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Analysis of the growth rate of heliospheric magnetic flux rope instabilities

Bachelor's Thesis

This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

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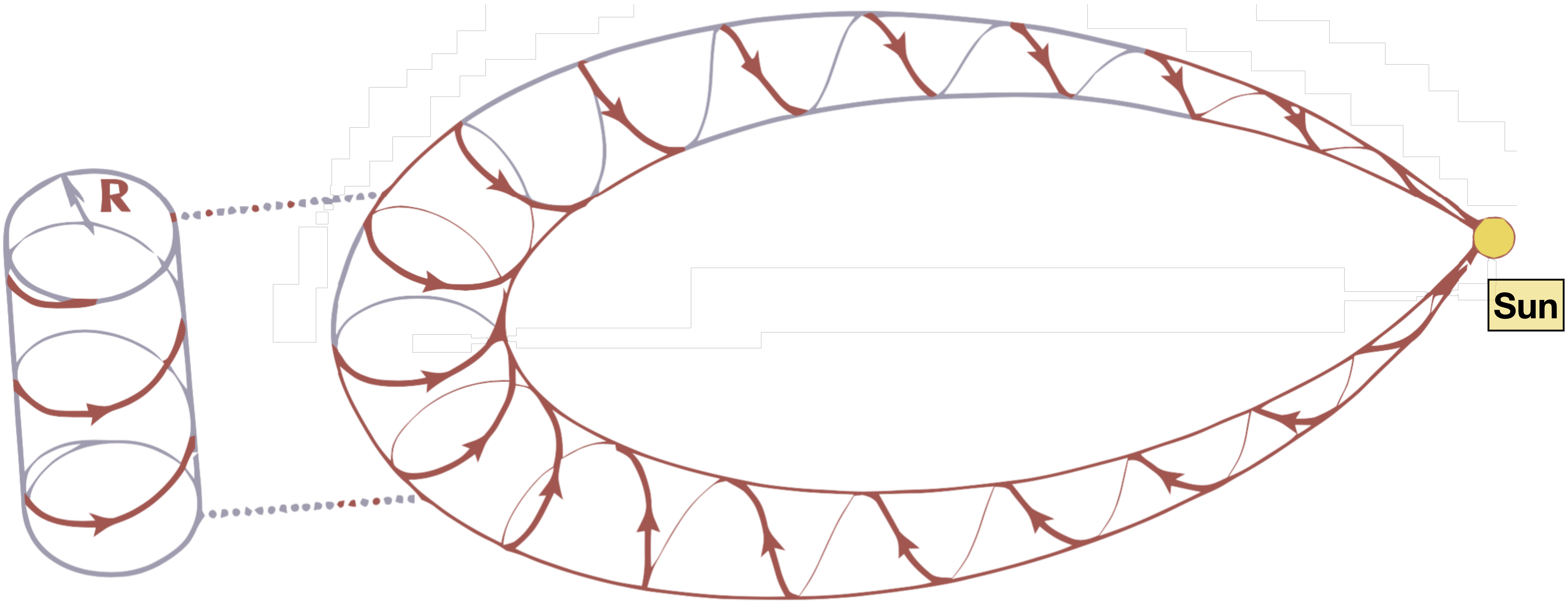
1. Plasma instabilities in MFRs

Coronal mass ejections (CMEs)

Magnetic flux ropes (MFRs) in magnetic clouds



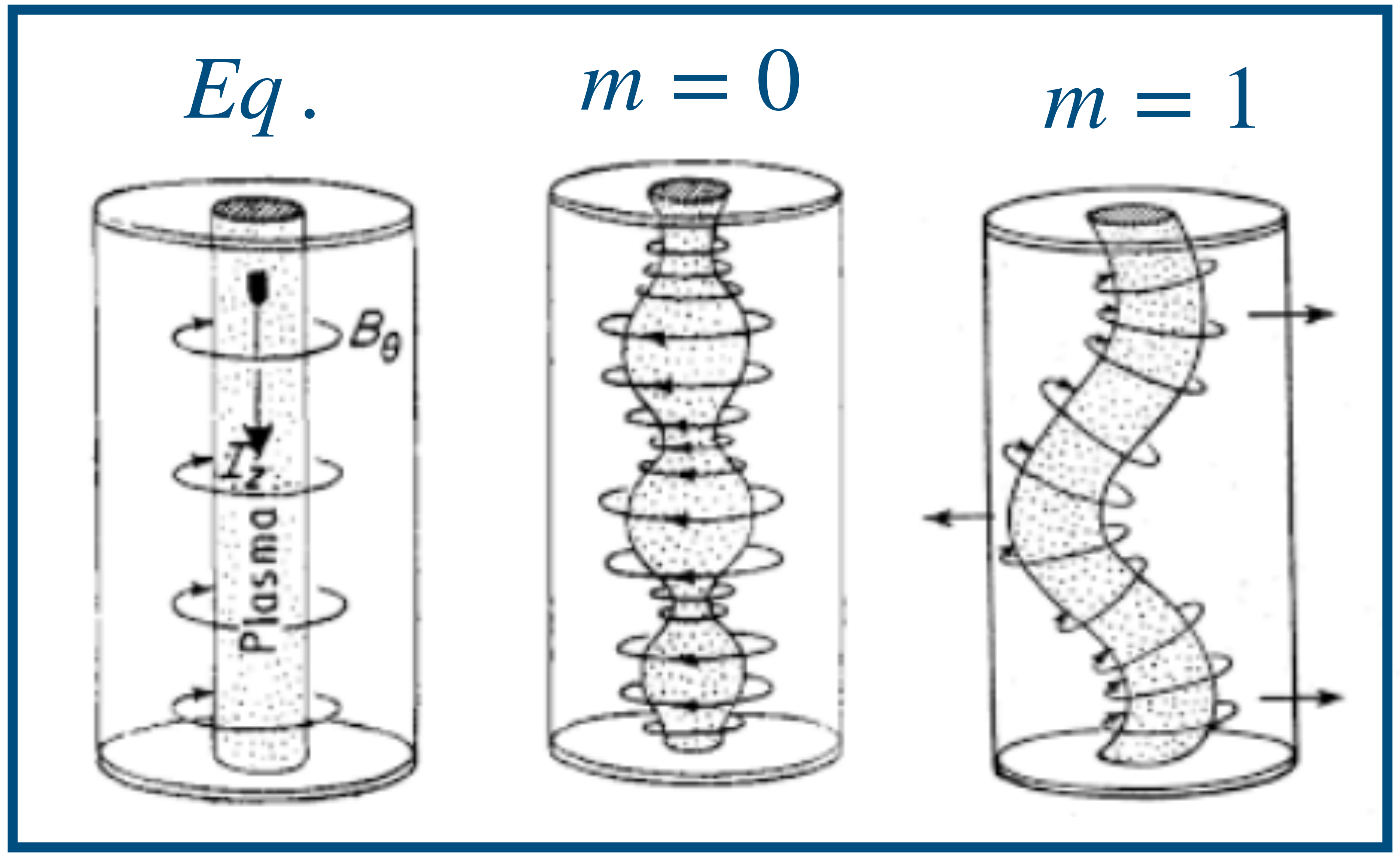
Schematic representation of a magnetic cloud and its flux rope structure, with its cylindrical approximation. Original from Demoulin & Dasso (A&A, 2009).

Plasma instabilities in MFRs

- We consider Fourier displacements:

$$\boldsymbol{\xi}(r, \theta, z) = \widetilde{\boldsymbol{\xi}}(r)\, e^{i(m\theta + kz)}$$

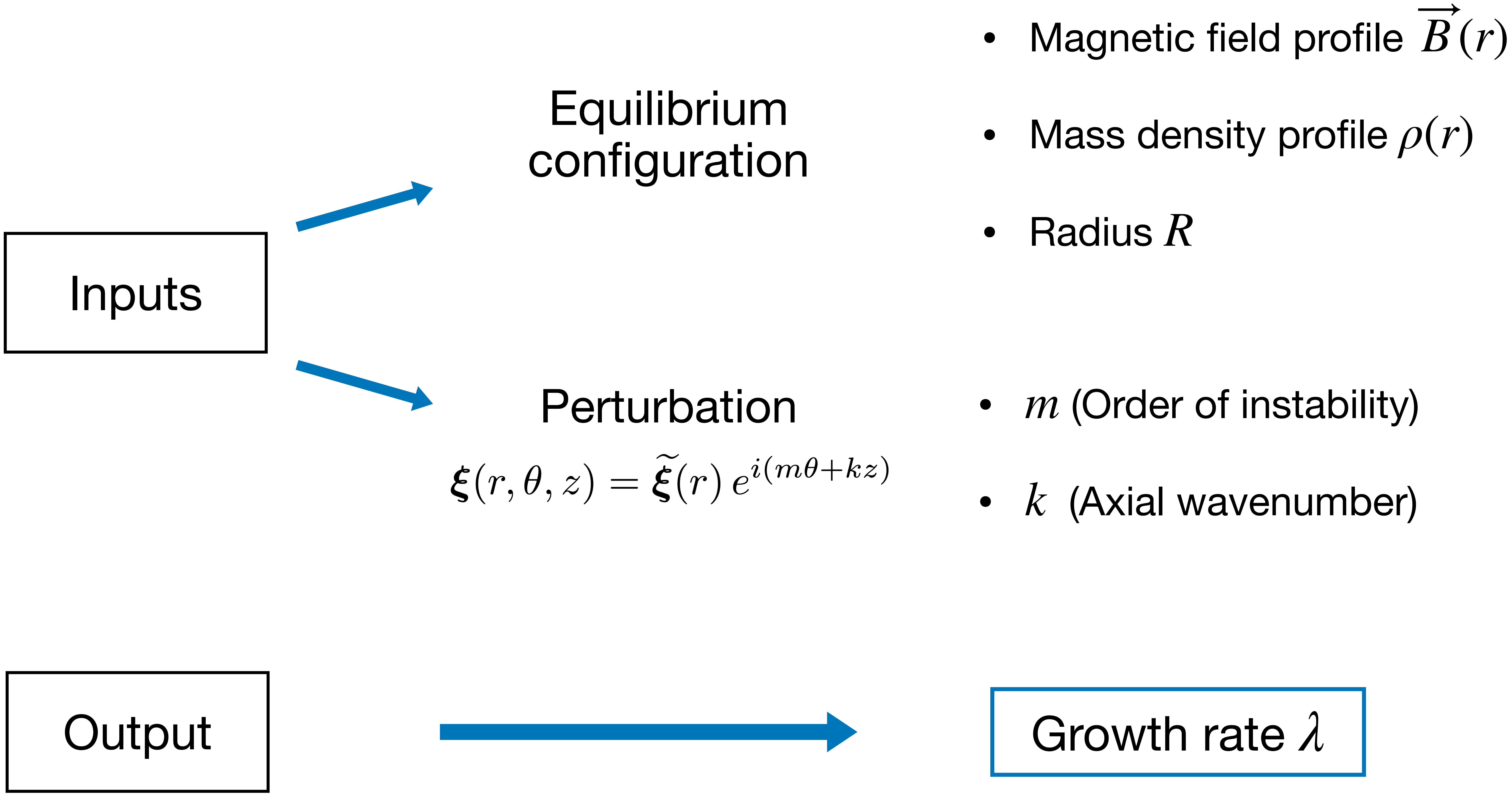
- The azimuthal wave number *m* determines the order of the instability:



Cylindrical plasma equilibrium and instabilities of different order *m*.
Extracted from Sadouni (ApJ, 2020).

Goals of this work

- Generalize Linton et. al. (ApJ, 1996) to study instabilities of any order m
- Compare the growth rates of such instabilities
- Understand the effect of twist and Lorentz forces on flux rope instabilities


Inputs
Equilibrium configuration
Magnetic field profile $\vec{B}(r)$
Mass density profile $\rho(r)$
Radius R
Perturbation
$\boldsymbol{\xi}(r,\theta,z) = \widetilde{\boldsymbol{\xi}}(r)\, e^{i(m\theta+kz)}$
m (Order of instability)
k (Axial wavenumber)
Output
Growth rate λ

2. Magnetic field modeling

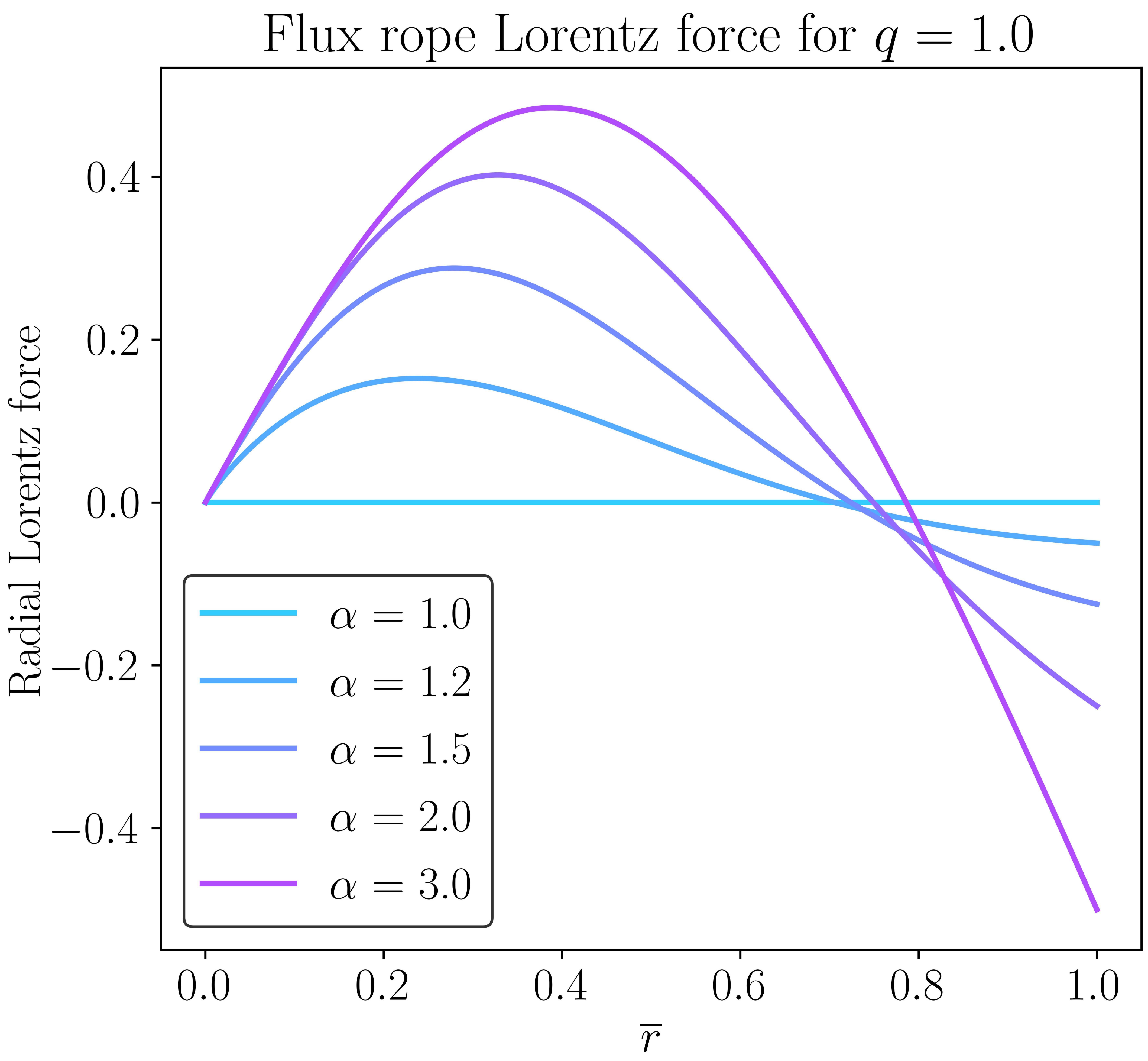
The modified Gold-Hoyle model

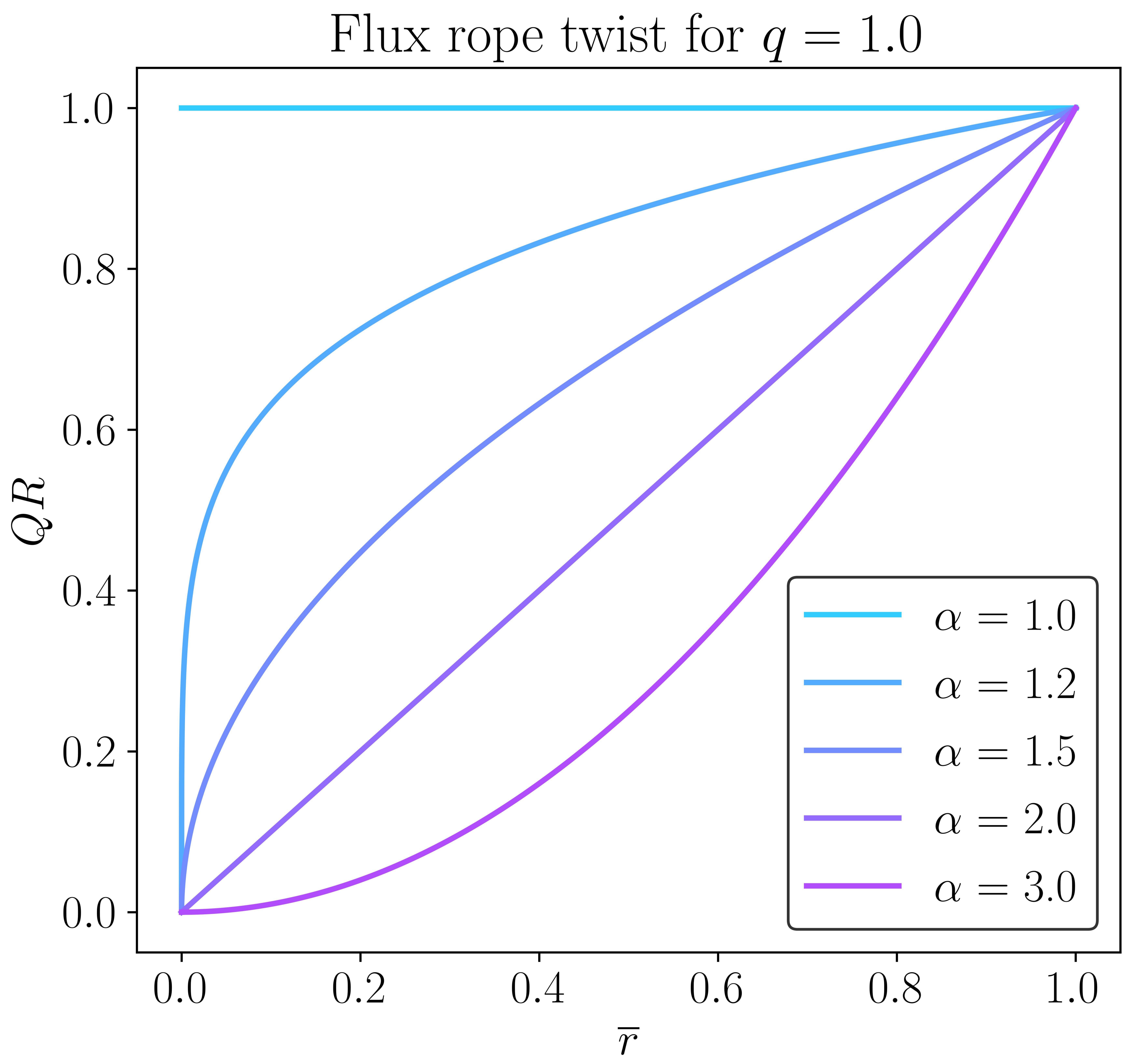
- Given the parameters q and α:

$$\boxed{B_z(\overline{r}) = \frac{B_0}{1 + q^2\overline{r}^2}, \quad B_\theta(\overline{r}) = q\overline{r}^\alpha B_z(\overline{r})}$$

- For $\alpha = 1$, we recover the Gold-Hoyle force-free model with uniform twist q.
- q is the *twist parameter*.
- α is the *force parameter*.

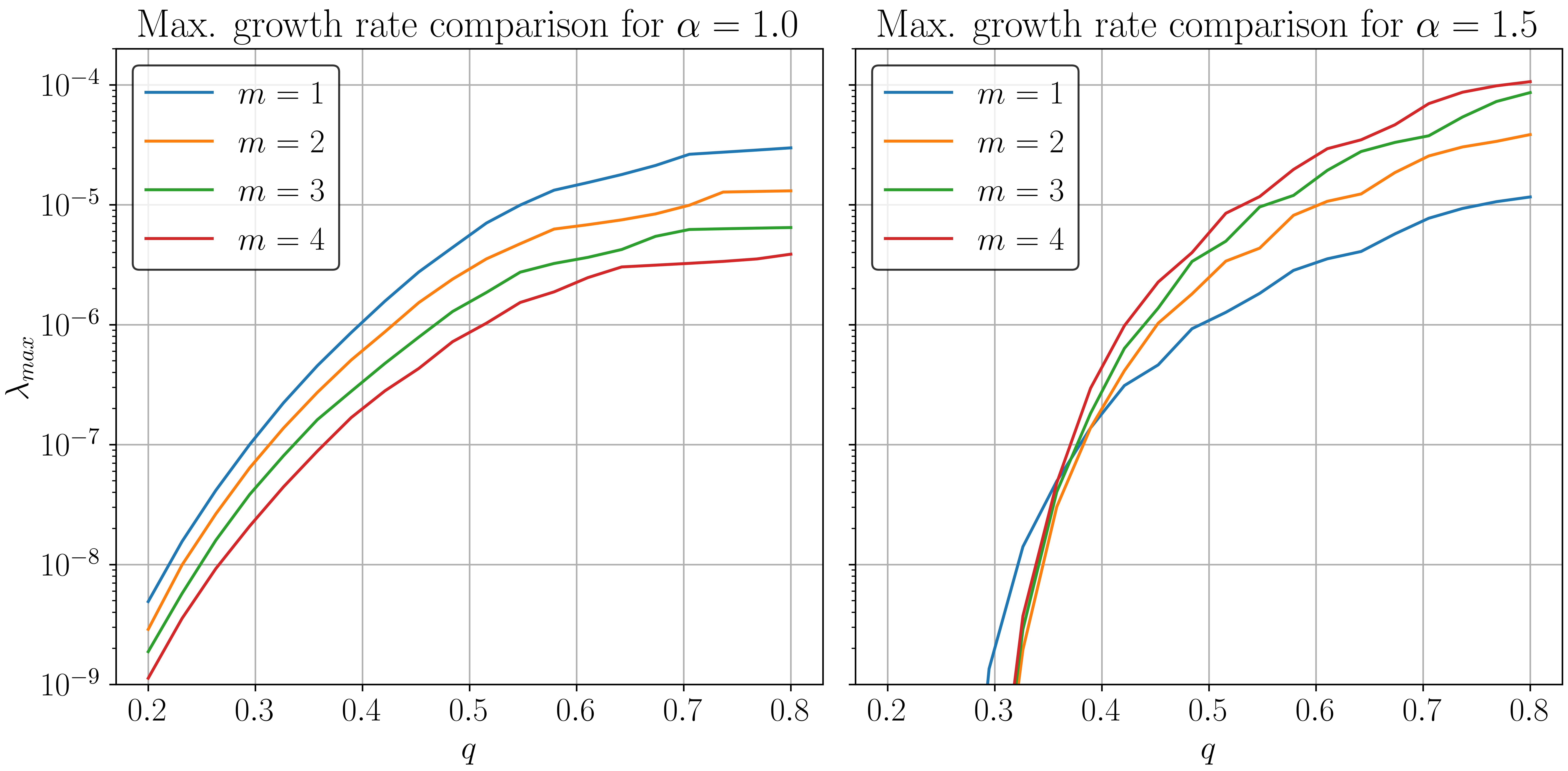
The modified Gold-Hoyle model



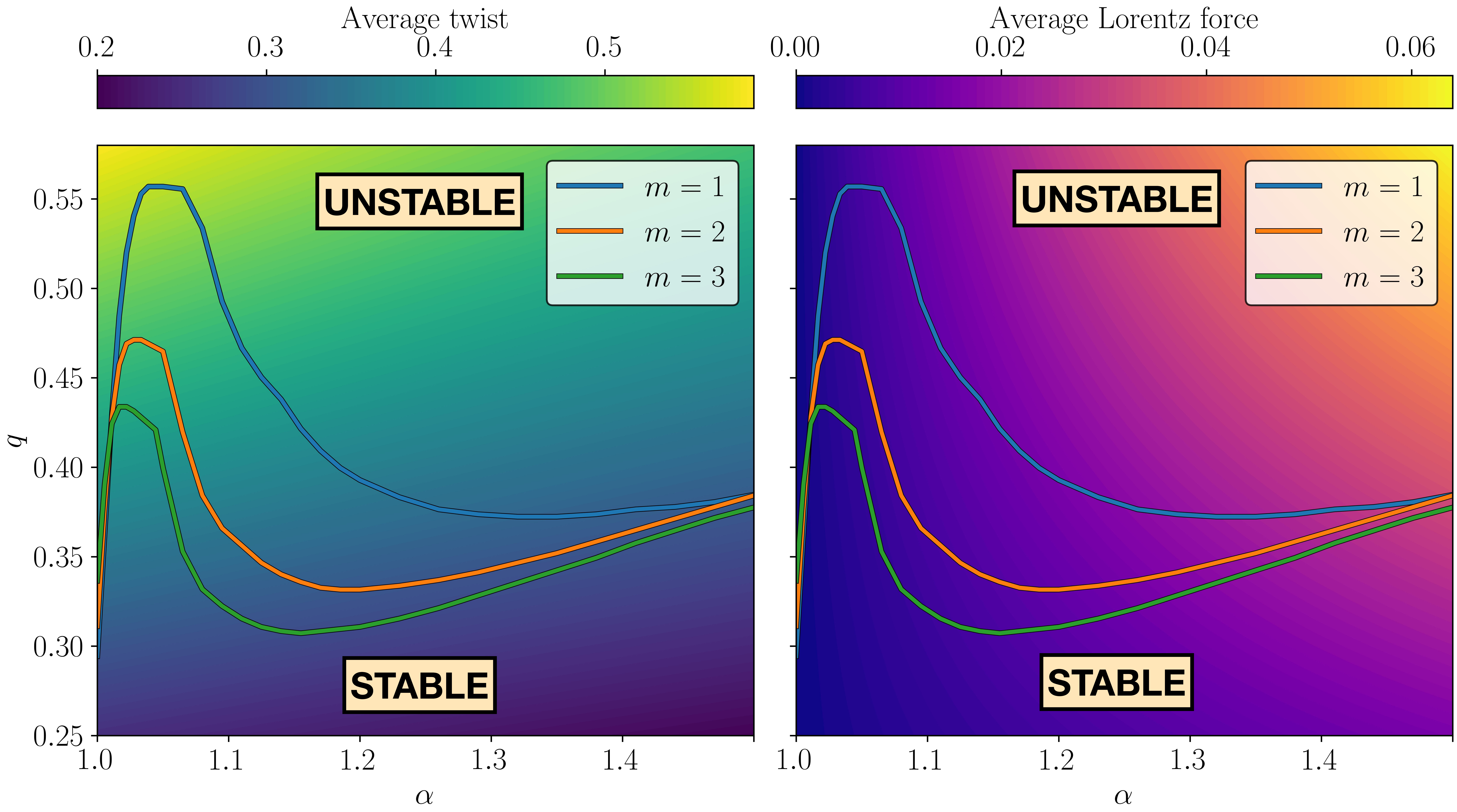


3. Presentation of results

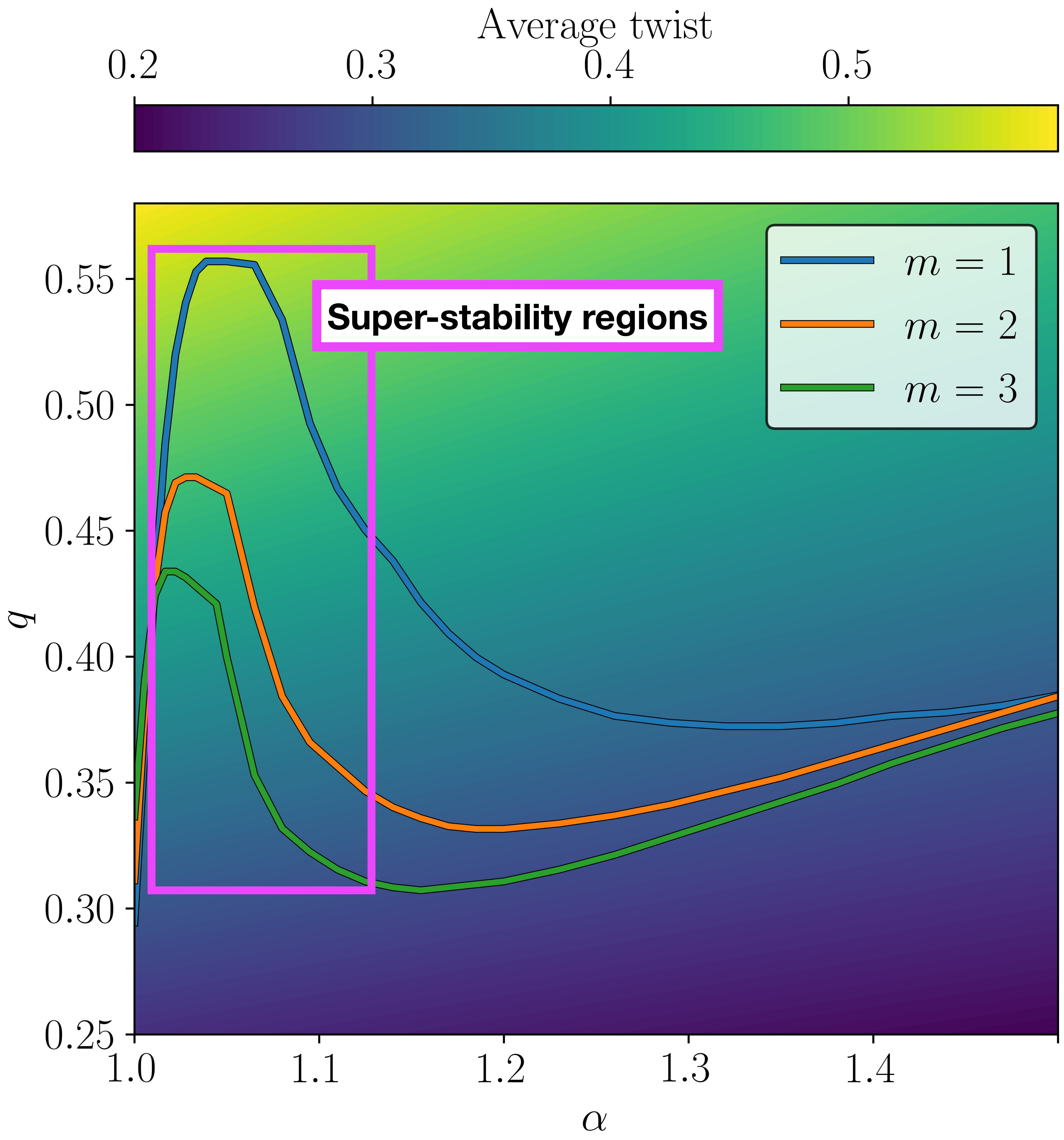
Plotting the maximum growth rate

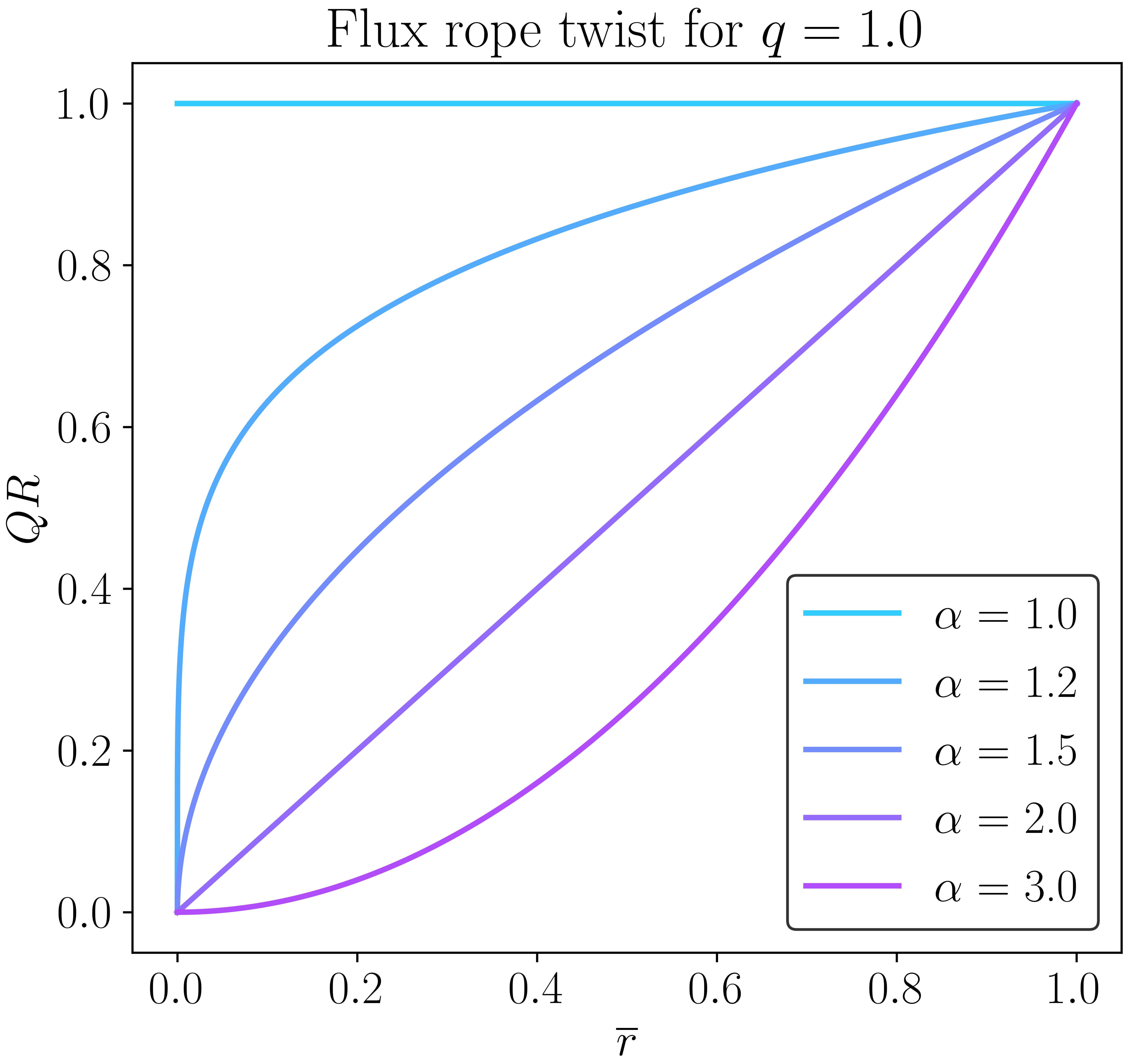


Stability curves



Superstability





4. Key takeaways

Key takeaways

- Linton's equations have been generalized to instabilities of any order m.
- $m = 0$ is always stable, but instabilities were found for $m \neq 0$, for $k \approx -mq$.
- More rapid instabilities take place in highly twisted MFRs.
- The kink instability seems to dominate in force-free structures.
- When Lorentz forces come into play, there can be an instability inversion.
- For simplicity, big assumptions have been made.

Thank you.

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