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Armed and/or dangerous?

Galactic spiral generation in tidal encounters

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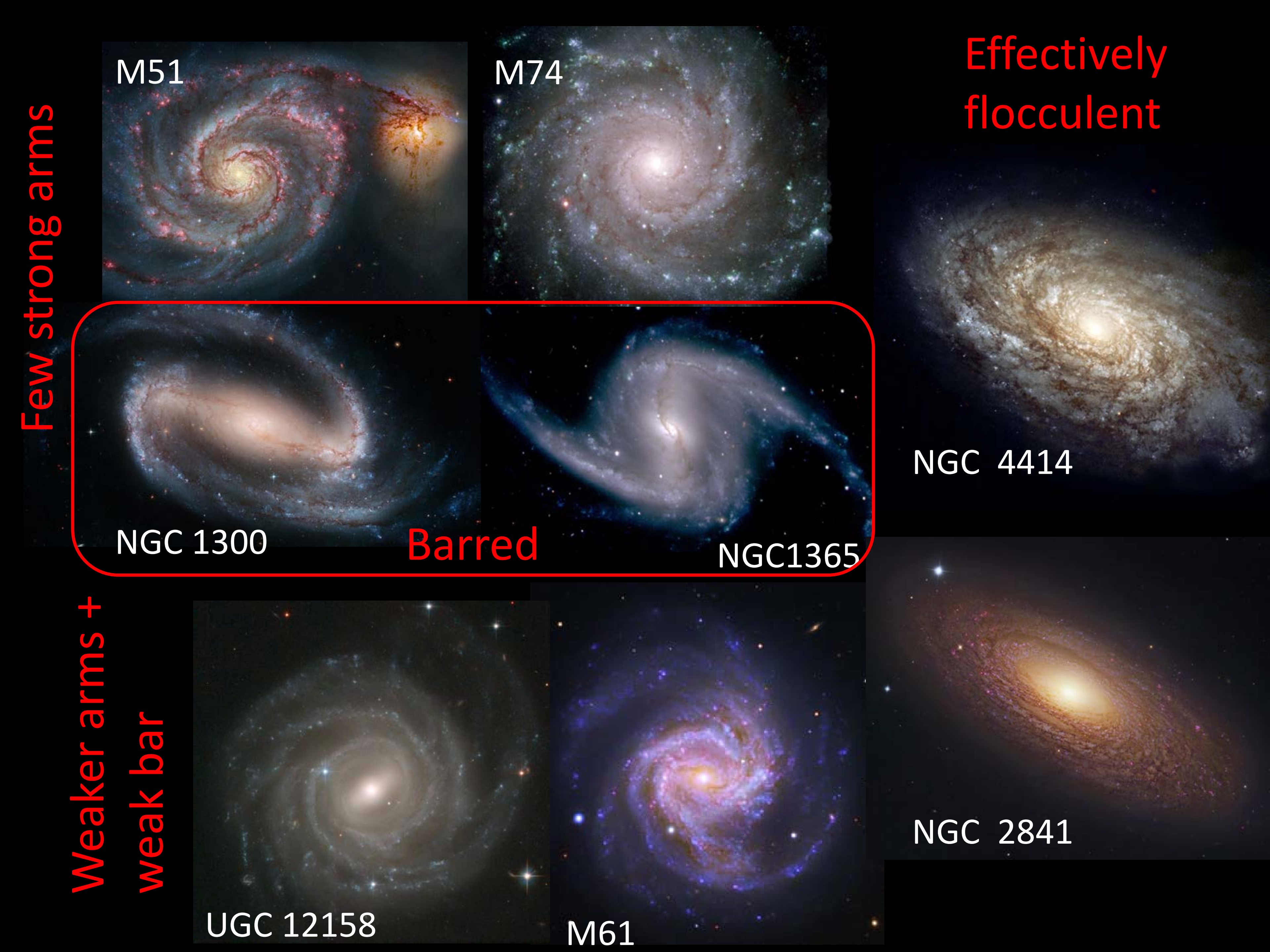


Effectively flocculent
Few strong arms
M51
M74
NGC 4414
NGC 1300
Barred
NGC1365
Weaker arms + weak bar
UGC 12158
M61
NGC 2841

Galactic Arm Features

- What is the driving force behind this ensemble of arm features?

- The “Winding problem” complicates matters: spiral arms are common in disc galaxies but flat rotation curves should wind up any patterns in the disc.

  -> Need some mechanism to drive spiral arms that overcomes differential rotation…

Galactic Arm Features

Spiral density wave theory

+: Can create many different morphologies

- : Weak direct evidence (num. or obs)

Transient and recurrent gravitational instabilities

+: Easily made in simulations

- : Isolated N=2 cases are hard to maintain

Bar driven spiral arms

+: Best way of maintaining N=2

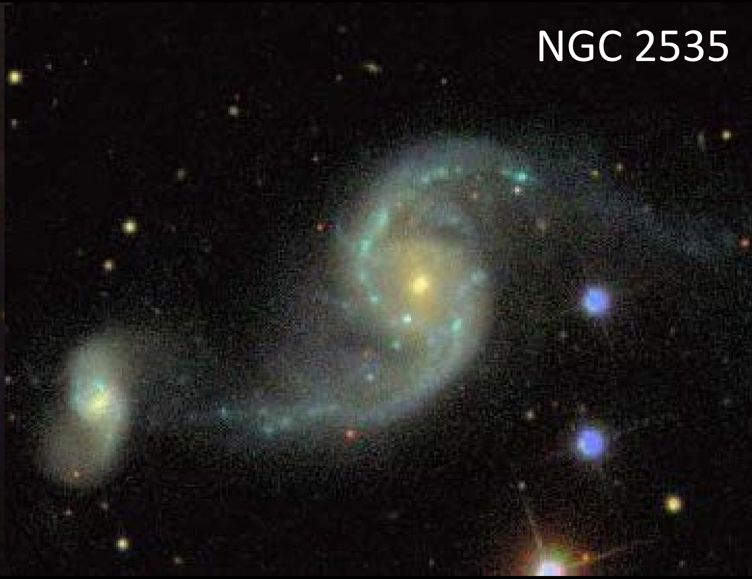
- : Not all N=2 galaxies are barred!

Companion driven arms/bridges/tails

+: Can create bar-free N=2

- : Maintainable? Sufficiently frequent strong cases?

Perturbed Arm Features



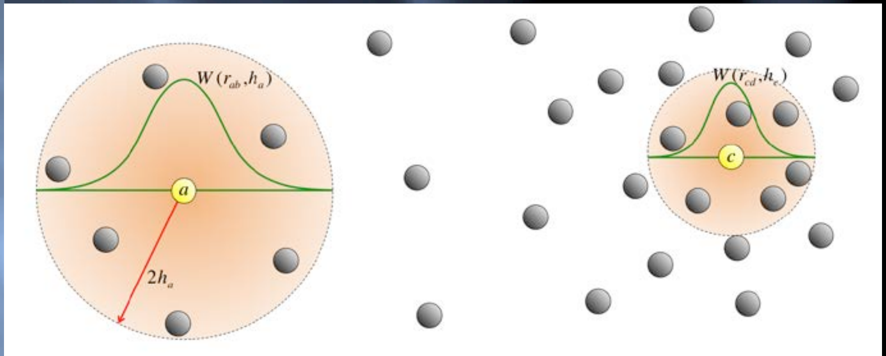
- Ok, why do we care?
  - The best way of making *N*=2 spirals that are unbarred.
  - Can generate "weird" galaxies.
- Also influences bars, rings and tails/bridges.

Perturbed Arm Features

- See what kind of structures are induced by perturbing bodies.
- How arm morphology depends on perturber mass, impact parameter etc.
- How the arm structure differs compared to the isolated case?
- What is the limiting case, beyond which the disc is "on it's own".

Simulations: SPH

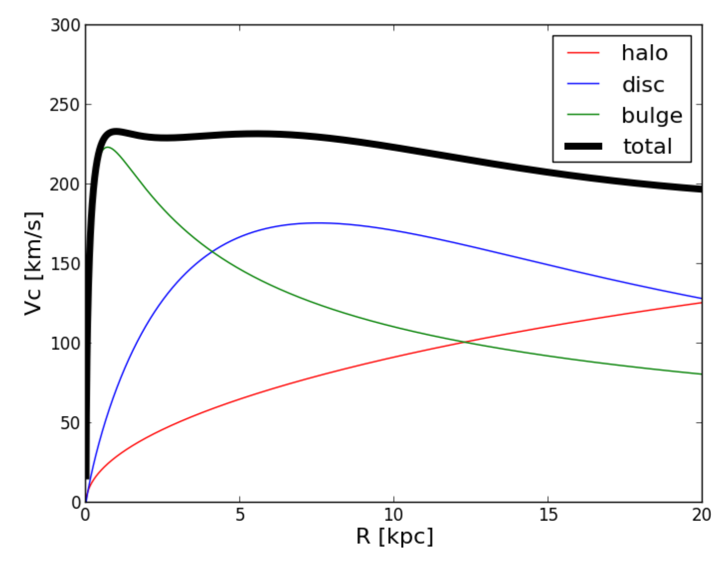
- Evolution of gas is simulated using SPH (GASOLINE; Wadsley 2013).
- Fluid discretized into packets.
- Gas is isothermal (10,000K), for now…

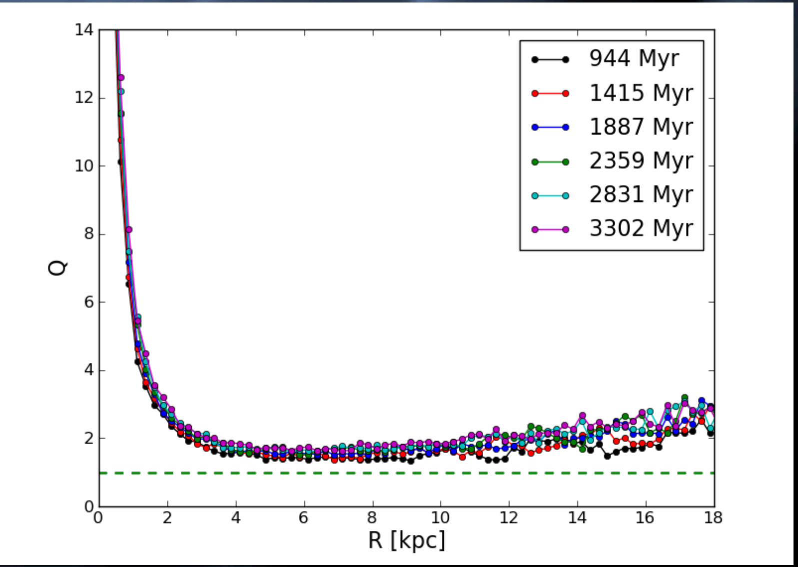


- Focus on disc galaxies with a moderate gas content (10% stellar mass).
- System includes *N*-body stars (disc+bulge), live halo, gas disc and point mass companion.

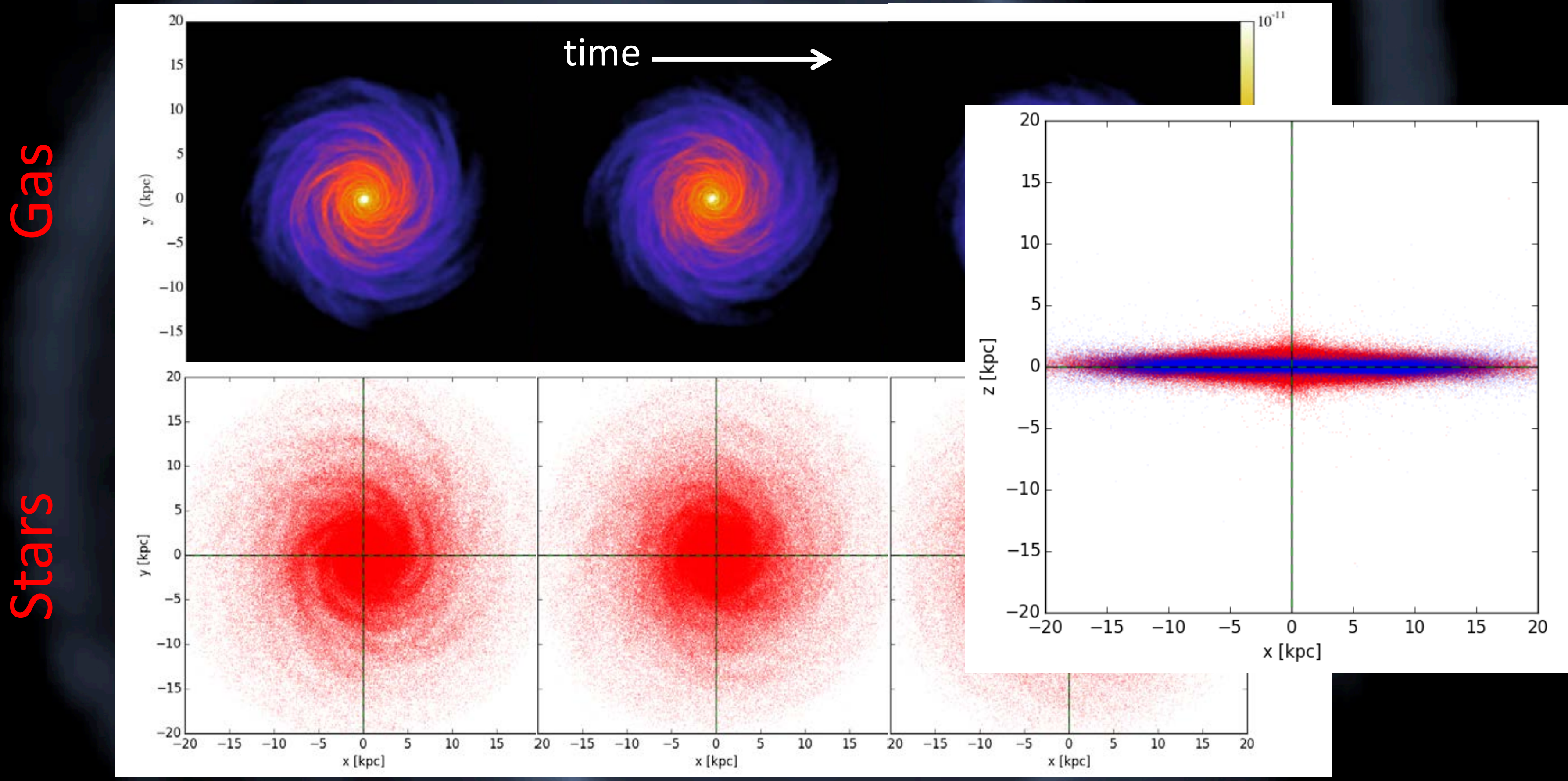
The Isolated Galaxy

- Galaxy components (bulge, disc, halo) tailored to create a standard Milky Way-like galaxy with flat rotation.
- Halo and stellar disc mass ratio determines magnitude of “swing amplification” which determines arm number.
- Bulge adds a “Q-barrier” resisting bar formation.





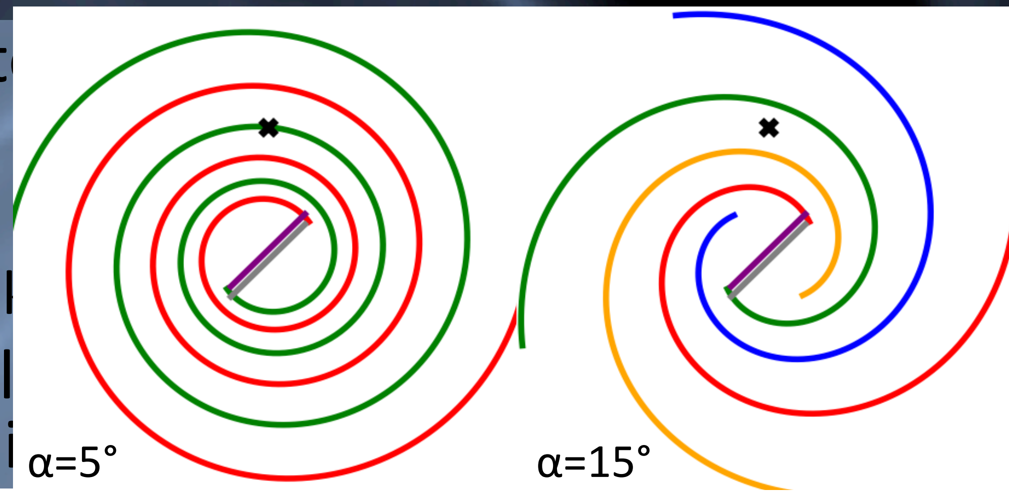
The Isolated Galaxy

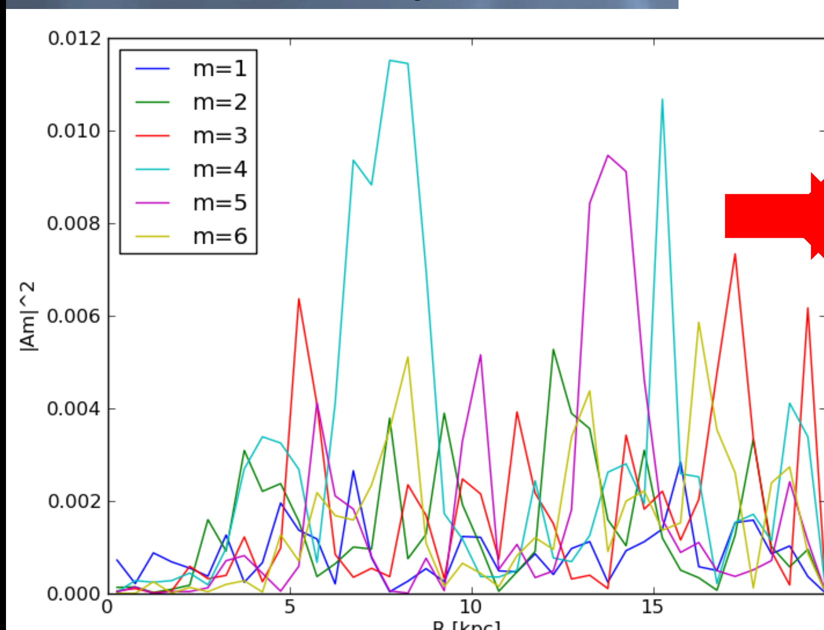


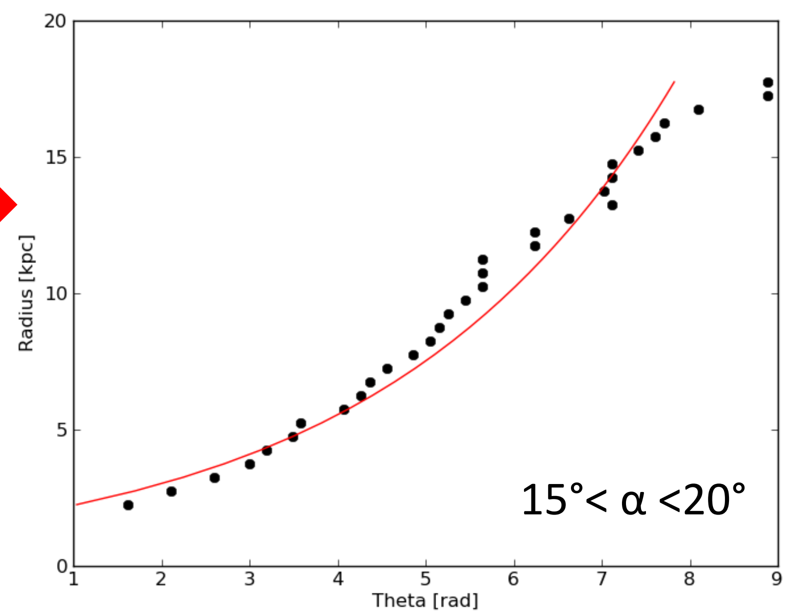
- The galaxy evolved in isolation, many smaller arms formed.
- Galaxy is effectively flocculent after 1Gyr ($Q_s \approx 2$).

The Isolated Galaxy

- Interesting paramet
  - Arm number, *N*
  - Pitch angle, α
  - Pattern speed, Ω_p [k
- Rather than simply l numerically determi







The Perturbed Model

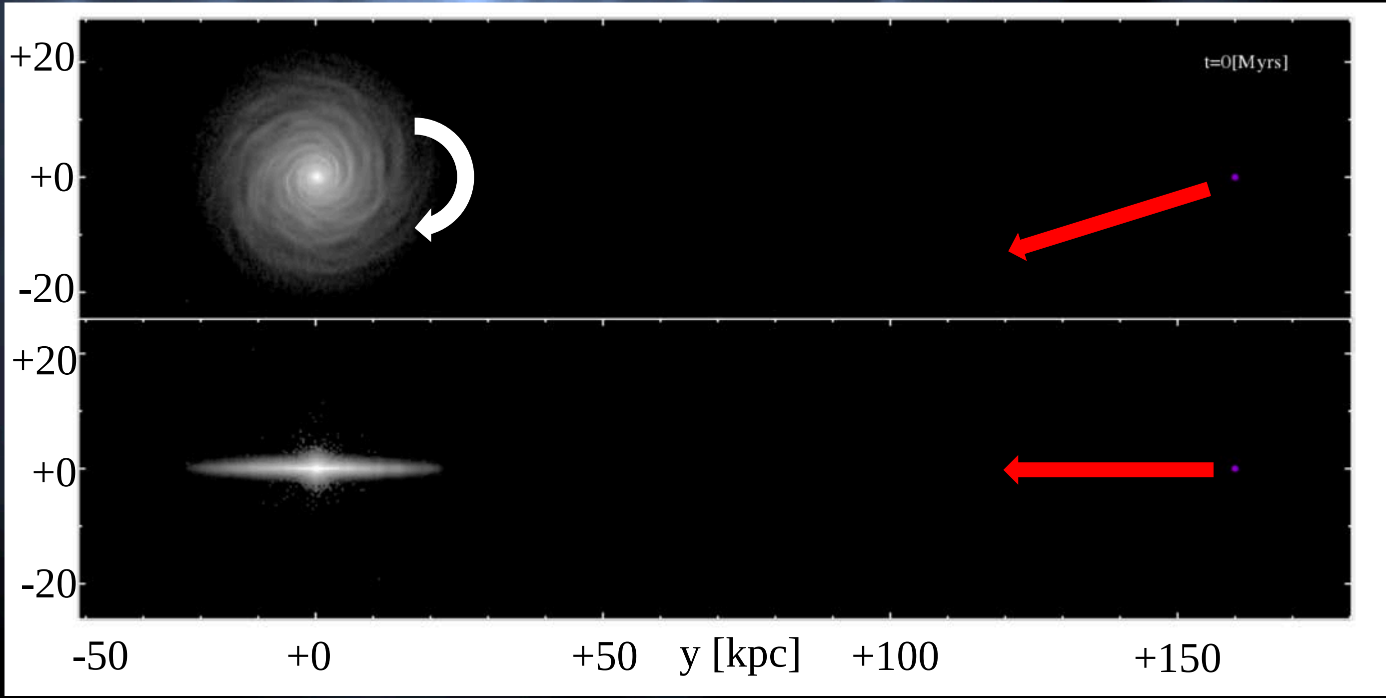
- Model the perturbing companion as a point mass for simplicity, though tests with resolved dwarfs show little difference.
- Allow for 500Myr of pre-evolution (though still 1Gyr until interaction).

V_p= 50km/s

M_p= 2x10^{10} $M_{\circ}$

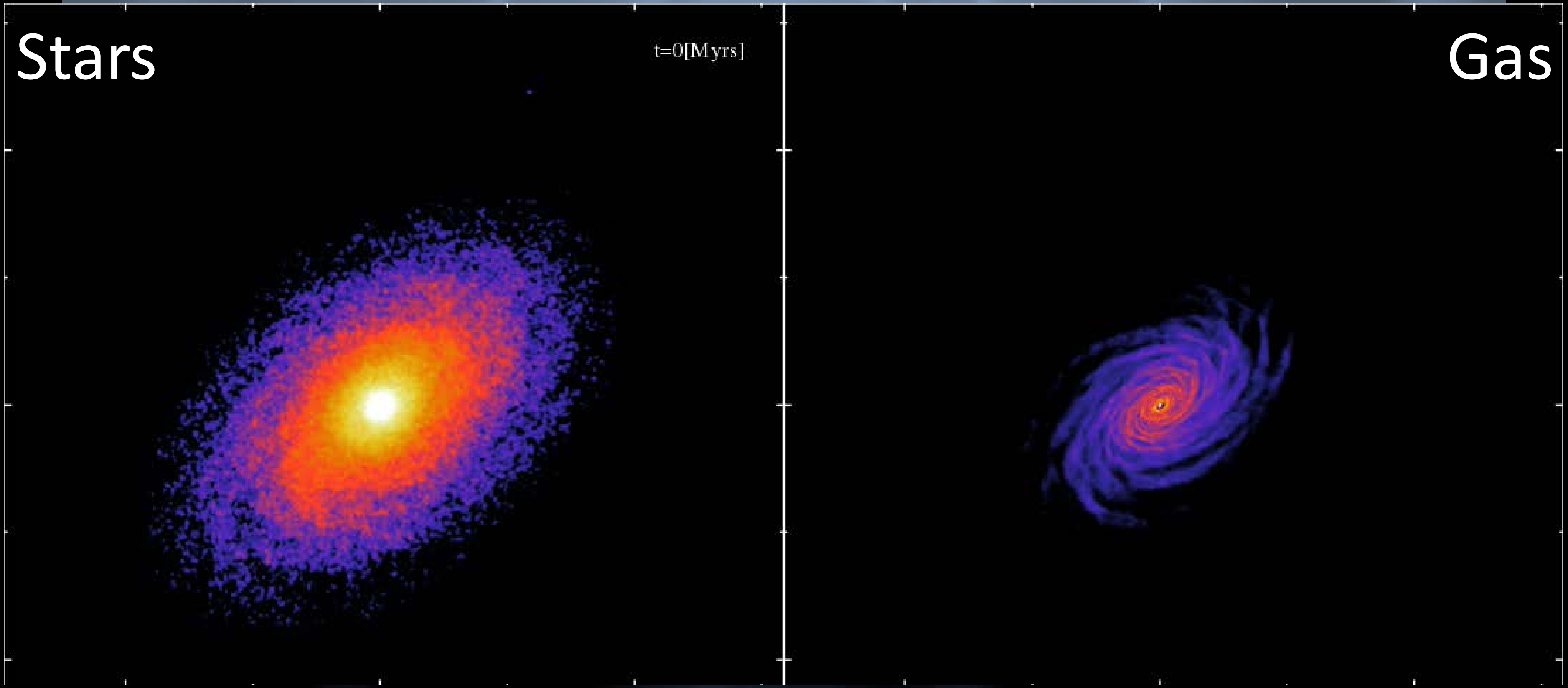
(0.3 M_d)

a_p= 40kpc



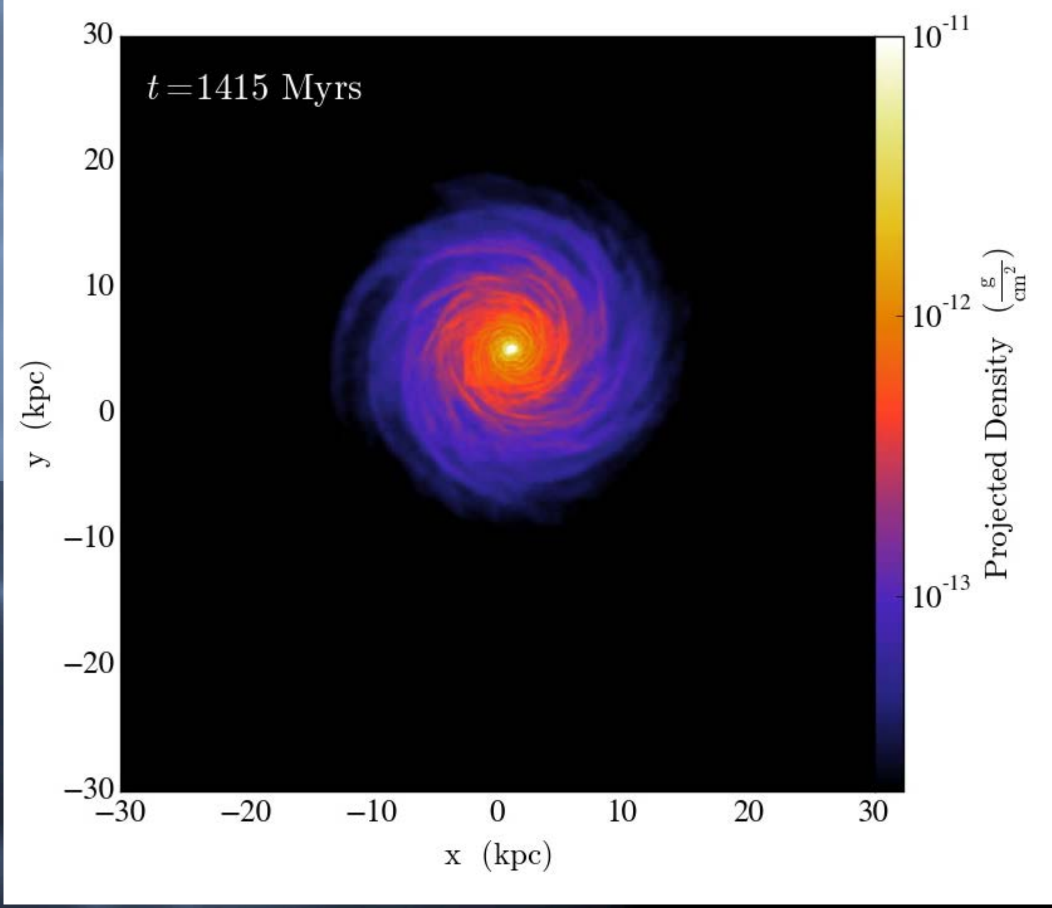
The Perturbed Model

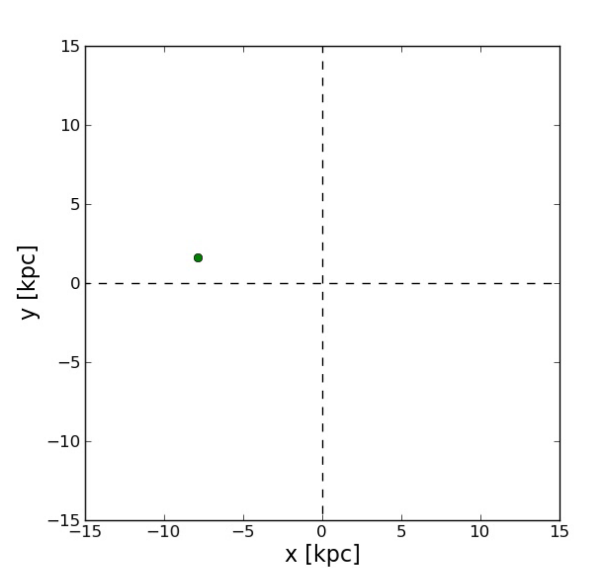
- Low resolution movie of our main model, showing evolution of stars and gas. The companion comes from top-right.



Fiducial Model

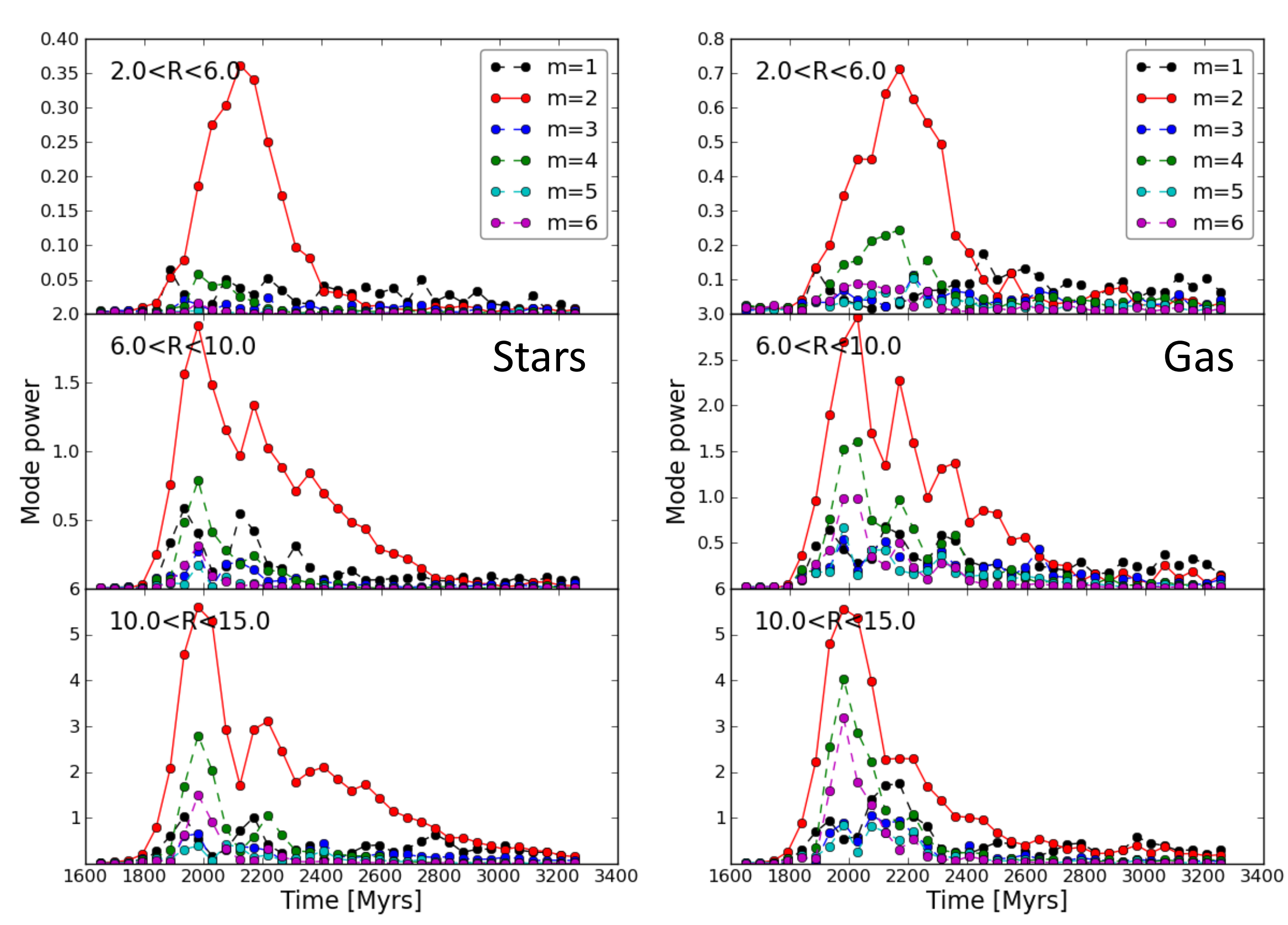
- Fiducial model shows initial strong perturbation.
- Lower amplitude spiral arms then persist for multiple galactic rotations.





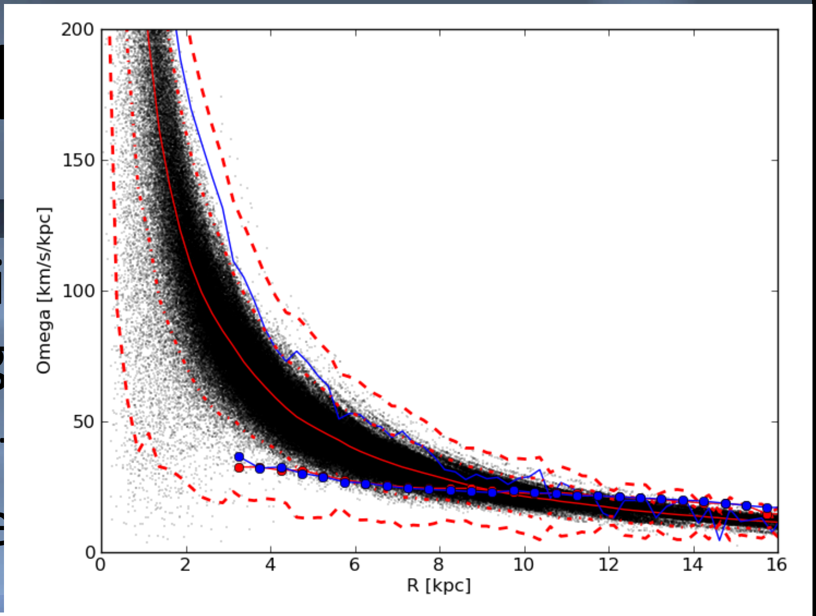
Fiducial Model

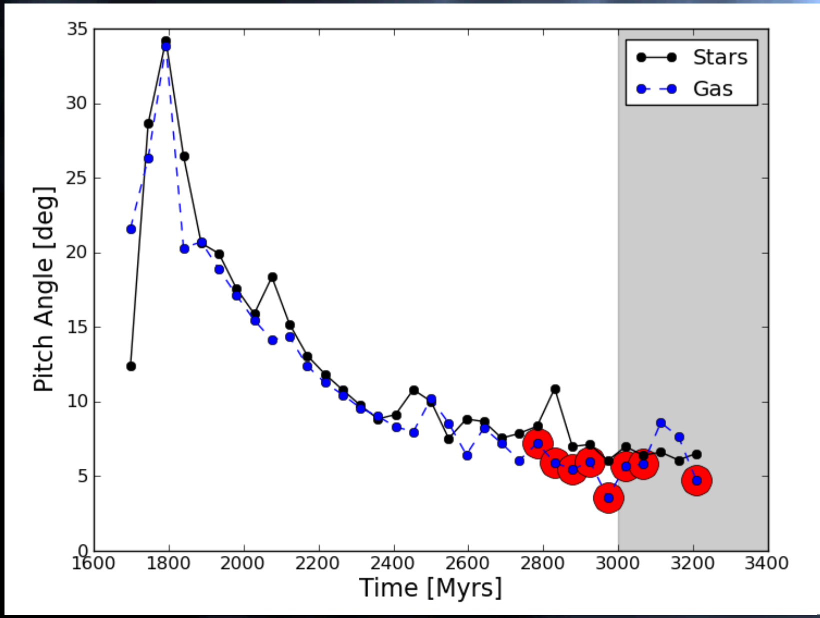
- Fourier mode analysis as a function of time.
- A clear *N*=2 mode that decays on the order of a Gyr.
- N=1 and N=4 mode also show have power.

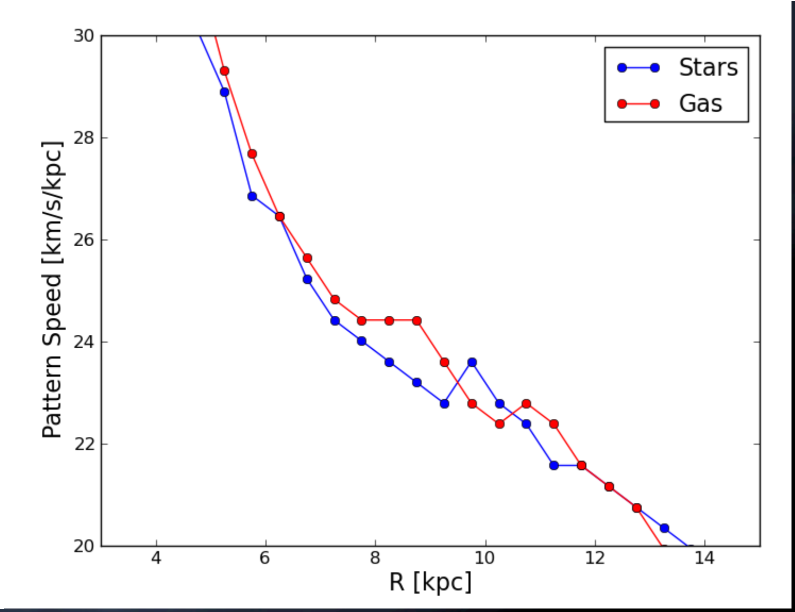


Fiducial I

- Measured pitch angle (log-spi
over time, due to the winding
- Pattern speed also not a cons
However, not quite material e



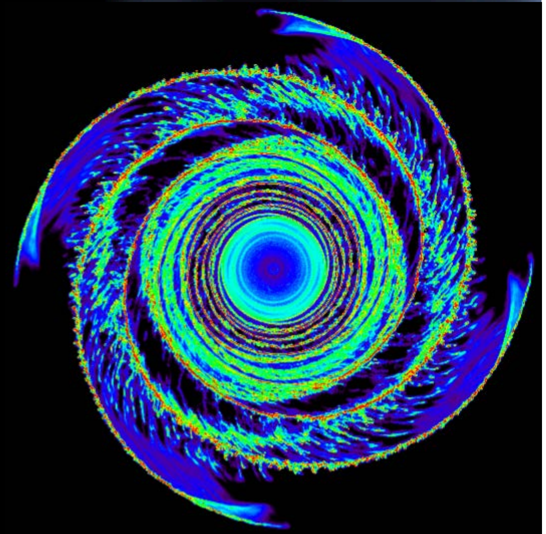




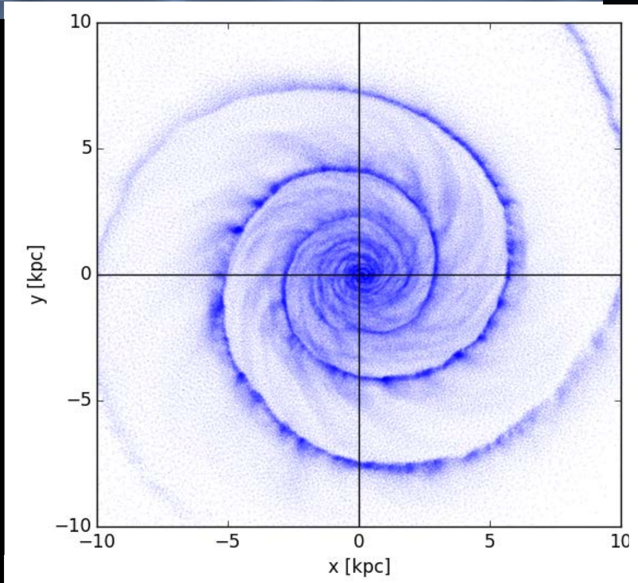
spiral arms tend have 5°<α<30° in external galaxies e.g. Kennicutt 1981

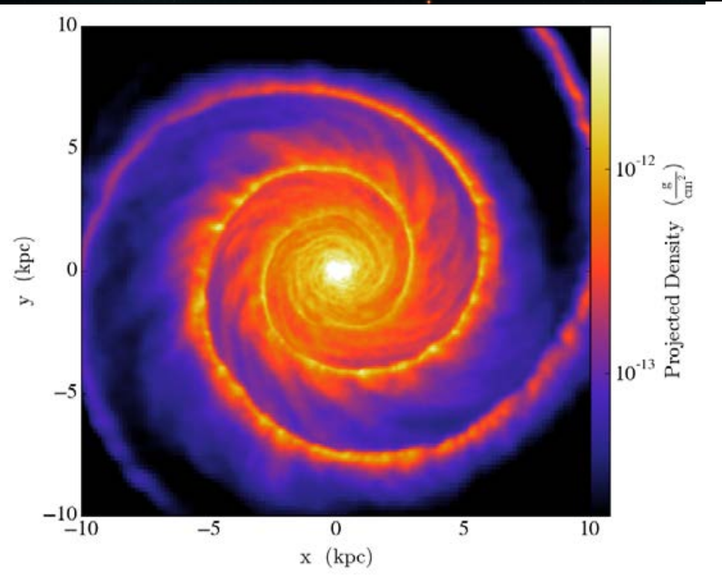
Feathers and Spurs

- Spurs and feathers are features seen in grand design spirals.
- Sites of star formation and GMC's.
- Seen if our calculations too, if resolution and interaction is sufficient.



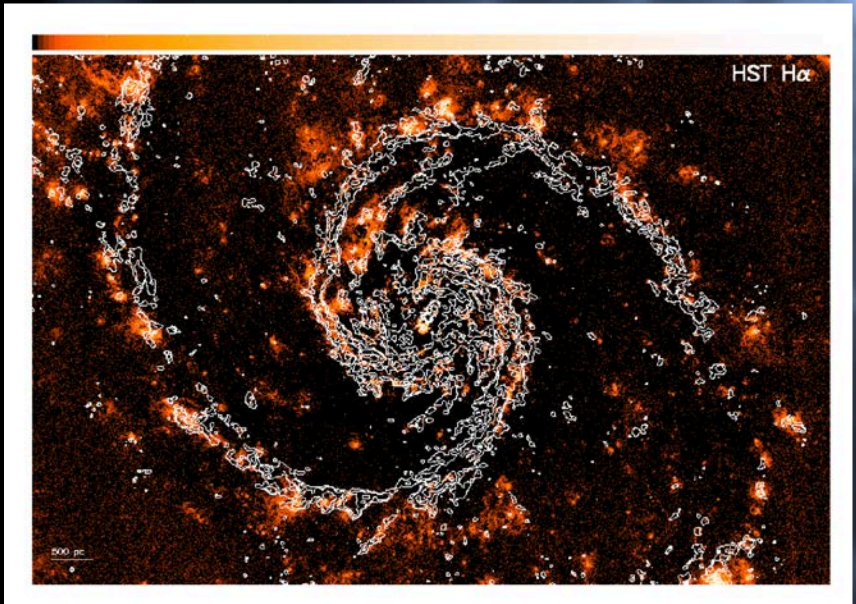
Cold gas in fixed potential



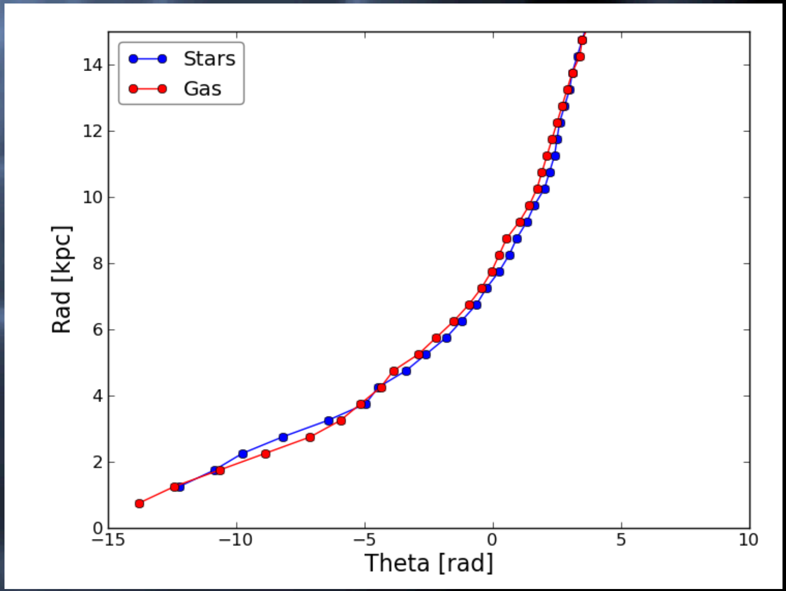


Arm-Bar offset?

- It is seen in some external galaxies that the separate components of spiral arms may be offset from each other (GMC's, star formation, OB stars etc).
- This is seen in M51, where the gas and stellar population are not coincident in the spiral arms.



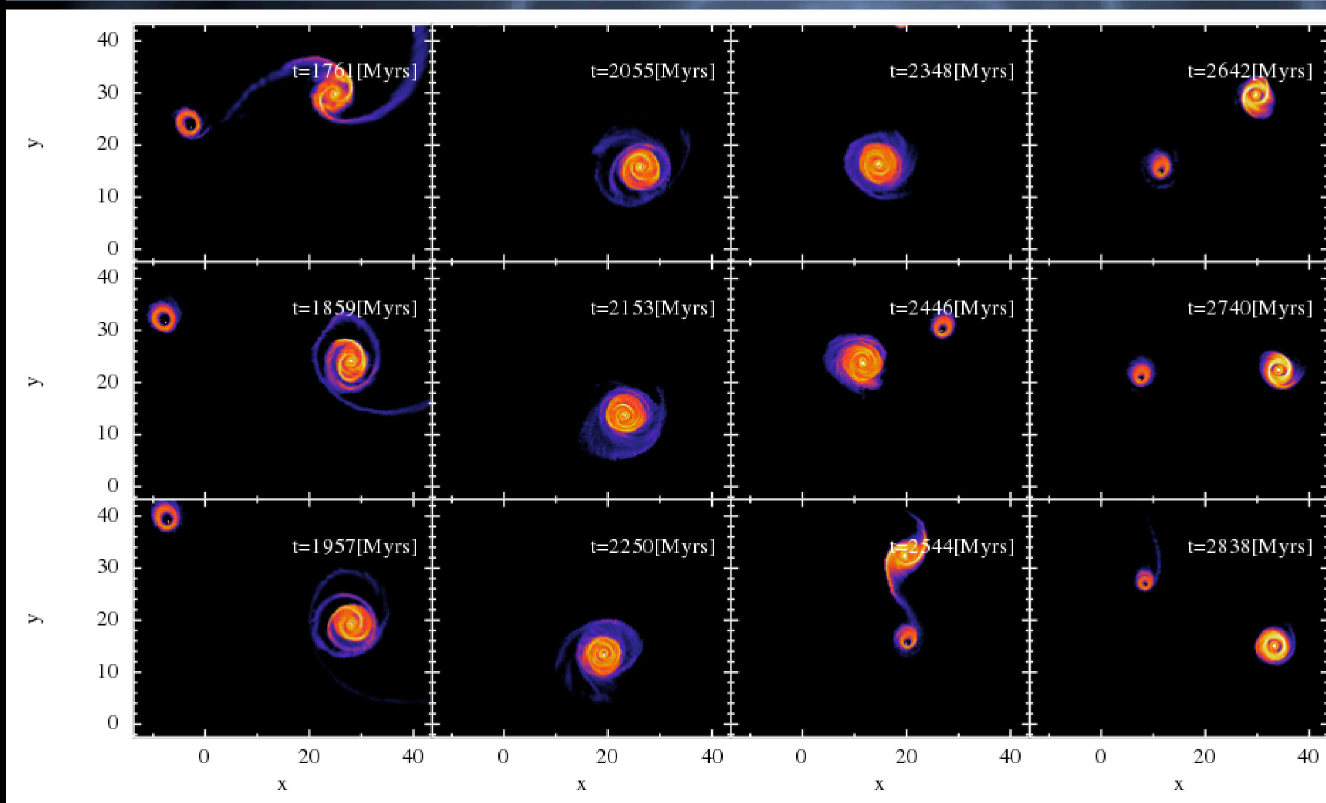
H-alpha in M51 (CO contours)
Schinnerer et al. (2013)

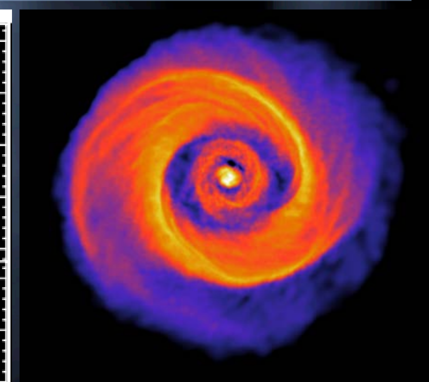


See a very marginal offset between stars and gas.

Variation by mass: heavy

- High mass companion, now $0.6M_d$. Much stronger and the interaction tends to be highly destructive.
- Companion strongly bound, so now comes in for second strong interaction.

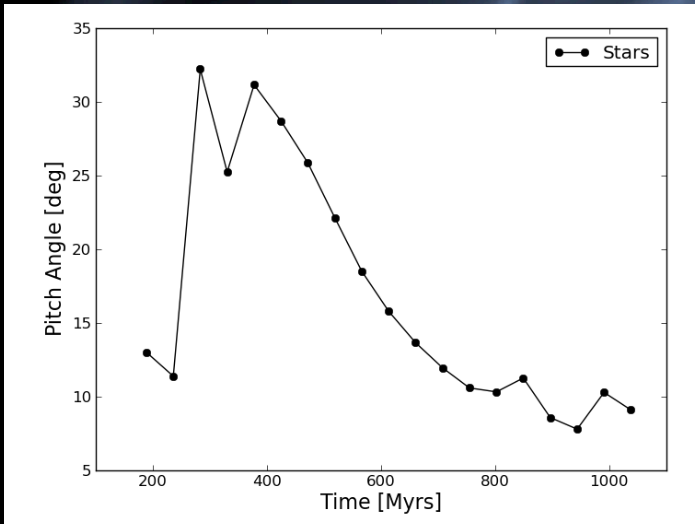


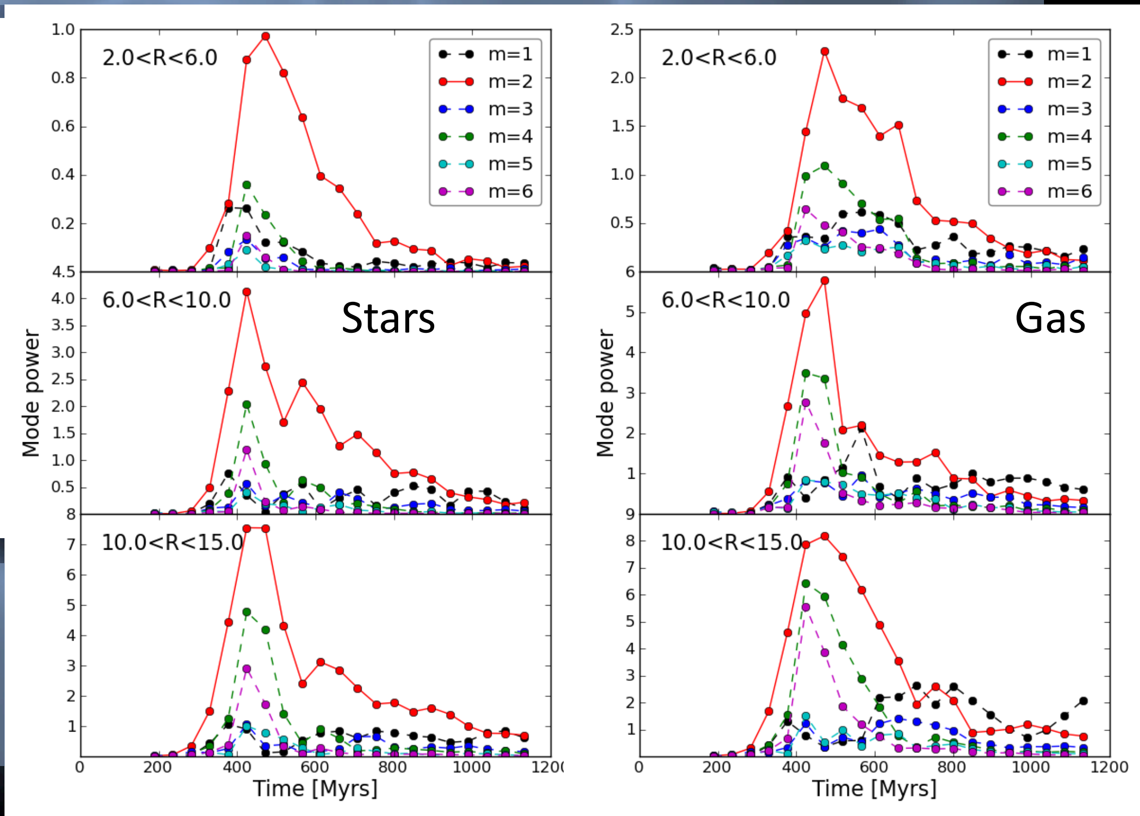



NGC 5701

Variation by mass: heavy

- Overall mode power very similar to the normal model.
- The main difference is that the *N*=1 mode is much stronger in the gas

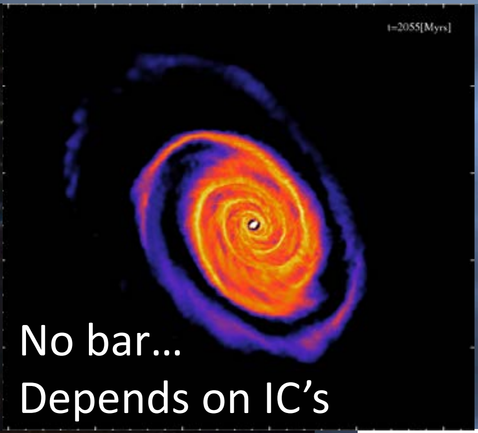


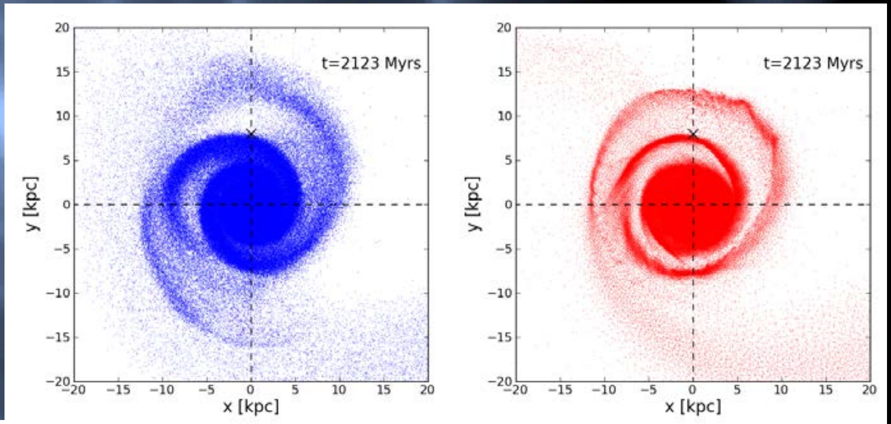


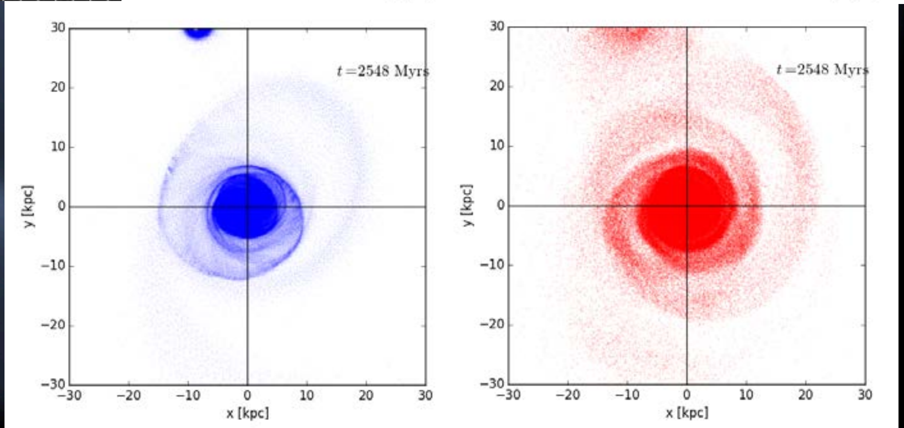
- No strong change in pitch angles either.

Variation by mass: heavy

- The higher mass interaction (0.6Md) induces some more exotic arms structures.
- Can drive rings, and *N*=1 arm structures, but these features are very short lived in comparison to the *N*=2 features.

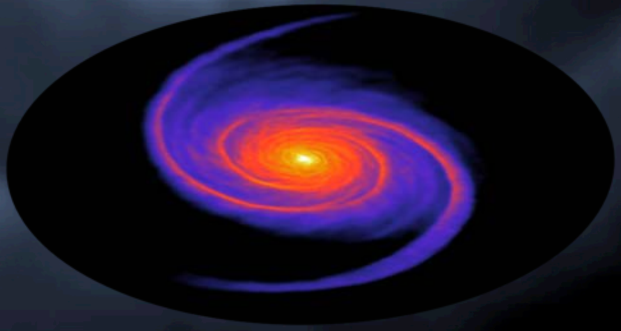


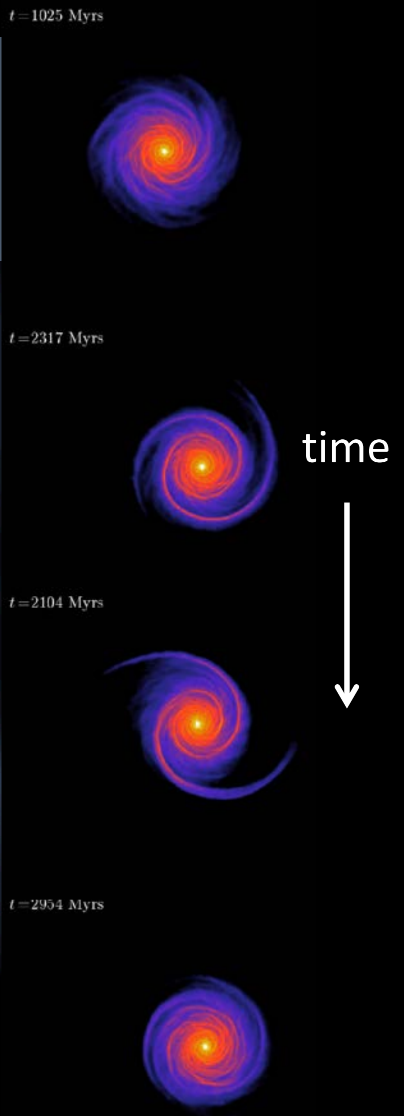




Variation by mass: light

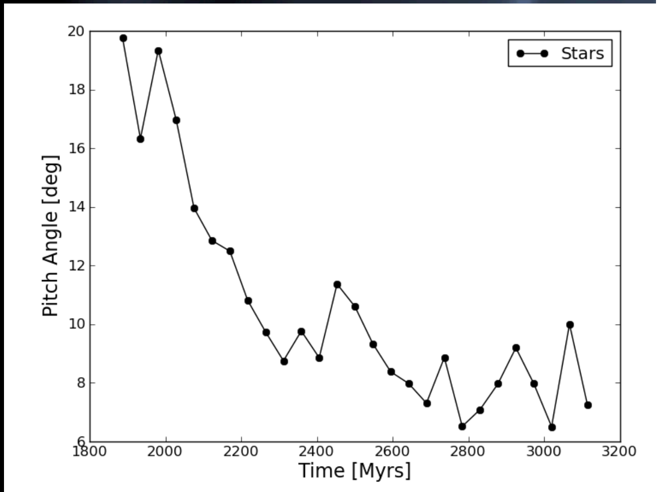
- Aim to investigate the lowest mass needed to induce spiral structure in the disc.
- As the mass is lowered the N=2 response becomes weaker in the inner disc.
- This leaves a featureless inner disc with an outer 2-armed structure.

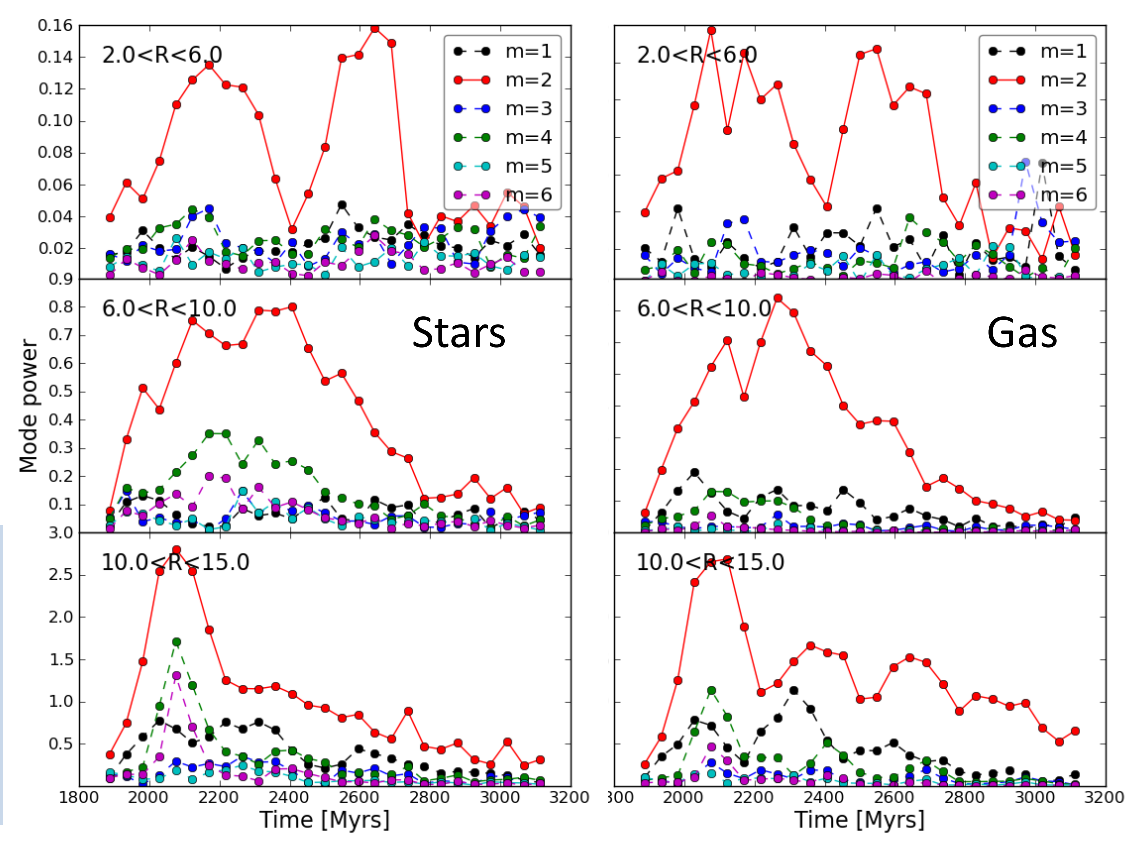




Variation by mass: light

- For a lighter perturber the power of the *N*=2 mode is much weaker, though still dominant.

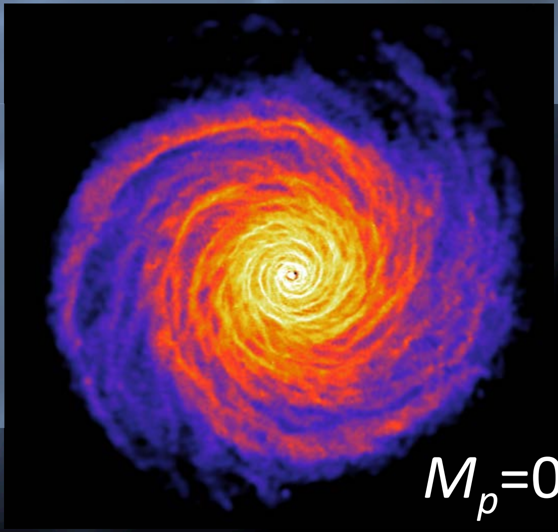




- The driven pitch angle of the N=2 mode has a much lower maximum.

Variation by mass: limiting case

- If very low mass, pass through disc (is captured) or must move very fast, then the effect id barely felt (impulse is so small)
- The limiting mass case for a grazing orbit is around 0.125 our fiducial value, i.e. 0.04Md. Though these arms are extremely transient and confined to the outer disc.
- This is well within the range of the Milky Way's LMC, which is roughly 0.2Md.



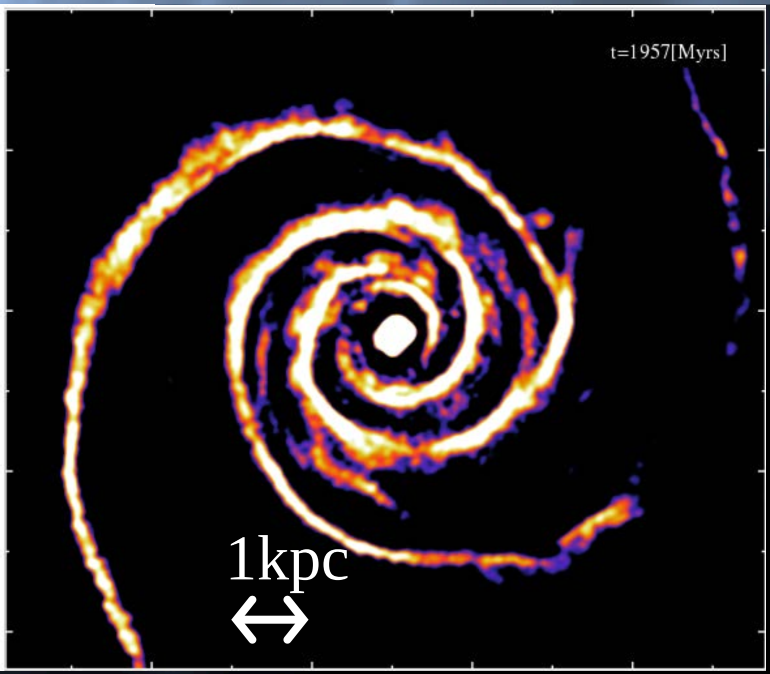
M_p=0.08M_d

Variation by orbit

- While the mass and velocity/periastron passage determine the host morphology, the inclination appears to have less of an impact (providing orbit is still grazing).
- Matching specific galaxies exactly likely requires a case-by-case orbital configuration (e.g. M51).

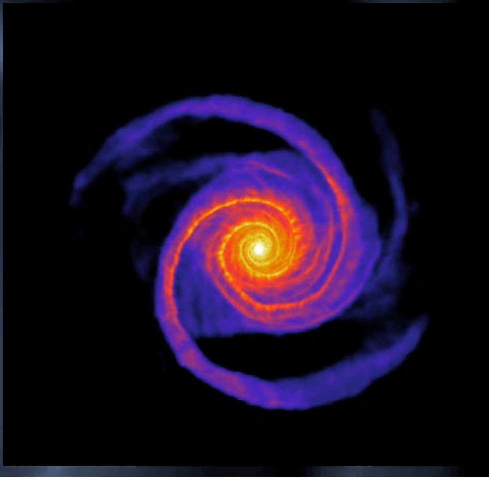
Heavy isolated galaxy as host?

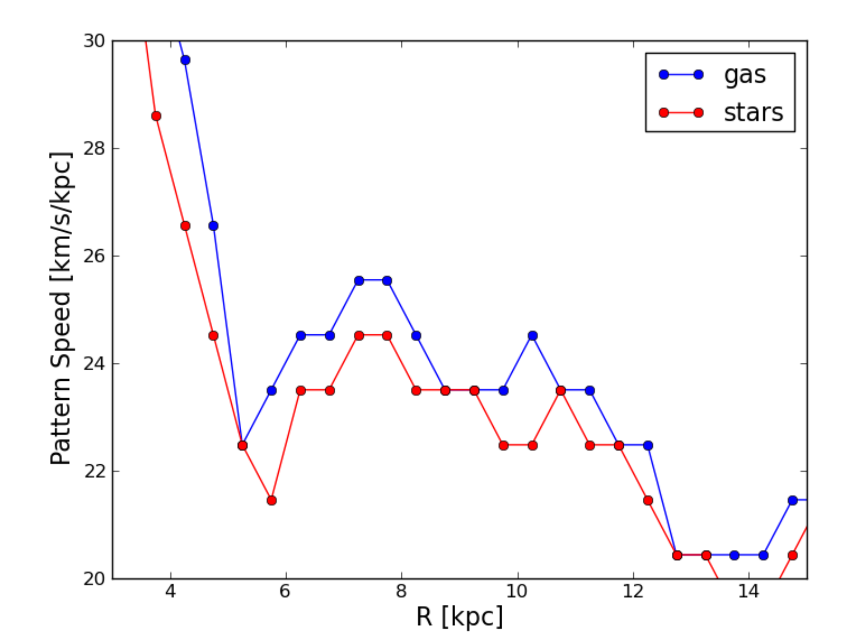
- We have so far showed results from using a relatively low mass stellar disc. Instead try with a higher mass disc.
- Inherent arm modes are drowned out, while morphology is very similar to low mass case, the spirals are more pronounced…

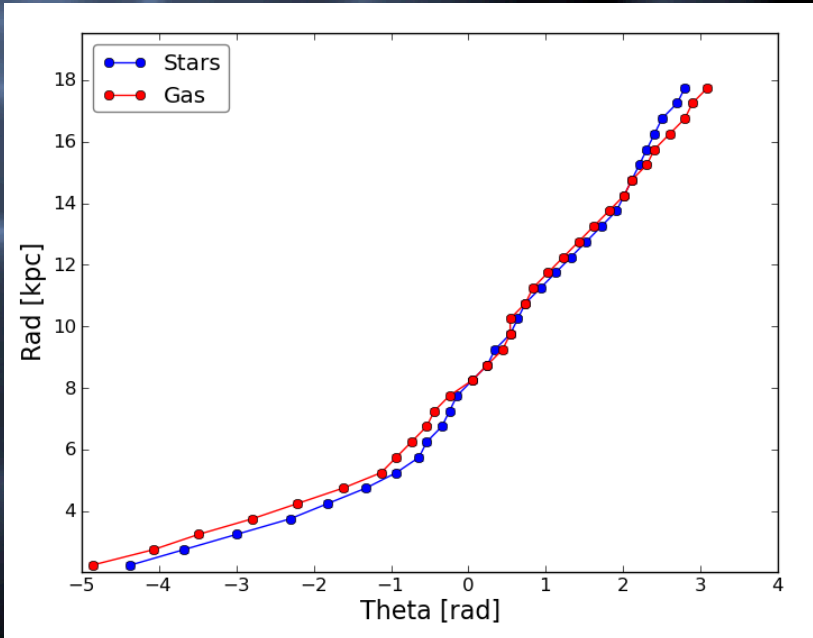


VS Isolated Spirals

- Isolated arms (pitch, pattern speed).
- The arms are driven by a much heavier disc than previously.
- The offset is less clear, and pattern speed is not a smooth function of *R*.

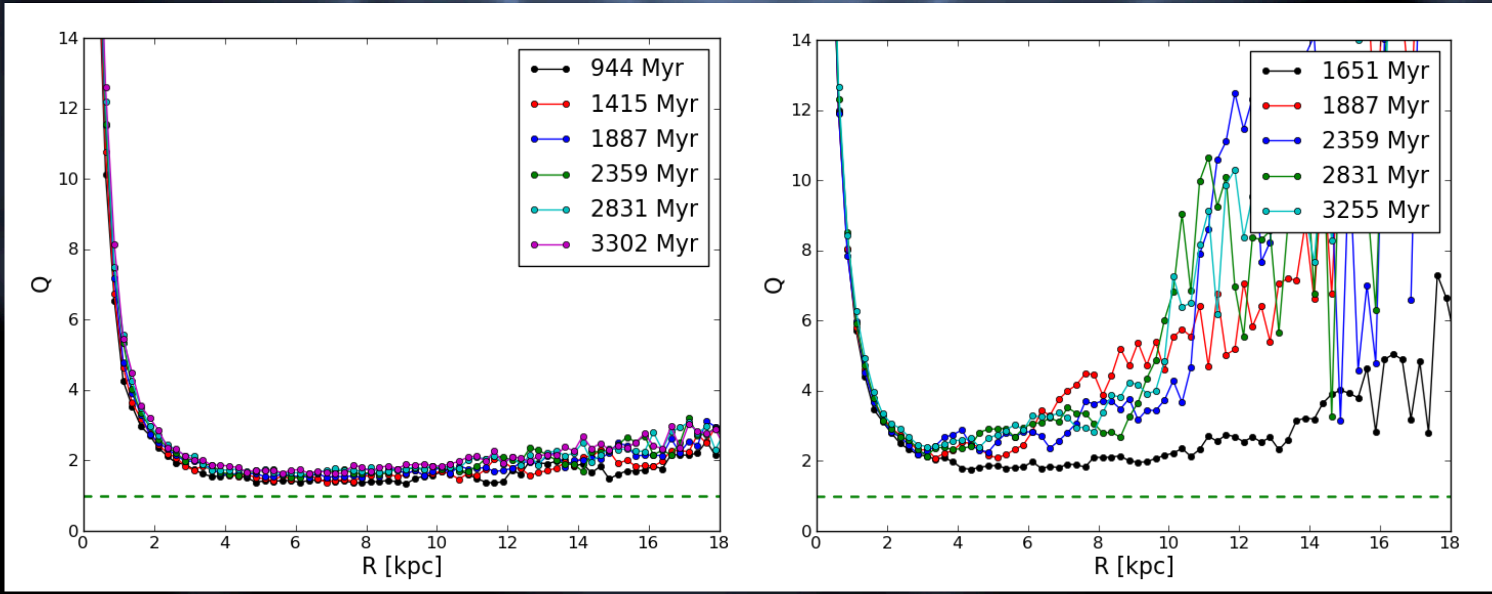






VS Isolated Spirals

- One bonus; the disc maintains it's stability for much longer periods than the perturbed disc.
- For the *N*=2 driven by an interaction, the disc is made very stable to arm formation in isolated due to the much greater velocity dispersion.
- The heavy isolated disc however can continue to form arms, though the *N*=2 mode is more difficult to maintain without a bar.



Concluding Remarks

- Many different competing mechanisms of generating spiral structure.
- N = 2 spirals are generated effectively in tidal encounters. While disc structure is also transient, there the arms are not quite material.
- Limits on driving pseudo-steady two-armed structure the disc are $0.08<M_p/M_d<0.6$.
- Can reproduce the arms structures of many different galaxies, subject of further investigation including additional physical processes.

Thank you all for your time and attention

Any questions?