Proposed LIGO ·Virgo-NASU Joint Observations

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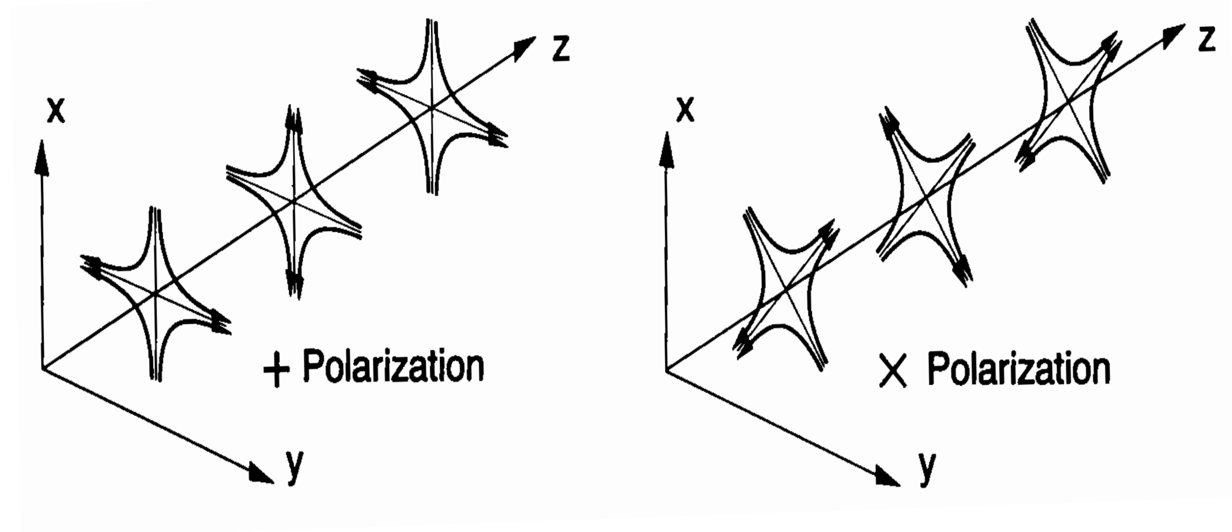
Gravitational Waves

+ and X polarizations



Roughly speaking, gravitational waves are analogous to EM waves with replacement of $e^2 \leftrightarrow -m$, but have difference coming from G-field(tensor field), EM-field(vector field)

o Accelerating mass ⇒ gravitational waves

(Accelerating charge ⇒ EM waves)

o Energy conservation ⇒ no monopole radiation

(Charge conservation ⇒ no monopole radiation)

o Momentum conversation ⇒ no dipole radiation

$$\dot{\boldsymbol{d}} = \sum_A m_A \dot{\boldsymbol{x}}_A = \boldsymbol{p} \qquad \ddot{\boldsymbol{d}} = 0$$

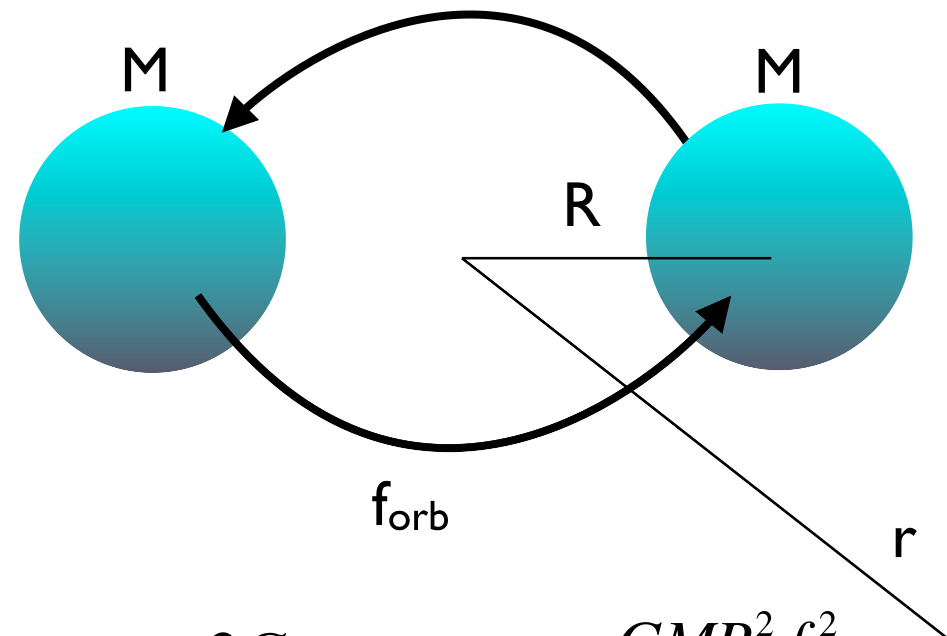
(EM waves begin with dipole moment.)

$$L_{dipole} = (2/3)e^2 \boldsymbol{a}^2 = (2/3)e^2 \ddot{\boldsymbol{d}}^2$$

(MTW '*Gravitation*')

o GW has + and X polarizations in TT-gauge.

Order estimate of GW amplitude



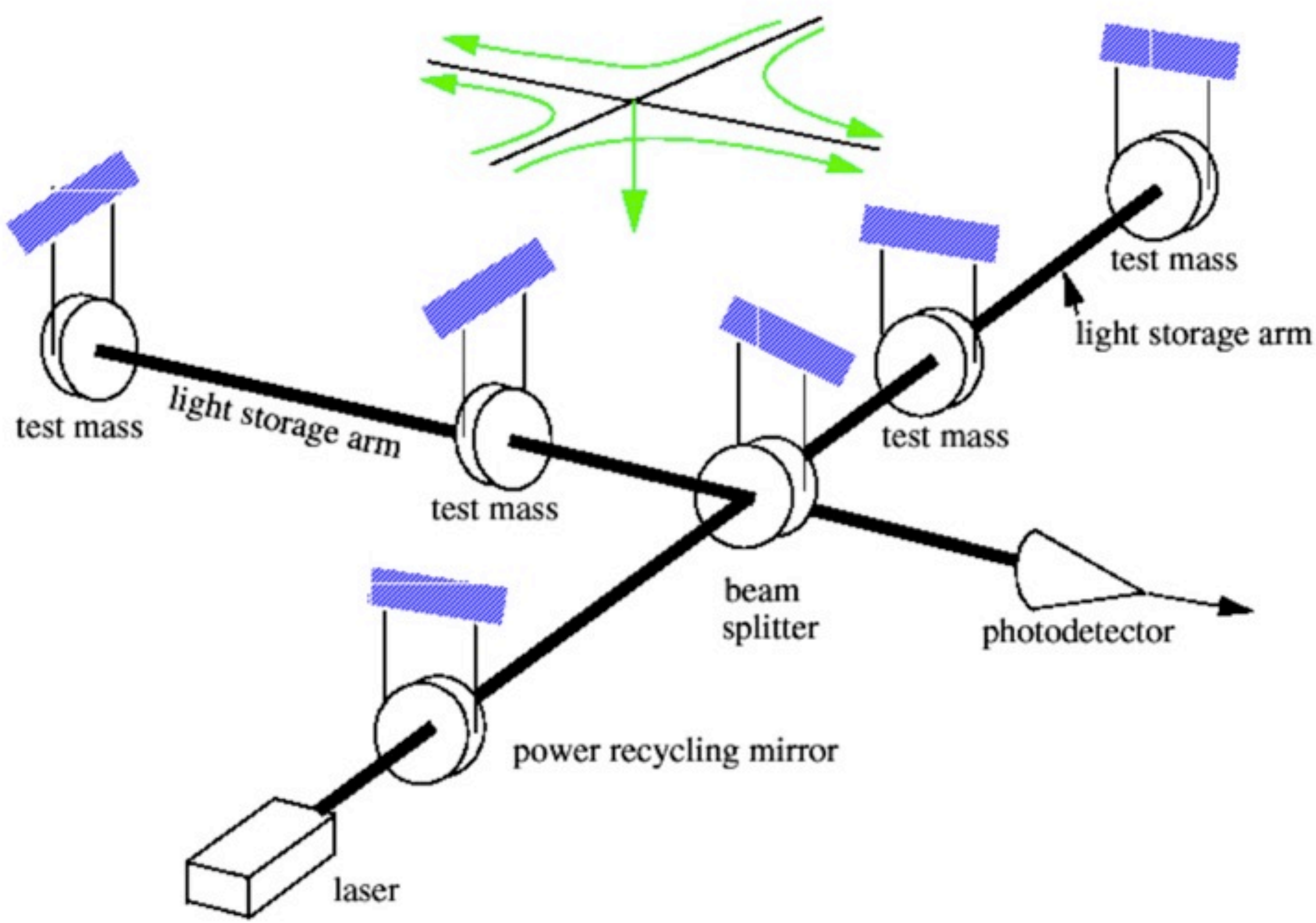
$$h_{\mu\nu} = \frac{2G}{c^4 r} \ddot{I}_{\mu\nu} \quad \Rightarrow \quad h \approx \frac{GMR^2 f_{orb}^2}{c^4 r}$$

M ~ 10^{30}kg
R ~ 20km
f_{orb} ~400Hz
r ~ 10^{21}m

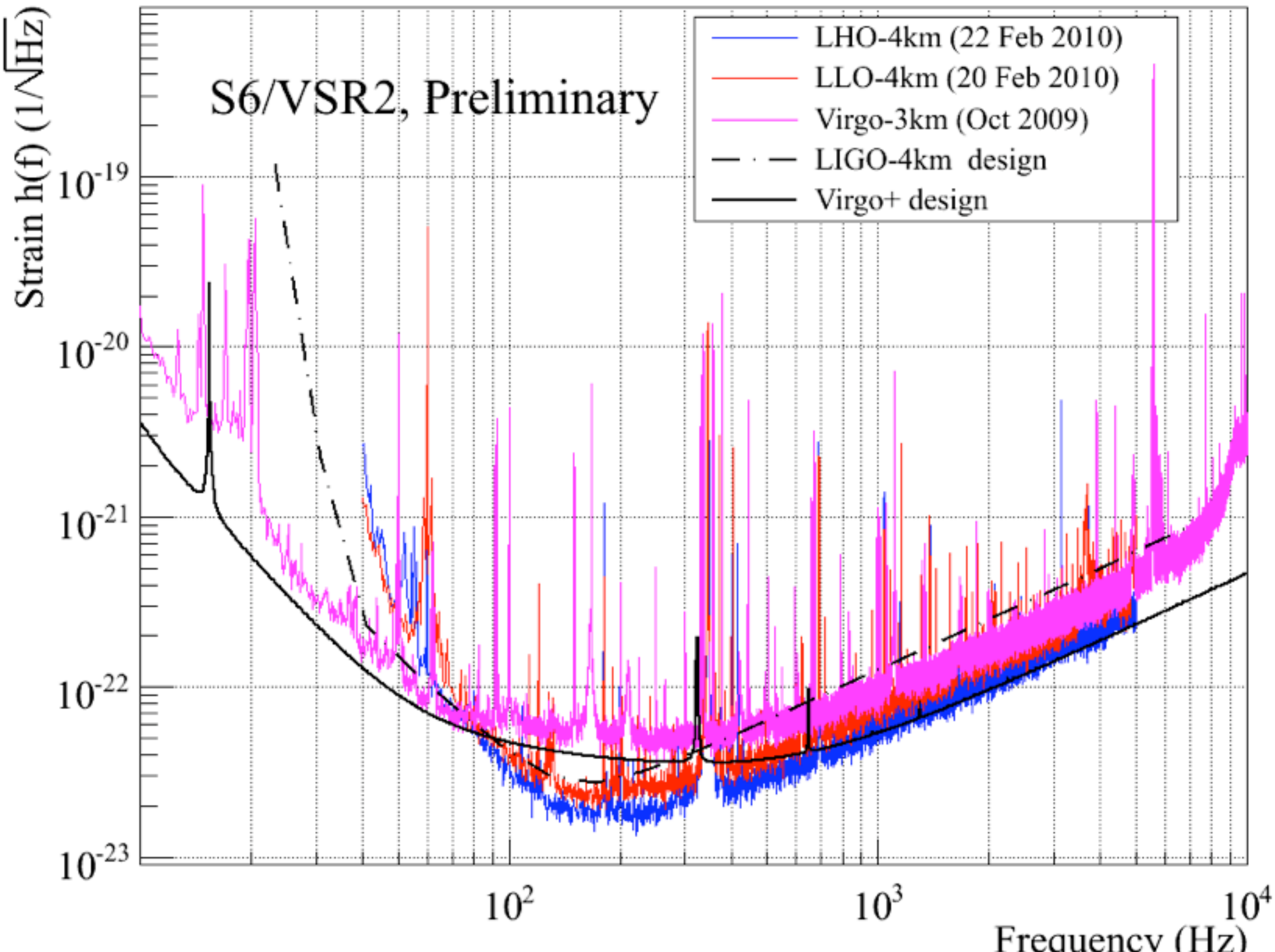
⇨ h ~ 10^{-22}

Interferometric Gravitational Wave Detector

When an interferometer interferes with a gravitational wave, the interferometer detects the signal as a phase difference between lasers coming from each arm.

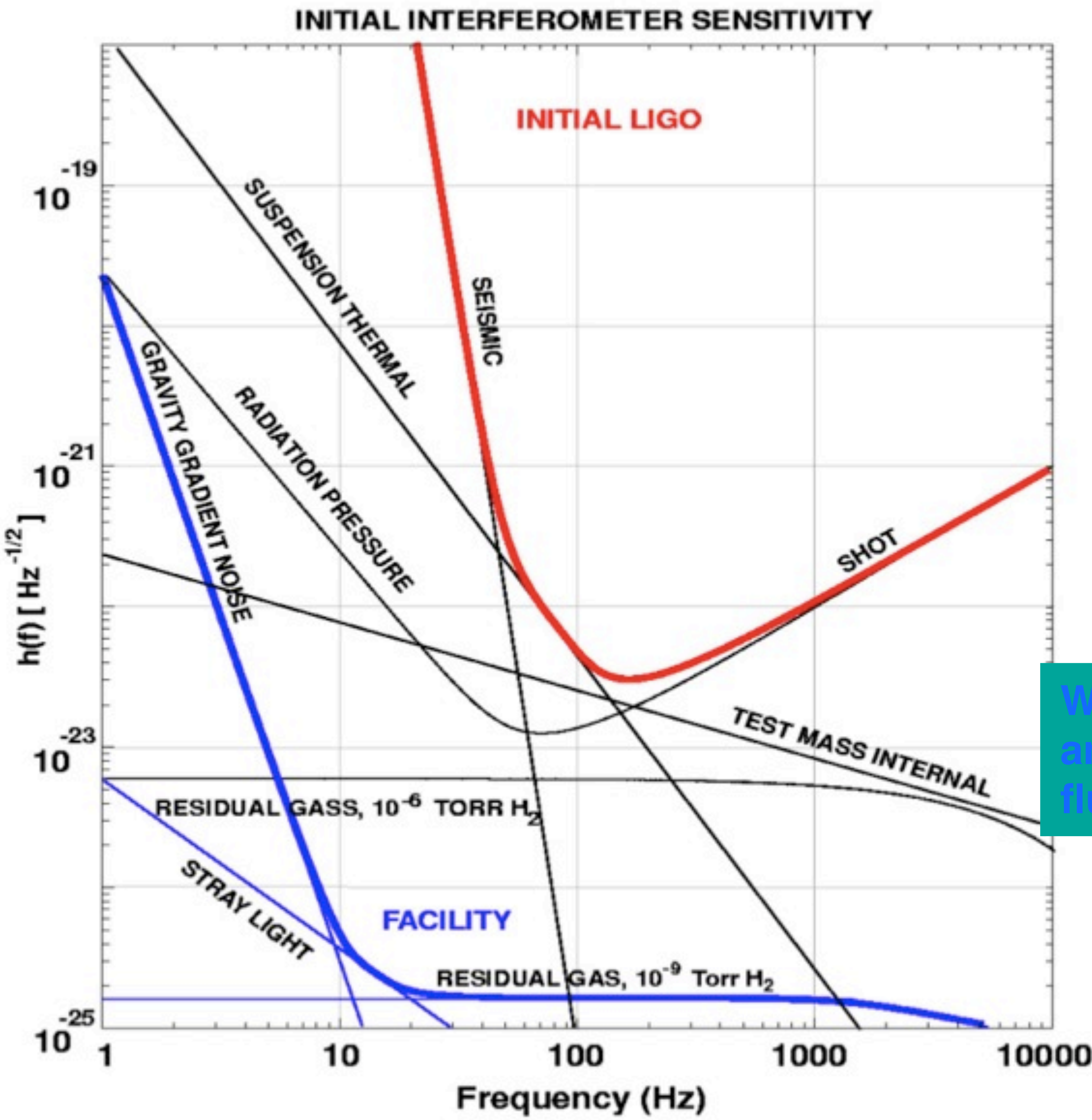


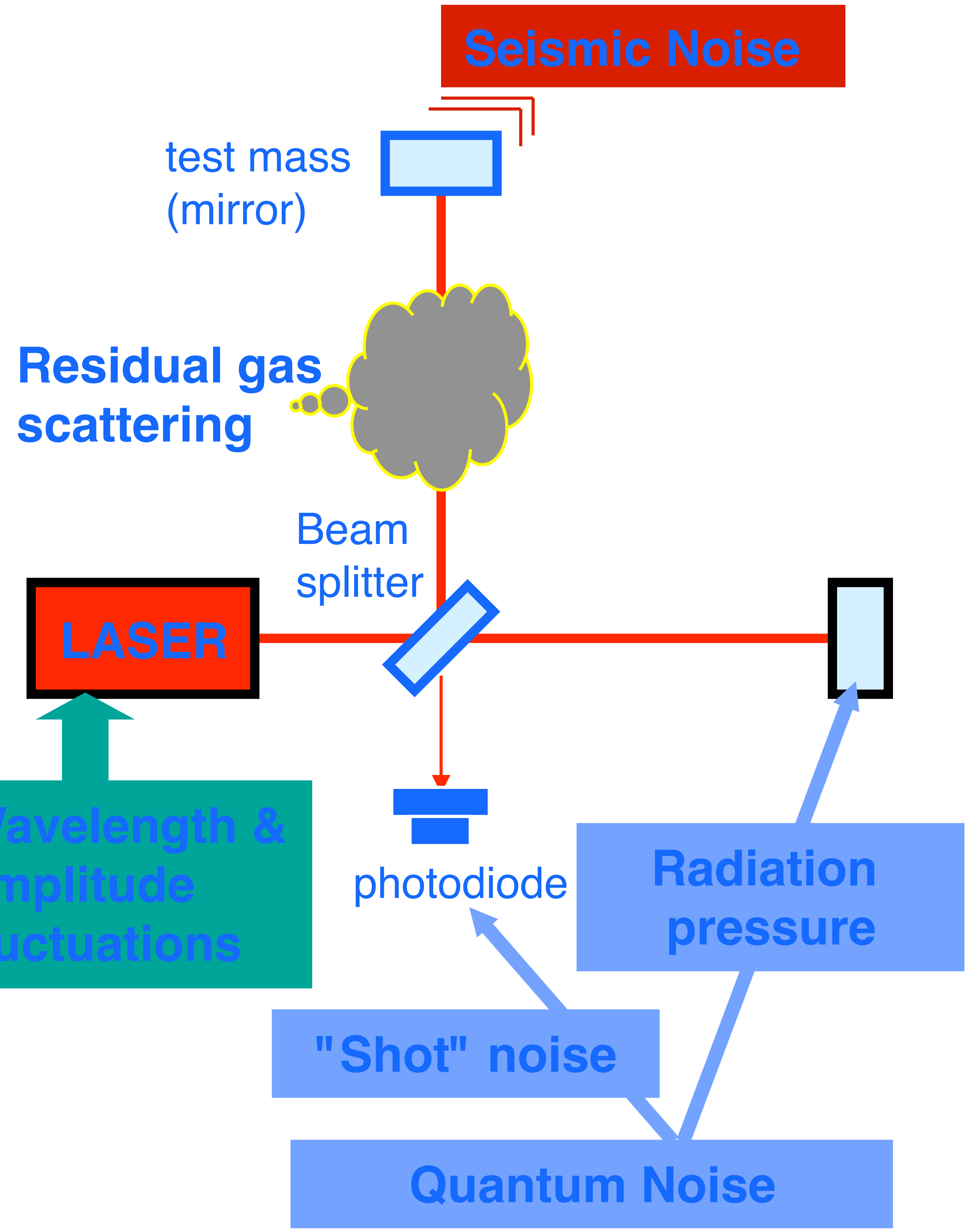
Detector sensitivity



http://wwwcascina.virgo.infn.it/DataAnalysis/Calibration/Sensitivity/

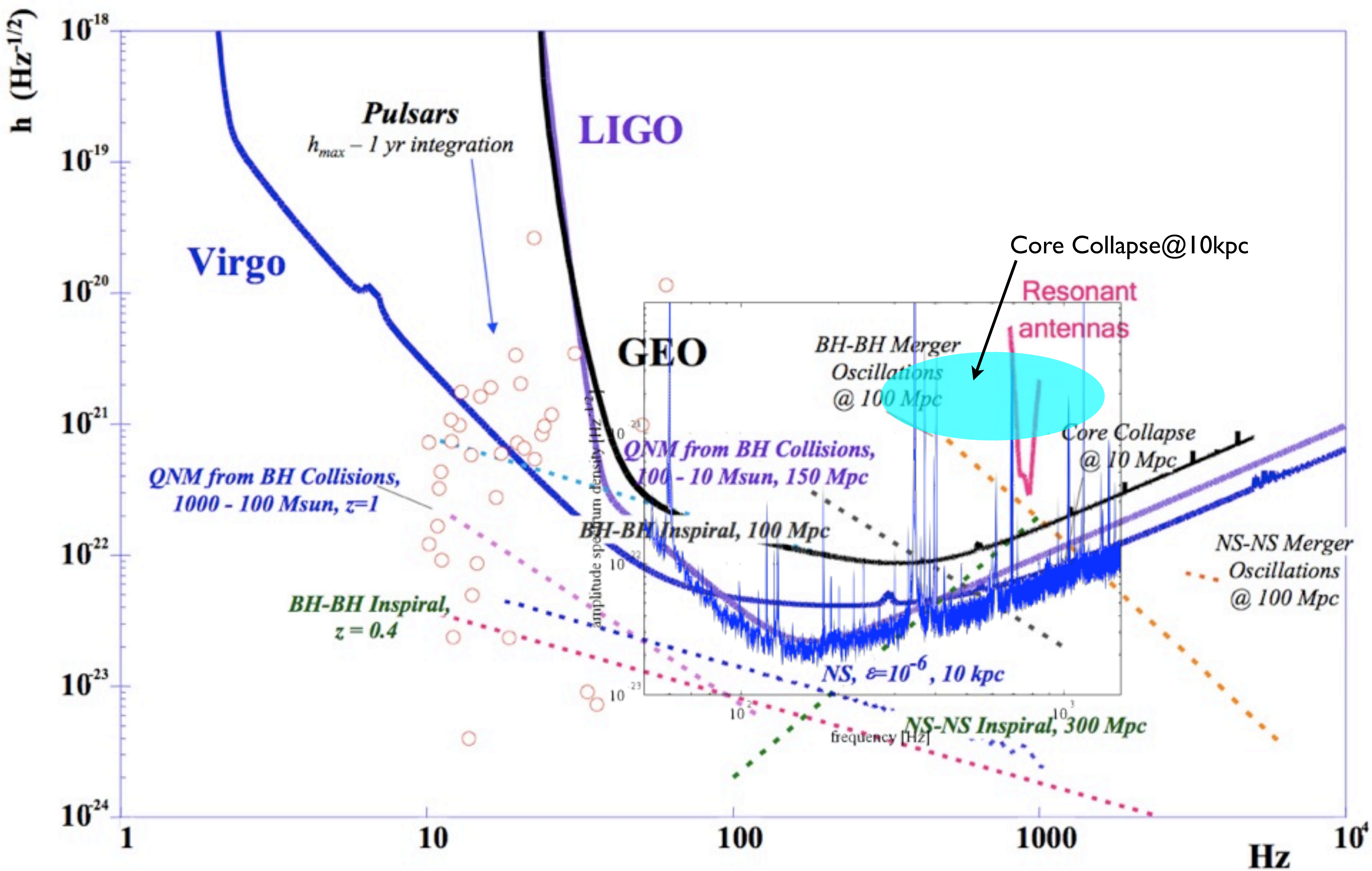
Limits to Sensitivity





LIGO-G0900681

LIGO sensitivity to astrophysical events



World wide detector network

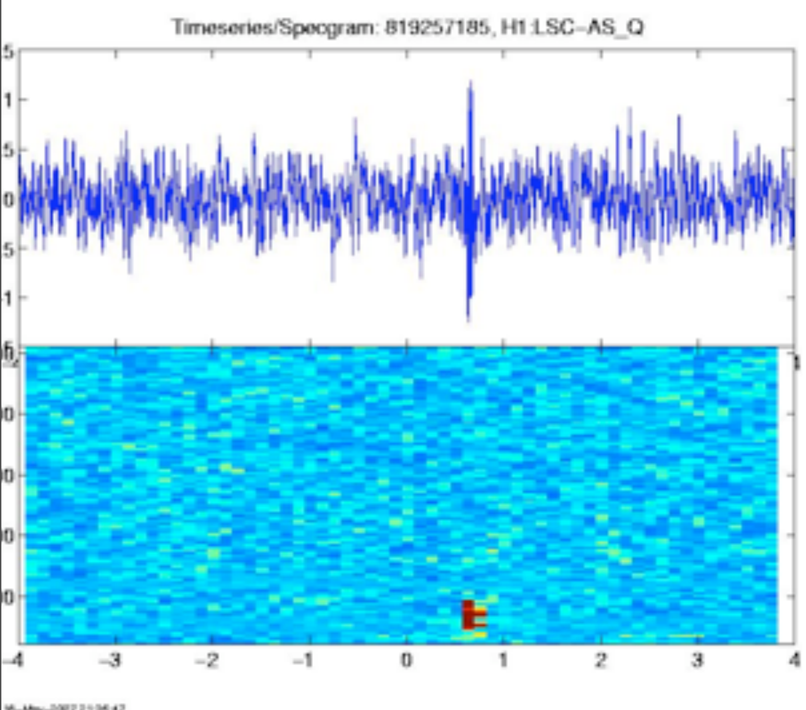
The network gives us

- o Reconstruction of astrophysical parameters: sky location, polarization waveform, ...
- o Reduction of false alarm rate by coincidence analysis
- o Better detection confidence

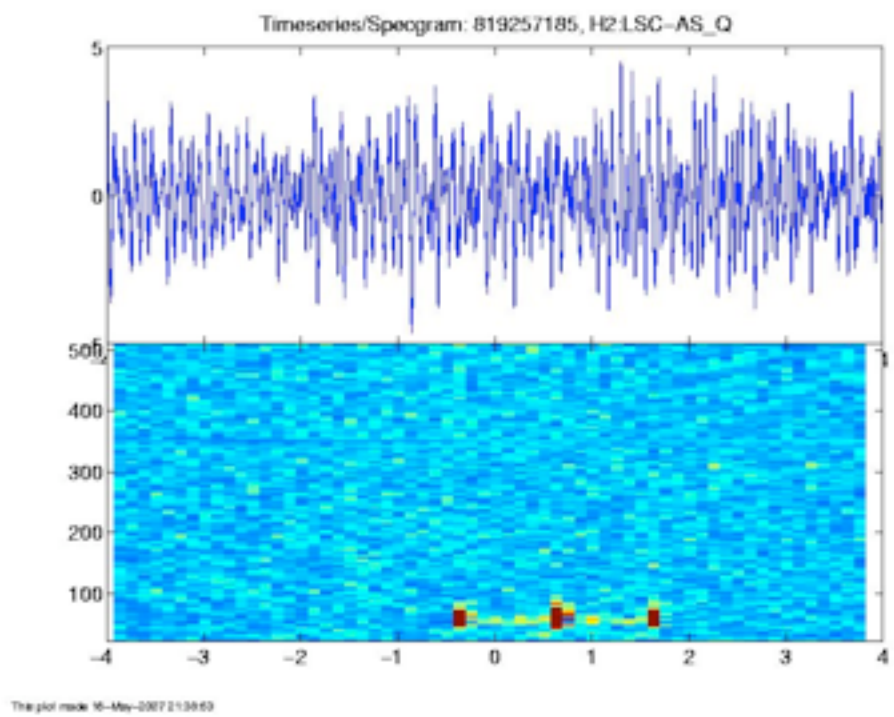
But we have still many unknown coincidences.....

Lots of spam from interferometers

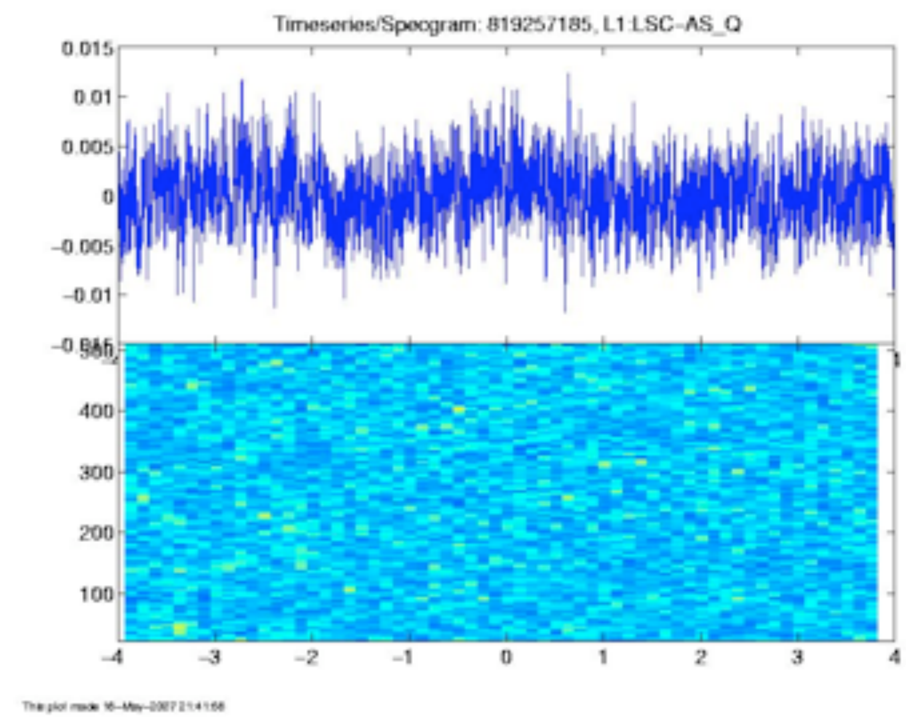
H1



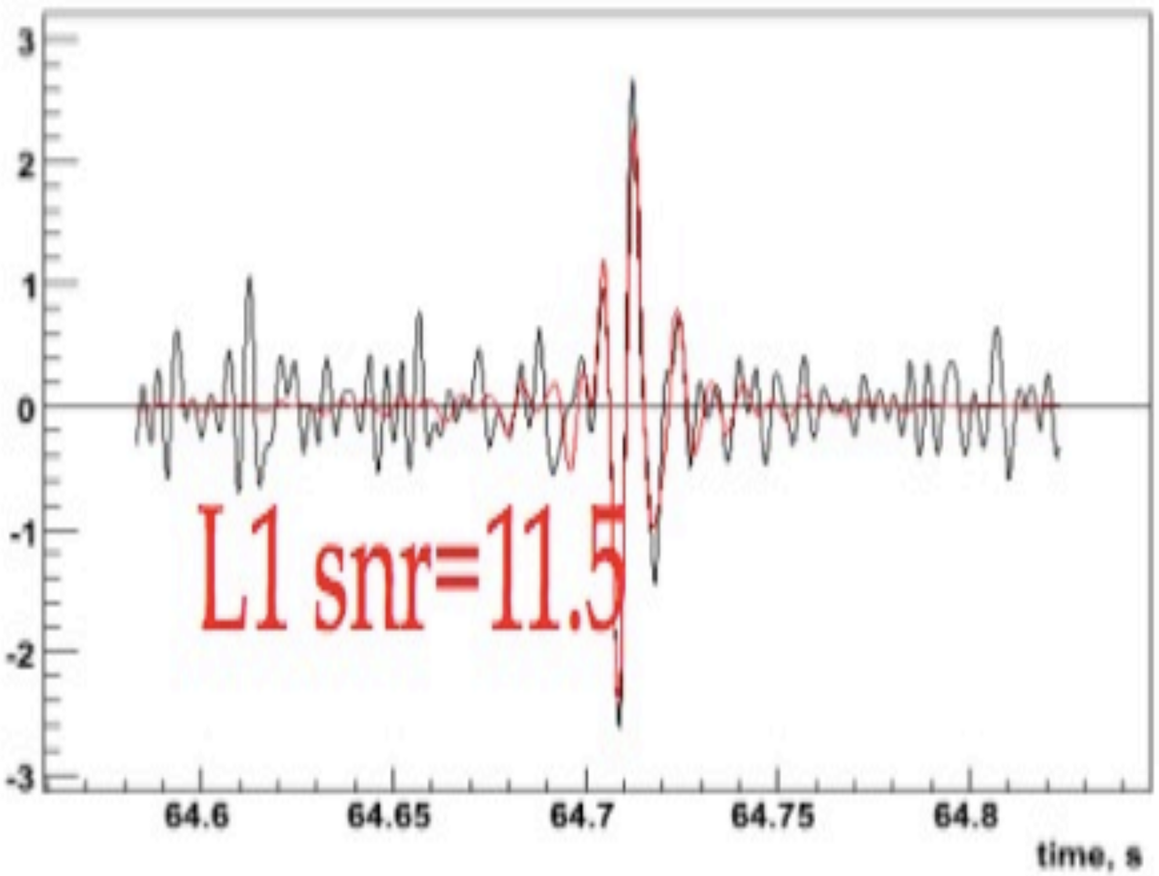
H2

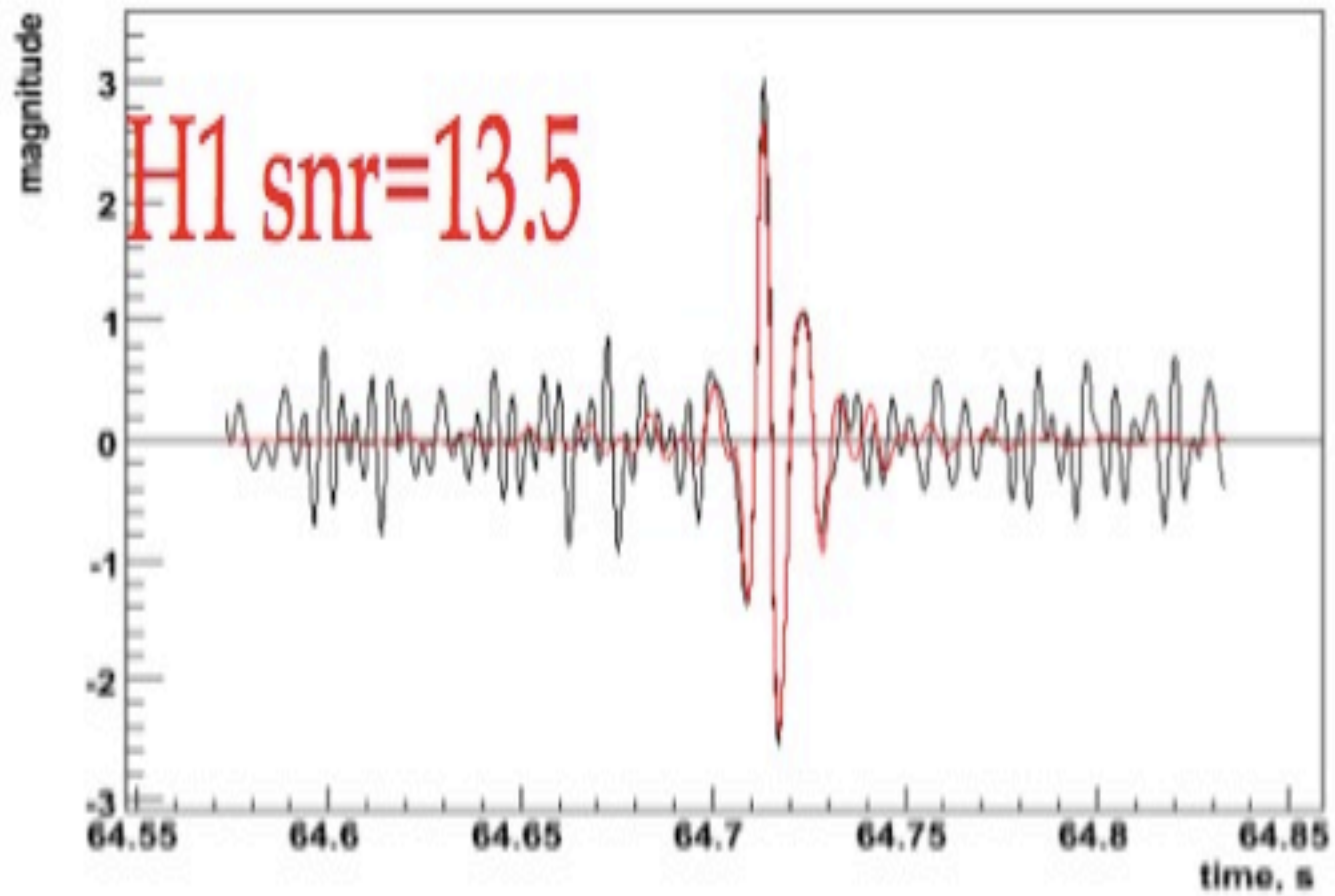


L1



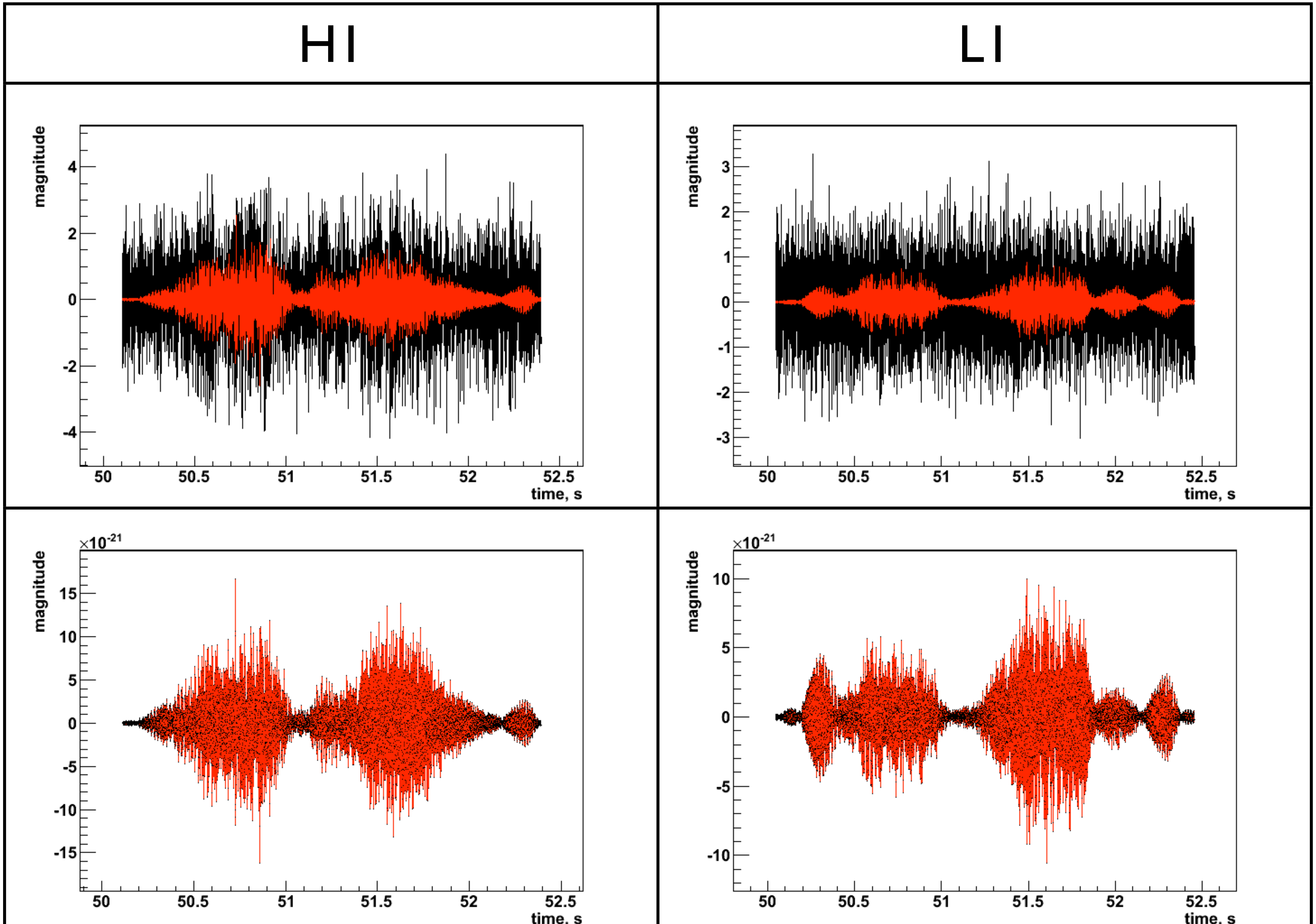
Event candidate



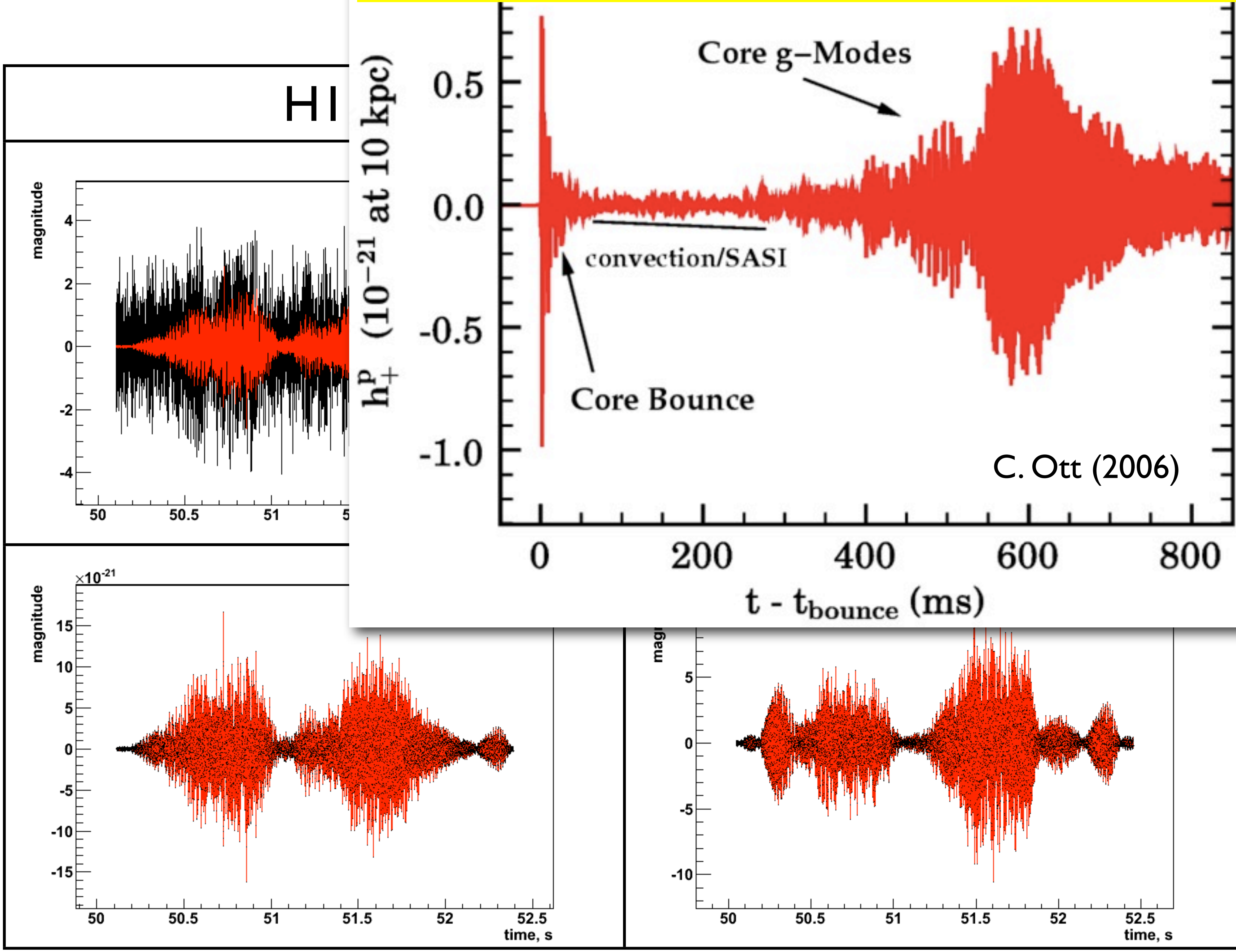


- Discovered by burst analysis group quickly
- Many similar pulses in all three LIGO interferometers
- Difficulties in establishing accidental coincidence rate
  - Initial estimate (KW)1/3yrs, later estimates (CWB)1/30yrs
- Burst group not unanimous in bringing event forward
- Decision by DAC not to proceed to Detection committee

Unknown correlated signal



Gravitational Wave from Supernova



What signals can be accepted conventionally?

3 sigma effect « **evidence** »
5 sigma effect « **discovery** »

3σ means a probability ~ 0.27%
5σ means a probability ~ **$6x10^{-7}$**!

Translated to our field:
Claim for GW discovery " a (burst) candidate must have a chance < 10^{-6} to have been produced by background

Way to reach the 5-sigma level

equinox event : **P ~ 1 %** (after cat3 DQ/vetoes)

Need to gain 4 orders of magnitude!

Two way:
o Reducing background noise
o Astrophysical counterpart

Coincidences with astrophysical counterpart

Temporal coincidence

Spacial coincidence

Temporal Coincidence

Run duration T.
- Candidate with f.a.p. P from time slides.
- Coincidence with external event, coincidence window Δt.
- N such external events during the run.

Gain in f.a.p. ~ Δt x N/T (rate of external events x coincidence window)

Ex.: $\Delta t \sim 180$ s, N/T ~ 1/day => **gain ~ 2×10^{-3}**

Spacial coincidence

External counterpart assumed to be well localized.
Position reconstruction from the LV network:
angular accuracy ~ few degrees (say *A* degrees)
Gain in f.a.p. ~ $(A/180)^2$

If *A* ~2 deg. **gain ~10^{-4}** !
Even if *A* ~20 deg. **gain ~10^{-2}**

Spacio-temporal coincidence

Combine both time and spatial coincidences:

Final f.a.p. ~ P x (Δt x N/T) x (*A*/180)^2

1% 1% 1%

Reach 10^{-6}!

LIGOVirgo-NASU joint observations

o WJN events

- So far several transients were detected and some of them have been published.
- Only radio transient events which have coincidence during S5.

o Source model

- ??

o Radio-GW emission model

- Binary neutron star coalescence:
  One of two NSs is magnetar with B~10^{12}-10^{15}B
  Energy is converted into plasma,...
  The observable flux is ~2mJy for a source at 100Mpc
- Plasma excitation through relativistic MHD
  A GW causes excitations of waves in the fluid(Alfven wave, slow, fast magnetosonic waves)
- Photon acceleration due to a GW
-
- ...

Coincidence with LIGO--Nasu

Detectors in science mode around WJN events

WJN J 1039+3300

- GPS: 821639626, (RA[deg],DEC[deg])=(159.86,+33)
- H1,H2 were in science mode in 10000[s] around the events

WJN J 0951+3300

- GPS: 821119786, (RA[deg],DEC[deg])=(147.84,+33)
- Part of H1,H2,L1 data were in science mode in 10000[s] around the events

WJN J0205+4142

- GPS: 819627463, (RA[deg],DEC[deg])=(30.946,+41.7)
- H1,H2,L1 were in science mode in 10000[s] around the events

WJN J0202+4142

- GPS: 850991014, (RA[deg],DEC[deg])=(30.275,+41.7)
- H1,H2,L1 were in science mode in 10000[s] around the events

LIGO Scientific Collaboration

LIGO

LSC

University of Maryland

Michigan

University of Strathclyde

Tsinghua University

University of Cambridge

ACIGA

Montana State University

PAH

University of Washington

Loyola University New Orleans

Syracuse University

Trinity University

University of Wisconsin Milwaukee

ANU The Australian National University

University of Glasgow

Università degli Studi del Sannio

San José State University

LSU

UTB TSC

The University of Western Australia

NASA Goddard Space Flight Center

Andrews University

California Institute of Technology

Northwestern University

Moscow State University

R·I·T

The University of Adelaide Australia

PAN

Massachusetts Institute of Technology

Southeastern

GEO 600

Embry-Riddle Aeronautical University

University of Massachusetts Amherst

University of Southampton

The University of New Hampshire

PennState

Carleton College

Cardiff University

Universitat de les Illes Balears

Washington State University

UF University of Florida

The University of Mississippi

Charles Sturt University

NAOJ

University of Rochester

University of Minnesota

Southern University

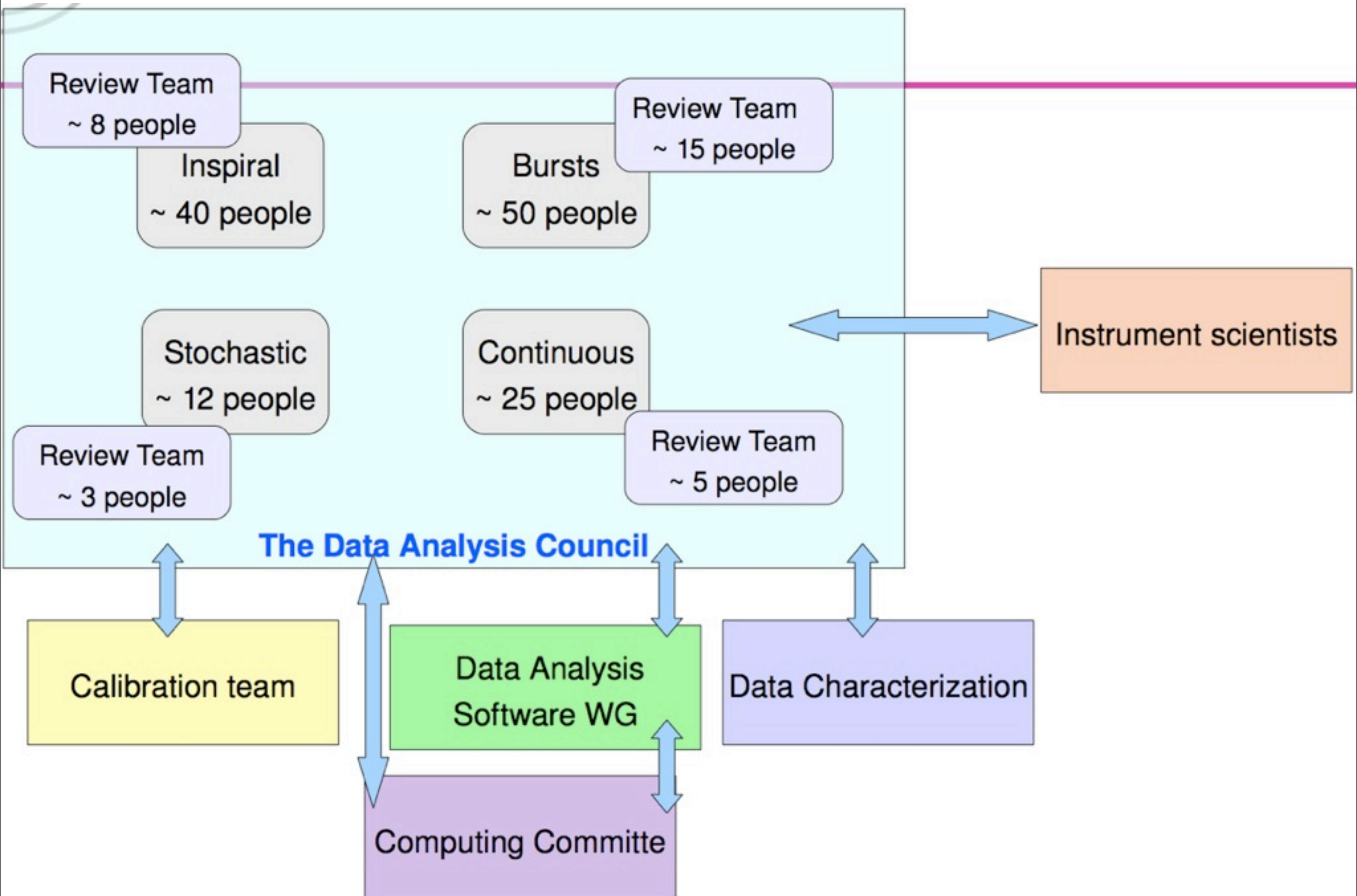
Hobart and William Smith Colleges

Science & Technology Facilities Council Rutherford Appleton Laboratory

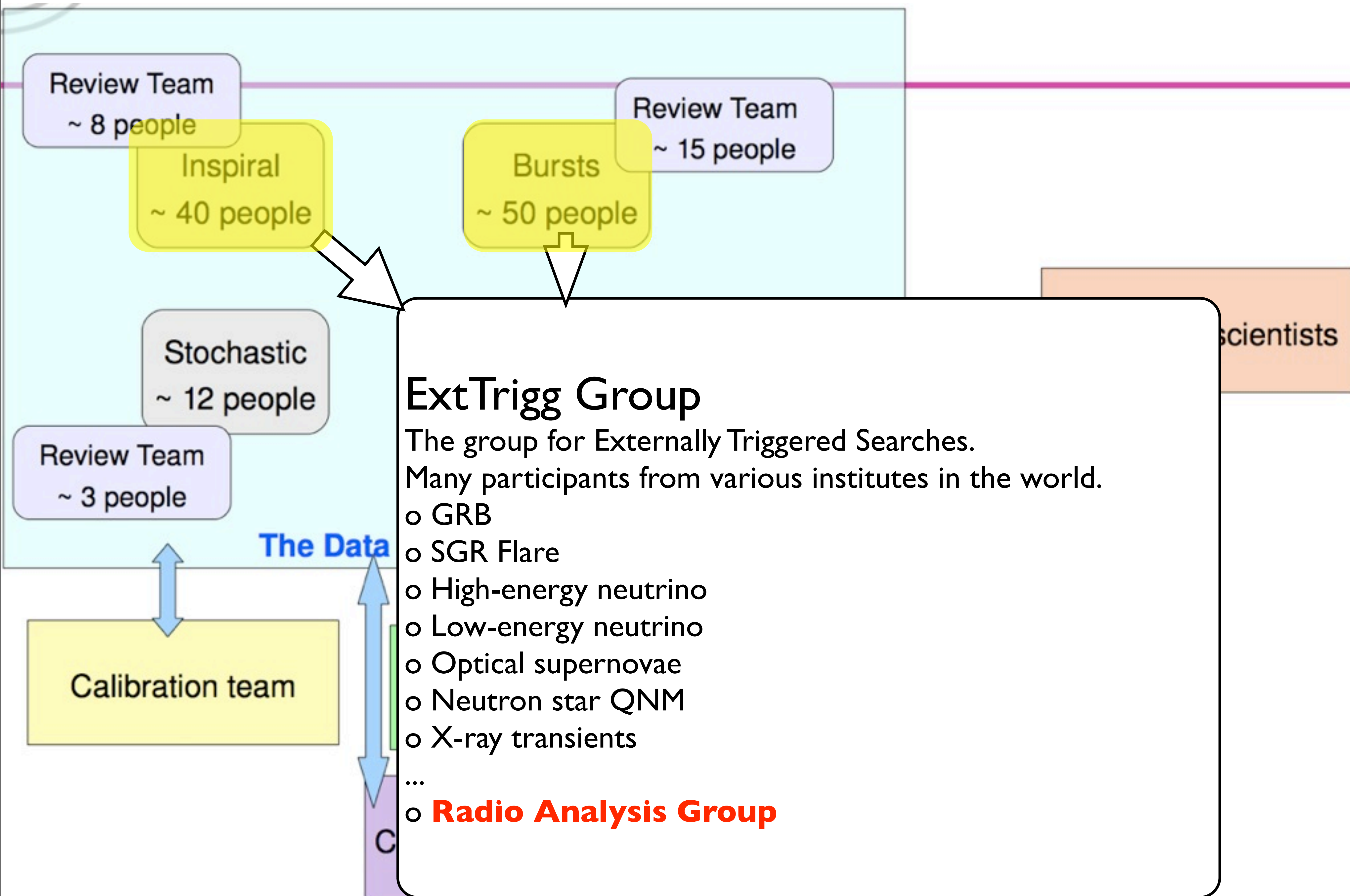
Universität Hannover

LIGO Astr... 12 April 2010

LIGO organization of data analysis



LIGO organization of data analysis



ExtTrigg Group

The group for Externally Triggered Searches.
Many participants from various institutes in the world.

- o GRB
- o SGR Flare
- o High-energy neutrino
- o Low-energy neutrino
- o Optical supernovae
- o Neutron star QNM
- o X-ray transients

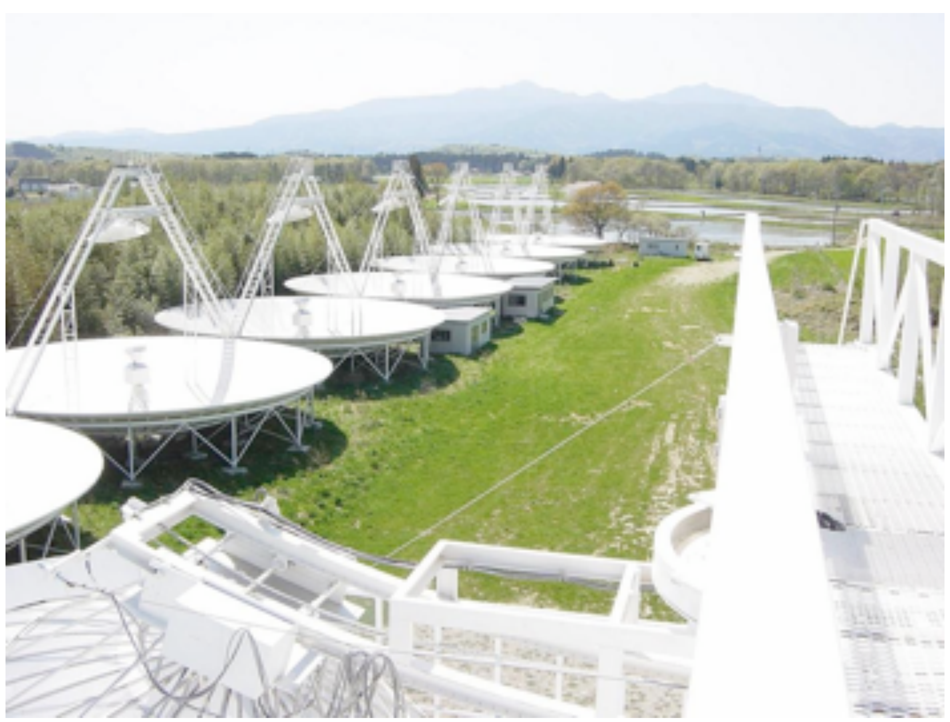
...

- o **Radio Analysis Group**

Radio telescopes to join

Instrument	Band	Type	Field of View	Slew Time
LOFAR	40-240 MHz	Array	30° beam(s)	Software
ETA	29-47 MHz	Array	Two 30° beams	Software
LWA	10-88 MHz	Array	Three ~ 8° beams	Software
NRAO Green Bank	300MHz-50 GHz	Dish	0.027 sq. deg. (at 1 GHz)	18°/minute
ARECIBO	312 MHz - 10.2 GHz (ALFA: 1.225 - 1.525 GHz)	Dish	15 arcmin @ 312 MHz 0.5 arcmin @ 10.2 GHz (ALFA: 10 arcmin @ 3.5 arcmin resolution (7 beams))	< 16 min

and NASU



Purpose	Radio Interferometers for Wide Field Survey Eight 20 m diameter spherical dish antennas+ A 30 m diameter spherical dish antenna
System Noise Temperature	Appoximately 80K
Observing frequency	1.42 GHz
Bandwidth	20 MHz
Site	Nasu-Shiobara, Tochigi prefecture
Target	Radio Transients, Radio counterparts of EGRET un-id sources, Pulsars
Sensitivity	Several hundred mJy (1 sec integration)

http://www.astro.phys.waseda.ac.jp/index-e.html

MOU between LIGOVirgo-LOFAR

- Introduction
  - コラボレーションの目的と期待される成果。
  - MOUで決めること。
- A. Description of Participating Groups
  - LOFAR
  - LIGO, VIRGO, GEO
- B. General Policies and Provisions
  - このMOUはそれぞれが行う他との共同研究やデータ交換を妨げない。

4. This MOU does not prevent the parties from establishing other agreements on data exchange or external collaborations. The existence and general terms of any other agreements that are scientifically related will be freely shared among the parties of this MOU.

  - PIはそれぞれの機関にMOUを認めてもらう。
- C. Description of Planned Work
  - LOFARはearly phaseのため計画の一部しか実行出来ない場合もある。
  - LOFARのイベントリストについてpublish、unpublishに関わらず公開。
  - LVCはGWイベント候補の天球位置、時刻を提供する。(follow-up of GW events by LOFAR)
  - Pulsar glitchを含むデータの公開

- C. Notes
  - イベント解析が遅れてLOFARの検出したイベント候補についてLOFAR側の発表を遅らせる可能性もある。(数ヶ月)

3. Because of the extensive time required to fully characterize LSC-VIRGO data, and because of the blind injection challenge, it will probably take several months to arrive at the final verdict on any event candidate. During that time, the existence of a possible event candidate (if any) will be kept strictly confidential by LOFAR, the LSC, and Virgo.

- D. Scope and Timeline
  - 2010年夏から秋にかけて実施する予定。
  - データ交換の中断もあり得る。
- E. Appropriate use of Data and Other Information

1. All parties agree that any data or data products received from the other parties shall be used only for the purposes of the collaborative work covered by this agreement, and shall be held confidential (unless already made public). Any public release of data would not affect the goals or terms of this project.

- F. Publications and Presentations

1. All LOFAR Transients KSP observations that have *not* been triggered by LSC-VIRGO event candidates, and all LOFAR observations not involving the LOFAR Transients KSP, and all LSC-VIRGO analyses that do not make use of LOFAR image data (either for confirmation or non-confirmation of event candidates), are not affected by this agreement.

3. Publication or other presentation of results related to the collaborative work, whether they are detection statements or not, will follow the usual principles for scientific credit and authorship. We can anticipate some possible scenarios:

   - If either the LOFAR Transients KSP on the one hand or LSC-VIRGO on the other hand can make a detection/evidence claim based solely on a *separate* analysis of their own data and in the absence of corroborating evidence from the other party, then each party may choose to publish their result separately and independently of the other.

   - An independent or joint follow-up article may complement an independent "discovery" paper.

   - If neither the LOFAR Transients KSP nor LSC-VIRGO can make a claim of a detection/evidence based solely on a separate analysis of their own data, but a joint analysis results in a detection or substantial evidence for a signal, that will be published in a jointly authored article.

   - If there is no discovery, a joint paper may be written to state upper-limits and associated astrophysical interpretations.

   - A joint technical paper (without observational results) may be written to describe the project and methods.

Merit, demerit

Merit from LIGO side

- o 共同観測を始める前に決めごとを整理しておけば後の議論が短縮できる。
- o 既にMOUのテンプレートがある。
- o 重力波検出から発表までのプロセスが見えるので混乱が起きない。
- o 重力波の検出の可能性が高まる。

Merit of NASU side

- o 重力波を検出した場合、喜びを共有できる。論文も。
- o 人的な交流が期待できる。

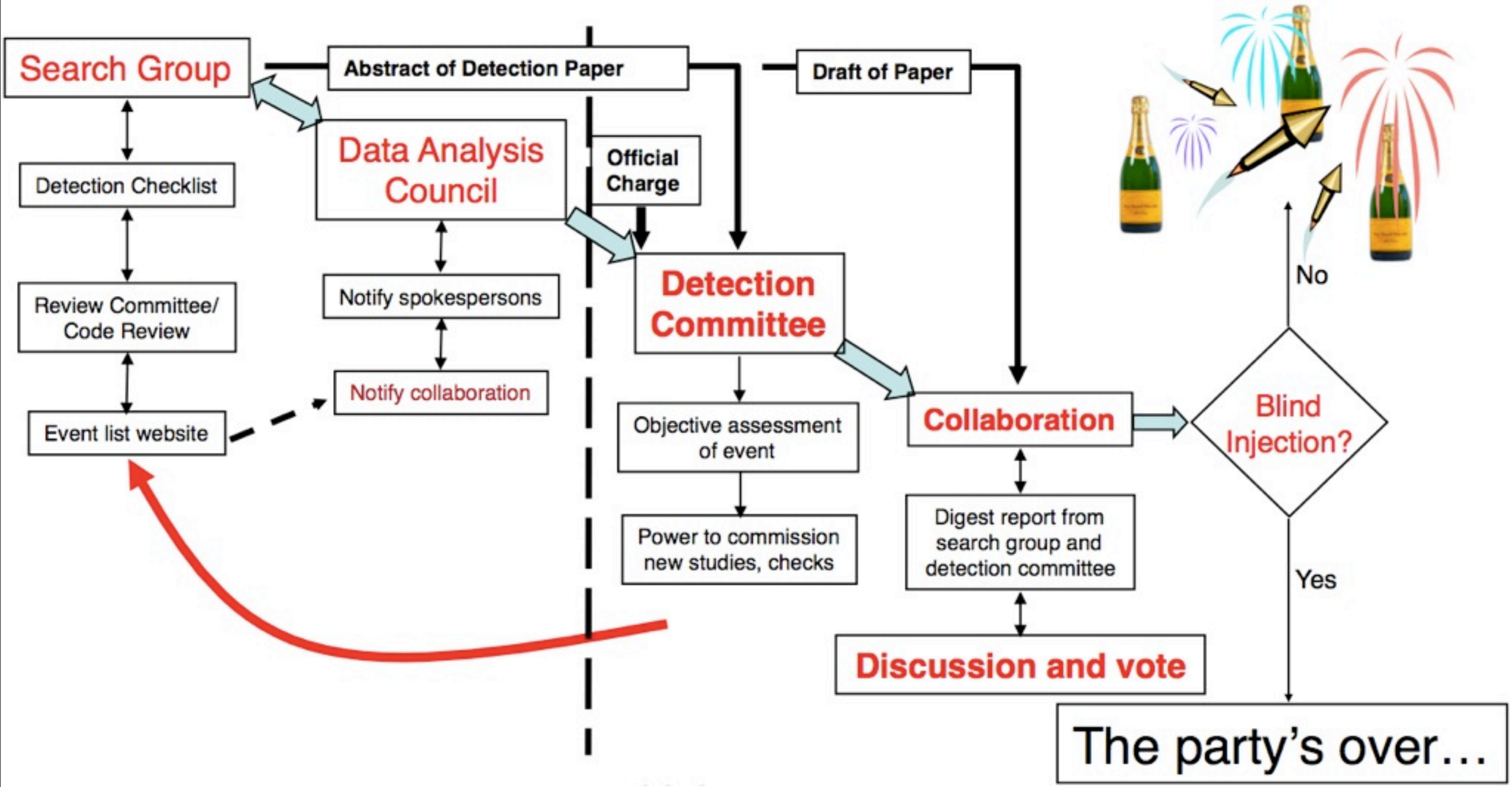
DeMerit of NASU side

- o MOUを作成するのに時間がかかる

NASUからの要請

o コインシデンスイベントに関して、LIGO側が解析している間(数ヶ月？)、情報のプロテクションはNASUとLIGOにコインシデンスがあるという情報のみにかけられ、NASU側の他の共同研究に影響しない。

Detection Procedure Workflow



R. Weiss (MIT)

交流財源

住友財団基礎科学研究助成

http://www.sumitomo.or.jp/
2010年４月15日から６月30日

最大500万

稲森財団

http://www.inamori-f.or.jp/ja_fd_gra_out.html
明記されていない

100万

矢崎科学技術振興記念財団(ただし、テーマはエネルギー、新材料、情報)

http://www.yazaki-group.com/zaidan/kennkyu_jyosei/page2.html
６月１日〜　８月３１日

3年で200万(一般)or 100万(35歳以下)

財団法人理工学振興会

http://www.titech-tlo.or.jp/
9月はじめと思われる。

20万

スカンジナビア･ニッポン　ササカワ財団

http://www.swejap.a.se/SJSF/Templates/SJSFPage.aspx?id=880
1月半ば

100万上限

笹川科学研究助成

http://www.jss.or.jp/sasagawa/index.html
10月半ば

100万