

**Galaxy clusters
as
cosmological probes**

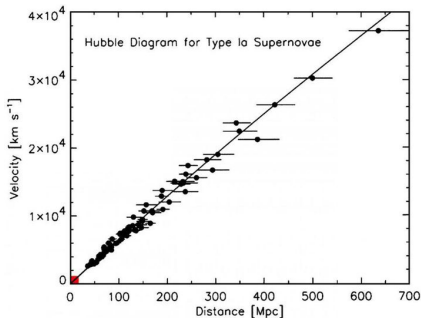
Basics of cosmology

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- Hubble constant

$$\mathbf{v} = H_0 \mathbf{r}$$

$$h = \frac{H_0}{100 \text{ km s}^{-1} \text{ Mpc}^{-1}}$$



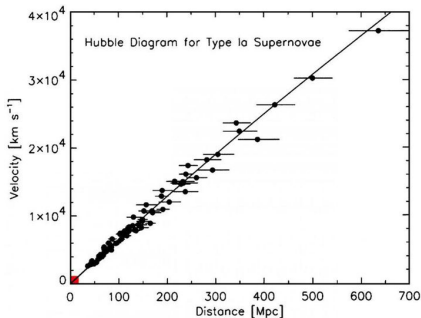
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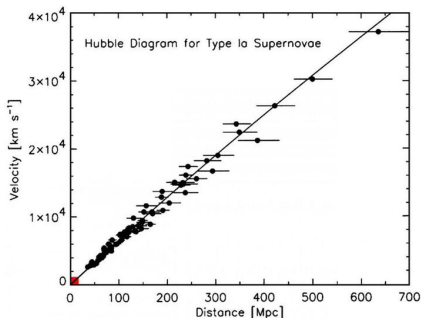
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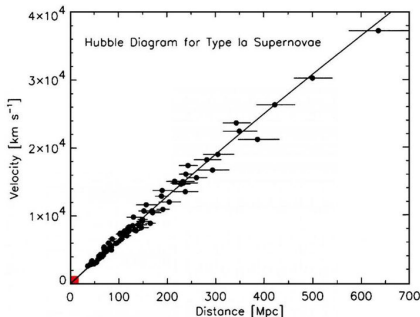
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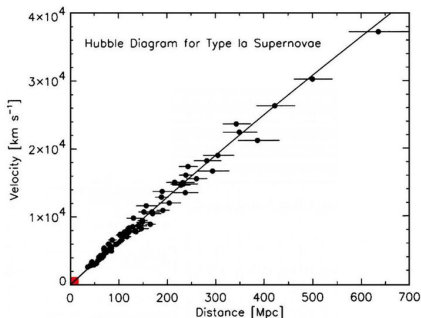
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$$\Omega \equiv \Omega_m + \Omega_\Lambda + \dots = 1 - \Omega_k$$



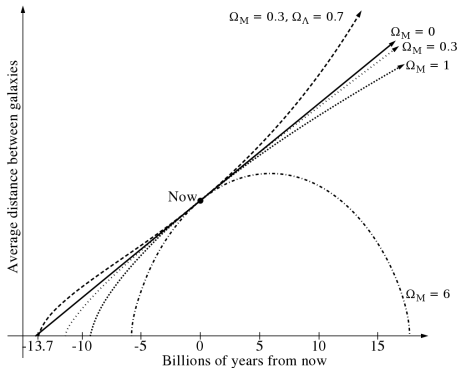
Cosmologies

$$p = w\rho c^2$$

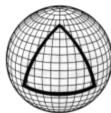
$$w(a) = w_0 + w_a(1 + a)$$

Cosmology	Ω	Ω_m	Ω_Λ	Ω_k	w_0	w_a
SCDM	1	1	-	0	-	-
OCDM	< 1	< 1	-	> 0	-	-
Λ CDM	1	≈ 0.3	≈ 0.7	0	-1	-
XCDM	1	≈ 0.3	≈ 0.7	0	$\neq -1$	-
CPL	1	≈ 0.3	≈ 0.7	0	$\neq -1$	$\neq 0$

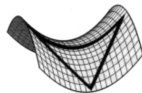
Possible deaths of the Universe



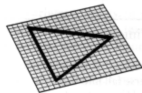
Ω_m	Ω_Λ	w	k	Universe	death
> 1	-	-	> 0	closed	"Big Crunch"
1	-	-	0	flat	"Big Freeze"
< 1	-	-	< 0	open	"Big Freeze"
0.3	0.7	-1	0	flat	"Big Freeze"
0.3	0.7	> -1	0	flat	"Big Freeze"
0.3	0.7	< -1	0	flat	"Big Rip"



Positive Curvature



Negative Curvature



Flat Curvature

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Galaxy clusters I

- virial radius $M_{\text{vir}} = \frac{4\pi}{3} r_{\text{vir}}^3 \Delta_c \rho_c$ $\Delta_c = 200, 500, 2500$

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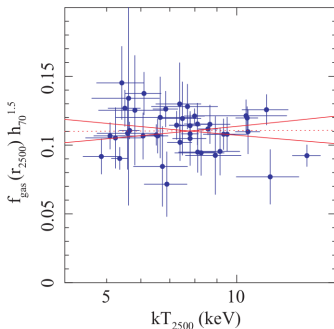
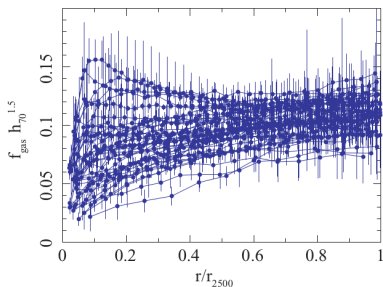
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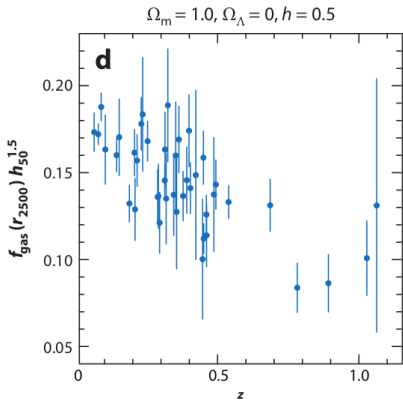
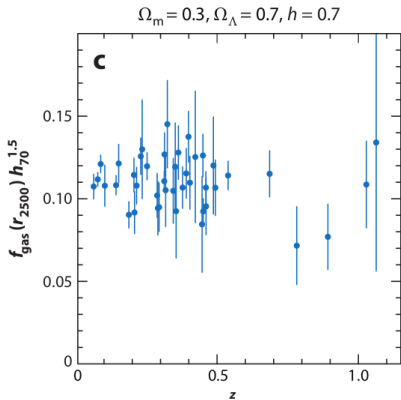
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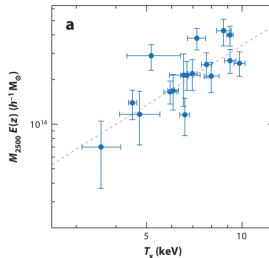
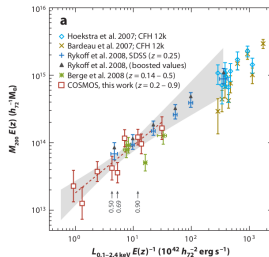
Galaxy clusters I



Galaxy clusters II

- local abundance & evolution
 - scaling relations

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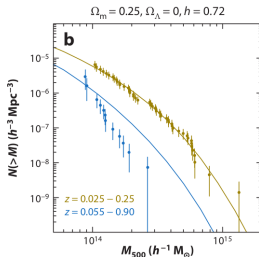
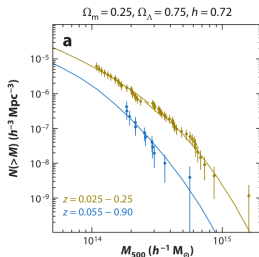


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$$N(> M) = f(M, z)$$

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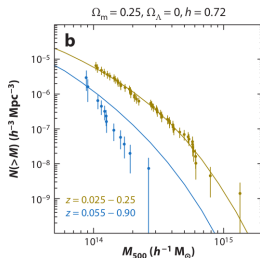
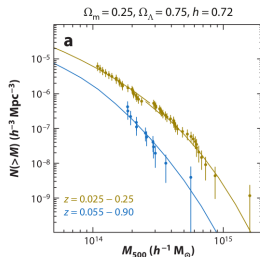
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$$N(> M) = f(M, z)$$

- XSZ distances
 - X-ray observations
 - Sunyaev-Zeldovich effect

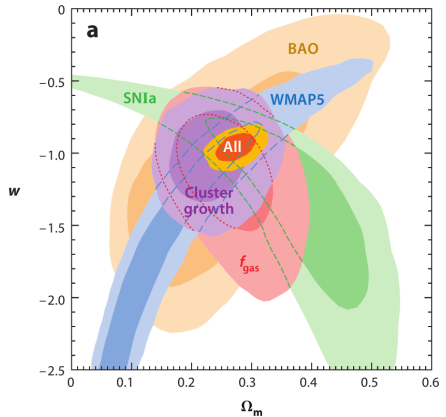
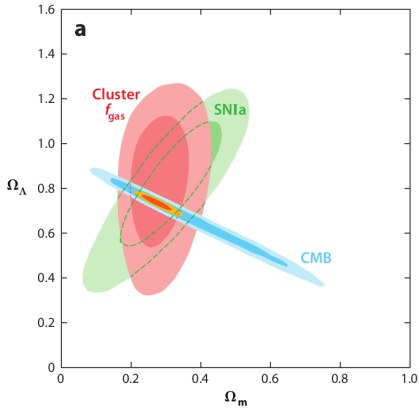
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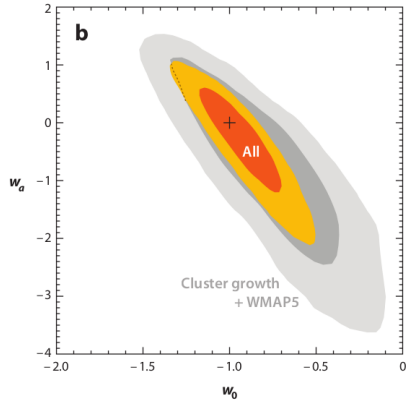
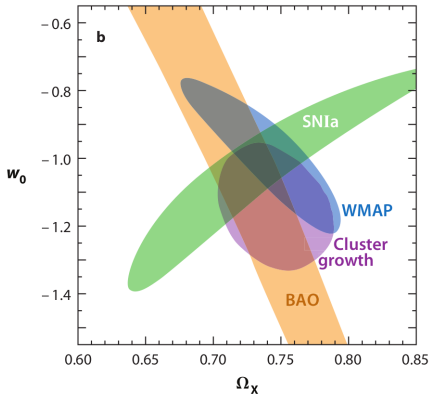
Cosmological constraints

Reference ^c	Data	σ_8	Ω_m	Ω_{DE}	w	b
Local abundance and evolution^d						
M10	X-ray	0.82 ± 0.05	0.23 ± 0.04	$1 - \Omega_m$	-1.01 ± 0.20	
V09	X-ray	0.81 ± 0.04	0.26 ± 0.08	$1 - \Omega_m$	-1.14 ± 0.21	
Local abundance only						
R10	optical	0.80 ± 0.07	0.28 ± 0.07	$1 - \Omega_m$	-1	
H09	X-ray	0.88 ± 0.04	0.3	$1 - \Omega_m$	-1	
Local abundance and clustering						
S03	X-ray	$0.71^{+0.13}_{-0.16}$	$0.34^{+0.09}_{-0.08}$	$1 - \Omega_m$	-1	
Gas-mass fraction						
A08	X-ray		0.27 ± 0.06	0.86 ± 0.19	-1	
A08	X-ray		0.28 ± 0.06	$1 - \Omega_m$	$-1.14^{+0.27}_{-0.35}$	
E09	X-ray		0.32 ± 0.05	$1 - \Omega_m$	$-1.1^{+0.7}_{-0.6}$	
L06	X-ray+SZ		$0.40^{+0.28}_{-0.20}$	$1 - \Omega_m$	-1	
XSZ distances						
B06	X-ray+SZ		0.3	$1 - \Omega_m$	-1	$0.77^{+0.11}_{-0.09}$
S04	X-ray+SZ		0.3	$1 - \Omega_m$	-1	0.69 ± 0.08

Cosmological constraints



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References

<https://arxiv.org/abs/0706.0033>

<https://arxiv.org/abs/astro-ph/0405340>

<https://arxiv.org/abs/1103.4829>

Quiz!

Go to www.menti.com

and use the code **81 88 20 1**