CTA perspective for the gamma–ray luminosity–SFR correlation

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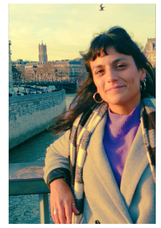

Introduction

Star-forming galaxies (SFGs) are unique gamma-ray emitters. The observation of a correlation between their non-thermal luminosity and their star-formation rate (SFR) strongly suggests that these gamma rays result from interactions of cosmic rays (CRs) injected by phenomena connected with the SFR, such as supernova remnants and massive star winds. Such a correlation could also provide insight on how global properties of galaxies, such as magnetic (B), velocity (v) and density (n) fields scale with the SFR, thereby possibly unveiling crucial aspects connected to their origin. We previously investigated the multi-wavelength emission of the CR population in SFGs, namely in the bands of γ-rays [1], radio [2], and X-ray and MeV [3]. These works showed evidence that at high SFR the γ-ray emission is dominated by protons cooling, while at low SFR the importance of CR escape increases. In this work, we aim to investigate the effect of gamma-ray absorption processes and CRs transport footprints in SFGs at very high energies (VHE) in terms of the luminosity–SFR correlations. We develop a model that reproduces the non-thermal emission in SFGs from radio to GeV, using the SFR as an independent variable. We build the correlation in the CTA energy range and explore how proton maximum energy and the absorption inside galaxies and en route to Earth impact the modelled correlation.

The SFGs emission model

We build a One-Zone model for CRs transport and interaction in SFGs.

1. Treating each galaxy as a cylinder of radius R and semi-height H, we solve the following transport equation:

$$-\partial_E \sum N\dot{E} + \frac{N}{\tau_{\rm esc}} = Q, \qquad (1)$$

where:

- $\tau_{\rm esc}$ accounts for advection and diffusion.
- $\dot{E}_e$: Ionization, Bremsstrahlung, Synchrotron, Inverse Compton
- $\dot{E}_p$: Ionization, p-p
- $Q = Q_o E^{-\gamma} \exp\left[-E/E_{\rm max}\right]$, $Q_o \propto$ SFR

2. We model the SFR-dependence of effective fields as:

$$F = F_0\,(\mathrm{SFR})^{\beta}, \qquad (2)$$

where F = (B, v, n), following [1] and [2].

3. We calculate the spectral energy distribution in a wide range of SFRs (Fig.2).

4. We build the correlation by integrating the luminosity in:

- The *Fermi* band (0.1–100 GeV) to compare the result with the observed correlation (left panel of Fig. 3).
- Two bands that will be accessible to CTA: 0.1–10 TeV and 10–100 TeV (middle and right panel of Fig. 3) to explore the intervening physical processes.

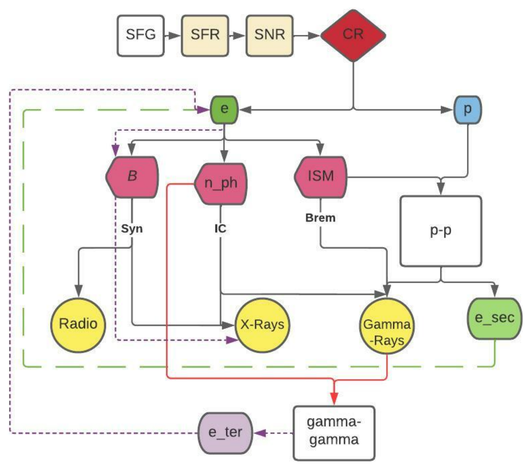

Figure 1: Scheme showing the contribution of each radiative process and generation of particles at different energy ranges.

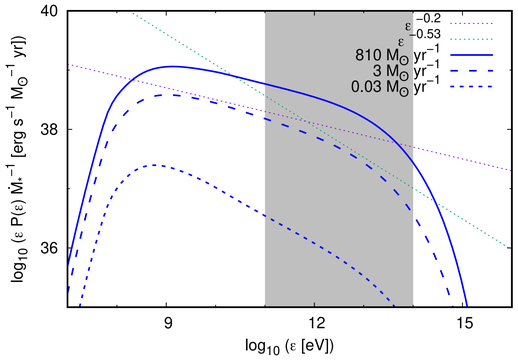

Figure 2: Normalised SED for three different SFR values.

Results

We find that internal absorption affects the correlation at SFRs $> 10\ \mathrm{M_\odot yr^{-1}}$ for the highest range of CTA. The effect of the external absorption and the variation of the proton maximum energy also changes the correlation's normalisation in this range. However, none of these effects is noticeable in the lower energy range of CTA.

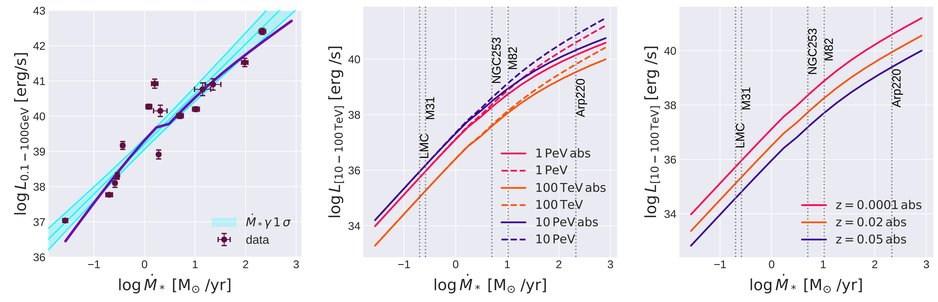

Figure 3: The modelled L_γ–SFR correlations.

Discussions and conclusions

- We find that the internal absorption and the change in the maximum energy substantially impact the correlation in the highest energy range.
- The impact of the external absorption is strong at higher redshift. Nevertheless, we do not expect to observe with CTA galaxies at $z \gtrsim 0.02$.
- The high energy band provides key information on particle transport because of the possible strong footprints of particle diffusion.
- In light of upcoming CTA observations, we conclude that the luminosity–SFR correlation in the VHE band can guide us in improving our understanding of CR transport and radiative processes in SFGs.

References

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