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Back to the green valley: how to rejuvenate an S0 galaxy through minor mergers

COLLABORATORS: Roberto Rampazzo, Antonietta Marino, Alessandro Trani, Brunetto Ziosi, Mario Spera, Alessandra Ferri, Andrea Moretti

EWASS 2015, Sp3, Tenerife, Canary Islands, June 22nd 2015

OUTLINE

1. Why do we care about star formation in S0 galaxies?

2. State-of-the art simulations

3. My models for minor mergers
   - → gas rings
   - → stellar and gaseous halos
   - → star formation

4. Discussion: how many minor mergers?

5. Conclusions

1. Why do we care about star formation in S0 galaxies?

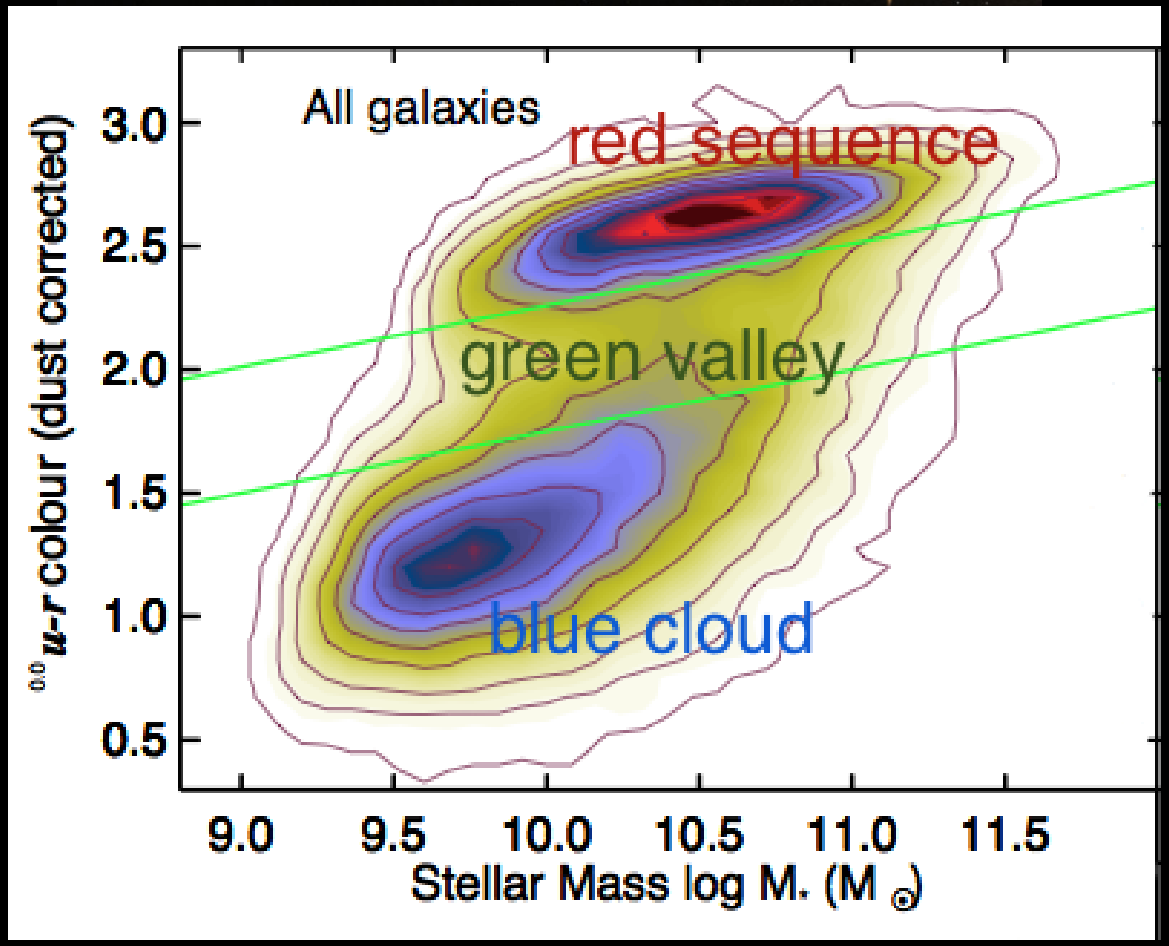
1. S0 galaxies are peculiar objects: have disc but are mainly gas poor (early type galaxies with a disc!)

2. star formation rate (SFR) is >0 in many S0 galaxies

Most ellipticals are read and dead

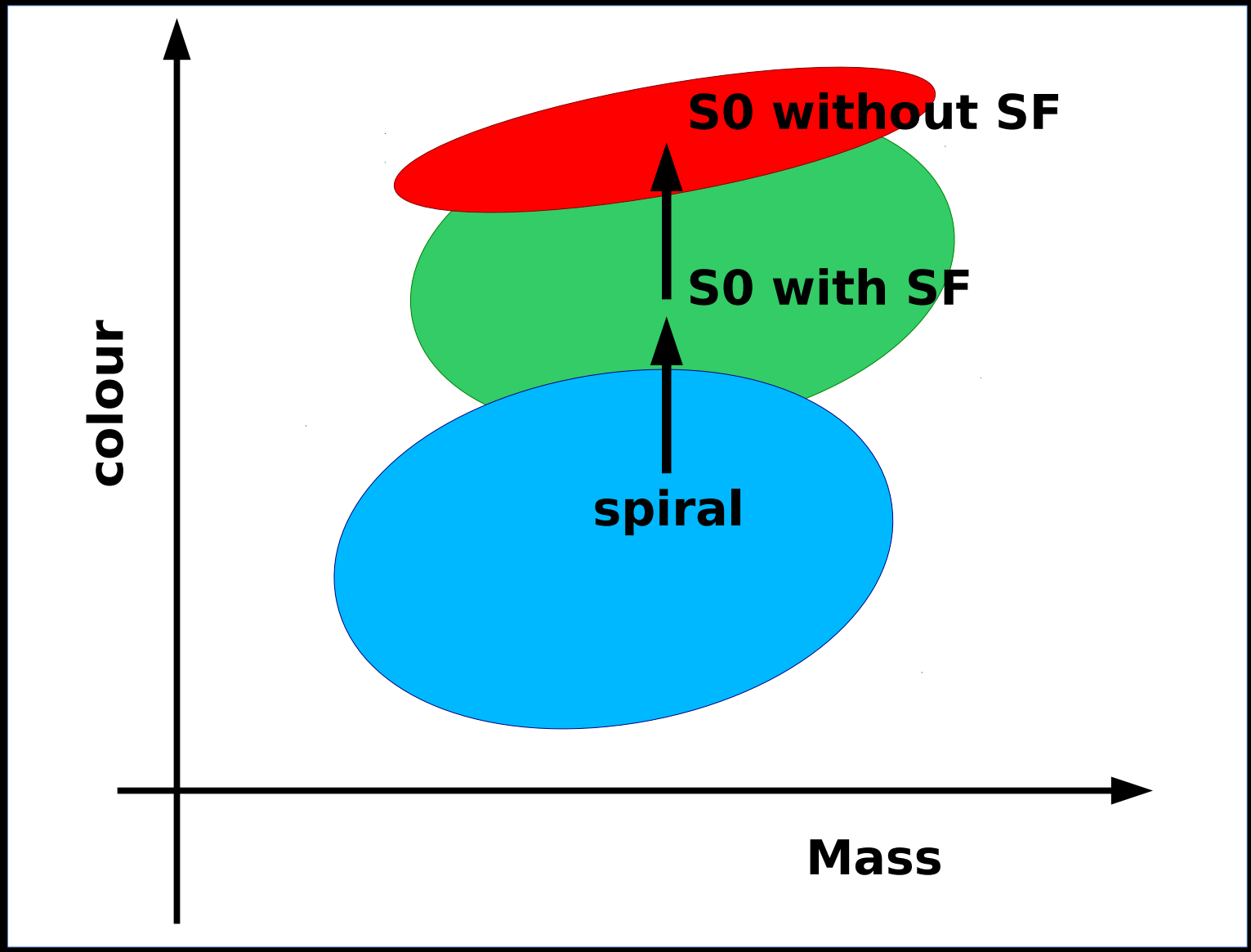
Most spirals are blue and alive

Half of S0 galaxies are in between (GREEN VALLEY)



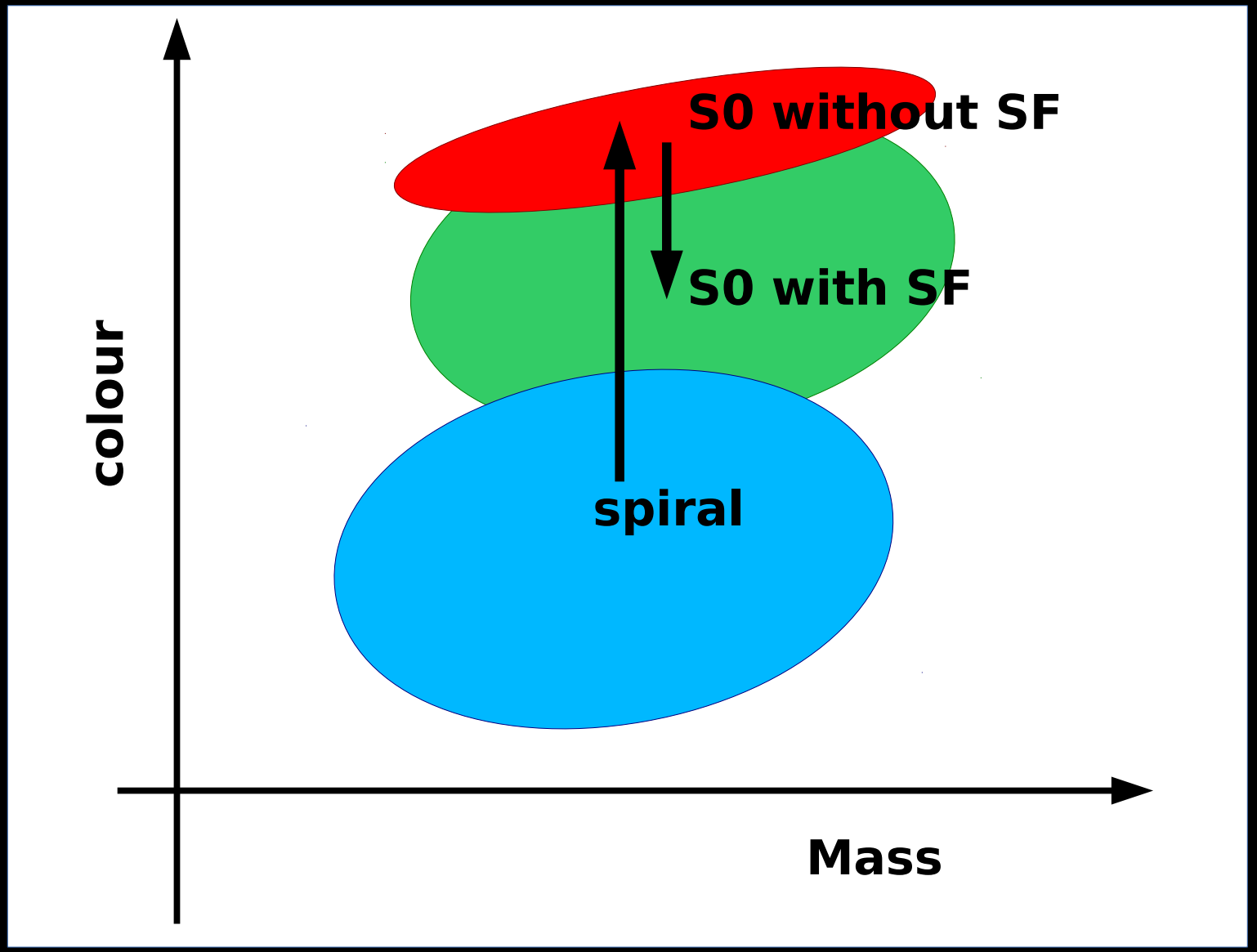
Credits: galaxy zoo

STAR FORMATION FADING (or recycling) ?



e.g. Salim et al. 2012

ACCRETION OF FRESH GAS (from mergers or accretion) ?



e.g. Salim et al. 2012

1. Why do we care about star formation in S0 galaxies?

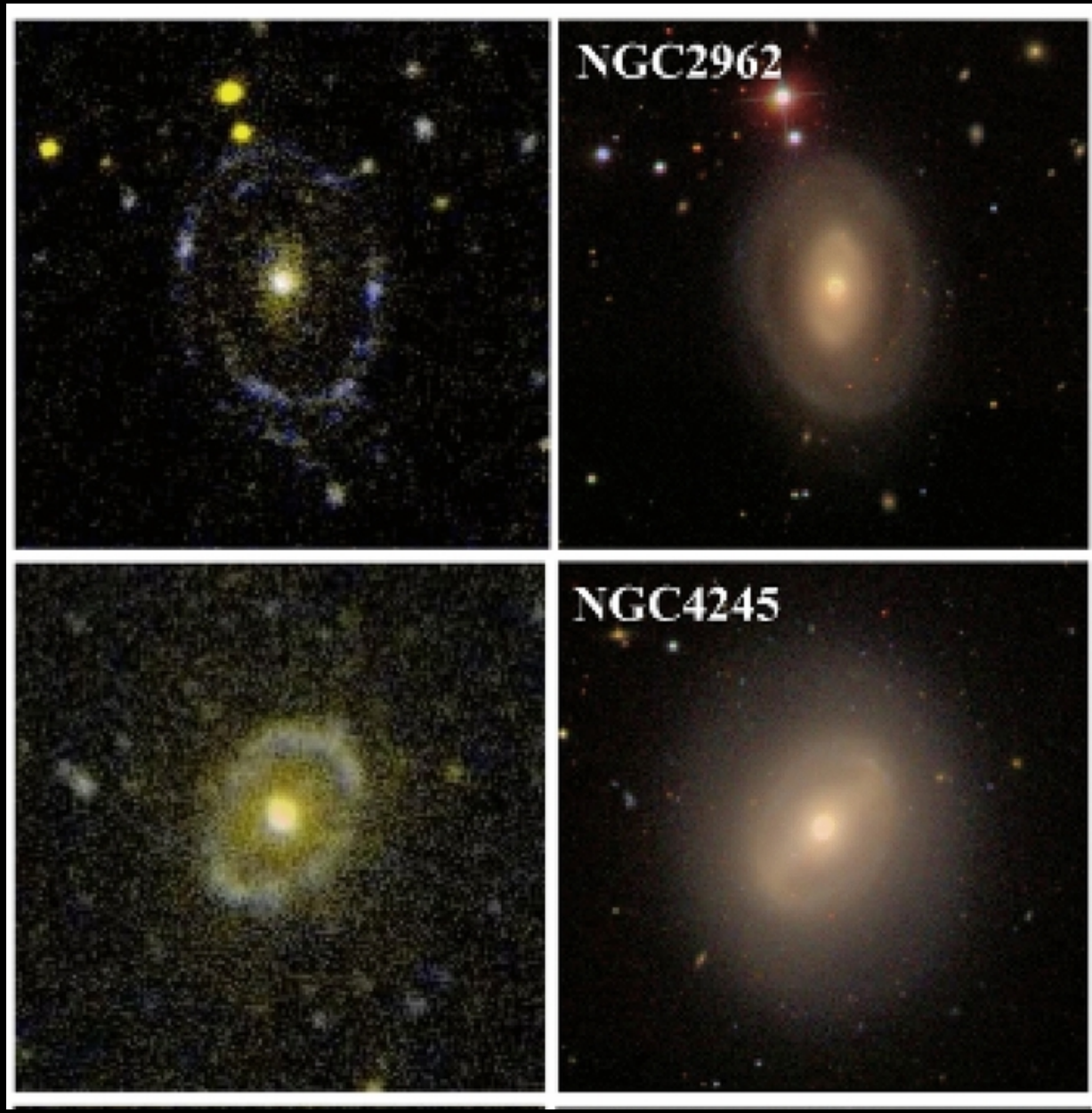
3. if we consider only S0 with SF (~0.5 Msun yr^{-1}, Salim+ 2012), most have RINGS (or ring-like structures)

- rings are EXTENDED (>25 kpc) or SMALL (<15 kpc)

~ 50% of rings are in BARRED galaxies (controversial)

HOW DO RINGS FORM??

Salim & Marino+ 2011, Salim+ 2012, Laurikainen+ 2013



From Marino et al. 2011

1. Why do we care about star formation in S0 galaxies?

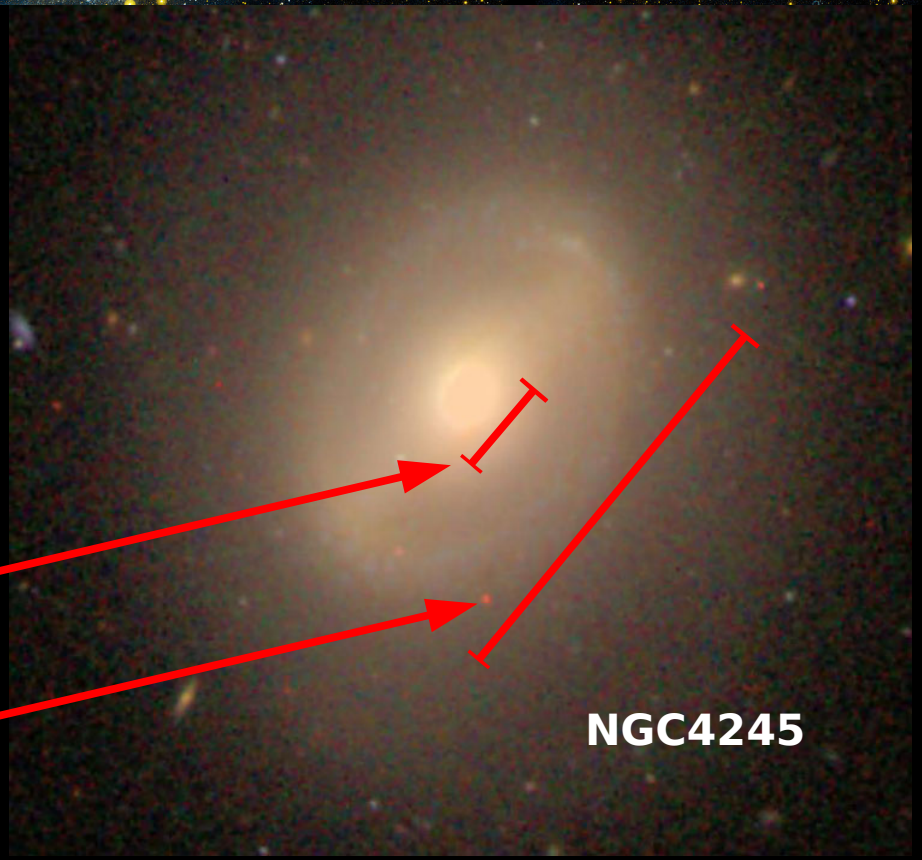
HOW DO RINGS FORM??

INTERNAL MECHANISMS:

→ fading star formation might proceed in rings

→ SECULAR EVOLUTION, e.g. a BAR favours accumulation of gas in resonances

can be internal mechanism but also support of an external mechanism!

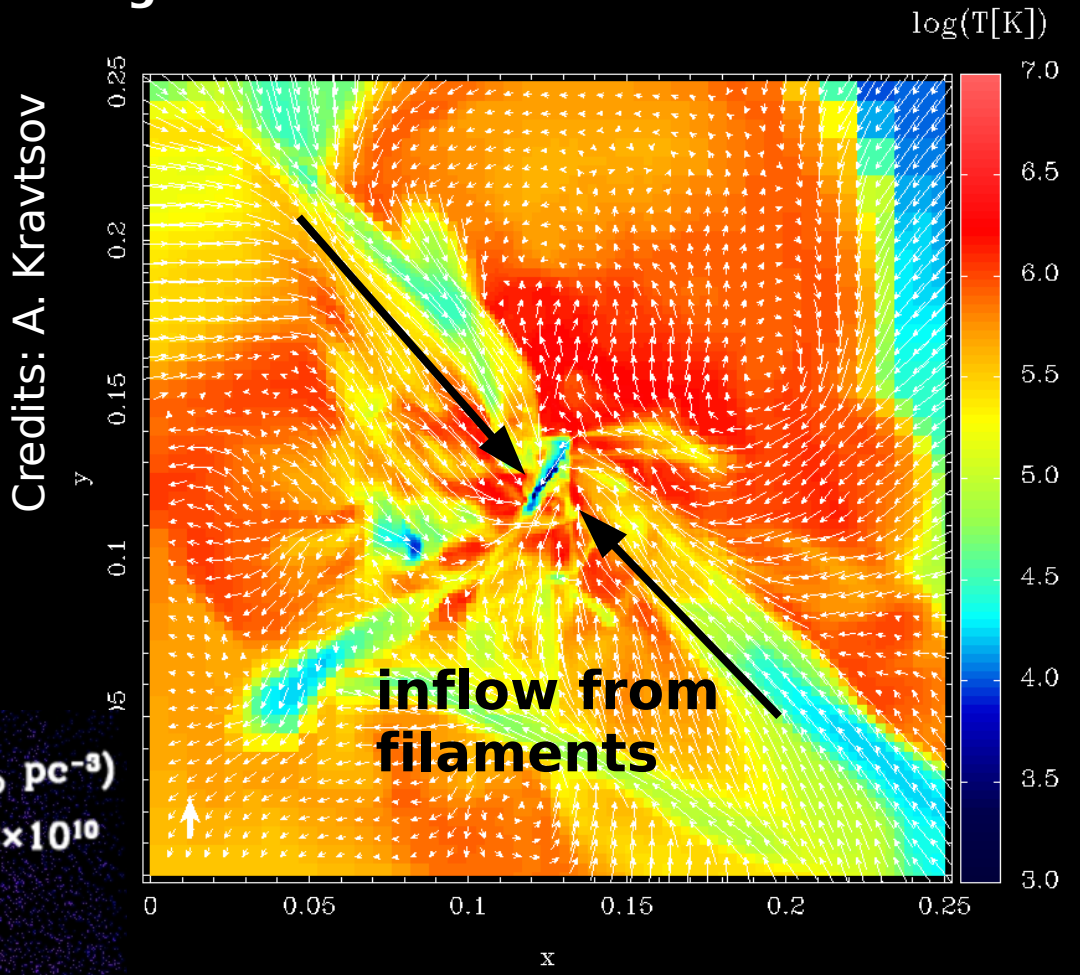


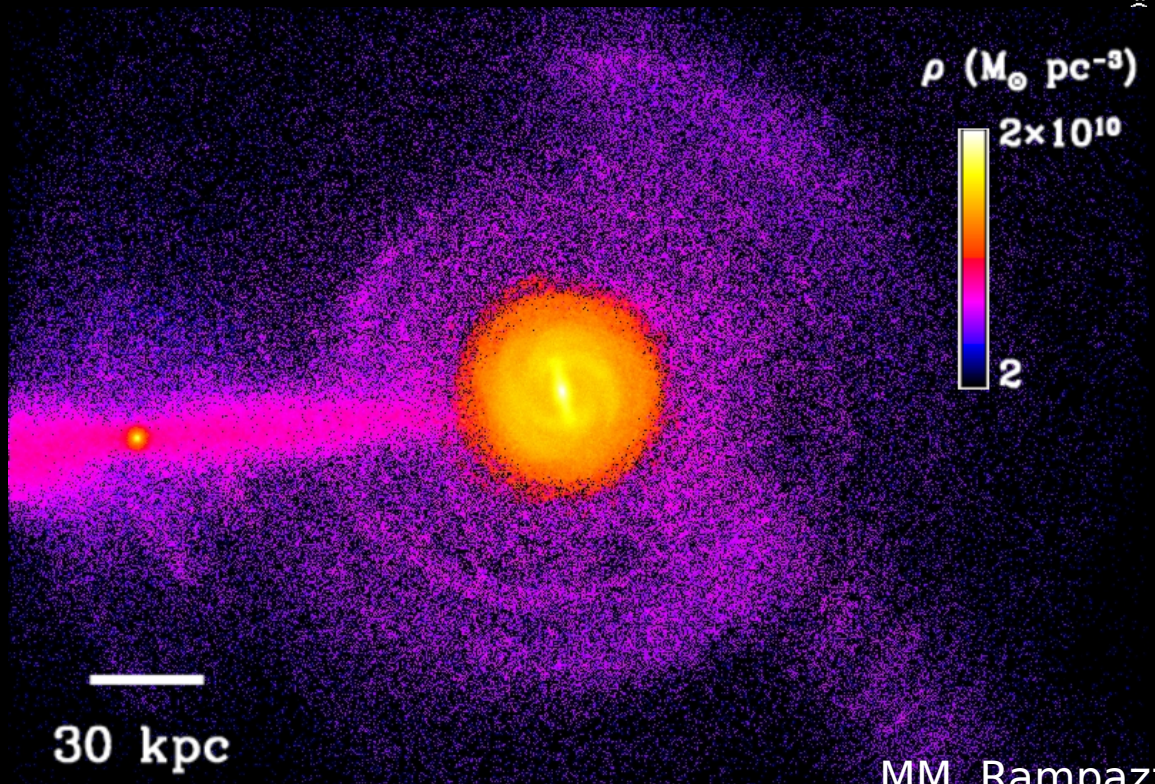
1. Why do we care about star formation in S0 galaxies?

HOW DO RINGS FORM??

EXTERNAL MECHANISMS:

→ accretion of smooth gas (e.g. filaments or cooling halo) from environment





→ mergers with gas-rich satellites

MM, Rampazzo & Marino 2015

HOW DO RINGS FORM??

According to Salim+ 2012

INTERNAL MECHANISMS:

→ fading star formation might proceed in rings

→ SECULAR EVOLUTION, e.g. a BAR favours accumulation of gas in resonances

EXTERNAL MECHANISMS:

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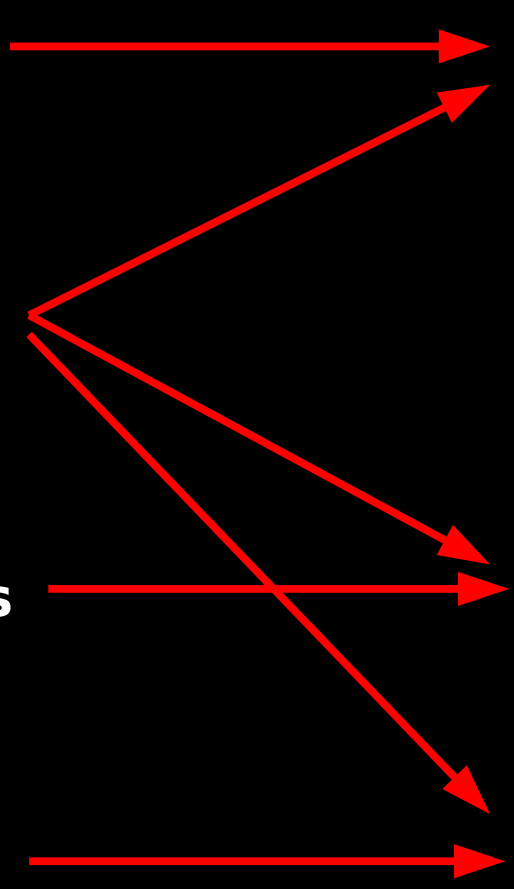
→ mergers with gas-rich satellites



~25%
(likely no more because rejuvenated S0s have larger discs than passive S0s)

~55%

~20%

Salim+ 2012 predict accretion to be more important than minor merger because rings are smooth and signs of disturbance rare

1. Why do we care about star formation in S0 galaxies?

HOW DO RINGS FORM??

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DO WE EXPECT VISIBLE DISTURBANCES FROM MINOR MERGERS?

HOW LONG DO THESE DISTURBANCES LAST?

→ **MINOR MERGER SIMULATIONS**

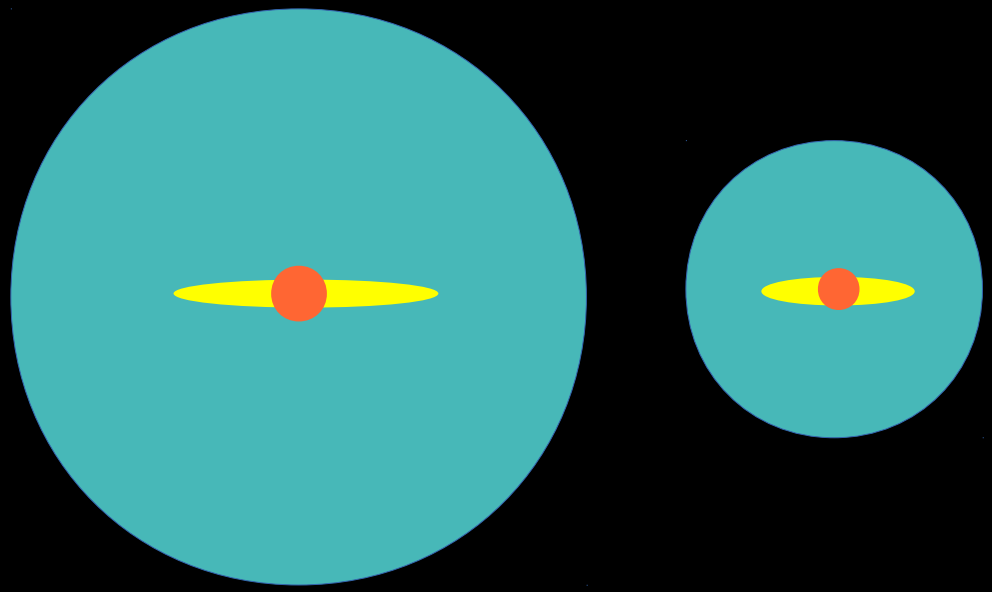
2. State-of-the-art simulations

It is hard to resolve details of minor mergers in cosmological simulations (dwarf galaxies are small)!

→ collisions between equilibrium-models of galaxies (Widrow & Dubynski 2005)

Navarro, Frenk & White DM profile

$$\rho(r) \propto r^{-1}(1+r)^{-2}$$



Hernquist bulge

$$\rho(r) \propto r^{-1}(1+r)^{-3}$$

Exponential disc

$$\rho(R,z) \propto \exp(-R)\,\mathrm{sech}^2(z)$$

→ nearly radial orbits (eccentricity ~1, marginally unbound)

cosmological simulations indicate that most mergers occur with eccentricity ~1 and large impact parameter (eg Khochfar & Burkert 2006)

→ N-body/smoothed particle hydrodynamics (SPH)

gasoline (Wadsley+ 2004)

ChaNGa (Jetley+ 2008, 2010; Menon+ 2014)

Star formation is a stochastic process:

gas particle denser than 0.1 cm^-3,
in an overdense region, in a converging flow,
and Jeans unstable collapses to a star
if probability p is sufficiently large

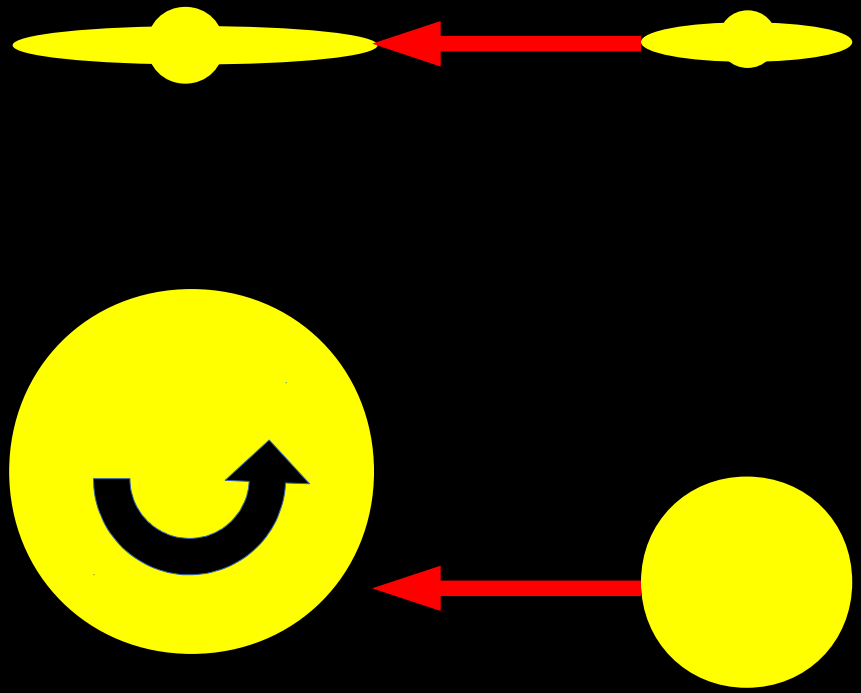
$$p = \frac{m_{\rm gas}}{m_{\rm star}} \left[1 - \exp\left(-\epsilon\, \Delta t / t_{\rm dyn}\right)\right]$$

enforces Schmidt law

Core-collapse supernovae: blast-wave model

Only thermal feedback
Gas does not cool down for a while after SN (Stinson+ 2006)

3. Models for minor mergers



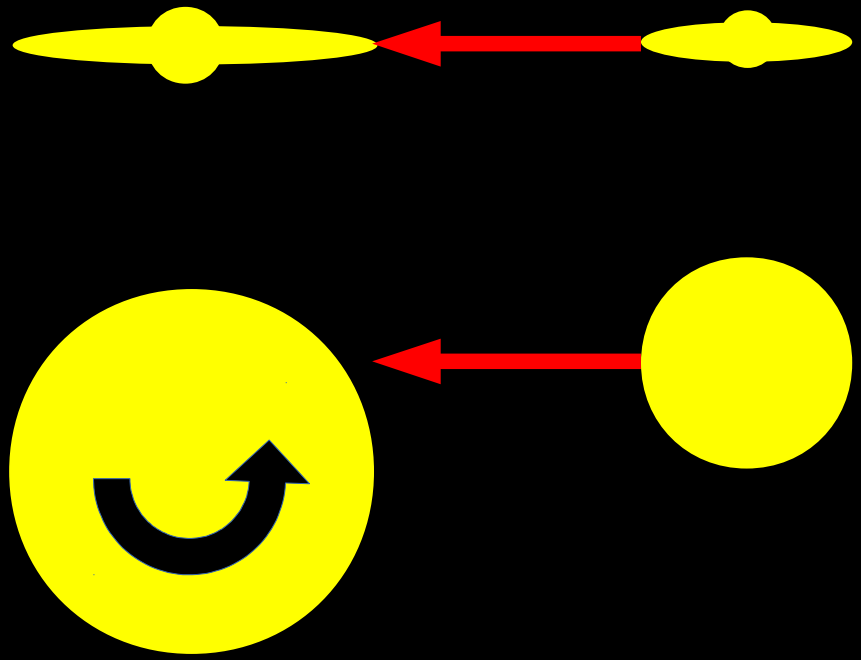
No gas in S0
Gas mass in satellite~2x10^8 M$\odot$
Mass ratio 1/20
Eccentricity ~1
Marginally unbound

Different orbits:

COPLANAR orbits:
- run A:
impact parameter~10kpc
retrograde

MM, Rampazzo, Marino 2015

3. Models for minor mergers



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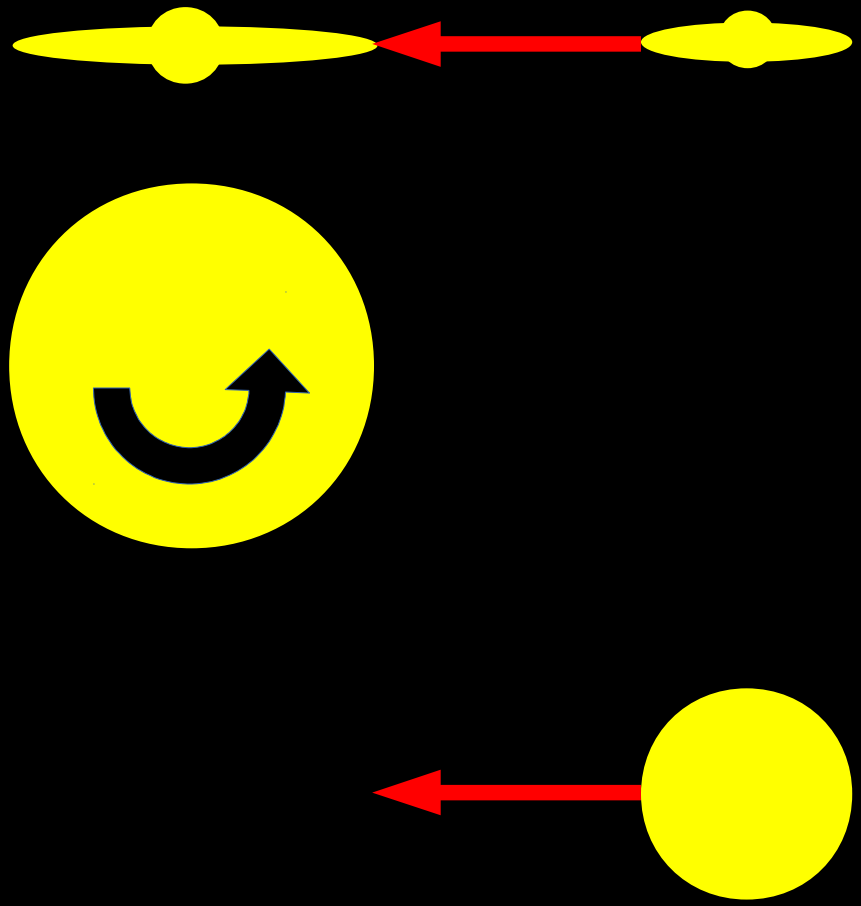

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Different orbits:

COPLANAR orbits:
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- run B:
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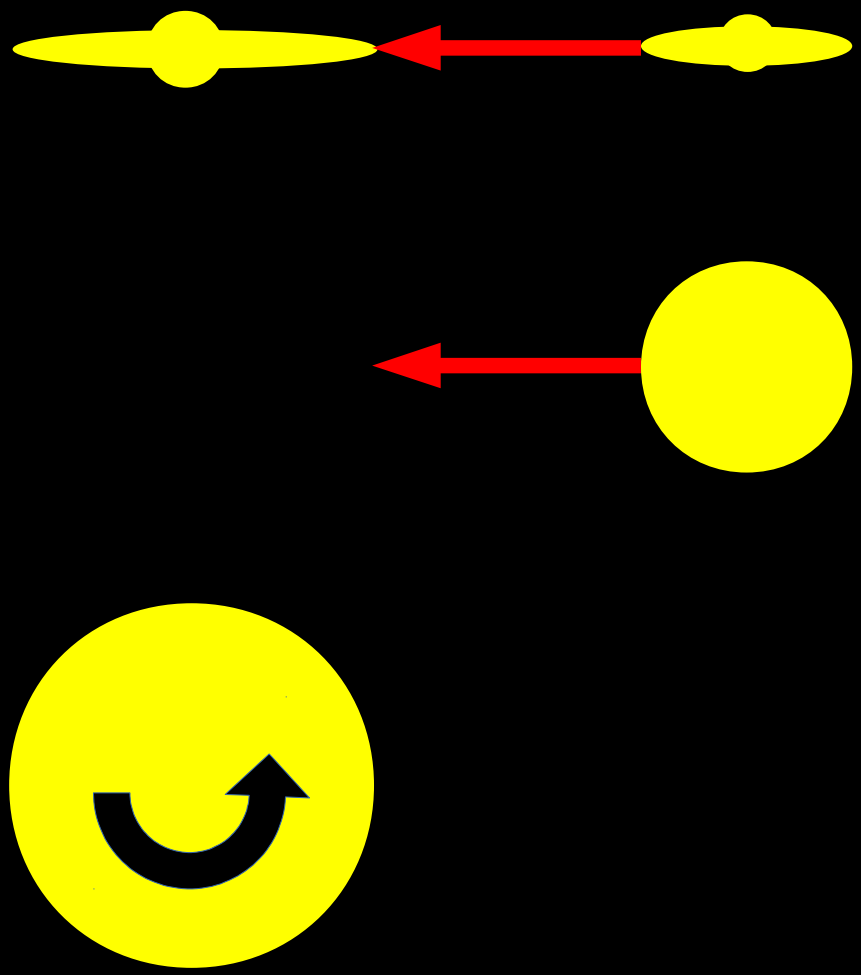
prograde
- run E:
impact parameter~30kpc
retrograde

MM, Rampazzo, Marino 2015

3. Models for minor mergers



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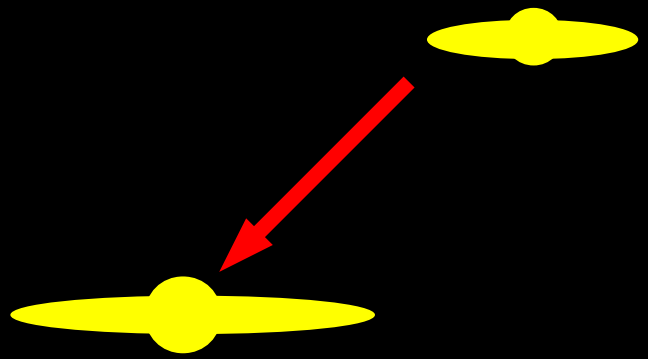
prograde

MM, Rampazzo, Marino 2015

3. Models for minor mergers



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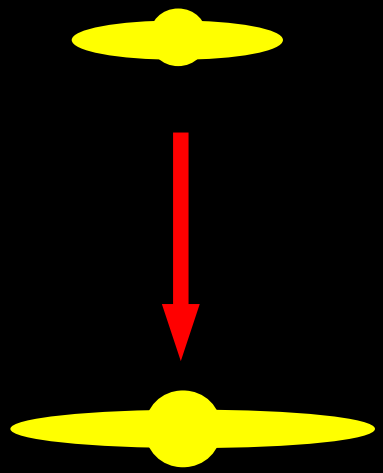
- run E:
impact parameter~30kpc
retrograde
- run F:
impact parameter~30kpc
prograde

NON-COPLANAR:
- runC:
satellite is ~45 DEG
impact parameter~10kpc

MM, Rampazzo, Marino 2015

3. Models for minor mergers



MM, Rampazzo, Marino 2015

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- run F:
impact parameter~30kpc
prograde

NON-COPLANAR:
- runC:
satellite is ~45 DEG
impact parameter~10kpc
- runD:
satellite is ~90 DEG
impact parameter~10kpc

3. Models for minor mergers: two examples

run A:

coplanar
impact parameter~10kpc
retrograde

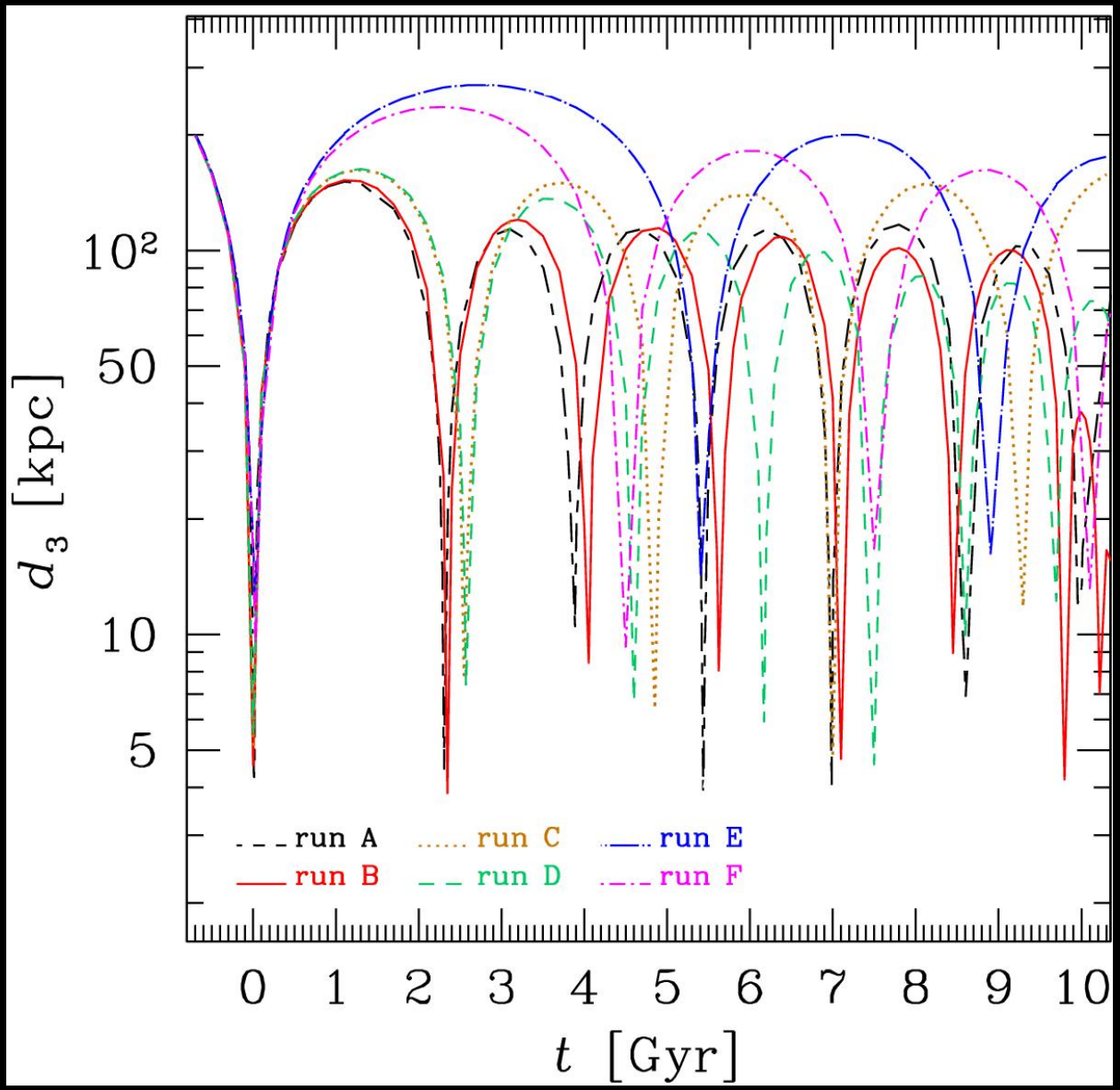
MOVIE run A

runD:

non-coplanar → satellite is ~90 DEG
impact parameter~10kpc

MOVIE run D

3. Models for minor mergers



Mass ratio 1/20
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Different orbits:

COPLANAR orbits:
- **run A:**
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- **run B:**
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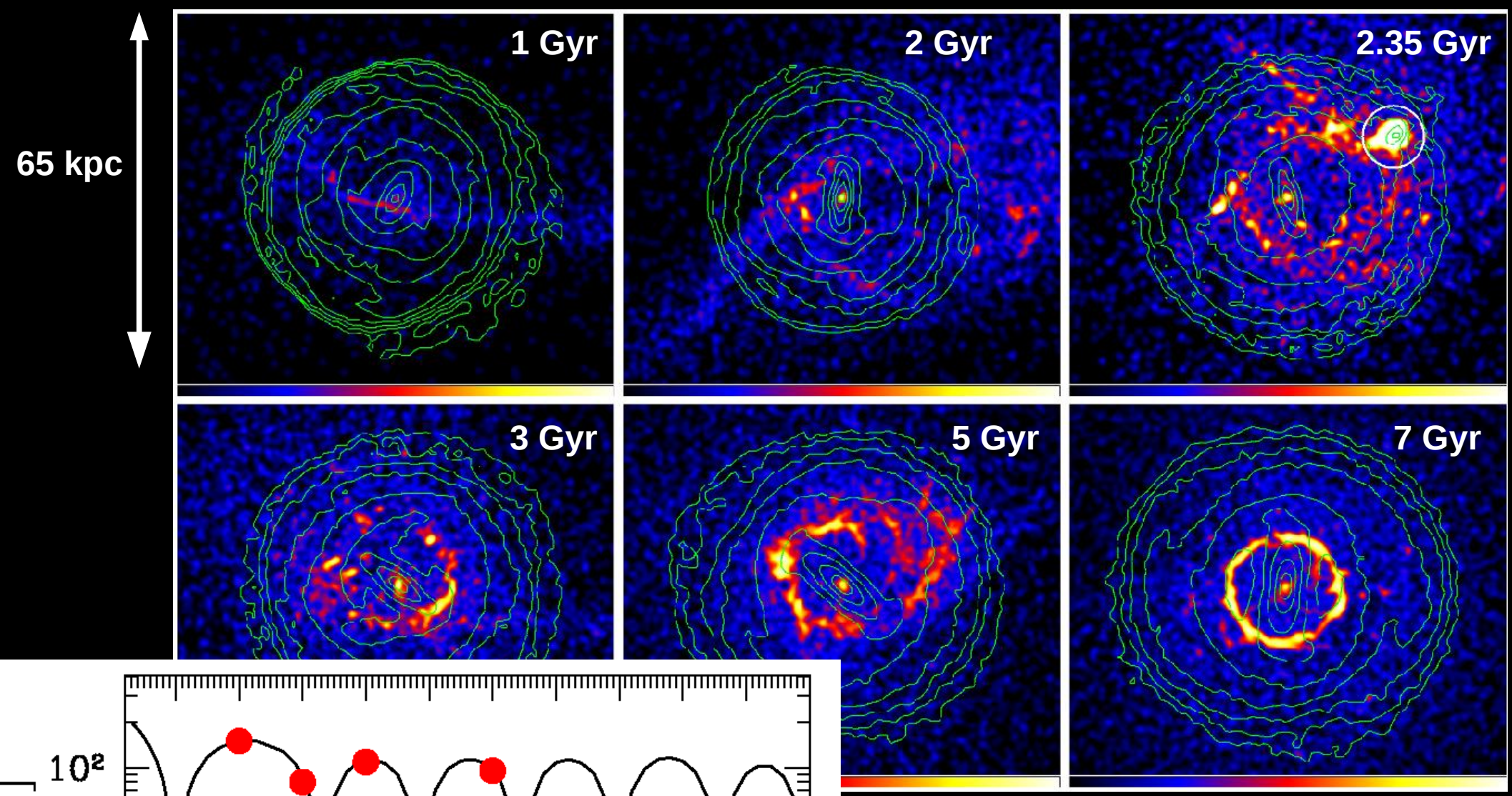
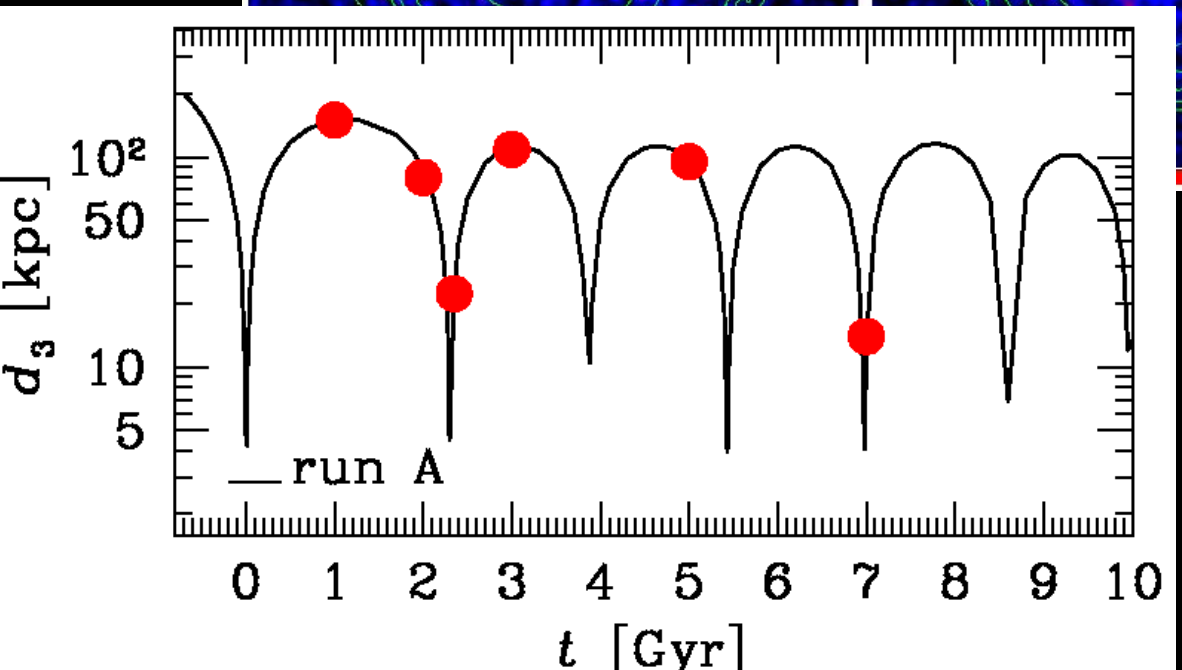
- **run E:**
  impact parameter~30kpc
  retrograde
- **run F:**
  impact parameter~30kpc
  prograde

NON-COPLANAR:
- **runC:**
  satellite is ~45 DEG
- **runD:**
  satellite is ~90 DEG

MM, Rampazzo, Marino 2015



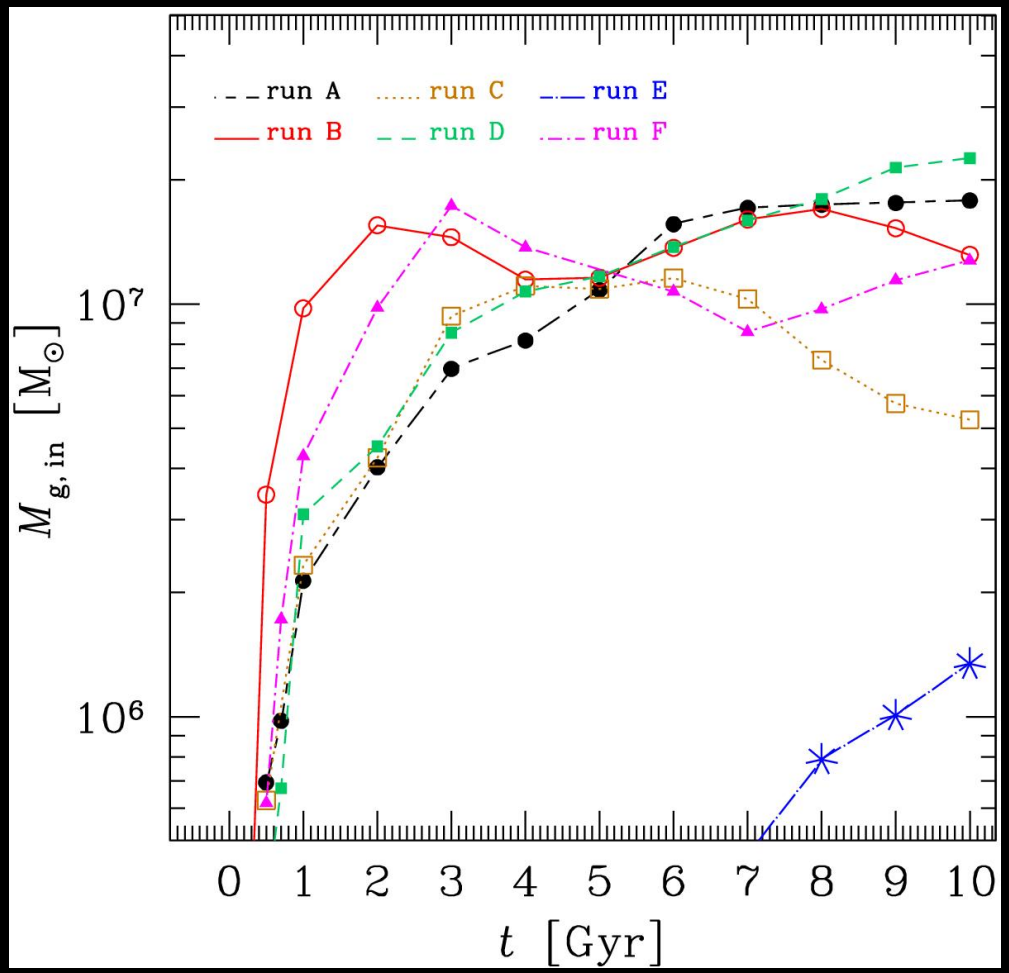


Snapshots from run A and position on the orbit:

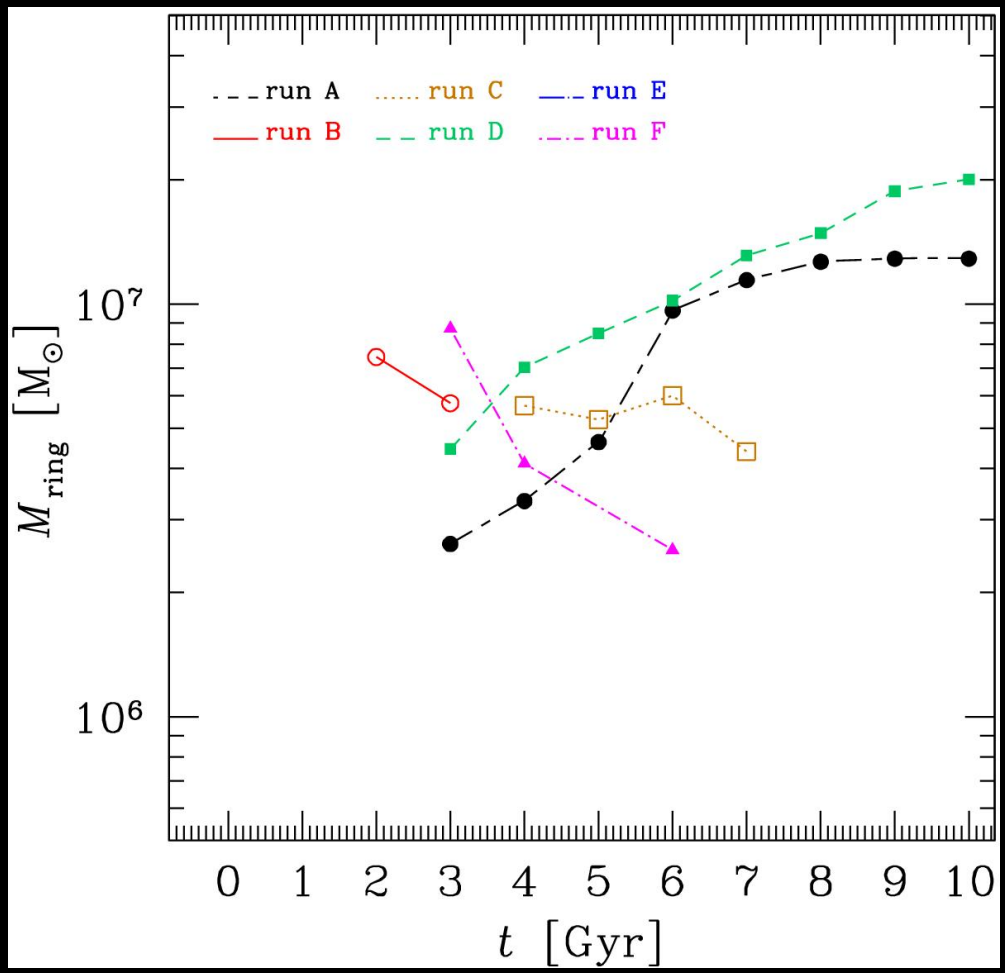
gas ring starts building at ~1 Gyr (after first periapsis)
gas ring is long-lived
RING IS RETROGRADE WRT DISC!!!

3. Models for minor mergers

Gas mass in the innermost ~ 15 kpc



Gas mass in a ring



In all runs gas is stripped in <~3 Gyr ~1/10 of total gas is accreted in the inner parts of S0

EXCEPTION: run E with impact parameter 30 kpc and retrograde

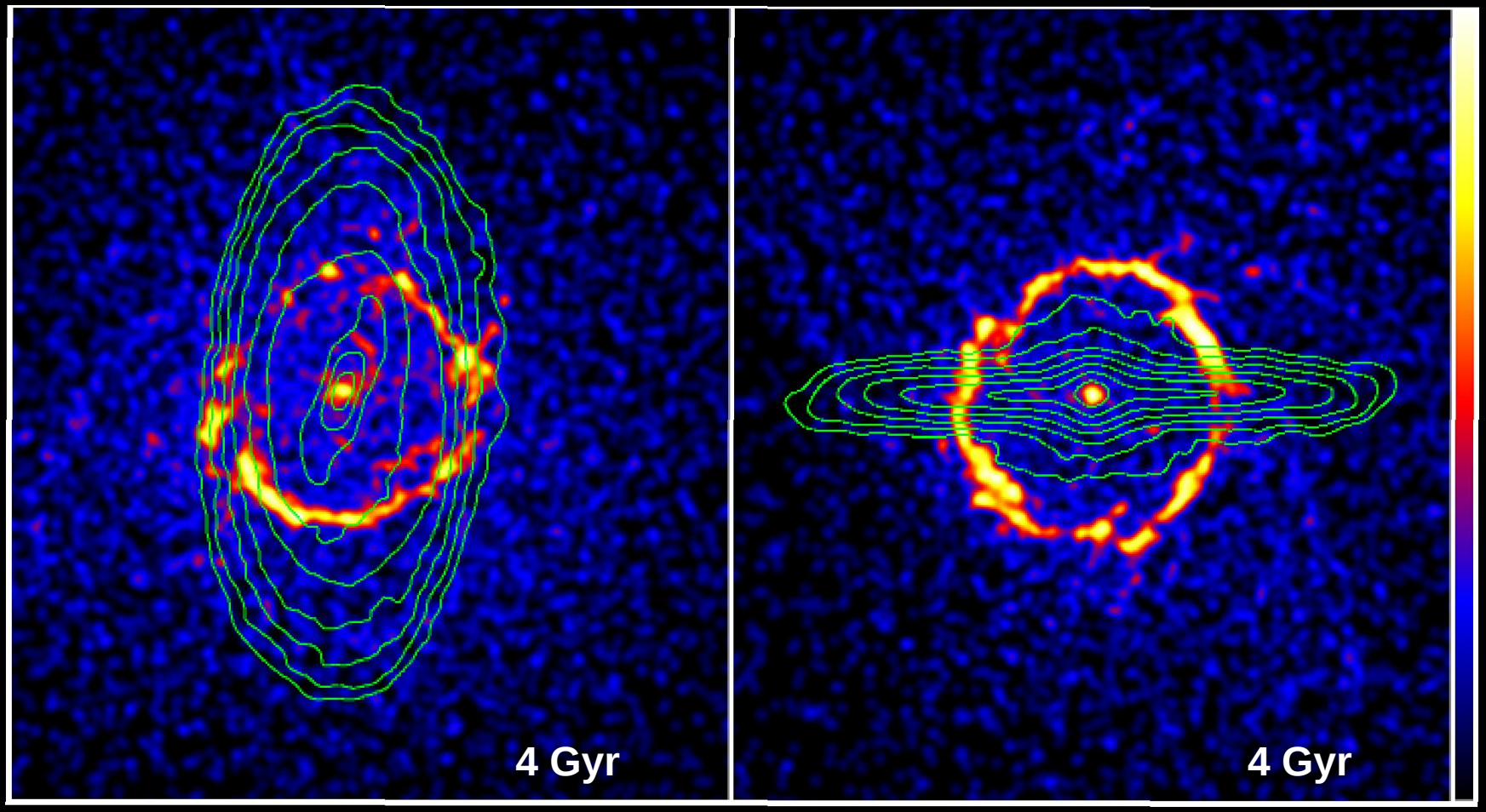
Ring is SHORT-LIVED in prograde runs and if inclination~45 DEG

Ring is LONG-LIVED in retrograde run A And in POLAR run D

3. Models for minor mergers

INCLINATION 45 DEG

INCLINATION 90 DEG



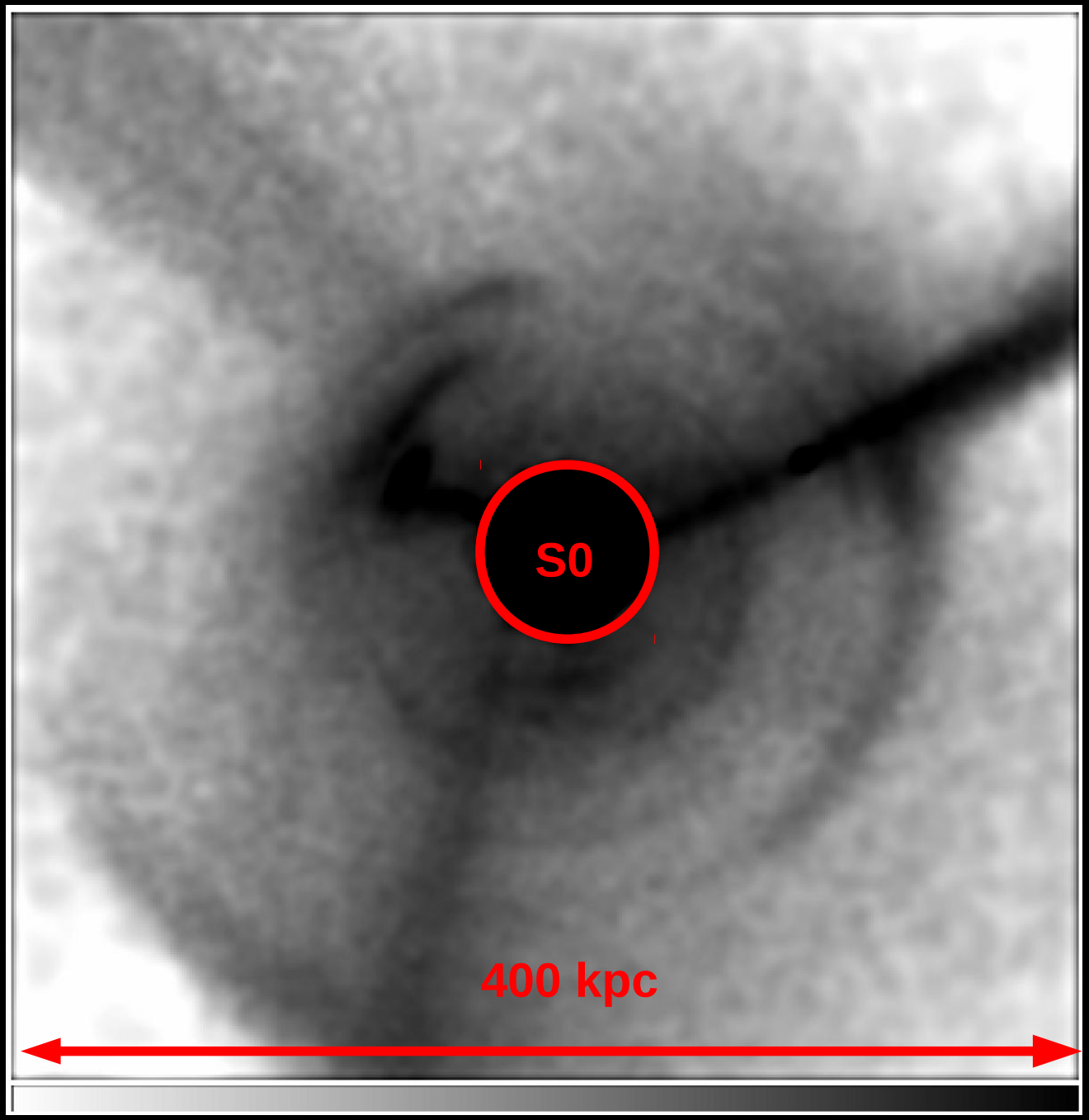
RING PRESERVES INCLINATION
OF SATELLITE'S ORBIT

LONG-LIVED POLAR RING
If inclination 90 DEG !!!

But disappears early if ~45 DEG

WE FIND RETROGRADE RINGS AND POLAR RINGS: NOT SUPPORTED BY BAR!

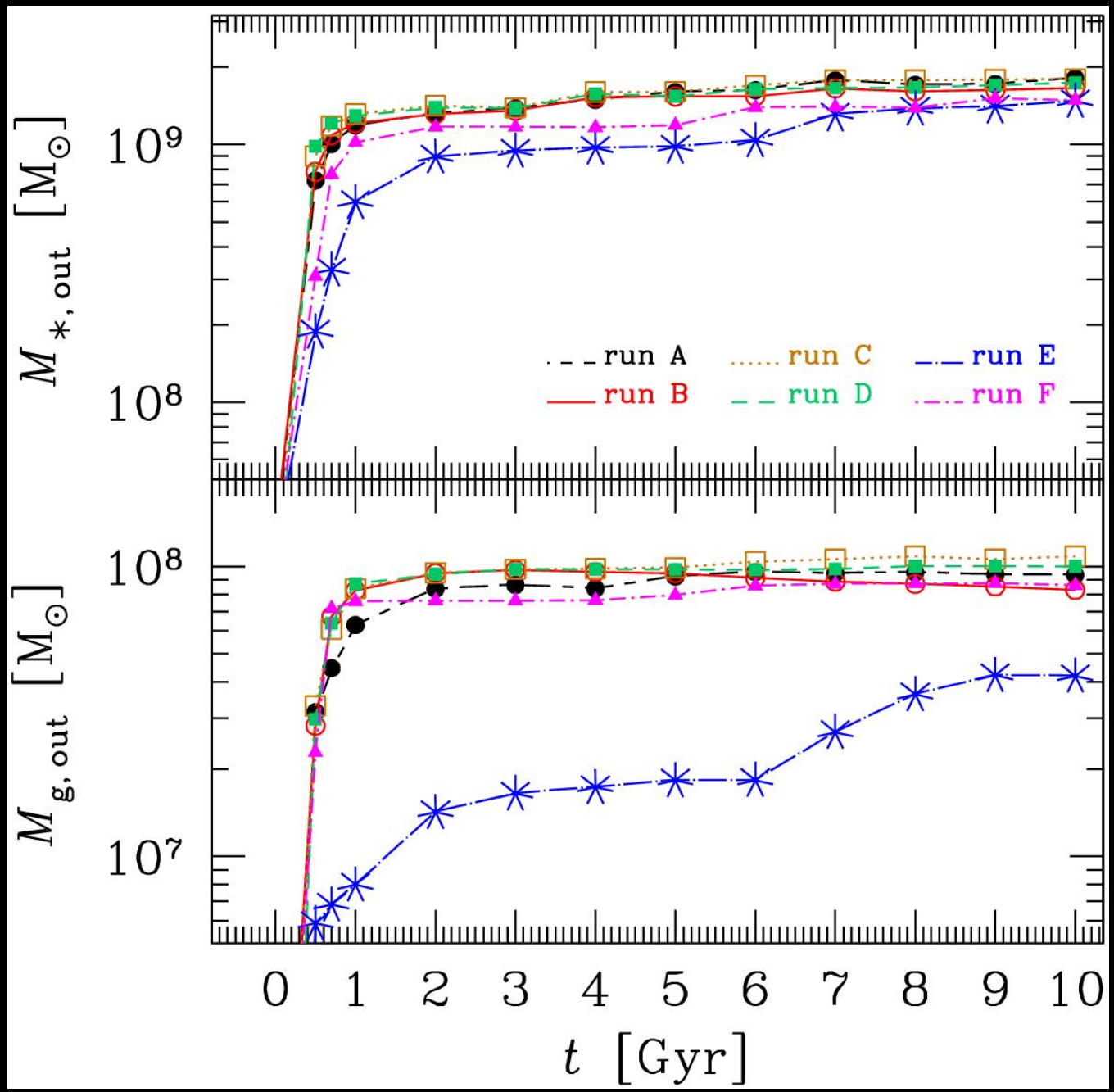
What happens in the outer parts of the S0?



Long-lived shells

Shell density is very low ($<10^{-5}$ times density of disc)

What happens in the outer parts of the S0?



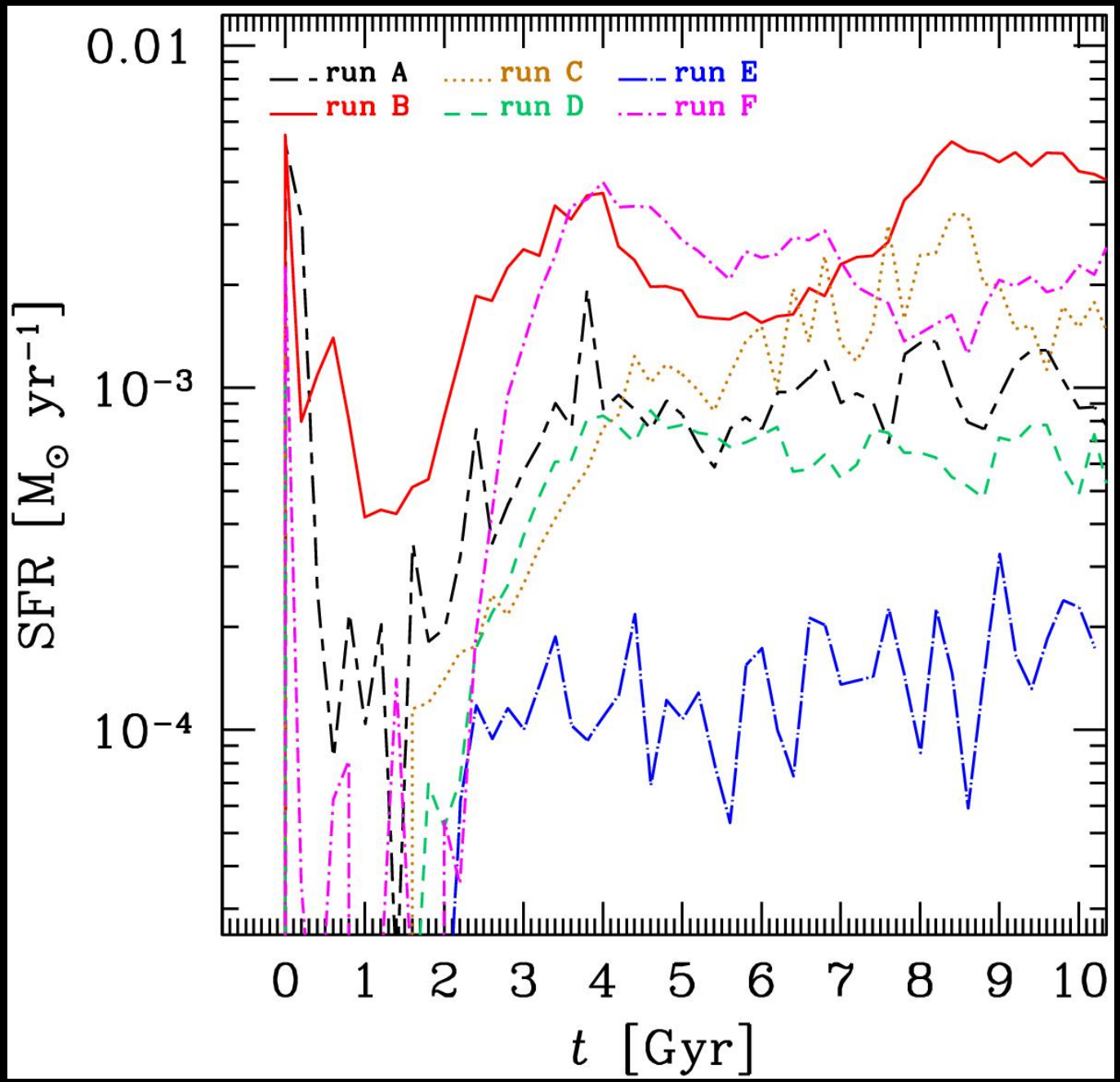
Most satellite stars are stripped but not accreted by S0

HALO!

Most gas is stripped but not accreted by S0

HOT HALO!

STAR FORMATION HISTORY:



Merger triggers long-lived episode of star formation at low rate

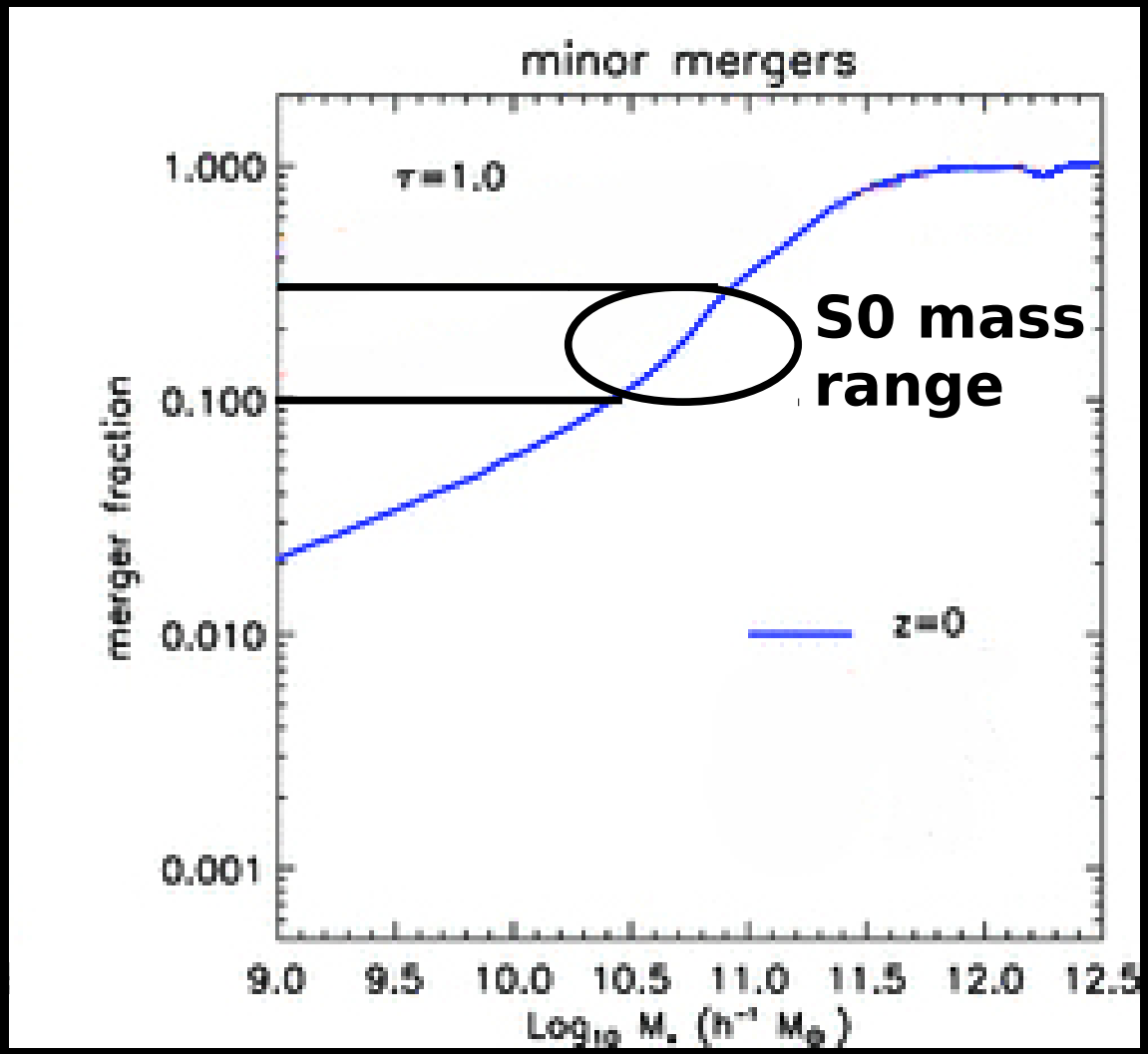
- first burst of the satellite

- then burst in the S0, lasting for >8 Gyr

4. Discussion: how many minor mergers?

Which % of rejuvenated S0s minor mergers account for??

Millennium simulation + semi-analytical models:
10-30% of S0 galaxies suffer minor merger at *z*~0



+our simulations show that SF episode is long lived

→ 10-30% S0 galaxies show signs of rejuvenation today

→ minor mergers can account for most S0 rejuvenation episodes

(Springel+ 2005; Bertone & Conselice 2009)

Which % of rejuvenated S0s minor mergers account for??

BUT..

- there is some friction between cosmological simulations and major merger data (Bertone & Conselice 2009)
Are we sure that minor merger estimates are ok?

- ~25% of all local galaxies show signatures of minor mergers but only 1/10 of SF rate can be accounted for by minor mergers (Sancisi+ 2008, Di Teodoro & Fraternali 2014, but sample of LATE type galaxies)

- large uncertainties in observations:
~16 to 56 % ETGs have shells (Reduzzi+ 1996, Duc+2014; Seiter & Schweitzer 1990)

only ~16% ETGs have signs of minor mergers (Duc+2014)

5. CONCLUSIONS:

– About 50% of S0 galaxies have SF: populate green valley

– Is this fading SF or rejuvenation? It might be both..

– Minor mergers might trigger formation of long-lived rings of gas, gas haloes, shells of stars, and episodes of star formation (MM, Rampazzo & Marino 2015)

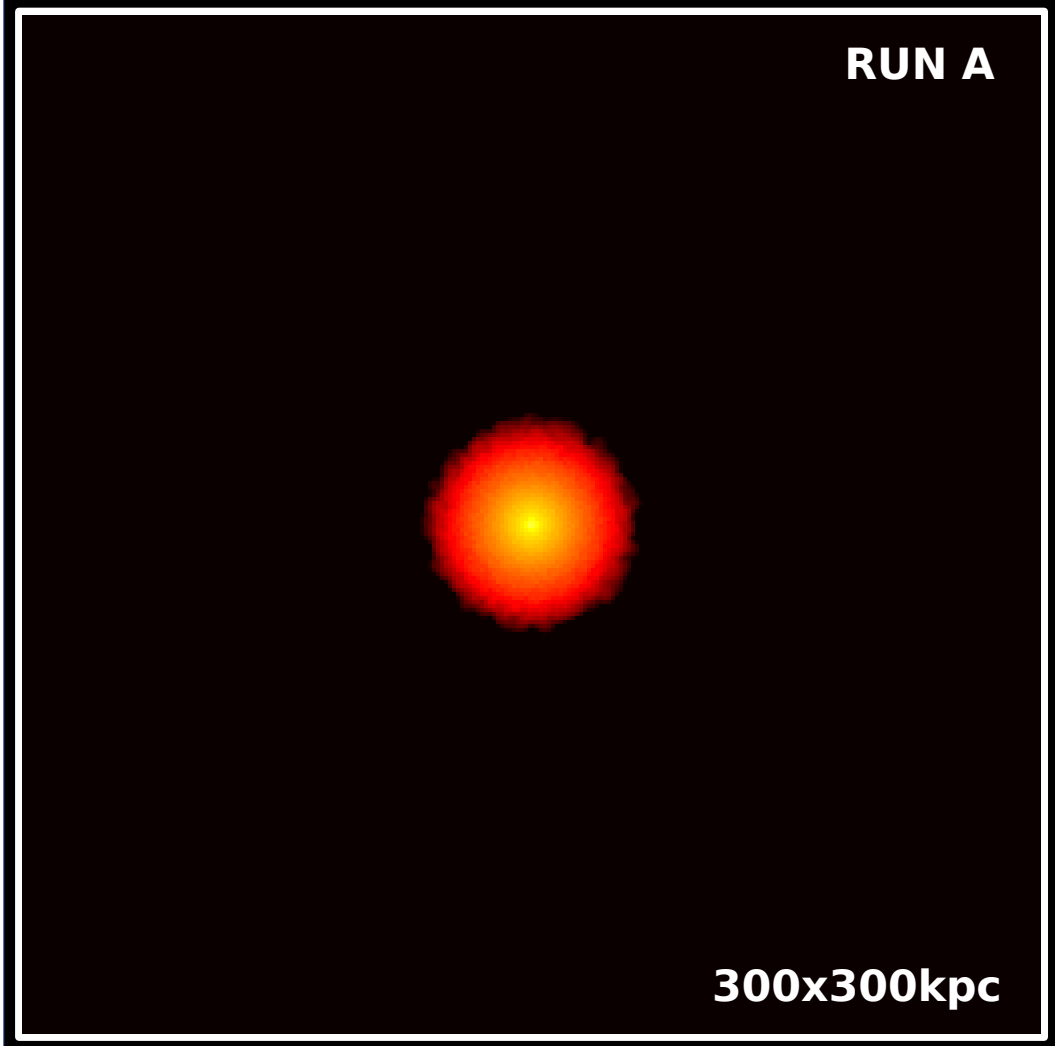
– Rings form especially if satellite orbit is RETROGRADE or POLAR → important to understand the role of bars

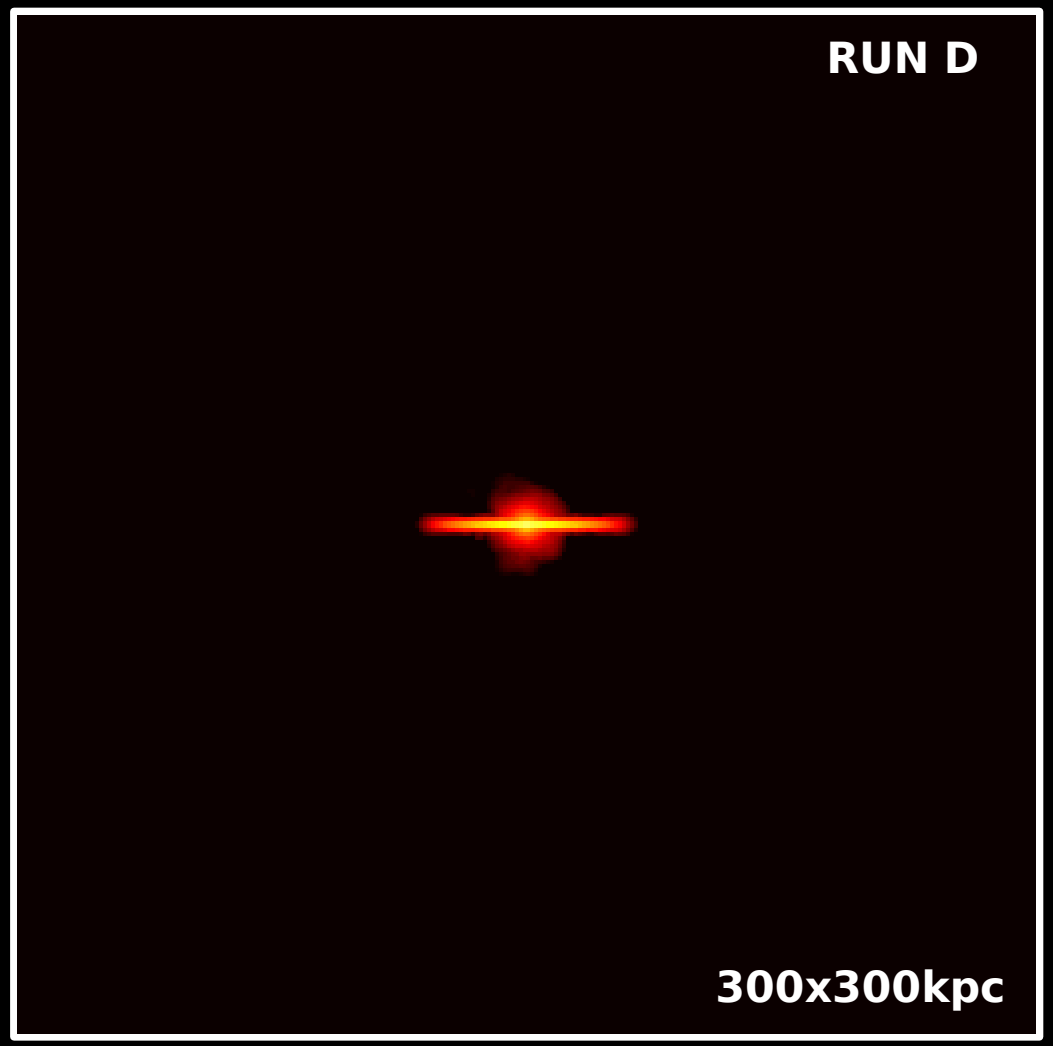
– Shells and gas halos are ubiquitous and long-lived but faint

- Combining our results with cosmological simulations we find that minor mergers can account for most (all?) rejuvenated S0s but several caveats might be taken into account

THANK YOU!

3. Models for minor mergers





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