Anisotropic satellite quenching in galaxy clusters up to $z \sim 1$ detected by the HSC-SSP survey

Subaru Users Meeting FY2022 @NAOJ+zoom (1st, Feb., 2023)

Ando et al. 2023, MNRAS, 519, 13
(arXiv: 2209.00015)

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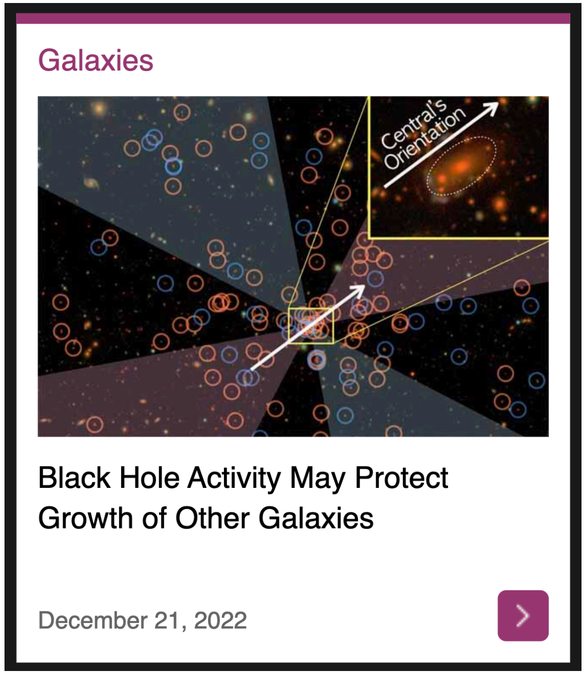
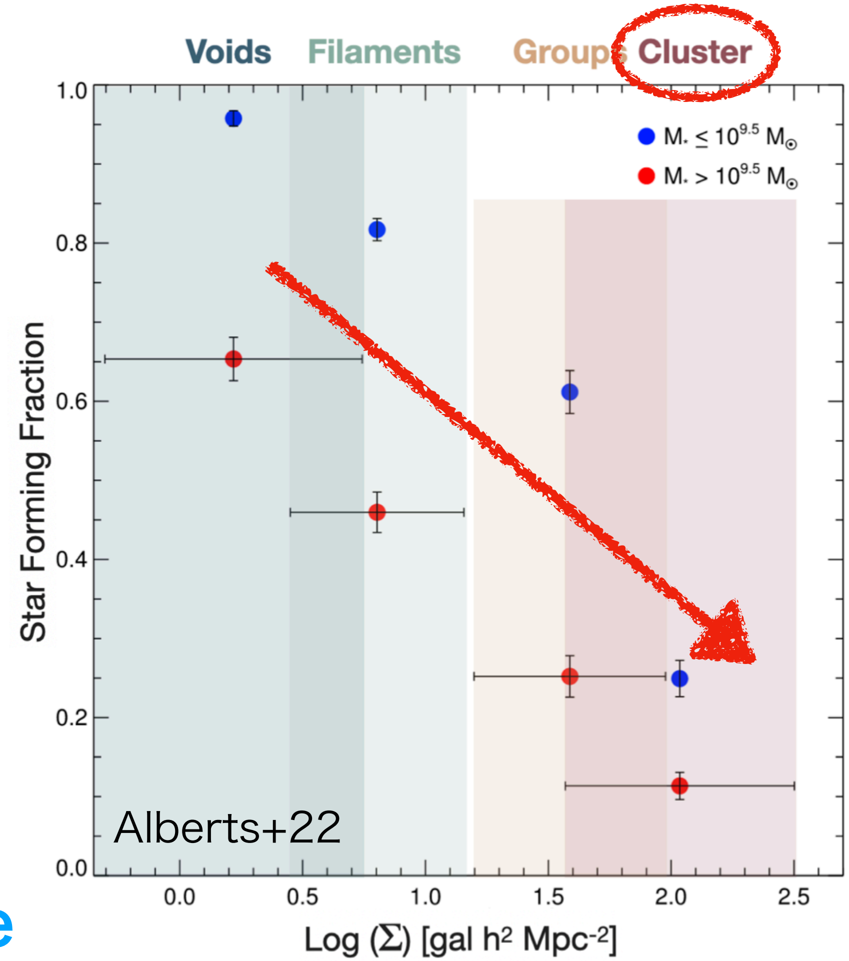
HSC-SSP Project:439



Press Release from Subaru

Introduction — Quenching in clusters

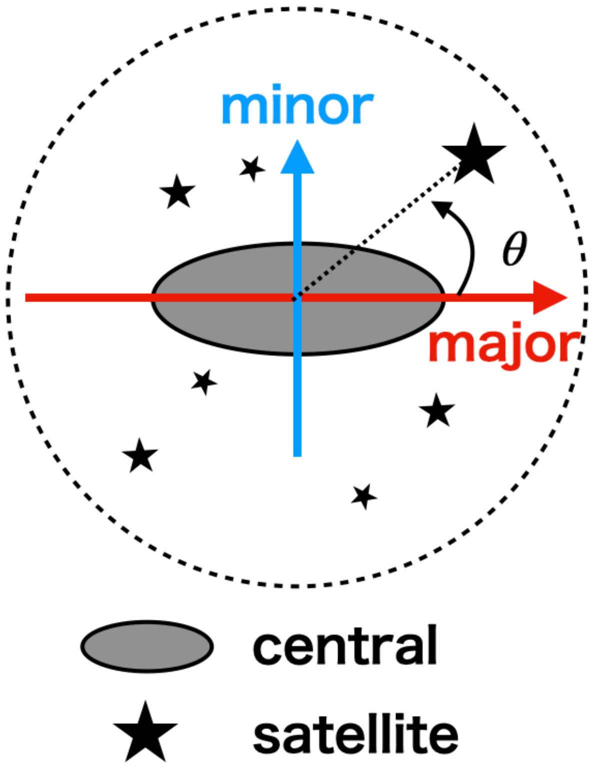
- Star formation activity depends on **environment**
- Groups/clusters are dominated by **quiescent population**
  - ram-pressure stripping (RPS) / strangulation / interactions



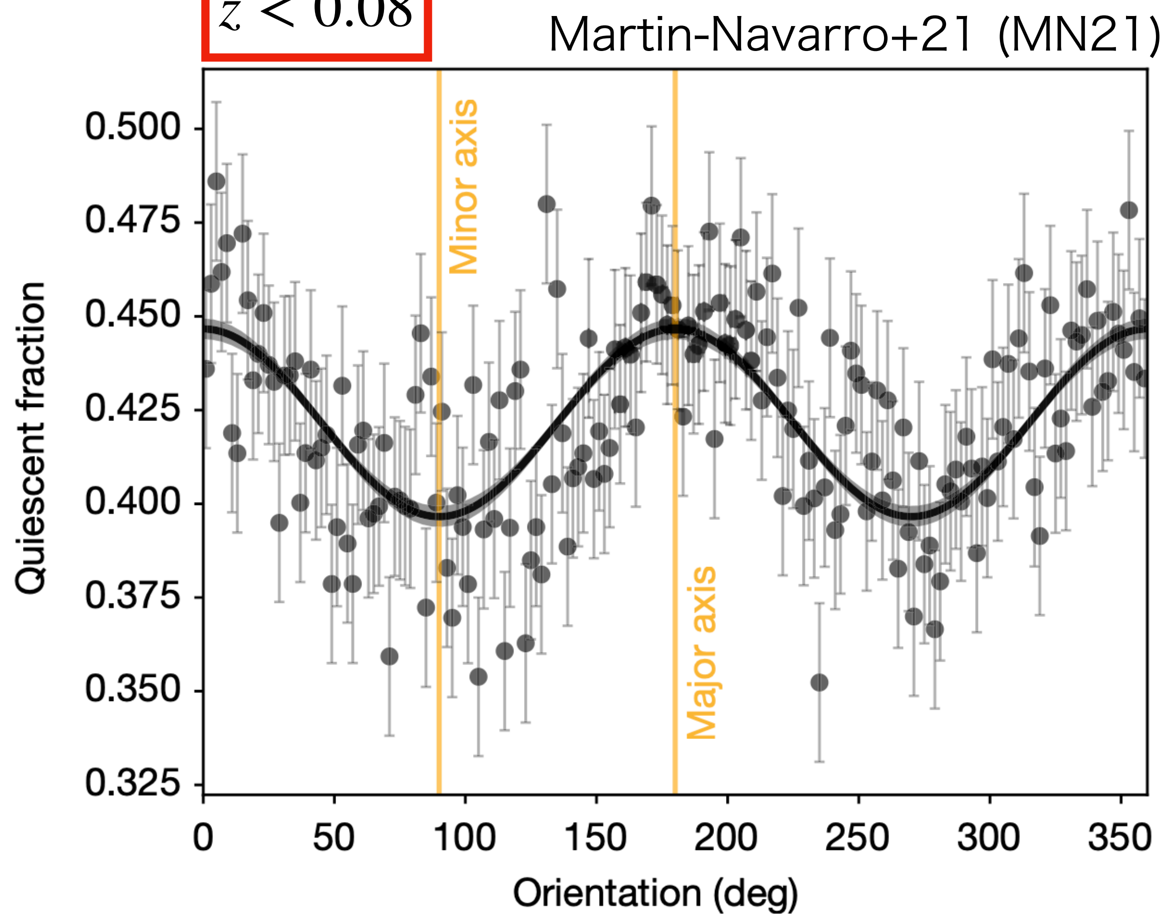
less dense

denser

- Quenching in groups/clusters occurs “anisotropically”
  (**larger f_q along the major axis** <—> **lower f_q along the minor axis**)

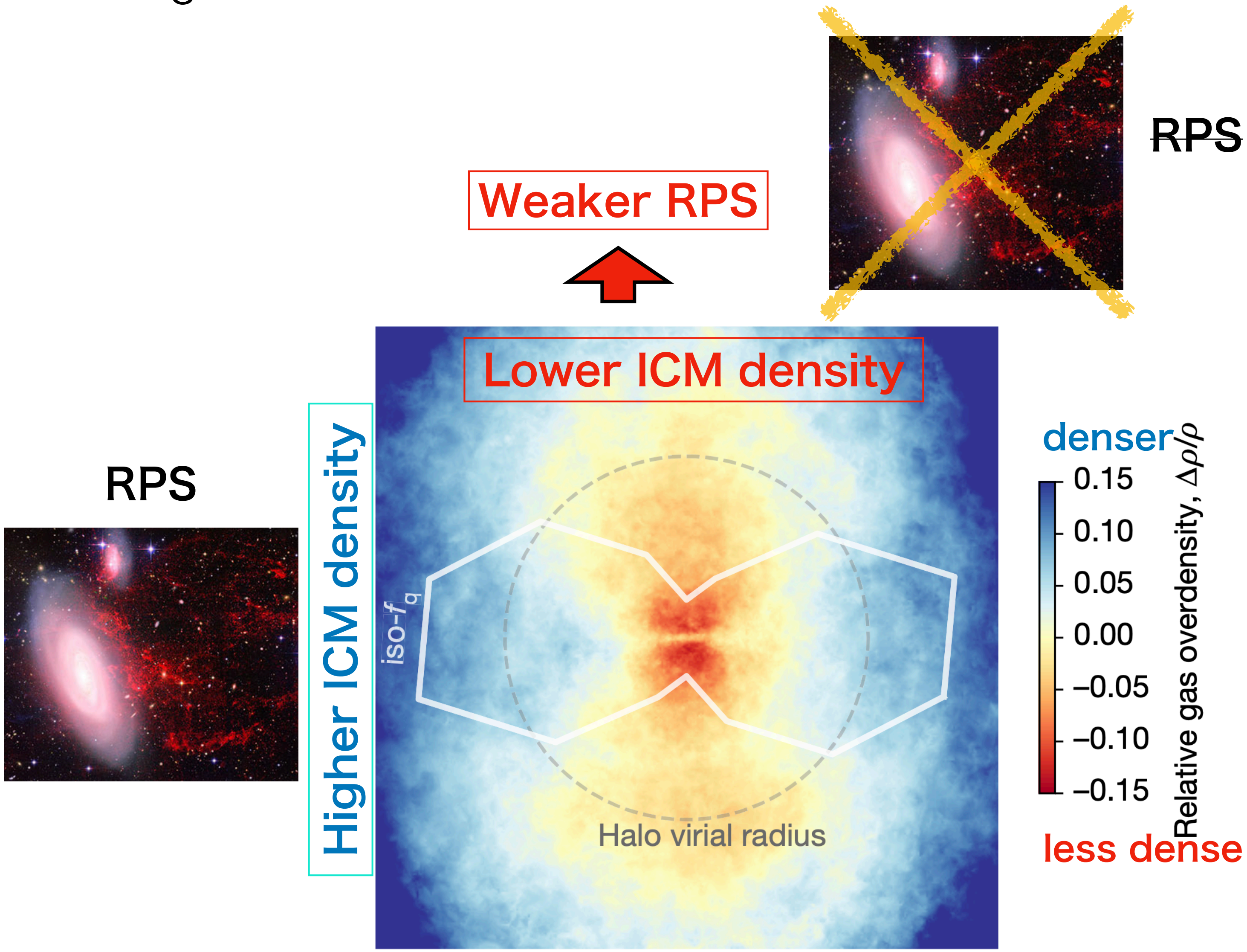


$z < 0.08$



Introduction — Anisotropic satellite quenching

- Interpretation (MN21): strength of RPS is anisotropic within halo
  (∵ Anisotropic ICM density due to AGN feedback of central galaxies)
  ➡ constraining on feedback model ??



- Is anisotropic quenching ubiquitous over wide redshift range?
  - only few studies at low-z (MN21@$z \sim 0.08$, Stott 22@$z \sim 0.5$)
  - need large sample (∵ small amplitude)

➡ **Large galaxy and cluster sample from the HSC-SSP (WIDE)**

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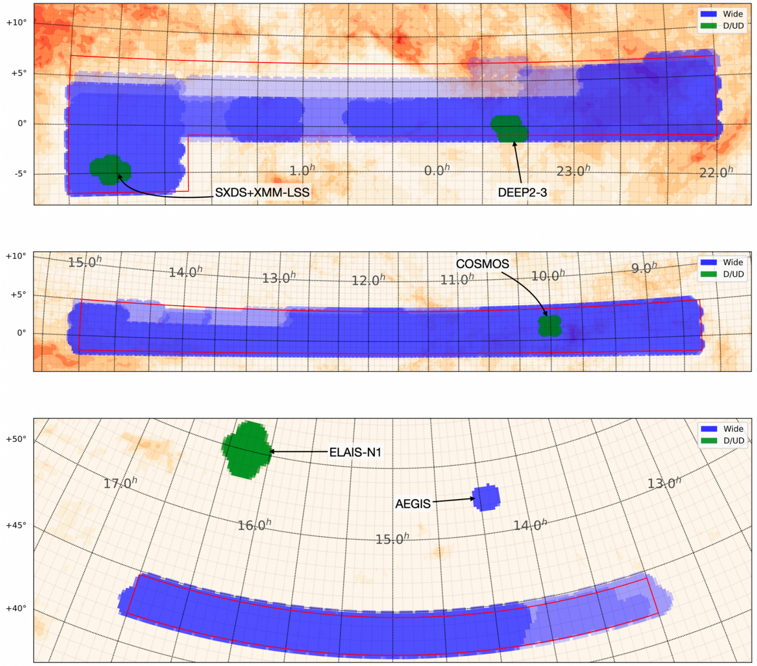
HSC-SSP WIDE



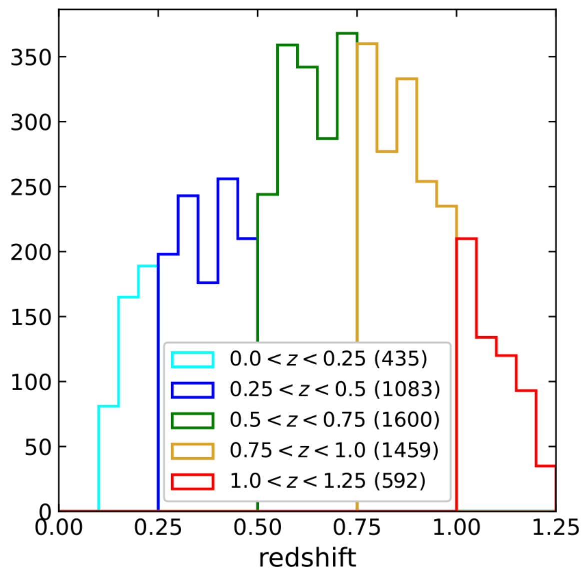
Aihara+22

Sample

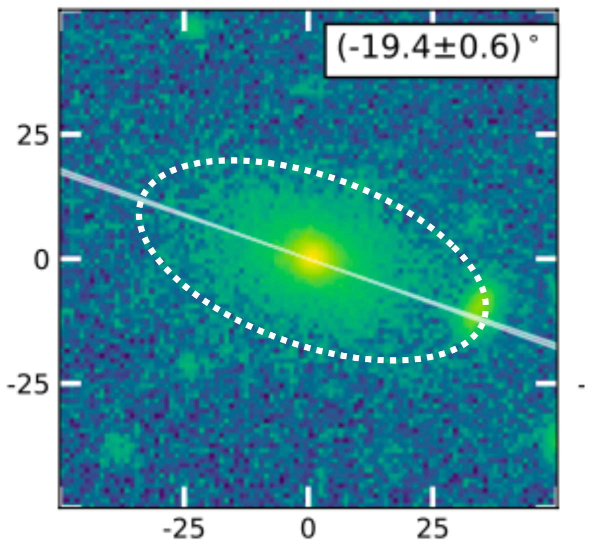
- Galaxy: HSC-SSP S21A WIDE ($\sim 800\,\mathrm{deg}^2$) (Mizuki photo-z; Tanaka+15)
  - $\log(M_*/M_\odot) > 10$
  - QG: $\mathrm{sSFR} < 10^{-11}\,\mathrm{yr}^{-1}$, SFG: $\mathrm{sSFR} > 10^{-11}\,\mathrm{yr}^{-1}$
- Cluster: CAMIRA Cluster catalog (S20A; Oguri+18)
  - > 5000 **clusters** @$0.1 < z < 1.25$
  - satellite selection: $\Delta z \leq 0.05 \times (1 + z_{\mathrm{cls}})$ & $\Delta r \leq 1\,(2) \times r_{200\mathrm{m}}$

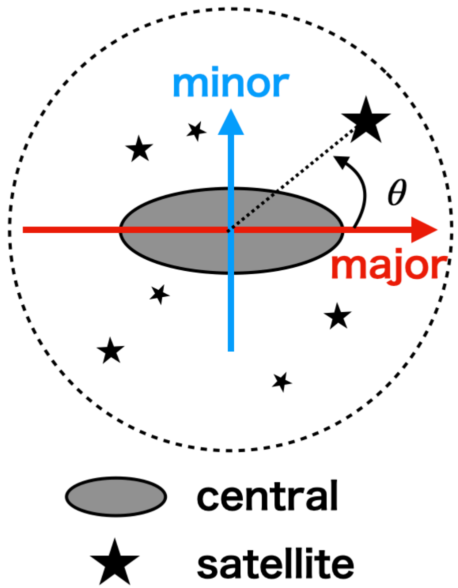
➡ calculate $f_{\mathrm{q}} = f_{\mathrm{q}}(\theta)$

cluster redshift distribution

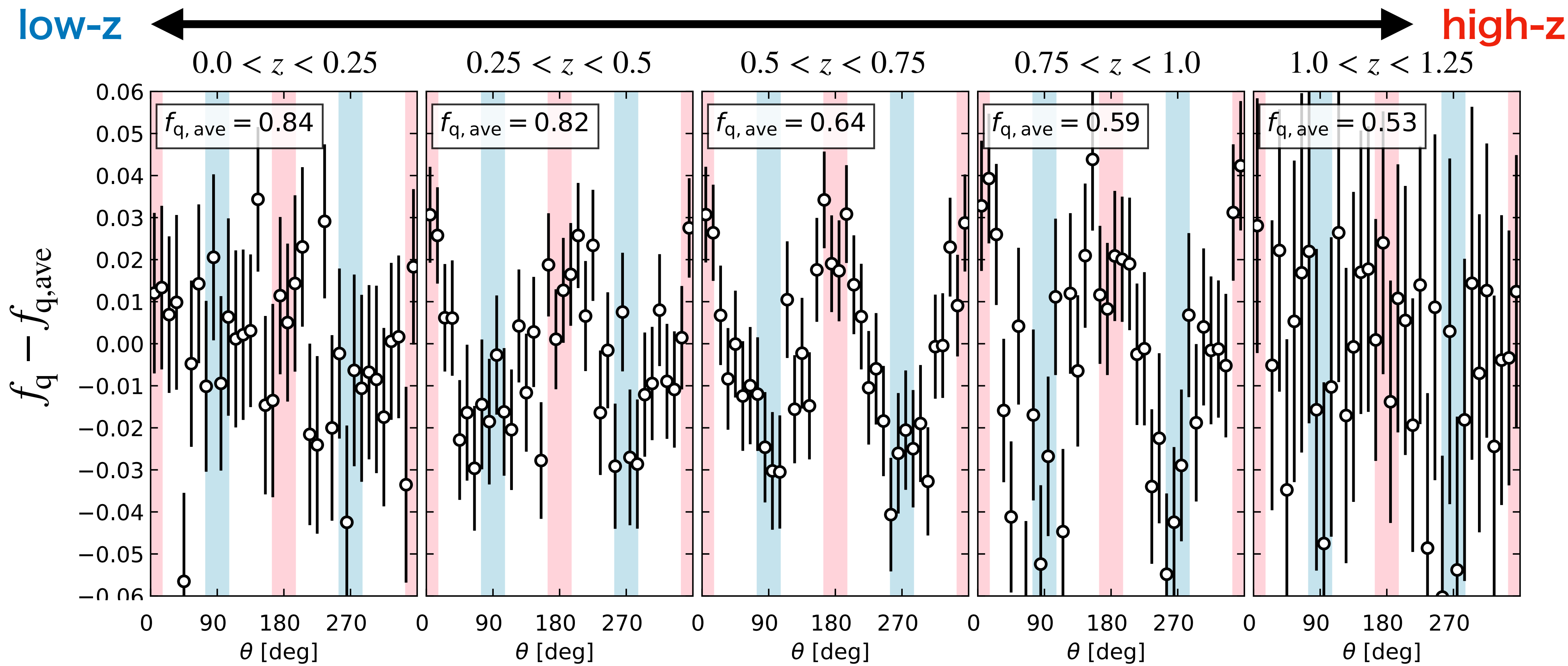


PA estimate ex.)

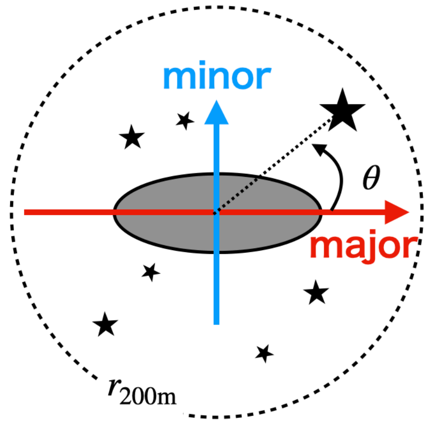




Result: quiescent fraction as a function of orientation angle



- Periodical fluctuation at $0.25 < z < 1$
  - f_q is **higher** (**lower**) around the **major** (**minor**) axis
  - Model fitting by sinusoidal function



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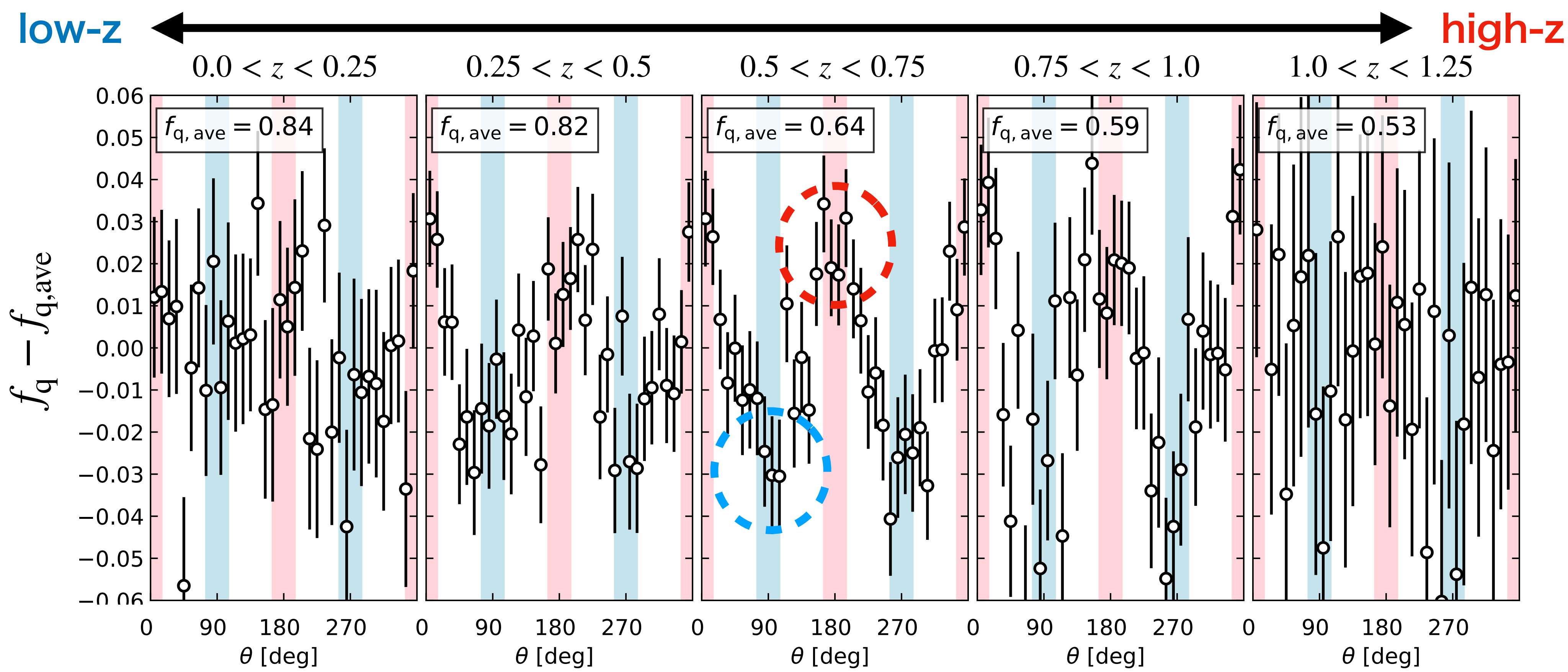

- Periodical fluctuation at $0.25 < z < 1$
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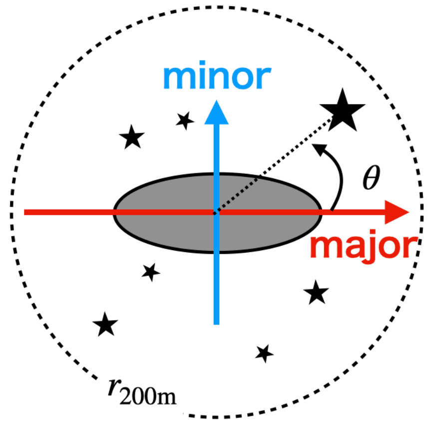

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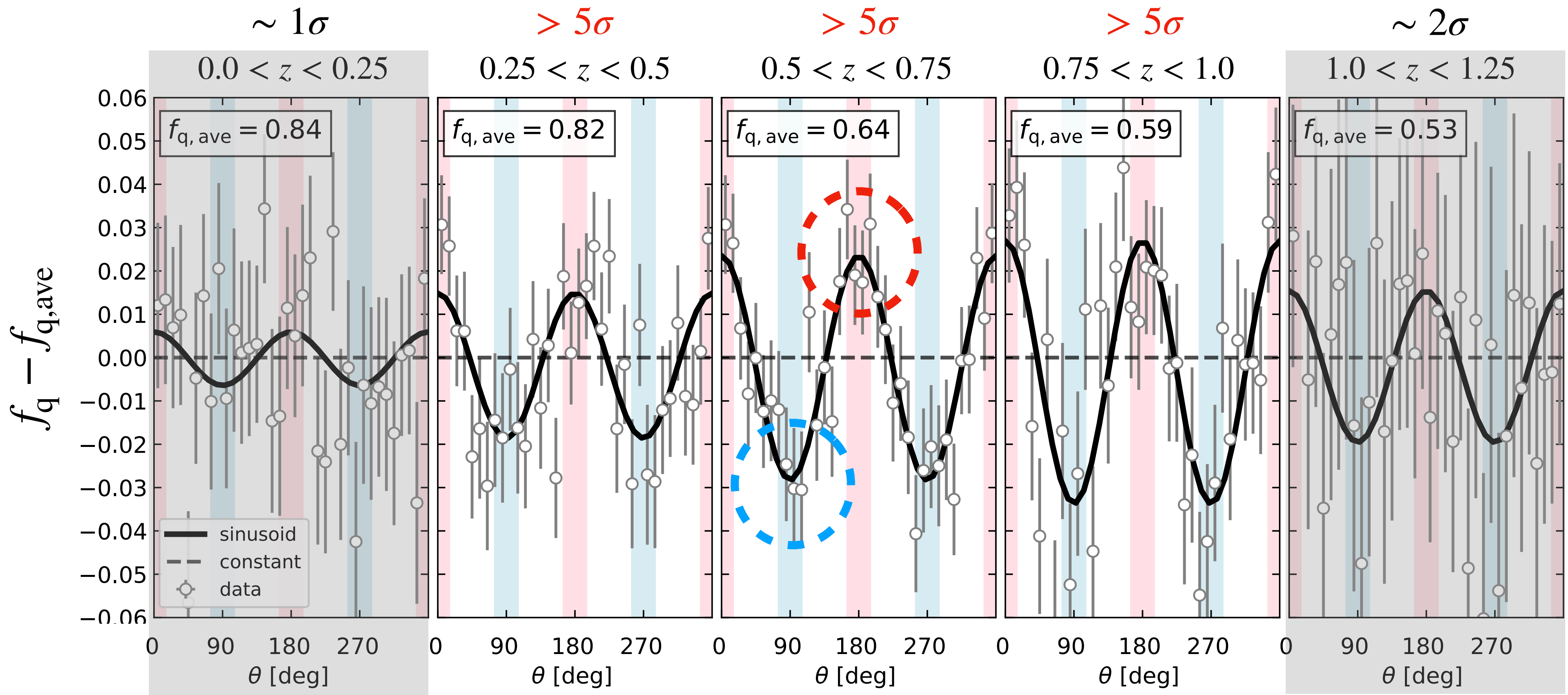
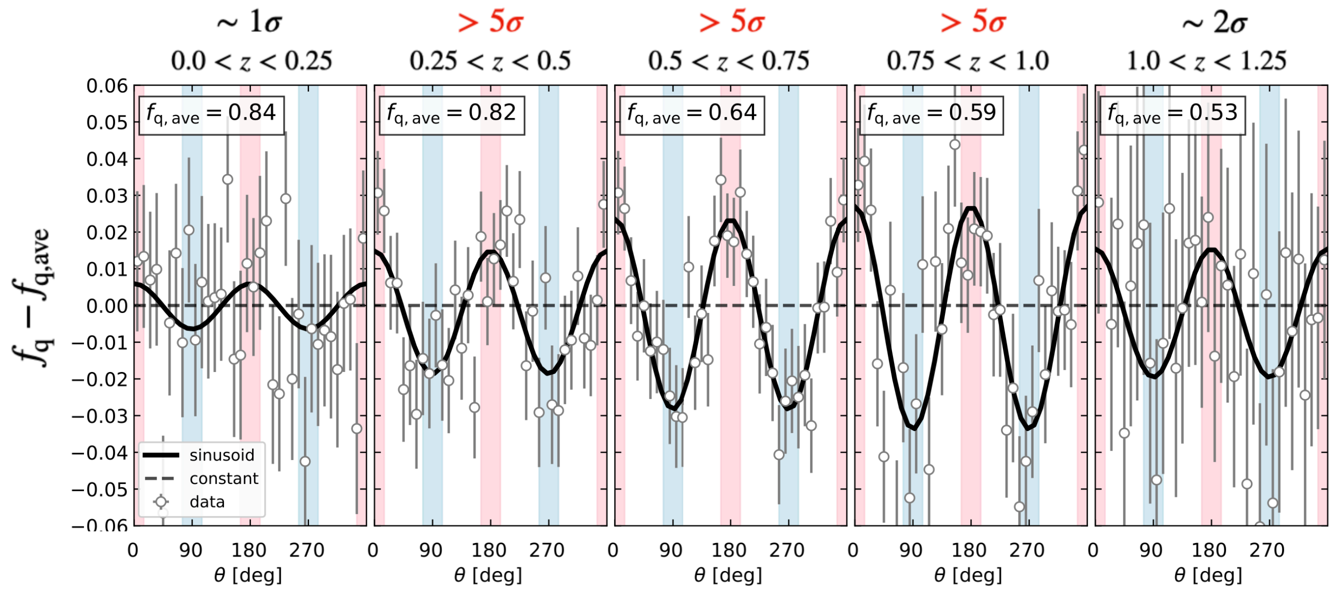
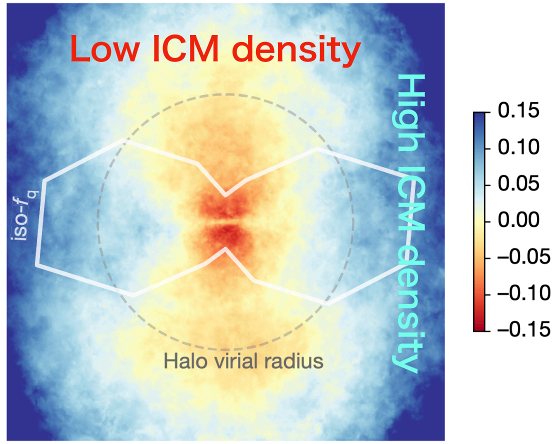


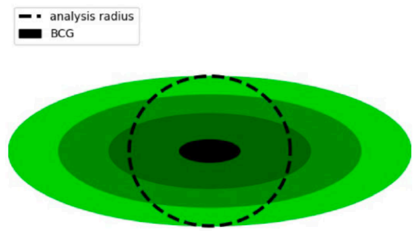
- Sinusoidal function well fits the data at $0.25 < z < 1$ ($> 5\sigma$)
- The sinusoids much better fit ($\chi^2_\nu \sim 1$) than the constants ($\chi^2_\nu > 2$)

$$\boxed{f_q = A_q \cos(2\theta) + f_{q,0}}$$

Discussion: what are origins of the observed anisotropy?

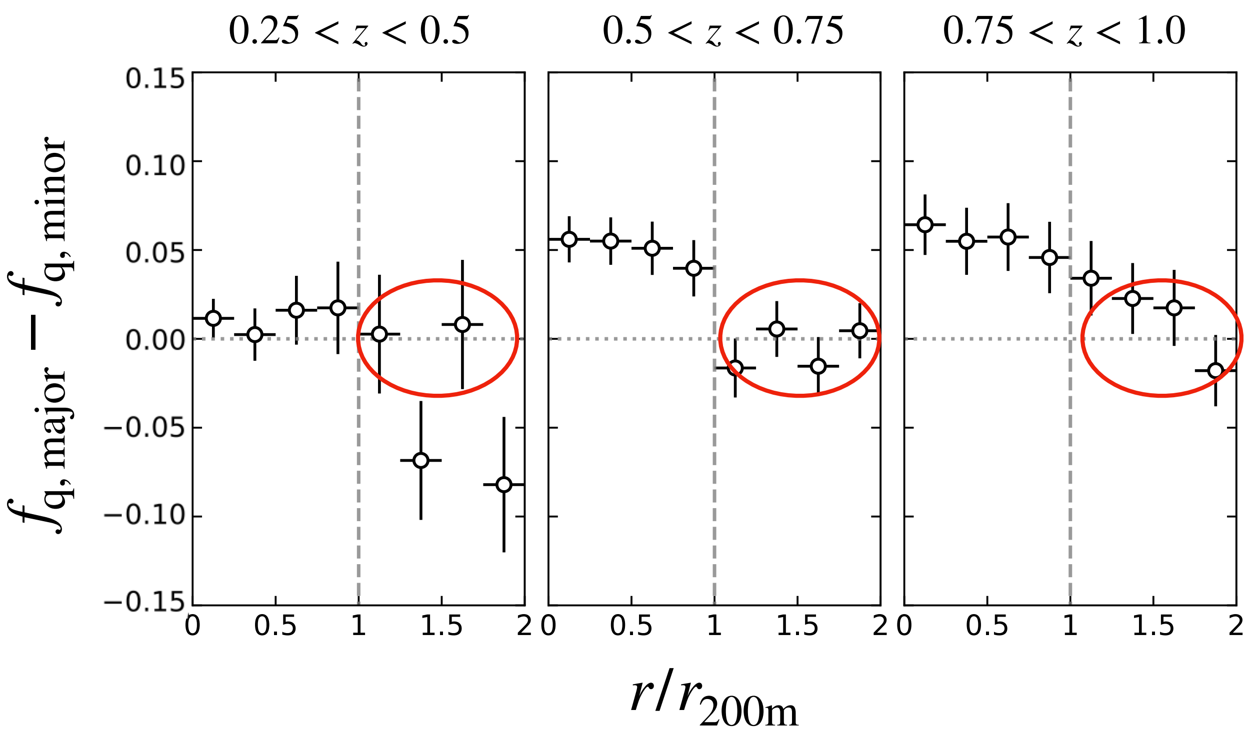


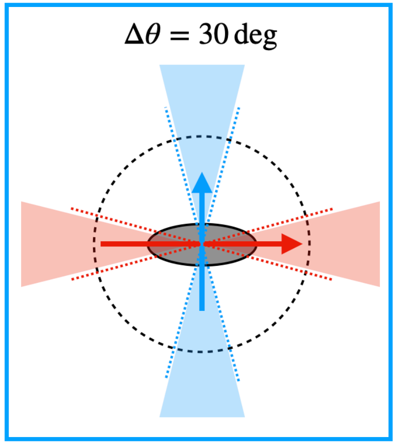




Physical Origin	ref.
(A) The anisotropy in strength of RPS	MN21
(B) Anisotropic matter density b/w the two axes	Stott 22
(C) Pre-processed galaxies accreted from the major axis direction	Huang+16

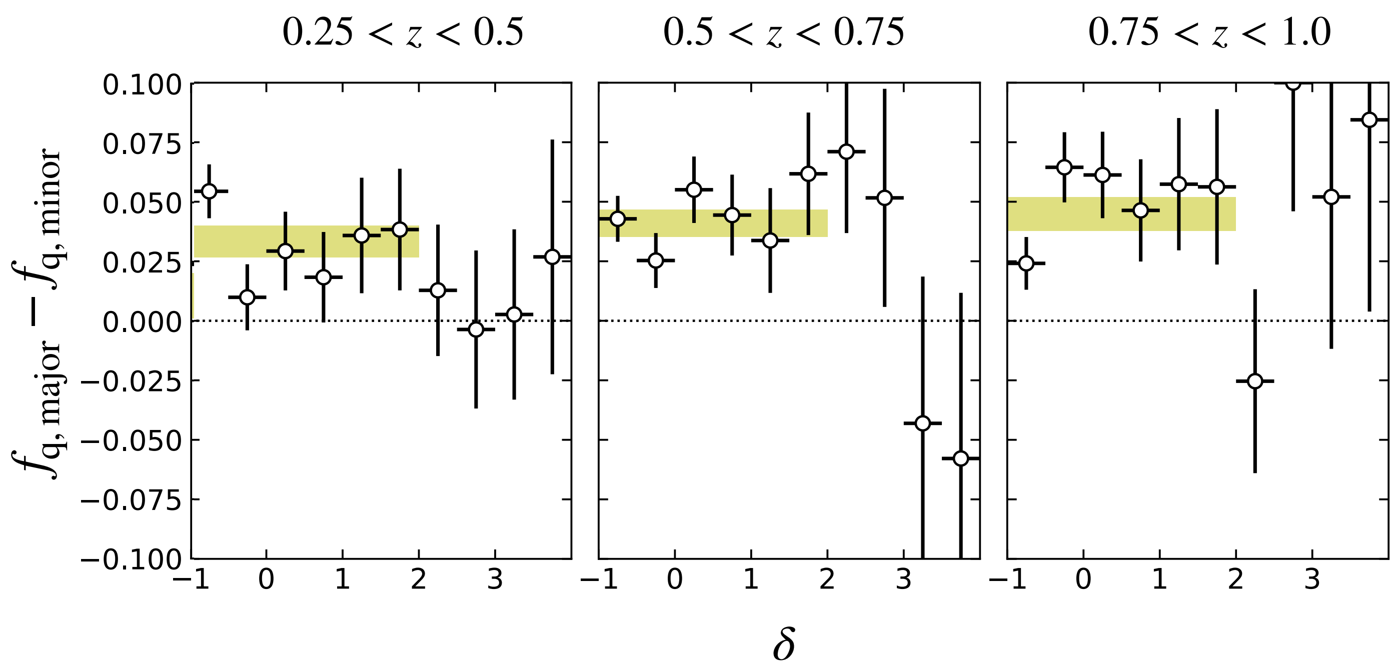
Radial dependence

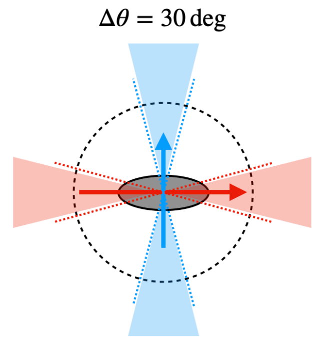




- $f_{\rm q}(r)$ around the major and minor axes ($\Delta\theta = 30\,\rm deg$)
  - Excess of $f_{\rm q}$ is only significant at $r < r_{\rm 200m}$
  - Anisotropic quenching **does not occur outside of a halo**

Local density dependence



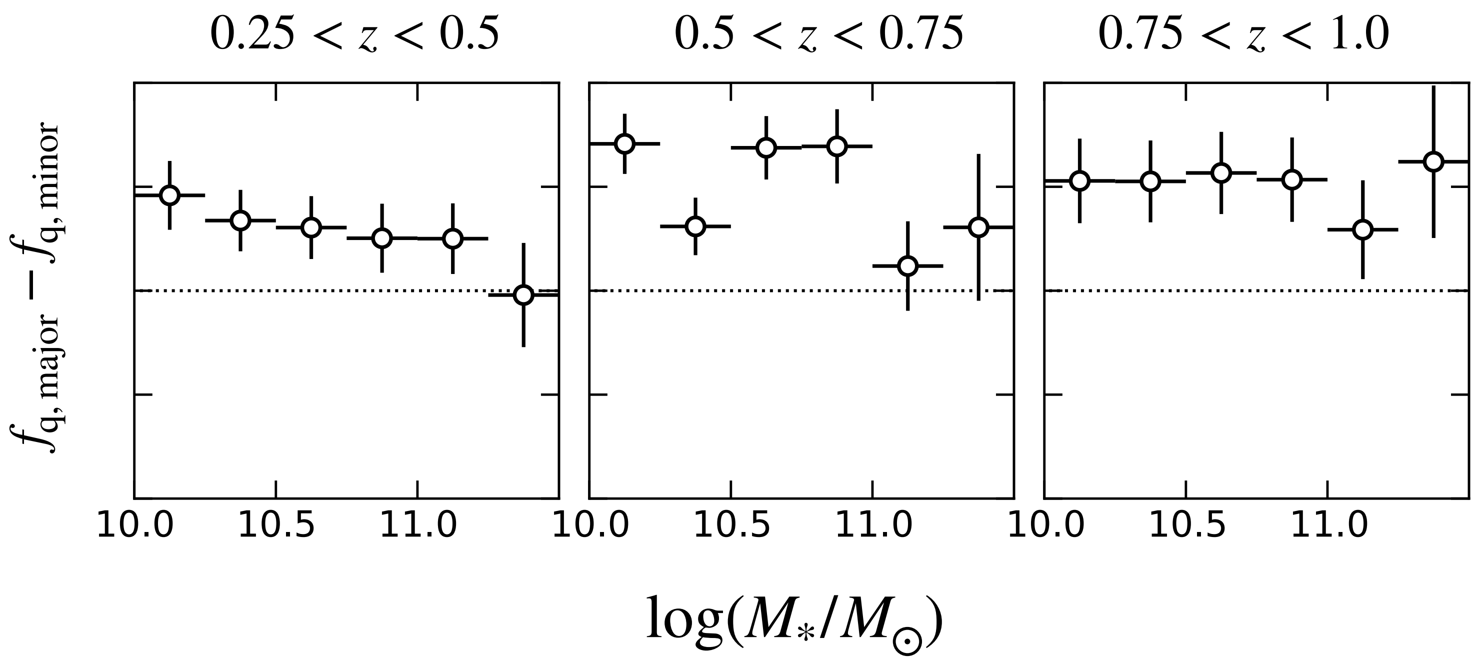


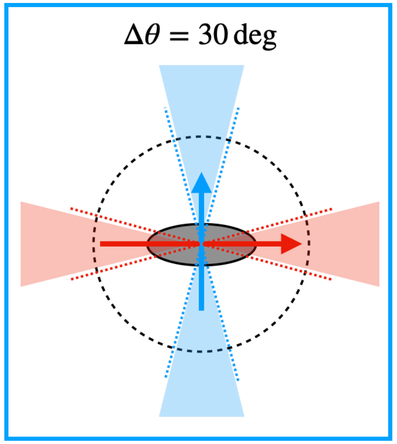
$$\rho_i = \sum_j \frac{1}{2\pi a^2} \exp\left(-\frac{d_{i,j}}{2a^2}\right)$$

$$\delta_i = \frac{\rho_i}{\bar{\rho}} - 1$$

- $f_q(\sigma)$ within r_{200m} ($\Delta\theta = 30\,\mathrm{deg}$)
  - f_q is higher around the major axis even at fixed local density
  - Anisotropy is **not just caused by the difference in the local density b/w the two axes**

Stellar mass dependence





- $f_\mathrm{q}(M_*)$ within $r_{200\mathrm{m}}$ ($\Delta\theta = 30\,\mathrm{deg}$)
  - f_q is higher along the major axis
  - **no clear stellar mass dependence**

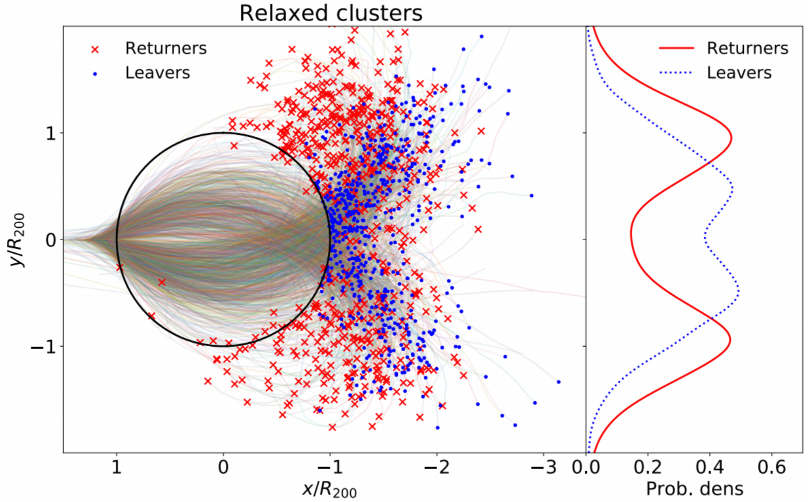
Discussion: timescales of quenching

- For anisotropic quenching to be observed, satellites need to be quenched before their orientation will be changed
  - At most one cluster crossing time (cf. Kuchner+21), $\sim 2\,\mathrm{Gyr}$.

- Representative quenching mechanisms in clusters
  - ram-pressure stripping: $\lesssim 1\,\mathrm{Gyr}$
  - harassment: $\gtrsim 3\,\mathrm{Gyr}$
  - strangulation: $\gtrsim 7\,\mathrm{Gyr}$

➡ **ram-pressure stripping is preferred** in terms of quenching timescale

Kuchner+21



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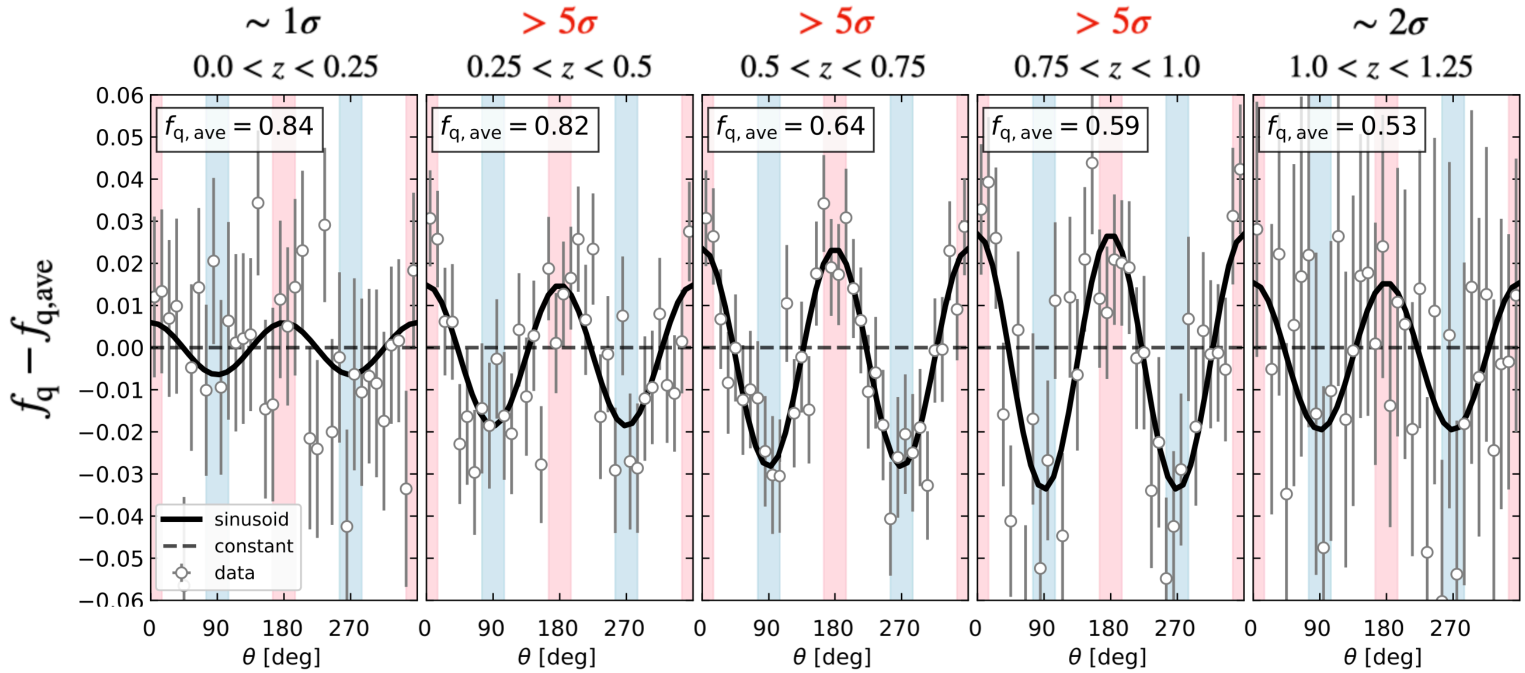

Physical Origin	radial	density	mass	timescale
(A) The anisotropy in strength of RPS	○		△	○
(B) Anisotropic matter density b/w the two axes		×		
(C) Pre-processed galaxies accreted from the major axis direction	×			

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- We have clearly detected anisotropic quenching in clusters at $0.25 < z < 1$.
- The anisotropy in the strength of ram-pressure stripping may be the physical origin of this phenomenon.
- Future prospectives:
  - Extending this study beyond $z = 1$ (ongoing with other cluster data)
  - Reproducing the anisotropic quenching in a simulation