



# Projet UNIX

## ft\_contrast

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*Summary:* This project belong to a set of many others, that are all connected to the J-Gravity project.

- Parallel processing
- GPGPU Programming (Cuda and OpenCL)
- Network programing

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# **Chapter I**

## **Short introduction to life and universe**

# Savoir sans Frontières

<http://www.savoir-sans-frontieres.com>

# BIG BANG

Jean-Pierre Petit



The Association Knowledge without Borders, founded and chaired by Professor Jean-Pierre Petit, astrophysicist, aims at spreading scientific and technical knowledge in as many countries as possible and in as many languages as possible. To this end, all his popular scientific works, which cover a period of thirty years, and more particularly the illustrated albums he has created, are now freely accessible. Anyone is now free to duplicate the present file, either in digital form or in the form of printed copies and circulate these copies to libraries , within the context of schools or universities or associations whose aims would be the same as the association , provided that they do not derive any profit from this circulation and that they do not have any political, sectarian or confessional connotations. These pdf files may also be put on line in the computer networks of school and university libraries.



Jean-Pierre Petit intends to create numerous other works which will be accessible to a larger audience. Even illiterate people will be able to read them because the written parts will "speak" when the readers click on them. Thus it will be possible to use these works to support literacy schemes. Other albums will be "bilingual" in so far as it will be possible to switch from one language to another selected language with a mere click. Hence another tool made available to develop language skills.

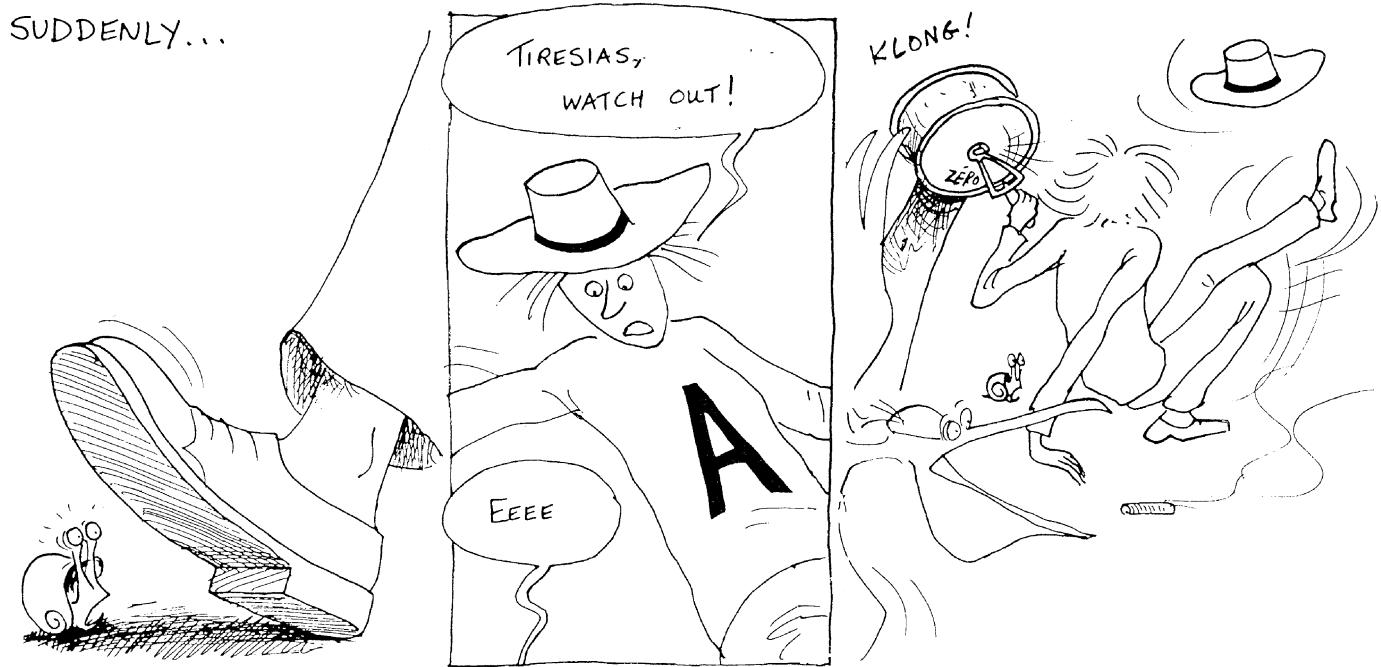
Jean-Pierre Petit was born in 1937. He made his career in French research. He worked as a plasma physicist, he directed a computer science centre, he has created softwares, he has published hundreds of articles in scientific magazines, dealing with subjects ranging from fluid mechanics to theoretical cosmology. He has published about thirty books which have been translated in numerous languages.

The association can be contacted on the following internet site:

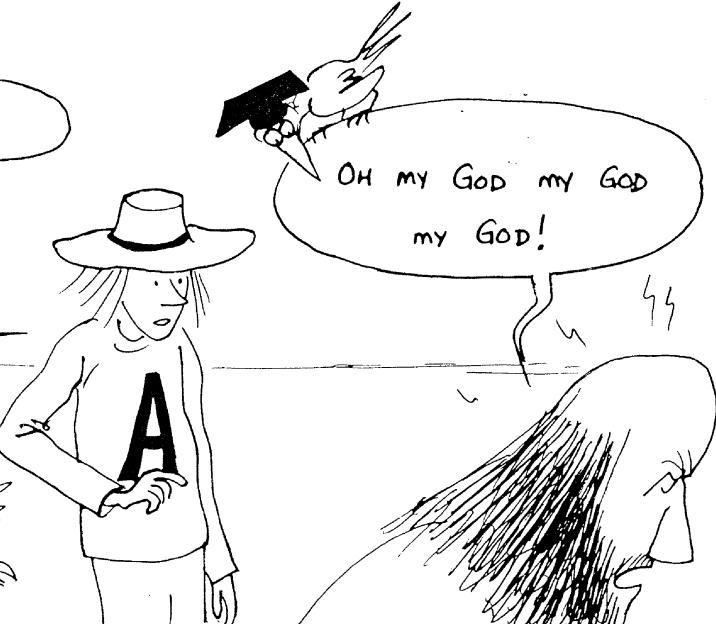
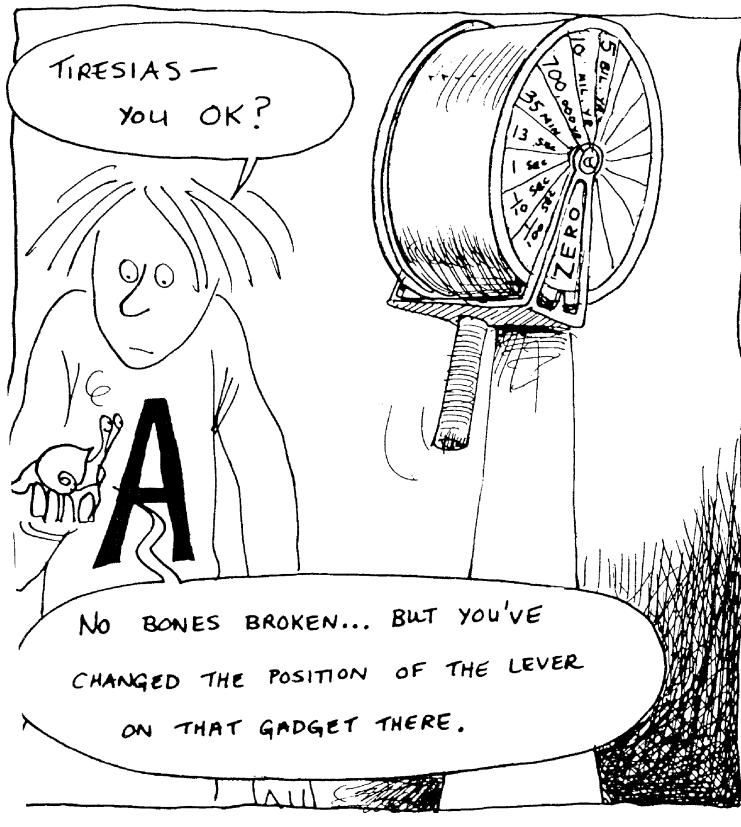
<http://savoir-sans-frontieres.com>

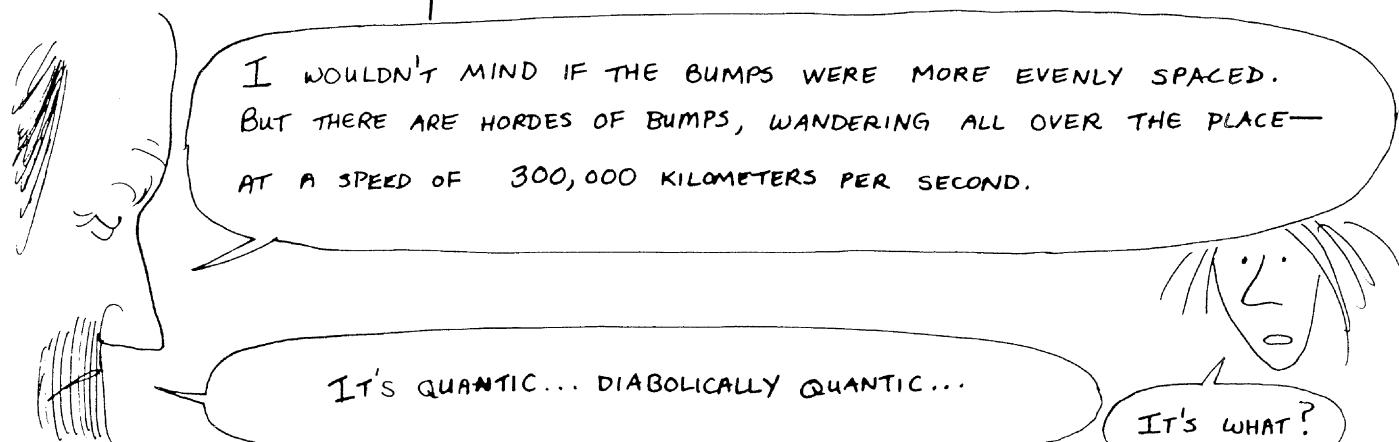
# PROLOGUE

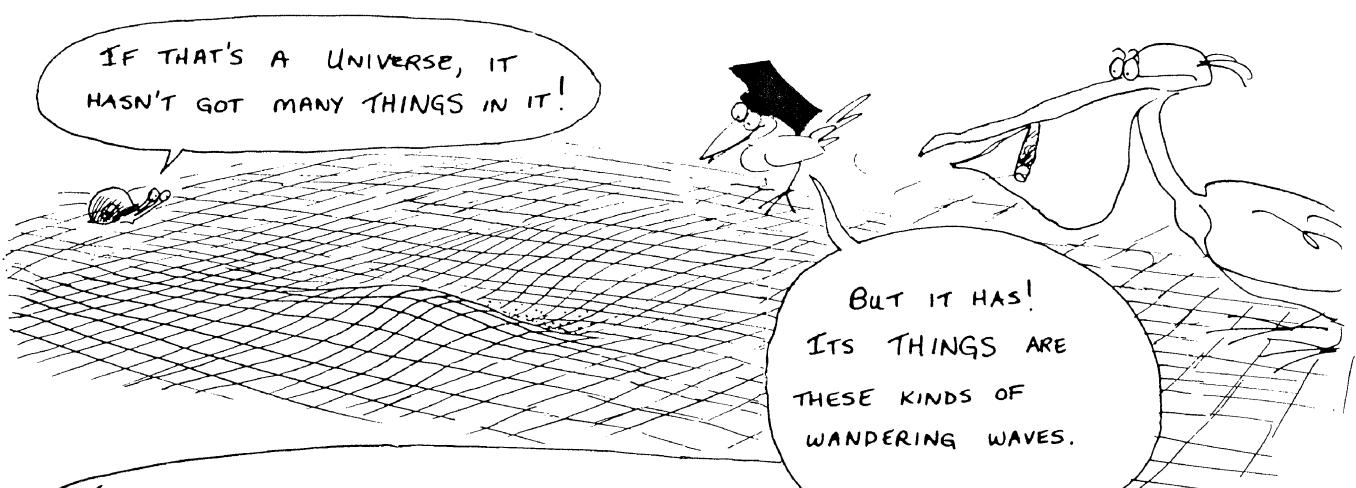




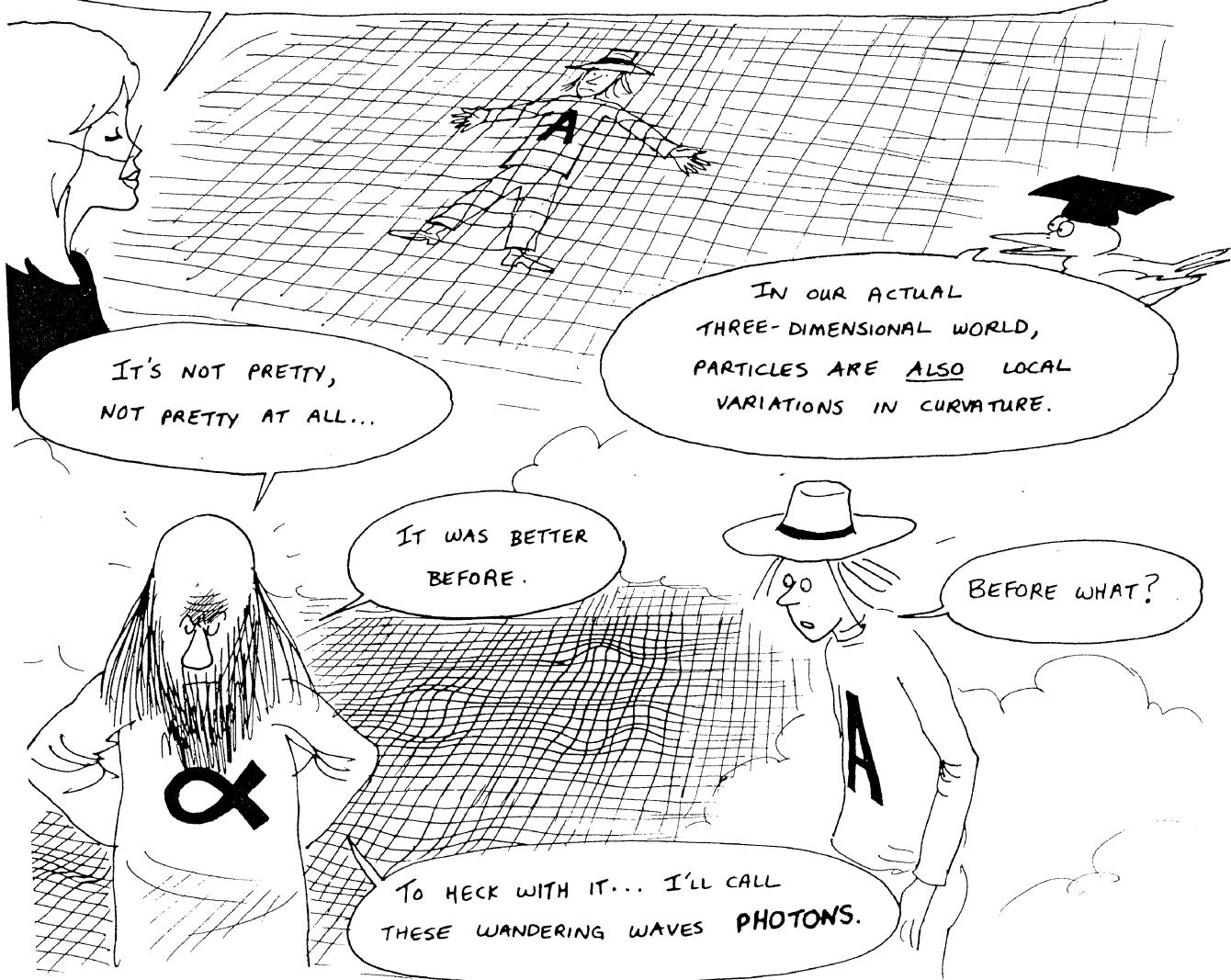
# THE VERY BEGINNING

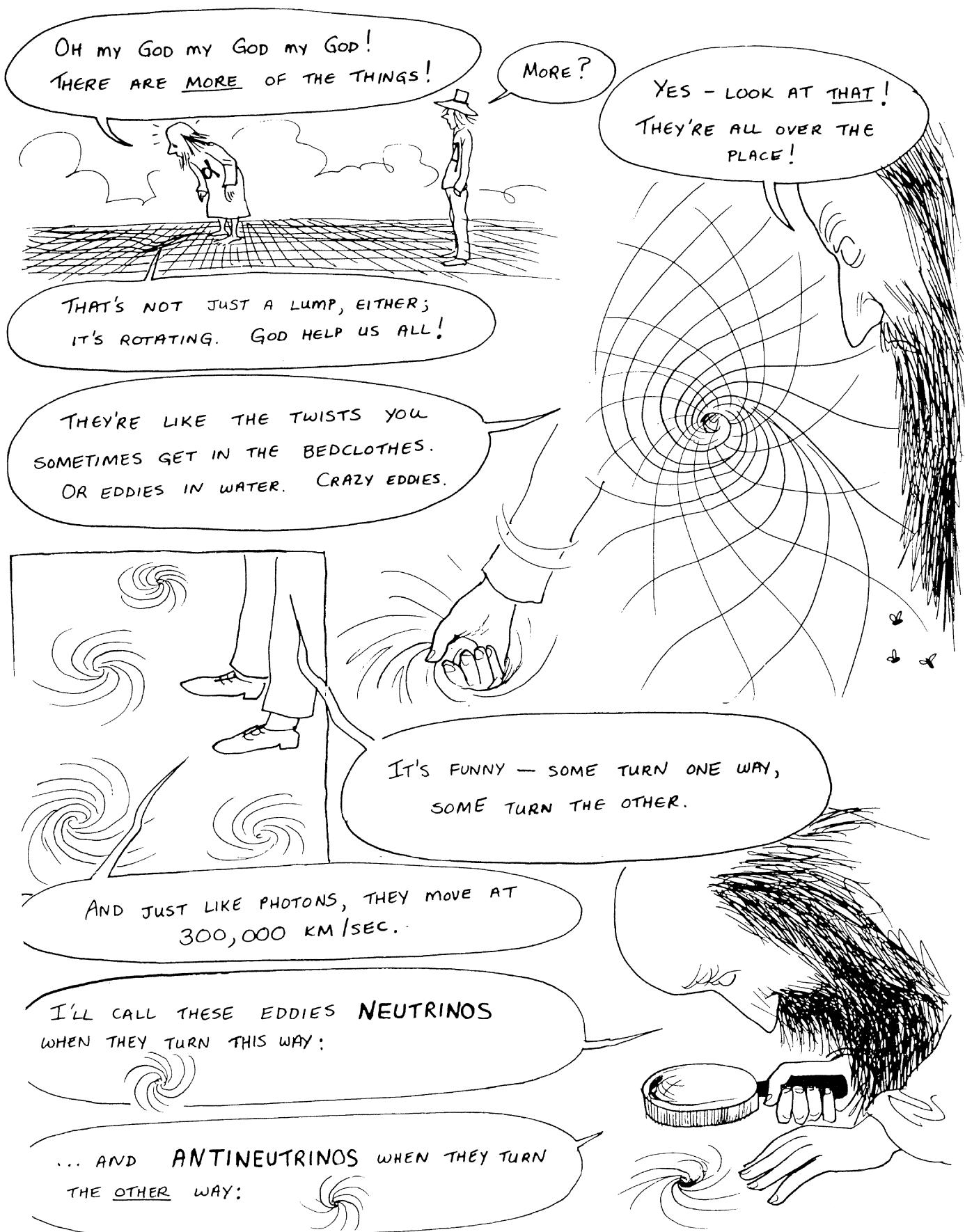


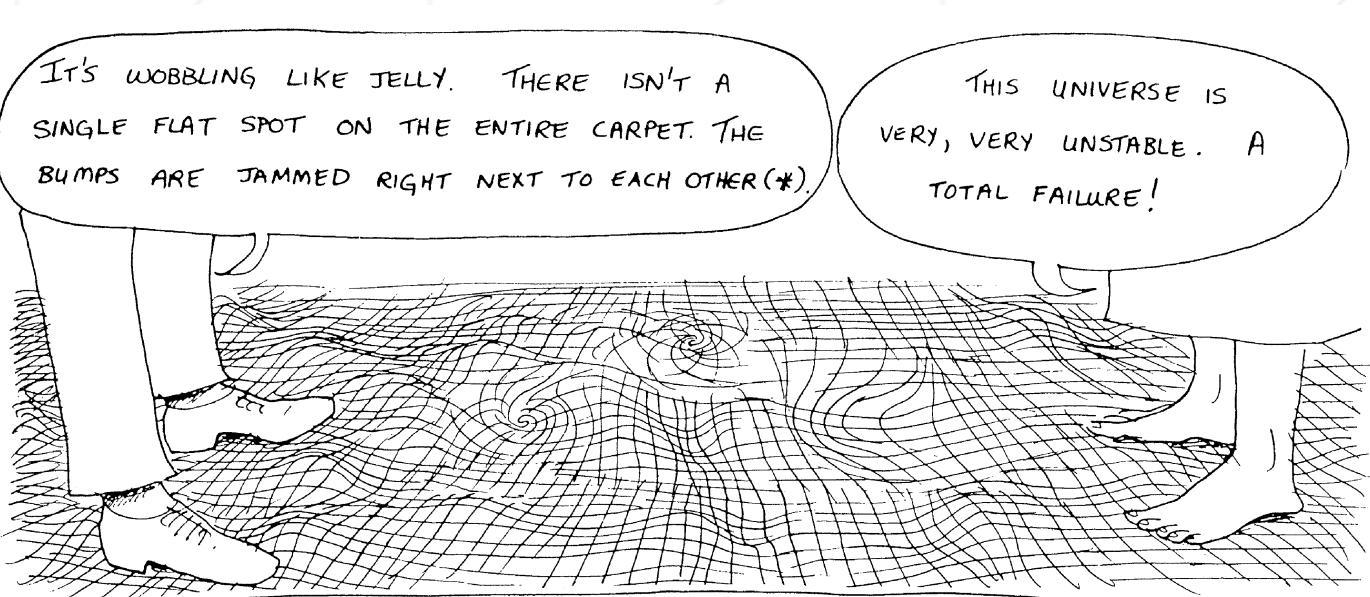




THIS PARTICULAR UNIVERSE ONLY HAS TWO DIMENSIONS, SO IT'S A SURFACE. BUMPS ON THE SURFACE CORRESPOND TO PARTICLES, MASSES, AND RADIATION. IF YOU WERE LIVING IN THIS TWO-DIMENSIONAL WORLD, THIS IS WHAT YOU'D LOOK LIKE.







IF ONLY THERE WERE SOME ORDER IN THERE SOMEWHERE.  
BUT IT'S A REAL DOG'S DINNER... EVERYTHING WANDERING ABOUT AT RANDOM.

AND I HATE GAMES OF CHANCE!

CHANCE, MY FRIEND,  
IS UTTERLY DIABOLICAL!

You SAID IT.

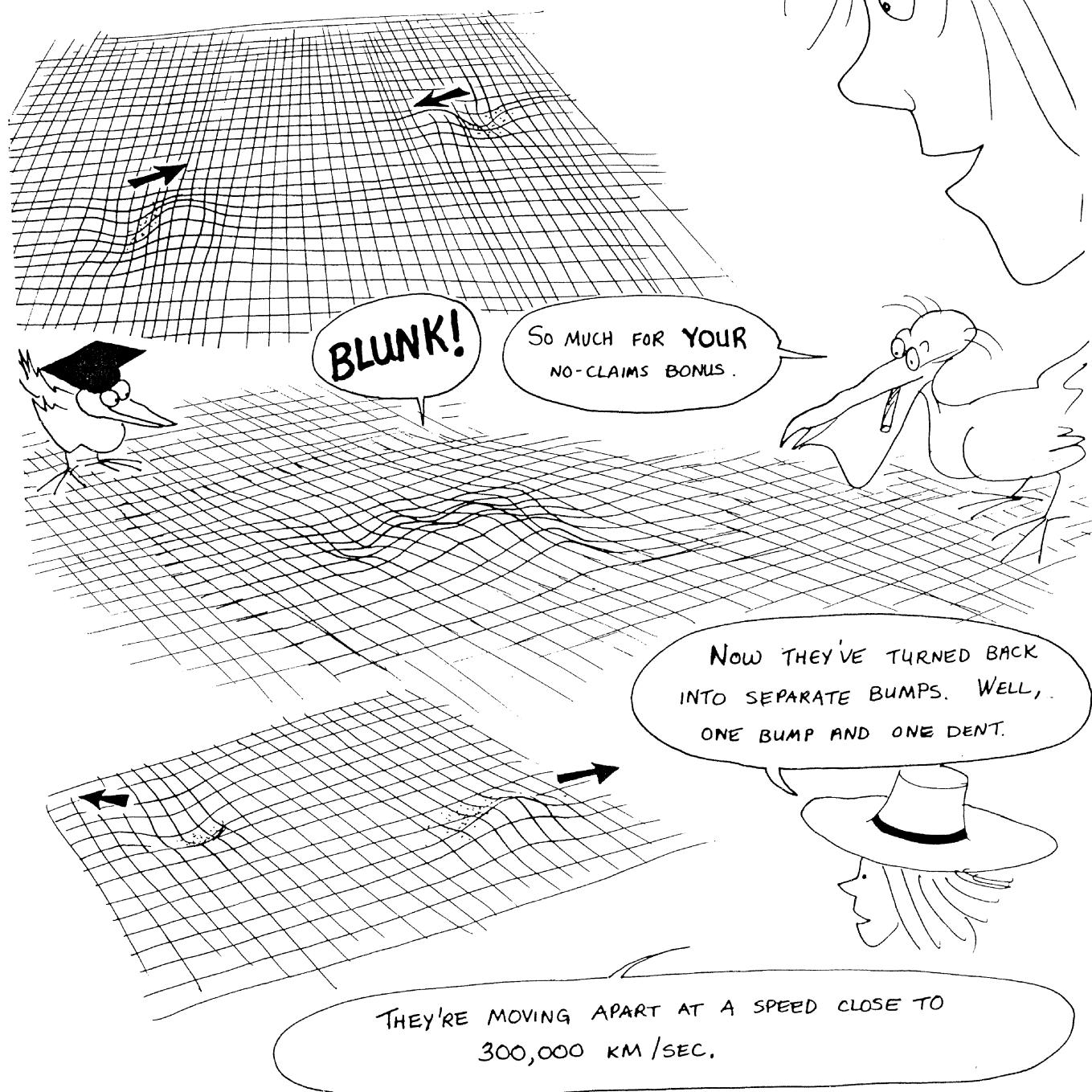
COSMOSOL  
THE UNIVERSAL  
COVERING

I DON'T EVEN LIKE  
PLAYING DICE...

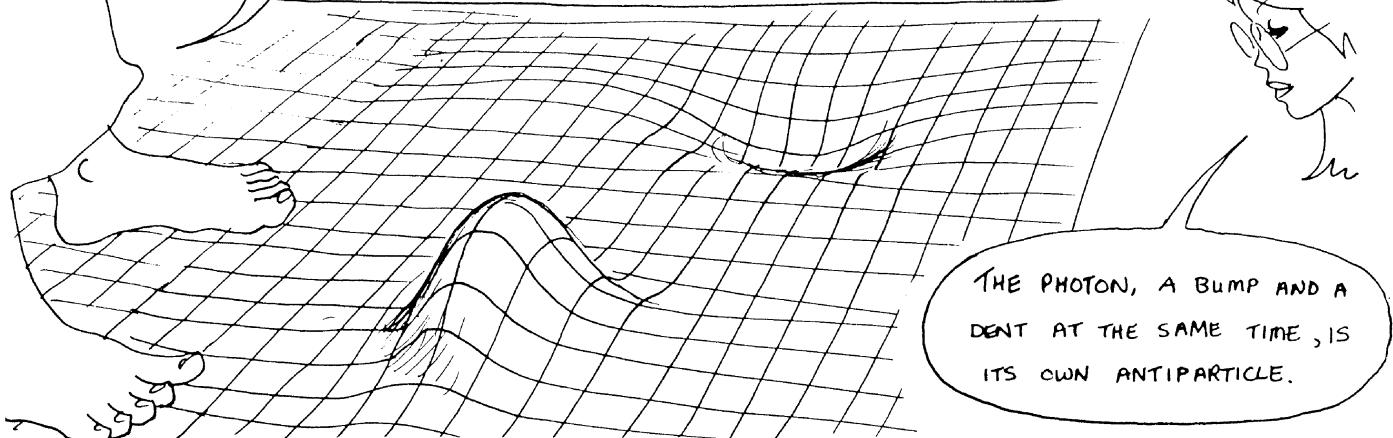
HEY, LOOK! THERE'S SOMETHING  
HAPPENING DOWN THERE!

(\*) A PROPERTY KNOWN AS BLACK BODY RADIATION  
(GOD KNOWS WHY).

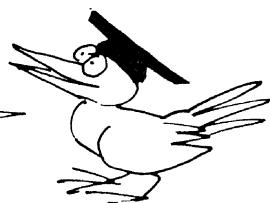
TWO OF THOSE PERAMBULATING  
PROTUBERANCES ARE ABOUT TO COLLIDE  
WITH EACH OTHER.



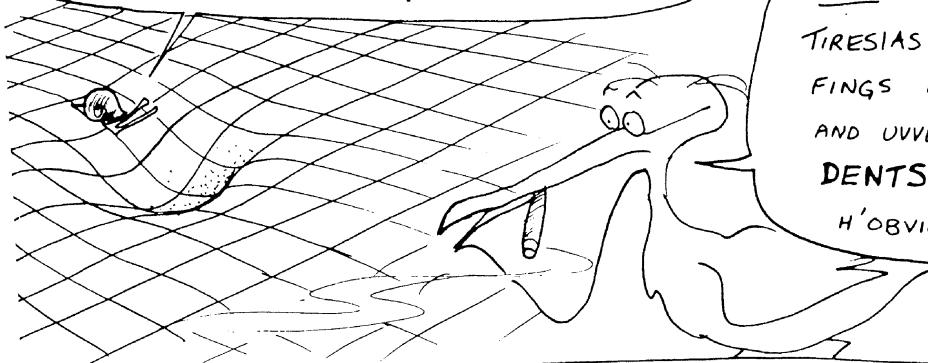
FINE. I'LL CALL THE BUMPS MATTER AND THE DENTS ANTIMATTER. THEY POSSESS CURVATURE, WHICH IMPLIES MASS.



MATTER AND ANTIMATTER, BORN FROM THE COLLISIONS OF PHOTONS, APPEAR AT RELATIVISTIC SPEEDS.



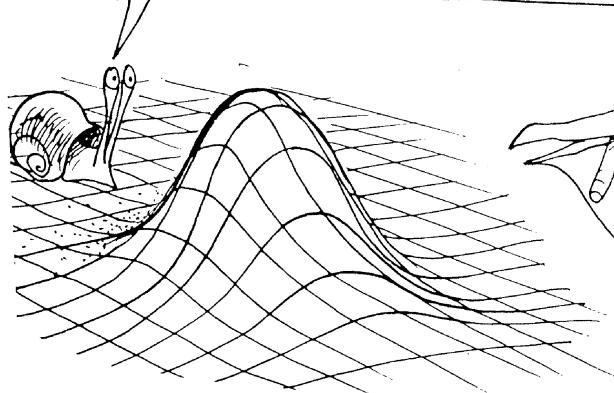
BUMP, DENT, THAT'S AN ARBITRARY DISTINCTION.



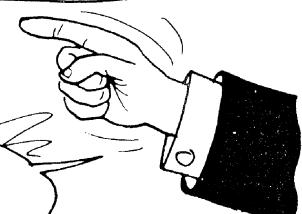
WOT'S THE POINT O'  
THAT PROFOUND REMARK,  
TIRESIAS OLD FRUIT? THERE'S  
FINGS WOT LOOKS LIKE BUMPS,  
AND UVVER FINGS WOT LOOKS LIKE  
DENTS. THAT SEEKS  
H'OBVIOUS ENOUGH...

THAT'S BECAUSE WE'RE ON THIS SIDE OF THE CARPET. IF WE WERE ON THE OTHER SIDE, THE BUMPS WOULD BECOME DENTS AND THE DENTS BUMPS.

YUR... BUT I CAN ONLY SEE ONE SIDE!



TIRESIAS!



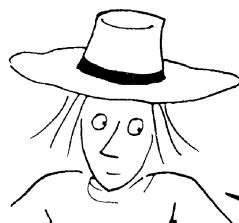


CREATIONS AND ANNIHILATIONS OF PARTICLES, BY MEANS OF PAIRS OF PHOTONS, FOLLOW EACH OTHER IN A FRANTIC RHYTHM. IN THIS CHAOTIC WORLD OF CEASELESS CHANGE, THERE ARE NO RECOGNIZABLE STRUCTURES. ONLY A SWARMING MASS OF PHOTONS, NEUTRINOS, ANTINEUTRINOS, AND A HOST OF OTHER PARTICLES AND ANTI PARTICLES, FLEETING AND VARIED. IT'S **CHAOS** (\*).



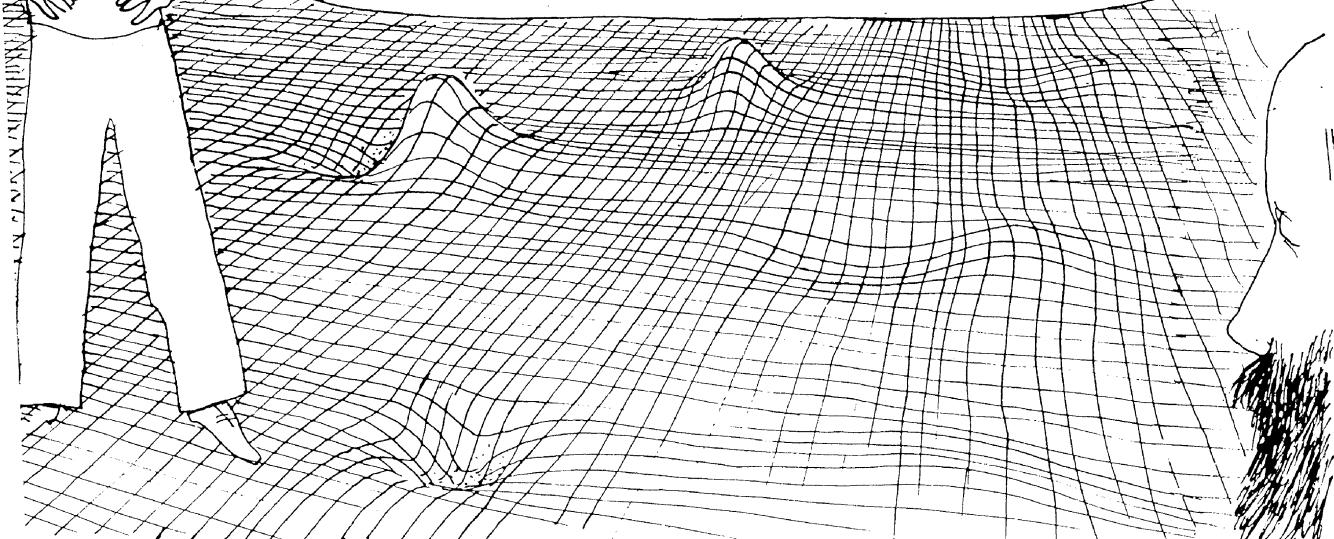
THAT MAKES ME WONDER  
ABOUT **SEXONS**.

WOT THE BLAZES ARE  
**SEXONS?**

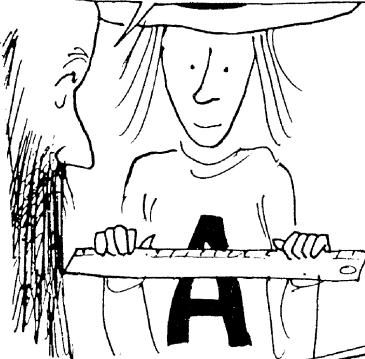


PARTICLES THAT SPEND THEIR TIME  
REPRODUCING.

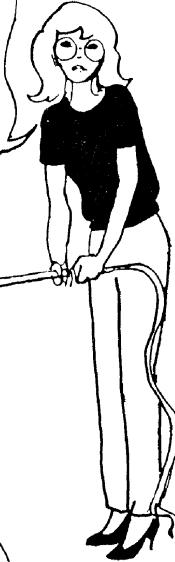
AS FAR AS I CAN SEE, YOU CAN HAVE WANDERING  
WAVES OF DIFFERENT SIZES, AS WELL AS TALL THIN  
BUMPS OR SHORT FAT ONES.



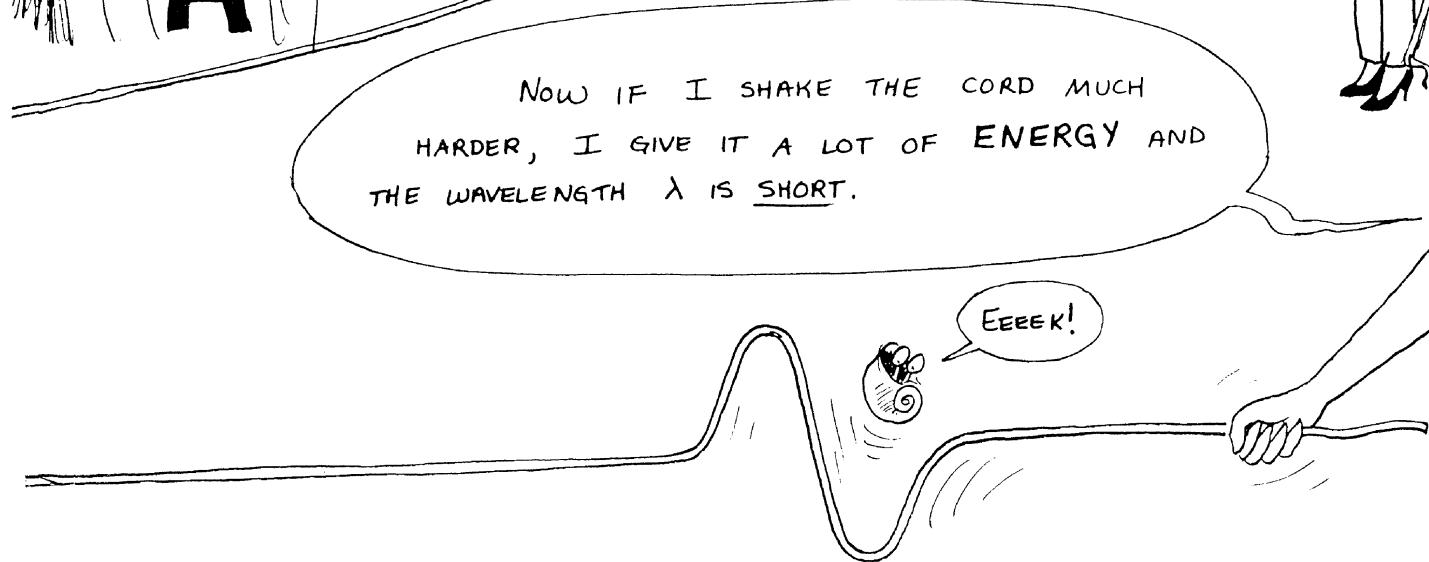
(\*) SEE THE BIBLE.



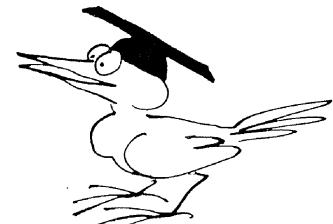
I'LL CALL THE SIZE OF THESE WANDERING WAVES — PHOTONS — THEIR WAVELENGTH  $\lambda$  (LAMBDA).



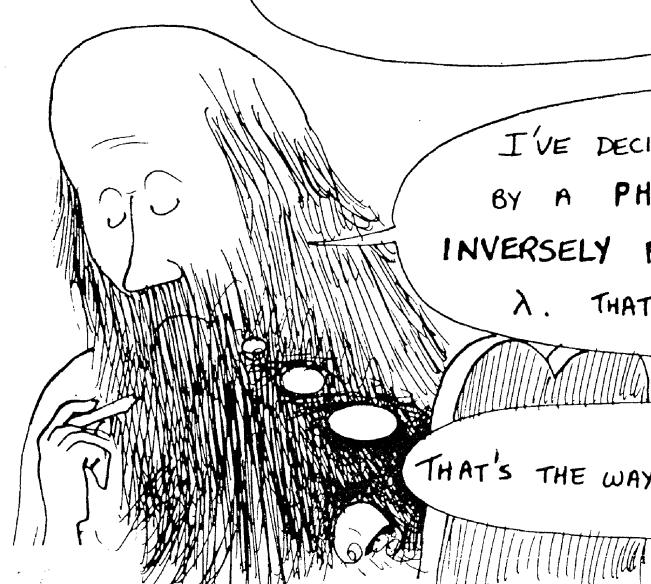
SUPPOSE I CREATE A TRAVELING WAVE BY SHAKING THIS ROPE. IF I SHAKE IT GENTLY I GIVE IT VERY LITTLE ENERGY AND THE WAVELENGTH  $\lambda$  IS LARGE.



NOW IF I SHAKE THE CORD MUCH HARDER, I GIVE IT A LOT OF ENERGY AND THE WAVELENGTH  $\lambda$  IS SHORT.



SO THE MORE ENERGY A TRAVELING WAVE HAS, THE SHORTER ITS WAVELENGTH MUST BE.



I'VE DECIDED THAT THE ENERGY CARRIED BY A PHOTON, A PARTICLE OF LIGHT, WILL BE INVERSELY PROPORTIONAL TO ITS WAVELENGTH  $\lambda$ . THAT IS,  $E$  VARIES AS  $\frac{1}{\lambda}$ .

THAT'S THE WAY IT WILL BE...

# THE SMALLER THINGS ARE THE HEAVIER THEY ARE

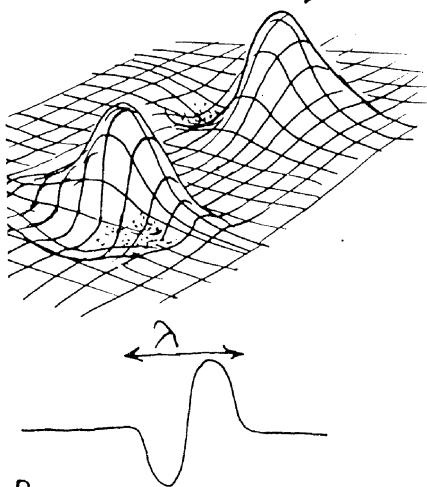


THAT'S OK FOR THESE WANDERING WAVELETS YOU'VE NAMED PHOTONS. BUT HOW ARE WE GOING TO TELL THE DIFFERENCE BETWEEN HIGH BUMPS AND LOW BUMPS? OR DENTS?

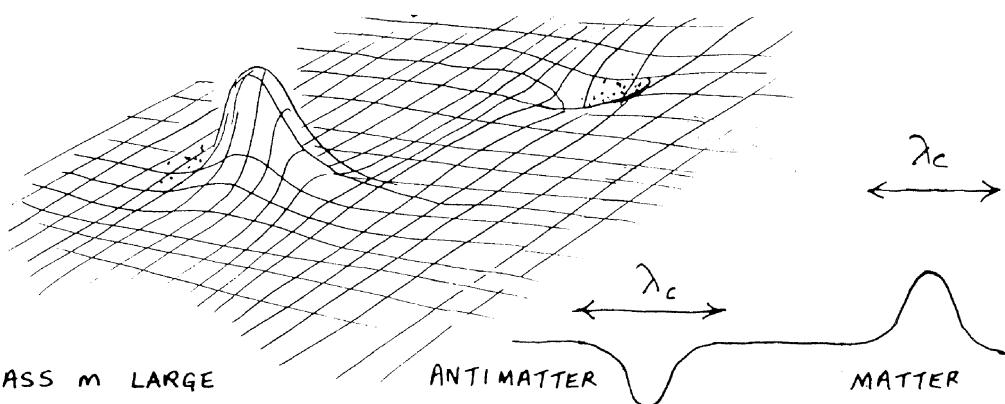
I'M GOING TO CALL THE SIZE OF THE BUMPS AND DENTS THEIR COMPTON WAVELENGTH  $\lambda_c$ . THEIR MASS  $m$  WILL BE INVERSELY PROPORTIONAL. SO  $m$  VARIES AS  $\frac{1}{\lambda_c}$ .

HIGHLY ENERGETIC PHOTONS, HAVING A SHORT WAVELENGTH, PRODUCE PARTICLES (AND ANTI PARTICLES) THAT ARE TALL AND NARROW; THAT IS, HAVE A LARGE MASS  $m$ .

$\lambda$  SMALL



$\lambda_c$  SMALL: COMPTON WAVELENGTH SHORT.

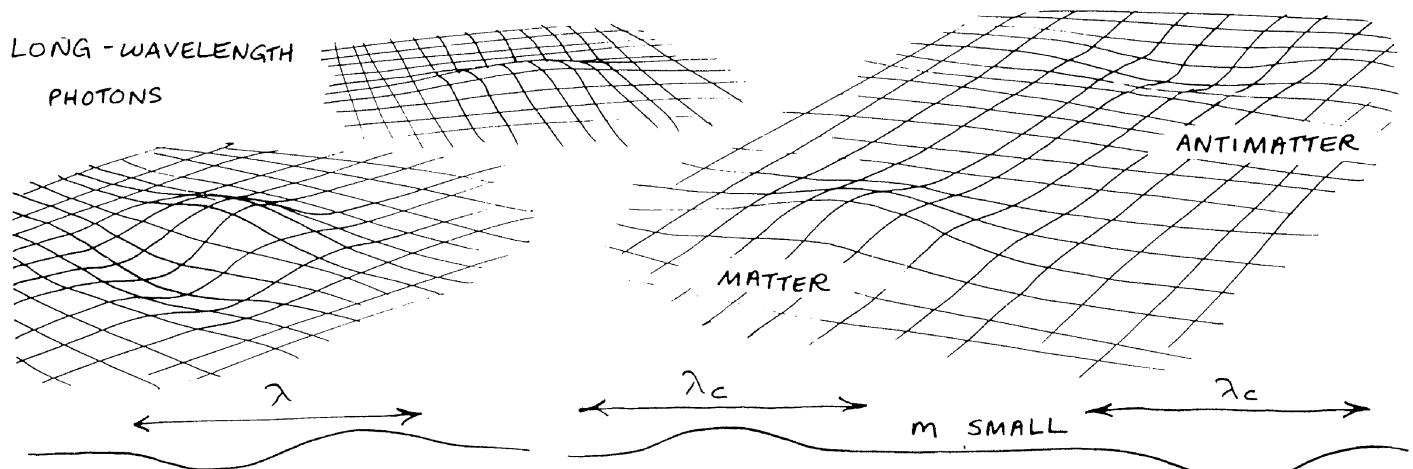


PHOTONS

MASS  $m$  LARGE

ANTIMATTER

MATTER



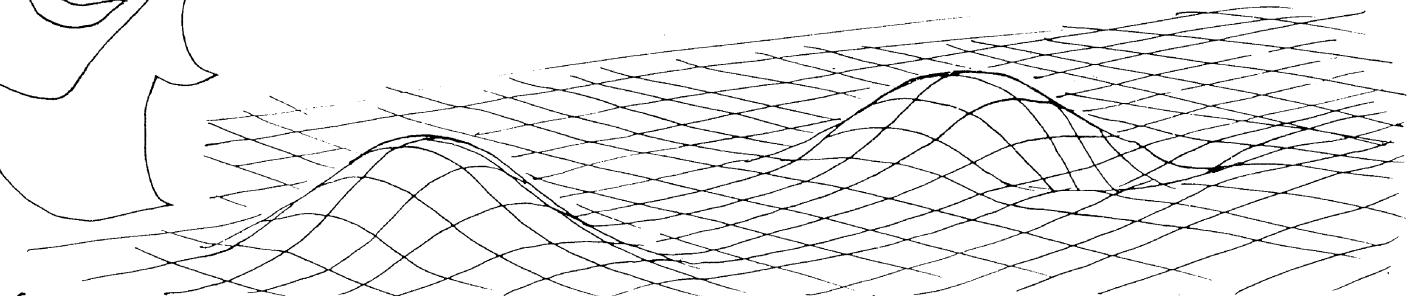
LONG-WAVELENGTH PHOTONS → PARTICLES WITH LONG COMPTON WAVELENGTH.

CONVERSELY, PHOTONS WITH RELATIVELY LOW ENERGY GIVE RISE TO A PARTICLE-ANTIPARTICLE PAIR WITH LONG COMPTON WAVELENGTH. THAT IS,  
LOW MASS:  $\lambda_c$  LARGE,  $m$  SMALL.

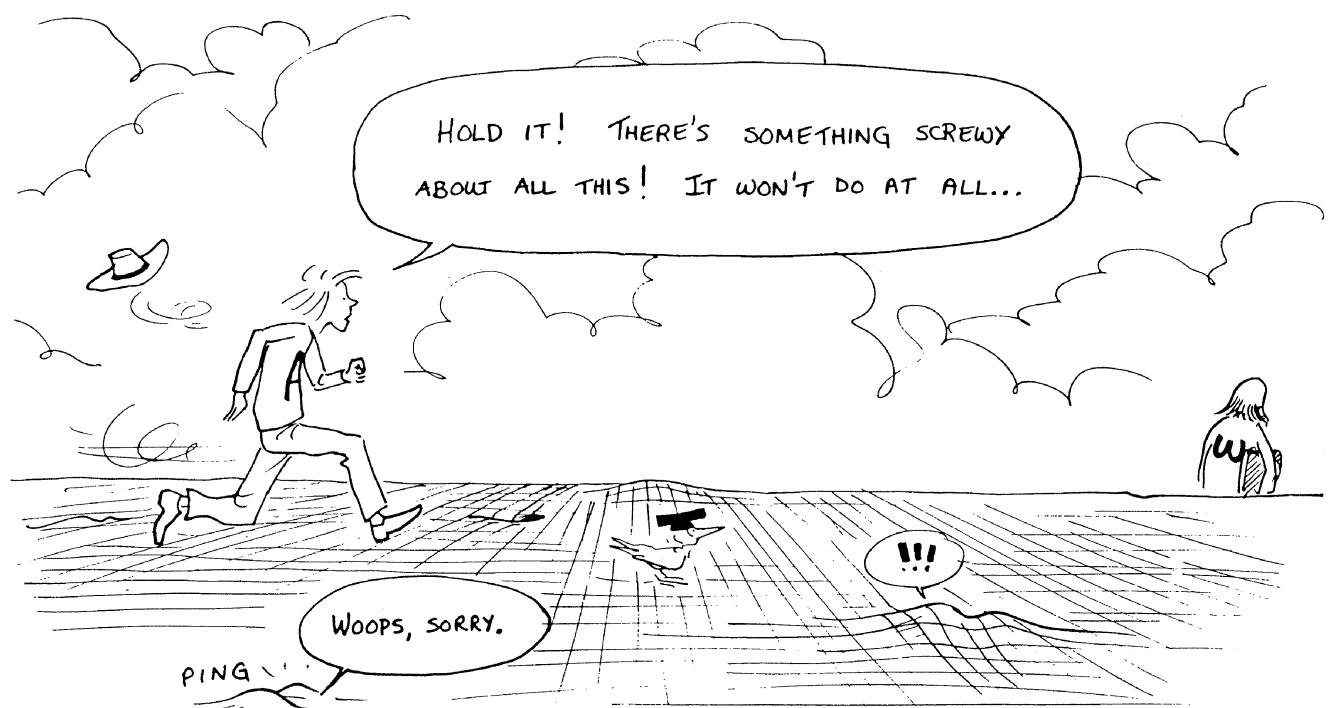


IN FACT, IT'S REALLY A LOT SIMPLER. I CAN ASSUME THAT  $\lambda = \lambda_c$ , IN OTHER WORDS THAT THE PARTICLES (AND ANTIPARTICLES) ARE THE SAME "SIZE" AS THE PHOTONS THAT CREATED THEM.

AND THAT MEANS THAT ONCE YOU KNOW THE **MASS** OF ANY PARTICLE, YOU CAN IMMEDIATELY DEDUCE THE WAVELENGTH OF THE RADIATION THAT CREATED IT.



(\*) REMEMBER THAT  $E$  (ENERGY) EQUALS  $m$  (MASS). SEE EVERYTHING IS RELATIVE, SAME SERIES.



PROTONS AND NEUTRONS HAVE ALMOST THE SAME MASS.  
THEREFORE THEY HAVE THE SAME SIZE. BUT AN ELECTRON IS  
MUCH LIGHTER. LOGICALLY, THE ELECTRON MUST BE... LARGER?

THAT'S RIGHT. THE PROTON AND  
NEUTRON WEIGH  $1.66 \times 10^{-27}$  KG. THE  
ELECTRON WEIGHS  $9.1 \times 10^{-31}$  KG. SO IT'S  
1850 TIMES LIGHTER, THAT IS, 1850  
TIMES "BIGGER."

I ... ER...  
OH HECK...

HAVE YOU EVER  
SEEN A PROTON?

ER...  
NO.

WELL,  
THEN!

THE GENESIS OF TODAY IS  
UTTERLY FASCINATING.

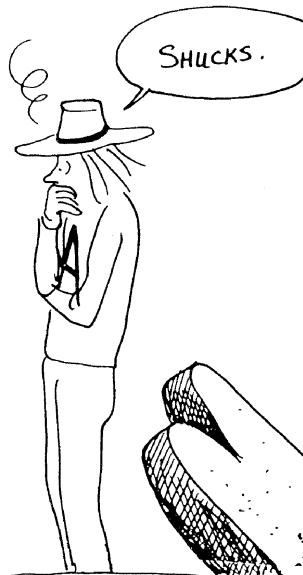
SOPHIE, WHAT ARE  
YOU MAKING?

A HYDROGEN ATOM MORE CLOSELY  
RESEMBLING REALITY. WITH A BIG ELECTRON  
AND A TINY PROTON MAKING UP ITS  
NUCLEUS.

My GOD my GOD my GOD! WHAT CHAOS! WELL...  
I THINK YOU PEOPLE CAN HELP ME PUT THIS JUMBLE INTO  
SOME SORT OF ORDER.

# RADIATION TEMPERATURE

$T_R$



SHUCKS.

THESE PHOTONS HAVE ALL SORTS OF DIFFERENT WAVELENGTHS AND ENERGIES. BUT OVERALL THERE IS A DEFINITE AVERAGE WAVELENGTH AND AN AVERAGE ENERGY.

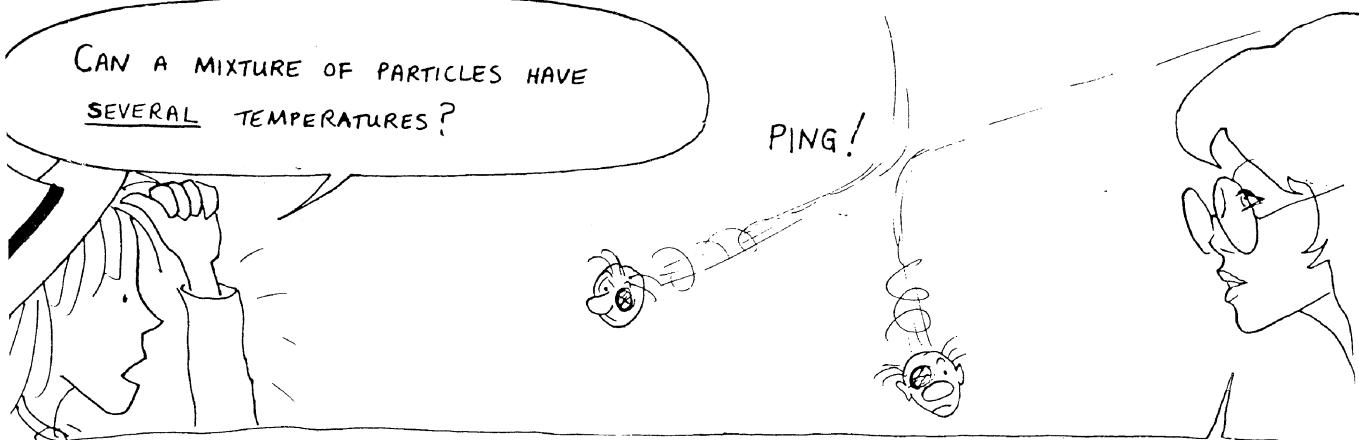


THE RADIATION TEMPERATURE  $T_R$  WILL BE THE VALUE OF THIS AVERAGE ENERGY OF PHOTONS.

WHAT A DISASTER...

## EQUILIBRIUM STATES

CAN A MIXTURE OF PARTICLES HAVE SEVERAL TEMPERATURES?

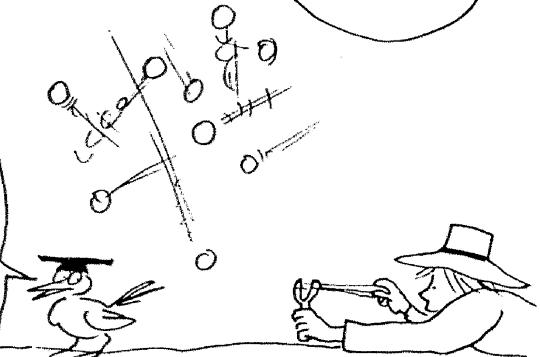


PING!

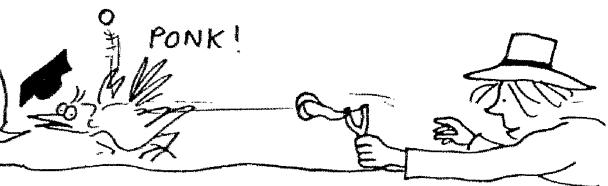
YES, BUT WE'LL SEE ABOUT THAT ON PAGE 46. FOR THE MOMENT LET'S JUST SAY THAT PARTICLES EXCHANGE ENERGY WITH EACH OTHER, OR WITH PHOTONS, THROUGH COLLISIONS. THIS MECHANISM TENDS TO REDISTRIBUTE THE TEMPERATURES, TO EQUALIZE THEM, SO PUTTING THE SYSTEM INTO A STATE OF THERMODYNAMIC EQUILIBRIUM.

# THE TEMPERATURE OF MATTER

ALL THESE MATERIAL PARTICLES HAVE VARIOUS MASSES  $m$  AND SPEEDS  $v$ . THE KINETIC ENERGY OF A PARTICLE IS  $\frac{1}{2}mv^2$ . BUT AGAIN, OVERALL THERE IS AN AVERAGE (THERMAL) ENERGY OF AGITATION.



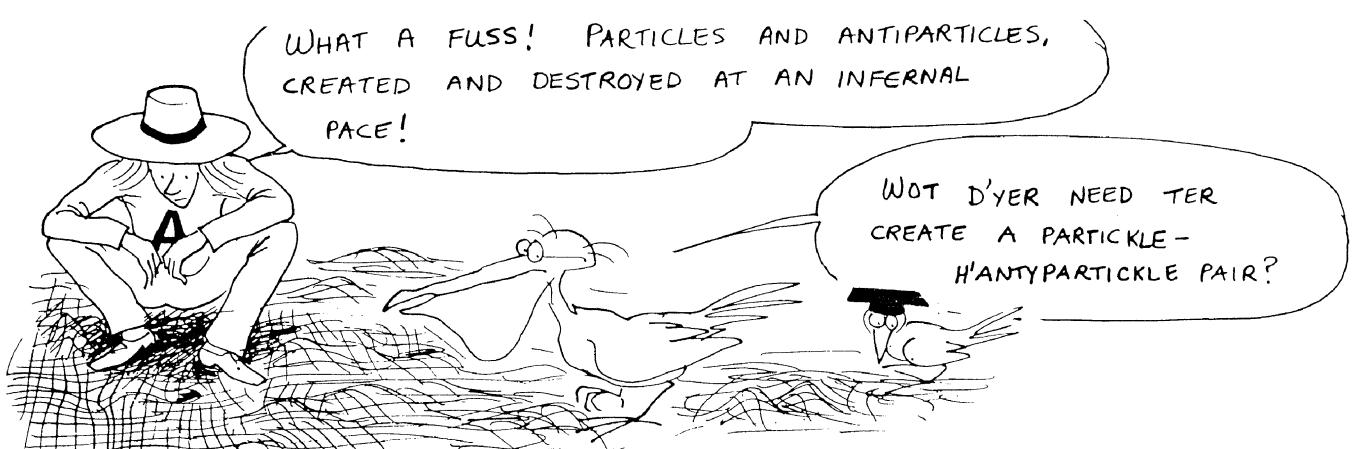
AND THE TEMPERATURE OF THE MATTER,  $T_m$ , IS THE VALUE OF THIS AVERAGE ENERGY OF THERMAL AGITATION.



# THERMODYNAMICS

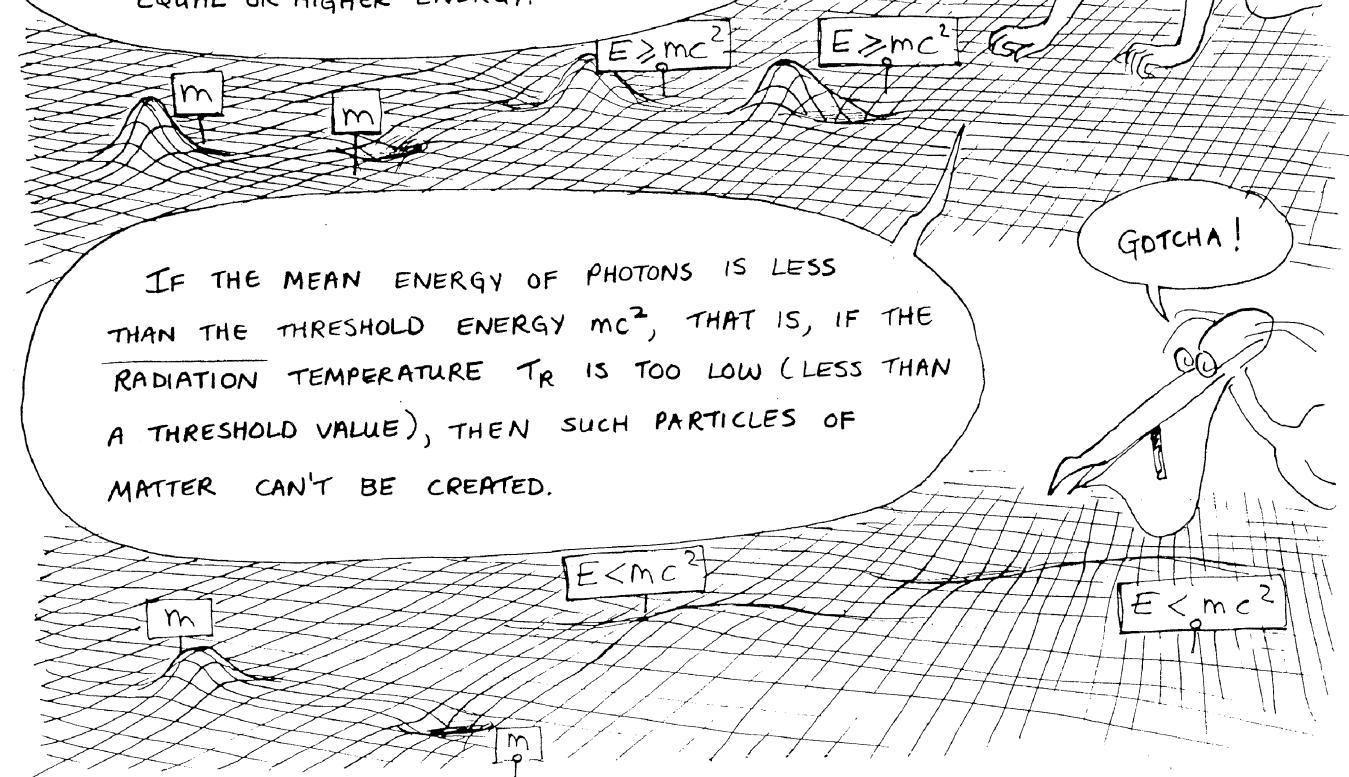
IF A PARTICLE HAS TOO MUCH ENERGY, IF IT'S TOO FAST, TOO "HOT," THEN A COLLISION WITH ANOTHER PARTICLE WILL SLOW IT DOWN. AND VICE VERSA IF IT'S TOO SLOW. IF THIS PHENOMENON OF ENERGY-COUPLING VIA COLLISIONS IS INTENSE ENOUGH, THEN NOT ONLY WILL THE TEMPERATURES BE EQUAL, BUT THEY'LL STAY EQUAL WHEN YOU EXPAND OR COMPRESS THE MIXTURE.





# THRESHOLD TEMPERATURE

TO CREATE A PARTICLE-ANTIPARTICLE PAIR WHOSE COMMON MASS IS  $m$ , YOU NEED AN ENERGY  $2mc^2$ , WHICH CAN BE PROVIDED BY A PAIR OF PHOTONS WITH EQUAL OR HIGHER ENERGY.



# THE EVOLUTION OF SPECIES

THE SURVIVAL OF A SPECIES OF PARTICLE IS ALWAYS PROBLEMATIC. IT CAN BE ASSURED BY A SUFFICIENTLY HIGH RATE OF PRODUCTION.

WHICH MEANS THAT THE RAYDIFICATION TEMP'RACHER  $T_R$  HAS TO BE HIGHER THAN THE FRESHOLD TEMP'RACHER FOR THAT SPECIES.

IF THE TEMPERATURE  $T_R$  IS LOWER THAN THE THRESHOLD, THERE ARE SEVERAL WAYS PARTICLES CAN DISAPPEAR.

THE MOST OBVIOUS IS ANNIHILATION BY AN ANTIPARTICLE...



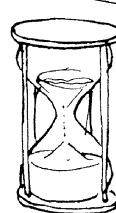
... OR A WHOLE HOST OF FATAL ENCOUNTERS WITH ANOTHER SPECIES.

THE COSMOS IS A RAT RACE!

IN ADDITION, PARTICLES HAVE THEIR OWN LIFETIMES. AFTER THESE HAVE PASSED(\*), THE PARTICLES DECOMPOSE SPONTANEOUSLY INTO OTHER PARTICLES, AND RADIATION.

(\*) ... THEIR RESERVE OF CHRONOL RUNS OUT:  
SEE EVERYTHING IS RELATIVE.

THE PROBLEM IS TO LAST OUT THE RACE...

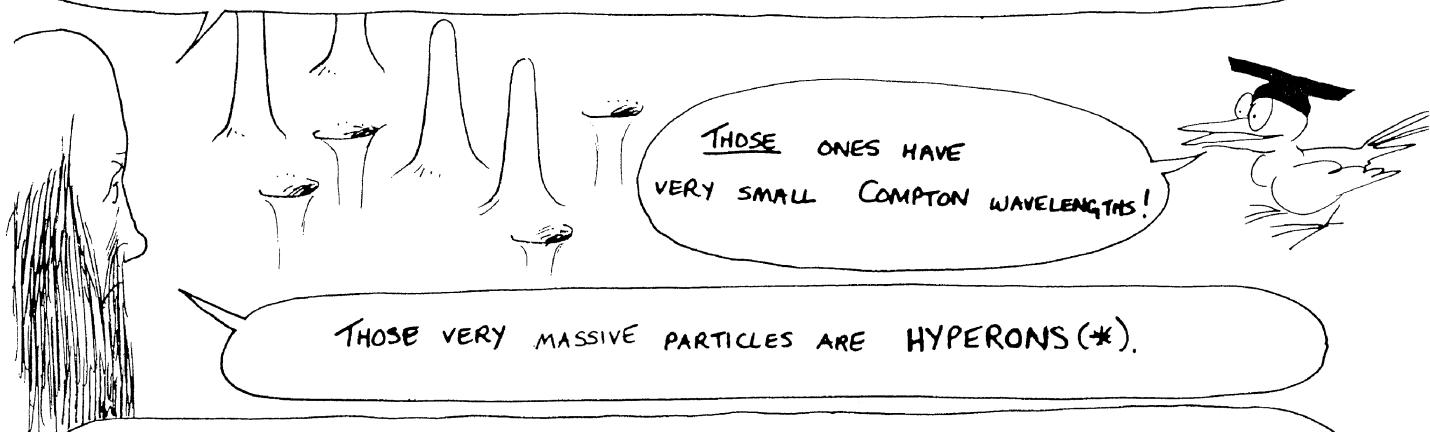




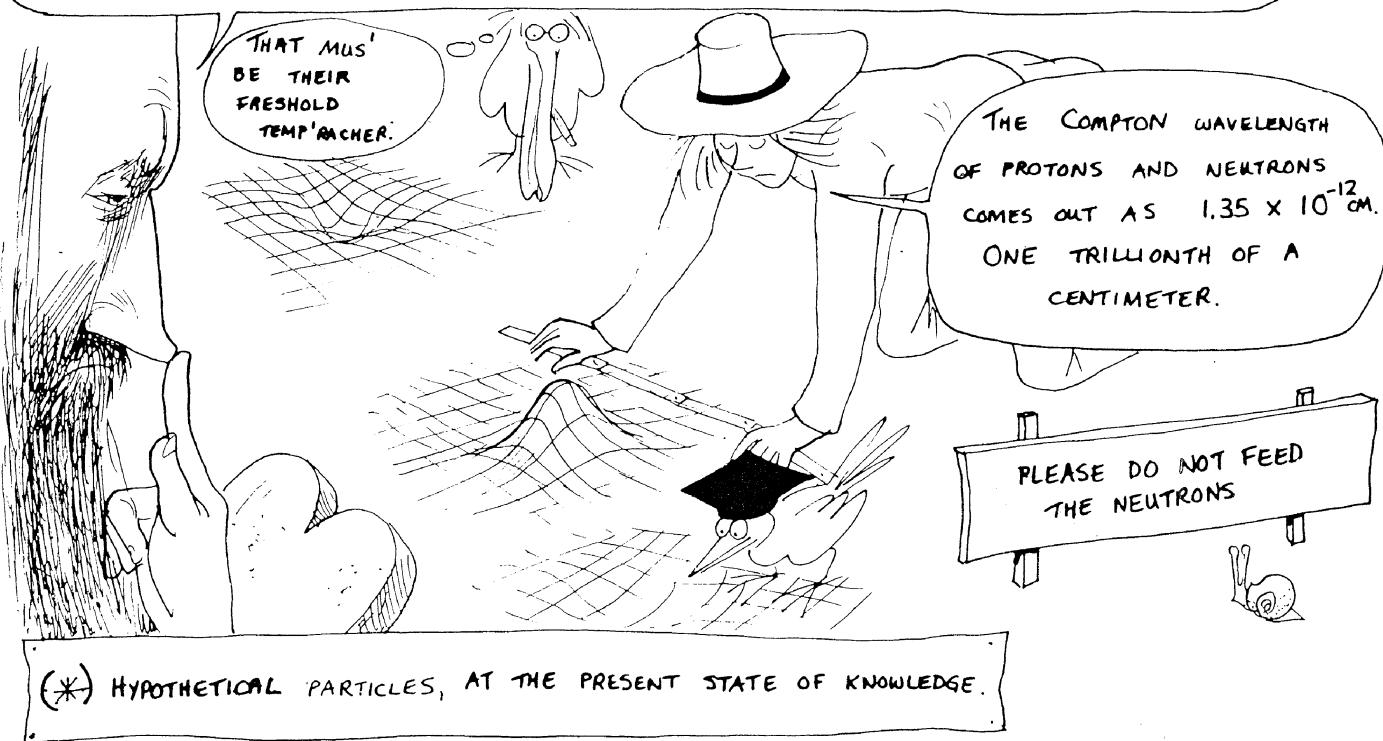


# ELEMENTARY PARTICLES

YOU THERE — INSTEAD OF FLAPPING YOUR ARMS ABOUT, HELP ME PUT SOME ORDER INTO THESE CRAZY ELEMENTARY PARTICLES.



THEN COME THE HADRONS. THE PROTON AND THE NEUTRON (AND OF COURSE THE ANTI-PROTON AND THE ANTI-NEUTRON) ARE AMONG THEM. THEY CAN COMBINE TO FORM NUCLEI. TO CREATE THESE PARTICLES, YOU NEED A RADIATION TEMPERATURE GREATER THAN  $10^{13}$  K, THAT IS, TEN TRILLION DEGREES.



HADRON COMES FROM HADROS, WHICH MEANS "HEFTY" IN GREEK.

BLIMEY - A GREEK-SPEAKIN' SNAIL!

OBVIOUSLY THERE ARE AS MANY ANTIHADRONS AS HADRONS.

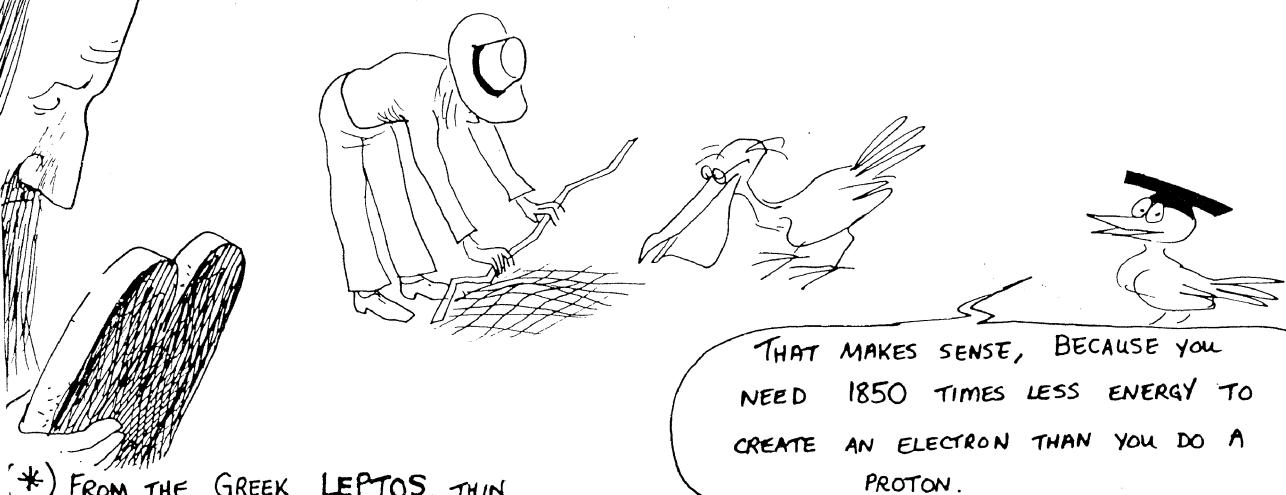
NOW, HERE COME THE LEPTONS(\*)

LEPTON

ANTILEPTON

TO CREATE THEM, YOU NEED A RADIATION TEMPERATURE OF 6 BILLION DEGREES - THEIR THRESHOLD TEMPERATURE.

THE BEST KNOWN LEPTON IS THE ELECTRON, AND ITS COUNTERPART THE ANTELECTRON, OR POSITRON. NOTE THAT THE THRESHOLD TEMPERATURE FOR CREATING ELECTRONS IS 1850 TIMES LOWER THAN THAT FOR PROTONS AND NEUTRONS.



(\*) FROM THE GREEK LEPTOS, THIN.

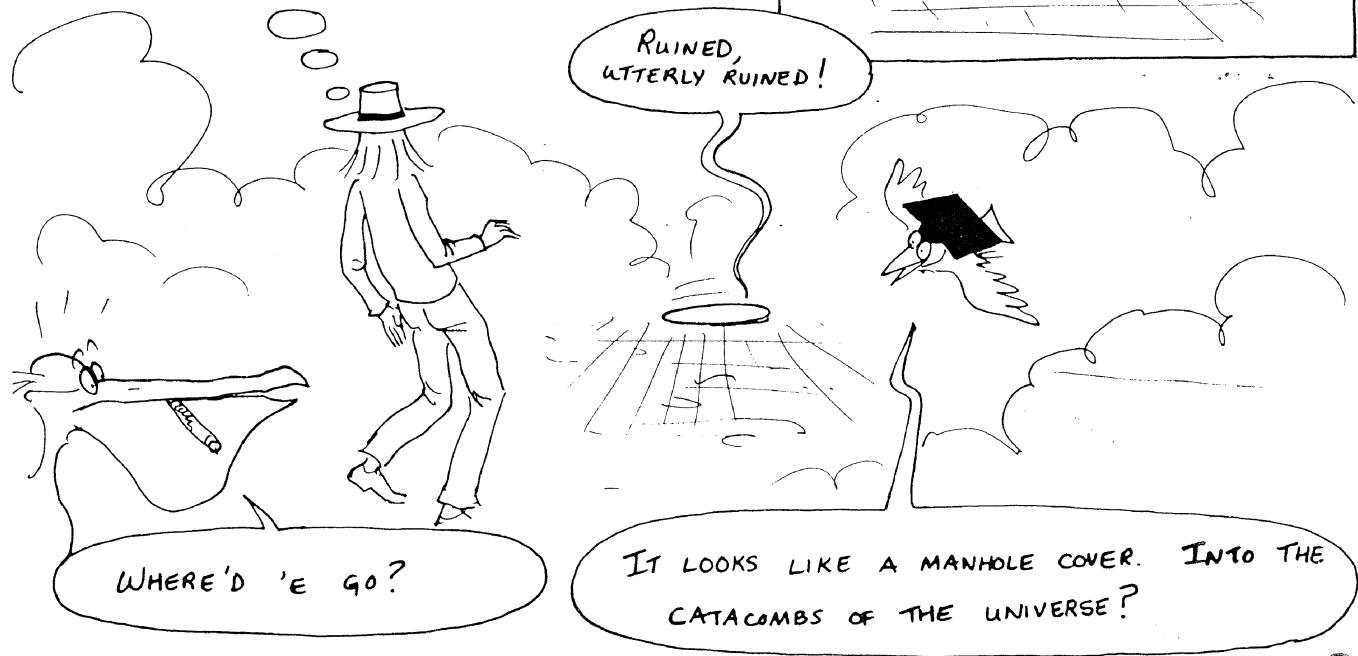
THAT MAKES SENSE, BECAUSE YOU NEED 1850 TIMES LESS ENERGY TO CREATE AN ELECTRON THAN YOU DO A PROTON.

# EVERYTHING FALLS APART



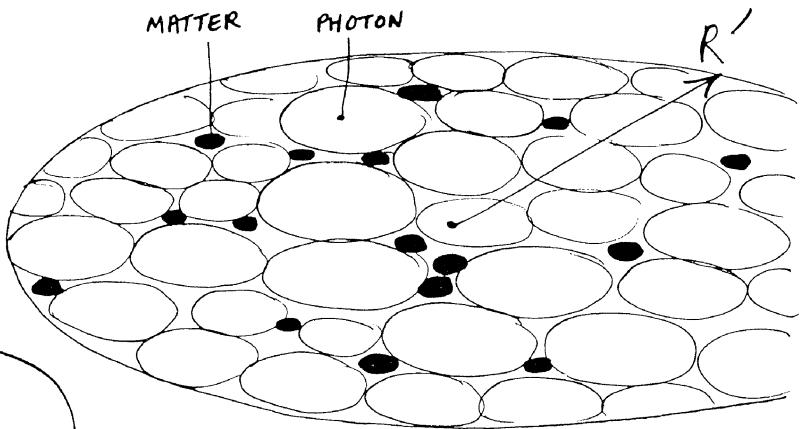
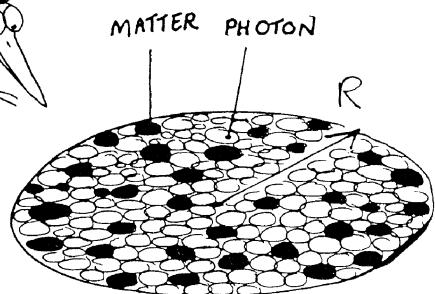
THE SITUATION WAS TERRIBLY CHRONOGENIC - TIME COULD HARDLY WAIT TO APPEAR. THE CHRONOTRON STARTED UP, THEREBY PRODUCING THE FIRST EVENT, THE FIRST INSTANT.





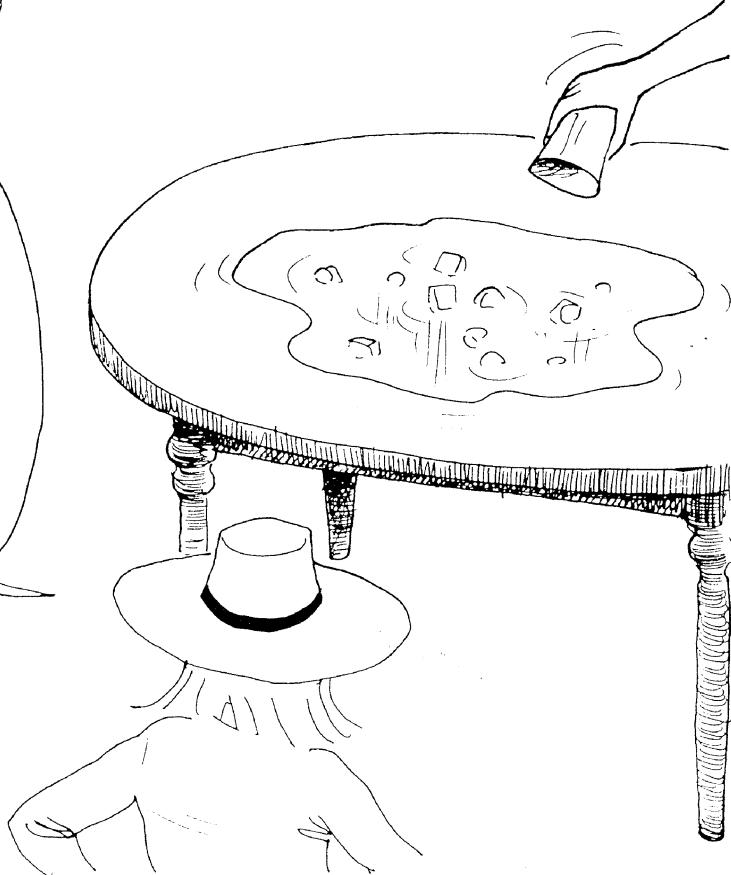
# THE CONSERVATION OF MASS

LOOK WHAT'S HAPPENING. THE PHOTONS ARE GETTING BIGGER. PARTICLES OF MATTER ARE STAYING THE SAME SIZE.



THE MATTER SEEMS UNRESPONSIVE. FRIGID!

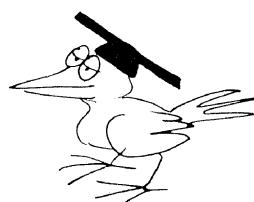
THAT MAKES ME THINK OF WHAT HAPPENS IF YOU UPSET A GLASS OF ICE WATER ON A TABLE. THE WATER SPREADS OUT. THE ICE CUBES GO ALONG TOO, BUT KEEP THEIR SHAPE AND SIZE.



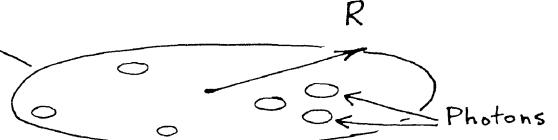
BECAUSE THE SIZE OF PARTICLES OF MATTER IS RELATED TO THEIR MASS,  
I DEDUCE THAT MASS IS CONSERVED.



ON THE OTHER HAND, THE PHOTONS  
SPREAD OUT, SO ARE LOSING ENERGY.



IF  $R$  IS THE RADIUS OF THE UNIVERSE, THEN,  
SINCE THE WAVELENGTH  $\lambda$  OF PHOTONS UNDERGOES  
THE SAME EXPANSION ( $\lambda$  VARIES LIKE  $R$ ), I ALSO  
DEDUCE THAT THE RADIATION TEMPERATURE, WHICH  
VARIES AS  $\frac{1}{\lambda}$ , DECREASES AS  $\frac{1}{R}$ .



IT'S HAPPENING JUST AS IF  
THE UNIVERSE CREATES ITS OWN  
SPACE, ITS COSMOTOPE (\*), BY  
SECRETING... EMPTINESS...



MATTER AND LIGHT ARE JUST TWO DIFFERENT FORMS OF  
THE SAME ENTITY: ENERGY/MATTER. THE PHOTONS RETAIN  
THEIR SPEED OF 300,000 KM/SEC BUT LOSE ENERGY.

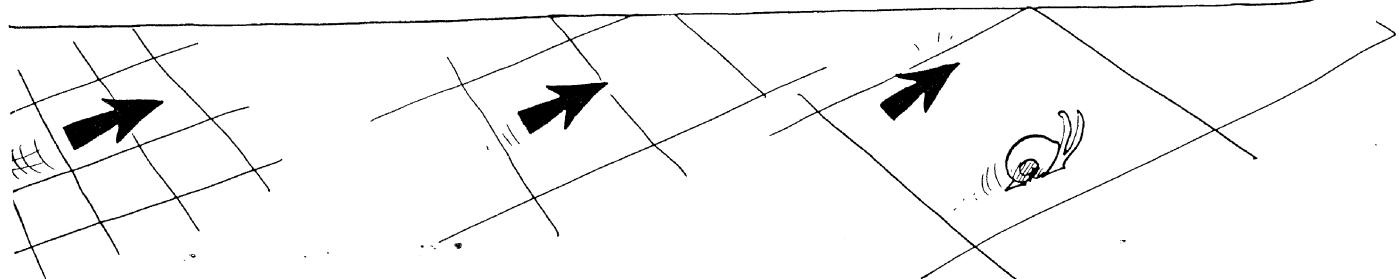
(\*) FROM COSMOS (COSMOS) AND TOPOS (PLACE). THE  
PLACE THAT THE UNIVERSE INHABITS.

HERE'S A GOOD WAY TO VISUALIZE THE WAY THE PHOTON SPREADS OUT AND THE ACCOMPANYING ENERGY LOSS.



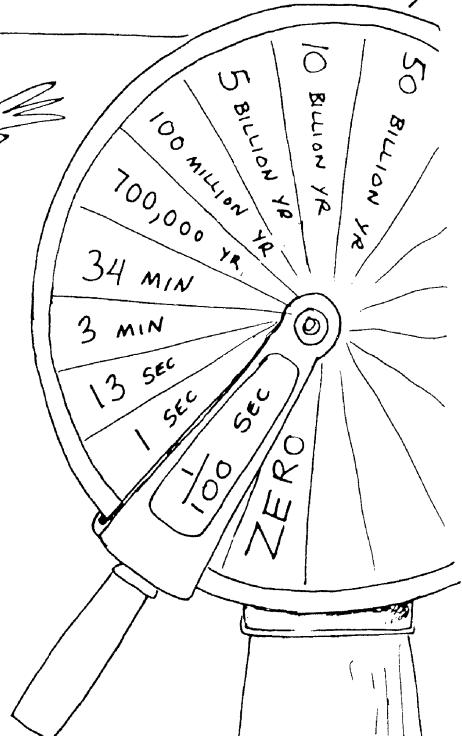
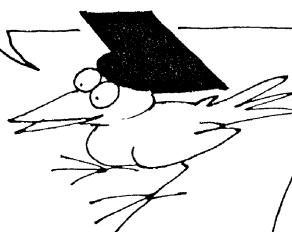
BUT HOW DOES MATTER BEHAVE DURING THIS EXPANSION?

THE UNIVERSE SECRETES SPACE LIKE A CREATURE GROWING A SHELL. THE MORE TIME PASSES, THE MORE SPACE PARTICLES HAVE TO MOVE AROUND IN. WHEN THE SIZE OF THE UNIVERSE DOUBLES, THE SPEED OF AGITATION OF PARTICLES HALVES. SO THEIR KINETIC ENERGY IS DIVIDED BY 4. THE SPEED OF AGITATION VARIES AS THE INVERSE OF THE RADIUS  $R$  OF THE UNIVERSE, WHEREAS THE TEMPERATURE OF MATTER VARIES AS  $\frac{1}{R^2}$



BUT... WE SAW JUST NOW THAT THE RADIATION TEMPERATURE  $T_R$  VARIES AS  $\frac{1}{R}$ . SO MATTER TENDS TO COOL DOWN QUICKER THAN RADIATION?

EFFECTIVELY. BUT PHOTON-MATTER COLLISIONS REHEAT IT. THEY HAPPEN FREQUENTLY ENOUGH TO MAINTAIN A STATE OF THERMODYNAMIC EQUILIBRIUM ( $T_R = T_m$ ) FOR A CERTAIN PERIOD OF TIME.

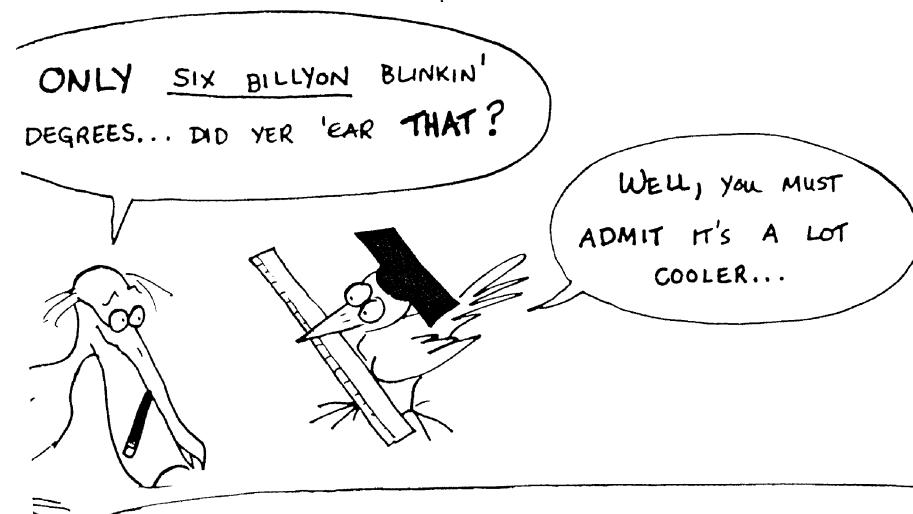
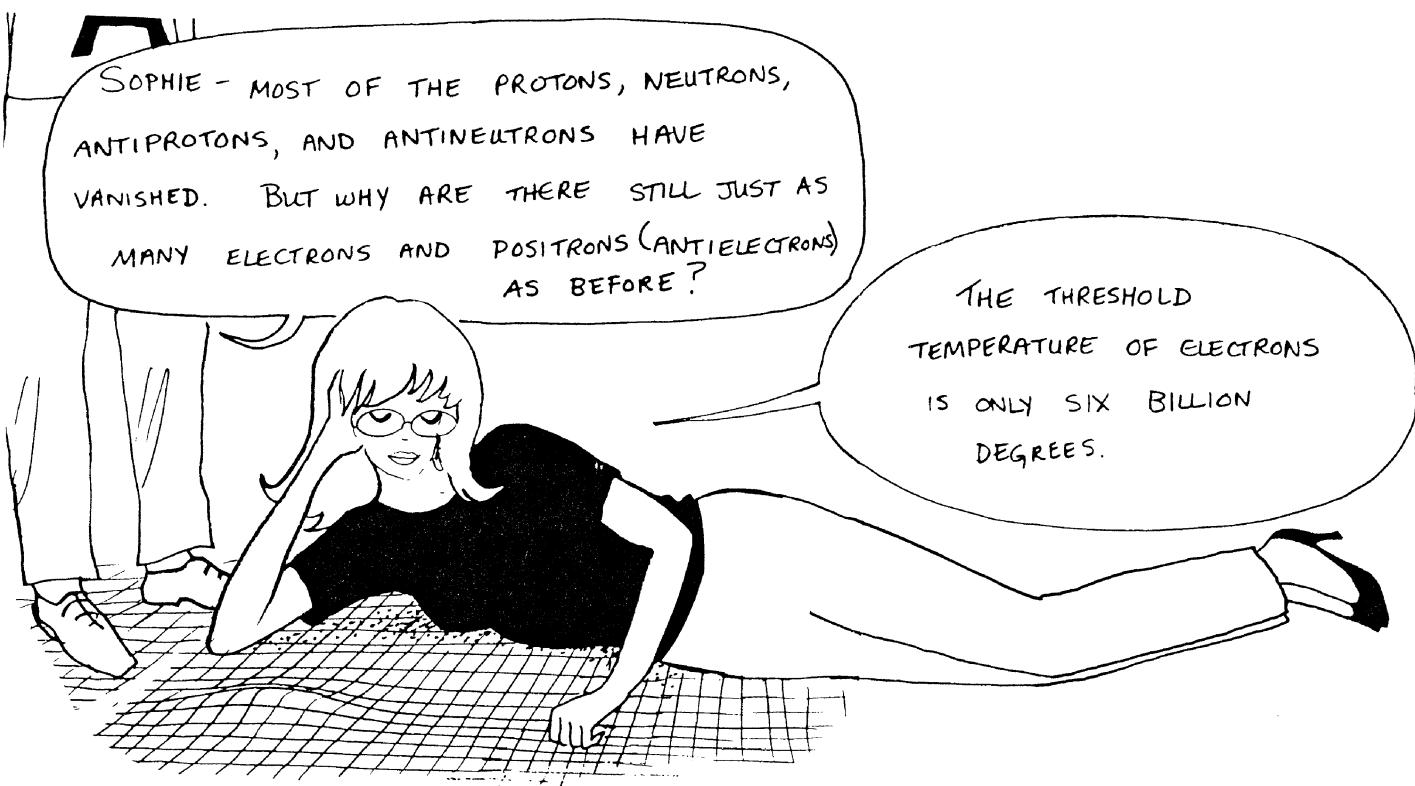


A HUNDREDTH OF A SECOND

PROTONS, NEUTRONS, ANTI-PROTONS,  
AND ANTI-NEUTRONS ONLY GO AT ONE  
TENTH THE SPEED OF LIGHT C.



THE TEMPERATURE ( $T_R = T_m$ ) HAS DROPPED TO A HUNDRED BILLION DEGREES, WELL BELOW THEIR THRESHOLD TEMPERATURE OF TEN TRILLION DEGREES. THEY'VE ANNIHILATED EACH OTHER IN PAIRS AT A TREMENDOUS RATE AND ONLY ONE IN A BILLION SURVIVES.



NOW THAT'S REALLY BIZARRE... THE TEMPERATURE IS 100 BILLION DEGREES... PROTONS, NEUTRONS, AND THEIR ANTI PARTICLES MOVE AT ONE TENTH OF THE SPEED OF LIGHT. BUT ELECTRONS ARE STILL RELATIVISTIC.



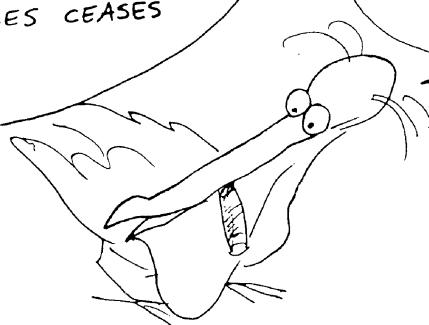
THE SYSTEM IS STILL IN A STATE OF THERMODYNAMIC EQUILIBRIUM:  
THE COUPLING BETWEEN ALL PARTICLE SPECIES, AND RADIATION, IS STILL INTENSE.  
THE KINETIC ENERGIES OF PARTICLES OF MATTER ARE, ON AVERAGE, EQUAL:  
 $\frac{1}{2} m_{\text{PROTON}} (v_{\text{PROTON}})^2 = \frac{1}{2} m_{\text{ELECTRON}} (v_{\text{ELECTRON}})^2$ .



LET ME SEE... SINCE THE MASS OF THE ELECTRON IS 1850 TIMES SMALLER THAN THAT OF THE PROTON, THEN IN ORDER TO COMPENSATE (AT A GIVEN TEMPERATURE), THE SPEED OF AGITATION OF THE ELECTRON MUST BE MUCH HIGHER.

IN FACT, SINCE THE THRESHOLD ENERGY FOR THE CREATION OF A PARTICLE OF MASS  $m$  IS JUST  $mc^2$ , THEN AS SOON AS THE SYSTEM COOLS TO THE POINT AT WHICH ITS SPEED OF AGITATION  $v$  IS NOTICEABLY SMALLER THAN  $c$ , THE CREATION OF THESE PARTICLES CEASES AND THEIR POPULATION DROPS DRAMATICALLY.

IN OTHER WORDS:  
IF A POPULATION OF PARTICLES OF MATTER STOPS BEIN' RELATIVISTIC, IT GETS DECIIMATED!





FOR A WHILE, NOTHING MIGHT REMAIN EXCEPT PHOTONS ... THERE'S A POSSIBILITY...

... MAYBE SOME PLACE ELSE THERE ARE UNIVERSES THAT MISFIRED.

ONE OF THE MAJOR MYSTERIES OF COSMOLOGY IS HAVING NO EXPLANATION OF WHY MATTER AND ANTIMATTER DIDN'T JUST ANNIHILATE EACH OTHER COMPLETELY.

AT THIS POINT IN THE TALE, IT'S ALWAYS THE SAME... THERE COMES A MOMENT WHEN THE PROBLEM OF ANTIMATTER IS JUST SWEPT UNDER THE CARPET...  
PFFFFT! ANTIMATTER ALL GONE!

TIRESIAS, LET ME REMIND YOU OF OUR RULES. ONLY FACTS! NO WILD SPECULATIONS.

I'M GETTING FED UP WITH EPISTOOPS.

PSSSSST!

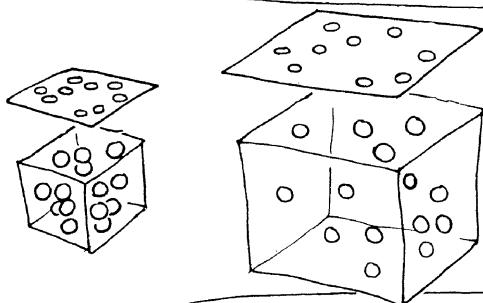
# THE RADIATION ERA

THERE'S NOT A LOT IN THE UNIVERSE AT THE MOMENT, APART FROM LIGHT.

HMM... TOO SOON FOR GAIN' FISSION...

THE ENERGY/MATTER,  
WHICH WAS EQUALLY DIVIDED

INTO MATTER, ANTIMATTER, PHOTONS, AND NEUTRINOS, IS NOW ALMOST EXCLUSIVELY IN THE FORM OF PHOTONS AND NEUTRINOS— RADIATION.  
EVERY TIME THE RADIUS  $R$  OF THE UNIVERSE DOUBLES, THE DENSITY OF MATTER DECREASES. IT'S A SIMPLE MATTER OF DILUTION...



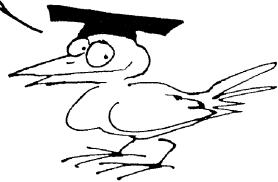
ON THE TWO-DIMENSIONAL CARPET UNIVERSE, WHEN  $R$  DOUBLES, THE DENSITY IS DIVIDED BY  $2 \times 2 = 4$ . IN OUR THREE-DIMENSIONAL UNIVERSE, IT IS ACTUALLY DIVIDED BY  $2 \times 2 \times 2 = 8$ .

THE DENSITY OF MATTER VARIES AS THE INVERSE CUBE OF THE "SIZE," THE "RADIUS"  $R$ , OF THE UNIVERSE.

BUT FOR US PHOTONS IT'S MUCH MORE DRAMATIC, THE EXPANSION USES UP ALMOST ALL OF OUR ENERGY, BIT BY BIT. THE AMOUNT OF ENERGY/MATTER THAT WE CARRY DECREASES AS THE INVERSE OF THE RADIUS  $R$  OF THE UNIVERSE.

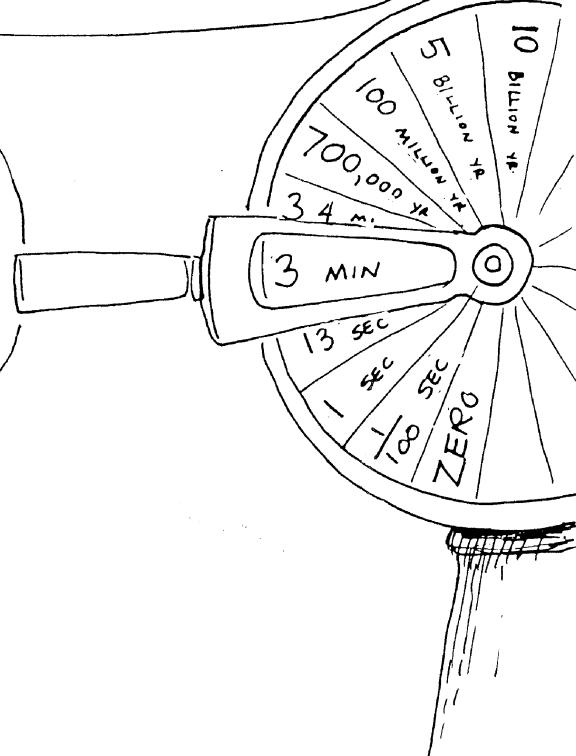
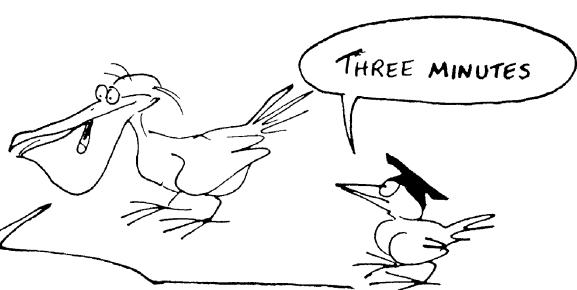
WHICH MEANS THAT THE DENSITY OF ENERGY/MATTER OCCURRING IN THE FORM OF PHOTONS VARIES AS THE INVERSE FOURTH POWER OF  $R$ .

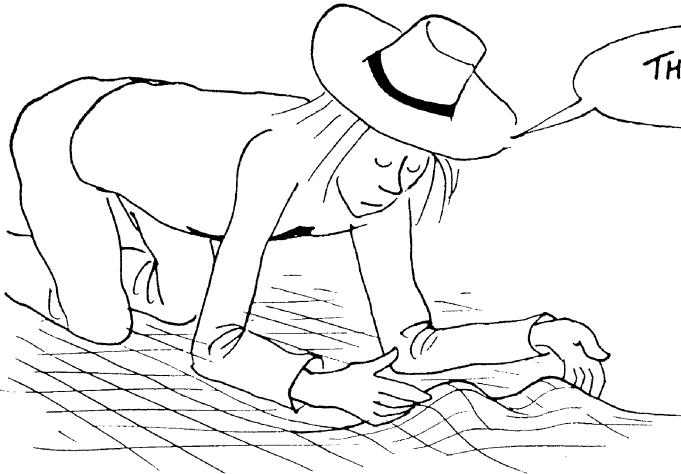
ALL THE WHILE MATTER REMAINS COUPLED TO PHOTONS, IT IS CONTINUALLY REHEATED. THIS HAPPENS UNTIL THE COMMON TEMPERATURE ( $T_R = T_m$ ) FALLS TO 3000 DEGREES — WHICH TAKES ABOUT 700,000 YEARS.



## NUCLEOSYNTHESIS

WOW... COMPARED TO WHERE WE WERE ON PAGE 31, THE FIRST HUNDREDTH OF A SECOND, THE SIZE  $R$  OF THE UNIVERSE HAS MULTIPLIED A HUNDREDFOLD, AND THE TEMPERATURE ( $T_R = T_m$ ) HAS FALLEN TO A BILLION DEGREES. THERE'S ALMOST NOTHING LEFT. NOW WHAT?



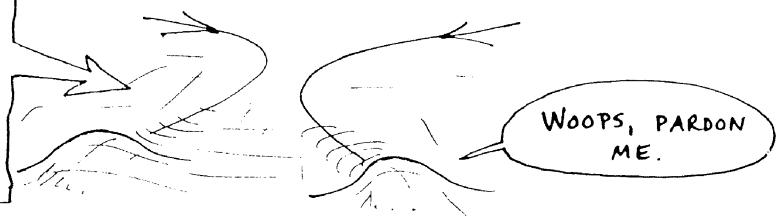


THEY START BY REPELLING EACH OTHER.



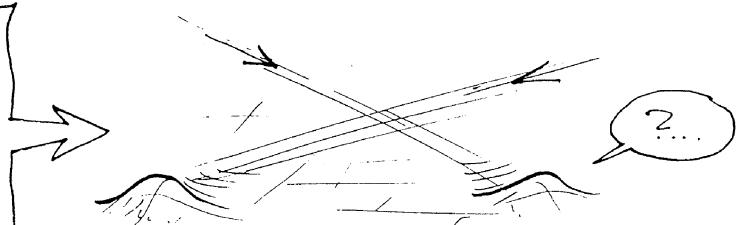
PLOK  
THEN THEY ATTRACT EACH OTHER  
TO FORM A SINGLE OBJECT.

WHEN TWO BUMPS COLLIDE, THREE  
THINGS CAN HAPPEN... IF THEY  
ARE MOVING SLOWLY, THEY BOUNCE  
OFF EACH OTHER...



Woops, pardon  
me.

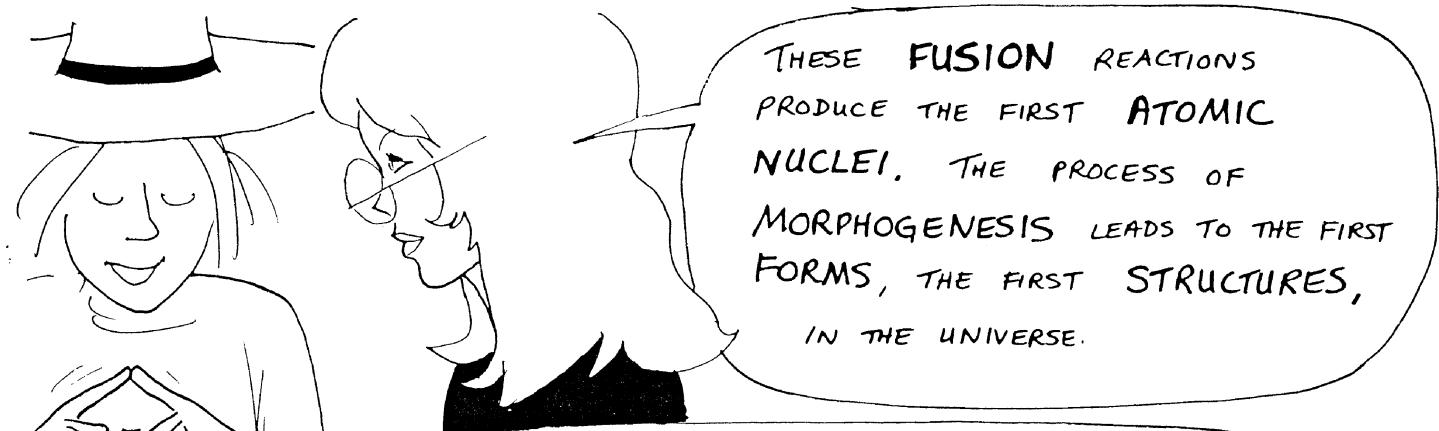
WHEN THE BUMPS ARE MOVING VERY  
QUICKLY, THEY CROSS EACH OTHER'S  
PATHS SO FAST THAT THEY DON'T  
HAVE TIME TO INTERACT.



THEY CAN ONLY JOIN TOGETHER  
IN A DEFINITE RANGE OF VELOCITY  
OF AGITATION (TEMPERATURE).



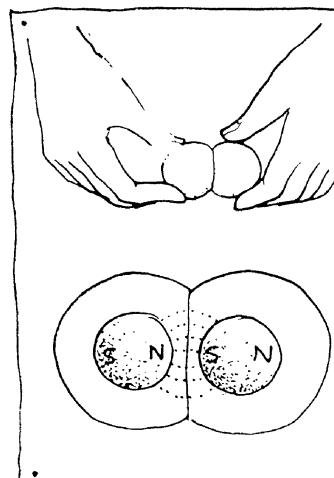
AND A VIOLENT COLLISION WITH A  
THIRD PARTICLE BREAKS UP THE  
STRUCTURE FORMED IN THIS WAY.



A

IT'S AN AMUSING LITTLE TRICK, THAT. THERE'S AN ATTRACTIVE FORCE AND A REPULSIVE FORCE. AT LARGE DISTANCES, THE REPULSIVE FORCE WINS; AT SMALL DISTANCES, THE OPPOSITE HAPPENS.

I'M GOING TO TAKE SOME MAGNETS, AND COAT THEM IN RUBBER.



THE RUBBER COMPRESSES EASILY, SO IF I PRESS TWO SPHERES AGAINST EACH OTHER THEY'LL STAY STUCK TOGETHER BY THE MAGNETIC FORCE.

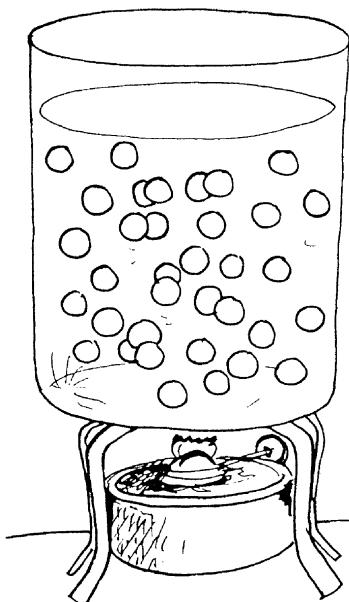


NOW I'LL TIP THEM INTO A LARGE TUB OF WATER...



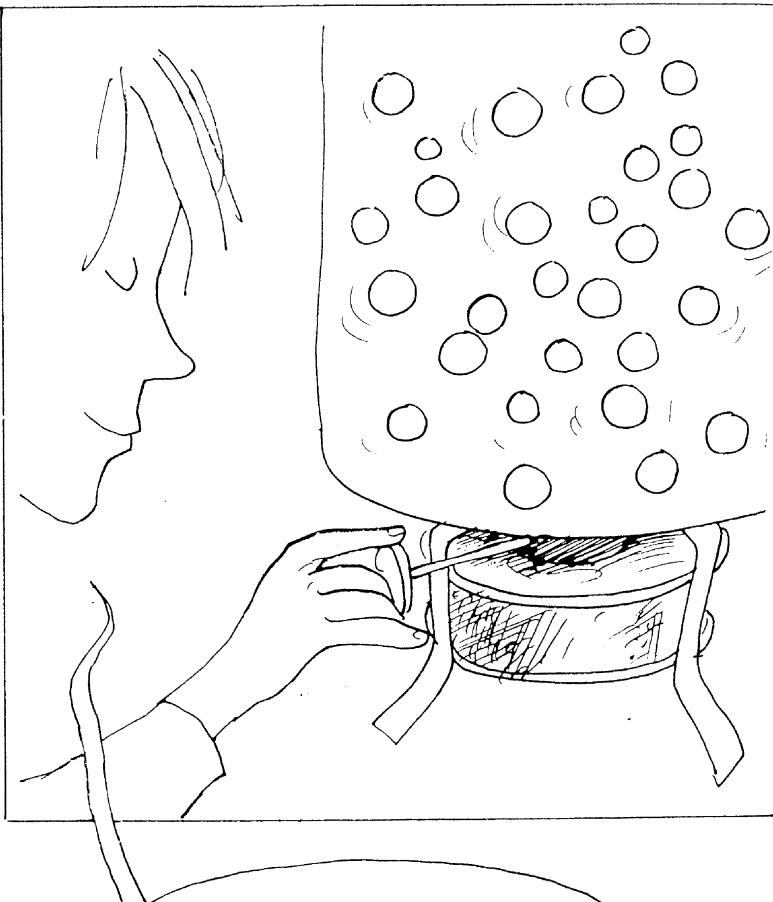
... SO THEY CAN MOVE AROUND.

TWO FORCES COME INTO PLAY. AN ATTRACTIVE FORCE : MAGNETISM.  
A REPULSIVE FORCE: THE ELASTICITY OF THE RUBBER COATING.  
WHEN THE BALLS TOUCH, THE ELASTIC FORCES COME INTO PLAY. THE  
STRENGTH OF THE MAGNETISM IS ARRANGED SO THAT WHEN THE RUBBER  
IS COMPRESSED FAR ENOUGH, IT TAKES OVER. THERE IS AN INTERMEDIATE  
POSITION AT WHICH THE FORCES BALANCE OUT.



THE RUBBER IS LIGHT ENOUGH FOR THE  
DENSITY OF THE SPHERES TO BE ESSENTIALLY  
EQUAL TO THAT OF WATER. NOW I'LL  
HEAT UP THE ACTION A LITTLE...

WHEN THE TEMPERATURE IS LOW,  
THE BALLS BOUNCE GENTLY OFF  
EACH OTHER, AND NOTHING HAPPENS.  
WHEN THEY BUMP INTO EACH OTHER,  
THEY DON'T HAVE ENOUGH ENERGY TO  
COMPRESS THE RUBBER FAR ENOUGH  
FOR THE MAGNETIC FORCE TO COME  
INTO PLAY. THE MAGNETISM CAN  
ONLY ACT AT SHORT RANGE.

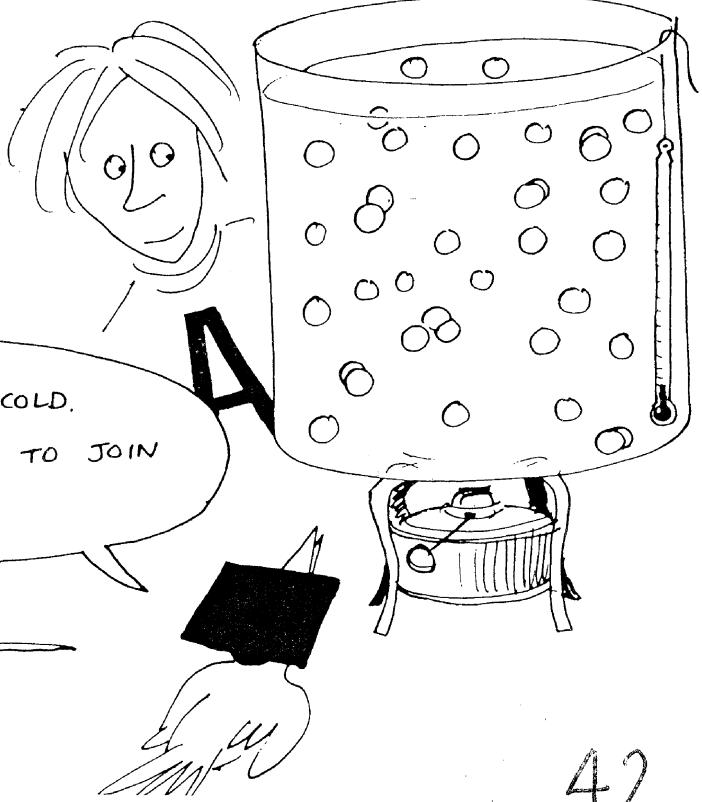


OK, I'LL TURN UP  
THE HEAT.

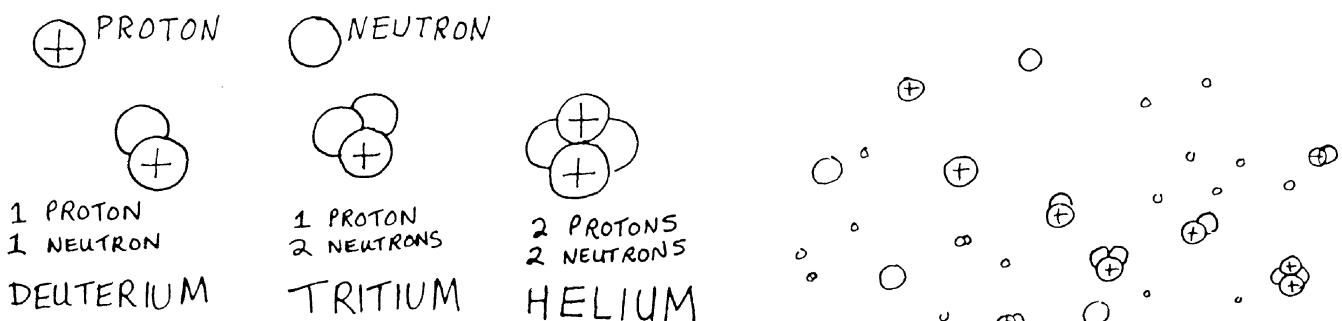




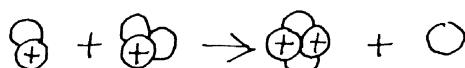
ARCHIE ALLOWS THE WATER TO COOL. THE TURBULENCE DECREASES. AT A CERTAIN MOMENT, SOME OF THE BALLS COUPLE TOGETHER. BUT, SINCE THE TEMPERATURE CONTINUES TO DROP, THIS NUCLEOSYNTHESIS STOPS.



THE SAME THING HAPPENS WHEN THE TEMPERATURE OF THE UNIVERSE DROPS BELOW A FEW **BILLION DEGREES**. THAT IS, AFTER A FEW **MINUTES** THEN STRUCTURES WITH TWO, THREE, OR FOUR "BALLS" CAN FORM.



BUT THE DEUTERIUM AND TRITIUM SO CREATED CAN COMBINE BY A NUCLEAR REACTION:



DEUTERIUM + TRITIUM GIVES HELIUM + NEUTRON

AT THIS POINT, THE UNIVERSE IS A HYDROGEN BOMB.

A small thought bubble containing a drawing of a simple atomic model with three spheres arranged in a triangle. A question mark is placed next to the text.

SO, EVERYTHING TURNS INTO HELIUM?

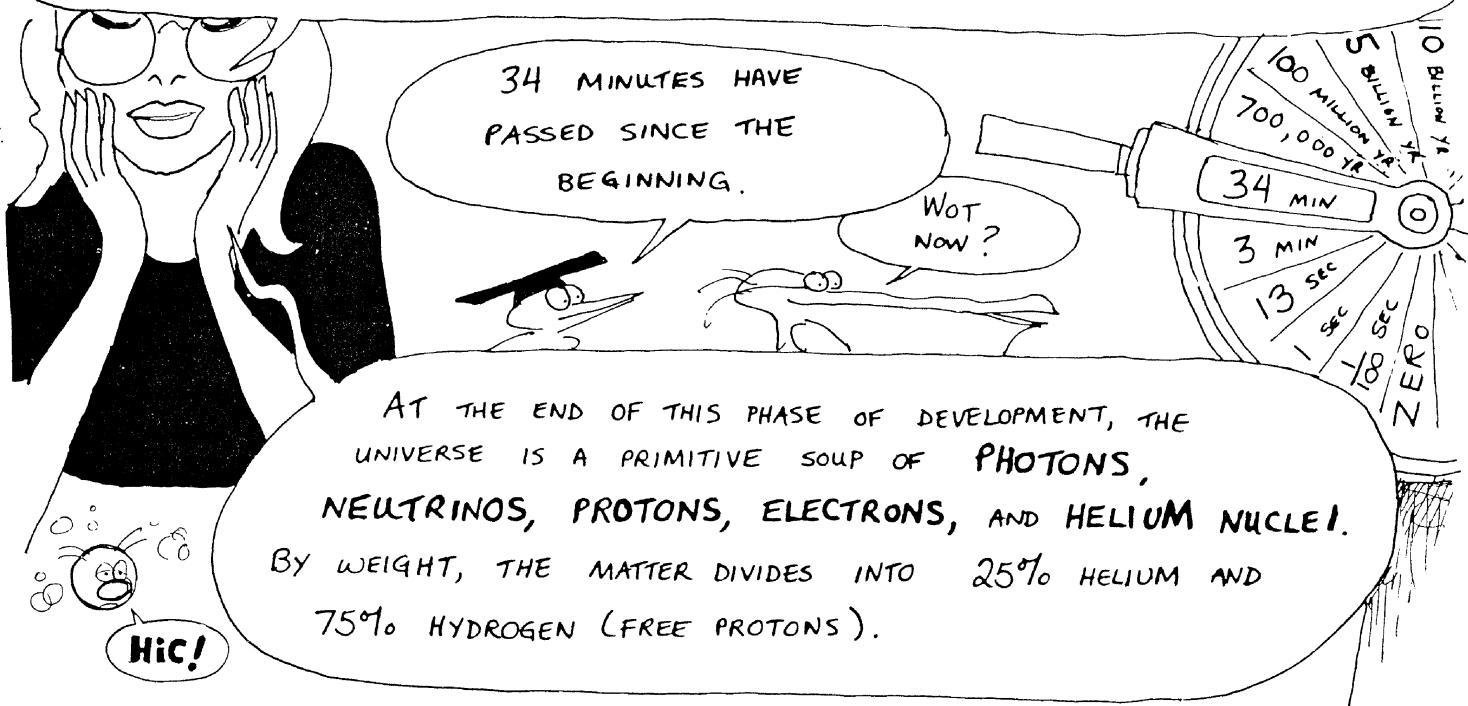
A thought bubble containing a drawing of a complex atomic model with many spheres arranged in a compact, symmetric cluster. The text describes the properties of the helium nucleus.

THE HELIUM NUCLEUS IS VERY SYMMETRIC, COMPACT, AND ROBUST. IF THE TEMPERATURE WERE TO STAY CONSTANT, THEN ALL MATTER WOULD TURN INTO HELIUM. BUT AFTER 34 MINUTES, THE TEMPERATURE FALLS TO 300 MILLION DEGREES AND THE NUCLEOSYNTHESIS STOPS.

A thought bubble containing text about the end of nucleosynthesis. It features a drawing of a hand holding a pencil.

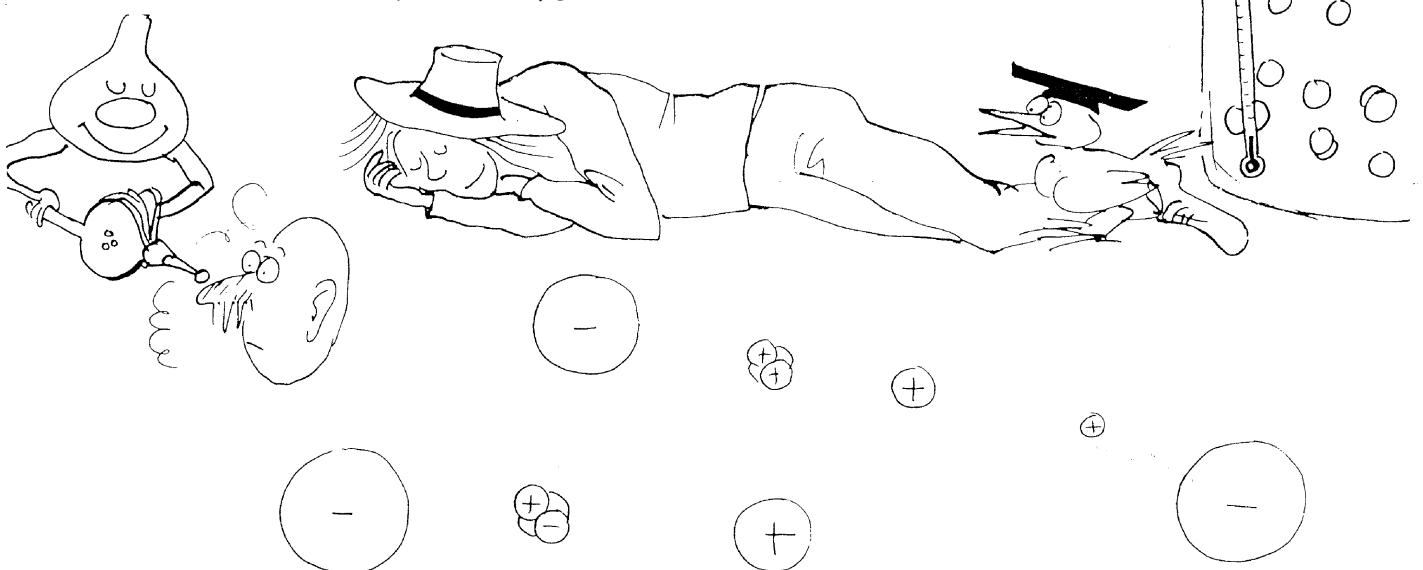
NEUTRONS) NO LONGER HAVE ENOUGH VELOCITY TO OVERCOME ELECTROSTATIC REPULSION. THE GAME IS PLAYED OUT.

THE REMAINING FREE NEUTRONS DISINTEGRATE. THEY ARE NATURALLY UNSTABLE, AND TRANSFORM — IN 109 SECONDS — INTO A PROTON-ELECTRON PAIR.



AT THE END OF THIS PHASE OF DEVELOPMENT, THE UNIVERSE IS A PRIMITIVE SOUP OF PHOTONS, NEUTRINOS, PROTONS, ELECTRONS, AND HELIUM NUCLEI. BY WEIGHT, THE MATTER DIVIDES INTO 25% HELIUM AND 75% HYDROGEN (FREE PROTONS).

FOR 700,000 YEARS... NOTHING HAPPENS. THE UNIVERSE CONTINUES TO EXPAND, AND THE PHOTONS EXPAND WITH IT. THE PHOTON GAS CONTINUES TO HEAT THE MATTER, AND THE TEMPERATURES  $T_R$  AND  $T_m$  STAY EQUAL (THERMODYNAMIC EQUILIBRIUM).

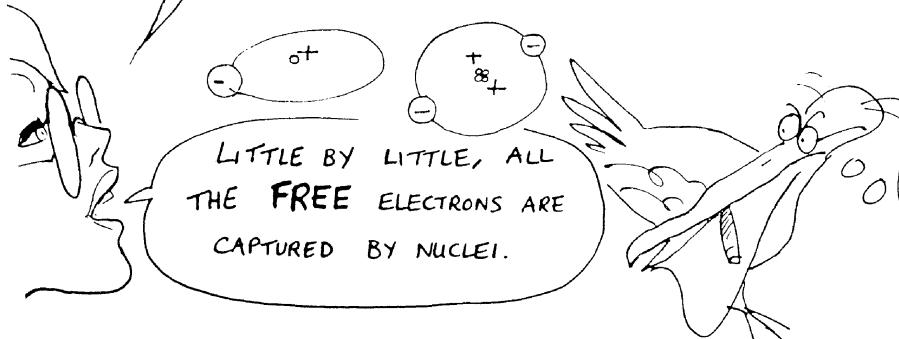
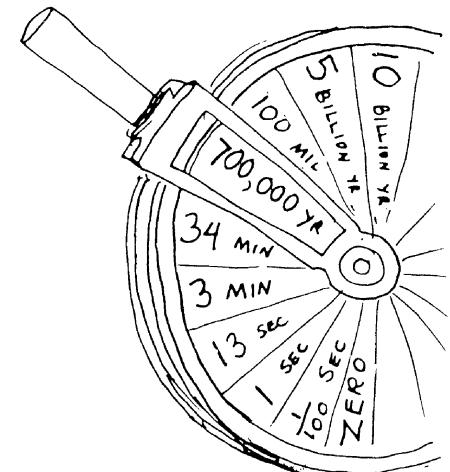


AND THE TEMPERATURE DROPS TO 3000 DEGREES KELVIN

# THE TRANSPARENT UNIVERSE

ANOTHER MORPHOGENETIC MECHANISM

COMES INTO PLAY. ELECTRICAL FORCES TEND TO ATTRACT ELECTRONS TO NUCLEI TO FORM ATOMS. THERMAL AGITATION IS SUFFICIENTLY LOW NOT TO BREAK THESE STRUCTURES UP AS SOON AS THEY ARE FORMED, IN COLLISIONS WITH OTHER ATOMS OR WITH OTHER INGREDIENTS OF THE SOUP.



THESE CRAZY BLOOMIN' ATOMS... WIV 'NORMOUS GREAT EE-LECKTRONS... GIVES ME THE CREEPS, IT DOES!

AND THE UNIVERSE BECOMES TRANSPARENT.

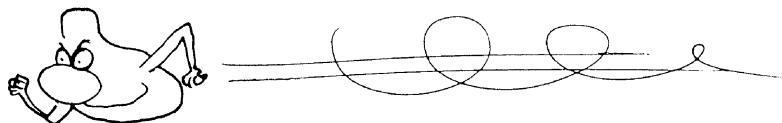
WHAT DO YOU MEAN, BECOMES TRANSPARENT?  
DO YOU MEAN IT WAS OPAQUE BEFORE?

BEFORE, PHOTONS WERE CONSTANTLY INTERACTING WITH MATTER. NO PHOTON COULD TRAVEL VERY FAR WITHOUT BUMPING INTO SOMETHING IN THE SOUP.

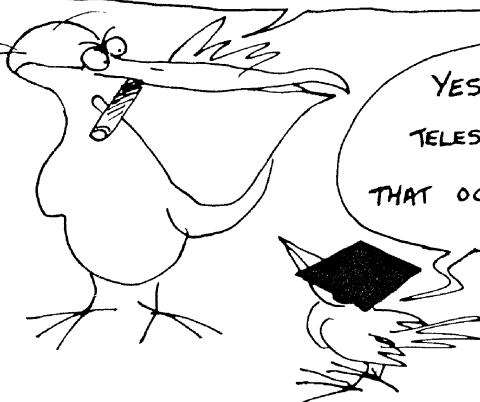


# DECOUPLING

ONCE IT WAS OVER, PHOTONS COULD TRAVERSE THE LENGTH OF THE UNIVERSE WITHOUT NOTICING THAT MATTER EXISTED. PHOTONS AND MATTER WERE **DECOPLED**. FOR TWO REASONS. FIRST, THERE WAS A LOT OF ROOM. SECOND, PHOTONS INTERACT LESS WITH NEUTRAL MATTER (ATOMS).



'ERE, 'ANG ON... WHEN YER LOOKS FROUGH A TELLYSCOPE, YER LOOKS "STRAIGHT INTO THE PAST," DONTCHA?



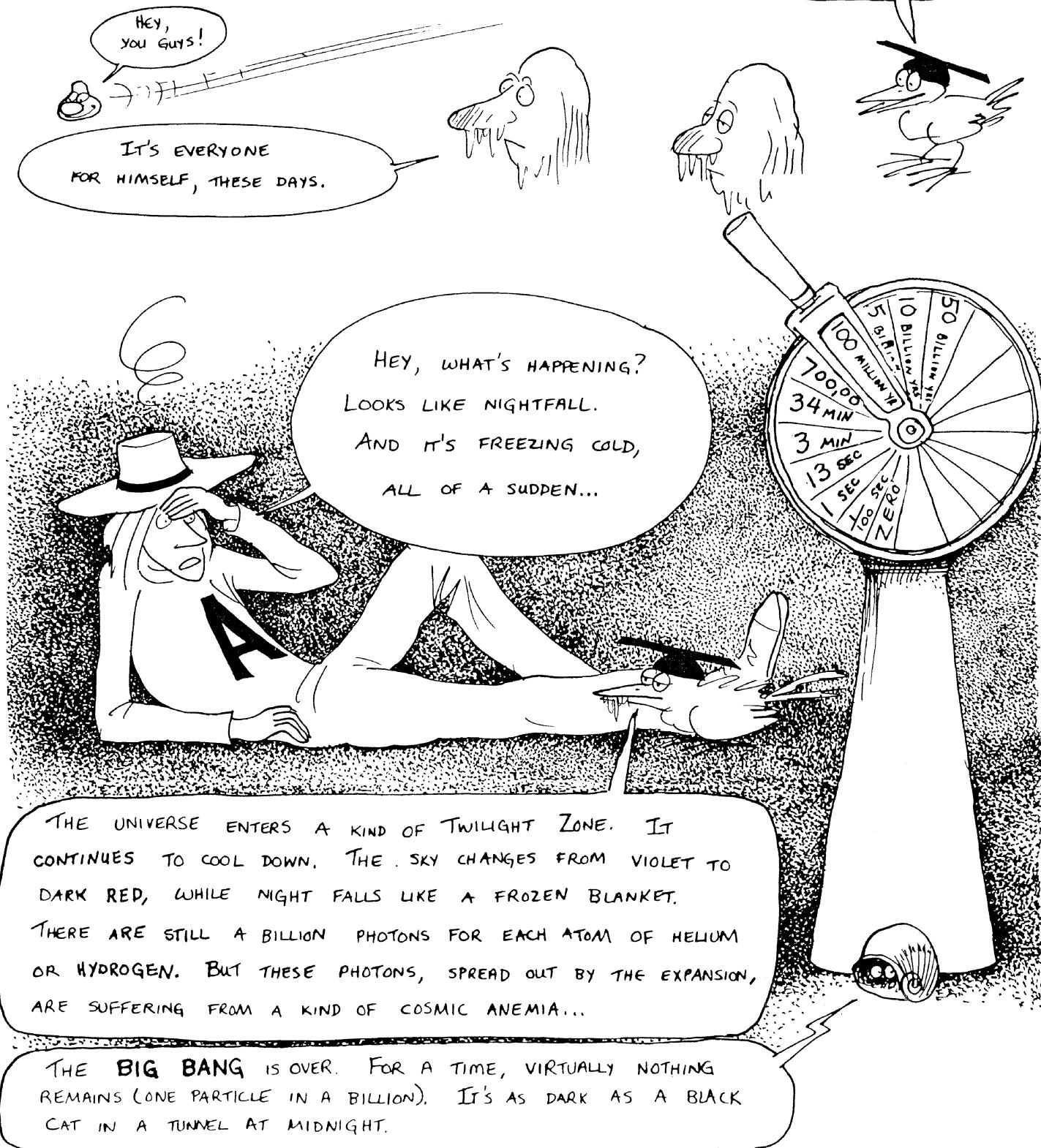
YES, BUT EVEN WITH A FANTASTICALLY POWERFUL TELESCOPE, YOU WOULDN'T BE ABLE TO OBSERVE A PHENOMENON THAT OCCURRED WHEN THE UNIVERSE WAS ONLY 700,000 YEARS OLD.

SO, THE PAST... THE VERY ANCIENT PAST OF THE UNIVERSE MUST ALWAYS STAY VAGUE AN' 'AZY, RIGHT?

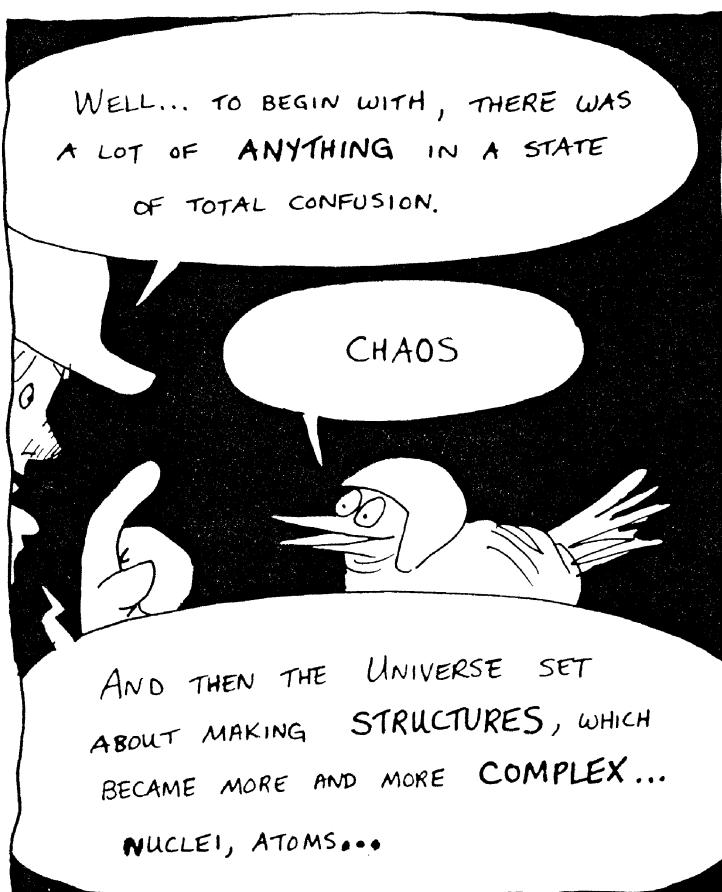
YES - IT'S IMPOSSIBLE TO PSYCHOANALYZE THE UNIVERSE.



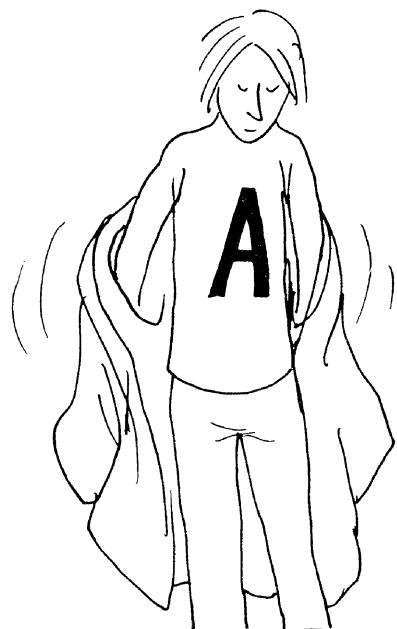
ONCE MATTER AND PHOTONS CEASE TO INTERACT AND EXCHANGE ENERGY, THERMODYNAMIC EQUILIBRIUM IS DESTROYED, AND THE TEMPERATURE  $T_m$  OF MATTER STARTS TO DROP VERY RAPIDLY (AS THE INVERSE SQUARE OF THE RADIUS  $R$  OF THE UNIVERSE); WHILE THE TEMPERATURE  $T_r$  OF PHOTONS — THE RADIATION TEMPERATURE — DECREASES MORE SLOWLY, AS  $\frac{1}{R}$ .



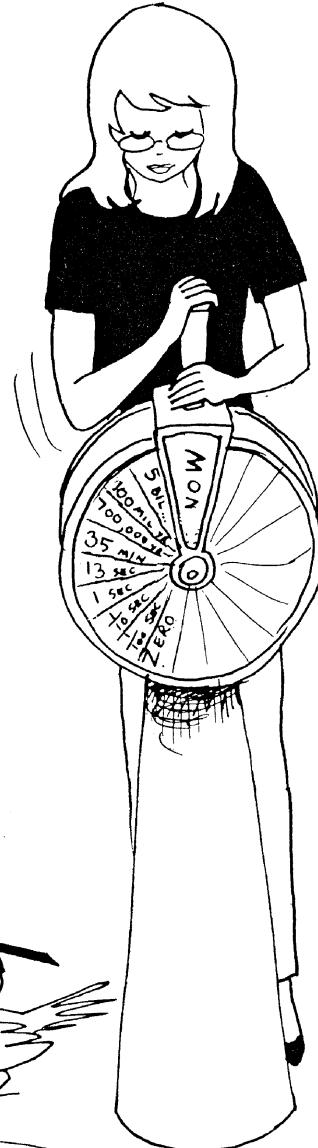




TO ANSWER LENNY'S QUESTION, LET'S LEAVE  
THIS CARPET UNIVERSE AND RETURN OURSELVES TO  
THE PRESENT.

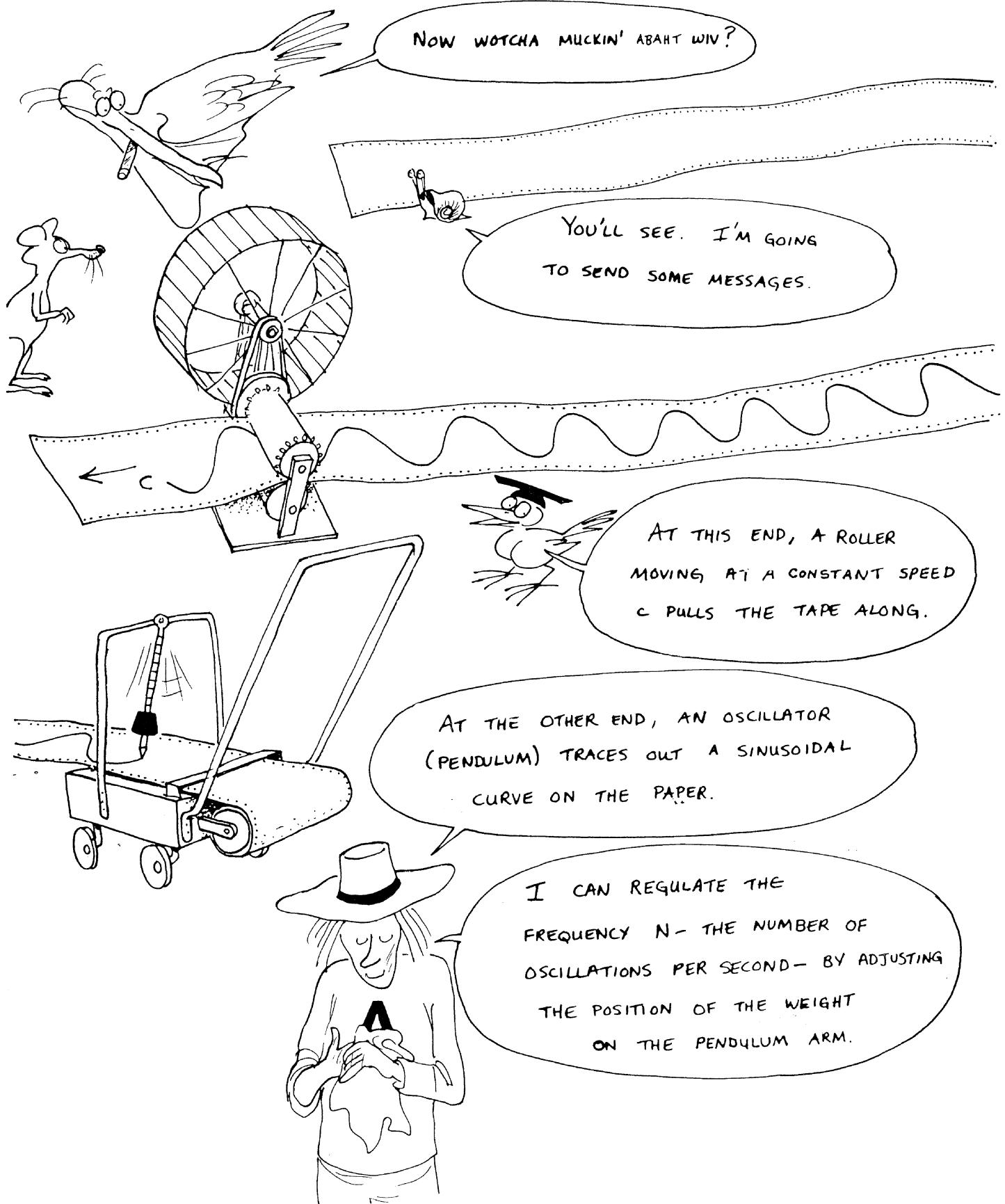


AND WHAT COMES NEXT?  
THE FORMATION OF GALAXIES,  
STARS...?  
YOU'RE LEAVING THAT  
BIT OUT?

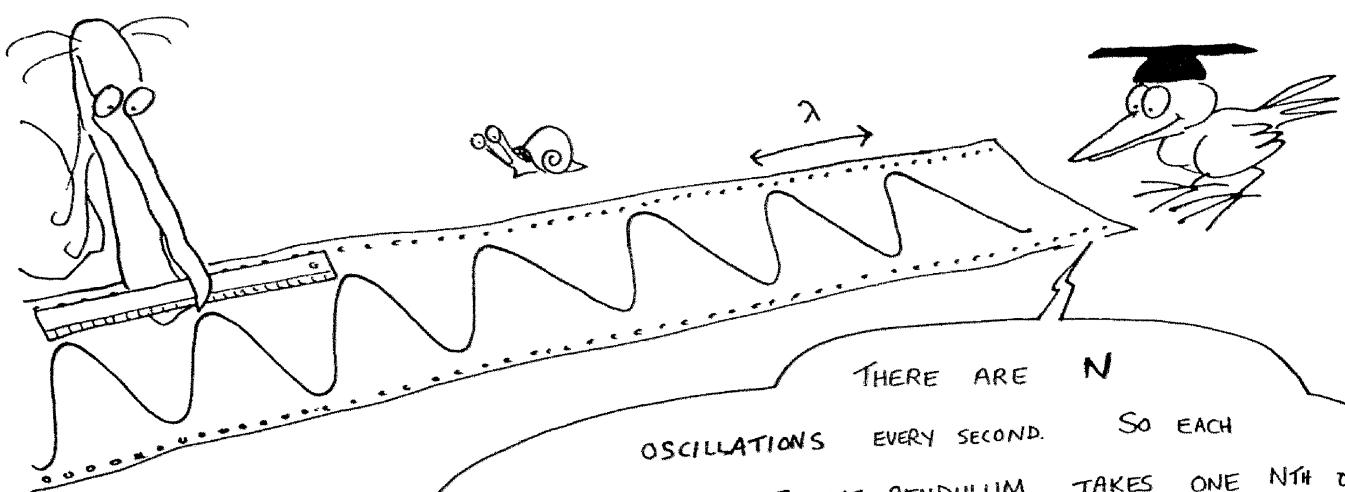


THAT'S ALL FOR NOW, TIRESIAS.  
LENNY'S HAD ENOUGH!

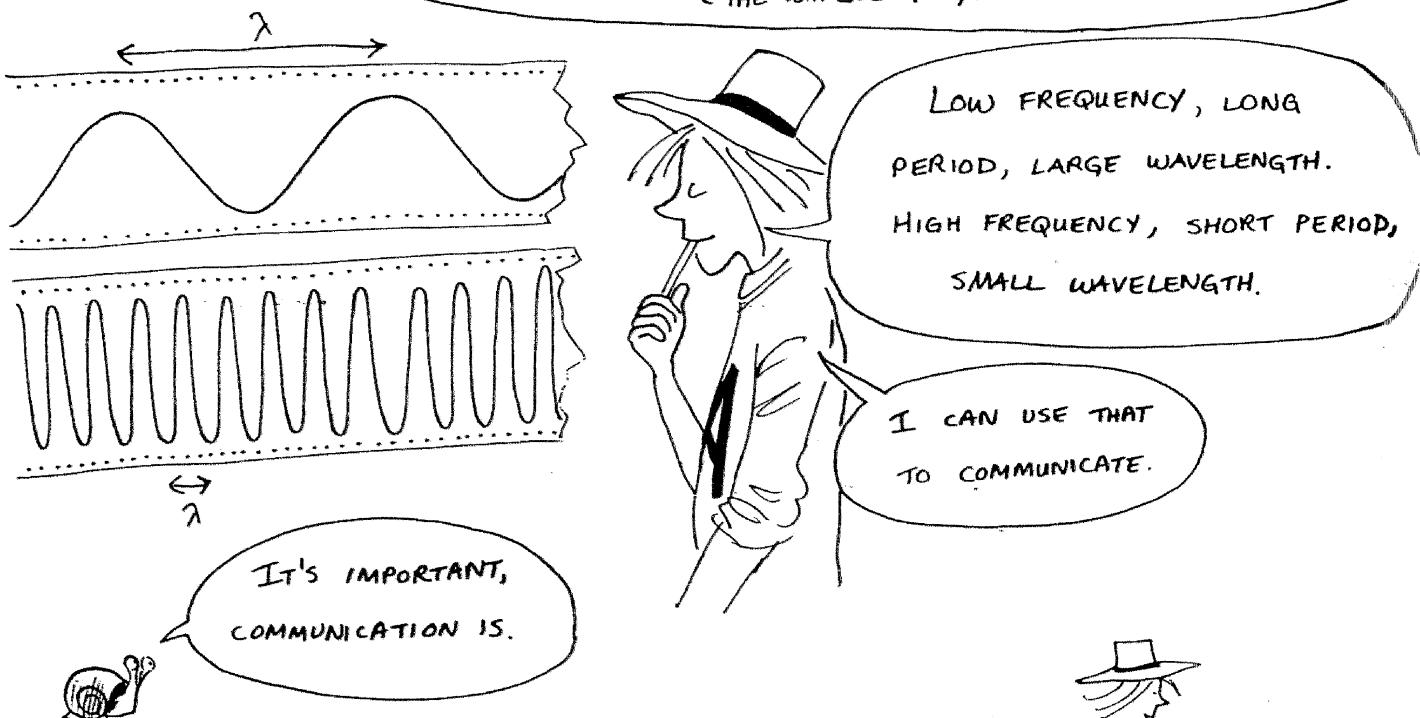
# THE DOPPLER EFFECT



RIGHTY-HO! AN' I CAN MEASURE THE WAVELENGTH OF THE SIGNAL RECEIVED!

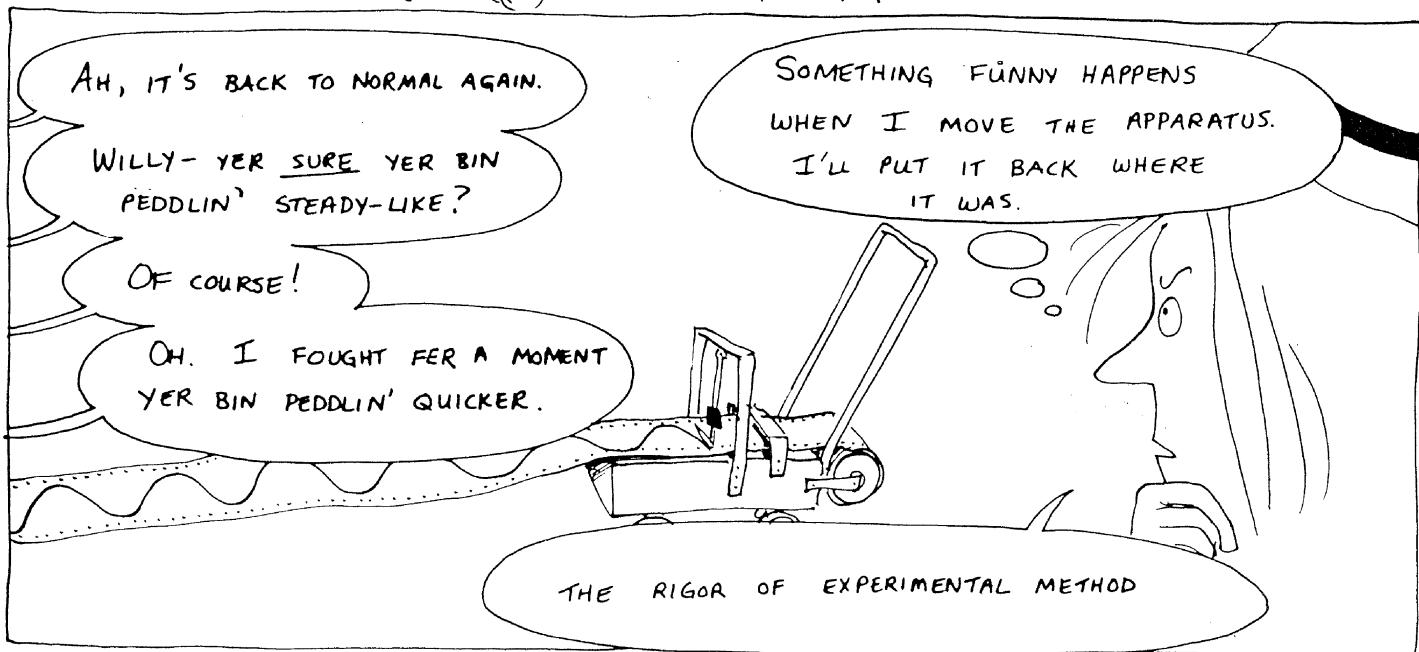
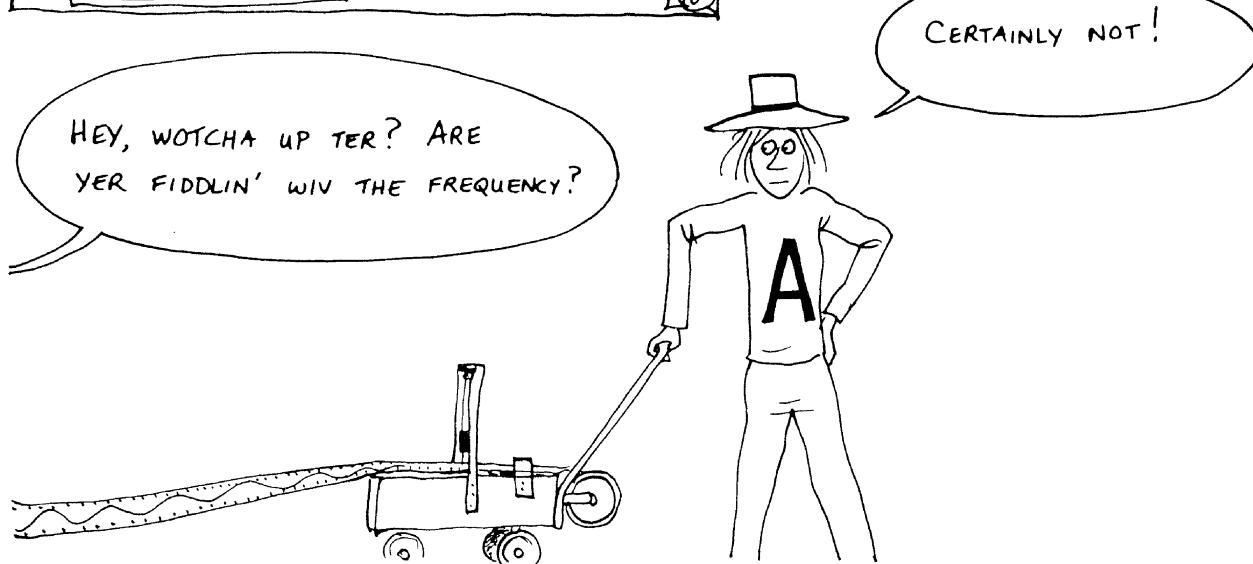
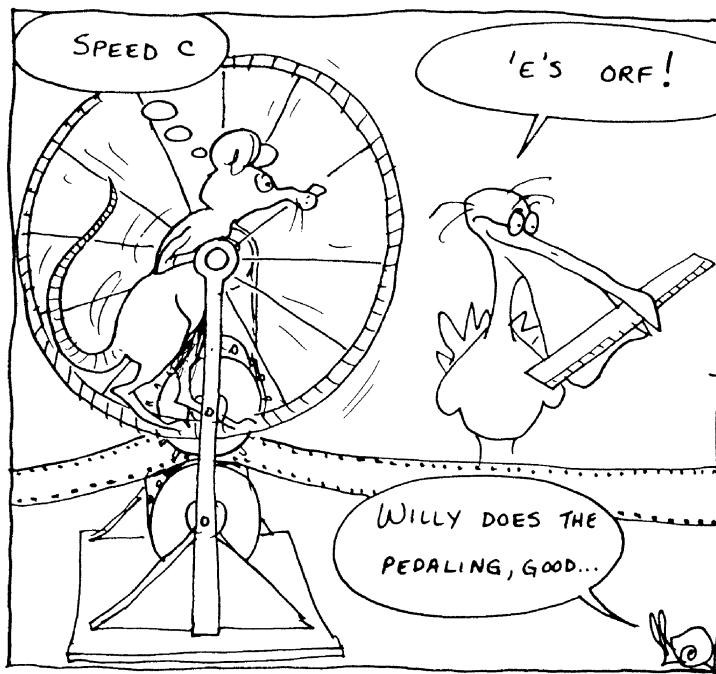


THERE ARE  $N$  OSCILLATIONS EVERY SECOND. SO EACH TO-AND-FRO OF THE PENDULUM TAKES ONE  $\frac{1}{N}$ TH OF A SECOND; THAT'S THE PERIOD OF THE WAVE. DURING THAT TIME, THE TAPE MOVES A DISTANCE  $\lambda = \frac{C}{N}$  (THE WAVELENGTH).



GOOD. I'LL TRY AN EXPERIMENTAL LONG-DISTANCE TRANSMISSION.





!!!

WILLY, GET PEDDLIN', DAMMIT!

I AM PEDALING  
YOU TWERP!

IF YOU DON'T LIKE IT, YOU CAN DO  
THE JOB INSTEAD OF ME!



HOLD IT, HOLD IT! WHAT'S  
THE PROBLEM?

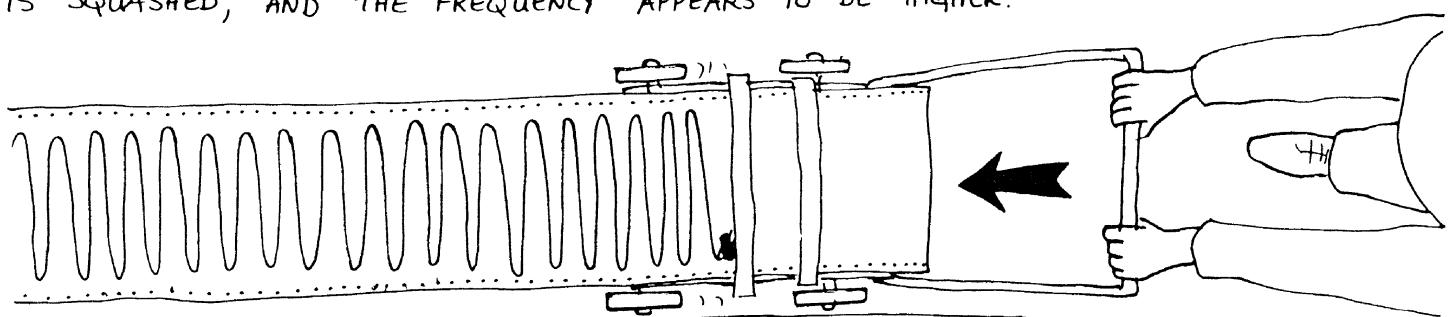


IT'S BACK TO NORMAL AGAIN NOW.

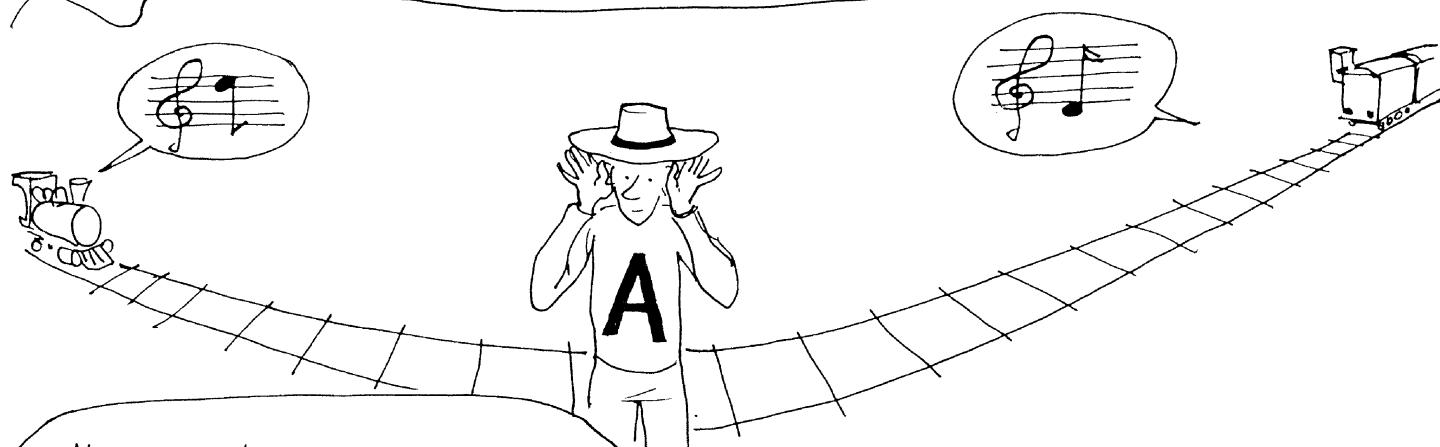
BUT A WHILE AGO THE WAVELENGTH  
SUDDENLY INCREASED (A). THAT IS, THE APPARENT  
FREQUENCY OF THE RECEIVED SIGNAL DROPPED. THEN,  
AFTER AN INTERVAL OF NORMAL RECEPTION (B), THE FREQUENCY  
INCREASED (C) ... THAT IS, THE WAVELENGTH  $\lambda$  GOT SHORTER  
AGAIN.



WHEN THE CART RETURNS, ADVANCING ALONG THE TAPE, THE SINUSOID IS SQUASHED, AND THE FREQUENCY APPEARS TO BE HIGHER.



THAT'S EXACTLY WHAT HAPPENS WHEN YOU LISTEN TO THE WHISTLE OF A TRAIN PASSING AT HIGH SPEED. WHEN IT'S APPROACHING, THE SOUND SEEMS HIGHER; WHEN IT PASSES THE SOUND CHANGES TO A LOWER NOTE.



HEY, THAT'S INTERESTING... WITH A SYSTEM LIKE THAT, IF I KNOW AHEAD OF TIME THE WAVELENGTH OF THE SIGNAL BEING EMITTED BY A MOTIONLESS SOURCE, I CAN CALCULATE THE SPEED OF APPROACH OR RECEDITION OF THE SOURCE.

AND WHAT HOLDS FOR SOUND IS ALSO TRUE OF LIGHT. OBJECTS THAT ARE MOVING AWAY LOOK MORE RED, AND THOSE THAT ARE APPROACHING LOOK MORE BLUE.

FAIR ENOUGH - LET'S TRY THE EXPERIMENT AGAIN.

MAN YOUR POST,  
WILLY.

'E'S CHANGED THE FREQUENCY?

OR ELSE HE'S MOVING  
AWAY.

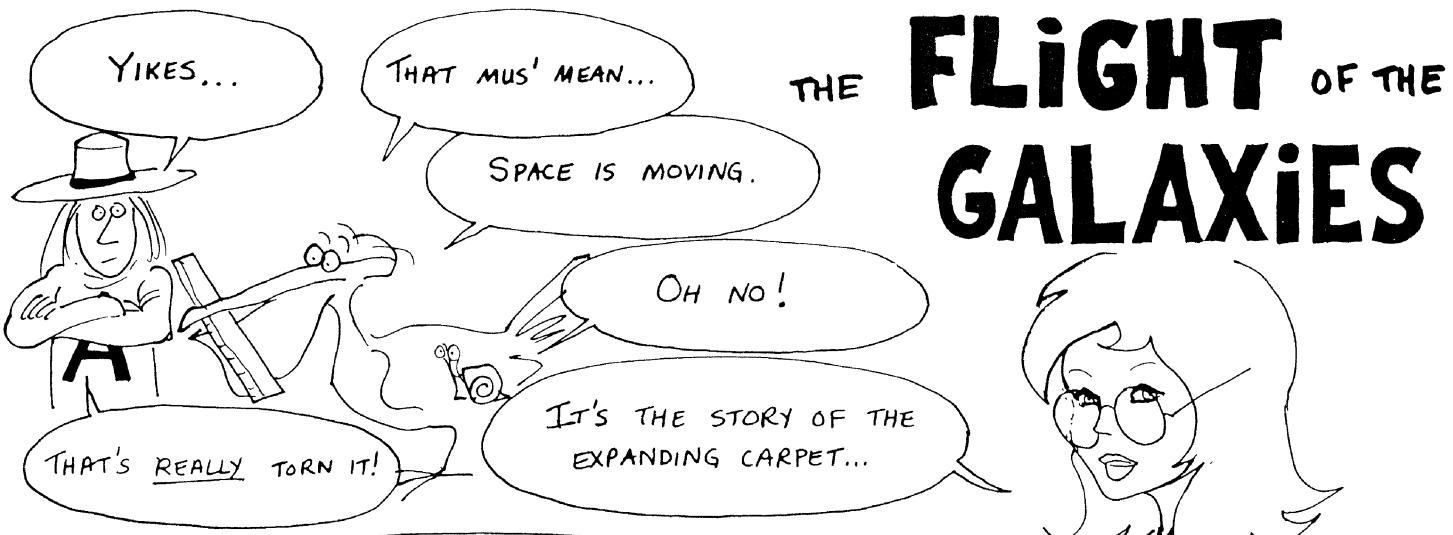
IT'S HAPPENING AGAIN,  
JUST LIKE LAST TIME.

YUR THAT'S IT!

'E'S STILL MOVIN' ORF!

No, YOU BUNCH OF DUMMIES,  
I AM NOT MOVING OFF!  
I'M HERE!

AND THE OSCILLATOR'S  
STILL OVER THERE.



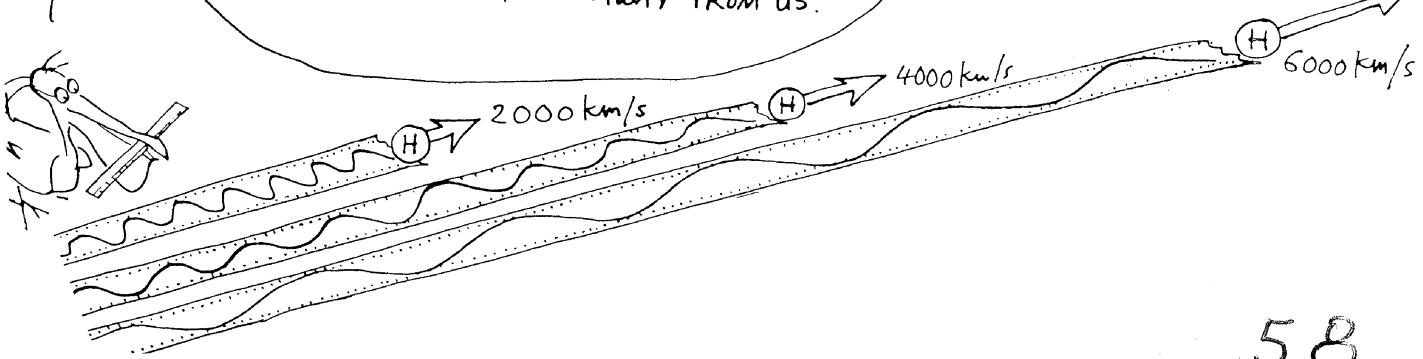
# THE FLiGHT OF THE GALAXiES

AND THAT WAS HOW, IN 1930, EDWIN HUBBLE DISCOVERED THE EXPANSION OF THE UNIVERSE, BY NOTICING THAT DISTANT GALAXIES WERE MOVING AWAY FROM US. BECAUSE OF THE DOPPLER-FIZEAU EFFECT, THEY APPEARED REDDER AND REDDER, THE FURTHER DISTANT THEY WERE.



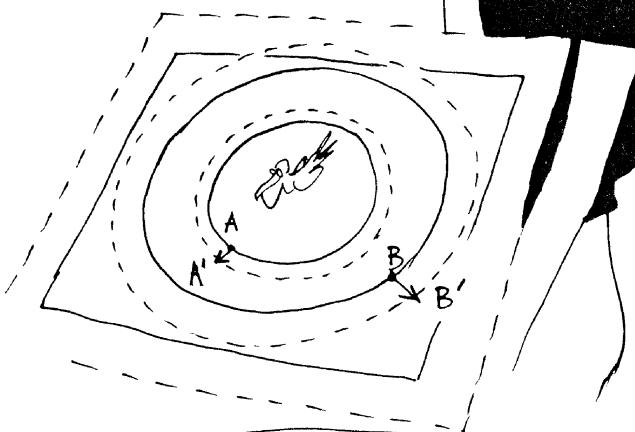
THESE 'YDROGEN ATOMS EMIT LIGHT AT A WAVELENGTH OF 1 CM, IN THEORY. THE DOPPLER EFFECT SHOWS A SPEED OF RECESSION OF 2000, 4000, AND 6000 KM/SEC.

HUBBLE COULD ESTIMATE THE DISTANCE SEPARATING US FROM THESE GALAXIES, BY CONSIDERING THEIR APPARENT LUMINOSITY. HE DEDUCED THAT THE VELOCITY OF RECESSION WAS PROPORTIONAL TO THEIR DISTANCE AWAY FROM US.



UMPF. SO WOZZAT MEAN? FINGS  
H'ACCELLYRATE WHEN THEY GET FURTHER  
AWAY FROM US?

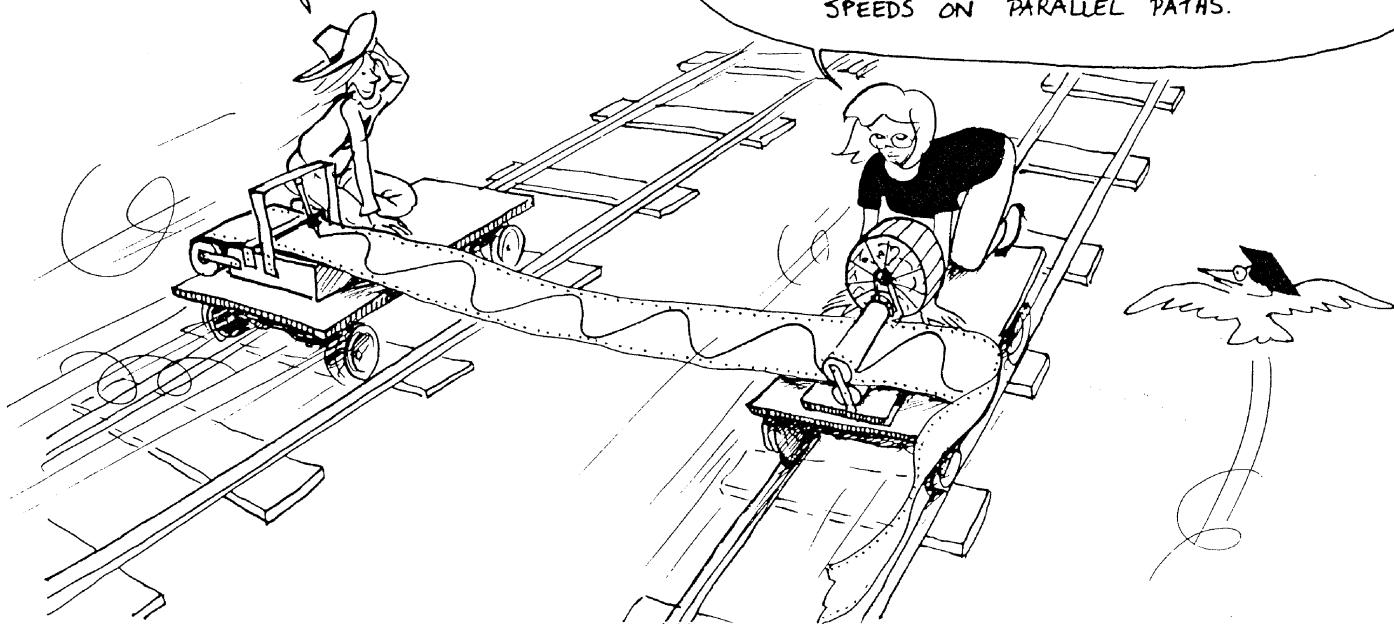
NOT EXACTLY. THE CARPET  
EXPANDS IN ALL DIRECTIONS. IMAGINE  
A POINT A WHICH, AT TIME  $t=0$ ,  
IS ONE METER AWAY. AFTER ONE  
SECOND, IT IS AT 1.2 METERS. SO ITS  
SPEED OF RECESSION IS 20 CM/SEC.

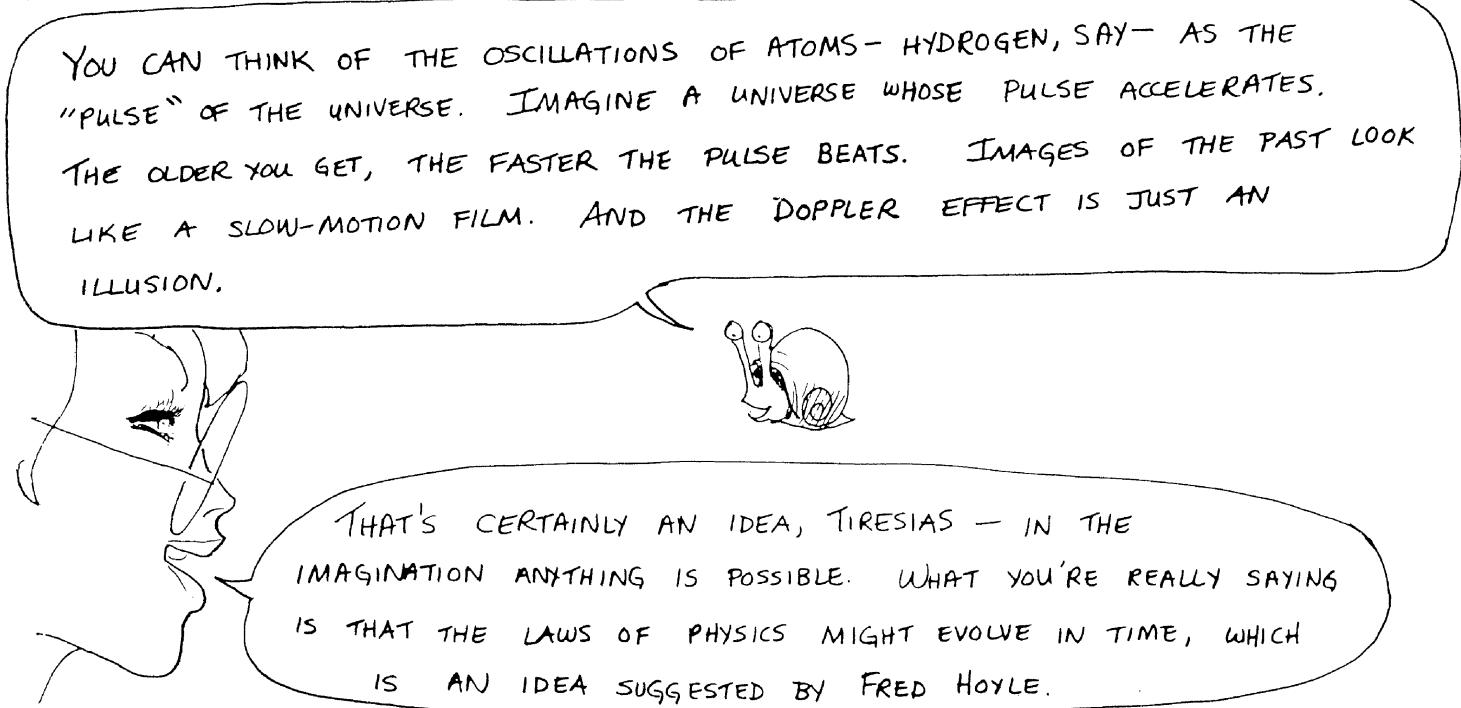
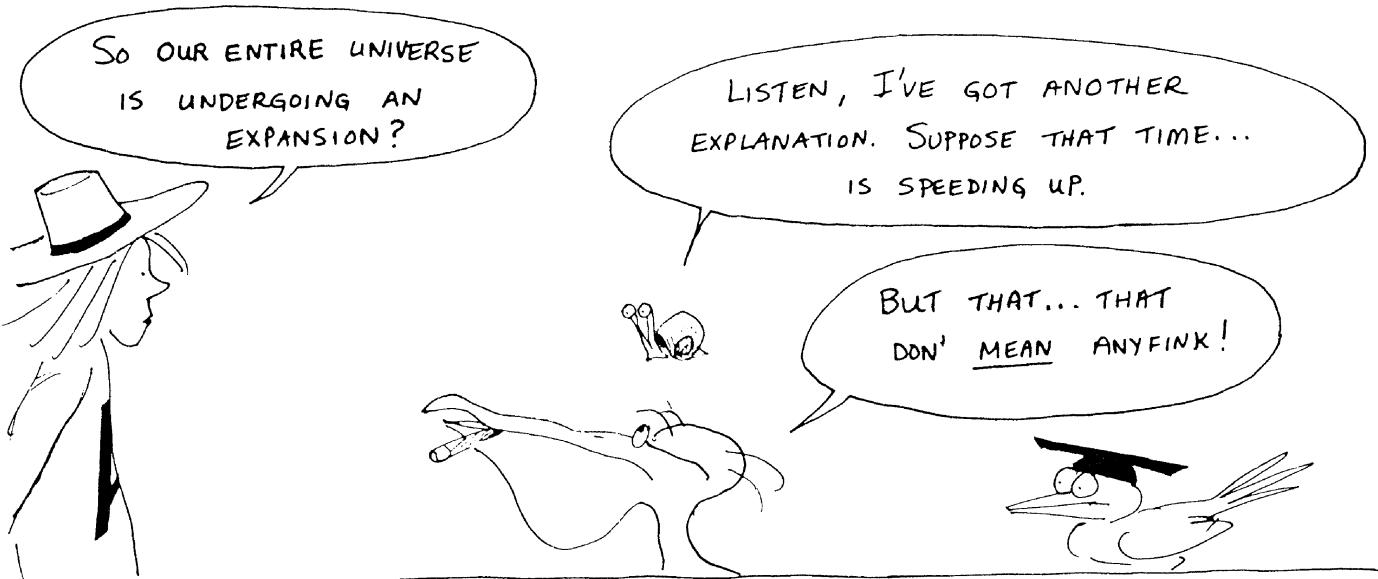


IN THE SAME PERIOD OF TIME,  
A POINT B, SITUATED INITIALLY 2  
METERS AWAY, ENDS UP AT A DISTANCE  
OF 2.4 METERS (AT B'). AND ITS  
SPEED OF RECESSION RELATIVE  
TO YOU IS 40 CM/SEC.

THE DOPPLER EFFECT TELLS  
YOU RELATIVE VELOCITIES.

THERE'S NO VARIATION OF THE  
WAVELENGTH IF BOTH TRANSMITTER  
AND RECEIVER MOVE AT THE SAME  
SPEEDS ON PARALLEL PATHS.





A WHILE BACK, WE SAW THAT ONLY ONE PHOTON IN A BILLION WAS TRANSFORMED INTO MATTER.

AND ANTIMATTER!

SO THERE SHOULD STILL BE A LARGE NUMBER OF THESE PRIMITIVE PHOTONS, ABOUT 500 PER CUBIC CENTIMETER. (AND AS MANY NEUTRINOS, BUT THEY'RE HARDER TO DETECT.)

THEIR WAVELENGTH SHOULD BE ABOUT 5 MM, WHICH CORRESPONDS TO A RADIATION TEMPERATURE  $T_R$  OF 3 DEGREES ABSOLUTE ( $-270^\circ\text{C}$ ).

THESE PHOTONS, OF VERY LOW ENERGY, WERE DETECTED BY PENZIAS AND WILSON IN 1964. THEY ARE THE CINDERS OF THE BIG BANG; TANGIBLE PROOF OF THE GREAT COSMIC DANCE.

OH CRIKEY...

EEEEP!

# FRIEDMANN MODELS

SOPHIE - WHAT CAUSES THE H' EXPANSION OF THE UNIVERSE?

IT'S THE PRESSURE FORCES. IT HAPPENS BECAUSE THE UNIVERSE EXPLODED LIKE A BOMB.

AND DOES NOTHING OPPOSE THIS EXPANSION?

THE FORCE OF GRAVITY TENDS TO MAKE THE UNIVERSE COME TOGETHER AGAIN-TO IMPLODE.

SO CAN'T YER FINK OF A UNIVERSE WHERE THESE FORCES, PRESSURE AN' GRAVITATION, BALANCE AHT?

IT CAN BE SHOWN THAT SUCH A BALANCE IS IMPOSSIBLE. THE SLIGHTEST DISTURBANCE AWAY FROM BALANCE, AND THIS "STATIC" UNIVERSE WOULD EITHER IMPLODE OR EXPLODE.

EXPLOSION

IMPLOSION

# THE COSMOLOGICAL HORIZON

SOPHIE - ACCORDING TO  
HUBBLE'S LAW, THE SPEED OF RECESSION  
OF OBJECTS INCREASES WITH THEIR  
DISTANCE...

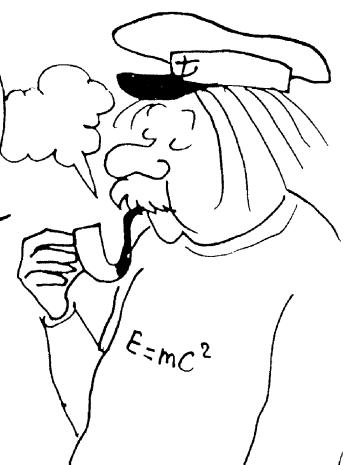
SO, LOGICALLY, THERE SHOULD  
EXIST OBJECTS THAT REcede FROM US  
AT SPEEDS EQUAL TO, OR GREATER THAN,  
THE SPEED OF LIGHT!?

WHY NOT? IF A PLANE  
FLIES PAST ME AT SUPERSONIC  
SPEED, I CAN STILL HEAR THE  
SONIC BOOM.

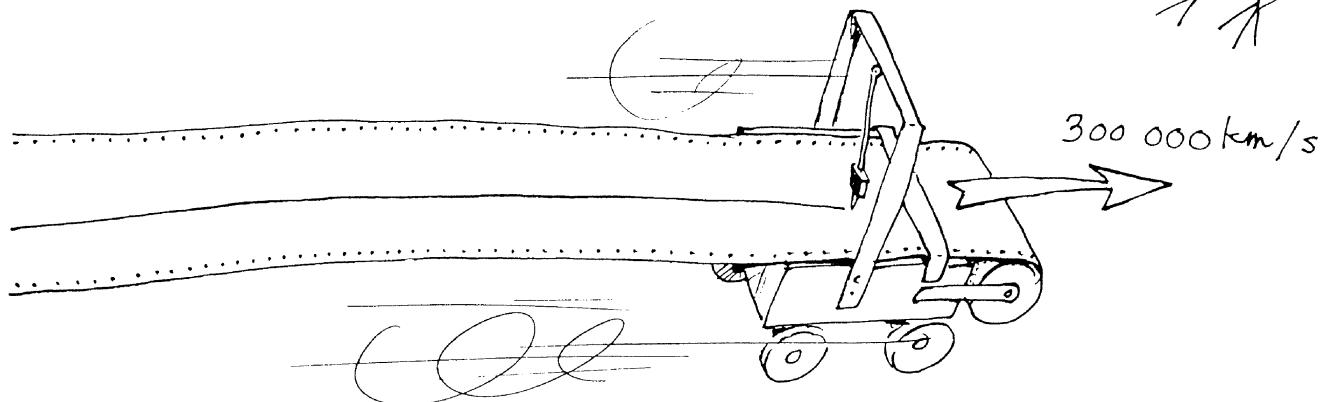
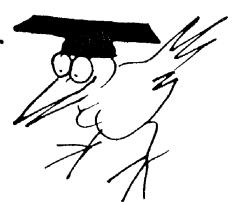
MY DEARS, YOU HAVE  
TO LOOK AT THINGS IN  
A DIFFERENT LIGHT.

BUT... WE COULDN'T  
RECEIVE LIGHT FROM  
THOSE!

DER PHENOMENON OF MOTION HAS EIN EFFECT ON DER TIME (\*). EIN OBJECT VOT MOOFS AT A SPEED APPROACHING DAT OF LIGHT, 300,000 KM/SEC, SEEMS- RELATIVE TO US, DE OBSERVERS - TO BE IN A DIFFERENT "TIME BUBBLE." VE OBSERVE ITS MESSAGE AS A KIND OF SLOW-MOTION FILM.



AND IF THIS OBJECT MOVES AWAY FROM US AT THE SPEED OF LIGHT ITSELF, THE TIME DISCONNECTION BECOMES TOTAL. ITS TIME SEEMS TO FLOW LIKE TREACLE.



BECAUSE OF THIS SLIPAGE, THIS SKIDDING OF TIMES RELATIVE TO EACH OTHER, THE FREQUENCY OF WAVES AT THE RECEIVER IS LOWERED. AND THIS PHENOMENON, A RELATIVISTIC EFFECT, ACTS IN ADDITION TO THE DOPPLER EFFECT. WHEN THE VELOCITY OF RECESSION OF THE TRANSMITTER, RELATIVE TO US, REACHES C, THEN THE FREQUENCY OF THE RECEIVED WAVES FALLS TO ZERO. THE SAME GOES FOR THE ENERGY, THE WAVES AND THE MESSAGE!

WAVES OF ZERO FREQUENCY ARE  
WAVES GOODBYE!

(\*) SEE EVERYTHING IS RELATIVE, SAME SERIES.

FOR THE OBJECTS THAT SURROUND US, A RELATIVE VELOCITY EQUAL TO 300,000 KM/SEC IS ATTAINED ON A SPHERE CALLED THE HORIZON. IT IS NOT THE FRONTIER OF THE THINGS THAT EXIST; BUT THE FRONTIER OF THE THINGS WE CAN KNOW ABOUT. THE ACCESSIBLE UNIVERSE IS JUST A TINY PART OF THE VASTER UNIVERSE. THIS HORIZON IS AT A DISTANCE OF SOME TENS OF BILLIONS OF LIGHT-YEARS. THE RANGE OF THE MOST POWERFUL TELESCOPE ON THE EARTH TODAY, THE PALOMAR TELESCOPE, IS ABOUT 1 BILLION LIGHT-YEARS.

The Boss

SO WHAT, NOW, IS THE MEANING OF THE RADIUS  $R$  OF THE UNIVERSE?



OUR STORY BEGAN WHEN THE UNIVERSE WAS AGED ONE HUNDREDTH OF A SECOND. IMAGINE THAT AT THAT MOMENT WE HAD DRAWN A CIRCLE, OR BETTER A SPHERE, OF RADIUS  $R$ . THEN FOLLOW THE EXPANSION OF THAT SPHERE OF REFERENCE AS TIME FLOWS. THAT'S ALL.

BY DOING THAT, WE DON'T PREJUDGE WHETHER SPACE IS FINITE OR INFINITE (\*).



SHE'S GOT LOVELY EYES...

'ERE, YOU TWO!

THIS CARTOON BOOK ISN'T FINISHED YET!

YOU'RE STILL NEEDED.

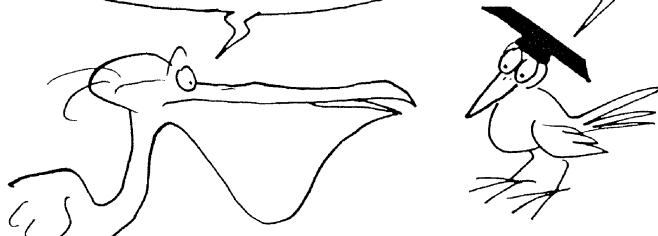
HI-HI-HI

(\*) SEE HERE'S LOOKING AT EUCLID, SAME SERIES.

TELL ME, THEN: INSTEAD  
OF H'EXPLOPIN' COULD  
OUR UNIVERSE IMplode?

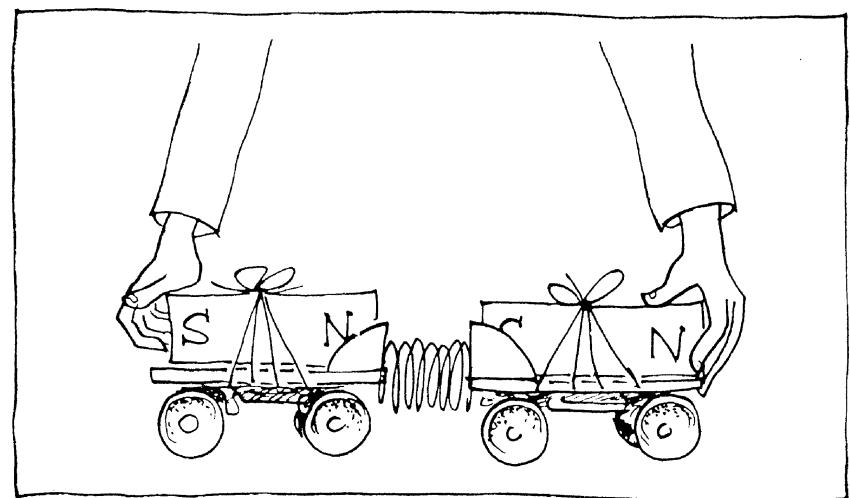
IN A SENSE  
THERE'S THAT  
POSSIBILITY.

IN FACT, IT'S POSSIBLE  
THAT TIME MIGHT DECIDE TO  
RUN BACKWARDS...

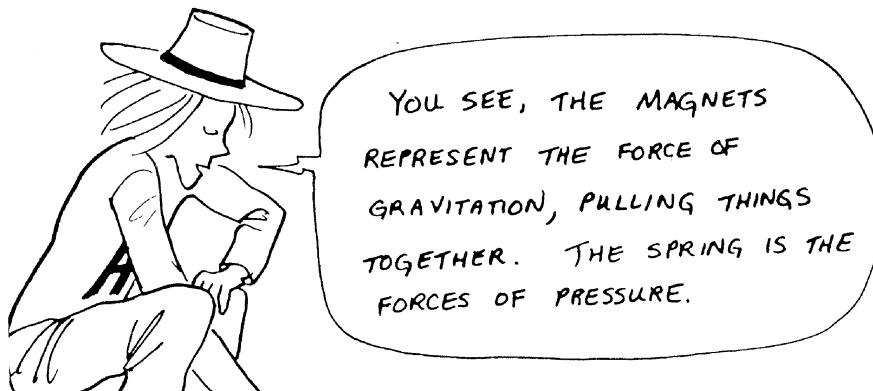


Tsss!

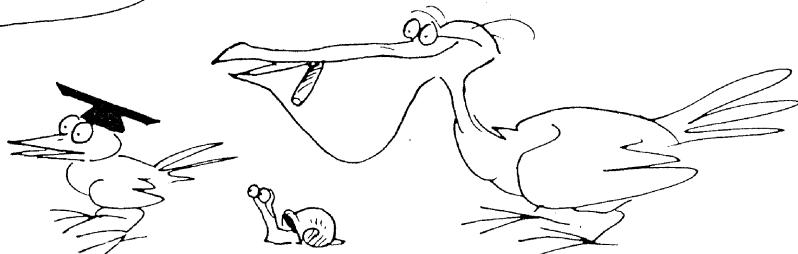
ANOTHER GADGET,  
ARCHIE?

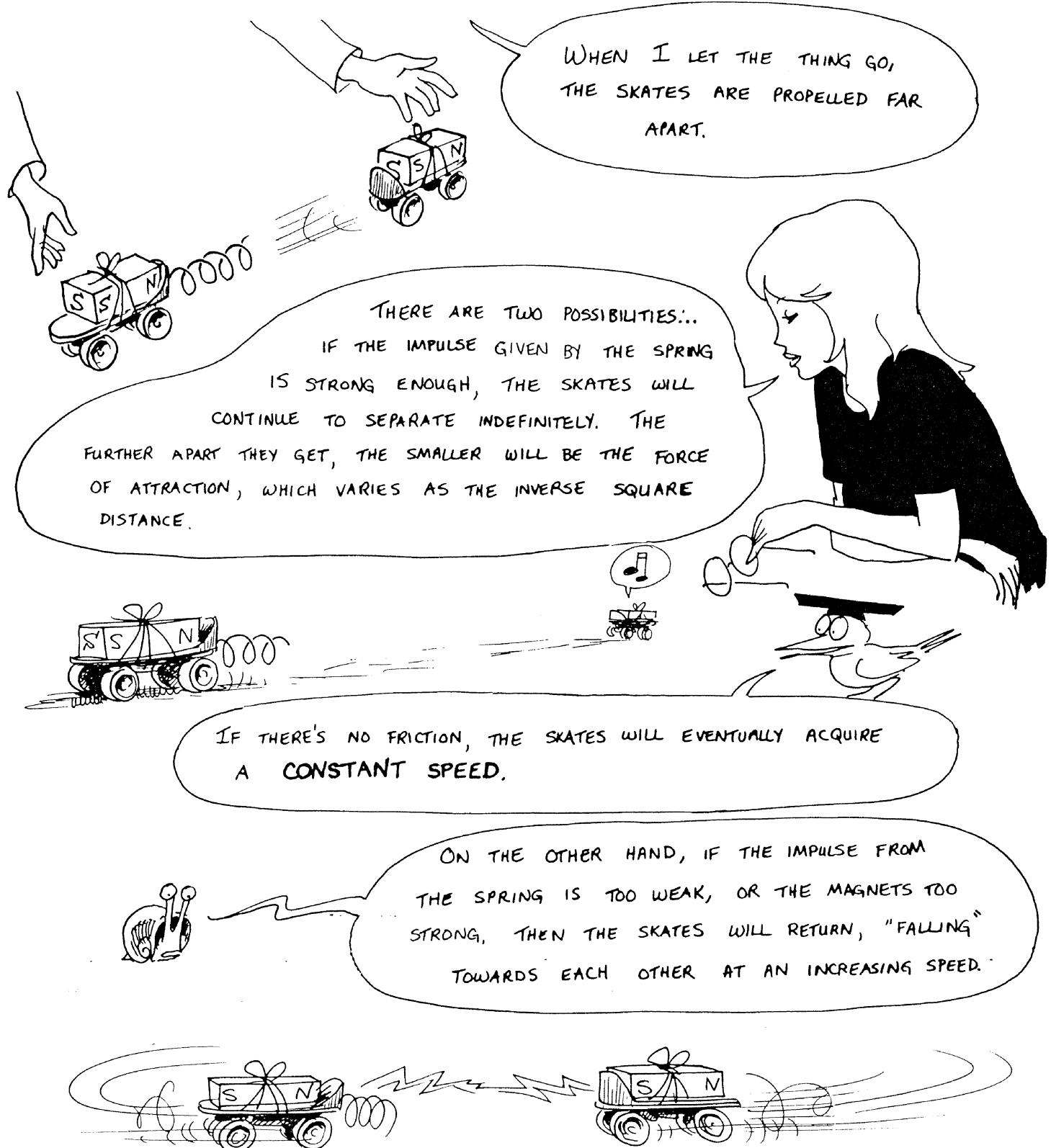


ARCHIE HAS ATTACHED TWO MAGNETS TO  
ROLLER SKATES, MAKING THEM ATTRACTED TO  
EACH OTHER. BUT A COMPRESSED STRING TRIES  
TO PUSH THE SKATES APART AGAIN.



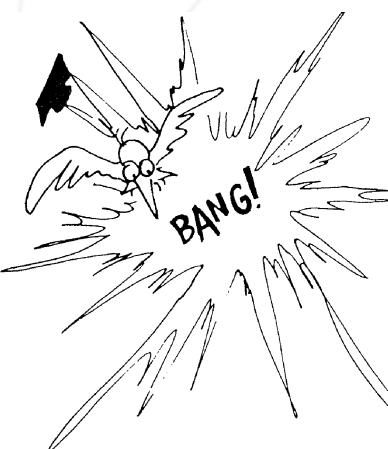
YOU SEE, THE MAGNETS  
REPRESENT THE FORCE OF  
GRAVITATION, PULLING THINGS  
TOGETHER. THE SPRING IS THE  
FORCES OF PRESSURE.





THIS SUGGESTS TWO POSSIBLE TYPES OF UNIVERSE:

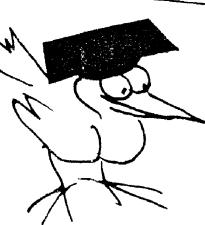
FIRST SCENARIO: THE EXPANSION CONTINUES INDEFINITELY. WHEN THE LAST STARS BECOME EXTINCT, THERE WILL BE ETERNAL NIGHT, ABSOLUTE COLD, THERMAL DEATH.



SECOND SCENARIO: THE FORCES OF GRAVITY FINALLY WIN OUT. AFTER REACHING ITS MAXIMAL EXTENSION, THE UNIVERSE "FALLS BACK ON ITSELF. ALL STRUCTURES—GALAXIES, STARS—ARE SQUASHED FLAT. THE VERY ATOMS ARE BROKEN. AND THE **BIG BANG** UNBANGS ITSELF AGAIN... READY FOR A NEW REBOUND OF THE UNIVERSE, AND A NEW PHASE OF EXPANSION.

THE SWISS MATHEMATICIAN  
**FRIEDMANN** INVENTED THE FIRST  
NONSTATIC MODELS OF THE  
UNIVERSE IN 1930.

IF I HAD KNOWN DER  
UNIVERSE COULD BE NONSTATIONARY,  
I WOULD HA' DISCOFERED DEM  
BEFORE FRIEDMANN (\*).



MR. ALBERT, WHO—AT THE COST OF ABSOLUTELY IMPOSSIBLE MATHEMATICAL ACROBATICS—HAD BOTCHED UP HIS STATIONARY MODEL IN 1917, WAS SOMEWHAT PEEVED. FRIEDMANN HAD STOLEN HIS VICTORY. HE SULKED ABOUT GENERAL RELATIVITY FOR MANY LONG YEARS.



ACCORDING TO THE FRIEDMANN MODELS, THE UNIVERSE UNDERGOES INDEFINITE EXPANSION IF THE (PRESENT) DENSITY OF MATTER IS LESS THAN  $5 \times 10^{-30}$  GRAMS PER CUBIC CENTIMETER. THE UNIVERSE WOULD THEN HAVE AN INFINITE VOLUME, AN INFINITE SPATIAL EXTENT.

(\*) AUTHENTIC REMARK OF EINSTEIN.

# THE GEOMETRY OF THE UNIVERSE

THE UNIVERSE IS, TO US, A FOUR-DIMENSIONAL HYPERSURFACE, IN WHICH SPACE AND TIME ARE INTERMINGLED. THE IDEAS DISCUSSED ABOVE CORRESPOND TO DIFFERENT PRESENTATIONS OF THIS UNIVERSAL ENTITY THAT IS SPACE-TIME.

WHAT SHAPE IS THE UNIVERSE?

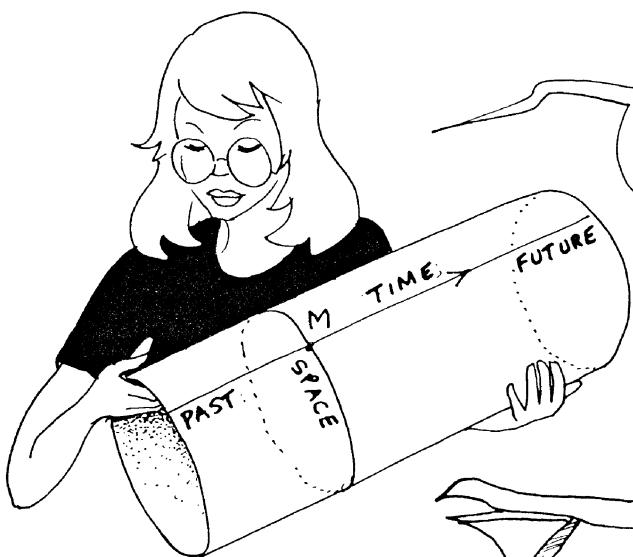


RECALL THAT THE NUMBER OF DIMENSIONS OF A SPACE IS THE NUMBER OF QUANTITIES NEEDED TO DEFINE THE POSITION OF A POINT WITHIN IT.



IN DRAWINGS, WE CAN ONLY REPRESENT SPACES OF TWO DIMENSIONS, SURFACES. SO WE CAN STUDY A SPACE-TIME WITH TWO DIMENSIONS, ONE OF SPACE AND ONE OF TIME.



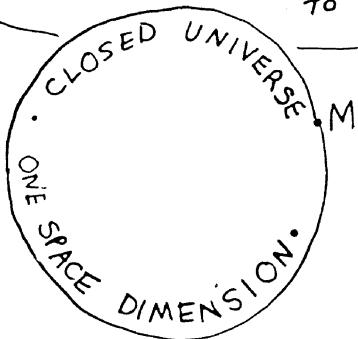


IN THIS WAY THE FIRST MODEL OF A CLOSED UNIVERSE, THE STATIC MODEL OF EINSTEIN, IS REPRESENTED AS A CYLINDER.

LESSEE NAR... IF I UNNERSTAN', WE'RE INSIDE THE CYLINDER?

No, ON IT!

AT A GIVEN INSTANT, AN OBJECT IS REPRESENTED BY A POINT M ON THE SURFACE; AND THE UNIVERSE AT THAT INSTANT REDUCES TO A CIRCLE.

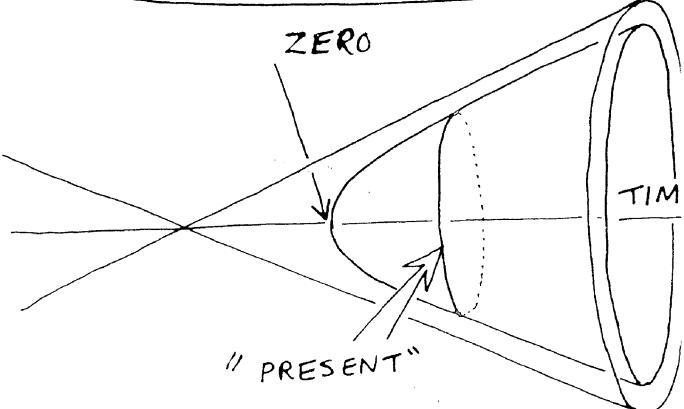


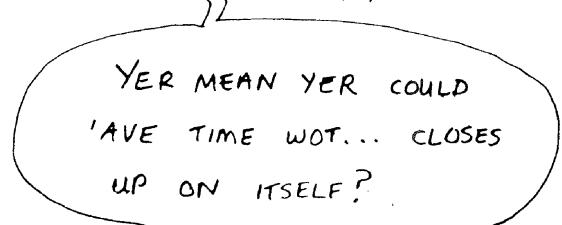
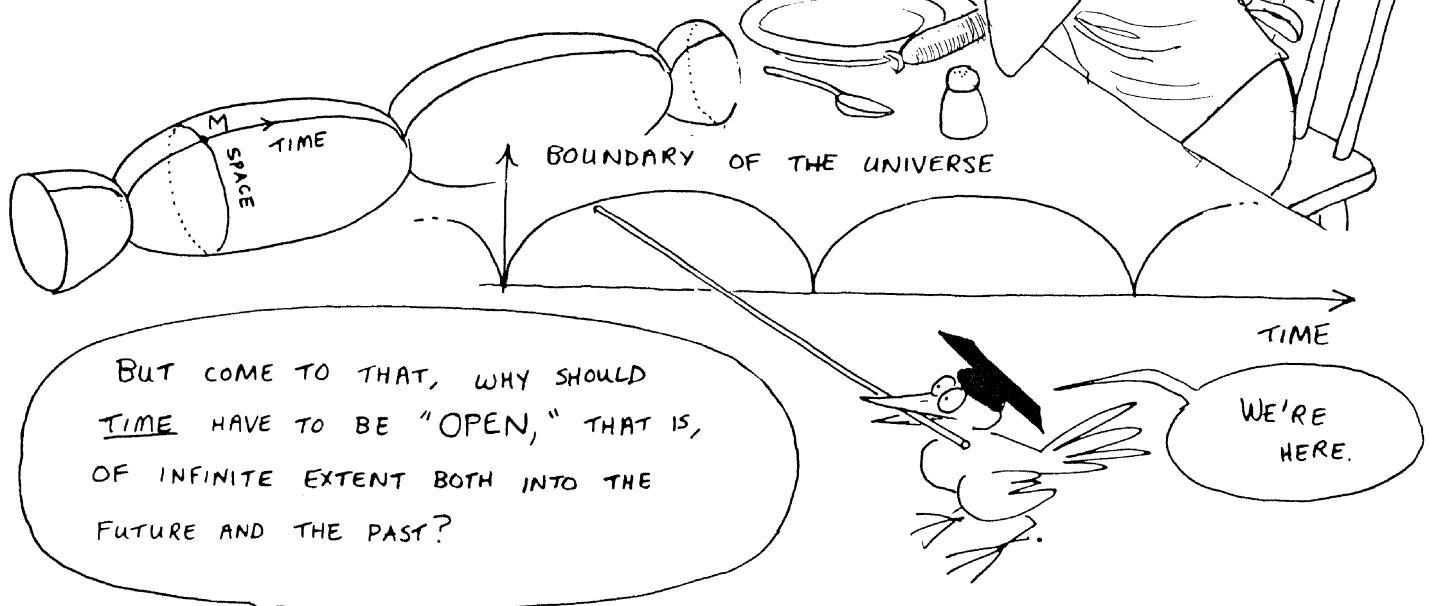
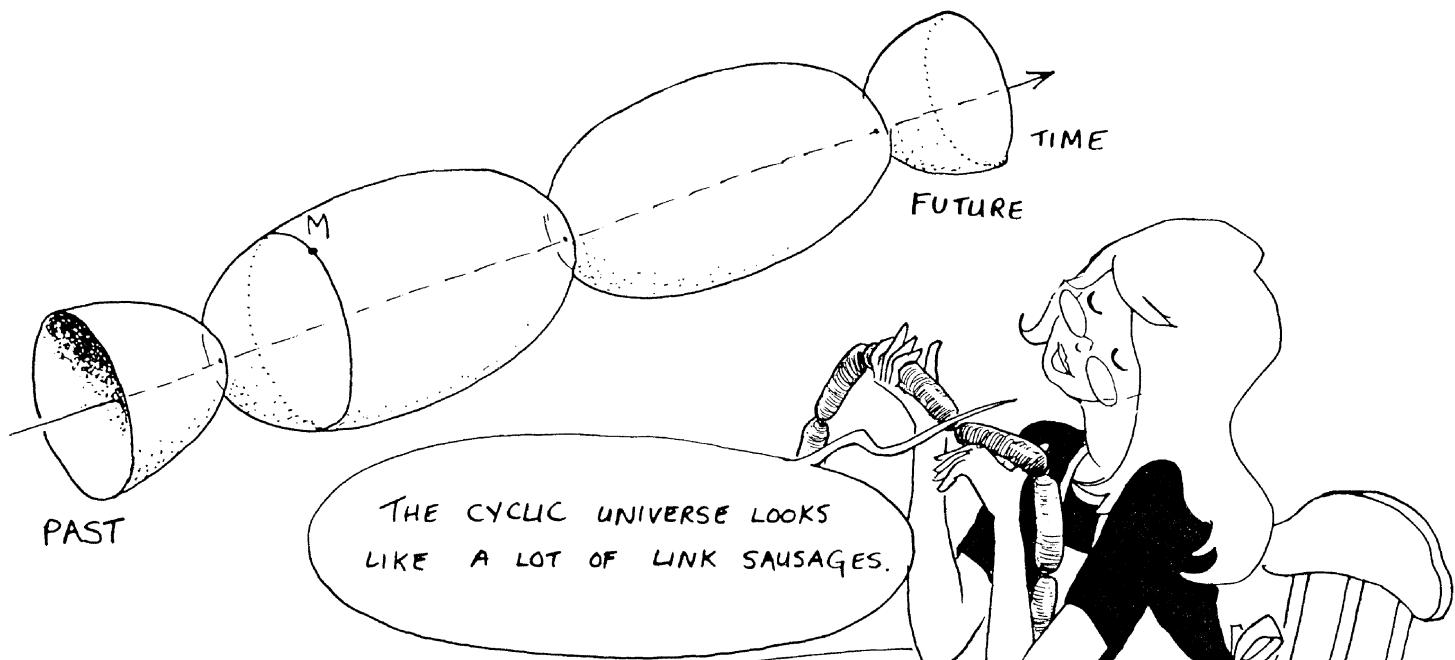
IF THE OBJECT IS MOTIONLESS IT DESCRIBES A GENERATOR OF THE CYLINDER (A LINE ALONG ITS LENGTH) AS TIME FLOWS.



IT IS EASY TO REPRESENT THE EXPANSION OF THIS CLOSED UNIVERSE AS A FUNCTION OF TIME, GIVING A NONSTATIONARY MODEL OF THE UNIVERSE.

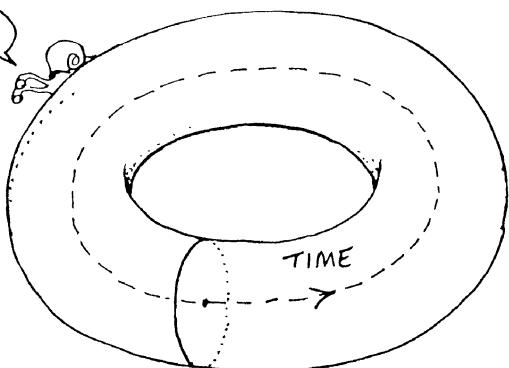
FOR EXAMPLE, HERE'S A TWO-DIMENSIONAL PICTURE OF AN INDEFINITELY EXPANDING SPACE-TIME.





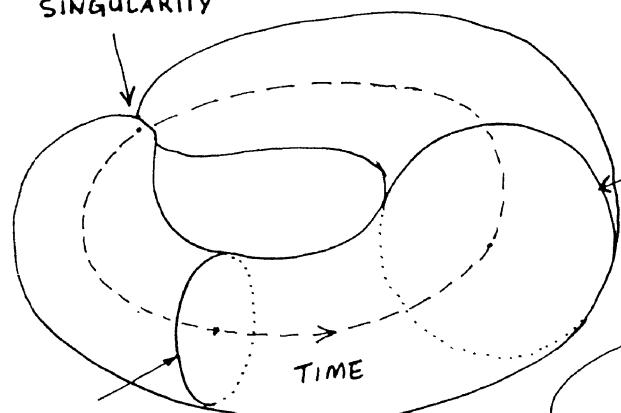
NO PROBLEM... IF  
YOU CLOSE THE EINSTEIN MODEL  
UP ON ITSELF, YOU GET... A  
TORUS.

HERE WE  
ARE AGAIN!



IN THIS TOTALLY CLOSED SPACE-TIME, THE SAME EVENTS  
REPEAT THEMSELVES OVER AND OVER AGAIN, AFTER A TIME  $T$   
WHICH IS THE PERIOD OF THIS WEIRD UNIVERSE.

BIG BANG  
SINGULARITY



YOU CAN ALSO MAKE A CYCLIC  
UNIVERSE COLLAPSE ON ITSELF.

STATE OF MAXIMAL  
EXPANSION



IT'S A STRING OF SAUSAGES, CLOSED UP ON  
ITSELF, WITH JUST ONE SAUSAGE!

OH, LOOK AT LENNY!!!



HE'S CRACKED UP  
COMPLETELY. YOU COULD  
SEE IT COMING...

# EPilogue

SO THAT'S WHAT WE KNOW  
ABOUT THE BEGINNING OF  
THE UNIVERSE.



AT LEAST, THAT'S WHAT  
WE CURRENTLY THINK WE  
KNOW. IT'S CHANGED  
INNUMERABLE TIMES IN  
THE LAST 5000 YEARS!

"THE EFFORT TO UNDERSTAND THE  
UNIVERSE IS ONE OF THE VERY FEW  
THINGS THAT LIFTS HUMAN LIFE A  
LITTLE ABOVE THE LEVEL OF FARCE, AND  
GIVES IT SOME OF THE GRACE OF  
TRAGEDY."

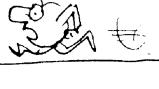
STEVEN WEINBERG  
THE FIRST THREE MINUTES



THE  
**END**

# THE COSMODRAMA



TIME	TEMPERATURE	DENSITY	PHENOMENA
BEFORE...	$T \geq 10^{12}$ DEG		?
$\frac{1}{1000}$ SEC	300 BILLION DEG.		UNDIFFERENTIATED SOUP OF PHOTONS, NEUTRINOS, ANTINEUTRINOS (THE PHOTON IS ITS OWN ANTI PARTICLE), PROTONS, ANTI PROTONS, NEUTRONS, ANTINEUTRONS, ELECTRONS, AND ANTI ELECTRONS (POSITRONS).
$\frac{1}{100}$ SEC	100 BILLION DEG.	4 BILLION GM/CM <sup>3</sup>	SLAUGHTER OF THE HADRONS (PROTONS, ANTI PROTONS, NEUTRONS, ANTINEUTRONS). ONE IN A BILLION REMAINS. THE REST HAVE BEEN ANNIHILATED BY THEIR ANTI PARTICLES, PRODUCING PHOTONS.
$\frac{1}{10}$ SEC	30 BILLION DEG.		NOT A LOT. TOO HOT FOR ATOMIC NUCLEI TO FORM.
1 SEC	10 BILLION DEG.	380,000 GM/CM <sup>3</sup>	NEUTRINOS "LIVE THEIR OWN LIVES" AND CEASE TO INTERACT WITH MATTER.
13 SEC	3 BILLION DEG.		BATTLE BETWEEN THE ELECTRONS AND THE ANTI ELECTRONS. AGAIN ONLY ONE IN A BILLION SURVIVES.
3 MIN	1 BILLION DEG.		NUCLEOSYNTHESIS: FORMATION OF HELIUM NUCLEI. DISAPPEARANCE OF FREE NEUTRONS (LIFETIME: 10 <sup>9</sup> SEC).
35 MIN	300 MILLION DEG.	1 GM/CM <sup>3</sup>	NUCLEOSYNTHESIS FULLY ACHIEVED: 25% HELIUM, 75% HYDROGEN.
700,000 YR	3000 DEG.		AFTER THE ANNIHILATION OF ALMOST ALL MATTER AND ANTIMATTER, THE UNIVERSE ENTERS THE "RADIATIVE ERA" WHERE MATTER/ENERGY OCCURS CHIEFLY AS RADIATION. WHEN THE TEMPERATURE DROPS TO 3000°, NEUTRAL ATOMS FORM AND PHOTONS CEASE TO INTERACT WITH MATTER: THE "TRANSPARENT" UNIVERSE.
100 MILLION YR	$T_R = -173^\circ\text{C}$ $T_m = -267^\circ\text{C}$		NO LONGER REHEATED BY PHOTONS, NEUTRAL ATOMS OF HELIUM AND HYDROGEN UNDERGO A RAPID DROP IN TEMPERATURE. FORMATION OF GALAXIES AND THE FIRST STARS.
5 BILLION YR			FORMATION OF THE EARTH.
10 BILLION YR	$T_R = -270^\circ\text{C}$	$10^{-30}$ GM/CM <sup>3</sup>	EMERGENCE OF LIFE.
TODAY			INVENTION OF THE ATOMIC BOMB...



# Chapter II

## You are my contrast

This is a simple exercice. We will apply contrast to a picture. Because we are nice guy, we will use the .pgm format for picture.

A contrast is very simple. As you know a picture is composed of pixel. To contrast the picture, you must apply on each pixel a mathematic formula :

$$\text{resultPixel} = \text{pixelColor} * (\text{contrastLevel}) * \text{maxGreyLevel}$$

|**MANDATORY**| The `ft_contrast` command take the `-c` contrast level, a % between 0 and 100, the `-f` which is the input in PGM format and a `-o` output file name

```
> ft_contrast -f image.pgm -c 12 -o pouet.pgm
```



All command when run with a `-c 100` mean that the ouput file is exactly the same as the input file but pixel values are calculated.

# Chapter III

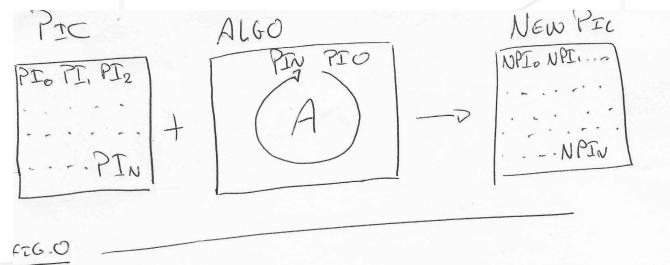
## Fork you fork me

### III.1 Thread pool

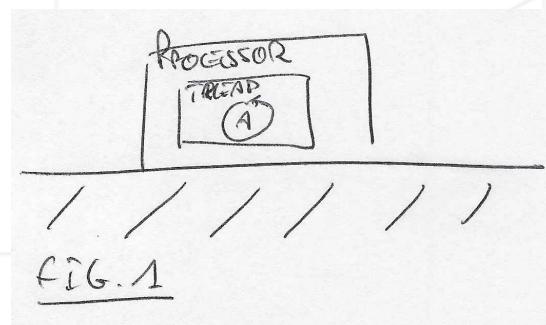
After you have tested it, let introduce a problematic: a large picture. Obviously on your computer, there is more than a processor. First, try the `htop` command and read the associate man. We will provide you a large scale picute: `orion.pgm`

Run your command against that picture, and, **on the same time**, run the `htop` command (you can launch it wiht `time` command). You should see that there is only one processor in use over several one. It's time to introduce: **parallel computing**.

When you coded that program, you created an Algo like "*I go through all pixel, and I change it's value*", like this drawing:



To be executed, this algo is transformed as a processus, a thread + the algo, inside a processor:



But, there is a problem with that: If you have a multiprocessor computer, which is now always the case, your algo work only on a processor instead of using the whole capacity of the computer:

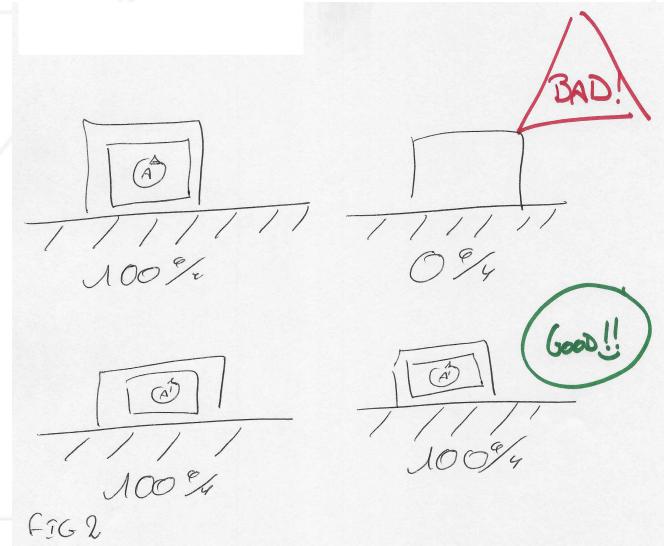


FIG 2

HA! my God! EVIL! BAD! NOT GOOD! UGLY!

To handle that, you have to change your algo from  $A$  to  $A'$ . Note that on execution, you will launch a several  $A'$  processus:  $A'_0, A'_1, A'_2, \dots, A'_n$

That means, that you have to create a thread each time you will run a  $A'_n$  job:  $T_1, T_2, T_3, \dots, T_n$ . Imagine ! You could create thousand of processus. And this is real time consuming. Because in the system, creating a thread an heavy duty. So you want to go faster... but you go slower at the end: "*the path of hell and often paved with good intention*"

Real Ladies and real gentlemen, elegant people are not... pork! the famous expression is: *create thread as a pork!*:

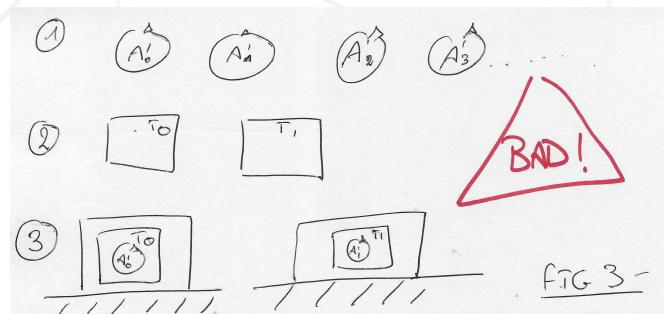


FIG 3 -

So please, create your own thread library, which will use thread in a thread pool. You pre-launch a certain amount of threads... and when you need to execute an  $A'$  algo... you ask him to do it, and after this thread doesn't die but wait for the next task to do.



In C library, there are `pthread` that create (more or less as `fork`) new thread that can execute code.

So write back your `ft_contrast` command:

1. |MANDATORY| `ft_contrast_th`: change your algo, and try to execute parallel threads to do the contrast,
2. |MANDATORY| `ft_contrast_tp`: change your algo, and try to execute parallel threads to do the contrast, but by using your `libft_thpool.a`.

So the good idea, is to launch, when you call your thread pool library, a certain amount of threads (depends usually how many proc / thread unit you have on your system) and each time you have to execute a task you wake up your thread so it will handle it.

You can use the file `ft_thpool.h` provided with the subject (this file is incomplete, so you are more than welcome to add anything you want).

The Library should be used like that :

### III.2 Man page:

- `fork(2)`,
- `pthread_create(3)`,
- `pthread_cleanup_push(3)`,
- `pthread_detach(3)`,
- `pthread_exit(3)`,
- `pthread_join(3)`.

Write the C code for a new command `ft_contrast_tp`. Try back your command, and verify that the CPU's are at full speed to create your contrast filter and goes faster than the first `ft_contrast`.

### III.3 Authorized langage, functions and syscall

Authorized langage is C. Compilation option will `-Wall ...` as usual

If you are using a function out of that list, you **must** be able to justify why, and remember, when you need speed, sometimes it's better to got a dedicated function than a standard C library one, that work for all case.

- `malloc,`
- `free,`
- `open,`
- `close,`
- `write,`
- `read,`
- `lseek,`
- `read,`
- `fork,`
- `printf` function family (see `man 3 printf`)
- `pthread_create,`
- `pthread_cleanup_push,`
- `pthread_detach,`
- `pthread_exit,`
- `pthread_join,`
- `pthread_mutex_init,`
- `pthread_cond_init,`
- `pthread_cond_wait,`
- `pthread_cond_signal.`

### III.4 Example

```

/*
 */
#include <ft_tpool.h>

/*
 */
typedef struct      s_my_data_struct {
    int             ret;
    char            info_to_pass;
} t_my_data_struct;

/*
 */
void                my_job_to_exec(void *param)
{
    t_my_data_struct *my;

    my=(t_my_data_struct *)param;

    if ()// I do something with my->ret work
        my->ret=SUCCESS;
    else
        my->ret=FAILURE;
}

int                 main(int ac, char **av)
{
    t_tp_thread     *my_tp;
    t_my_data_struct *data;

    my_tp=tp_create(8);
    tp_add_task(my_tp, my_job_to_exec, (void *)data); //we can add several jobs
    tp_wait_for_queue(my_tp);
    if (data->ret == SUCCESS)
        //that was a success
    else
        //that was a failure
}

```

### III.5 Mandatory

- You must have a Makefile that generate the lib and the executable,
- You must be able to re-use the library
- The library must at least have the following function (see proto in `ft_thpool.h` :
  - `tp_create`, create a the thread pool,
  - `tp_exec_queue_add`, add a job in queue,
  - `tp_wait_for_queue`, blocking function which is deblocked when all current in job job queue are executed.

- The pthread must work... each should be able to launch a job.

## III.6 Optionnal

In all `ft_contrast`, you must must write the testing main to your corrector. nnifnite loop to wait. The program must be in asynchrounous mode.

### III.6.1 blocking and no loop

There is only one way to wait for another job to be executed. The blocking asynchronous method: imagine A and B thread. A *wait* for B and when B has finish, it send a *signal* to job A that he can continue.

If you use a loop in A, like a *while* to wait for B, A will use 100% of CPU waiting for B: **The ugliest think you can ever program**. If you do that, in your job a day or an another, you lose immedialty your alumini status and your name will be writen on the wall of shame for 10 generation. You grand-grand-grand-grand...-grand childrens will be under the shame too.

Because you are beginers, as babies, I accept you to poo in your panties but.. .and maybe you use the while method. This here is the option that give you the opportunity to become an adult: rewrite your thread library using `pthread_cond_wait` and `pthread_cond_signal`.

### III.6.2 tp\_get\_nbr\_proc

This function return very gently the amount of processor units (or threads) on the current computer. Usually your thread pool create that amount of thread ready to execute.

### III.6.3 TP\_ON\_START | TP\_ON\_EXEC

Actually, when you start the library, you start all thread, which are resource consumers, but until you got a job to execute, they do nothing. You are using resource for nothing. Instead of the *infinite loop waiting*, there is no shame. Depends, sometimes you preferre to use resources first, when you launh your program, and go faster afterwards.

So in industry standard, when you use your `tp_create` function, you “*do nothing*” and you create your first thread when you really need it.

Rewrite the function `tp_create`, to add an option `TP_ON_START` or `TP_ON_EXEC`, which permit to choose if you want to create your thread right after th create or at execution.

### III.6.4 tp\_wait\_for\_queue with option

For `ft_contrast` you can run parallel computing, and wait for all job to stop before merging the final file. But you can imagine that some parallel compouting algo tree can be different. Like you have 6 jobs to execute, A, B, C, E, F, G, and you can execute A, B, F, G but C must wait for A and B to be executed before started and G must wait for C, F and G...

Add, as parameters to the `tp_wait_for_queue` which job(s) your waiting before you continue.

## **Chapter IV**

### **Thanks Brittany**

I would like you to send a short twit to thank's Brittany: Without her, I would never had enough time to create for you this kind of subject... thanks Brit ! :-D

<https://twitter.com/brittanybir42> and you must remember that you should not click on anylink like that !