How runaway stars boost galactic outflows

Eric P. Andersson[1]★, Oscar Agertz[1] and Florent Renaud[1]
[1] *Department of Astronomy and Theoretical Physics, Lund Observatory, Box 43, SE-221 00 Lund, Sweden*

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ABSTRACT
Roughly ten per cent of OB stars are kicked out of their natal clusters before ending their life as supernovae. These so called runaway stars can travel hundreds of parsecs into the low-density interstellar medium, where momentum and energy from stellar feedback is efficiently deposited. In this work we explore how this mechanism affects large scale properties of the galaxy, such as outflows. To do so we use a new model which treats OB stars and their associated feedback processes on a star-by-star basis. With this model we compare two hydrodynamical simulations of Milky Way-like galaxies, one where we include runaways, and one where we ignore them. Including runaway stars leads to twice as many supernovae explosions in regions with gas densities ranging from 10^{-5} cm^{-3} to 10^{-3} cm^{-3}. This results in more efficient heating of the inter-arm regions, and drives strong galactic winds with mass loading factors boosted by up to one order of magnitude. These outflows produce a more massive and extended multi-phase circumgalactic medium, as well as a population of dense clouds in the halo. Conversely, since less energy and momentum is released in the dense star forming regions, the cold phase of the interstellar medium is less disturbed by feedback effects.

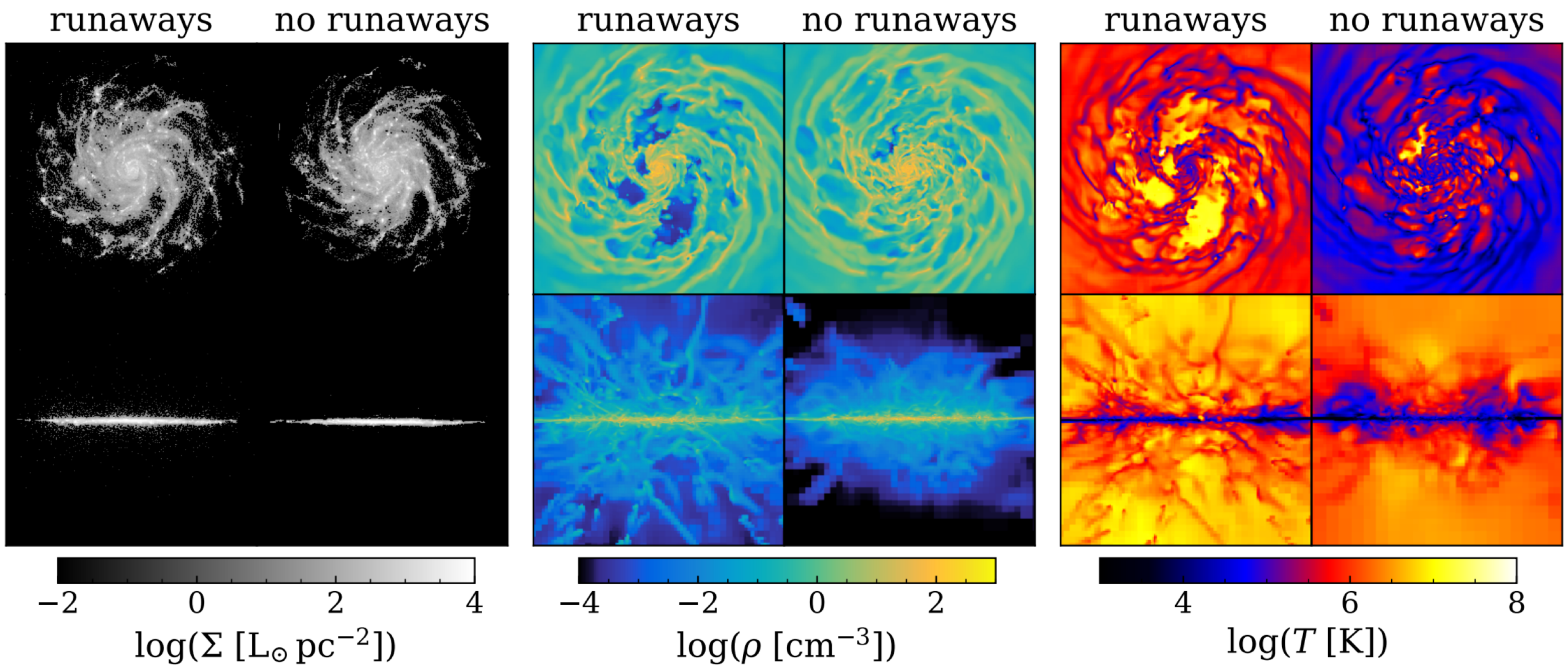
Key words: galaxies: evolution – galaxies: star formation – stars: massive

1 INTRODUCTION

The Λ-Cold Dark Matter (ΛCDM) paradigm has been highly successful in explaining and predicting a variety of observed properties, such as large scale structure, halo clustering and galaxy scaling relations (Eisenstein et al. 2005; Springel et al. 2005; Viel et al. 2008; Reid et al. 2010; Klypin et al. 2011; Komatsu et al. 2011; Somerville & Davé 2015). Nonetheless, this model has also encountered challenges related to the 'baryon cycle', i.e. how galaxies accrete and expel their gas. Galaxy formation is an inefficient process, with at most ∼ 1/3 of the cosmological baryon fraction being turned into stars in galaxies as massive as the Milky Way,

Keller et al. 2014; Simpson et al. 2015; Hopkins et al. 2018). This effort has made it possible to model galactic outflows in a cosmological context as an emergent property of clustered star formation, with simulations now matching a range of observed galaxy properties (e.g. Hopkins et al. 2014; Agertz & Kravtsov 2015, 2016), as well as properties of the turbulent ISM and giant molecular clouds (GMCs) (Grisdale et al. 2017, 2018, 2019).

Adding to the success of stellar feedback models, simulations of entire galaxies has improved significantly in the recent years with parsec, or even sub-parsec spatial resolution and mass resolution reaching a few solar masses enabling models to capture the



Моделируют 2 изолированные галактики типа MW, с убегающими звездами и без них. Пространственное разрешение – 6 пк, рассматривают интервал времени 250 млн.лет

$$f_v \propto v^{-\beta},$$

rate based on Dale & Bonnell (2008) given by

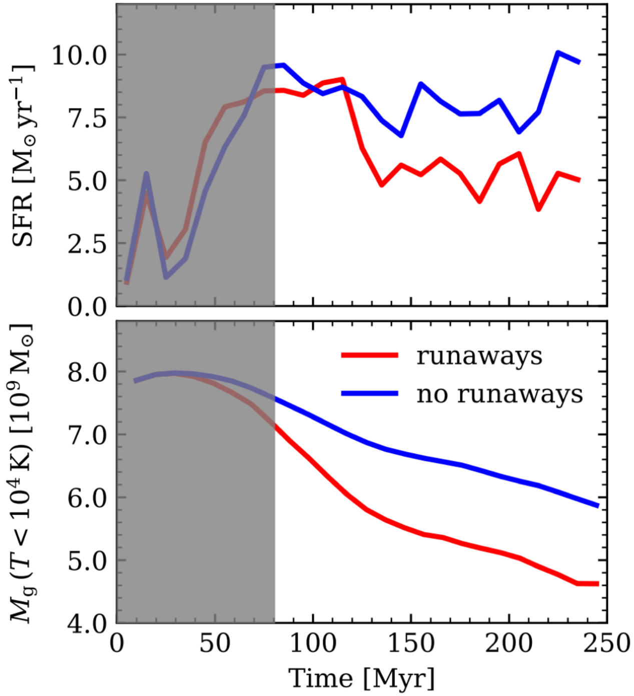
$$\dot{M} = 10^{-5}\left(\frac{M_b}{30\,M_\odot}\right)^4 Z^\gamma\,M_\odot\,yr^{-1},$$

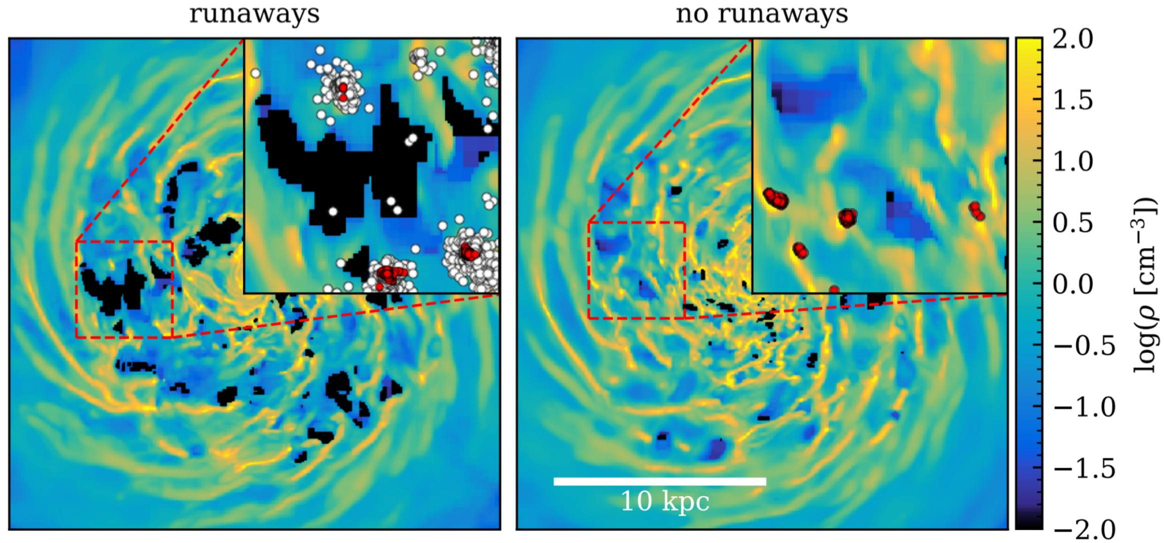
in elements heavier than He). To determine t_{MS} our model uses a stellar age-mass-metallicity fit by Raiteri et al. (1996), who found

$$\log t_{MS} = a_0(Z) + a_1(Z)\log m + a_2(Z)(\log m)^2, \quad (7)$$

where the coefficients are given by

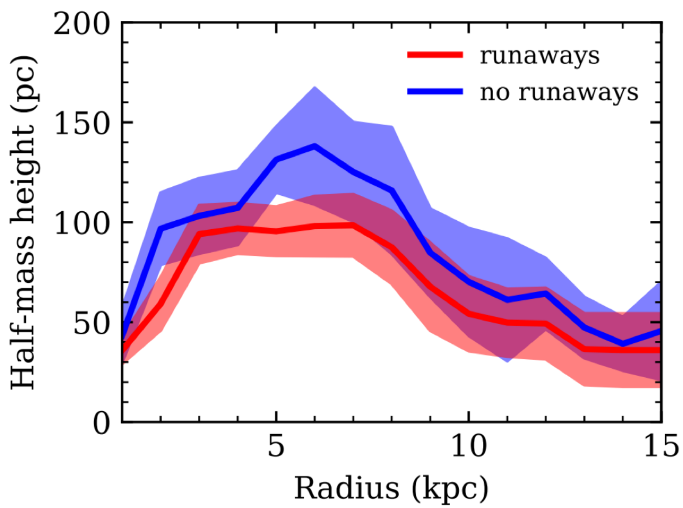
$$\begin{aligned} a_0(Z) &= 10.13 + 0.07547\log Z - 0.008084(\log Z)^2,\\ a_1(Z) &= -4.424 - 0.7939\log Z - 0.1187(\log Z)^2,\\ a_2(Z) &= 1.262 + 0.3385\log Z + 0.05417(\log Z)^2. \end{aligned} \quad (8)$$

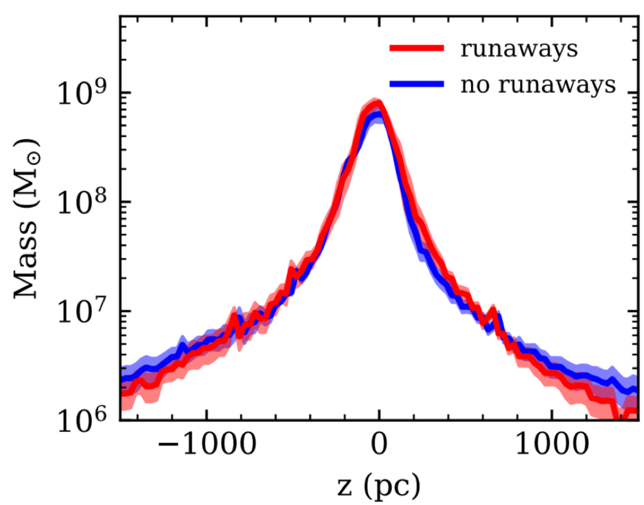


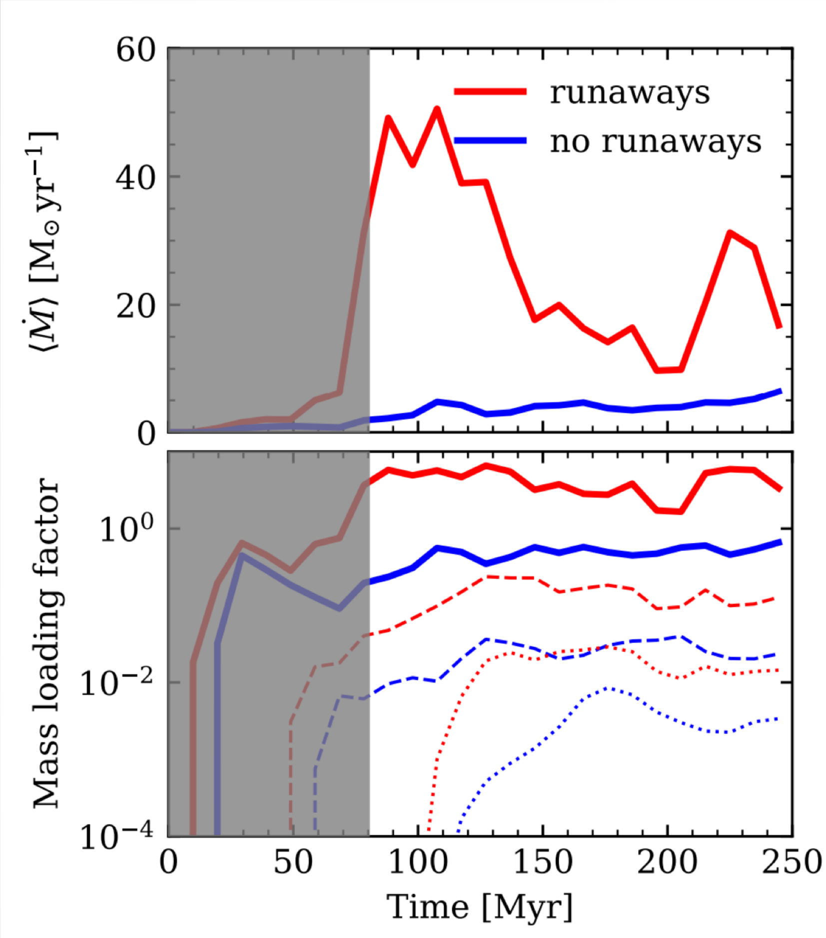


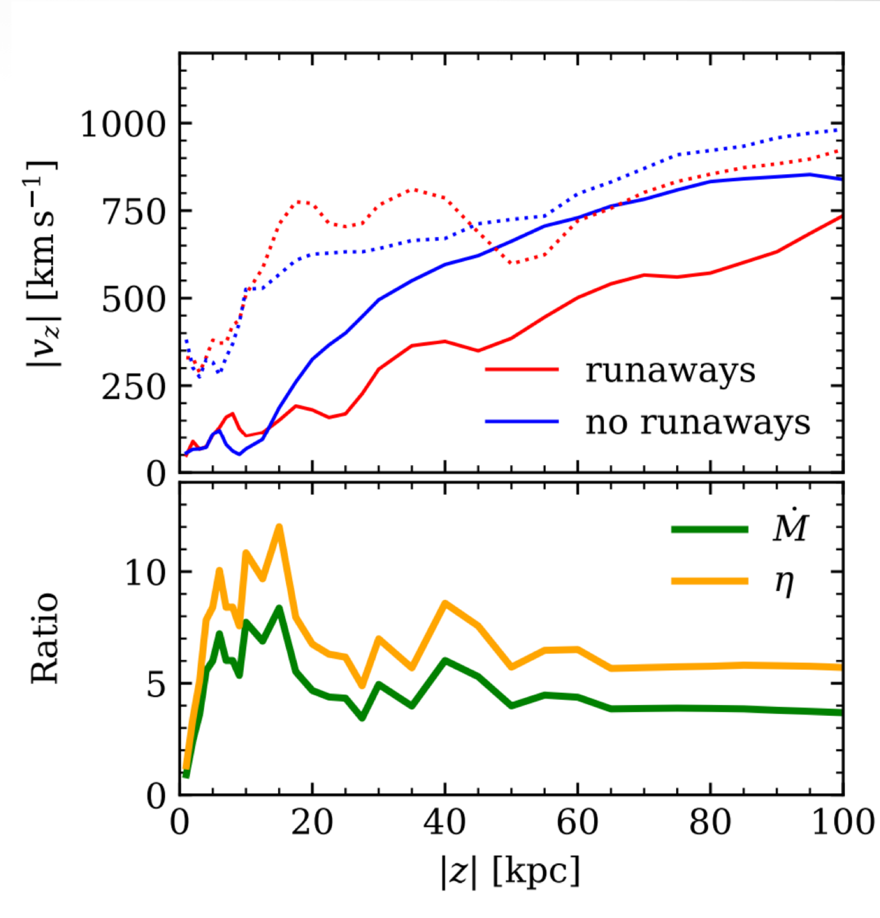
Темп звездообразования повышен. Успешно формируются большие оболочки.

На структуру холодного диск эффекта почти не оказывается.





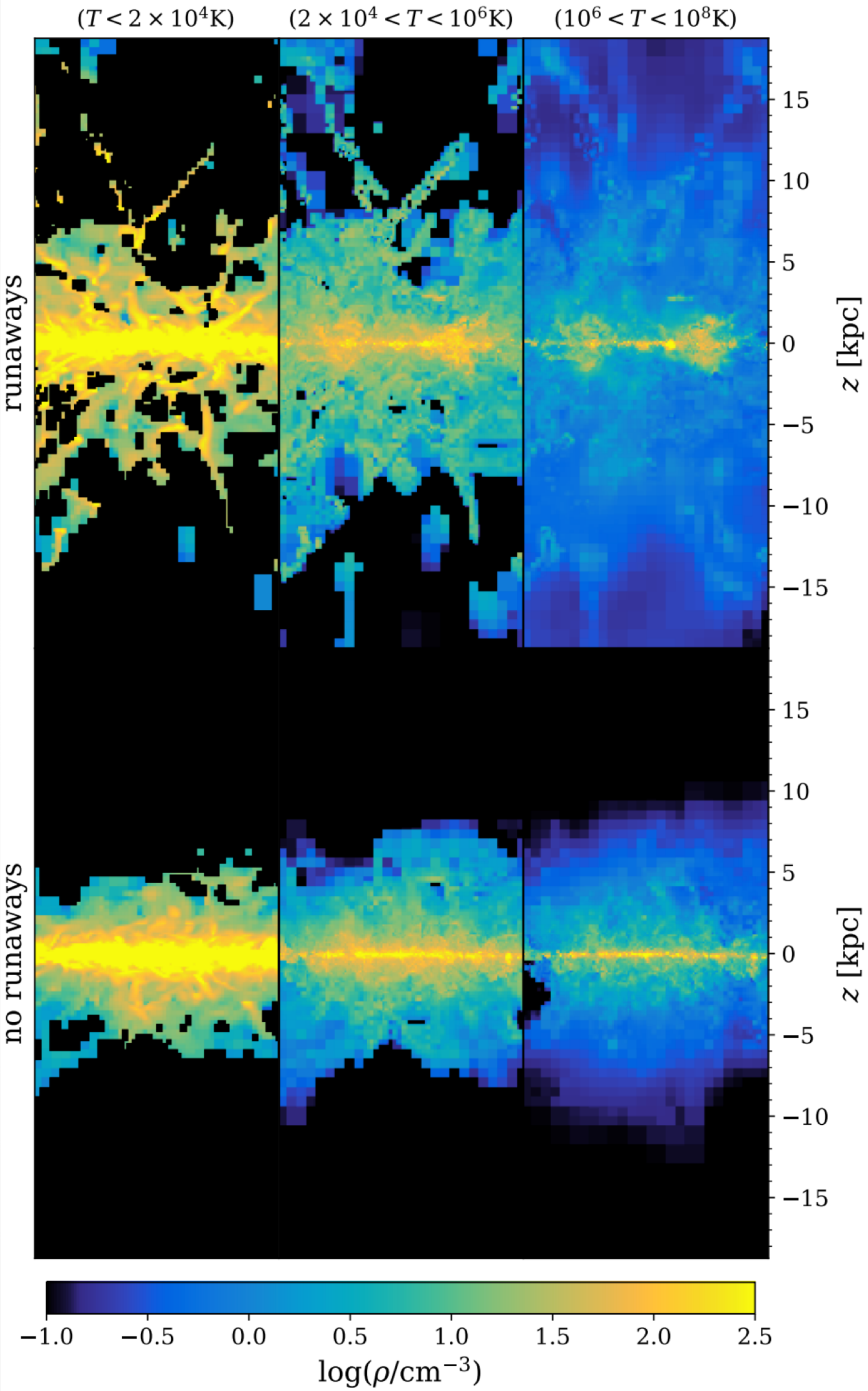




mass loading factor, defined as

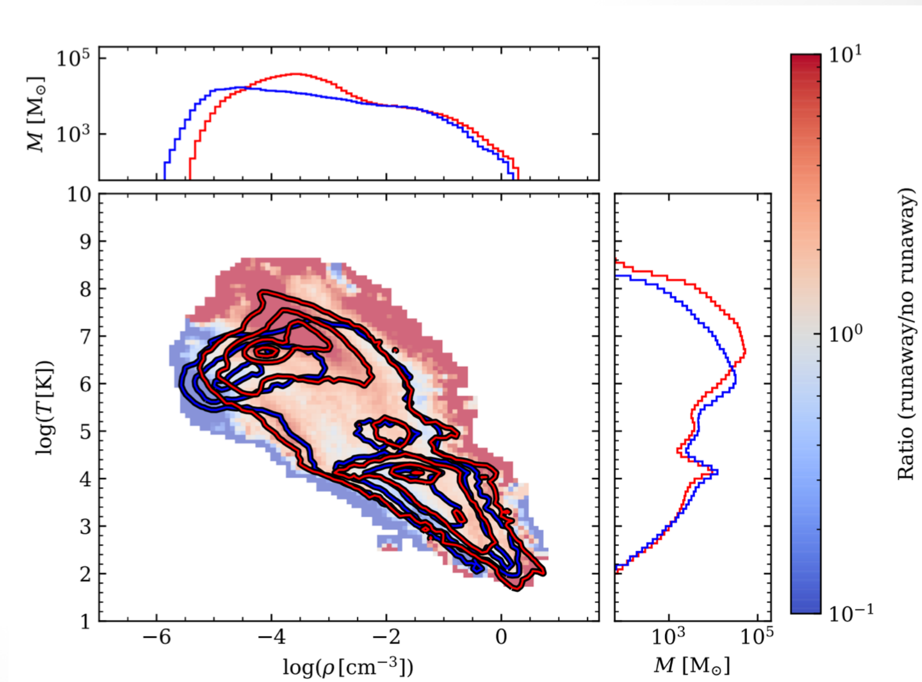
$$\eta = \frac{\langle \dot{M} \rangle}{\mathrm{SFR}}.$$

Outflow существенно увеличивается



Убегающие ОВ-звезды приводят к более структурированному гало, большему относительному содержанию в нем горячего газа.

Если их не учитывать – получим бОльшую фракцию теплого диффузного газа



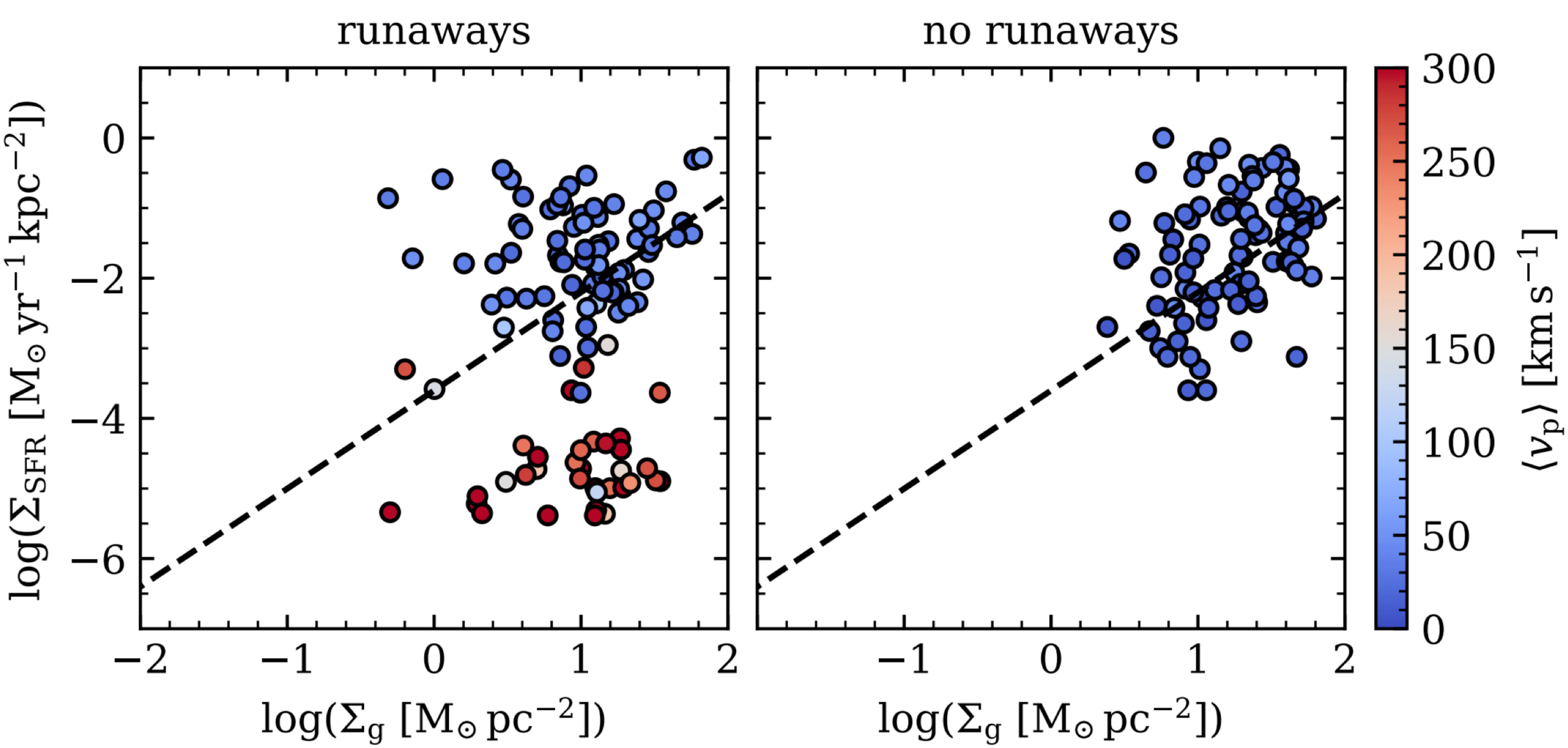


Figure 10. Resolved Kennicutt-Schmidt relation, Σ_{SFR} versus Σ_g, comparing the runaway model (right) to the model ignoring runaway stars (left). Each point is a measurement from a 1 kpc square in the 24 kpc wide face-on view of the galaxy using data from our last output. To compute the star formation rate we use an age bin of 2 Myr. The colours show the mean velocity of all these stars, calculated after removing the velocity component coming from the rotational velocity. The grey dashed line shows the empirical relation fitted by Daddi et al. (2010) for disc galaxies. The `runaways` simulation includes a group of points with star formation rates $\sim 10^{-5}\ M_\odot\ yr^{-1}\ kpc^{-2}$ which corresponds to runaway stars, as is indicated by the high velocity of the stars in these points.

Вклад убегающих звезд может приводить к понижению эффективности звездообразования.

Выводы

- Убегающие OB-звезды приводят к существенному увеличению числа SNe в областях низкой плотности. Это приводит к существенному увеличению эффектов от outflow (mass loading factor, Mdot)
- Холодный газ (T<10^4) в диске менее возмущена при учете убегающих звезд. Несмотря на увеличенный эффект фидбэка, на холодный диск это почти не влияет
- Учет индивидуальных убегающих OB-звезд сложен (высокая стоимость вычислений), так что включить ее в космологические модели пока нереально (только через sub-grid)