Progression over time from clumpy to smooth exponential disks

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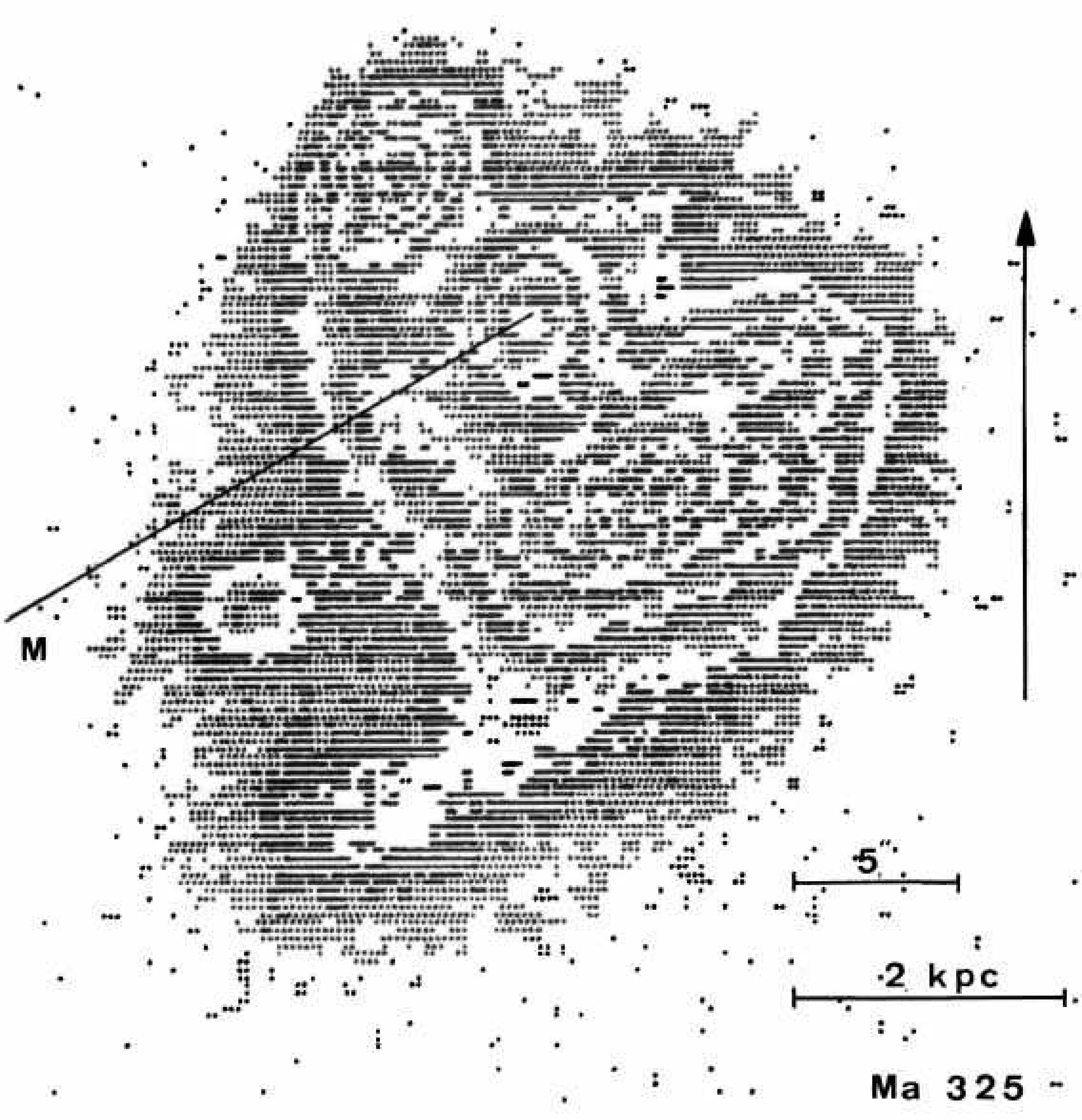
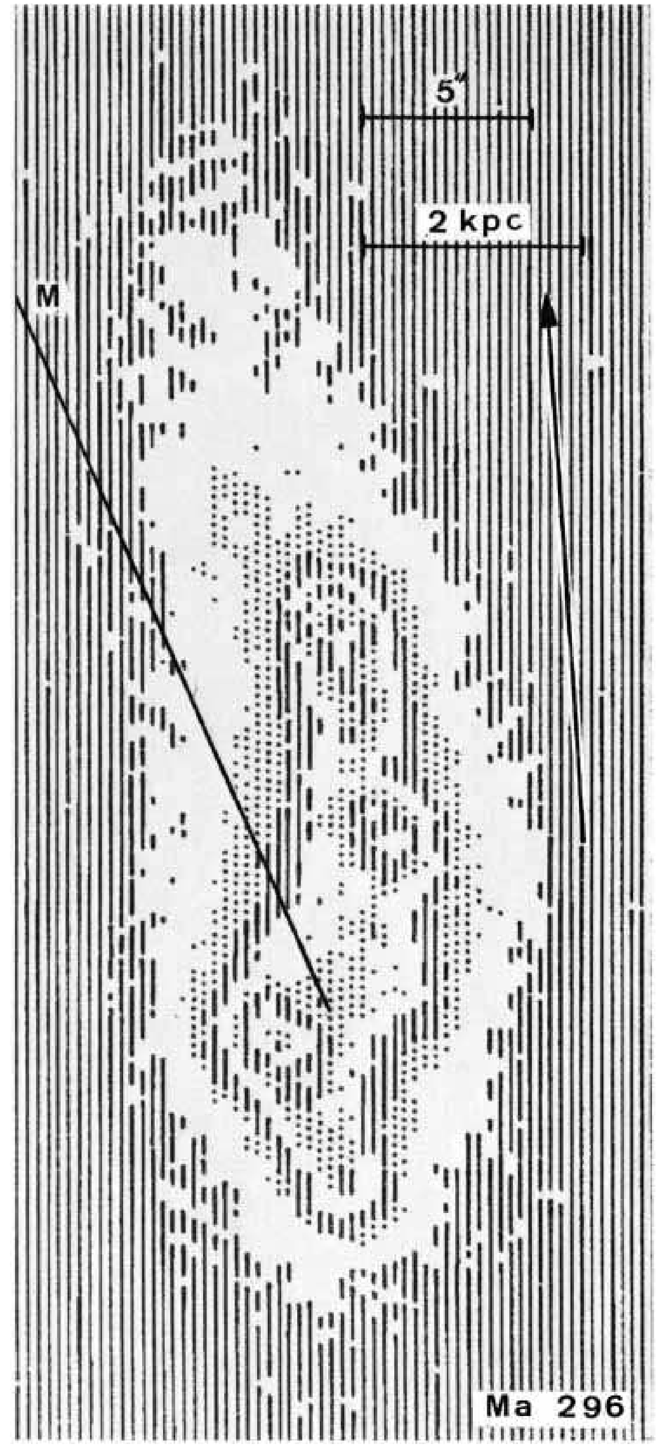
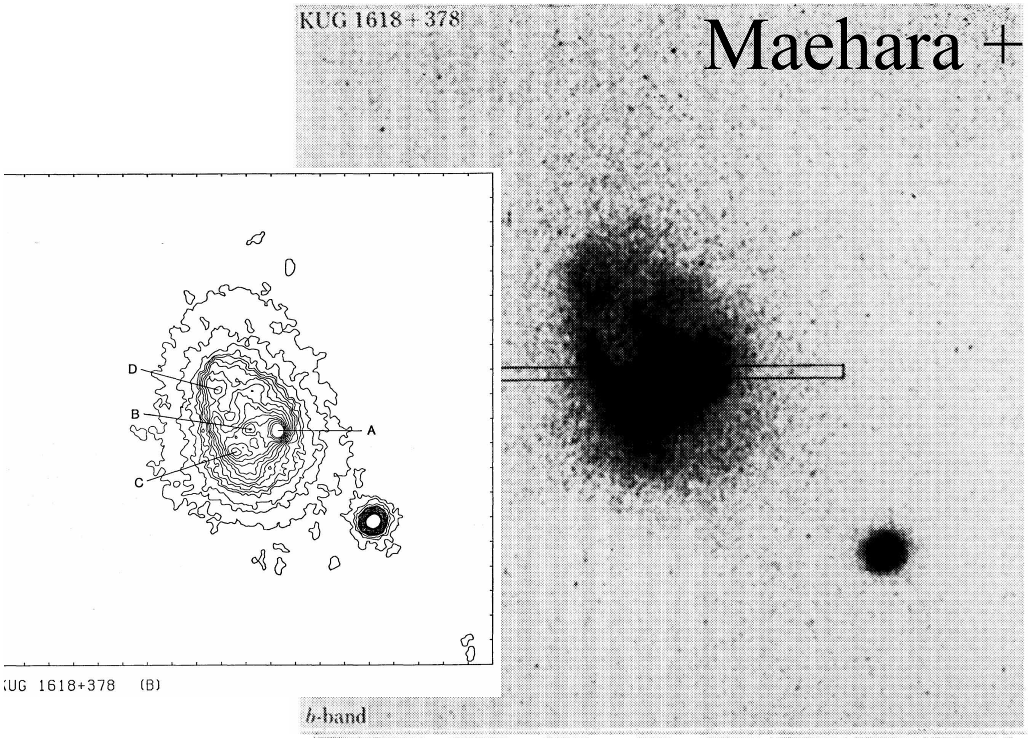
The clumps in the clumpiest *local* L* galaxies are like UDF clumps.

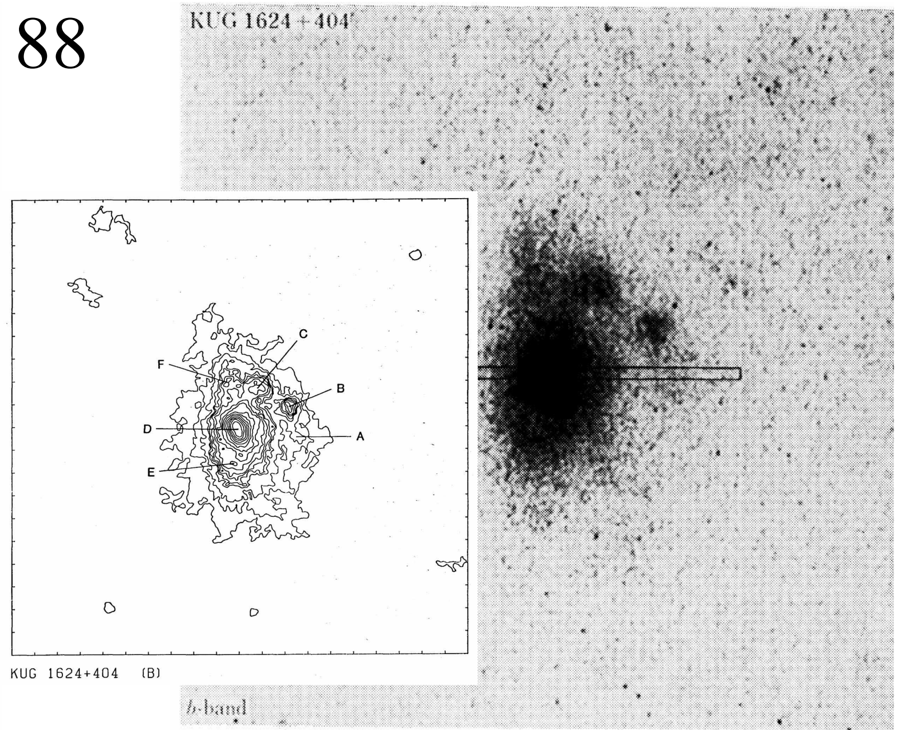




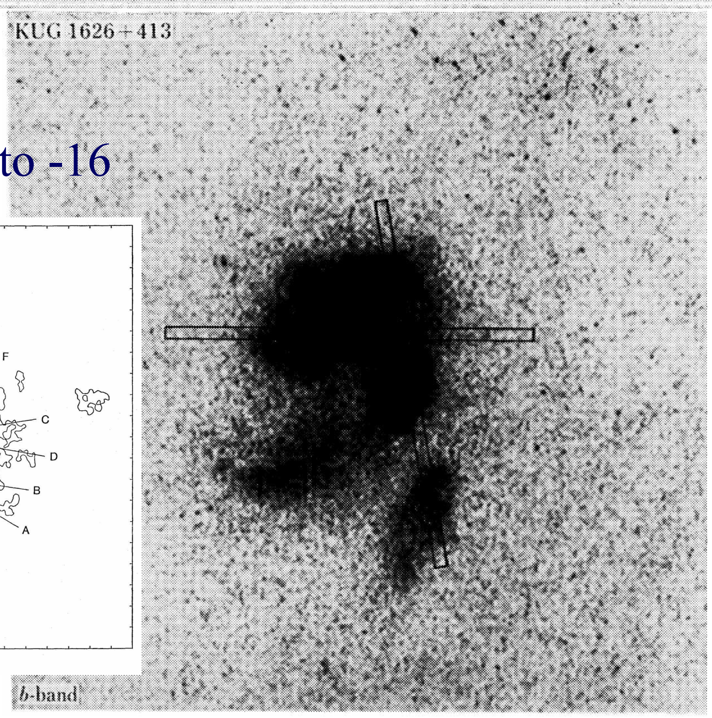
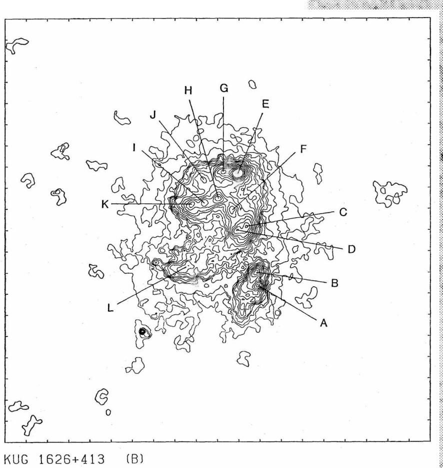
“Clumpy Irregular Galaxies”
Casini & Heidmann 1976

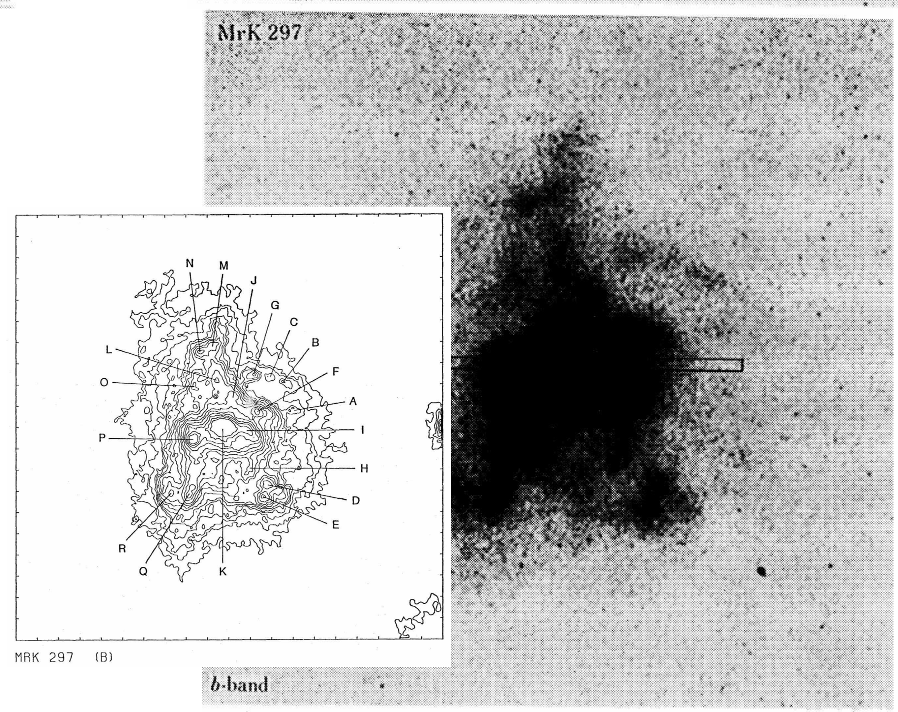
Maehara + 88





D=60-120 Mpc
clump size~2”
clump Mb~-11 to -16

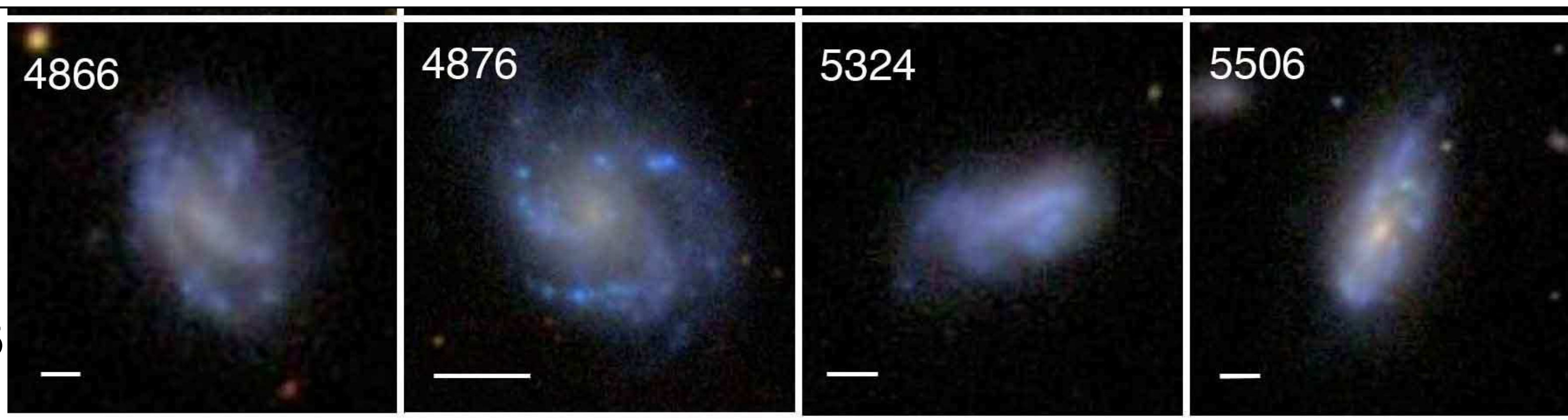


Kiso UV Survey (Local) Galaxies of the clumpy type

Type Ic (large blue clumps), and Type Ig (a single large clump)

Kiso Survey of Ultraviolet Excess Galaxies

Miyauchi-Isobe, Maehara & Nakajima 2010



EE+13

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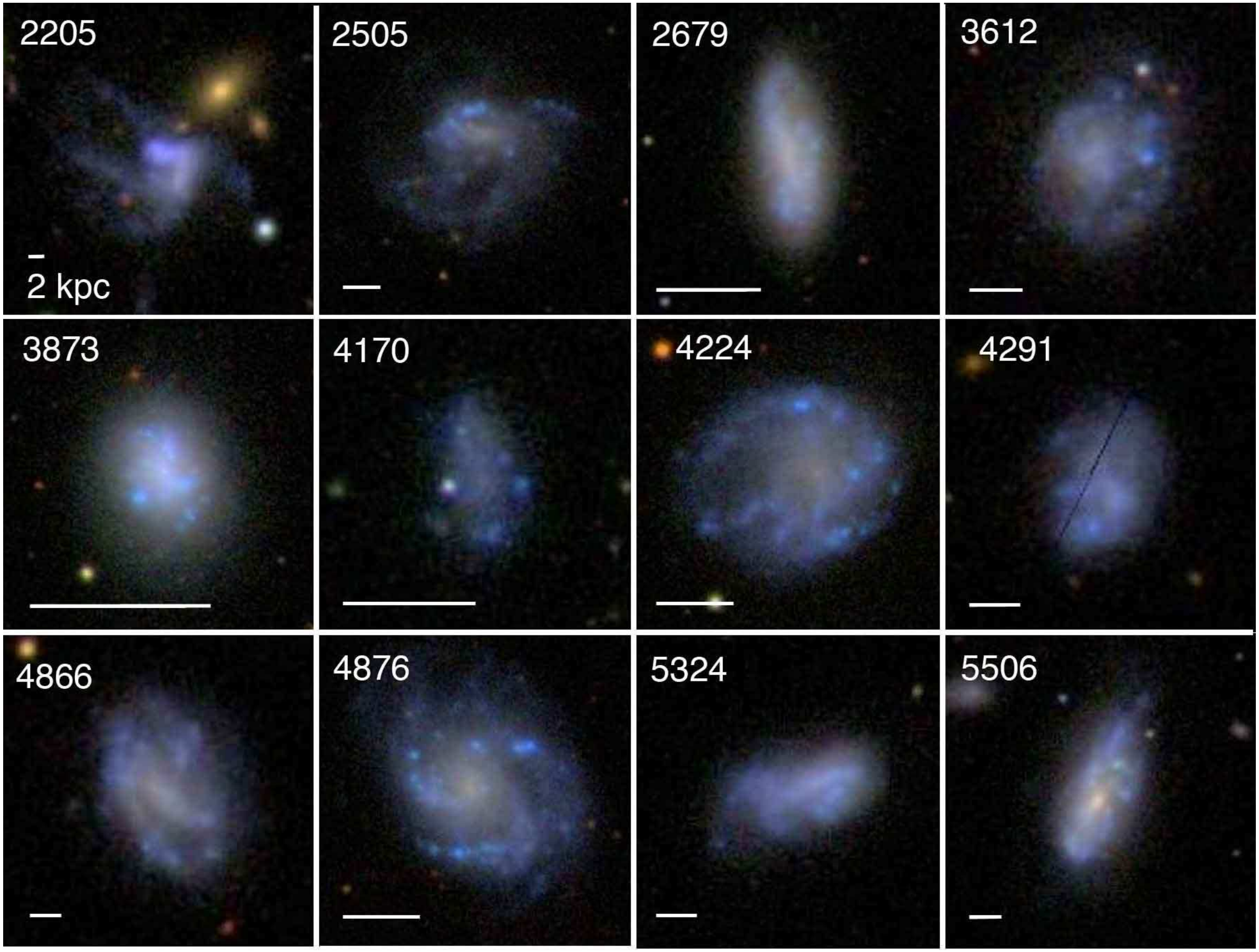

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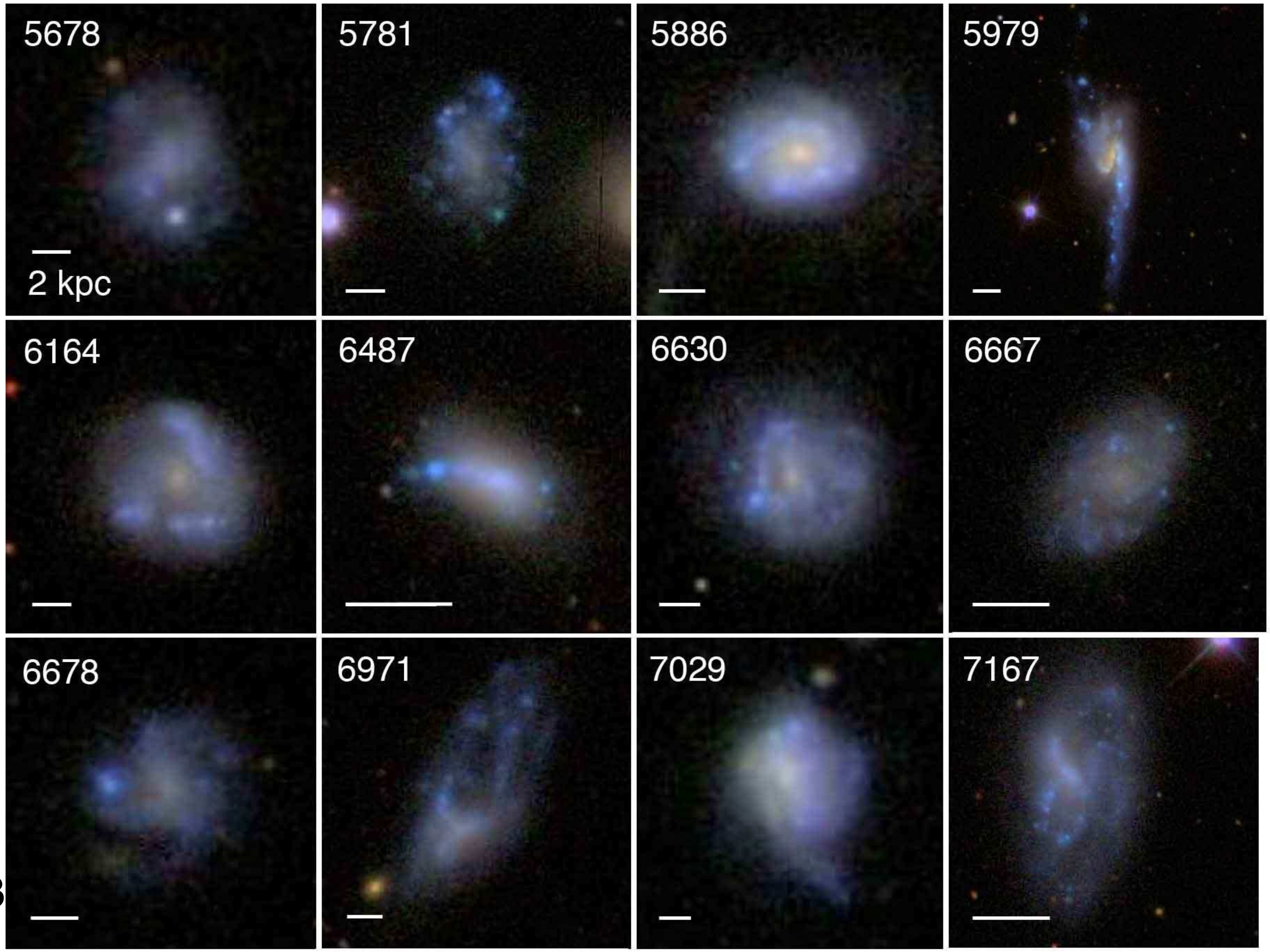

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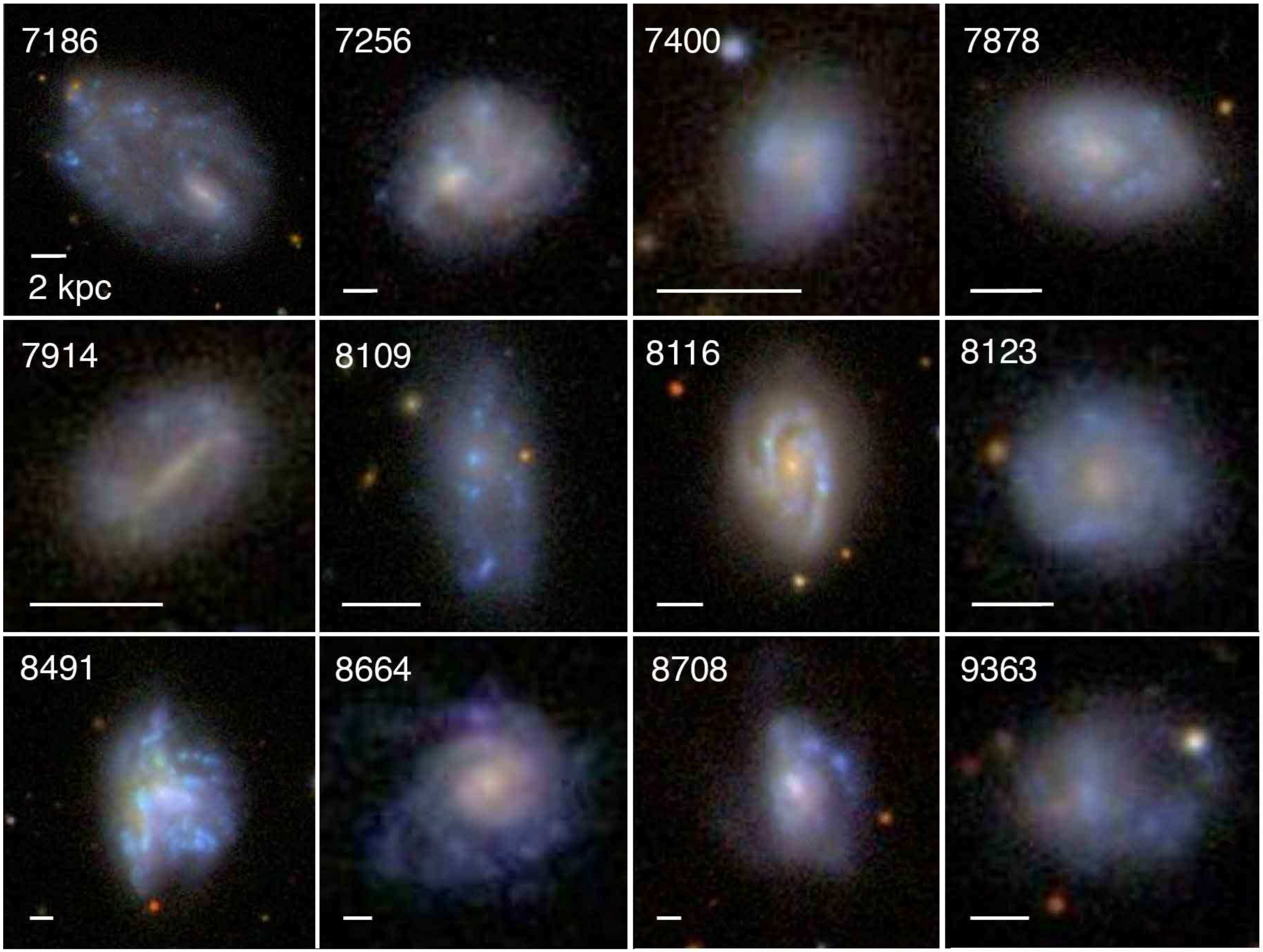

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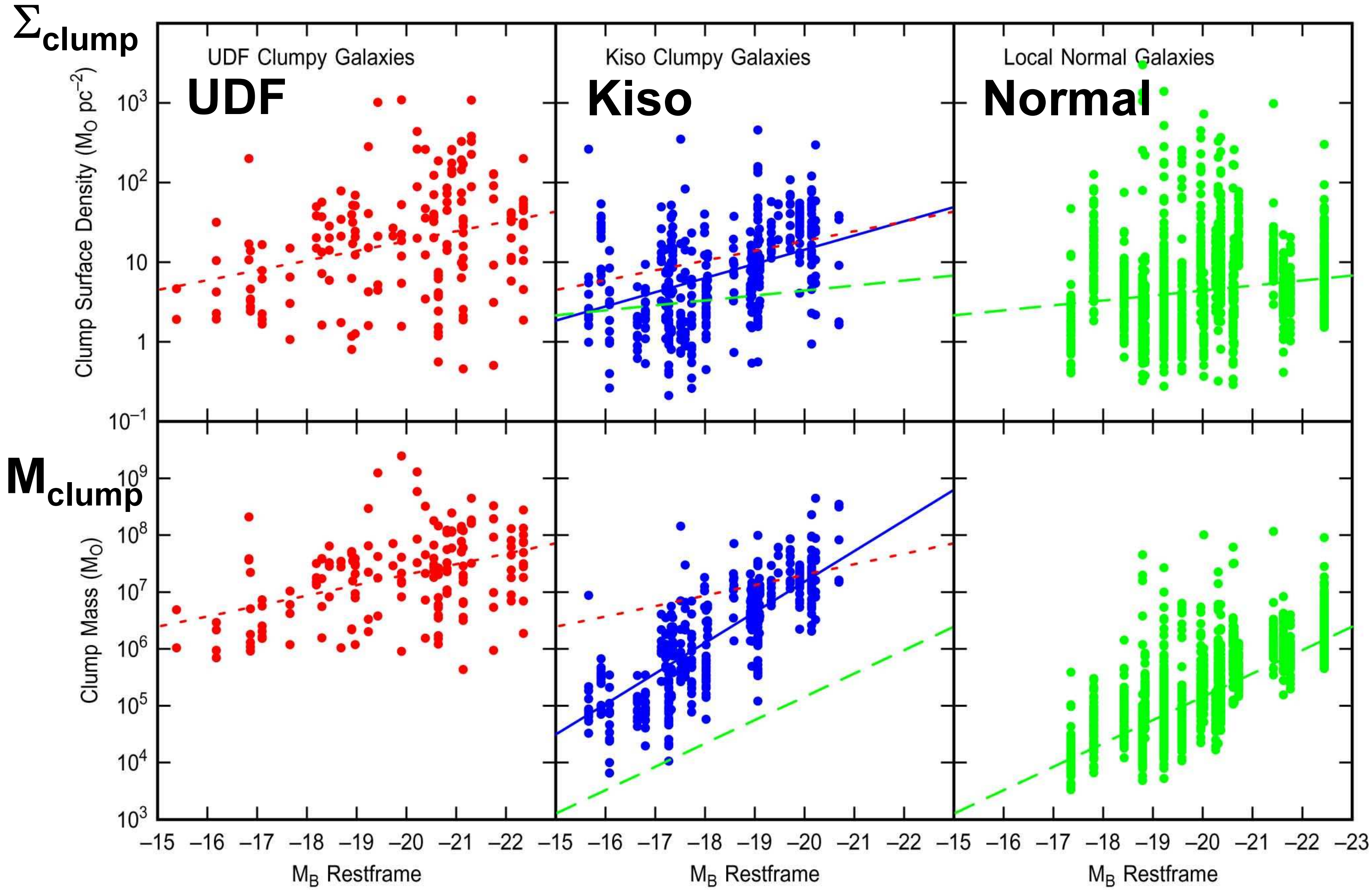
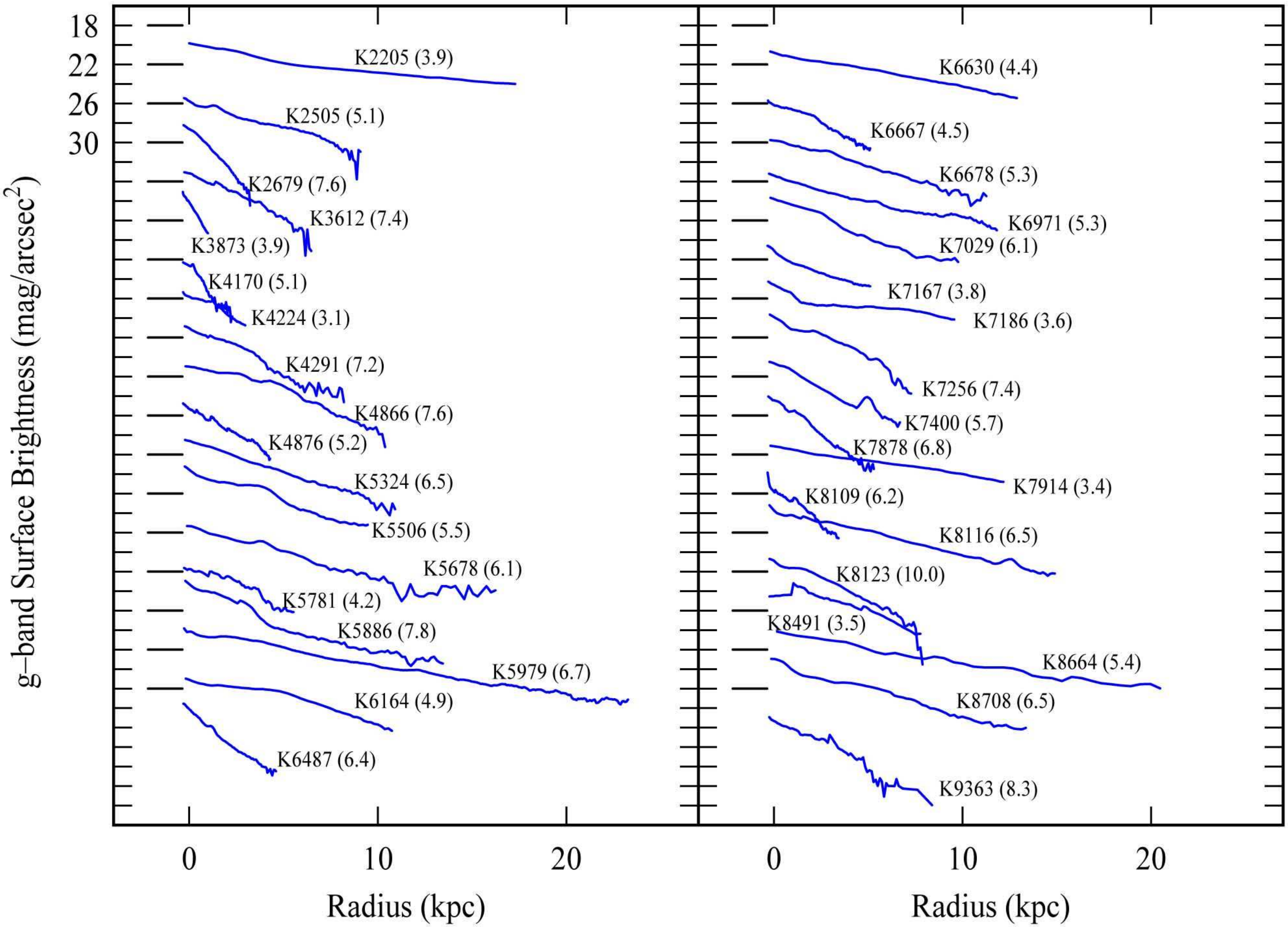


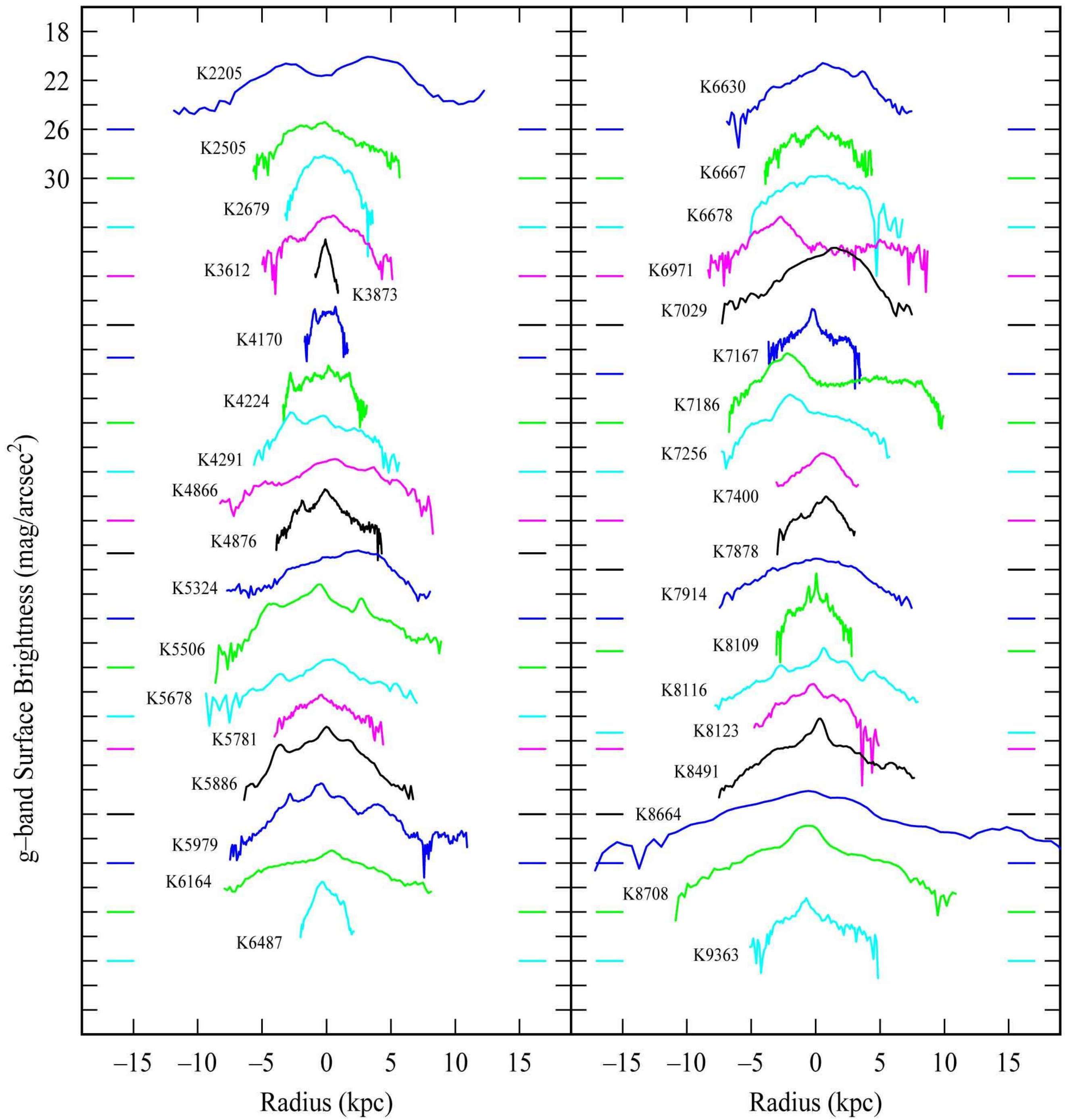
Comparison of clump mass (bottom) and clump surface density (top) for UDF, Kiso, Normal galaxies. The largest Kiso clumps are comparable to UDF clumps for the same galaxy magnitude.

EE+13



Kiso galaxy azimuthally averaged radial profiles: bumpy exponential

Kiso major axis profiles



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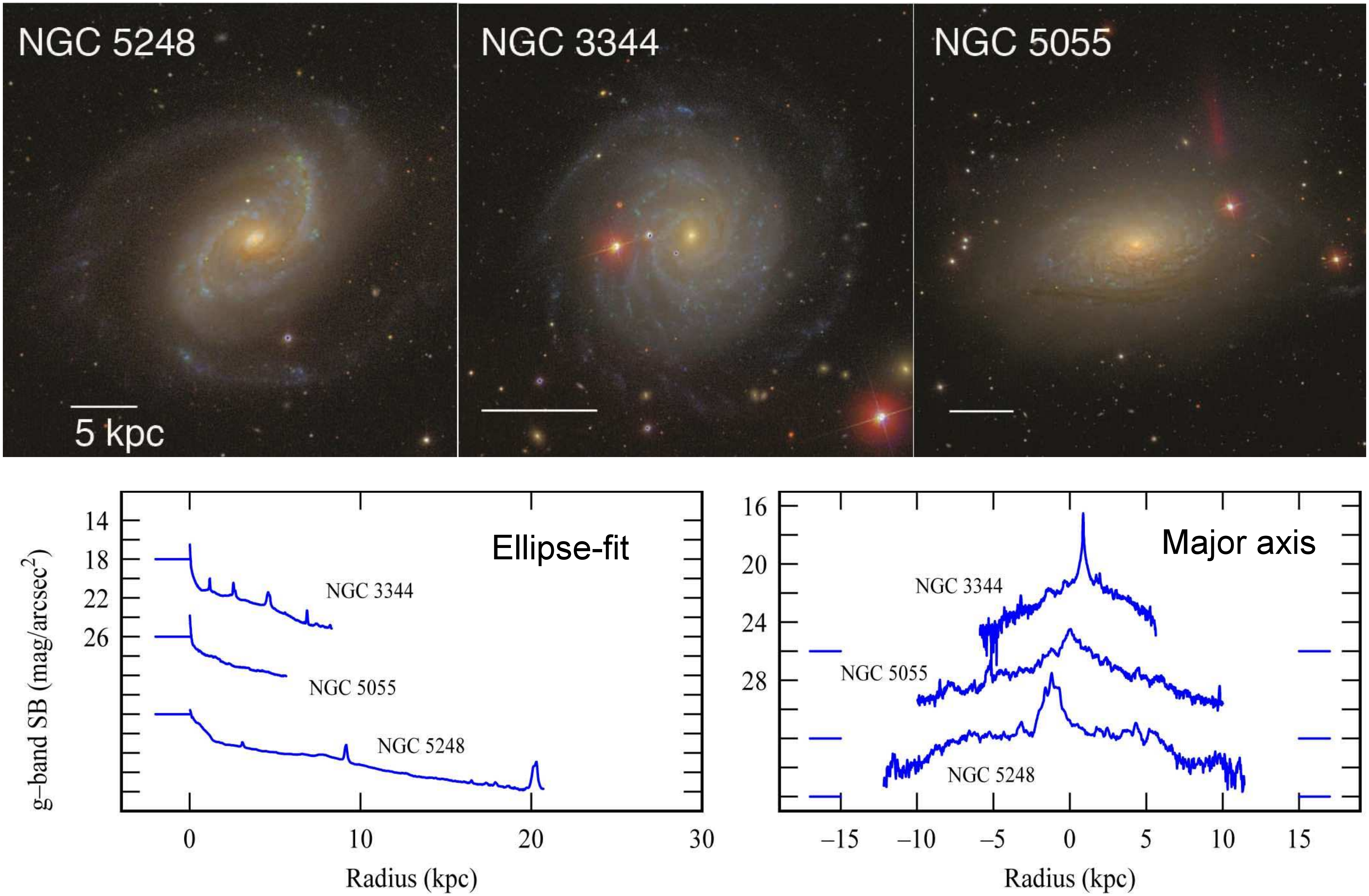

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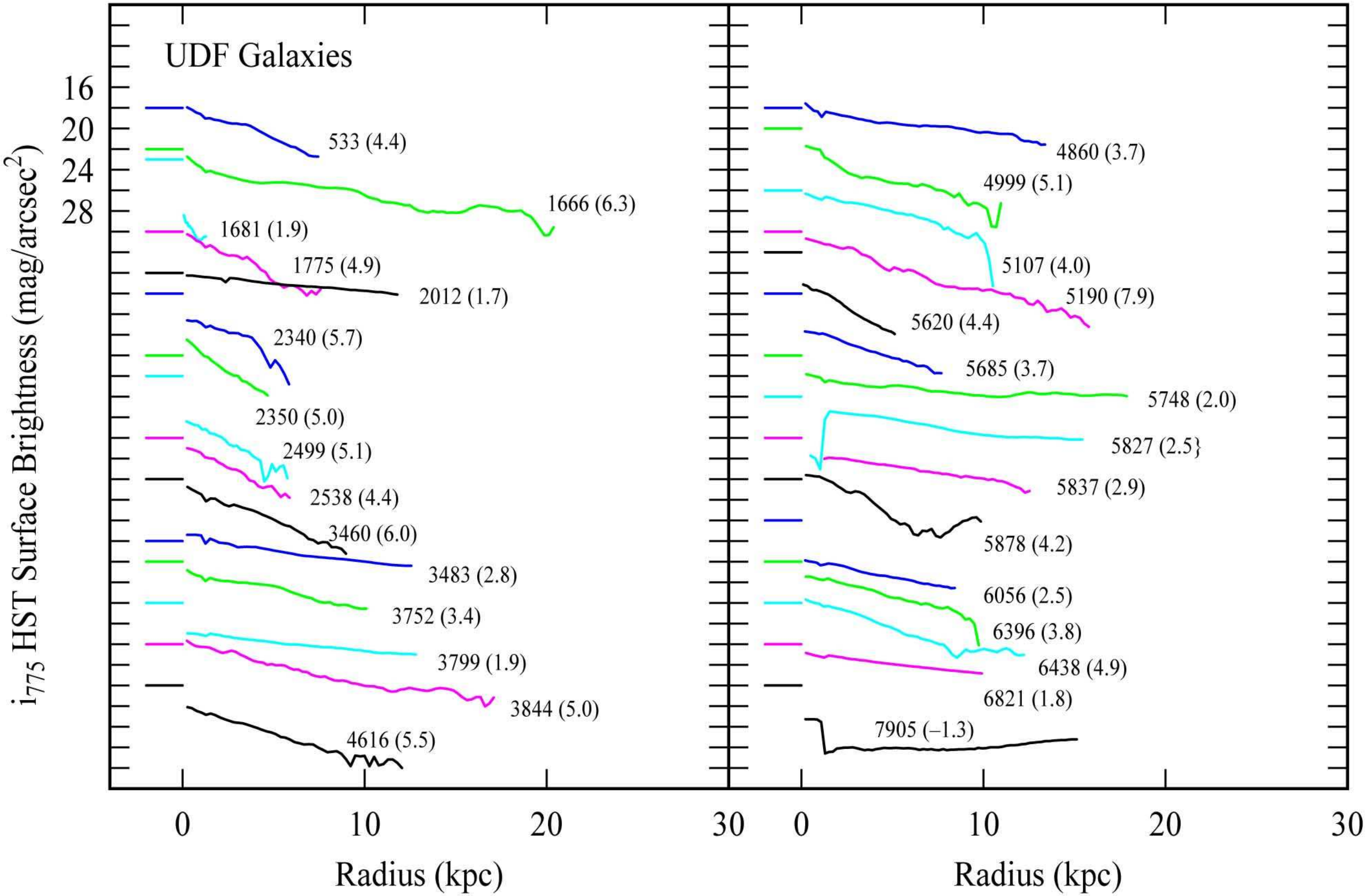
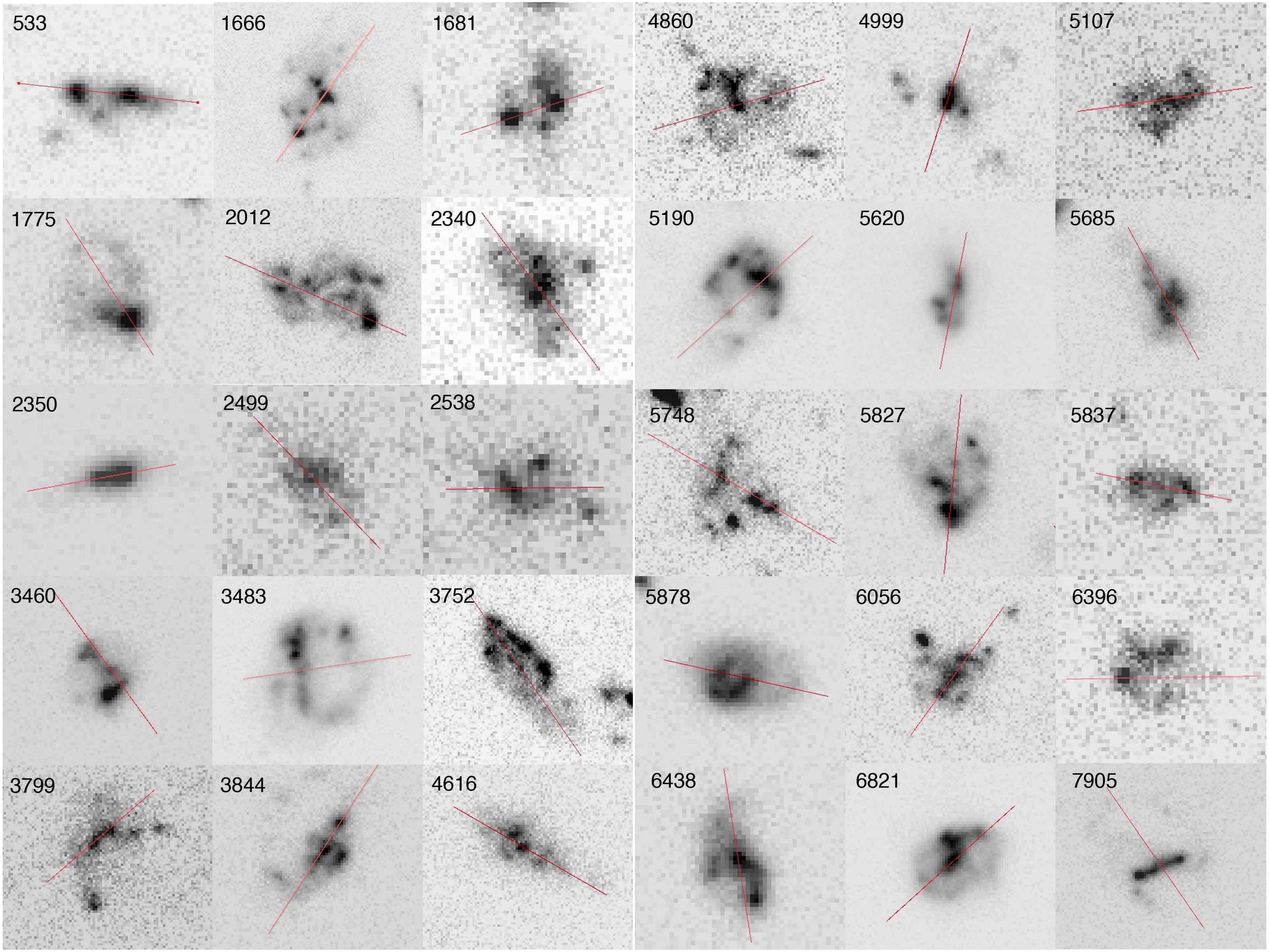
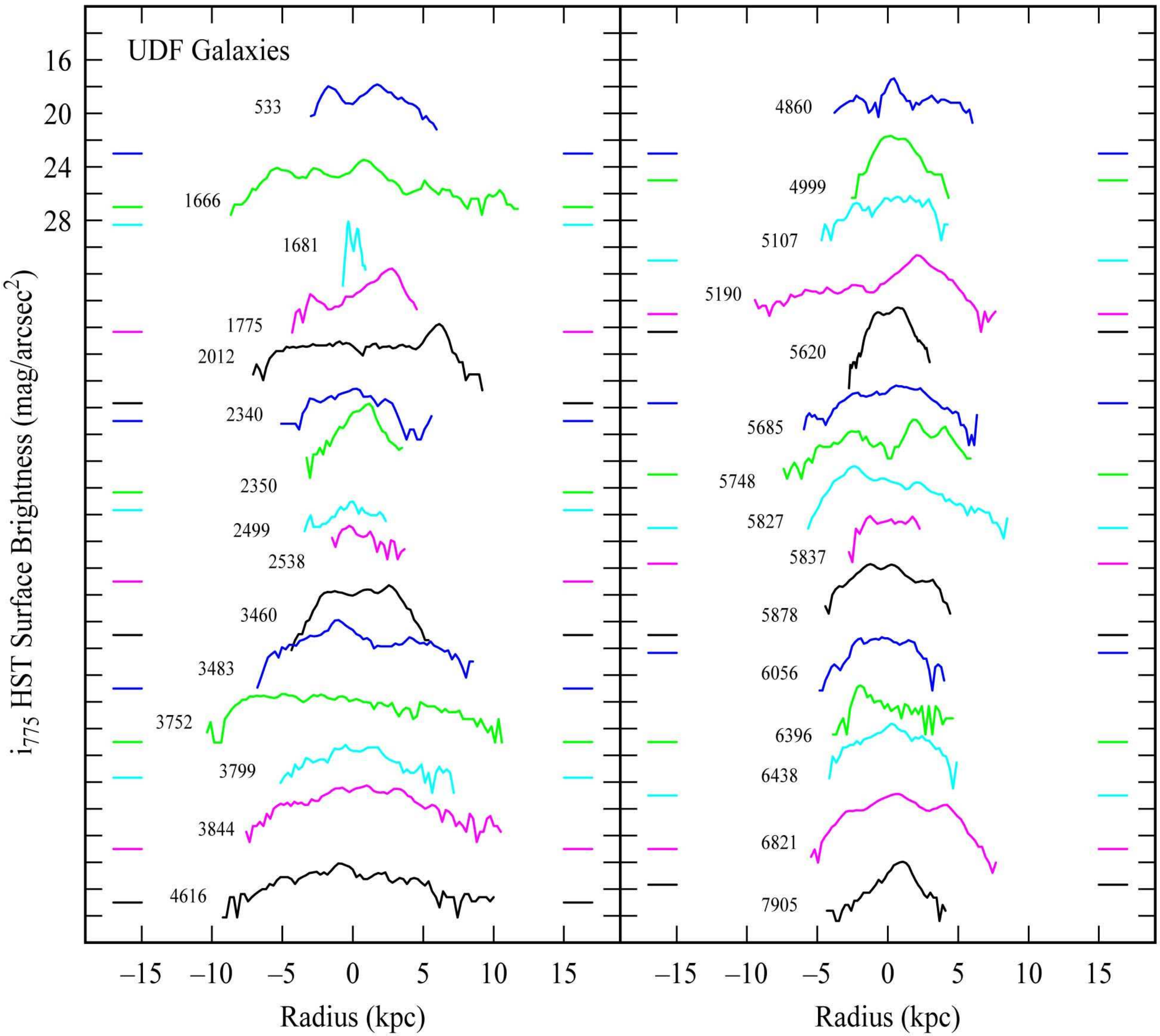
Local normal spirals



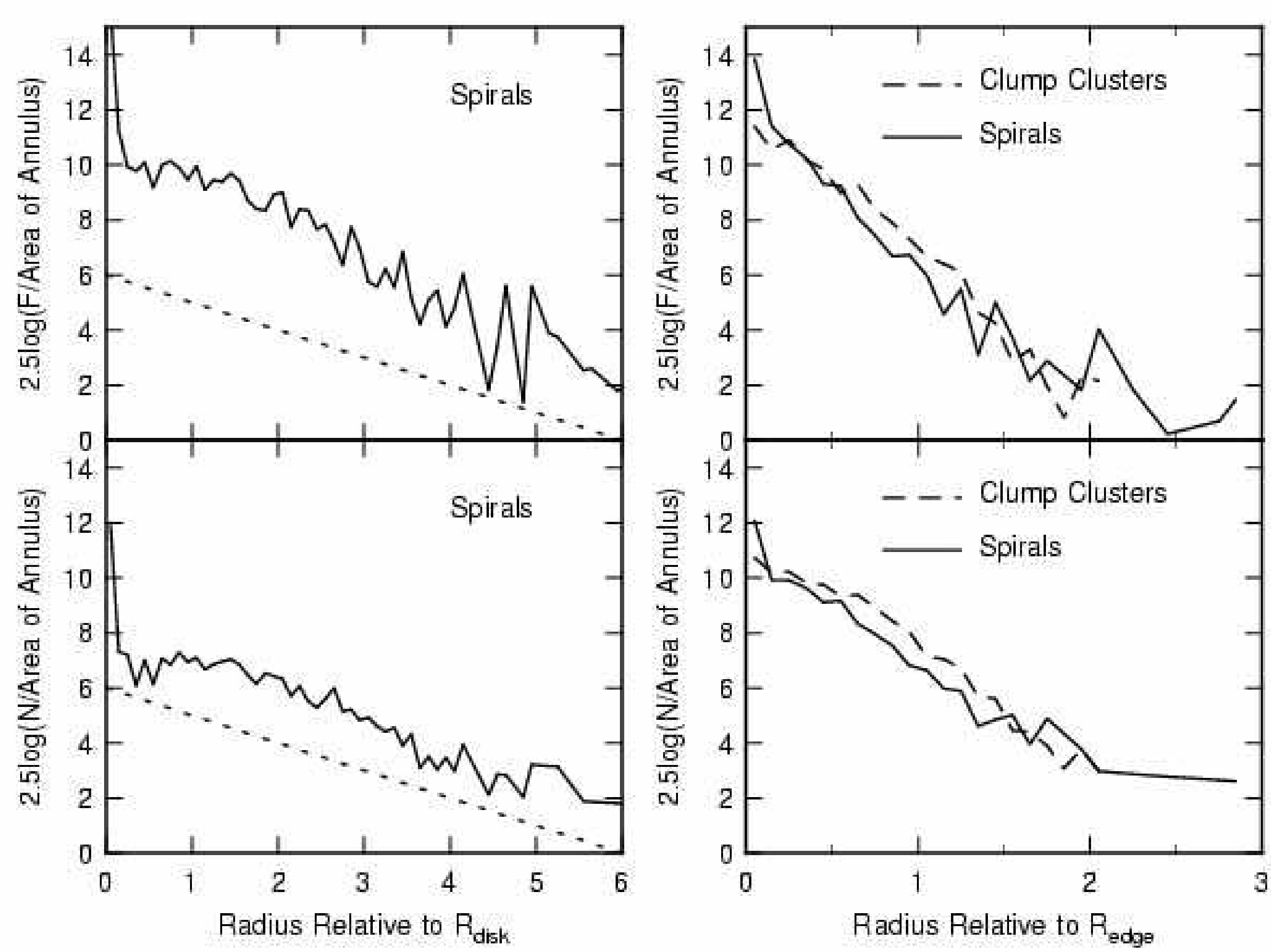
UDF clumpy galaxy average radial profiles: mostly exponential


533
1666
1681
4860
4999
5107
1775
2012
2340
5190
5620
5685
2350
2499
2538
5748
5827
5837
3460
3483
3752
5878
6056
6396
3799
3844
4616
6438
6821
7905

UDF strip profiles



EE+13



632 clumps in spirals

904 clumps in clumpy galaxies

In UDF clumpy disks: a different kind of exponential

Clump number/area (bottom) and total clump flux/area (top) for spirals and clumpy galaxies in the UDF have the same exponential radial profiles when scaled to the disk edge (2-σ contour)

→ *smoothed out clumps make an exponential disk* EE+05

Intermediate stages between high-z clumpies and low-z spirals: spiral-like clumps and clumpy spirals

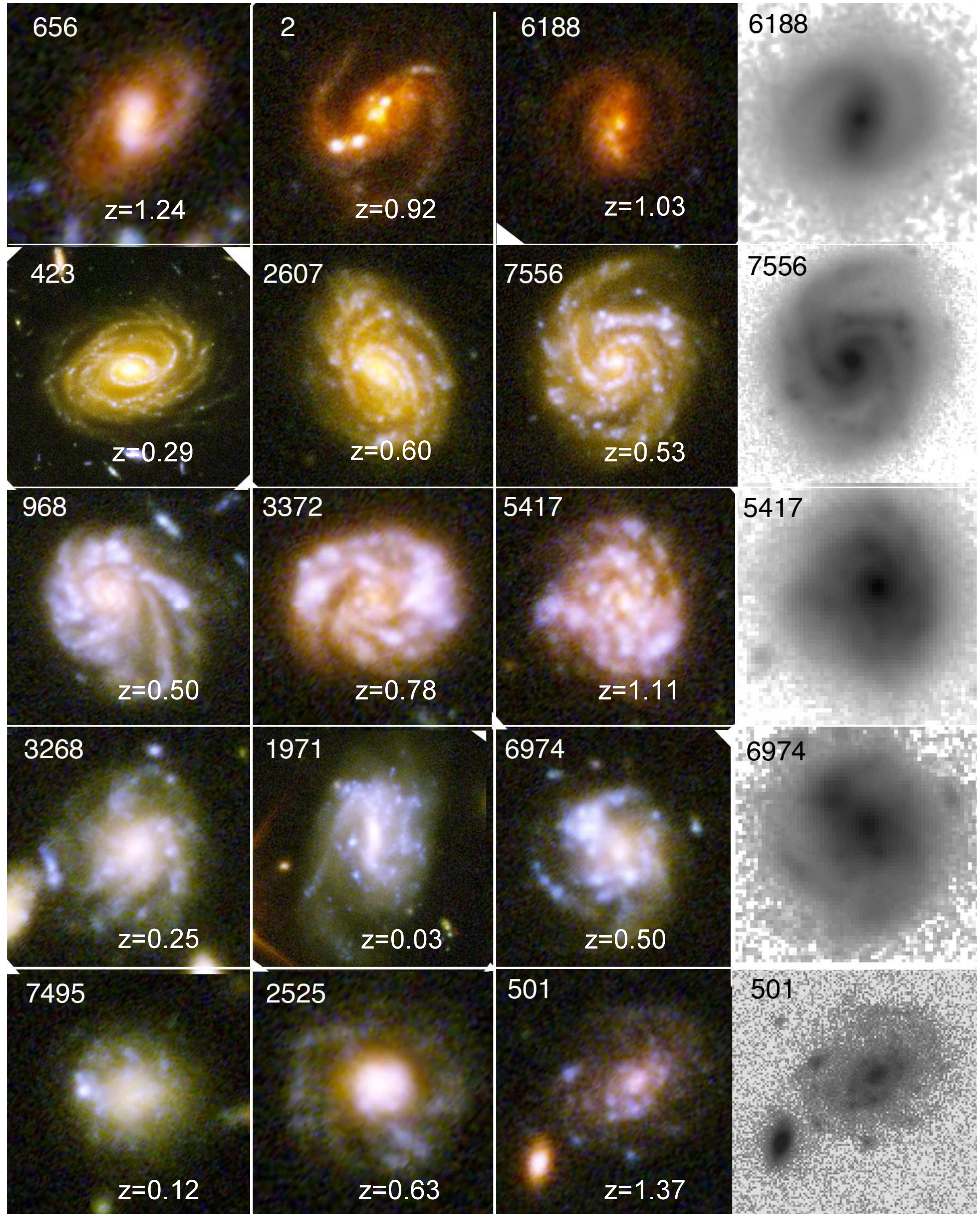
Elmegreen +13: Looking for thick or irregular arms in the HST UDF

Grand Design

Multiple Thin Arm

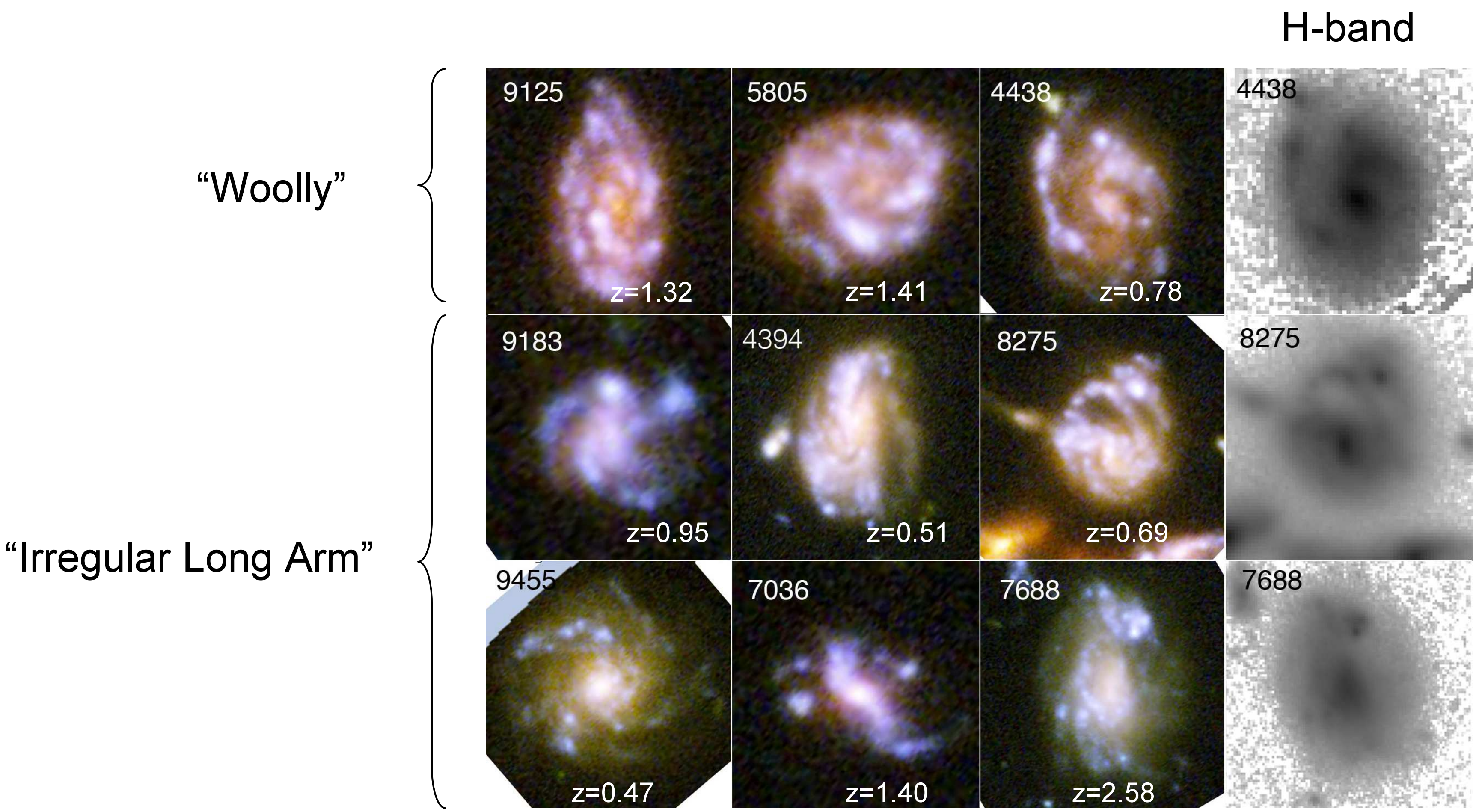
Intermediate? { "Woolly" / "Irregular Long Arm" }

Flocculent

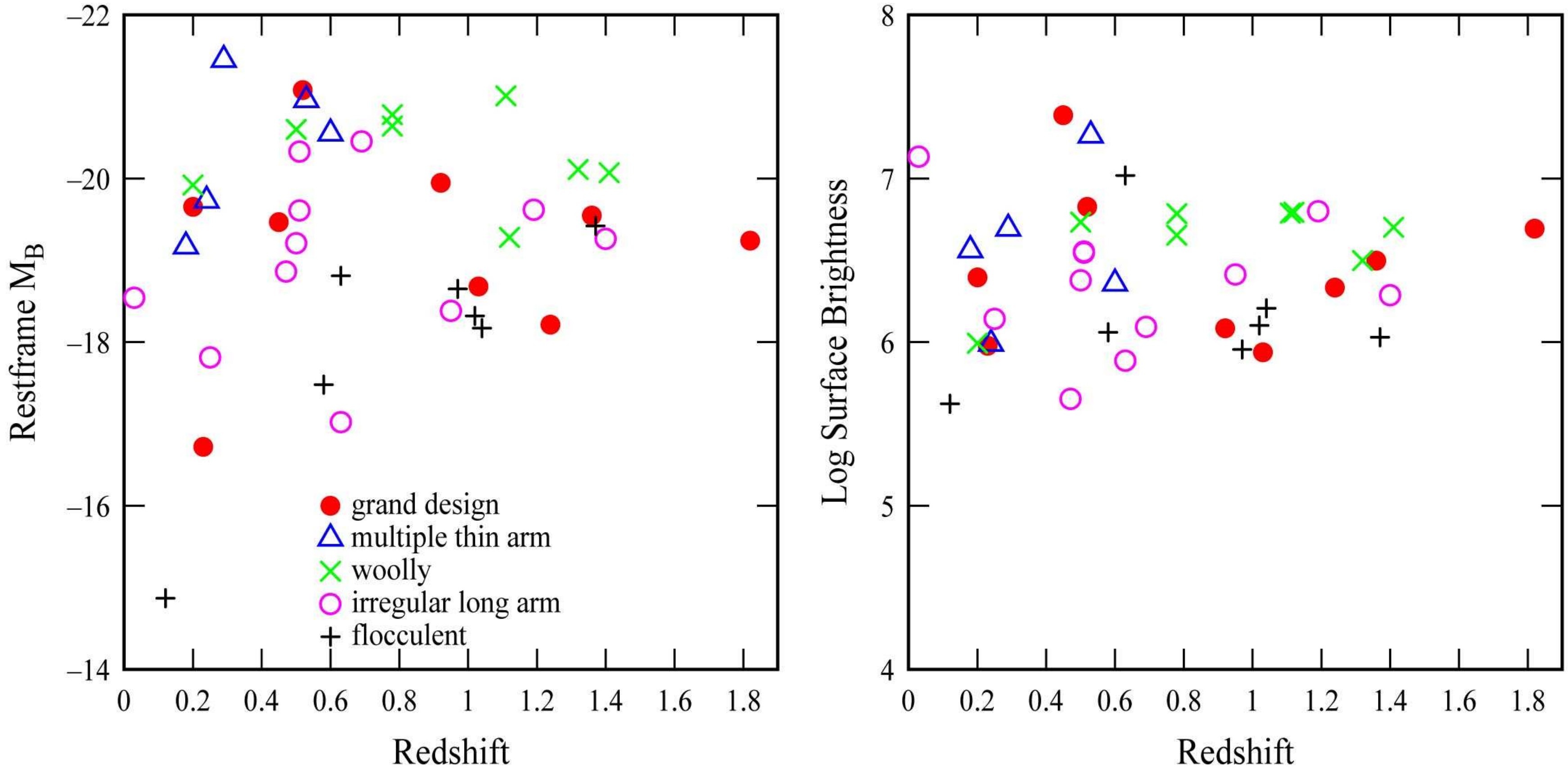


color = ACS B, V, I
B/W = WFC3 H band

More examples of the intermediate types ("wild spirals"):

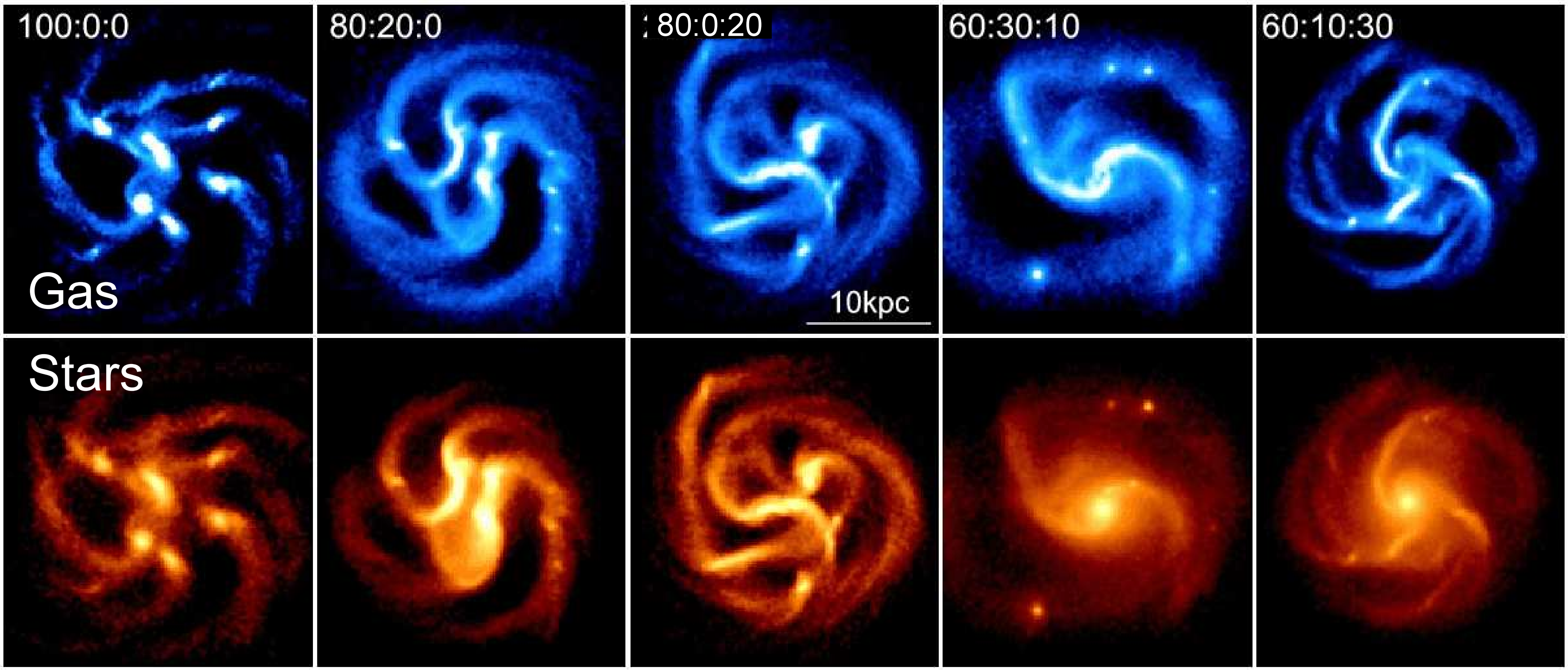


(Not a resolution difference: new types span a wide range of redshift, and beyond z~1, spatial resolution is about constant anyway.)



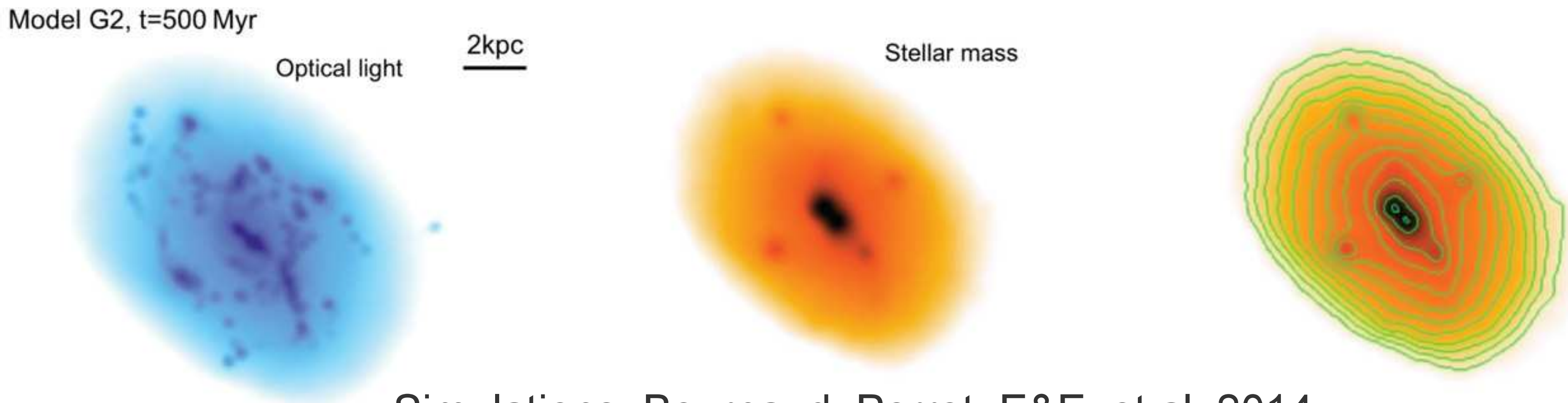
- Earliest spiral in the UDF is a grand design: z~1.8
- Earliest Multiple Thin-Arm at z~0.6
- Multiple Thin-Arm and Woolly galaxies are largest and brightest
- Flocculents are the faintest

When do spirals appear?
varying percentage of disk:bulge:halo

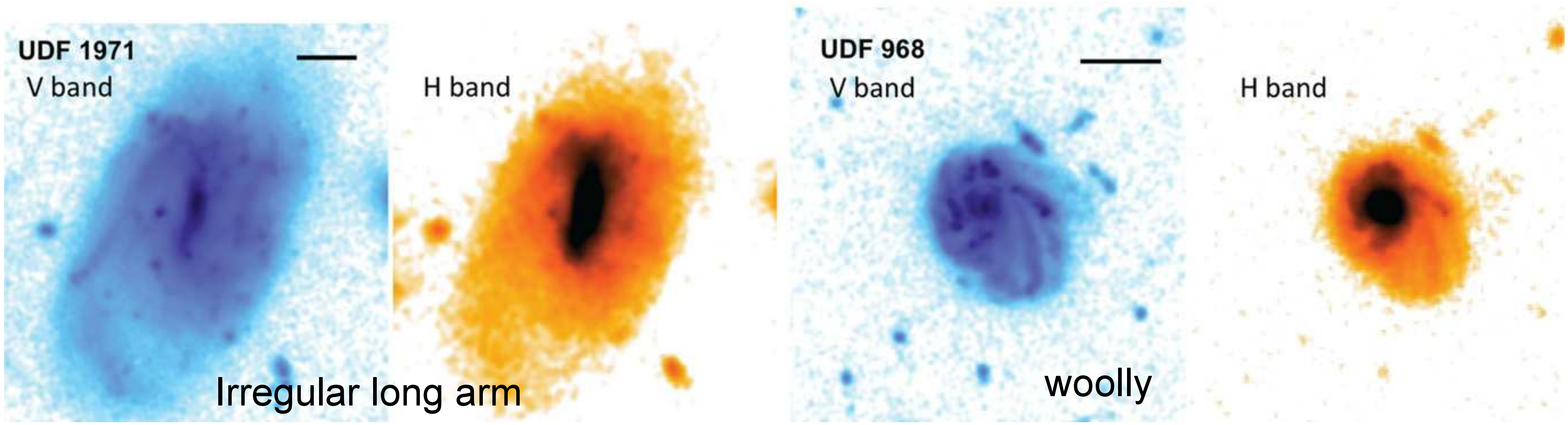


The clumpy phase is disk-dominated (>80% stars + gas in disk).
Thick disks, bulges and stellar halos (from the clumpy/merger phase), precede the main spiral phase.

Bournaud & Elmegreen 09



Simulations: Bournaud, Perret, E&E, et al. 2014

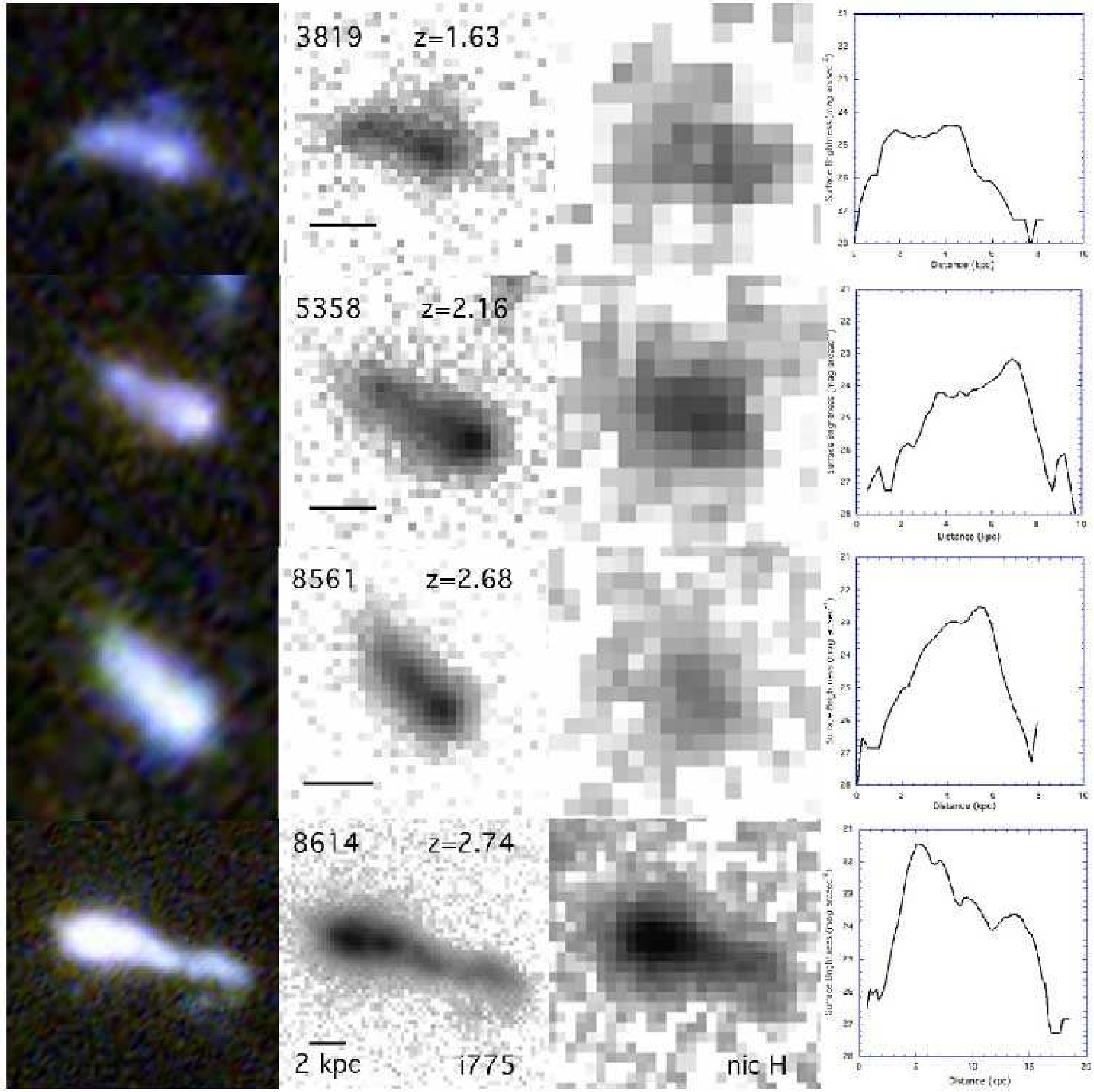


UDF spiral-like: E&E 2014

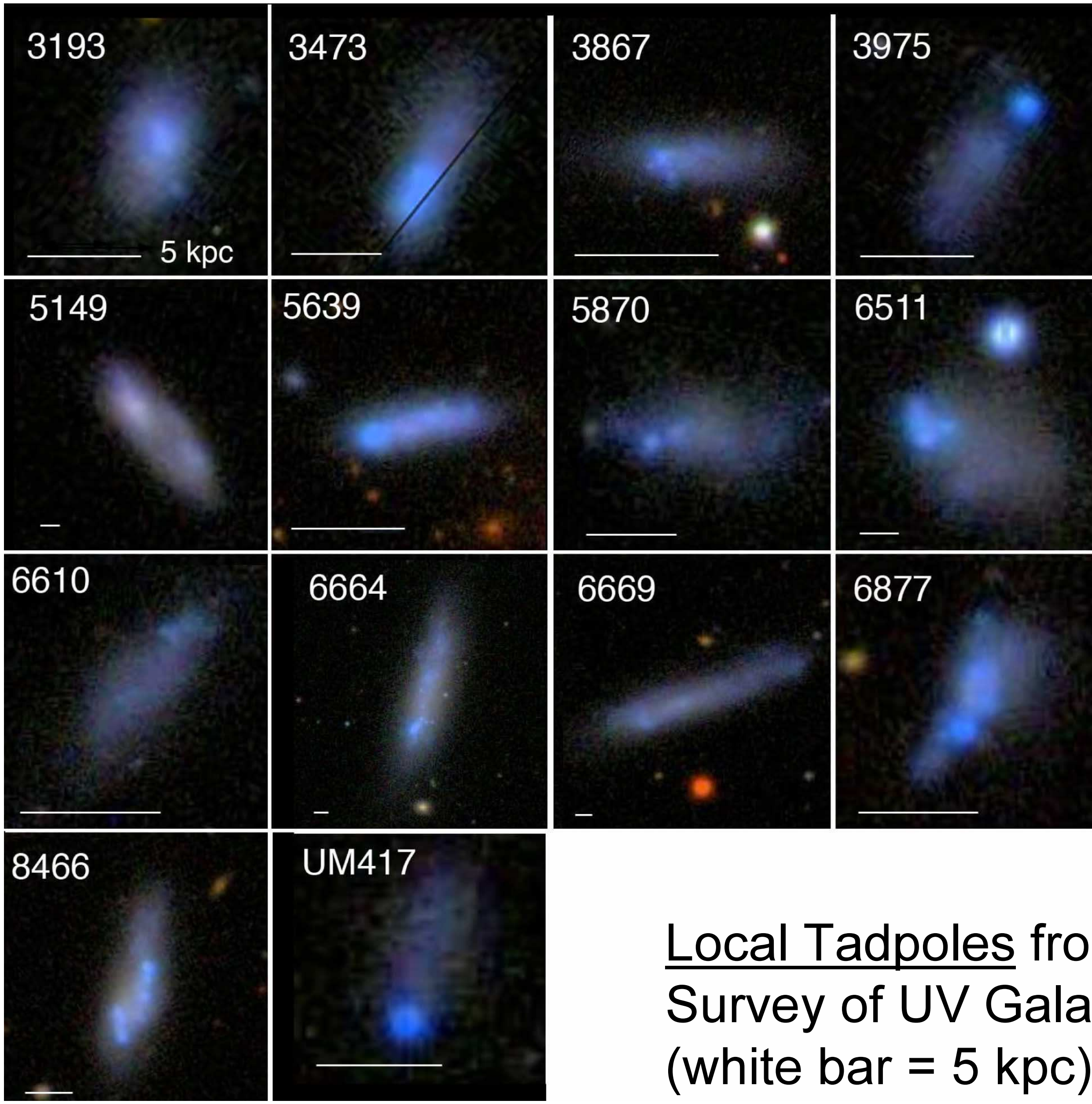
“Un-evolved” Galaxies: Tadpoles & Extremely Metal Poor Galaxies

(75% of XMP galaxies ($Z<0.1$) are tadpoles – Morales et al. 2011)

Tadpole galaxies are common (10%) in the HST Ultra Deep Field (z~2)

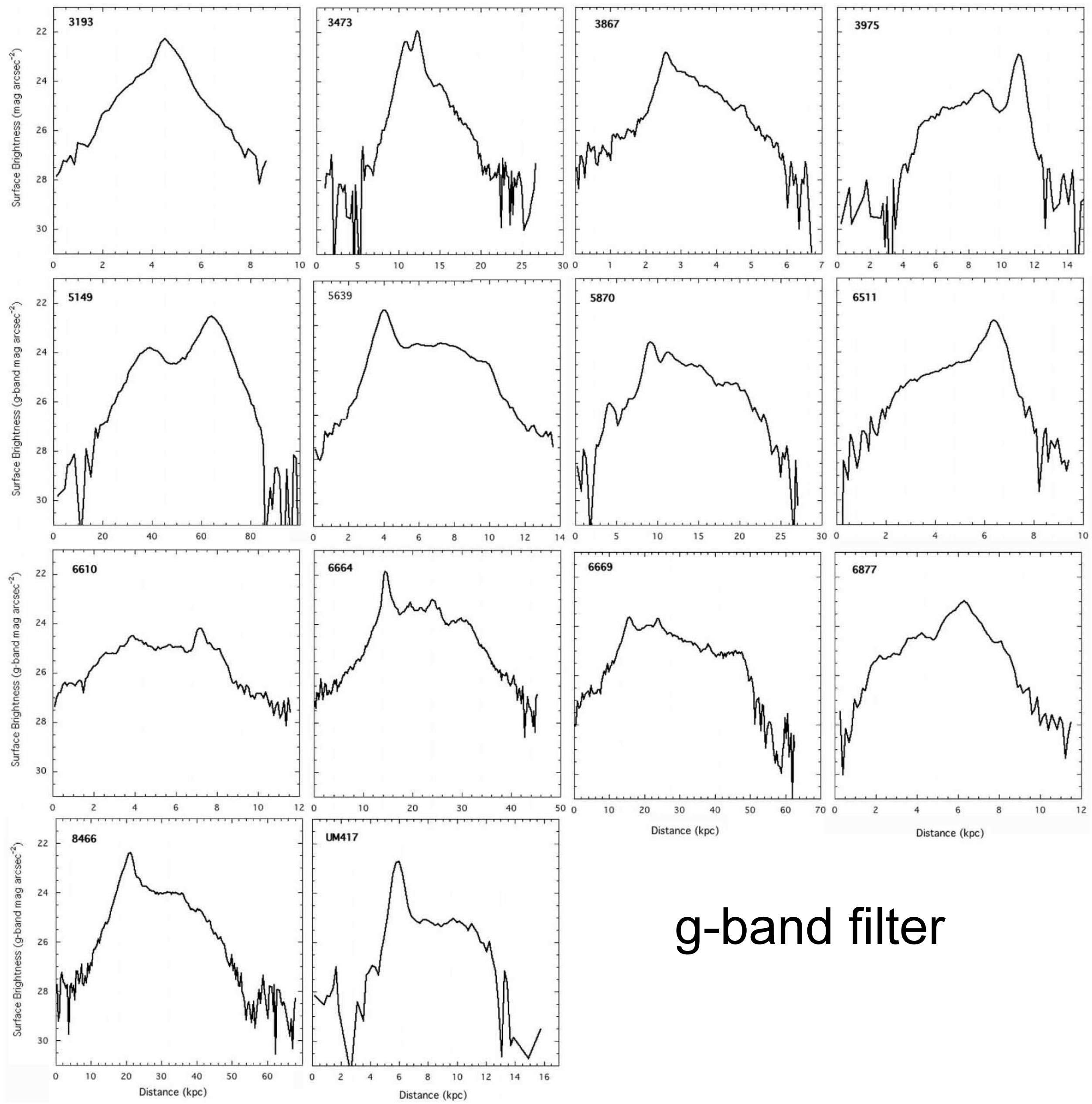


EE10



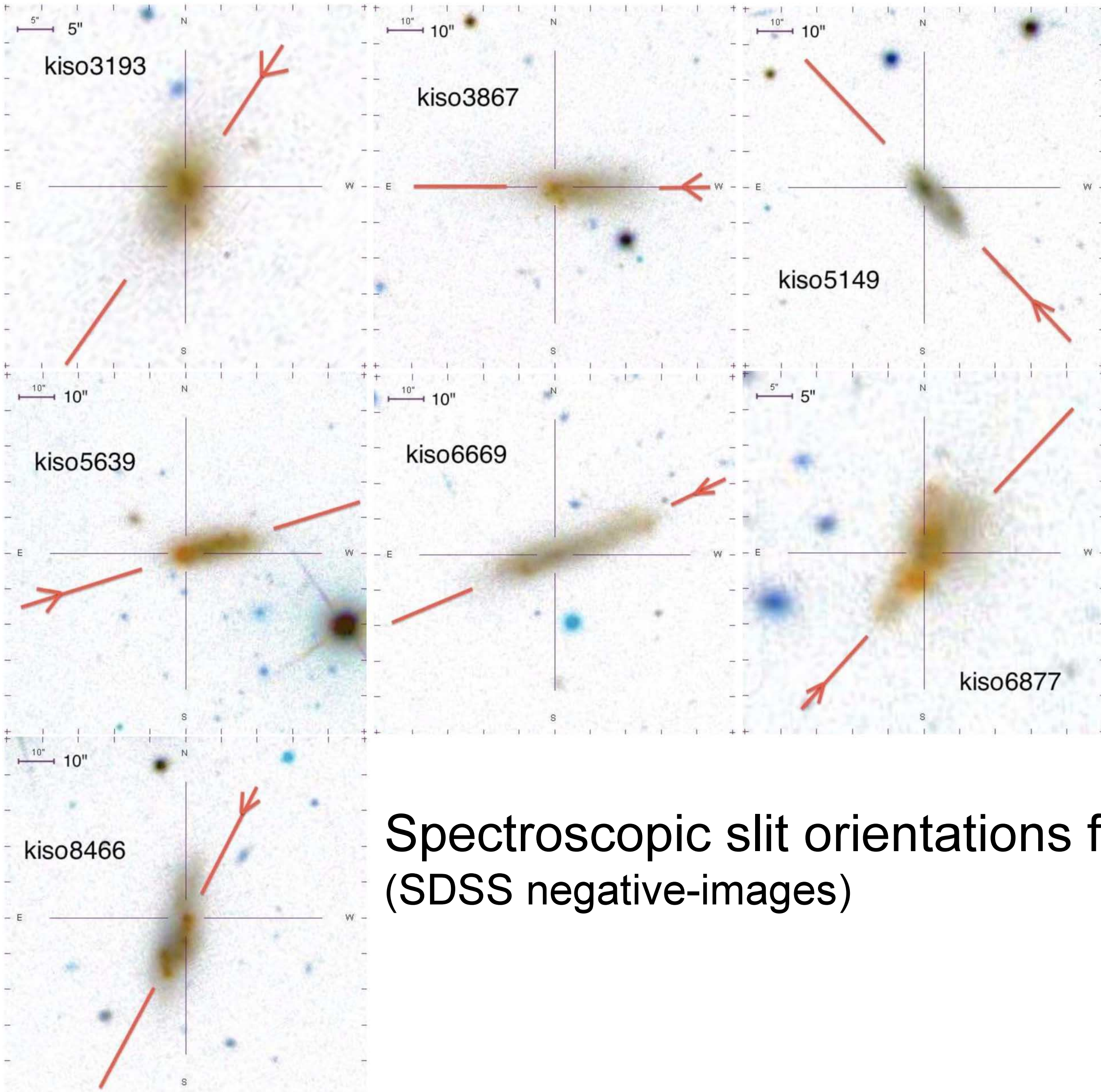
<u>Local Tadpoles</u> from Kiso Survey of UV Galaxies (white bar = 5 kpc)

E+12



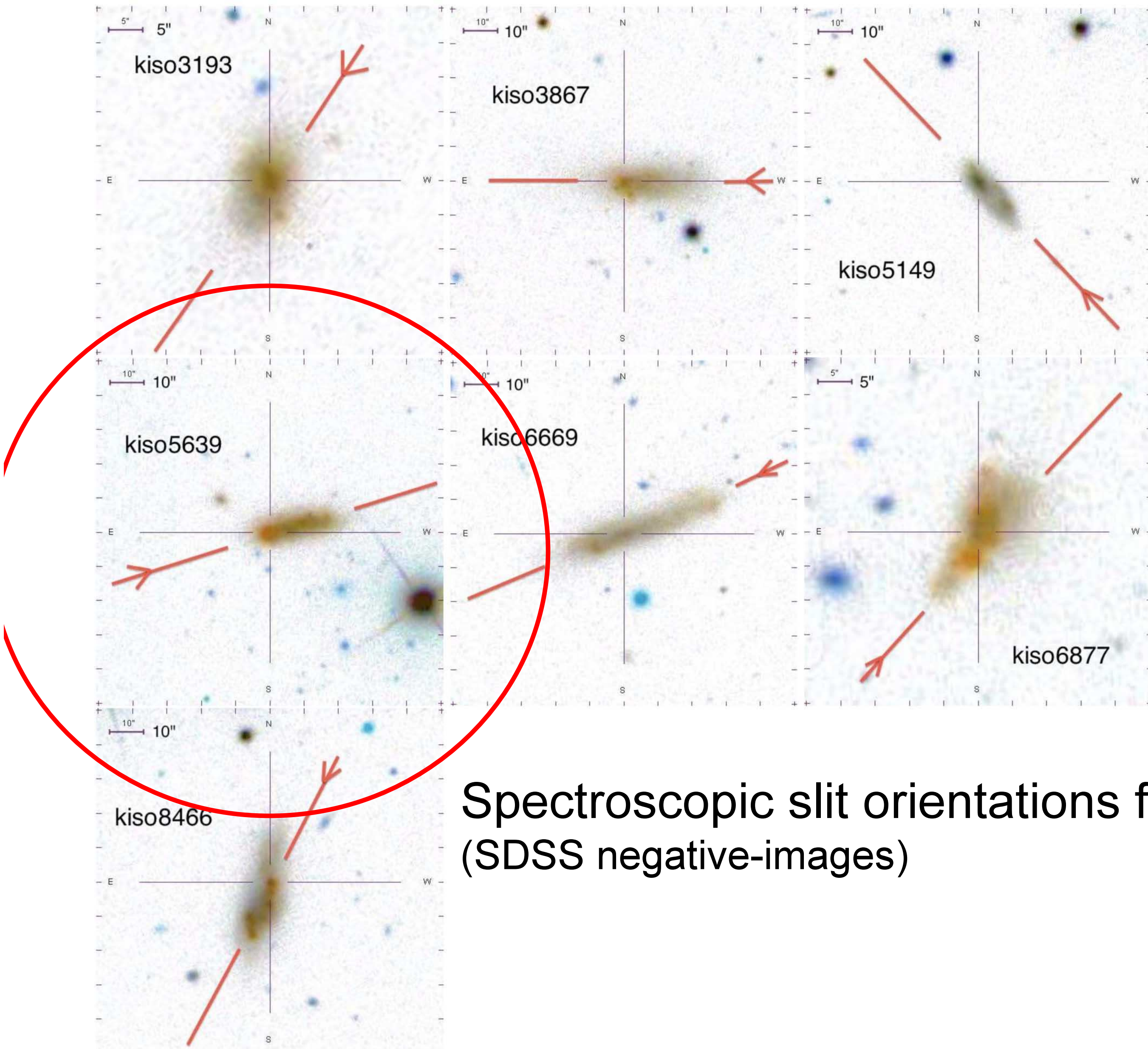
g-band filter

E+12



Spectroscopic slit orientations for local Tadpoles
(SDSS negative-images)

Sanchez Almeida, Munoz-Tunon, Elmegreen, Elmegreen, & Mendez-Abreu 2013



Spectroscopic slit orientations for local Tadpoles

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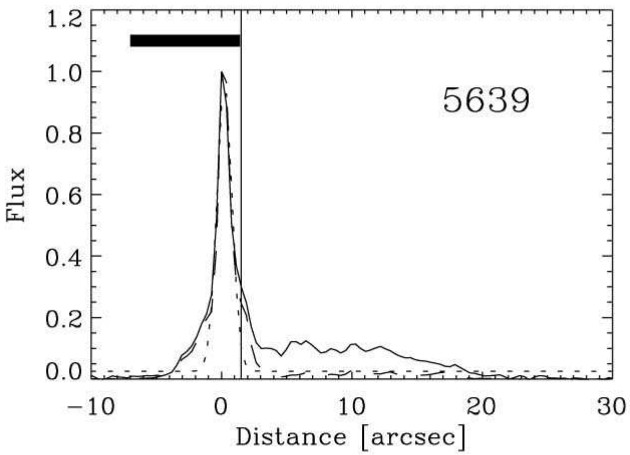
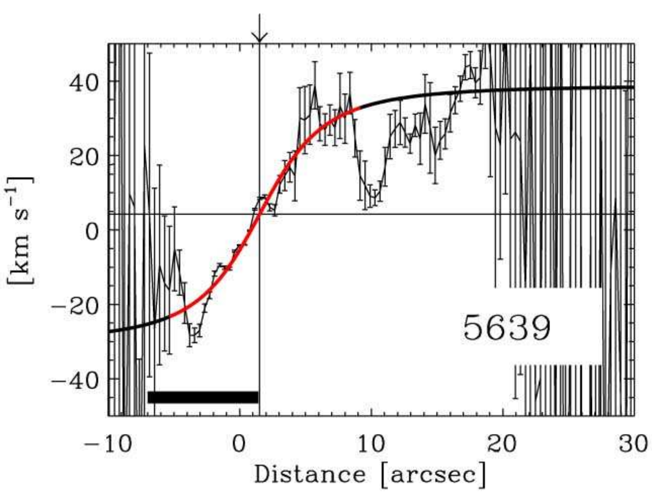
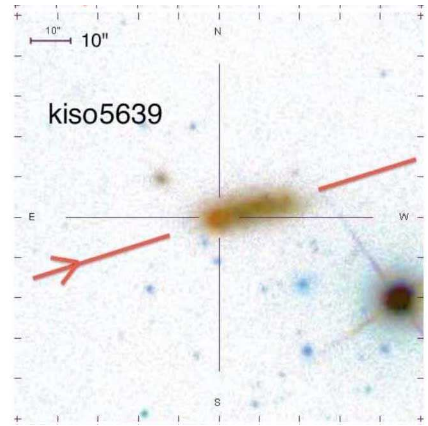
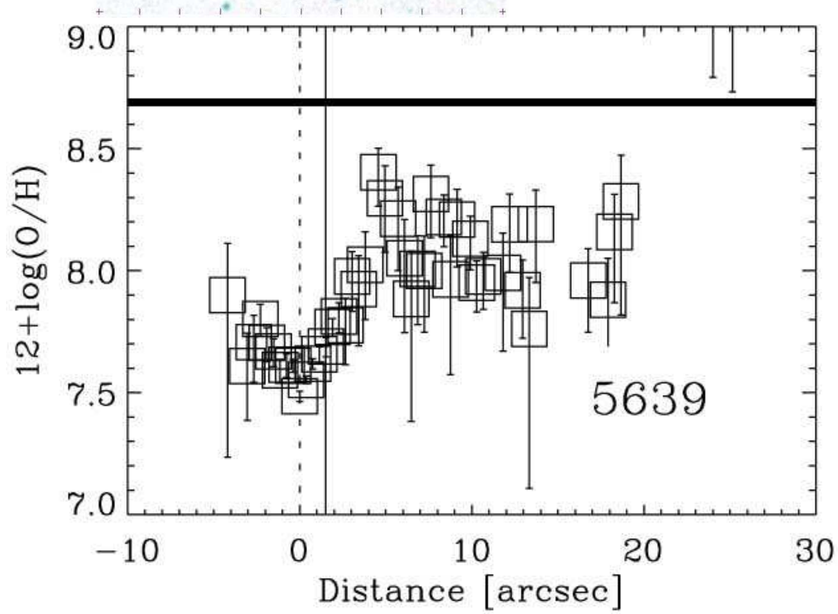
Flux (solid lines) and Ha (dashed lines)





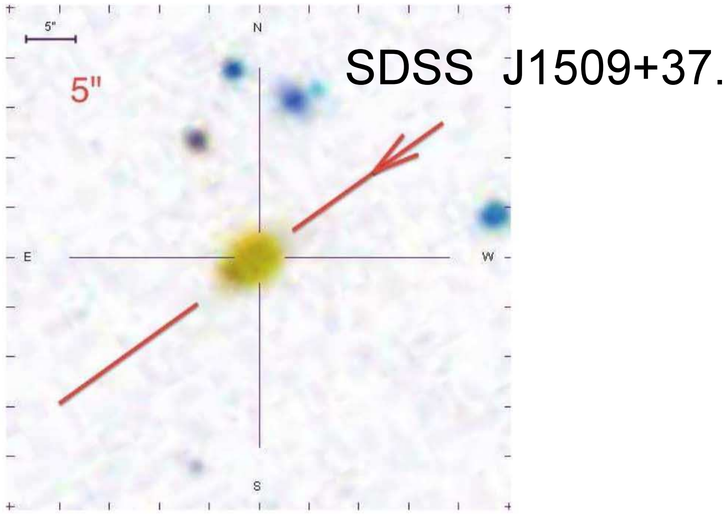
Rotation curve for Kiso 5639
(zero-point = head, bar = 1 kpc).

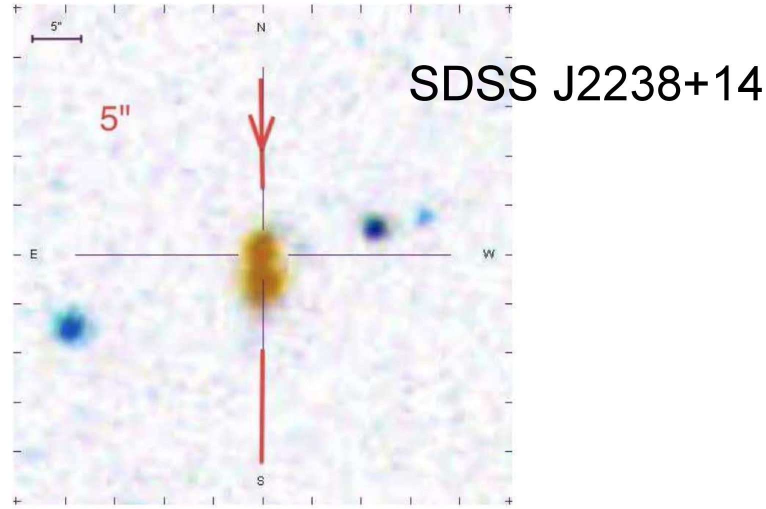


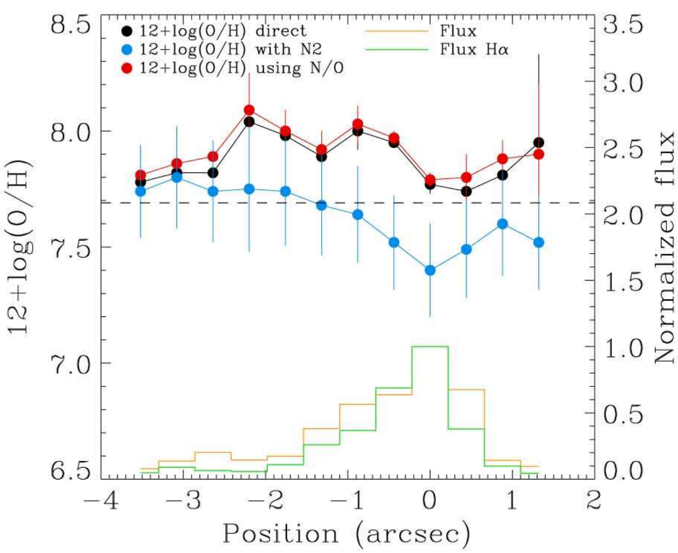


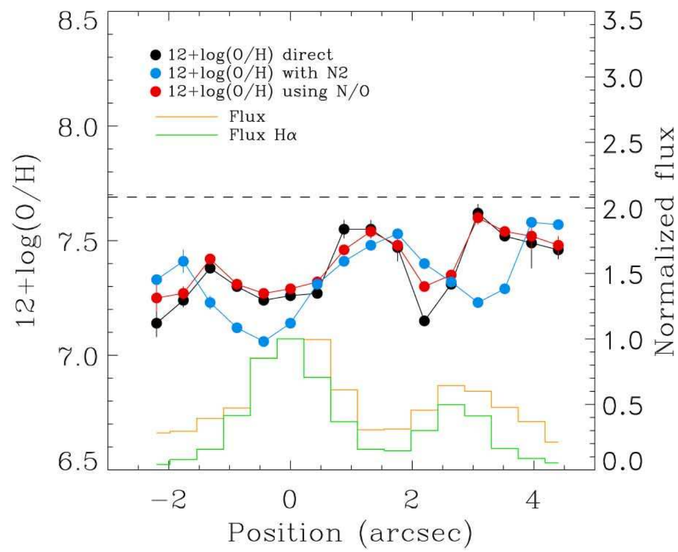
Low Oxygen abundance in head.
Thick line = solar metallicity
(strong line method using N/H)

Sanchez Almeida, et al. 2013









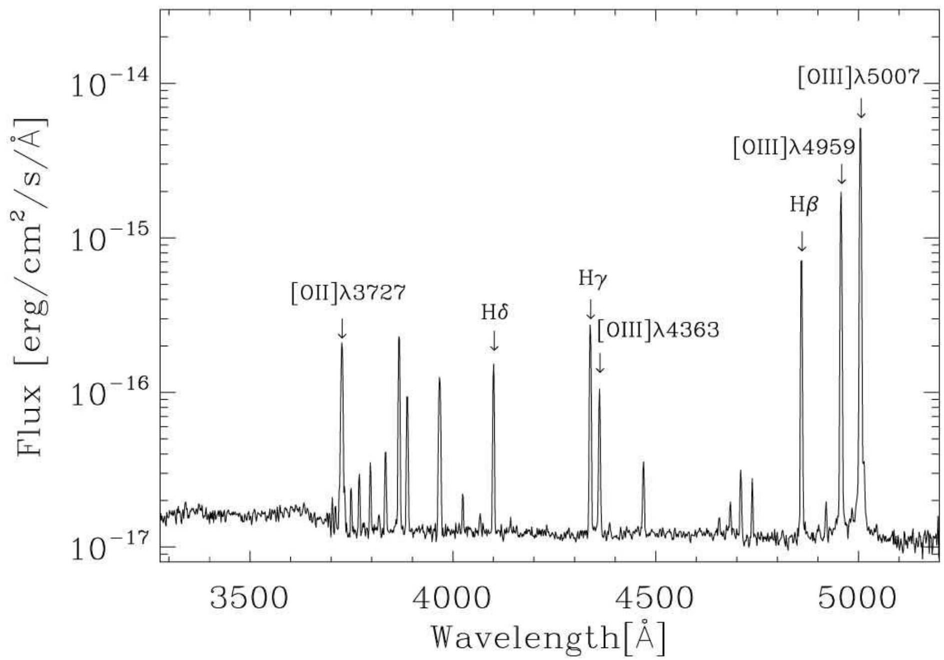
XMP Galaxies: metallicity & flux along slit

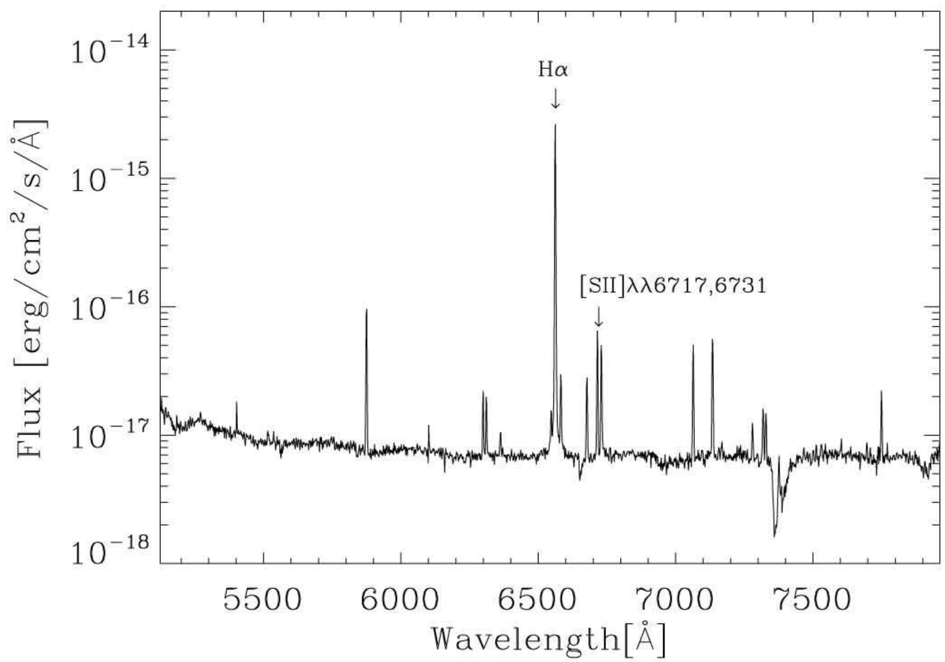
(direct method = black solid line, modified direct method = red; N_2 method = blue).

Integrated flux = orange, Hα flux = green; Dashed line = 0.1 solar

Sánchez Almeida, Morales, Muñoz-Tuñón,
Elmegreen, Elmegreen, Méndez-Abreu, 2014

Sample XMP spectra with William Hershel Telescope





Sanchez Almeida, Munoz-Tunon, Elmegreen, Elmegreen, & Mendez-Abreu 2013

Conclusions

- Disk galaxies become smoother as they evolve
  - cosmic accretion rate (turbulence, SFR, fgas, …) is decreasing

  … but their radial profiles are "somewhat" exponential the whole time.

- Local examples of highly irregular galaxies ("barely exponential") may still be in their main accretion phase
  - low mass, gas rich, extremely metal poor galaxies
  - tadpoles, BCDs, …
  - Half of those we have observed show metallicity dips at their star-forming regions suggestive of cosmic accretion there (hotspot accretion?)
  - and HI gas around some BCDs has even lower metallicity than the HII regions (IZw18: Lebouteiller +13, Pox 36: Lebouteiller +09; for 29 XMPs in Filho +13)

- Exponential profiles may result from mass redistribution (clumps and wild spirals?) following the main accretion