Extraplanar emission in isolated edge-on late-type galaxies. I. The Hα distribution versus to the old and young stellar discs.⋆

Minerva M. Sardaneta,[1] † Philippe Amram,[2] Roberto Rampazzo,[3] Margarita Rosado,[1] Mónica Sánchez-Cr
Isaura Fuentes-Carrera[4] and Soumavo Ghosh[5]
[1] Universidad Nacional Autónoma de México. Instituto de Astronomía. A.P. 70-264, 04510. Ciudad de México, México
[2] Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France
[3] INAF-Osservatorio Astrofisico di Asiago,Via dell'Osservatorio 8, 36012 Asiago, Italy
[4] Escuela Superior de Física y Matemáticas, Instituto Politécnico Nacional, U.P. Adolfo López Mateos, C.P.07738, Ciudad de México, México
[5] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

Isolated galaxies are the ideal reference sample to study the galaxy structure minimising potential environmental effects. We selected a complete sample of 14 nearby, late-type, highly inclined ($i \geq 80°$), isolated galaxies from the Catalogue of Isolated Galaxies (CIG) which offers a vertical view of their disc structure. We aim to study extraplanar Diffuse Ionized Gas (eDIG) by comparing the old and young disc components traced by near-infrared (*NIR*) and Ultraviolet (*UV*) imaging with the Hα emission structure. We obtained Hα monochromatic maps from the Fabry-Perot (FP) interferometry, while the old and young discs structures are obtained from the photometric analysis of the 2MASS K_s-band, and GALEX *NUV* and *FUV* images, thereby identifying the stellar disc and whether the eDIG is present. The Hα morphology is peculiar in CIG 71, CIG 183, CIG 593 showing clear asymmetries. In general, geometric parameters (isophotal position angle, peak light distribution, inclination) measured from Hα, *UV* and *NIR* show minimal differences (e.g. $\Delta i \leq \pm 10°$), suggesting that interaction does not play a significant role in shaping the morphology, as expected in isolated galaxies. From Hα maps, the eDIG was detected vertically in 11 out of 14 galaxies. Although the fraction of eDIG is high, the comparison between our sample and a generic sample of inclined spirals suggests that the phenomenon is uncorrelated to the galaxy environment. As suggested by the extraplanar *UV* emission found in 13 out of 14 galaxies the star formation extends well beyond the disc defined by the Hα map.

Key words: galaxies: haloes – galaxies: evolution – galaxies: ISM – galaxies: photometry – galaxies: stellar content – galaxies: fundamental parameters

1 INTRODUCTION

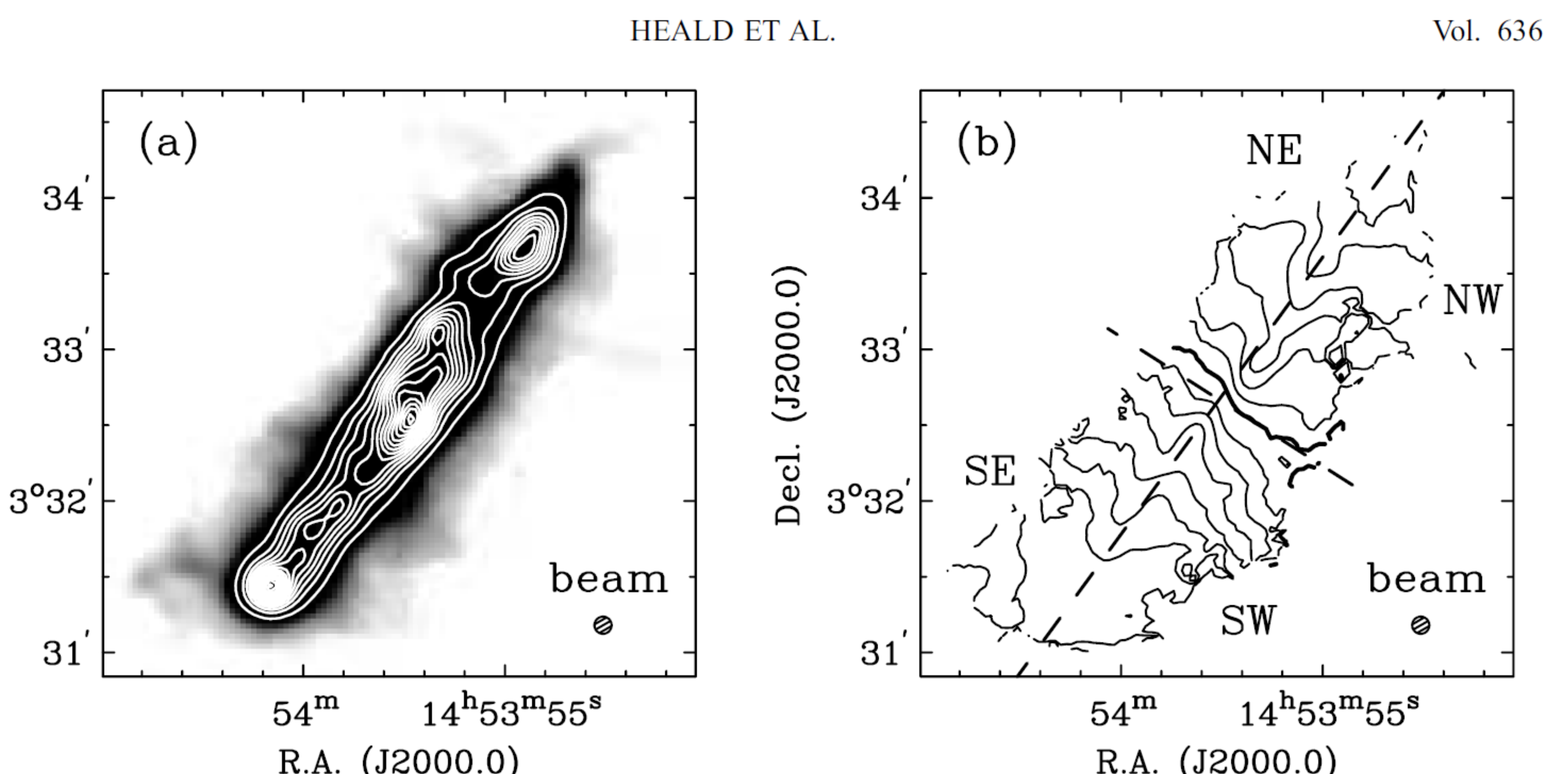
'scars', although they have probably not experienced gravitational influences from their close neighbours over the past billion years.

- Исследуется распределение яркости диффузного ионизованного газа (eDIG) и «звездного» ультрафиолета на разном расстоянии от плоскости диска

ИДЕЯ

- **Рассмотреть** изолированные галактики (чтобы исключить эффекты взаимодействия) , наблюдаемые edge-on ($i \geq 80^\circ$).
- **Цель**: сравнить вертикальное распределение *old and young discs structures.*
- **Диффузный газ и ультрафиолет на z = 1-2 кпс – факт известный.**
- **Для эмиссионного газа предлагались объяснения:** вертикальные потоки газа от областей SF (фонтаны), рассеяние света на пыли, аккреция газа и пыли на диск, ионизация газа, связанная с внешним воздействием, деформация диска приливными силами со стороны соседей, ram pressure (e.g. Tomičić et al. 2021; Sardaneta et al. 2022; Boselli et al. 2022) .

NGC 5775, IFP, Hα
Из работы Heald et al, 2006



Самые разные мнения

- **Для UV вне плоскости диска (UV halo) предлагалось**:
- – galactic scattered radiation, magneto-hydrodynamic phenomena, or dust accretion from the circumgalactic or intergalactic medium.
- *Shinn & Seon, 2015: The observed images are generally well-reproduced by two dust layers and one light source layer, whose vertical and radial distributions have exponential profiles*

The presence of extraplanar emission in late-type spirals is a direct consequence of SFR in the underlying galactic disc (e.g Rossa & Dettmar 2000, 2003a).

We compared monochromatic Hα images with the *NIR* 2MASS *Ks*-band and *UV* from GALEX archive images.

Диск рассматривается внутри эллипса, ограниченного K-изофотой на уровне 3σ.

Выборка галактик (из CIG) для T > 5, z <0.02

CIG Name (1)	Other Name (2)	RA (J2000) (hh mm ss) (3)	Dec (J2000) (° ‘ “) (4)	V_{sys} (km s^{-1}) (5)	Distance (Mpc) (6)	i (deg) (7)	K_s (mag) (8)	$D_{25}(B)$ (kpc) (9)	Type (10)	S_{60} (Jy) (11)	S_{100} (Jy) (12)	L_{FIR} (10^{43} erg s^{-1}) (13)
71	UGC 01391	01 55 15.8	+10 00 49.2	5901	84.3	83.8	10.8	35.4	Sc	0.66	1.38	6.79
95	UGC 01733	02 15 20.6	+22 00 22.0	4418	63.1	86.5	11.6	33.4	Sc-w	0.22	0.64	1.49
159	UGC 03326	05 39 37.1	+77 18 44.9	4121	58.9	85.4	9.6	60.8	*Scd:	1.10	3.57	3.26
171	UGC 03474	06 32 37.6	+71 33 39.5	3634	51.9	84.0	10.1	33.8	*Scd:	0.57	1.43	4.40
183	UGC 03791	07 18 31.8	+27 09 28.7	5090	72.7	80.4	11.4	26.0	*Sd :	0.49	1.38	2.78
201	UGC 03979	07 44 31.0	+67 16 24.9	4061	58.0	80.9	10.6	31.4	SA(rs)c	1.18	2.86	3.39
329	UGC 05010	09 24 55.1	+26 46 28.8	4096	58.5	81.3	9.3	42.8	SA(rs)b	0.30	1.34	1.61
416	UGC 05642	10 25 41.8	+11 44 20.8	2322	33.2	81.1	11.6	18.0	Sd -pec	0.52	1.16	2.69
593	UGC 08598	13 36 40.7	+20 12 00.5	4909	70.1	83.2	10.8	35.5	SBx(s)b:	0.09	0.40	0.53
847	UGC 11132	18 09 26.2	+38 47 39.9	2837	40.5	81.2	10.7	24.6	*Sb	0.59	1.98	5.74
906	UGC 11723	21 20 17.5	-01 41 03.6	4899	70.0	80.9	10.0	37.9	Sbc	1.97	5.95	11.51
922	UGC 11785	21 39 26.8	+02 49 37.6	4074	58.2	84.2	11.0	29.4	Scd-w	0.31	1.62	2.57
936	UGC 11859	21 58 07.4	+01 00 32.3	3011	43.0	85.7	11.4	38.7	Sc:	0.71	1.49	1.13
1003	UGC 12304	23 01 08.3	+05 39 15.7	3470	49.6	82.5	10.3	22.9	Scd	2.06	4.57	15.07

Columns: (1) CIG galaxy name; (2) UGC galaxy name; (3) and (4) wcs coordinates (J2000); (5) V_{sys}: systemic velocity from NED; (6) heliocentric distance to the galaxy; (7) i: inclination computed using the relation 1 (see the text); (8) K_s: apparent K_s-band magnitude from NED; (9) $D_{25}(B)$: optical diameter in the B-band from NED; (10) Hubble classification from Buta et al. (2019) and, if not available, from NED (*); (11) and (12) flux densities at 25 μm, 60 μm and 100 μm in Jy from Lisenfeld et al. (2007); (13) *FIR* luminosity computed with the equation 4 (see Section 6.2).

Изолированность галактик

CIG	Neighbours	Distance	
Name		(arcsec)	(kpc)
(1)	(2)	(3)	(4)
71	4	941	384.6
95	71	362	110.7
159	34	456	130.2
171	91	152	38.2
183	25	784	276.3
201	57	109	30.6
329	101	316	89.6
416	168	362	58.3
593	26	739	251.2
847	79	644	126.4
906	28	391	132.7
922	97	197	55.6
936	88	234	48.8
1003	77	118	28.4

Columns: (1) CIG galaxy name; (2) number of neighbours in a physical radius of 0.5 Mpc; (3) and (4) distance to the nearest neighbour in arcseconds and kpc respectively given the heliocentric galactic distance listed in Table 1.

ДАННЫЕ

- IFP (GHASP) 1.93m telescope at the *Observatoire de Haute-Provence*

(Hα emission) – В ДАННОЙ РАБОТЕ

- Изображения R-DSS, 2MASS, GALEX, IRAS.

- Особое внимание: неопределенности в оценках угла наклона, зависимость от спектрального диапазона.
- Использование K-band images для оценки геометрии звездного компонента галактики

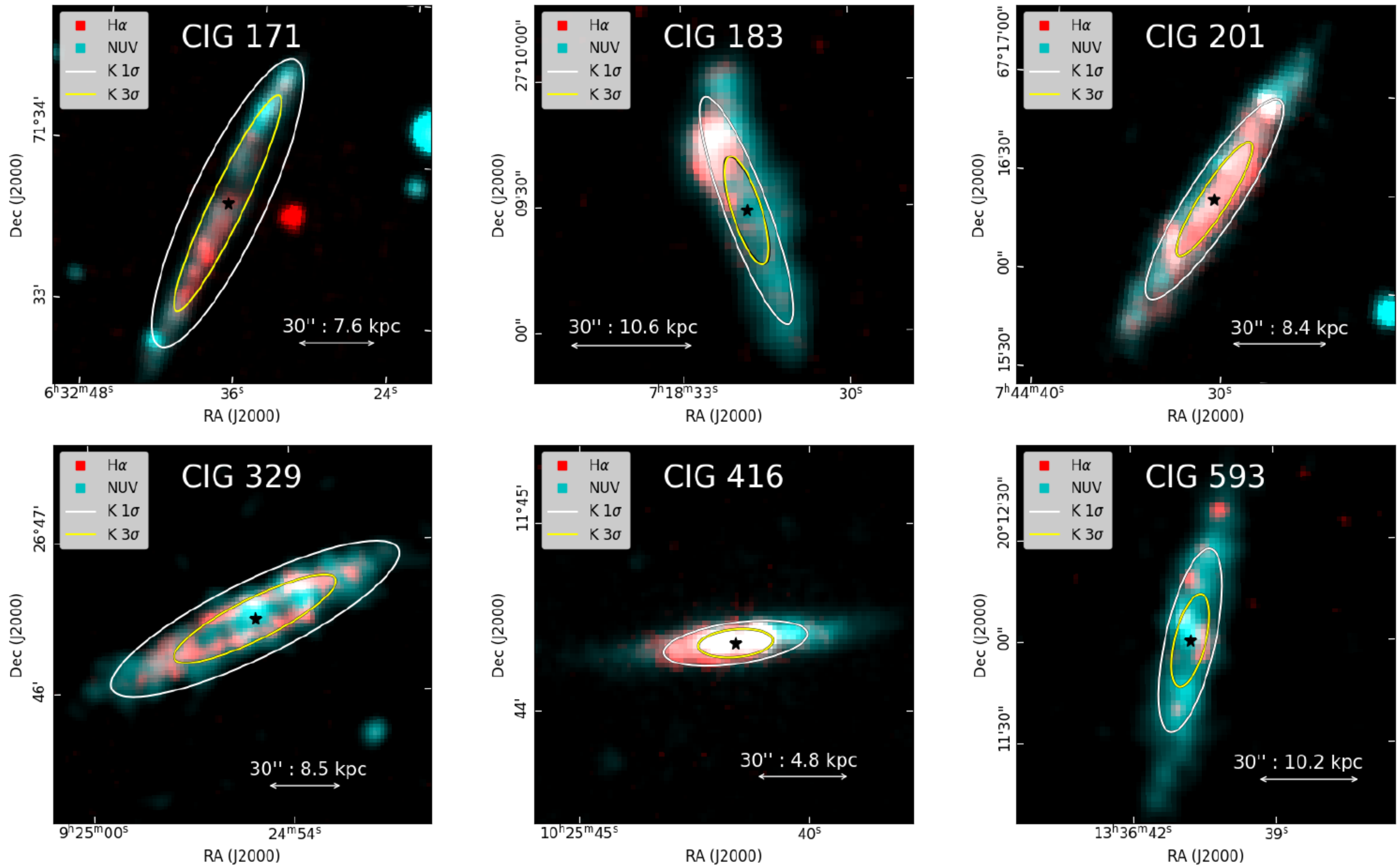


Figure 1. Superposition of the respective FP Hα monochromatic map and GALEX *NUV* image of the galaxies in our sample. The ellipses fitted to the surface brightness level at 1σ (white) and 3σ (yellow) of the typical background noise (see e.g. Jarrett et al. 2000) of the respective 2MASS K_s-band image are overlain on the respective map. To distinguish the extraplanar material of each galaxy, the old stellar disc plane is traced by the ellipse fitted to the 3σ surface brightness level. We have masked the nearest and brightest field stars to each galaxy in the *UV*-band images. At the distance of each galaxy (see Table 1) the kpc measure equivalent to 30 arcsec is indicated with an arrow.

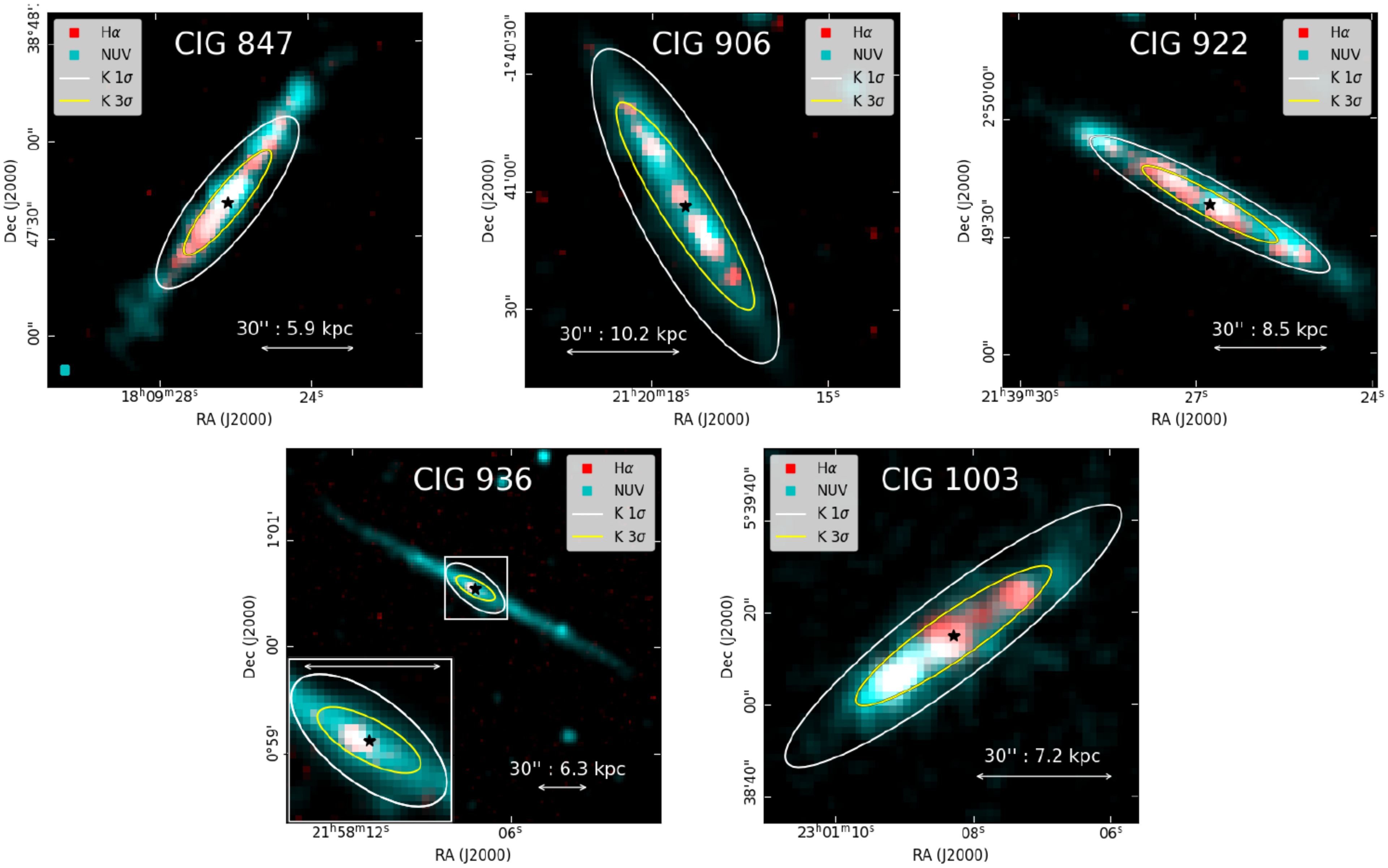
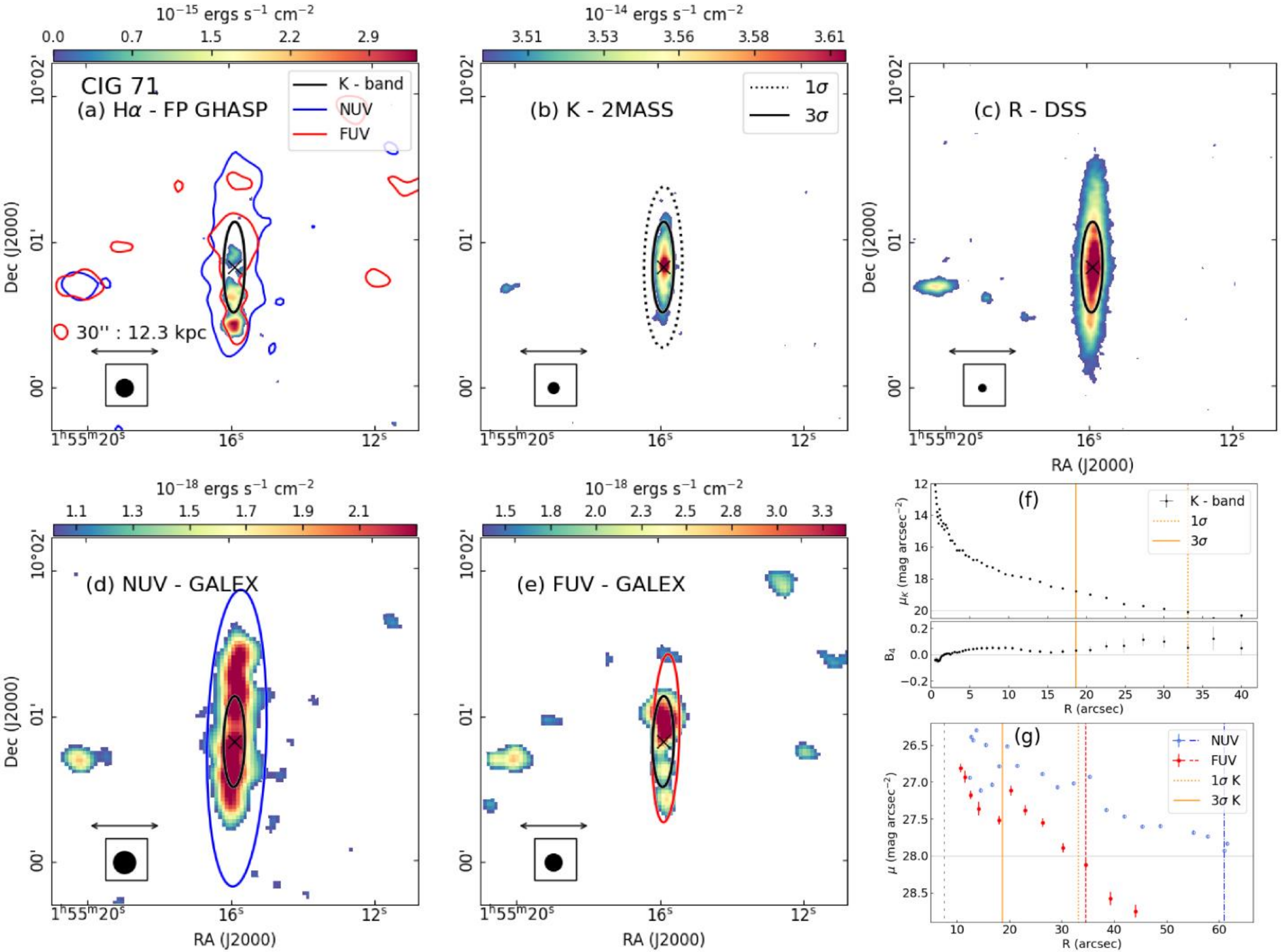


Figure 1. Continue.

Пример: фотометрия CIG 71



В разных галактиках ситуация различна

In the vertical direction, the Hα monochromatic maps display eDIG configurations such as

- filamentary structures in CIG 71, 329, 593 and 1003;
- layers of diffuse gas in CIG 201, 329, 416; and
- patches or detached clouds of ionized gas emission in CIG 95, 159, 593, 922, 847 and 1003.
- We have not detected any extraplanar Hα emission in the vertical direction in CIG 171, 906 and 936.

Важен учет радиального градиента ярости (из-за того, что диски не точно с ребра).

- Кружки – “our sample”
- Квадраты – более полная выборка (Rossa & Dettmar 2003)
- Пустые символы – нет eDIG.

Вывод – наличие eDIG
не зависит от принадлежности
к группам или парам;

В галактиках edge-on эмиссия
eDIG отсутствует чаще всего не там,
 где низкая яркость в FIR, а там, где пыль
более холодная.

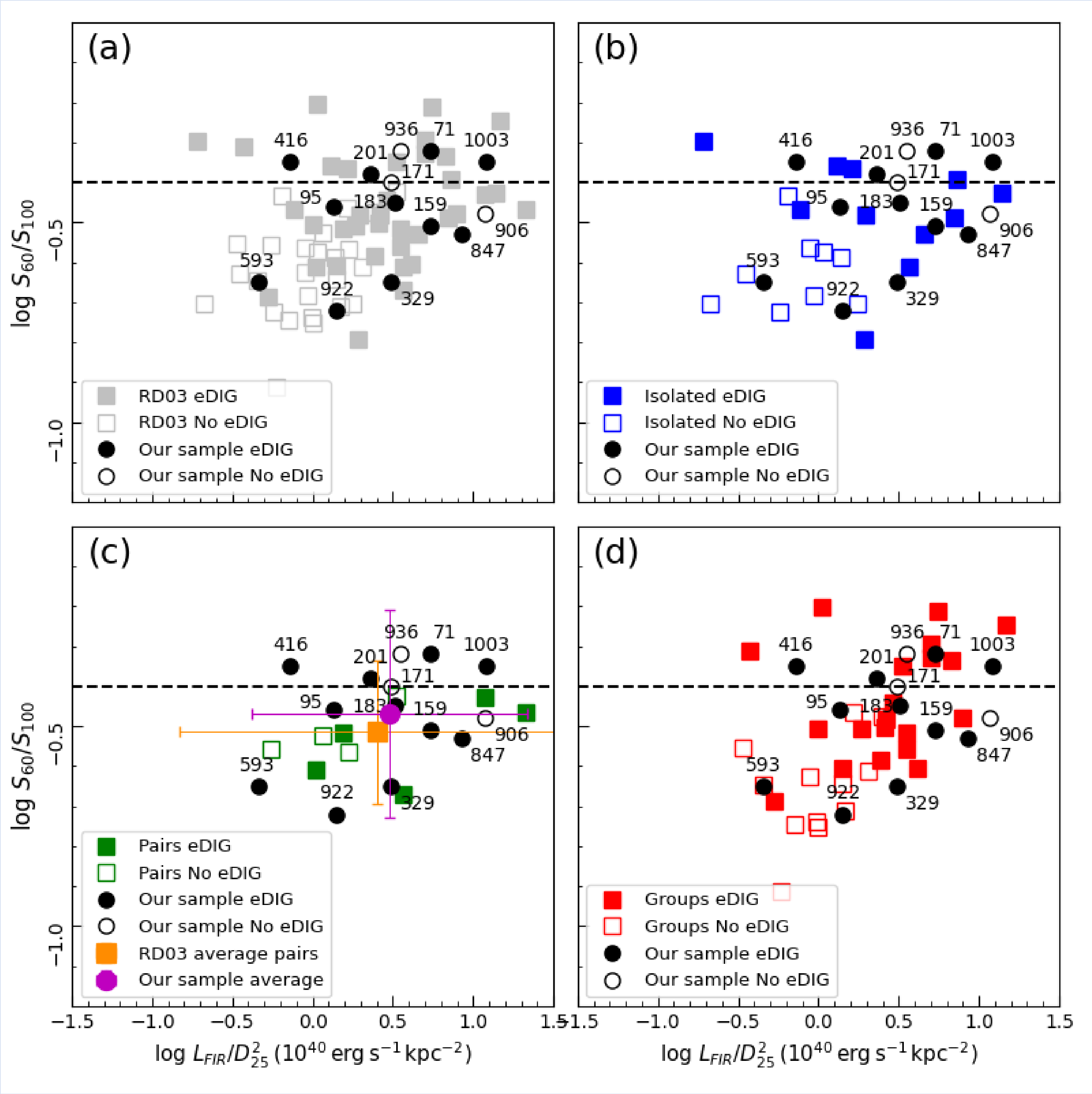


Table 7. Maximum radial (r) and vertical (z) distance reached by the extra-planar component in *UV* and Hα emission.

CIG Name (1)	*MIR* M_* (10^9 $M_\odot$) (2)	*NUV* z (kpc) (3)	*NUV* r (kpc) (4)	*FUV* z (kpc) (5)	*FUV* r (kpc) (6)	Hα z (kpc) (7)	Hα r (kpc) (8)	Hα eDIG morphology (9)	Morphological features (10)
71	14.1	4.2	8.8	2.0	3.9	1.2	4.7	E(r)	A, Ph, UV,
95	3.6	1.8	12.1	1.8	12.1	1.8	10.4	E(r), H II-R	Ph, UV
159	3.8	1.4	10.7	...	1.7	0.5	9.6	E(r), H II-R	W, L(Hα), L(FUV), T
171	1.4	1.9	6.2	...	5.6	...	4.8	E(r), H II-R	A, UV
183	8.1	4.5	8.0	2.6	8.0	2.8	8.0	E(r)(z), H II-R, P	A, W, K, Ph
201	5.1	2.3	10.0	2.3	8.9	1.8	8.7	E(r)(z), P, F	A, K
329	31.8	3.3	8.1	1.8	6.2	1.7	4.1	E(r)(z), F	B, A, UV
416	2.6	1.2	7.1	1.1	6.2	1.0	2.9	E(r)(z), H II-R, F	A, K, UV
593	12.1	2.5	13.0	2.1	11.0	1.6	9.3	H II-R	A, W, UV, L(Hα)
847	11.9	0.9	8.3	1.0	8.6	0.3	4.3	E(r), H II-R	W, K, Ph
906	5.1	3.1	8.0	2.9	8.0	...	1.4	F	Ph, UV, L(Hα)
922	4.3	1.9	9.1	1.5	9.1	1.0	4.5	E(r), H II-R	A, W, UV
936	1.0	1.7	18.4	...	17.7	...	1.4	H II-R	UV, L(Hα), T
1003	6.0	3.2	4.4	1.3	1.2	1.2	...	E(z), F	A, W, K, UV

UV: disc dominated by UV halo

Columns: (1) CIG galaxy name; (2) Stellar mass (M_*) computed with *Wide-field Infrared Survey Explorer* (WISE) data at *MIR* band (see equation C1); (3) and (4), (5) and (6) and (7) and (8) averaged maximum radial (r) and vertical (z) distance reached by the extra-planar component at *NUV*, *NUV* and Hα emission, respectively; (9) morphological description of the extraplanar warm gas component or eDIG: E: extended emission in radial (r)- or vertical (z)-direction mostly, P: patches, F: filaments, H II-R: extraplanar H II region; (10) morphological features in different wavelengths: B: bar, A: asymmetric disc, W: warped disc, K: multiple inner emission knots, Ph: unmatching photometric maxima, UV: disc dominated by the UV halo, L(λ): Low emission detected in the wavelength band λ. T: thin disc structure.

Выводы

- eDIG наблюдается в абсолютном большинстве случаев (в 11 из 14 галактик), подтверждая связь eDIG со звездообразованием
- B NUV вертикальная протяженность диска достигает неск. Кпс. The oldest star formation occurring between $\sim$10 and 100 Myrs extends well beyond the disc defined by the Hα map which traces the most recent SF.
- We did not find evidence that the environment plays a role in the presence of the eDIG incidence. This confirms that the presence of eDIG in late-type spirals is a direct consequence of the SFR.
- Further investigation of the specific mechanisms driving *UV* haloes *(вокруг дисков)* is needed to fully understand their origin.
- **Следующим этапом будет исследование кинематики eDIG**