Molecular gas and star formation in galaxy mergers: Differences between S+S and S+E pairs.

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Abstract:

We study 88 close galaxy major-merger pairs (44 S+E pairs and 44 S+S pairs) which are in different phases of the interaction with the goal to find out what drives the generally observed enhancement of the star formation rate (SFR) during galaxy mergers. **We find:**

- An enhancement of the SFR, molecular gas fraction (M_{H2}/M_{star}) and molecular-to-atomic mass ratio (M_{H2}/M_{HI}) for galaxies in S+S pairs, but not in S+E pairs.
- No difference in the total gas content ($(M_{H2}+M_{HI})/M_{star}$).
- The molecular-to-atomic gas ratio was significantly higher in the subsample with signs of morphological interaction compared to the subsample without.

Together, these results suggest that star formation enhancement in close major-merger pairs occurs mainly in S+S pairs after the first close encounter (indicated by interaction signs) because the HI gas is compressed in to star-forming molecular gas by the tidal torques. This effect is much weakened in S+E pairs.

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Molecular gas and star formation rate (SFR) in galaxy mergers

- There is general agreement that galaxy mergers can increase SFR and molecular gas content, both from observations and modeling.
- The amount of the enhancement depends on the parameters of the galaxies (mass ratio, gas fraction), on the orbital parameters of the interacting galaxies (e.g. Kennicutt et al. 1987; Xu & Sulentic 1990), and on the phase of the interaction (e.g. Di Matteo et al. 2007; Cox et al. 2008; Scudder et al. 2012, Renaud et al. 2014).
- The predicted maximum enhancement is in most cases not very large (e.g. Di Matteo et al. 2008).
- Enhancement in SFR is only found in S+S, but not in S+E pairs (Park & Choi, 2009, Xu+2010, Cao+2016, Moon+2019)
- Simulations (e.g. di Matteo+2007) do not predict this difference.

- **How can we make progress in our understanding of the enhancement of the specific SFR (sSFR)?**
- We decompose the sSFR in the following way and study each term individually by observations:

$$sSFR = SFR/M_* = M_{gas}/M_* \times M_{H2}/M_{gas} \times SFR/M_{H2}$$

- Where:
  - M_{gas}/M_* → depends on galaxy type and on large scale environment
  - M_{H2}/M_{gas} → depends on physical conditions of the ISM on scales > kpc processes
  - SFR/M_{H2} → depends on local conditions on GMC scales (~100pc)

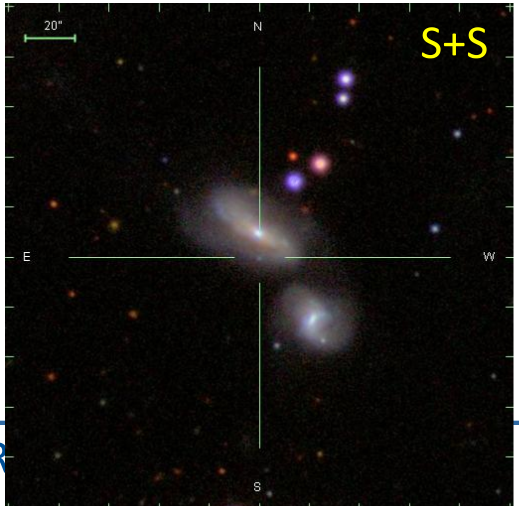
Sample and observational data

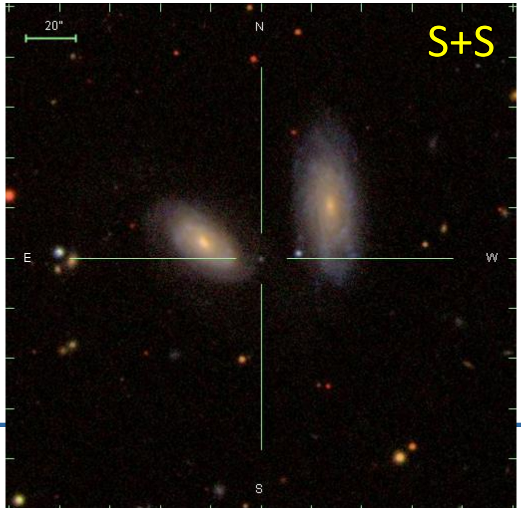
- The KPAIR sample is a mass-selected (from Ks-band), local sample (Donavan+2009, Xu+2012) of close merger pairs (distance 5-20 h^{-1} kpc) with a mass ratio between the galaxies < 2.5
- A subsample (HKPAR, 44 S+S and 44 S+E) were observed by **Herschel** (PACS+SPIRE), z = 0.007 - 0.1, which allows to calculate SFR (from L_{FIR}) and M_{dust} as a proxy for the gas mass (Cao et al. 2016).
- HI data from GBT exists for 70 pairs (Zuo+2018).
- Molecular gas data from IRAM 30m CO observations for 78 spiral galaxies, 55 in S+S pairs, 23 in S+E pairs (E galaxies were not observed)

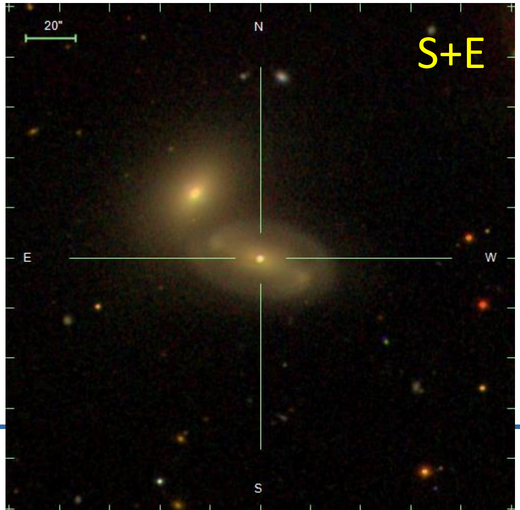
- **Galaxies were classified** visually into three subclasses according to their interaction stage (JUS: Not showing any merger signs, INT: Showing interaction signal, MER: Pairs in the process of merging)

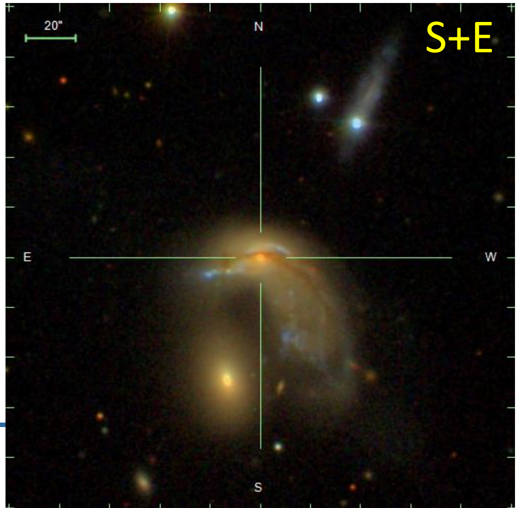
- **Previous studies** for this sample showed a moderate enhancement of the sSFR (Xu+2010, Cao+2016), but only for galaxies in S+S pair.

Some examples:





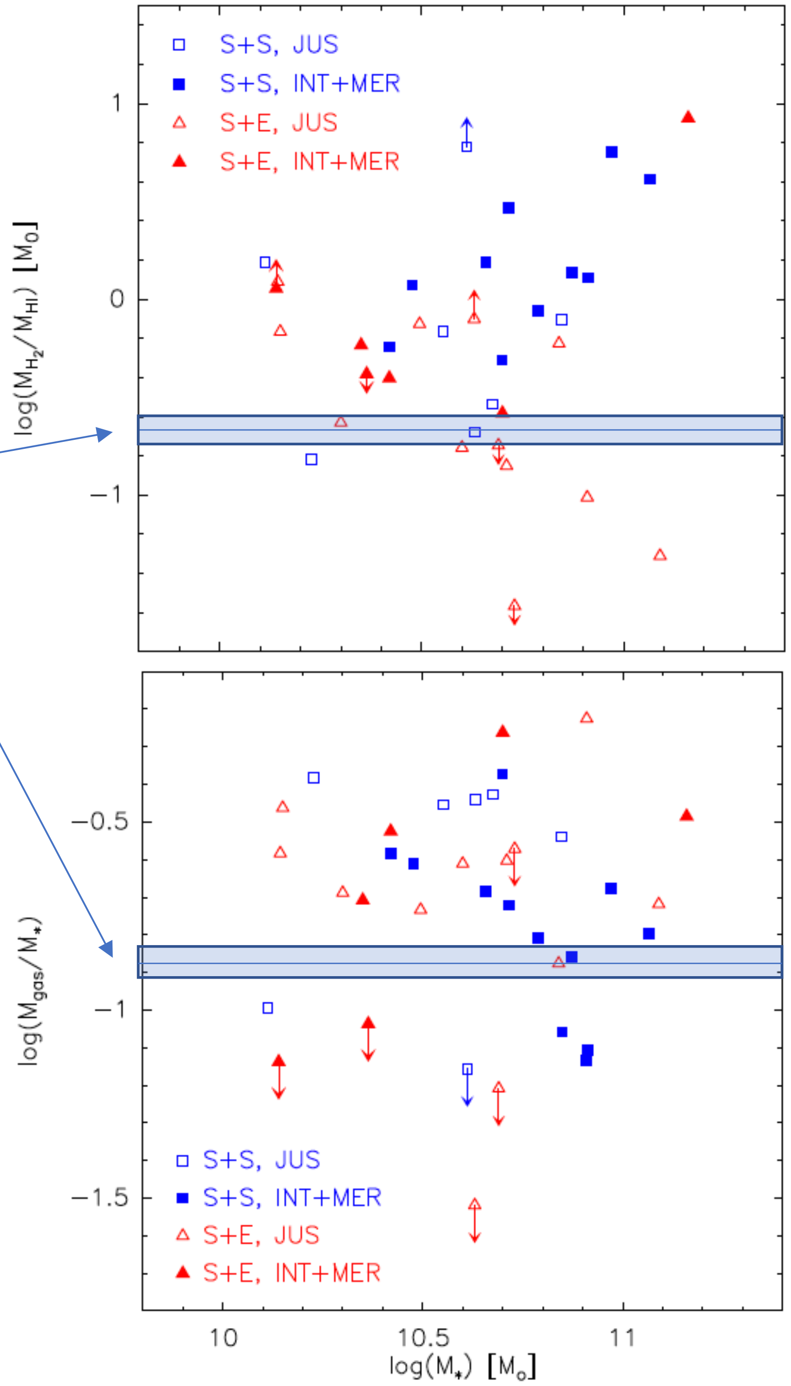




Results

Molecular-to-atomic hydrogen mass ratio: → There is a higher M_{H2}/M_{HI} for spirals in S+S pairs (3σ) and for galaxies in a later interaction stage (4σ).

Comparison sample:
xCOLDGAS (Saintonge+2017)
AMIGA (Lisenfeld+2011)



Total gas content ($M_{H2}+M_{HI}$):

No difference with respect to the comparison sample for any of the subgroups.

Star formation efficiency ($SFE = SFR/M_{H2}$):

No significant enhancement of the SFE in any of the subgroups with respect to the comparison samples.
A 3σ difference between S+S and S+E pairs.

What drives the enhancement of the sSFR in interactions?

We can decompose: sSFR = SFR/Mstar= M_{gas}/M_{star} * M_{H2}/M_{gas} * SFR/M_{H2} and conclude:

1. M_{gas}/M_{star} = constant → available amount of gas has no influence on the enhancement of SF
2. Molecular gas increases (both M_{H2}/M_* and M_{H2}/M_{HI}) as interaction proceeds → Conversion of HI → H_2 is an important process during the interaction and to a large extent responsible for the enhancement of SF. Whereas previous studies (Braine & Combes 93, Combes+94, Casasola+04, Violino+18, Pan+19) also find an increase of M_{H2} in interaction galaxies, ours is the first to shows the effect for different interaction phases.
3. We find no significant enhancement of SFE. In agreement with other studies who find no enhancement or weak enhancement (Violino+19, Pan+19).

⇒ The enhancement of the sSFR S+S merger is mostly due to the formation of M_{H2} from M_{HI}.

Why is there a difference between S+S and S+E pairs?

S+E pairs show no enhancement in any of the parameters. Possible reasons that have been suggested are:

1. S+E pairs have less total gas because they live in more gas-poor halos → discarded
2. Quenching effect of an x-ray halo around the elliptical galaxy which may strip or evaporate cold ($HI+H_2$) gas (Hwang+2012) → discarded because M_{gas} is not different between S+S and S+E pairs.
3. Hydrodynamical effects are expected to be more important in S+S where gas of both galaxies interacts than in S+E pairs. <u>But</u>: SFE shows no different between early (no hydrodynamical effects) and late interaction phase (presence of hydrodynamical effects).
4. Stabilizing effect of bulges. Simulations have shown that bulges can supress the tidal effects during and after interactions (Mihos & Hernquist 1996; Di Matteo et al. 2008; Cox et al. 2008). This could explain our results *if* spirals in S+E pairs were earlier types than spirals in S+S pair.

We are currently investigating point (4) by a more detailed morphological classification of the merger sample.