2018.08.31, IAU Focus Meeting: Warm and Hot Baryonic Matter In the Cosmos

The Hot Baryons Contained in the Circum-Galactic Medium Around Massive Isolated Spiral Galaxies

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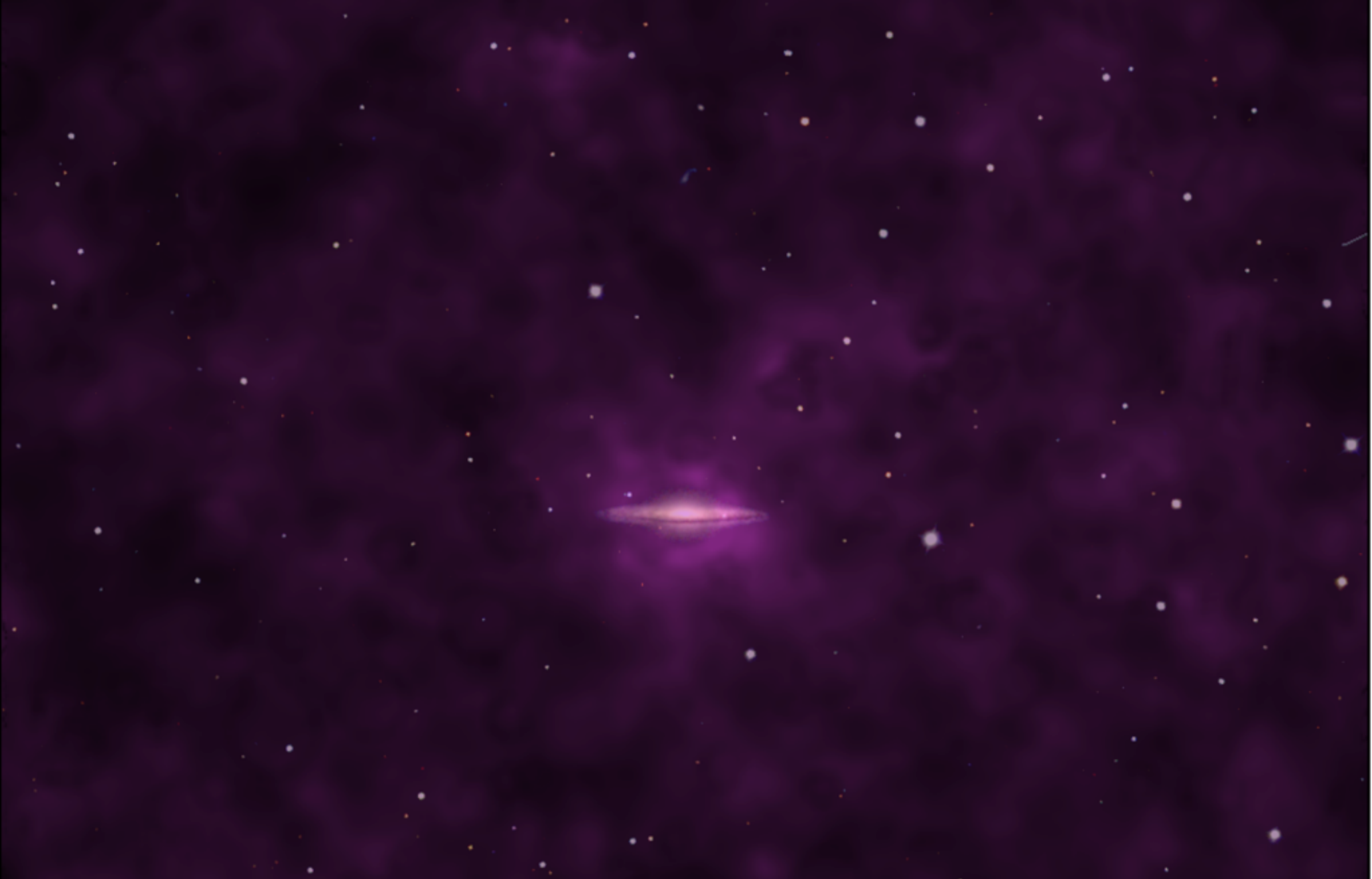
Collaborators: **Joel N. Bregman** (UMich); **Q. Daniel Wang** (UMass); **Robert A. Crain** (Liverpool John Moores U); **Michael E. Anderson** (MPIA); **Shangjia Zhang** (Now a graduate student in U Nevada, Las Vegas)

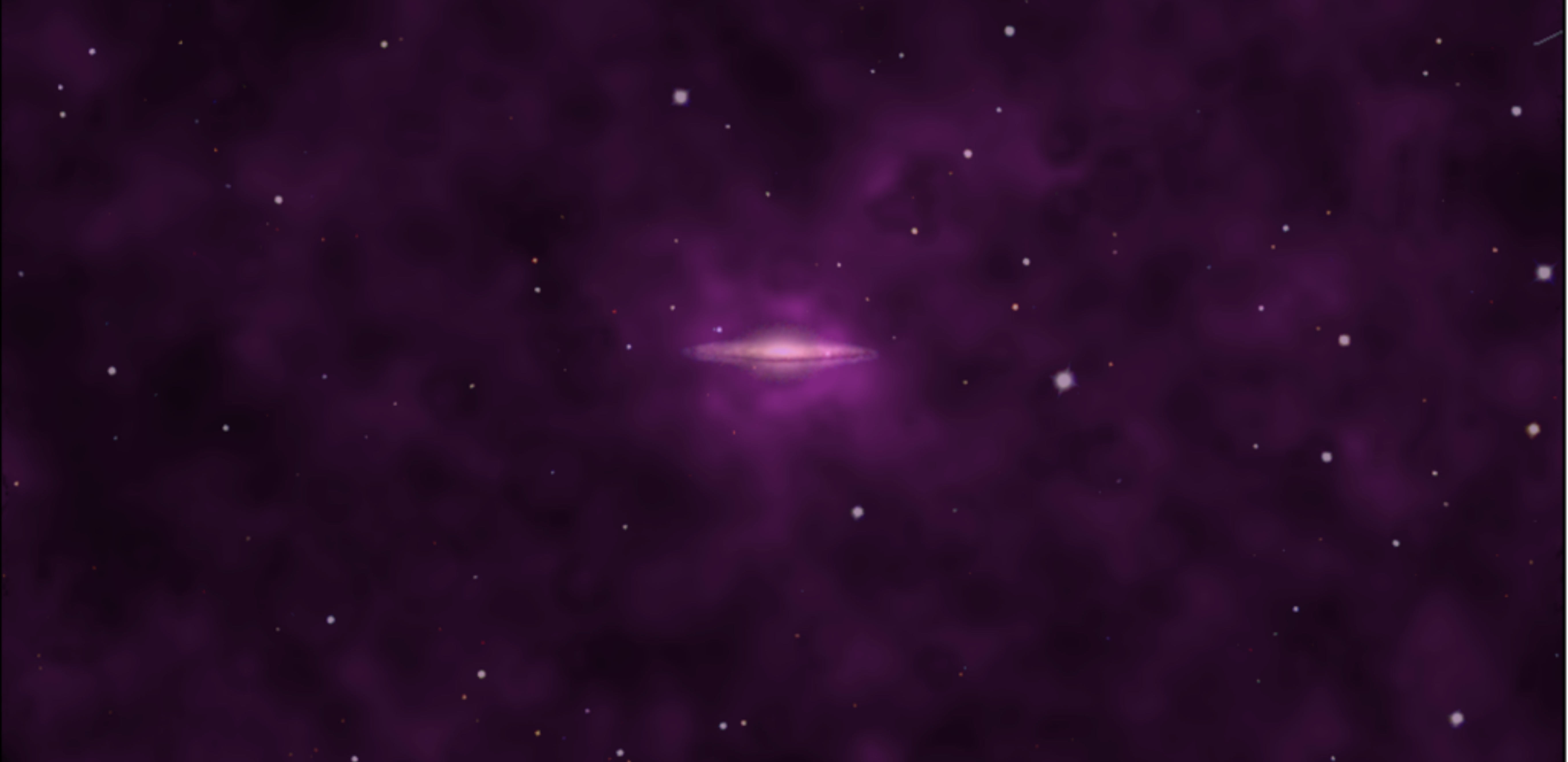
Papers of the Circum-Galactic Medium of MASsive Spirals (**CGM-MASS**) project:
Paper I: NGC5908 (2016, ApJ, 830, 134)
Paper II: Sample and statistical analysis (2017, ApJS, 233, 20)
Paper III: Stacking analysis (2018, ApJL, 855, 24)



ESA press release image of CGM-MASS

https://www.esa.int/Our_Activities/Space_Science/Where_is_the_Universe_s_missing_matter

The extended hot circum-galactic medium (CGM) potentially contains a large fraction of the missing baryons.



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The radial extension, dynamical state, metallicity, total mass of hot CGM and their dependence on other galaxy properties.

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The **extended hot circum-galactic medium (CGM)** potentially contains a large fraction of the missing baryons.

The radial extension, dynamical state, metallicity, total mass of hot CGM and their dependence on other galaxy properties.

Massive isolated spiral: **massive** enough as a closed box of baryons and the virial temperature in X-ray emitting range, and **clean** enough in environment and formation history, not seriously affected by current feedback and mergers.

ESA press release image of CGM-MASS

https://www.esa.int/Our_Activities/Space_Science/Where_is_the_Universe_s_missing_matter

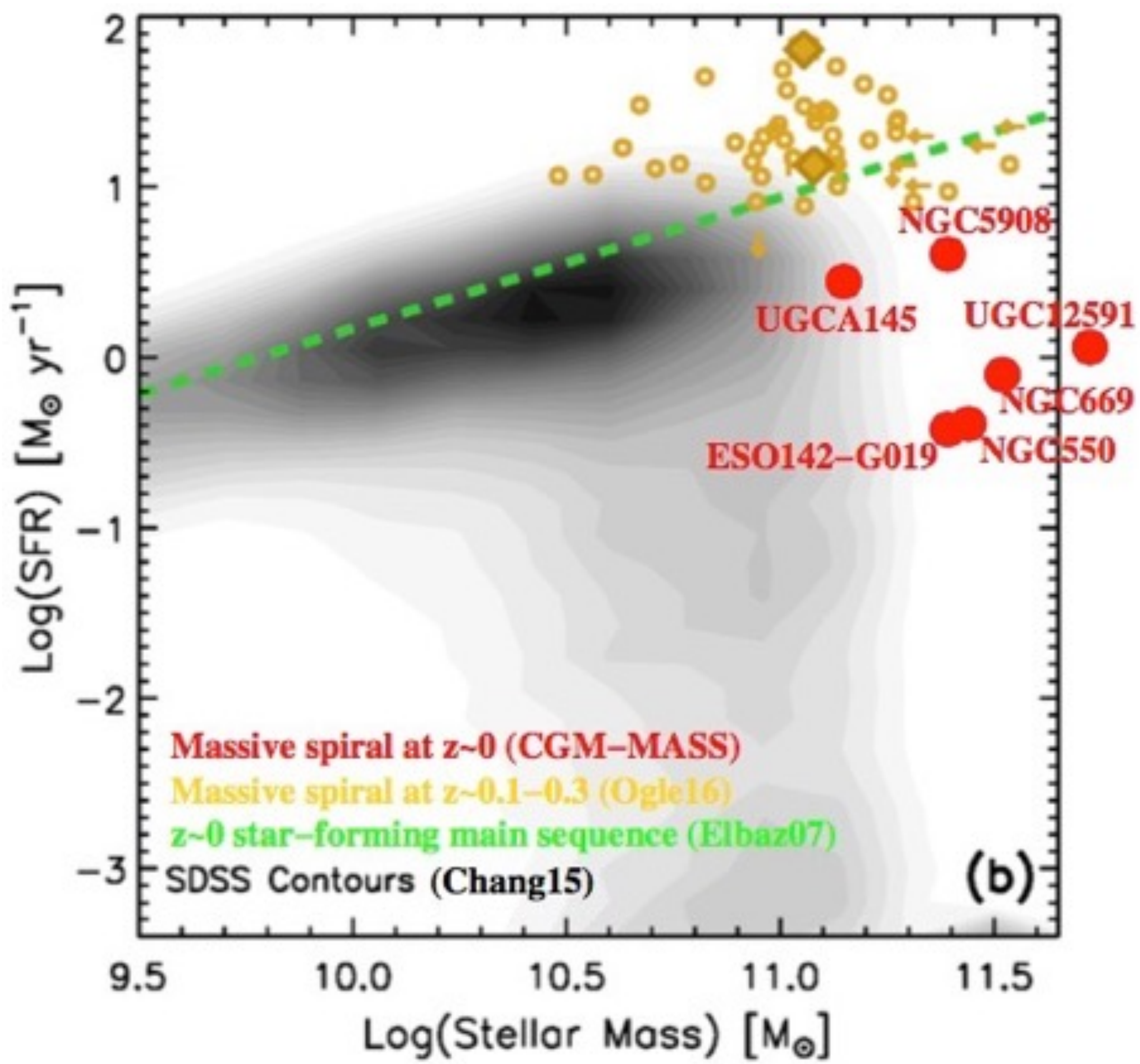
The CGM-MASS Sample

Name	Dist	v_{rot}	$\log M_*$	SFR	$\log M_{200}$	r_{200}	ObsID	t_{XMM}
	Mpc	km/s	$\log M_\odot$	$M_\odot$ yr^{-1}	$\log M_\odot$	kpc (arcm)		ks
NGC 669	77.8	356.1	11.58	4.4	12.94	428 (18.9)	0741300201	123.9
ESO142-G019	64.6	351.3	11.39	0.7	12.92	422 (22.5)	0741300301	91.9
NGC 5908	51.9	347.5	11.45	8.9	12.91	417 (27.6)	0741300101	45.5
UGCA 145	69.3	329.1	11.43	5.7	12.83	393 (19.5)	0741300401	111.6
NGC 550	93.1	317.9	11.56	-	12.78	379 (14.0)	0741300501	73.0
+UGC12591							0741300601	75.0

Selected from 7678 giant spirals in NED:

1. Rotation velocity v_{rot}>300 km/s
2. M_*>1.5x10^{11}Msun
3. d<100Mpc
4. Galactic foreground N_H<10^{21}cm^{-2}
5. No bright companion within ~200kpc.

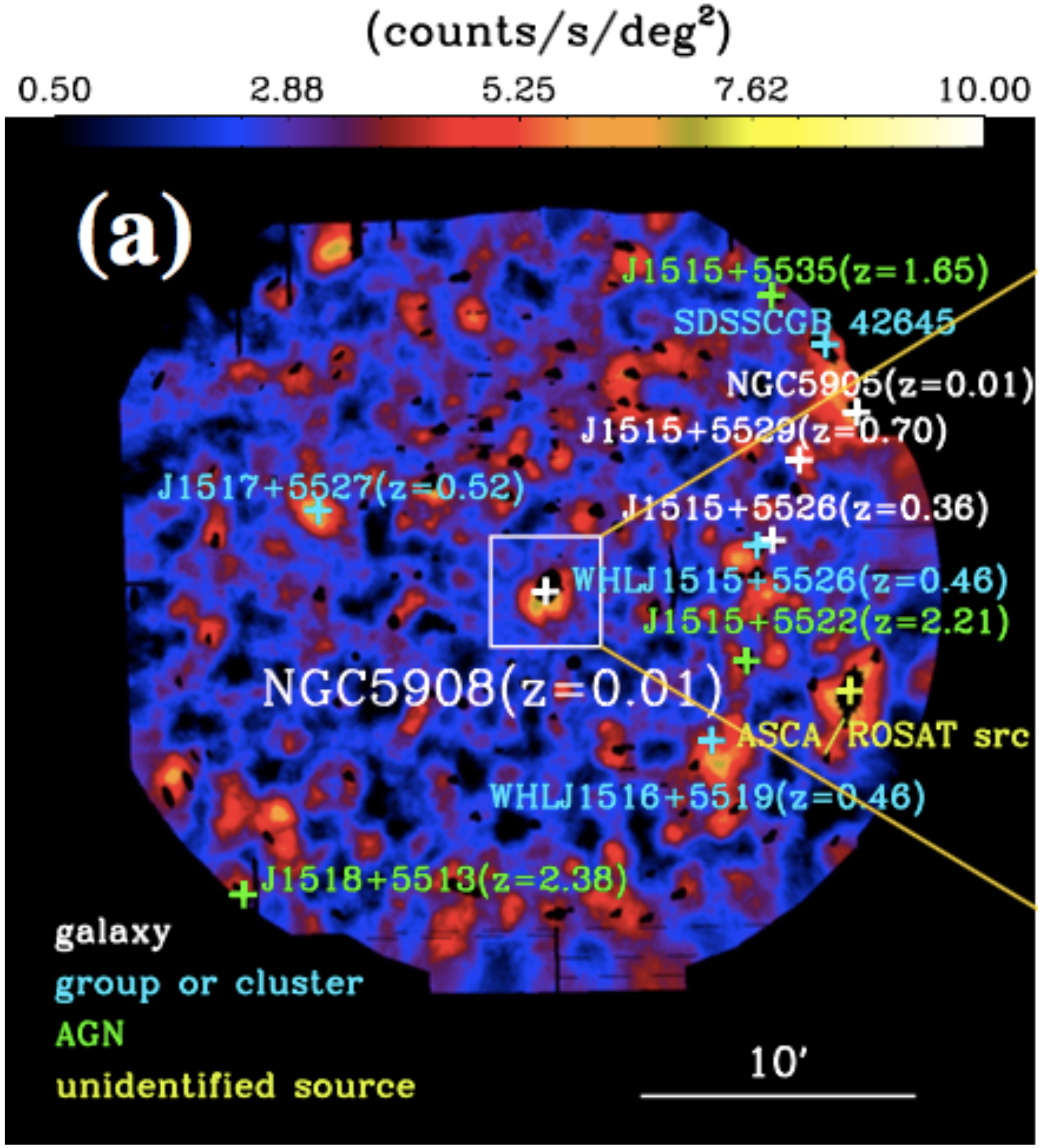
XMM-Newton AO-13/14 Large Program (490 ks; PI: Li Jiang-Tao)

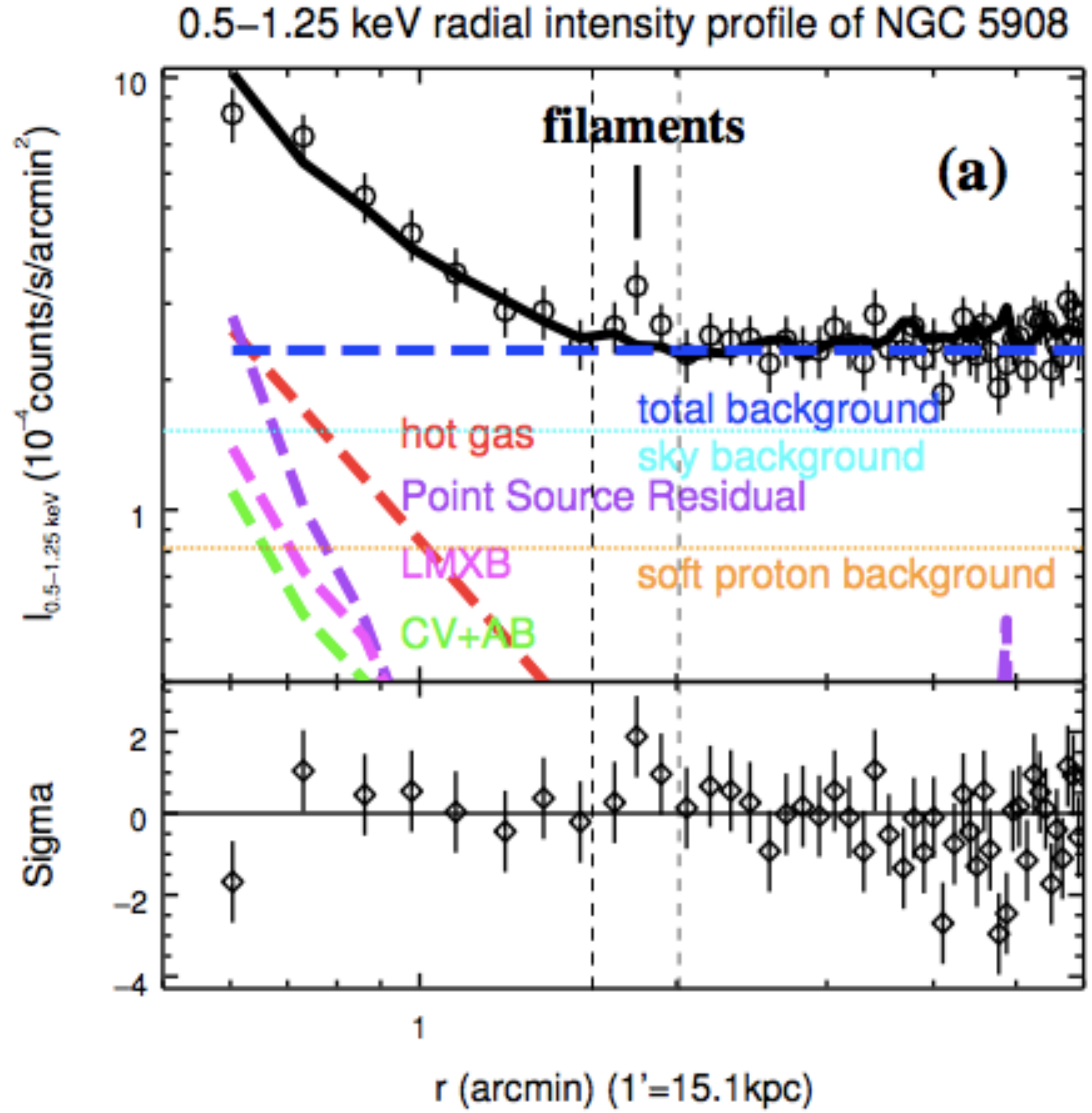


SFR v.s. M_*, originally from Ogle et al. 2016, ApJ, 817, 109

Data Analysis

- XMM-Newton Soft X-ray image of NGC5908 and the surrounding region

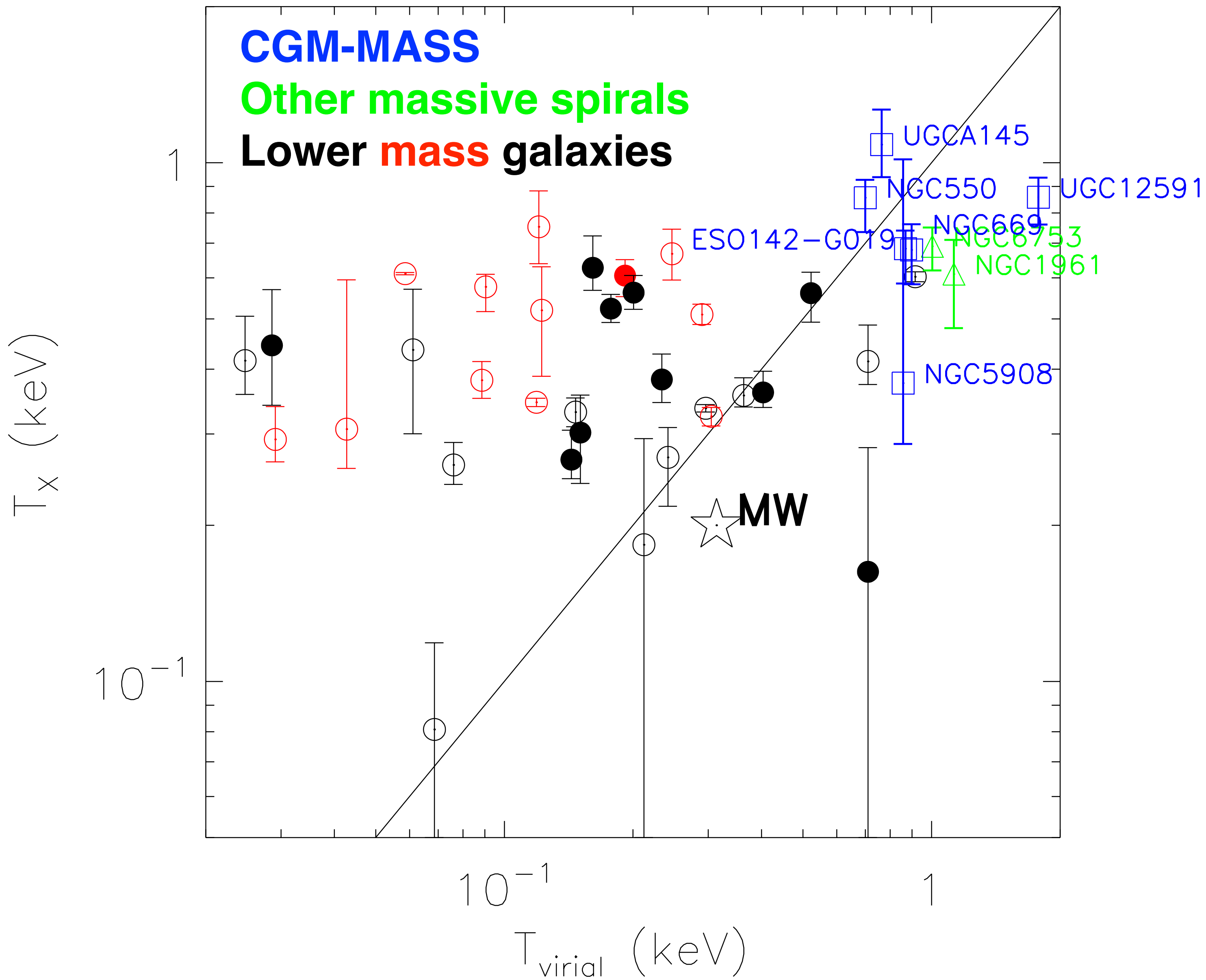




$$I = I_0[1 + (r/r_c)^2]^{0.5-3\beta}$$

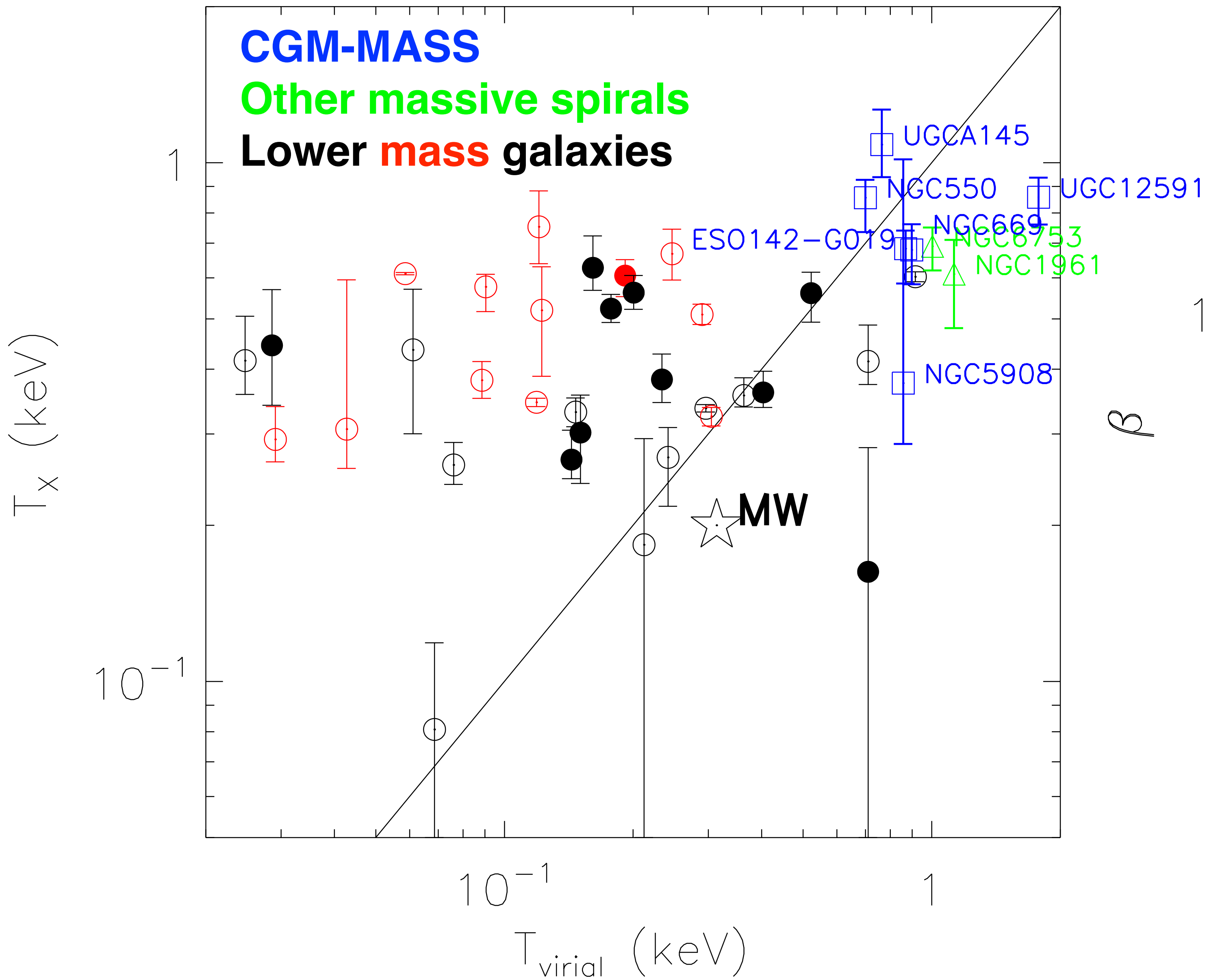
- Fitted with a beta-function plus background and stellar components.

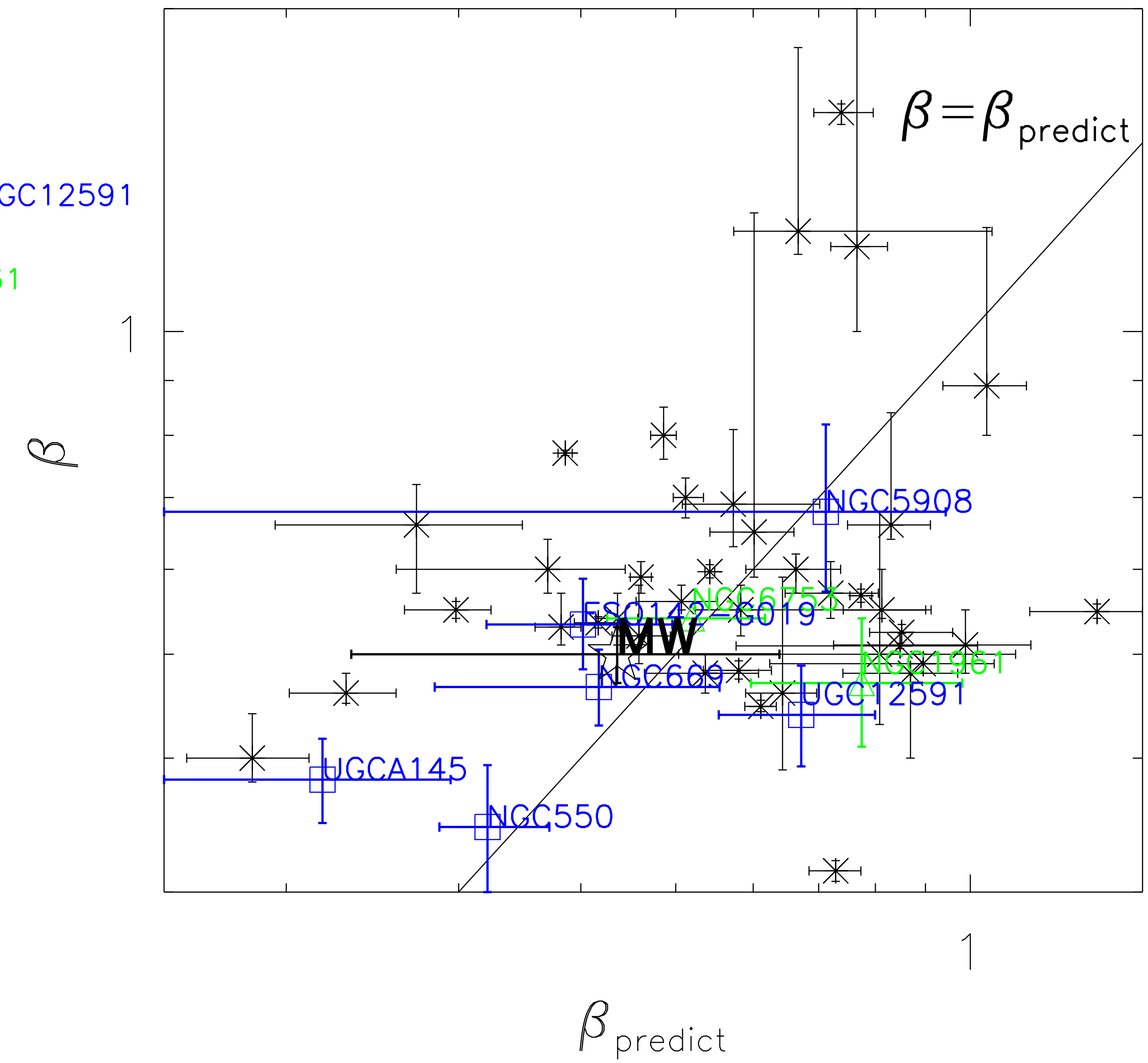
Dynamical state



- For low-mass galaxies, $T_X > T_{virial}$ because of non-gravitational heating, while for massive spirals, $T_X \sim T_{virial}$.

Dynamical state





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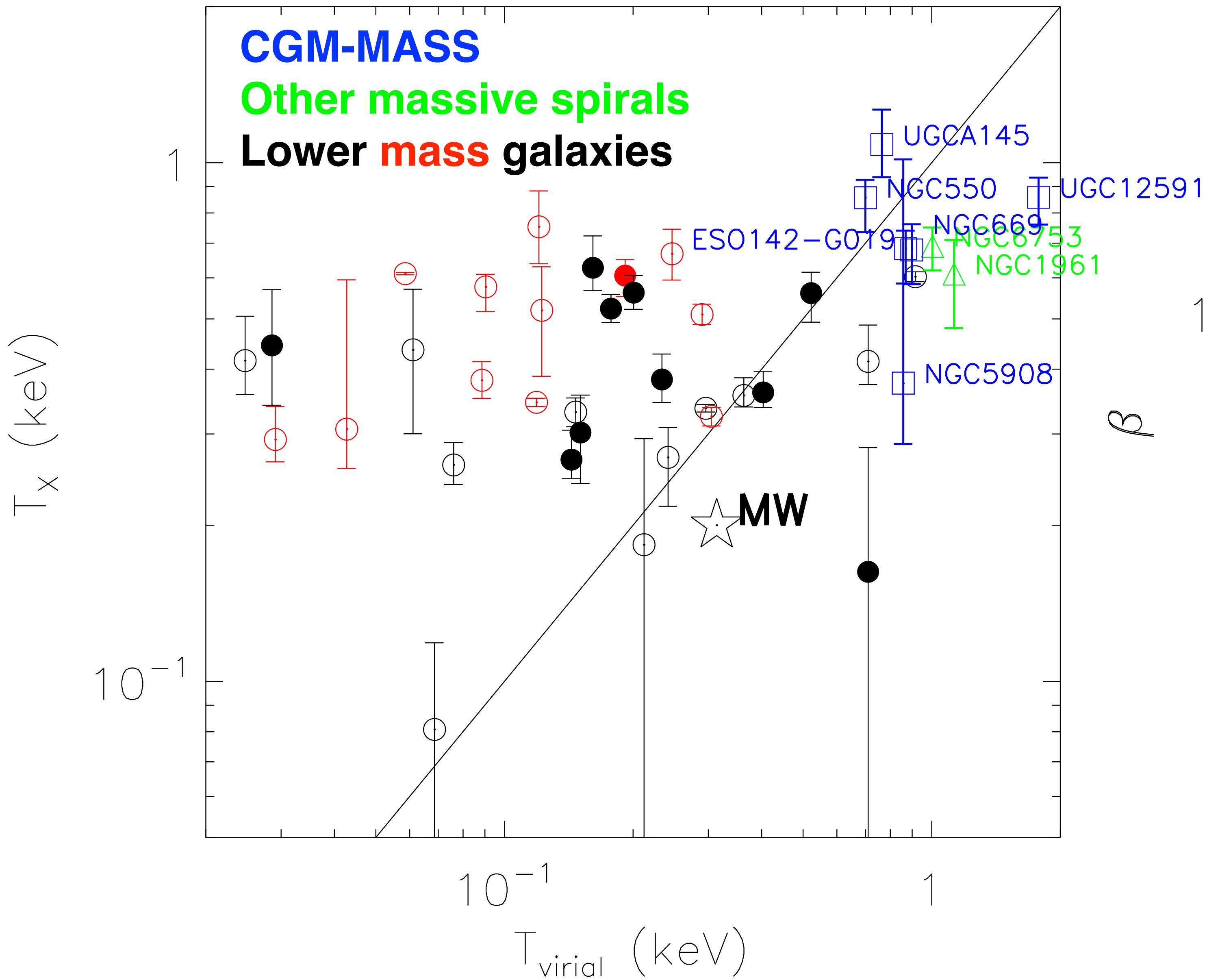

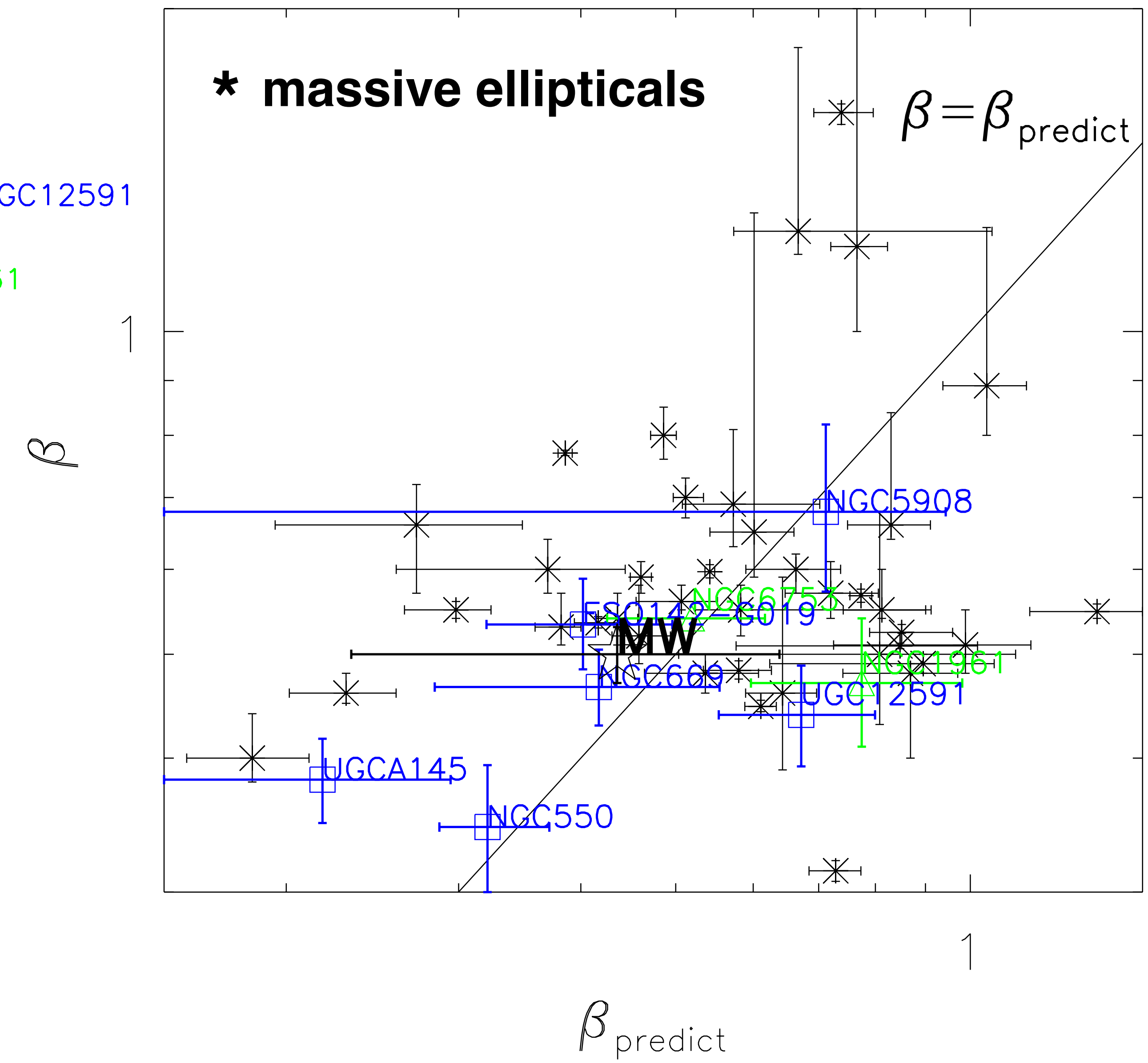

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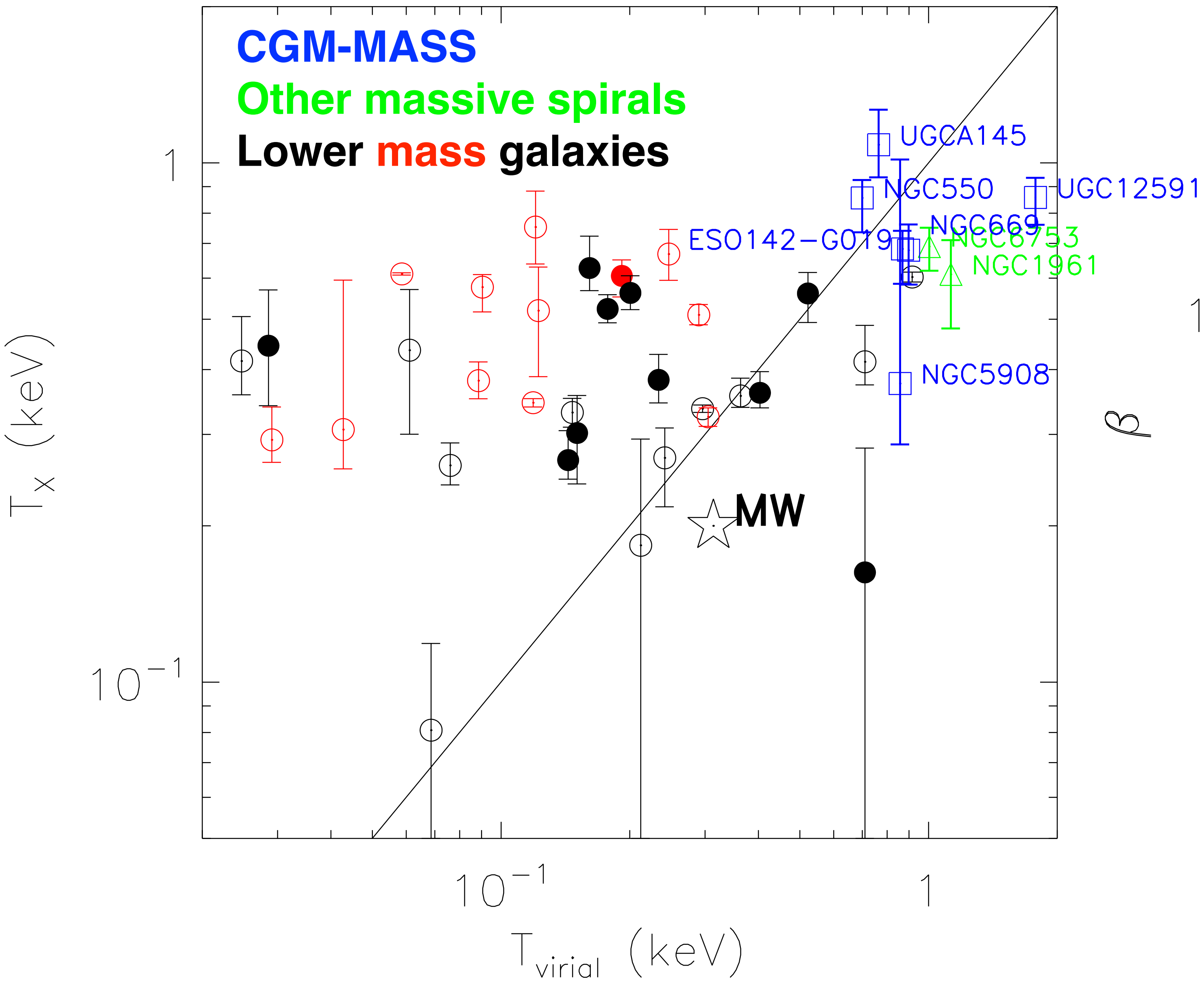

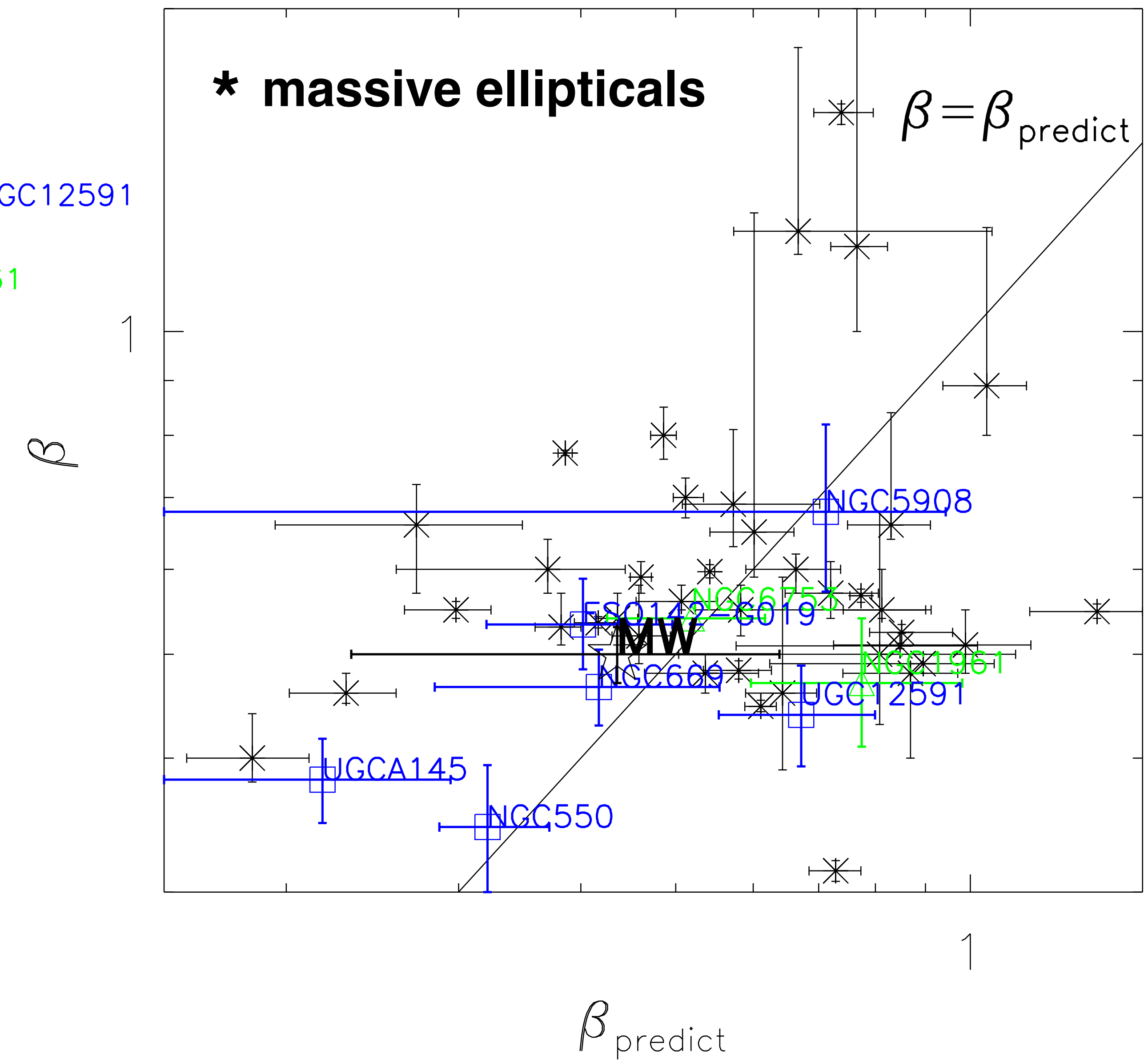

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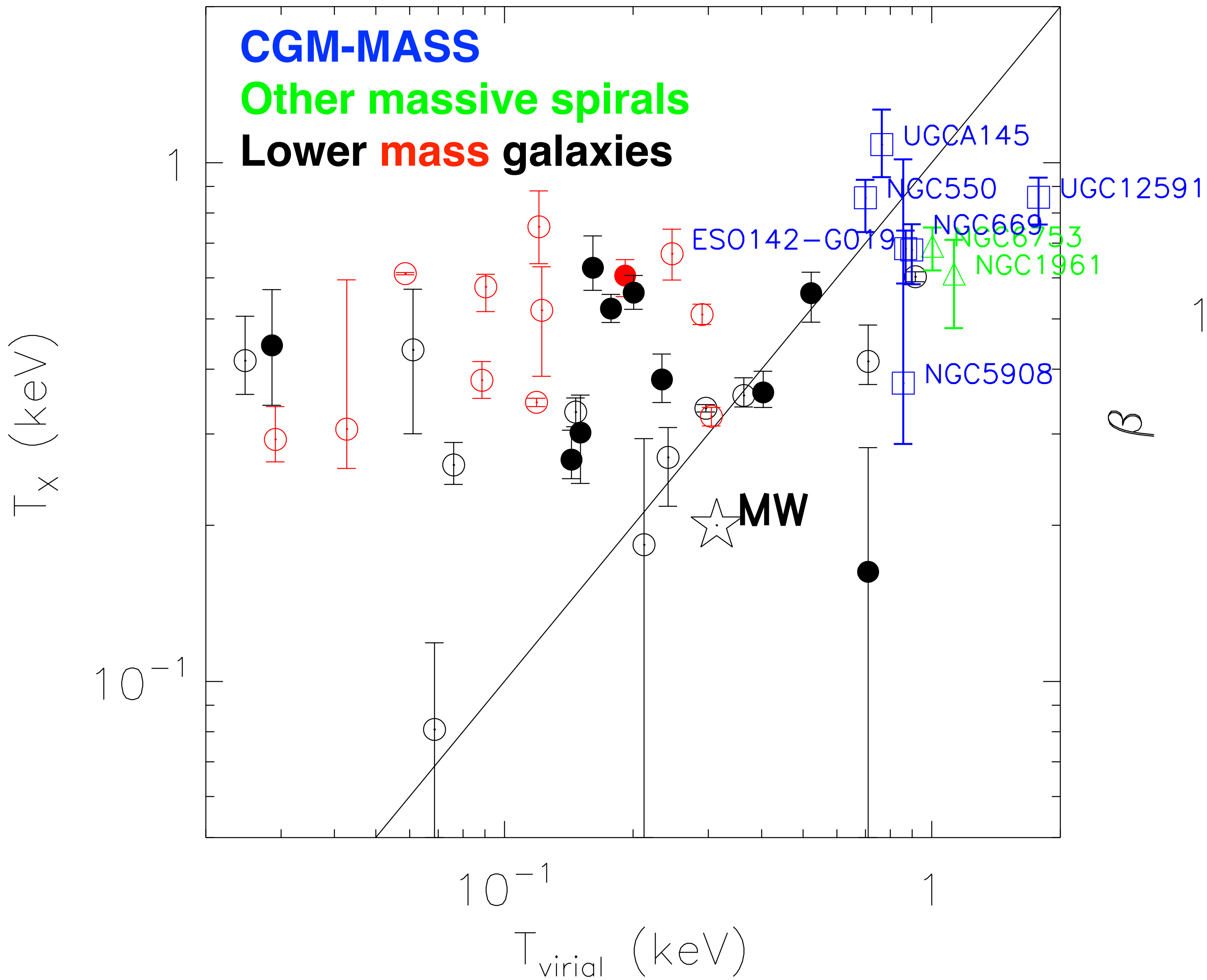
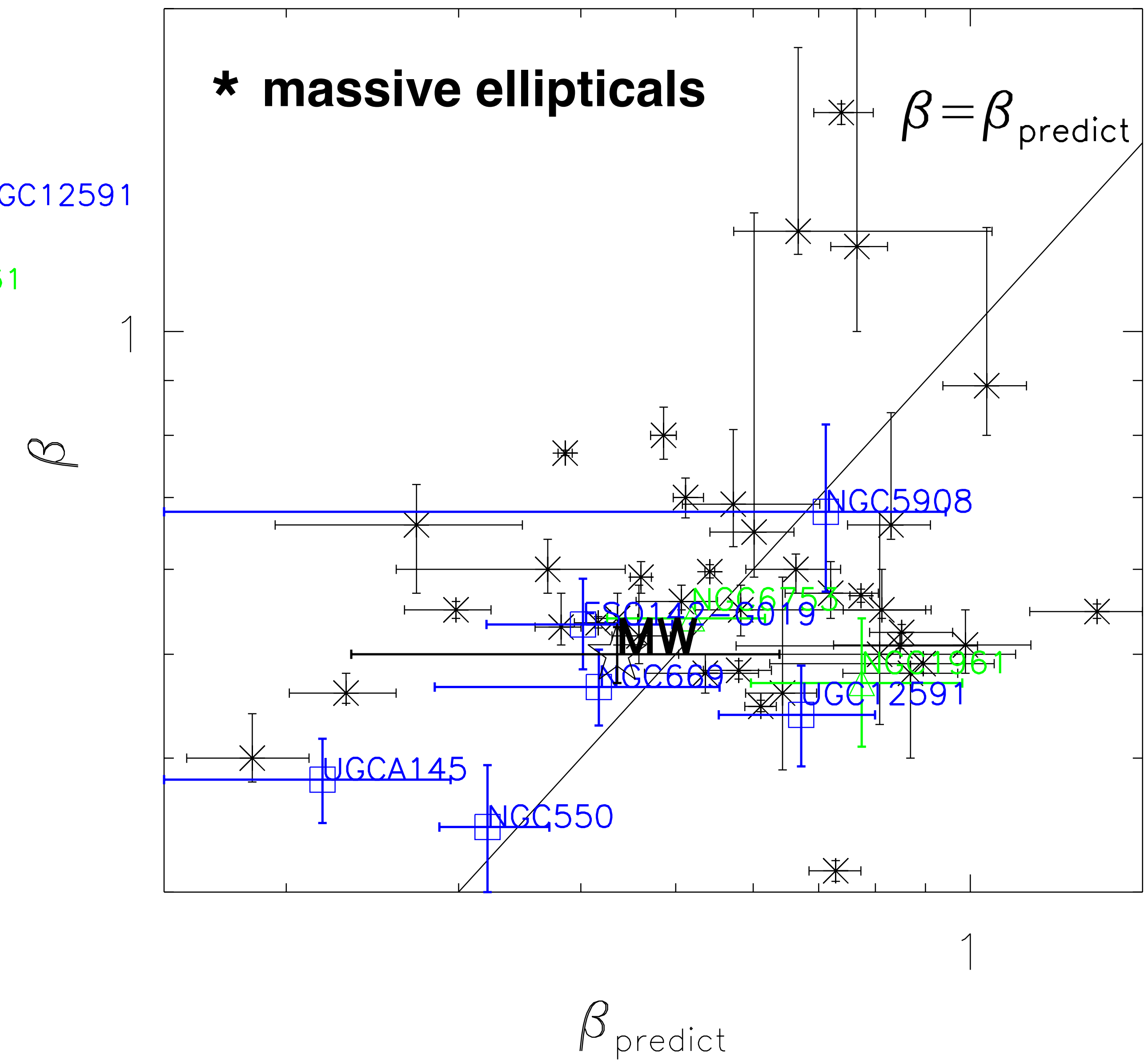
- For an isothermal hydrostatic halo

Dynamical state





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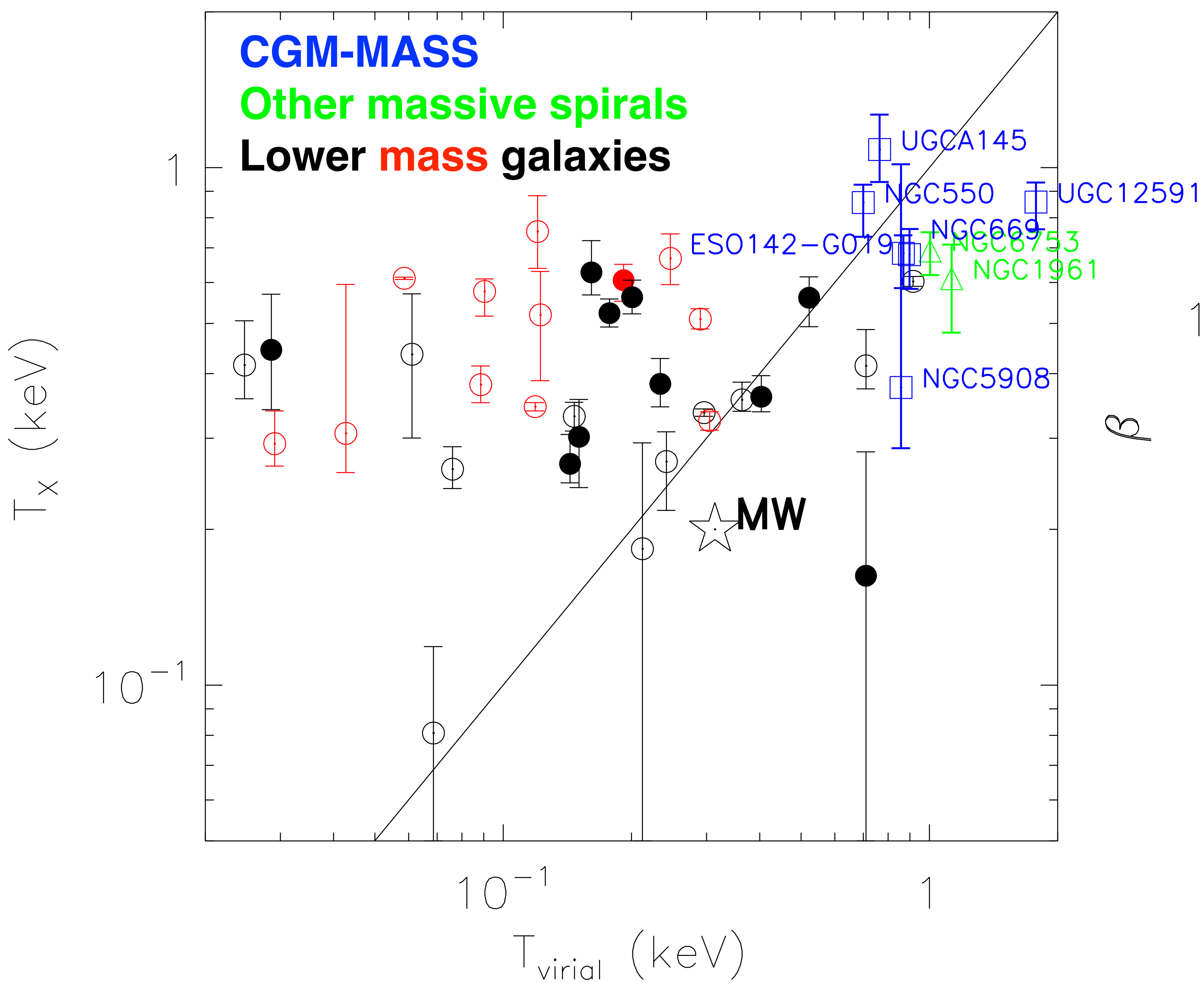
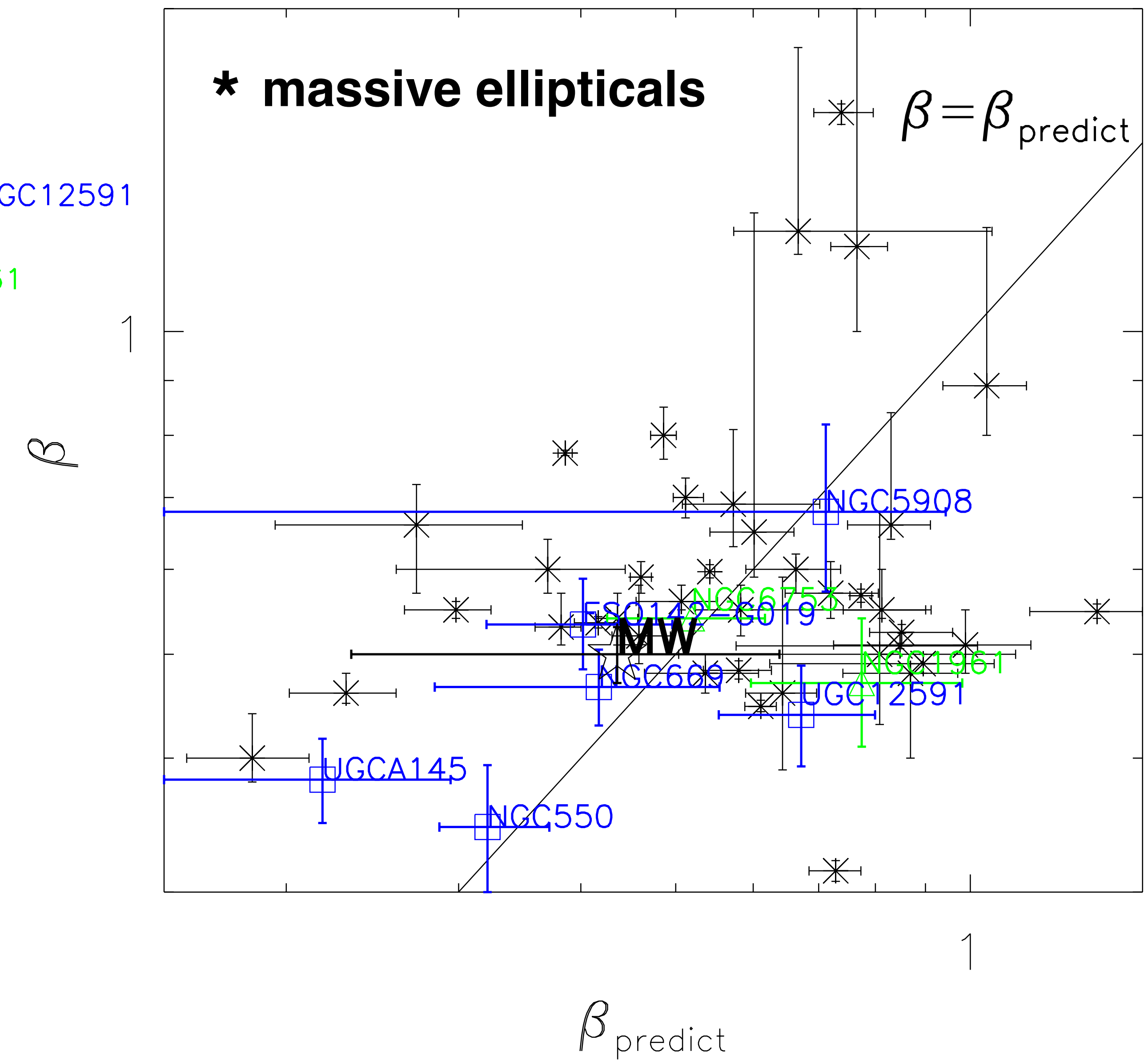
$$\beta_{\rm predict} = \mu m_{\rm H} \sigma_{\rm v}^2 / 3 k_{\rm B} T_{\rm X}$$

Dynamical state





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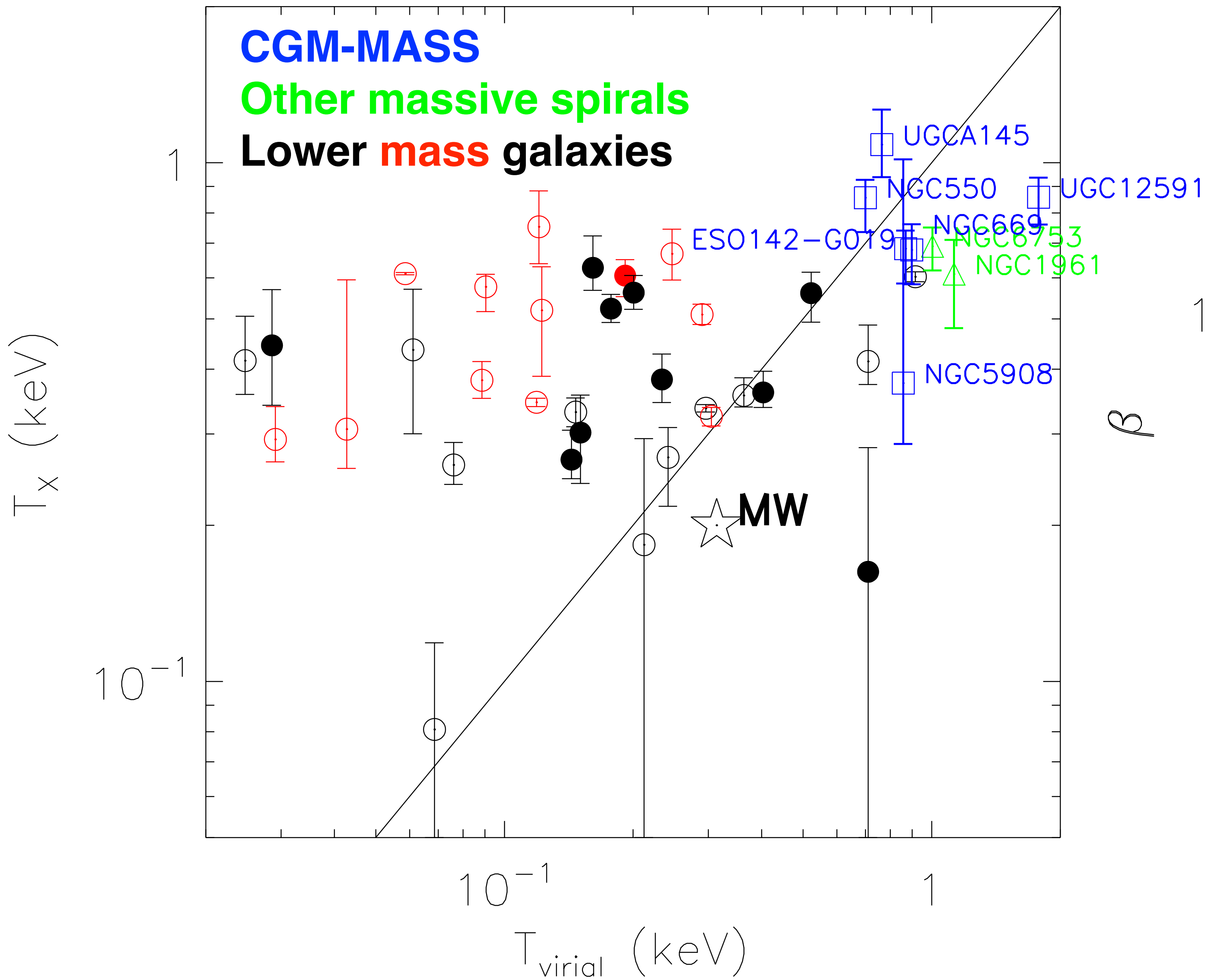

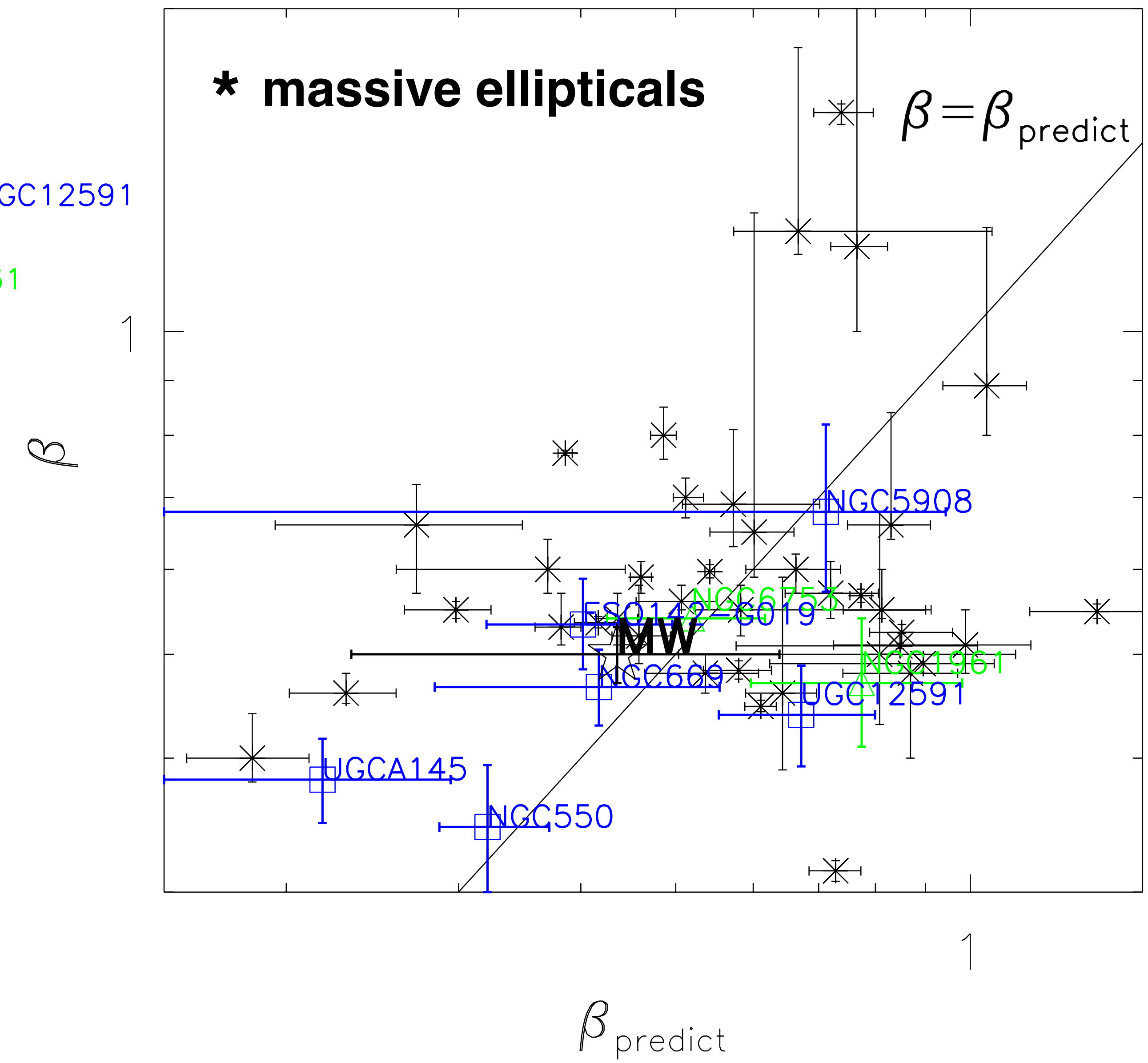

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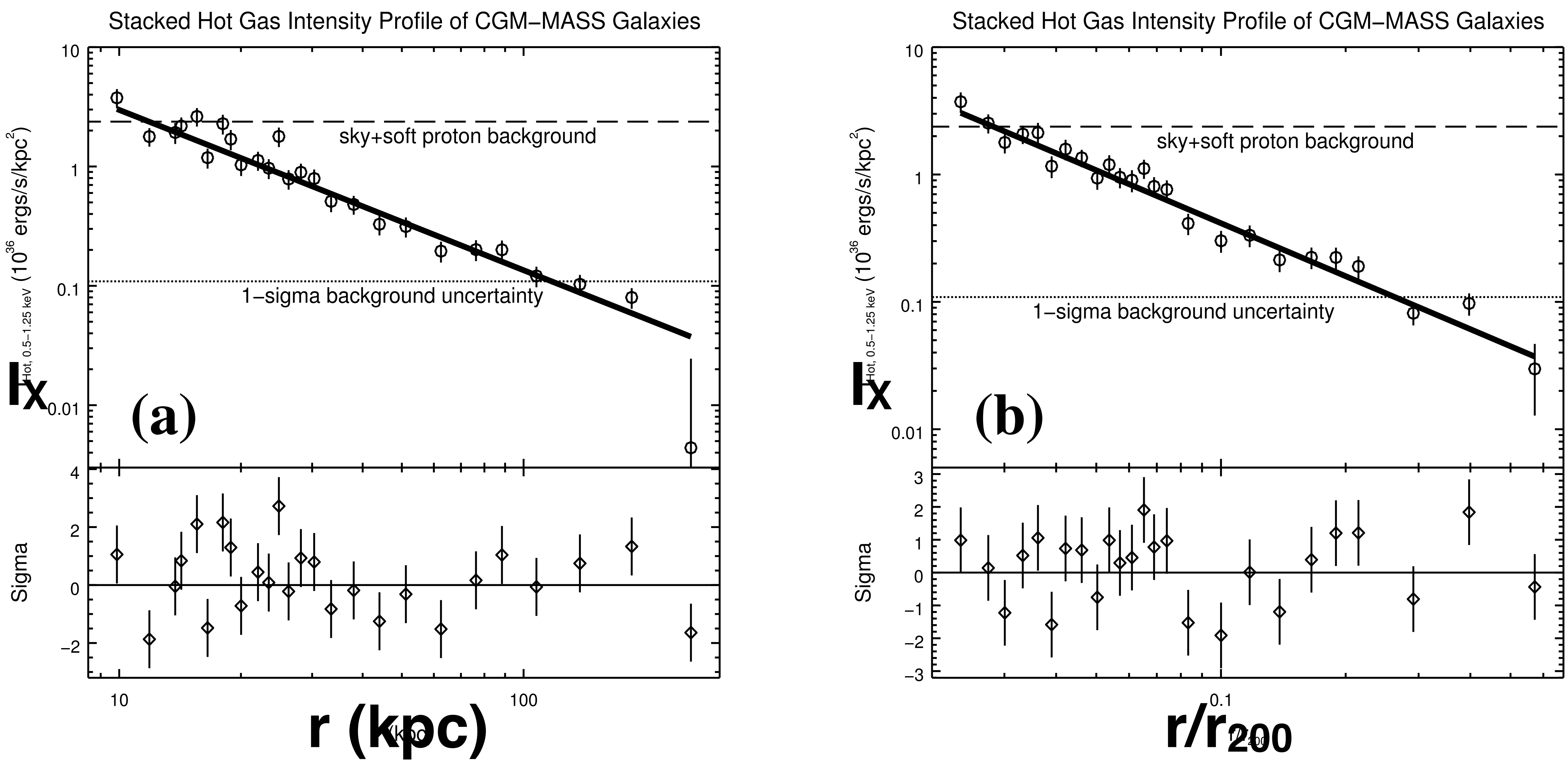
Gravitational heating and a hydrostatic halo?

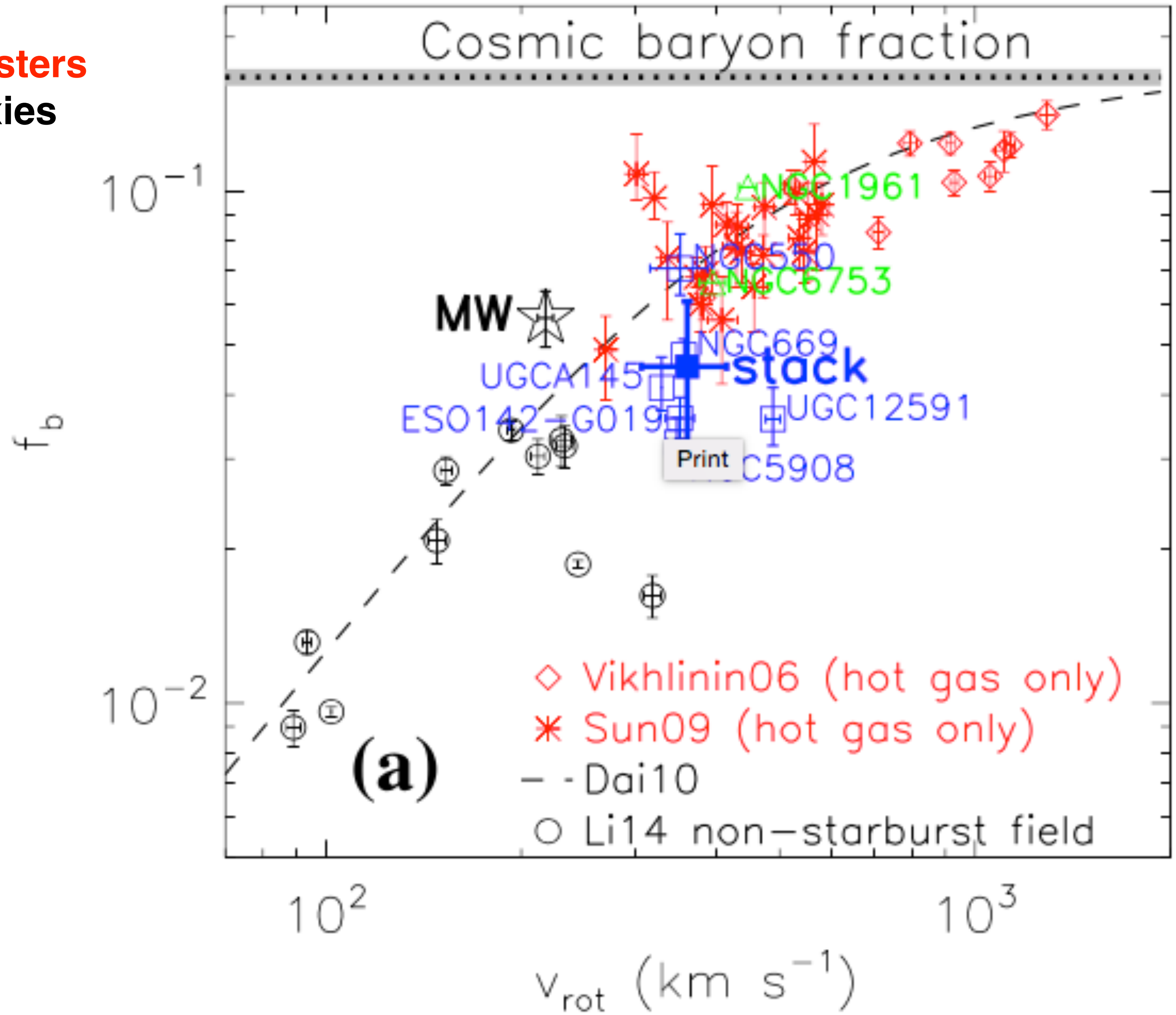
Stacked Radial Soft X-ray Intensity Profile



- Hot gas emission is detected above 1-sigma at r~130kpc~0.25r_{200}. The slope of the soft X-ray intensity profile does not change at r<0.5r_{200}.

Baryon Budget

groups and clusters
low-mass galaxies



- ~(27+-16)% of the expected baryons are detected in stars (M_*~$2.8\times10^{11}M_{sun}$) and the hot CGM [M_{hot}~$1.3\times10^{11}M_{sun}$; ~(8+-4)% of the expected baryons].
- Cold gas being studied with new observations, but typically less important (M_{H2}~$10^{10}M_{sun}$; M_{HI}~$6\times10^9M_{sun}$ for the most gas-rich galaxy NGC5908).

Summary: Mass budget of the hot CGM

- Temperature and radial distribution of hot CGM is largely determined by the gravity of the galaxy.

- The radial distribution of hot CGM follows the same slope to ~$0.5r_{200}$.

- Hot CGM within r_{200} cannot account for the missing baryons (~27% of the expected baryons detected in hot gas and stars), even if we consider a flattened profile at $r>0.5r_{200}$ (~39% in the flattened CGM and stars).

Summary: Mass budget of the hot CGM

<u>Where are the missing baryons?</u>

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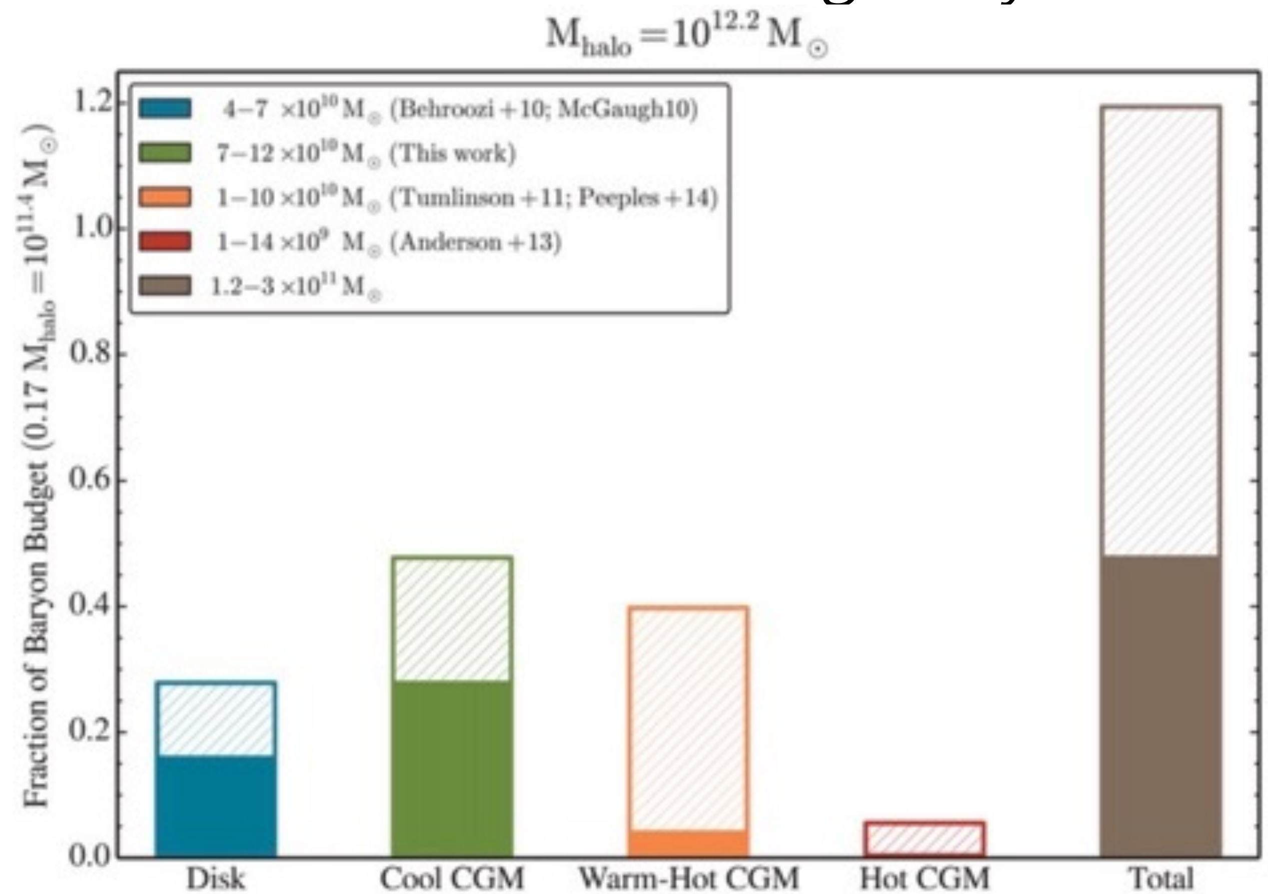

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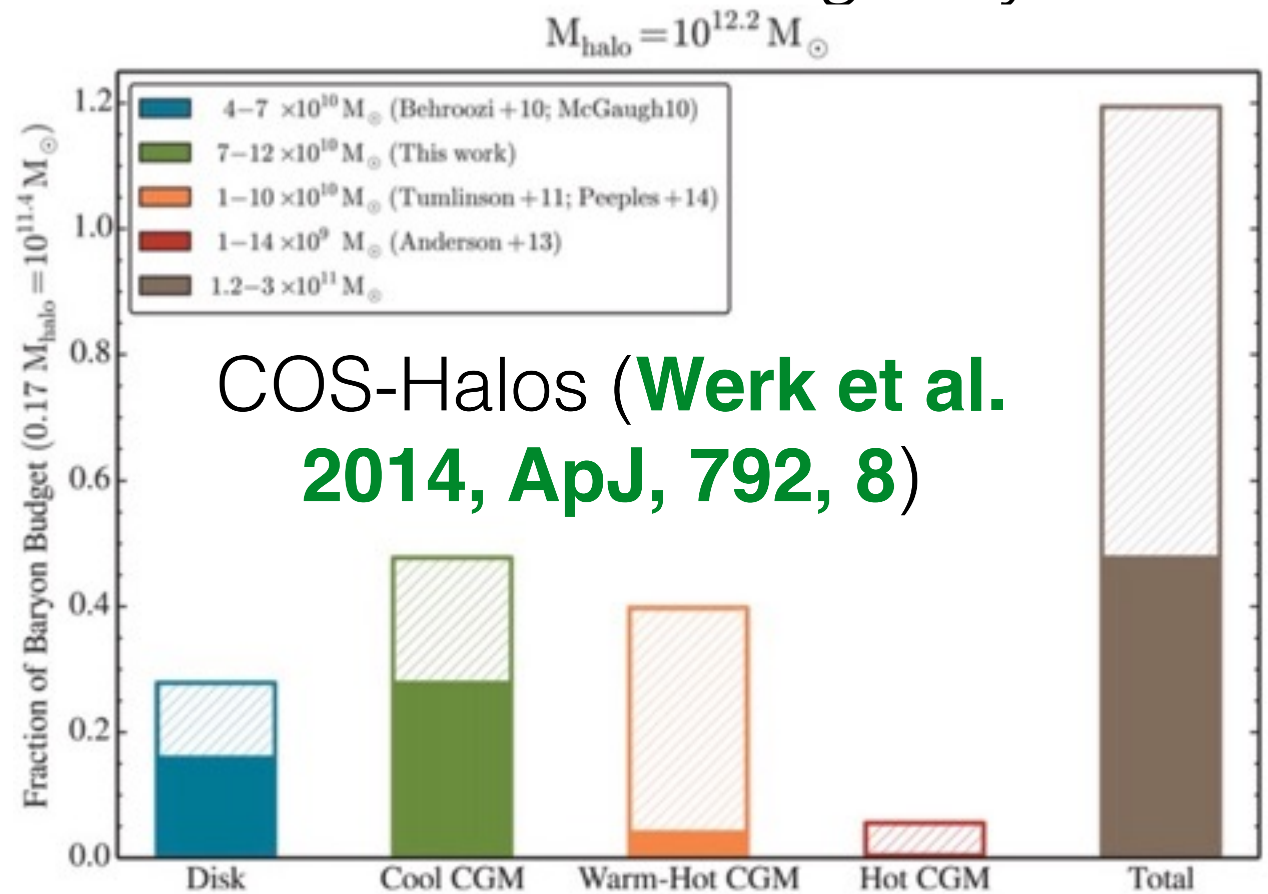

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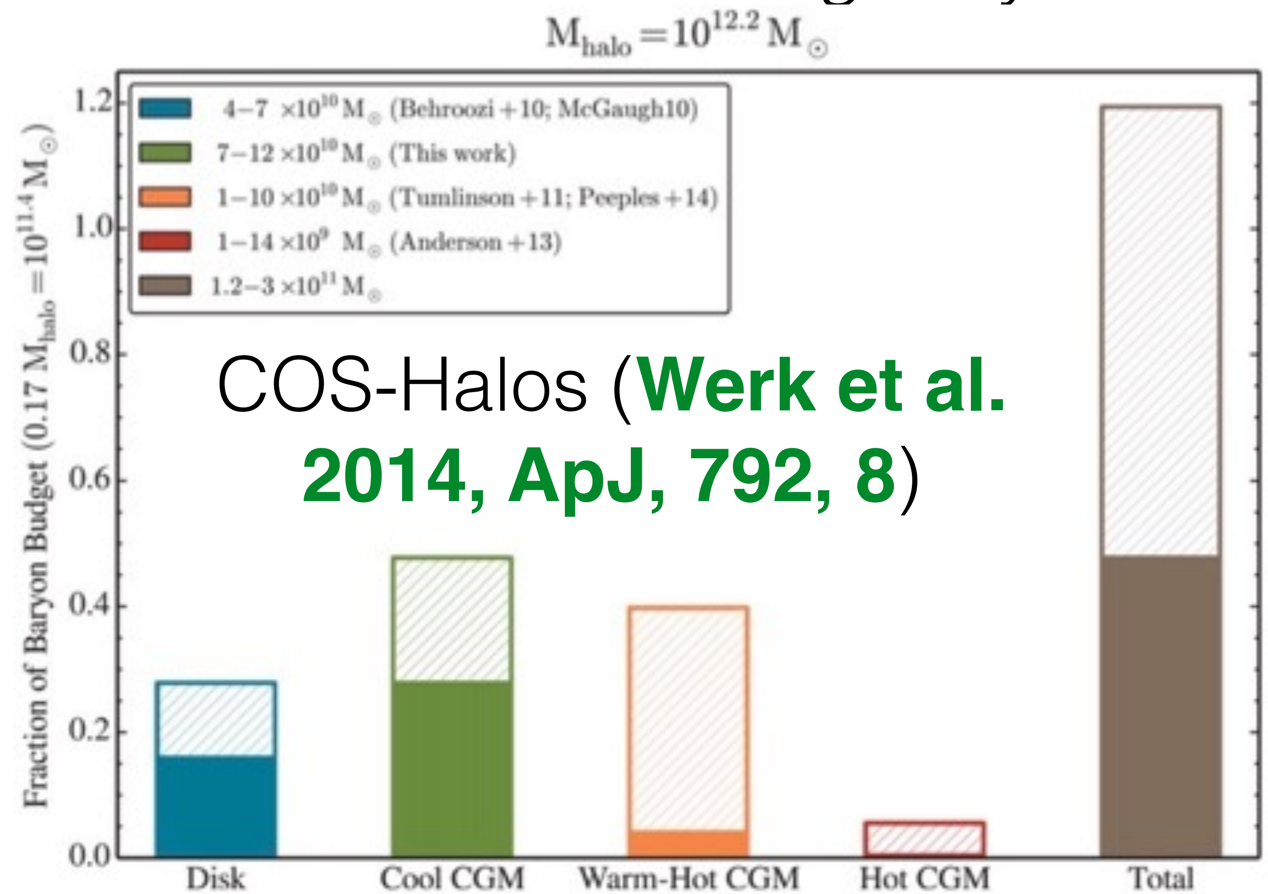
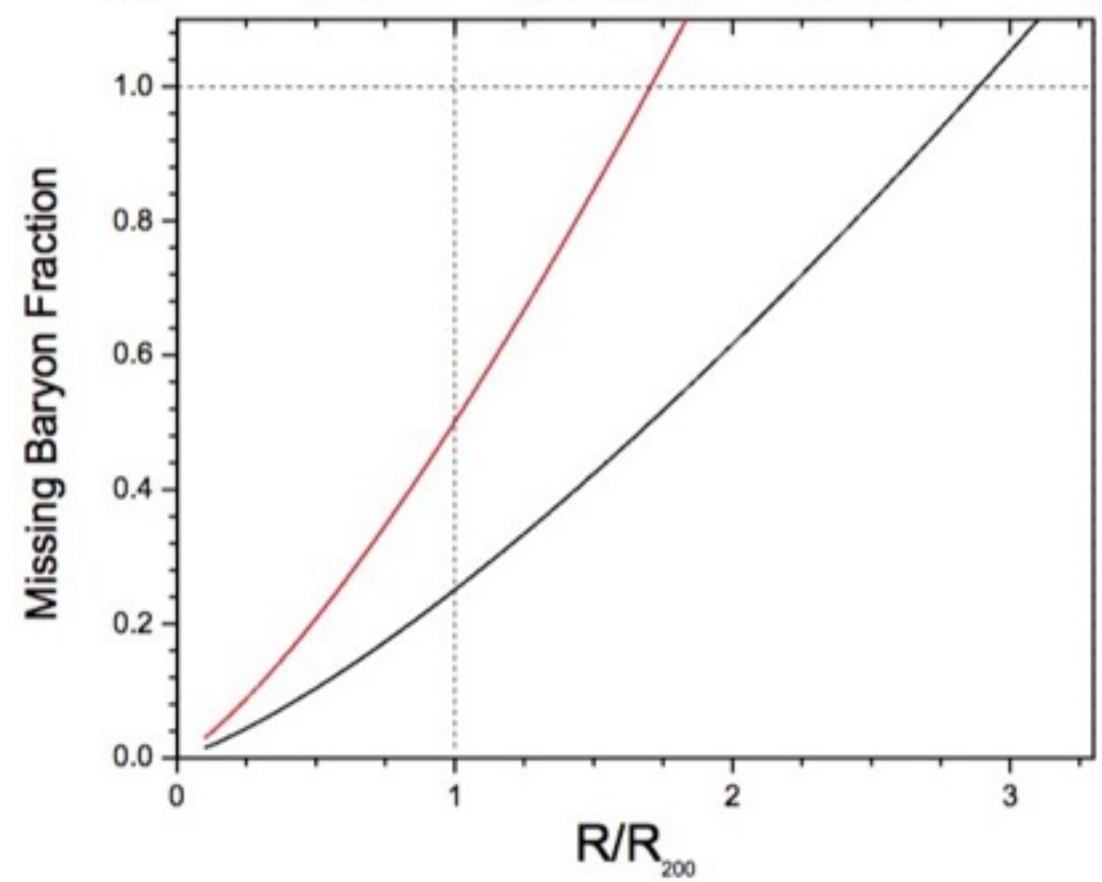


COS-Halos (**Werk et al. 2014, ApJ, 792, 8**)



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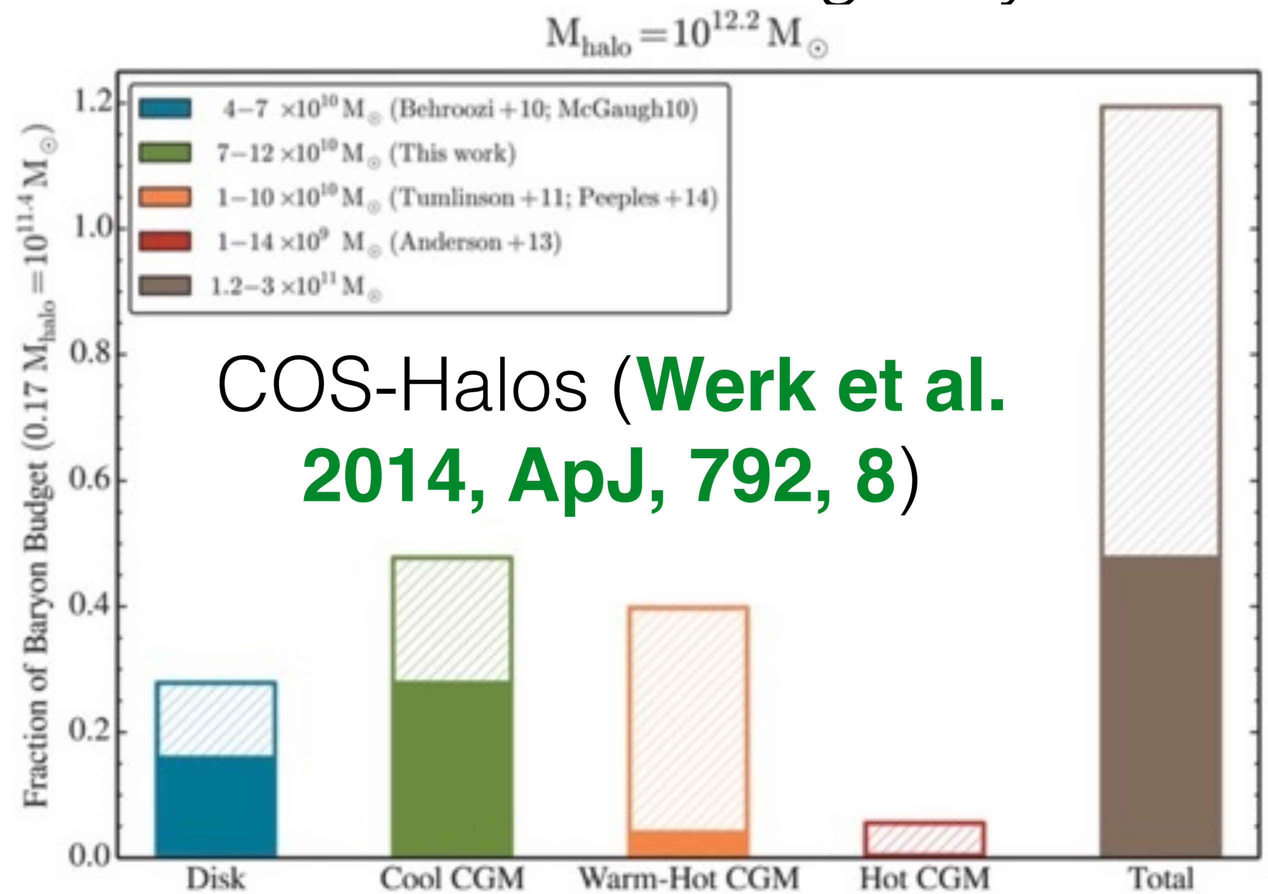

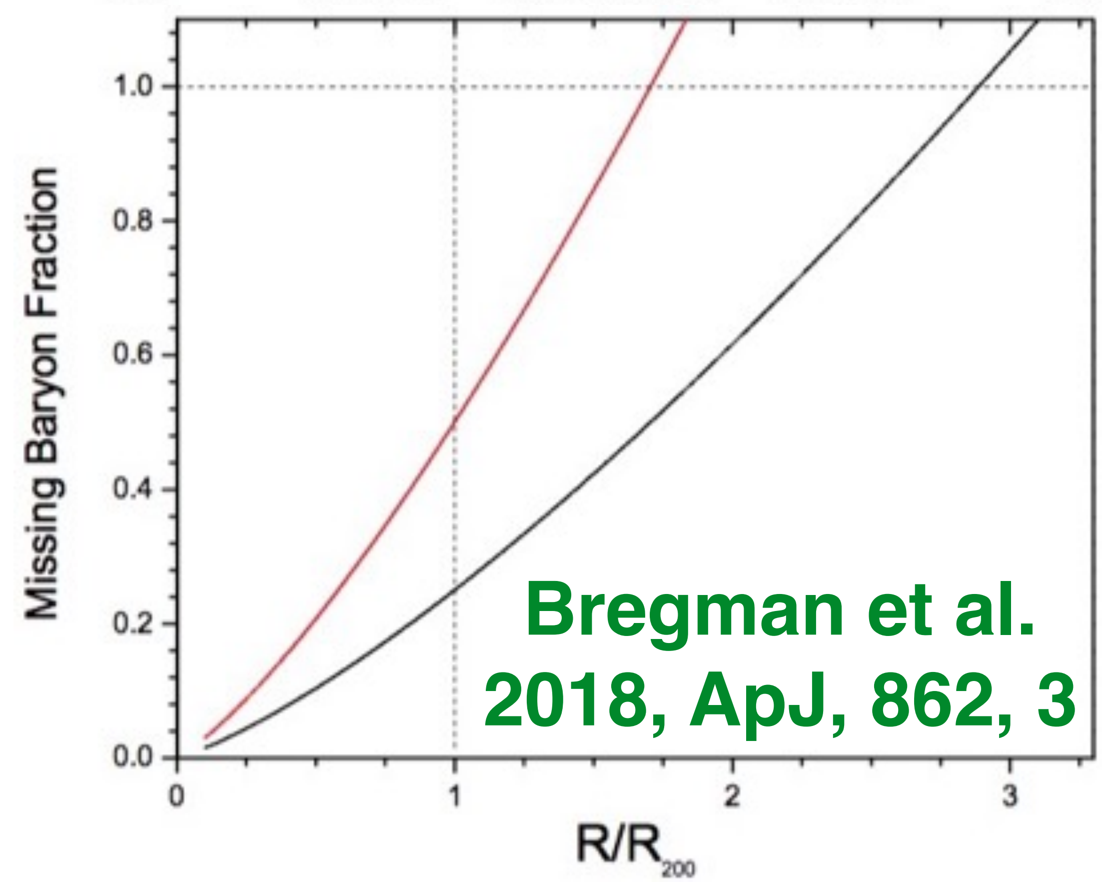

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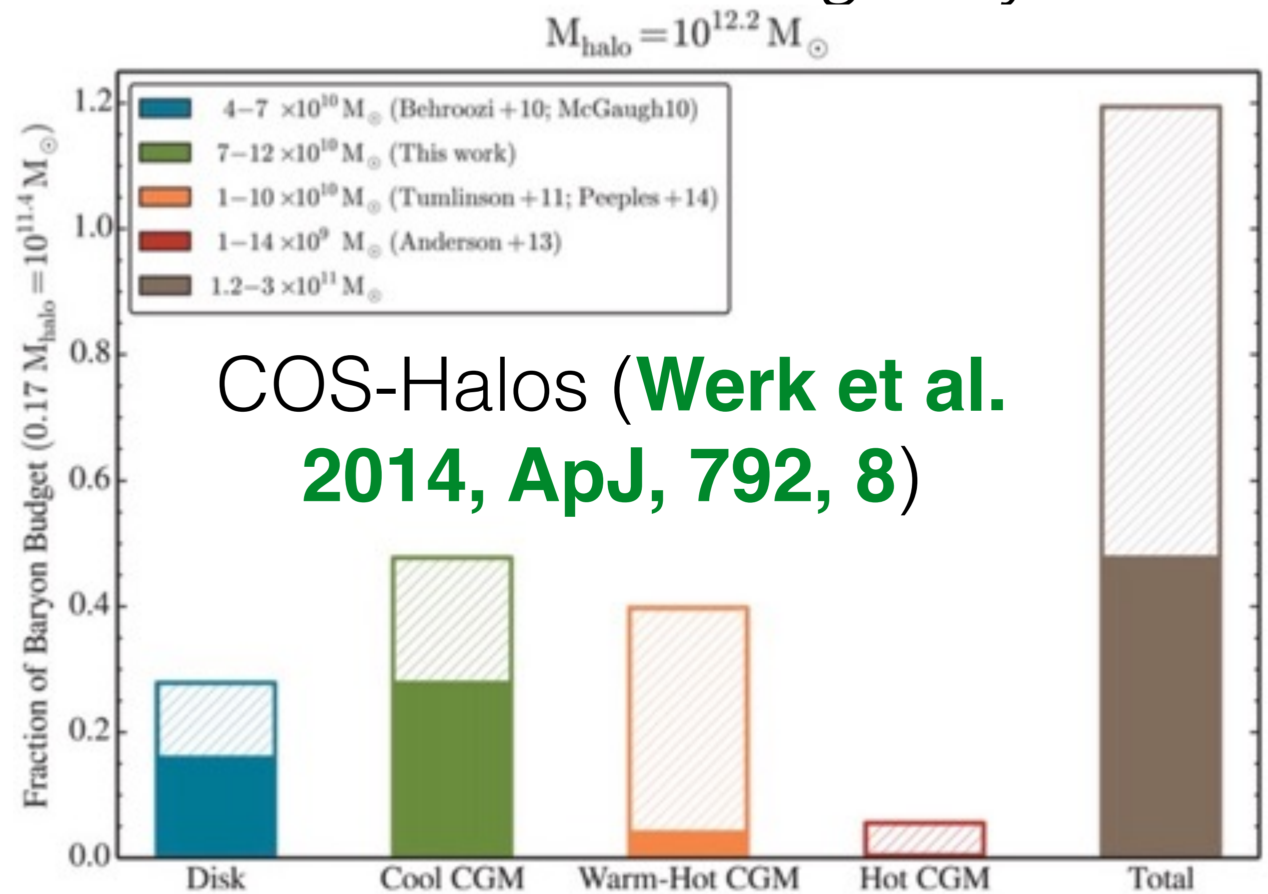
<u>Different phase or different place</u> ?

<u>Where are the missing baryons?</u>



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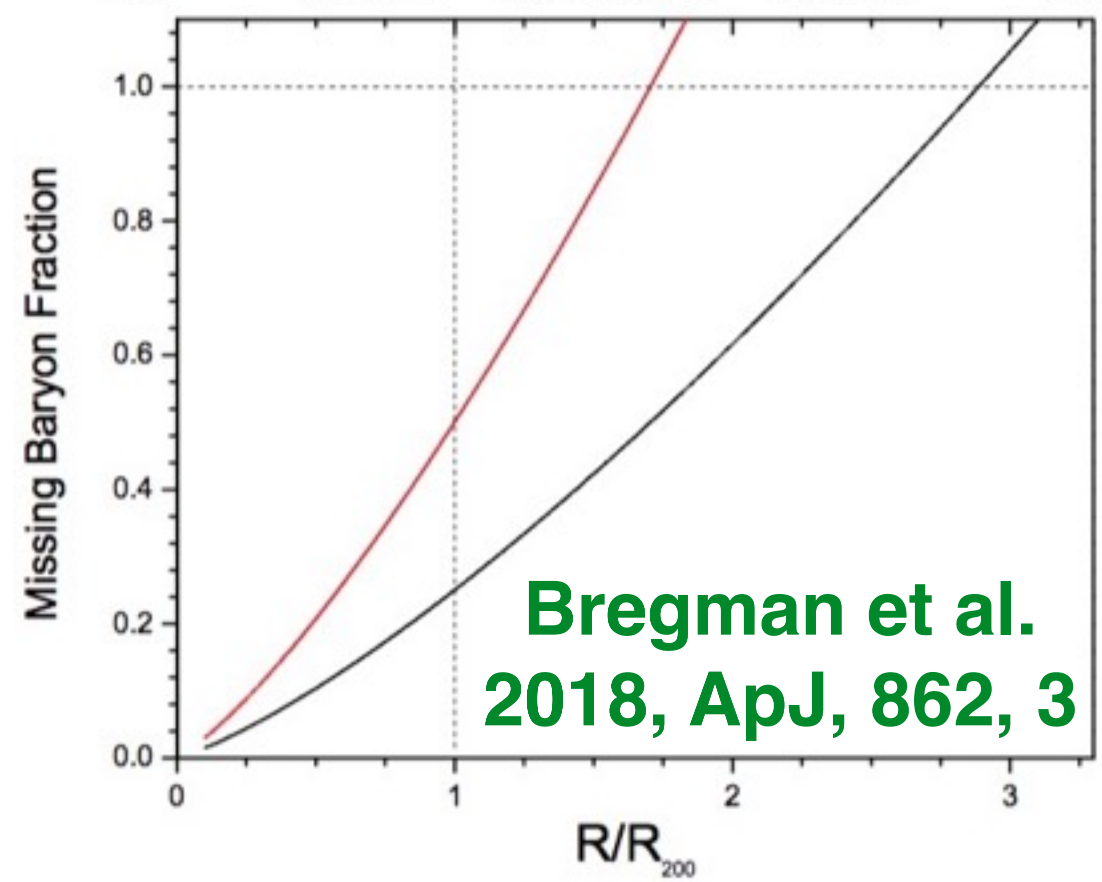
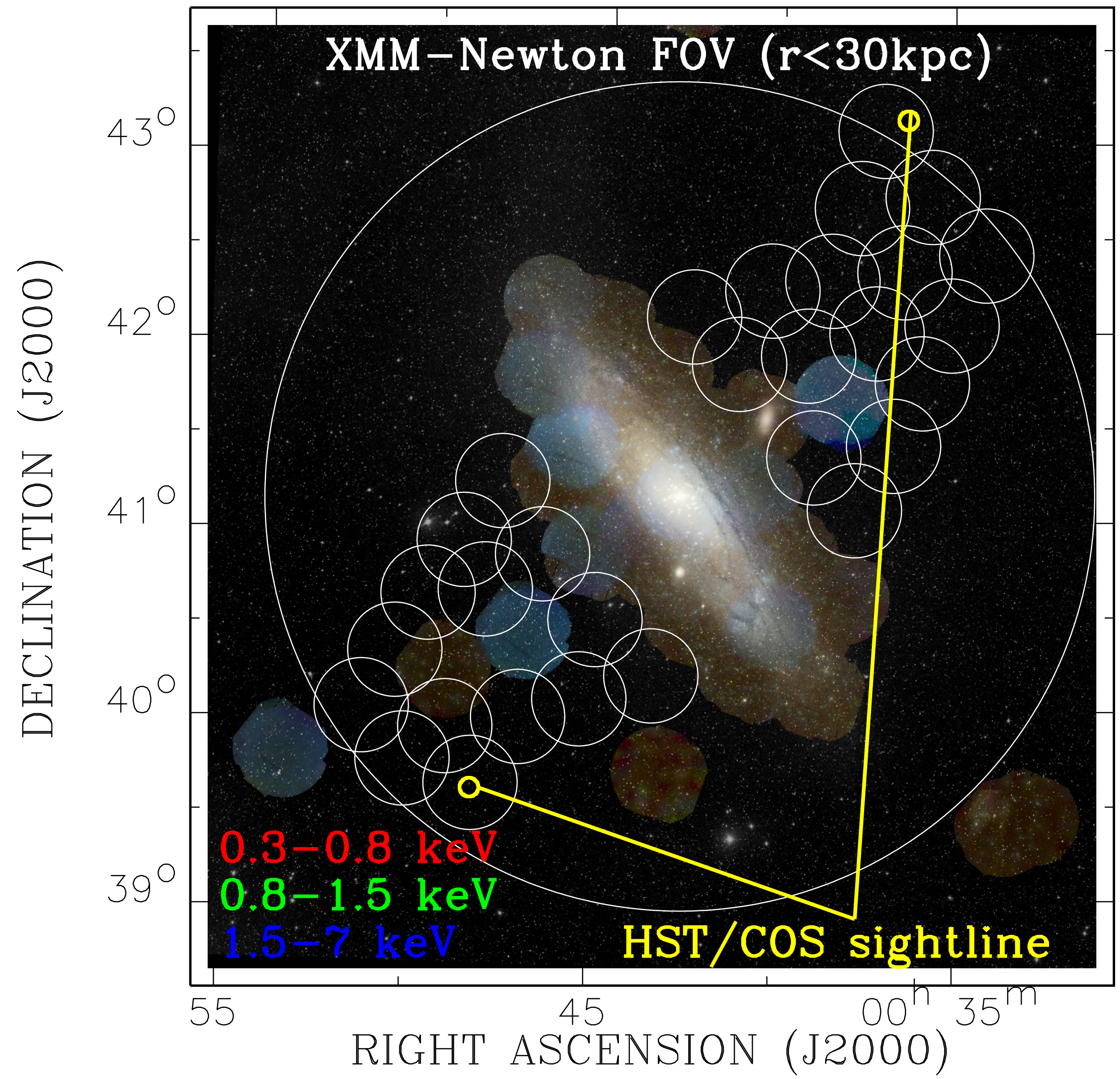
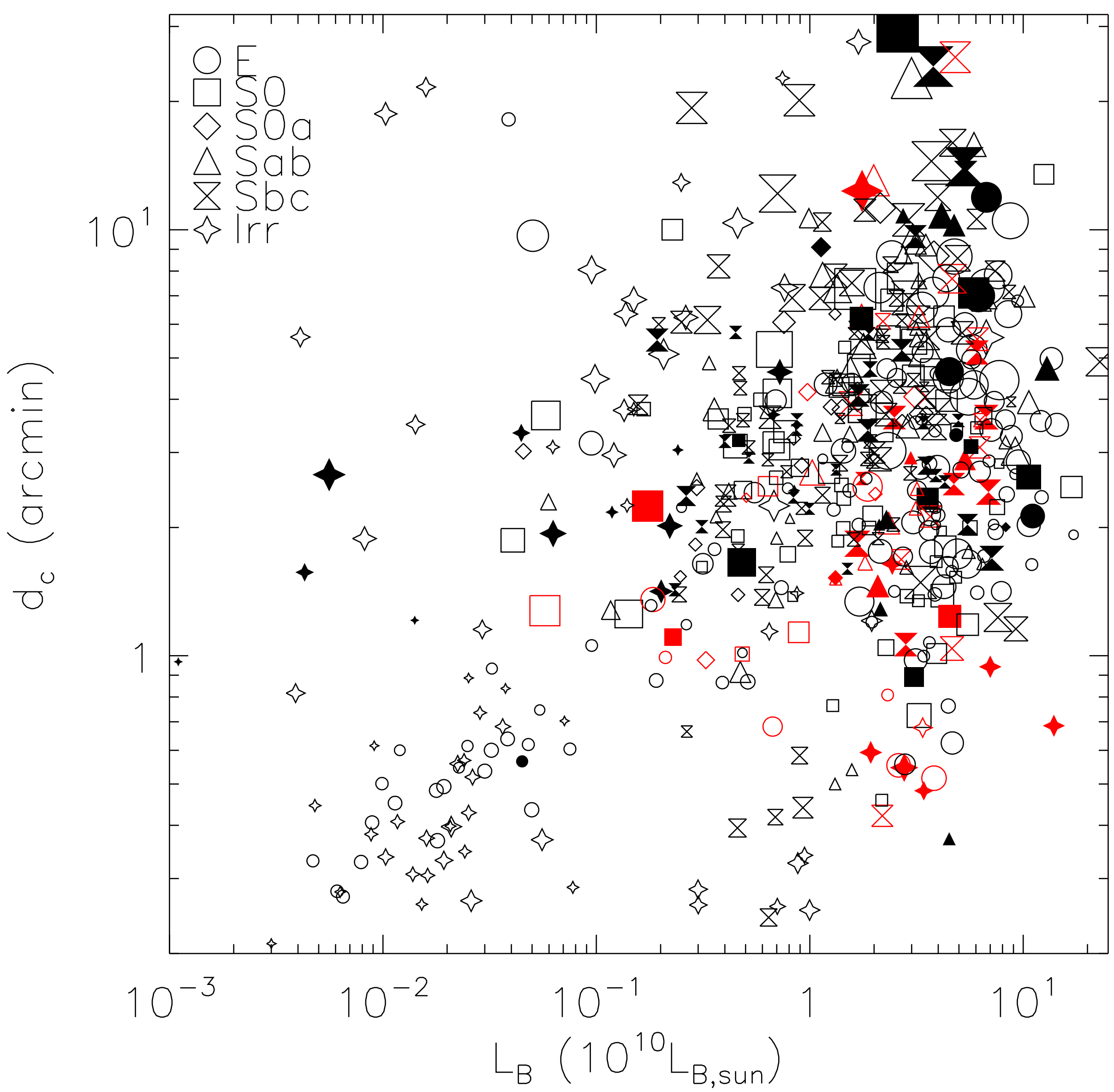


Bregman et al. 2018, ApJ, 862, 3

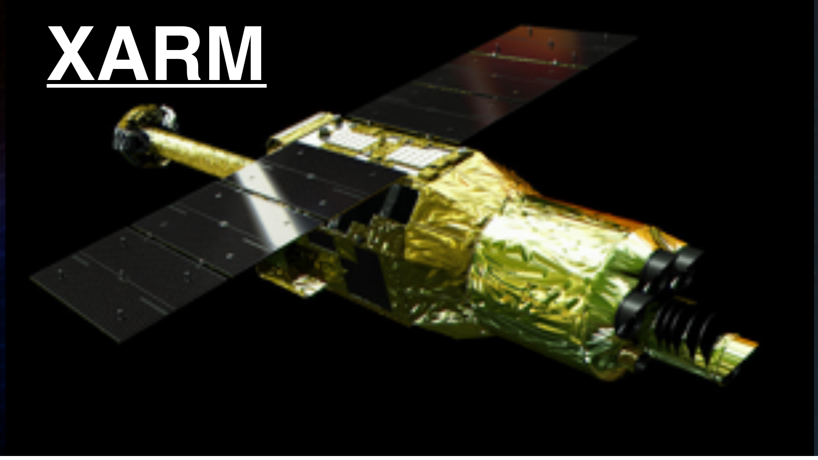
Future Work

- XMM-Newton Legacy Survey of M31 Halo — Searching for the Missing Accreted Hot CGM Around Our Massive Neighbor. (**XMM-Newton AO-16** Large Program, 510 ks; PI: Li Jiang-Tao).

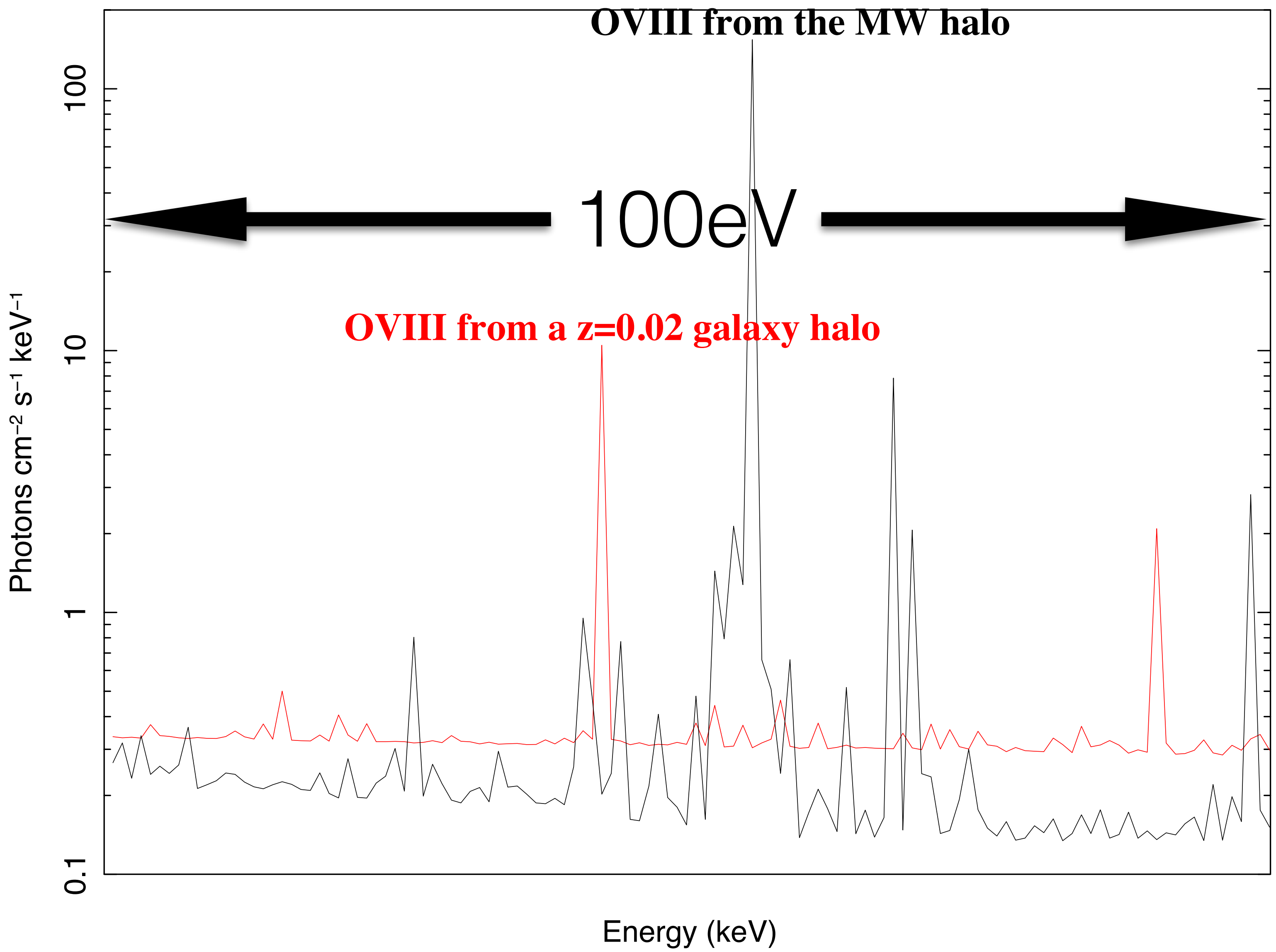




- Hot circum-galactic medium as a legacy of Chandra archive (**Chandra Cycle 20** archival program, 528 galaxies selected from Chandra archive; PI: Li Jiang-Tao)



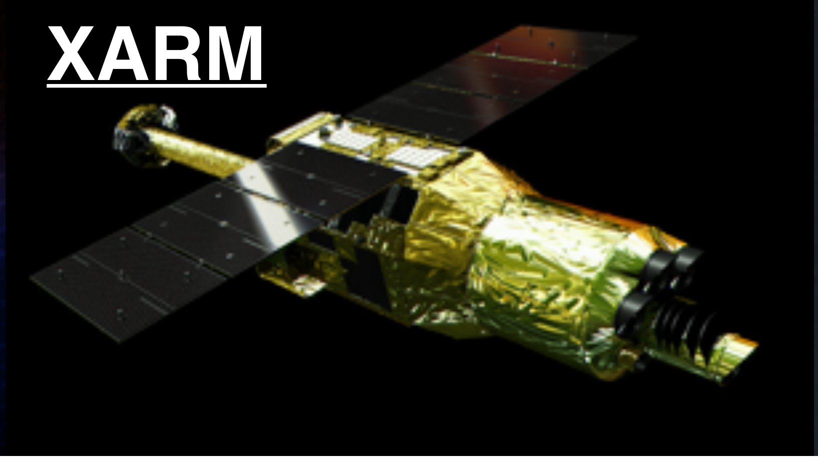
Super DIOS; HUBS (Hot Universe Baryon Surveyor)



Narrow-band imaging of the extended hot CGM with Future X-ray missions

Separate the emission lines from the local CGM at z~0.01-0.02 (d~50-100Mpc) and the MW halo.

Extremely low background



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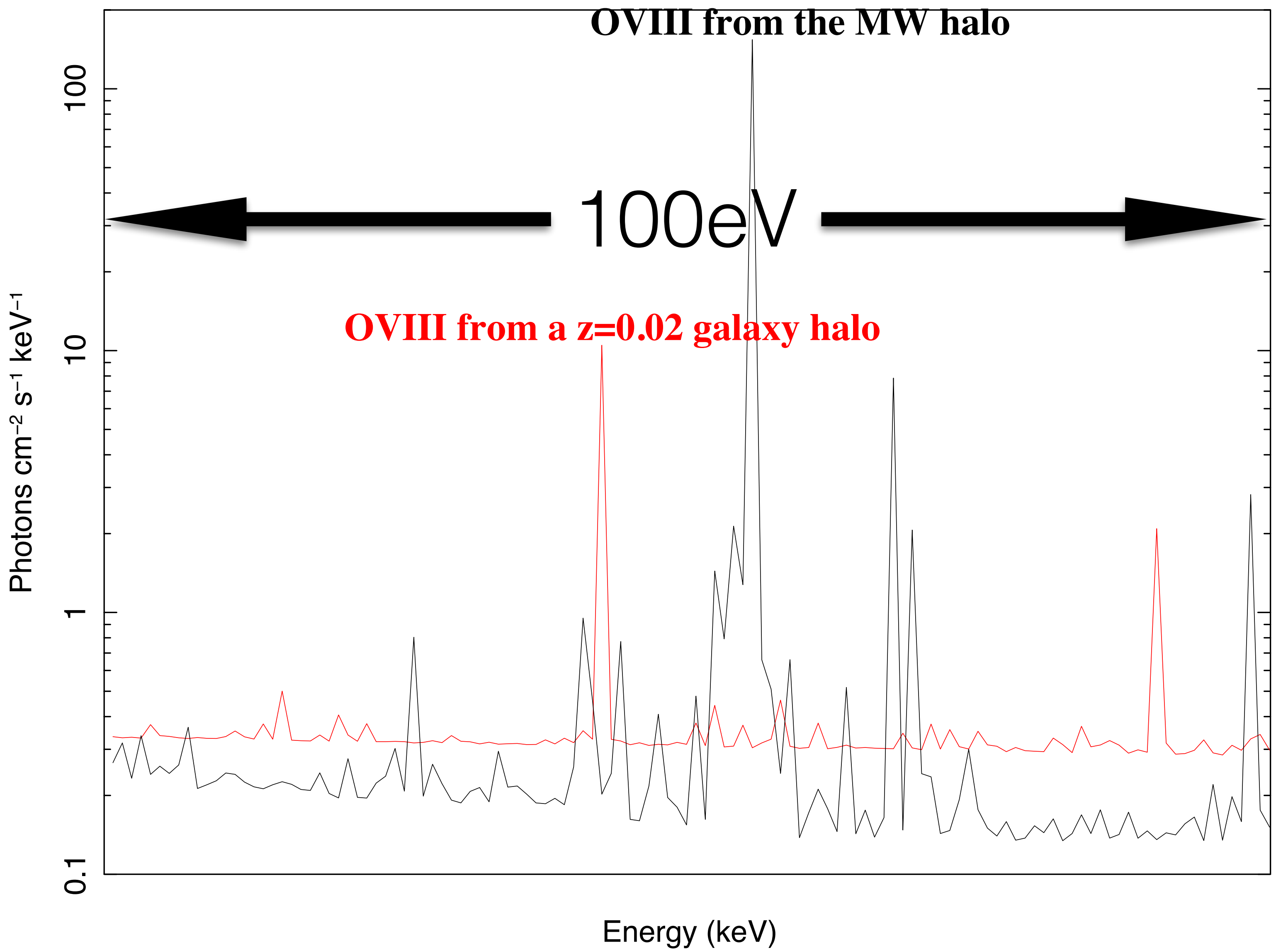

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Thank you very much!