The Role of Gas in Galaxy Mergers

Florent Renaud
Lund Observatory
@renaudflo
Signatures of past events

• Trace (part of) galaxy build-up
Extended H\textsubscript{i}

from P.-A. Duc
Stephan's Quintet

- **Tidal features** (or their absence) help constraining formation scenarios
  Hibbard et al. (1995)

- **Hints on large-scale intergalactic structures**

Image from D. Martinez-Delgado

NGC 7331

u+g+r (MegaCam @CFHT, 28.5 mag/arcsec²)
Stephan’s Quintet
Outer tail

- Long H\textsc{i} tail
  Williams et al. (2002)
  Xu et al. (2003)

- Signature of past interaction with remote galaxy
  Renaud et al. (2010)

Duc & Renaud (2013)
Stephan's Quintet
Outer tail

- Must be compared to stellar features
- Ram pressure?
Starbursts

• *Temporary* (~10-100 Myr) enhancements of the SFR
  Di Matteo et al. (2007)

• Most of SF in central regions *(in advanced mergers)*
  Sanders & Mirabel (1996)

• Due to gas inflows *(negative torques inside co-rotation)*
  Keel (1985)
  Barnes & Hernquist (1991)

• But also a non-negligible off-nuclear activity
  Wang et al. (2004)
  Hancock et al. (2009)
  Chien & Barnes (2010)
  Smith et al. (2014)
  Moreno et al. (2015)
  Elmegreen et al. (2016, 2017)
  …
Off-nuclear starbursts

- **Shocks**
  (cloud-cloud, cloud-reservoir)
  Jog & Solomon (1992)
  Barnes (2004)

- **Also bursts outside overlaps**

- **At large separations**
  Ellison et al. (2008)
  Scudder et al. (2012)
Off-nuclear starbursts

• Tidal and turbulent compression
  Renaud et al. (2008, 2014)
  Jog (2015)

• Increase turbulence and change its nature
  Irwin (1994)
  Elmegreen et al. (1995)

• Form denser structures
  Hennebelle & Falgaronne (2012)
  Federrath et al. (2014)

• Possibly change the IMF
  (if modified turbulence propagates to sub-pc scales)
  Renaud et al. (2014)
  + Chabrier et al. (2014)

NGC 4093/39
PDFs and KS laws

- Increase turbulence \rightarrow increase SFR
  and remain on Kennicutt's law

- Make turbulence compressive \rightarrow increase SFE
  and move to the starburst regime

Renaud et al. (2014)

Observations from
Kennicutt et al. (1998, 2007)
Bigiel et al. (2008)
Tacconi et al. (2010)
Daddi et al. (2010)

Analytical model from Renaud et al. (2012)

cf. talks on Monday/Tuesday
"Scaling relations"
A cluster-galaxy connection? 

Renaud (in prep.) 

- giant ellipticals
- ellipticals
- dwarf ellipticals
- compact ellipticals
- dwarf spheroidals
- extended clusters
- tidal dwarfs
- ultra compact dwarfs
- ultra faint objects
- globular clusters
- nuclear clusters
- young massive clusters

Role of interactions and mergers

- yes
- likely
- maybe
- no

circa 2010

summer 2017
Formation of massive clusters

- **Schechter mass function**
  (= power-law * exp)

- **Young globulars?**
  (not obvious because of different metallicities, environments and evolutions)

Portegies-Zwart et al. (2010)
Formation of massive clusters

- Massive clusters form at high SFR
  Johnson et al. (2017)

- What about efficiency?

Data from C. Johnson
Same SFR, different physics

- Possibly detectable in SLEDs and $\alpha_{\text{CO}}$
  Bournaud et al. (2015)

- A starburst and a disk: same SFR but different ISM → different cluster formation
  Renaud et al. (in prep.)
Same SFR, different CFR

- Different physics (turbulence) from different relative roles of compression, shocks and inflows
Destruction of low-mass clusters

- Tidal shocks: energy shift $\langle \Delta E \rangle$
  (disk crossings + GMC collisions + DM substructures) Ostriker et al. (1972), Spitzer (1987), D’Onghia et al. (2010), Amorisco et al. (2016)

- Don’t forget diffusion (2nd order)
  Aguilar et al. (1988), Kundic & Ostriker et al. (1995)

- Accelerates mass-loss and evolution
  (e.g. core-collapse)
  Gnedin et al. (1999)

- Possible transition to a peaked CMF
  Baumgardt et al. (1998), Vesperini et al. (2001)

- But tides are self-limiting
  (repeated shocks don’t do much)
  Gieles & Renaud (2016)
Formation of UCDs

- **Example: W3 in NGC 7252**
  Maraston et al. (2004)

- **At the high-mass end of the CMF**
  Mieske et al. (2002, 2012)

- **Just the extreme of a single regime**
  (more gas, more compression)
  Renaud et al. (2015)

- **or possibly formed hierarchically**
  Fellhauer & Kroupa (2005)

- **or as a tidally stripped nuclei**
  Bassino et al. (1994), Bekki & Couch (2001)

- ** Likely a mix of all scenarios**
  Brodie et al. (2011), Pfeffer et al. (2014)
Formation of TDGs

- Whip effect: accumulation of gas near the tip of the tails
  Duc et al. (2004, 2011)

- Tidal compression
  Plöckinger (2015)
  Renaud et al. (2015)

- Need extra potential from extended DM halo
  Bournaud et al. (2003)

- or a MOND-like potential
  Tiret & Combes (2007)
  Renaud et al. (2016)

- Alignments along tails
  (cf. planes of satellites)
  Pawlowski et al. (2017)

- Still no predictive theory on TDG formation
Disk-reformation and morphological quenching

- Star formation in a disk
- Stellar disk $\rightarrow$ spheroid
  - Moore et al. (1998)
- Hot halo helps to reform (slowly) a gas disk
  - Athanassoula et al. (2016)
  - Peschken et al. (2017)
- Increased local stability $\rightarrow$ quenched early-type
  - Martig et al. (2009)
- or possibly reform a stellar (thin) disk
  (several Gyr)
Beware of quenching

- Satellites get quenched faster than centrals → different processes
  van den Bosch et al. (2008), Bahe & McCarthy (2015)

cf. talks tomorrow “Quenching”
Ram pressure stripping
Gunn & Gott (1972), Quilis et al. (2000)

- **Dominant mechanism for satellites**
  Simpson et al. (2017)

- **Fast (~ 200 Myr)**
  Steinhäuser et al. (2016)

- **Complete stripping is rare**
  if some gas is left → redistribution

- **If weak → compression → SF boost**
  Ebeling et al. (2014)

Read & Hayfield (2012)
AGN fueling

• Torques $\rightarrow$ inflows $\rightarrow$ fuel AGN
  Cox et al. (2006), Ellison et al. (2011)

• Enhanced inflows $\rightarrow$ radio-loud AGN
  Chiaberge et al. (2015)

• Feedback regulates BH, NC and galaxy growth
  Di Matteo et al. (2005)
  Hopkins et al. (2010)
SMBH merger

- **SMBH binary**
  Quinlan & Hernquist (1997)
  Escala et al. (2004)
  Gualandris & Merritt (2012)

- **Final parsec problem**
  (lack of material to exchange momentum with)
  Milosavljevic & Merritt (2003)
  Gualandris et al. (2017)

- **More friction if gas-rich**
  → faster coalescence
  Mayer et al. (2007, 2008)
  Khan et al. (2016)

- **Powerful gravitational waves**
  Mayer et al. (2007, 2008)
  Khan et al. (2016)
Weak burst in clumpy disks

- **Clumps in gas-rich disks** (from VDIs)
  Bournaud et al. (2011)
  Elmegreen et al. (2007)
  Genzel et al. (2008)
  Zanella et al. (2015)

- **Intrinsic high SFR**
  Bournaud et al. (2011)

- **Saturation of the SF triggers**
  (compressive tides, turbulence)
  Fensch et al. (2017)

- **No strong SFR boost**
  Hopkins et al. (2013)
  Perret et al. (2014)
  Scudder et al. (2015)
Summary

What gas can do in interacting galaxies:

- trace past interactions better than stars (H\(_I\) tails, shells)
- slow down things (dynamical friction)
- fuel starbursts (inflows, shocks, compression)
- delay star formation (tidal debris falling back)
- form massive stellar systems YMCs, TDGs, UCDs, NCs
- destroy low-mass clusters (tidal shocks)
- quench satellites (ram pressure)
- fuel AGNs (radio-loud)
- merge SMBHs (faster with gas)
- change the IMF?? (bottom-heavy in ETGs)