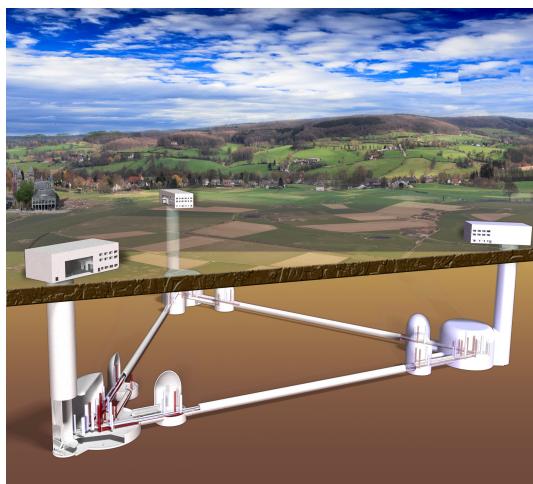


# Gravitational wave data

Advanced Virgo

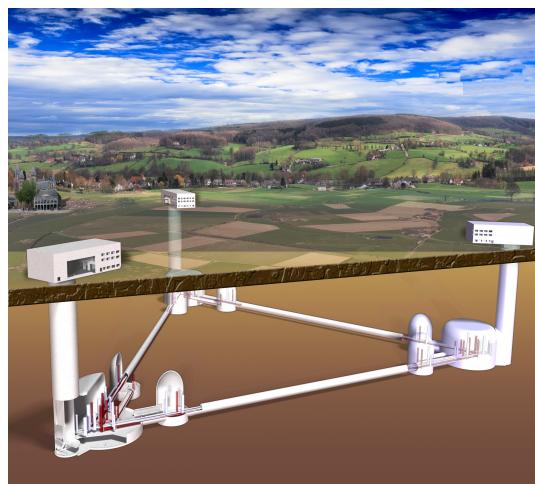
Eric Chassande-Mottin

Asterics DADI 1<sup>st</sup> Tech Forum  
Sep 17 2015, Strasbourg, France



# Direct detection of gravitational waves

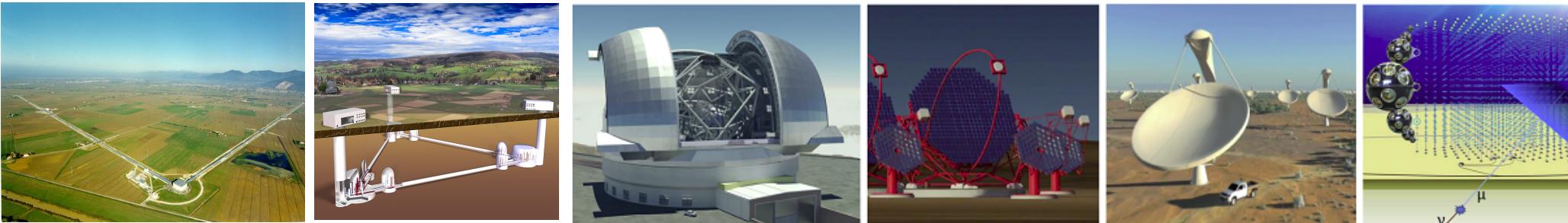
- **Gravitational waves**
  - Predicted by Einstein's General Relativity
  - Propagating distortions of space-time
  - Generated by cataclysmic events involving massive, compact astrophysical objects (black hole, neutron star)
- **Develop a new astronomy based on GW**
  - Complementary to photons: “multi-messenger”



# GW detectors and related institutions

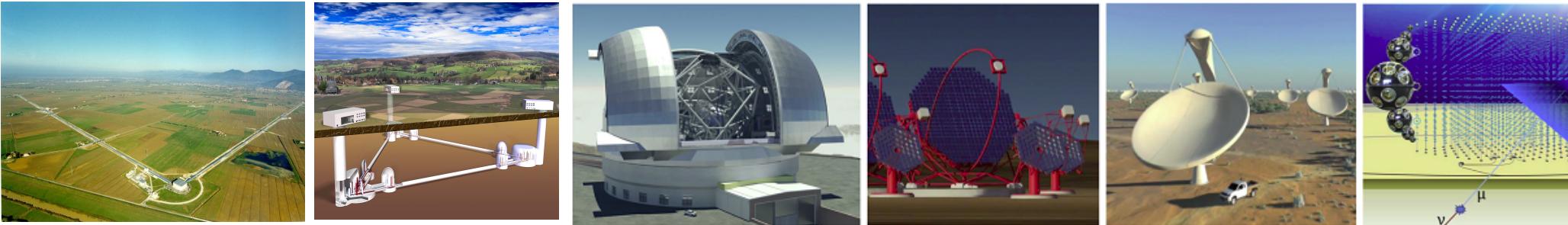
Km-scale Michelson type interferometers – high-precision metrology

- **Einstein Telescope** (3<sup>rd</sup> generation detector)
  - ✓ FP7 design study (2011).
    - ASPERA roadmap. **Candidate ESFRI**
- **Advanced Virgo “pathfinder”** (2<sup>nd</sup> generation)
- **European Gravitational Observatory, EGO**
  - CNRS-INFN consortium with other partners
  - Manages Virgo site (Italy) and hosts ET coordination



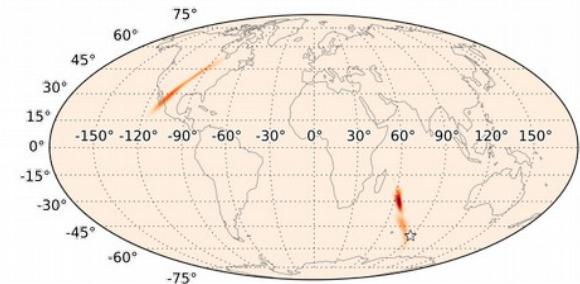
## Advanced Virgo – status

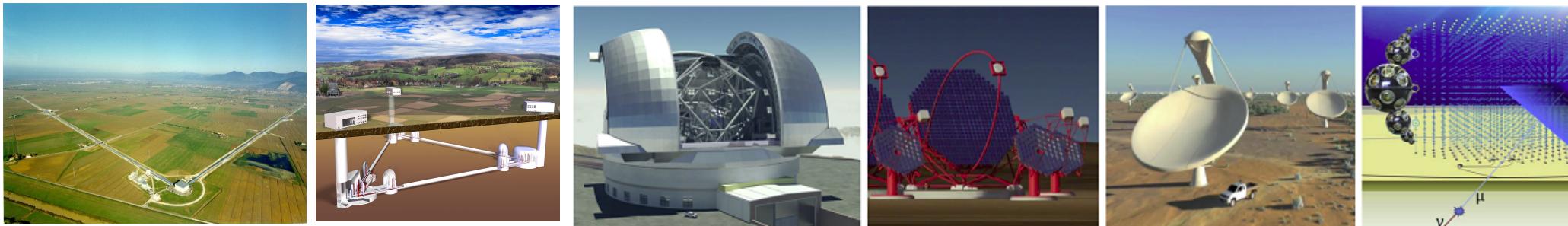
- 1<sup>st</sup> generation of Virgo operated between 2007-2012
  - ✓ Data sharing and joint analysis with US based LIGO
  - ✓ No detection so far
- Upgrading: **x 10 sensitivity** → x 1000 in the event rate
  - ✓ Observability horizon for binary neutron stars : 140 Mpc
  - ✓ Current BNS event rate estimates: few to tenth events/yr
- **Science data upcoming!**
  - ✓ Advanced LIGO 1<sup>st</sup> science run imminent
  - ✓ Advanced Virgo will take data jointly with aLIGO in 2016
- Opportunities for **multimessenger astrophysics**
  - ✓ Search for electromagnetic counterpart (i.e., afterglow, flare...)
  - ✓ Extensive **electromagnetic follow-up program** inc. LOFAR, HESS, CTA, ...



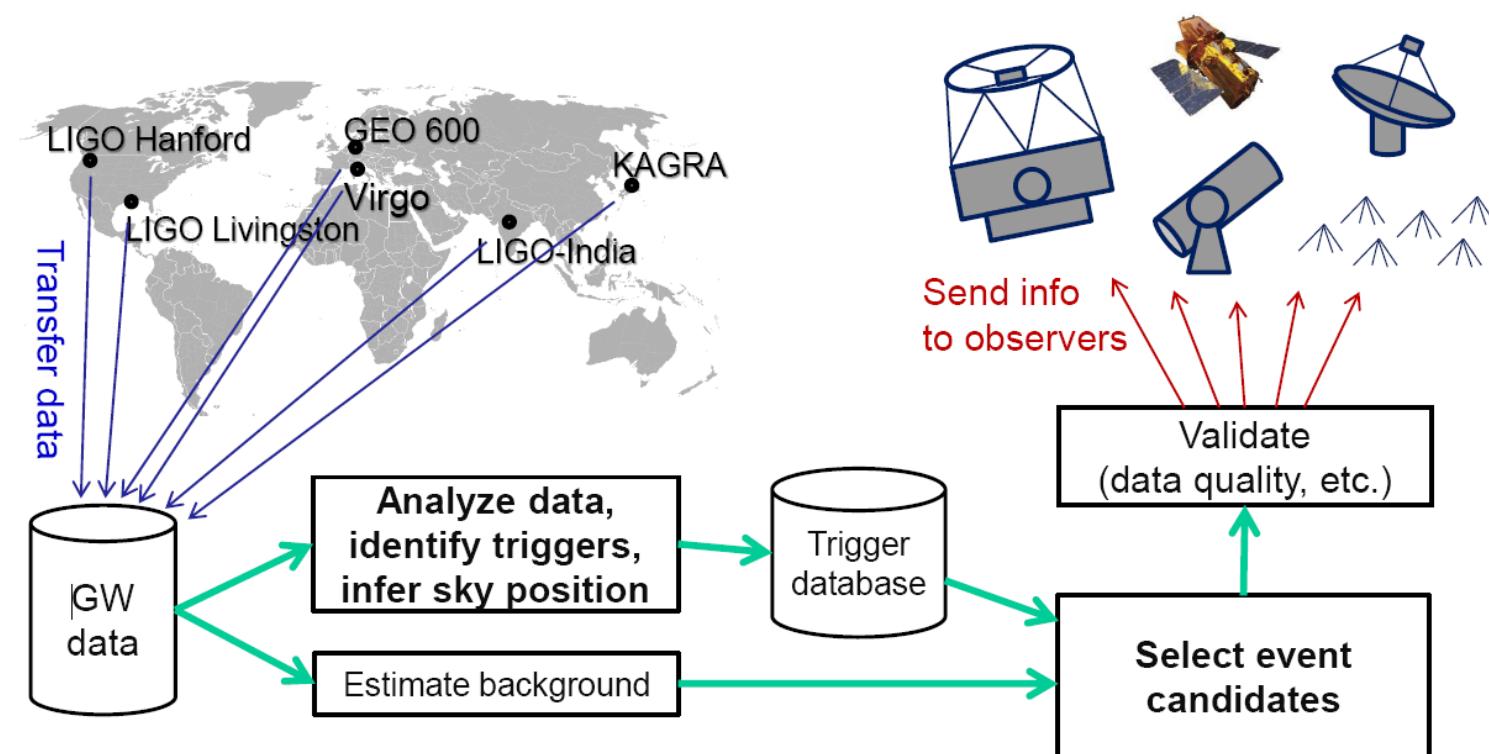
# GW related-challenges

- Low-latency analysis of **distant** detectors
  - ✓ Background rejection – “glitches”
- Alert generation within **minutes**
  - ✓ Allow the observation of prompt emission and short-duration (hours) afterglows
- GW error is **large** by astronomical standards
  - ✓ Few 100 sq degrees – Needle in the haystack: many galaxies
  - ✓ Prioritize regions to follow-up
  - ✓ Rejection of unrelated electromagnetic transients





# LIGO-Virgo GW alert system



Identify significant transients worth following up

**Distribute alerts to observing partners within 5-10 mins**

# Enabling EM follow-up (1)

## GraceDB – Gravitational Wave Candidate Event DB

HOME | SEARCH | CREATE | REPORTS | RSS | LATEST | OPTIONS | AUTHENTICATED AS: ERIC CHASSANDE-MOTTIN

### Basic Info

UID	Labels	Group	Pipeline	Search	Instruments	GPS Time ▾	Event Time	FAR (Hz)	Links	UTC ▾	Submitted
G158249	CBC	MBTAOnline		H1,L1		1117621400.2060	1.372e-06	Data	2015-06-06 10:24:49 UTC		

### Coinc Tables

End Time		1117621400.2060	Single Inspiral Tables		
Channel			IFO	L1	H1
End Time					
Template Duration	None		1117621400.219121932	1117621400.206010103	
Effective Distance	177.7525				
COA Phase	-0.2746053				
Mass 1	7.365417				
Mass 2	1.861673				
$\eta$	0.16105389				
F Final	None				
SNR	13.6718		SNR	12.637432	5.2167654
$\chi^2$	None				
$\chi^2$ DOF	None				
spin1z	-0.2383012				
spin2z	0.0005419254				

### Neighbors [-5,+5]

No neighbors in range.

**Low latency analysis**  
**Preliminary alert in 3-5 mins**

Rapid preliminary sky position  
Initial alert issued in 5-10 mins  
includes: time, significance, sky map

**Detailed analysis: Bayesian parameter estimation**  
**Alert updates or retraction within hours**

### Event Log Messages (add)

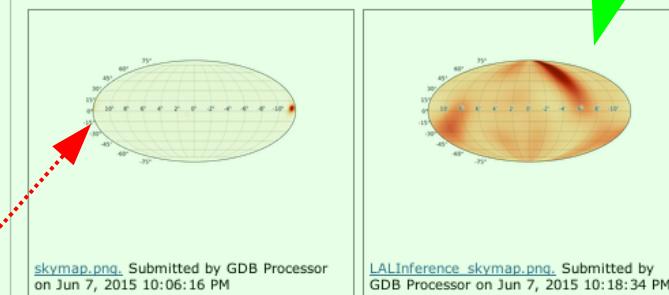
#### Analyst Comments

LLO Local ▾	Log Entry Created	Submitter	Comment
	Jun 7, 2015 5:18:52 PM	GDB Processor	No unblind injections window [-5,+5] seconds
	Jun 7, 2015 5:06:33 PM	GDB Processor	No unblind injections window [-5,+5] seconds

#### Noise Curves

LLO Local ▾	Log Entry Created	Submitter	Comment
	Jun 6, 2015 5:24:54 AM	MBTA Alert	PSDs <a href="#">psd.xml.gz</a>

#### Sky Localization



[skymap.png](#), Submitted by GDB Processor on Jun 7, 2015 10:06:16 PM

[LALInference\\_skymap.png](#), Submitted by GDB Processor on Jun 7, 2015 10:18:34 PM

LLO Local ▾	Log Entry Created	Submitter	Comment
	Jun 7, 2015 5:18:25 PM	SkymapViewer	<a href="#">LALInference_skymap.json</a>
	Jun 7, 2015 5:06:01 PM	SkymapViewer	<a href="#">skymap.json</a>
	Jun 7, 2015 5:05:55 PM	GDB Processor	INFO:BAYESTAR:uploaded sky map <a href="#">skymap.json</a>

#### External Coincidence

#### Parameter Estimation

#### EM Observations

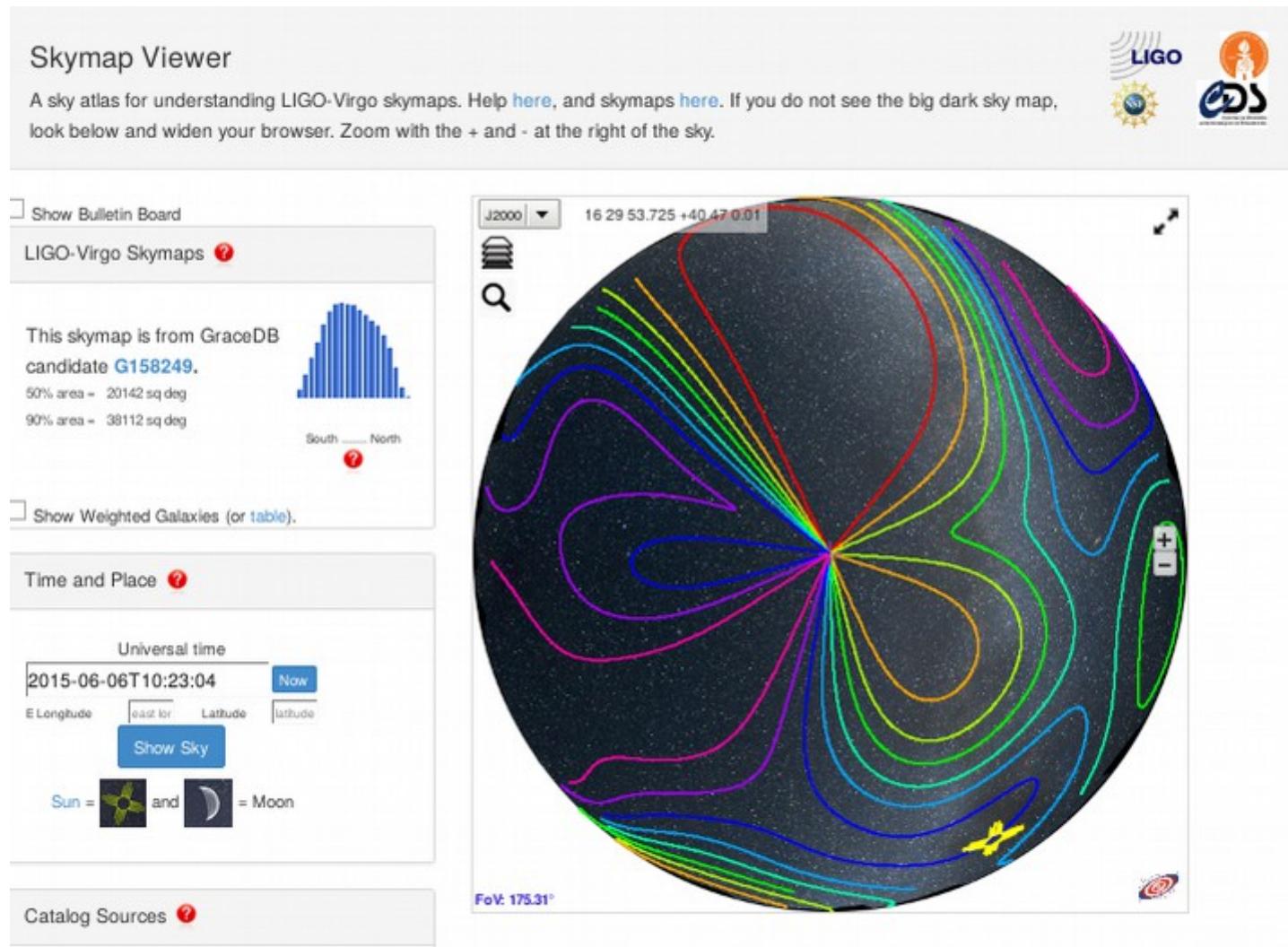
#### Full Event Log

[View in SkymapViewer!](#)

[View in SkymapViewer!](#)

**Coincident astrophysical event or EM follow-up observations**

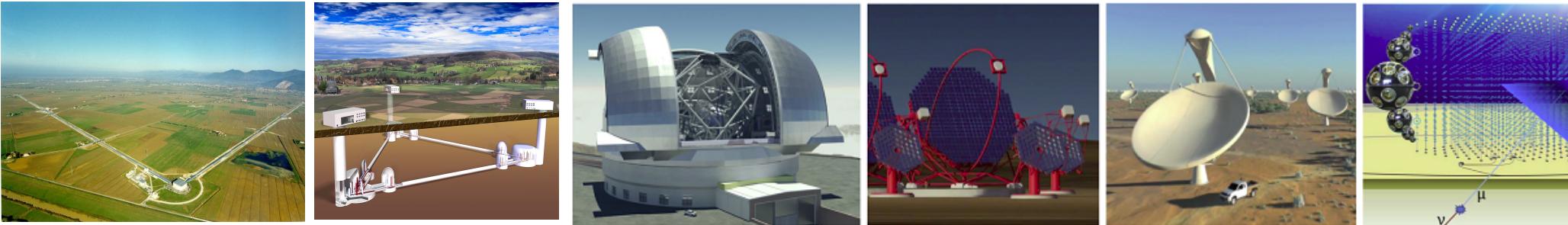
# Enabling EM follow-up (2)



# Enabling EM follow-up (3)

## Example of preliminary alert formatted as a VO event

```
<?xml version="1.0" encoding="UTF-8"?>
<voe:VOEvent xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:voe="http://www.ivoa.net/xml/VOEvent/v2.0"
  xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v2.0
    http://www.ivoa.net/xml/VOEvent-v2.0.xsd" version="2.0" role="test"
  ivorn="ivo://gwnet/gcn_sender#M137606-1-Preliminary">
  <Who>
    <Date>2015-04-22T21:12:08</Date>
    <Author>
      <contactName>LIGO Scientific Collaboration and Virgo Collaboration</contactName>
    </Author>
  </Who>
  <What>
    <Param name="Pkt_Ser_Num" dataType="string" value="1"/>
    <Param name="GraceID" dataType="string" value="M137606" ucd="meta.id">
      <Description>Identifier in GraceDB</Description>
    </Param>
    <Param name="AlertType" dataType="string" value="Preliminary" ucd="meta.version" unit="">
      <Description>VOEvent alert type</Description>
    </Param>
    <Param name="EventPage" dataType="string" value="https://gracedb.ligo.org/events/M137606" ucd="meta.ref.url">
      <Description>Web page for evolving status of this candidate event</Description>
    </Param>
    <Param name="Instruments" dataType="string" value="H1,L1" ucd="meta.code">
      <Description>List of instruments used in analysis to identify this event</Description>
    </Param>
    <Param name="FAR" dataType="float" value="3.77232633462e-14" ucd="arith.rate;stat.falsealarm" unit="Hz">
      <Description>False alarm rate for GW candidates with this strength or greater</Description>
    </Param>
    <Param name="Pipeline" dataType="string" value="gstlal" ucd="meta.code" unit="">
      <Description>Low-latency data analysis pipeline</Description>
    </Param>
    <Param name="Search" dataType="string" value="MDC" ucd="meta.code" unit="">
      <Description>Specific low-latency search</Description>
    </Param>
    <Param name="ChirpMass" dataType="float" value="1.12945318222" ucd="phys.mass" unit="solar mass">
      <Description>Estimated CBC chirp mass</Description>
    </Param>
    <Param name="Eta" dataType="float" value="0.245523989341" ucd="phys.mass;arith.factor" unit="">
      <Description>Estimated ratio of reduced mass to total mass</Description>
    </Param>
    <Param name="MaxDistance" dataType="float" value="111.63056" ucd="pos.distance" unit="Mpc">
      <Description>Estimated maximum distance for CBC event</Description>
    </Param>
  </What>
  <WhereWhen>
    <ObsDataLocation>
      <ObservatoryLocation id="LIGO Virgo"/>
      <ObservationLocation>
        <AstroCoordSystem id="UTC-FK5-GEO"/>
        <AstroCoords coord_system_id="UTC-FK5-GEO">
          <Time>
            <TimeInstant>
              <ISOTime>2010-09-27T14:09:05.425029</ISOTime>
            </TimeInstant>
          </Time>
          <Position2D>
            <Value2>
              <C1>0.000000</C1>
              <C2>0.000000</C2>
            </Value2>
            <Error2Radius>180.000000</Error2Radius>
          </Position2D>
        </AstroCoords>
      </ObservationLocation>
    </ObsDataLocation>
  </WhereWhen>
  <How>
    <Description>Candidate gravitational wave event identified by low-latency analysis</Description>
    <Description>H1: LIGO Hanford 4 km gravitational wave detector</Description>
    <Description>L1: LIGO Livingston 4 km gravitational wave detector</Description>
  </How>
  <Description>Report of a candidate gravitational wave event</Description>
</voe:VOEvent>
```



## Access model to GW data

- We operate currently under **a close-data model**
  - ✓ Assessing GW event significance is difficult  
Drawing conclusions from the data requires a wide range of expertise
- We have a **plan for public release**
  - ✓ After first 4 alerts, <https://dcc.ligo.org/LIGO-M1300550>
- Preparing the **future** – Two type of data products
  - ✓ Alerts/candidate events – Connection to the VO?
  - ✓ Science data? – LIGO open science center  
<https://losc.ligo.org>



# LIGO Open Science Center

LIGO is operated by California Institute of Technology and Massachusetts Institute of Technology and supported by the U.S. National Science Foundation.

[Getting Started](#)

[Tutorials](#)

[Data & Catalogs](#)

[Timelines](#)

[My Sources](#)

[Software](#)

[GPS ↔ UTC](#)

[About LIGO](#)

[Student Projects](#)

[Acknowledgement](#)

## Welcome to the LIGO Open Science Center

[About LIGO](#)

[Get Started with LIGO data](#)

[Join the E-mail list for updates](#)

**NEW - Public release of LIGO S6 data! [news item](#) and [S6 data](#)**

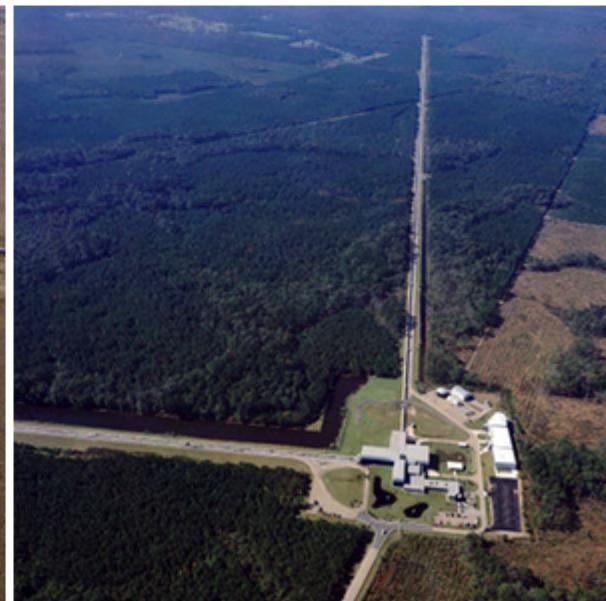
For background on the LIGO Open Science Center, see [arXiv:1410.4839](#).

For general information on LIGO, please visit [ligo.org](#).

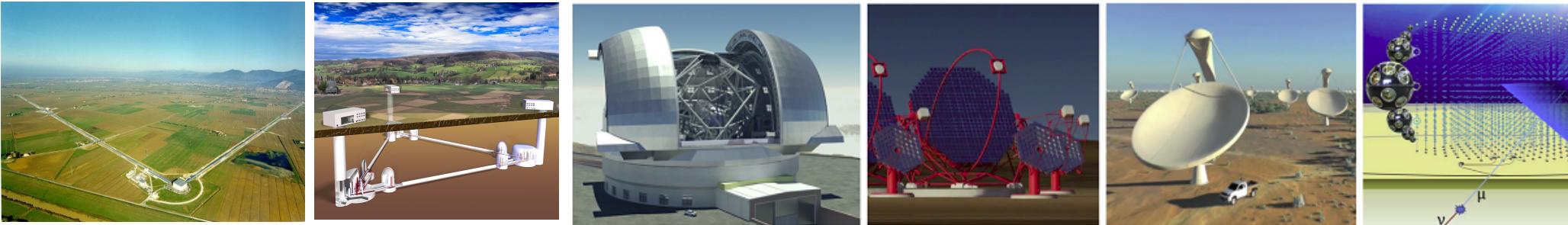
If you have LSC credentials, you may go to the [development site](#).



[LIGO Hanford Observatory, Washington \(image: C.Gray\)](#)



[LIGO Livingston Observatory, Louisiana \(image: J.Giaime\)](#)



# Multimessenger astrophysics with GWs

- Connection with DADI topics
  - ✓ Preparation of future data access model
    - Candidate events – “easy part” (VOevent)
    - Science data – very different than conventional astronomical data
  - ✓ Cross-correlation with catalogs of nearby galaxies
  - ✓ Cross-matching with other astronomical transients
    - Rejection of unrelated transients (variable stars, AGN, ...)