Dynamical study of a solar prominence.

Why this study ? :
The physics program of French High-Schools (TS= last year before "*baccalauréat*") includes study of various movements, like free fall, with an initial speed, in the uniform field of gravity. (as well as other movements under the action of a constant force). This activity enters into this framework.

Be aware that this study is obviously very very simplified.

Problems:

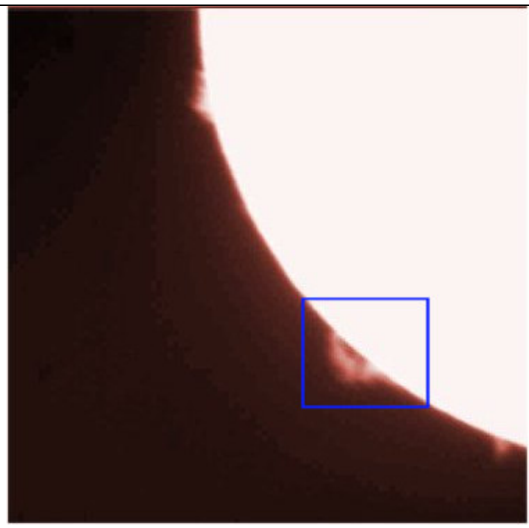
A solar prominence, with a shape of arch, has been observed (see documents):

What is the ejection velocity of the solar matter, when it leaves the solar surface?

Document 1: What is a solar prominence?
(Information drawn from the "Cosmographic Dictionary":
http://www.cosmovisions.com/prominence.htm)

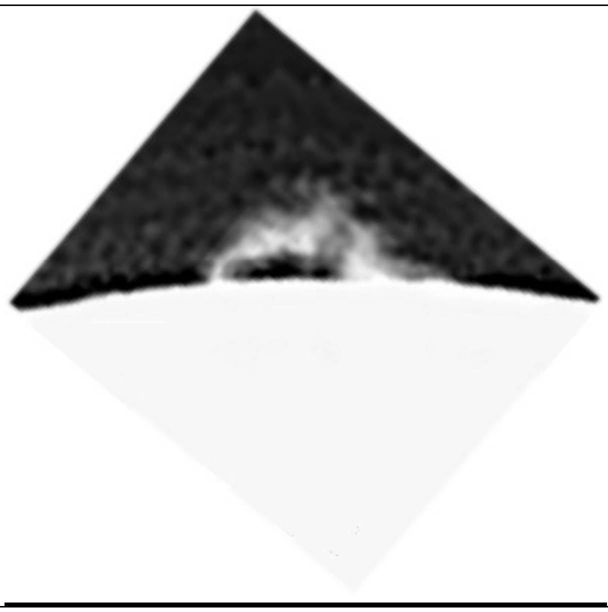
"**Prominence (or Filament).** - Gas jet above the surface of the Sun associated with its magnetic activity. Born in the chromosphere, the prominences develop in the crown under the effect of strong magnetic fields.
Encycl: Like the spots, as well, the prominences had been noticed, with the naked eye, since a long time, but without attaching a quite great importance to it. It was after the eclipse of 1842 that they held for the first time the attention of the astronomers. Progresses of photography and spectroscopy enable to study them seriously…
The astronomers thus became aware of their gigantism. Lockyer and Respighi thus observed some which extended up to 300 000 km above the Sun surface, half of the Sun radius. One perceived the complexity of the phenomena they correspond to. One could make go up with an observation published in 1883 by Young, who saw a fragment being detached and rising in space during twelve minutes with a speed of approximately 200 km per second, the first coronal ejection to be recorded.

Document 2:

This picture is a photography of a solar prominence with a shape of arch, catch in Nantes, on Thursday 17 Mars 2006, towards 15h, using Coronado refractor (PST = Personnal Solar Telescope) + Webcam, modified with black and white sensor. CCD of this one is at the focus of the objective. These refractor are provided, by construction, with a "H-alpha" filter, which transmits only the red wavelength line at λ = 656,3 nm of Hydrogen. Notice: the picture is from a film (avi), at the origin in black and white, and colourised with Paint Shop Pro.	

Document 3 :

A part of the preceding image, was treated by data processing software
- to emphasize the details
- to have the surface of the Sun "horizontal"
- so that the movement is carried out from left to the right (probably)



Document 4

One traced using a image-processing software, the circle which merges with solar surface: this allows to find the position Ω of the centre of the Sun.

<u>Assumptions defining the framework of the problem: (modeling)</u>

- We consider that the material of the arch is subjected only to his "solar weight", that means the gravitational attraction of the Sun
- Thus, we neglect any other force, including magnetic forces.
- We will believe that the solar referential is Galilean. Hence, we will neglect all effects due to his rotation
- It is supposed that the picture corresponds to an arch in a plan perpendicular to the direction of aiming.

Data:

- mass of the Sun Ms = $1{,}99.10^{30}$ kg
- radius of the Sun Rs = $6{,}95\ 10^{5}$ km
- Gravitational constant G = $6{,}67.10^{-11}$ I.S.U.

<u>One way to estimate the speed of ejection:</u>

From the assumptions formulated higher, it results the study of the movement of a mass m regarded as specific in the field of uniform gravity of the Sun. In this case the movement is parabolic, of the measurement of the range of the "shooting" and the arrow length, i.e. the maximum height reached, it is possible to find the firing angle (between the initial speed Vo and the with the local horizontal line) as well as the value of initial speed.

An example of detailed progression:

1. Calculate value of gravity g on the surface of the Sun, starting from the Newton's law of universal gravitation

2. On the image of document 2, the matter is ejected from the surface of the Sun, from point O, with a speed Vo, forming an angle α with the horizontal line, at the date t=0.

- Measure the range of the shooting and the arrow length y_s in pixels
- As the same, measure the solar radius (in pixels).

3. Interpretation:
By a dynamical analysis of the movement of a material point P, pertaining to the arch and of mass m, show that:

$$x(t) = Vo.\cos(\alpha).t$$

and $$y(t)= - \tfrac{1}{2} g.t^2 + Vo.\sin(\alpha).t$$

* assessment of the forces, and application of the Newton's second law .

4. By eliminating time t, find the equation of the trajectory:

$$y = - \frac{g}{2.Vo^2.\cos(\alpha)} . x^2 + \tan(\alpha). x$$

5. The range of the shooting corresponds to the x-coordinate x_p, (different of 0), such as $y(x_p) = 0$
   - Determine the literal expression of x_p according to α, g, Vo
   - Determine, in the same way, the literal expression of maximum height reached y_s, (the arrow length)
   - Then find that : $y_s/x_p = \frac{1}{4} \tan(\alpha)$

Numerical applications:

1. Calculate the value of α in radians, then in degrees
2. Remember that the solar radius is about $6{,}95\ 10^5$ km (= 695 000 km).
   - Which is the range x_p , in km of this "shooting"?
   - Knowing the value of and x_p, which is the value of Vo?

Conclusion: Say if the value found, looks like a good value. Justify by a comparison with a value given in this page.

3. Calculate the maximum height reached, ys, above the solar surface, and then comment the following sentence, drawn from the text above: ... "the astronomers thus became aware of their gigantism..."

Complementary data: Earth's diameter d=12800 km

Answers :

- $g = 275\ m.s^{-2}$
- x_p=112 pixels ; y_s = 35 pixels
  α = 0,896 rad ≈ 51 °

- solar radius R = 325 pixels On this picture the shooting is 36 pixels - Beware of the scale !!
  then x_p= 36*692000/325 ≈ 76600 km
- y_s = 35*76600/112 ≈ 24000 km
- Vo ≈ 145 km/s
- Value of the same order of magnitude as that given in the text (200 km/s); this speed obviously depends of the size of the studied prominence.

- We can qualify the prominences of gigantic because the height reached is close to twice the terrestrial radius.

The material, the day or the picture was taken