On the inner structures of spiral arms
in grand design galaxies

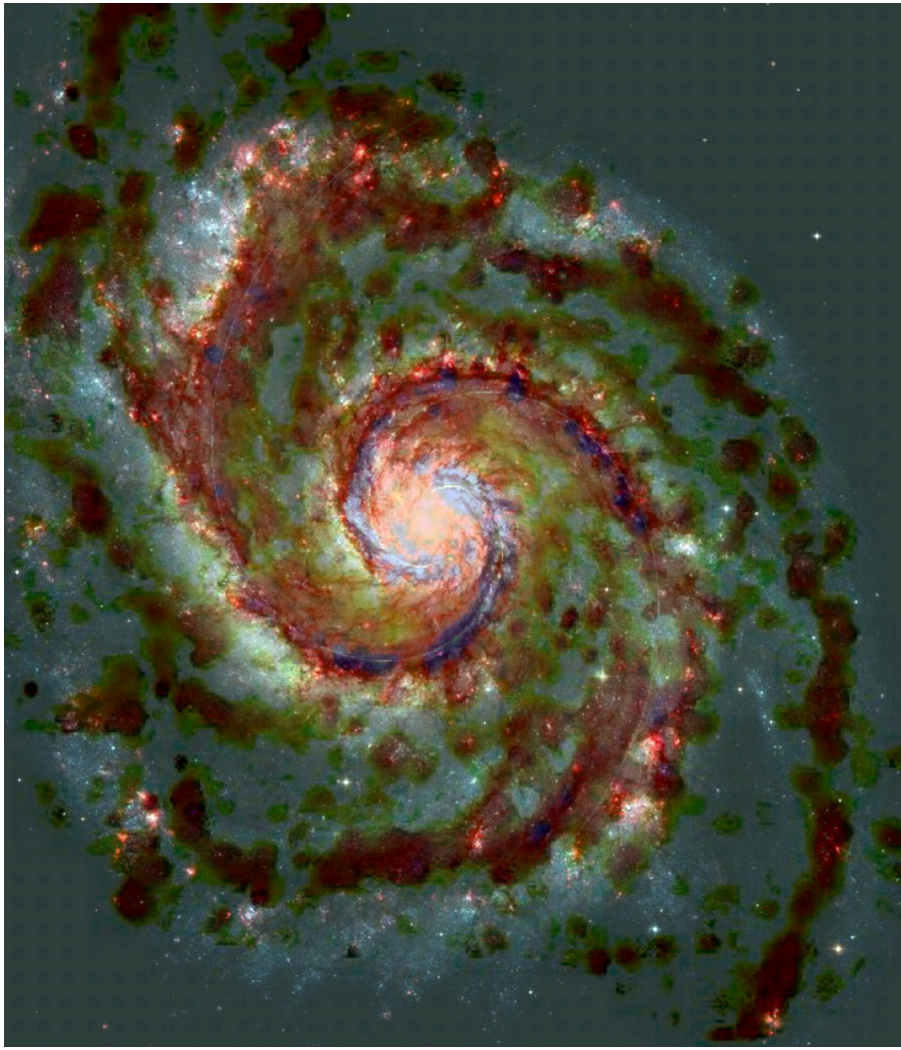
Yuri N. Efremov

Sternberg Astronomical Institute, MSU, Moscow

Structures (components) across an arm

Often - dust (gas) lane, HII regions, young stars, older stars (age gradient)
Sometimes – no dust lane, no age gradient

M51 HST ACS



M51 HST ACS + CO

Structures along an arm

NGC 5248

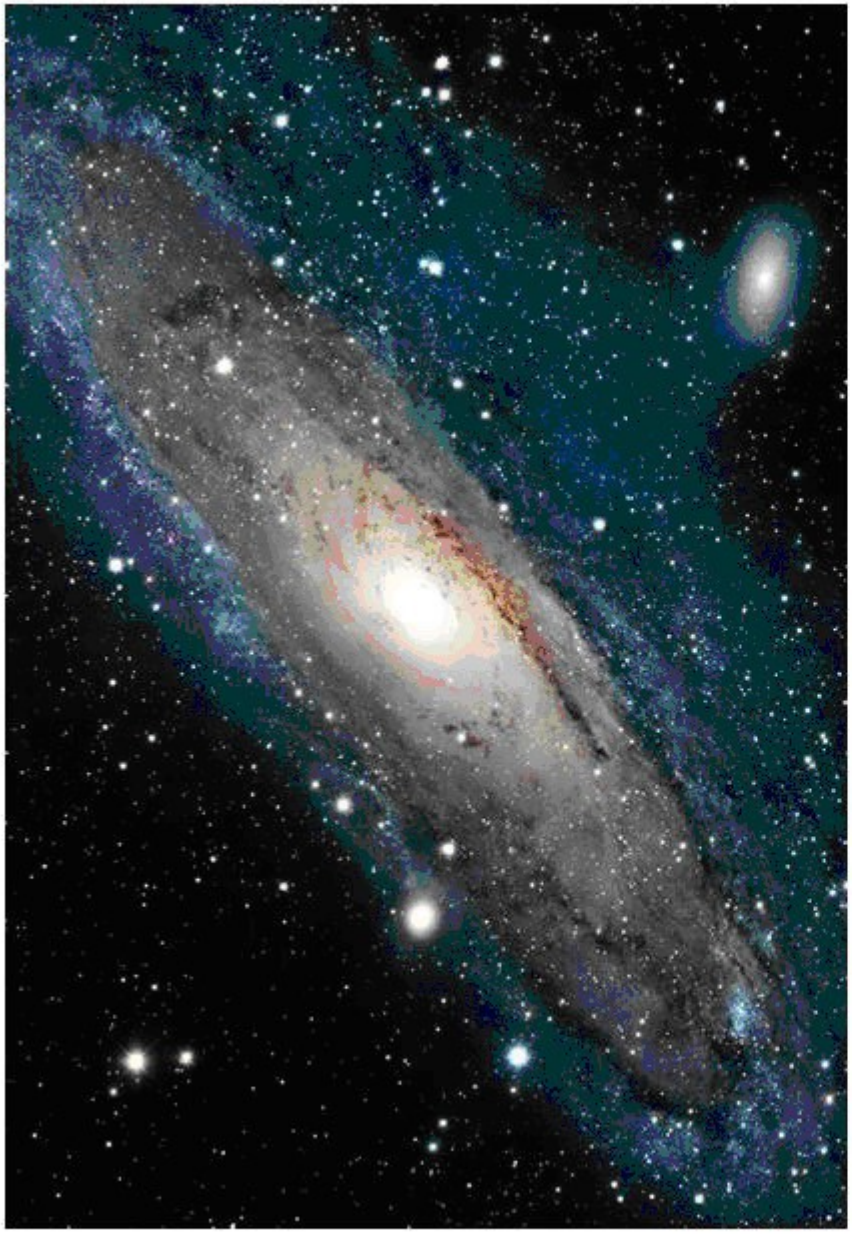
NGC 895

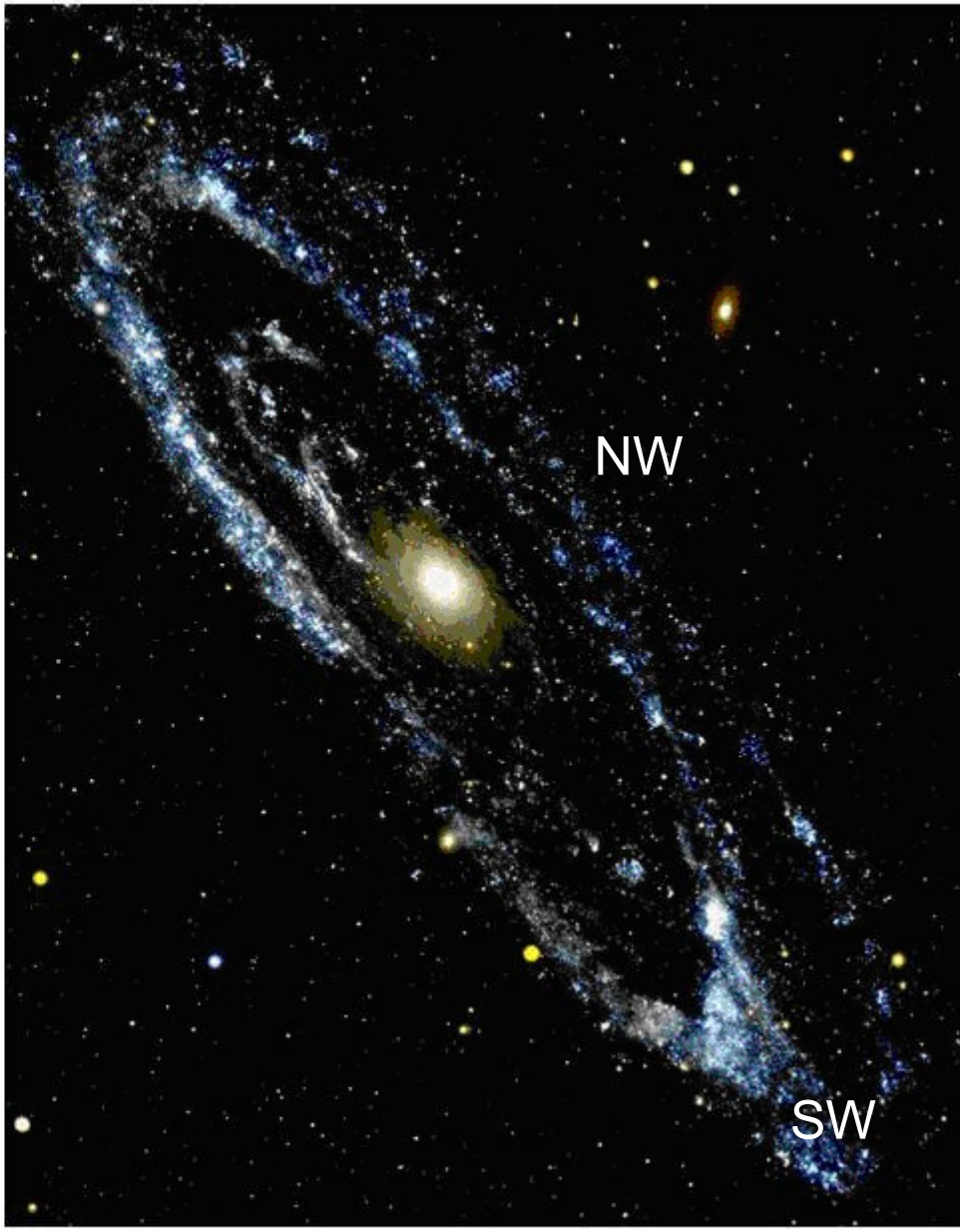
NGC 5033

NGC 5371

Elmegreen & Elmegreen (1983) - (regular) chains of star complexes in 22 grand design galaxies (amongst some 200 studied).
In 7 galaxies such a chain is in one arm only.

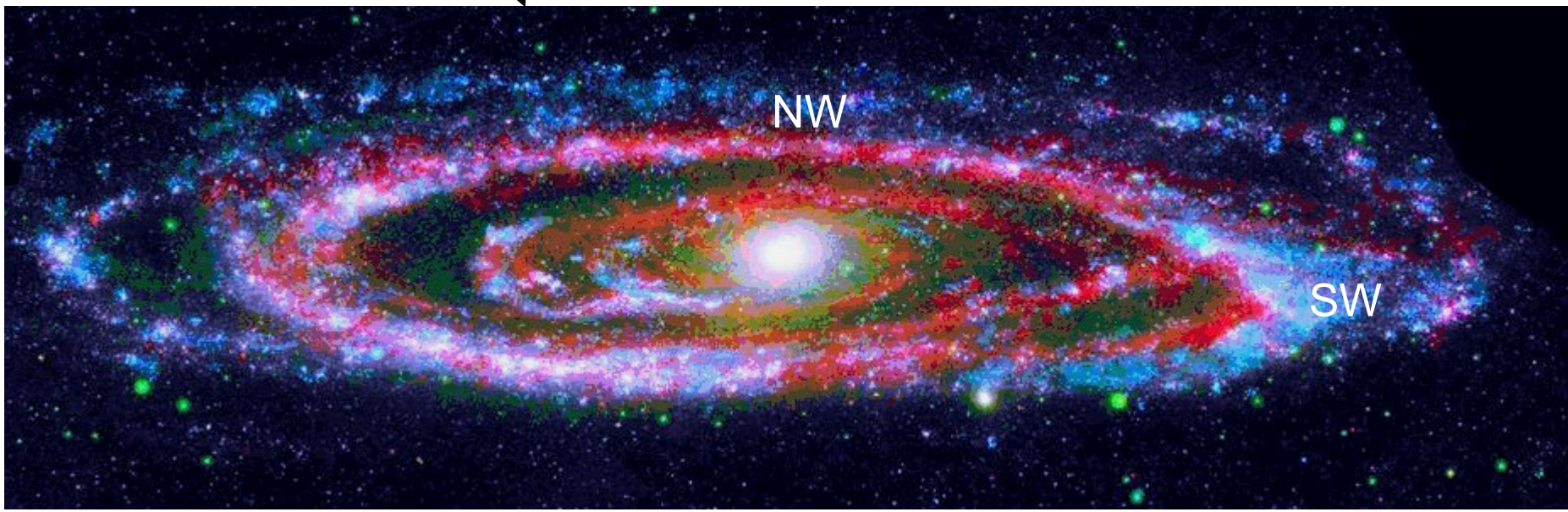
M31



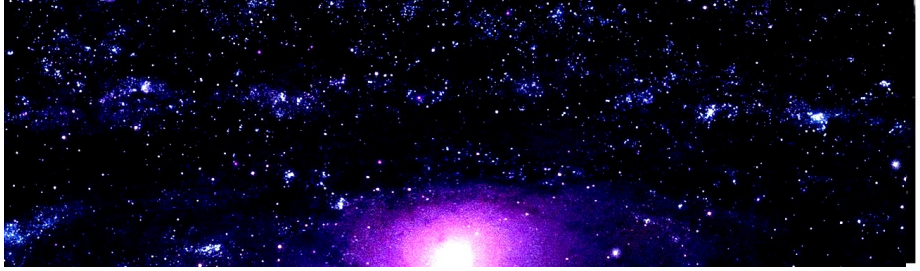


GALEX, far UV

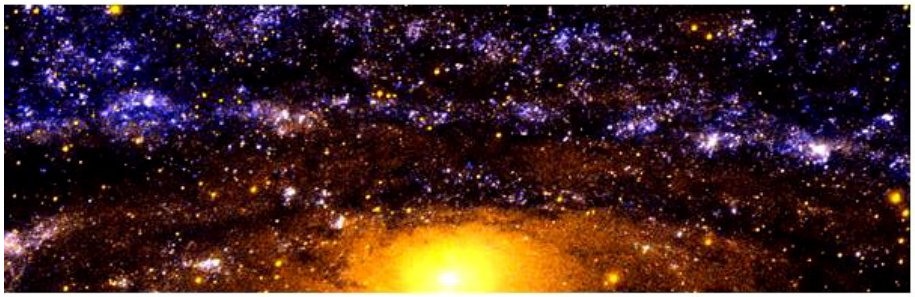
A regular string of star complexes is located in the north-western arm of M31; these have about the same size, 0.6 kpc with spacing of 1.1 kpc (Efremov, 2010). Within the same arm segment, a regular magnetic field with a wavelength of 2.3 kpc was found by Beck et al.(1989). This wavelength is twice as large as the spacing between complexes and suggest that these were formed as a result of the magneto-gravitational instability developed along the arm.



GALEX (blue, young stars 50 – 100 Myr)
Spitzer (red, warm dust)



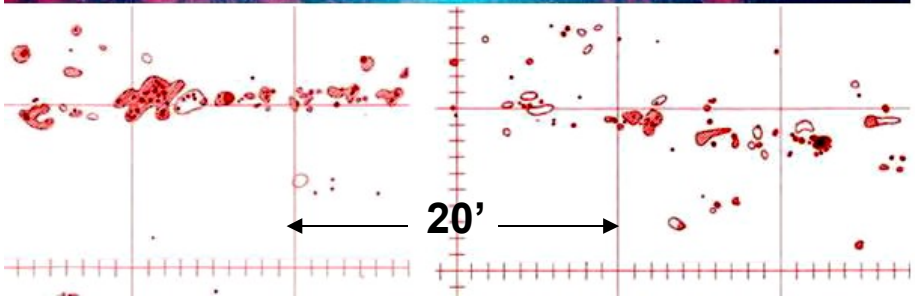
Swift, very far UV



GALEX, FAR UV

GALEX+Spitzer

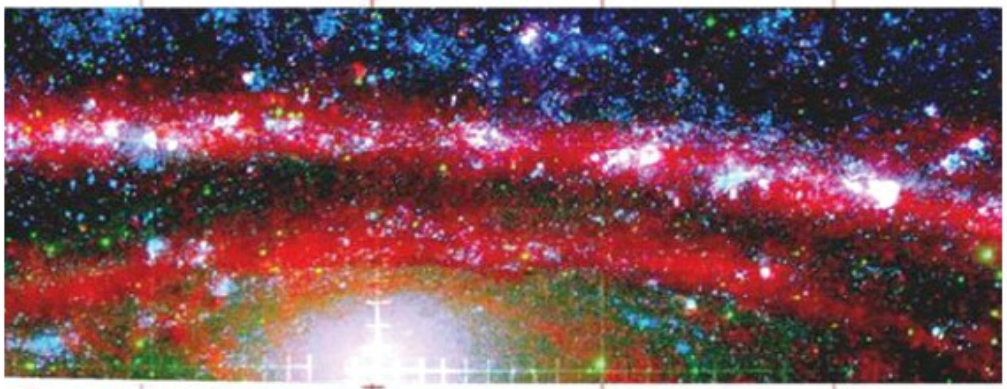
Spitzer



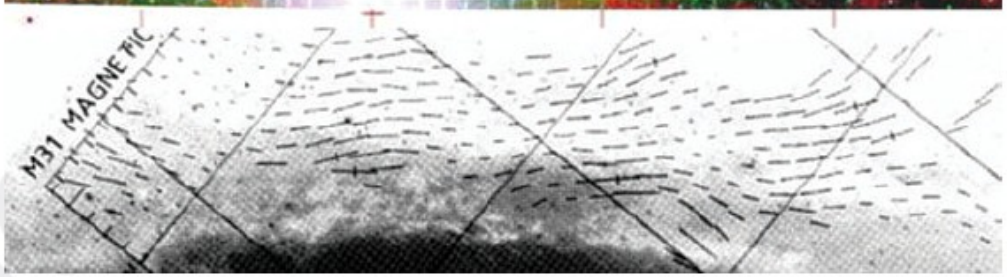
HII map, Pellet et al, 1978

Swift

degree of polarization
(Beck et al., 1989)

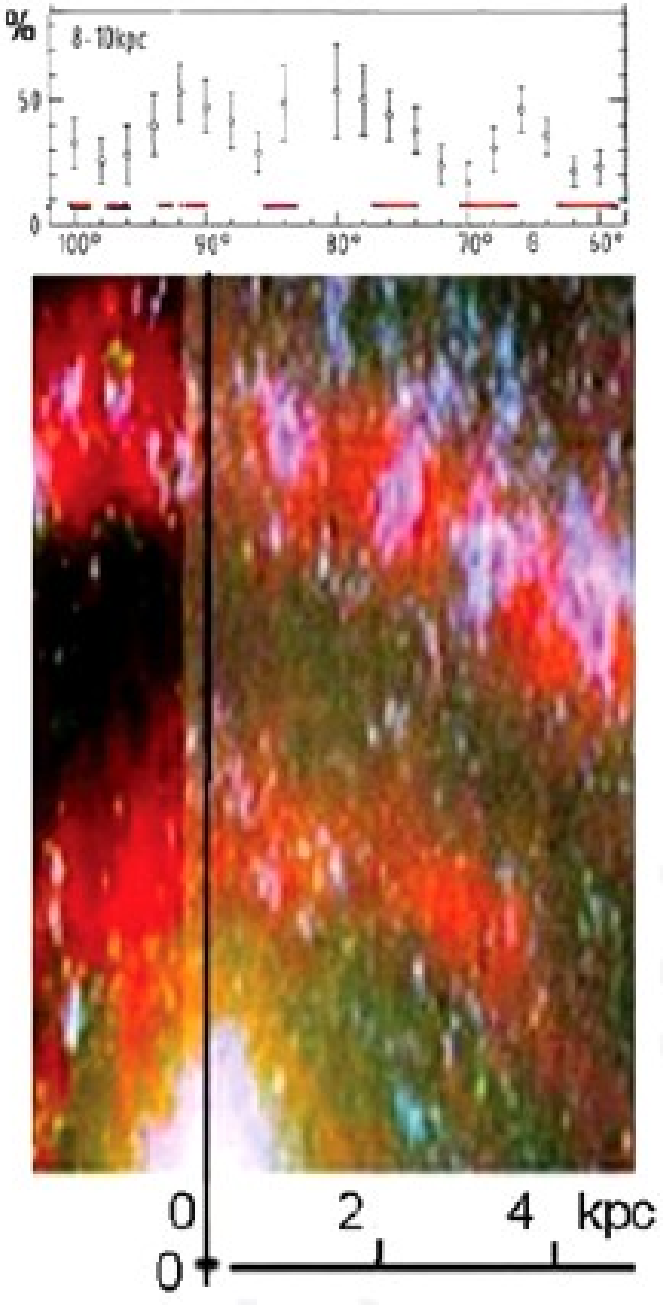


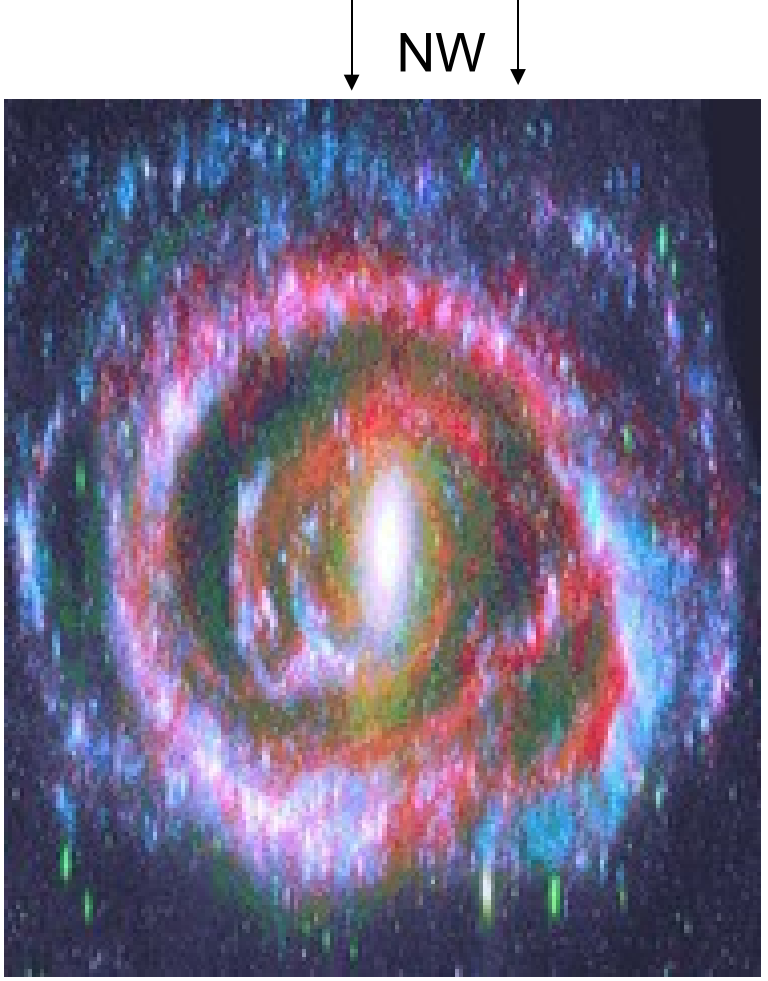
GALEX+*Spitzer*+HII regions



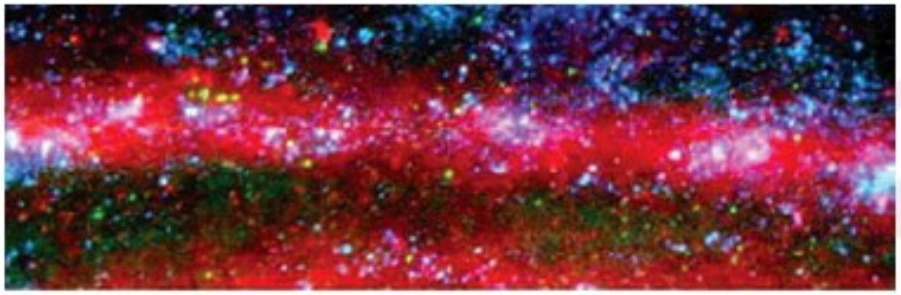
orientation of the magnetic field
(Beck et al., 1989)

P6.3

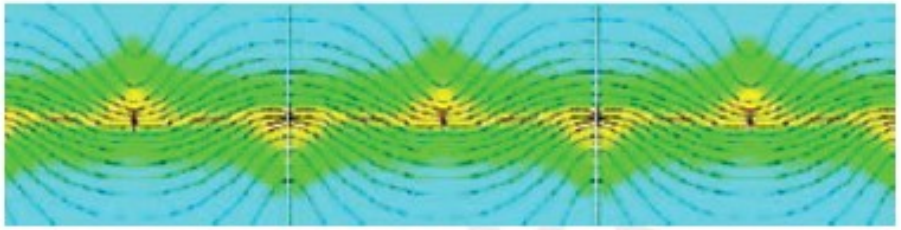




In this NW arm segment:
field wavelength **2.3** kpc ***(Beck et al. 1989***), spacing of complexes **1.1** kpc – half of the field wavelength. Most complexes located at polarisation (magnetic field) extrema

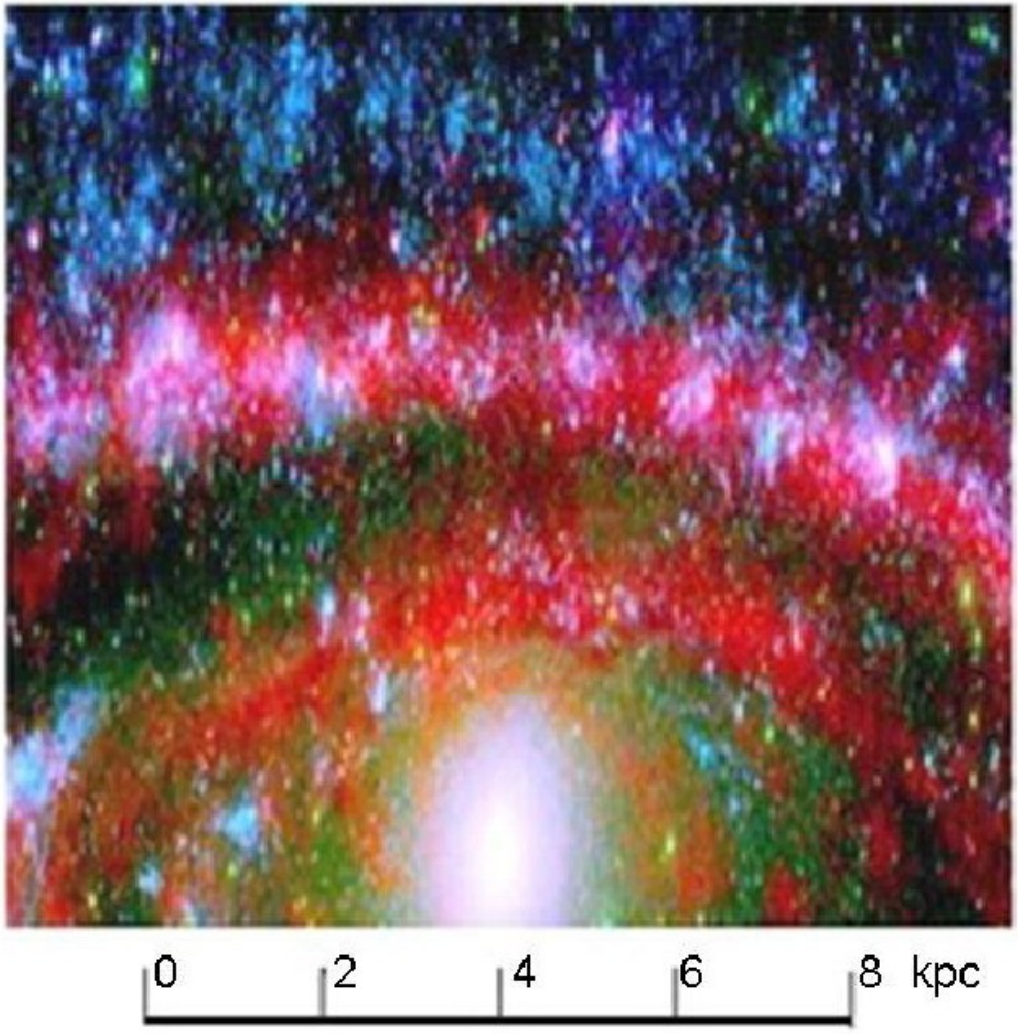


Observed structure of the M31 NW arm. Warm dust (red), young stars (blue)



Theoretical pattern of gas (green), denser star-forming gas (yellow) and magnetic field lines (***in Z-direction***, composed from fig. 3 in Mouschovias et al. 2009).

M31 plane inclination is 12 degree to line of sight.
This is the case when such an inclination might be useful...
Owing it , we may probably see deviations from the plane



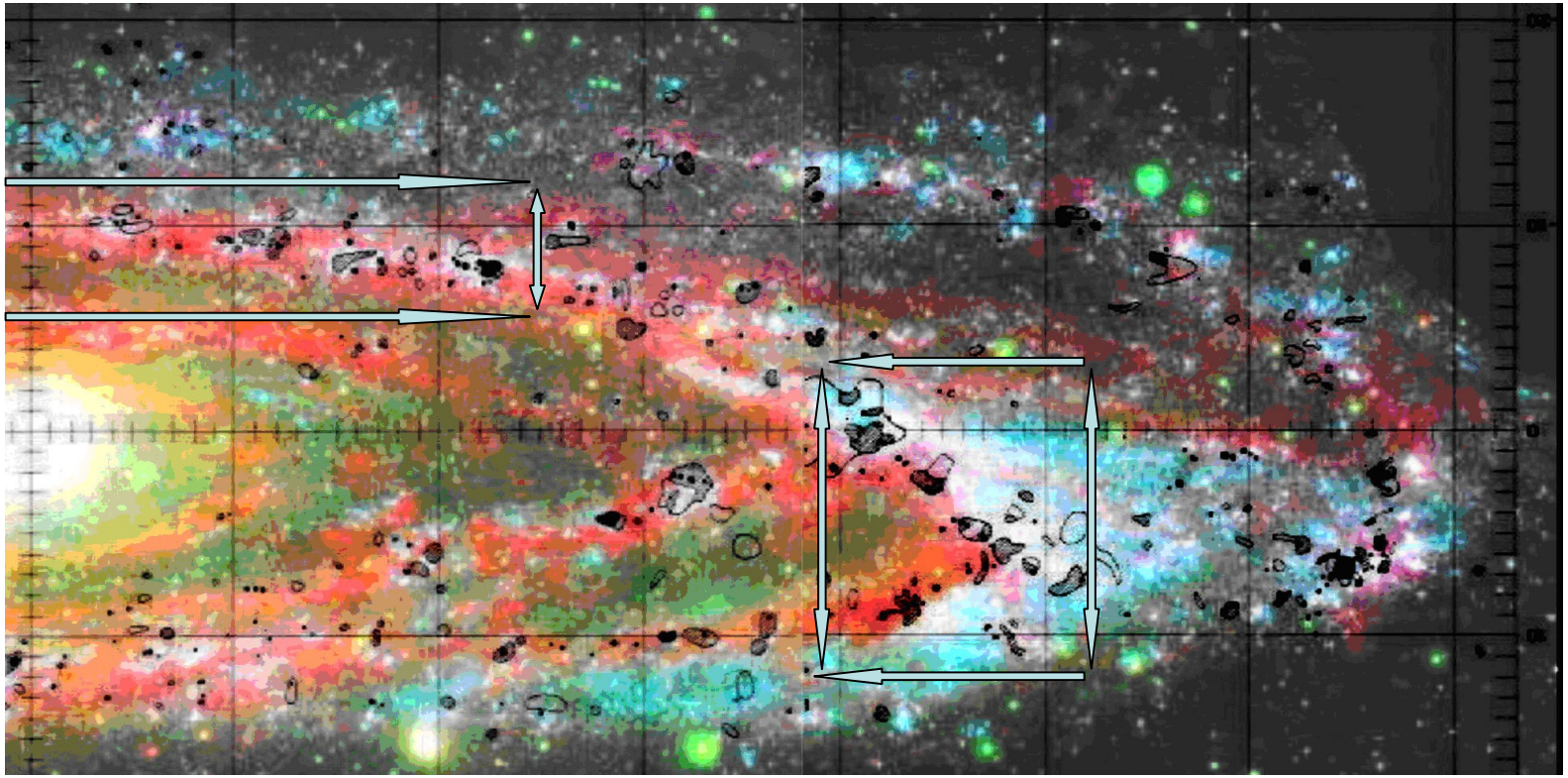
i = 12 deg (elongated)

i = 16 deg (roundish)

M31 plane corrugation or similar inclination of each complex plane to M31 plane (like it is the case for the Gould Belt complex plane) ?

M 31

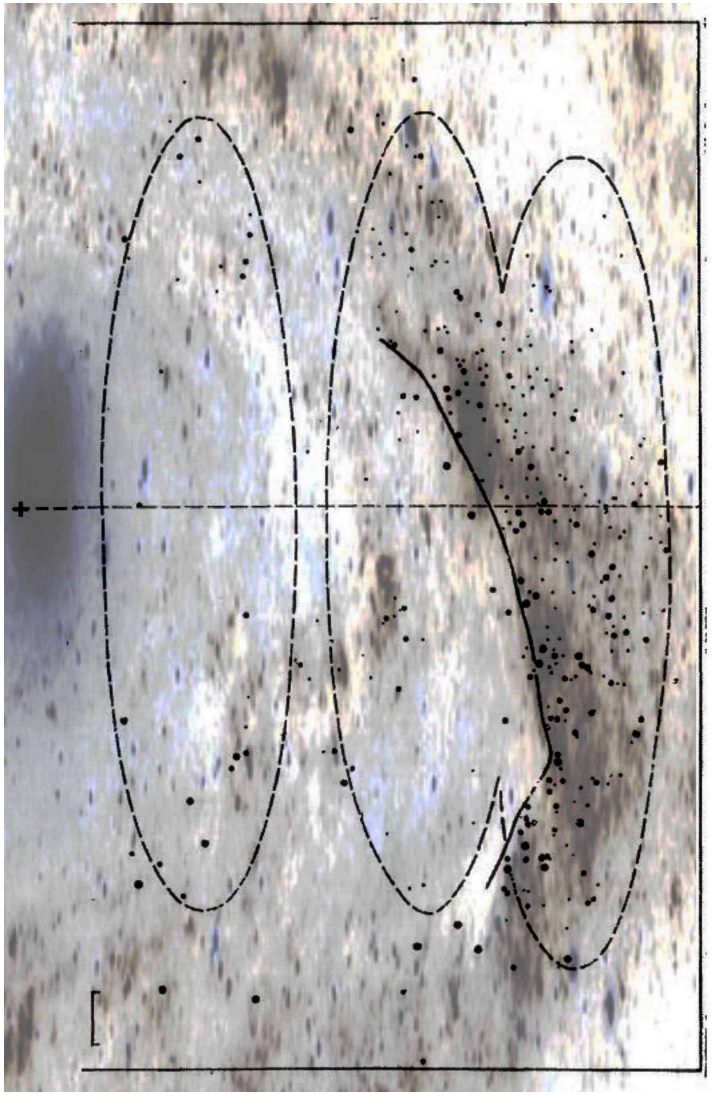
blue - young stars, red – warm dust, black contours - HII regions



NW arm – HII regions **inside** star complexes **inside** gas/dust lane

SW arm - HII regions **between** gas/dust and stellar arm,
age gradient across the arm – SHOCK WAVE signatures -
and NO discrete complexes!

Cepheid period (age) gradient across the SW arm



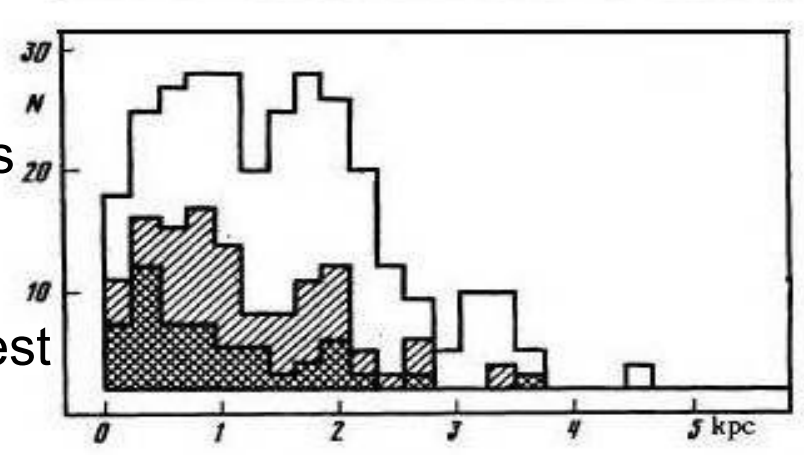
Baade's Cepheids in M31 plane
Overlaid with GALEX image

i = 12 deg

All cepheids

Young

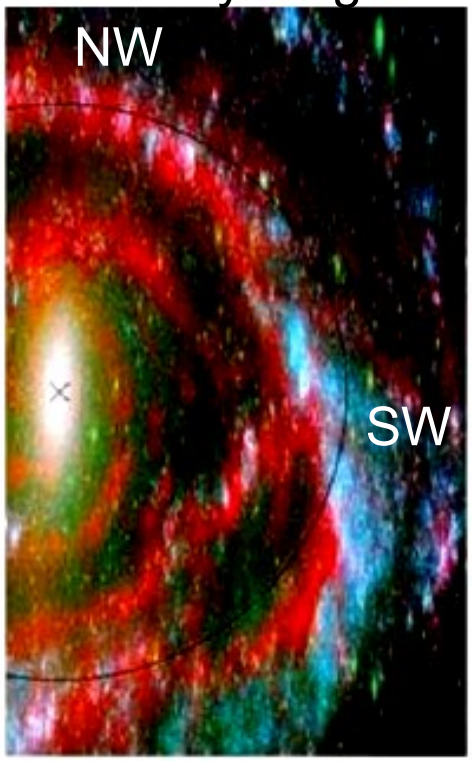
The youngest



Cepheid distribution in distance from the SW arm edge.

The upper histogram shows all the periods, the median histogram shows periods longer than 10 d and the bottom histogram shows periods longer than 15 d. According the period–age relation, the longer the period, the younger a Cepheid (Efremov 1978, 2003). Note that these ages do not suffer from light extinction.

Dust and young stars



a

HI gas and HII regions

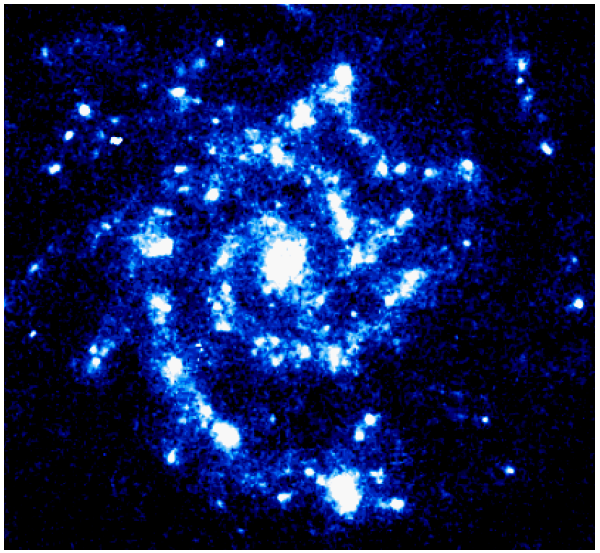
b

Suggestion – the different appearance of NW and SW arms explained by the spiral shock wave in the latter arm, connected with its large (~25 deg) pitch-angle, whereas it is about 0 deg in the NW arm. The classical density wave theory of spiral arms affirms – the gas density increase is function of the velocity difference (of galaxy and spiral pattern) component, orthogonal to the local arm direction. **The larger arm's pitch-angle, the stronger shock wave.**

No complexes in the SW arm because a shock wave destroy the regular magnetic field? Is it a rule?

Optical image

UV (*UIT* image)

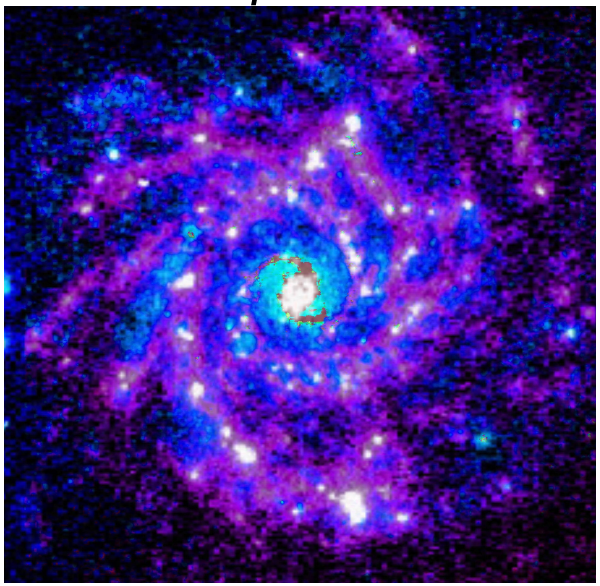


M74 = NGC 628

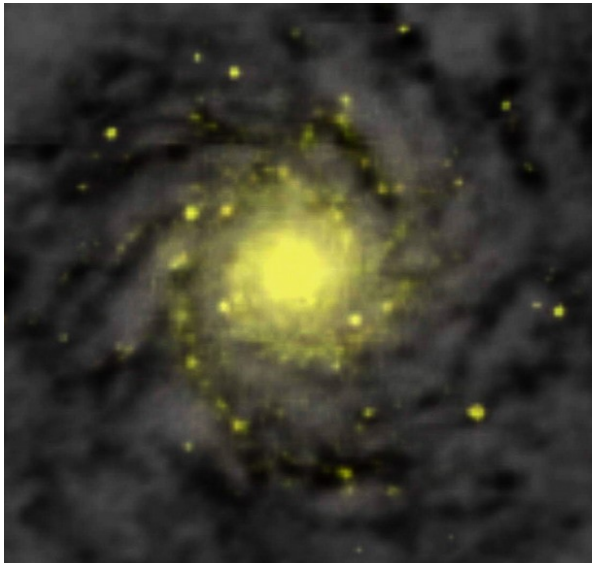
Seems to confirm above conclusions:

Warm dust lane (*Spitzer)* is **not** upstream the arm, but connects complexes (*UIT*), like it is the case in M31 NW arm

UIT + *Spitzer*



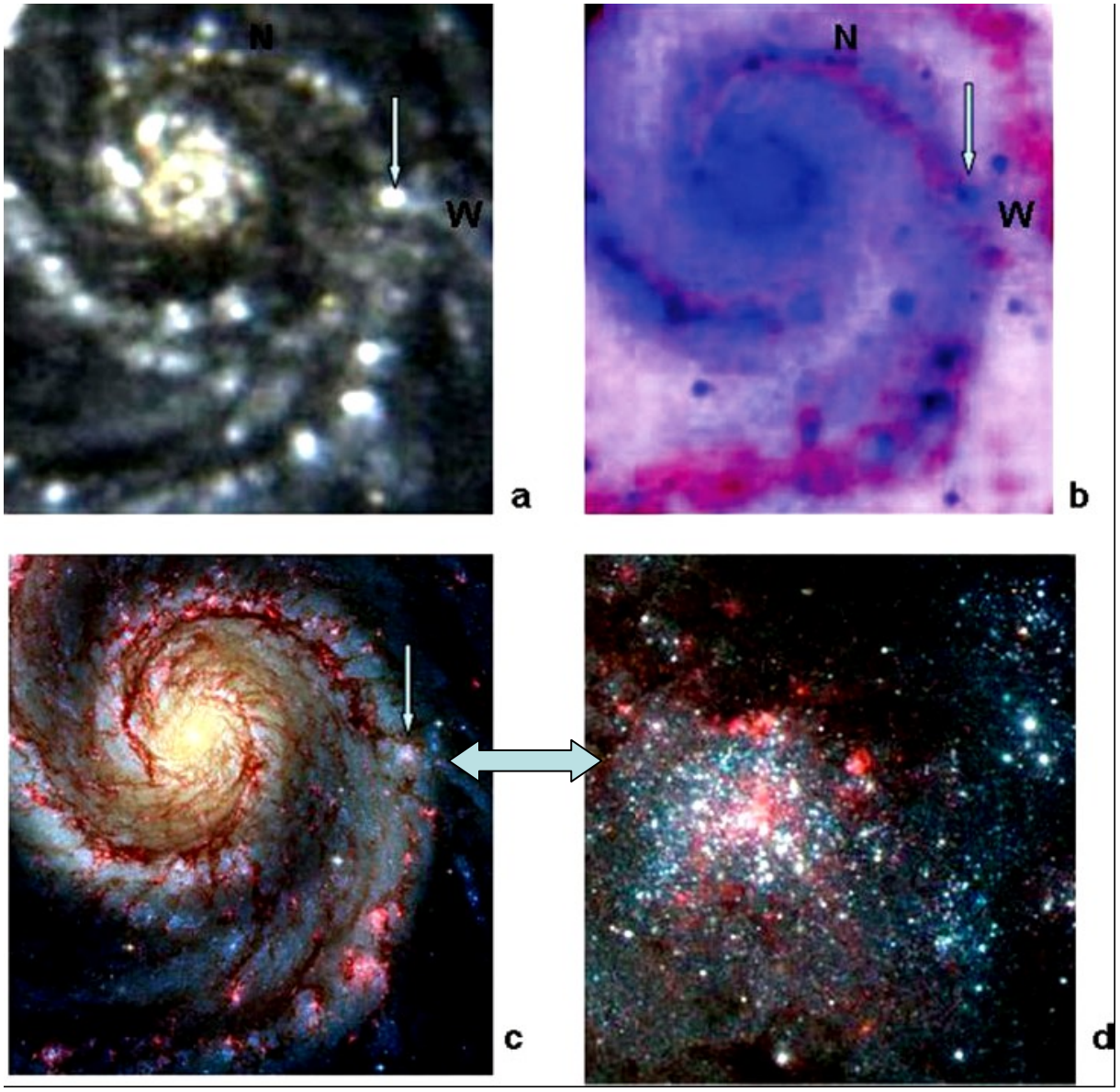
DSS (yellow) + HI



M51 = NGC 5194

GALEX

HI + DSS



HST ACS

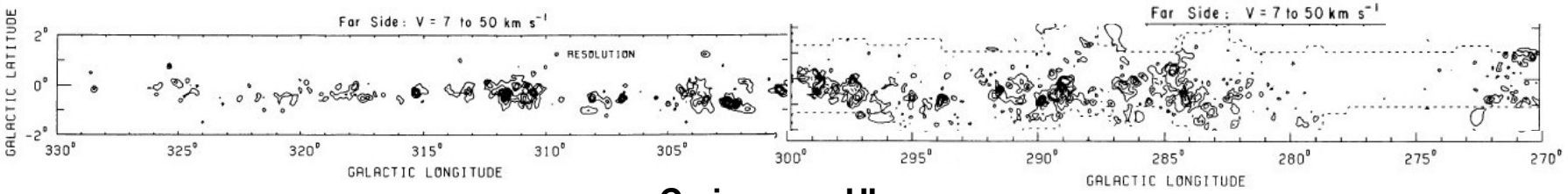
M100 = NGC 4321

Does not contradict too

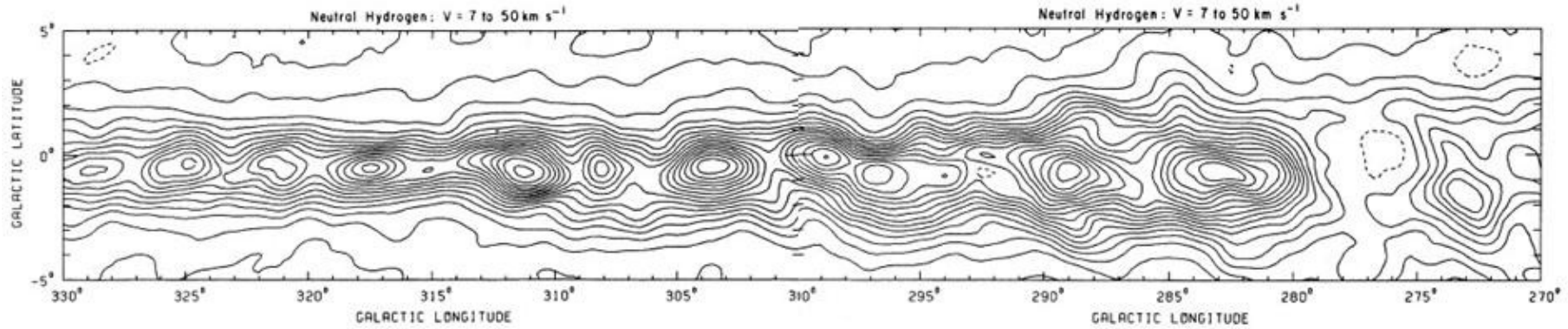
NGC 6946 – regular spiral magnetic field is **between** optical arms. There are about no discrete star complexes in the latter. The unique blue round complex hosting a young supermassive cluster is at a spur edge.

Discrete superclouds in Car and Cyg arms are seen directly in sky

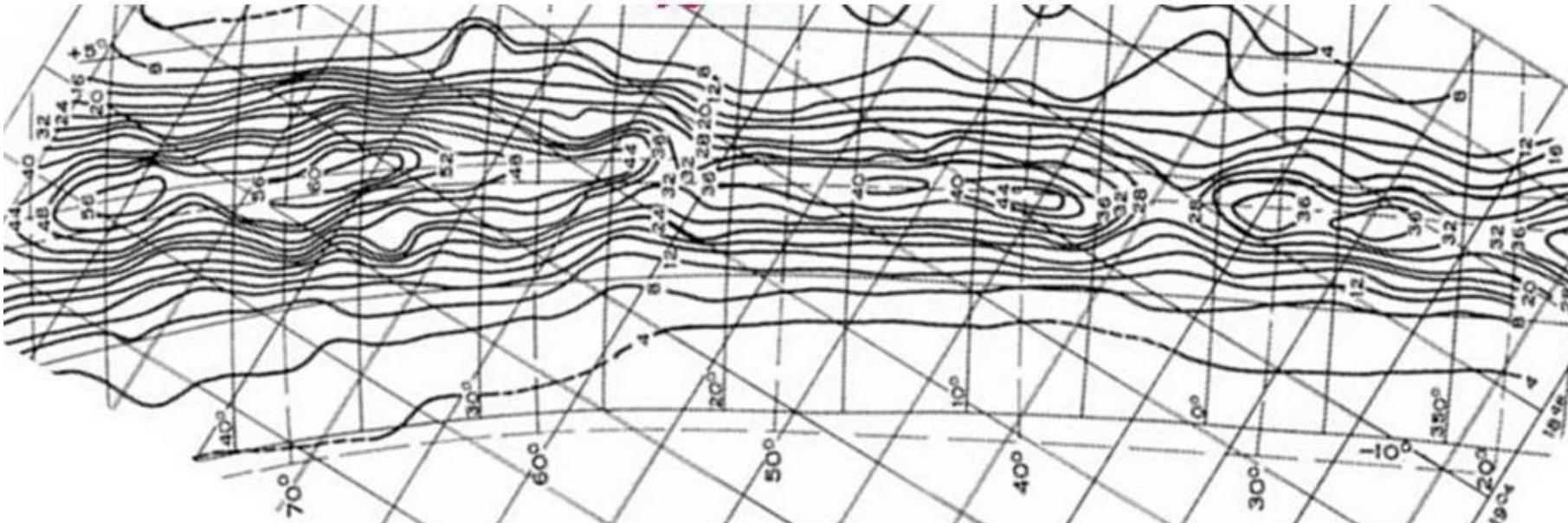
Carina arm, CO *Grabelsky et al., 1987*



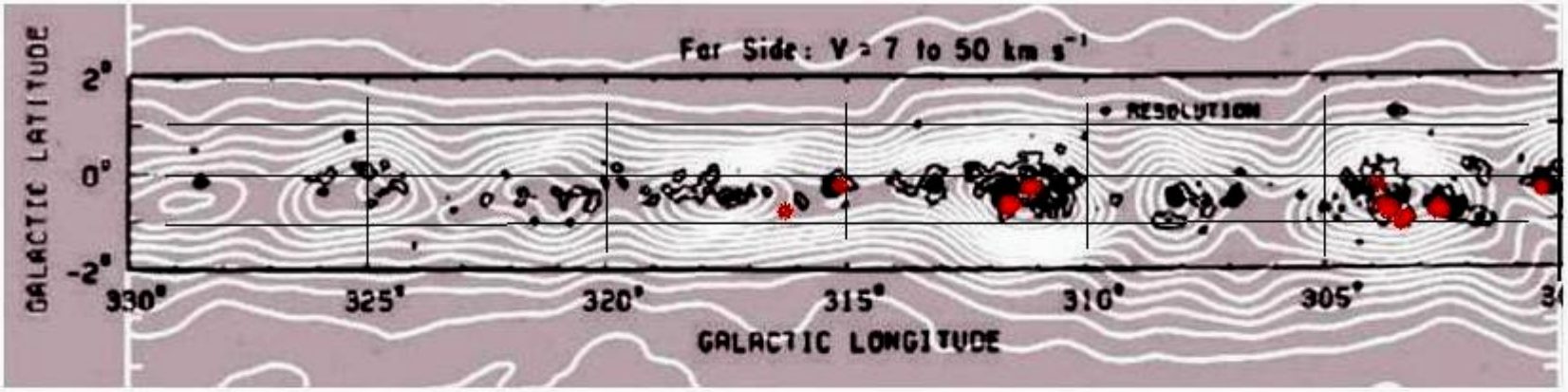
Carina arm, HI



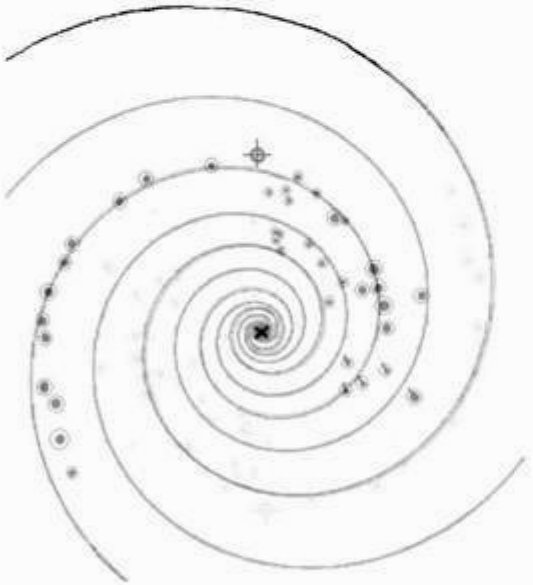
Cygnus (Outer) arm, HI *McGee &Milton, 1966*

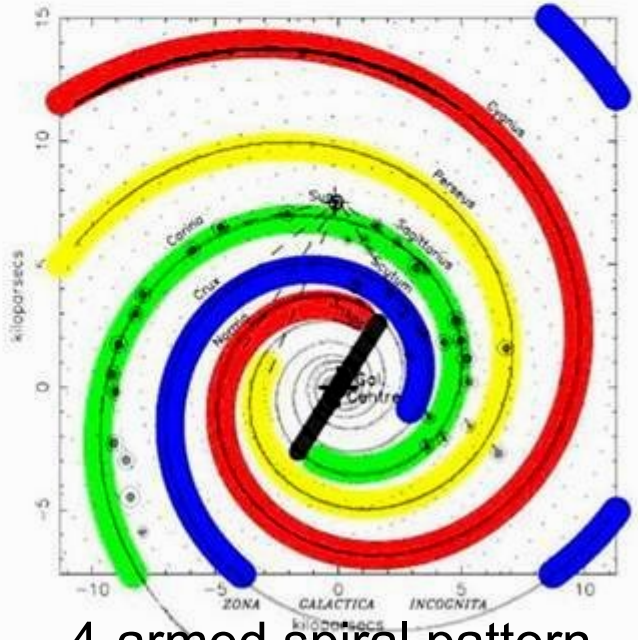


Carina arm



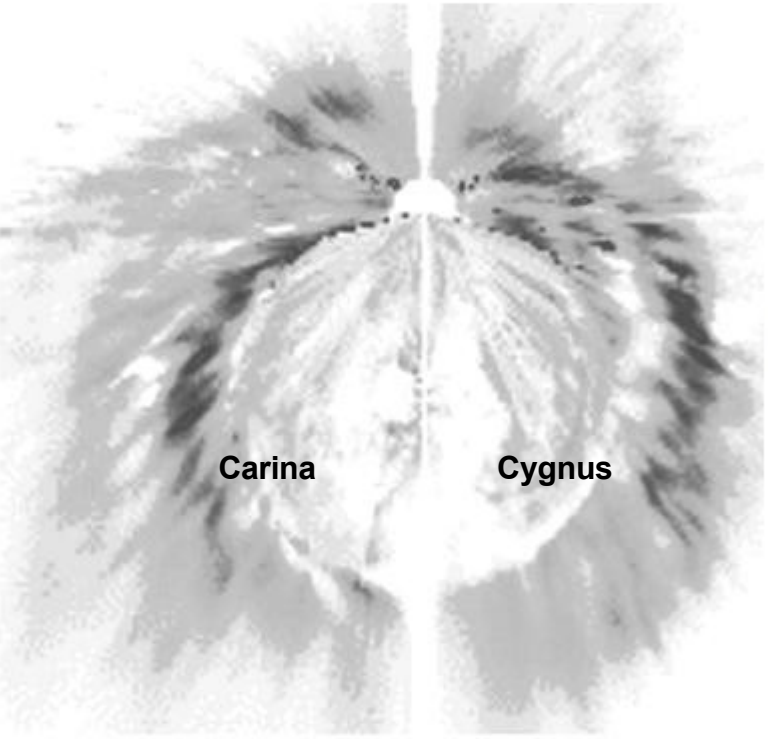
Chain of HI superclouds (white) and GMC inside them (black)



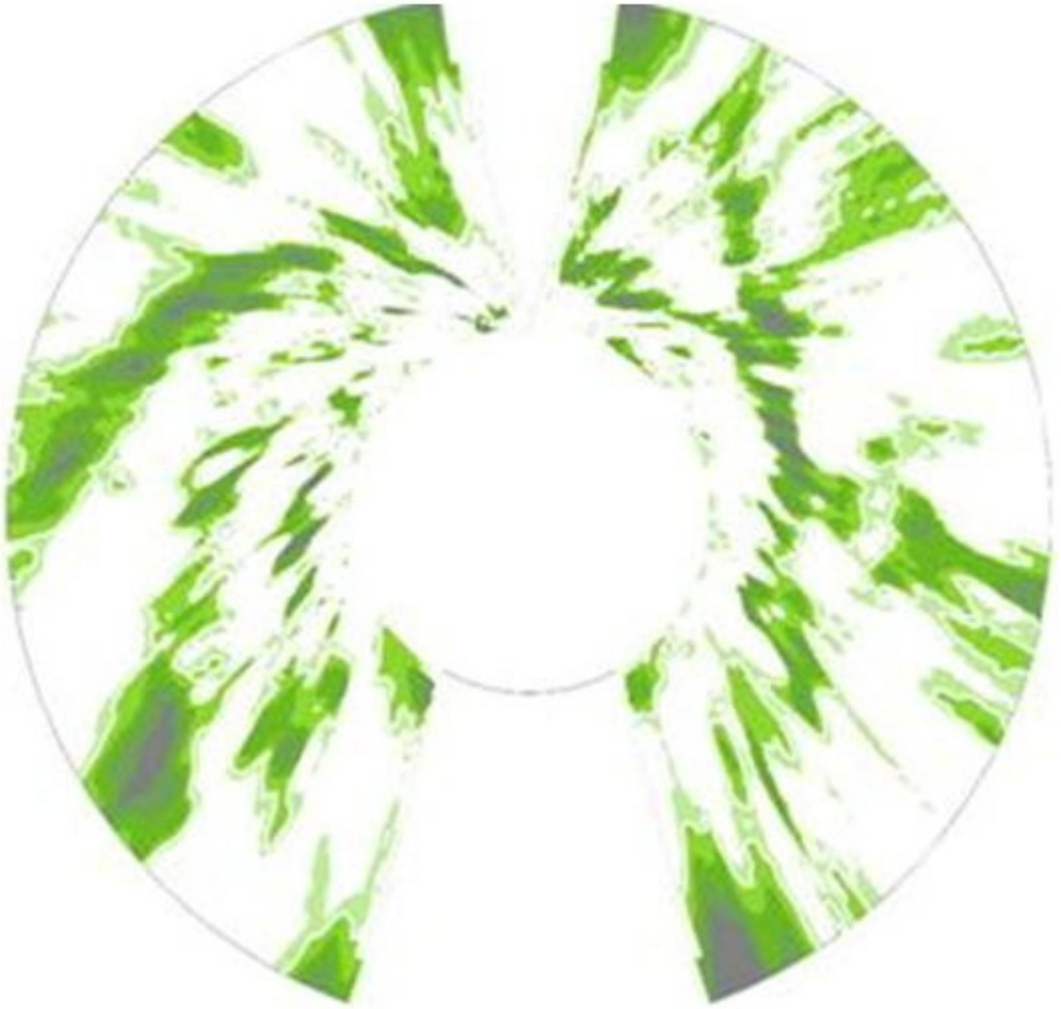


HI superclouds along Car-Sgr arm. 4-armed spiral pattern obtained by this arm rotation coincides with Vallee (1995, 2008) scheme

Spiral arms of the Galaxy from HI data



Nakanishi & Sofue (2003)



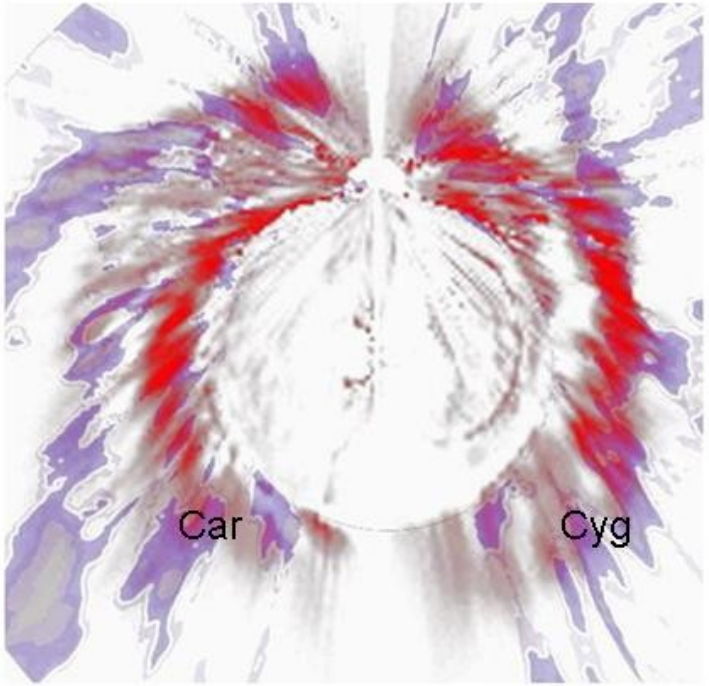
Levine et al. (2006)

Fragmentation in HI superclouds is seen, noted first by McGee & Milton (1966).

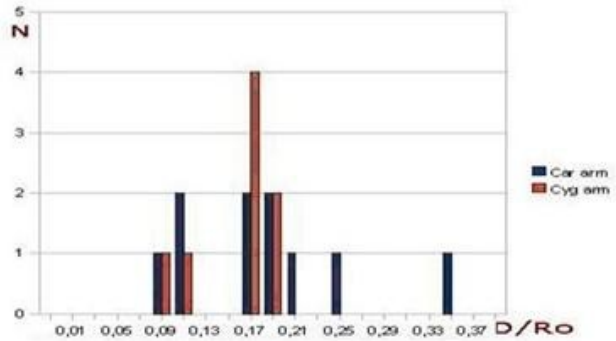
Overlay of HI MW patterns

M31
HI(brown) and CO (green) patterns

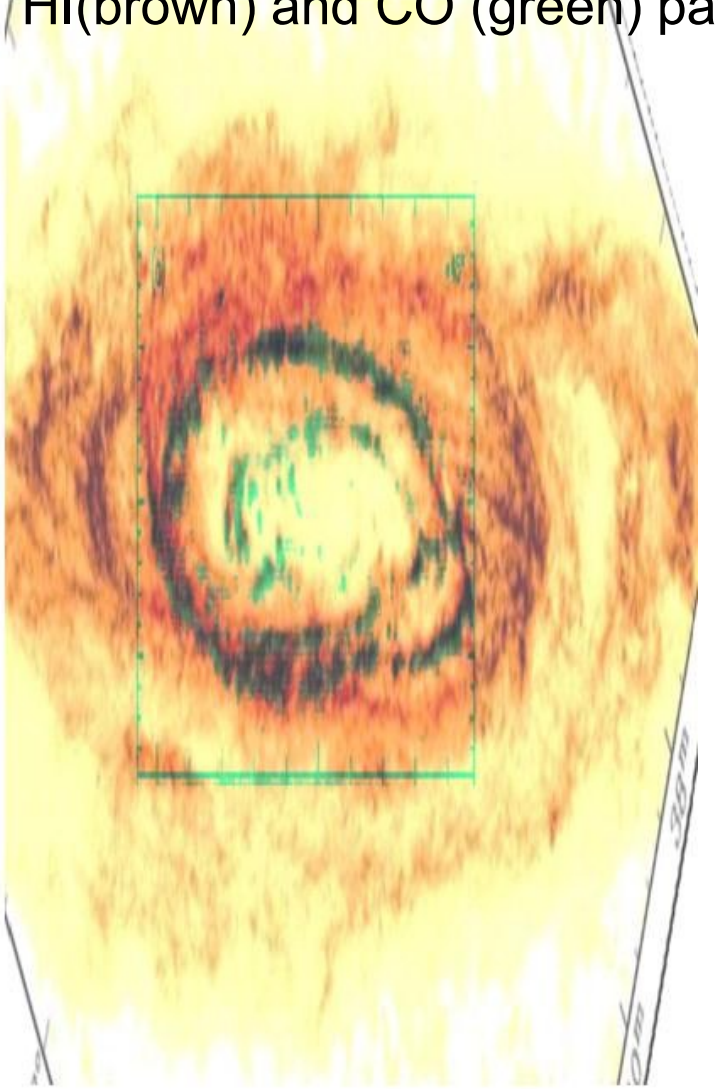
a



b



c



Spacing of HI superclouds along strong HI Car and Cyg arms
displays two prefered values – a guess for the regular field along the arms

Conclusions

Anticorrelation seemingly exists between spiral shock signatures in a spiral arm and presence of regular chain of star complexes along the arm. It is displayed best in different arms of M 31 (NGC 224) and M 74 (NGC 628). Probable explanation is formation of chains of star complexes in result of the magneto-gravitational instability, developing in presence of the *regular* magnetic field along an arm. A strong spiral shock leads to active star formation and may prevent arising of such a field or destroy the latter. The regular bi-modal spacing of HI superclouds is found in Carina and Cygnus (Outer) arms of our Galaxy, which may be an indirect evidence for the occurence of regular magnetic field along these arms.