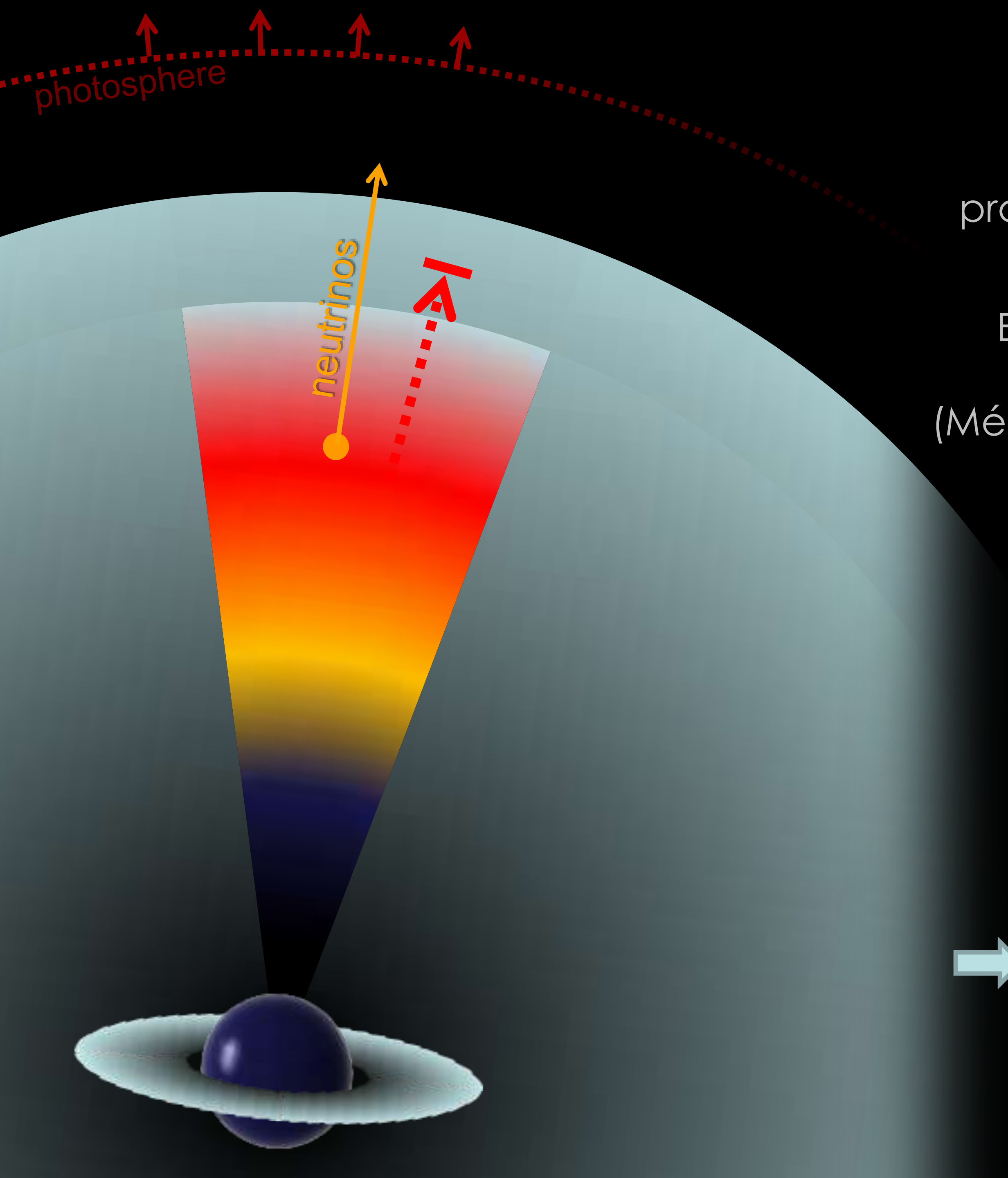
High energy neutrinos produced in relativistic jets



High energy neutrinos
produced in relativistic jets

Even when the jet is (still)
inside the star
(Mészáros & Waxman, 2001)

⇨ precursor neutrinos
⇨ choked GRBs



High energy neutrinos produced in relativistic jets

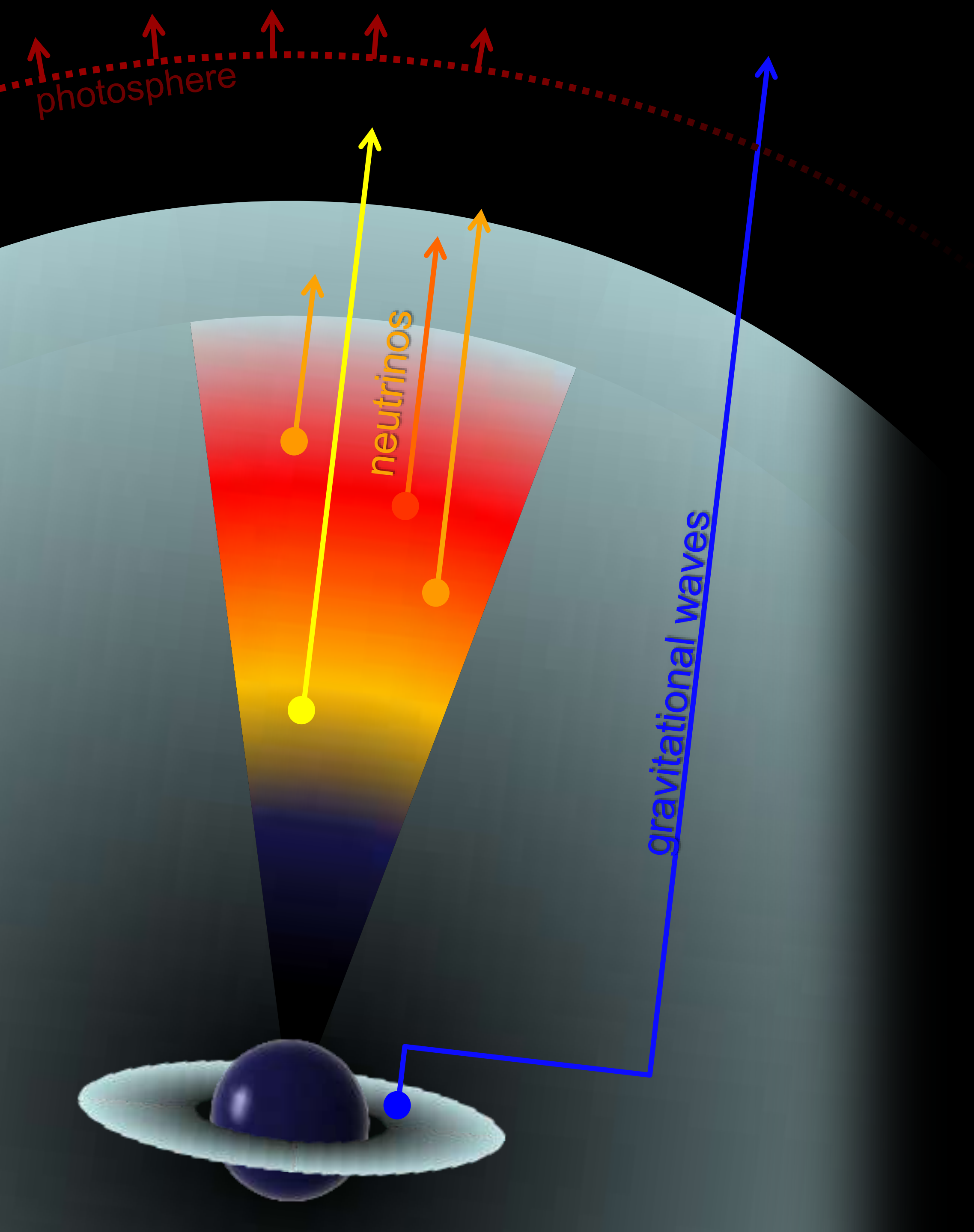
Even when the jet is (still) inside the star (Mészáros & Waxman, 2001)

→ precursor neutrinos
→ choked GRBs

Energy-dependent neutrino absorption in envelope

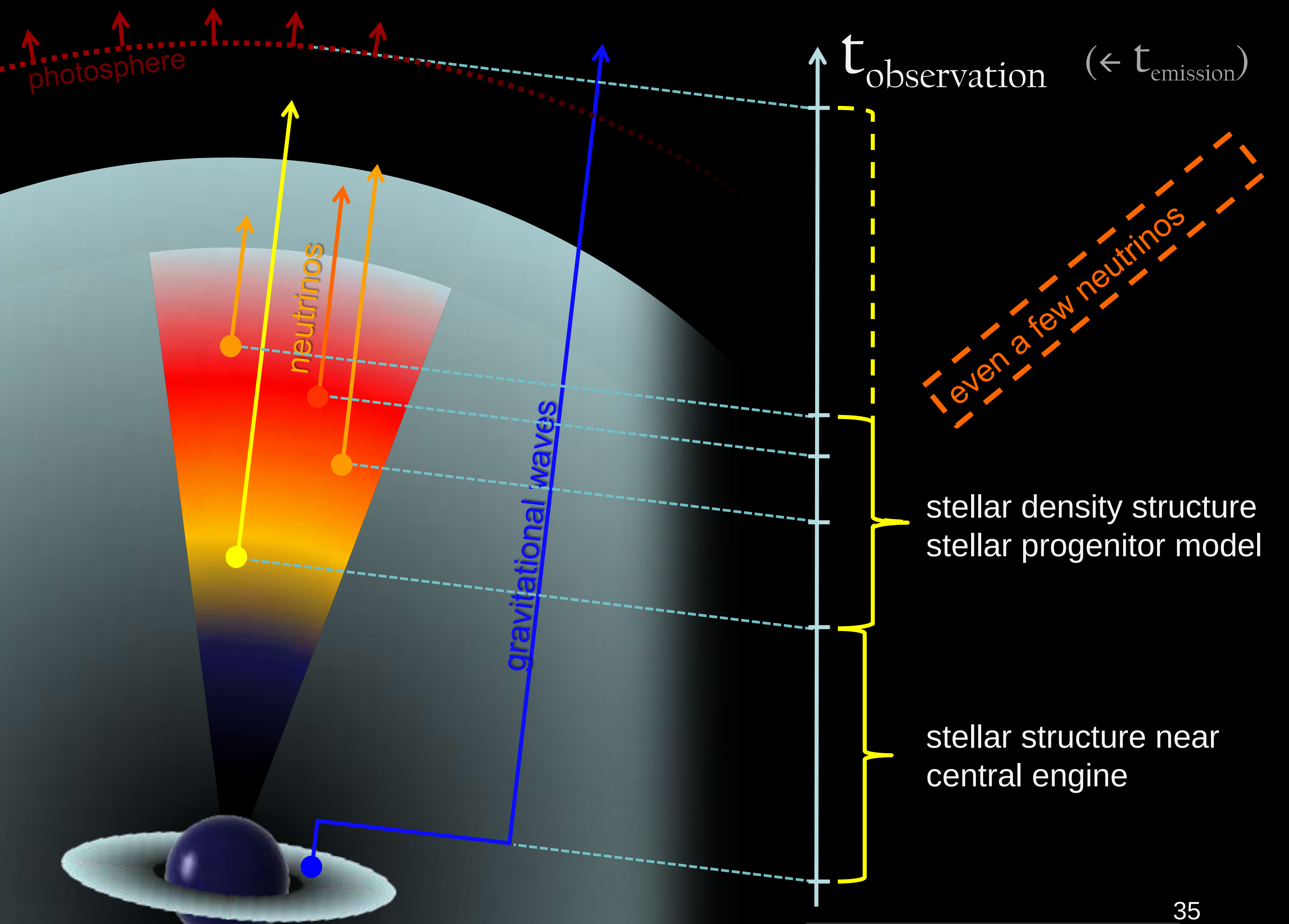
→ Neutrino tomography

(Razzaque, Mészáros & Waxman, 2003)



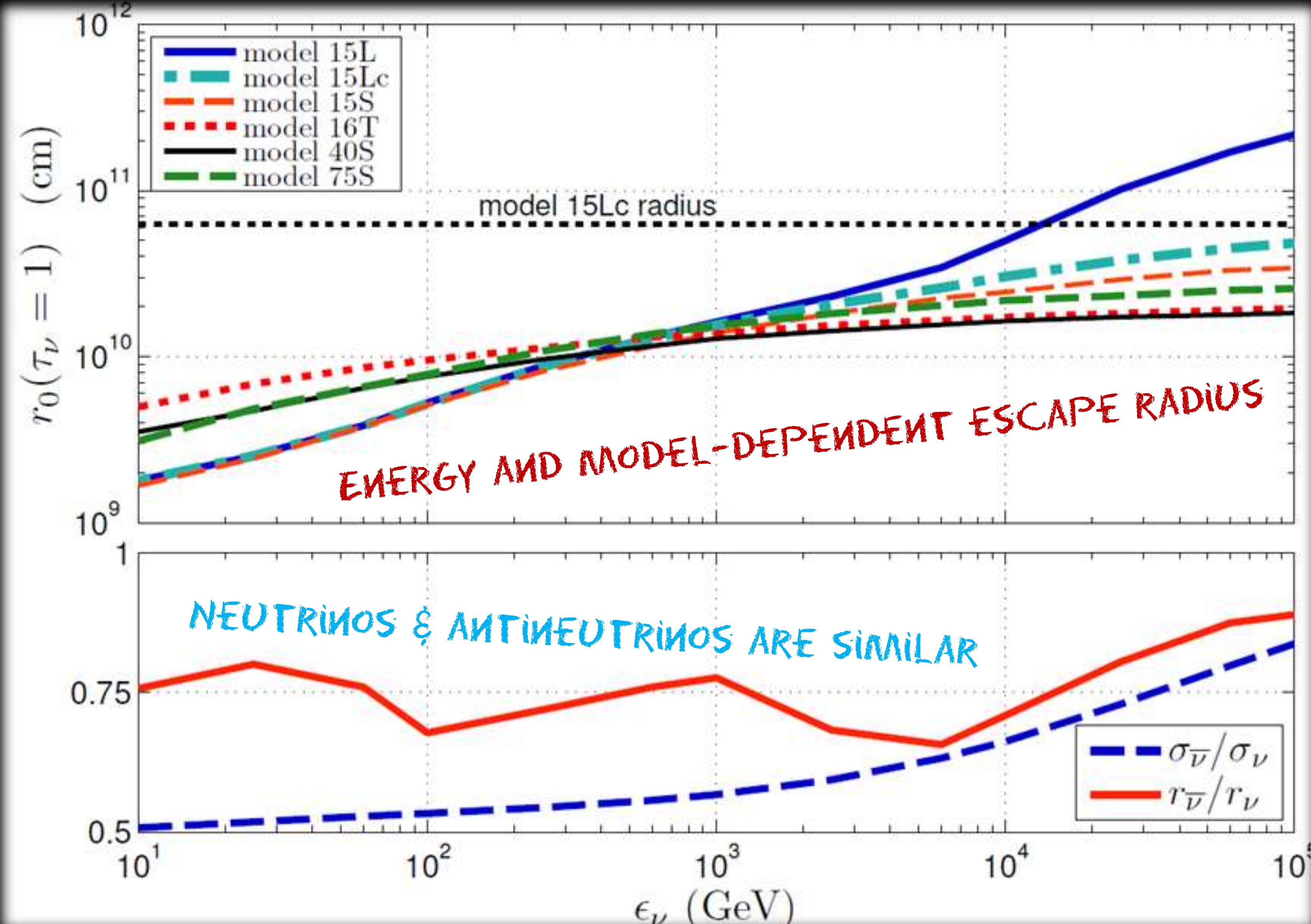
neutrino energy cutoff
changes with the
advancing jet head

→ emission time



Bartos et al. PRD 2012

"Neutrinosphere"



Bartos et al. PRD 2012

Takeaway

- Gravitational waves are highly suitable for *realtime multimessenger* searches:
  exciting new opportunities (soon!)

- GeV neutrinos and IceCube-DeepCore provide a new opportunity to test GRB models

- Even a few high-energy neutrinos can be informative about the source