



# Theories of spiral structure formation & duration

Dobbs & Baba (2014), Sellwood (2011)

Yara Beekhuizen & Myrdhin van der Zwet | 02-04-26

Dobbs & Baba (2014)

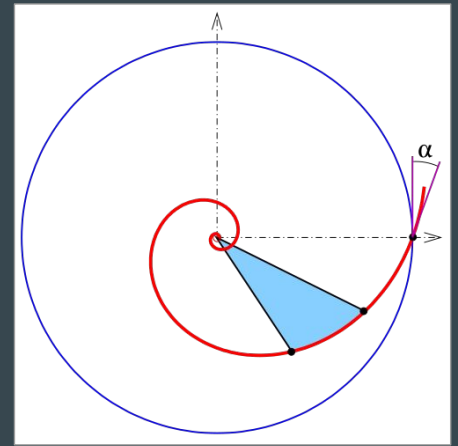
# Spiral arm properties and structure

Three kinematic types of spiral arms:

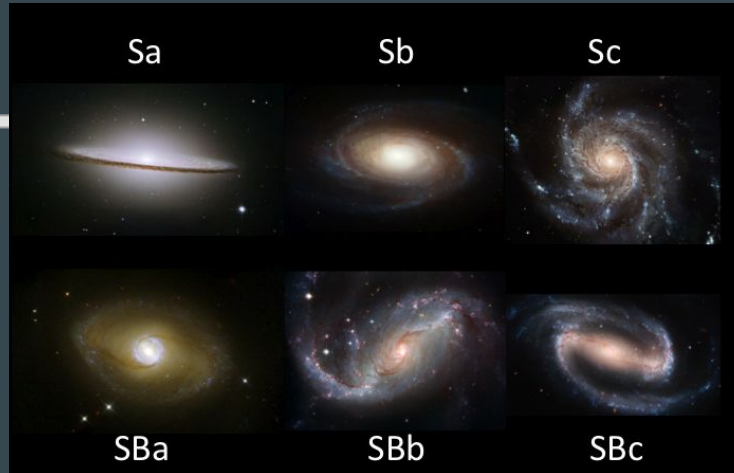
1. Material arms (obey disk kinematics)
2. Kinematic spiral arms (rotate slower than disk angular velocity)
3. Stationary spiral arms (rotate rigidly, do not wind)

Properties of spiral arms:

1. Number of spiral arms ( $m$ )
2. Pitch angle
3. Amplitude
4. Arm shape
5. **Lifetime**



Wikipedia: Pitch angle of a spiral



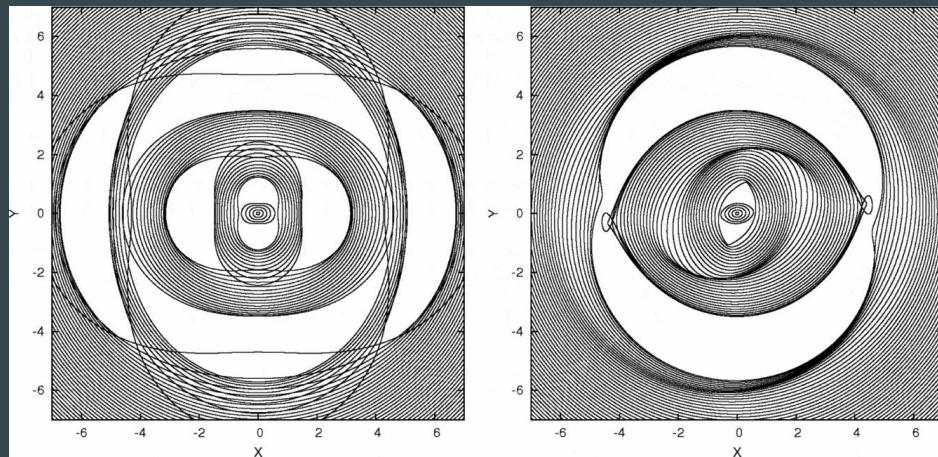
Hubble Space Telescope

Dobbs & Baba (2014)

# Spiral arm properties and structure

## Different formation mechanisms

1. bars
2. tidal interactions
3. stochastic star formation
4. dark matter haloes
5. quasi-stationary density wave theory (swing amplifications, global modes)
6. recurrent transient spiral instabilities



Dobbs & Baba (2014)



Laurine Moreau Illustrations

Spiral arms often start from the bar

- 70% of barred galaxies have 2 arms
- 30% of unbarred galaxies have 2 arms

Dobbs & Baba (2014)

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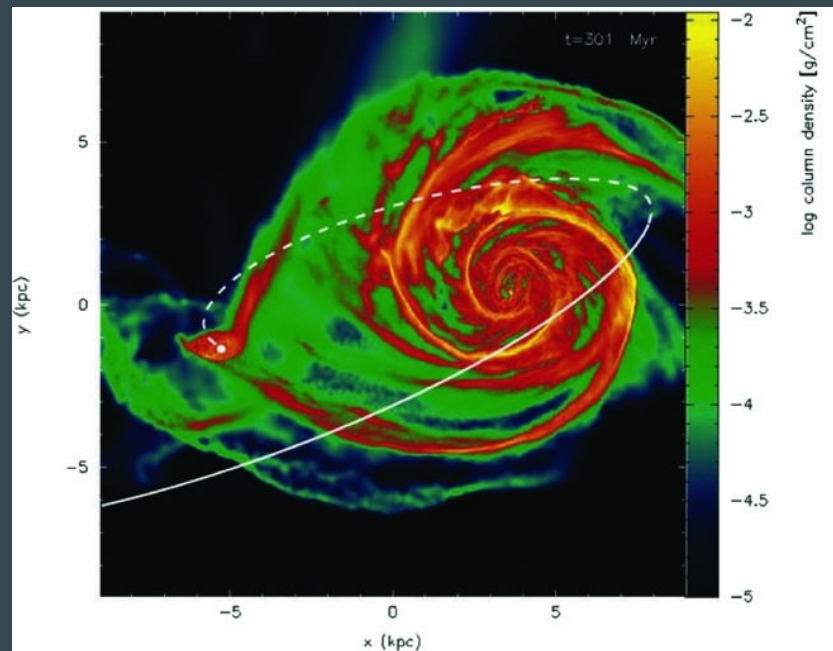
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Difficult to produce  $m=2$  spirals except by tidal interactions or bars

Lifetime plays important role:

- how much winding
- how much decay/damping



Dobbs & Baba (2014)

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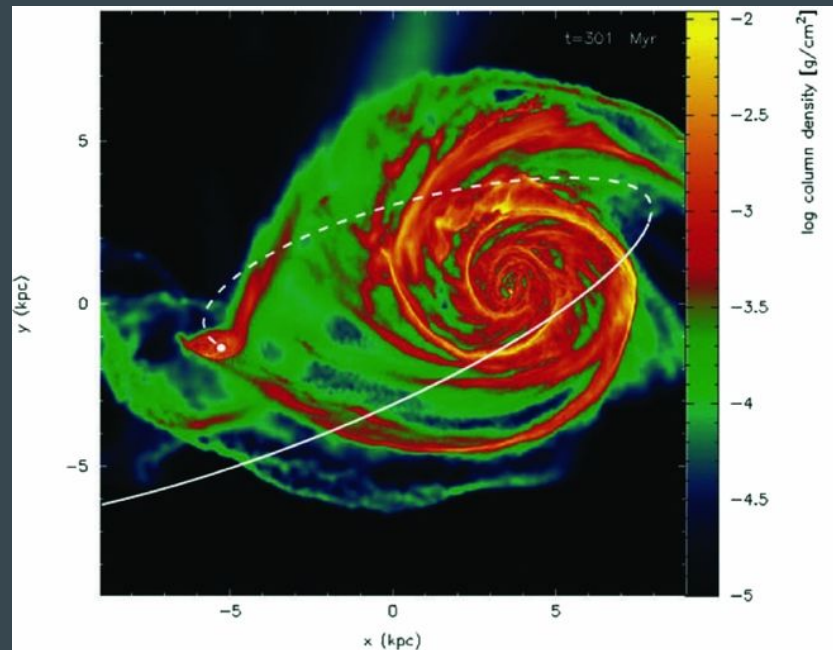
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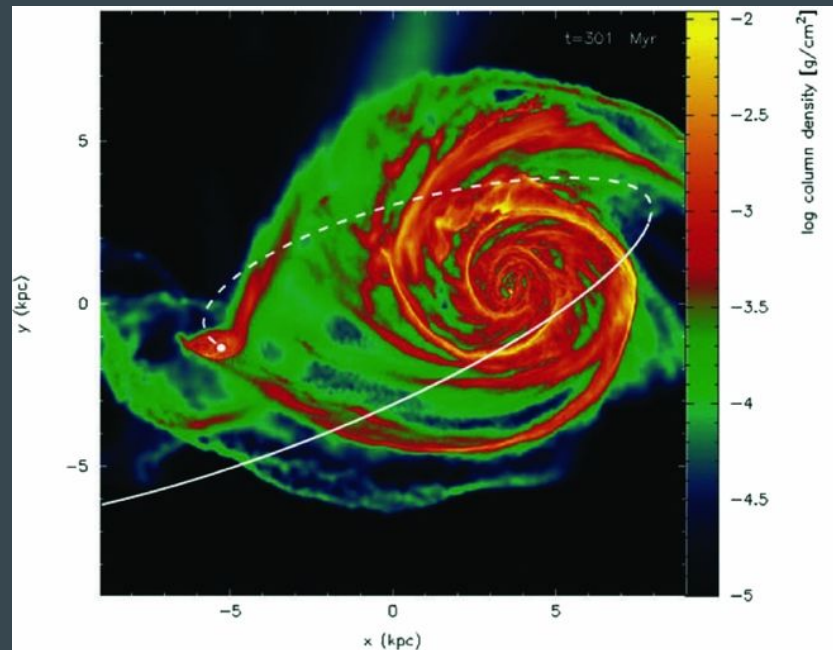
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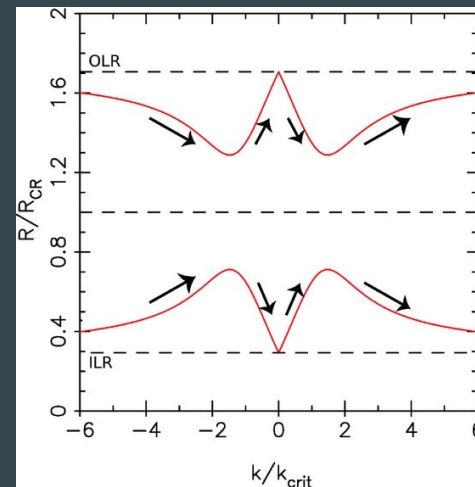
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  2. tidal interactions
  3. stochastic star formation = secondary effect
  4. dark matter haloes = speculative
  5. **quasi-stationary density wave theory (swing amplifications, global modes)**
  6. recurrent transient spiral instabilities
- Global spiral arms are slowly evolving patterns that rotate with fixed pattern speeds
  - Based on theory by Lin & Shu (1964)
  - Long and short stellar density waves cannot pass through Lindblad resonances
  - Swing amplification sustains waves between ILR and OLR
  - Swing amplification changes trailing/leading wave and amplifies when crossing CR
  - Angular momentum transport through disk
  - Global modes remedy issues in current theory

$$(\omega - m\Omega)^2 = c_s^2 k^2 + \kappa^2 - 2\pi G \Sigma_0 |k|$$

$$Q \equiv \frac{\kappa c_s}{\pi G \Sigma_0}$$

Toomre parameter  
 $Q < 1$ : unstable disk

$$\kappa = \sqrt{R \frac{\partial \Omega^2}{\partial R} + 4\Omega^2}$$



Dobbs & Baba (2014)

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## Different formation mechanisms

1. bars
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5. quasi-stationary density wave theory (swing amplifications, global modes)
6. **recurrent transient spiral instabilities**
  - Undergo cycles: breaking up and reconnecting to large scale patterns
  - Seen in simulations!

Sellwood (2011)

# Long lived spirals

Donner & Thomasson (1994) ~ Long lived spiral?

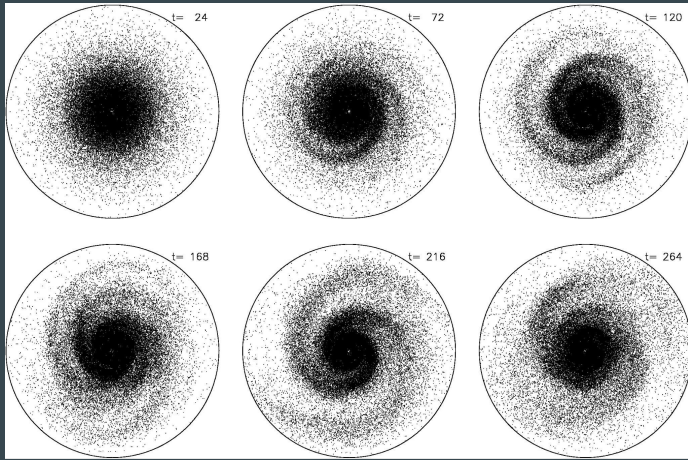


Fig. 7 Sellwood (2014)

Sellwood (2011)

# Long lived spirals

Donner & Thomasson (1994) ~ Long lived spiral?

- Different frequencies at same radius
- *Superposition of waves with differing pattern speeds*

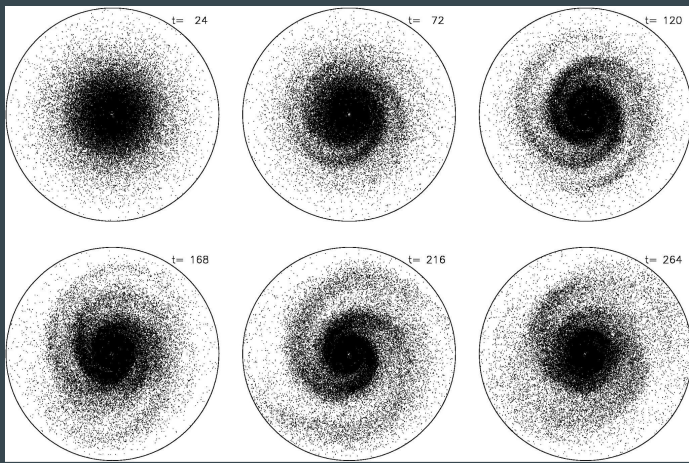


Fig. 7 Sellwood (2014)

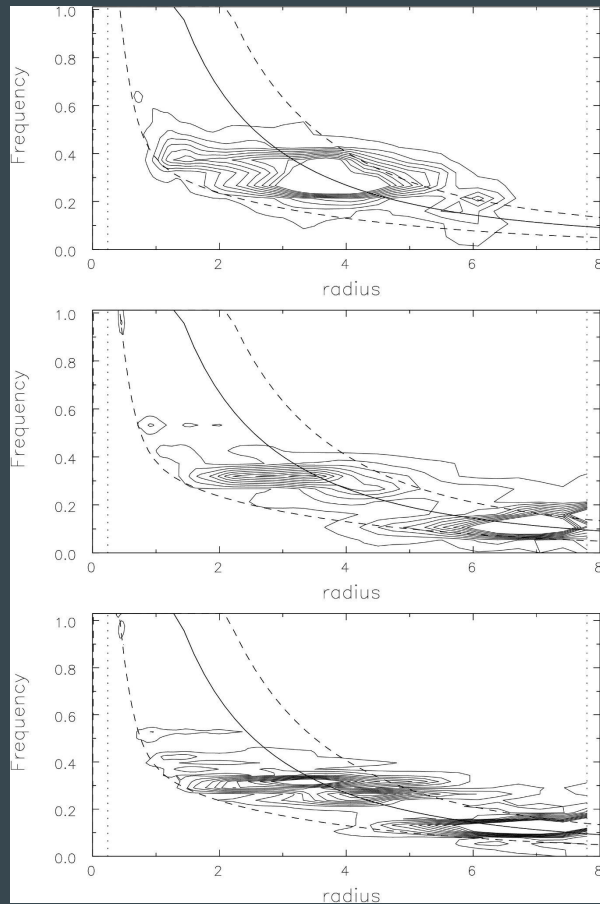


Fig. 8 Sellwood (2014)

Sellwood (2011)

# Short Lived Transient Spiral

## Recurrent cycle of groove modes?

- Deficiency in narrow range of angular momentum
- Unstable groove results in large-scale instability
- Spiral pattern is unstable mode
  - Lasts for few rotations
  - Provokes new instability when decaying
- Not found by Sellwood (2012)

## Dynamic Spirals

- Dynamic equilibrium between shear and self-gravity
  - Shear stretches and breaks spirals locally
  - Self-gravity over-densities that make up spirals
- Swing amplified instabilities

Dobbs & Baba (2014), Sellwood (2011)

# Spiral arm mechanism and evolution

Global modes solve issues with quasi-stationary density wave theory

- Assumes rigid body rotation
- Require self-regulating mechanisms
- Global modes are not supported in simulations by Sellwood (2011)

Simulations seem to point to the transient recurrent spiral arm mechanism

- Sellwood (2011) supports this scenario