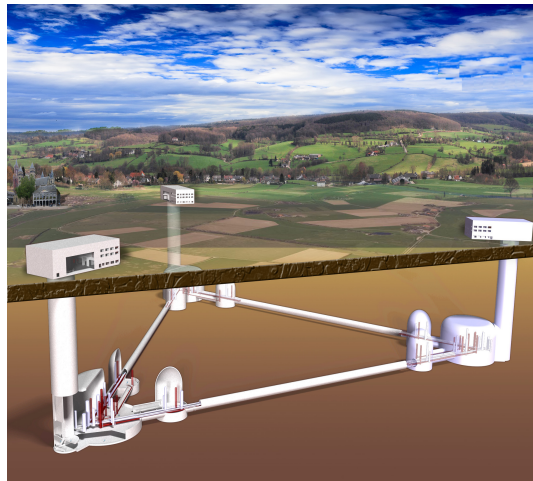


Gravitational wave data

Advanced Virgo

Eric Chassande-Mottin

Asterics DADI 1st Tech Forum
Sep 17 2015, Strasbourg, France



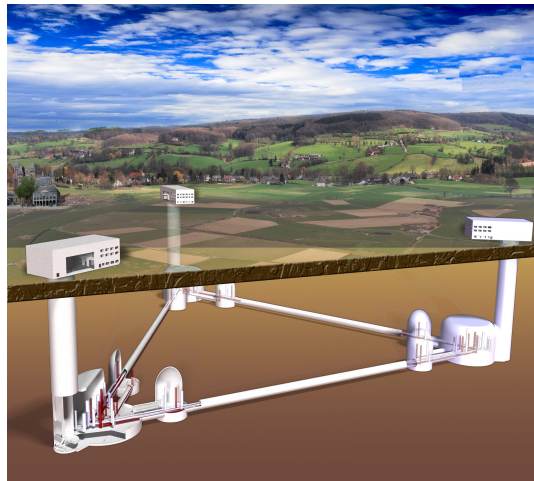
Direct detection of gravitational waves

- **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**

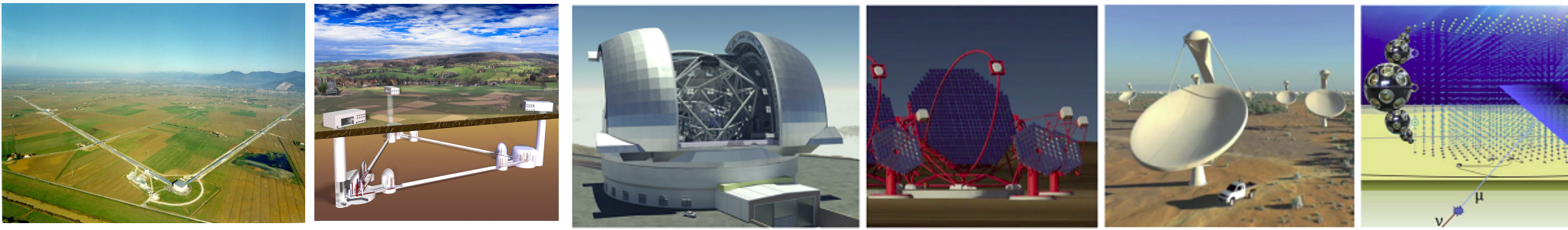
- Complementary to photons: “multi-messenger”



GW detectors and related institutions

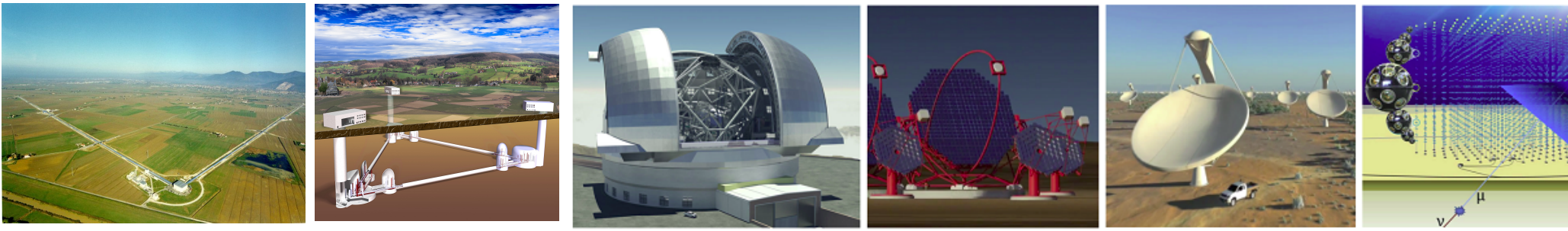
Km-scale Michelson type interferometers – high-precision metrology

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



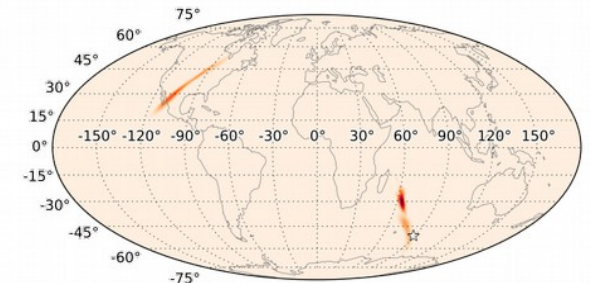
Advanced Virgo – status

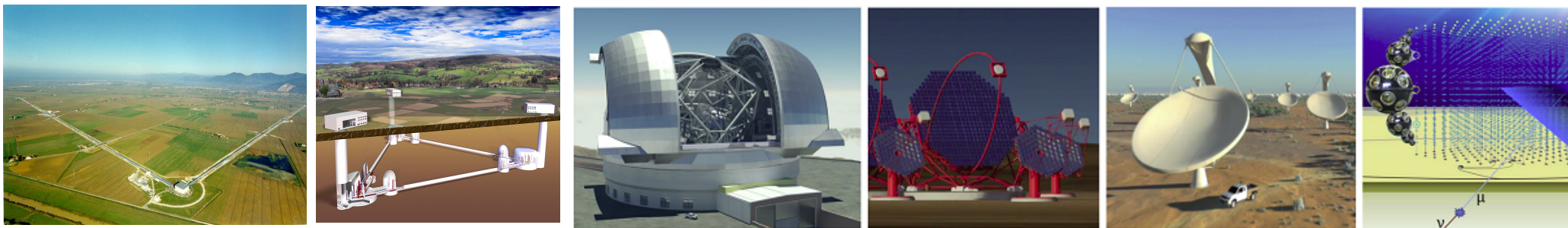
- 1st generation of Virgo operated between 2007-2012
 - ✓ Data sharing and joint analysis with US based LIGO
 - ✓ No detection so far
- Upgrading: **x 10 sensitivity** → x 1000 in the event rate
 - ✓ Observability horizon for binary neutron stars : 140 Mpc
 - ✓ Current BNS event rate estimates: few to tenth events/yr
- **Science data upcoming!**
 - ✓ Advanced LIGO 1st 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, ...



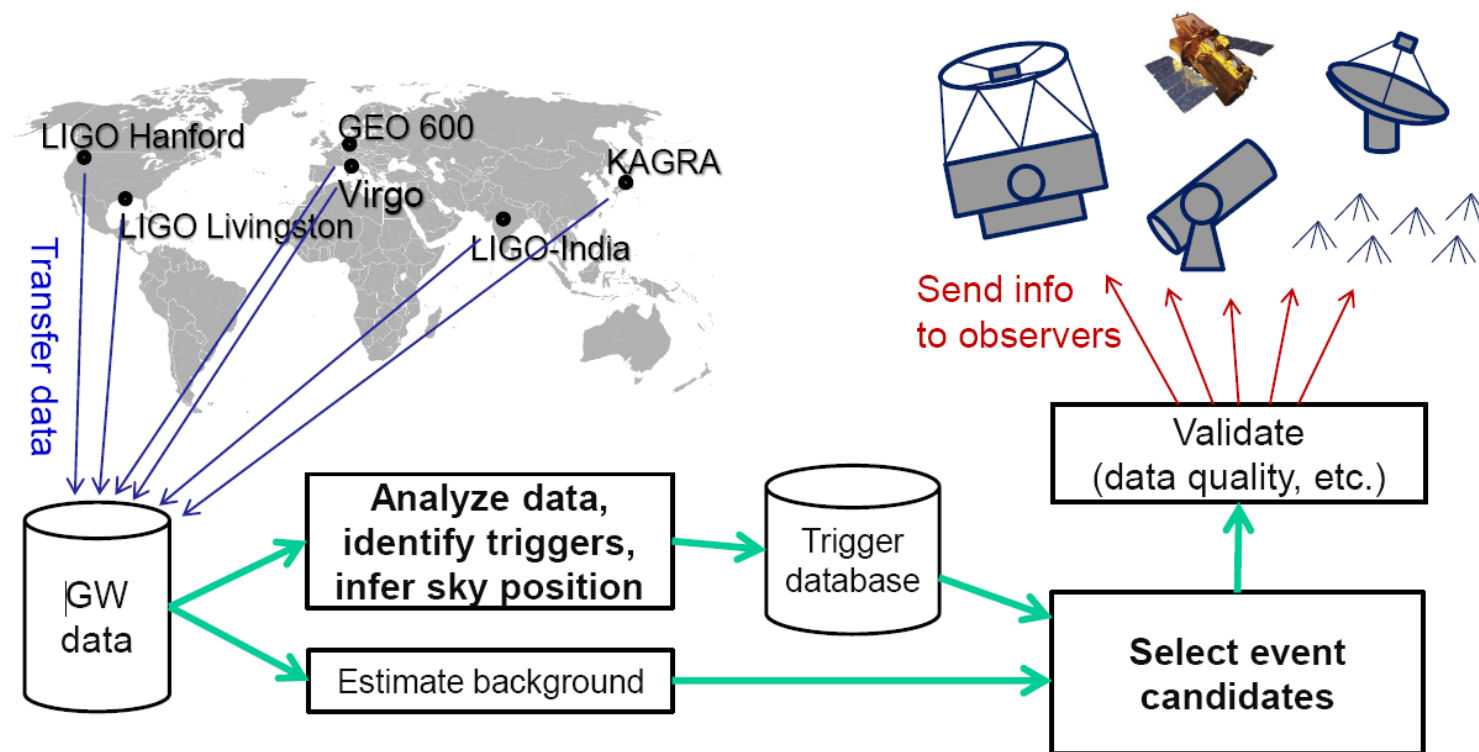
GW related-challenges

- 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
Total Mass	9.2271
Chirp Mass	3.0849
SNR	13.6718
False Alarm Probability	

Single Inspiral Tables

IFO	L1	H1
Channel		
End Time	1117621400.219121932	1117621400.206010103
Template Duration	None	None
Effective Distance	177.7525	459.68568
COA Phase	-0.2746053	-1.0825006
Mass 1	7.365417	7.365417
Mass 2	1.861673	1.861673
η	0.16105389	0.16105389
F Final	None	None
SNR	12.637432	5.2167654
χ^2	None	None
χ^2 DOF	None	None
spin1z	-0.2383012	-0.2383012
spin2z	0.0005419254	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)

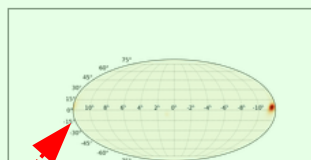
Analyst Comments

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

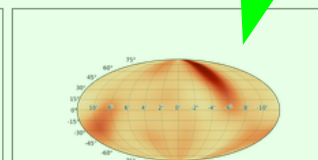
Noise Curves

LLO Local Log Entry Created	Submitter	Comment
Jun 6, 2015 5:24:54 AM	MBTA Alert	PSDs psd.xml

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	LALInference_skymap.ison View in SkymapViewer!
Jun 7, 2015 5:06:01 PM	SkymapViewer	skymap.ison View in SkymapViewer!
Jun 7, 2015 5:05:55 PM	GDB Processor	INFO: BAYESTAR: uploaded sky map skymap.png

External Coincidence

Parameter Estimation

EM Observations


Full Event Log

Coincident astrophysical event or EM follow-up observations

Enabling EM follow-up (2)

Skymap Viewer


A sky atlas for understanding LIGO-Virgo skymaps. Help [here](#), and skymaps [here](#). If you do not see the big dark sky map, look below and widen your browser. Zoom with the + and - at the right of the sky.




Show Bulletin Board

LIGO-Virgo Skymaps

This skymap is from GraceDB candidate [G158249](#).
50% area = 20142 sq deg
90% area = 38112 sq deg



South — North 



Show Weighted Galaxies (or [table](#)).

Time and Place

Universal time
2015-06-06T10:23:04 [Now](#)

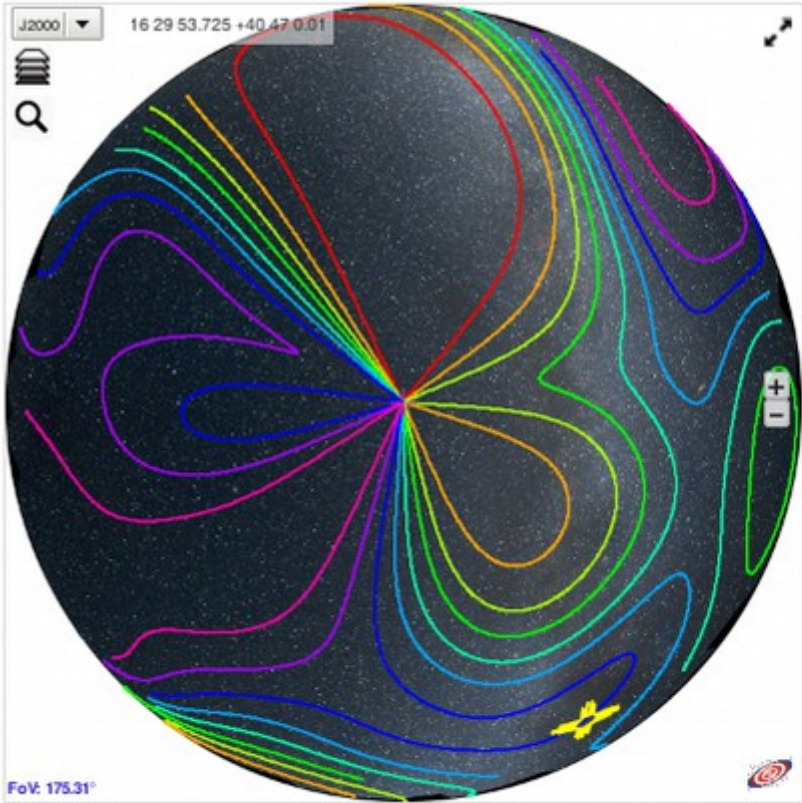
E Longitude Latitude

[Show Sky](#)

Sun =  and  = Moon

Catalog Sources

J2000 16 29 53.725 +40 47 0.01



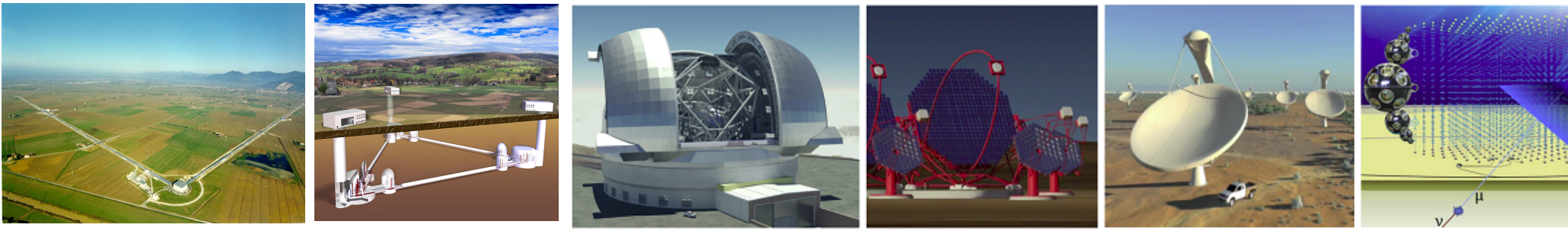
FoV: 175.31°

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/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>
</VOEvent>
```

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<WhereWhen>
  <ObsDataLocation>
    <ObservatoryLocation id="LIGO Virgo"/>
    <ObservationLocation>
      <AstroCoordSystem id="UTC-FK5-GEO"/>
      <AstroCoords coord_system_id="UTC-FK5-GEO">
        <Time>
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            <ISOTime>2010-09-27T14:09:05.425029</ISOTime>
          </TimeInstant>
        </Time>
        <Position2D>
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            <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

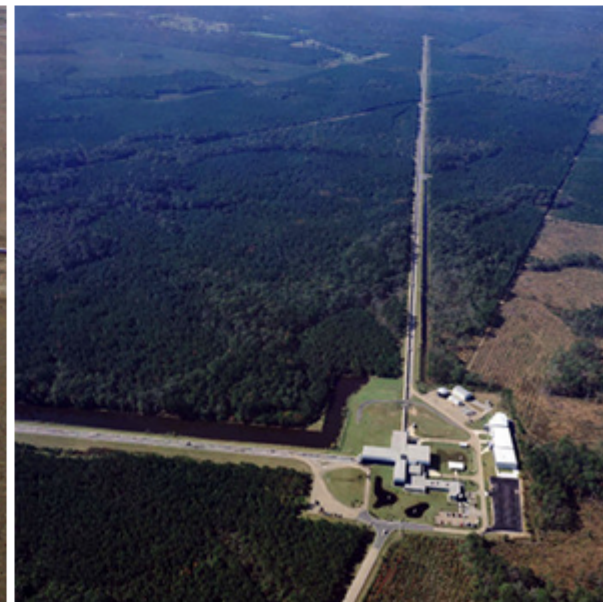
For background on the LIGO Open Science Center, see [arXiv:1410.4839](https://arxiv.org/abs/1410.4839).

For general information on LIGO, please visit ligo.org.

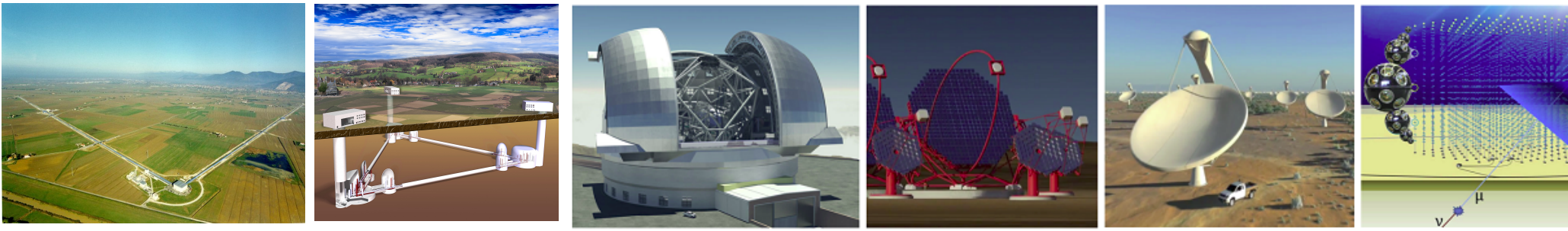
If you have LSC credentials, you may go to the [development site](#).



LIGO Hanford Observatory, Washington (image: C.Gray)



LIGO Livingston Observatory, Louisiana (image: J.Glaime)



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, ...)