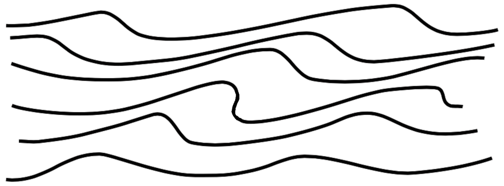
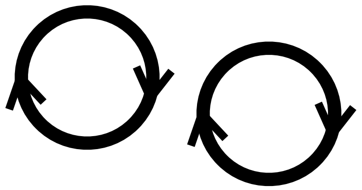
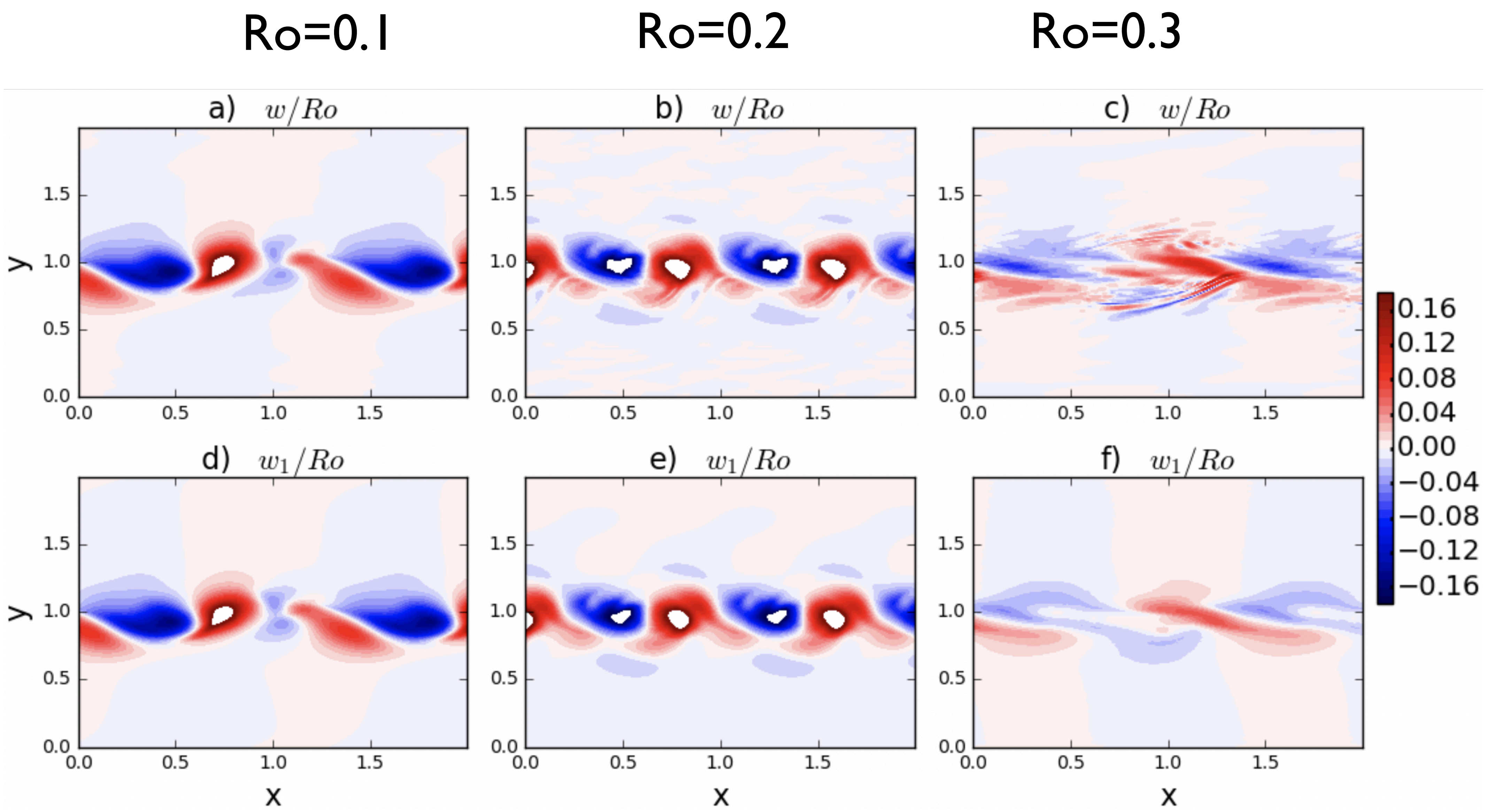
Gravity wave generation by shear instability of balanced flow



Internal gravity waves
(fast and unbalanced)



Mesoscale eddies
(slow and balanced)



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Spontaneous Loss of Balance

→ Balanced flow generates IGWs spontaneously

- in accordance with the non-existence of an invariant slow manifold

DIFFERENT MECHANISMS:

- Lighthill radiation (Ford et al. 2000, Saujani & Shepherd 2002)
  [small Fr, $Ro > 1$]
- Shear instabilities (Eden et al. 2019ab)
  [Convective, Symmetric]
- Ageostrophic instabilities (Chouksey et al. 2021,

Flow Decomposition Methods

MODAL DECOMPOSITION

- using eigenvectors of the linearized matrix of state variables (u, v, ϕ)

→ **WARN ET. AL (1995)**

- two timescales < slow ---- balanced; fast ---- unbalanced
- expansion in Rossby number (Ro) to higher orders
- n^{th} order balanced state
- 1^{st} order balanced state : QG

Small Ro — waves at higher order

Large Ro — waves already at lower orders

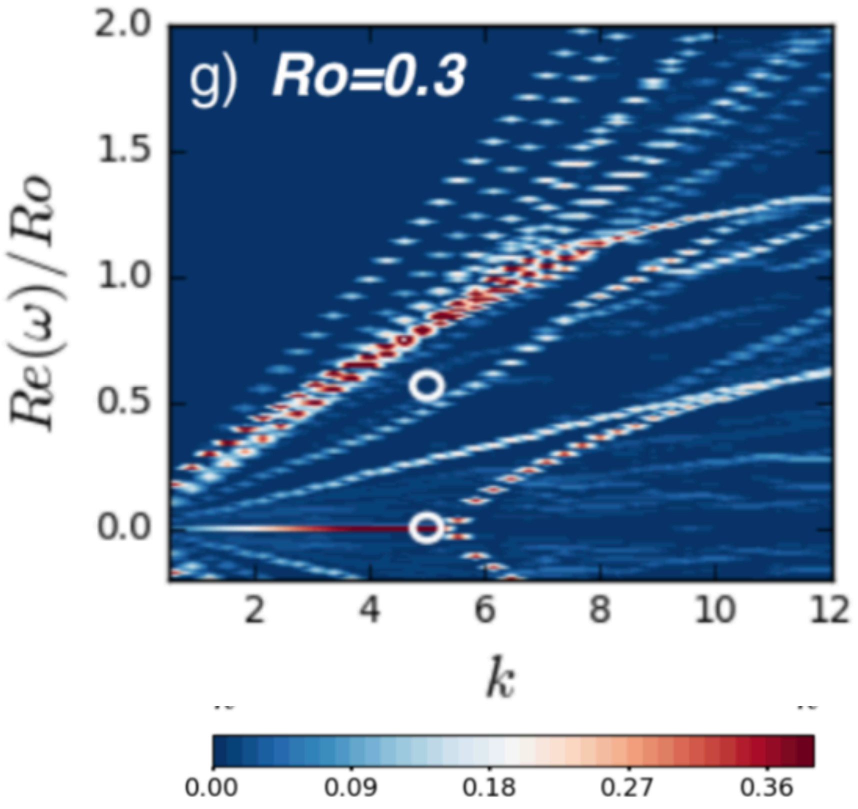
Flow Decomposition Methods

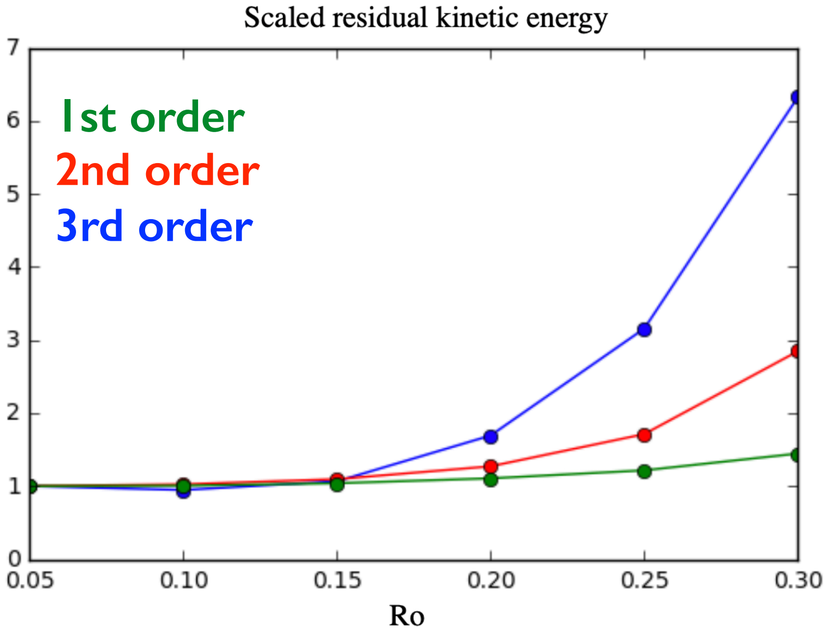
→ WARN ET. AL (1995)

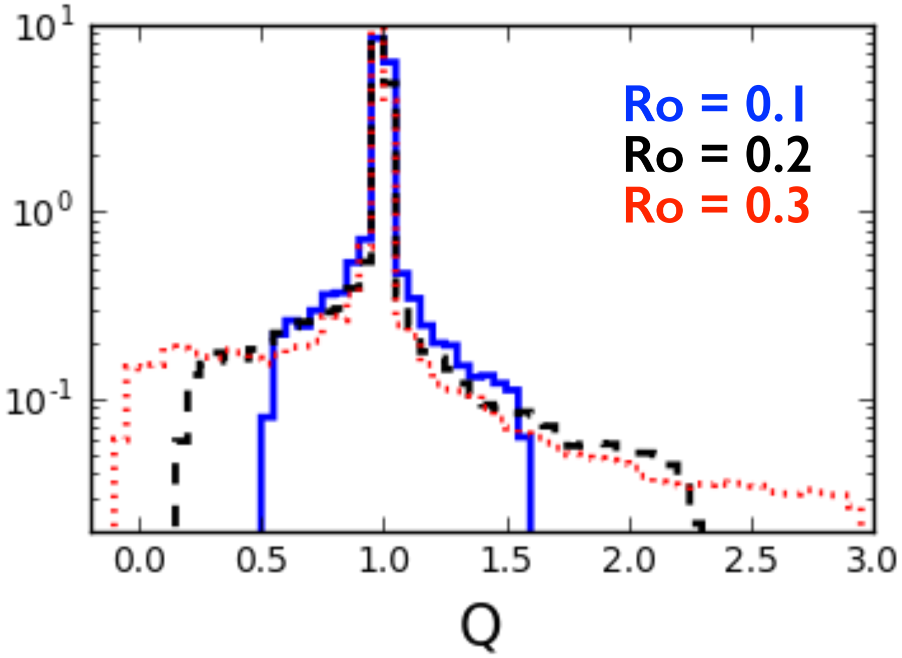
- wave energy exponential with Ro (large Ro, higher orders)
- Shear instabilities
  - convective / symmetric
- Ageostrophic instabilities

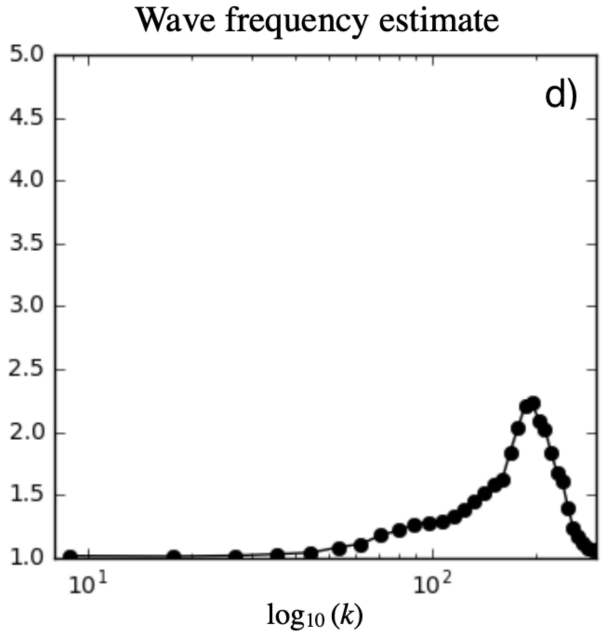
} Dominant Mech.

- Spontaneous emission → WEAK







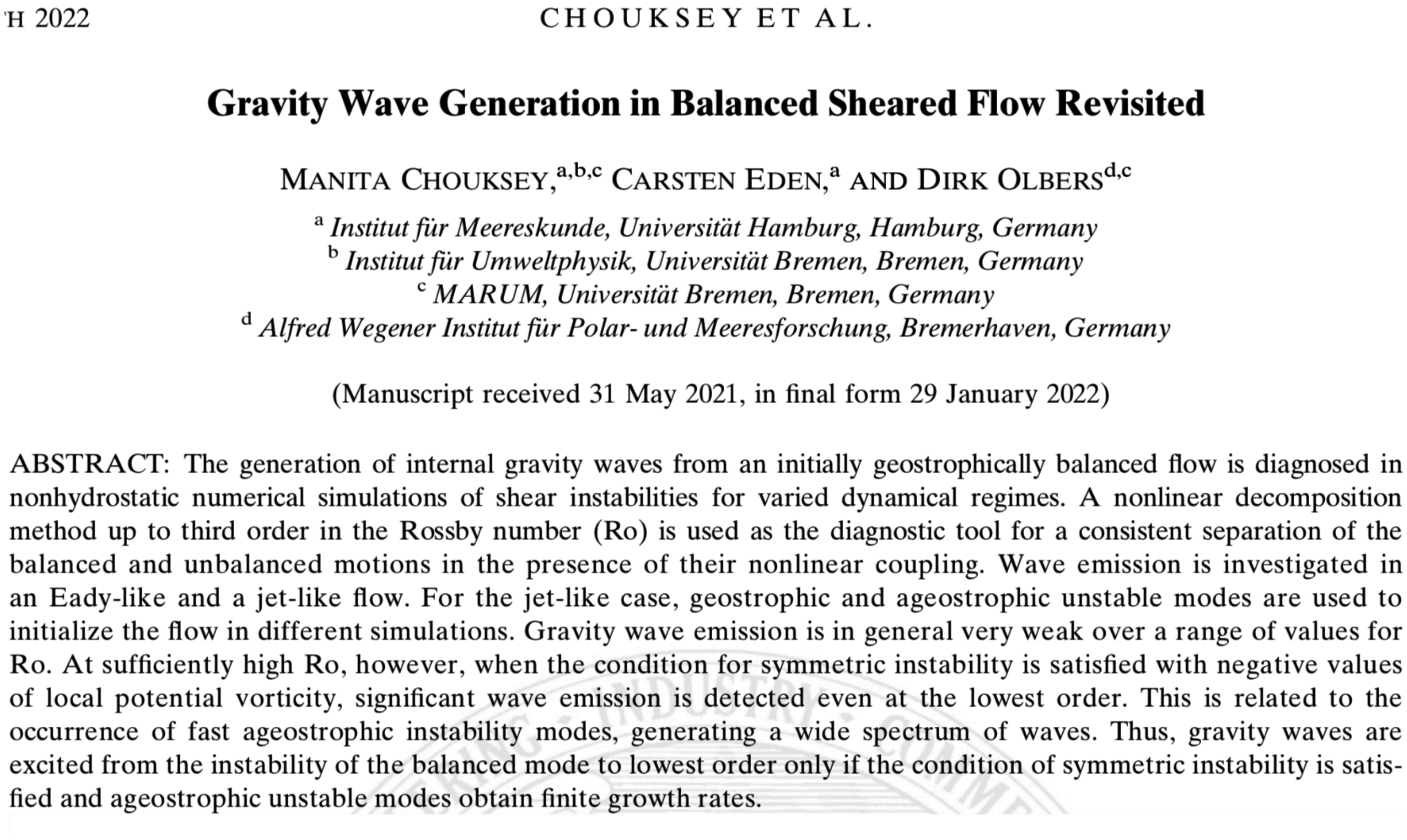


SUMMARY

- Nonlinear modal decomposition is achieved and implemented up to 4th order in Rossby number (Ro), for varied regimes.
- Internal wave emission is more pronounced at higher orders and at larger Ro.
- Wave emission scales exponentially with Ro, for large Ro.
- Wave emission from an initially balanced flow occurs prominently by shear instabilities of the flow (convective, symmetric), and the role of spontaneous loss of balance is weak.

Relevant literature

- Details:
  - Chouksey, M., Eden, C., Olbers, D., 2022. *Gravity wave emission in balanced sheared flow revisited.* *JPO*



Gravity Wave Generation in Balanced Sheared Flow Revisited

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ABSTRACT: The generation of internal gravity waves from an initially geostrophically balanced flow is diagnosed in nonhydrostatic numerical simulations of shear instabilities for varied dynamical regimes. A nonlinear decomposition method up to third order in the Rossby number (Ro) is used as the diagnostic tool for a consistent separation of the balanced and unbalanced motions in the presence of their nonlinear coupling. Wave emission is investigated in an Eady-like and a jet-like flow. For the jet-like case, geostrophic and ageostrophic unstable modes are used to initialize the flow in different simulations. Gravity wave emission is in general very weak over a range of values for Ro. At sufficiently high Ro, however, when the condition for symmetric instability is satisfied with negative values of local potential vorticity, significant wave emission is detected even at the lowest order. This is related to the occurrence of fast ageostrophic instability modes, generating a wide spectrum of waves. Thus, gravity waves are excited from the instability of the balanced mode to lowest order only if the condition of symmetric instability is satisfied and ageostrophic unstable modes obtain finite growth rates.

Further details:

- Chouksey, M., 2018. *Disentangling gravity waves from balanced flow,* PhD Thesis, Universität Hamburg and Max-Planck Institut für Meteorologie.
- Chouksey, M., Eden, C. and Brüggemann, N., 2018. *Internal gravity wave emission in different dynamical regimes.* JPO
- Eden, C., Chouksey, M. and Olbers, D., 2019. *Gravity wave emission by shear instability.* JPO
- Eden, C., Chouksey, M. and Olbers, D., 2019. *Mixed Rossby–gravity wave–wave interactions.* JPO

Decomposition of Modes

$$\partial_t z = i \underbrace{\mathcal{L}\cdot z}_{\text{Linear}} + \underbrace{N(z)}_{\text{Non-linear}}$$

$$\mathcal{L} = \begin{pmatrix} 0 & -if & -k \\ if & 0 & -l \\ -kc_n^2 & -lc_n^2 & 0 \end{pmatrix}$$

$$\tilde{z} = \begin{pmatrix} \tilde{u} \\ \tilde{v} \\ \tilde{p} \end{pmatrix}$$

BALANCED (slow)		UNBALANCED (fast)
$\omega^0 = 0$	Eigenvalues	$\omega^\pm = \pm\sqrt{f^2 + c_n^2 k_n^2}$
q^0, p^0	Eigenvectors	$q^\pm, p^\pm$
$R^0 = q^0 \cdot p^0$	Projection matrix	$R^\pm = q^\pm \cdot p^\pm$

PROJECTION : $g^s = R^s \cdot \tilde{z}$, $(s = 0, \pm)$