# Spin-Alignment of Dark Matter Subhaloes

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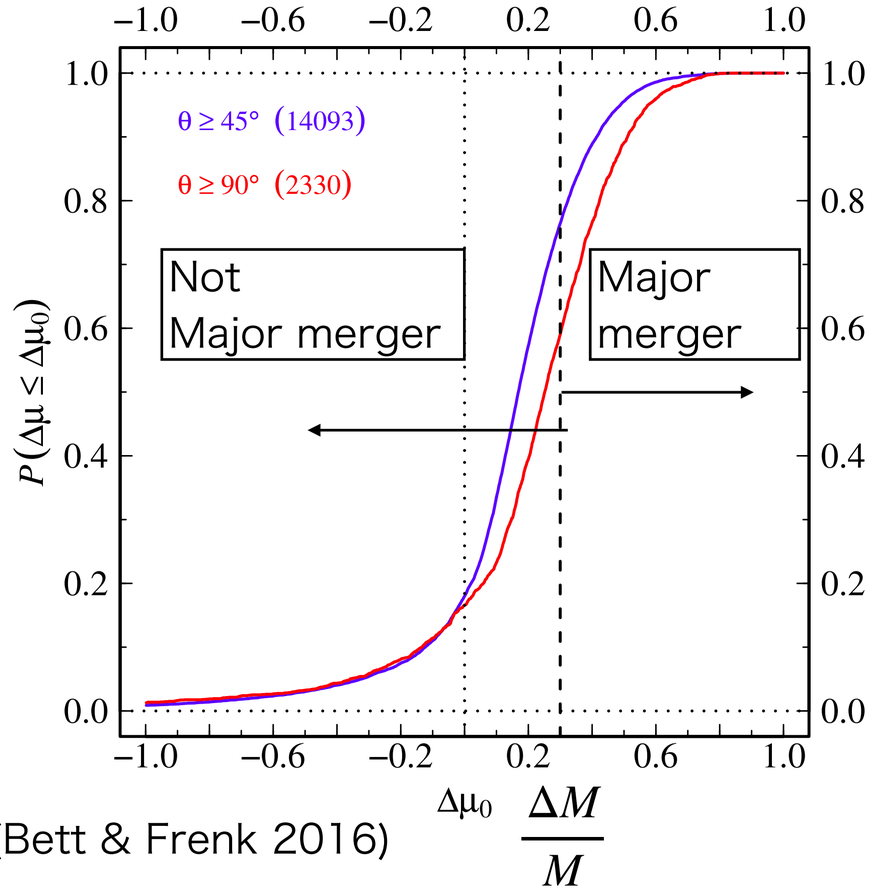
# Introduction : The evolution of spin direction




(Bett & Frenk 2016)

Cumulative distribution of $\Delta M/M$ of the halo with a large change in spin direction.

**The evolution the direction of the spin (angular momentum vector) of halo is not clear**

・Bett & Frenk (2016) investigates the distribution of $\Delta M/M$ in haloes of large changes in spin direction.

・About 70% of halos have large change in spin direction **without major merger.**

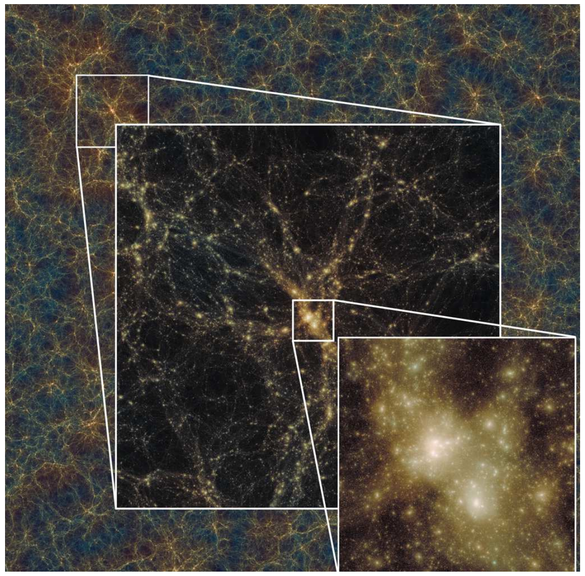
**What changes the direction of spin?**

**In this study, we investigate the effect of a nearby large halo on the change in spin direction.**

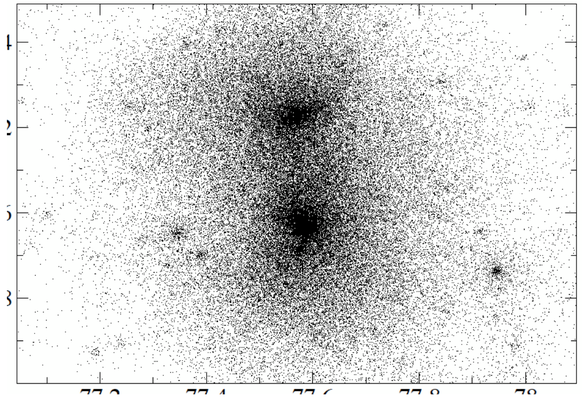
# **Data:** Cosmological N-body simulation data

| Simulation | $L\,(h^{-1}\mathrm{Mpc})$ | $m_p\,(h^{-1}M_\odot)$ | $N$ | Reference |
|---|---|---|---|---|
| $\nu^2\mathrm{GC}-\mathrm{S}$ | 280 | $2.20\times10^8$ | $2048^3$ | Ishiyama et al. 2015 |

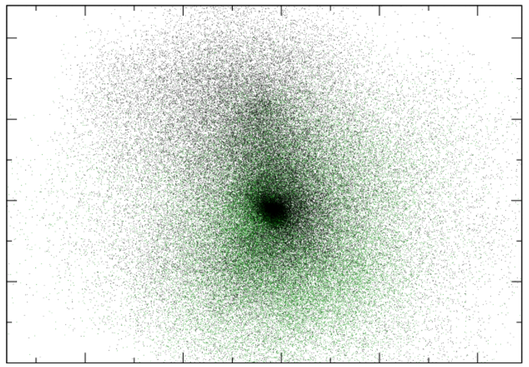
Halo finder：ROCKSTAR (Behroozi+2013a)
Merger tree：consistent tree (Behroozi+2013b)



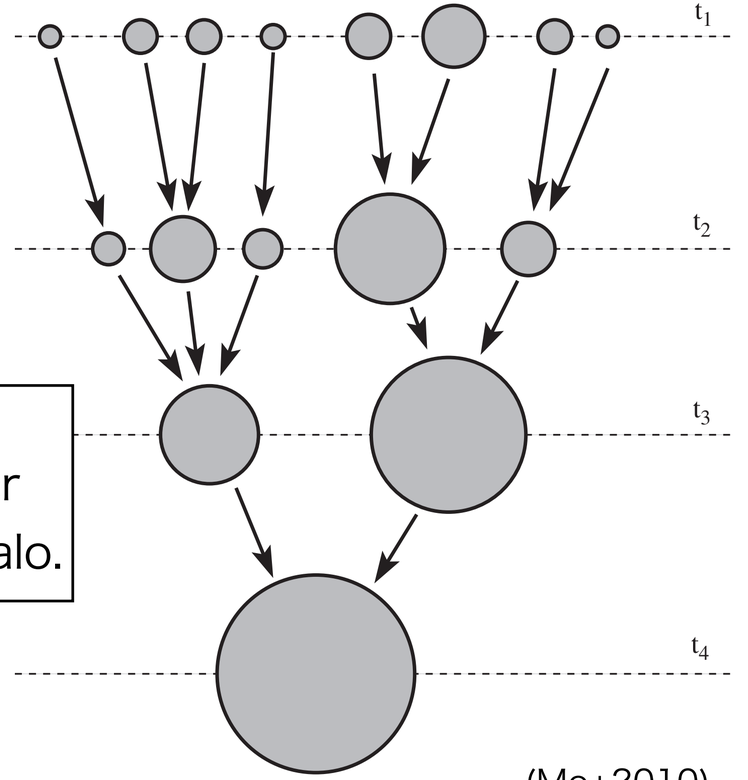
(Ishiyama+2015)



Halo finder detects halo from simulation data in each snapshot



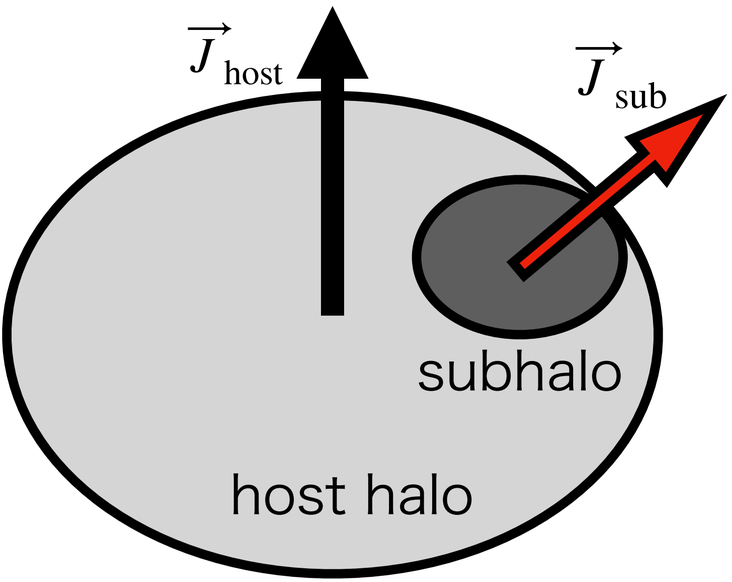
By creating a merger tree data, we obtain the merger history and evolution of halo.



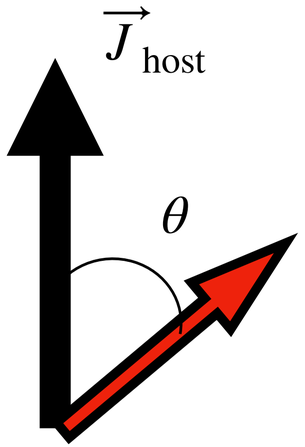

(Mo+2010)

From this merger tree,
we obtain $X, M_{\mathrm{vir}}, R_{\mathrm{vir}}, \vec{J}$(spin)
and host-subhalo relationship

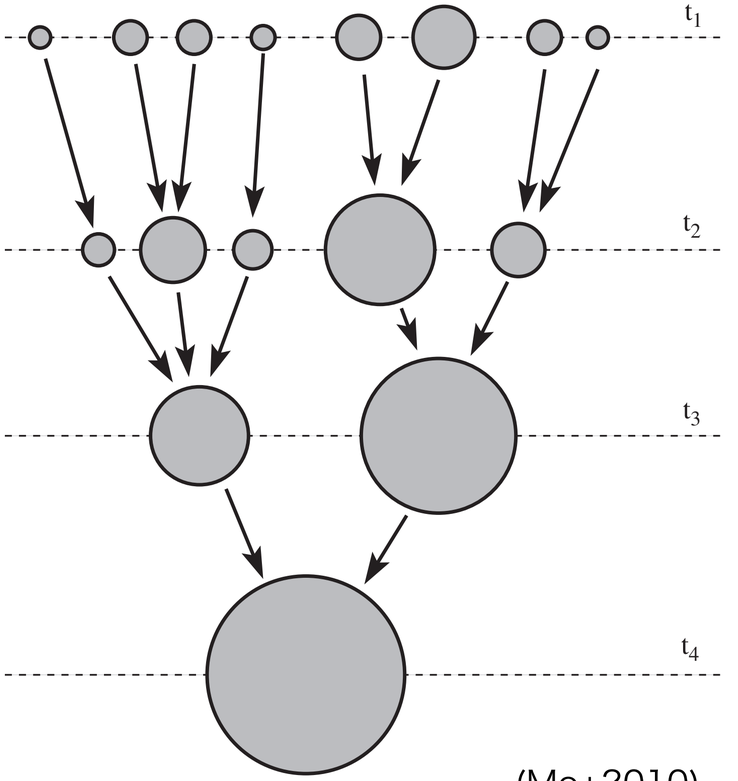
# Analysis: The angle between $\vec{J}_{\rm sub}$ and $\vec{J}_{\rm host}$



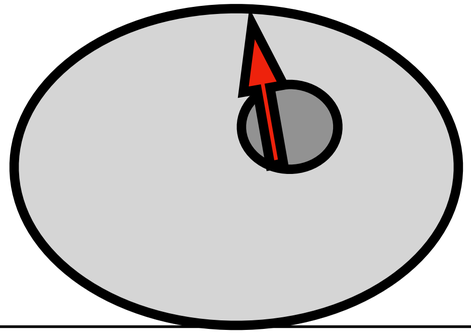

We calculate the angle between $\vec{J}_{\rm sub}$ and $\vec{J}_{\rm host}$, and the subhalo position from the center of the host halo.



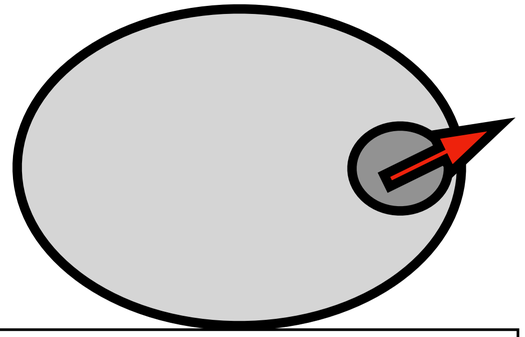

$$\cos\theta = \frac{\overrightarrow{J_{\rm host}} \cdot \overrightarrow{J_{\rm sub}}}{|\overrightarrow{J_{\rm host}}||\overrightarrow{J_{\rm sub}}|}$$




(Mo+2010)



Center of host halo



Outskirt of host halo

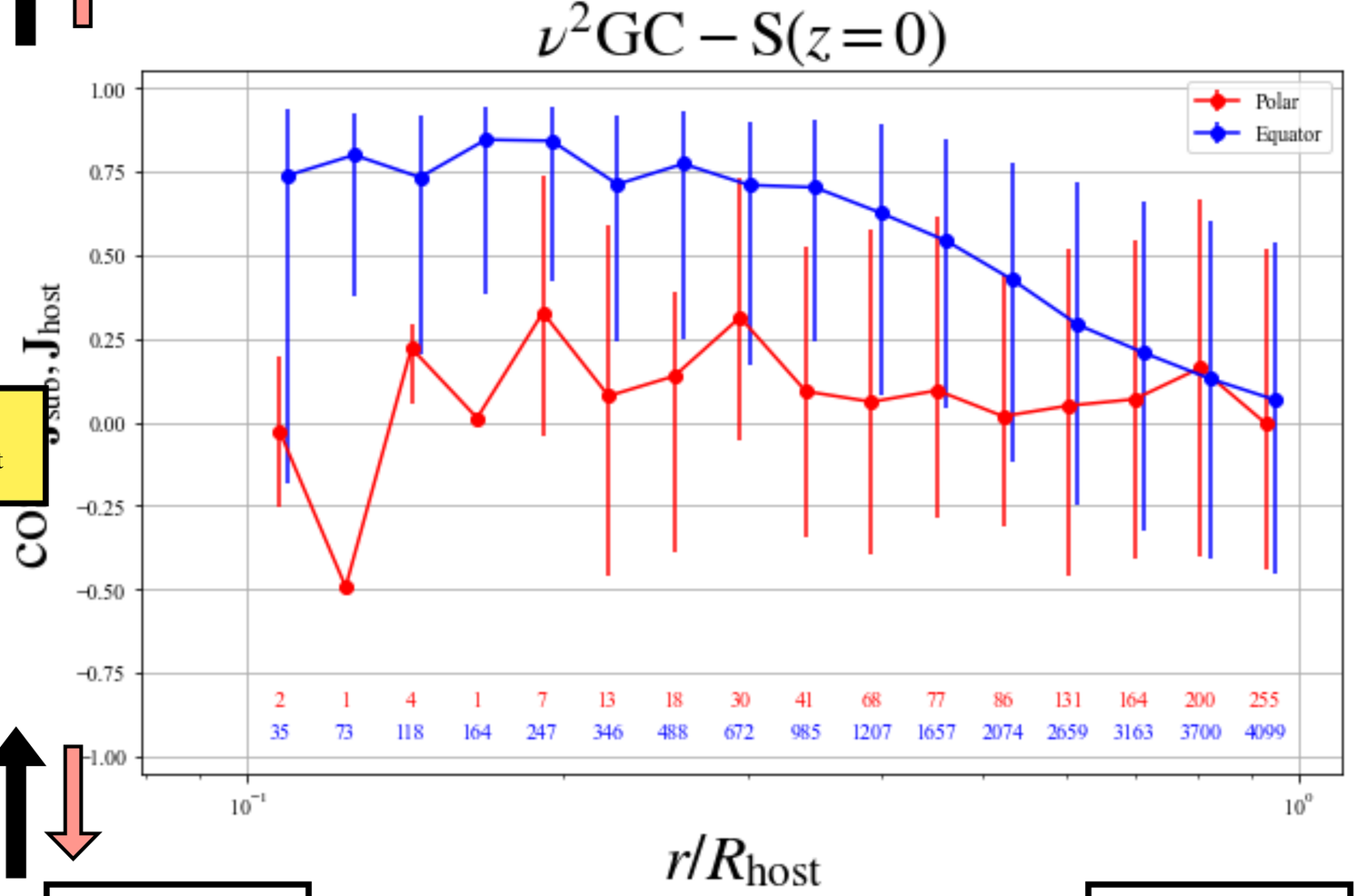
We investigate the relationship between the position of the subhalo and $\cos\theta$, and discuss the effect of the host halo.

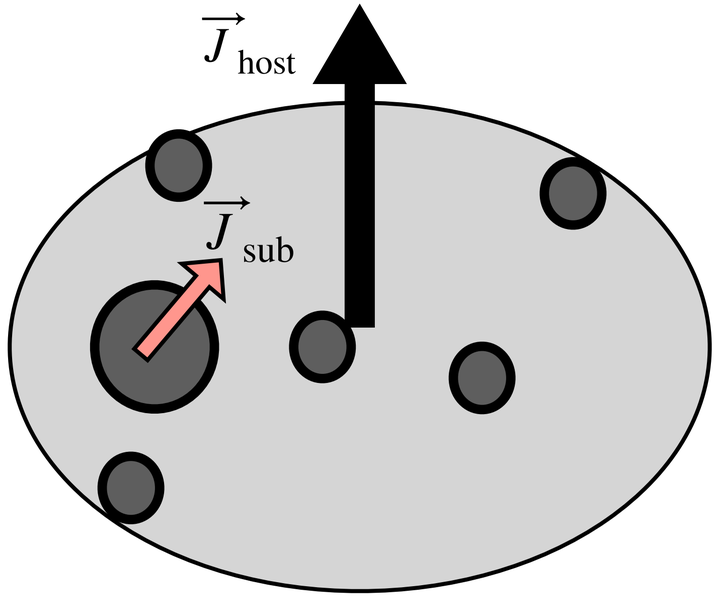
# Result : Correlation between position and $\cos\theta$

Same direction

$\vec{J}_{\rm sub}$ and $\vec{J}_{\rm host}$

Opposite direction




Center of host halo

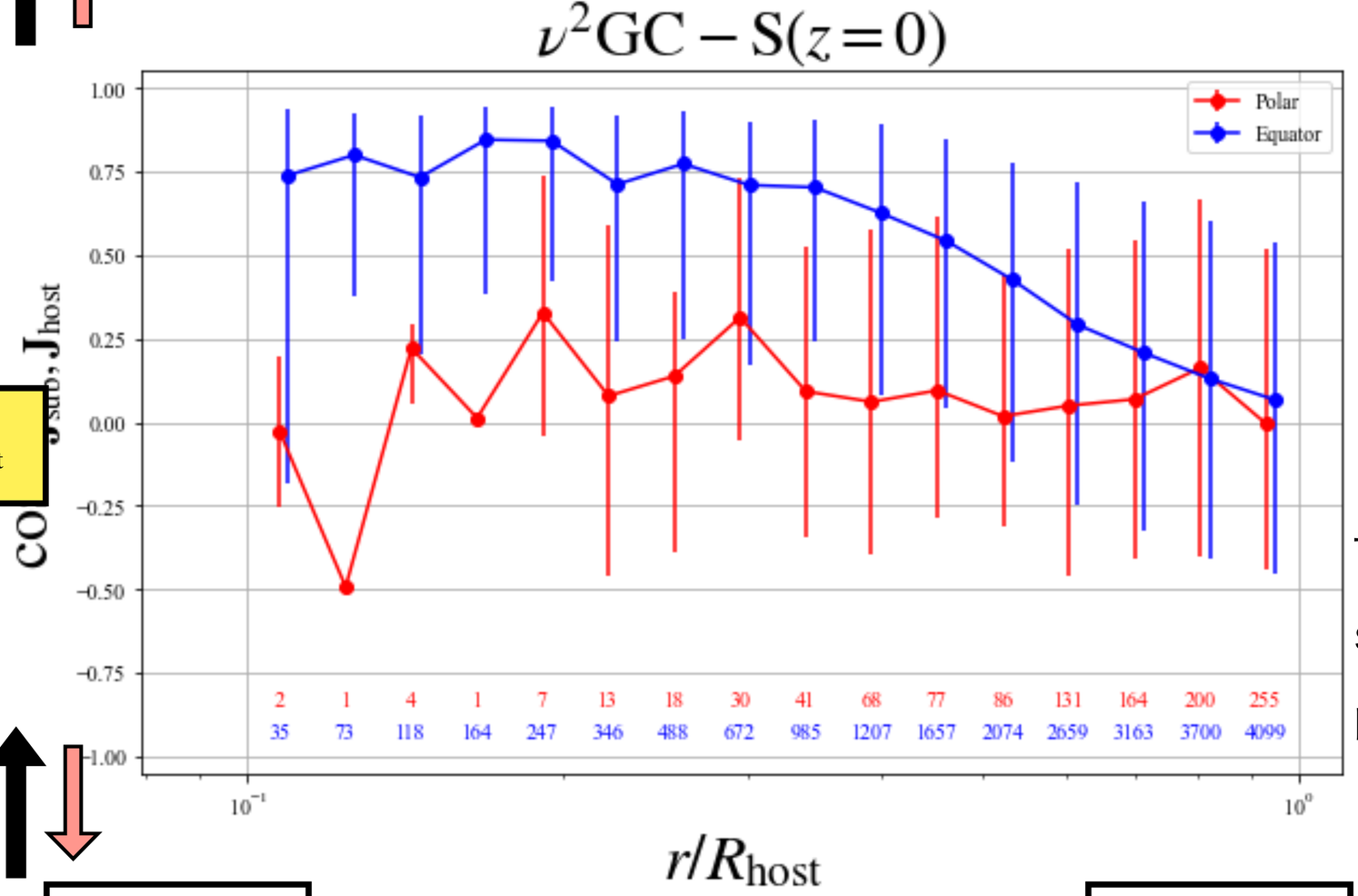
Outskirt of host halo

# Result : Correlation between position and $\cos\theta$

Same direction

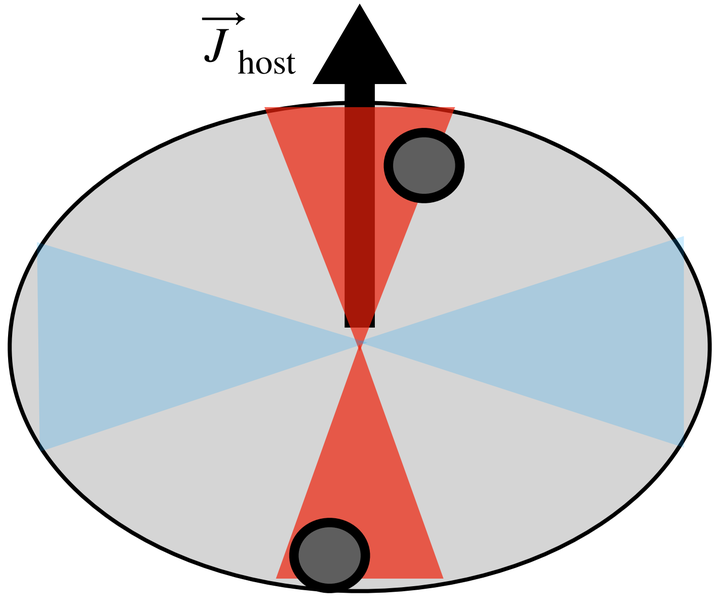
$\vec{J}_{\rm sub}$ and $\vec{J}_{\rm host}$

Opposite direction




Center of host halo

Outskirt of host halo



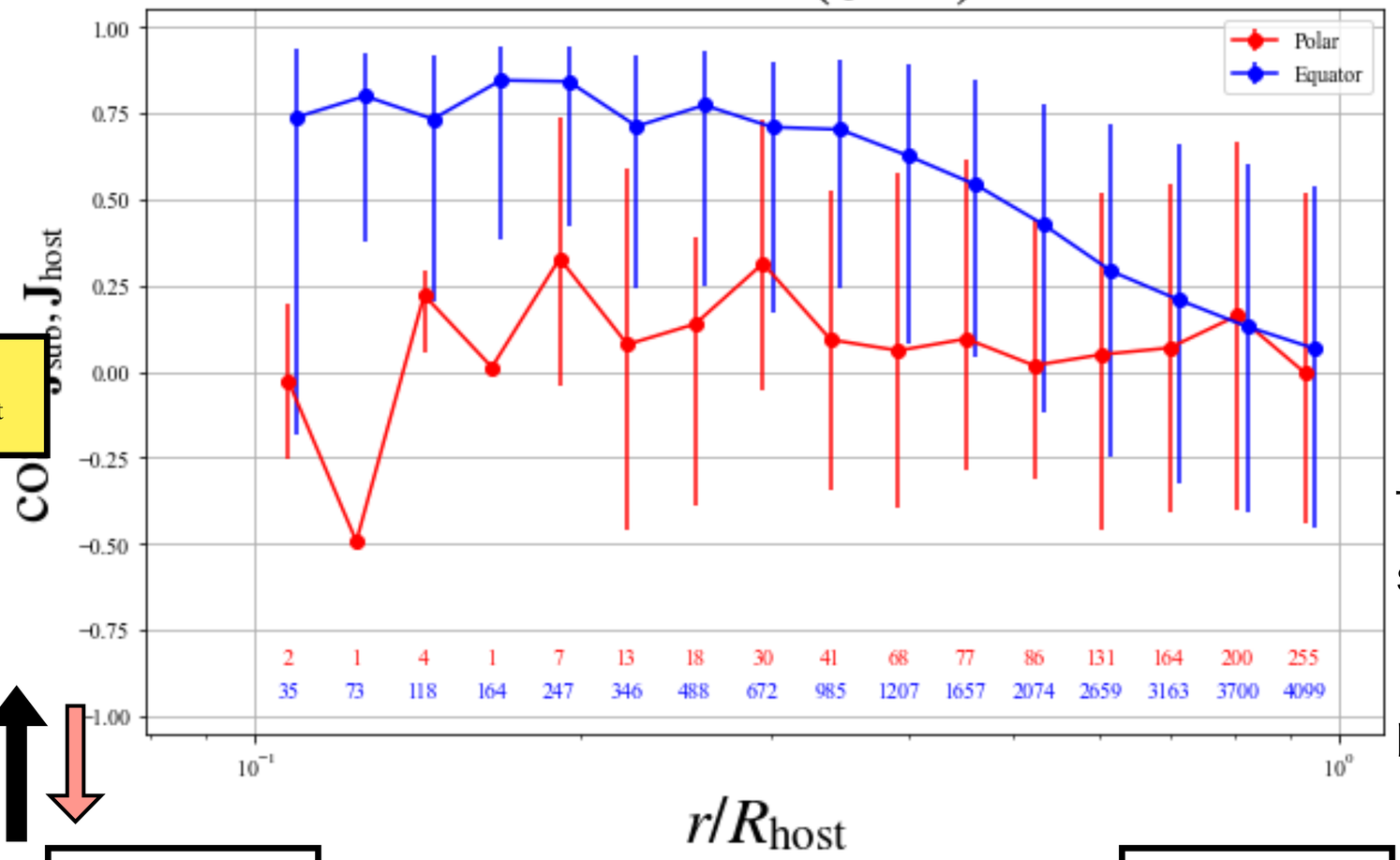

The red line represents a subhalo located parallel to $\vec{J}_{\rm host}$, polar direction of host haloes.

# Result : Correlation between position and $\cos\theta$

Same direction

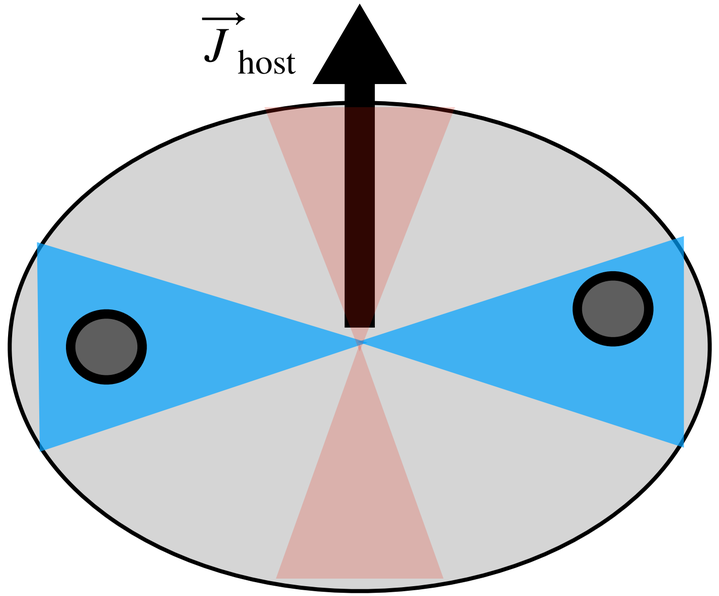
$\vec{J}_{\rm sub}$ and $\vec{J}_{\rm host}$

Opposite direction




Center of host halo

Outskirt of host halo



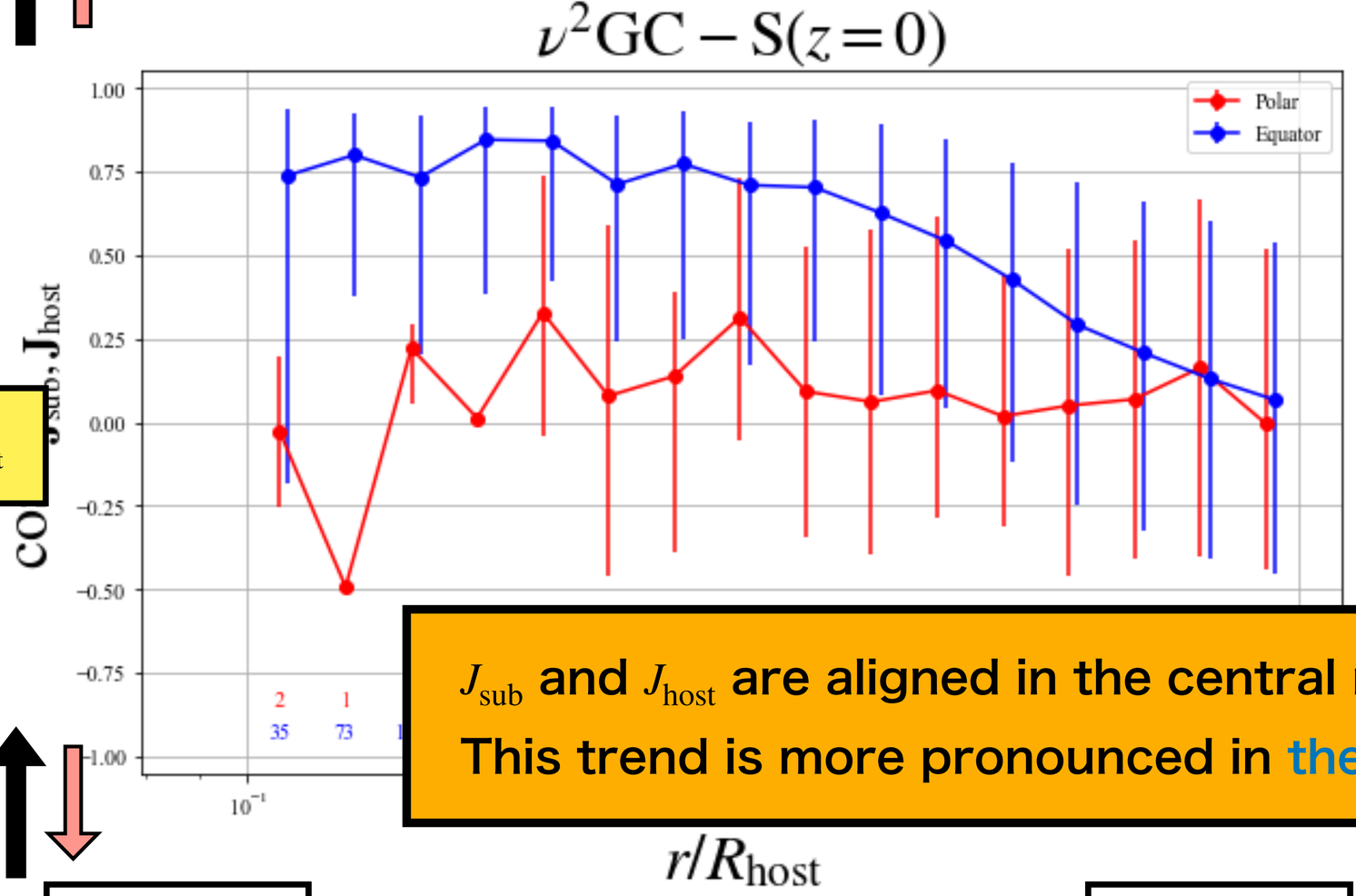

The blue line represents a subhalo located perpendicular to $\vec{J}_{\rm host}$, equatorial direction of host haloes.

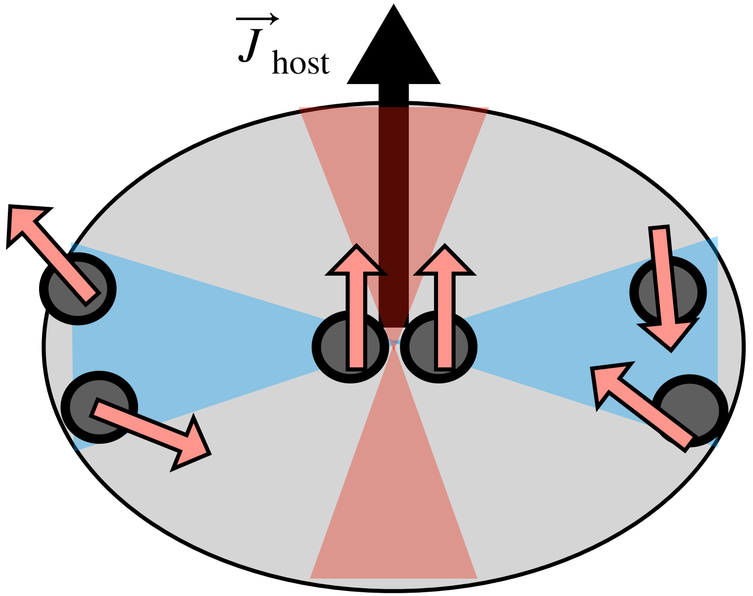
# Result : Correlation between position and $\cos\theta$

Same direction

$\vec{J}_{\rm sub}$ and $\vec{J}_{\rm host}$

Opposite direction




$J_{\rm sub}$ and $J_{\rm host}$ are aligned in the central region.

This trend is more pronounced in the equatorial direction.

Center of host halo

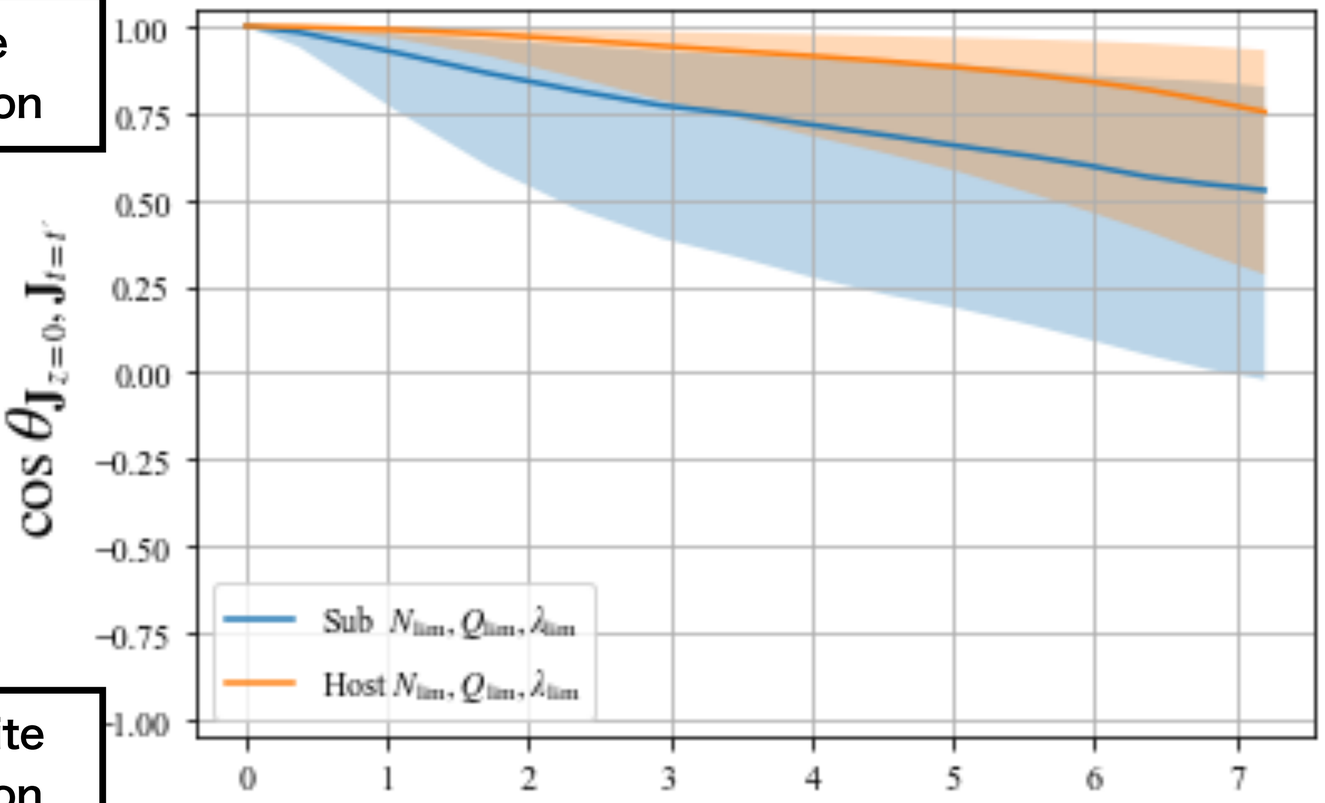
Outskirt of host halo

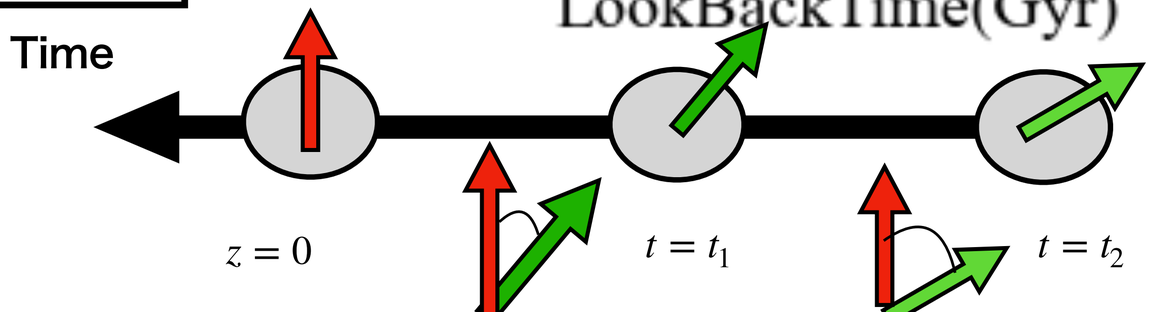
# Result : History of host/subhaloes spin direction

The angle between $\vec{J}(z=0)$ and $\vec{J}(T=T')$

Same direction

Opposite direction




This figure shows the direction of the spin of the halo at a time over N Gyrs.

The y-axis represent the angle between the $\vec{J}$ of $z=0$ and N Gyrs before.

Orange: host halo

Blue: subhalo

**Host halo:**

Spin direction has not changed over time.

**Subhalo:**

Spin direction is changing over time.

# Result : History of host/subhaloes $J/M$

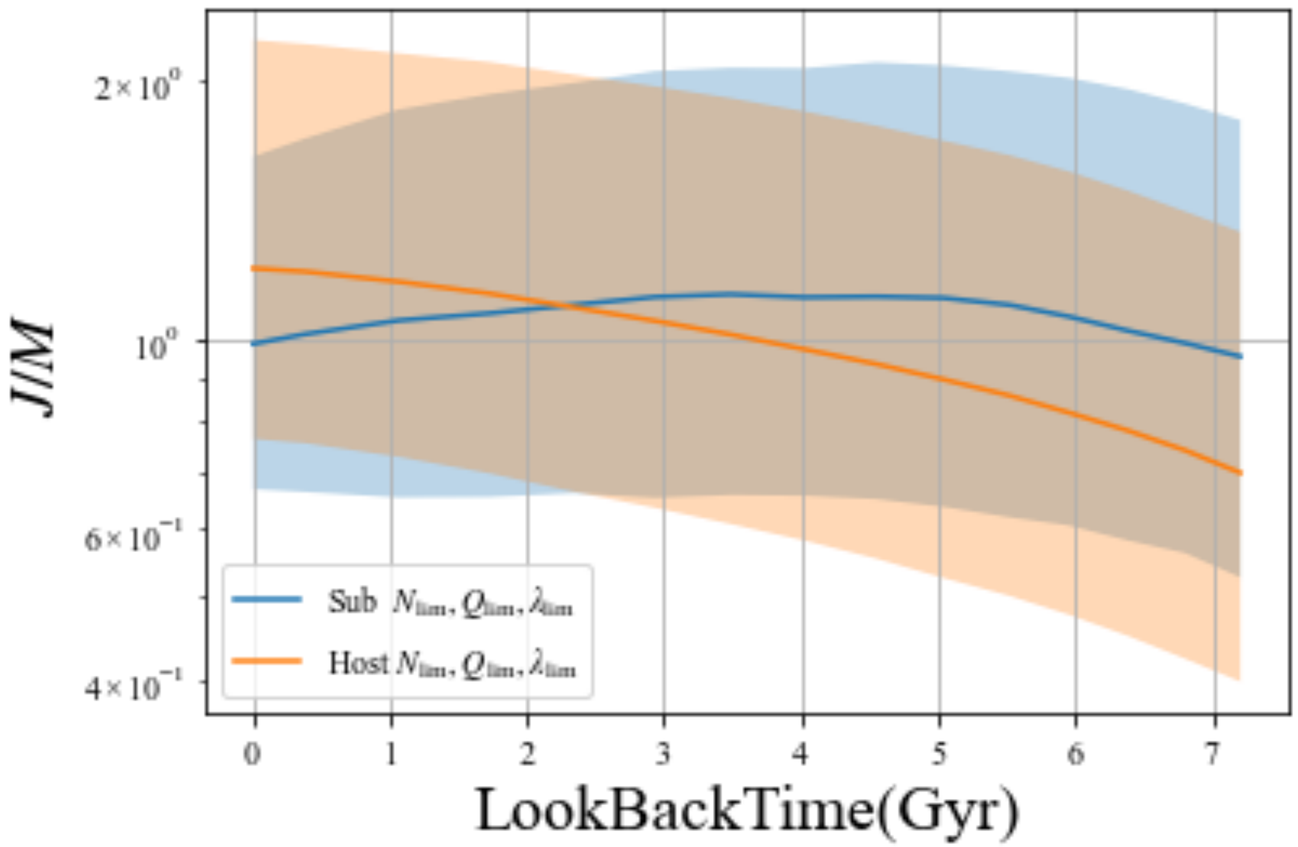
This figure shows history of $J/M$

[$J/M$ : specific angular momentum]

Orange: host halo

Blue: subhalo

History of $J/M$ (specific angular momentum)




**Host halo:**

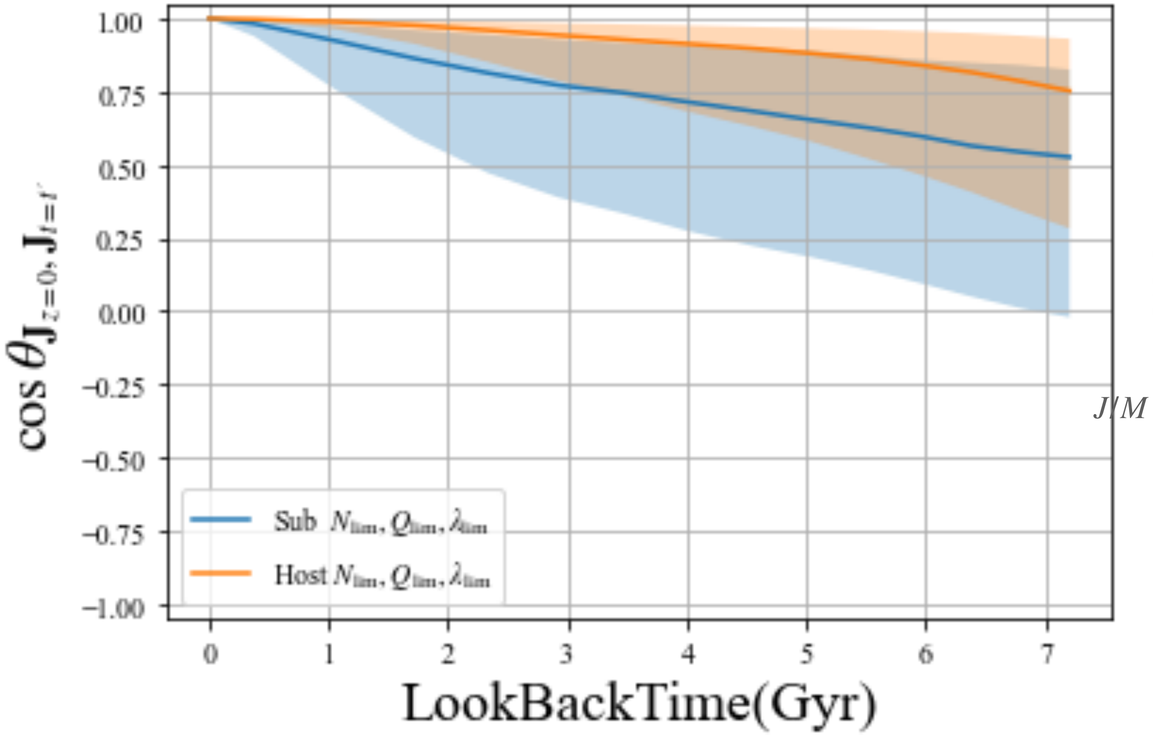
$J/M$ is growing over time

**Subhalo:**

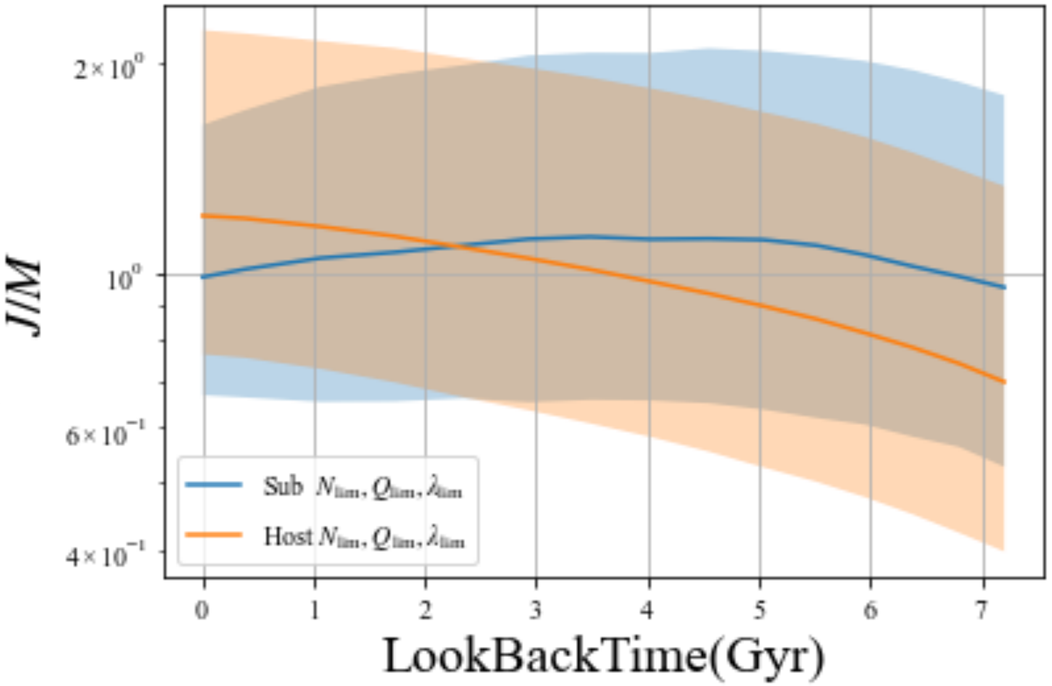
$J/M$ is constant over time

# Result : History of host/subhaloes spin

The angle between $\vec{J}(z=0)$ and $\vec{J}(T=T')$




History of $J/M$ (specific angular momentum)




| | Spin direction | J/M |
|---|---|---|
| Host halo | Not Changing | Growing |
| Subhalo | Changing | Not Growing |

# Summary

- The direction of $\vec{J}_{\mathrm{sub}}$ subhalo spin
  - $\vec{J}_{\mathrm{sub}}$ and $\vec{J}_{\mathrm{host}}$ are aligned at the central region of host haloes
  - This tendency depends on direction of subhalo's position

- Evolution of $\vec{J}_{\mathrm{sub}}$ and $\vec{J}_{\mathrm{host}}$
  - The spin of host halo is changing for $J/M$, but not for the direction
  - The spin of subhalo is changing for the direction, but not for $J/M$(specific angular momentum)

- Discussion
  - The mechanism for which the spin of the subhalo changes is not yet understood, and is currently under analysis.