Struggling with Entropy

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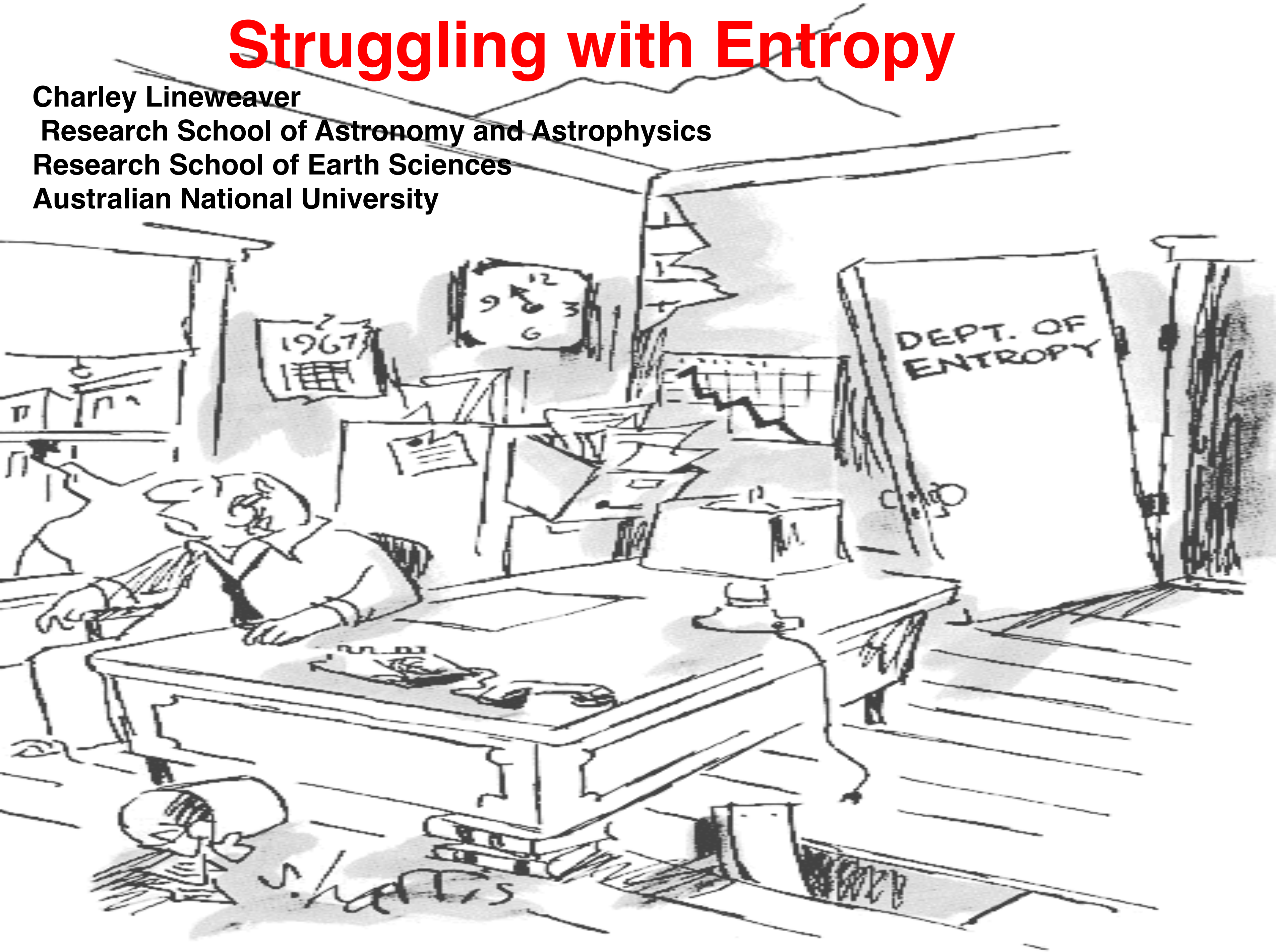
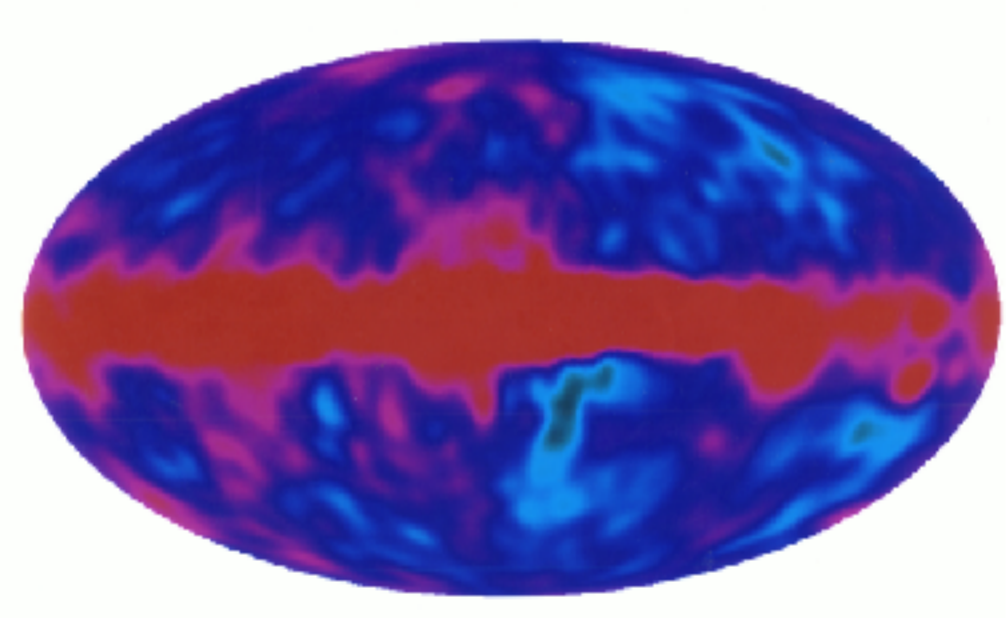
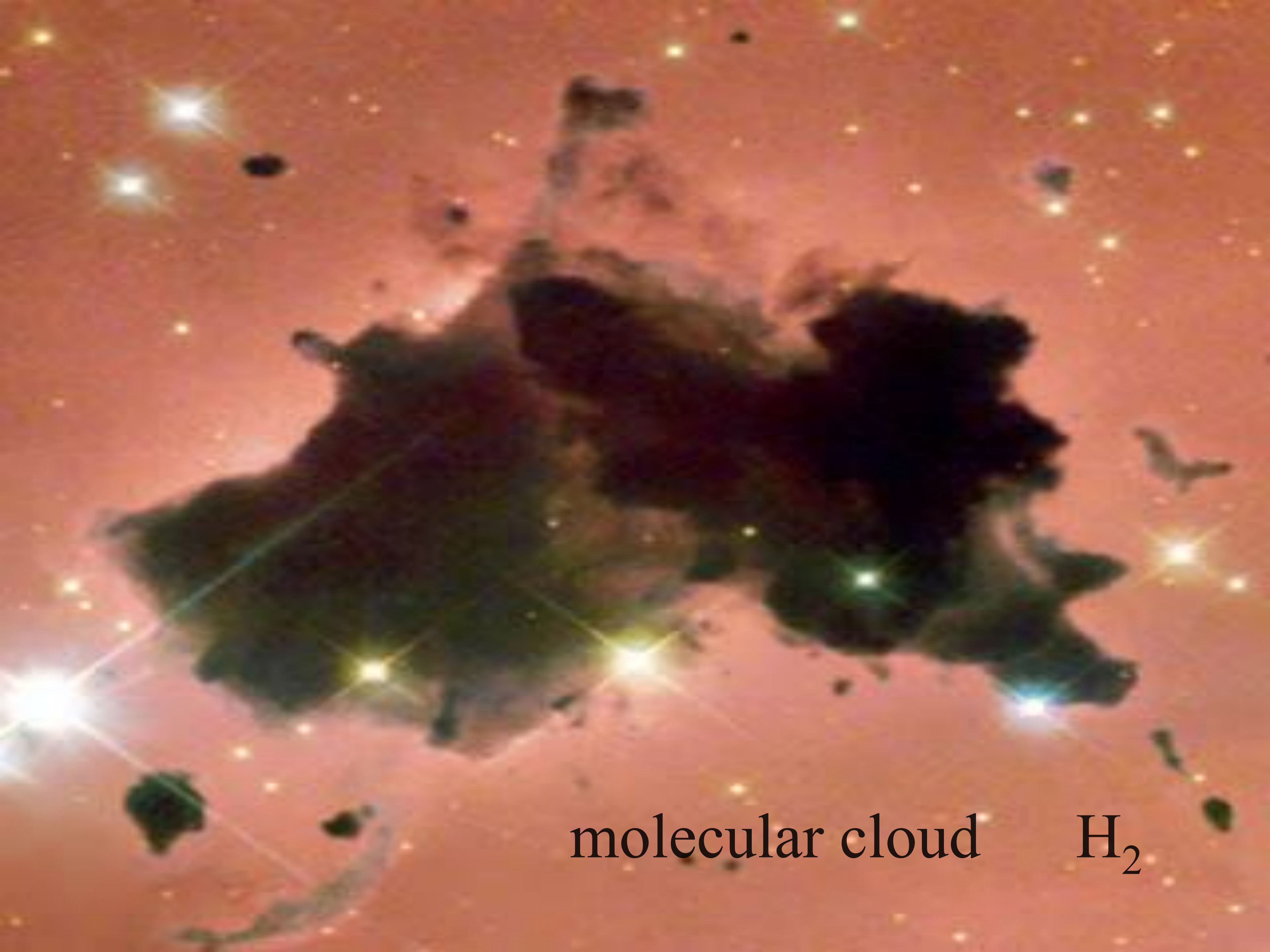


CMB and Aliens



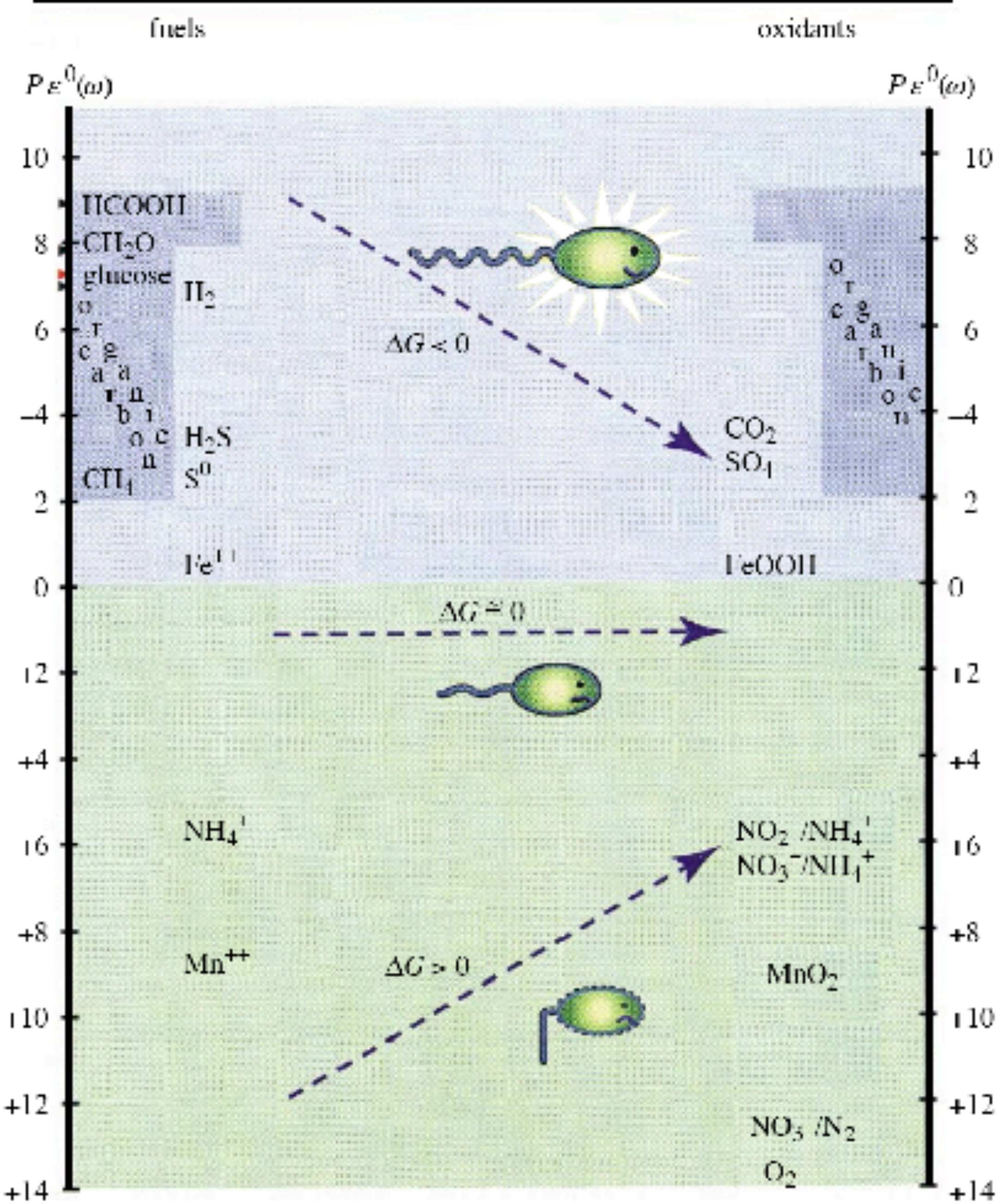

molecular cloud
H_2


life form CHON

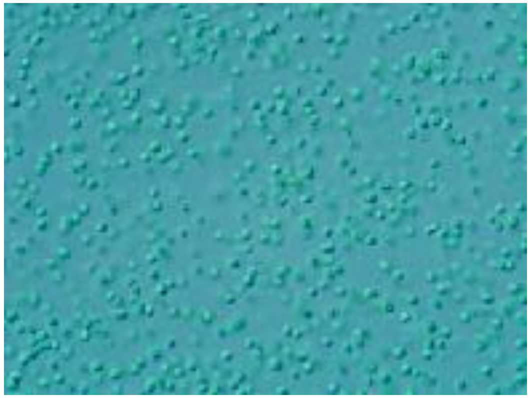
Life forms, refrigerators
and all other irreversible processes

$$dS \geq 0$$

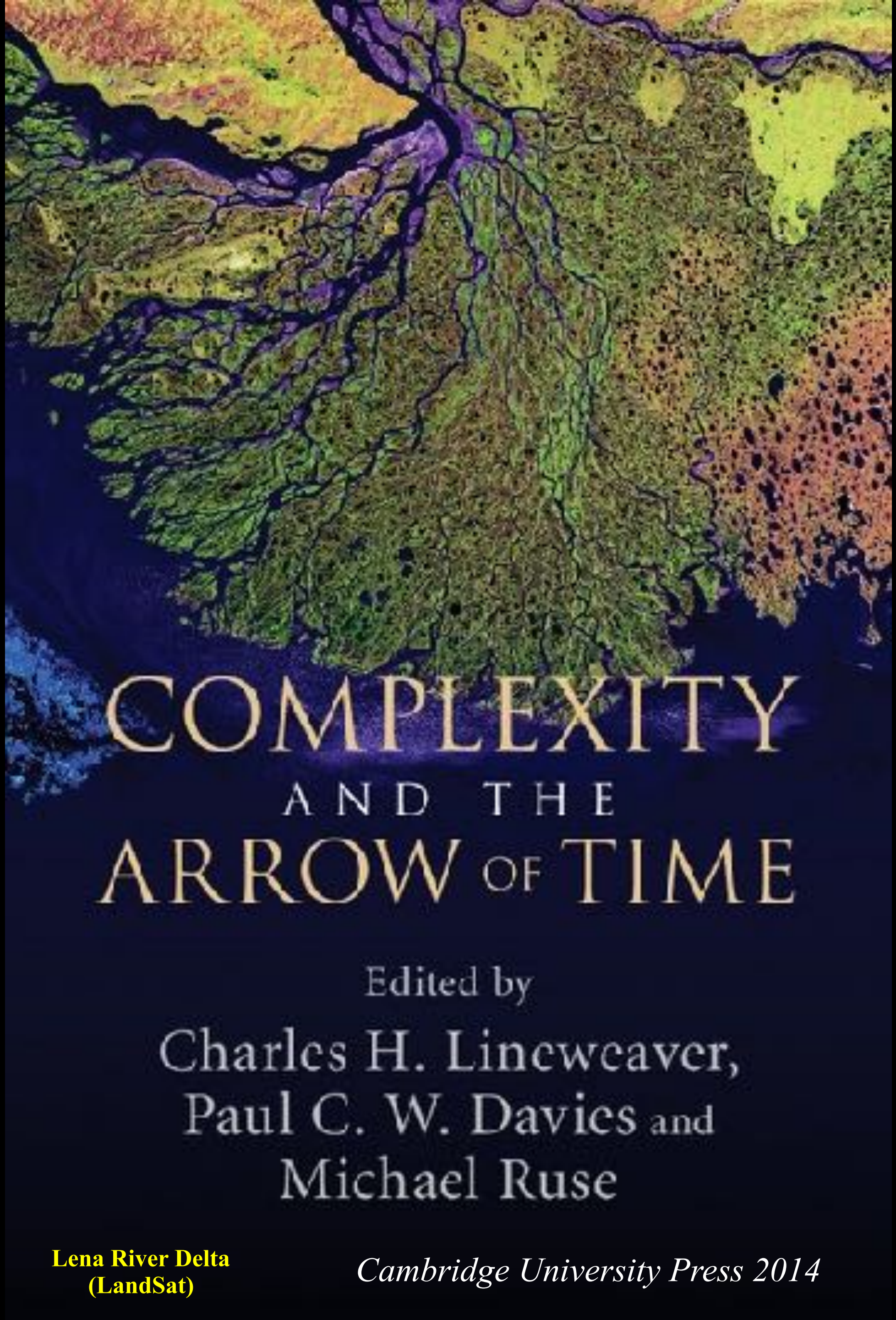
thermodynamics
it's not just a good idea... it's the law!



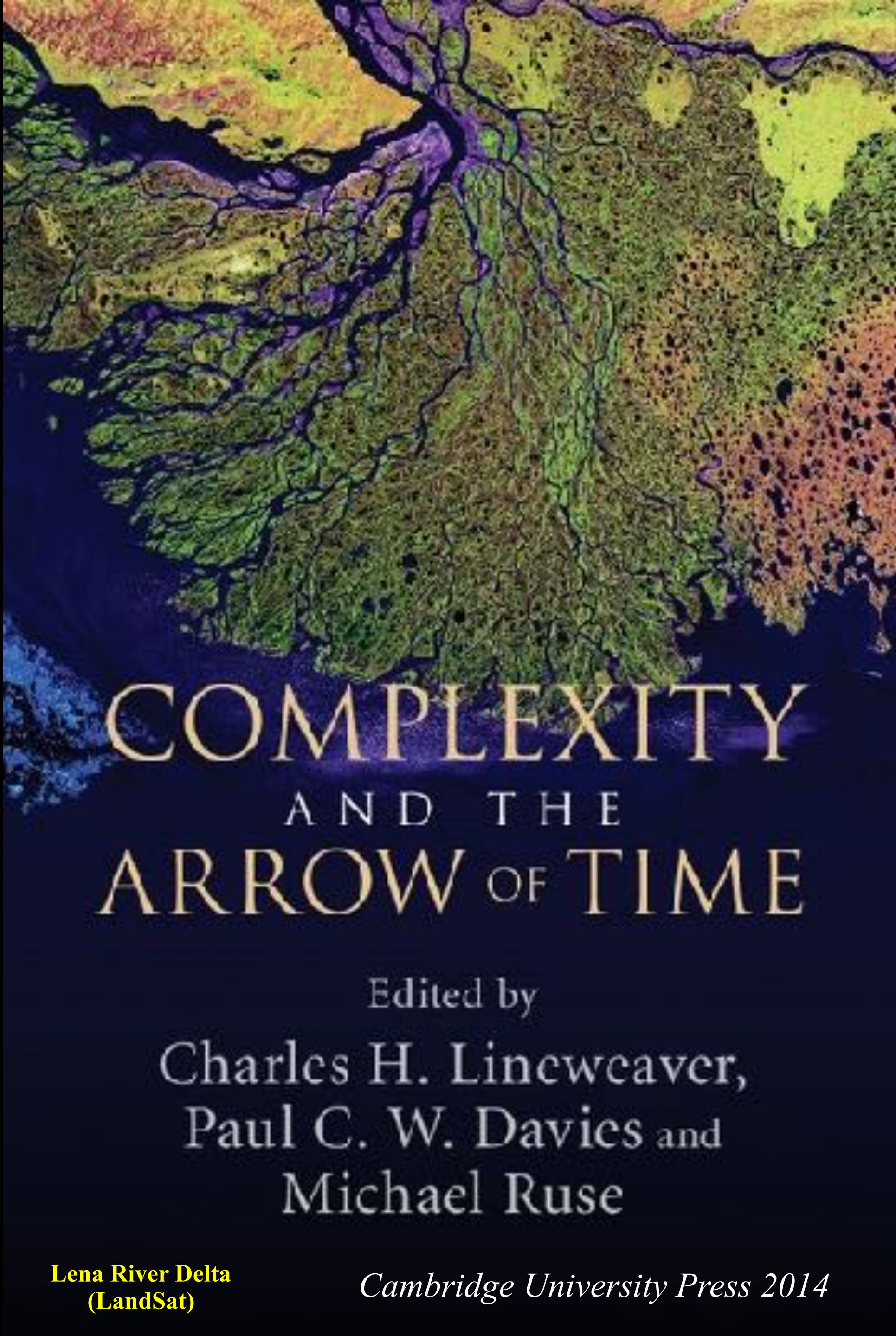
Prochlorococcus
100 octillion (10^{29}) individuals



Nealson and Conrad 1999



Is the complexity of the universe increasing?

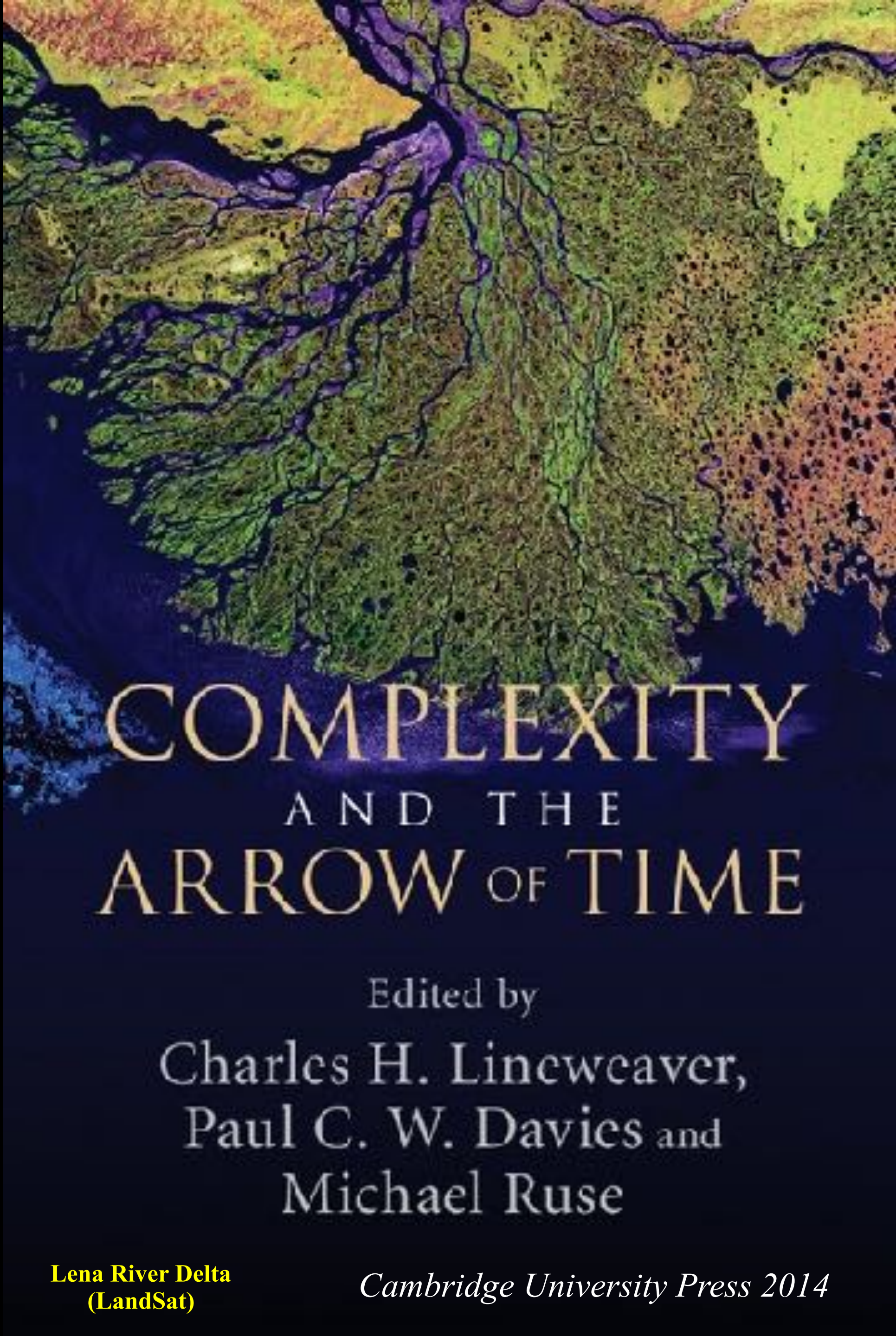


Lena River Delta (LandSat)

Cambridge University Press 2014

Is the complexity of the universe increasing?

**Many definitions of complextity
but all of them require free energy.
All require an entropy gap ΔS
between the entropy of the universe
and the maximum entropy of the universe.**



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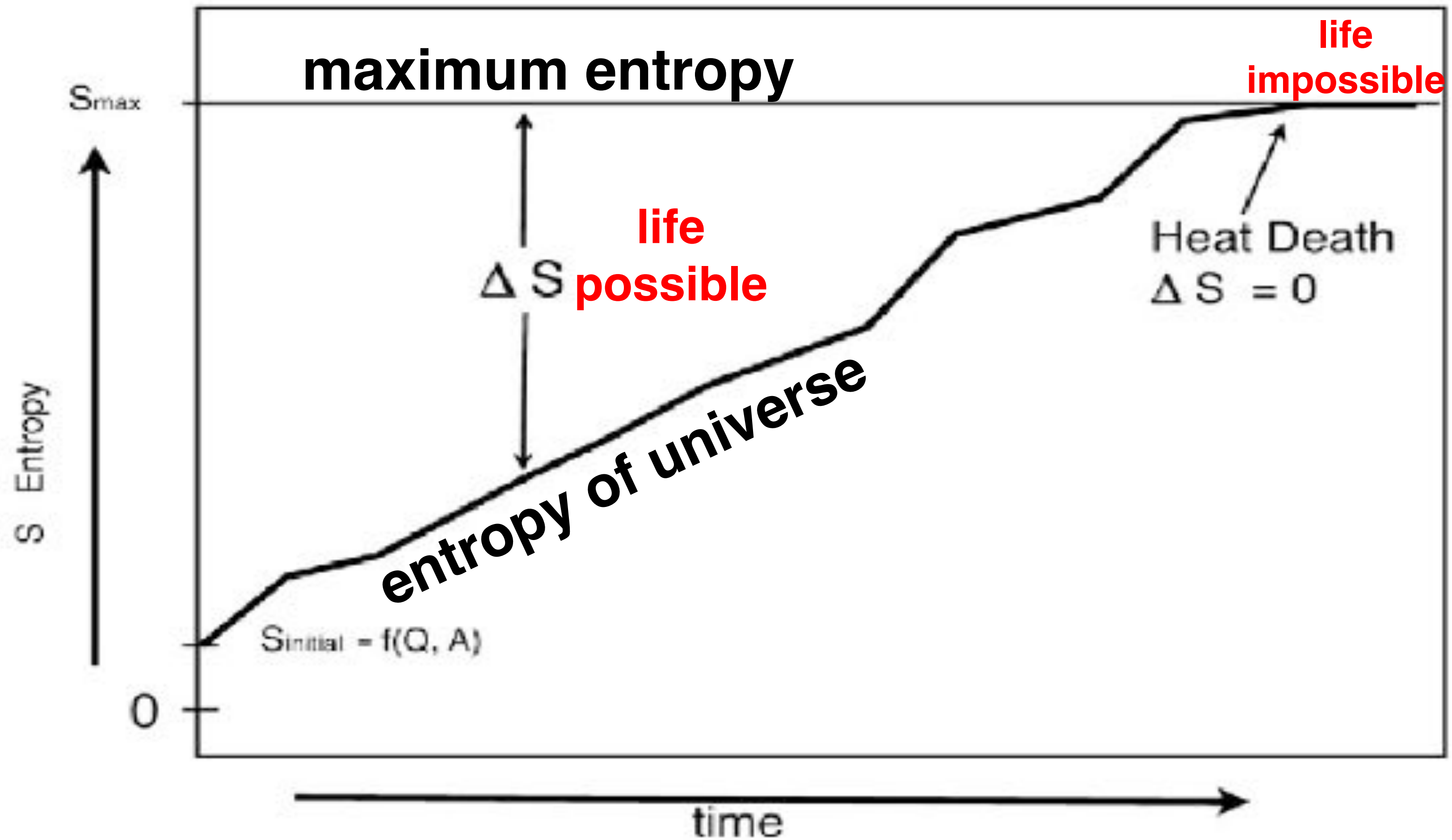
How can complexity keep increasing if we are headed for a heat death?

Second law of cosmobiology



Life and all other dissipative structures in the universe depend on the non-equilibrium of the universe and the availability of free energy. Within the standard ΛCDM cosmology, we quantify this non-equilibrium as the difference between the maximum entropy the universe will ever have (within the comoving volume of the current particle horizon), and the monotonically increasing entropy of the universe within the same comoving volume. When $S_{max} - S_{uni}(t) \approx 0$ the universe will reach an effective heat death from which no more free energy can be extracted.

Astrophysical Journal 2010

A LARGER ESTIMATE OF THE ENTROPY OF THE UNIVERSE

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ABSTRACT

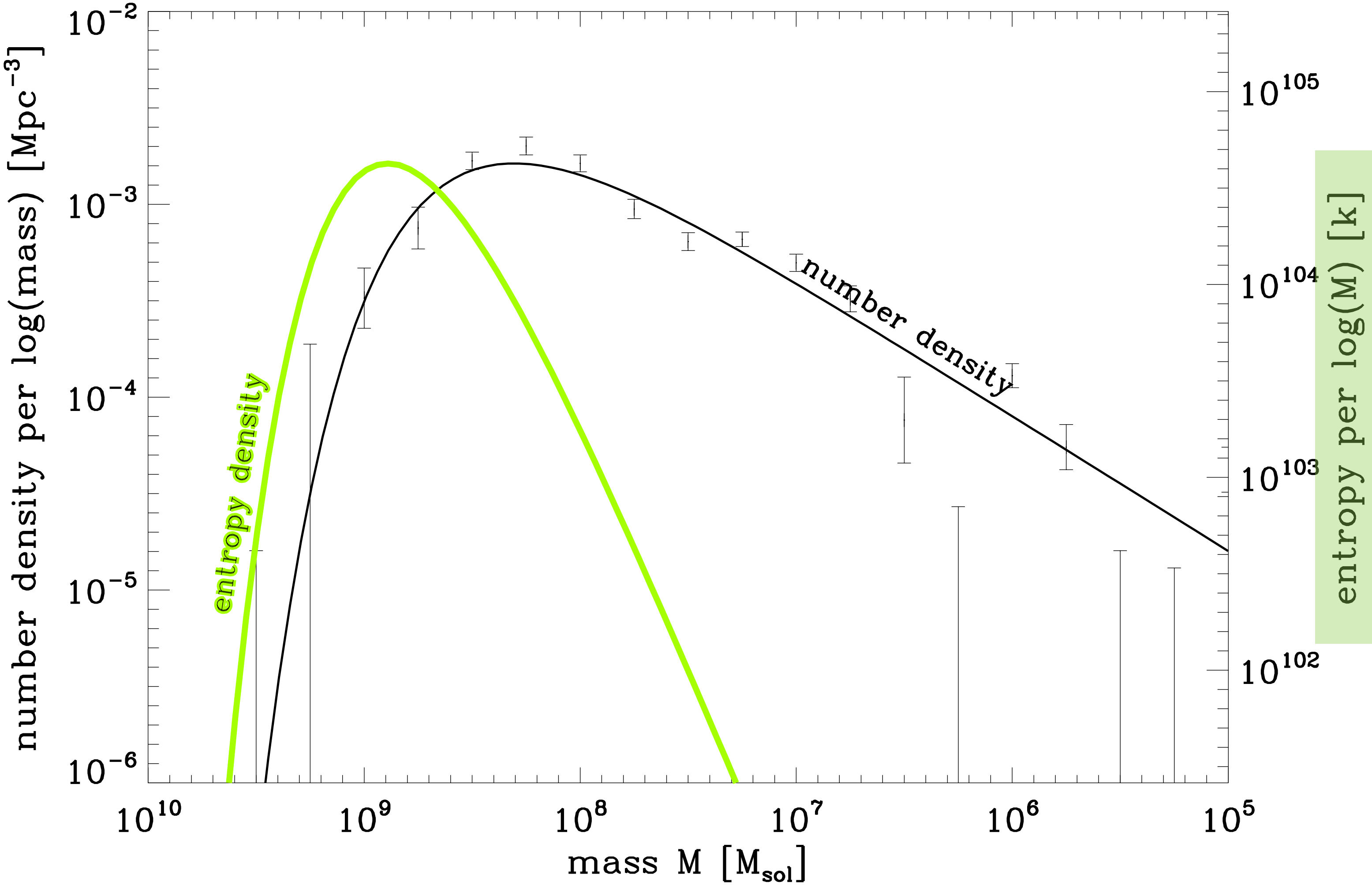
Using recent measurements of the supermassive black hole (SMBH) mass function, we find that SMBHs are the largest contributor to the entropy of the observable universe, contributing at least an order of magnitude more entropy than previously estimated. The total entropy of the observable universe is correspondingly higher, and is $S_{obs} = 3.1^{+3.0}_{-1.7} \times 10^{104} k$. We calculate the entropy of the current cosmic event horizon to be $S_{CEH} = 2.6 \pm 0.3 \times 10^{122} k$, dwarfing the entropy of its interior, $S_{CEH\,int} = 1.2^{+1.1}_{-0.7} \times 10^{103} k$. We make the first tentative estimate of the entropy of weakly interacting massive particle dark matter within the observable universe, $S_{dm} = 10^{88\pm1} k$. We highlight several caveats pertaining to these estimates and make recommendations for future work.

The initial low gravitational entropy of the universe as the origin of design in nature.
Lineweaver and Egan 2011 (Chapter in Origin of Design, Edt Seckbach et al, Springer

Component	Entropy S $[k]$ (previous work)	Entropy S $[k]$	Entropy Density s $[k\ m^{-3}]$
SMBHs S_{SMBH}	10^{101} [26], 10^{102} [3]	$2.9^{+2.8}_{-1.6} \times 10^{104}$	$8.4^{+8.2}_{-4.7} \times 10^{23}$
Stellar BHs S_{SBH}	10^{97} [3], 10^{98} [1]	$5.6 \times 10^{97^{+1.2}_{-0.6}}$	$1.6 \times 10^{17^{+1.2}_{-0.6}}$
CMB S_{γ}	10^{88} [1, 3, 26], 10^{89} [34]	$5.104 \pm 0.011 \times 10^{89}$	$1.478 \pm 0.003 \times 10^{9}$
Relic Neutrinos S_{ν}	10^{88} [3], 10^{89} [34]	$4.87 \pm 0.01 \times 10^{89}$	$1.41 \pm 0.01 \times 10^{9}$
Dark Matter S_{DM}	–	$1.0 \times 10^{88 \pm 1}$	$2.9 \times 10^{7 \pm 1}$
Relic Gravitons S_{g}	10^{86} [3]	$2.8 \times 10^{86 \pm 1.3}$	$1.2 \times 10^{6 \pm 1.3}$
Non-Relic Photons $S_{\gamma *}$	10^{86} [1, 3, 35]	–	–
ISM & IGM S_{gas}	–	$4 \times 10^{81 \pm 0.5}$	$1.2 \times 10^{1 \pm 0.5}$
Stars S_{*}	10^{79} [3]	$1.2 \times 10^{80 \pm 0.4}$	$3.5 \times 10^{-1 \pm 0.4}$
Total S_{uni}	**10^{101} [26], 10^{102} [3]**	**$2.9^{+2.8}_{-1.6} \times 10^{104}$**	**$8.4^{+8.2}_{-4.7} \times 10^{23}$**

[1] Frautschi 1982
[3] Frampton et al 2008
[26] Penrose 2004
[34] Kolb & Turner 1981
[35] Bousso et al 2007

Black hole mass function



$$S_{BH} \propto k\, M^2$$

May 2, 1992

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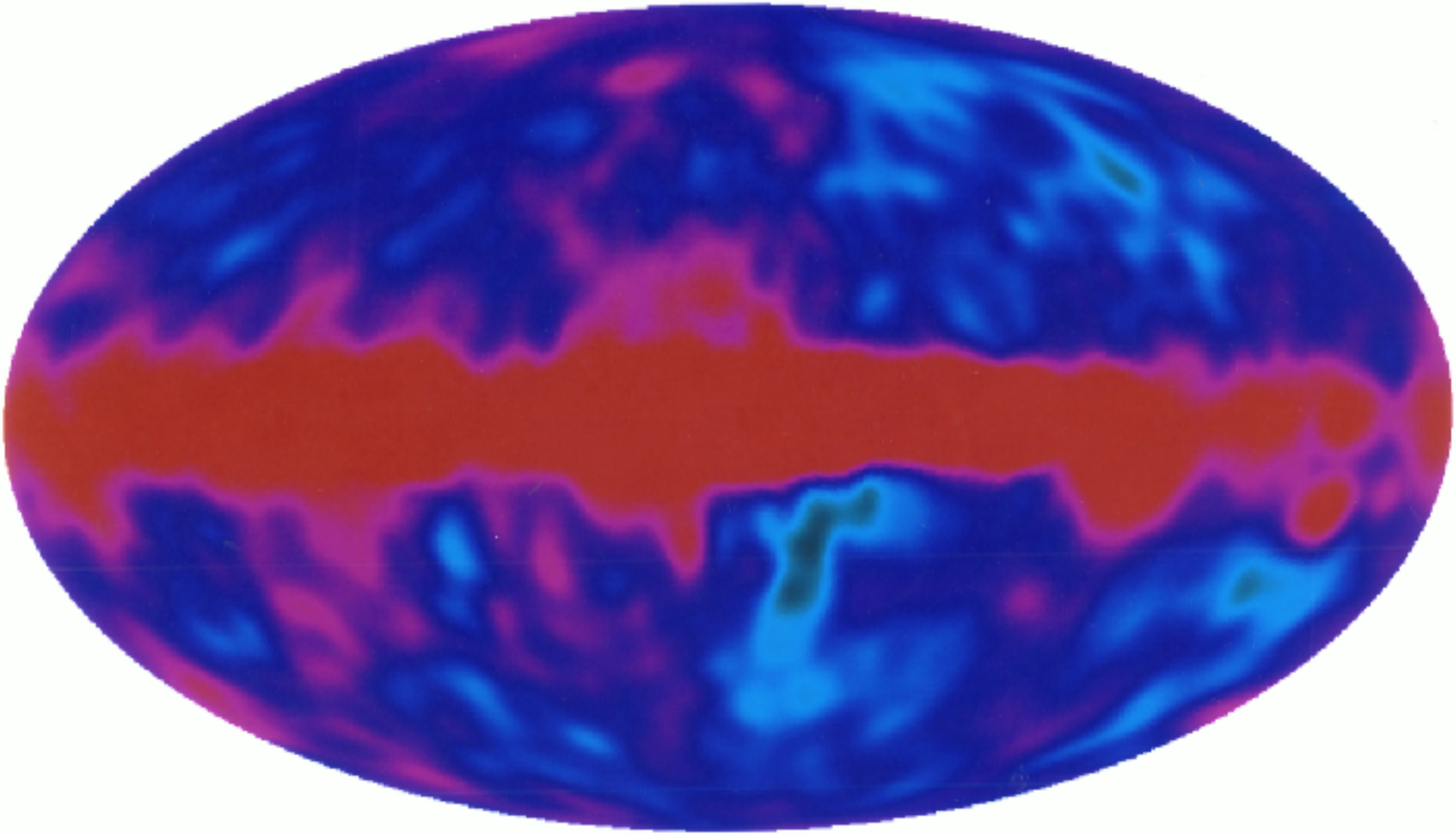
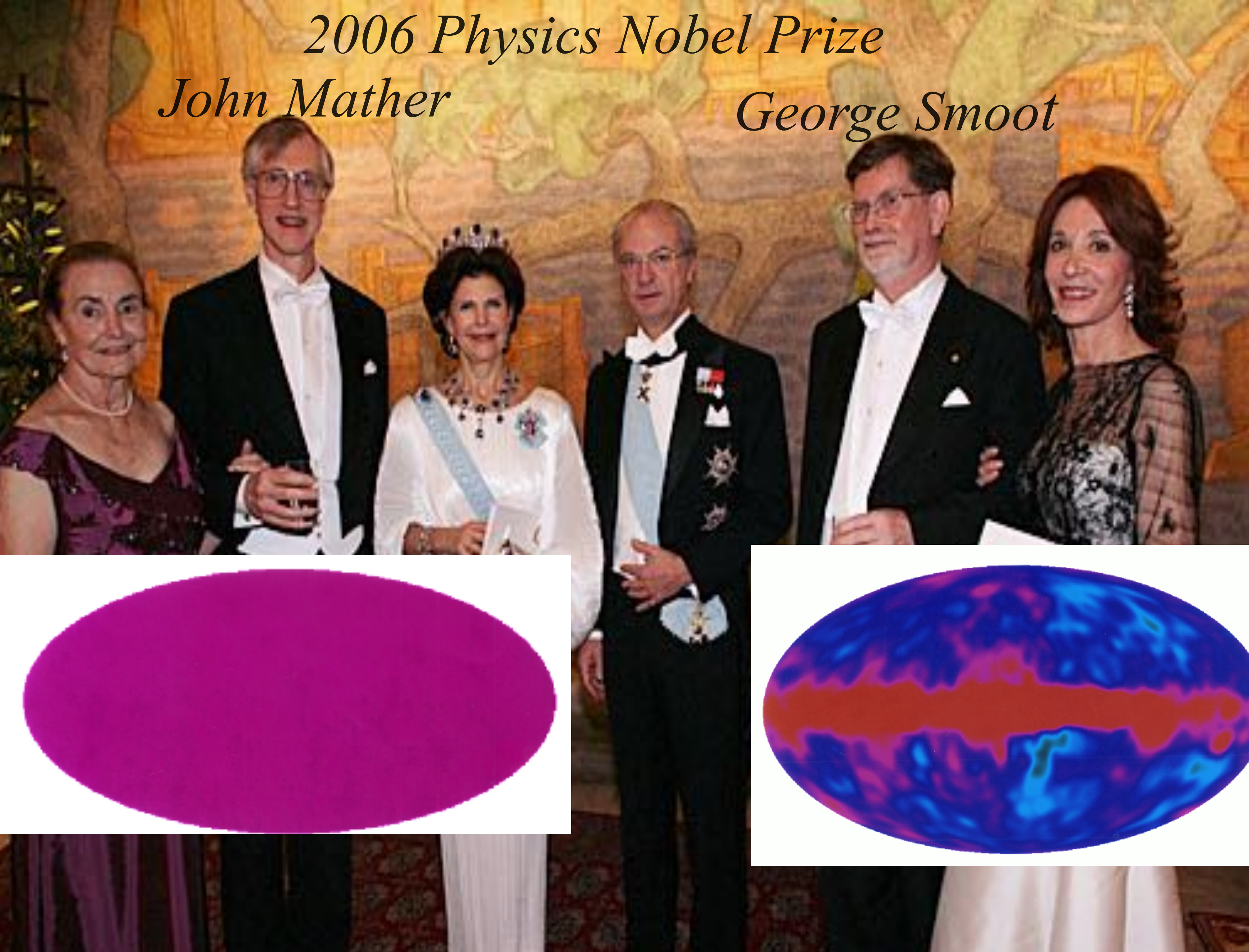
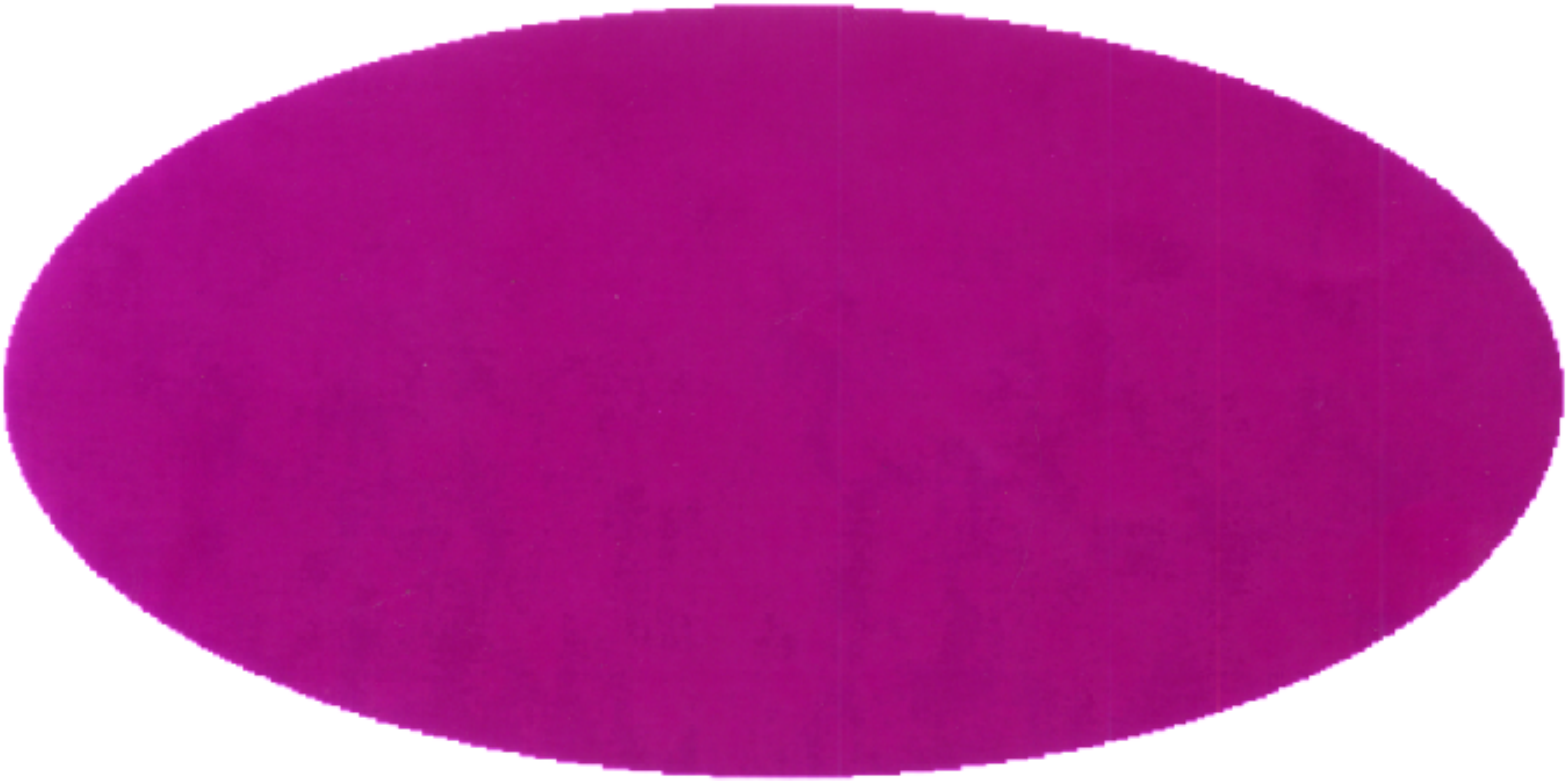


2006 Physics Nobel Prize



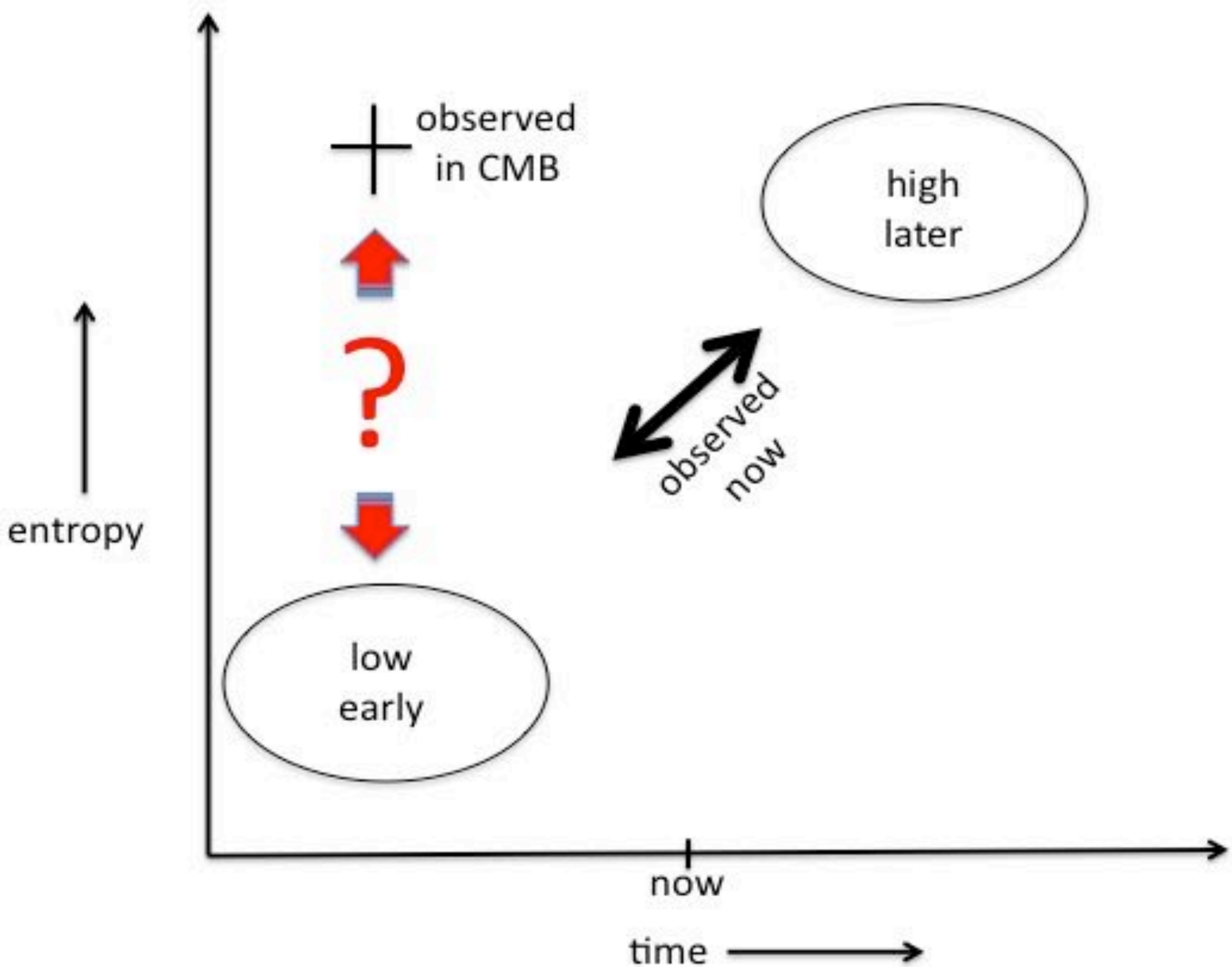
The universe 380,000 years after the big bang.



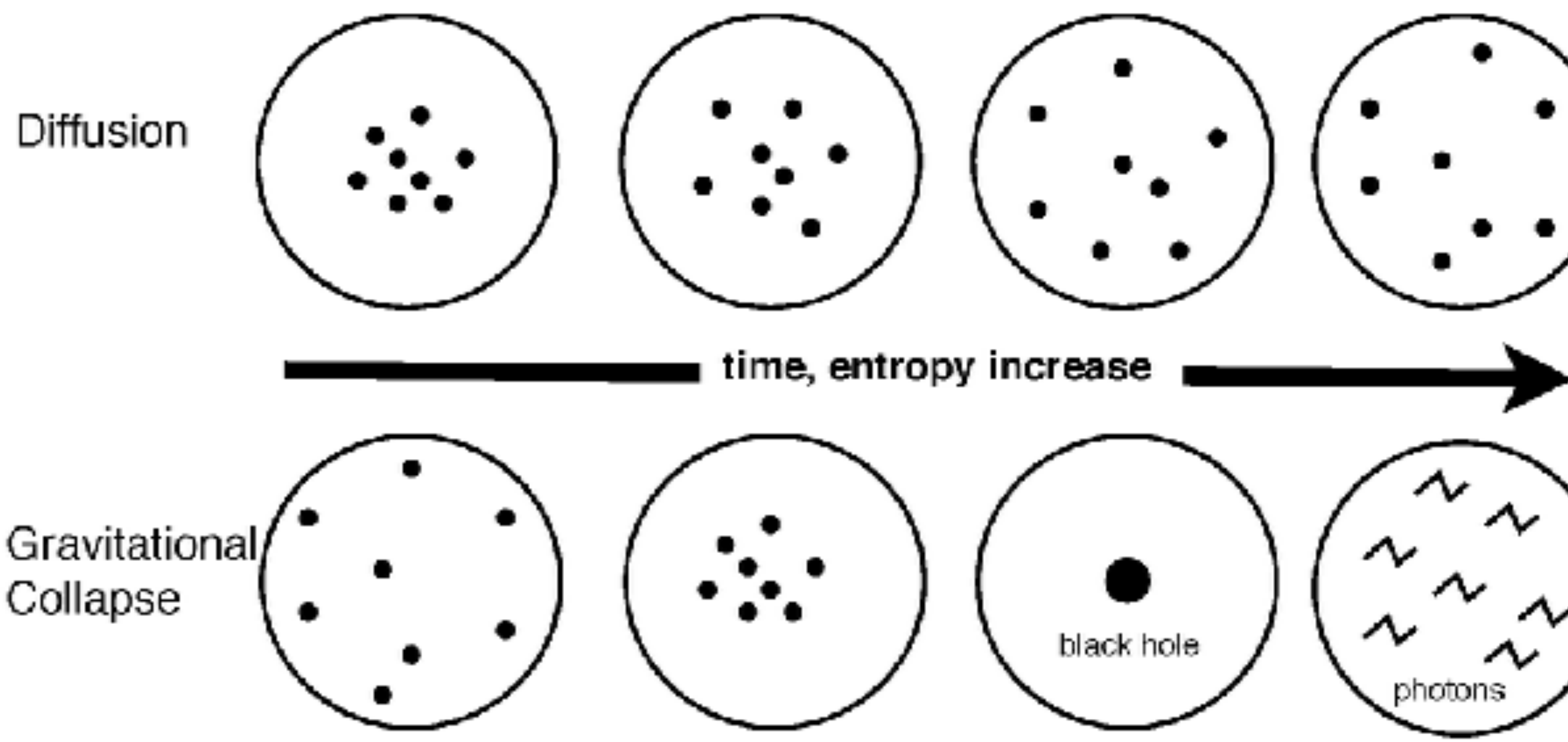
Full Sky Map of the Cosmic Microwave Background

COBE FIRAS and DMR instruments

The Initial Entropy Problem

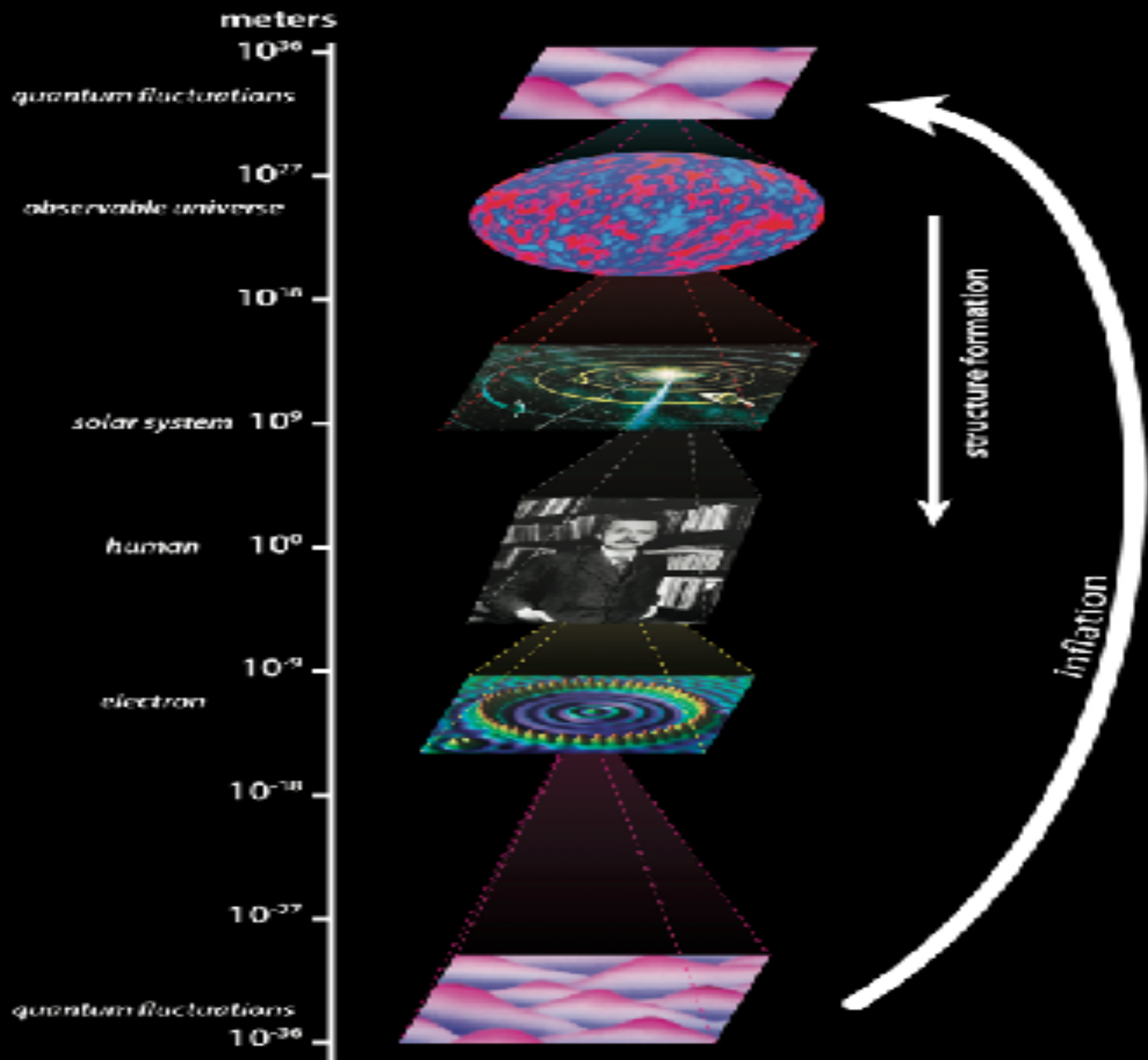


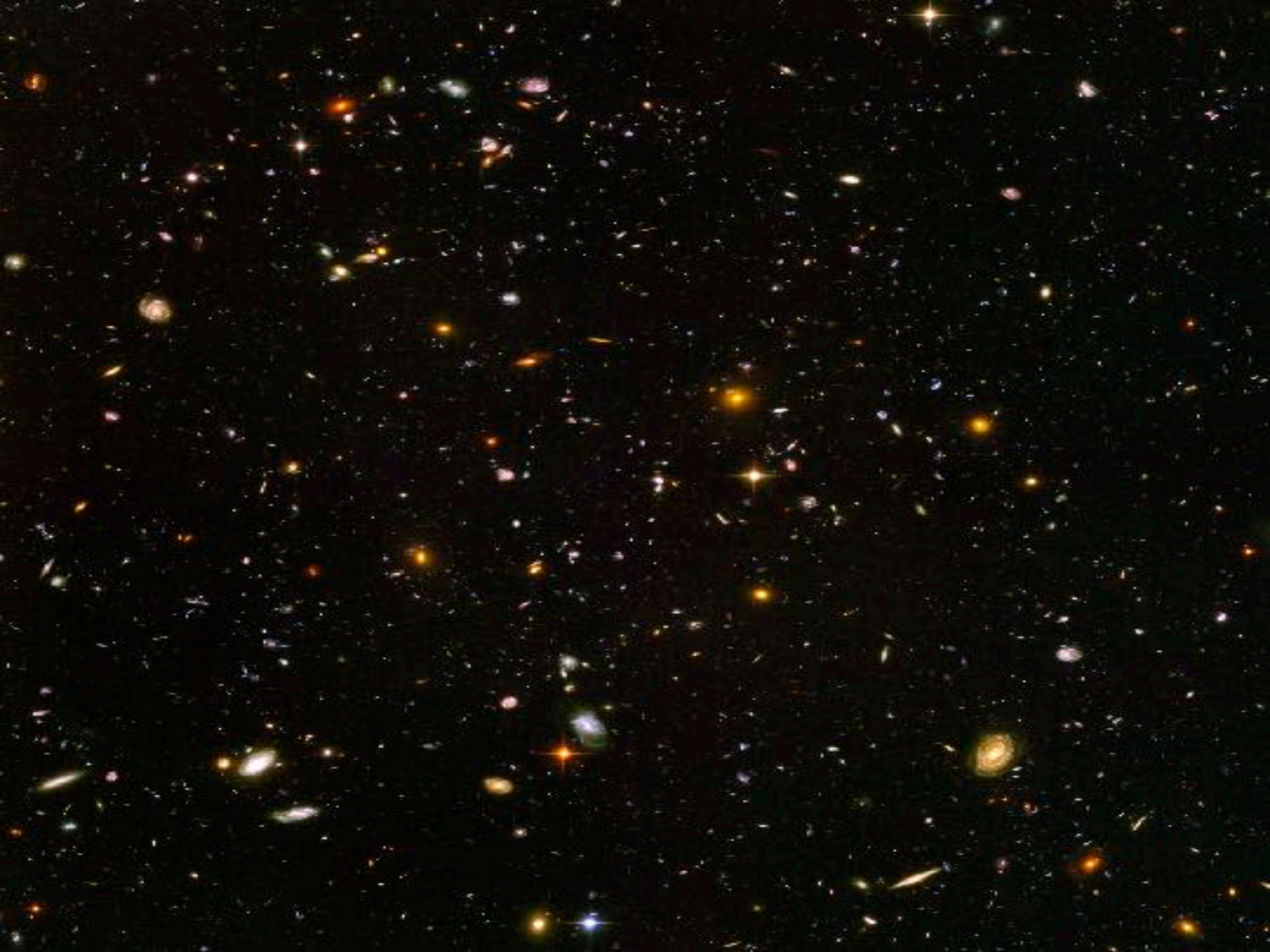
kinetic energy dominated system: heat capacity > 0



gravity dominated system: heat capacity < 0

Origin of Structure





Beware "temporal provincialism*":

The tendency to slip in assumptions about $\dot{S} > 0$
(and thus tunings of initial conditions)
without even realizing it

Related issues:

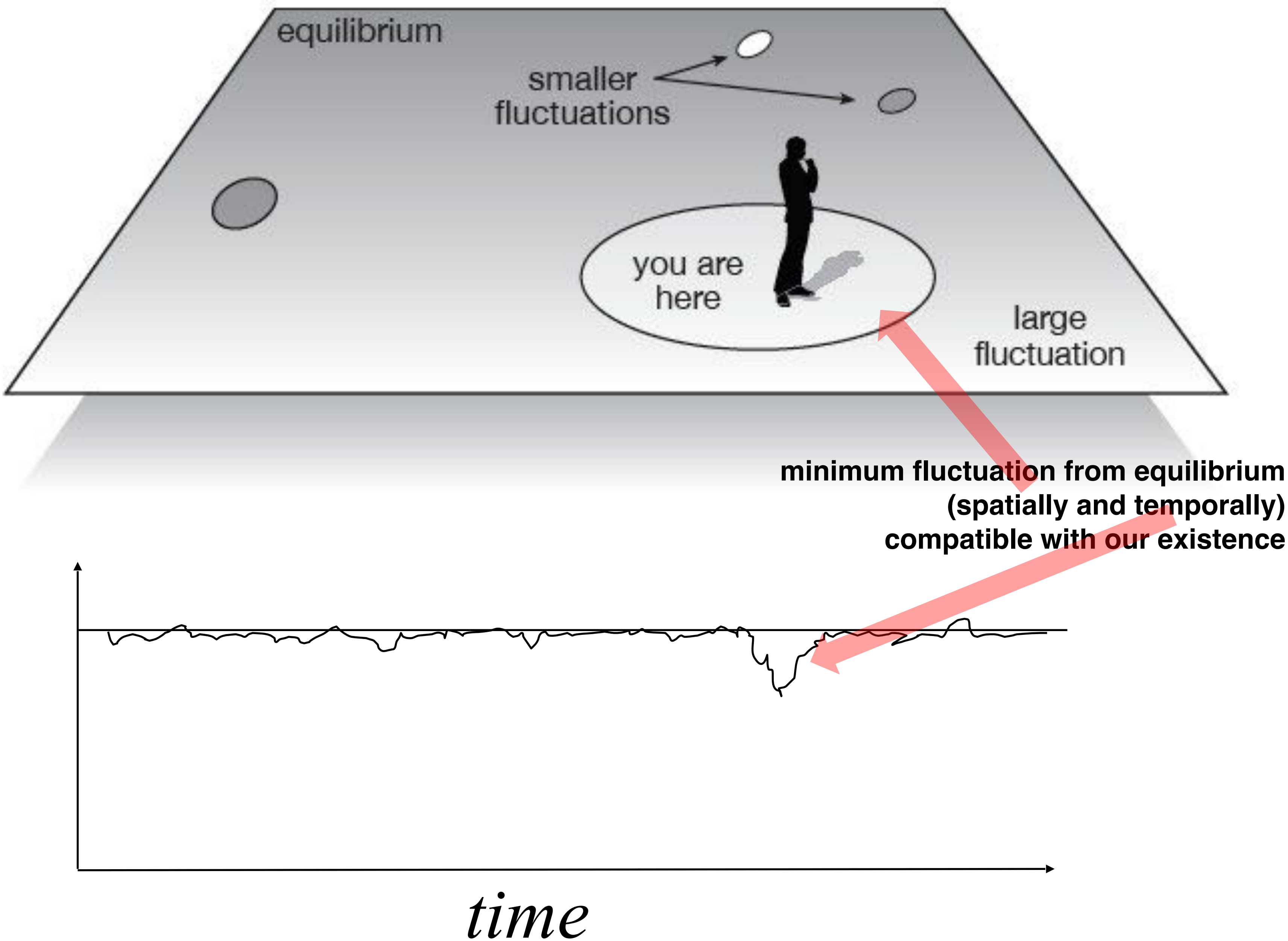
- Arrival Terminals

* L. Susskind

"Temporal Provincialism" ?
you can't argue with a cup of coffee

$$dS \geq 0$$

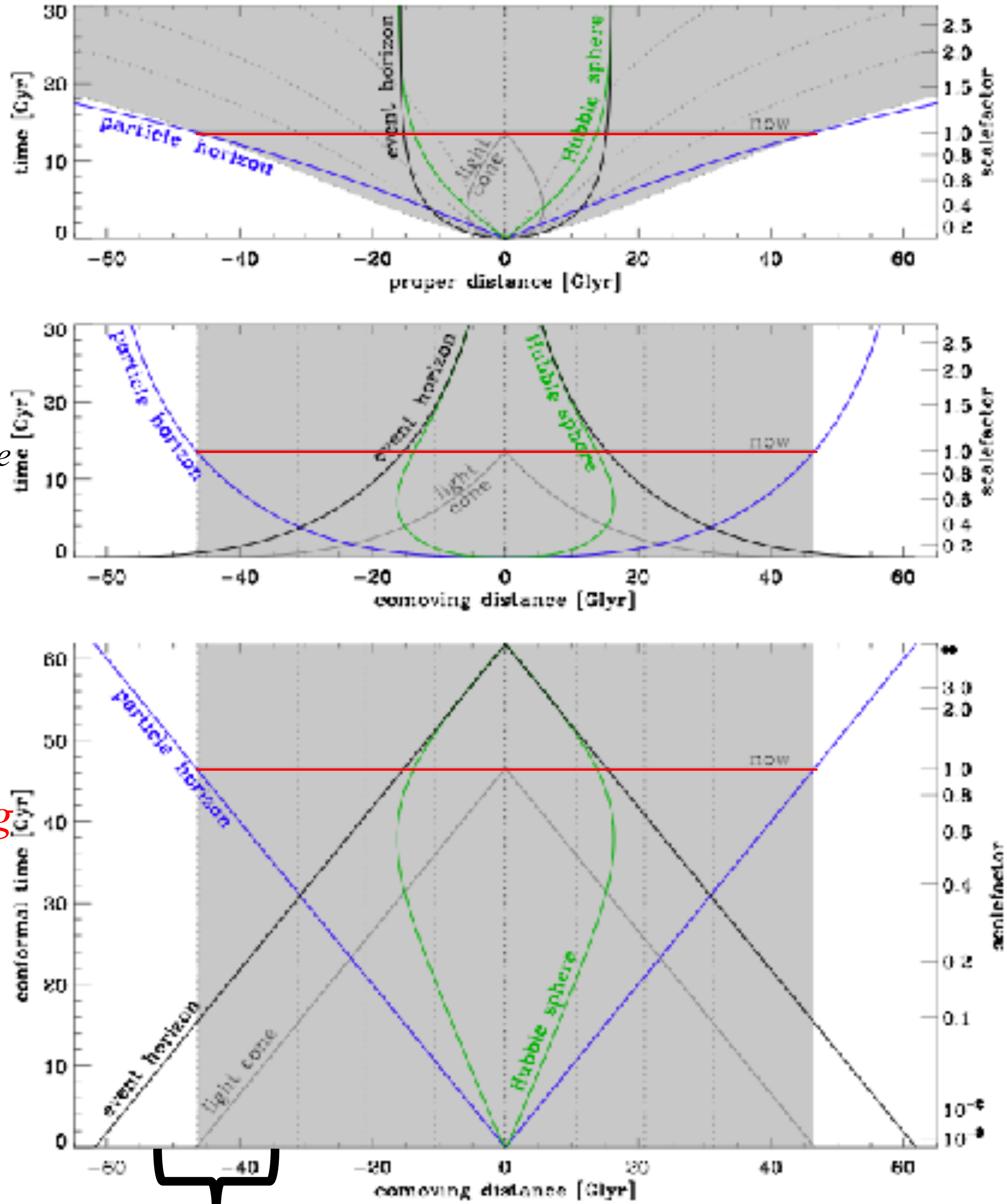
the low entropy of our universe interpreted as a fluctuation away from an average equilibrium universe



$V(t_o)$= red line

$V(t)$= grey area

= comoving volume of the current particle horizon



ΛCDM

NB: V is larger than the observable universe in the past and smaller than the observable universe in the future.

as time goes by, we see more of the universe which seems to be just like the universe we have been observing

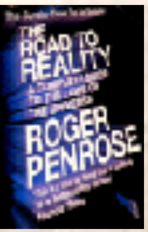
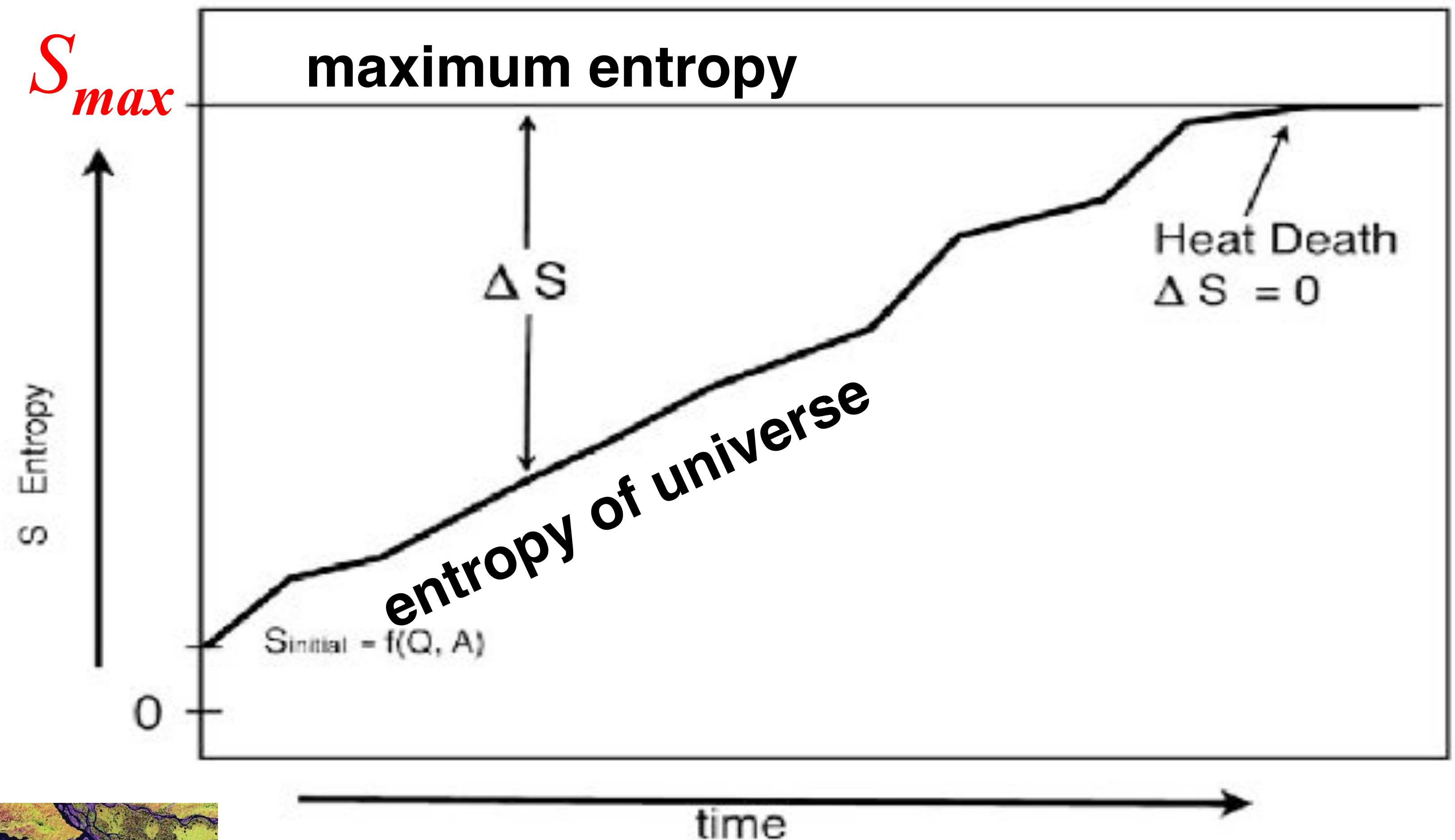
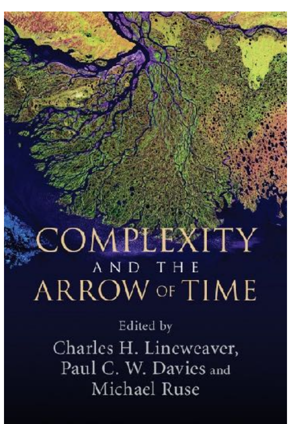


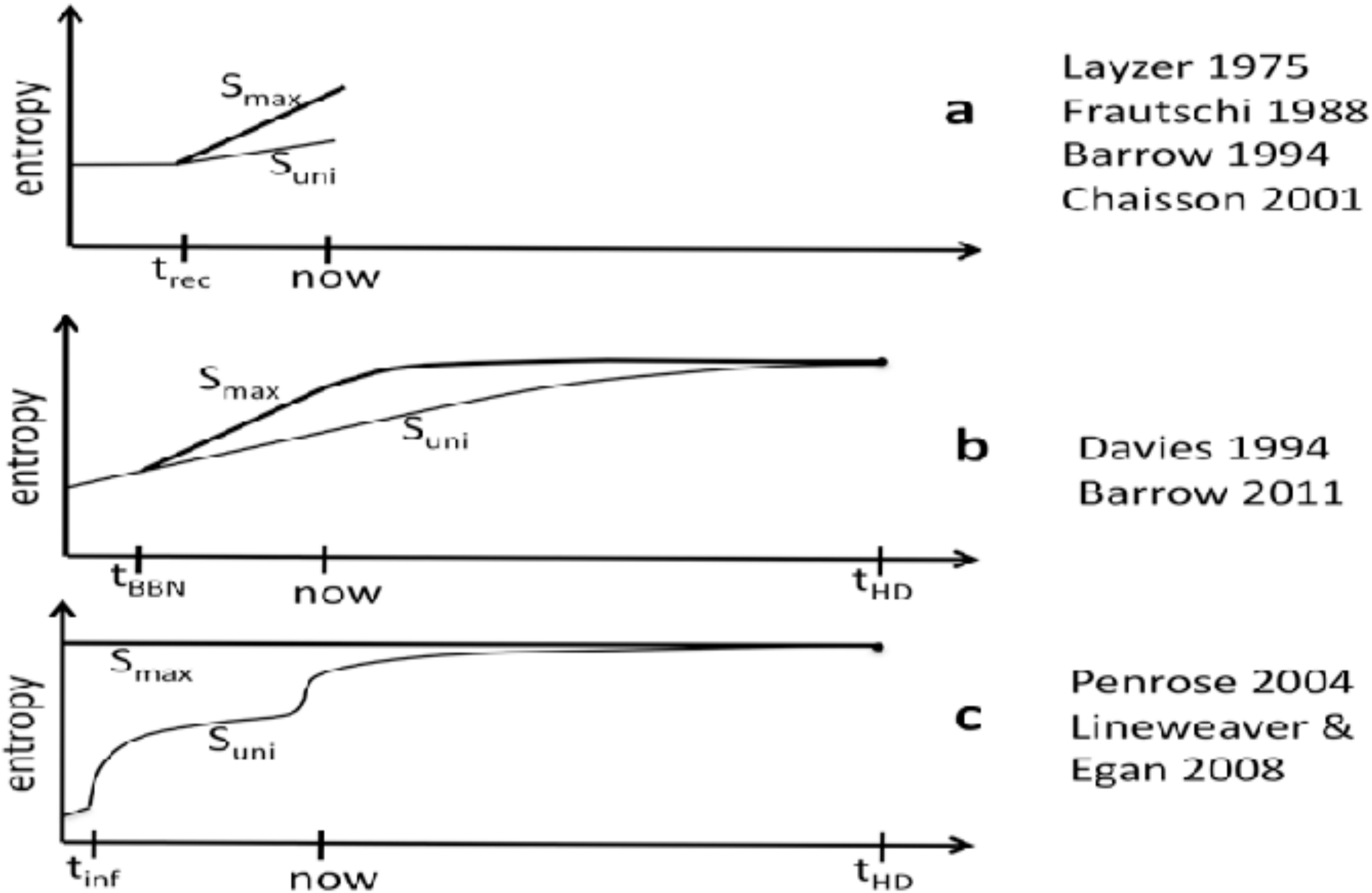
Fig. 7.19. In order to produce a universe resembling the one in which we live, the Creator would have to aim for an absurdly tiny volume of the phase space of possible universes – about $1/10^{10^{123}}$ of the entire volume, for the situation under consideration. (The pin, and the spot aimed for, are not drawn to scale!)

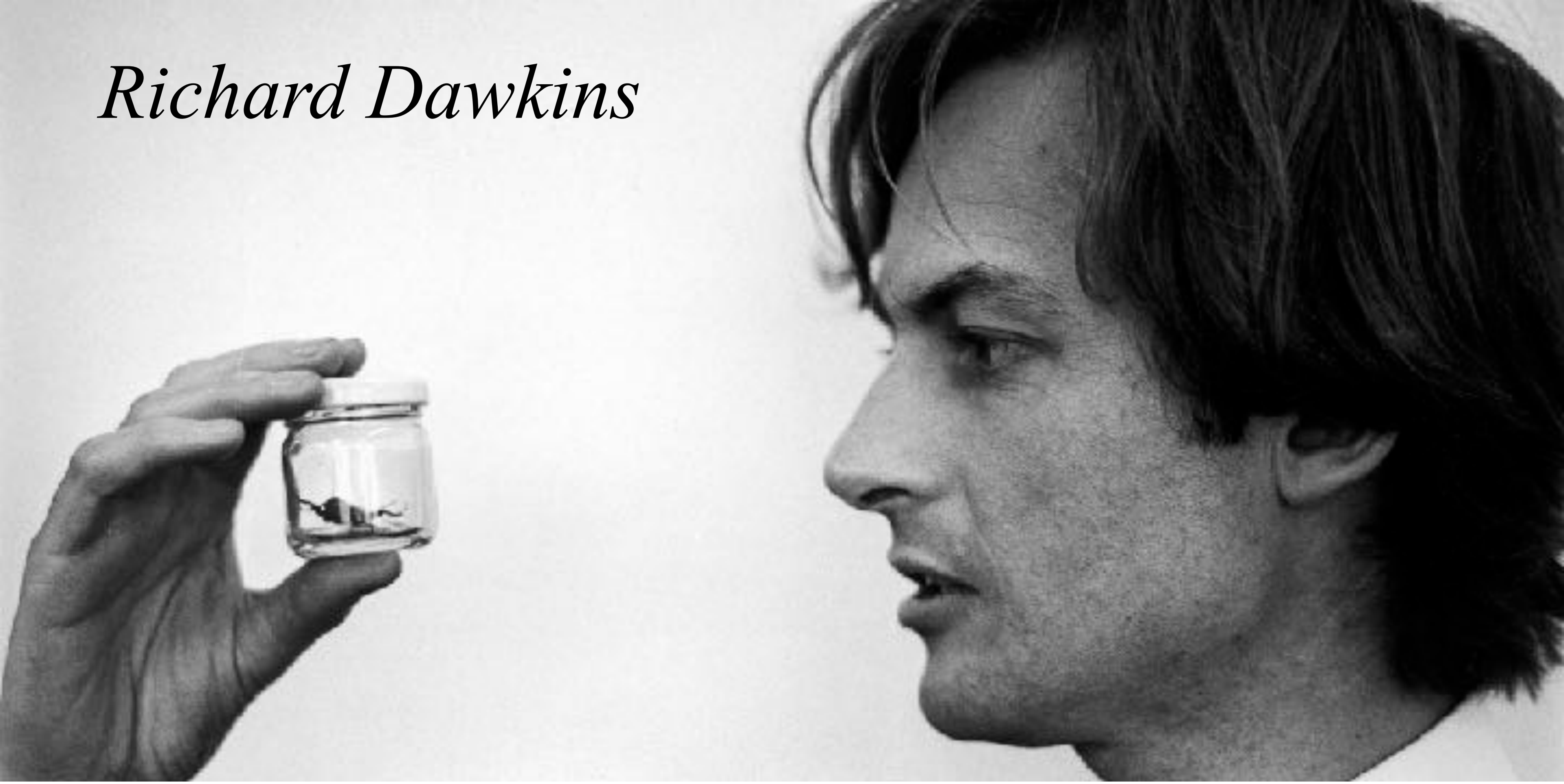
If you have to invoke fine-tuning to pick out a low entropy initial condition from a gigantic equilibrium-dominated phase space, why not dispense with the imagined phase space and just start with the most natural low entropy initial condition you can think of.

(cut out the middle man)


S_{max}
maximum entropy
Δ S
Heat Death
Δ S = 0
entropy of universe
S Entropy
$S_{initial}$ = f(Q, A)
0
time


COMPLEXITY
AND THE
ARROW OF TIME
Edited by
Charles H. Lineweaver,
Paul C. W. Davies and
Michael Ruse


entropy
S_{max}
S_{uni}
t_{rec}
now
a
Layzer 1975
Frautschi 1988
Barrow 1994
Chaisson 2001
entropy
S_{max}
S_{uni}
t_{BBN}
now
t_{HD}
b
Davies 1994
Barrow 2011
entropy
S_{max}
S_{uni}
t_{inf}
now
t_{HD}
c
Penrose 2004
Lineweaver &
Egan 2008

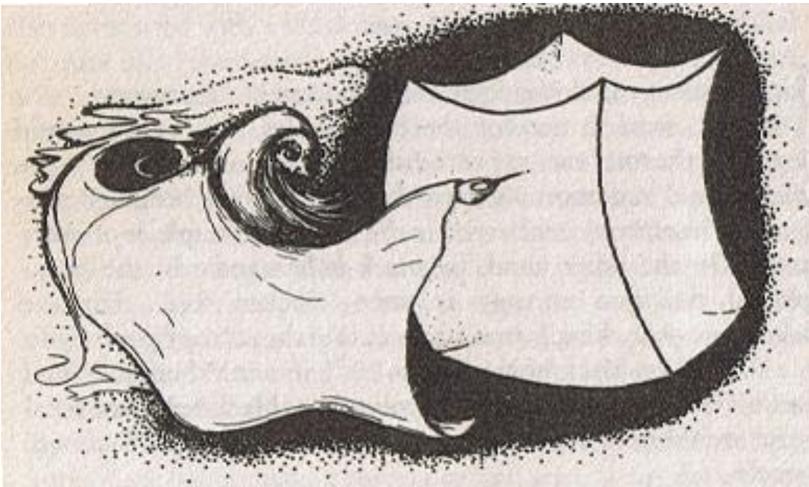


We, the living, should feel lucky.
Just think of all the people who haven't been born.

$$P = N_{living} \,/\, N_{non\text{-}living}$$
$$P \sim 0$$

To determine probability, or luck, or "tuning"
you need to know:
1) what has been selected
and
2) what it has been selected from

ie you need to know what is and what could have been.
Contrafactuals are problematic



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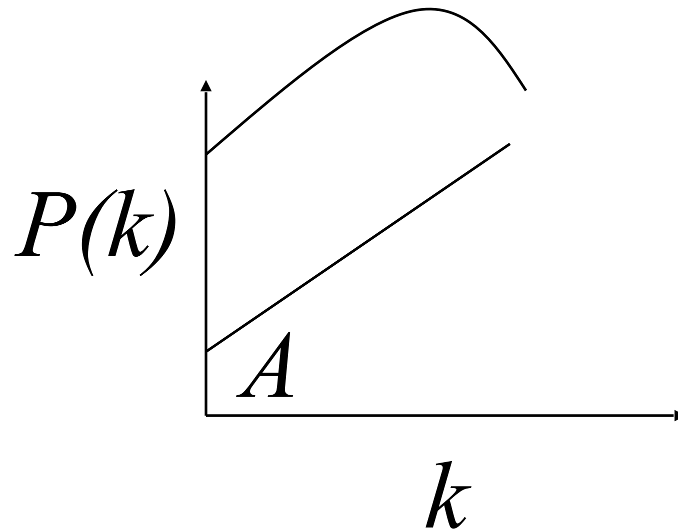
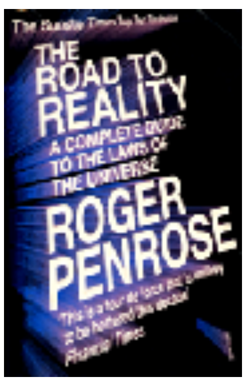
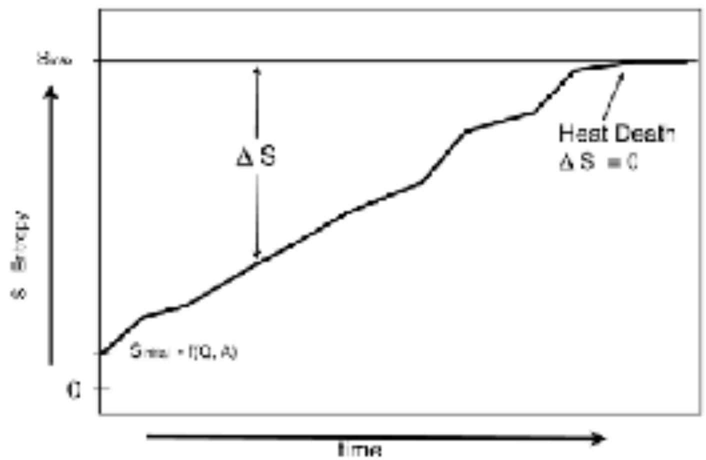
$$P(k,t) \sim A\, T^2(k,t)\, k^n$$







S(t) ~ P(t)?

Fig. 9. The universe starts off at low entropy (not zero) due to the low level of density perturbations in the early universe—low Q and low A (e.g., [90]) where "low" means less than the maximum value S_{max}. At S_{max} all the energy density of the universe is in massless particles in equilibrium at a common temperature. Thus the universe starts off with a large entropy gap ΔS. The parameters Q and A are the observable normalizations of the primordial density fluctuations and set the initial gravitational entropy of the universe. There is no general agreement on the curve shown here. See for example Fig. 7.3 in [14] and Fig. 1.2 in [21].