

**Observing
Ram Pressure Stripping
and
Morphological Transformation
in the Coma Cluster**

Michael Gregg

University of California, Davis

Michael West

Lowell Observatory

Background: Ram Pressure Stripping

- The ISM in a disk galaxy falling through a cluster experiences a ram pressure against the hot intracluster gas of magnitude,

$$P_r \approx \rho_e v^2$$

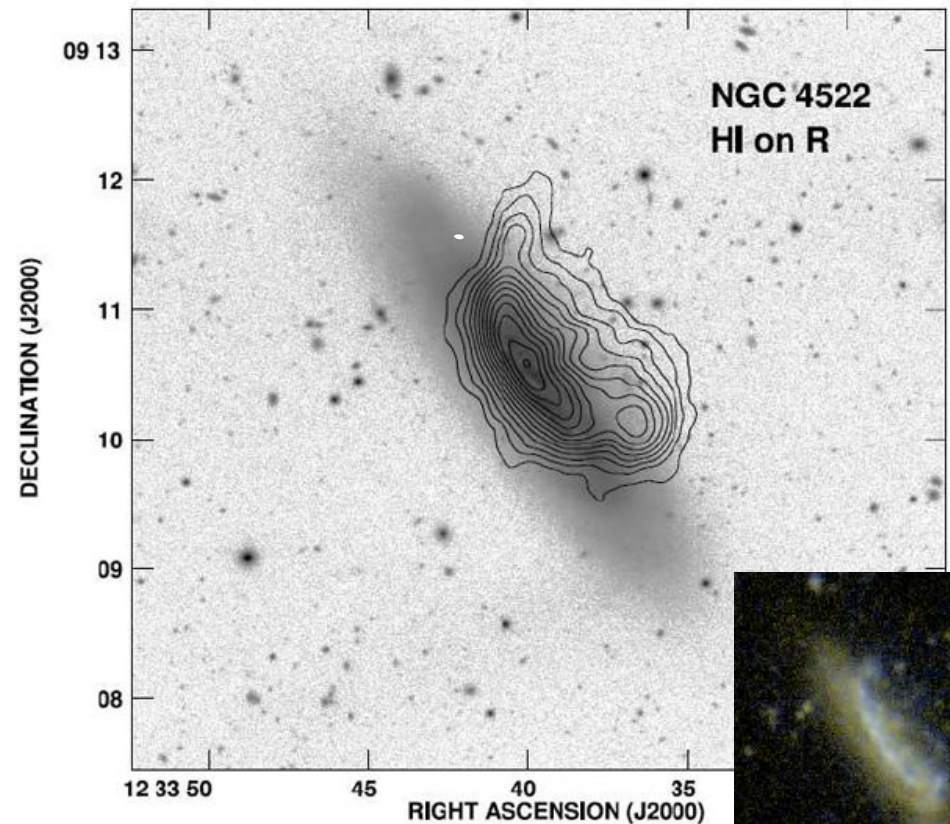
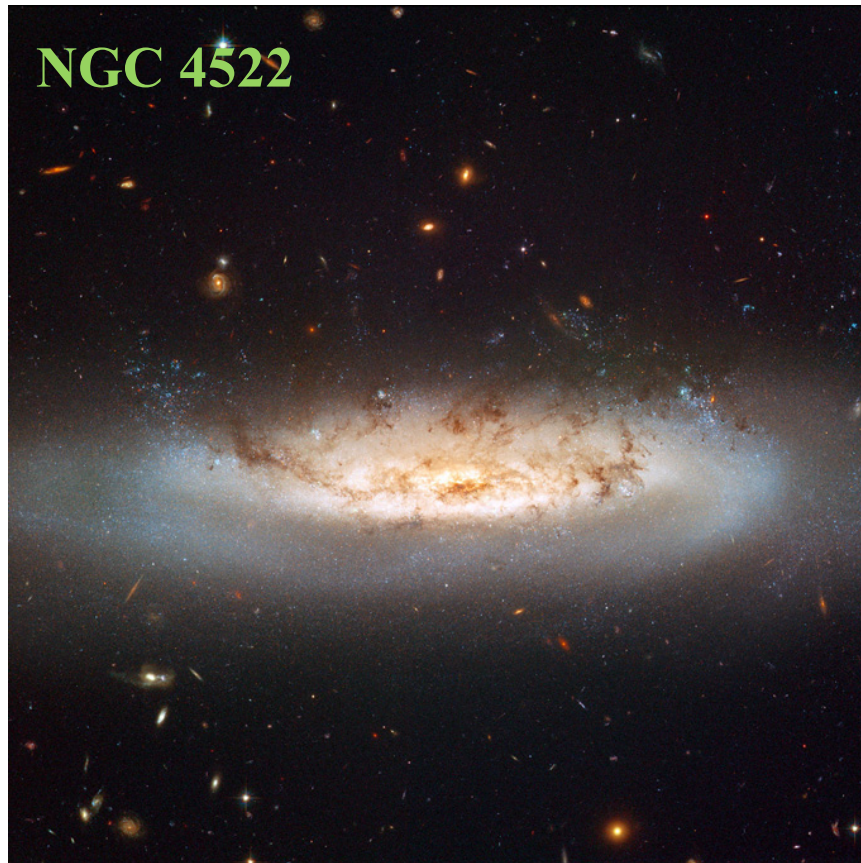
where ρ_e is the ICM density and v is the speed of the galaxy (Gunn & Gott 1972).

- If this pressure exceeds the restoring force of a disk galaxy's ISM, gas is removed.
- For typical cluster conditions with galaxy speeds of 1000 to 2000 km/s and densities of a few particles per cm^3 , the gas from normal spirals is removed in a single passage through the cluster core, a single free-fall time of several times 10^8 to 10^9 yrs.
- Effective means of transforming large spirals into gas-free S0s, thereby at least partially explaining the density-morphology relation (Dressler 1980).
- While the process is perhaps more efficient in today's clusters, at early times there were many more spirals when rich clusters were first coming together at early epochs.



Artist's conception of gas removal from a large spiral (ICRAR/STScI/ESA).

Ram Pressure Stripping Examples in Virgo



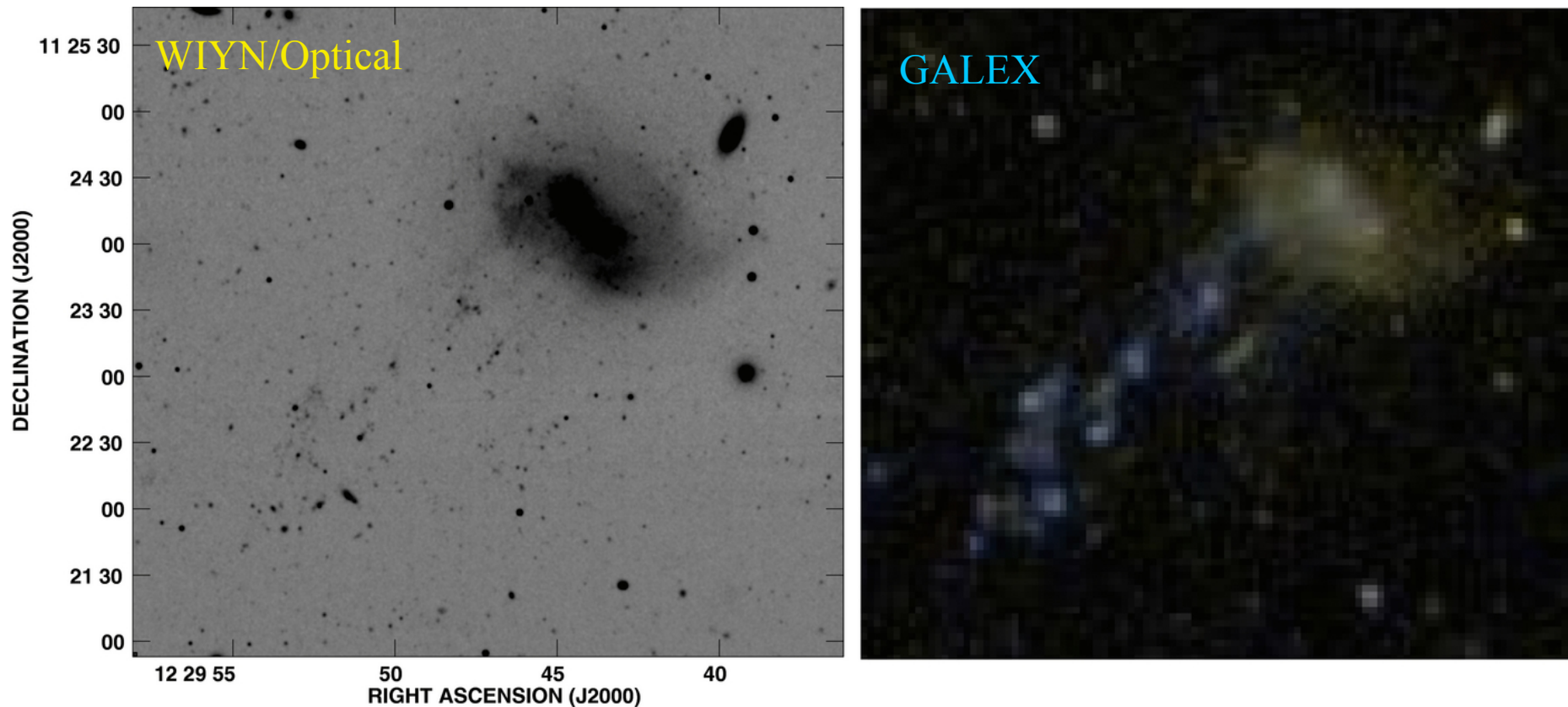
- With **HST** resolution, it is possible to identify examples of ram pressure stripping -- such as **NGC 4522** in Virgo (Abramson & Kenney 2014).
- **VLA** HI images also reveal an asymmetric gas distribution coincident with the remaining dust, and **GALEX** reveals star formation following the trend.

Ram Pressure Stripping Examples in Virgo



Another Virgo example of ram pressure stripping in **NGC 4402** as it falls towards the cluster core (toward bottom left). Dust (brown) trails behind the galaxy, while the leading edge is dust-free (blue-white) (Kenney et al. 2010).

Ram Pressure Stripping Examples in Virgo



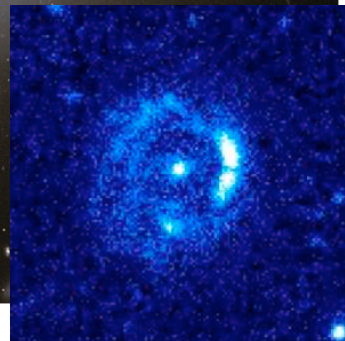
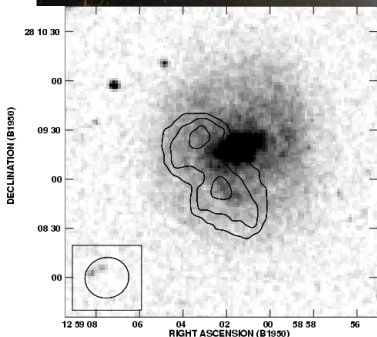
- While the stripped gas is usually immediately heated and joins the hot ICM, sometimes new star formation can occur in the stripped gas, as shown in this example of the dwarf galaxy IC3418 (Kenney et al. 2014), creating the distinctive appearance of ‘**jellyfish**’ galaxies.

Ram Pressure Stripping in Coma

ACS/WFC images of NGC4921 (GO10842) reveal an unusual disk morphology.



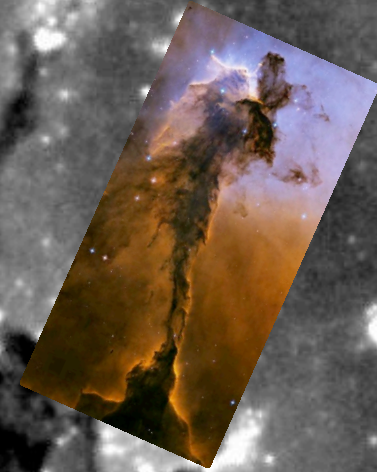
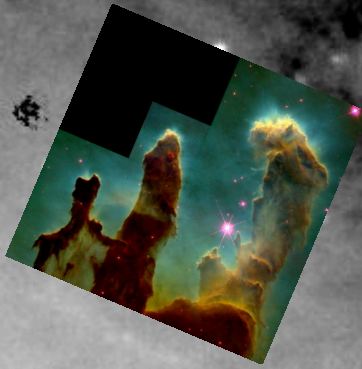
- Very smooth stellar distribution
- Anemic spiral arm structure
- Transition morphology of S0/a
- VLA and GALEX show global asymmetries indicating stripping of gas and induced star formation (Kenney et al. 2015)



- Plus, curious-looking dusty features...

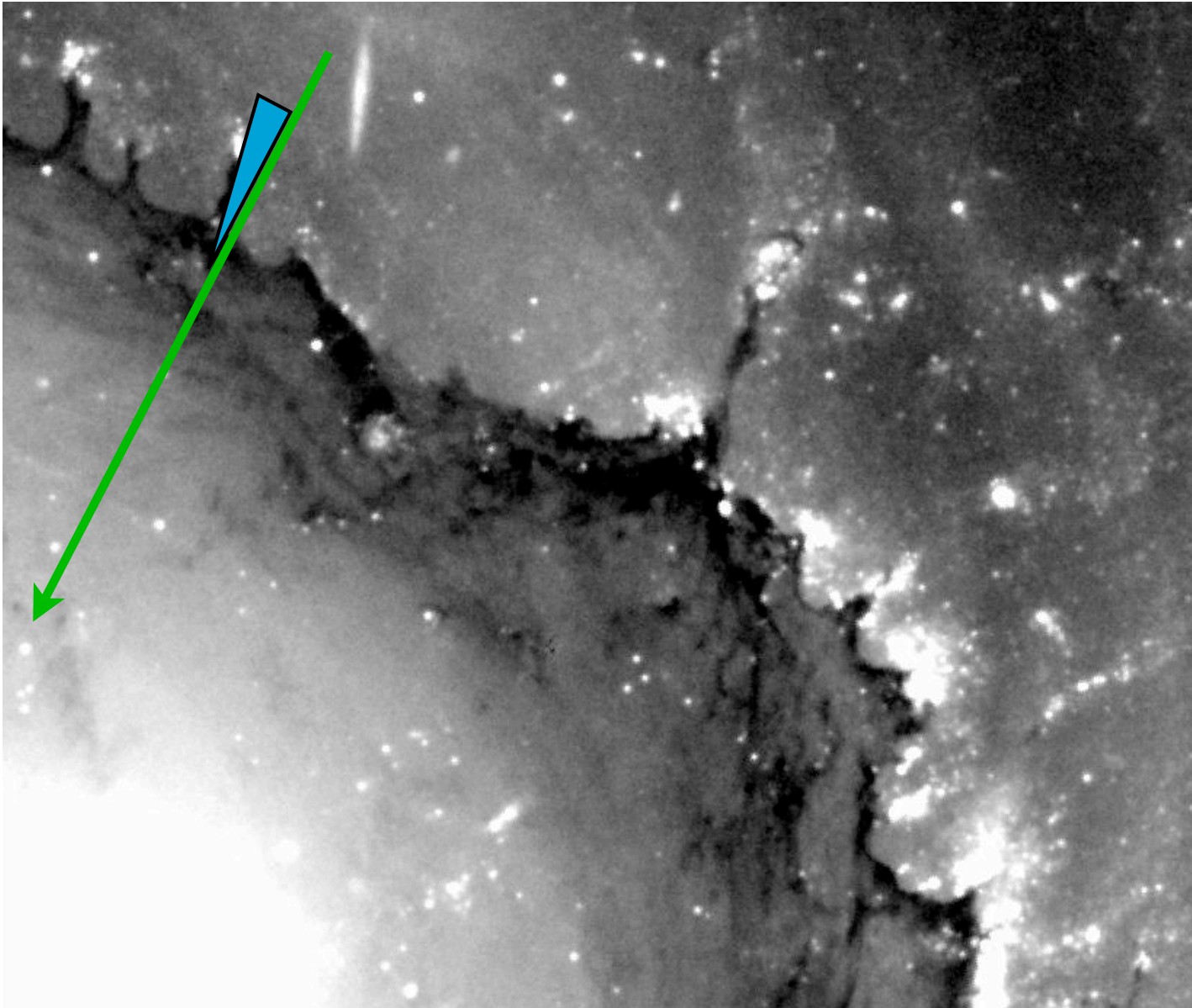
Ram Pressure Stripping in Coma





- **Long dusty pillars with star formation at the terminus.**
- **Created by interaction of ISM and ICM**
- **Factor of ~800 in size larger than the Eagle Nebula features, ~ 0.5 to 2.5 kpc.**

Pillars are relatively transient features.



Geometry: length of pillars results from motion through ICM; tilt results from rotation of disk:
 $\arctan(300/1700) \sim 10^\circ$

Takes 6×10^5 yrs to create a 1 kpc feature; this is also consistent with tilt.

Ages of features also can come from associated star clusters.

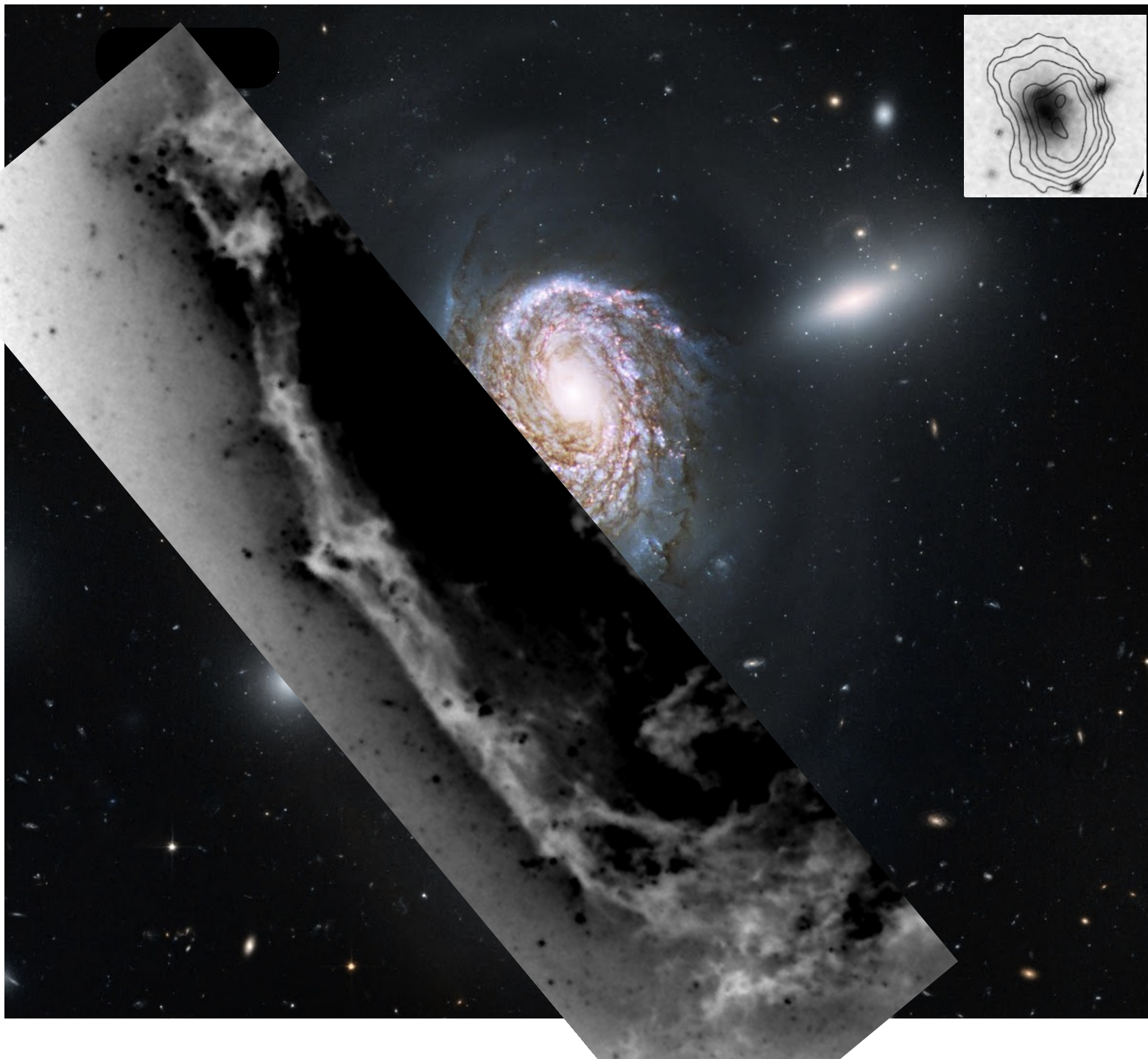
- ‘Strings-of-pearls’ from older epochs of star formation \Rightarrow transient on $10^6 - 10^7$ yr timescales, much less than a disk rotation or free fall.
- Rivulets of dust behind the largest pillars.

NGC4911 appears at first to be a more normal spiral with intense star formation.



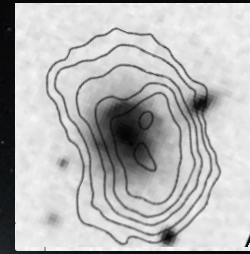
- Lopsided HI;
LSB extended
disk

NGC4911 appears at first to be a more normal spiral with intense star formation.



- Lopsided HI; LSB extended disk
- Long ionization front, clear on one side, dusty on the other
- Rivulets of dust behind front; beginnings of pillars; other crazy dust patterns

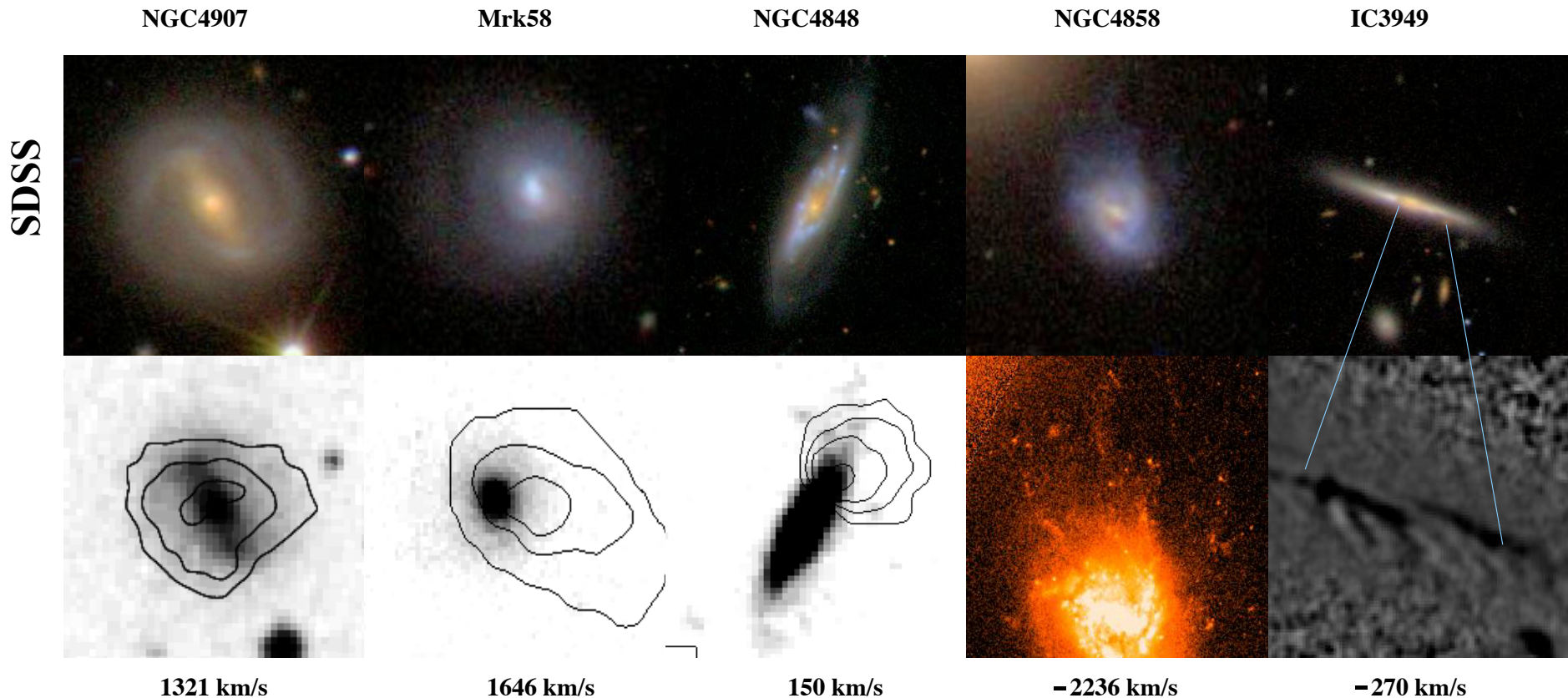
at first to be a more normal spiral with intense star formation.



- Lopsided HI; LSB extended disk
- Long ionization front, clear on one side, dusty on the other
- Rivulets of dust behind front; beginnings of pillars; other crazy dust patterns
- Earlier stage of stripping than NGC4921

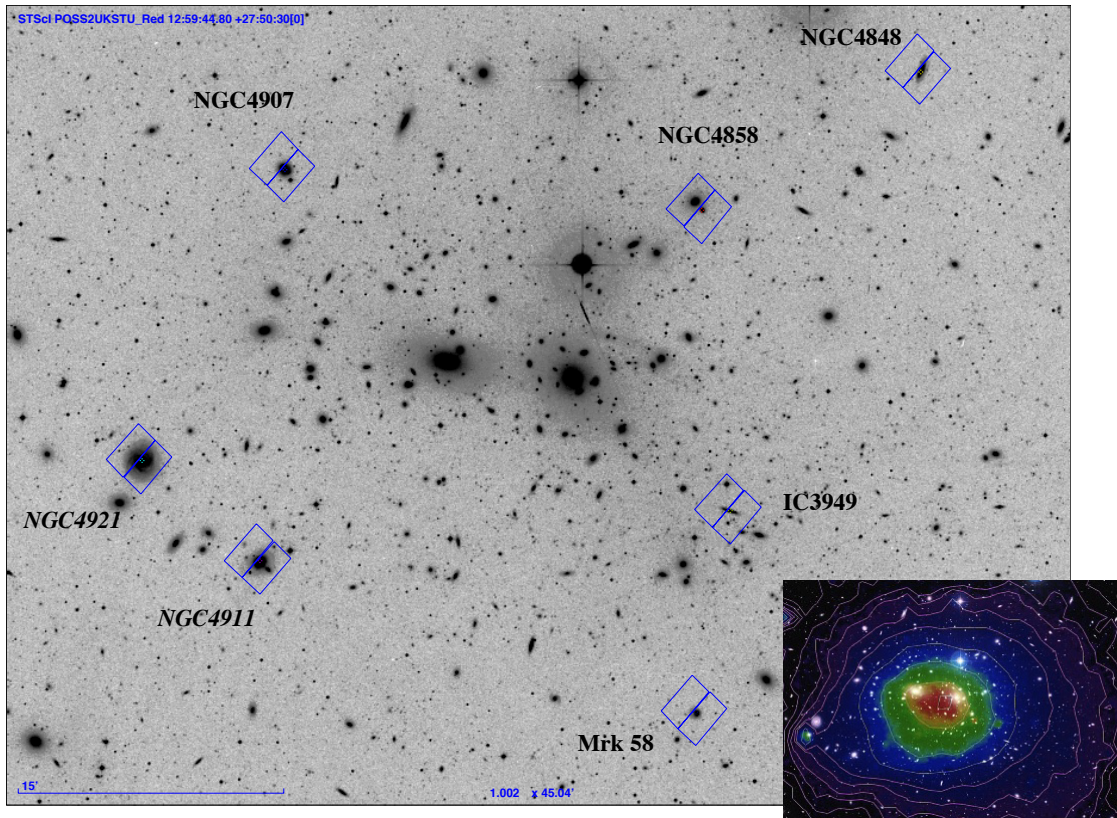
Ram Pressure Stripping in Coma

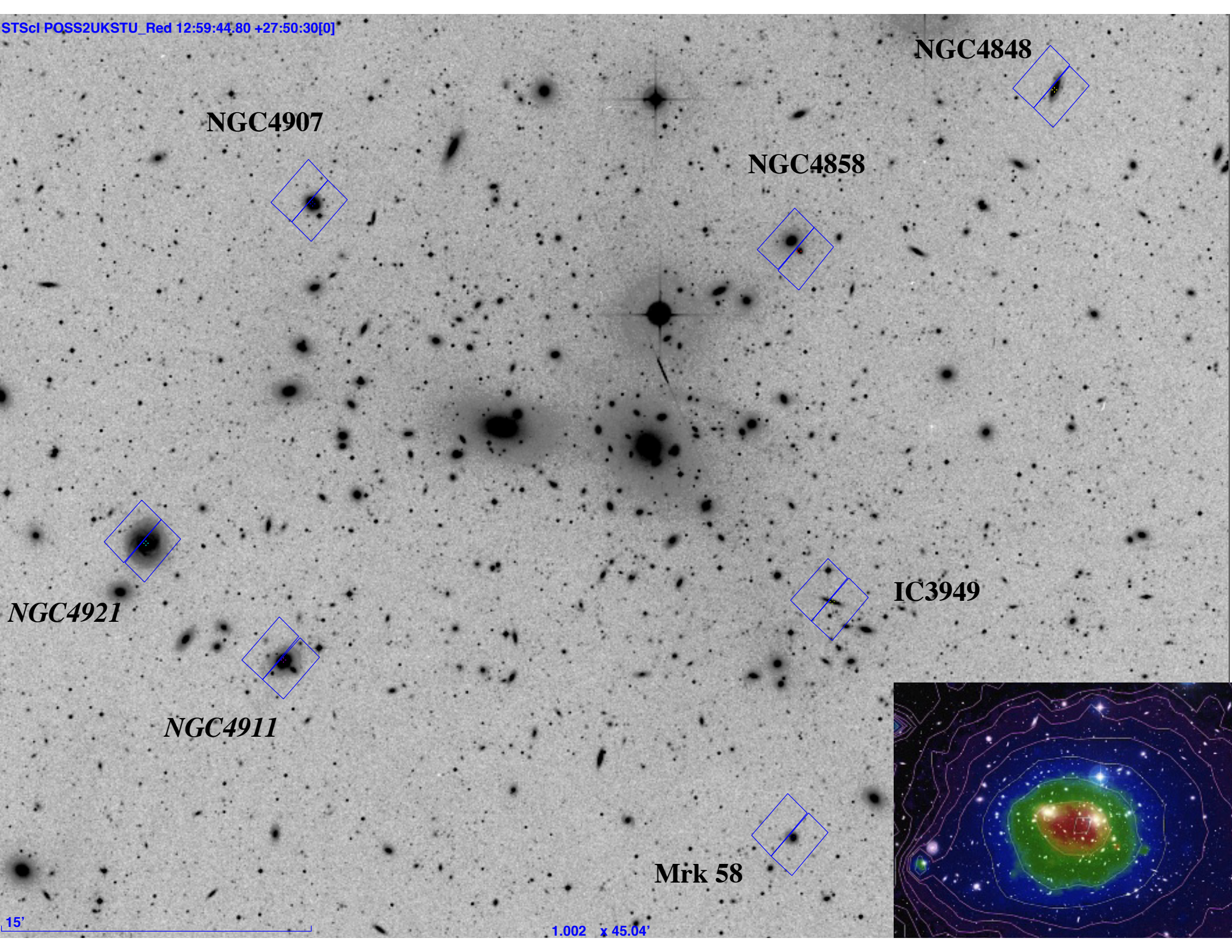
- With NGC4911 and NGC4921 as motivation, we chose five additional spirals around Coma to image with WFC3/UVIS.
- Targets identified using VLA HI data (Bravo et al. Coma survey) and inspection of GALEX and short exposure WFPC2 data.



Ram Pressure Stripping in Coma

- NGC4848, NGC4858, IC3949, Mrk58, and NGC4907
- Used Xtra-wide filters F350LP and F600LP to go deep; sensitive to UV and red light.
- Distributed in a ring around the core, on the outskirts of the bright X-ray emission.





NGC4907

NGC4848

NGC4858

IC3949

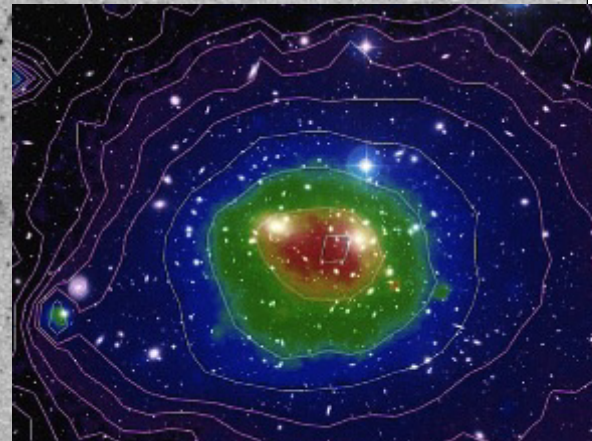
NGC4921

NGC4911

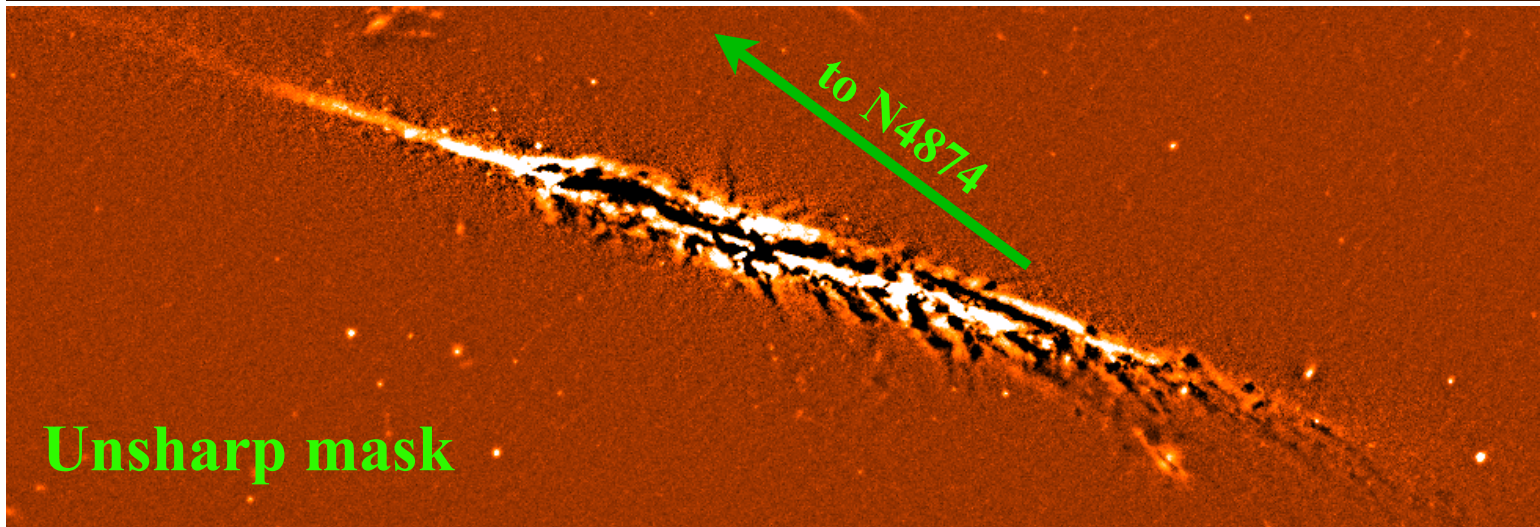
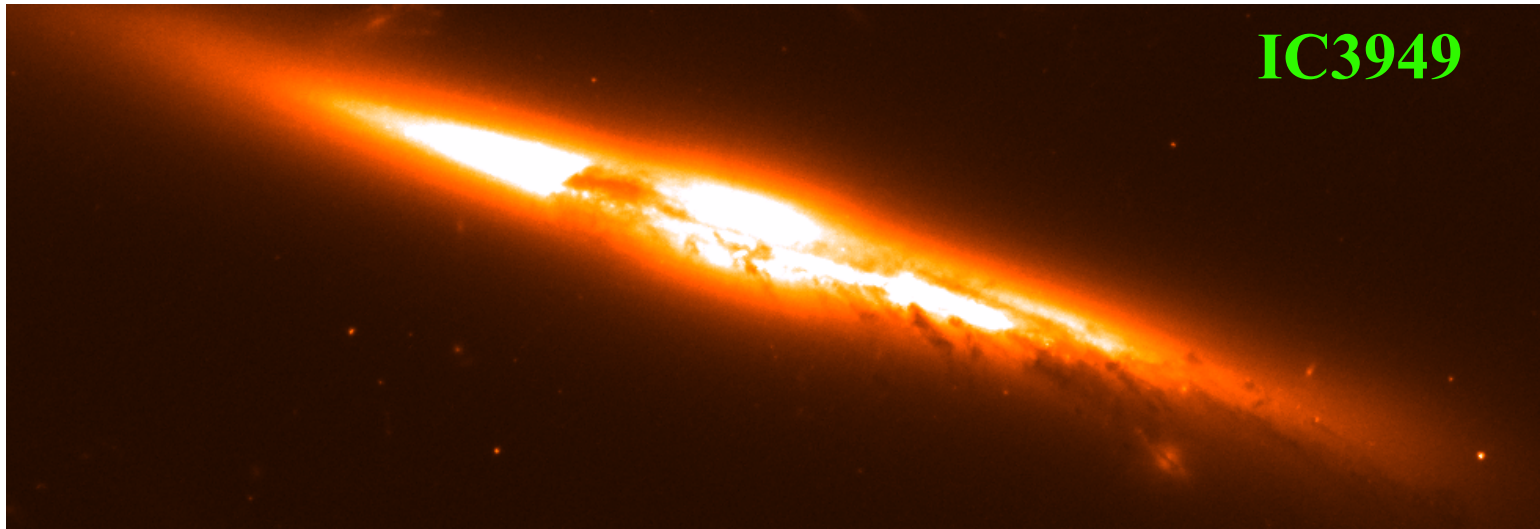
Mrk 58

15'

1.002 x 45.04'



F350LP image of IC3949



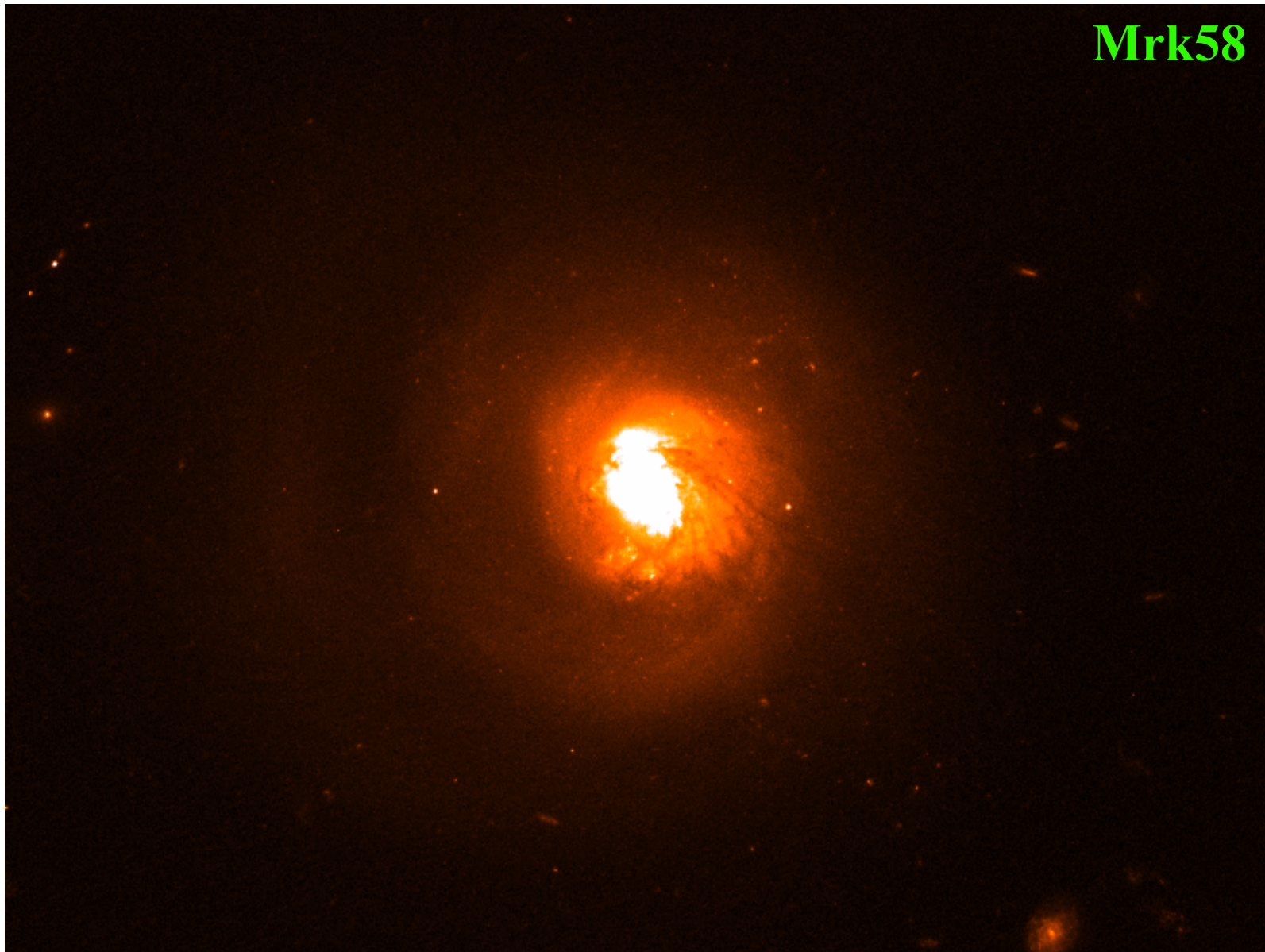
Gas and dust being rapidly stripped

Leading edge has been cleaned already - implies surprisingly short timescale for removal of gas, and/or non-uniform density distribution of ICM.

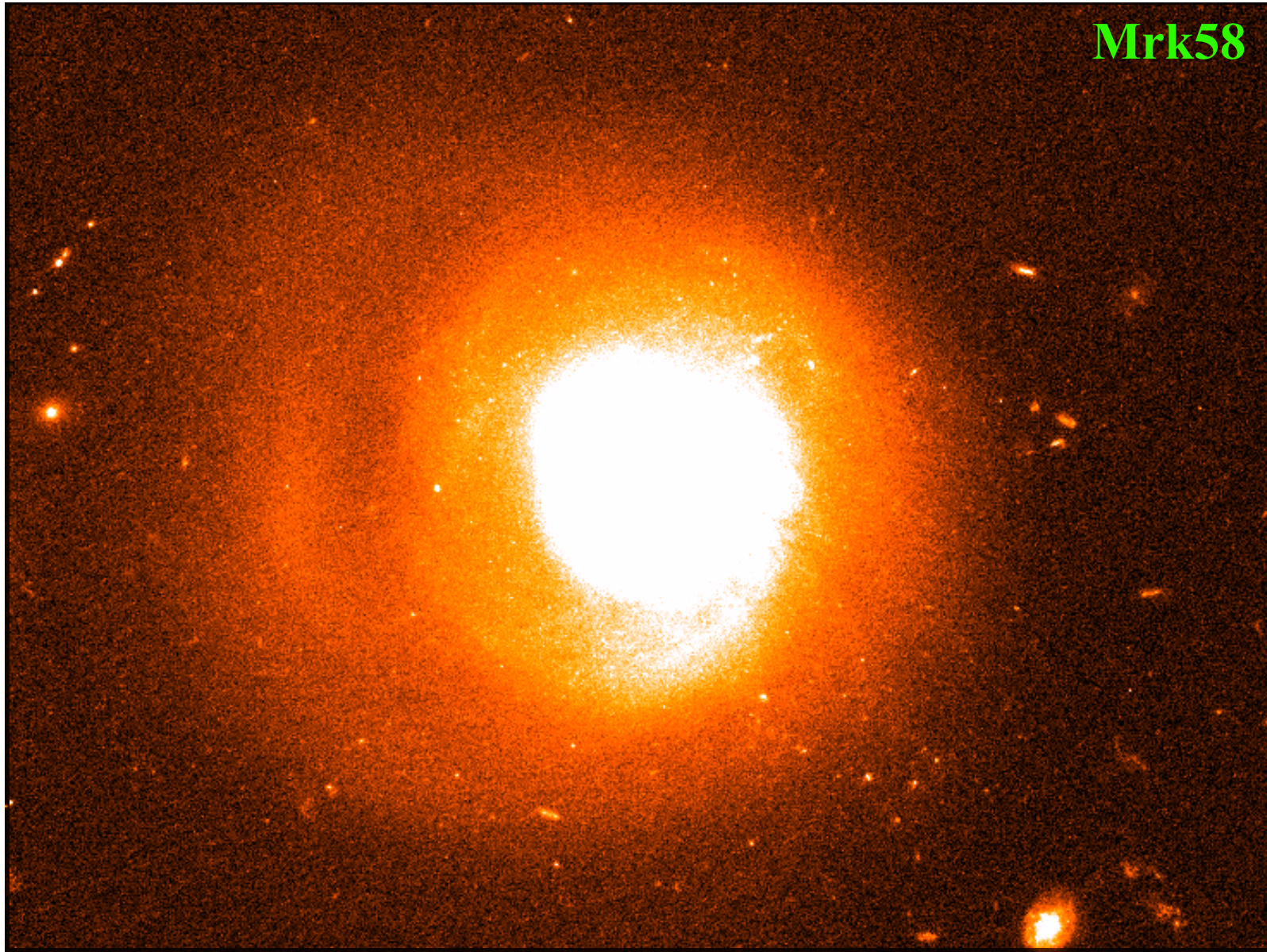
Stripping features often indicate general direction of cluster center.

Low apparent relative velocity \Rightarrow motion in plane of sky.

F350LP image of Mrk58

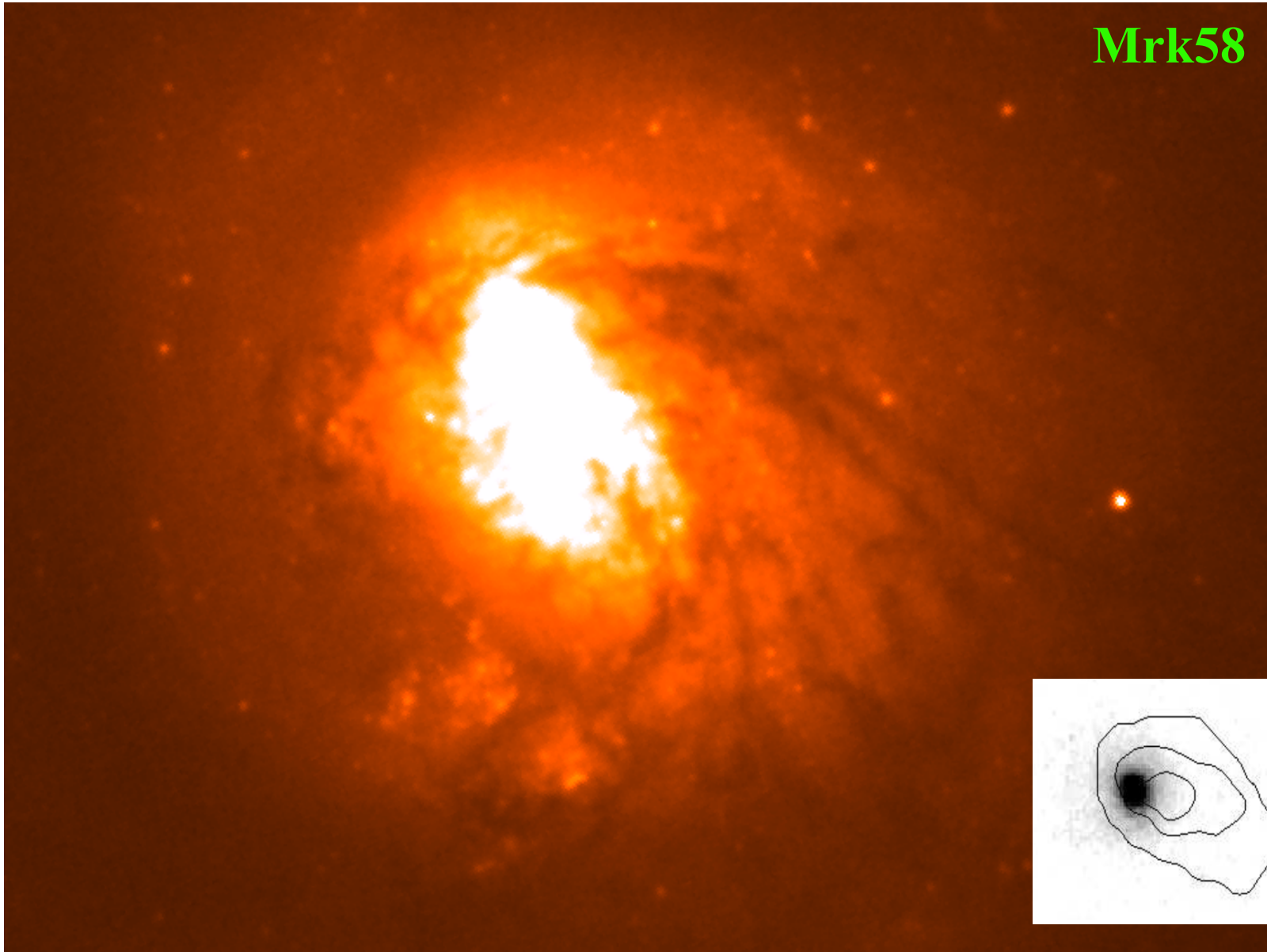


F350LP image of Mrk58



Smooth lsb
disk (also in
SDSS image)

F350LP image of Mrk58



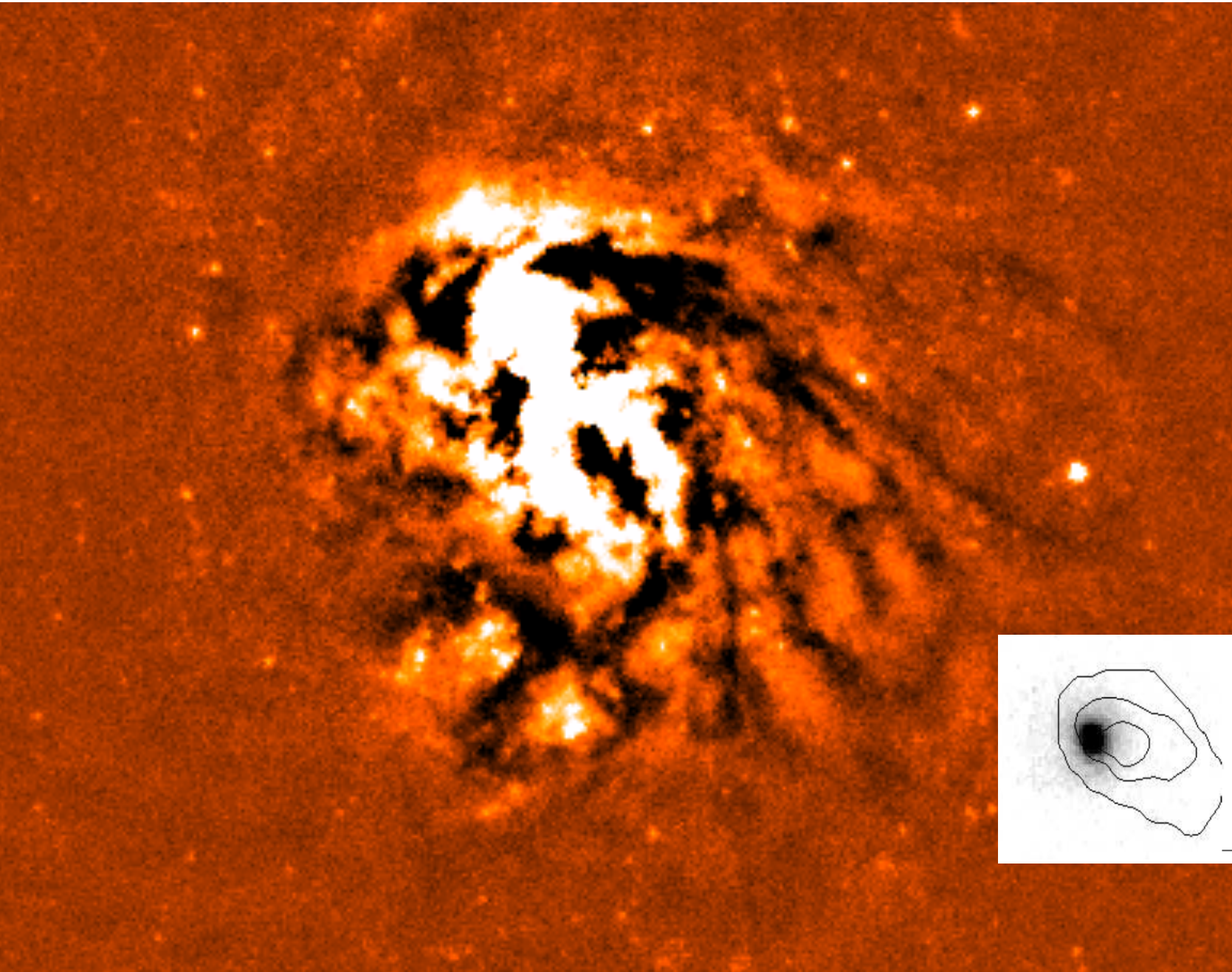
Mrk58

Smooth lsb
disk (also in
SDSS image)

Dust lanes all
on one side,
and radial or
tangential
rather than
spiral

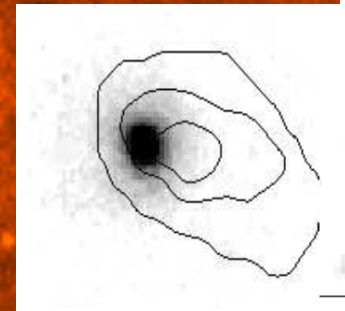
HI all on
one side

F350LP image of Mrk58



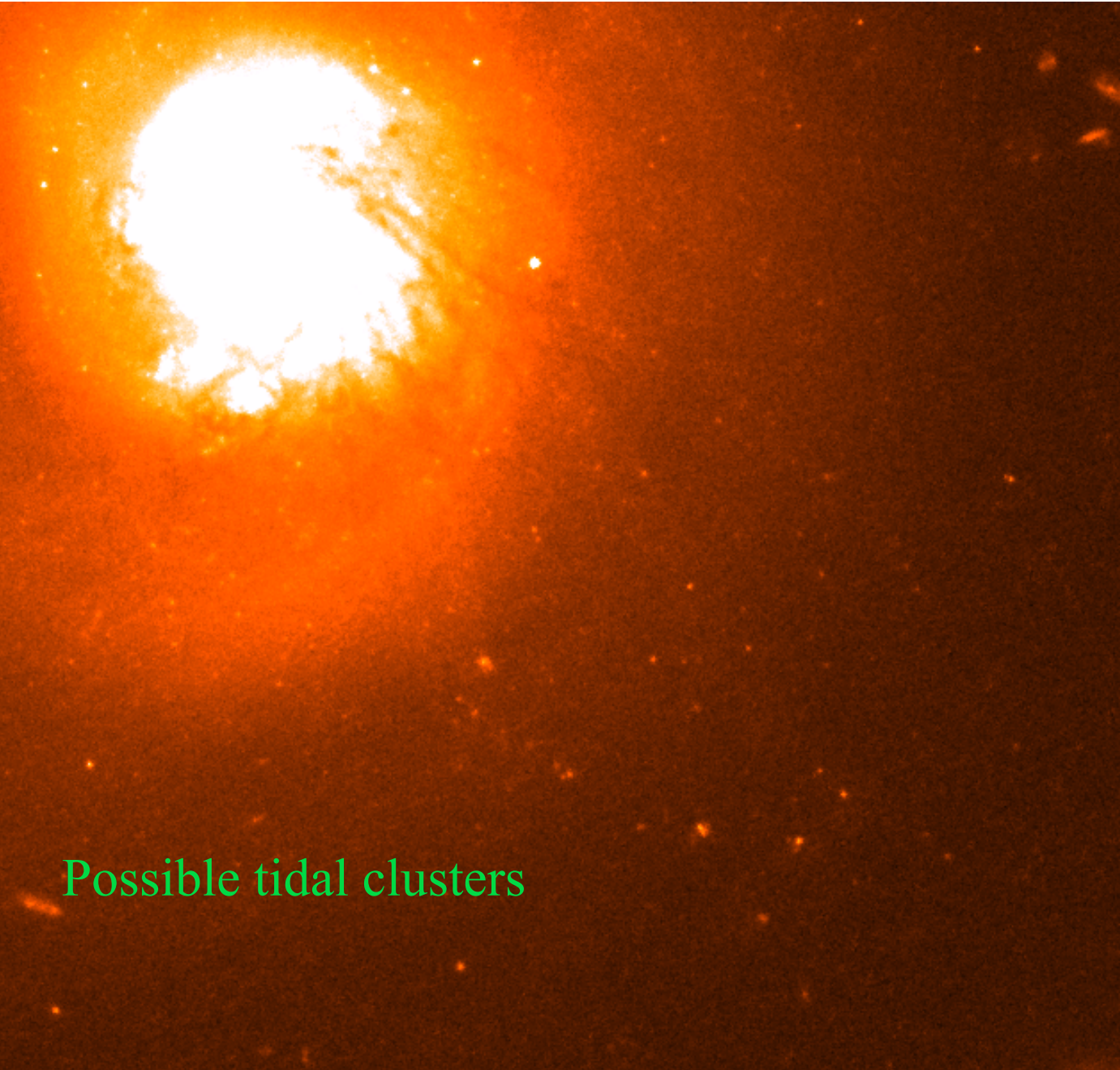
Smooth lsb
disk (also in
SDSS image)

Dust lanes all
on one side,
and radial or
tangential
rather than
spiral

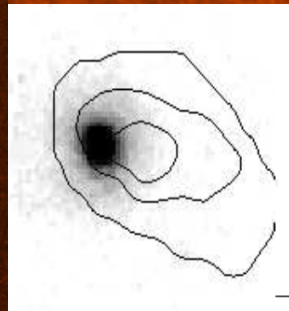
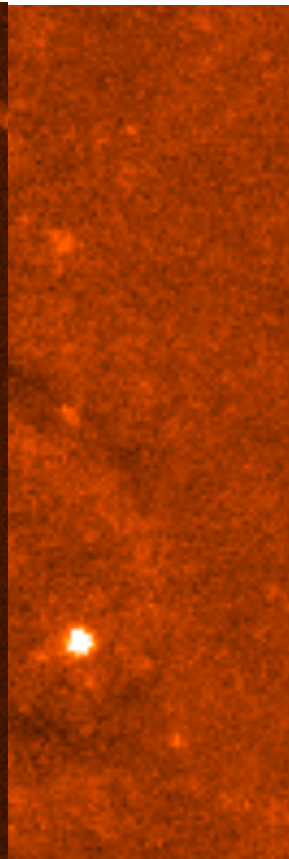


HI all on
one side

F350LP image of Mrk58



Possible tidal clusters

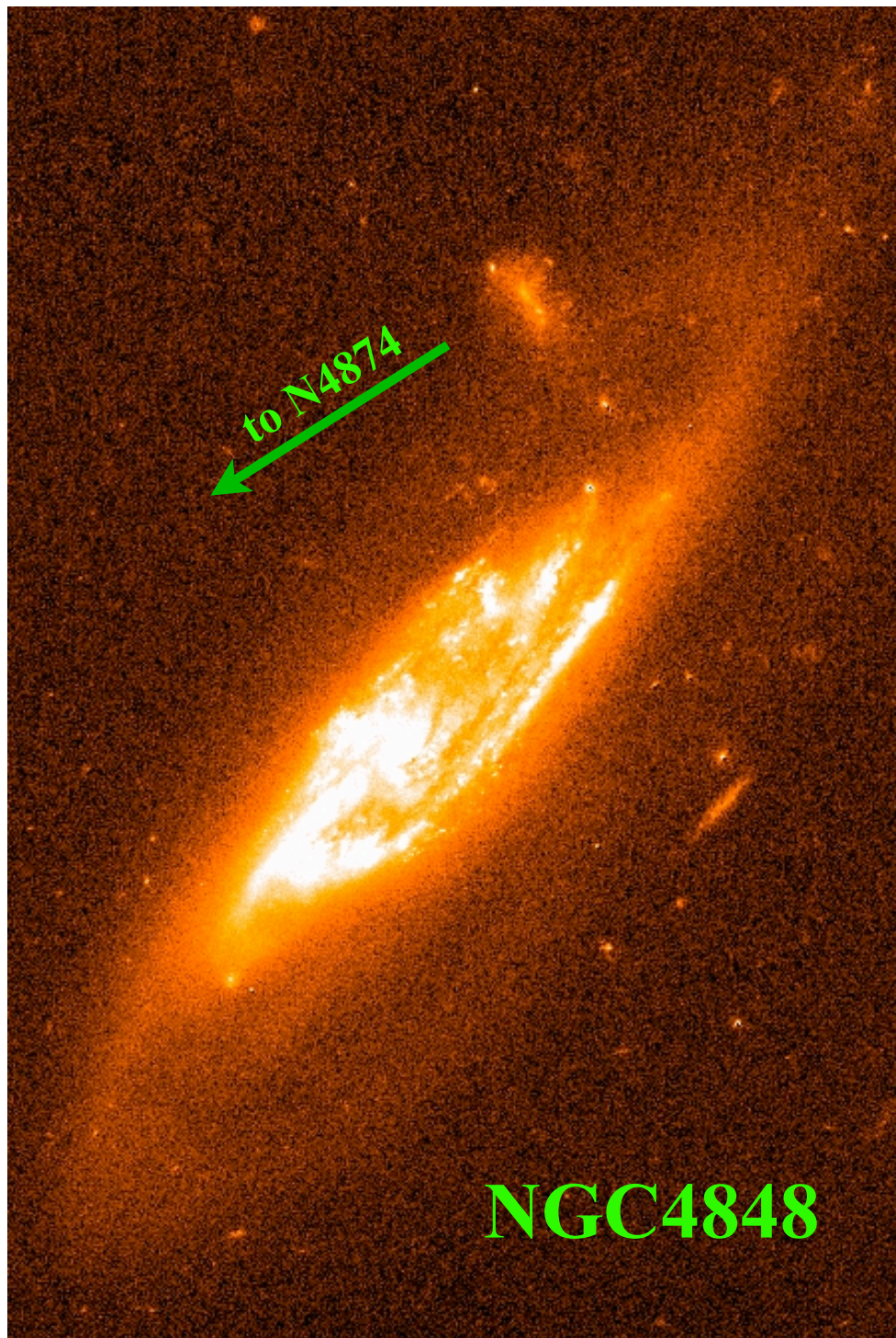


Smooth lsb
disk (also in
SDSS image)

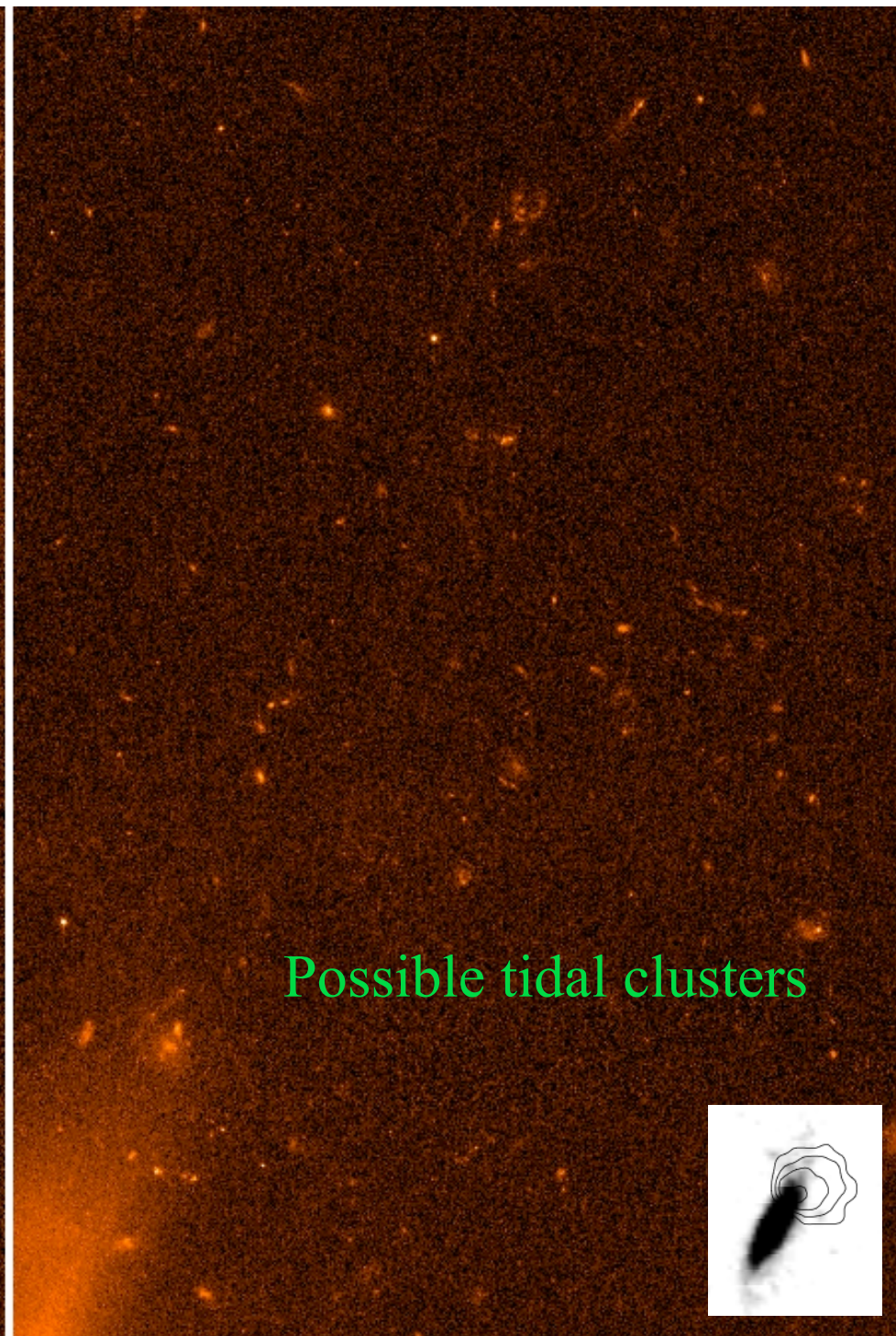
Dust lanes all
on one side,
and radial or
tangential
rather than
spiral

HI all on
one side

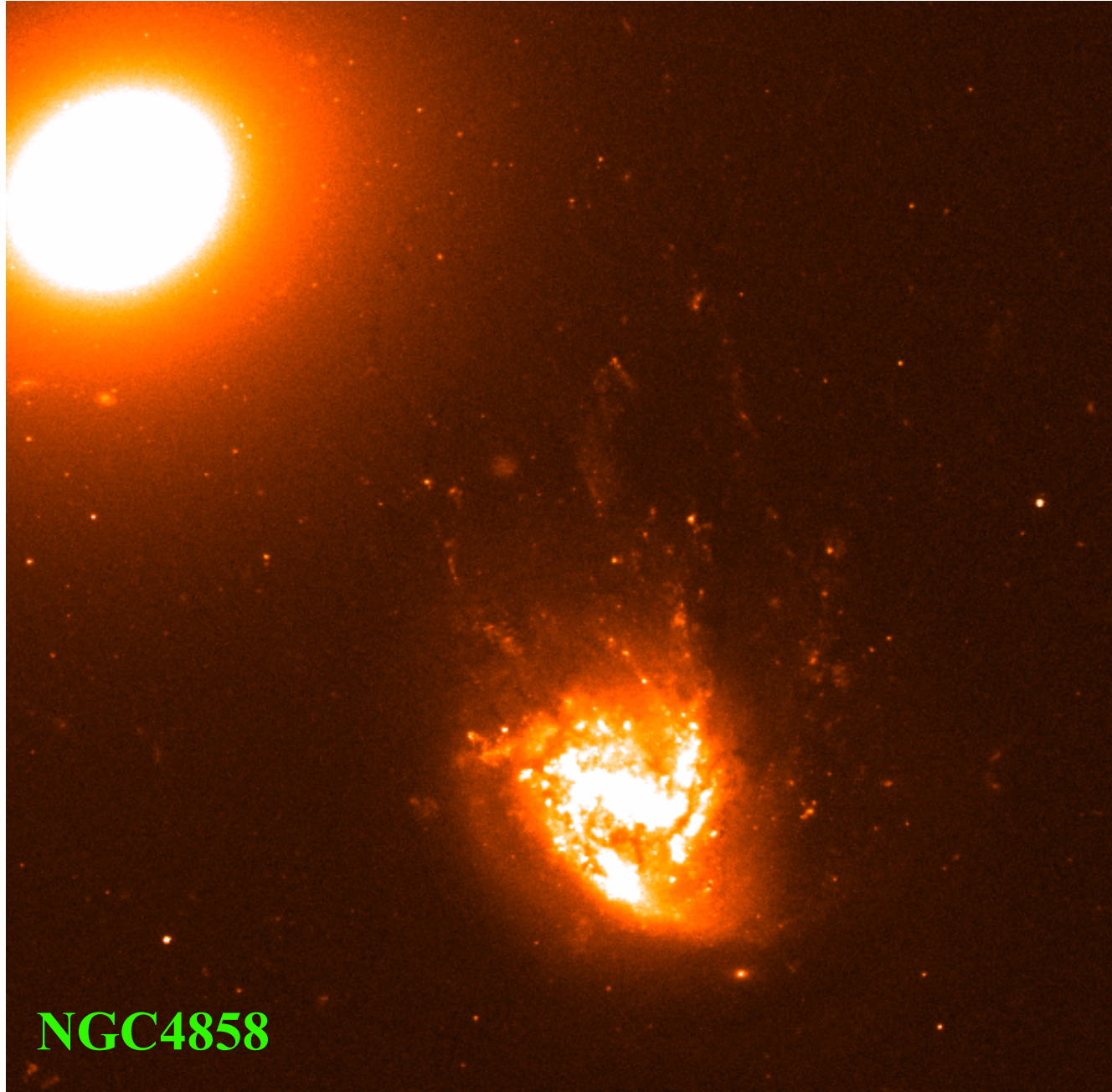
F350LP image of NGC4848



Jellyfish object in Coma



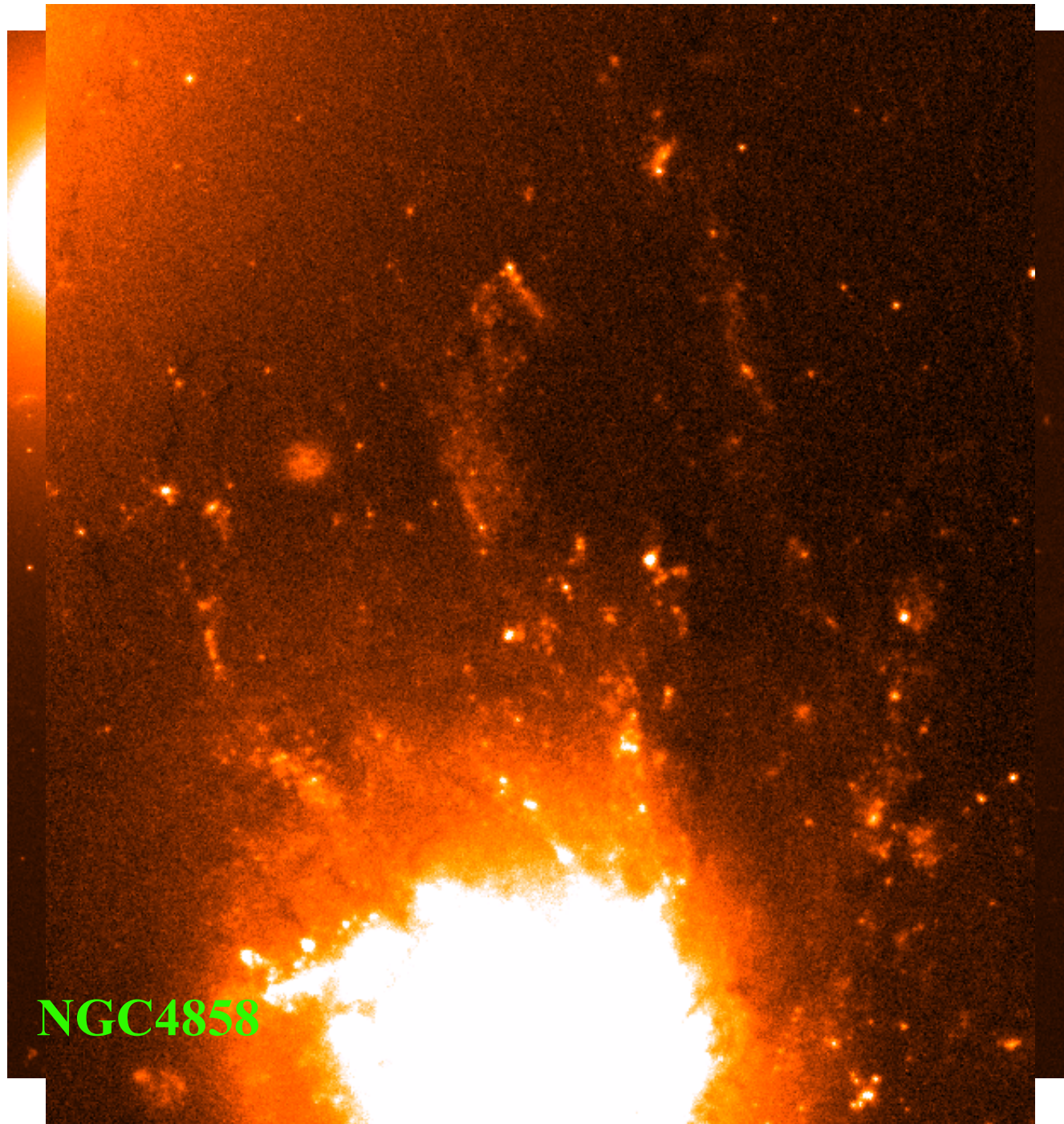
F350LP image of NGC4858



NGC4858

F350LP image of NGC4858

A spectacular jellyfish object in Coma



Individual tidal clusters in N4858, N4848, and Mrk58 are bright enough for spectroscopy at Keck (maybe 2018) , can yield ages, abundances, etc. of material being added to ICM.

Ram Pressure Stripping in Coma Summary

- WFC3/UVIS images reveal that at least six of the seven brightest spirals in Coma exhibit clear signs of ram pressure stripping.
- The rapid gas removal from the disks will quickly drive spirals to become S0's; at least three of the sample exhibit extended low surface brightness or anemic disks.
- Two and possibly three of the objects are 'jellyfish', trailing star formation in their wake through the ICM.
- The new clusters and stars are continuing to build the intergalactic population in Coma at the present epoch.
- The new clusters will age and fade, eventually becoming indistinguishable from intergalactic globulars.
- The stripped gas augments the ICM, speeding up the evolution through increased ram pressure.
- Spectroscopic follow-up with Keck to come...