








Comparing the Inner and Outer Star Forming Complexes in the Nearby Spiral Galaxies NGC 628, NGC 5457 and NGC 6946 using UVIT Observations

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ABSTRACT

We present a far-UV (FUV) study of the star-forming complexes (SFCs) in three nearby galaxies using the Ultraviolet Imaging Telescope (UVIT). The galaxies are close to face-on and show significant outer disk star formation. Two of them are isolated (NGC 628, NGC 6946), and one is interacting with distant companions (NGC 5457). We compared the properties of the SFCs inside and outside the optical radius (R_{25}). We estimated the sizes, star formation rates (SFRs), metallicities, and the Toomre Q parameter of the SFCs. We find that the outer disk SFCs are at least ten times smaller in area than those in the inner disk. The SFR per unit area (Σ_{SFR}) in both regions have similar mean values, but the outer SFCs have a much smaller range of Σ_{SFR} . They are also metal-poor compared to the inner disk SFCs. The FUV emission is well correlated with the neutral hydrogen gas (HI) distribution and is detected within and near several HI holes. Our estimation of the Q parameter in the outer disks of the two isolated galaxies suggests that their outer disks are stable ($Q > 1$). However, their FUV images indicate that there is ongoing star formation in these regions. This suggests that there may be some non-luminous mass or dark matter in their outer disks, which increases the disk surface density and supports the formation of local gravitational instabilities. In the interacting galaxy, NGC 5457, the baryonic surface density is sufficient ($Q < 1$) to trigger local disk instabilities in the outer disk.

Keywords: Ultraviolet astronomy (1736); Spiral galaxies (1560); Galaxy interactions (600); Star forming regions (1565); HI shells (728)

Мех-мы, регулирующие SF, во внутренних и внешних областях галактик, д.б. различными

- Цель: сравнение комплексов SF трех S- галактик: NGC628, NGC6946, NGC5457 с использованием UVIT.
- Особенности внешних областей: низкая плотность диска, низкое содержание пыли и мол.газа, низкая металличность.
- 30% галактик, богатых газом, имеют области SF за пределами R25. Низкая эффективность SFE. Это XUV-диски.
- Во внутренних областях SF связано со спиральями, с расширяющимися оболочками HI (SF triggering), и тесно коррелирует с плотностью газа (закон KS) и звездного диска.
- Во внешних областях появление SF – рез-т локального сжатия газа.

- UVIT (Indian Space Research Organization)

D38cm. (сравн.GALEX - 50cm).

Разрешение 1.4'' (сравн.GALEX - 5'').

FUV; 130 - 180 nm, NUV; 200 - 300 nm.

(сравн.GALEX - 135-280 nm).

Основное преимущество - высокое разрешение.

For NGC 628, we obtained both FUV and NUV data from the UVIT archive. For NGC6946 and NGC5457-FUV only. Недостающие данные - из GALEX (но выделенных областей SF из-за этого меньше)

HI data - from THINGS survey.

Table 3. Number of FUV bright SFCs inside and outside R_{25} .

Galaxy	Inner complexes	Outer complexes
(1)	(2)	(3)
NGC 0628	668	38
NGC 5457	1386	39
NGC 6946	480	64

Масштаб ~ 30 pc/''

Характерные
размеры комплексов
SF: неск.сотен пк.

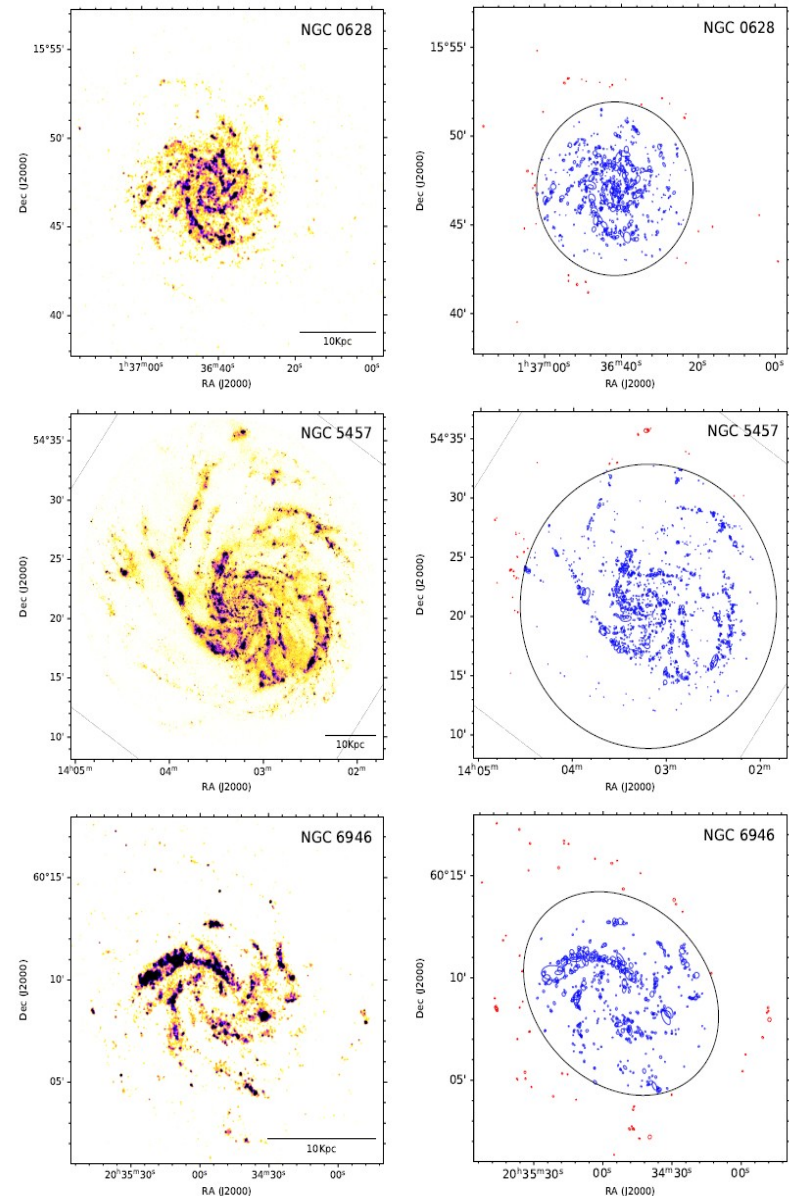
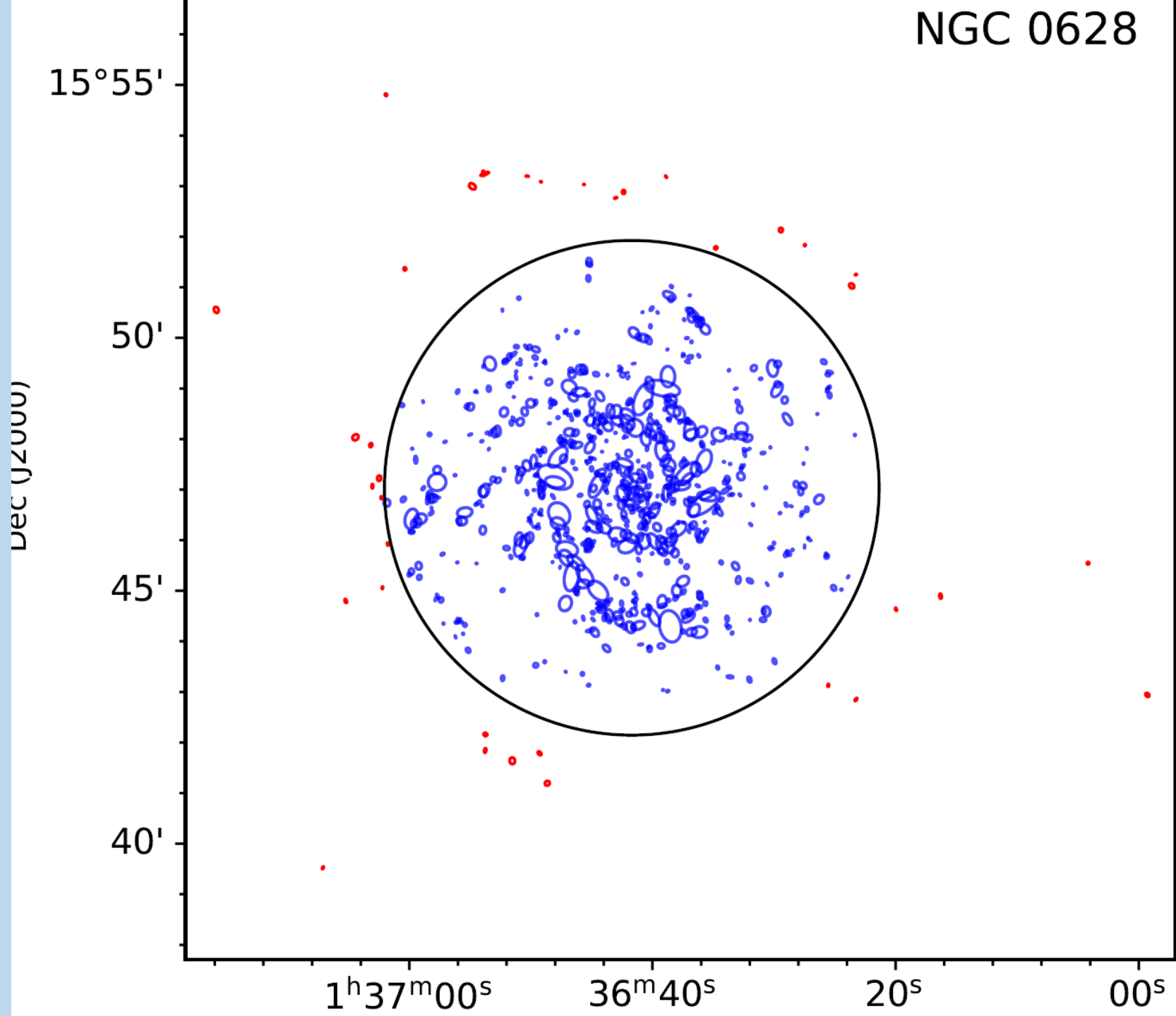


Figure 1. Left panels: UVIT FUV images of NGC 628, NGC 5457 and NGC 6946. Right panels: The locations of SFCs plotted on the FUV images. The black ellipses represent the R_{25} radii of the galaxies. The blue and red marks indicate the location and size of the inner and outer SFCs respectively.

NGC 0628



NGC 5457

Dec (J2000)

54°35'

30'

25'

20'

15'

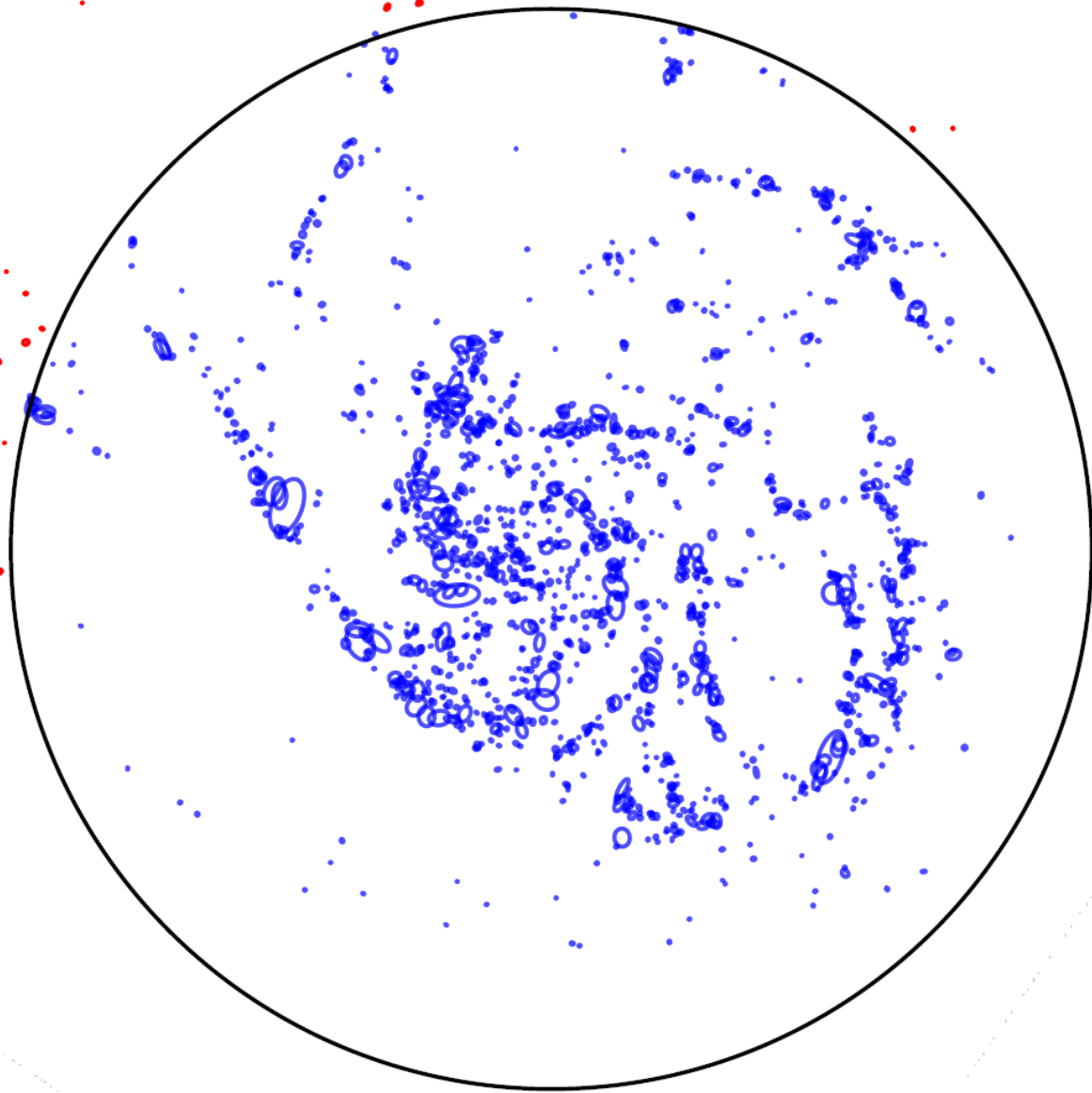
10'

14^h05^m

04^m

03^m

02^m



NGC 6946

Dec (J2000)

60°15'

10'

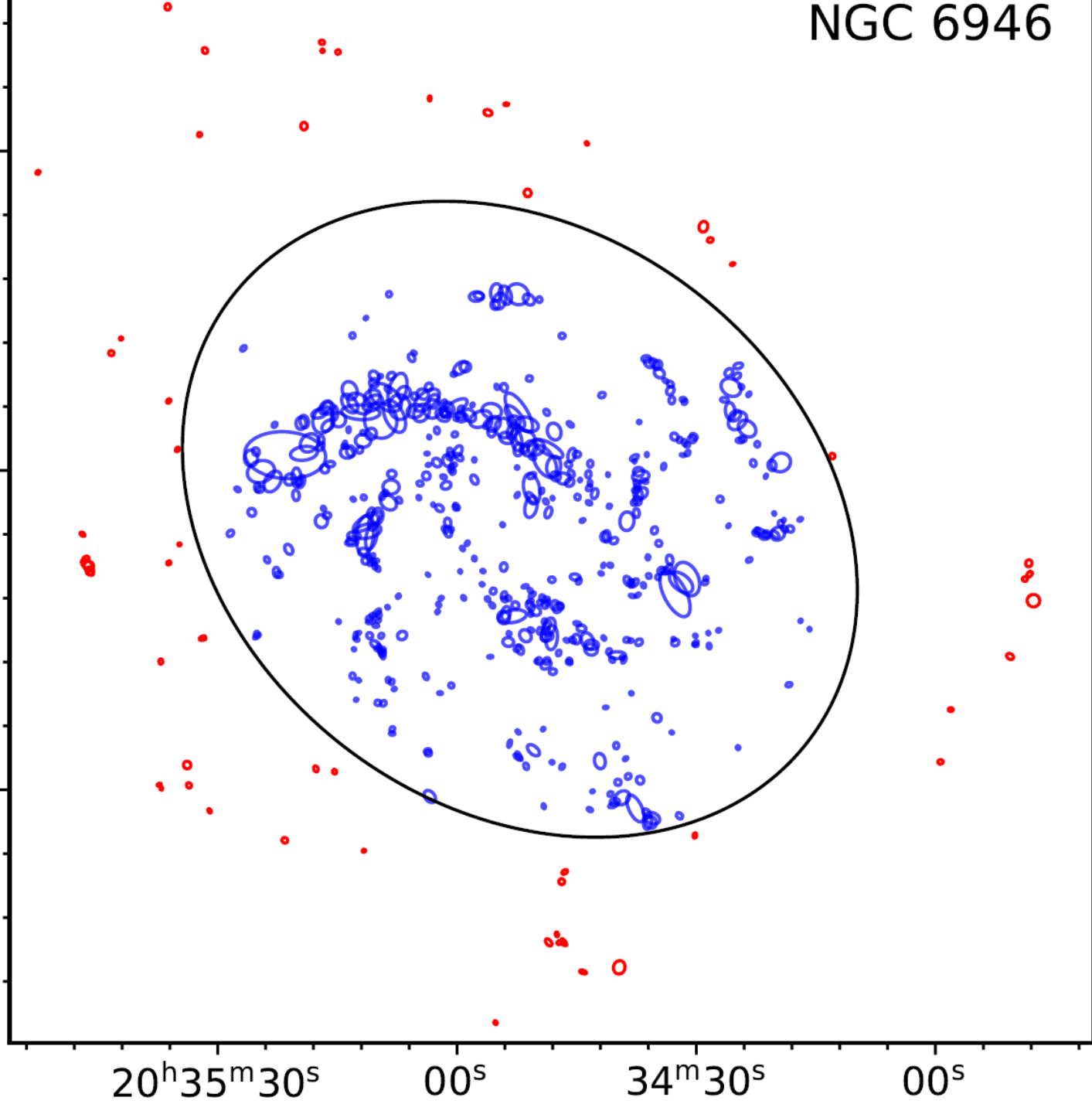
05'

20^h35^m30^s

00^s

34^m30^s

00^s



Распределение по площадям

$$Area = \pi \times a \times b \quad (1)$$

where a and b are the semi-major and semi-minor axes of the extracted elliptical SFCs in kpc. Fig. 2 shows the histogram of the area of these complexes for all three galaxies.

Внешние диски содержат более мелкие комплексы

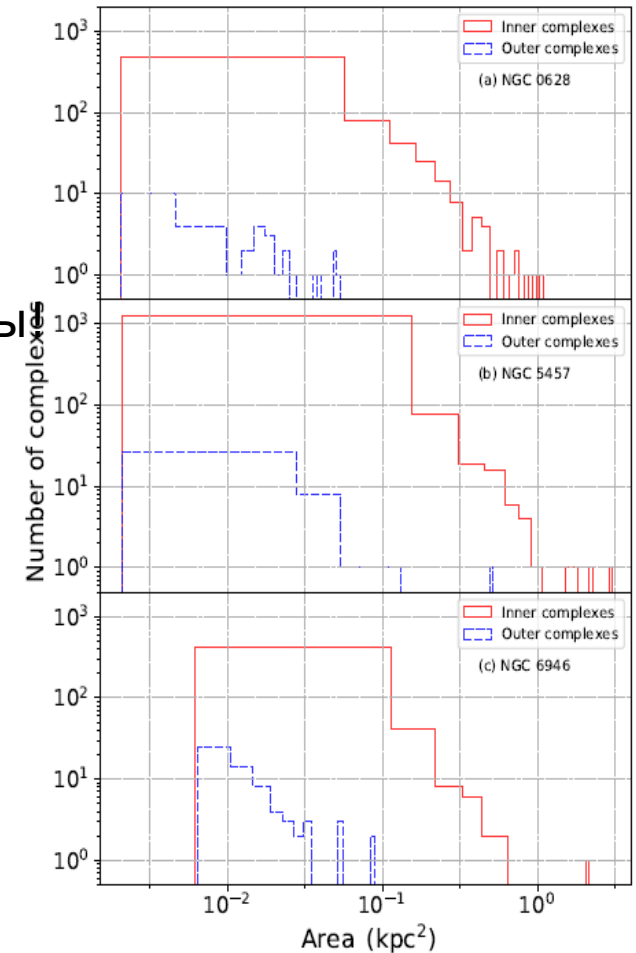


Figure 2. Histogram of area for SFCs in (a) NGC 628, (b) NGC 5457 and (c) NGC 6946. The histograms for inner and outer complexes are shown with solid and dashed lines respectively.

We calculated the Σ_{SFR} (not corrected for internal extinction) for each complex in all three galaxies using the following formula (Leroy et al. 2008; Salim et al. 2007):

$$\Sigma_{SFR(UV)} = 8.1 \times 10^{-2} \cos(i) I_{FUV} \quad (3)$$

Пов.плотности SFR примерно одинаковы во внешних и внутр. областях

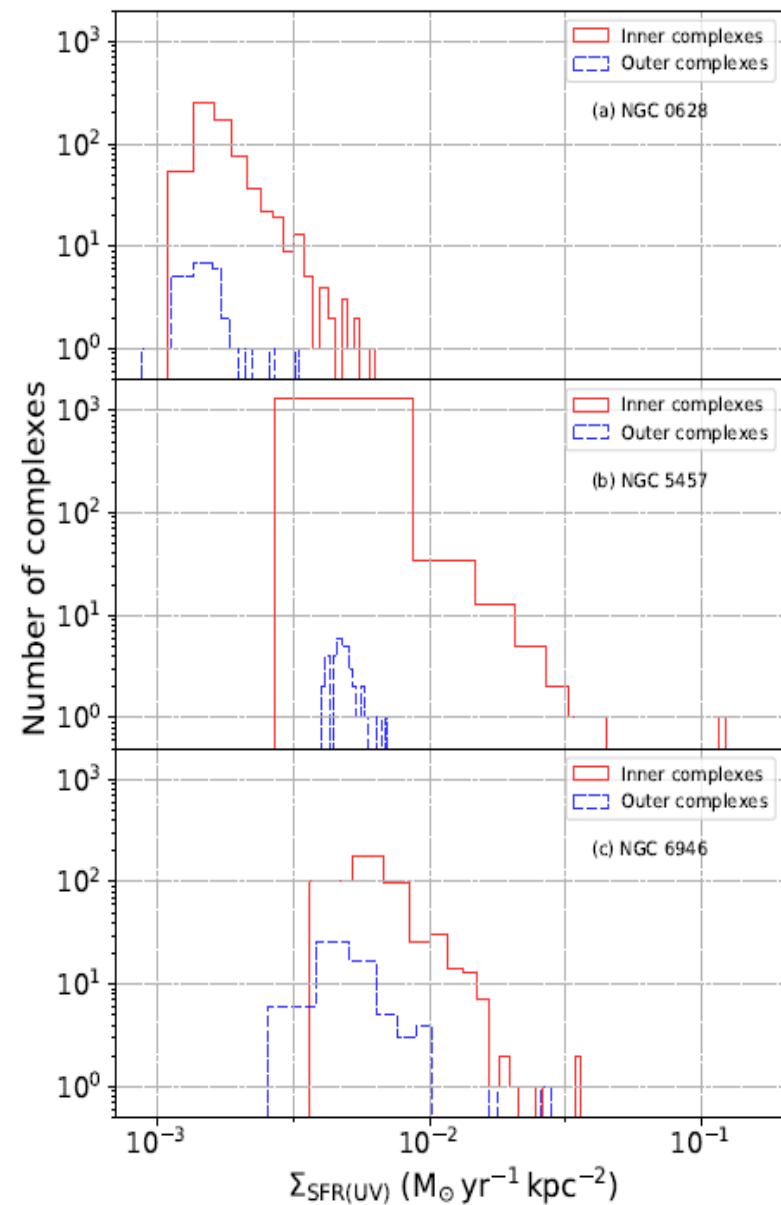


Figure 3. Histograms of the $\Sigma_{SFR(UV)}$ in (a) NGC 628, (b) NGC 5457 and (c) NGC 6946. The histograms for inner and outer complexes are shown with solid and dashed lines respectively.

Возраст: SSP Starburst99
 Показаны highest (0.05)
 and lowest ($4 \cdot 10^{-4}$)
 metallicity tracks.

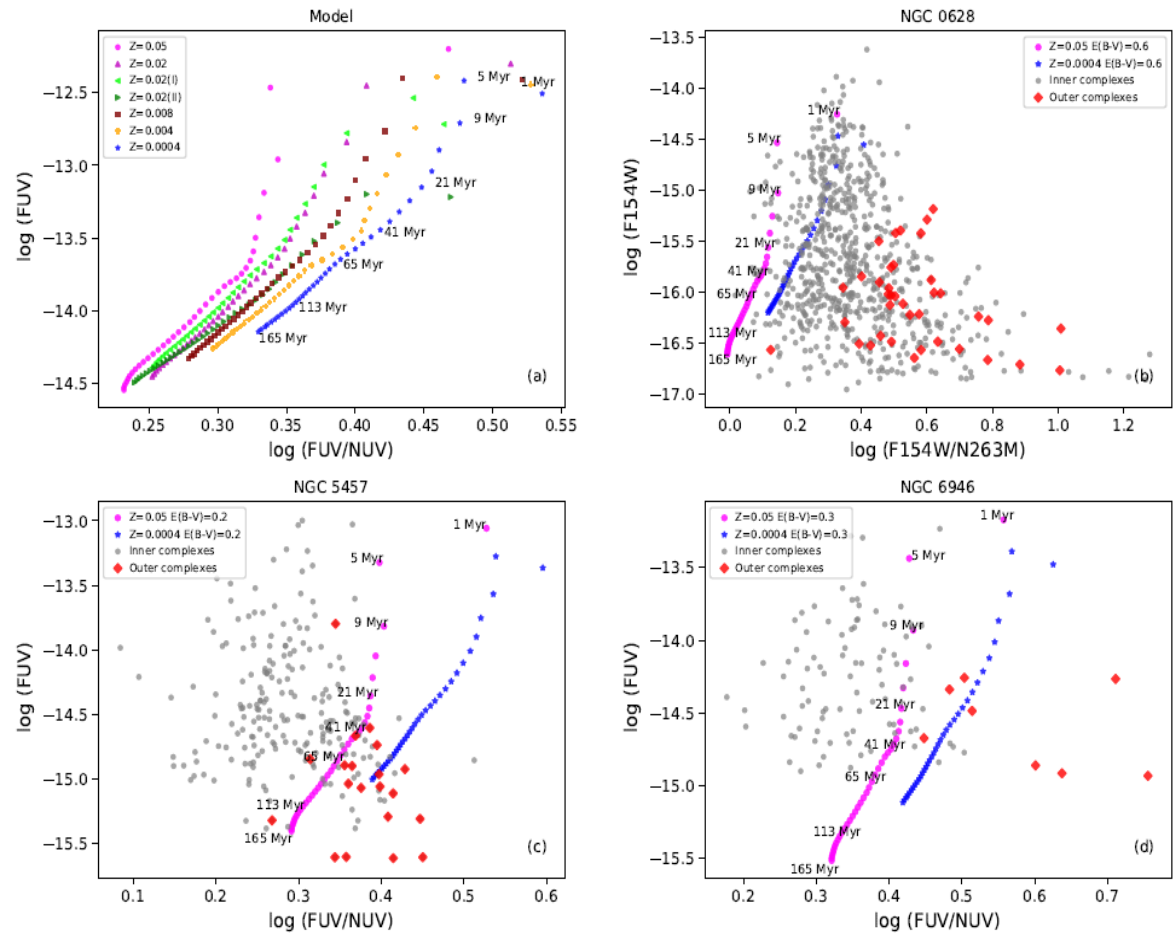
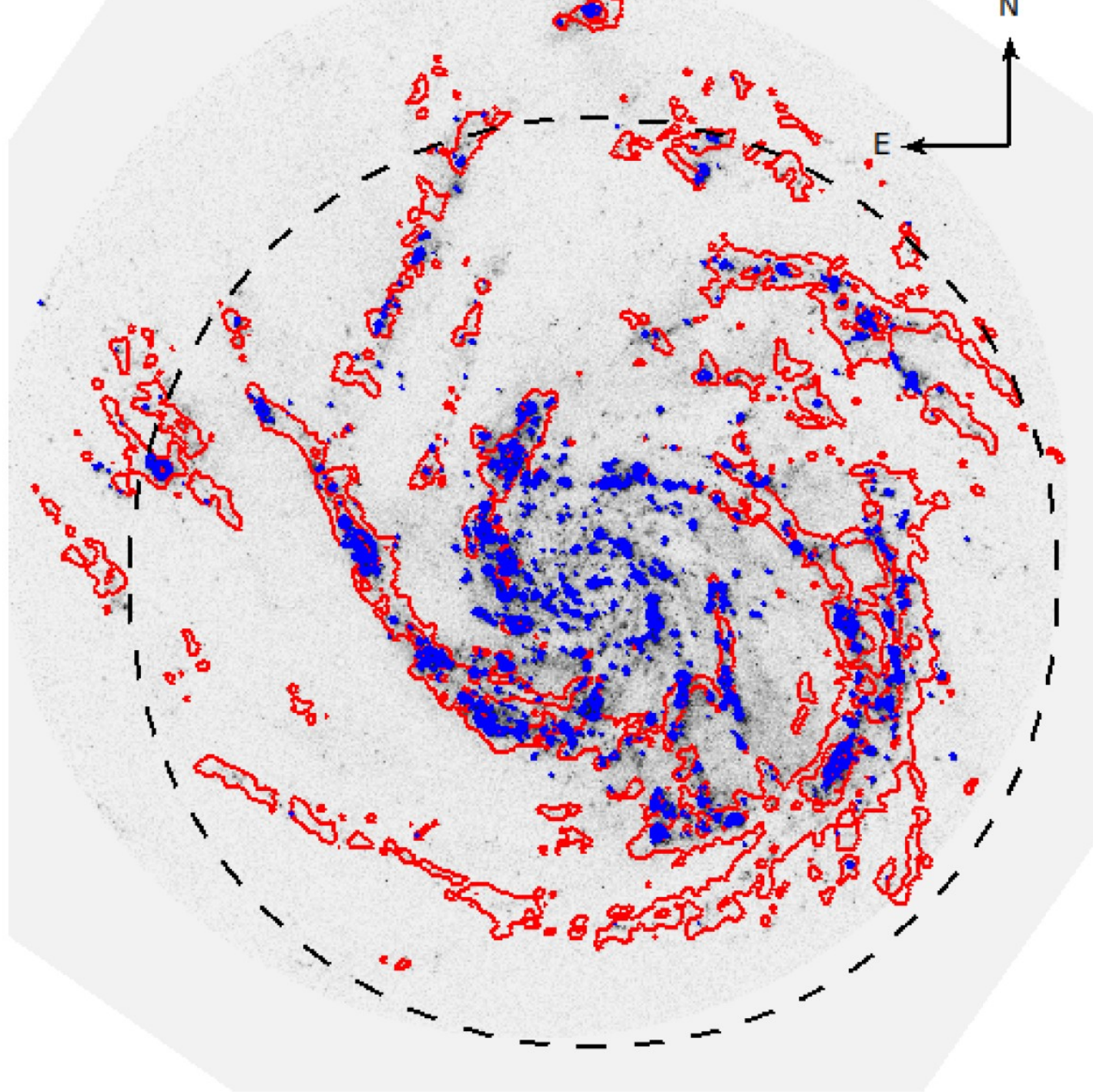


Figure 4. Log(FUV) versus log(FUV/NUV) plot for SFCs. (a) model generated using starburst with metallicities ($Z=0.0004$ to $Z=0.05$) and ages (1 to 165 Myr). $Z=0.02(I)$ and $Z=0.02(II)$ represents the tracks for truncated salpeter IMF and for slope 3.3 respectively. (b), (c) and (d) panels show the SFCs in NGC 628, NGC 5457 and NGC 6946 respectively. Grey points and red diamonds represent the inner and outer SFCs respectively. The magenta ($Z=0.05$) and blue ($Z=0.0004$) tracks represents the models after including reddening of host galaxy.



Голубой цвет – FUV
 Контуры HI-holes-
 из литературы
*We found that a random
 distribution gives a
 correlation of 23 %,
 while the original holes
 indicate a 33 % corre-
 lation.* We can confidently
 state that the HI-holes
 and SFCs as traced by FUV,
 are correlated.
**We found that there are
 significantly fewer holes
 beyond R25 for all three
 galaxies.**

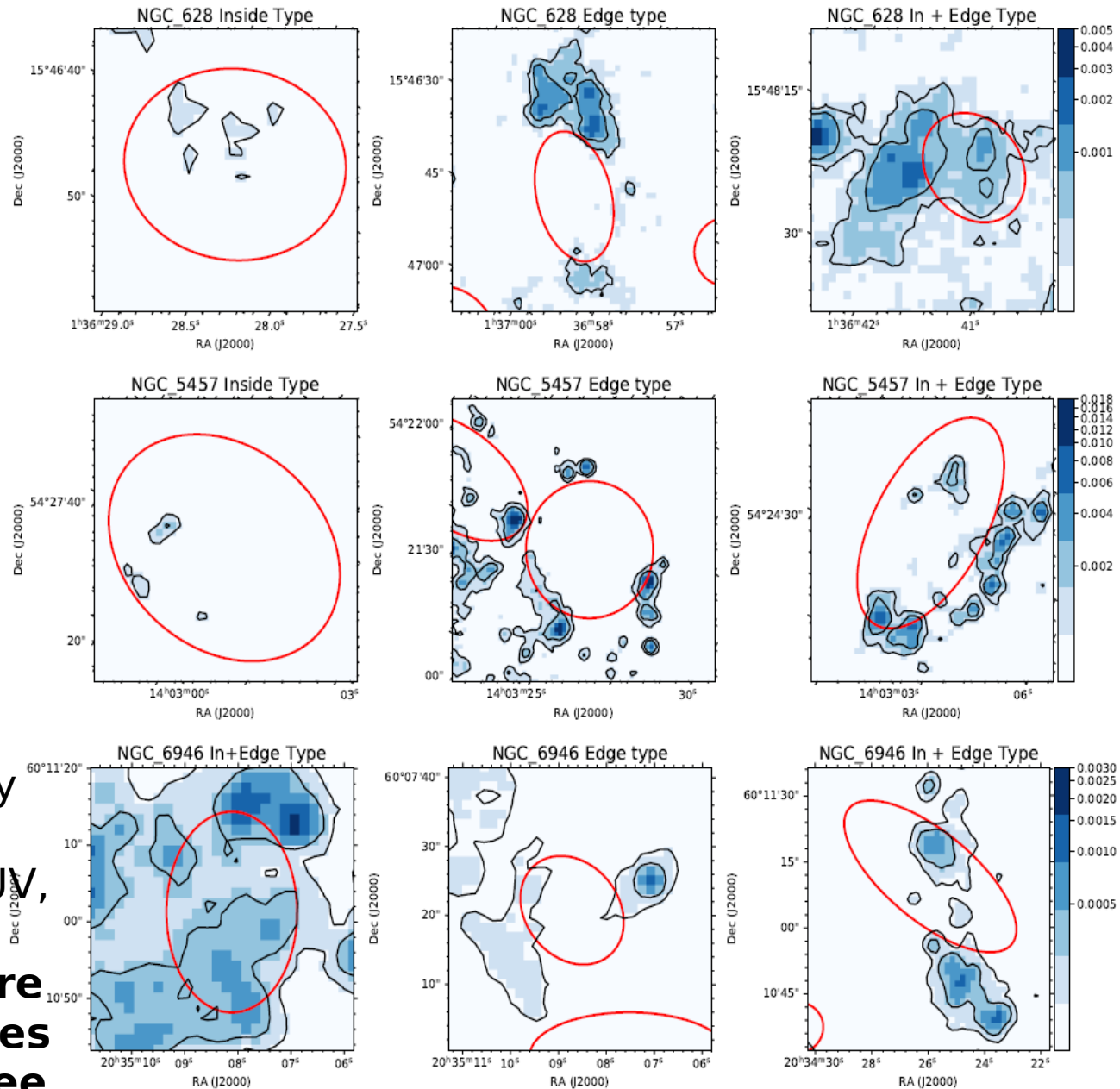


Figure 6. Examples of some of the HI holes associated with FUV emission. The red solid ellipses represent the HI hole boundaries. The blue shaded region shown is the FUV emissions in counts per second. The FUV emission is in logarithmic scale with lower and upper bound of 2.5 and 100 sigma respectively. It is divided into 3 contour levels and 6 color-bar levels

Оценка устойчивости газового слоя

- Локальные плотности HI - по THINGS (в пределах площади SFCs, (after convolution) corrected for inclination)??
- Для оценки ширины линий использовался spectral stacking.

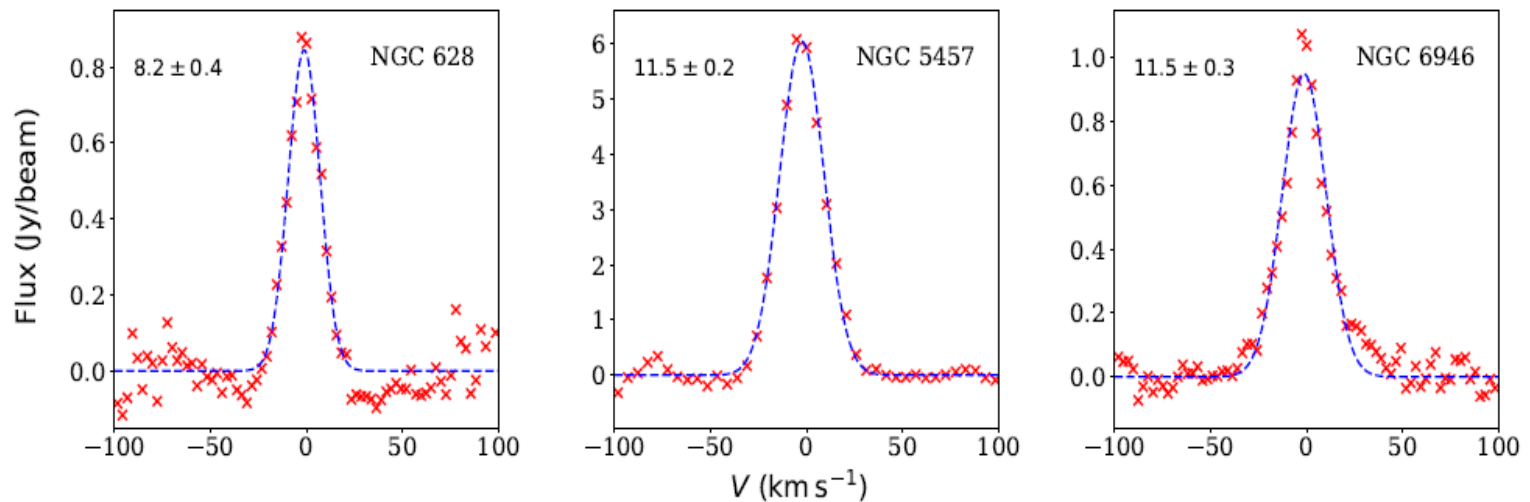


Figure 7. The stacked HI spectra of the outer SFCs in our sample galaxies. The red crosses in each panel represent the stacked spectrum, whereas the blue dashed lines represent the single-Gaussian fits to them. The respective σ_g values are quoted in the top left corners of each panel in the units of km s^{-1} . See the text for more details.

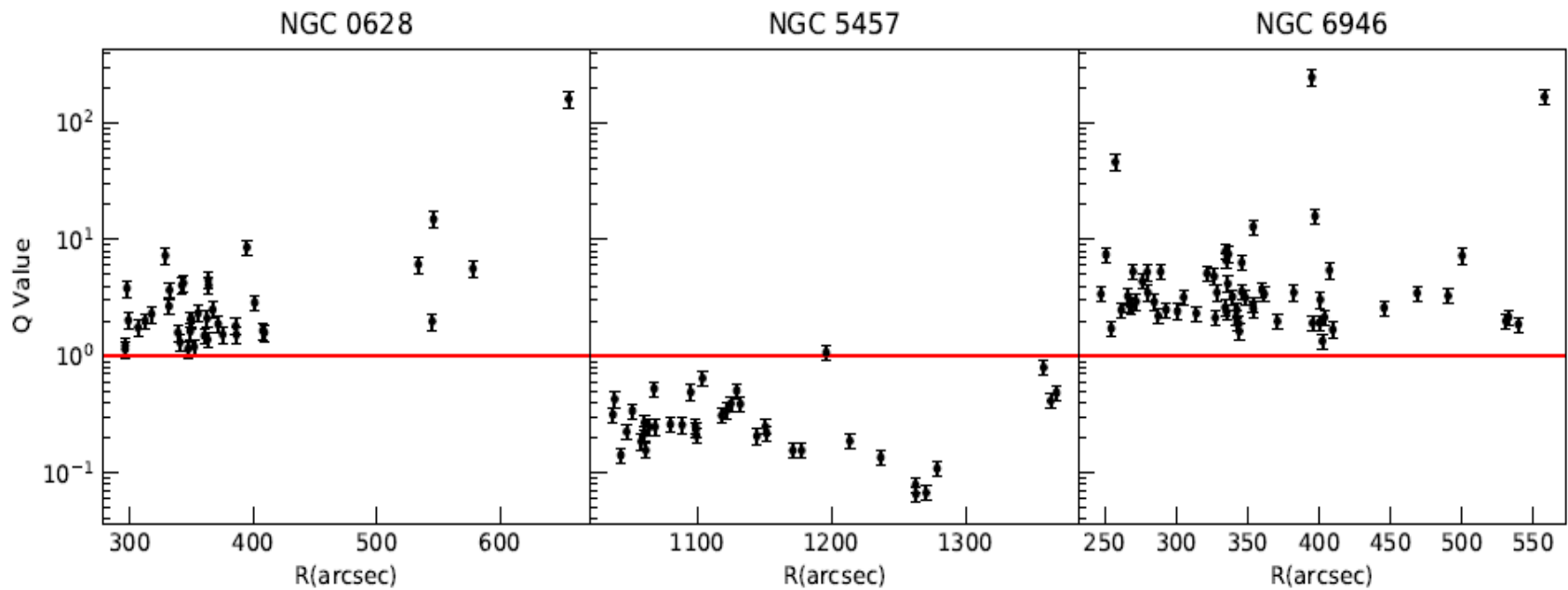


Figure 8. Toomre Q parameter for the three galaxies. The red horizontal line shows $Q=1$.

ВЫВОДЫ

- Подтверждаются различные режимы SF во внешних и внутр.областях. Внешнее SF характеризуется более мелкими и компактными комплексами SF. The outer disk star formation is due to local disk instabilities, which could be stochastic in nature or perhaps driven by cold gas accretion.

- Во внешних областях --низкая металличность. Фактор, затрудняющий SF.

- Показано влияние HI holes на формирование звездных комплексов.

Однако во внешних областях мало дыр HI. This suggests that massive star formation, which often results in the formation of HI holes, is not common in the outer disks of galaxies.

- В двух г-ках из трех (неустойчивость - в NGC5457) SF идет во внешних областях несмотря на их грав. устойчивость.

This suggests that there may be some non- luminous mass or dark matter in their outer disks, which helps increase the disk surface density and supports the formation of local gravitational instabilities.

Примечание. 1. Не рассмотрены масштабы неустойчивости. 2. В NGC5457 есть внешние ветви.

GALEXGR6 AIS color~1

