Higgs Portal Into Hidden Sectors

Might the LHC See Nothing?

The usual answer is:

A Higgs particle must show up, at least.

But that is not guaranteed. In fact, there are quite simple, phenomenologically unobjectionable models in which the Higgs particle becomes effectively invisible.

How to Hide Higgs

Take the standard model, and add an SU(3)xSU(2)xU(1) singlet real scalar field *phantom* field η.

All the couplings of gauge fields to fermions, and of both to the Higgs field doublet remain as they were in the original standard model.

The Higgs potential is modified, however:

$$V(\phi,\eta) = -\mu_1^2\,\phi^\dagger\phi + \lambda_1(\phi^\dagger\phi)^2$$

$$-\mu_2^2\,\eta^2 + \lambda_2\,\eta^4 \;\boxed{-\kappa\,\phi^\dagger\phi\,\eta^2}$$

The upshot is that the two mass eigenstates (=particles) are created by mixtures of the conventional Higgs field and the phantom field.

The phantom component contributes nothing to the amplitude for production from conventional particle sources, i.e. quarks and gluons.

Thus the same overall production rate of Higgs particles is now divided between two lines.

Rather than one channel with S/N = 2, for the same exposure you'll get two channels with S/N=1.

Of course, it's easy to generalize this model. With more phantom fields, one has more division.

5 x 1 $\sigma \neq 5 \sigma$.

It gets worse. The phantoms might actually be the "Higgs fields" of an entire new sector, that has its own gauge fields and matter.

Then the Higgs-phantom mixtures can also decay into particles of the new sector, which are effectively invisible.

So not only is production divided, but also decay is diluted.

Example 1: Induced Scale Model

$$G = SU(4) \times SU(3) \times SU(2) \times U(1)$$

SU(4) is a new strong interaction that supports spontaneous chiral symmetry breaking and thus a σ-model.

$$V(\phi, \vec{\sigma}) = -\mu_1^2 \phi^\dagger \phi + \lambda_1 (\phi^\dagger \phi)^2 - \mu_2^2 \vec{\sigma}^2 + \lambda_2 (\vec{\sigma}^2)^2$$
$$- \kappa \phi^\dagger \phi \vec{\sigma}^2$$

We can imagine $\mu_1^2 = 0$, and no classical masses in the theory anywhe

The σ_0 can decay into its massless "pions". So we get dilution.

Example 2: Mirror World Model

$$G = SU(3)\times SU(2)\times U(1)\times SU(3)'\times SU(2)'\times U(1)'$$

Parallel matter content, including a phantom Higgs doublet ϕ'.

$$V(\phi,\phi') = \ldots - \kappa(\phi^{+}\phi)(\phi'^{+}\phi')$$

Degree of dilution depends on width of κ.

This model has a large literature.

A More General Formulation

The standard model has a remarkable closure property:

General principles (locality, Lorentz invariance, gauge invariance, renormalizability), given the particle content, greatly restrict the couplings.

With one exception, the couplings are all dimensionless ($\hbar = c = 1$). Alternatively we say they are strictly renormalizable, or that they involve invariant operators with mass dimension = 4.

The exception is the Higgs mass term $\mu^2\phi^+\phi$.

If we build on the dimension 4 invariant operators, by coupling in other fields, we get higher dimension operators. They represent non-renormalizable interactions.

In the Lagrangian, such interactions must appear with coefficients of the form Λ^{-p}, with $p>0$ and Λ a (presumably large) mass scale.

We invoke the suppression of higher-dimension operators to explain B conservation, absence of flavor-changing neutral currents, $g \cong 2$, etc.

So SU(3)xSU(2)xU(1) singlet scalar fields will tend to couple in through the exceptional term.

The sort of coupling we encountered in our simple examples is likely to be the way hidden sectors communicate with standard model degrees of freedom, much more generally.

Neutral Higgs particles plausibly provide our best portal into hidden sectors.

In an absolutely minimal, “purely neutral” Higgs sector, the portal will be challenging to exploit. In more complex Higgs sectors, as in SUSY, we can access it indirectly, e.g. through missing energy in decays of charged Higgs particles.

Motivations

Hippocratic oath

Stacks and throats

Plays well with SUSY

Flavor and axions

Hippocratic Oath

First, do no harm.

Mixing in singlets does not upset the unification of couplings, nor does it introduce any flavor problems.

Stacks and Throats

In string theory, hidden sectors easily arise from far-away (in the extra dimensions) stacks of D-branes or orbifold points.

The original $E_8 x E_8$ heterotic string was an early incarnation of a hidden sector.

Plays Well With SUSY

Hidden sectors are introduced in several mechanisms of SUSY breaking (gravity-mediated, gauge-mediated).

The NMSSM, which introduces a singlet field, has been advocated on phenomenological grounds. It eases "naturality" problems.

Flavor and Axions

Flavor symmetries, if they exist, are plausibly associated with hidden sectors. (We'd need to break such symmetries, but not SU(3)xSU(2)xU(1), at a high scale.)

Axion physics is the best-motivated and most developed example.

Axion Basics

The theory of the strong interaction (QCD) admits a parameter, θ, that is observed to be unnaturally small ($\theta < 10^{-9}$).

This can be understood by promoting translation of θ to an asymptotic symmetry (Peccei–Quinn symmetry) that is spontaneously broken.

The axion field is established at the Peccei–Quinn (PQ) transition, $\Phi = F e^{i\theta}$.

It stores energy, due to its initial misalignment, roughly proportional to $F \sin^2\theta_0$.

For $T \geq 1$ GeV, θ stays frozen at θ_0. Then it relaxes to 0, liberating the stored energy.

If no inflation occurs after the PQ transition then the correlation length, which is no larger than the horizon at the transition, corresponds to a very small length in the present universe.

We therefore average over $\sin^2\theta_0$.

$F \sim 10^{12}$ GeV corresponds to the observed dark matter density.

If inflation occurs after the PQ transition, then the correlated volume inflates to include the entire presently observed universe.

Therefore we shouldn’t average.

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. This is bad news for the emergence of complex structure, let alone observers.

Selection effects must be considered.

θ_0 controls the dark matter density, but it has little or no effect on anything else. So we know what the prior measure is. (Namely $d\theta_0$ for θ_0, $d\sin^2\theta_0$ for ρ_{DM}/ρ_b.)

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

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

The theory may be right, or it may be wrong, but it is hard to imagine a clearer case for applying anthropic reasoning.

Tegmark, Aguirre, Rees, FW astro-ph/0511774

Making User-Friendly Structures

The Fragility of Life

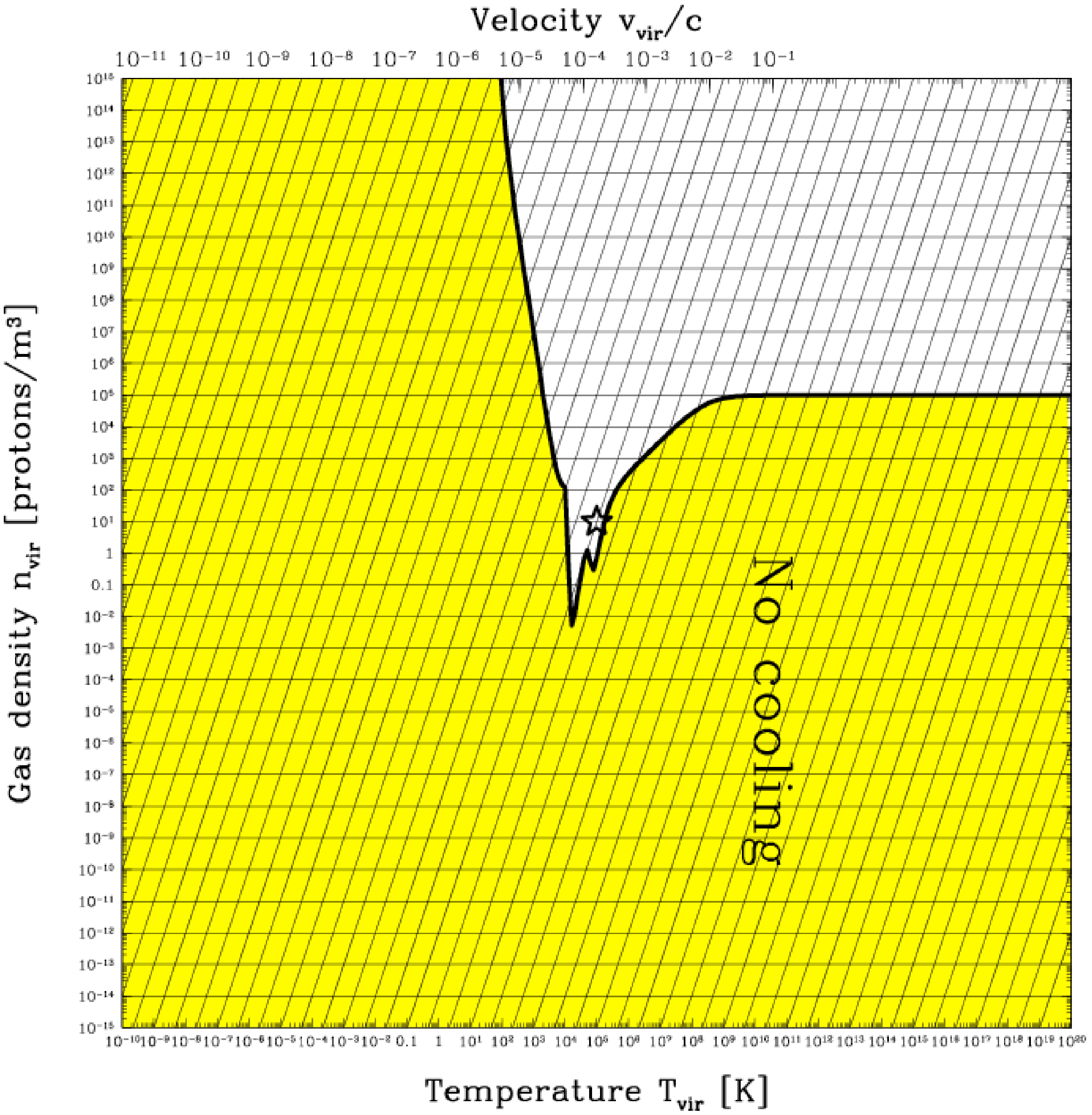
Lots of things can go wrong when you try to make nice solar systems, starting with small seed fluctuations:

The (ordinary, baryonic) matter might fail to cool, so it sloshes around and remains diffuse:

density ↑

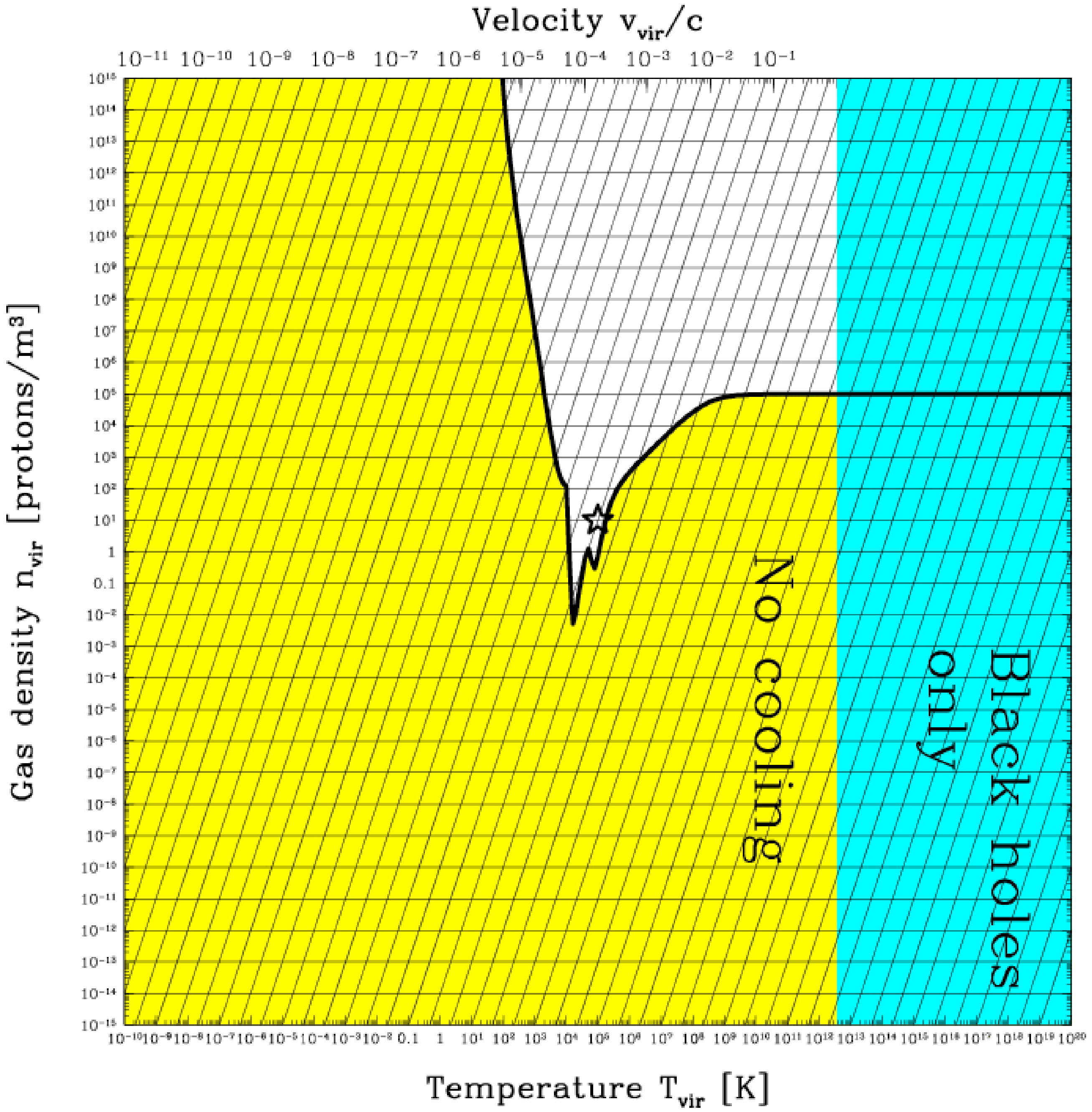
time ↓

size ↓



contrast →

Your fluctuations might collapse into black holes:



density ↑

time ↓

size ↓

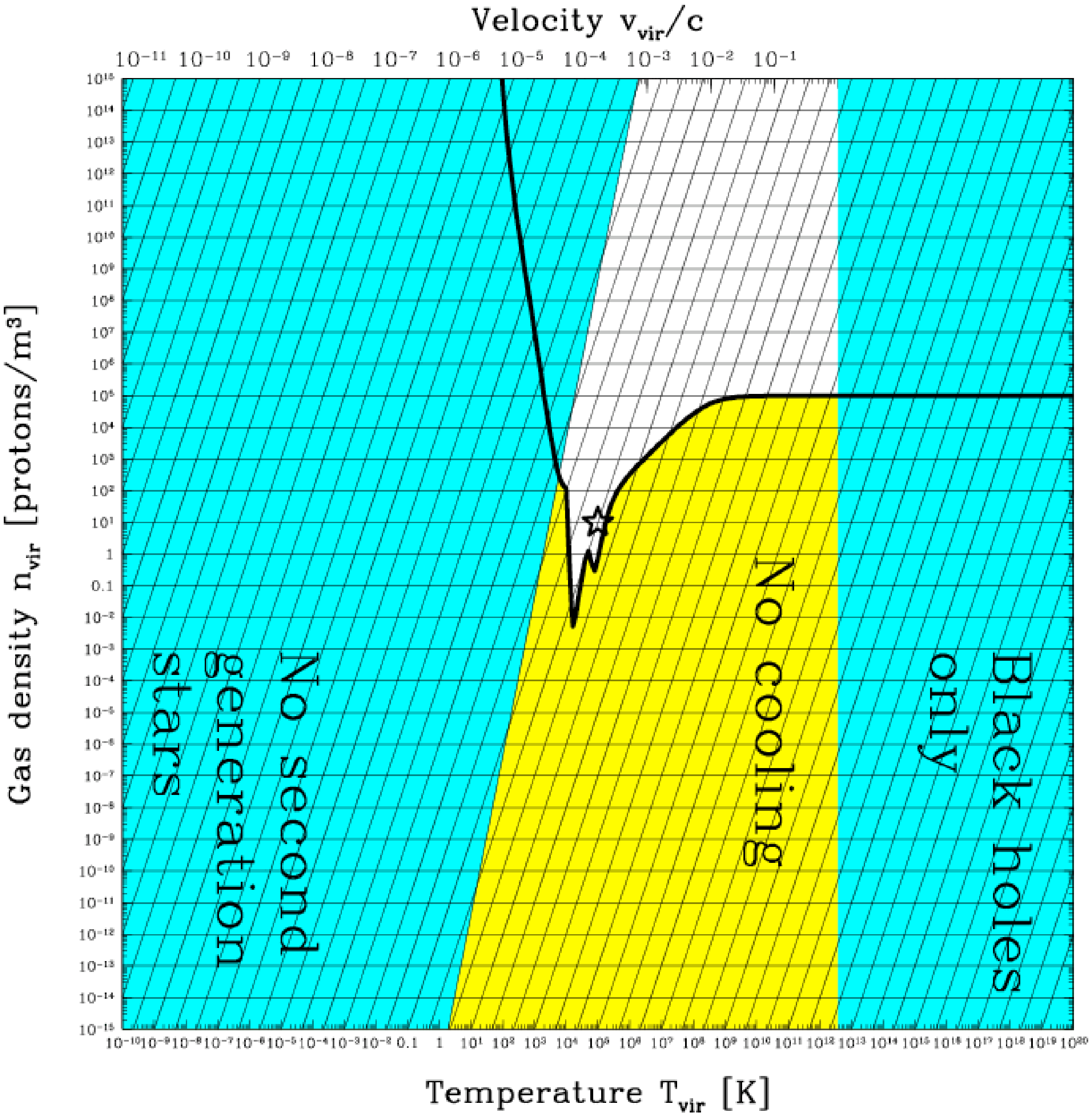
contrast →

The matter might get swept out by the first supernovae:

density ↑

time ↓

size ↓



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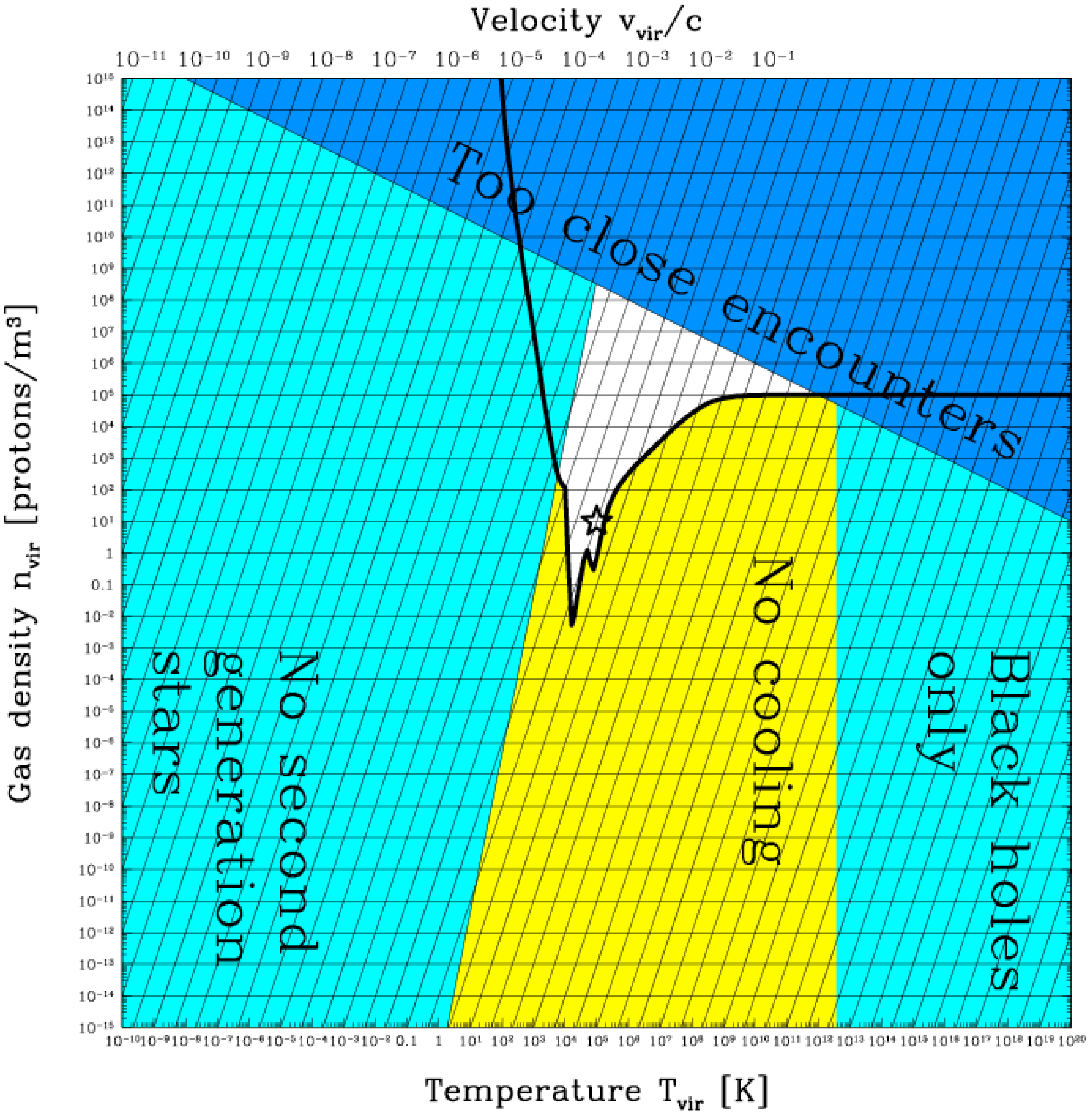
There might be no safe haven from disruptive encounters:

density ↑

time ↓

size ↓



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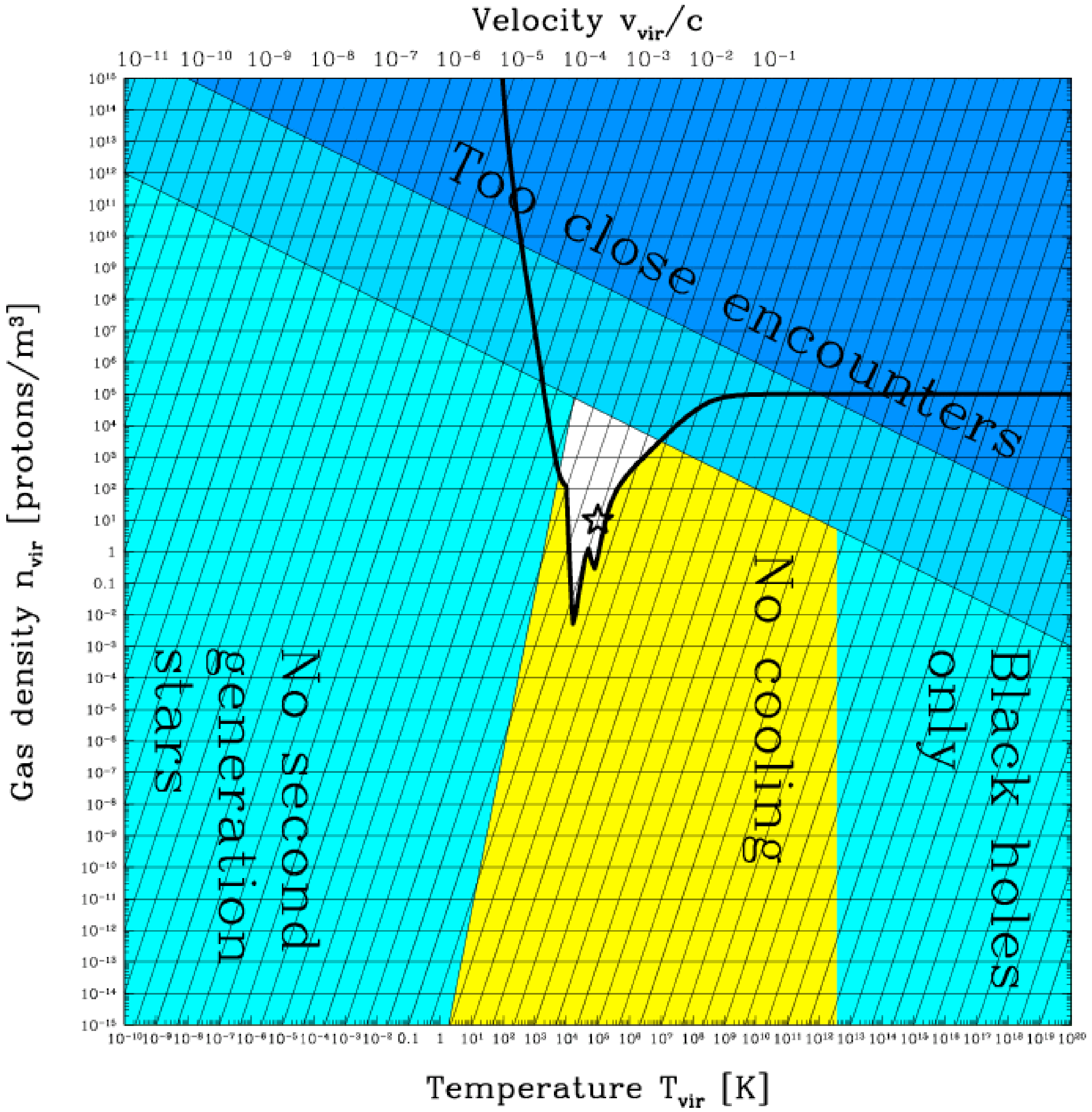
density ↑

time ↓

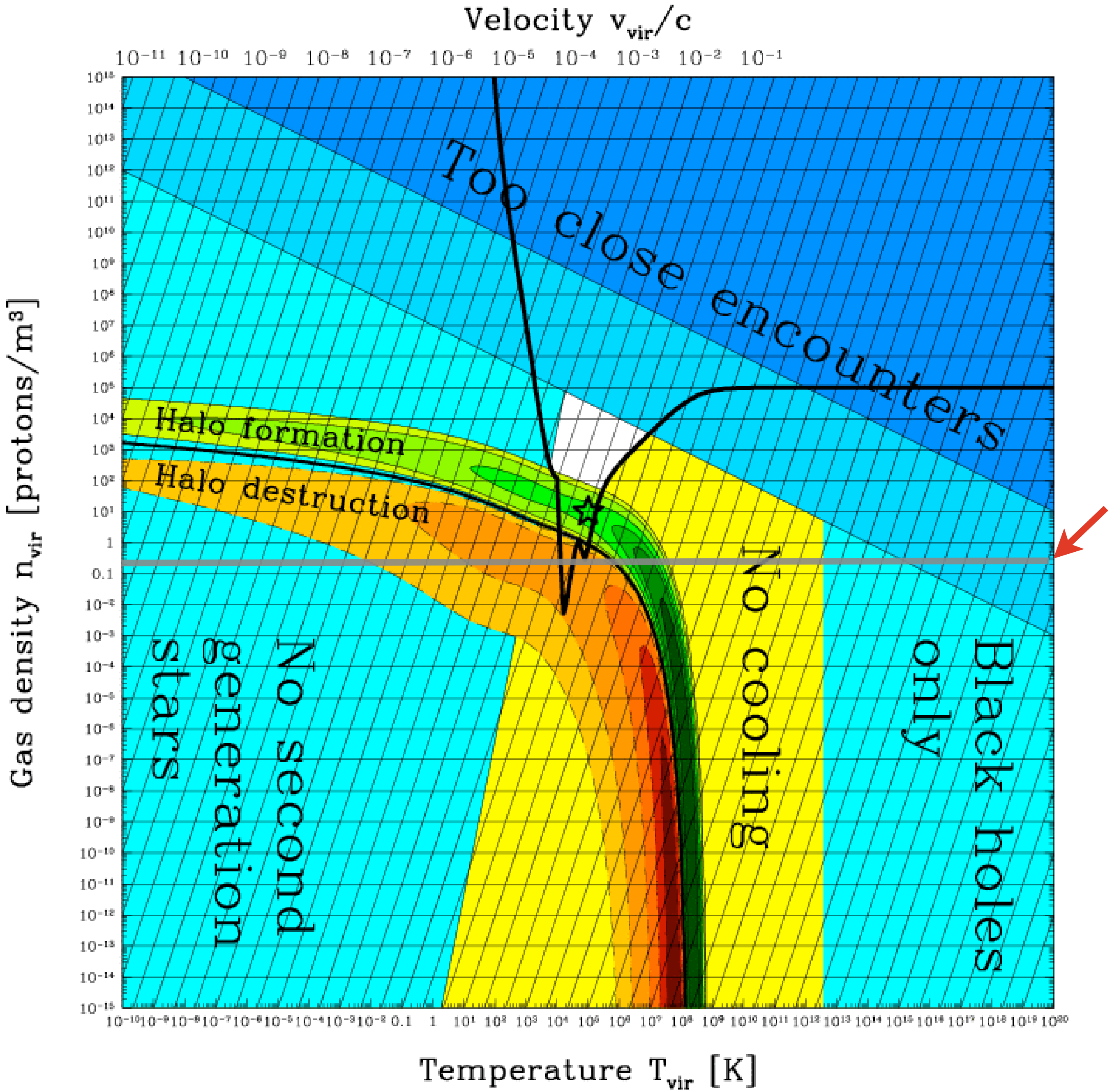
size ↓



contrast →

We can compare the potentially user-friendly seeds with what we get from primordial fluctuations.

Here is what we get with the observed fluctuation spectrum and dark matter density:



density ↑

time ↓

size ↓

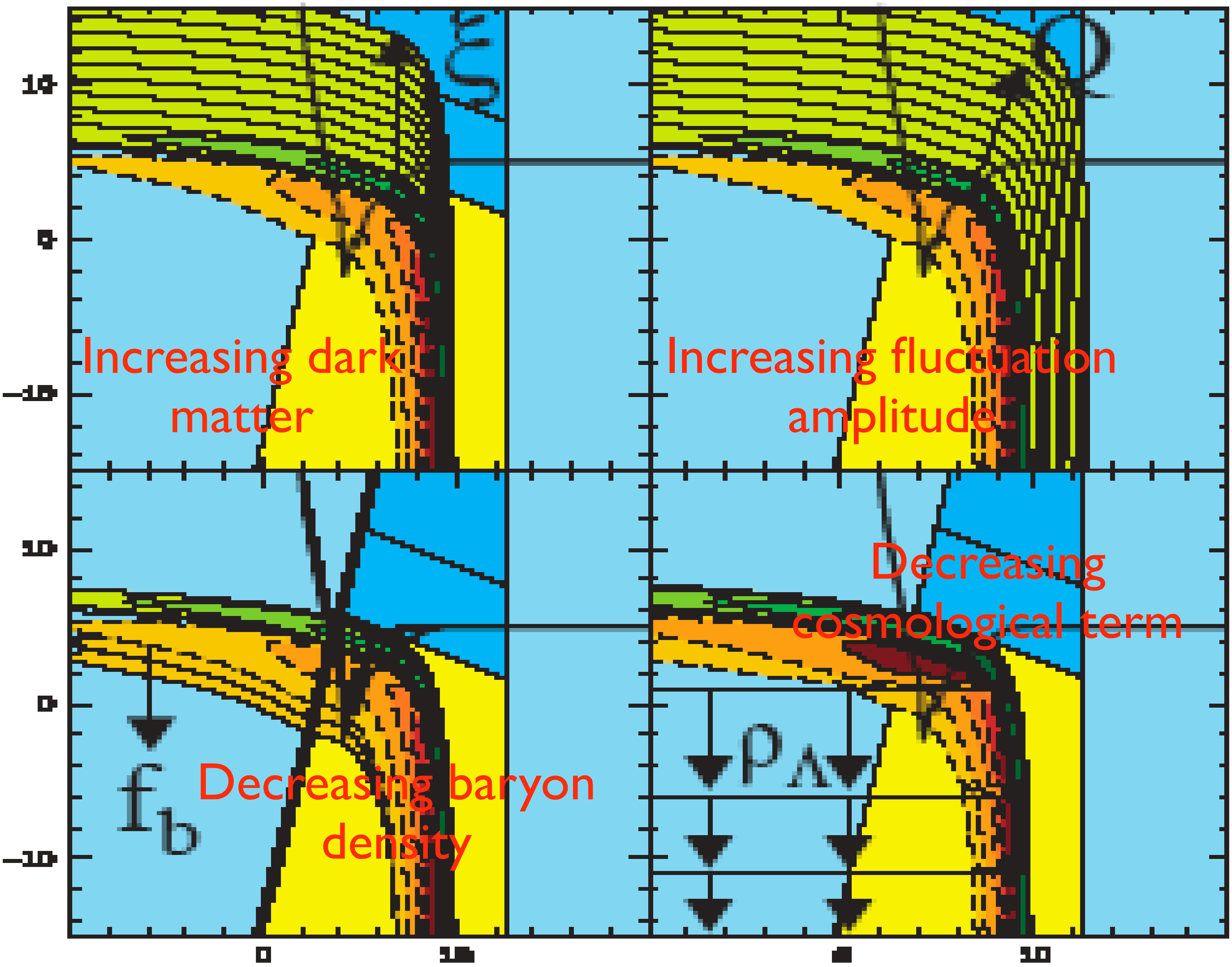
contrast →

Λ cutoff

The cosmological term cuts off growth.

This calculation gives a semi-quantitative explanation of the characteristic size of galaxies. (Note: So far, what we've done is conventional astrophysics.)

Now we can consider the effect of changing parameters governing the primordial fluctuations:



Increasing dark matter

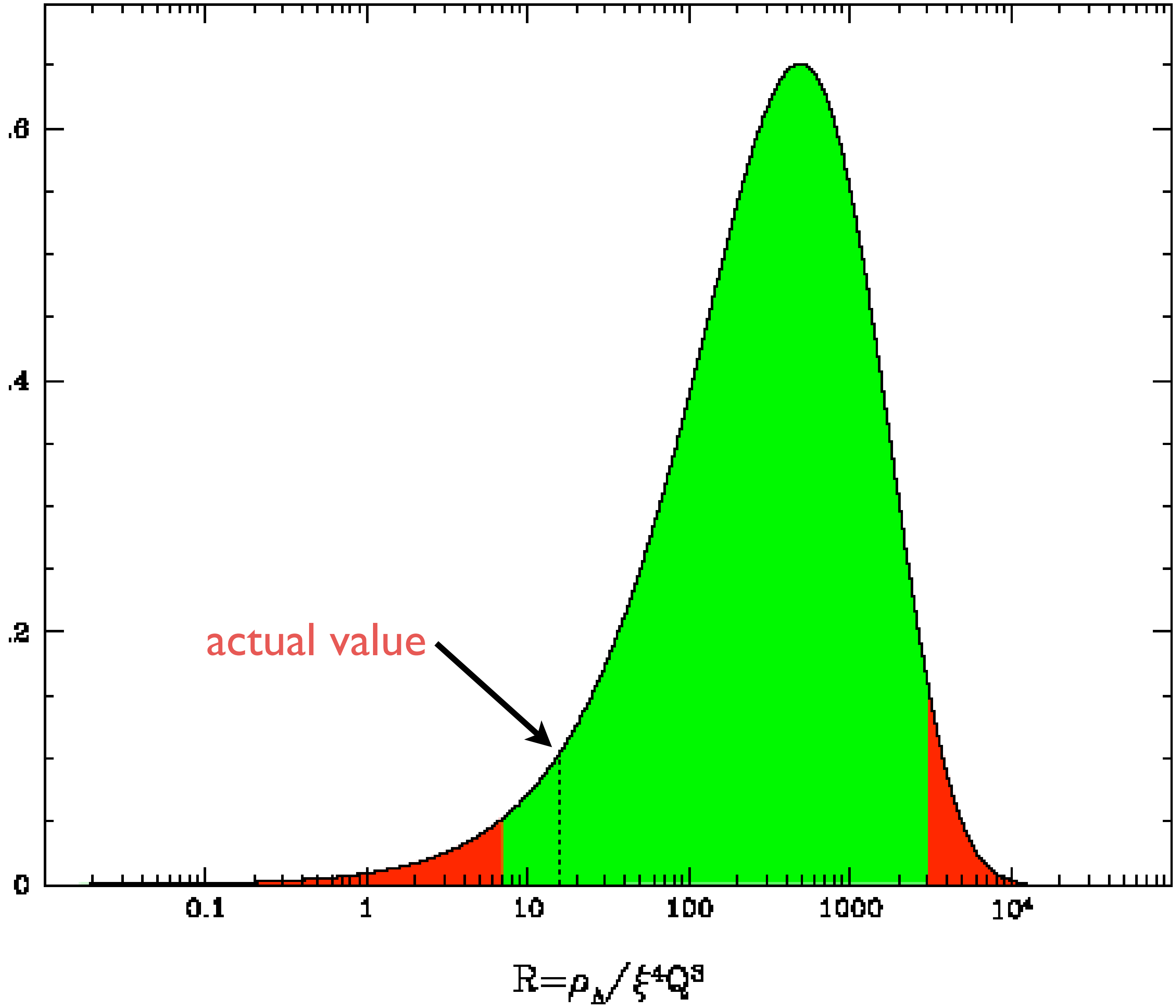
Increasing fluctuation amplitude

Decreasing baryon density

Decreasing cosmological term

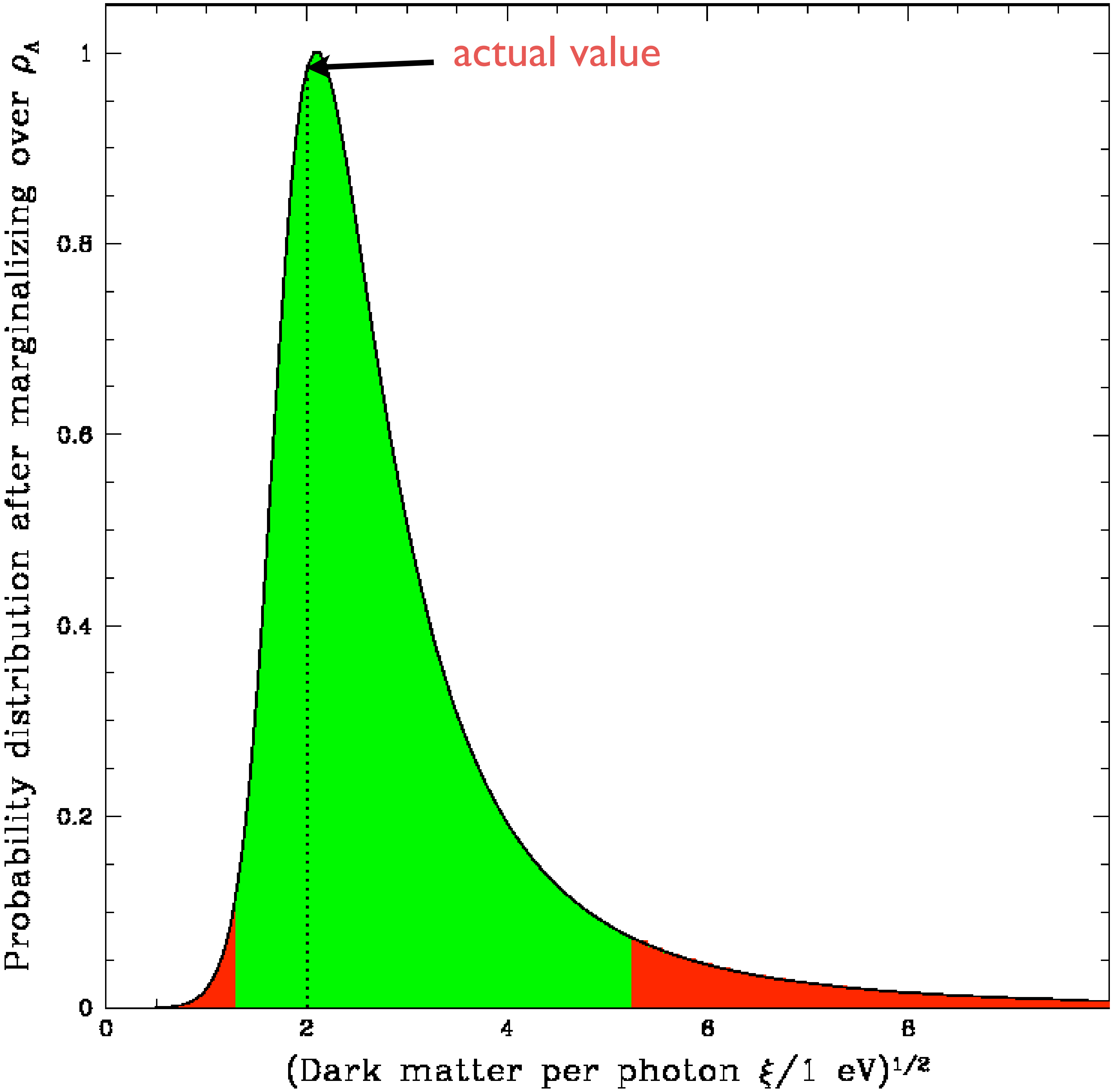
We can calculate probability distributions *per baryon in the user-friendly region*.

Here is the ρ_λ distribution, given a flat prior:



actual value

Here is the θ_0 distribution near 0, translated into dark matter density:



actual value

Scholium

(= Comments)

The scenario with inflation after the PQ transition removes some annoying difficulties of the traditional alternative (axion strings, domain walls).

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

... or by direct axion detection (F~10^{12} GeV)!

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

The theoretical success of axion cosmology emphasizes that if SUSY, and a dark matter candidate, are found at LHC, it will be important to pin its properties down and calculate its cosmological production.

Because if it's not enough, axions will happily - and naturally - supply the deficit.

Summary

Several important ideas suggest the existence of hidden sectors.

Neutral Higgs fields provide a possible portal into such sectors. The consequences could be dramatic.

Axion cosmology, which helps motivate these ideas, looks better than ever.