Astronomy reaching out to Particle Physics

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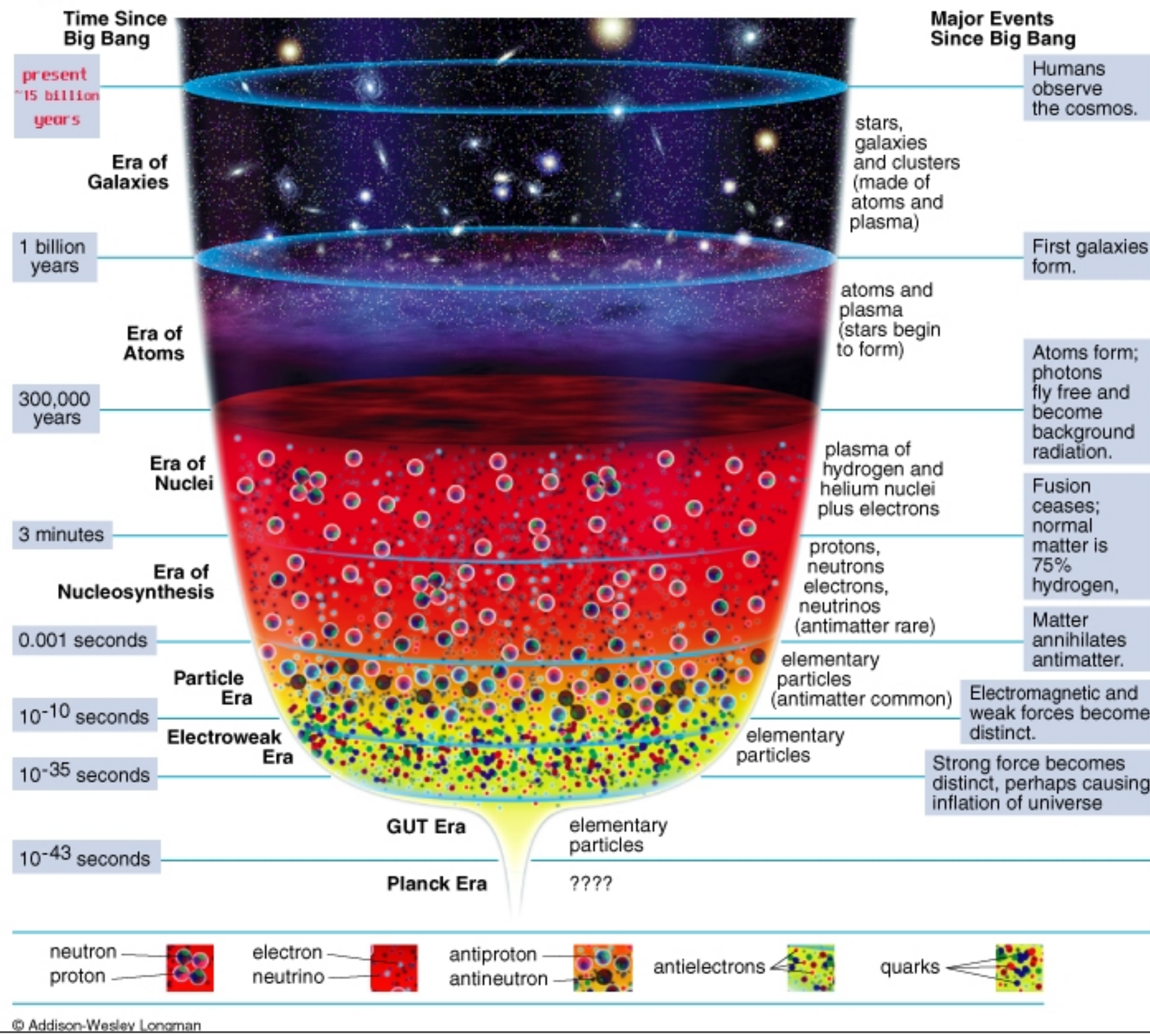
Structure and history of the Universe depend on mass/energy content

- Geometry of the universe
- Expansion history
- Structure formation (linear and non-linear)
- High energy astronomical sources
- Sources of gravitational waves

The history of the Universe

$$\frac{T}{10^{10}\mathrm{K}} \sim \frac{kT}{1\mathrm{Mev}} \sim \left[\frac{\rho}{10^{7}\mathrm{g\ cm^{-3}}}\right]^{1/4} \sim \left[\frac{\rho_m}{1\mathrm{g\ cm^{-3}}}\right]^{1/3} \sim \frac{1+z}{10^{10}} \sim \left[\frac{t}{1\ \mathrm{sec}}\right]^{-1/2}$$

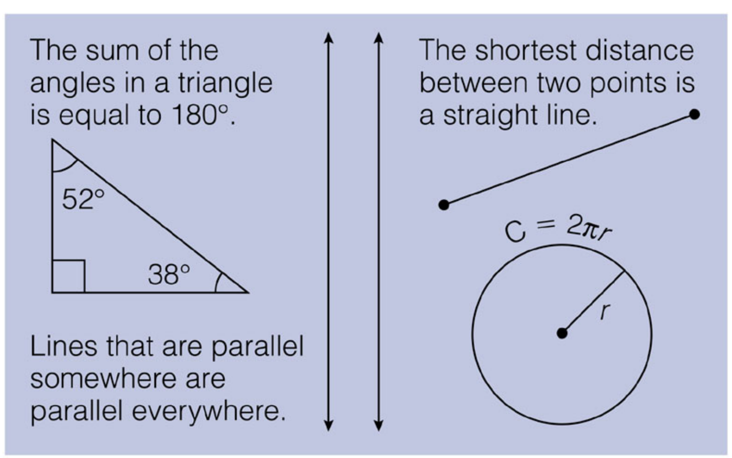


Astronomical objects as high-energy and massive sources

gamma ray bursts;
hypernovae;
supernovae;
cosmic ray sources;
mergers of black holes and of neutron stars;
dense and massive dark matter halos;
etc

Global Geometry

K=0



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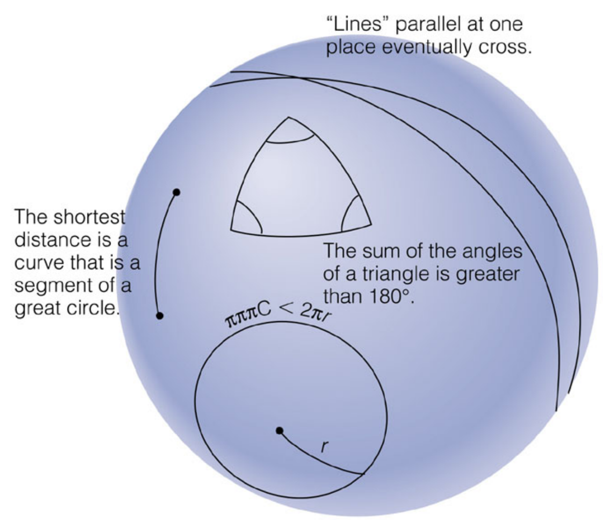
K=+1



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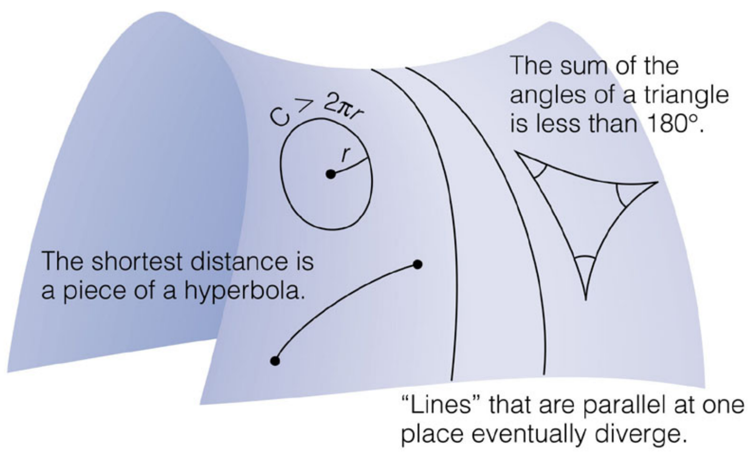
K=-1



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$$K = \left(\frac{H_0 a_0}{c}\right)^2 [\Omega_{\text{total},0} - 1]$$

The expansion of the Universe

$$\frac{1}{a}\frac{d^2a}{dt^2} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right)$$

where $\rho = \sum_i \rho_i$ and p related to ρ via the equation of state:

$$p = p(\rho) = \sum_i w_i \rho_i c^2, \quad i = r, M, \Lambda, \epsilon, \cdots$$

$$w_r = 1/3; \qquad w_M = 0; \qquad w_\Lambda = -1; \qquad w_\epsilon = [-1, -1/3)$$

Expansion rate and distances

$$H(z) = \left(\frac{\dot{a}}{a}\right)(z) = H_0 E(z)$$

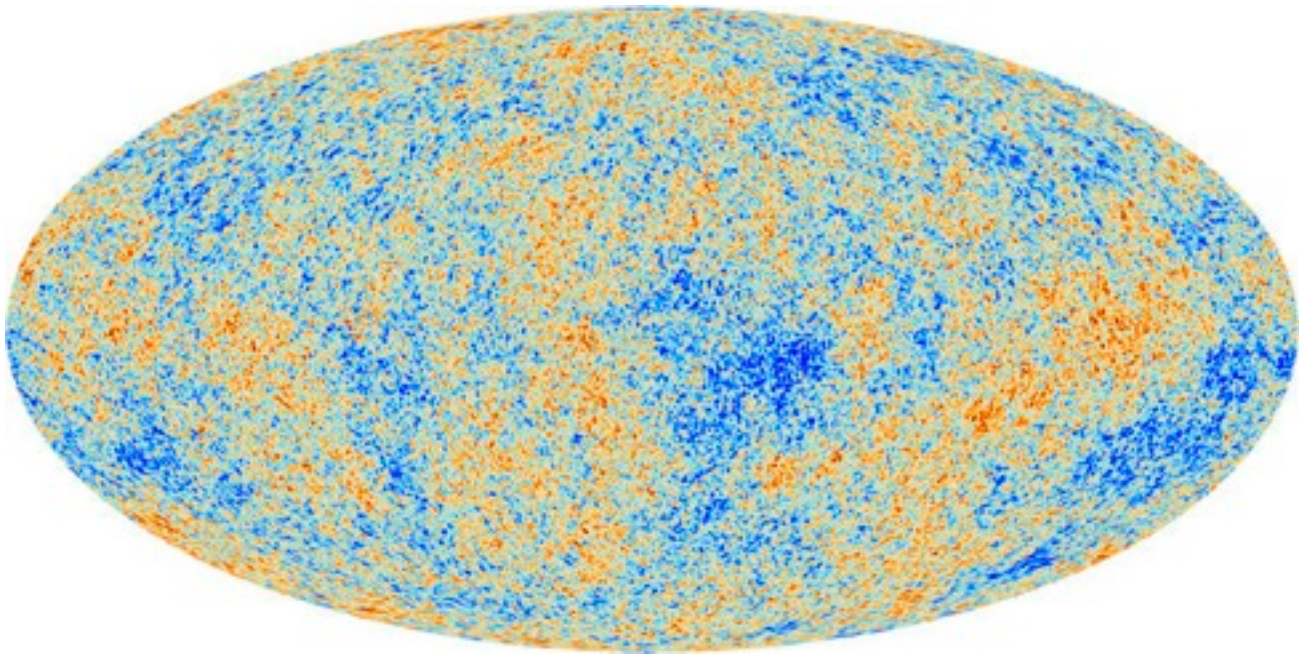
$$E^2(z) = (1-\Omega_0)(1+z)^2 + \Omega_{\epsilon,0}(1+z)^{3(1+w)} + \Omega_{\mathrm{m},0}(1+z)^3 + \Omega_{\mathrm{r},0}(1+z)^4$$

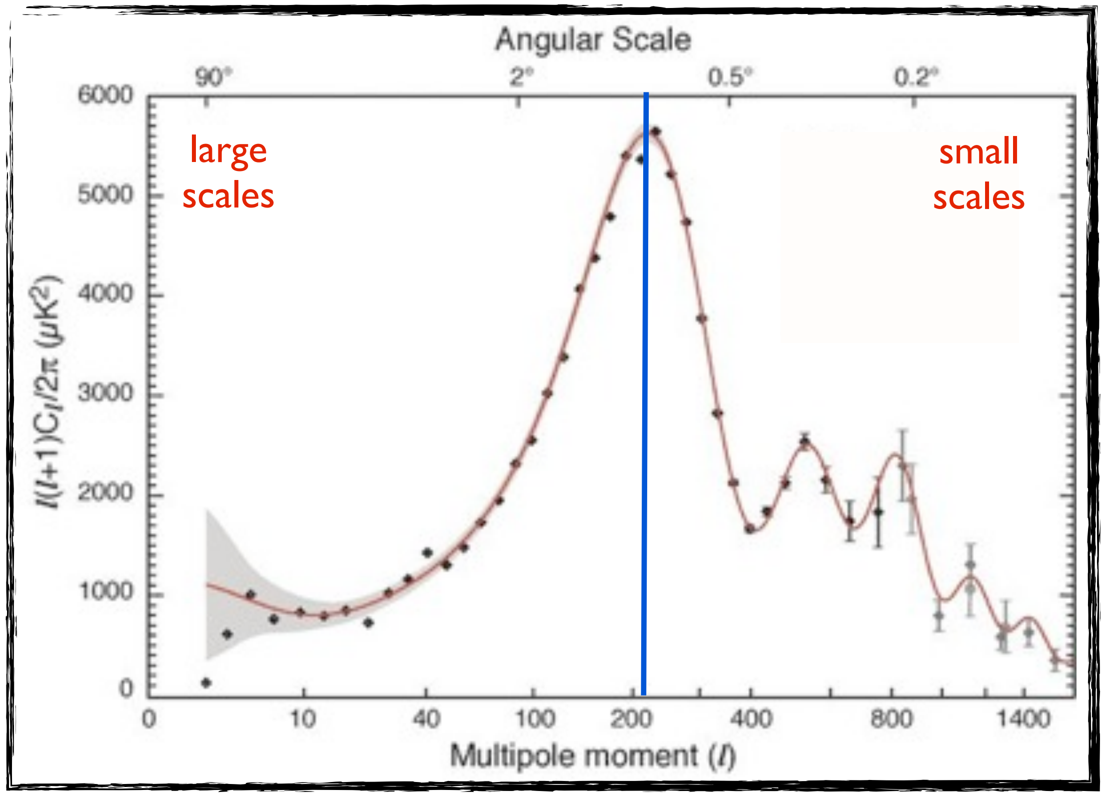
$$d_L = \left(\frac{L}{4\pi F}\right)^{1/2} = a_0 r(1+z)\,; \qquad d_A = \frac{D}{\theta} = \frac{a_0 r}{1+z}$$

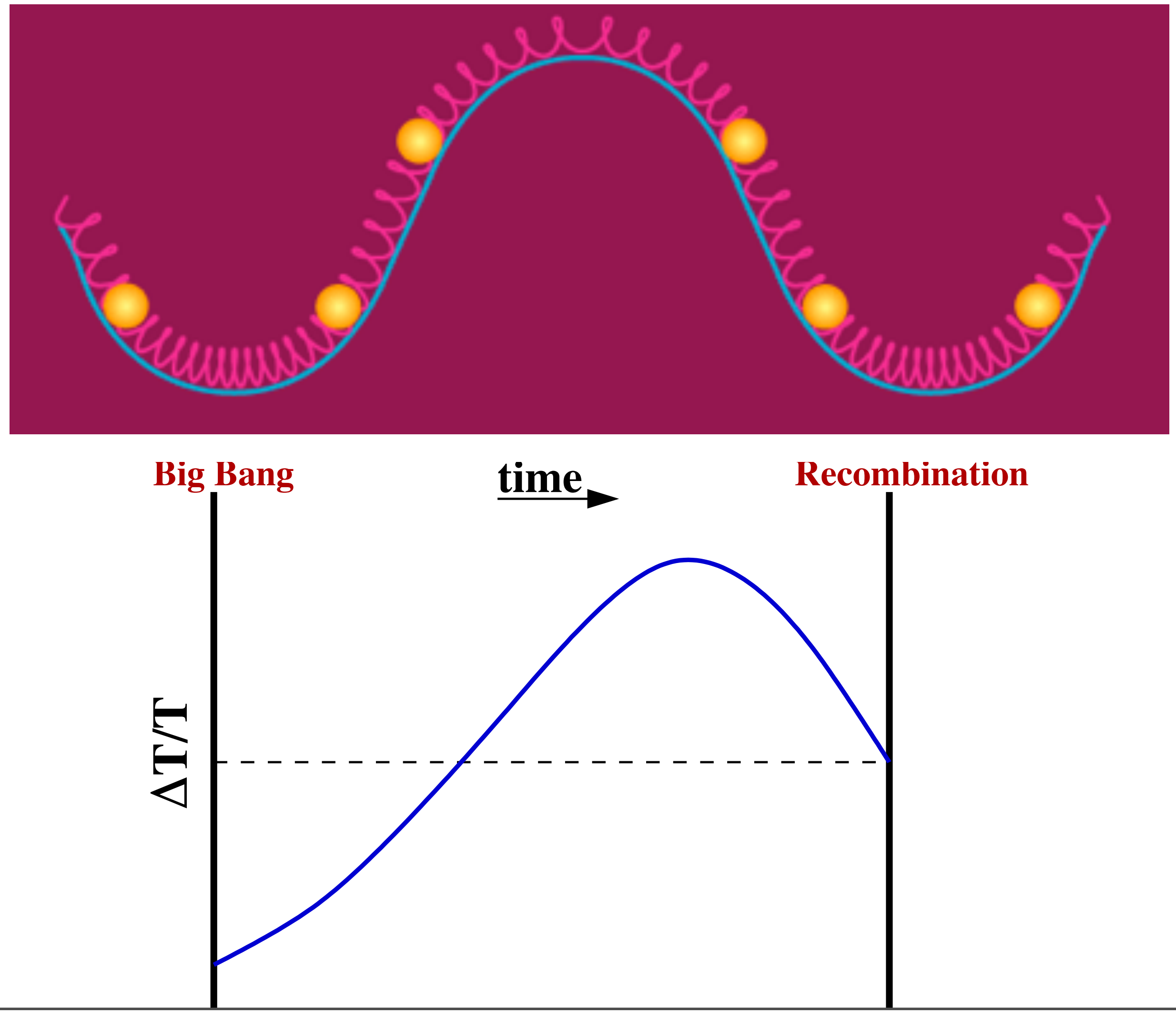
$$r = f_K\left[\frac{c}{H_0 a_0}\int_0^z \frac{dz}{E(z)}\right]\,.$$

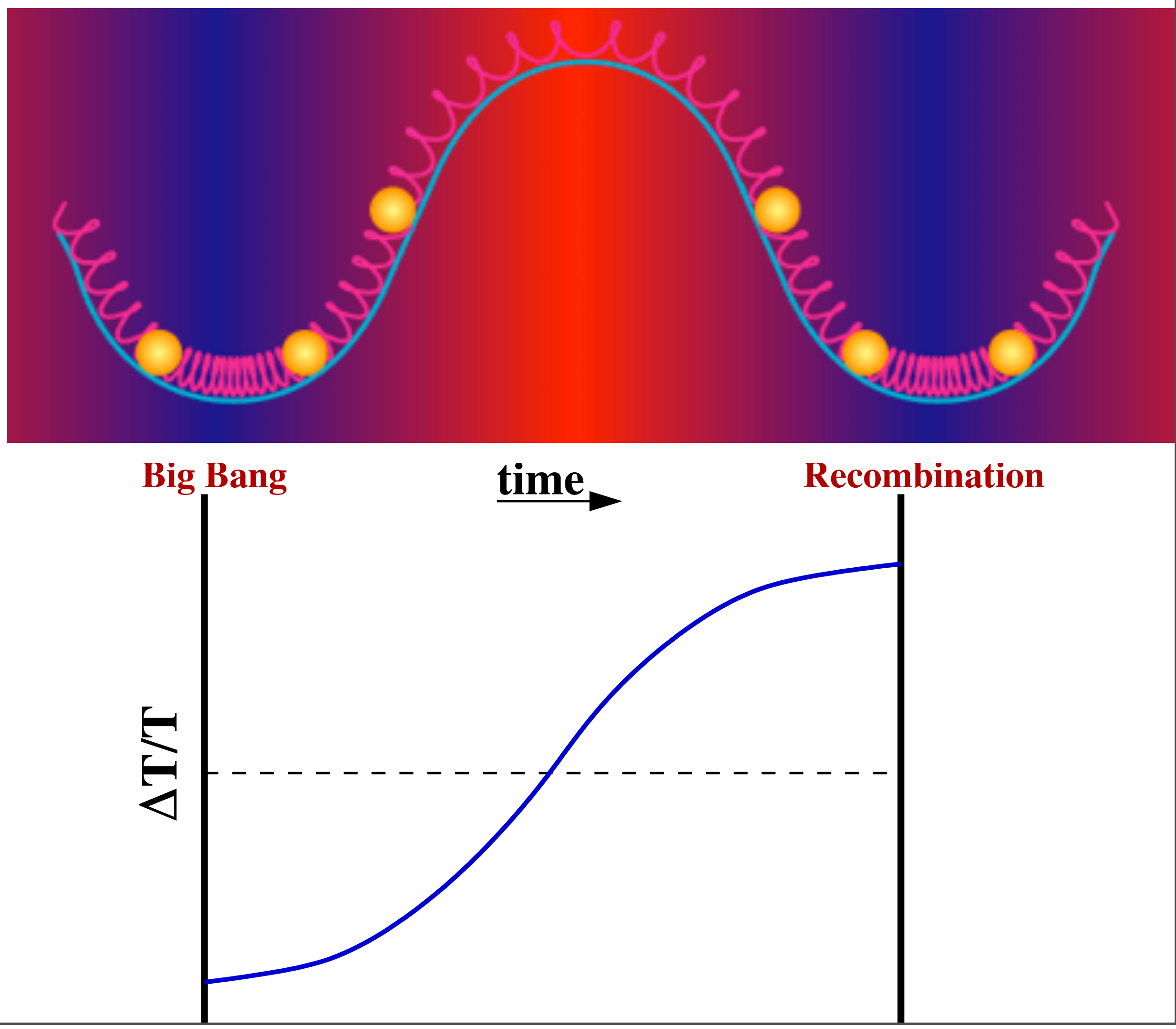
$$f_K(\chi) = \begin{cases} \sin\chi & (K=+1) \\ \chi & (K=0) \\ \sinh\chi & (K=-1) \end{cases}$$

CMB acoustic peaks: angular vz physical scales



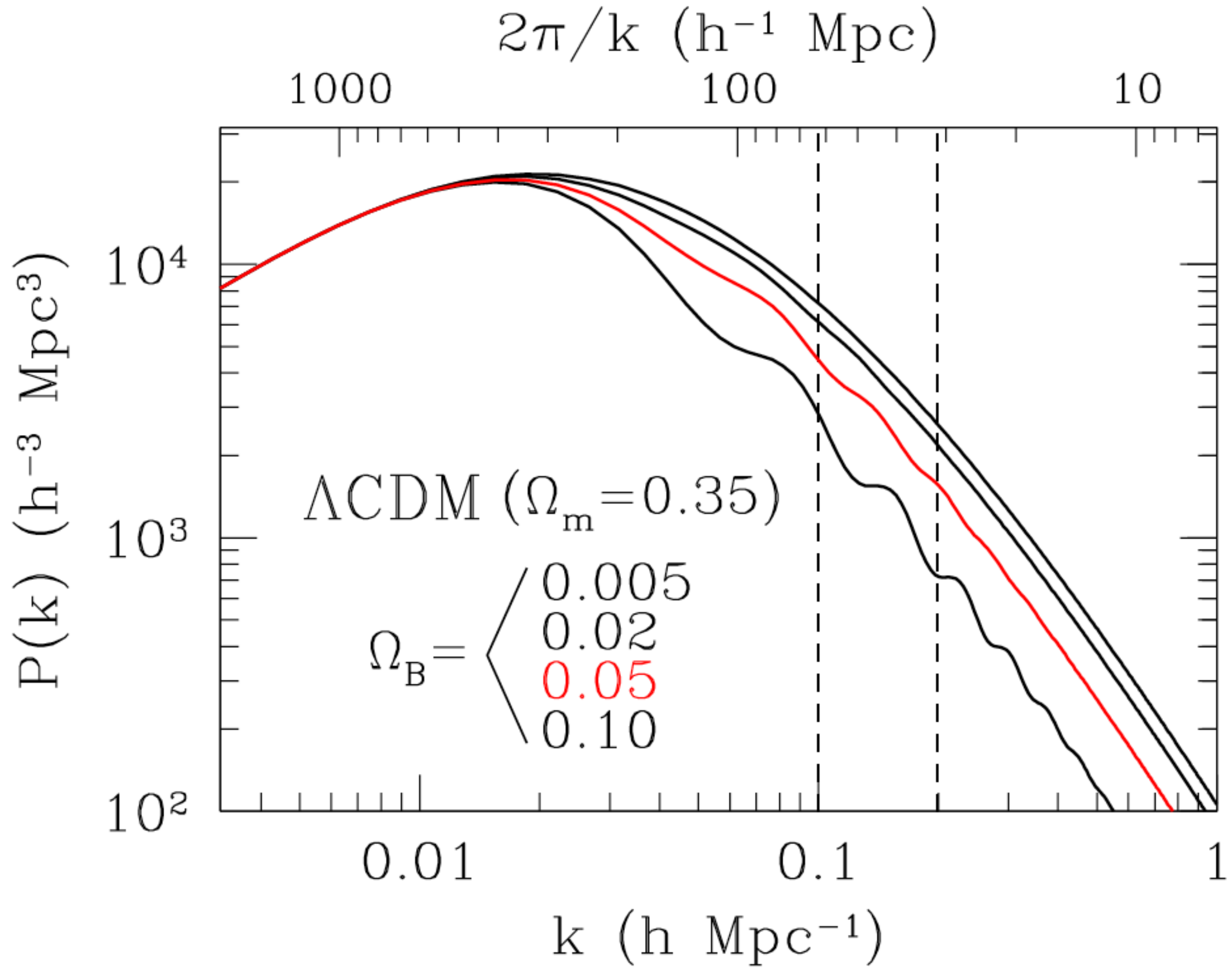


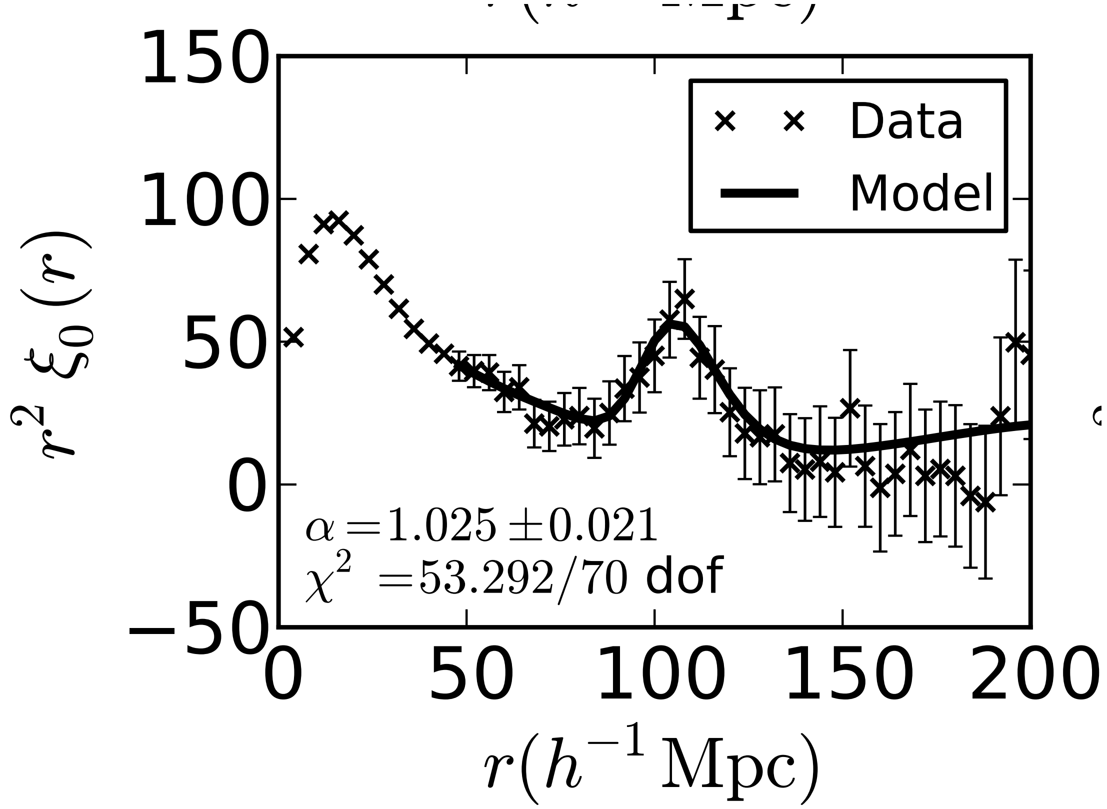


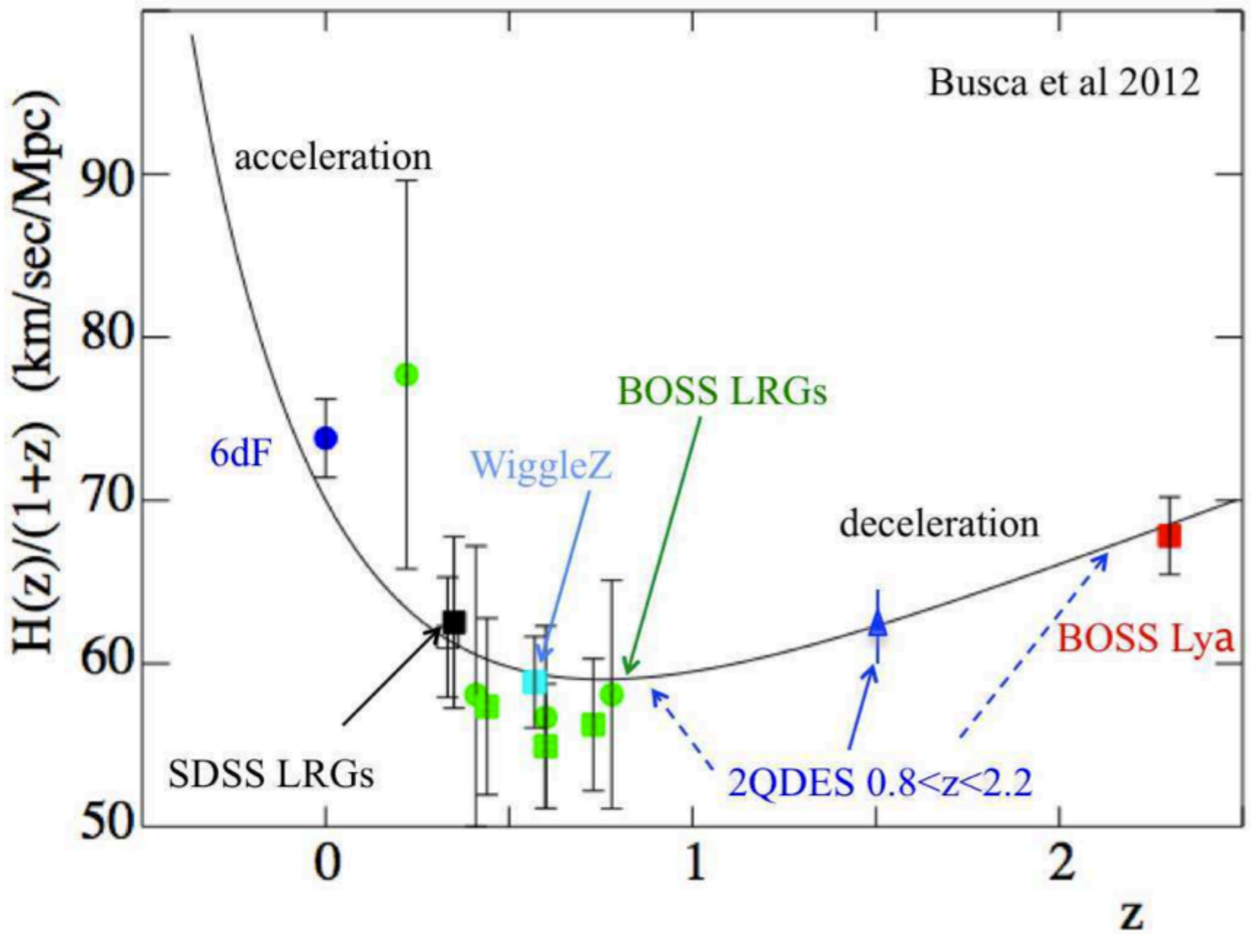


BAO:

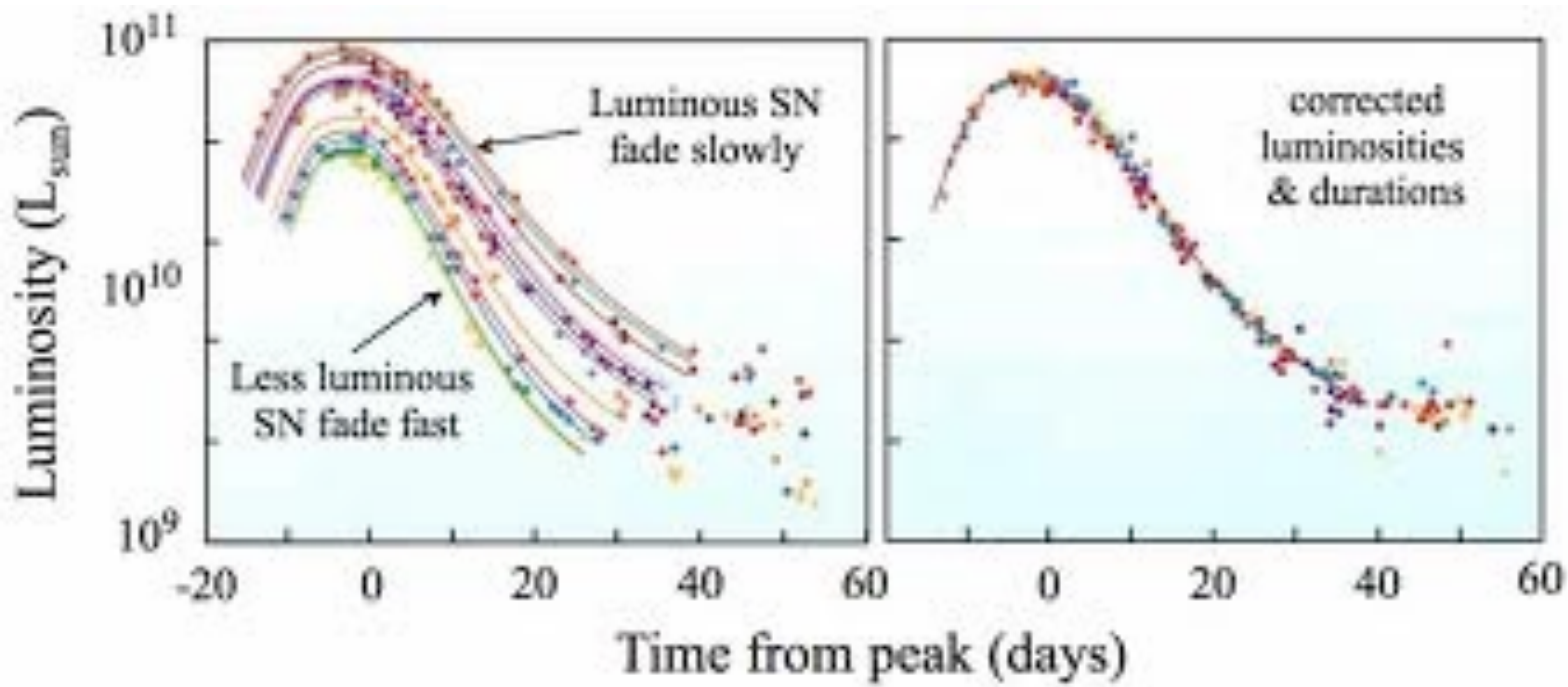
Baryonic Acoustic Oscillation



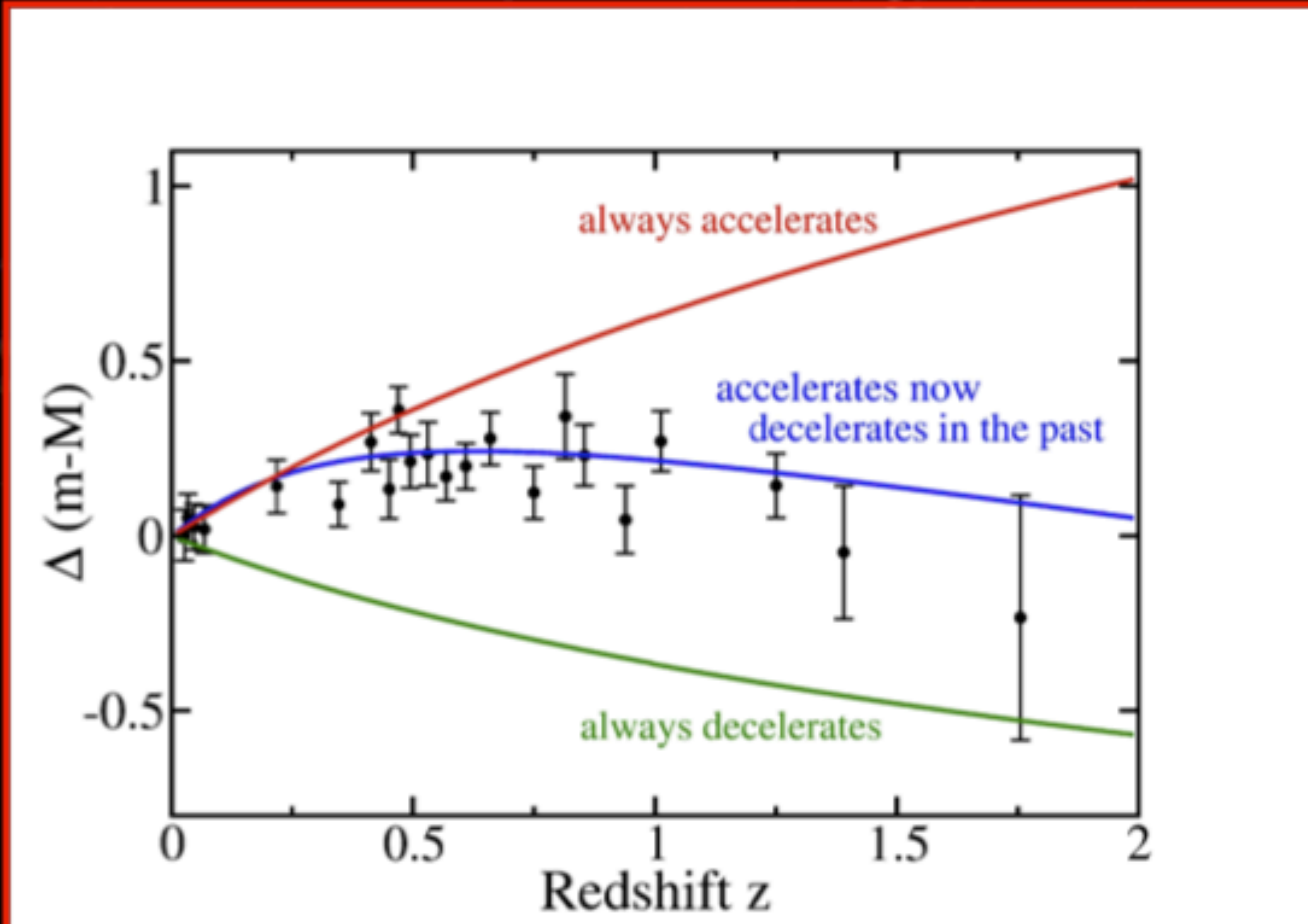




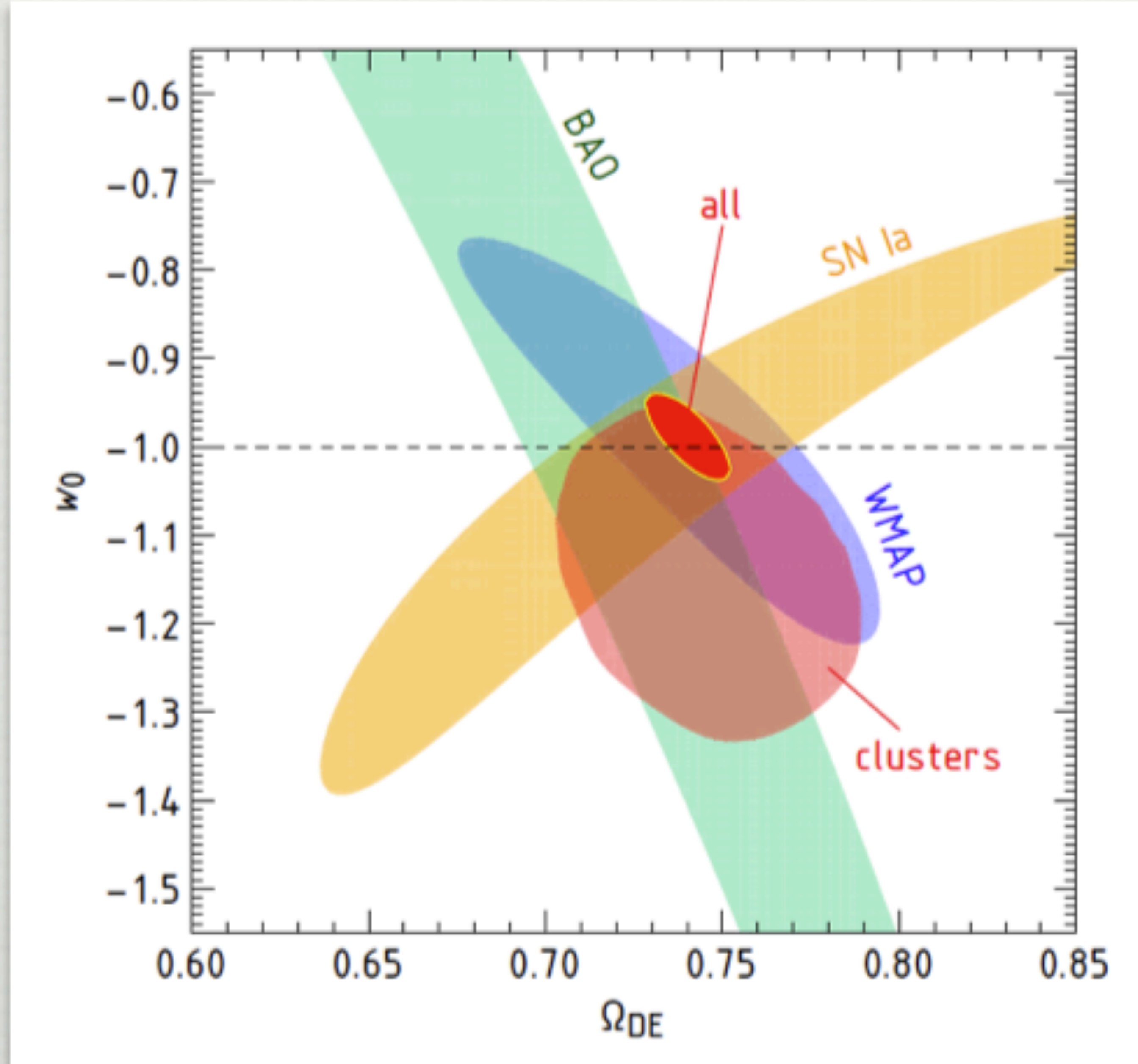
Supernovae as ‘standard’ candles



Evidence for past acceleration
Important reality check



HST ACS Sample of high-z SNe: A. Riess et al, Ap.J **607**, 665 (2004)



$w_0 = -0.99$ ± 0.045 (stat) (± 0.067 without clusters)

± 0.039 (sys) (± 0.076)

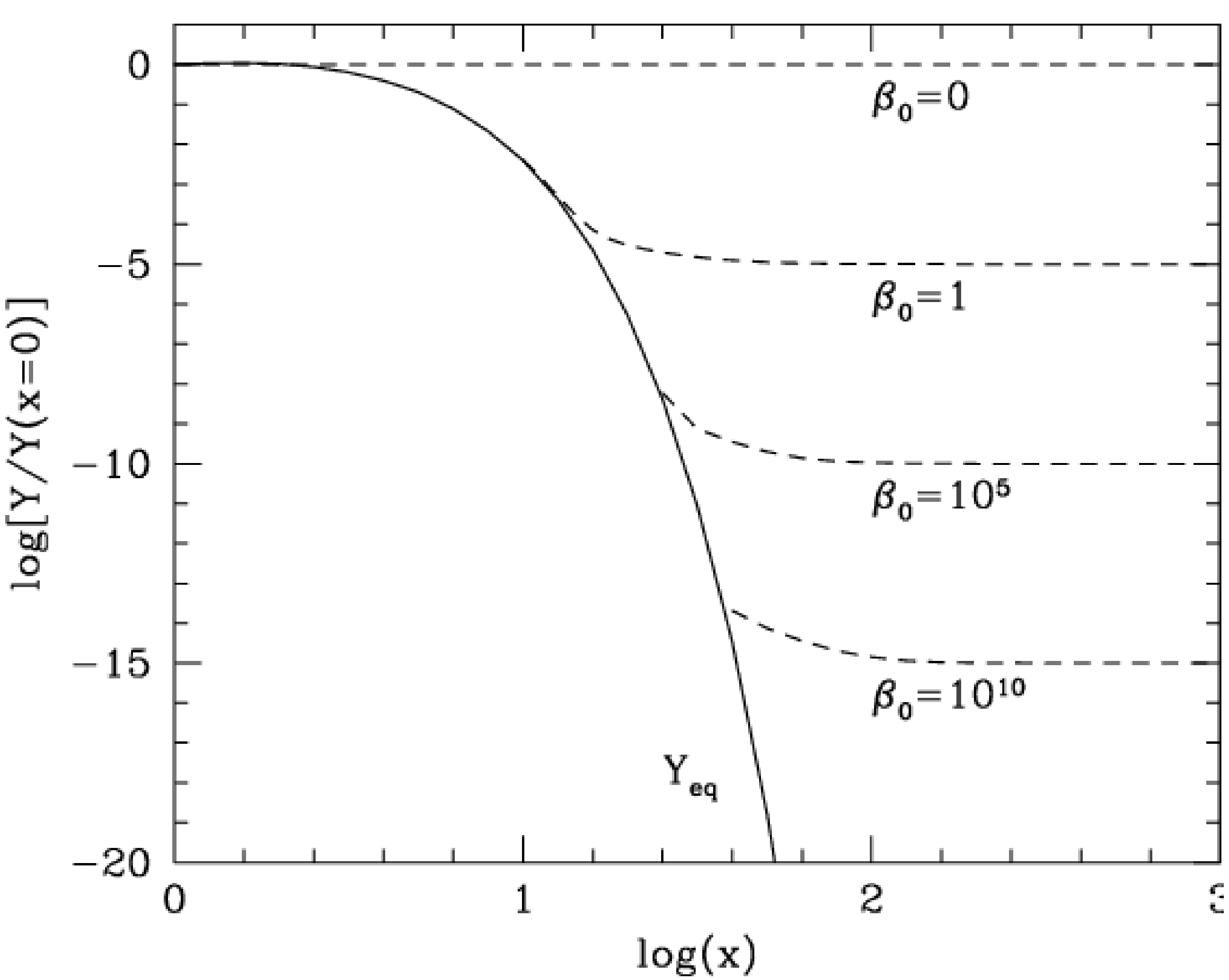
2009 ApJ 692 1060

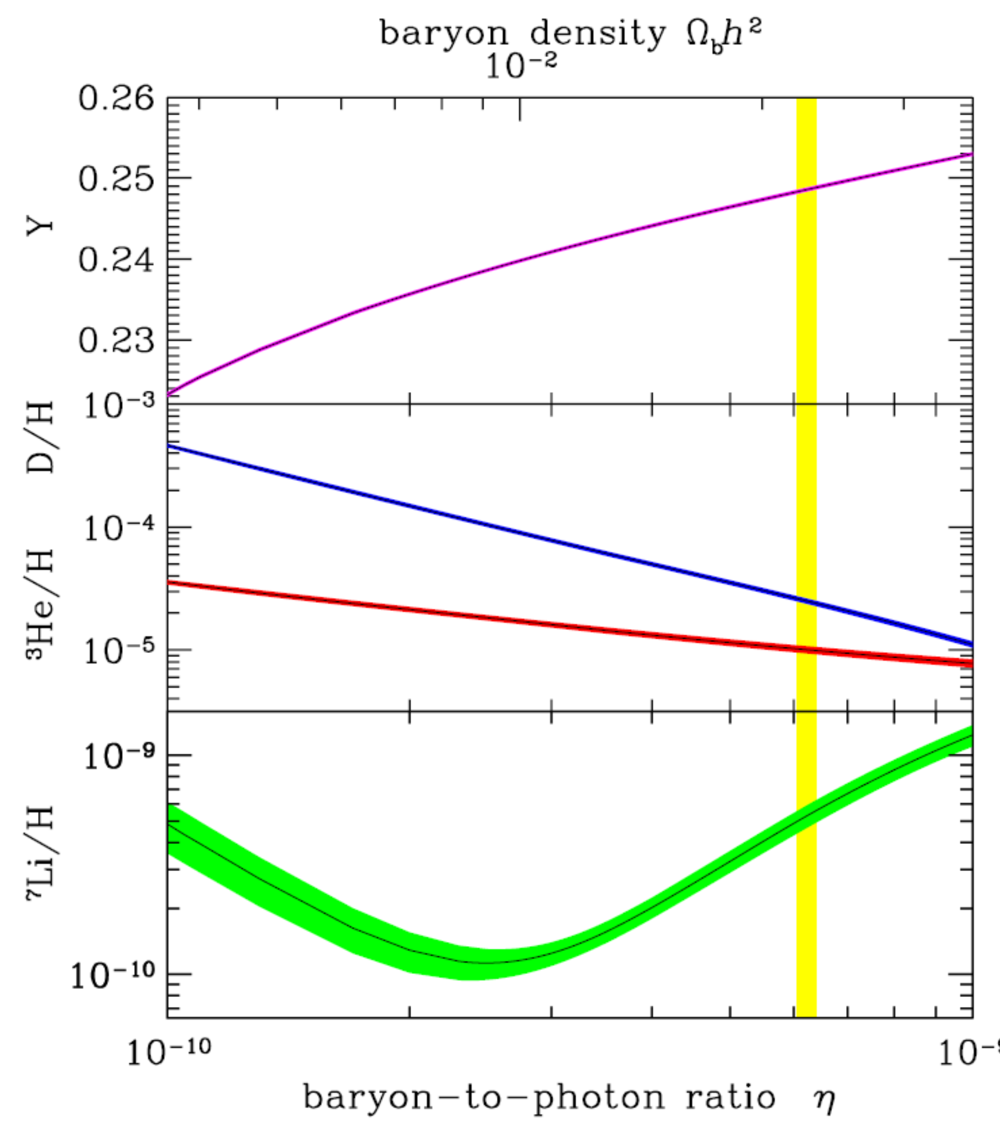
Density of relic particles

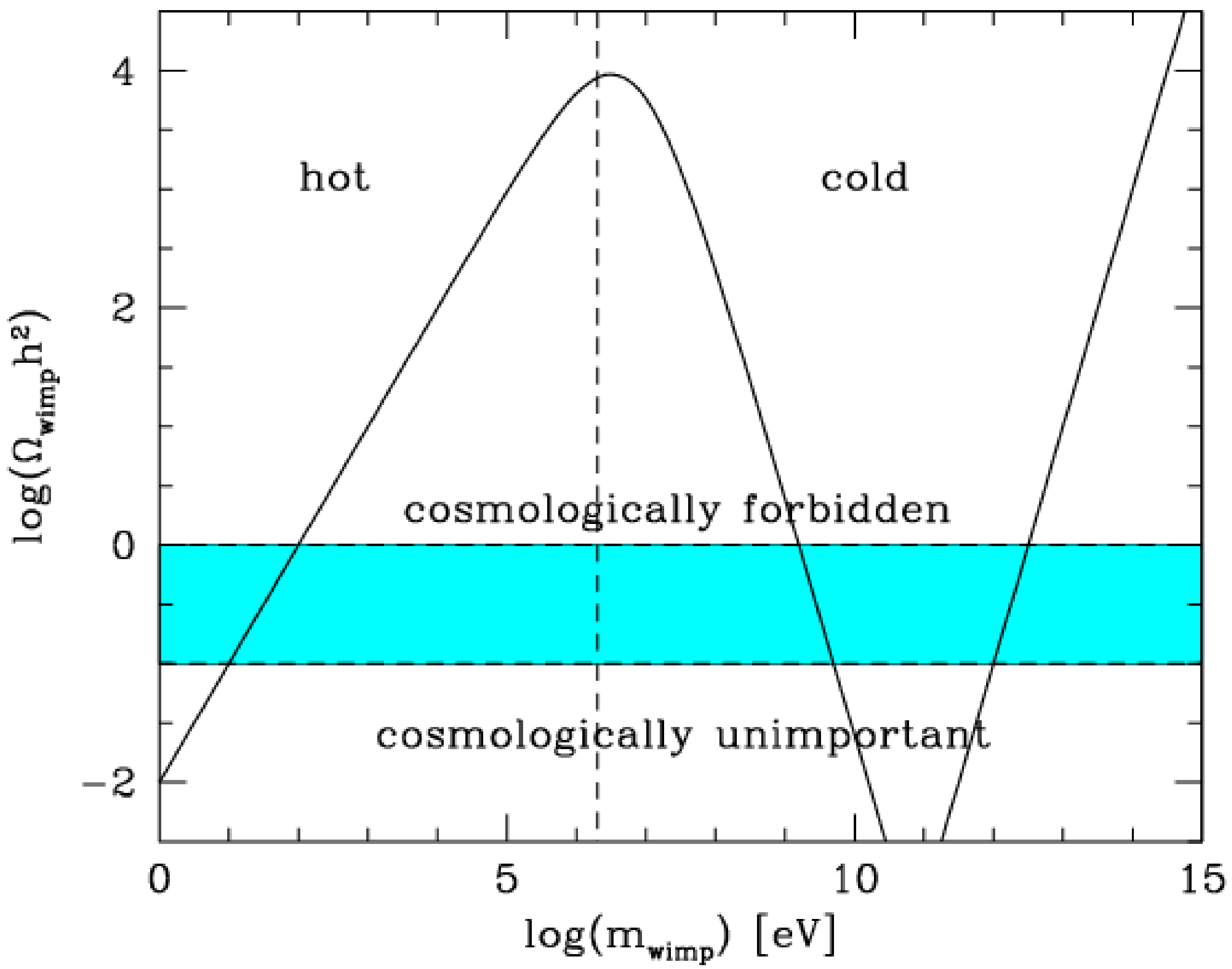
$$\frac{dn_i}{dt} + 3\,H(t)\,n_i = \int C_i[f]\,d^3p$$

$$\frac{dn_i}{dt} + 3\,H(t)\,n_i = \beta(T)(n_{eq,i}^2 - n_i^2)\,.$$

BBNS constraining on g_r: $\Delta Y_p \sim 0.01 g_r$







$$\Omega_{\rm WIMP} \approx \frac{0.1}{h^2}\left(\frac{3\times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle\sigma v\rangle}\right)$$

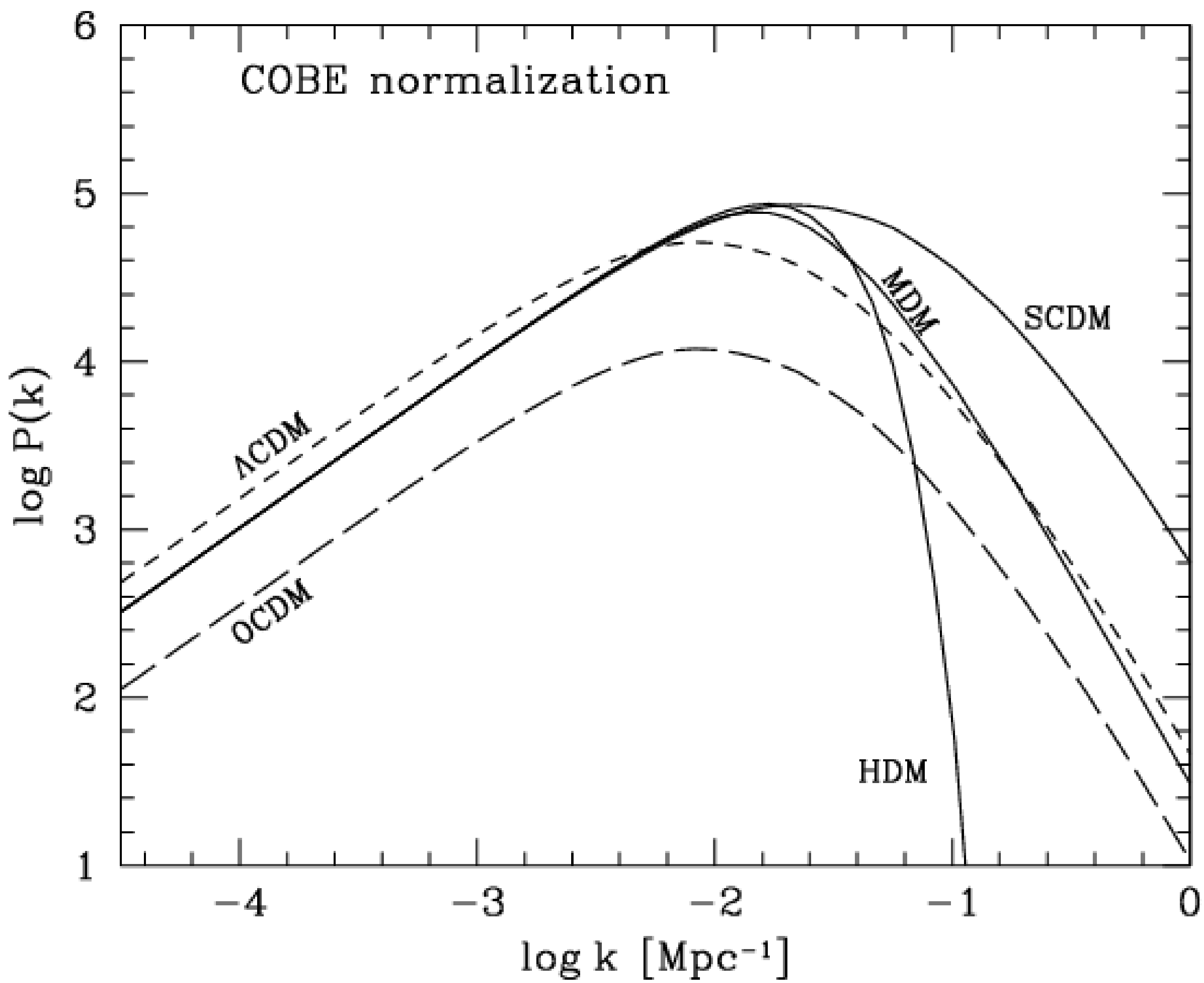
$$\Omega_{\rm DM,obs} \qquad \text{needs} \qquad \langle\sigma v\rangle \approx 3\times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}$$

Structure formation: linear regime

$$\frac{\partial^2 \delta}{\partial t^2} + 2\frac{\dot{a}}{a}\frac{\partial \delta}{\partial t} = 4\pi G\bar{\rho}\delta + (\text{vel. dispersion term})$$

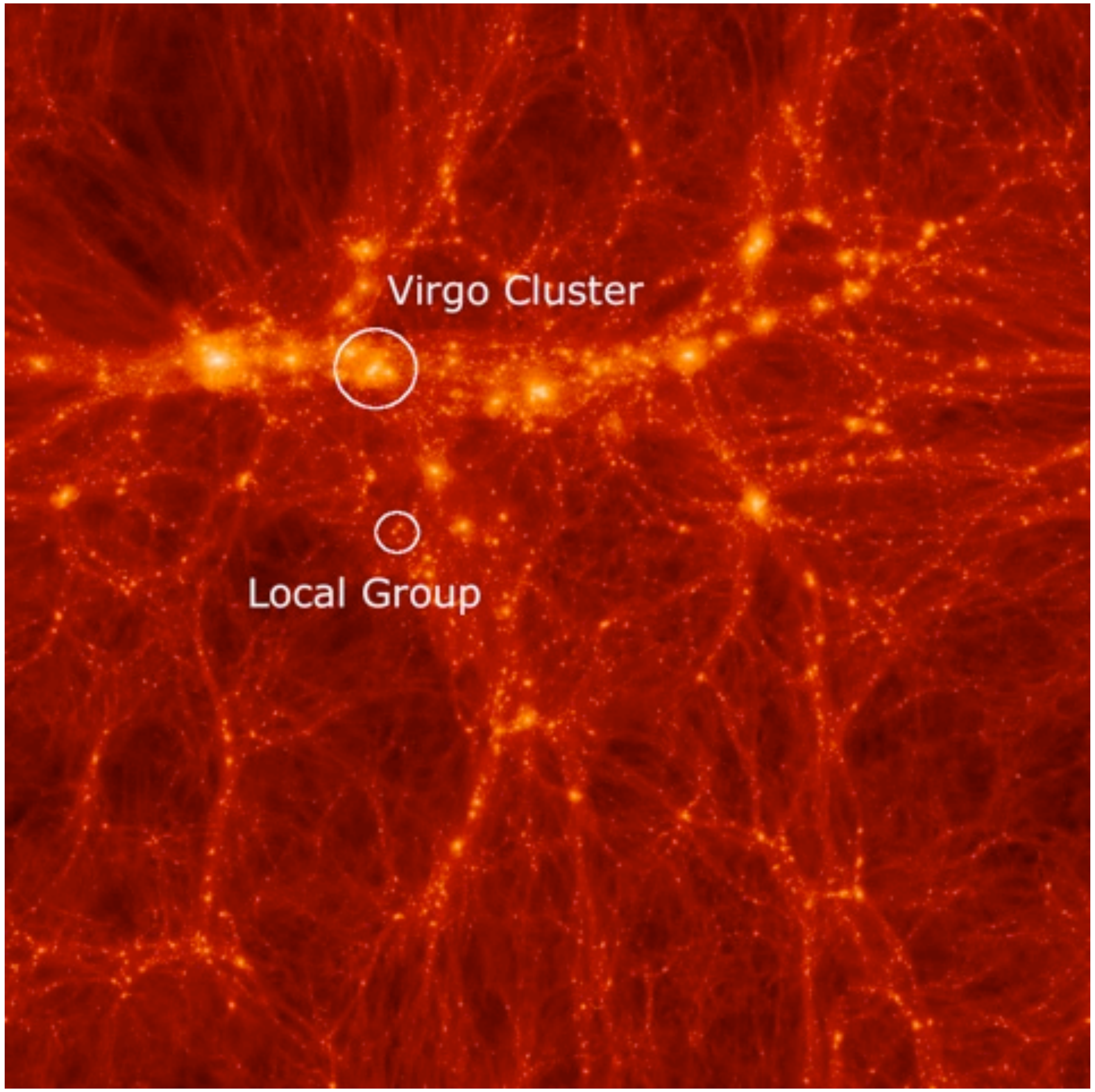
Depends on mass/energy content

Depends on particle properties:
cold, warm, hot

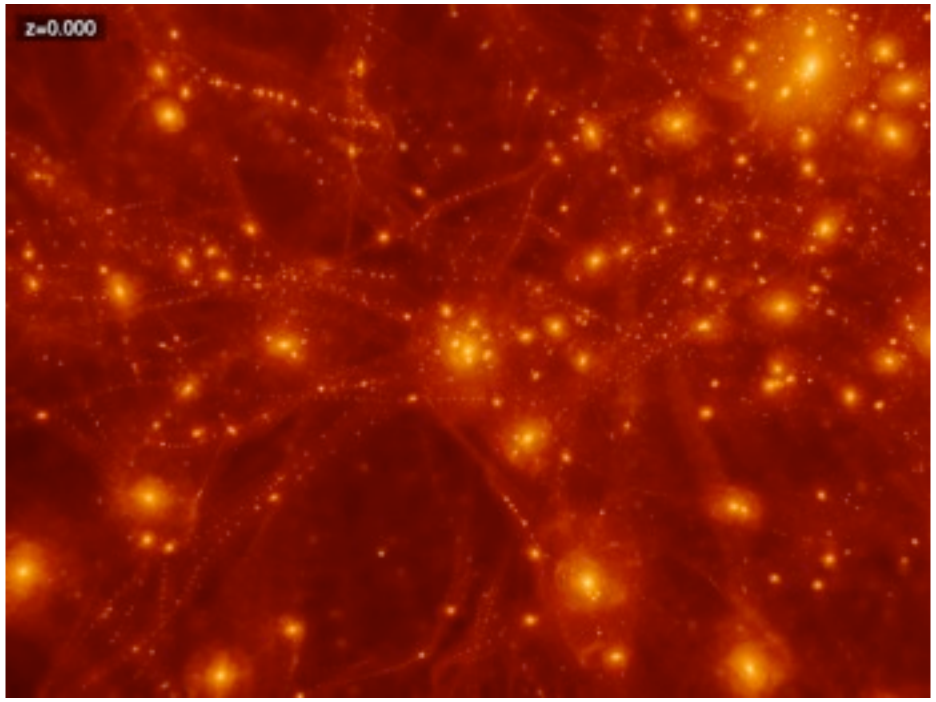


COBE normalization
ΛCDM
OCDM
MDM
SCDM
HDM
log P(k)
log k [Mpc⁻¹]
6
5
4
3
2
1
−4
−3
−2
−1
0

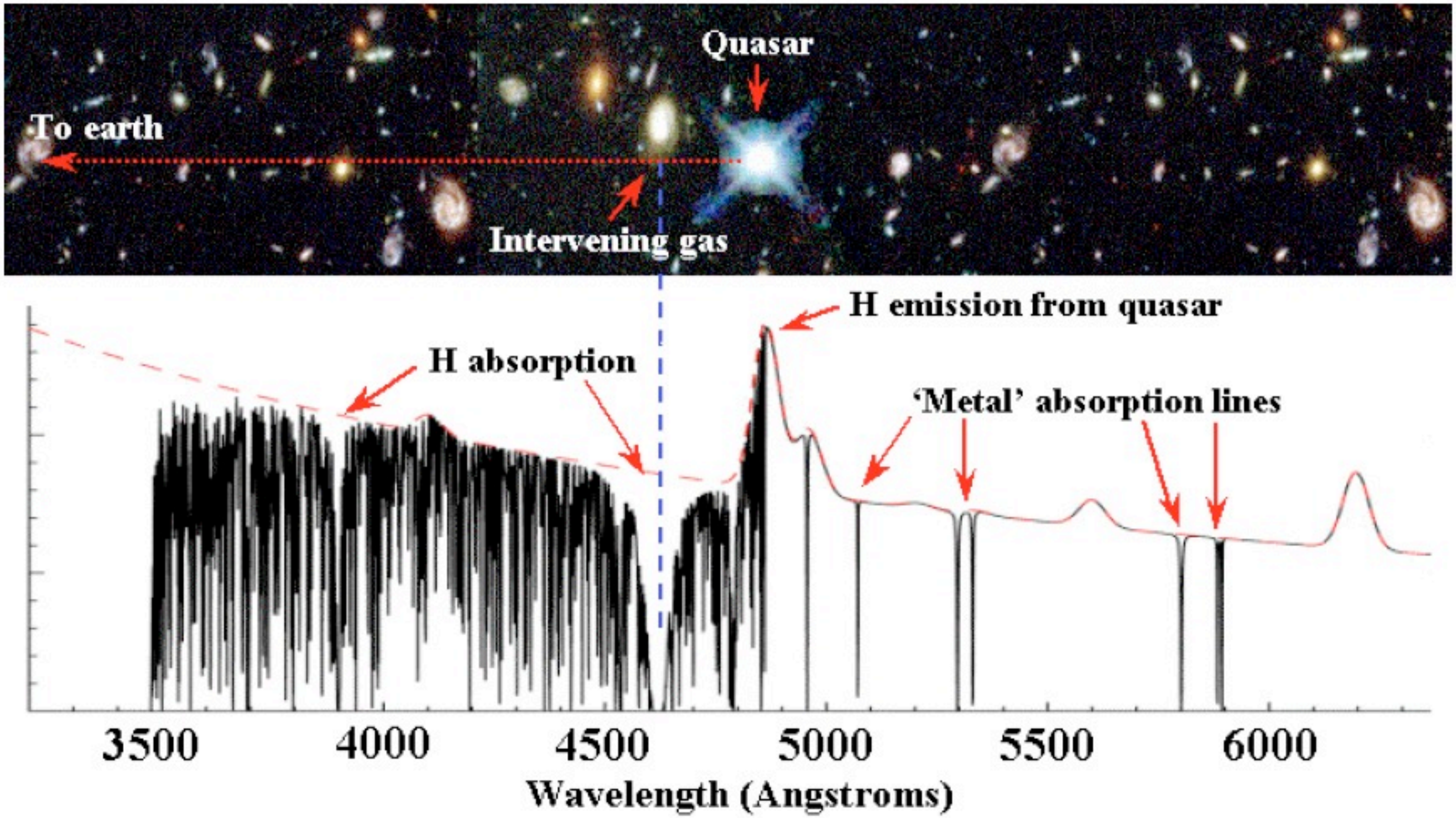
CDM



WDM (m=keV)



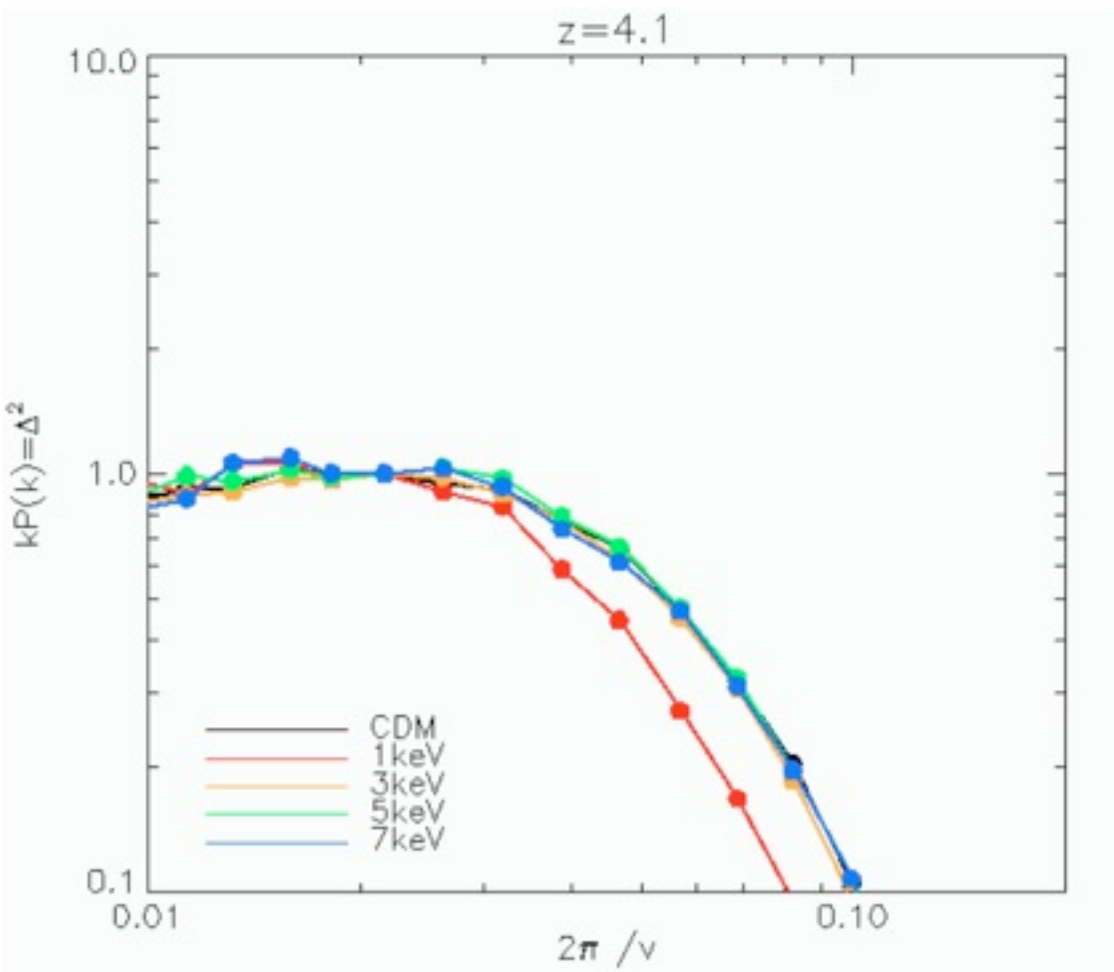
Lyman-alpha forest:

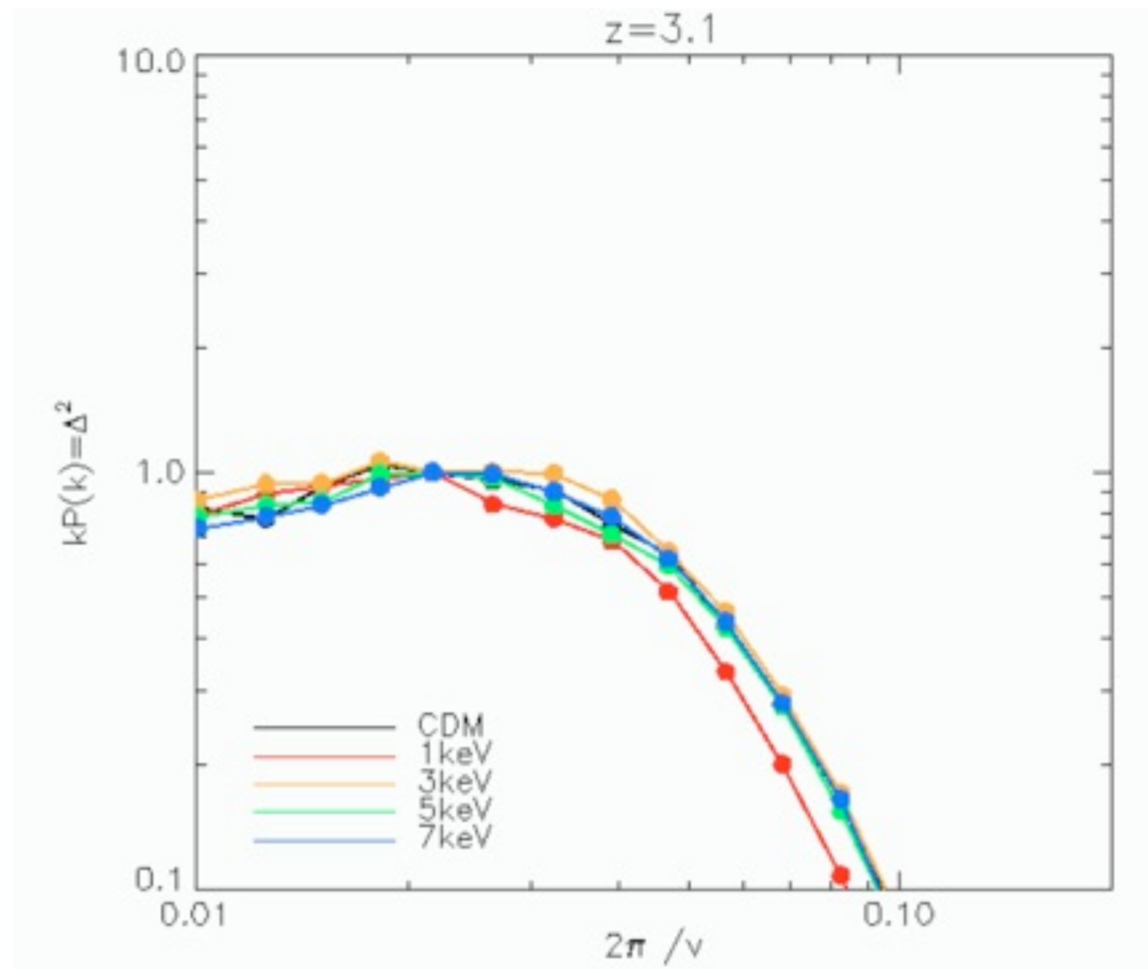


Quasar spectra sample the matter distribution along the line of sight

Predicted Lyman alpha forest power spectra

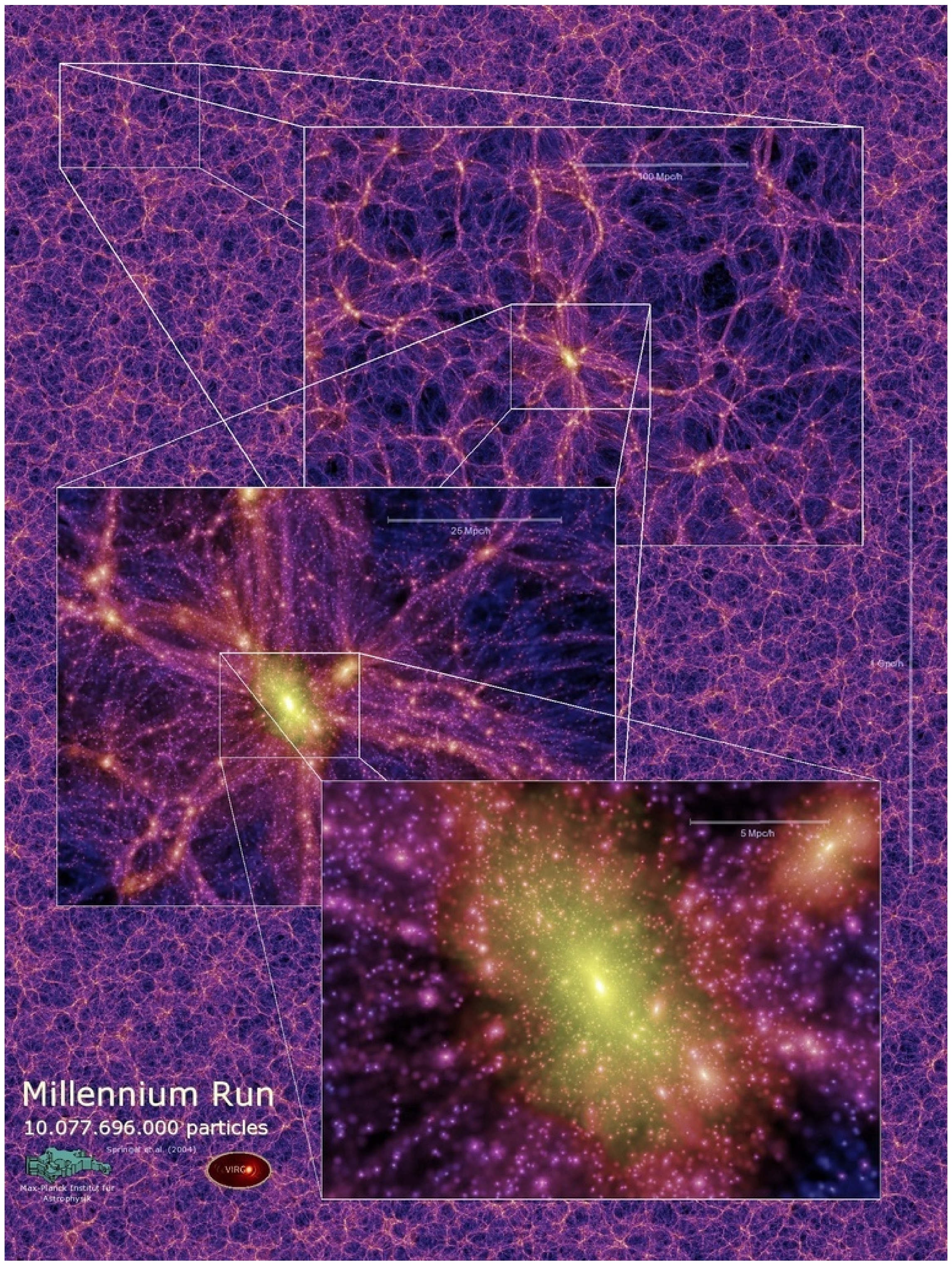
dark matter: 1keV / 3 keV / 5keV / 7keV / CDM



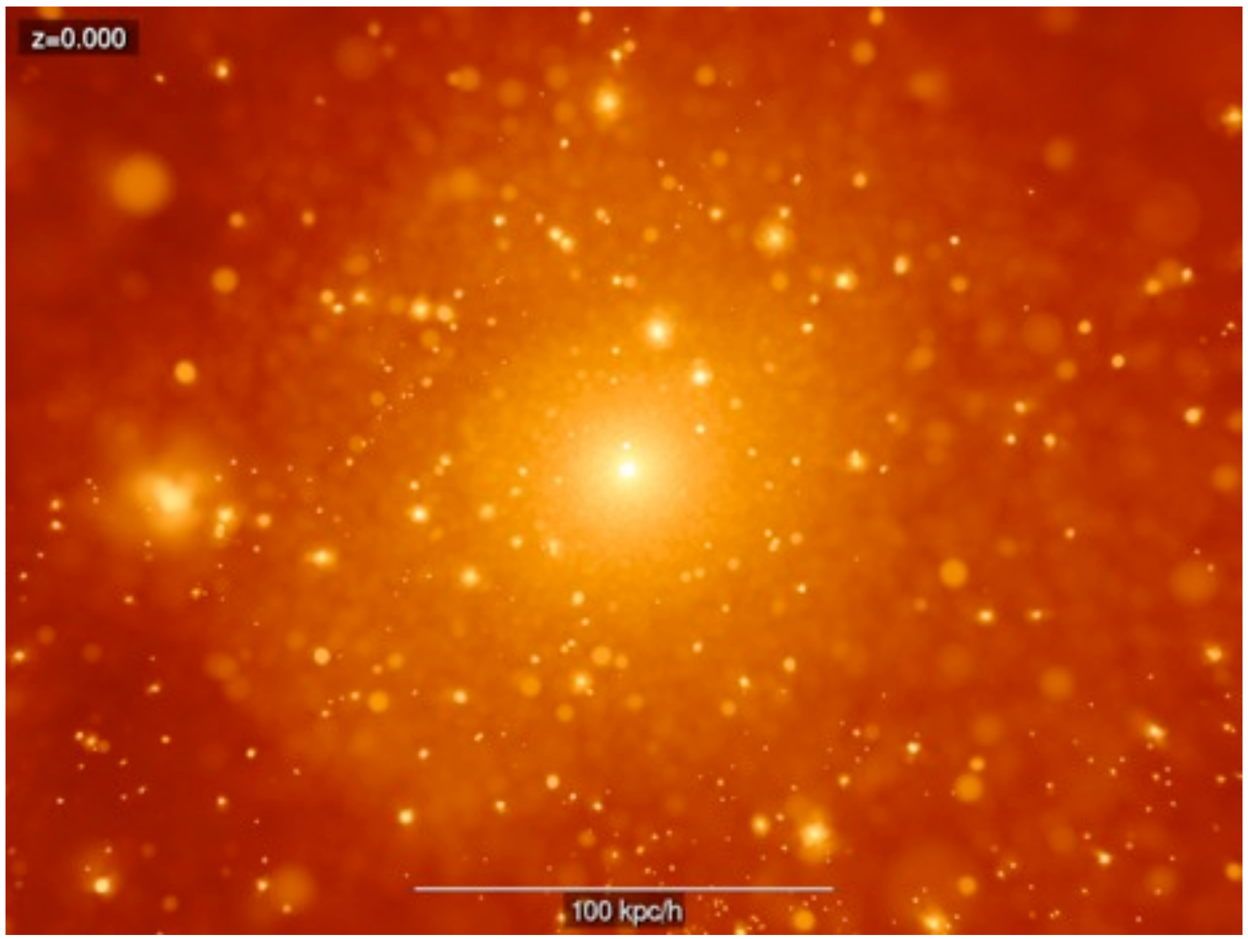


Needs m>1kev

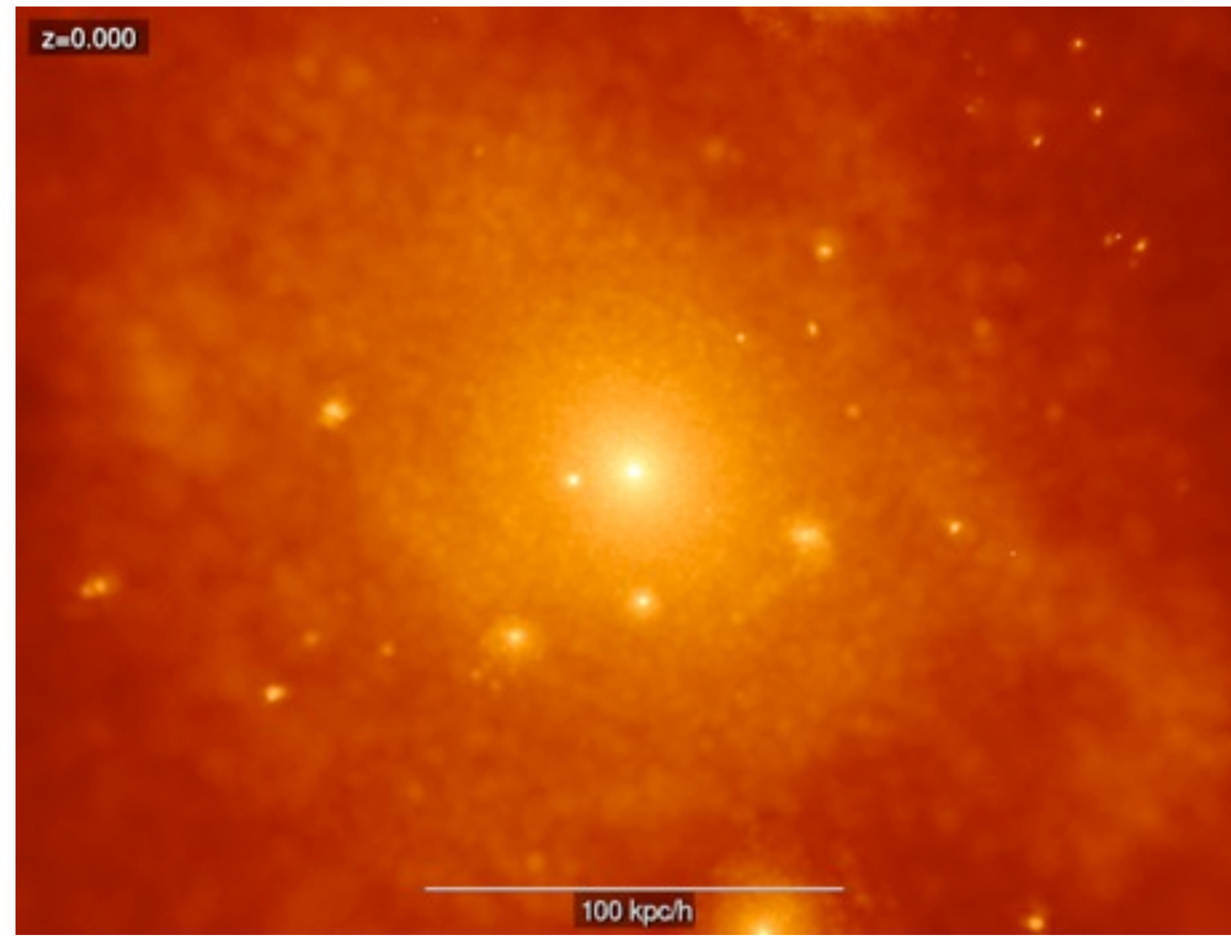
Structure formation: nonlinear regime



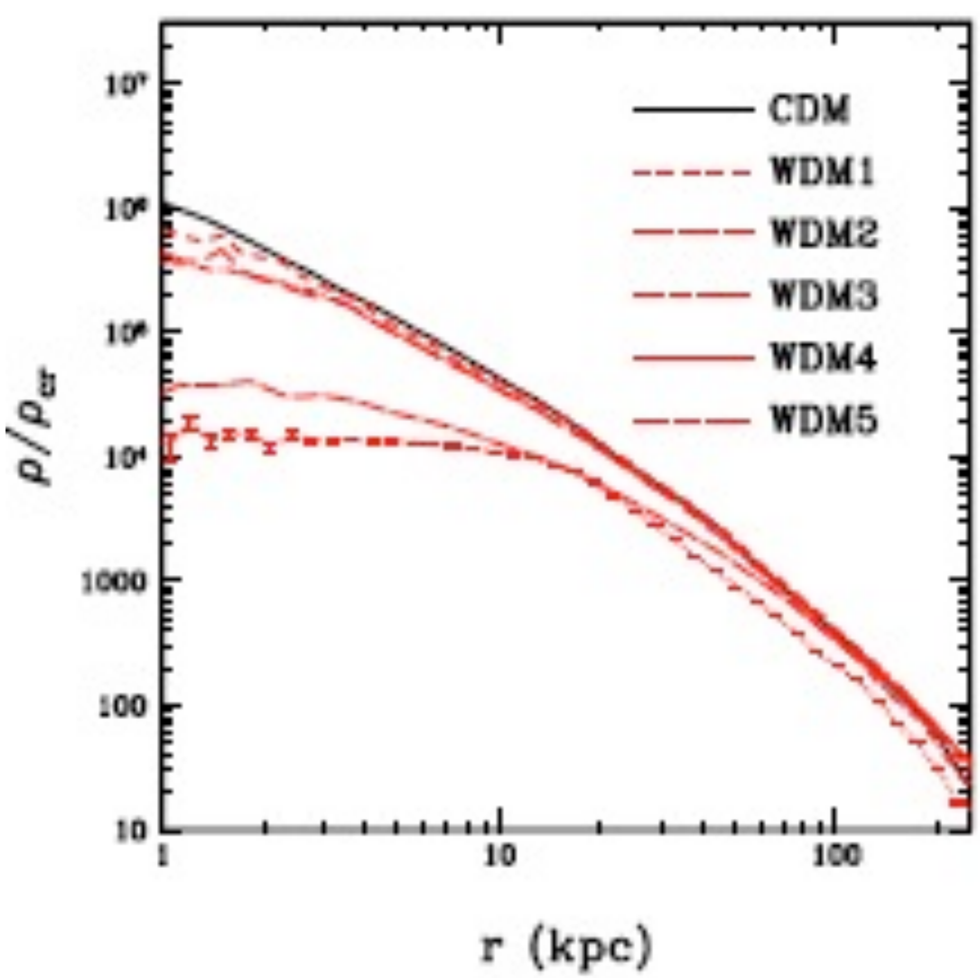
CDM; MW-halo



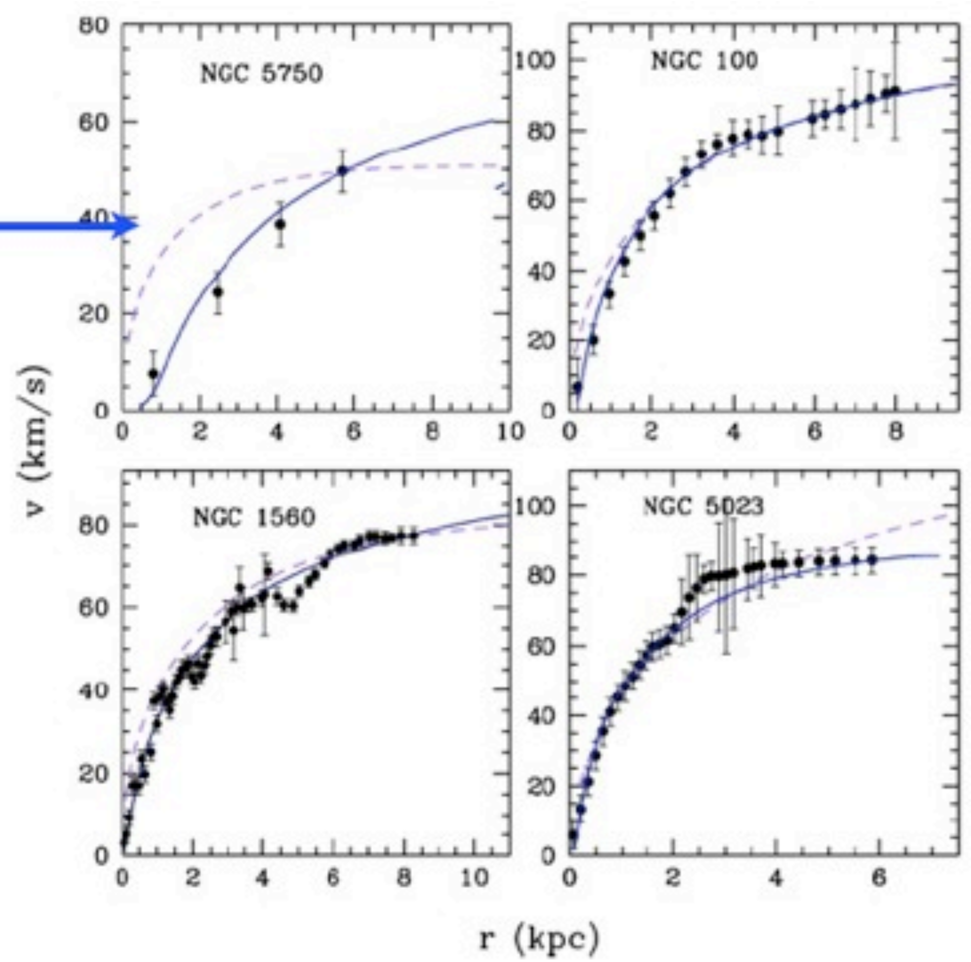
WDM (m=keV)



Halo density profiles



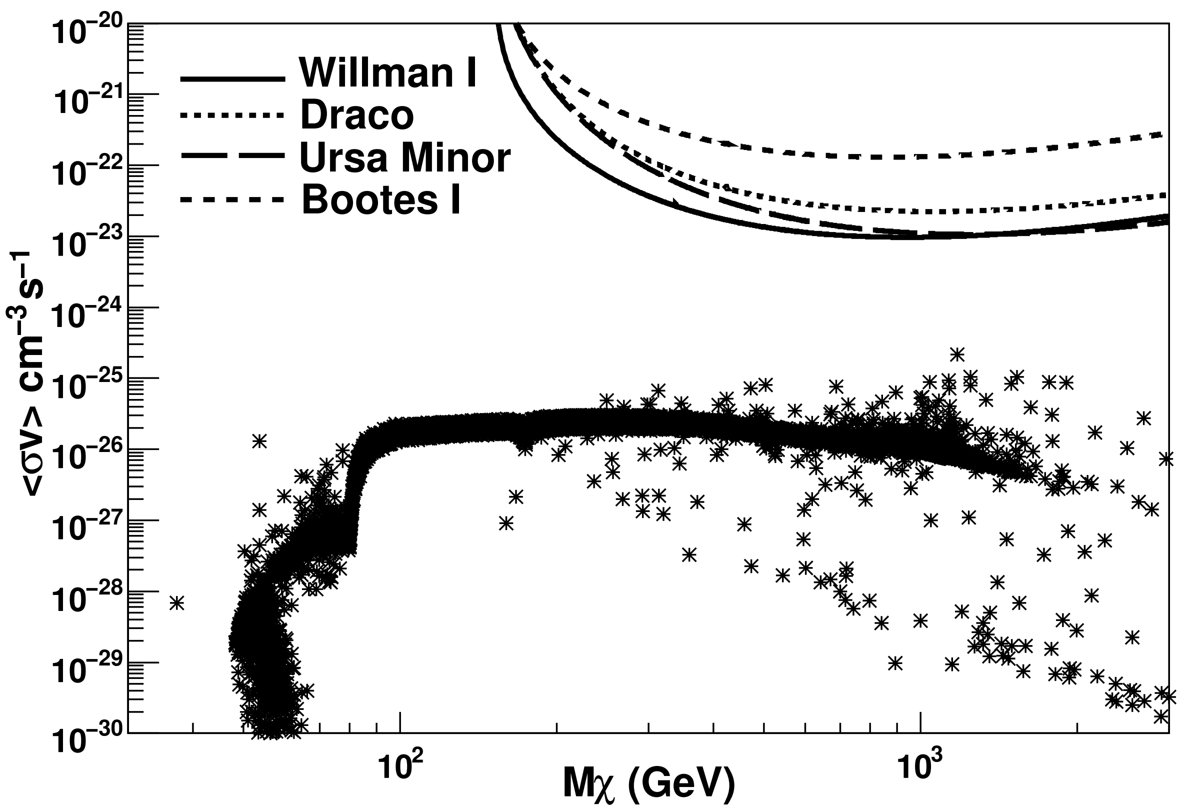
cusp/core problem?

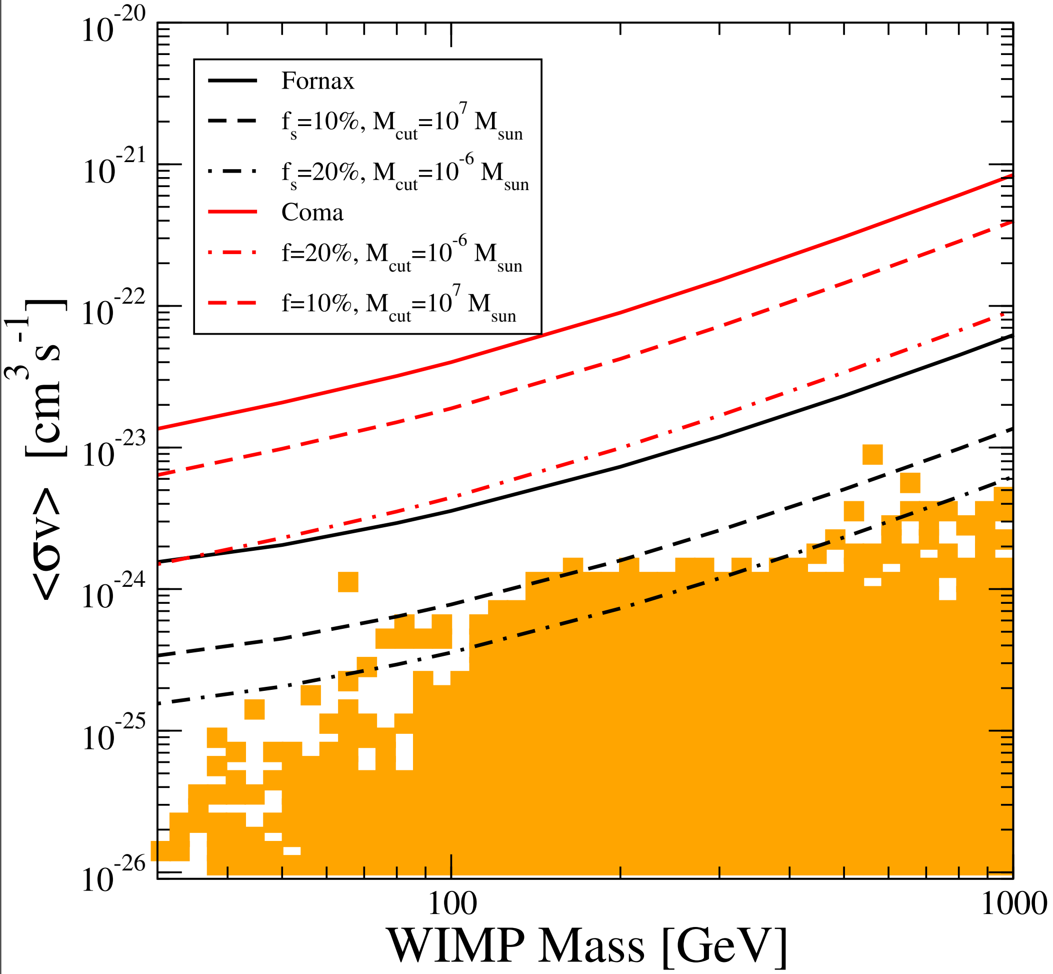


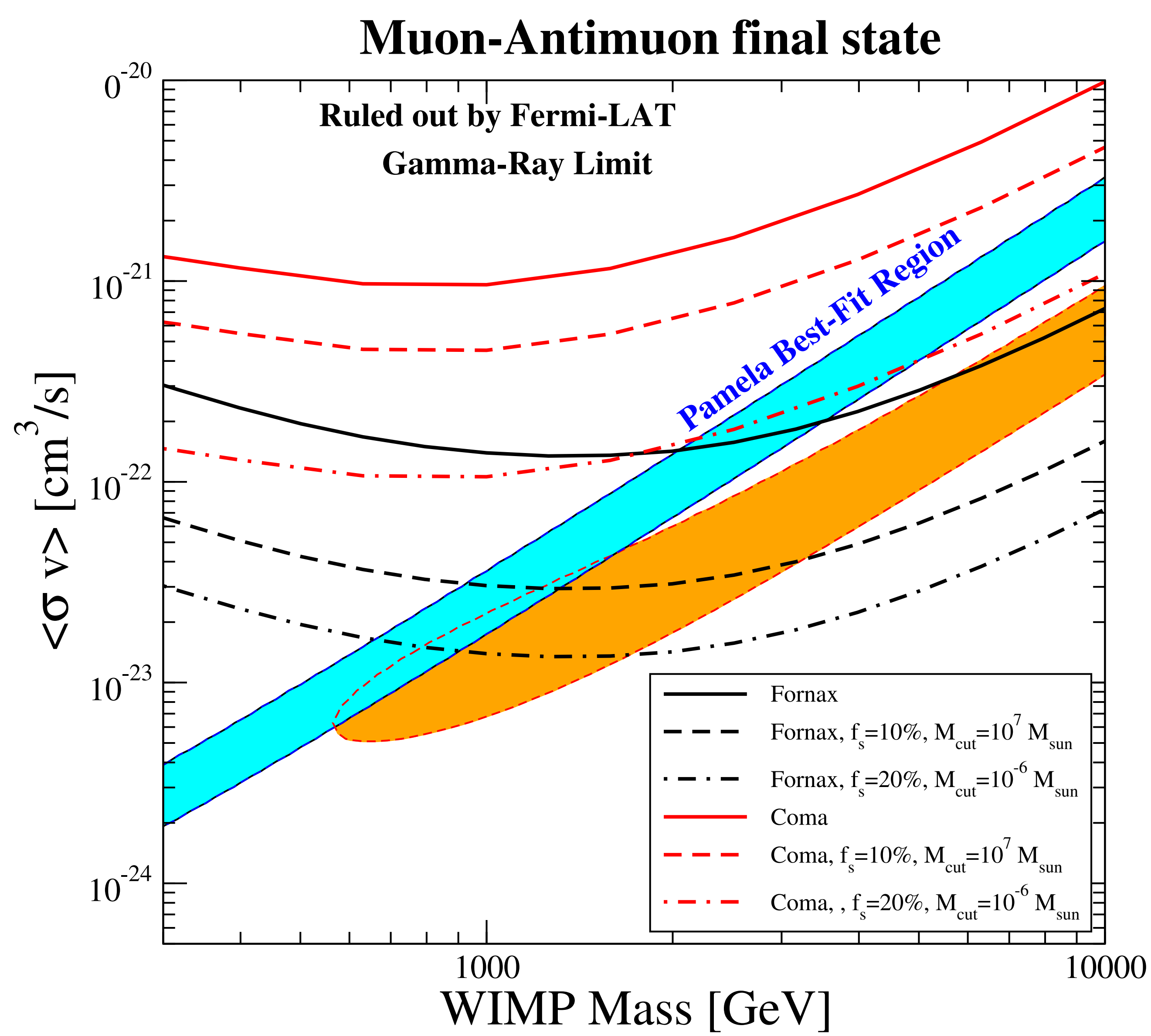
Testing Particle Physics with Astronomical Sources

Final State	Dominant Signals
$W^{\pm}$, Z, gluon, quarks (u, d, c, s, t, b)	p, $\bar{p}$, D, $\bar{D}$, $e^{\pm}$, γ, ν
e	$e^{\pm}$
μ	$e^{\pm}$, ν
τ	$e^{\pm}$, γ, ν
γ	γ
ν	ν

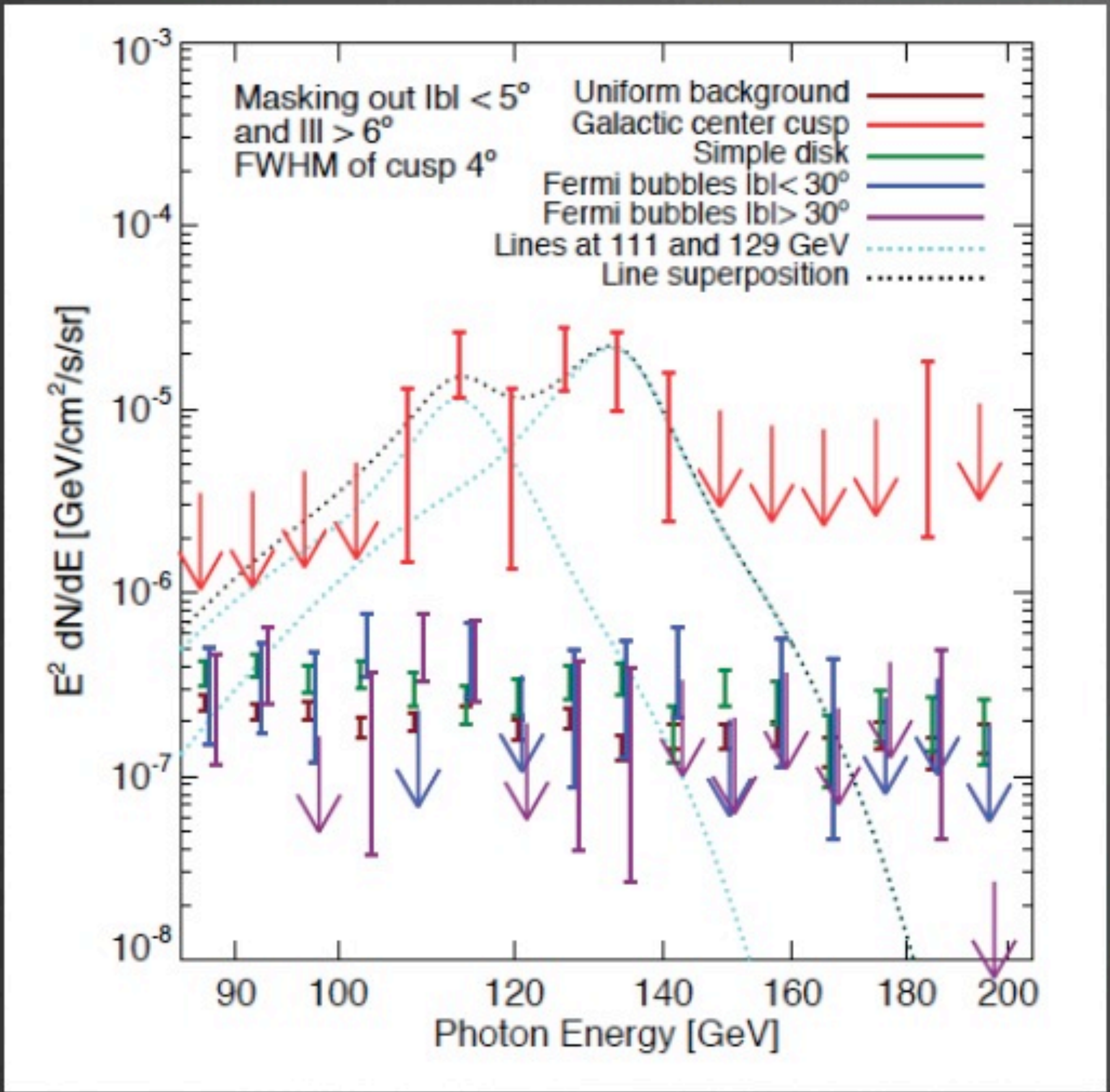
Current status







Not from large scale Fermi bubbles



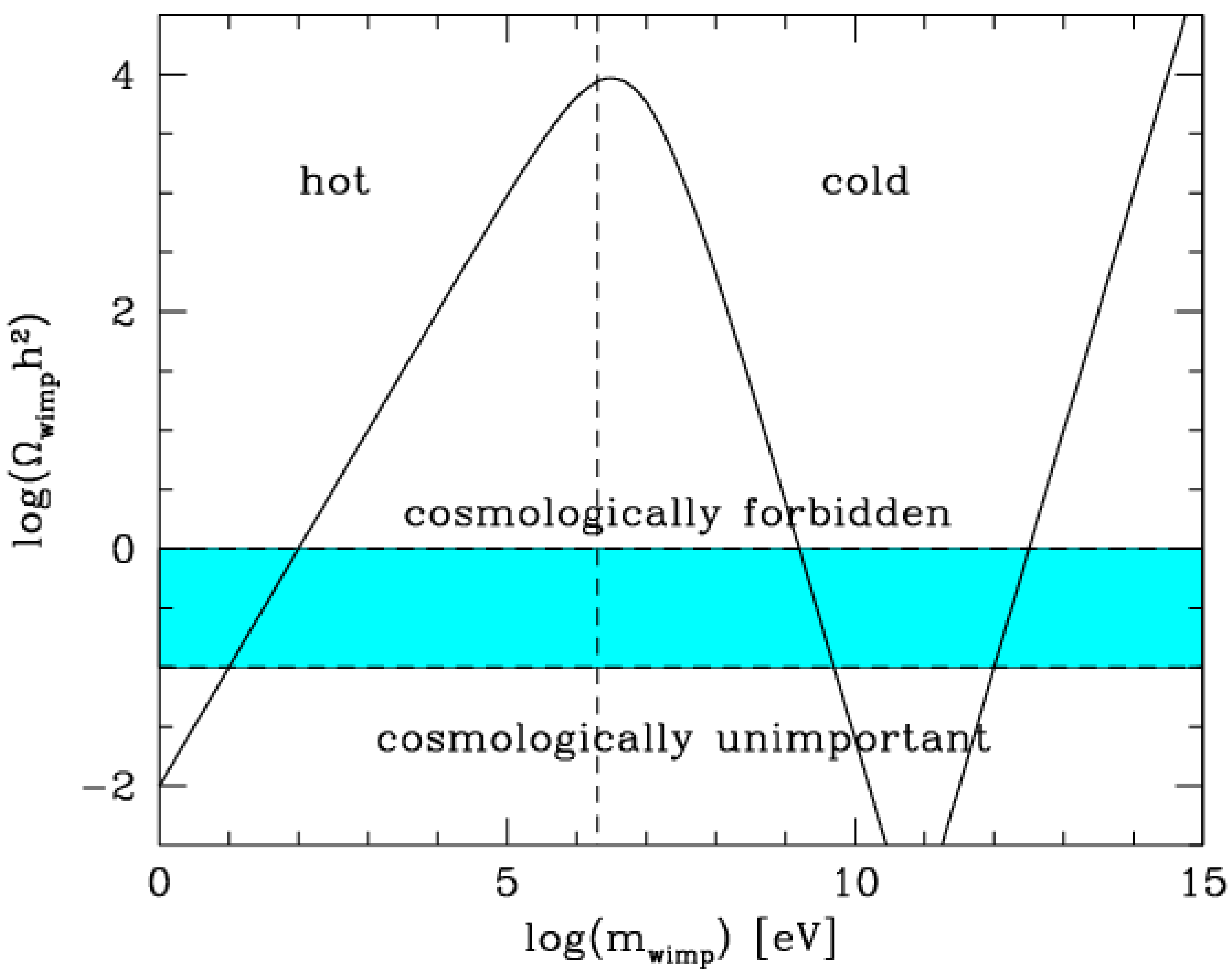
1) $\chi+\chi \rightarrow \gamma+\gamma$

2): $\chi+\chi \rightarrow Z^0+\gamma$

$E\,\gamma = m_x - M_z^2/4m_x$

A pair of lines at
110.8±4.4 GeV and 128.8±2.7 GeV

Consistent with single line at
127.3 ± 2.7 GeV



hot
cold
cosmologically forbidden
cosmologically unimportant
4
2
0
−2
0
5
10
15
log($\Omega_{wimp}h^2$)
log(m_{wimp}) [eV]

120 GeV ????

Conclusions

- Current cosmology and particle physics are closed linked
- Cosmology provides a testbed for particle physics that is difficult to have in lab.
- Universities have an advantage here