

# What's Happening at the Frontiers of Physics?

**What's Happening  
at the  
Frontiers of Physics?**

Dr Steve Barrett 13 Nov 2008

**The Department of Physics**

33 Academic Staff	R + T + A
68 Research Staff	R
22 Technical Staff	R + T
9 Administrative Staff	A
250 Undergraduate Students	
50 Postgraduate students	

WHAFP Introduction 2

**Research Areas**

Particle Physics

Nanophysics

Nuclear Physics

Astrophysics

WHAFP Introduction 3

**Particle Physics**

What we know...

**Structure within the Atom**

**Quark**  
Size <math>< 10^{-19}</math> m

**Nucleus**  
Size =  $10^{-14}$  m

**Electron**  
Size <math>< 10^{-18}</math> m

**Neutron and Proton**  
Size =  $10^{-15}$  m

**Atom**  
Size =  $10^{-10}$  m

If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

# What's Happening at the Frontiers of Physics?

Particle Physics

What we know...

Baryons $qqq$ and Antibaryons $\bar{q}\bar{q}\bar{q}$						Mesons $q\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of baryons.						Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass $\text{GeV}/c^2$	Spin	Symbol	Name	Quark content	Electric charge	Mass $\text{GeV}/c^2$	Spin
$p$	proton	$uud$	1	0.938	1/2	$\pi^+$	pion	$u\bar{d}$	+1	0.140	0
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2	$K^-$	kaon	$s\bar{u}$	-1	0.494	0
$n$	neutron	$udd$	0	0.940	1/2	$\rho^+$	rho	$u\bar{d}$	+1	0.770	1
$\Lambda$	lambda	$uds$	0	1.116	1/2	$B^0$	B-zero	$d\bar{b}$	0	5.279	0
$\Omega^-$	omega	$sss$	-1	1.672	3/2	$\eta_c$	eta-c	$c\bar{c}$	0	2.980	0

Particle Physics

What we know...

Standard Model

FERMIONS						BOSONS					
Leptons $\text{spin} = 1/2$			Quarks $\text{spin} = 1/2$			Unified Electroweak $\text{spin} = 1$			Strong (color) $\text{spin} = 1$		
Flavor	Mass $\text{GeV}/c^2$	Electric charge	Flavor	Approx. Mass $\text{GeV}/c^2$	Electric charge	Name	Mass $\text{GeV}/c^2$	Electric charge	Name	Mass $\text{GeV}/c^2$	Electric charge
$\nu_e$ electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3	$\gamma$ photon	0	0	g gluon	0	0
e electron	0.000511	-1	d down	0.006	-1/3	$W^-$	80.4	-1			
$\nu_\mu$ muon neutrino	$<0.0002$	0	c charm	1.3	2/3	$W^+$	80.4	+1			
$\mu$ muon	0.106	-1	s strange	0.1	-1/3	$Z^0$	91.187	0			
$\nu_\tau$ tau neutrino	$<0.02$	0	t top	175	2/3						
$\tau$ tau	1.7771	-1	b bottom	4.3	-1/3						

Particle Physics

What we **don't** know...

**Why** are there **4** fundamental forces?

**Why** does the **Standard Model** have **3** families of particles?

**Why** does the **Standard Model** need **19** adjustable parameters to make it work?

Where does **gravity** fit in?  
*The Standard Model encompasses all of the fundamental forces except gravity — a rather important oversight, don't you think?*

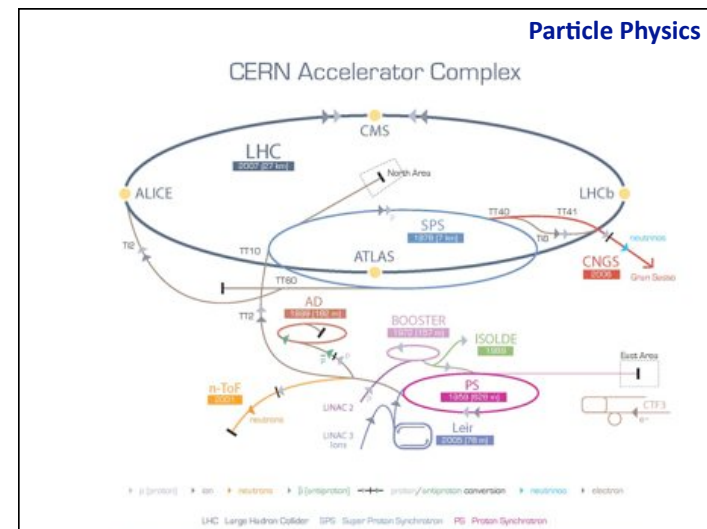
**Why** is there an imbalance between **matter** and **anti-matter**?

Does space have more than **3 dimensions**?

What is **dark matter** actually made of?

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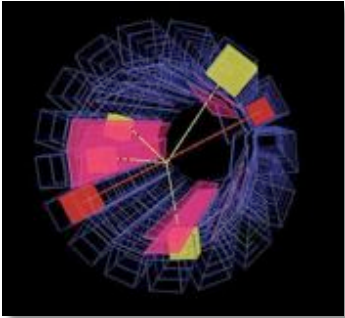
WHAFF Particle Physics 7



# What's Happening at the Frontiers of Physics?

**Particle Physics**

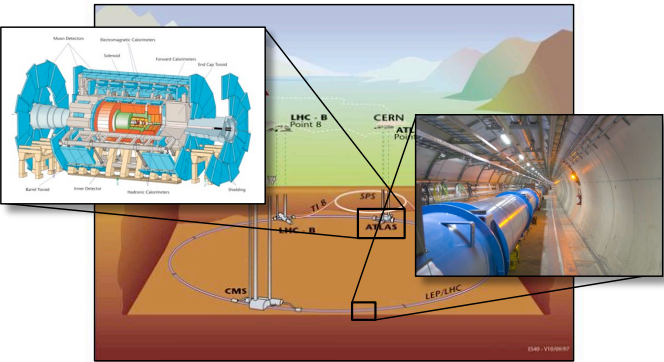
Detecting anti-matter



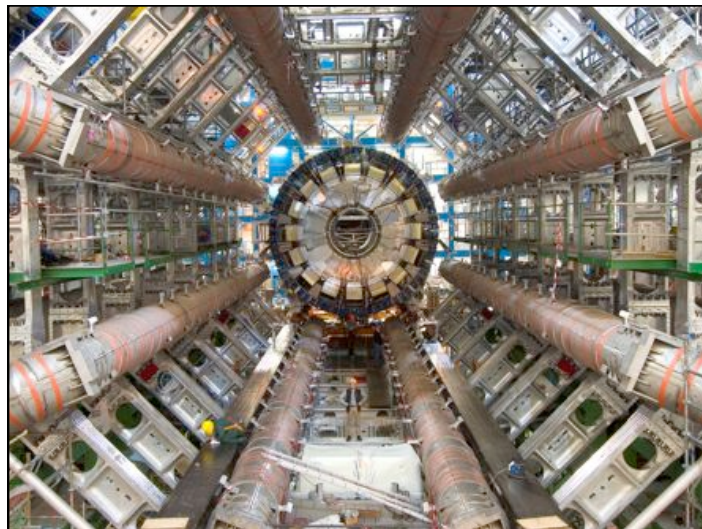
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**Particle Physics**

The Large Hadron Collider

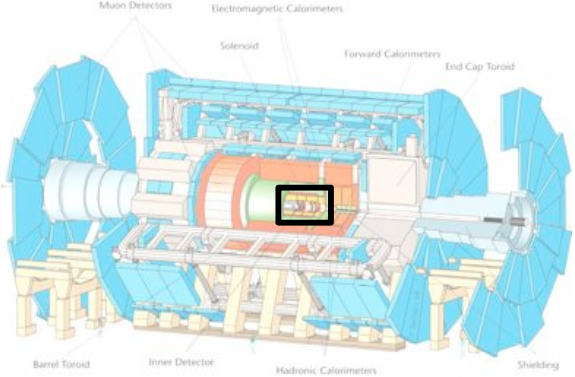


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**ATLAS**

What is Liverpool doing?



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# What's Happening at the Frontiers of Physics?

ATLAS

What is Liverpool doing?

Muon Detectors    Electromagnetic Calorimeters

Barrel Toroid    Inner Detector    Hadronic Calorimeters    Shielding

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ATLAS

Disk DC T...    November 2004

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Neutrino Physics

Flux of neutrinos from the Sun not as high as models require.

Why? Neutrinos **change** on their way from the Sun to the Earth.

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Neutrino Physics

Flux of neutrinos from the Sun not as high as models require.  
 Why? Neutrinos **change** on their way from the Sun to the Earth.  
 Try to reproduce this change 'locally' on Earth: The **T2K** project.

Kamoko, Gifu    TOKAI    295 km    S-K

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# What's Happening at the Frontiers of Physics?

## Neutrino Physics

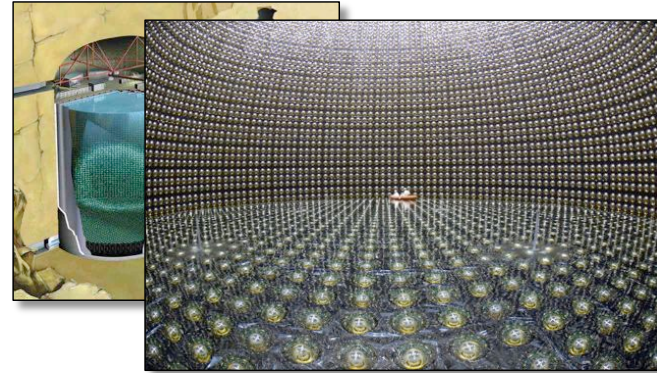


WHAFP Particle Physics / Neutrinos / Cerenkov

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## Neutrino Physics

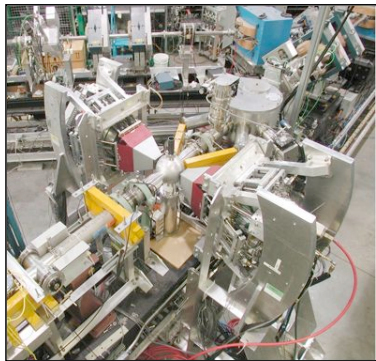
Super-Kamiokande detector



WHAFP Particle Physics / Neutrinos

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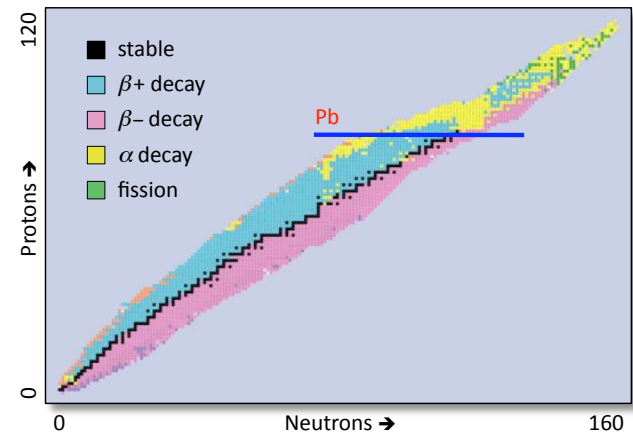
## Nuclear Physics



WHAFP Nuclear Physics

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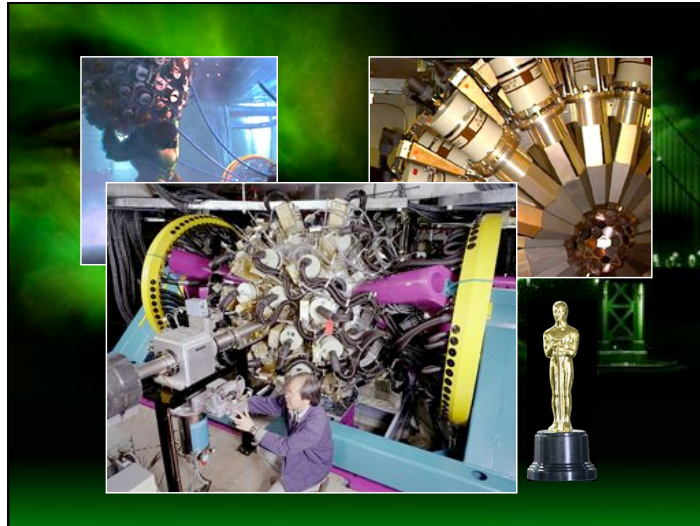
## Nuclear Physics



WHAFP Nuclear Physics

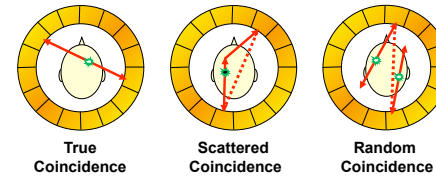
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# What's Happening at the Frontiers of Physics?



## Nuclear Physics

Spin-offs into medical imaging



WHAFP Nuclear Physics

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## NanoPhysics

In the field of NanoPhysics the questions are rather different.

Some of the questions are 'big' questions...

Can we understand **emergence** — how complex systems arise from relatively simple interactions?

Can manipulation of **atoms** provide insight into the **life sciences**?

Can the laws of Physics be applied to a living **cell**?

Can we build a (useful) **quantum computer**?

Rather than having **10,000** physicists working on **6** questions,  
there are **10,000** physicists working on **10,000** questions...

WHAFP NanoPhysics

## NanoPhysics

Can we make a (cheap) material **stronger** than diamond?

How exactly do **snow flakes** grow?

Can we make a **superconductor** that works at  $T > \text{Room Temp}$ ?

What is the origin of **sonoluminescence**?

Can we understand **soft** condensed matter (like glassy materials)?

Can we make and use **single-molecule** sensors?

Can we make **single-atom** memory devices?


...and these are just **some** of the questions – the ones with an “s” !


WHAFP NanoPhysics



# What's Happening at the Frontiers of Physics?

**Astrophysics**

Astrophysics is not an area of expertise for 

But it is for 

Hence we created an **Astrophysics degree programme** with experts in Physics (UoL) and Astronomy (JMU).

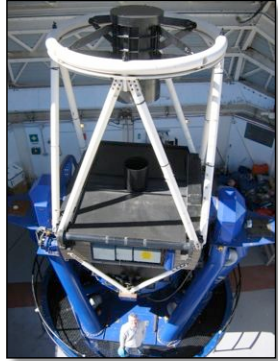
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**Astrophysics**

Liverpool operates the world's largest fully robotic telescope.

The key is fast response — if something interesting happens out there, the telescope can interrupt the current observation and be 're-tasked' in seconds.



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**Astrophysics**

The Liverpool Telescope has been joined by two others...

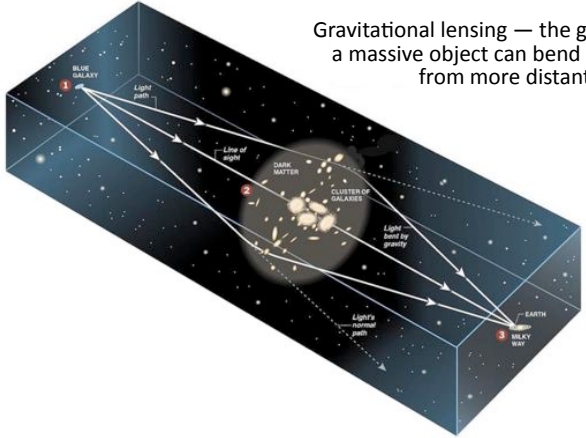


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**Astrophysics**

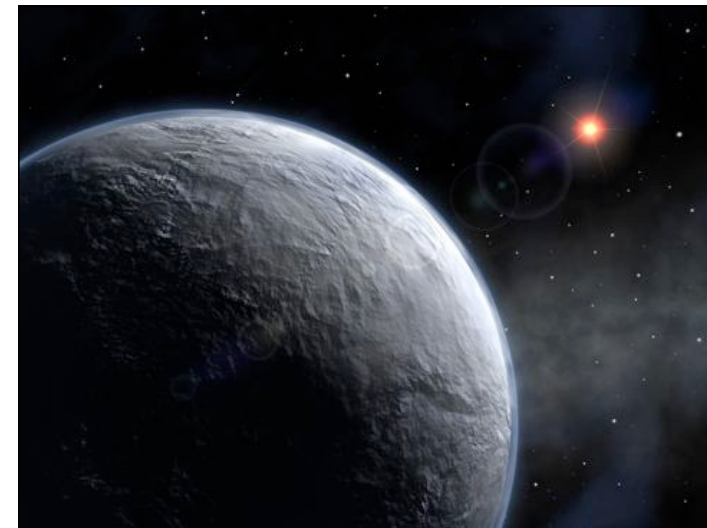
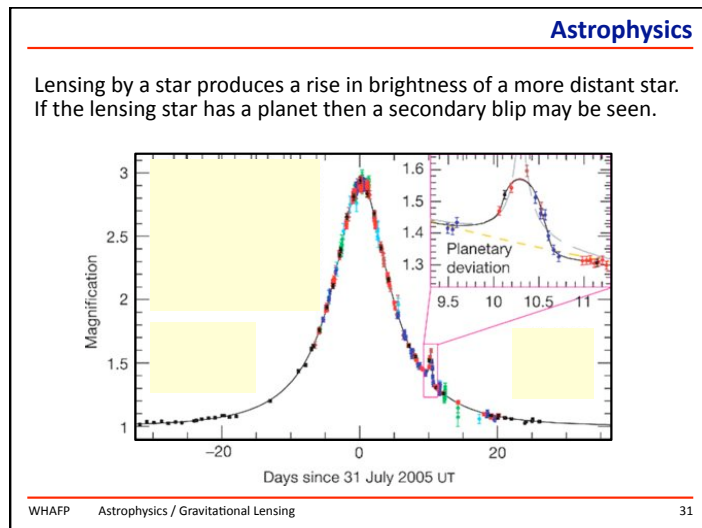
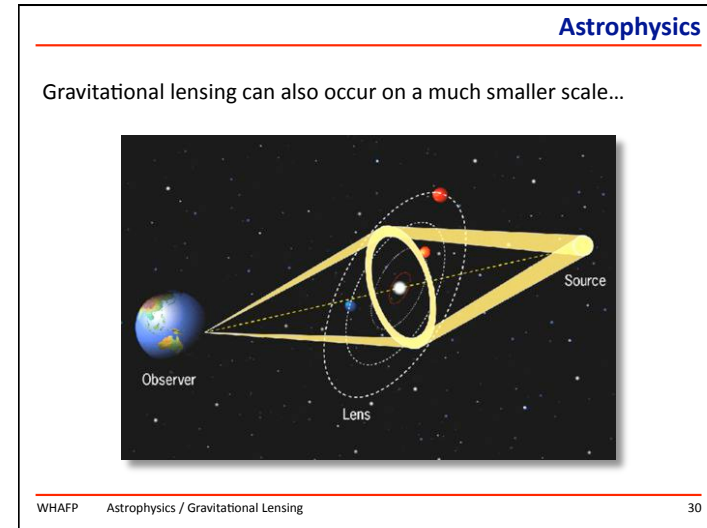
Gravitational lensing — the gravity of a massive object can bend the light from more distant objects



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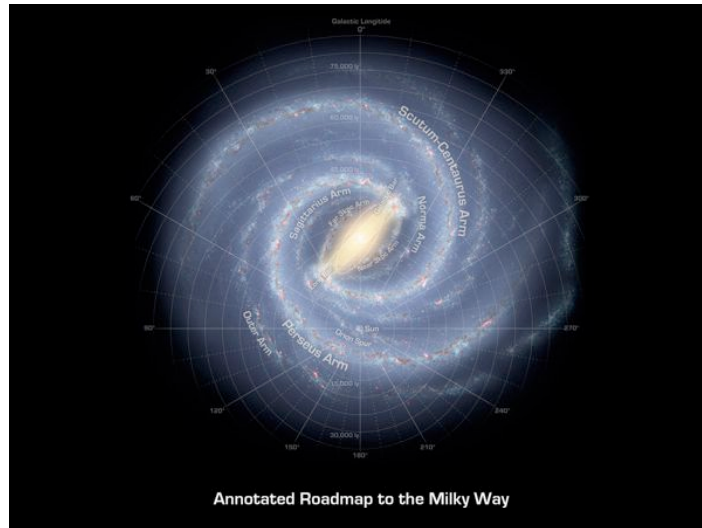
WHAFP    Astrophysics / Gravitational Lensing    28

# What's Happening at the Frontiers of Physics?





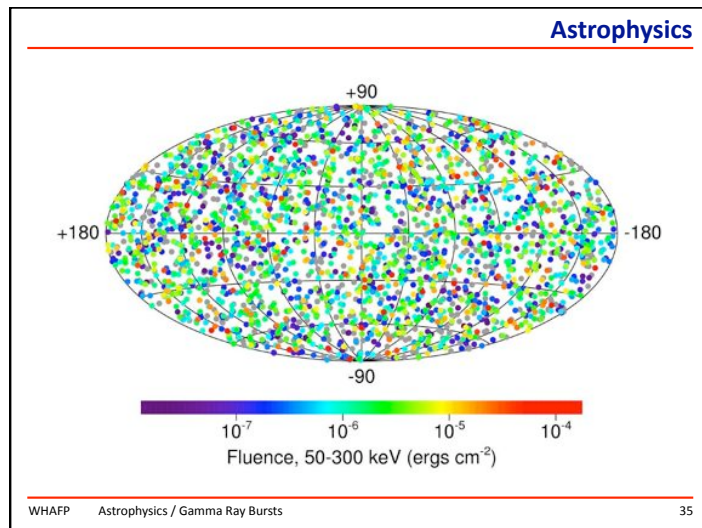
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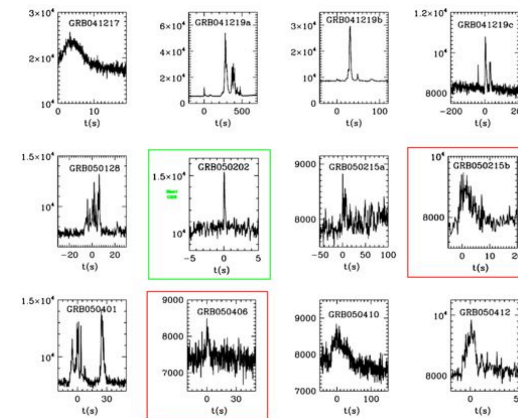
## Astrophysics

In the 1960s satellites designed to monitor nuclear explosions on Earth discovered extra-terrestrial bursts of gamma rays.

Burst and Transient Source Experiment (**BATSE**) detector launched in late 1980s to investigate further.




## Astrophysics



# What's Happening at the Frontiers of Physics?

**Astrophysics**



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**Astrophysics**

We hope that any 'interesting' events occur well away from the Earth...

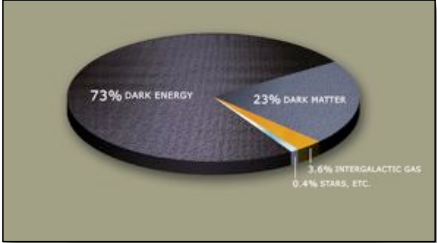
...otherwise we are toast!



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**Astrophysics**

The really big question...



Component	Percentage
Dark Energy	73%
Dark Matter	23%
Intergalactic Gas	3.6%
Stars, etc.	0.4%

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LIVERPOOL



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