



THE TRUE COLORS OF THE MILKY WAY

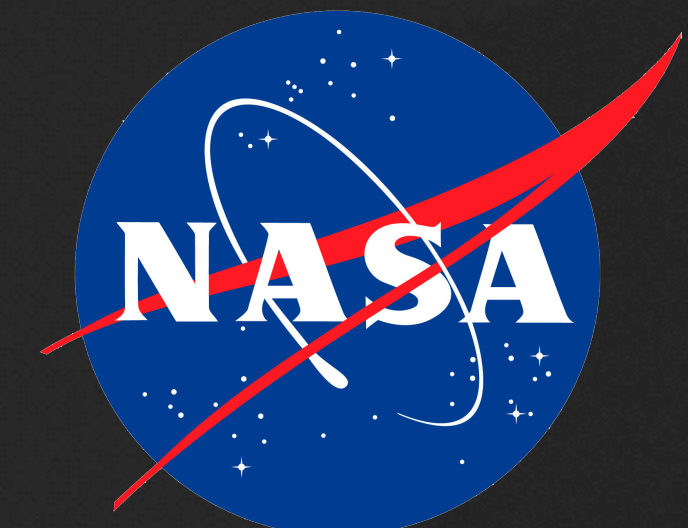
PROF. BRETT ANDREWS
UNIVERSITY OF PITTSBURGH



Dr. Timothy Licquia
University of Pittsburgh PhD 2016



Dr. Catherine Fielder
University of Pittsburgh PhD 2022



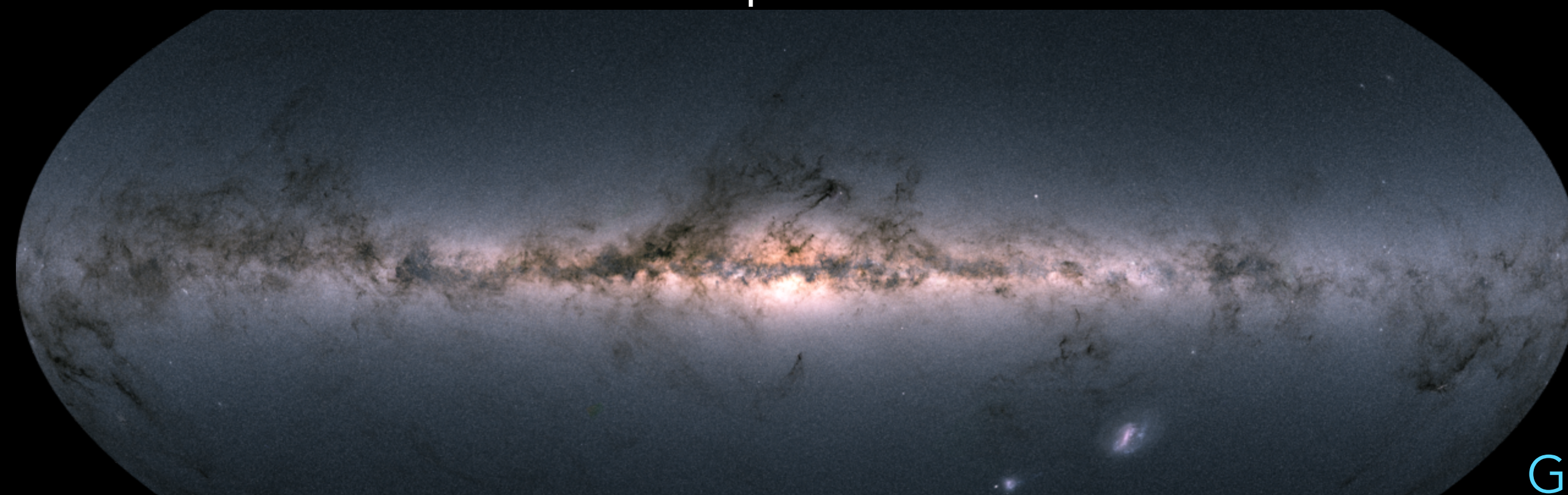
THE MILKY WAY: THE MOST STUNNING STRUCTURE IN THE SKY



BRUNO GILLI/ESO

BUT OUR VIEW INTO THE HEART OF THE MILKY WAY IS OBSCURED
BY INTERSTELLAR DUST BECAUSE WE LIVE IN THE DISK

Optical



GAIA/ESA

Infrared



R.HURT (IPAC/CALTECH)

ONLY A LITTLE DUST HAS A HUGE IMPACT ON
HOW WE SEE OUR WORLD (OR GALAXY!)



AP

SO IT DOESN'T LOOK LIKE MOST SPIRAL GALAXIES



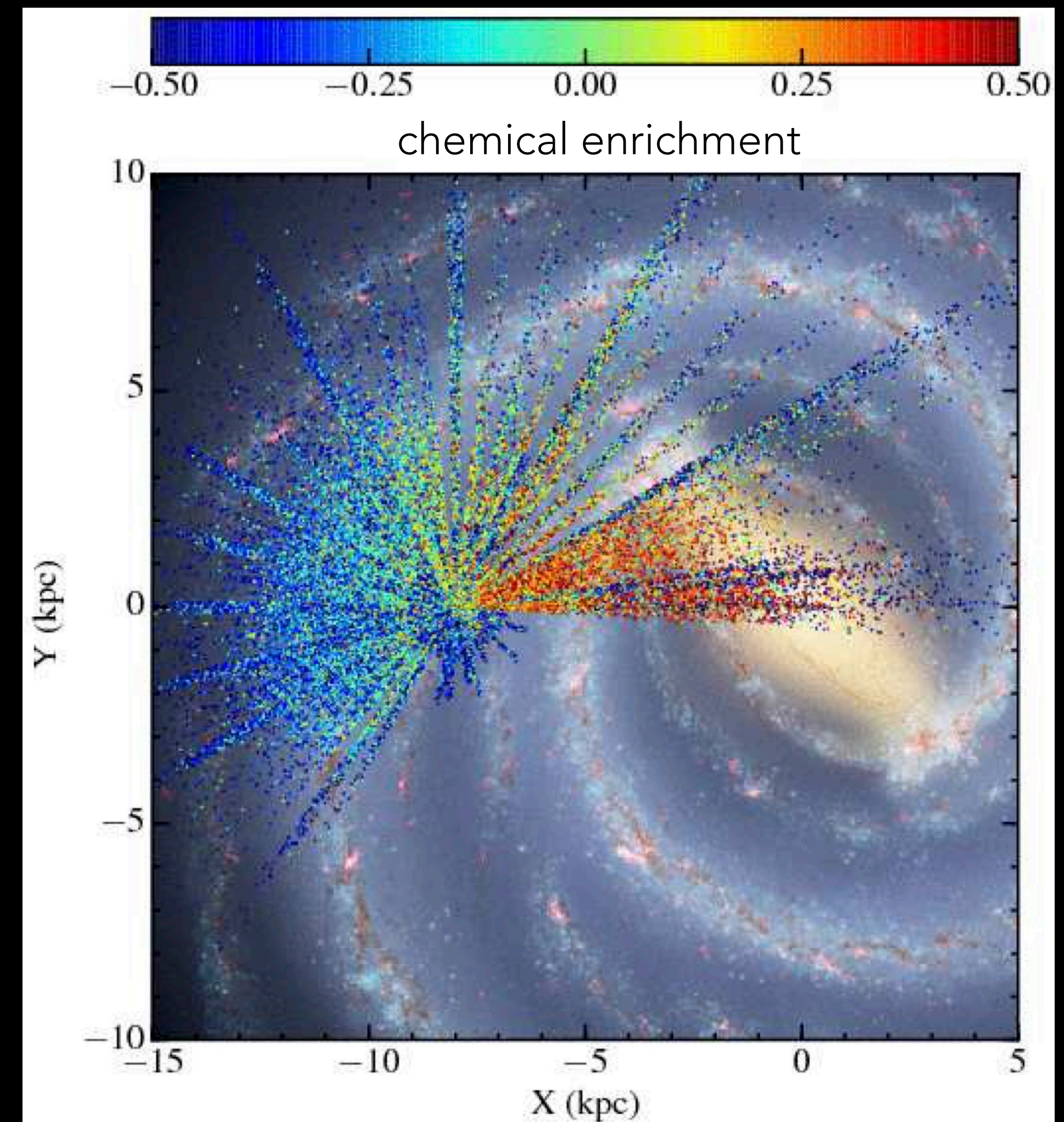
THE MILKY WAY: A UNIQUE WINDOW INTO GALAXY FORMATION



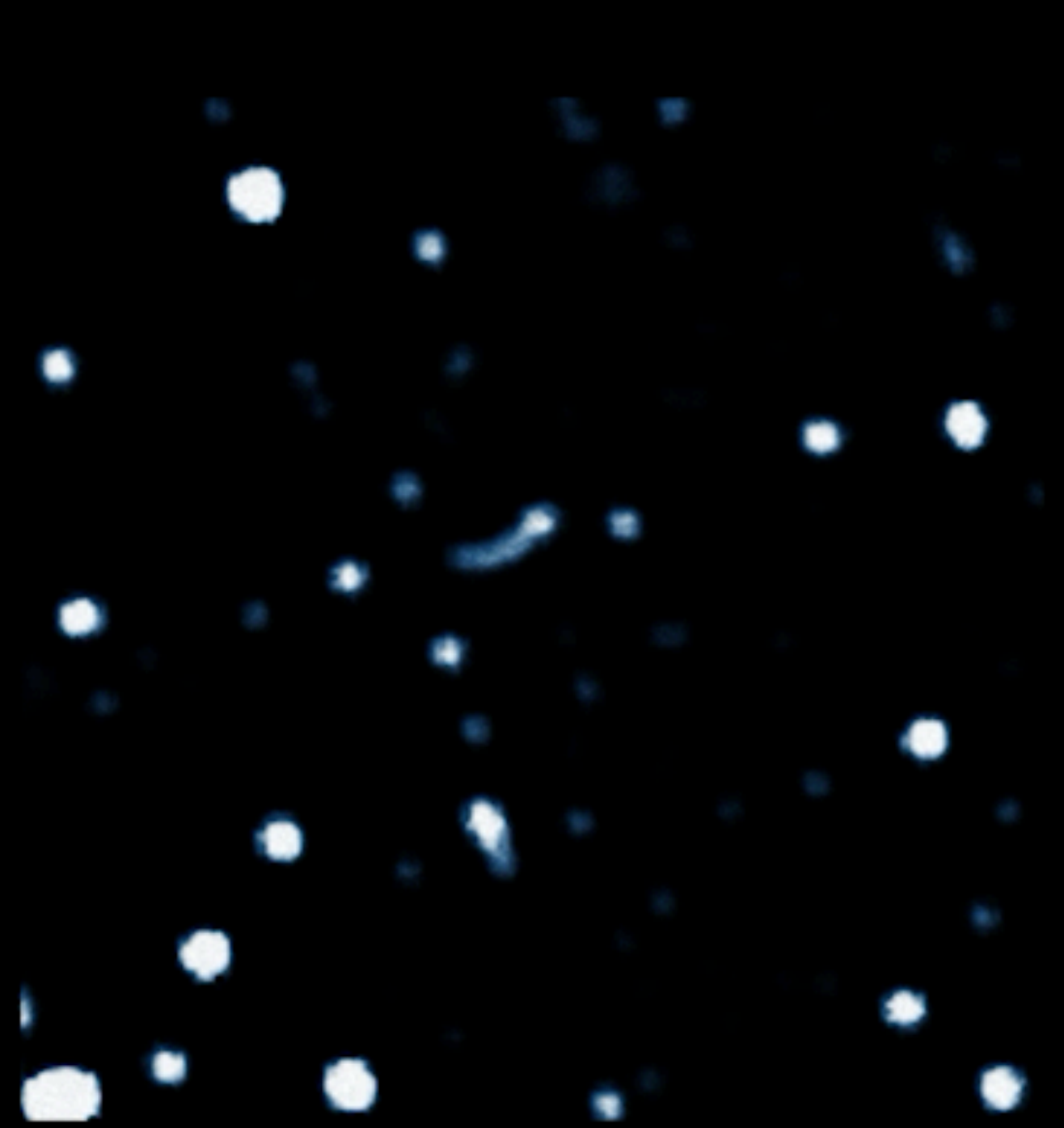
- Andromeda is 1,000,000x farther away than the nearest star.
- For all but a handful of the 100 billion galaxies in the Universe, we cannot see individual stars.

THE MILKY WAY: A GALACTIC ARCHAEOLOGY DIG SITE

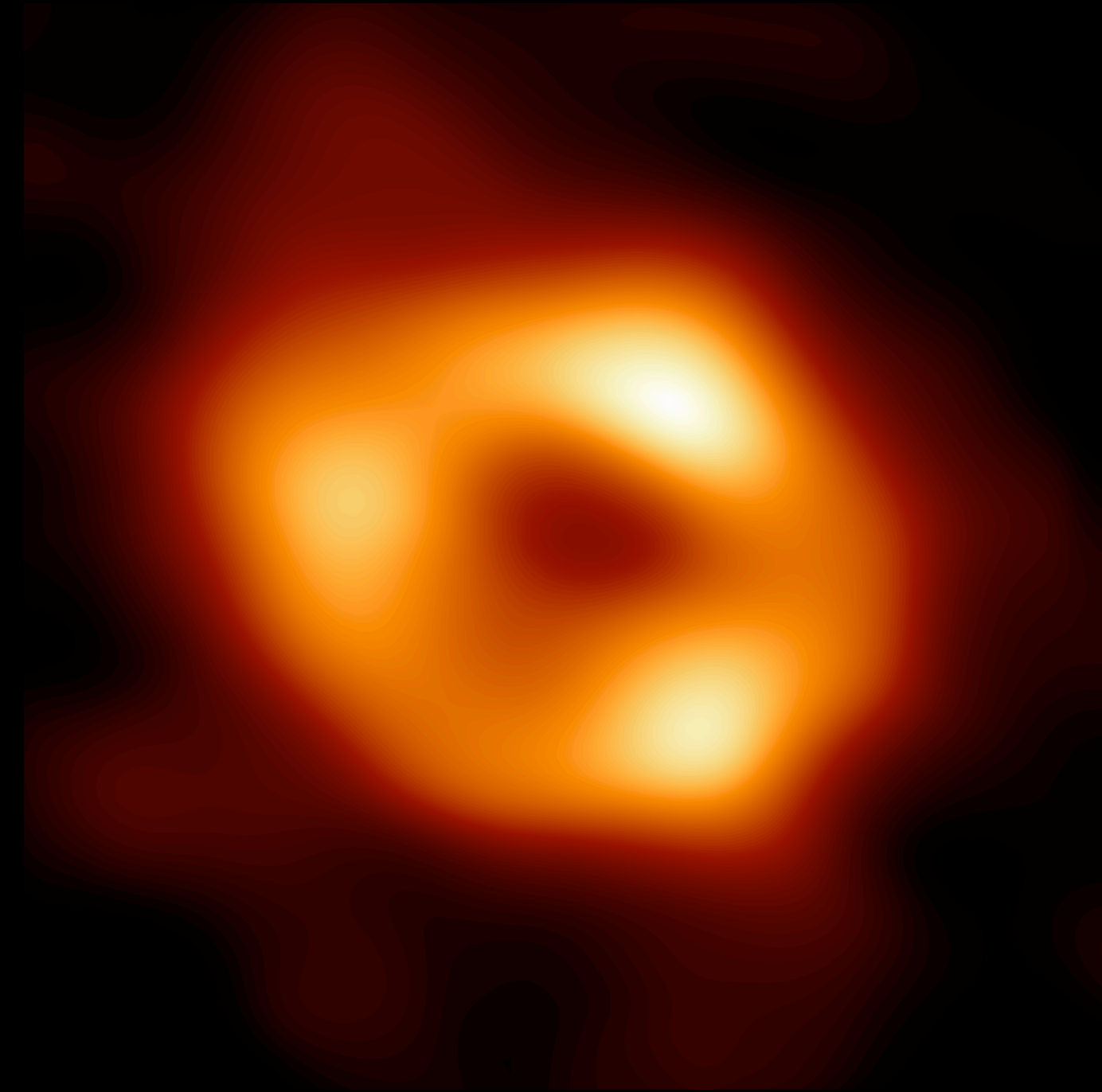
- In the Milky Way we can precisely measure for millions of individual stars:
 - Location and velocity
 - Chemical enrichment
- Which allows us to reconstruct the formation history of the Milky Way.



THE MILKY WAY: A ROSETTA STONE FOR GALAXIES



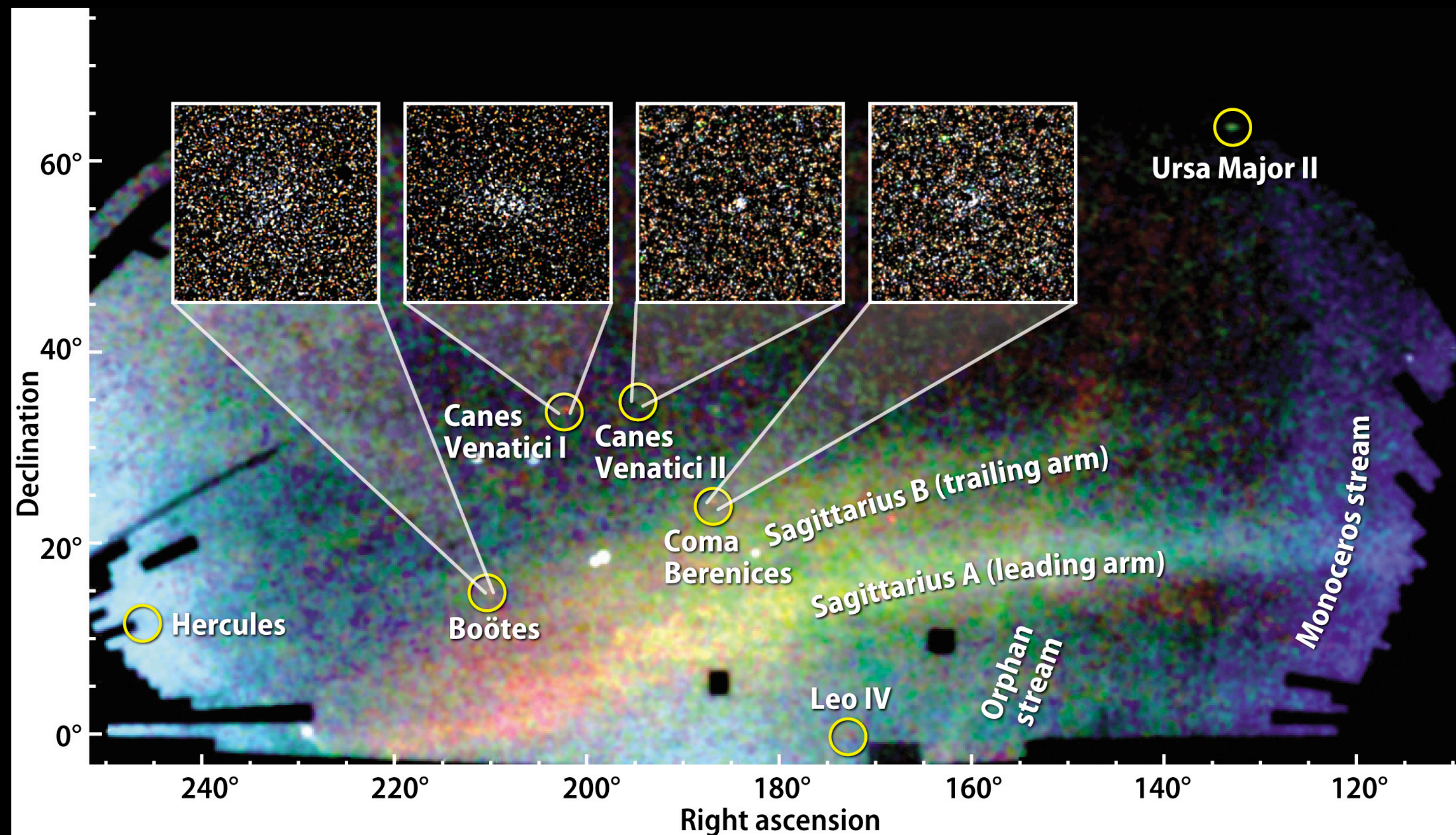
ESO



EHT

The best evidence for the existence of **Supermassive Black Holes**.

THE MILKY WAY: A ROSETTA STONE FOR GALAXIES



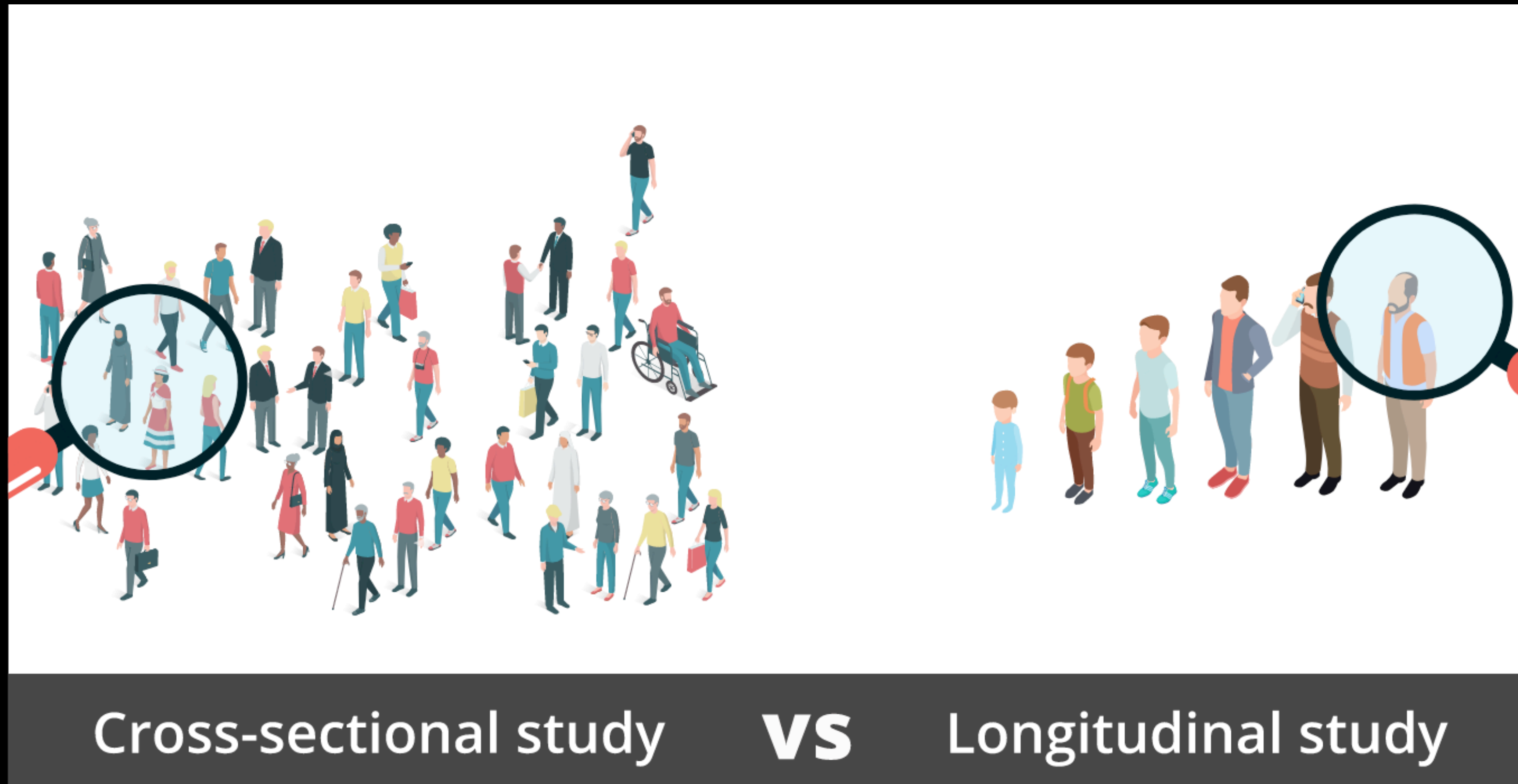
- We can see individual satellite galaxies getting ripped apart by the Milky Way's gravitational field as they merging with it.
- Very difficult to observe for other galaxies!
- Brightness drops as distance squared.
- Much higher spatial resolution for nearby objects.

THE MILKY WAY WASN'T BORN AS WE SEE IT TODAY



- Mergers: galaxies and their invisible but more much massive dark matter halos
- Star Formation (conversion of gas into stars)
- Chemical Evolution (production of elements necessary for life)

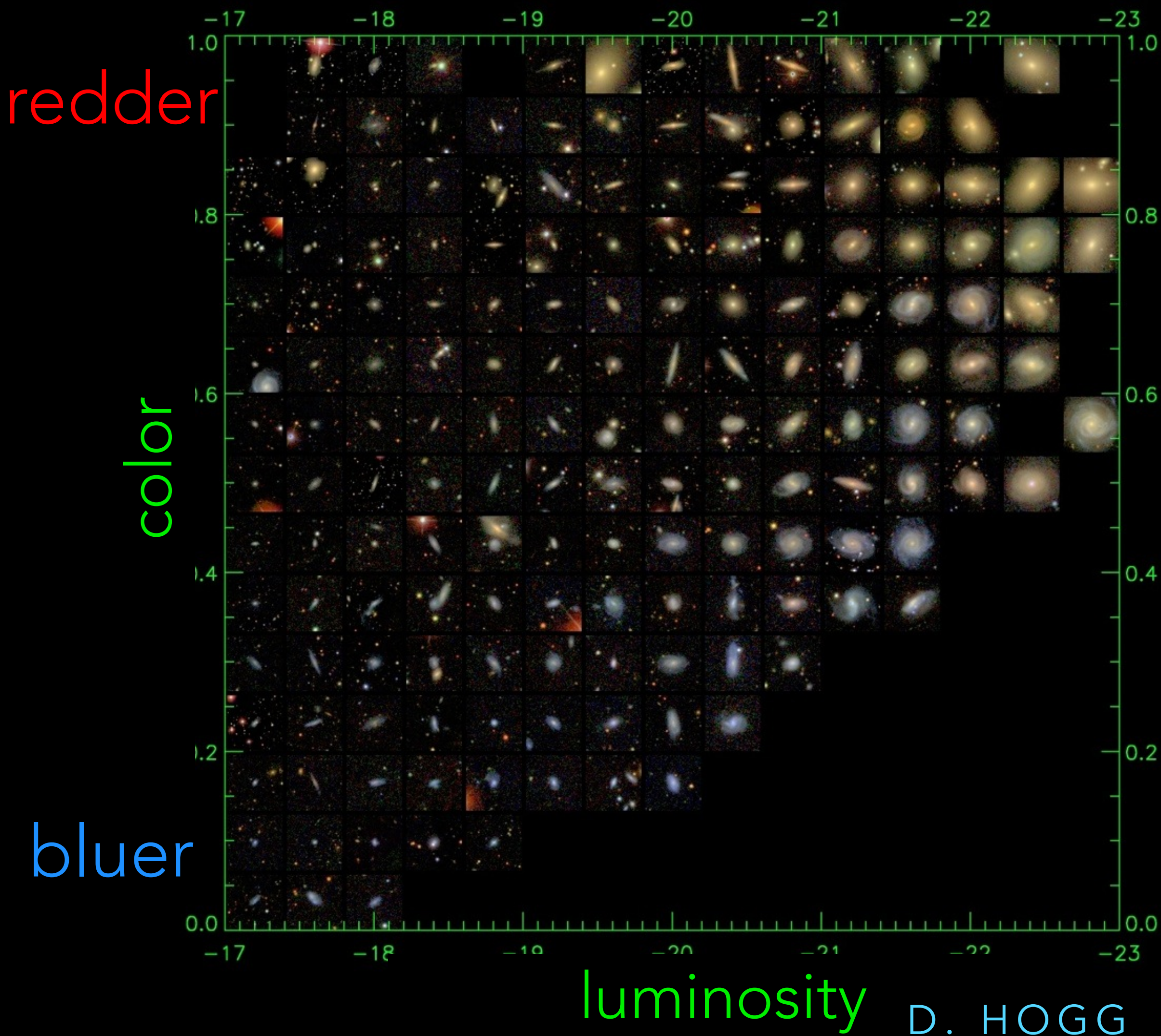
TWO COMPLEMENTARY APPROACHES FOR STUDYING HOW GALAXIES FORM AND EVOLVE



Galaxy surveys
(at different epochs)

Milky Way
(Galaxy Archaeology)

COLOR AND LUMINOSITY ARE KEY TOOLS FOR STUDYING GALAXY POPULATIONS

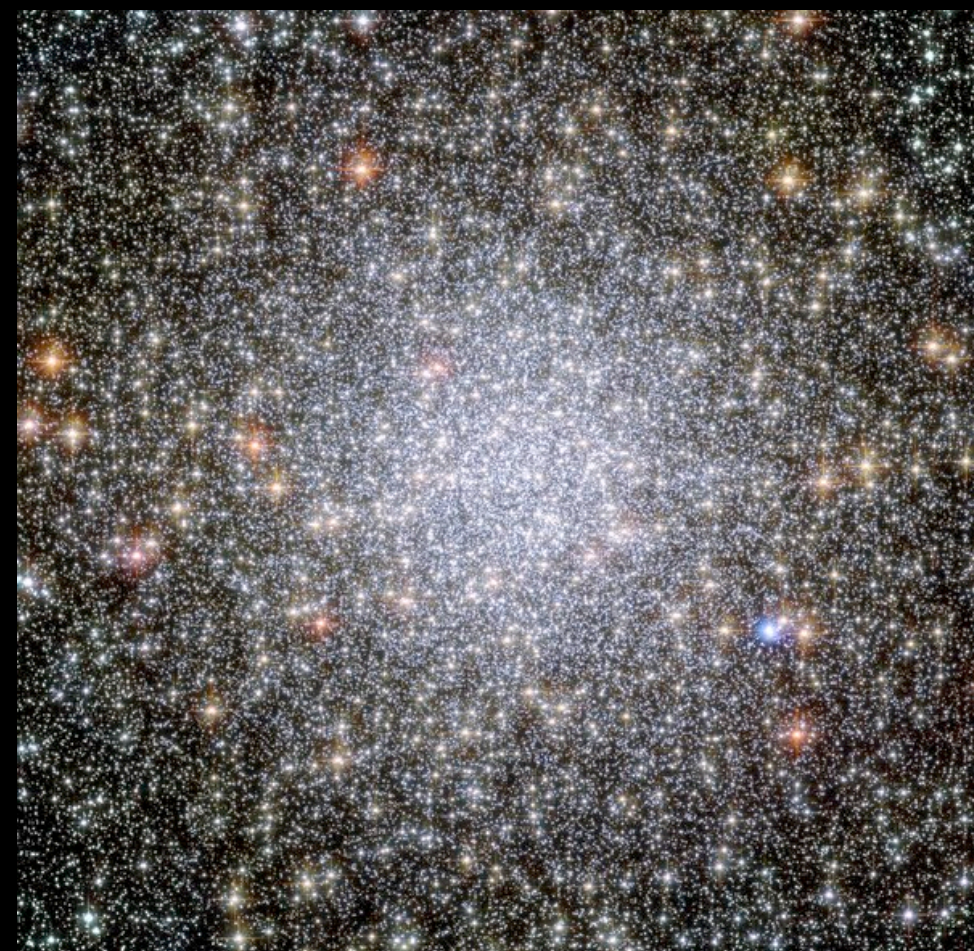


- They are the **easiest** and often the **only** properties that we measure for a galaxy, especially for the earliest epochs of the universe.
- **Color** and **luminosity** provide key clues to the history of star formation.

COLOR REFLECTS THE AGE OF THE STARS



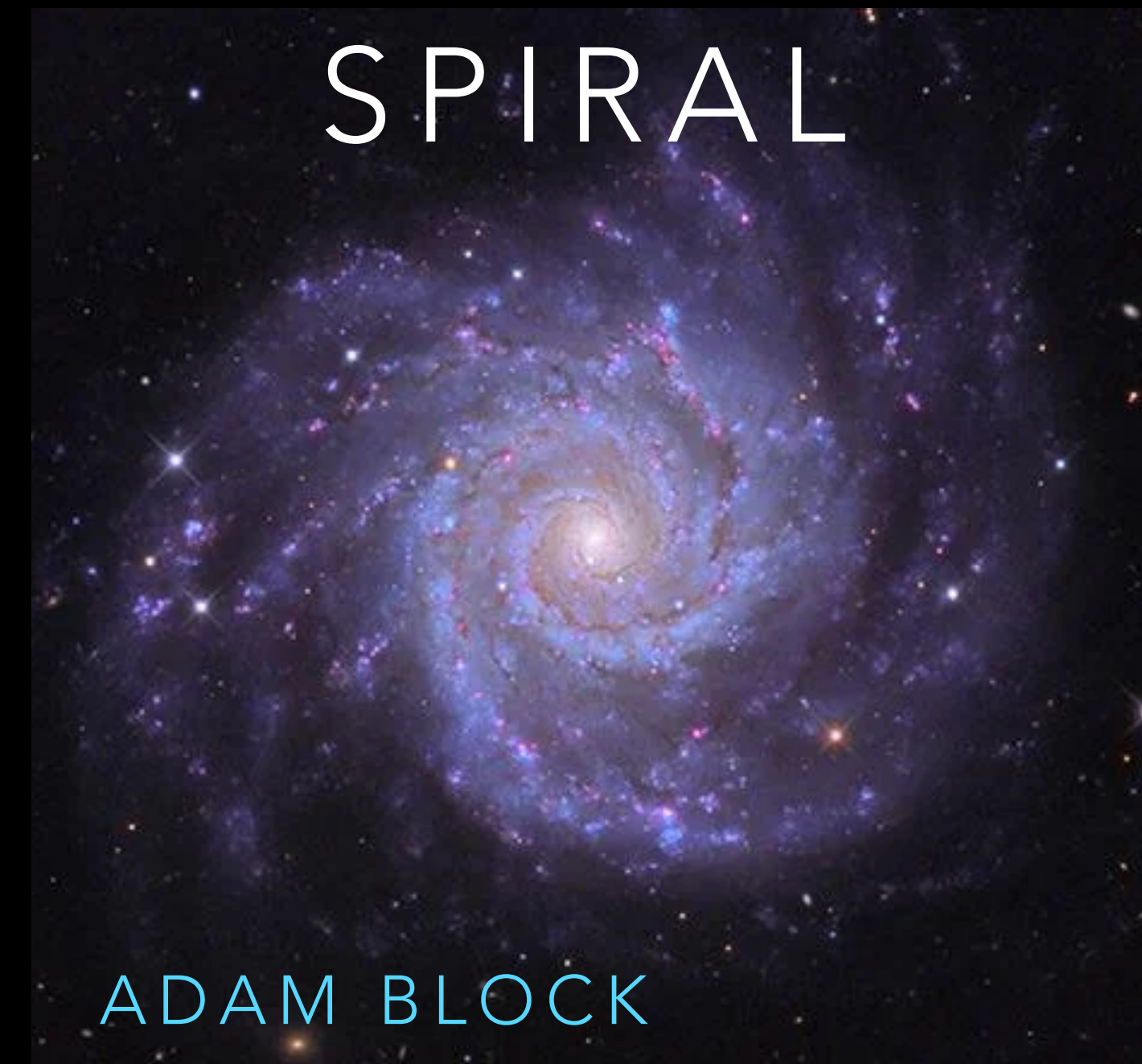
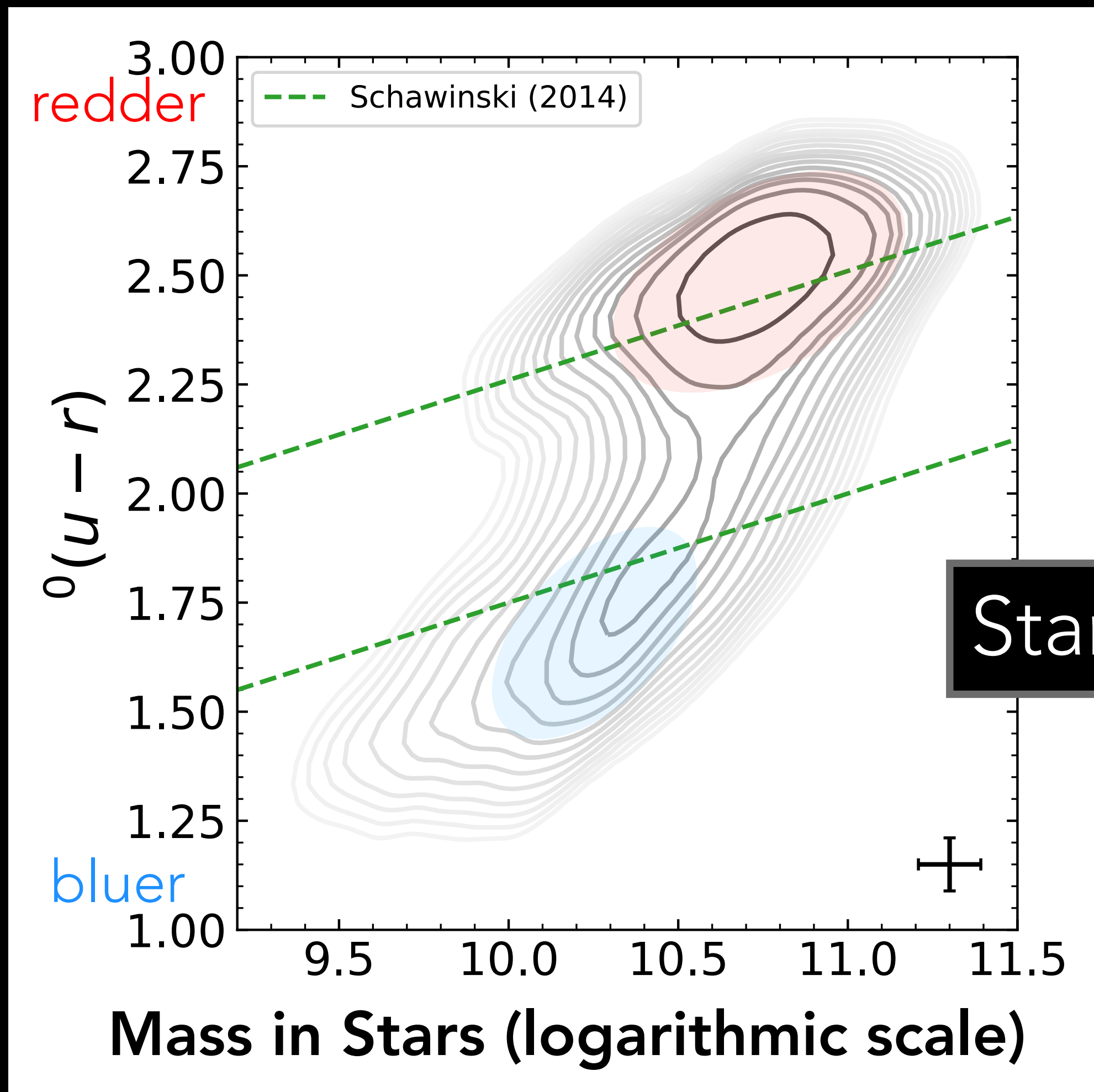
WIKIPEDIA



WIKIPEDIA

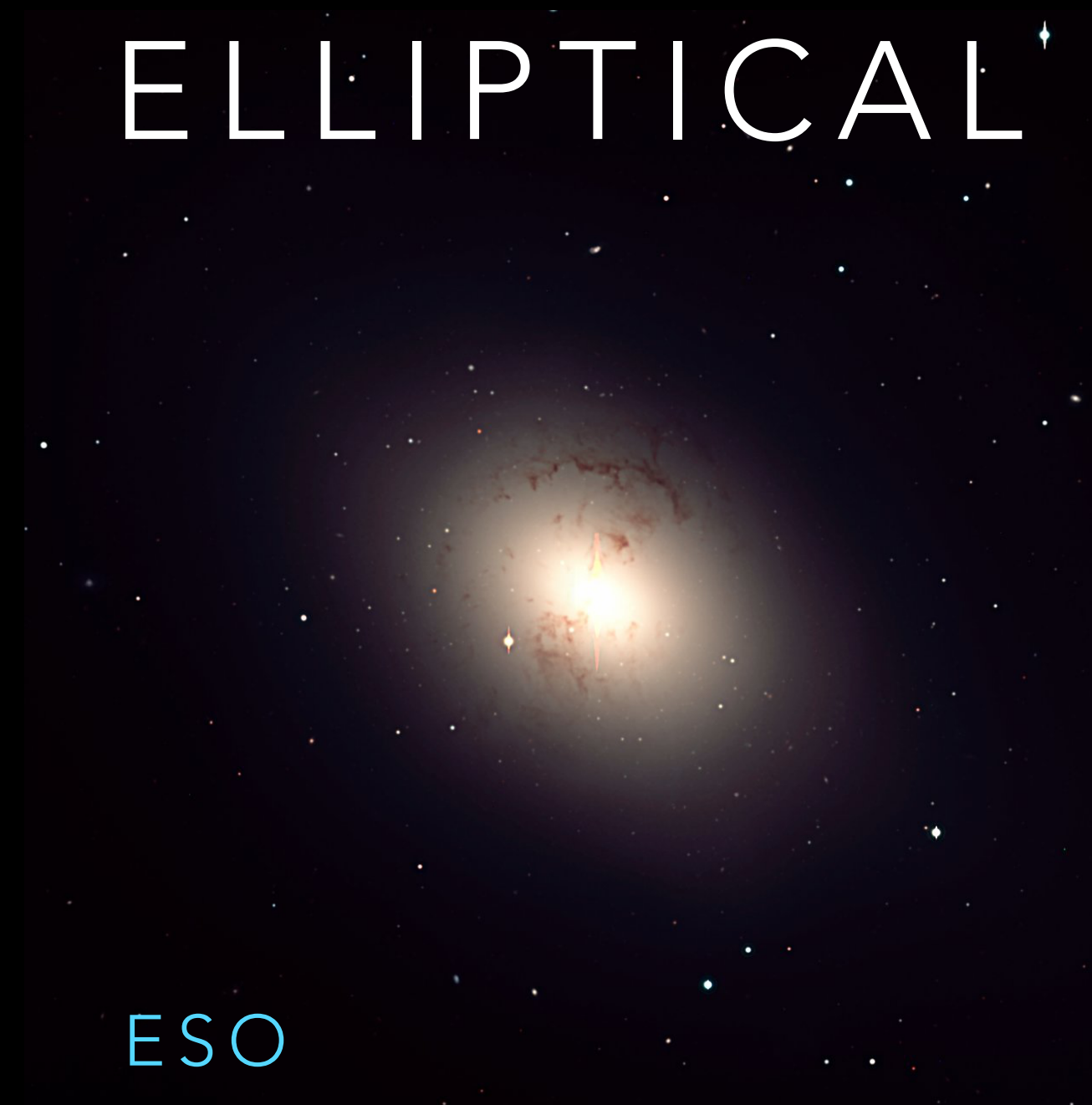
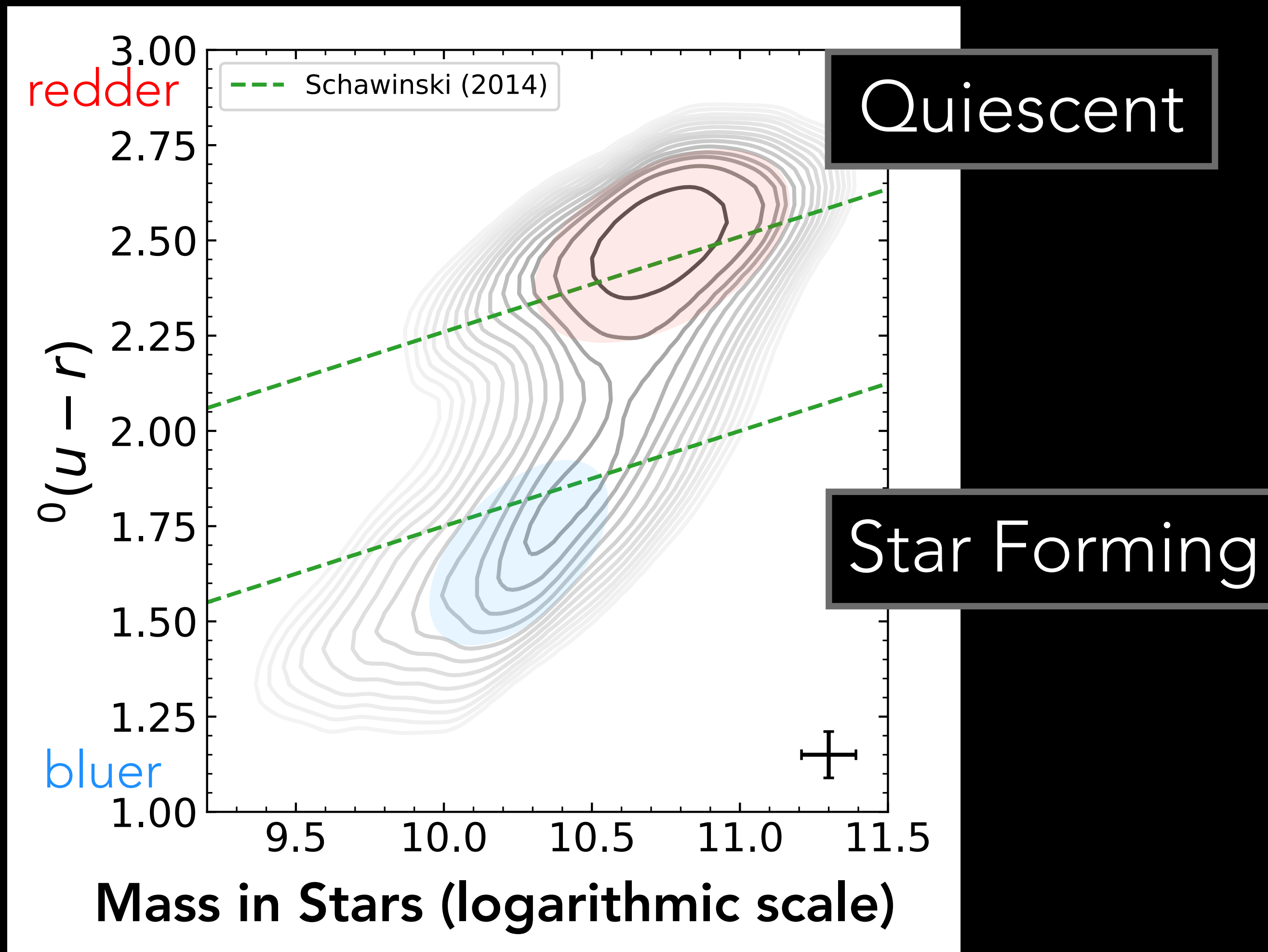
- Young populations of stars are **blue** because they still have the most massive stars, which are the bluest and brightest.
- As the population of stars ages, the bluest and brightest stars die off, leaving the **redder** and lower mass stars to dominate the light produced.
- All galaxies must have formed stars at some point. Some stopped forming stars and transitioned from **blue** to **red**. Very few resume forming stars after stopping, so changing from **red** to **blue** is rare.

TWO MAIN CLASSES OF GALAXIES



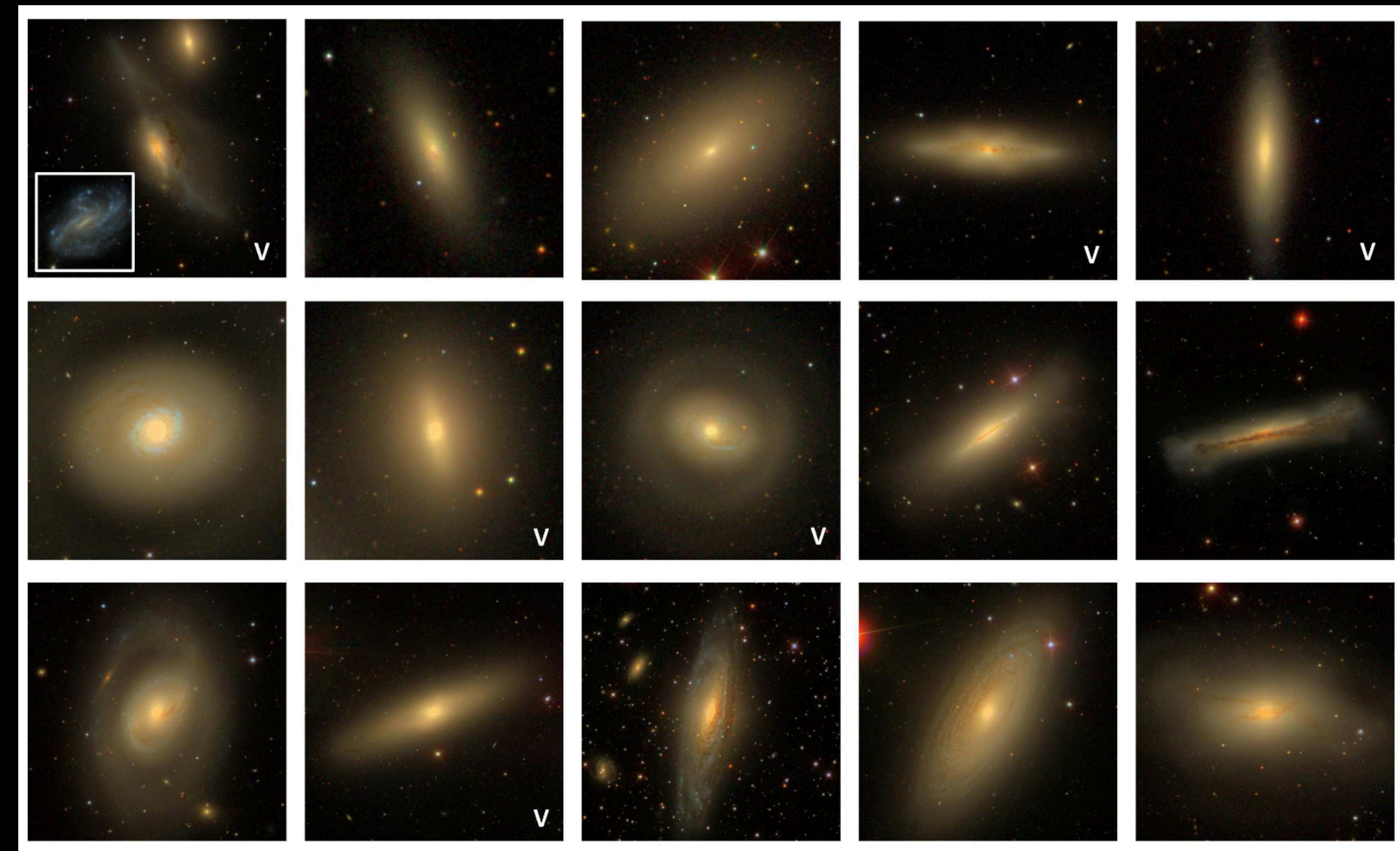
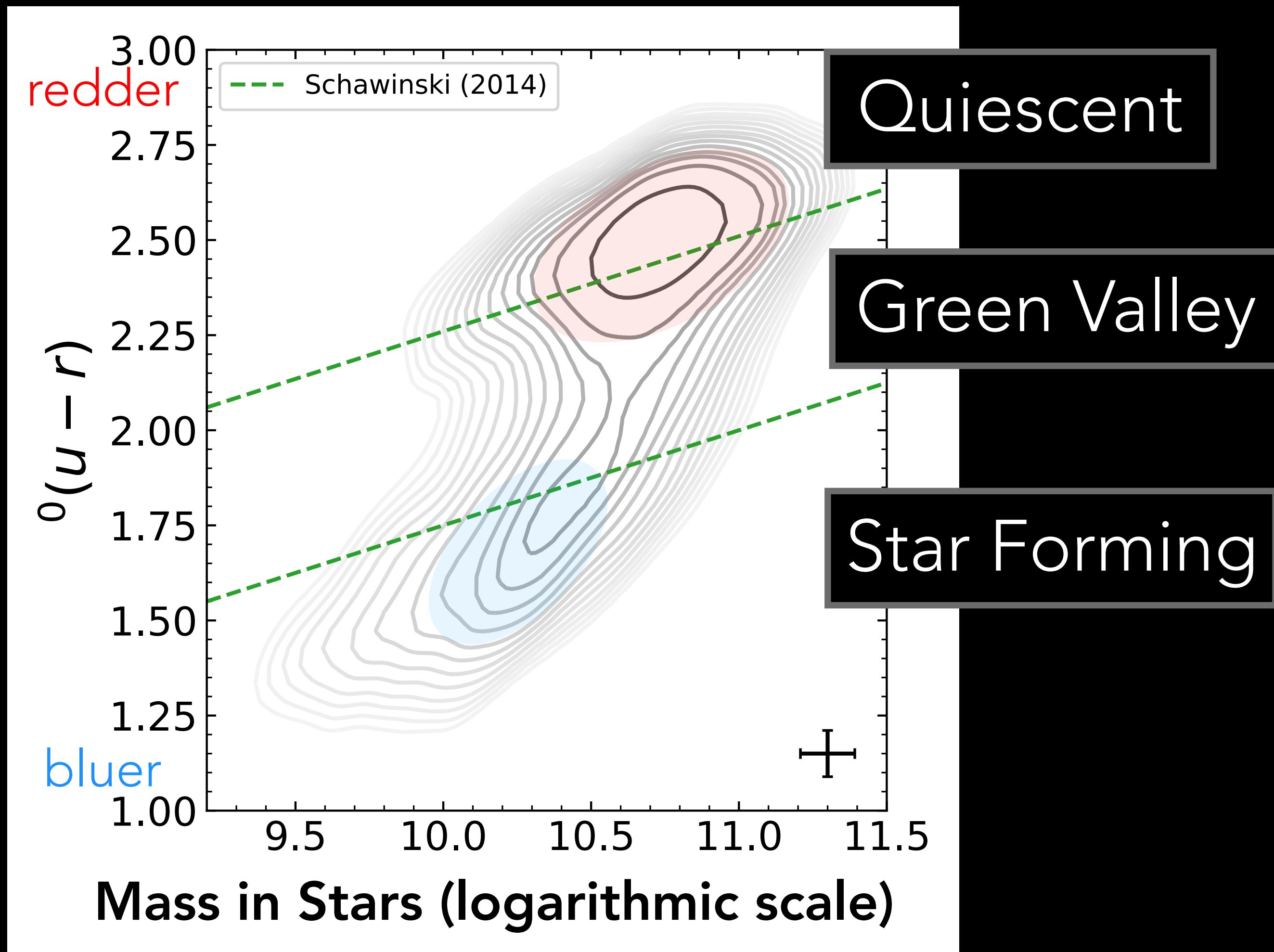
Blue star-forming disk galaxies

TWO MAIN CLASSES OF GALAXIES



Red quiescent (retired)
elliptical galaxies

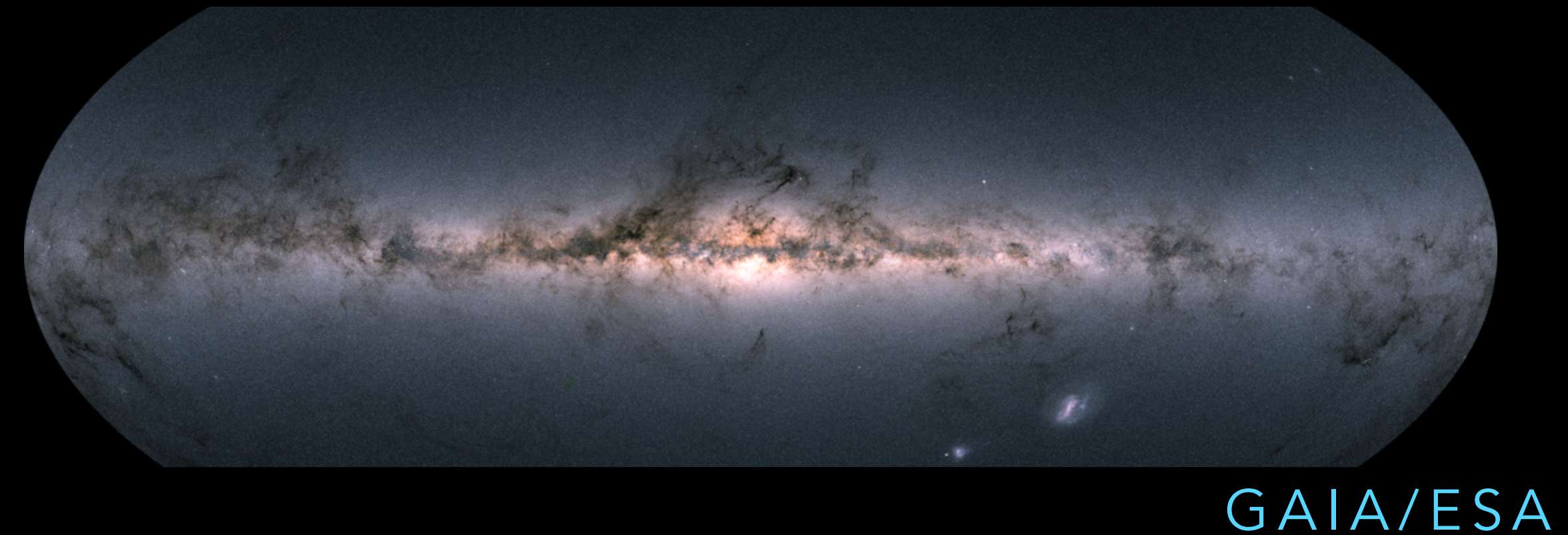
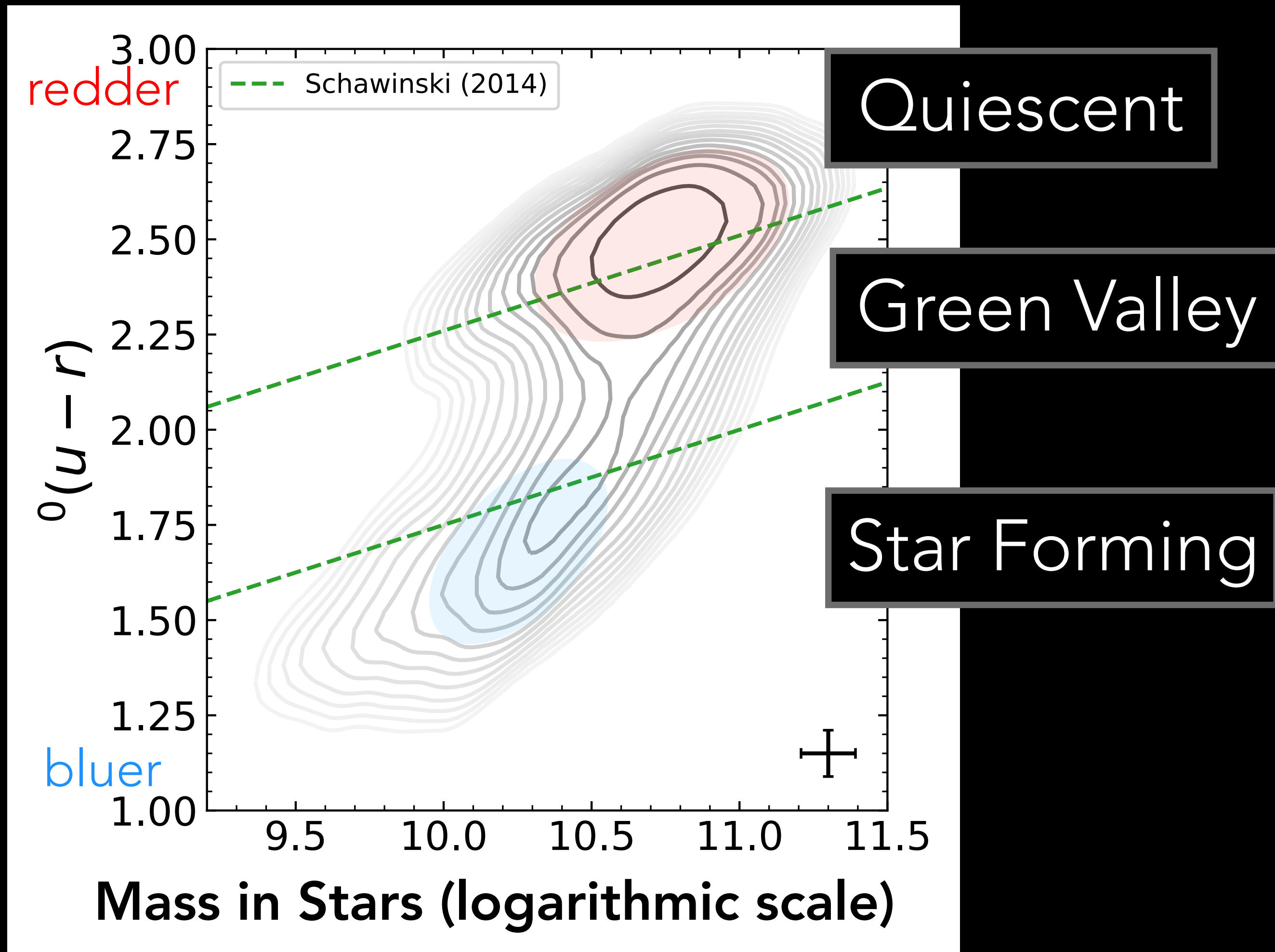
TWO MAIN CLASSES OF GALAXIES



S. SALIM

Relatively few transition galaxies in the "Green Valley."

WHERE DOES THE MILKY WAY FIT IN?



Dust prevents us from directly measuring the Milky Way's color and luminosity, hindering our ability to connect the Milky Way to broader galaxy populations.

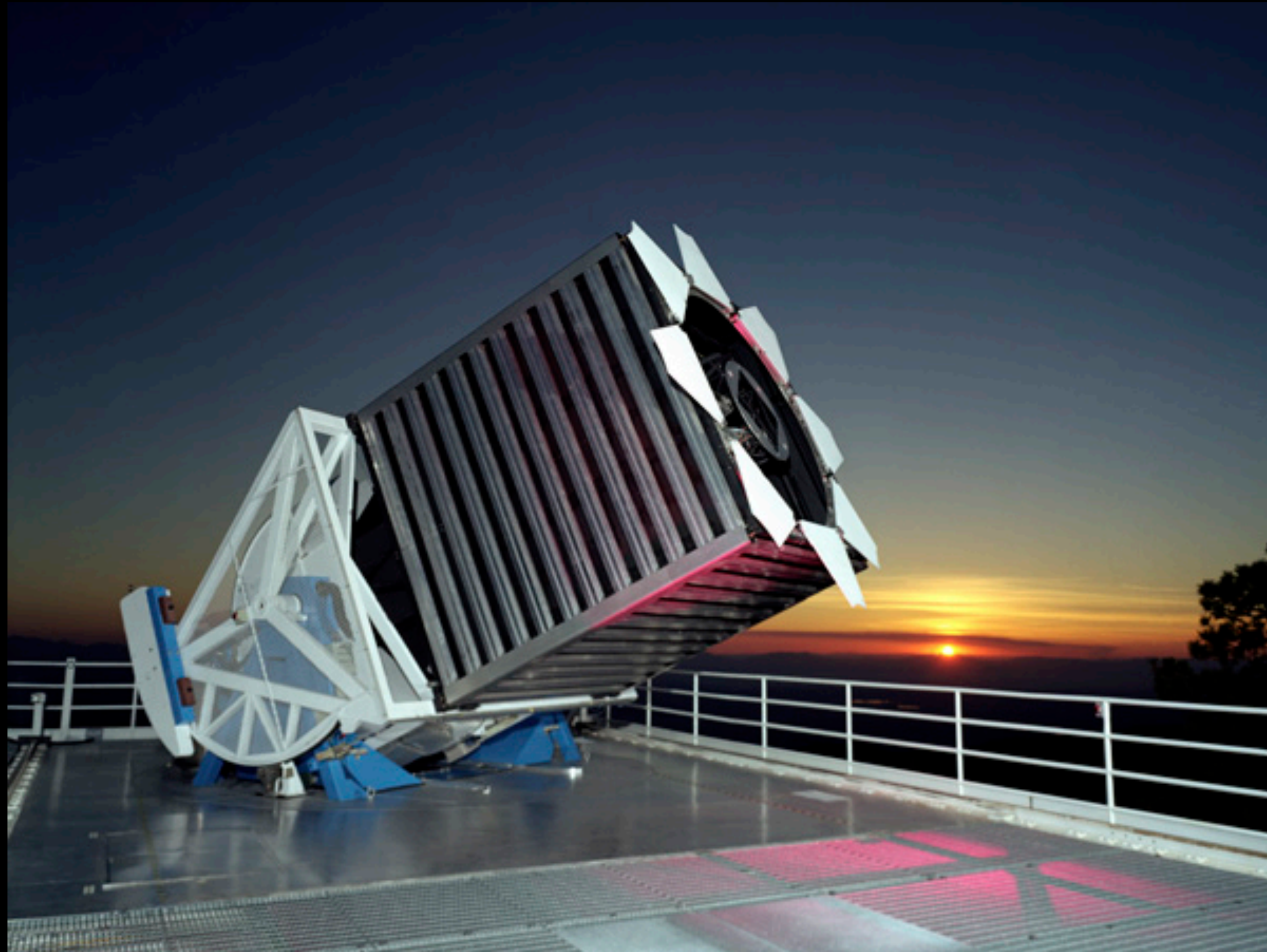
OUR PLAN: STUDY MILKY WAY DOPPELGÄNGERS



LICQUIA+ 2016

- Estimate the Milky Way's colors by looking at its doppelgängers, which we chose using a few key parameters that are well-measured for both the Milky Way and other nearby galaxies.

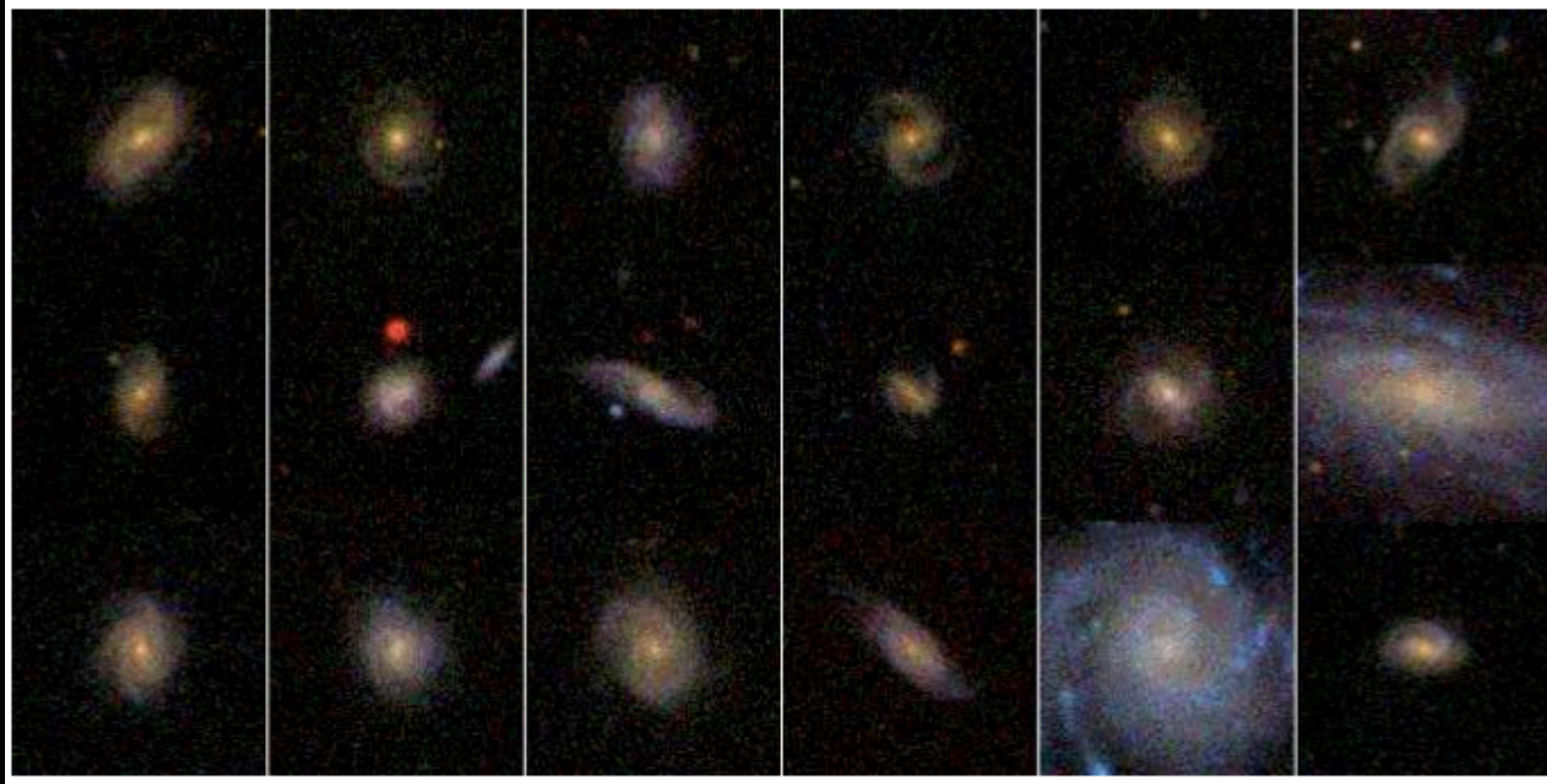
MINING THE SLOAN DIGITAL SKY SURVEY



- The Sloan Digital Sky Survey ushered in a new era of large wide-field and multi-wavelength surveys.
- Pitt was one of the partner institutions that produced the Sloan Digital Sky Survey.

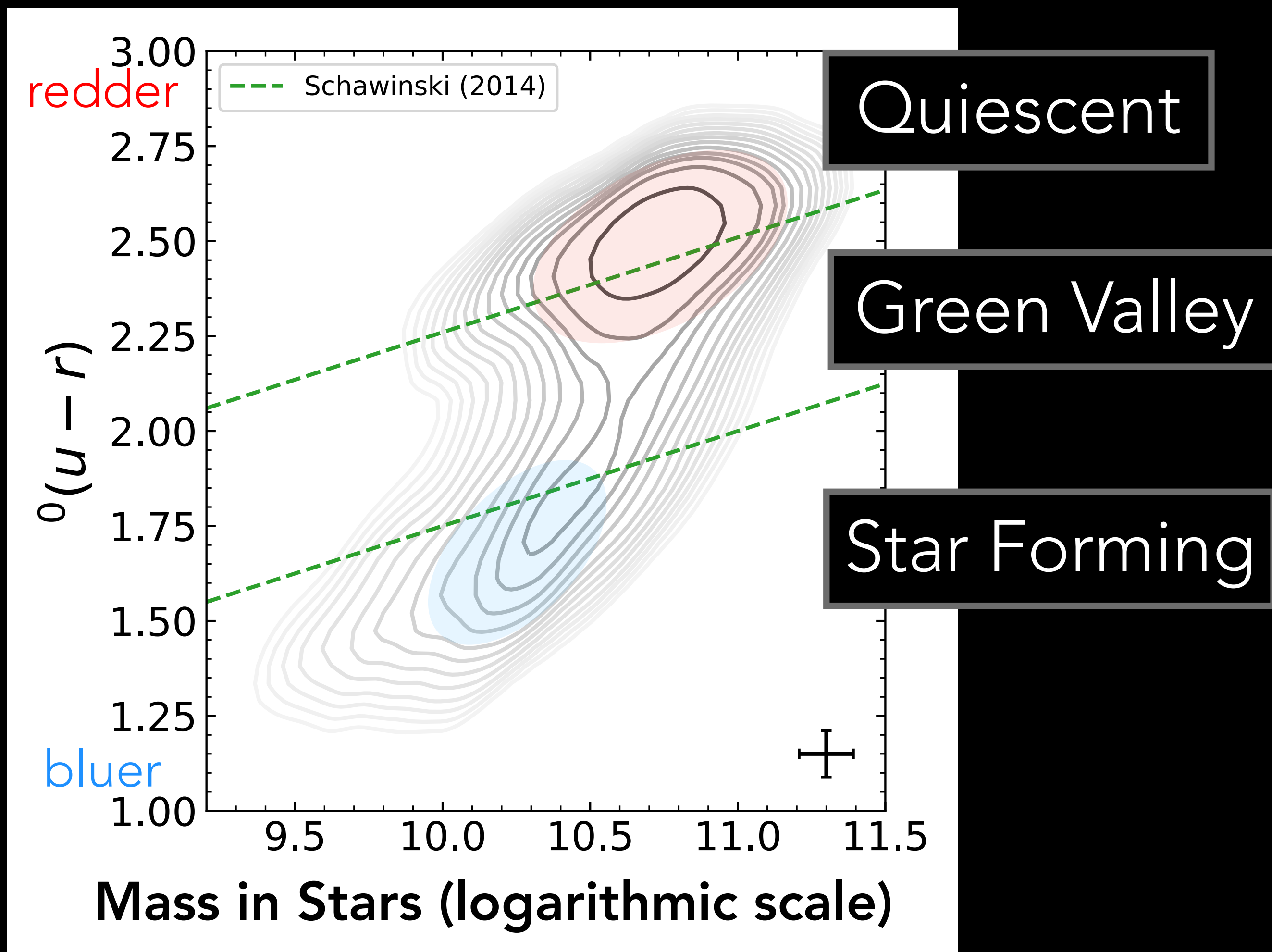
SDSS

MINING THE SLOAN DIGITAL SKY SURVEY



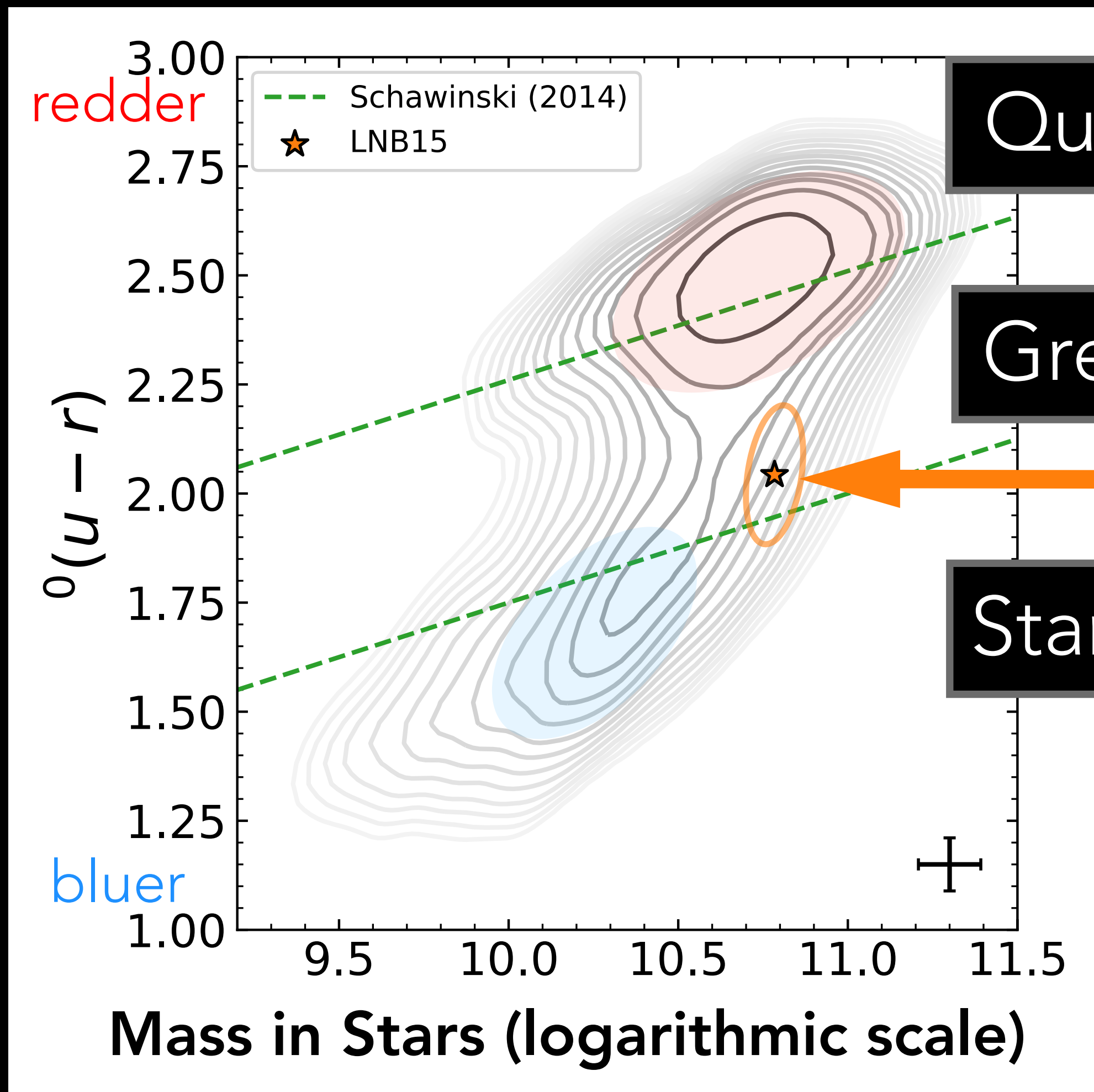
- Its large and uniform sample of galaxy observations forms a rich dataset for data mining projects like ours.

IS THE MILKY WAY BLUE OR RED?



IS THE MILKY WAY BLUE OR RED?

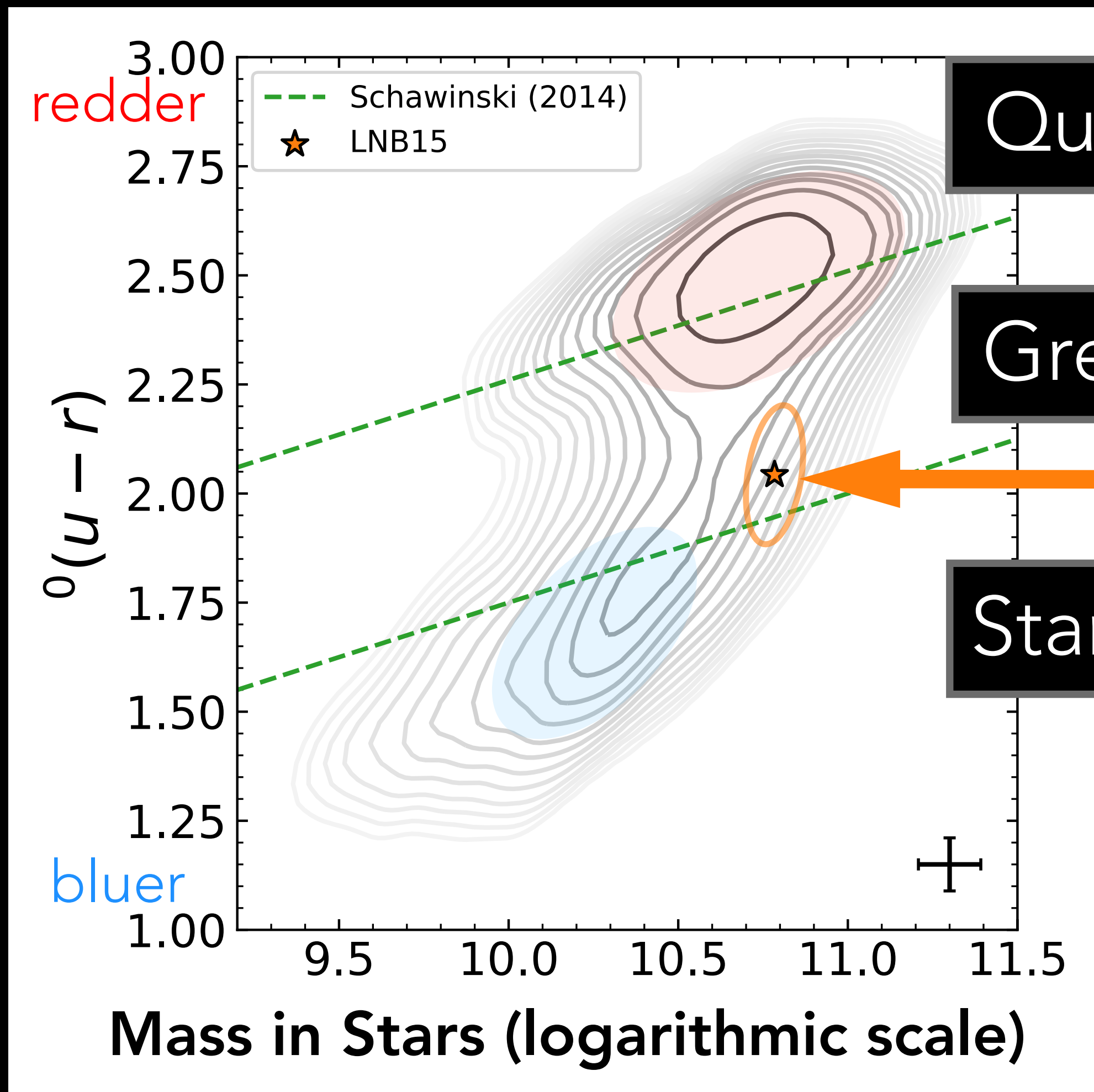
YES...



Average of Milky Way
doppelgängers

The Milky Way is either one of the reddest
blue galaxies or one of the bluest red
galaxies.

IS THE MILKY WAY BLUE OR RED? YES...WHICH MAKES IT GREEN?

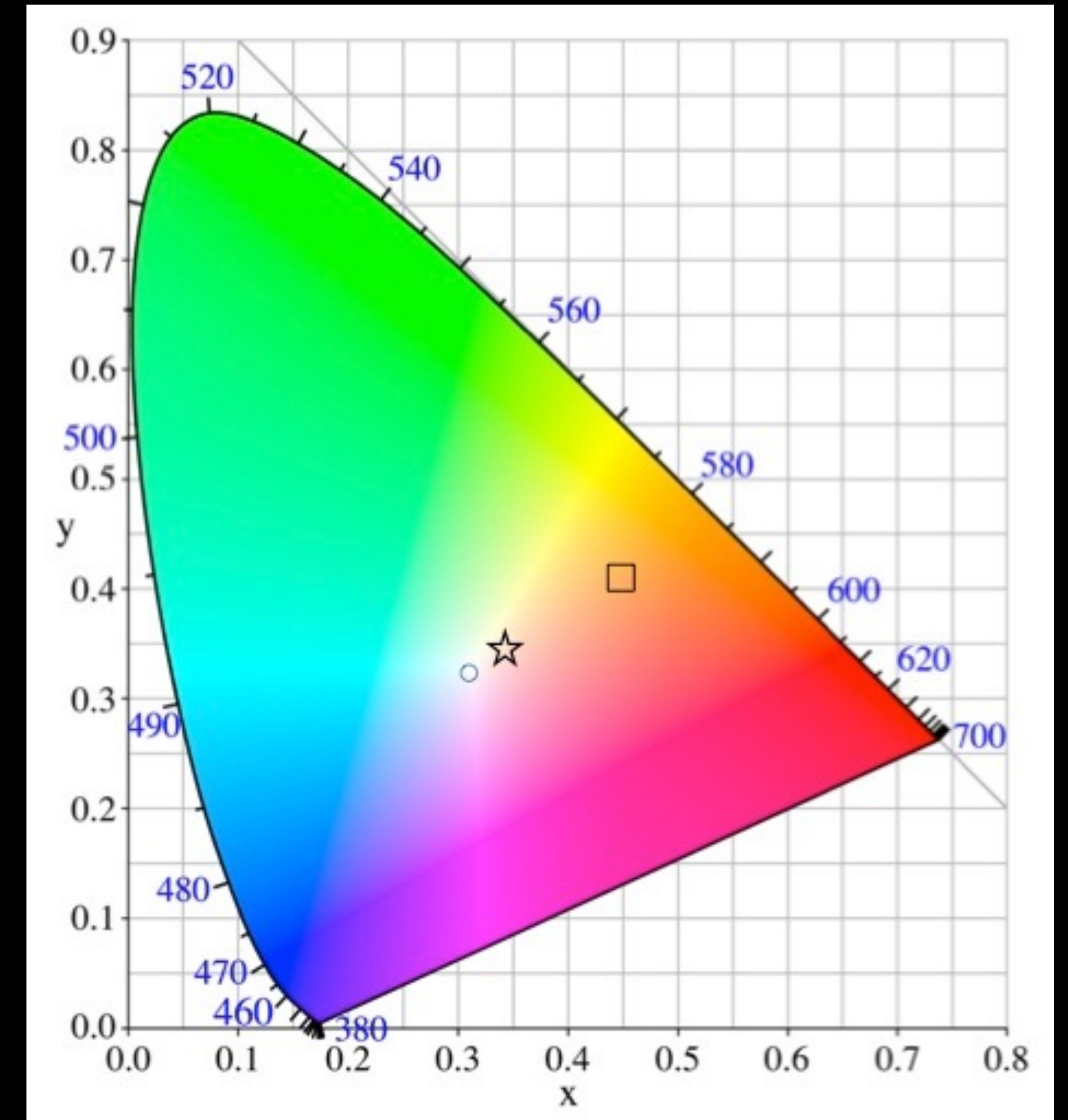


Average of Milky Way
doppelgängers

In optical colors, the Milky Way lies in the
"Green Valley."

IS THE MILKY WAY BLUE OR RED?
YES...WHICH MAKES IT GREEN?
WELL, NOT QUITE.

- In isolation, we would perceive the Milky Way as **white** like new spring snow seen in early morning light.
- Color temperature of 4840 K, which is
 - redder than white on a TV (6500 K), but
 - bluer than incandescent lights (3800 K).



CIE 1931 Chromaticity Diagram
Colors relative to D65 (wikimedia.org)

IS THE MILKY WAY BLUE OR RED?
YES...WHICH MAKES IT GREEN?
WELL, NOT QUITE.

- We would perceive the Milky Way as **white** with a hint of lavender or yellow-beige, depending on the standard used.

Galaxy Colors Relative to D50 Standard Illuminant
(early morning light)

The Milky Way



Reddest galaxies observed

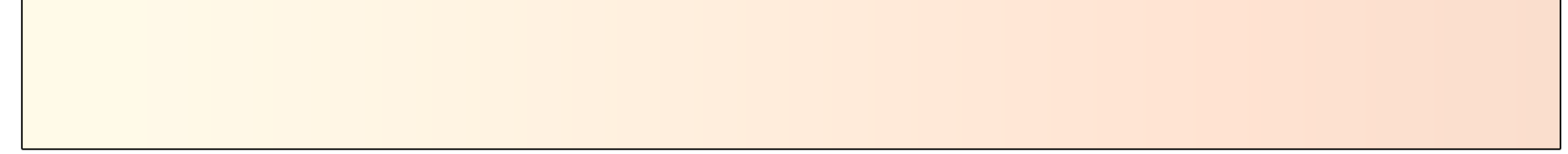


Bluest galaxies observed



Galaxy Colors Relative to D65 Standard Illuminant
(noontime light)

The Milky Way



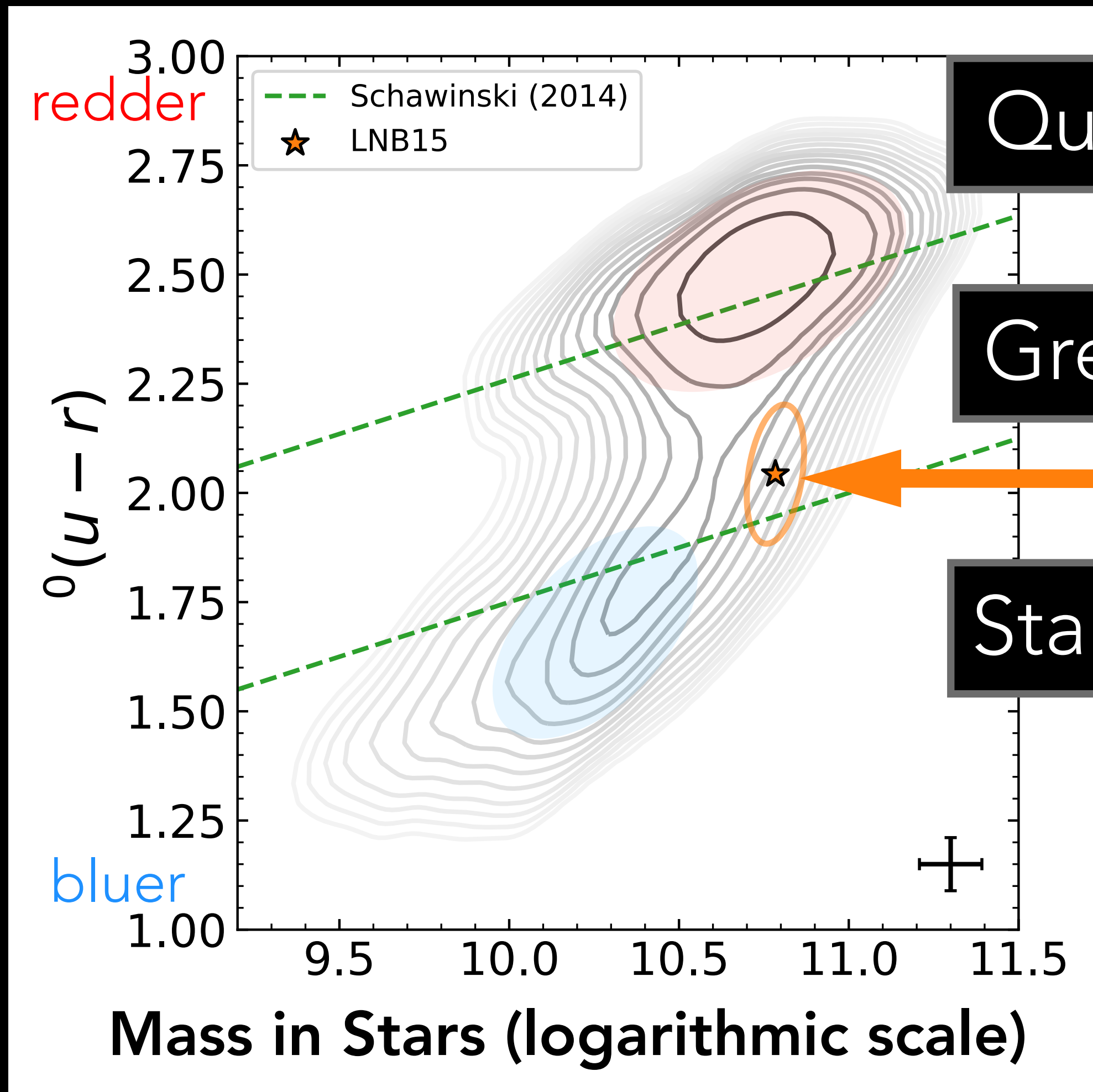
Reddest galaxies observed



Bluest galaxies observed



IS THE MILKY WAY BLUE OR RED? YES...WHICH MAKES IT GREEN?



Average of Milky Way
doppelgängers

- In optical colors, the Milky Way lies in the "Green Valley."
- Is the Milky Way transitioning from a star-forming galaxy to a quiescent galaxy?

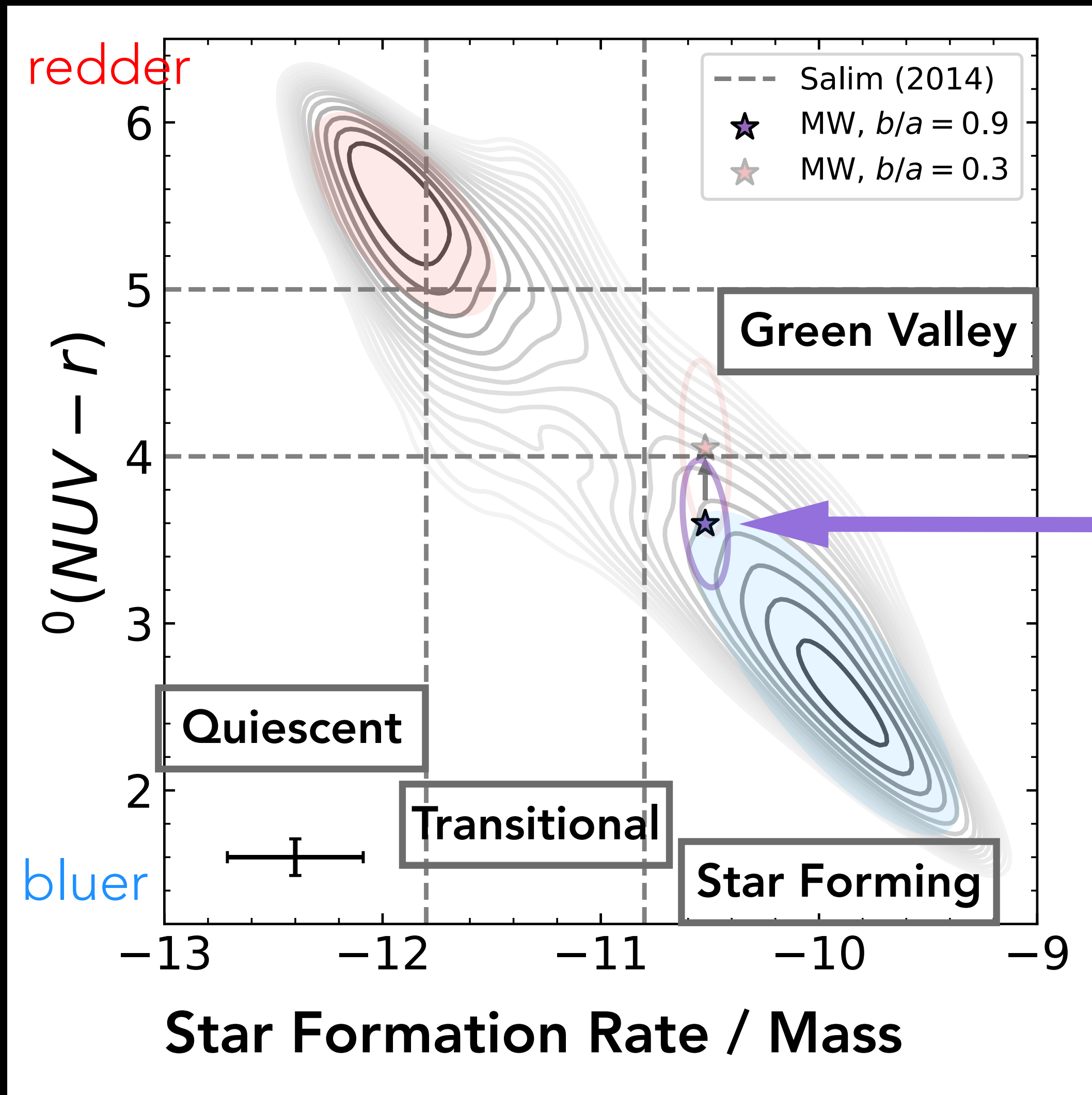
UV AND IR ARE BETTER TRACERS OF RECENT STAR FORMATION



ULTRAVIOLET

INFRARED

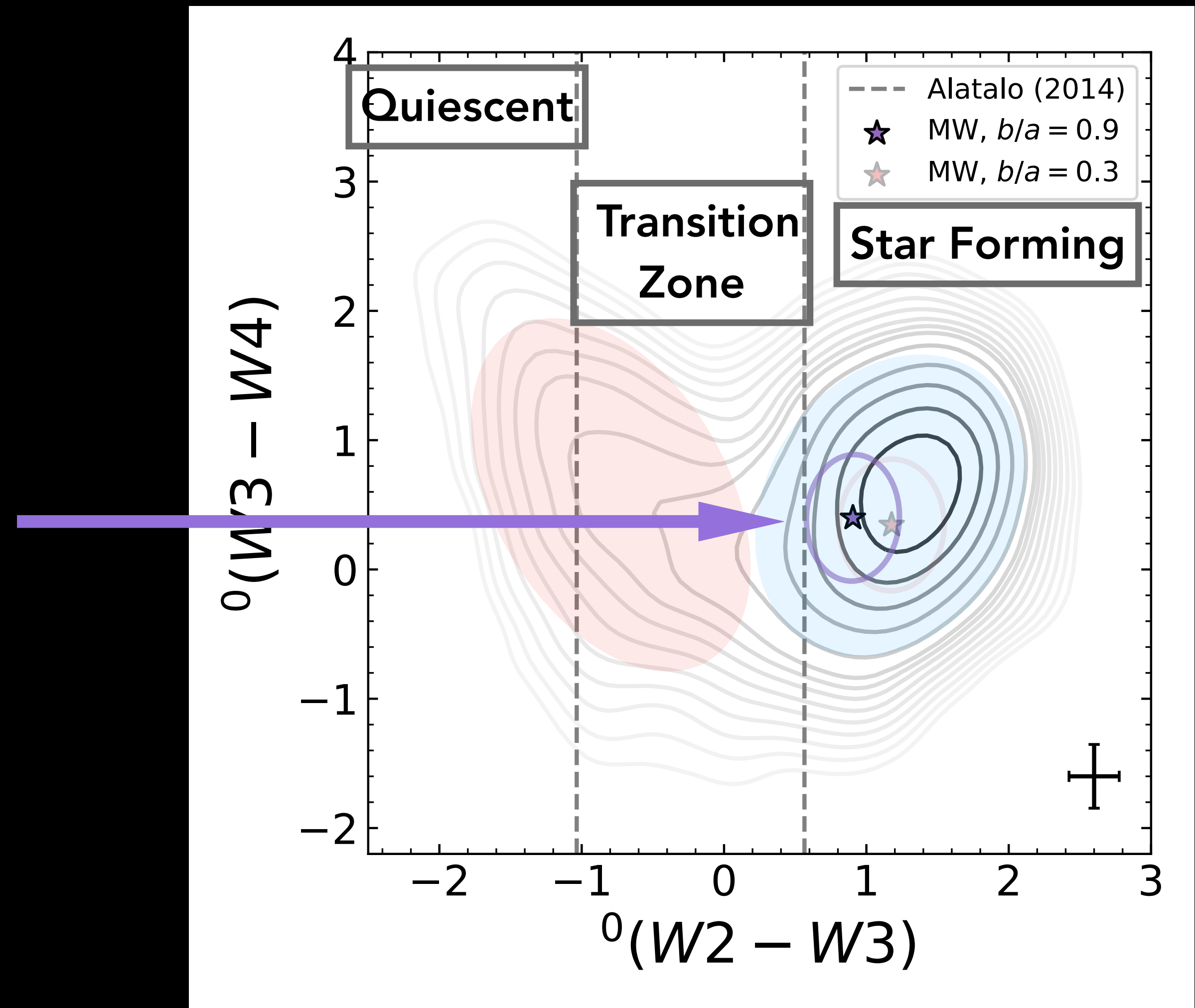
UV: THE MILKY WAY IS ON THE STAR-FORMING SIDE OF THE TRANSITION ZONE



Average of Milky Way
doppelgänger

IR: THE MILKY WAY IS ON THE STAR-FORMING SIDE OF THE TRANSITION ZONE

Average of Milky Way
doppelgängers

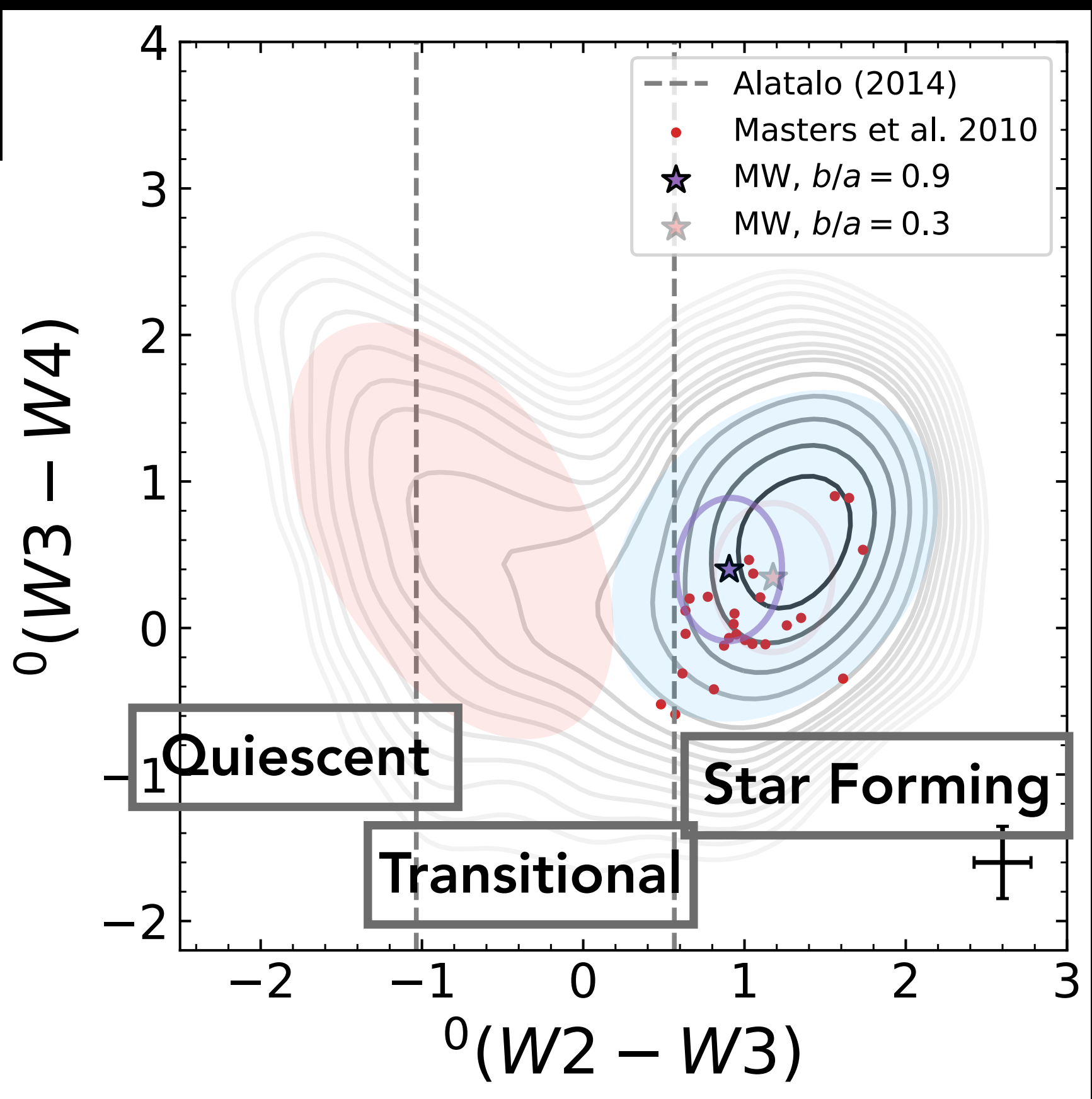
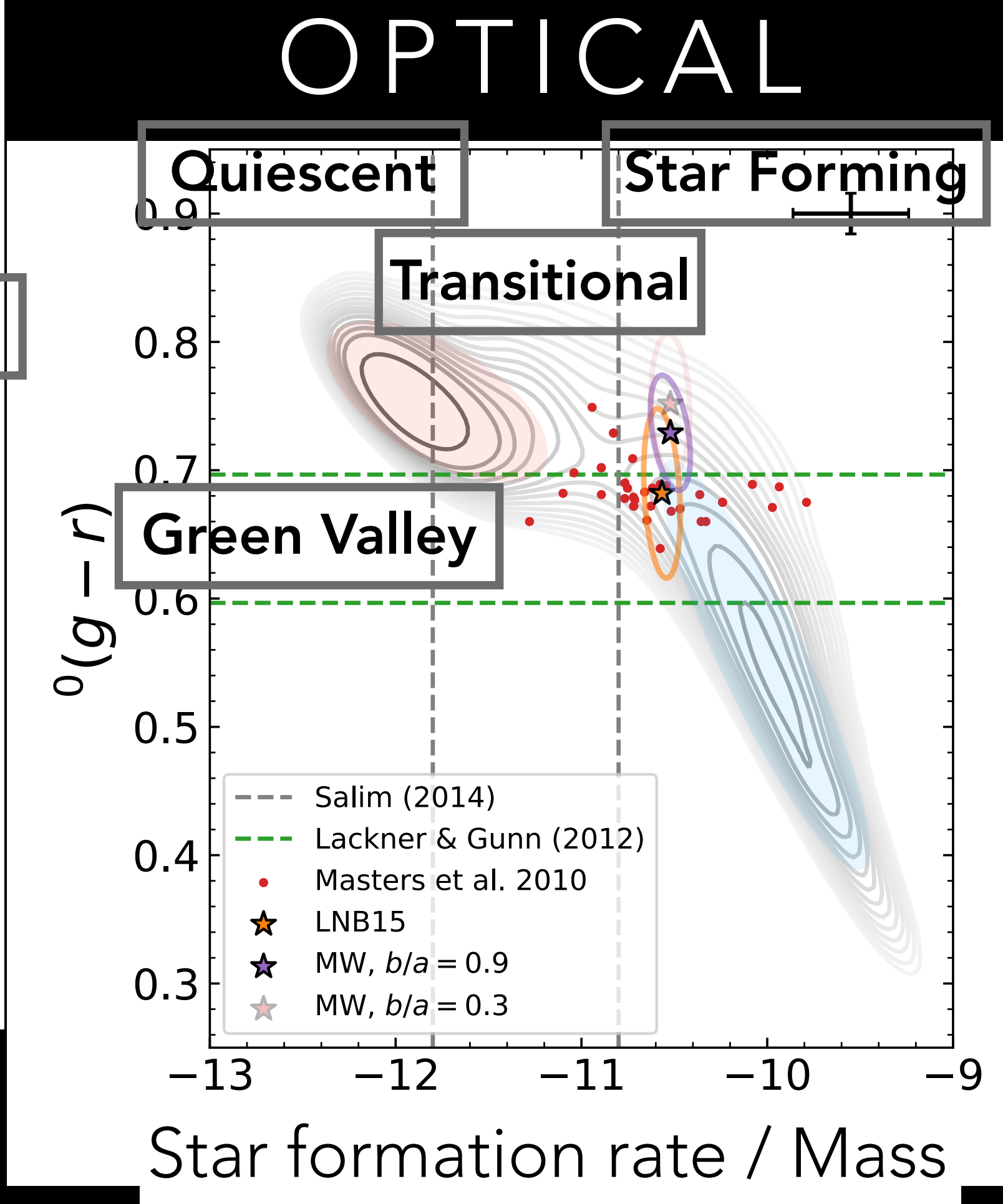
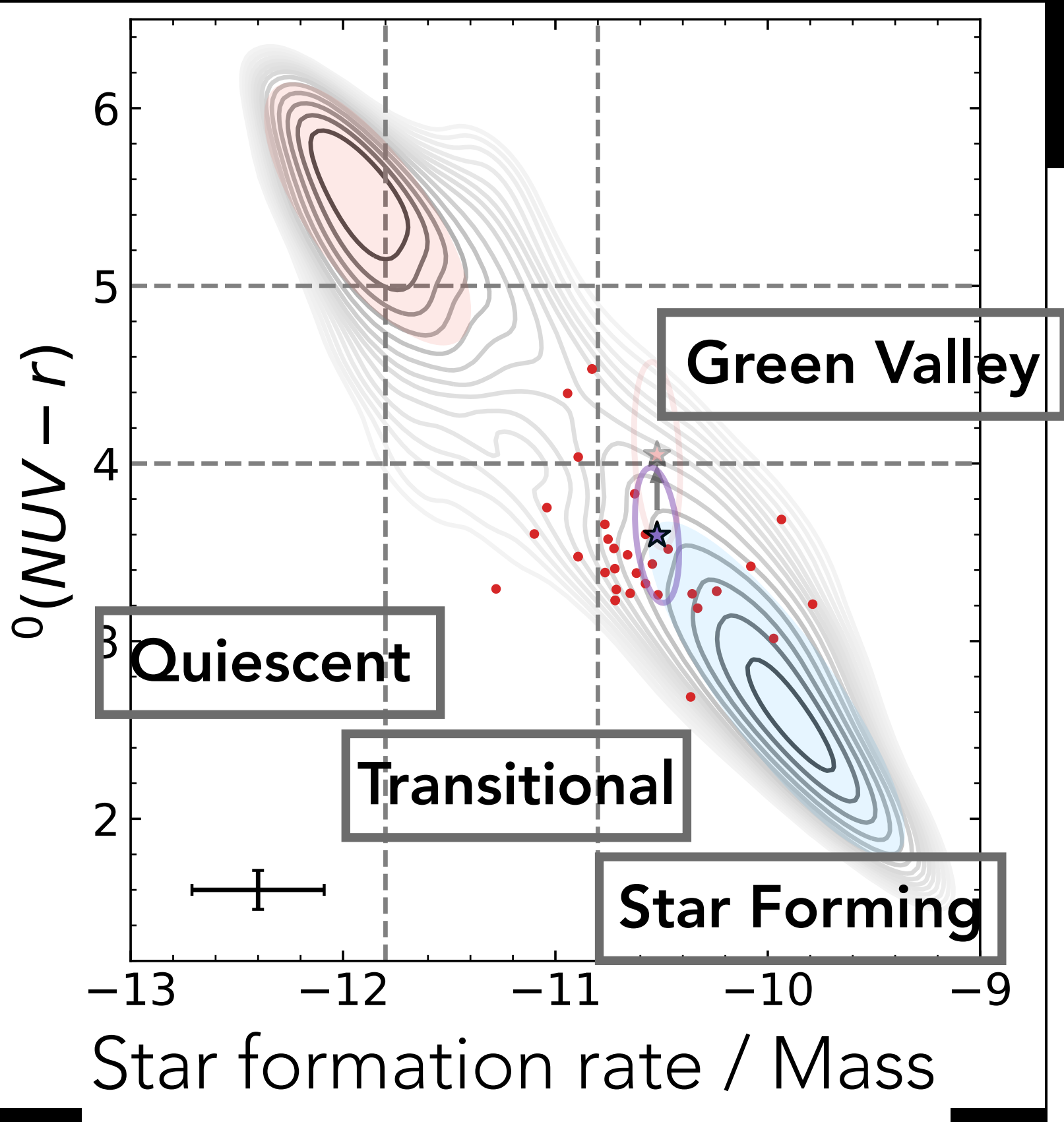


IS THE MILKY WAY IN THE GREEN VALLEY?

- In optical colors, the Milky Way lies in the “Green Valley,” the transition zone between star forming and quiescent galaxies.
- However, it lies on the star-forming side of the “Green Valley” in the UV and IR...

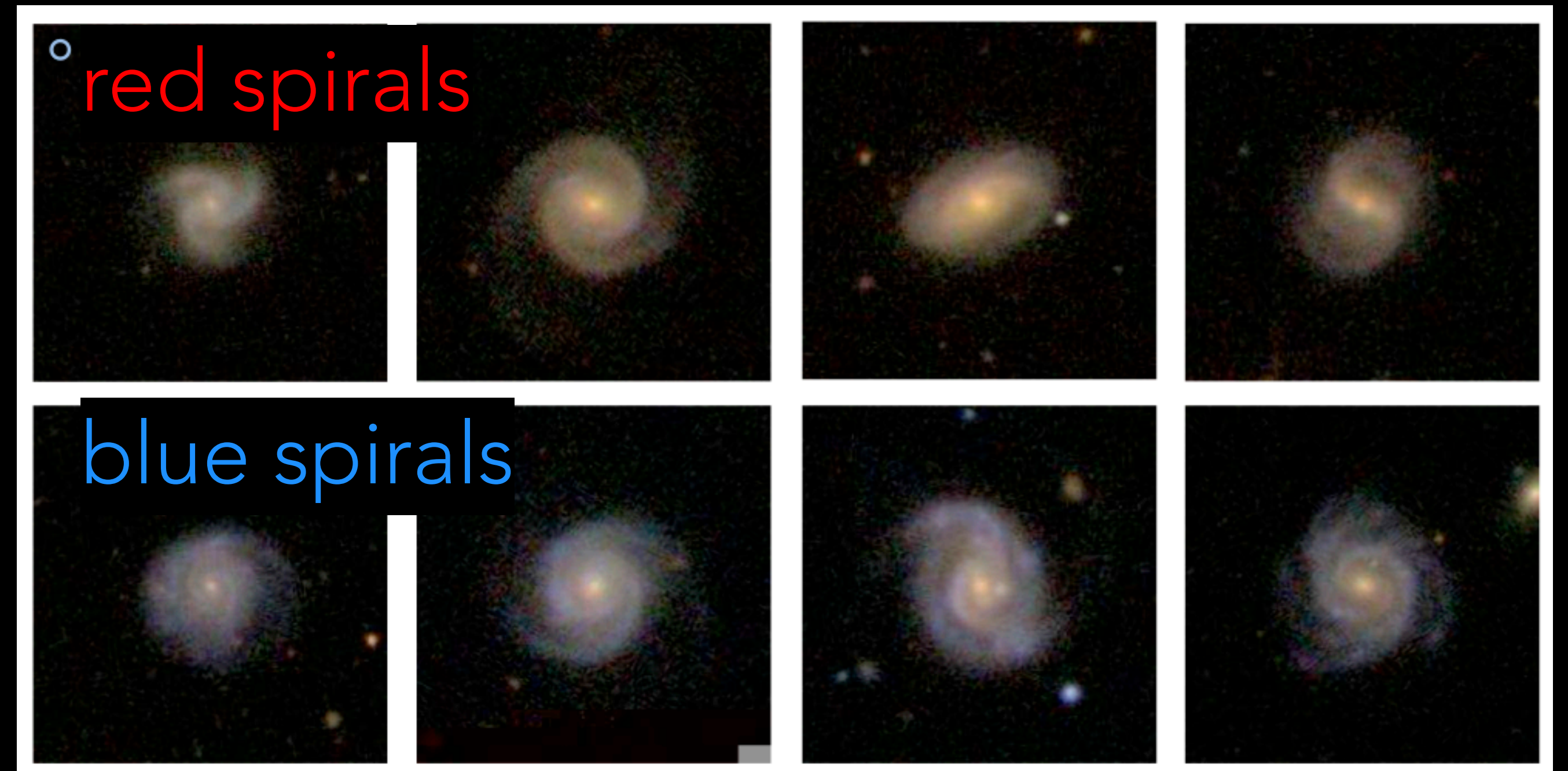
...SUGGESTING THAT THE MILKY WAY IS **NOT** A CLASSICAL GREEN VALLEY GALAXY BUT RATHER A **RED SPIRAL**

MID-IR



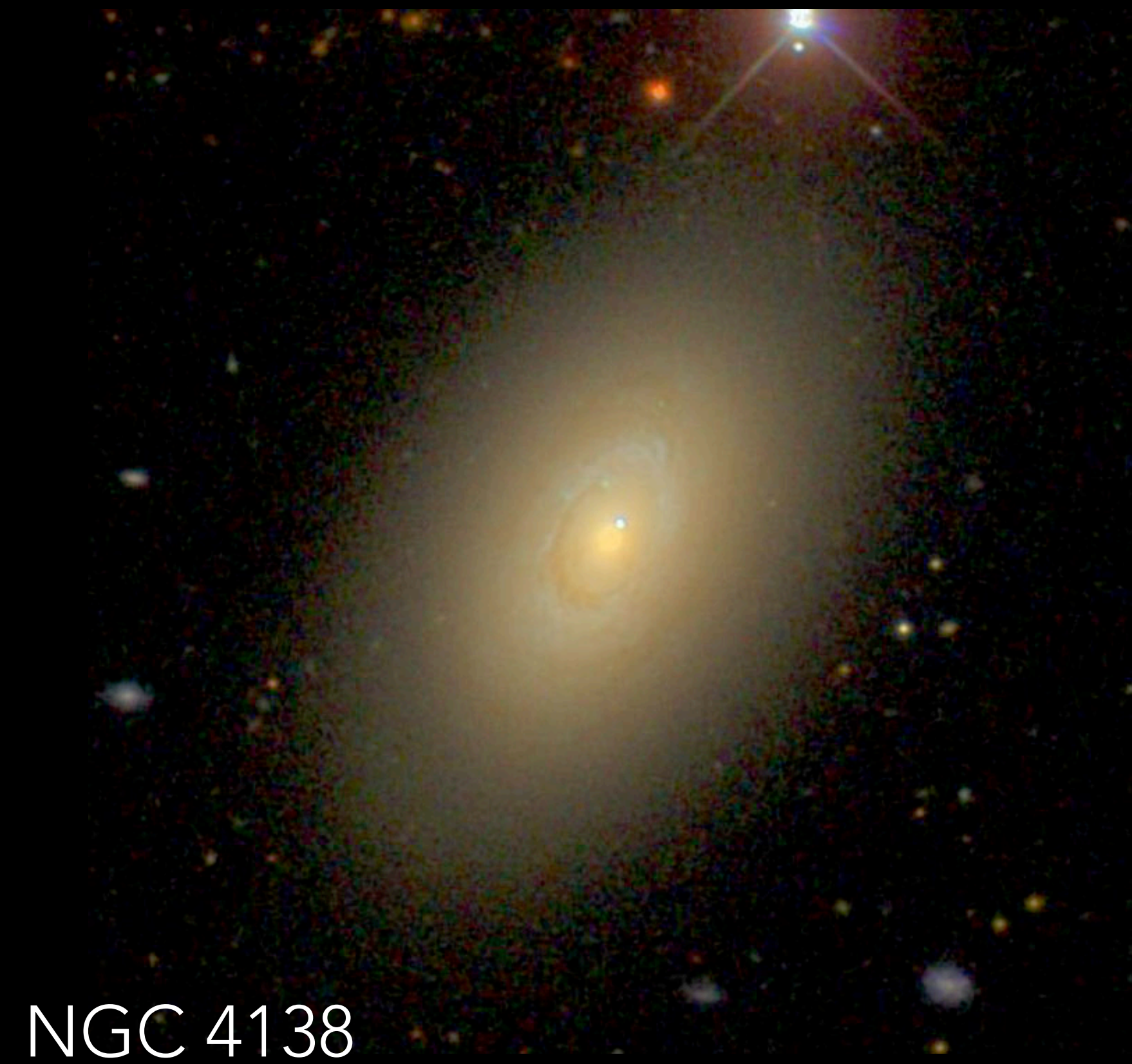
RED SPIRALS

- **Red spirals** are massive spirals that have a large population of older stars (which makes them **red** in optical colors).
- But **red spirals** are bright in the UV and are actively forming stars, though typically at lower rates than blue spirals.



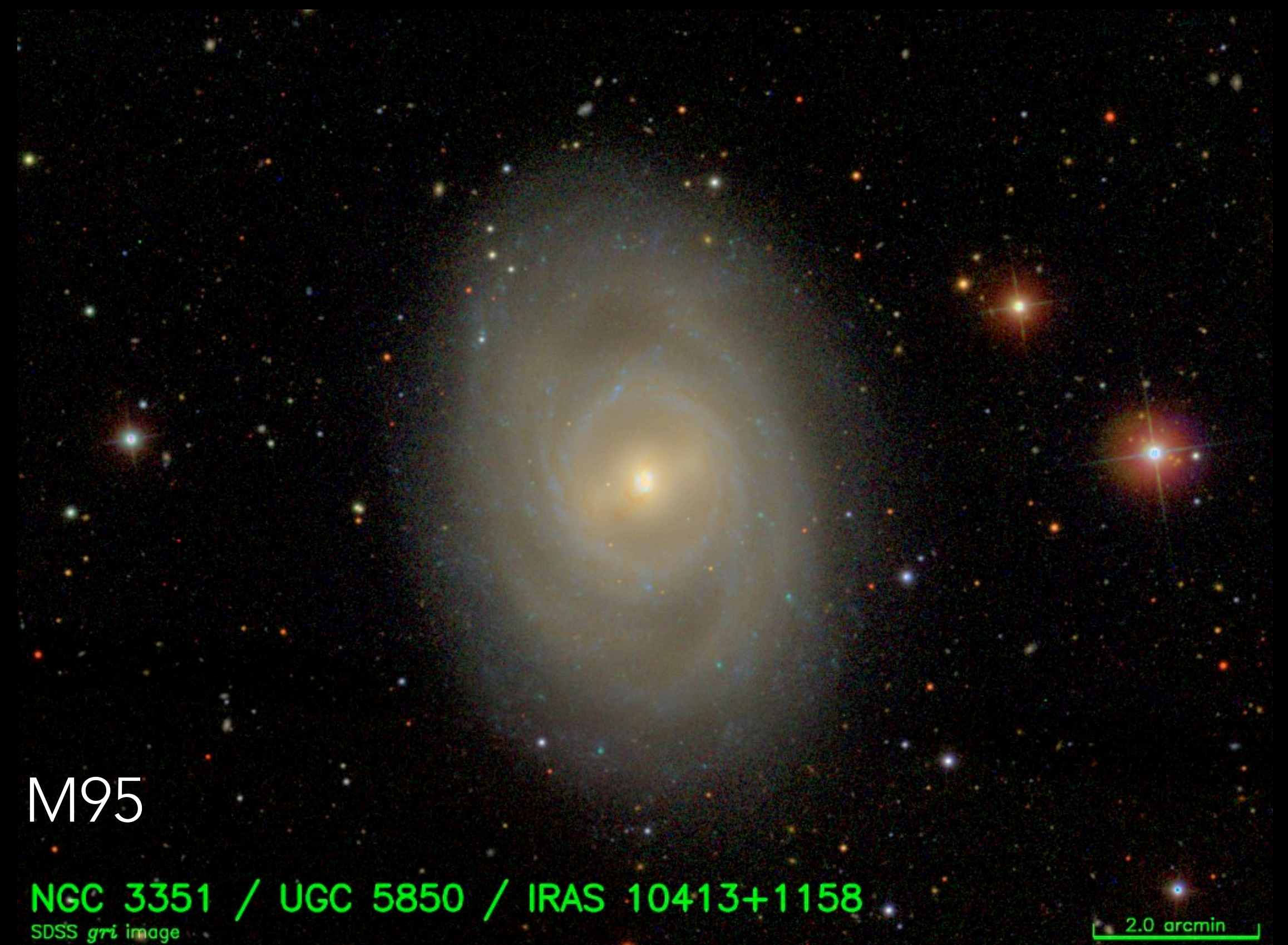
MASTERS+ 2010

THE TRUE COLORS OF THE MILKY WAY: THE CLOSEST MILKY WAY DOPPELGÄNGERS IN UV-OPTICAL-IR COLORS



NGC 4138

CSELIGMAN.COM

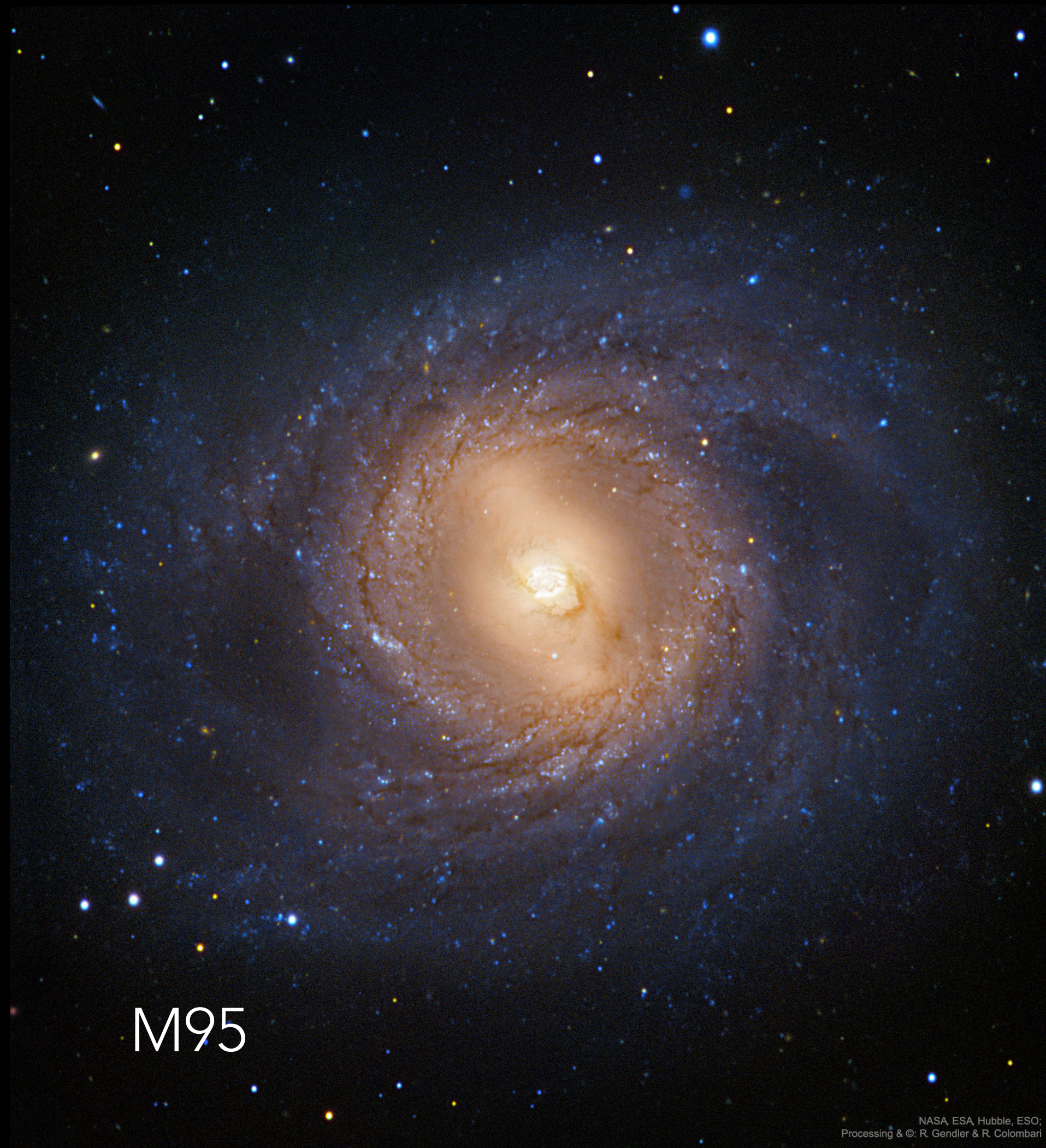


M95

NGC 3351 / UGC 5850 / IRAS 10413+1158
SDSS *gri* image

M. BLANTON, D. HOGG, SDSS

THE MILKY WAY: A RARE RED SPIRAL



In optical colors, the Milky Way lies in the "Green Valley," the transition zone between star forming and quiescent galaxies.

However, it lies on the star-forming side of the "Green Valley" in the UV and IR...

...suggesting that the Milky Way is **not** a classical Green Valley galaxy but rather a **red spiral** that is likely slowly becoming quiescent.