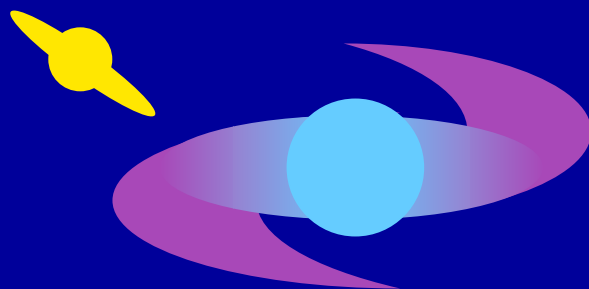


# Forming Young Bulges within Existing Disks: Statistical Evidence for External Drivers



*Sheila Kannappan (UT Austin)  
with Rolf Jansen (ASU) & Elizabeth Barton (Arizona)*

# Forming Young Bulges within Existing Disks

Many bulges are younger & diskier than expected.

- Colors

surprisingly blue bulges, correlated bulge/inner-disk colors  
(e.g. Peletier, Balcells, et al, Carollo et al, Ellis et al)

- Structure

exponential light profiles, correlated bulge/disk scale lengths  
(e.g. Andredakis et al, MacArthur, Courteau, et al)

- Kinematics

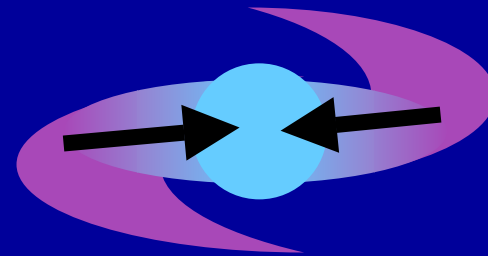
disky  $v/\sigma$  ratios, Faber-Jackson outliers (Kormendy & Illingworth)

# Forming Young Bulges within Existing Disks

Bulges must evolve late, within & together with disks.

Secular Scenario:

- Bar instability
- Disk gas inflow
- Central starburst
- Dissolution of bar



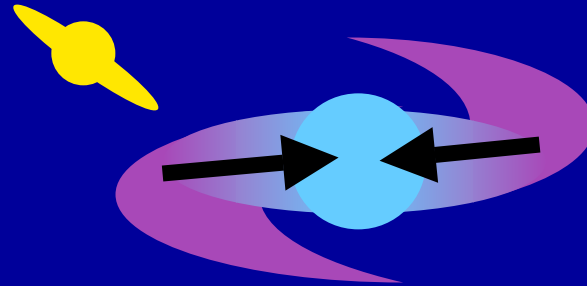
*e.g. Pfenniger & Norman,  
Friedli & Benz*

# Forming Young Bulges within Existing Disks

Bulges must evolve late, within & together with disks.

Secular Scenario:

- Bar instability
- Disk gas inflow
- Central starburst
- Dissolution of bar



Triggered Scenario:

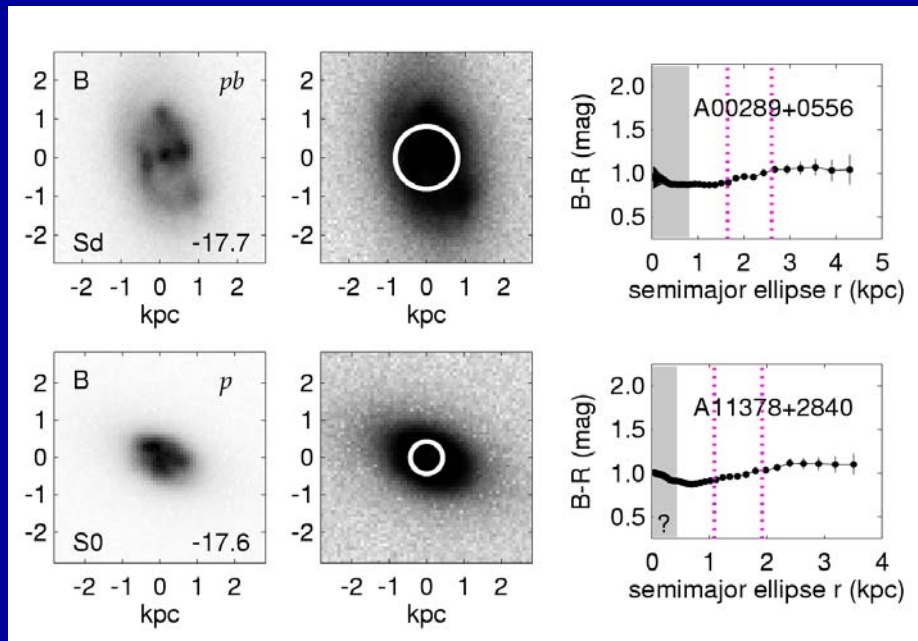
Just add neighbor.

*e.g. Pfenniger & Norman,  
Friedli & Benz, Hernquist & Mihos....*

# Breaking the Degeneracy

Kannappan, Jansen & Barton 2003

Strategy: catch bulges in the act of forming...



blue center criterion :

$$\Delta(B-R) > 0$$

(outer color – inner color)

“inner” = inside 50% radius

“outer” = from 50% to 75%

...and test for  
outside influences

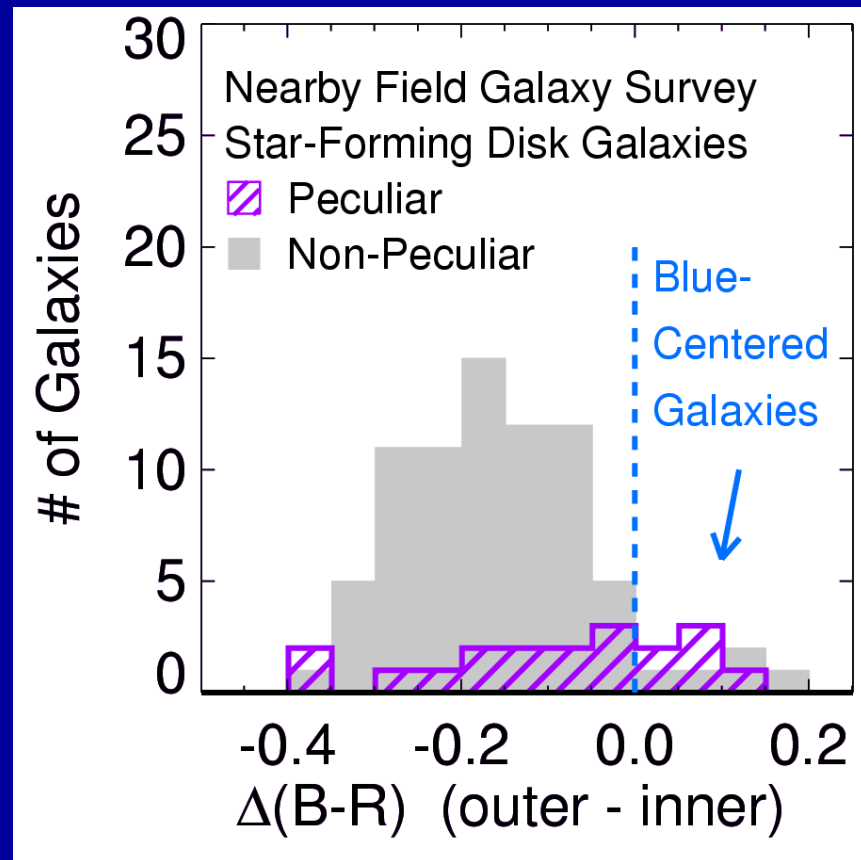
# Statistical Evidence for External Drivers

Blue centers correlate with evidence for interactions and mergers.

peculiarity:  
99% confidence

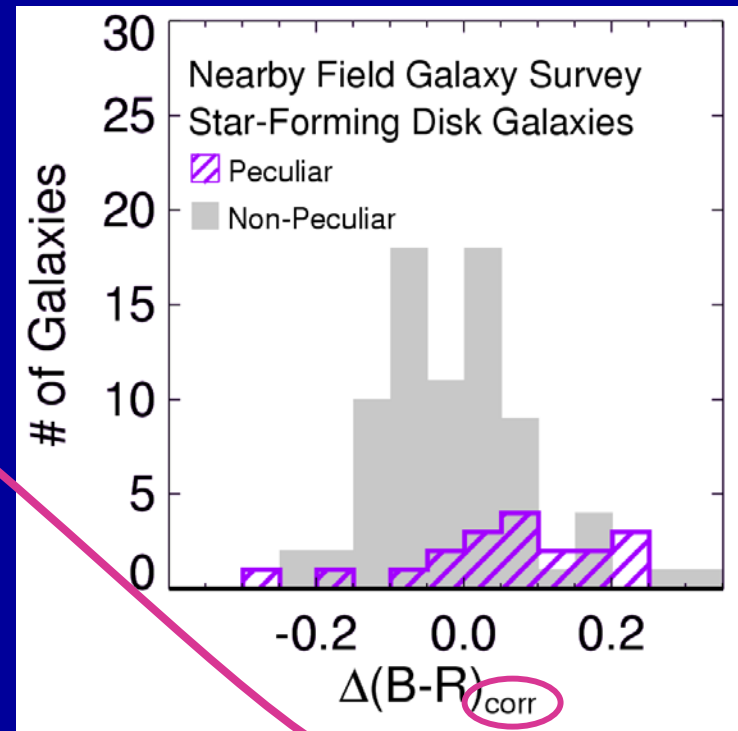
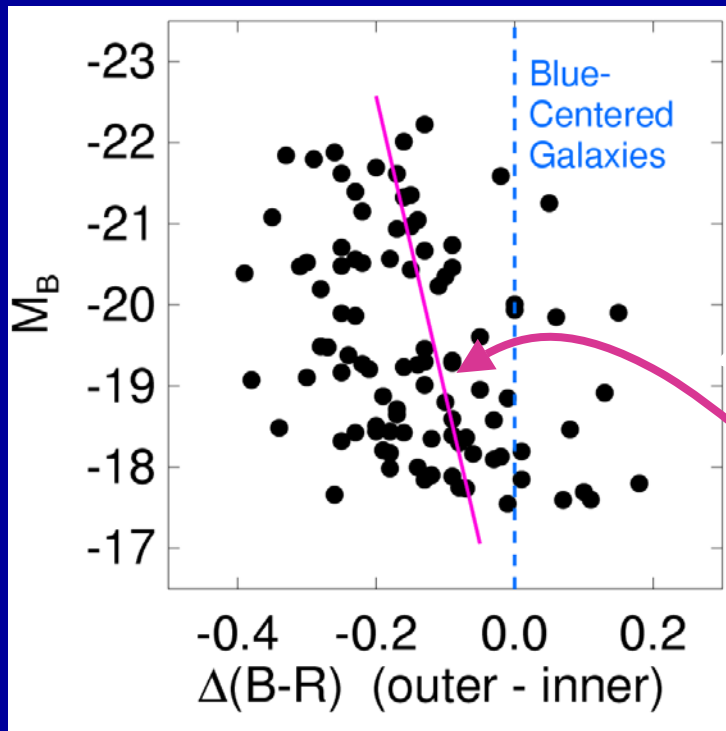
UVC companion:  
95% confidence

some evidence:  
all 11 galaxies



# Statistical Evidence for External Drivers

Peculiarity result does not reflect luminosity trend.



(also Tully et al 1996, Jansen et al 2000)

# Statistical Evidence for External Drivers

## KEY POINT

*Not just:*

interactions & mergers can cause blue centers

*But:*

in a statistically fair sample, blue centers  
usually reflect interactions & mergers

# Forming Young Bulges within Existing Disks

Blue-centered galaxies plausibly reflect an *important mode of bulge growth within disks.*

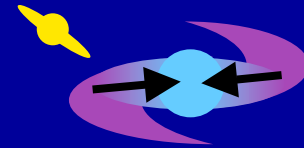
- central growth → bulge growth  
(spatial scales match)
- growth within disks  
(non-destructive interactions: small companions)
- substantial growth  
(pop. synth. model galaxies: bulge sizes ~double after fading)
- life stage for most disk galaxies (bright galaxies masked?)  
(10% of sample and 1-2 Gyr duty cycle → > 50% of disk galaxies)

*see paper  
for details*

# Forming Young Bulges within Existing Disks: Statistical Evidence for External Drivers

## The Big Picture (A Suggestion):

Late-epoch bulge growth within disks =  
“high-resolution” hierarchical galaxy formation



## Open Questions:

- Does the luminosity trend reflect “downsizing”?
  - high-z analogues, bulge rejuvenation (*Ellis et al.*)
- Will bulges formed in this way be “disky”?
  - exponential profiles and/or disk kinematics  
(*Scannapieco & Tissera simulations say yes...*)