CO MOLECULAR GAS

AND EARLY-TYPE GALAXIES AND PSEUDOBULGES

COLE TREYTURIK

Contents

CO MOLECULAR GAS

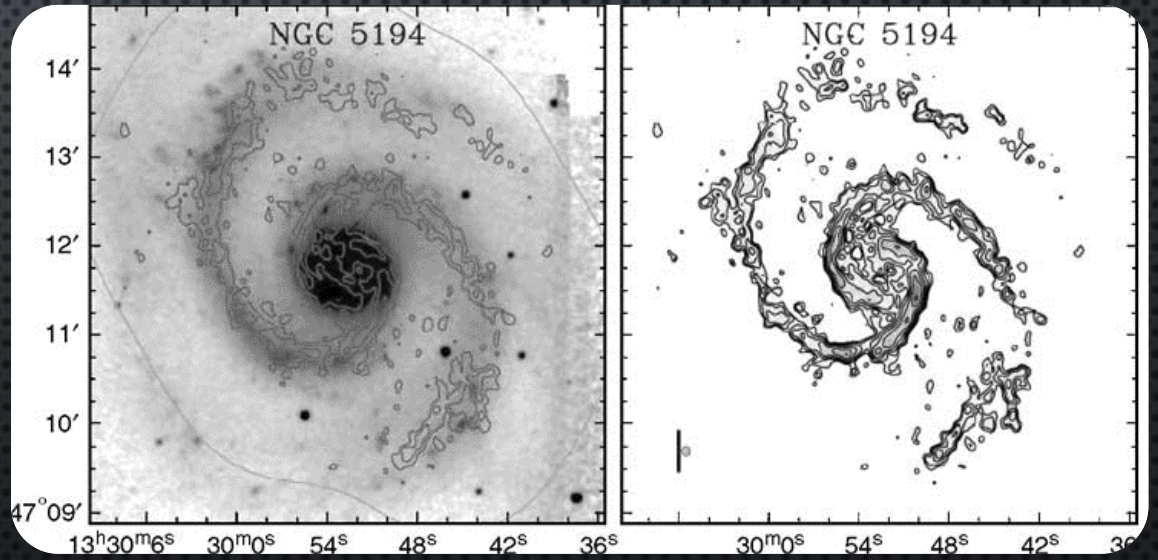
M. GAS CARBO CARBONIS MONOXIDE

WHAT IS CO MOLECULAR GAS?

- Discovered astronomically in 1970
- Second most abundant molecular gas
  - Around 1 CO for every 10^4 H_2 locally
- Frequently found in molecular clouds

IMPORTANCE TO ASTRONOMY

- We can't see H_2 gas
  - Symmetric molecule
  - Cold H_2 barely emits
- We can see CO gas
  - Asymmetric molecule
  - Emits at ~10K
- Can be used as a tracer of H_2



EMISSION & DETECTION

- MOST READILY OBSERVED TRANSITION LINE IS $J = 1 \rightarrow 0$
  - 2.6 MM LINE
  - CAN BE OBSERVED FROM THE GROUND
- EXCITED THROUGH COLLISIONS WITH H_2 AND THROUGH RADIATIVE TRAPPING
- OPTICALLY THICK GIVEN TYPICAL MOLECULAR CLOUD DENSITIES

Molecule	*Transition*	*Frequency* ν	*Wavelength* λ	E_{upper}/k_B (K)	[a] *Typical* n_H (cm^{-3})
CO	$J = 1 \rightarrow 0$	115.3 GHz	2.6 mm	5.5	~100
	$J = 2 \rightarrow 1$	230.5 GHz	1.3 mm	17	~1 000
	$J = 3 \rightarrow 2$	345.8 GHz	0.87 mm	34	10^3–10^4

CONVERSION FROM CO TO H_2

- Relationship between CO line strength and H_2 density for the $J = 1 \rightarrow 0$ transition
- *X* is the conversion factor
- Standard *X* for the Milky Way is
  $X = (2.3 \rightarrow 2.8) \times 10^{20}\ cm^{-2}\ (K\ km\ s^{-1})^{-1}$
- *X* varies based on metallicity and galactic morphology
  $X = (0.6 \rightarrow 10) \times 10^{20}\ cm^{-2}\ (K\ km\ s^{-1})^{-1}$

$$\left[\frac{\mathcal{N}_{H_2}}{\mathrm{cm}^{-2}}\right] = X \int_v \left[\frac{T_B[CO(J = 1 \rightarrow 0)]}{\mathrm{K}}\right] \left[\frac{dv}{\mathrm{km\,s}^{-1}}\right]$$

Uses and Applications

- Can be used to trace non-emitting molecular hydrogen
- Brightness of emission lines accurately reflects local temperature
- High resolution kinematic data can be used to detect anomalies such as black holes

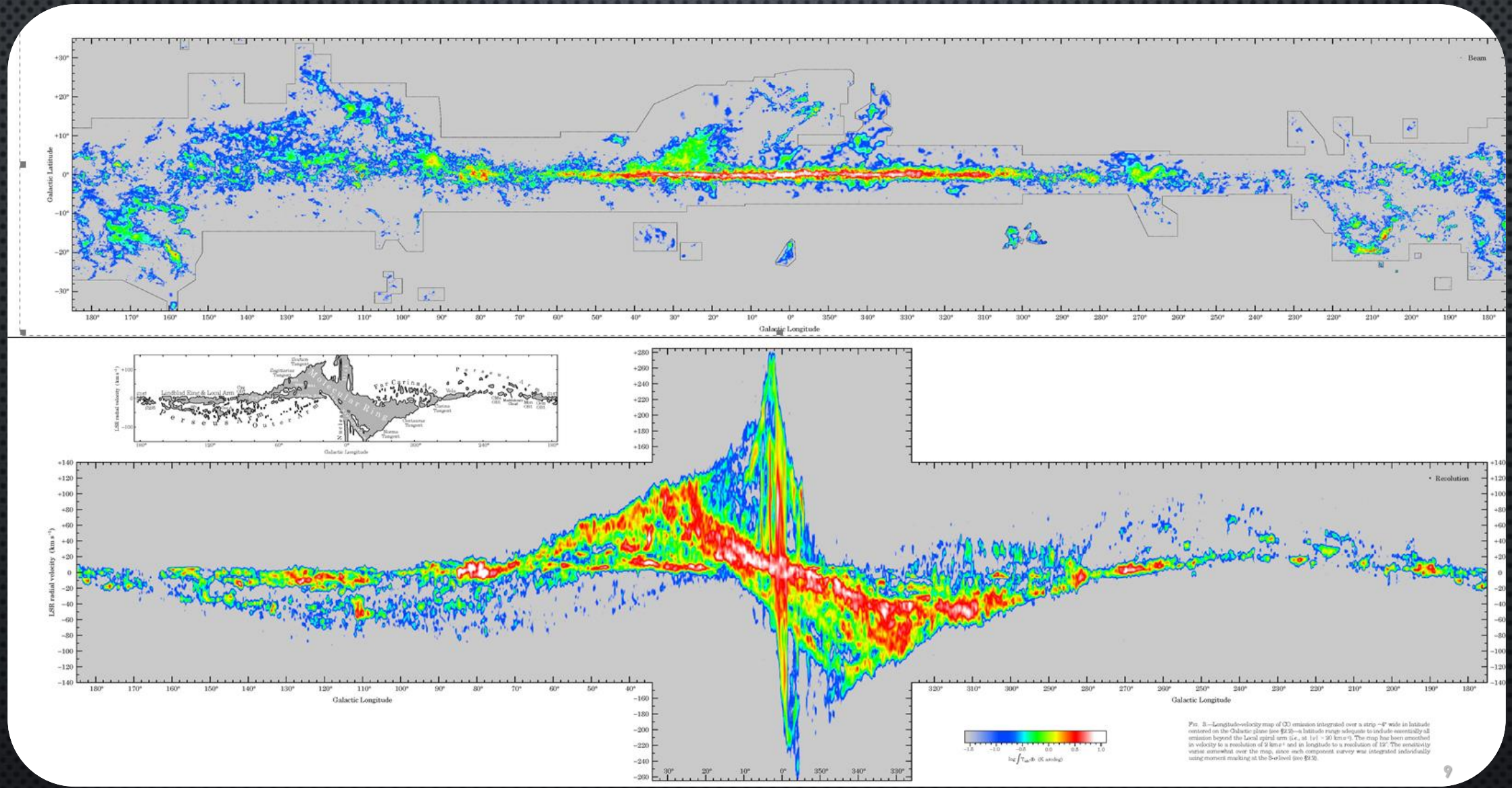


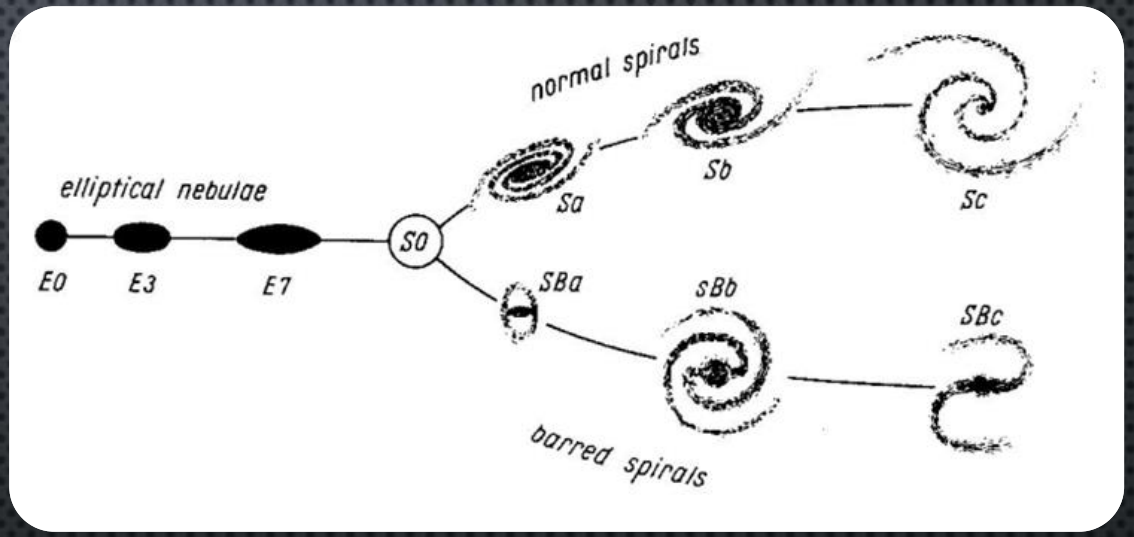
FIG. 3.—Longitude-velocity map of CO emission integrated over a strip −4° wide in latitude centered on the Galactic plane (see §2.3)—a latitude range adequate to include essentially all emission beyond the Local spiral arm (i.e., at $|v| > 30$ km s^{-1}). The map has been smoothed in velocity to a resolution of 2 km s^{-1} and in longitude to a resolution of 12′. The sensitivity varies somewhat over the map, since each component survey was integrated individually using moment masking at the 3-σ level (see §2.5).

EARLY-TYPE GALAXIES

PRIMO-GENUS GALAXIES

WHAT IS AN EARLY-TYPE GALAXY?

- STEMS FROM THE APPEARANCE OF THE HUBBLE TUNING FORK DIAGRAM
- INTERPRETATION THAT GALAXIES EVOLVED ALONG THE DIAGRAM, FROM LEFT TO RIGHT



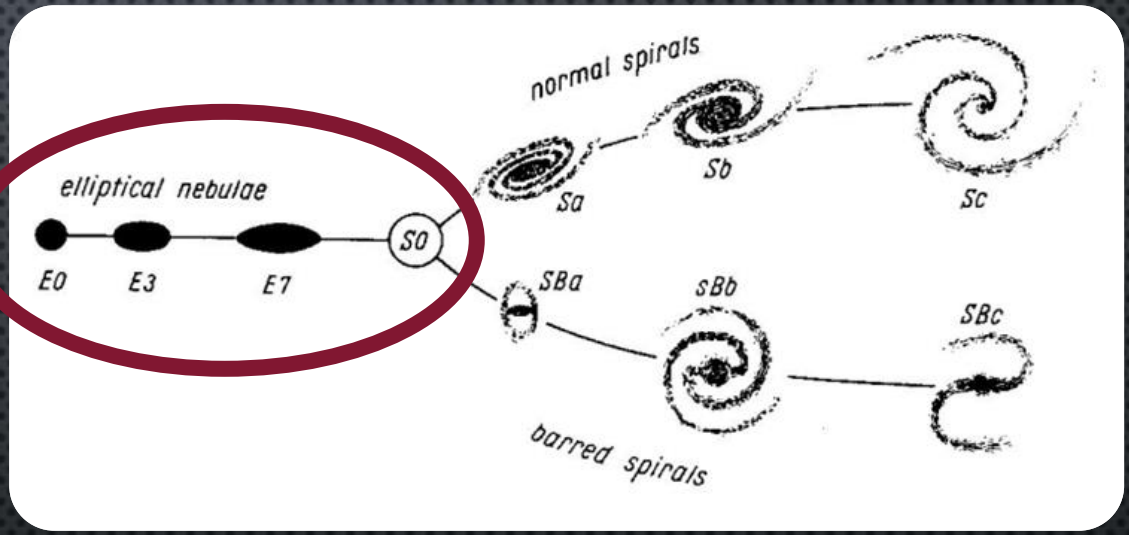
“THE NOMENCLATURE, IT IS EMPHASIZED, REFERS TO POSITION IN THE SEQUENCE, AND TEMPORAL CONNOTATIONS ARE MADE AT ONE'S PERIL. THE ENTIRE CLASSIFICATION IS PURELY EMPIRICAL AND WITHOUT PREJUDICE TO THEORIES OF EVOLUTION…”

EDWIN HUBBLE

THE CLASSIFICATION OF SPIRAL NEBULAE, 1927

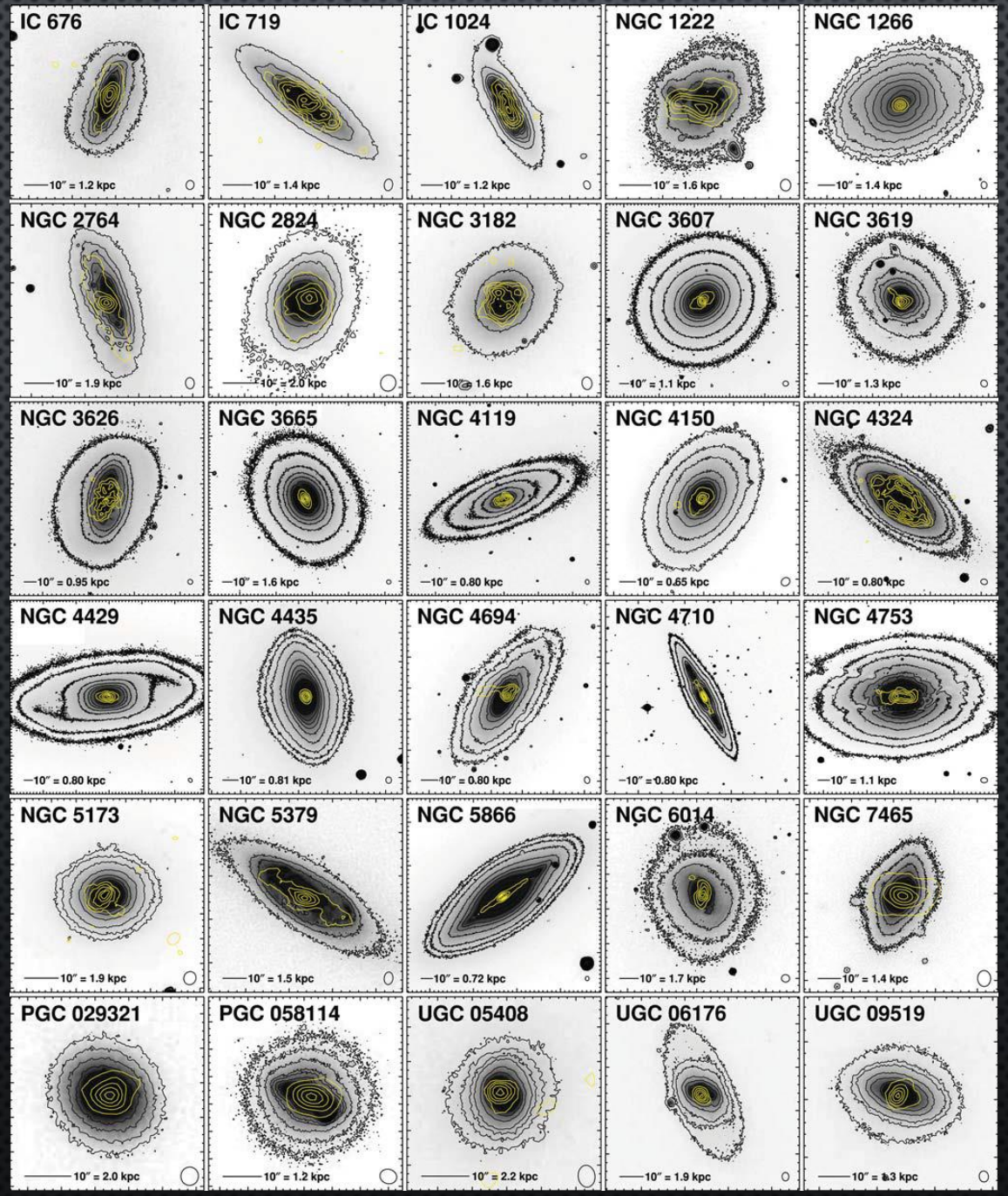
WHAT IS AN EARLY-TYPE GALAXY?

- GALAXIES TO THE LEFT OF THE FORK ARE KNOWN AS "EARLY-TYPE GALAXIES"
  - E0 – E7, S0
- GALAXIES TO THE RIGHT OF THE FORK ARE KNOWN AS "LATE-TYPE GALAXIES"
  - SA – SC, SBA - SBC



Properties of Early-Type Galaxies

- Properties of ellipticals!
- Do not exhibit much active star formation
  - Typically thought to not contain very much gas
- Stars do not follow an orderly rotation
  - Instead experience more random motion


IC 676
10″ = 1.2 kpc
IC 719
10″ = 1.4 kpc
IC 1024
10″ = 1.2 kpc
NGC 1222
10″ = 1.6 kpc
NGC 1266
10″ = 1.4 kpc
NGC 2764
10″ = 1.9 kpc
NGC 2824
10″ = 2.0 kpc
NGC 3182
10″ = 1.6 kpc
NGC 3607
10″ = 1.1 kpc
NGC 3619
10″ = 1.3 kpc
NGC 3626
10″ = 0.95 kpc
NGC 3665
10″ = 1.6 kpc
NGC 4119
10″ = 0.80 kpc
NGC 4150
10″ = 0.65 kpc
NGC 4324
10″ = 0.80 kpc
NGC 4429
10″ = 0.80 kpc
NGC 4435
10″ = 0.81 kpc
NGC 4694
10″ = 0.80 kpc
NGC 4710
10″ = 0.80 kpc
NGC 4753
10″ = 1.1 kpc
NGC 5173
10″ = 1.9 kpc
NGC 5379
10″ = 1.5 kpc
NGC 5866
10″ = 0.72 kpc
NGC 6014
10″ = 1.7 kpc
NGC 7465
10″ = 1.4 kpc
PGC 029321
10″ = 2.0 kpc
PGC 058114
10″ = 1.2 kpc
UGC 05408
10″ = 2.2 kpc
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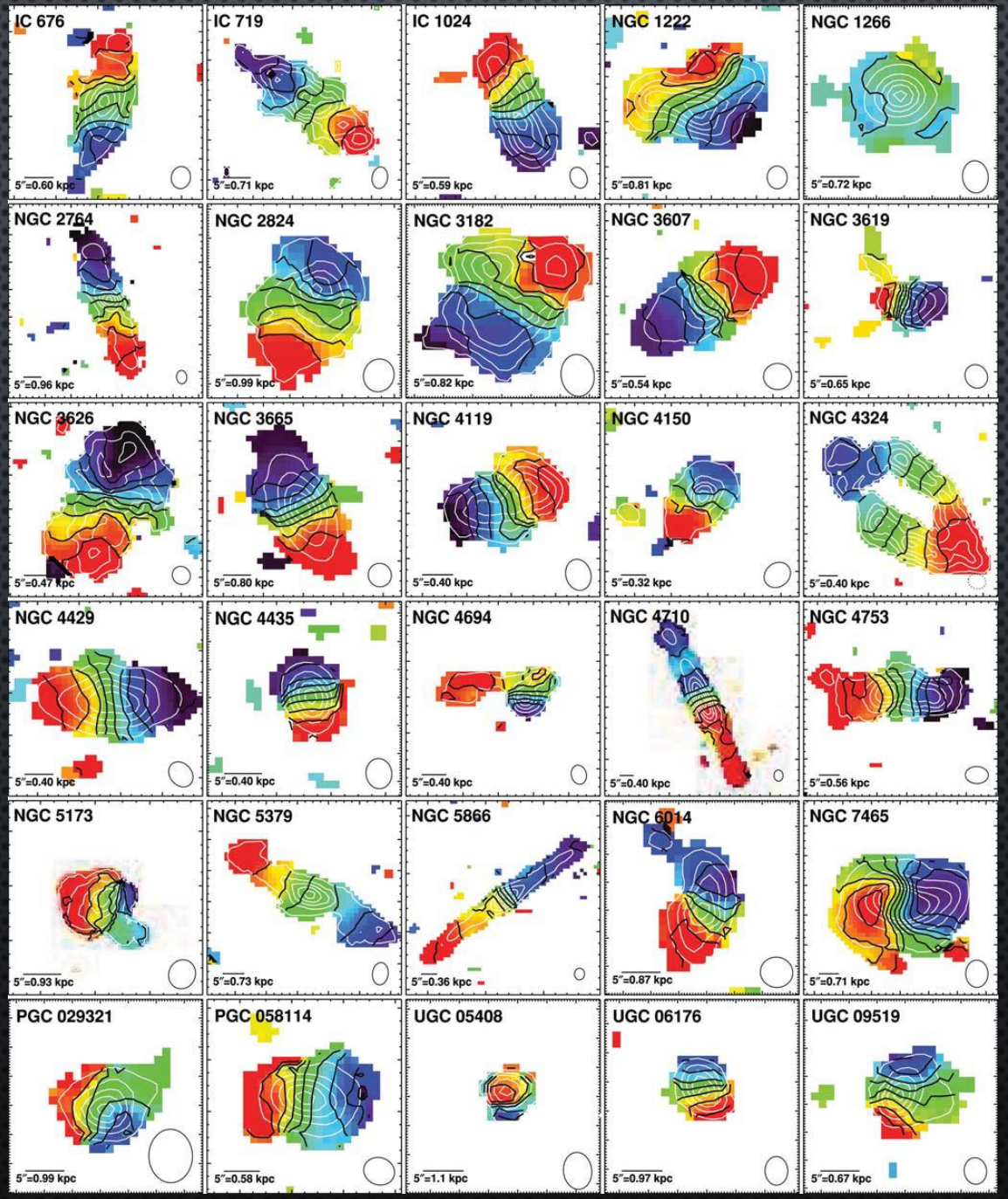
10″ = 1.9 kpc
UGC 09519
10″ = 1.3 kpc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NGC 4324
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UGC 06176
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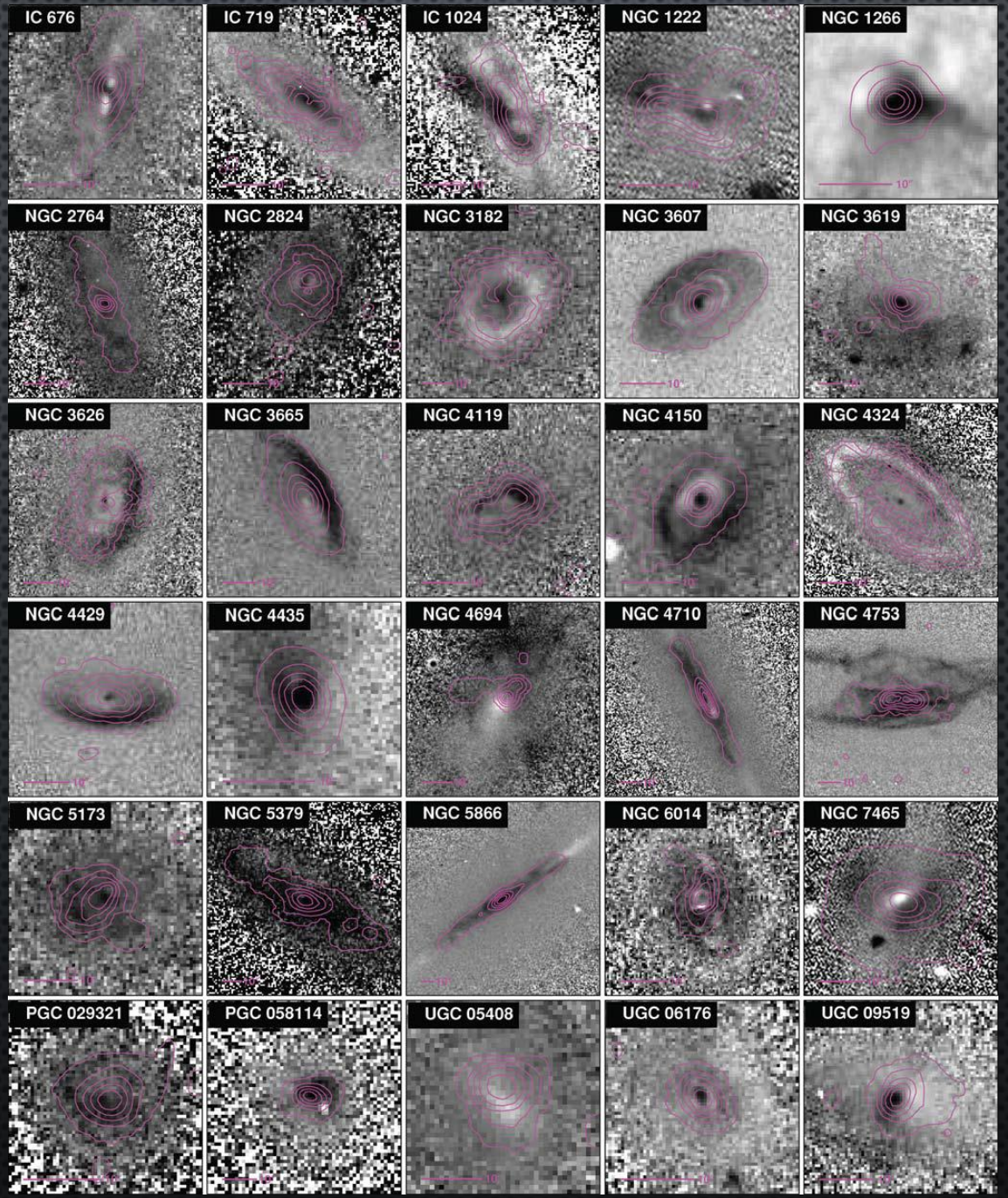
5″=0.67 kpc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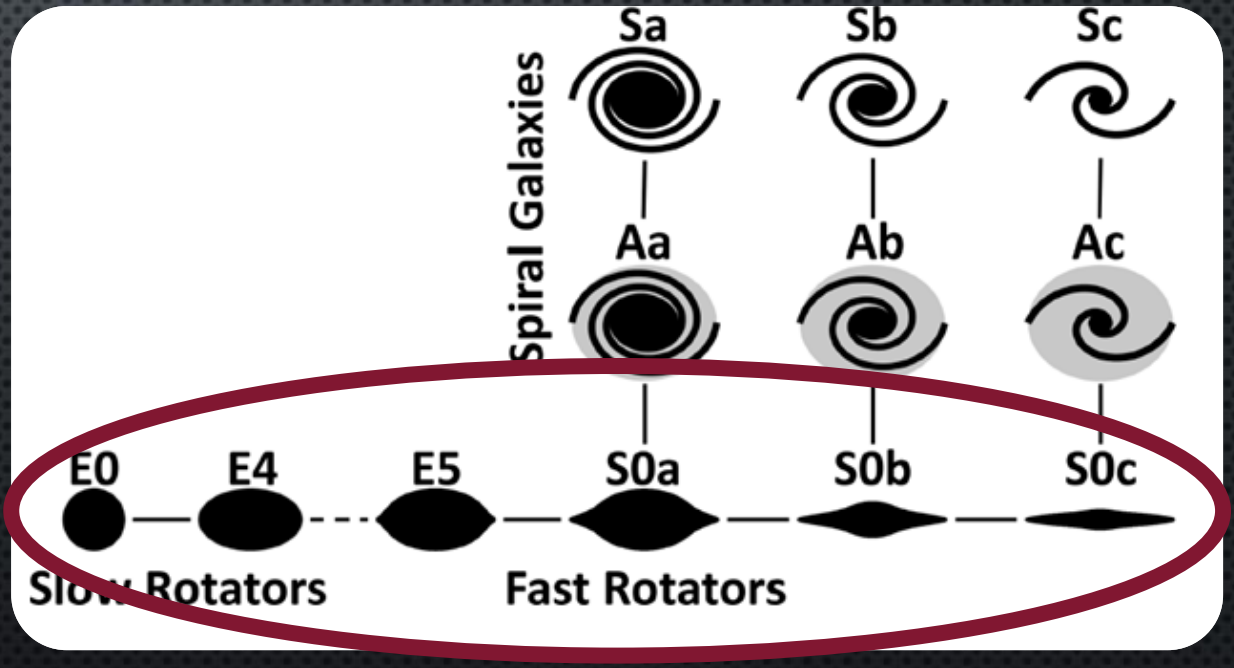
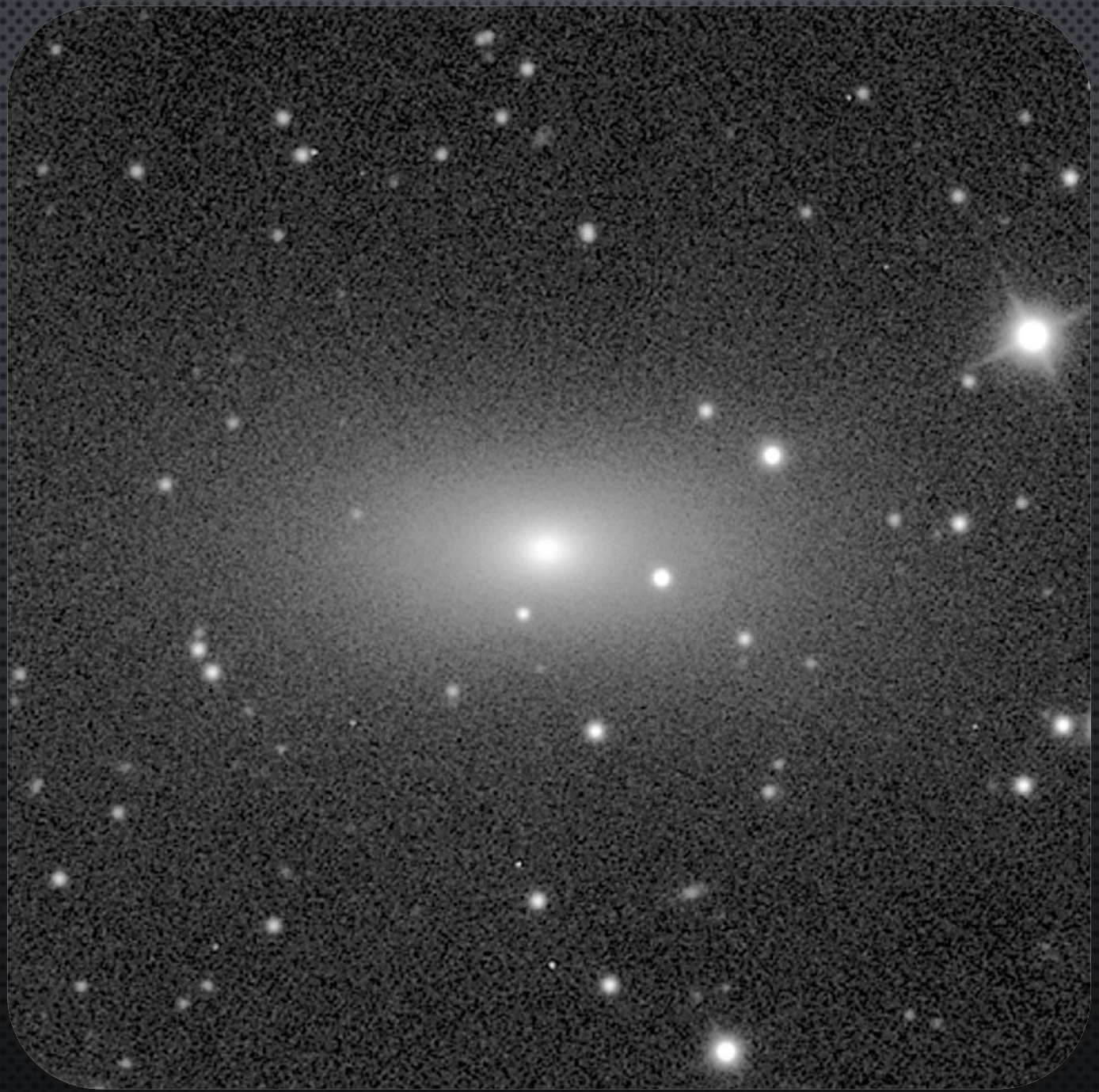
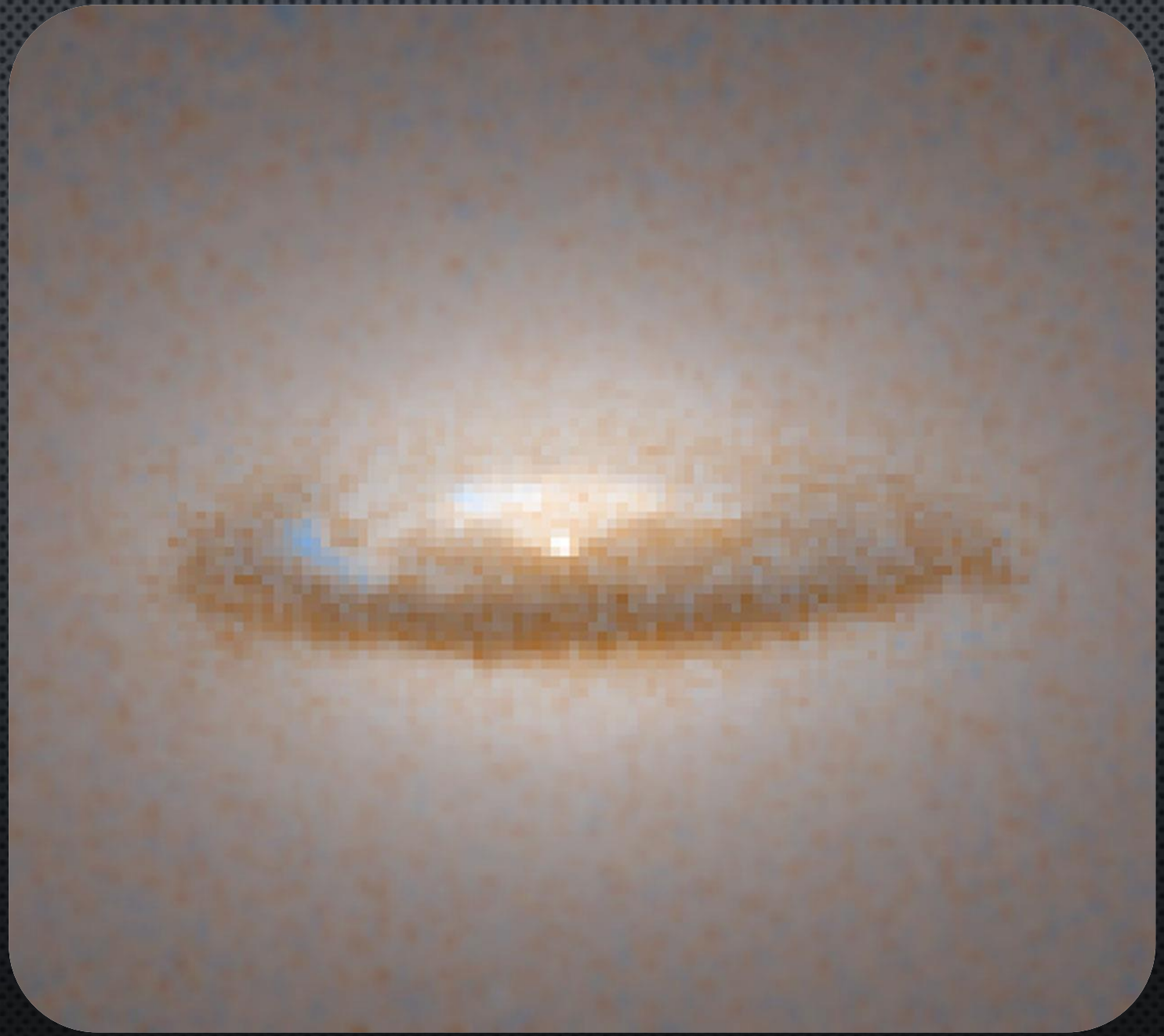
UGC 05408
UGC 06176
UGC 09519

ACTUAL PROPERTIES OF EARLY-TYPE GALAXIES

- STILL DO NOT EXHIBIT MUCH ACTIVE STAR FORMATION
  - DO CONTAIN GAS AND DUST: CO IS QUITE PROMINENT
- STARS CAN FOLLOW AN ORDERLY ORBIT







PSEUDOBULGES

TUMORES PSEUDO-

What is a pseudobulge?

- Classical bulges have properties similar to those of elliptical galaxies
  - Primarily composed of older stars
    - Results in a reddish hue
  - Stars have more random, less ordered orbits
    - Results in a typically spherical shape
  - Lack gas and dust
    - Typically very little star formation

WHAT IS A PSEUDOBULGE?

- Pseudobulges have properties more akin to those of spiral galaxies
  - Stars orbit in an orderly fashion, similar to the stars in the outer disk
    - Results in a disk-like shape; "disk-like bulges"
  - Contain similar amounts of gas as in the outer disk
    - Similar star formation rate as in typical disk galaxies

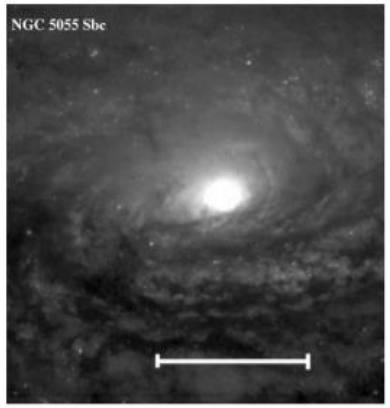
Morphology

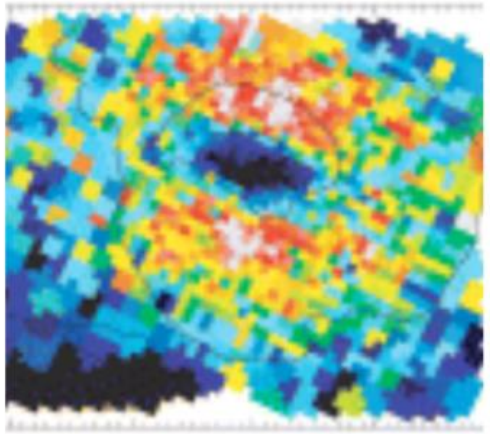
Kinematics

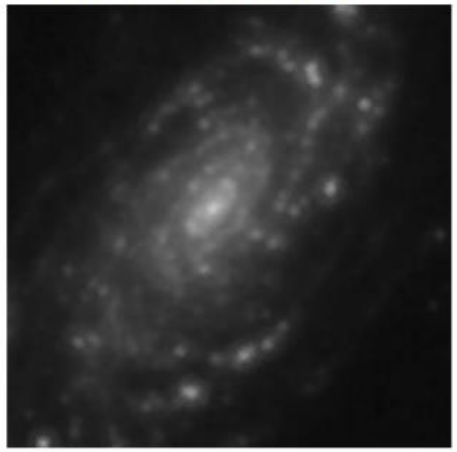
Star Formation

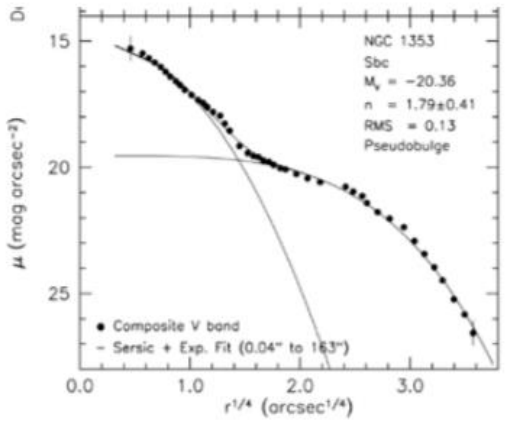
Structure

Pseudobulge

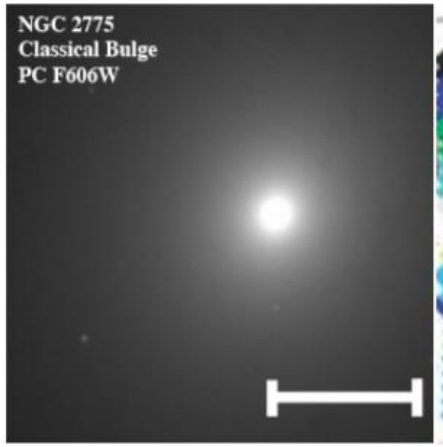


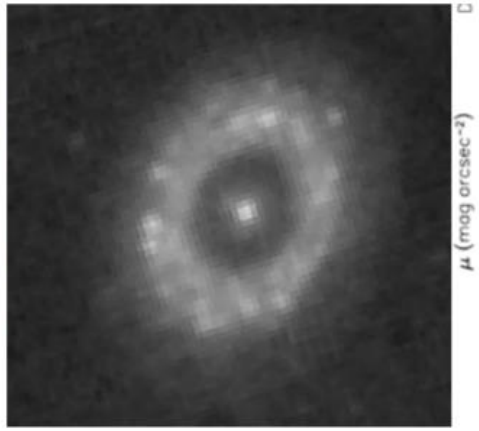


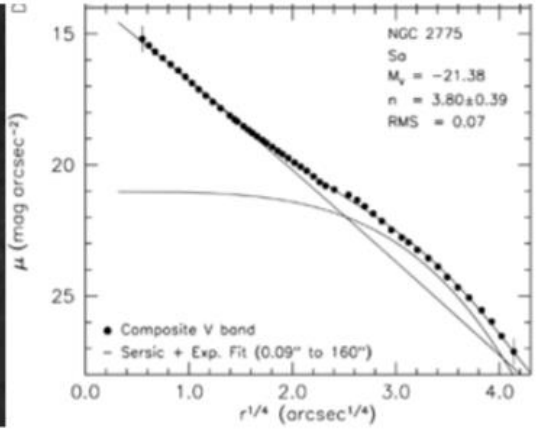




Classical







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