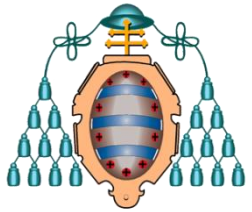
# Teaching Classical Mechanics with Smartphones: acceleration and trajectory

María Vélez
Physics Department


Real Sociedad Española de Física



UNIVERSIDAD DE OVIEDO

## Universidad de Oviedo

*Departamento de Física*

*María Vélez*

*Jaime Ferrer*

*Amador García-Fuente*

*María del Rosario Díaz Crespo*

*Isidro González Caballero*

*Javier Fernández*

*Departamento de Informática*

*Susana Irene Díaz*

*María Rita Sierra*

*Cesar Alonso*

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*IES Valle de Aller*

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*Consejería Educación*

Maria Luisa del Valle

*IES Aramo*

Mª Fernanda Fernandez Varela

## Real Sociedad Española de Física

*Sección Asturias*

*Jorge Pisonero*

*Victor García*

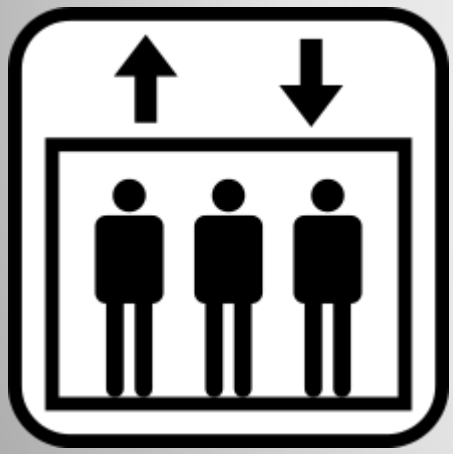
Physics and Math (1st University year)

Physics Olympiad (final high school year)

***2016/2017***

***2017/2018***

***2018/2019***



**Basic Mechanics Theory Course:**
***Simple kinematics examples***

## Constant Speed

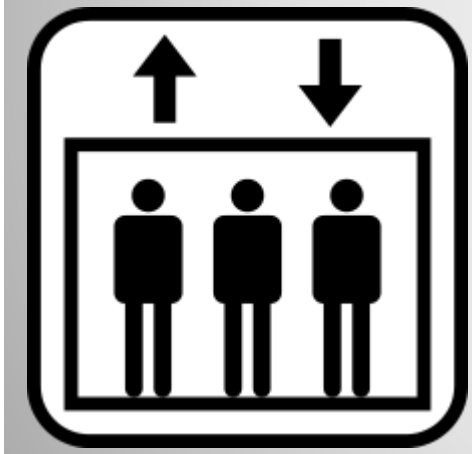
$a = 0$
$v = v_o$
$x = x_o + v_o t$

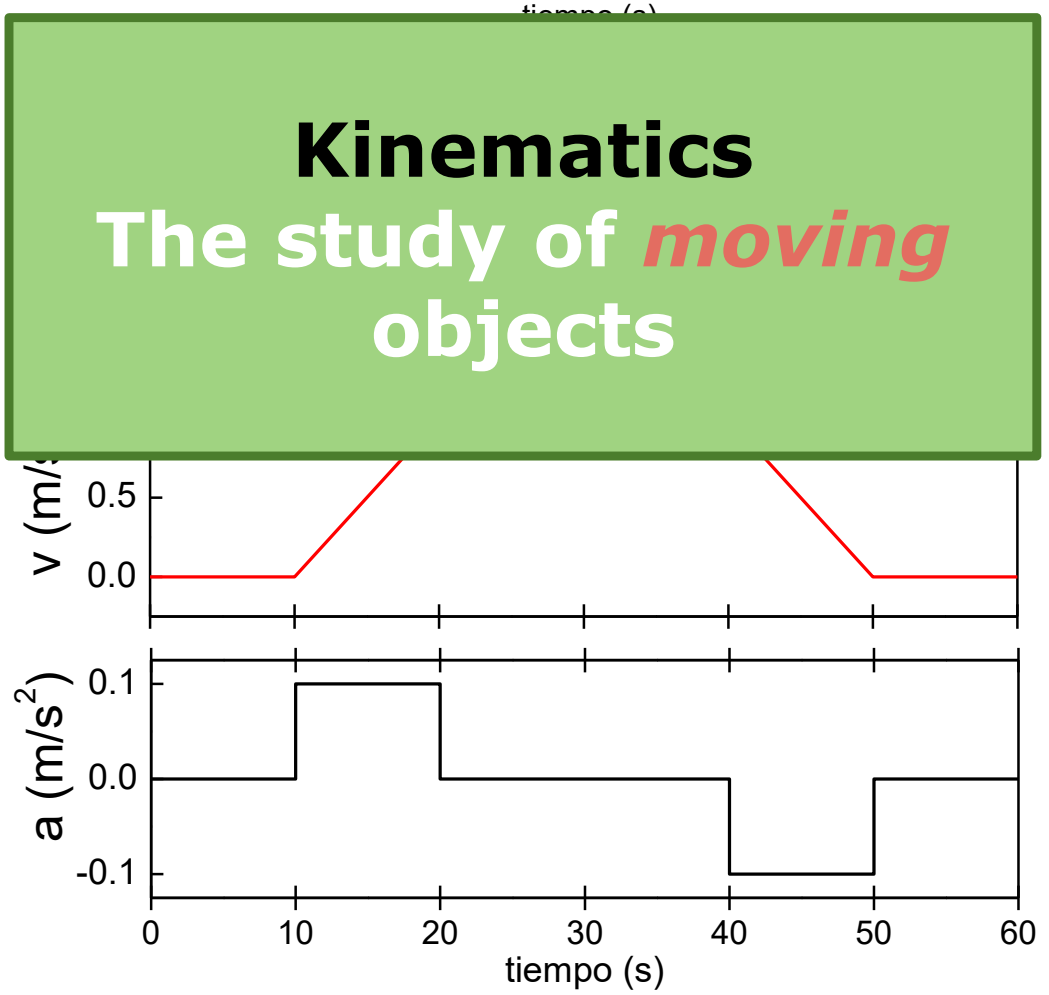
## Constant acceleration

$a = a_o$
$v = v_o + a_o t$
$x = x_o + v_o t + \frac{1}{2} a_o t^2$

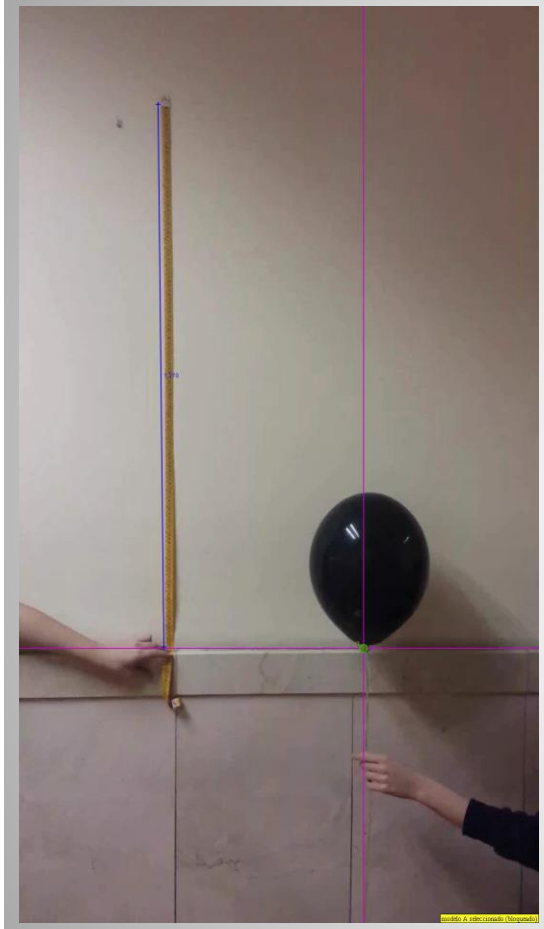
# Rectilinear motion in an elevator

# Kinematics
## The study of *moving* objects

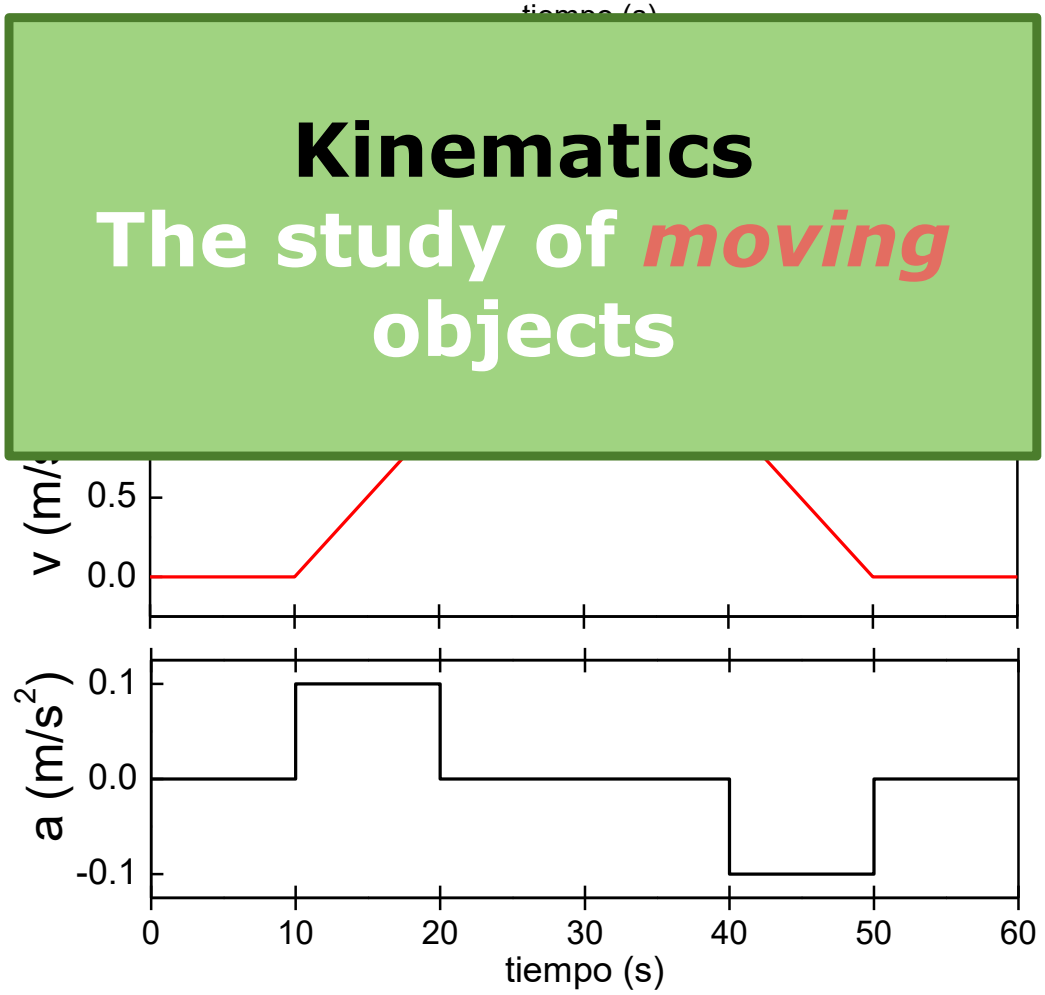





# Rectilinear motion in an elevator

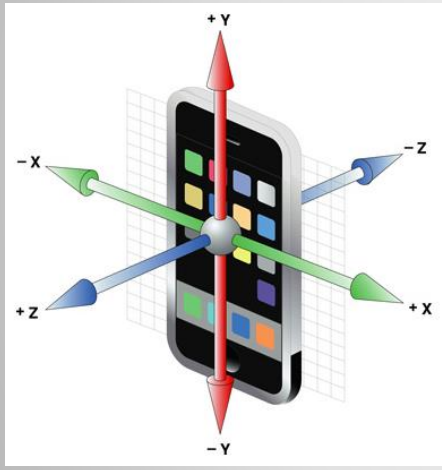


# Kinematics
## The study of *moving* objects




# Rectilinear motion of a balloon

**Videos**




**Accelerometer**

**Basic Mechanics Theory Course**

**Starting from Trajectory data**

$$x(t)$$
$$v(t) = dx/dt$$
$$a(t) = dv/dt$$

**Starting from Newton second law**

$$a(t) = F/m$$
$$v(t) = vo + \int a(t)\,dt$$
$$x(t) = xo + \int v(t)\,dt$$

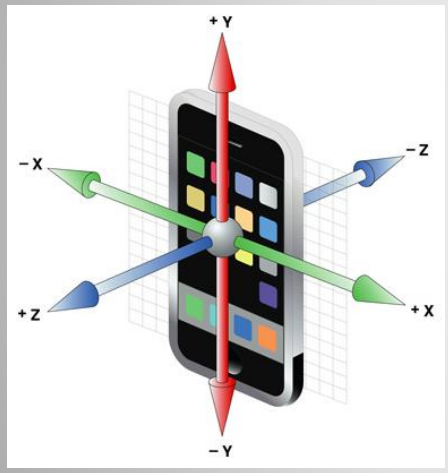
# Differentiation *vs.* Integration

# Outline

- **Didactic goals**
- **Accelerometer data**
  - Data acquisition
  - Analysis of data files
  - Numerical integration
- **Trajectory data**
  - Tracker software from OSP
  - Motion videos
  - Kinematic and Dynamic models

# Didactic goals

- **Use of Smartphone technology for experiments beyond traditional classroom or lab settings**
  - Smartphone sensors (accelerometer and video)
  - Autonomous learning (planning, creativity)
  - Team work (scientific discussion, social abilities)
- **Coordinated learning across different subjects**
  - Basic Mechanics (Physics/Math)
  - Introduction to Computational Physics (Physics)
  - Informatic Tools (Math)
- **Development of transverse competencies**
  - Theory+Experiment+Computation




**Starting from Newton second law**

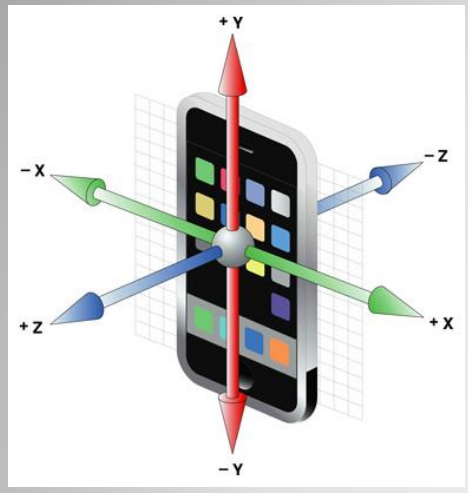
$$a(t) = F/m$$

$$v(t) = vo + \int a(t)\,dt$$

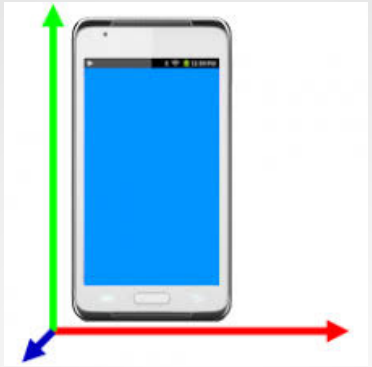
$$x(t) = xo + \int v(t)\,dt$$

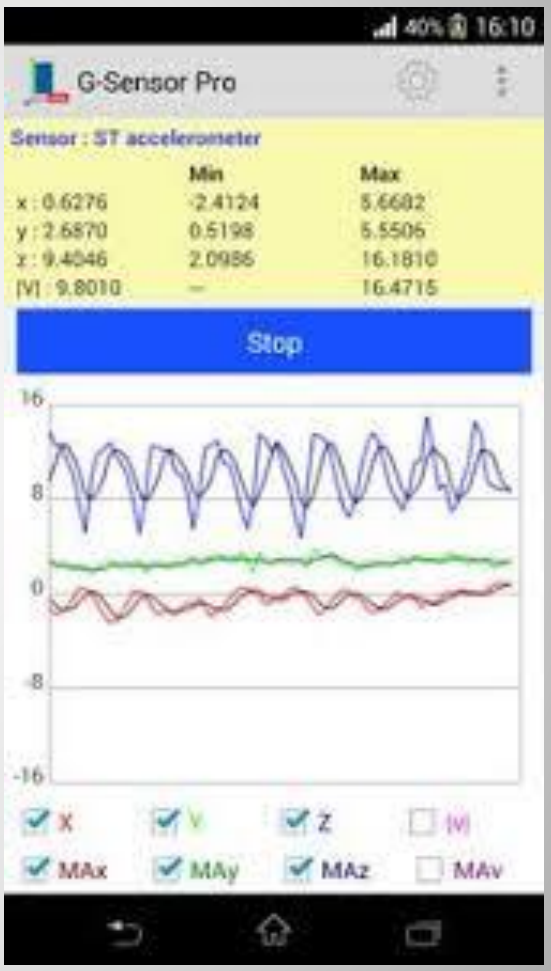
# Smartphone accelerometer

## Data Acquisition, Data Analysis, Numerical Integration




## *Android Free App*: G Sensor logger



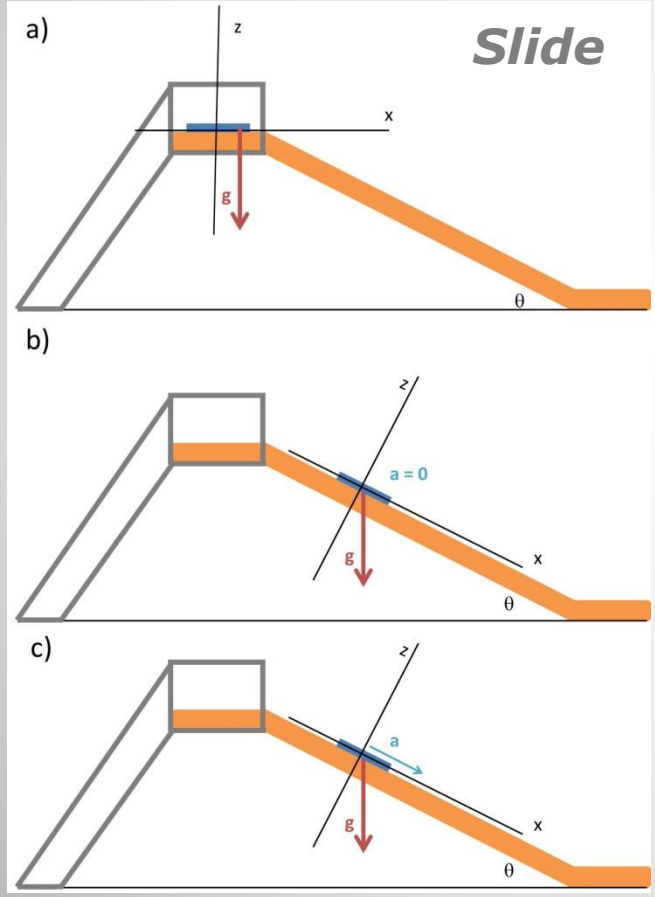


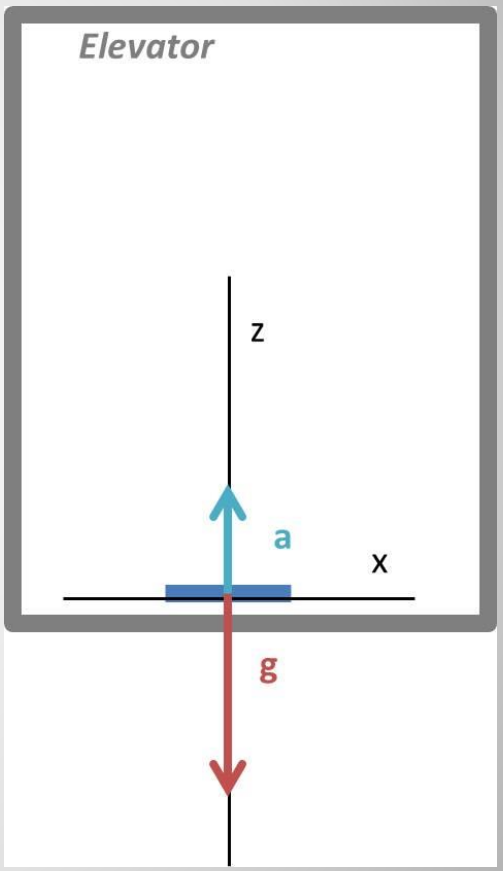

```
# Accelerometer Data File
# Started @Mon Sep 19 20:07:25 GMT+02:00 2016
 #
# data format:
# so we have 4 columns with values separated by the " "
# X Y Z time_from_previous_sample(ms)

# sensor speed set to:FASTEST
# units set to: m/sec^2
# gravity NOT filtered out
# Accuracy: HIGH
-0.001      0.008      9.84       0
0.01        0.012      9.823      10
-0.019      0.01       9.837      9
0.0         -0.002     9.844      12
-0.026      0.006      9.835      11
```

# Smartphone accelerometer: Data acquisition

**Basic Mechanics:** autonomous data acquisition in simple problems of rectilinear motion.



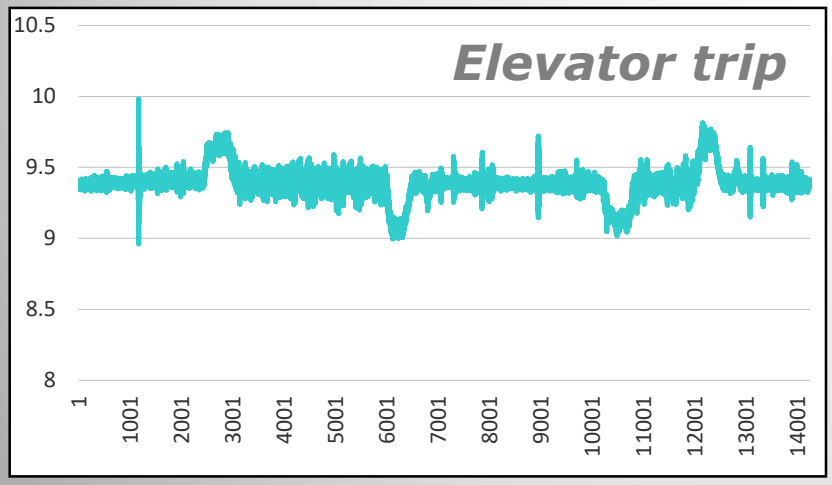



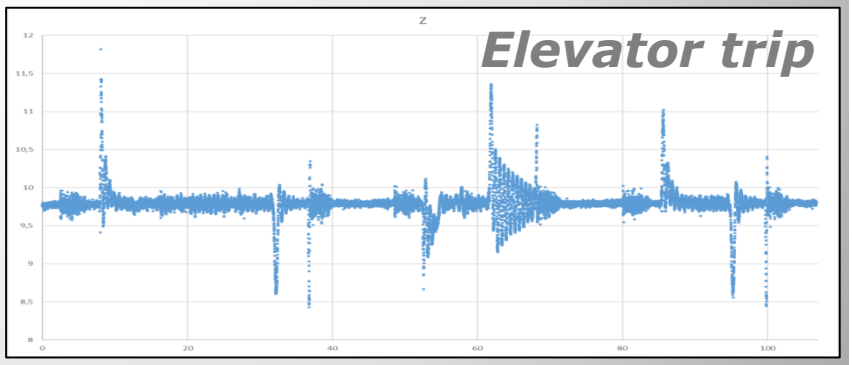

## Smartphone accelerometer: Data acquisition

**Introduction to Computational Physics** Excel spreadsheet

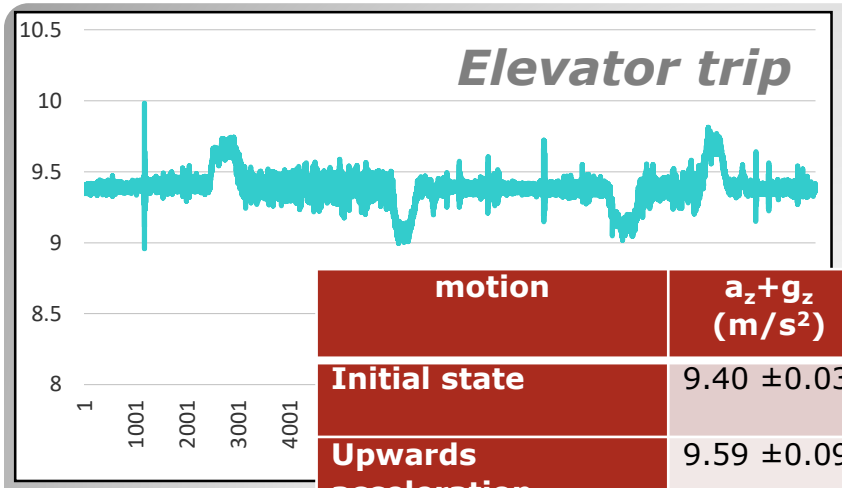
**Informatic Tools** Plot Workshop

***Import data, make graphs, calculate averages and statistical errors***




# Smartphone accelerometer: Data Analysis




$a = 0$
$v = v_o$
$z = z_o + v_o t$

$a = a_o$
$v = v_o + a_o t$
$z = z_o + v_o t + \frac{1}{2} a_o t^2$

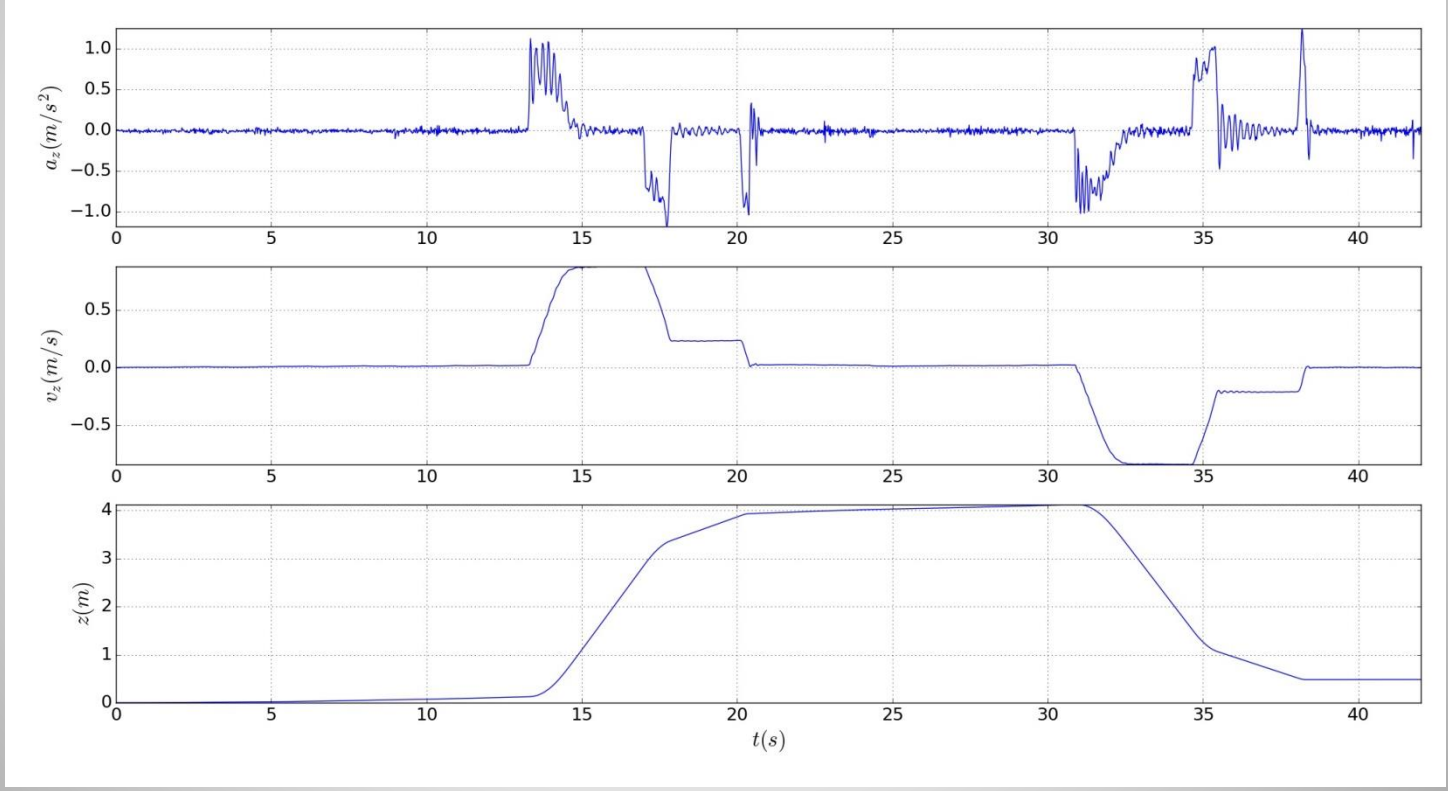
| motion | $a_z+g_z$ (m/s²) | $(a_z+g_z)-g_z$ (m/s²) | Dt (s) | $V_i$ (m/s) | $V_f$ (m/s) | $Z_i$ (m) | $Z_f$ (m) |
|---|---|---|---|---|---|---|---|
| Initial state | 9.40 ±0.03 | 0 | 12.12 | 0 | 0 | 0 | 0 |
| Upwards acceleration | 9.59 ±0.09 | +0.19 | 3.38 | 0 | 0.65 | 0 | 1.10 |
| Upwards uniform motion | 9.39 ±0.06 | 0 | 14.5 | 0.65 | 0.65 | 1.102 | 10.55 |
| Upwards decceleration | 9.17 ±0.12 | -0.22 | 2.7 | 0.65 | 0.05 | 10.55 | 11.52 |
| Intermediate Stop | 9.38 ±0.03 | 0 | 18.5 | 0 | 0 | 11.52 | 11.52 |
| Downwards acceleration | 9.16 ±0.07 | -0.22 | 2.89 | 0 | -0.63 | 11.52 | 10.61 |
| Downwards uniform motion | 9.39 ±0.06 | 0 | 6.17 | -0.63 | -0.63 | 10.61 | 6.74 |
| Downwards decceleration | 9.60 ±0.12 | +0.22 | 2.64 | -0.63 | -0.05 | 6.74 | 5.83 |
| Final Stop | 9.39 ±0.03 | 0 | 8.3 | 0 | 0 | 5.83 | 5.83 |

# Smartphone accelerometer: Data Analysis

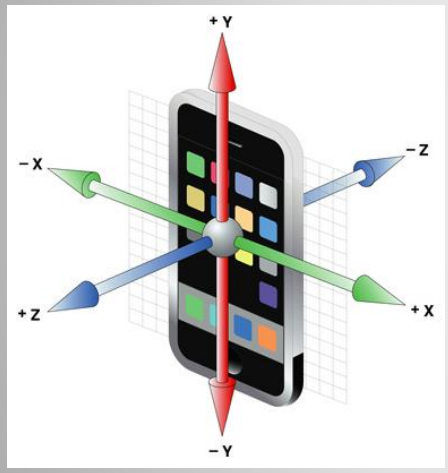
# Euler integration of acceleration, velocity data

$$v(0) = 0$$
$$v(t_{i+1}) = v(t_i) + a_z(t_i) \times (t_{i+1} - t_i)$$

$$z(0) = z_0$$
$$z(t_{i+1}) = z(t_i) + v(t_i) \times (t_{i+1} - t_i)$$




**Smartphone accelerometer: Numerical integration**




**Starting from Trajectory data**

$$x(t)$$
$$v(t) = dx/dt$$
$$a(t) = dv/dt$$

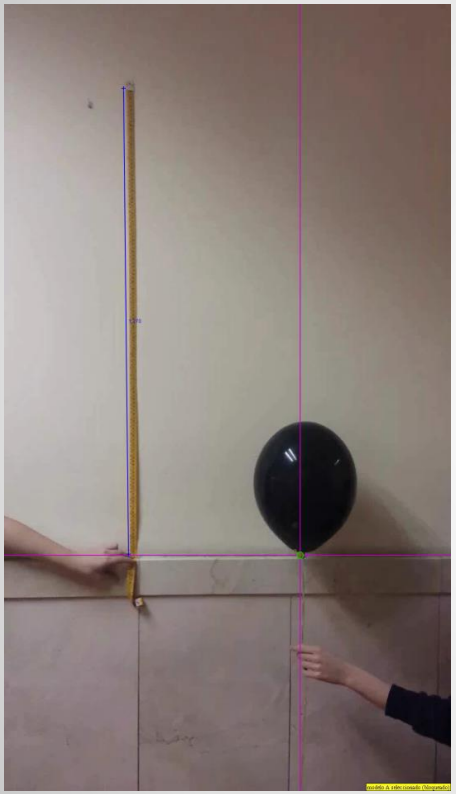
# Trajectory data from Smartphone videos

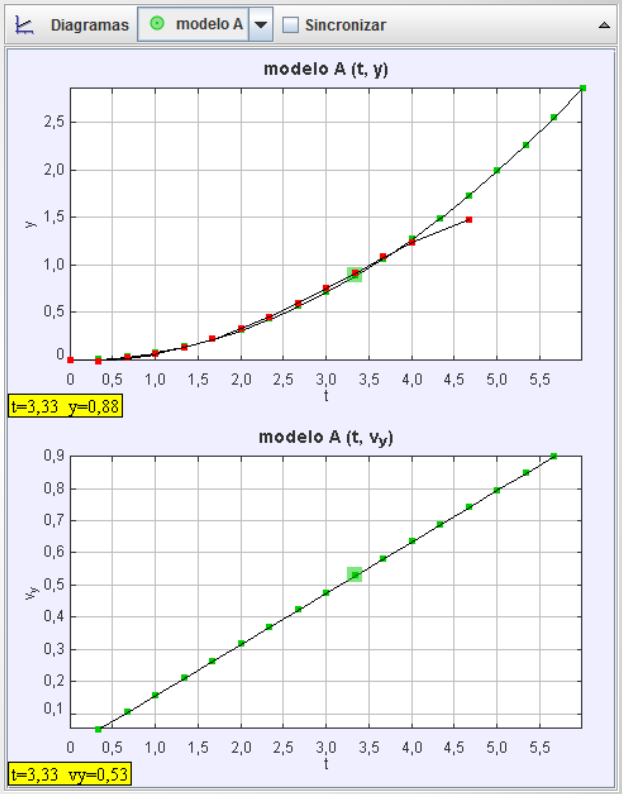
Tracker software from OSP, Motion videos, Kinematic and Dynamic models

open source physics

Tracker
Video Analysis and Modeling Tool

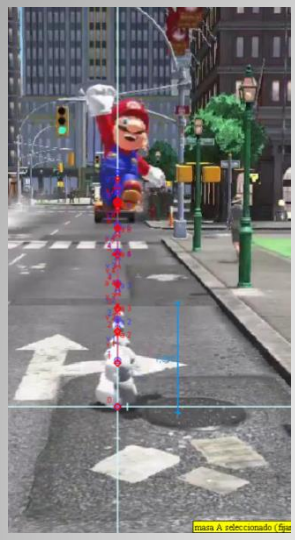
AAPT PHYSICS EDUCATION
American Association of Physics Teachers
Enhancing the understanding and appreciation of physics through teaching



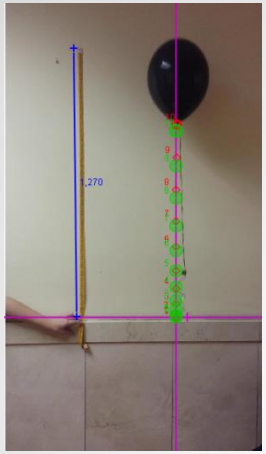



https://physlets.org/tracker/

# Trajectory data: Tracker Software from OSP



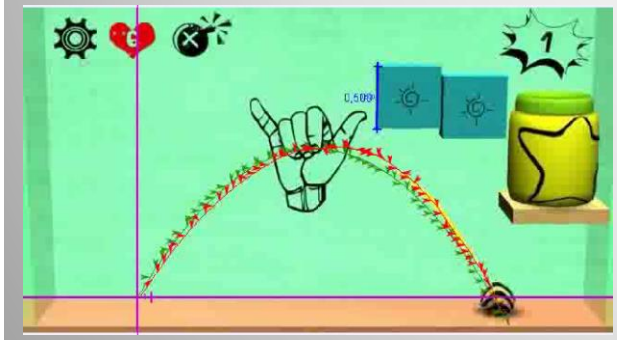
Arquimedes



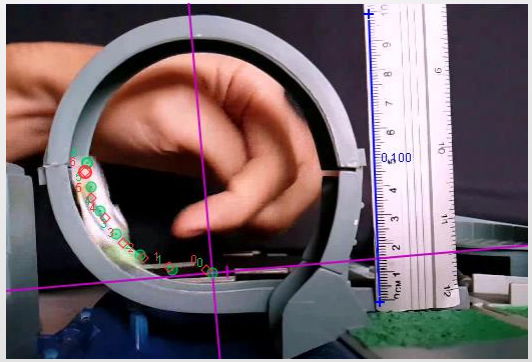
Ball rolling down a plane

Pendulum

Gravity in videogames



Car in a loop



**Student videos**

- Team work
- Creativity

# Trajectory data: Motion Videos

1. Record video of simple, planar motion

1. Import into Tracker software

2. Select time scale, initial and final time (fps)

3. Pixel/meter calibration using size of known object in video

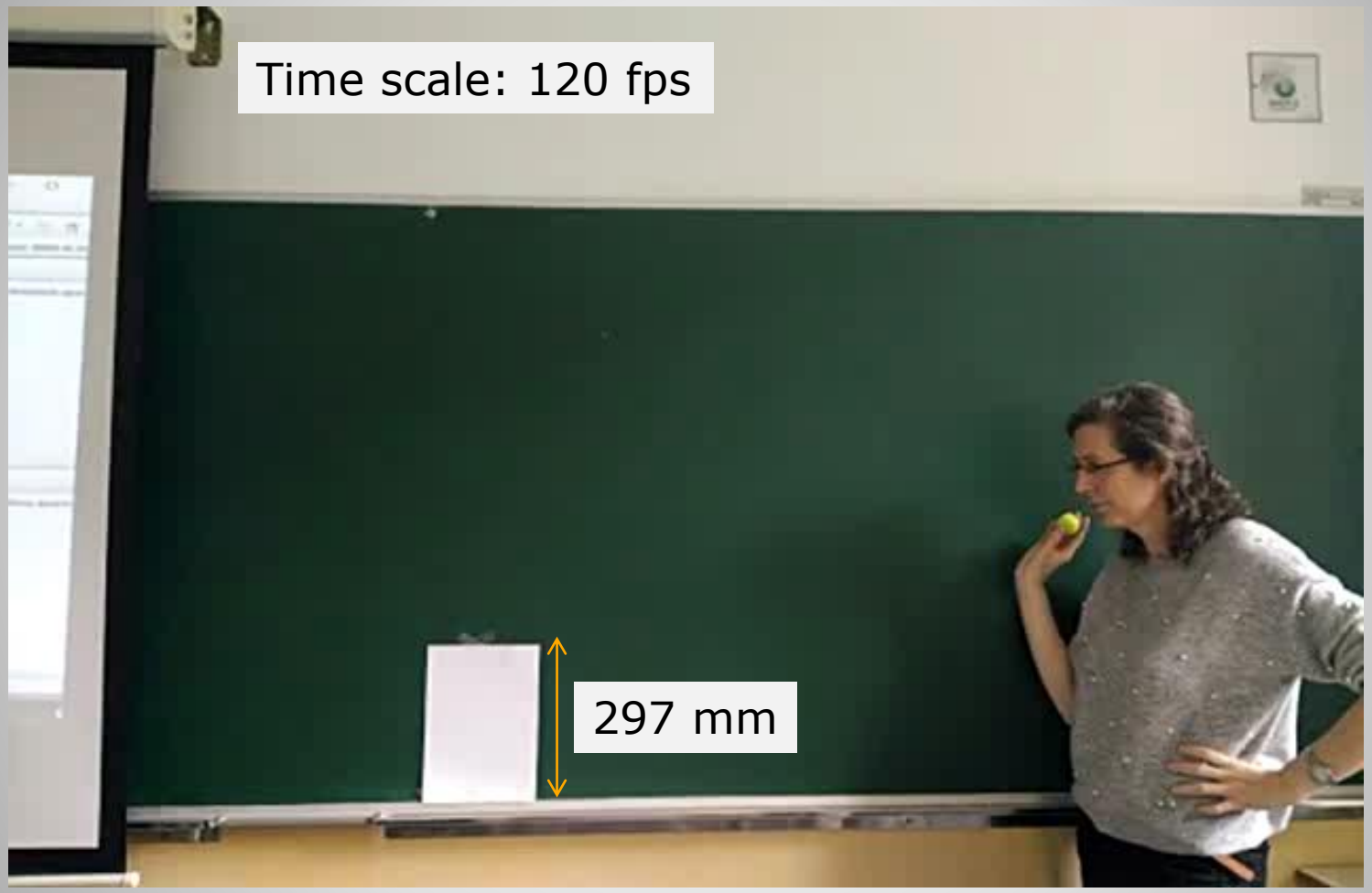
4. Define coordinate axes


5. Define moving object position in each image frame to obtain experimental trajectory data

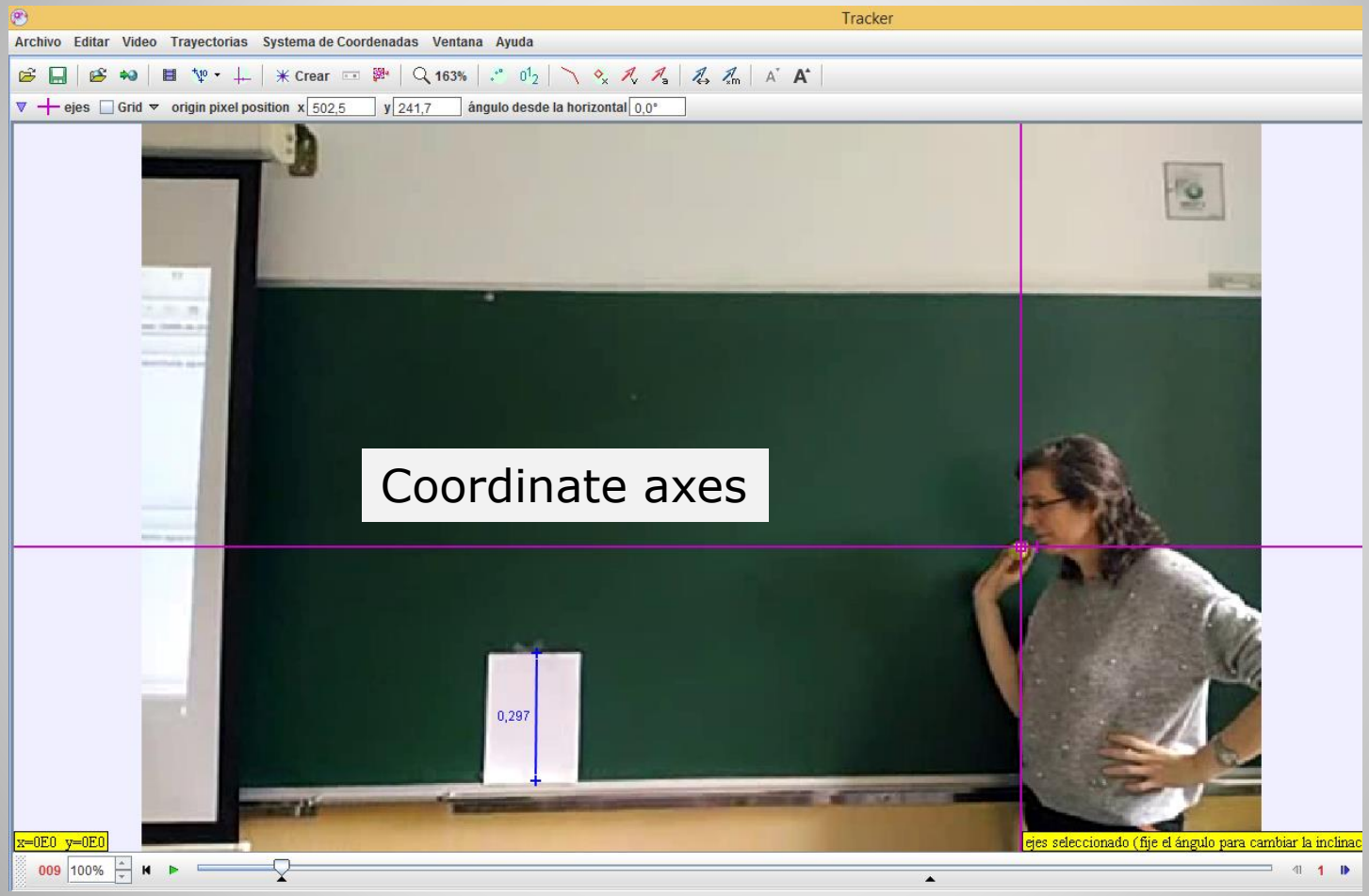
6. Visualize velocity and acceleration vectors

7. Analyze trajectory with kinematic or dynamic models

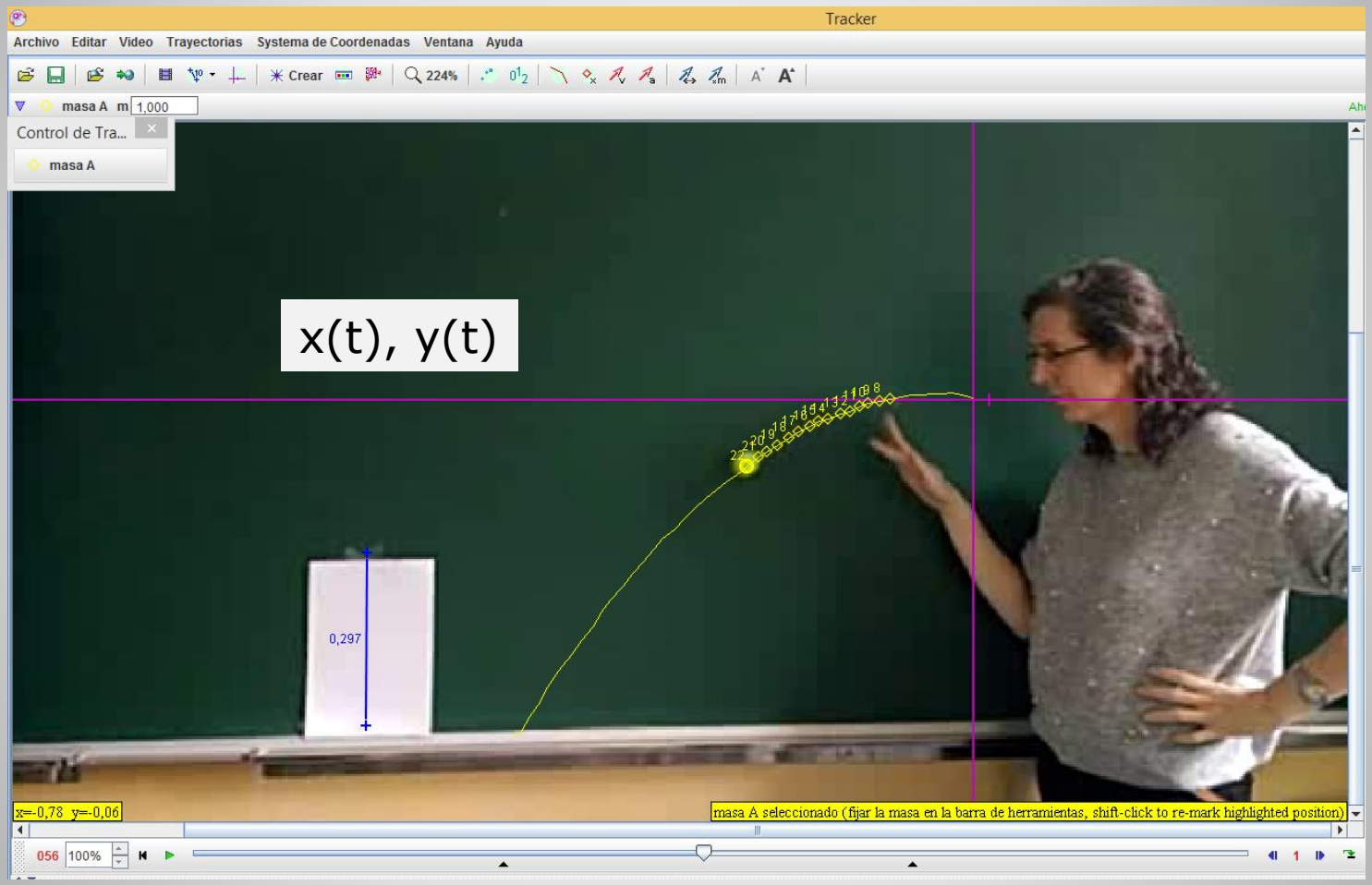
# Trajectory data: Motion Videos




# Trajectory data: Motion Videos

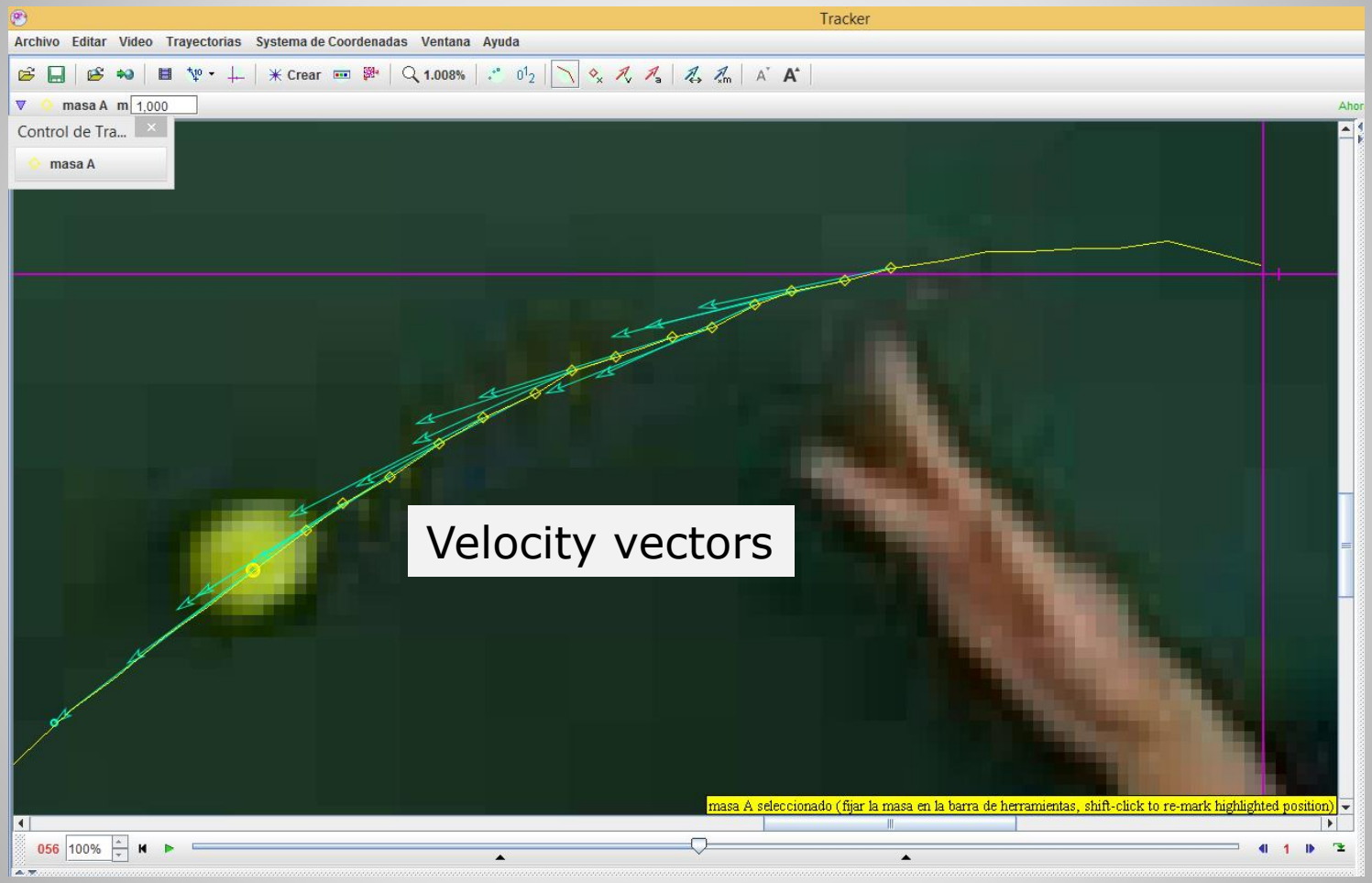



# Trajectory data: Motion Videos



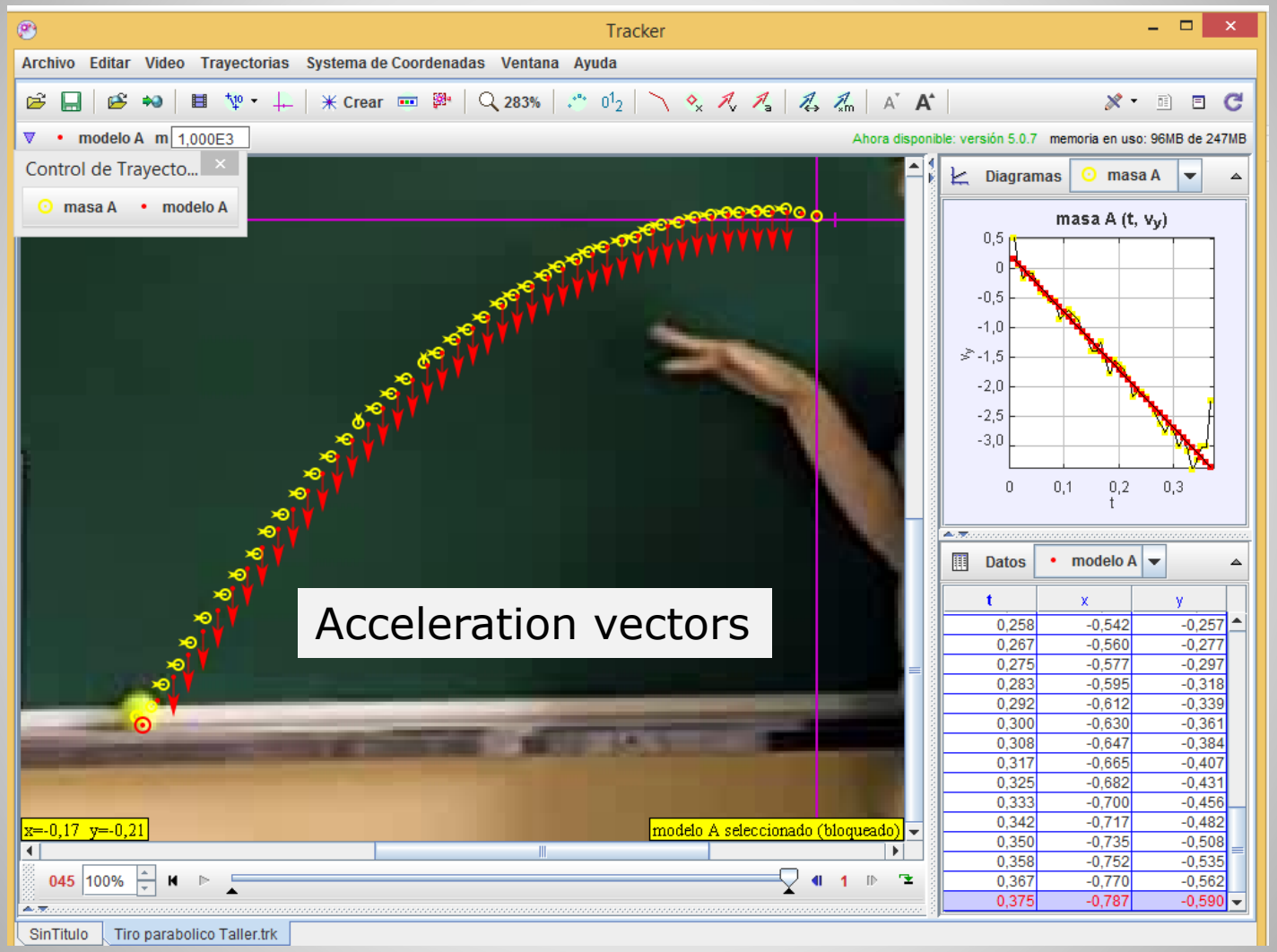

# Trajectory data: Motion Videos

# Numerical differentiation




# Trajectory data: Motion Videos

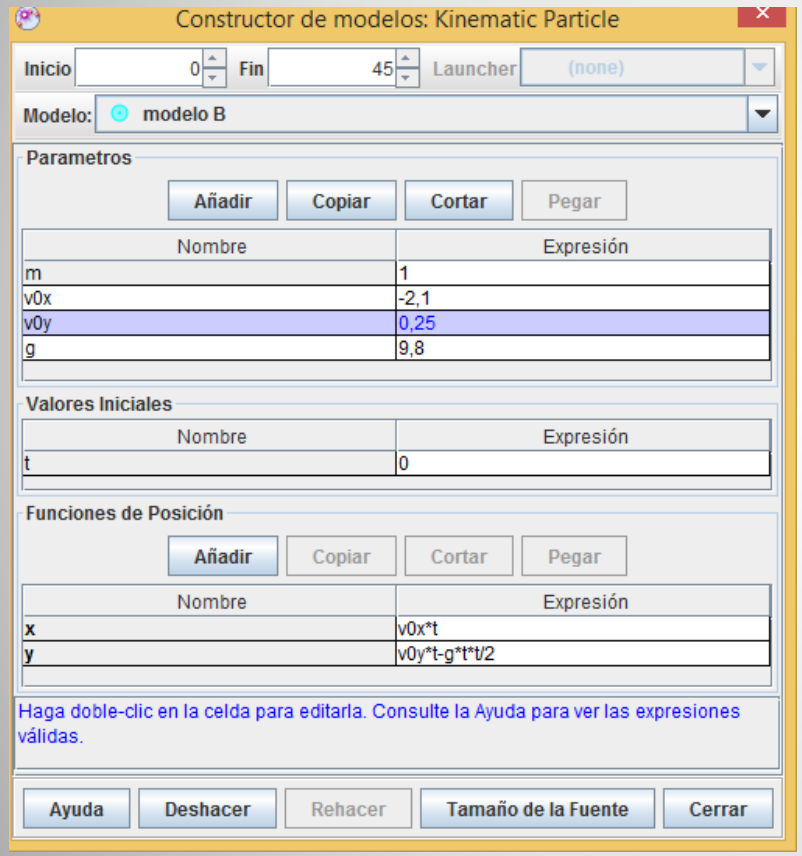
# Numerical differentiation

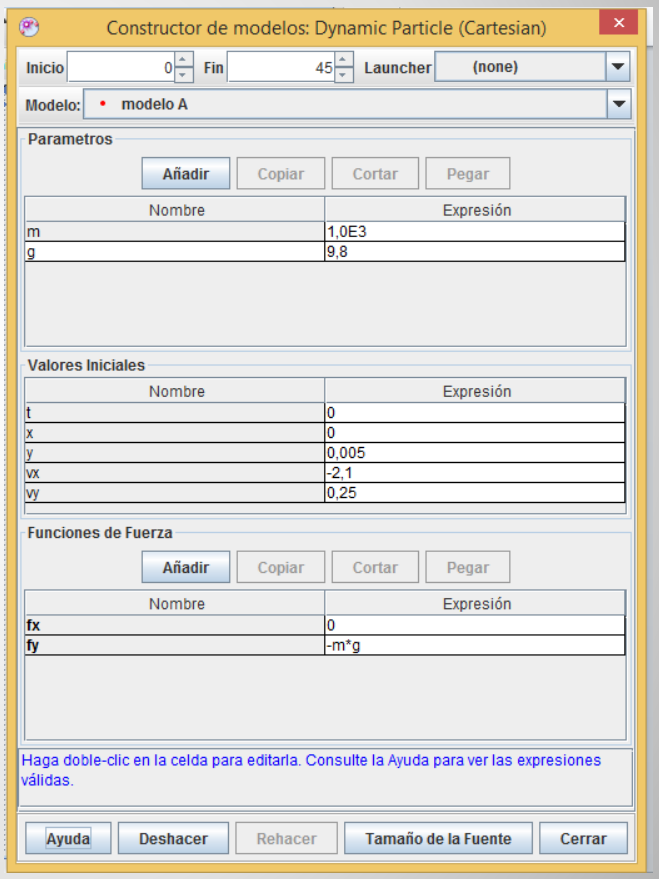



**Trajectory data: Motion Videos**

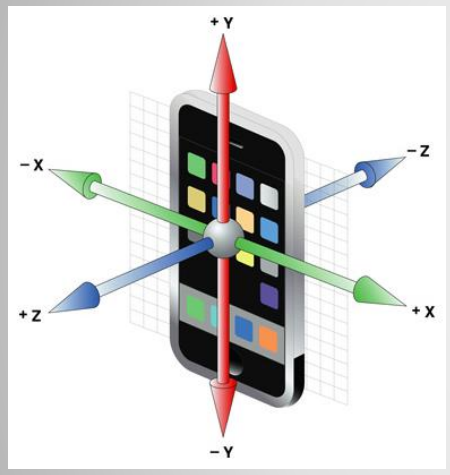
$$x = x_o + v_o t$$
$$y = y_o + v_o t - \tfrac{1}{2} g t^2$$

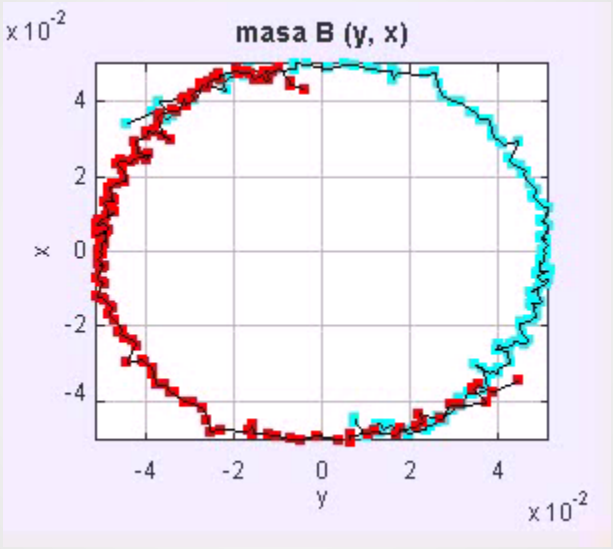
$$a(t) = F/m$$
$$v(t) = v_o + \int a(t)\, dt$$
$$x(t) = x_o + \int v(t)\, dt$$

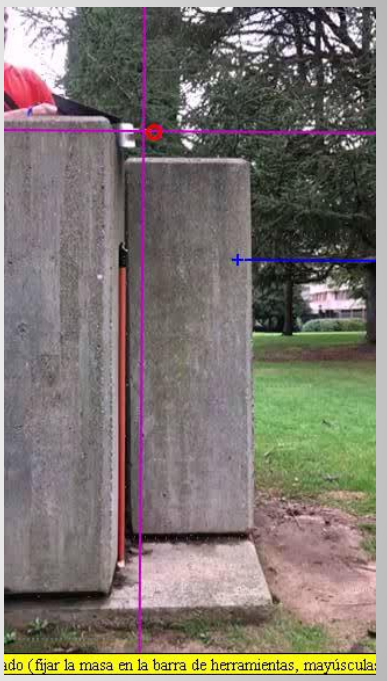



# Trajectory data: Kinematic and Dynamic models




**Experimental proof of Murphy's law**

# Results of innovation project

## Academic indicators, shared innovation resources

| Subject | Participation | Satisfaction (max. 5) | Academic results (improvement over average) |
|---|---|---|---|
| Basic Mechanics | 70-90 % | 3.1 | 60% |
| Informatic Tools | 100% | 3.5 | 53% |
| Introduction to Computational Physics | 50% | 3.9 | 73% |

**150 students/year**

# Academic Indicators

Revista Española de Física **31** (2017) 36

Real Sociedad Española de Física

R.S.E.F.

## Móviles en clase de Mecánica: estudio del movimiento de un ascensor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J. Fernández Menéndez
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M. Vélez
Dpto. Física, Universidad de Oviedo, Oviedo, CINN (CSIC-Universidad de Oviedo), El Entrego, España


Notas de clase

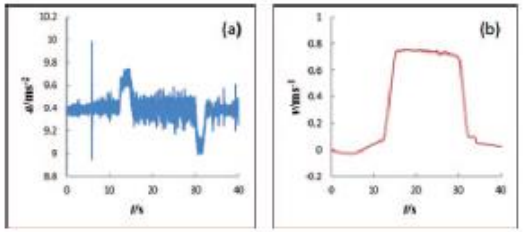
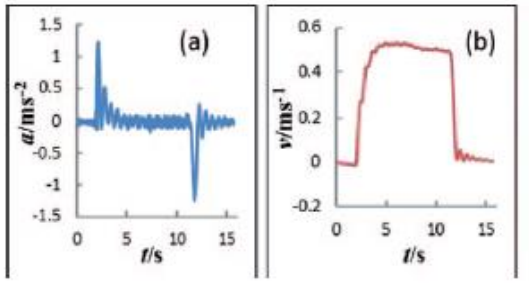



Figura 2. (a) Aceleración, $a$, en función del tiempo, $t$, durante el trayecto de subida del ascensor entre dos plantas de un edificio; (b) Velocidad, $v$, en función del tiempo, $t$, obtenida mediante una integral numérica de los datos del panel (a). Nótese la variación aparente de la velocidad en periodos que deberían ser de reposo (0-10 s y 32-40 s) a causa de variaciones suaves en $g$.




**Shared innovation resources beyond Physics and Math degrees at Science Faculty of University of Oviedo**

# Shared Accelerometer computational exercises

PICUP Partnership for Integration of Computation into Undergraduate Physics

Home | Exercise Sets | Faculty Commons | Resources | Community

Exercise Sets » Study of rectilinear motion with a smartphone: Elevators and Slides

This Exercise Set has been submitted for peer review, but it has not yet been accepted for publication in the PICUP collection.

## Study of rectilinear motion with a smartphone: Elevators and Slides

Developed by R.D. Crespo, A. García-Fuente, M. R. Sierra and M. Vélez


In this set of exercises students will measure the time dependence of the acceleration in different situations using the internal accelerometer of their Smartphones. Two experiments are proposed: the uniform acceleration motion of the Smartphone going down a slide and the rectilinear motion of an elevator going from one floor to the other. The students will import the acceleration vs. time data, plot them and obtain averages on the chosen time intervals in order to analyze them with simple mechanics models. They will also perform a numerical integration of the elevator acceleration in order to obtain the time dependent velocity and position and compare it with the actual experimental trajectory.

**Subject Areas** Mechanics and Experimental Labs

**Level** First Year

https://www.compadre.org/PICUP/exercises/exercise.cfm?I=314&A=Smartphone

**Shared innovation resources beyond Physics and Math degrees at Science Faculty of University of Oviedo**

# Physics Olympiads at Asturias


**9th March 2019**

- **60 students (2 BAC)**
- **20 High school centers**
- **3 students selected for National Olympic contest**

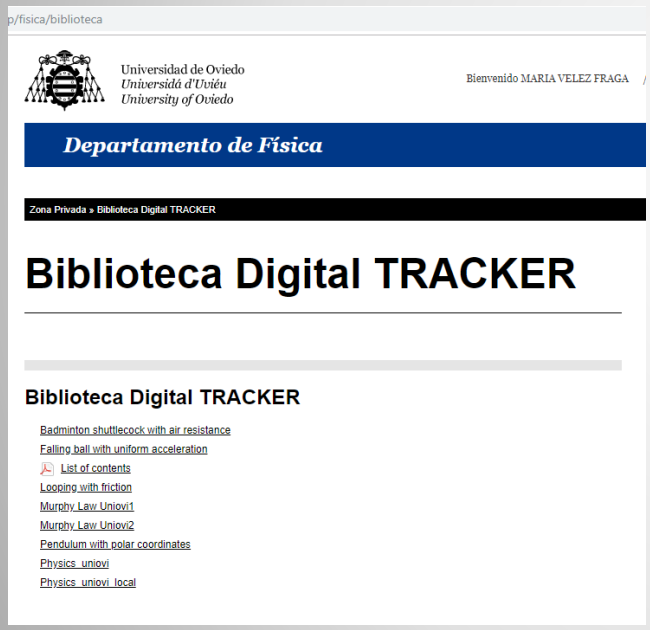
Real Sociedad Española de Física
R.S.E.F.

- **Tracker workshop for 12 High School Teachers**
- **Tracker laboratory for selected students**

**Shared innovation resources beyond Physics and Math degrees at Science Faculty of University of Oviedo**

# Shared Tracker Digital libraries

**Physics Department at Univ. Oviedo**




**Open Source Physics Web page**

http://www.per-central.org/items/detail.cfm?ID=14553

Open digital library… coming soon

**Sharing innovation resources beyond Physics and Math degrees at Science Faculty of University of Oviedo**

# Conclussions

- **Smartphone** as a *lab in your pocket* technology: accelerometer and video
- **Coordination** between different subjects
- **Autonomous learning**, team work, creativity
- **Networking** at different teaching levels