Periodicity makes galactic shocks unstable

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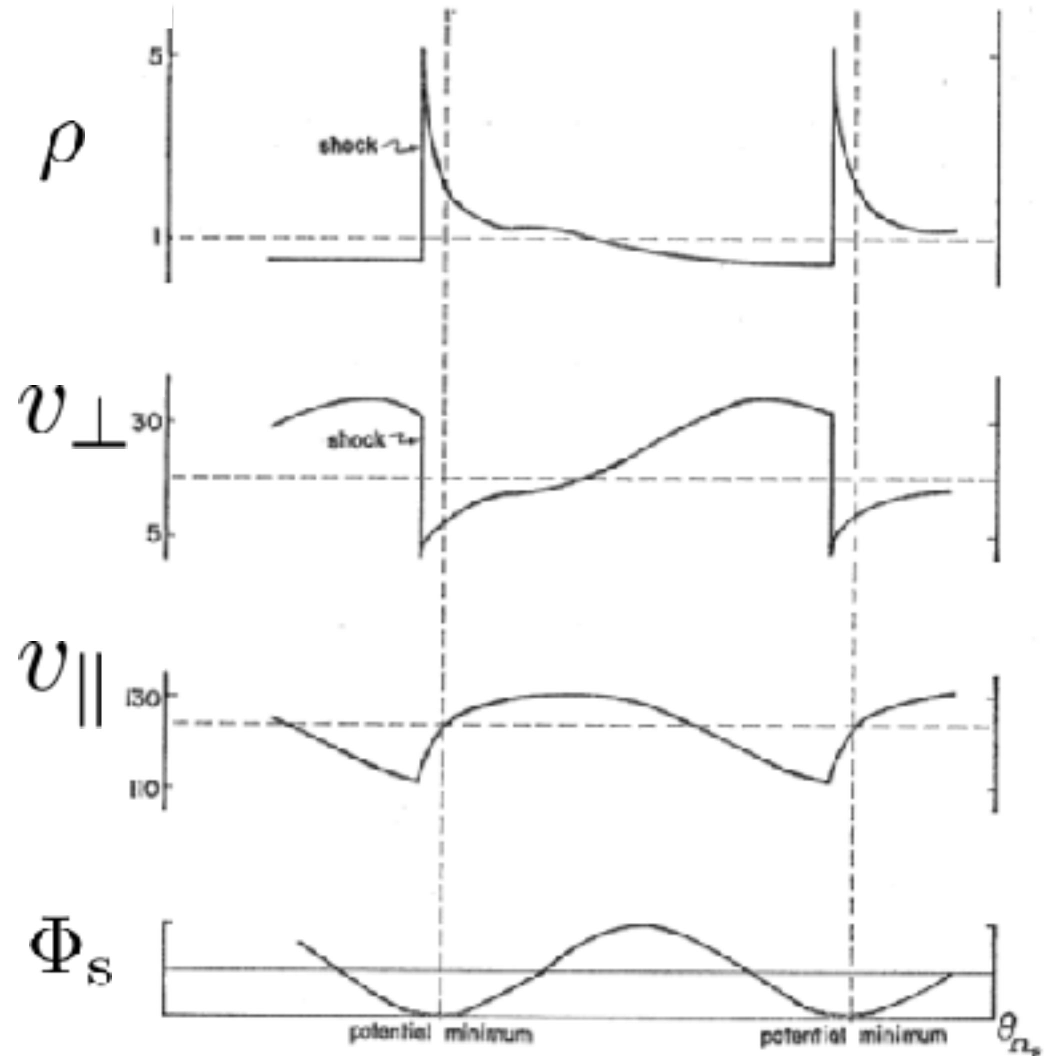
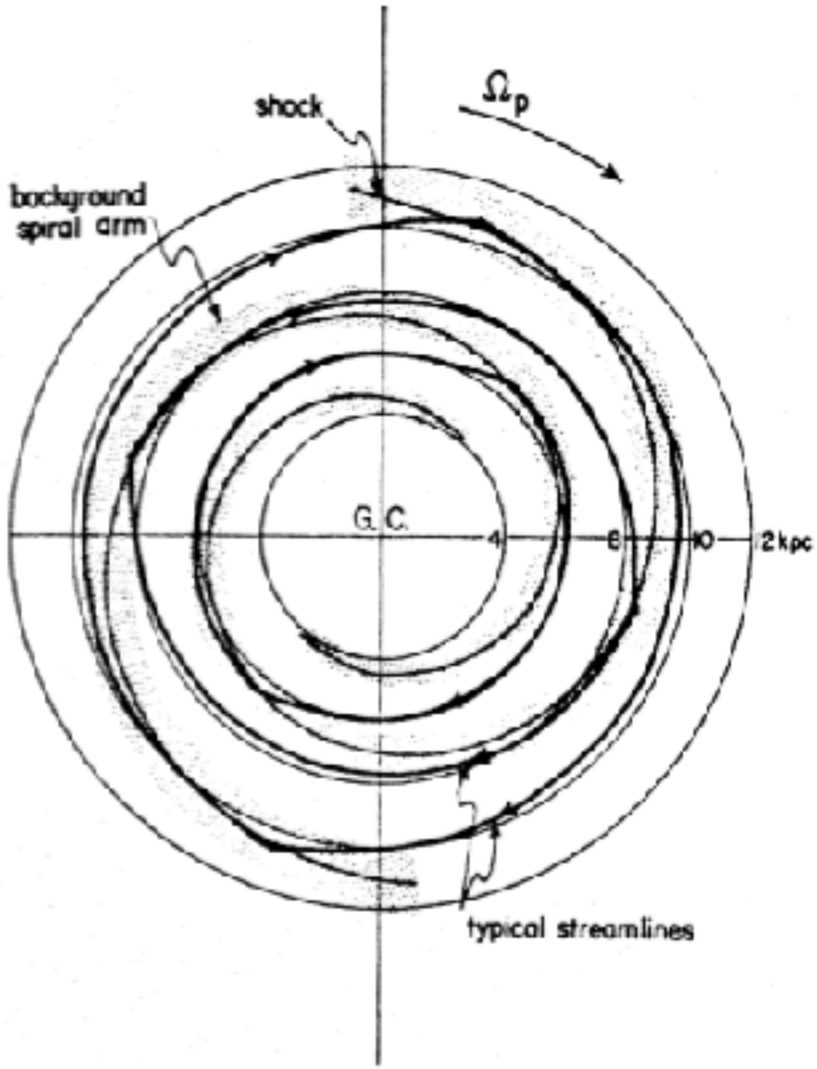
Roberts1969

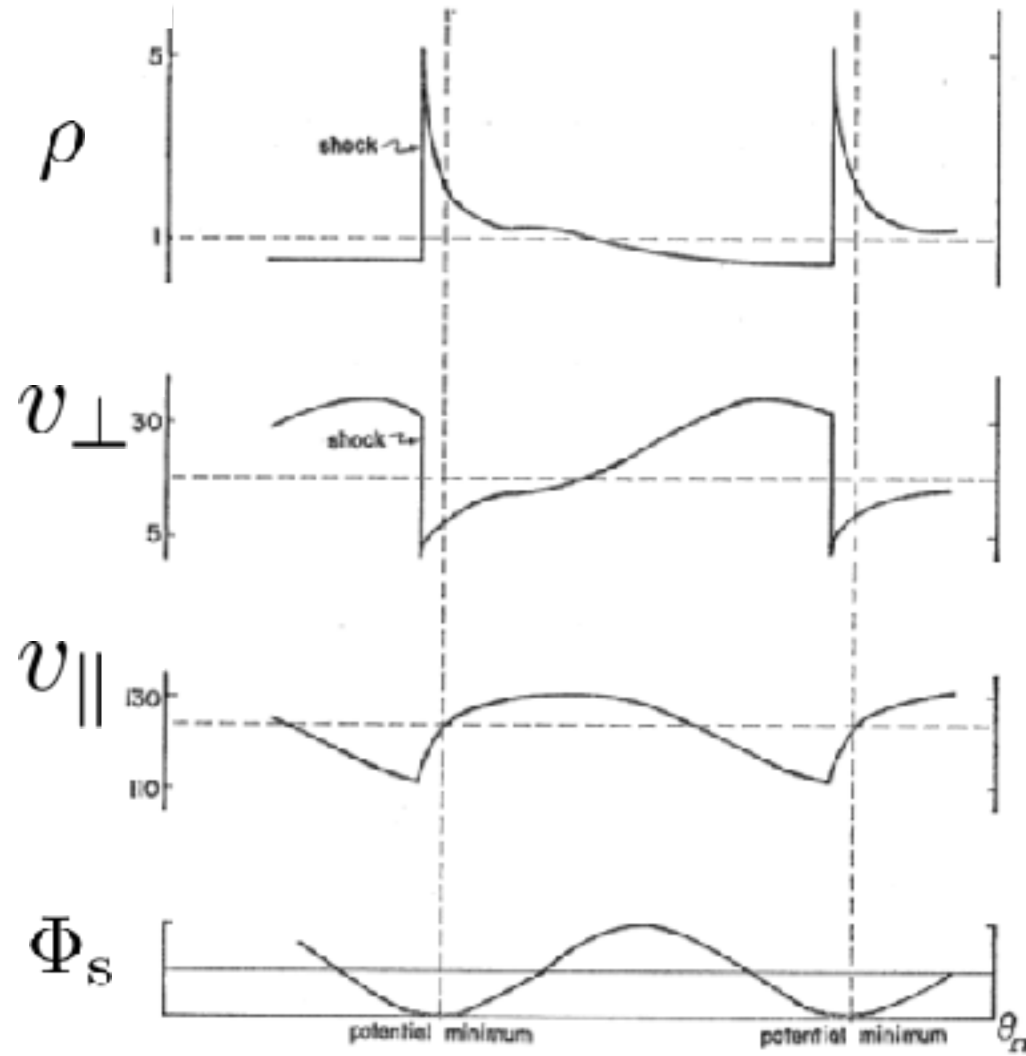
- **Stationary spiral shocks** can result as gas response to externally imposed spiral potential
- **No self-gravity**
- **Isothermal gas**



Coordinate perpendicular to spiral arm

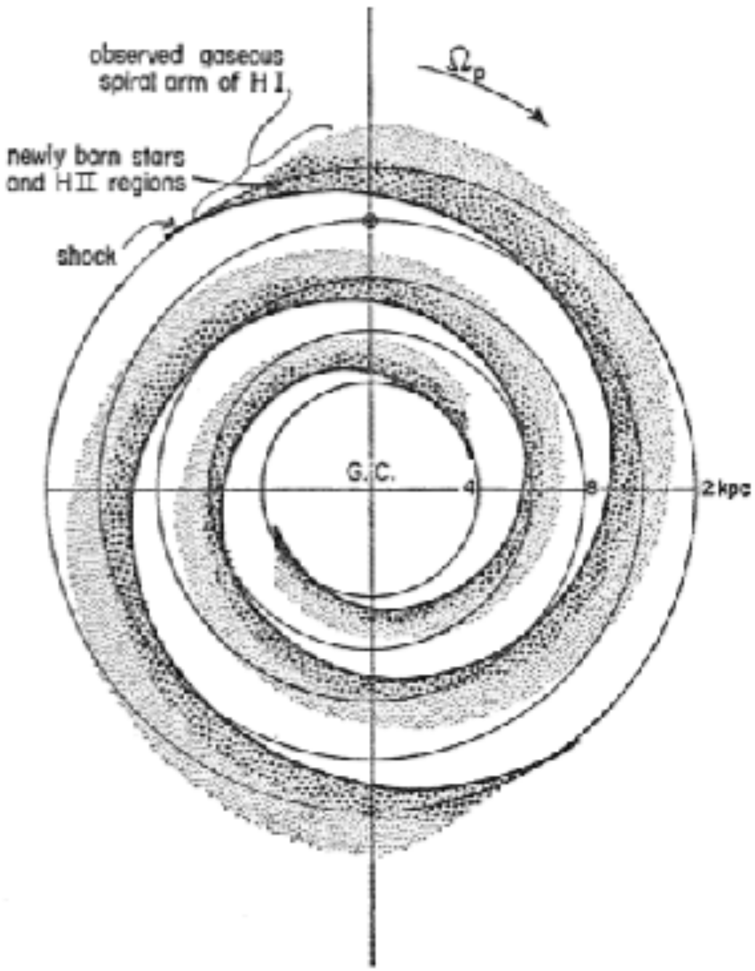
Roberts1969

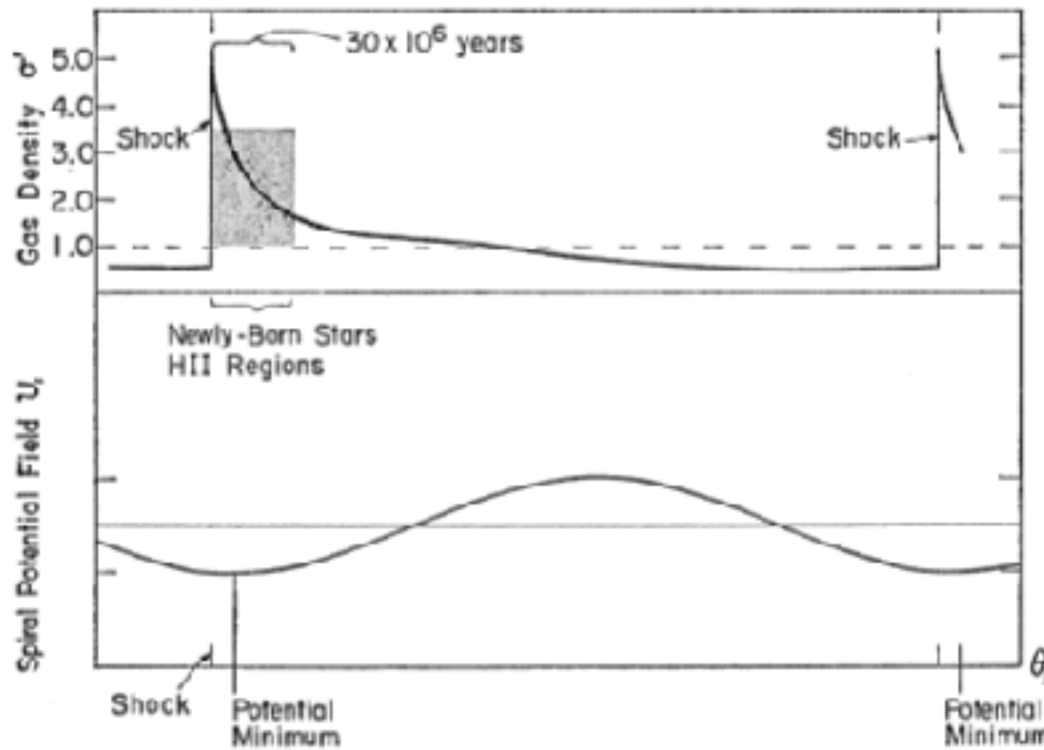




Coordinate perpendicular to spiral arm

Implications for star formation

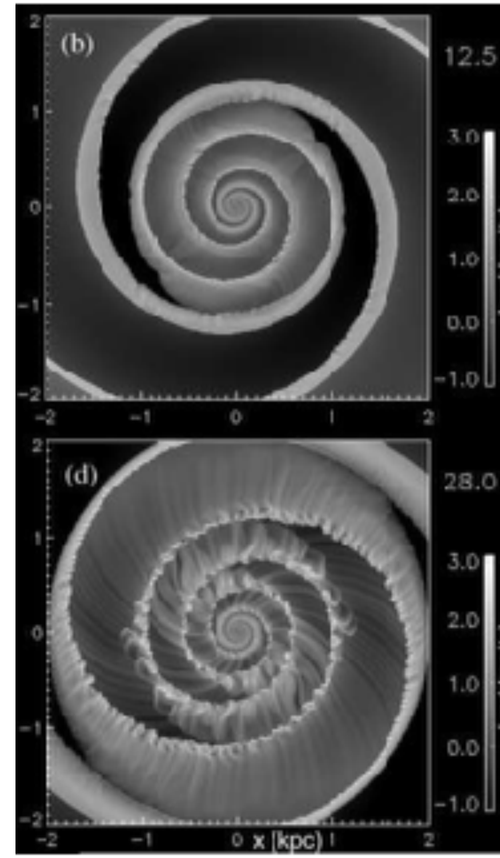




Coordinate perpendicular to spiral arm

Are these shocks stable?

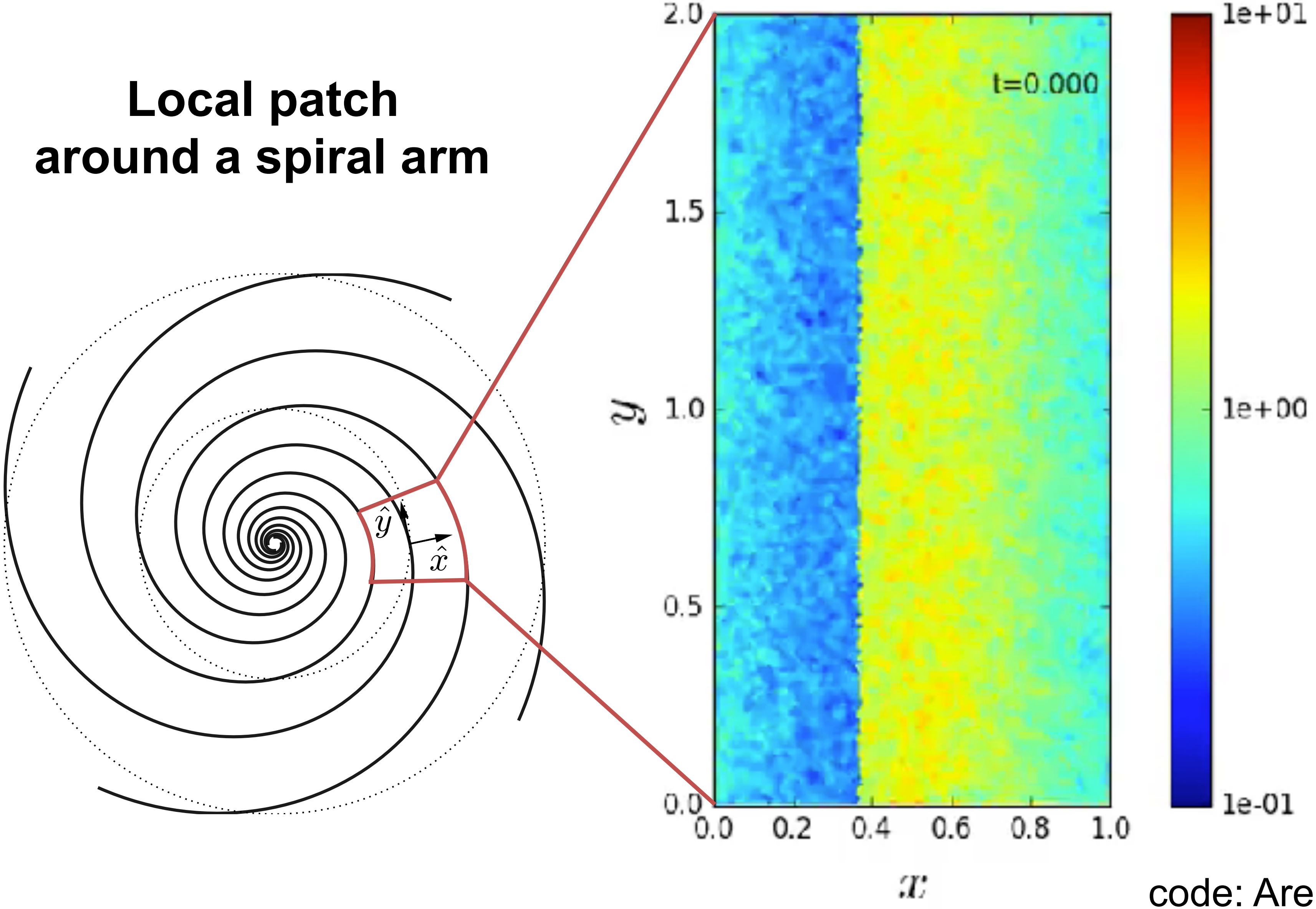
- **Shocks are usually stable** against corrugation of surface **(**D’yakov&Kontorovich classic result)
- Hence, people argued if instabilities are present is because:
  - **self-gravity** (because of high compression at shocks)
  - **shear** in the post-shock region.
- **70s, 80s, 90s**: several papers find **no evidence of instability.** Topic was thought to be dead…until
- **2000s**: Wada&Koda2004 revitalise the question. They run isothermal, 2D, non-self gravitating simulations and find “**wiggle instability**”. Interpret as KH. Some say is numerical artefact.
- **2010s:** New studies appear and **this time they find shocks to be unstable**.
(e.g. Lee&Shu2012, KimKimKim2014)



1. **Contradictory results**: new&old papers study the same problem but obtain different results! Why?? Who is right?
2. **Is it just Kelvin-Helmholtz as some say (e.g. review by Shu2016) or is there more?**

Zoom

Local patch around a spiral arm

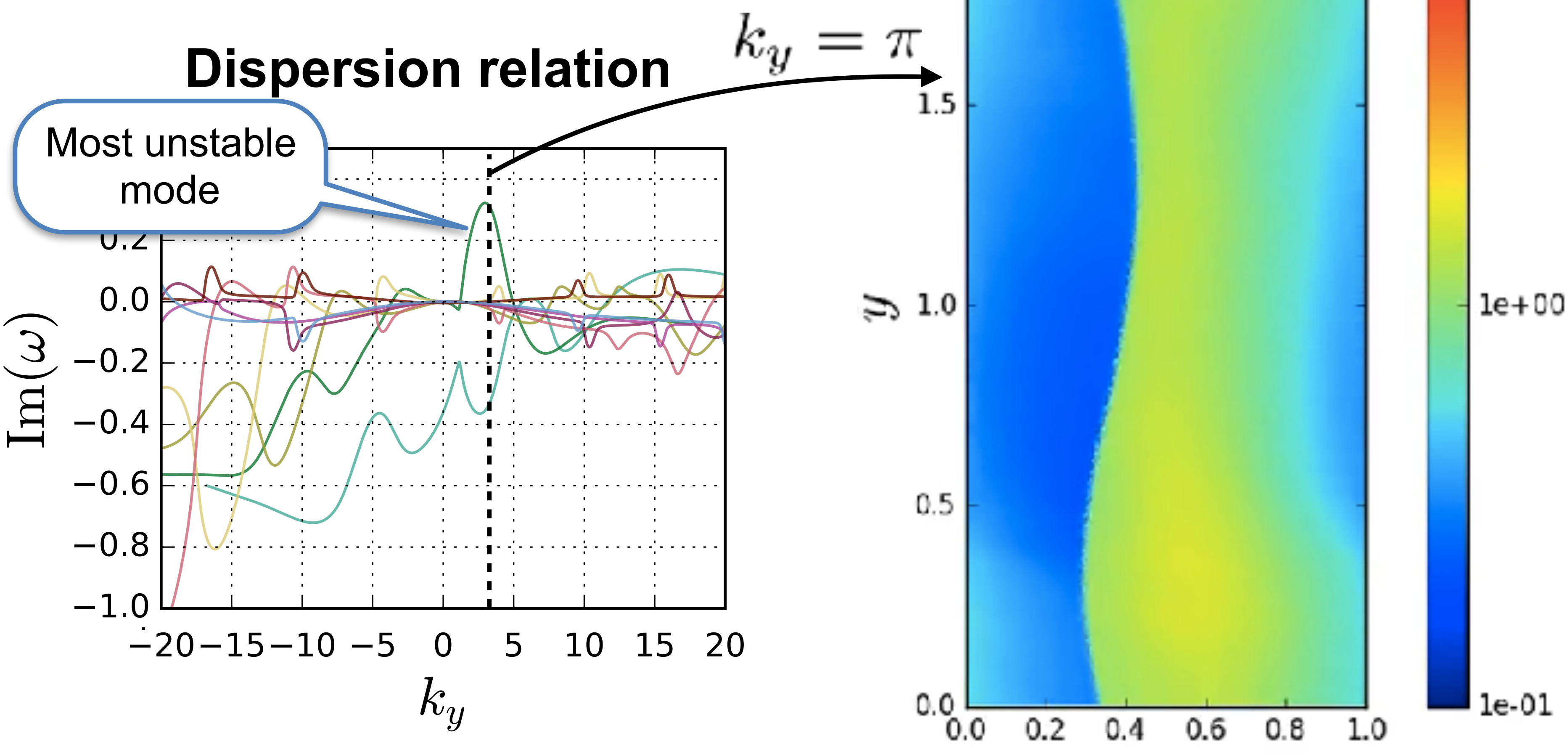


code: Arepo

Confirmed by linear analysis

$$\rho = \rho_0(x) + \rho_1(x)\exp(ik_y y - i\omega t)$$

$$\mathbf{v} = \mathbf{v}_0(x) + \mathbf{v}_1(x)\exp(ik_y y - i\omega t)$$



Assumptions: 2D, isothermal

Physical interpretation

- In D’yakov-Kontorovich analysis in which the upstream flow is left unperturbed, the shock is stable but can oscillate and emit small waves at some **characteristic frequencies**.
- However, if in the DK problem one sends **incident waves from upstream towards the shock**, these can be greatly amplified or even blow everything up if sent with the proper frequencies of the system.
- What happens if spontaneously emitted waves are somehow allowed to re-enter the shock from upstream? This is what happens with periodic boundary conditions. The shock can **``resonate with itself”**

Conclusions

- **Stability depends on boundary conditions.** This explains apparently contradictory results
- **Galactic shocks are always unstable** because they are essentially periodic
- **The periodic shock instability is distinct from KH** otherwise it would not disappear by switching boundary conditions
- Relevant for **feathering/spurs of spiral arms.** (e.g. M51) and **Galactic centre bar shocks**
- For strong spiral potentials a **parasitic KH** can also be present on top of the periodic shock instability

Thank You!

Extra

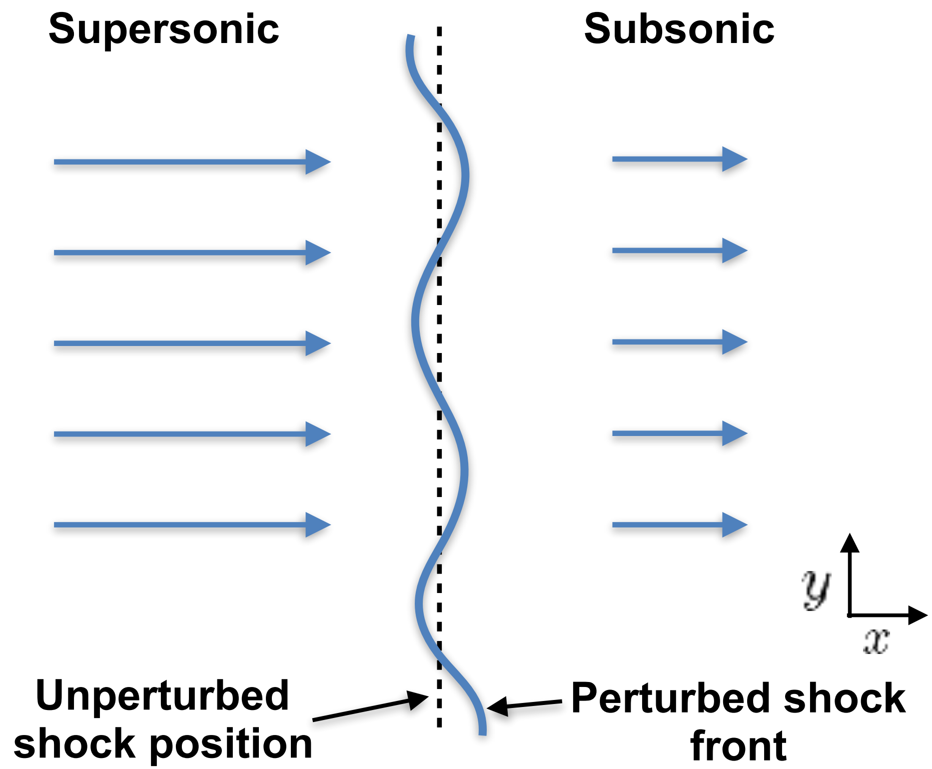
Linearise around steady state and find eigenmodes

$$\rho = \rho_0(x) + \rho_1(x)\exp(ik_y y - i\omega t)$$

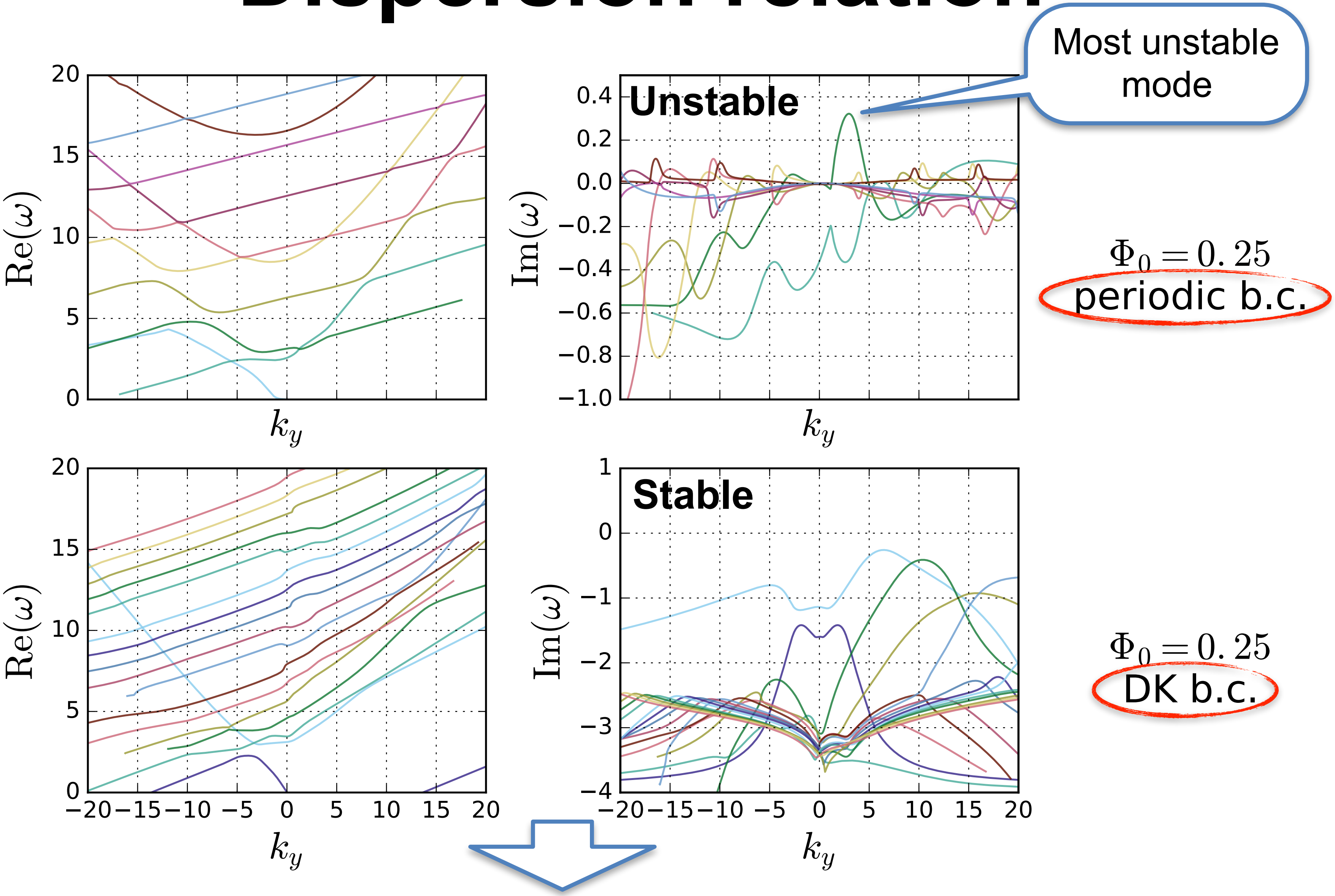
$$\mathbf{v} = \mathbf{v}_0(x) + \mathbf{v}_1(x)\exp(ik_y y - i\omega t)$$

Two types of boundary conditions

1. **Periodic**
2. **D'yakov-Kontorovich** (upstream flow unperturbed because supersonic)



Dispersion relation



Changing boundary conditions can make the instability disappear!