Detection of the self-regulation of star formation in galaxy discs

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ABSTRACT

Stellar feedback has a notable influence on the formation and evolution of galaxies. However, direct observational evidence is scarce. We have performed stellar population analysis using MUSE optical spectra of the spiral galaxy NGC 628 and find that current maximum star formation in spatially resolved regions is regulated according to the level of star formation in the recent past. We propose a model based on the self-regulator or "bathtub" models, but for spatially resolved regions of the galaxy. We name it the "resolved self-regulator model" and show that the predictions of this model are in agreement with the presented observations. We observe star formation self-regulation and estimate the mass-loading factor, $\eta = 2.5 \pm 0.5$, consistent with values predicted by galaxy formation models. The method described here will help provide better constraints on those models.

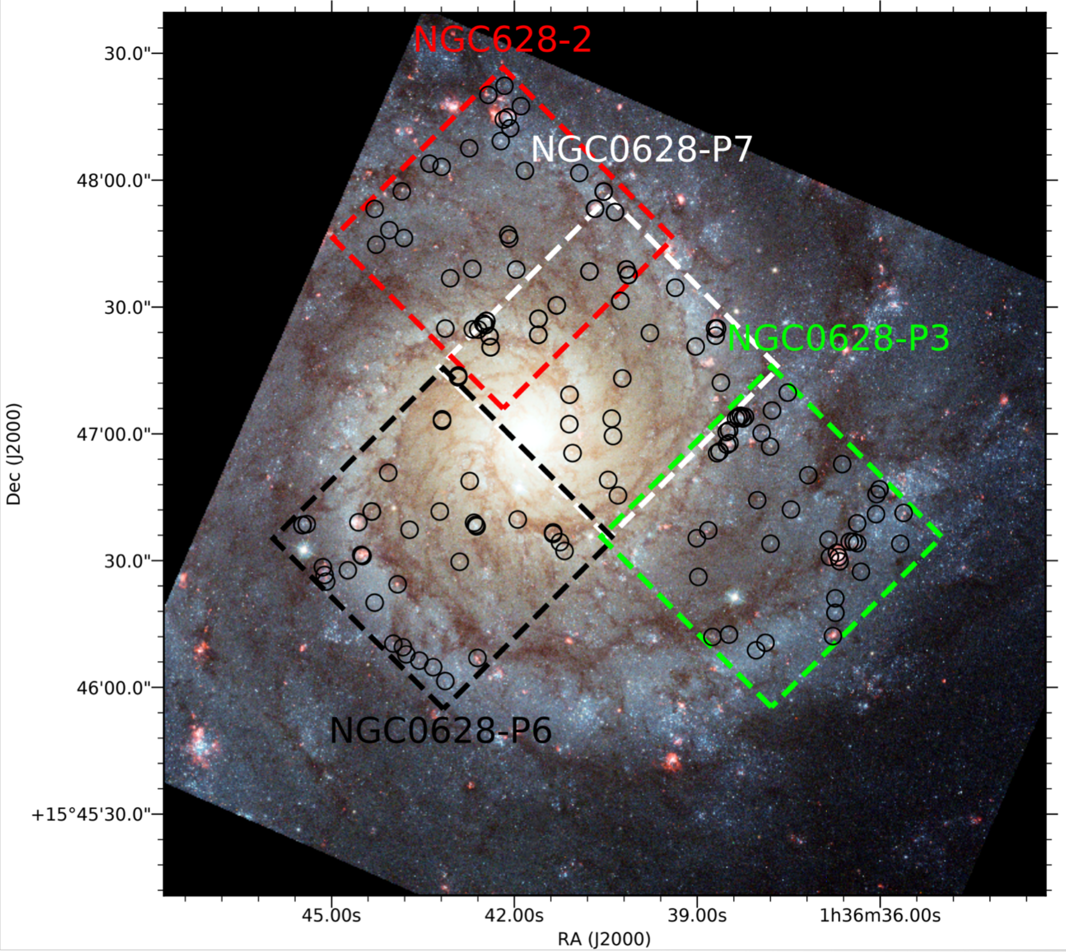
Key words: galaxies: evolution – galaxies: formation – galaxies: star formation – galaxies: stellar content

1 INTRODUCTION

reconciliation of the observed properties of galaxies with those from standard galaxy formation models (Hopkins et al.

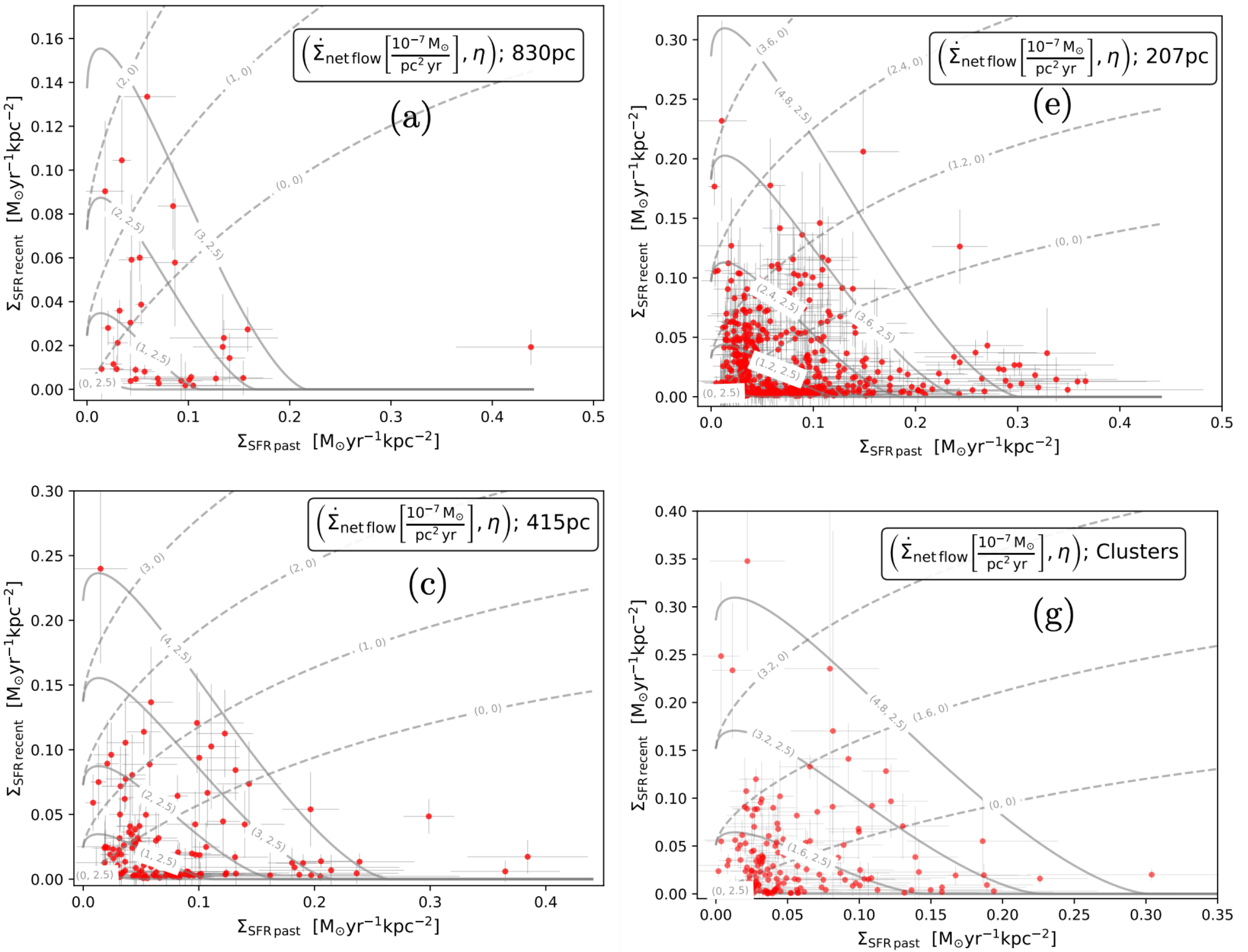
4 поля MUSE

Разбивают каждое поле 3 способами на бины: на 9, 36 и 144 квадратных региона (разрешение 830, 415, 207 пк) + анализируют спектры в круговых апертурах R=87 пк (отдельные скопления)



В каждом бине спектр фиттируют кодом SINOPSIS (Fritz et al. 2007, 2017): Не делают никаких предположений о форме SFH. Используют обновленные модельные спектры Bruzual & Charlot для SSP (Werle+2019) с 3 металличностями (Z=0.04, 0.02, 0.004) и 12 возрастами (2, 4, 7, 20, 57, 200, 570 Myr, 1, 3, 5.75, 10 и 14 Gyr). Эмиссию для t<20Myr добавляют из моделей CLOUDY

В итоге оставляют 4 бина по возрасту в SFH (20 Myr, 570 Myr, 5.7 Gyr, 14 Gyr), анализируют первые два.



$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; 830pc
(a)
(2, 0)
(1, 0)
(0, 0)
(2, 2.5)
(3, 2.5)
(1, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\rm SFR\,past}$ $[M_\odot yr^{-1} kpc^{-2}]$
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.0
0.1
0.2
0.3
0.4
0.5
$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; 207pc
(e)
(3.6, 0)
(2.4, 0)
(4.8, 2.5)
(1.2, 0)
(0, 0)
(2.4, 2.5)
(3.6, 2.5)
(1.2, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\rm SFR\,past}$ $[M_\odot yr^{-1} kpc^{-2}]$
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.0
0.1
0.2
0.3
0.4
0.5
$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; 415pc
(c)
(3, 0)
(2, 0)
(4, 2.5)
(1, 0)
(0, 0)
(2, 2.5)
(3, 2.5)
(1, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\rm SFR\,past}$ $[M_\odot yr^{-1} kpc^{-2}]$
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.0
0.1
0.2
0.3
0.4
$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; Clusters
(g)
(3.2, 0)
(4.8, 2.5)
(1.6, 0)
(3.2, 2.5)
(0, 0)
(1.6, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\rm SFR\,past}$ $[M_\odot yr^{-1} kpc^{-2}]$
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35

$$\dot{M}_{\rm gas} = \dot{M}_{\rm in} - {\rm SFR}(1 - R + \eta) \quad (1)$$

where R is the fraction of the mass that is returned to the interstellar medium, and η is the “mass loading factor”,

$$\dot{M}_{\rm out} = \eta {\rm SFR}. \quad (2)$$

Resolved self-regulator model для одиночных звезд (Burkert 2017):

$$\dot{\Sigma}_{\rm gas} = \dot{\Sigma}_{\rm net\ flow} - \Sigma_{\rm SFR}(1 - R + \eta) \quad (3)$$

Усредняют для больших областей (скопления, комплексы)

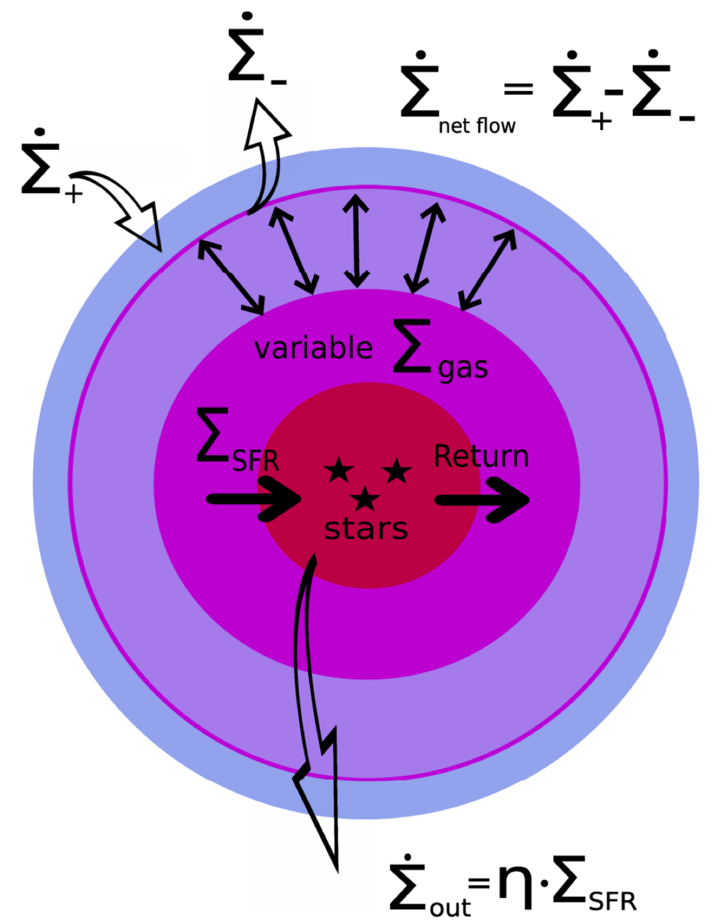
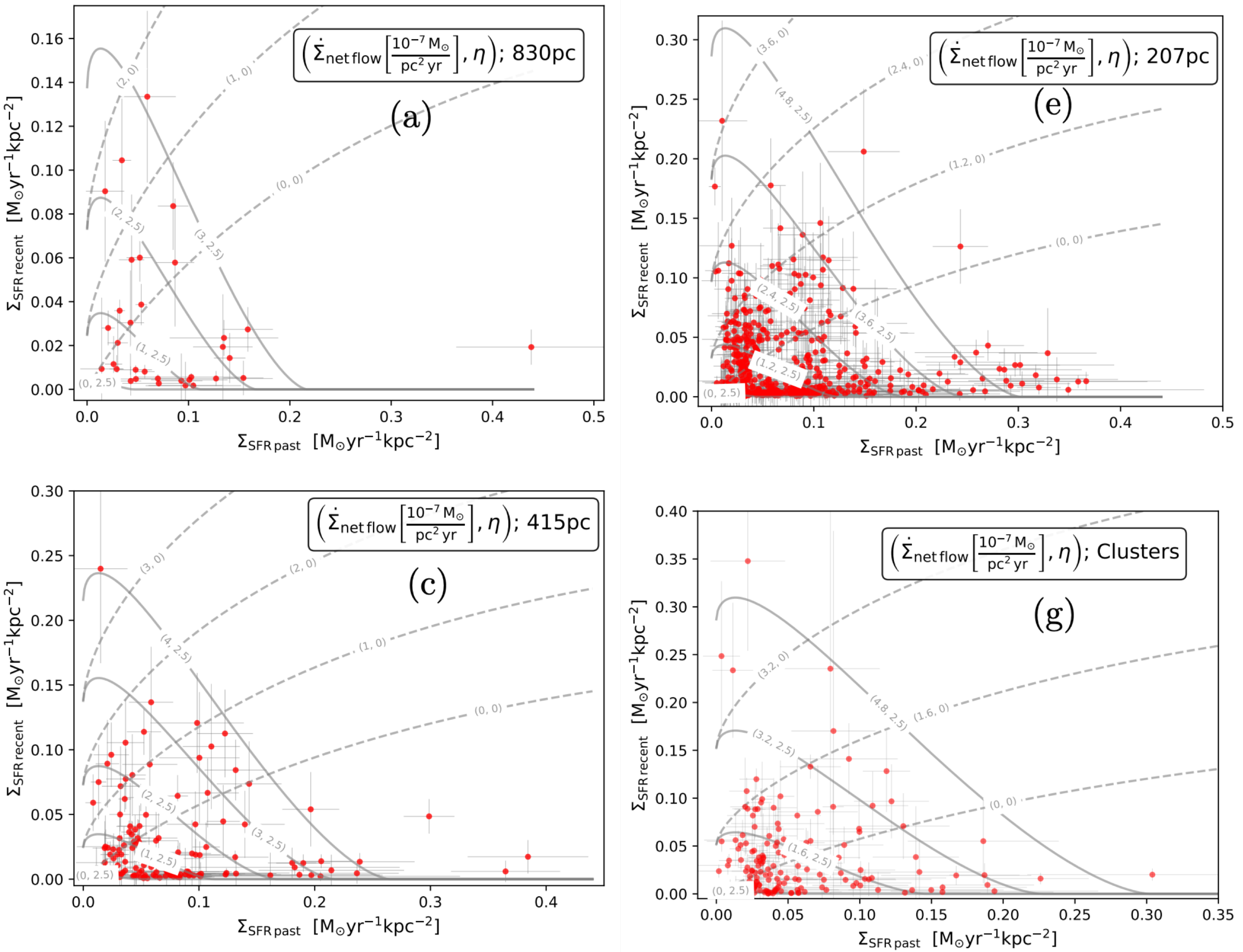


Figure 3. Resolved self-regulator model for a star forming region. The different layers within the circles refer to different components. The stellar disc and the star forming region are co-rotating. Invoking mass conservation, this model relates $\dot{\Sigma}_{\rm gas}$, $\dot{\Sigma}_{\rm net\,flow}$, $\dot{\Sigma}_{\rm out}$, and $\Sigma_{\rm SFR}$.

$$\dot{\overline{\Sigma}}_{\rm gas} = \dot{\overline{\Sigma}}_{\rm net\,flow} - \overline{\Sigma}_{\rm SFR}(1 - R + \eta) \tag{5}$$

where the average is done in the whole region we observe. We can derive or approximate the average quantities from the observations reported in the previous section. We have measured the $\overline{\Sigma}_{\rm SFR\,past}$, as the sum of individual star forming regions that are affecting the present measured $\overline{\Sigma}_{\rm SFR\,recent}$. We convert $\dot{\overline{\Sigma}}_{\rm gas}$ into $\frac{\overline{\Sigma}_{\rm SFR\,recent} - \overline{\Sigma}_{\rm SFR\,past}}{\Delta t}$. We rewrite Eq. 5 assuming that the $\Sigma_{\rm SFR}$ and the $\Sigma_{\rm gas}$ are related by the Kennicutt-Schmidt (KS) law (Kennicutt 1998), $\Sigma_{\rm SFR} = A\Sigma_{\rm gas}^N$:

$$\overline{\Sigma}_{\rm SFR\,recent} = A\left\{\left[\dot{\overline{\Sigma}}_{\rm net\,flow} - \overline{\Sigma}_{\rm SFR\,past}(1 - R + \eta)\right]\Delta t + \left[\frac{\overline{\Sigma}_{\rm SFR\,past}}{A}\right]^{\frac{1}{N}}\right\}^N . \tag{6}$$



$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; 830pc
(a)
(2, 0)
(1, 0)
(0, 0)
(2, 2.5)
(3, 2.5)
(1, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
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0.00
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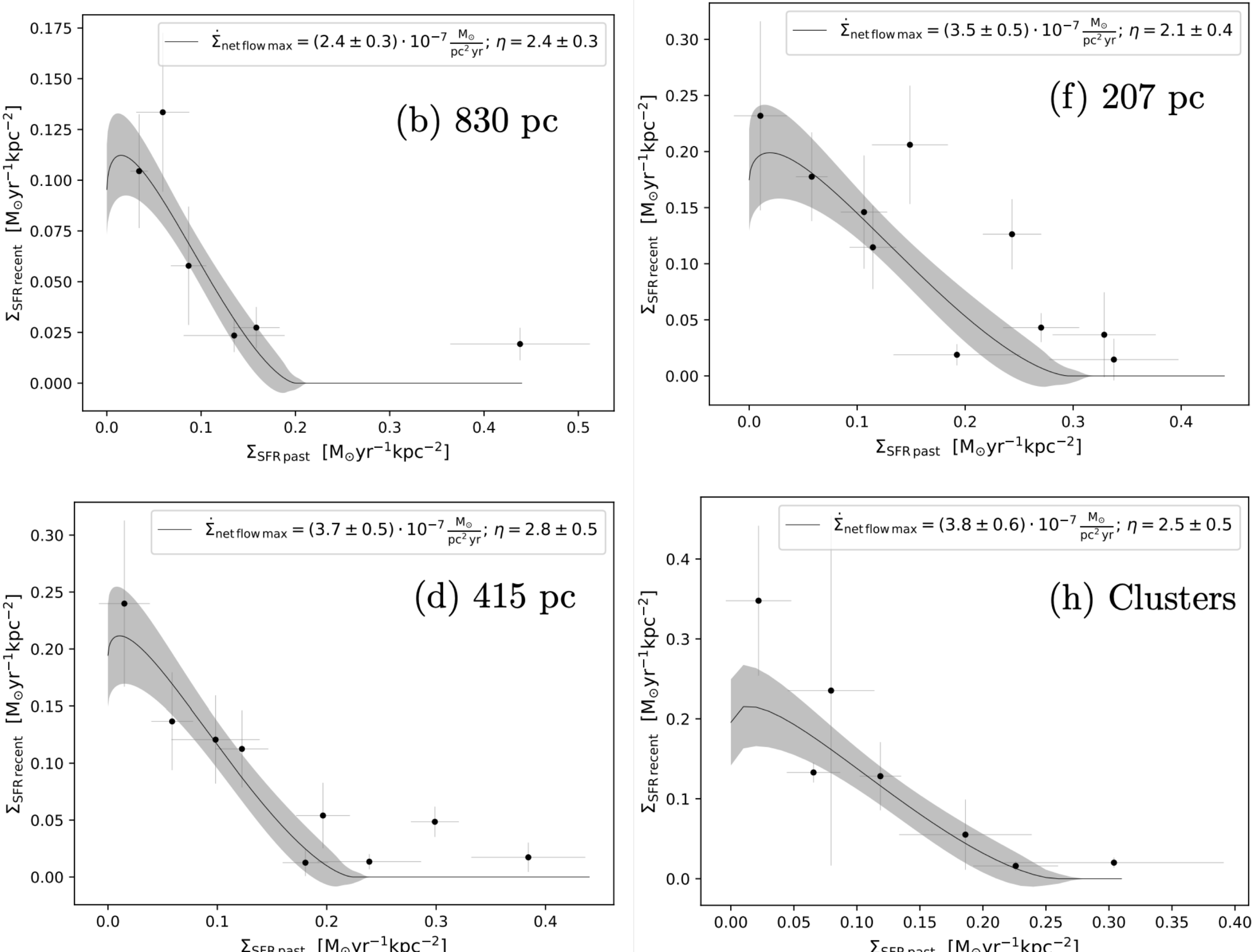
0.08
0.10
0.12
0.14
0.16
0.0
0.1
0.2
0.3
0.4
0.5
$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; 207pc
(e)
(3.6, 0)
(2.4, 0)
(4.8, 2.5)
(1.2, 0)
(0, 0)
(2.4, 2.5)
(3.6, 2.5)
(1.2, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\rm SFR\,past}$ $[M_\odot yr^{-1} kpc^{-2}]$
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.0
0.1
0.2
0.3
0.4
0.5
$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; 415pc
(c)
(3, 0)
(2, 0)
(4, 2.5)
(1, 0)
(0, 0)
(2, 2.5)
(3, 2.5)
(1, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\rm SFR\,past}$ $[M_\odot yr^{-1} kpc^{-2}]$
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.0
0.1
0.2
0.3
0.4
$\left(\dot{\Sigma}_{\rm net\,flow}\left[\frac{10^{-7}\,M_\odot}{pc^2\,yr}\right], \eta\right)$; Clusters
(g)
(3.2, 0)
(4.8, 2.5)
(1.6, 0)
(3.2, 2.5)
(0, 0)
(1.6, 2.5)
(0, 2.5)
$\Sigma_{\rm SFR\,recent}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\rm SFR\,past}$ $[M_\odot yr^{-1} kpc^{-2}]$
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35



$\dot{\Sigma}_{\mathrm{net\,flow\,max}} = (2.4 \pm 0.3) \cdot 10^{-7} \frac{M_\odot}{pc^2\,yr}$; $\eta = 2.4 \pm 0.3$
(b) 830 pc
$\Sigma_{\mathrm{SFR\,recent}}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\mathrm{SFR\,past}}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\dot{\Sigma}_{\mathrm{net\,flow\,max}} = (3.5 \pm 0.5) \cdot 10^{-7} \frac{M_\odot}{pc^2\,yr}$; $\eta = 2.1 \pm 0.4$
(f) 207 pc
$\Sigma_{\mathrm{SFR\,recent}}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\mathrm{SFR\,past}}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\dot{\Sigma}_{\mathrm{net\,flow\,max}} = (3.7 \pm 0.5) \cdot 10^{-7} \frac{M_\odot}{pc^2\,yr}$; $\eta = 2.8 \pm 0.5$
(d) 415 pc
$\Sigma_{\mathrm{SFR\,recent}}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\mathrm{SFR\,past}}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\dot{\Sigma}_{\mathrm{net\,flow\,max}} = (3.8 \pm 0.6) \cdot 10^{-7} \frac{M_\odot}{pc^2\,yr}$; $\eta = 2.5 \pm 0.5$
(h) Clusters
$\Sigma_{\mathrm{SFR\,recent}}$ $[M_\odot yr^{-1} kpc^{-2}]$
$\Sigma_{\mathrm{SFR\,past}}$ $[M_\odot yr^{-1} kpc^{-2}]$