Relating gas and star formation in the HI dominated regime

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Abstract

Aim: To determine the Kennicutt-Schmidt type relation between (atomic) gas and star formation rate (SFR) in HI dominated nearby dwarf irregular galaxies and HI dominated regions of nearby spiral galaxies.

Data: HI interferometric maps from the FIGGS and THINGS surveys complemented by FUV and 24μm data.

Method: Average surface densities of (atomic) gas and SFR determined over the optical disk for dwarfs, over regions 400 pc across in dwarfs and spirals, over regions 1 kpc across in spirals.

Caveat: There is a limit below which the measured SFR cannot be trusted in the low SFR regime.

Results: Globally dwarfs show linear K-S relation, but order of magnitude less efficient than in central regions of spirals. For 400 pc / 1 kpc regions, mean SFR surface density in gas density bins show same trend in HI dominated gas.

Motivation

Observations:

- The Schmidt relation between surface densities (Σs) of gas and star formation rate (SFR) over entire galactic disks → power law with index 1.4 (Kennicutt 1998).
- Recent spatially resolved studies of the relation in nearby galaxies:
  Bigiel et al. 2008, 2010 → variation with radius, extremely inefficient at large radii
  Roychowdhury et al. 2009, 2011 → inefficient conversion of gas to stars in dwarfs
  Bolatto et al. 2011, Leroy et al. 2013 → a linear relation between Σ_{H_2} and Σ_{SFR}
- Observations seem to indicate a two-step process for converting gas to stars:
  HI beyond some threshold → **H_2** follows linear K-S law → stars.

Applications:

- Semi-empirical models of star formation have been proposed which replicate this two step process (Krumholz, McKee & Tumlinson 2009; Ostriker, McKee & Leroy 2010).
- Galaxy formation simulation accurately trace dark matter halos only → all hydrodynamical simulations or semi-analytical models of galaxy formation necessarily use the empirical relations or the semi-empirical models based on them as recipes for converting gas to stars.

But, the nature of the relation between gas and star formation in the HI dominated interstellar medium (ISM) of galaxies, especially low metallicity dwarf galaxies, is observationally not well constrained ...

Data and procedure

Nearby dwarf galaxies:

- Faint Irregular Galaxy GMRT Survey → HI (Begum et al. 2008)
  - $M_B > -14.5$, $M_{HI} \sim 10^7\ M_\odot$ or less, $Z \sim 0.1\ Z_\odot$
  - 41 galaxies with archival *GALEX* FUV data → measuring SFR
  - 30 galaxies with 6m BTA / archival Hα data → measuring SFR
  - 16 galaxies with 24 μm *Spitzer MIPS* data → dust attenuation correction

Nearby spiral galaxies:

- The HI Nearby Galaxy Survey → HI (Walter et al. 2008)
  - IRAM HERA CO Line Extragalactic Survey → H_2 (Leroy et al. 2009)
  - Archival *GALEX* FUV data → measuring SFR
  - 24 μm *Spitzer MIPS* data → dust attenuation correction
  - 10 galaxies with azimuthal metallicity variation (Moustakas et al. 2010)

Procedure:

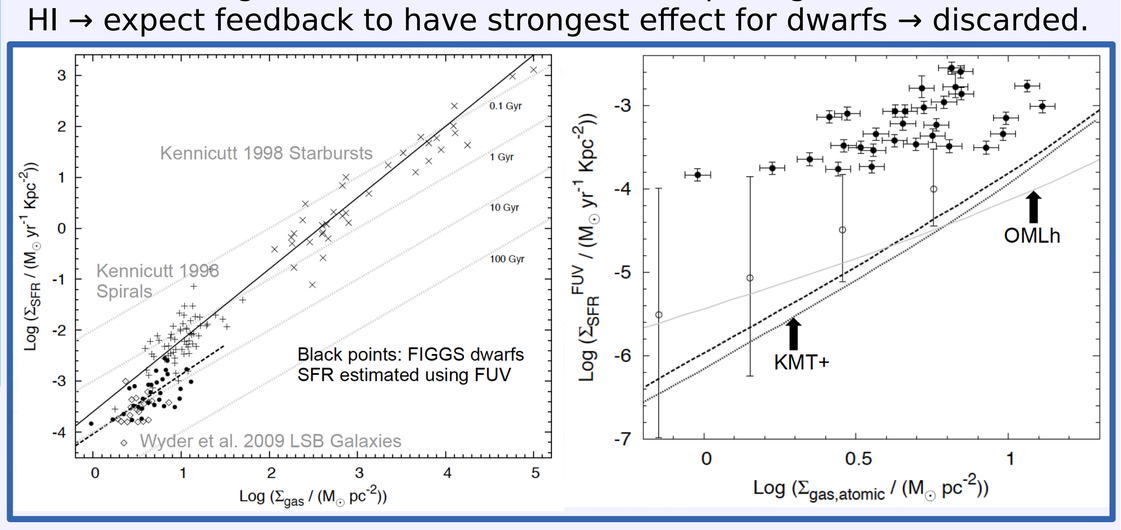
- SFRs calculated using standard calibrations (Kennicutt & Evans 2013; Leroy et al. 2008) taking into account flux reprocessed by dust within galaxy, extra correction for low metallicities using Raiter et al. (2010).
- Average surface densities of atomic gas and SFR calculated:
  over optical (Holmberg) disks of the dwarfs
  over 400 pc-a-side boxes for dwarfs and spirals
  over 1 kpc-a-side boxes for spirals (also including molecular hydrogen)

Measuring low SFRs

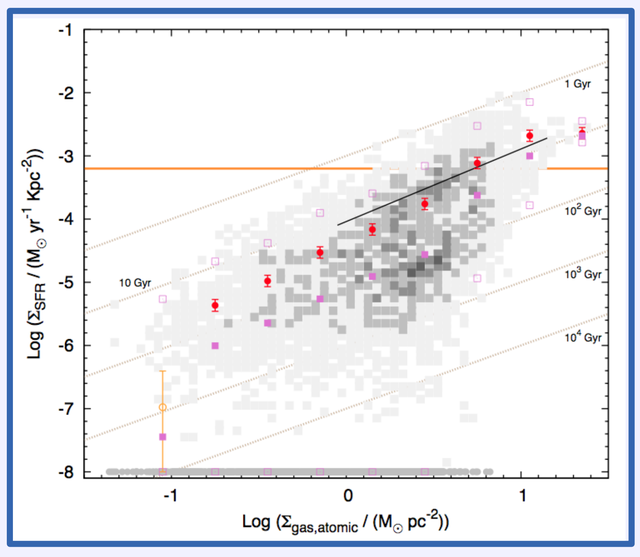
- FUV emission predominantly traces ≥ 3 $M_\odot$ stars, Hα ≥ 17 $M_\odot$ stars → SFR calibrations sensitive to stochasticity in high mass star formation at low SFRs
- Using Stochastically Lighting Up Galaxies code da Silva et al. (2014) show that:
  Bursty star formation → measured SFR offset to lower value than true SFR and this offset increases with decreasing SFR.
  Insufficient sampling of the high mass end of the IMF → scatter in measured SFR increases with decreasing SFR.
- Due to finite separation between sites of star formation, with increasing resolution the scatter in measured SFR will increase (Kruijssen & Longmore 2014).
- Using SLUG, we determine that **SFR_{FUV} is not trustworthy for:**
  Log SFR / ($M_\odot$ yr^{-1}) < - 4, and $SFR_{H\alpha}$ for Log SFR / ($M_\odot$ yr^{-1}) < - 2.5.
- We are left with too few measurements using Hα, all results presented use FUV.

Results: Dwarfs

- ~ 20% of the galaxies show evidence of morphological disturbance in HI → expect feedback to have strongest effect for dwarfs → discarded.



- In left panel, the dashed line shows the bivariate fit to **optical disk-averaged values** for dwarfs with a **slope of 1.15**, the bold line is the canonical K-S law → **dwarfs are forming stars inefficiently.**
- In right panel the disk-averaged values for dwarfs are shown (filled circles). The open circles are the median values in the extreme outskirts of spirals (Bigiel et al. 2010). Expected variations for two different 0.1 $Z_\odot$ models (OMLh: Bolatto et al. 2011; KMT+: Krumholz 2014) are shown. **Are dwarfs more efficient than spiral outskirts?**
- Below the **400 pc region-by-region comparison** shown by greyscale contours.



The orange line represents the **limiting Σ_{SFR}, most regions lie below limit.**

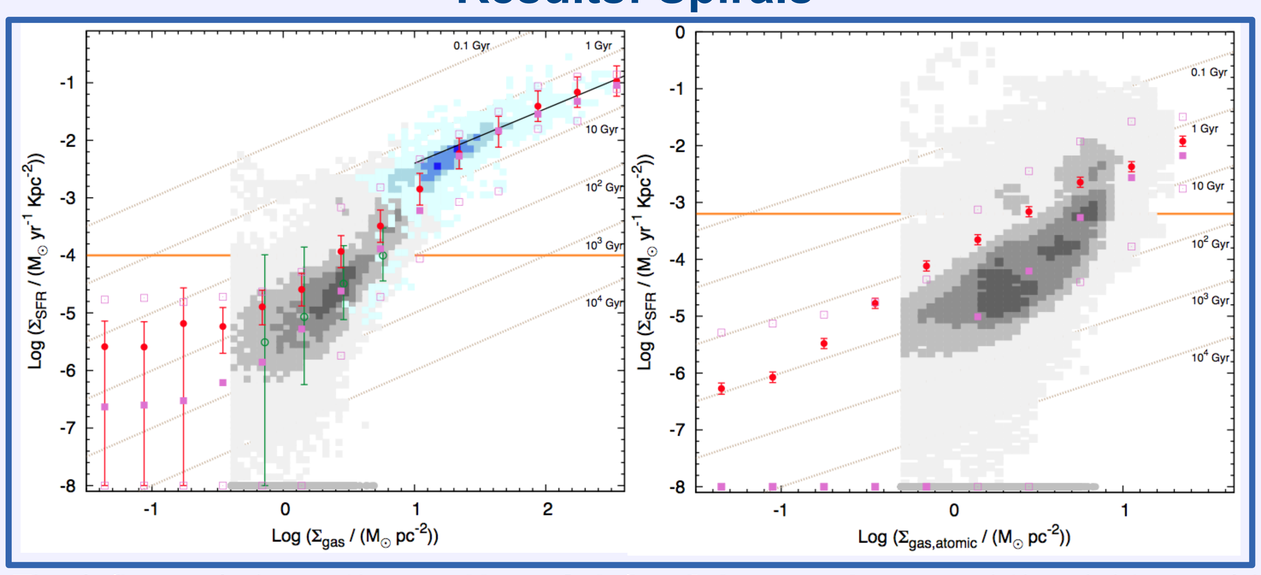
The filled purple squares show the median value in HI column density bins.

The low/negative FUV fluxes are represented by the grey points at Σ_{SFR} = - 8.

When one considers **the mean Σ_{SFR} in each bin** by summing up SFR more than the limiting value (filled red circles) →

HI is being converted into stars with τ_{dep} ~ few 10s of Gyr.

Results: Spirals



- The left panel shows the **scatter plot for 1 kpc regions**, and the right panel is for **400 pc regions in spirals –** greyscale contours represent points without H_2 and the blue shaded contours (left panel) represent points with H_2 measurement.
- Contours shown down to Σ_{gas} plotted in Bigiel et al. (2010).
- Orange line represent the **limiting Σ_{SFR}, most individual regions below it.**
- In the left panel the bold line is the linear H_2 K-S law, to which the higher column density points converge.
- The **median represented by the filled purple squares agree well with Bigiel et al. (2010)'s values** (open green circles in the left panel).
- We consider **the mean Σ_{SFR} in each gas column density bin**, calculated using total SFRs in each bin which are safely above the limiting value.
- **One observes that the gas in the outskirts of spirals is not extremely inefficient but has τ_{dep} ~ few 10s of Gyr as in dwarfs.**