

# Characterizing Nearby Galaxies

Based on Multi-wavelength Imaging and Spatially Resolved Spectroscopy

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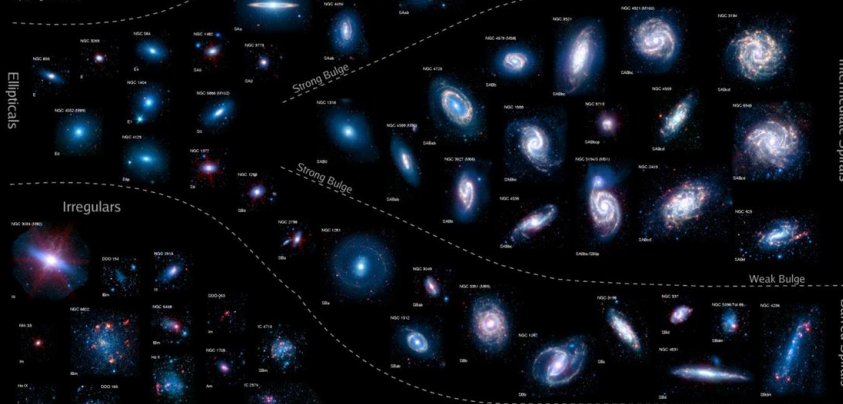


Meet the Neighbors  
The Spitzer Local Volume Legacy Survey

## The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 77 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning-Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies, and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0  $\mu\text{m}$ , and MIPS (the Multiband Imaging Photometer for Spitzer) at 24  $\mu\text{m}$ .

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation. More information can be found at: <http://sings.stsci.edu/>

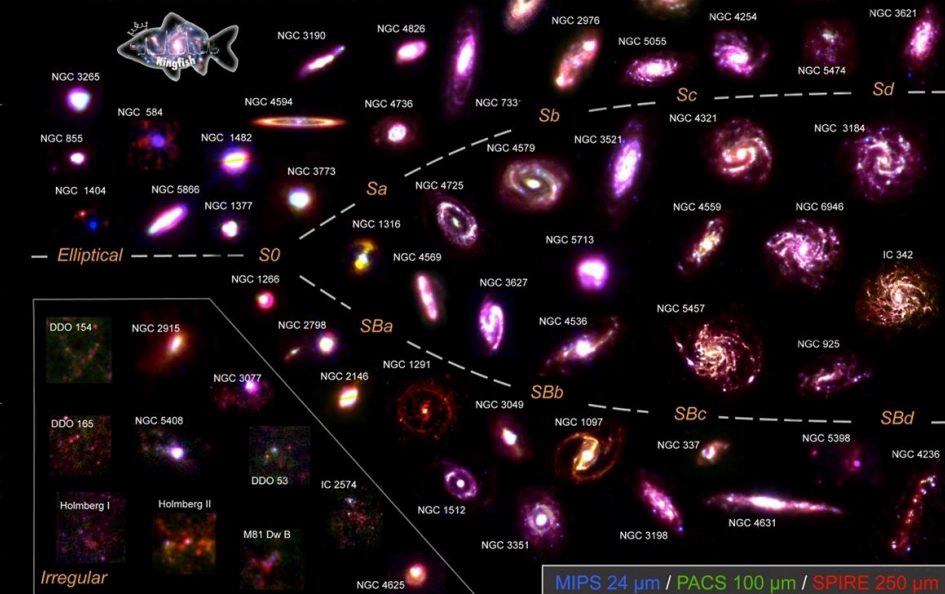


Prostar and composite images created from SINGS observations by Karl O. Gordon (co-PI), Blue/RAC 3.6  $\mu\text{m}$  (stars), Green/RAC 8.0  $\mu\text{m}$  (anomalous features from dust grains/molecules), Red/MIPS 24  $\mu\text{m}$  (spiral arms only)

SINGS Team  
Robert Kennicutt, Jr., Principle Investigator, Debra Calzetti (Deputy Principle Investigator), Charles Engelbracht, (Technical Contact), Lee Armus, George Bendo, Catherine BGL, Brett Bourke, Chris Conroy, Daniel Daley, Steve Dey, Joel Gerber, Robert Goicoechea, David Hatzidimitriou, Tony Jarrett, Lee Marshall, Gábor Lénárt, Adam L. Longmire, Matthew Smith, Heidi Stier, John Moustakas, Elizabeth M. Smeaton, George Patai, Maria Rosa, Helene Roussel, Karik Sheth, J.D. Smith, Michelle Thumy, Fabian Walter & George Helou.

## Kingfish (Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel)

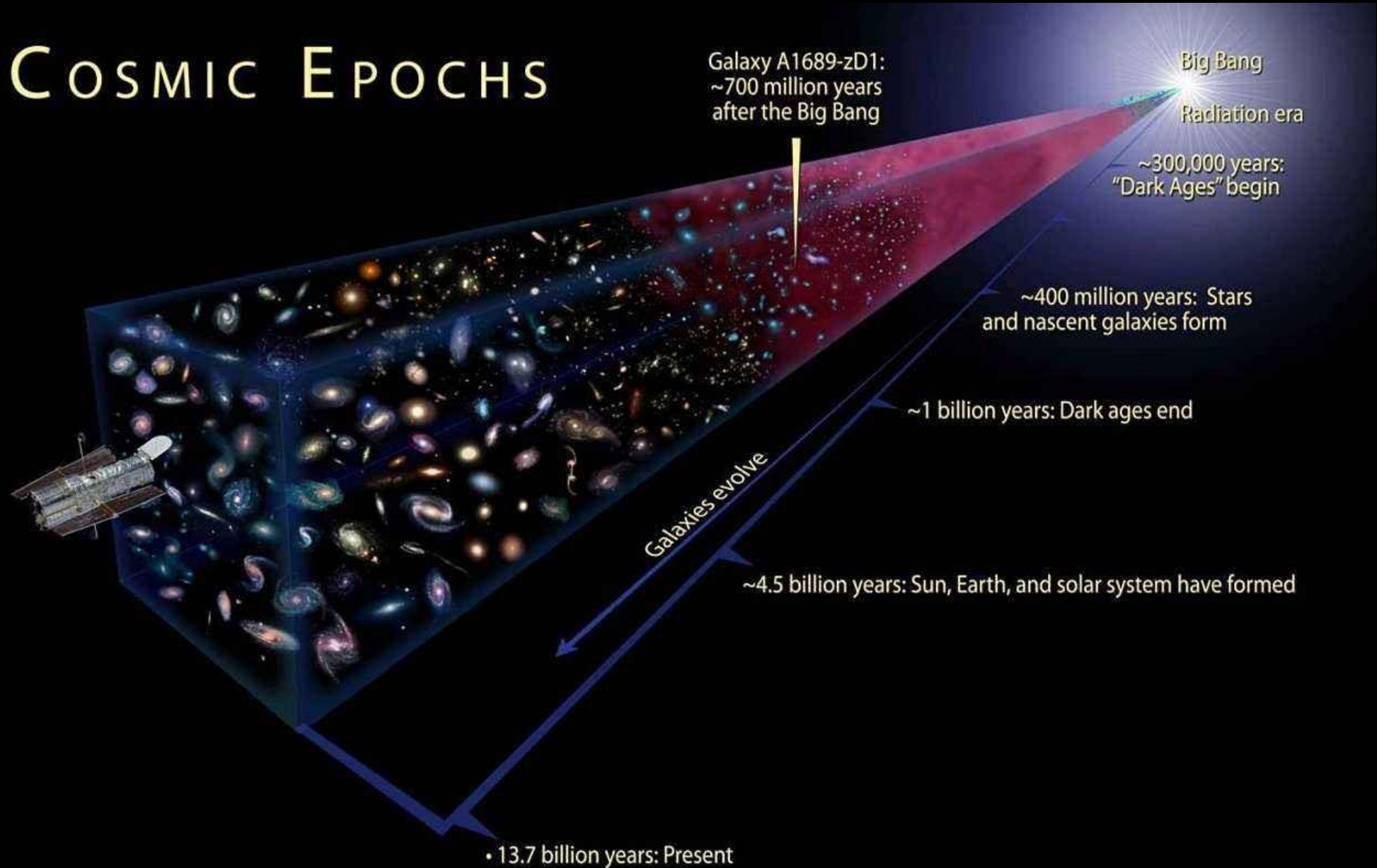
<http://www.ast.cam.ac.uk/research/kingfish>



MIPS 24  $\mu\text{m}$  / PACS 100  $\mu\text{m}$  / SPIRE 250  $\mu\text{m}$

# Nearby Galaxies

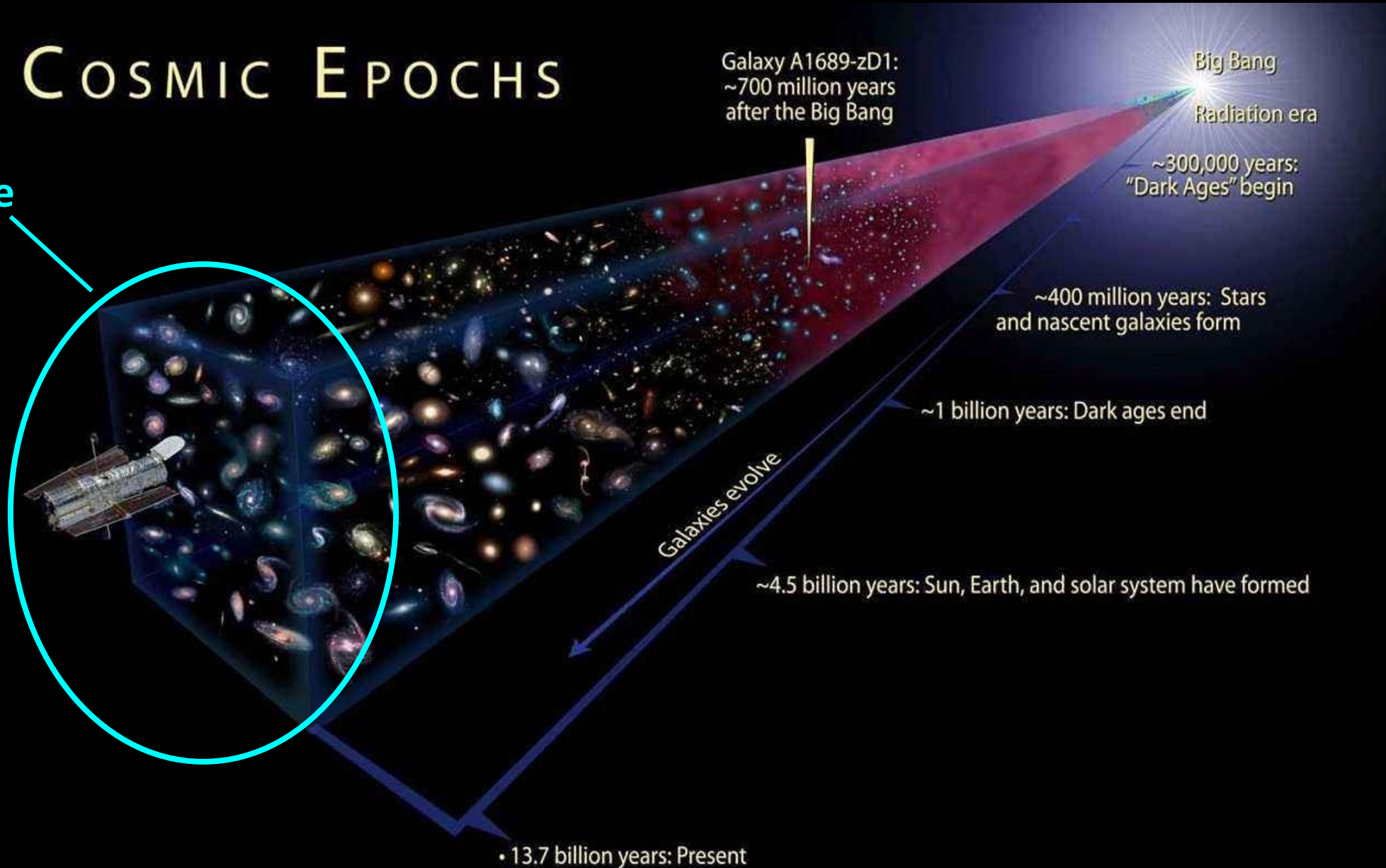
## COSMIC EPOCHS



# Nearby Galaxies

## COSMIC EPOCHS

Nearby Galaxies  
in the Local Universe

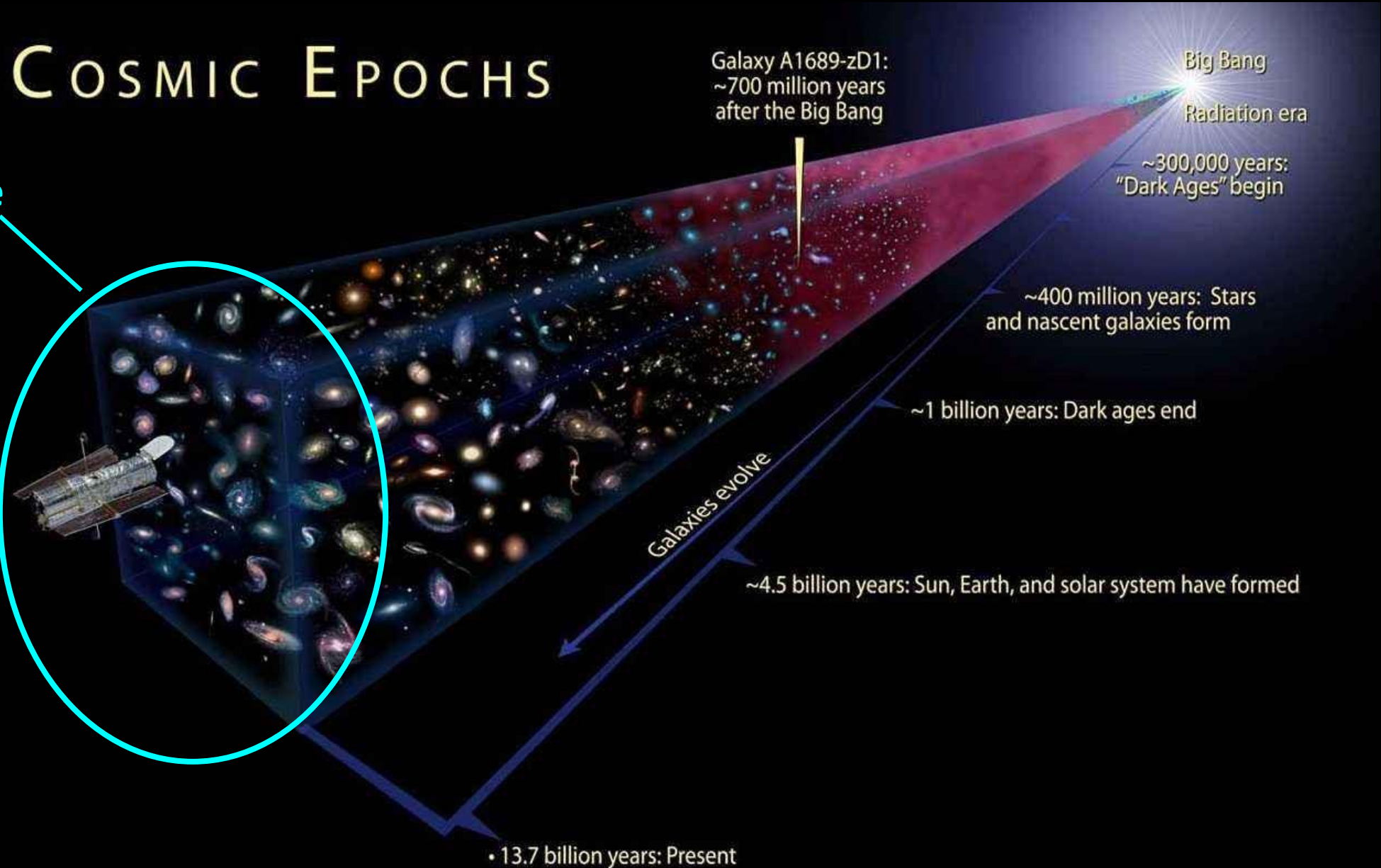


# Nearby Galaxies

## COSMIC EPOCHS

### Nearby Galaxies in the Local Universe

*Mature Bodies*  
*Annual Rings*  
*Fossil Imprints*



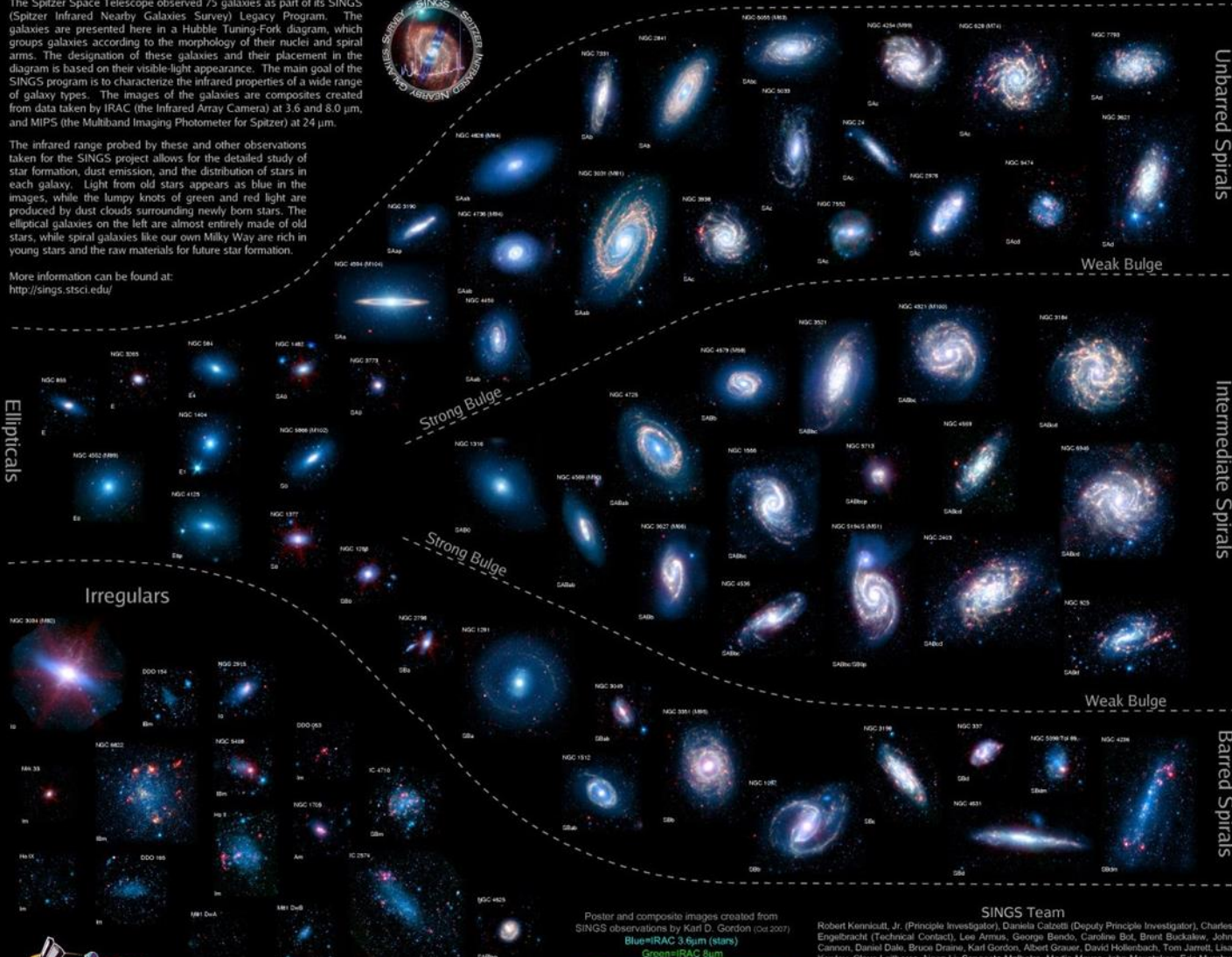
# Nearby Galaxies

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Ellipticals

Irregulars

Strong Bulge

Strong Bulge

Unbarred Spirals

Intermediate Spirals

Barred Spirals

Weak Bulge

Weak Bulge



Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)  
 Blue=IRAC 3.6 $\mu\text{m}$  (stars)  
 Green=IRAC 8 $\mu\text{m}$   
 (aromatic features from dust grains/molecules)  
 Red=MIPS 24 $\mu\text{m}$  (warm dust)

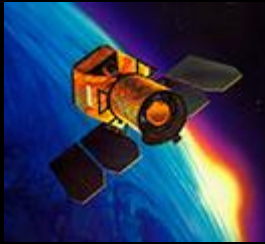
### SINGS Team

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# Nearby Galaxies

**GALEX**



**WISE**



**Spitzer**



**Herschel**

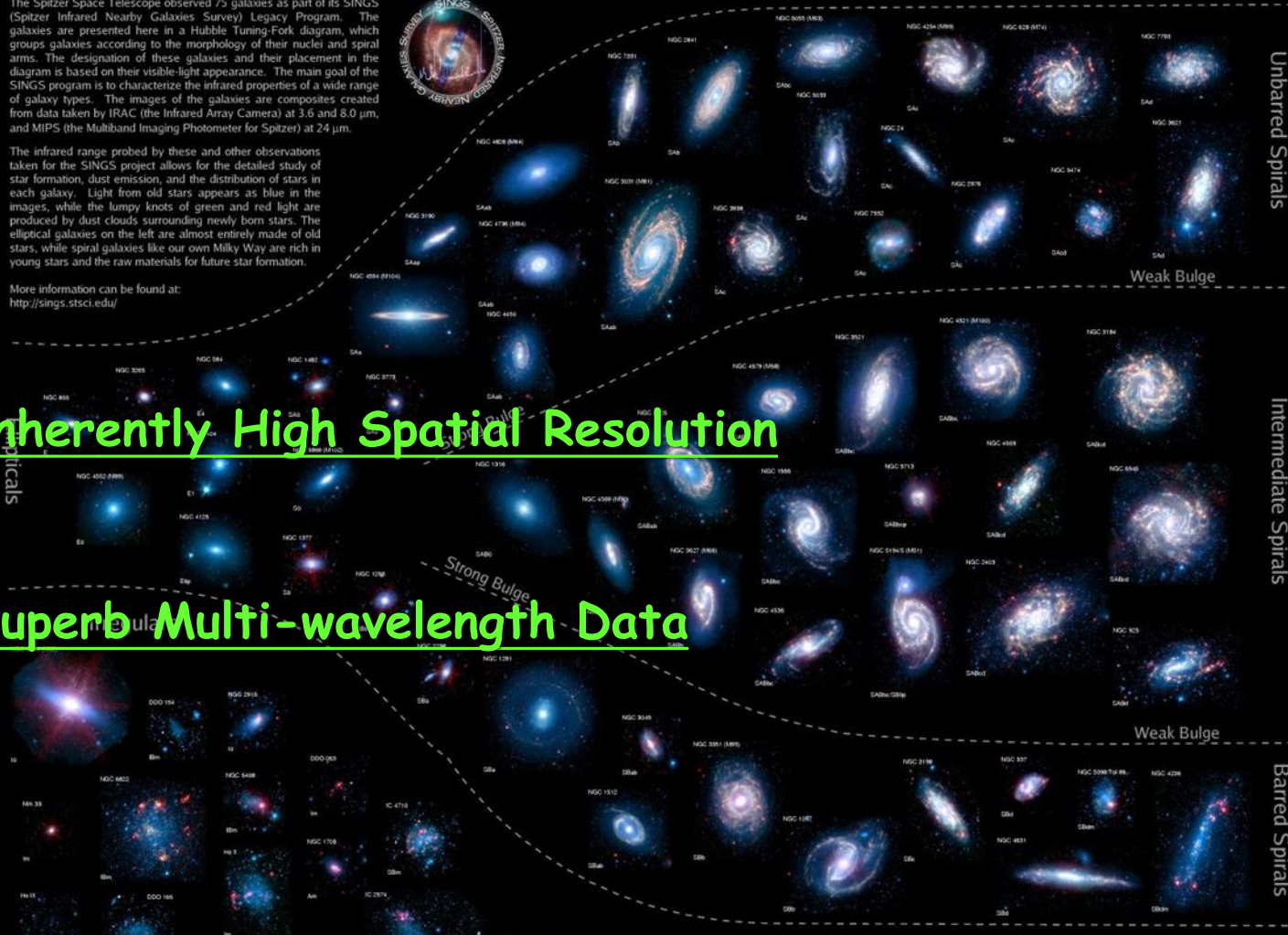


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● Inherently High Spatial Resolution

● Superb Multi-wavelength Data



**SDSS**



**BATC**



**2MASS**

Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)  
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# *Approach: Multi-wavelength Imaging*



**FUV**

**NUV**



**u**

**g**

**r**

**i**

**z**



**J**

**H**

**K<sub>s</sub>**



**3.6  $\mu\text{m}$**



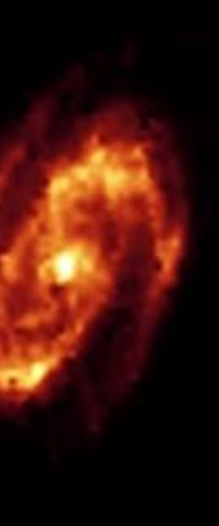
**8.0  $\mu\text{m}$**



**24  $\mu\text{m}$**



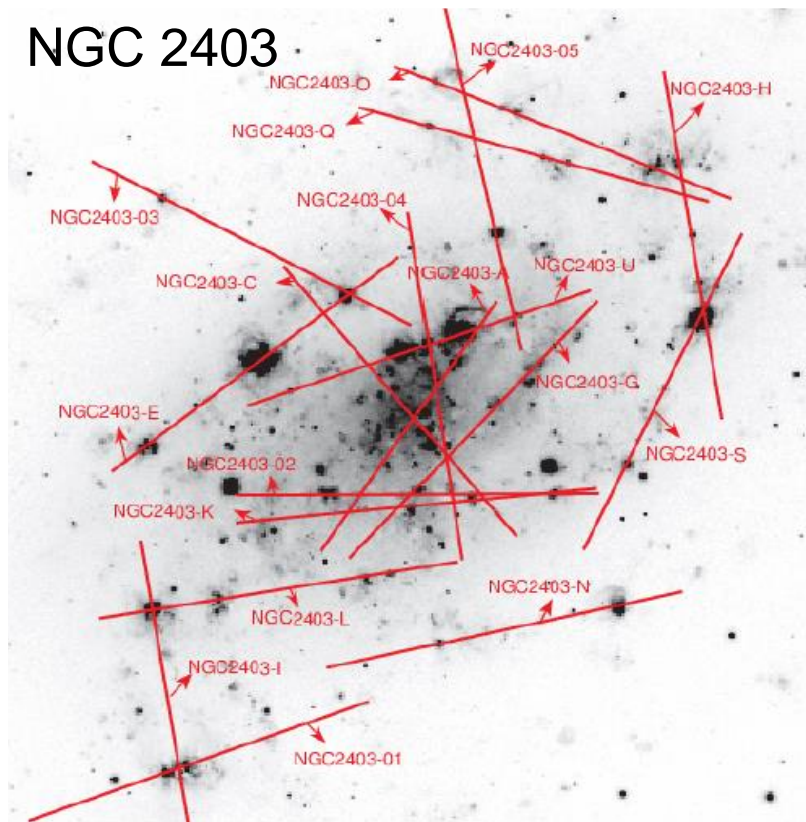
**70  $\mu\text{m}$**



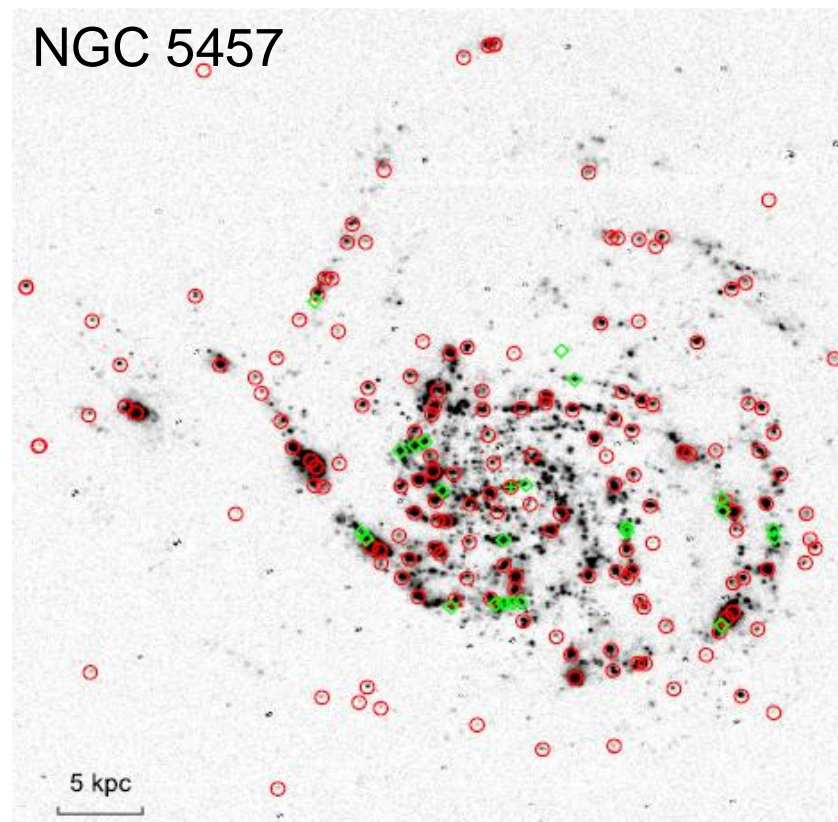
**160  $\mu\text{m}$**



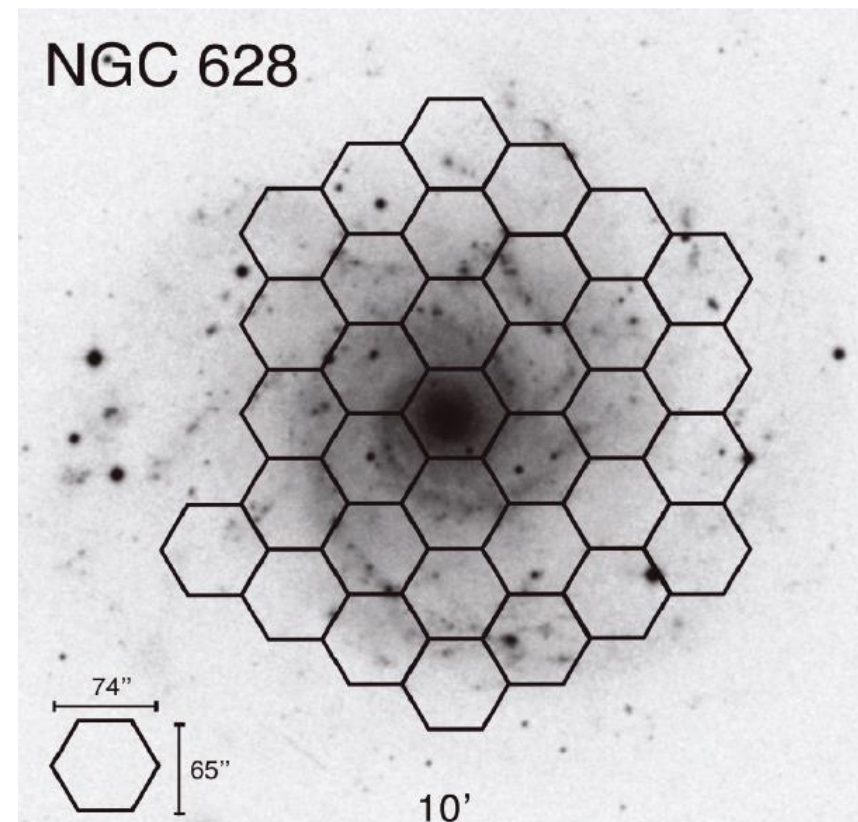
# *Approach: Spatially Resolved Spectroscopy*



**Slit**

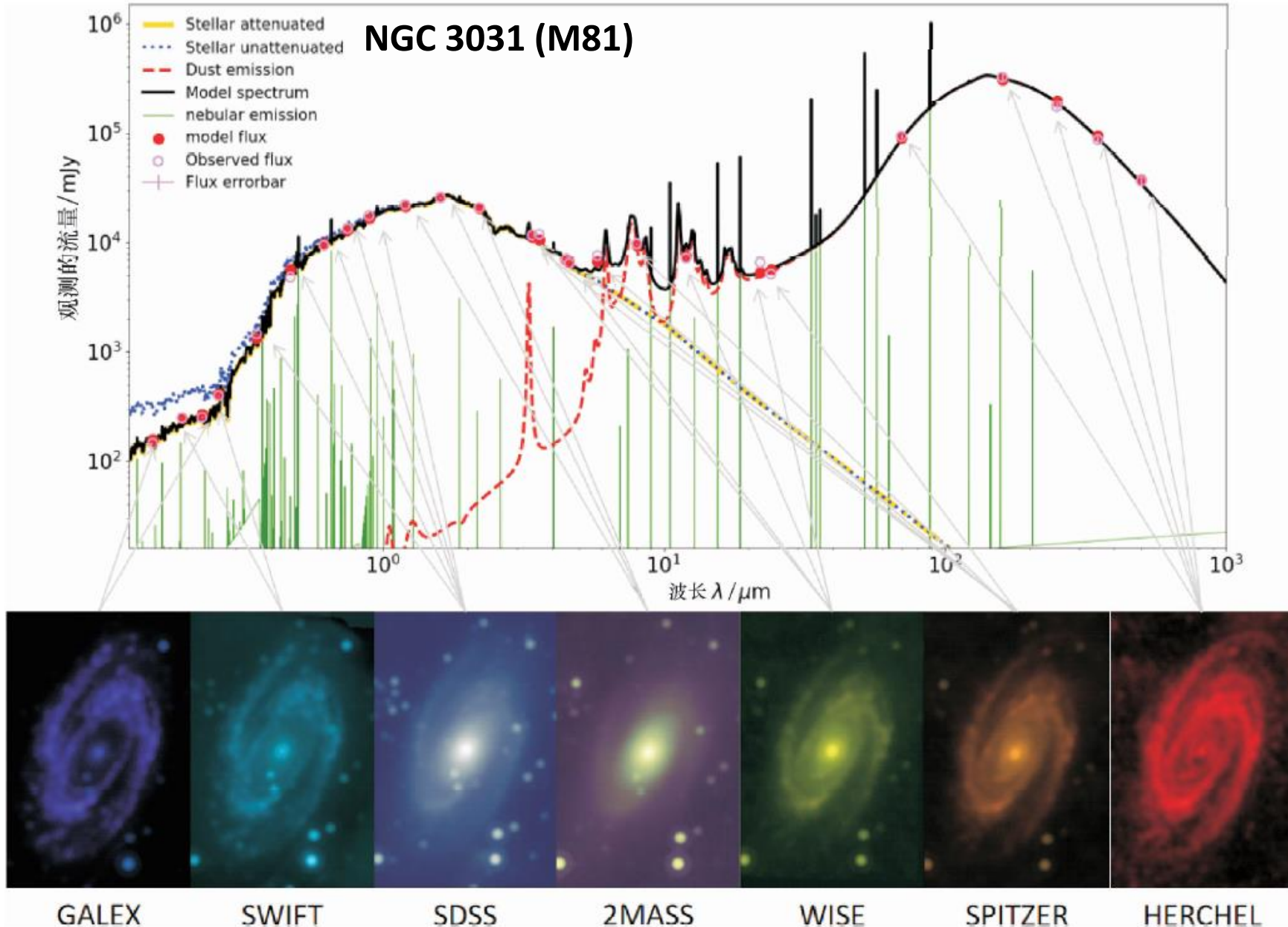


**Fiber**



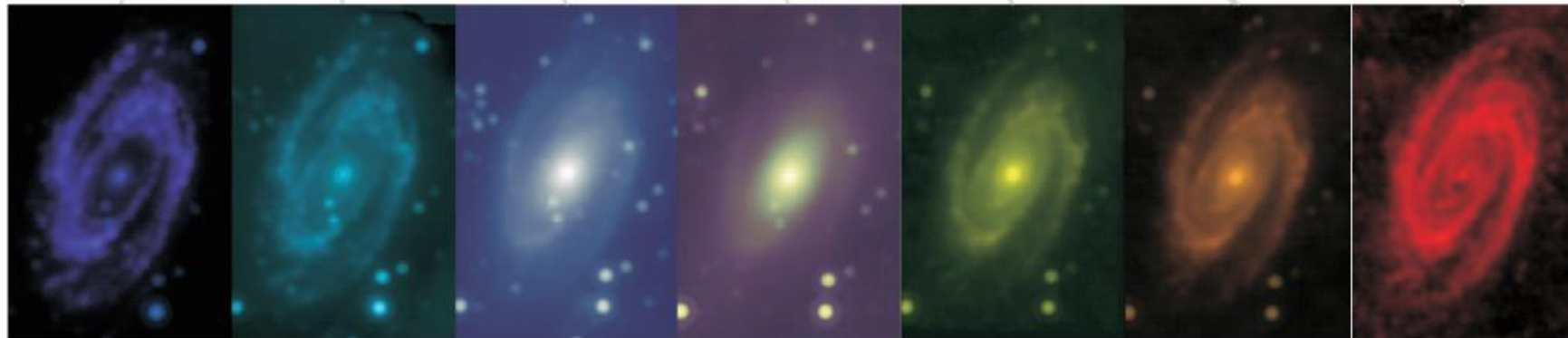
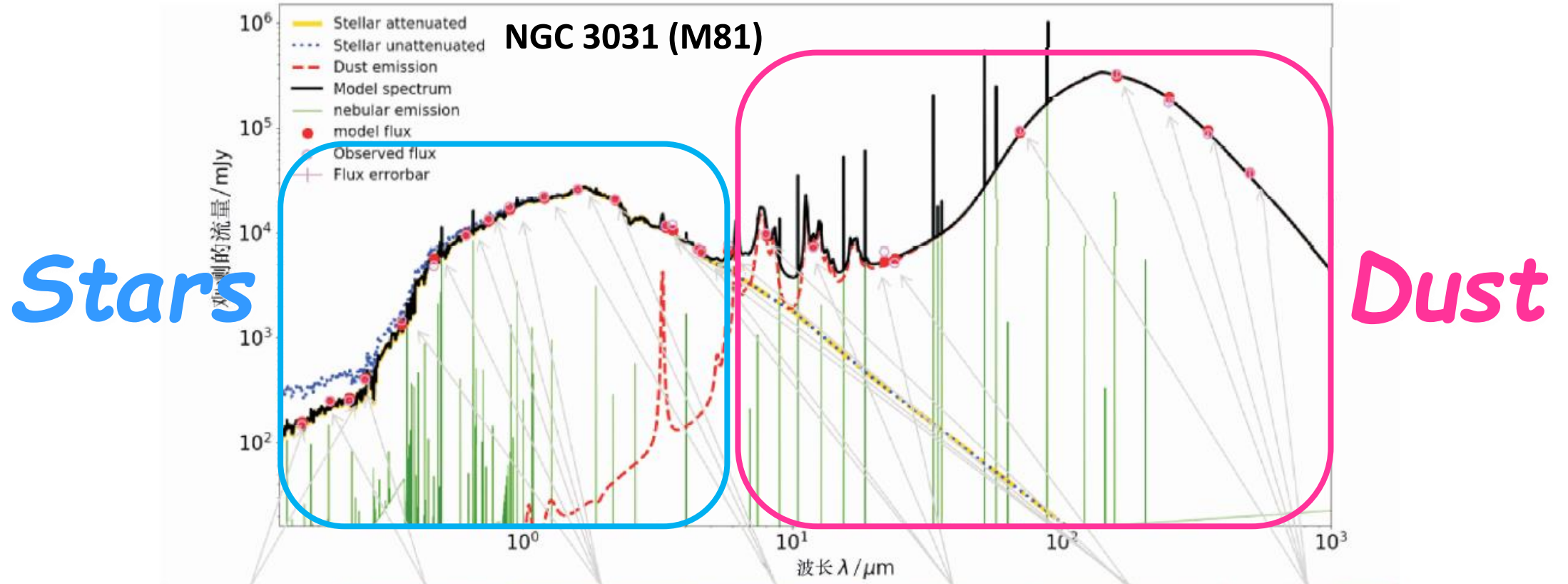
**IFU**

# Multi-wavelength Imaging $\Rightarrow$ 2D Colors/SEDs



(Gong & Mao 2023)

# Multi-wavelength Imaging $\Rightarrow$ 2D Colors/SEDs



GALEX

SWIFT

SDSS

2MASS

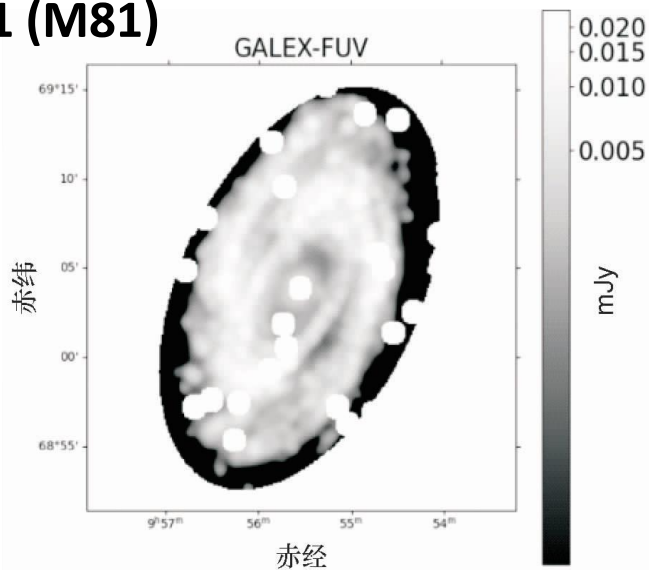
WISE

SPITZER

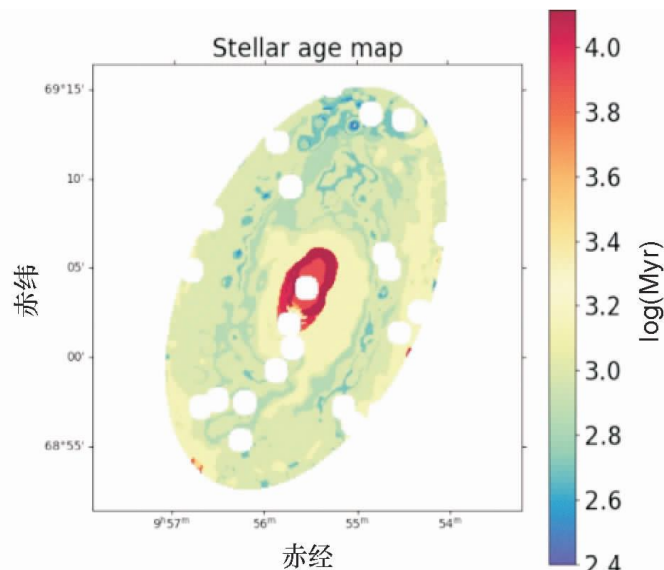
HERCHEL

# Multi-wavelength Imaging $\Rightarrow$ 2D Para. Maps

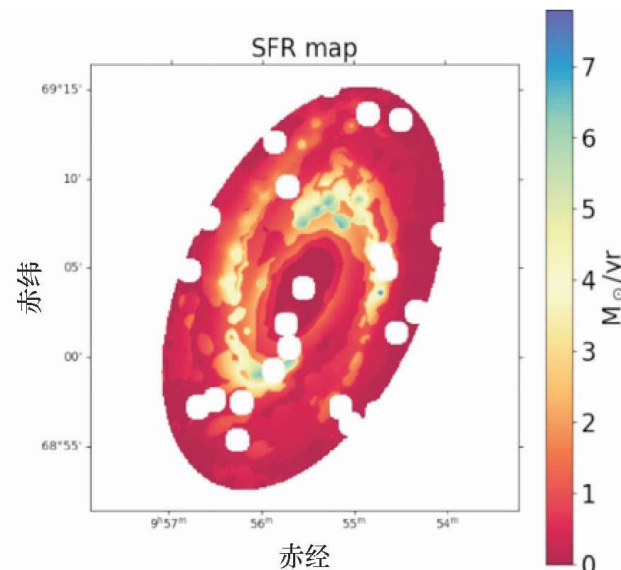
NGC 3031 (M81)



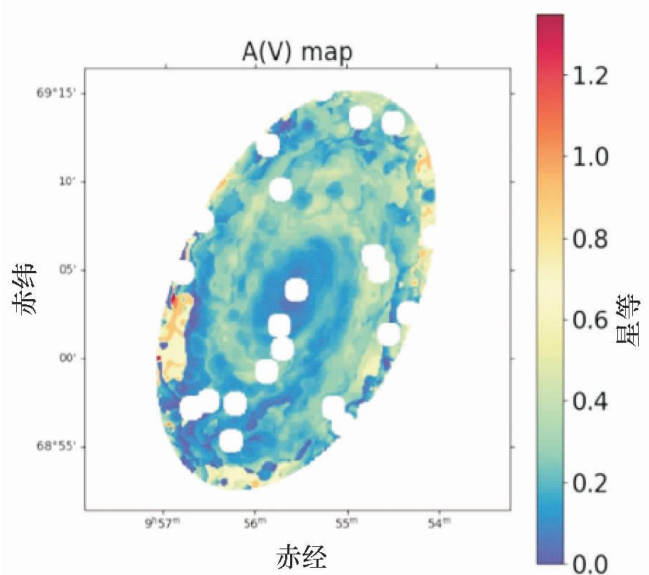
(a) GALEX-FUV观测图像



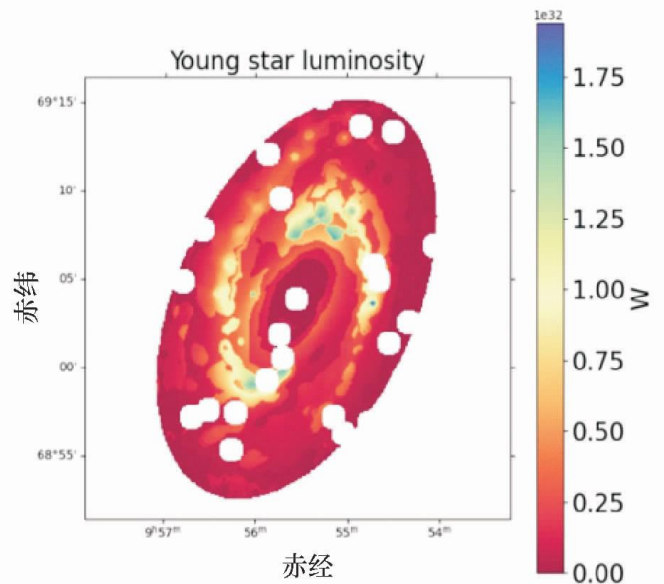
(b) 空间分辨SED拟合得到的恒星年龄



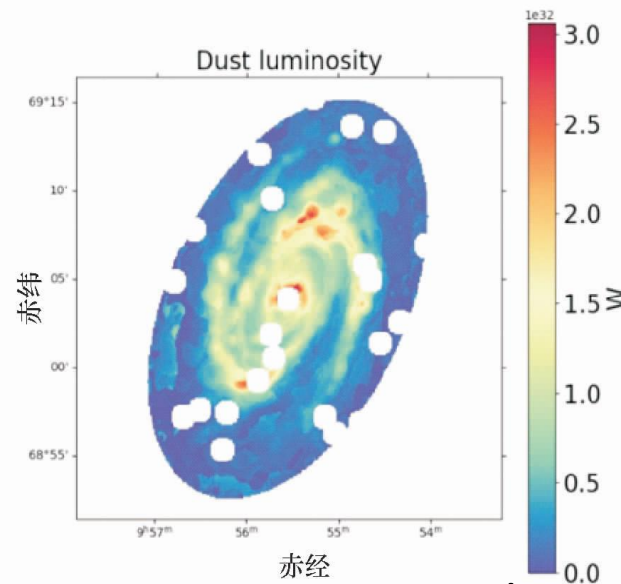
(c) SFR分布图



(d) V波段尘埃消光



(e) 年轻恒星光度

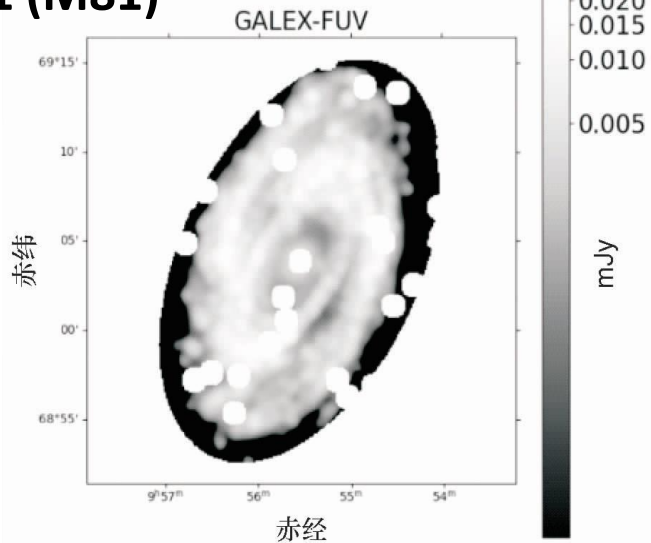


(f) 尘埃光度的分布图

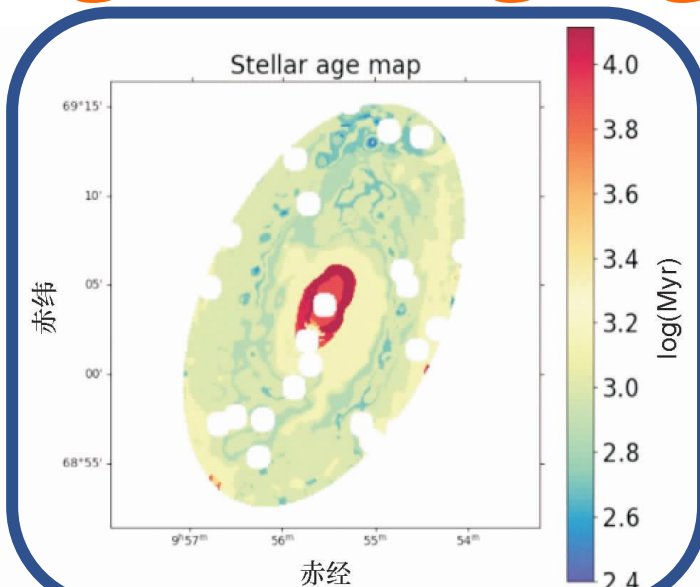
(Gong & Mao 2023)

# Multi-wavelength Imaging $\Rightarrow$ Evolution

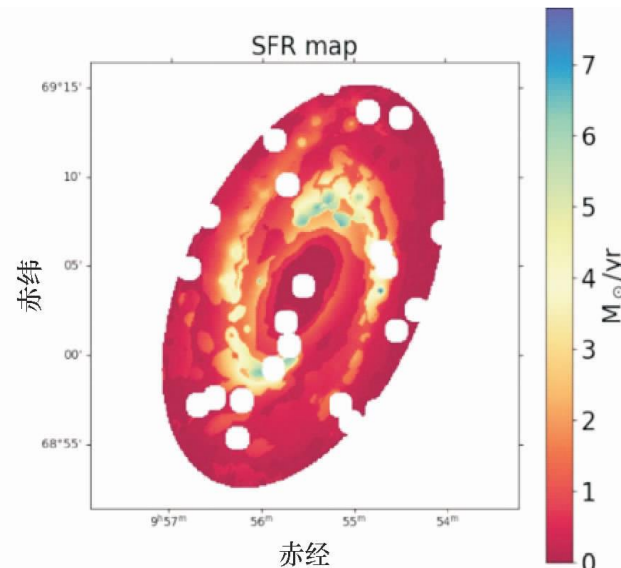
NGC 3031 (M81)



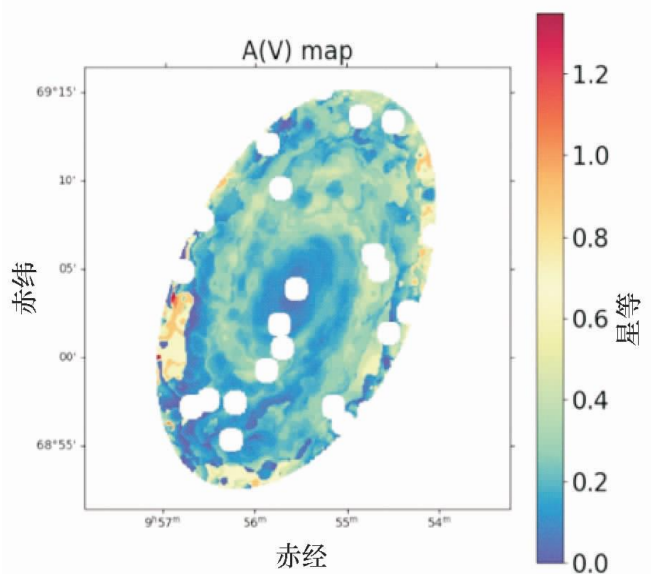
(a) GALEX-FUV观测图像



(b) 应用Aged SED拟合得到的恒星年龄

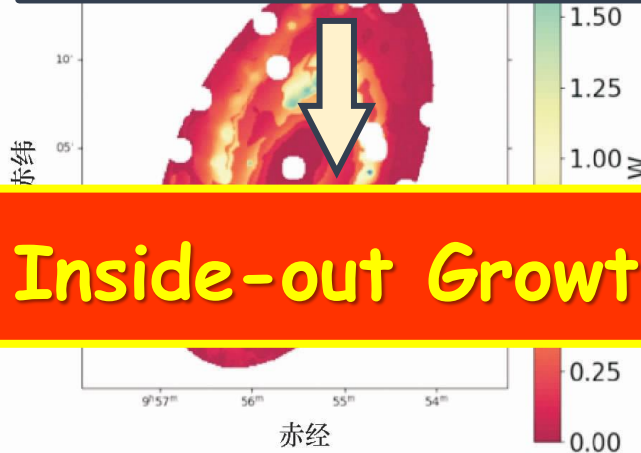


(c) SFR分布图

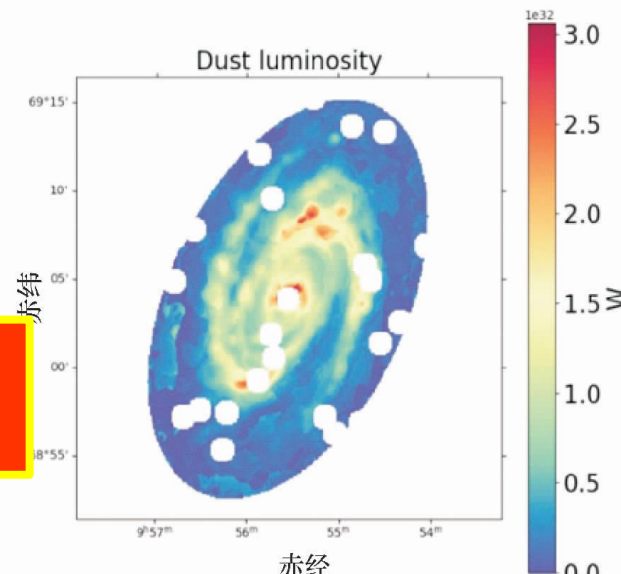


(d) V波段尘埃消光

**Age-Gradients**



**Inside-out Growth**



(f) 尘埃光度的分布图

(Gong & Mao 2023)

# ***Galaxies: Bulges & Disks***

**Two Fundamental Morphological Shapes of Stellar Systems**

***Bulges/Ellips/Sphs***

***Disks***



**Major Mergers**

**Secular Evolution**

***Galaxies as a Complexity***



# ***Galaxies: Bulges & Disks***

**Two Fundamental Morphological Shapes of Stellar Systems**

***Bulges/Ellips/Sphs***

***Disks***



**Major Mergers**

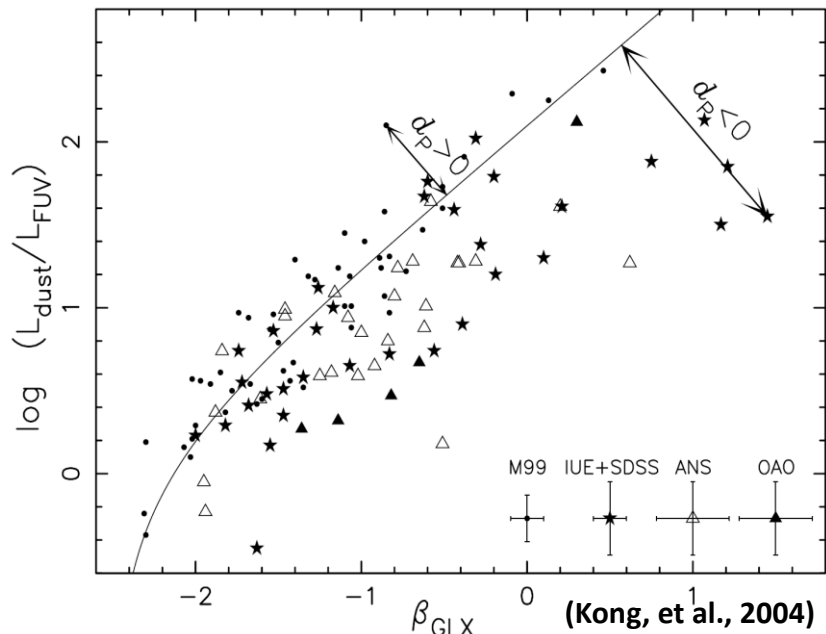
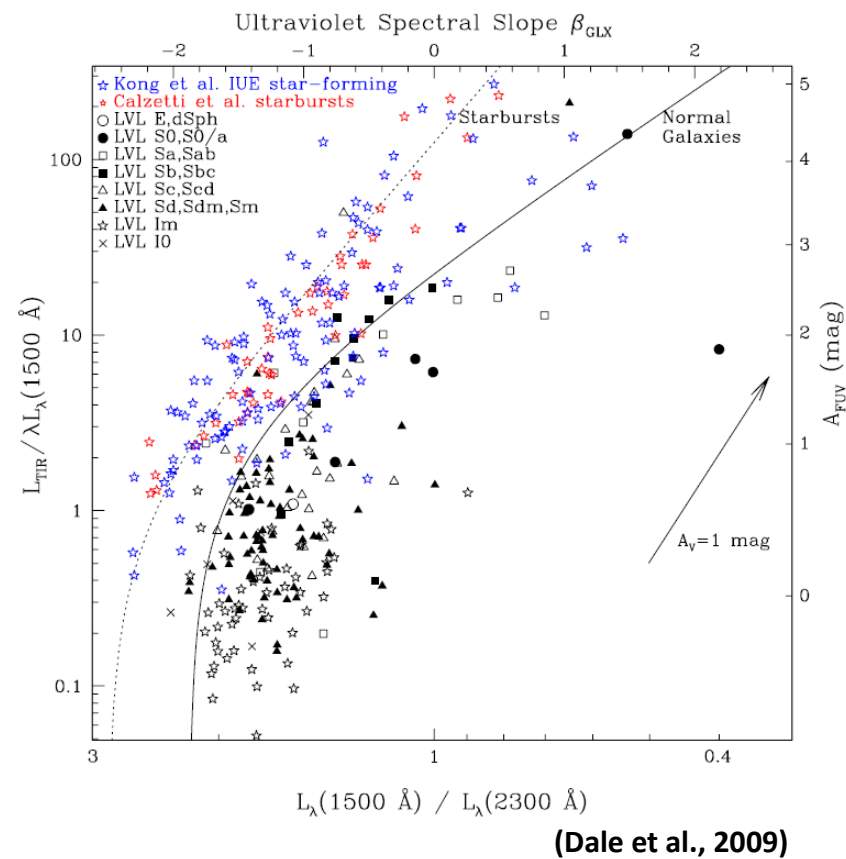
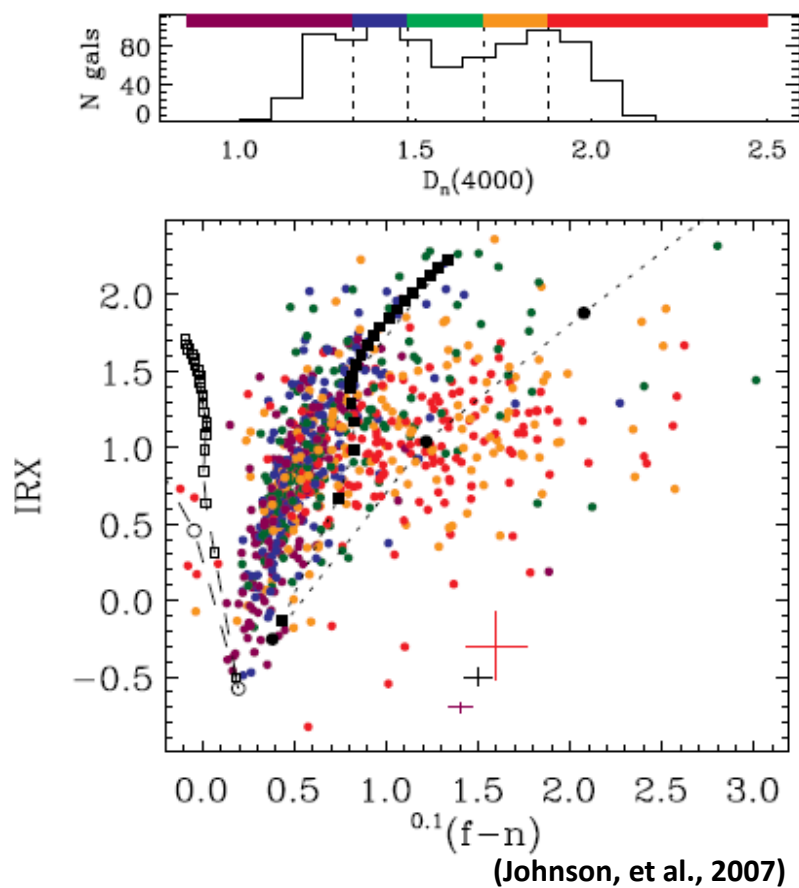
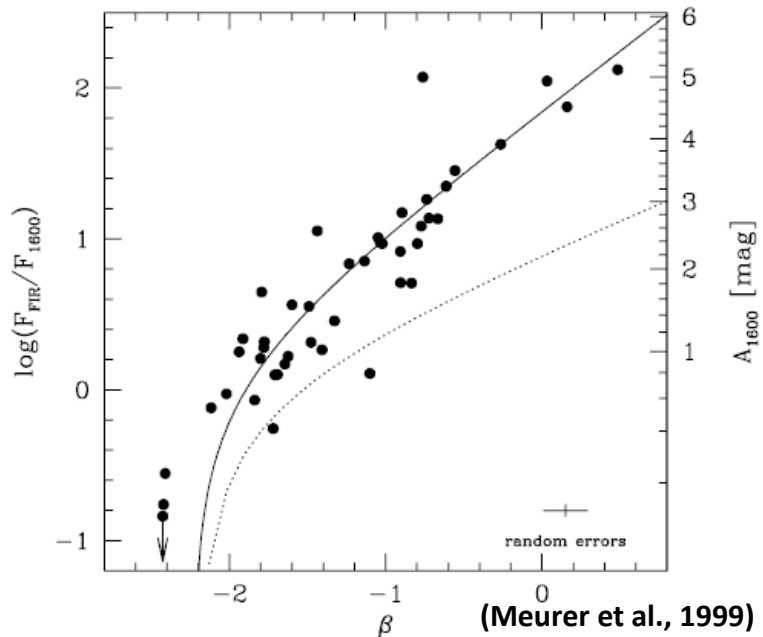
**Secular Evolution**

***Galaxies as a Complexity***

***Bulge - Disk Separation***

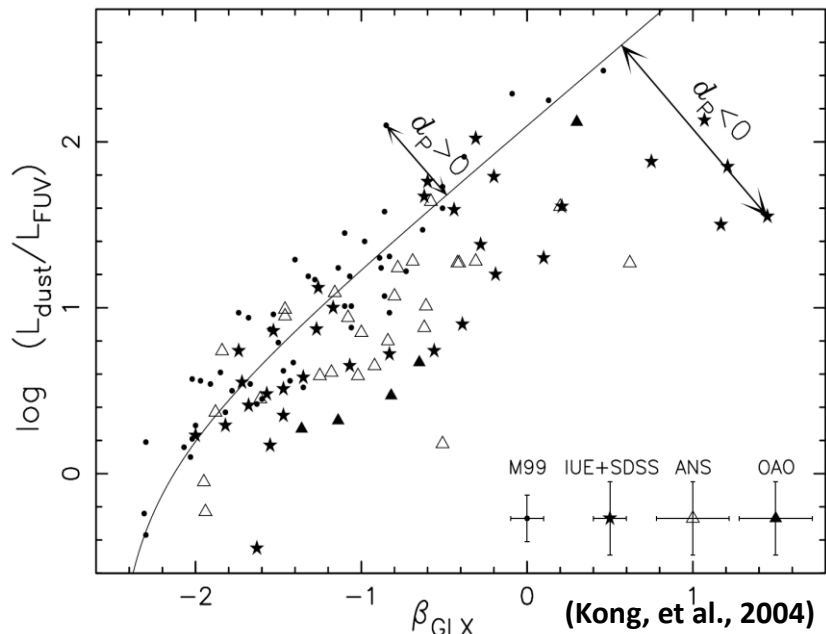
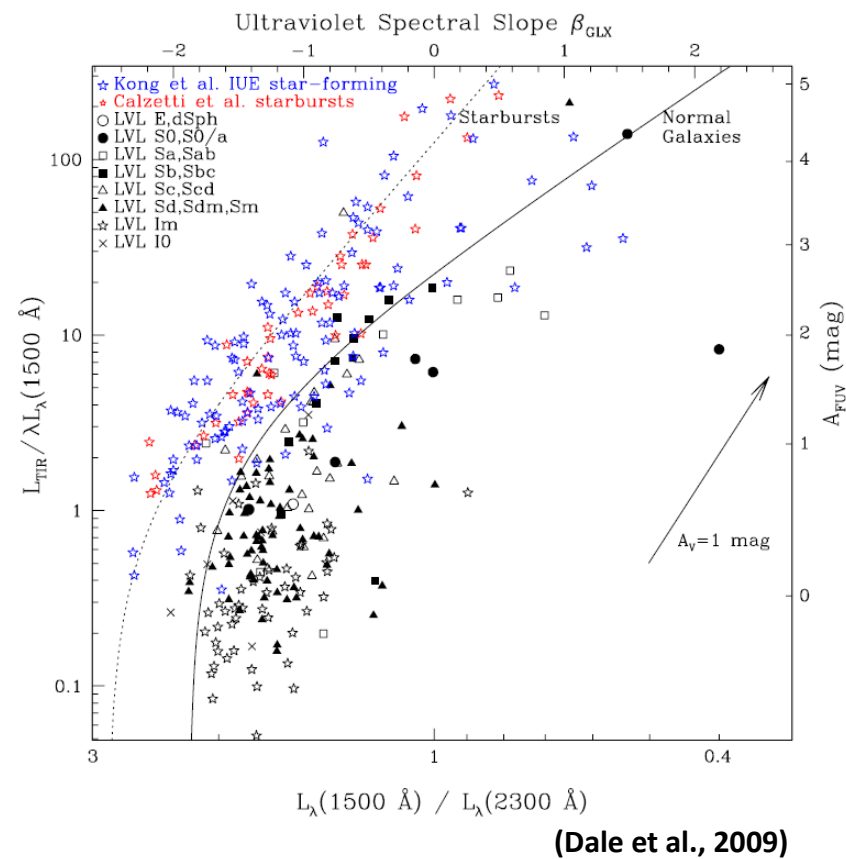
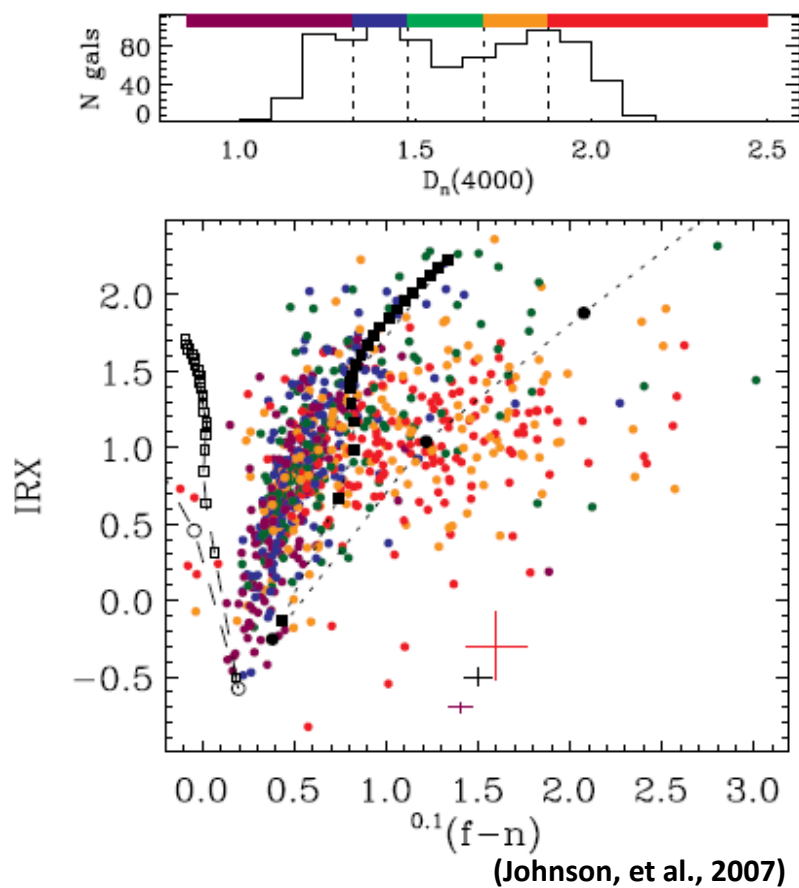
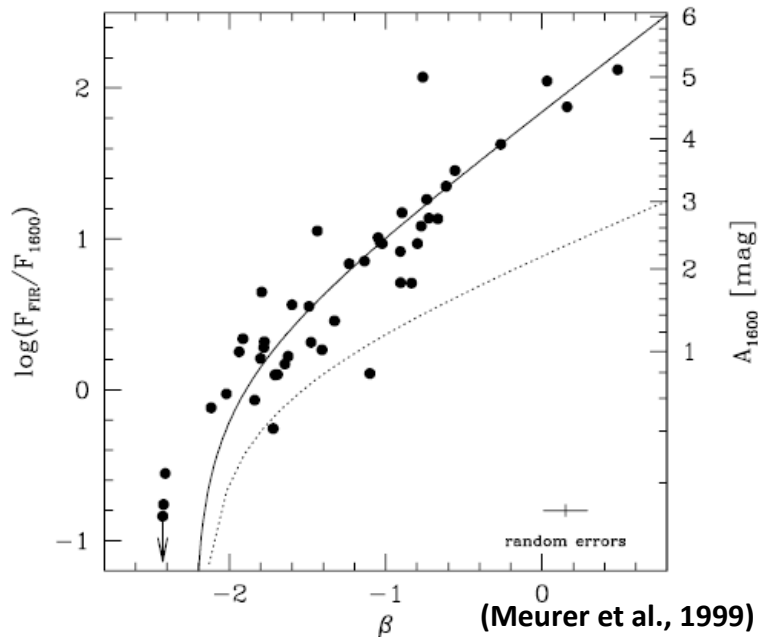
**A Comprehensive Understanding of Galaxies and their Subsystems**

# Galaxies: IRX- $\beta$ Relation





# Galaxies: IRX- $\beta$ Relation



**UV Conundrum** 😞

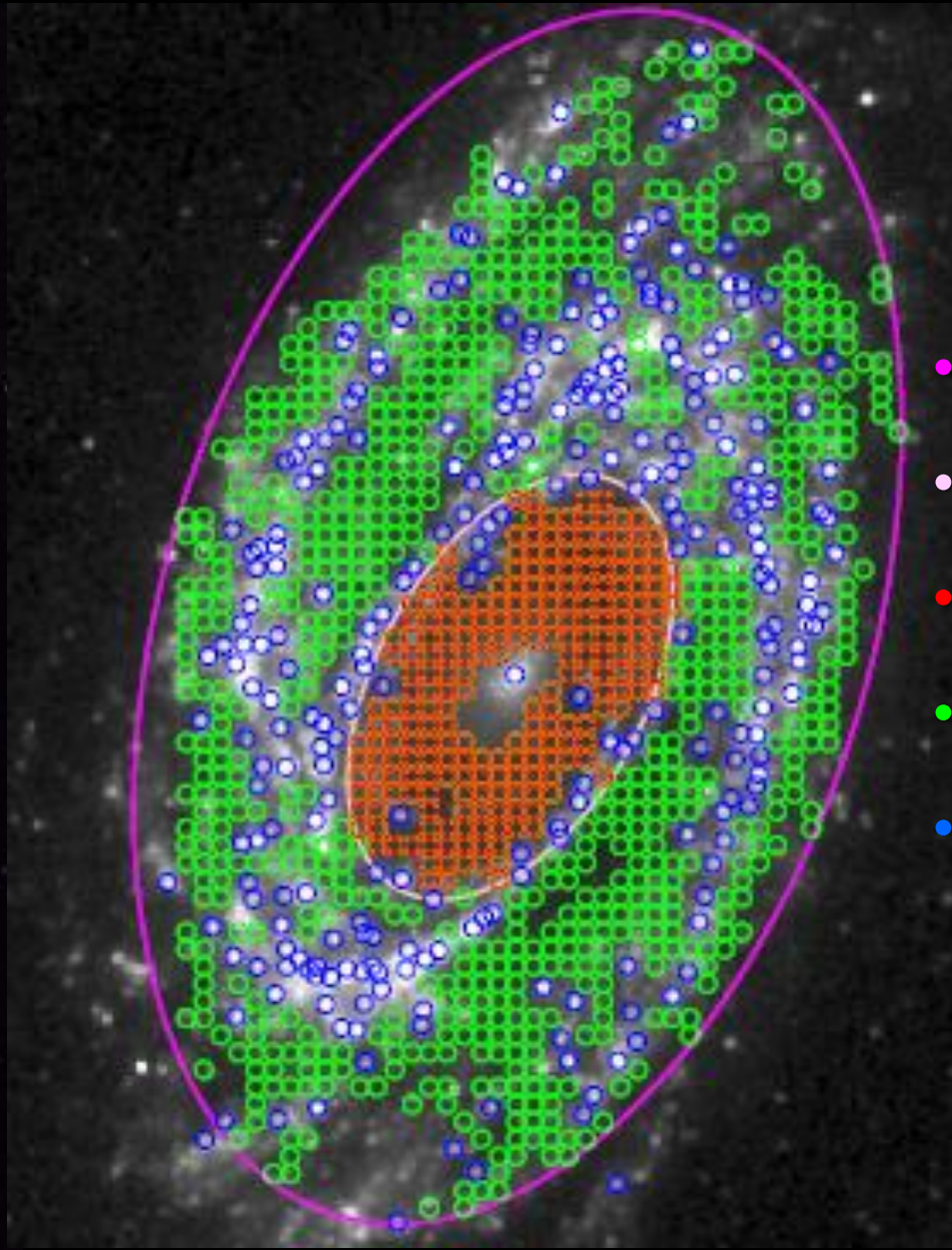
# ***Image Analysis: Bulge - Disk Categorization***

NGC 3031 (M81)



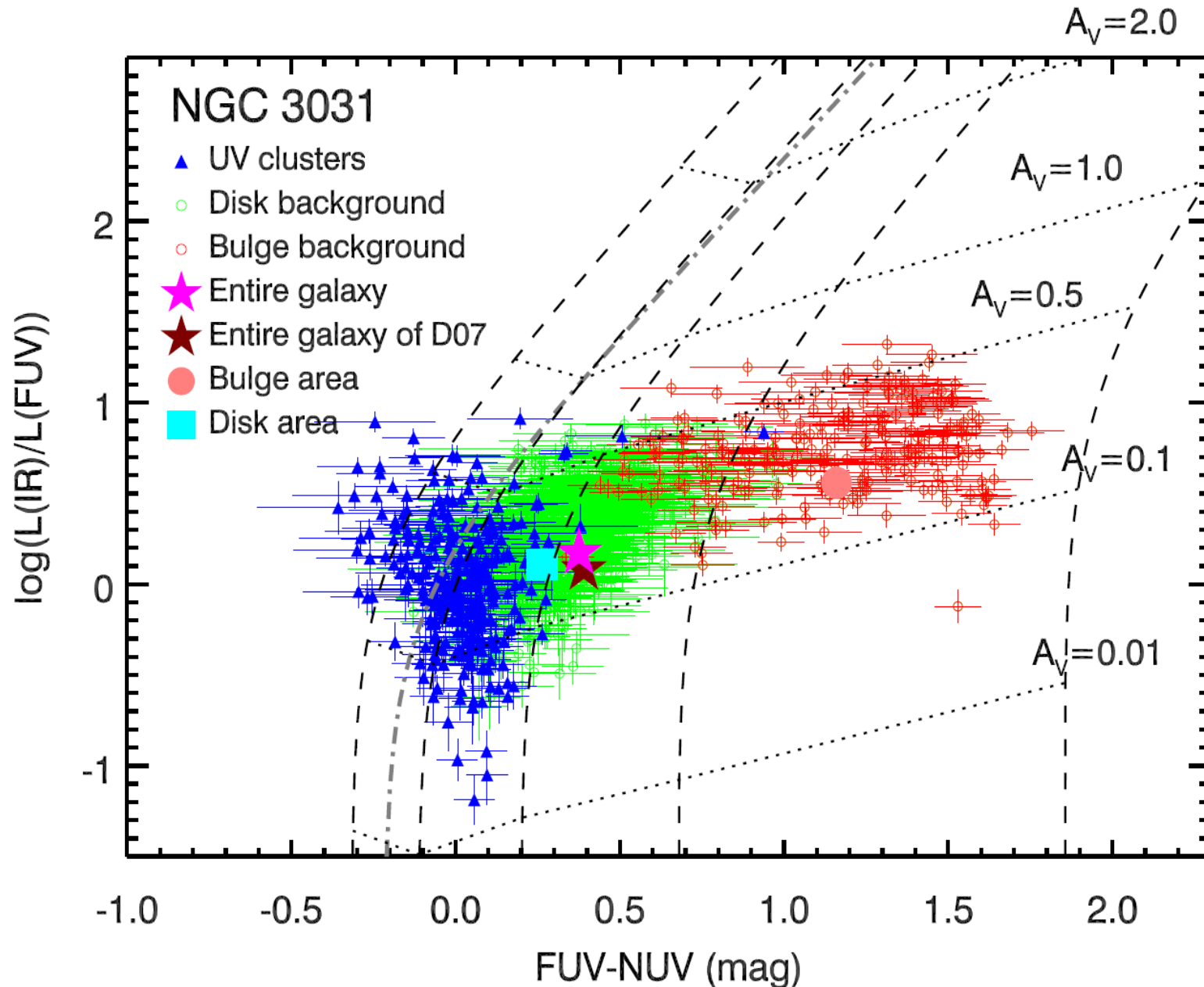
# *Image Analysis: Bulge - Disk Categorization*

NGC 3031 (M81)



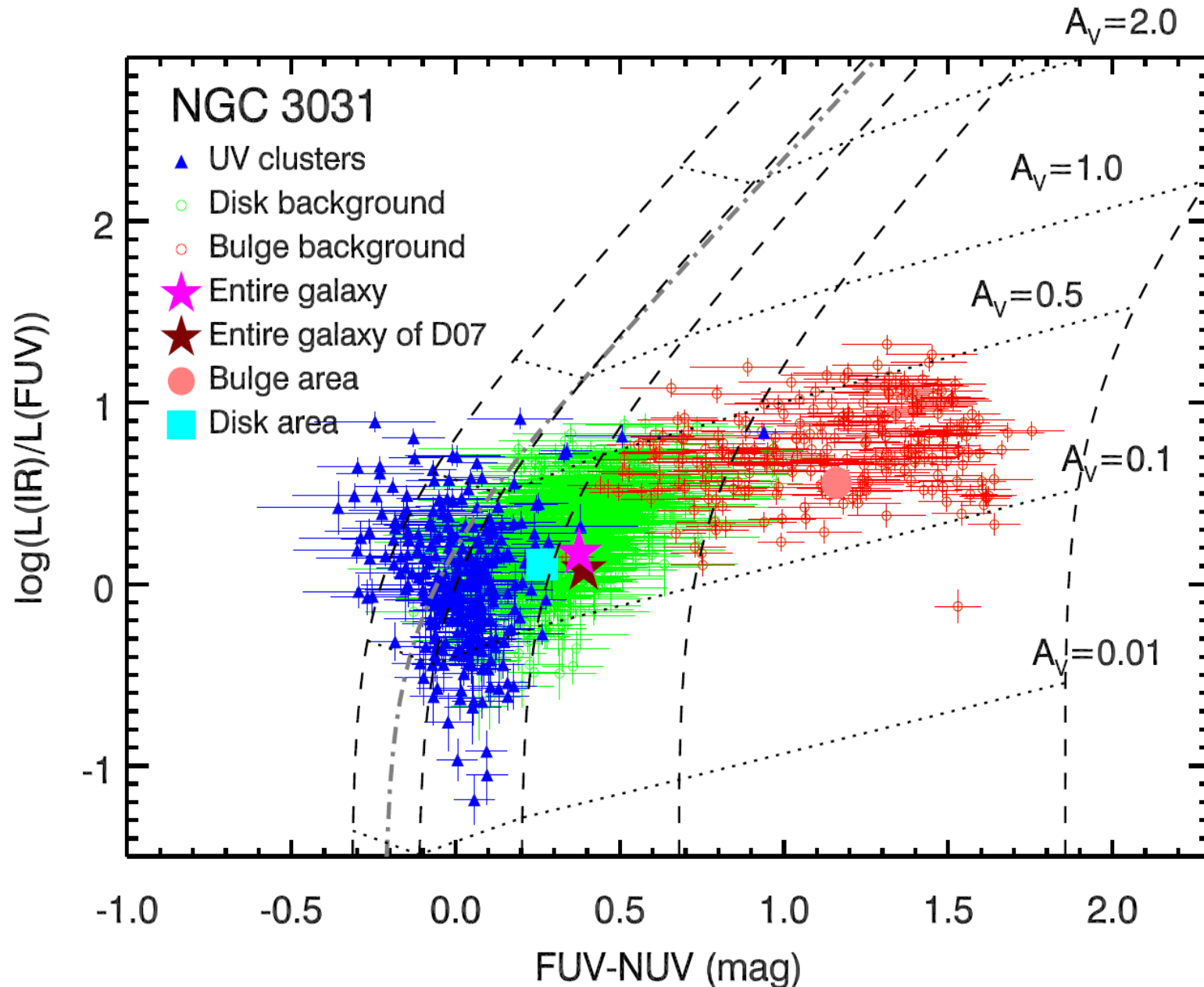
- *Integrated Galaxies*
- *Integrated Bulge*
- *Bulge Diffuse Regions*
- *Disk Diffuse Regions*
- *UV Clusters*

# Image Analysis: Bulge - Disk Categorization



- **Integrated Galaxies**
- *Integrated Bulge*
- **Bulge Diffuse Regions**
- **Disk Diffuse Regions**
- **UV Clusters**

# Image Analysis: Bulge - Disk Categorization

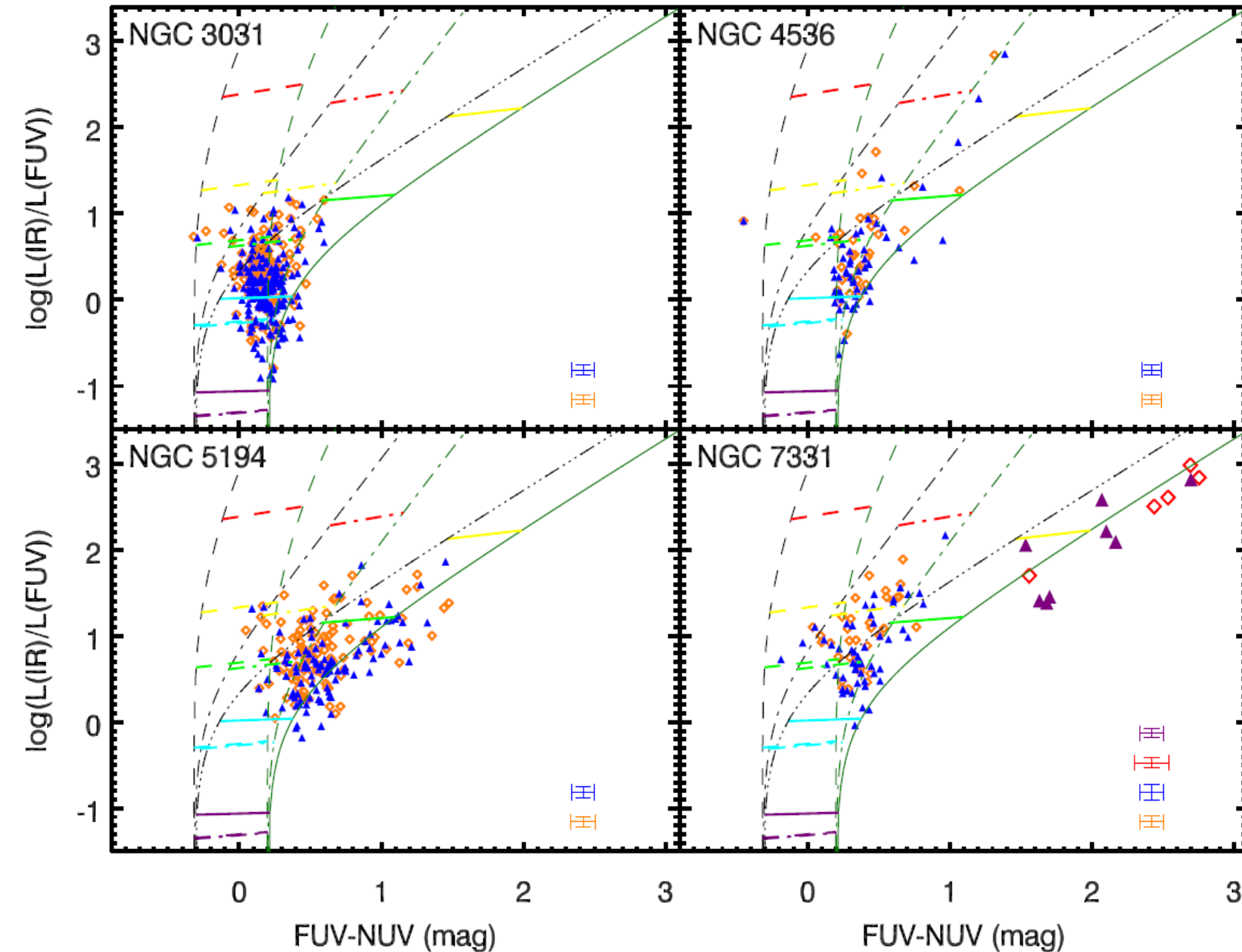


- **Integrated Galaxies**
- *Integrated Bulge*
- **Bulge Diffuse Regions**
- **Disk Diffuse Regions**
- **UV Clusters**



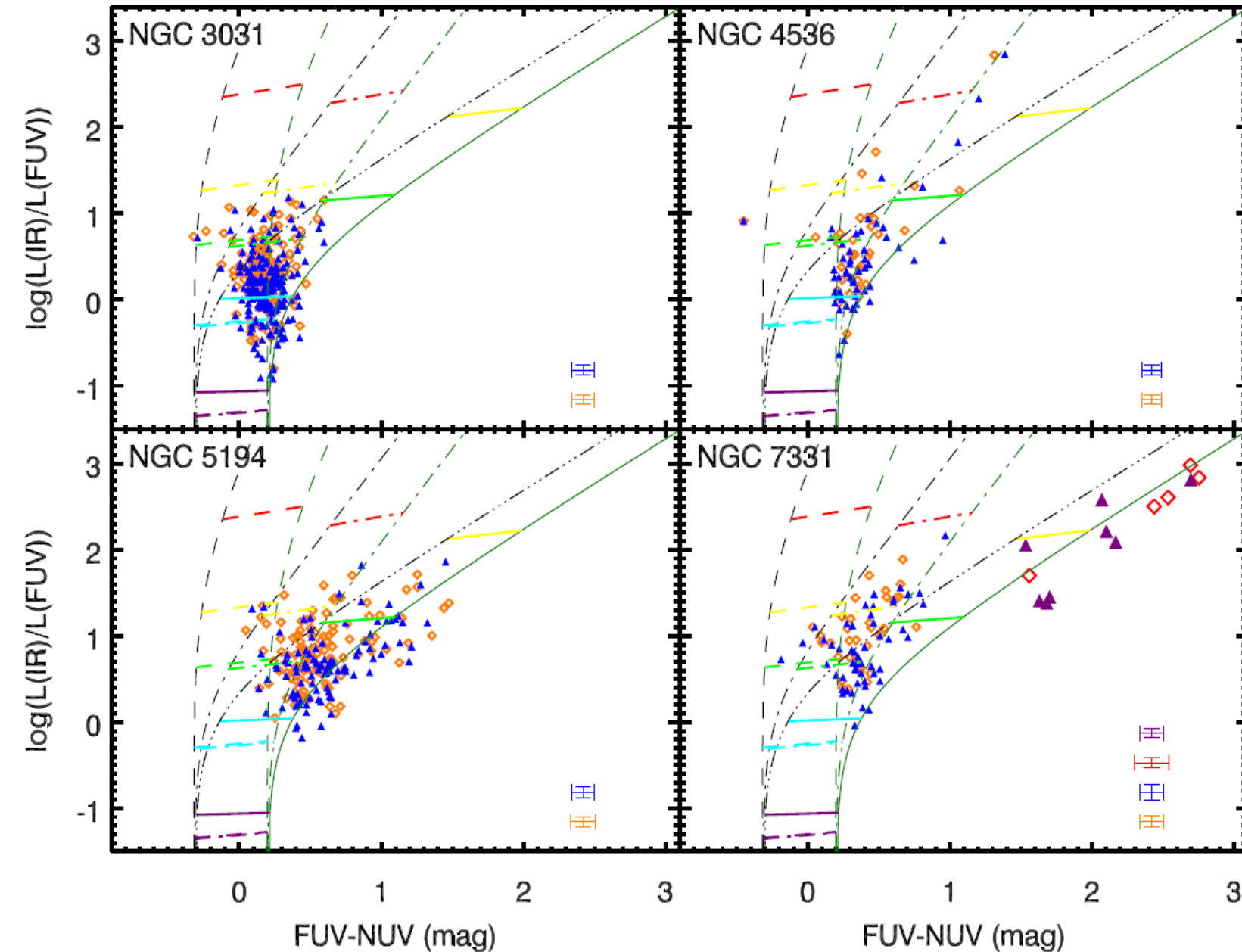
**Age Effects**

# Image Analysis: Bulge - Disk Categorization



- *Integrated Galaxies*
- *Integrated Bulge*
- *Bulge Diffuse Regions*
- *Disk Diffuse Regions*
- **UV Clusters + IR Clusters**

# Image Analysis: Bulge - Disk Categorization



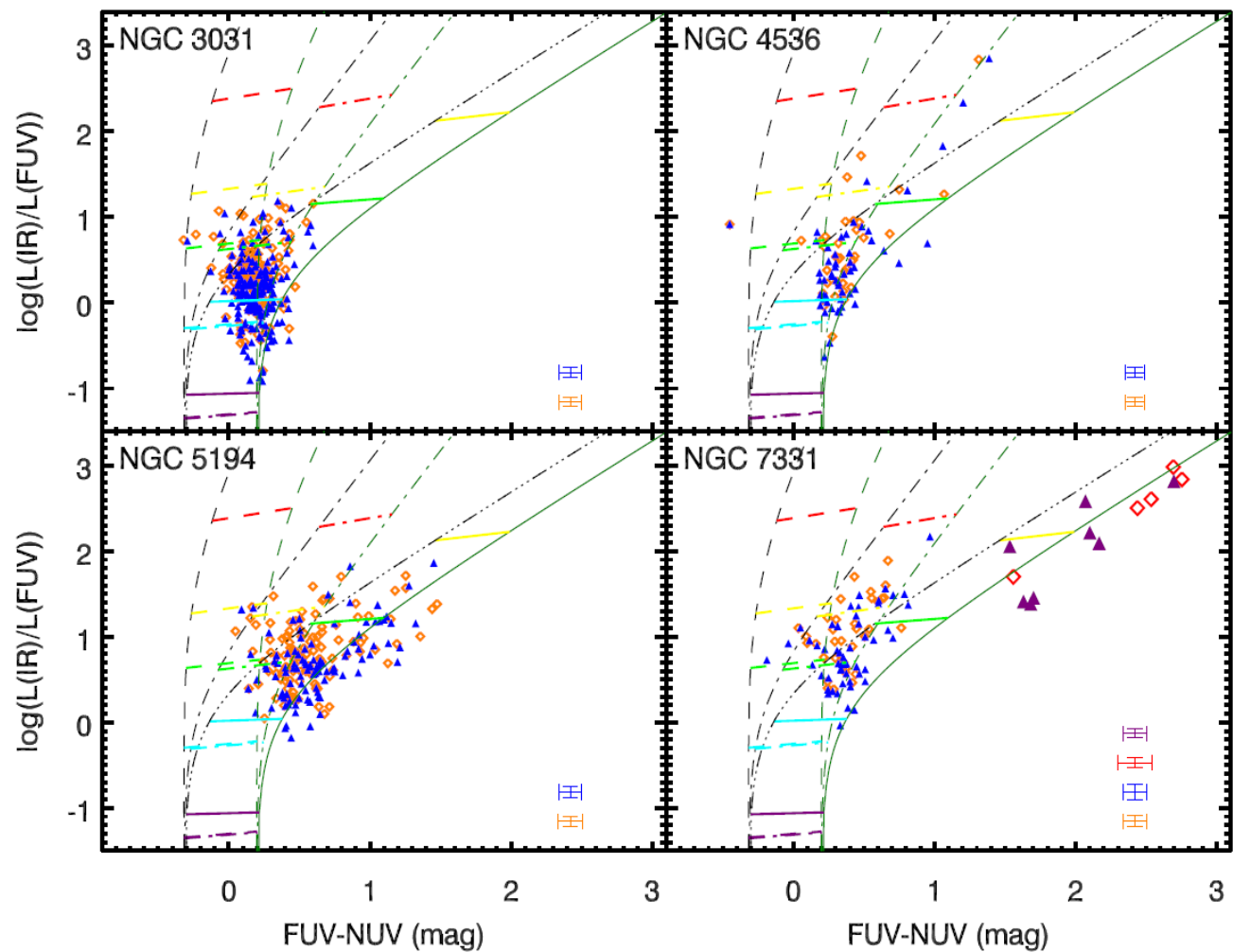
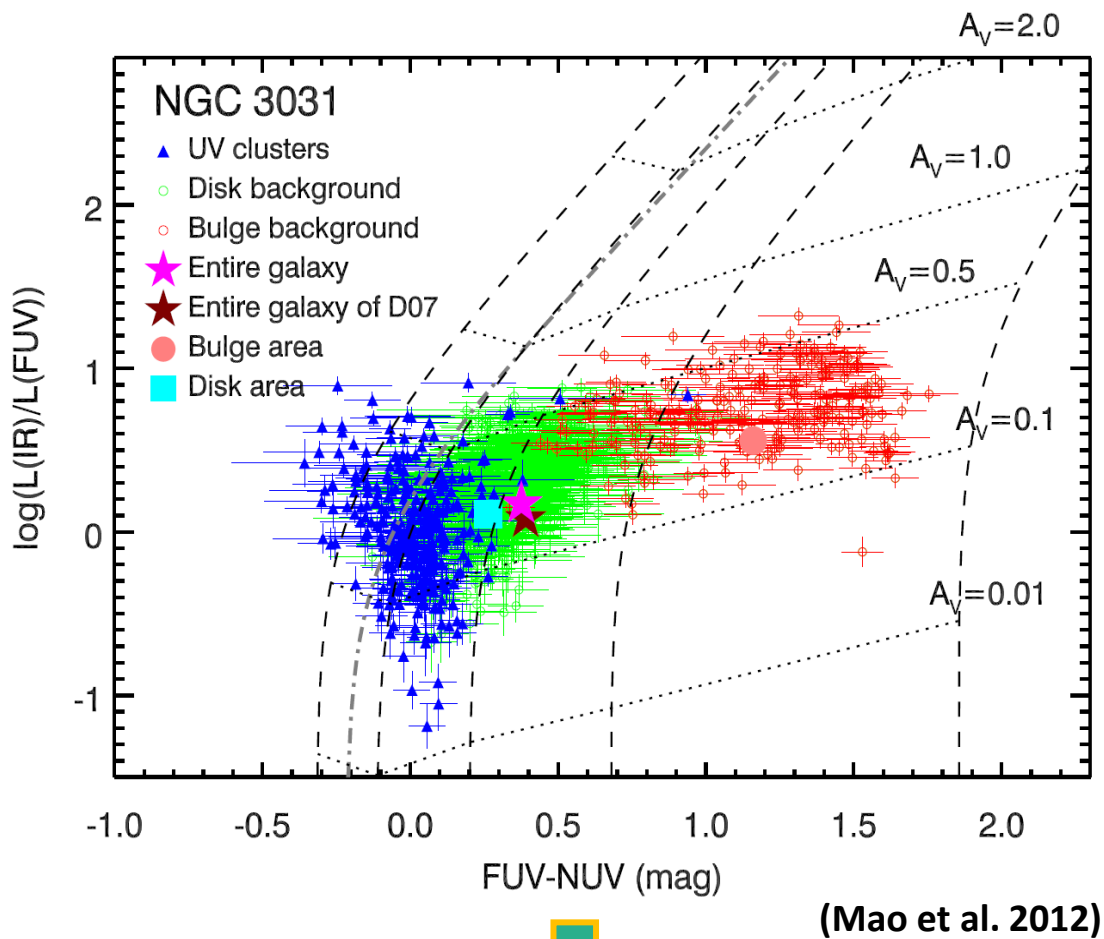
- *Integrated Galaxies*
- *Integrated Bulge*
- *Bulge Diffuse Regions*
- *Disk Diffuse Regions*
- **UV Clusters + IR Clusters**



**Dust-attenuation Effects**

**Impact of Attenuation Laws**

# Image Analysis: Bulge - Disk Categorization



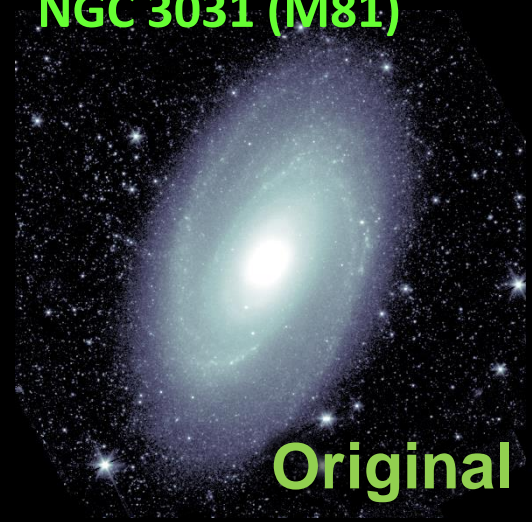
(Mao et al. 2014)

★ Solve the Age-Attenuation Degeneracy 🙌



# ***Image Analysis: Bulge - Disk Decomposition***

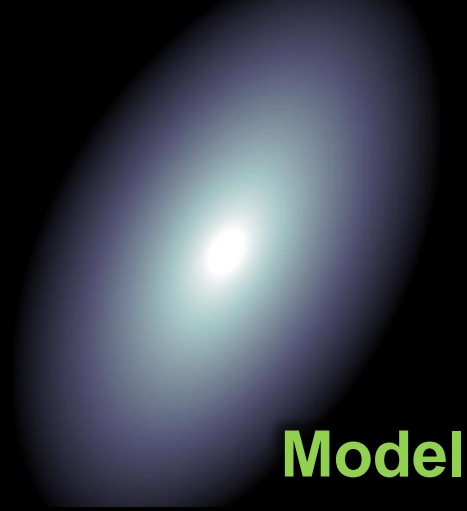
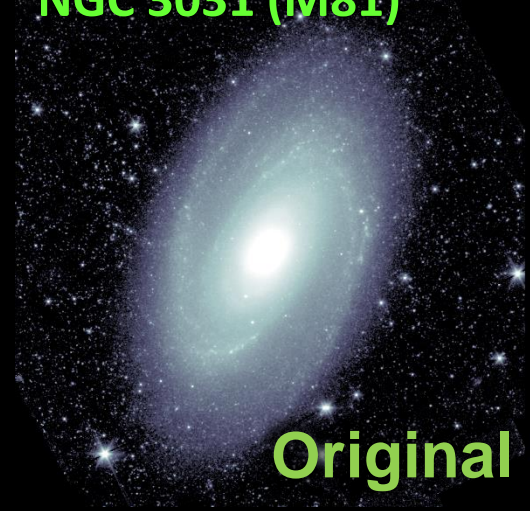
NGC 3031 (M81)



Original

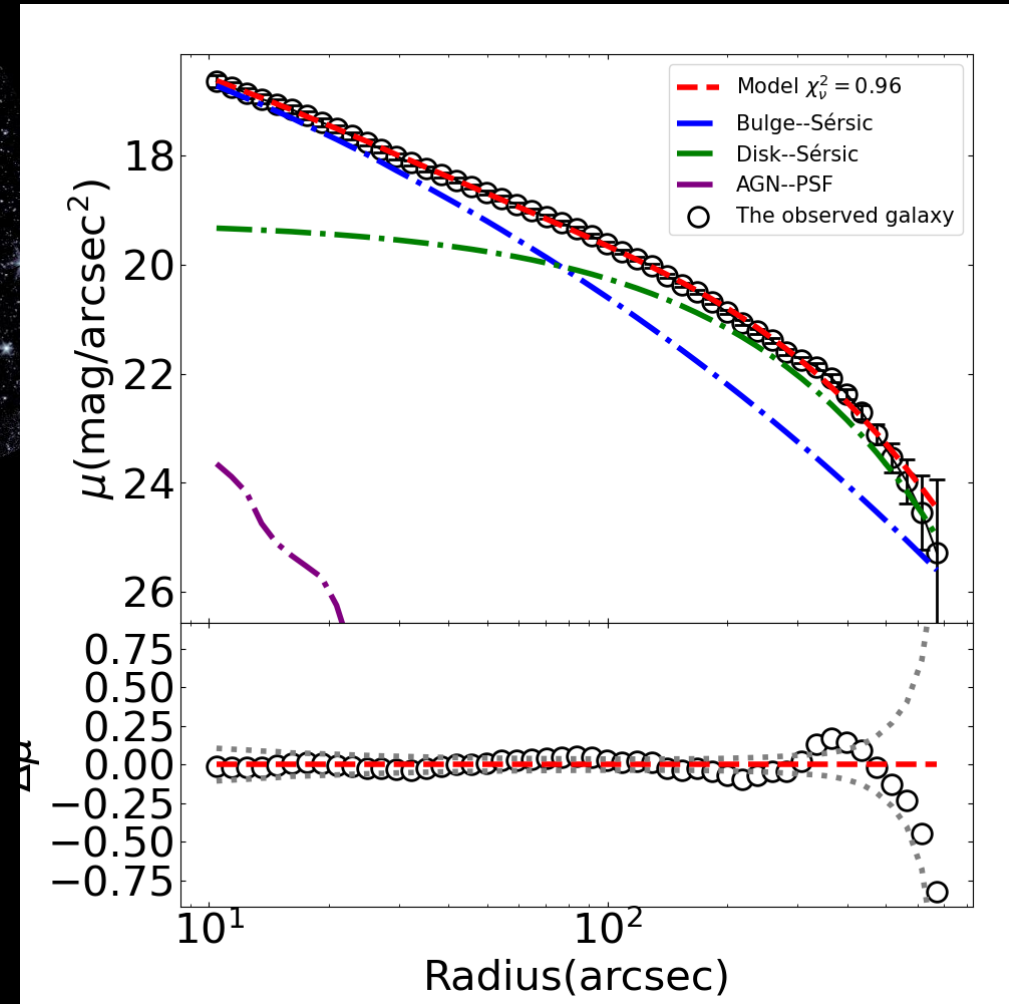
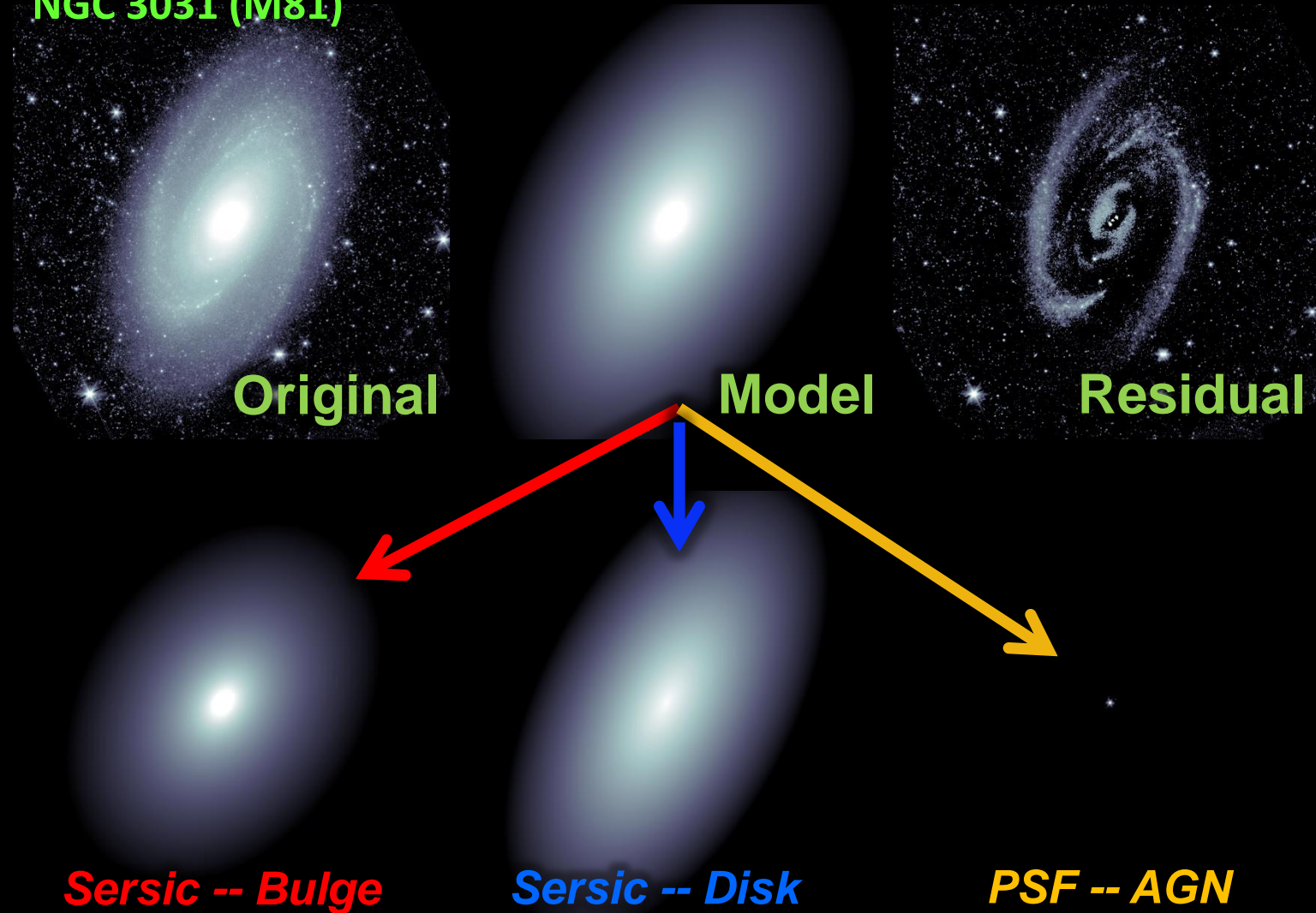
# *Image Analysis: Bulge - Disk Decomposition*

NGC 3031 (M81)



# Image Analysis: Bulge - Disk Decomposition

NGC 3031 (M81)




Spitzer-IRAC 4.5  $\mu\text{m}$  as an example

The decomposition with the two-Sersic components is carried out in 20-band images.

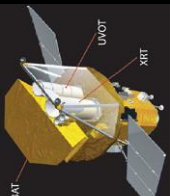
# Image Analysis: Bulge - Disk Decomposition



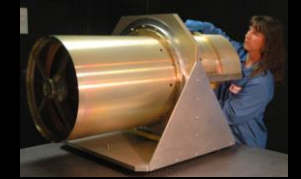
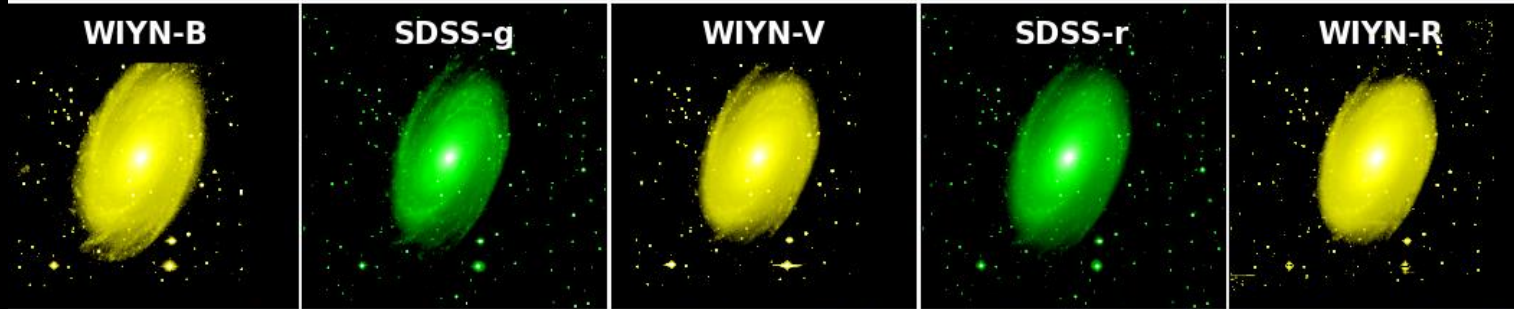
**GALEX:**  
FUV, NUV



**2MASS:**  
J, H, Ks



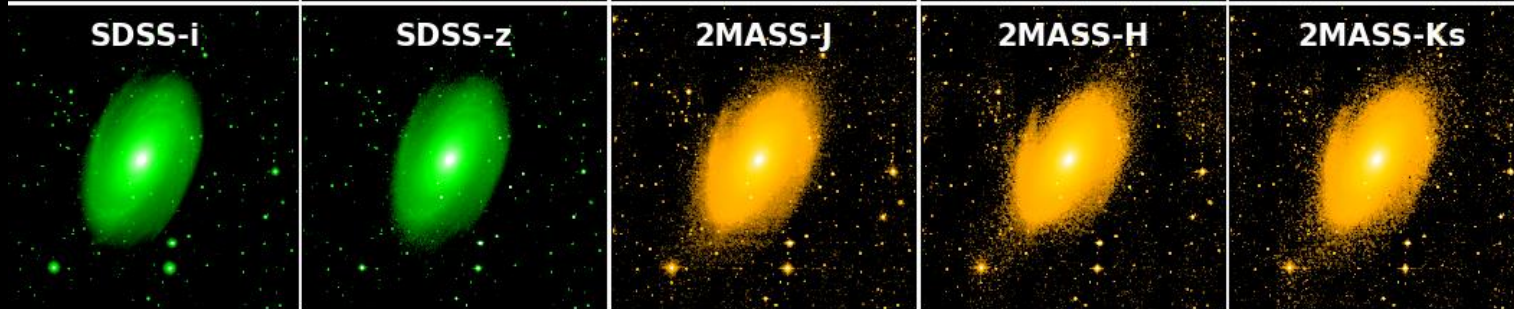
**Swift:**  
UVW1, UVW2



**WISE:**  
W1, W2



**WIYN:**  
B, R, V



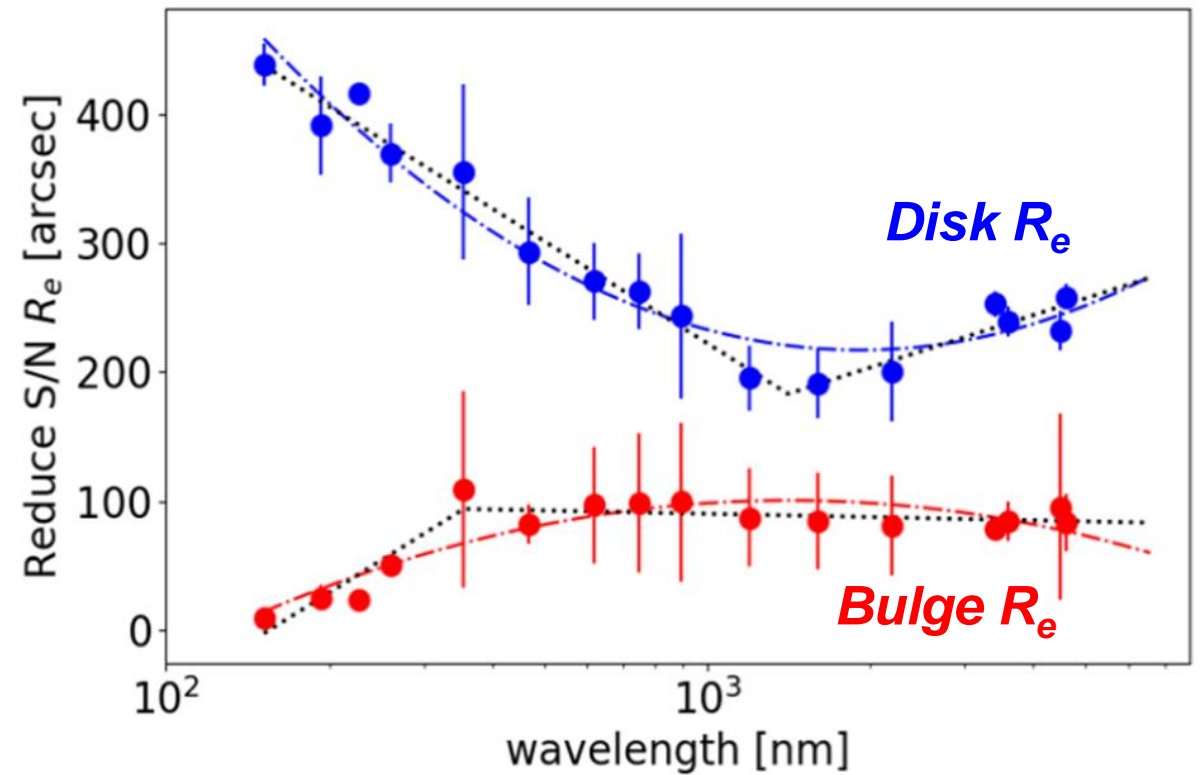
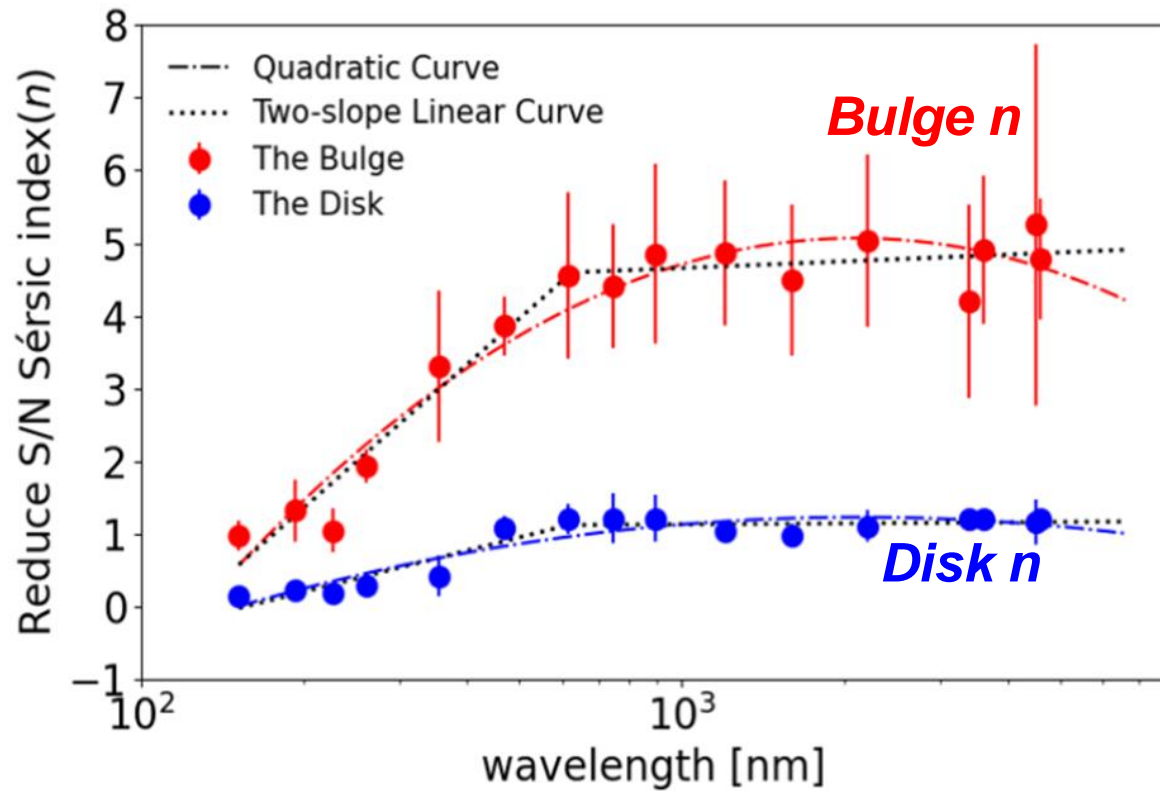
**SDSS:**  
u, g, r, i, z



IRAC-3.6, 4.5, 5.8  $\mu\text{m}$   
(Gong & Mao et al. 2023)

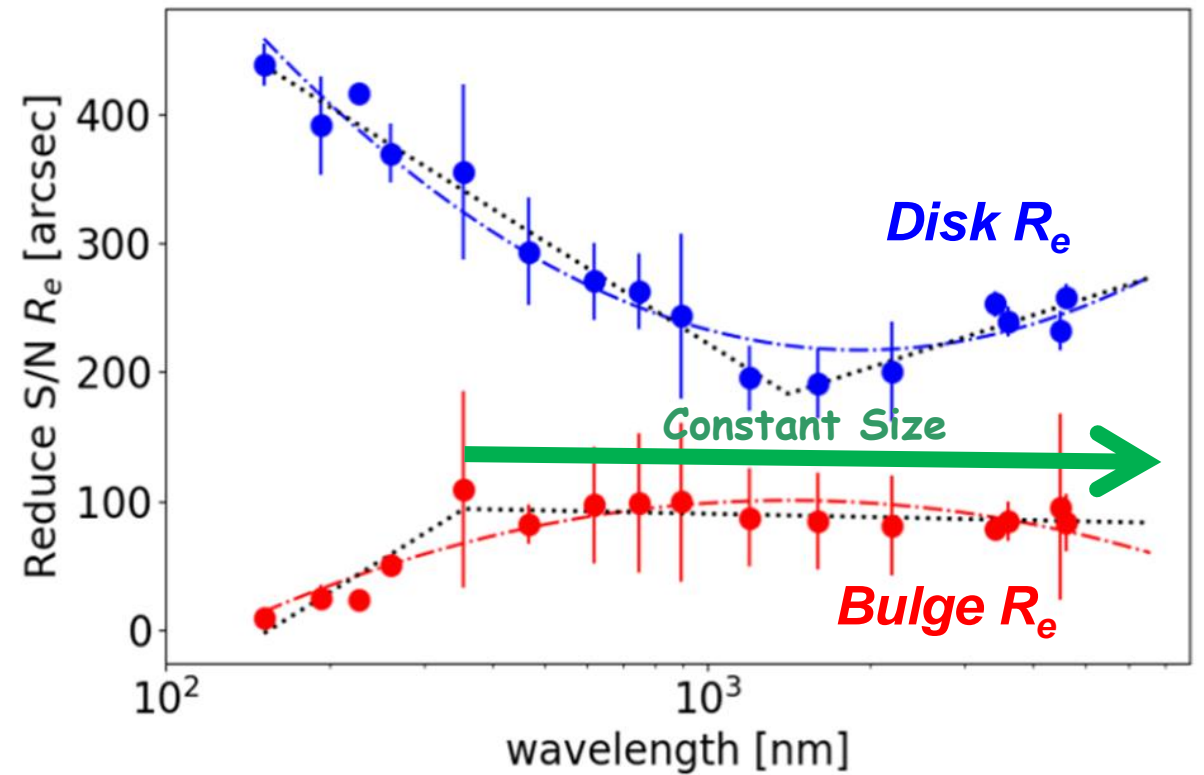
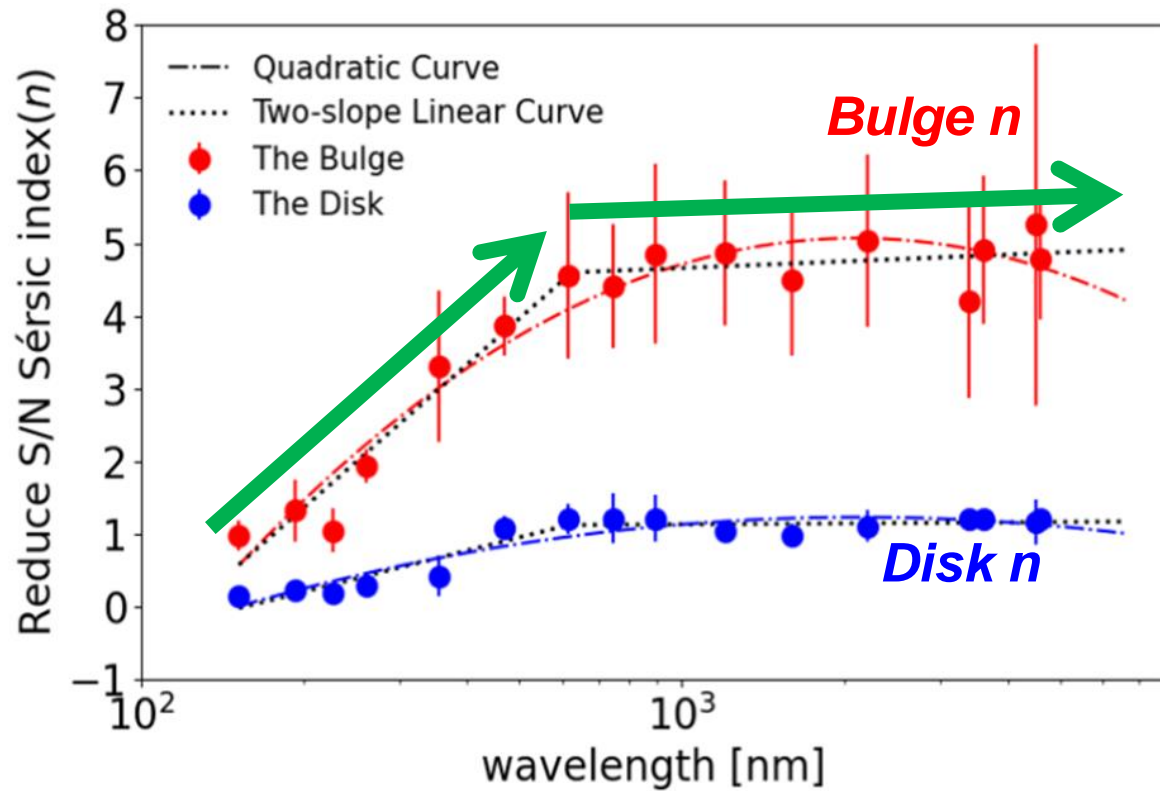
# Image Analysis: Bulge - Disk Decomposition

NGC 3031 (M81)



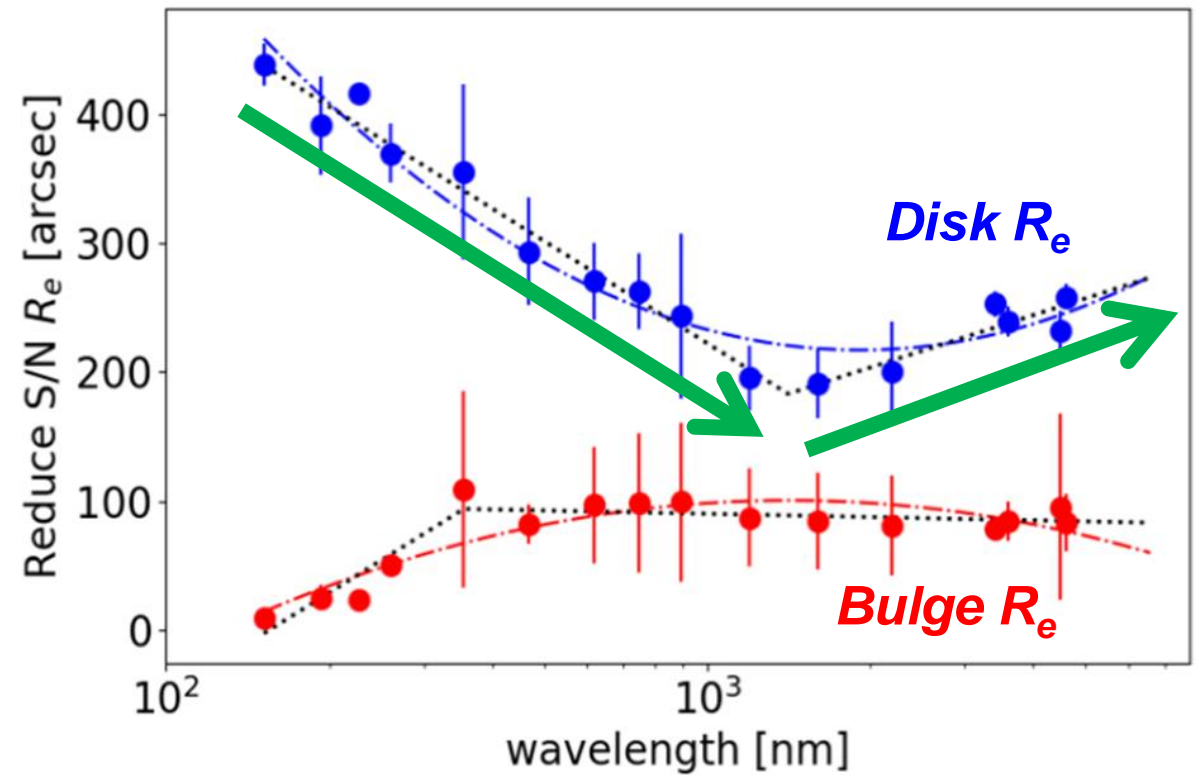
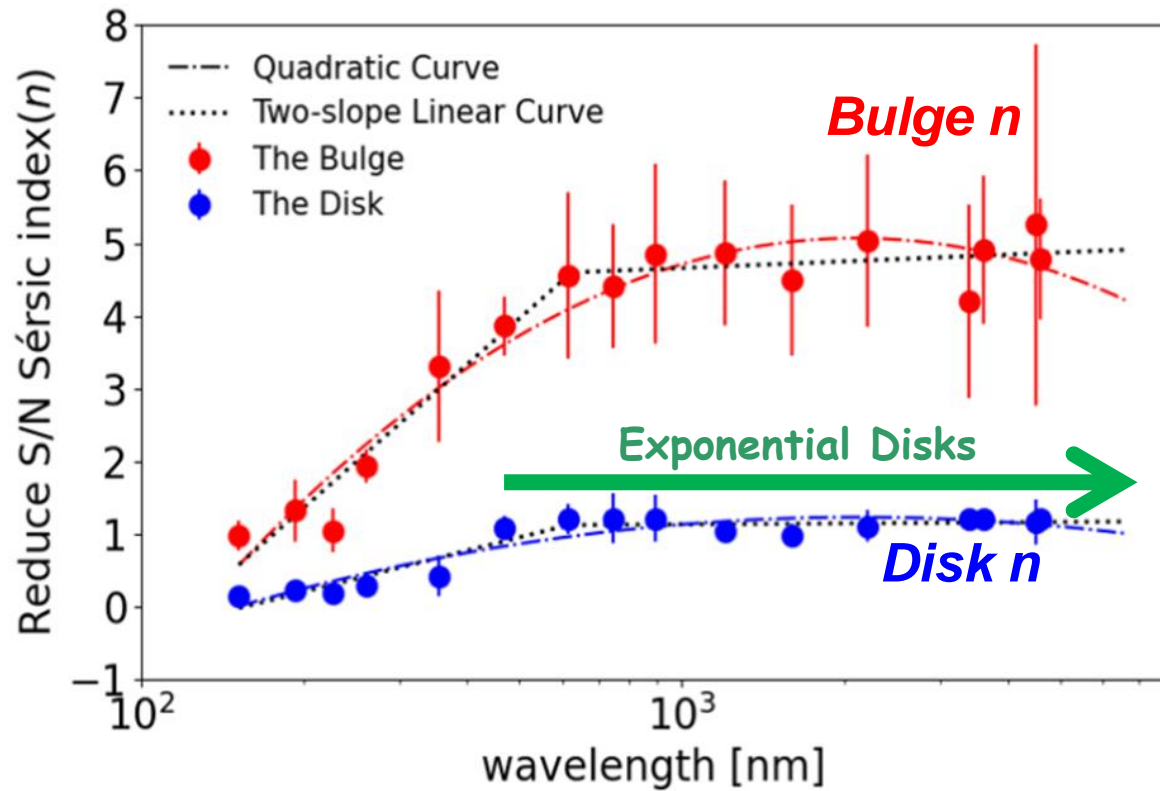
# Image Analysis: Bulge - Disk Decomposition

NGC 3031 (M81)



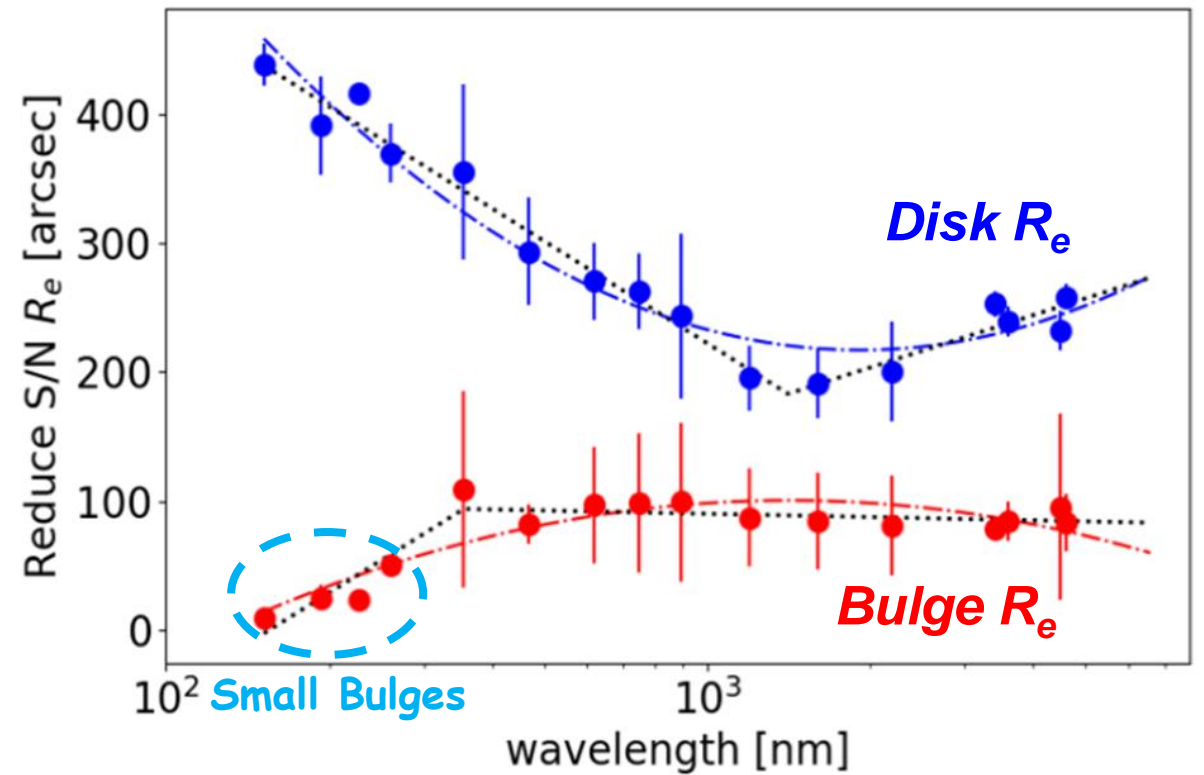
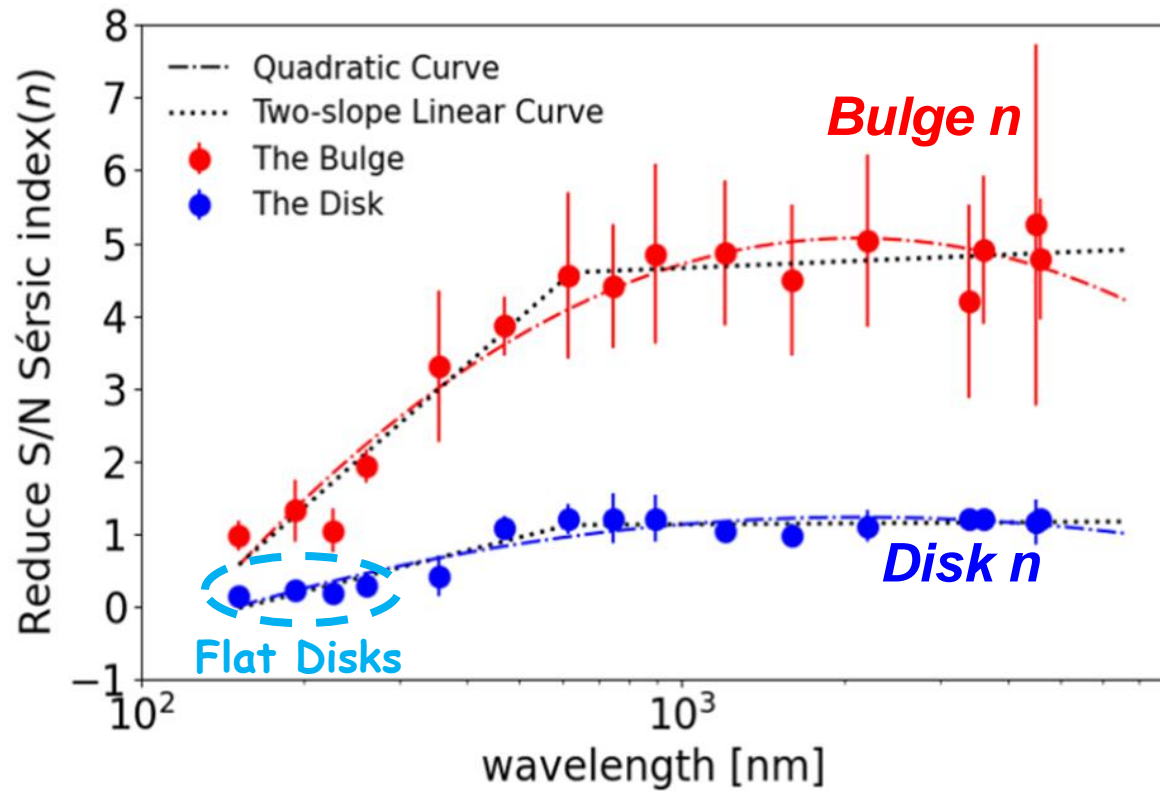
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NGC 3031 (M81)



# Image Analysis: Bulge - Disk Decomposition

NGC 3031 (M81)



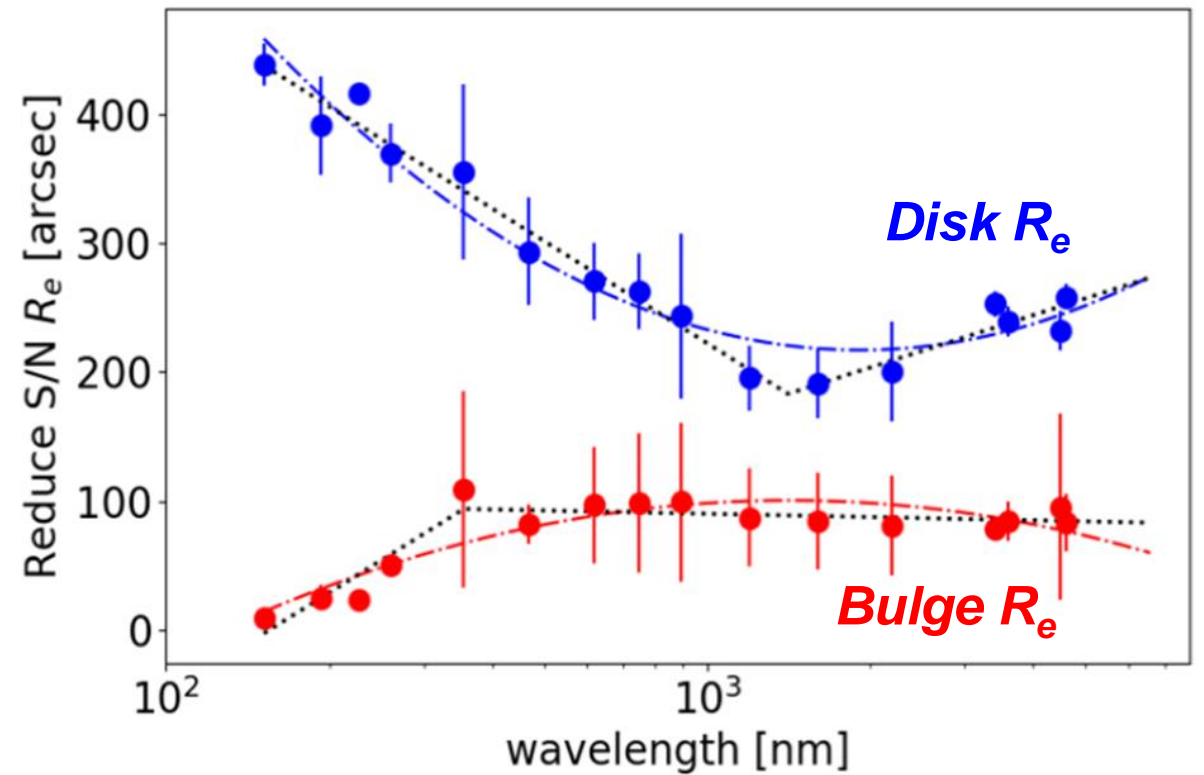
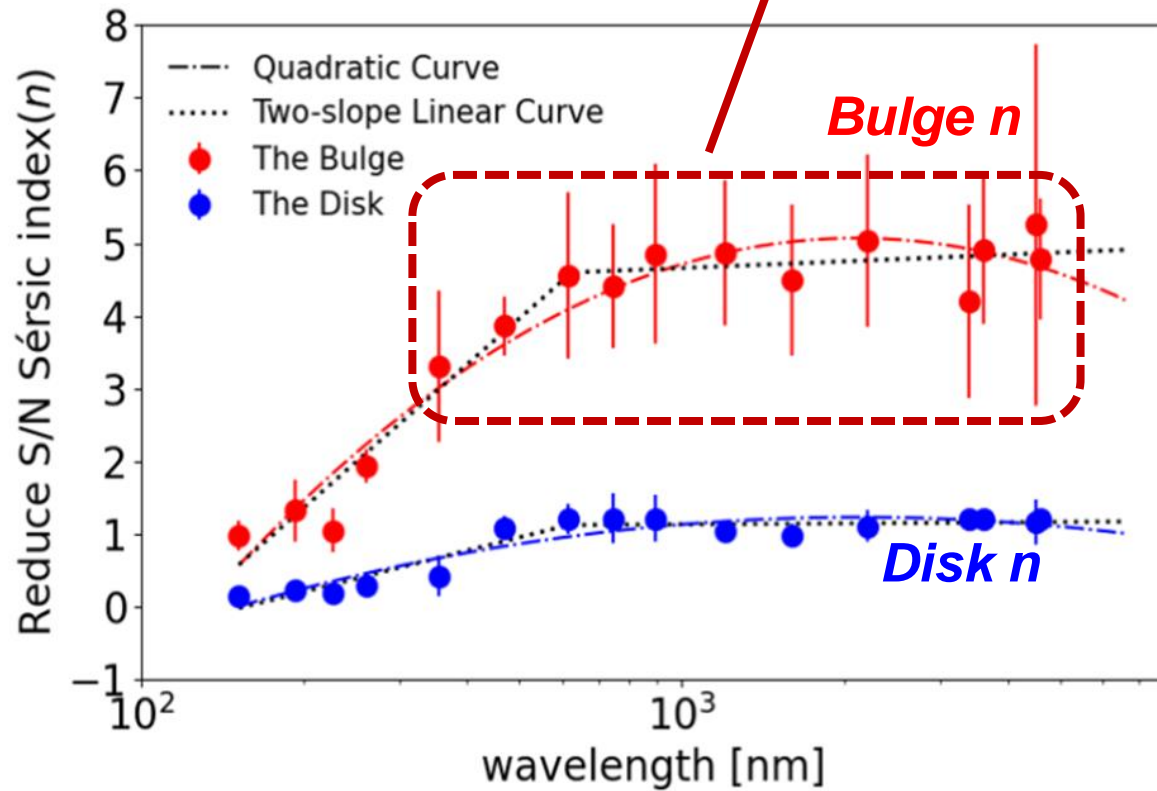


# Image Analysis: Bulge - Disk Decomposition

## Classical Bulges

( $n \sim 3-5$ )

NGC 3031 (M81)

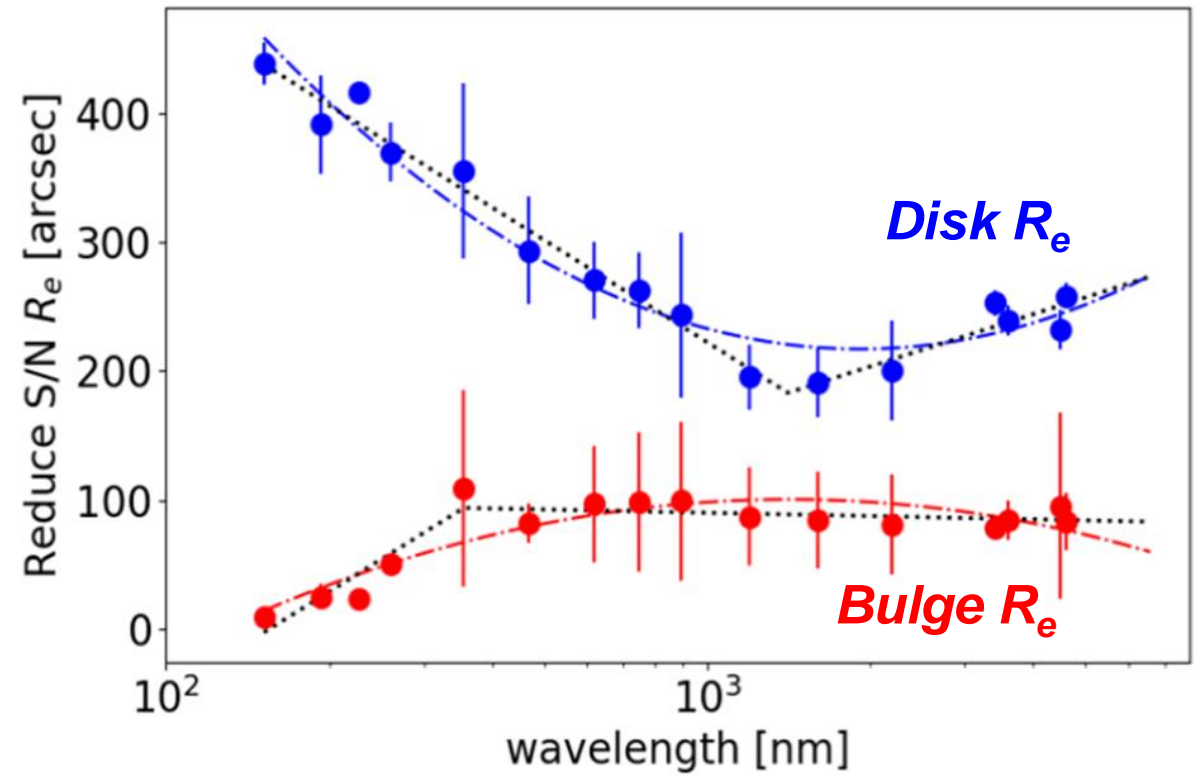
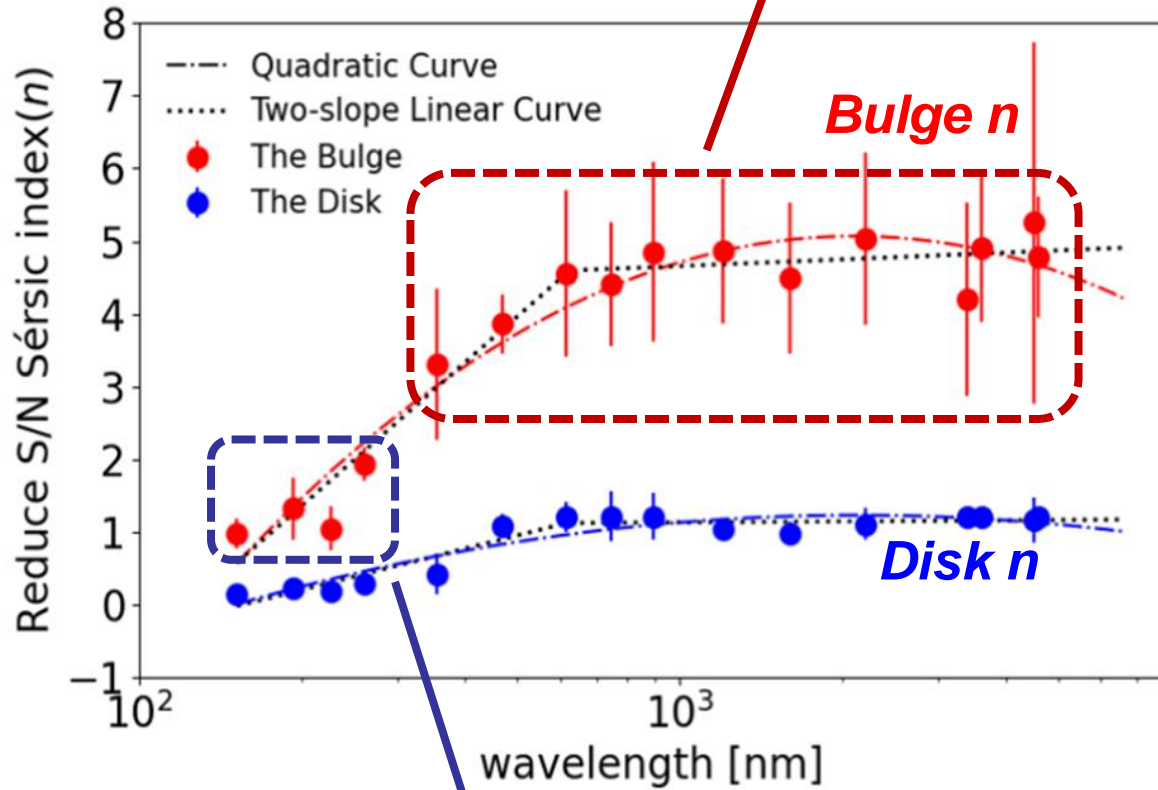


# Image Analysis: Bulge - Disk Decomposition

## Classical Bulges

( $n \sim 3-5$ )

NGC 3031 (M81)



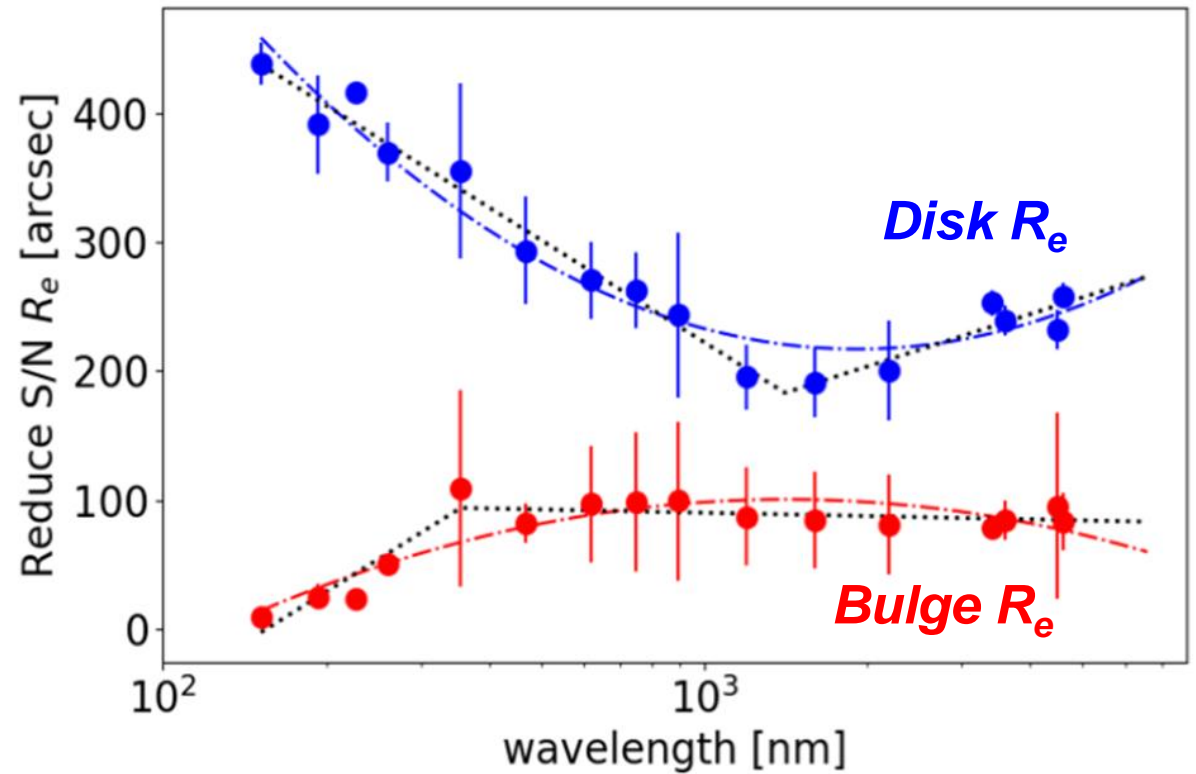
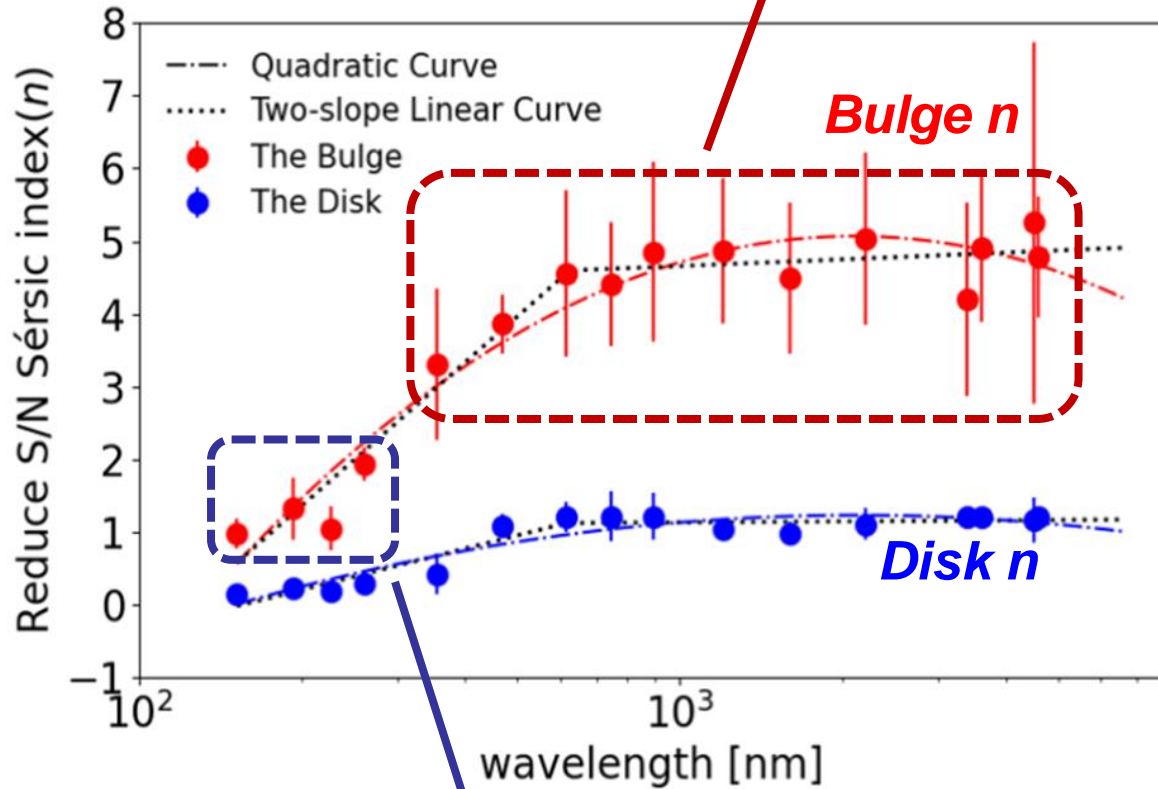
Pseudo-bulges or no Bulge  
( $n \sim 1-2$ )

# Image Analysis: Bulge - Disk Decomposition

## Classical Bulges

( $n \sim 3-5$ )

NGC 3031 (M81)



## Pseudo-bulges or no Bulge

( $n \sim 1-2$ )

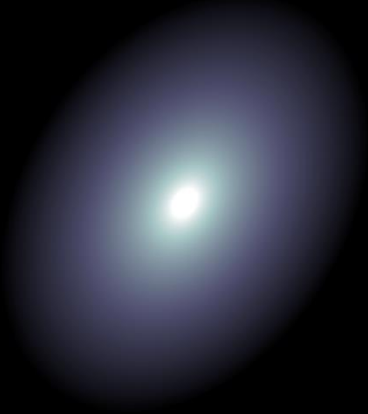


**We are quite likely to miss classical bulges through restframe UV channels !**



**Next Work**

# *Bulge + Disk Synthesis*



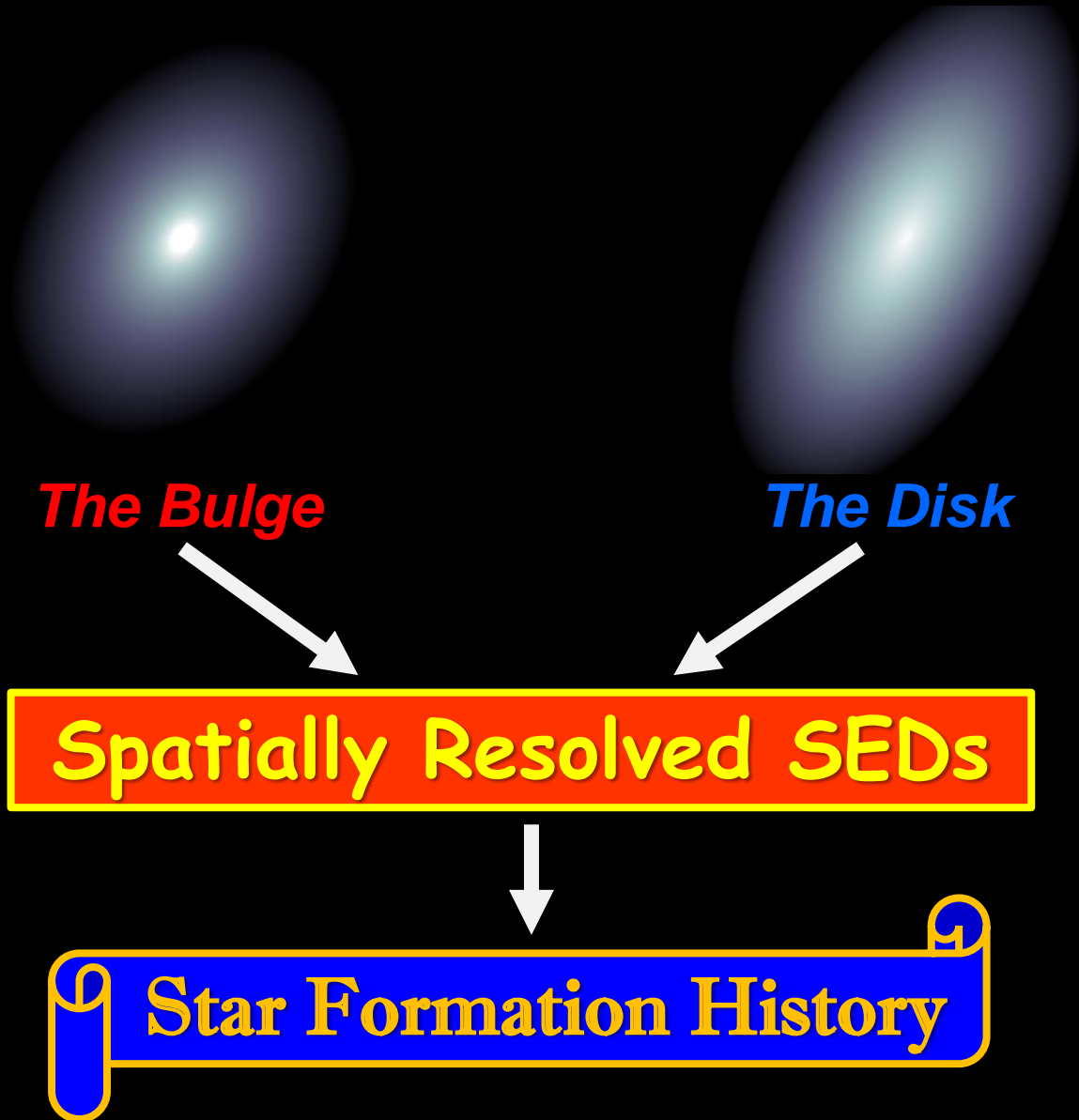
*The Bulge*



*The Disk*

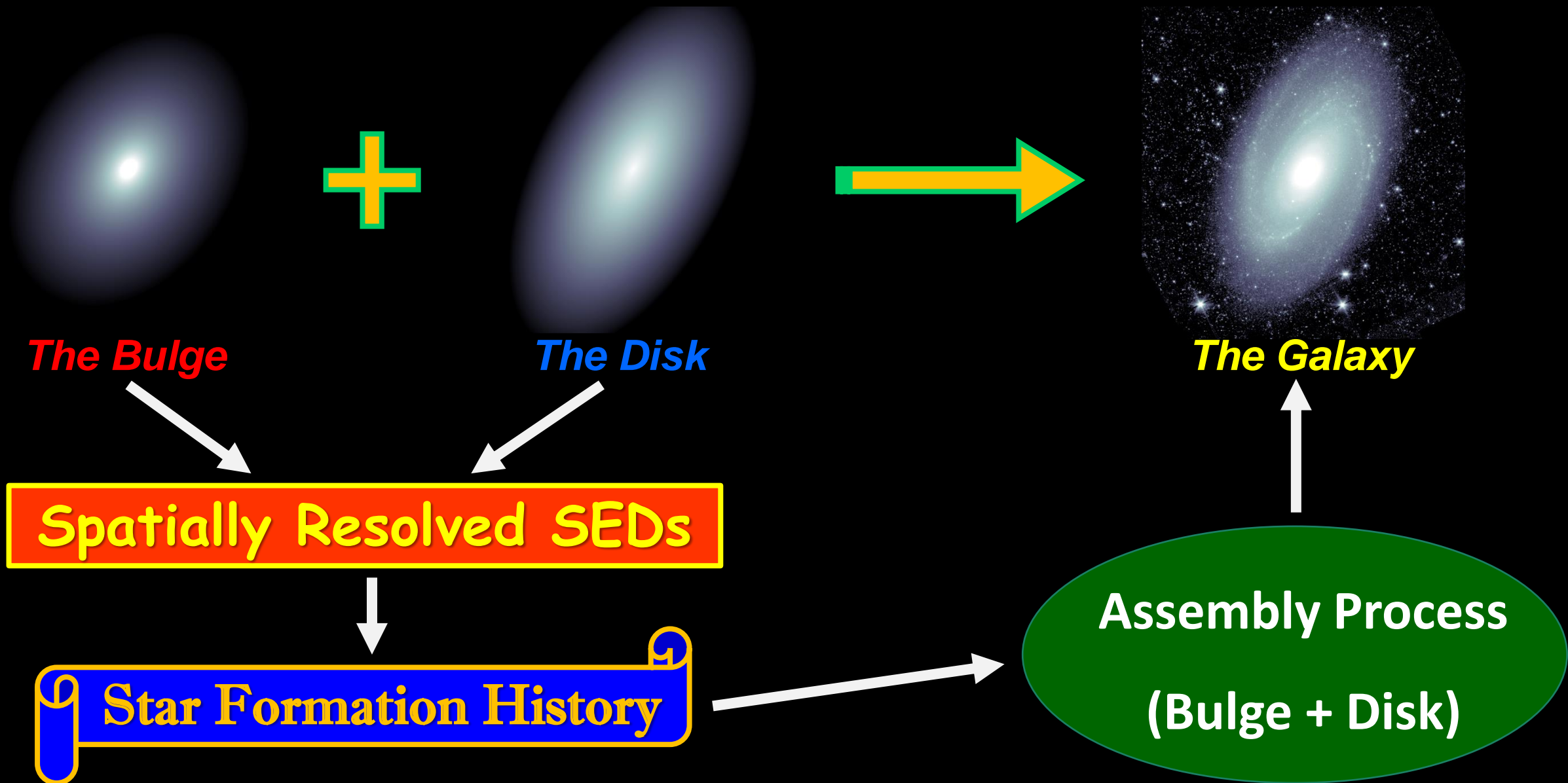
## Next Work

## *Bulge + Disk Synthesis*



# Next Work

## *Bulge + Disk Synthesis*



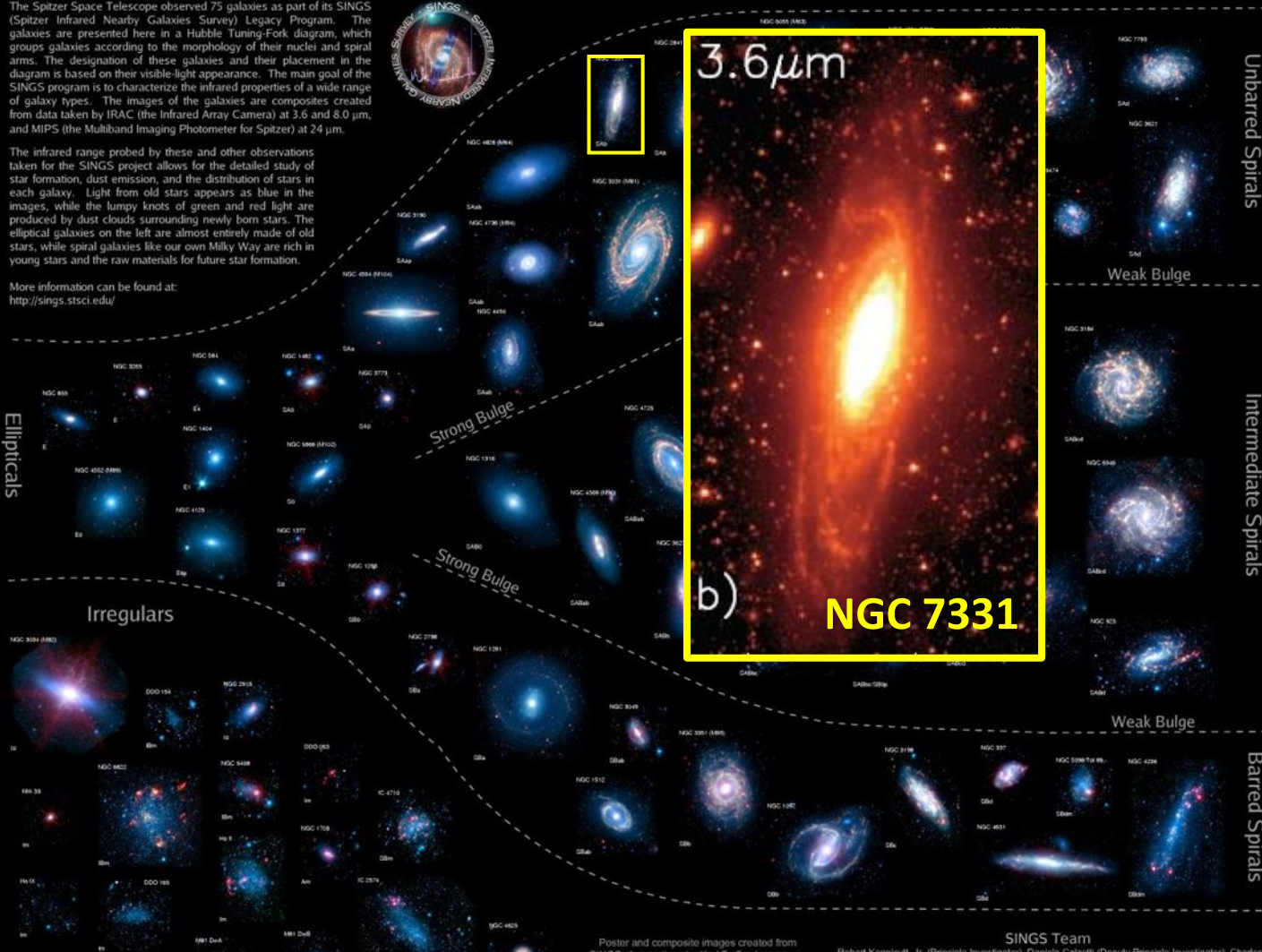
# Nearby Galaxies

## The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

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The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at: <http://sings.stsci.edu/>

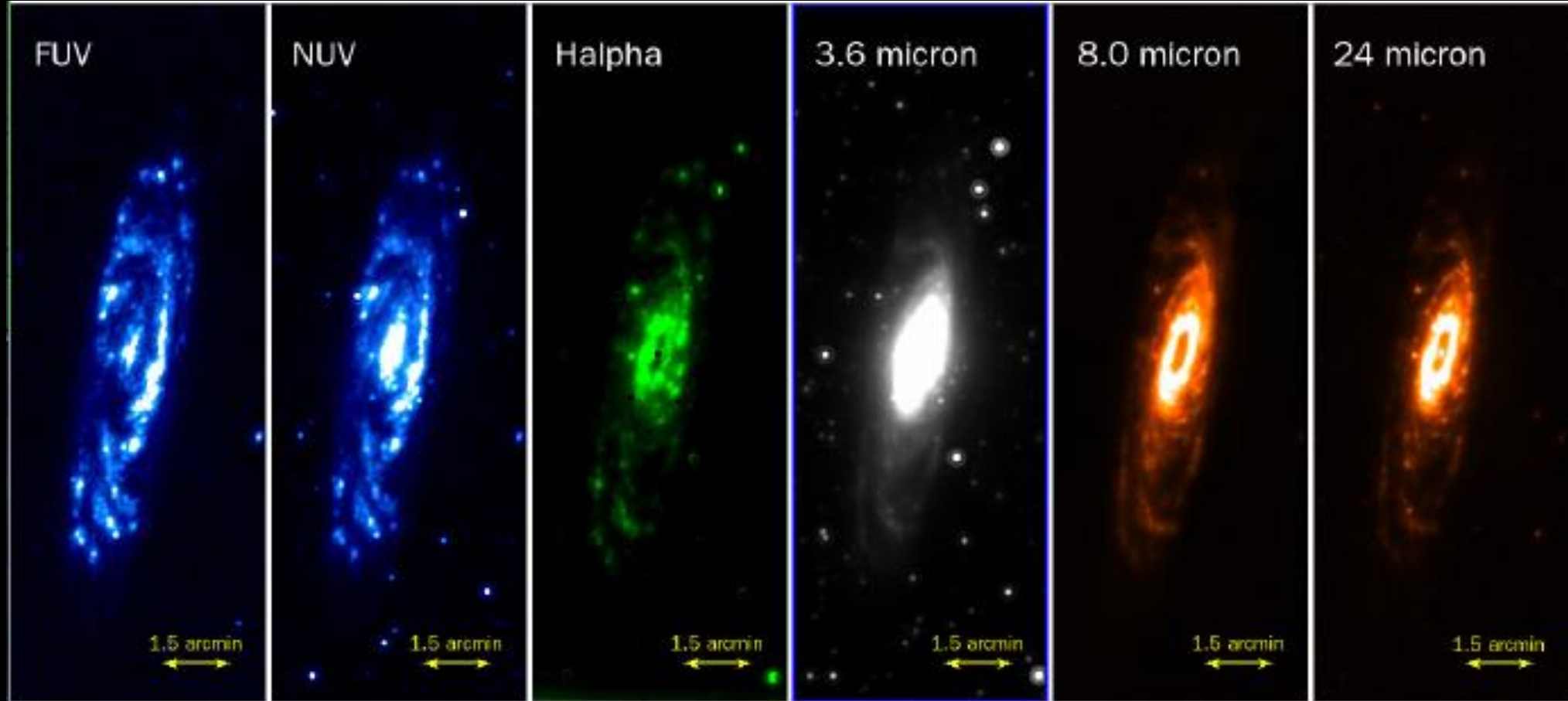


Poster and composite images created from SINGS observations by Karl D. Gordon (Oct 2007)  
 Blue=IRAC 3.6 $\mu\text{m}$  (stars)  
 Green=IRAC 8 $\mu\text{m}$   
 (aromatic features from dust grains/molecules)  
 Red=MIPS 24 $\mu\text{m}$  (warm dust)

**SINGS Team**  
 Robert Kennicutt, Jr. (Principle Investigator), Daniela Calzetti (Deputy Principle Investigator), Charles Engelbracht (Technical Contact), Lee Armus, George Bendo, Caroline Bot, Brent Bruckshaw, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Aigen Li, Sangeeta Malhotra, Martin Meyer, John Mousliskas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kartik Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Helou

# *Image Analysis: Bulge - Disk Decomposition*

## NGC 7331 Multi-wavelength Study

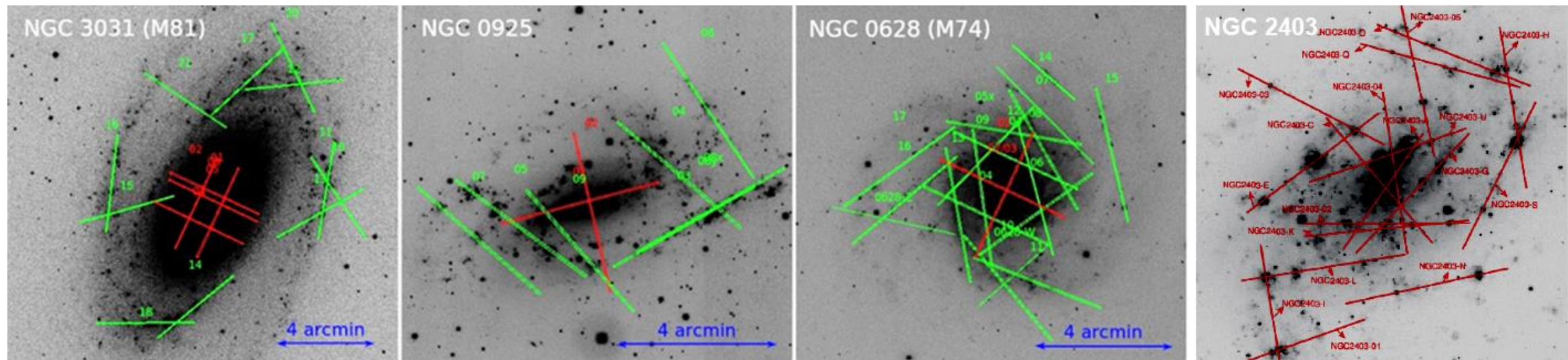


(Mou & Mao et al. 2024, in prep.)



# *Spectroscopic Analysis: Resolving Galaxies*

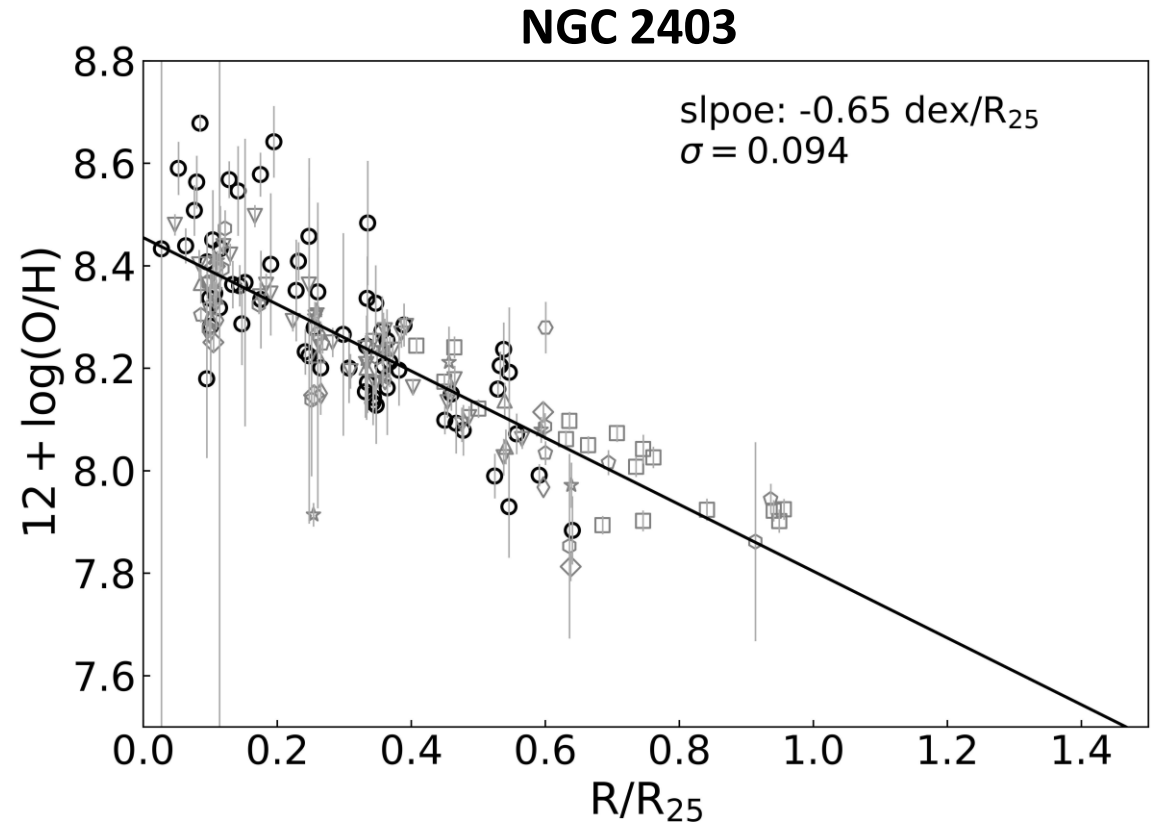
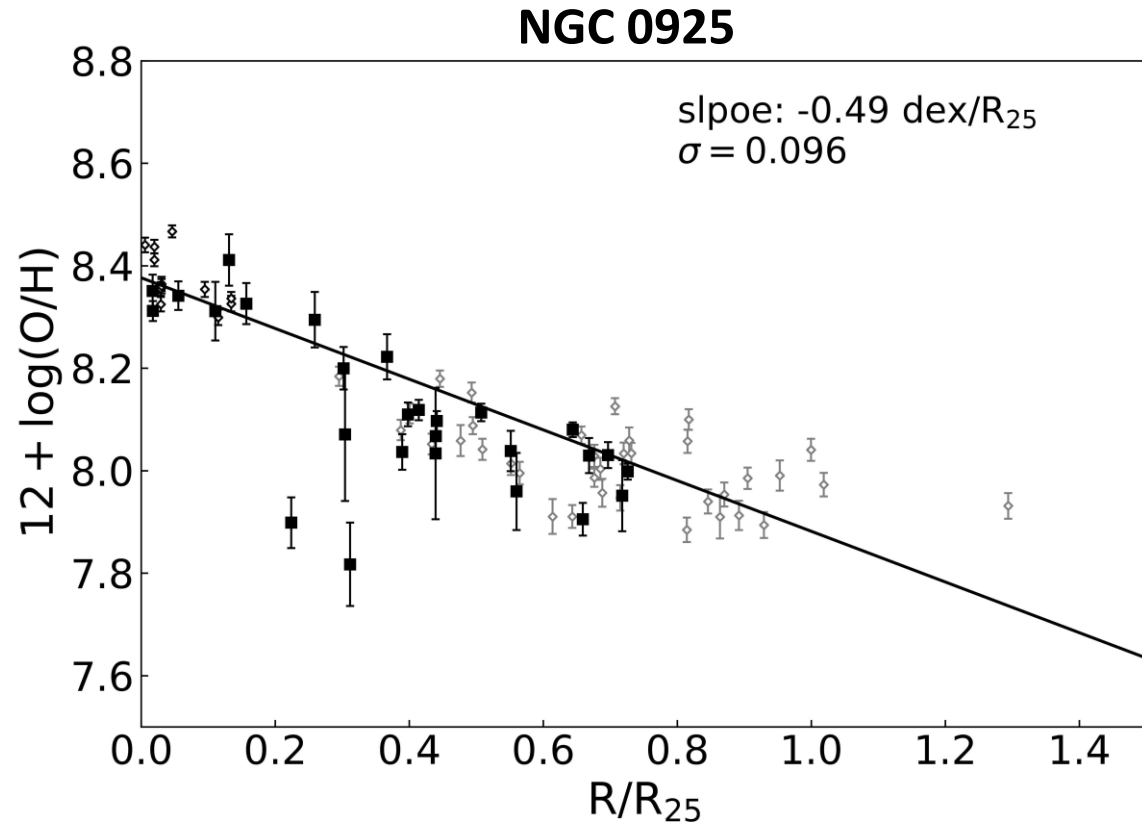
## **Long-Slit Spectroscopic Observations with the 2.16 m**



(Kong et al. 2014)

# *Spectroscopic Analysis: Resolving Galaxies*

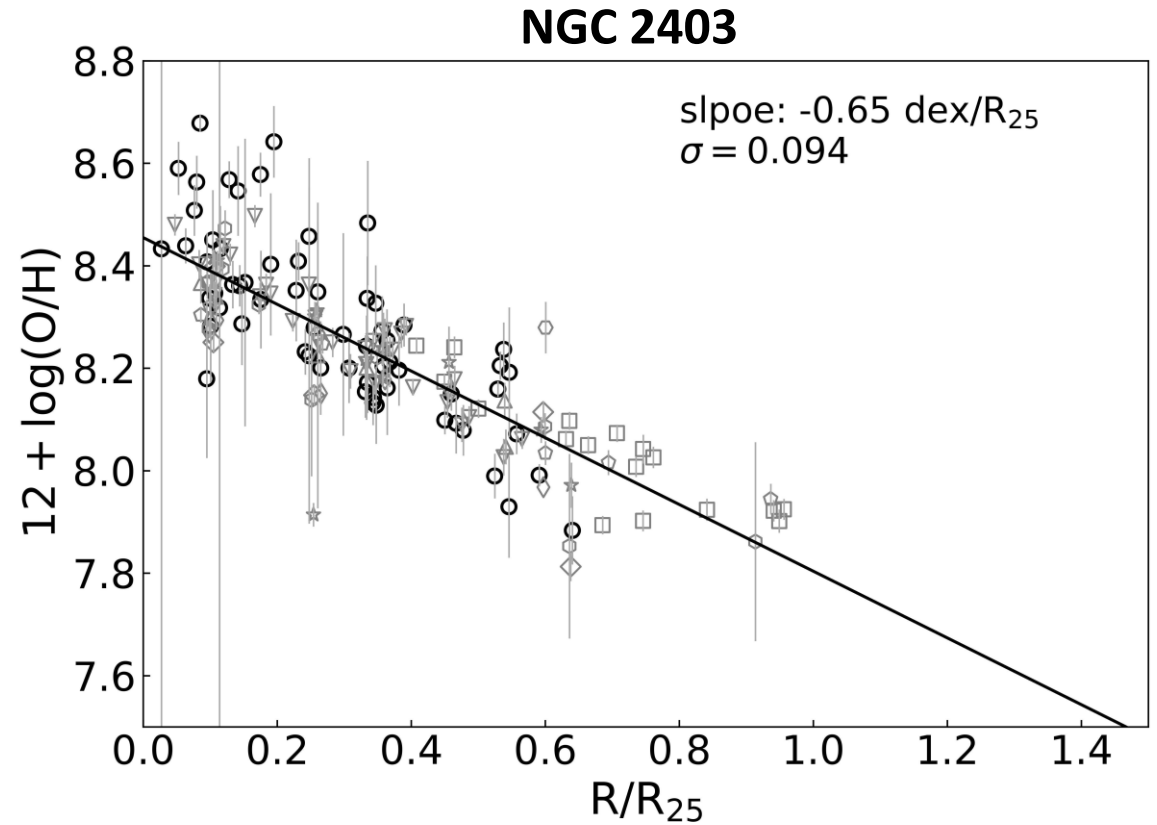
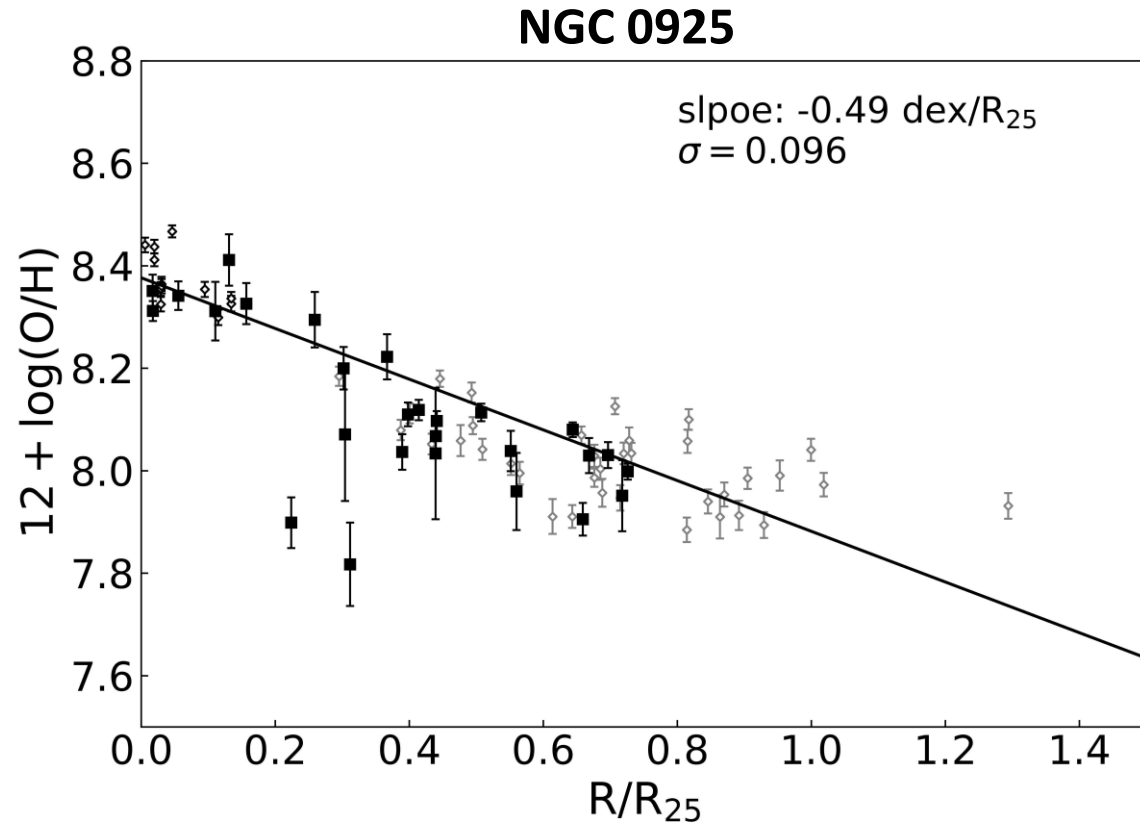
## Metallicity Gradients in Galaxies



— Relics of Chemical Evolution of Galaxies

# *Spectroscopic Analysis: Resolving Galaxies*

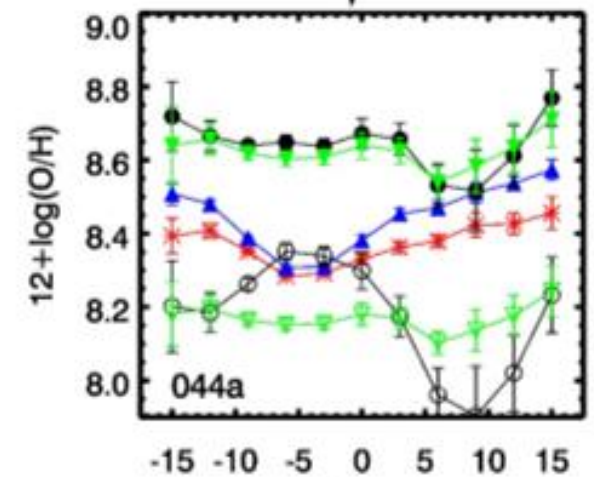
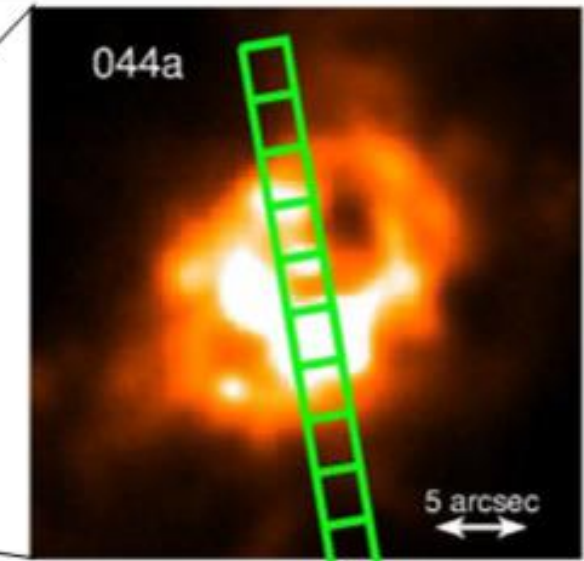
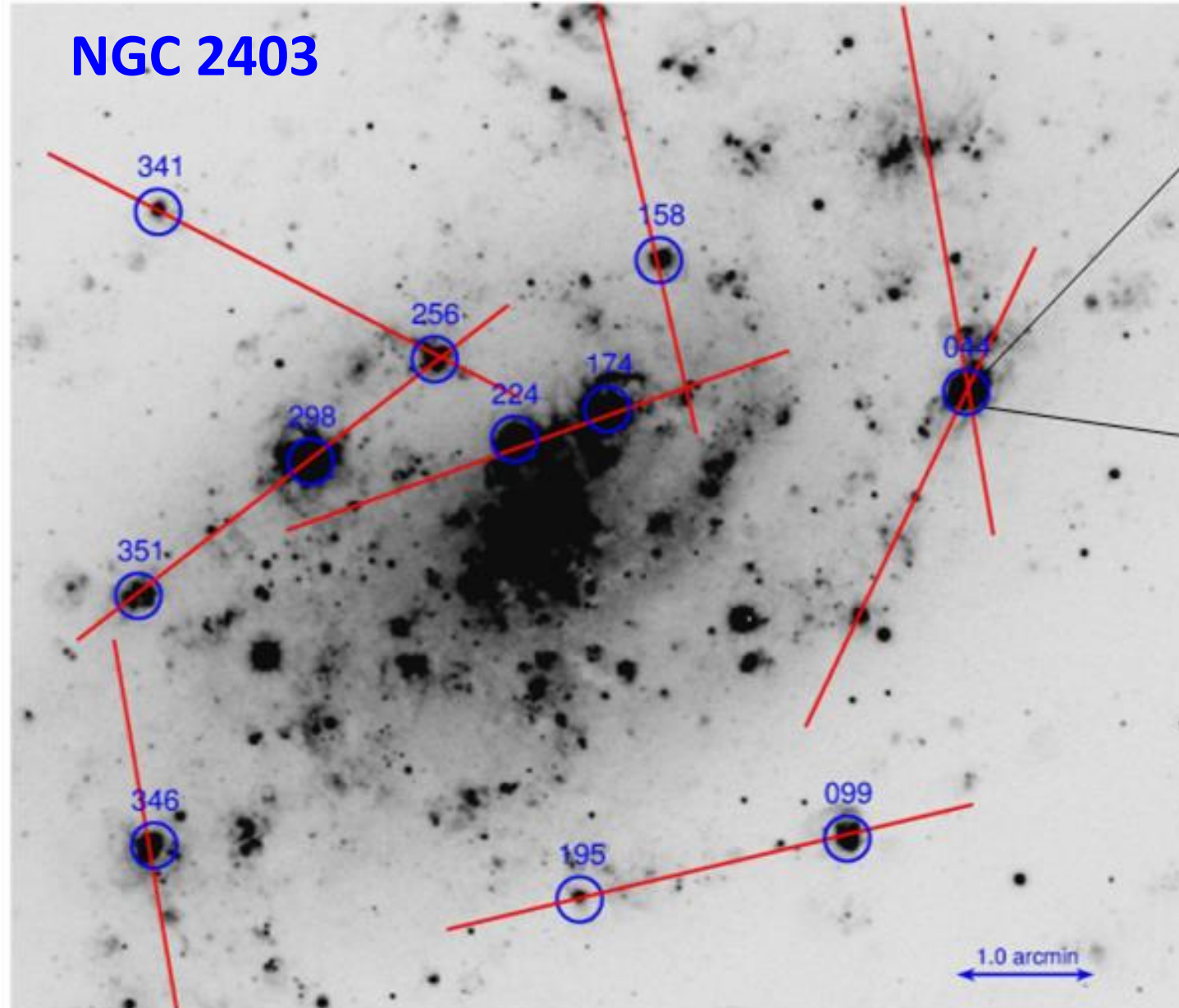
## Metallicity Gradients in Galaxies



— Relics of Chemical Evolution of Galaxies

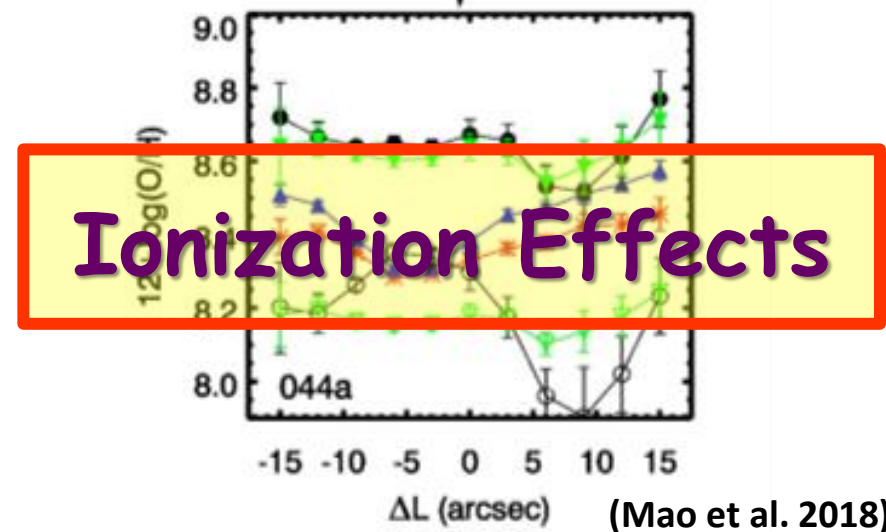
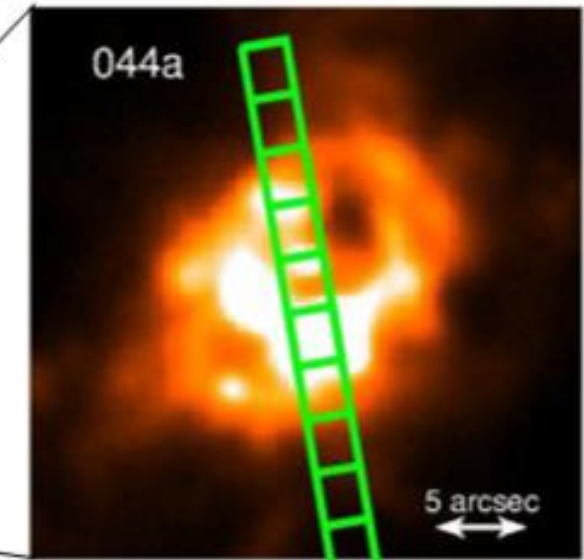
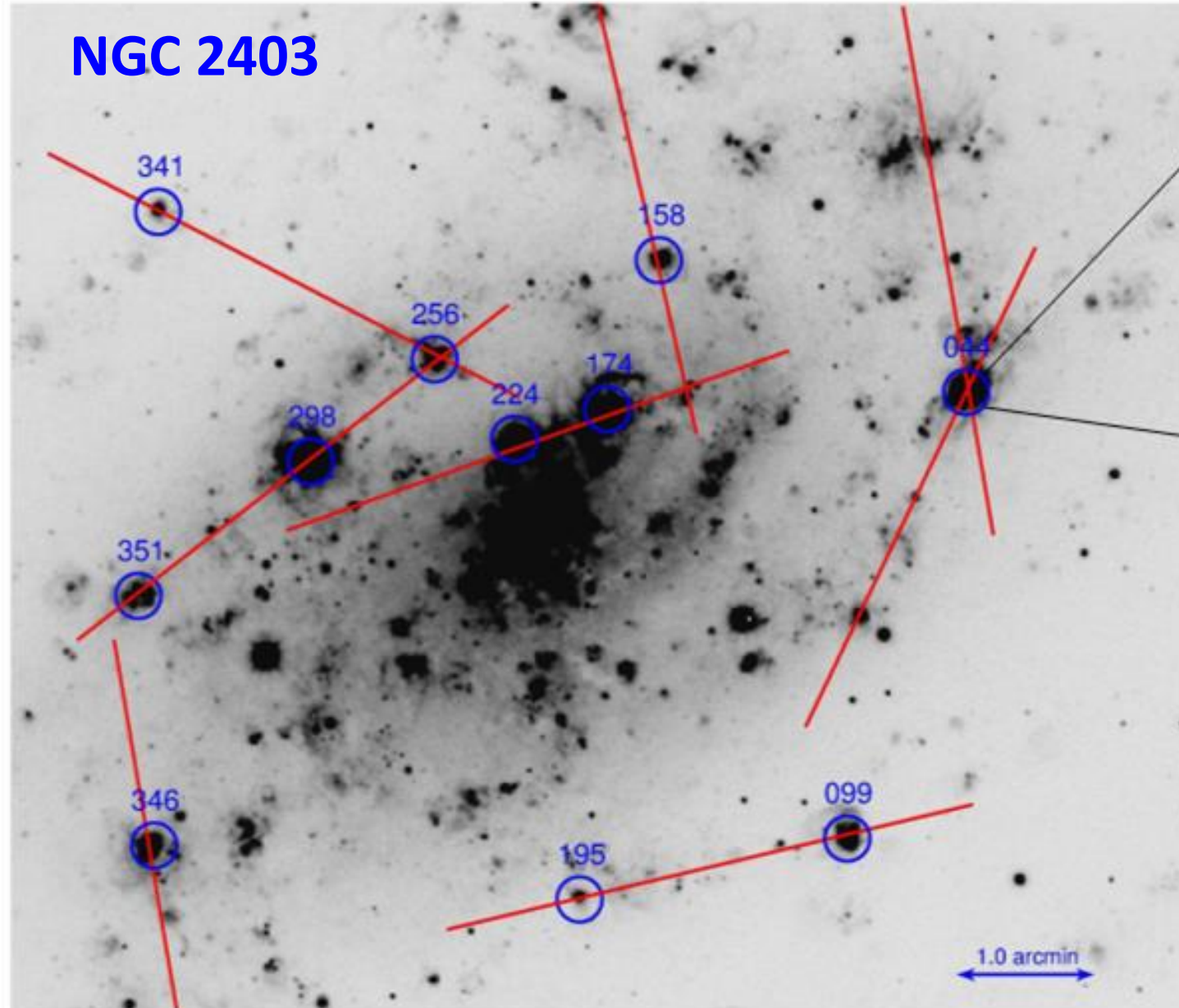
⚠ However, empirical diagnostics for metallicity are complicated. ⚠

# *Spectroscopic Analysis: Resolving HII Regions*

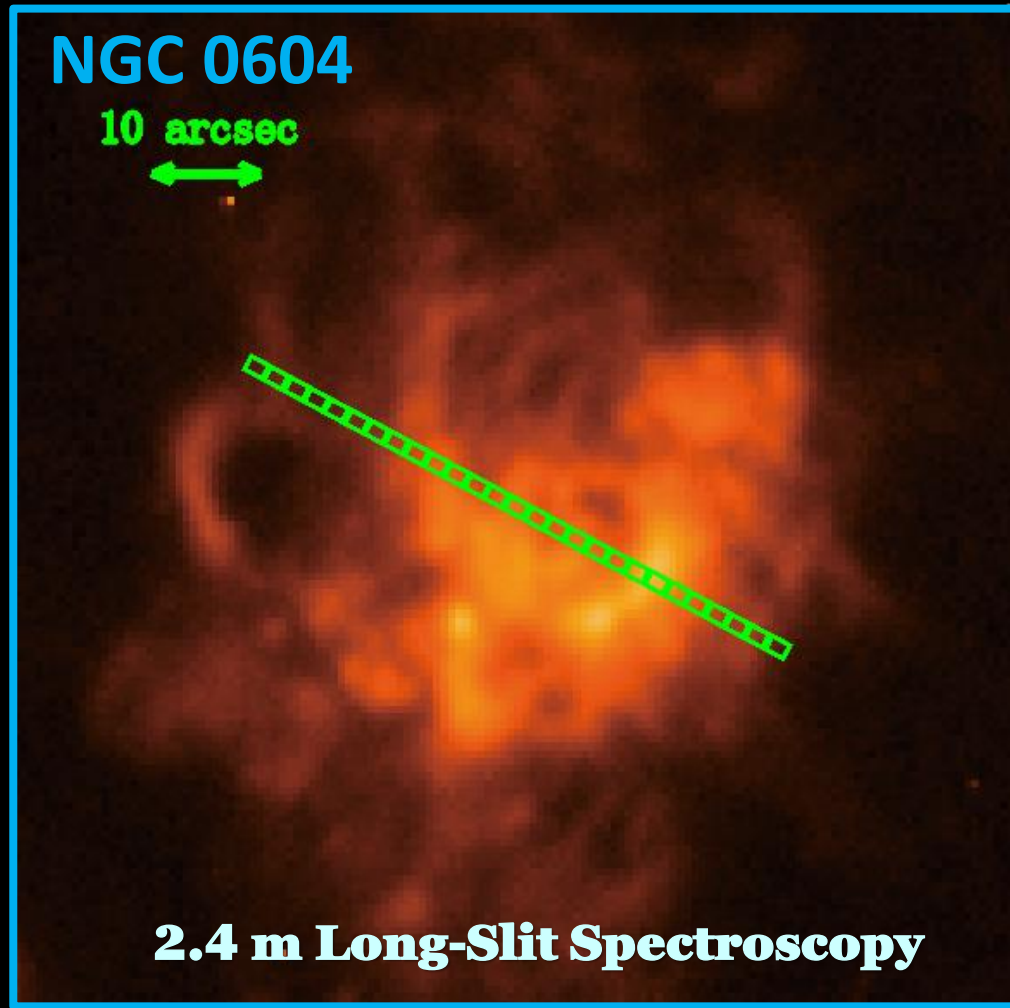


(Mao et al. 2018)

# *Spectroscopic Analysis: Resolving HII Regions*

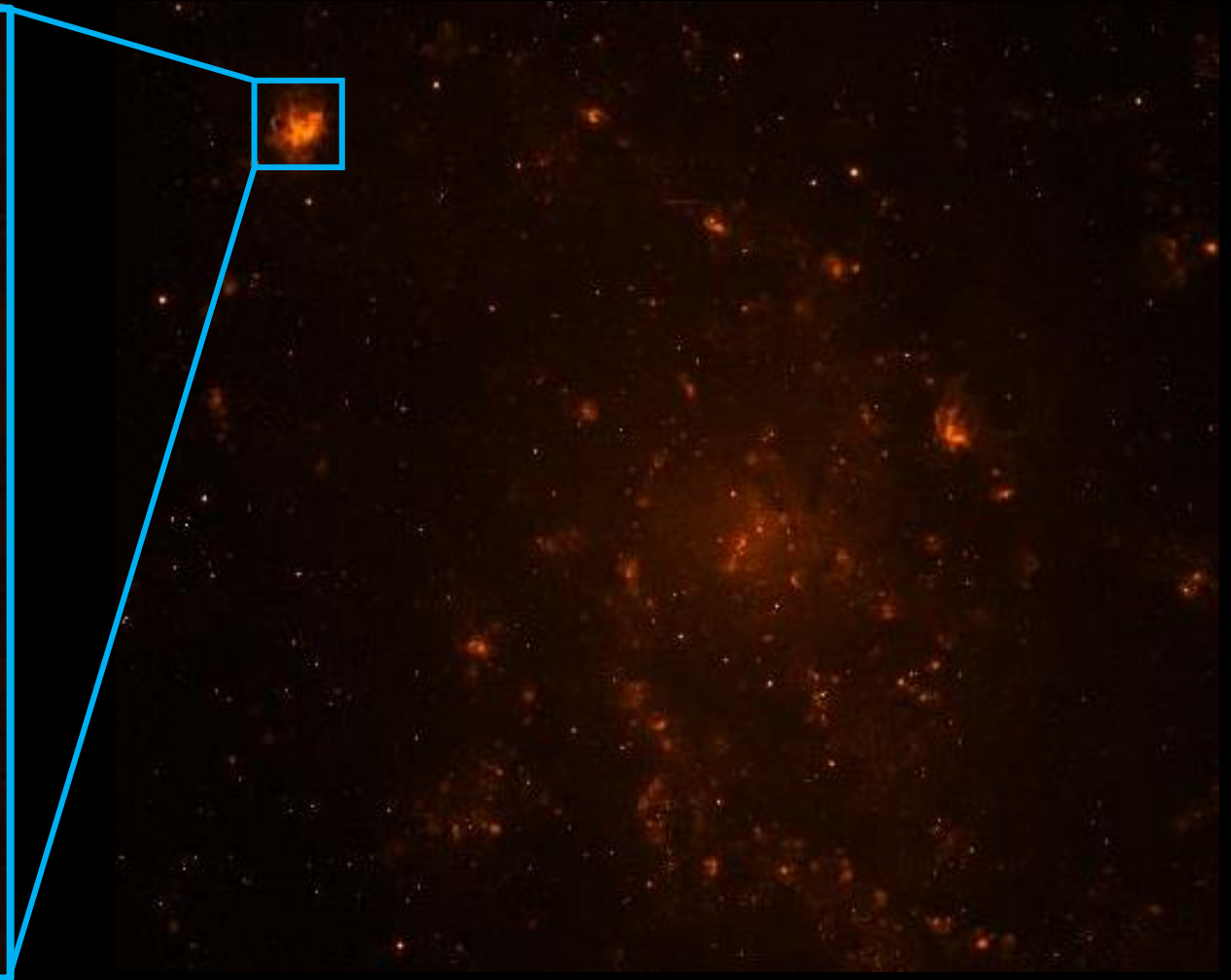


# *Spectroscopic Analysis: Resolving HII Regions*



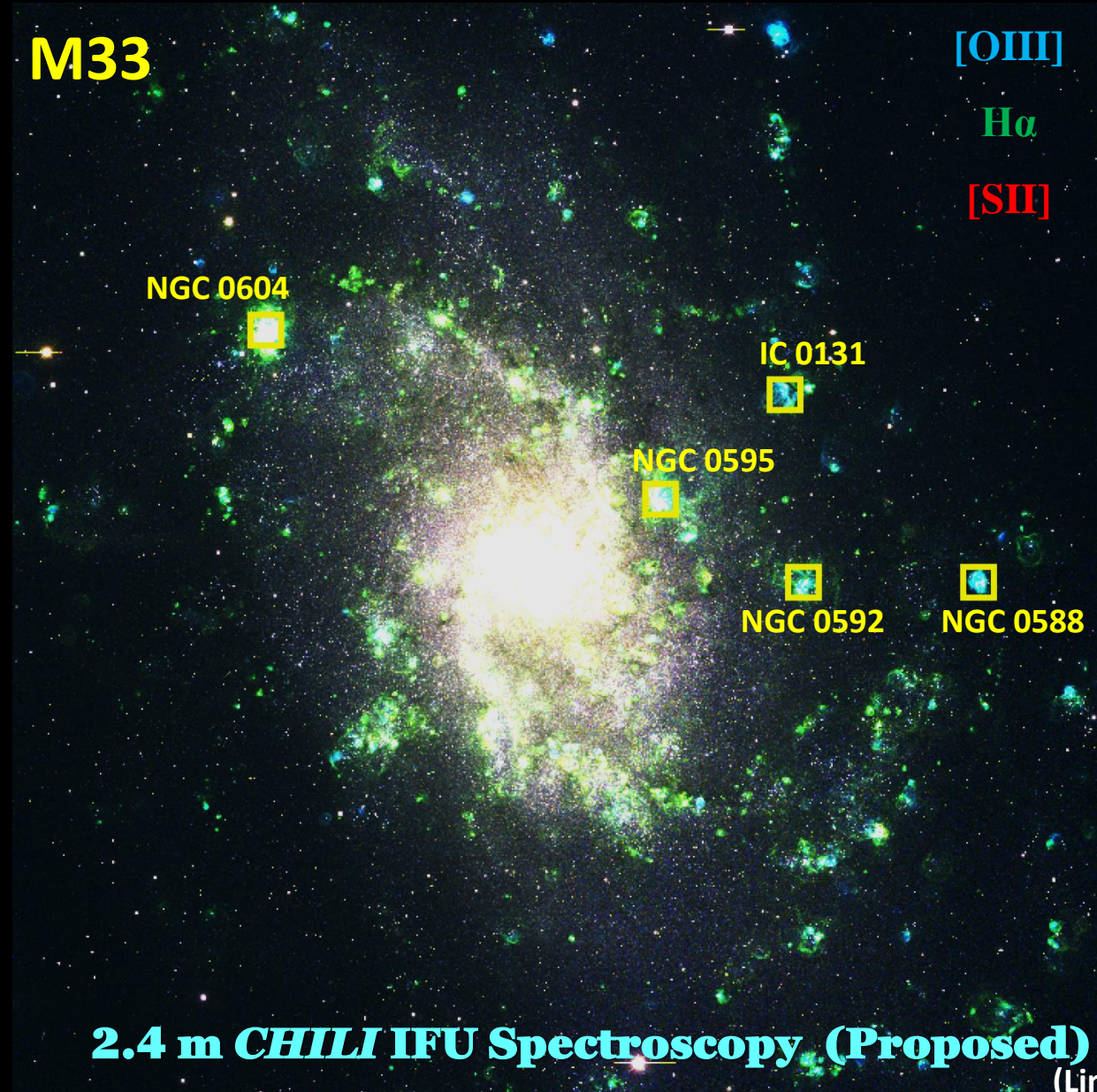
Positions of 27 Apertures Placed in NGC 0604

*H $\alpha$*  Narrow-band Image for NGC 0604



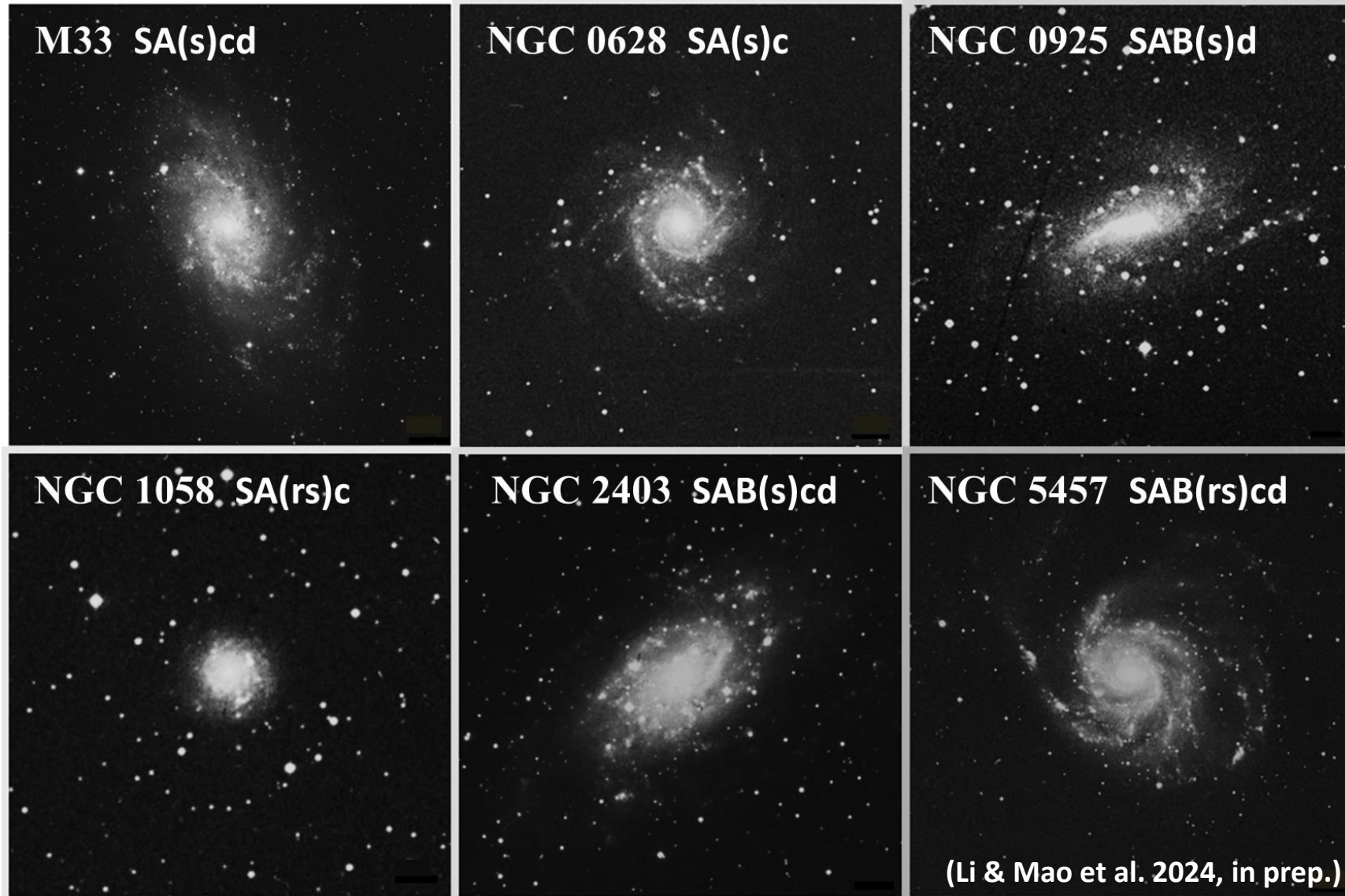
*H $\alpha$*  Narrow-band Image for M33

# *Spectroscopic Analysis: Resolving HII Regions*



# *Statistics*

## Empirical Metallicity Gradients in 6 Nearby Spiral Galaxies





# **[ Nearby Galaxies ] ➤ Galaxy Formation and Evolution**

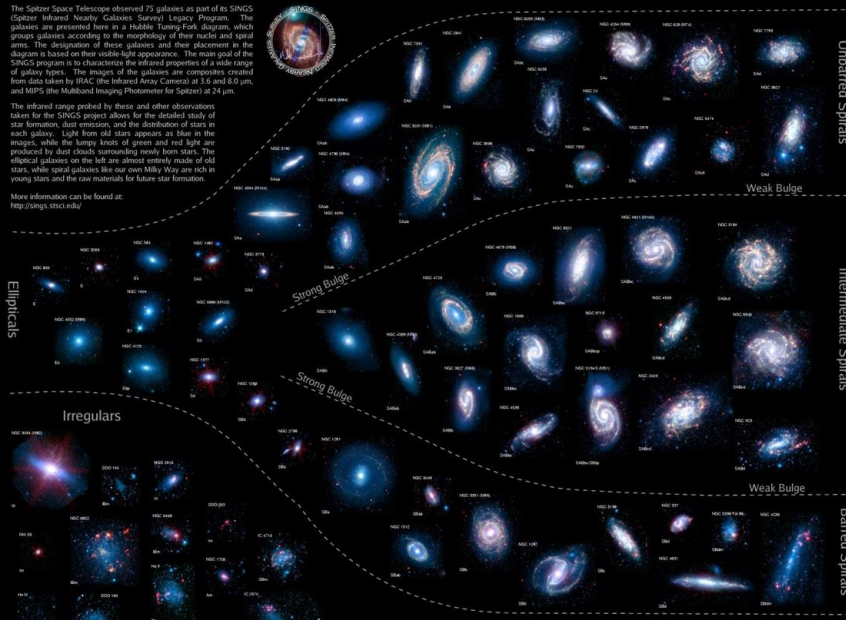


**Meet the Neighbors**  
The Spitzer Local Volume Legacy Survey

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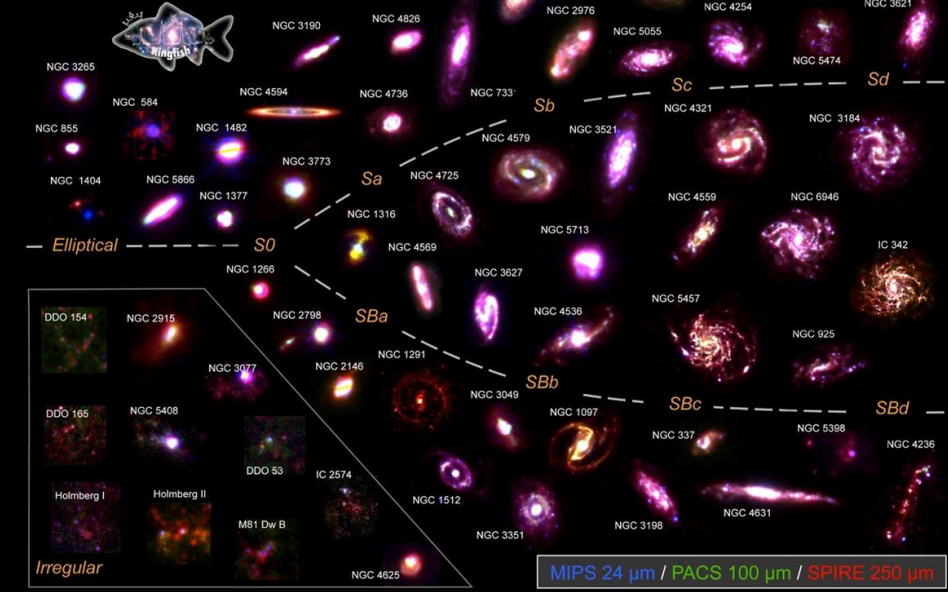


Proctor and composite images created from SINGS observations by Karl O. Gordon (on left); Blue/IRAC 3.6  $\mu\text{m}$  (stars); Green/IRAC 8.0  $\mu\text{m}$  (anomalous features from dust grains/molecules); Red/MIPS 24  $\mu\text{m}$  (star-forming areas).

**SINGS Team**  
Robert Kennicutt, Jr., Principle Investigator; Charles C. Desai, Deputy Principle Investigator; Charles Engelbracht, Technical Contact; Lee Anna, George Benelli, Catherine Bid, Brett Bokan, John Carilli, Daniel Daley, Wayne Dancy, Joel Gerwig, Robert Goetz, David Hershman, Tom Jarrett, Lee Marshall, Gabe Lerner, Adam Le, Gregorio Matelli, Martin Meier, John Moseley, Erik Moseley, Michael Ragan, George Rieke, Maria Rosa, Helmi Rosani, Kirk Sheth, J.D. Smith, Michelle Thumm, Fabian Walter & George Hodge.

## Kingfish (Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel)

<http://www.ast.cam.ac.uk/research/kingfish>



MIPS 24  $\mu\text{m}$  / PACS 100  $\mu\text{m}$  / SPIRE 250  $\mu\text{m}$

# **[ Nearby Galaxies ] ➤ Galaxy Formation and Evolution**

## **➤ Natural Laboratories for Experimenting on Astrophysical Processes**

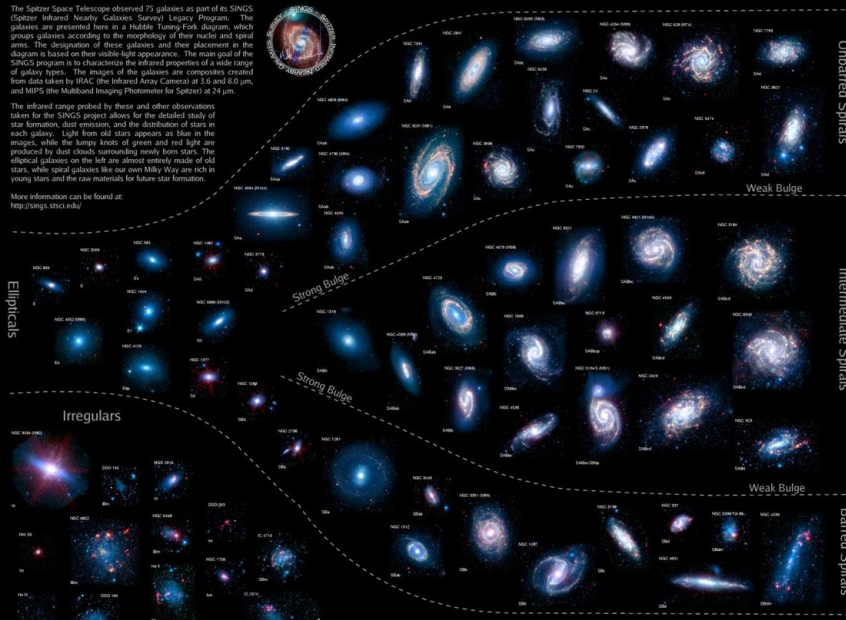


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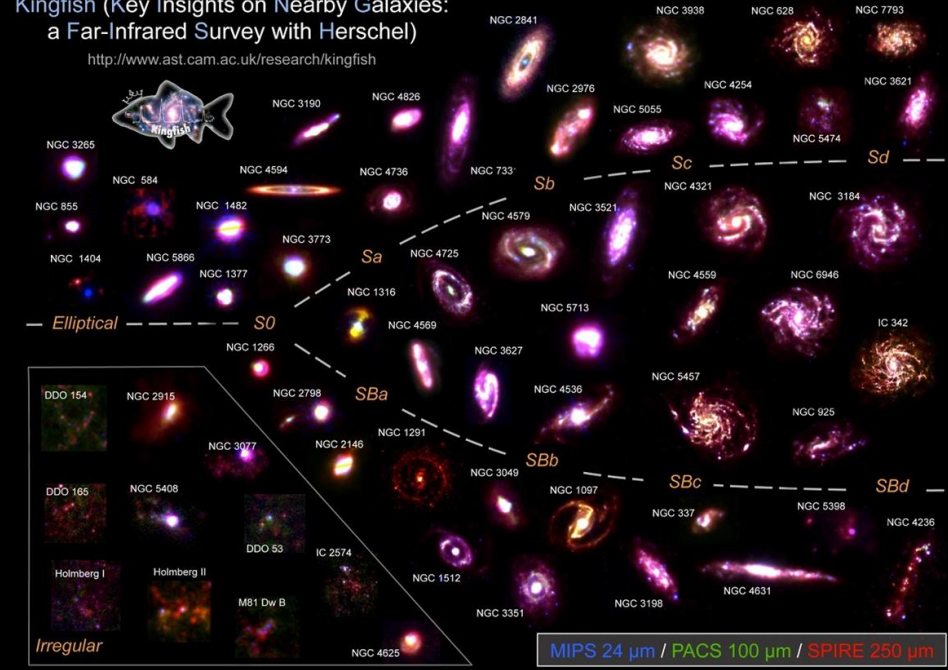


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Blue/IRAC 3.6  $\mu\text{m}$  (stars)  
Green/IRAC 8.0  $\mu\text{m}$   
Red/MIPS 24  $\mu\text{m}$  (dust grains/molecules)

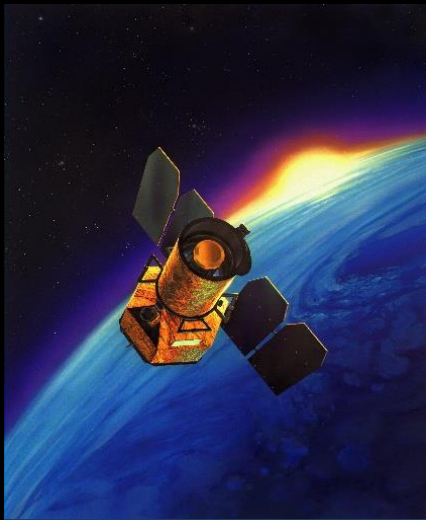
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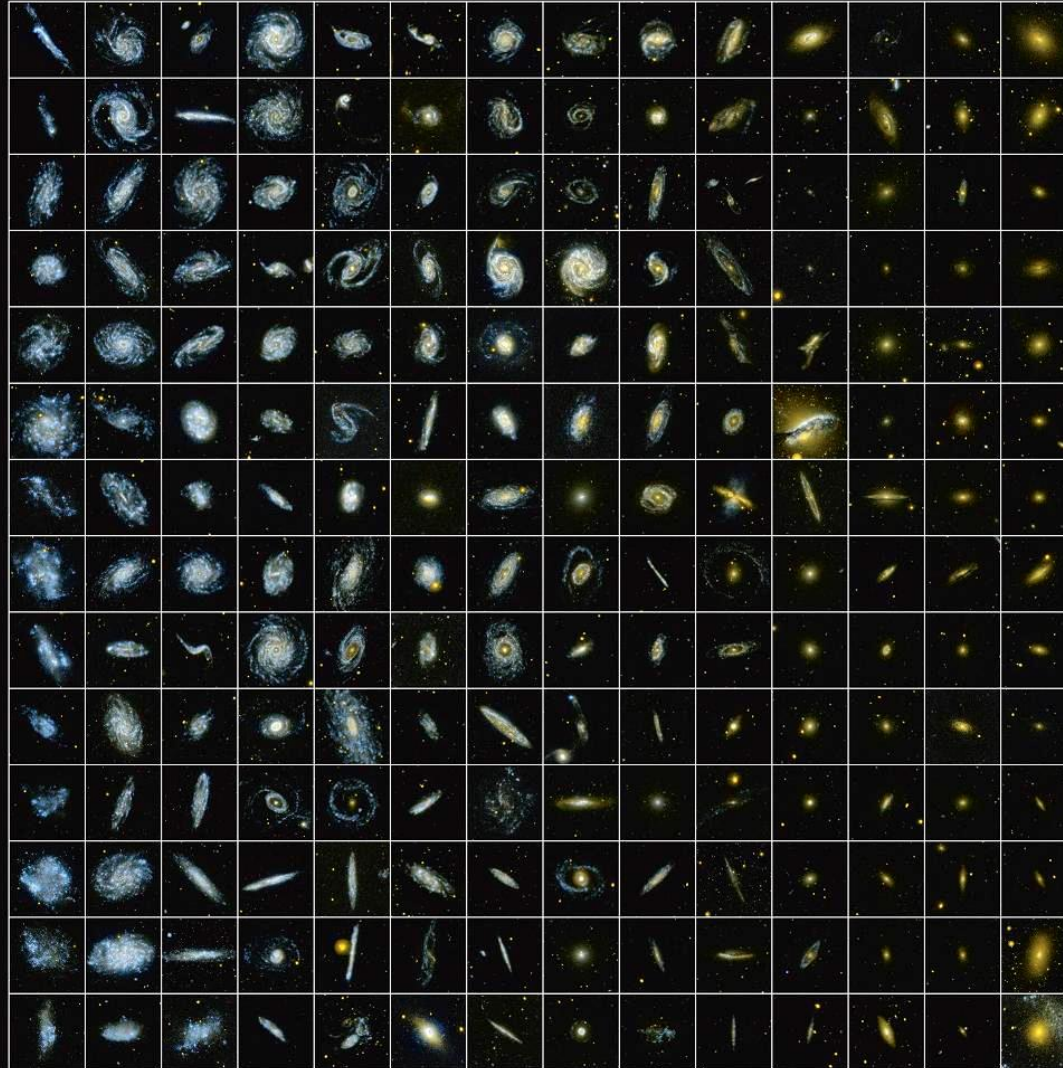
MIPS 24  $\mu\text{m}$  / PACS 100  $\mu\text{m}$  / SPIRE 250  $\mu\text{m}$



**Nearby  
Galaxy  
Survey  
of  
GALEX**

**GALEX** Galaxy Evolution Explorer

**Ultraviolet Atlas of Nearby Galaxies**



# *Special Issue: XUV Disks*

**NGC 5236 (M83) @ Opt.**



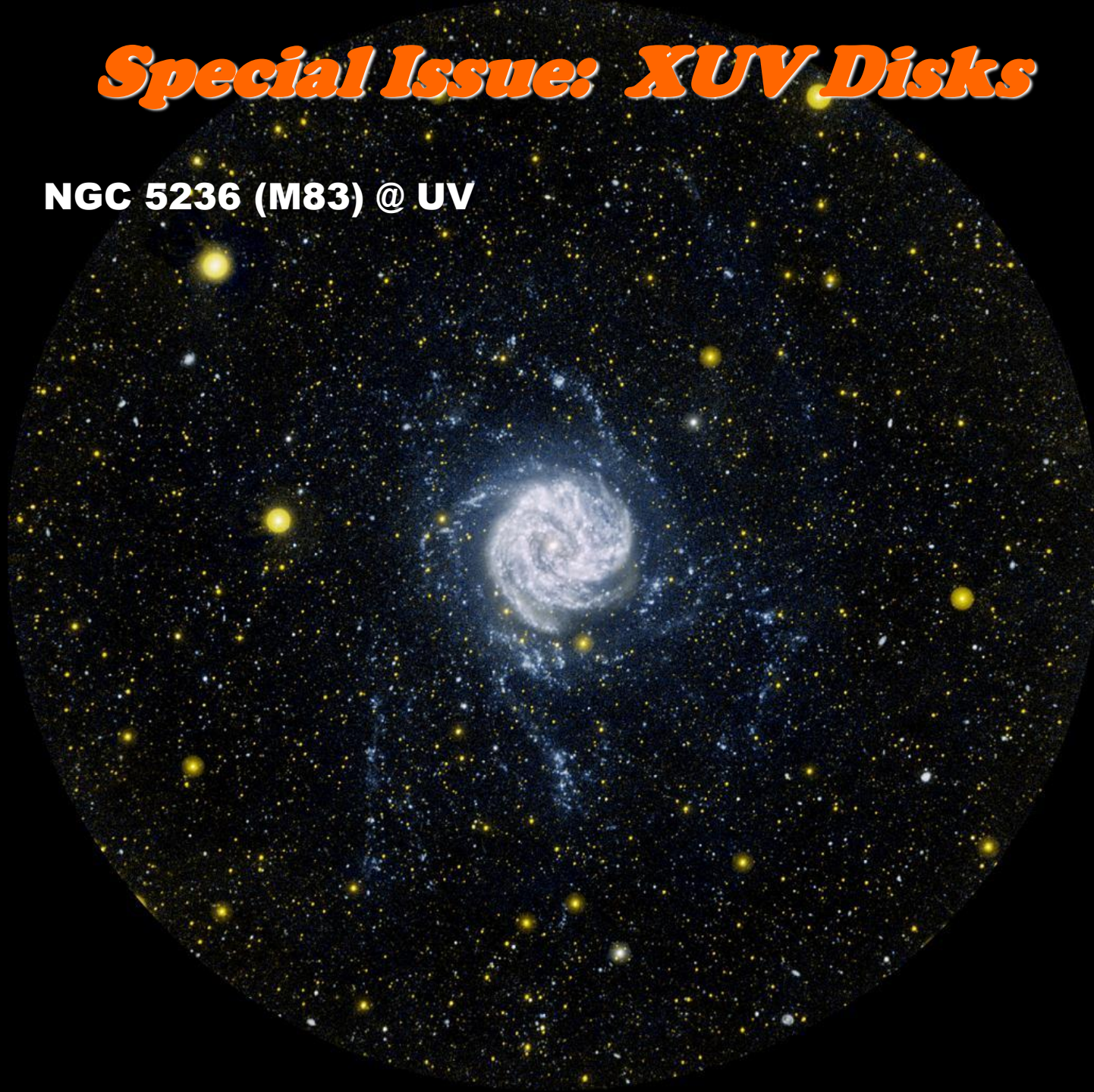
# *Special Issue: XUV Disks*

**NGC 5236 (M83) @ Opt.**



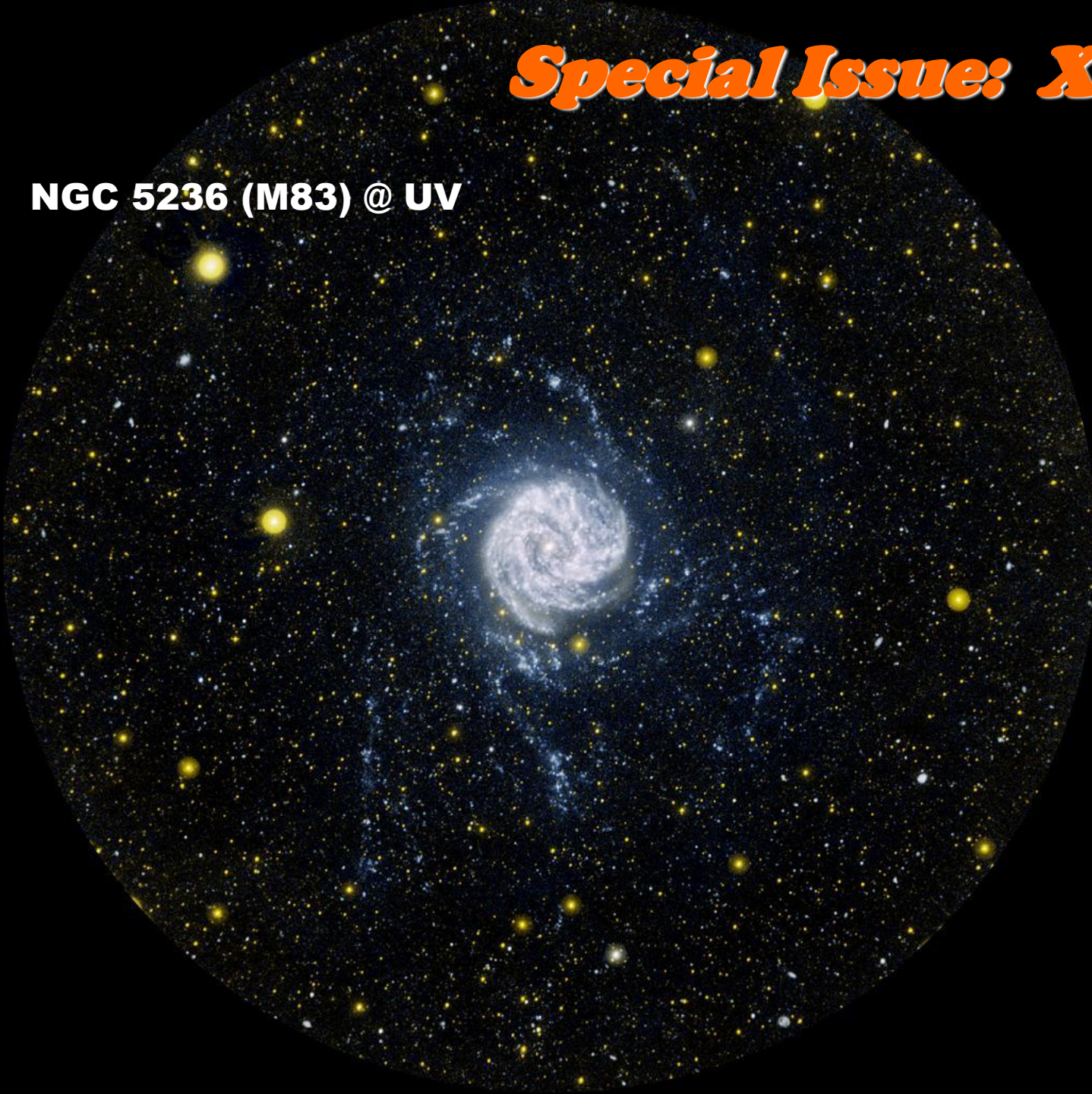
***Special Issue: XUV Disks***

**NGC 5236 (M83) @ UV**



# *Special Issue: XUV Disks*

**NGC 5236 (M83) @ UV**

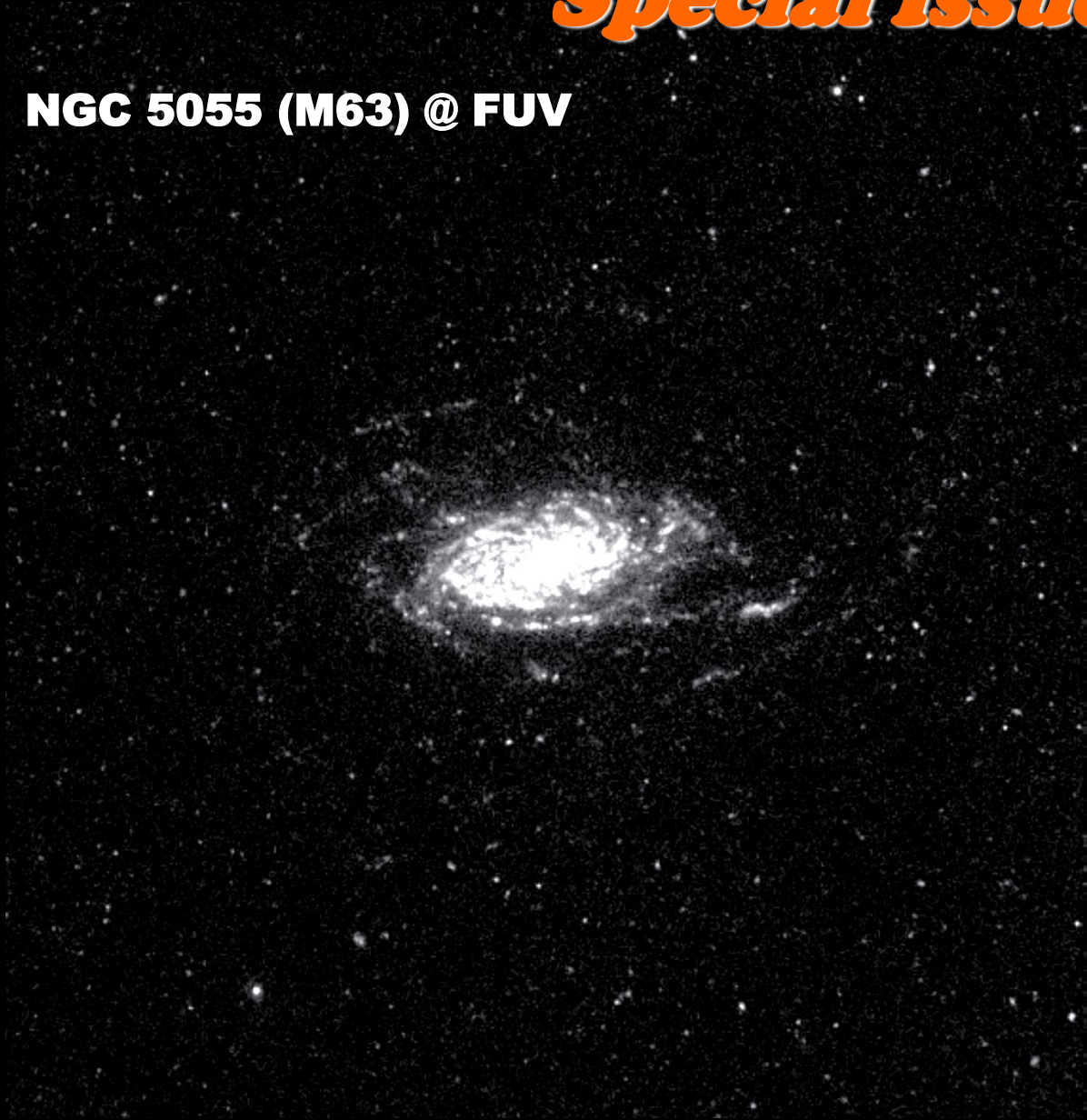


**NGC 5236 (M83) @ Opt.**



# *Special Issue: XUV Disks*

**NGC 5055 (M63) @ FUV**



**NGC 5055 (M63) @ NIR**

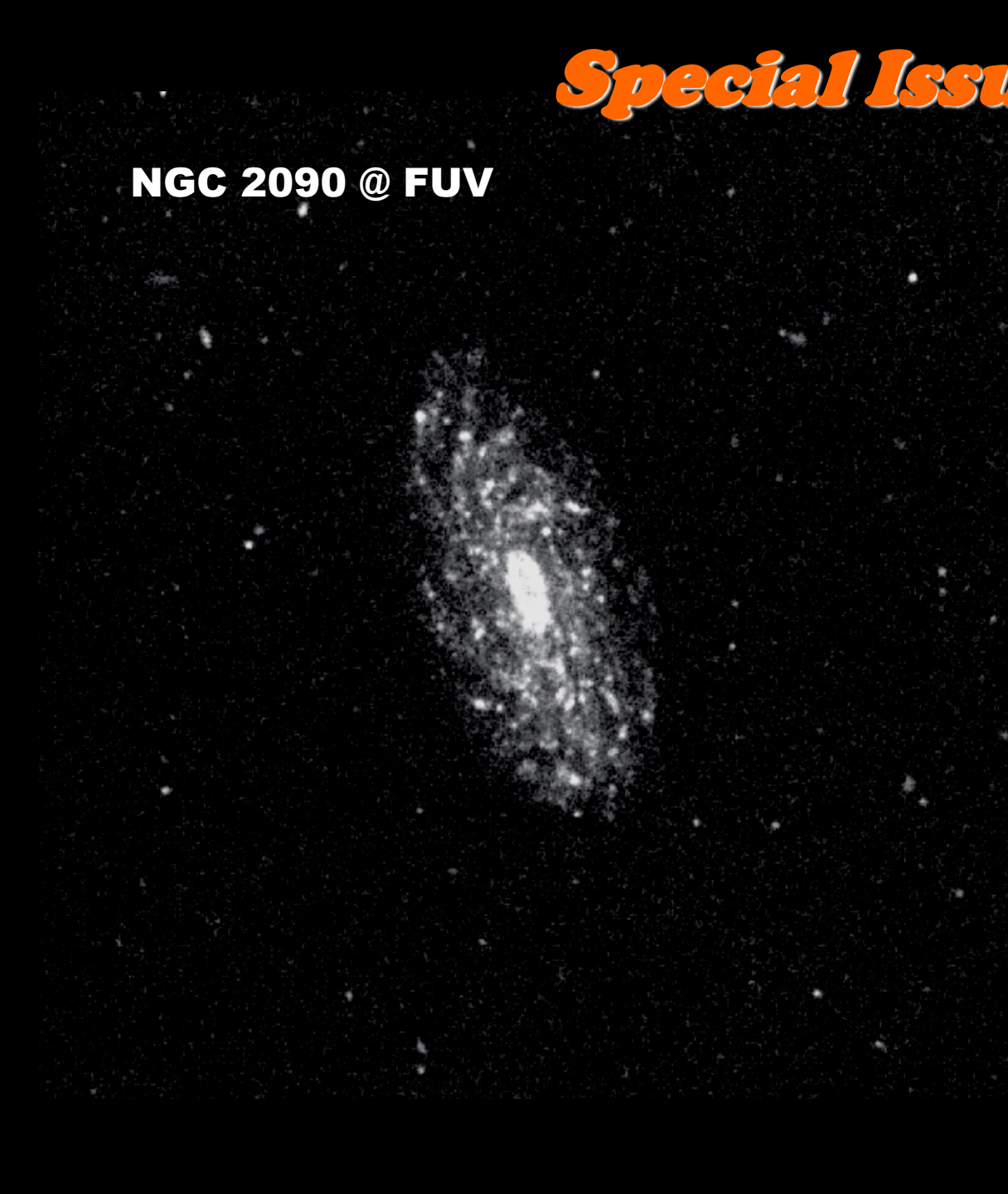




# *Special Issue: XUV Disks*

**NGC 2090 @ FUV**

**NGC 2090 @ NIR**



# *Implications for MePhiSTo*

To Observe Nearby Galaxies

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To Observe Nearby Galaxies

- **Large FoV** ⇒ ***Sufficient* Sky Coverage**  
⇒ ***Precise* Background Estimates**
- **Multiple Exposures** ⇒ ***High* S/N (Combined)**