Gravitational waves, high-energy neutrinos, and astrophysical search optimization

Imre Bartos
Columbia University

AMON workshop Penn State Dec 3 2015

Photosphere?

Neutrinos?

Compact object
+ relativistic outflow

Gravitational waves?

merger of dead stars

core-collapse of massive star

PNS

- progenitor
- onset of relativistic outflow
- jet parameters
- acceleration mechanism in jet
- population
- supranuclear EOS
- cosmology

merger of
dead stars

LIGO

VIRGO

core-collapse
of massive star

IceCube

?

PNS

- progenitor
- onset of relativistic outflow
- jet parameters
- acceleration mechanism in jet
- population
- supranuclear EOS
- cosmology

photosphere

neutrinos

gravitational waves

Razzaque+ 2003
Bartos+ 2012

observer

Galaxy
distribution

observer

GW
horizon distance

Galaxy
distribution

Weak beaming (~ 1.5)

Galaxy
distribution

observer

GW
horizon distance

neutrino
detection probability

Beaming for LL-GRB from late time radio observations

(<14; Liang et al., 2007)

observer

GW
horizon distance

neutrino
detection probability

GW+neutrino
horizon distance

observer

GW
horizon distance

neutrino
detection probability

GW+neutrino
horizon distance

PeV neutrinos
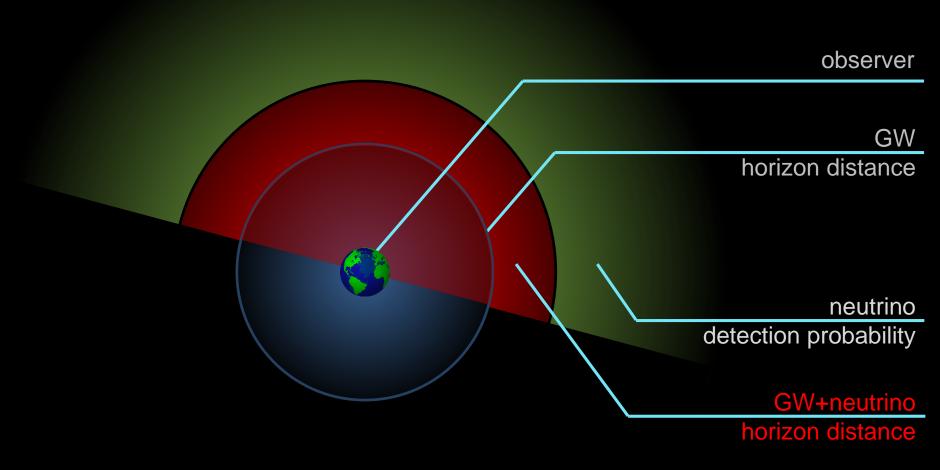
MULTIMESSENGER ANALYSIS: THE INGREDIENTS

Baret, Bartos+ 2012

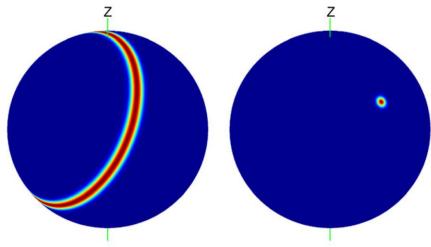|	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ANTARES	5L	10L	12L							KM3NeT
Ice Cube	9s	22s	40s	59s	79s	Ice Cube 86 strings				
LIGO	S5		S6						Advanced LIGO	
VIRGO	VSR1		VSR2	VSR3	VSR4				Advanced VIRGO	

GW and neutrino detectors are "all-sky"
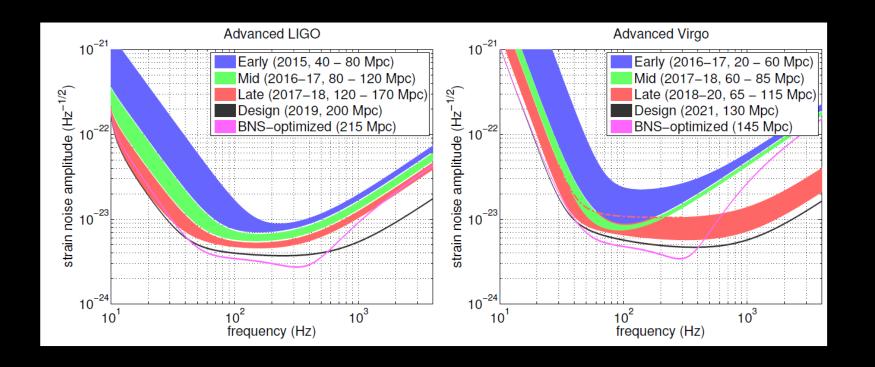
Neutrinos allow better pointing for EM follow-up searches

prompt search for significant events

"all-sky" GW+ν search
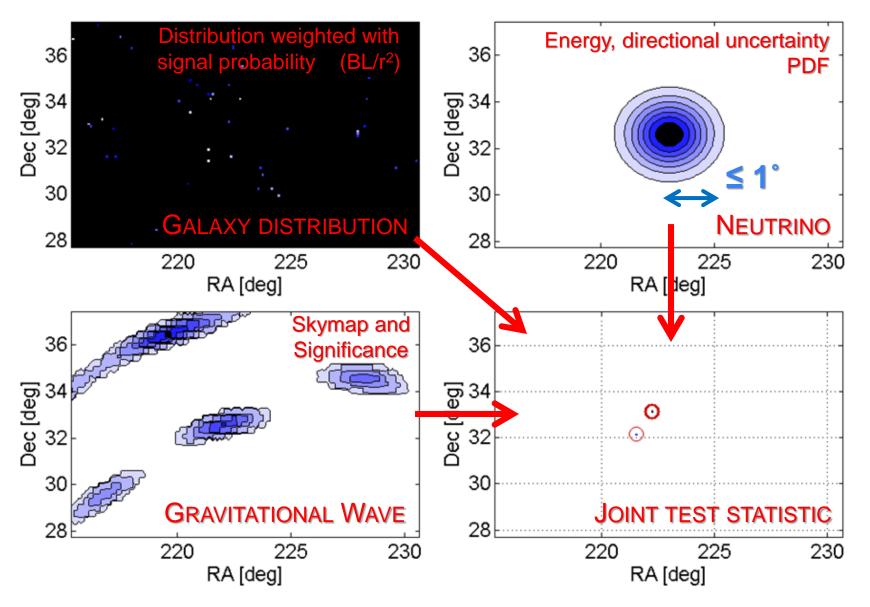
Advanced LIGO
- Early (2015, 40 – 80 Mpc)
- Mid (2016–17, 80 – 120 Mpc)
- Late (2017–18, 120 – 170 Mpc)
- Design (2019, 200 Mpc)
- BNS-optimized (215 Mpc)

Advanced Virgo
- Early (2016–17, 20 – 60 Mpc)
- Mid (2017–18, 60 – 85 Mpc)
- Late (2018–20, 65 – 115 Mpc)
- Design (2021, 130 Mpc)
- BNS-optimized (145 Mpc)

SENSITIVITY TIMELINE

Aasi et al. 2013
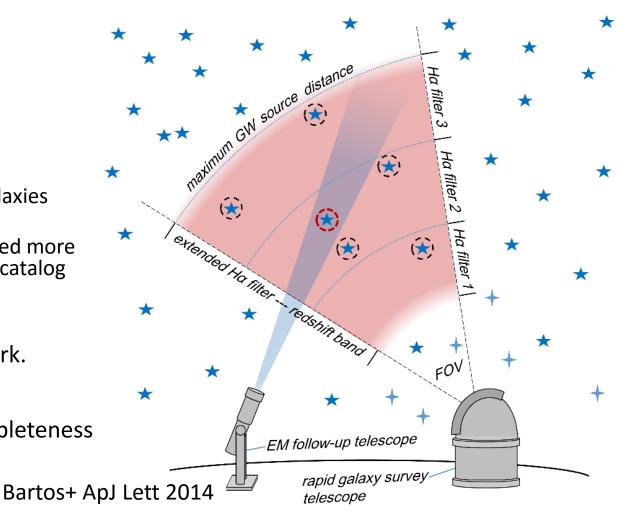
Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc)		BNS Range (Mpc)		Number of BNS Detections	% BNS Localized within	
		LIGO	Virgo	LIGO	Virgo		$5\deg^2$	$20\deg^2$
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

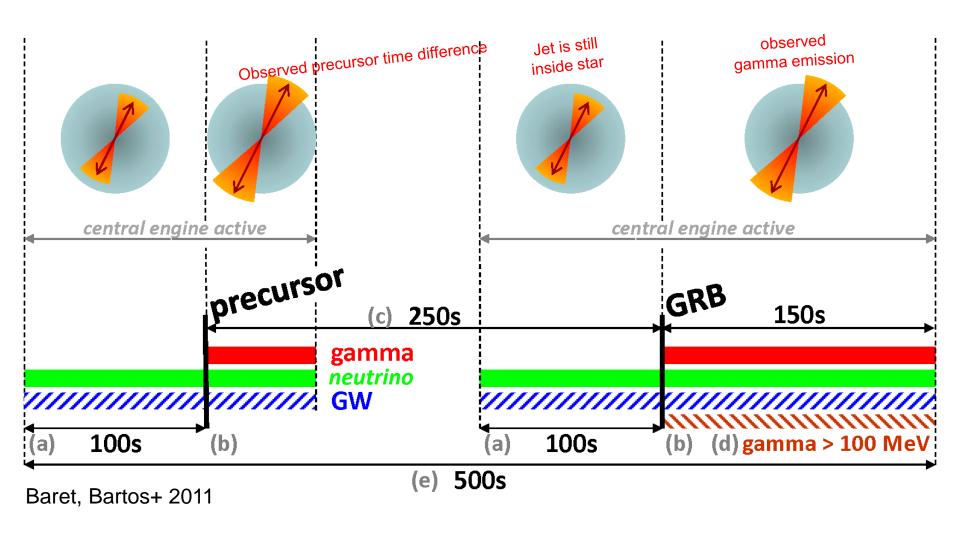# MULTIMESSENGER ANALYSIS: THE INGREDIENTS

Baret, Bartos+ 2012

Cataloging 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

- Meter class telescopes work.

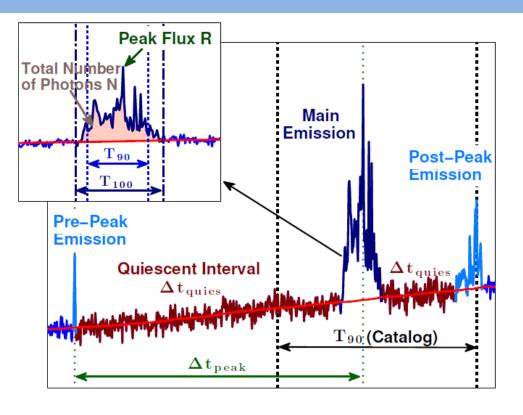- Don't need very high completeness (Hanna+ 2014)

Bartos+ ApJ Lett 2014

astrophysical search optimization

Observed precursor time difference

Jet is still inside star

observed gamma emission

central engine active

central engine active

precursor

GRB

(c) 250s

150s

gamma

neutrino

GW

gamma > 100 MeV

(a) 100s

(b)

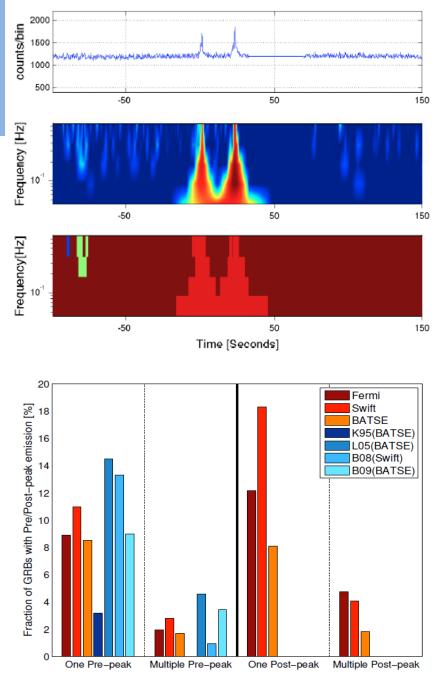(a) 100s

(b) (d)

(e) 500s

Baret, Bartos+ 2011
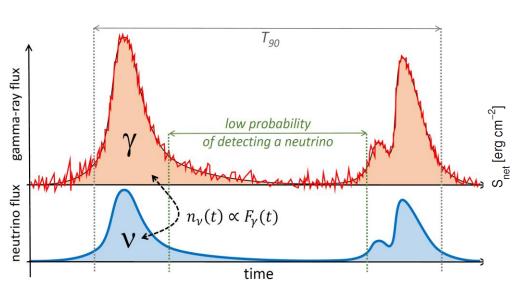
Coincidence time window: 500s

GRB EMISSION EPISODES (PRECURSORS)

Automated survey of BATSE, Fermi and Swift GRBs (2710)
Conclusion --- precursors likely from same central engine activity
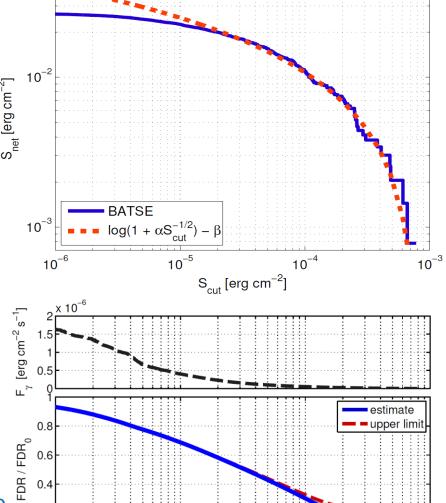
Charisi, Marka, Bartos MNRAS 2014

Bartos+ PRL 2013

Gamma-ray --- neutrino emission mechanism is connected → temporal correlation

--- GRB fluence & neutrino fluence linearly correlated (117 GRBs, from Hummer+ PRL 2012)

Using temporal correlation can decrease False Alarm Rate by x100

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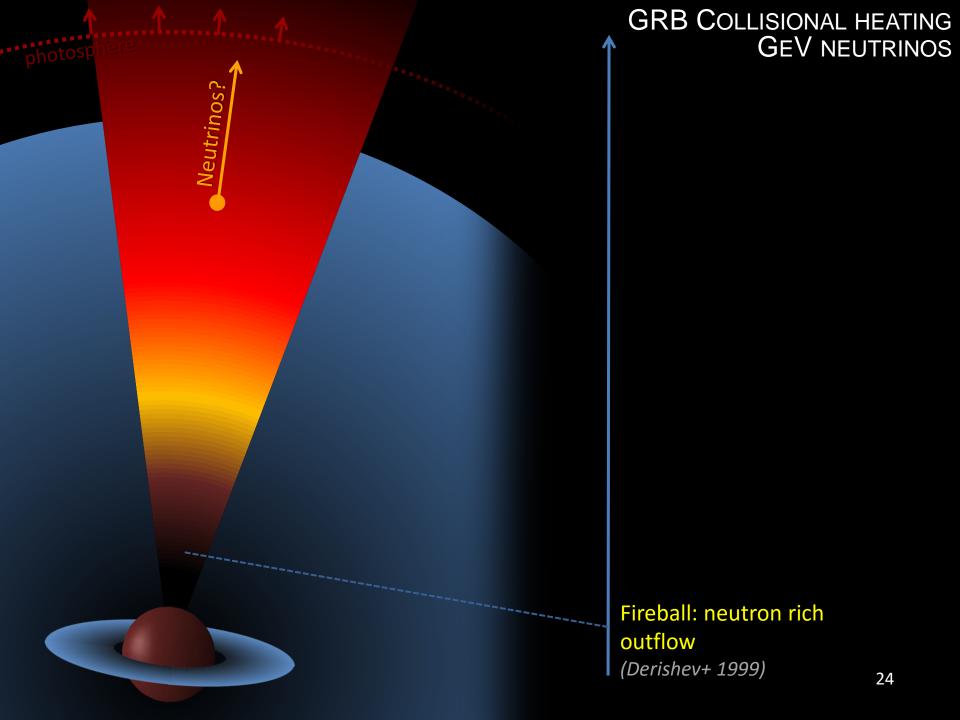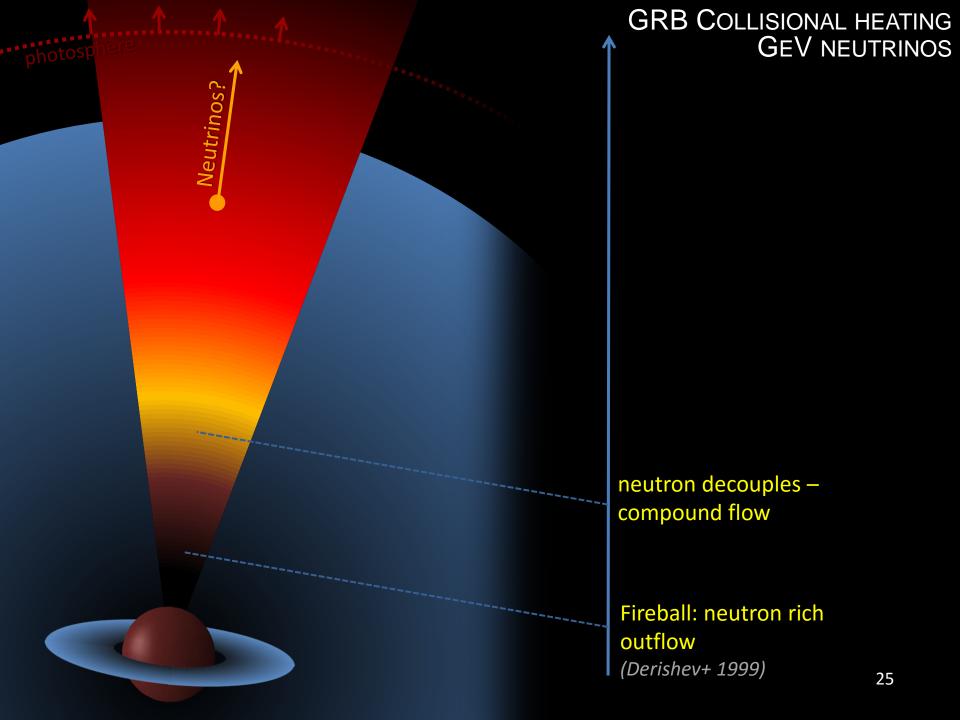   ~ few GeV neutrino

Bartos, Marka PRD(R) 2014

photosphere

Neutrinos?

Fireball: neutron rich outflow

(Derishev+ 1999)

24

GRB COLLISIONAL HEATING
GEV NEUTRINOS

photosphere

Neutrinos?

neutron decouples –
compound flow

Fireball: neutron rich
outflow
(Derishev+ 1999)

photosphere

Neutrinos?

n-p collisions $\rightarrow \gamma + \nu$

neutron decouples –
compound flow

Fireball: neutron rich
outflow
(Derishev+ 1999)

γ released – explains
observed spectrum!
(Beloborodov 2010)

~1 MeV

n-p collisions → γ + ν

Neutrinos?

photosphere

neutron decouples –
compound flow

Fireball: neutron rich
outflow
(Derishev+ 1999)

27

Bartos+ PRL 2013

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

60 DOM's, 17m spacing

IceCube-DeepCore

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

($\varepsilon_\nu \sim 0.1\ \Gamma$ GeV)

GRB: $100 < \Gamma < 1000$ ✔

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

→ 1 neutrino is already
    interesting!

$\delta \sim 5^\circ$

$T \sim 100$ s

Expanding the GW horizon distance with astrophysics

Bartos, Marka PRL 2015

Beyond the GW horizon distance with astrophysics

NS

NS
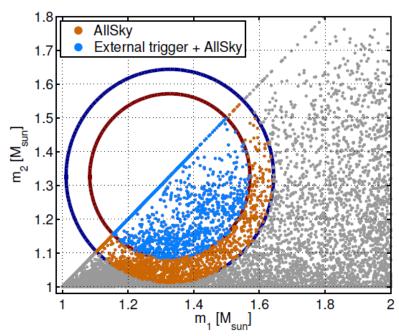
Bartos, Marka PRL 2015

Detection rate improvement

All-sky	14%
External trigger	61%

Implications to AMON

- GW+neutrinos well suited for AMON

- share detailed source information

- response as short as minutes ideal

- incorporate astrophysics / source catalog