A Low Frequency Interferometer
a window of opportunity

Riccardo DeSalvo

About these ideas

- Started from a study of low frequency feasibility
- Found some astrophysical motivations
  - (will skip rapidly through it)
- Found a window of opportunity for realizing it in a short time scale, tell you how

- This presentation is an hybrid between scientific and political one

- It is all hypothetical so far.

GW interferometer oversimplified fundamentals

- The sensitivity of a GW interferometer is constrained between two slanted walls and a floor
  - The shot noise wall on the high freq. side,
    - Pushed at higher frequency by more stored power
  - The radiation pressure fluctuation at low freq.
    - Pushed at lower frequency by less stored power
  - And below, The thermal noise floor
    - Controlled by spot size and quality factors
- The separation of the two walls is determined by the mirror mass
- Seismic, suspension, and even gravity gradient noise are manageable

GW I advancement game

- Presently the walls are spaced more than the observable (useful) frequency range and the sensitivity curve looks like a wide valley.
- Most of the efforts for advanced GW interferometer development is in the direction of lowering the thermal noise floor
  - By glassy suspensions in A-LIGO
  - By cryogenics in LCGT
- The more one will win on thermal noise floor,

  the more the sensitivity curve will look like a narrow canyon.

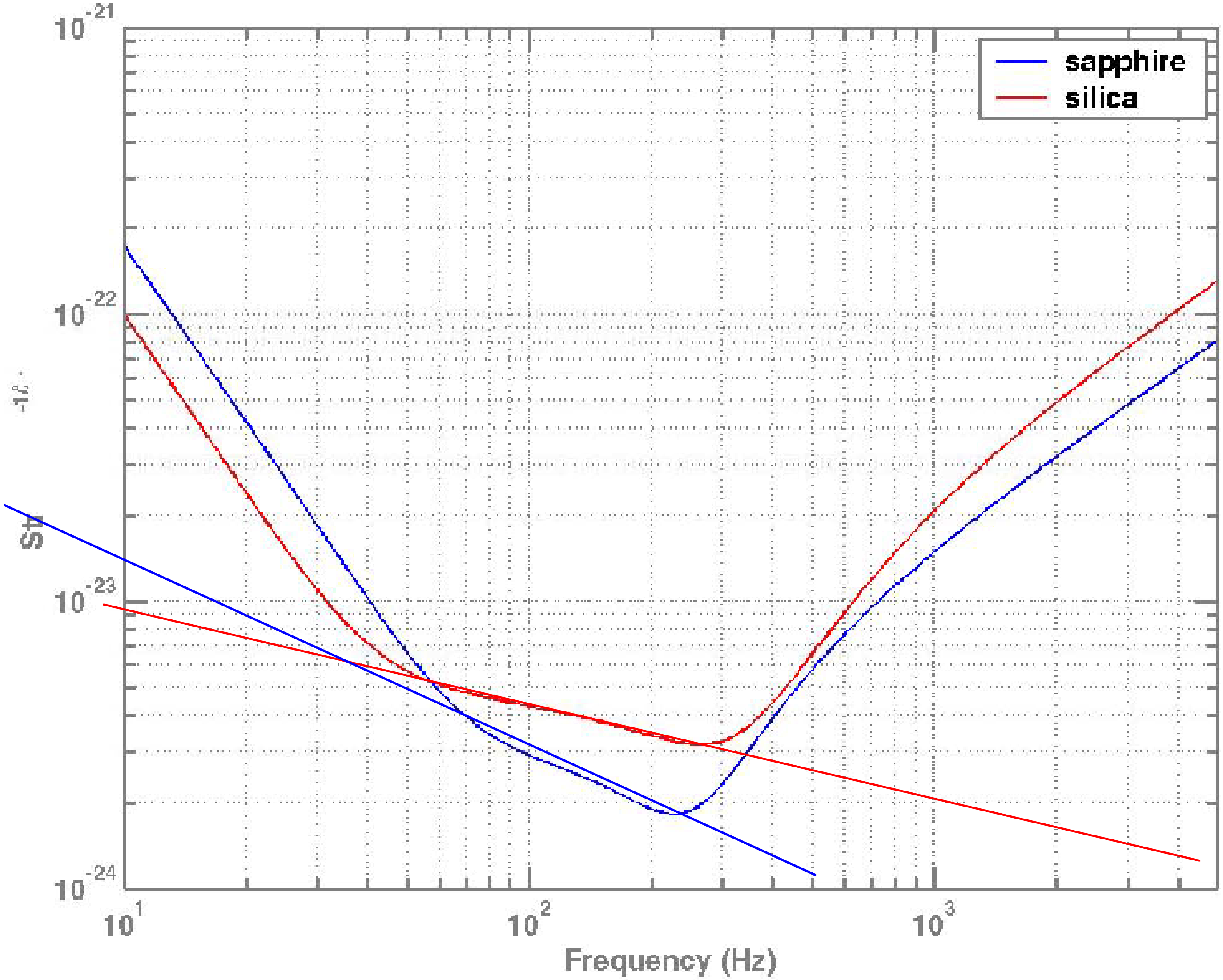
The position in the frequency range of the sensitivity canyon in determined by the stored power in the arms

GW I next step? the Dual interferometer

- Contrary to the case in Virgo and LIGO,

  in cryogenic GW I the canyon will be so narrow that a xylophone of interferometers will be necessary.
- In advanced interferometers we start seeing this effect and can already profit from twin interferometers
  - (not omozygote interferometers, though,
  - Need to be different enough)
- Need GW I optimized for different frequency ranges, => the dual interferometer.

Shifting the canyons



- These two curves are shifted by a small difference in stored power
- Note the different TN slope, sapphire optimal at H.F. fused silica at L.F.

Taking advantage of dual interferometers

- Can use different materials for different f. ranges
- Can design optimized suspensions
- Dual interferometer in each site will greatly enhance online time for coincidence with other GW I
- Will have wider sensitivity coverage
- Will have large coverage overlap in the prime (central) frequency range from radically different GW I thus improving credibility
- A L.F. GW I will give free hunting license to its H.F. brother for narrow band searches.
- A L.F. interferometer needs not to worry about the H.F. end, so that it can be simplified and focus, later on, to the gravity gradient limit

- Low power requirements (simplify optical layout)
  - Can reduce circulating power by factors of 10 to 100
  - Can increase finesse and further reduce input power
- Can use larger fused silica masses to reduce the thermal noise with larger beam spots (Tsubono’s presentation) >>>
- Can reduce seismic wall below 6 Hz (Virgo seismic attenuation scheme and no shot noise requirements)
- Can reduce suspension thermal noise with longer or more elaborate suspensions

大型ミラーを用いた次世代レーザー干渉計重力波検出器
Proposal of a next-generation GW detector using huge mirrors

April 10, 2001

坪野公夫

abstract

大型ミラーを用いたレーザー干渉計重力波検出器の性能および実現可能性の評価をおこなう．大型ミラーを使うことにより、不確定性原理で決まる限界を下げることができる．また、鏡面でのビームサイズを大きくとるデザインを採用することにより、ハイパワー照射が可能となりショットノイズを下げることができる．同時に、大型化によってミラーおよび懸架システム全般の熱雑音を小さくすることができる．これにより本設計の大型ミラーを用いたレーザー干渉計は、室温動作であるにもかかわらず次世代高感度重力波検出器としての性能をもつことが可能である．

Abstract

Evaluation of performance and feasibility of a laser GW interferometer using large mirrors.

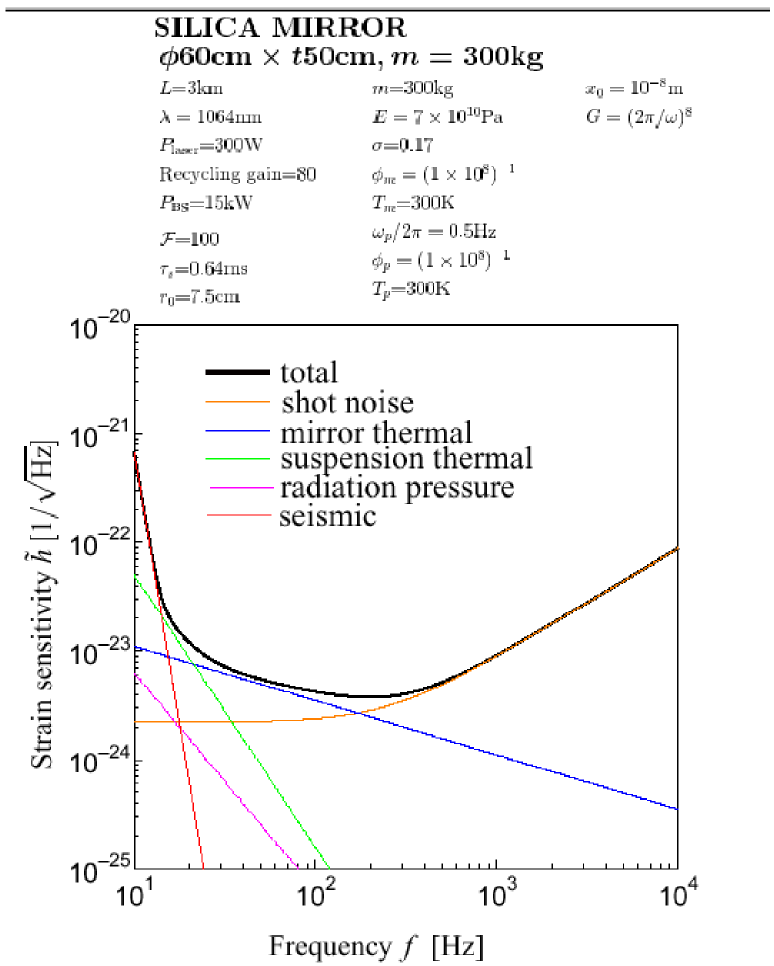
By using large mirrors the limit imposed by quantum mechanics can be reduced.

By enlarging the beam size on the mirror surface it is possible to use large power to reduce shot noise.

At the time by enlarging the mass the thermal noise of the mirror and the suspensions can be reduced.

Because of this the interferometer using large mirror can have the necessary performance even at room temperature.

Tsubono’s idea



Also see Shoemaker’s bench estimations

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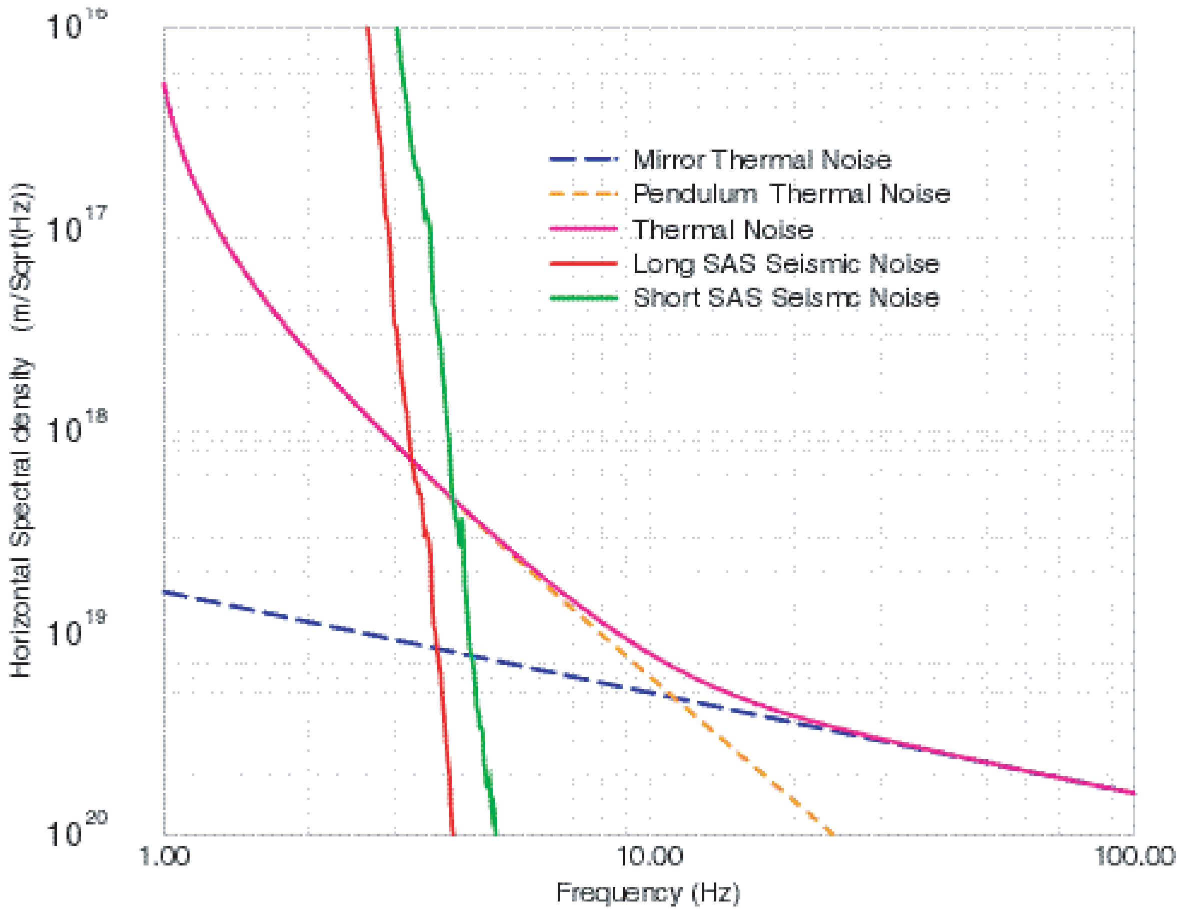
Reducing the gap to LISA



Will need gravity gradient substraction

Riccardo DeSalvo
August 14th 2001

Other

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LIGO

Why do we need to cover the L.F. range

- Lots of well known reasons, just a new one,
  - Also listen to Francesco

Intermediate mass black holes

One of the most enigmatic results to emerge from X-ray population studies of spiral and other luminous star forming galaxies is the discovery of unresolved X-ray sources which appear to have luminosities factors of 10 to 100's times the Eddington luminosity for a neutron star (e.g. Roberts

Chandra High-Resolution Camera Observations of the Luminous X-Ray Source in the Starburst Galaxy M82

P. Kaaret[1], A.H. Prestwich[1], A. Zezas[1], S.S. Murray[1], D.-W. Kim[1], R.E. Kilgard[1], E.M. Schlegel[1] and M.J. Ward[2]
[1] *Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA*
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Intermediate mass BH

luminosity AGN. However, many are well outside the central regions of the galaxies and require an alternative explanation. Some of these highly luminous x-ray sources may be

interstellar medium (Fabian & Terlevich 1996), or they may be accretion powered binary sources, in which case they are excellent black hole candidates with masses near or above 10 $M_{\odot}$ (Makishima et al. 2000). Deciding between these various alternatives has been complicated by the limited spatial resolution of pre-Chandra X-ray missions.

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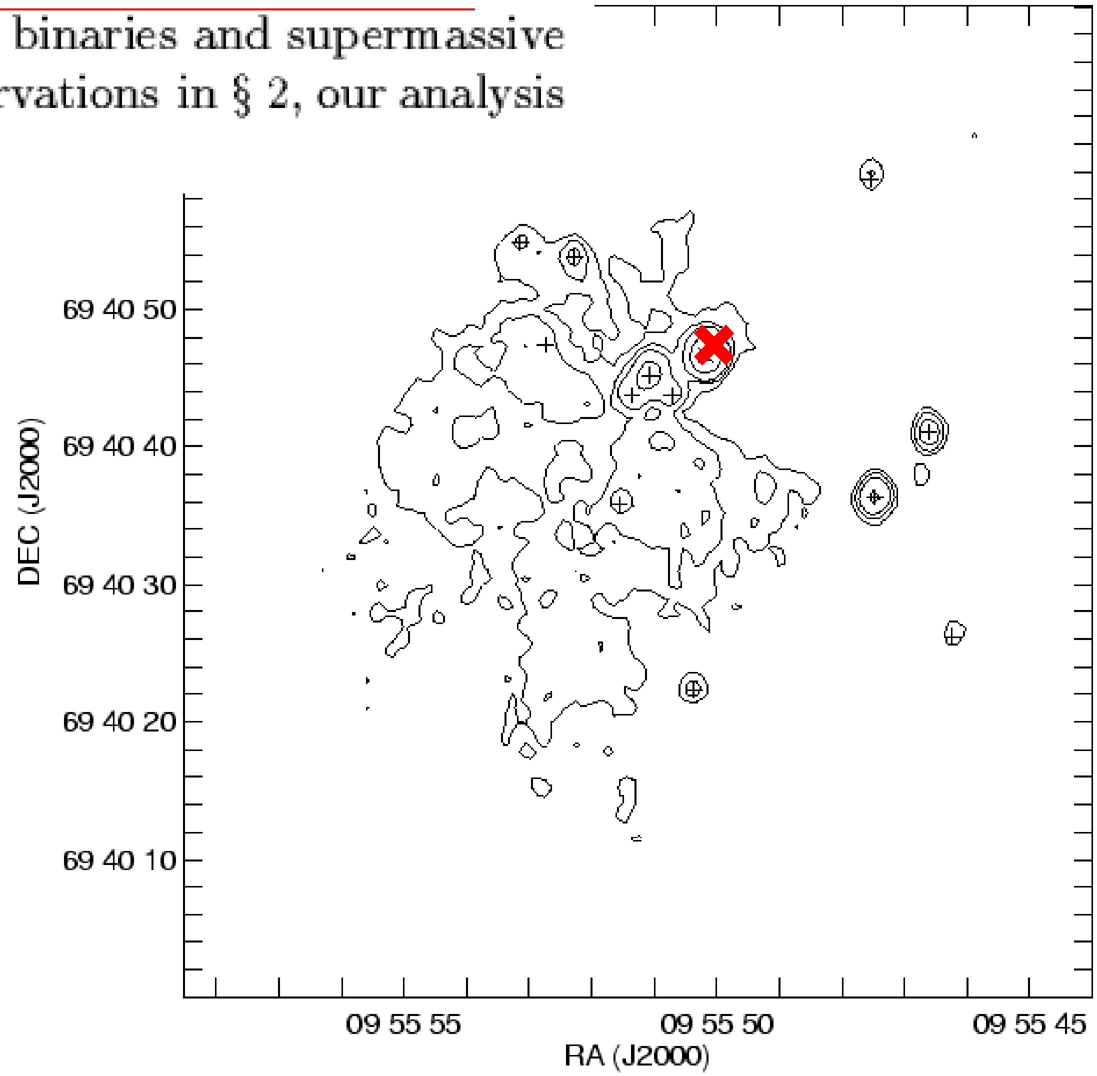
Intermediate mass BH

the brightest Chandra source. Our results suggest that this source may be a black hole with a mass intermediate between stellar-mass Galactic x-ray binaries and supermassive black holes. We describe the observations in § 2, our analysis in § 3, and conclude in § 4.



LIGO

More on IMBH
A short lived donor is needed

(ii) The assumption of mild beaming ($b \sim 0.1 - 0.01$) reduces M_1 to values already observed for Galactic X–ray binaries, and suggests that ULXs represent a shortlived phase of their evolution. The most likely candidate for this is the thermal–timescale mass transfer episode inevitable in a very wide class of intermediate– and high–mass X–ray binaries. This in turn suggests a link to the Galactic microquasars (cf King, 1998, quoted in Mirabel & Rodriguez, 1999). The short donor lifetime in high–mass X–ray binaries would explain why ULXs are associated with young stellar populations.

The major theoretical uncertainty for (ii) above is whether beaming is a natural consequence of high accretion rates.

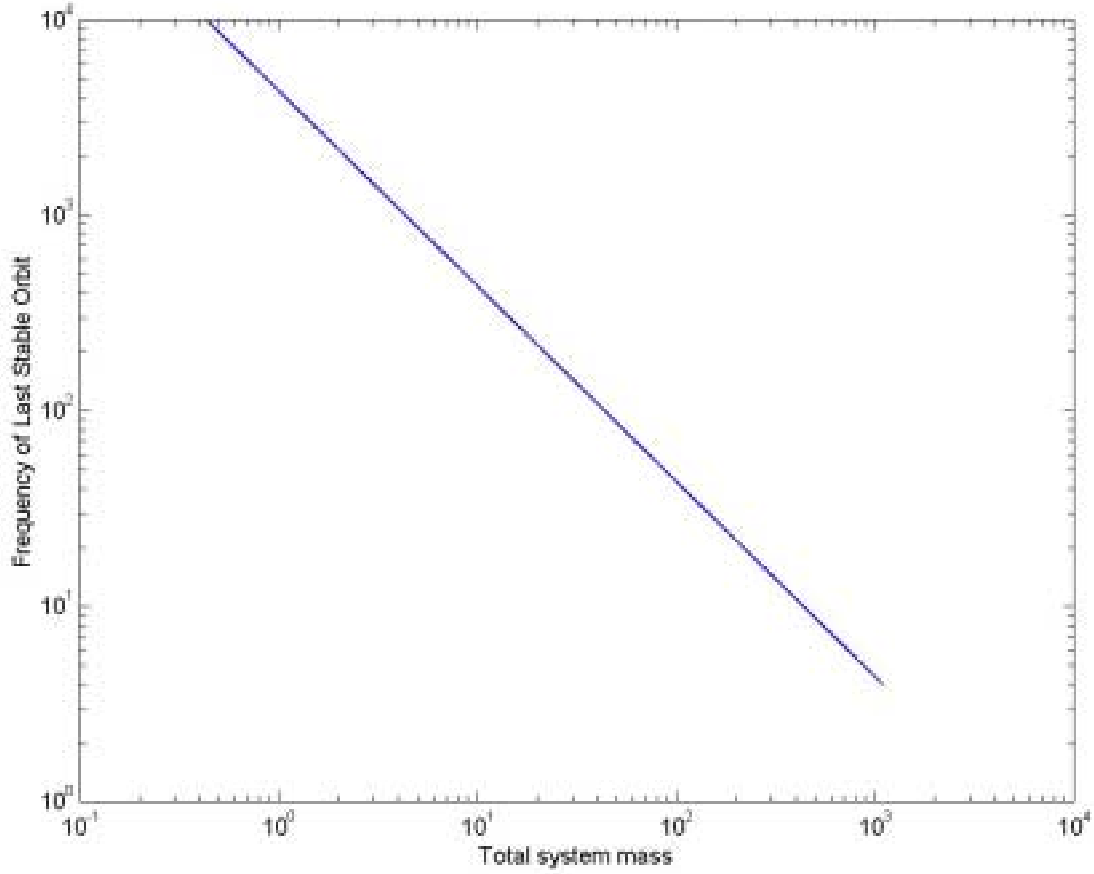
ULTRALUMINOUS X–RAY SOURCES IN EXTERNAL GALAXIES

A.R. King[1], M.B. Davies[1], M.J. Ward[1], G. Fabbiano[2] & M. Elvis[2]

More on IMBH
A short lived donor is needed

Beaming,
the necessity of a donor for visibility and the
short lifetime of donors
make for a large populations ! !
A donor is a binary, how many BH binary?
How many of them are BH binaries?
How many are hardened in inspiralers?

IM-BH coalesce at low frequency



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A surprizing reason for better coverage of high frequency range

- 1987-A oblated, spinning-down NS
- Spinning at 467.5 Hz, spinning down and precessing as required by GW emission from a 10^{-6} oblate NS
- Nautilus being tuned and beefed up for detection possibly within a year

1987-A oblated, spinning-down NS

A 2.14 ms Candidate Optical Pulsar in SN1987A

J. Middleditch[1,2]

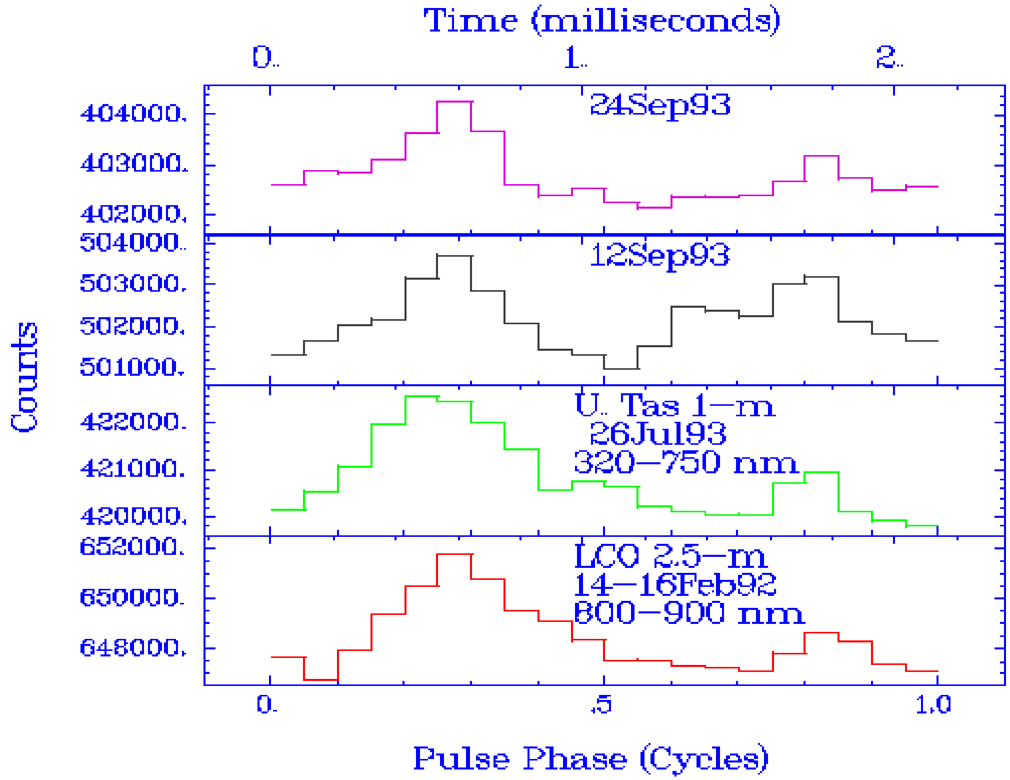

Figure 1. The pulse profiles for the 2.14 ms periodicity detected on UT 26 July, 12 Sep. and 24 Sep. '93 with the 1-m telescope are plotted against the UT 14-16 Feb. '92 detection with the LCO 2.5-m telescope.

1987-A oblated, spinning-down NS

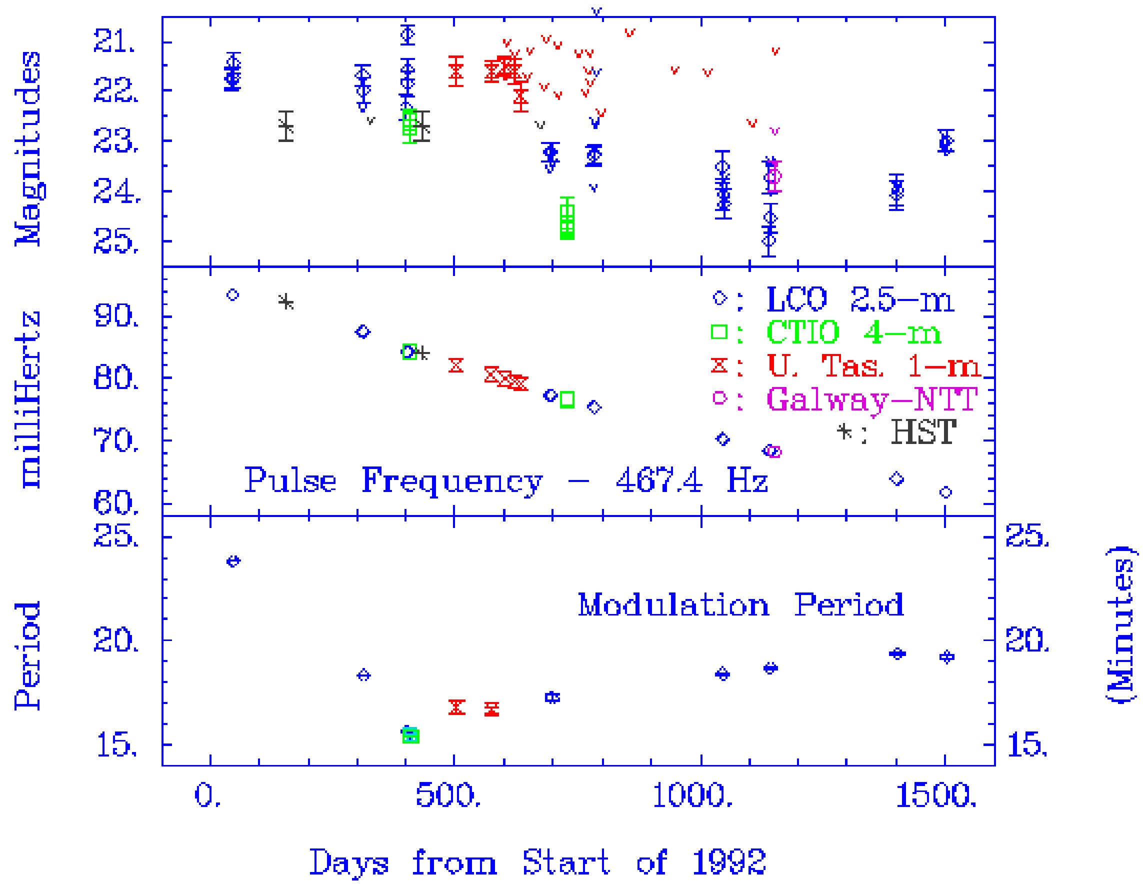

Figure 4. The time histories of the ~1,000 s modulation period (lower), the ~ 467.5 Hz pulse frequency (middle), and the inferred I flux (upper) for points earlier than day 500, V + R + I composite for LCO and CTIO points afterward, and S20 band magnitude for HST, Galway/NTT, and U. Tas. points. The 'v' symbols are upper limits.

1987-A oblated, spinning-down NS

A 2.14 ms Candidate Optical Pulsar in SN1987A

J. Middleditch[1,2]

Abstract.

We have monitored Supernova 1987A in optical/near-infrared bands from a few weeks following its birth until the present time in order to search for a pulsar remnant. We have found an apparent pattern of emission near the frequency of 467.5 Hz – a 2.14 ms pulsar candidate, first detected in data taken on the remnant at the Las Campanas Observatory (LCO) 2.5-m Dupont telescope during 14-16 Feb. 1992 UT. We detected further signals near the 2.14 ms period on numerous occasions over the next four years in data taken with a variety of telescopes, data systems and detectors, at a number of ground- and space-based observatories. The sequence of detections of this signal from Feb. '92 through August '93, prior to its apparent subsequent fading, is highly improbable ($< 10^{-10}$ for any noise source). We also find evidence for modulation of the 2.14 ms period with a ~1,000 s period which, when taken with the high spindown of the source (2-3$\times 10^{-10}$ Hz/s), is consistent with precession and spindown via gravitational radiation of a neutron star with a non-axisymmetric oblateness of $\sim 10^{-6}$, and an implied gravitational luminosity exceeding that of the Crab Nebula pulsar by an order of magnitude.

1987-A oblated, spinning-down NS

Implications of the Discovery of a Millisecond Pulsar in SN 1987A

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(Received)

From the observation of a millisecond pulsar in SN 1987A, the following implications are obtained. 1) The pulsar spindown in SN 1987A is caused by radiating gravitational waves rather than by magnetic dipole radiation and/or relativistic pulsar winds. 2) A mildly deformed shock wave would be formed at the core-collapse and explosion in SN 1987A, which is consistent with the conclusion given in Nagataki (2000). 3) The gravitational waves from the pulsar should be detected in several years using a Fabry-Perot-Michelson interferometer as the gravitational detector, such as LIGO and TAMA. 4) The neutrino oscillation model is not a promising model for the explanation of the kick velocity of the pulsar in SN 1987A. The hydrodynamical instability model is more favored.

of $1/\sqrt{\text{Hz}}$. We can find that detection of the gravitational wave from the pulsar is possible within a reasonable time when gravitational detectors such as LIGO[21)] and TAMA[22)], whose sensitivities are of order $h' \sim 10^{-22}$ $\text{Hz}^{-1/2}$, are running.

Additional reason to narrowband A-LIGO at High Frequency

- At L.F. we believe that we know the inspiral physics
- At mergers we will need the maximum possible sensitivity to directly detect wave shapes to make physics and constrain theories

So why a L.F. GW-Interferometer?

- This source may be detected by bars, but as there is one there will be many to look for,
- will need sensitivity at high frequency
- => narrowband scans

- => Better have a low frequency interferometer in both tubes to free up the H.F. ones.

Desirability and Feasibility

- Need a dual GW-I to cover both fronts
- Interest in Europe (Japan) to contribute

  LF GW Interferometers to complement A-LIGO
  - Scientific, to take advantage of the Virgo technology
  - Financial, not enough money in the next five years for a full second European interferometer but interest for a second European effort
  - Staging, will be personnel availability in the right time frame
- Will build more WW.Collaboration for future enterprises
- Price tag for LIGO
  - Commit to, later- on, complement an A-LIGO HF GWI inside Virgo
  - Concentrate efforts contributing on LCGT for a cryogenic R&D effort for the future

Is a LF-GWI for LIGO too big a challenge?

- Many ways it will be a bread and butter and K.I.S.S. interferometer than A-LIGO (and cheaper)
- Lower power
- Fused silica optics
- Passive wherever possible
  - Many less degrees of freedom (1/10)
- Will require much less development
- Will focus all efforts into best possible mirrors and lowest suspension thermal noise

Who builds a LF GWI for LIGO?
Boundary conditions ! !

- Will not draw energies from advanced LIGO
  - Does not mean will not draw information an support
- Cannot draw energy from Virgo until I will be fully operational
- Will not draw energies from TAMA until its sensitivity will become negligible compared with the three larger brothers but:

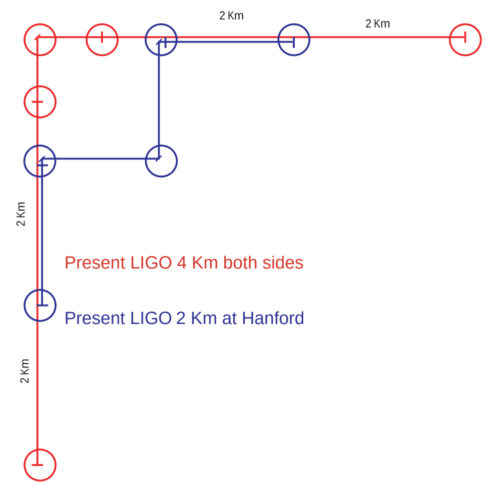
  Propose to valorize it using it as the development laboratory of LF development (equivalent of LASTI)

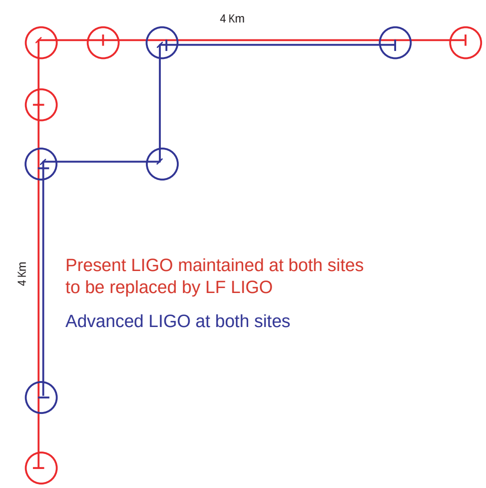
- Complete support to the cryogenic efforts of LCGT to make it the precursor of a family of cryogenic GWIs.

Who could build a LF GWI for LIGO?

- Initially a small seed staff
- Hope to attract external collaborators
- Will come after Virgo and take advantage of the TAMA and Virgo and LIGO I experiences
- Will get manpower support from external contributors, as well as construction TAMA and Virgo teams as they get freed up while the LIGO people are busy building LIGO II

A-LIGO and LIGO- LF GWI installation scheme





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A-LIGO and LIGO-LF GWI installation scheme

(Shoemaker's suggestion)

- Install 2 broad band advanced LIGOs in a folded configuration maintaining the 2 LIGO 4 Km operational.
  - This way LIGO, at that point debugged, will remain operational and continue taking data while advanced LIGO starts-up
- Close the gate valves and install Low Frequency LIGO in place of the old LIGO without even breaking the vacuum of Advanced LIGO
  - This way one can pre-assemble LF GWI for LIGO and install it in relatively few day shifts while taking high quality data in evening and nights with Advanced LIGO
- As LF GWI for LIGOs starts up, A-LIGO will progressively narrow band.

Master Plan

- Get an expression of interest here and now
- Organize a Low Frequency Interferometer working group meeting at LSC meetings and in between
- Verify within 12 months if the idea is sound, affective and feasible
- Solicit collaborators, funding and contributions for realization

  (should not weaken A-LIGO or other ongoing projects by competing for manpower/funding)
- In parallel continue on the cryogenic developments focussing on LCGT for a next generation of GW Interferometers to give a clear mission
- Interested persons to get in touch with me to start LF-WG