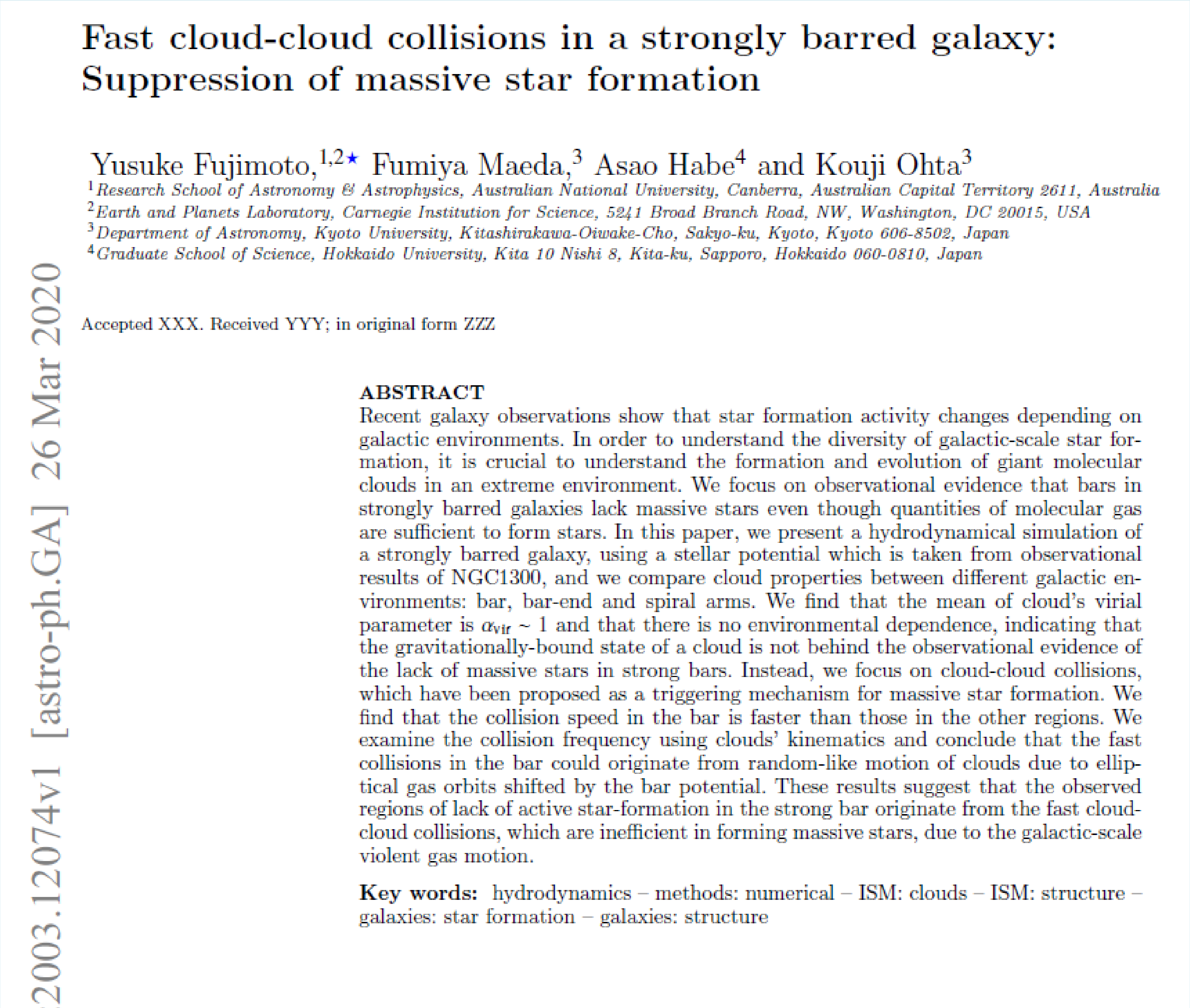

# Fast cloud-cloud collisions in a strongly barred galaxy: Suppression of massive star formation

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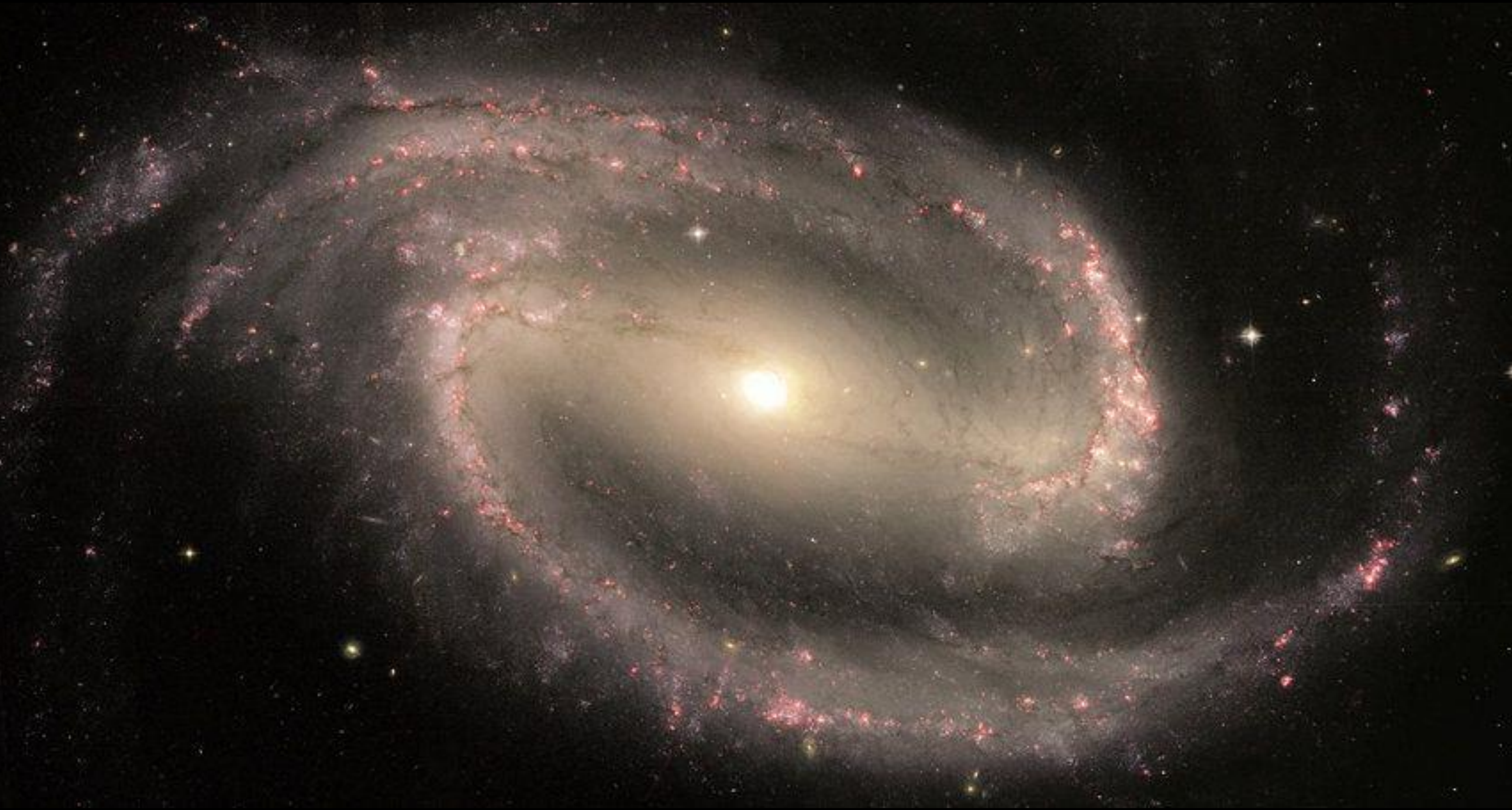
## ABSTRACT

Recent galaxy observations show that star formation activity changes depending on galactic environments. In order to understand the diversity of galactic-scale star formation, it is crucial to understand the formation and evolution of giant molecular clouds in an extreme environment. We focus on observational evidence that bars in strongly barred galaxies lack massive stars even though quantities of molecular gas are sufficient to form stars. In this paper, we present a hydrodynamical simulation of a strongly barred galaxy, using a stellar potential which is taken from observational results of NGC1300, and we compare cloud properties between different galactic environments: bar, bar-end and spiral arms. We find that the mean of cloud's virial parameter is $\alpha_{\rm vir} \sim 1$ and that there is no environmental dependence, indicating that the gravitationally-bound state of a cloud is not behind the observational evidence of the lack of massive stars in strong bars. Instead, we focus on cloud-cloud collisions, which have been proposed as a triggering mechanism for massive star formation. We find that the collision speed in the bar is faster than those in the other regions. We examine the collision frequency using clouds' kinematics and conclude that the fast collisions in the bar could originate from random-like motion of clouds due to elliptical gas orbits shifted by the bar potential. These results suggest that the observed regions of lack of active star-formation in the strong bar originate from the fast cloud-cloud collisions, which are inefficient in forming massive stars, due to the galactic-scale violent gas motion.

**Key words:** hydrodynamics – methods: numerical – ISM: clouds – ISM: structure – galaxies: star formation – galaxies: structure

- Факт: в области бара (кроме спиралей поздних типов) SFR обычно понижена даже при наличии газа *(кроме спиралей поздних типов)* . Это объясняется наличием ударных волн, возбуждающих сильные турбулентные движения (ссылки). Но как это может затронуть формирование GMCs и уже готовые GMCs?
- К тому же, с другой стороны, cl-cl collisions должны стимулировать SF (ссылки) . Вопрос дискуссионный.
- In order to unveil the cause for the low star formation efficiency in the bar region clearly, studying a barred galaxy with a strong bar is ideal, where the symptom of absence of star formation is most clearly seen.
- Выбрана галактика NGC1300.



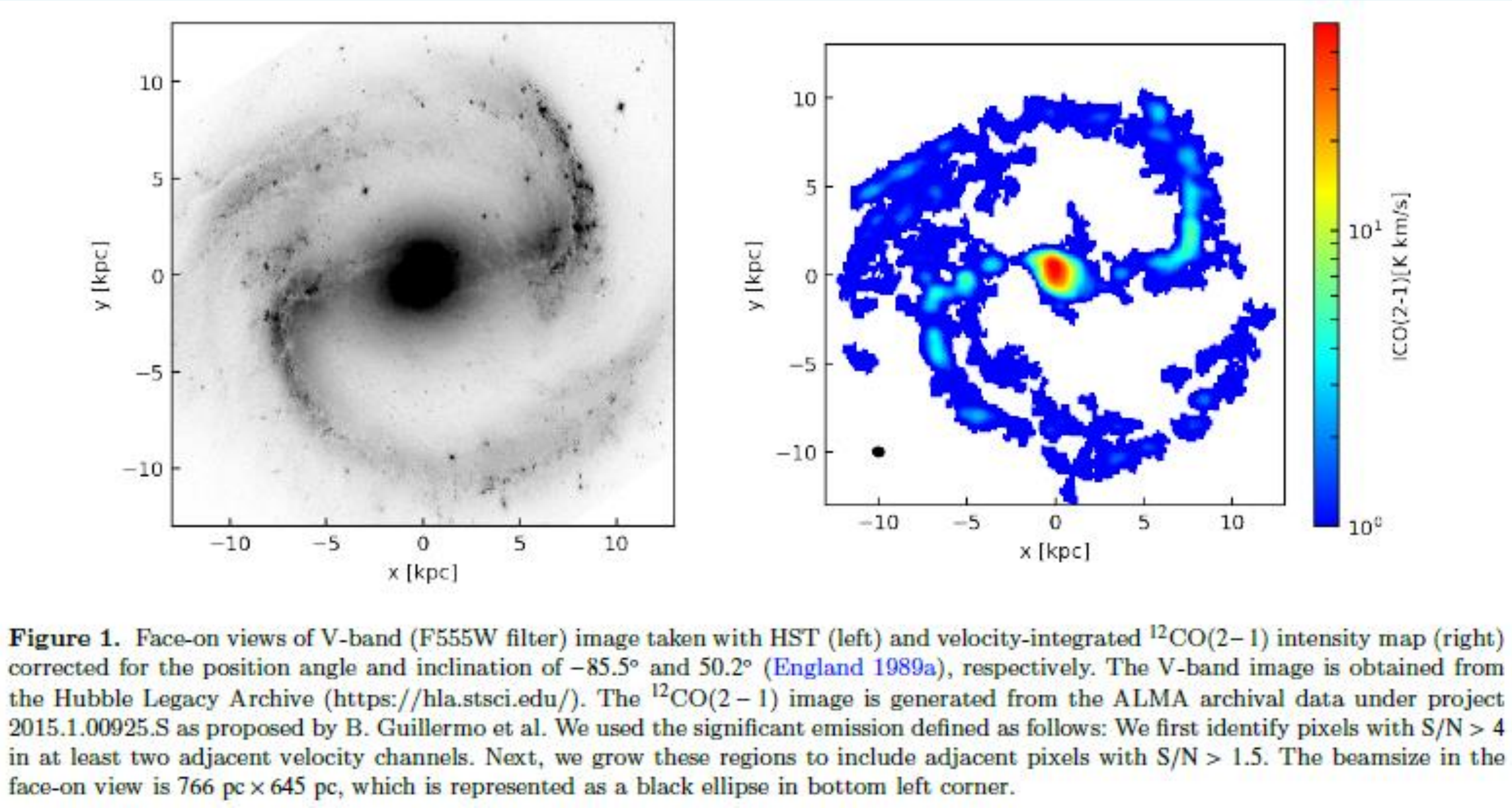


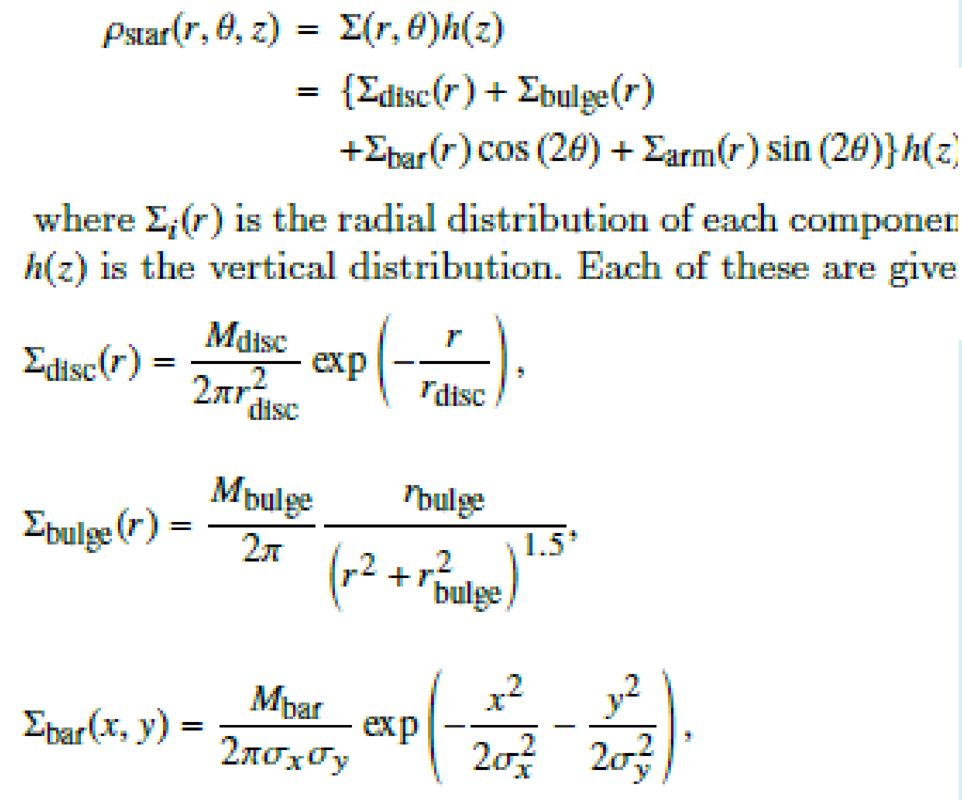
**Figure 1.** Face-on views of V-band (F555W filter) image taken with HST (left) and velocity-integrated $^{12}$CO(2−1) intensity map (right) corrected for the position angle and inclination of −85.5° and 50.2° (England 1989a), respectively. The V-band image is obtained from the Hubble Legacy Archive (https://hla.stsci.edu/). The $^{12}$CO(2 − 1) image is generated from the ALMA archival data under project 2015.1.00925.S as proposed by B. Guillermo et al. We used the significant emission defined as follows: We first identify pixels with S/N > 4 in at least two adjacent velocity channels. Next, we grow these regions to include adjacent pixels with S/N > 1.5. The beamsize in the face-on view is 766 pc × 645 pc, which is represented as a black ellipse in bottom left corner.

- Вопрос: почему газовые облака в баре не рождают массивных звезд? Что мешает им сколлапсировать?

# Simulations

- 3D гидродинамика + радиационное охлаждение облаков + heating by FUV. Солнечные значения металличности и пыль/газ ratio.

# Модель галактики
# Массы компонент --по England 1989



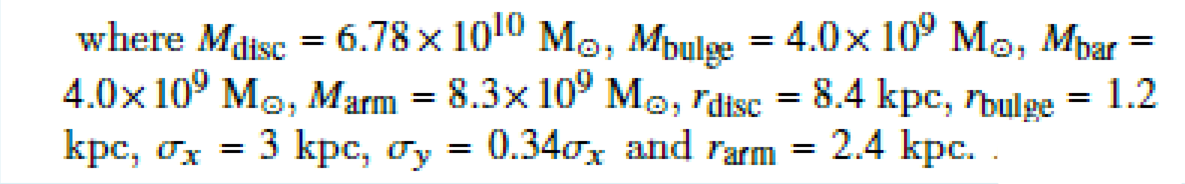
$$\rho_{\rm star}(r,\theta,z) = \Sigma(r,\theta)h(z)$$
$$= \{\Sigma_{\rm disc}(r) + \Sigma_{\rm bulge}(r) + \Sigma_{\rm bar}(r)\cos(2\theta) + \Sigma_{\rm arm}(r)\sin(2\theta)\}h(z$$

where $\Sigma_i(r)$ is the radial distribution of each componen
$h(z)$ is the vertical distribution. Each of these are give

$$\Sigma_{\rm disc}(r) = \frac{M_{\rm disc}}{2\pi r_{\rm disc}^2}\exp\left(-\frac{r}{r_{\rm disc}}\right),$$

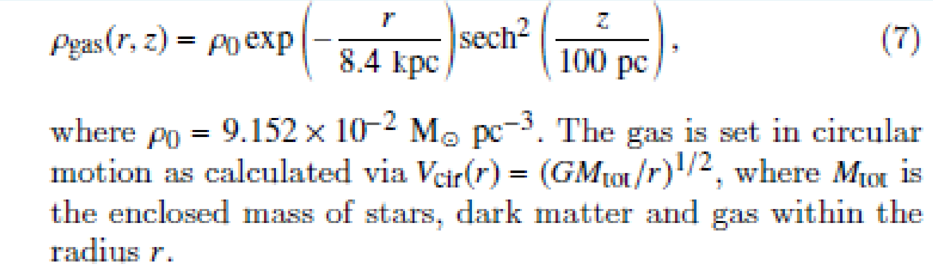
$$\Sigma_{\rm bulge}(r) = \frac{M_{\rm bulge}}{2\pi}\frac{r_{\rm bulge}}{\left(r^2 + r_{\rm bulge}^2\right)^{1.5}},$$

$$\Sigma_{\rm bar}(x,y) = \frac{M_{\rm bar}}{2\pi\sigma_x\sigma_y}\exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}\right),$$



where $M_{\rm disc} = 6.78\times10^{10}$ M$_\odot$, $M_{\rm bulge} = 4.0\times10^{9}$ M$_\odot$, $M_{\rm bar} = 4.0\times10^{9}$ M$_\odot$, $M_{\rm arm} = 8.3\times10^{9}$ M$_\odot$, $r_{\rm disc} = 8.4$ kpc, $r_{\rm bulge} = 1.2$ kpc, $\sigma_x = 3$ kpc, $\sigma_y = 0.34\sigma_x$ and $r_{\rm arm} = 2.4$ kpc.

GAS:



$$\rho_{\rm gas}(r,z) = \rho_0\exp\left(-\frac{r}{8.4\ {\rm kpc}}\right){\rm sech}^2\left(\frac{z}{100\ {\rm pc}}\right), \qquad (7)$$

where $\rho_0 = 9.152\times10^{-2}$ M$_\odot$ pc$^{-3}$. The gas is set in circular motion as calculated via $V_{\rm cir}(r) = (GM_{\rm tot}/r)^{1/2}$, where $M_{\rm tot}$ is the enclosed mass of stars, dark matter and gas within the radius $r$.

## Газ: HI+H2.

Начальное распределение осесимметрично.

# Начальный момент

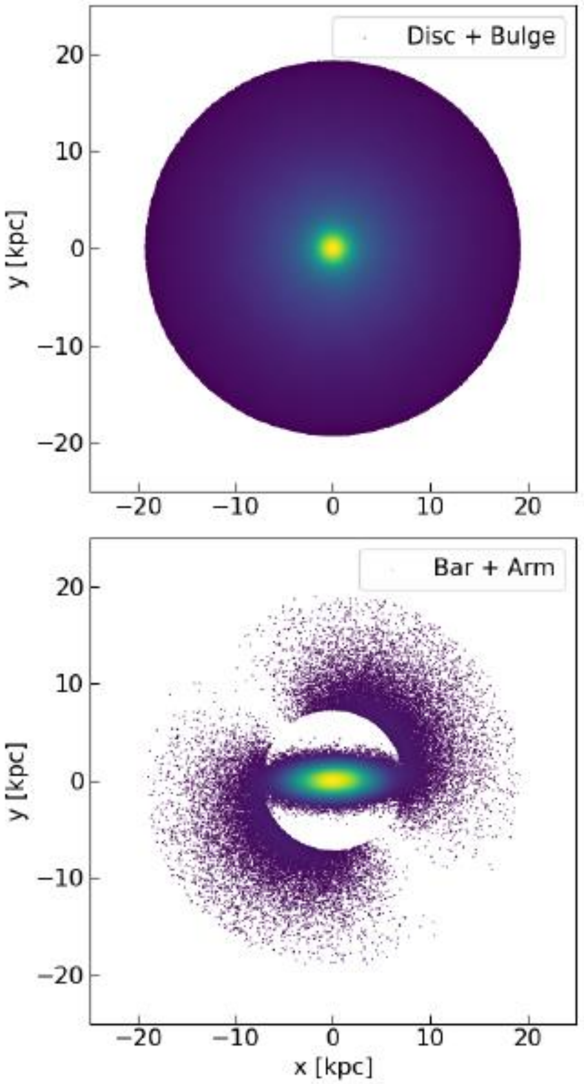


**Figure 2.** The stellar component of the galactic potential. Top panel shows the axisymmetric star particle distribution (disc and bulge). Bottom panel shows the non-axisymmetric star particle distribution (bar and arm), which rotates clockwise at a constant pattern speed.

Показаны только звездные компоненты

Через 150-200млн лет -стационарная картина. Критическая плотность газа для облаков принималась от 100 до 400 см$^{-3}$

**ПОКАЗАНЫ:**

- **Плотность**
- **Температура**
- **Газ с n>100 cm$^{-3}$**

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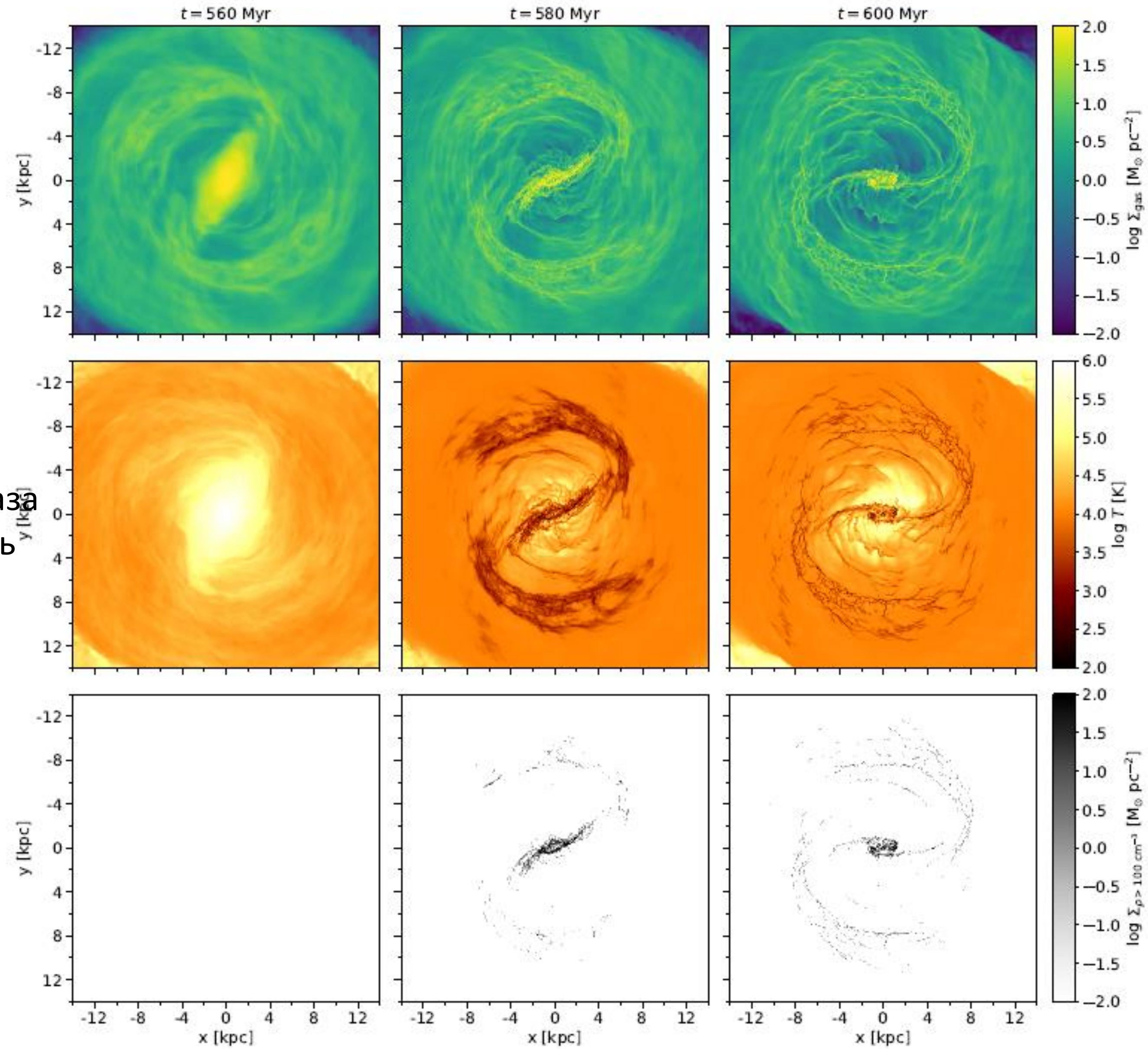


**Figure 3.** The global gas distribution in the face-on galactic disc. Left to right, the images show the disc at $t$ = 560, 580 and 600 Myr. Top to bottom, the images show the gas surface density, the density-weighted gas temperature and the surface density of dense gas of $\geq 100$ cm$^{-3}$. The galactic disc rotates clockwise.

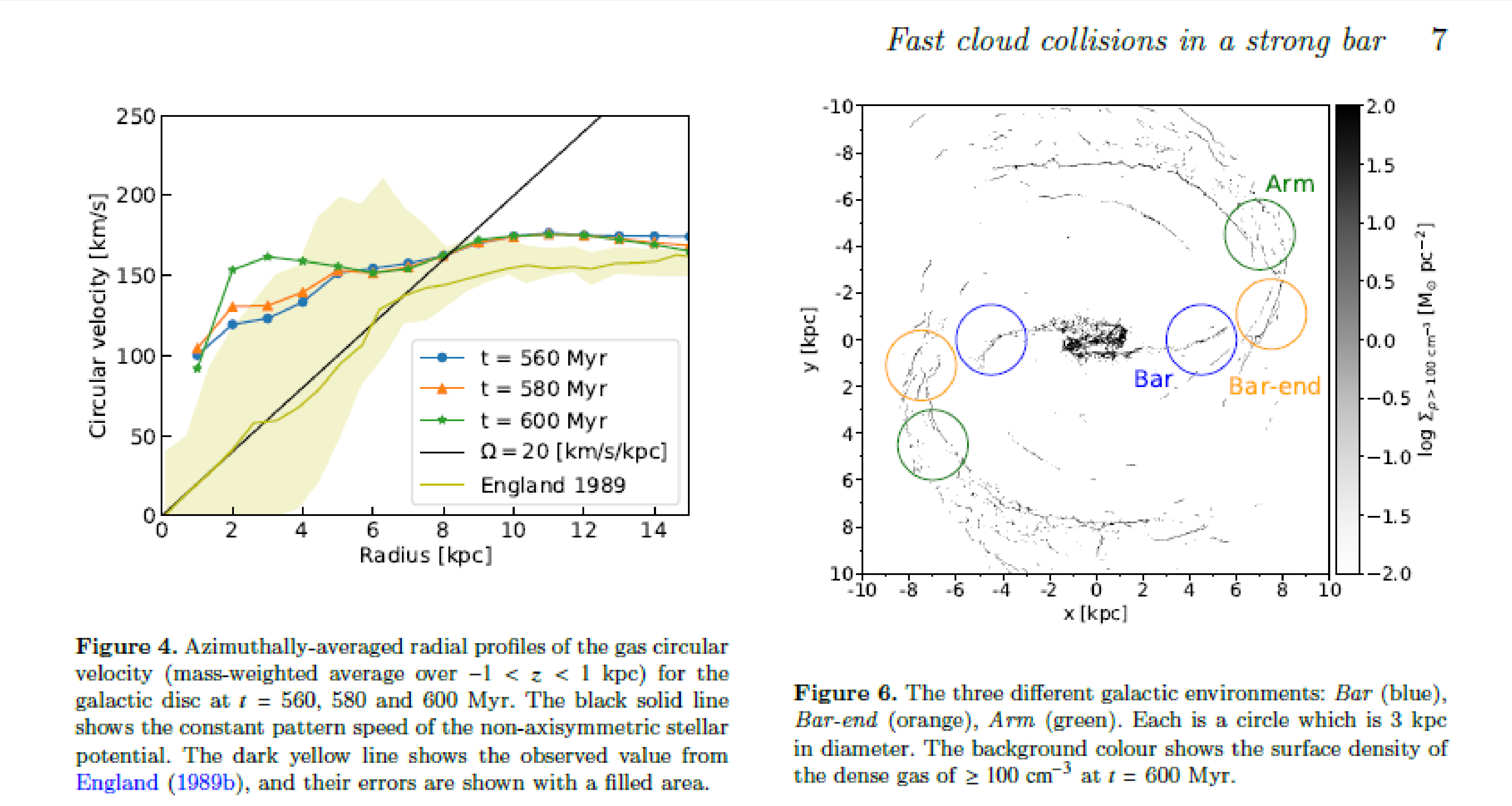


**Figure 4.** Azimuthally-averaged radial profiles of the gas circular velocity (mass-weighted average over $-1 < z < 1$ kpc) for the galactic disc at $t$ = 560, 580 and 600 Myr. The black solid line shows the constant pattern speed of the non-axisymmetric stellar potential. The dark yellow line shows the observed value from England (1989b), and their errors are shown with a filled area.

**Figure 6.** The three different galactic environments: *Bar* (blue), *Bar-end* (orange), *Arm* (green). Each is a circle which is 3 kpc in diameter. The background colour shows the surface density of the dense gas of $\geq 100$ cm$^{-3}$ at $t$ = 600 Myr.

**Вириальные свойства облаков в баре и в спиралях оказались одинаковыми. Они рождаются с $\alpha_{vir}$ ~ 1. Значит, дело не в образовании облаков.**

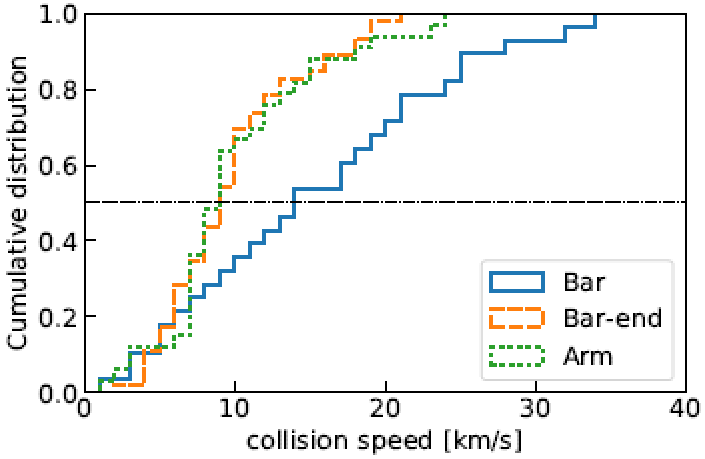
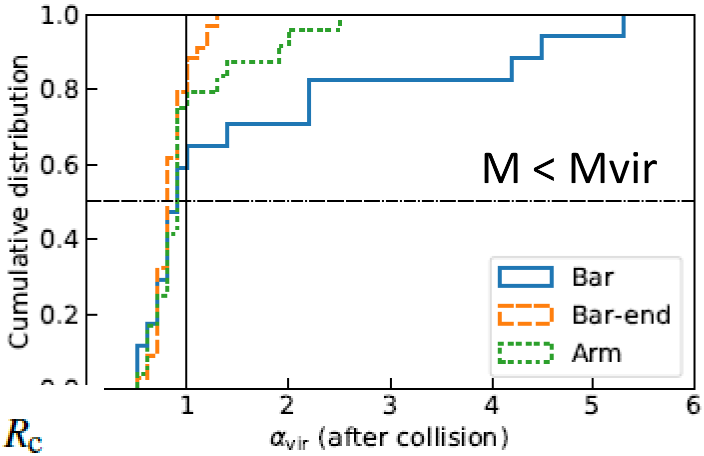


**Figure 8.** Normalized cumulative distribution function of the cloud-cloud collision speed. The samples are the collisions occurred in 20 Myr between $t$ = 590 and 610 Myr, as shown in Table 1.



$$\alpha_{\rm vir} = \frac{5\sigma_c^2 R_c}{G M_c}.$$

**Figure 11.** Normalized cumulative distribution function of the virial parameter of clouds after cloud-cloud collisions. The samples are the collisions occurred in 20 Myr between $t$ = 590 and 610 Myr, as shown in Table 1. The collision whose mass ratio is less than 0.1 is excluded because we do not expect that such a collision can create a compressed shocked region which could possess massive cloud cores.

The high-speed collisions in the Bar originate from the global galactic gas motion; the gas flow is highly elongated by the bar potential, that induces dispersion in the clouds' motion, that can cause violent cloud-cloud collisions. The high-speed collision can make clouds gravitationally unbound

# Основные выводы

- Формирующиеся облака мало различаются по массам в баре и в спиральной ветви. Основное отличие – не в массе облаков или в частоте их столкновений, а в скорости столкновений – из-за сильных некруговых движений в баре (вытянутые орбиты). Этим объясняется низкий темп звездообразования.

**Galaxy NGC 1512**

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