Secular Processes and Galaxy Evolution

Karen Masters
Sectional Evolution

OED: (Definition #7)

Secular: In scientific use, of process of change: Having a period of enormous length; continuing through long ages. (i.e. a slow process)
Secular Evolution in Galaxies

Early(use?) use in extragalactic astronomy:

“A morphological survey of bar, lens, and ring components in galaxies: Secular evolution in galaxy structure”


Since a bar creates a large, non-axisymmetric distortion in the gravitational potential field, with which other stars can interact, a not surprising conclusion will be that secular evolution plays a major role in changing galaxy structure.

Duus and Freeman (1975) have suggested that inner rings are manufactured out of disk material rearranged by the bar. One of the main suggestions of this paper is that secular evolution processes may generally be important in galaxies.
Secular Evolution in Galaxies

Common usage (in extragalactic astronomy):
- slow internal evolution (redistribution of material because of bars, or spirals)
- slow external evolution (ie. slow accretion of gas; harassment/strangulation).

Contrast:
- (fast) mergers, ram pressure stripping etc.
Processes of Galaxy Evolution

Star formation
Gas recycling
Metal enrichment
Energy feedback (supernova etc)

Protogalactic collapse
Galaxy mergers
RAM pressure striping

Internal Secular Evolution
• Disk instabilities
• Dark matter halos
• Bars and ovals
• Spiral structure
• Nuclear black holes
• Galactic winds and fountains

Environmental Secular Evolution
• Prolonged gas infall
• Minor mergers
• Galaxy harassment

Location

Time scale
Fast
Slow

Internal
External

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(adapted from Kormendy & Kennicutt 2004)
Hierarchical galaxy evolution
Hierarchical galaxy evolution

“Galaxies evolve mostly through merging”
– a dynamically fast, non-secular process.....

Most work in galaxy evolution in last 30 years on these processes...

Is secular evolution important?

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Hierarchical merging can’t explain everything

- Really thin disks
- Really late type spirals (>15% bulgeless)

- Major mergers are rare:
  - Local merger fraction 1-3% of (Darg et al. 2010)
  - Massive galaxies (M>10^{10} Msun) have few mergers after z~1 (Conselice et al. 2008)
  - Last major merger of Milky Way ~10 Gyrs

Merging clearly occurs, but is it the dominant process for galaxy evolution?
Most galaxies are discs

Lotz et al. 2008
Most early-types rotate

ATLAS-3D Parent Sample

Virgo Cluster

Use 10th neighbour on spheres

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Build up of red sequence is mostly due to spirals turning red...

See Bundy et al. 2010 for build up with z
Entering the Secular Era...

Last major merger of Milky Way – 10-12 Gyrs ago (Gilmore et al. 2002)

Conselice et al. 2008 – number of mergers (based on CAS on HUDF)

- very few major mergers at z<1
External Secular Processes

Brook et al. 2009

Four example galaxies chosen to have last major merger at z>1.5

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Processess of Internal Secular Evolution

- Angular momentum transfer by
  - Spiral arms
  - Bars
- Disk heating (thickening)
- Growth of bars
- Growth of pseudobulges
General dynamical principles

- Galaxies are self-gravitating systems (stars, gas, DM floating around together in space)

- Self-gravitating systems have negative specific energy
  - Can lower energy by increasing central density and flinging away the edges

- So discs spread in radius
  - Inner parts shrink
  - Outer parts grow

M101 imaged by Mike Hyde
Stellar Orbits

Non closing rosettes
(spioraph pattern)

or:
• epicycles around a “guiding centre” which has a fixed angular velocity ($\Omega_\phi$)

or:
• in the rotating frame: radial oscillations with period $\Omega_R$
Stellar Orbits

Non closing rosettes (spirograph pattern)

or:
• epicycles around a “guiding centre” which has a fixed angular velocity ($\Omega_\phi$)

or:
• in the rotating frame: radial oscillations with period $\Omega_R$
Resonant Frequencies

Integer number of radial oscillations in an integer number of pattern rotations.

Outer Lindblad Resonance:
\[ \Omega_p = \Omega_\phi - \Omega_R \]

Inner Lindblad Resonance:
\[ \Omega_p = \Omega_\phi + \Omega_R \]

Exchange of AM occurs at resonances

Co-rotation – guiding centre period matches pattern speed

\[ m(\Omega_p - \Omega_\phi) = l\Omega_R, \]
Galactic Bars

Forming a bar is easy - they are natural way to stabilize a self gravitating disc

• why do some disc galaxies not have them.....?
Response of Gas to Resonances

Gas moves ~ 1 kpc per Gyr.

Athanassoula (1992)

Any non-axisymmetry can do this – just longer timescales.

Figure 5, Kormendy & Kennicutt 2004
Bar evolution

- Bars enable exchange of angular momentum -> they move material around...
  - growing central concentrations (pseudo-bulges)
  - sparking central star formation
  - feeding AGN?
  - using up gas more quickly?
  - limiting external in fall of gas (beyond co-rotation)
Galaxy Pair NGC 1512 / NGC 1510

NUV (GALEX, blue) + H I (ATCA, green) + R (DSS, red) + MIR (Spitzer, luminosity on NGC 1512 center)

Optical image shows the stellar distribution. Near ultraviolet image traces the star forming region.
The H I image is the neutral gas component, the data are from the LVHis (The Local Volume Hi Survey) project.

Angel R. López-Sánchez & Bärbel Koribalski
CSIRO / Australia Telescope National Facility
Evidence for Secular Processes
Evidence for Secular Processes

Elmegreen & Elmegreen 1985

Earlier type spirals have longer bars

Bars get longer as they age and make disc galaxies grow bulges.....
Barred Red Spirals in Galaxy Zoo

Red, massive disk galaxies are much more likely to have strong bars than blue disk galaxies...

Hint of bimodality?

Masters et al. 2010 (MNRAS 405, 783)
Masters et al. 2011 (MNRAS 411, 2026)
(Also seen in RC3; Nair & Abraham 2010; Giordani et al. 2010)
Disc dominated - low bar fraction except where very red

Bulge dominated - high bar fraction at all colours
Evidence for Secular Processes

Star formation rate

Stellar mass

Sersic Index (bulge)

Central stellar density

Secular evolution?
Evidence for Secular Processes

Cheung et al. (submitted)
Bar length as a proxy for age

More massive central concentrations the older the bar
Bars Affecting Starformation

Ellison et al. 2011

60% enhancement

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Bars affecting star formation?

At fixed $M_{\text{star}}$

- gas poor galaxies more likely to have bar than gas rich

Driven by gas (HI) content

$\Rightarrow$ at fixed mass correlation with HI content persists
Bars in Gas Rich Spirals...

Resolved HI surveys for gas (VLA observations scheduled this autumn)

Old stars | New stars | Gas

Simulation (Athanassoula et al. 2013)

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Bars Changing Disc Structure

Fainter central surface brightness and longer scale lengths.
Sanchez-Janssen & Gadotti 2013
Changing Metallicity

![Graph showing metallicity versus total stellar mass (log M_☉).](image)

- 0.06 dex enhancement

Ellison et al. 2011

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Evidence for Secular Evolution?

Schematic of result from Leauthaud et al. (2012) based on weak lensing halo masses in COSMOS field.

Star formation quenching at constant $M_*/M_h$ (not fixed $M_h$ or $M_*/M_{bulge}$)
Disk instabilities

Classic disk stability criteria (Efstathiou et al. 1982):

\[ \frac{V_{\text{max}}}{(G N M_{\text{disk}}/r_{\text{disk}})^{0.5}} \leq 1, \]

Could disc instabilities contribute to global star formation quenching in disc galaxies?
“Every galaxy is dynamically evolving”

- Kormendy & Kennicutt 2004
The Future is Secular...

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The Future is Secular…

Adslabs.org (search on “secular evolution” galaxies)
Karen Masters: "Revealing Bars with Galaxy Zoo", 13th May 2013 @KarenLMasters