

Title: Present status (and near-term expectations) for gravitational-wave observations using ground-based laser interferometers

Date: Feb 15, 2011 03:00 PM

URL: <http://pirsa.org/11020144>

Abstract:



**Slides**

Slide 1  
The status of and expectations for gravitational-wave observation (using ground-based laser interferometers)

Slide 2  
Outline  
What this talk is about:  
- The industrial landscape for ground-based gravitational-wave observatories  
- Planned and under construction  
- There will be a strong emphasis on the observation of compact binary systems  
What this talk is not about (sorry):  
- Other gravitational-wave observatories either such as space  
- Early entry space-based detectors, proposed advanced detectors

Slide 3  
Outline  
I. Description of gravitational-wave observatories  
- Planning the design (mid-2000s/2007) to going online (2015/2020)  
II. Searches for compact binaries  
- Expected rates for compact binaries to search results  
III. Planned advanced detectors  
- Advanced LIGO/Virgo, LIGO, LIGO-Australia??  
IV. Searches for compact binaries  
- Expected rates  
V. The Dark Ages (from now to 2015/2020)

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# The status of and expectations for gravitational-wave observation (using ground-based laser interferometers)

Chad Hanna (Perimeter Institute)  
On behalf of the LIGO Scientific Collaboration and the Virgo Collaboration



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**Tasks**

- Master Pages
- Layouts
- Table Design
- Custom Animation
- Slide Transition





**Slides**

Slide 1  
The status of and expectations for gravitational-wave observation using ground-based laser interferometers

Slide 2  
Outline

Slide 3  
Outline

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# Outline

## What this talk is about:

- The status and prospects for ground-based gravitational wave astronomy.
- Planned advanced detectors.
- There will be a strong emphasis on the observation of compact binary systems.

## What this talk is not about (sorry):

- Other gravitational-wave experiment efforts such as, pulsar timing arrays, space based based detectors, theoretical advanced detectors.

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**Slides**

Slide 1: The status of and expectations for gravitational-wave observation using ground-based laser interferometers

Slide 2: Outline

Slide 3: Outline

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LIGO Scientific Collaboration



# Outline

- I. Description of past/present detectors
  - a) Reaching initial design sensitivity (2005-2007)
  - b) going beyond (2009-2010)
- II. Searches for compact binaries
  - a) Expected rates for current searches
  - b) Search results
- III. Planned advanced detectors
  - a) Advanced LIGO/Virgo, LCGT, LIGO Australia ??
- IV. Searches for compact binaries
  - a) Expected rates
- V. The Dark Age (from now until ALIGO)

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Slides

Slide 2

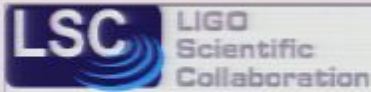
Slide 3

Slide 4

Slide 5

Part I. Past/present Detectors

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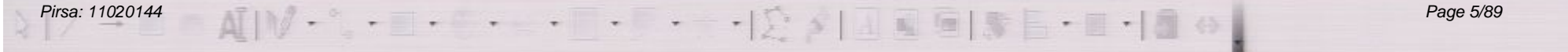
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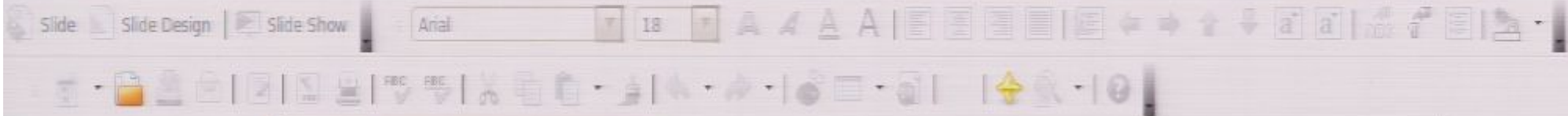
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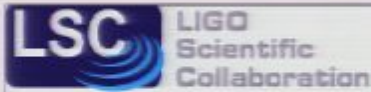
Slide 2

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Slide 4

Part I. Past/present Detectors

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# First some news...

## CITA and PI are the first Canadian institutions to join the LSC

Kipp Cannon and I petitioned (successfully) for a joint CITA/PI membership in September and are signing an MOU now.



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**Slides**

- 1. Overview of past/present detectors
  - in Planning the Design strategy (2008/09)
  - in going forward (2009/10)
- 2. Searches for improved detectors
  - in Experimental or next generation
  - in Search results
- 3. Planned advanced detectors
  - in Advanced LIGO/ Virgo LIGO Advanced 17
- 4. Searches for compact binaries
  - in Expected results
- 5. The Dark Ages from now and ALIGO

Slide 3

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**Slide 4**

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Slide 5

**Slide 5**

Part I. Past/present Detectors

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LIGO Scientific Collaboration



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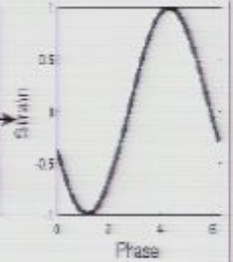




**Slides**

- Slide 3: A list of search results for 'Compact for use'.
- Slide 4: 'First some news...' with text about CITA and PI joining the LSC. Includes the PI logo.
- Slide 5: 'Part I. Past/present Detectors' with a small diagram of a detector arm.

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# Part I. Past/present Detectors

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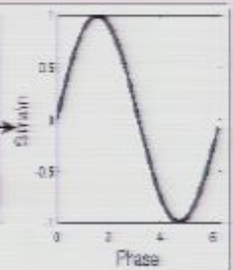
- Master Pages
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- Table Design
- Custom Animation
- Slide Transition



**Slides**

- Slide 3: A list of search results for 'past/present detectors'.
- Slide 4: 'First some news...' with text about CITA and PI joining the LSC and the PI logo.
- Slide 5: 'Part I. Past/present Detectors' with a small diagram of a detector arm.

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# Part I. Past/present Detectors

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- 1. Description of past/present detectors
- 2. Searching for compact binaries
- 3. Planned advanced detectors
- 4. Searching for compact binaries
- 5. The Dark Ages from now and LIGO

Slide 3

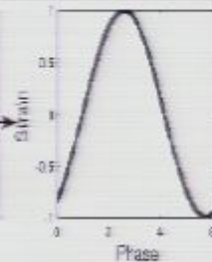
**LSC**  
**First some news...**  
 CITTA and PI are the first Canadian institutions to join the LSC  
 Hope Centre and I've learned successfully from a past CITAPI membership in September and are signing an MOU soon

Slide 4

**LSC**  
**Part I. Past/present Detectors**

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# Part I. Past/present Detectors

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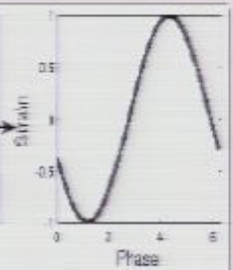
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# Part I. Past/present Detectors

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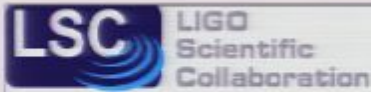
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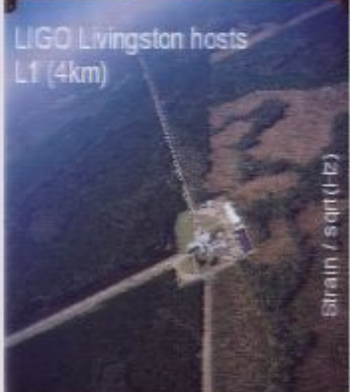




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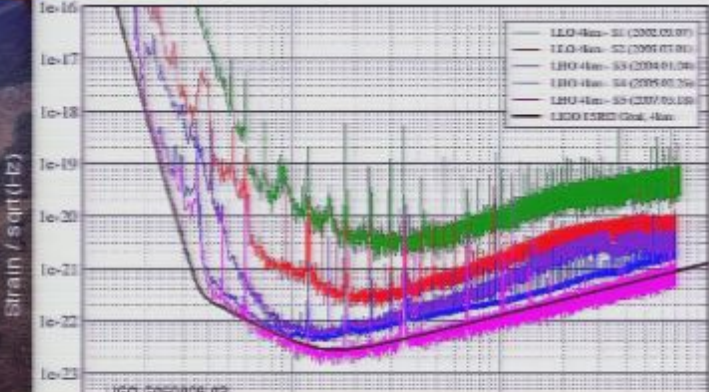


# Reaching design sensitivity LIGO's Fifth Science Run (S5) 2005 - 2007



LIGO's first science run (S1) took place in 2002. Following, there was a steady march towards design sensitivity that occurred during the fifth science run (S5). S5 lasted for 2 years and took ~1yr of triple coincident data with the three LIGO detectors H1, H2, L1.

Virgo joined in 2007, but unfortunately below their design sensitivity.





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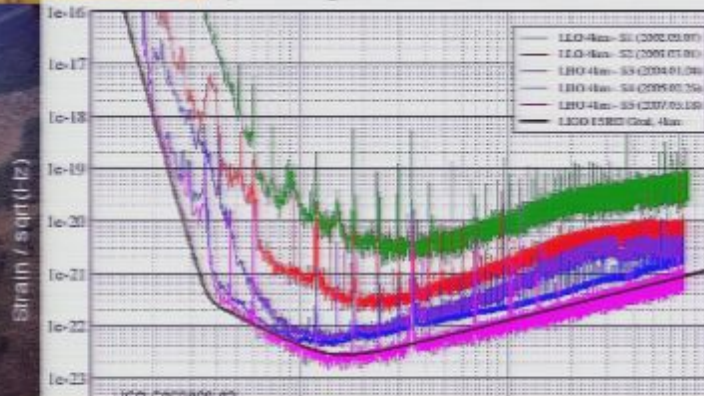
# Reaching design sensitivity LIGO's Fifth Science Run (S5) 2005 - 2007

LIGO Hanford hosts H1 (4km) and H2 (2km)



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# Reaching design sensitivity LIGO's Fifth Science Run (S5) 2005 - 2007

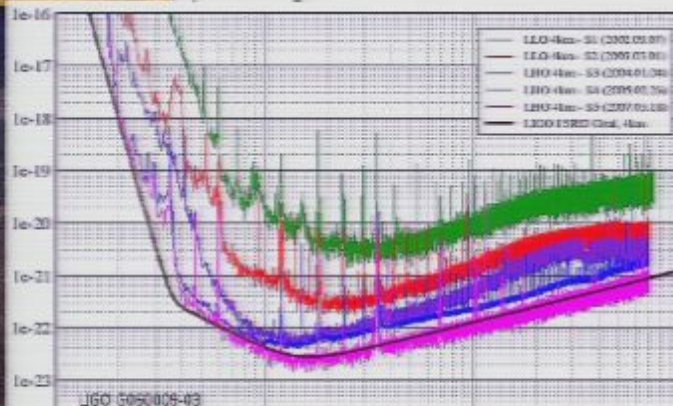


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# VIRGO

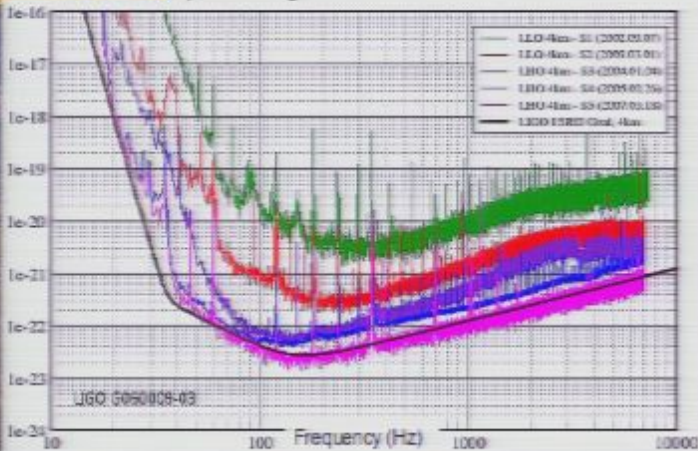
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# VIRGO

## LIGO's Fifth Science Run (S5) 2005 - 2007

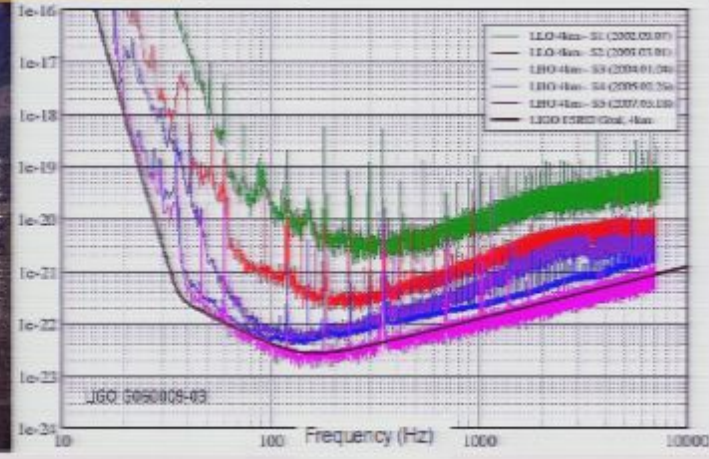
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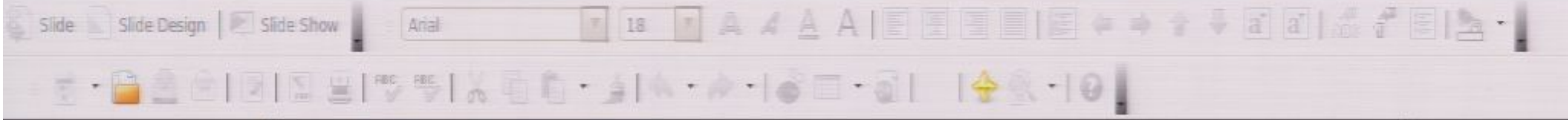
LIGO Livingston hosts L1 (4km)

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## LIGO's 6th Science Run (S6) 2009 - 2010

LIGO's S6 run aimed to improve the sensitivity by ~2 over S5. This goal was not realized until the end of the run and mostly at high frequencies (meaning not quite a full factor of 2 improvement in range)

LIGO's H2 detector was **not** operated. Instead Virgo participated for most of the run providing a three site coincidence network capable of sky localization.

The run ended after only ~1 year so as to **not** push back the Advanced detector installations.

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- Master Pages
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Part II. Searches for

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LIGO's H2 detector was **not** operated. Instead Virgo participated for most of the run providing a three site coincidence network capable of sky localization.

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Tasks

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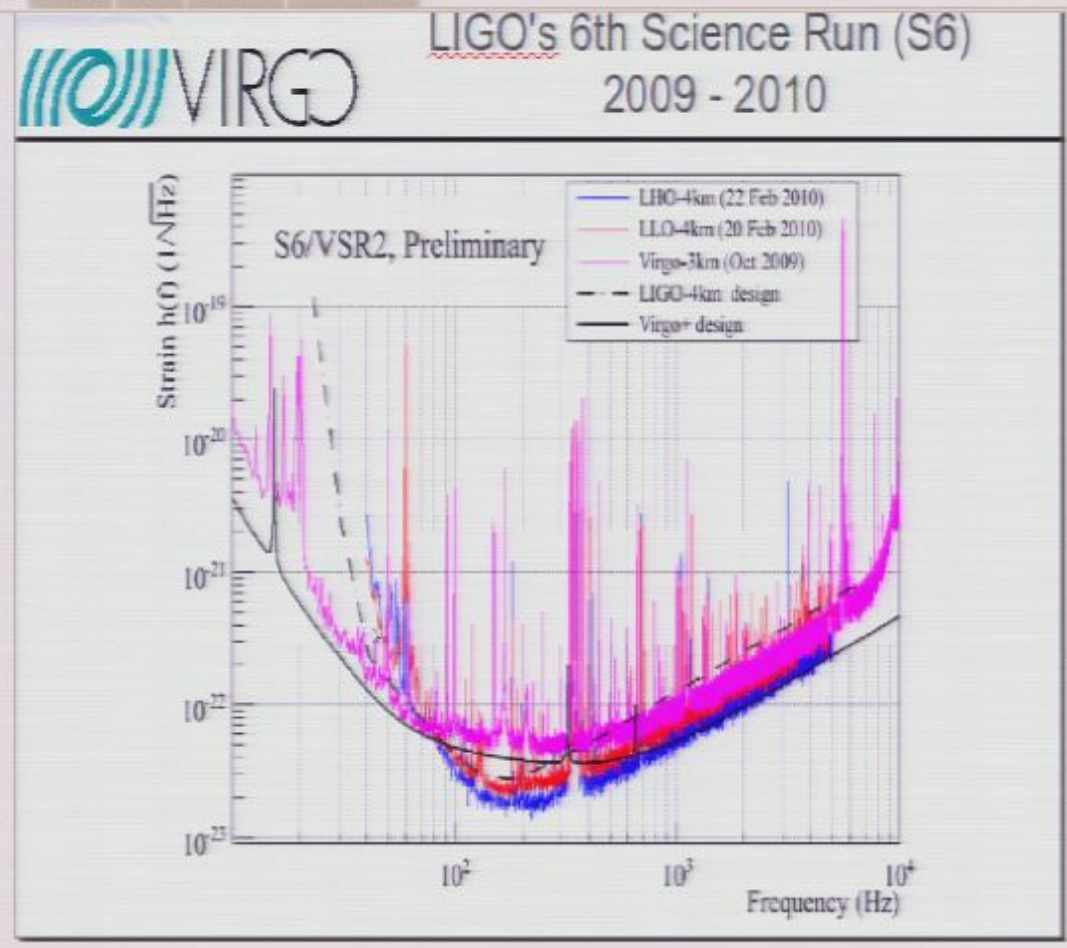
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Part II. Searches for

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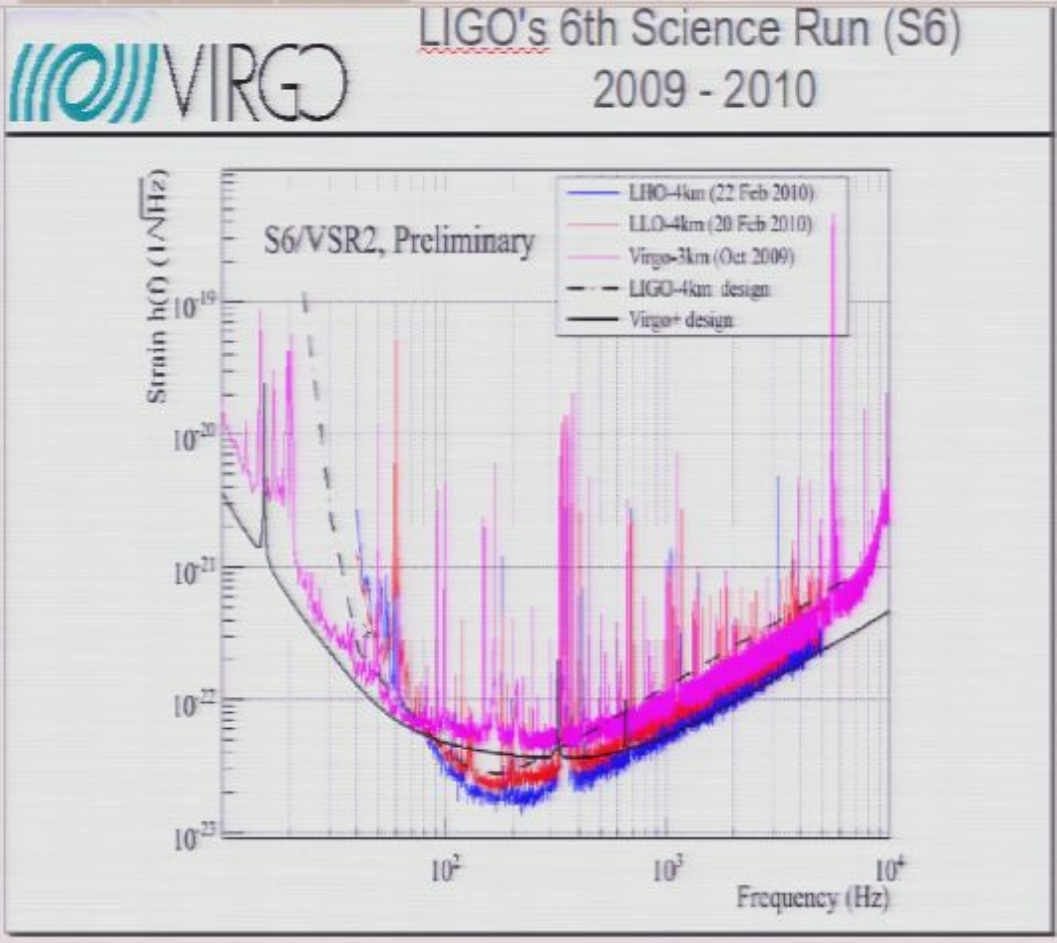
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Part II. Searches for compact binary Coalescence

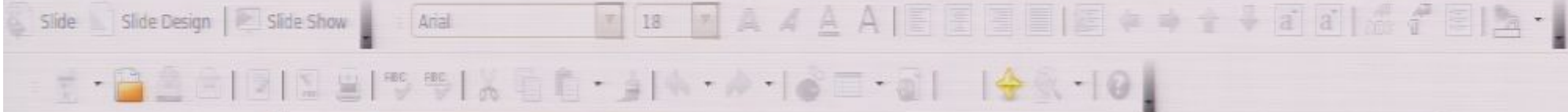
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- Master Pages
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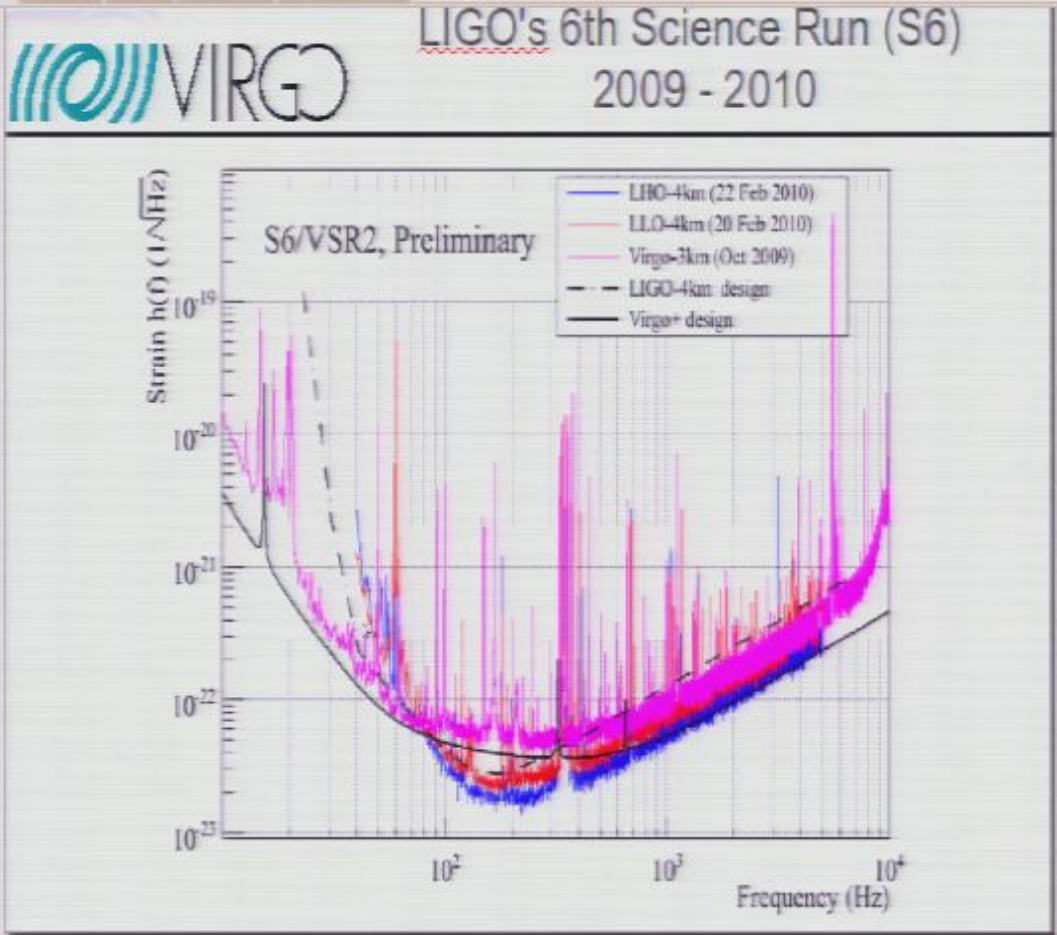
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Part II. Searches for compact binary Coalescence

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- Master Pages
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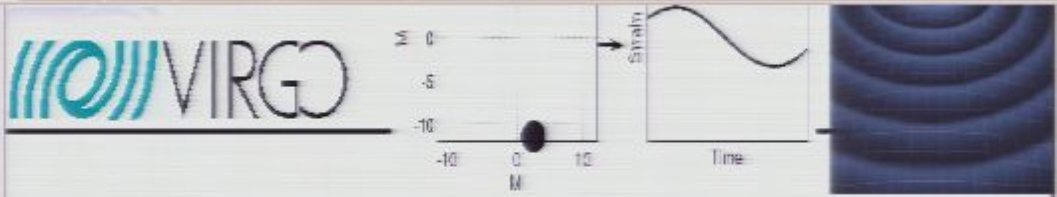
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# Part II. Searches for compact binary Coalescence

(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)

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- Master Pages
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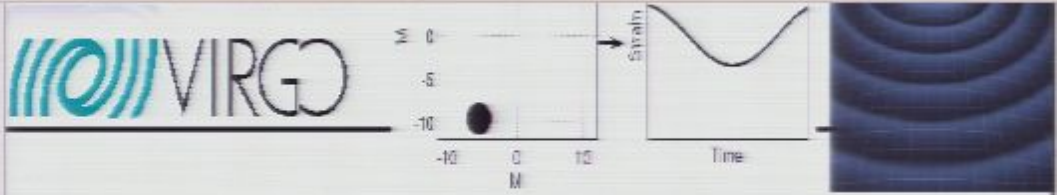
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Tasks

- Master Pages
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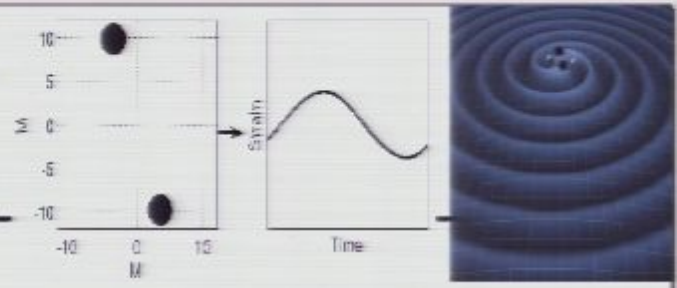
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# Part II. Searches for compact binary Coalescence

(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)

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Tasks

- Master Pages
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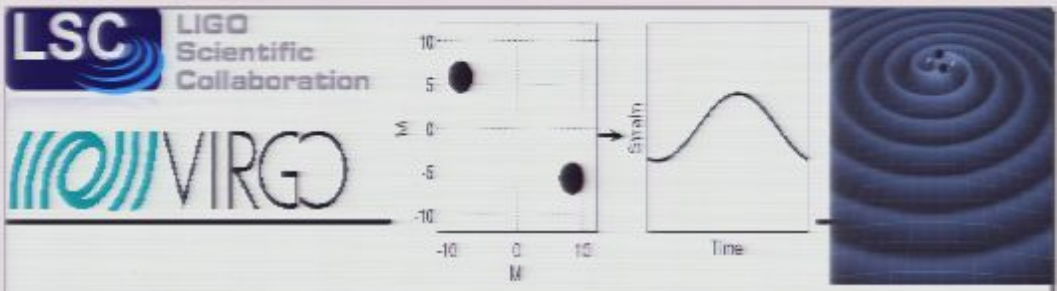
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Tasks

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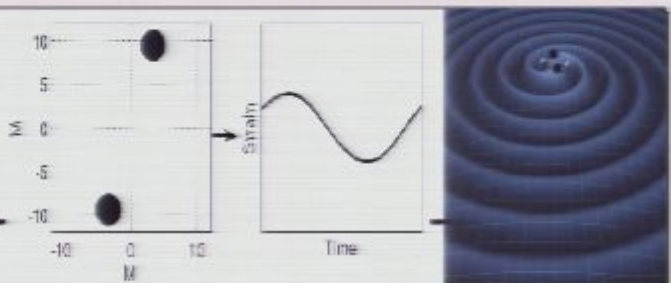
**Slides**

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# Part II. Searches for compact binary Coalescence

(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)

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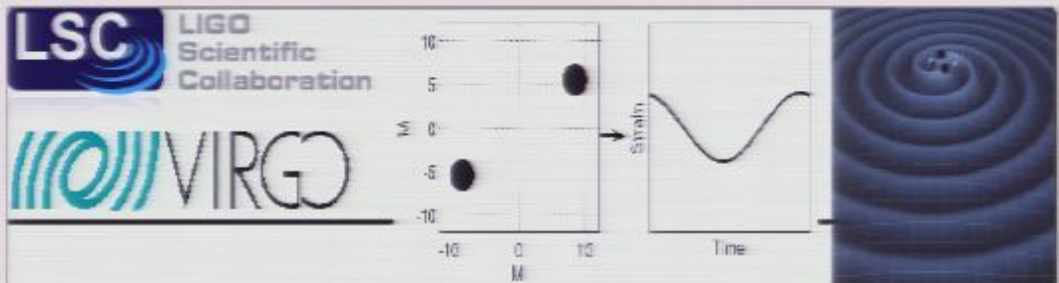
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(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)

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LIGO 9th Science Run (S5) 2009-2010

LIGO S5 ran aimed to improve the sensitivity by ~2 over S4. The goal was not reached until the end of the run and mostly at high frequencies (missing out on a full factor of 2 improvement in range).

LIGO S5 detector was networked. Instead of single antennas the result of the run consisted of three data streams network capable of day operations.

The networked effort only ~1 year as we reached peak with the advanced detector in operation.

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Beyond design sensitivity

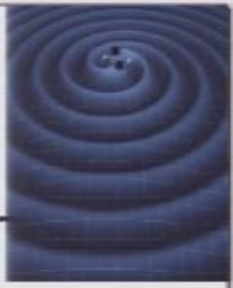
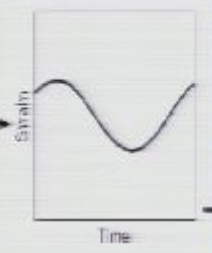
LIGO 9th Science Run (S5) 2009-2010

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Part II. Searches for compact binary Coalescence

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# Part II. Searches for compact binary Coalescence

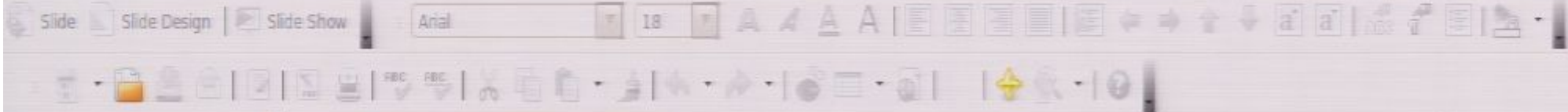
(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)

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Slides

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LSC VIRGO Science Run (SR) 2009-2010

LIGO SR is aimed to improve the sensitivity by ~2 over O3. The goal was to reduce the noise at the noise and mostly at high frequencies (reaching noise level a full factor of 2 improvement in range).

LIGO SR detector was networked. Improved Virgo contributed the most to the noise reduction in three sites. Some data is networked capable of sky localization.

The run lasted for only ~1 year as a network with the Advanced detector installations.

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Beyond design sensitivity

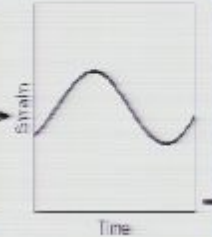
LSC VIRGO Science Run (SR) 2009-2010

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Part II. Searches for compact binary Coalescence

(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)

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# Part II. Searches for compact binary Coalescence

(Black hole and Neutron star binaries inspiraling and eventually merging due to the emission of gravitational radiation)

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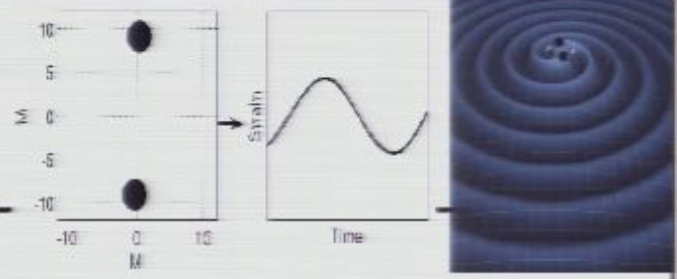
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# Part II. Searches for compact binary Coalescence

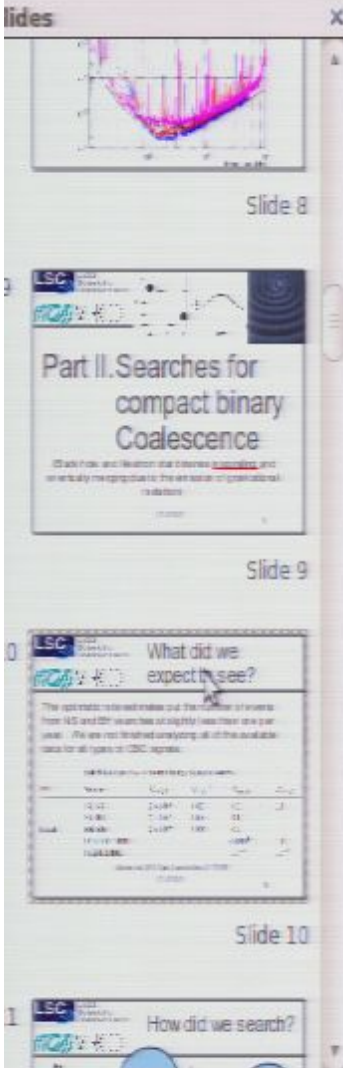
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# What did we expect to see?

The optimistic rate estimates put the number of events from NS and BH searches at slightly less than one per year. We are not finished analyzing all of the available data for all types of CBC signals.

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source <sup>a</sup>	$\dot{N}_{low} \text{ yr}^{-1}$	$\dot{N}_{re} \text{ yr}^{-1}$	$\dot{N}_{high} \text{ yr}^{-1}$	$\dot{N}_{max} \text{ yr}^{-1}$
Initial	NS-NS	$2 \times 10^{-4}$	0.02	0.2	0.6
	NS-BH	$7 \times 10^{-5}$	0.004	0.1	
Initial	BH-BH	$2 \times 10^{-4}$	0.007	0.5	
	IMRI into IMBH			$<0.001^b$	$0.01^c$
	IMBH-IMBH			$10^{-4d}$	$10^{-7e}$

J Abadie et al 2010 Class. Quantum Grav. 27 173001

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Initial	NS-NS	$2 \times 10^{-4}$	0.02	0.2	0.6
	NS-BH	$7 \times 10^{-5}$	0.004	0.1	
Initial	BH-BH	$2 \times 10^{-4}$	0.007	0.5	
	IMRI into IMBH			$<0.001^b$	$0.01^c$
	IMBH-IMBH			$10^{-4d}$	$10^{-7e}$

J Abadie et al 2010 Class. Quantum Grav. 27 173001

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Slides

Part II. Searches for compact binary Coalescence  
Slide 9

What did we expect to see?  
Slide 10

How did we search?  
Slide 11

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# What did we expect to see?

The optimistic rate estimates put the number of events from NS and BH searches at slightly less than one per year. We are not finished analyzing all of the available data for all types of CBC signals.

Table 5. Detection rates for compact binary coalescence sources.

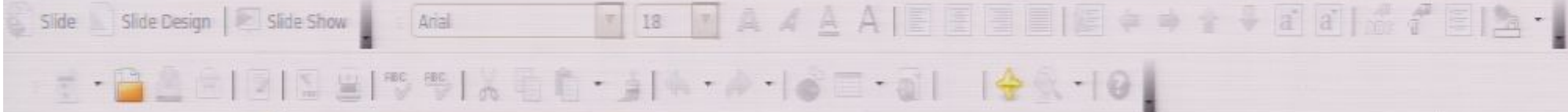
IFO	Source <sup>a</sup>	$\dot{N}_{low} \text{ yr}^{-1}$	$\dot{N}_{re} \text{ yr}^{-1}$	$\dot{N}_{high} \text{ yr}^{-1}$	$\dot{N}_{max} \text{ yr}^{-1}$
Initial	NS-NS	$2 \times 10^{-4}$	0.02	0.2	0.6
	NS-BH	$7 \times 10^{-5}$	0.004	0.1	
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J Abadie et al 2010 Class. Quantum Grav. 27 173001

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- Slide Transition



**Slides**

Part II. Searches for compact binary Coalescence

Slide 9

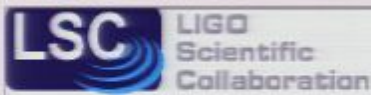
What did we expect to see?

Slide 10

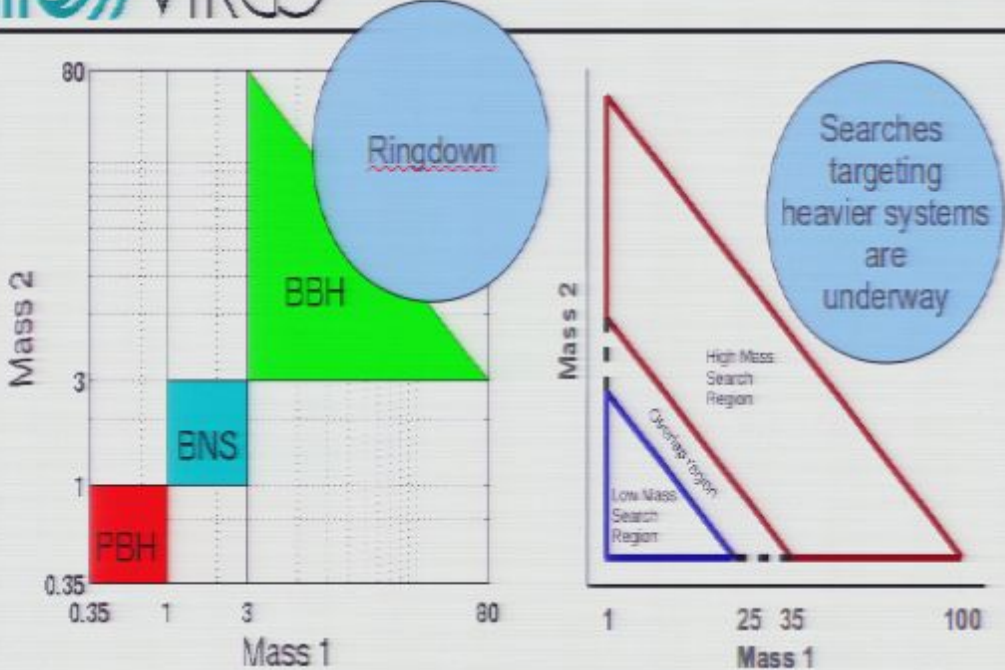
How did we search?

Slide 11

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# How did we search?



S4 Feb.-Mar. 2005

S5, Nov 2005 – Sep 2007

Similar for S6 (July 2009 – Oct 2010)

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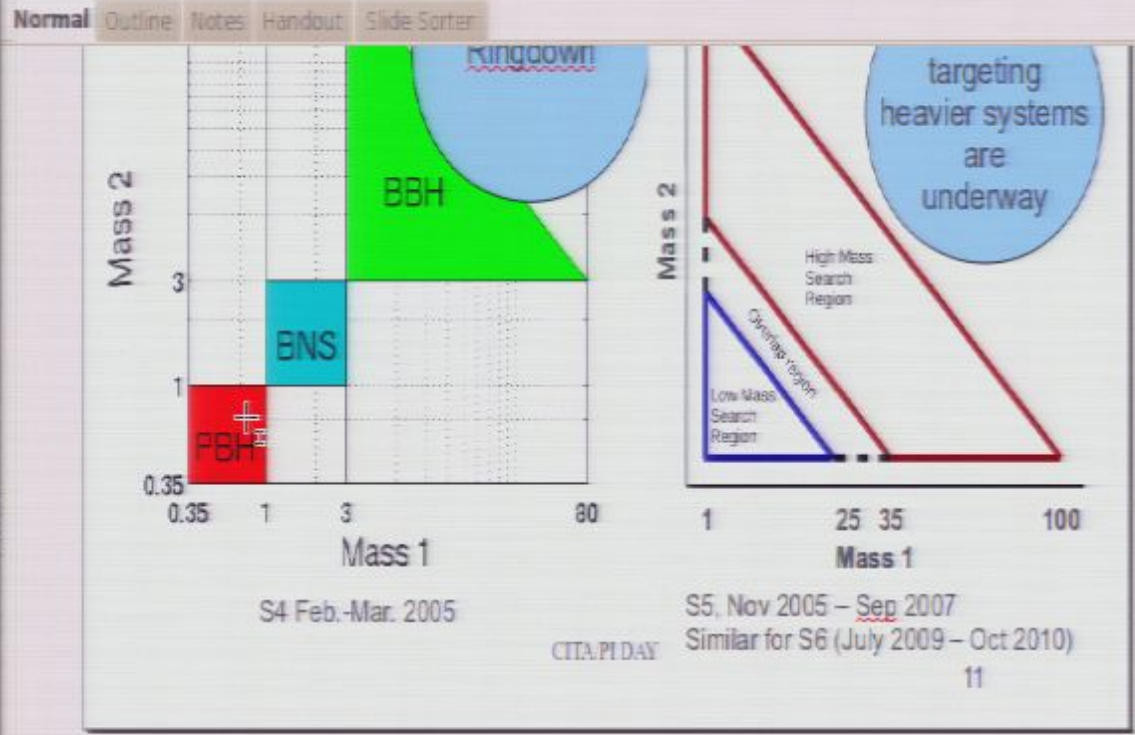


**Slides**

Part II. Searches for compact binary Coalescence  
Slide 9

What did we expect to see?  
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How did we search?  
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**Tasks**

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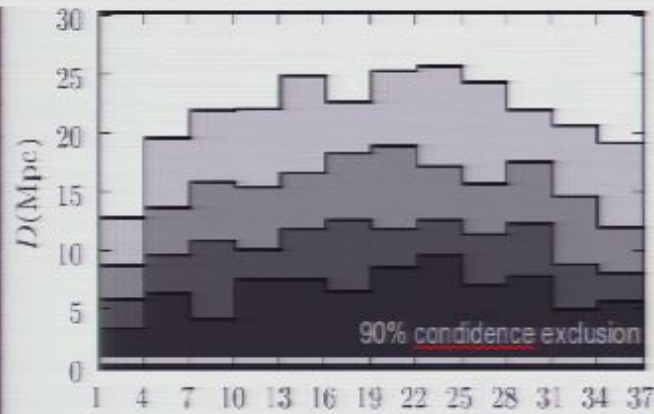
Slide 12

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But, we constrained the rates (weakly, more on that later) and ruled out a compact binary merger as causing a GRB in Andromeda.



Astrophys J 681:1419-1426, 2008

$m_2(M_{\odot})$

We did not rule out any plausible soft gamma repeater models.

Tasks

- Master Pages
- Layouts
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Slides

Slide 11

2 LSC What did we actually see?  
The short answer: Not much  
But, we constrained the rates (weakly, more on that later) and ruled out a compact binary merger as causing a GRB in Andromeda.

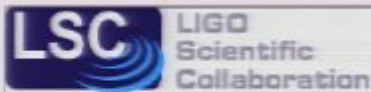
Slide 12

3 LSC What happened along the way?  
In no particular order:  
1. The LIGO-VIRGO collaboration with other gravitational wave observatories and pulsar timing arrays (PTAs) are currently conducting searches for compact binaries in the millihertz band.  
2. We significantly improve our knowledge of compact binary coalescence through numerical relativity simulations. This applies to inspirals and mergers of binary black holes and neutron stars. We have also improved our understanding of the final stages of compact binary coalescence in some models.  
3. We have also improved our understanding of the final stages of compact binary coalescence in some models.

Slide 13

4 LSC Searching for binary black holes  
Only a small fraction of binary star systems are expected to form black holes. Only a small fraction of those are expected to form binary black holes, which are thought to be the most common source of gravitational waves.  
Recently, however, there have been observations of binary black holes with large black holes.

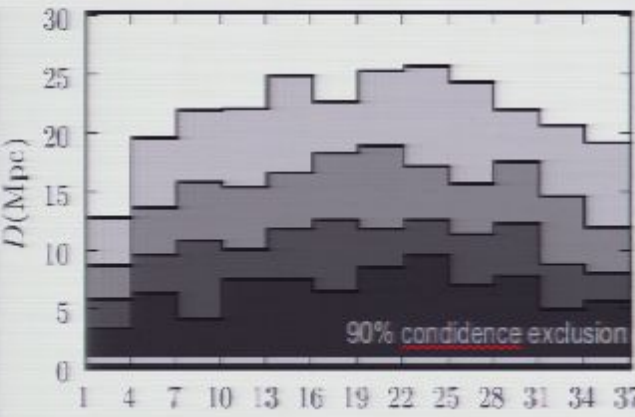
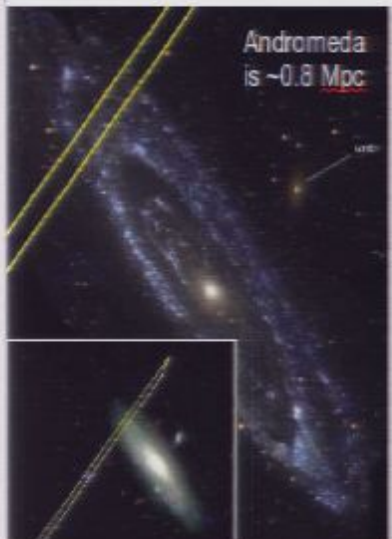
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But, we constrained the rates (weakly, more on that later) and ruled out a compact binary merger as causing a GRB in Andromeda.



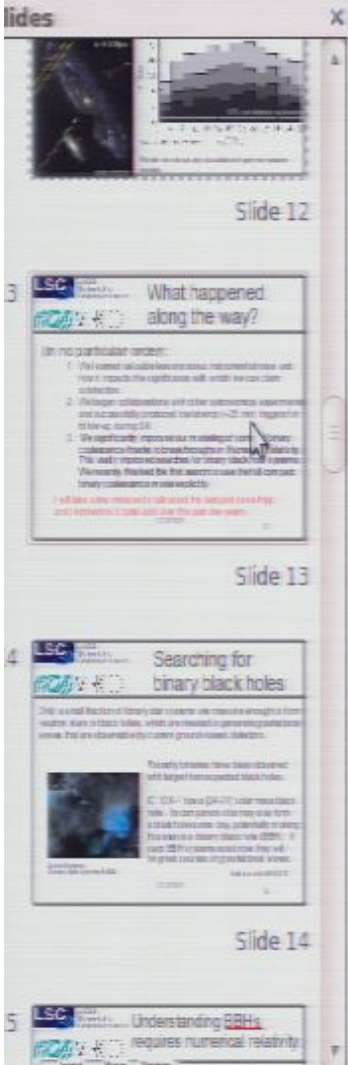
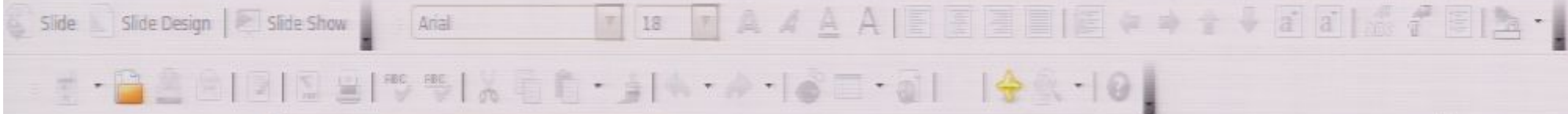
Astrophys J 681:1419-1428, 2008

$m_2 (M_\odot)$

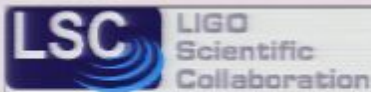
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Tasks

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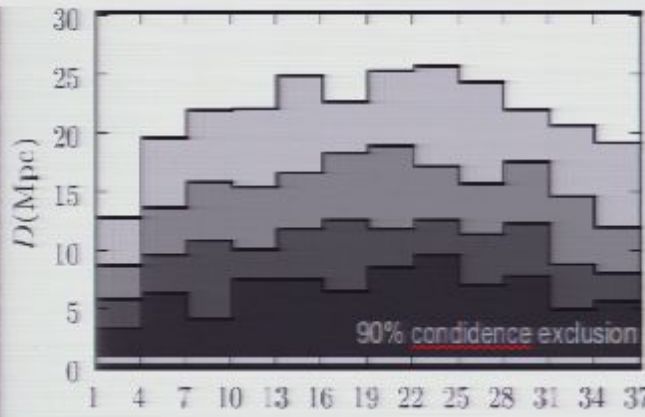
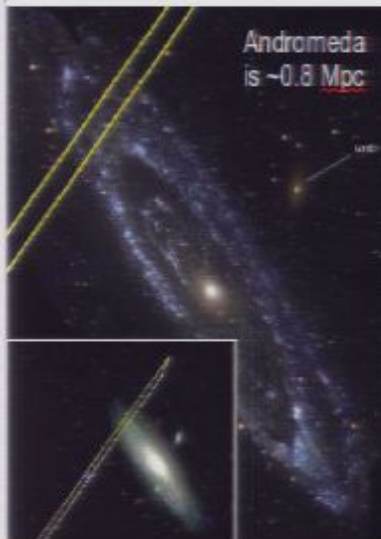
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# What did we actually see?

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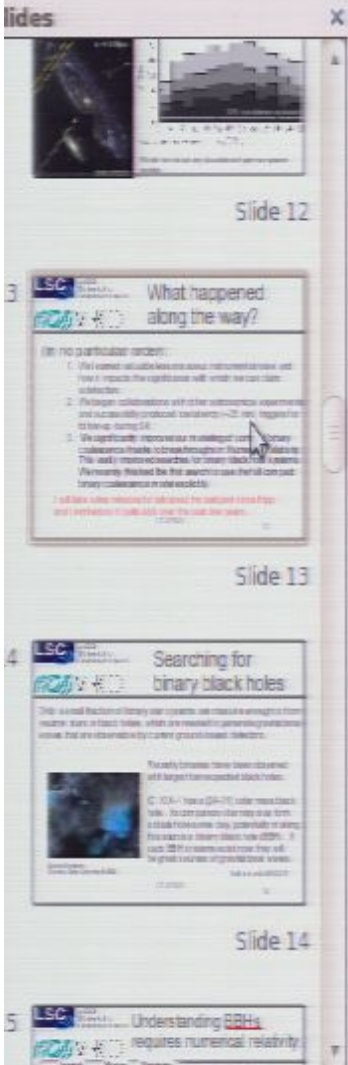
Astrophys J 681:1419-1428, 2008

$m_2 (M_{\odot})$

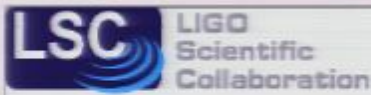
We did not rule out any plausible soft gamma repeater







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# What happened along the way?

(in no particular order):

1. We learned valuable lessons about instrumental noise and how it impacts the significance with which we can claim a detection.
2. We began collaborations with other astronomical experiments and successfully produced low latency (~25 min) triggers for follow-up during S6
3. We significantly improved our modeling of compact binary coalescence thanks to breakthroughs in Numerical Relativity. This vastly improved searches for binary black hole systems. We recently finished the first search to use the full compact binary coalescence model explicitly.

I will take a few minutes to talk about the last part since Kipp and I worked on it quite a bit over the past few years.

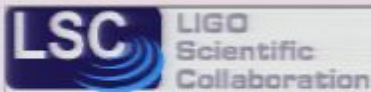




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- 3 Slide 13
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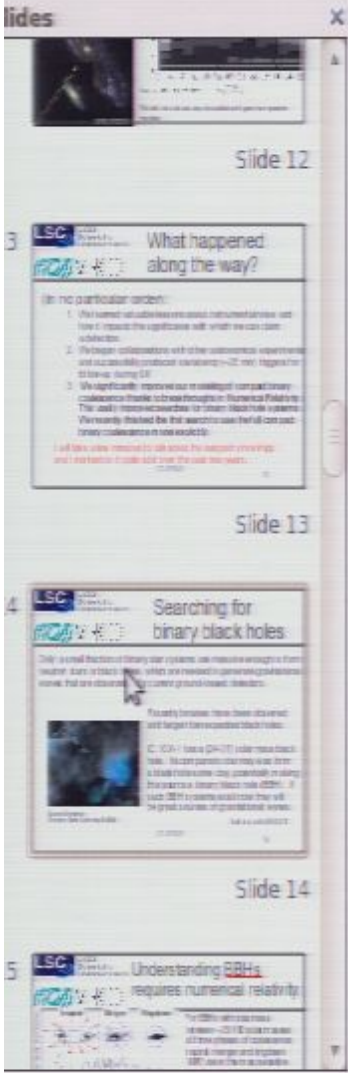
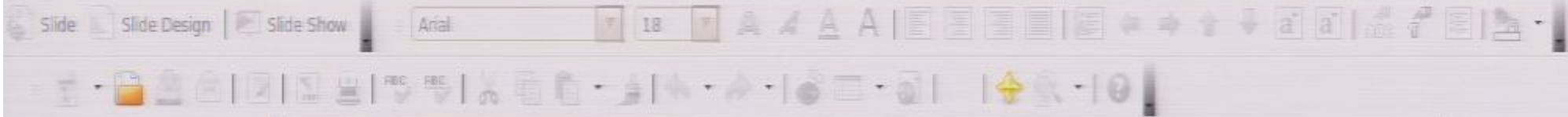
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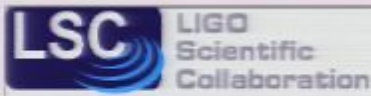
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# Searching for binary black holes

Only a small fraction of binary star systems are massive enough to form neutron stars or black holes, which are needed to generate gravitational waves that are observable by current ground-based detectors.



Recently binaries have been observed with larger than expected black holes.

IC 10 X-1 has a [24-31] solar mass black hole. Its companion star may also form a black hole some day, potentially making this source a binary black hole (BBH). If such BBH systems exist now they will be great sources of gravitational waves.

Aurore Simonnet  
Sonoma State University/NASA

Bulik et al. arXiv:0803.3516



Slide Slide Design Slide Show Arial 18

**Slides**

Slide 13: What happened along the way?

Slide 14: Searching for binary black holes

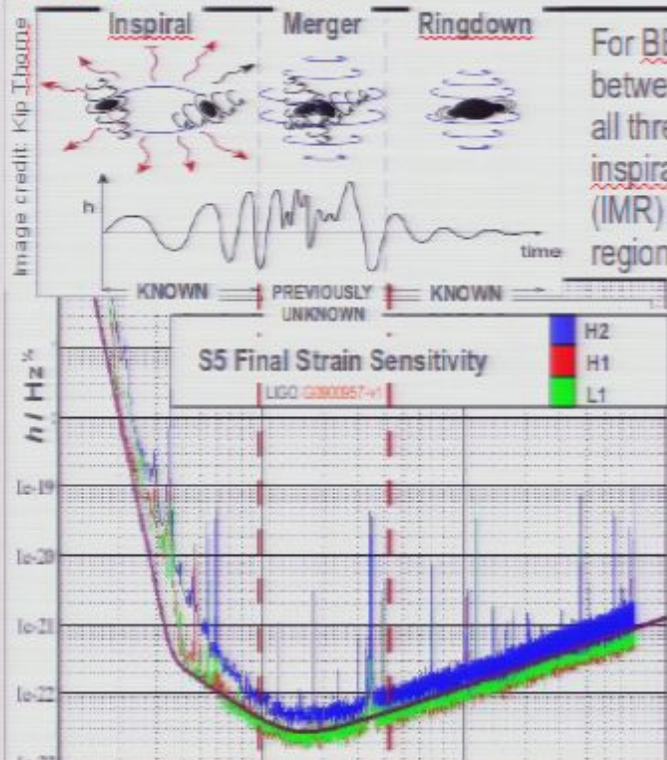
Slide 15: Understanding BBHs requires numerical relativity

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**LSC** LIGO Scientific Collaboration

# Understanding BBHs requires numerical relativity.

**VIRGO**



For BBHs with total mass between ~25-100 solar masses all three phases of coalescence, inspiral, merger and ringdown (IMR) are in the most sensitive region of the LIGO detectors.

Post Newtonian theory describes the inspiral...

BH perturbation theory describes the ringdown...

Recently numerical relativity described the merger and evolved BBHs through all 3 phases

**Tasks**

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Slides

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Slide 16

Previous results

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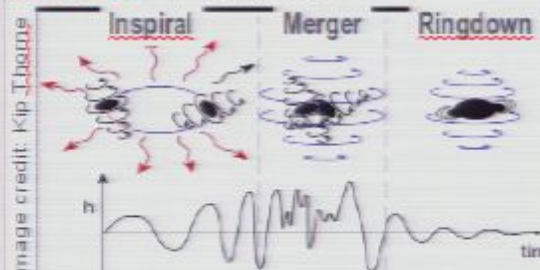


LIGO Scientific Collaboration

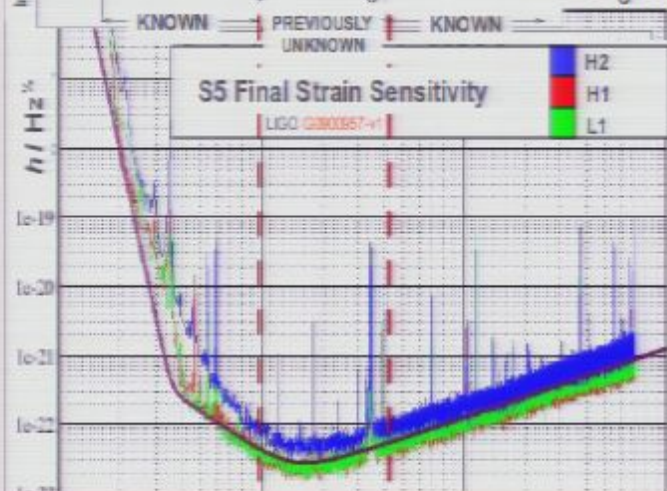
# Understanding BBHs



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Tasks

- Master Pages
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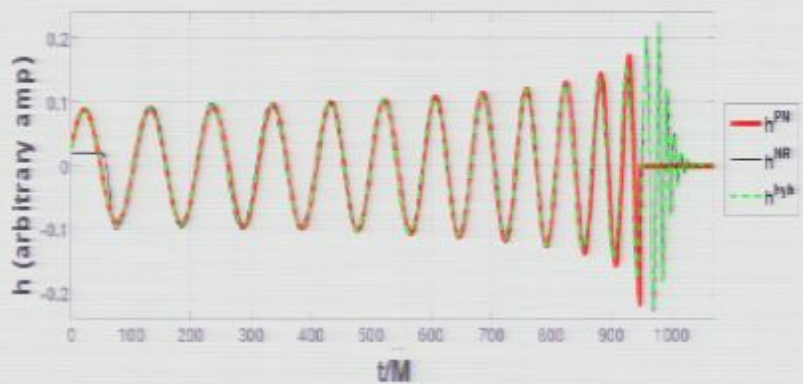
Previous results

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**LSC** LIGO Scientific Collaboration

# Inspiral-Merger-Ringdown

**VIRGO** waveform modeling



Since the numerical relativity community began simulating BBH mergers various analytic and phenomenological waveform models have been developed. We can make direct use of them in this search rather than searching for the three phases of coalescence separately.

Bucannano et al. Phys. Rev. D 76, 104049 (2007). Alith et al. Class. Quant. Grav. 24, S689-S700 (2007) and subsequent references

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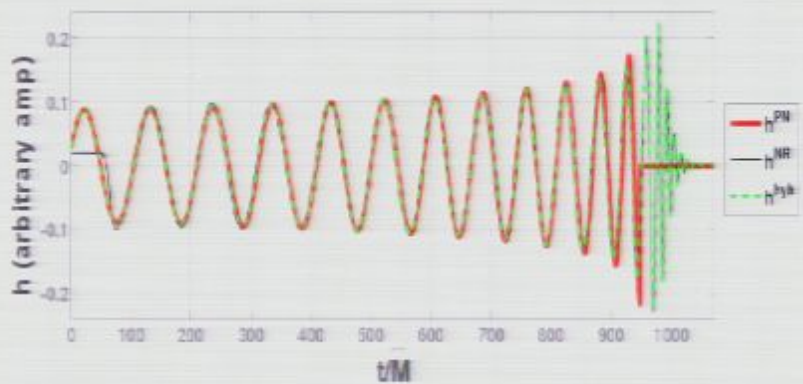
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**LSC** LIGO Scientific Collaboration

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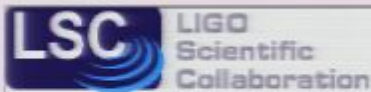
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# Previous results

No gravitational waves from compact binary coalescence have been directly detected. However rate limits have been constrained.

$$R_{90\%} \propto (VT)^{-1}$$

Where V is the volume of space that the search was sensitive to (Mpc<sup>3</sup>) and T is the observation time (note that previous rates were also computed using blue light of the galaxies surveyed in units of 10<sup>10</sup> blue solar luminosity.)

S4 BBH (inspiral only ~40 solar masses)  $R_{90\%} = 6000 \text{ Mpc}^3 \text{ Myr}^{-1}$   
Phys. Rev. D 77 062002 (2008)

S4 Ringdown (85 – 390 solar masses)  $R_{90\%} = 32 \text{ Mpc}^3 \text{ Myr}^{-1}$   
Phys. Rev. D 80 062001 (2009)

S5 BBH (inspiral only ~30 solar masses)  $R_{90\%} = 6 \text{ Mpc}^3 \text{ Myr}^{-1}$   
Phys. Rev. D 82 102001 (2010)

Compared to the optimistic rate prediction for

A 10,10 solar mass binary  $R_{90\%} = 0.3 \text{ Mpc}^3 \text{ Myr}^{-1}$   
Class. Quant. Grav. 27 173001 (2010)

Tasks

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Slide 10

7 LSC Previous results

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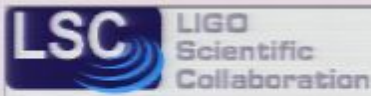
8 LSC S5 results

Slide 18

9 LSC

Part III. Planned advanced detectors

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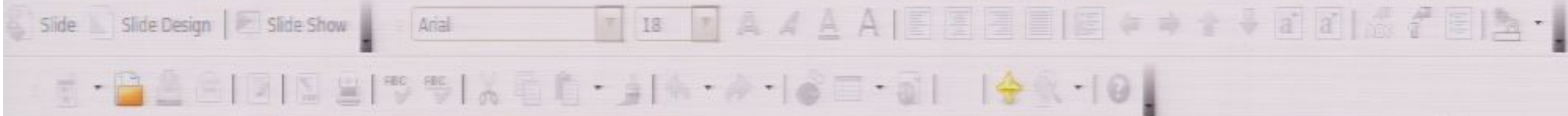
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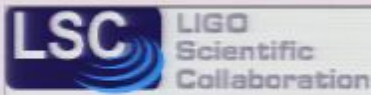
- Master Pages
- Layouts
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- Slide Transition



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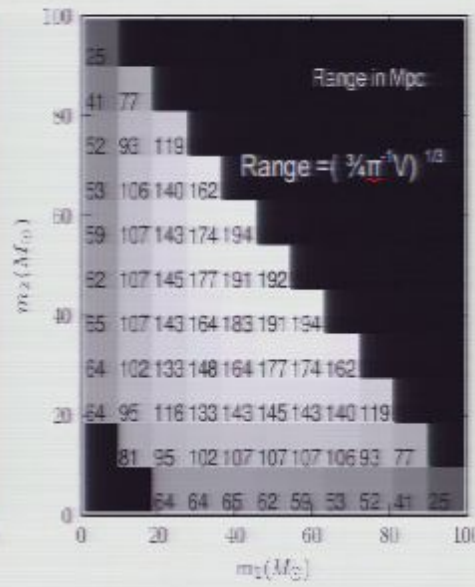
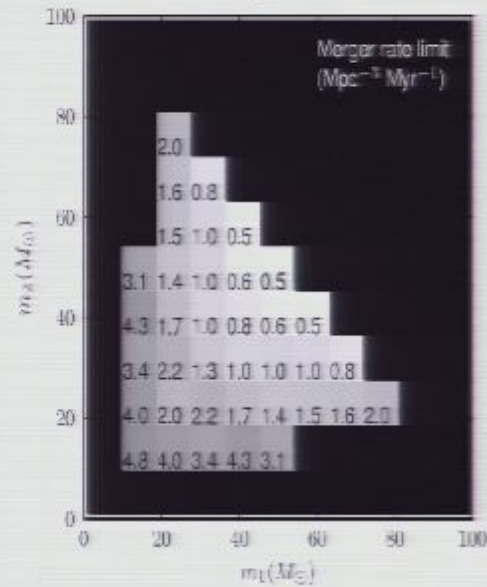
- Slide 10
- Slide 17
- Slide 18
- Part III. Planned advanced detectors

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# S5 results

No gravitational waves from compact binary coalescence have been directly detected. However rate limits have been constrained.



Paper will appear on arxiv in few days

Tasks

- Master Pages
- Layouts
- Table Design
- Custom Animation
- Slide Transition



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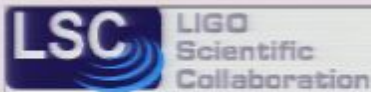
Slides

7 Previous results

8 S5 results

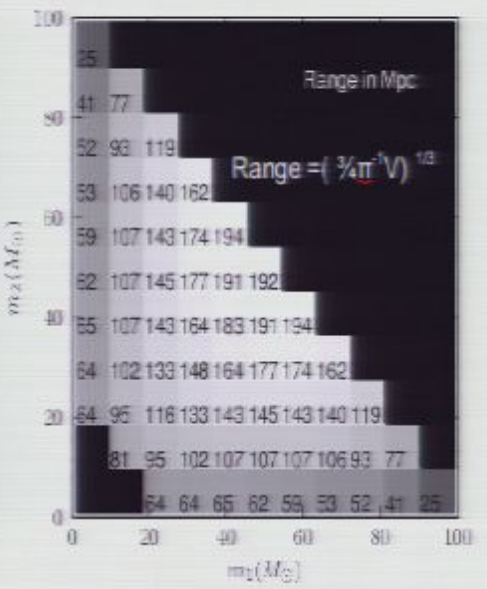
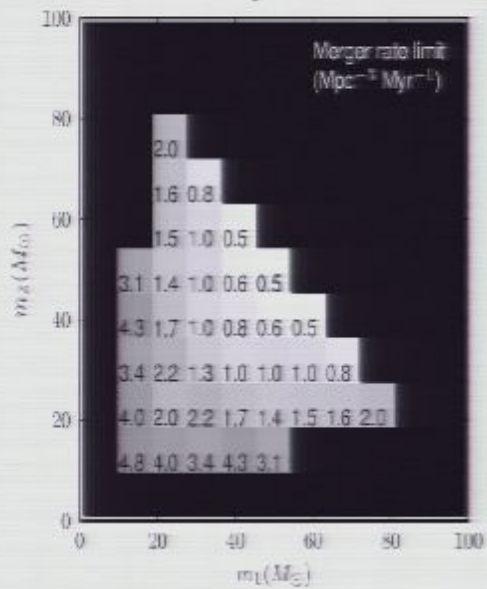
9 Part III. Planned advanced detectors

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# S5 results

No gravitational waves from compact binary coalescence have been directly detected. However rate limits have been constrained.



Paper will appear on [arxiv](#) in few days

Tasks

- Master Pages
- Layouts
- Table Design
- Custom Animation
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**Slides**

- 7 Previous results  
Slide 17
- 8 S5 results  
Slide 18
- 9 Part III. Planned advanced detectors  
Slide 19

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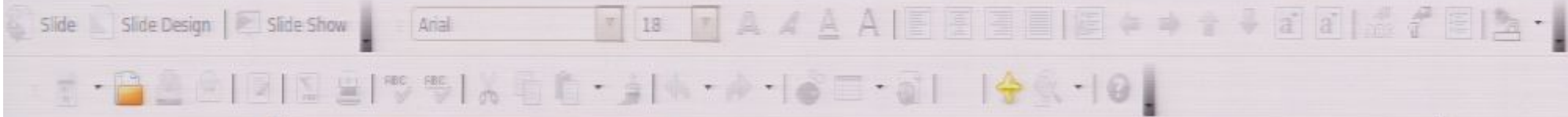


# Part III. Planned advanced detectors

**Tasks**

- Master Pages
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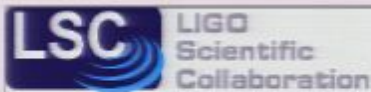
**Slides**

9 LSC  
Part III. Planned advanced detectors  
Slide 19

10 LSC  
Global network  
Slide 20

11 LSC  
Global network  
What does the advanced network look like?  
When do we get it?

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# Global network



**LCGT IS FUNDED!**

**Future LIGO Australia??**

Stan Whitcomb  
NSF Annual Review  
6 November 2007  
Caltech

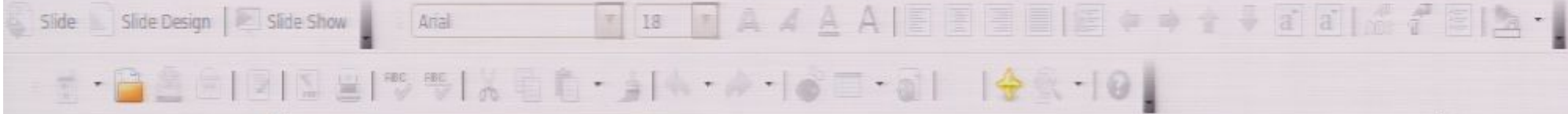
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- Master Pages
- Layouts
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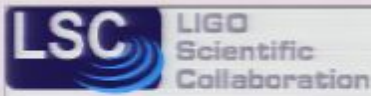
Slides

9 LSC  
Part III. Planned advanced detectors  
Slide 19

10 LSC  
Global network  
Slide 20

11 LSC  
Global network  
What does the advanced network look like?  
- For more sensitivity: +10 to range, -100 to sensitivity  
- For better coverage: More observatories in more places to increase signal-to-noise ratio  
- Larger baseline: This improves resolution capability  
When do we get it?  
- Advanced LIGO (LSC) ready by 2015, complete by 2018  
- Advanced Virgo (with other observatories)  
- LIGO Australia (NSF) to be built (deadline Oct 2011)  
- LCGT (Laser Cores) to be funded, construction start 2012

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# Global network



**LCGT IS FUNDED!**

**Future LIGO Australia??**

Stan Whitcomb  
NSF Annual Review  
6 November 2007  
Caltech

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- Master Pages
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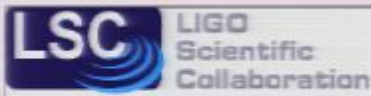
**Slides**

0 Global network  
Slide 20

1 Global network  
Slide 21

2 Advanced LIGO  
Slide 22

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# Global network

## What does the advanced network look like?

- Far more sensitive. ~10 in range, ~1000 in event rate.
- Far better coverage. More detectors = more likely to observe a signal at multiple sites.
- Longer baseline. This improves localization ability.

## When do we get it?

- Advanced LIGO (US, data by 2013, complete by 2015)
- Advanced Virgo (sometime soon after?)
- LIGO Australia (ASAP if funded, deadline Oct 2011)
- LCGT (Later this decade? Funded, but working out Details.)

**Tasks**

- Master Pages
- Layouts
- Table Design
- Custom Animation
- Slide Transition



**Slides**

1 Global network  
What does the advanced network look like?  
- Fewer sensors, -10 m range, -1000 m/s travel  
- Fewer sensors, -10 m range, -1000 m/s travel  
- Larger baseline - This improves resolution  
When do we get it?  
- Advanced LIGO (US, Italy) 2015, completion 2019  
- Advanced Virgo (France, Spain) 2017  
- LIGO Australia (ADAP) 2018, completion Oct 2019  
- LIGO (Europe) 2018, completion Oct 2019

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2 Advanced LIGO  
Timeline diagram showing milestones from 2010 to 2013.

Slide 22

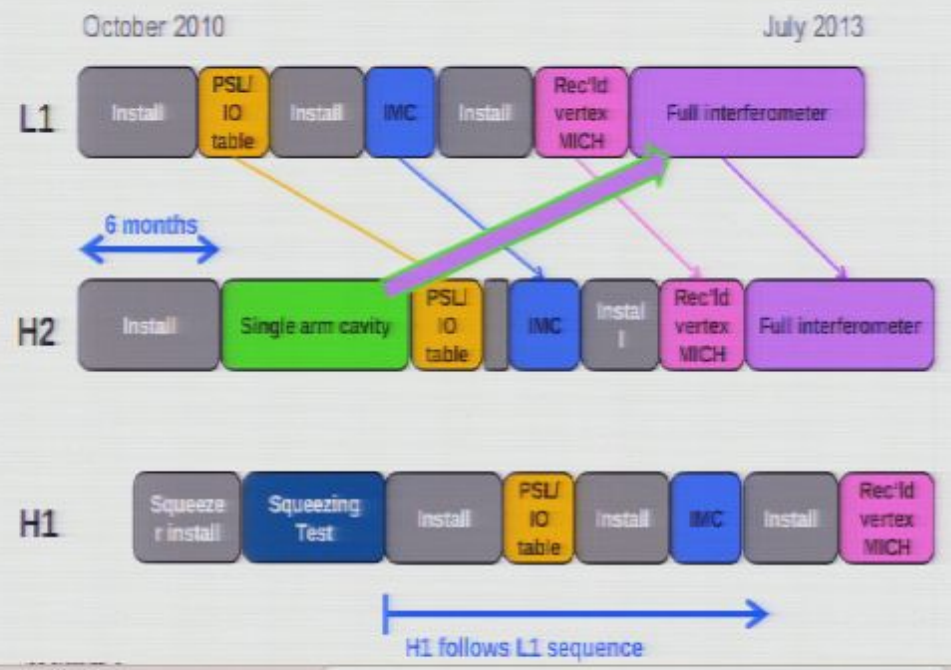
3 Advanced LIGO  
Graph showing various parameters over time.

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# Advanced LIGO

Advanced LIGO (US sites) will likely be first. Data may only be a few years away.



**Tasks**

- Master Pages
- Layouts
- Table Design
- Custom Animation
- Slide Transition






Slides

Part IV. Future searches for compact binaries.

Slide 24

5 LSC Number of sources increased by ~1000



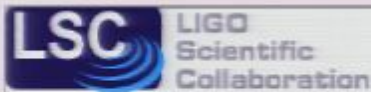
Slide 25

6 LSC What do we expect to see? (ideally)

Year	PSL/IO table	IMC	Rec'd vertex MICH	Full interferometer
10-11	2.4M	14	1	0
11-12	7.3M	18	1	0
12-13	24.6M	18	1	0
13-14	41.1M	18	1	0
14-15	41.1M	18	1	0
15-16	41.1M	18	1	0
16-17	41.1M	18	1	0
17-18	41.1M	18	1	0
18-19	41.1M	18	1	0
19-20	41.1M	18	1	0
20-21	41.1M	18	1	0
21-22	41.1M	18	1	0
22-23	41.1M	18	1	0
23-24	41.1M	18	1	0
24-25	41.1M	18	1	0
25-26	41.1M	18	1	0
26-27	41.1M	18	1	0
27-28	41.1M	18	1	0
28-29	41.1M	18	1	0
29-30	41.1M	18	1	0
30-31	41.1M	18	1	0
31-32	41.1M	18	1	0
32-33	41.1M	18	1	0
33-34	41.1M	18	1	0
34-35	41.1M	18	1	0
35-36	41.1M	18	1	0
36-37	41.1M	18	1	0
37-38	41.1M	18	1	0
38-39	41.1M	18	1	0
39-40	41.1M	18	1	0
40-41	41.1M	18	1	0
41-42	41.1M	18	1	0
42-43	41.1M	18	1	0
43-44	41.1M	18	1	0
44-45	41.1M	18	1	0
45-46	41.1M	18	1	0
46-47	41.1M	18	1	0
47-48	41.1M	18	1	0
48-49	41.1M	18	1	0
49-50	41.1M	18	1	0
50-51	41.1M	18	1	0
51-52	41.1M	18	1	0
52-53	41.1M	18	1	0
53-54	41.1M	18	1	0
54-55	41.1M	18	1	0
55-56	41.1M	18	1	0
56-57	41.1M	18	1	0
57-58	41.1M	18	1	0
58-59	41.1M	18	1	0
59-60	41.1M	18	1	0
60-61	41.1M	18	1	0
61-62	41.1M	18	1	0
62-63	41.1M	18	1	0
63-64	41.1M	18	1	0
64-65	41.1M	18	1	0
65-66	41.1M	18	1	0
66-67	41.1M	18	1	0
67-68	41.1M	18	1	0
68-69	41.1M	18	1	0
69-70	41.1M	18	1	0
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71-72	41.1M	18	1	0
72-73	41.1M	18	1	0
73-74	41.1M	18	1	0
74-75	41.1M	18	1	0
75-76	41.1M	18	1	0
76-77	41.1M	18	1	0
77-78	41.1M	18	1	0
78-79	41.1M	18	1	0
79-80	41.1M	18	1	0
80-81	41.1M	18	1	0
81-82	41.1M	18	1	0
82-83	41.1M	18	1	0
83-84	41.1M	18	1	0
84-85	41.1M	18	1	0
85-86	41.1M	18	1	0
86-87	41.1M	18	1	0
87-88	41.1M	18	1	0
88-89	41.1M	18	1	0
89-90	41.1M	18	1	0
90-91	41.1M	18	1	0
91-92	41.1M	18	1	0
92-93	41.1M	18	1	0
93-94	41.1M	18	1	0
94-95	41.1M	18	1	0
95-96	41.1M	18	1	0
96-97	41.1M	18	1	0
97-98	41.1M	18	1	0
98-99	41.1M	18	1	0
99-100	41.1M	18	1	0

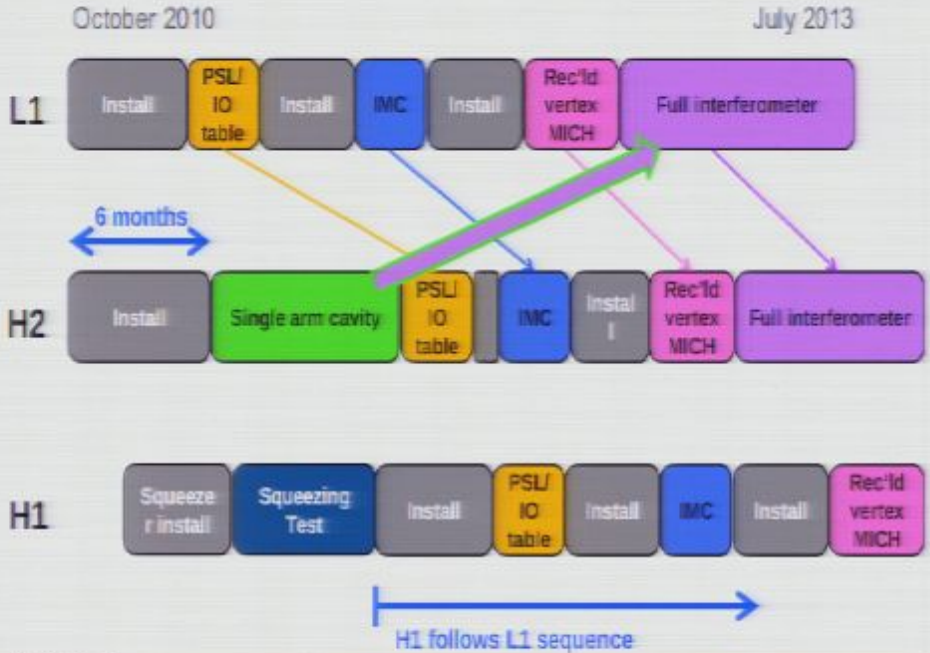
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# Advanced LIGO

Advanced LIGO (US sites) will likely be first. Data may only be a few years away.



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**Slides**

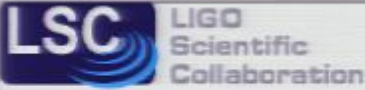

4 LSC Part IV. Future searches for compact binaries. Slide 24

5 LSC Number of sources increased by ~1000. Range will increase by 10. Volume by 1000. The number of uniformly distributed sources will increase by 1000. Slide 25

6 LSC What do we expect to see? (ideally)

Year	Number of sources	Volume	Range	Number of sources
2010	100	1000	10	100
2011	1000	10000	100	1000
2012	10000	100000	1000	10000
2013	100000	1000000	10000	100000
2014	1000000	10000000	100000	1000000
2015	10000000	100000000	1000000	10000000

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# Part IV. Future searches for compact binaries.

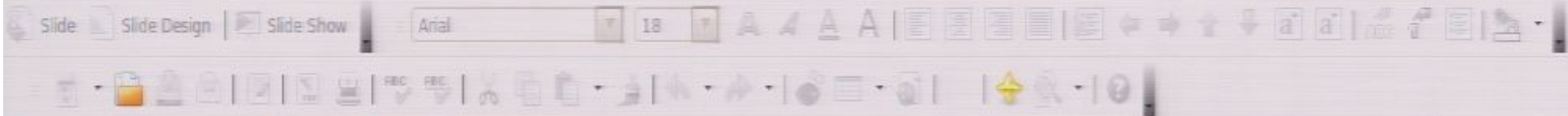
CITAPI DAY 24

**Tasks**

- Master Pages
- Layouts
- Table Design
- Custom Animation
- Slide Transition







Slides

4 LSC  
Part IV. Future searches for compact binaries.  
Slide 24

5 LSC  
Number of sources increased by ~1000  
Range will increase by 10. Volume by 1000. The number of uniformly or Galaxy distributed sources will increase by 1000.  
Slide 25

6 LSC  
What do we expect to see? (ideally)

Year	Number of sources	Volume	Range
2010	~100	~1000	~10
2015	~1000	~1000000	~100
2020	~10000	~1000000000	~1000

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# Number of sources increased by ~1000



Range will increase by 10. Volume by 1000. The number of uniformly or Galaxy distributed sources will increase by 1000.

Tasks

- Master Pages
- Layouts
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**Slides**

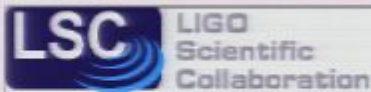
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Slide 27

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# What do we expect to see? (ideally)

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source <sup>a</sup>	$\dot{N}_{low} \text{ yr}^{-1}$	$\dot{N}_{re} \text{ yr}^{-1}$	$\dot{N}_{high} \text{ yr}^{-1}$	$\dot{N}_{max} \text{ yr}^{-1}$
Initial	NS-NS	$2 \times 10^{-4}$	0.02	0.2	0.6
	NS-BH	$7 \times 10^{-5}$	0.004	0.1	
	BH-BH	$2 \times 10^{-4}$	0.007	0.5	
	IMRI into IMBH			$<0.001^b$	$0.01^c$
Advanced	IMBH-IMBH			$10^{-4d}$	$10^{-3e}$
	NS-NS	0.4	40	400	1000
	NS-BH	0.2	10	300	
	BH-BH	0.4	20	1000	
	IMRI into IMBH			$10^b$	$300^c$
	IMBH-IMBH			$0.1^d$	$1^e$

Sources distributed uniformly implies  
 $32 > \text{SNR } 8$   
 $4 > \text{SNR } 16$

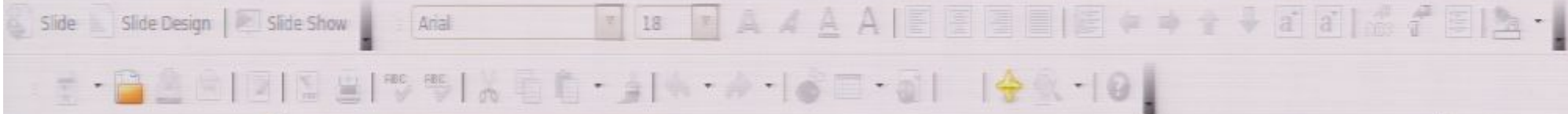
J Abadie et al 2010 Class. Quantum Grav. 27, 173001

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**Tasks**

- Master Pages
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**Slides**

Slide 25: increased by ~1000

Slide 26: What do we expect to see? (ideally)

Slide 27: What do we expect to see? (Realistically)

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# What do we expect to see? (ideally)

Table 5. Detection rates for compact binary coalescence sources.

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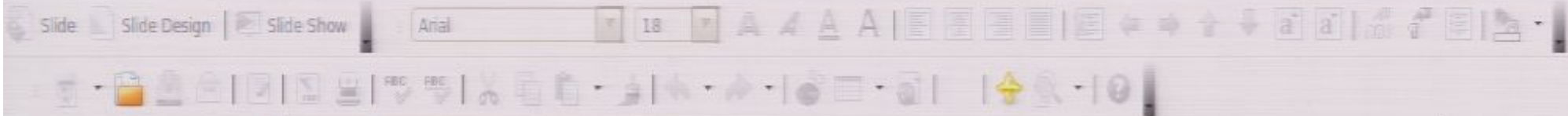
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**Tasks**

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Slides

Slide 24

5 LSC Number of sources increased by ~1000. Range will increase by 10. Volume by 1000. The number of uniformly or Galaxy distributed sources will increase by 1000.

Slide 25

6 LSC What do we expect to see? (ideally)

Slide 26

7 LSC What do we expect to see? (Realistically)

It is unfortunately very likely that Advanced LIGO will not begin operation at its design sensitivity. What if it is a factor of 2 less sensitive? How long will it take to commission?

40 events -- 5 events, all near threshold.

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# What do we expect to see? (ideally)

Table 5: Detection rates for compact binary coalescence sources.

IFO	Source <sup>a</sup>	$\dot{N}_{low} \text{ yr}^{-1}$	$\dot{N}_{re} \text{ yr}^{-1}$	$\dot{N}_{high} \text{ yr}^{-1}$	$\dot{N}_{max} \text{ yr}^{-1}$
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J Abadie et al 2010 Class. Quantum Grav. 27 173001

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Tasks

- Master Pages
- Layouts
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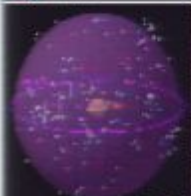


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Slide 24

5 LSC Number of sources increased by ~1000



Slide 25

6 LSC What do we expect to see? (ideally)

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IMRI into IMBH			10 <sup>b</sup>	300 <sup>c</sup>
IMBH-IMBH			0.1 <sup>d</sup>	1 <sup>e</sup>

Slide 26

7 LSC What do we expect to see? (Realistically)

It is unfortunately very likely that Advanced LIGO will not begin operation at its design sensitivity. What if it is a factor of 2 less sensitive? How long will it take to commission?

40 events → 5 events, all near threshold

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## What do we expect to see? (ideally)

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source <sup>a</sup>	$\dot{N}_{low}$ yr <sup>-1</sup>	$\dot{N}_{re}$ yr <sup>-1</sup>	$\dot{N}_{high}$ yr <sup>-1</sup>	$\dot{N}_{max}$ yr <sup>-1</sup>
Initial	NS-NS	2 × 10 <sup>-4</sup>	0.02	0.2	0.6
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Sources distributed uniformly implies

32 > SNR 8

4 > SNR 16

1 > SNR 25

J Abadie et al 2010 Class. Quantum Grav. 27 173001

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Tasks

- Master Pages
- Layouts
- Table Design
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- Slide Transition

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Slides

Slide	Title
1	...
26	What do we expect to see? (Realistically)
27	...
28	Part V. What do we do during the Dark Age?

Slide 26

7 What do we expect to see? (Realistically)

- It is unfortunately very likely that Advanced LIGO will not begin operation at its design sensitivity. What if it is a factor of 2 less sensitive? How long will it take to commission?
- 40 events → 5 events, all near threshold. Can we make confident detection(s) early? YES! But it will require a lot of work...

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8 Part V. What do we do during the Dark Age?



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## What do we expect to see? (ideally)

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source <sup>a</sup>	$\dot{N}_{low} \text{ yr}^{-1}$	$\dot{N}_{re} \text{ yr}^{-1}$	$\dot{N}_{high} \text{ yr}^{-1}$	$\dot{N}_{max} \text{ yr}^{-1}$
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Sources distributed uniformly implies [J. Abadie et al 2010 Class. Quantum Grav. 27 173001](#)

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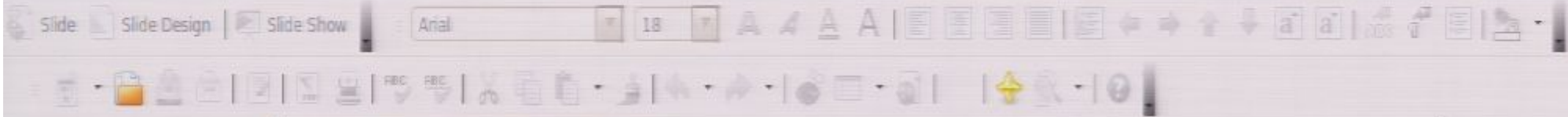
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Tasks

- Master Pages
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Slides

Slide	Title	Thumbnail
1	...	...
26	...	...
27	What do we expect to see? (Realistically)	
28	Part V. What do we do during the Dark Age?	

Slide 26

7 What do we expect to see? (Realistically)

It is unfortunately very likely that Advanced LIGO will not begin operation at its design sensitivity. What if it is a factor of 2 less sensitive? How long will it take to commission?

40 events → 5 events, all near threshold  
Can we make confident detection(s) early?  
YES! But it will require a lot of work...

Slide 27

8 Part V. What do we do during the Dark Age?

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Collaboration

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Tasks

- Master Pages
- Layouts
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Slides

6 LSC What do we expect to see? (ideally)

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7 LSC What do we expect to see? (Realistically)

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8 LSC Part V. What do we do during the Dark Age?

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Collaboration VIRGO

# What do we expect to see? (ideally)

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source <sup>a</sup>	$\dot{N}_{low} \text{ yr}^{-1}$	$\dot{N}_{re} \text{ yr}^{-1}$	$\dot{N}_{high} \text{ yr}^{-1}$	$\dot{N}_{max} \text{ yr}^{-1}$
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Sources distributed uniformly implies

J Abadie et al 2010 Class. Quantum Grav. 27 173001

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- Master Pages
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- Slide Transition





Slides


6. **LSC** What do we expect to see? (ideally)

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7. **LSC** What do we expect to see? (Realistically)


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8. **LSC** Part V. What do we do during the Dark Age?



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## What do we expect to see? (Realistically)

It is unfortunately very likely that Advanced LIGO will not begin operation at its design sensitivity. What if it is a factor of 2 less sensitive? How long will it take to commission?

**40 events → 5 events, all near threshold**  
**Can we make confident detection(s) early?**  
**YES! But it will require a lot of work...**

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Tasks

- Master Pages
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Collaboration Part V. What do we do during the Dark Age?

What follows is a lot of my personal speculation.

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- Master Pages
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**Slides**

Slide 26: what do we expect to see? (Ideally)

Slide 27: What do we expect to see? (Realistically)

Slide 28: Part V. What do we do during the Dark Age?

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# Part V. What do we do during the Dark Age?



What follows is a lot of my personal speculation.

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**Tasks**

- Master Pages
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# The Dark Age won't be very long

It is already February 2011...  
...in 2.5 years we can expect the first ALIGO data

What do we do while we wait?

- There is still ongoing analysis with the previous data. In fact, some searches have not begun.
- We have learned a lot about our analysis techniques and know that there is room for improvement before ALIGO (we need the time!).
- We will use this time to assure we are ready to make the first detections.

Tasks

- Master Pages
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VIRGO

# What improvements will we make?

- Improving our confidence in detections
- The first events will be near threshold (statistically)
  - We have to be able to pin down the false-alarm probability (FAP).

- How can we improve our confidence?
- Improved detector characterization schemes. We need to know when the detector is misbehaving.
  - Improved background estimation, understanding how instrumental glitches effect the analysis.
  - EM coincidence.

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**Slides**

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Slide 31

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# What improvements will we make?

## Improving our confidence in detections

- The first events will be near threshold (statistically)
- We have to be able to pin down the false-alarm probability (FAP).

## How can we improve our confidence?

- Improved detector characterization schemes. We need to know when the detector is misbehaving.
- Improved background estimation, understanding how instrumental glitches effect the analysis.
- EM coincidence.

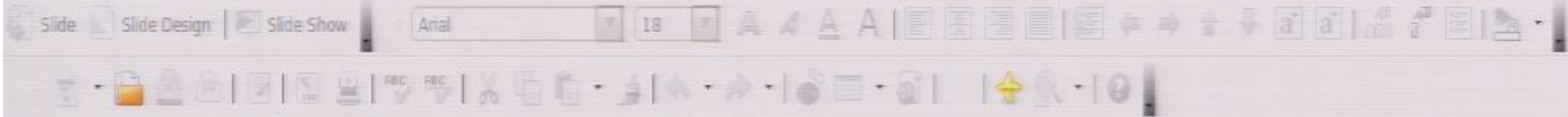
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**Tasks**

- Master Pages
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# EM coincidence

VIRGO

There are two ways to conduct a coincident gravitational-wave / EM search

- 1) Use EM events to trigger GW searches.
- 2) Use GW searches to trigger EM searches.

The former is easy. As long as GW detectors were on we can examine the data post facto.

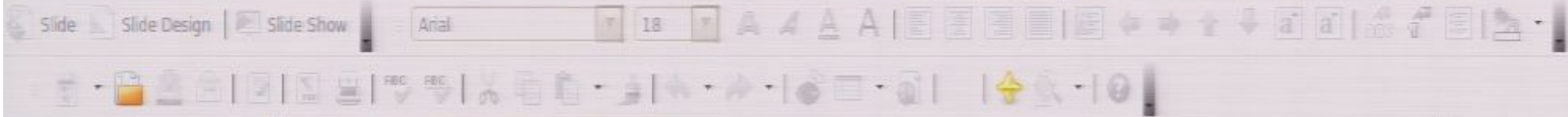
The latter requires more work. We need rapid analysis and localization.

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**Slides**

- Slide 30: Improving our confidence in detections. The first events will be near threshold (statistically). We have to be able to pin down the false alarm probability (FAP). How can we improve our confidence? Improved detector characterization schemes, we need to know when the detector is misbehaving. Improved background estimation, understanding how instrumental glitches affect the analysis. EM coincidence.
- Slide 31: **EM coincidence**. There are two ways to conduct a coincident gravitational-wave / EM search. 1) Use EM events to trigger GW searches. 2) Use GW searches to trigger EM searches. The former is easy. As long as GW detectors were on we can examine the data post facto. The latter requires more work. We need rapid analysis and localization.
- Slide 32: **Telescopes used in S6**. A world map showing the locations of various telescopes used in the S6 project.

Normal Outline Notes Handout Slide Sorter

**LSC Scientific Collaboration**

# EM coincidence

**VIRGO**

There are two ways to conduct a coincident gravitational-wave / EM search

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- 2) Use GW searches to trigger EM searches.

The former is easy. As long as GW detectors were on we can examine the data post facto.

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**Tasks**

- Master Pages
- Layouts
- Table Design
- Custom Animation
- Slide Transition





Slides

Slide 30

1 LSC Scientific Collaboration EM coincidence

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Slide 31

2 LSC Telescopes used in S6

Slide 32

3 LSC Latency in S6 and ALIGO goals?

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LSC Scientific Collaboration

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VIRGO

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Slides

Slide 30

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2 LSC Scientific Collaboration Telescopes used in S6

Slide 32

3 LSC Scientific Collaboration Latency in S6 and ALIGO goals?

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# Scientific Collaboration Telescopes used in S6

Used in winter and autumn run  autumn run only



B. Hughes, GWPAW 2011  
On behalf of LVC LIGO-GL100009

This will expand dramatically in ALIGO CITAPI DAY

Tasks

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LSC Scientific Collaboration

# Telescopes used in S6

VIRGO

Used in winter and autumn run  autumn run only



This will expand dramatically in ALIGO CITA.PI DAY

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**LSC Scientific Collaboration**

**VIRGO**

# Latency in S6 and ALIGO goals?

LIGO-G1100009

```

    graph LR
      H1[H1 data] --> DV1[DQ/vetoes]
      L1[L1 data] --> DV2[DQ/vetoes]
      V1[V1 data] --> DV3[DQ/vetoes]
      DV1 --> CC[Data copied to computer centers]
      DV2 --> CC
      DV3 --> CC
      CC --> EG[Event generation]
      EG --> GA[GraCEDb archive]
      GA --> LUMIN((LUMIN))
      GA --> GEM((GEM))
      LUMIN --> HVE[Humans validate event]
      GEM --> HVE
      HVE --> AT[alerts to telescopes]
  
```

Pointing and event downselection

Time required:	<1 min.	~1 min.	<1 min.	2-5 min.	<1 min	2-3 min.	10-20 min.	Total Latency: ~30 min.
Goals ?	< 1 min	~10 s	Integrate with EG?	Remove altogether?	Total ~1 min	We need a better handle on FAP!		

B. Hughes, GWPAW 2011  
On behalf of LVC

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Tasks

- Master Pages
- Layouts
- Table Design
- Custom Animation
- Slide Transition





Slides

Slide 32

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Normal Outline Notes Handout Slide Sorter



Scientific Collaboration



# Stay tuned...

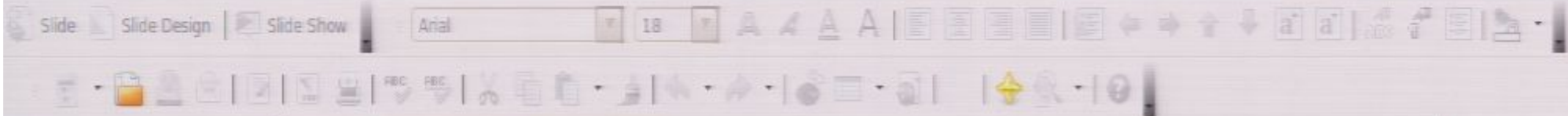
Analysis of the current data is not finished.  
There may still be a serendipitous discovery!

Many of us will be extremely busy preparing for ALIGO in the next 3 years. We have to be at the top of our game to make the best use of the first few years of ALIGO data. Confident detections, early, will be a great help to the field.

Thanks for listening!

Tasks

- Master Pages
- Layouts
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- Custom Animation
- Slide Transition



Slides

Slide 32

Slide 33

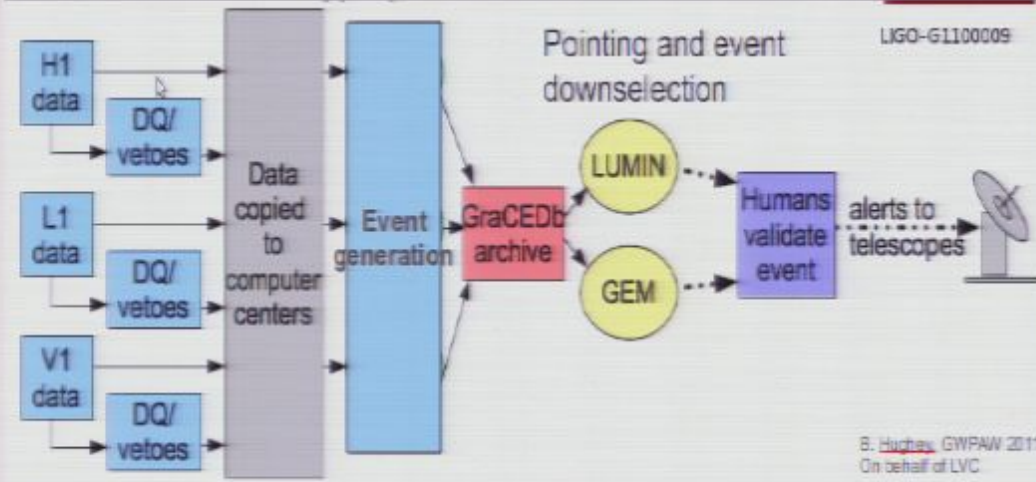
Slide 34

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LSC Scientific Collaboration

VIRGO

# Latency in S6 and ALIGO goals?



Time required:	<1 min.	~1 min.	<1 min.	2-5 min.	<1 min	2-3 min.	10-20 min.	Total Latency:	~30 min.
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Goals ?

< 1 min      ~10 s      Integrate with EG?      Remove altogether?      Total ~1 min

We need a better handle on FAP!

CITA.PI DAY

Tasks

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Slides

Slide 32

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Tasks

- Master Pages
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No Signal

VGA-1



No Signal

VGA-1

No Signal

VGA-1



No Signal

VGA-1

No Signal

VGA-1



No Signal

VGA-1

No Signal

VGA-1



No Signal

VGA-1

No Signal

VGA-1



No Signal

VGA-1