Observations of Electromagnetic Waves Associated with Gravitational Wave Events

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Gravitational Radiation from slowly moving object

- Unlike electromagnetic wave radiation, dipole radiation is forbidden
- GW is contributed by the time variation of the quadrupole moment

$$Q \sim MR^2$$

$$h \sim \frac{\delta L}{L} \sim \frac{2G}{c^4 r}\ddot{Q}$$

Estimation of GW Amplitude

- Quadrupole Kinetic Energy

$$\ddot{Q} \sim \frac{MR^2}{\Delta t^2} \lesssim Mc^2$$

  - Strain amplitude of an object at distance *r*, mass *M* becomes

$$h \lesssim \frac{2G}{c^4 r} Mc^2 = \frac{R_s}{r} \sim 5 \times 10^{-21} \left(\frac{M}{10\mathrm{M}_\odot}\right) \left(\frac{200\mathrm{Mpc}}{r}\right)$$

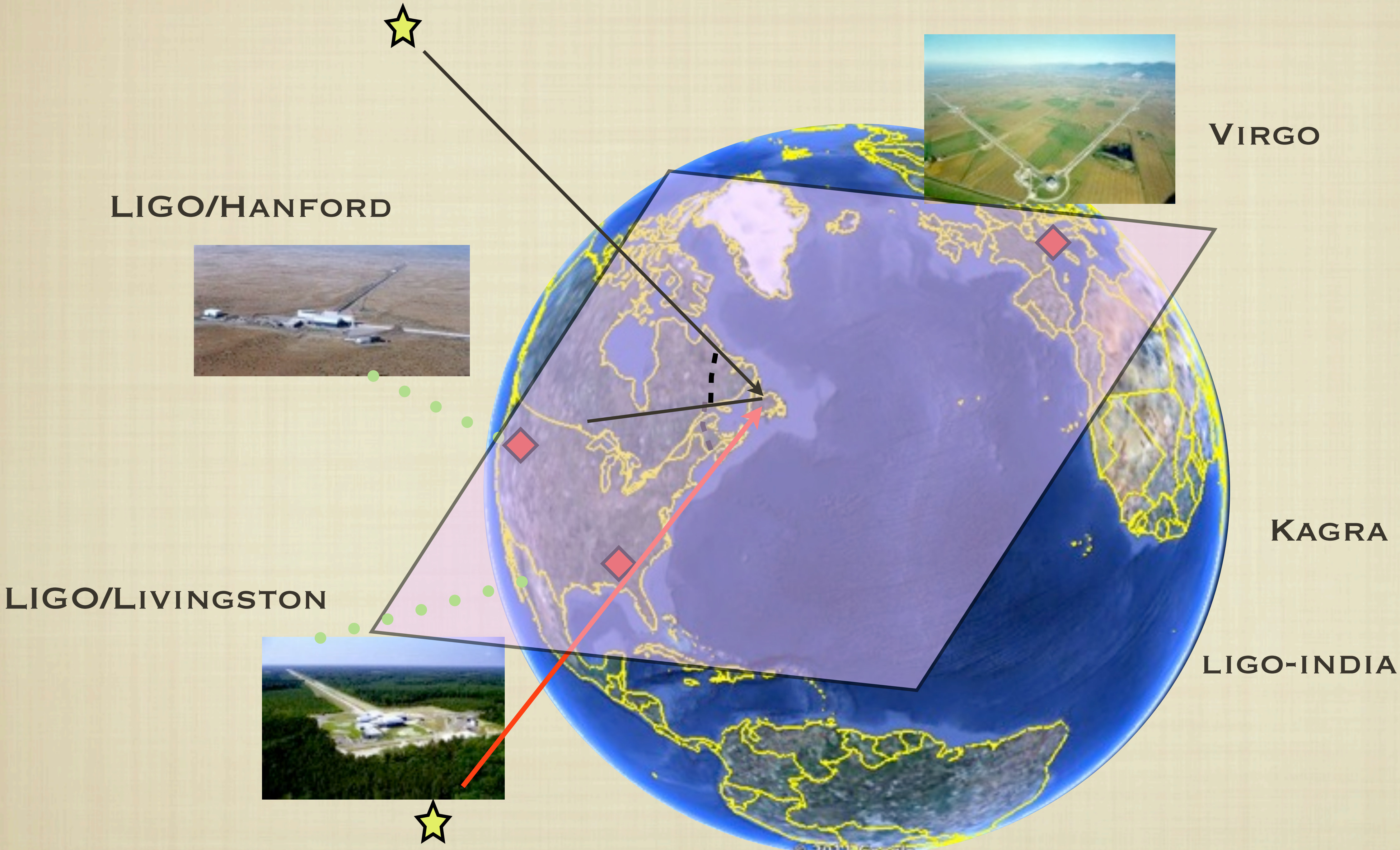
R_s: Schwarzschild Radius

- $h=10^{-21}$ corresponds to 0.03 mm change for a distance of 1 pc = 3.26 light year!

GW detectors

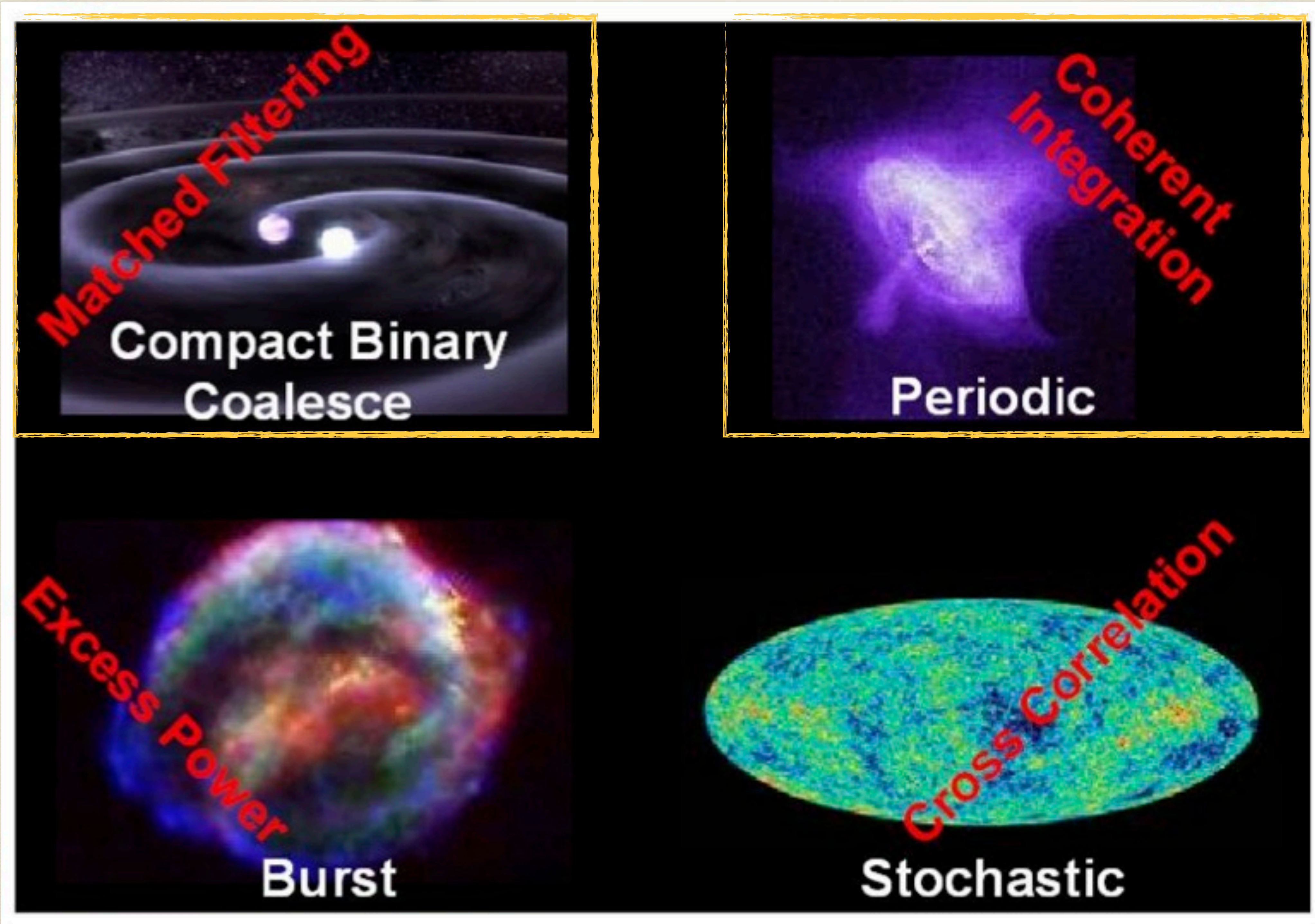
- Most of the current detectors are based on laser interferometer
  - LIGO (Laser Interferometer Gravitational-wave Observatory): Hanford, WA; and Livingston, LA
  - Virgo: Cascina (near Pisa)
  - KAGRA: Kamioka mine in Japan, under construction
  - LIGO India: under review

Multiple detectors are needed for Confirmation and triangulation



Slide Courtesy: S. H. Oh

Types of sources



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Compact Binary Coalescences

- Neutron Star (NS) - NS Binary merger
  - Expected rate based on 'observed systems', and thus thought to be most reliable
  - Candidate of Short Gamma-Ray Bursts, and simultaneous detection of GW and EM radiation is possible (and desirable)
- Neutron Star (NS) - Black Hole (BH)
  - Expected rate is very uncertain
  - Electromagnetic radiation may follow
- BH-BH
  - Detection rate could be comparable to NS-NS events
    - Rare, but strong: the horizon is larger
  - Globular cluster could be an important place for the production of BH-BH binaries (Bae et al. 2013, submitted).

NS (radio pulsar) binaries which coalesce within Hubble time (5 NS-NS)

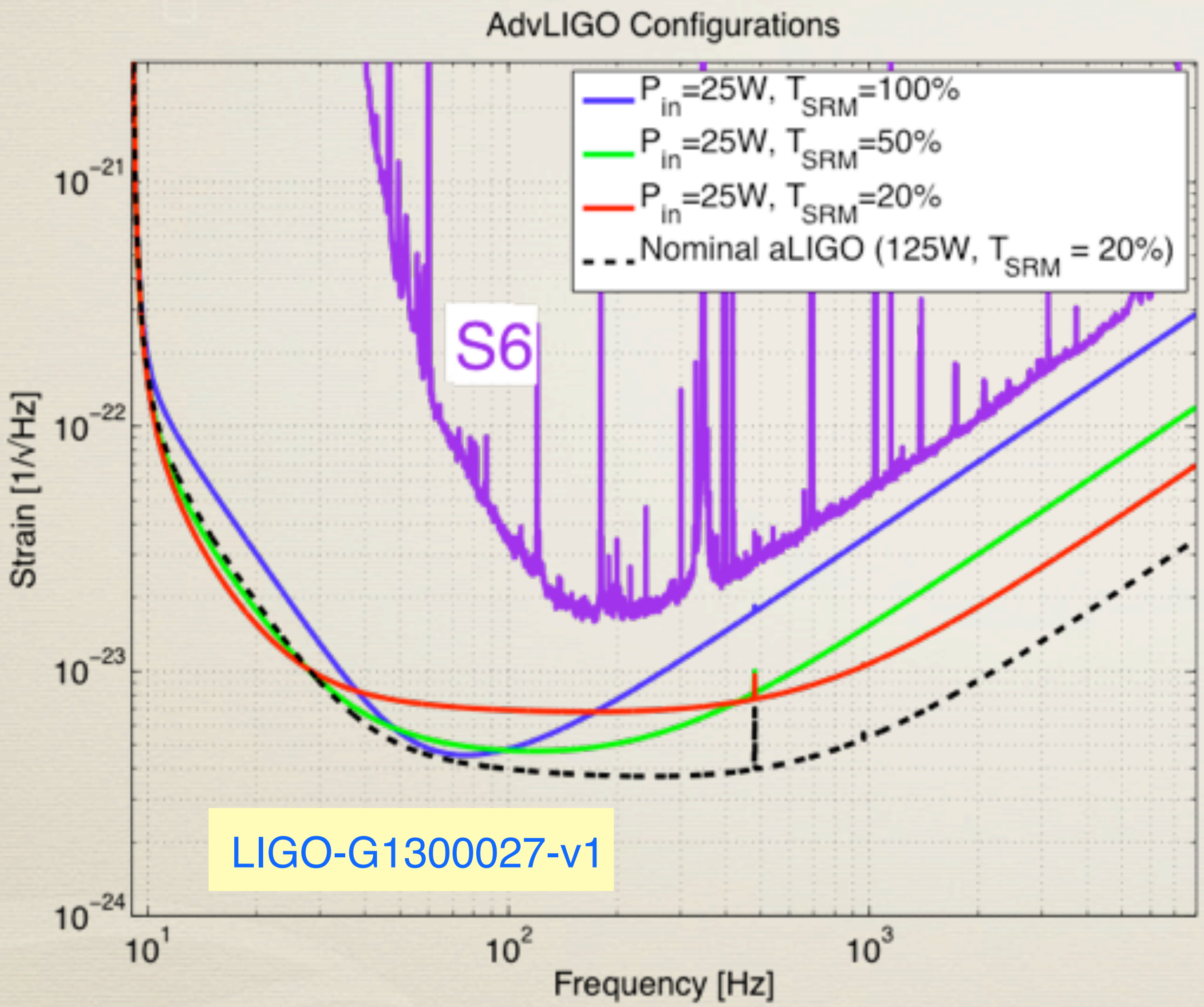
Slide courtesy: Changhwan Lee (PNU)

PSR	P (ms)	P_b (hr)	e	Total Mass $M_\odot$	τ_c (Myr)	τ_{GW} (Myr)	
J0737−3039A	22.70	2.45	0.088	2.58	210	87	(2003)
J0737−3039B	2773	2.45	0.088	2.58	50	87	(2004)
B1534+12	37.90	10.10	0.274	2.75	248	2690	(1990)
J1756−2251	28.46	7.67	0.181	2.57	444	1690	(2004)
B1913+16	59.03	7.75	0.617	2.83	108	310	(1975)
B2127+11C	30.53	8.04	0.681	2.71	969	220	(1990)
J1141−6545†	393.90	4.74	0.172	2.30	1.4	590	(2000)

Globular Cluster : different origin/evolution

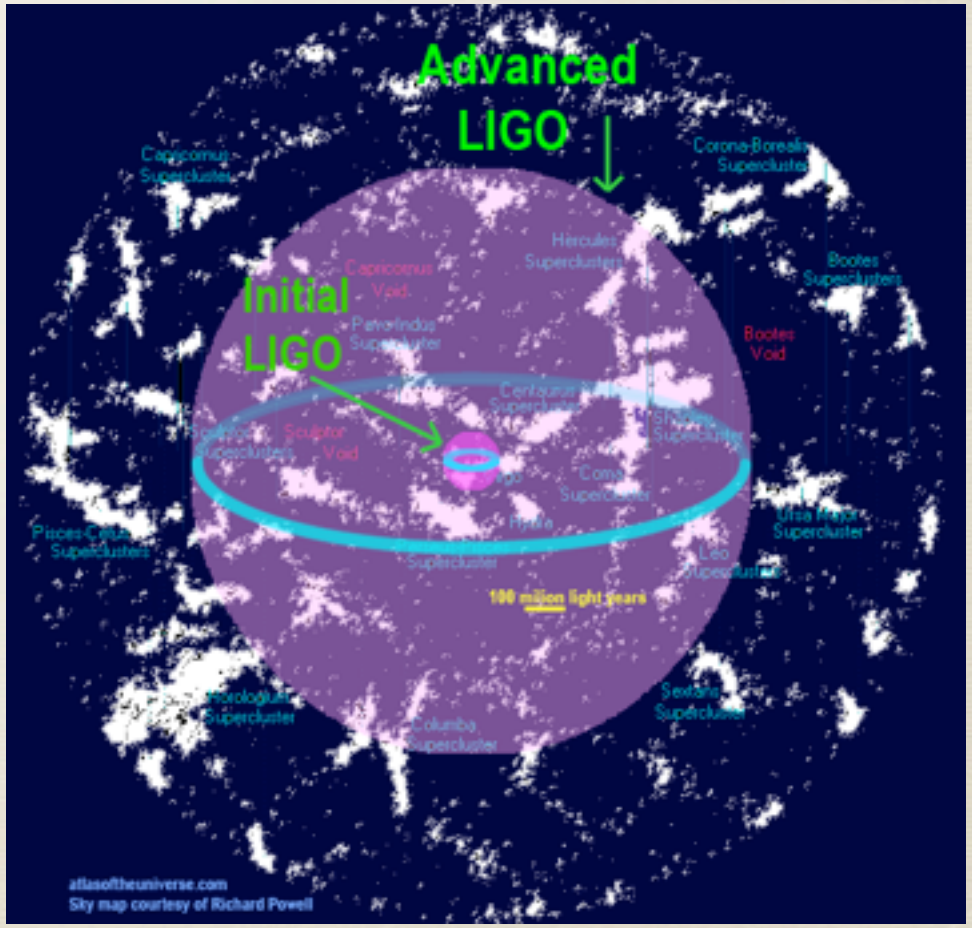
White Dwarf companion

Sensitivities of current and upcoming detectors

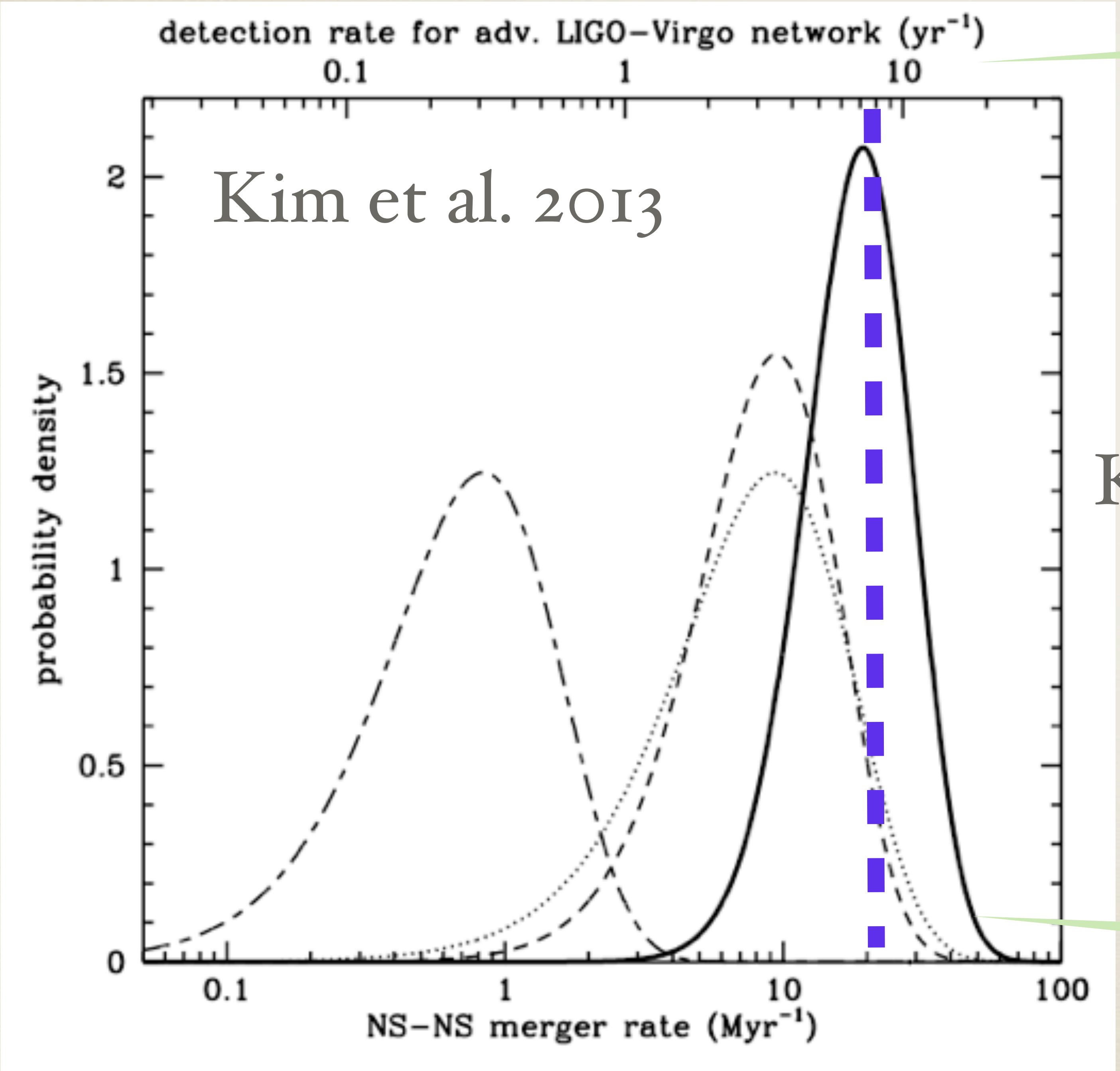


NS-NS range:

- Current: 25-30 Mpc
- Advanced: ~200 Mpc



How often we will see coalescence events?



~10 /year within advanced detector ranges

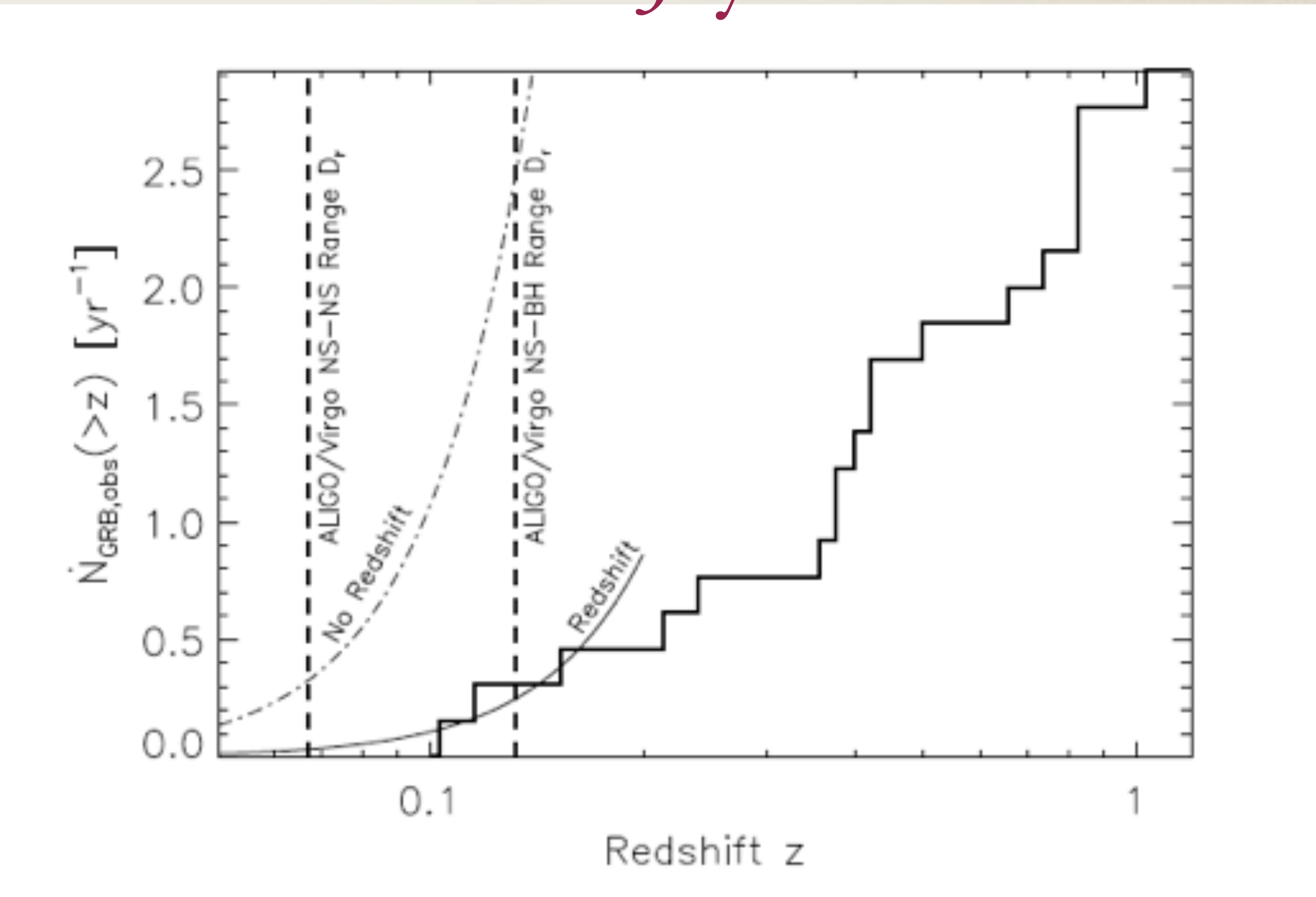
Kim et al. 2013, submitted

In our galaxy, ~20/Myr

NS-NS mergers versus Short GRB

- SGRB is thought to be produced by NS-NS mergers
- But there is a big discrepancy between the estimated NS-NS merger rate and SGRB occurrence
  - Beaming?
  - Wrong estimates?

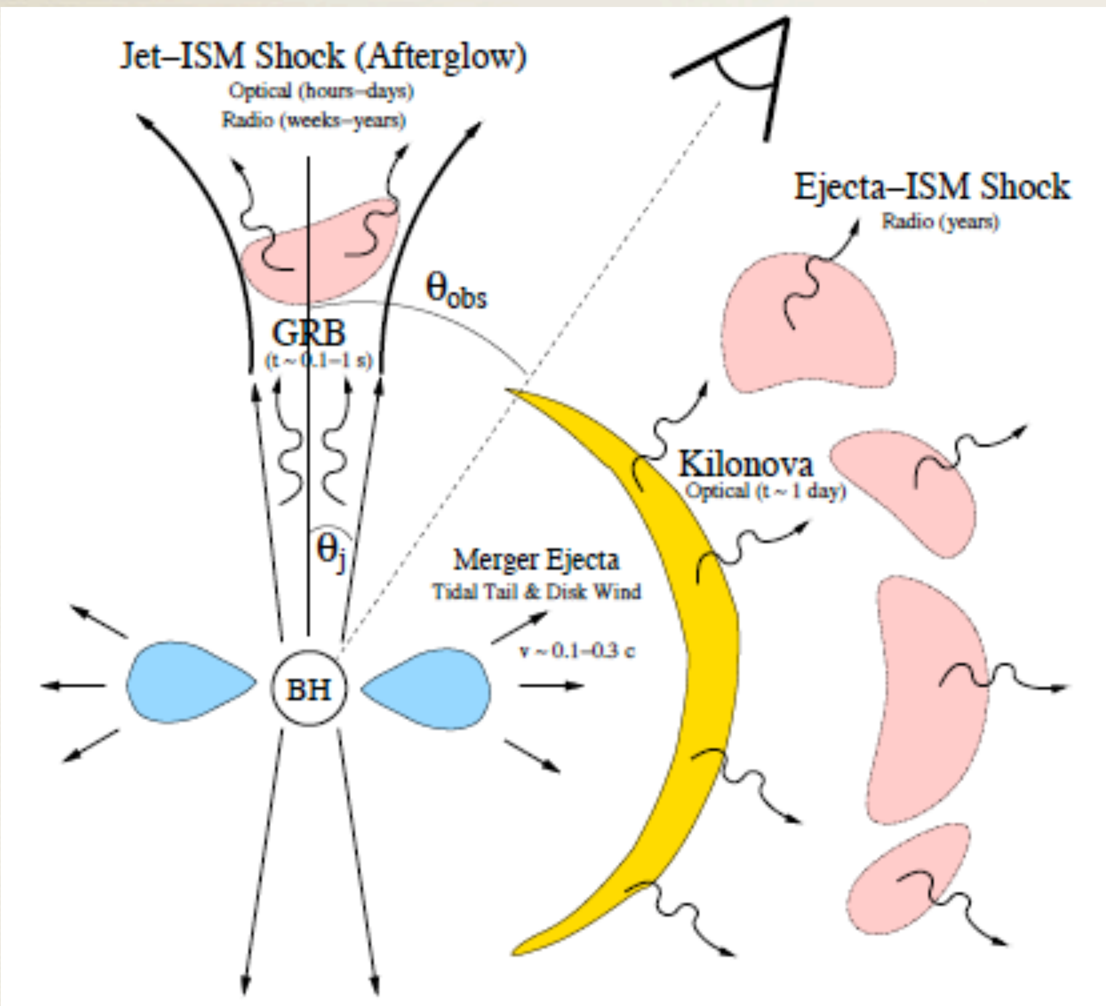
- Estimated NS-NS rate ~20/yr
- SGRB rate ~0.3 /yr



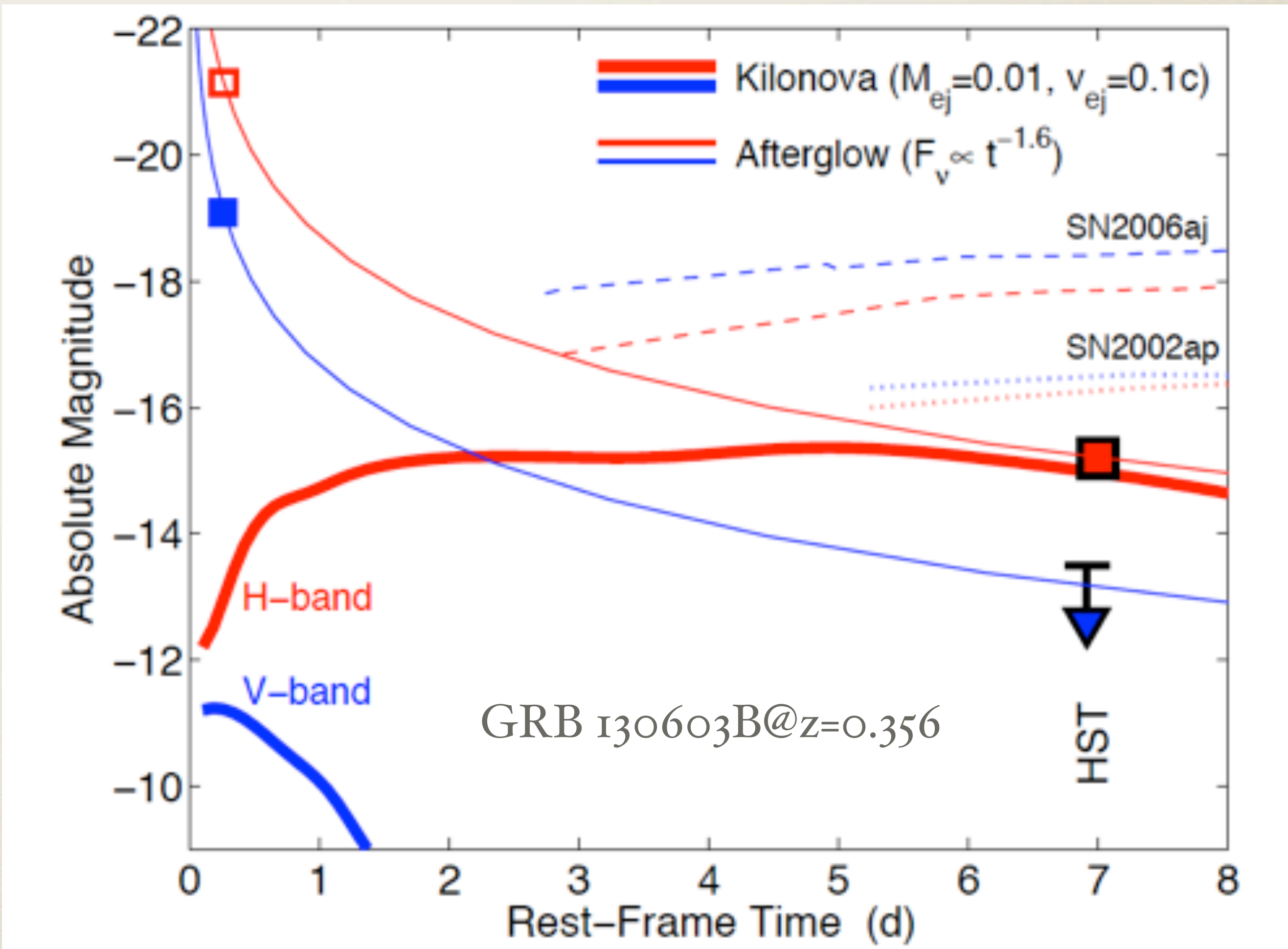
Metzger & Berger 2012

EM emission from NS-NS or NS-BH Merger

- Powered by accretion onto a BH formed just after the merger
- Gamma-ray by relativistic jet
- Optical afterglow due to Jet-ISM shock
- Kilonova due to radioactive emission by r-rpocess elements
- Since afterglow fades rapidly, early detection is very important



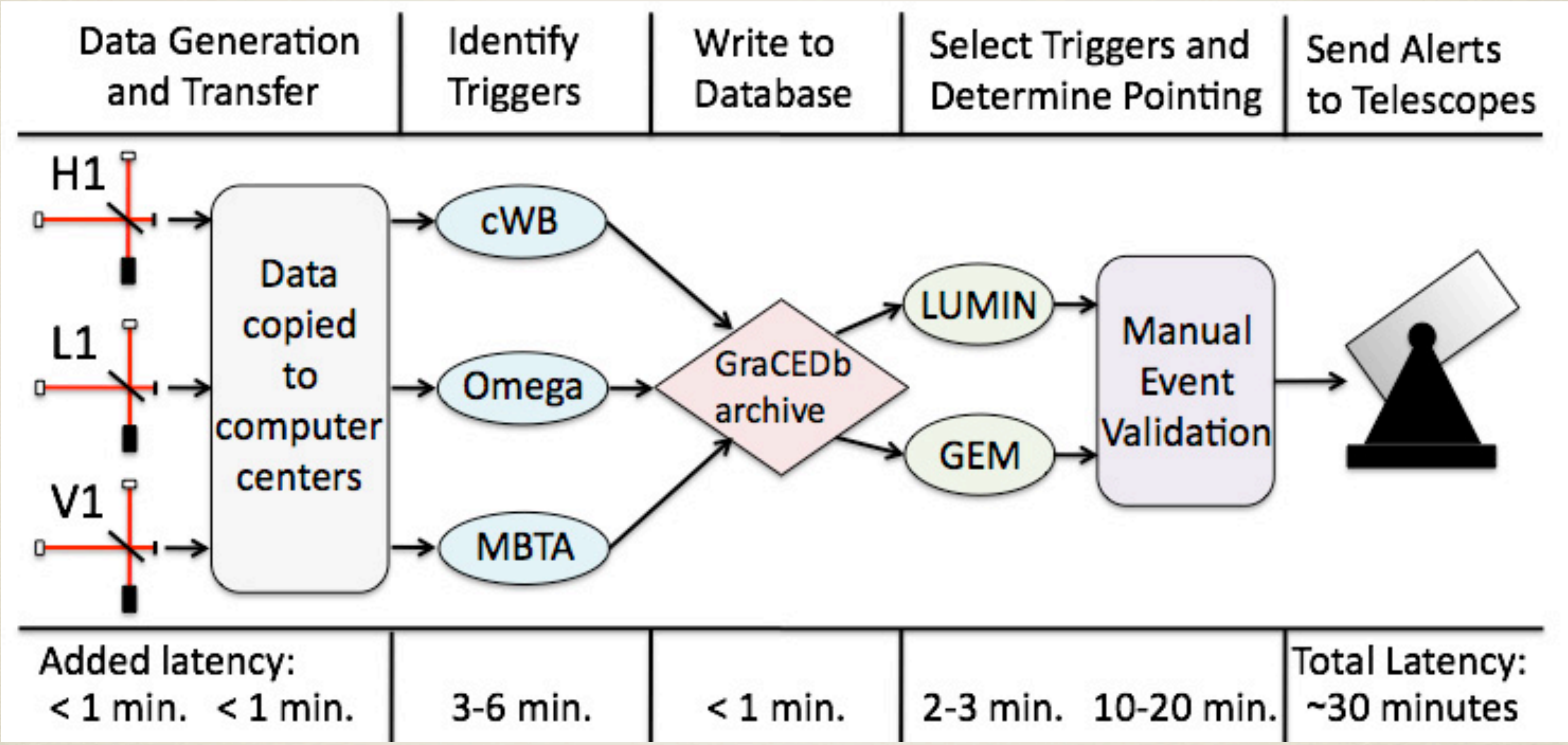
Metzger & Berger, 2012



Berger et al. 2013

13년 10월 16일 수요일

LSC's low latency pipeline for EM followup



Abadie et al., 2012

GW-EM Followup Program in LSC

- GW has not been detected yet, and the we have to be careful about the announcement of the detection
- LSC needs help from observational astronomers in confirming the GW signal
    - While sharing the "trigger" information, the information should be kept confidential until final confirmation.
    - LSC announced call for LOI to wide community, and is now discussing how to arrange MOUs between LSC and interested groups/partners.
    - In Korea, SNU astronomy submitted an LOI, led by Myungshin Im

Currently Operating Network (EM Follow-up LOI)

SNUO 0.6m Telescope (RC)
Currently, 20’ x 20’ CCD
1 degree imager in future
with focal reducer

Maidanak 1.5m (RC)
SNUCAM 4k x 4k Camear
(20’ x 20’; Im et al. 2010)

Slide Courtesy: Myungshin Im

KASI Facilities

SOAO 0.6m (RC)
2k x 2k CCD camera
(20' x 20')

LOAO 1m (RC)
4k x 4k Camera
(20' x 20')
Workhorse for
GRB follow-up

BOAO 1.8m
KASINICS NIR Camera

Slide Courtesy: Myungshin Im

Corrected Dall-Kirkham 43cm Telescope (SSO)

- Manufacturer: Planewave Instruments
- Coma-free, curvature corrected field of view out to 2 degree
- Remote operation through internet + automatic operation
- To be at SSO/Australia (2014)

Slide Courtesy: Myungshin Im

Plan for the Network of Telescopes for Monitoring of various transients

Korea: 0.6 or 0.7m telescope

US: 0.7-1m Telescope in Arizona or New Mexico

Uzbekistan: 1.5m telescope

Spain: 0.7m telescope

China or Thailand: 0.7m telescipe

Namibia: 0.5m Telescope

Australia: 0.7m telescope

Chile: 1m telescope

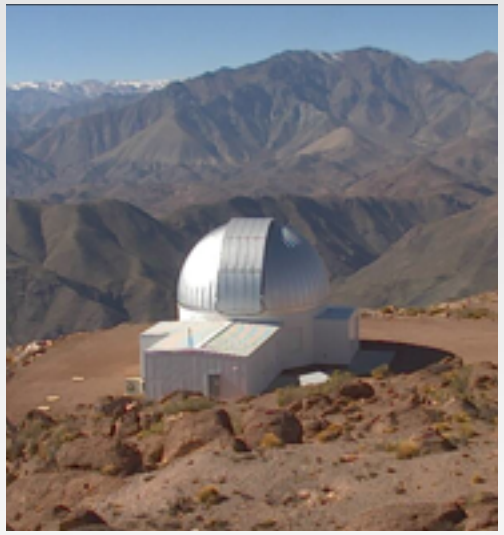
Slide Courtesy: Myungshin Im

Another Possible Facility: KMT-Net

Slide Courtesy: Seunglee Kim

Three telescopes at Chile, South Africa and Australia



Status

- Installation of the observation system at three host sites : to be completed by the **middle of 2014**
  - start Galactic bulge monitoring and seven awarded survey sciences for the non-bulge period

Comparison of wide-field optical telescopes

Telescope	Camera	FOV	Site	Target
PanSTARRS 1.8m x 4	1400M pixel CCD	7.0 deg^2	Haleakala, USA	All sky survey
MOA 1.8m	80M pixel CCD	2.4 deg^2	Mt. John, New Zealand	Galactic Bulge
KMTNet 1.6m x 3	**340M pixel CCD**	**4.0 deg^2**	**CTIO – SAAO – SSO**	**Galactic Bulge**
SkyMapper 1.35m	268M pixel CCD	5.7 deg^2	SSO, Australia	All sky survey
OGLE-IV 1.3m	268M pixel CCD	1.4 deg^2	LCO, Chile	Galactic Bulge

GW related activities in Korea

- Regular annual summer schools since 2008
  - Managed by Korean Gravitational Wave Group and sponsored by Asia-Pacific Center for Theoretical Physics (APCTP) and Yukawa Institute for Theoretical Physics (YITP) with other supports.
  - Lecturers mainly from many countries (including China, Japan & Korea).
  - Students mostly from Korea, Japan, China and Taiwan
  - Subject ranges from General Relativity, Numerical Relativity, GW and Astrophysics
- KGWG is a member of LIGO Scientific Collaboration (LSC), and KAGRA.
  - Data Analysis for LSC and KAGRA
  - Small experiments for KAGRA
- Conferences
  - GW: New frontier, Jan 16-18 2013 @SNU
  - Next Amaldi Meeting, June 21-25, 2015 @Gwangju
- Next two Gravitational Wave Physics and Astrophysics Workshop (GWPAW) will be held in Asia: 2013 @ India & 2015@Japan

Prospect of GW Research

- First detection is likely in a few years
- The first event is expected to be due to BNS or BBH coalescence
  - Annual event rate a few **10s per year** for NS-NS
    - EM followup is very important
- GW will become a useful tool to explore the universe
  - Parameters of compact objects: mass, spin, radius (NS)
  - What is the fate of massive stars
  - How black holes grow?
  - Standard siren: probing the geometry of the universe
  - The universe beyond the last scattering surface (i.e., $z>1000$)