Key numbers

- Fluctuation amplitude (Q)
- Vacuum energy (lambda)

- Baryon/photon ratio
- Baryon/dark matter ratio

KEY ‘COSMIC NUMBERS’:

when (if ever) will we be able to explain their values, in the same way we understand the cosmic He abundance

FLUCTUATION AMPLITUDE

$$Q \cong 10^{-5}\left(\sim \frac{\Delta T}{T} \right)$$

→ *Bound Systems* with Gravitational Binding Energy* QMc^2

And Virial Velocity $Q^{1/2}c$

Max Non-Linear Scale

→

$Q^{1/2}$ x (Hubble Radius).

*Formation of Bound System Requires Expansion Factor of >~ Q^{-1} After System Enters Horizon.

AN ANAEMIC UNIVERSE ($Q = 10^{-6}$)

Small loosely-bound galaxies form later than in our universe; star formation is still possible, but processed material is likely to be expelled from shallow potential wells. There may be no second-generation stars containing heavy elements, and so no planetary systems at all.

If Q were significantly lower than 10^{-6}, then gas would be unable to cool with a Hubble time.*

In a Λ-dominated universe, isolated clumps could survive for an infinite time without merging into a larger scale of hierarchy. So eventually, for any $Q > 10^{-8}$, a 'star' could form – but by that time there would be merely one minihalo within the entire event horizon!

POSSIBLE UNIVERSE WITH *Q* = 10^{-4}

**perhaps <u>more interesting than ours!</u>*

Masses >~ 10^{14} $M_{\odot}$ condense at 3.10^{8} yrs into huge disc galaxies with orbital velocity ~2000 km/sec (gas would cool efficiently via Compton cooling, leading probably to efficient star formation).

These would, after 10^{10} yrs, be in clusters of
>~ 10^{16} $M_{\odot}$.

There would be a larger range of non-linear scales than in our actual universe. Only possible ‘disfavouring’ feature is that stellar systems may be too packed together to permit unperturbed planetary orbits.

UNIVERSE WITH $Q > 10^{-3}$

Monster overdensities (up to $10^{18}\ M_{\odot}$) condense out early enough that they trap the CMB radiation, and collapse as radiation-pressure-dominated hypermassive objects unable to fragment*. This leads to universe of vast holes, clustered on scales up to several percent of Hubble radius (and probably pervaded by intense ‘hard’ radiation).

It isn’t obvious that much baryonic material would ever go into stars. (If so they would be in very compact highly bound systems.)

**This does not require pre-combination collapse. Collapse at (say)* 10^7 *years would lead to sufficient partial reionization (via strong shocks) to recouple the baryons and CMB.*

Key numbers

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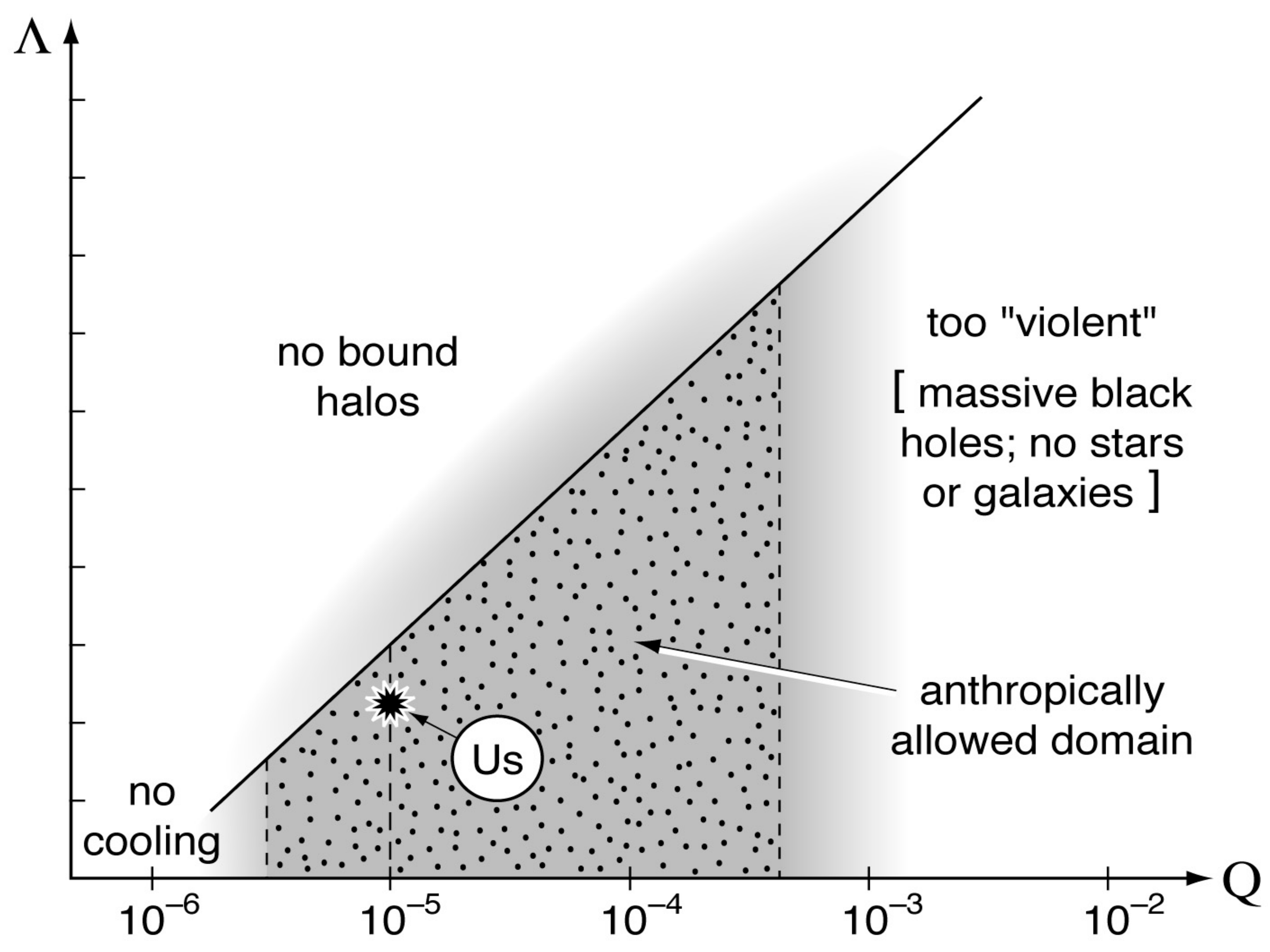

Λ
Q
no bound halos
too "violent"
[massive black holes; no stars or galaxies]
anthropically allowed domain
Us
no cooling
10^−6
10^−5
10^−4
10^−3
10^−2

Key numbers

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- Vacuum energy (lambda)

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- Baryon/dark matter ratio