Local Group Analogs in a cosmological context:

Relating the velocity structure to the cosmic web

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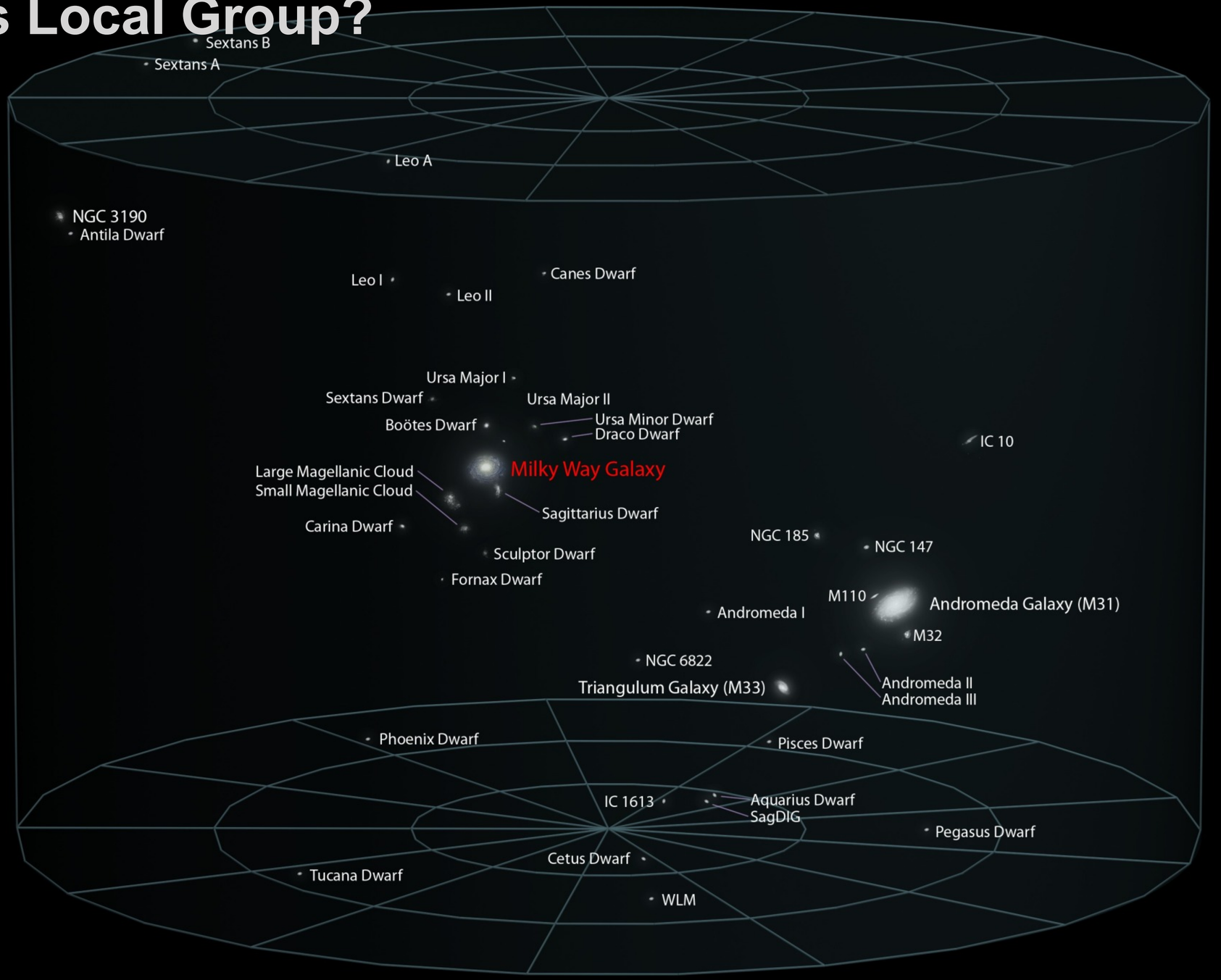
(13mins) ***National Astronomical Meeting*** Jul. 8, 2025 @ Durham

https://space.fandom.com/wiki/Local_Group

- **What is Local Group?**



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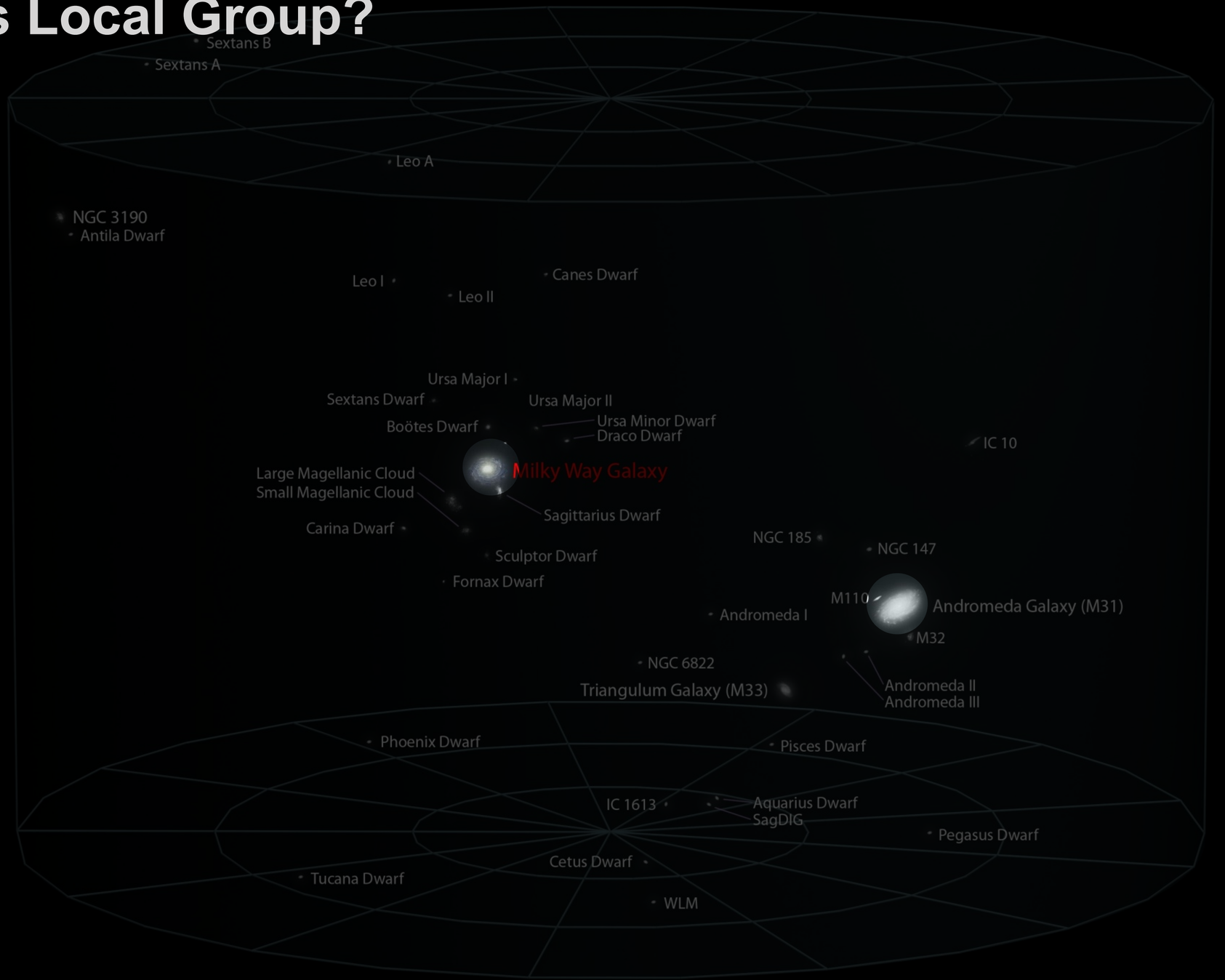

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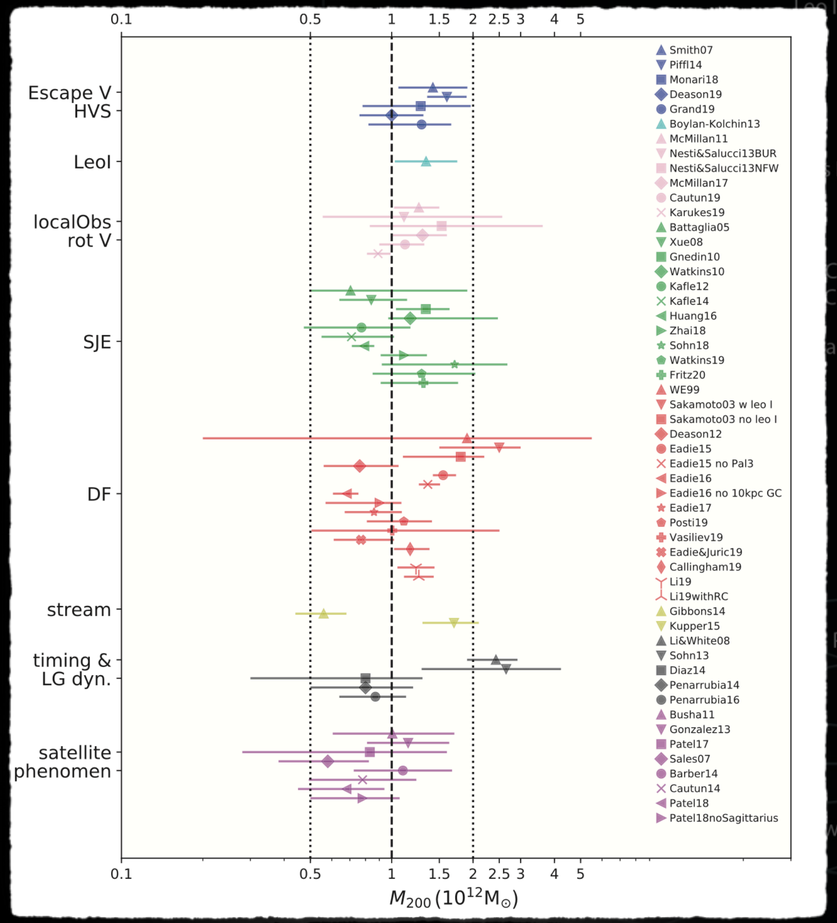
• What is Local Group?

✦Milky Way mass ~ $10^{12}h^{-1}M_{sun}$

e.g. Wang+20



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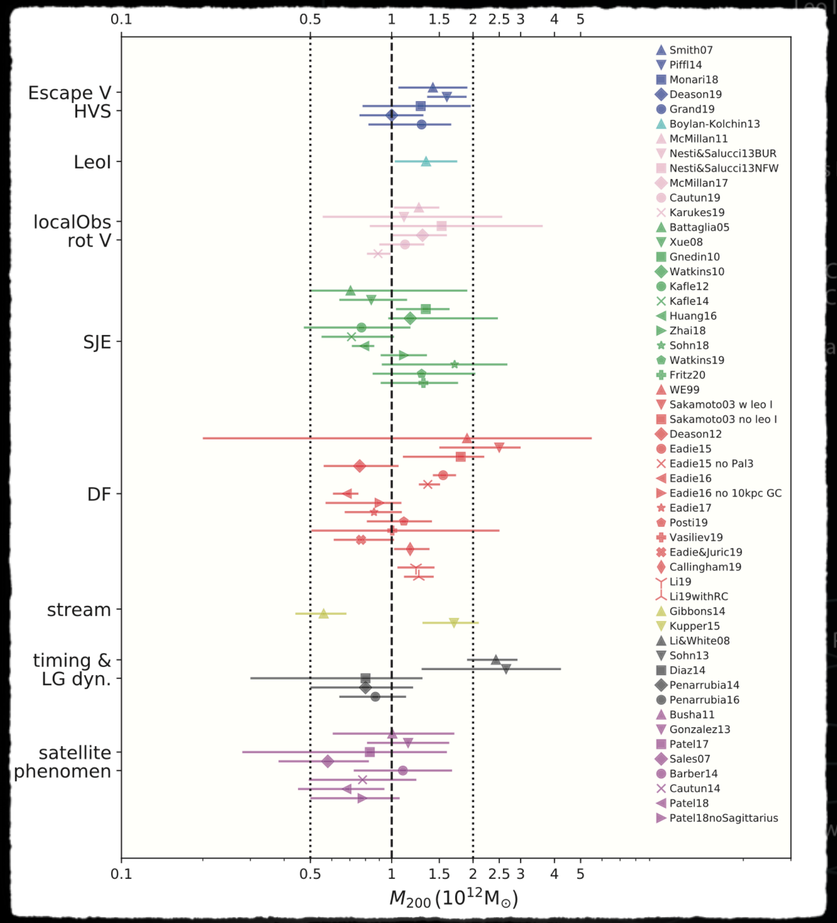

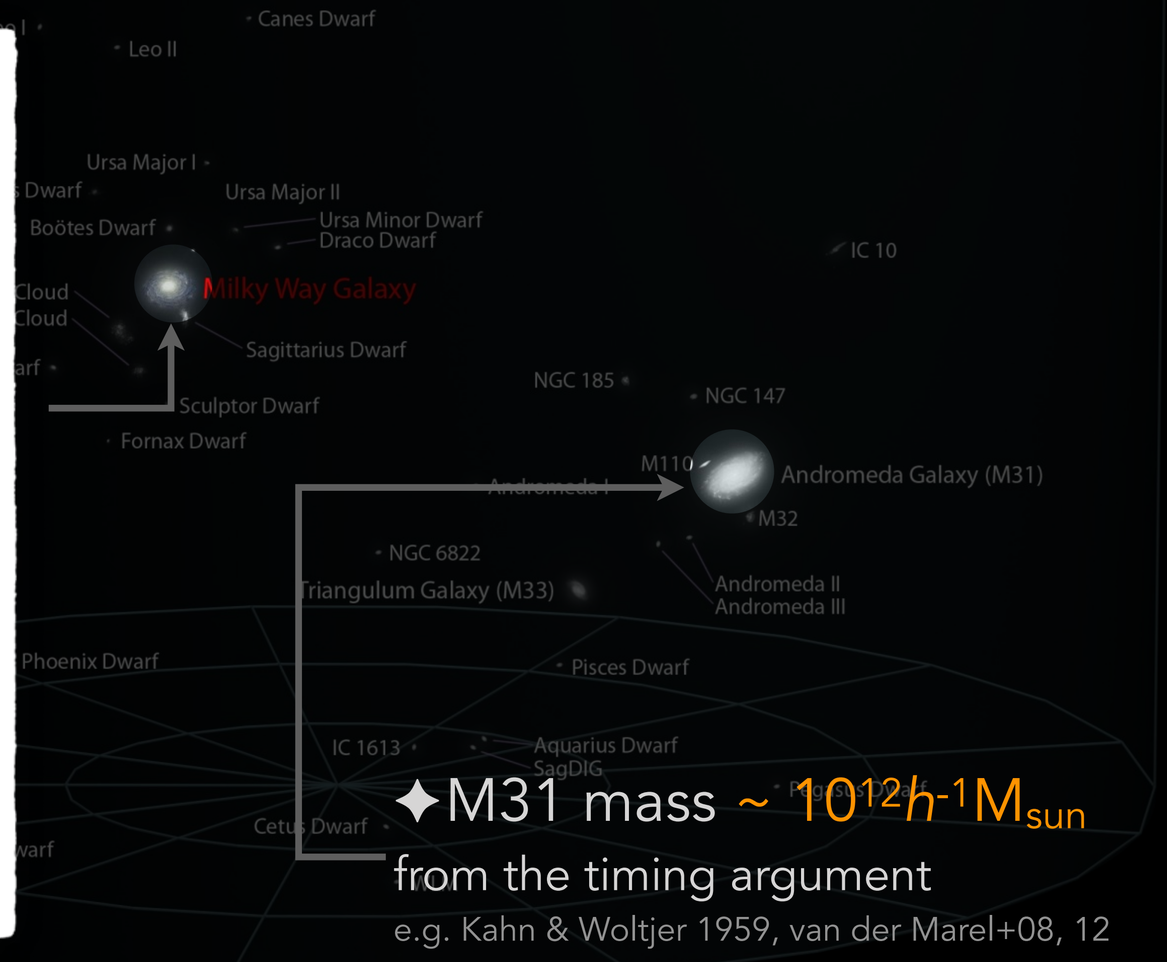

✦M31 mass ~ $10^{12}h^{-1}M_{sun}$

from the timing argument

e.g. Kahn & Woltjer 1959, van der Marel+08, 12

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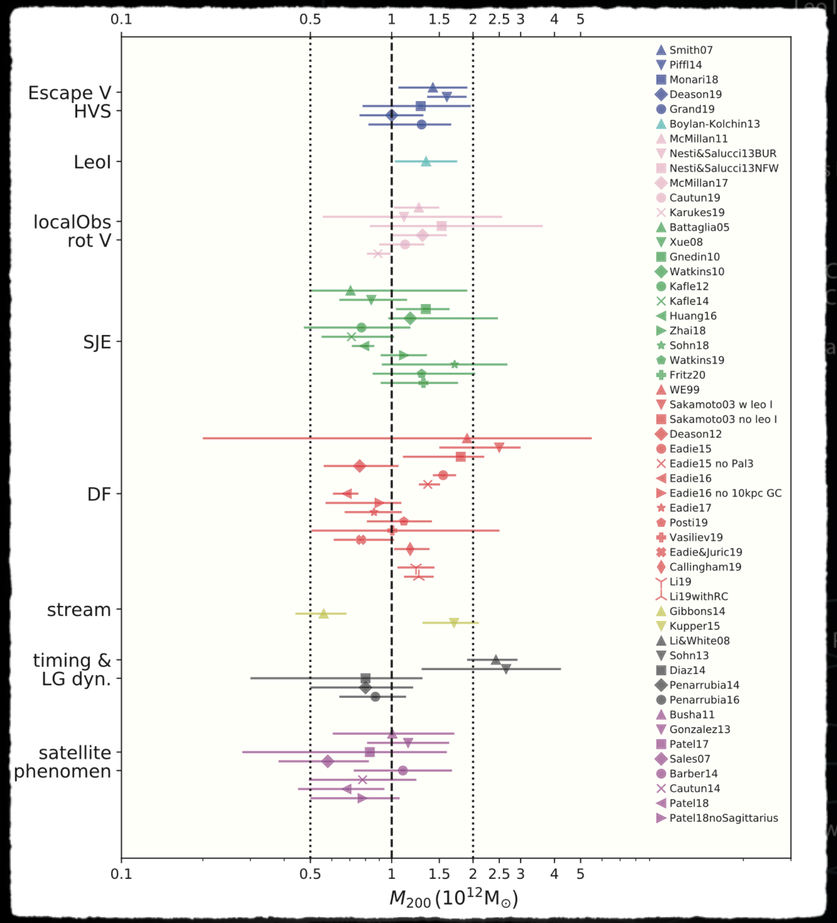

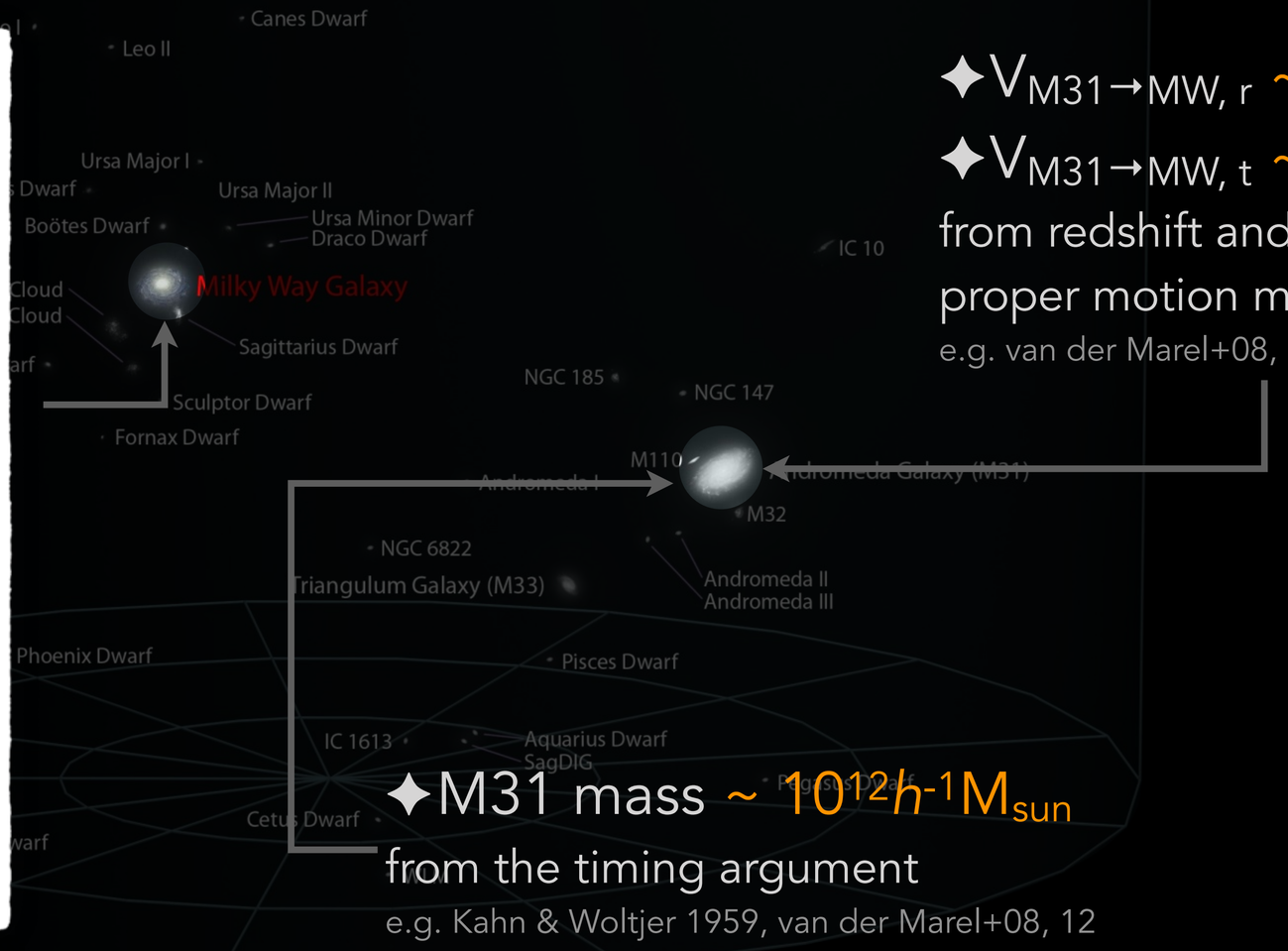

✦$V_{M31\rightarrow MW,\,r}$ ~ -110 km/s

✦$V_{M31\rightarrow MW,\,t}$ ~ 80 km/s

from redshift and

proper motion measurement

e.g. van der Marel+08, 12, Salomon+21

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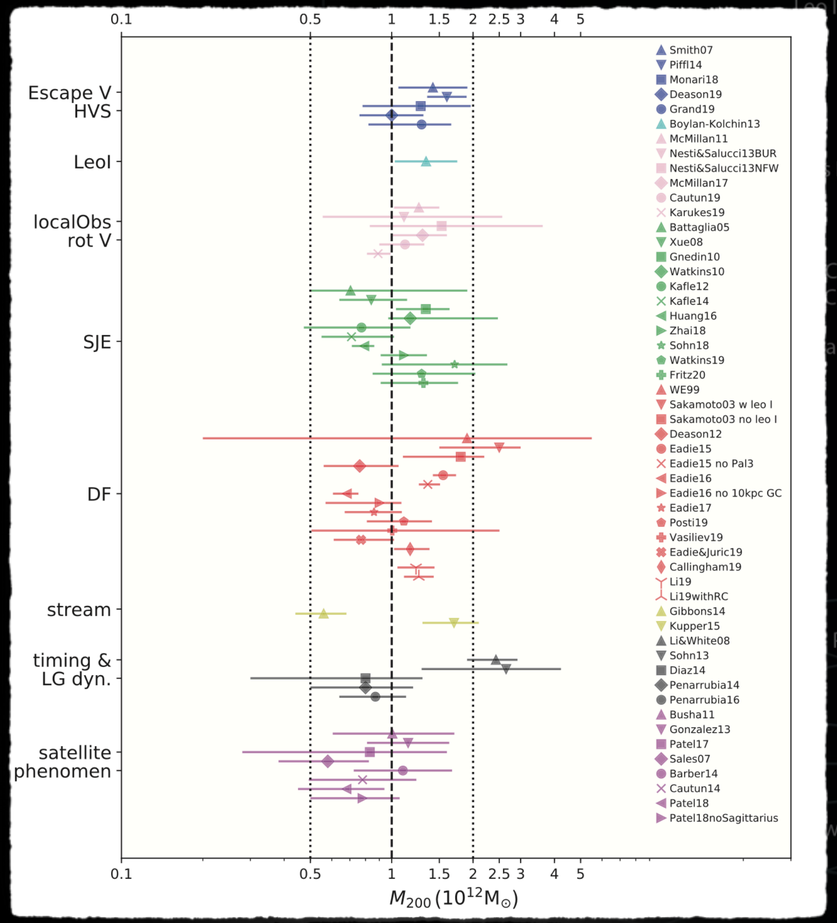

✦MW-M31 separation: ~785kpc

from the Tip of the Red Giant Branch (TRGB)

e,g, McConnachie+05

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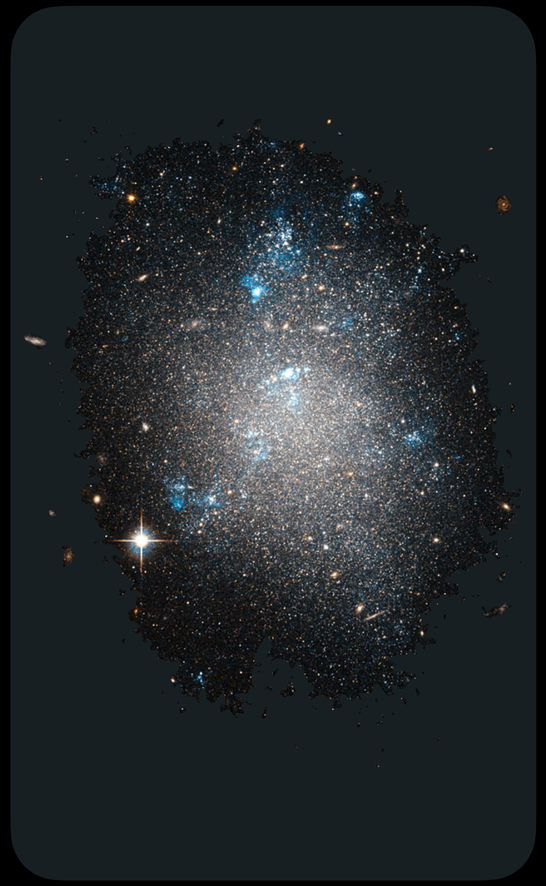
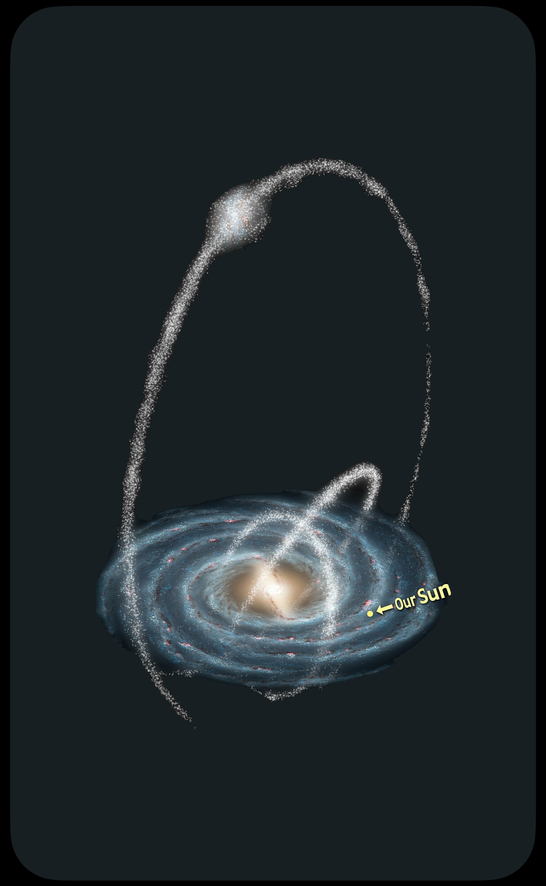
- **What can we learn from the Local Group**

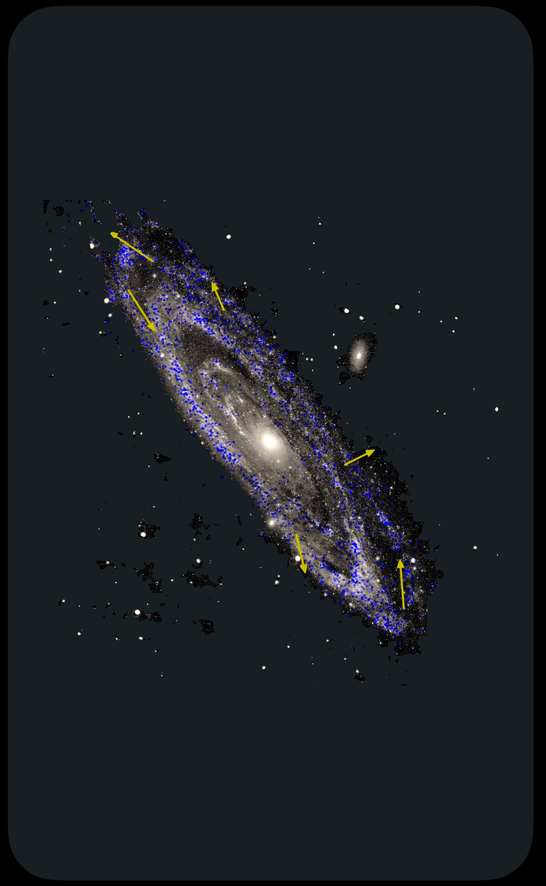
Many things that are **only observable** in our Local Group:



Dwarf galaxies



Stellar streams

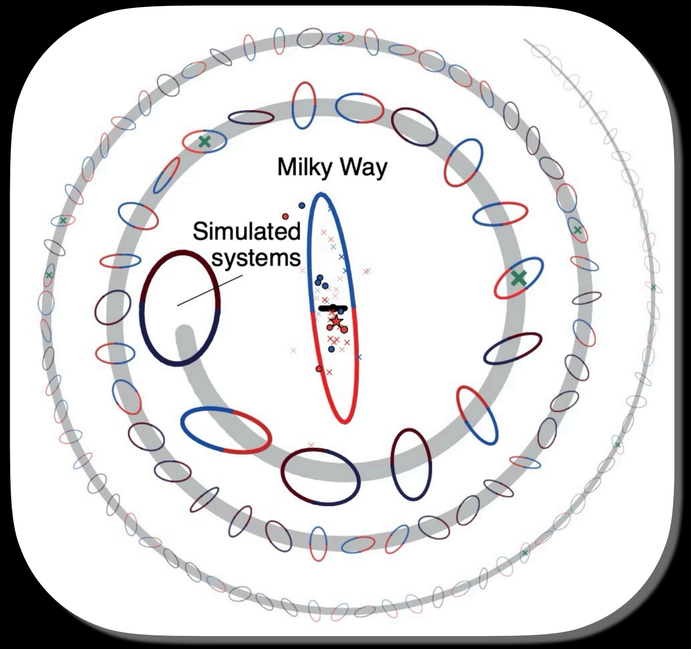


Proper motion

- **New universe crisis from our Local Group**

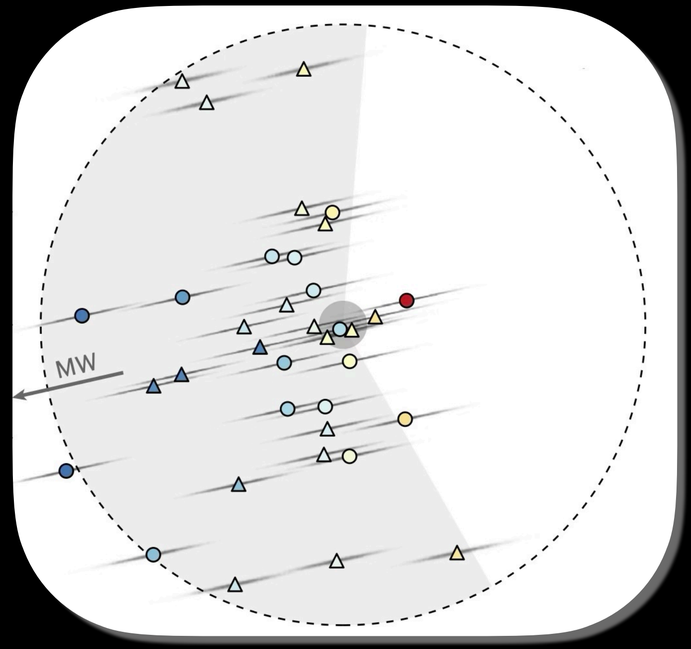
Satellite Plane

Kroupa+2005, Pawlowski+2012, Pawlowski & Kroupa 2013, Pawlowski+2015, Libeskind+2015, Pawlowski 2021, etc.



Satellite Lopsidedness

McConnachie & Irwin 2006, Conn+2012, Savino+2022, Kanehisa+2025, etc.



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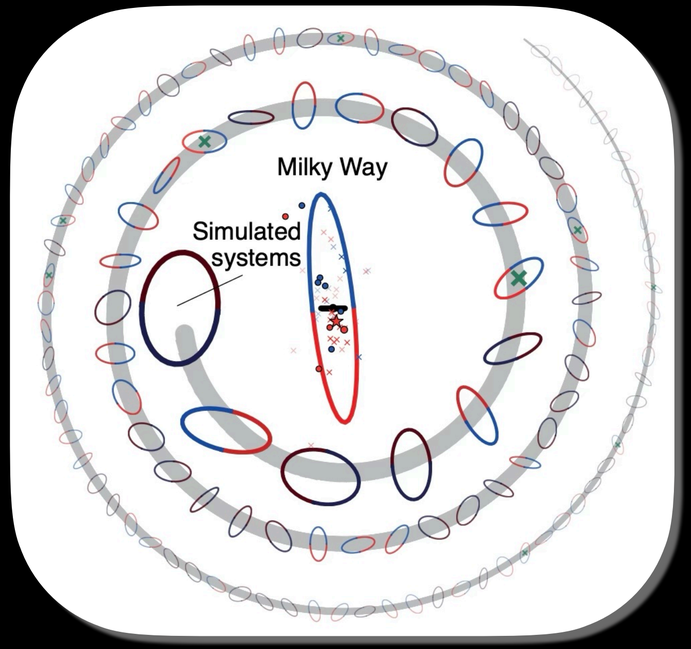

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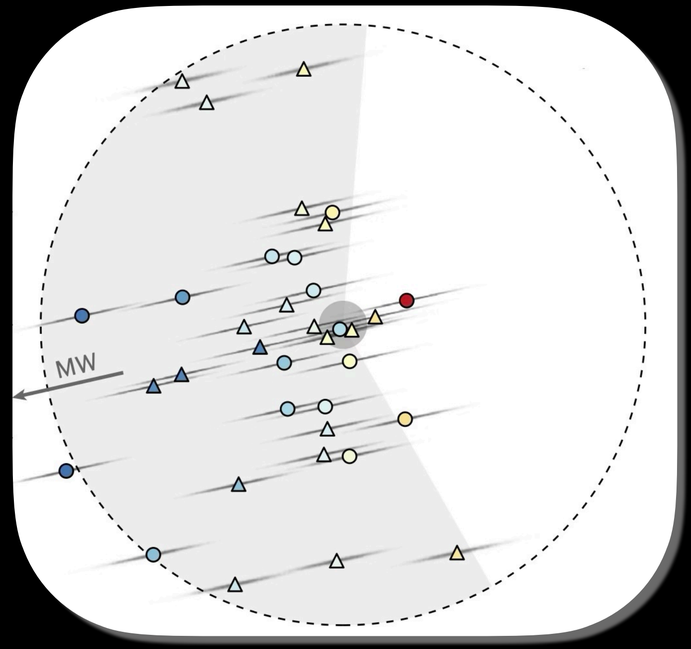

These peculiar properties of our Local Group made it either

- a **challenge** to LCDM cosmology and our galaxy formation paradigm
- or just an unfortunate **outlier**

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There are tons of evidence that

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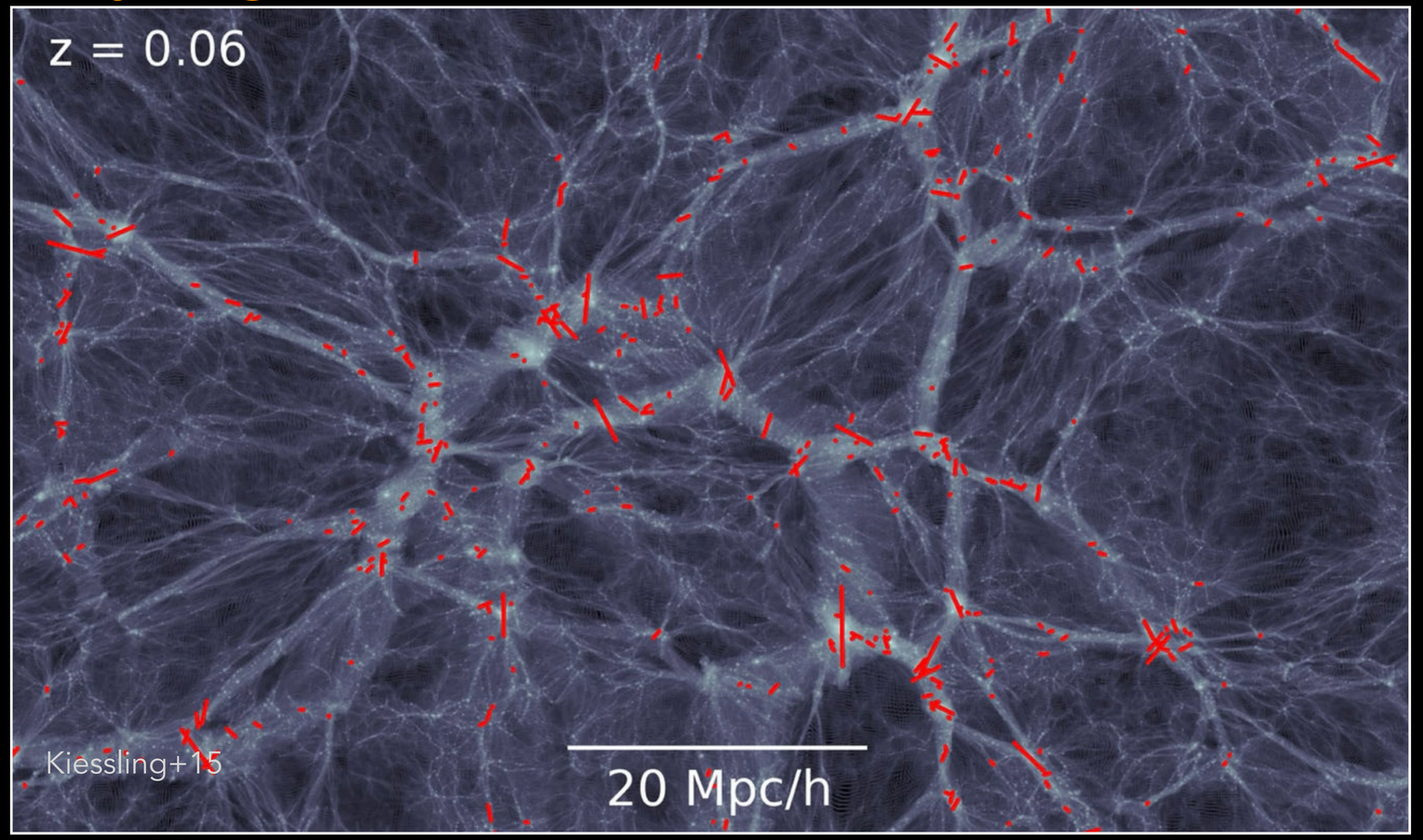
galaxy alignment



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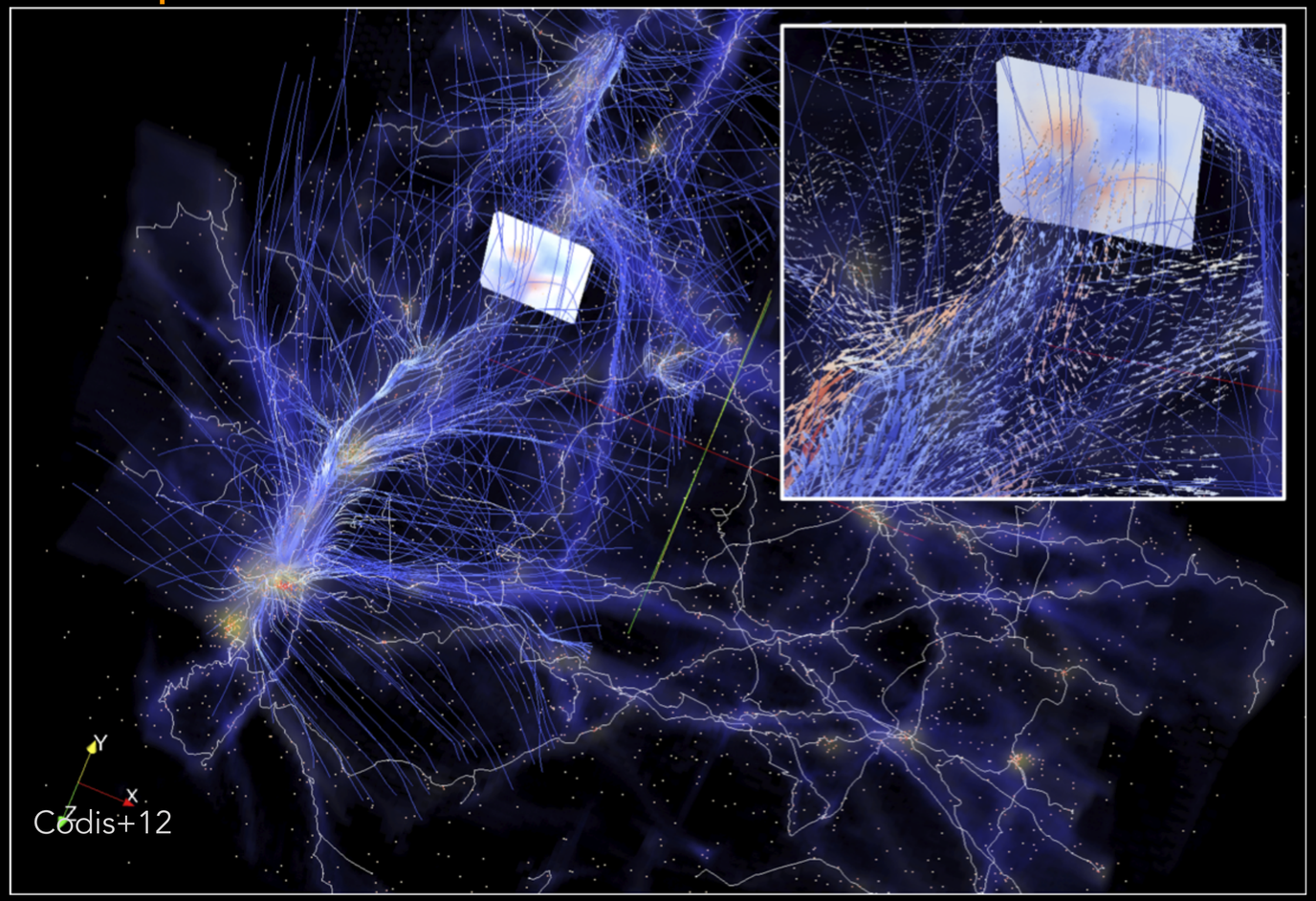
halo spin



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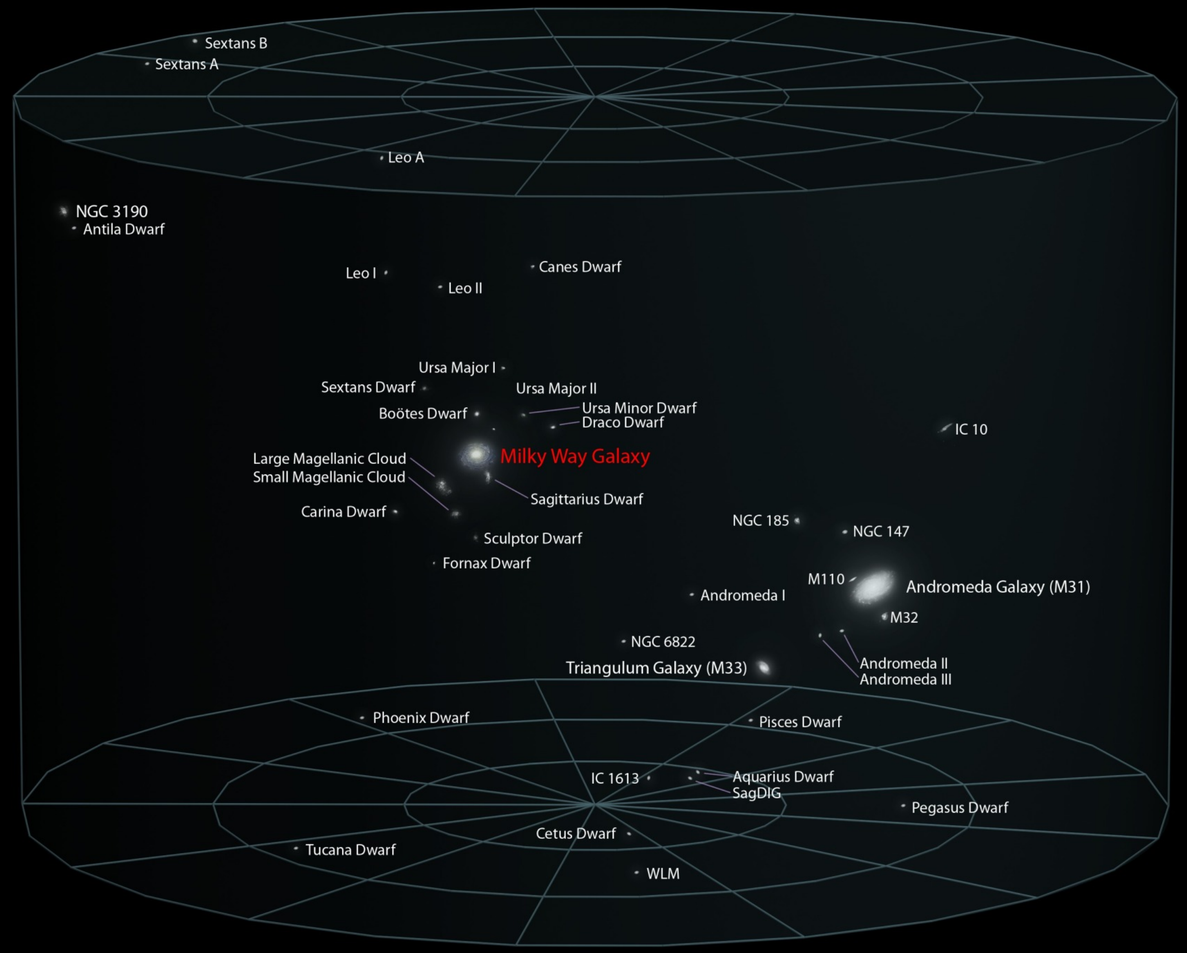
Local Group Analogue?



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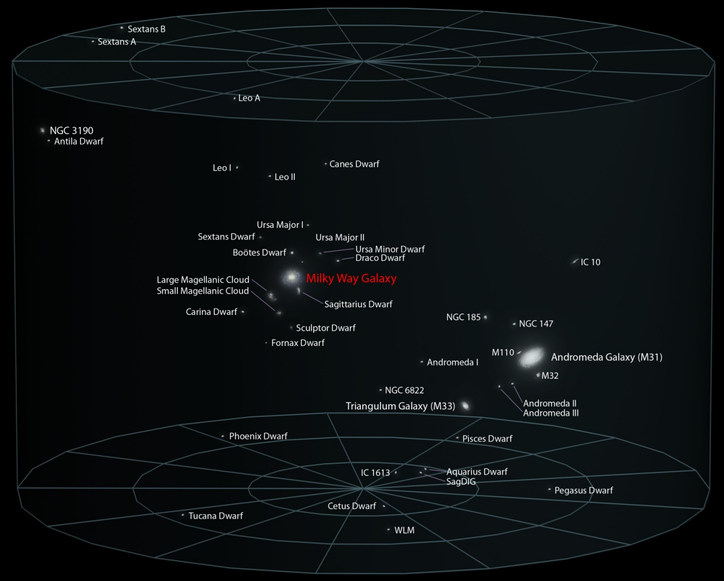

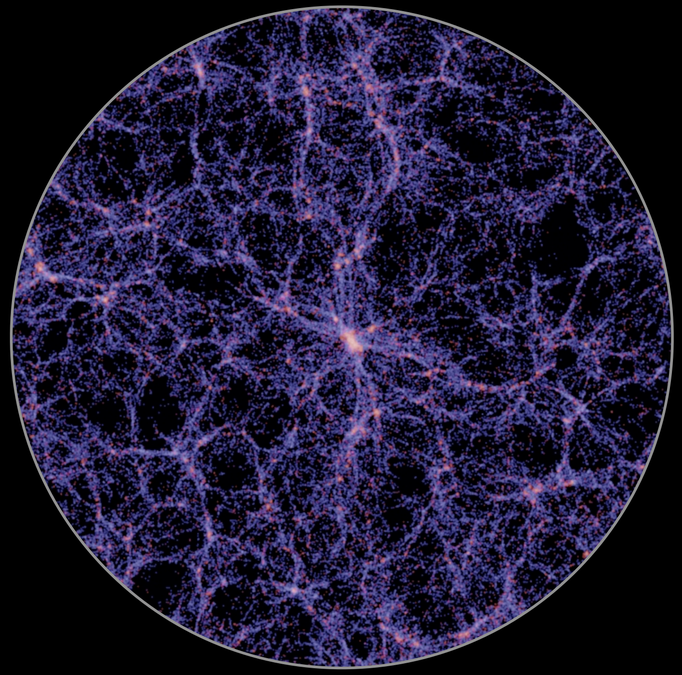

Local Group Analogue

Large-scale Cosmic Web

Our peculiar Local Group caused by **peculiar Large-scale environment**?

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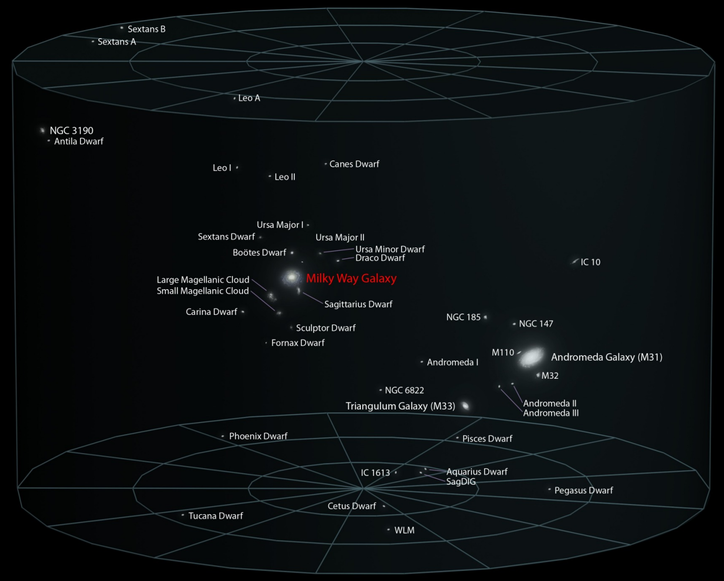

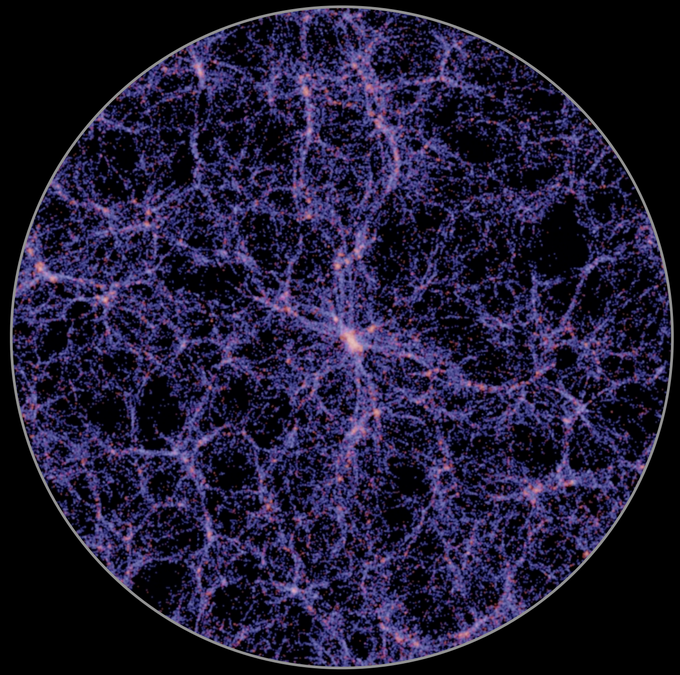

Local Group Analogue

Large-scale Cosmic Web

Yes! We are living in a peculiar large-scale environment.
(see Libeskind+2015)

Our peculiar Local Group caused by **peculiar Large-scale environment**?

- Quantifying Local Group Analogue and Cosmic Web

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  - two $10^{12} M_{sun}/h$ halos
  - separated by ~500kpc/h
  - in a relatively isolated environment

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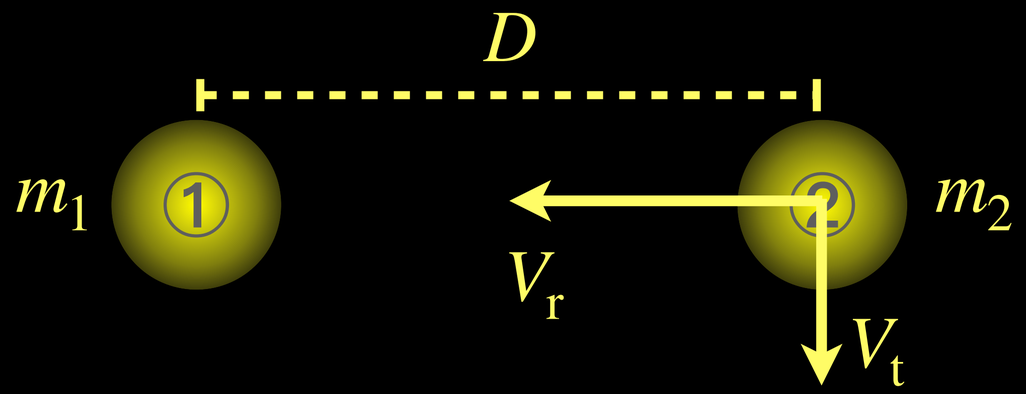

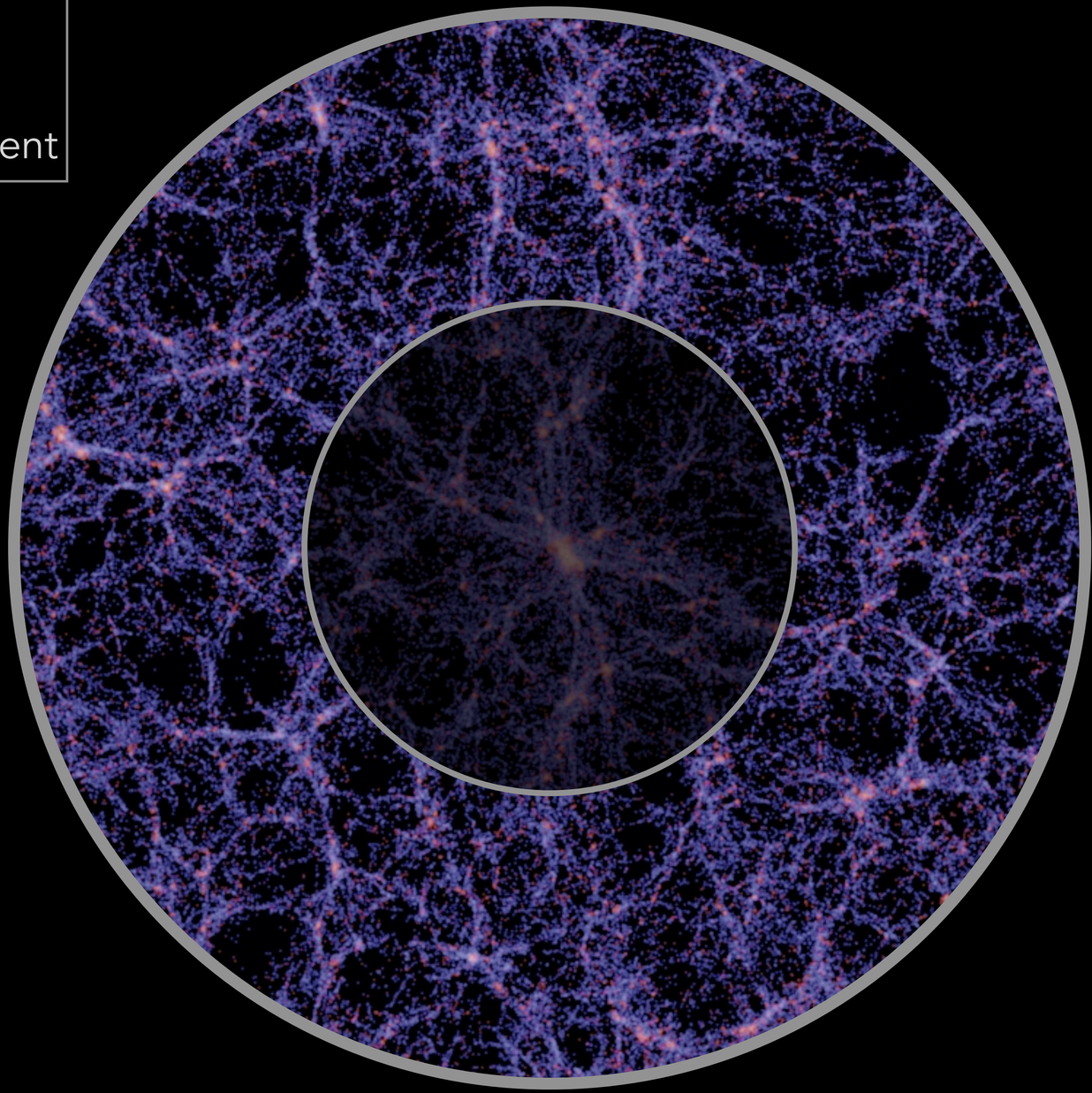

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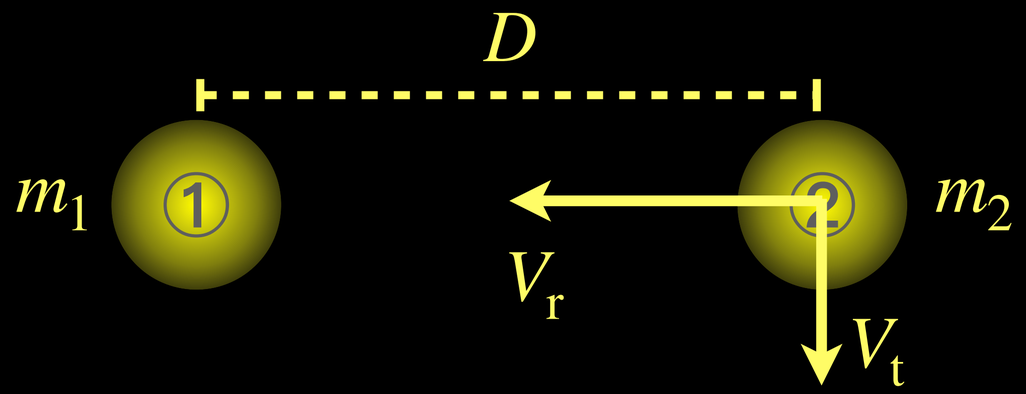
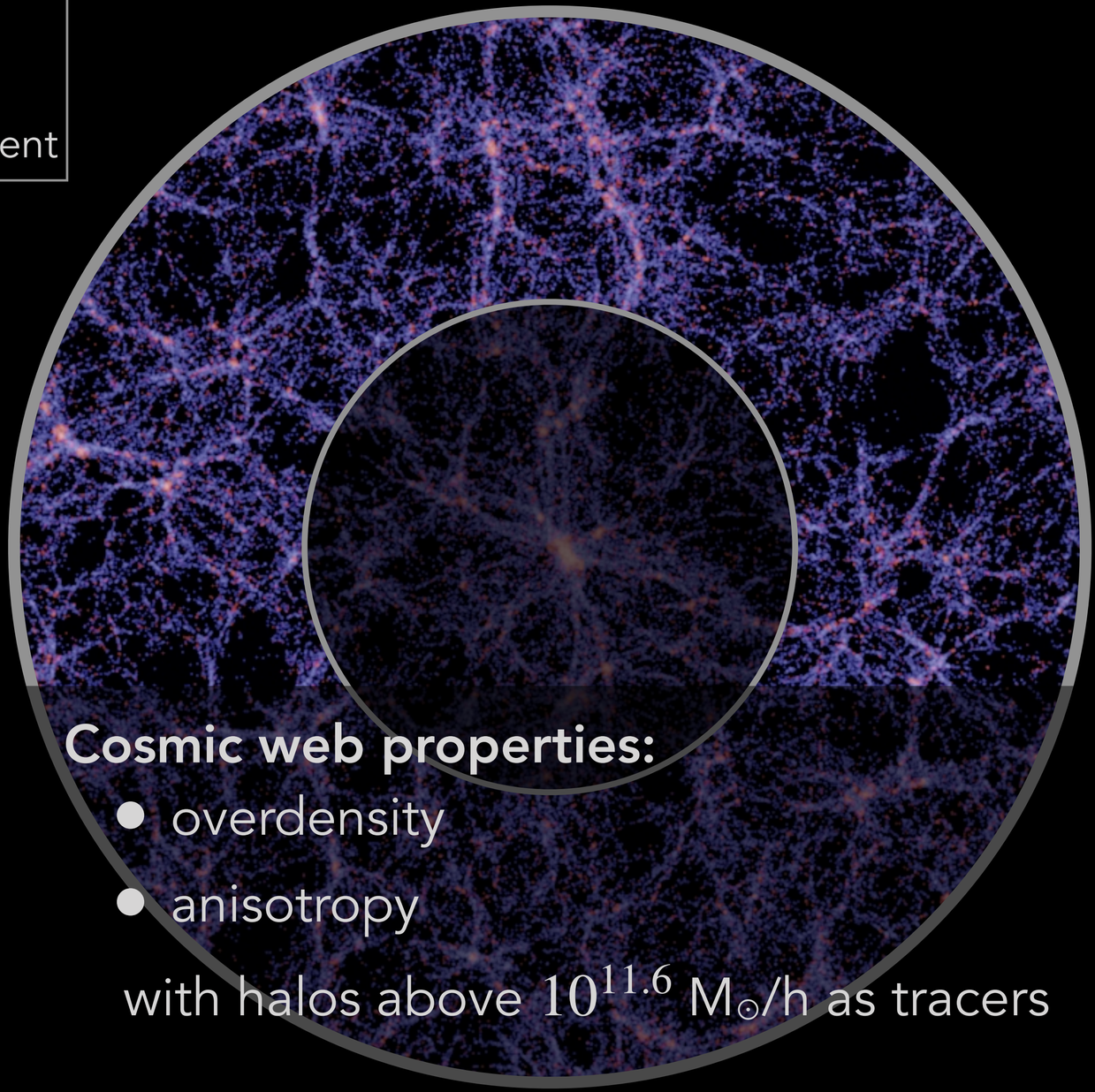


Local Group Analogues property:

- Gravitational coupling energy

$$E_{\text{coupling}} = \frac{1}{2}\frac{m_1 m_2}{m_1 + m_2}V^2 - \frac{G m_1 m_2}{D}$$

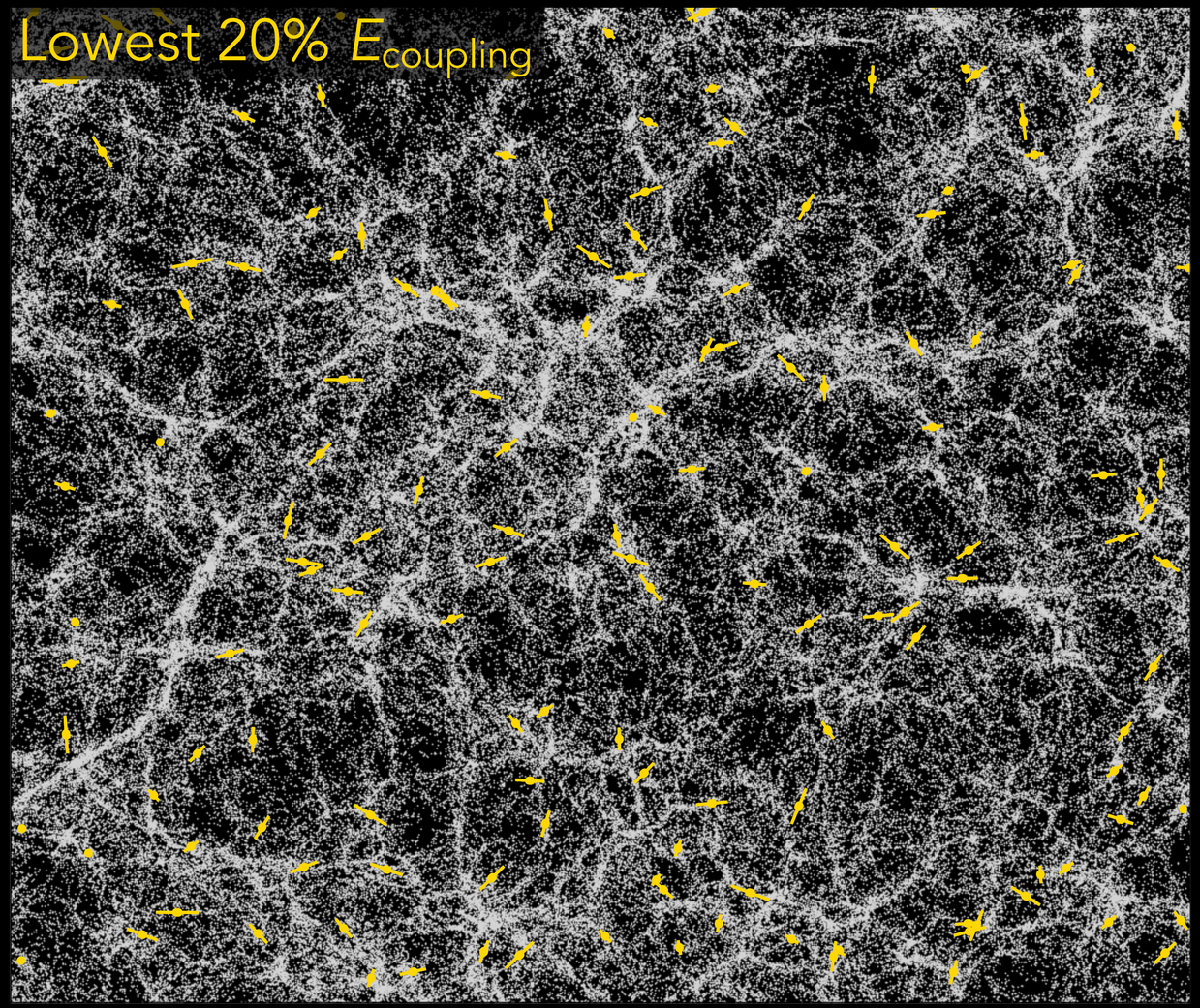


Cosmic web properties:

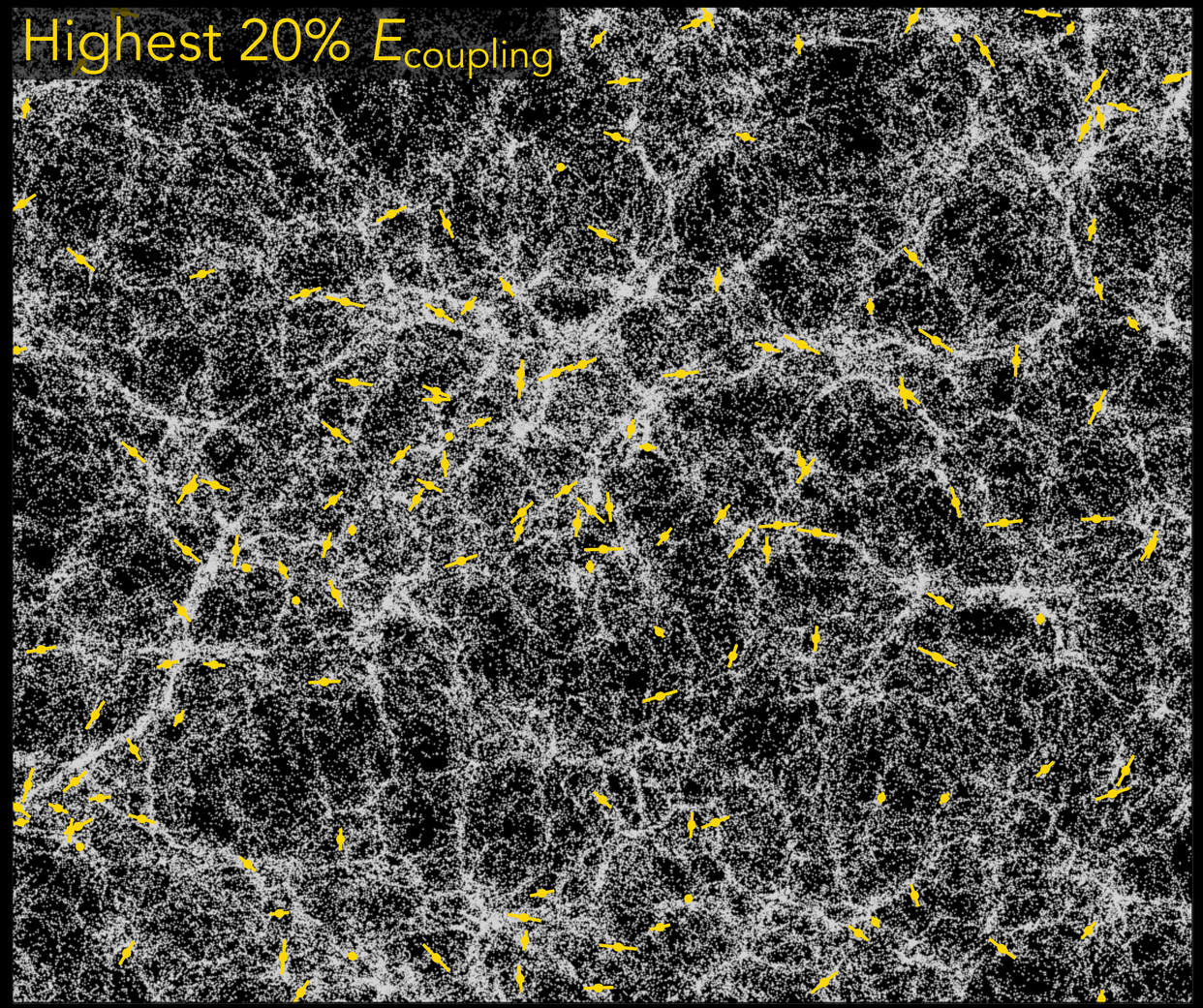
- overdensity
- anisotropy

with halos above $10^{11.6}$ $M_\odot/h$ as tracers

- **Correlations between Local Group Analogue and Cosmic Web**



Weak clustering



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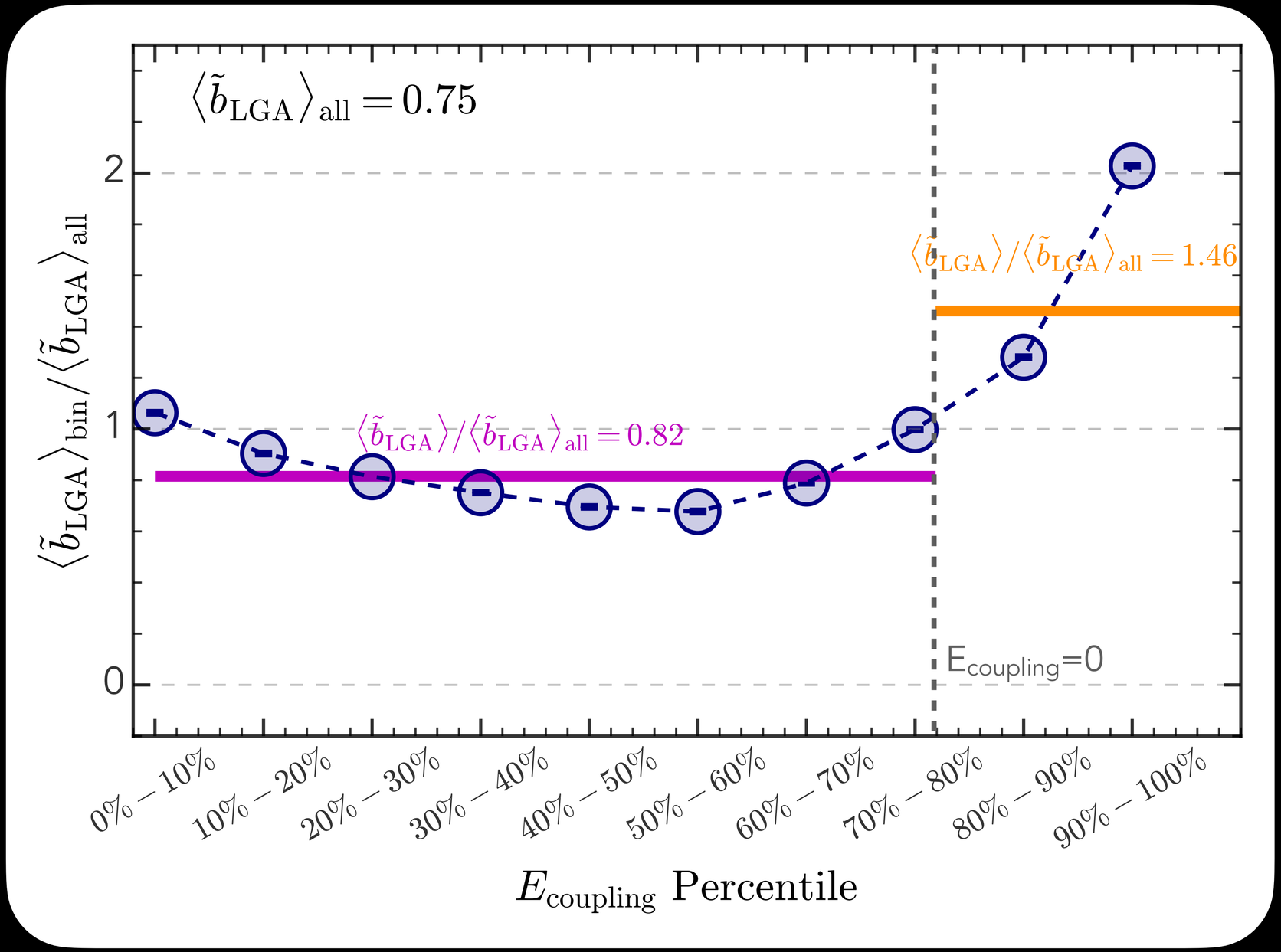

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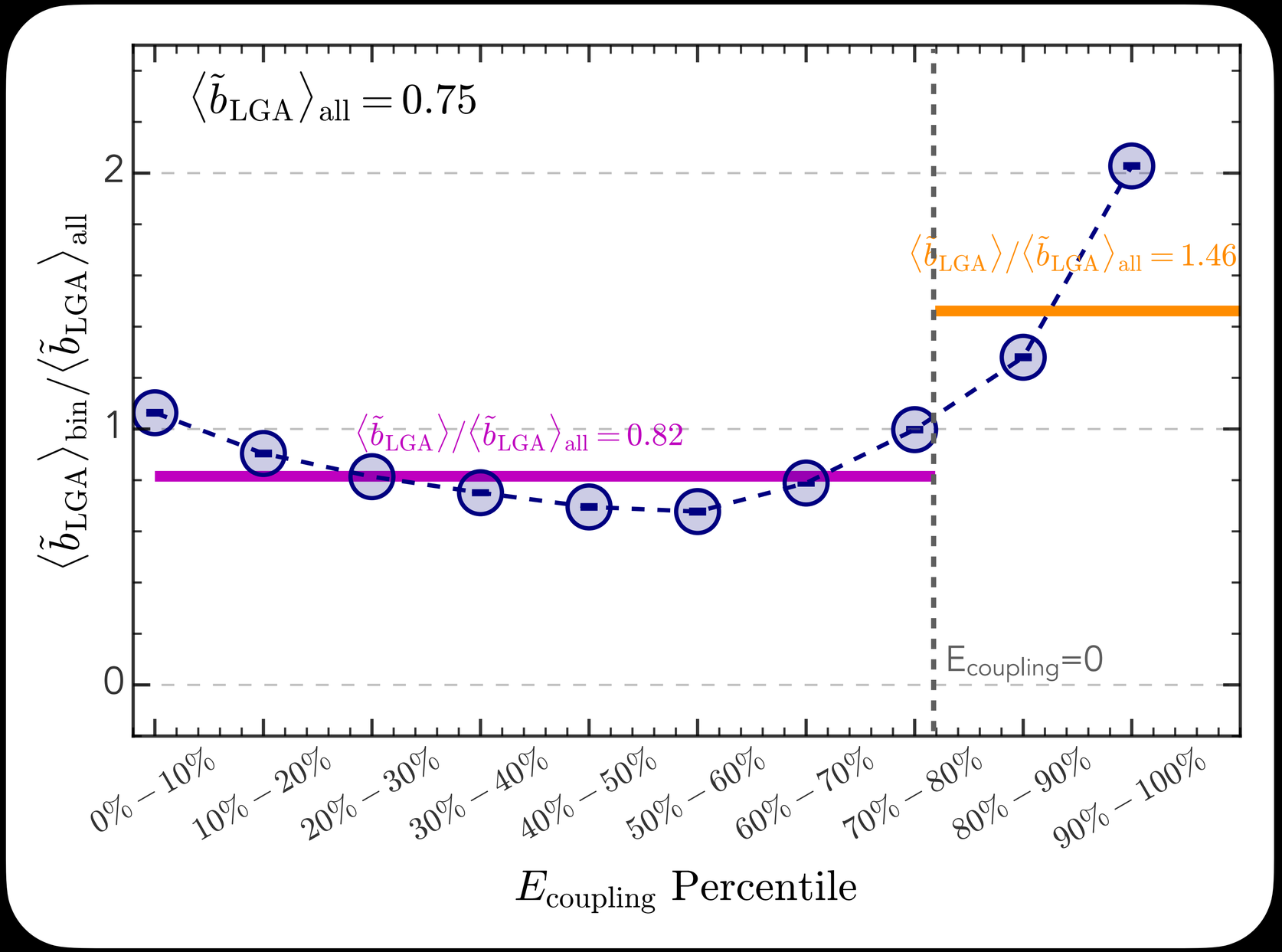

~80%

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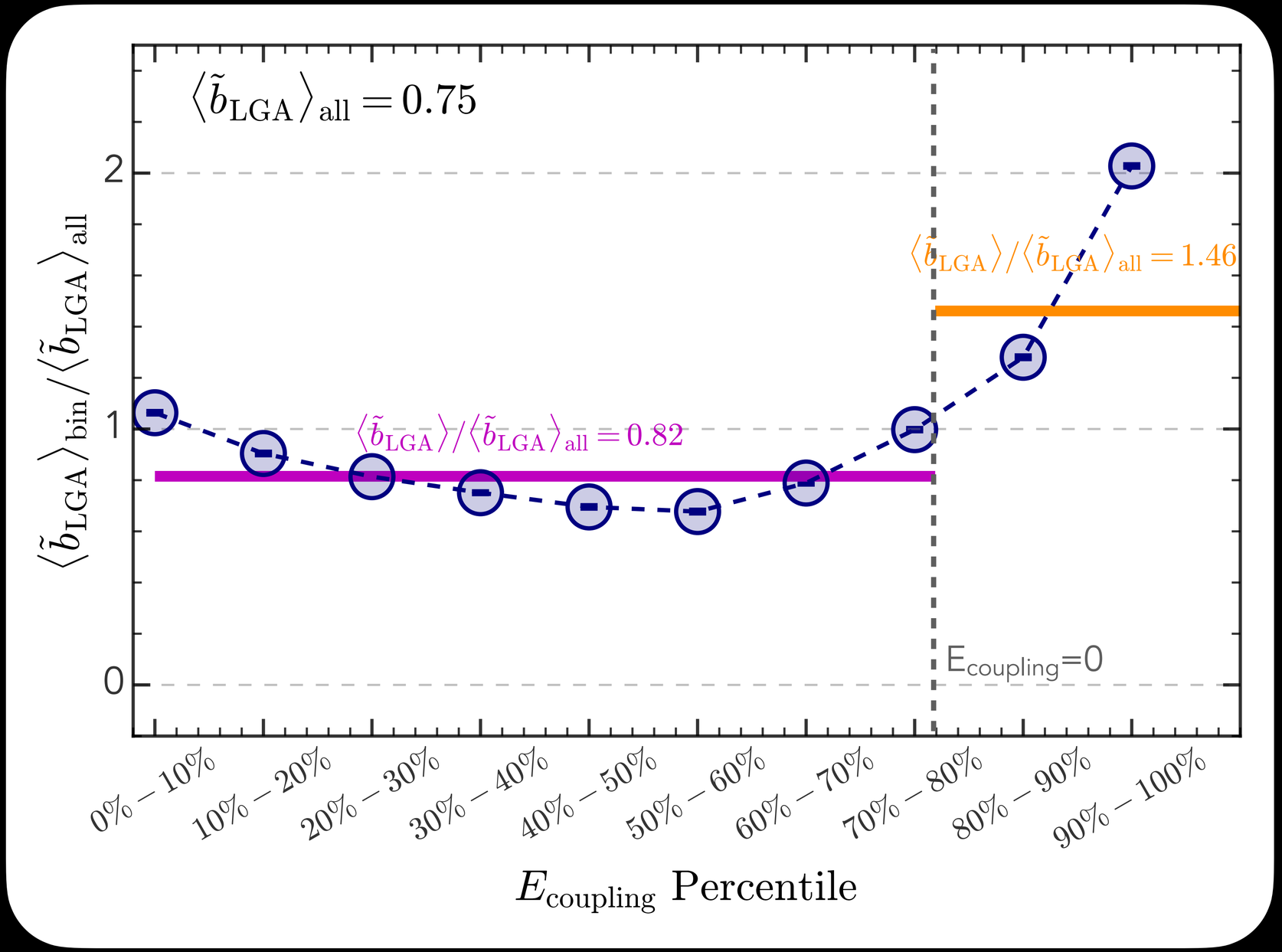

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Halo assembly bias for formation time only differs by ~60%.

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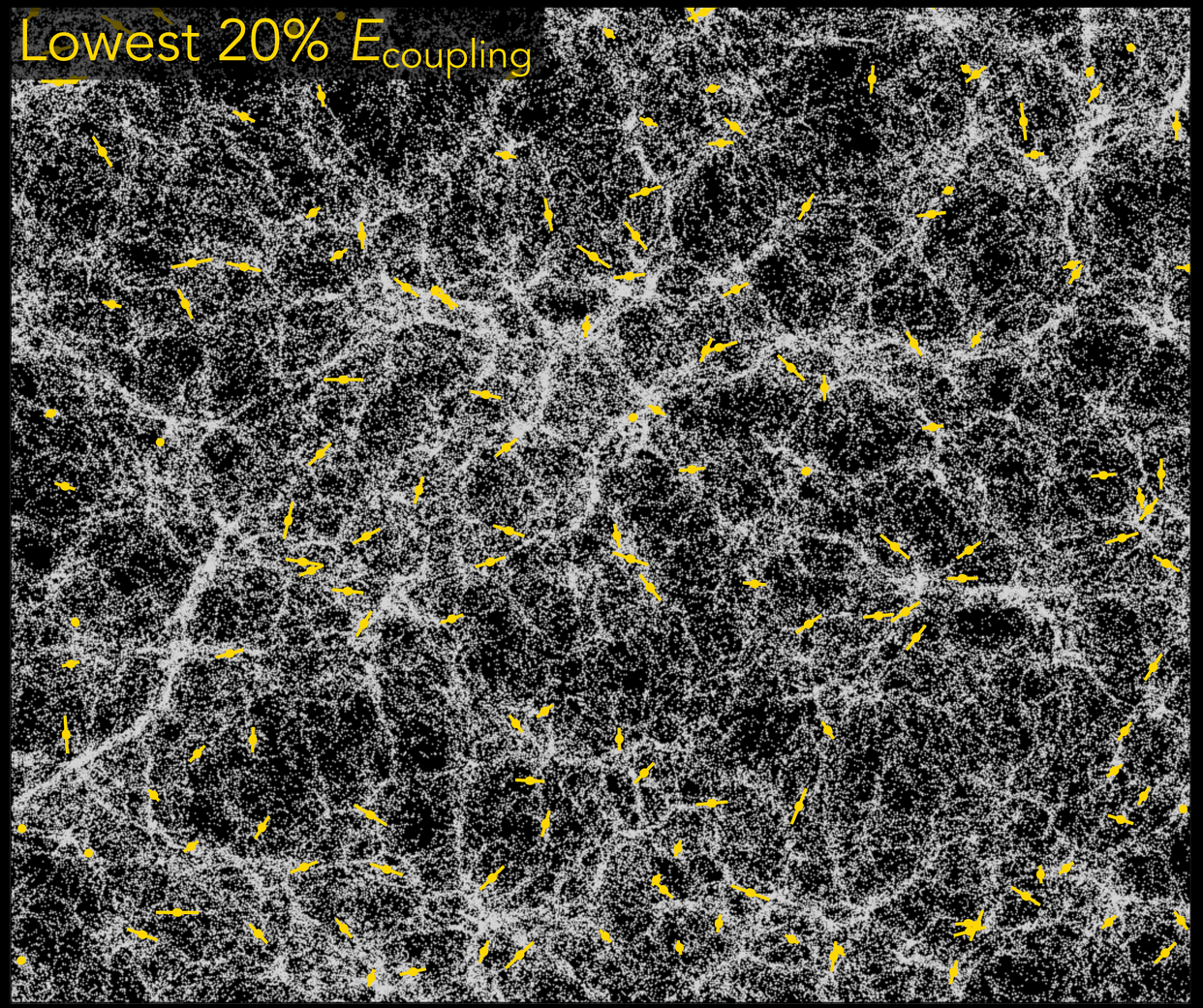

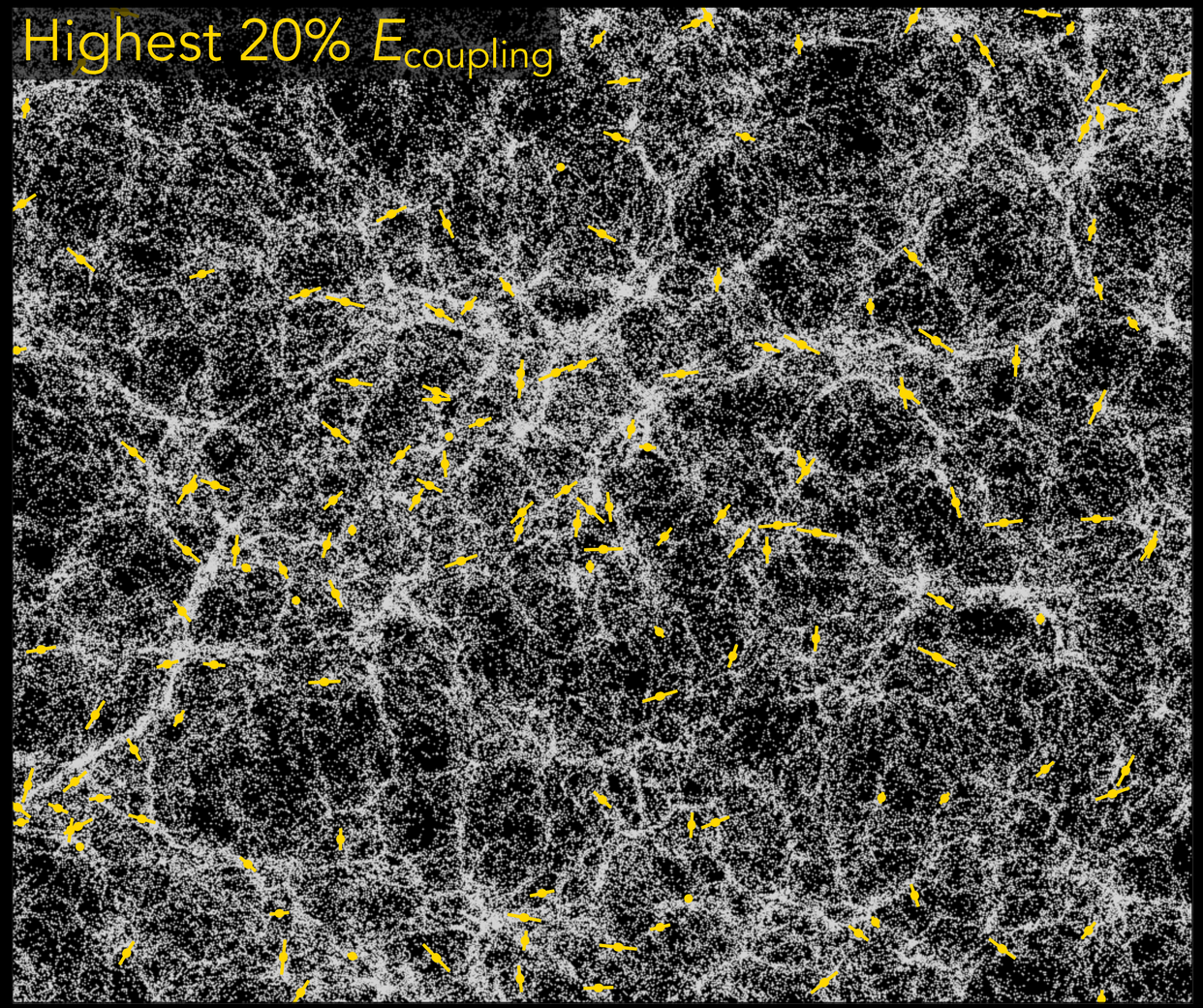

Aligned to filament

Random alignment

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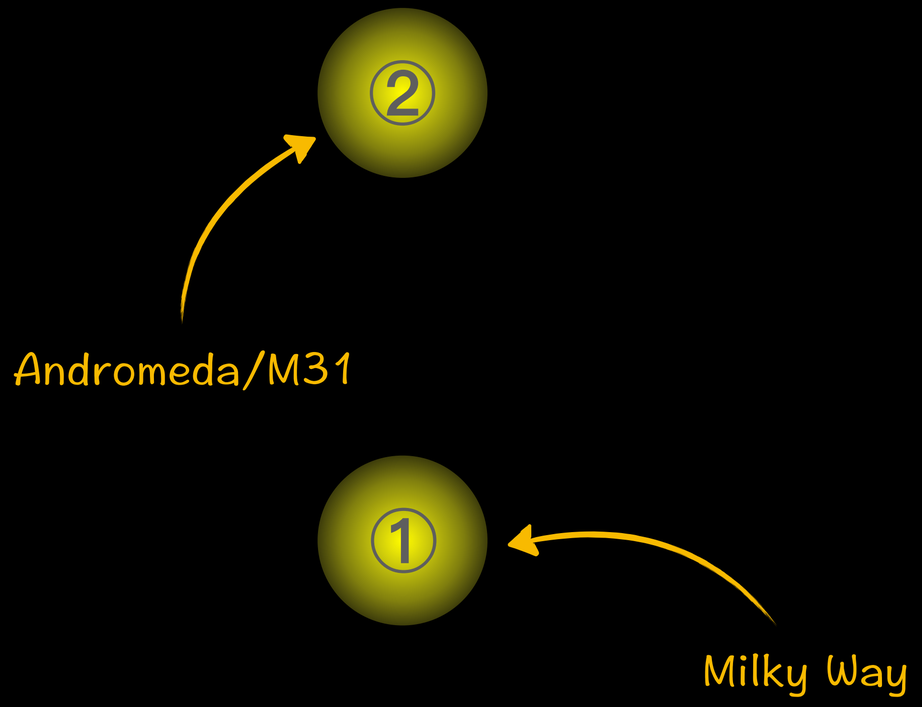

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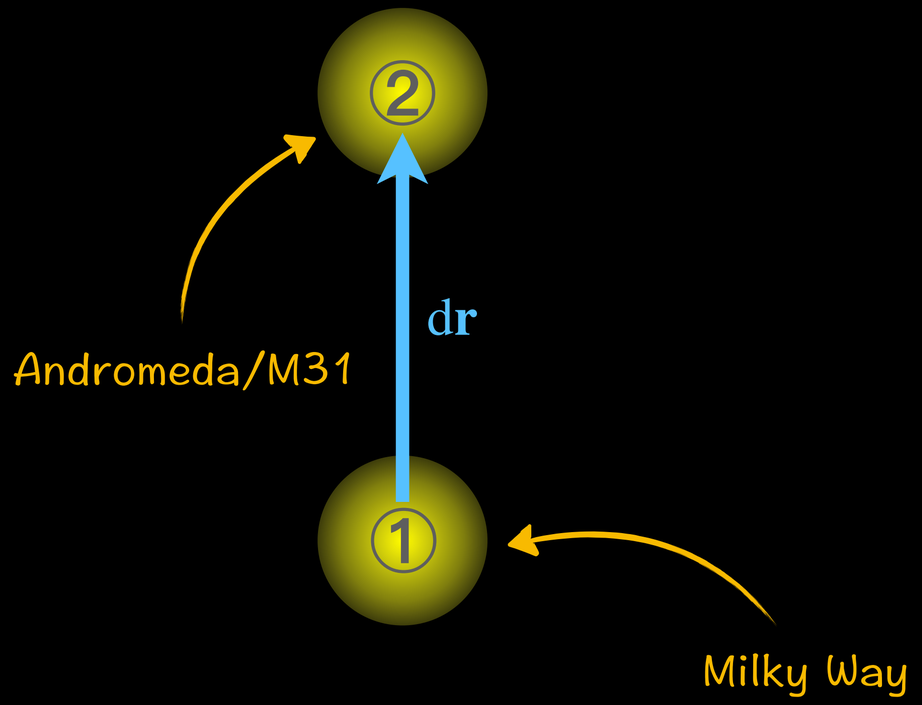

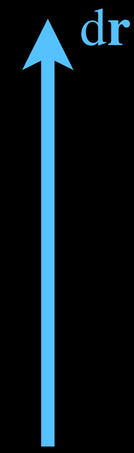

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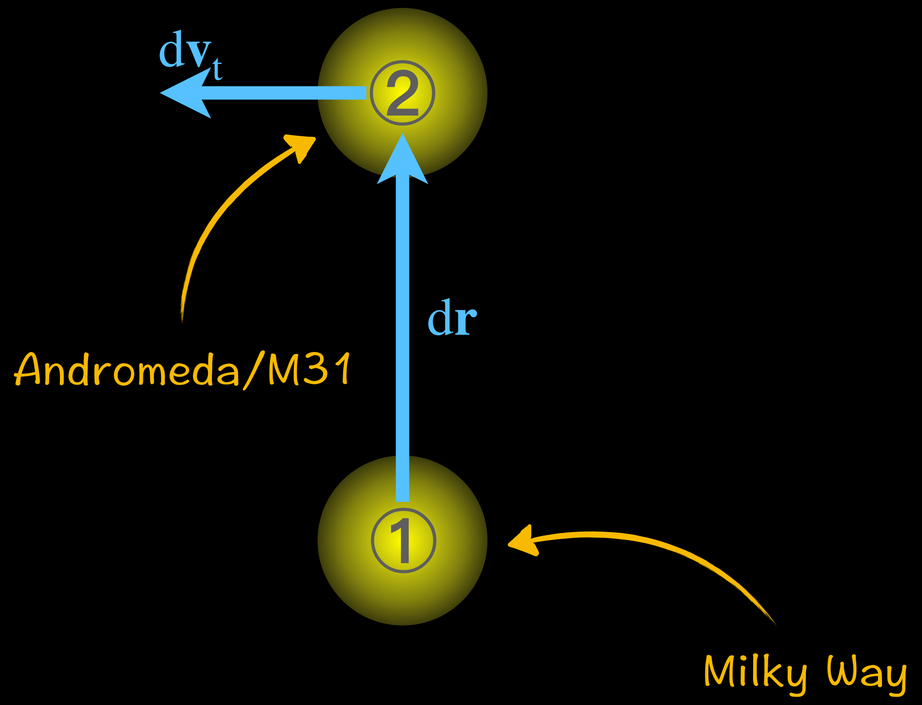

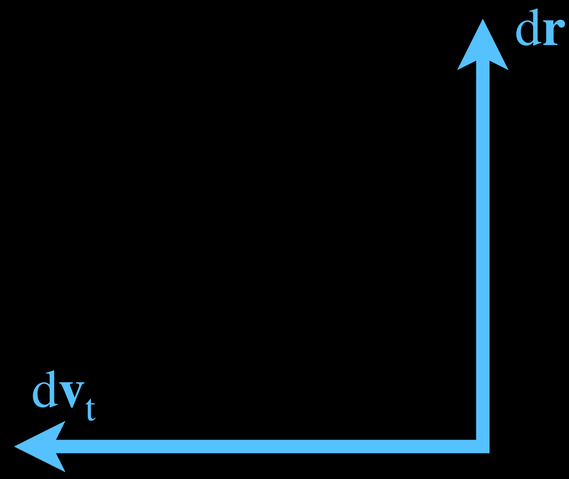

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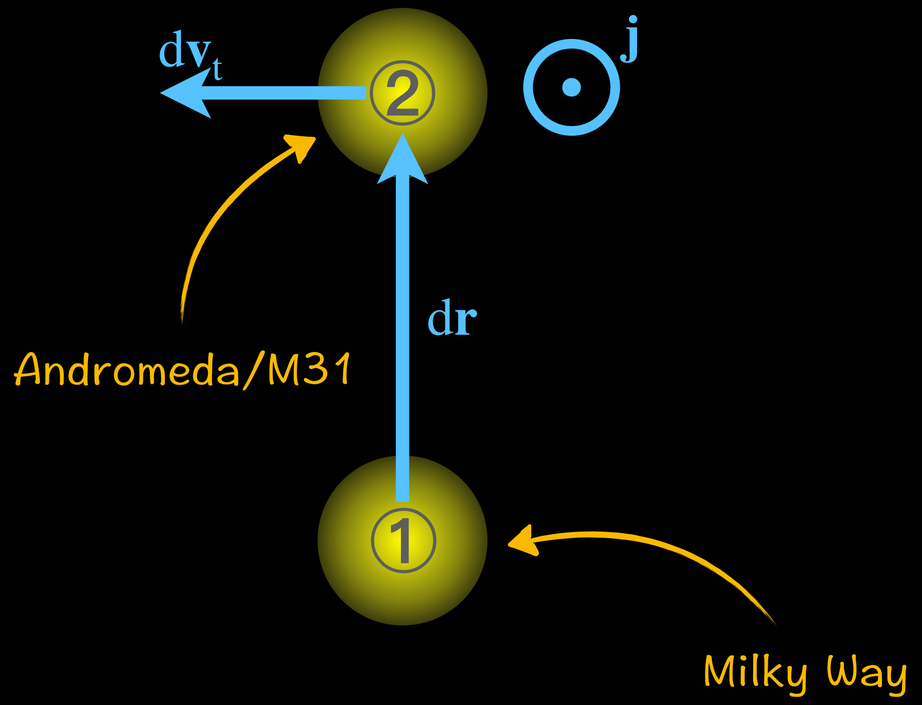

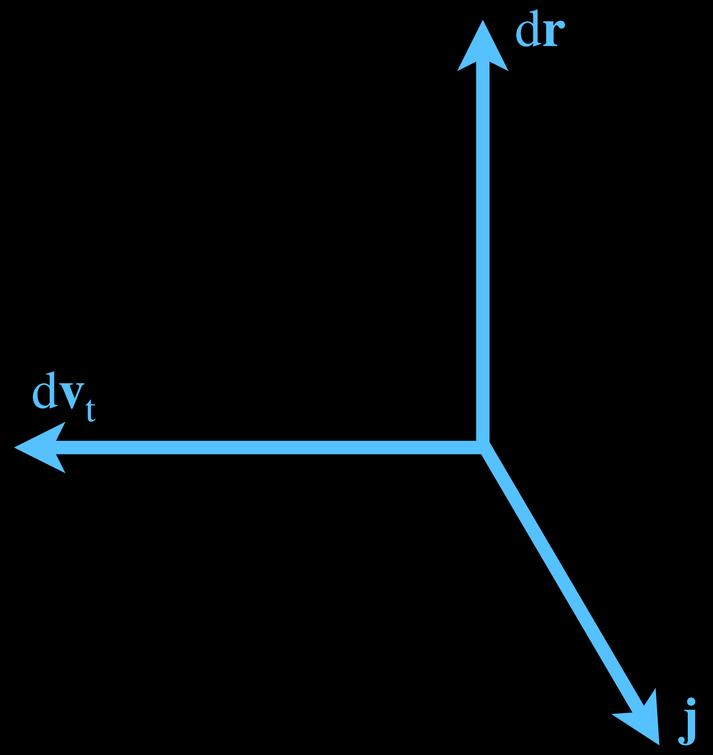

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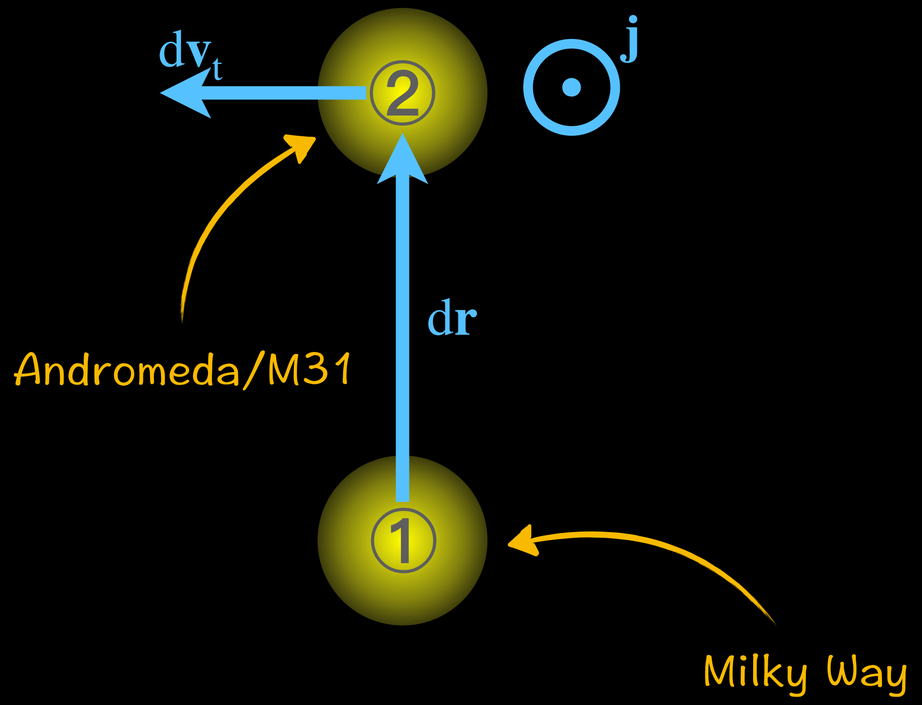

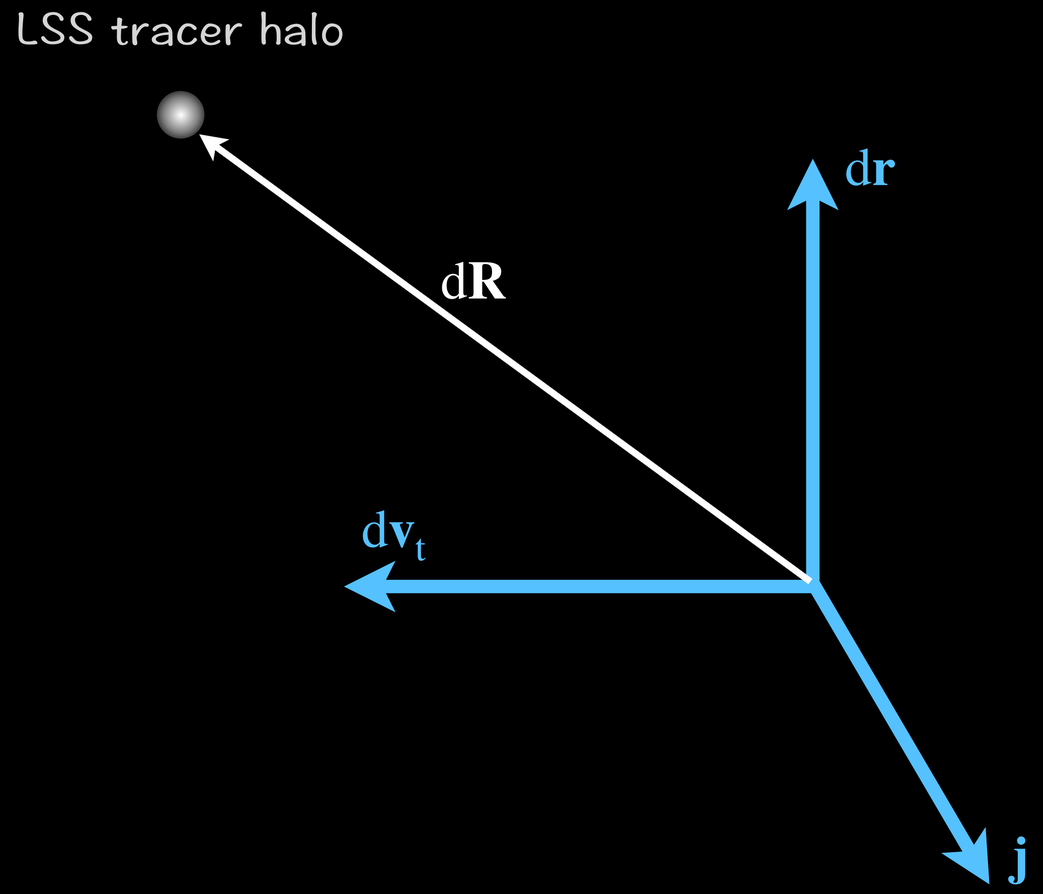

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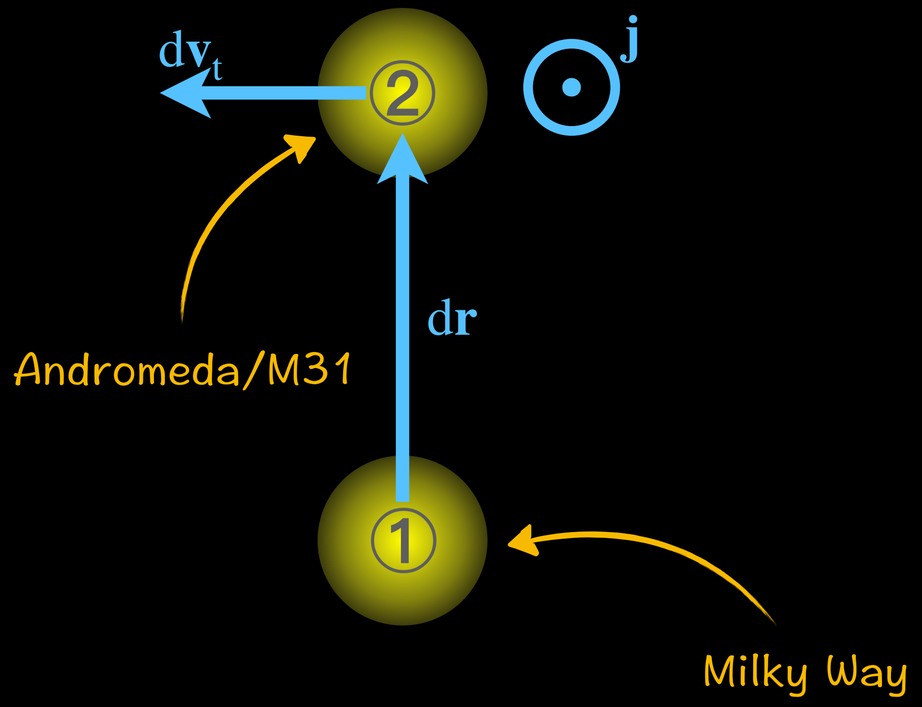

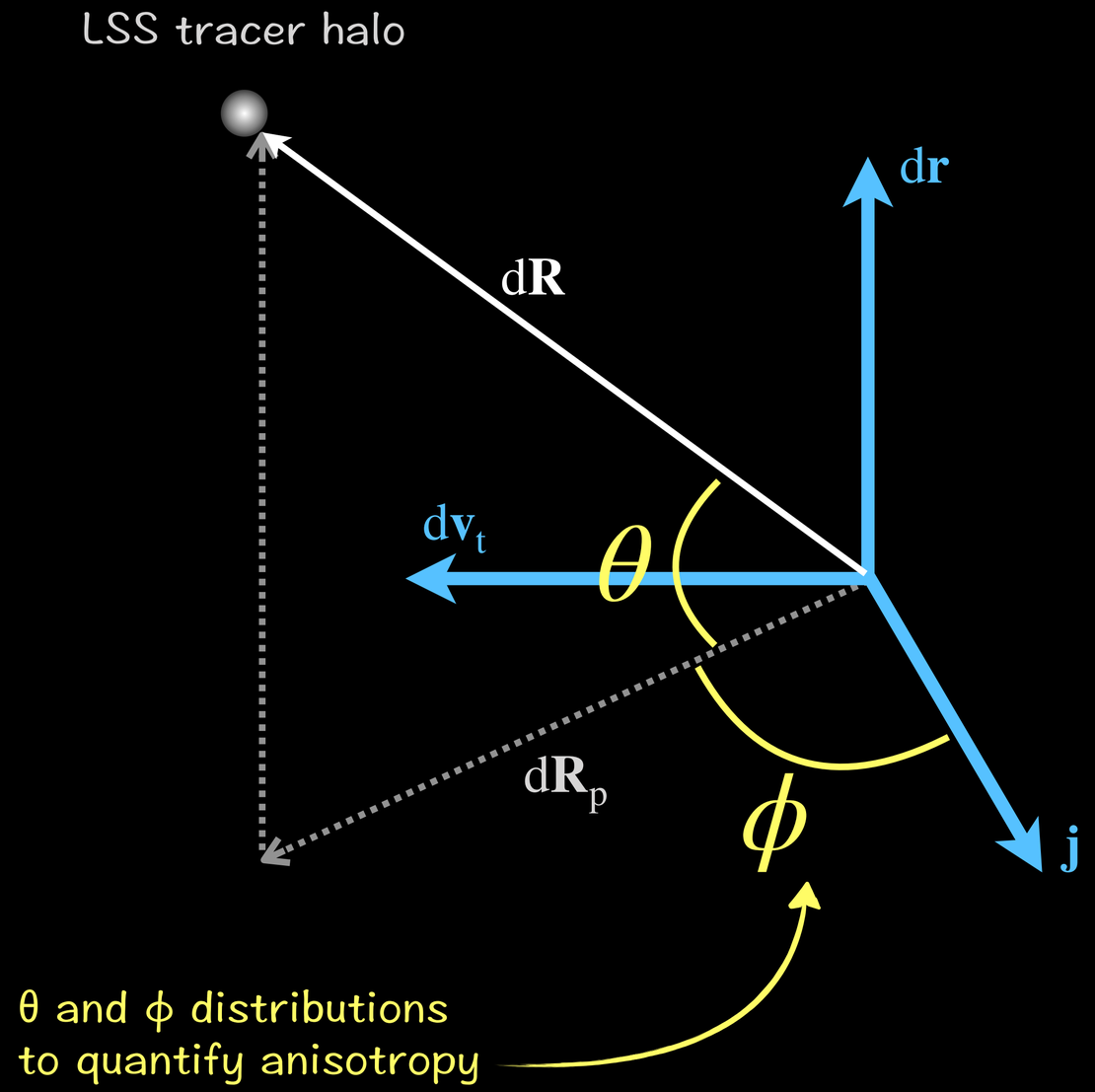

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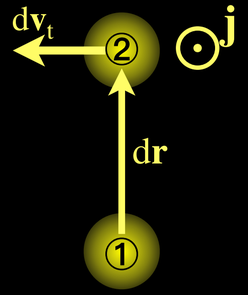

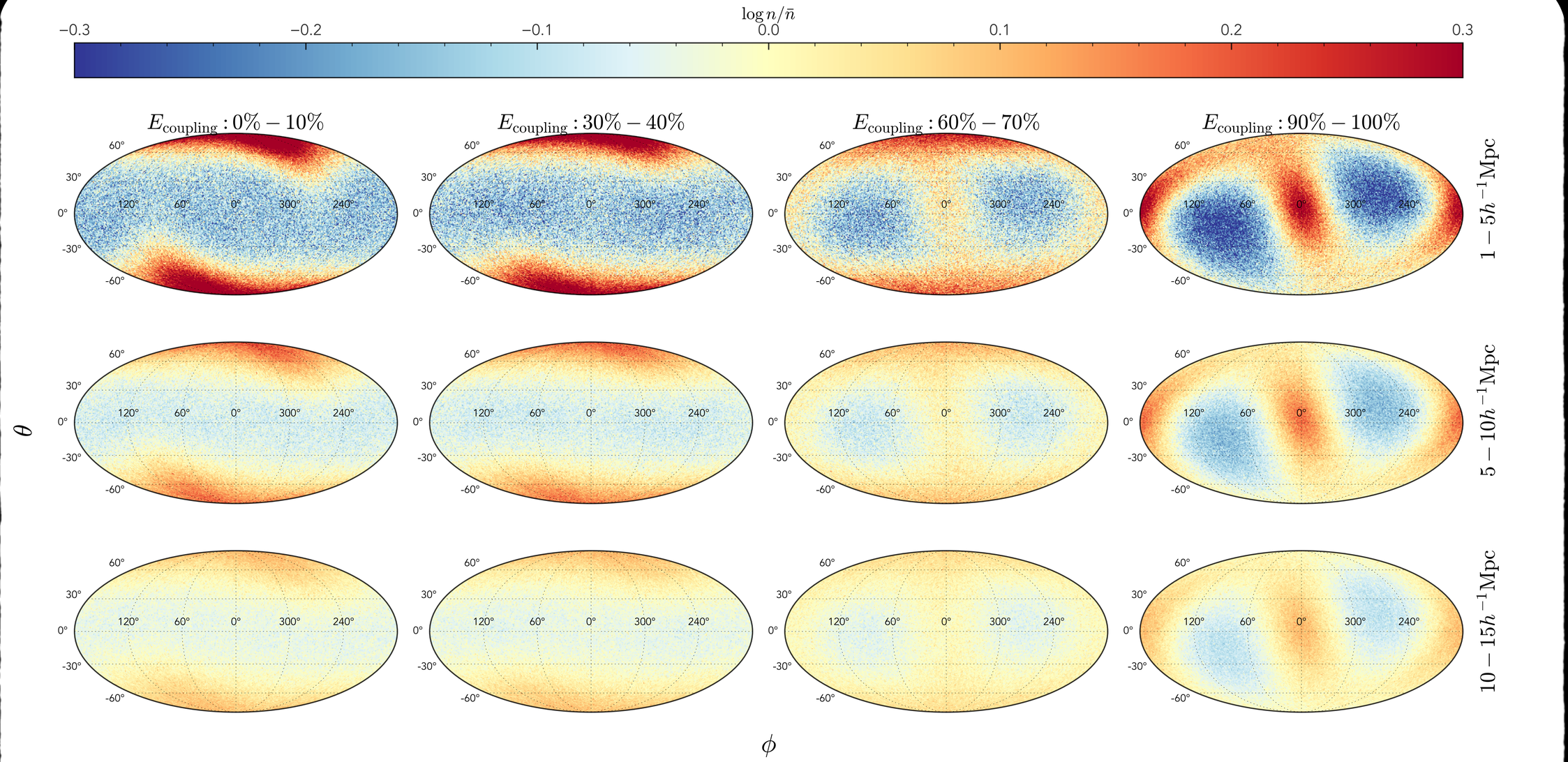

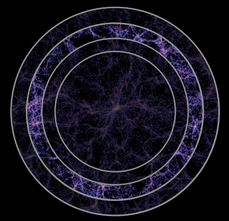

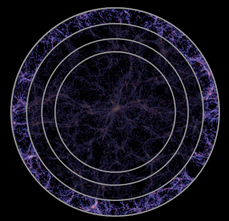

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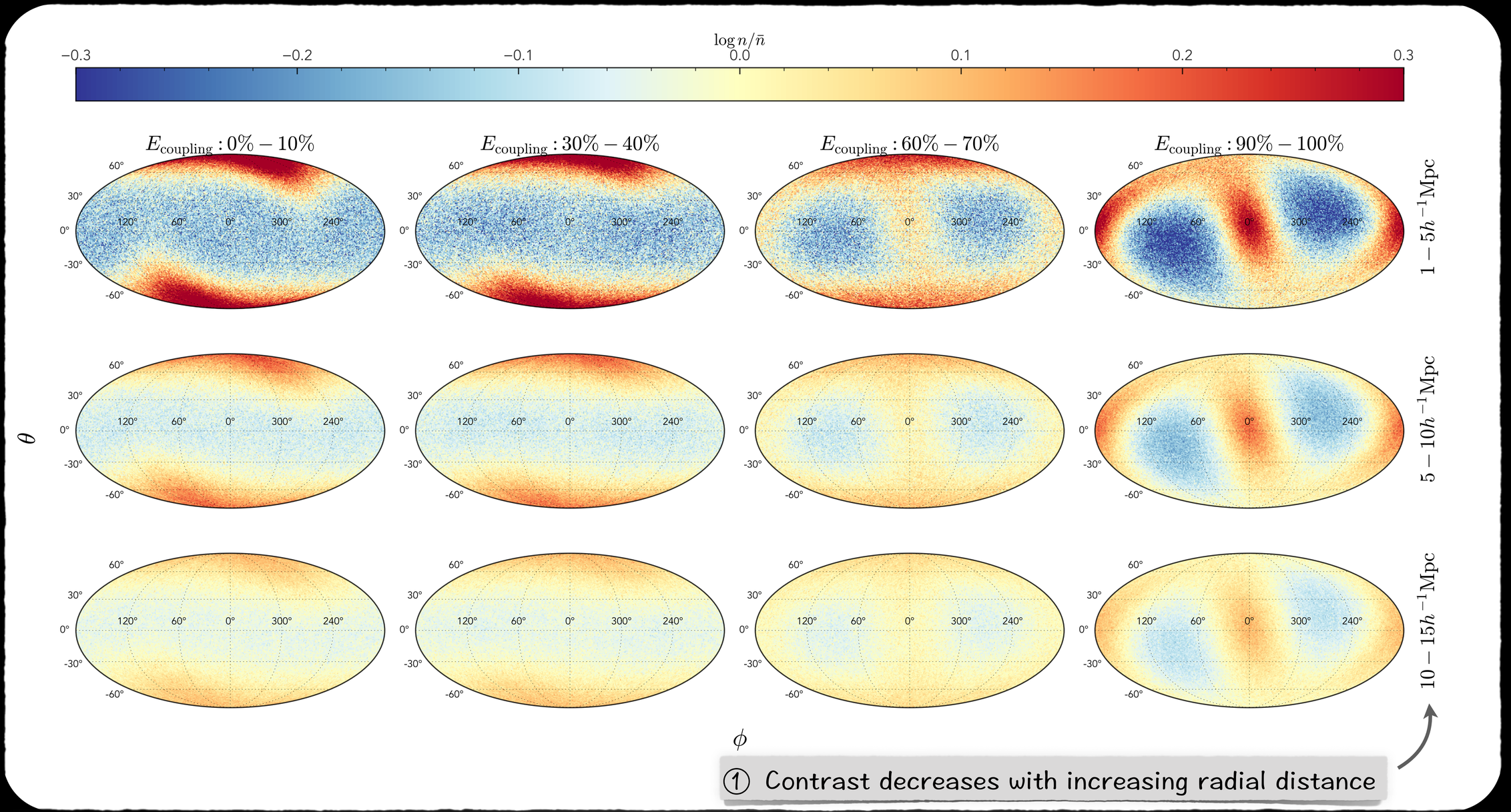

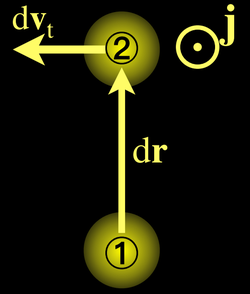

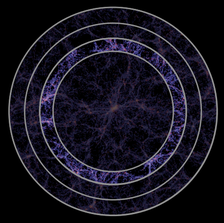

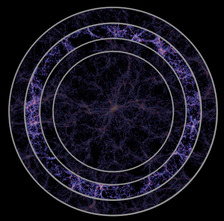

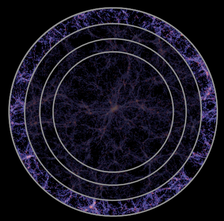

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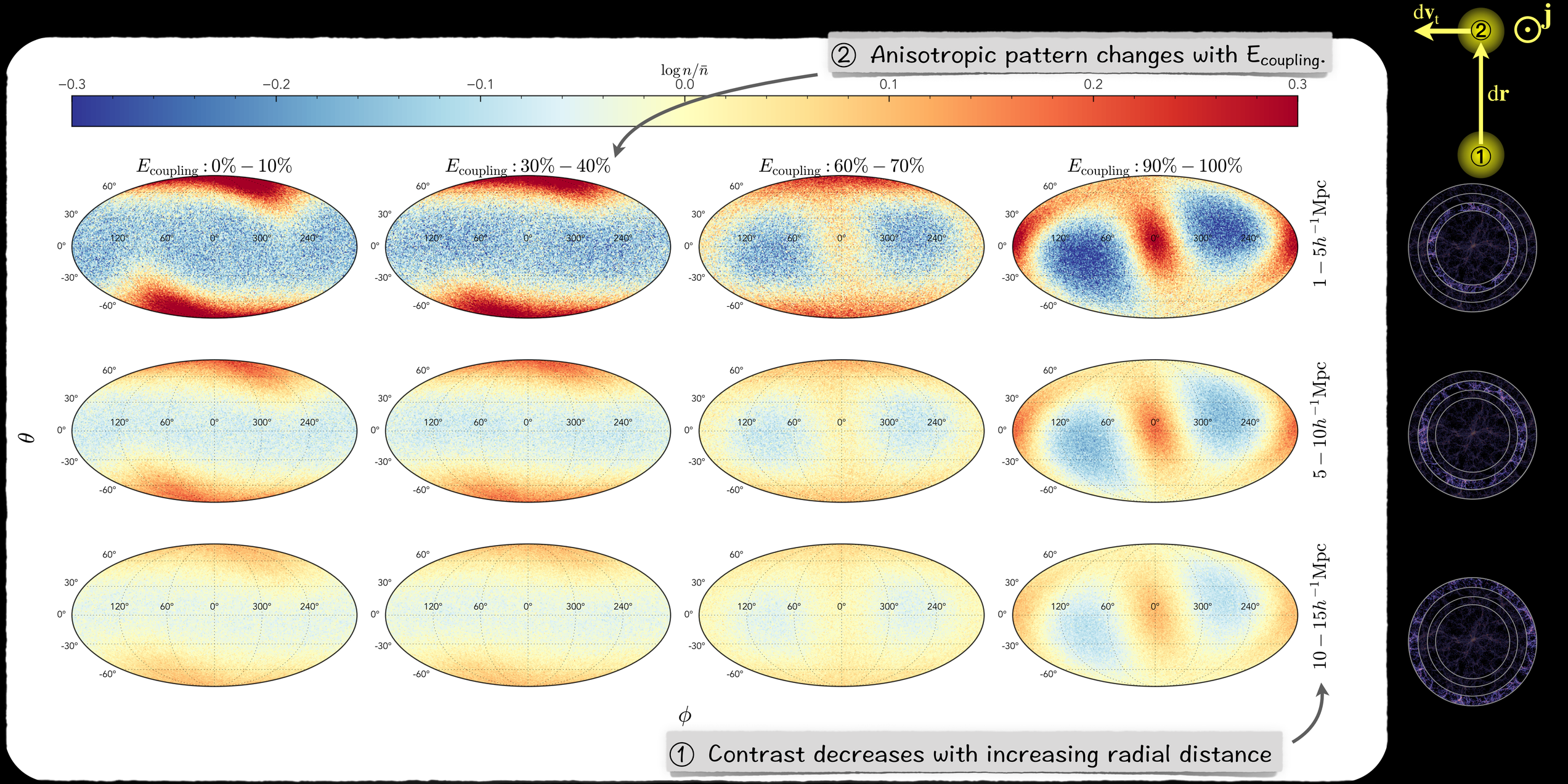

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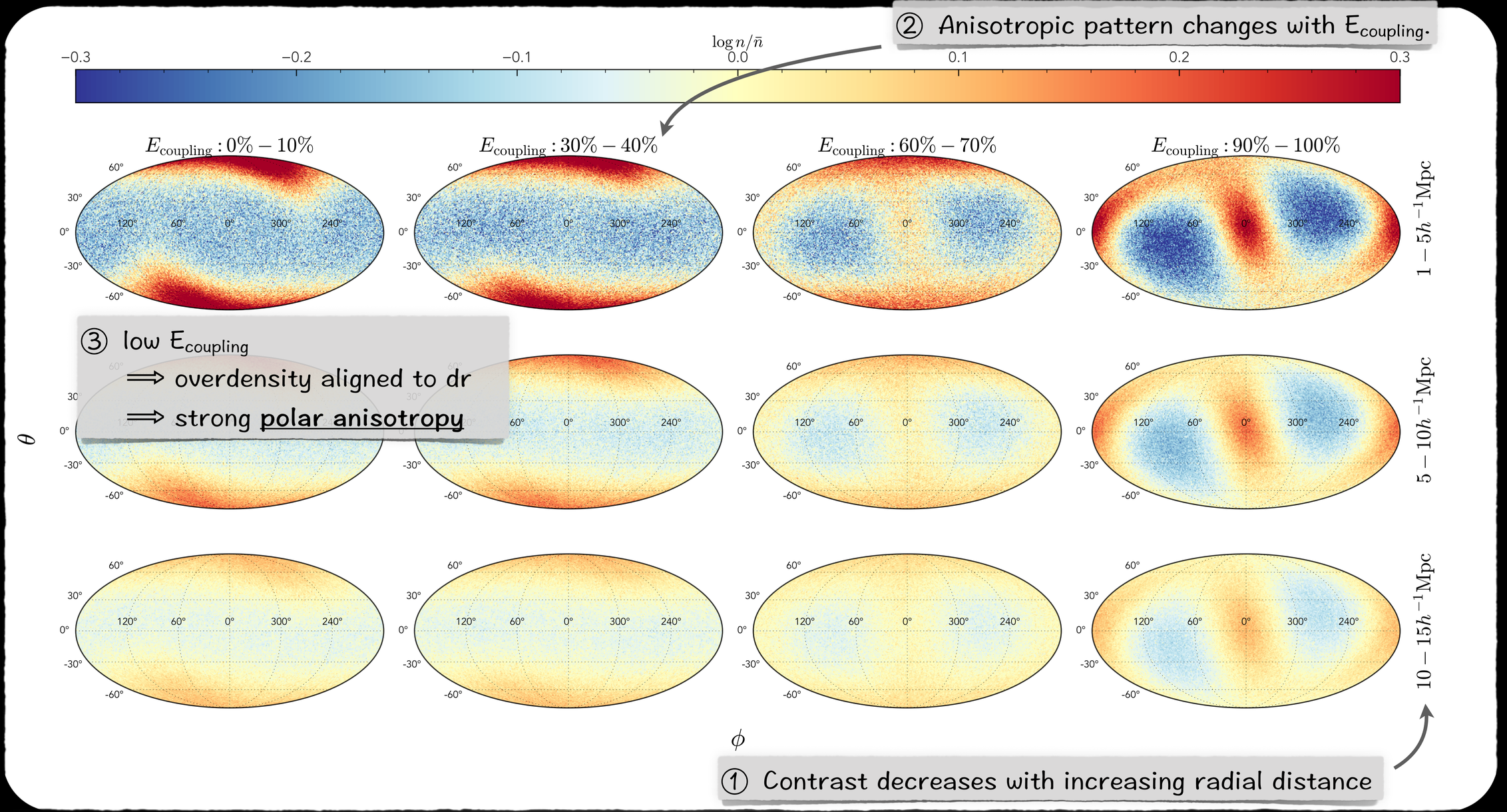

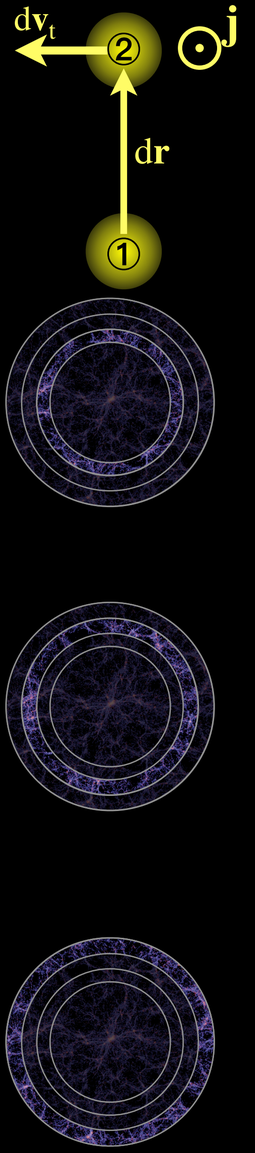

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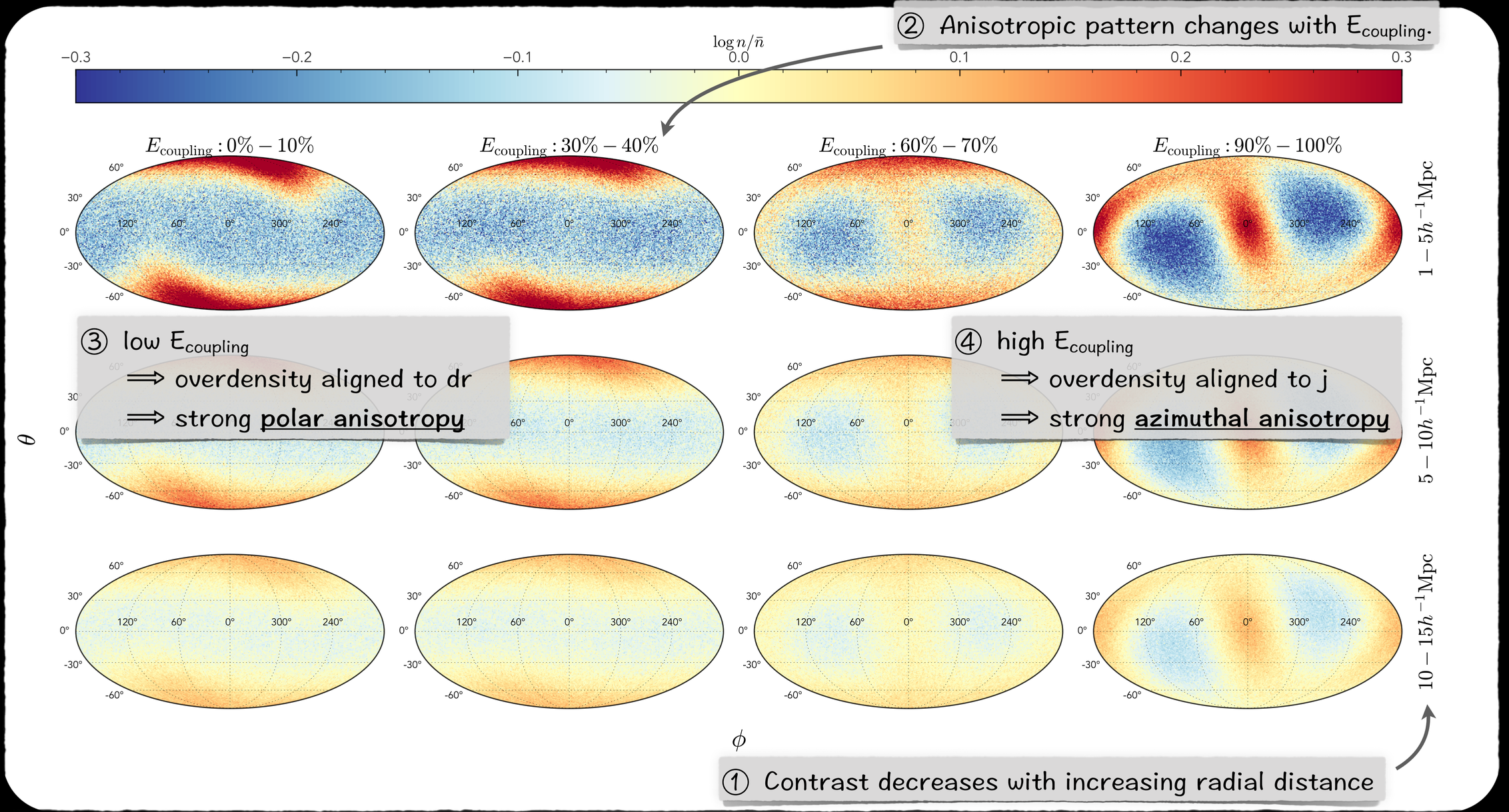

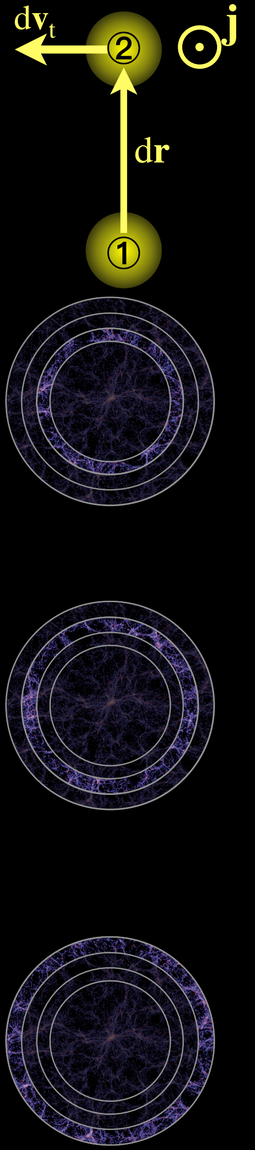

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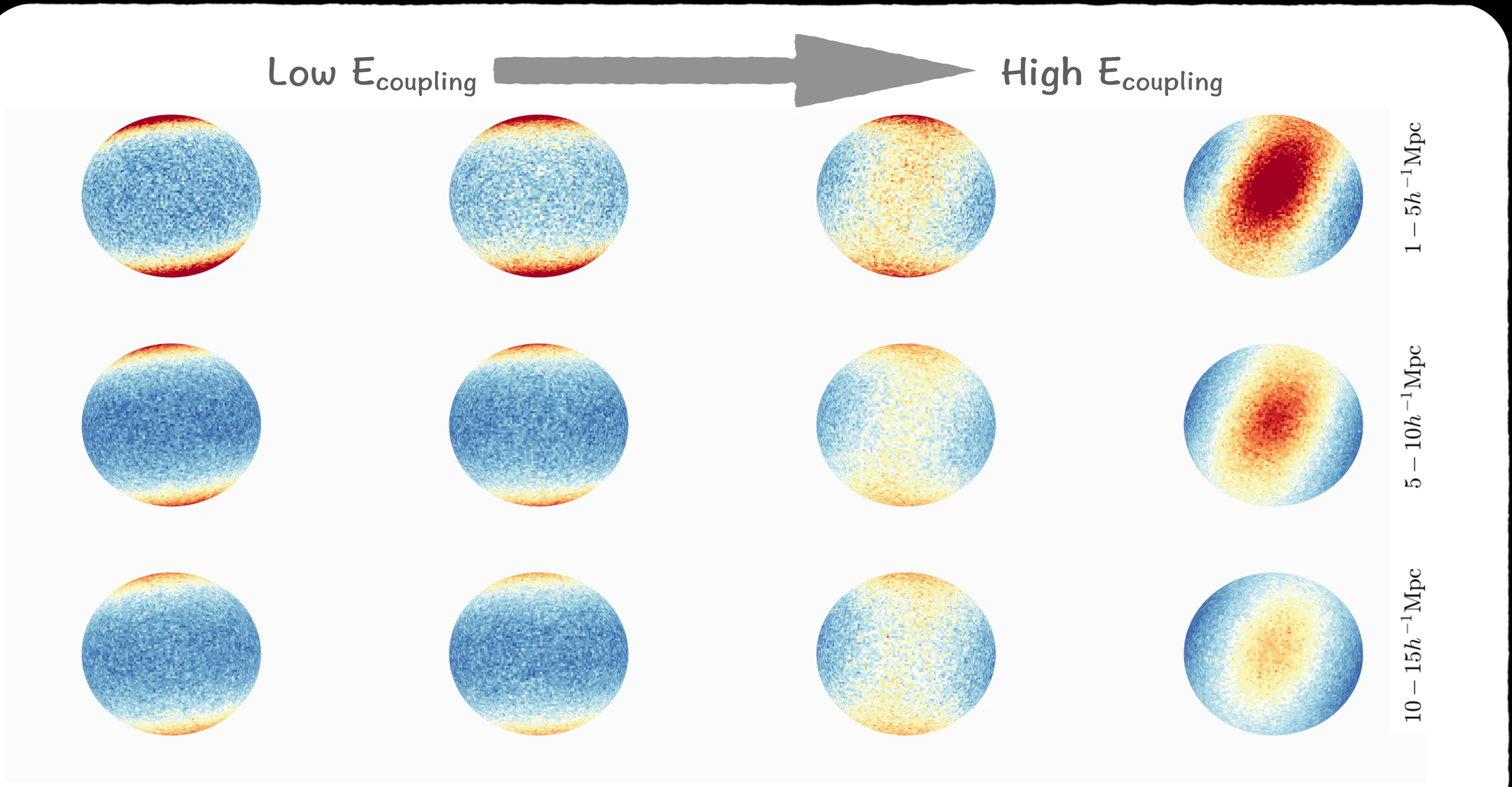

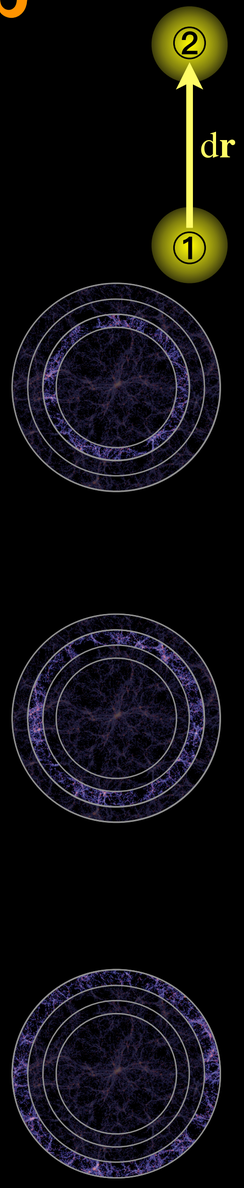

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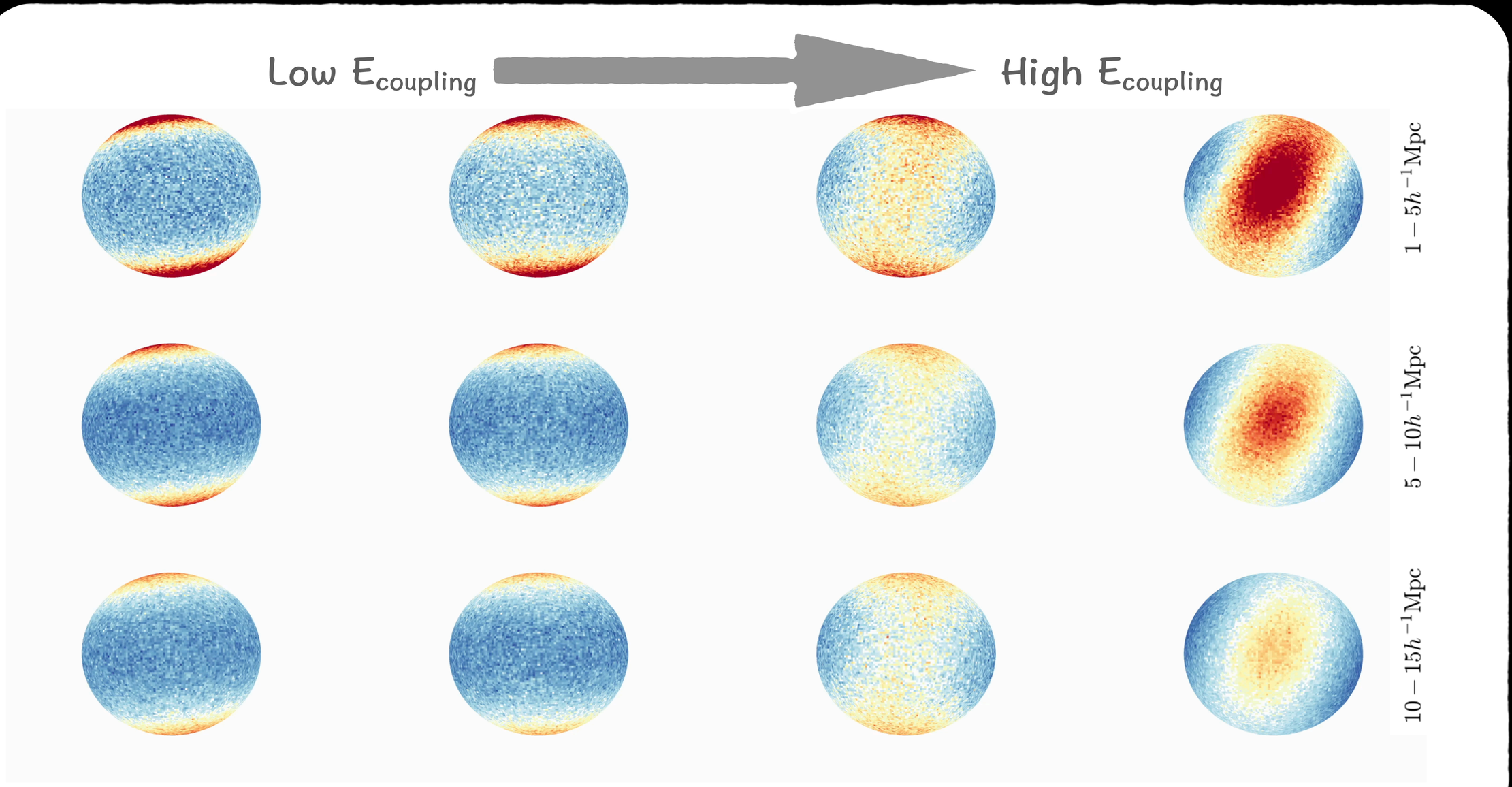
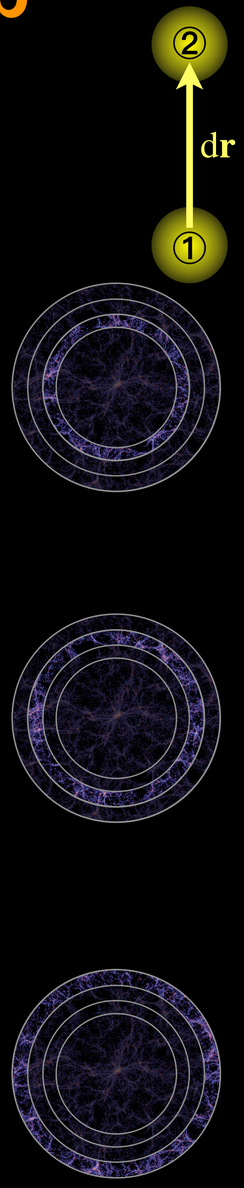


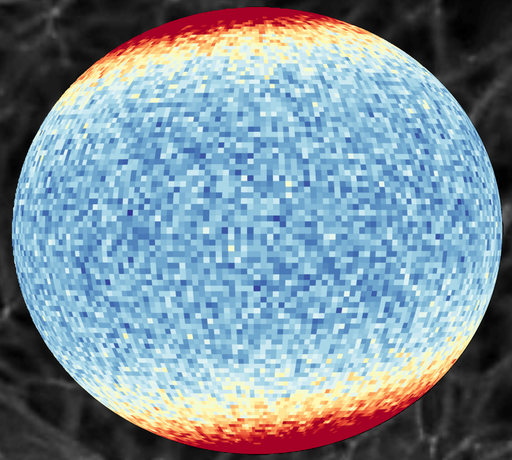


two $10^{12} M_{sun}/h$ halos, separated by ~500kpc/h

Take home: We found **Local Group Analogues** with ...

Low $E_{coupling}$

- live in **low-density** regions
- **displacement vec aligned** to LSS
- **strong polar** anisotropy
- **weak azimuthal** anisotropy



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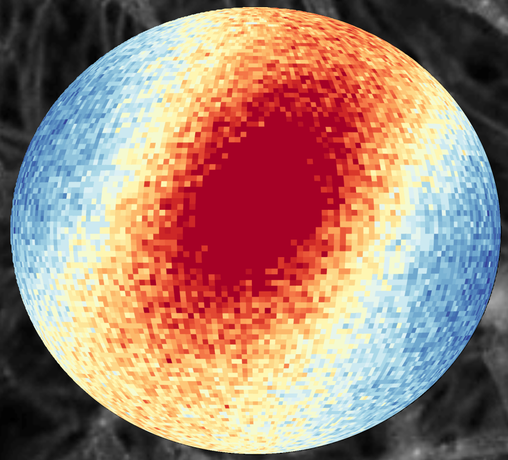

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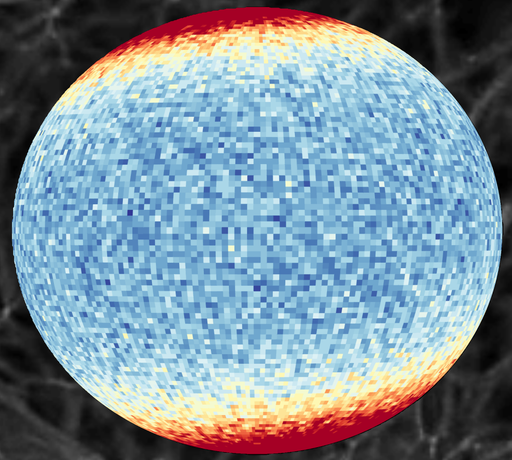

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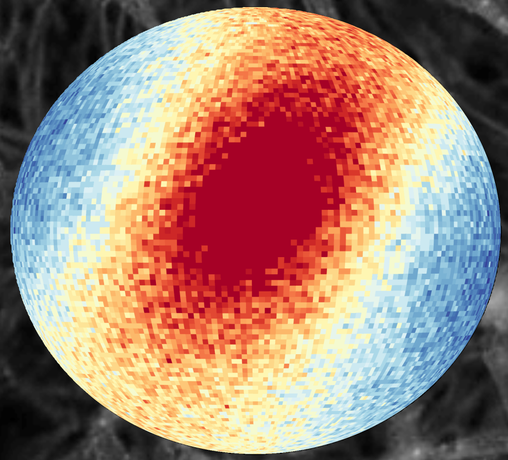

• Local Group Analogue

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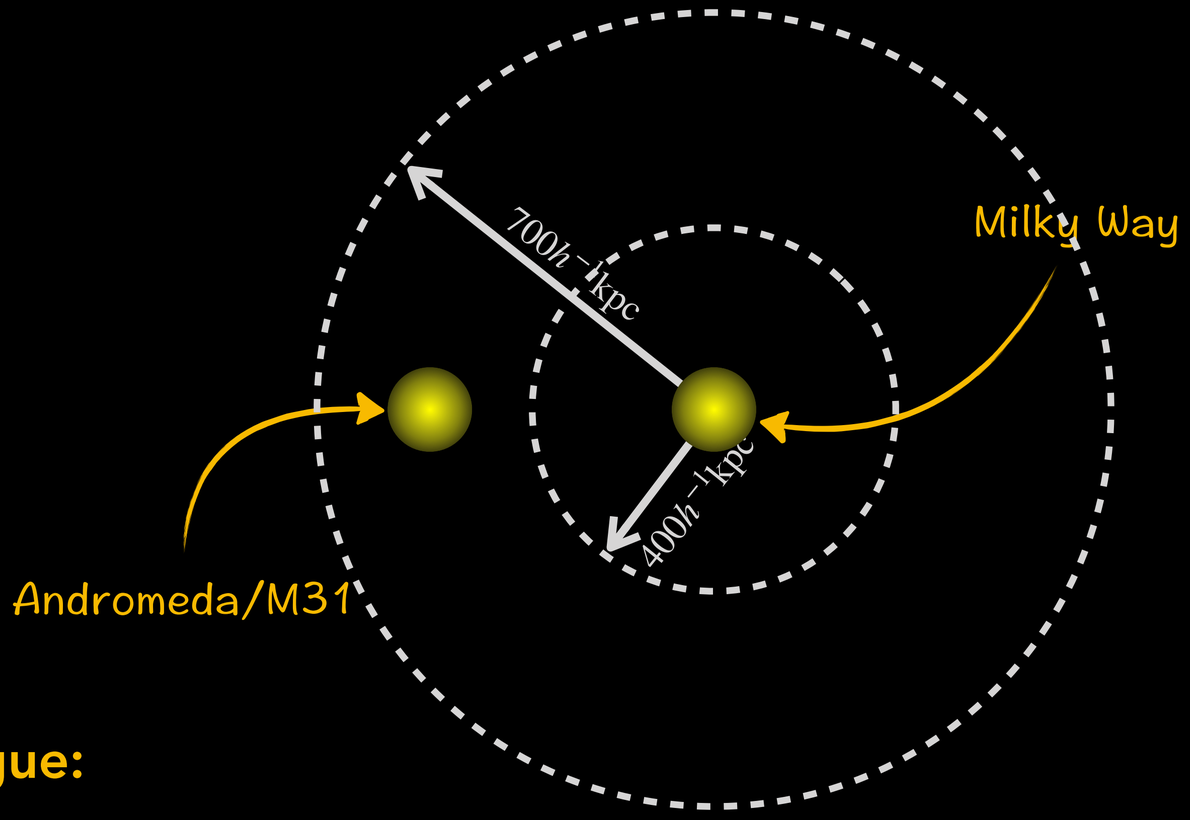
- One MW with Mhalo ~ $10^{12\pm0.3}$ $M_\odot/h$

• Local Group Analogue



Local Group Analogue:

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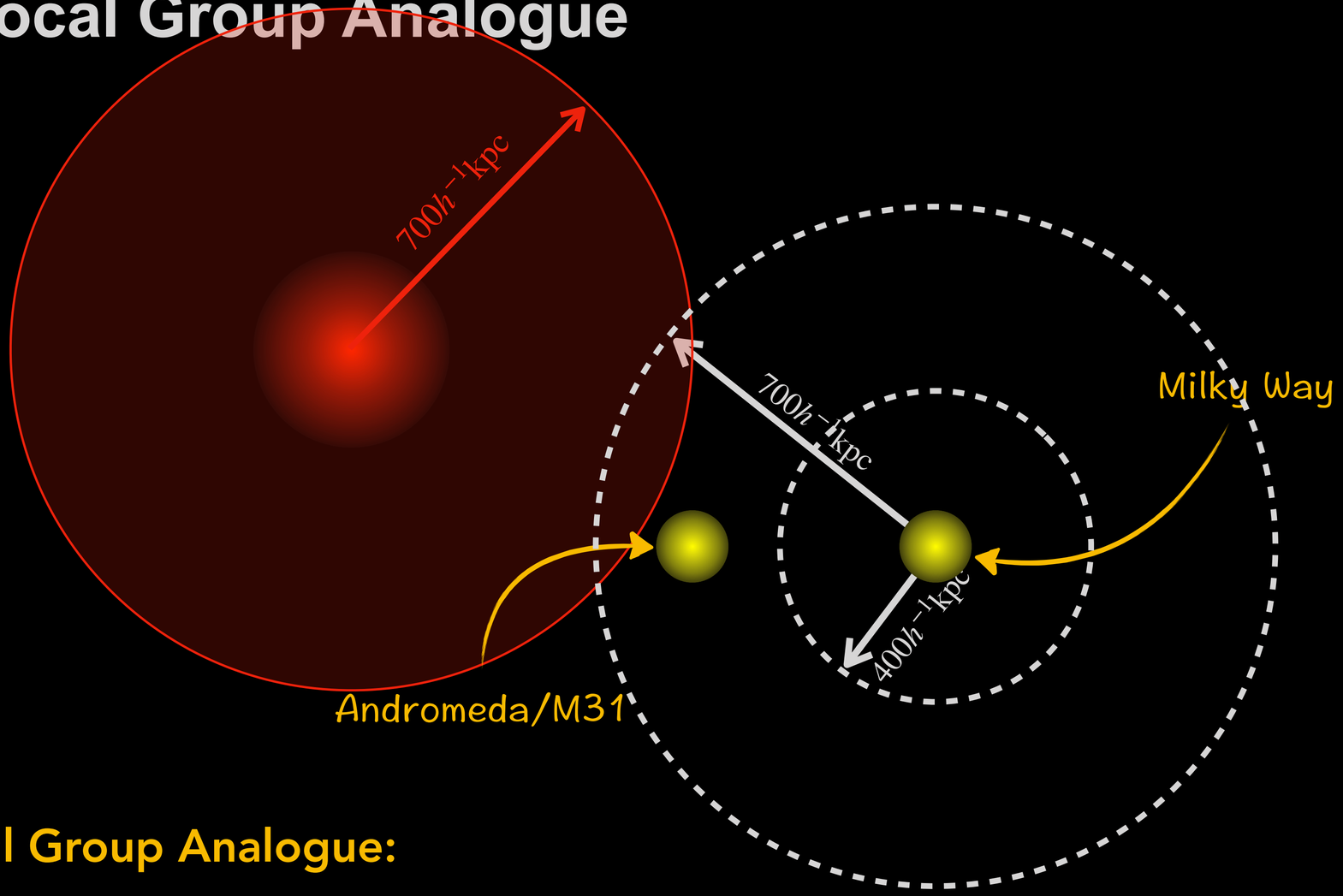
- One MW-like-companion within [400, 700] kpc/h

- **Local Group Analogue**



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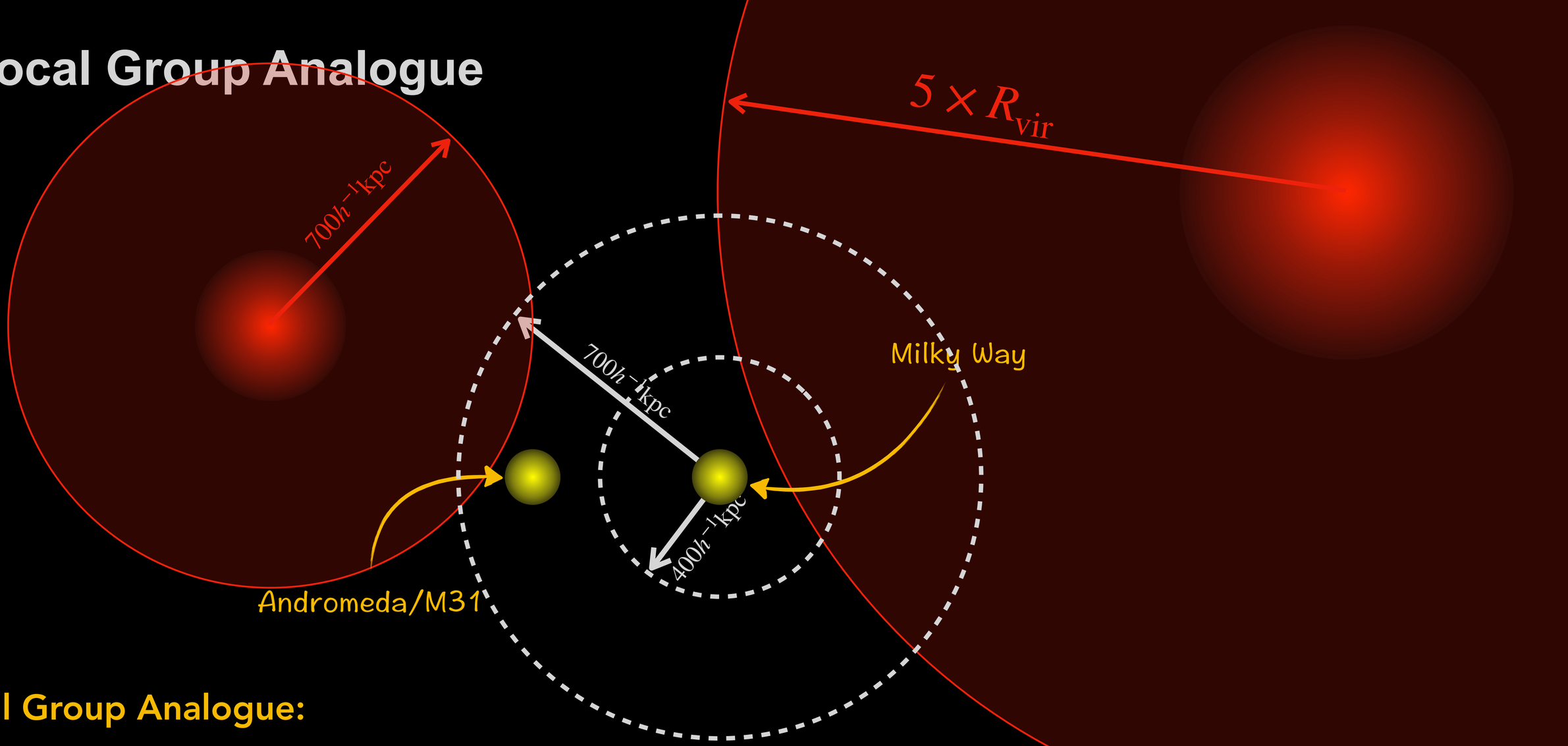

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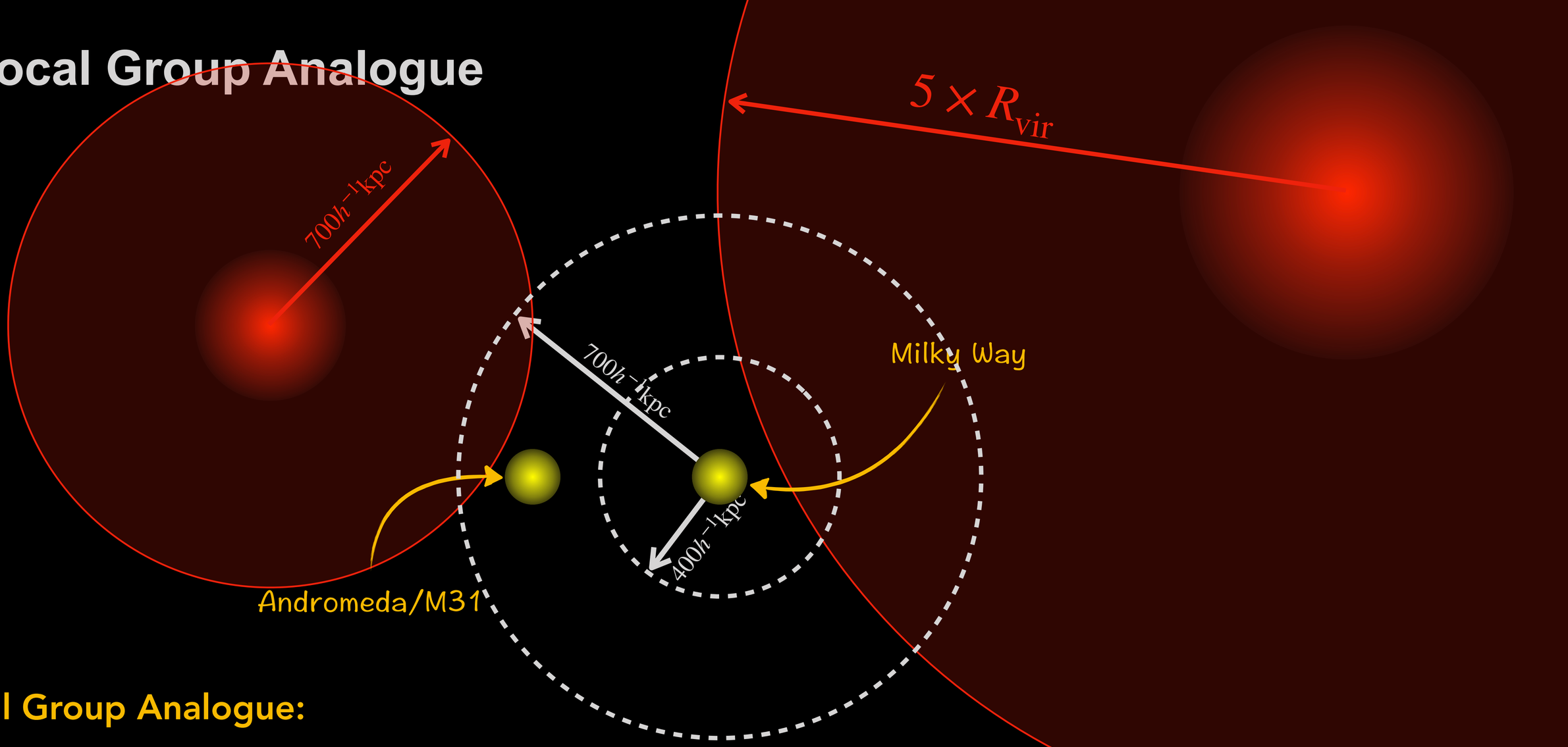

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- > $5R_{vir}$ away from other massive halos

ABACUSSUMMIT simulation:

- contains 25 $(2\text{Gpc}/h)^3$ boxes
- particle mass of 2 x $10^9 M_{sun}/h$

- **Correlations** between **Local Group Analogue** and **Cosmic Web**

- **coupling energy**:

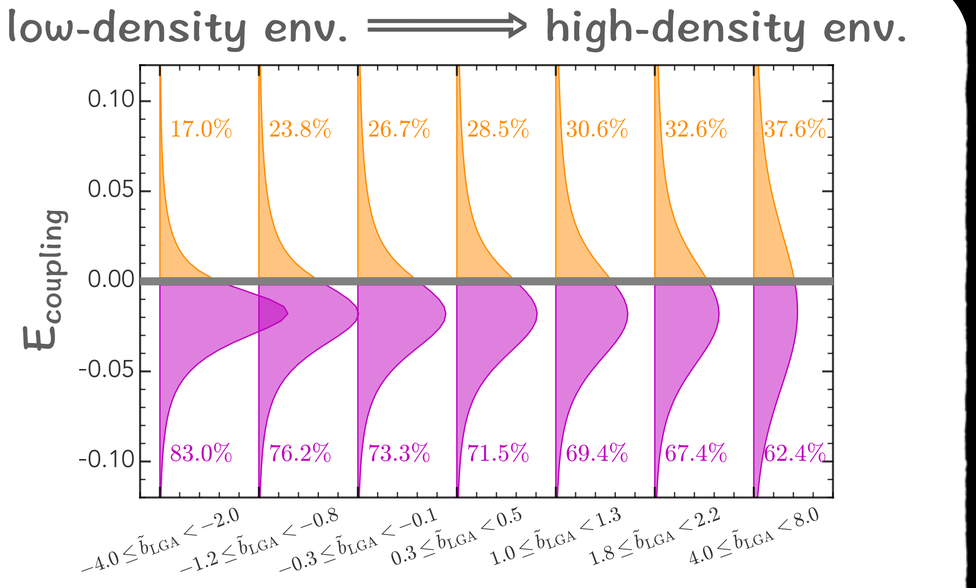
$$E_{\mathrm{coupling}} = \frac{1}{2}\frac{m_1 m_2}{m_1 + m_2}V^2 - \frac{G m_1 m_2}{\|\mathrm{d}\mathbf{r}\|}$$

- large-scale **bias**:

$$\tilde{b}_{\mathrm{LGA}}(r) = \delta(r)/\xi_{\mathrm{mm}}(r)$$

traced by halos above $10^{11.6} M_\odot/h$

• Correlations between Local Group Analogue and Cosmic Web



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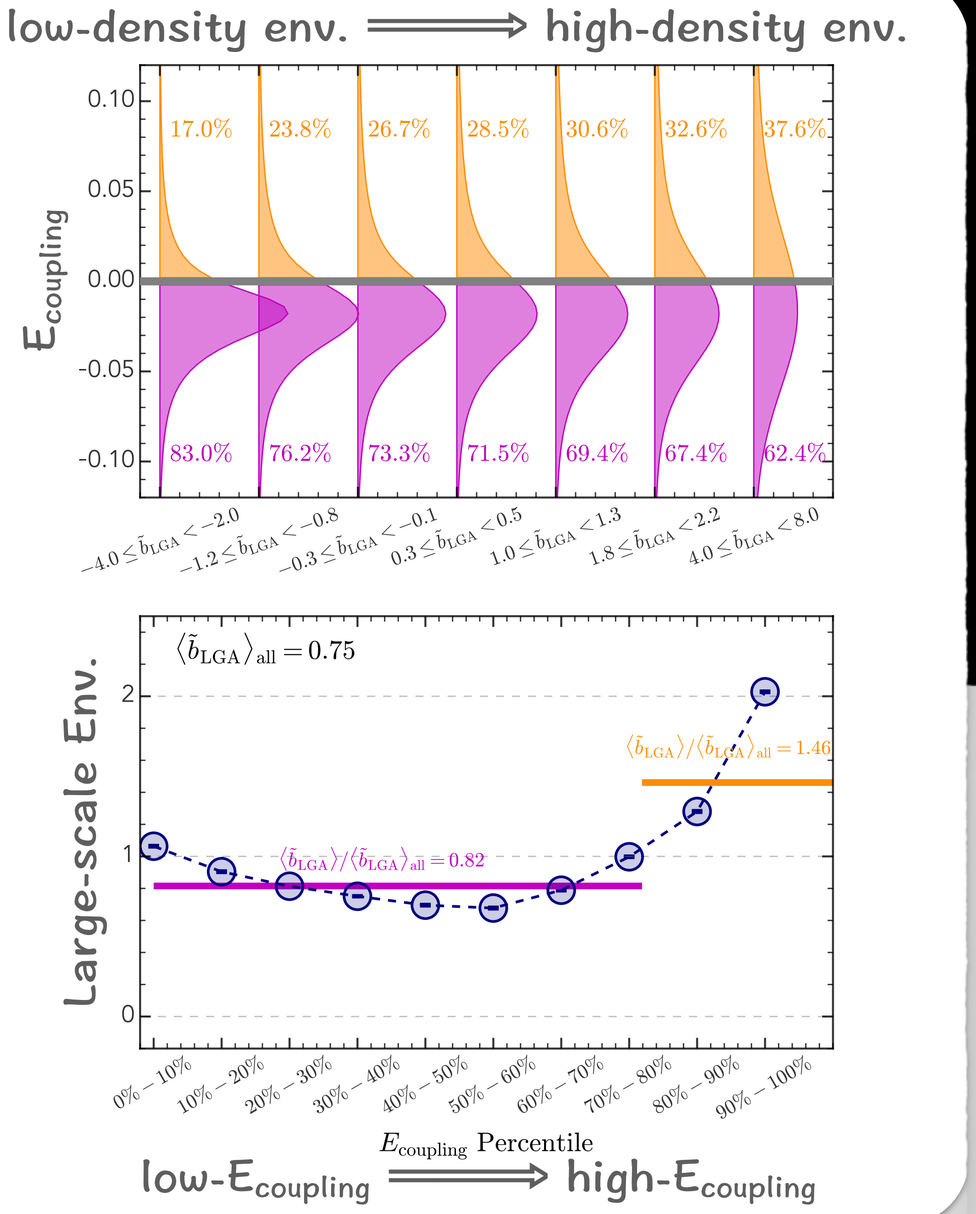

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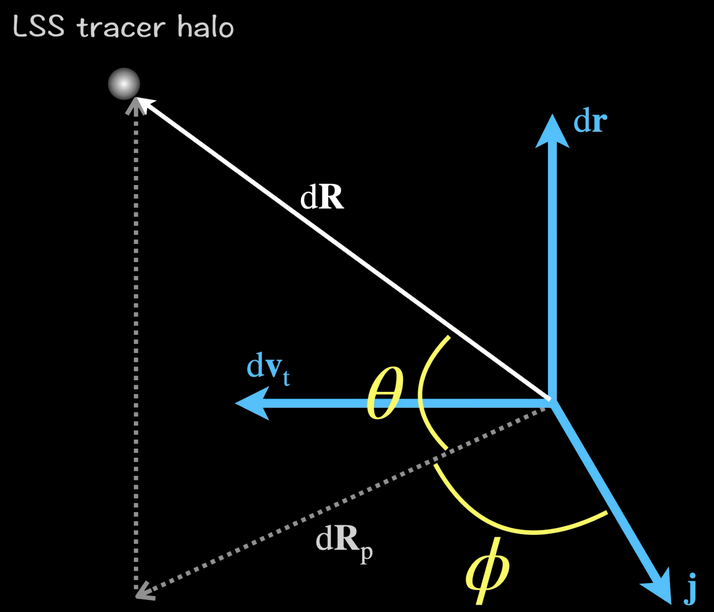
- LGAs in higher-density regions have **higher $E_{\rm coupling}$.**
- Higher-$E_{\rm coupling}$ LGAs live in **denser regions** and the large-scale bias differs by **~80%**.
  ⟹ strong "**secondary halo bias**" effect

• Correlations between Local Group Analogue and Cosmic Web

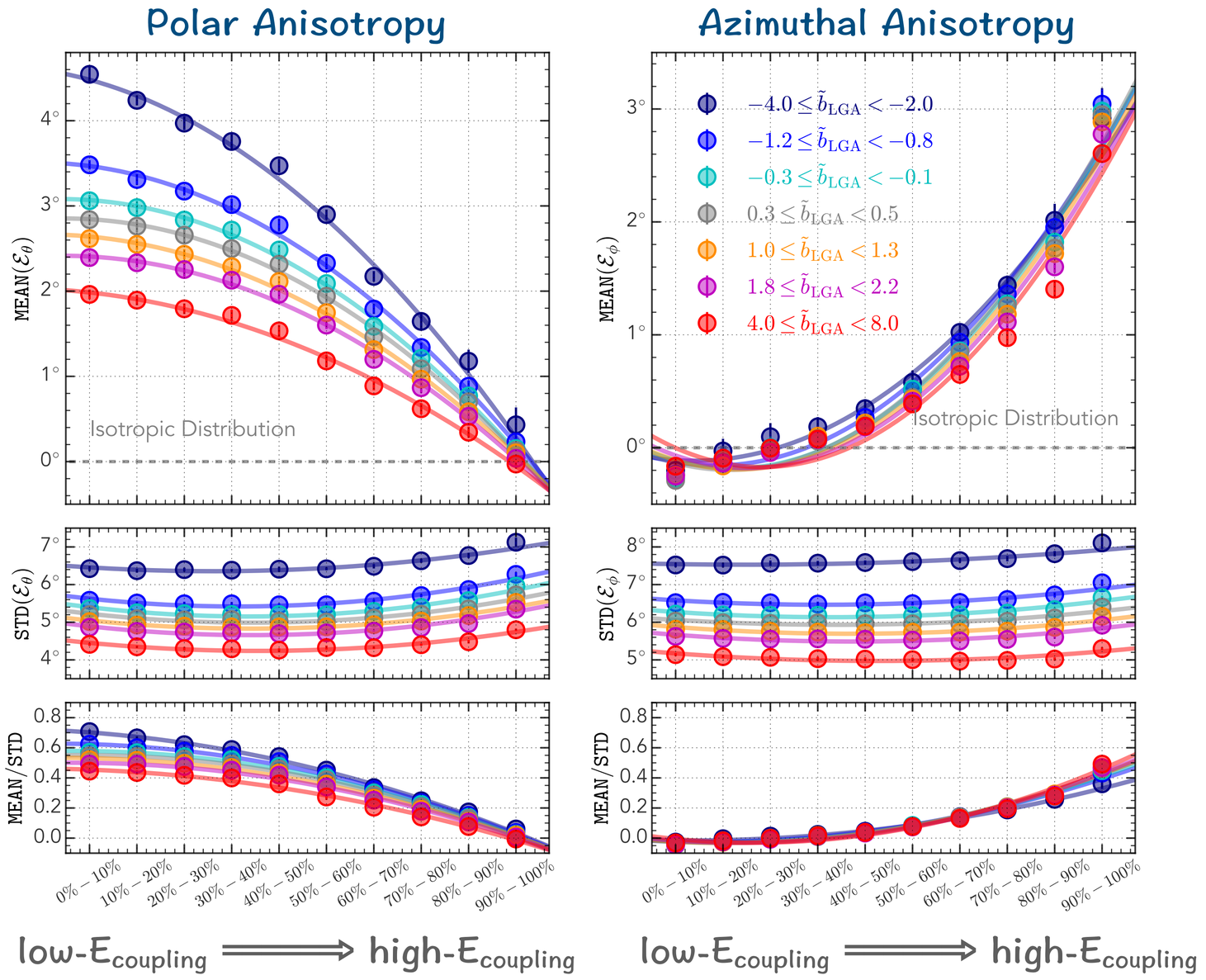


deviation from isotropy:

$$\mathcal{E}_\theta = \langle|\theta_i|\rangle_{\text{tracer}} - \langle|\theta|\rangle_{\text{isotro}}$$

$$\mathcal{E}_\phi = \left\langle\left||\phi_i| - \frac{\pi}{2}\right|\right\rangle_{\text{tracer}} - \left\langle\left||\phi| - \frac{\pi}{2}\right|\right\rangle_{\text{isotro}}$$

within the 5-15Mpc/h shell



• Anisotropic environment of our Local Group