The Impact of Minor Mergers

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Phil Hopkins (Berkeley)
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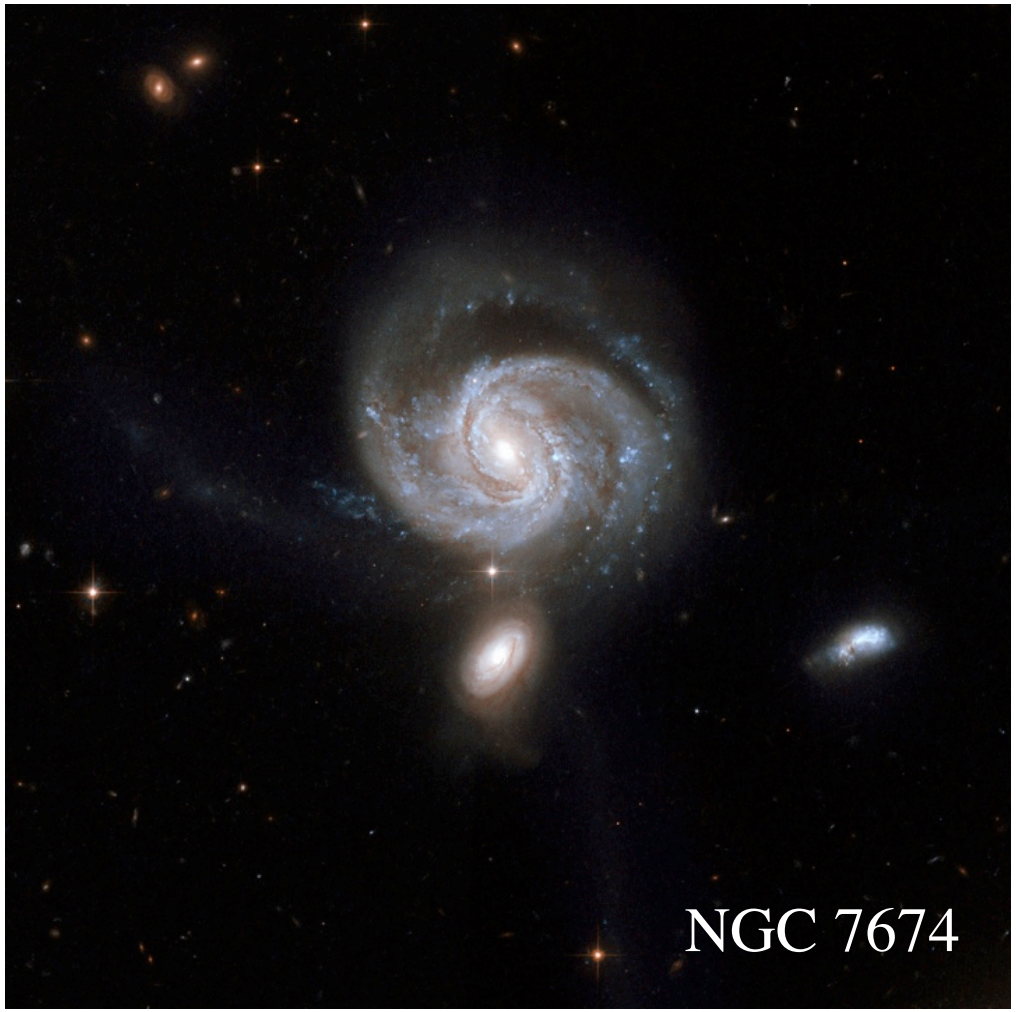

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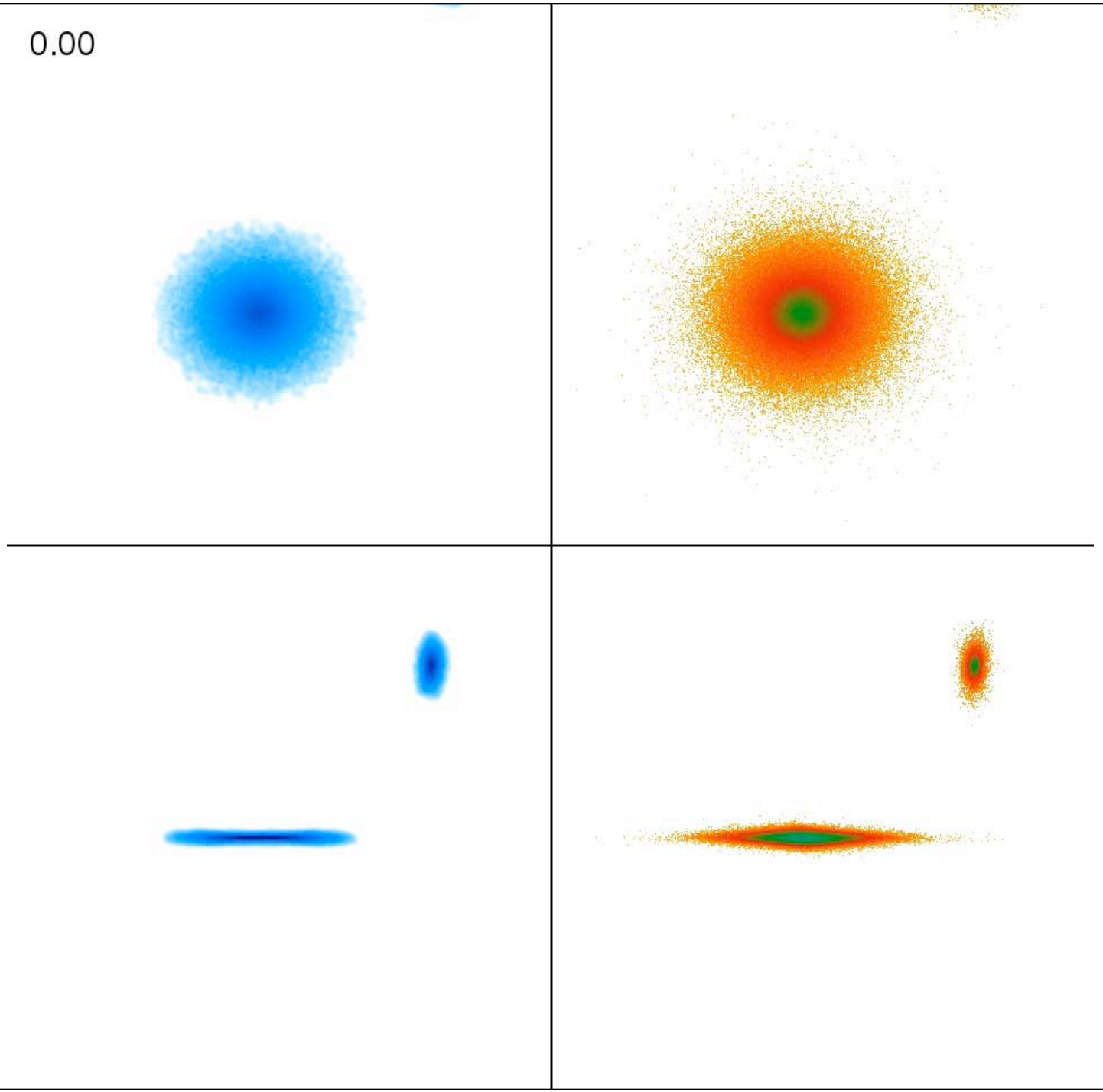
1:8 Minor Merger

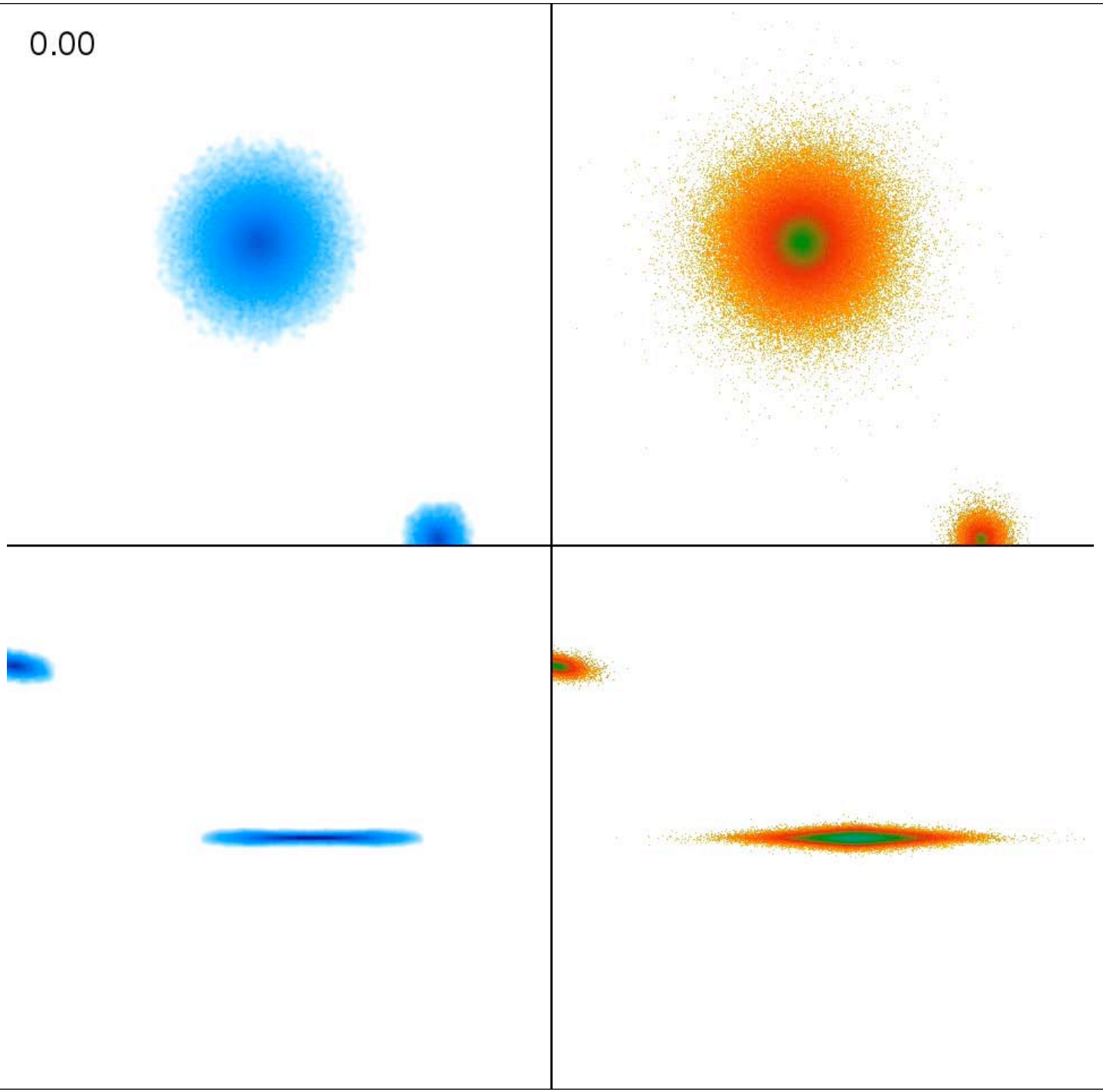


blue=
projected gas
density

color=
projected stellar
density

1:8 Minor Merger

(retrograde version of previous encounter)

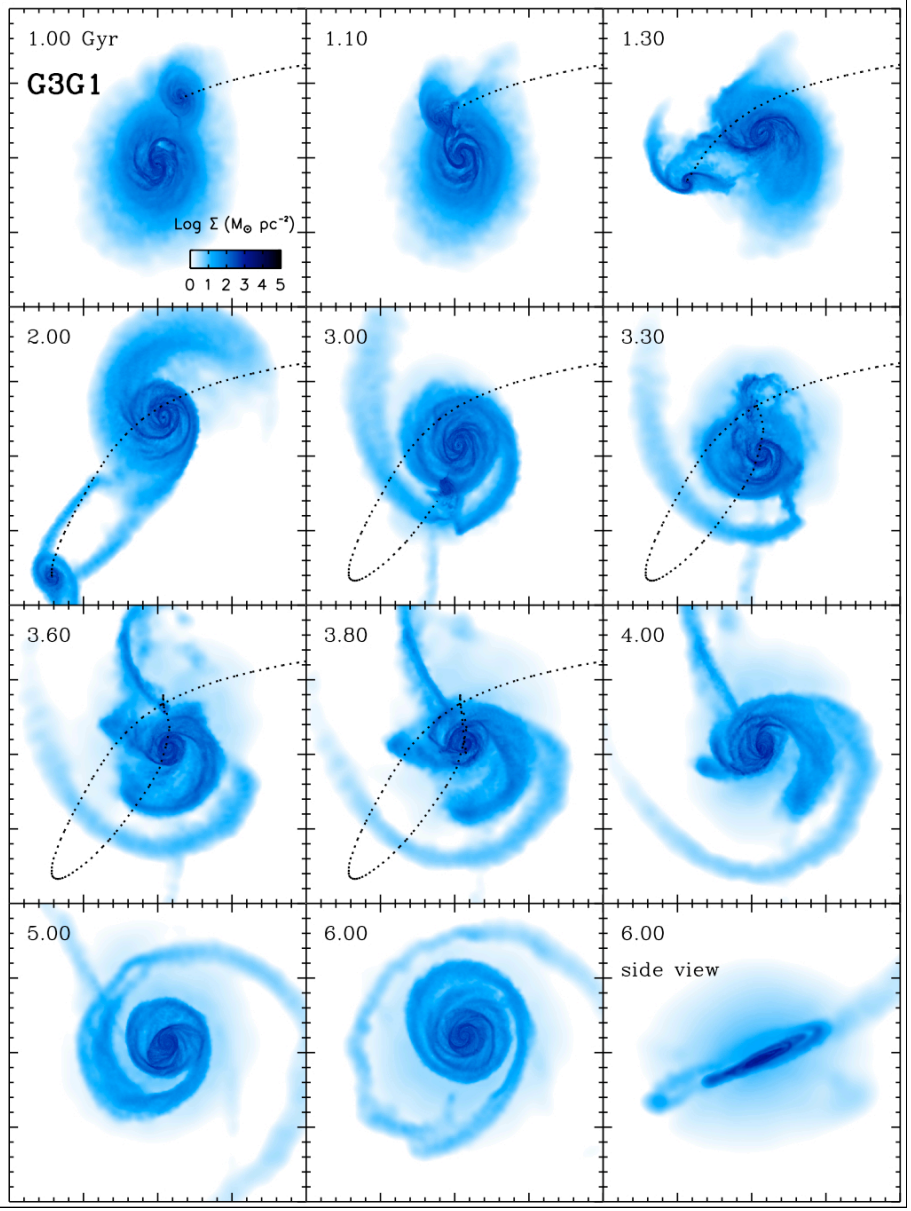


blue= projected gas density

color= projected stellar density

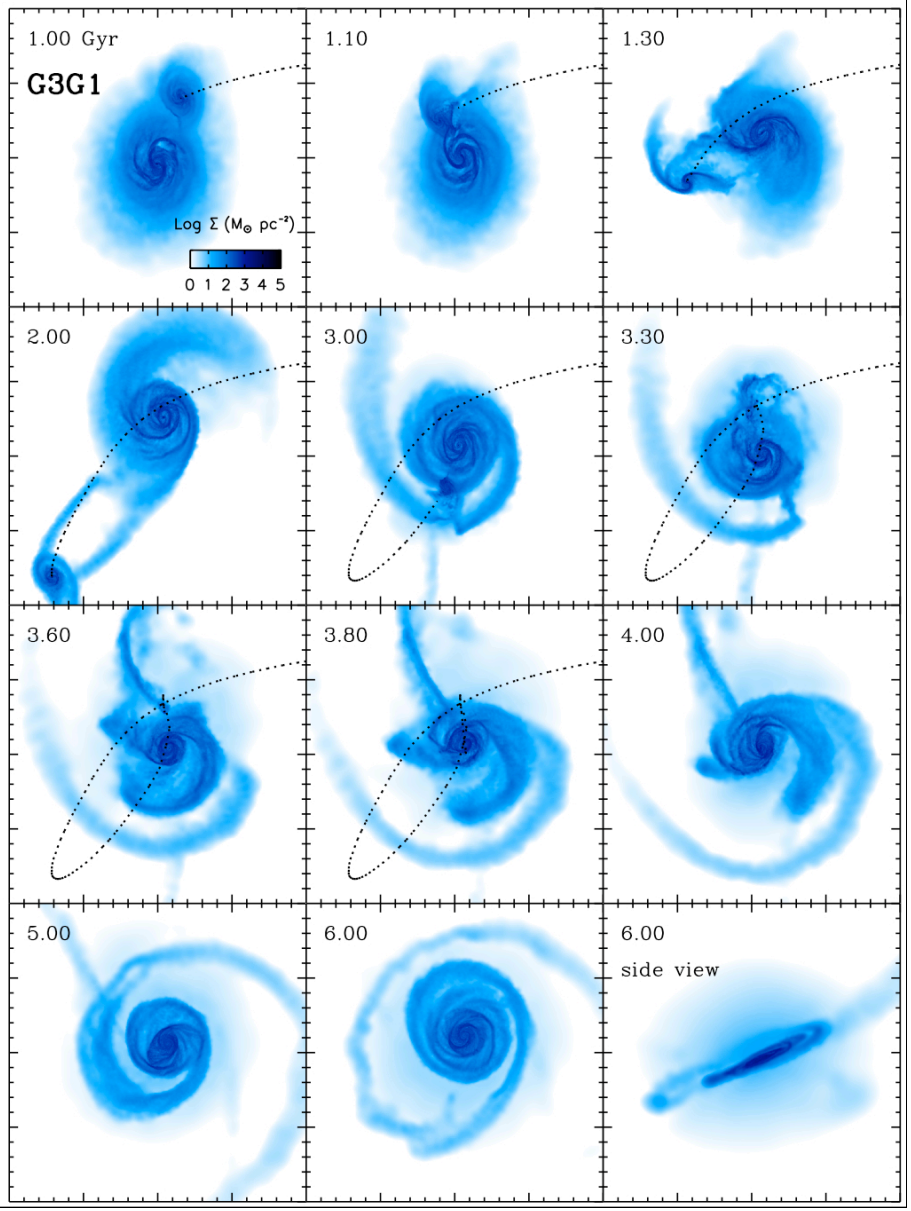
Galaxy Mergers Simulations

- Simulations: 3-D, time-dependence using GADGET2
- Include
  - Springel & Hernquist “conservative-entropy” SPH
  - Star formation (sub-resolution)
  - Supernova feedback (sub-resolution)
  - (optionally) supernova-driven winds (sub-resolution)
  - Black hole growth, feedback (sub-resolution)
- Consider:
  - Binary mergers
  - varying mass ratios
  - Galaxy models motivated by local galaxies
  - large gas fractions: made possible by the treatment of SN feedback



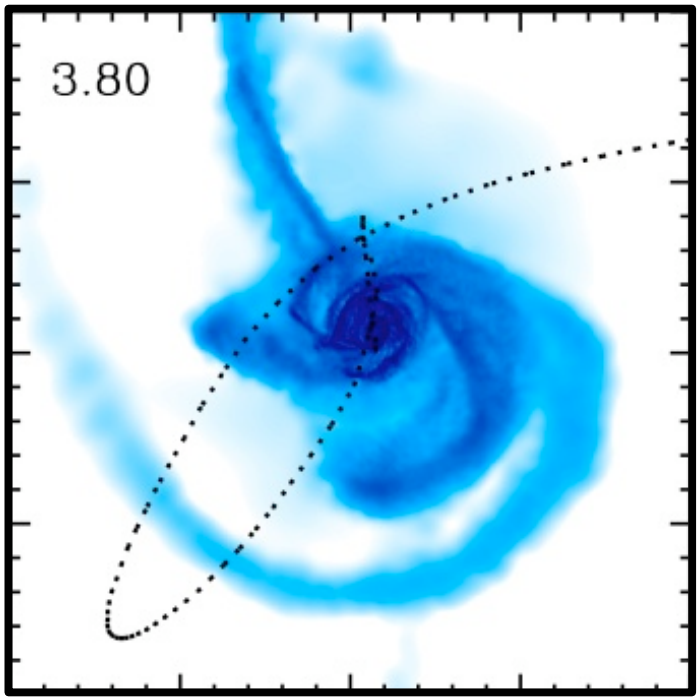
Impact of Minor Mergers

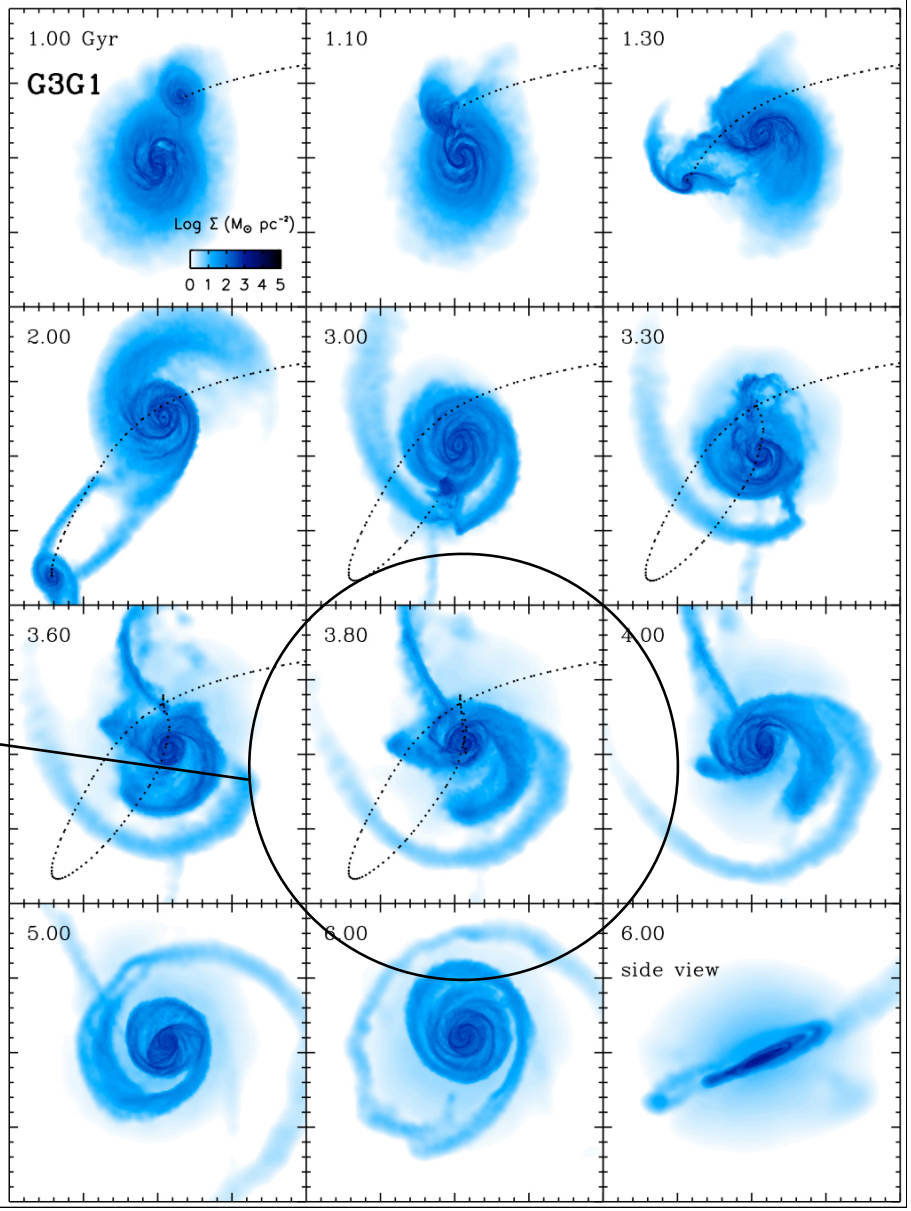
- Star formation
- Properties of merger remnants and implications for bulge formation and for the heating and survivability of galactic disks



Star Formation

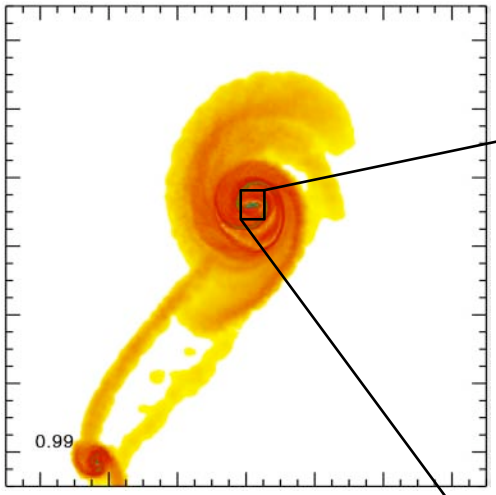
Orbit become radial during late stages of merger

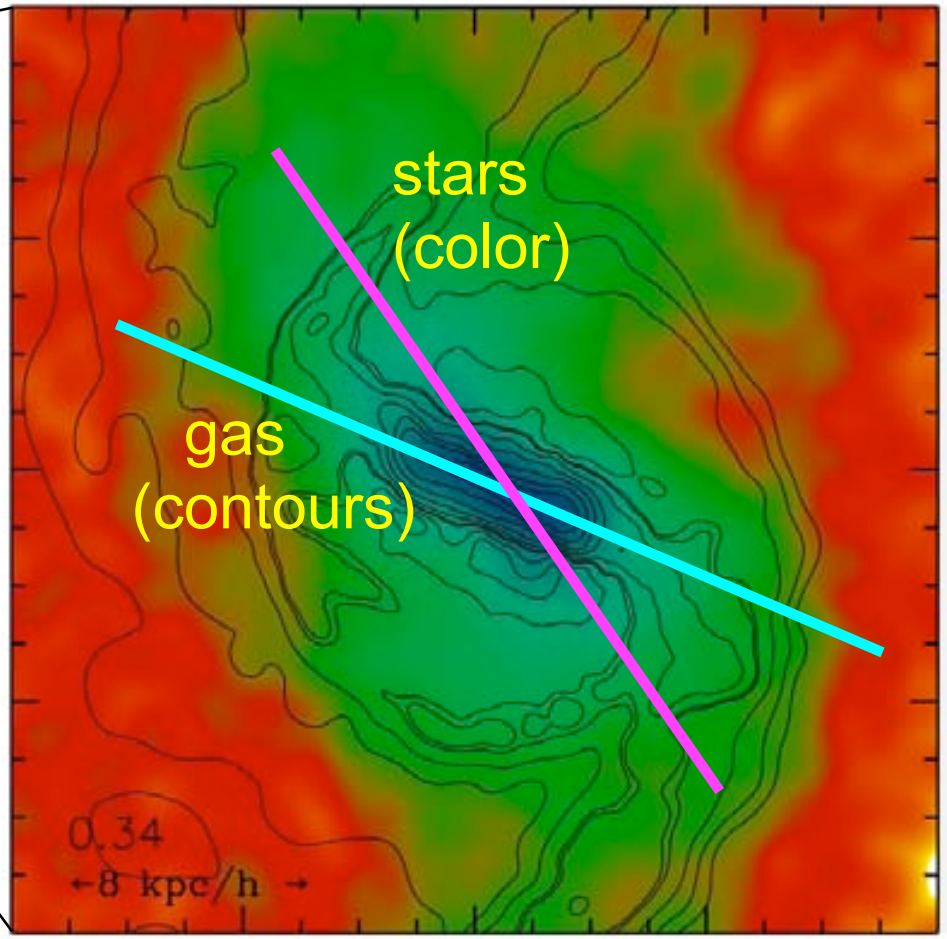


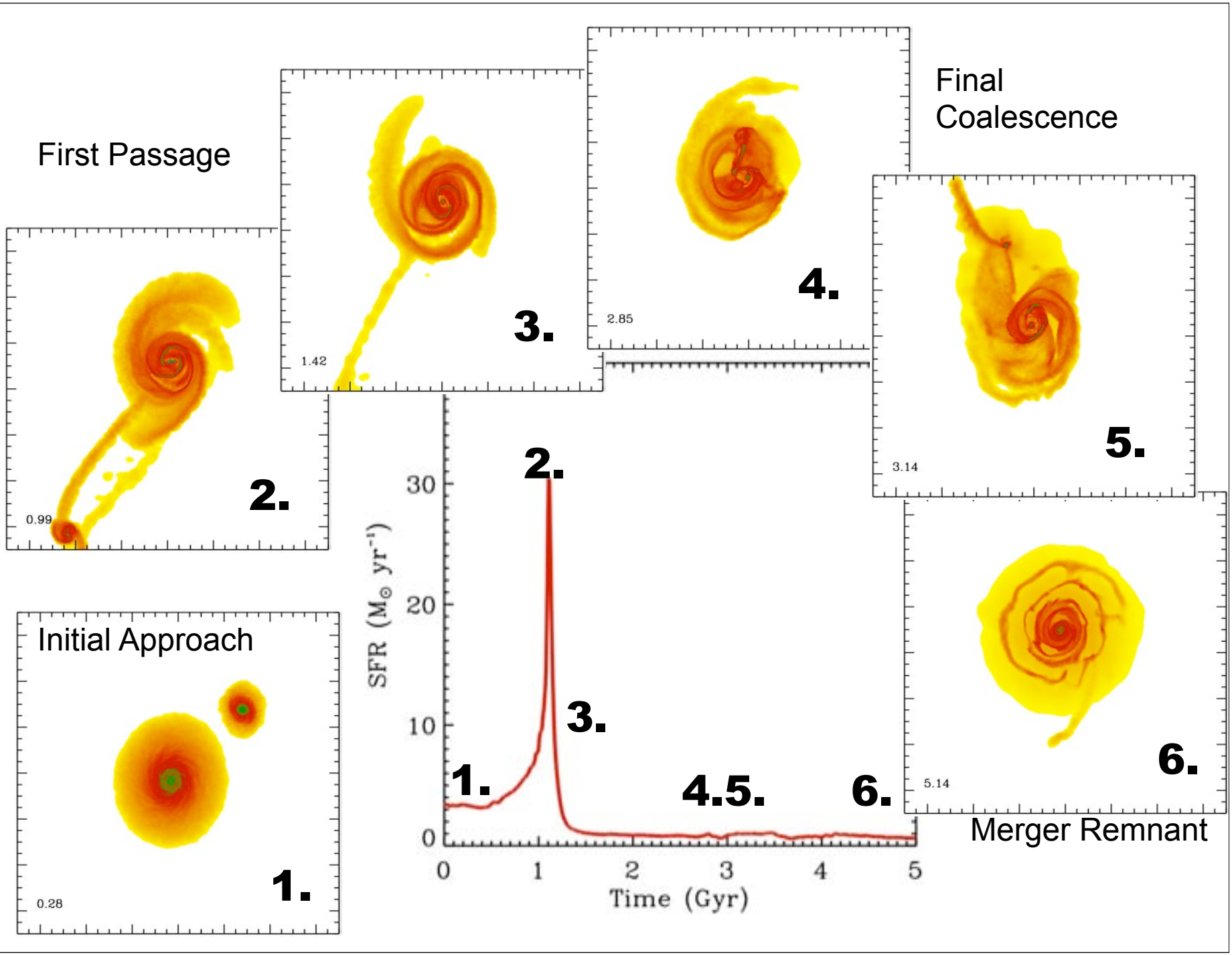


Star Formation

companions -- bars -- gas/star offset -- torques -- gas inflow (see, e.g., Barnes 92, Barnes & Hernquist 96, Mihos & Hernquist 94,96)






First Passage
Final
Coalescence
Initial Approach
Merger Remnant
1.
2.
3.
4.
5.
6.
0.28
0.99
1.42
2.85
3.14
5.14
SFR ($M_\odot$ yr^{-1})
Time (Gyr)
0
10
20
30
0
1
2
3
4
5

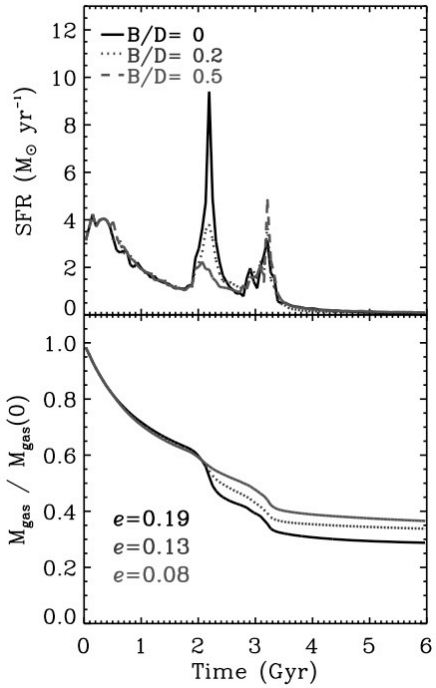
Star Formation

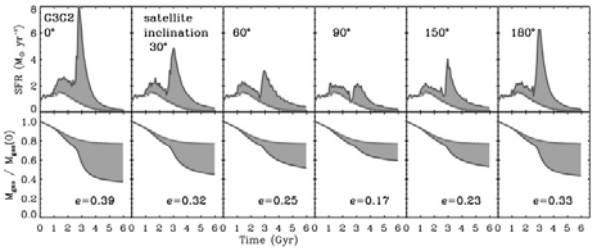
* Starbursts are produced by close tidal passages

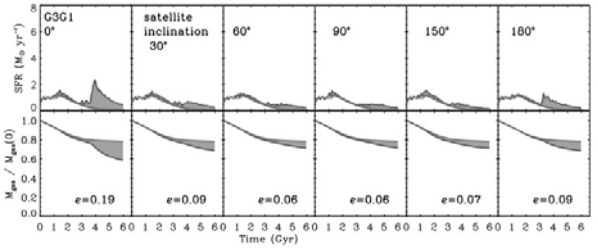
* Depend on “everything” -orbit, orientation, disk structure, etc. (our results are fully consistent with Mihos & Hernquist 1994, and moderately consistent with Di Matteo et al. 2007)

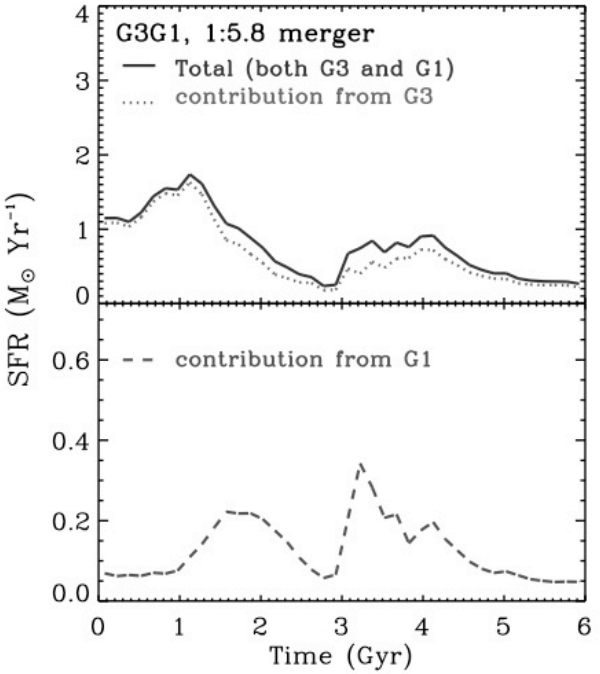
* Very little, if any, star formation induced for minor mergers below ~1:10

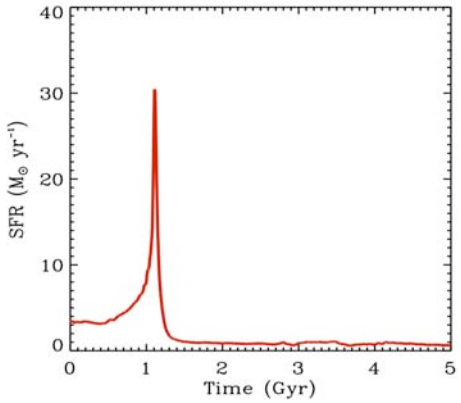
* Global SF dominated by primary (satellite may also experience a starburst)

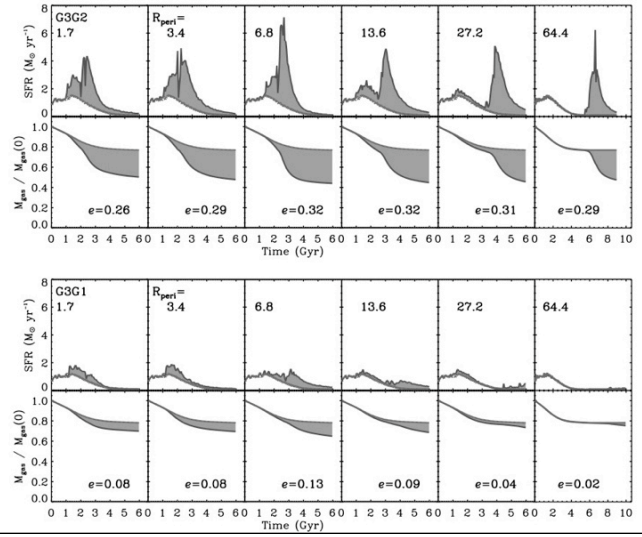












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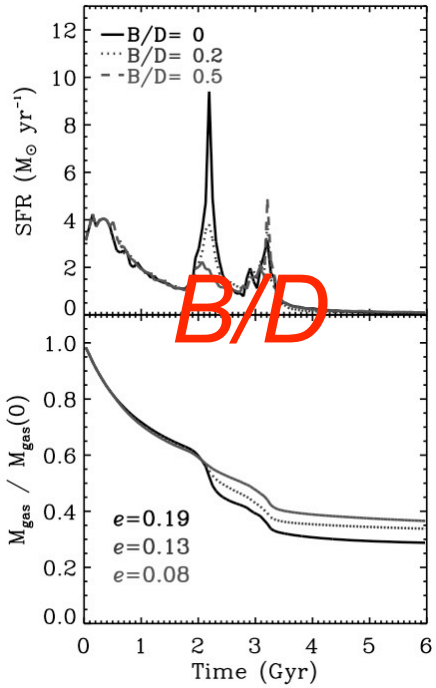

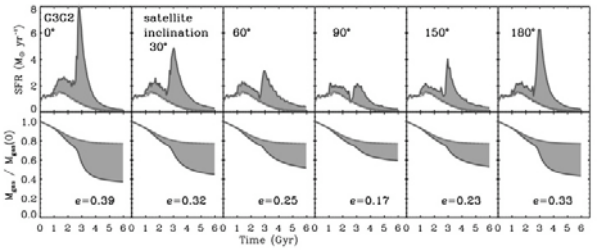

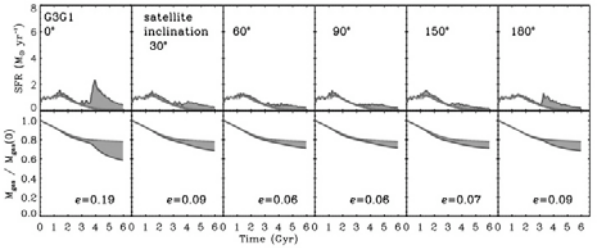

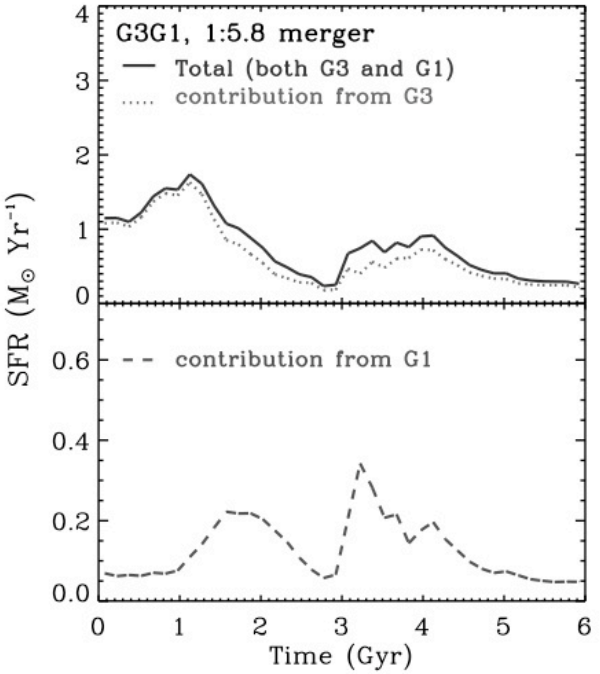

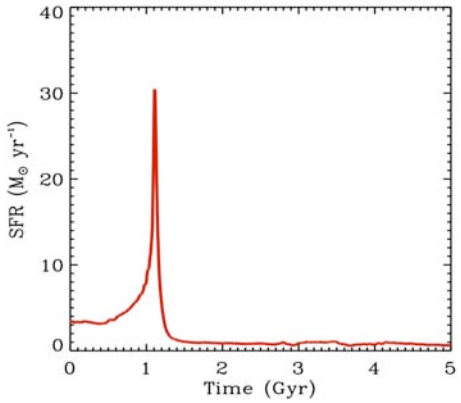

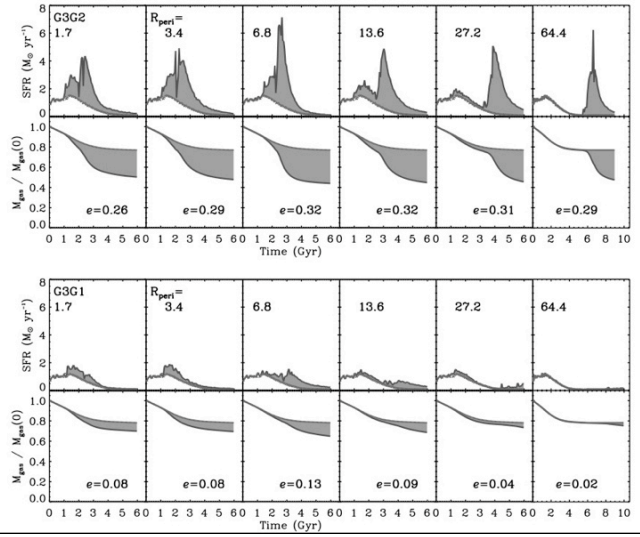

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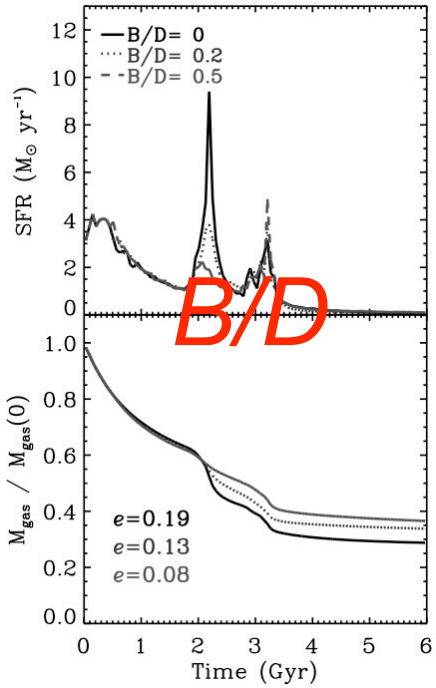

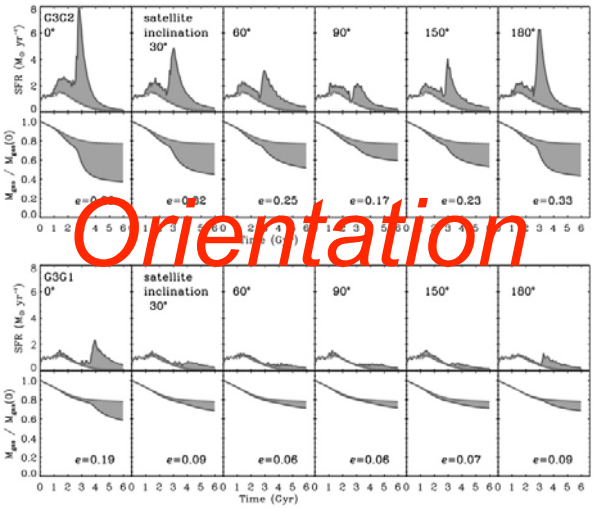

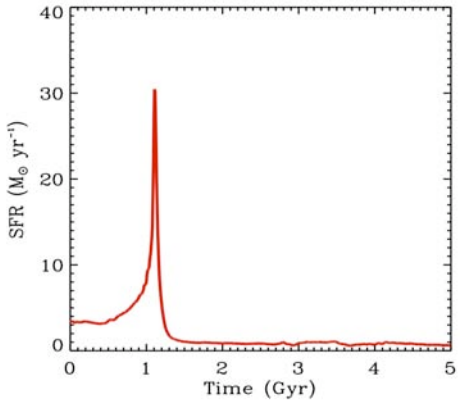

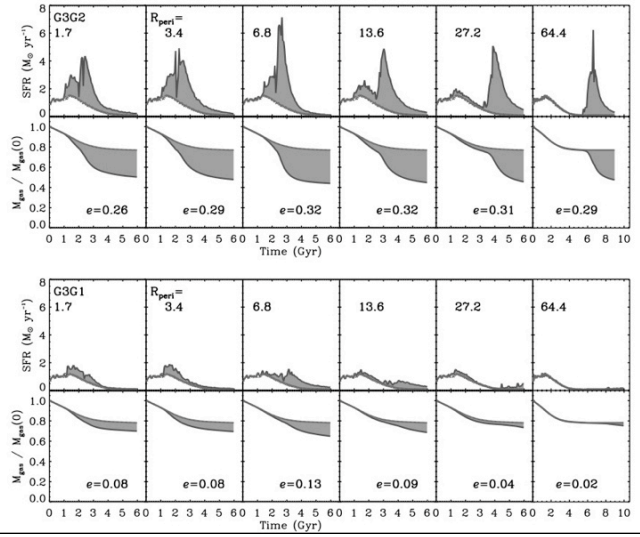

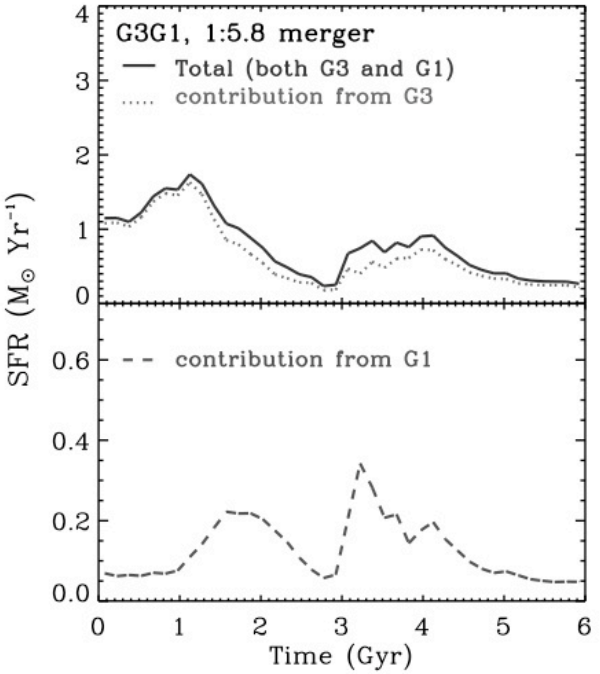

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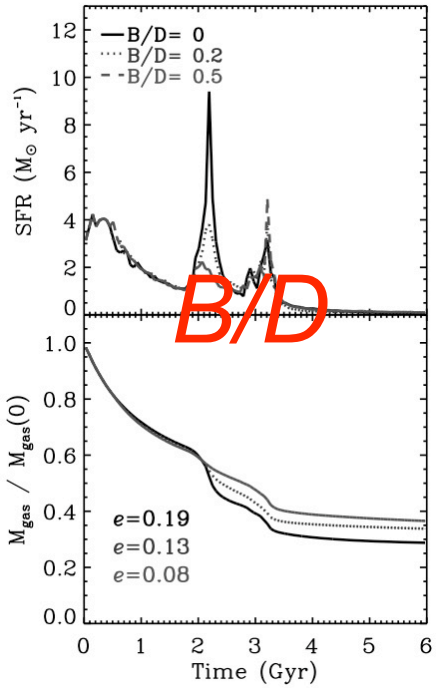
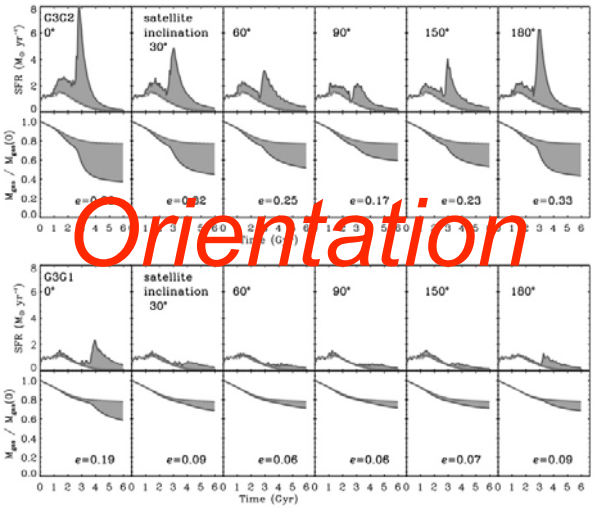
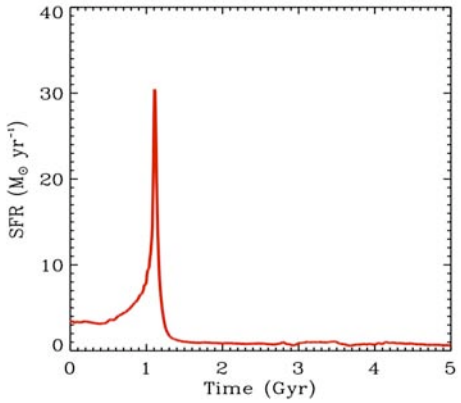
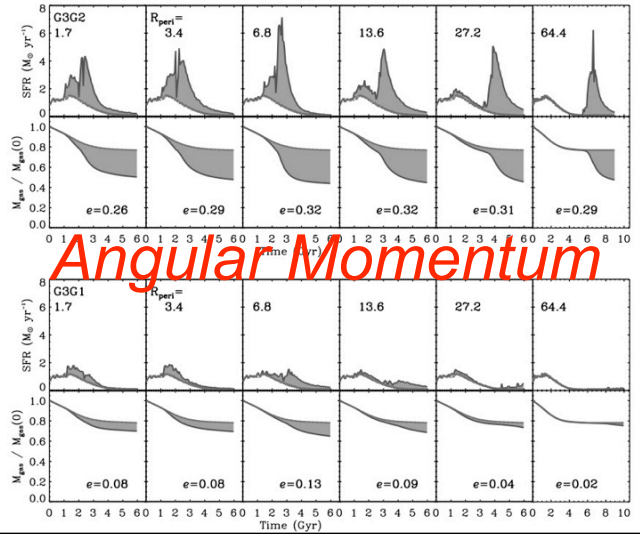


B/D

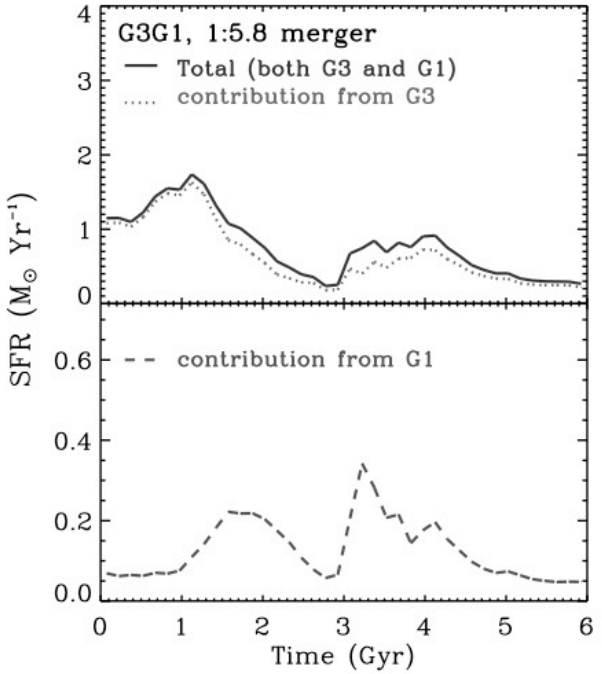


Orientation





Angular Momentum



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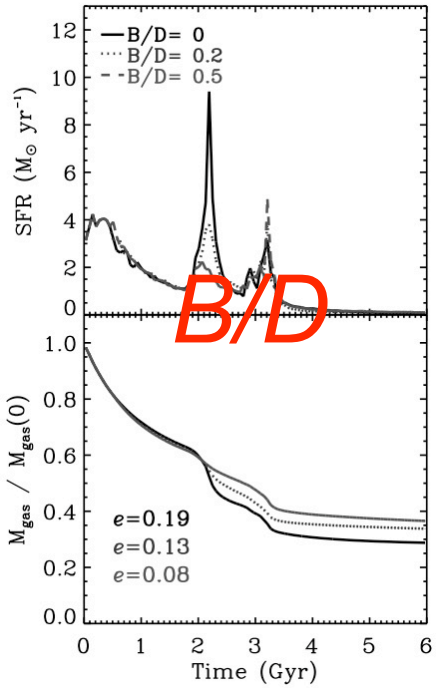
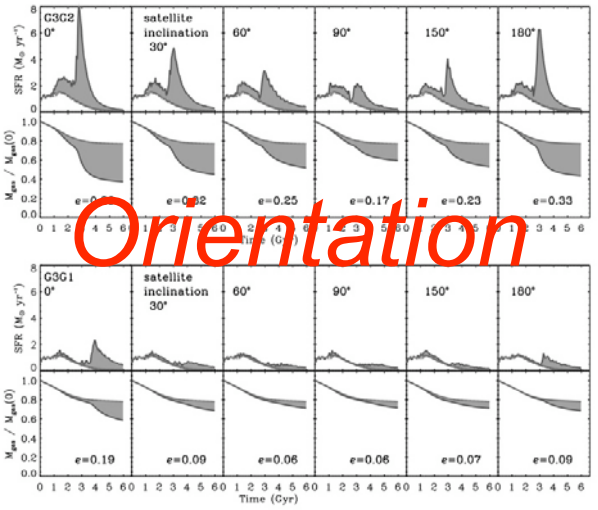
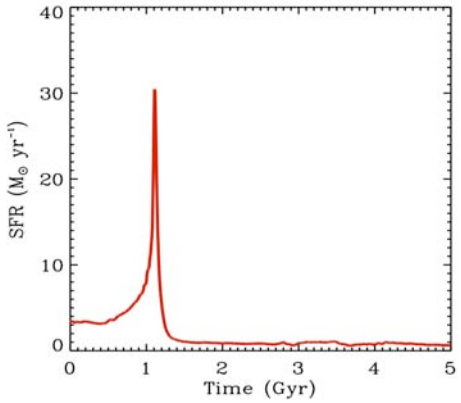
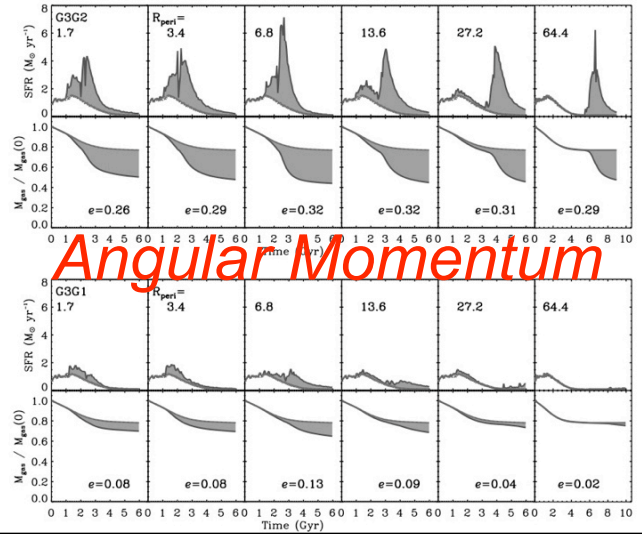


B/D



Orientation





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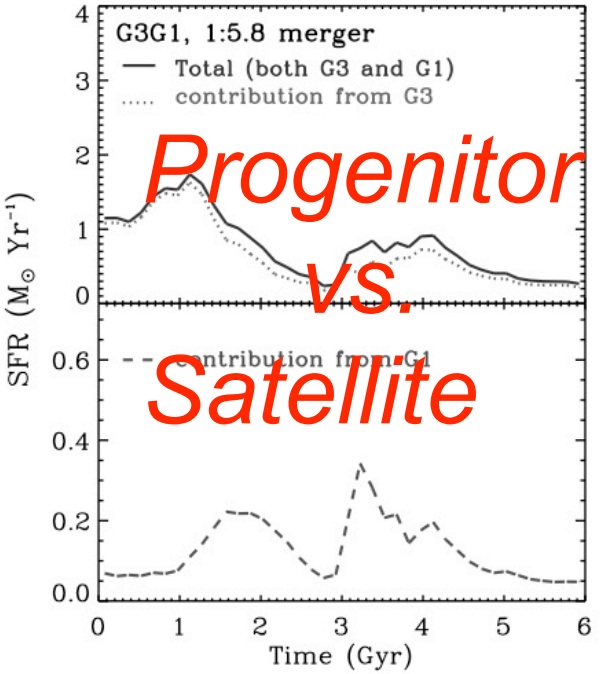
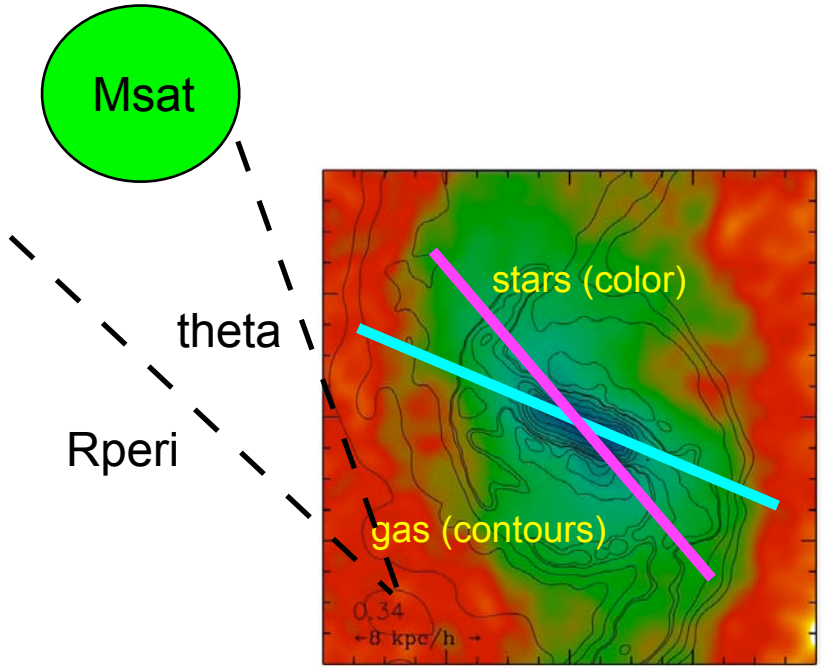


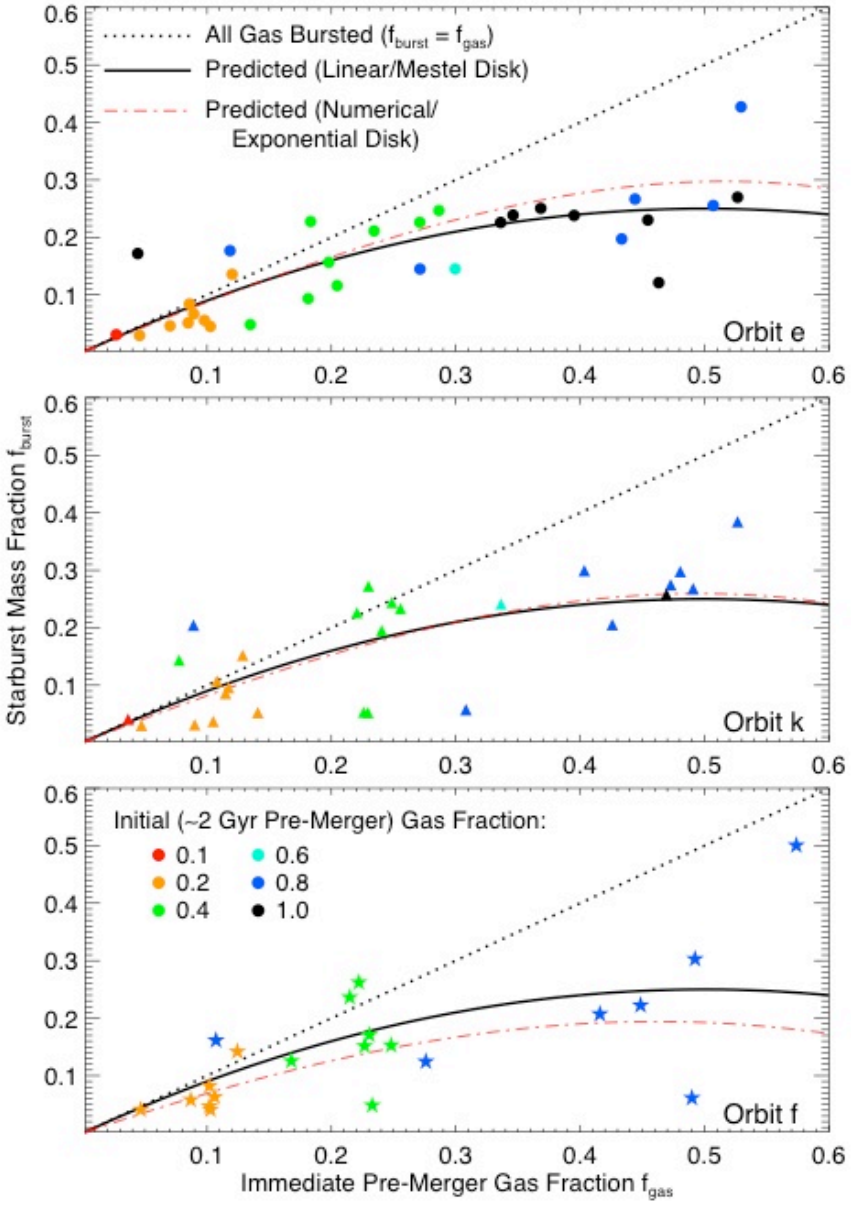
Progenitor vs. Satellite

Star Formation

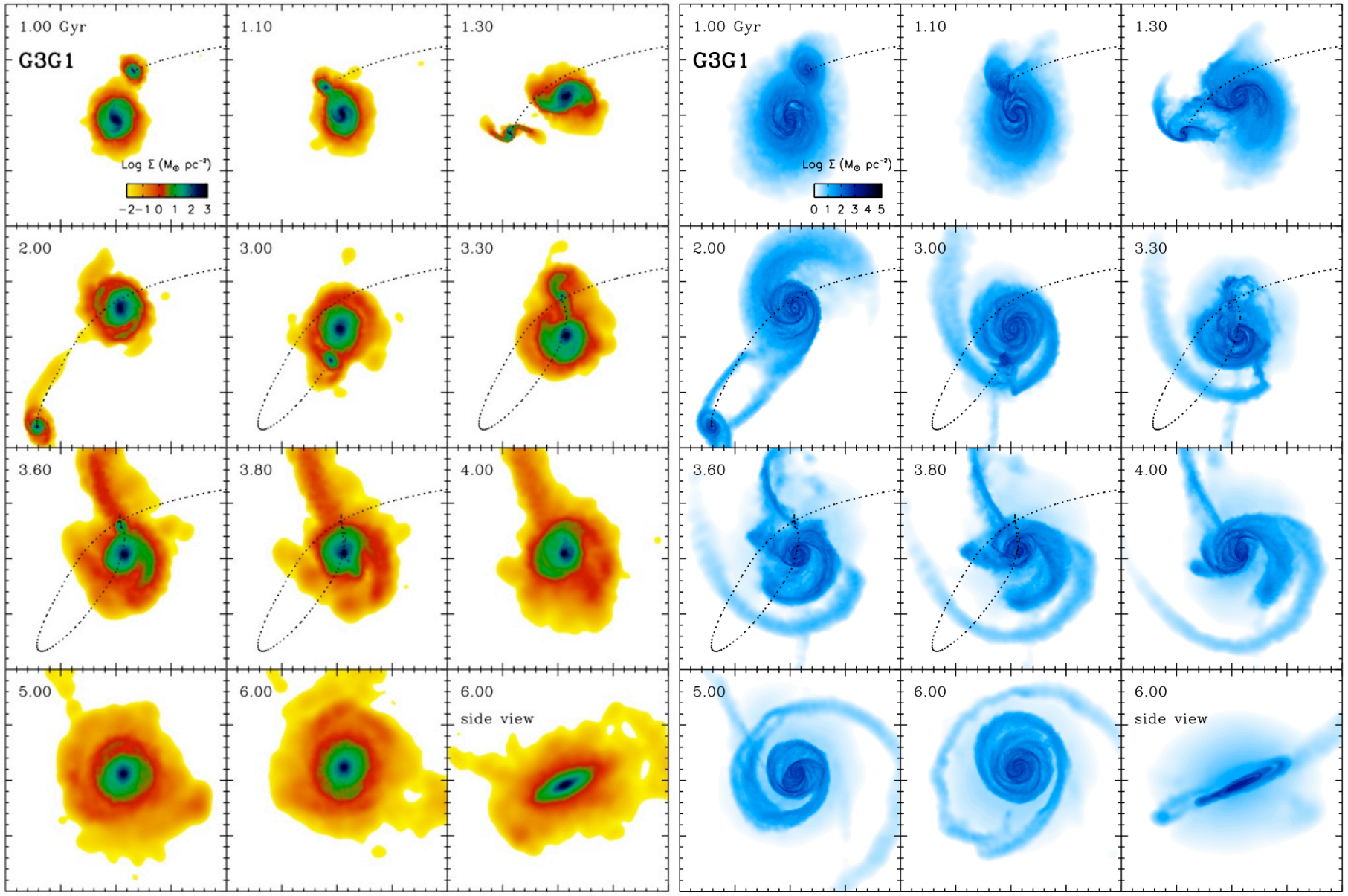
Hopkins et al. (2008) provides physical understanding of burst fraction.



fgas



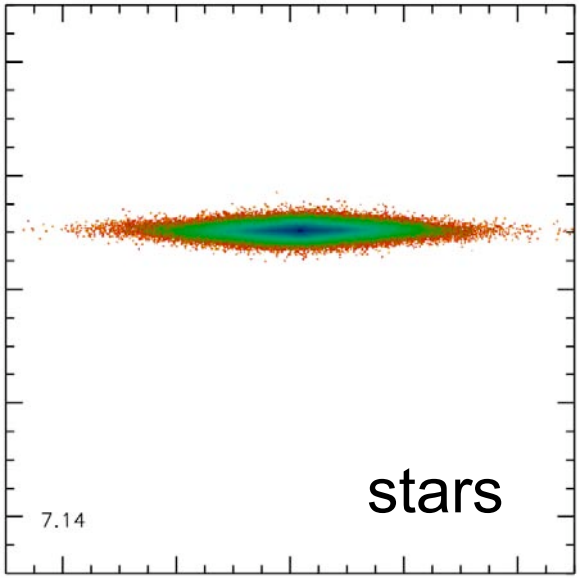
Morphology of Minor Merger Remnants

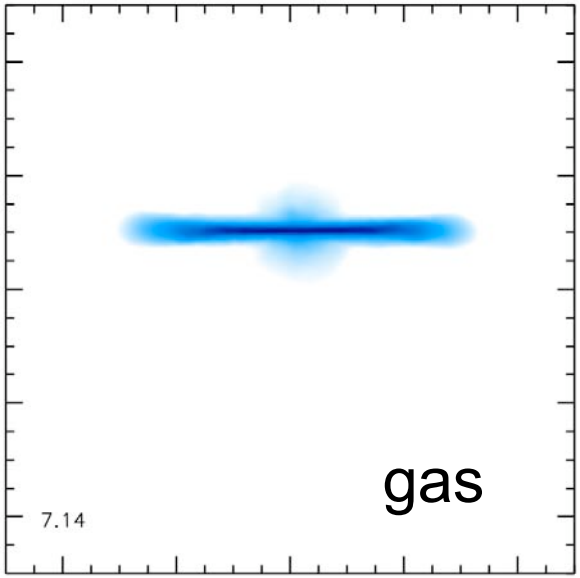


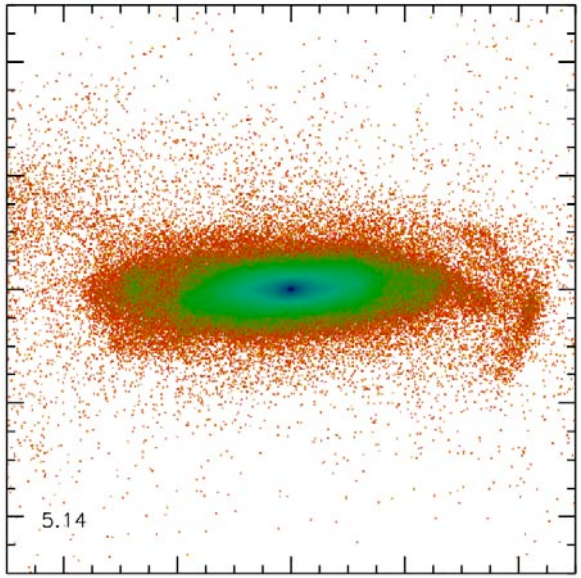
Impact of Minor Mergers

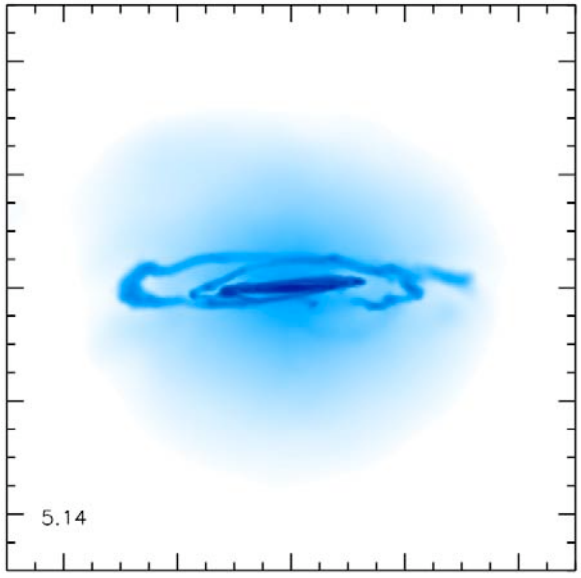
initial

post 1:8 merger



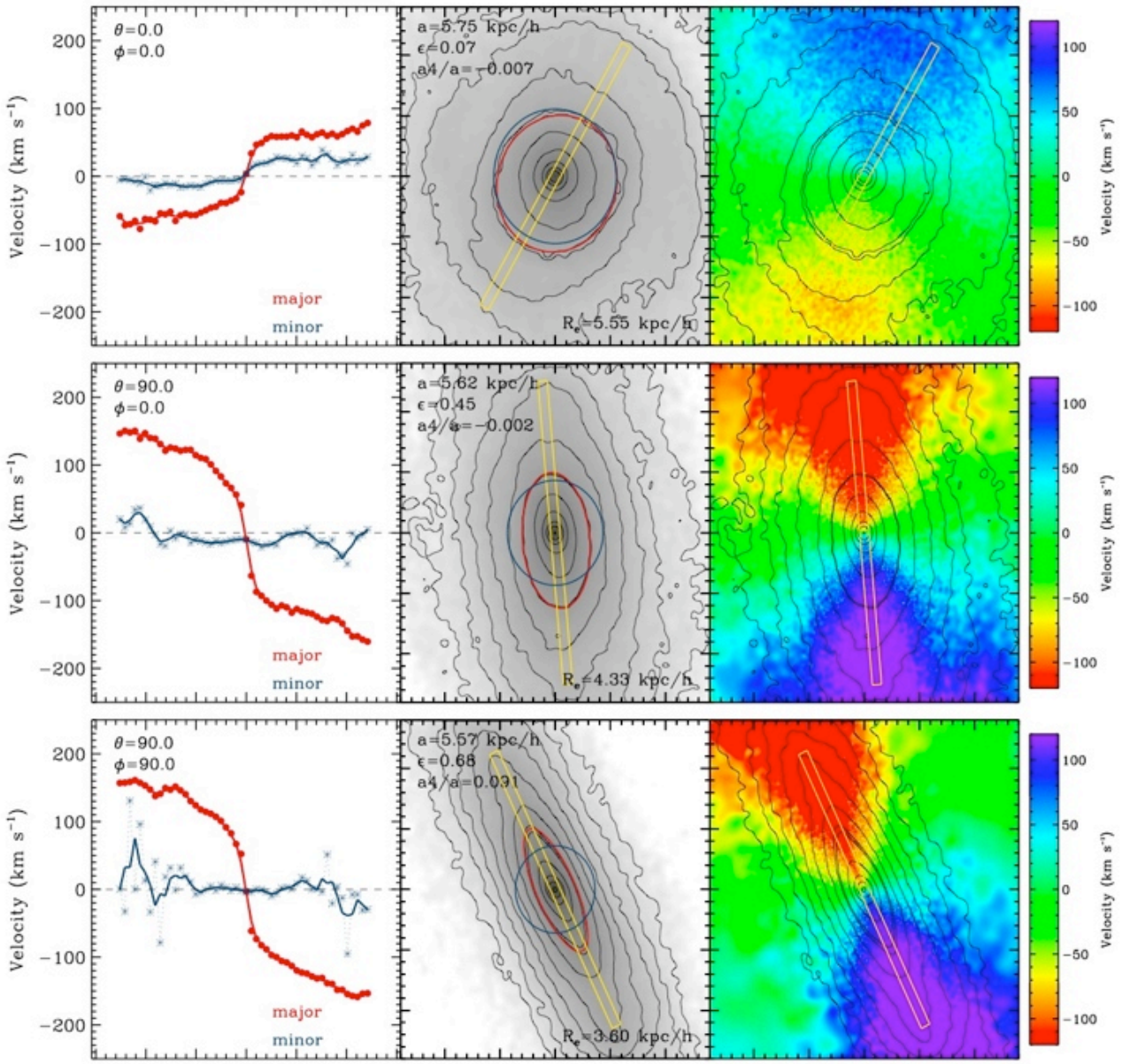






Impact of Minor Mergers

nearly co-planar (30 deg.), 1:8 remnant viewed from 3 orthogonal viewing angles.



Impact of Minor Mergers

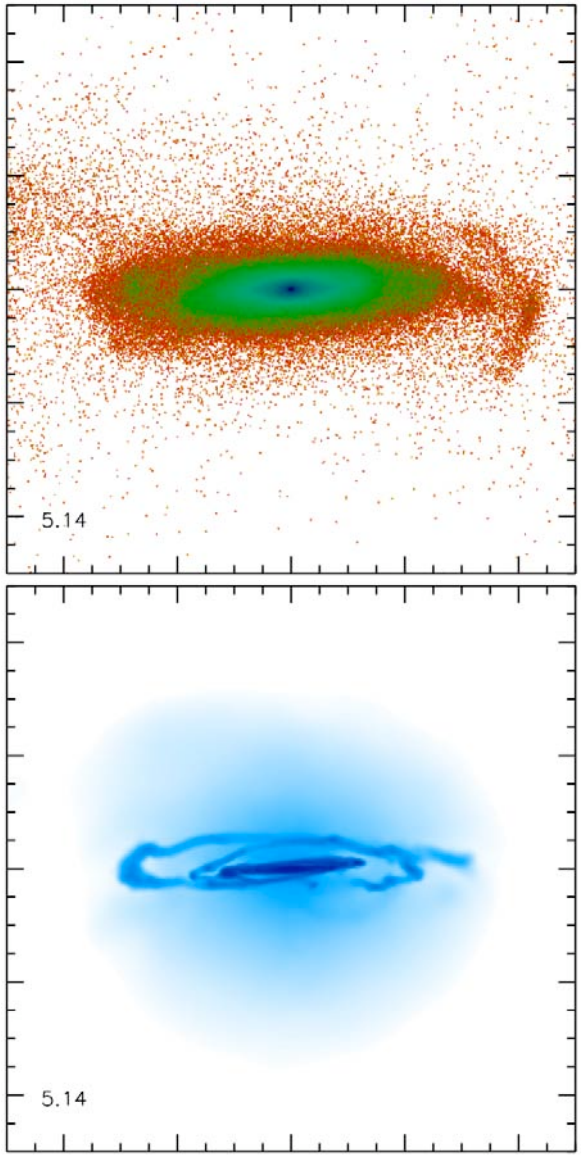
post 1:8 merger

- pronounced “fine” structure, much of which is at large radii (similar to the Monoceros ring? Younger et al. 2008, Kazantzidis et al. 2008)

- bulge-like concentration of stellar mass at remnant center

- stellar disk is thickened and heated

- thin, dynamically cool gaseous disk, with a warm diffuse component

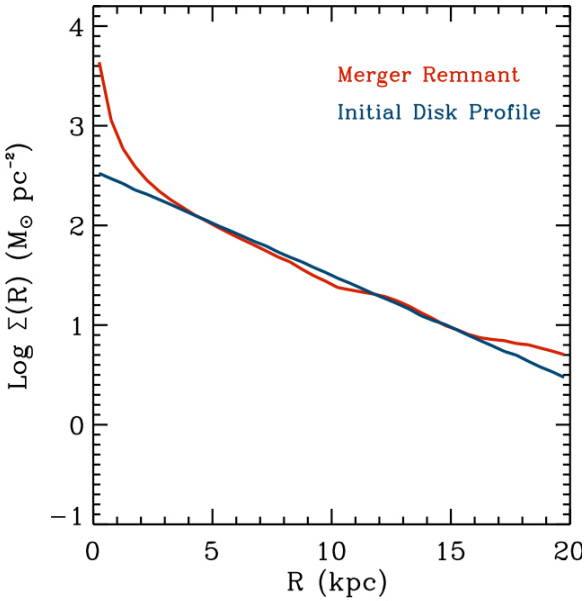


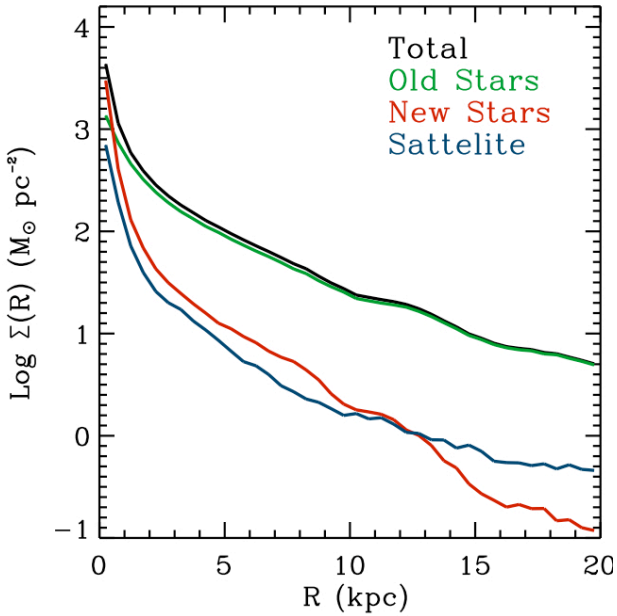
Bulge Formation

- Surface brightness profiles have a distinct bulge-like excess at galaxy center (a point made by many other authors, e.g., Aguerri et al. 01, Eliche-Moral et al. 06, Bournaud et al. 05,07, Naab & Trujillo 06, Combes talk yesterday)

- In models with gas/sf/fb, the central excess dominated by stars formed during the merger-induced starburst

- Remnant bulge and disk were both part of primary's disk material (might expect similar colors? Balcells talk thss morning).

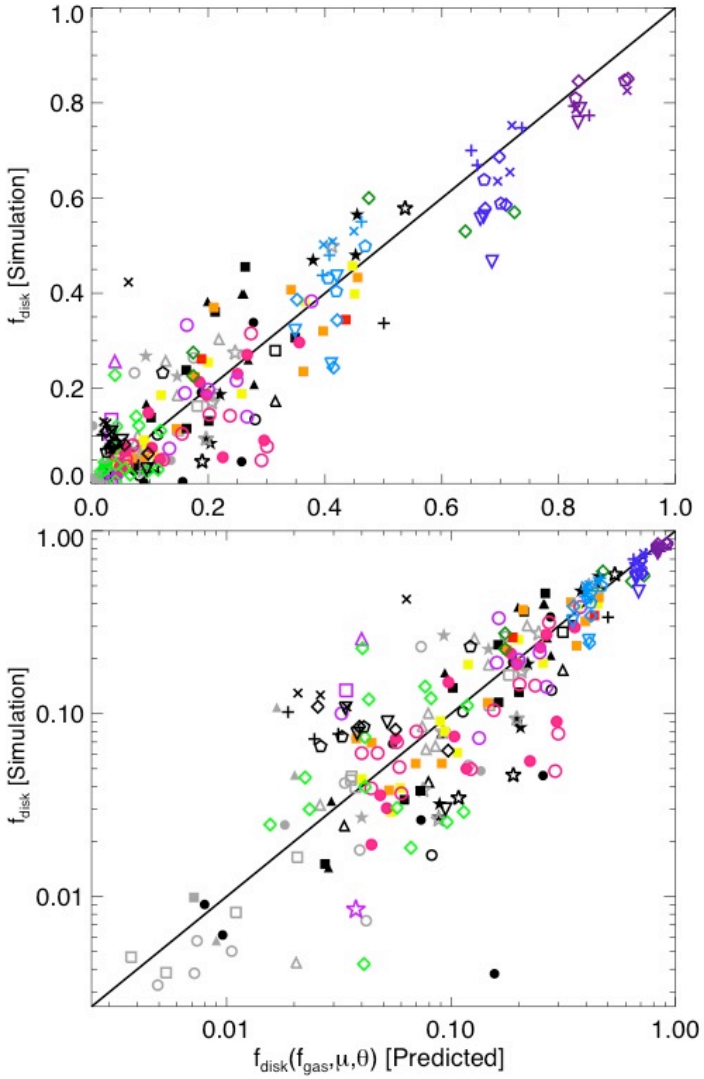




starburst fraction -> bulge

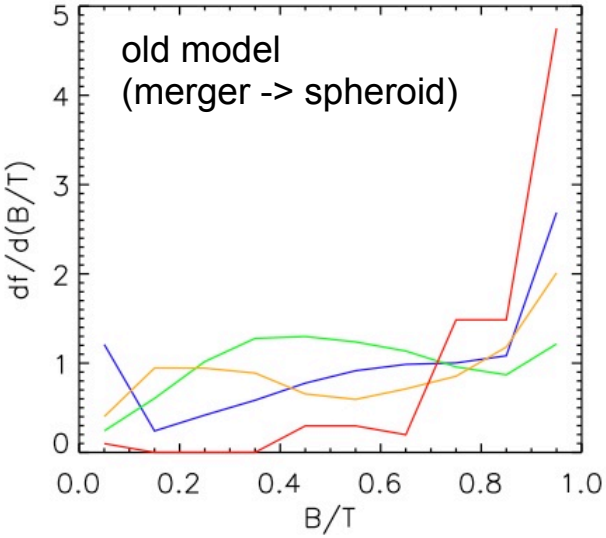
Bulge Formation

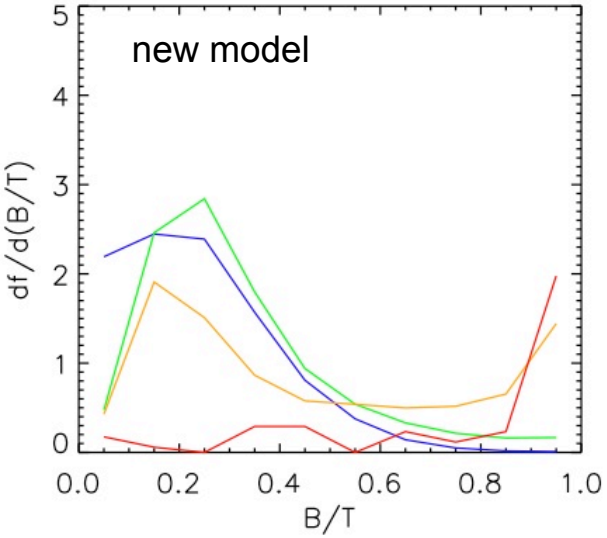
disk mass fraction (measured from simulations)



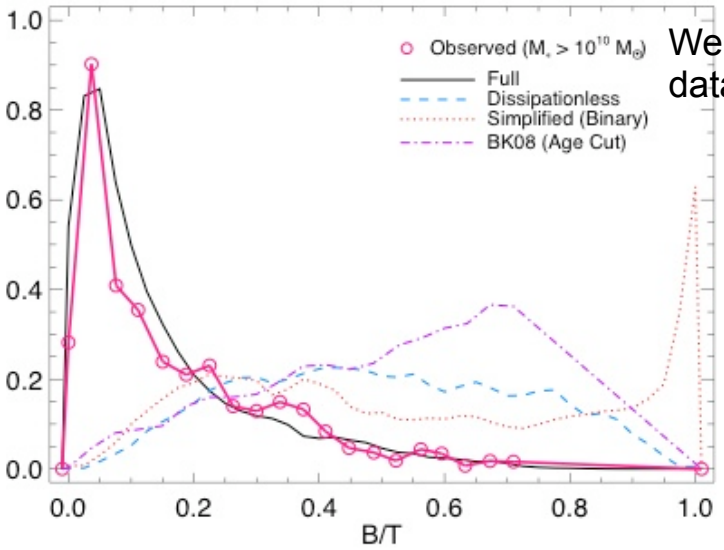
disk mass fraction (predicted, see Phil's talk on Friday)

Implications for B/D Ratio





Somerville et al. (in prep.) SAMs



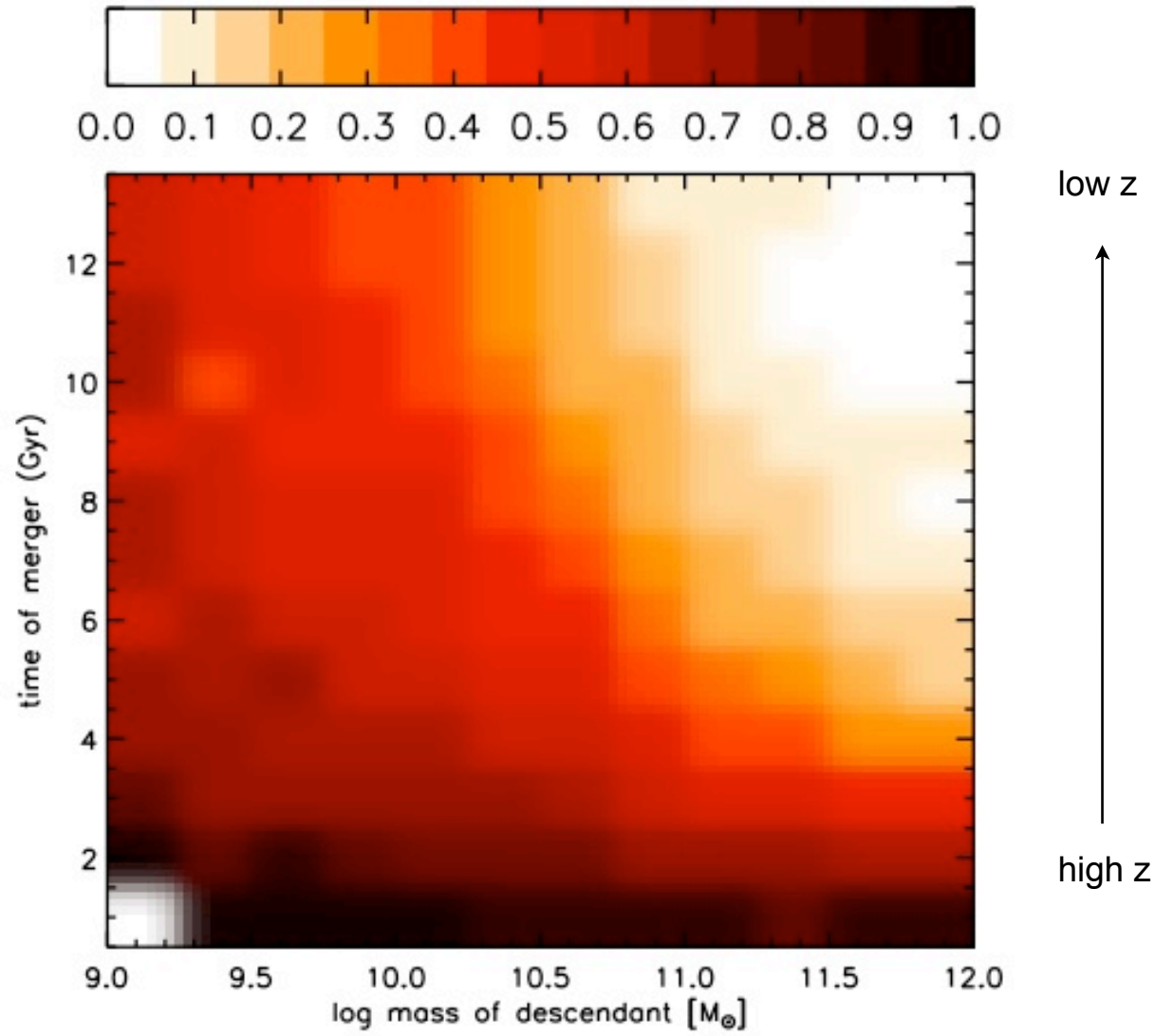
Weinzerl et al. data

Hopkins et al. (in prep.) SEMs

* Compare/ contrast to poster by Koda and Khochfar's talk earlier today.

Implications for B/D Ratio

Merger Gas Fraction

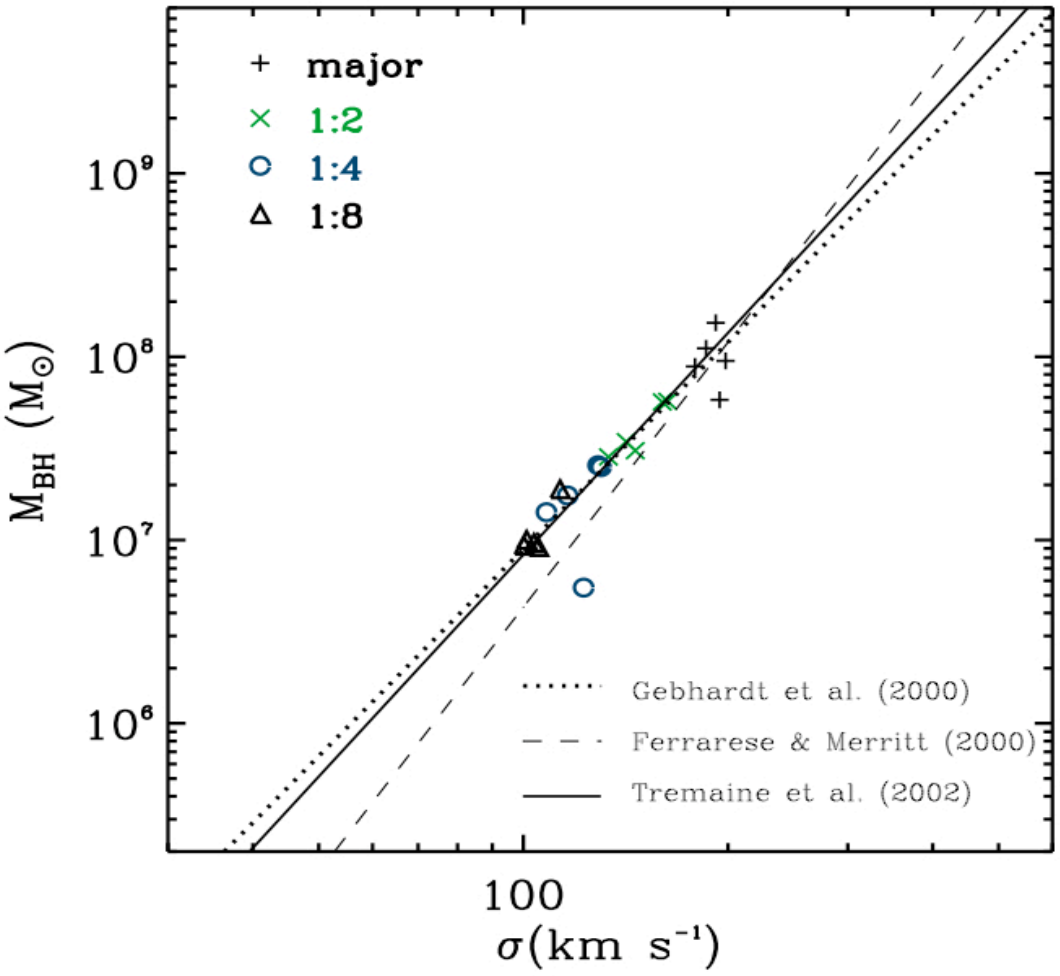


low z

high z

BH-Bulge Correlations

- BH growth is regulated by feedback and, similar to the case of major mergers, leads to a tight relation with properties of the stellar spheroid.

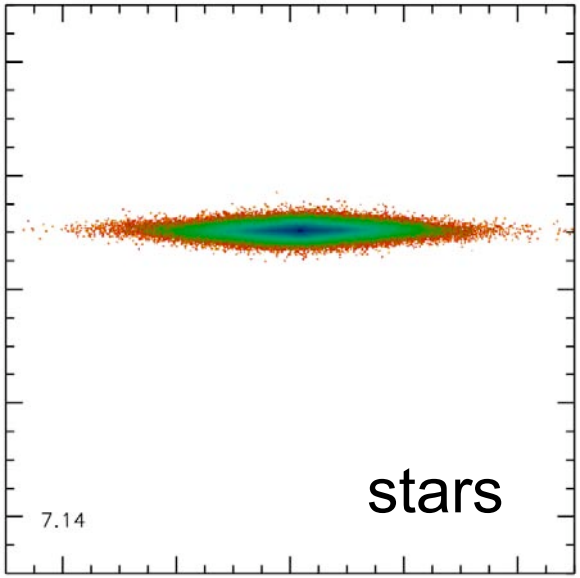


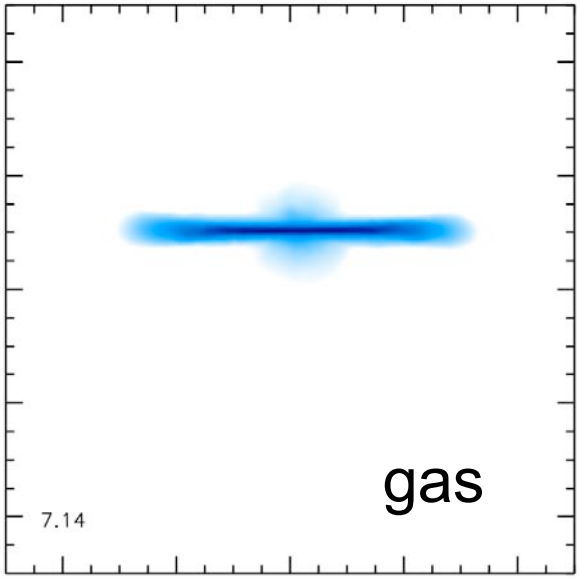
similar story to the major mergers - see, e.g., Di Matteo et al. (2005), Springel et al. (2005), & Hopkins et al. (2005/6/7/8)

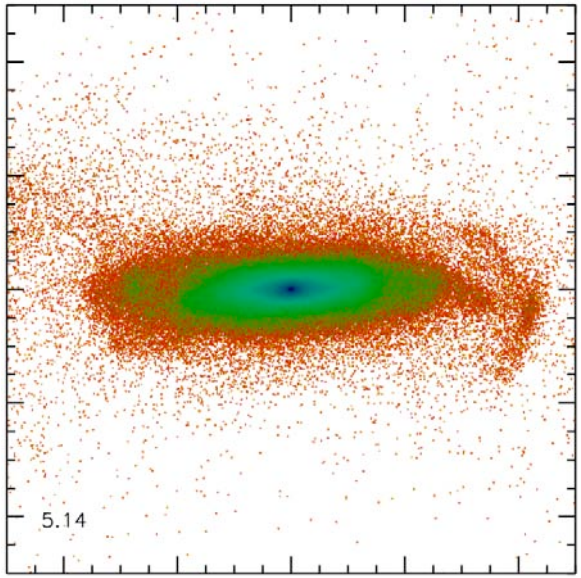
Impact of Minor Mergers

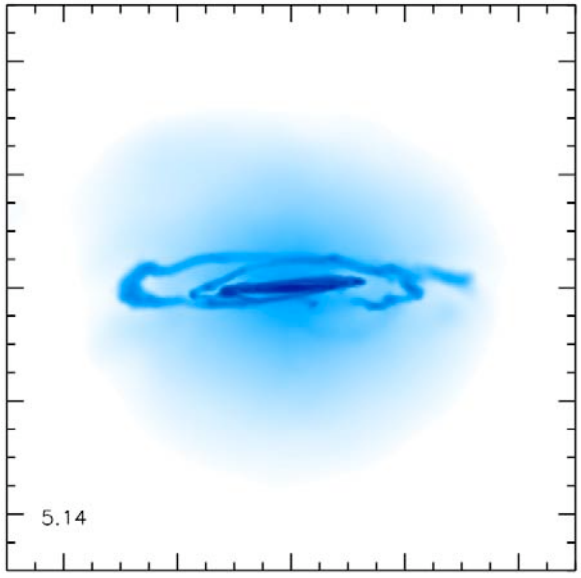
initial

post 1:8 merger

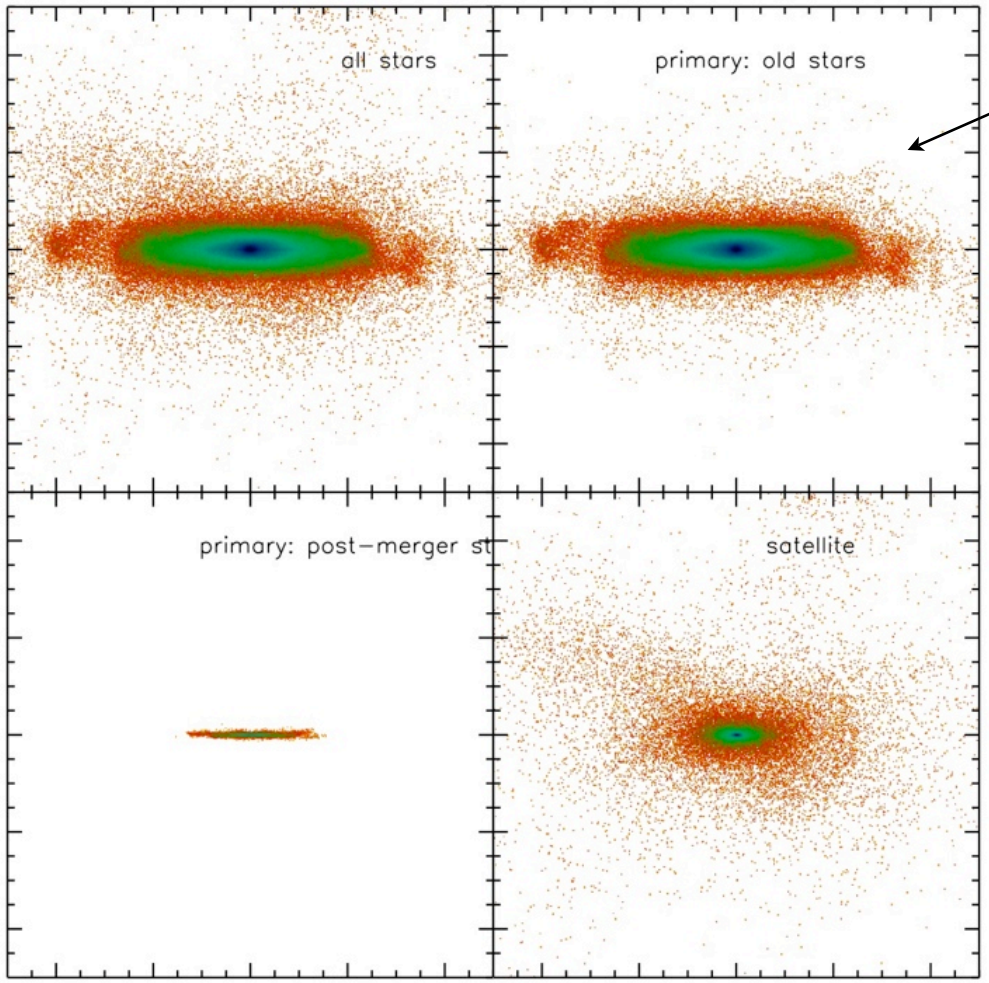




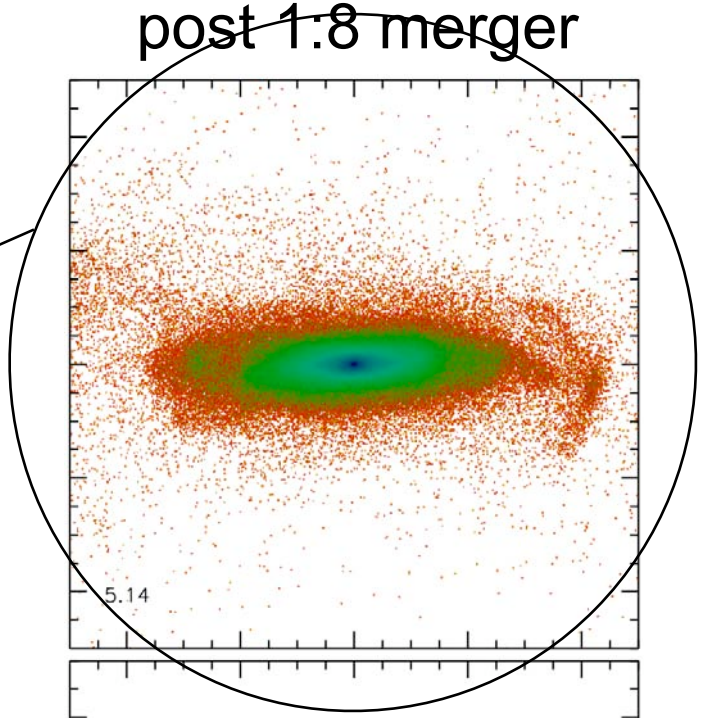


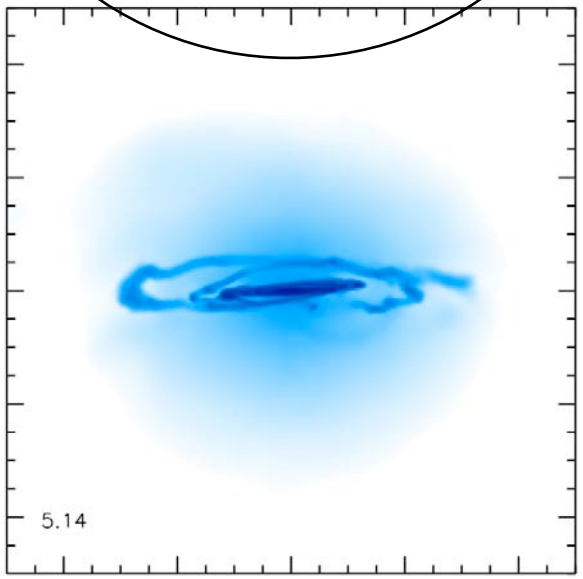


Impact of Minor Mergers



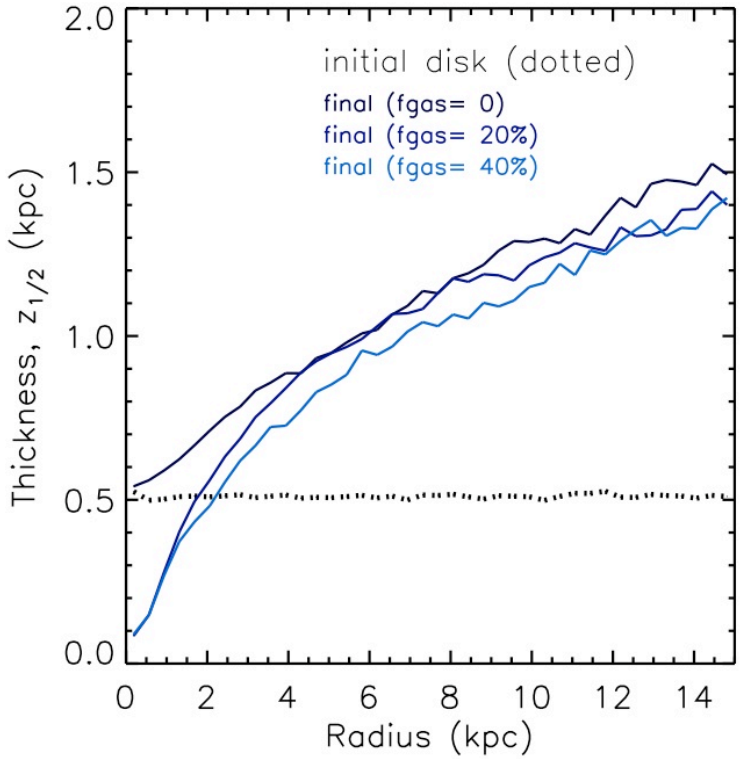
post 1:8 merger

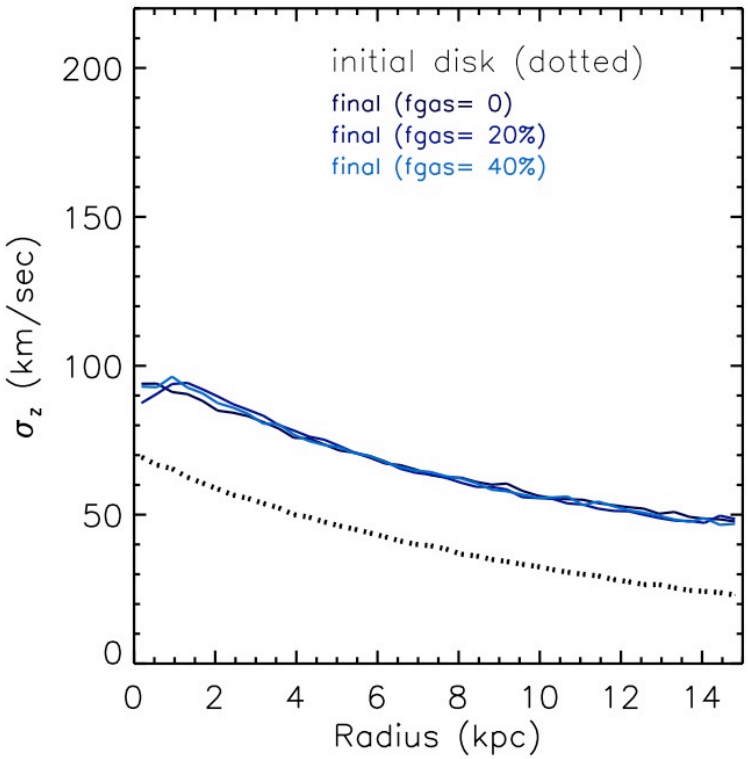




Implications for Galactic Disks

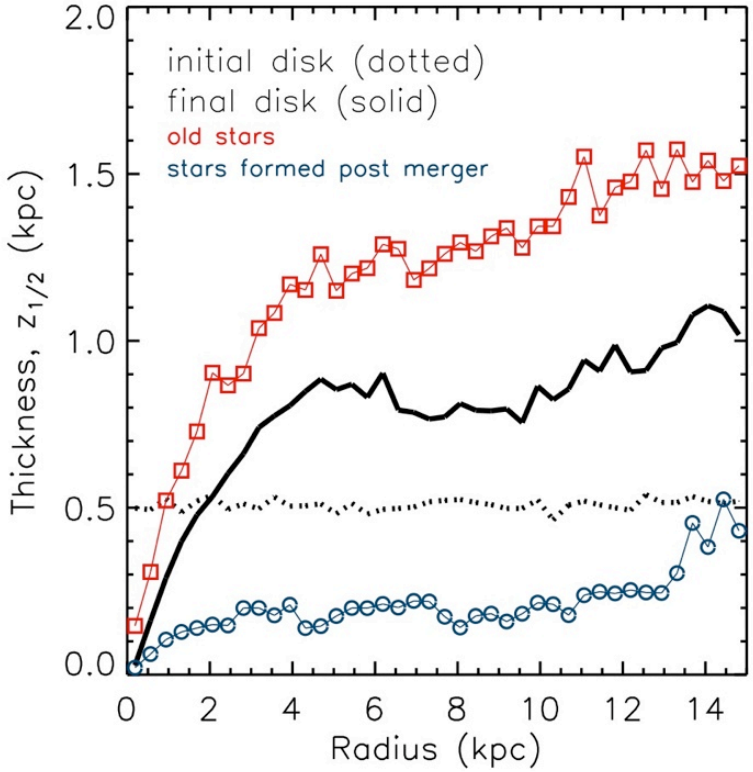
Mergers thicken and heat galactic disks (demonstrated by many authors, e.g., Quinn & Goodman 86, Hernquist & Quinn 86,90, Toth & Ostriker 92, Walker et al. 96, Velazquez & White 99, Kazantzidis et al. 08, see also Stewart's talk later today and poster by Purcell)

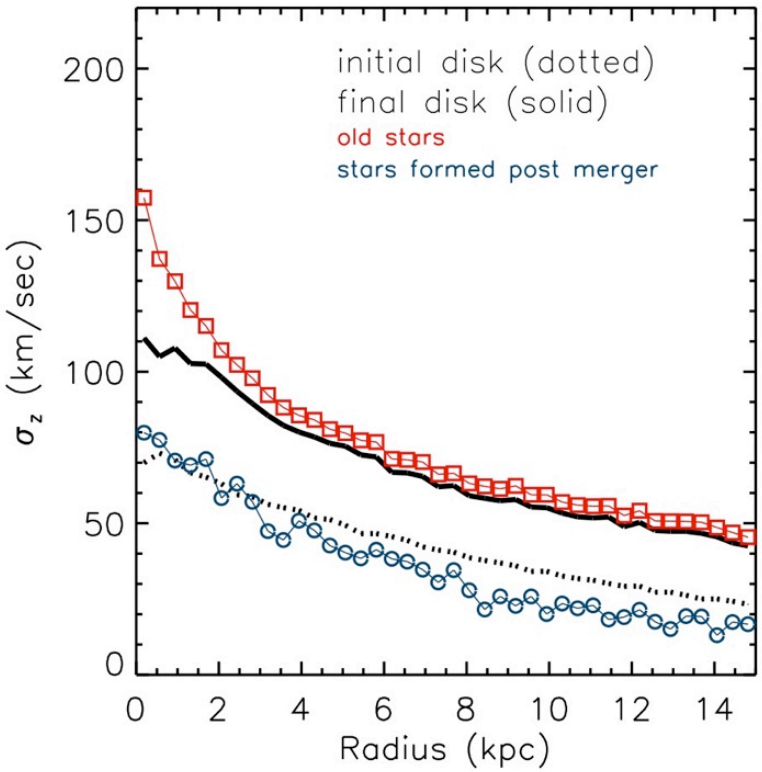




Implications for Galactic Disks

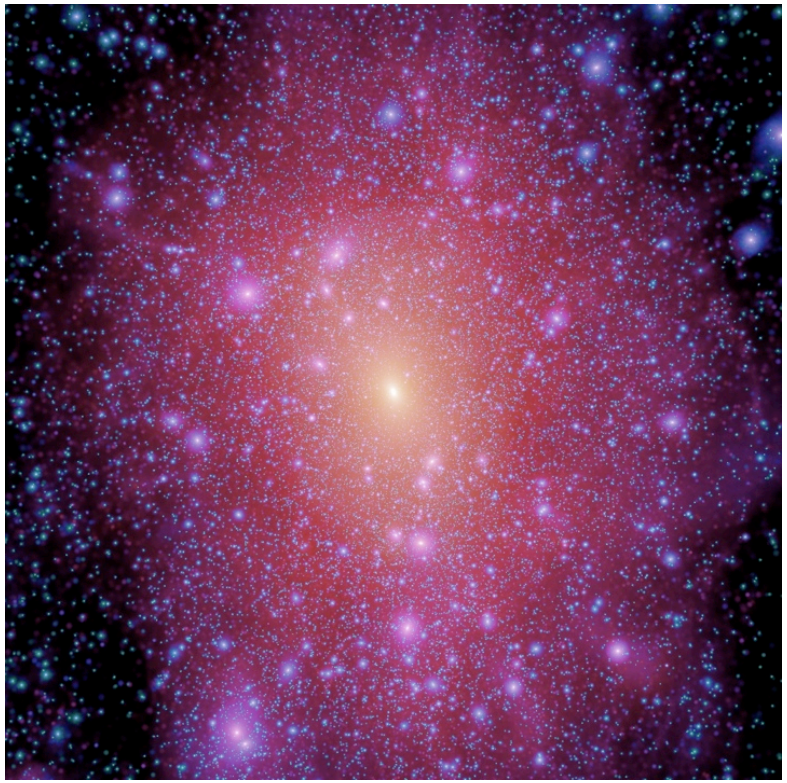
Stars formed in the remnant gas disk are thin and cold.
Supporting a long-stranding assertion.

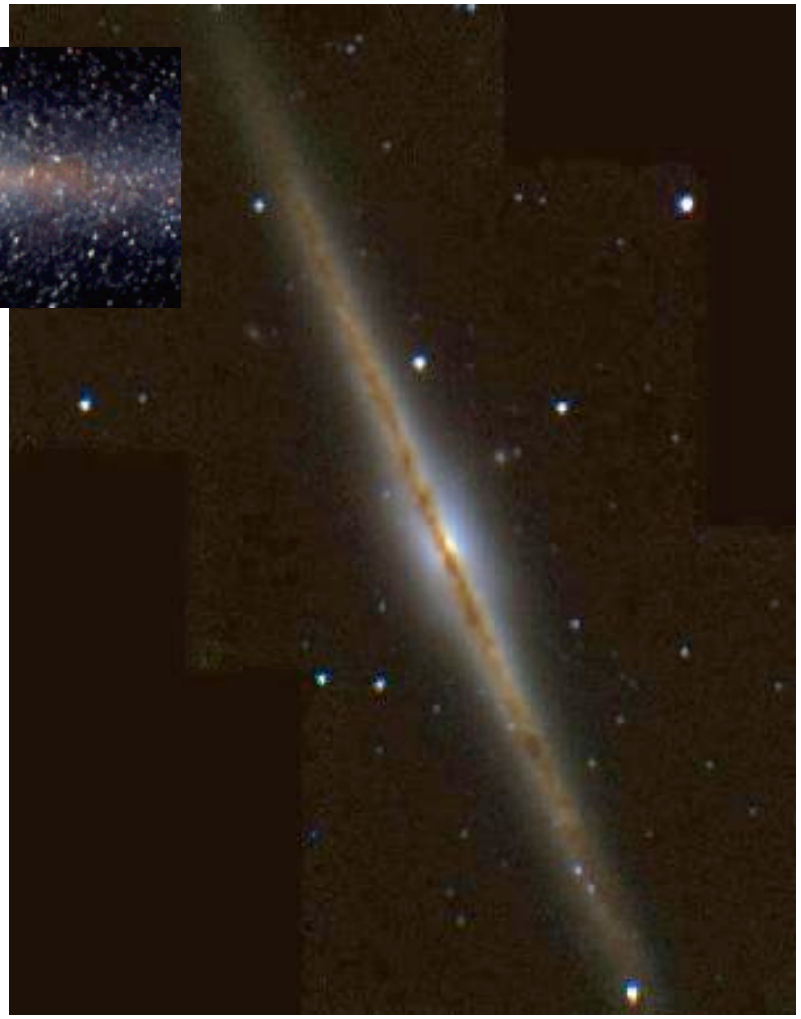




Implications for Galactic Disks

Unclear whether this can help to explain bulgeless (or non-classical bulge) galaxies.





The Impact of Minor Mergers

* We now have (the foundation of) a physical model that can predict the induced star formation and bulge growth during galaxy mergers.

* Many mergers, even major ones, can leave behind a disk component.

* This model can help to understand the abundance of low-B/T galaxies.

* Stars born from the remnant gaseous disk are thin and cold.

- Still a lot of work to be done ....