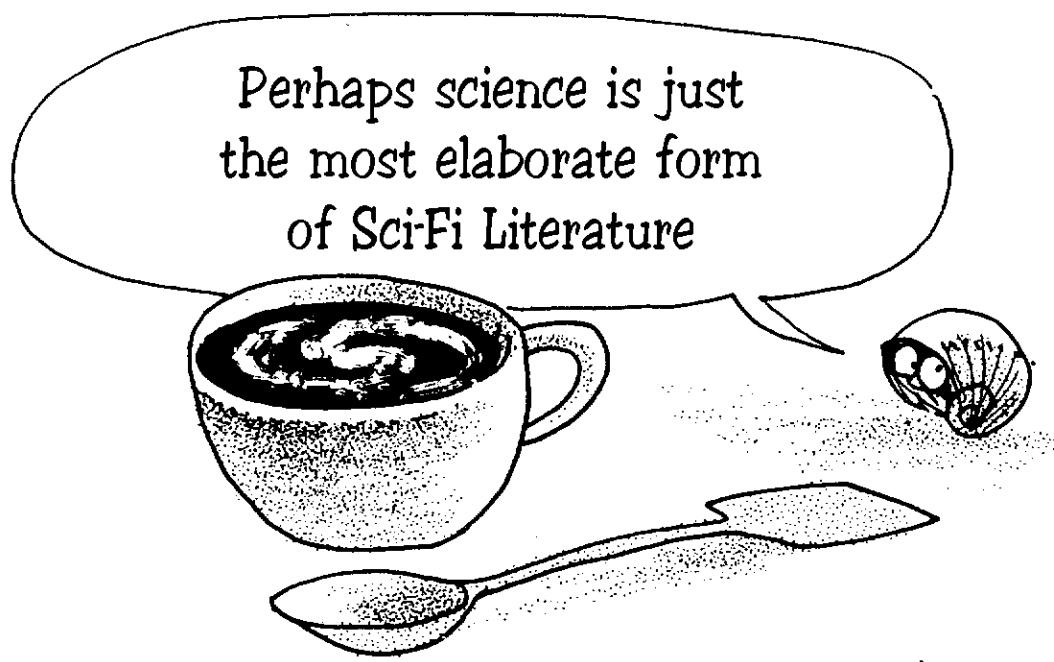
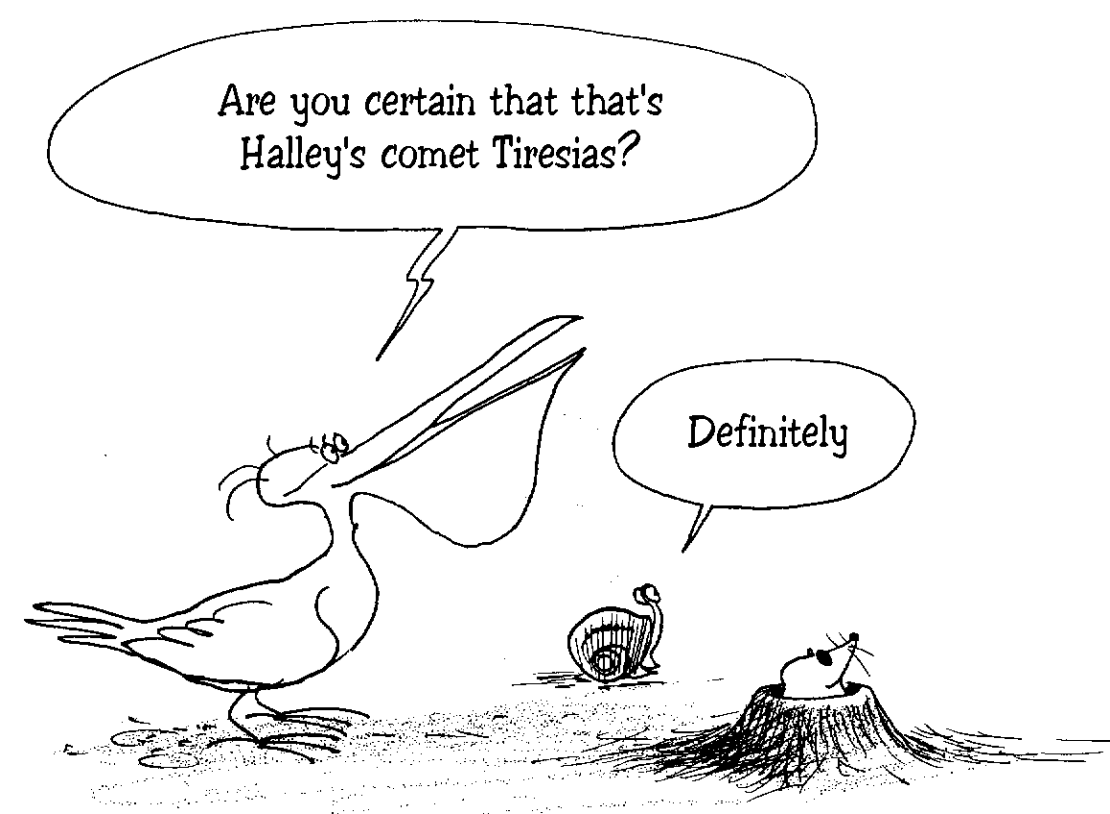
A THOUSAND BILLION SUNS

Jean~Pierre Petit

translated by John Murphy




Are you certain that that's Halley's comet Tiresias?
Definitely


It may be that the Universe
is just a vast operation of scientific vulgarisation:
God trying to help us understand something...

WARNiNG

ASTROPHYSICS is a **RECENT** science. Until a few years ago man received his information through THE DIRTY WINDOW OF THE ATMOSPHERE..

The **GALACTIC DYNAMIC** is still waiting for its KEPLER or its LAPLACE. We still do not know how to construct a satisfactory mathematical solution to the equation system describing the object we call a **GALAXY**.

In this area, theoreticians have been treading water for over a century!

Paradoxically, the childhood of the Universe (**BIG BANG**) is better understood than its early youth, which is still... nebulous.

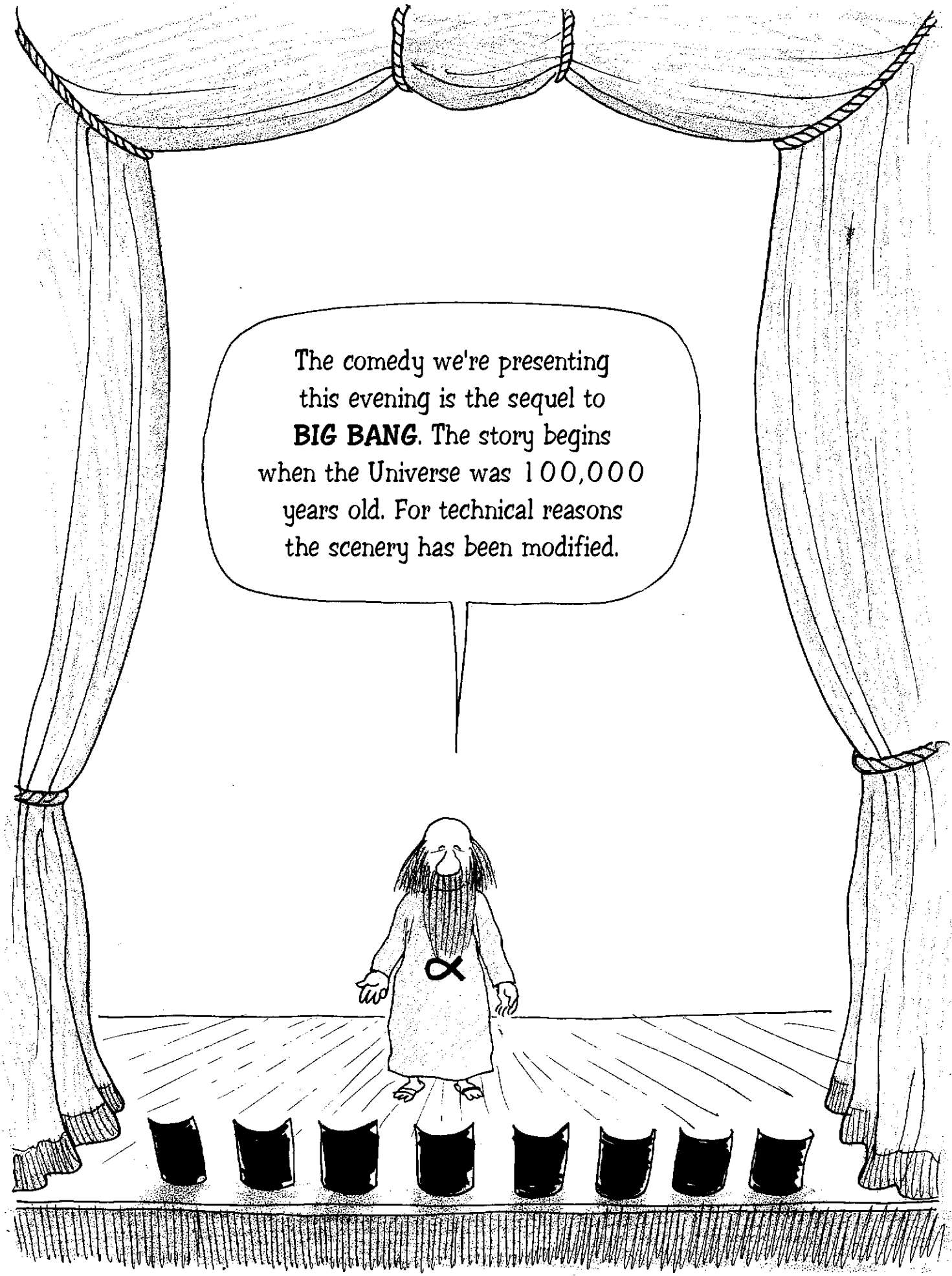
We're a long way from a consensus and perfectly contradictory theories exist concerning the birth and evolution of galaxies.

Information collected thanks to the space telescope, and treated by the most powerful computers, might allow us to arrive at something coherent in the future... more or less distant.

So the author has made personal choices. One day the following story will appear as a perspicacious synthesis.

Or as a load of nonsense.

Christmas 1985

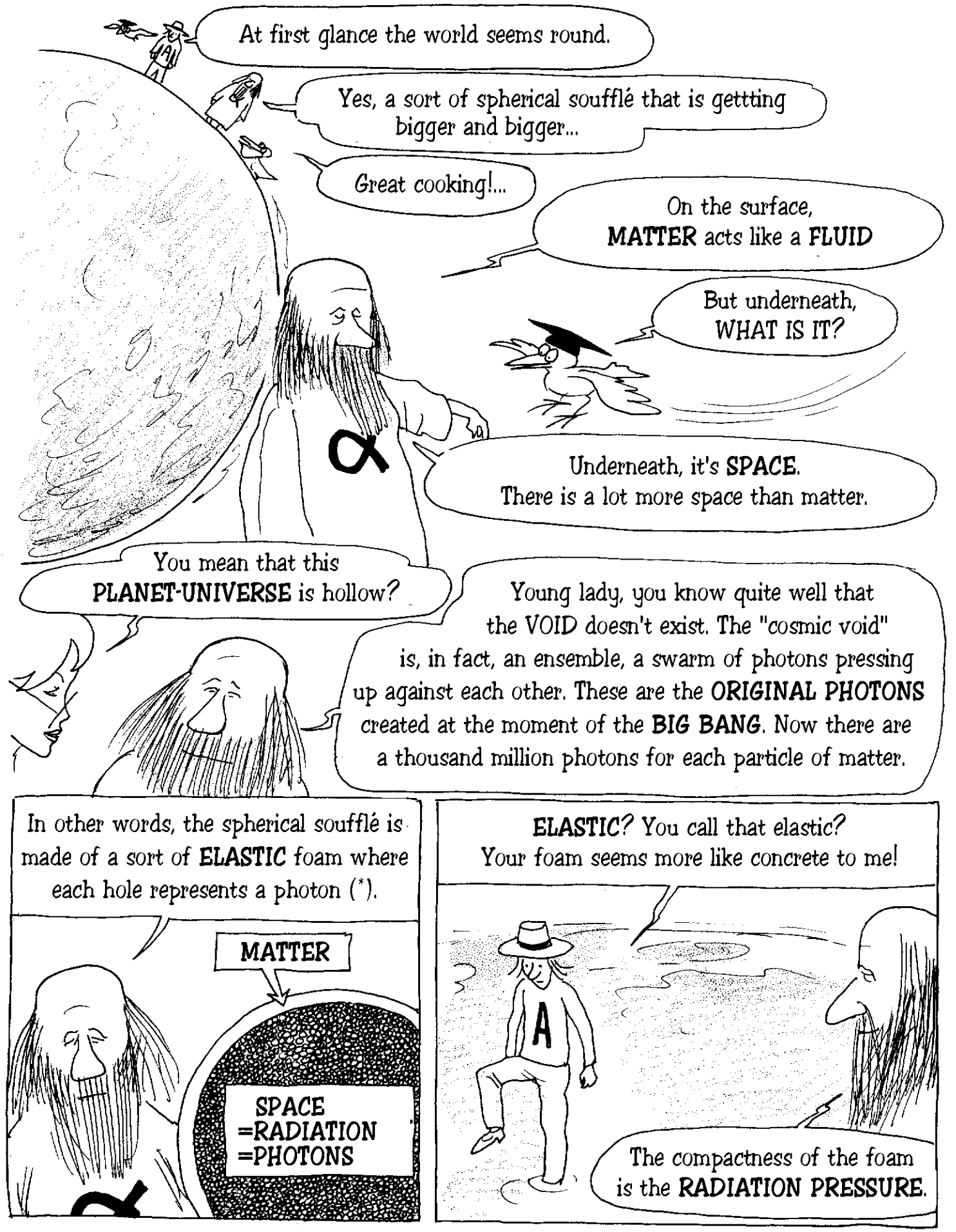

The comedy we're presenting this evening is the sequel to **BIG BANG**. The story begins when the Universe was 100,000 years old. For technical reasons the scenery has been modified.

THE PLANET UNIVERSE


This soup, young fellow, is **MATTER**
Ah, you're back again then!
In the beginnning the spirit of God floated above the waters...
quick...
Stop, iconoclast!
Oh look, it's a miracle.
Not at all, he's just got a foothold...
Ah yes, right enough!


Hey, what's that?
You know perfectly well, it's the CHRONOTRON (*)
What's the WEATHER like today?
Yes, and the temperature of the Universe is 8000°
100,000 years have passed since the BIG BANG
The FLUID-MATTER is strange. It seems like it sticks to the BOTTOM
It's PHOTONS, the REMAINS of the PRIMITIVE, COSMOLOGICAL RADIATION.
the world stagnates.
And what is this BOTTOM exactly?
I don't get it...

(*) See **BIG BANG.**



(*) The diameter of the holes corresponds to the photon's **WAVELENGTH**.

PRESSURE is something linked to **FLUIDS** isn't it?

Yes, but a group of photons is also a gas, which has pressure.

But the **VOID** is an ensemble of photons so the **VOID** is a gas! There's a thing!

In reality, **MATTER** and the "**VOID**", that is to say the original photon gas, form a **HOMOGENOUS MIXTURE**. But in this model, if I understand it correctly, you separated the two environments. The **EXPANSION** of this **PLANET-UNIVERSE**, which functions like a soufflé, makes the **RADIATION PRESSURE** decrease. As well as that, the thickness of the "fluid-matter" simulates the **VOLUMINAL-MASS**, which also decreases.

So how do these two environments interact?

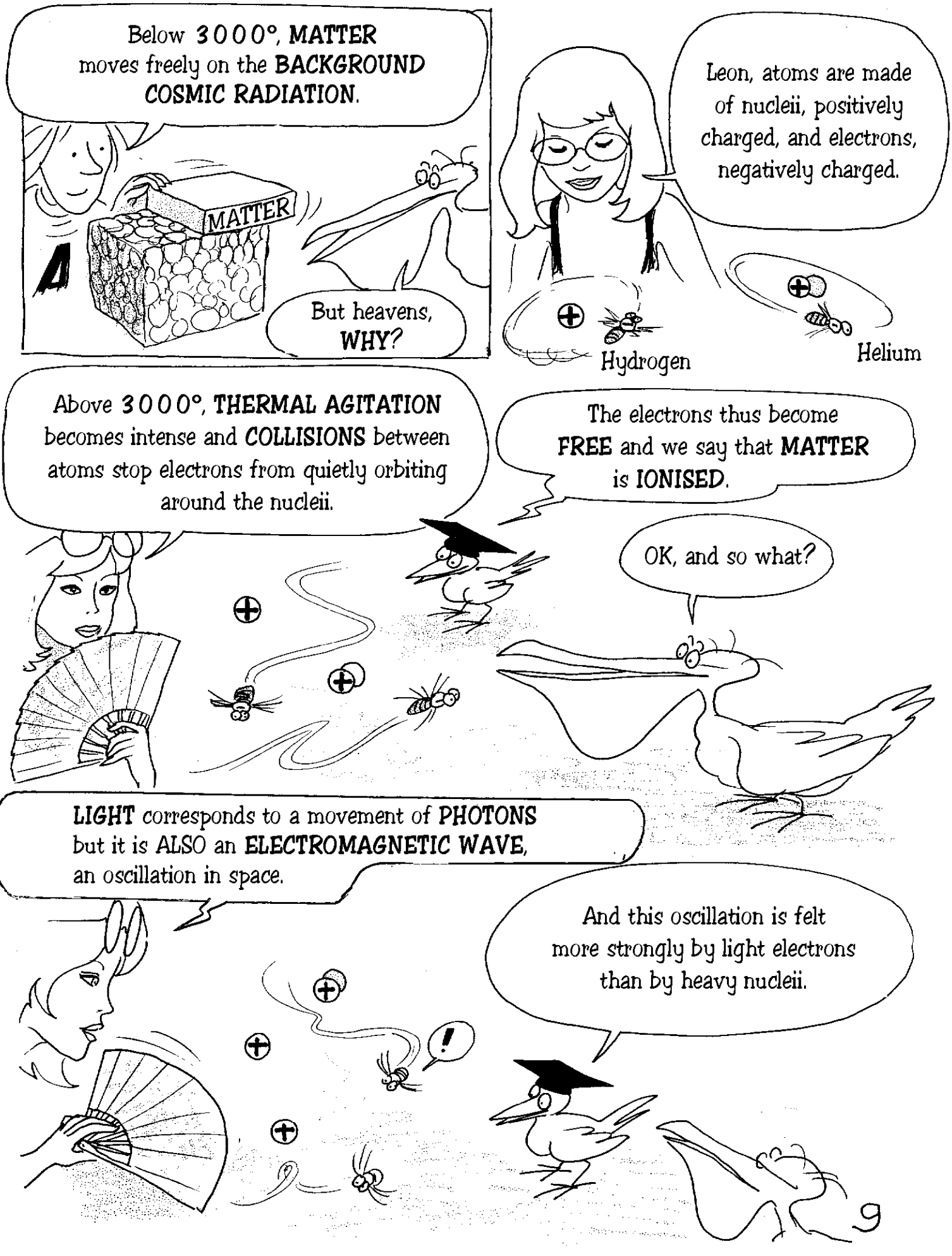
INTERACTION MATTER RADIATION

When the Universe had a temperature above **3000°**, matter was tightly **COUPLED** to the background radiation, the original photons.

MATTER

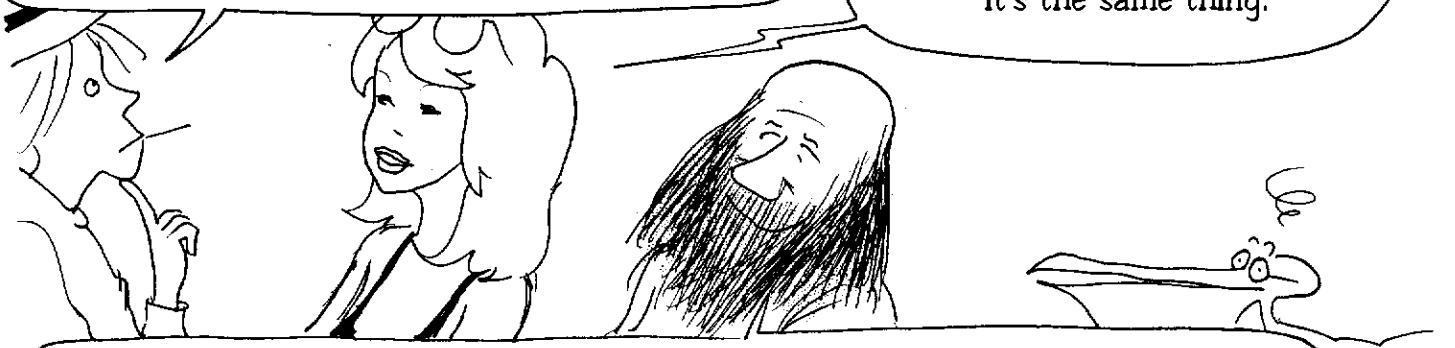
In the end it's as if matter was "stuck" onto the void.

WHAT?


Below 3000°, MATTER moves freely on the BACKGROUND COSMIC RADIATION.
MATTER
But heavens, WHY?
Leon, atoms are made of nucleii, positively charged, and electrons, negatively charged.
Hydrogen
Helium
Above 3000°, THERMAL AGITATION becomes intense and COLLISIONS between atoms stop electrons from quietly orbiting around the nucleii.
The electrons thus become FREE and we say that MATTER is IONISED.
OK, and so what?
LIGHT corresponds to a movement of PHOTONS but it is ALSO an ELECTROMAGNETIC WAVE, an oscillation in space.
And this oscillation is felt more strongly by light electrons than by heavy nucleii.
!

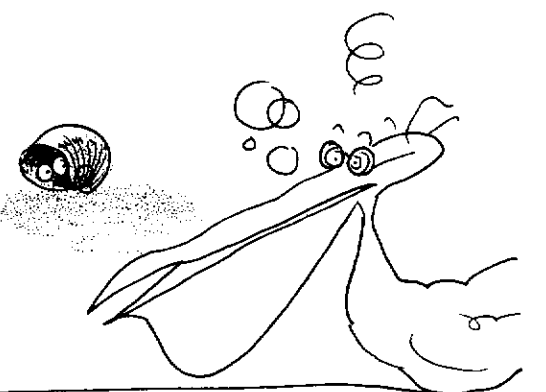
An oscillation that propagates in a gas is a pressure wave (*), a sonic wave. So light would be a... radiation wave, propagating at **300,000 km/s**.

In a gas the agitation speed of its elements is more or less equal to the speed of sound. In the "photon gas", it's the same thing.



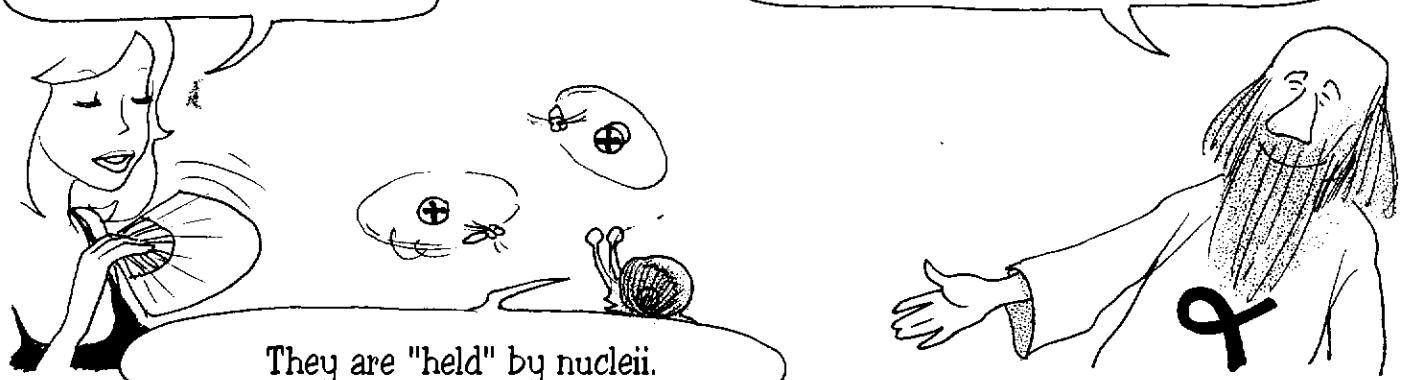
I must admit that this photon gas is one of my best inventions. In this case waves and particles **ARE ONE AND THE SAME**.

So, let's say:
1) An **IONISED GAS** interacts by rubbing against a "photon gas".
2) The "**VOID**" is, in fact, a "photon gas".
3) So ionised matter "sticks" to the void.



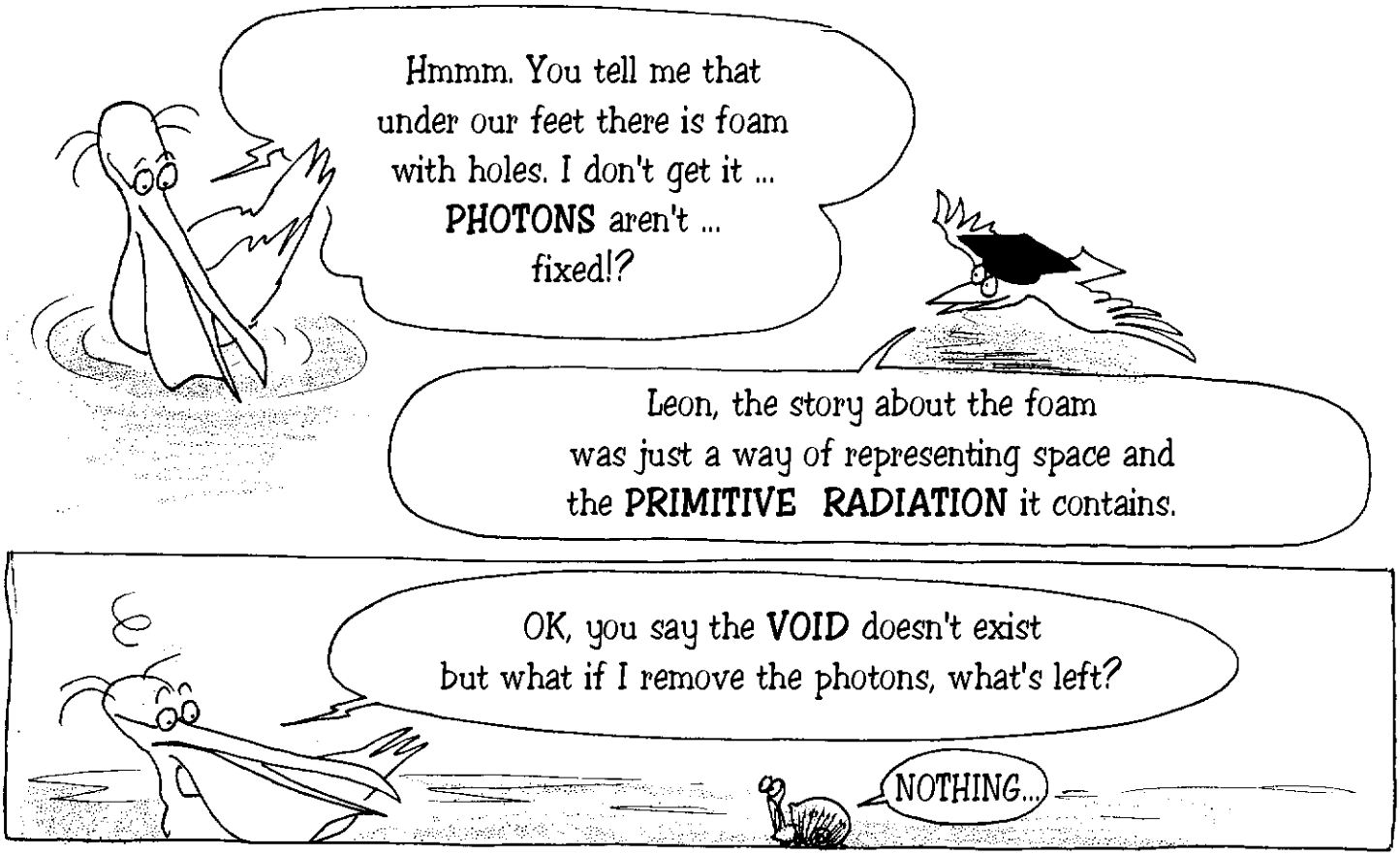
When the temperarature of matter in the Universe drops below **3000°**, electrons link with atoms and thus become a lot less sensitive to electromagnetic oscillations

The bond between **MATTER** and **BACKGROUND RADIATION** lessens and atoms can slide freely in the **VOID**.

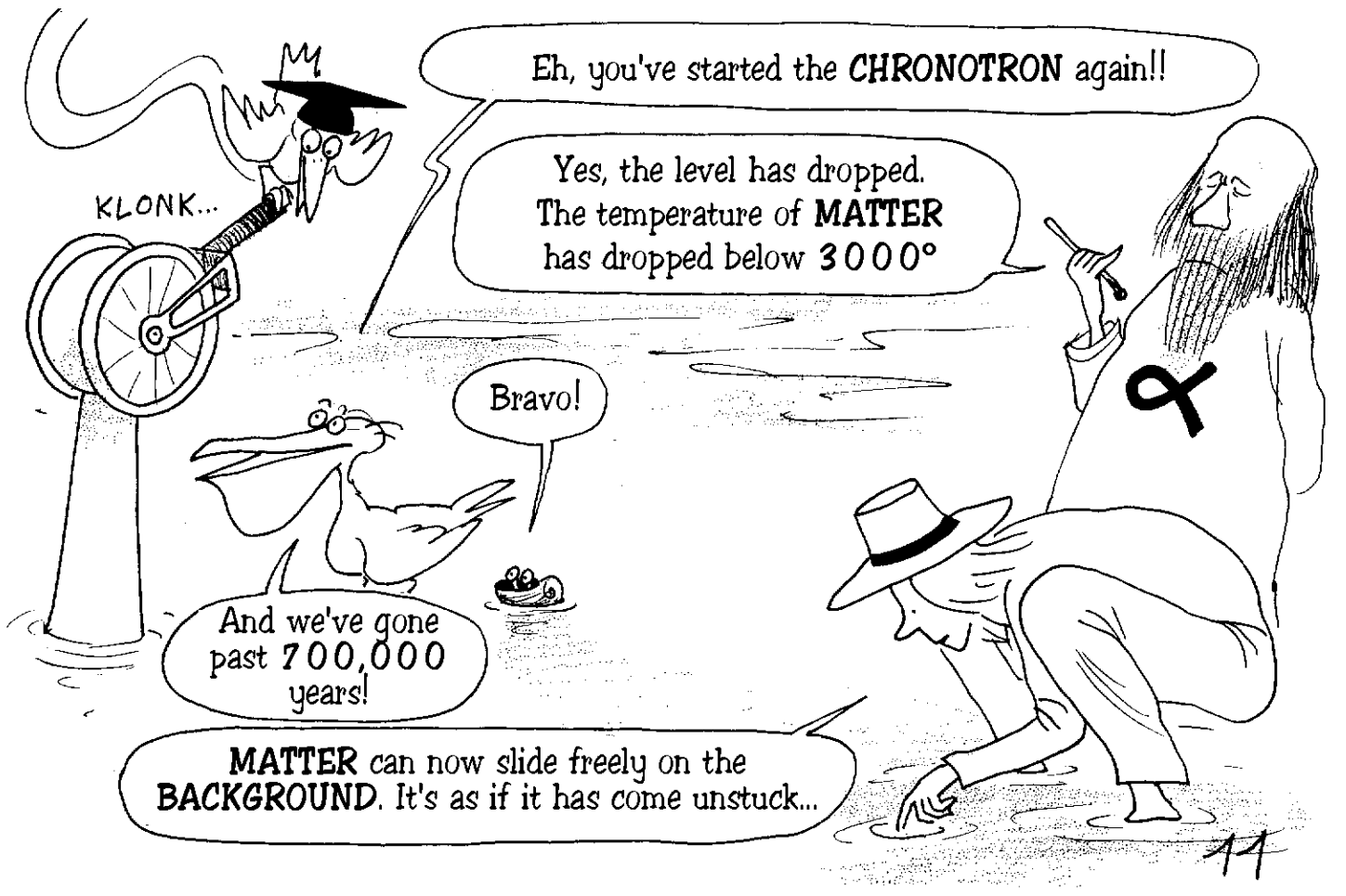


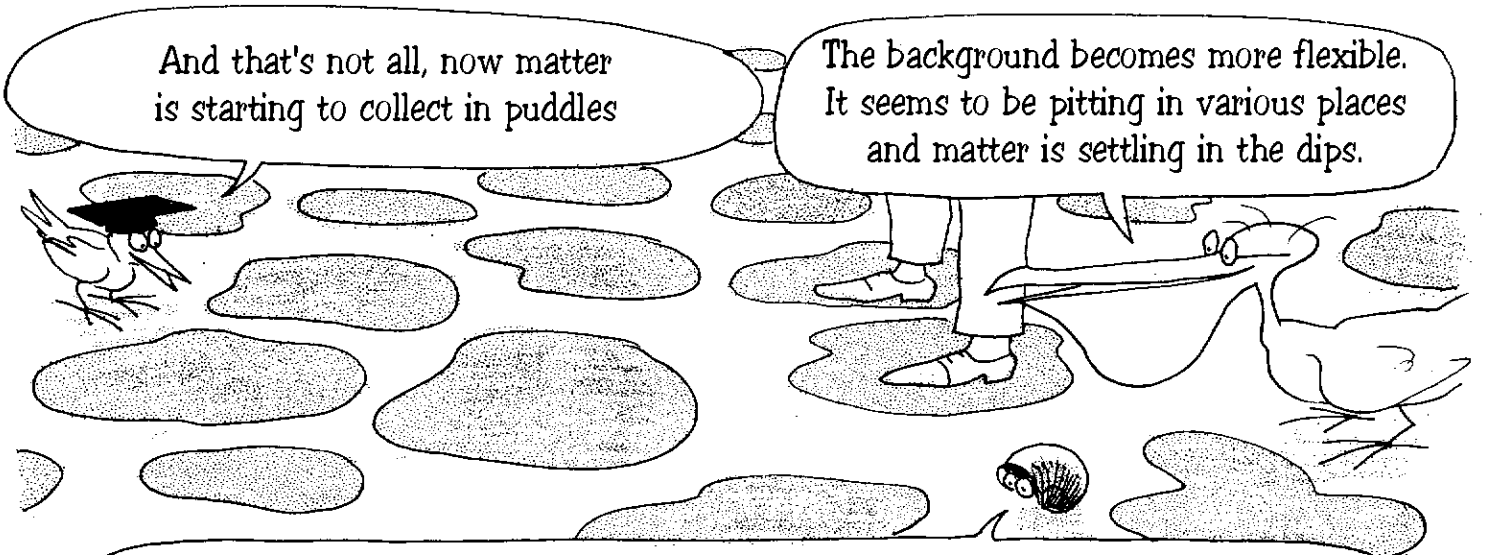
They are "held" by nucleii.

(*) See **FLIGHT OF FANCY**.


Hmmm. You tell me that under our feet there is foam with holes. I don't get it ... PHOTONS aren't ... fixed!?
Leon, the story about the foam was just a way of representing space and the PRIMITIVE RADIATION it contains.
OK, you say the VOID doesn't exist but what if I remove the photons, what's left?
NOTHING...

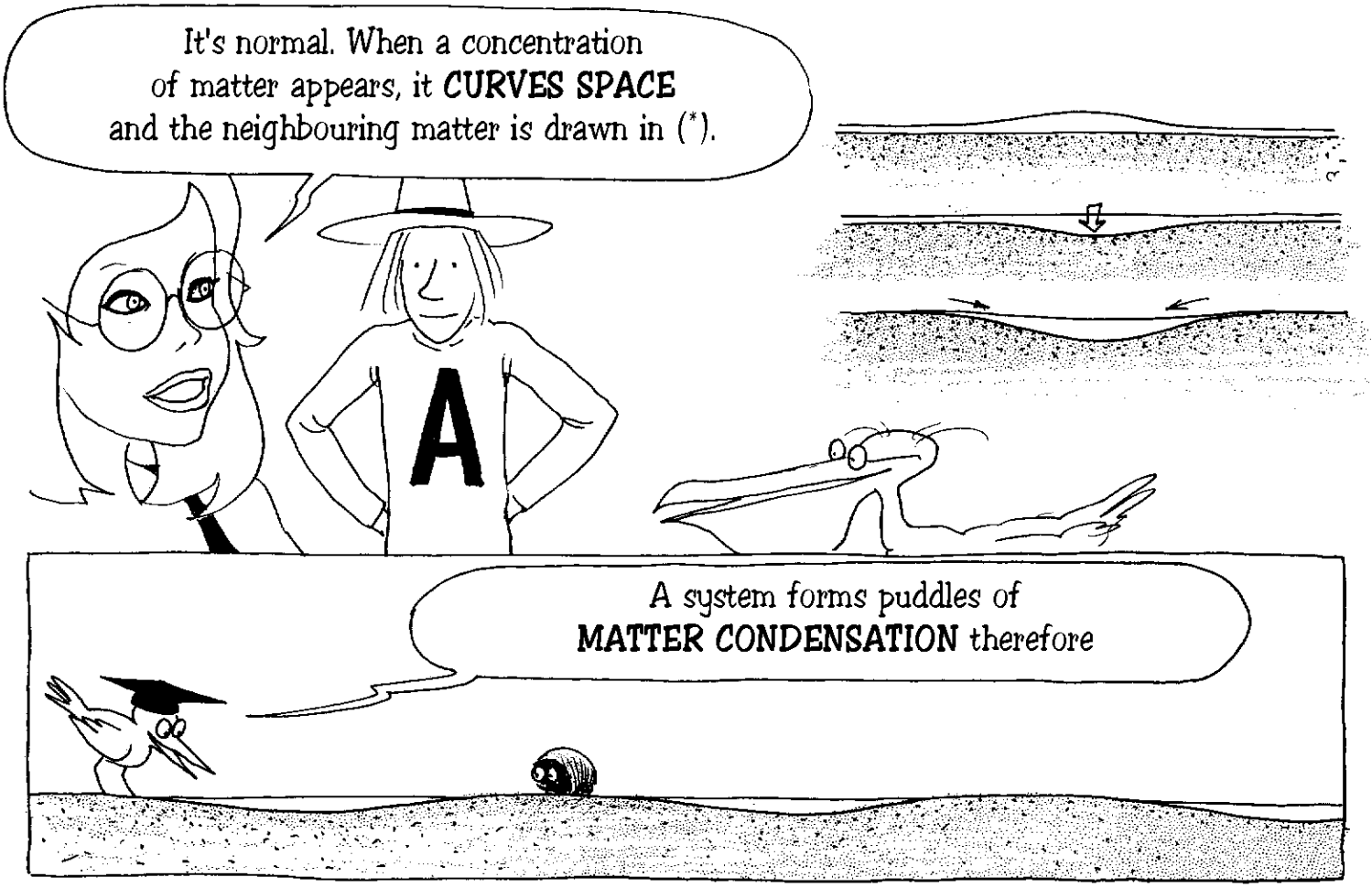
DECOUPLiNG


KLONK...
Eh, you've started the CHRONOTRON again!!
Yes, the level has dropped. The temperature of MATTER has dropped below 3000°
Bravo!
And we've gone past 700,000 years!
MATTER can now slide freely on the BACKGROUND. It's as if it has come unstuck...



Fluid-matter is heavy. It weighs on its support, which begins to sink.

GRAVITATIONAL INSTABILITY



(*) We say that a **GRAVITATIONAL ATTRACTION FIELD** has been created.


The dips aren't very deep in fact.
It's all pretty stagnant
A
The foam is still too **COMPACT** for deep pits to form. Even big pools only create tiny curvatures. You have to wait for the Universe to slacken for the support to have even a small amount of the elasticity needed.
RADIATION PRESSURE is still three tenths of thousandths atmospheres.
Three tenths of a thousand atmospheres !... You call that excessive pressure?
GRAVITATIONAL FORCE is so weak that this pressure is enough to counter its effects.
Ah yes, it's true... this force is the weakest of all those in the Universe.
So the compactness of the foam (radiation pressure) stops the support from creating dips and matter from condensing. The dilatation of the Universe lessens the compactness, this pressure. But how long do we have to wait before the force of gravity wins?
About 4.5 thousand million years.

While waiting, I'd like to know why all the dips are more or less of the same diameter, and why this diameter rather than another?

What do these condensations represent?

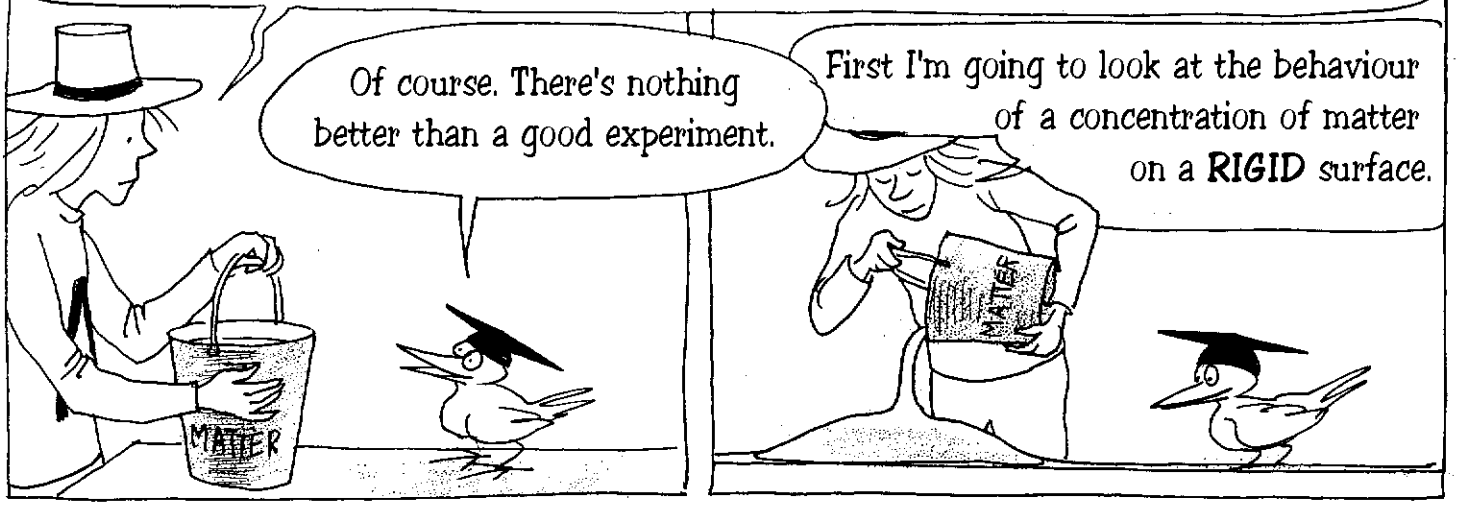
From ten to a hundred solar masses.

JEANS' LENGTH

And why are there dips? Why doesn't the Universe remain uniform. I'd like to know a good reason for such a phenomenon.

Of course. There's nothing better than a good experiment.

First I'm going to look at the behaviour of a concentration of matter on a **RIGID** surface.



It takes a little while to disperse, to spread out.

The force causing the matter's spread is **PRESSURE**, which incites it to take up as much room as possible.

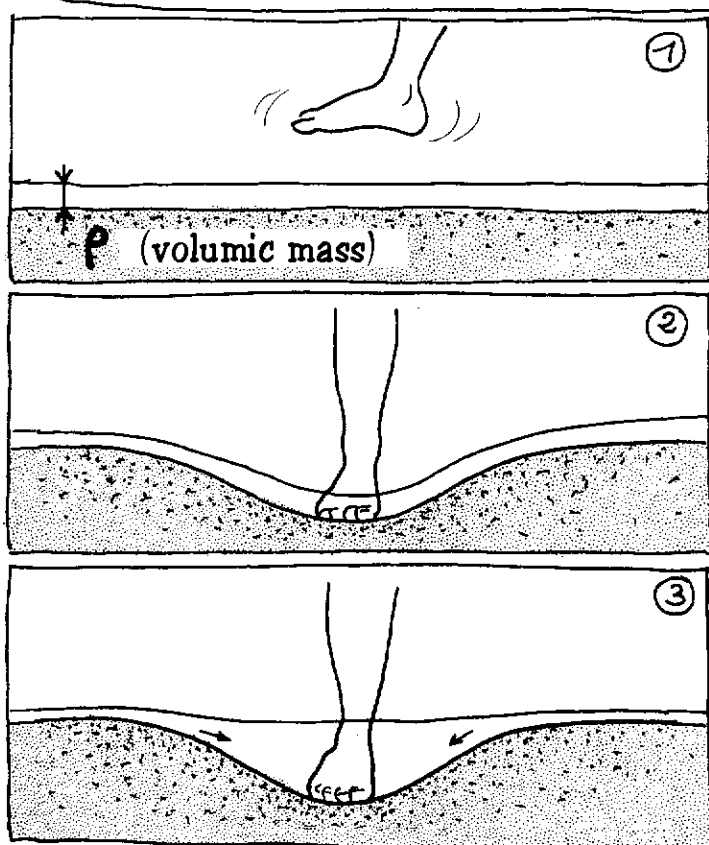
Apparently the time taken for a pool to spread, to double its dimensions, is proportional to its initial radius.

Secondly, the **HOTTER** the matter, the **QUICKER** it disperses.

That's normal. Temperature equals pressure: the hotter the milieu, the more intense the forces of dispersion, the pressure forces.

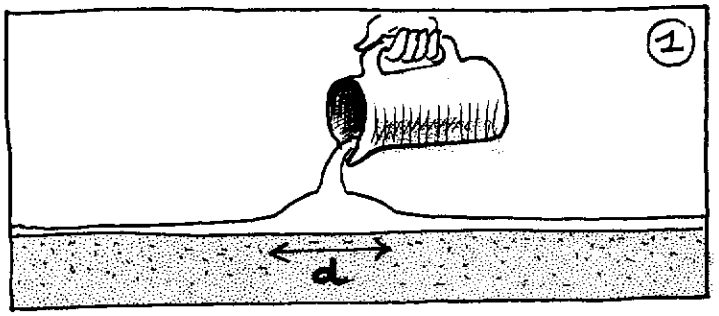
My goodness... what a building site.

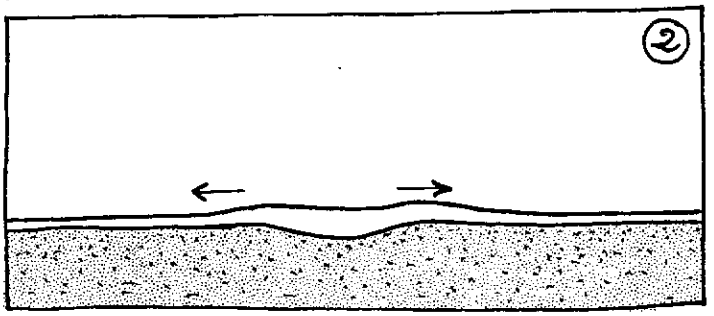
So I know more about the way a pool of matter tends to disperse. B, phase number two: I don't create **SUPERDENSITY**, but I do artifically accentuate the curvature of the elastic support.

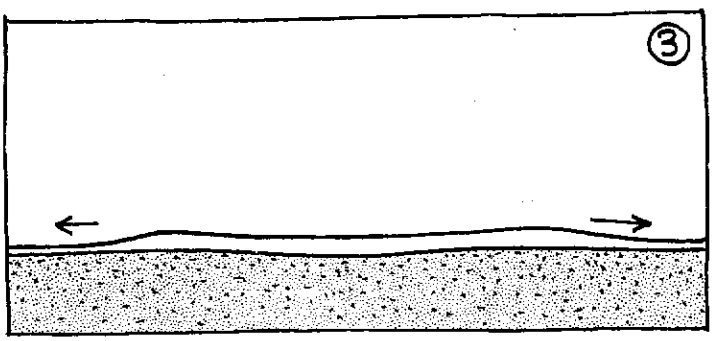


This artificially created depression fills in a time we call **ACCRETION TIME**, which is as short as the thickness of the fluid (which simulates the volumic mass) is great.

Now we have to conjugate the two effects...

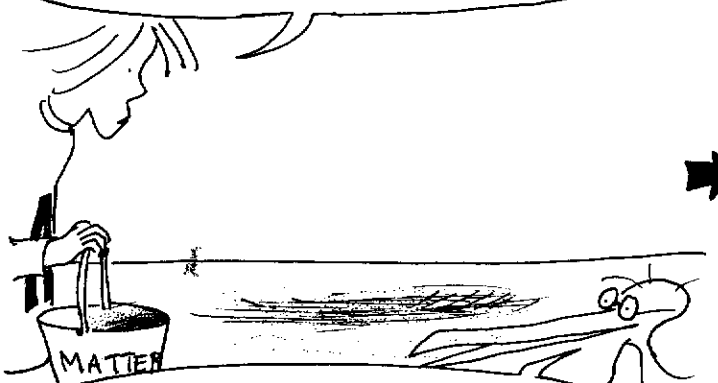




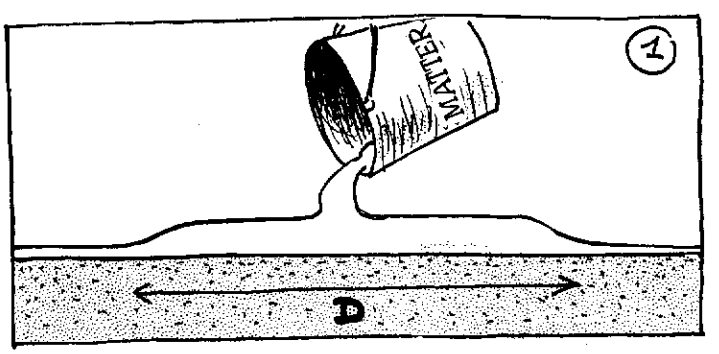


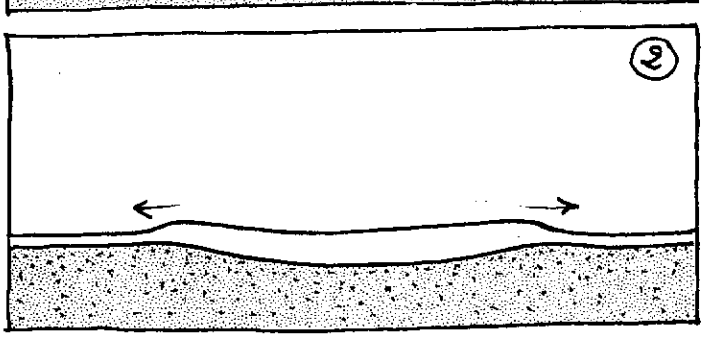
A small perturbation will have a short dispersion time. It won't have time to amplify and the dip will empty itself quicker than it fills.

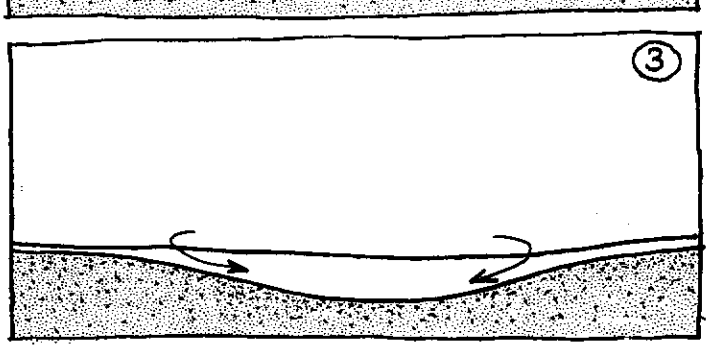
However, a **LARGE** perturbation will have a **LONGER** dispersion time. It will fill more quickly than it empties and will have a tendancy to amplify.

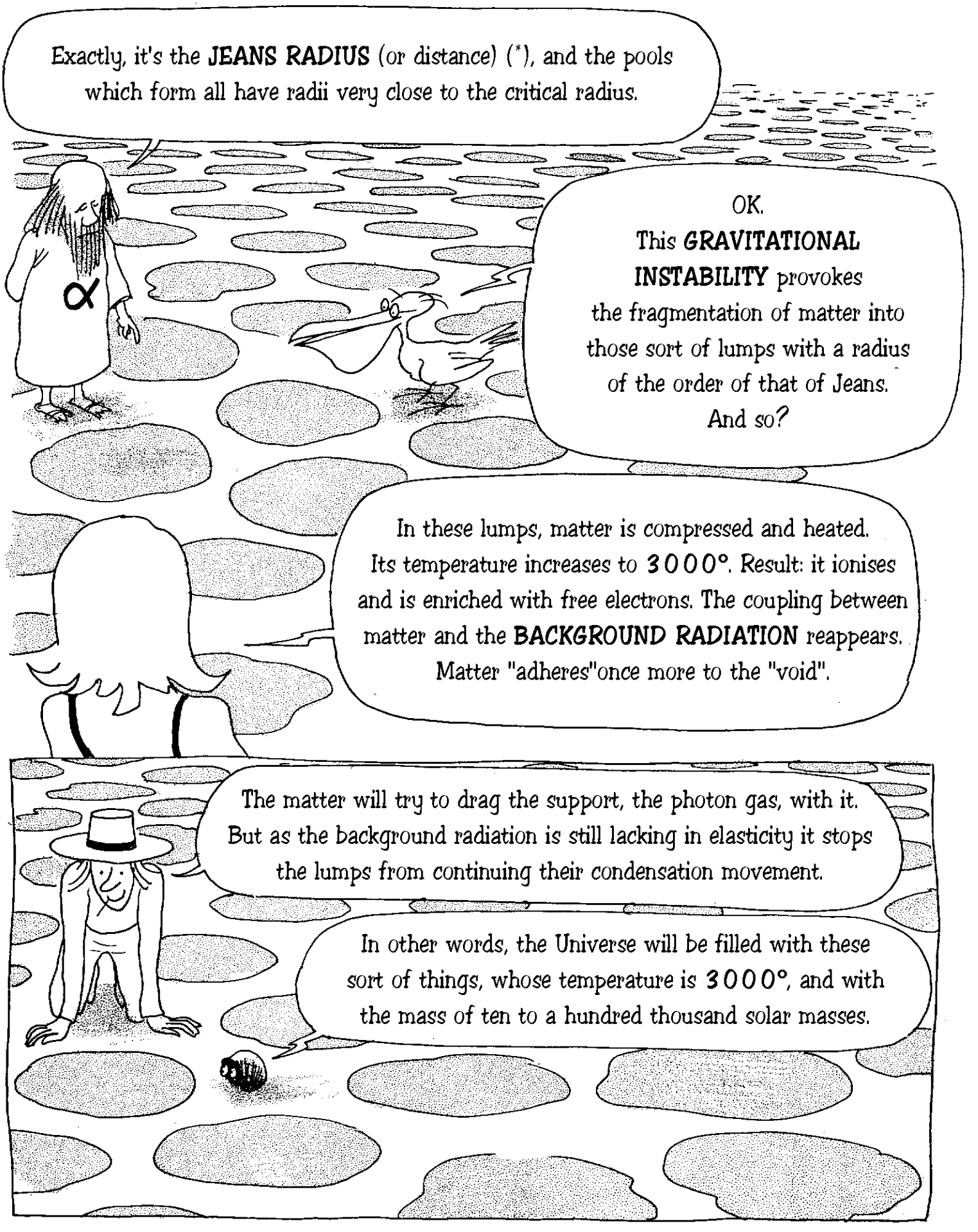


And I suppose that there's a critical radius beyond which amplification takes place?









(*) Sir James JEANS, English astronomer (1877-1946).

Nothing much happens after that. The expansion only separates the lumps from each other progressively. Before, the Universe was a mixture of hydrogen and helium atoms; now we could say it is an emulsion that extends further than we can see.

Flat, boring Universe...

THE MACROCOSM

And what if I changed the scale?

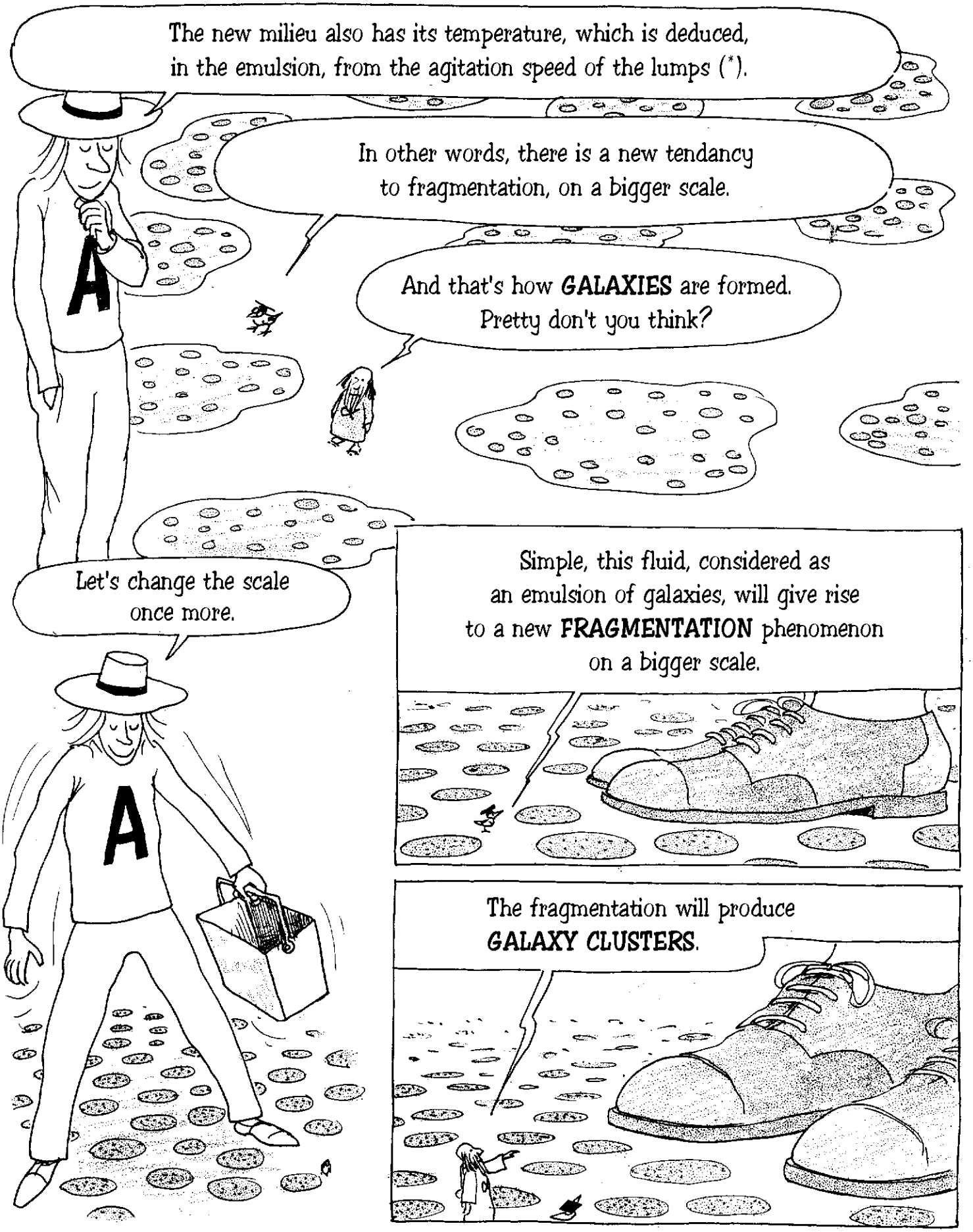
A

A

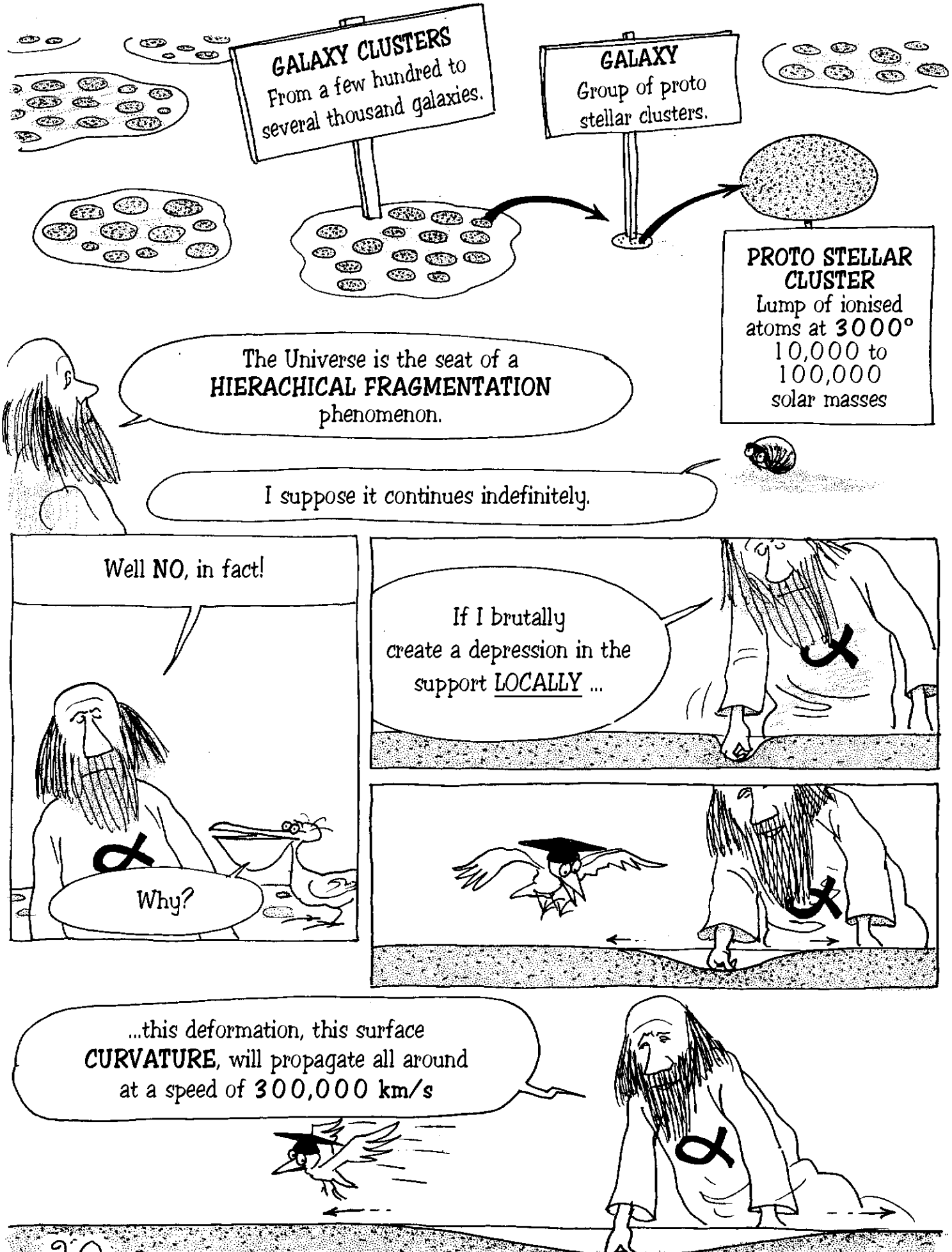
At that scale, matter is this sort of lumpy emulsion.

I'll tip it onto a rigid support and see how long it takes to disperse. Then I'll do it again on a flexible support.

In other words you're doing the same experiment as earlier but on a bigger scale.



(*) The **TEMPERATURE** is the measure of the average cinetic energy of the agitation of the elements, in a fluid milieu..

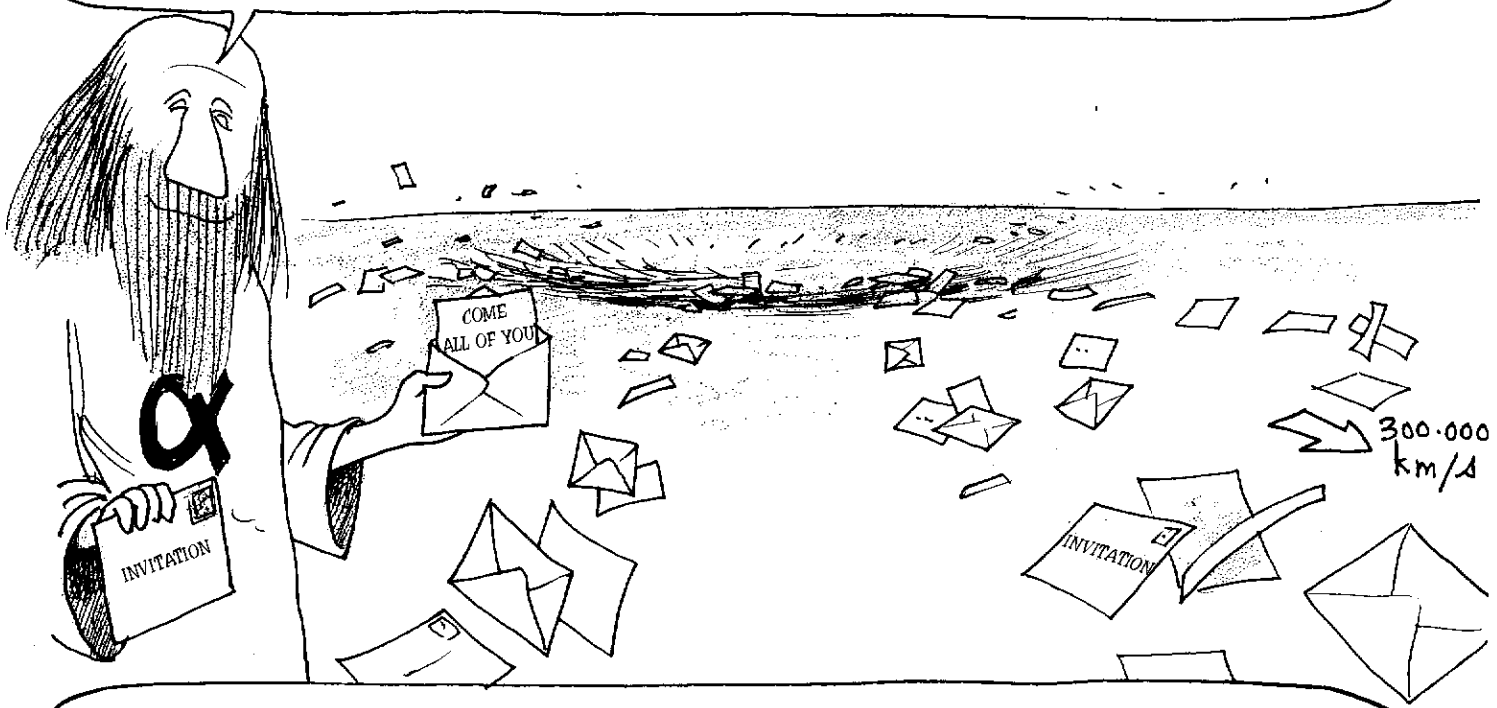

GALAXY CLUSTERS
From a few hundred to several thousand galaxies.
GALAXY
Group of proto stellar clusters.
PROTO STELLAR CLUSTER
Lump of ionised atoms at 3000°
10,000 to 100,000 solar masses
The Universe is the seat of a HIERACHICAL FRAGMENTATION phenomenon.
I suppose it continues indefinitely.
Well NO, in fact!
Why?
If I brutally create a depression in the support LOCALLY ...
...this deformation, this surface CURVATURE, will propagate all around at a speed of 300,000 km/s

So it is light that is being propagated then?

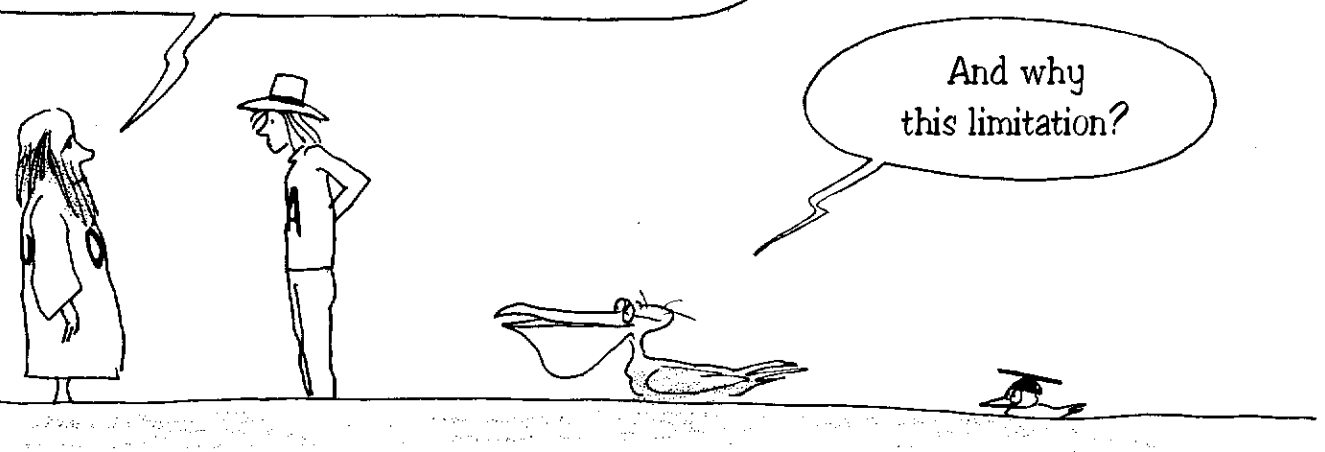
No, its a wave of curvature, a gravity wave

The **GRAVITATION FIELD** is propagated at the same speed as light

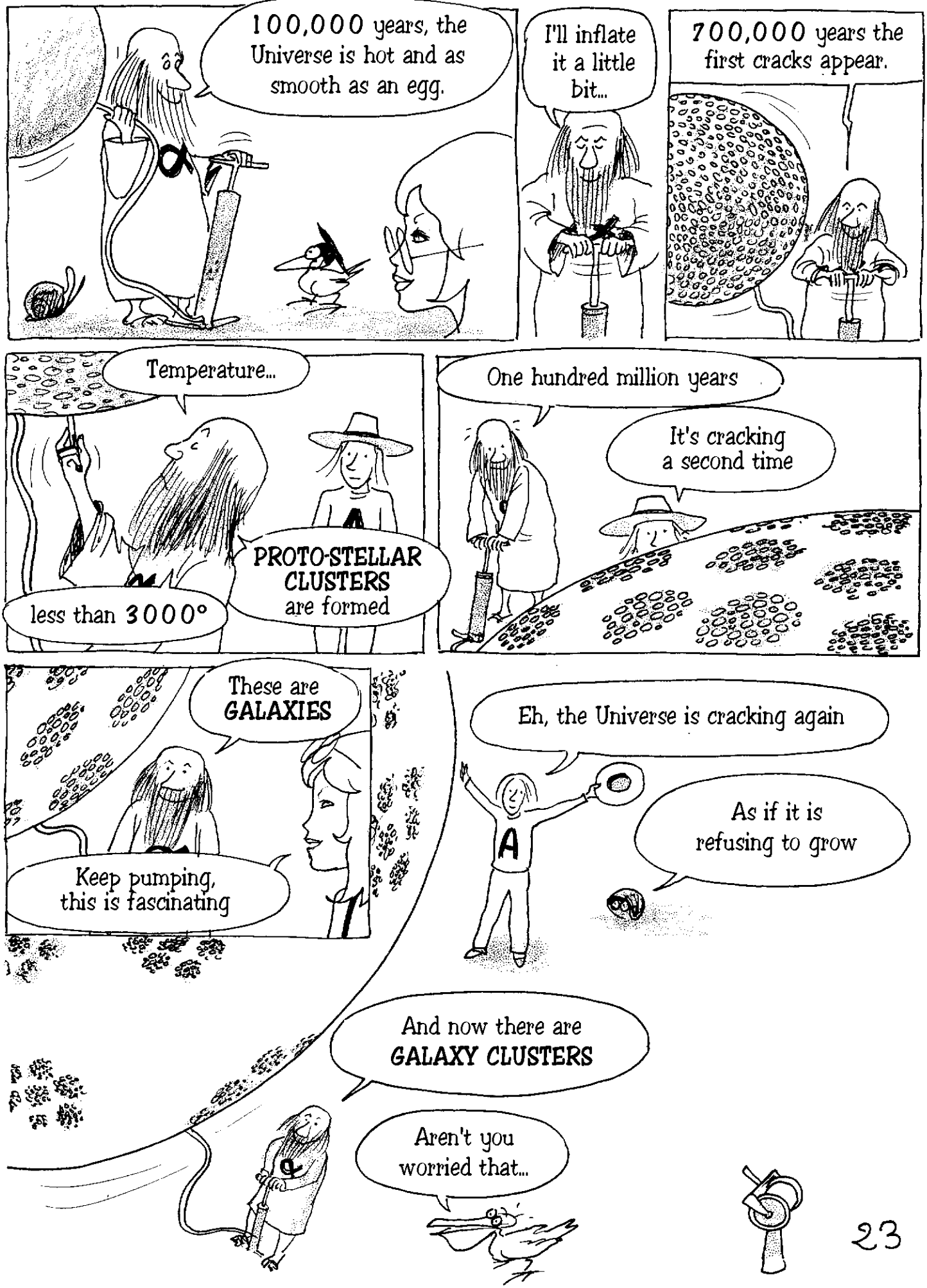
Through this propagation of curvature, all matter condensation "invites" surrounding matter to join it.

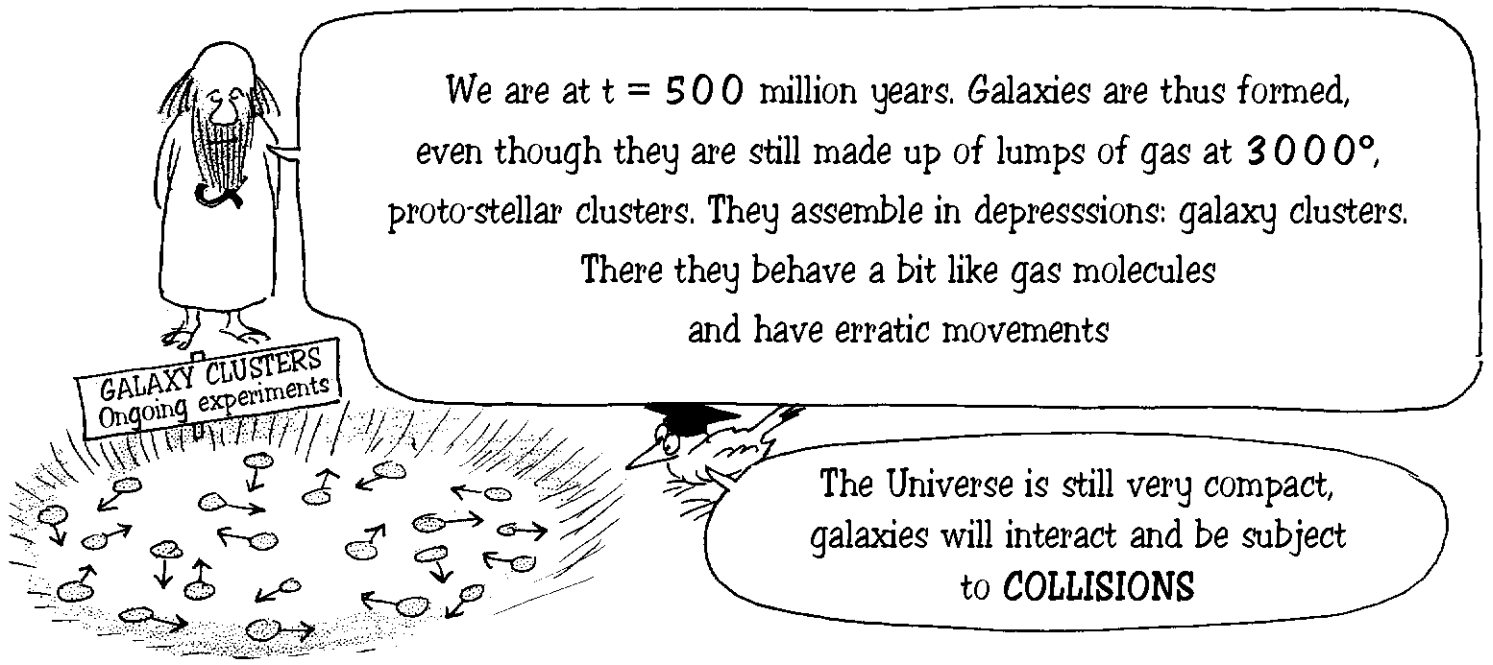


If a gravitational instability phenomenon occurs, interesting a region of space of diameter **D**, this will necessarily be inferior to **Ct**, where **C** is the speed of light and t the age of the universe.

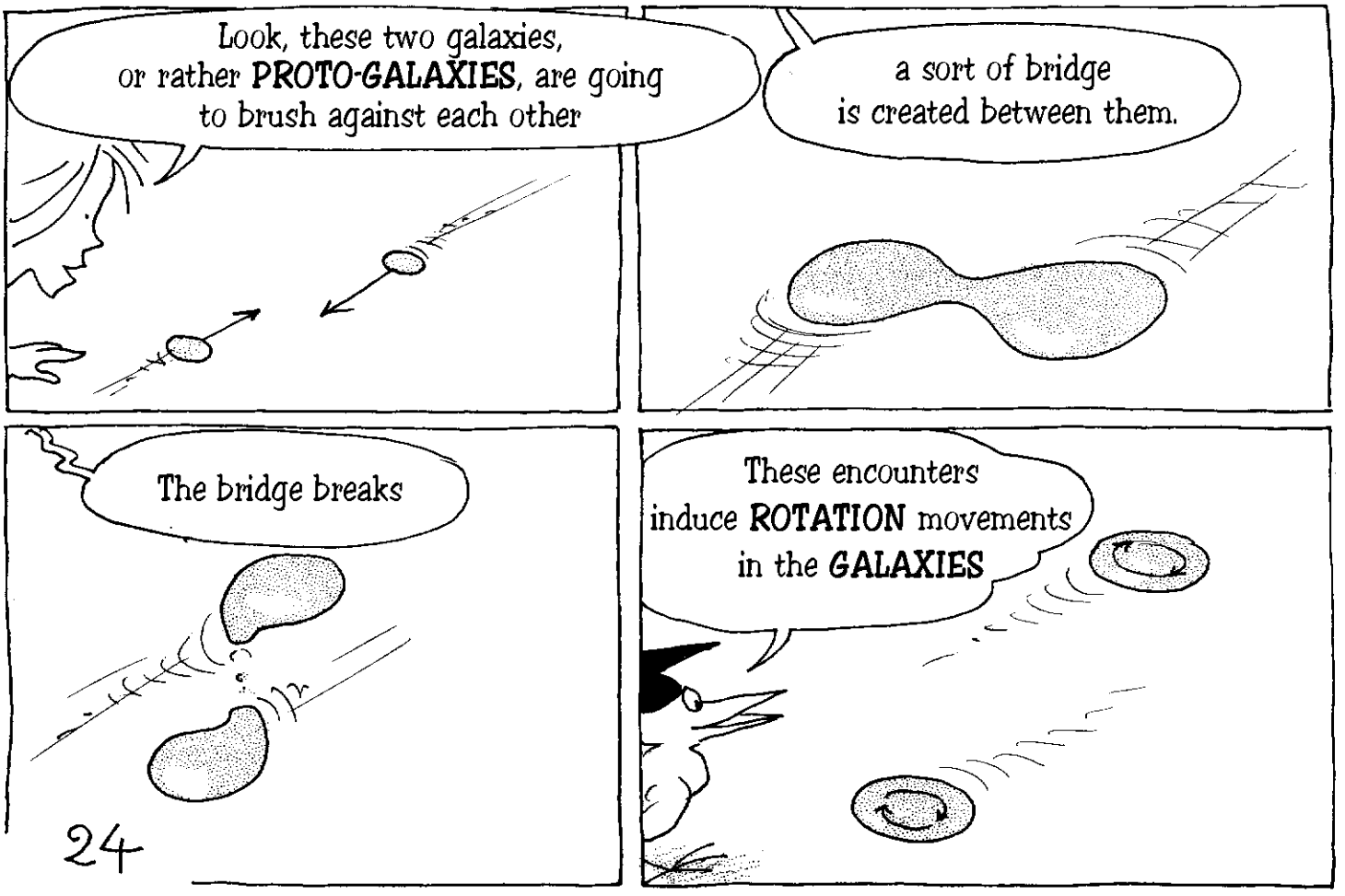



I've understood. Suppose that from France you want to summon people to a meeting to be held in 4 days. You could possibly invite everyone living in French territory but it would be impossible to invite those living outside because of the time required.
Of course. It's impossible to summon people to a meeting in less time than it takes for a letter to reach them.
The CHRONOTRON shows one hundred million years, THEREFORE the most vast structures that can exist now must have less than a hundred million light years diameter. That limits us to GALAXY CLUSTERS.
Those who are patient enough to wait for a dozen billion years will be able to see the constitution of SUPERCLUSTERS (clusters of galaxy clusters).
But the Universe is EXPANDING. Globally, it is dilating and locally, contracting...
You'll see...
It doesn't know what it wants!


100,000 years, the Universe is hot and as smooth as an egg.
I'll inflate it a little bit...
700,000 years the first cracks appear.
Temperature...
less than 3000°
PROTO-STELLAR CLUSTERS are formed
One hundred million years
It's cracking a second time
These are GALAXIES
Keep pumping, this is fascinating
Eh, the Universe is cracking again
As if it is refusing to grow
And now there are GALAXY CLUSTERS
Aren't you worried that...

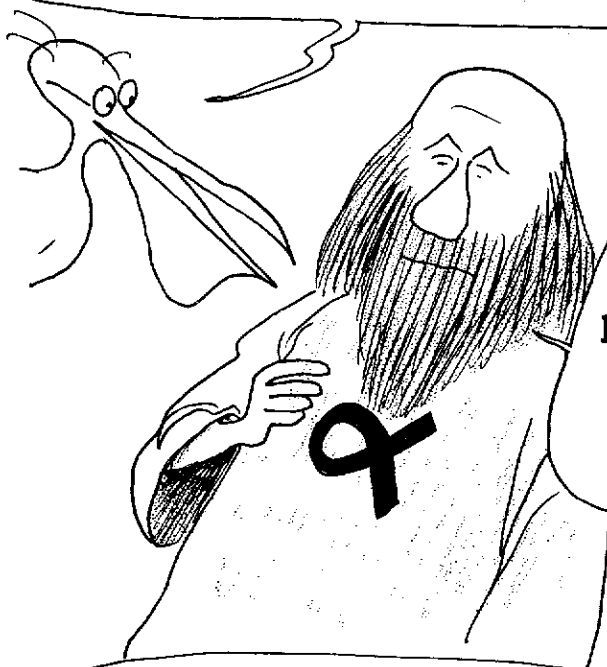


COLLISION EFFECTS



The same thing happens in a **GAS**. The same laws apply, on the scales of the infinitely great and infinitely small. **COLLISIONS** set the **GALAXIES-MOLECULES** into **ROTATION**. In this way the individual energy of galaxies will tend towards a distribution with equal shares of **TRANSLATION ENERGY** ($1/2\ m\ v^2$) and **ROTATION ENERGY**. This energy equidistribution, or **THERMODYNAMIC EQUILIBRIUM**, is what all fluids tend towards naturally (*)

In other words, it's the encounters between galaxies that **CREATE** the rotational movement?

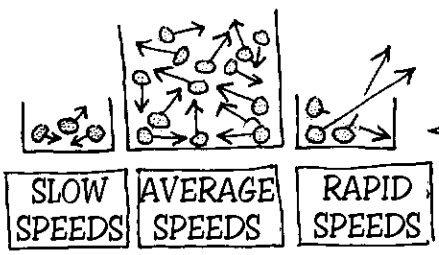


Only at the beginning. Young galaxies are subject to frequent collisions but **COSMIC EXPANSION** will soon distance them from each other and these collisions will soon become extremely rare.

In other words the rotation movement we observe today is just a souvenir of a time when the **DENSER** universe formed a **COLLISIONAL ENSEMBLE**.

(*) Second Principle of Thermodynamics

The elements have **AGITATION SPEEDS** near to an average value. But, from time to time, chance collisions create extremely rapid elements and extremely slow elements.



CIAO !

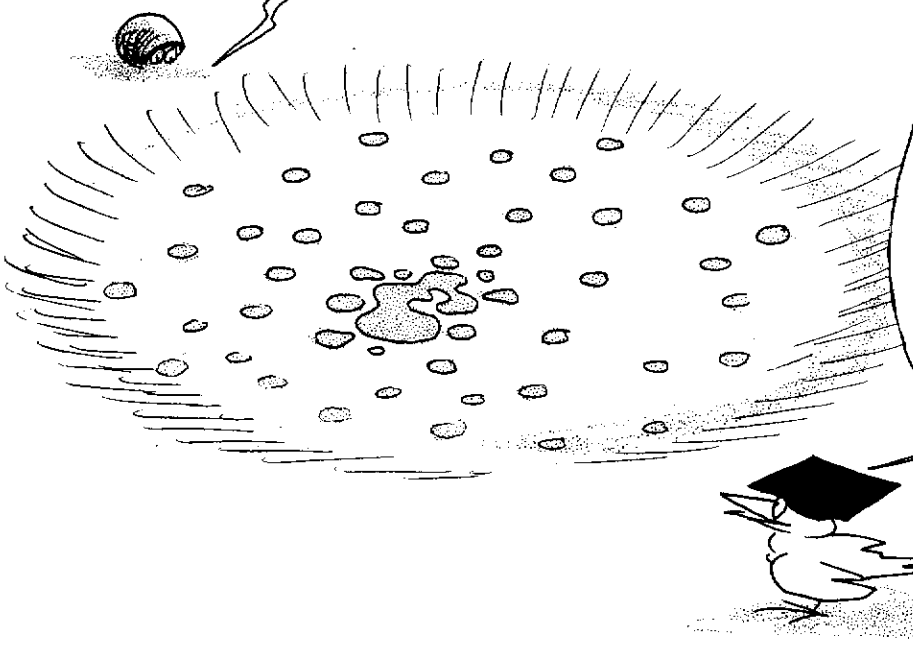
The elements, having thus acquired a superrapid speed, manage to escape from the dip and leave the cluster. This will happen if their speed goes beyond the **CLUSTER LIBERATION SPEED**.

As this type of superrapid element is constantly created because of successive collisions, such an **AUTO-GRAVITANT SYSTEM** would have a natural tendancy to lose its elements more or less quickly (*)

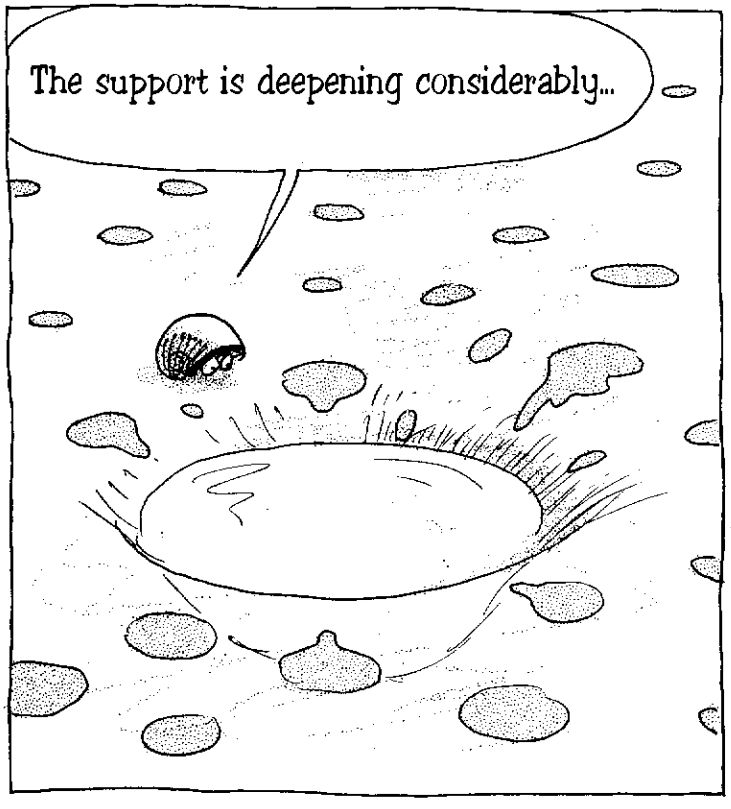
The vast majority of elements will simply go backwards and forwards in the dip.

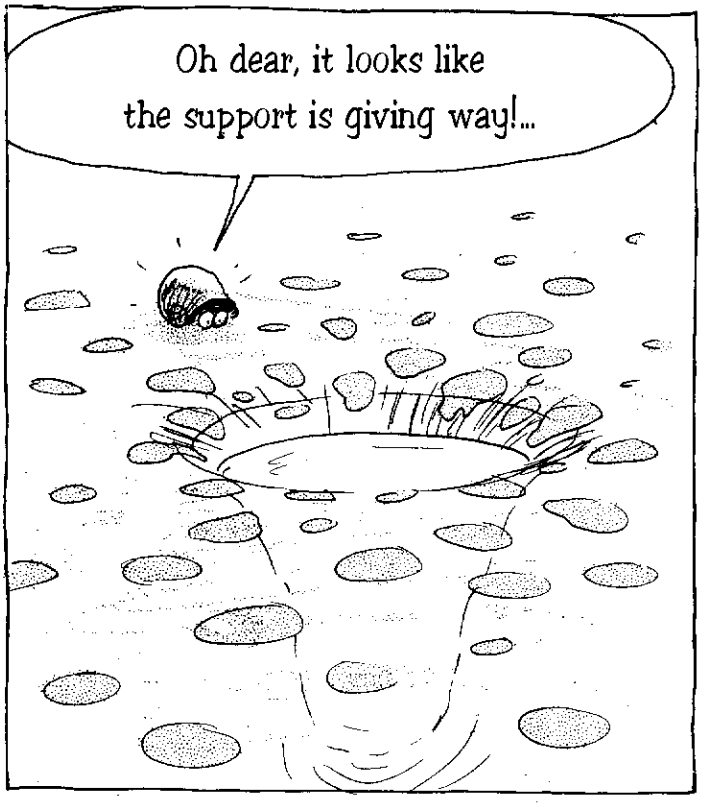
(*) **EVAPORATION SPEED** is proportional to the mass of the cluster.

Inversely, these same chance collisions will create **SUPER-SLOW ELEMENTS** which will have a tendancy to "fall" towards the centre of the **COLLISIONAL AUTO-GRAVITATIONAL SYSTEM** and will agglutinate. The centre of the **COLLISIONAL CLUSTERS** (where encounters between elements take place) will therefore have a tendancy to enrich themselves with elements that are increasingly **MASSIVE**.



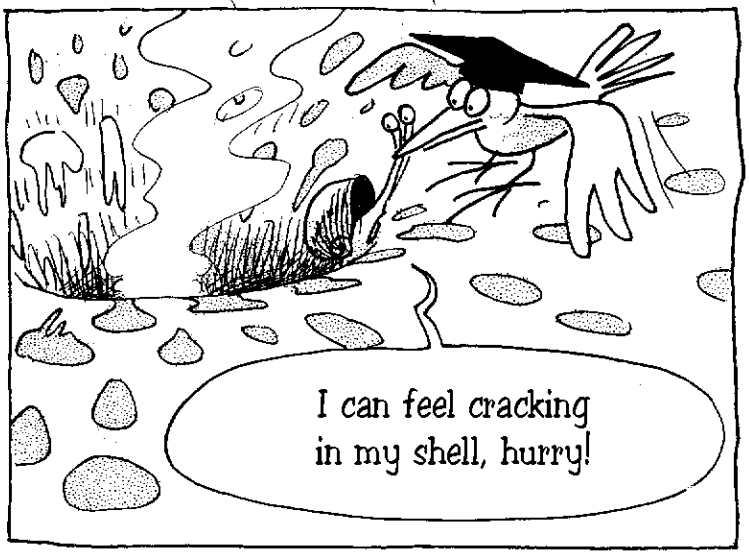
Look at what happens in the centre of this **GALAXY CLUSTER** for instance. SLOW galaxies agglutinate to give a **CARNIVOROUS GALAXY**!

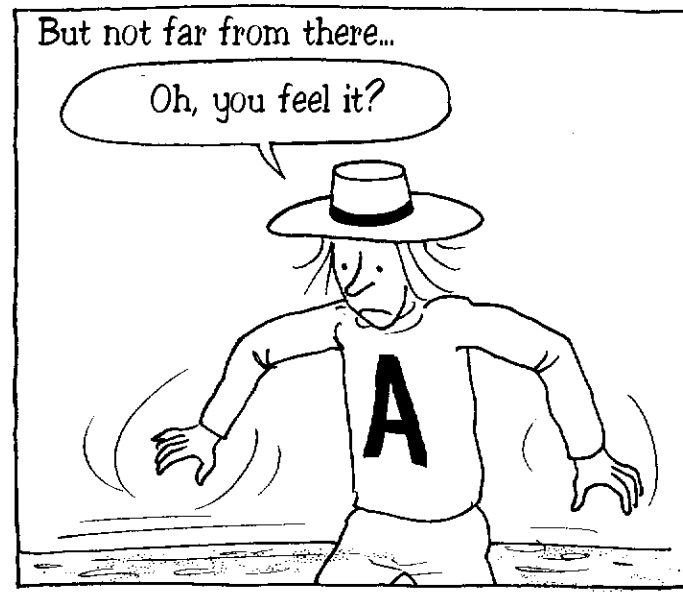


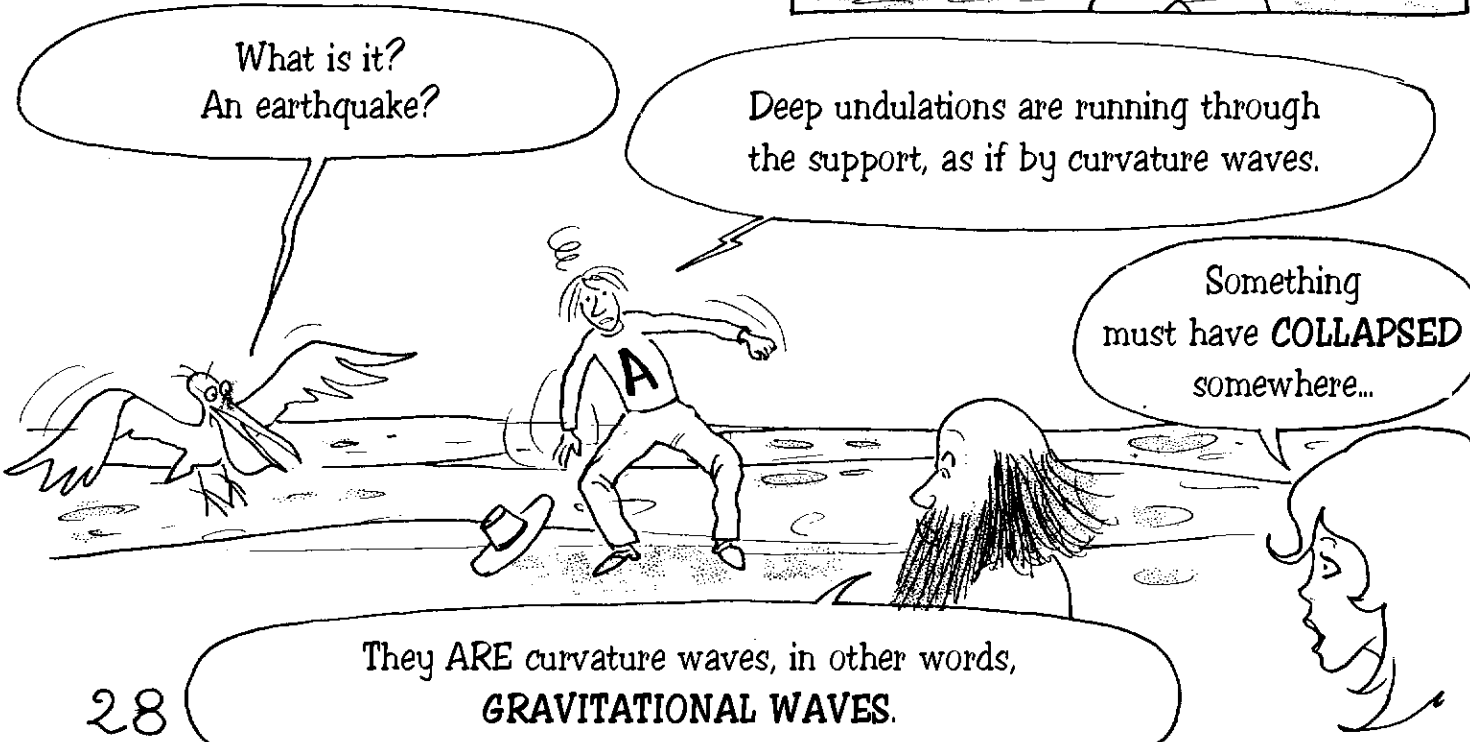


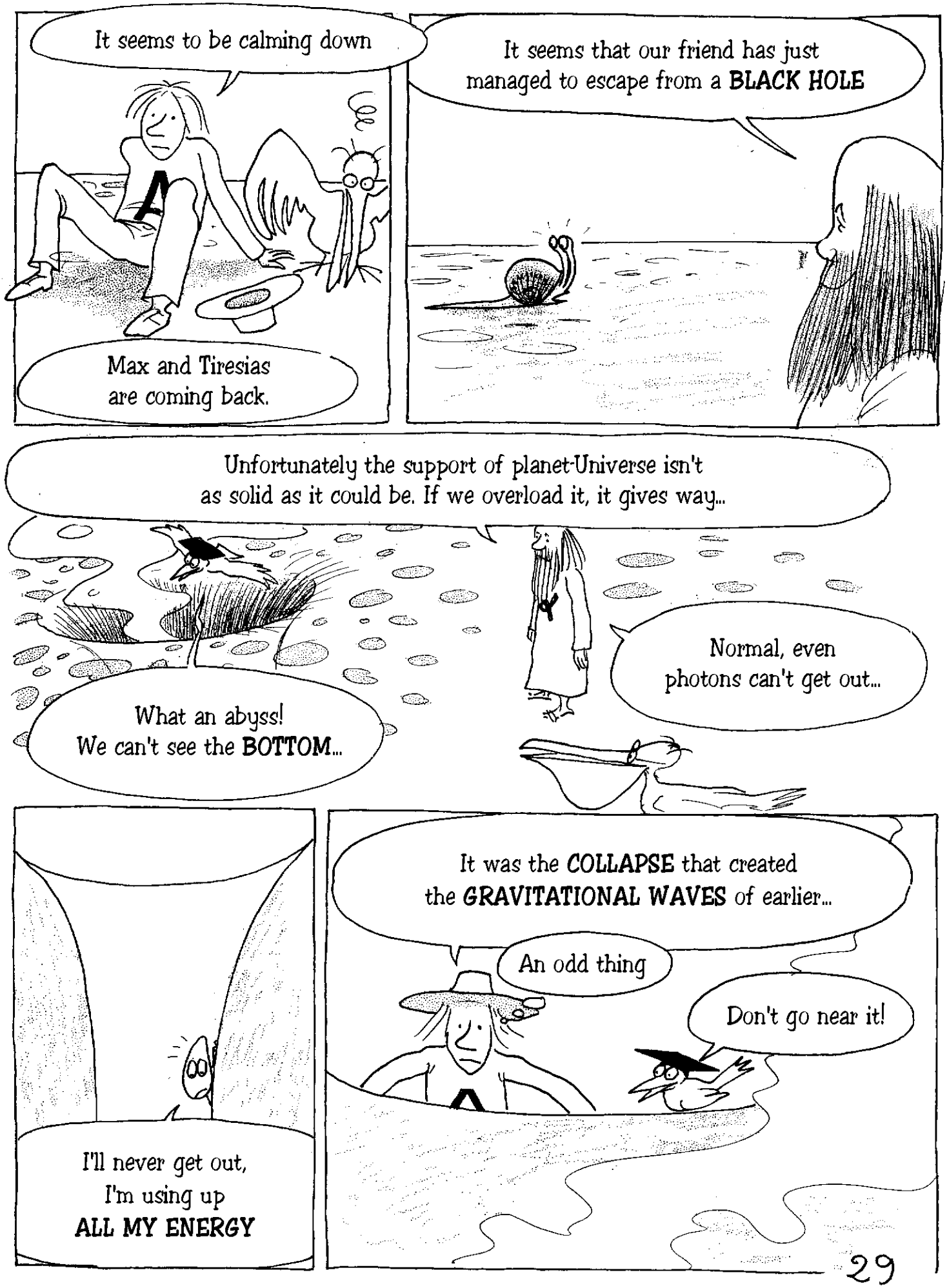
BLACK HOLES


Max, help, it's collapsing!
Goodness! Hang on Tiresias!
KRAÂÂK


I can feel cracking in my shell, hurry!


But not far from there...
Oh, you feel it?
A


What is it? An earthquake?
Deep undulations are running through the support, as if by curvature waves.
Something must have COLLAPSED somewhere...
A
They ARE curvature waves, in other words, GRAVITATIONAL WAVES.


It seems to be calming down
Max and Tiresias are coming back.
It seems that our friend has just managed to escape from a **BLACK HOLE**
Unfortunately the support of planet-Universe isn't as solid as it could be. If we overload it, it gives way...
What an abyss! We can't see the **BOTTOM**...
Normal, even photons can't get out...
I'll never get out, I'm using up **ALL MY ENERGY**
It was the **COLLAPSE** that created the **GRAVITATIONAL WAVES** of earlier...
An odd thing
Don't go near it!

So, to conclude, this Universe not only wants to collapse but also, as far as impermeability goes, it's zero!

THE GREAT FIREWORK DISPLAY

The **CHRONOTRON** shows that billions of years have passed. The Universe is fragmented. **COLLISIONS** have set **GALAXIES** into **ROTATION**.

EXPANSION has distanced all these objects from each other, to the point where they are now unaware of each other.

In these "**PROTOGALAXIES**" the basic element remains the concentration of ionised atoms, the **PROTO-STELLAR CLUSTER**, whose temperature is close to **3000°**, and which cannot collapse on itself because of this "adherence" to the **BACKGROUND RADIATION**

Anyone able to see the Universe at that time would have seen wooly nebulosities emitting diffused light.

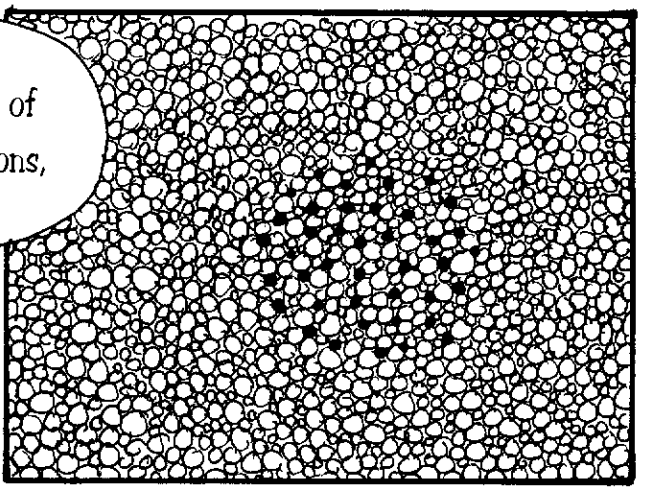
The support has become more flexible. The expansion of the Universe has reduced **RADIATION PRESSURE** considerably.

How could **CONDENSATION** of **MATTER** restart one day? If the lumps condense their temperature will automatically rise beyond **3000°** so adherence to the **BACKGROUND** will never end, and this background will be continually drawn into the condensation movement won't it?

PROTO-STELLAR CLUSTER

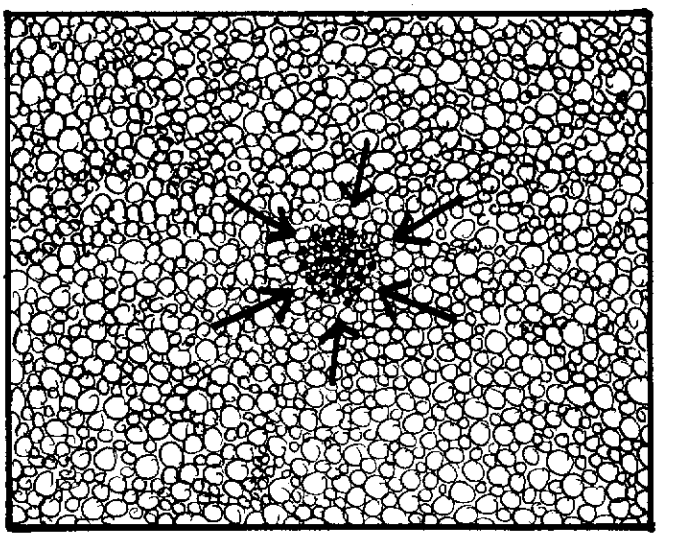
Exactly Leon, but now the forces of gravity in the proto-cluster will be able to "compress the **VOID**" made up of low energy photons.

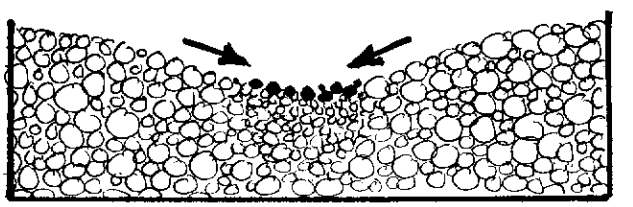
The region around the lump, where the **PROTO-STELLAR CLUSTER** could be compared to a mix of **MATTER** and "**EMPTINESS**", that is to say original photons, the ensemble being at a temperature of **3000°**



And when it condenses?

Matter isn't going to slide on space, the cosmological background radiation, but actually drag it with it, like this.





Wait, this happens at exactly the time when the radiation pressure would have dropped below a certain critical value. Unless I'm wrong, when that happens it will happen at the **SAME MOMENT** in the four corners of the Universe

It will be **FIAT LUX** (*). Here, have some sunglasses, it won't be long now...

I must say I'm rather pleased with a gadget that lets you set everything to start at the same instant throughout the Universe.

A

Very clever. And it's starting

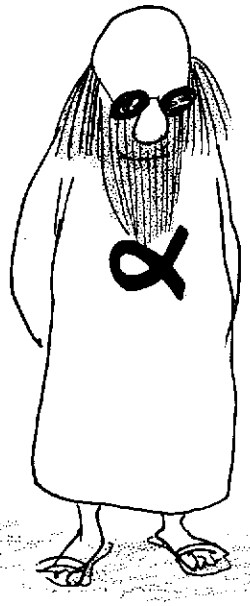
(*) In LATIN in the text.

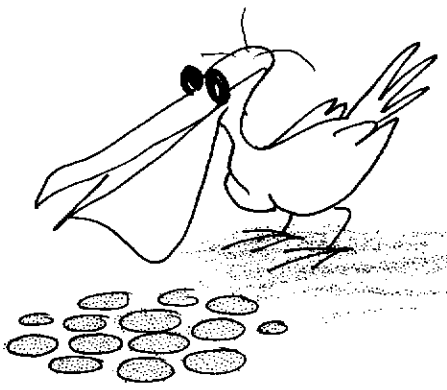
The **PROTO CLUSTERS CONTRACT**.
Their temperatures rise. The atoms emit a lot of ultra-violet energy and this manages to escape.

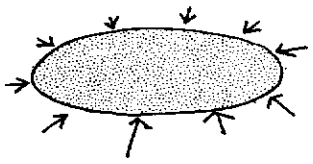
Look, the **PROTO-STELLAR CLUSTERS** are fragmenting.

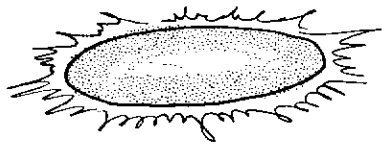
Why!?

Under the effect of gravity, matter has a natural tendancy to **FRAGMENT** into "cells" with a radius equal to the **JEANS RADIUS**. The higher the temperature, the higher it is. If the temperature drops suddenly, the Jeans radius diminishes and becomes less than the radius of the object. There is immediate fragmentation therefore.





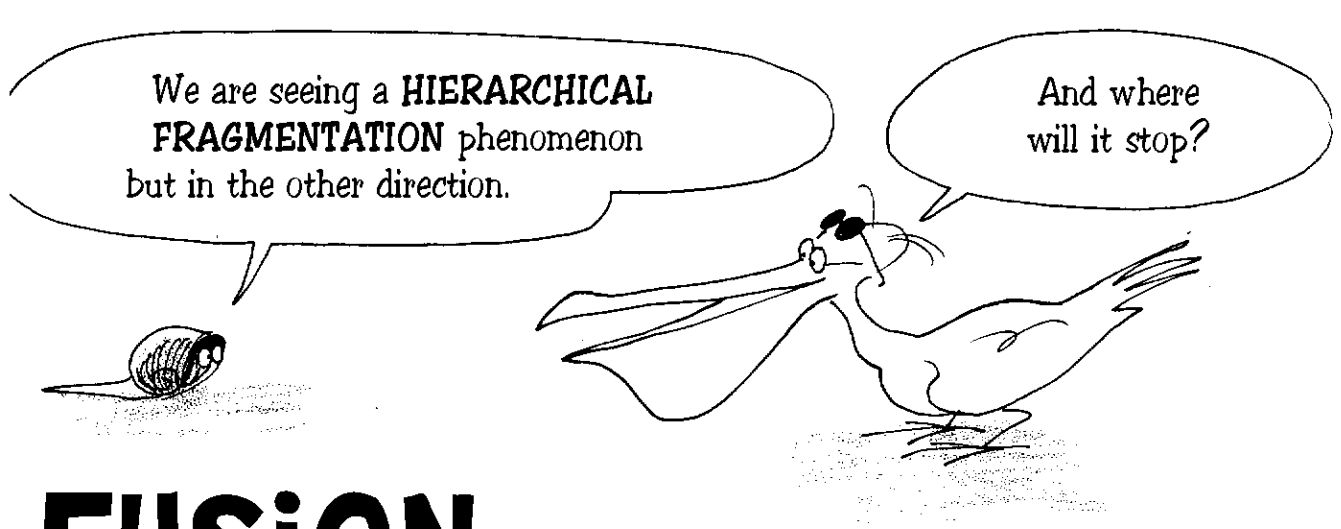




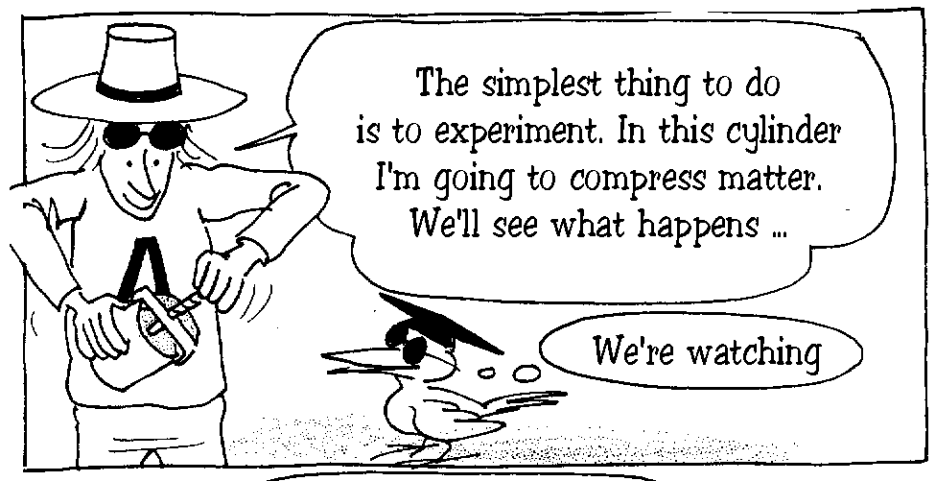
The lump contracts and heats up

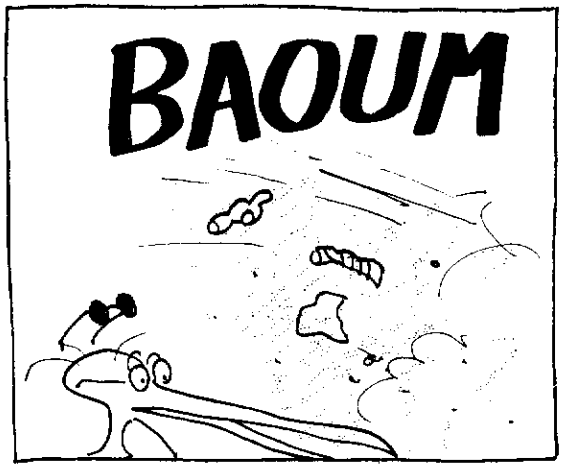
and suddenly emits UV radiation

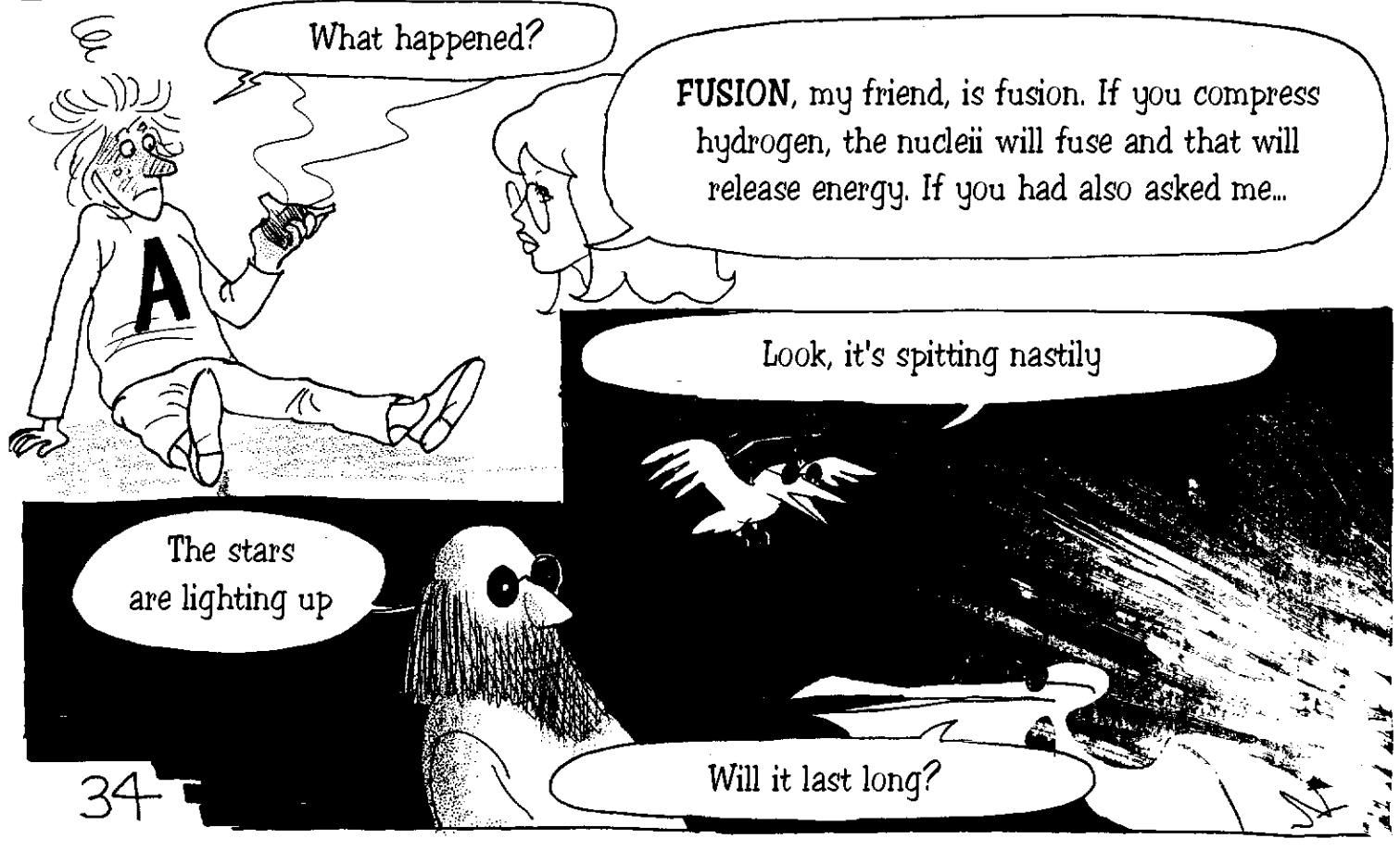
this cools it and it fragments


We are seeing a **HIERARCHICAL FRAGMENTATION** phenomenon but in the other direction.
And where will it stop?

FUSiON


The simplest thing to do is to experiment. In this cylinder I'm going to compress matter. We'll see what happens ...
We're watching


BAOUM


What happened?
FUSION, my friend, is fusion. If you compress hydrogen, the nucleii will fuse and that will release energy. If you had also asked me...
Look, it's spitting nastily
The stars are lighting up
Will it last long?


At this rate the youngsters will soon run out of hydrogen, but it won't be long before it calms down.
I'm glad about that!
A
So does all matter turn into stars like that?
A
Not quite. When a star is born it radiates light with no holding back, as well as matter. In doing so it heats up (and so stabilises) the surrounding matter or dislocates what was painfully being formed around it.
In other words, the GALAXY is a mixture of stars that emit a great quantity of RESIDUAL GAS.

Stars radiate energy and heat the gas, so increasing the **PRESSURE**...

GALAXY

And the **PRESSURE FORCES** dilate the gaseous halo.

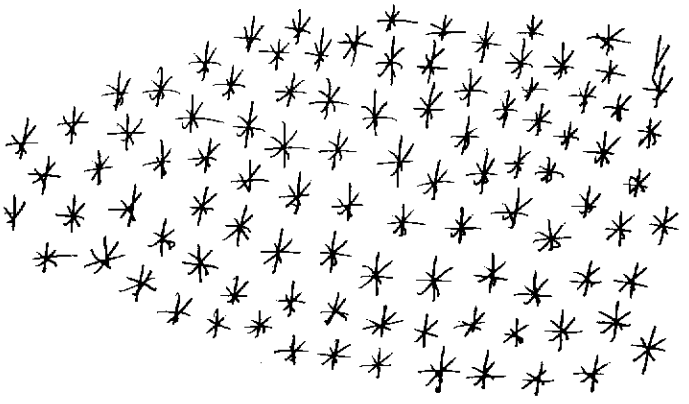
GAS

STAR GALAXY

RESIDUAL GAS

This "**GALACTIC ATMOSPHERE**" largely overruns the edge of the "**STAR GALAXY**"

This very massive galaxy (a thousand billion stars) seems to have completely lost its gas. Why?



It's true! Where has the **RESIDUAL GAS** gone?

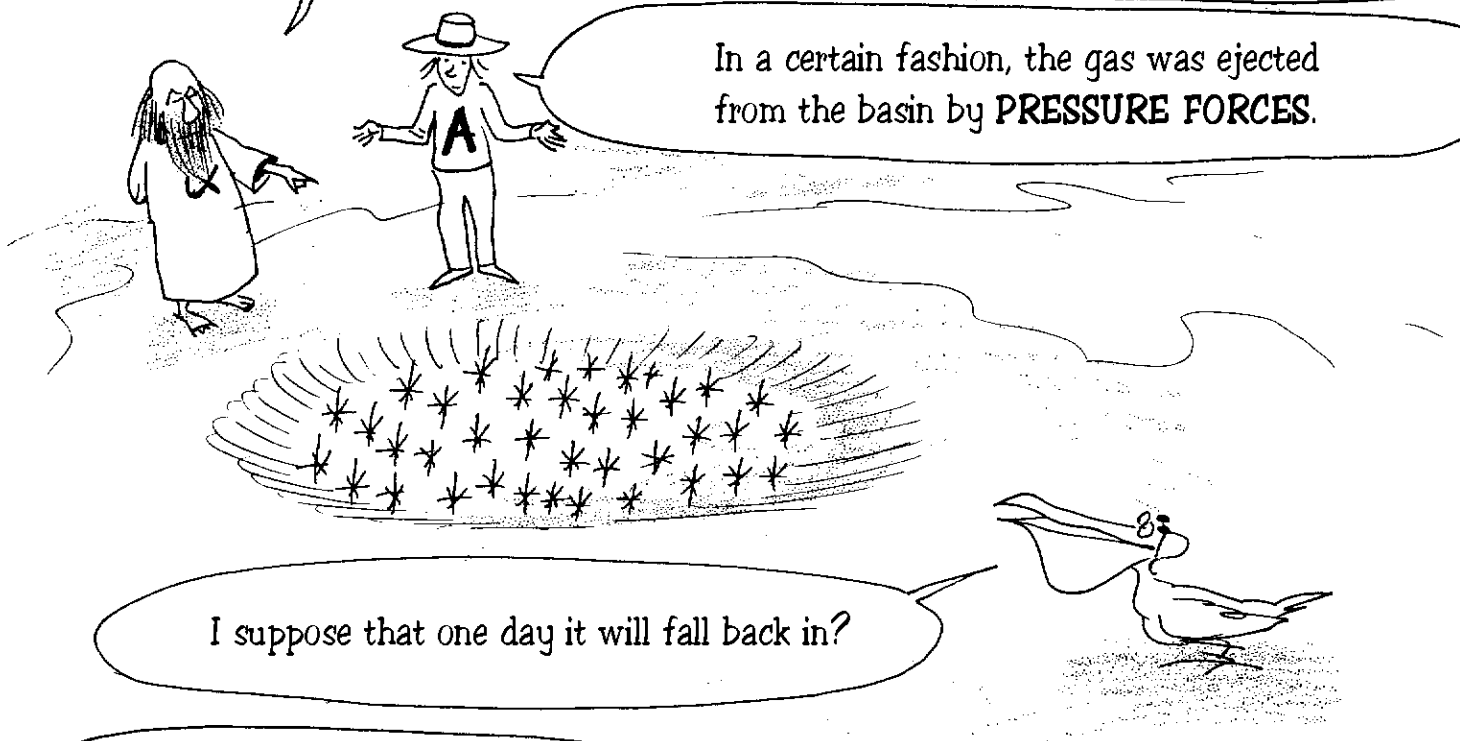
A

Maybe there wasn't any...

It's calmed down now. But when the thousand billion stars of this galaxy suddenly lit up it was a real **OVEN**.

In this way the **THERMAL AGITATION SPEED** (*) attained several hundred kilometers a second, a higher value than the **LIBERATION SPEED**. Then all the atoms of residual gas left the enormous basin of this galaxy.

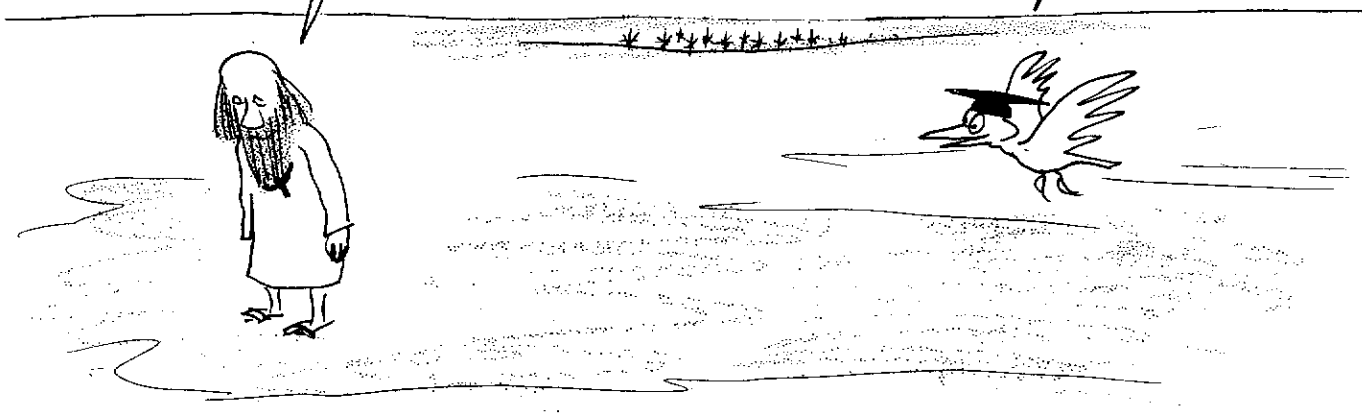
In a certain fashion, the gas was ejected from the basin by **PRESSURE FORCES**.



I suppose that one day it will fall back in?

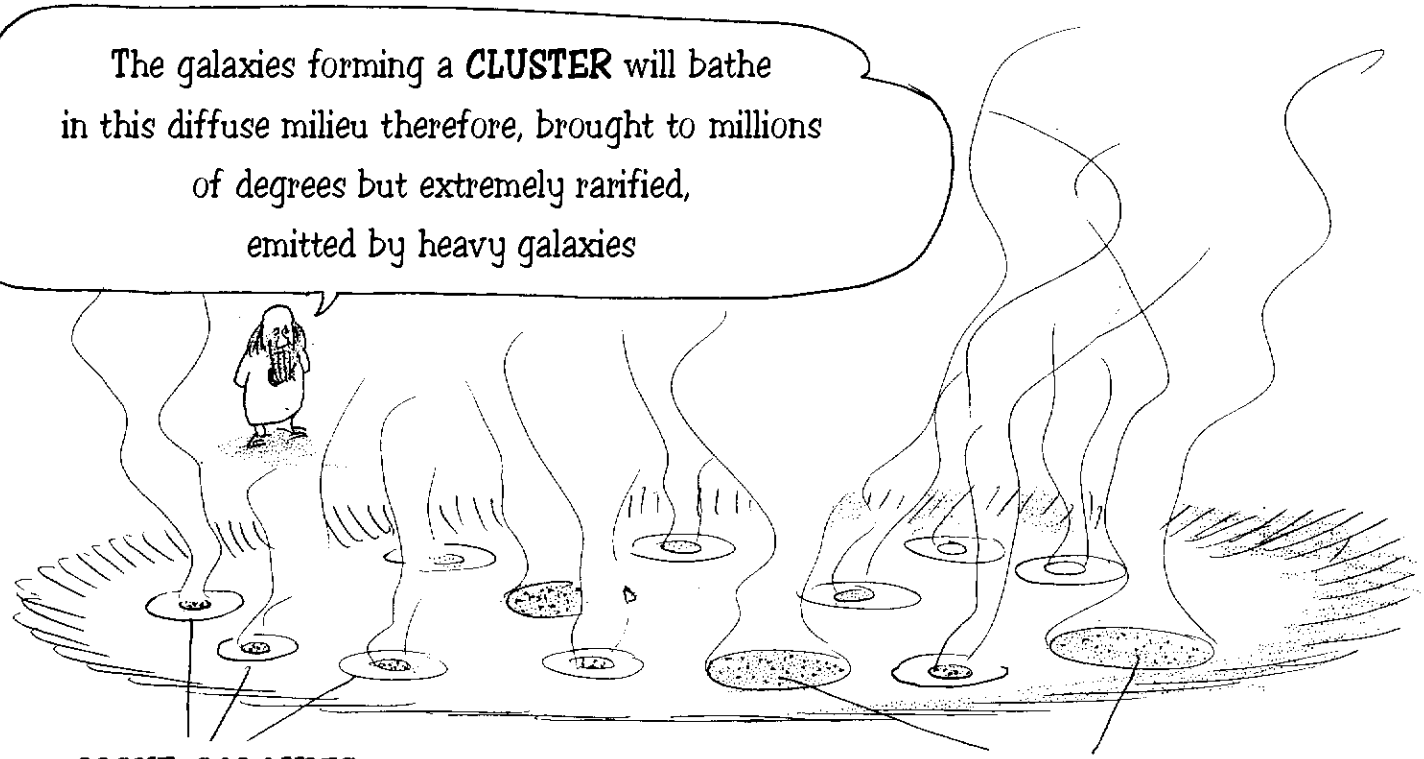
In this case the particles of residual gas have acquired too great a speed and have gone too far. They'll never come back. As well as that, the gas has become extremely rarified.

In other words, the atoms will never meet again and will... conserve their speed forever.



(*) See **FLIGHT OF FANCY**.

The galaxies forming a **CLUSTER** will bathe in this diffuse milieu therefore, brought to millions of degrees but extremely rarified, emitted by heavy galaxies



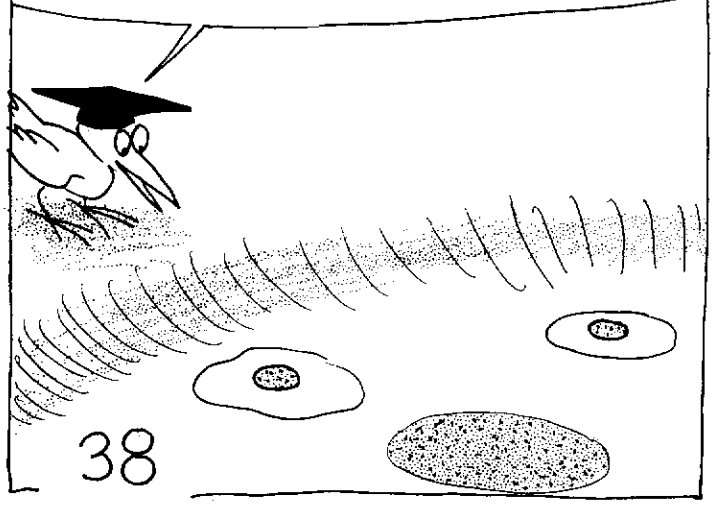
LIGHT GALAXIES

HEAVY GALAXIES

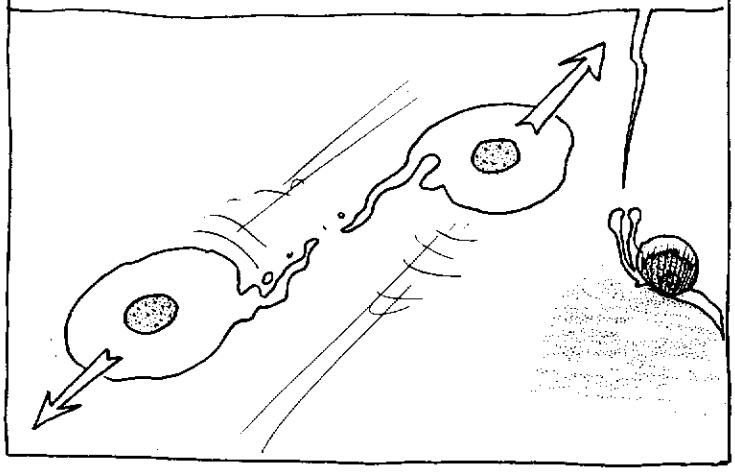
Light galaxies have less violent ovens. They retain their gas.

They evolve in the depression-cluster like eggs in a hot frying pan.

Light galaxies have a "white" and a "yolk", whereas heavy galaxies, called **ELLIPTIC**, only have a large yolk.

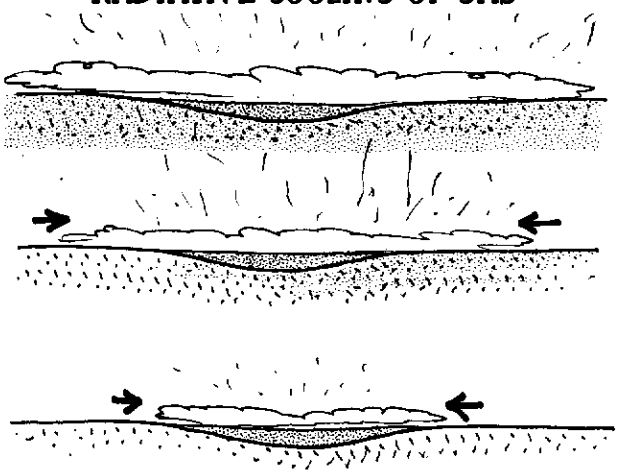


The residual gas halos of light galaxies increase the chances that these objects will interact. The rotation movement of the gas halos is accentuated.

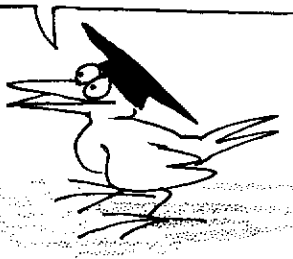



The stars have really calmed down. In relation to what they were at birth they've become simple embers
If they'd carried on at that rate they wouldn't have lasted long.
The residual gas of light galaxies emits radiation
Where does this raditation come from?
From atoms, look.
Two atoms collide...
... which is accompanied by radiation emission. During the operation, a part of the atoms' energy is converted into radiant energy.
The atoms' thermal agitation speed diminishes. This gaseous mass COOLS and who says TEMPERATURE says PRESSURE

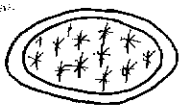
RADIATIVE COOLING OF GAS



With the weakening force of pressure, the residual **INTERSTELLAR** gas will quietly return to its place in the "galaxy-basin".



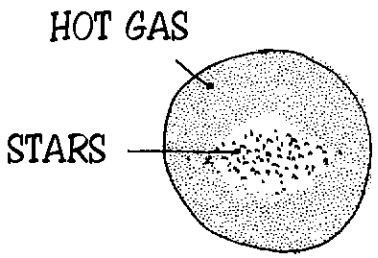
The "white" is back with the "yolk".

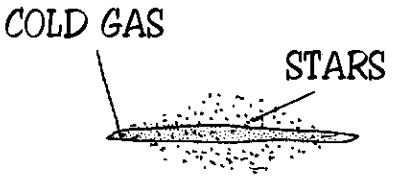


The **MODEL** presented here is a **2 dimensional** description (the third dimension being used to represent the curvature, the gravitational field, etc.). **GALAXIES** are three dimensional objects. Galaxies which don't rotate, or very little, would have a shape similar to that of a **SPHERE**. Howevever, galaxies in rapid rotation will be flattened like pancakes. Our galaxy, the **MILKY WAY**, turns on itself over **200** million years.

When the residual gaz falls back onto a galaxy, centrifugal force hinders its contraction in the radial direction. However nothing will oppose contraction according the axis of rotation. Interstellar gas, in galaxies, will have the shape of a **VERY FLAT DISC**.

The Management

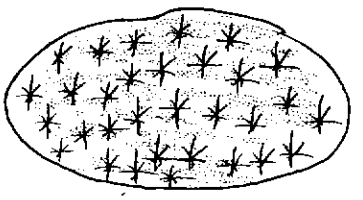




If I've understood it correctly, in the Universe there are essentially two types of galaxies:

→ Heavy galaxies, elliptical and practically without gas.

→ Lighter galaxies, with ten to a hundred billion stars which present themselves as a **MIXTURE** of two gases: the **GAS OF STARS** and **INTERSTELLAR GAS**.

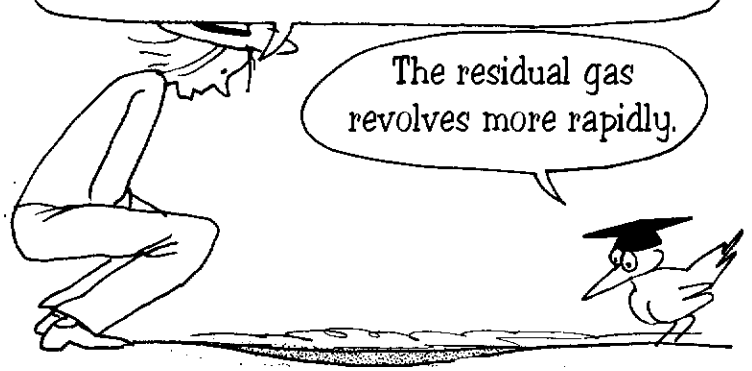


In effect, the **STELLAR SOUP** contains so many stars that it could be compared to the **MOLECULES OF A "STAR GAS"**.

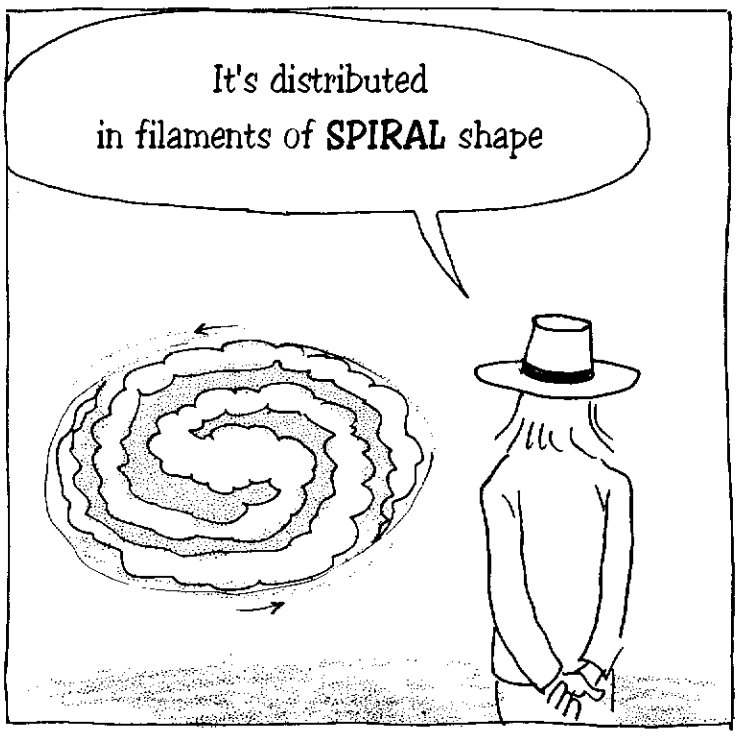
THE SPIRAL STRUCTURE

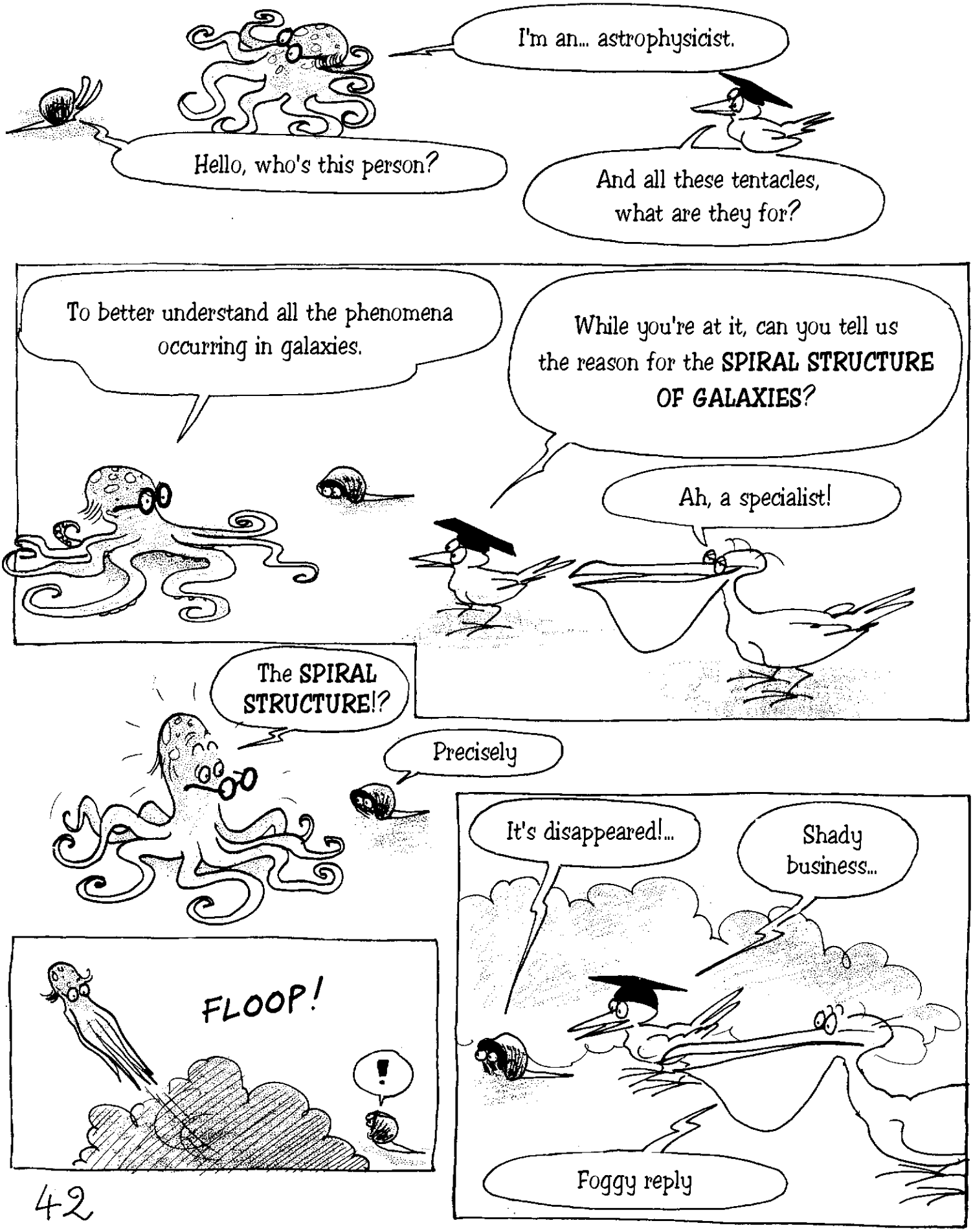
Look, something very singular is happening: interstellar gases and "star gas" are not revolving at the same speed, so the interstellar milieu becomes **HETEROGENOUS**.

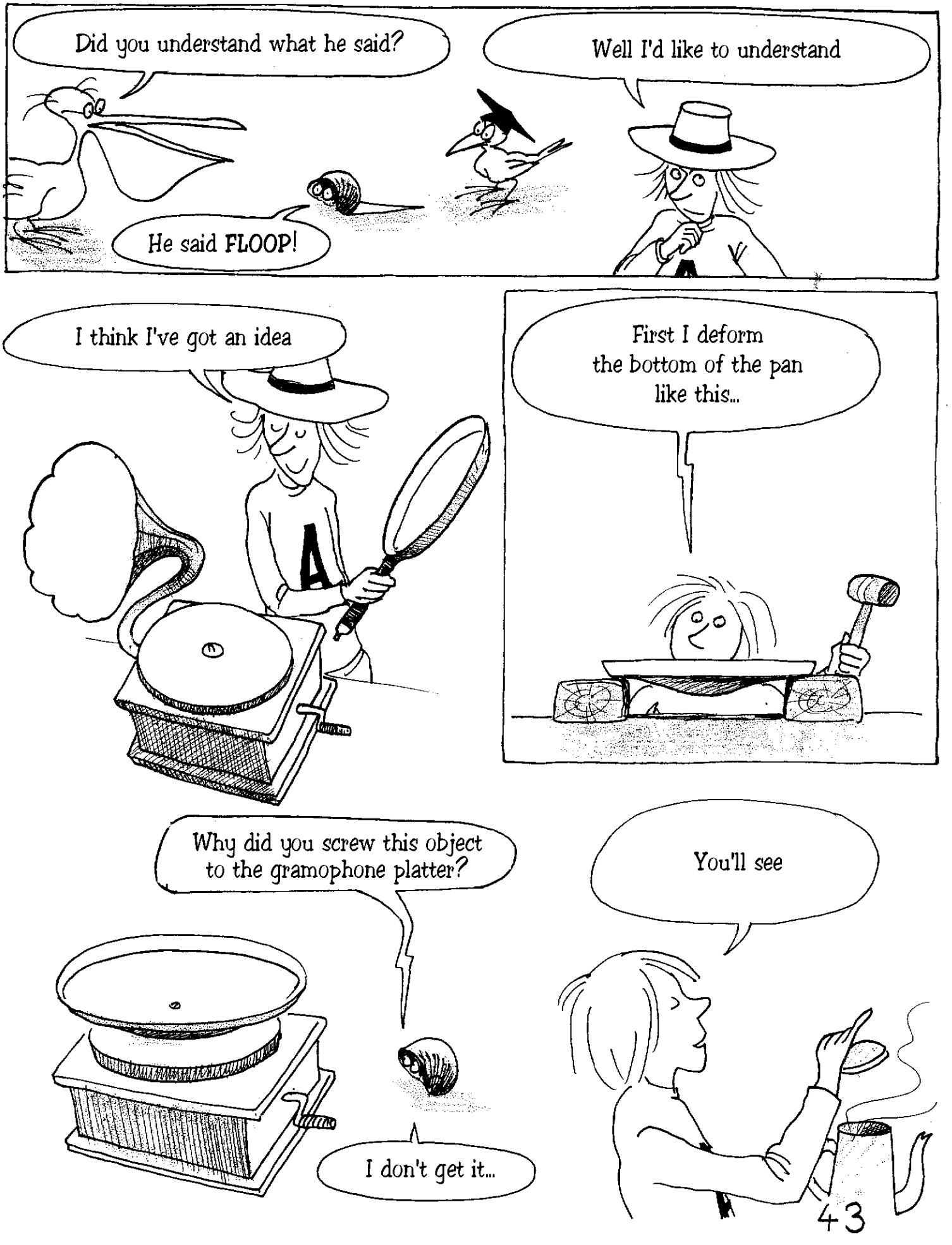
The residual gas revolves more rapidly.

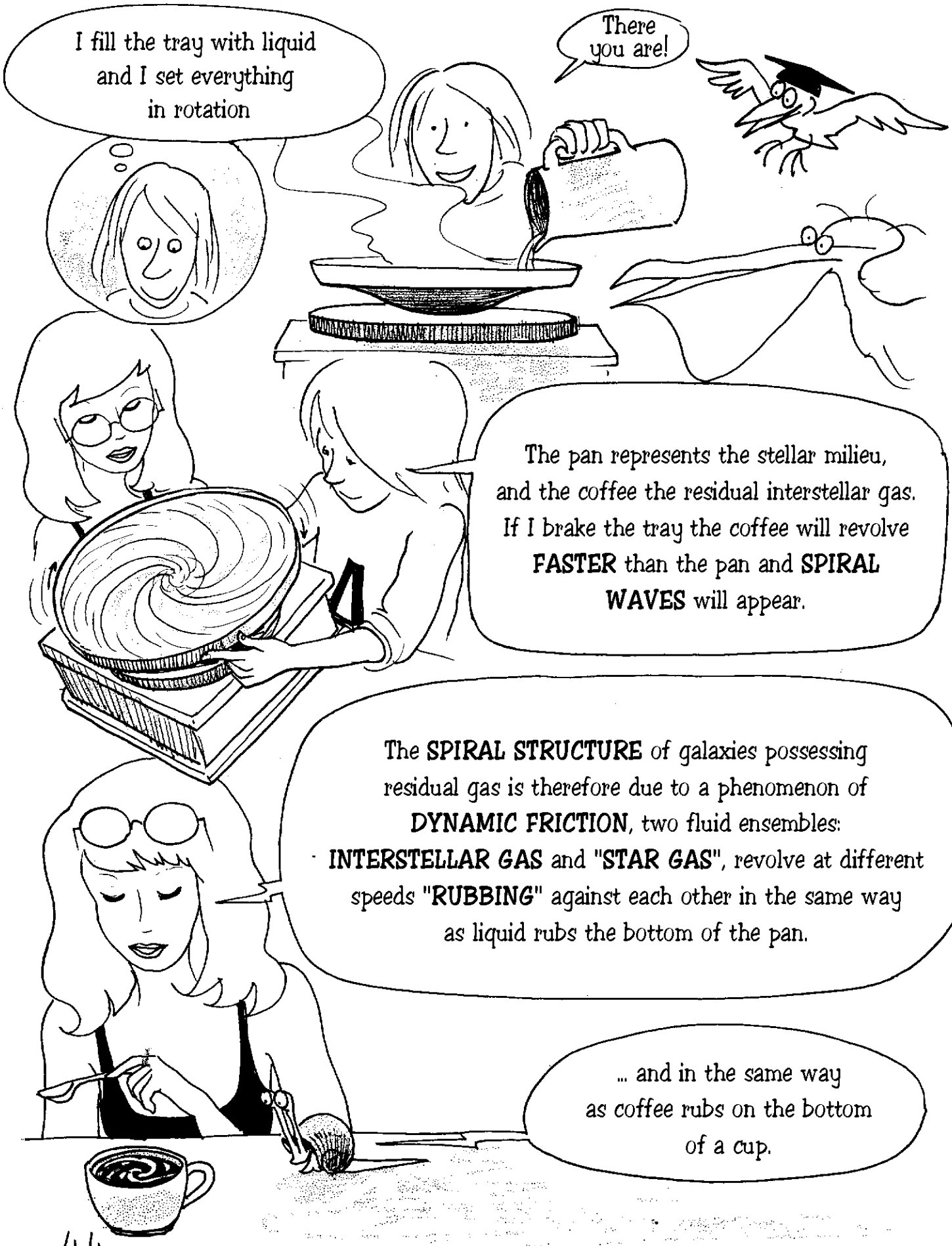


It's distributed in filaments of **SPIRAL** shape



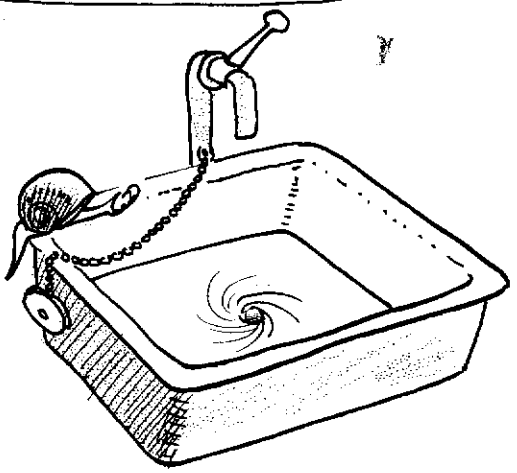

I'm an... astrophysicist.
Hello, who's this person?
And all these tentacles, what are they for?
To better understand all the phenomena occurring in galaxies.
While you're at it, can you tell us the reason for the SPIRAL STRUCTURE OF GALAXIES?
Ah, a specialist!
The SPIRAL STRUCTURE!?
Precisely
FLOOP!
!
It's disappeared!...
Shady business...
Foggy reply


Did you understand what he said?
He said FLOOP!
Well I'd like to understand
I think I've got an idea
First I deform the bottom of the pan like this...
Why did you screw this object to the gramophone platter?
I don't get it...
You'll see


I fill the tray with liquid and I set everything in rotation
There you are!
The pan represents the stellar milieu, and the coffee the residual interstellar gas. If I brake the tray the coffee will revolve **FASTER** than the pan and **SPIRAL WAVES** will appear.
The **SPIRAL STRUCTURE** of galaxies possessing residual gas is therefore due to a phenomenon of **DYNAMIC FRICTION**, two fluid ensembles: **INTERSTELLAR GAS** and "**STAR GAS**", revolve at different speeds "**RUBBING**" against each other in the same way as liquid rubs the bottom of the pan.
... and in the same way as coffee rubs on the bottom of a cup.

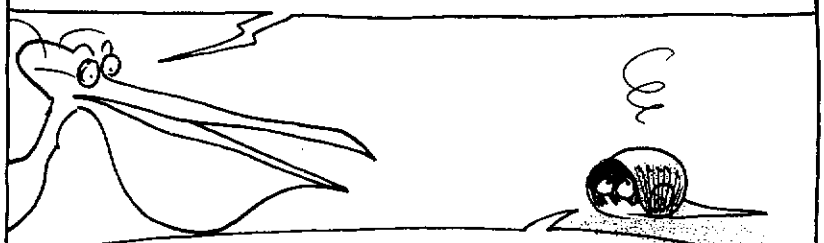
But why don't **ELLIPTICAL** galaxies have a spiral structure?

Simply because they don't have **RESIDUAL GAS**. They lost it at the moment of ignition of their **PRIMARY STARS**.



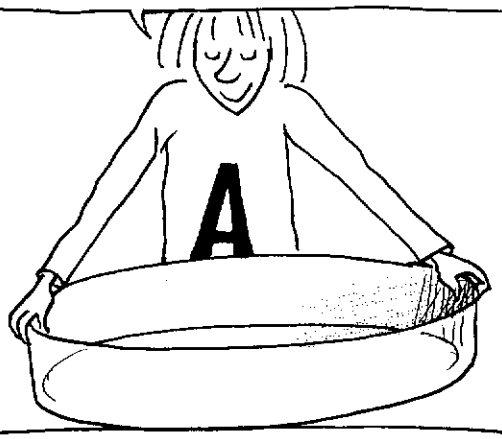
A DYNAMIC FRICTION phenomenon is also responsible for creating the spiral structure when a sink is emptied.

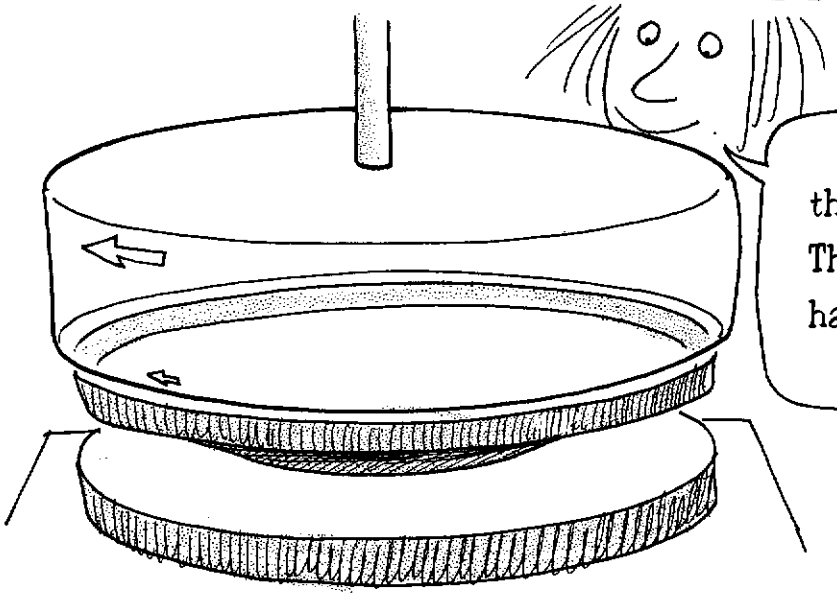
Hmm, what you're saying is serious. So the key to the mystery of spiral galaxies could be found at the bottom of coffee cups or sinks?!?



So could galaxies be the drain holes of the cosmos?

There we caused an interaction between a fluid and a solid wall. Let's try with a system in which two fluid masses interact.



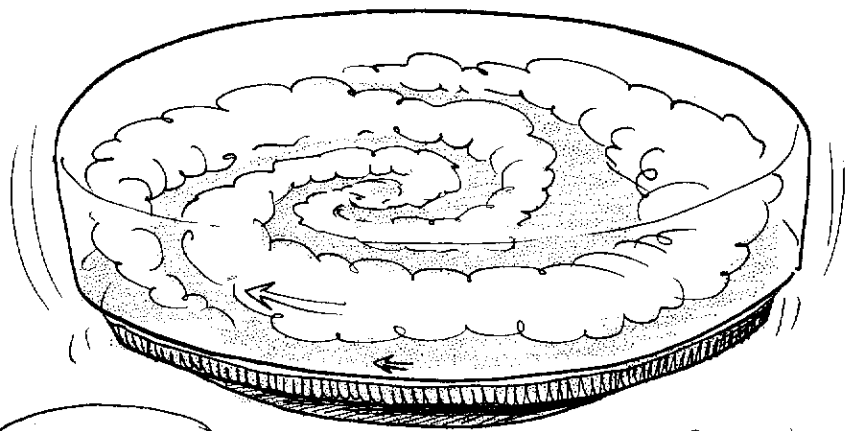


I've imprisoned the gas under this bell jar and put a liquid in my pan. Thanks to this system I can study what happens when a gaseous mass interacts with another fluid mass.

The rubbing together of liquid and gas is relatively weak. It will create very moderate local temperature and pressure fluctuations, a few per cent at most...

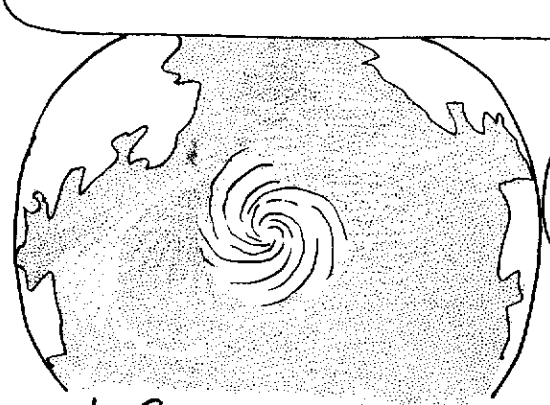
but my gas is supercharged with water vapour. It just wants to **CONDENSE** when there is the slightest temperature disturbance (*)

Look! Archibald has made a superb **ARTIFICIAL CYCLONE**



Very pretty!

My word Max, you're right!
In a cyclone, a mass of air supercharged with humidity "rubs" on its fluid support, this creates **PRESSURE** and **TEMPERATURE** perturbations which SET OFF the condensation of water vapour. This SECONDARY phenomenon violently reveals the PRIMARY spiral phenomenon. (**)



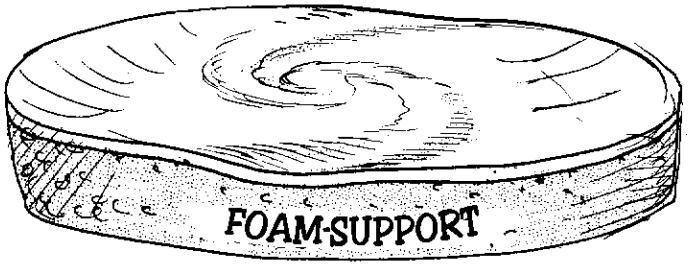
OK, but what has that got to do with galaxies? The spiral structure isn't a water vapour cloud after all.

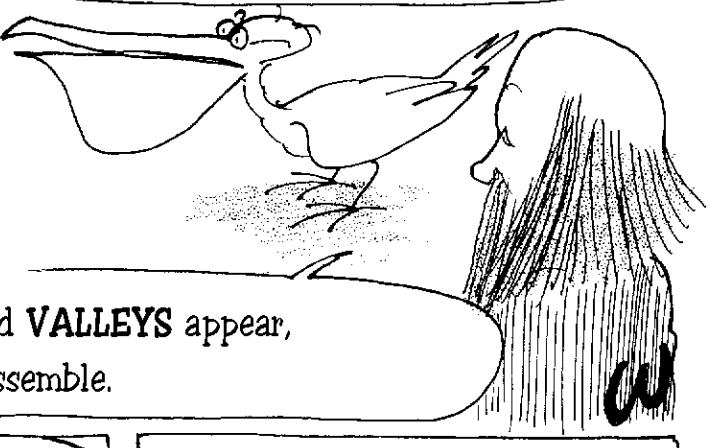
(*) **SUPERCRITICAL** vapour.

(**) A phenomenon which releases heat and feeds the cyclone with energy (but that's another story).

Let's return to our MODEL of galaxies. A fluid mass representing the "**STAR GAS**" turns in its "**BASIN**". It is topped by a mass of **RESIDUAL GAS** which revolves slightly faster. **DYNAMIC FRICTION** results and the **MASS** distribution varies, the perturbation having **SPIRAL** geometry.

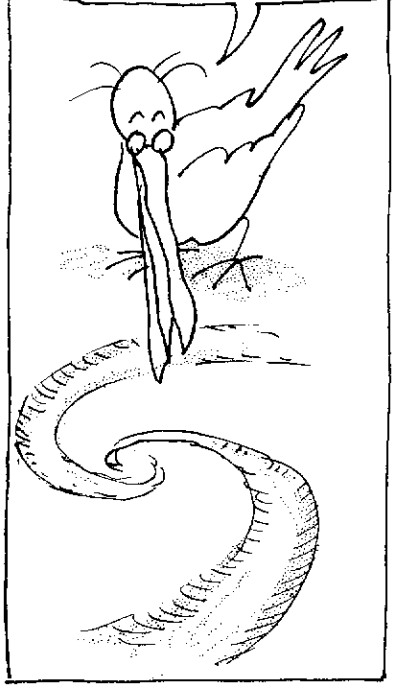
Every concentration of **MATTER** (star or gas) quicky mines into its foam-support. Where there is **MASS** there is **CURVATURE.**



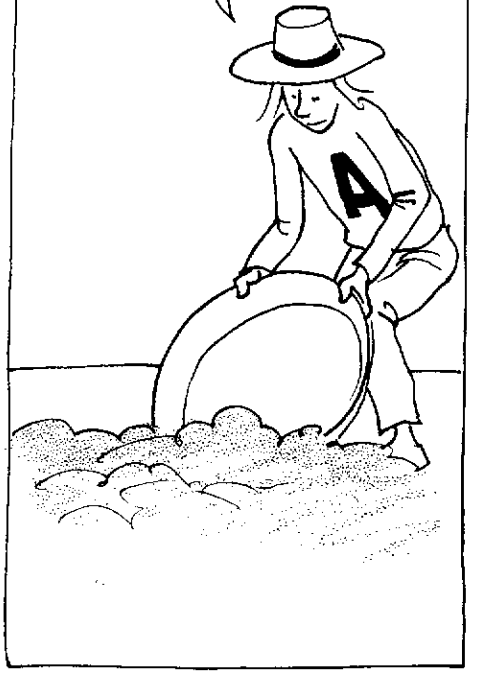


In other words, sorts of spiral shaped **VALLEYS** appear, where gas will tend to assemble.

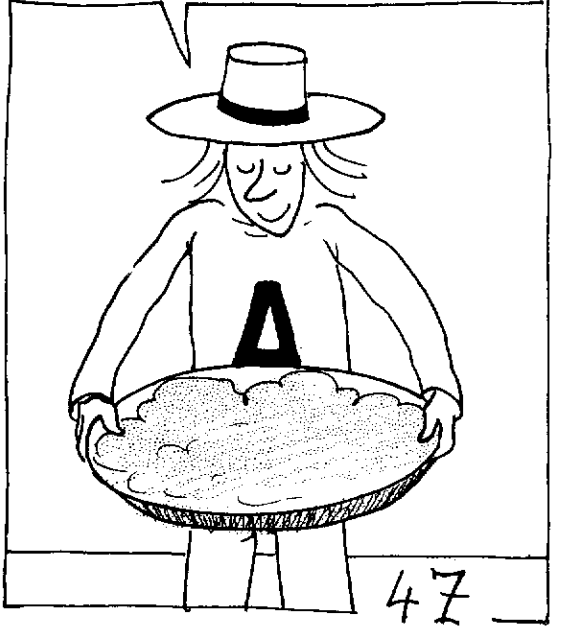
But I still can't see a water vapour concentration.



Let's collect a bit of interstellar gas



Let's look at what happens to interstellar gas when it "falls" into these 'valleys'



GALACTiC METABOLiSM

We'll go into a quiet corner far from any galaxy

What happens if I create a hollow in the foam-support? The gas will "fall" in...

Let's go!

We'll find the same phenomena as those described on pages 32 to 35

The gas will concentrate and heat up.

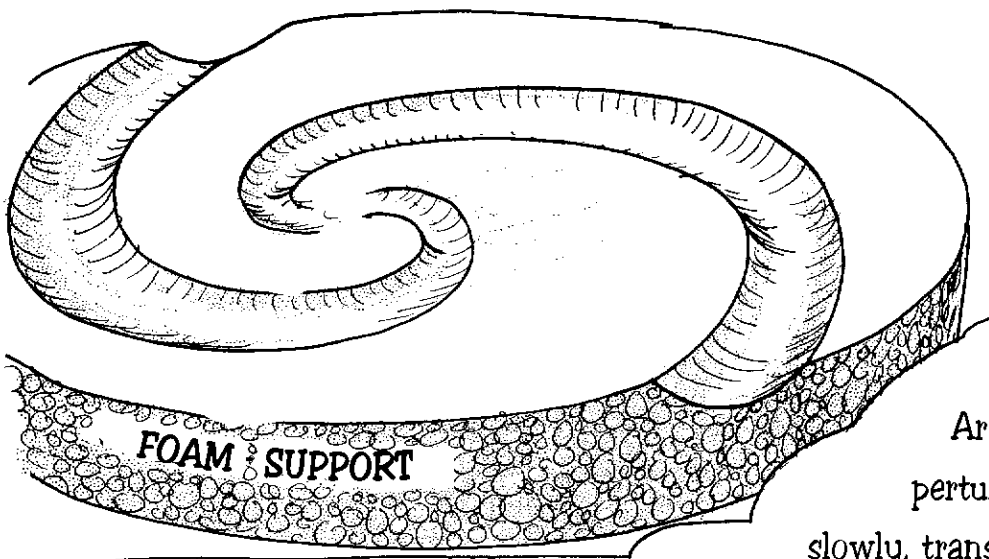
It then cools rapidly by radiation.

Destabilised, it fragments into a myriad of proto-stars which will immediately...

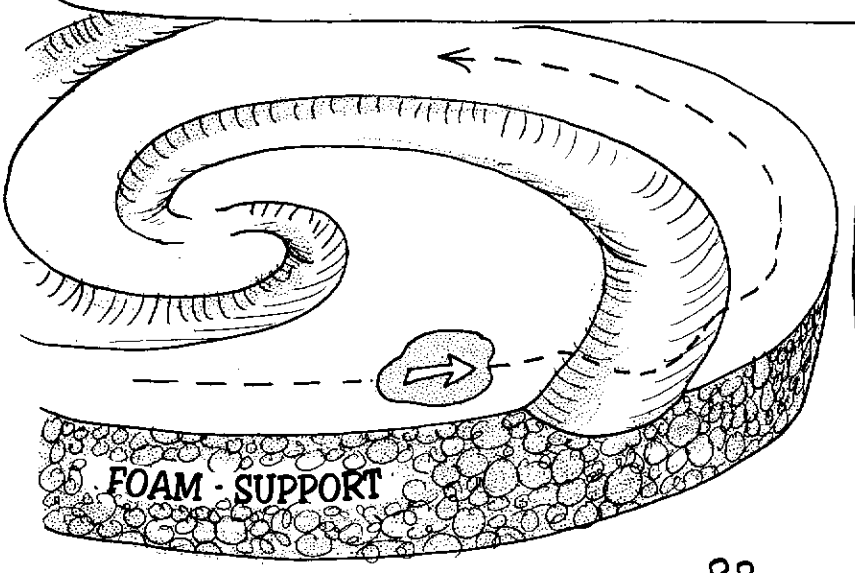
... light up and give **SECONDARY STARS.**

With this sort of ruler
I'm going to create a **VALLEY**

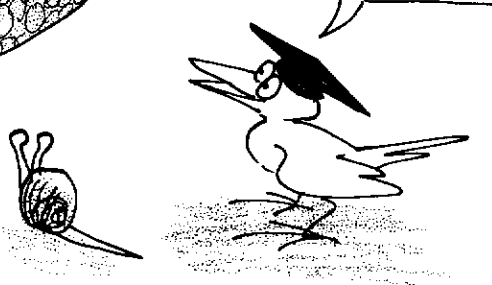
The same thing: stars are born
in the hollows of the valley.

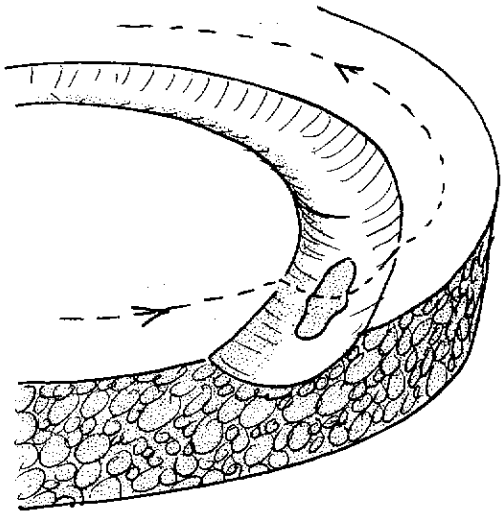


Archibald is right: the spiral perturbation, revolving very slowly, translates as these relatively shallow sides (a few per cent of the general hollow, the "galaxy-basin")

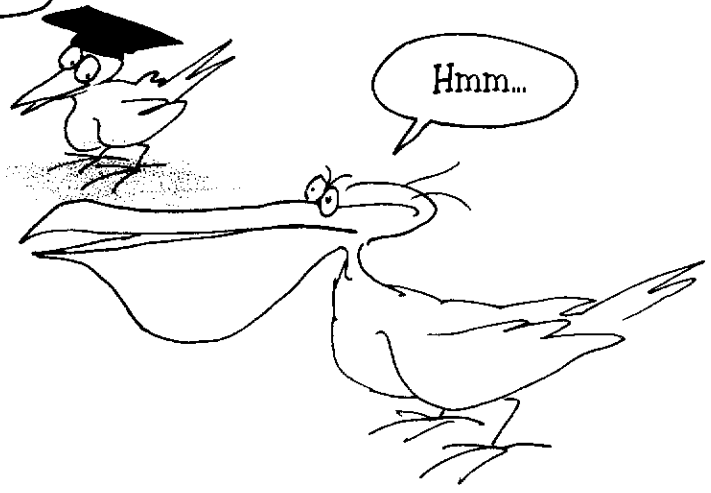


The interstellar gas revolves more rapidly than the spiral perturbation. Here we see an element of gas which is about to enter the "valley".





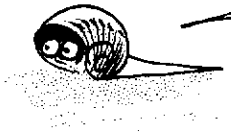
When it arrives at the bottom of the valley it finds itself compressed and gives birth, in passing, to a few **SECOND GENERATION STARS**. Then it quietly leaves. The **SPIRAL ARMS** are therefore the places where new stars are born.

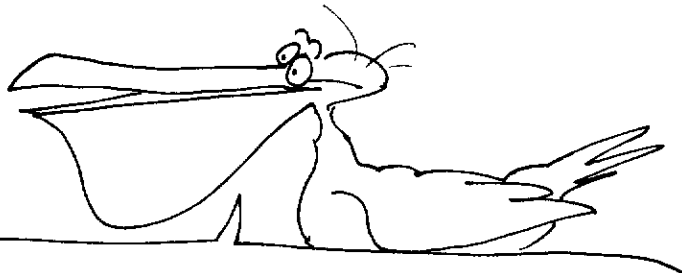


CYCLONES OF THE UNIVERSE

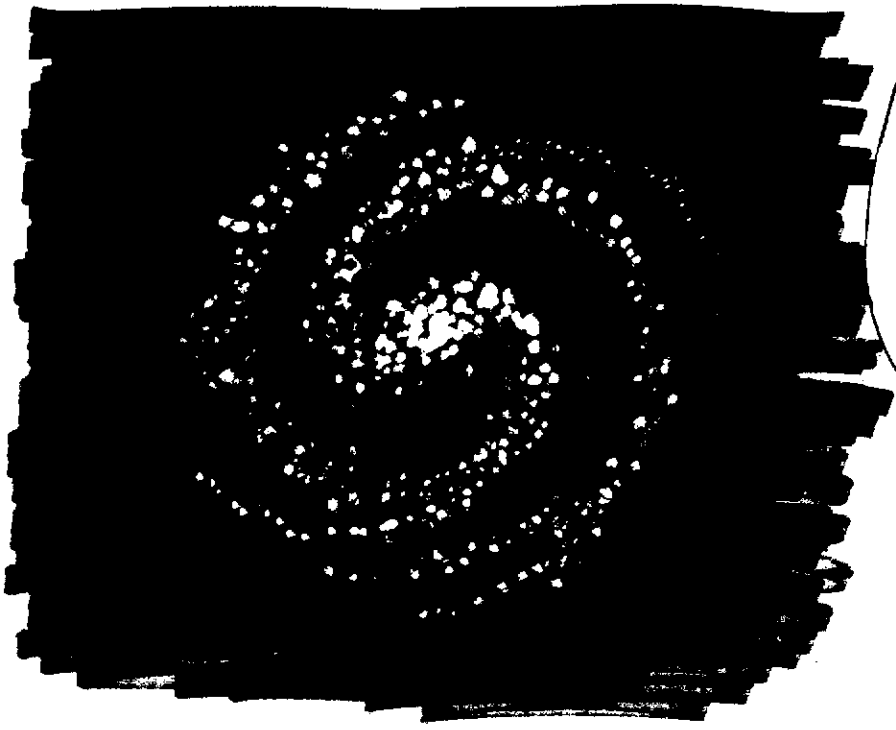
In terrestrial cyclones the initial perturbation is slight but the atmosphere, charged with humidity and therefore **UNSTABLE**, reveals the phenomenon of water vapour condensation.

In galaxies, the primitive spiral perturbation is also slight, but **UNSTABLE** interstellar gas reveals the phenomenon by setting off the condensation of matter.

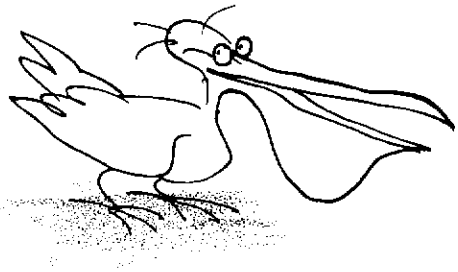




Your theory is very pretty but as for these second generation stars, we should find lots of them in the galaxy!



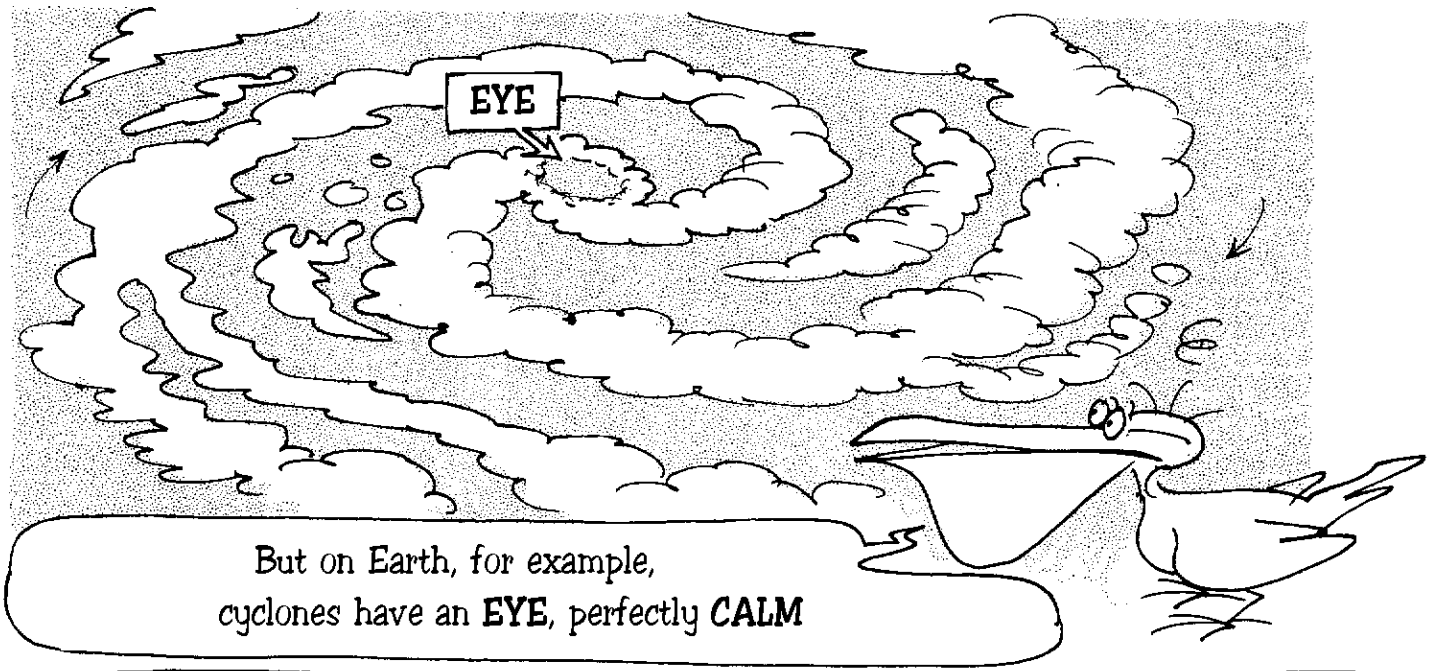
However we only find these young and very hot stars in the arms of the spiral, where they signal their presence by a strong illumination of the stellar gas.



But Leon, you're forgetting that these stars don't remain young for very long. Just long enough to burn a maximum amount of hydrogen. When they leave the arms they are already DYING, they're just embers.

And we can no longer detect them.

INTERSTELLAR GAS too is only clearly visible in the arms, where it is brightly lit by the young stars. Once it leaves the arms it becomes dark.



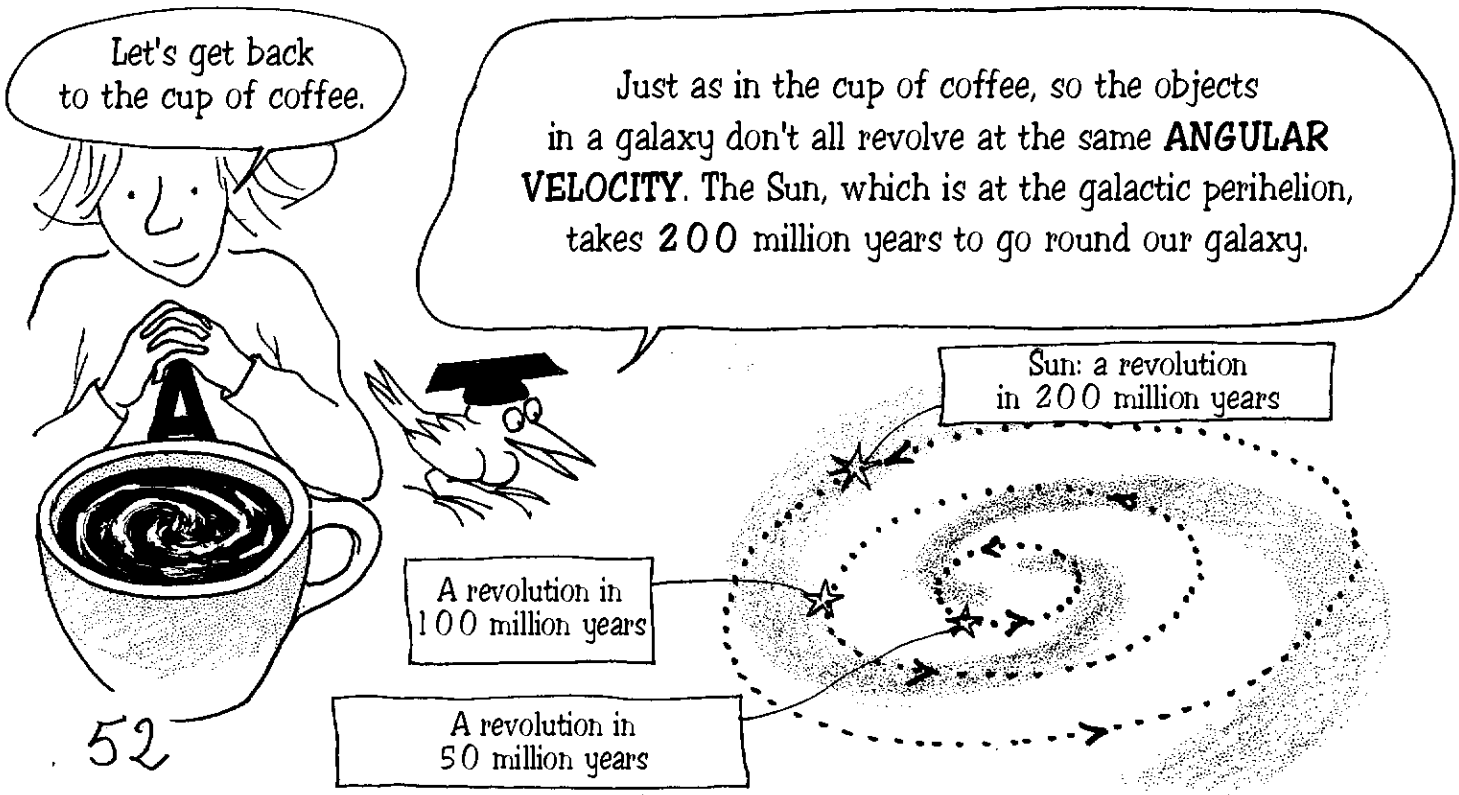
But on Earth, for example, cyclones have an **EYE**, perfectly **CALM**

And you know what, these **PLANET-UNIVERSE** cyclones also have a **CENTRAL EYE**!

DiFFERENTiAL ROTATiON

Let's get back to the cup of coffee.

Just as in the cup of coffee, so the objects in a galaxy don't all revolve at the same **ANGULAR VELOCITY**. The Sun, which is at the galactic perihelion, takes **200** million years to go round our galaxy.



In short, the centre of a galaxy revolves more quickly that its periphery.

They're sinks, obviously!

Since Tiresias almost disappeared into a black hole, he's become very wary.

That isn't silly. Lots of very nice people think that there is a big black hole at the centre of galaxies.

Here's a "**REAL**" galaxy, with movement in three dimensions.

Schematically, stars, which are elements of "star gas" (so assimilable to "molecules") cross the ultra-flat **GAS DISC** with each revolution

This explains why the interaction 'stellar milieu-interstellar milieu' is relatively weak.

GAS DISC

I suppose it is because they only interact with the gas when they cross the flat disc.

Exactly!

Firstly, in the centre of galaxies there aren't any stars, and secondly, their rotation period is shorter.

So in this region the interaction, the friction between the stellar and the interstellar milieus, is greater.

Once round in 50 million years.

Consequently, this structure will be more marked in the central region and could transform itself into a **BAR**

Let's get back to the gas. What happens if I let a lump of **INTERSTELLAR GAS** just do as it likes?

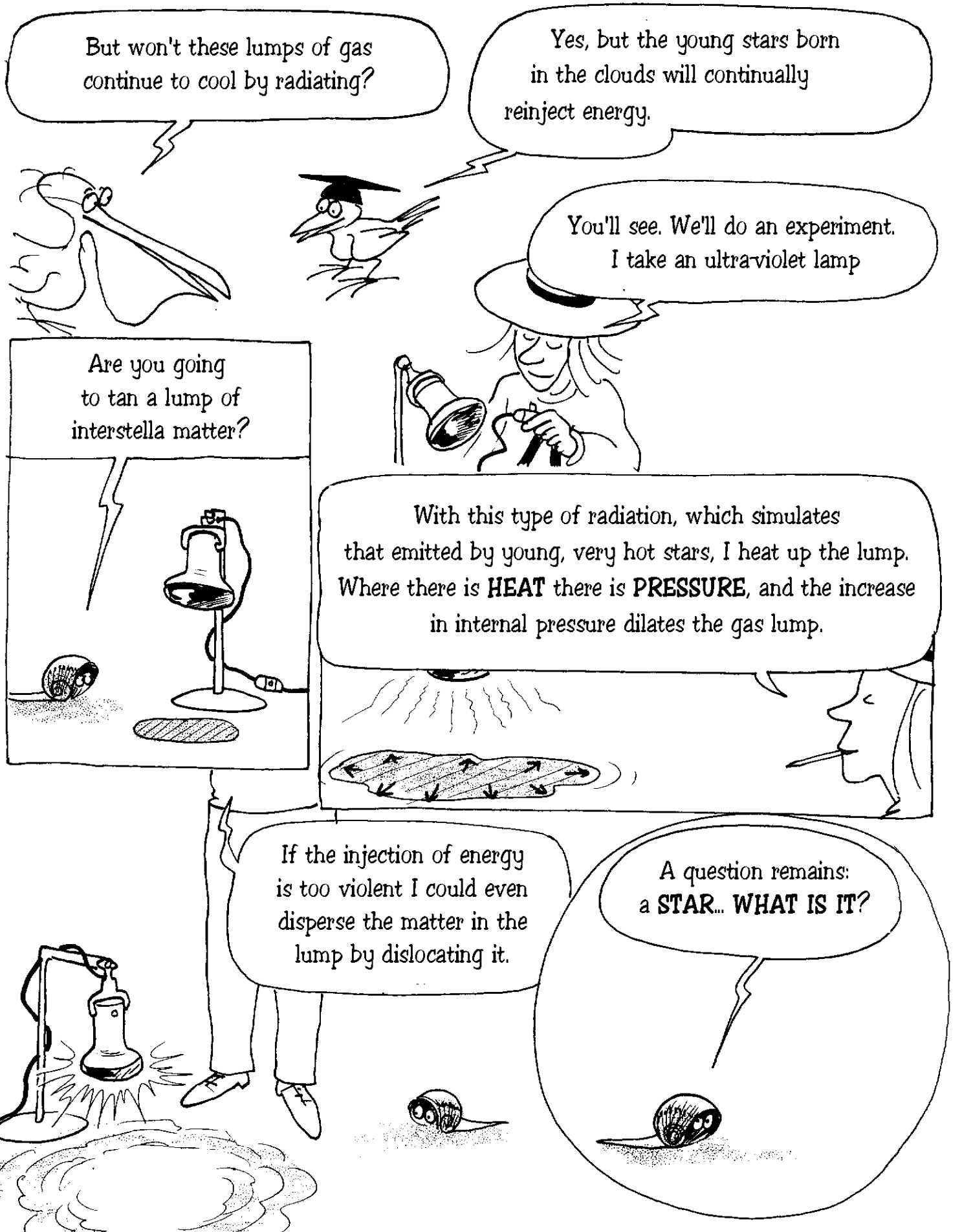
This time we won't intervene..

We'll just watch.

The gas is cooling naturally by radiation. Its Jeans distance diminishes and it fragments.

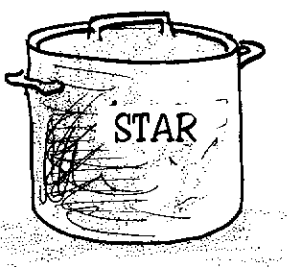
In the arms of galaxies the gas also has a tendancy to collect into large lumps whose radius is equal to the **JEANS RADIUS** (*)

(*) In "real" galaxies the thickness of the disc is also close to this radius.

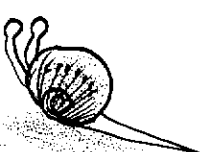

But won't these lumps of gas continue to cool by radiating?
Yes, but the young stars born in the clouds will continually reinject energy.
You'll see. We'll do an experiment. I take an ultra-violet lamp
Are you going to tan a lump of interstella matter?
With this type of radiation, which simulates that emitted by young, very hot stars, I heat up the lump. Where there is HEAT there is PRESSURE, and the increase in internal pressure dilates the gas lump.
If the injection of energy is too violent I could even disperse the matter in the lump by dislocating it.
A question remains: a STAR... WHAT IS IT?

STELLAR PHENOMENON

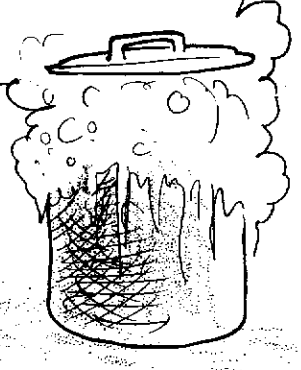
At the centre of a gas lump the temperature and pressure conditions become such that hydrogen **FUSION** occurs, emitting a great deal of energy.



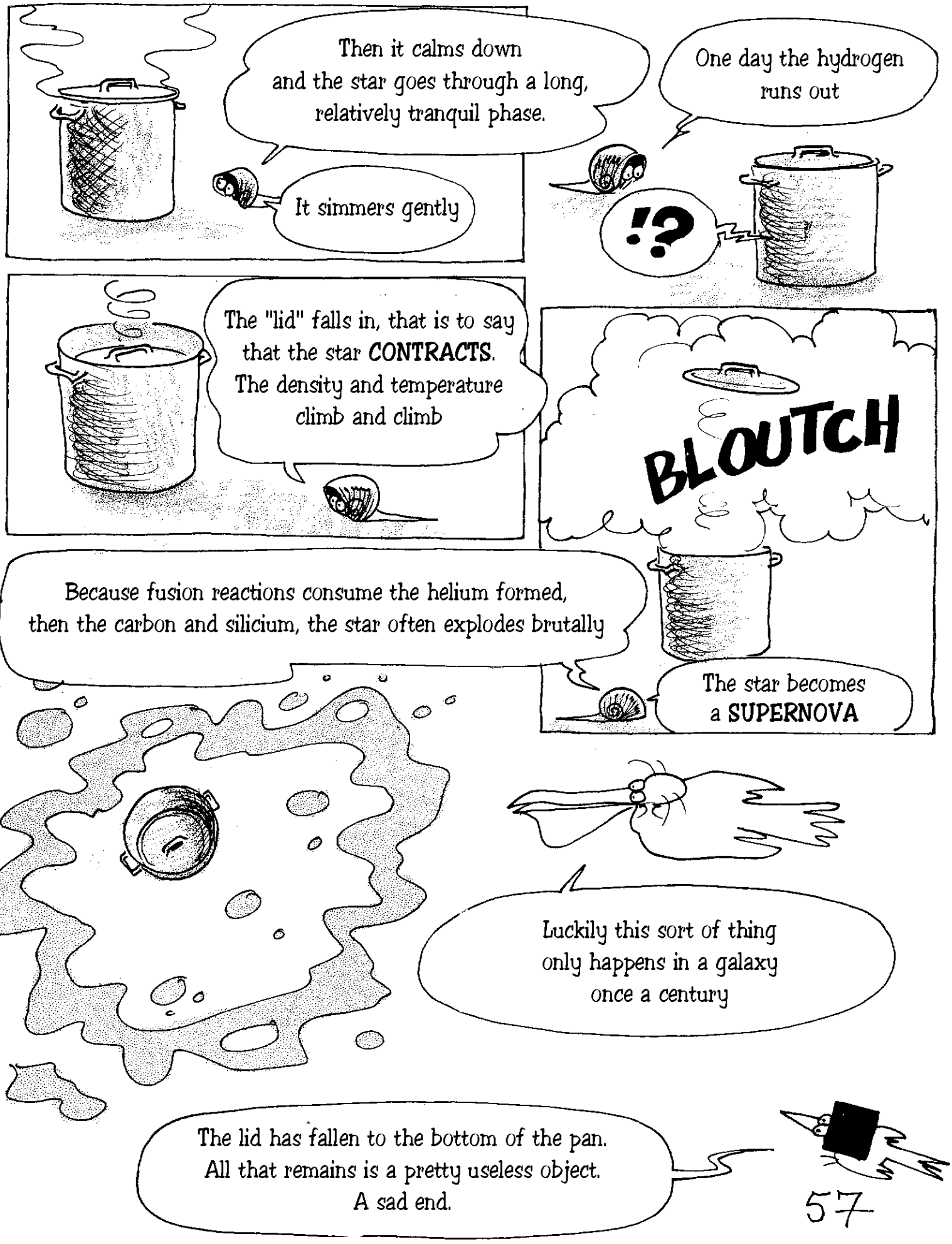
This increases the **PRESSURE** in the centre of the star even more. Don't forget that pressure is only the measure of the quantity of energy per unit of volume.



In short, a **STAR** is a sort of automatic stewpot, it heats up all by itself.



The **DIAMETER** of the star depends on the quantity of energy released. Immediately after its birth the star is extremely rich in hydrogen, so it 'burns' like a madman and dilates consideraby.


Then it calms down and the star goes through a long, relatively tranquil phase.
It simmers gently
One day the hydrogen runs out
!?
The "lid" falls in, that is to say that the star CONTRACTS. The density and temperature climb and climb
BLOUTCH
Because fusion reactions consume the helium formed, then the carbon and silicium, the star often explodes brutally
The star becomes a SUPERNOVA
Luckily this sort of thing only happens in a galaxy once a century
The lid has fallen to the bottom of the pan. All that remains is a pretty useless object. A sad end.

But Leon, once a century is a VERY rapid rhythm. Remember, a galaxy takes 200 million years to revolve on itself.

Heavens, that makes two million **SUPERNOVAE** per revolution!

The **SUPERNOVAE** project their debris for hundreds of light years (*)

Supernovae explode anywhere at any time and maintain great disorder in the interstellar milieu.

And these supernovae feed energy back into the interstellar gas.

CHPAF!

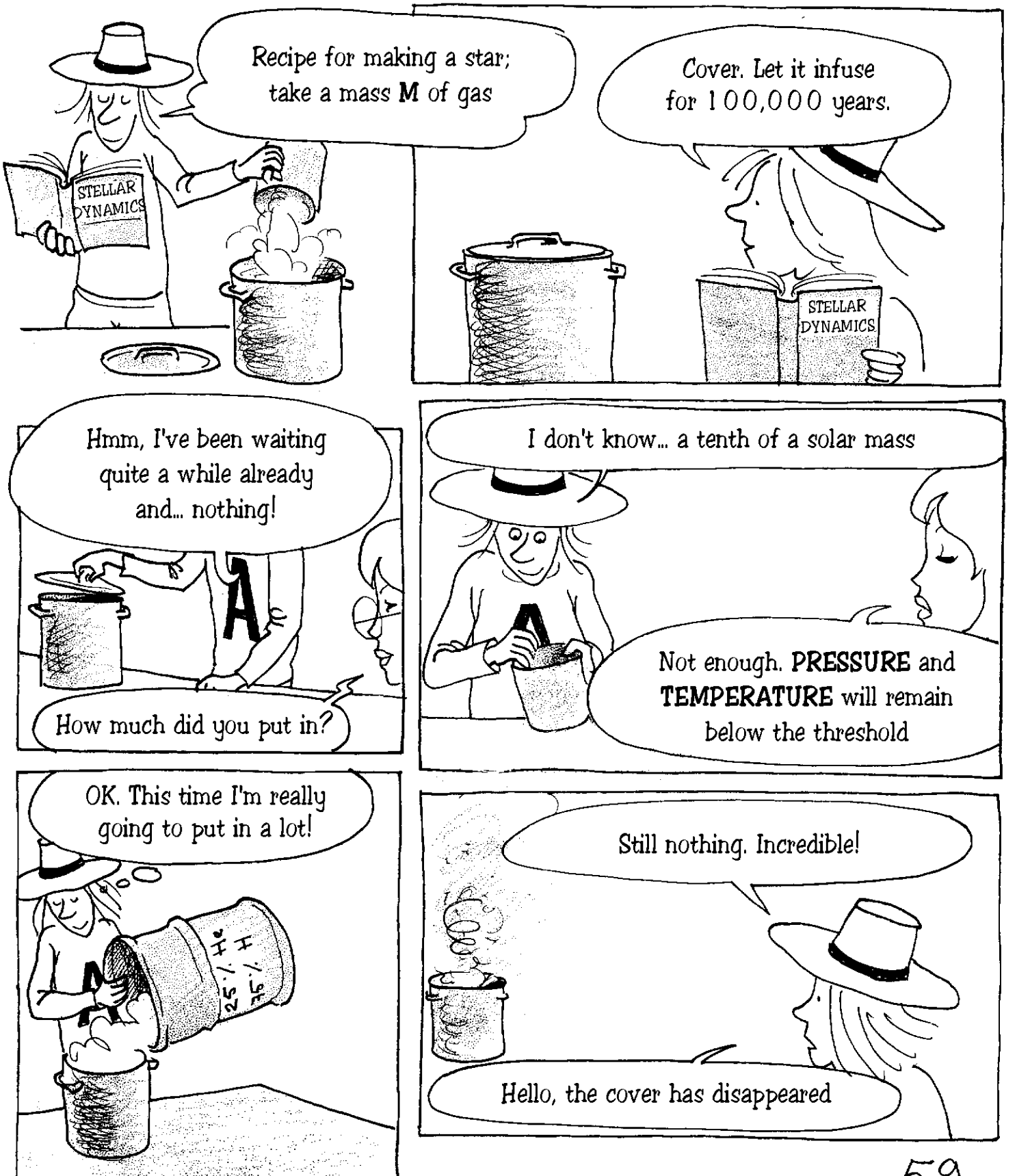
Another one that's gone bang.

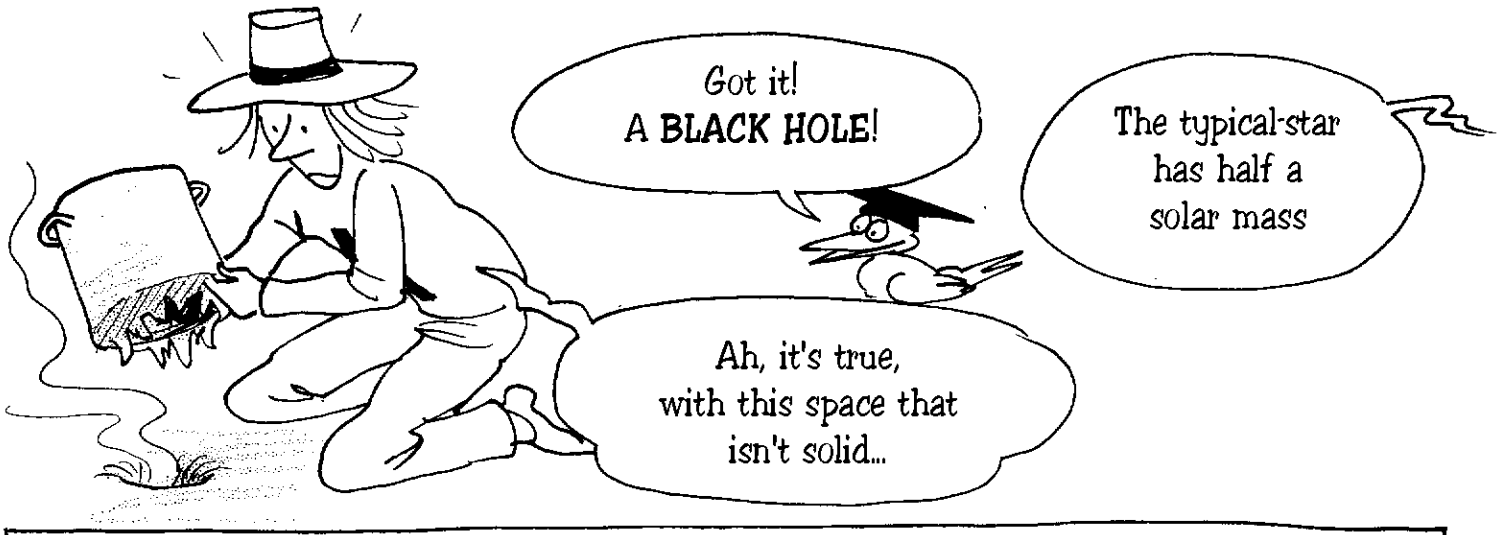
CHPAF!

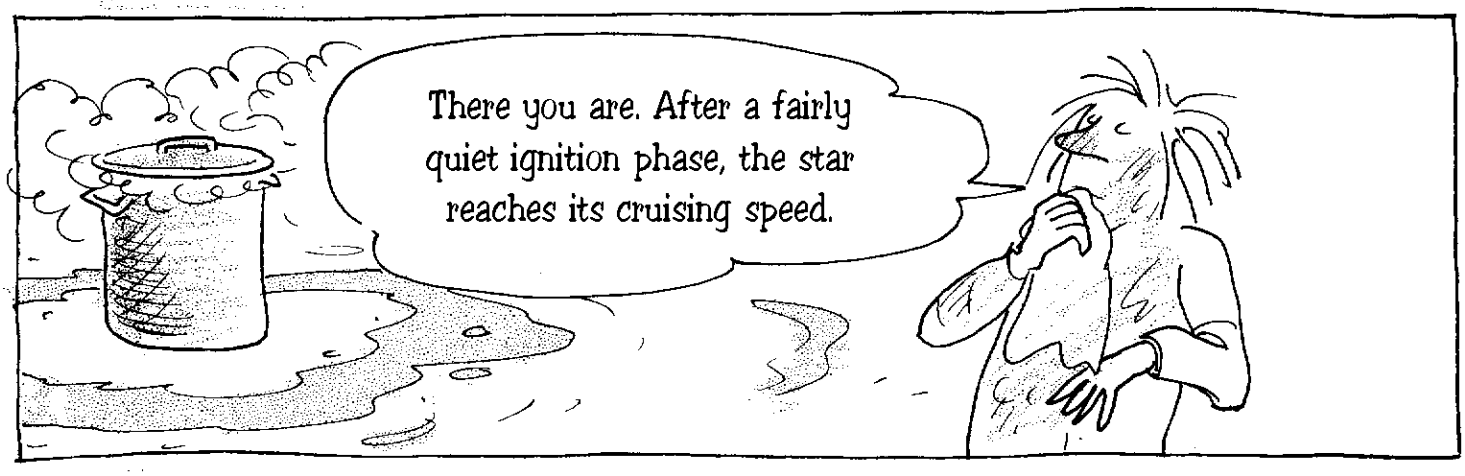
Let's go and find somewhere quieter.

(*) A galaxy has a diameter of a hundred million light years.

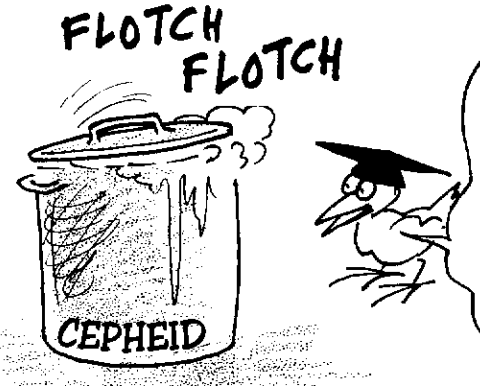
TYPES OF STARS







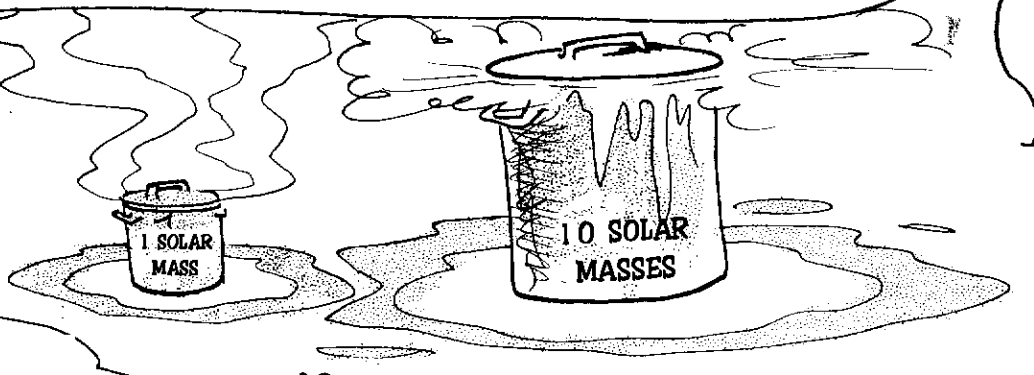
CEPHEIDS



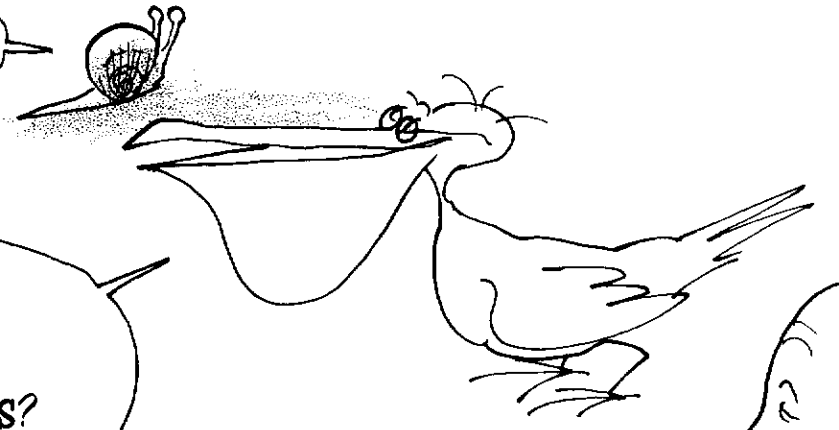
The greater the mass of a **CEPHEID**, the longer its period. A measure (parallax) of distance has allowed us to use these stars to measure the distance separating us from the Andromeda galaxy.

The Management

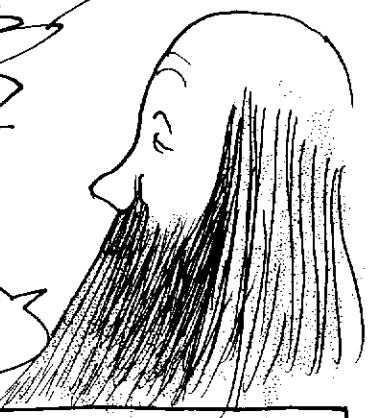
The more **MASSIVE** a star, the QUICKER it evolves.
A star of the solar type can burn peacefully for billions of years
but a young, massive star uses up its hydrogen in a million years.
It will have an explosive end.



Massive stars
are stars at risk.



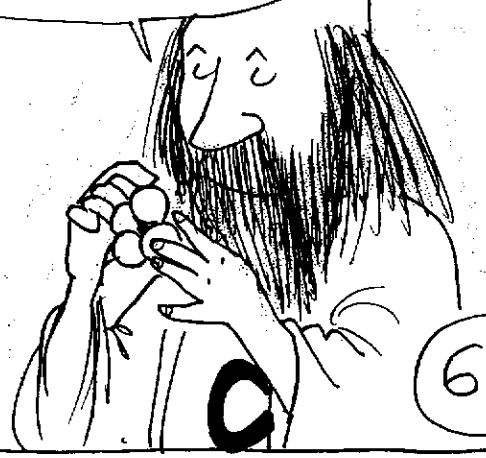
I'm going to ask
Tiresias a question:
WHAT USE ARE STARS?



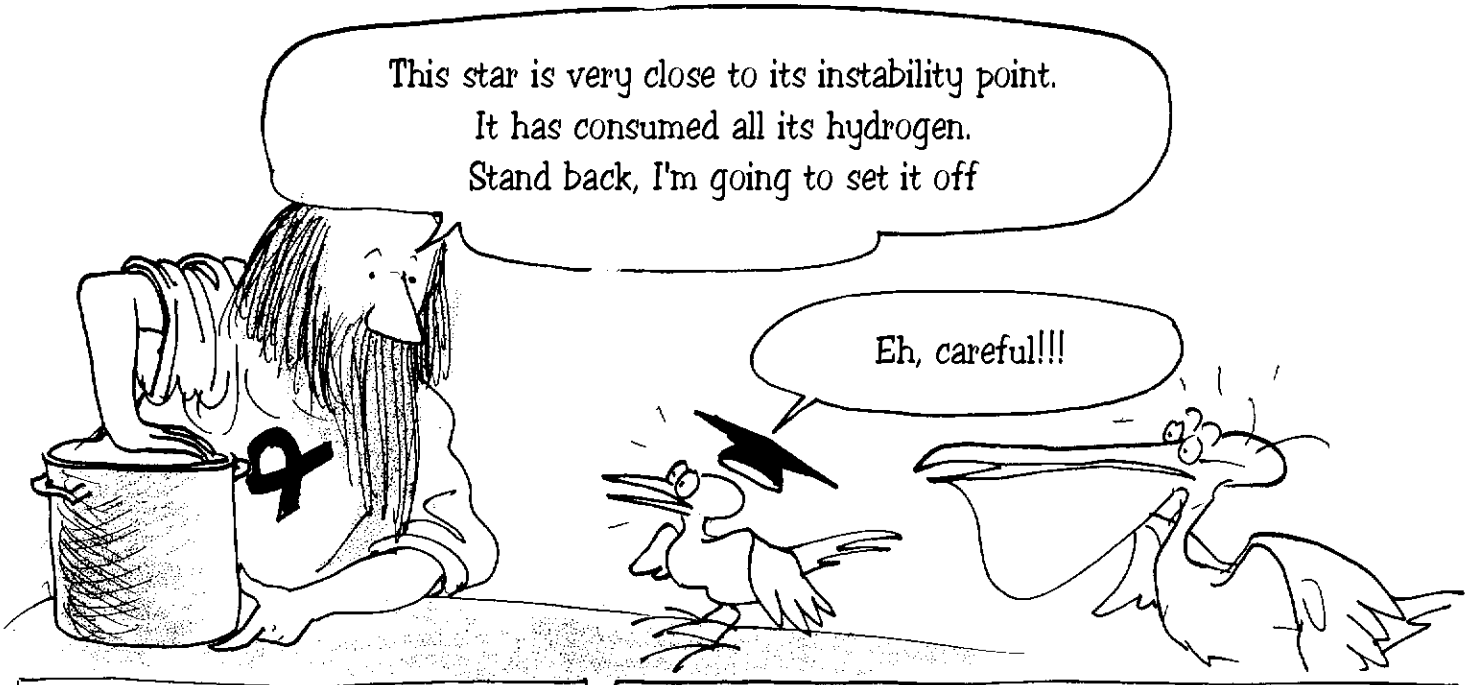
EXCELLENT QUESTION!

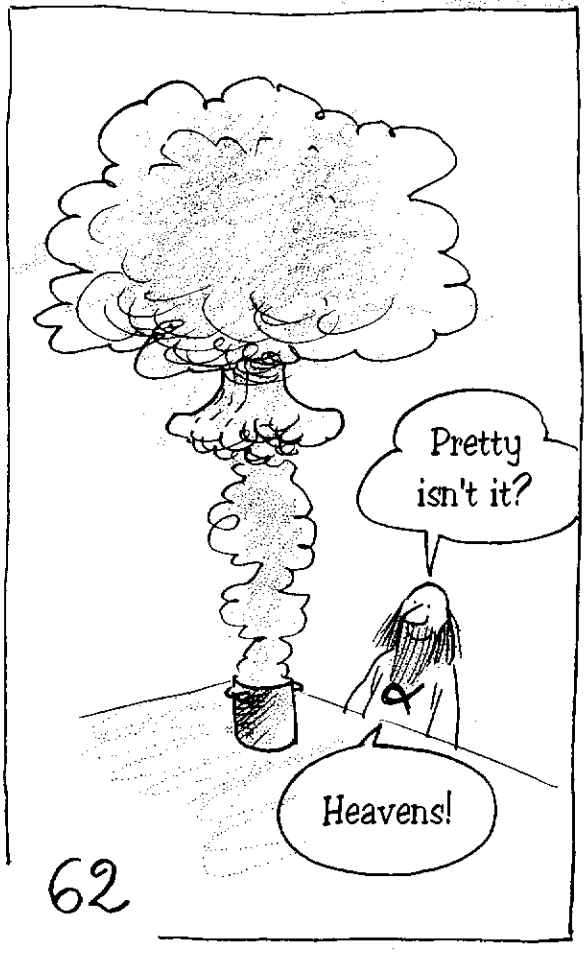
In the heart of stars, nucleii of atoms
are subjected to extremely high pressures.
The **FUSION** of four hydrogen
nucleii gives...

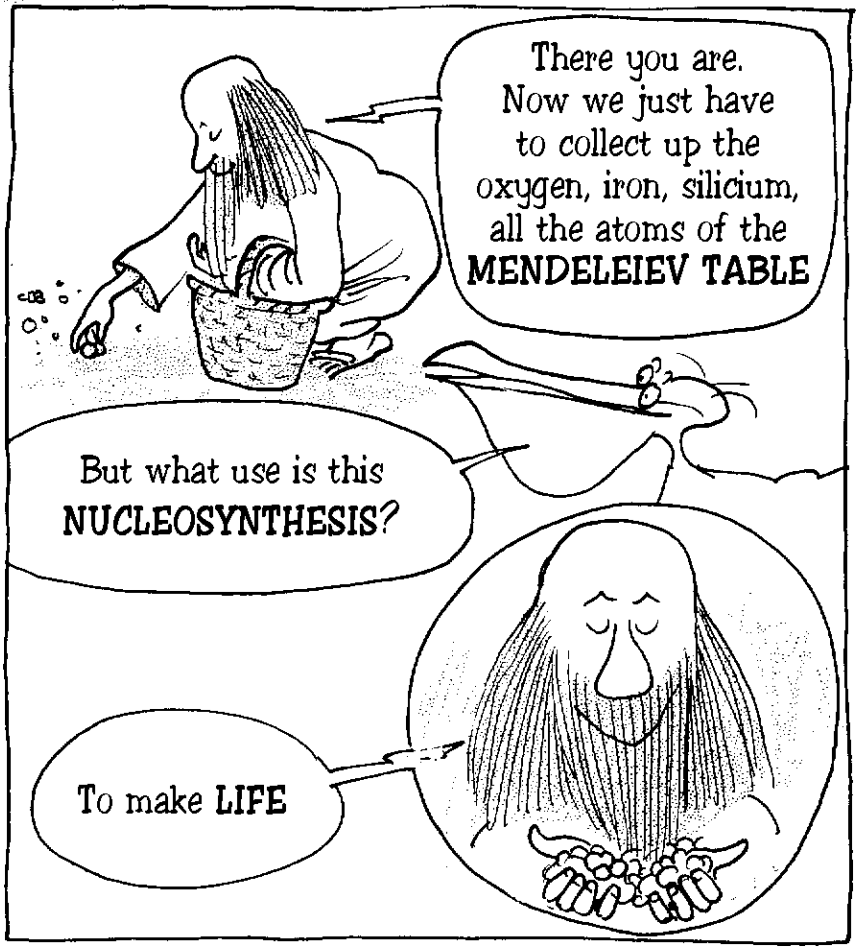
... helium



THE SPORES OF THE UNIVERSE

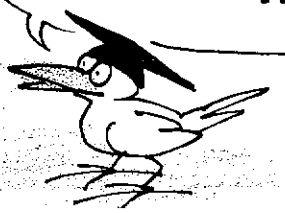






Heavy atoms agglomerate to give microscopic **DUST**...

...which would serve the **NATURAL CATALYST** to synthesise the **FIRST MOLECULES**



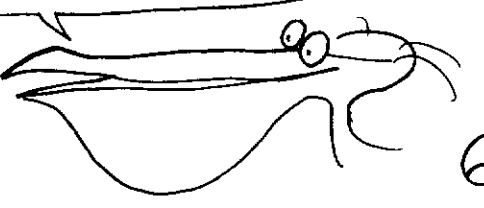
CLOUDS AND RAiN

The matter ejected by stars, either by a slow exhalation or through violent death, re-enriches the mass of interstellar gas

In sum, an atom, chosen randomly, may well have lived in many different stars, especially if it has a heavy nucleus

This cycle of the passage of atoms in stars is accompanied by a constant enriching in **HEAVY ELEMENTS**, metals for example: Iron, Nickel, Copper.

So the younger stars are, the richer they are in **METALS**!




Archibald, what are you doing?
Come with me
It's time to make a synthesis of all we know about galaxies
Here I have the best observational data
Of matter. First, two hundred billion stars.
A little bit of interstellar gas
We make it all turn
But... what's happening
Everything is disappearing !!?
Sophie, I'm dismayed. My galaxy has completely exploded yet I used the most recent observational data.
Failed completely...

MISSING MASS

In this representation centrifugal force is stronger than the force of gravitational attraction. The **MASS** involved is **TWO TIMES TOO WEAK**.

If we use the observational data as a base, the model doesn't fit at all. That's annoying...

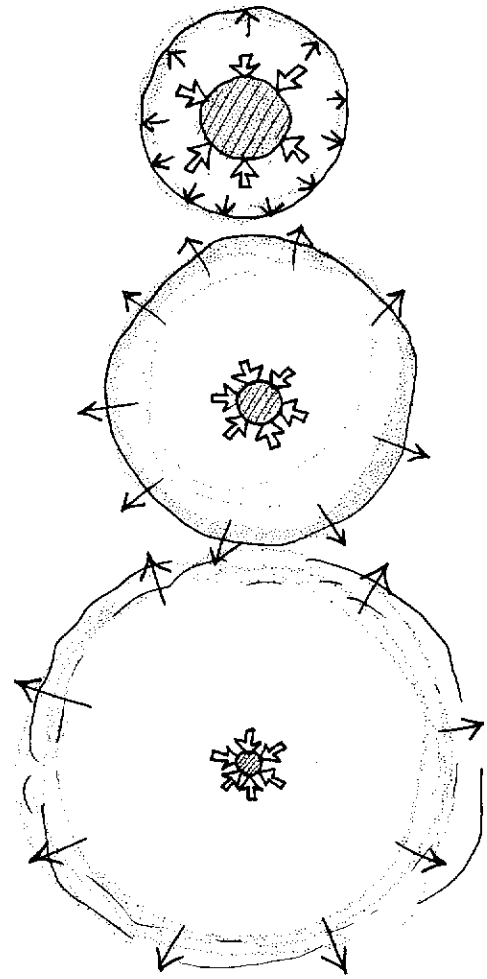
In other words:
LOST 200 MILLION STARS.
ANY INFORMATION ALLOWING THIS **MISSING MASS** TO BE FOUND IS VERY WELCOME

We can only count what we **SEE**

At the end of its life, when it expels a part of its mass, all that remains of the star is a residue called a **WHITE DWARF** or **BLACK DWARF**, usually emitting too weakly to be detected.

Which means that we're not able to detect the **INVISIBLE MASS** represented by the ashes of the primitive stars formed at the same time as the galaxy.

In an end of the type **SUPERNOVA**, the external layer of the star explodes. The resulting retrocompression can compress the central nucleus to the point where it changes into a **BLACK HOLE**



More objects that will avouid observation

Do any primitive stars remain, those born at the same time as the galaxy but that remain detectable?

Yes, in effect, some very old stars remain grouped in **GLOBULAR CLUSTERS** which have been burning for about fifteen billion years. And that in every galaxy, all born at the same time.

As for the others, they've been dispersed into the four corners of the galaxy, or have become black or white dwarves, or undetectable black holes.

STELLAR CLUSTERS

A globular cluster is a structure of a hundred thousand stars, which has persisted since the birth of galaxies (*)

But galaxies are sprinkled with small, recent clusters, now rapidly being dispersed

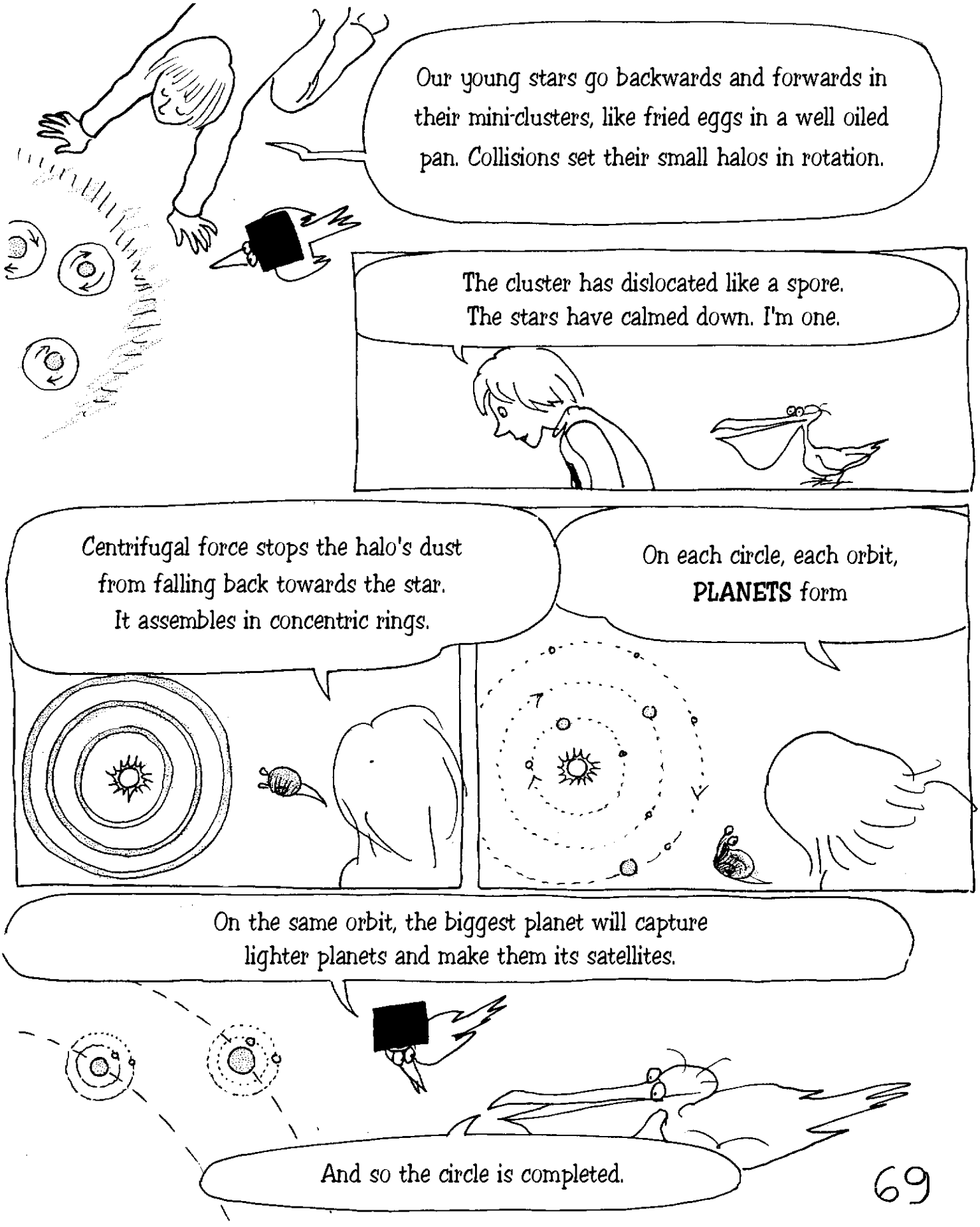
These mini-clusters represent basins with shallow edges where stars, accelerated according to the pot luck of collisions, can escape relatively easily.

When the cluster is dislocated, the stars shoot off haphazardly throughout the galaxy, alone or in couples (**DOUBLE STARS**)

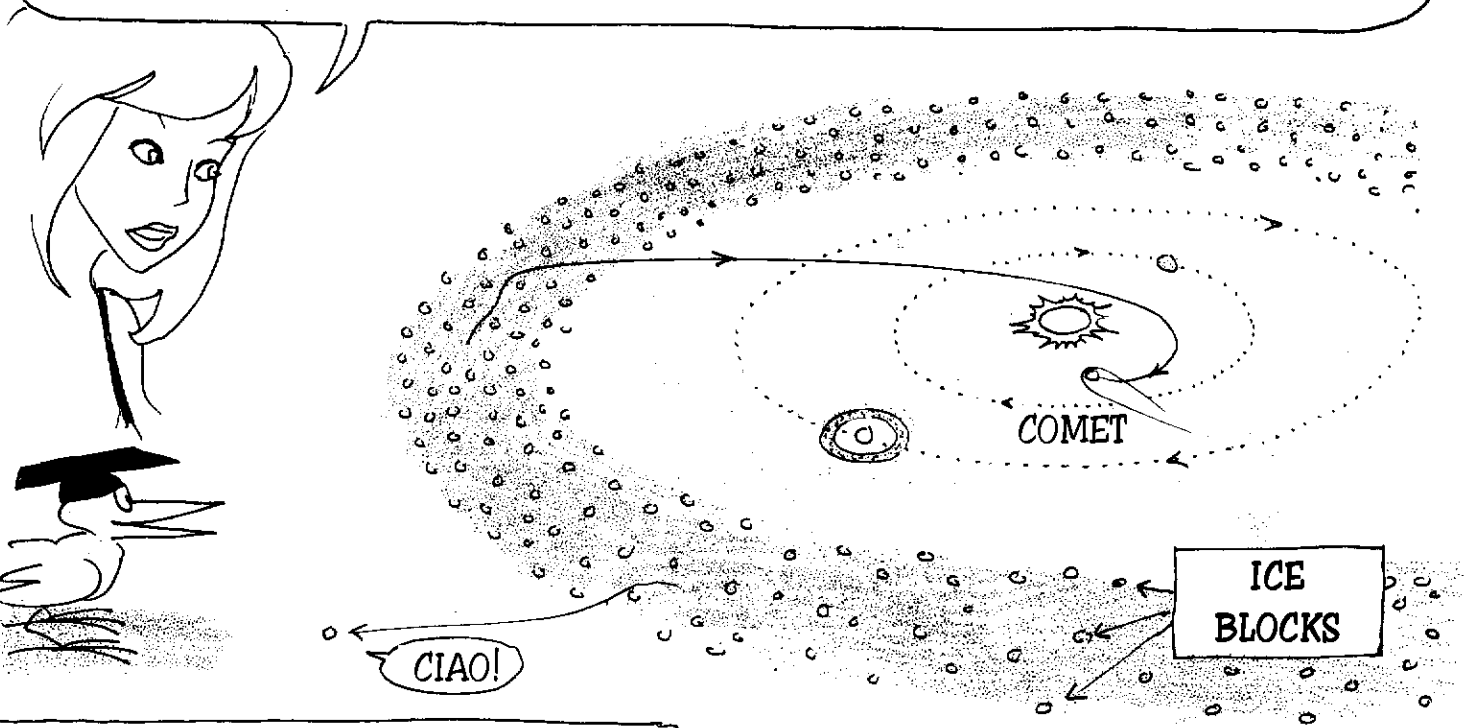
(*) The speed of evaporation of a collisional cluster is proportional to its mass.

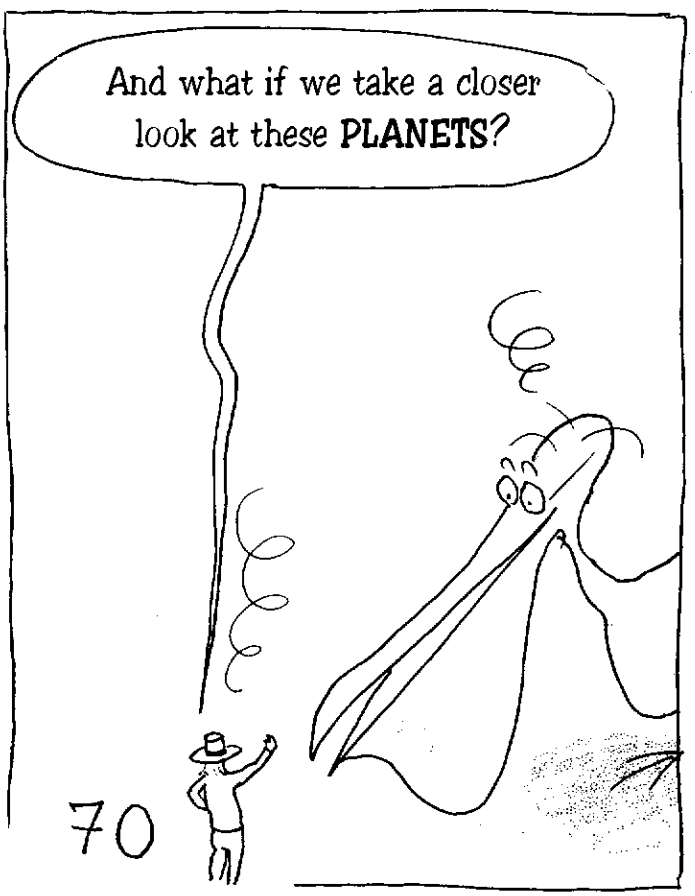

The formation of two stars, with similar or different masses, makes a **STABLE** system. These binary systems, very numerous in galaxies, are the sign of an ancient membership of a star cluster.
I suppose that galaxies also lose their stars?
For that to happen, the stars must acquire superspeeds, superior to escape velocity, via **COLLISIONS**. But, dispersed through the galaxy, the stars form an ensemble totally **NON-COLLISIONAL**. They almost never meet, so galaxies don't lose their stars.
Given the choice, I prefer that...
I'm observing this small cluster of stars that has just been born. Basically they behave like our young galaxies. They are hot and surrounded by a small halo of gas and dust: their atmosphere in a certain sense...

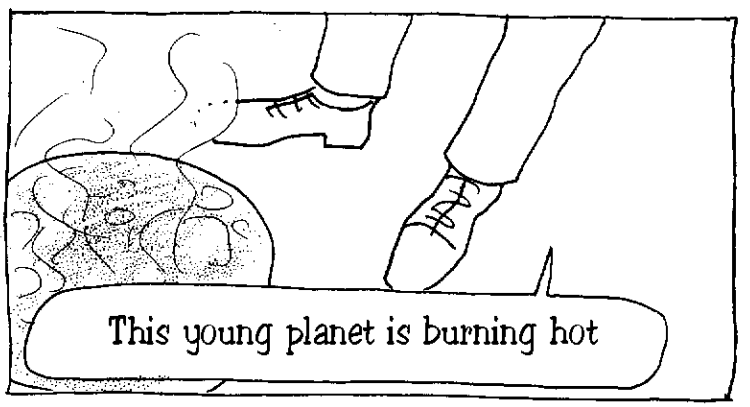
PLANETS

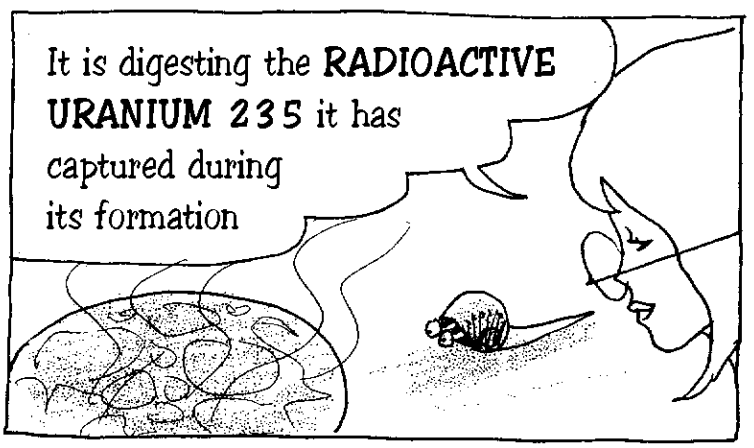

Our young stars go backwards and forwards in their mini-clusters, like fried eggs in a well oiled pan. Collisions set their small halos in rotation.
The cluster has dislocated like a spore. The stars have calmed down. I'm one.
Centrifugal force stops the halo's dust from falling back towards the star. It assembles in concentric rings.
On each circle, each orbit, **PLANETS** form
On the same orbit, the biggest planet will capture lighter planets and make them its satellites.
And so the circle is completed.

The **GASEOUS** part of this **PRIMITIVE STELLAR ATMOSPHERE** will condense into a sort of **HALO OF DIRTY SNOW**. A collision will occur from time to time between two elements of this belt. Either the bloc will be accelerated, in which case it will exit the **SOLAR SYSTEM**, or it will be slowed down and, in "falling" towards the system's centre, will become a **COMET**.

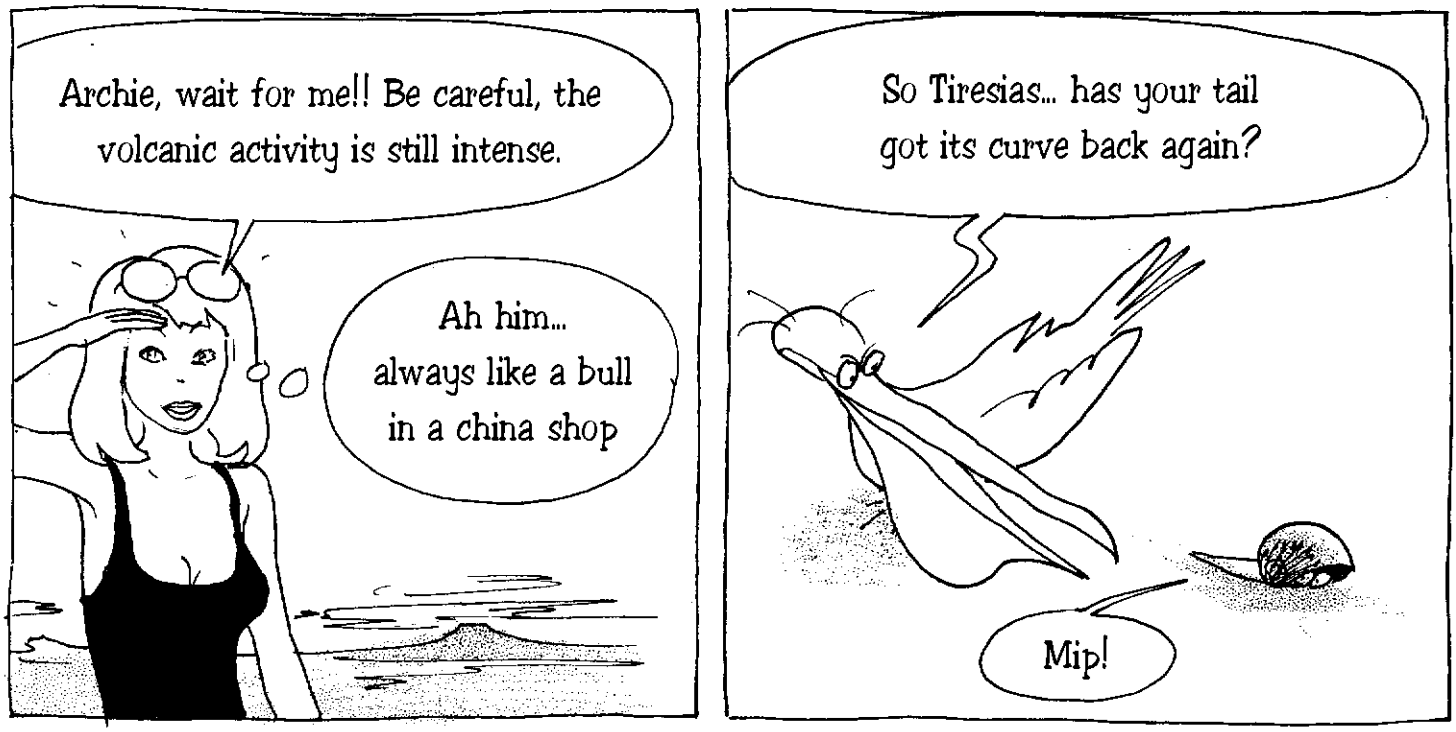


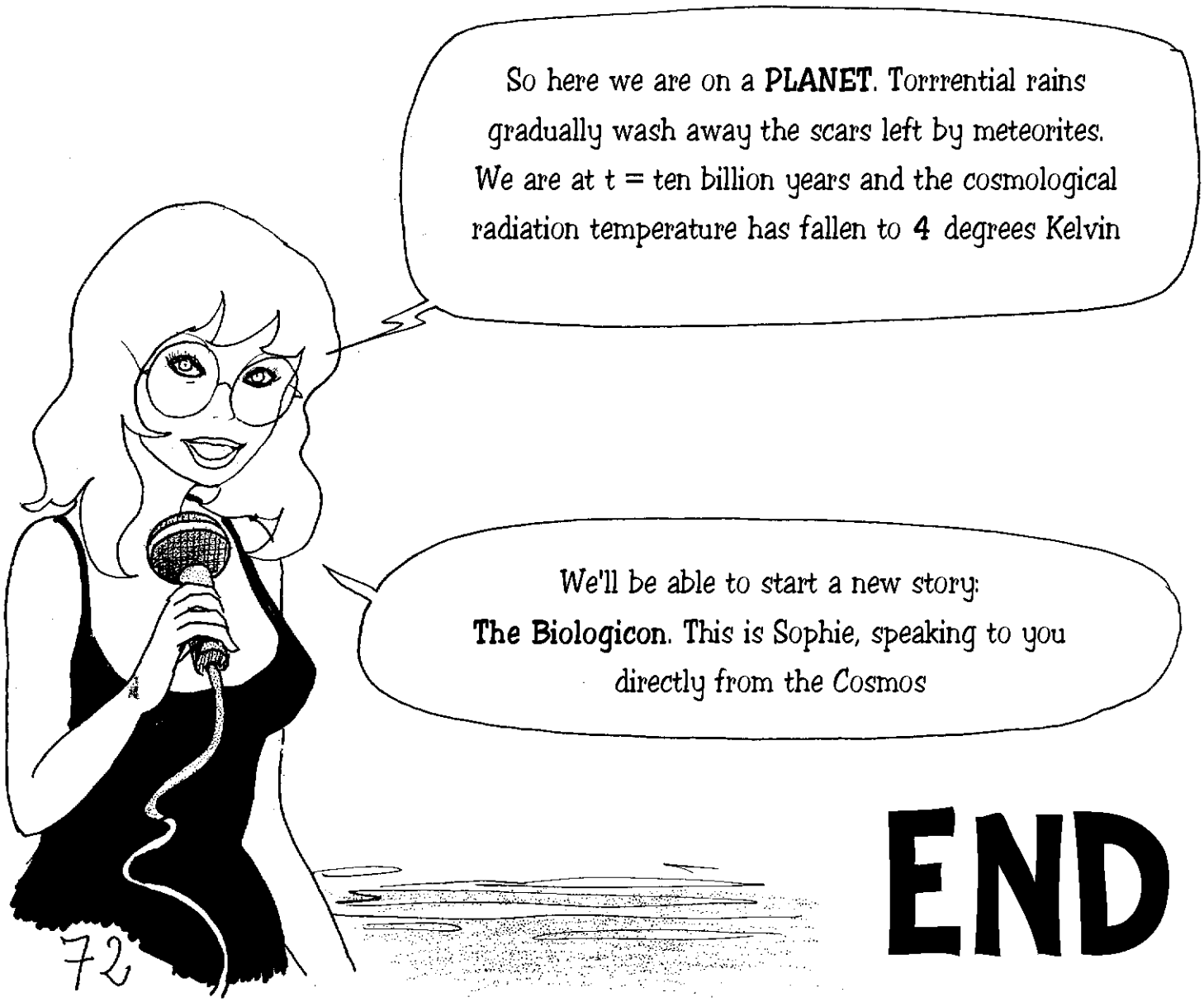







Theres a thing! At the time of their formation, the planets were NUCLEAR REACTORS!?
Why WERE? They still are. How else do you think the Earth maintains its core in fusion?
Ah!
It is also heated by all the meteorites that hit it when it "DOES THE HOUSEWORK"
Let's have a closer look
A


Archie, wait for me!! Be careful, the volcanic activity is still intense.
Ah him... always like a bull in a china shop
So Tiresias... has your tail got its curve back again?
Mip!


So here we are on a **PLANET**. Torrrential rains gradually wash away the scars left by meteorites. We are at t = ten billion years and the cosmological radiation temperature has fallen to **4** degrees Kelvin
We'll be able to start a new story: **The Biologicon**. This is Sophie, speaking to you directly from the Cosmos
END