



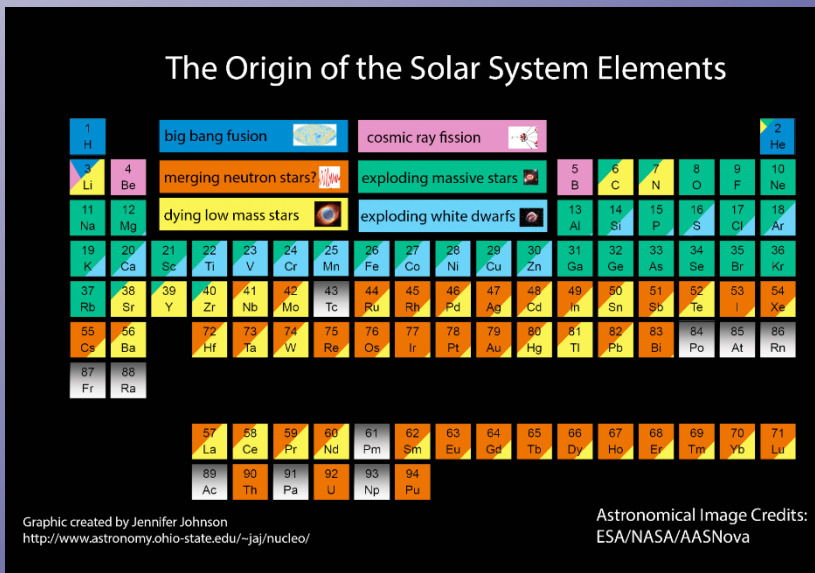
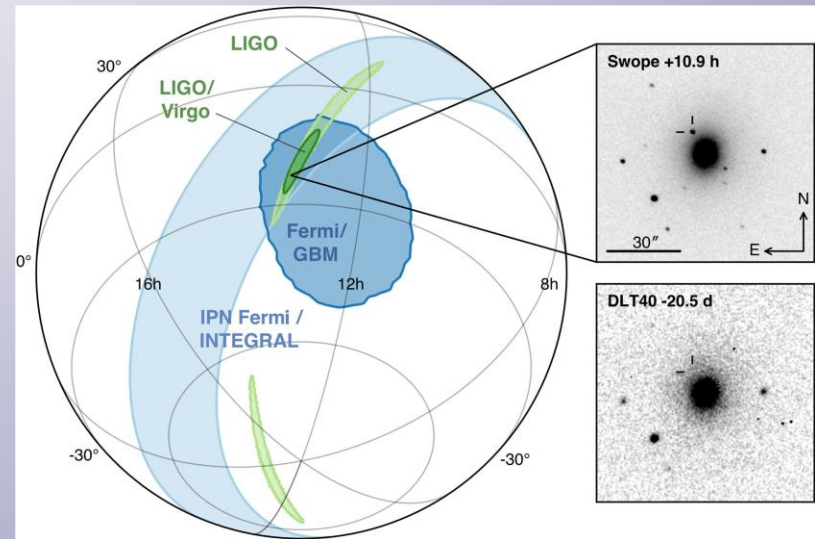
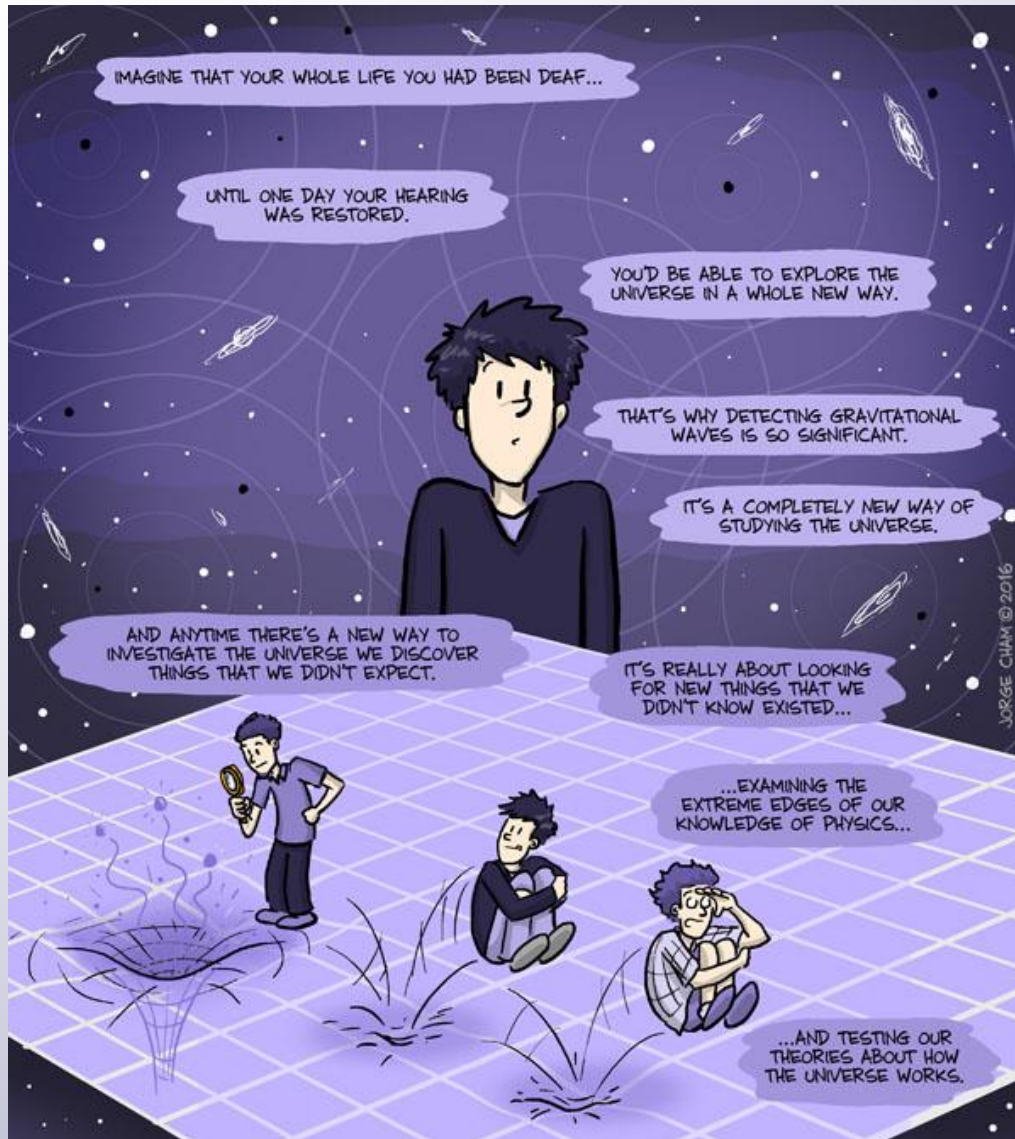
## Gravitational Wave Astronomy Module

V. Boschi (INFN, EGO)



Frontiers has been funded within the framework of the European Union Erasmus+ programme

# GW Astronomy



# Virgo and LIGO sensitivity

Imagine to drop a glass of wine (or water) in the ocean.....

**Ocean Surface (S):**

$$70\% \times 4\pi \times R_{\text{terra}}^2 =$$

$$0.7 \times 4 \times 3.14 \times (6.37e6 \text{ m})^2$$

$$\sim 3.6e14 \text{ m}^2$$

**Volume of the glass (V):**

$$\sim 0.25e-3 \text{ m}^3$$



**Increase of the global sea level:**

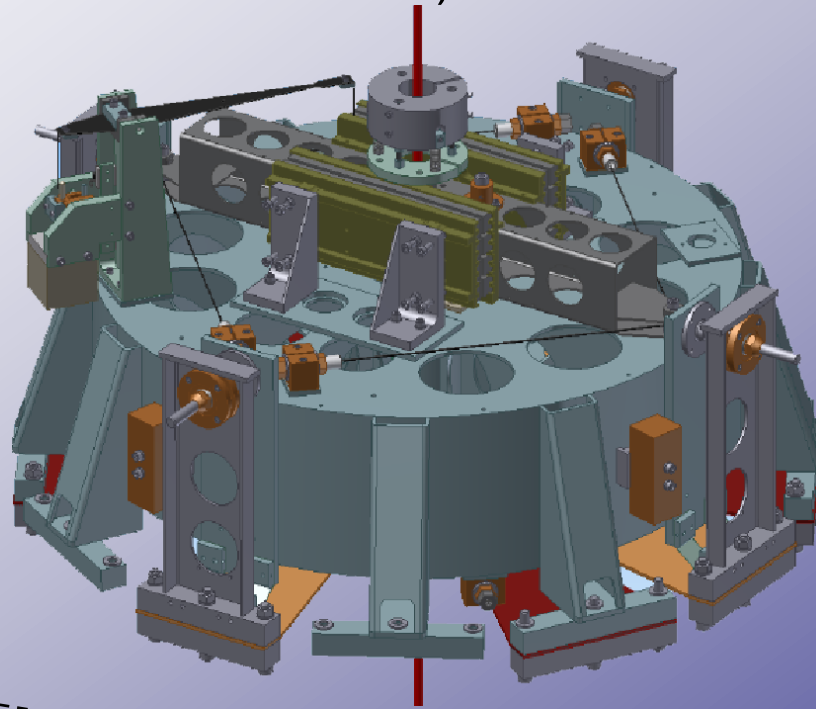
$$h \sim V / S \sim 1e-18 \text{ m}$$

This is the level of sensitivity we need to reach with GW detectors !!

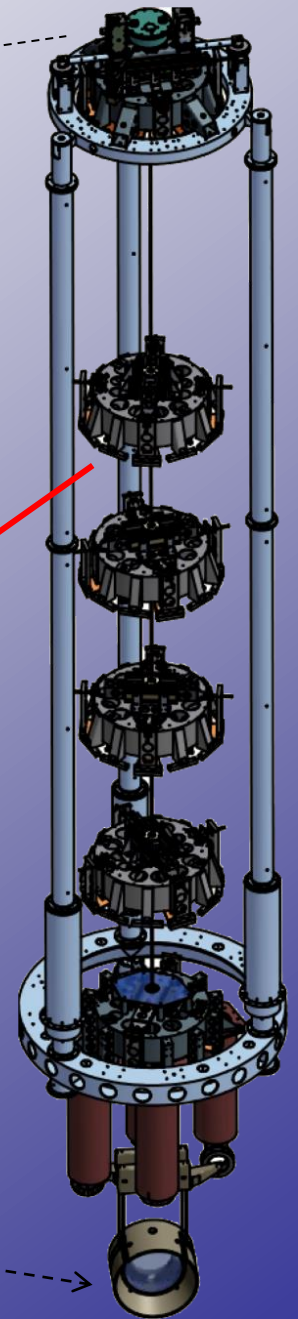


# VIRGO superattenuator

It's able to attenuate the seismic motion of the mirrors by more than a factor  $10^{12}$  (a million of a million times)



Standard filter



Suspended mirror



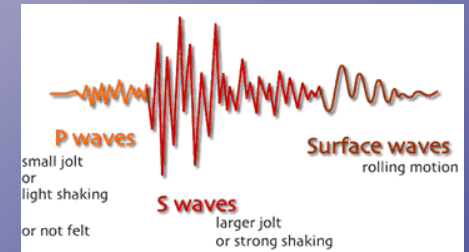
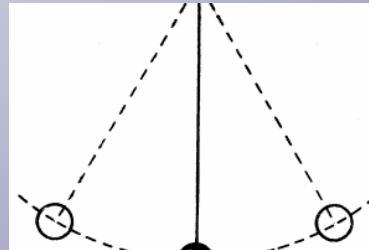
# GW Module

## The demonstrators

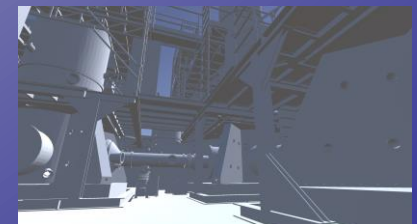
- *Discovering and building a Michelson interferometer*
- *The pendulum*
- *Earthquake Interferometer*
- *Finding Black Holes in a Chirp*
- **Gravitational Wave Noise Hunting**
- Control (Class)room
- VIRGO Virtual Visits



<http://www.frontiers-project.eu/gravitational-wave-astronomy/>



**SPACETIME QUEST**



# GW Demonstrators

## Build an interferometer in your class!

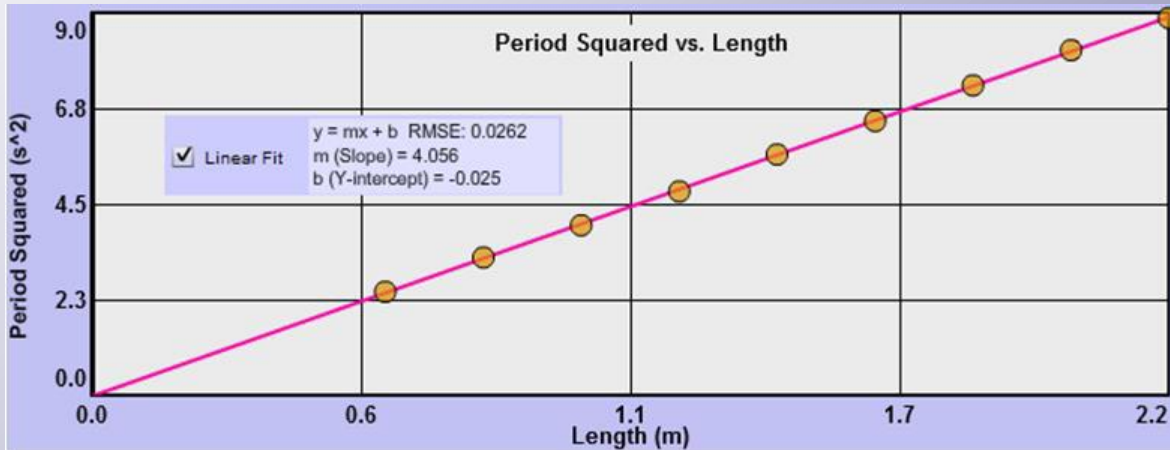
- We will assemble a Michelson interferometer using a small construction kit developed by NIKHEF, the Dutch National Institute for Subatomic Physics, a high energy and astroparticle physics laboratory in Amsterdam, Netherlands, which participates to the Virgo experiment.
- The NIKHEF interferometer costs around € 70 + VAT. The same interferometer can also be built with simple optical components.



# GW Demonstrators

## The pendulum

- In this lesson we will explore the pendulum, a very simple mechanical system but at the same time an extremely powerful tool for exploring physical phenomena such as oscillations, gravity, the transmission of vibrations and also the concepts of speed, acceleration, energy and resonance.





# GW Demonstrators

## Control (class)room

Whether you are detecting gravitational waves or measuring colliding particles, the control room is where all the magic happens !!





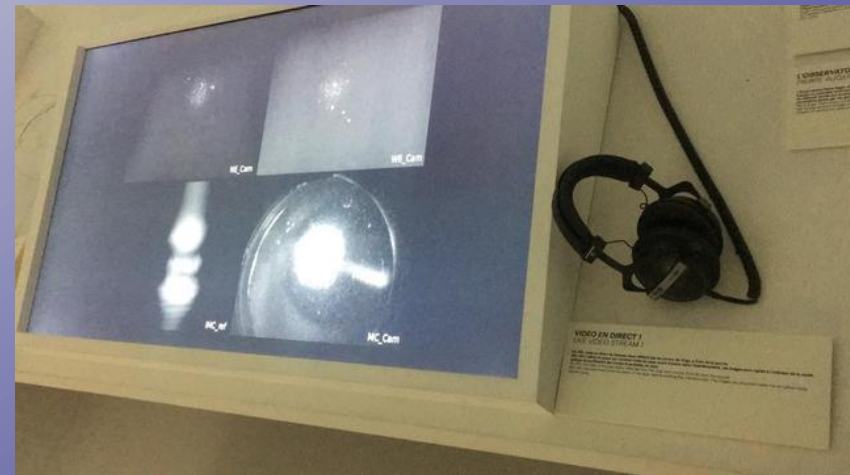
# GW Demonstrators

## Control (class)room

Using simply a set of PCs or Raspberry Pis you can have all the data shown in the control room in your class !!



#	DMS										ITF Mode: Commissioning (0d 0h 19m 19s)	ITF State: LOW_NOISE_3_SQZ (0d 7h 32m 32s)	UTC: 2019-11-01 08:11:57
Injection	SIB1_IP	SIB1_BENCH	SIB1_BR	SIB1_Vert	SIB1_TE	SIB1_Guard	SIB1_Electr						
	MC_IP	MC_PAY	MC_BR	MC_Vert	MC_TE	MC_Guard	MC_Electr						
	Laser	LaserAmpli	LaserChiller	SL_TempController	RFC	LNFS	PC						
Detection	MC_Power	PSTAB	IMC_AA	IMC_AA_GALVO	MC_FO_z	BPC	BPC_Electr						
	PD	QPD_B1p	QPD_B2		OMC	PicoDisable	Shutter						
	SDB1_IP	SDB1_LC	SDB1_BR	SDB1_Vert	SDB1_TE	SDB1_Guard	SDB1_Electr						
ISC	B2_8MHz_DPFI	B4_56MHz_DPFI	DARM_UGF	UNLOCK	SSFS_UGF	FmodErr	GIPC	EQ_Mode					
	B1p_DC	B4_112MHz_MAG	B7_DC	B8_DC	LSC_rms	ASC_rms	50Hz_FF	ViolinModes					
	BS_IP	BS_F7	BS_PAY	BS_BR	BS_Vert	BS_TE	BS_Guard	BS_Electr					
Suspensions	NI_IP	NI_F7	NI_PAY	NI_BR	NI_Vert	NI_TE	NI_Guard	NI_Electr					
	NE_IP	NE_F7	NE_PAY	NE_BR	NE_Vert	NE_TE	NE_Guard	NE_Electr					
	PR_IP	PR_F7	PR_PAY	PR_BR	PR_Vert	PR_TE	PR_Guard	PR_Electr					
Environment	SR_IP	SR_F7	SR_PAY	SR_BR	SR_Vert	SR_TE	SR_Guard	SR_Electr					
	WI_IP	WI_F7	WI_PAY	WI_BR	WI_Vert	WI_TE	WI_Guard	WI_Electr					
	WE_IP	WE_F7	WE_PAY	WE_BR	WE_Vert	WE_TE	WE_Guard	WE_Electr					
Infrastructures	CB_Hall	MC_Hall	TCS_Zones	NE_Hall	WE_Hall	WindActivity	Selision	BRMSMon					
	INJ_Area	DET_Area	EE_Room	DAQ_Room	External	DeadChannel	Lights	SeaActivity	WAB				
	ACS_CB_Hall	ACS_TCS_CHILRC	ACS_TB	ACS_DAQ_Room	ACS_EE_Room	ACS_MC	ACS_INJ	ACS_DET	ACS_NE	ACS_WAB			
VPM	UPS_TB	UPS_CB	UPS_MC	UPS_NE	UPS_WE	FlatChannel	ExitChannel	ACS_WE	ACS_CB_CR	ACS_COB			
	EIB_SBE	SDB2_SBE	SDB2_LC	SNEB_SBE	SNEB_LC	SWEB_SBE	SWEB_LC	SPRB_SBE	SPRB_LC				
	TCS	NE_RH	WE_RH	NI_CO2_Laser	WI_CO2_Laser	Chillers		TCS_Electr					
DAQ-Computing	SQZ	PLL	Squeeze	SQZ_AA	SQZ_Shutter	Cohe_CTRL	SQZ_Inj	Rack_TE					
	Vacuum	LargeValves	Clean_Air	TubeStations	TubePumps	MiniTowers	TurboLinks	RemDryPMP	VAC_SERVOS				
	DetectorSEnvironm	ControlRoom	Minitowers	ISC	Injection	TCS	Suspension	Vacuum	Metatron				
Calib_Hrec	DetectorMonitoring	DataCollection	Storage	DataAccess	Automation	DetChar							
	Latency	Disk	Timing	Timing_rtpc	Timing_dsp	Fast_DAC	ADCs_TE	Daq_Boxes_TE					
	Domains	DMS_machines	DetOp_machines	olservers	rtpcs	CollSwitchBoxes	INF_devices	ENV_devices	VAC_devices				
ITFOnCall	CalNE	CalWE	CalINJ	CalBS	CalPR	PCaNE	PCaWE	HOFI	NCAL	NoiseInjection			
	SoftwareAI	TemperaturesAI	InjectionAI	UpsAI	GeneratorAI	TcsAI							
	Hrec_RANGE_BNS	GraceDB_Alert	GRB_Alert	KANLAND_Alert	SNEWS_Alert	STATE_VECTOR							
DetChar-Ex-Trigger													

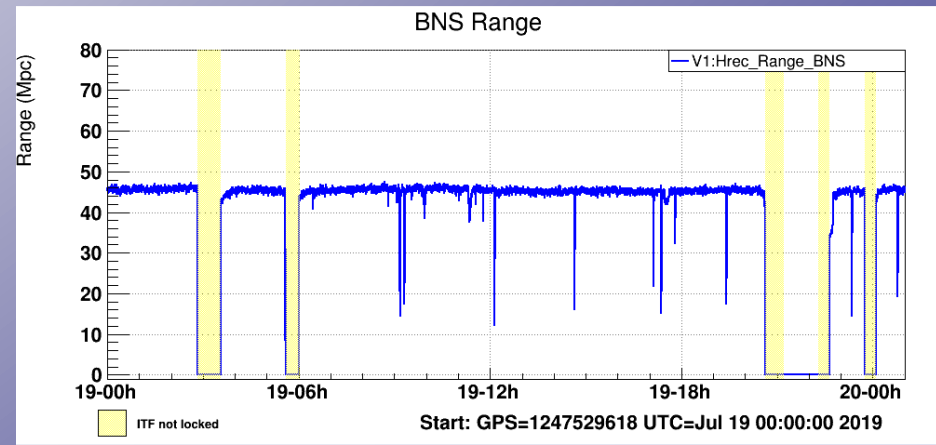


# GW Demonstrators

## Earthquake interferometer

How can you use Virgo data ? Control room data constitute a powerful tool to understand how the environment interact with the detector

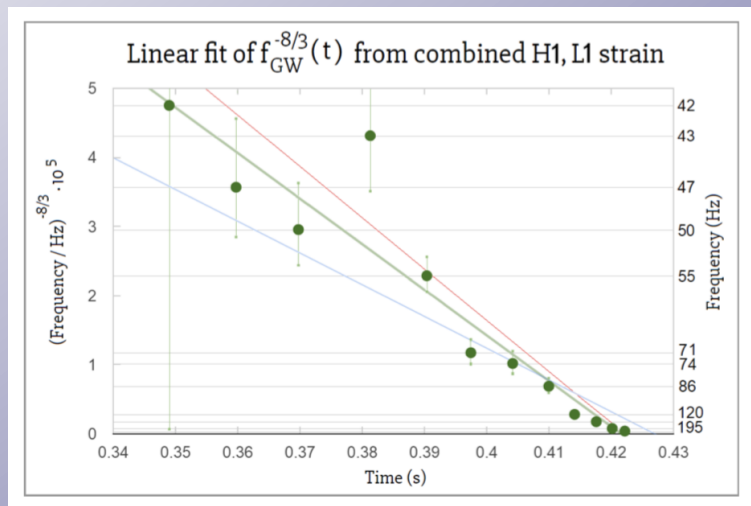
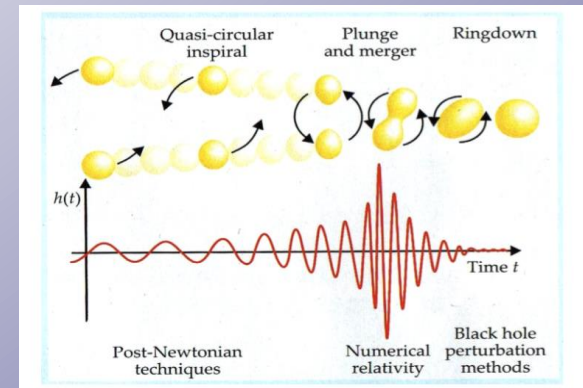
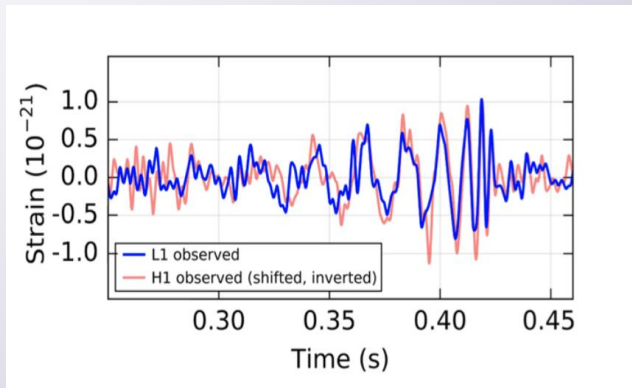
- What is the effect of the wind on Virgo ?
- What is the effect of the sea waves ?
- What happen when an earthquake reach the Virgo site ?



# GW Demonstrators

## Finding black holes in a chirp

Using LIGO/Virgo data, students will learn how to determine the masses and the radius of a binary system, to identify the two objects as black holes, and what are the fundamental properties and parameters of a black hole.



$$\mathcal{M} = \left[ \frac{5K}{(8\pi)^{8/3}} \right]^{3/5} \frac{c^3}{G}$$