

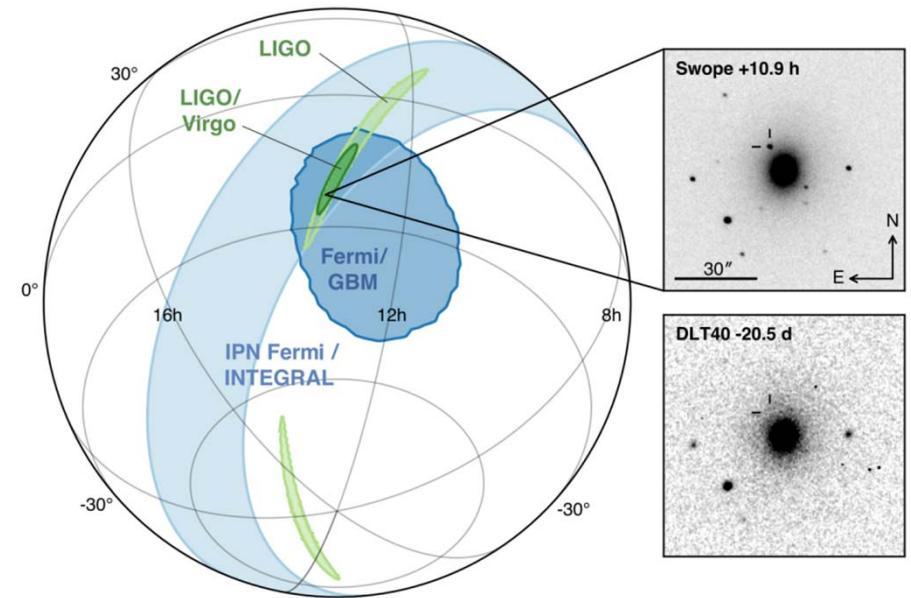
# Welcome and Introduction

SteemSTEM visit, September 20, 2018

**Nicolas Arnaud** ([narnaud@lal.in2p3.fr](mailto:narnaud@lal.in2p3.fr))

Laboratoire de l'Accélérateur Linéaire (CNRS/IN2P3 & Université Paris-Sud)

European Gravitational Observatory (Consortium, CNRS & INFN)



# Welcome!

- Welcome to the **European Gravitational Observatory (EGO)**
  - **Site of the Virgo experiment**
- Virgo is a **giant** (3-km arms) **suspended** and **recycled Michelson interferometer** designed to make **direct detections of gravitational wave (GW) signals**
- **Advanced Virgo (AdV)** is the second generation Virgo detector
  - **5-year upgrade** followed by a **successful data taking period in August 2017** and a **new upgrade period ongoing until the end of the year**
  - **Ultimate goal: improve the overall sensitivity by one order of magnitude**
- **Advanced Virgo joined the two Advanced LIGO (aLIGO) detectors on August 1, 2017 for a first common data taking period**
  - **Until August 25, 2017**
  - **Two major detections: GW170814 and GW170817**
- **Currently: commissioning period, following another major upgrade of the detector**
  - **Goal: improve the sensitivity by a factor  $\sim 2$**
  - **Target: new joint LIGO-Virgo data taking period starting early 2019**

# Outline

- Your **visit**
- The **Virgo collaboration**
- A few words about **EGO**
- A quick overview of our research field
  - **Detecting and studying gravitational waves**  
→ **Multi-messenger astronomy**
  - A glimpse of the **future**

# Program of today's visit

- **Indico** page: <https://events.ego-gw.it/indico/conferenceDisplay.py?confId=71>

## SteemSTEM community

chaired by Nicolas Arnaud (LAL (CNRS/IN2P3 & Université Paris-Sud))

Friday, 21 September 2018 from **08:00** to **20:00** (Europe/Rome)  
at **EGO, Virgo site**

### Material

[A selection of educational resources in English](#)

[Risorse didattiche in Italiano](#)

[Virgo news](#)

[Virgo public website](#)

[Virgo status](#)

[h -- The Gravitational Voice](#)

### Friday, 21 September 2018

- |               |  |
|---------------|--|
| 10:00 - 10:30 | Welcome, presentation of the visit and of EGO 30'<br>Speaker: Dr. Nicolas Arnaud (LAL (CNRS/IN2P3 & Université Paris-Sud))                                       |
| 10:30 - 11:30 | Conference 1h0'<br>Speaker: Dr. Valerio Boschi   |
| 11:30 - 13:00 | Tour of the facility 1h30'<br>Speaker: Dr. Valerio Boschi  |
| 13:00 - 13:45 | Q&A session 45'<br>Speakers: Dr. Nicolas Arnaud (LAL (CNRS/IN2P3 & Université Paris-Sud)), Dr. Valerio Boschi, Antonino Chiummo, Gary Hemming, Giuseppe Di Biase |
| 13:45 - 14:45 | Lunch at the EGO canteen   |



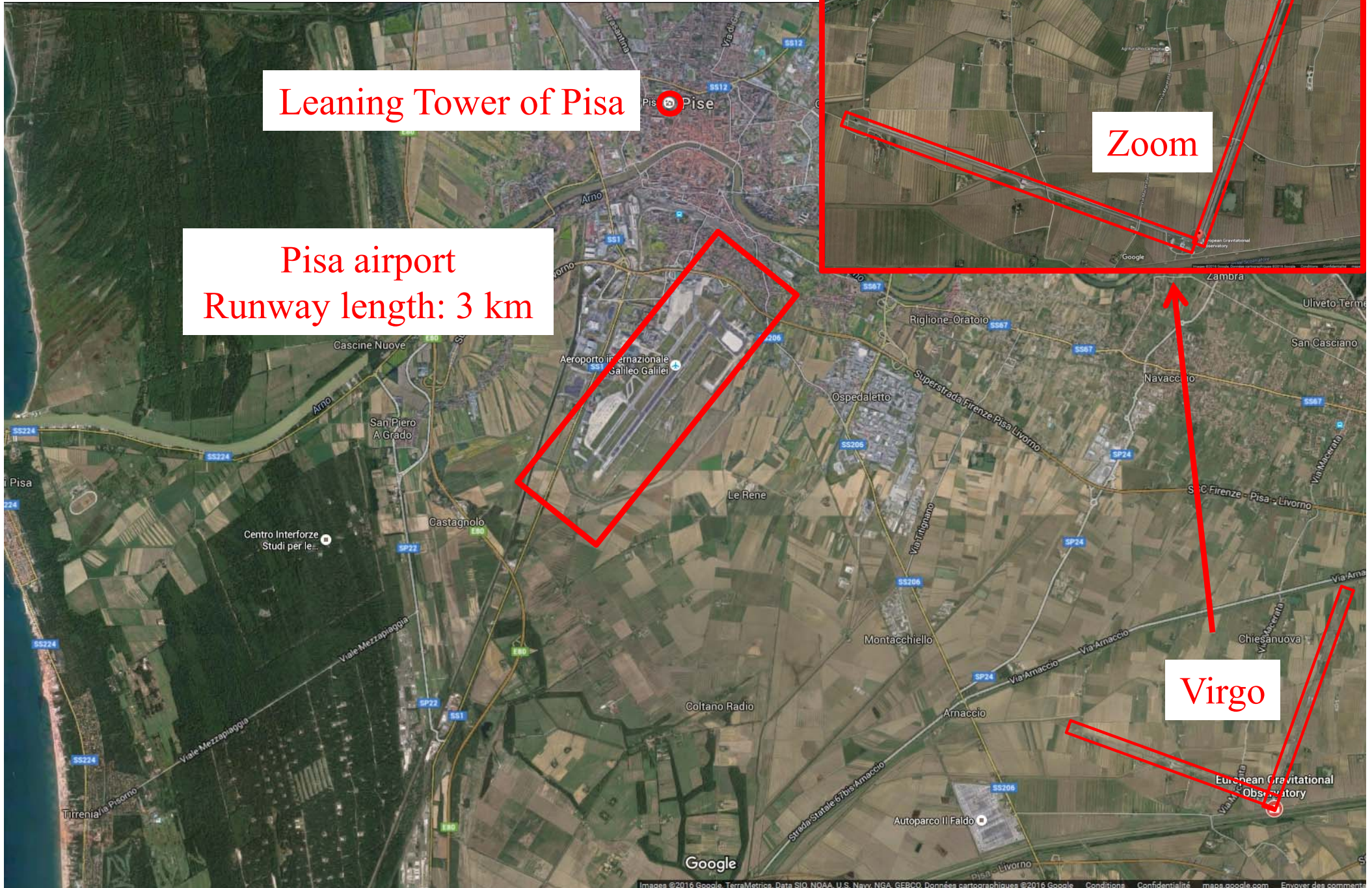
# The Virgo site

Leaning Tower of Pisa

Pisa airport  
Runway length: 3 km

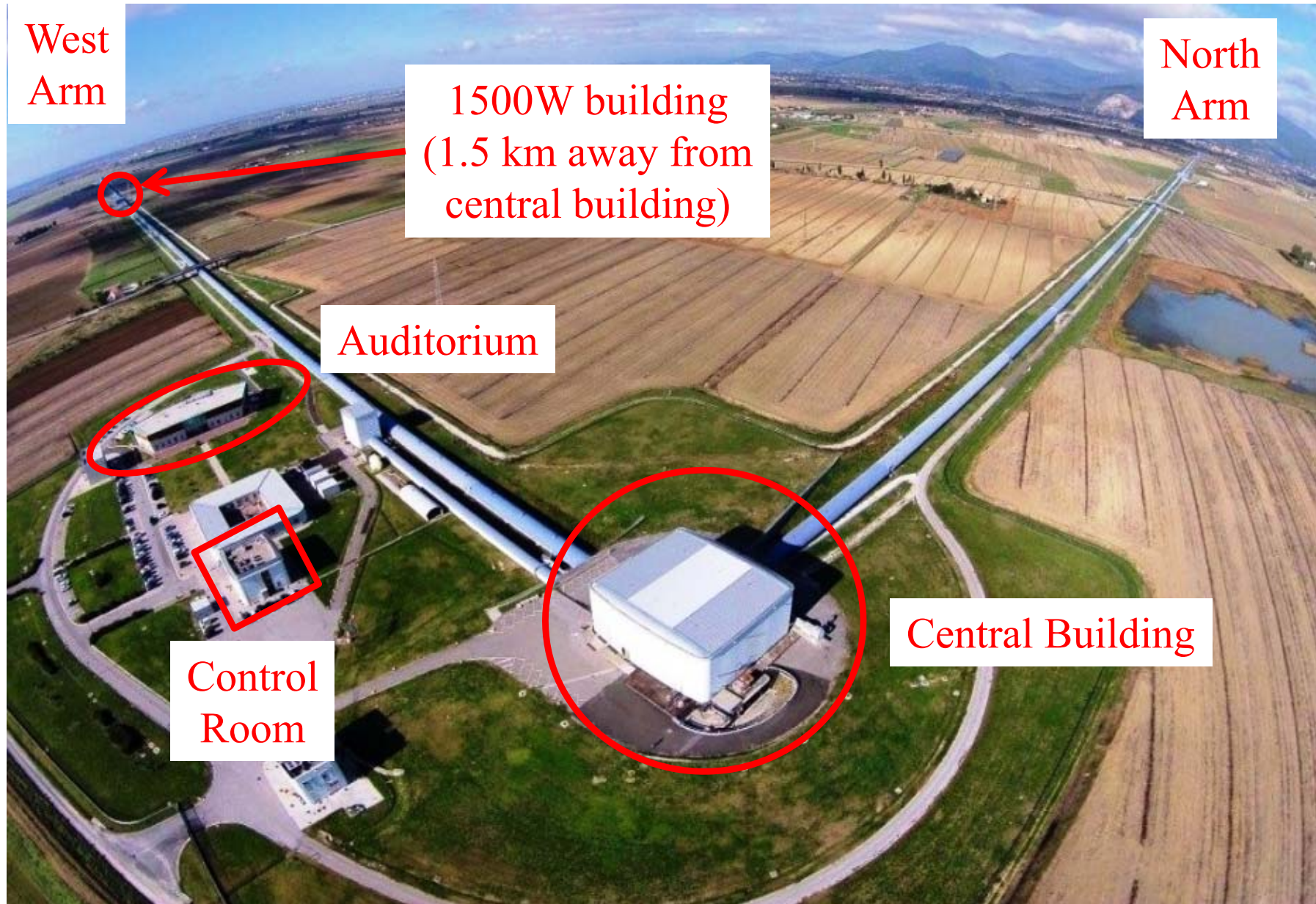
Zoom

Virgo





# Virgo from the sky





# The Virgo Collaboration

- 7 European countries



- 20+ groups

- About 300 members (LIGO: 750)



# The Virgo Collaboration

- 7 European countries



- 20+ groups

- About 300 members (LIGO: 750)

- Virgo was built by 11 CNRS (France) and INFN (Italy) laboratories

- Budget: ~150 M€

- Groups from the Netherlands, Poland, Hungary, Spain and Belgium joined later the project

- Advanced Virgo funding: ~20 M€

- Plus in-kind contribution from NIKHEF (NL)

- The EGO (European Gravitational Observatory) consortium is managing the Virgo site in Cascina. It provides the infrastructures and resources to ensure the detector construction and operation

APC Paris

ARTEMIS Nice

Barcelona University

EGO Cascina

INFN Firenze-Urbino

INFN Genova

INFN Napoli

INFN Perugia

INFN Pisa

INFN Roma La Sapienza

INFN Roma Tor Vergata

INFN Padova

INFN TIFPA

LAL Orsay – ESPCI Paris

LAPP Annecy

LKB Paris

LMA Lyon

NIKHEF Amsterdam

POLGRAW (Poland)

RADBOUD Uni. Nijmegen

RMKI Budapest

UC Louvain & U. Liège

Valence University

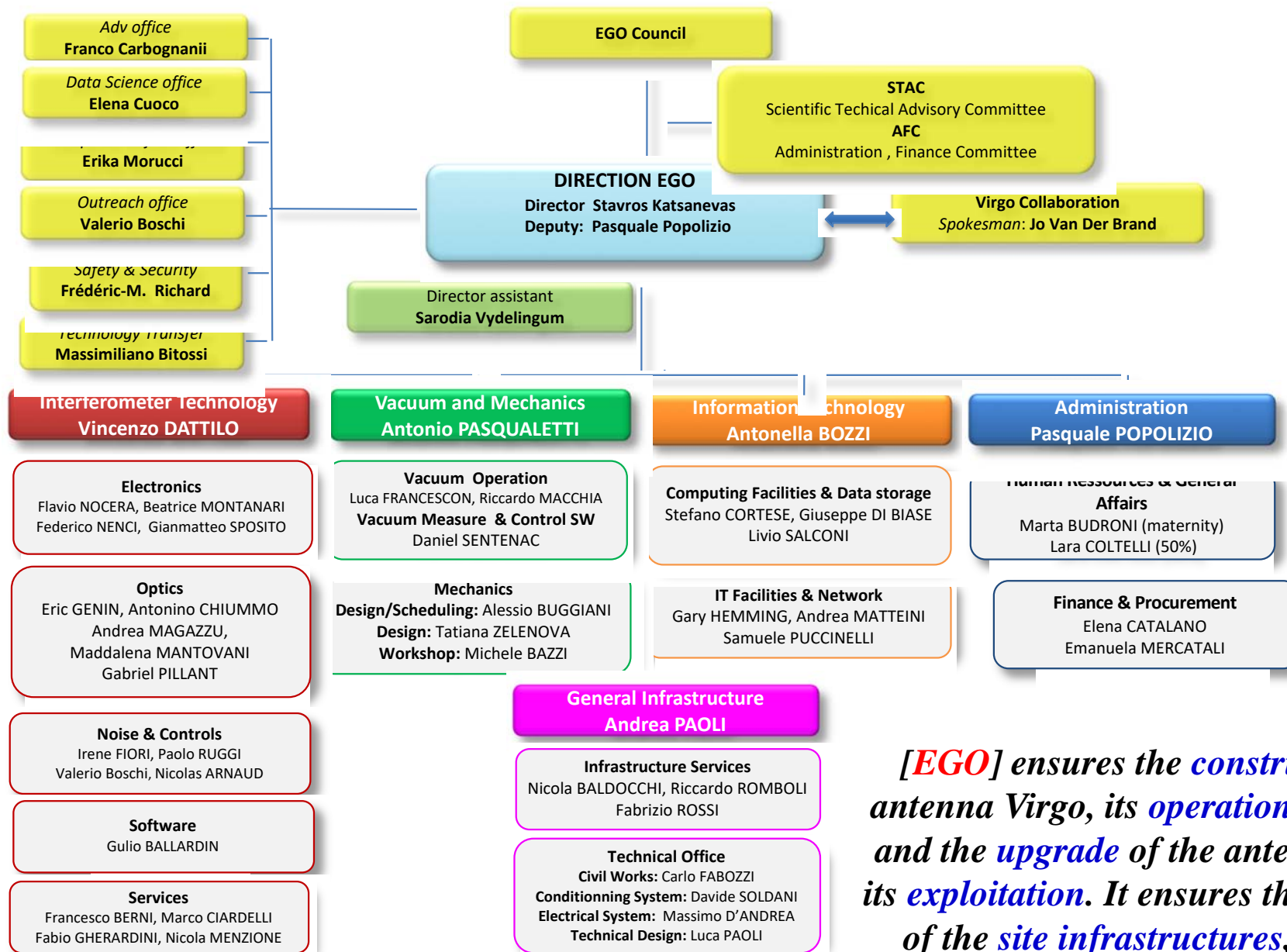


# A bit of history

- 1980's: Collaboration between **Alain Brillet** (CNRS, Orsay, lasers) and **Adalberto Giazotto** (INFN, Pisa, suspensions)
- 1989: **Proposal**
- June 27 1994: **Project approved** by CNRS and INFN
- May 1997: Final **design report**
- 2003: **End of construction phase**
- 2007-2010: **Data taking periods**
  - Virgo first, then Virgo+
- 2011-2016: **Upgrade to Advanced Virgo**
  - **2015: first direct detections of gravitational waves**
    - Data recorded by Advanced LIGO, jointly analyzed by LIGO and Virgo
- 2016-2017: **Advanced Virgo commissioning**
- 2017: **First joint Advanced LIGO – Advanced Virgo data taking period**
  - **August 2017: first detections** by the **LIGO-Virgo 3-detector network**



# EGO organization chart



***[EGO]** ensures the construction of the antenna Virgo, its operation, maintenance and the upgrade of the antenna as well as its exploitation. It ensures the maintenance of the site infrastructures, including a computer center and promotes an open cooperation in R&D.*

- 50 people, 10 M€ yearly budget



# Education and Outreach

- **ARGO**: **A**rt and **R**esearch of **G**ravitational **O**bservation



# Visits

- **Number of visitors doubling every year!**
  - Additional load on the people on-site
  - Commitment to be open to the general public
- Geographical origin
  - 40% Tuscany
  - 40% Italy, outside Tuscany
  - 20% abroad

→ More and more requests from higher education and/or distant groups
- Open days
  - Example: the **European Researchers' Night**  
→ Next Friday

## Number of visitors @ EGO



**La notte europea dei ricercatori 2018**  
European Gravitational Observatory

28 Settembre 2018

**BRIGHT 2018**  
LA NOTTE DEI RICERCATORI IN TOSCANA

[public.virgo-gw.eu/Bright2018](http://public.virgo-gw.eu/Bright2018) [www.virgo-gw.eu](http://www.virgo-gw.eu)

**11:00 Un caffè insieme a Marica Branchesi**

- Incontra Marica Branchesi ed altre personalità della ricerca delle onde gravitazionali di Virgo
- Un caffè insieme a M. Branchesi, A. Bozzi, J. Casanueva, C. De Rossi, I. Fiori, S. Katsanevas, M. Mantovani.
- A cura di P. Antolin e I. Marini.
- Luogo: Auditorium Liceo Scientifico 'U. Dini', via B. Croce 36, 56125 Pisa
- **POSTI LIMITATI**

**15:30 Tour di Virgo**

- A cosa serve Virgo? Come funziona? Vieni a visitare Virgo. Il grande orecchio che ascolta il suono dell'universo
- Con la partecipazione di V. Boschi, C. Bradaschia, V. Dattilo, I. Fiori.
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)
- **POSTI LIMITATI**

**16:00 Gelato Criogenico**

- Cosa possono avere in comune l'interferometro Virgo e il gelato? L'azoto liquido! Scoprire il perché durante una degustazione alla gelateria criogenica.
- Con la partecipazione di A. Pasqualetti, D. Sentenac e la Gelateria De' Cottelli
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)

**16:00 Stampa 3D**

- Cosa ci fa a Virgo una stampante 3D?
- Con la partecipazione di A. Buggiani
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)

**16:00 Informatica senza computer**

- Si può capire l'informatica senza usare i computer? Scoprirlo giocando con noi.
- Con la partecipazione di R. Cavalieri
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)

**16:00 Osservazioni astronomiche**

- Associazione astrofili di Pisa e Cascina
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)

**18:00 Seminario "Light is life"**

- Vieni a scoprire come la luce influenza la vita.
- Con la partecipazione di M. D'Andrea
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)

**19:00 Apericena con Marica Branchesi**

- Tutto quello che avresti sempre voluto sapere ma non hai mai osato chiedere. Prendi un aperitivo con Marica!
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)
- **POSTI LIMITATI**

**21:00 Music and Science Concert**

- Musica e scienza si incontrano con l'ensemble barocco il Rossignolo.
- Con la partecipazione di V. Boschi, il Rossignolo
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)
- **POSTI LIMITATI**

**22:00 Osservazioni astronomiche**

- Associazione astrofili di Pisa e Cascina
- Luogo: European Gravitational Observatory, via E. Amaldi, 56021 Cascina (PI)

Alcuni eventi hanno un numero limitato di posti disponibili. La prenotazione è obbligatoria  
Un servizio di bus navetta gratuito con partenza dalla stazione FS Pisa Centrale per EGO sarà messo a disposizione dei visitatori

[www.facebook.com/EGOVirgoCollaboration](https://www.facebook.com/EGOVirgoCollaboration) [www.twitter.com/ego\\_virgo](https://www.twitter.com/ego_virgo)



# 1916-2018: a century of progress

- **1916: GW prediction (Einstein)**

## **1957: Chapel Hill Conference**

- **1963: rotating BH solution (Kerr)**

- **1990's: CBC PN expansion**  
(Blanchet, **Damour**, Deruelle, Iyer, Will, Wiseman, etc.)

- **2000: BBH effective one-body approach** (Buonanno, **Damour**)

- **2006: BBH merger simulation**  
(Baker, Lousto, Pretorius, etc.)

*Theoretical developments*

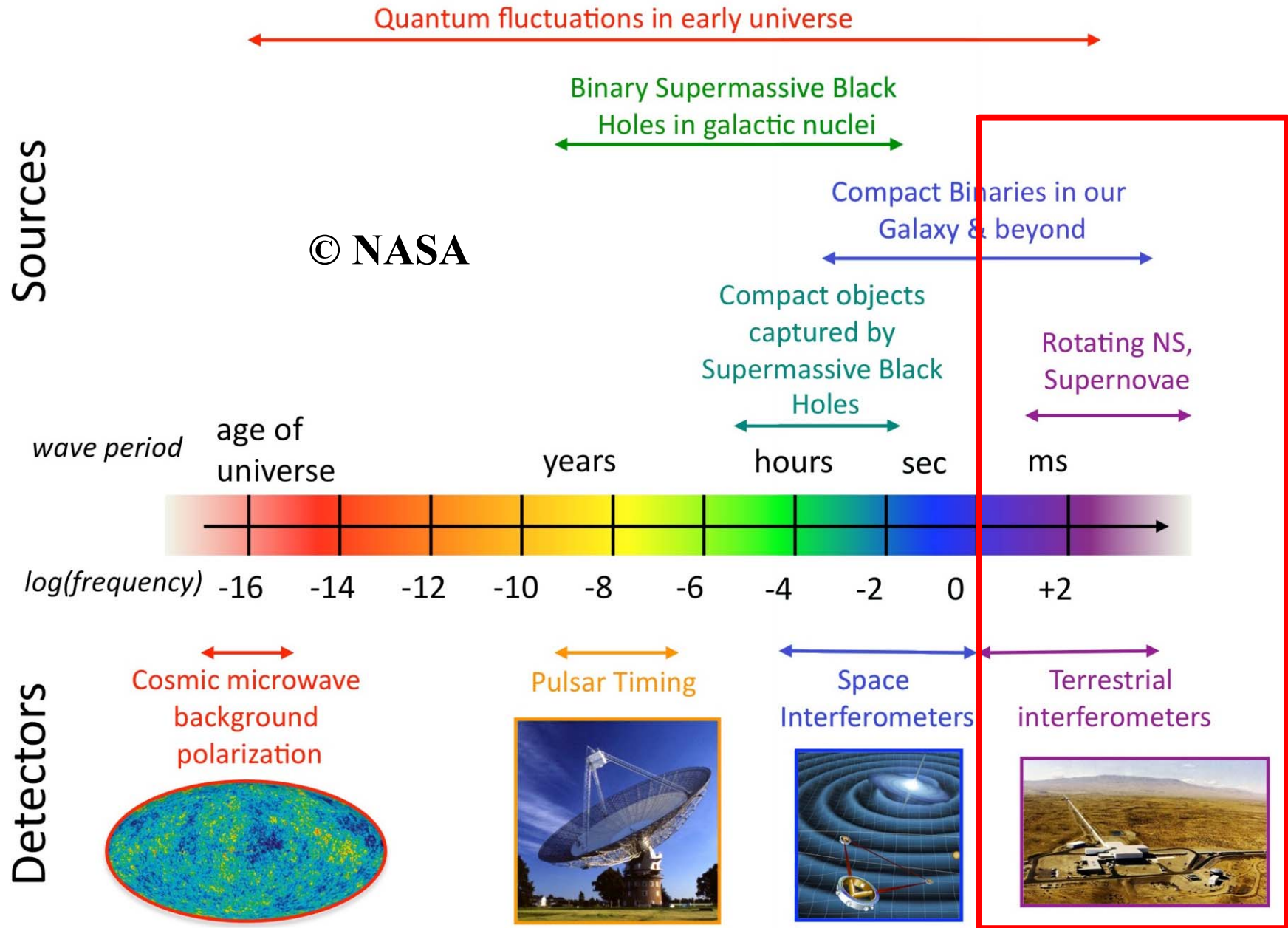
*Experiments*

(Bondi, Feynman, Pirani, etc.)

- **1960's: first Weber bars**
- **1970: first IFO prototype** (Forward)
- **1972: IFO design studies** (**Weiss**)
- **1974: PSRB 1913+16** (Hulse & Taylor)
- **1980's: IFO prototypes (10m-long)**  
(Caltech, Garching, Glasgow, Orsay)  
→ **End of 1980's: Virgo** (**Brillet, Giazotto**)  
and **LIGO proposals**
- **1990's: LIGO and Virgo funded**
- **2005-2011: initial IFO « science » » runs**
- **2007: LIGO-Virgo MoU**
- **First half of the 2010's: Upgrades**
- **2015: First Advanced LIGO run**
- **2017: First Advanced Virgo run**

**First GW  
Detections**

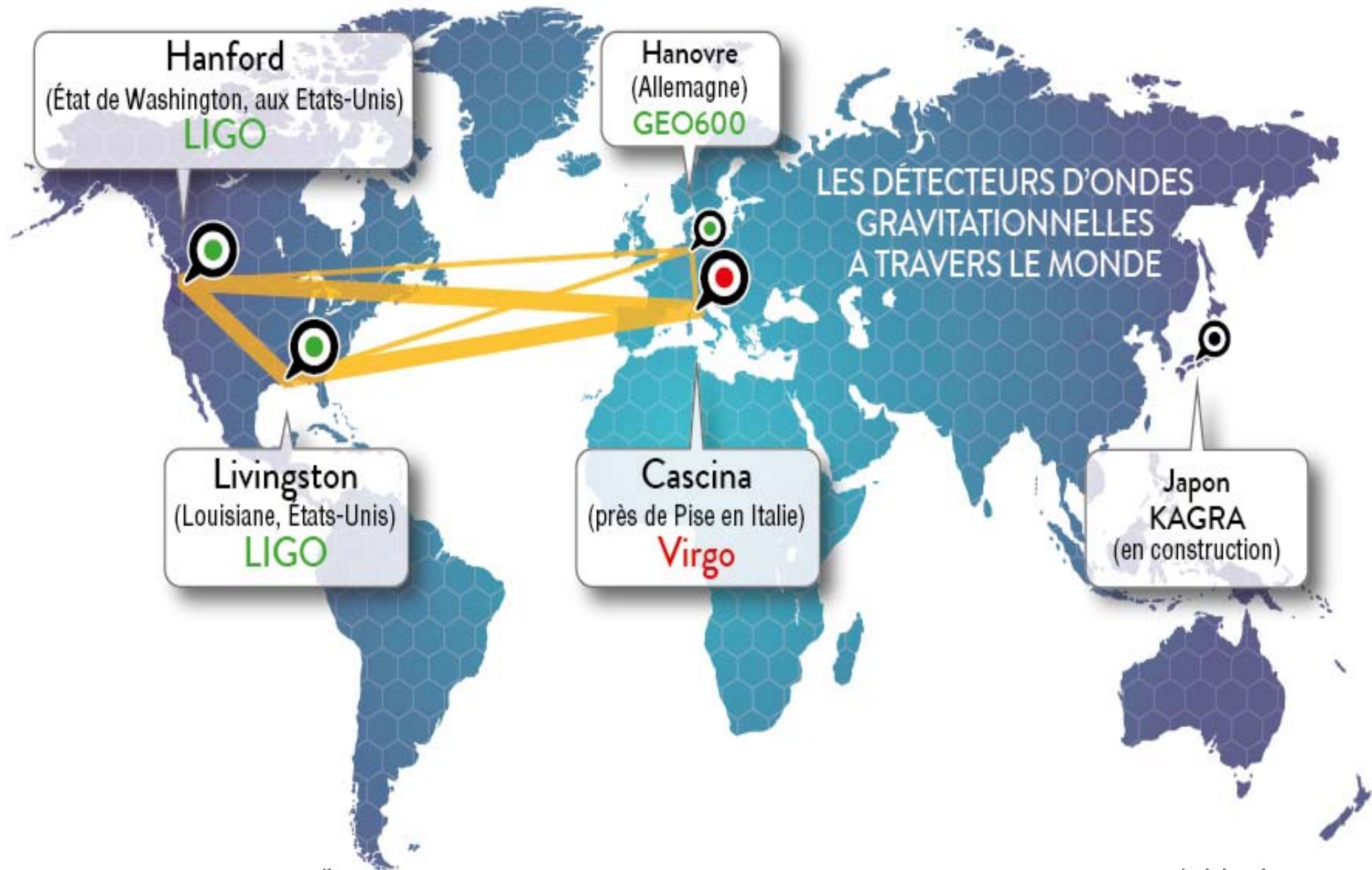
# Gravitational wave spectrum



LIGO, Virgo, etc.



# A network of interferometric detectors



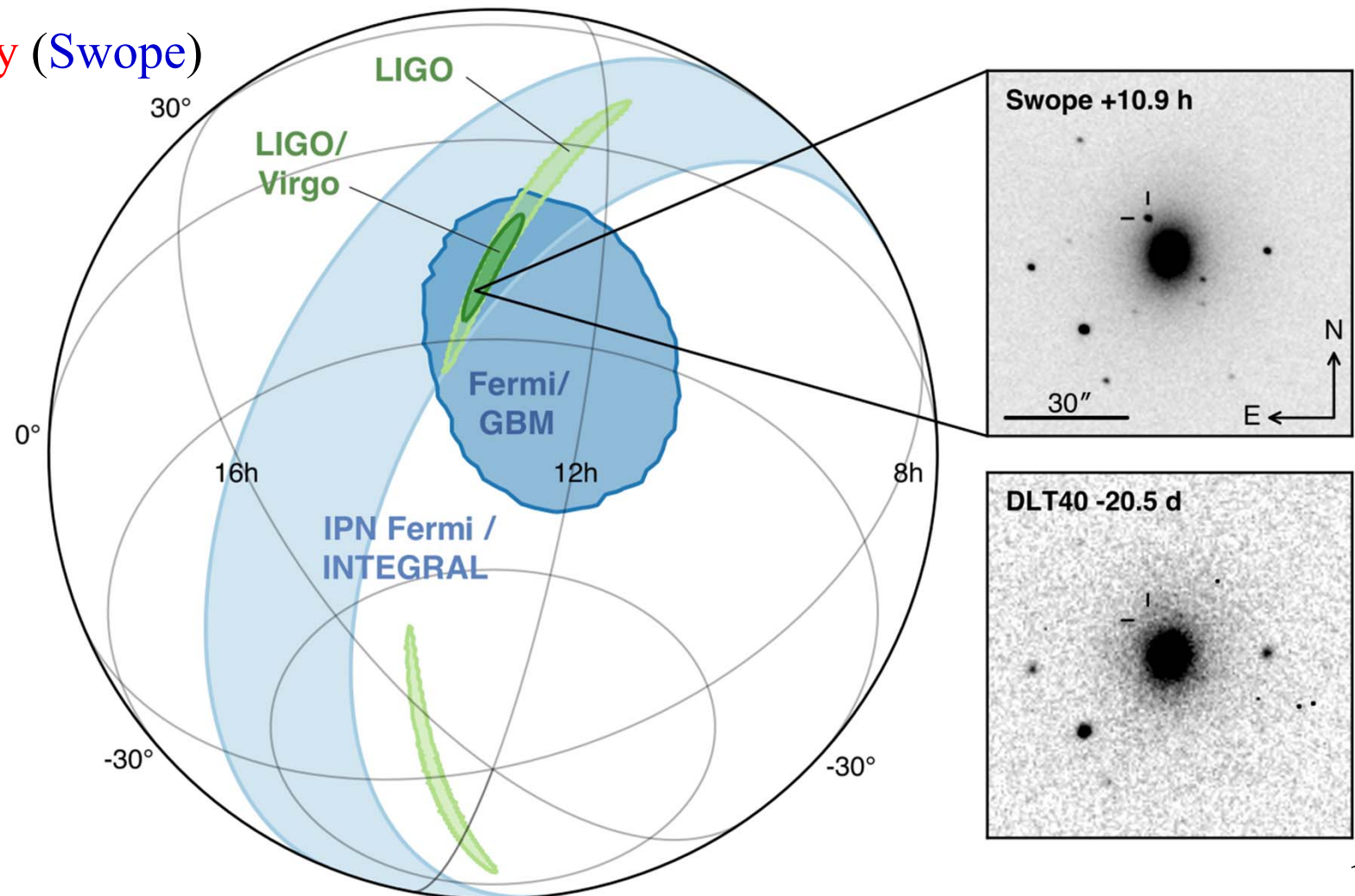


# A network of interferometric detectors



# GW170817: sky localizations & source position

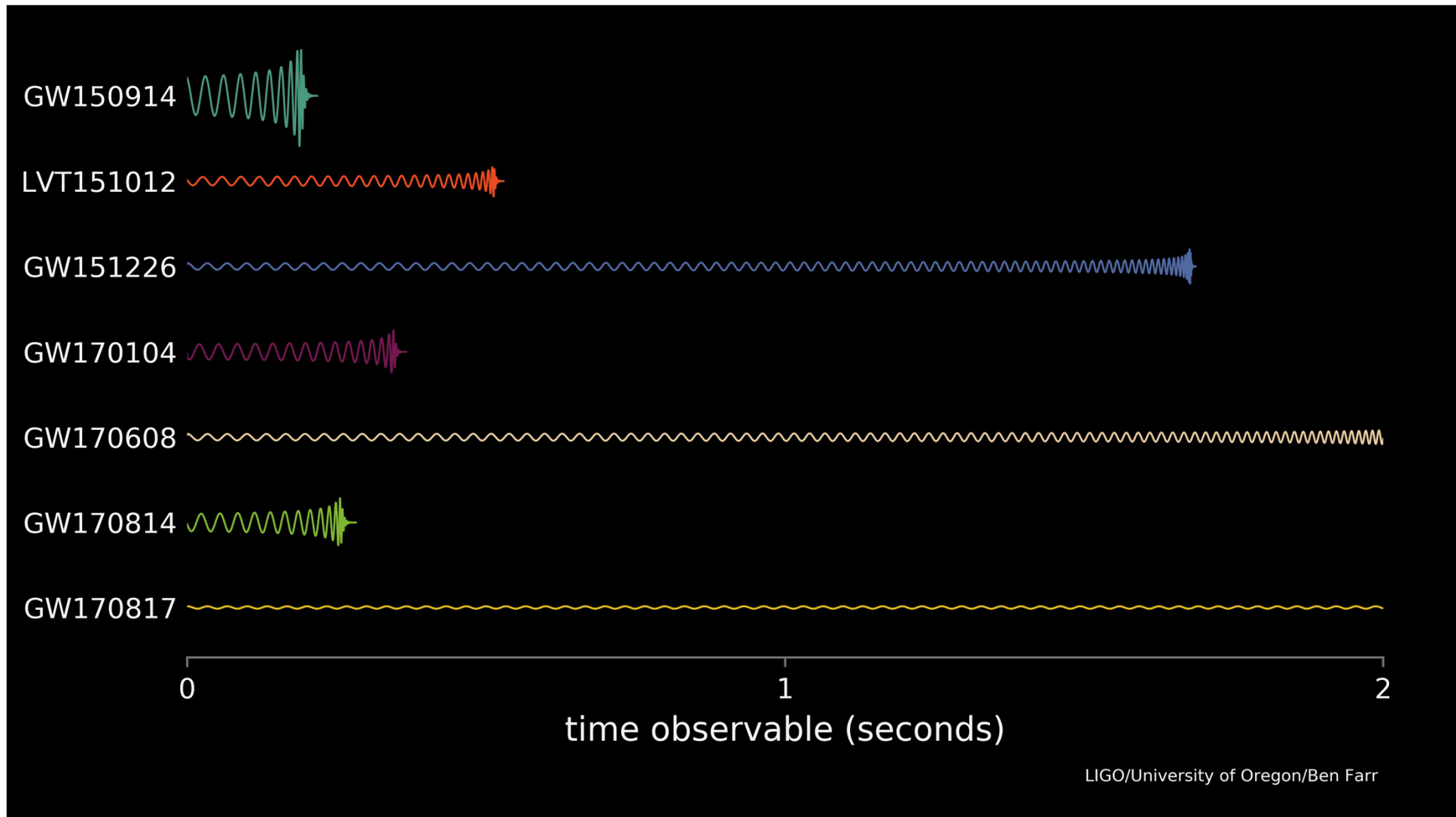
- **Green:** LIGO and **LIGO + Virgo**
- **Blue :** information from **gamma ray burst satellites**
- **Optical discovery (Swope)**



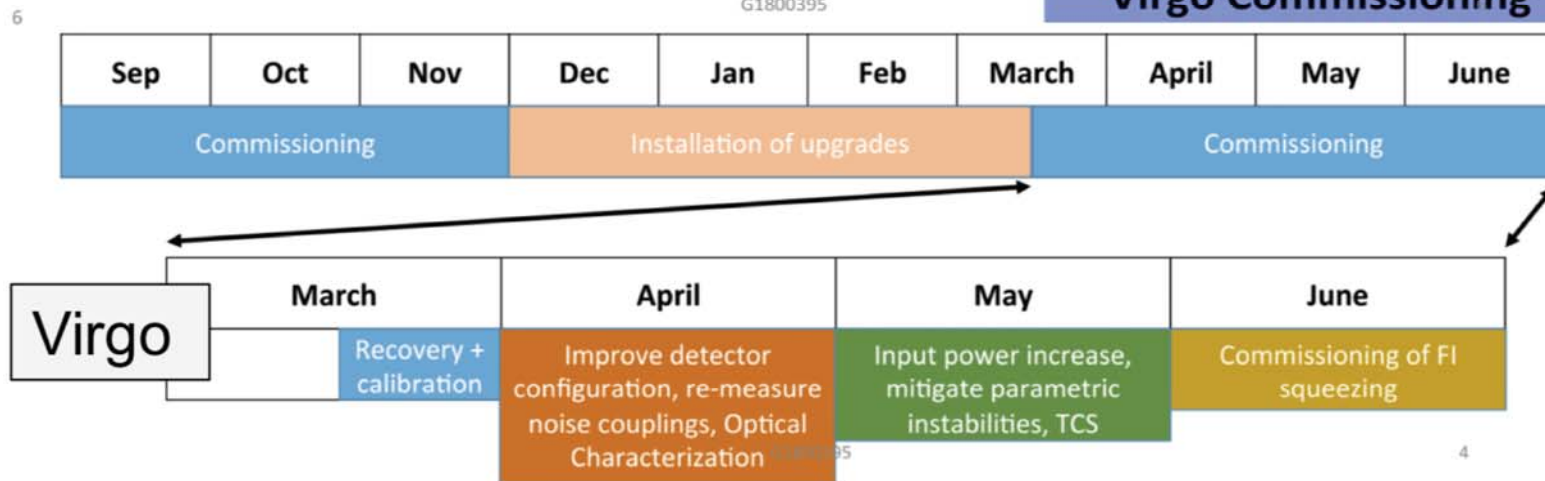
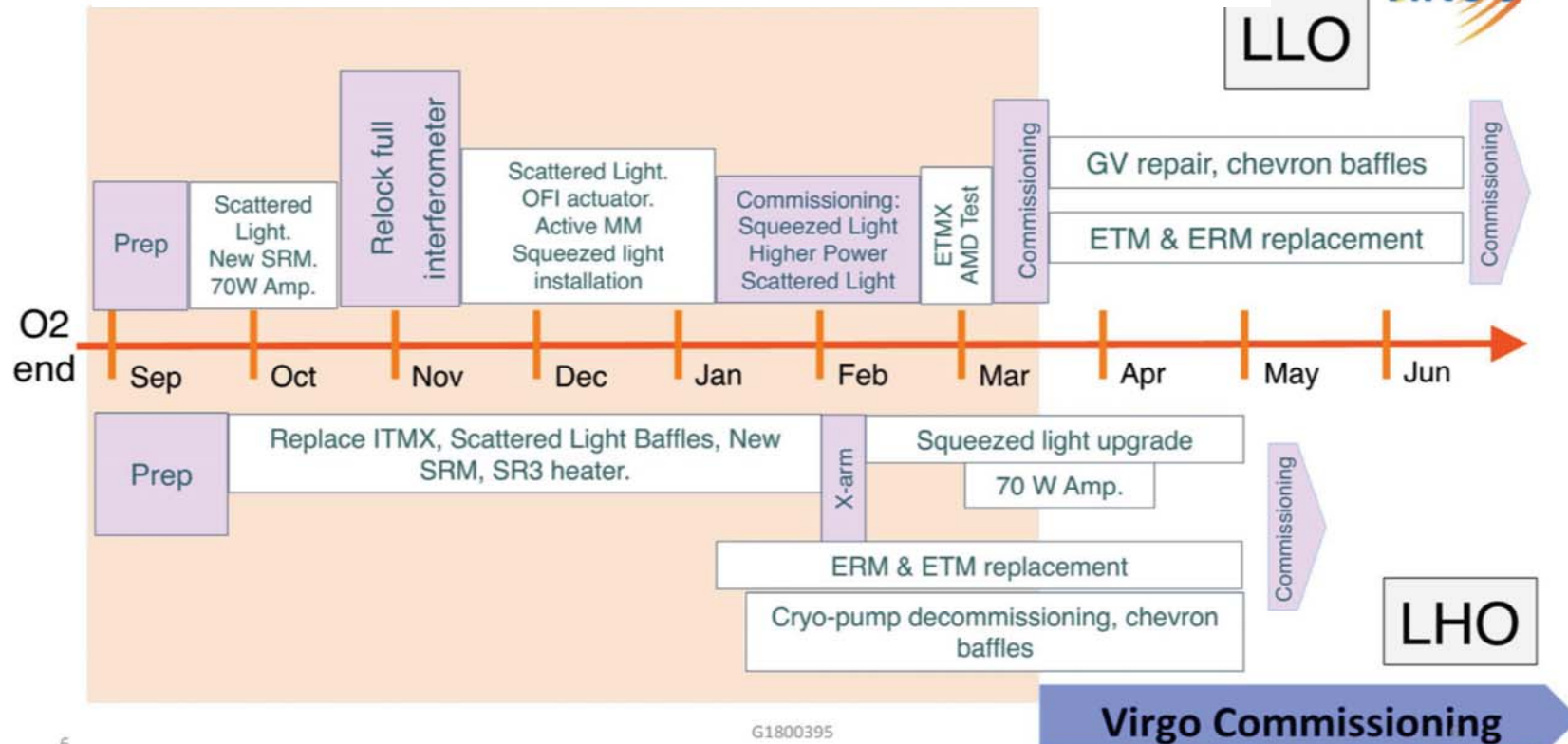


# Detections

- **Five binary black hole coalescences**
  - GW150914, GW151226, GW170104, GW170814, GW170608
- **One neutron star coalescence: GW170817**



# One year-long LIGO-Virgo shutdown



# One year-long LIGO-Virgo shutdown

- **Hardware upgrades**

- **Virgo**

- High-power laser (up to 60W)
- Monolithic suspensions
- Vacuum system
- Frequency-independent squeezing



- Installation of an array of seismic sensors to measure the Newtonian noise

- **Technical and environmental noise hunting**

- Use experience gained during the commissioning and O2 data taking phases
- Improve/tighten detector control

- **Virgo**

- Post-O2 commissioning phase until early December 2017
- Hardware upgrades until mid-March 2018
- Then back to commissioning until next Fall
  - ◆ **Work still in progress to get back to O2-like sensitivity levels**

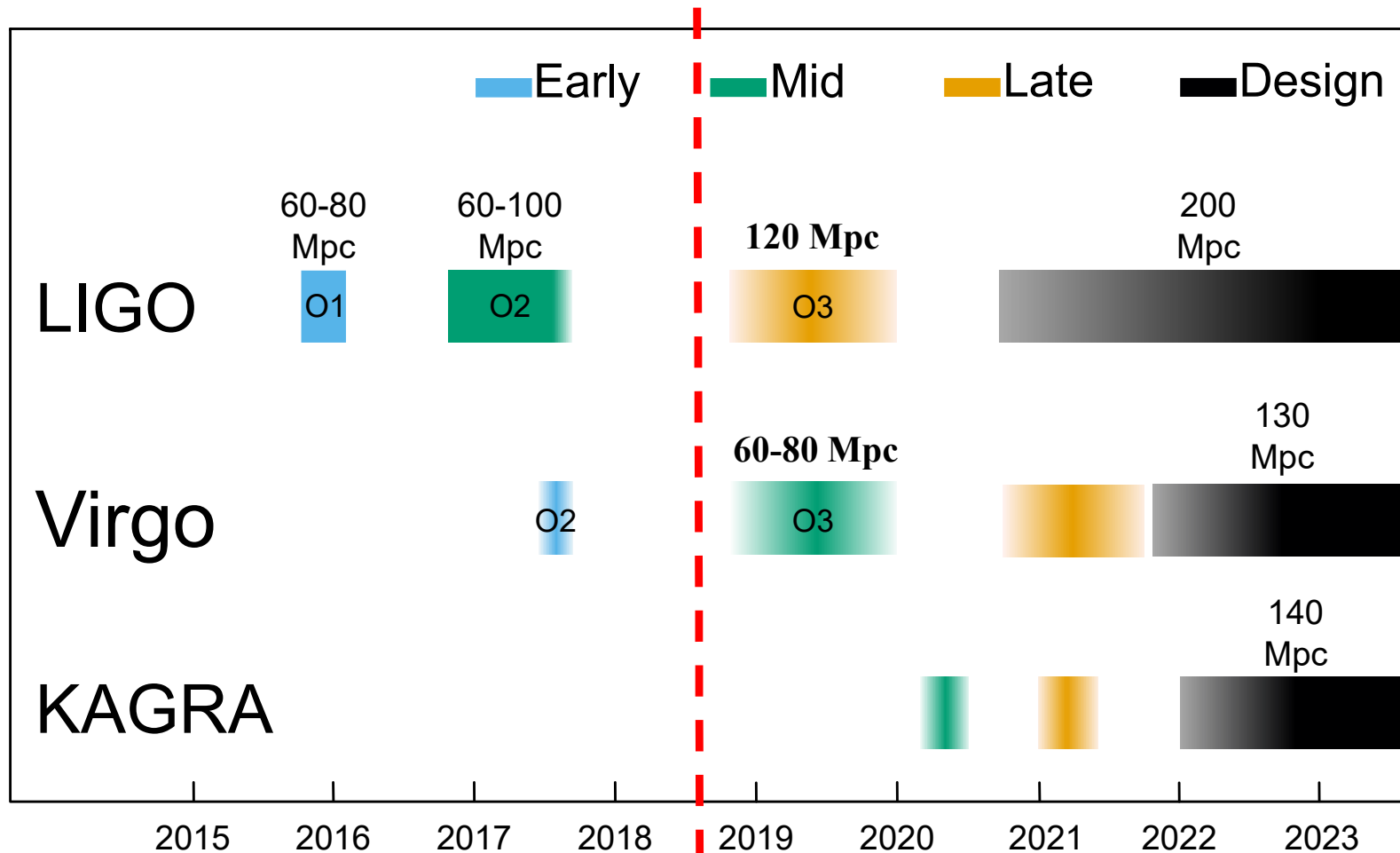
- **O3 run** will start end of 2018 (or early 2019) with the **three detectors online**

- **Sensitivity target** (BNS range, see next slide): **LIGO / Virgo = 120 / 60-85 Mpc**



# Observing scenario

- Sensitivity improvement over time
  - Expressed in terms of « Binary Neutron Star (BNS) range »
    - Sky-averaged distance up to which one can detect a BNS merger @ SNR = 8

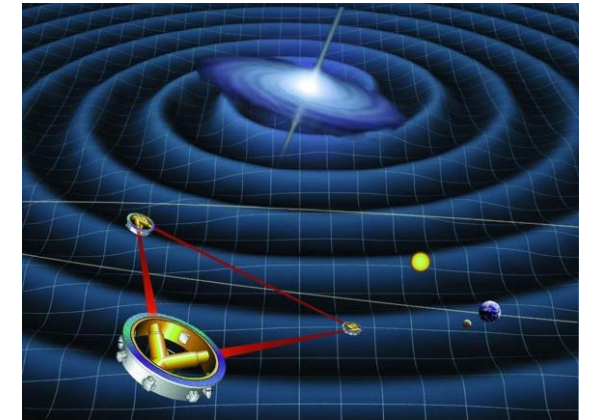


# On the longer term

- **Upgrades post-O3**

- Newtonian noise cancellation
- Frequency-dependent squeezing
- Signal recycling
- Full-power laser (up to 200 W)

→ **Virgo sensitivity goal:  $\sim 160$  Mpc**



- **After O4 (mid-2022): « Advanced Virgo + »**

→ Make the best possible use of the existing infrastructure

- Larger mirrors
- Improved coating

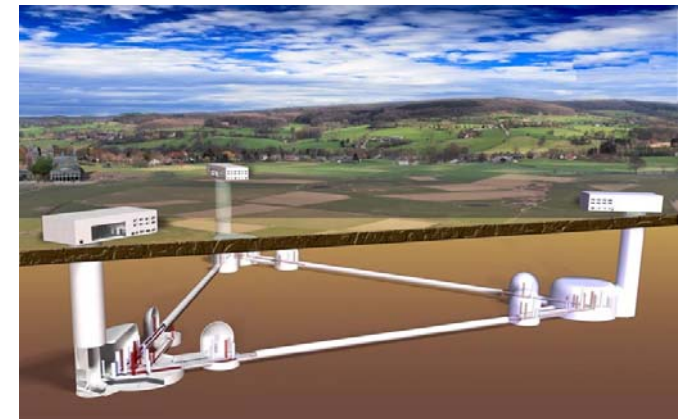
→ Reduce thermal noise

→ **Sensitivity goal:  $\sim 300$  Mpc**

- Launch of the **LISA** space mission scheduled for **2034**

- **Einstein Telescope**: around **2035**

- **Third-generation** interferometric gravitational-wave detector



# GW detector peak sensitivity evolution vs. time

