The General AntiParticle Spectrometer

A Balloon Experiment

Physics & Astronomy Open House
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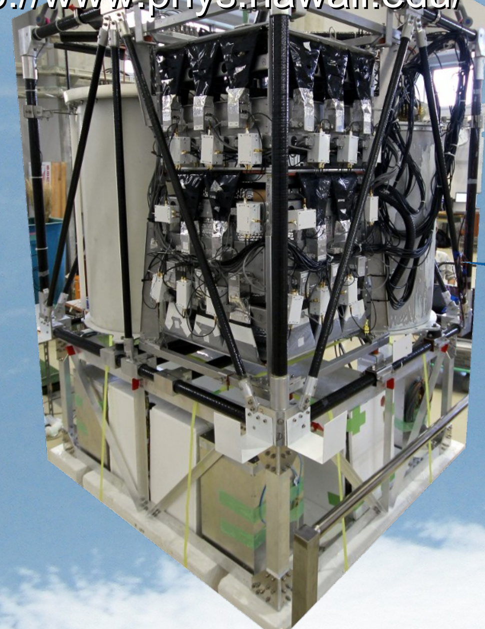


What is a Physicist?

Google search returns:

More recently?

A lot of pretty normal(?) people are into Physics.

Everybody likes to understand how stuff works, don't you think so?

Major requirement: *curiosity*

Not all about Math...

$n_a \sin\theta_a = n_b \sin\theta_b$ $\lambda = \lambda_0/n$ $n = c/v$

Total Internal Reflection: $\sin\theta_{crit} = n_b/n_a$

Geometric Optics

$m = \frac{y'}{y} = -\frac{s'}{s}$ $\frac{1}{s} + \frac{1}{s'} = \frac{2}{R}$ $f = \frac{R}{2}$

~~Reflection~~ Refraction at Spherical Surface

$\frac{n_a}{s} + \frac{n_b}{s'} = \frac{n_b - n_a}{R}$ $m = \frac{y'}{y} = -\frac{n_a s'}{n_b s}$ $\frac{n_a}{s} + \frac{n_b}{s'} = 0$

Thin Lenses

$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$ $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ () $f > 0$)($f < 0$

Two Source Light Interference

Light: $d\sin\theta = m\lambda$ Dark: $d\sin\theta = (m+\frac{1}{2})\lambda$

For Small Angles: $y_m = R(m\lambda/d)$

Phase Shift: $\phi = \frac{2\pi}{\lambda}(r_2 - r_1) = k(r_2 - r_1)$

Amplitude: $E_p = 2E|\cos(\phi/2)|$

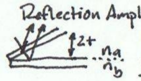
Intensity: $I = I_0 \cos^2(\phi/2)$

$I = I_0 \cos^2(\frac{1}{2}kd\sin\theta) = I_0 \cos^2(\frac{\pi d}{\lambda}\sin\theta)$

When $\phi = 0$ Intensity is ~~doubled~~ quadrupled and amplitude is doubled

Thin Film Interference

Reflection Amplitude: $E_r = E_i\left(\frac{n_a - n_b}{n_a + n_b}\right)$



Interference

Constructive: $2t = m\lambda$

Destructive: $2t = (m+\frac{1}{2})\lambda$

Those are both when $n_a > n_b$, otherwise the equations are switched

- Nonreflective Coating: $\frac{1}{4}\lambda$ thick and index of refraction less than lens
- Reflective Coating: $\frac{1}{4}\lambda$ thick and index of refraction higher than lens
- π phase shift when $n_a \to n_b$ & $n_a < n_b$

Single Slit Diffraction

Dark: $a\sin\theta = m\lambda$ Light: $a\sin\theta = (m+\frac{1}{2})\lambda$

Intensity: $I = I_0\left[\frac{\sin(\beta/2)}{\beta/2}\right]^2$ & $I_m \approx \frac{I_0}{(m+\frac{1}{2})^2\pi^2}$

Amplitude: $E_p = 2R\sin(\beta/2) = E_0\left(\frac{\sin(\beta/2)}{\beta/2}\right)$

where $E_0 = R\beta$ & $\beta = \frac{2\pi}{\lambda}a\sin\theta$

Resolving Power: $\sin\theta = 1.22(\lambda/D)$ $f_\# = \frac{f}{D}$

Multiple Slit Diffraction/Diffraction Grating

$d\sin\theta = m\lambda$ $R = (\lambda/\Delta\lambda) = Nm$ = chromatic resolv. pwr.

If there are n slits there will be n-1 minima between

$I = I_0\cos^2(\frac{\phi}{2})\left[\frac{\sin(\beta/2)}{\beta/2}\right]^2$ where

$\phi = \frac{2\pi d}{\lambda}\sin\theta$ & $\beta = \frac{2\pi a}{\lambda}\sin\theta$

X-Ray Diffraction

Bragg Condition (const.) $2d\sin\theta = m\lambda$

Polarization

Unpolarized: $I = \frac{1}{2}I_0$

Malus's Law: $I = I_{max}\cos^2\theta = I_m\cos^2(\omega t)$

Brewster Angle (polarized reflection)

$\tan\theta_p = (n_b/n_a)$

Relativity (Dilation)

$\gamma = 1/\sqrt{1 - u^2/c^2}$ $\Delta t = \gamma\Delta t_0$ $l = l_0/\gamma$

Lorentz Transformations

$V_x' = \frac{V_x - u}{1 - \left(\frac{uV_x}{c^2}\right)}$ $V_x = \frac{V_x' + u}{1 + \left(\frac{uV_x'}{c^2}\right)}$

$x' = \gamma(x - ut)$, $y' = y$, $z' = z$

General Coordinate Transformation:

$t' = \frac{t - ux/c^2}{\sqrt{1 - u^2/c^2}} = \gamma(t - ux/c^2)$

Doppler Effect

$f = \sqrt{(c+u)/(c-u)}$

Relativistic Momentum

Work and Energy

$\vec{p} = \gamma m_0 v$ $F = \gamma^3 m_0 a$

$m = \gamma m_0$ $K = (\gamma - 1)m_0 c^2$

$E = \gamma m_0 c^2 \Rightarrow E^2 = (mc^2)^2 + (pc)^2$

rest energy: $E_0 = mc^2$

Continuous Light Spectra

$I = \sigma T^4$ $\sigma = 5.67\times10^{-8}\,\frac{W}{m^2K^4}$

Wien-Displacement: $\lambda_m T = 2.9\times10^{-3}\,mK$

Planck Radiation Law:

$I(\lambda) = 2\pi hc^2/\lambda^5(e^{(hc)/(\lambda kT)} - 1)$

Photoelectric Effect

Photon: $E = hf = hc/\lambda$

$p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$

Particle: $E = p^2/2m$

$p = mv = h/\lambda$

$eV_0 = hf - \phi$ ϕ = work function

eV_0 = stopping potential

photoelectron: $K_{max} = \frac{1}{2}mv_{max}^2 = eV_0$

X-Rays

Braking Radiation: $eV_{ac} = hf_{max} = \frac{hc}{\lambda_{min}}$

Compton: $\lambda' - \lambda = \frac{h}{mc}(1 - \cos\theta)$

Atomic Spectral/Energy Levels

$E_i - E_f = hf = hc/\lambda$

$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ $R = 1.097\times10^{-7}\,m^{-1}$

GROUND STATE

$E_n = -\frac{hcR}{n}$ $E = -13.6Z^2 eV$

$\lambda = \frac{hc}{E}$

Bohr Model

angular momentum: $L = mvr = nh/2\pi$

orbital radii: $r = \frac{\epsilon_0 n^2 h^2}{\pi m e^2}$

orbital speed: $v = \frac{1}{\epsilon_0}\frac{e^2}{2nh}$

for photons:

$K = \frac{1}{2}mv^2 = \frac{1}{\epsilon_0^2}\frac{me^4}{8n^2h^2}$

$U = -\frac{1}{4\pi\epsilon_0}\frac{e^2}{r} = -\frac{1}{\epsilon_0}\frac{me^4}{4n^2h^2}$

$E = K + U$

De Broglie $\lambda = \frac{h}{p} = h/mv$

Electron Diffraction

$d\sin\theta = m\lambda$

de Broglie wavelength: $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV_{ba}}}$

Probability

$\Delta x\Delta p \geq \hbar$ $\Delta E\Delta t \geq \hbar$

Electron Microscope

resolving power: $\Delta x \sim \lambda = \frac{h}{\sqrt{2meV}}$

Quantum Mechanics

Energy Wells

$E_n = \frac{p^2}{2m} = \frac{n^2h^2}{8mL^2} = \frac{n^2\pi^2\hbar^2}{2mL^2}$

normal stationary state function

$\psi_n(L) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right)$

probability:

$P = \int_a^b|\psi(x)|^2dx = \left[\frac{2}{L}\left(\frac{x}{2} - \frac{L}{n\pi}\sin\left[\frac{2\pi nx}{L}\right]\right)\right]_a^b$

Hydrogen Atom

$E_n = \frac{-13.6\,eV\,Z^2}{n^2}\,eV$ $L = \sqrt{l(l+1)}\,\hbar$ $l = 0, 1, 2, 3, 4$ (s p d f g)

$L_z = m_l\hbar$ $-l \leq m_l < l$ & $l \leq n-1$

angle between $\vec{L}$ and z axis: $\cos\theta_L = L_z/L$

Constants

$h = 6.636\times10^{-34}\,J\cdot s$

$1eV = 1.602\times10^{-19}\,J$ $k_B = 1.38\times10^{-23}\,J/K = 8.617E{-5}\,eV/K$

Schrödinger Equation

$-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} + V\psi(x) = E\psi(x)$

if $\psi(x) = A(e^{i\alpha x} + e^{-i\alpha x})$

then $E = \frac{\hbar^2\alpha^2}{2m} + V$

Bohr Magnetron

$\mu_B = \frac{e\hbar}{2m} = 5.788\times10^{-5}\,eV/T$

$U = m_l\mu_B B$ (creates spectral lines)

$\Delta E = \mu_B B$

Electron Spin ($\pm\frac{1}{2}$) $S_z = \pm\frac{1}{2}\hbar$

$S = \hbar\sqrt{\frac{1}{2}(1 + \frac{1}{2})} = \sqrt{\frac{3}{4}}\,\hbar$

Molecular Bonds

Covalent: Share electrons $\sim 5eV$

Ionic: Opposite charges $\sim 5eV$

Van der Walls: Dipole moment $\sim 0.1eV$

Molecular Spectra $E = L^2/2I$

$E_l = \frac{\hbar^2}{2I}l(l+1)$ $I = \left(\frac{m_1m_2}{m_1+m_2}\right)r_0^2$

Vibrational Energy Levels

$\Delta E = \hbar\omega$ $E_n = (n+\frac{1}{2})\hbar\omega$

$E_{nl} = (n+\frac{1}{2})\hbar\sqrt{\frac{k'}{m_r}} + \frac{\hbar^2}{2I}l(l+1)$

Rocket Away from Earth Problem

$t' = \frac{-vL}{3E8}$ V is in units of c

L is in cm

Atom of mass M splits in half, pieces m move at V. What is the mass of each half in terms of M?

$Mc^2 = \frac{2mc^2}{\sqrt{1-v^2}}$

What keeps me going

stuff we know

stuff we don't know:
dark matter

→ makes me curious!

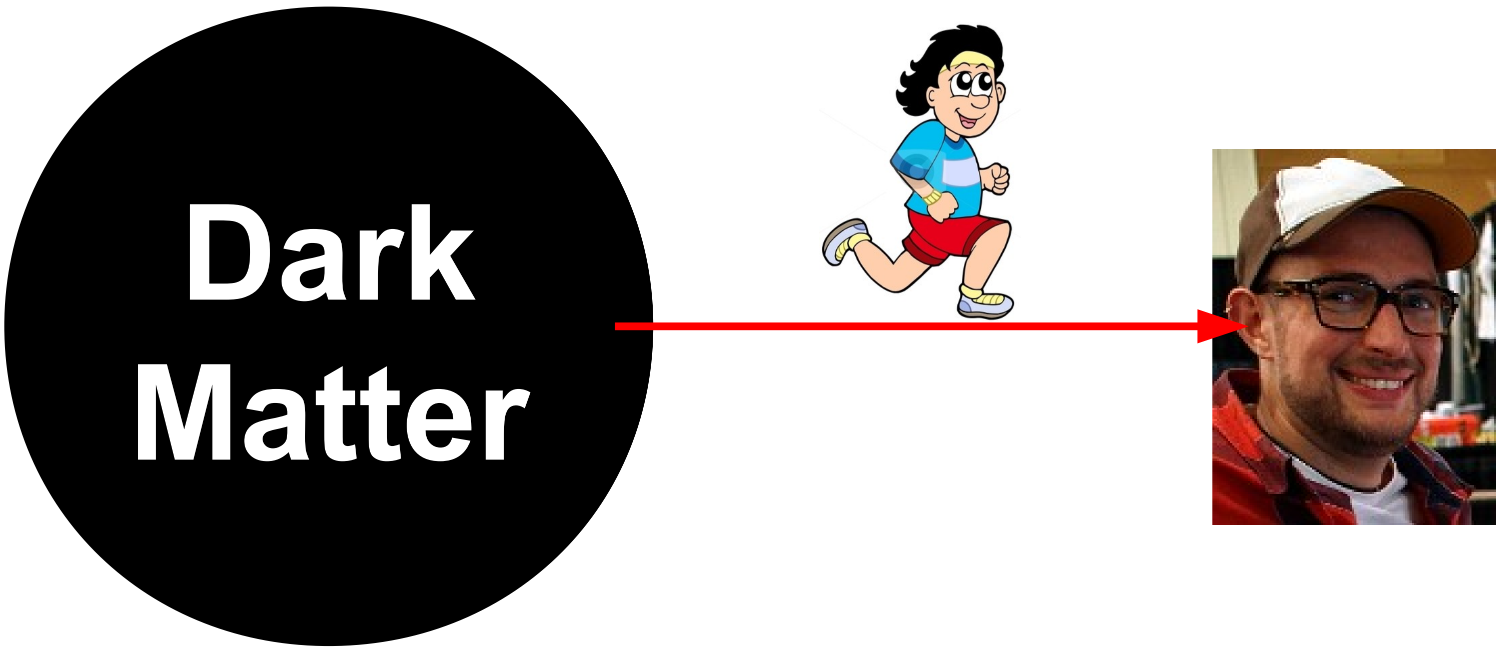
Dark Matter:

We know it's there!

Otherwise our whole Universe would look different.

So far: no proof for what it is exactly! :-(

Now what?



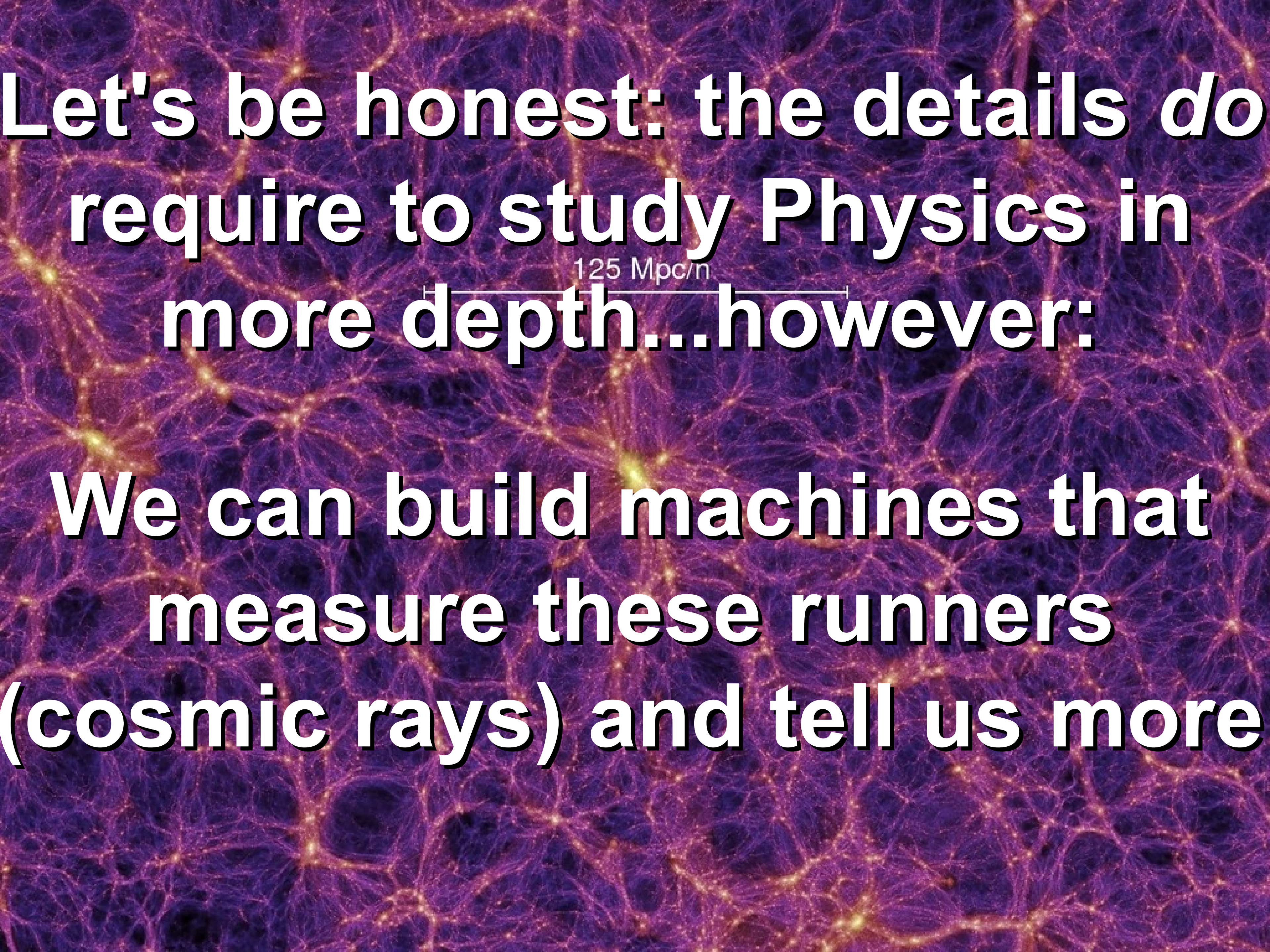
Why not ask somebody who has been there and runs fast?

Runners telling us about Dark Matter could be *cosmic rays*

?Cosmic rays - What is that?

It can get pretty violent out there, which can produce all sorts of things!

for example: protons and electrons (the matter we are made of)



Let's be honest: the details *do* require to study Physics in more depth...however:

We can build machines that measure these runners (cosmic rays) and tell us more

Where to put such an experiment?

The atmosphere acts as a roof for cosmic rays

Which is good to stay healthy, but bad to measure cosmic rays

when you are hiking at high altitudes

→ you are exhausted much faster

→ because there is less air too breathe

→ *roof for cosmic rays is getting weaker*

Therefore put the experiment as high as possible!
Space is great, but super expensive ($1,000,000 for 2lbs)

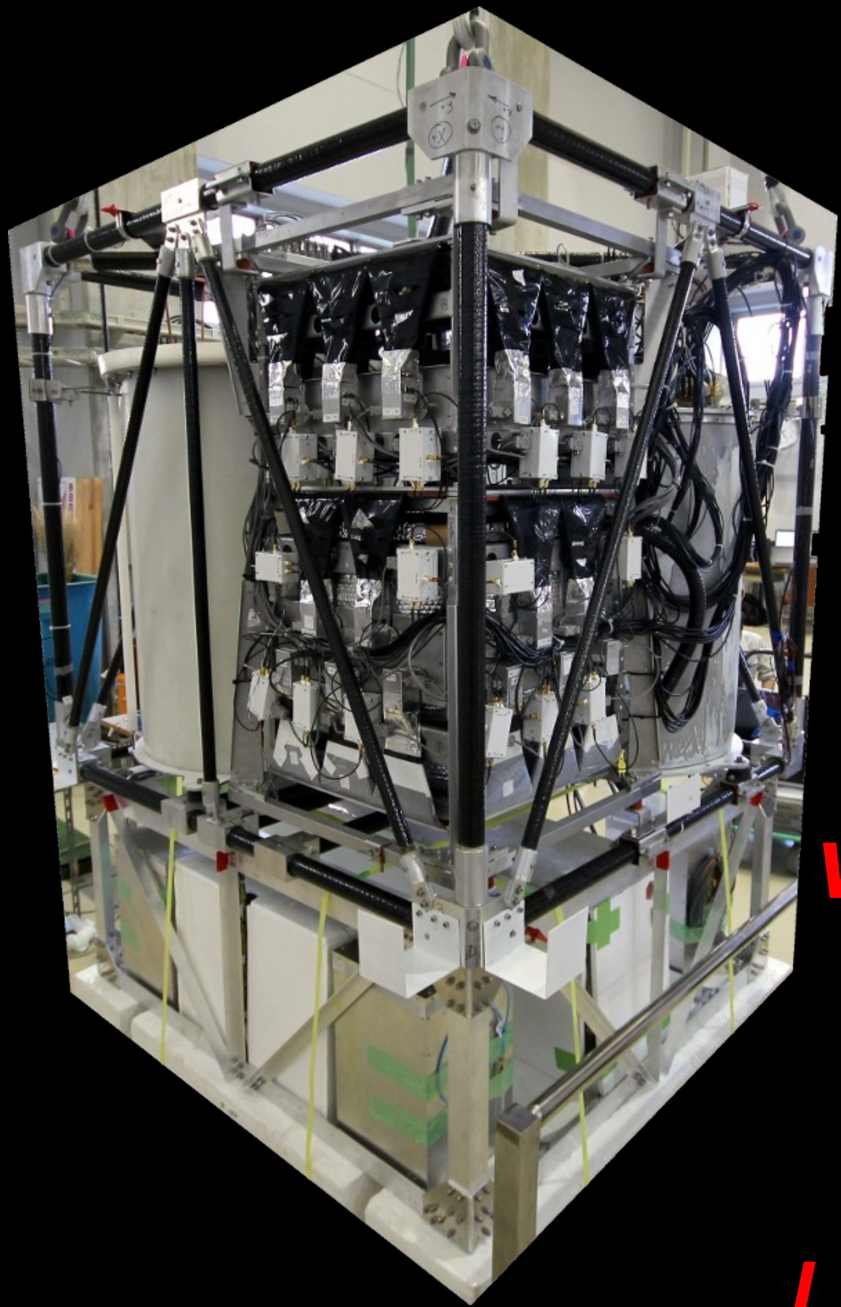
Therefore put the experiment as high as possible!

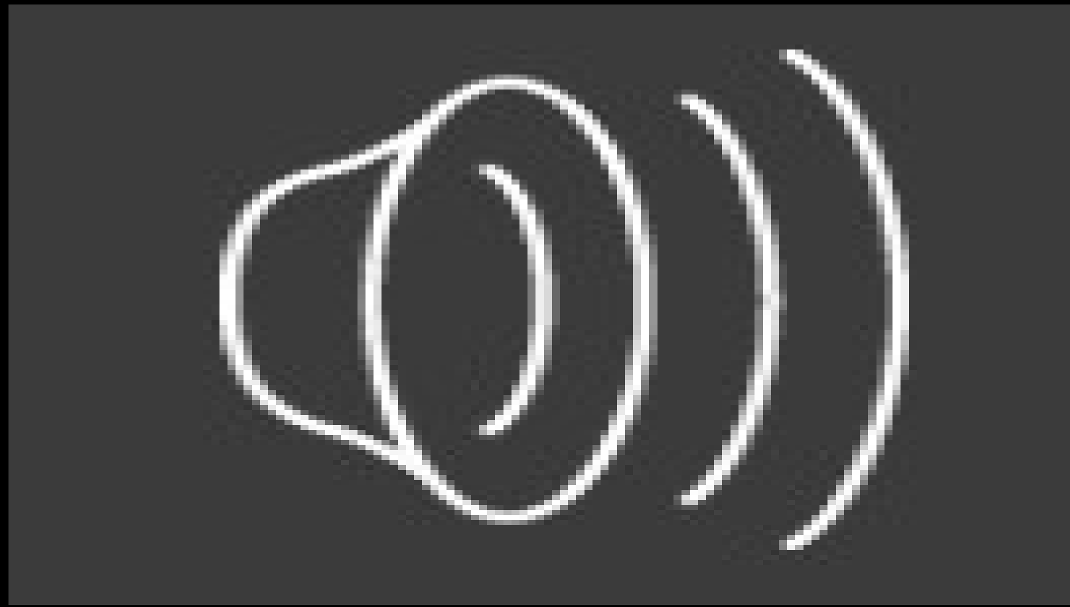
Space is great, but super expensive ($1,000,000 for 2lbs)

use balloons

that go up very very high

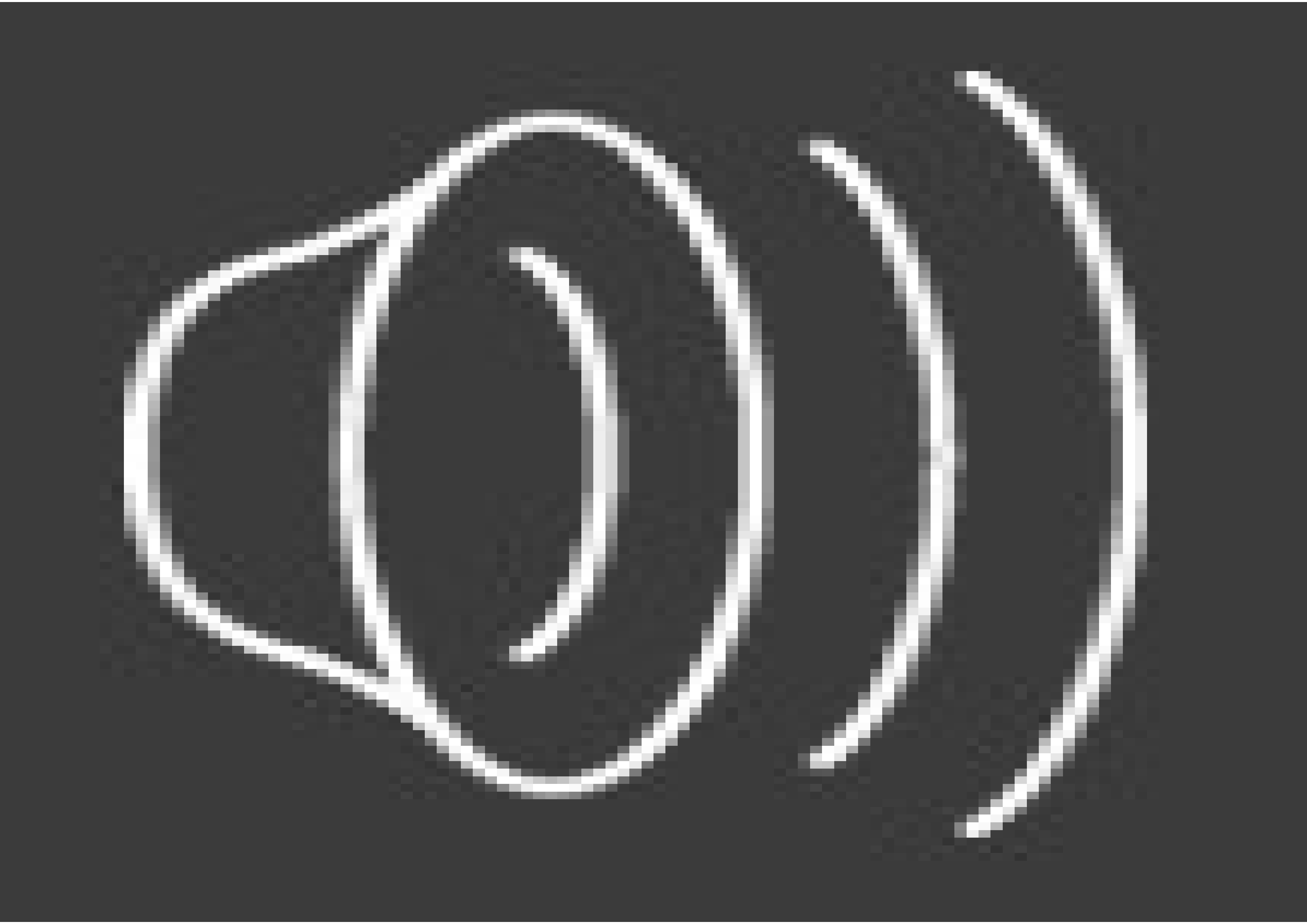
→ 25 miles above ground

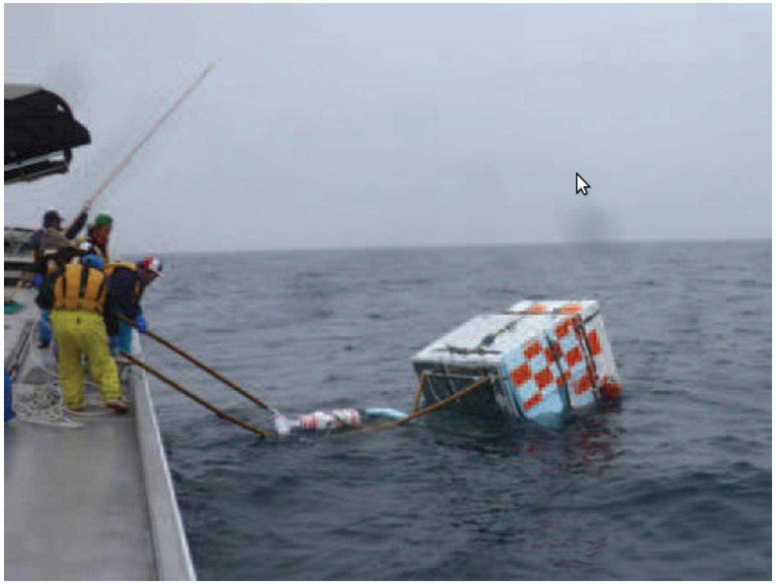




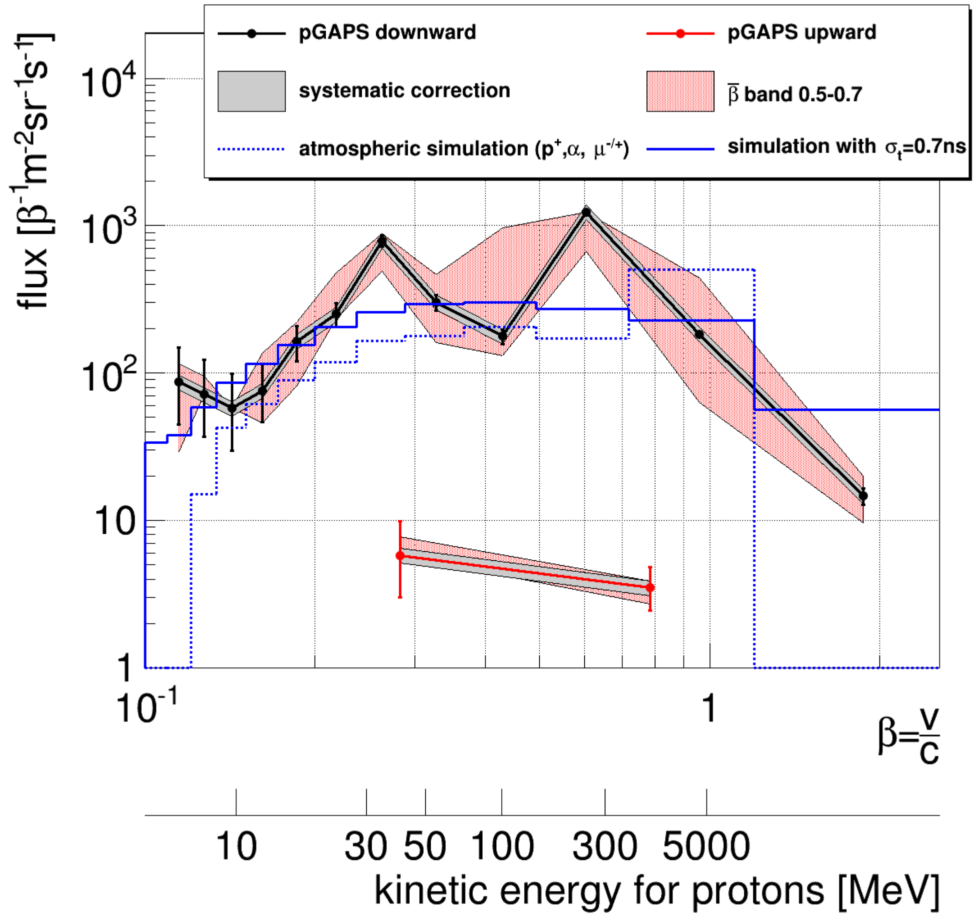
A lot of hands on work with all sorts of different tasks!

Playground for big kids: model building, crafting, LEGO, electronics, chemistry sets, computers





Experiment landed in the Pacific ocean!



We are just at the beginning to understand Dark Matter!

I could only present one way to look at the question

Will keep us busy for many years!

Please join us with your ideas!

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