Frontiers and Limits of Naturalness

45 Words and 1 Diagram of Philosophy

I suspect that **many** new concepts will be needed to understand the physical world (in the sense of reduction).

I suspect that many of those concepts will be only loosely connected.

Corollary: I suspect that creative opportunism will prove more fruitful than top-down, all-or-nothing theorizing.

Good Design Ideas? \ Selected?	Yes	No
Yes	Enlightenment	Knowledge
No	Temptation	Ignorance

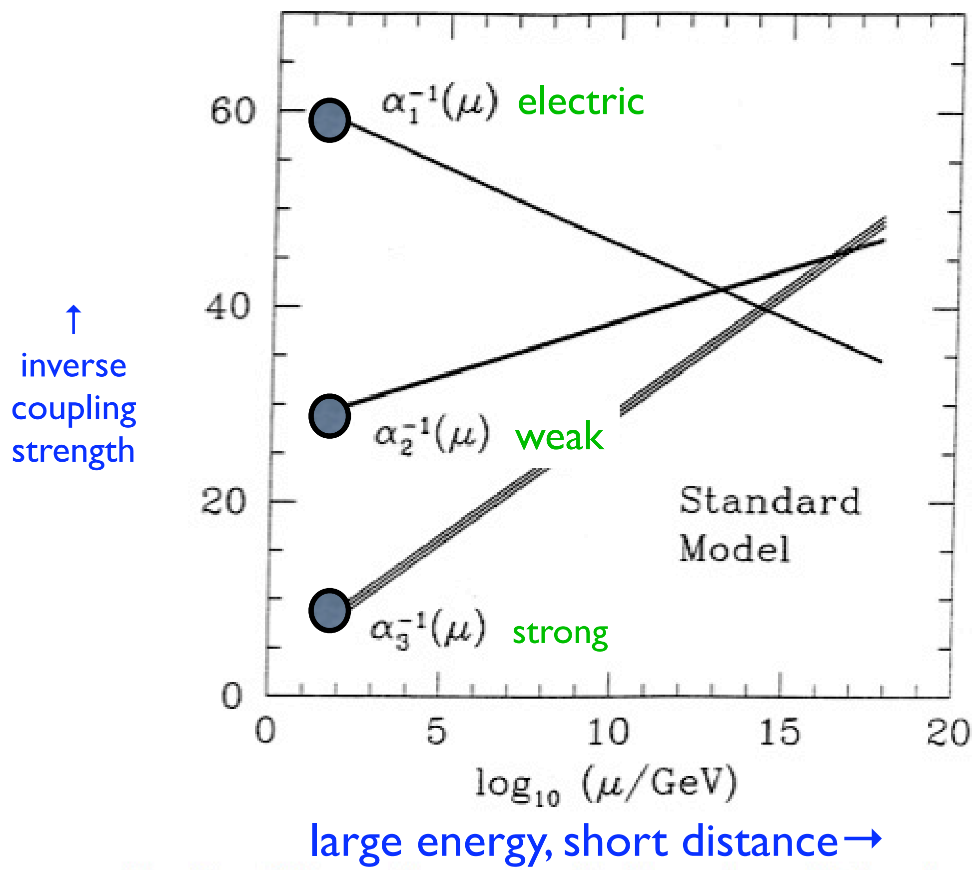
Naturalness as a Guide

Unification of couplings

"Excessive" proton lifetime

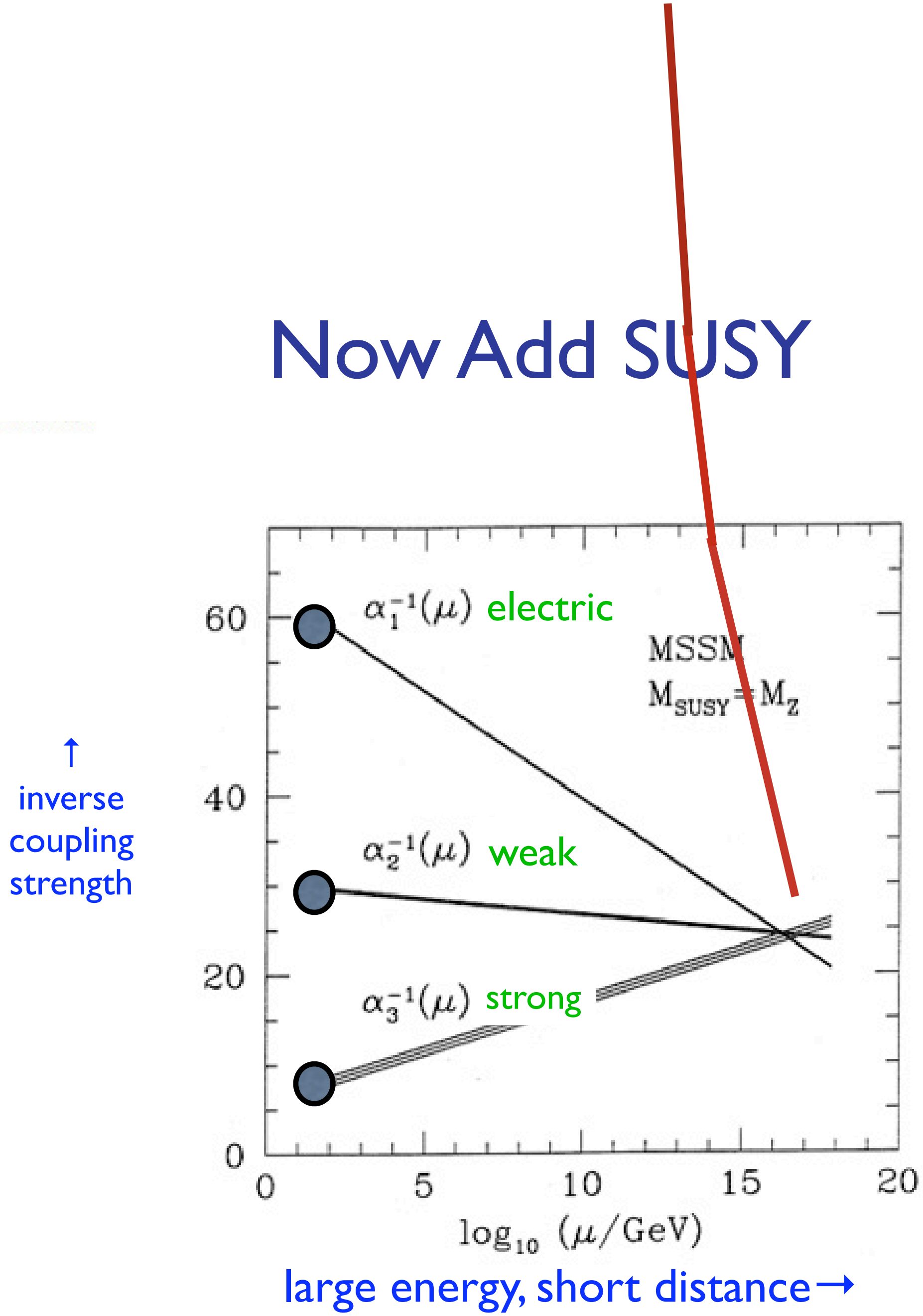
Tiny value of θ_{QCD}

Phantom sector?



↑
inverse
coupling
strength
60
40
20
0
0
5
10
15
20
$\alpha_1^{-1}(\mu)$ electric
$\alpha_2^{-1}(\mu)$ weak
$\alpha_3^{-1}(\mu)$ strong
Standard
Model
$\log_{10}(\mu/\mathrm{GeV})$
large energy, short distance→

Now Add SUSY



Gravity fits too!
(roughly)

Phantoms

A very real possibility, suggested by several theoretical ideas, is a “hidden sector” of SU(3)xSU(2)xU(1) singlet fields.

Naturalness suggests that the Higgs field could be the portal into such hidden sectors. This is due to the unique nature of the Higgs mass term within the SM, which allows an unsuppressed linking interaction.

$$\mathcal{L}_{\text{link}} = \eta \phi_s^\dagger \phi_s \sigma_p^2$$

Example: Scale Induction

It might be pretty, or even natural, to generate the electroweak mass scale starting from no (classical) mass scale.

To implement this, introduce an additional confining gauge theory (SU(4)?). Simplest version: the new theory contains only SU(3) xSU(2)xU(1) singlets. Generalization: condensate singlet. (This differs from technicolor.)

Through L_{link}, the phantom condensate induces a mass for the Higgs field.

The effective model could be a σ-model coupled to the SM. The "π" mesons could be truly massless.

Scholium

Dark matter could be lurking in a phantom sector.

So could ultra-light particles.

A phantom sector would render the neutral Higgs sector more challenging to study, but ultimately richer.

Conditioning on the Fragility of Life

Cosmological term

Nuclear chemistry

Axion dark matter

In axion cosmology, the final density depends on the PQ breaking scale f and the initial misalignment θ_0, approximately as $f \sin^2\theta_0$.

If no inflation occurs after the PQ transition, we average over $\sin^2\theta_0$, and $f \sim 10^{12}$ GeV corresponds to the observed ξ_{CDM}.

If inflation does occur after the PQ transition, we shouldn't average, and $f > 10^{12}$ GeV can be accommodated, using "atypically" small $\sin^2\theta_0$.

In this scenario, most of the multiverse is overwhelmingly axion-dominated, and inhospitable for life. Selection effects **must** be considered.

θ_0 controls the dark matter density, but it has little or no effect on anything else.

We do not have to get embroiled in questions of baby universe nucleation ...

... nor, for that matter, unification, supersymmetry, string theory ...

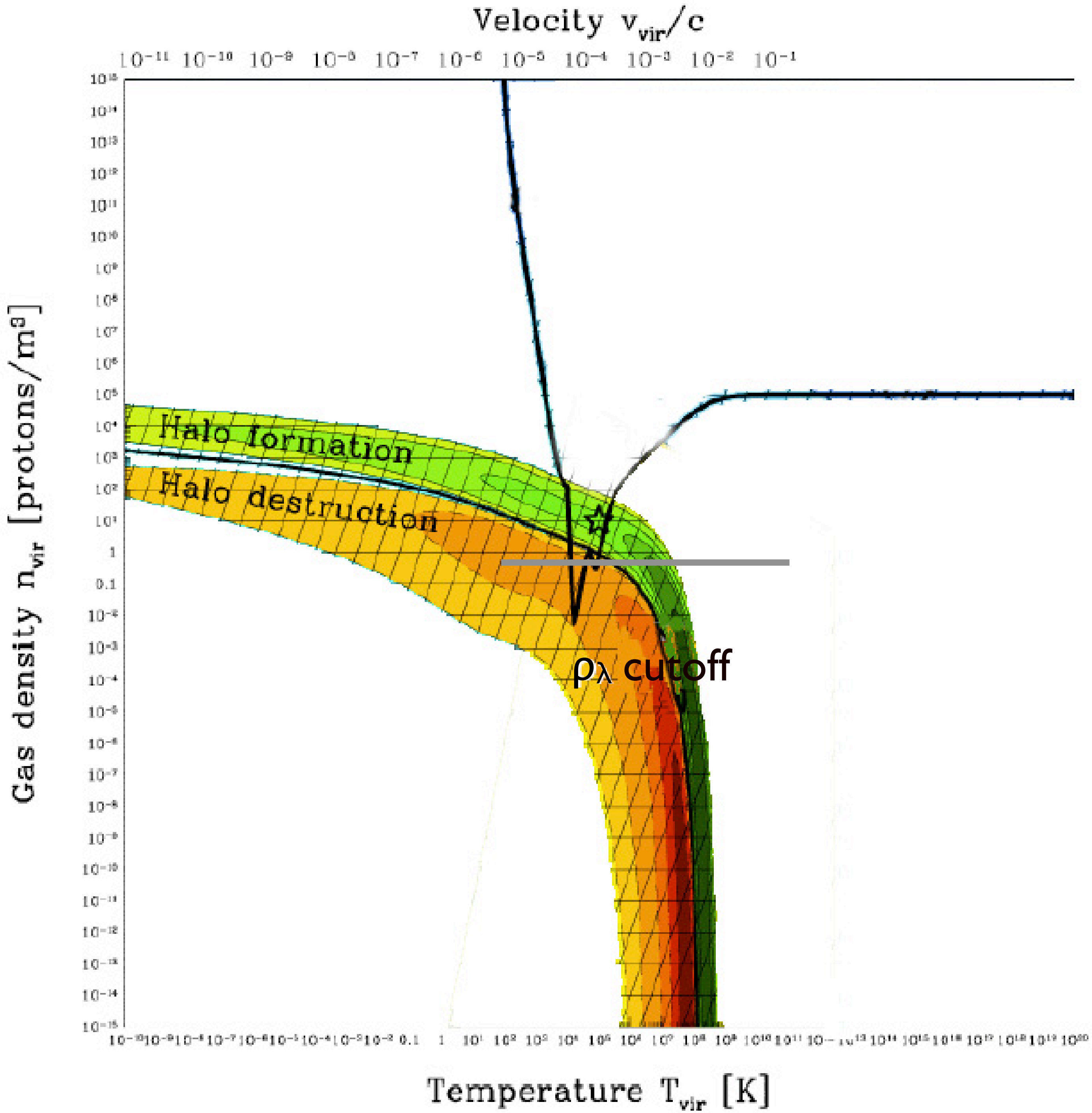
Constraints from Conditioning

Intellectual background: Given our values of the cosmological parameters, following out the fate of fluctuations provides a conventional, scientific explanation of the size of galaxies. (The existence of such a characteristic size is a striking fact of astrophysics.)

density ↑

time ↓

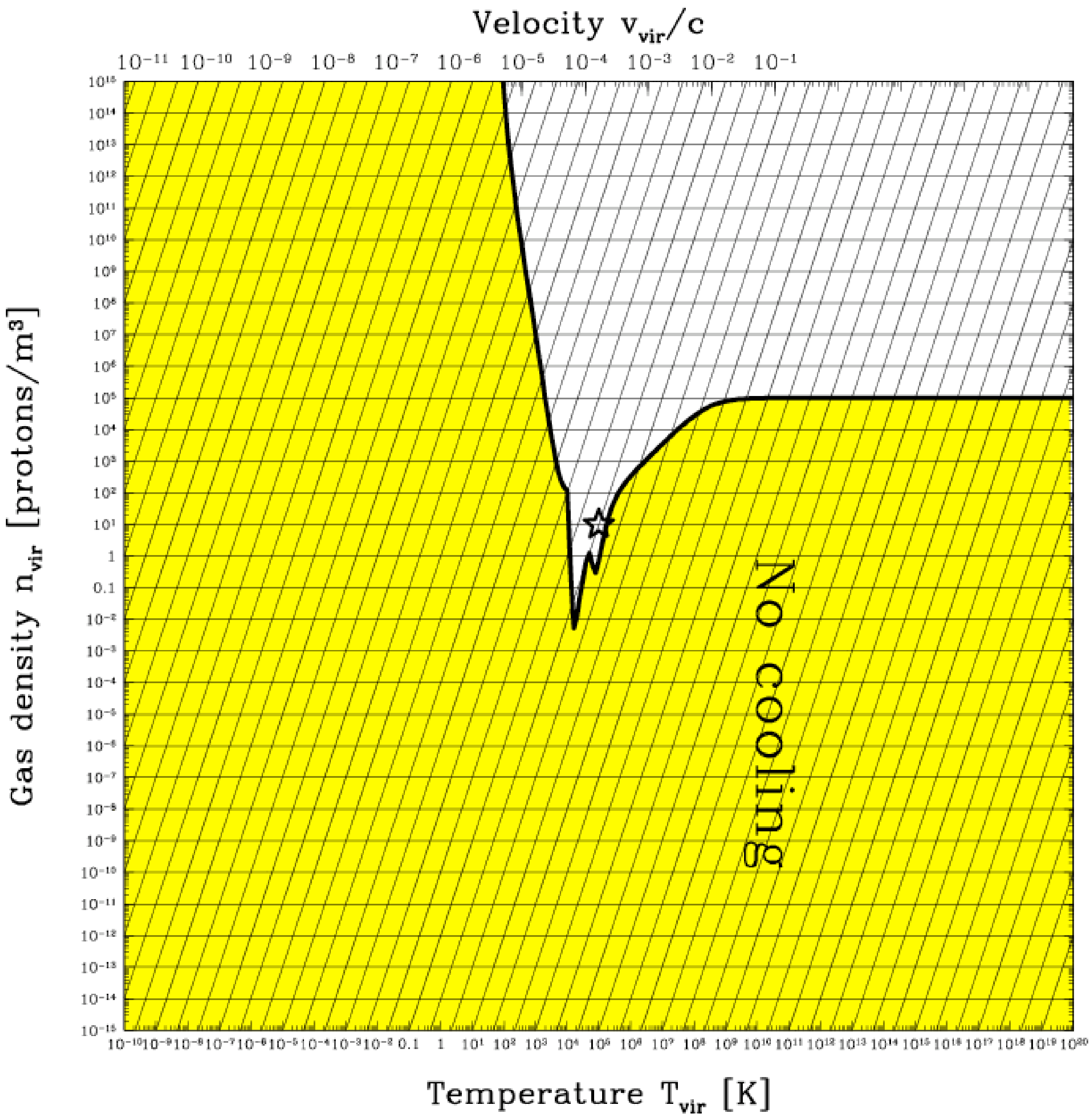
size ↓



contrast →

We were lucky, because lots of things can go wrong when you try to make nice user-friendly solar systems, starting with small seed fluctuations, following the cosmological SM.

The baryon matter might fail to cool, so it just sloshes around and remains diffuse (like dark matter).



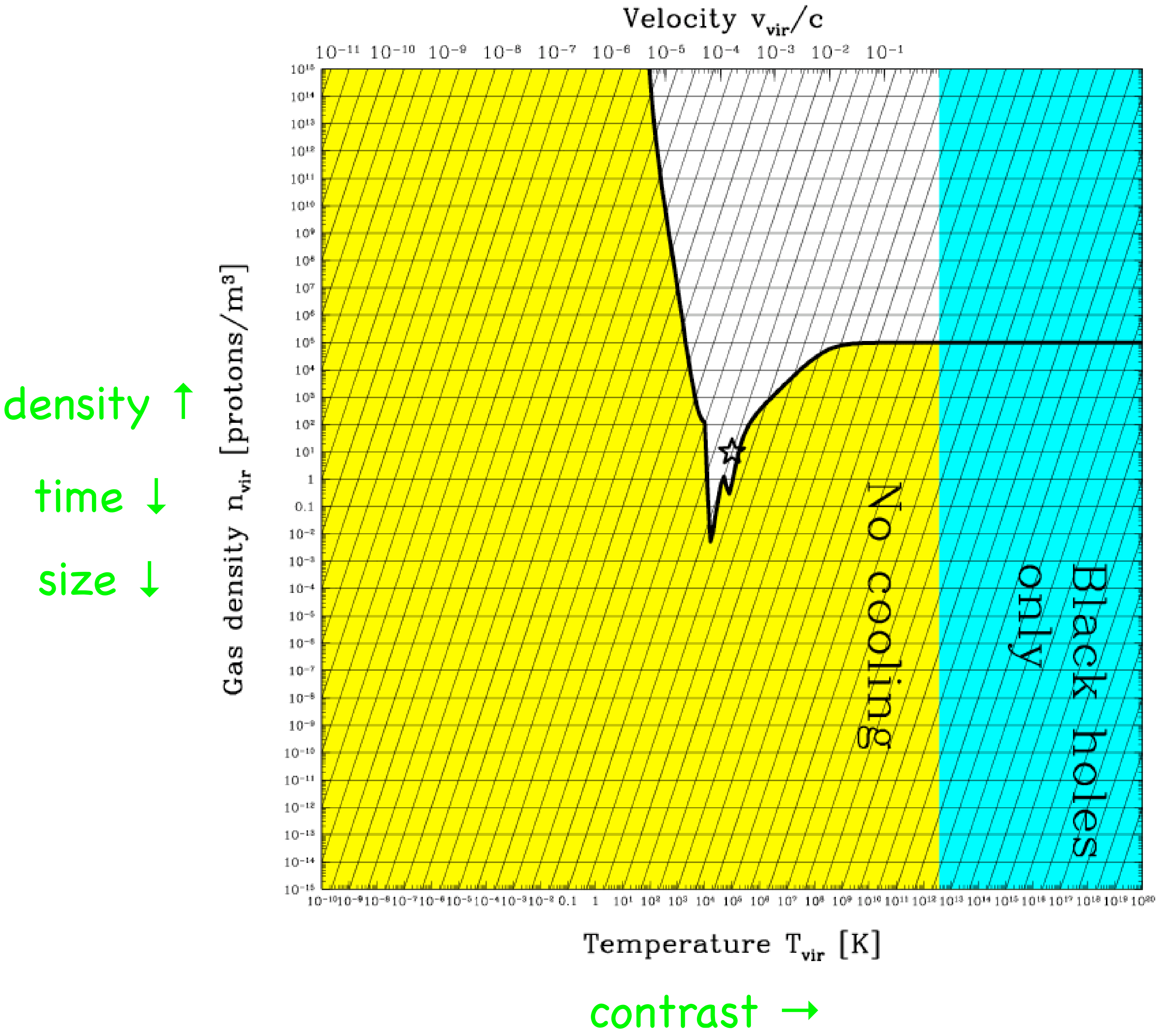
density ↑

time ↓

size ↓

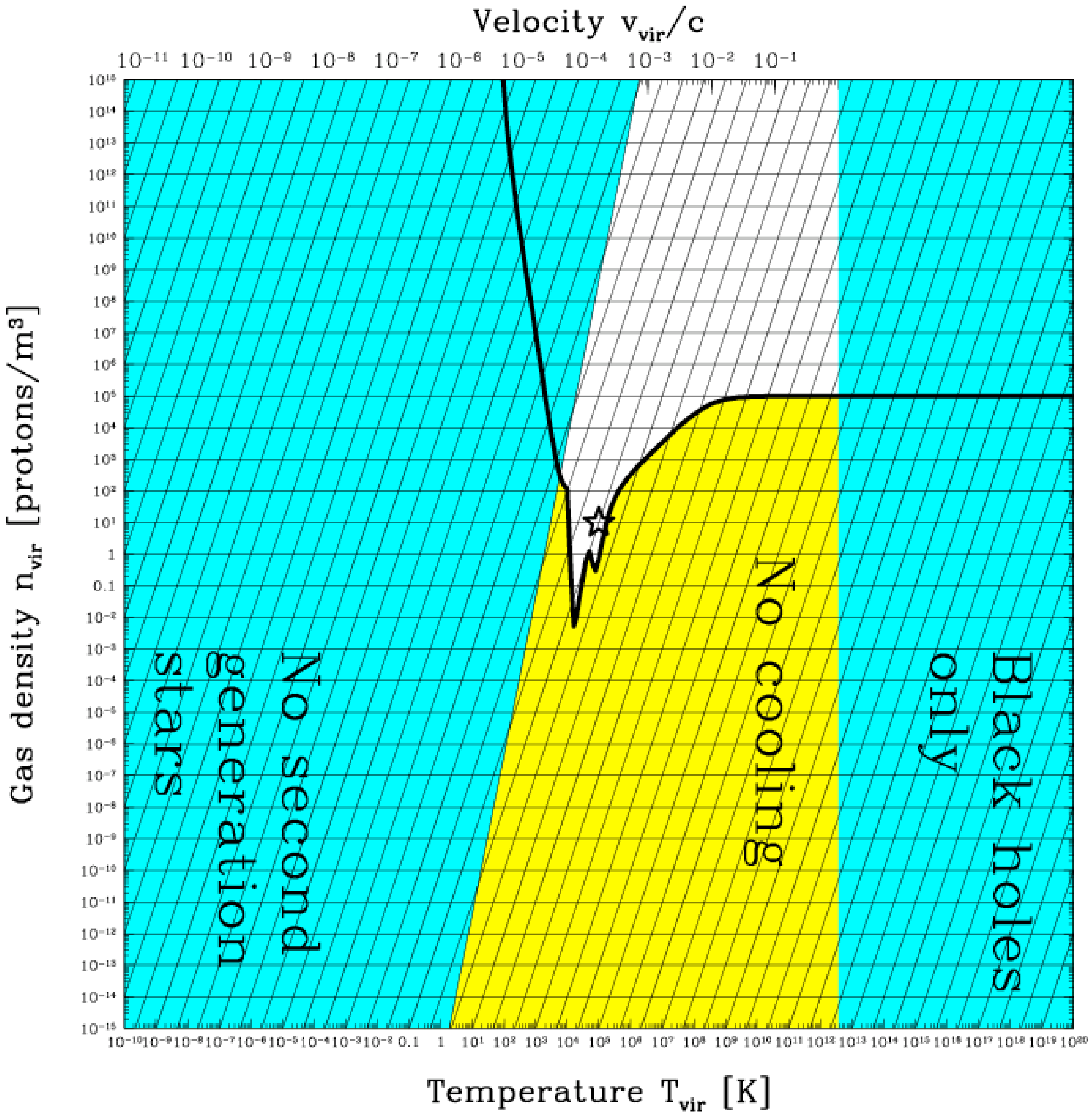
contrast →

Fluctuations can collapse into black holes.



Velocity v_{vir}/c
Gas density n_{vir} [protons/m³]
Temperature T_{vir} [K]
No cooling
Black holes only
density ↑
time ↓
size ↓
contrast →

The baryons might get swept out by the early supernovae.



density ↑

time ↓

size ↓

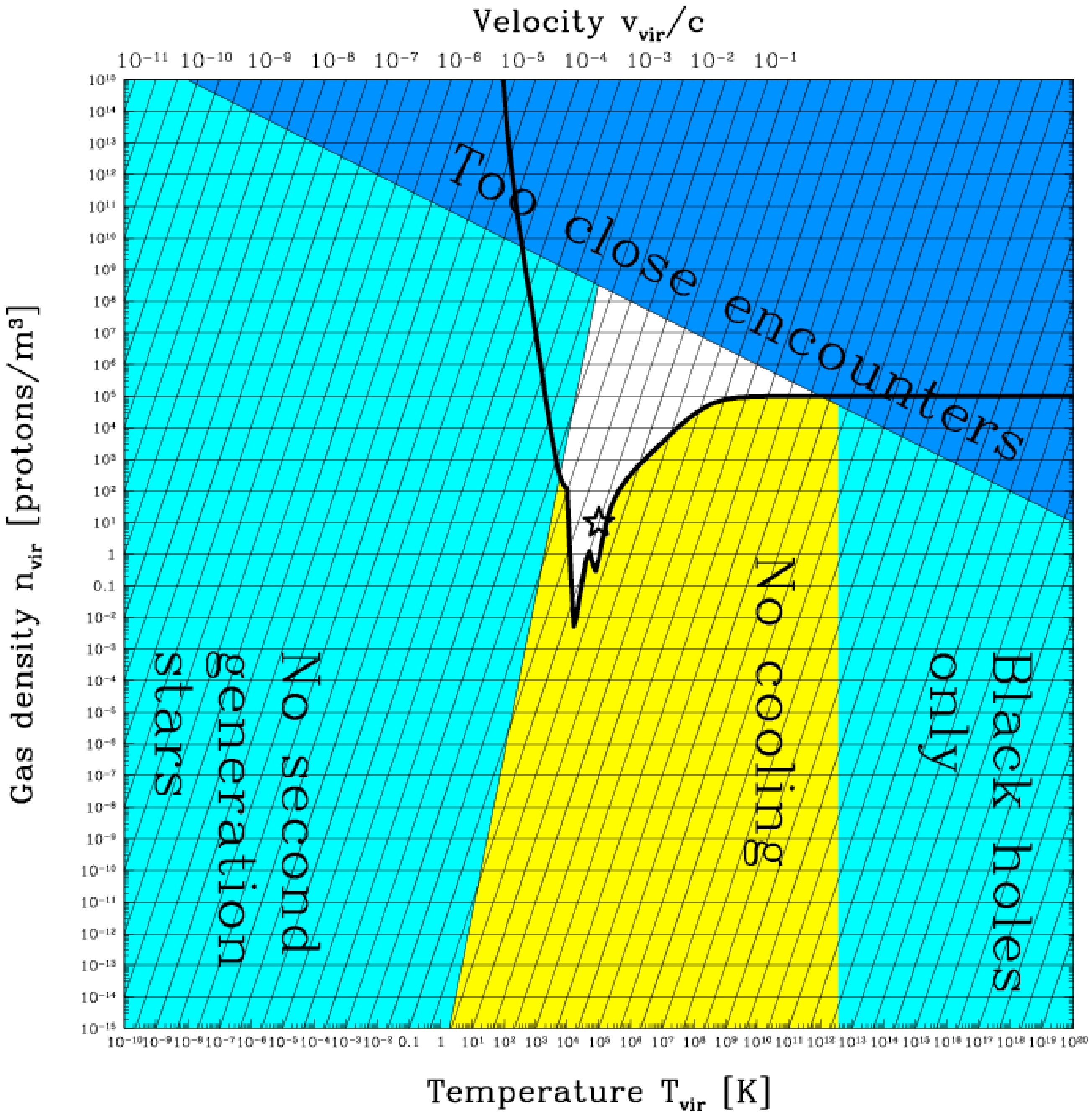
contrast →

There might be no safe haven from disruptive encounters.

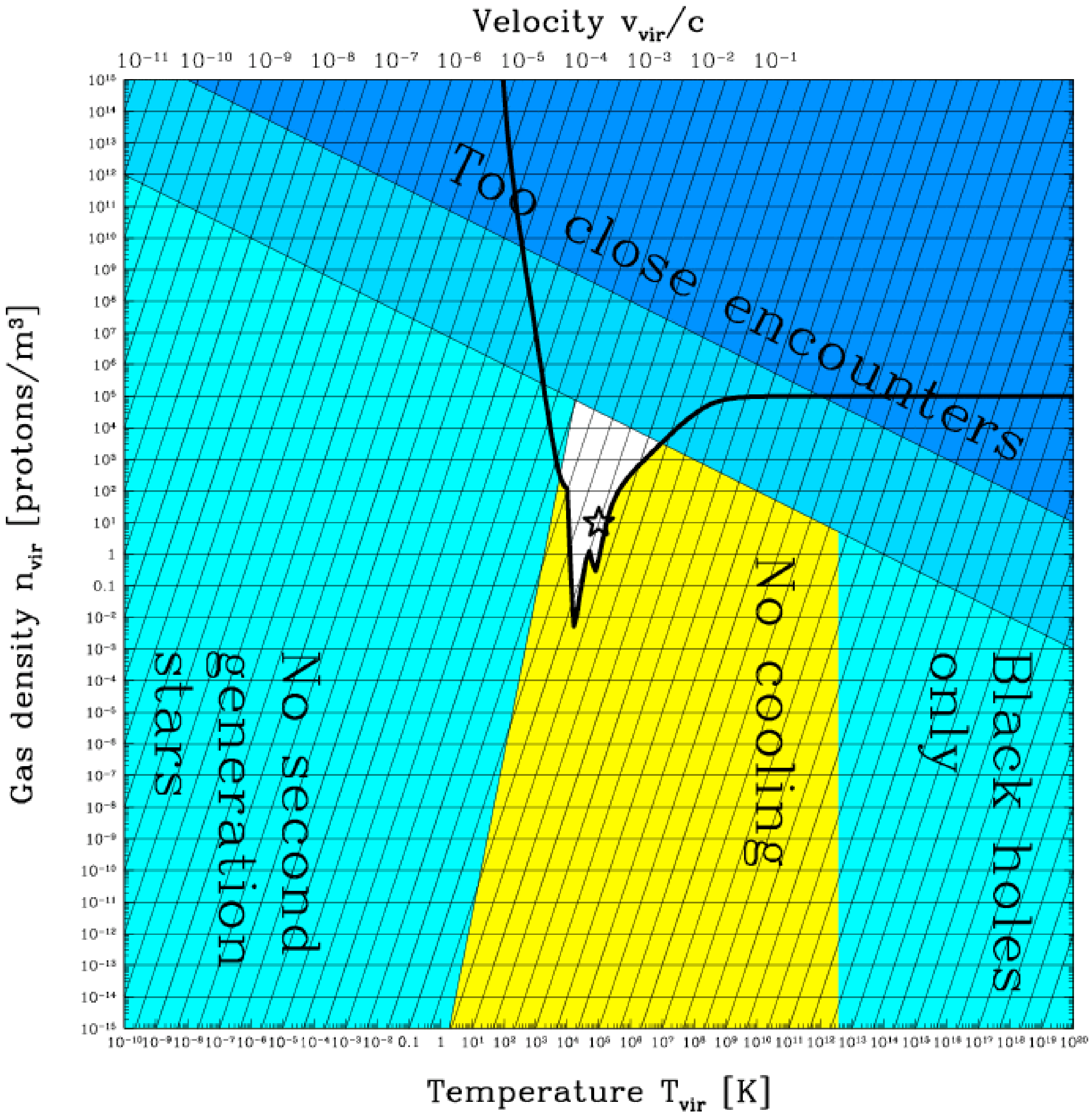
density ↑

time ↓

size ↓



contrast →



density ↑

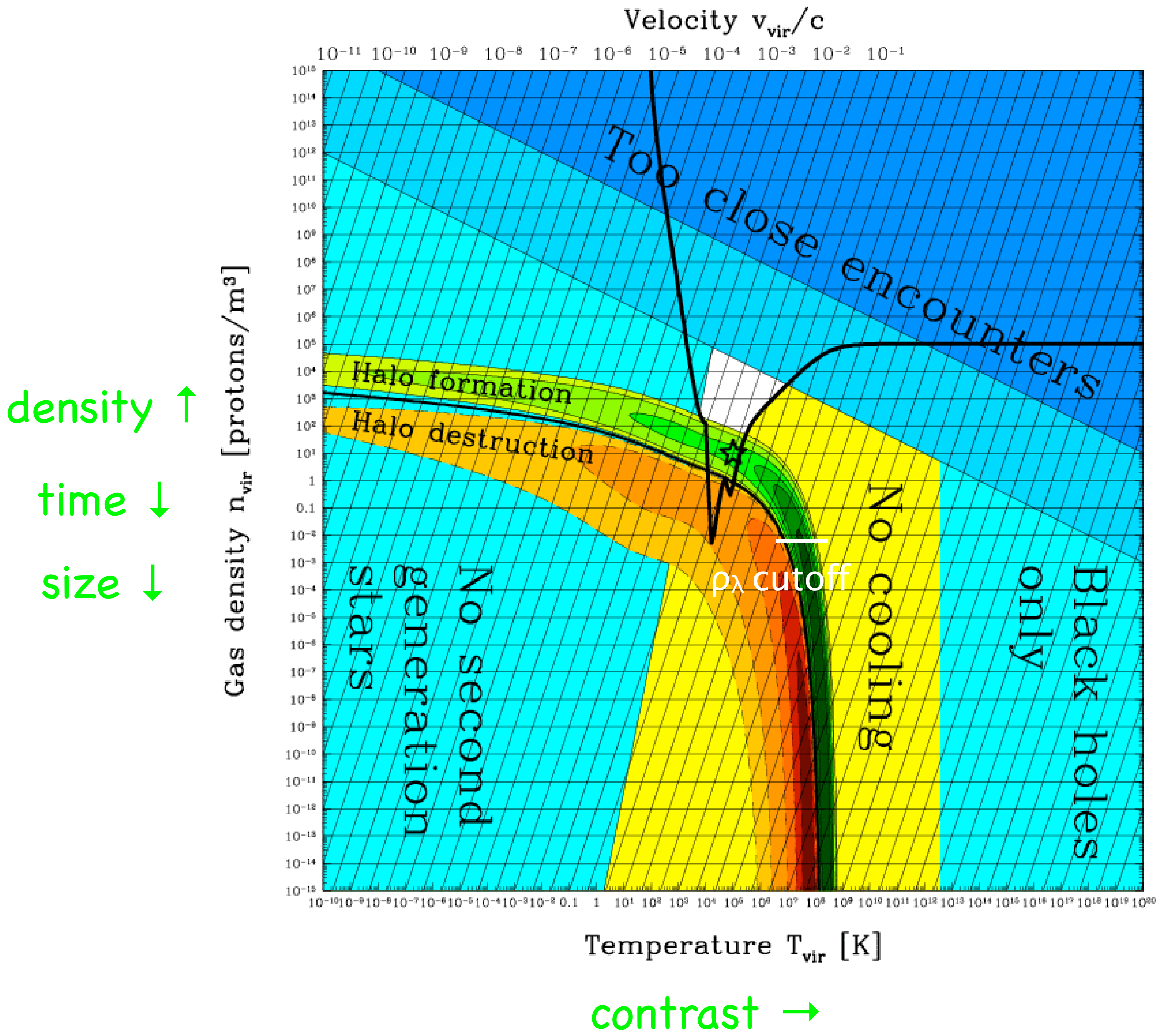
time ↓

size ↓

contrast →

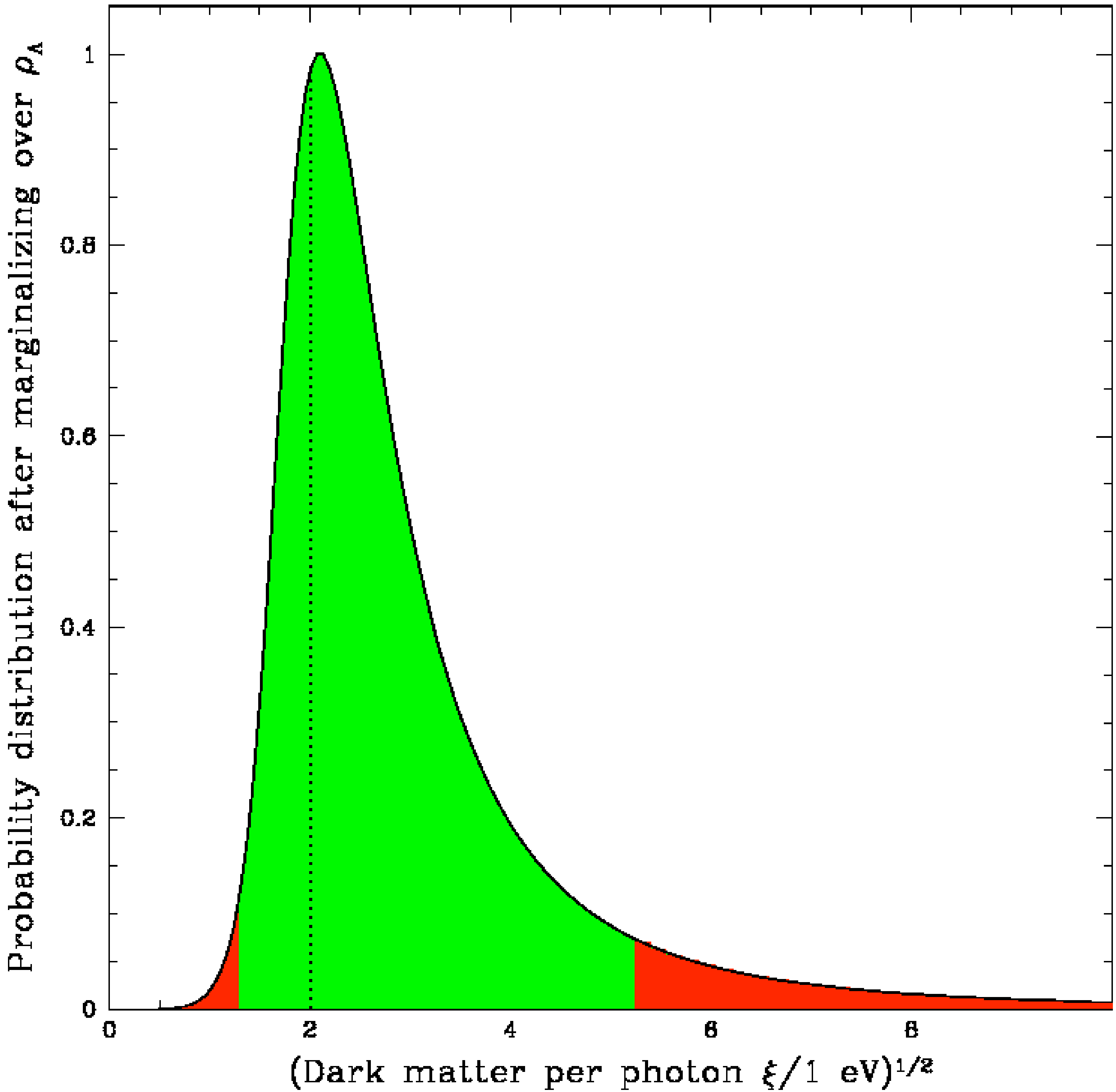
If we vary ρ_λ or $\xi^4 Q^3$, the banana can easily miss the sweet spot.

(Glossary: ρ_λ = dark energy density, Q = amplitude of scale-invariant fluctuations, ξ = dark matter mass/cosmic photon.)



density ↑
time ↓
size ↓
contrast →
Velocity v_{vir}/c
Gas density n_{vir} [protons/m³]
Temperature T_{vir} [K]
Too close encounters
Halo formation
Halo destruction
No second generation stars
No cooling
Black holes only
ρ_λ cutoff

Result: Probable dark matter density seen from baryons habitable regions, assuming uniform θ_0 prior



Probability distribution after marginalizing over ρ_Λ
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
(Dark matter per photon ξ/1 eV)$^{1/2}$

Scholium

Having inflation after the PQ transition avoids some annoying difficulties of the traditional alternative (axion strings, domain walls).

This scenario would be falsified by observing cosmological gravity waves of significant amplitude ...

... or by direct axion detection ($f \sim 10^{12}$ GeV)!

It could be "truthified" if we still have a dark matter deficit after LHC (+ ILC), through characteristic details of the dark matter distribution, or by seeing isocurvature fluctuations.

Model B: Mirror

Simply double the degrees of freedom of the standard model, to $SU(3)_s \times SU(2)_s \times U(1)_s \times SU(3)_p \times SU(2)_p \times U(1)_p$; matter representations (R,1)+(1,R).

The link term will couple them, leading to Higgs dilution, "missing" decay channels, ...

There is, however, a worm in the woodwork:

$$\mathcal{L}_{\text{hyper}} \propto F_s^{\alpha\beta} F_p^{\alpha\beta}$$

This opens the possibility of funny electric charges for the (former) phantoms, which might not have escaped notice.

It can be forbidden by enforcing e.g. C_p (but this requires changing the model, making the new sector vector-like).