

# Virgo Gravitational Wave Master Classes

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1). Maastricht University, 2). Ellinogermaniki Agogi

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# GW master classes

In early 2021, a great deal of prior discussion was done on the educational and scientific goals of the Master Classes

**Main key points:**

\* Teachers and students get introductory material on gravitational wave science

\* Proceed with an online exercise using Virgo resources

\* ..followed by discussion with scientists and comparing to other classes

**In brief: become real scientists for a day!**

FRONTIER

IDEAS FOR GRAVITATIONAL WAVE MASTERCLASS EXERCISES

E. Chaniotakis (Ellinogermaniki), V. Boschi (INFN)

INFN ELLINOGERMANIKI AGOGI

Virgo Week, 25/1/2021

Pedagogical Considerations regarding a Gravitational Wave Astronomy Masterclass

Manolis Chaniotakis, Ellinogermaniki Agogi

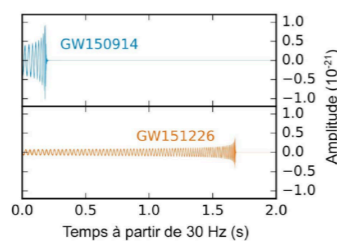


FRONTIER

Ideas toward a gravitational wave-based IMC session

IPPOG Meeting – CERN, November

Nicolas ARNAUD ([narnaud@lal.i](mailto:narnaud@lal.i))



EGO EUROPEAN GRAVITATIONAL OBSERVATORY



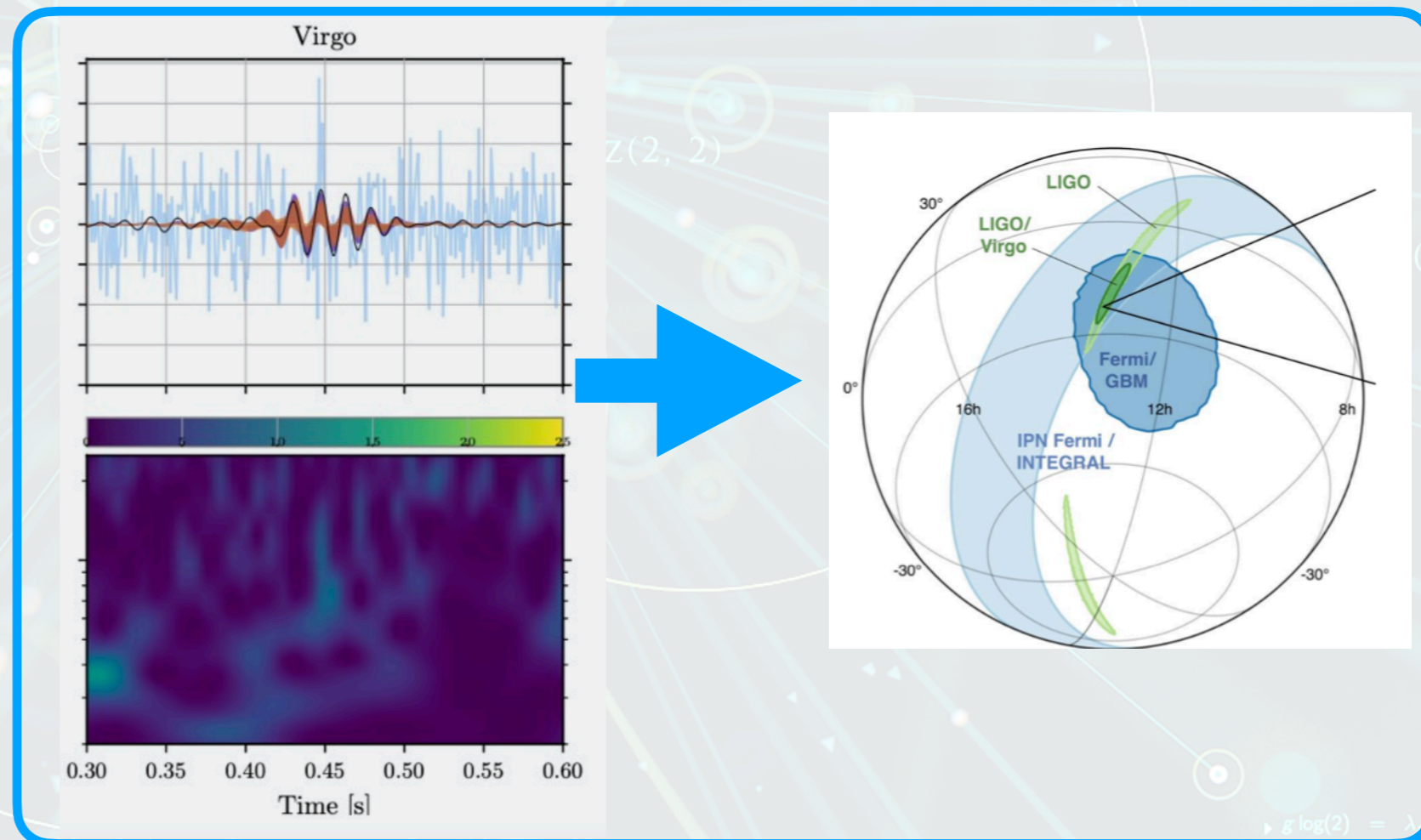
<https://wiki.virgo-gw.eu/Outreach/GW-Masterclasses>

# Master Class Exercises: from first example to fixed template

**Plan:** start with *one* Master Class Exercise to work out in detail and measure its effectiveness. Its form can next be used as a template for additional Master Class exercises.

## Possible topics:

- \* gravitational wave theory
- \* instrumentation
- \* data-analysis
- \* sky localisation



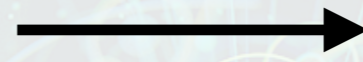
Nicolas Arnaud made a 'skeleton version' of the way our first exercise should look:

see:

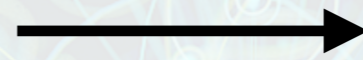
[https://wiki.virgo-gw.eu/pub/Outreach/GW-Masterclasses/20220531\\_GUIs.pdf](https://wiki.virgo-gw.eu/pub/Outreach/GW-Masterclasses/20220531_GUIs.pdf)

# GW Data analysis: Matched filtering

$$\frac{S}{N} = \sqrt{4 \int_0^\infty \frac{|\tilde{h}(f)|^2}{S_n(f)} df}$$

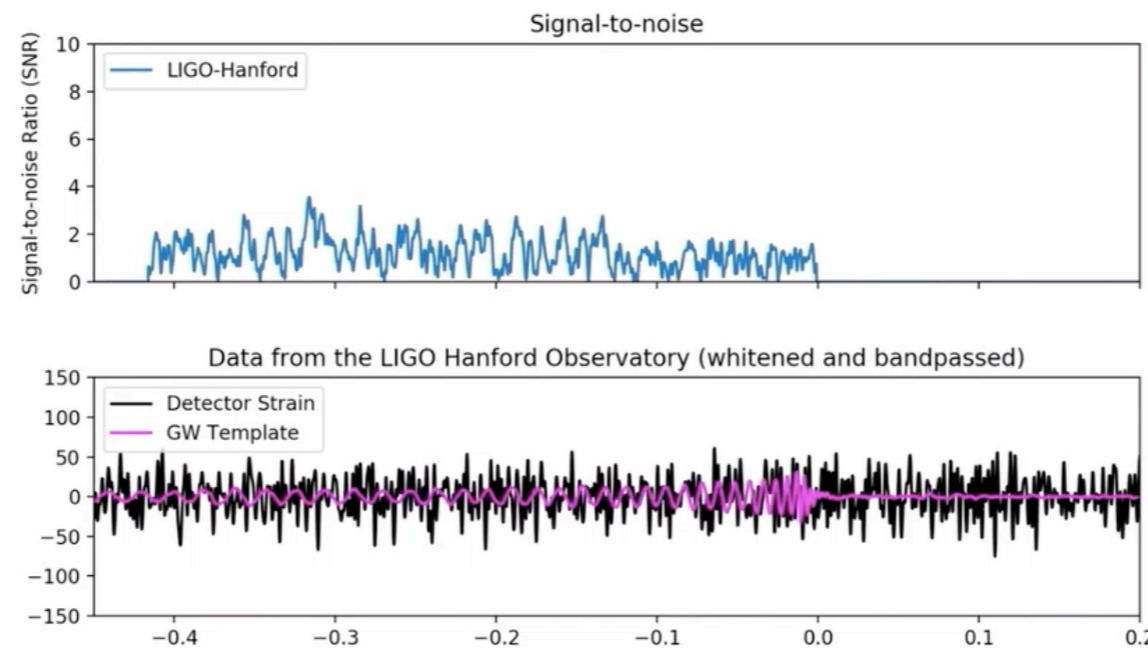


$h(f)$  = what one looks for



$S_n(f)$  = how one is thwarted by the detector

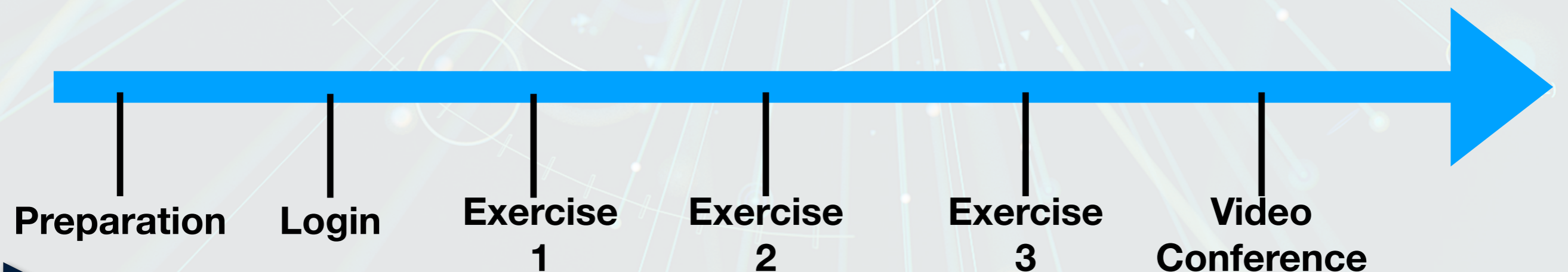
**Approach:** Try out gravitational waveform  $h(f)$  for different values of the parameter space, look for parameters that have highest SNR.



# Implementation

## Key physics questions addressed:

- \* How is gravitational wave detection done?
- \* How is data pre-processed?
- \* How to do parameter estimation once a gravitational wave has been found in the data?
- \* What is the role of coincidences in sky-localisation?



# Exercise 1 (40 minutes)

Training exercise on detecting gravitational waves and doing parameter estimation.

## Step 1:

Students do a series of trial exercises on triangular and Gaussian gravitational wave signals.

## Step 2:

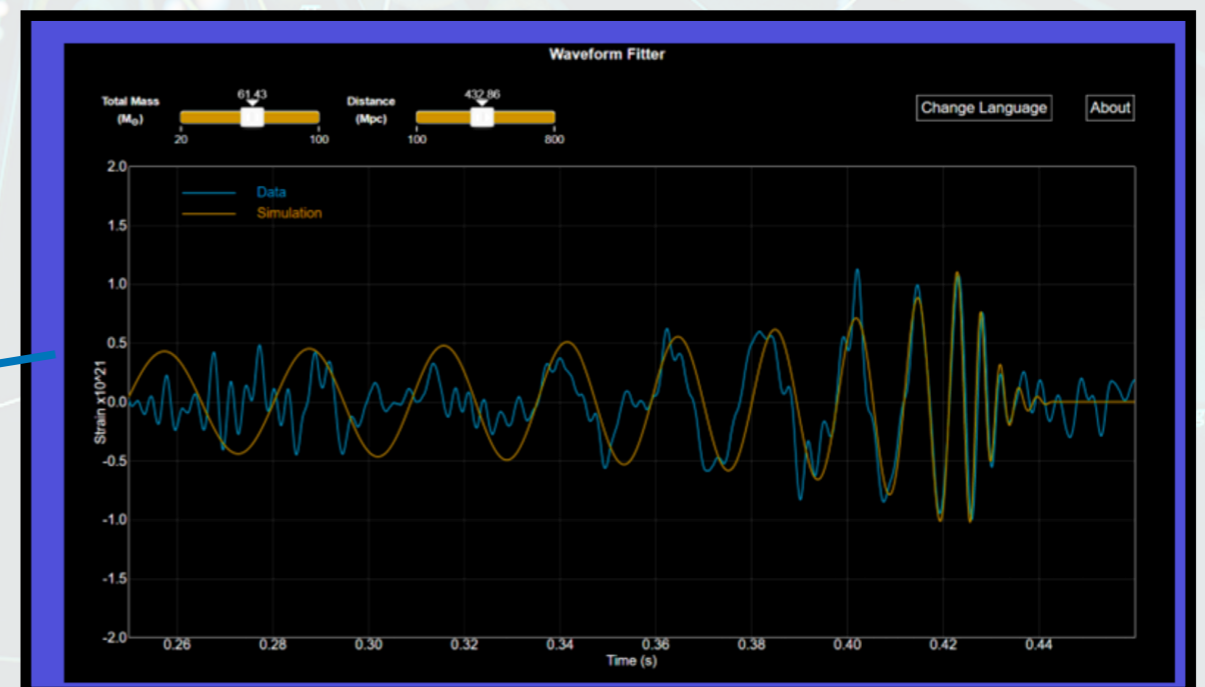
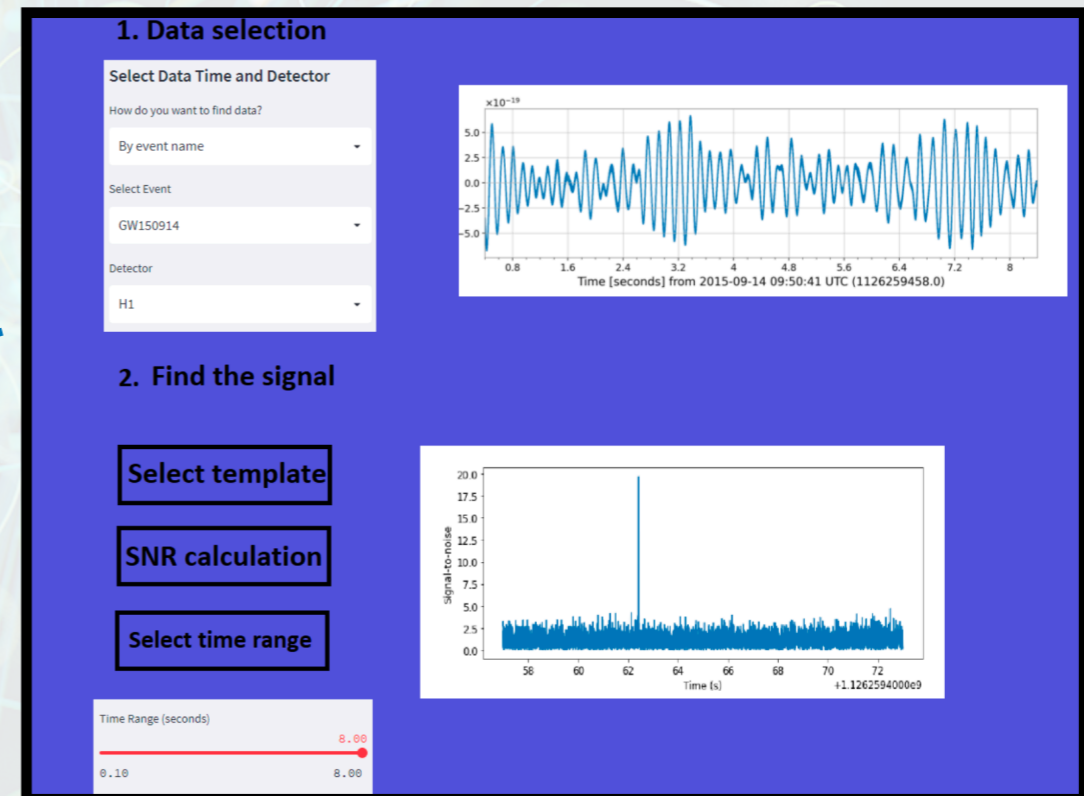
Students select a (real) data stretch from a GW detector, a template, and perform an SNR calculation

## Step 3:

Students whiten and bandpass their data around their signal

## Step 4:

Students perform parameter estimation



# Exercise 2 (60 minutes)

**Repeating detecting gravitational waves and doing parameter estimation.**

This time, it is not known beforehand that there is a GW hidden in the data, and the timing of the GW is to be determined by the students themselves.

The screenshot shows a software interface with four main sections:

- 1. Data selection:** Includes a dropdown for 'Select Data Time and Detector', a plot of 'Time (seconds) from 2015-09-14 09:50:41 UTC (112629458.0)', and a 'Detector' dropdown set to 'H1'.
- 2. Find the signal:** Features buttons for 'Select template', 'SNR calculation', and 'Select time range'. It shows a plot of 'signal (noise)' and a 'Noise or signal?' button.
- 3. Data whitening and bandpassing:** Includes a 'Whitened and band-passed data' plot, a 'Whiten?' checkbox, and a 'Band-pass frequency range (Hz)' slider. A red vertical line indicates the 'arrival time (GPS time)'. A 'Done. Go to next data stretch' button is at the bottom right.
- 4. Parameter estimation:** Shows a 'Waveform Filter' plot with a 'Done. Go to next data stretch' button.

	Nickname	Detector	Data stretch	Arrival time	Time range	Frequency range	Total mass	Distance	chisquare
Group name	Nickname 1	Detector 1	GWabc	GPS time 1	Time range 1	Freq. range 1	M1	d1	$\chi^2_1$
	Nickname 2	Detector 2	GWabc	GPS time 2	Time range 2	Freq. range 2	M2	d2	$\chi^2_2$
	Nickname 3	Detector 3	GWabc	GPS time 3	Time range 3	Freq. range 3	M3	d3	$\chi^2_3$

**Between each two groups of students:**

Determine trigger window between their detectors

# Exercise 3 (45 minutes)

Combining results from various groups and performing joint data-analysis to do sky localisation of the source of the gravitational wave signal.

$$\zeta(z) = \sum_{n=1}^{\infty} \frac{1}{n^z}$$

## Step 1:

Students watch video on sky localisation techniques.

## Step 2:

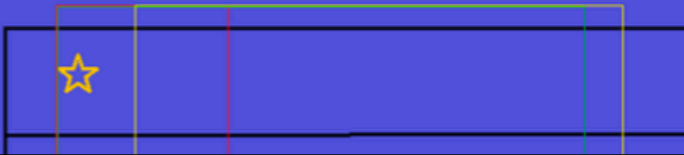
Students look for coincidences between their data sets, and manually select whether a GW coincidence has been found

## Step 3:

Students have the software perform the sky localisation

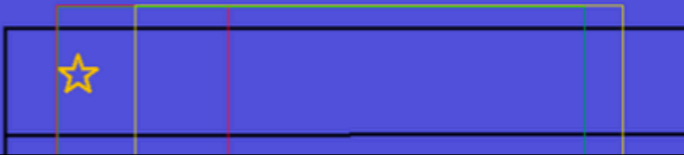
**Event GWabcdef**

Arrival time



Student 1/ Detector 1

Detector 1- Detector 3 window



Apply trigger window

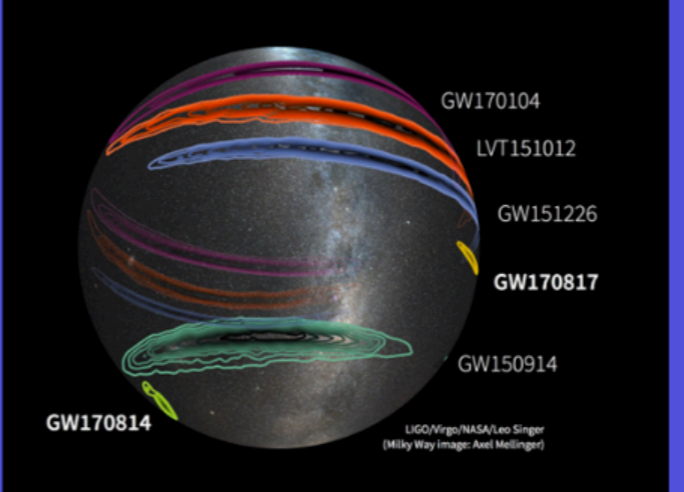
Yes  No

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**Sky localization**

Event	Mass (Msun)	Distance (MPc)	Time difference Det1-Det2 (ms)	$\Delta\theta$ 1-2	Time difference Det2-Det3 (ms)	$\Delta\theta$ 2-3	Time difference Det1-Det3 (ms)	$\Delta\theta$ 1-3	
GWabcd ef	AAA	XXX	YYY	ZZZ	WWW	DDD	VVV	BBB	Perform sky localization

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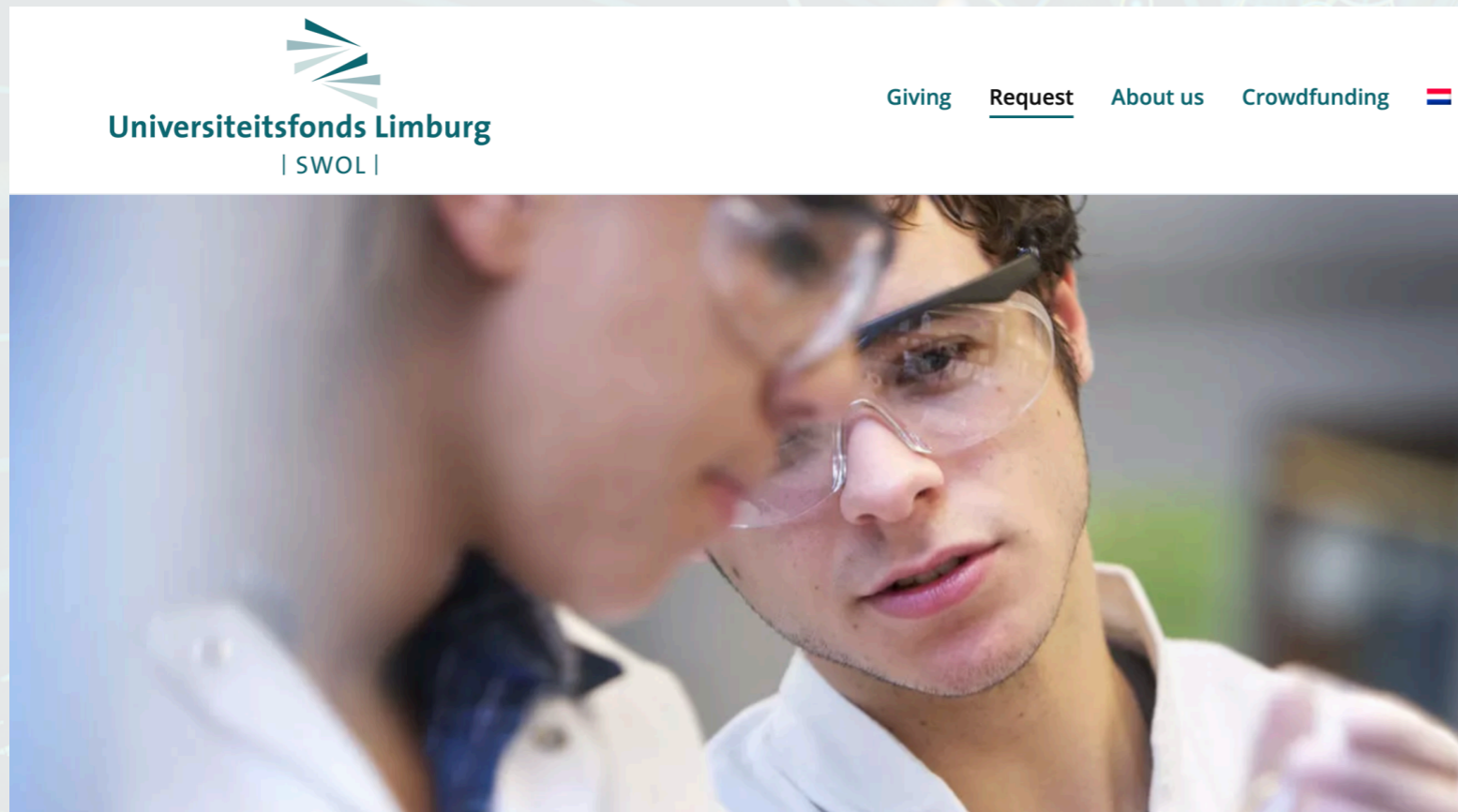
LIGO/Virgo/NASA/Leo Singer  
(Milky Way image: Axel Mellinger)

**GW source coordinates**



# Implementation

Resources have been collected



<https://www.ufl-swol.nl/en/>

- \* **University Funding Scheme,**
- \* **Aimed at science and education,**
- \* **Dispenses funds based on private donations,**
- \* **Funds requests up to €8000.**

## About the fund

University Fund Limburg/SWOL aims to support scientific research and education at Maastricht University. Science is a crucial building block to achieve a better future for next generations.

The Fund also seeks to foster good and mutually beneficial relationships between the university and the local community, as well as between itself and these parties. To achieve these objectives, the Fund is focused on the continued development of UM, the acquisition of financial resources from companies, government, funding bodies and private donors and the promotion of international activities among students and academic staff. In addition, the Fund works to strengthen ties between Maastricht University and its alumni, the business community and relevant civil society organisations.

**I wrote a proposal for the grant and was awarded it last year summer.**

# Timeline and next steps

- \* **Didactical design: fully finalised**
- \* **Necessary scientific resources (templates, stretches of data, widgets): collected**
- \* **Funds: requested and received**
- \* **Current status: discussion with developers for the coding/ implementation of Master Classes**

**Spring  
2023**

**Summer  
2023**

**December  
2023**

**May  
2024**

**Summer  
2024**

Creation of  
didactical design

Creation of  
mock design

Discussions  
with potential  
developers

Tentative  
delivery of the  
Master Class

Testing on  
target  
audiences

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Maastricht University