Title: Discussion Session 6

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Abstract:

Cosmological Natural Selection

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Did the universe evolve? Classical and Quantum Gravity 9 (1992) 173-191.

On the fate of black hole singularities and the parameters of the standard model gr-qc/9404011,

Using neutrons stars and primordial black holes to test theories of quantum gravity, astro-ph/9712189.

The Life of the Cosmos, 1997 Oxford University Press

Scientific alternatives to the anthropic principle, hep-th/0407213,

The status of cosmological natural selection, hep-th/0612185.

Time Reborn, 2013

The Singular Universe with Roberto M Unger.

The problem of the parameters of physics and cosmology

The standard model has 27 dimensionless parameters.

What sets the values of all these parameters?

We have a landscape of low energy parameters, analogous to the fitness landscape of population biology.

But its worse than just this: *the parameters have improbable values*

- ***The hierarchy problem:*** there are large ratios in the observed values

  $m_{proton}/m_{Planck} \sim 10^{-19}$

  $hG\Lambda \sim 10^{-120}$

  $m_{top}/m_e \sim 340{,}000$

- ***The special tuning problem:*** The observed parameters allow the existence of stable structures over a vast range of scales:

  Long lived stars

  ~100 stable nuclei

  complex chemistry

It turns out that there is only a small region of the parameter space which allows these structures.

Changes that destabilize nuclei:

A reversal of the sign of $\Delta m = m_{neutron} - m_{proton}$.

A small increase in Δm (compared to $m_{neutron}$ will destabalize helium and carbon.

An increase in $m_{electron}$ of order $m_{electron}$ itself, will destabalize helium and carbon.

An increase in $m_{neutrino}$ of order $m_{electron}$ itself, will destabalize helium and carbon.

A small increase in α will destabalize all nuclei.

A small decrease in α_{strong}, the strong coupling constant, will destablize all nuclei.

LONG LIVED STARS IMPOSE REQUIREMENTS:

Hydrogen burning stars are stable, photon pressure ~ gravity

$$\frac{m_{electron}}{m_{proton}} > \alpha^2 50^{-4/3}$$

$$G_{Newton} m_{proton}^2 < \alpha^{12}$$

Convective stars require:

$$G_{Newton} m_{proton}^2 \approx \left(\frac{m_{electron}}{m_{proton}}\right)^4 \alpha^{12}$$

The existence of supernova constrains the weak interaction:

$$G_{Fermi} m_{electron}^2 \approx \left(G_{Newton} m_{electron}^2\right)^{\frac{1}{4}} \left(\frac{m_{electron}}{m_{proton}}\right)^{\frac{1}{2}}$$

Charles Sanders Peirce (1893):

To suppose universal laws of nature capable of being apprehended by the mind and yet having no reason for their special forms, but standing inexplicable and irrational, is hardly a justifiable position. Uniformities are precisely the sort of facts that need to be accounted for. ***Law is par excellence the thing that wants a reason. Now the only possible way of accounting for the laws of nature, and for uniformity in general, is to suppose them results of evolution.***

To apply natural selection to a system it must have:

- A space of parameters for each entity, such as the genes.
- A mechanism of reproduction.
- A mechanism for those parameters to change, but slightly, from parent to child.
- Reproductive success depends strongly on the parameters.

Moreover, the method of reproduction should involve atomic physics and chemistry so that fitness can be sensitive to the special tunings of the observed parameters.

Hypotheses of cosmological natural selection

- Black hole singularities bounce to initiate new universes.

- The standard model parameters change randomly and slightly, on each bounce.

Note that black hole formation involves
atomic physics and chemistry so that fitness is
sensitive to the special tunings of the observed parameters.

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The fitness depends strongly on the parameters.

Fitness (p) =*average number of black holes created to the future of the bounce for a universe with parameters p.*

It is easy to show that the fitness does depend strongly on the parameters in the neighbourhood of the present low energy parameters.

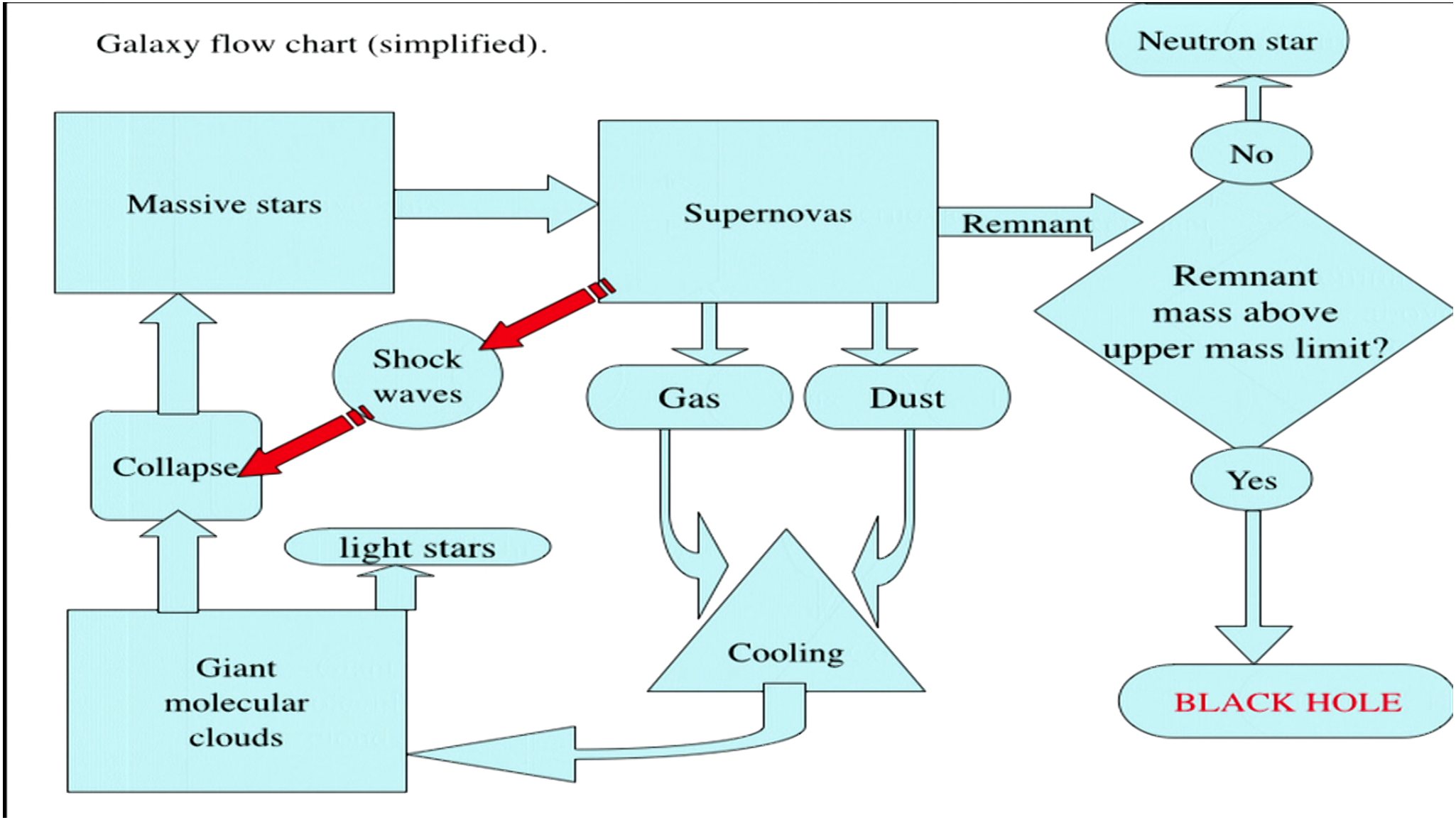
We can then apply standard arguments from population biology.

The standard arguments of population biology lead to the following conclusions for a high dimensional parameter space:

After a sufficient time, the population evolves to one where ρ_P is peaked around local extrema of the fitness function.

This implies:

Almost no local changes in the low energy parameters lead to increases in fitness
= expected number of black holes produced.


Galaxy flow chart (simplified).
Neutron star
No
Massive stars
Supernovas
Remnant
Remnant mass above upper mass limit?
Shock waves
Gas
Dust
Collapse
Yes
light stars
Cooling
Giant molecular clouds
BLACK HOLE

So the hypothesis that black hole production is locally extremized ***explains*** fine tuning for:

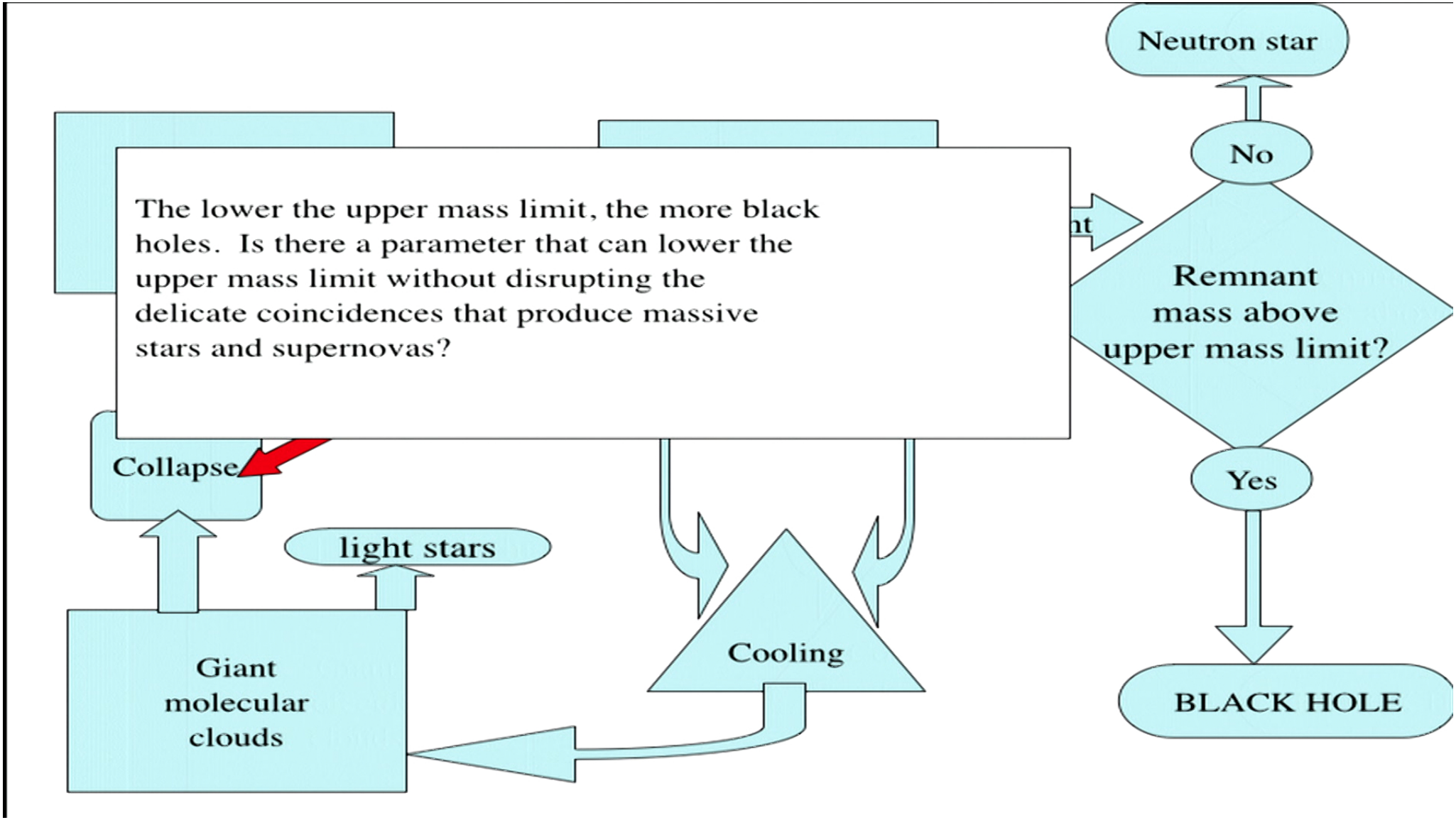
- Chemistry, particularly carbon and Oxygen
- Supernovas
- Long lived stars.

Hence, these explain all the coincidences noted above.

There is then a genuine, non-circular, explanation of why the universe is hospitable to our type of life. We can be here as a side effect of tuning the parameters to maximize reproduction of the Universe as a whole!

But to be taken seriously, a theory must make falsifiable predictions for doable experiments.

Two predictions, published in 1992:


Neutron star
No
The lower the upper mass limit, the more black holes. Is there a parameter that can lower the upper mass limit without disrupting the delicate coincidences that produce massive stars and supernovas?
Remnant mass above upper mass limit?
Collapse
Yes
light stars
Cooling
Giant molecular clouds
BLACK HOLE

"I know a way to make many more black holes. Just turn up $\delta = \delta\rho/\rho$ and lots of primordial black holes will be made."

Why not?

In single field inflation $\delta \sim \lambda$ the inflaton coupling.

But the universe expands like e^N where $N = \lambda^{-1/2}$.

So the volume of the universe produced is exponentially smaller.

Details show that the most black holes are produced when δ is at the critical value below which galaxies don't form.

But this is not true for more complex inflation models.

Hence, CNS predicts that, IF inflation is true, it is single field, single parameter.

Two kinds of landscape theories:

Time dependent	*Static*
Cosmological natural selection	Eternal inflation
Population evolves on the landscape	Static probability distribution
Highly non-random population.	Random, equilibrium population
Our universe is typical	Our universe is very untypical
Creation mechanism implies typical universes have surprising features not implied by our existence.	Anthropic principle must be invoked, all other parameters random.
Genuine falsifiable predictions. (Upper mass limit of neutron stars ~ 2 solar masses.)	**No falsifiable predictions**