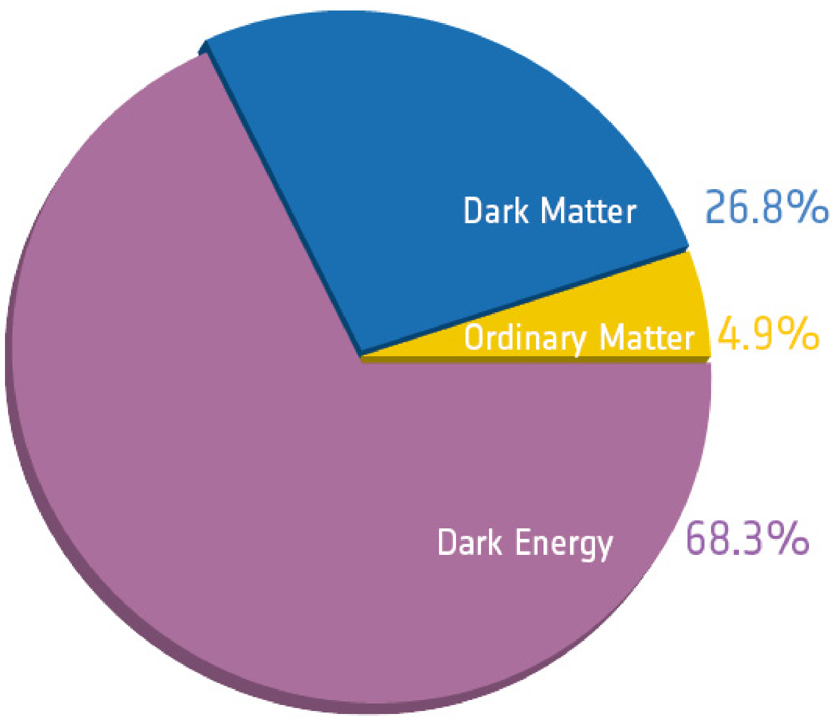
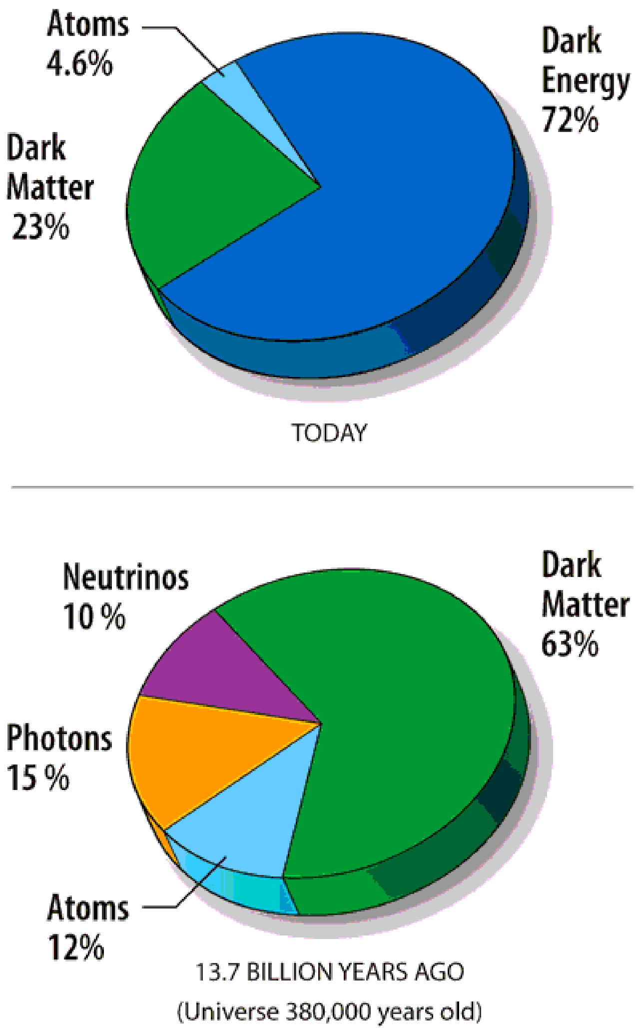
COSMIC π

Matter inventory: Planck 2013

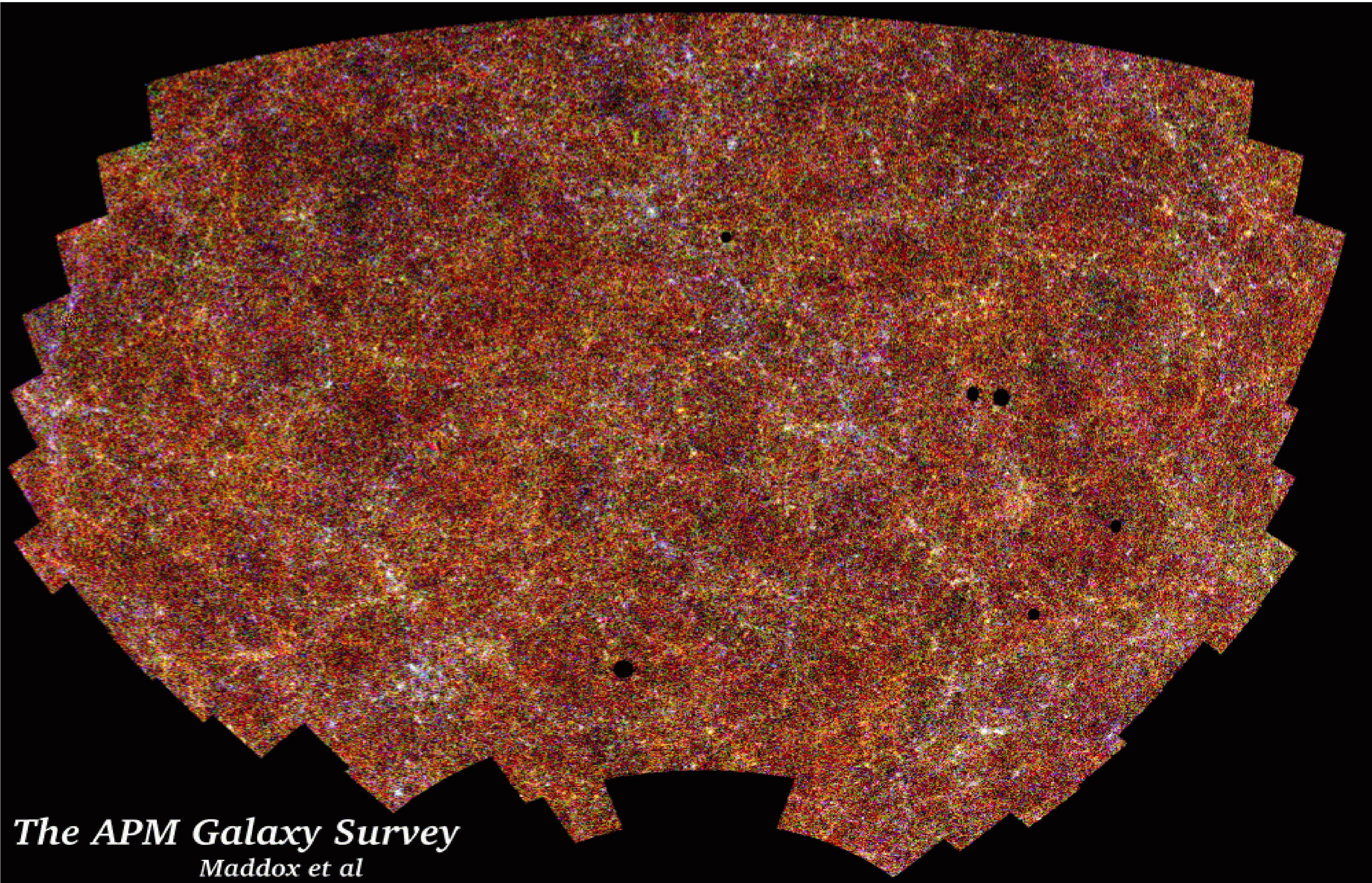


Matter inventory: WMAP: today and at decoupling

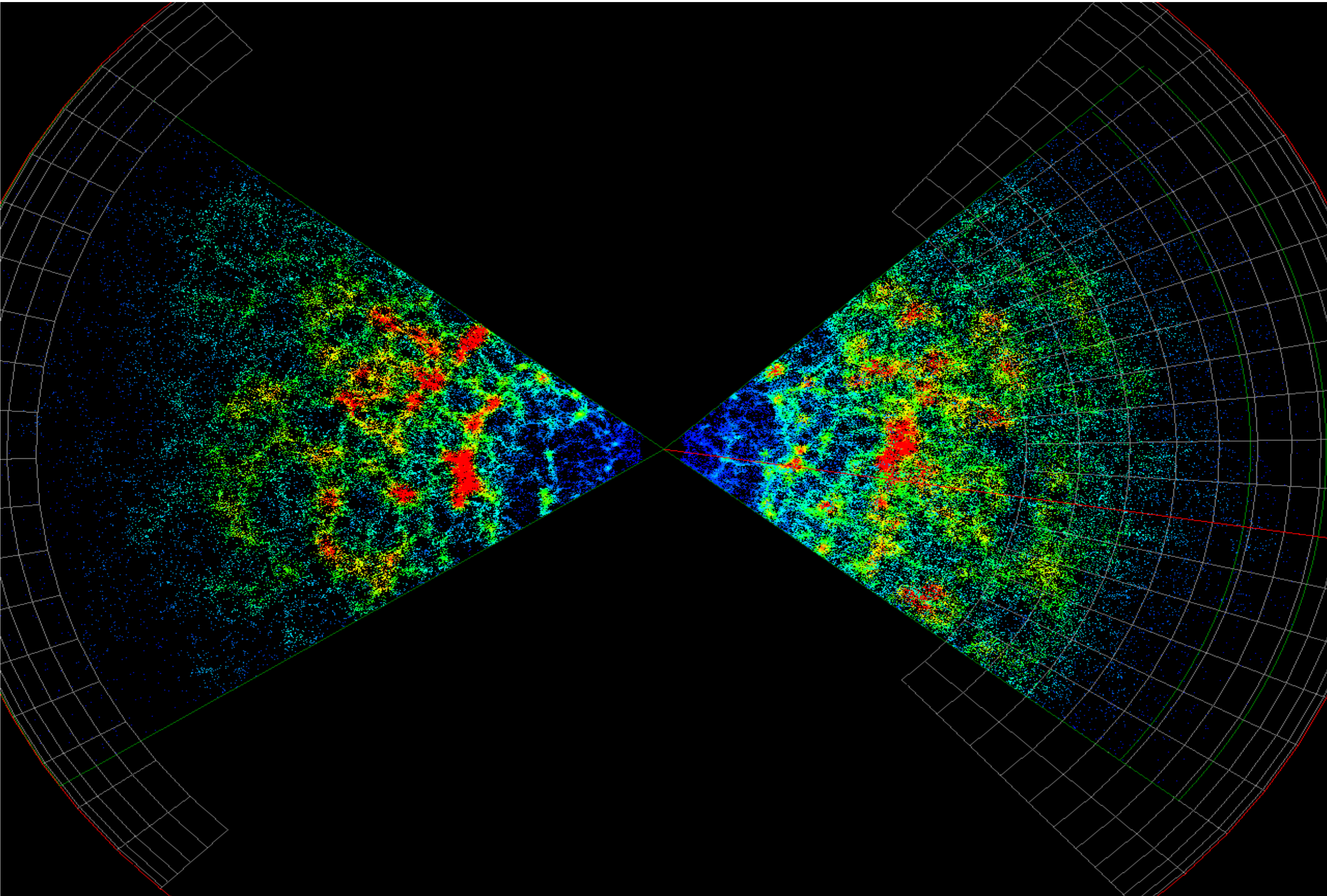


COSMOLOGICAL PRINCIPLE

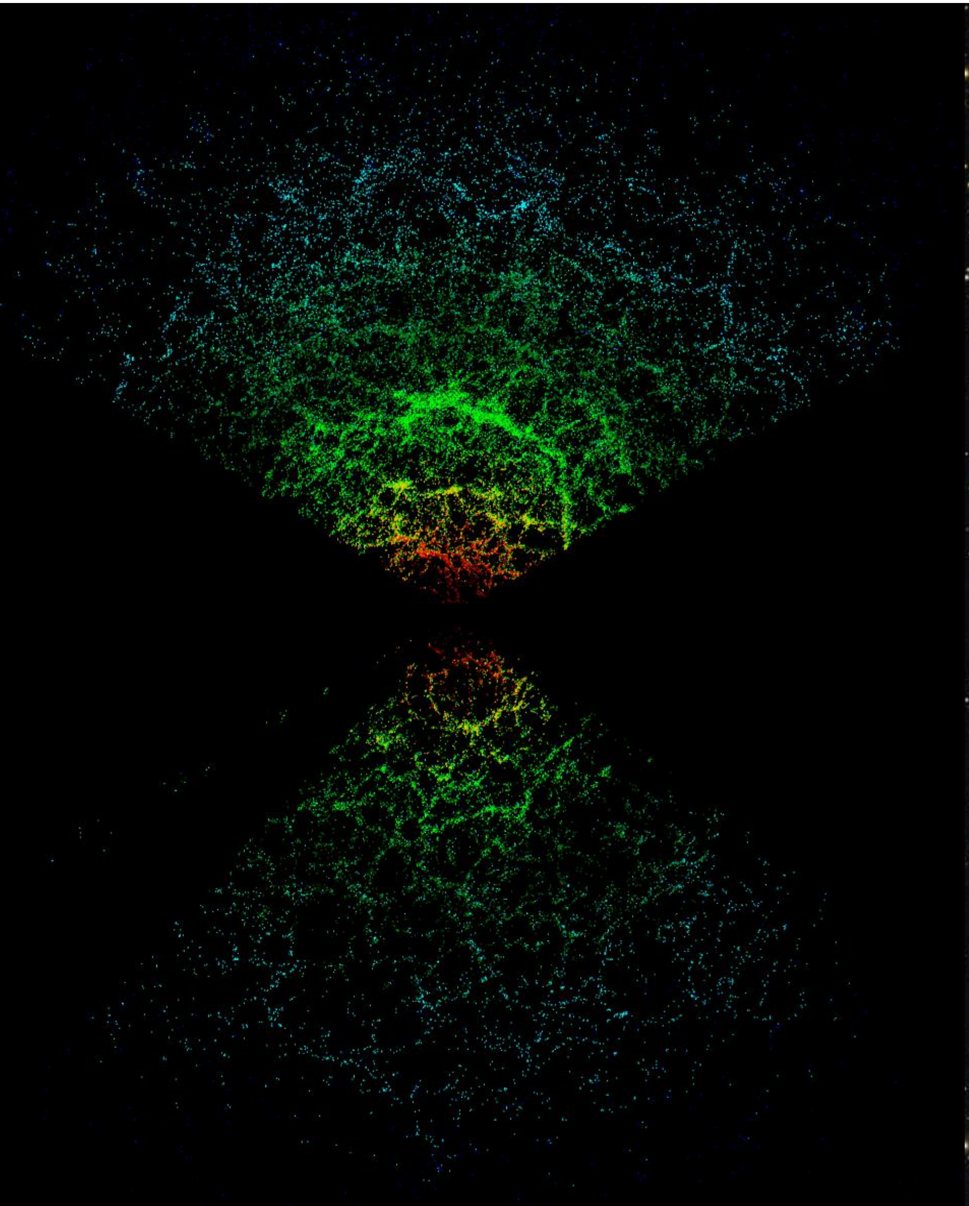
- The Universe is homogeneous on large scales: APM survey



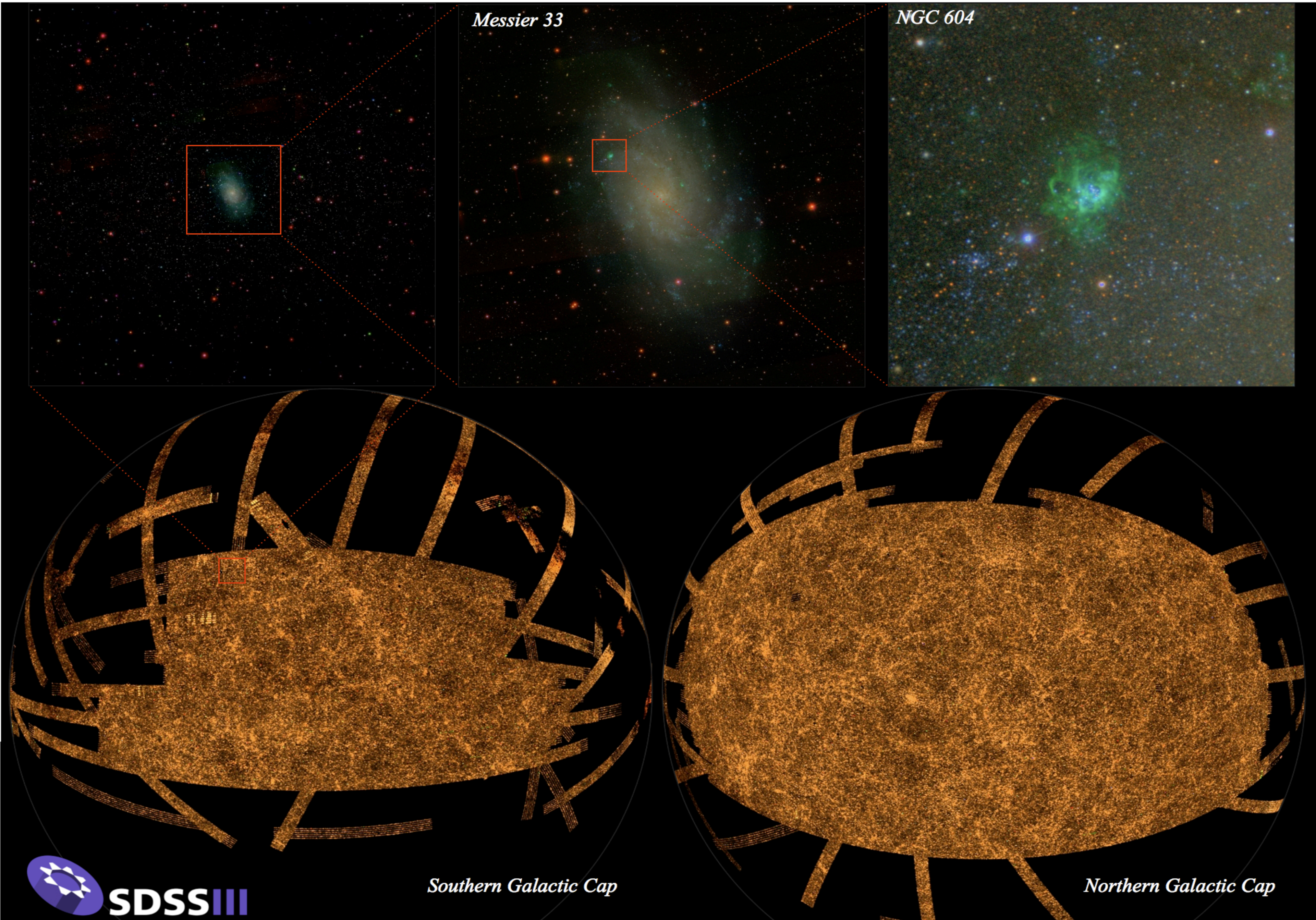
● The Universe is homogeneous on large scales:
LSS redshift surveys: 2dF, SDSS; CMB: Planck, WMAP



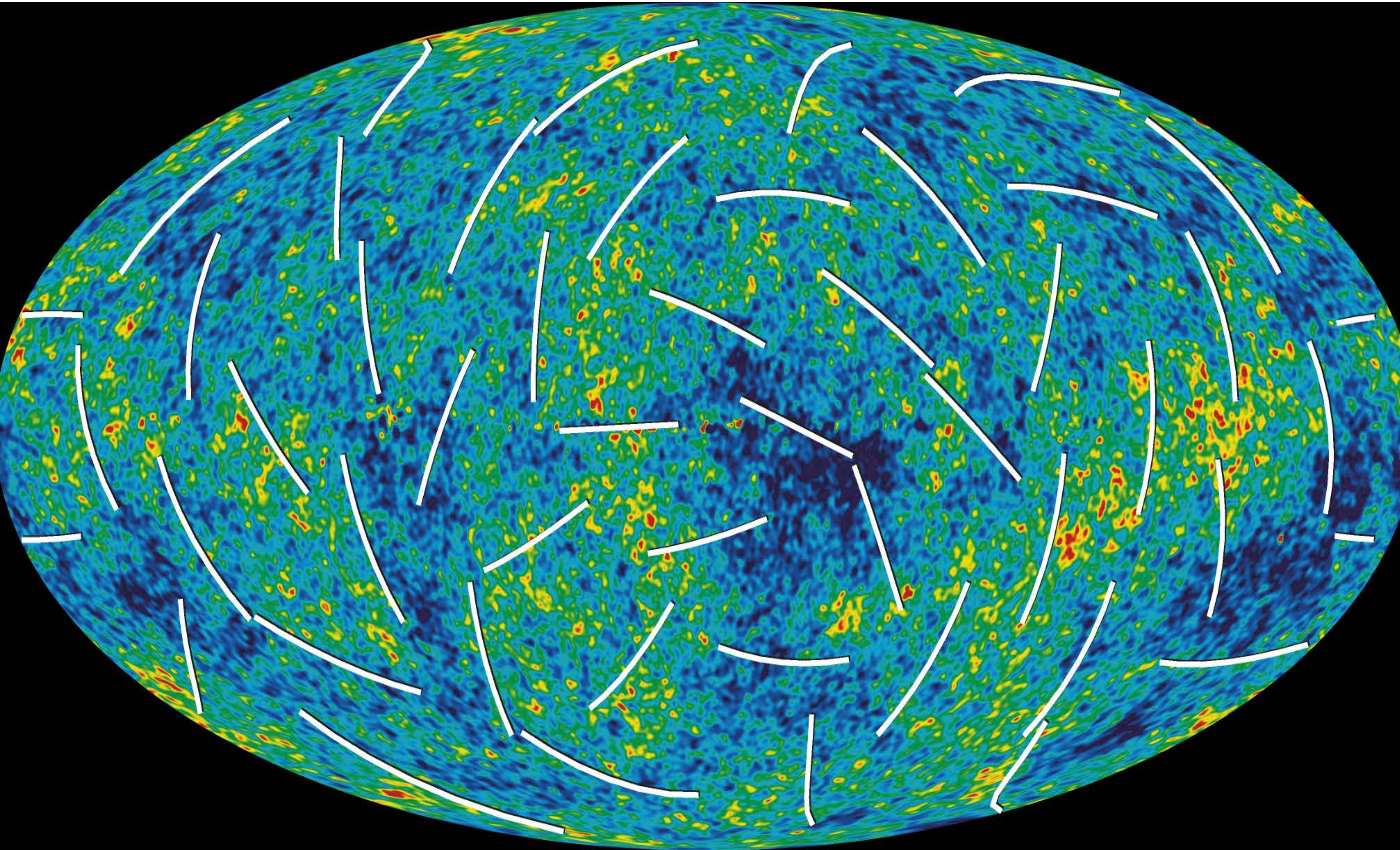
SDSS



SDSSIII 2011

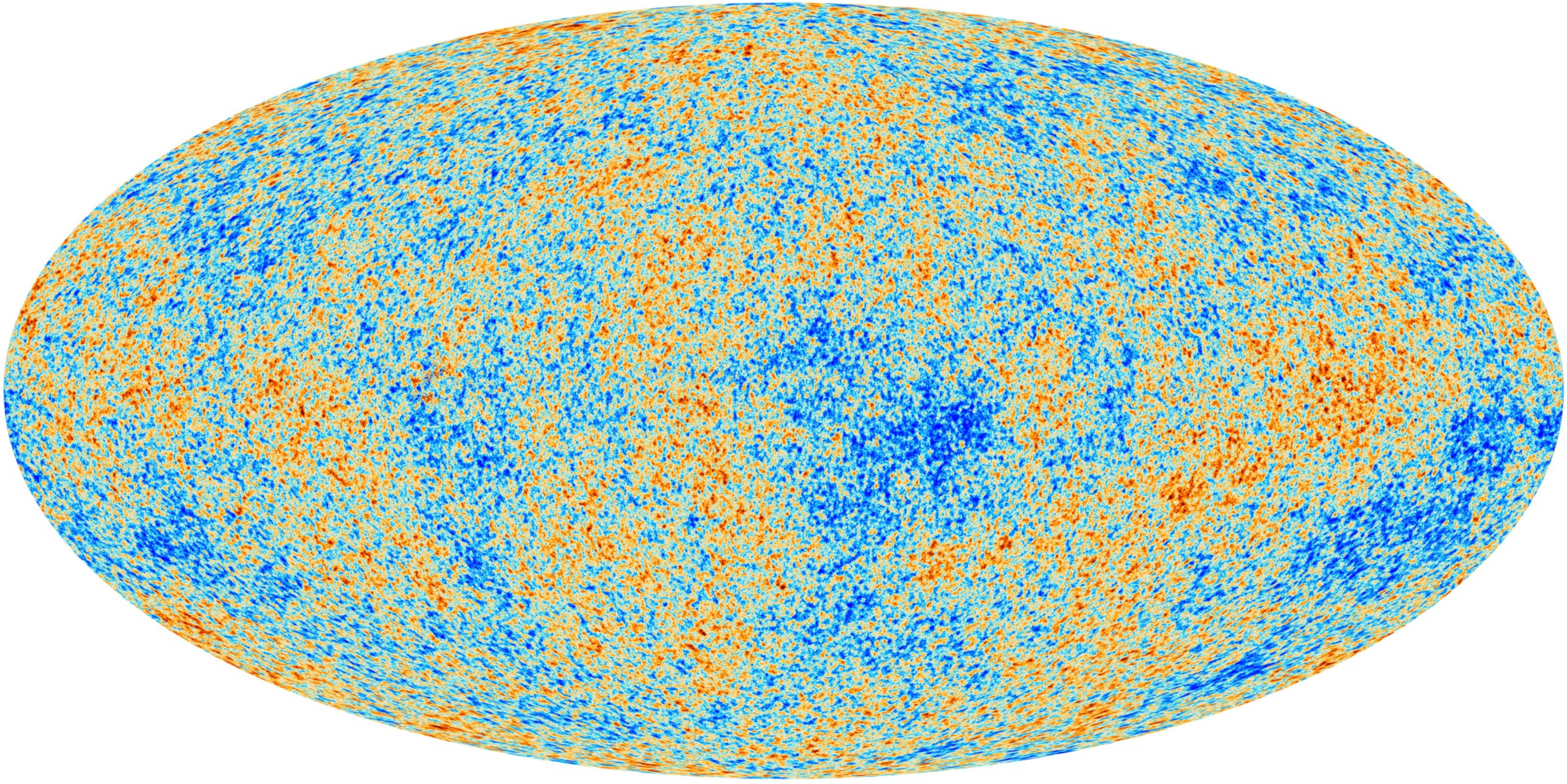


CMB: WMAP

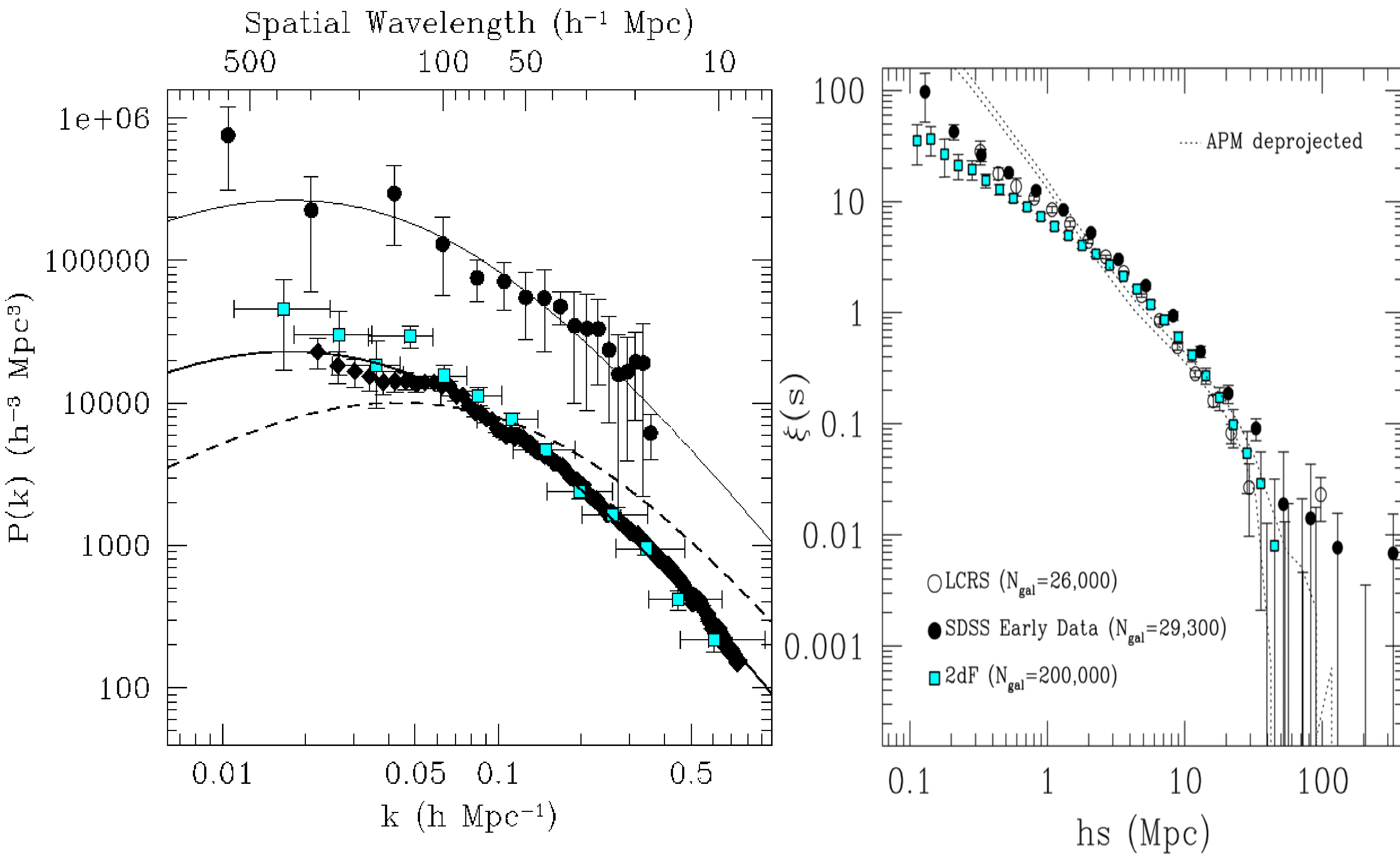


CMB: Planck 2013

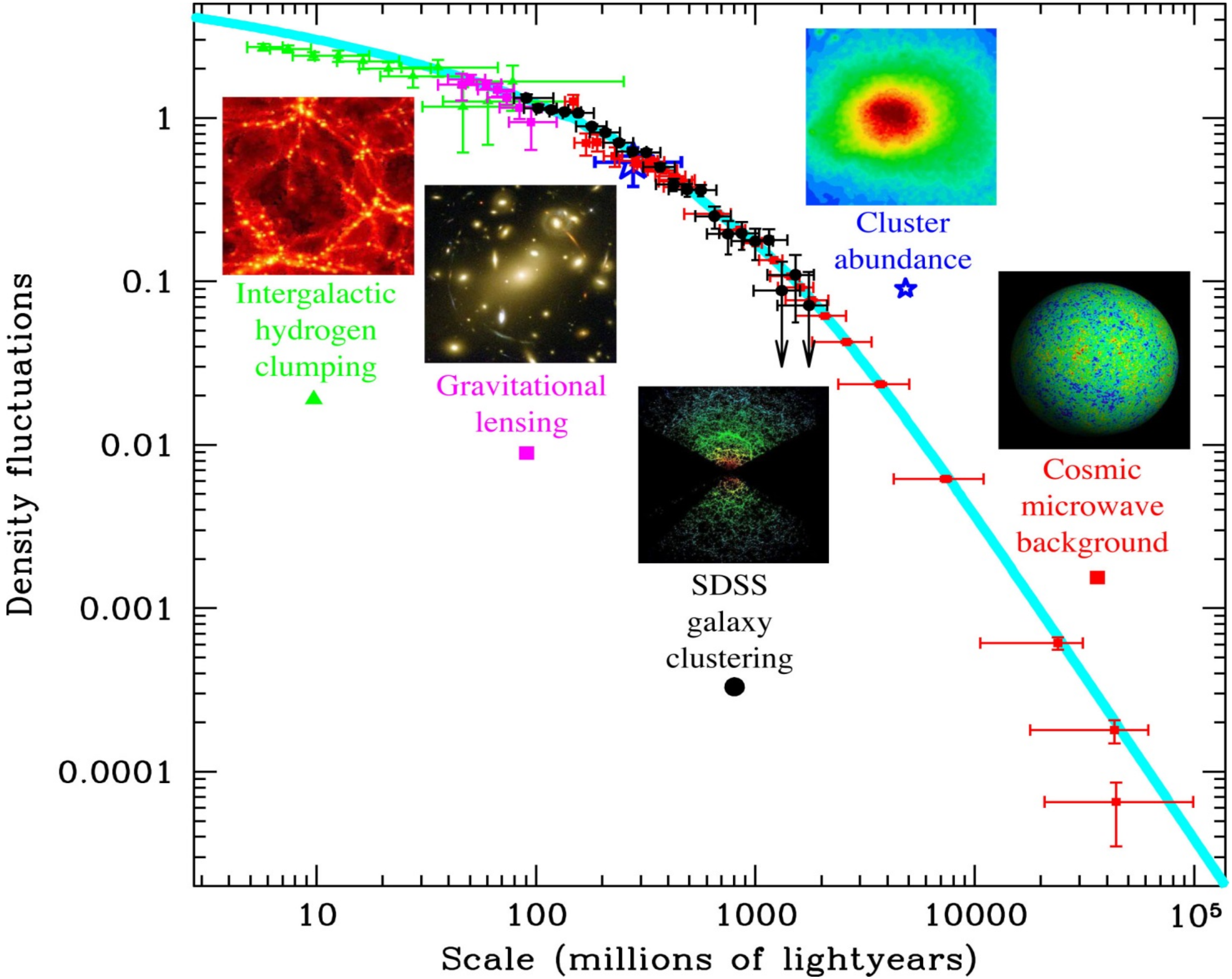
- homogeneity & isotropy at the level 10^{-4}

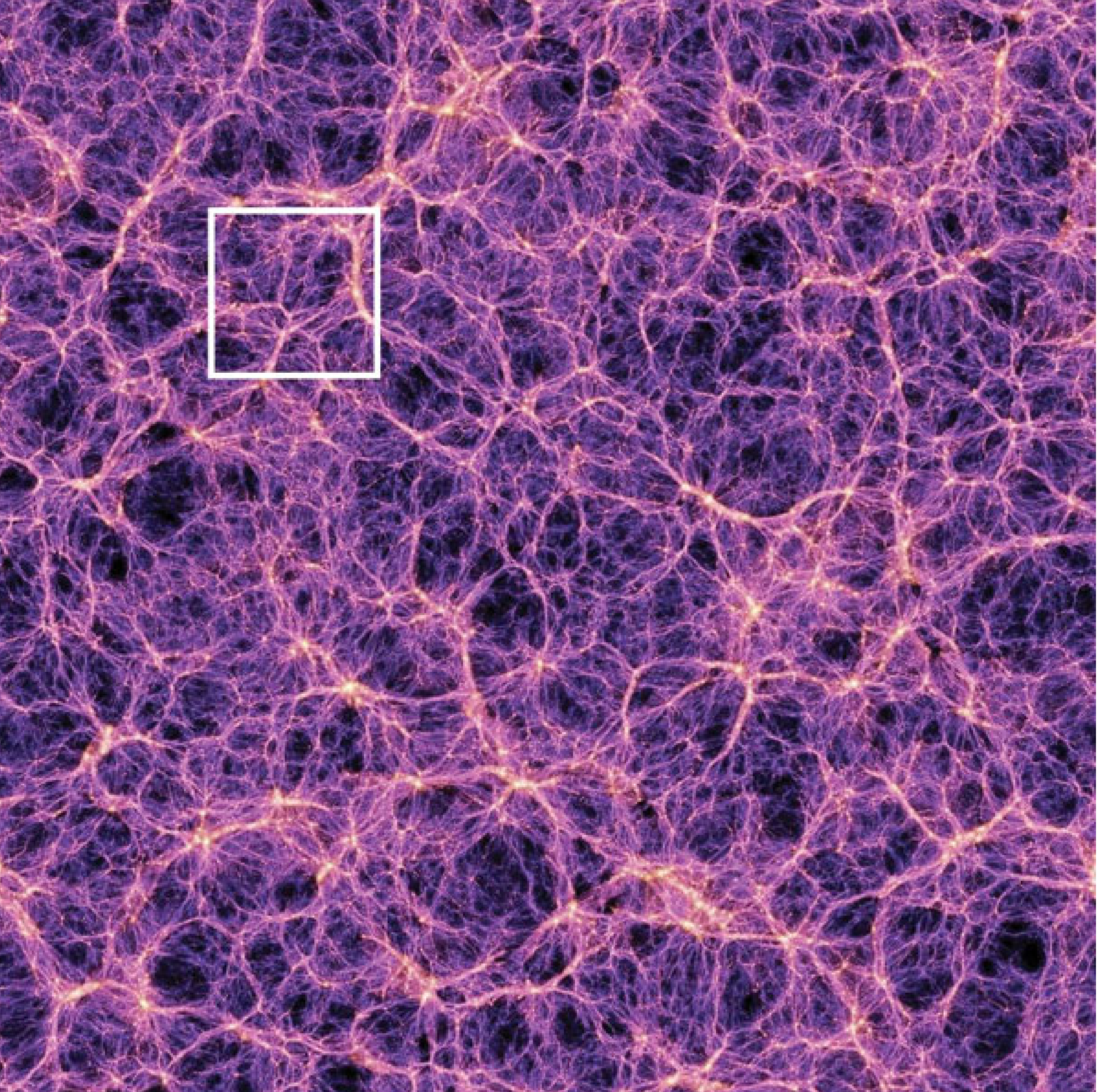


Galaxy-galaxy correlation function: 2dF
(2 degree field galaxy redshift survey)



Galaxy-galaxy correlation function: SDSS
(Sloan Digital Sky Survey)





COSMIC WEB

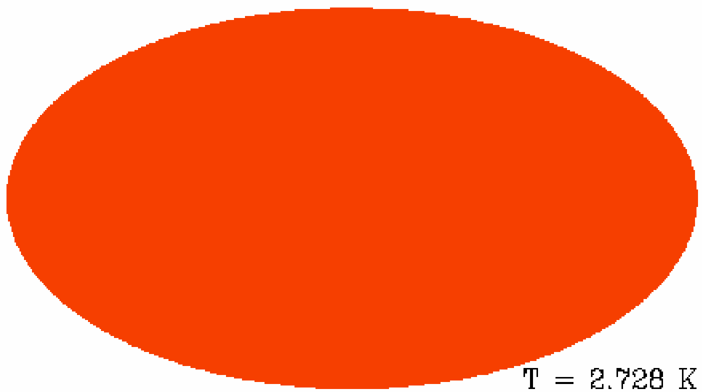
SDSS movies

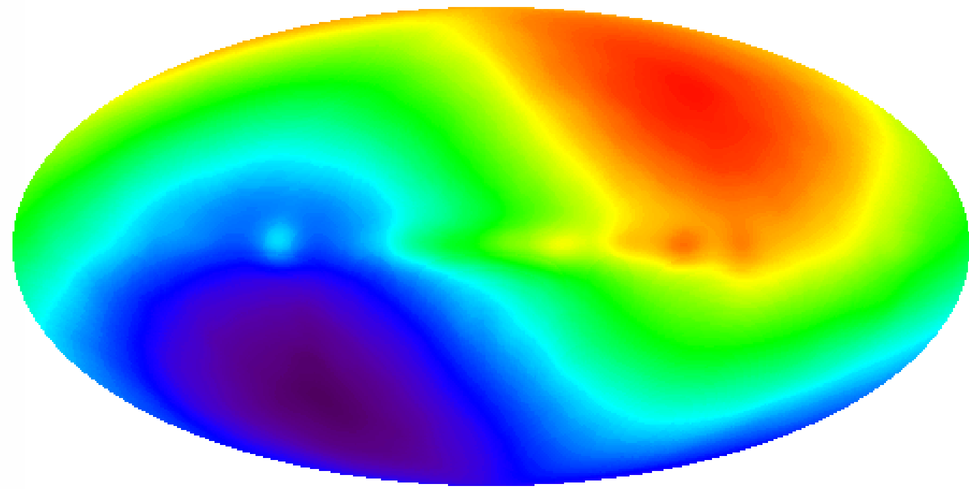
Sloan movie april 18

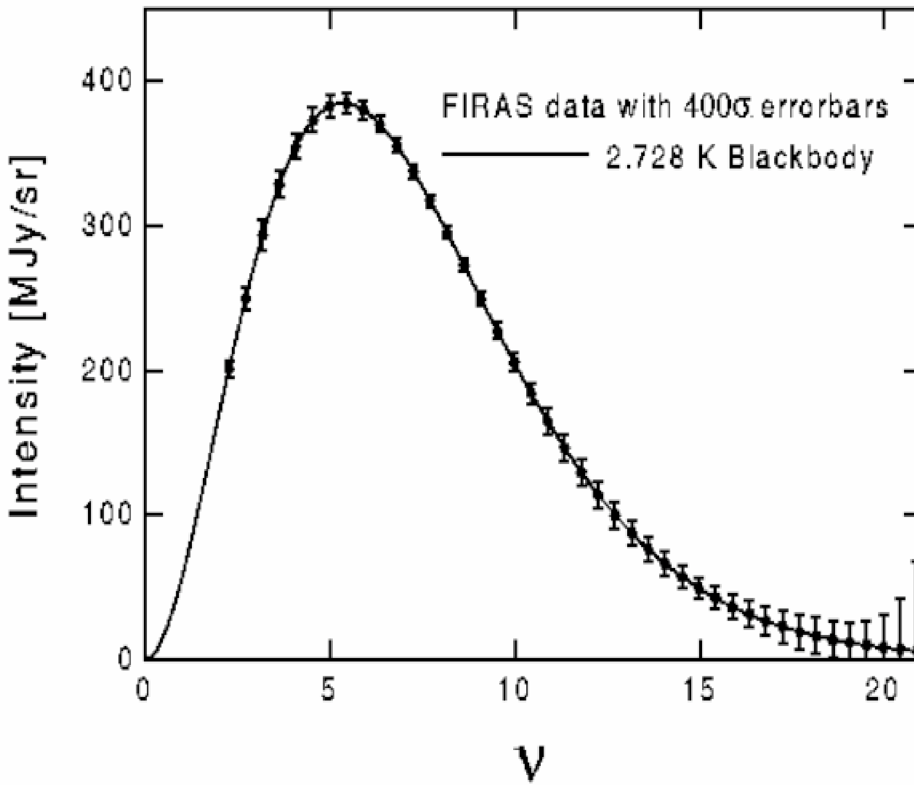
SDSS-DR4

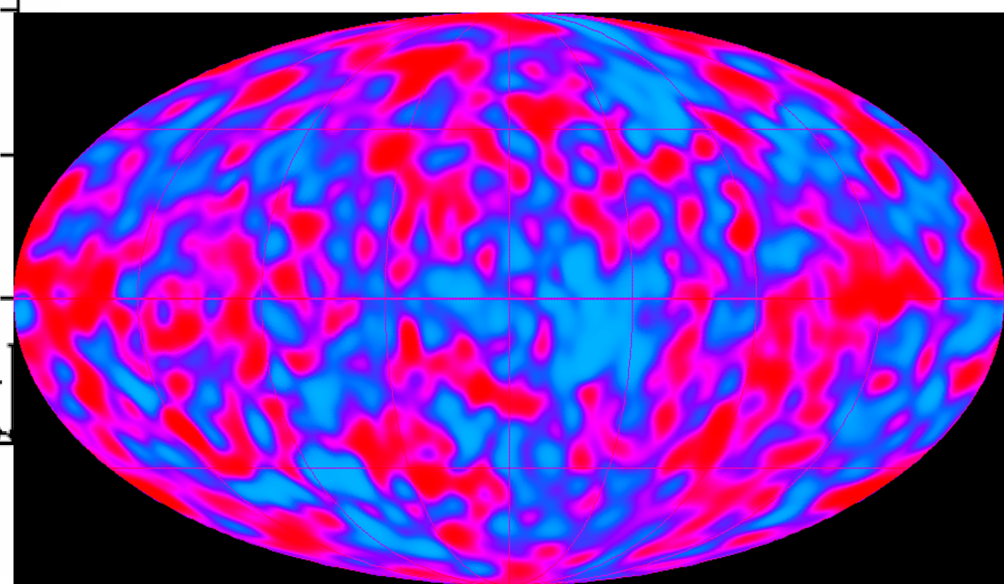
CMB: COBE satellite 1992

- inhomogeneities in photon temperature at the level 10^{-4}

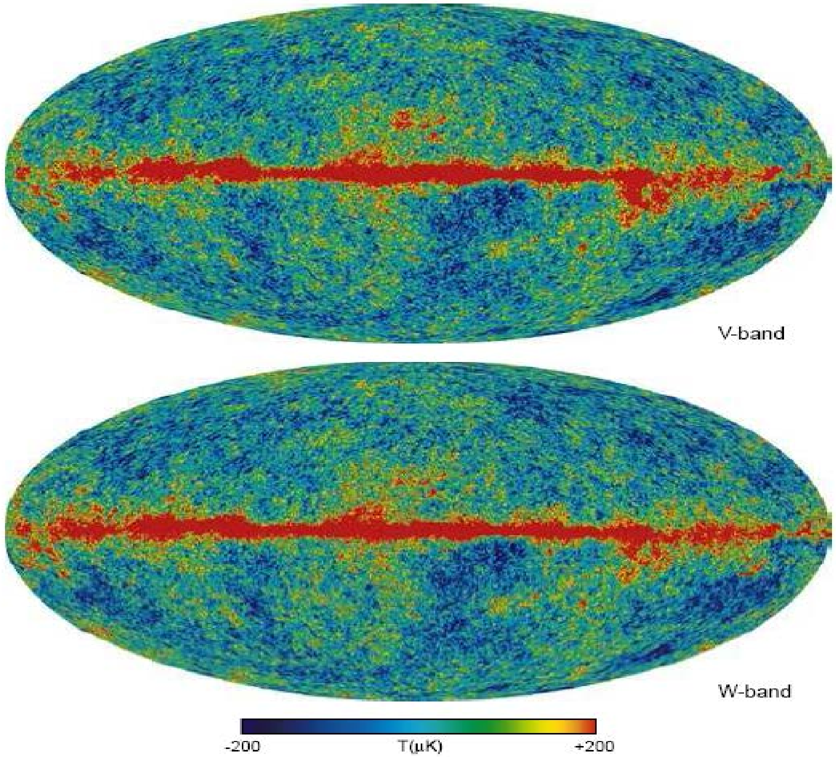


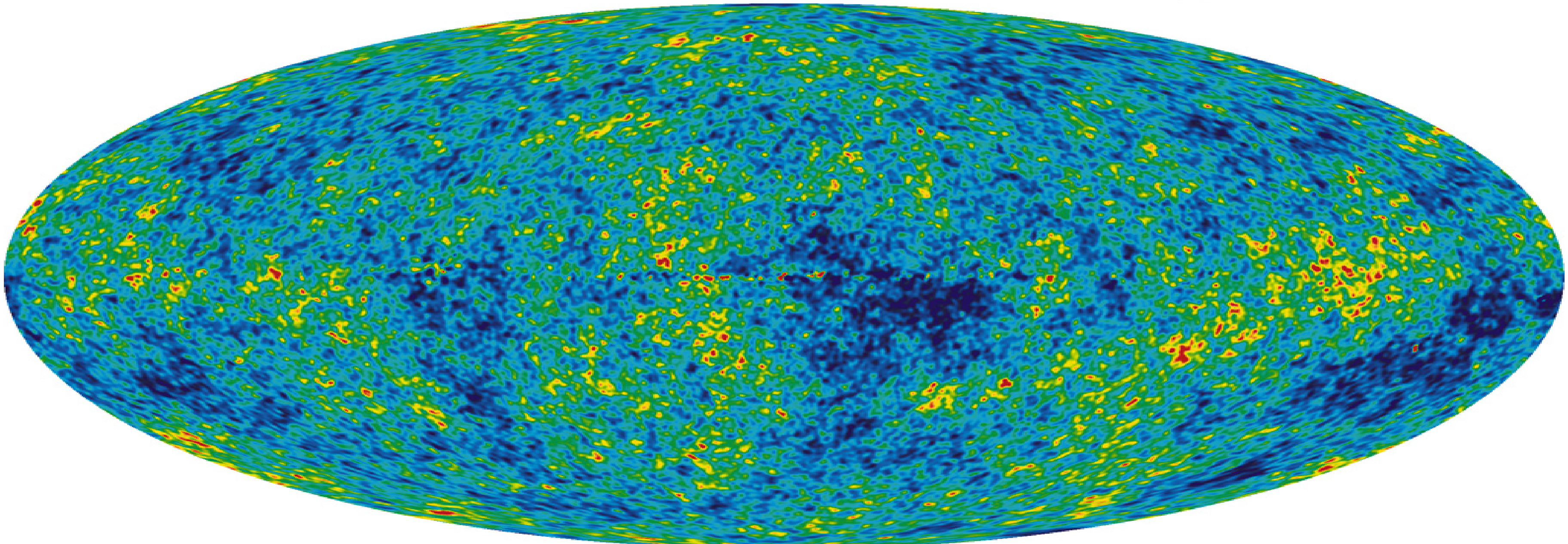






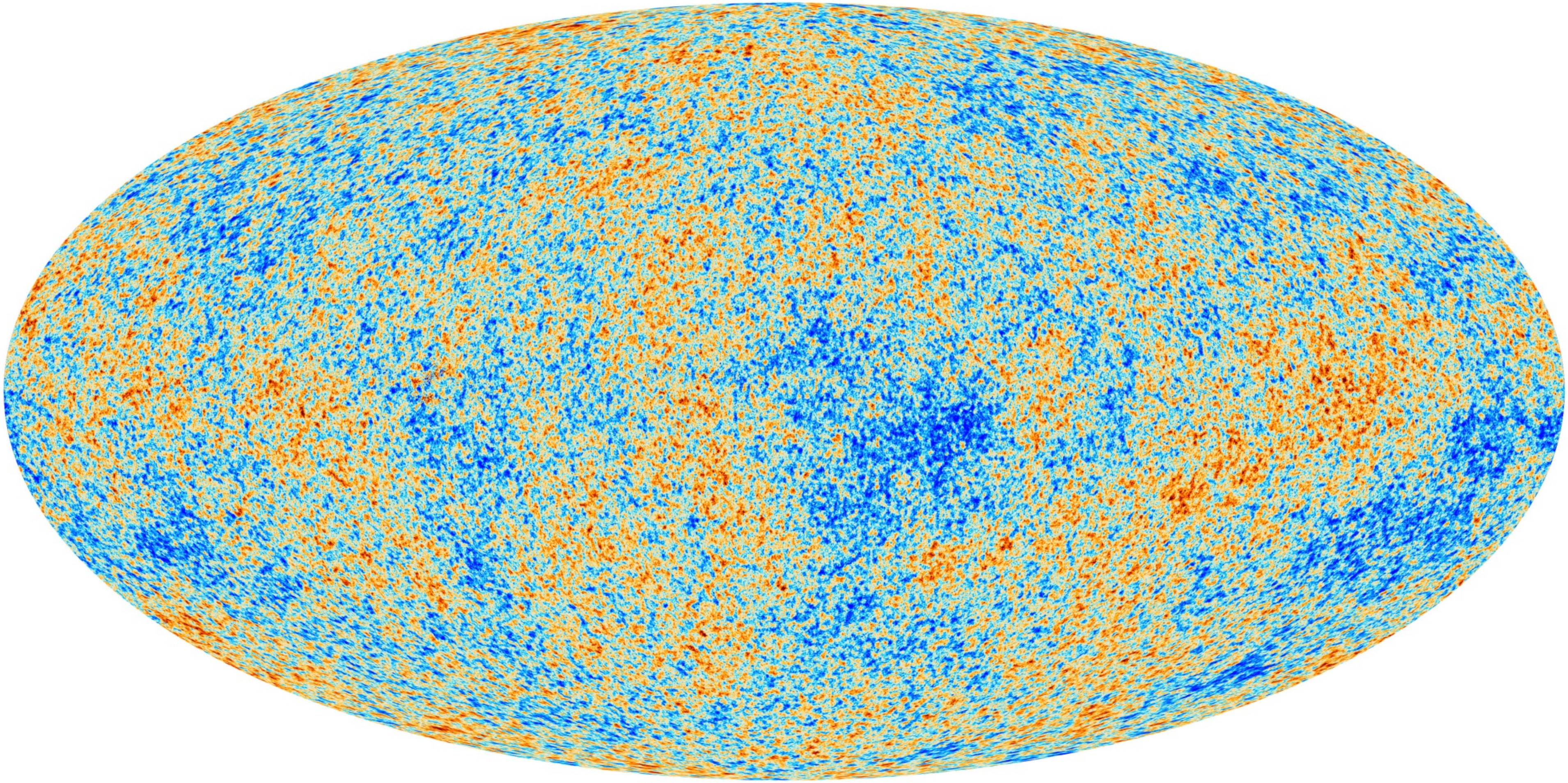
WMAP satellite
2000+: maps



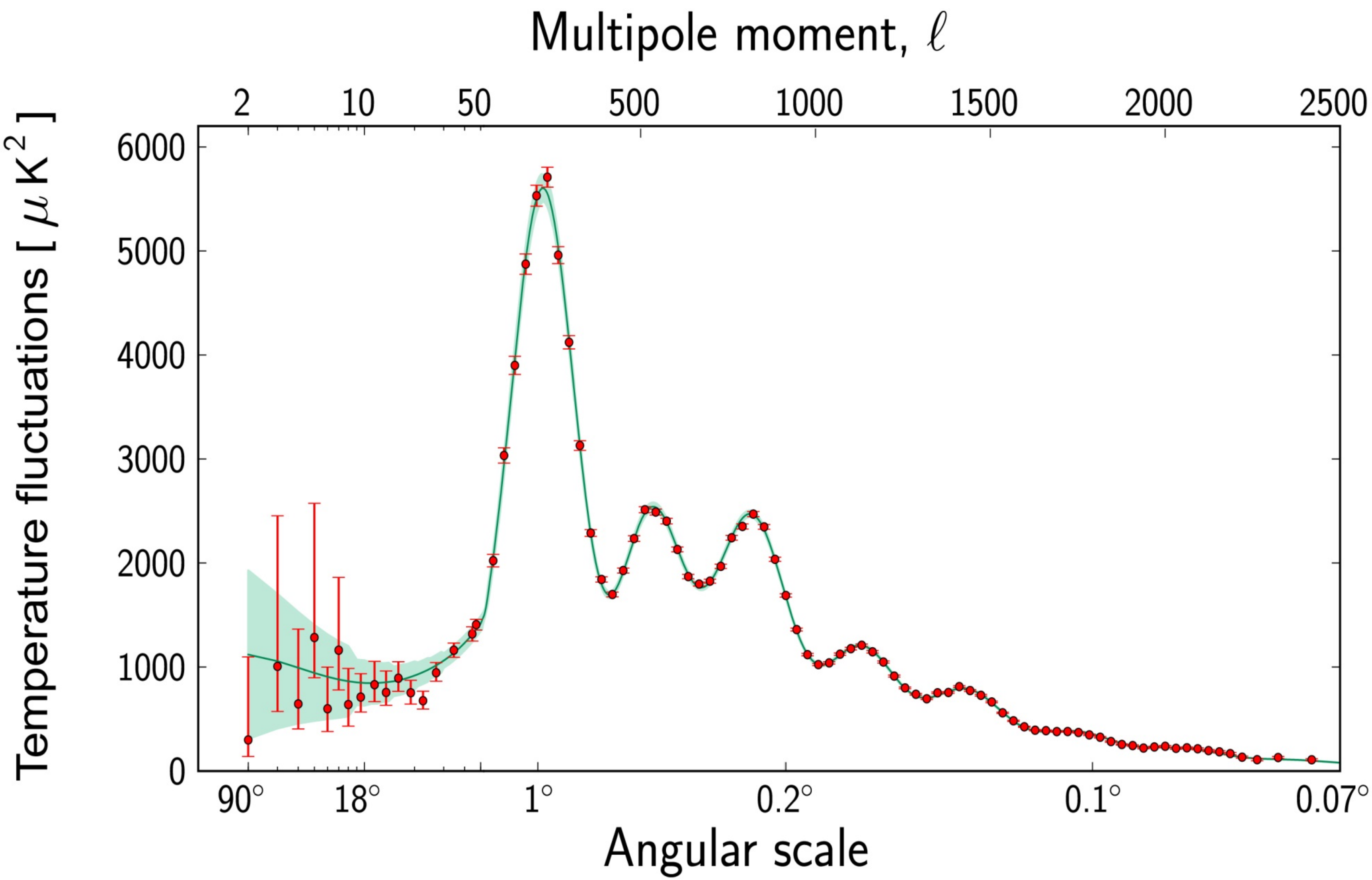


CMB: Planck 2013

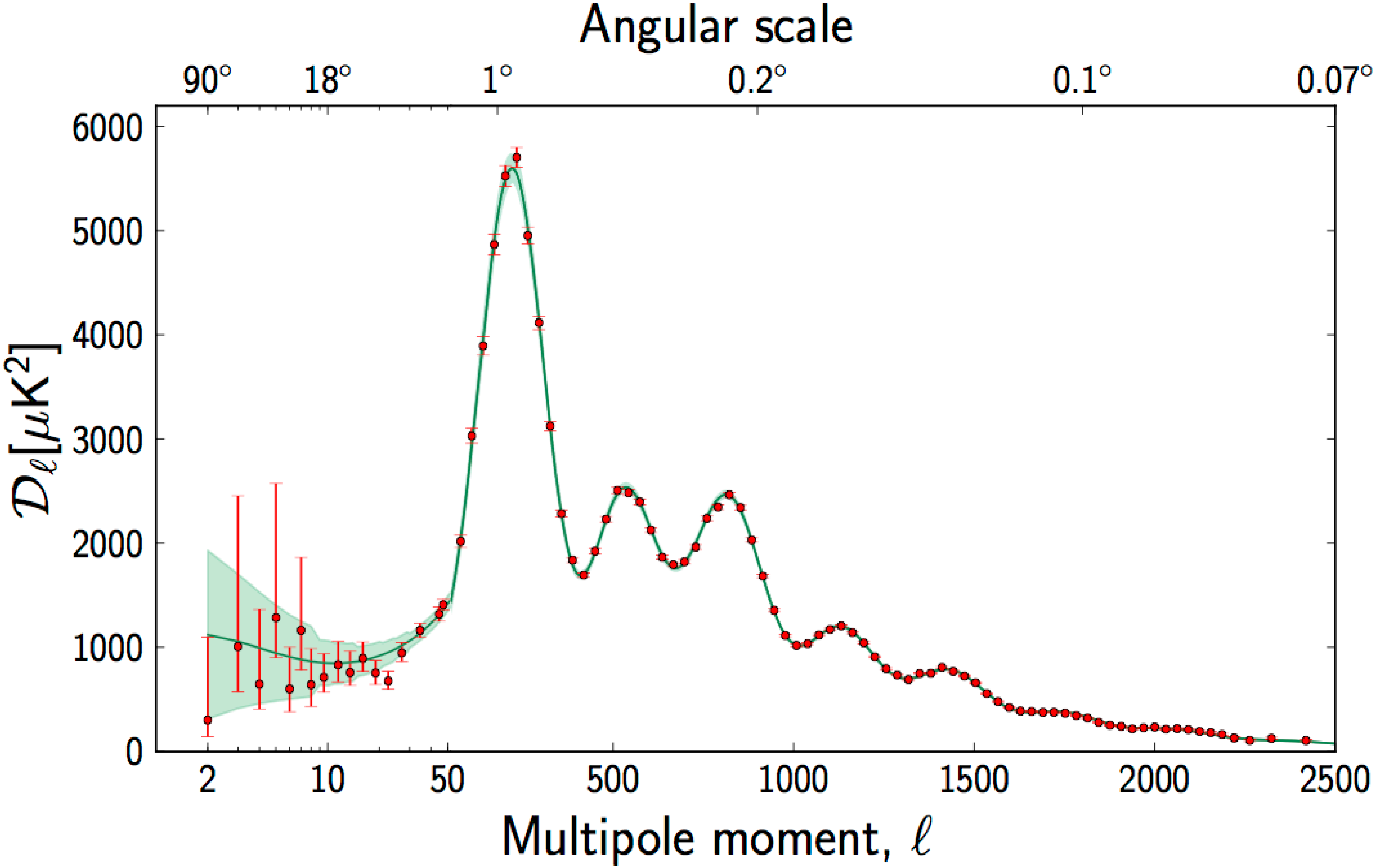
- homogeneity & isotropy at the level 10^{-4}



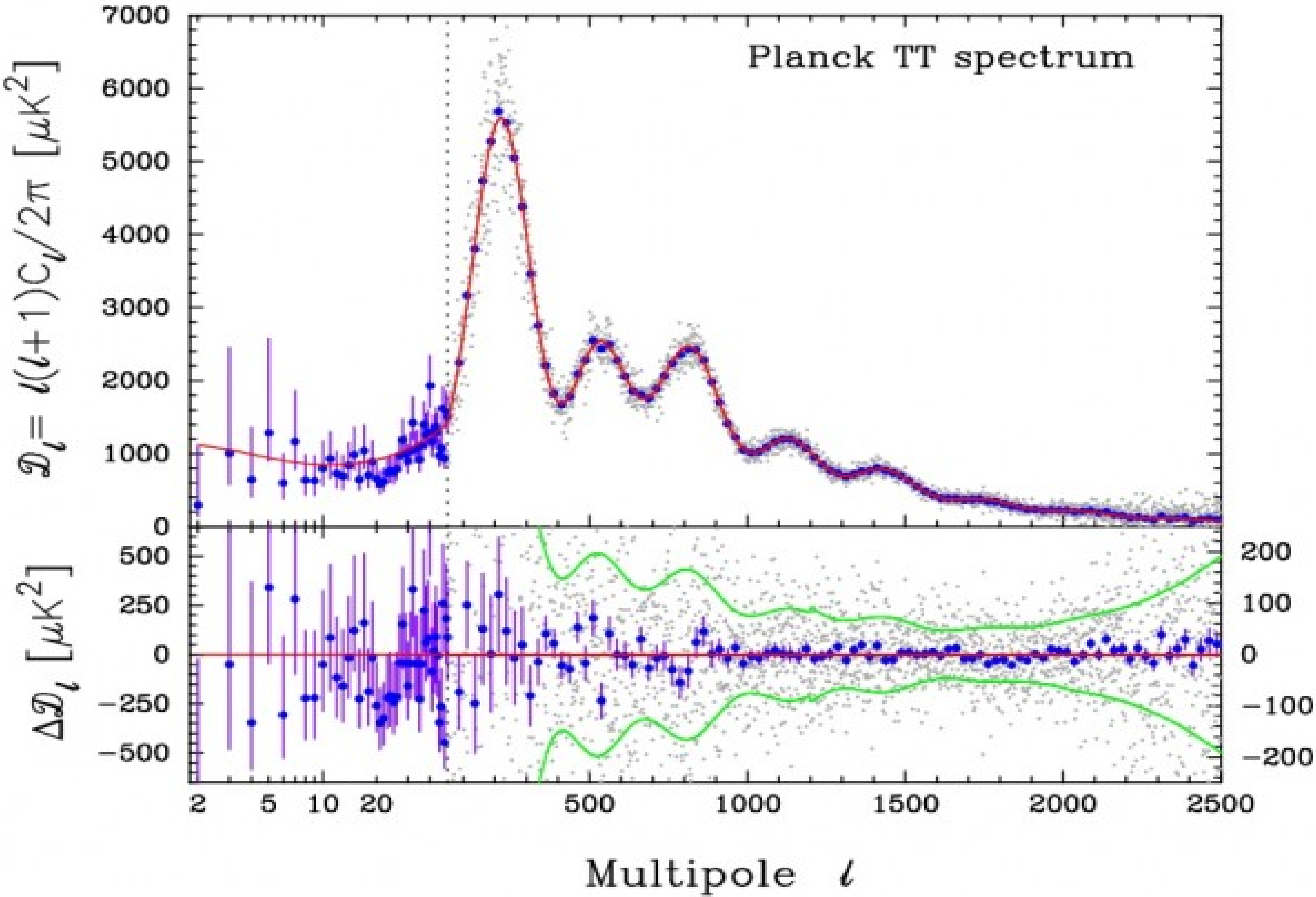
CMB spectrum: Planck



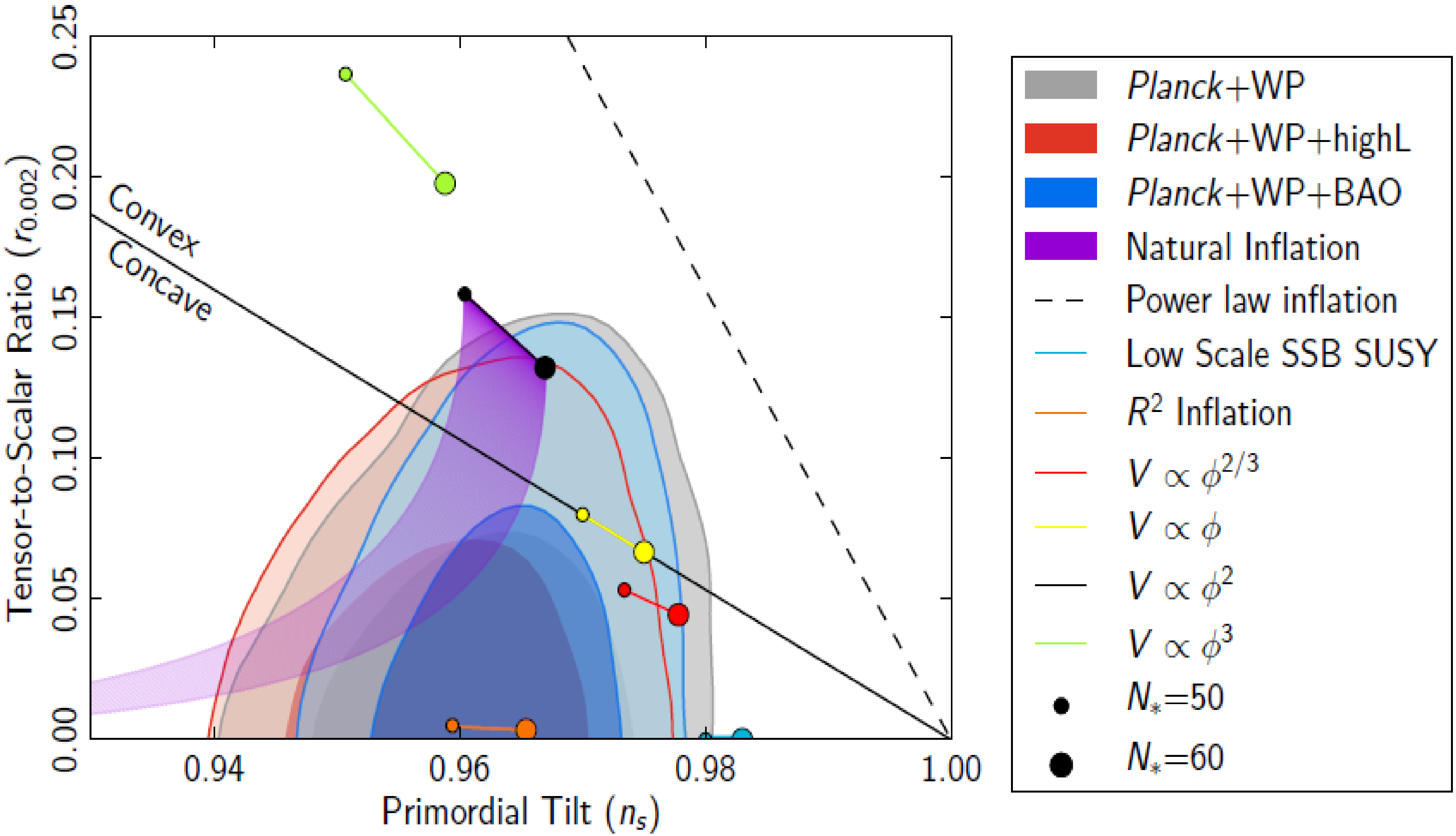
CMB spectrum: Planck 2



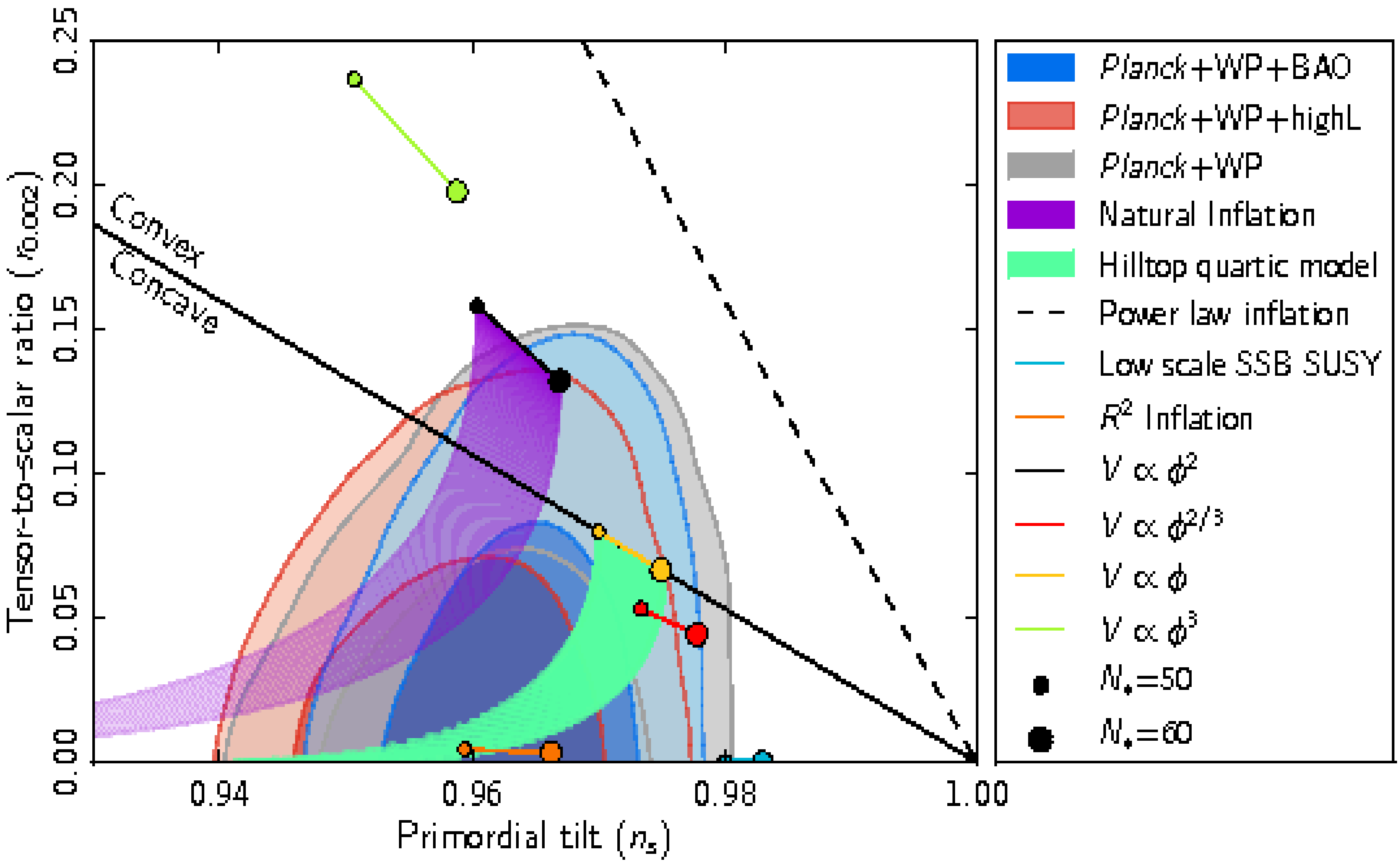
CMB spectrum: Planck 3



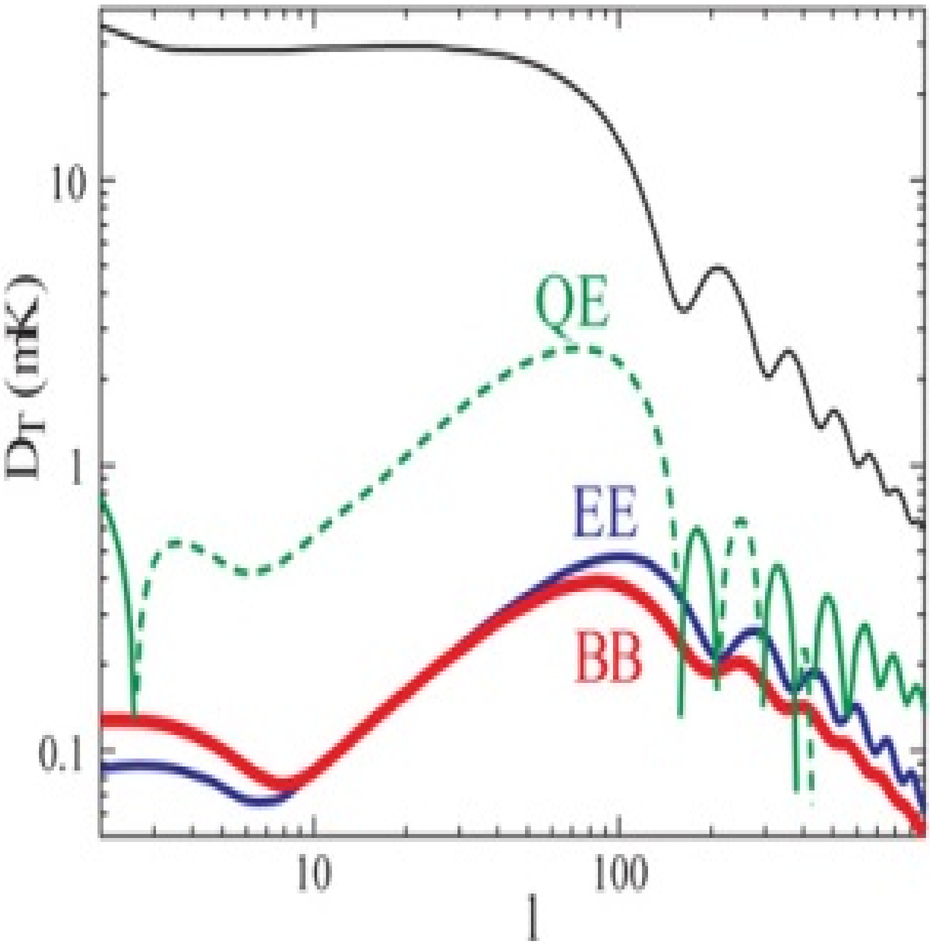
Planck constraints inflation 2013

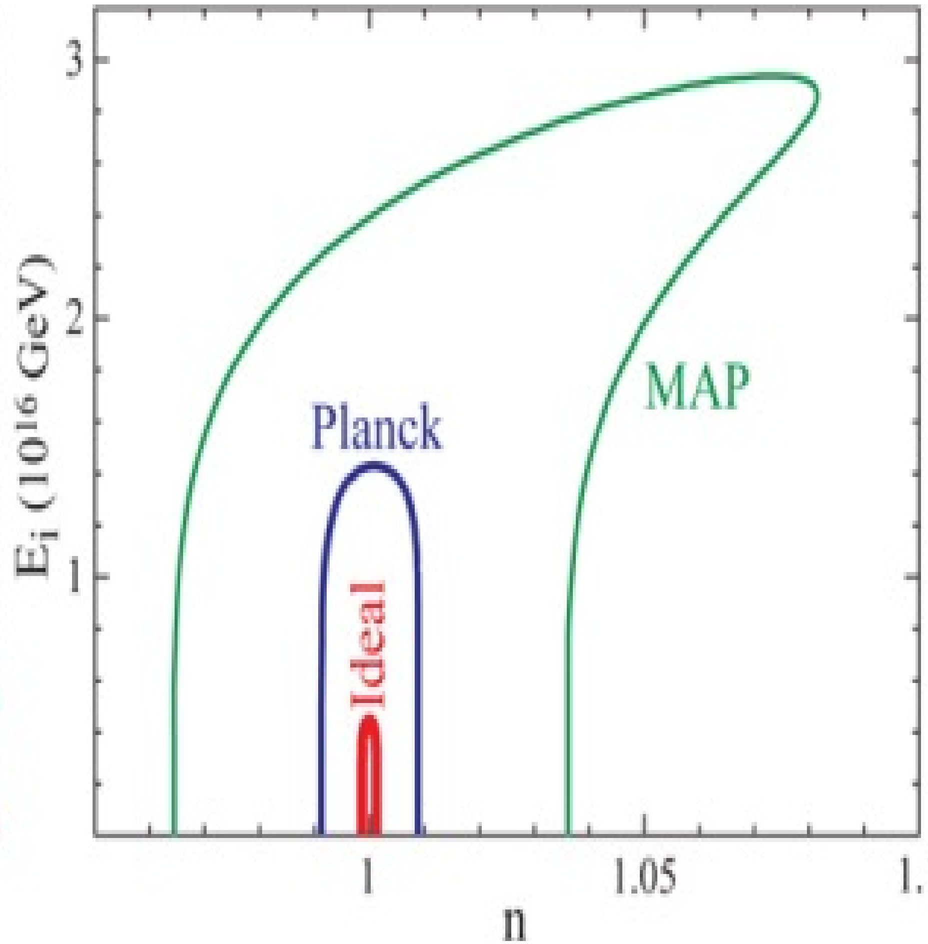


Planck constraints inflation 2013 2

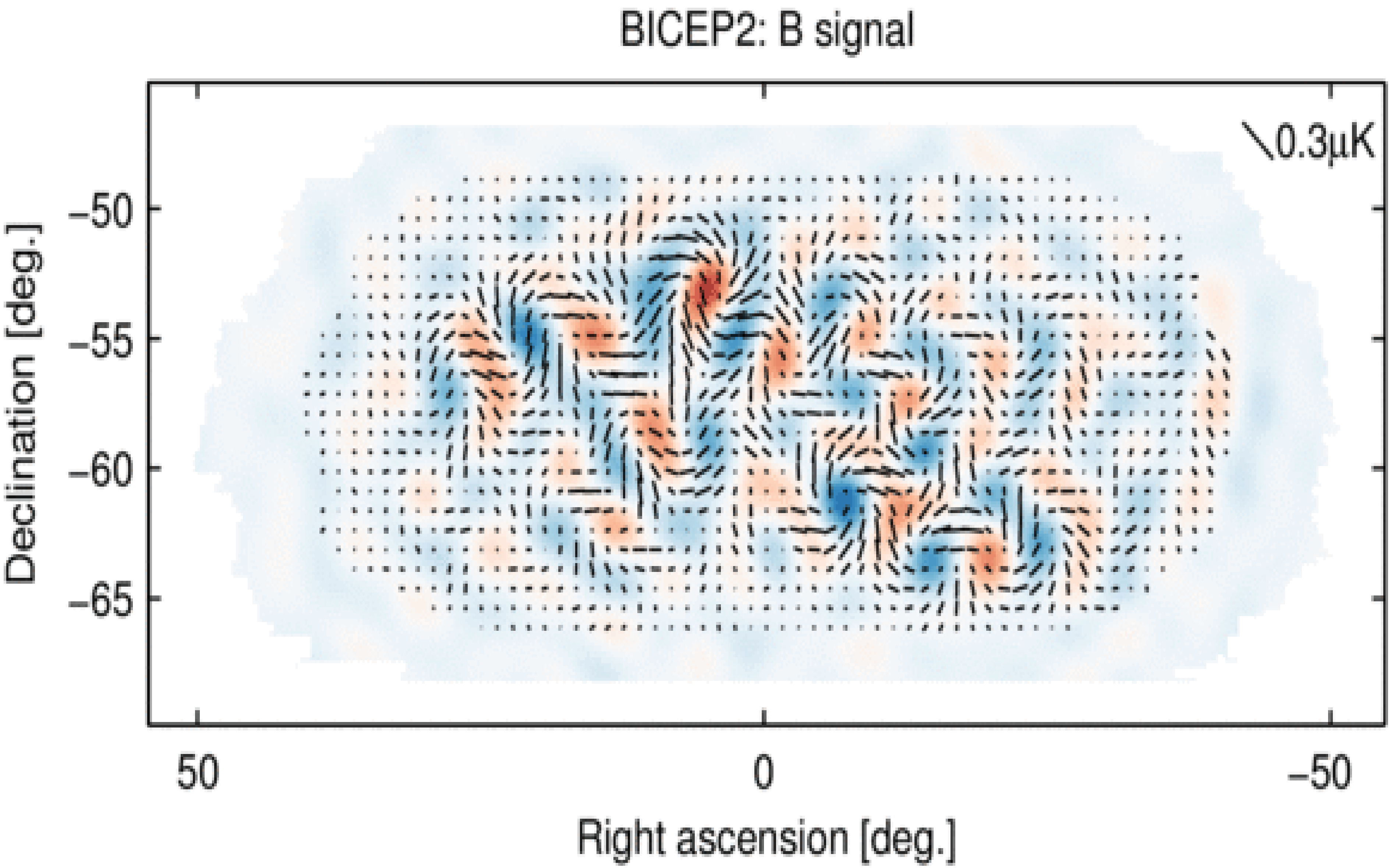


CMB spectrum: Planck+WMAP polarization

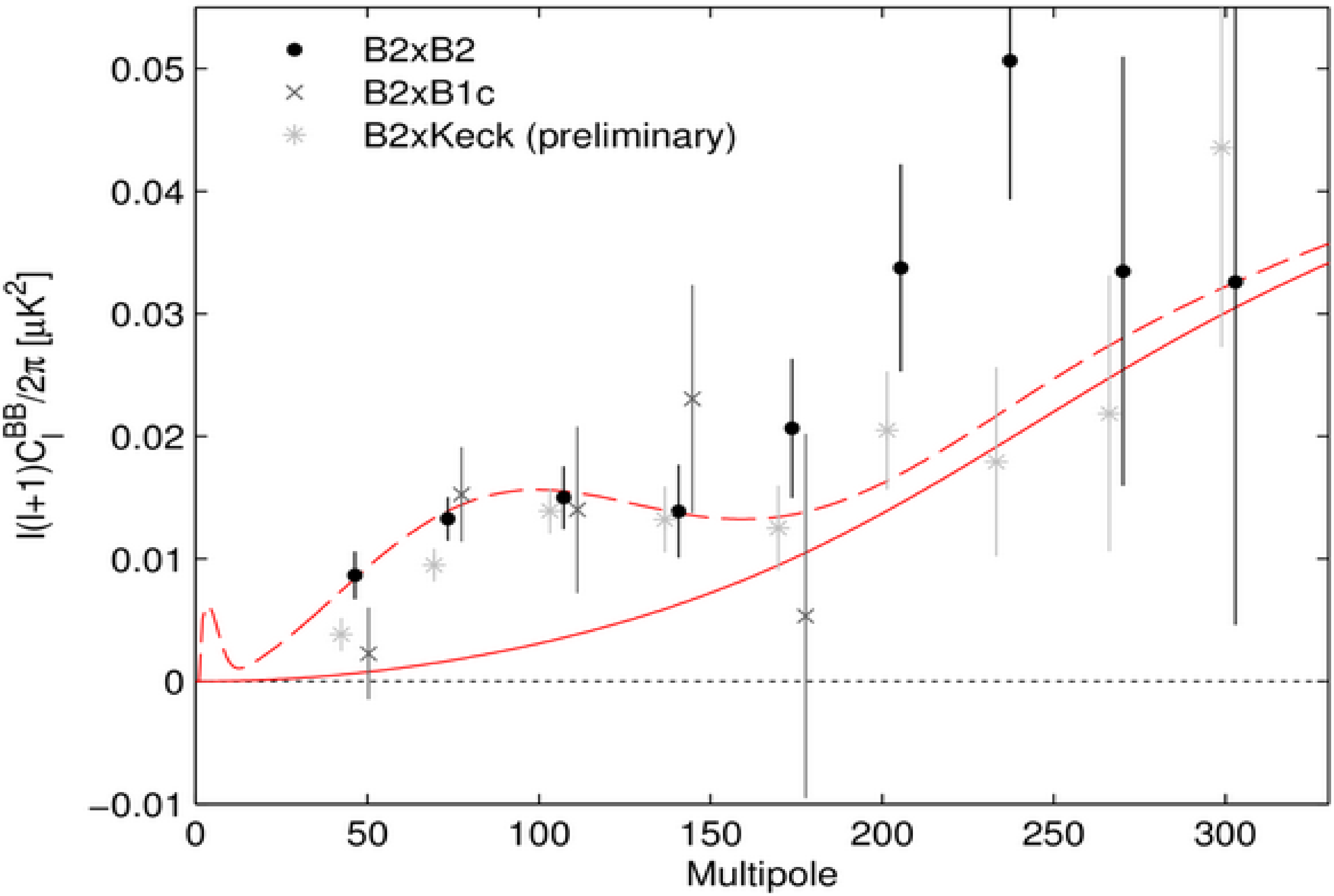




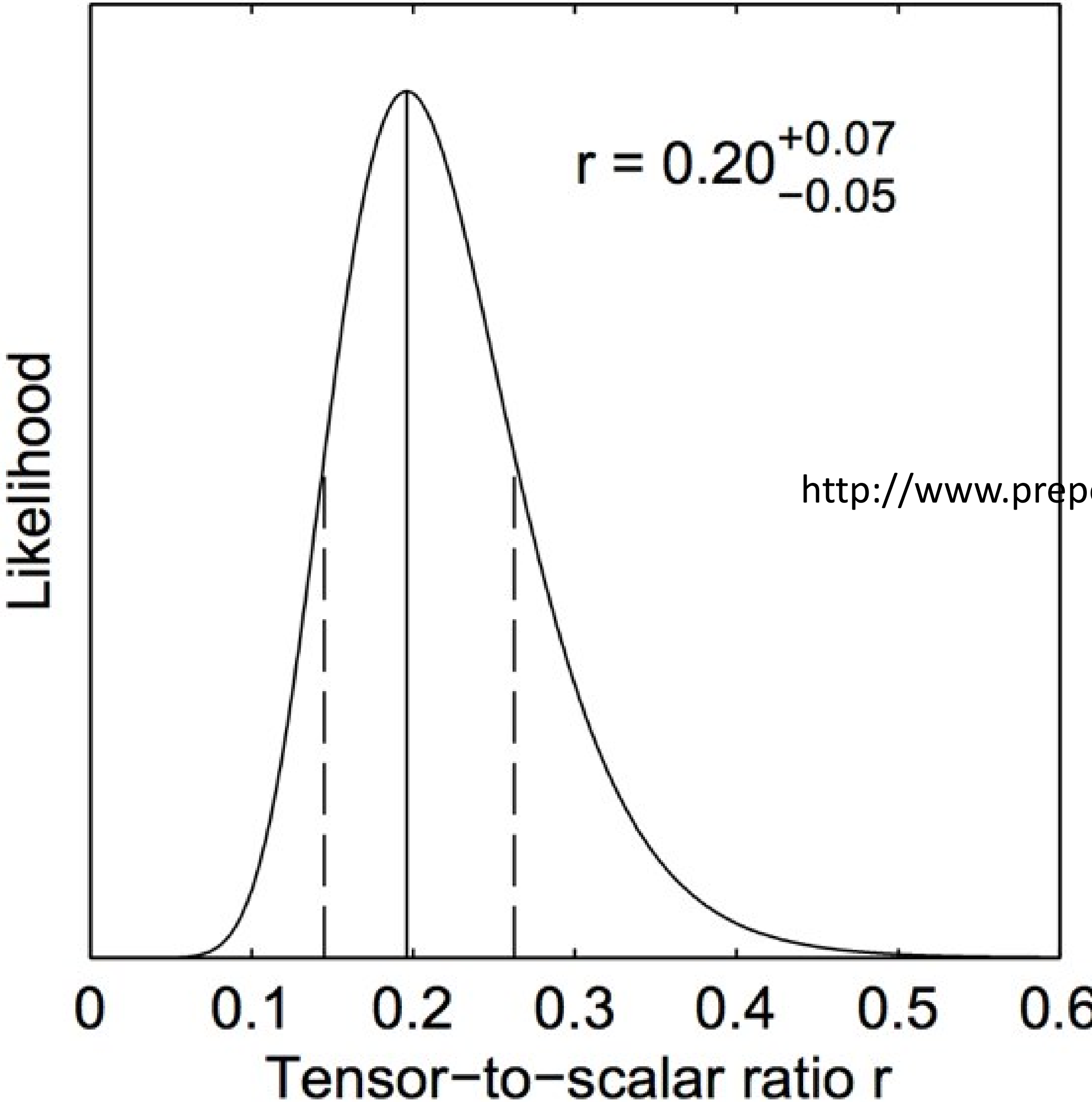
CMB spectrum: BICEP 2: Mar 17 2014



CMB spectrum: BICEP 2: Mar 17 2014

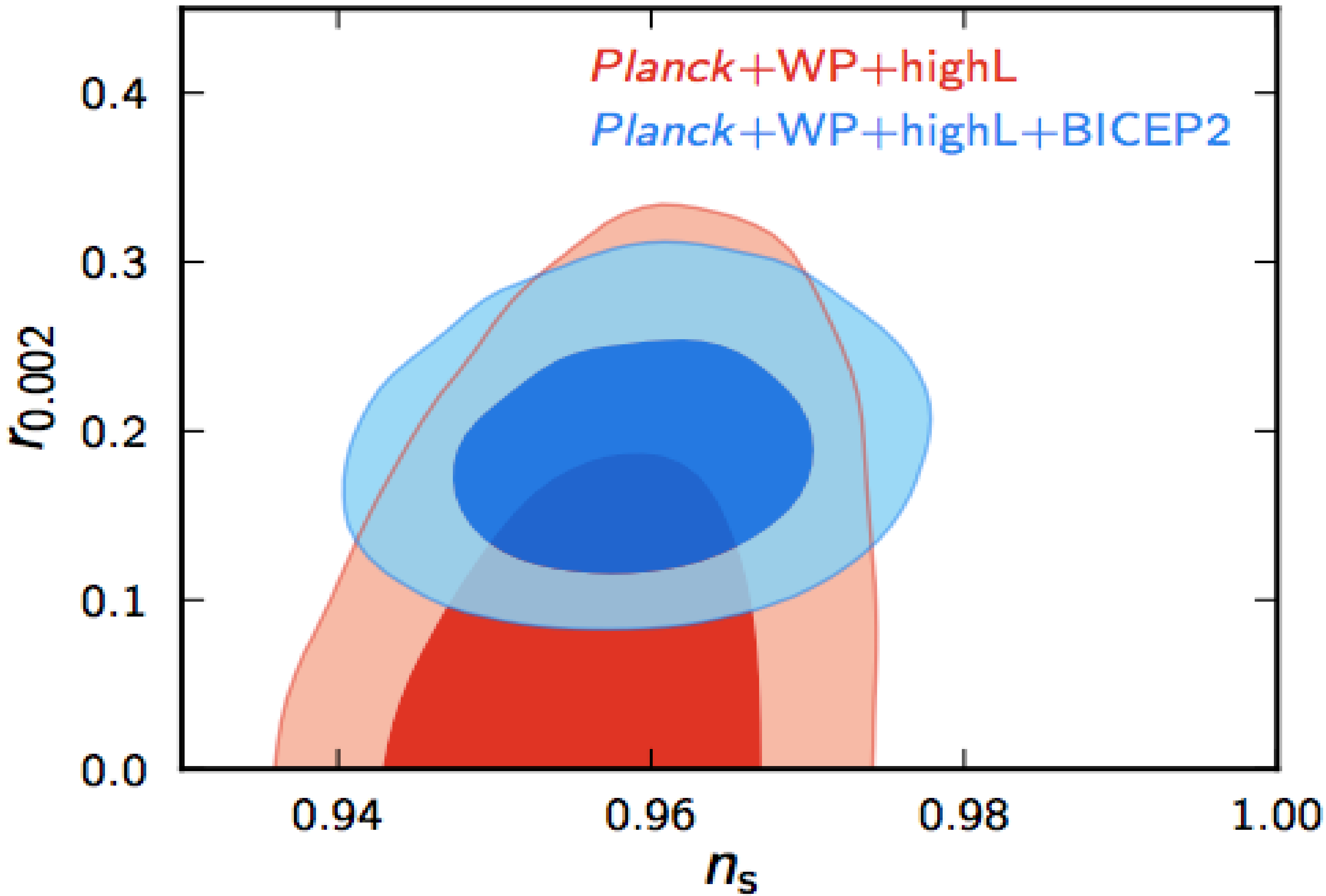


CMB spectrum: BICEP 2: Mar 17 2014



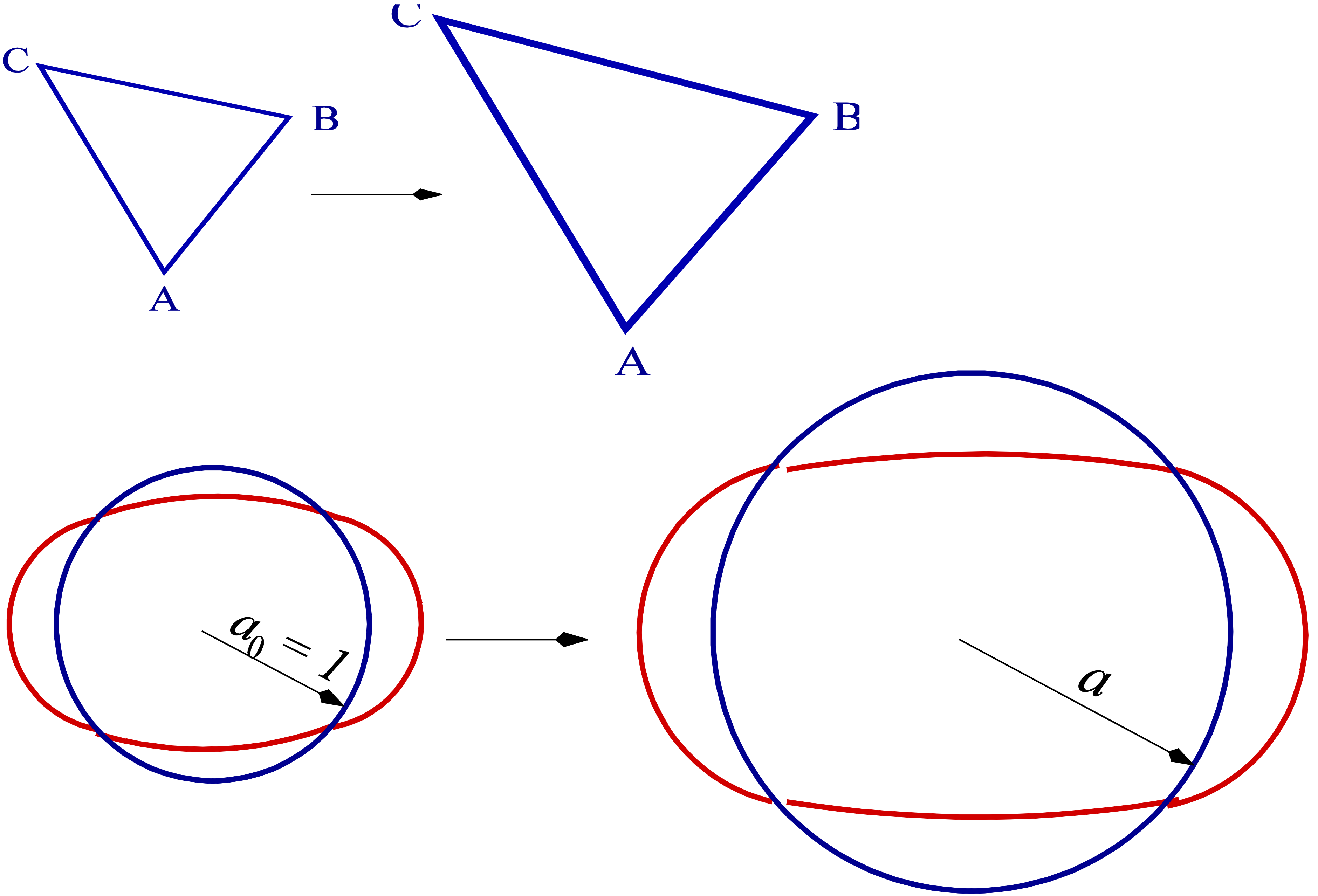
http://www.preposterousuniverse.com/blog/

CMB spectrum: BICEP 2: Mar 17 2014



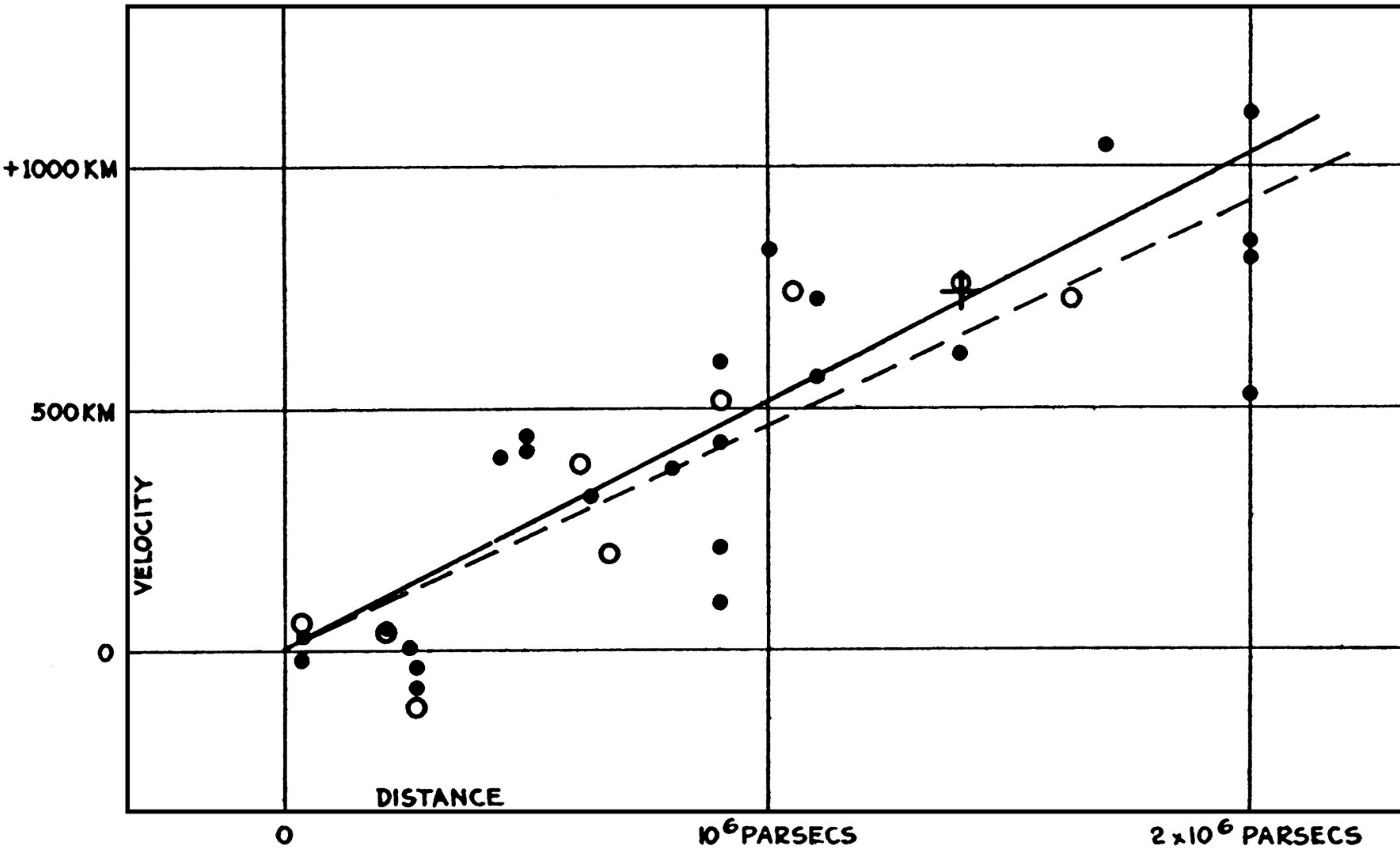
EXPANDING UNIVERSE

EXPANDING UNIVERSE



EXPANDING UNIVERSE

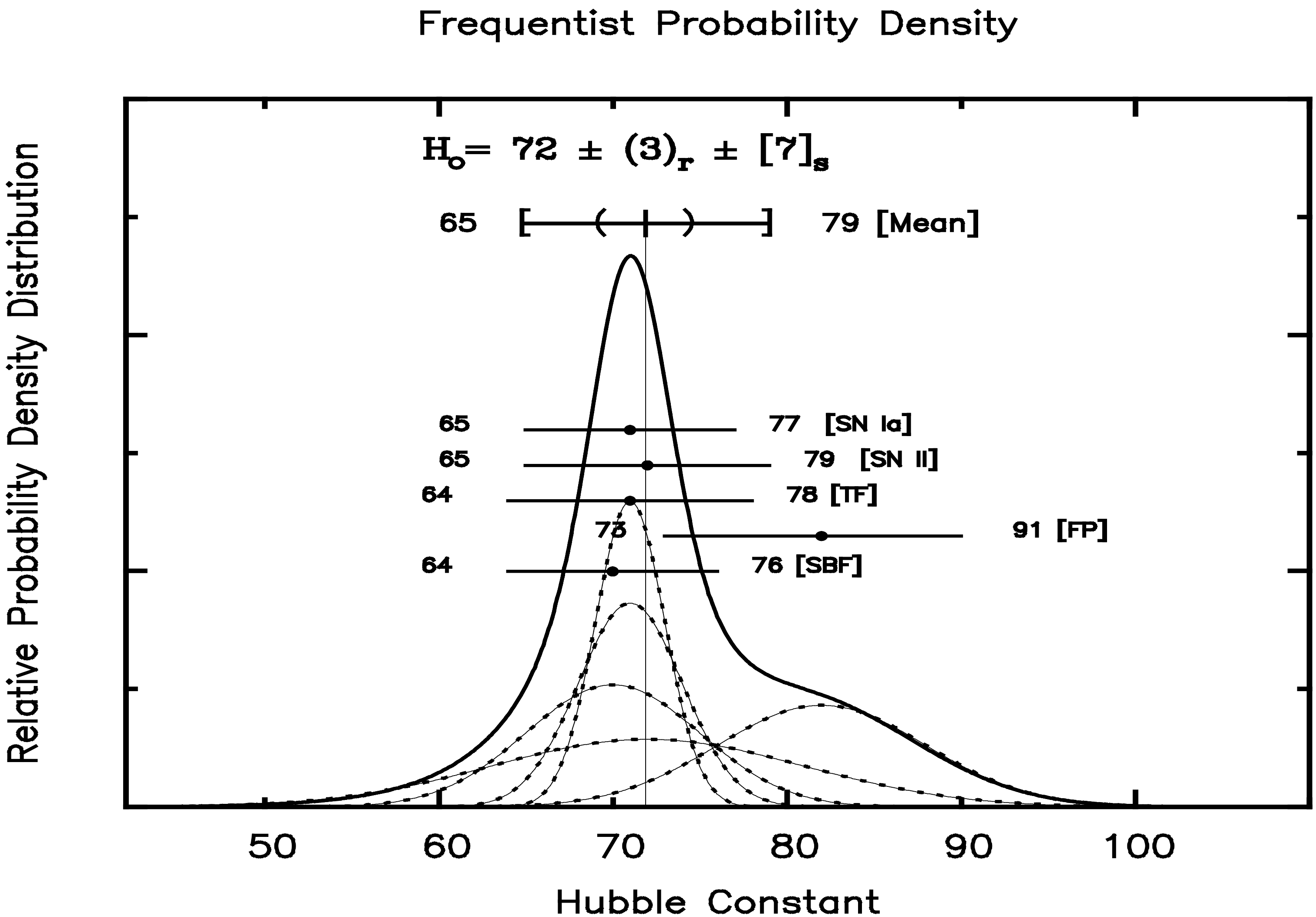
HUBBLE 1929



EXPANDING UNIVERSE

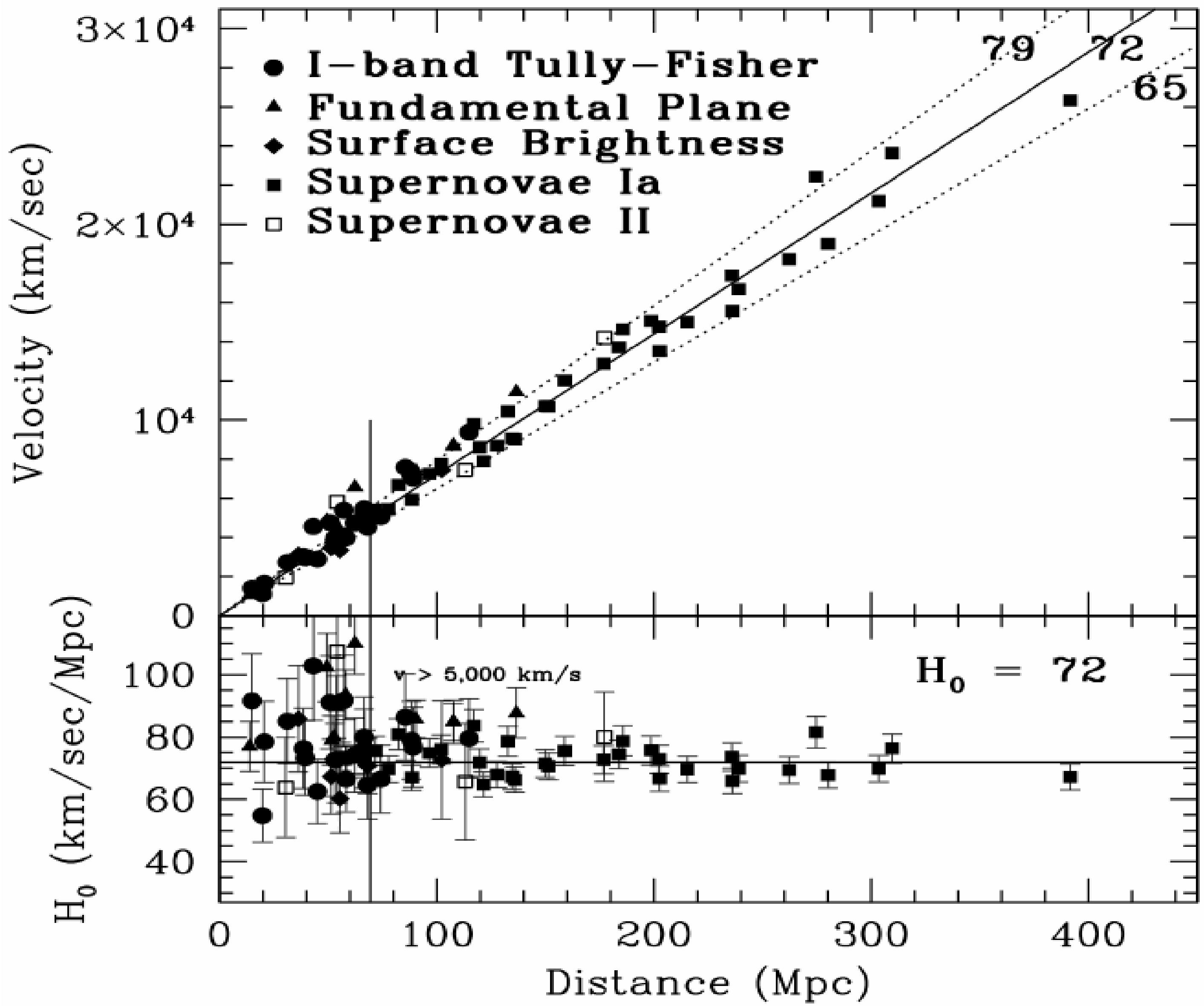
Hubble Space Telescope Key Project (HST-KP)

- distance ladder: parallax, cepheids, SNae 1A



EXPANDING UNIVERSE

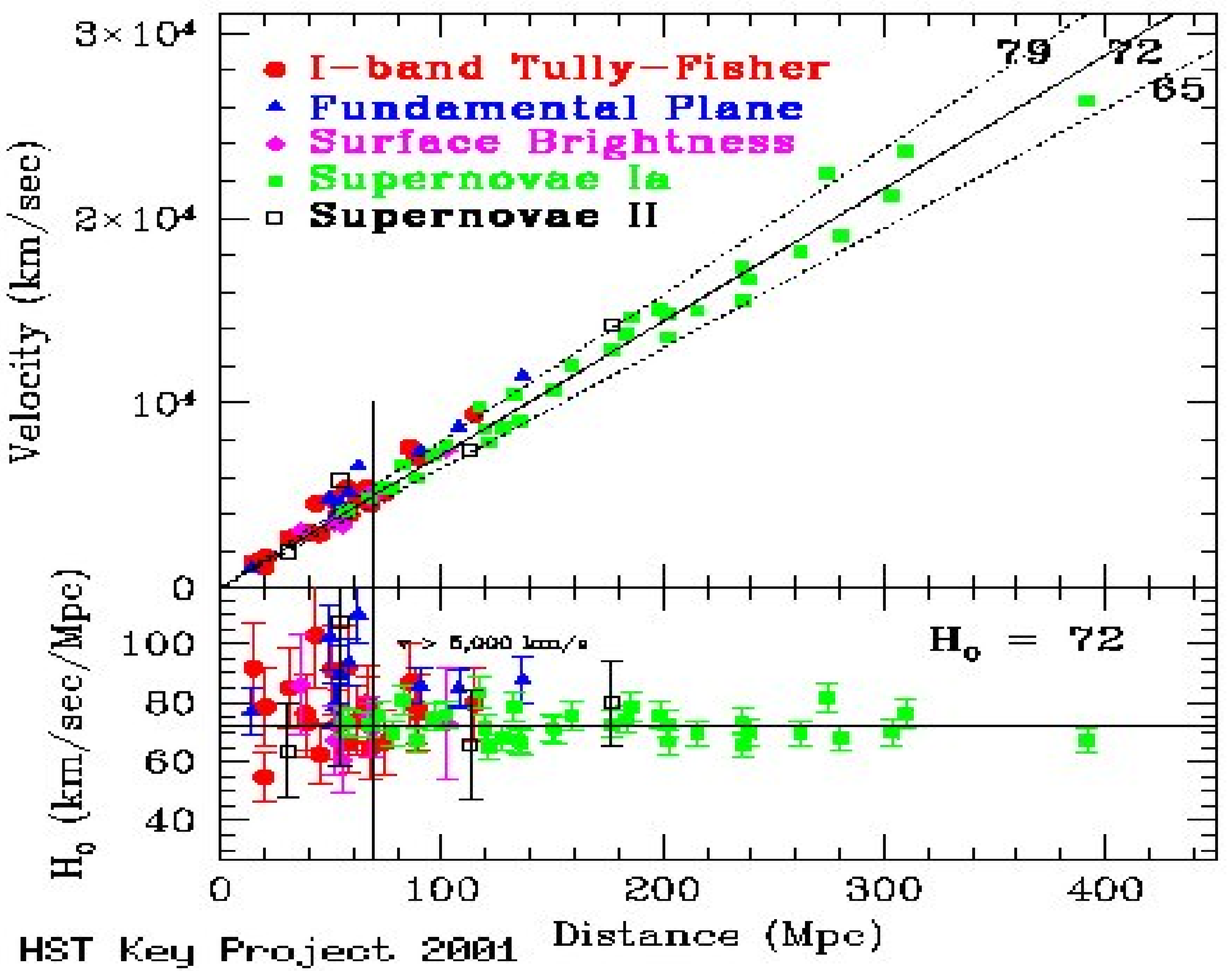
Hubble Space Telescope Key Project (HST-KP)



EXPANDING UNIVERSE

Hubble Space Telescope Key Project (HST-KP)

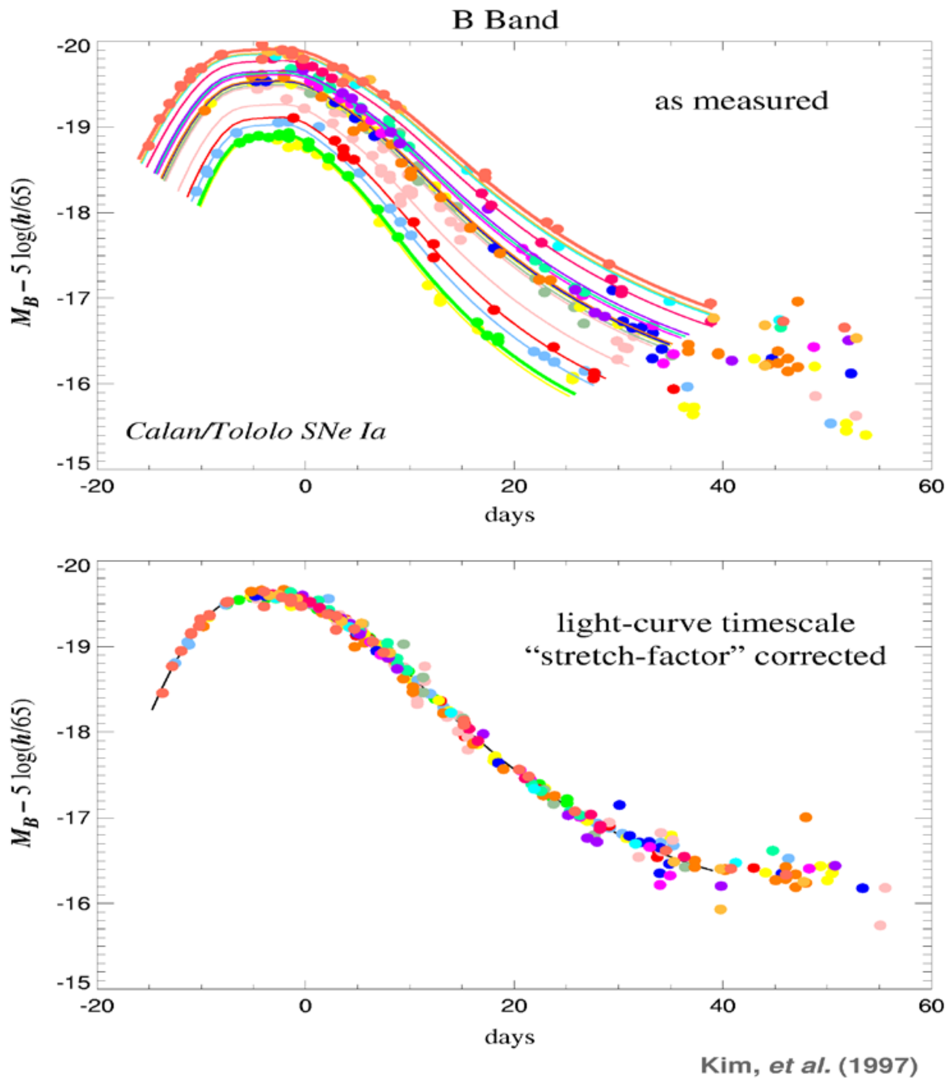
- distance ladder: parallax, <u>cepheids</u>, SNae 1A



ACCELERATING UNIVERSE

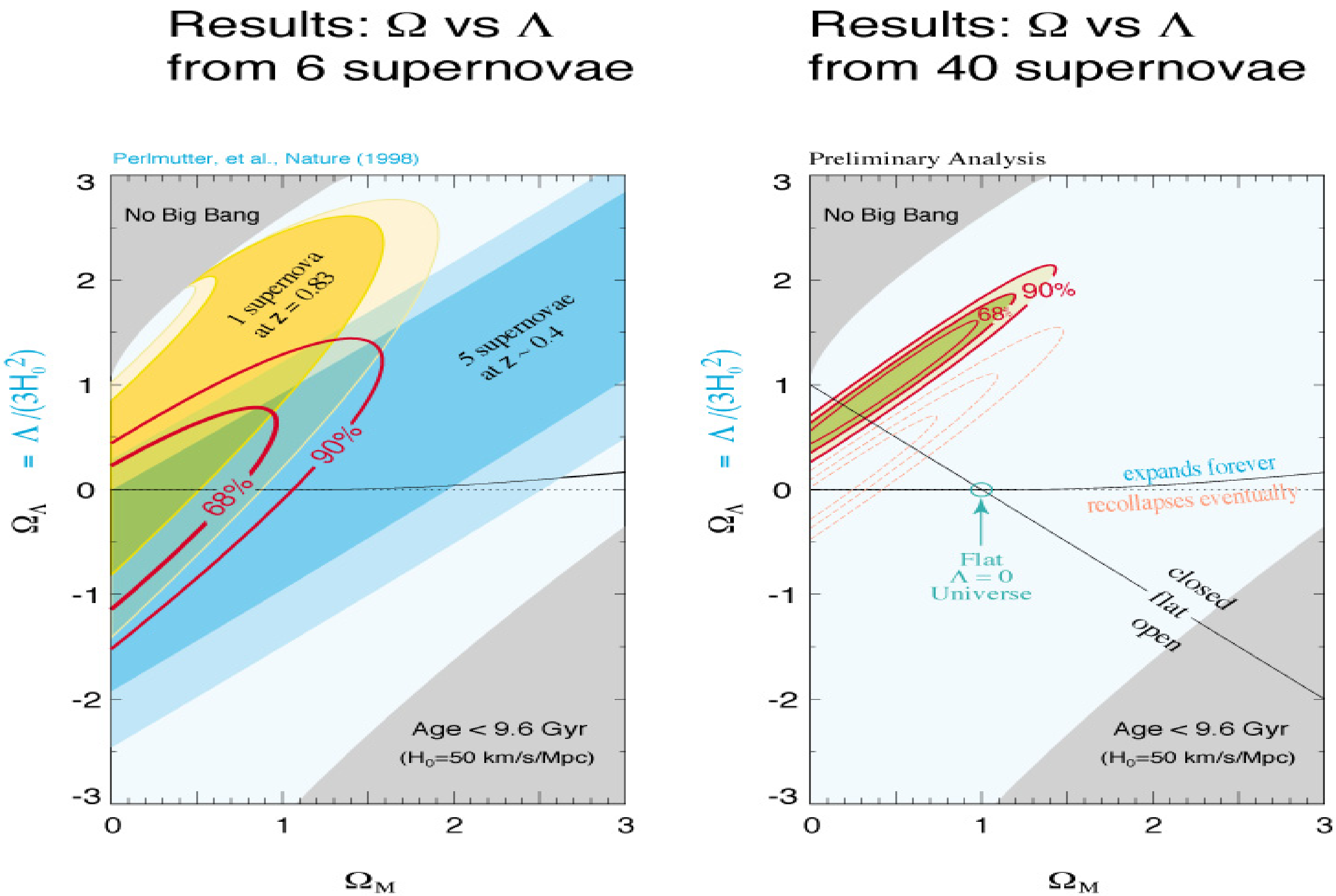
Supernovae Cosmology Project, High-z Supernovae survey

- distance ladder: parallax, cepheids, <u>SNae 1A</u>



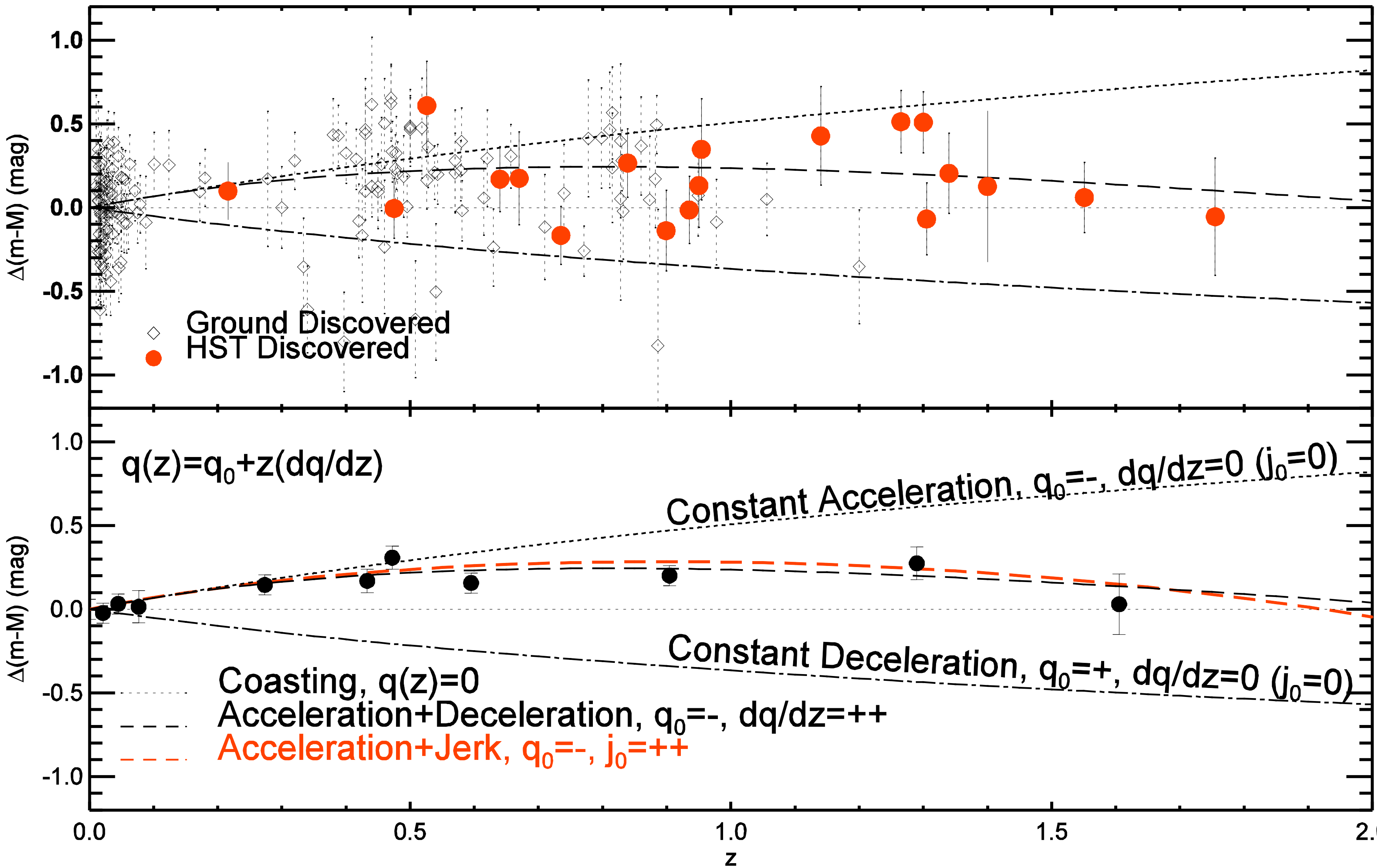
ACCELERATING UNIVERSE

Late 1990s

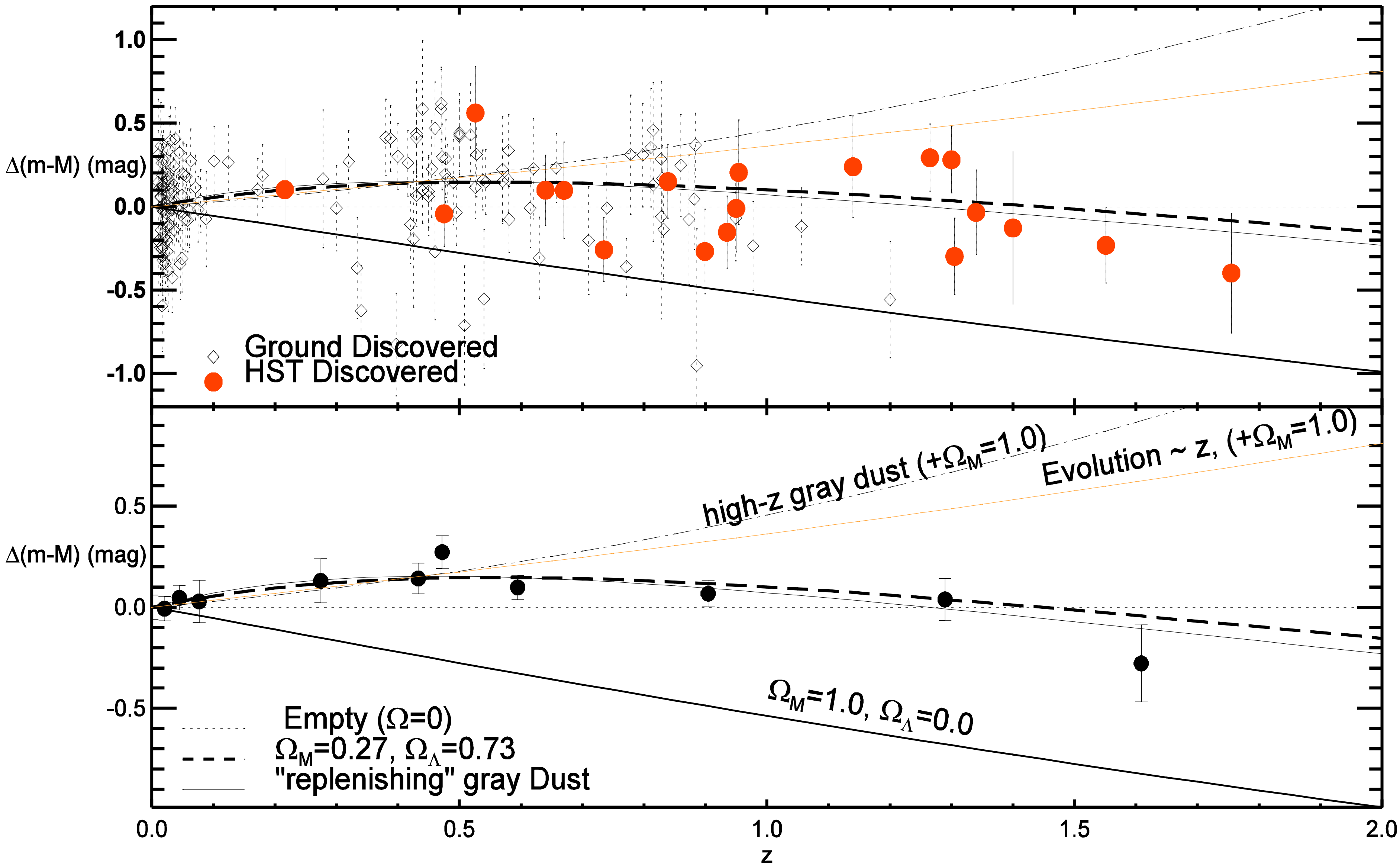


These two plots show the best-fit confidence regions on the Ω_M-vs-Ω_Λ plane for the 6-supernova fit presented in the Nature (1998) paper and for a more extensive 40-supernova fit (preliminary analysis). The left plot demonstrates that with a range of redshifts from 0.4 to 0.85, the approximately straight slope of the confidence region at a given redshift begins to rotate, allowing an intersection region (shown in green) to isolate measurements of Ω_M and Ω_Λ separately, not just in linear combination (see Goobar & Perlmutter, Ap.J. 1995). With the larger sample of supernovae shown on the right plot, the statistical uncertainty is now small enough—and the confidence regions narrow enough—that the systematic uncertainty is the dominant source of error. The dashed-line confidence region on the right plot shows our preliminary estimate of this systematic uncertainty (shown in the direction of 0.2 lower apperant magnitudes for the high redshift supernovae). Further analysis should reduce this uncertainty. The best-fit confidence region (in green on the right plot) is centered at $\Omega_M = 0.5$, $\Omega_\Lambda = 1.0$. This confidence region lies along the line of $\Omega_\Lambda = \Omega_M + 0.5$, which is not parallel to the lines of constant deceleration $q_0 = \Omega_M/2 - \Omega_\Lambda$. Note that the confidence regions do not include the "standard model" inflationary universe with no cosmological constant (shown as a green circle at the intersection of the flat-universe line and the $\Lambda = 0$ line). The confidence regions do suggest that we live in a universe that will expand forever.

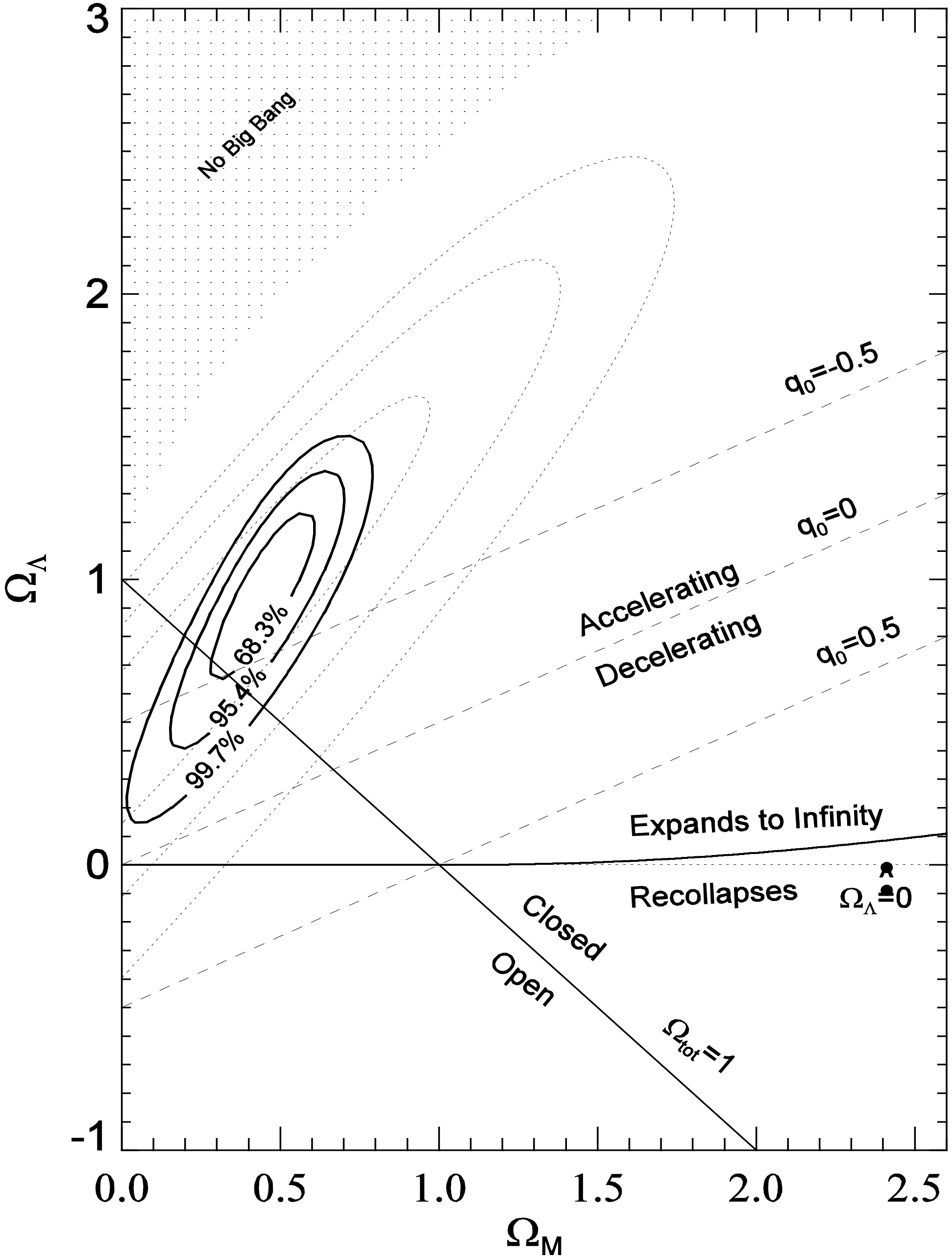
ACCELERATING UNIVERSE



ACCELERATING UNIVERSE



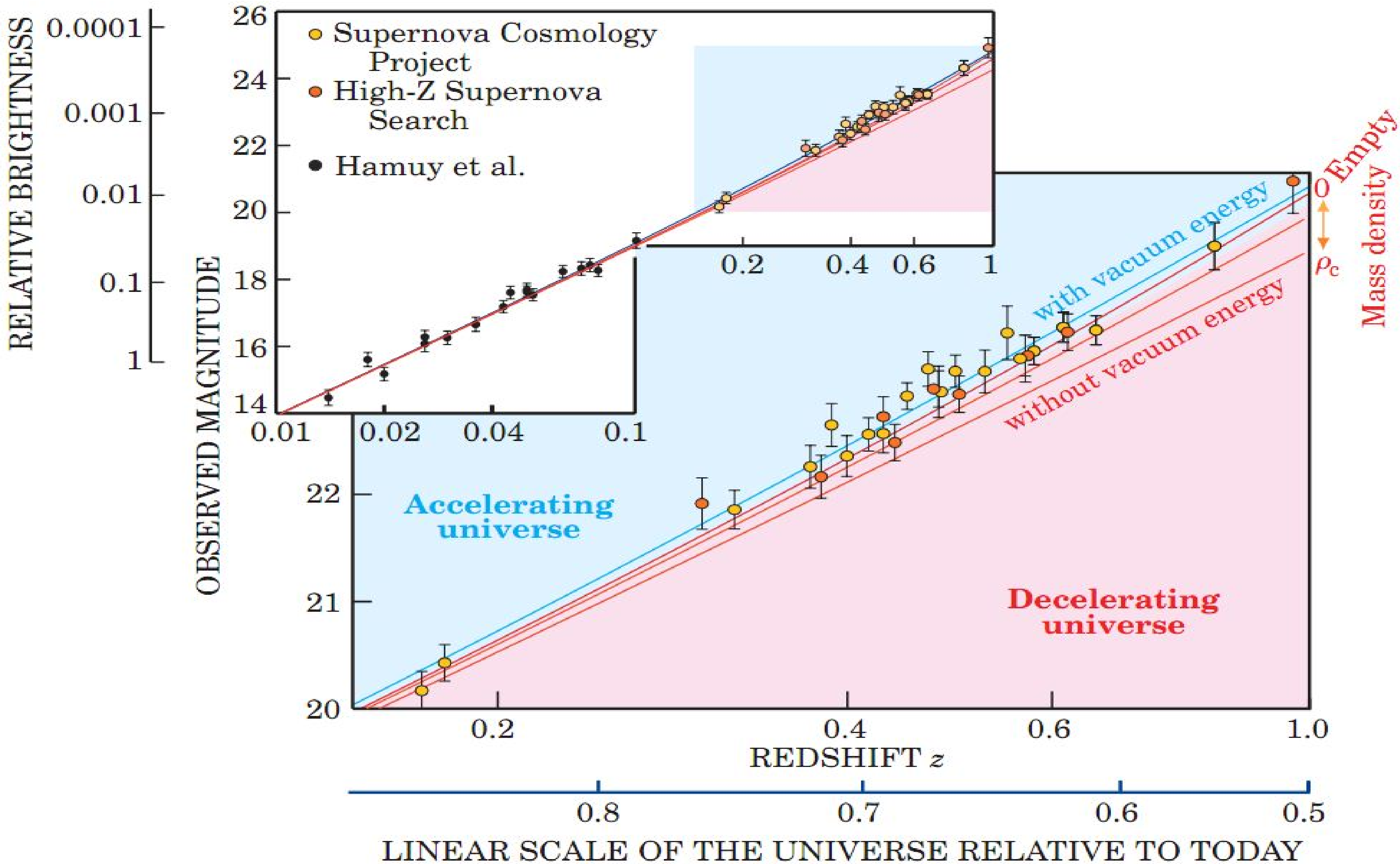
ACCELERATING UNIVERSE



Late 1990s

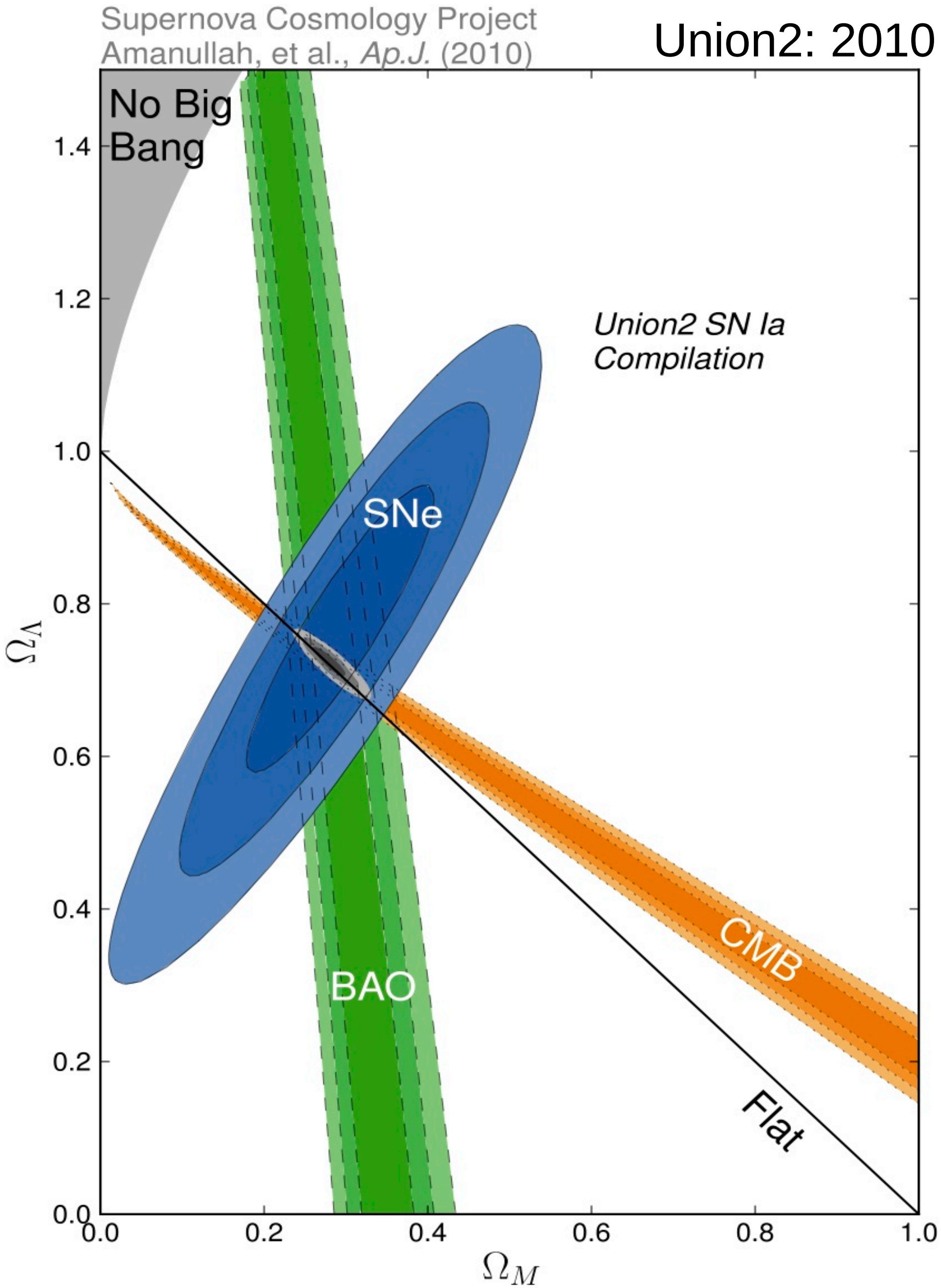
ACCELERATING UNIVERSE

Early 2000s: fate of the Universe



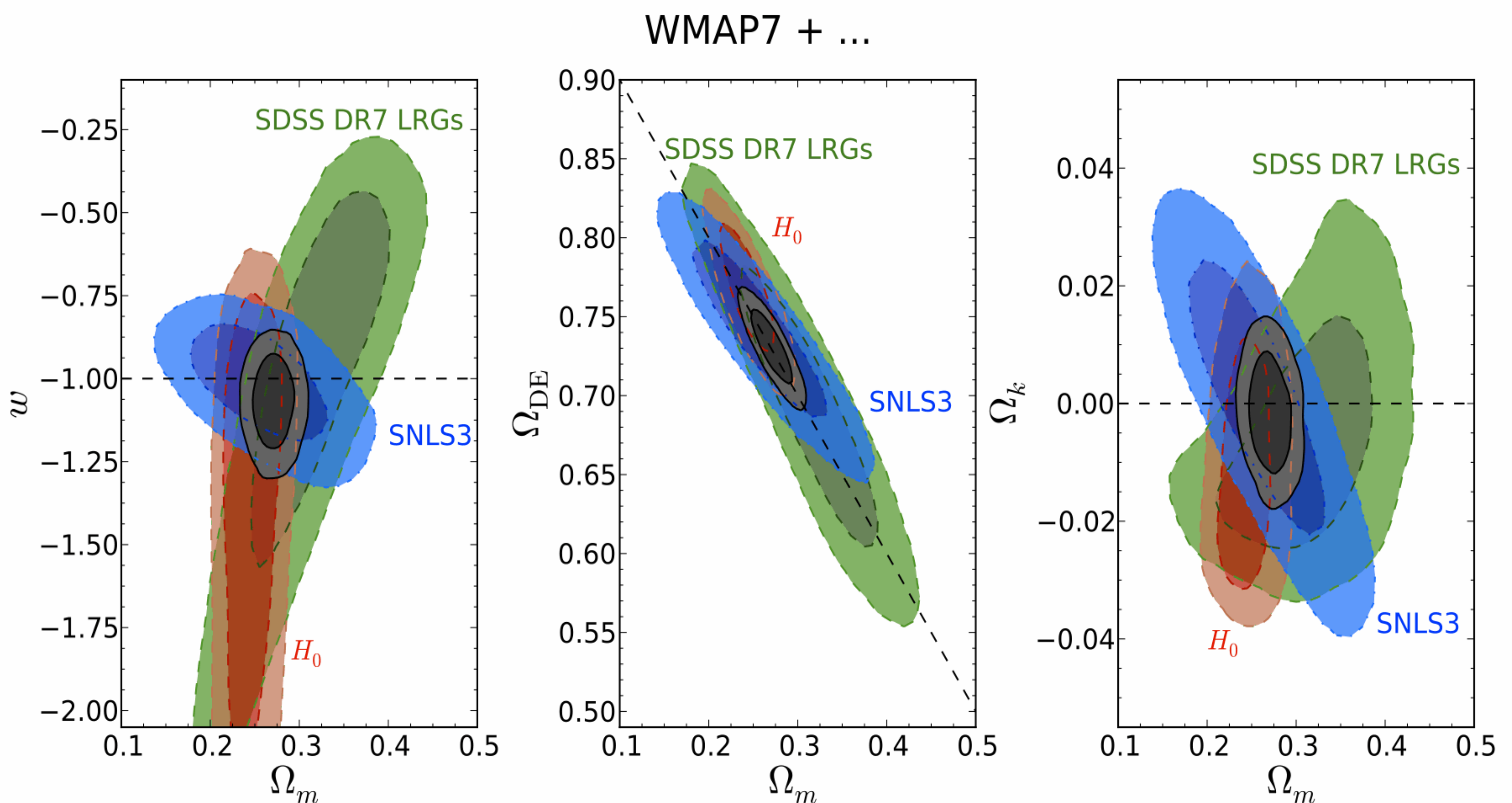
ACCELERATING UNIVERSE

Union2: 2010



ACCELERATING UNIVERSE

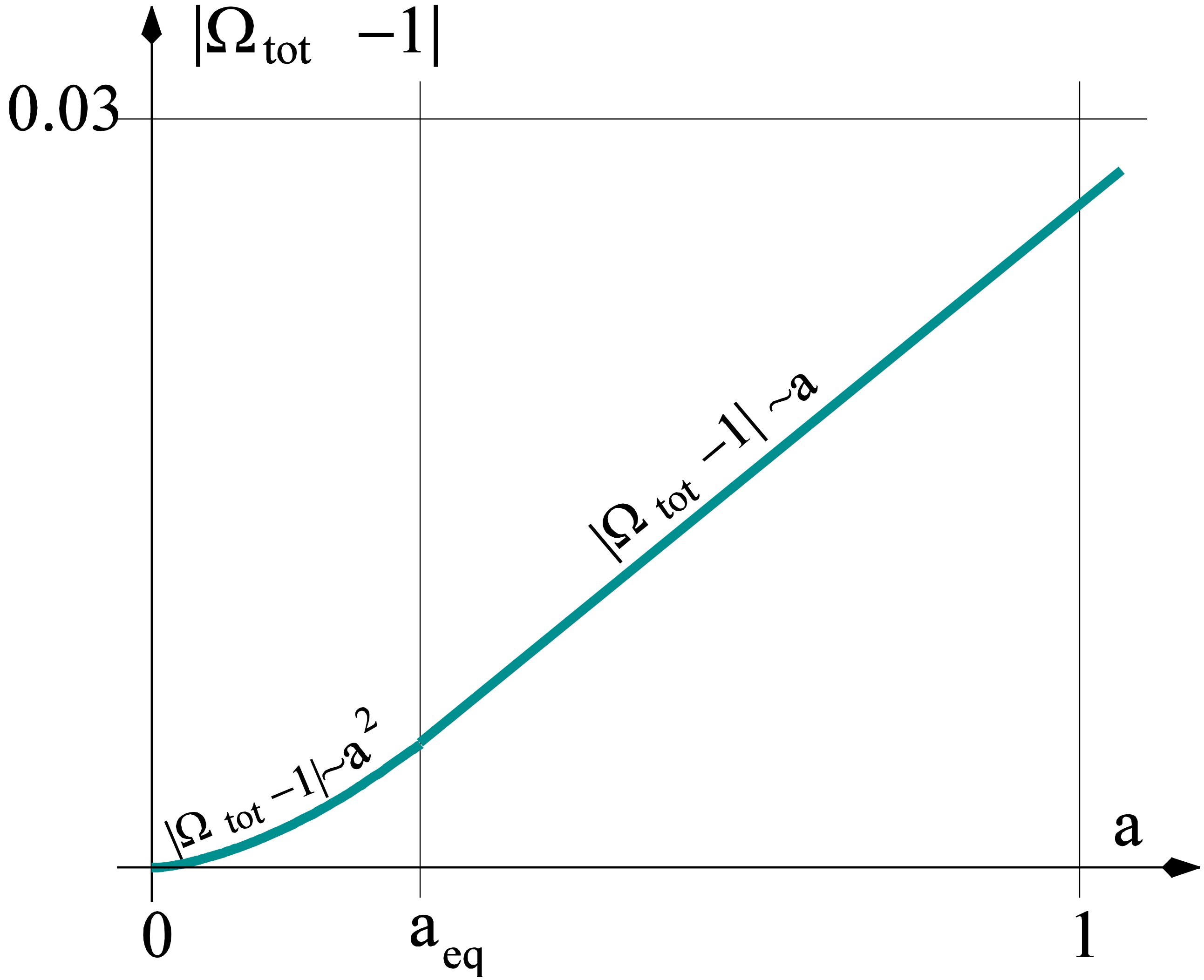
Legacy Survey 2010: SNLS3



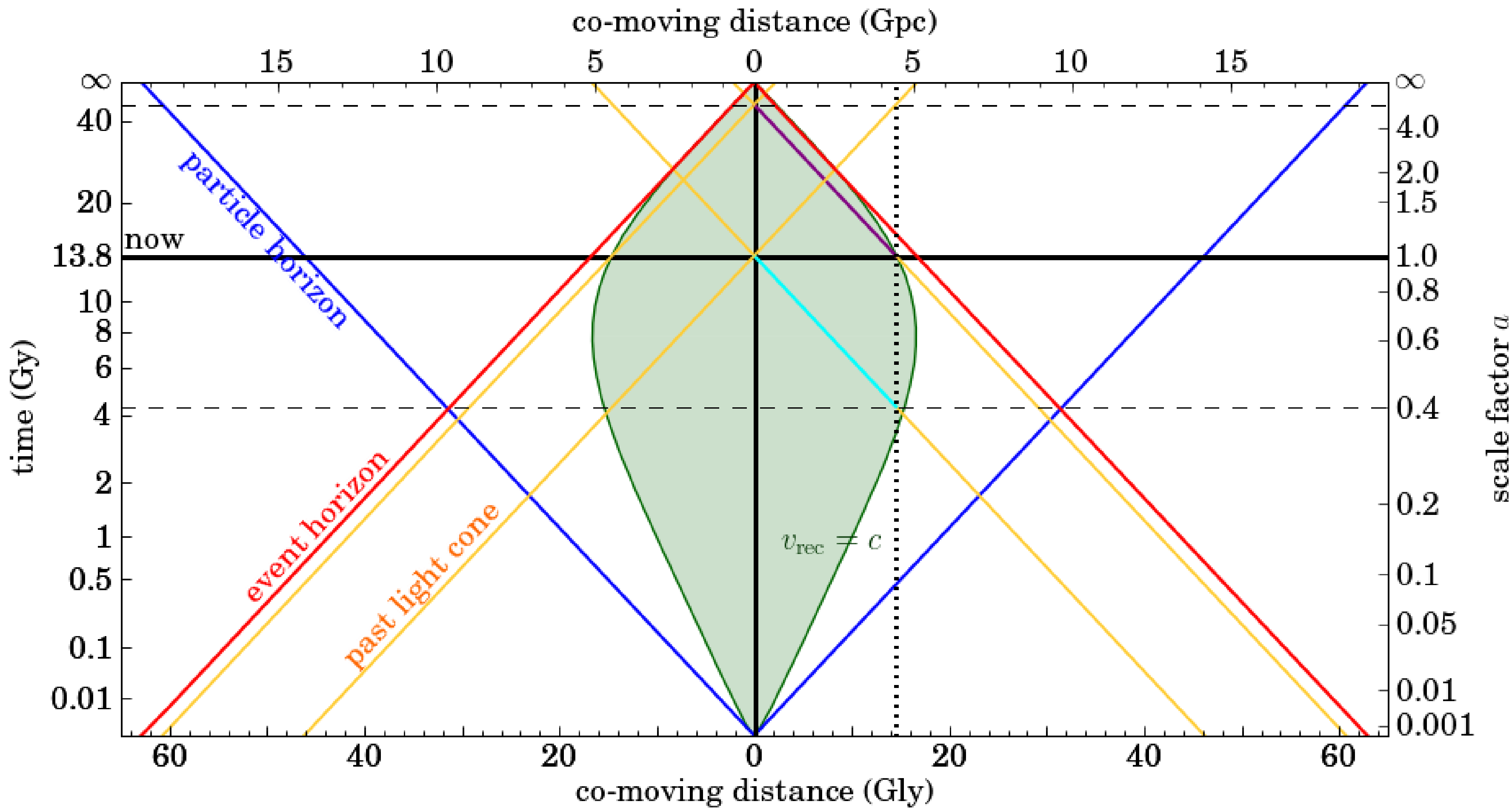
ACCELERATING UNIVERSE

SDSS+LS+: 2014: 1401.4064

FLATNESS PROBLEM

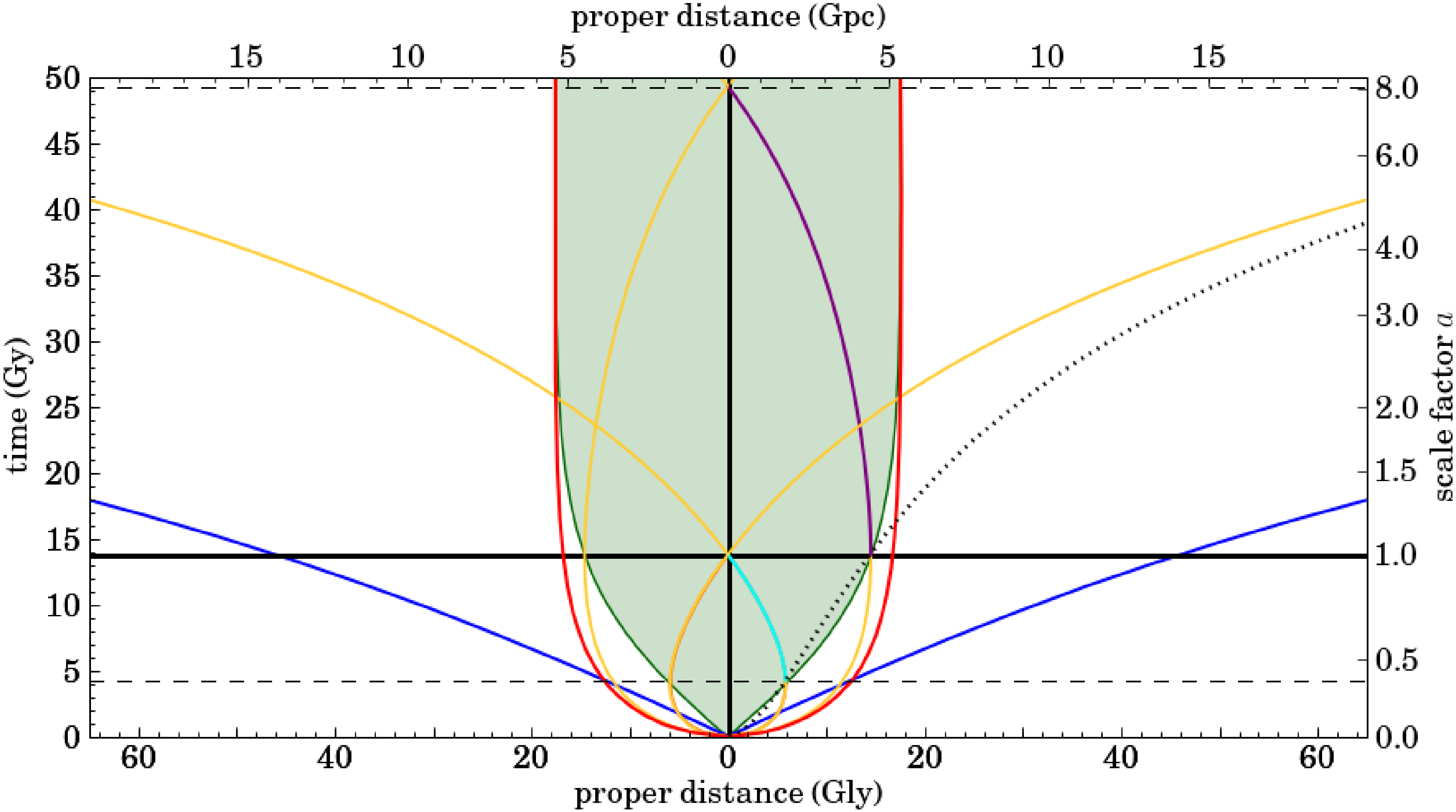


HORIZONS



The black solid lines indicate our present position. The blue line is the particle horizon through time, the red line is the event horizon, the green area is the Hubble sphere. The dotted black line is a co-moving galaxy that is currently located on the Hubble radius. Its photons that we observe today have travelled on the cyan path (they were emitted at t=4.3Gy). Its photons that it emits today (t=13.8Gy) will travel on the purple path (they will reach us at t=49Gy).

HORIZONS



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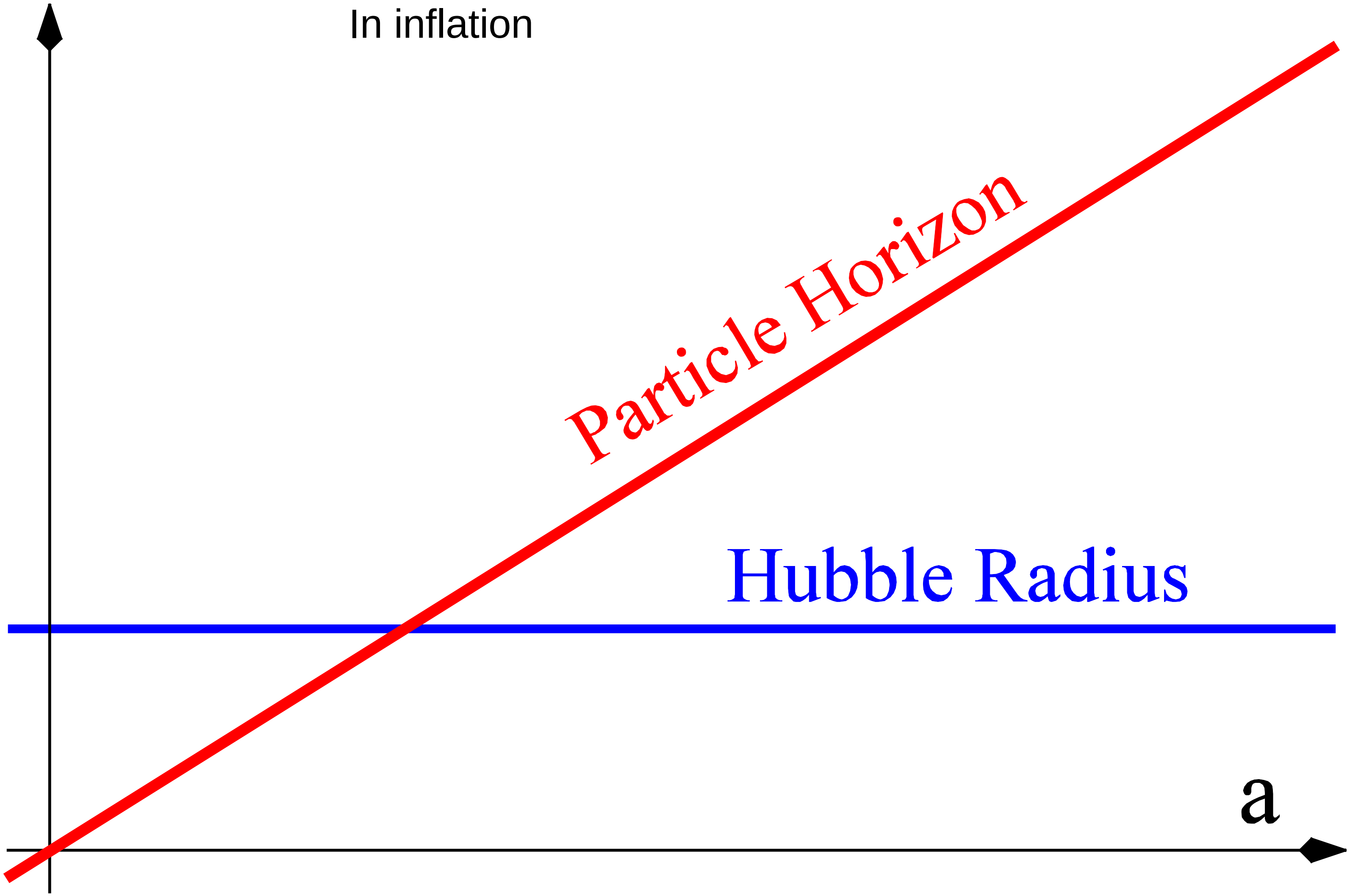
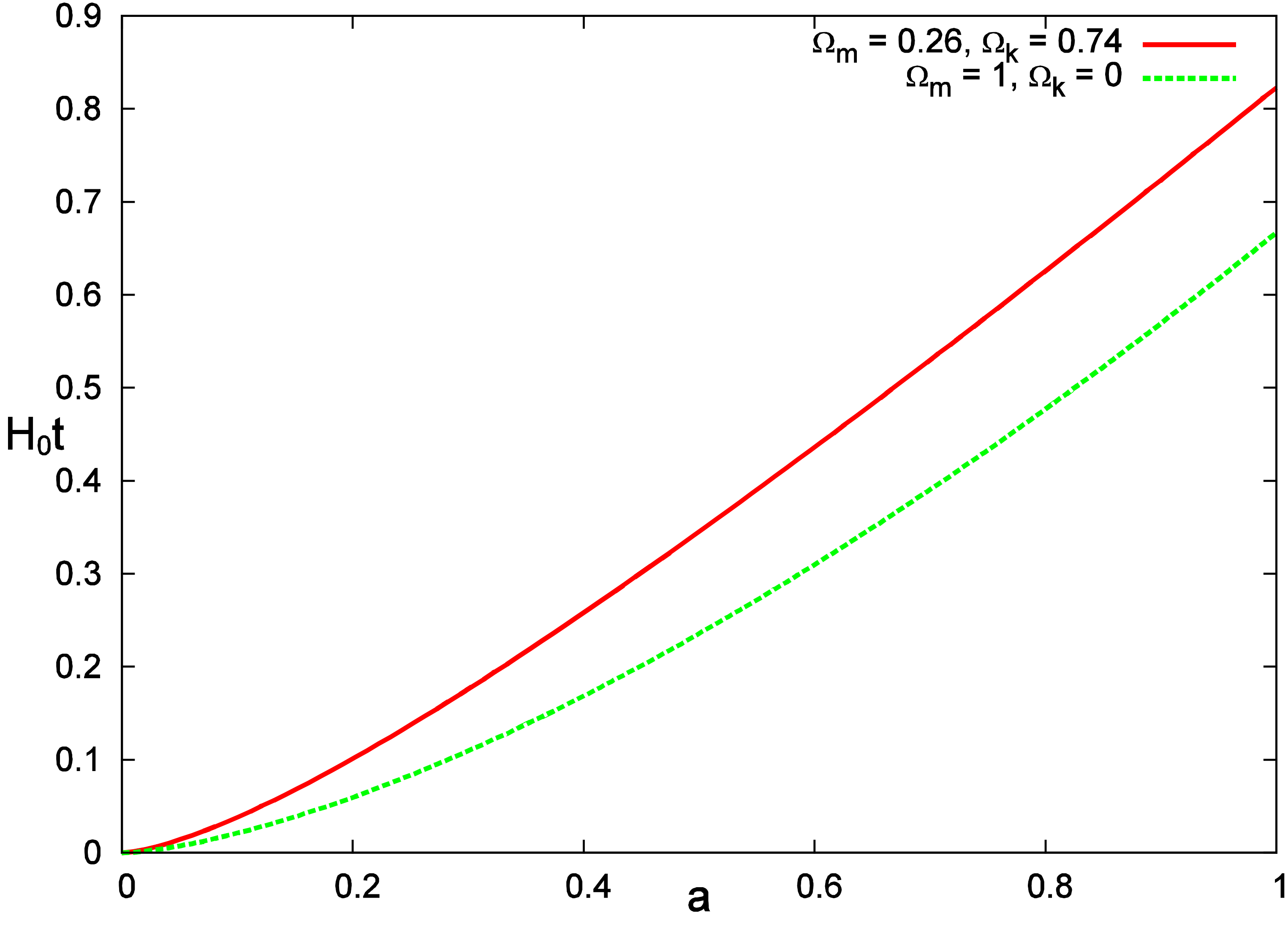
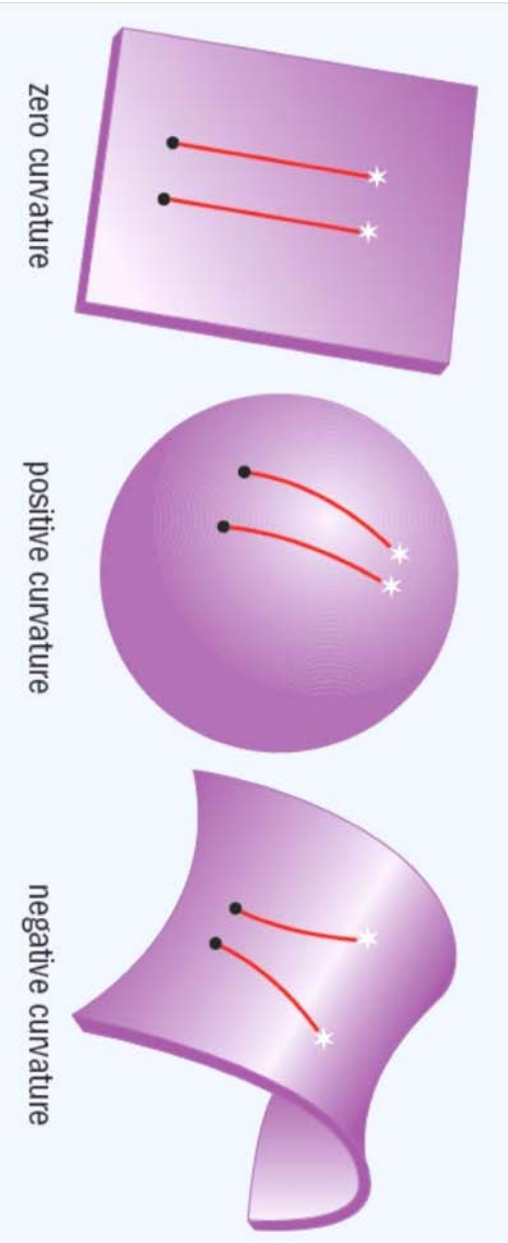
HORIZONS

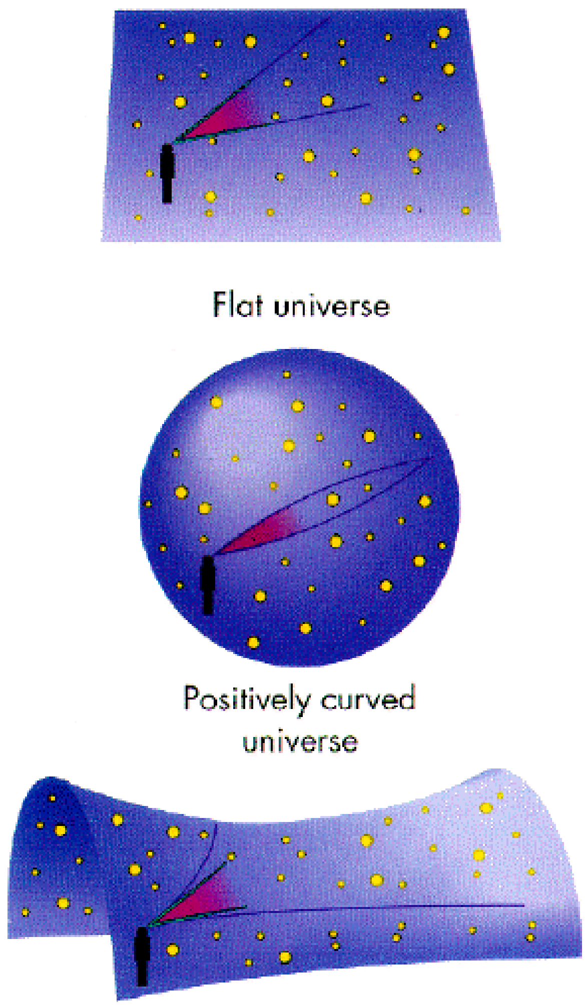


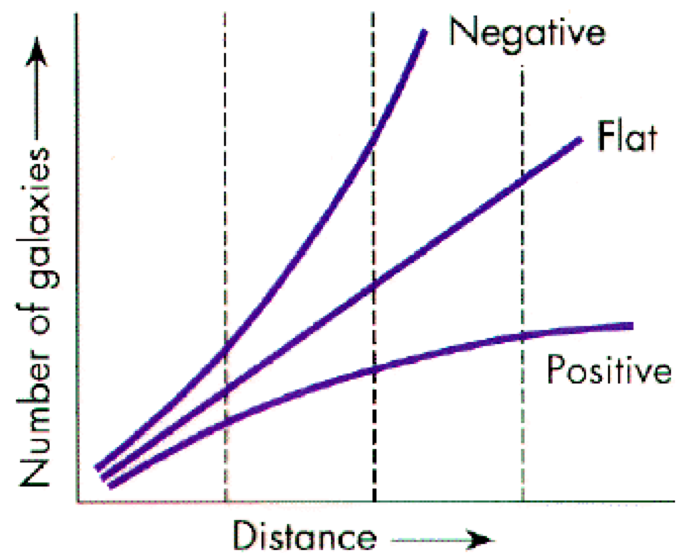
AGE



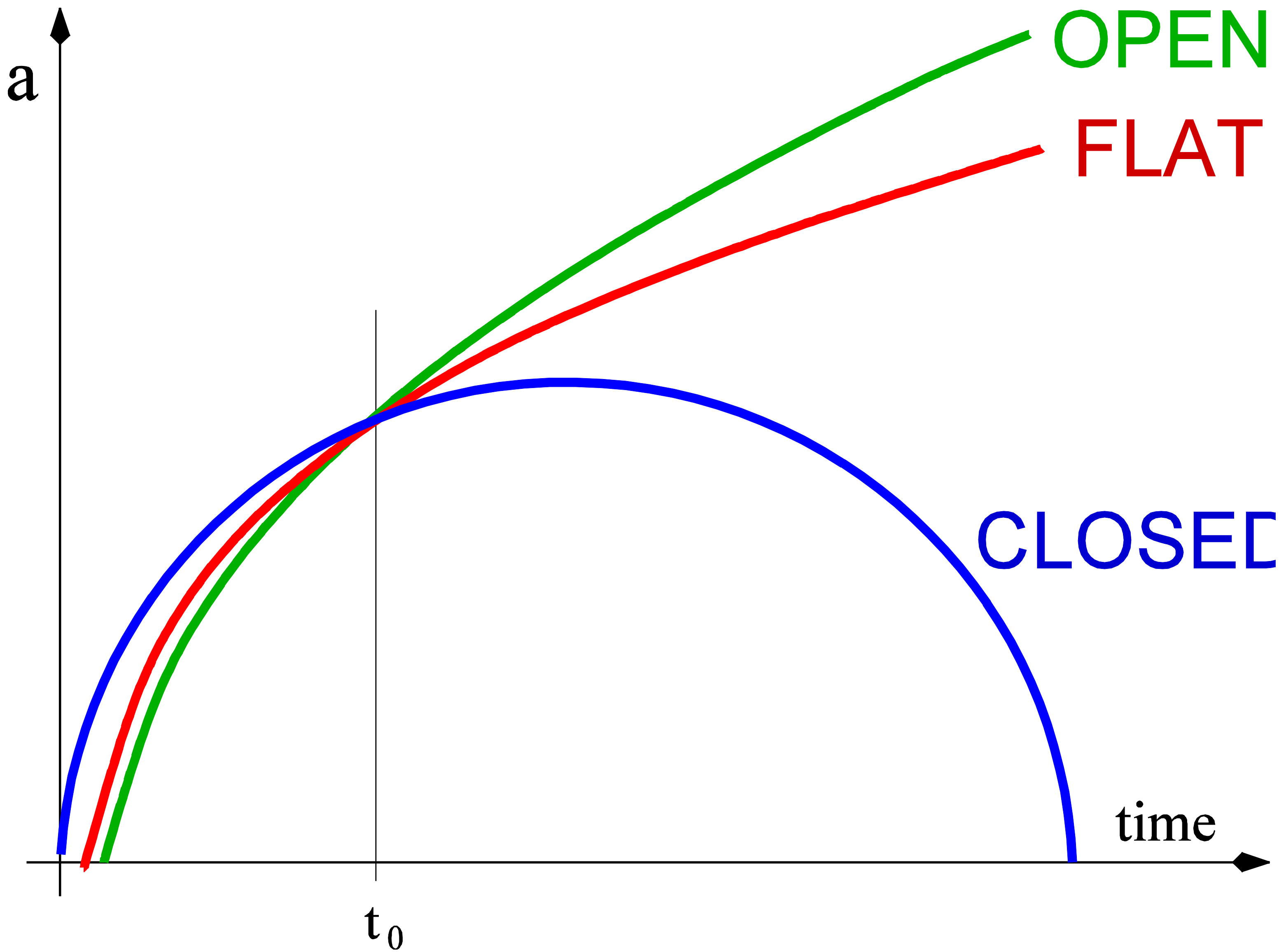
GEOMETRY & FATE



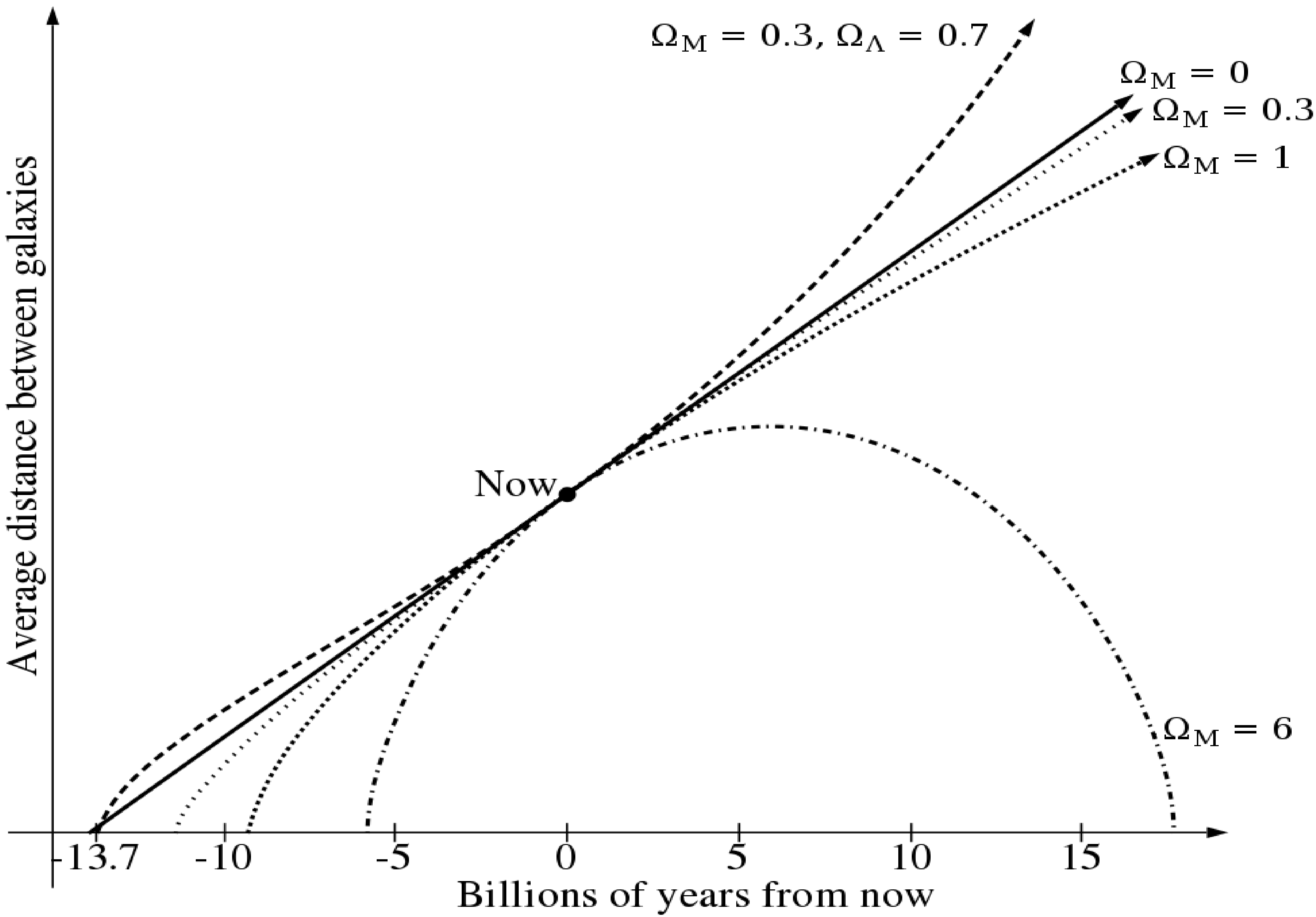

Flat universe
Positively curved universe
Negatively curved universe



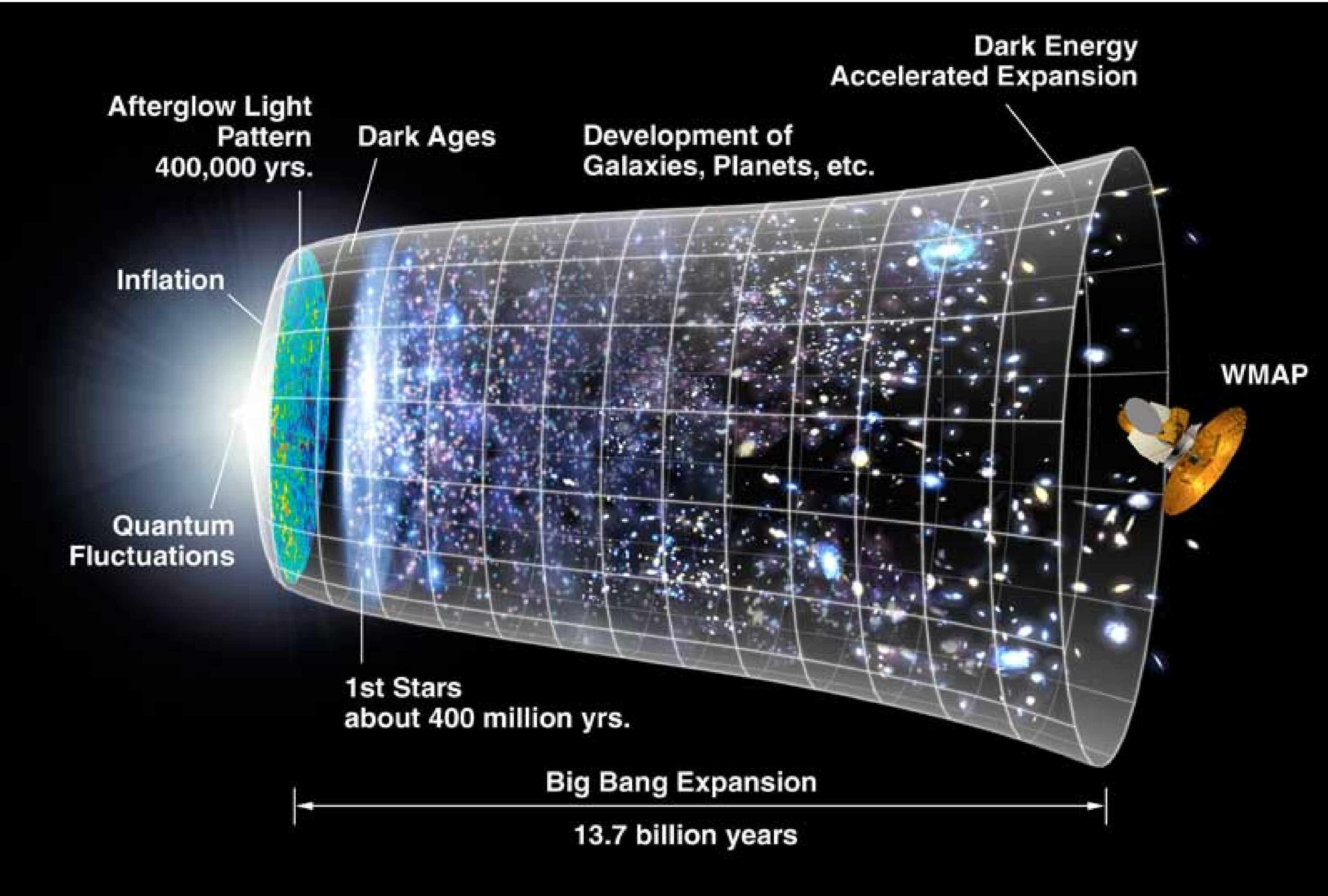
GEOMETRY & FATE



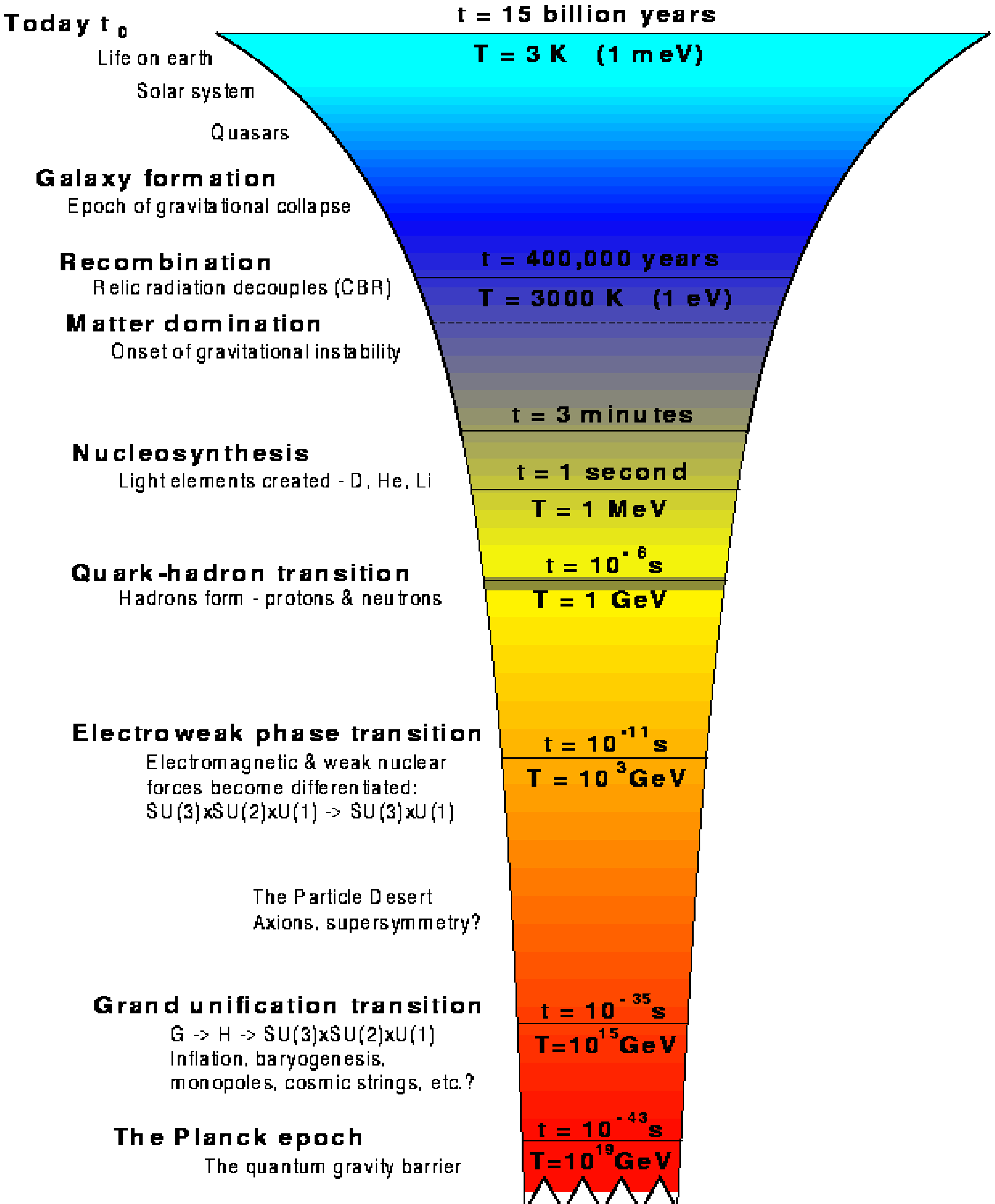
GEOMETRY & FATE



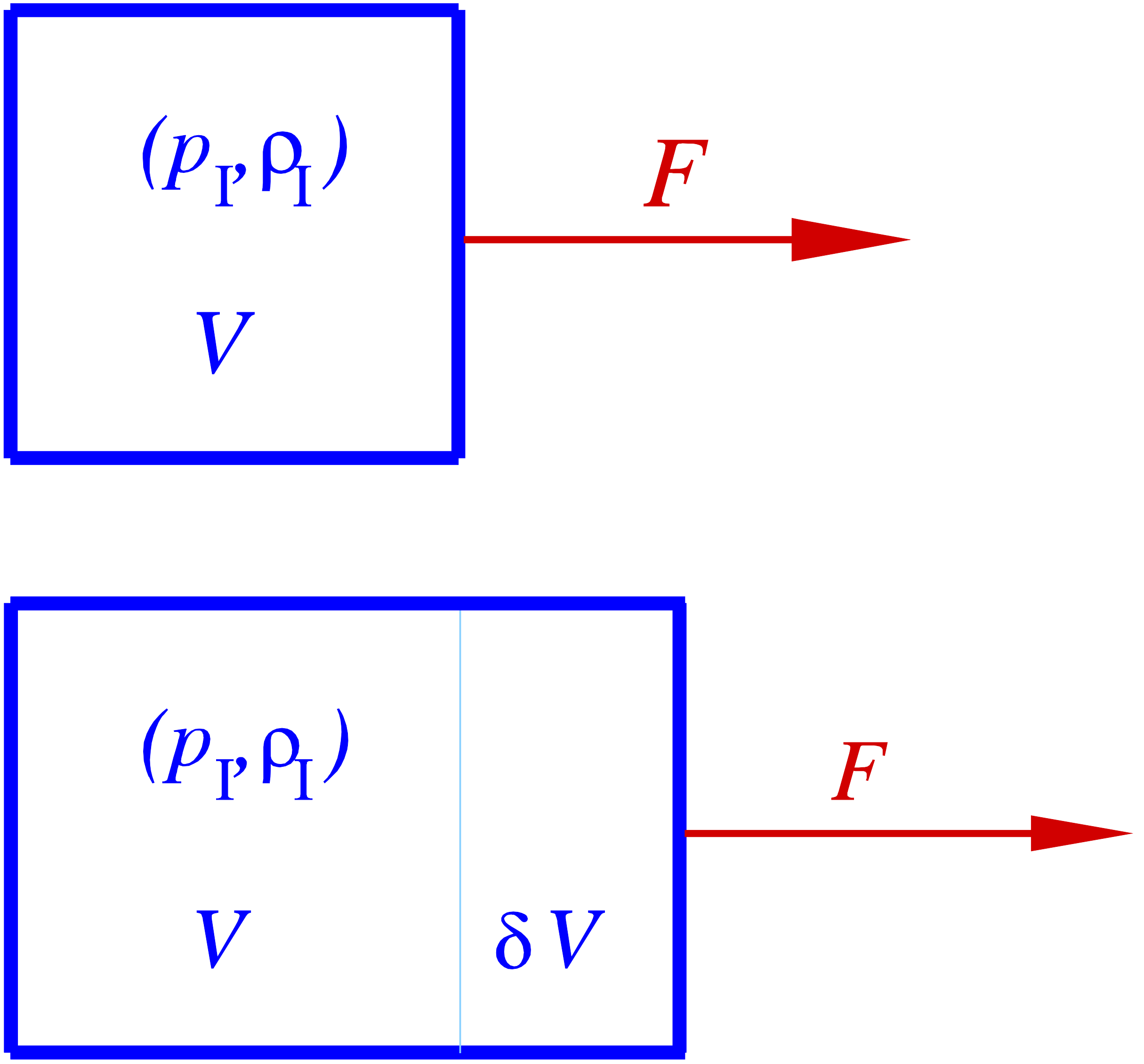
HISTORY OF UNIVERSE



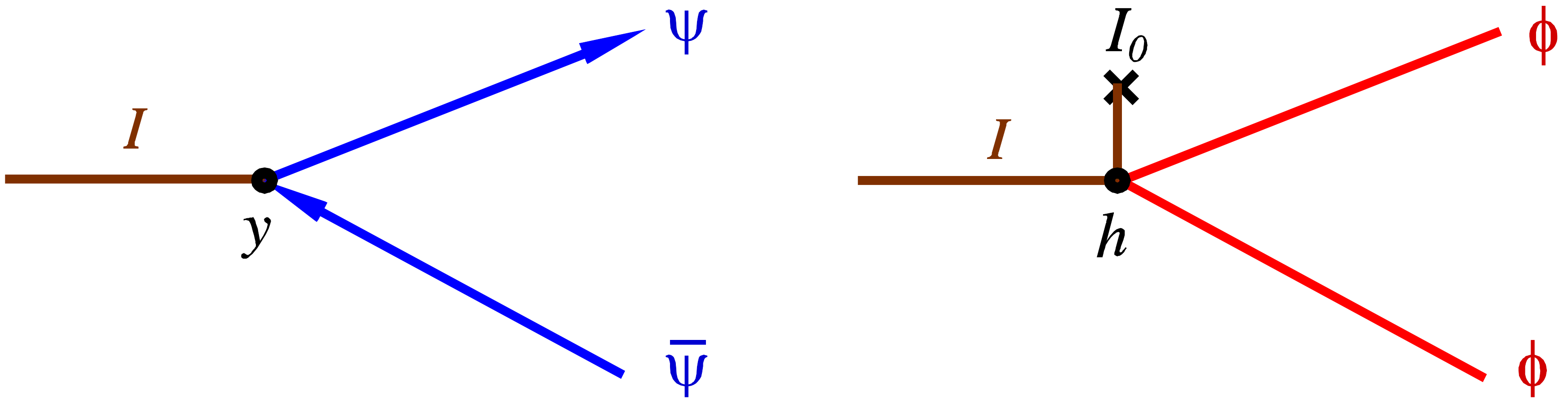
HISTORY OF UNIVERSE



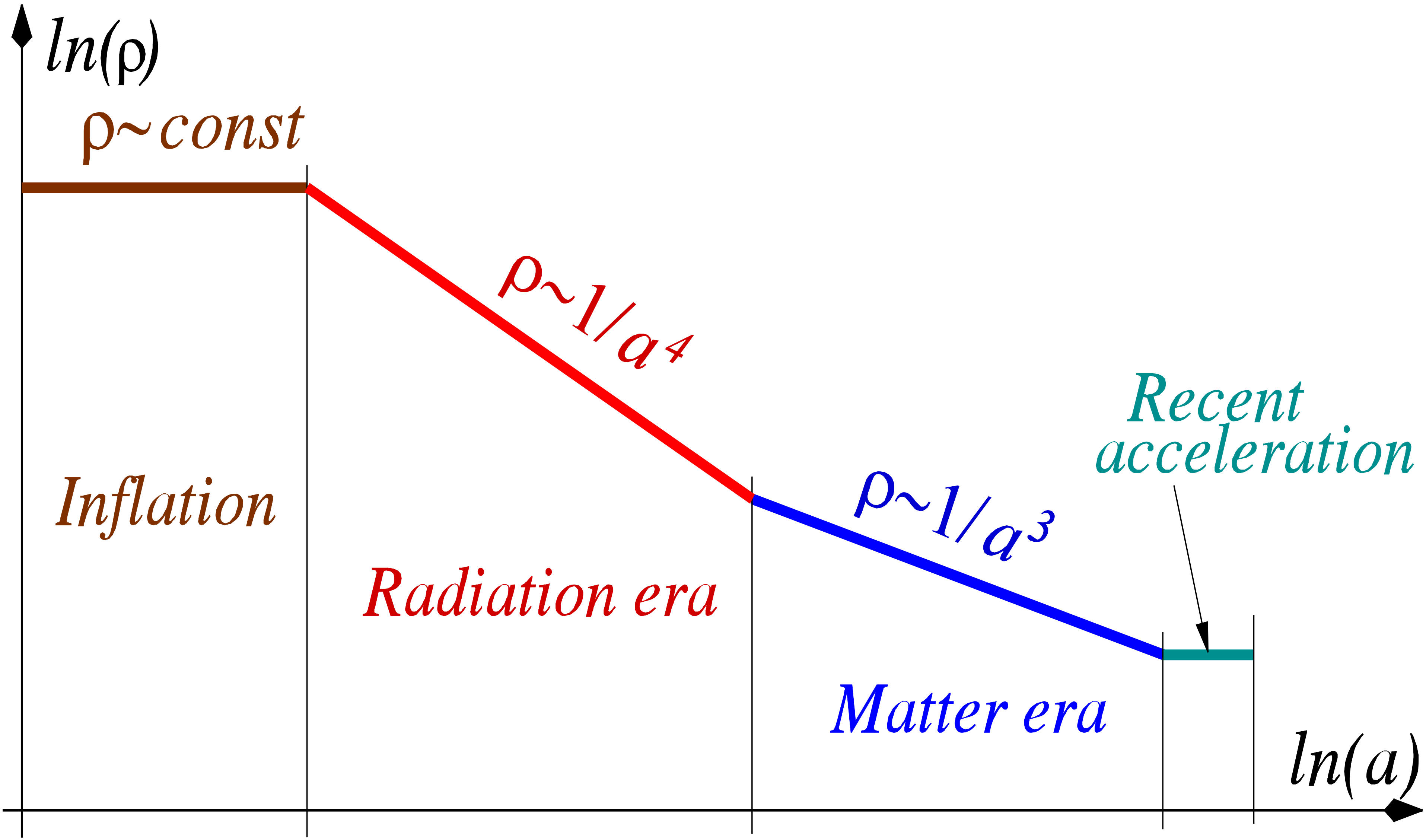
COSMIC INFLATION: PARADIGM



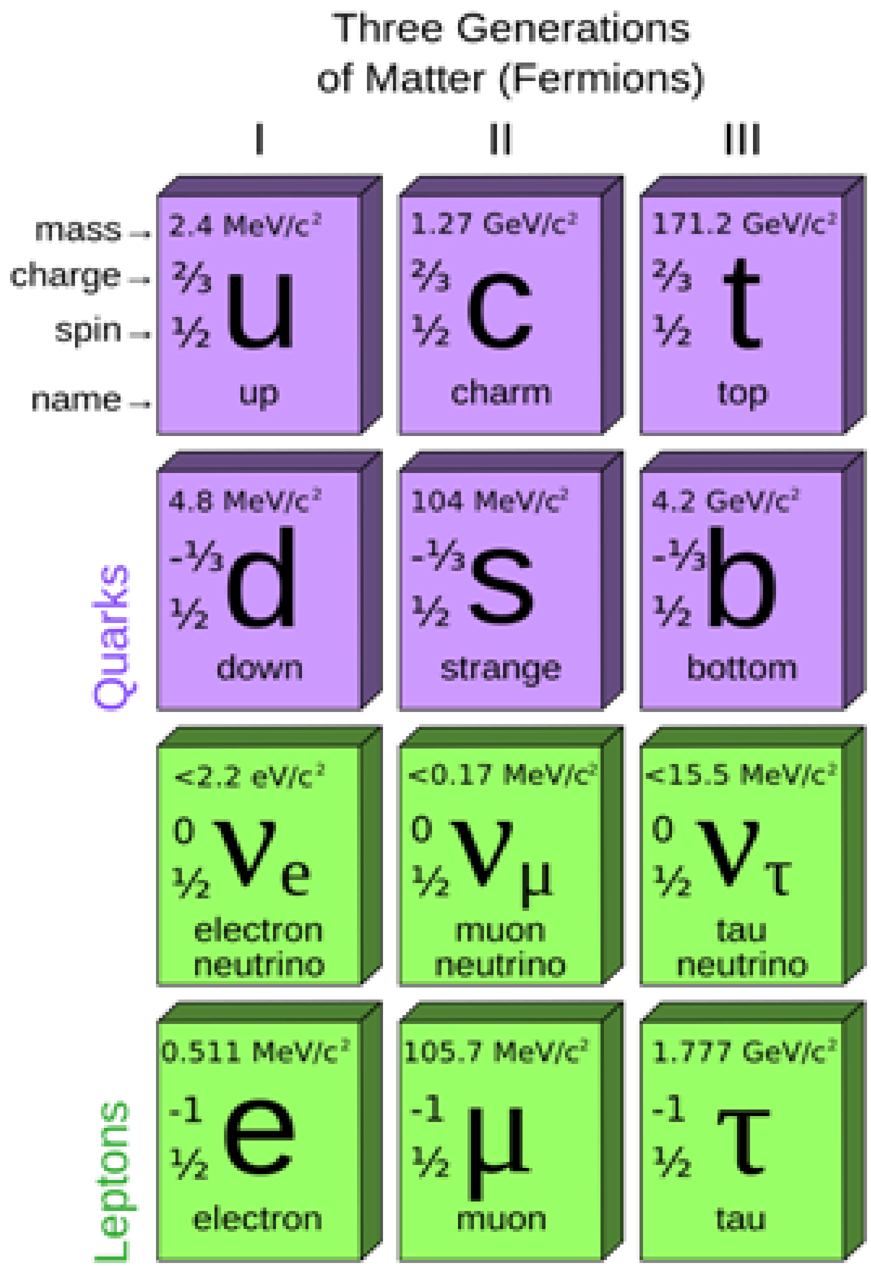
UNIVERSE REHEATING: PERTURBATIVE



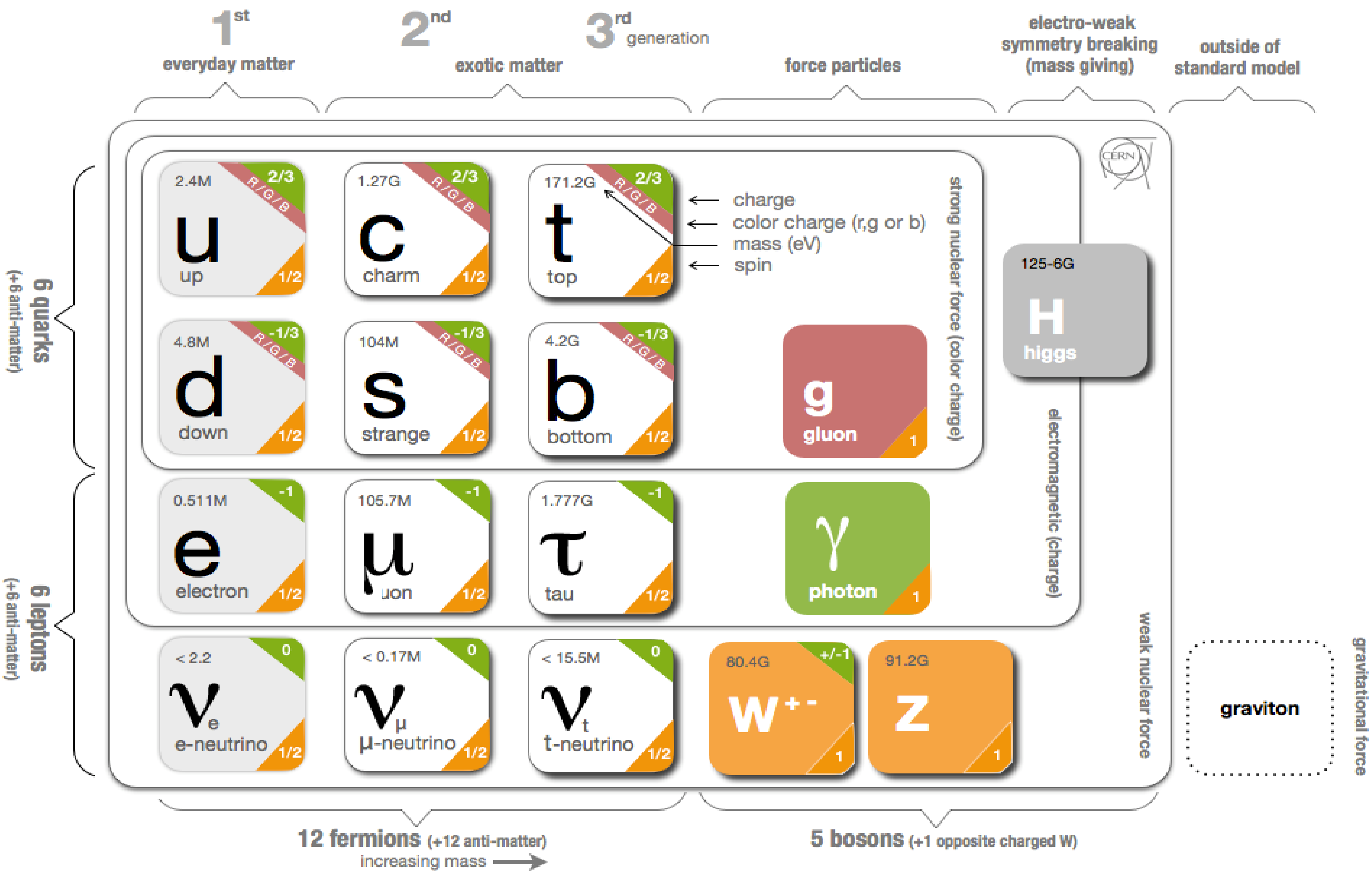
UNIVERSE EVOLUTION: ENERGY



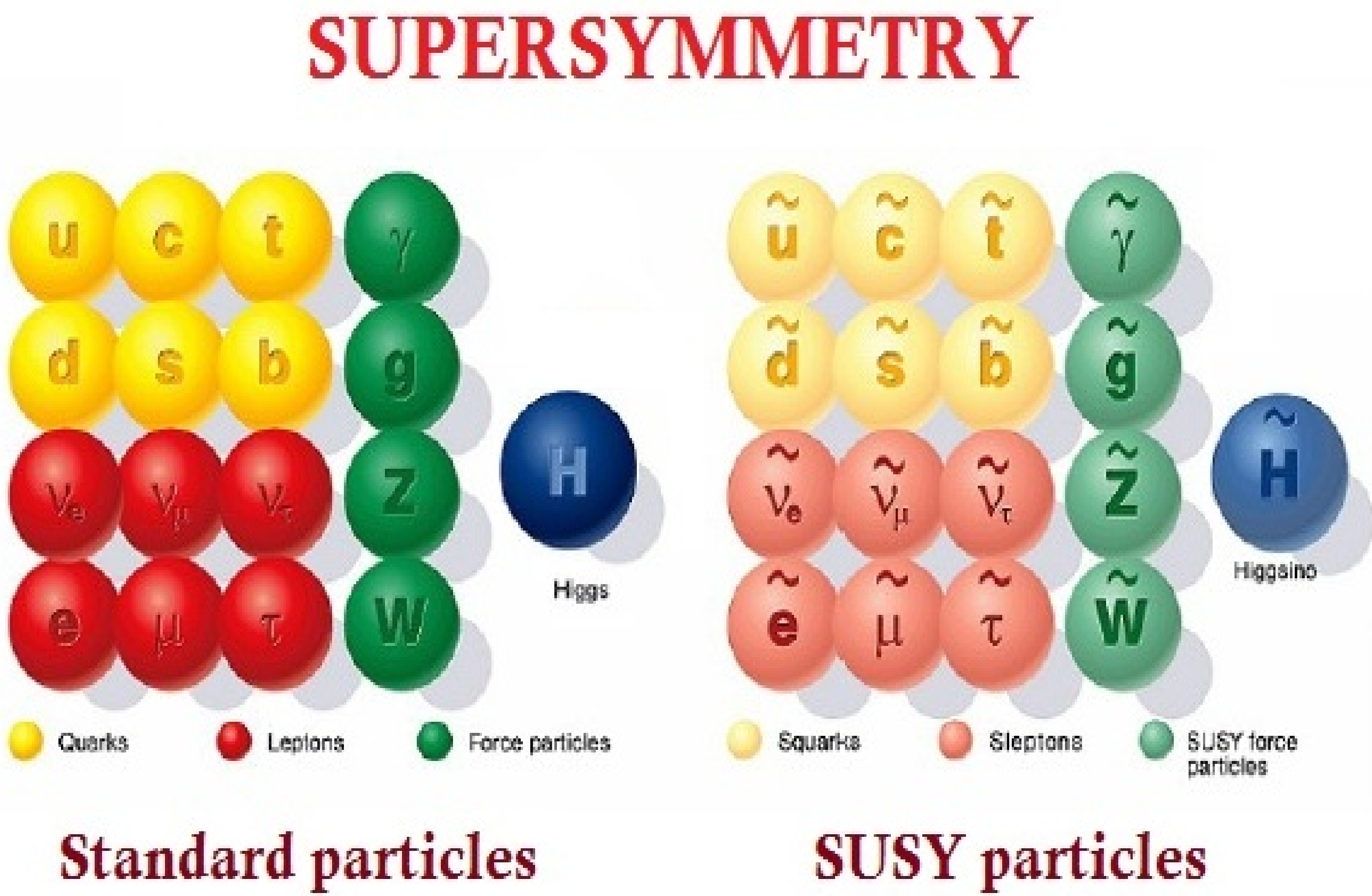
STANDARD MODEL: MATTER PARTICLES



STANDARD MODEL: PARTICLES

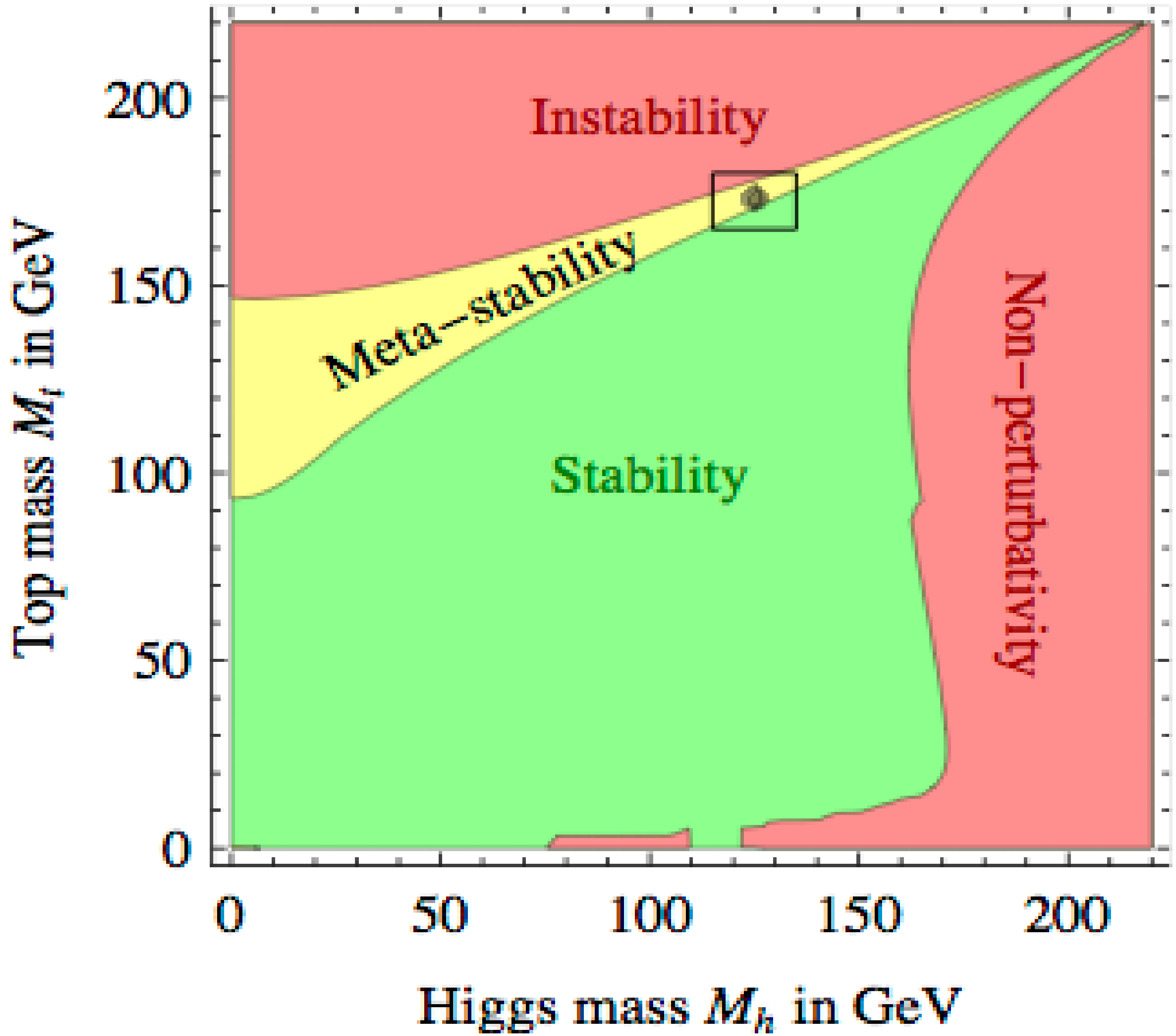


STANDARD MODEL EXTENSIONS: SUSY



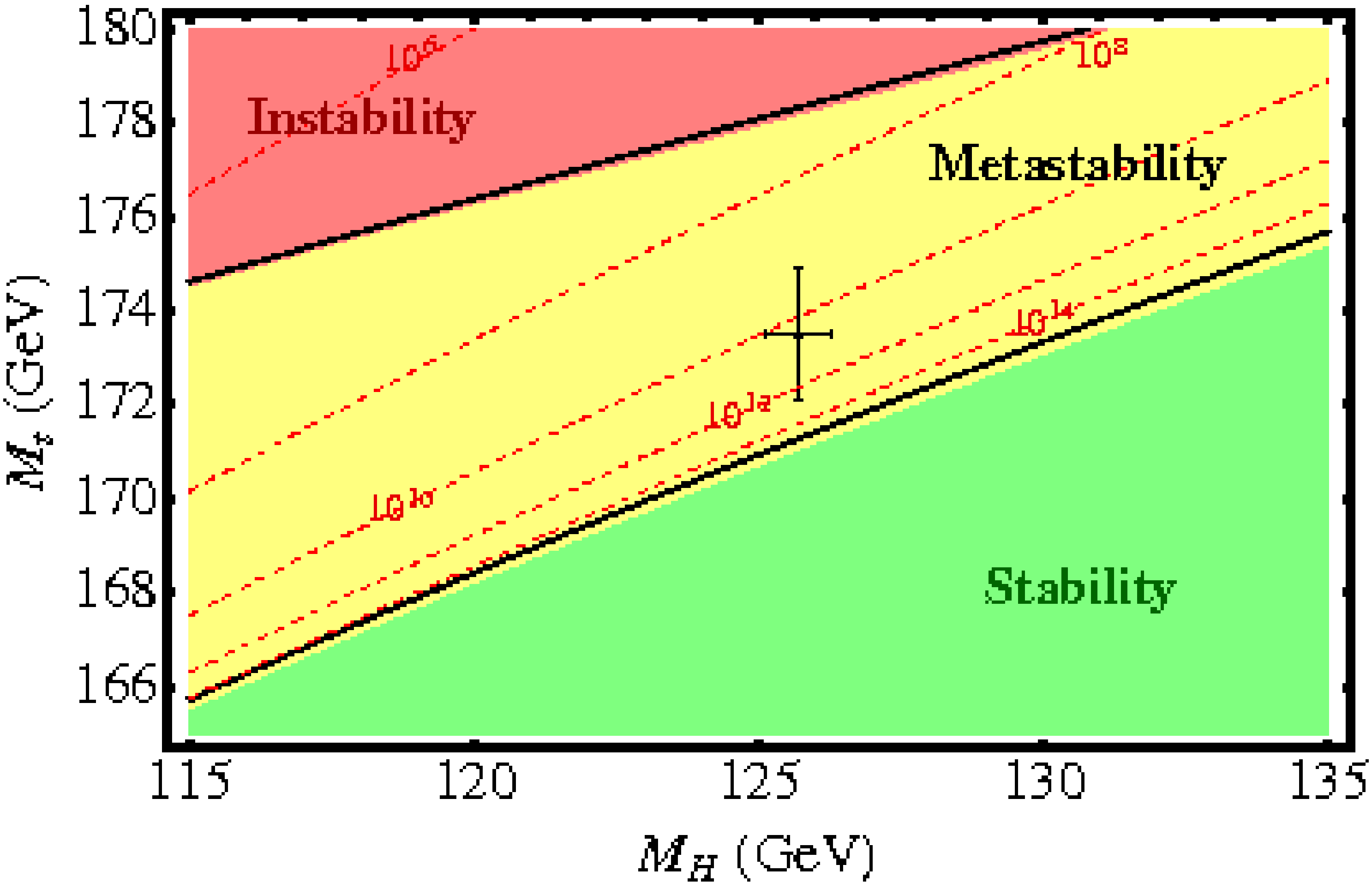
STANDARD MODEL: (META)STABILITY

2012



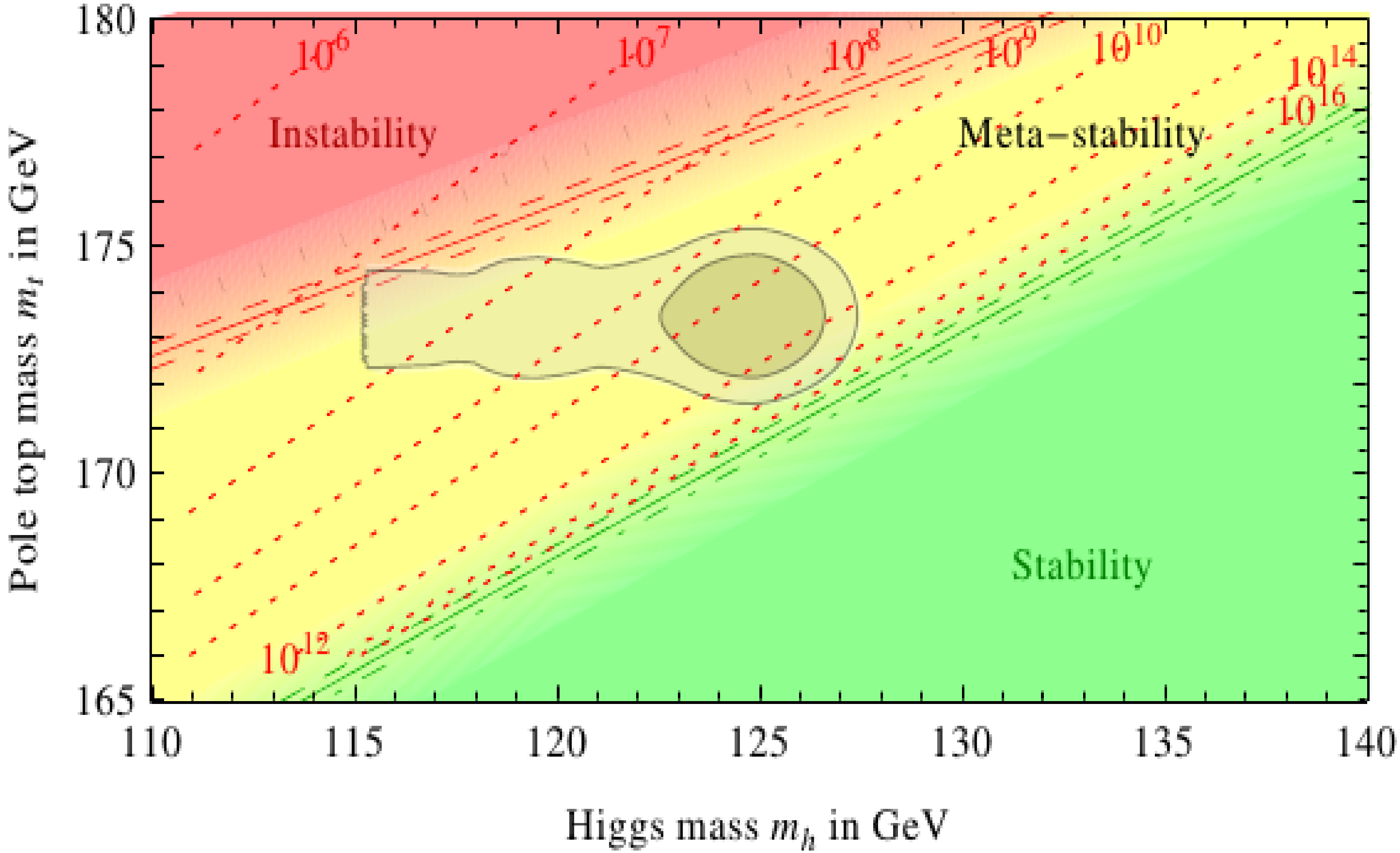
STANDARD MODEL: (META)STABILITY

2013



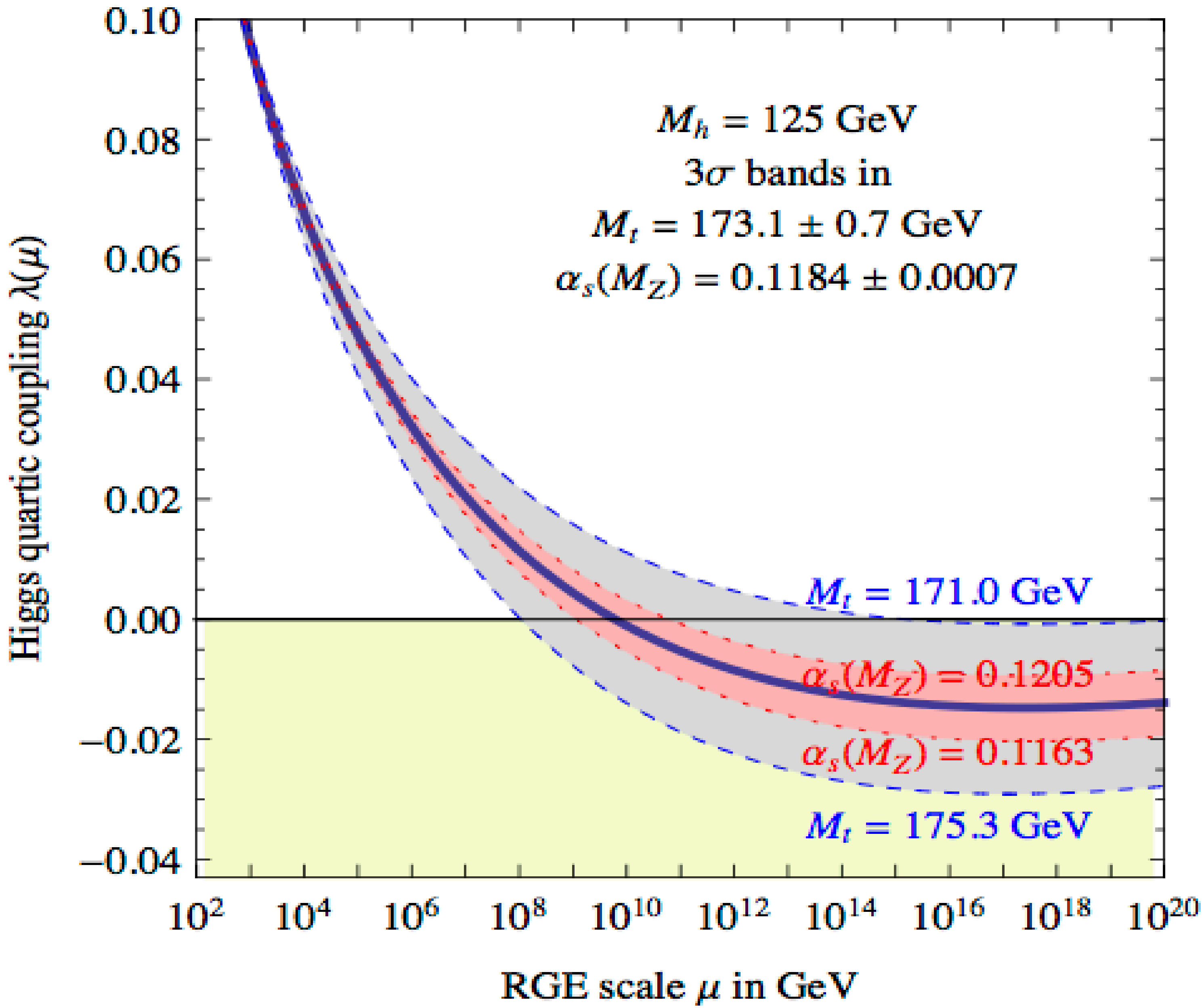
STANDARD MODEL: (META)STABILITY

2013



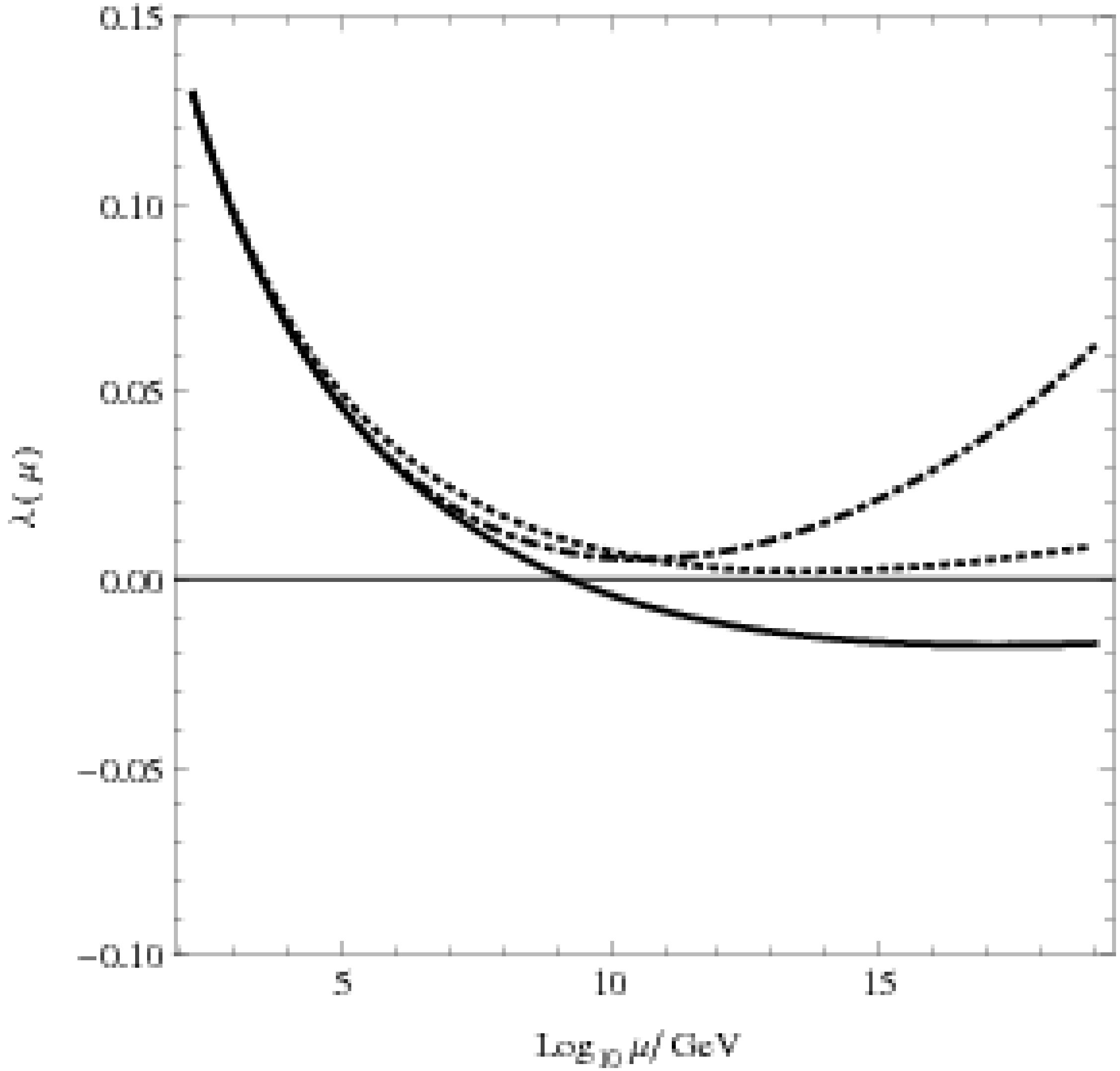
STANDARD MODEL: (META)STABILITY

2013



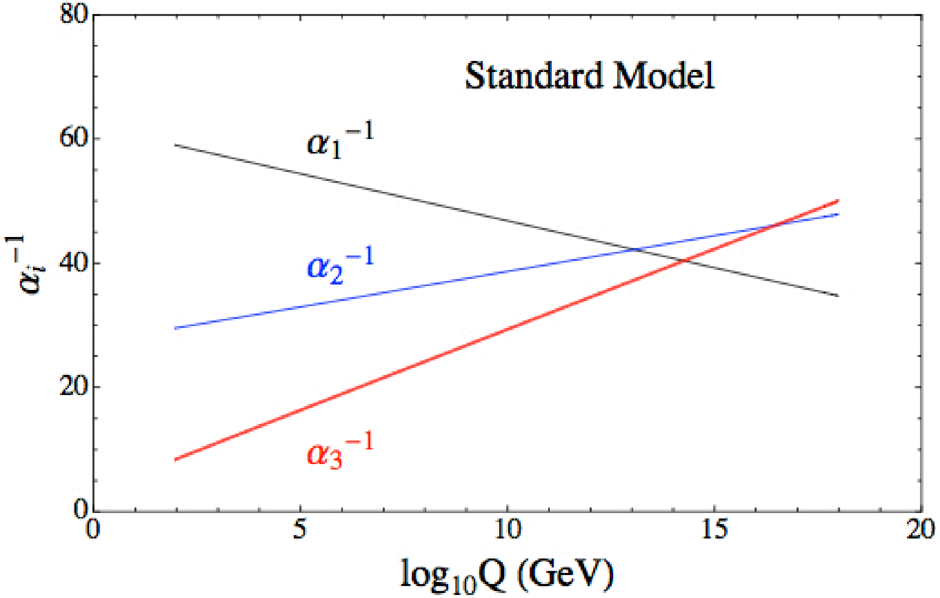
STANDARD MODEL: STABILIZING

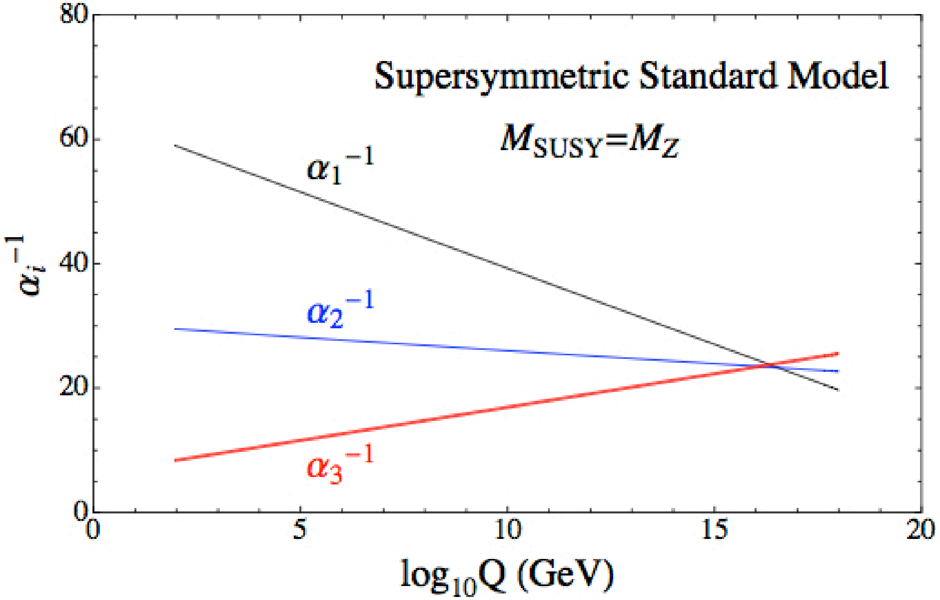
solid: SM;
dashed:
with singlet



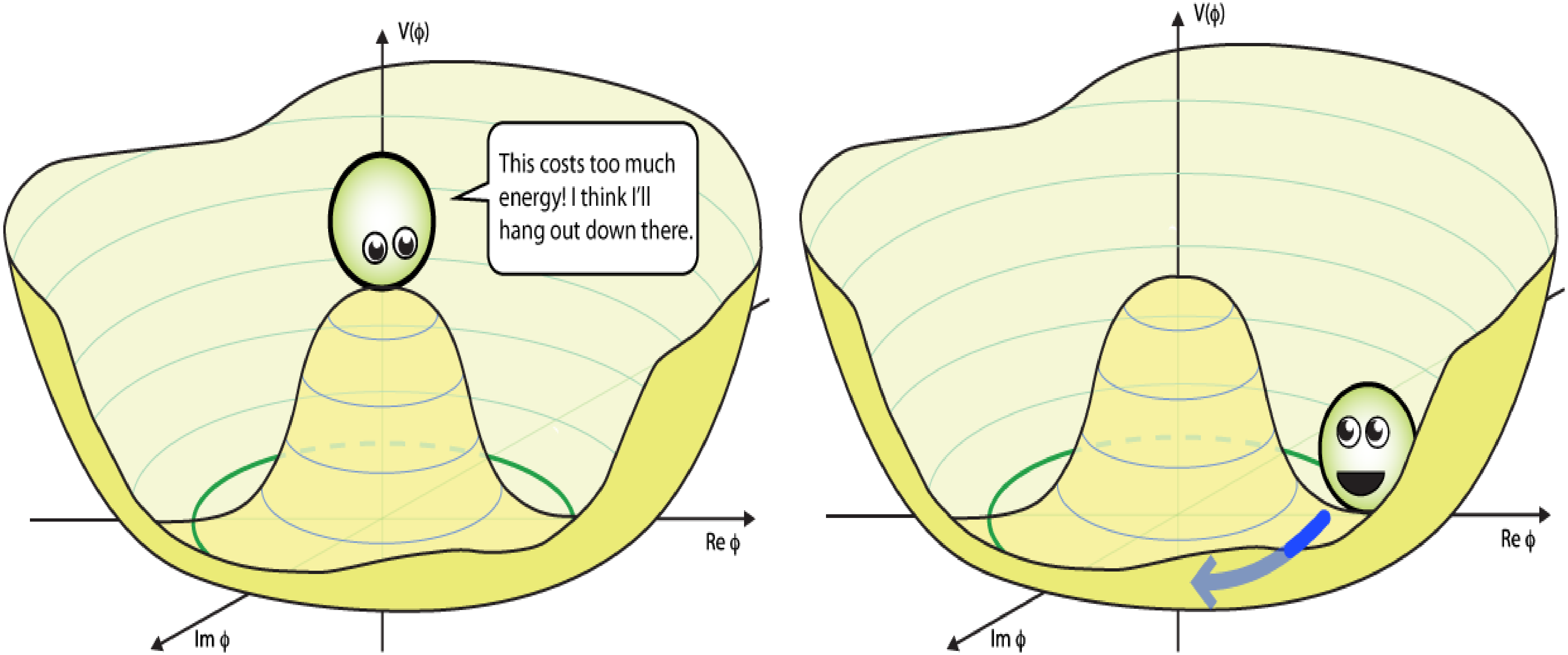
GRAND UNIFICATION: WITH(OUT) SUSY

$\alpha 1$=EM $U(1)_{EM}$
$\alpha 2$=weak $SU(2)_W$
$\alpha 3$=strong $SU(3)_C$





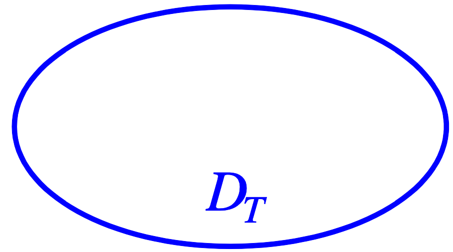
ELECTROWEAK TRANSITION: HIGGS POTENTIAL



- (PSEUDO) GOLDSTONE MODE

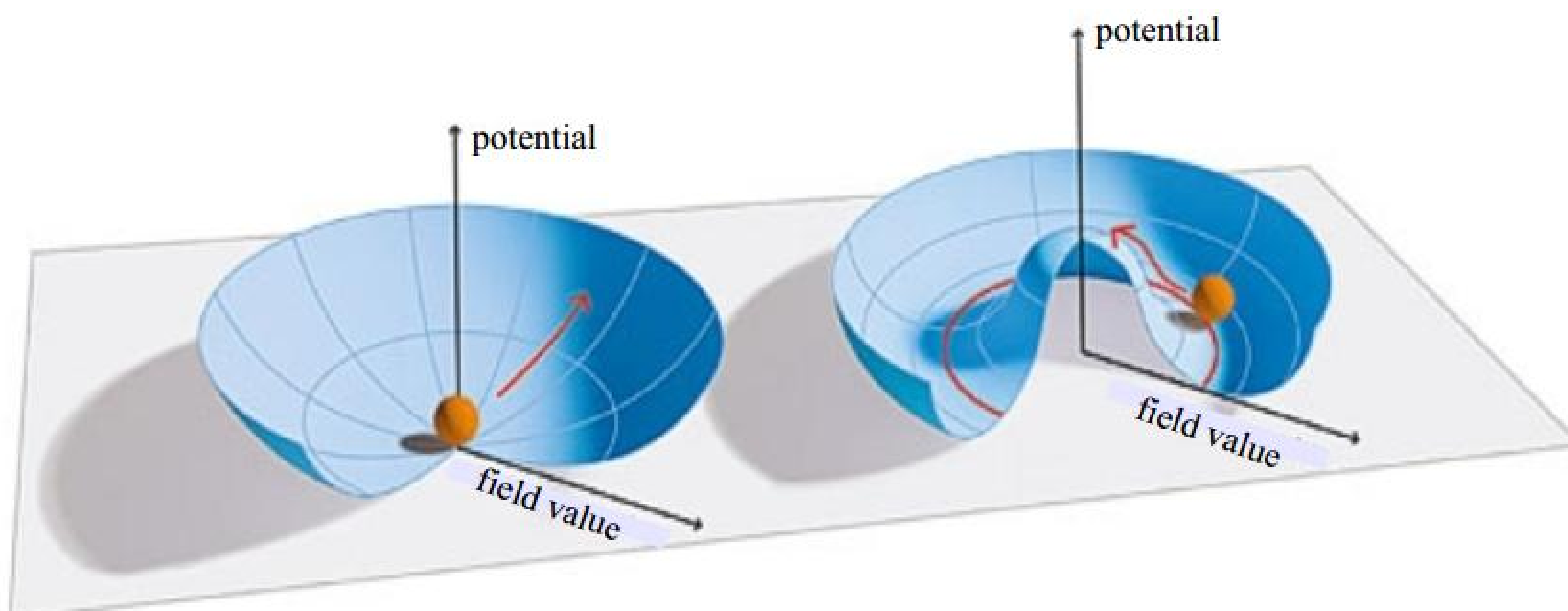
ELECTROWEAK TRANSITION: 1 LOOP

- CONTRIBUTION TO THE EFFECTIVE ACTION OF THERMAL 1 LOOP BUBBLE DIAGRAM



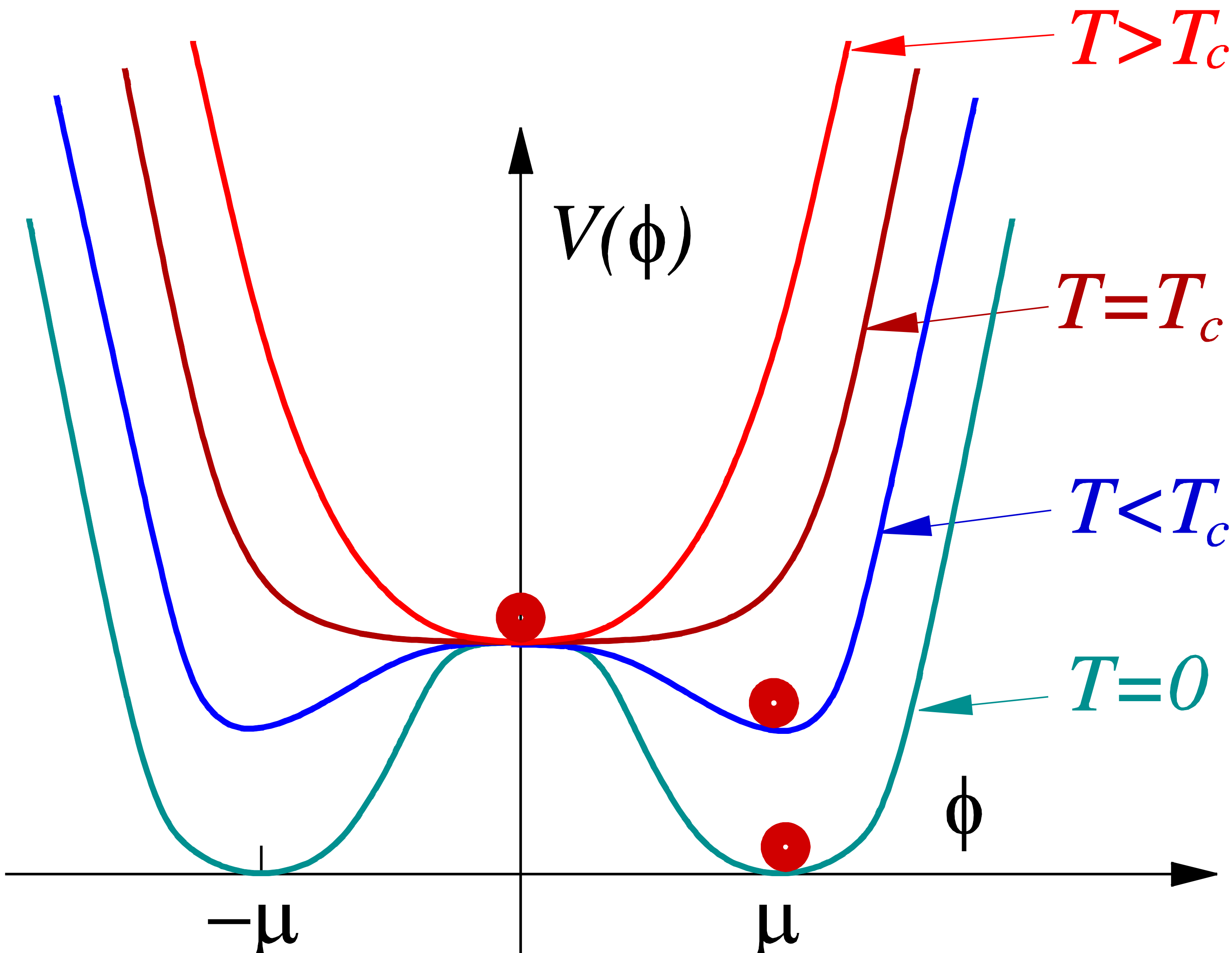
- AT HIGH TEMPERATURES RESTORES THE SYMMETRY

→ HIGH T → LOW T



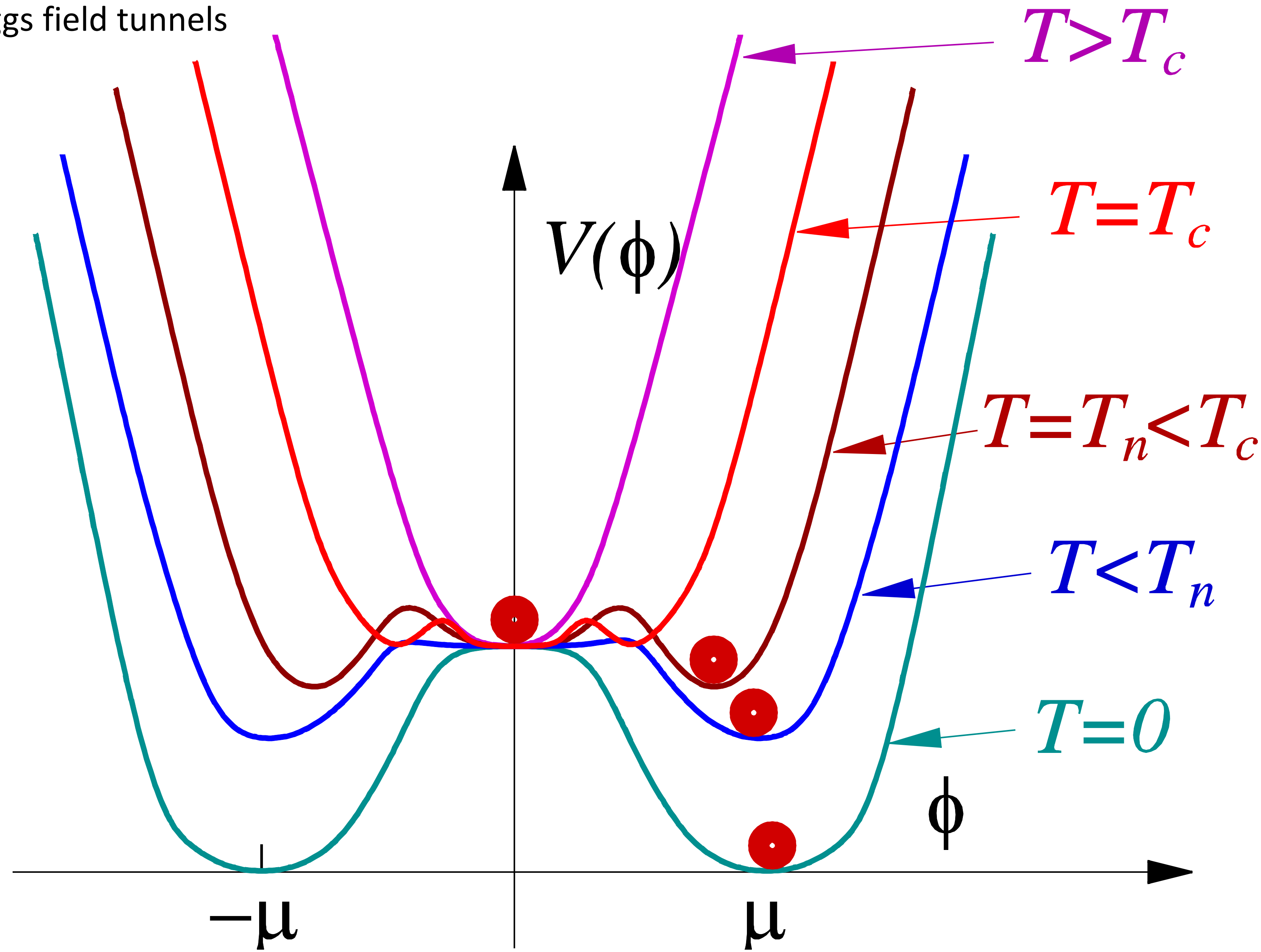
ELECTROWEAK TRANSITION: 2ndORDER

- Higgs field `rolls'



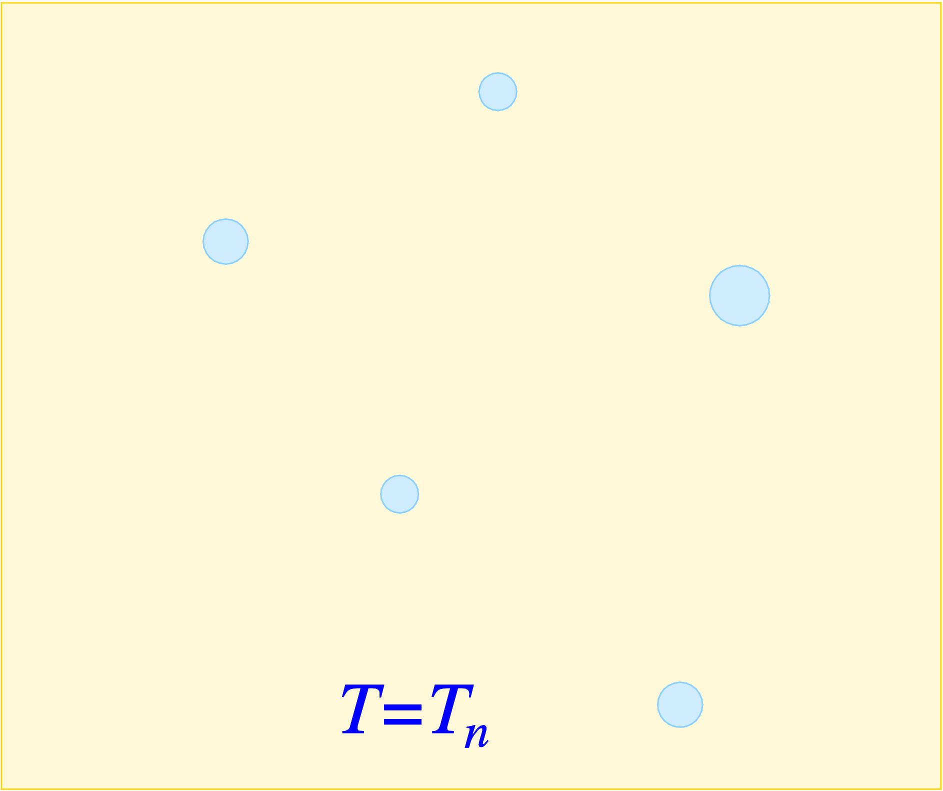
ELECTROWEAK TRANSITION: 1st ORDER

- Higgs field tunnels

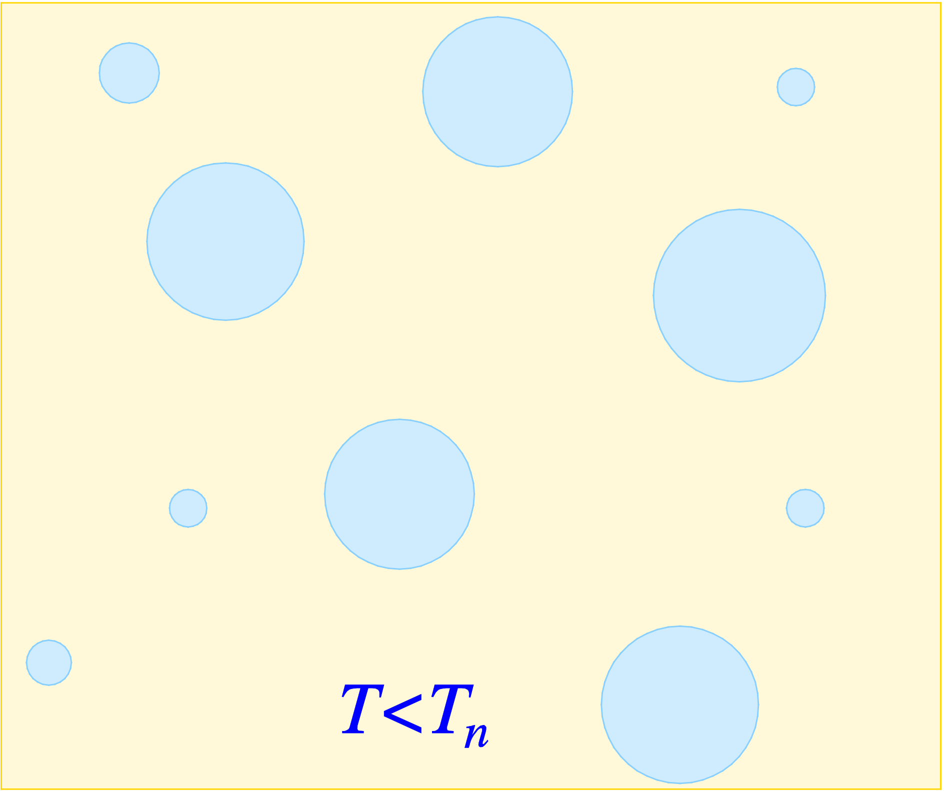


EW TRANSITION: NUCLEATION

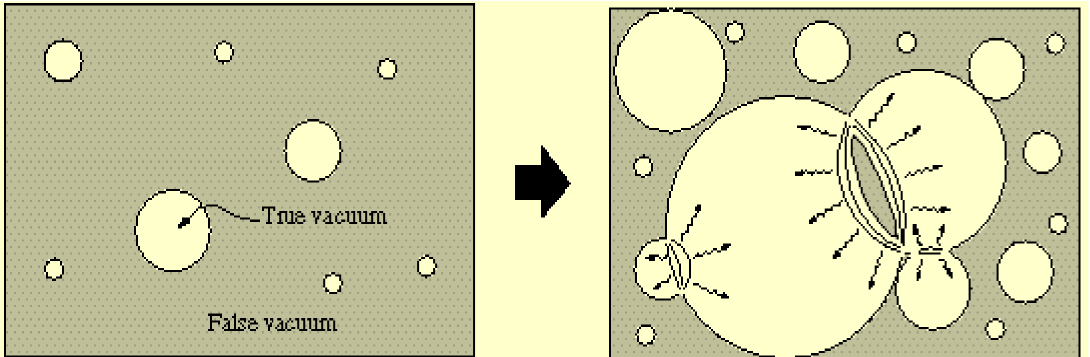
- EARLIER (HIGHER T)



- LATER (LOWER T)

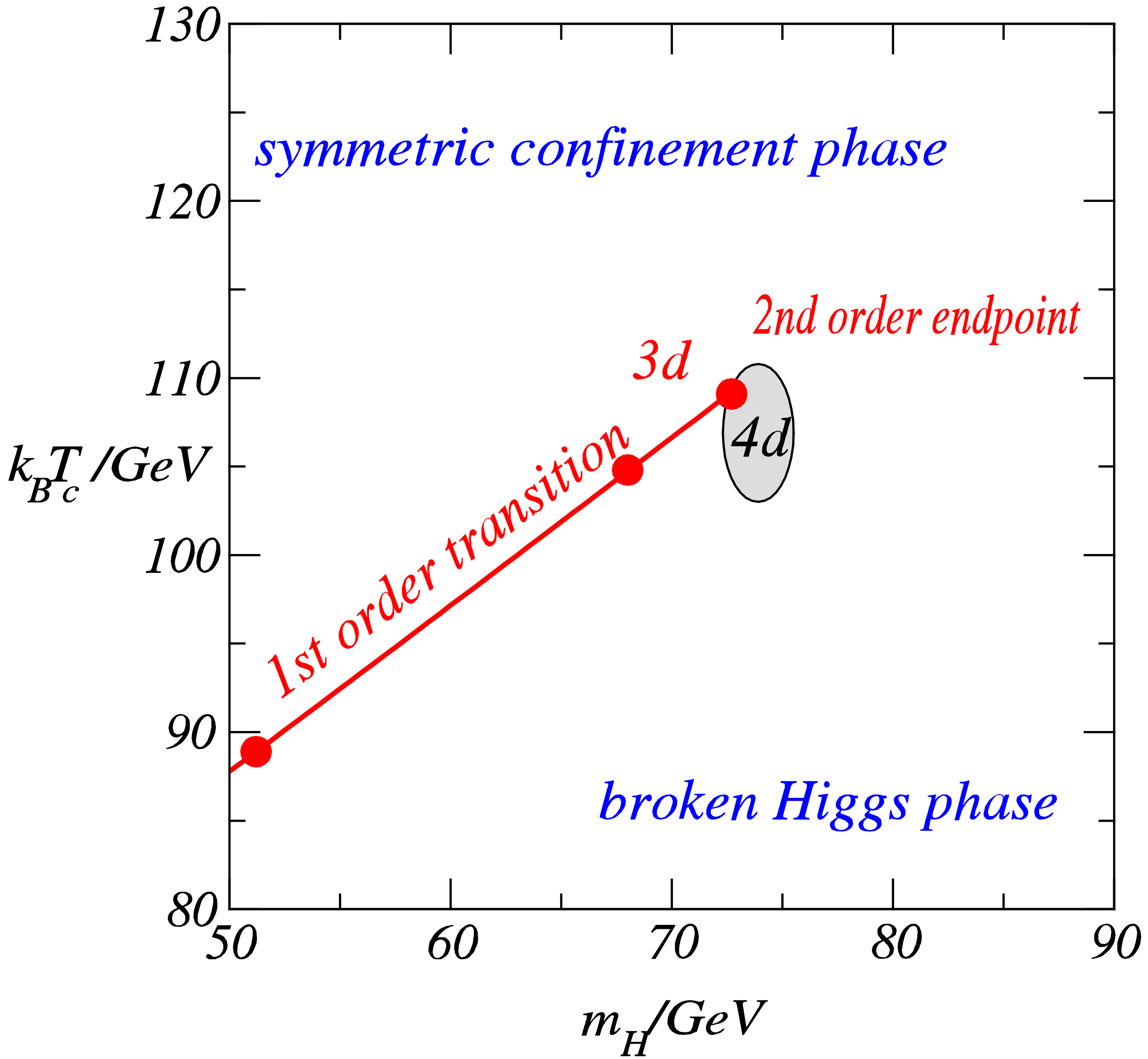


- EVENTUALLY… ☹



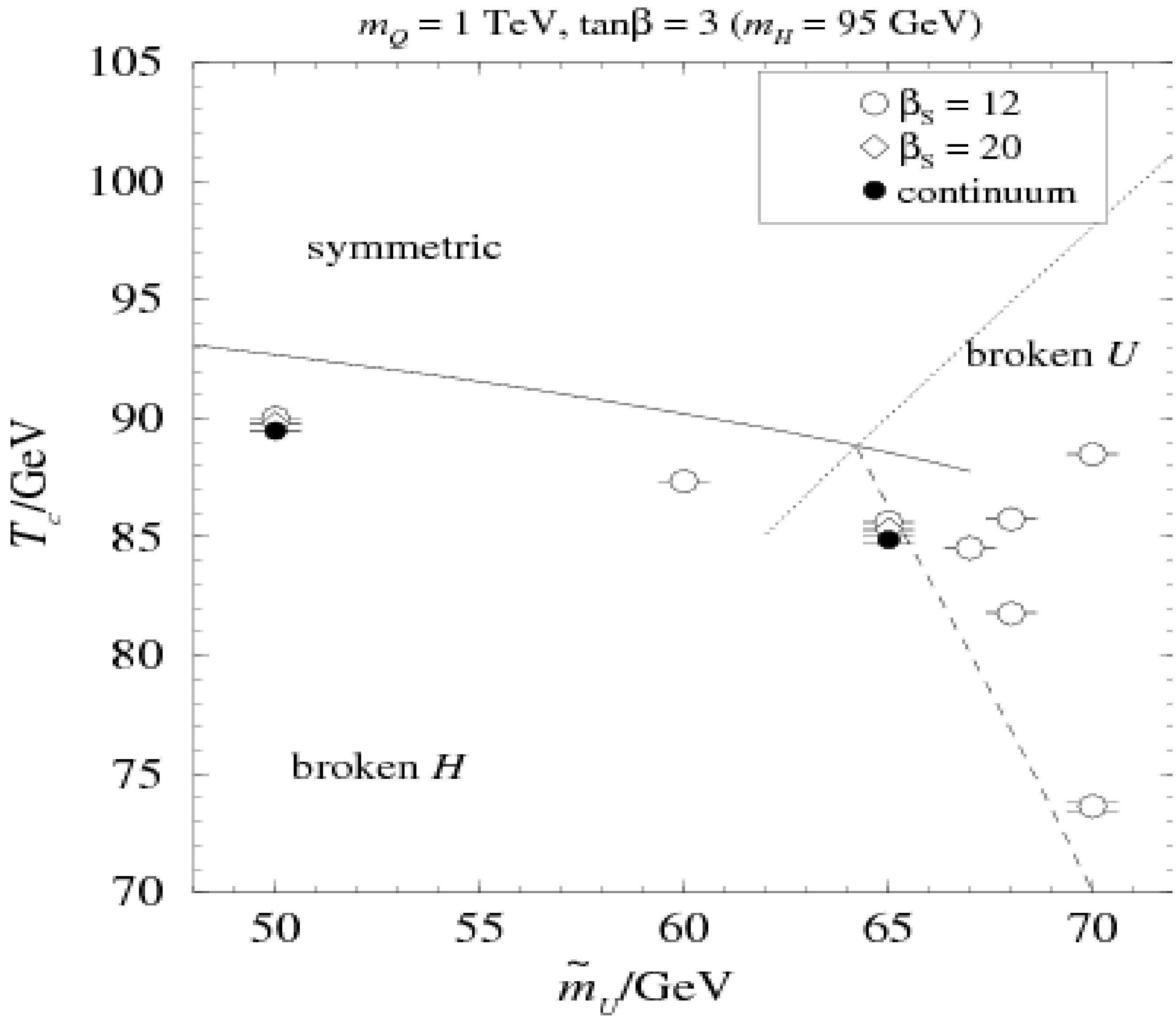
GRAVITATIONAL WAVES?

EW TRANSITION: STANDARD MODEL



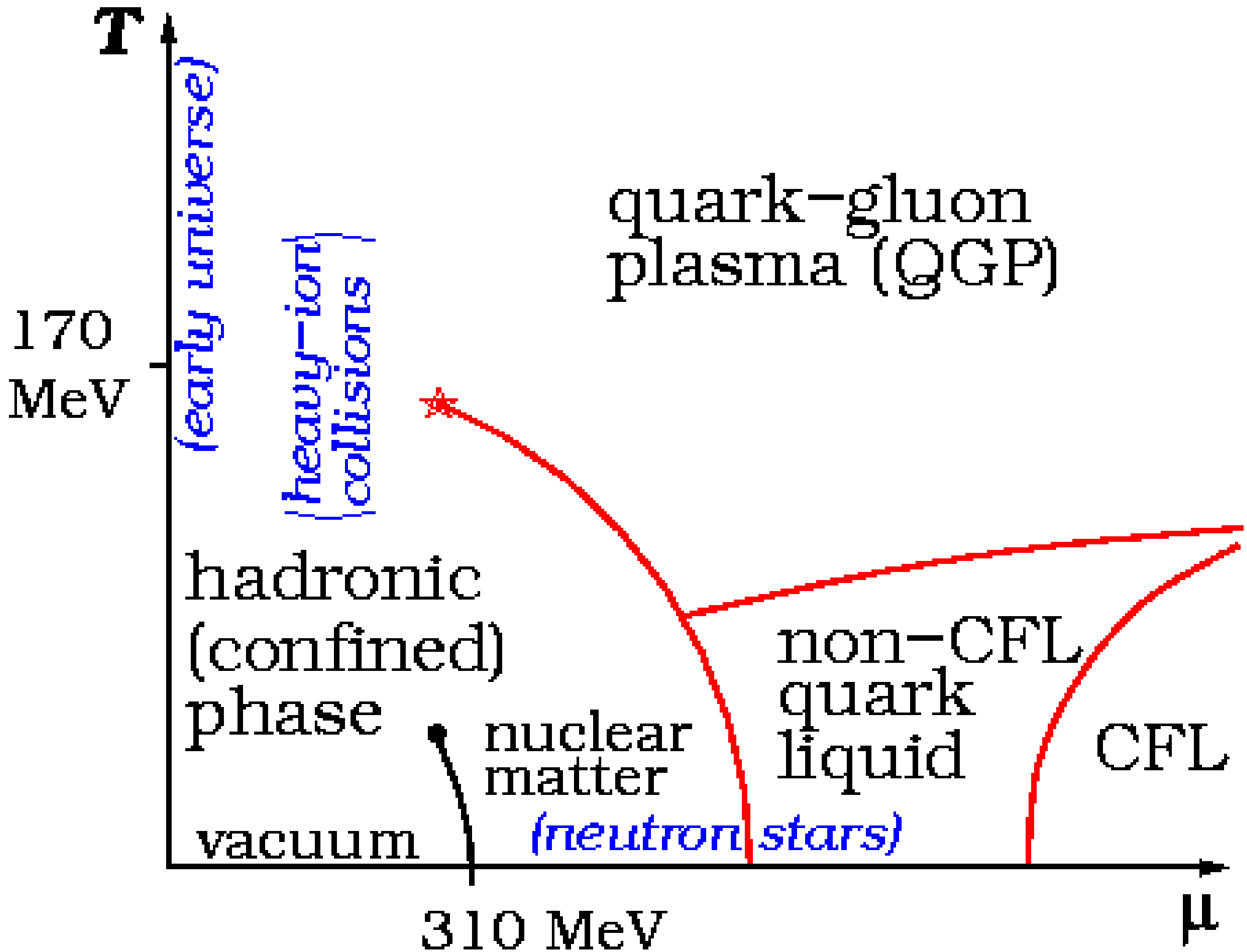
EW TRANSITION: SUSY (MSSM)

- PHASE TRANSITION CAN BE MUCH STRONGER (1st ORDER)



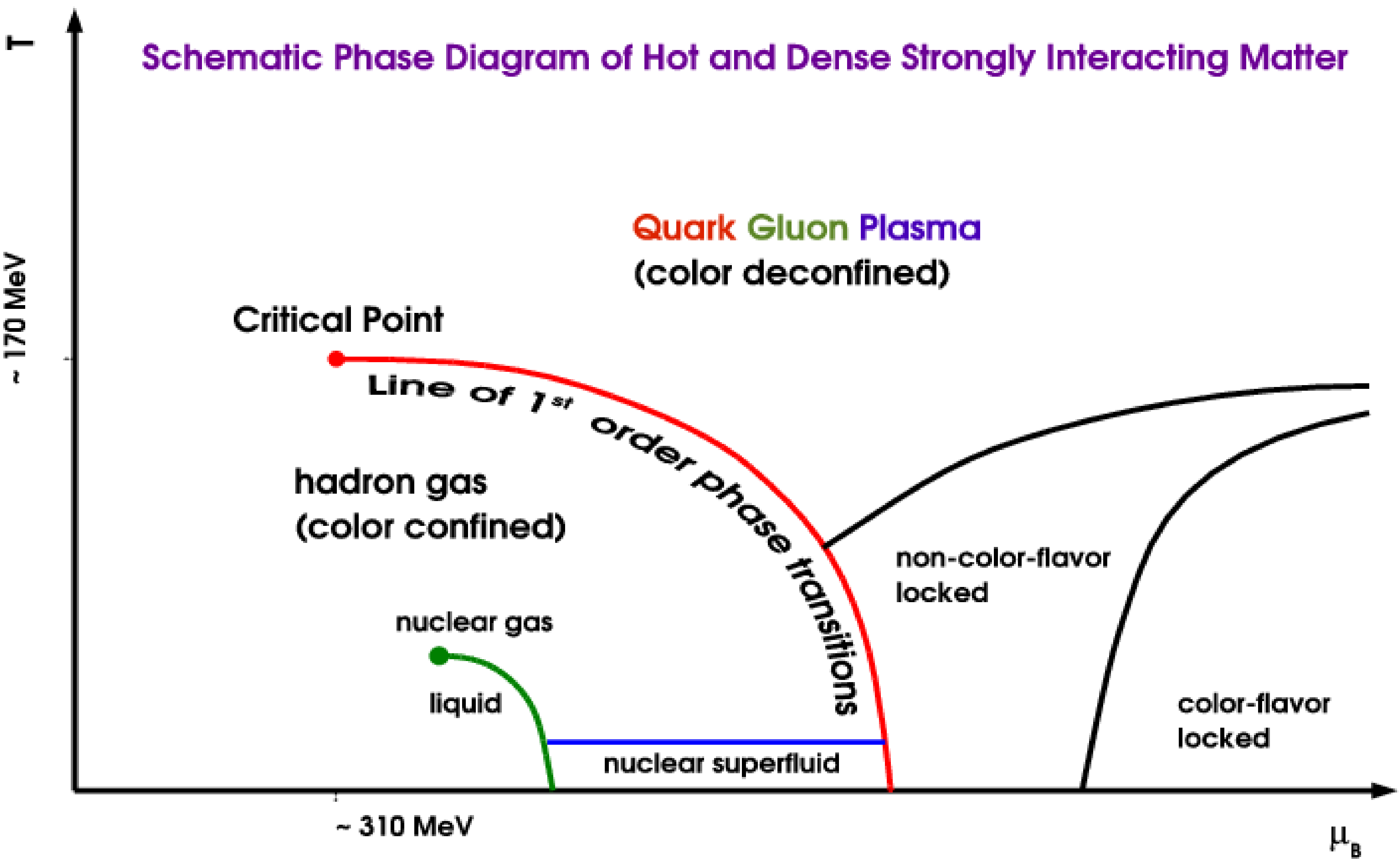
QCD TRANSITION: PHASE DIAGRAM

- HADRONIC PHASE: chiral condensate; CFL: quark condensate



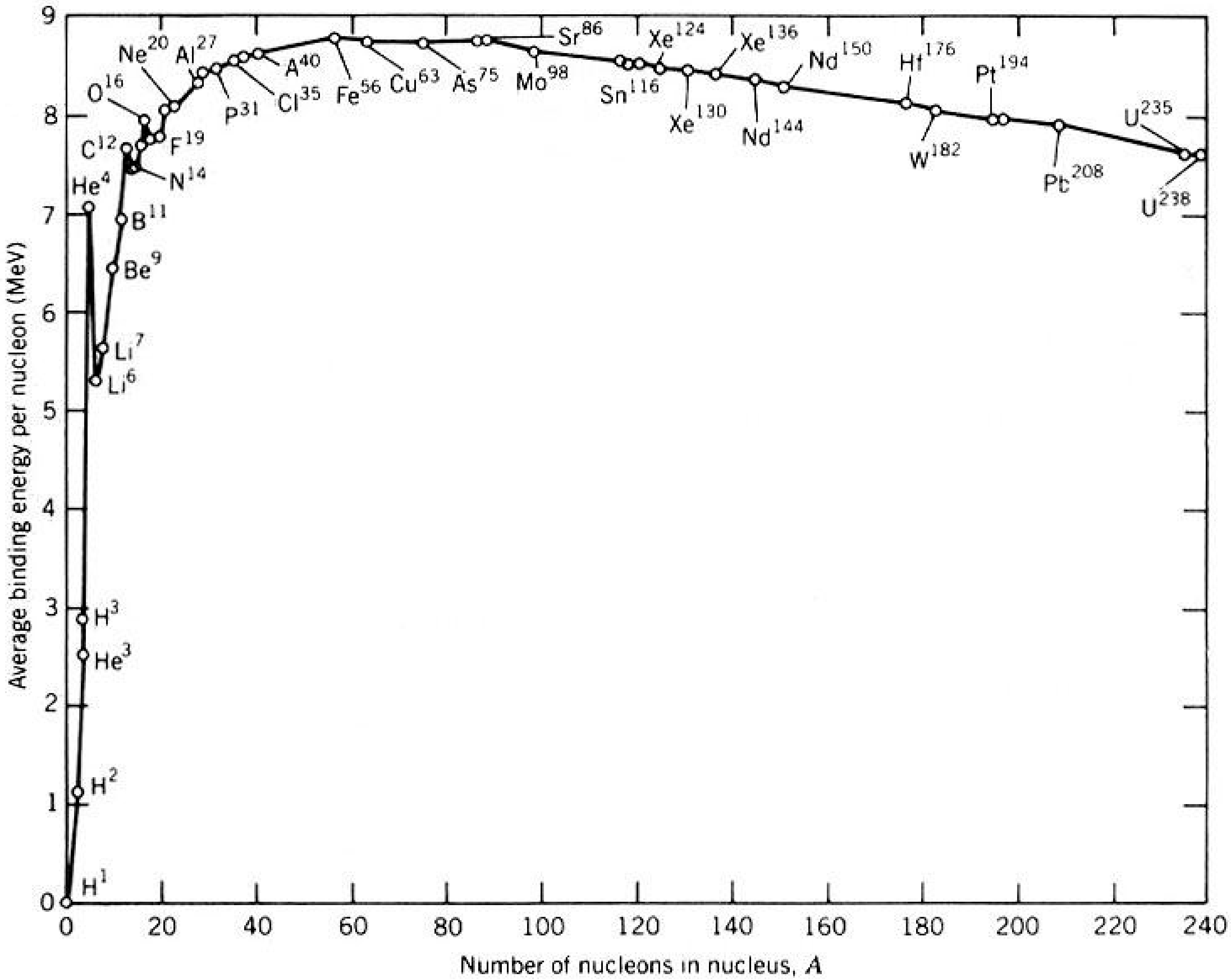
QCD TRANSITION: PHASE DIAGRAM

- HADRONIC PHASE: chiral condensate; CFL: quark condensate



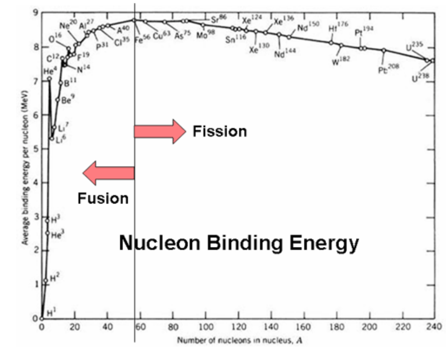
BBN: BINDING ENERGIES

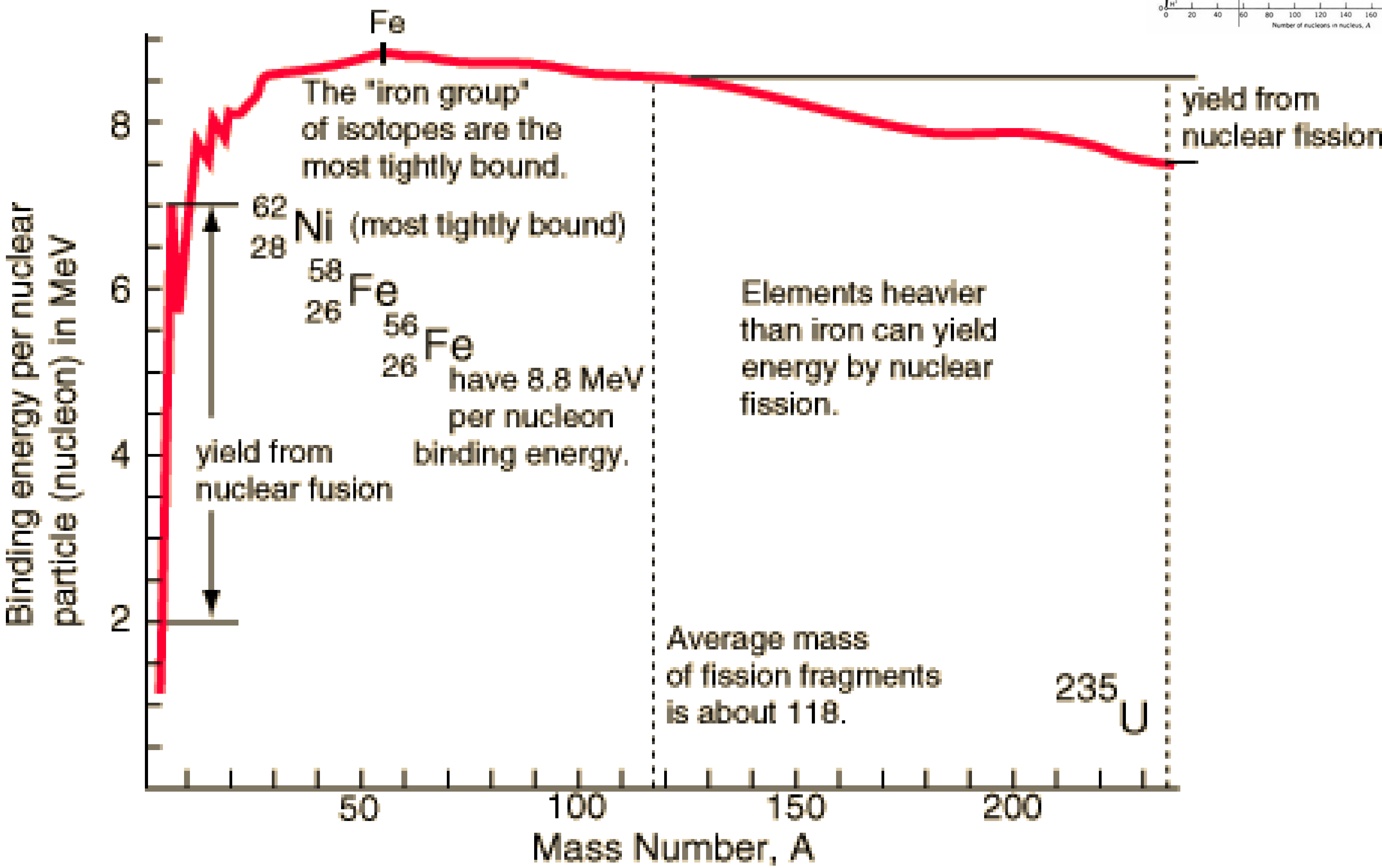
- Fe: most stable nucleus; He: very stable (4He-> 12C jump).



BBN: BINDING ENERGIES

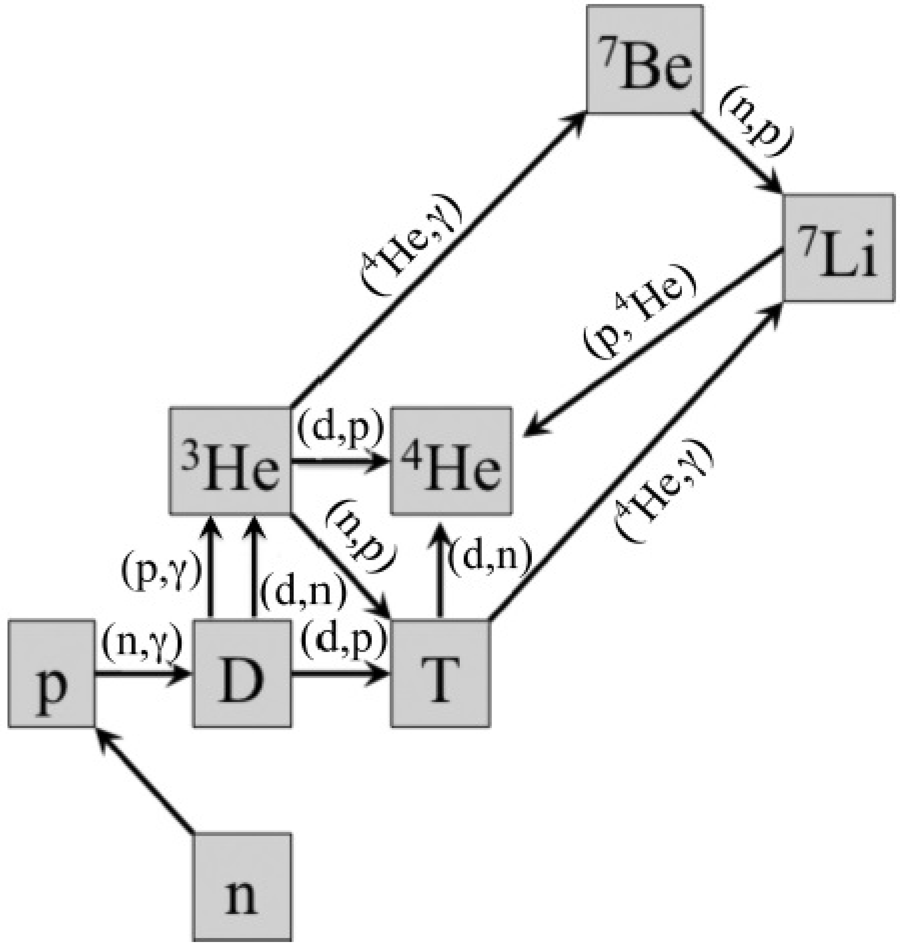
- Fission and Fusion





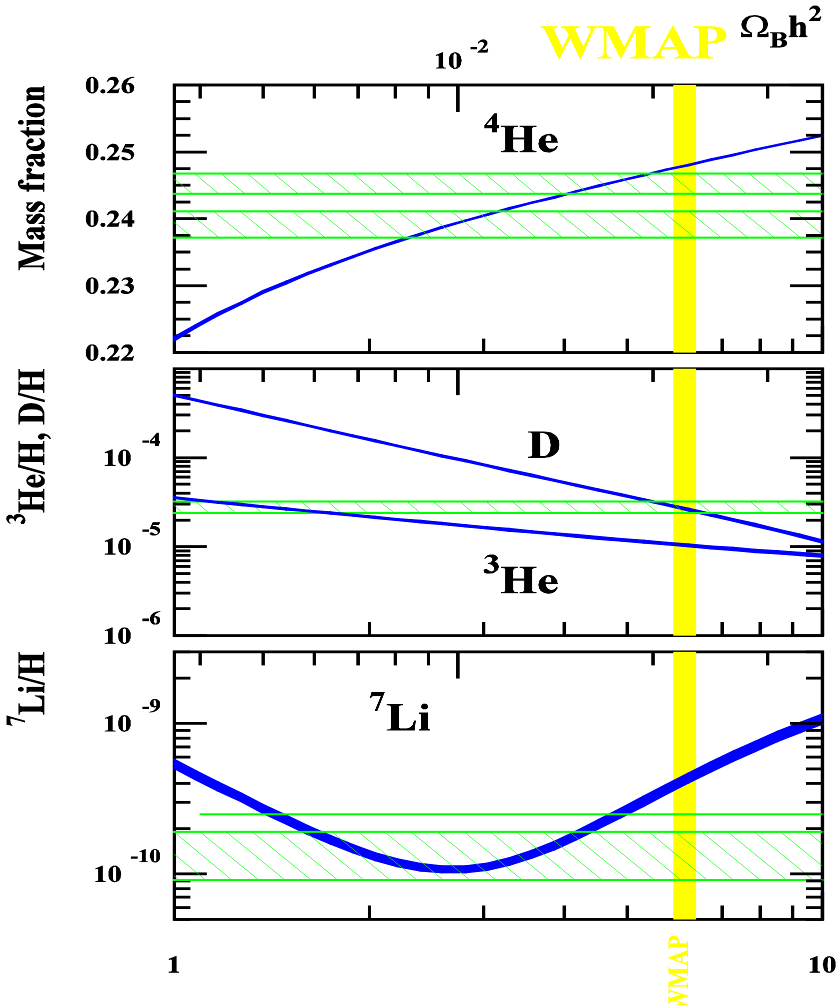
BBN: MAIN INTERACTIONS

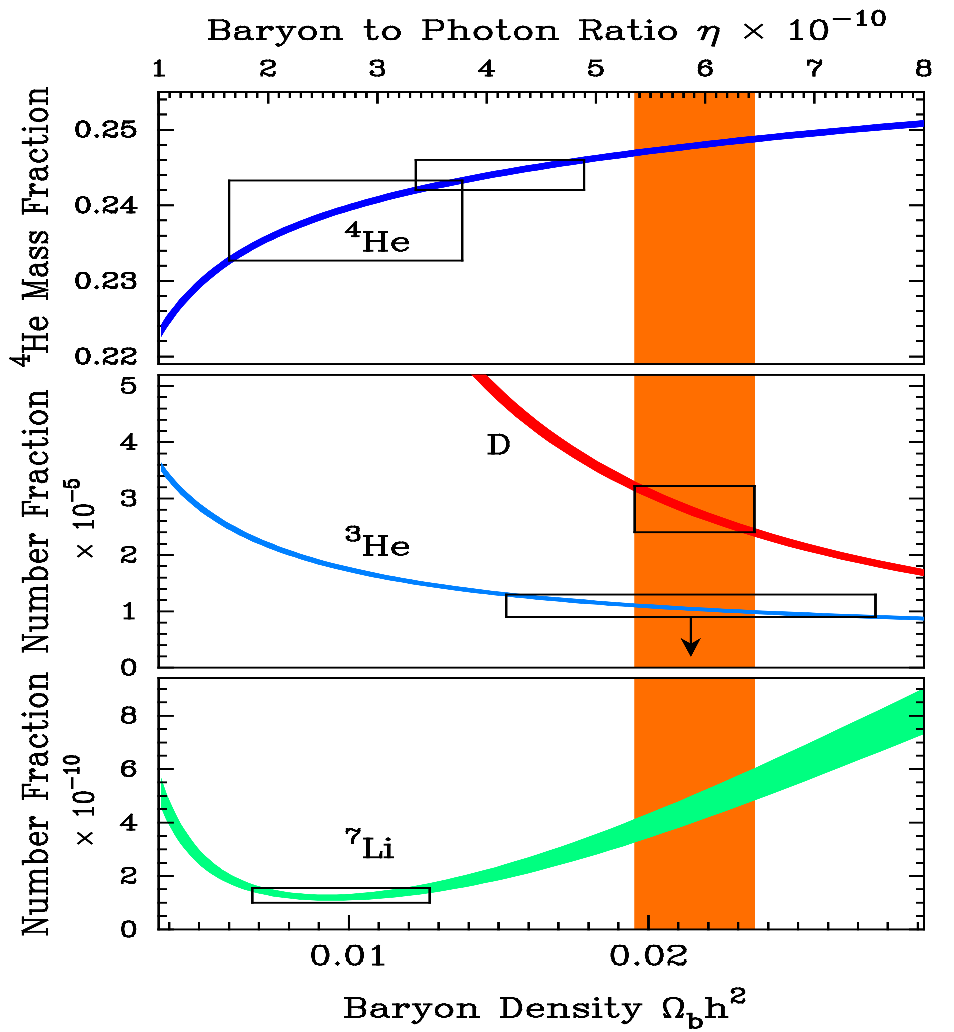
- Fission and Fusion



BBN: ABUNDANCES

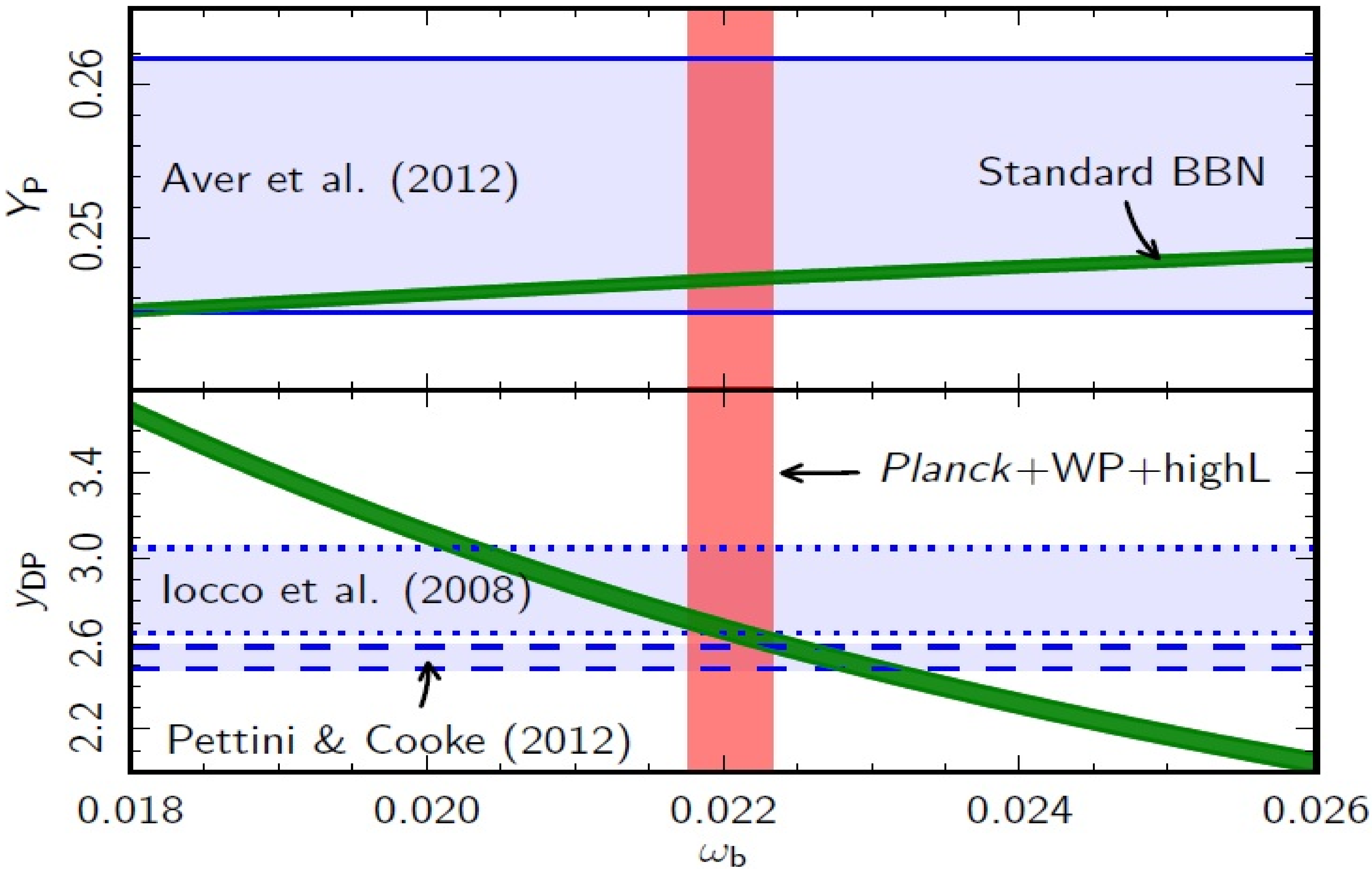
- D: standard; 3He ok; 4He some tension; 6Li & 7Li: tension





BBN: ABUNDANCES

- Planck (2013) constraints



BBN: ABUNDANCES

- 7Li problem