

SHADOWS, MIRRORS & FORCES

• ONE REASON FOR RICH DIVERSITY IS SHEER NO. OF PARTICLE.

• THOUGH TINY NUMBER OF DISTINCT PARTICLES THERE ARE

$\sim 10^{78}$ ATOMS/PROTONS IN THE UNIVERSE

THIS IS AN INTERESTING NUMBER

IN AN ATOM : $\frac{F_{\text{ELECTRIC}}}{F_{\text{GRAV}}}$ between

electron & proton is $\sim 10^{39}$

$\frac{R_{\text{proton}}}{R_{\text{obs, univ}}} \sim 10^{-39}$

[PROTON : PROTON]
 $\sim 10^{36}$

$10^{39} \times 10^{39} = 10^{78}$ coincidence?

NOT REALLY : ONLY 1 LARGE NO.

$$\frac{F_{\text{elec}}}{F_{\text{grav}}} \bigg|_{\text{proton-proton}} \sim 10^{36}$$

ASSEMBLE ATOMS : 10^{24} SUGAR CUBE
 10^{40} MOUNTAIN / ASTEROID

$$F_{\text{GRAVITY}} \propto \frac{M}{R} \propto \frac{N}{N^{1/3}} \propto N^{2/3}$$

GRAVITY DOMINATES WHEN $N \sim 10^{54} \Rightarrow \underline{\text{JUPITER}}$

* ANYTHING BIGGER $\Rightarrow$ STAR

$$\frac{R_{\text{protons}}}{R_{\text{obs, univ}}} = \frac{t_{\gamma, \text{proton}}}{t_{\gamma, \text{universe}}} \approx \frac{t_{\gamma, \text{proton}}}{t_{\gamma, \text{life of star}}}$$

$t_{\gamma, \text{star}} \approx$ time for ~~the~~ energy to leak out of star

• DRUNKARD'S WALK

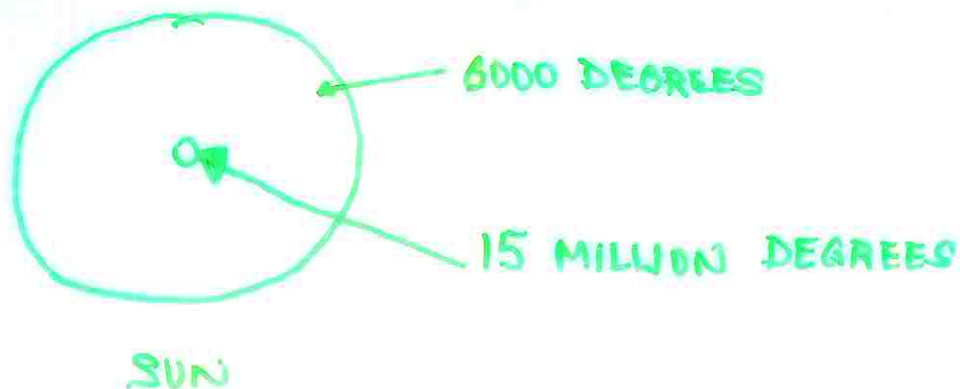
• $t_{\text{escape}} \propto \# \text{ steps} \cdot t_{\gamma, \text{proton}} \propto N^{2/3} t_{\gamma, \text{proton}}$

$$\text{FOR SUN (typical)} : \frac{t_{\gamma, \text{proton}}}{t_{\gamma, *}} \approx 10^{-39}$$

WHAT DOES A STAR HAVE TO DO WITH ALL THIS?

FORMATION OF STAR

- GAS OF PROTONS & ELECTRONS COLLAPSES [GRAVITY]
- NUCLEAR & ELECTROMAGNETIC FORCES BATTLE IT OUT
- GAS GETS HOT $\rightarrow$ PRESSURE



IF NOTHING ELSE HAPPENS $\rightarrow$ GAS RADIATES
PRESSURE $\downarrow$
SUN SHRINKS TO $\frac{1}{2}$ PRESENT
SIZE IN 10 MILLION YRS

* TIMESCALE FOR EMERGENCE OF LIFE

WEAK INTERACTION CONVERTS $p^+ \rightarrow n^0 + e^+$
ALLOWING NEUTRONS, PROTONS TO FUSE $\Rightarrow$ He^{2+} nuclei
AND RELEASING LOTS OF ENERGY !!

START WITH 4 PROTONS

$$M_i = 4m_p$$

END-UP WITH 2 PROTON, 2 NEUTRONS BOUND

$$M_f = M_{\text{He}}$$



$M_i \neq M_f$ in fact $M_{\text{He}} < M_{4\text{H}}$

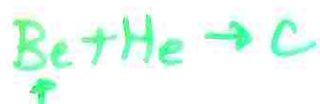
$$E = \Delta M c^2 \Rightarrow \text{energy released.}$$

YOW WEAK INTERACTION IS WEAK & SLOW
OR ELSE RAPID NUCLEAR FUSION $\rightarrow$ NO TIME FOR...

EVENTUALLY $\text{H} \rightarrow \text{He}$ IN CORE
 $\rightarrow \text{C, N, O} \dots \text{Fe}$

MAJOR EXPLOSIONS $\Rightarrow$ ENRICHMENT [LIFE]

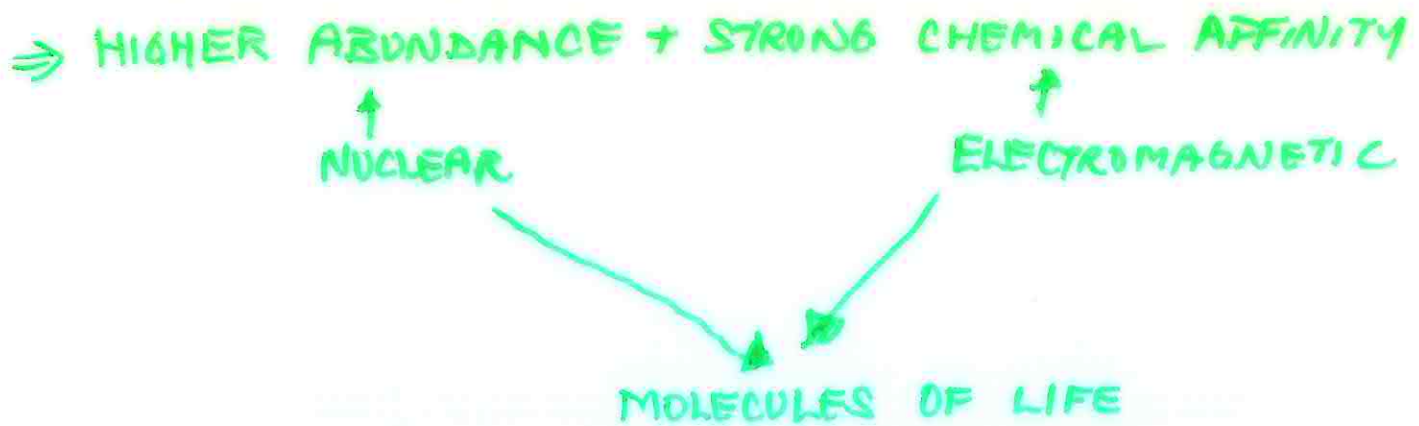
BUT WHY IS C, O MORE COMMON?



IS THERE ENOUGH TIME?

A NUCLEAR FINE-TUNING ALLOWS

$\text{Be} + \text{He} \rightarrow \text{C}$ RAPIDLY BUT NOT $\text{C} + \text{He} \rightarrow \text{O}$



IF GRAVITY WERE 10^{10} STRONGER THAN PRESENT $\left[\frac{F_{\text{elec}}}{F_{\text{grav}}} \sim 10^{26} \right]$

- N MUCH SMALLER BEFORE GRAVITY WINS
- LIFETIME MUCH SHORTER (STARS) YEARS VS. 10 BILLION
- MORE DENSELY PACKED GALAXIES [SOLAR SYSTEMS DISRUPTED]
• NO STABLE ORBITS
- PLANETS WOULD BE 10^{15} SMALLER
- SIZE OF LIFE FORMS $\propto$ GRAVITY : STRONGER GRAVITY
↓
SMALL (INSECT-LIKE) LIFE
- BUT MICRO-PHYSICS NOT CHANGED ⇒ NO TIME FOR EVOLUTION

DIMENSIONS OF SPACE: 3, NOT 2 OR 4
FOR STABLE PLANET ORBITS.

SIR MARTIN REES: JUST 6 NUMBERS

$$N = \frac{F_{\text{elec}}}{F_{\text{grav}}} \Big|_{\text{proton-proton}} \sim 10^{36}$$

ϵ = how strongly nuclei bind together

Ω = total amount of matter in universe

• too high $\Rightarrow$ Big Crunch

• too low $\Rightarrow$ no galaxies [no recycling, etc.]

~ 0.3 [0, 1]

Λ = dark energy ~ 0.7 [0, 10^{20}]
 $\uparrow$ no galaxies, etc.

Q : ripples in early universe

- too high $\Rightarrow$ Black Holes

- too low $\Rightarrow$ no structure

D : DIMENSIONS.

FINE-TUNING OR MULTIVERSE.

SYMMETRY IN NATURE ①

- SCIENTIST & SCIENCE JOURNALS OFTEN "PLAY UP" SPECIFIC PHYSICAL PHENOMENON
- MUCH MORE INTERESTING IS UNDERLYING FRAMEWORK →

STRUCTURE OF PHYSICAL REALITY

LIBRETTO	VS.	MUSIC [OPERA]
↓		↓
STORY/VOCALS		FRAMEWORK STRUCTURE CONNECTION

↳ MANY INDIVIDUAL SUBTEXTS
TIED TOGETHER BY
SINGLE COHESIVE FRAMEWORK

- BOTH ARE IMPORTANT BUT LATTER CONSIDERED MORE FUNDAMENTAL.
- LATTER IS MANIFESTATIONS.

• DIVERSITY OF PHYSICAL PHENOMENA
→ SINGLE UNDERLYING EXPLANATION

• FUNDAMENTAL SCIENCE IS INTERESTED
IN THIS UNDERLYING FRAMEWORK

• COME TO REALIZE THAT AT ITS VERY
HEART, NATURE IS "BEAUTIFUL".

• SEARCH FOR THIS AESTHETICS OF NATURE
IS THE DRIVING FORCE OF CONTEMPORARY
PHYSICS.

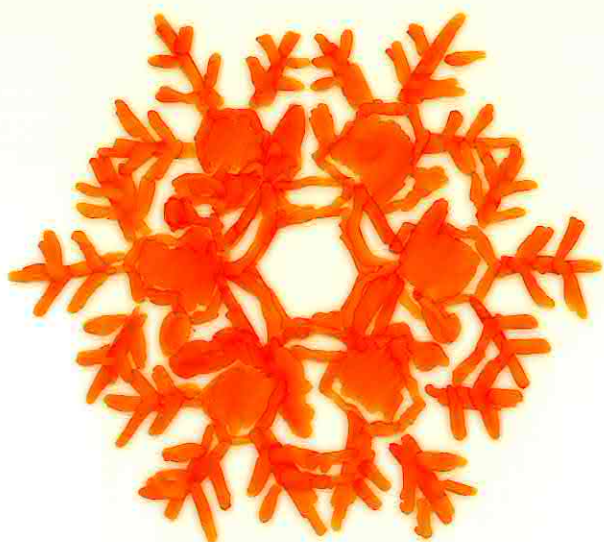
• WHAT DOES "BEAUTIFUL" MEAN?

- LOADED TERM

- PERCEPTION OF BEAUTY IN EVERYDAY
SENSE IS TIED TO PSYCHOLOGICAL,
CULTURAL, SOCIAL & EVEN BIOLOGICAL
INFLUENCES.

- NATURE'S BEAUTY IS IN HER VERY DESIGN.
SHE MANIFESTS SYMMETRIES UPON
SYMMETRIES.

GEOMETRIC SYMMETRY:



SYMMETRY $\Rightarrow$ INVARIANCE

* ROTATION

* REFLECTION / FOLD

What can one do and still leave figure unchanged?

PHYSICIST:

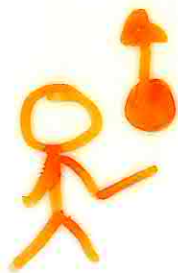
What can one do and still leave physical reality unchanged?

Do physicists with different perspectives see physical reality differently?

TRANSLATION SYMMETRY:

NO SPECIAL PLACE IN UNIVERSE.

- LAWS HERE ARE SAME AS LAWS THERE [RELATIONSHIPS]



• ACROSS EARTH → COSMOS

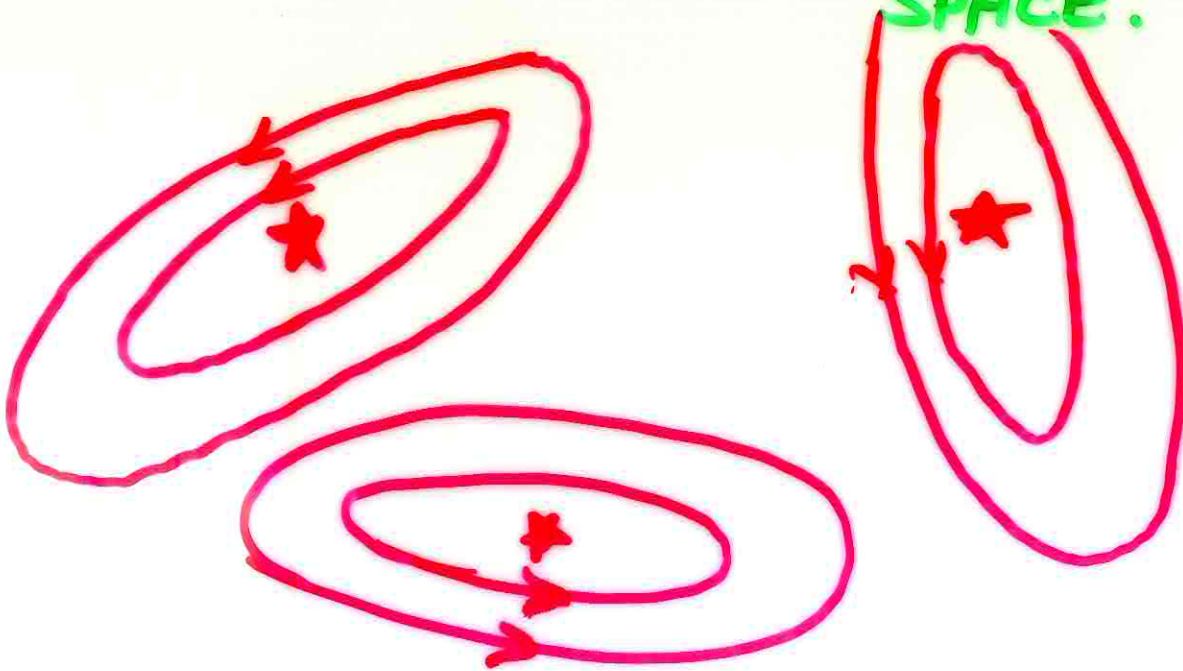
IS EARTH AT CENTER OF SOLAR SYSTEM OR THE SUN?

[TUSI, URDI, SHATIR]

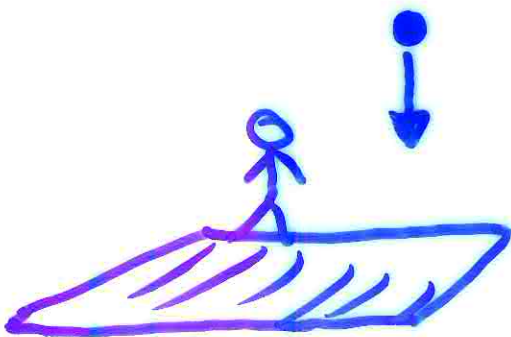
[GALILEO, KEPLER]

ROTATIONAL SYMMETRY:

→ NO SPECIAL DIRECTION IN SPACE.



THERE IS NO UP & DOWN [GREEKS]



NEWTON → GRAVITY

