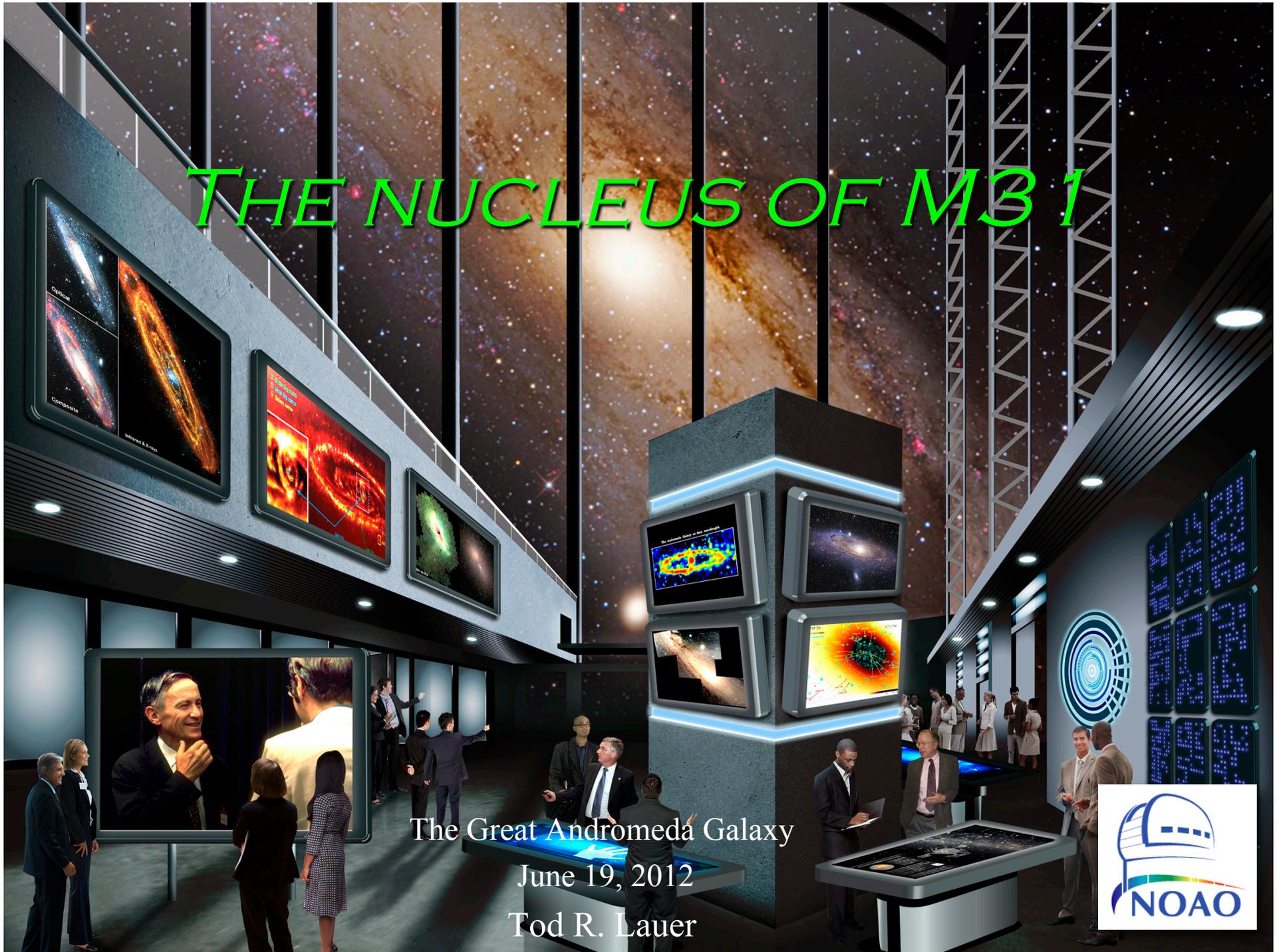


# THE NUCLEUS OF M31



The Great Andromeda Galaxy

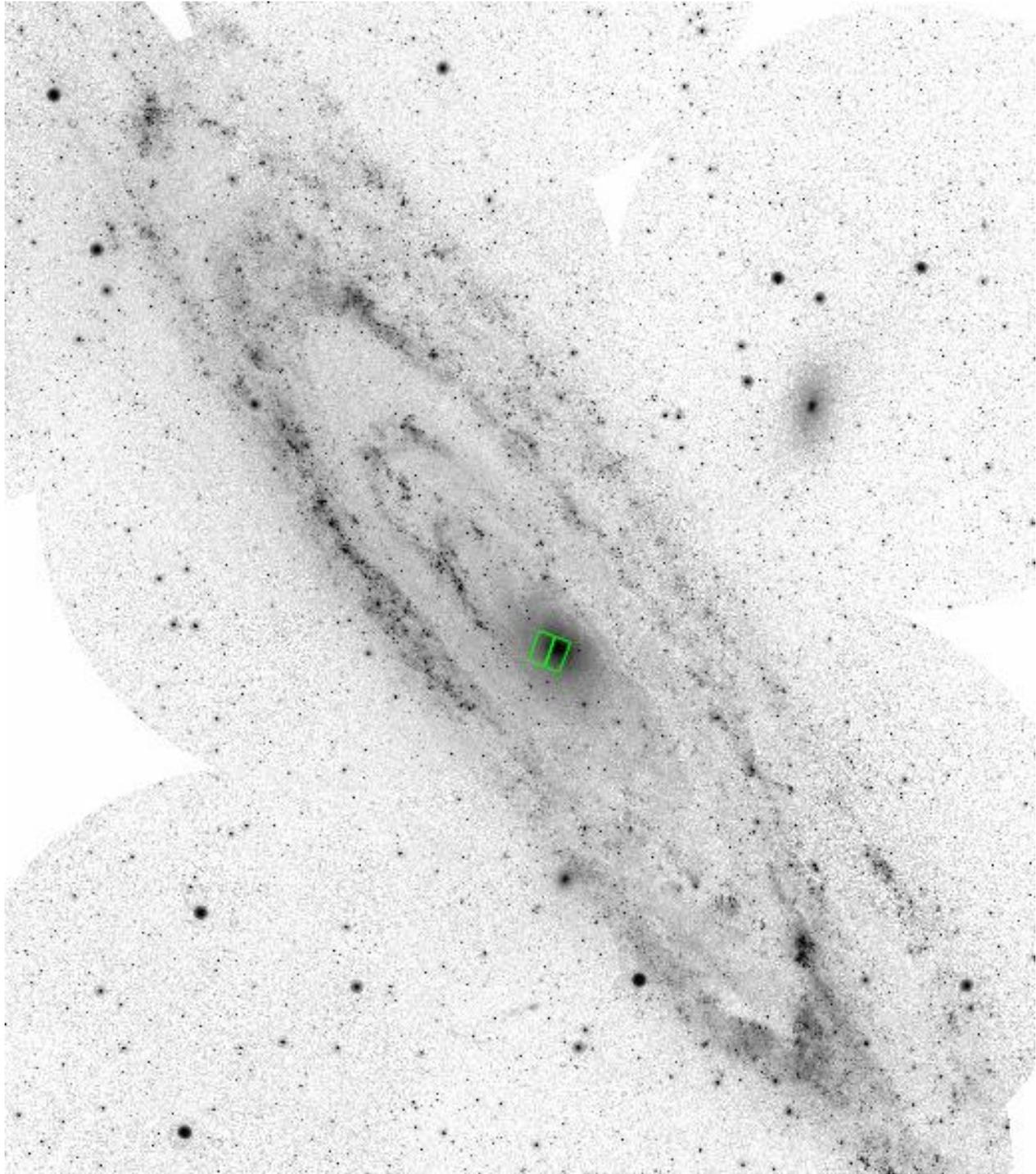
June 19, 2012

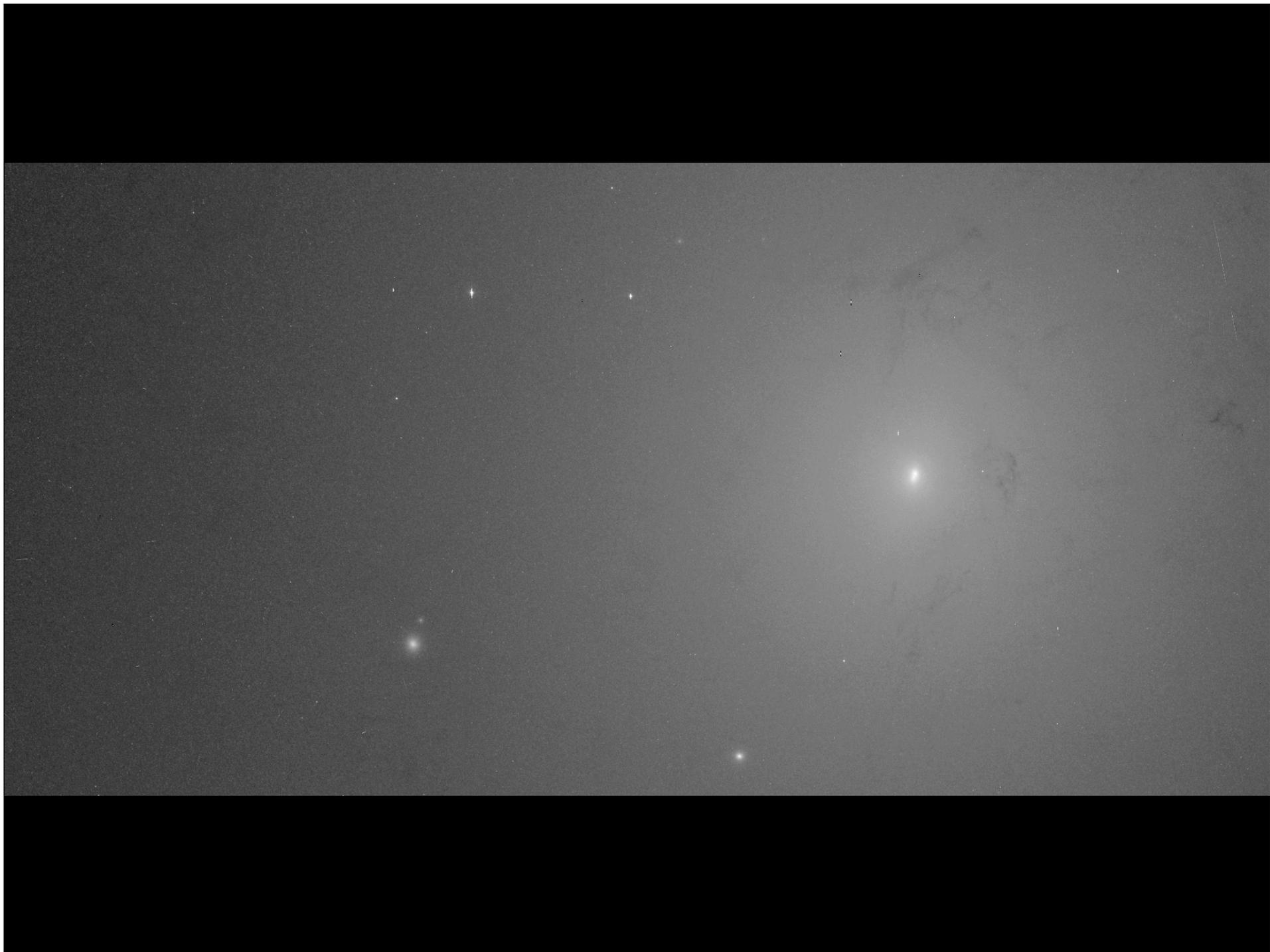
Tod R. Lauer



# *THE NUCLEUS OF M31*

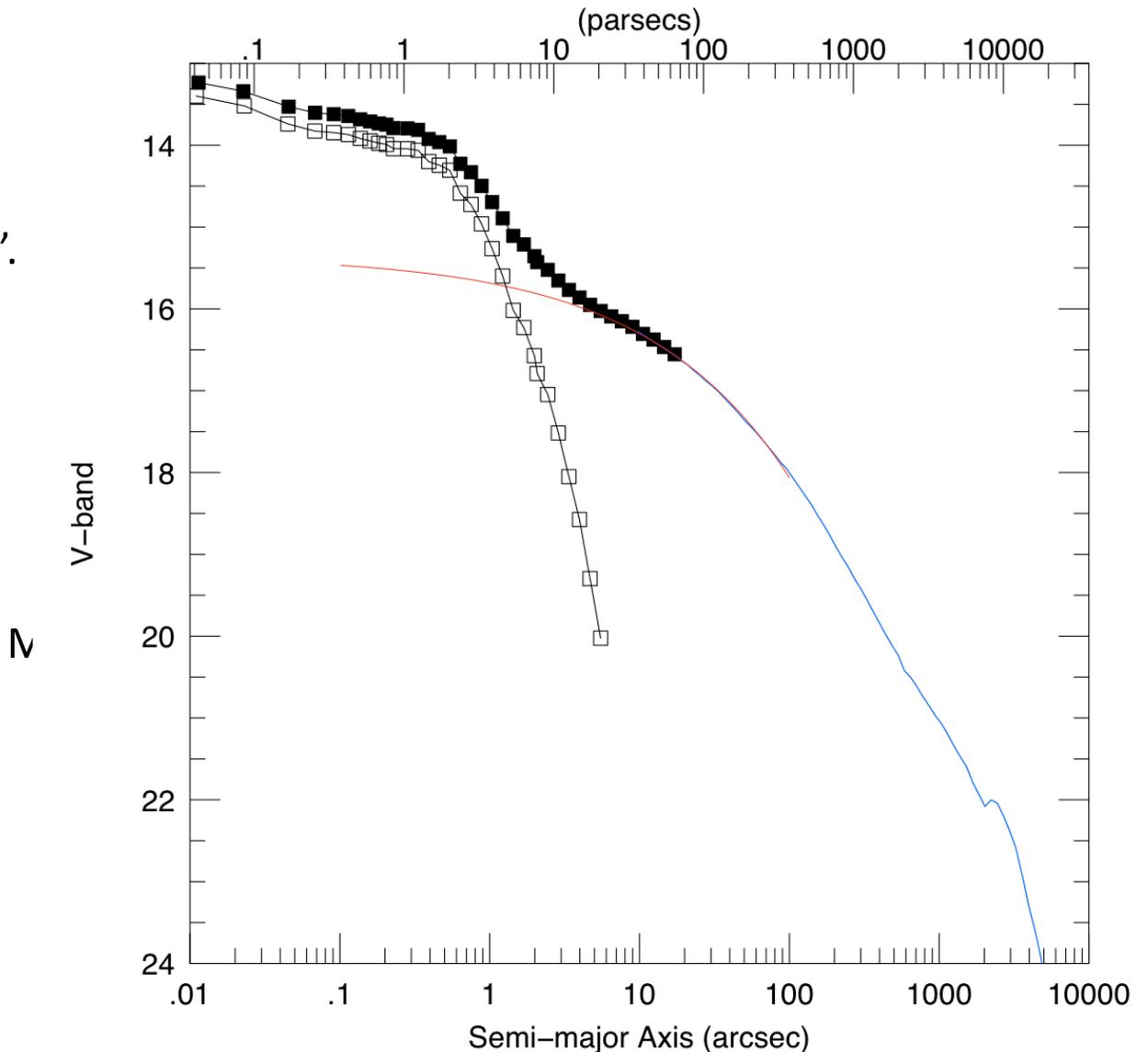
- Prototypical nuclear “star cluster”
- Location of a supermassive black hole, *angularly*  $\sim 4\times$  smaller than MW BH.
- Example, as in MW, of recent star formation in close proximity to BH.
- Asymmetric disk, prototype for structures seen in more distant galaxies.





# M31 Nucleus Properties

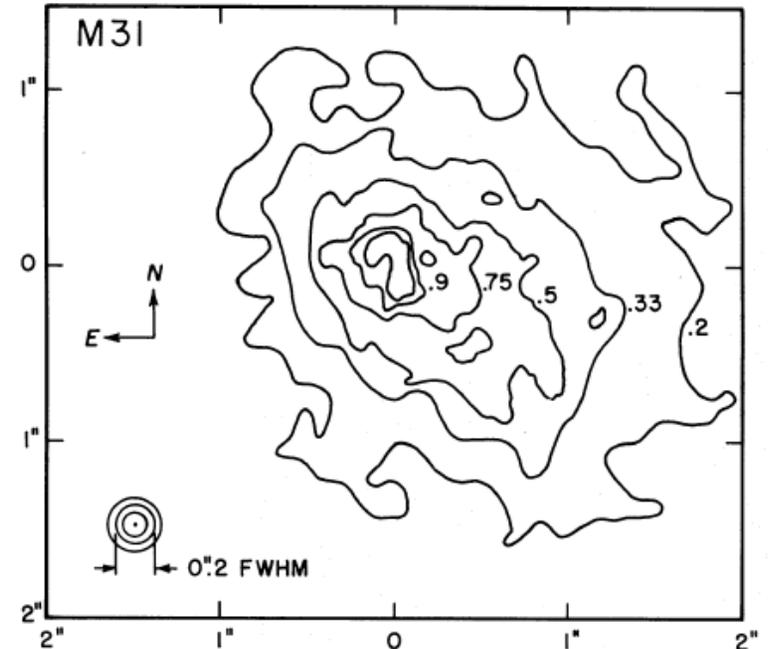
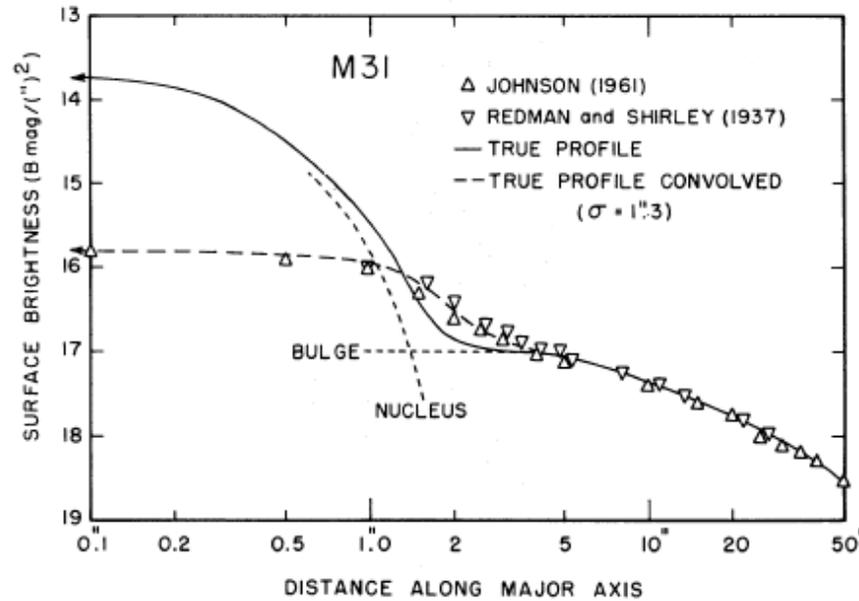
- $M_V = -12.9$  or  
 $L_V \sim 1.3 \times 10^7 L_\odot$
- Extent  $\sim 15$ pc or  $4''$ ,  
dominates  $r < 5$ pc or  $1.3''$ .
- Fall-off  $I(r) \sim r^{-2.2}$
- Double at  $\sim 2$ pc. Bulge-  
centric at  $r > 2.5$ pc,  $15^\circ$   
twist.
- Young stars at  $r < 0.4$  pc,  
 $\rho > 10^6 L_\odot/\text{pc}^3$
- Central black hole  
 $\sim 10^8 M_\odot$
- “Tremaine disk” redder  
than bulge  $\Delta V-I = 0.09$
- Center SBF dominated,  
 $S/N \sim 10$

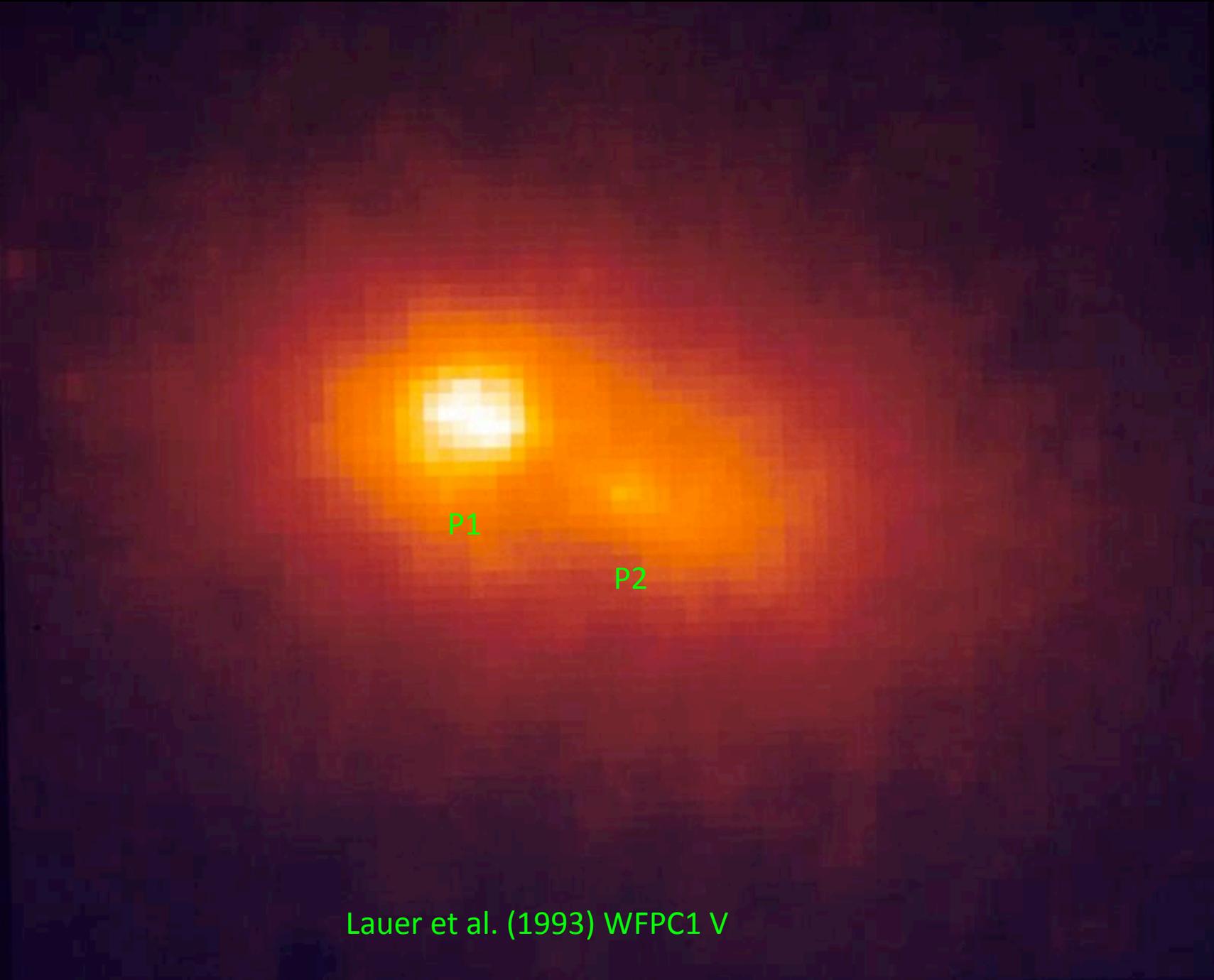


# Light, Danielson, & Schwarzschild (1974)

M31 Nucleus 0.2 arsec resolution with Stratoscope II

P1 resolved, P2, not detected, center of bulge not known, but presumed to be P1.





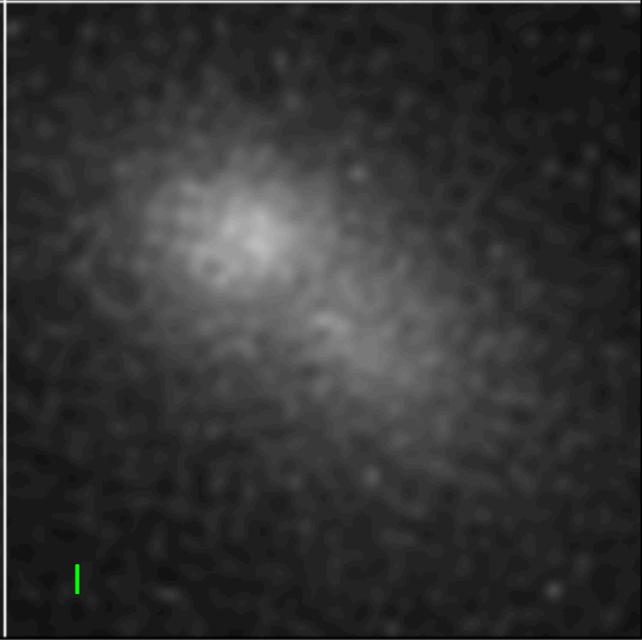
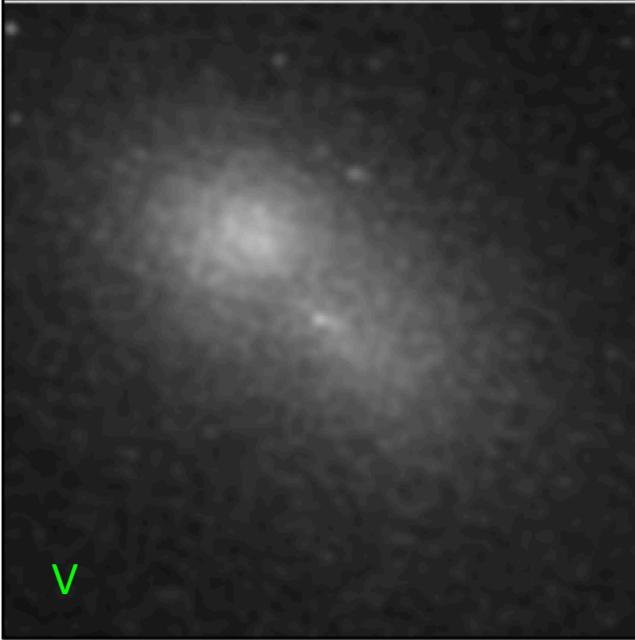
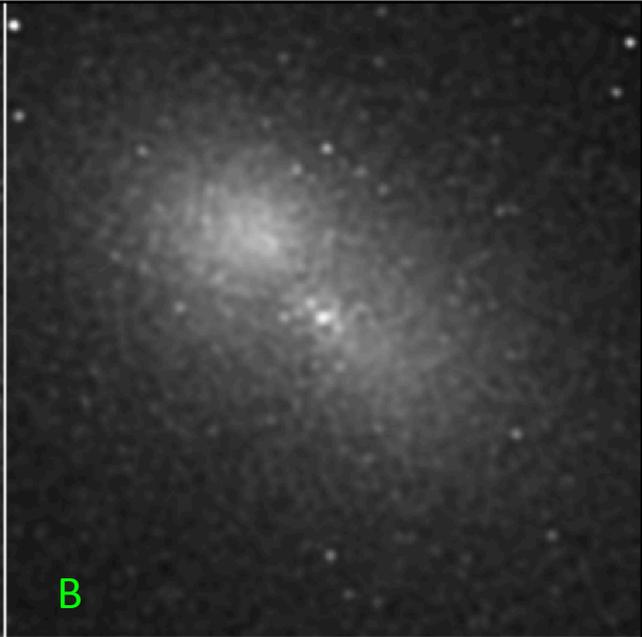
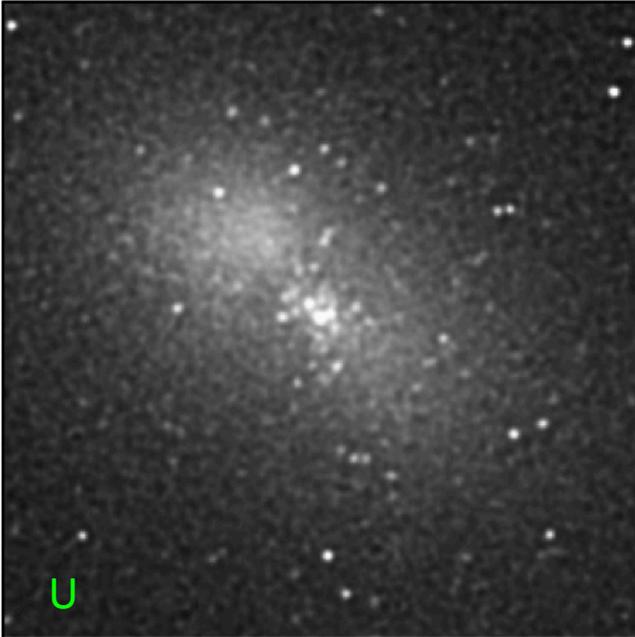
Lauer et al. (1993) WFPC1 V



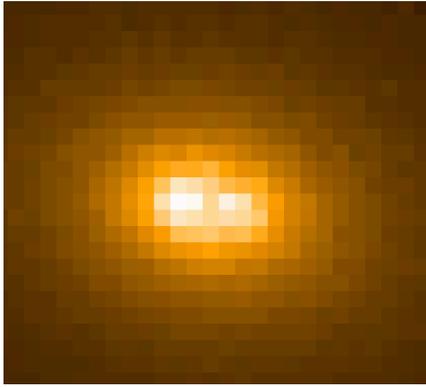
Lauer et al. (1998) WFPC2 UVI



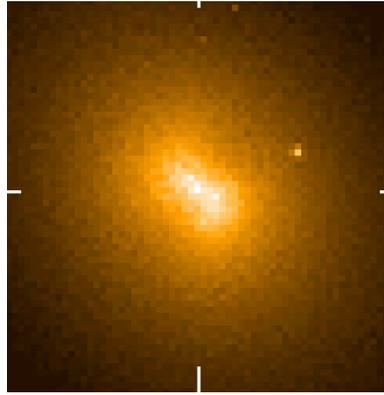
Lauer et al. (2012) ACS/HRC UB + WFPC2 VI



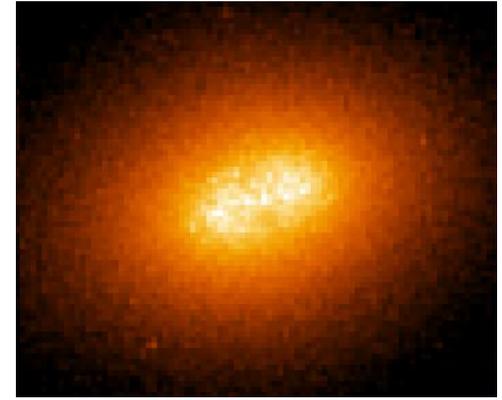
# Double Nuclei on $\sim 10\text{pc}$ Scales



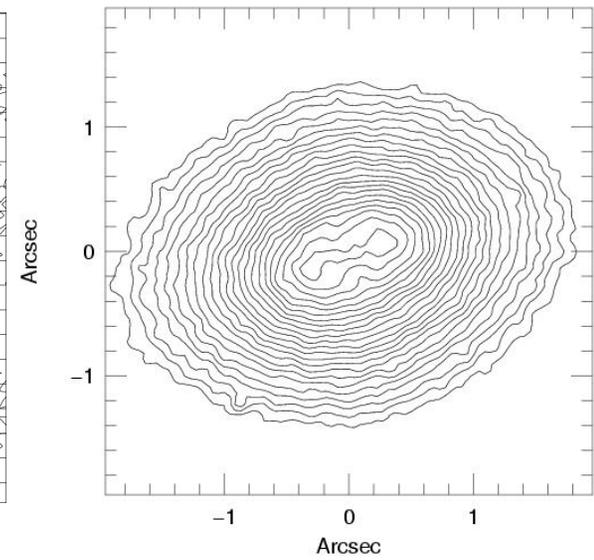
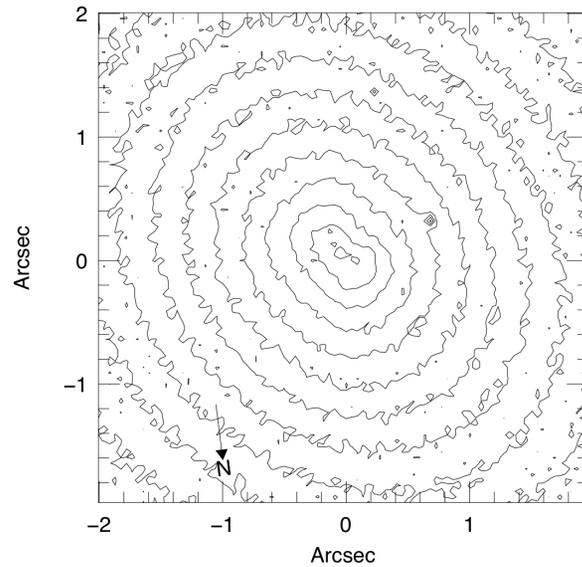
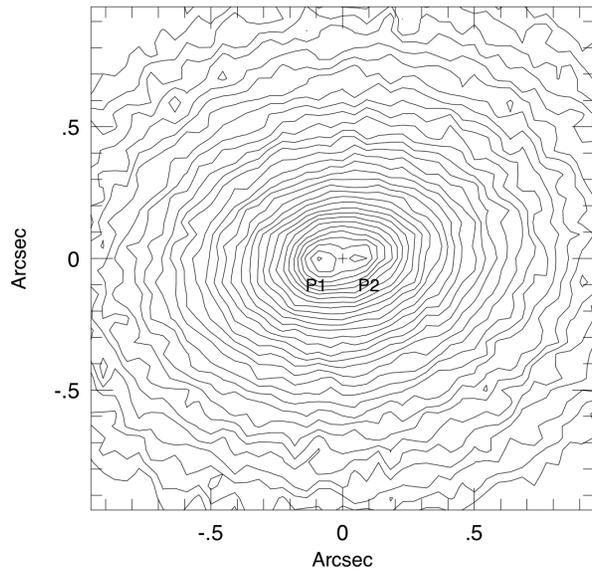
NGC 4486B

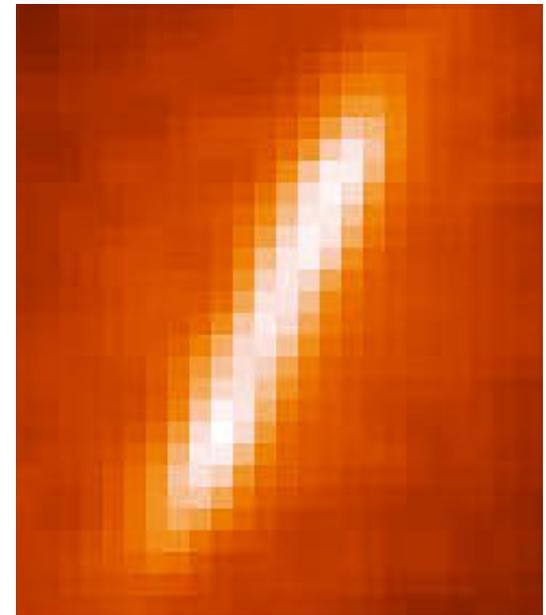
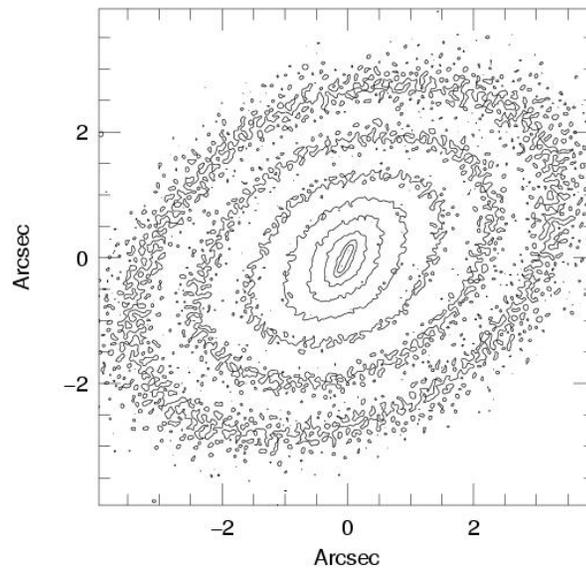
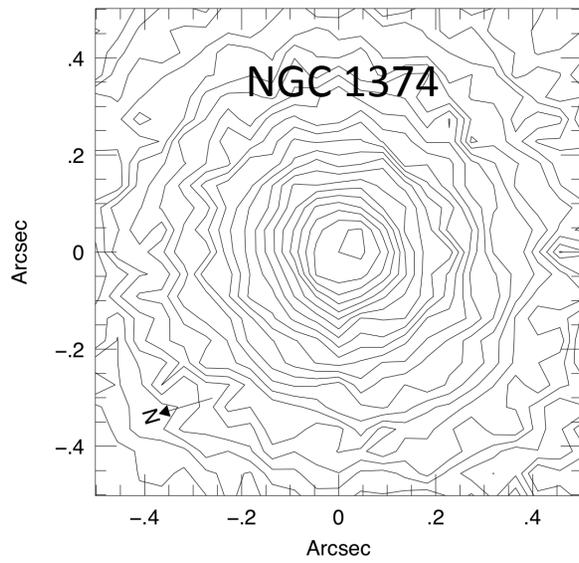
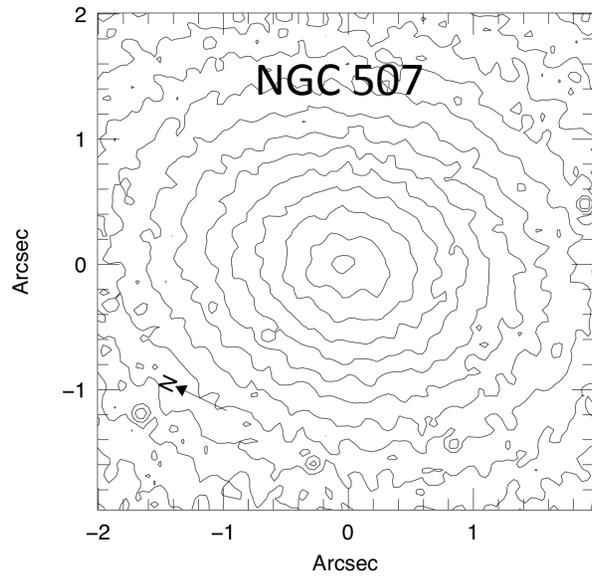


NGC 4382

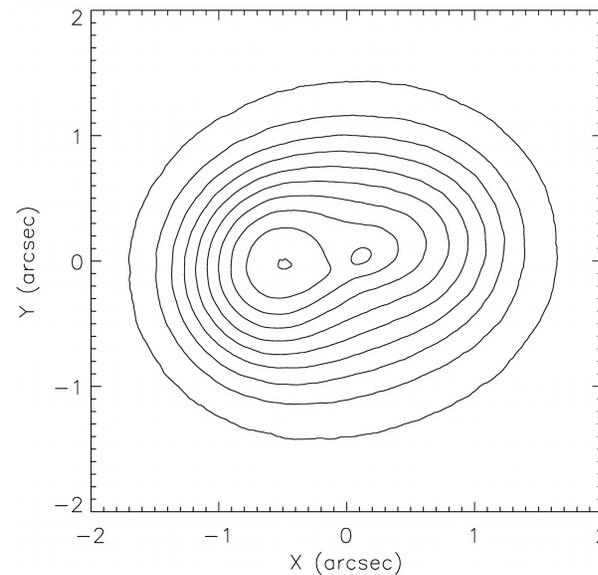
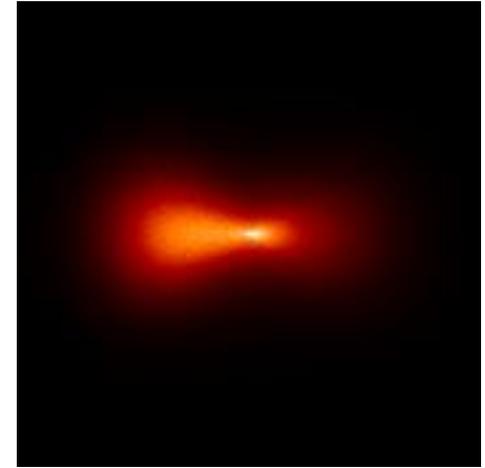
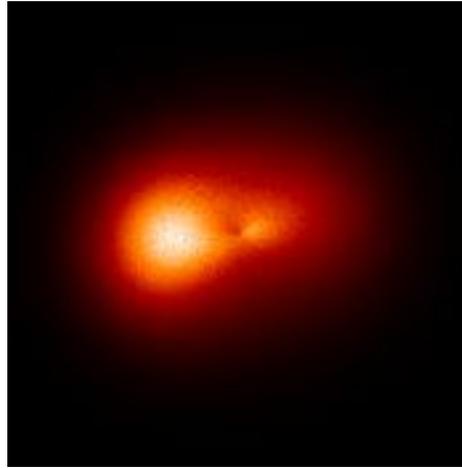
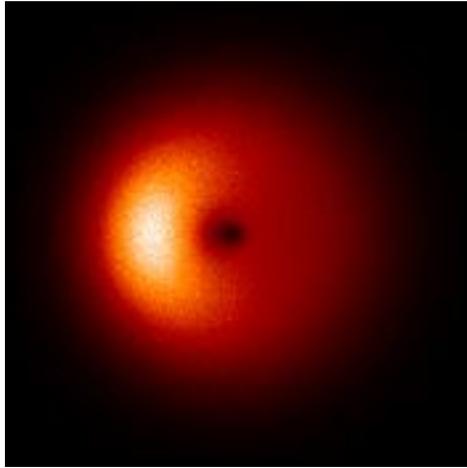


NGC 6876



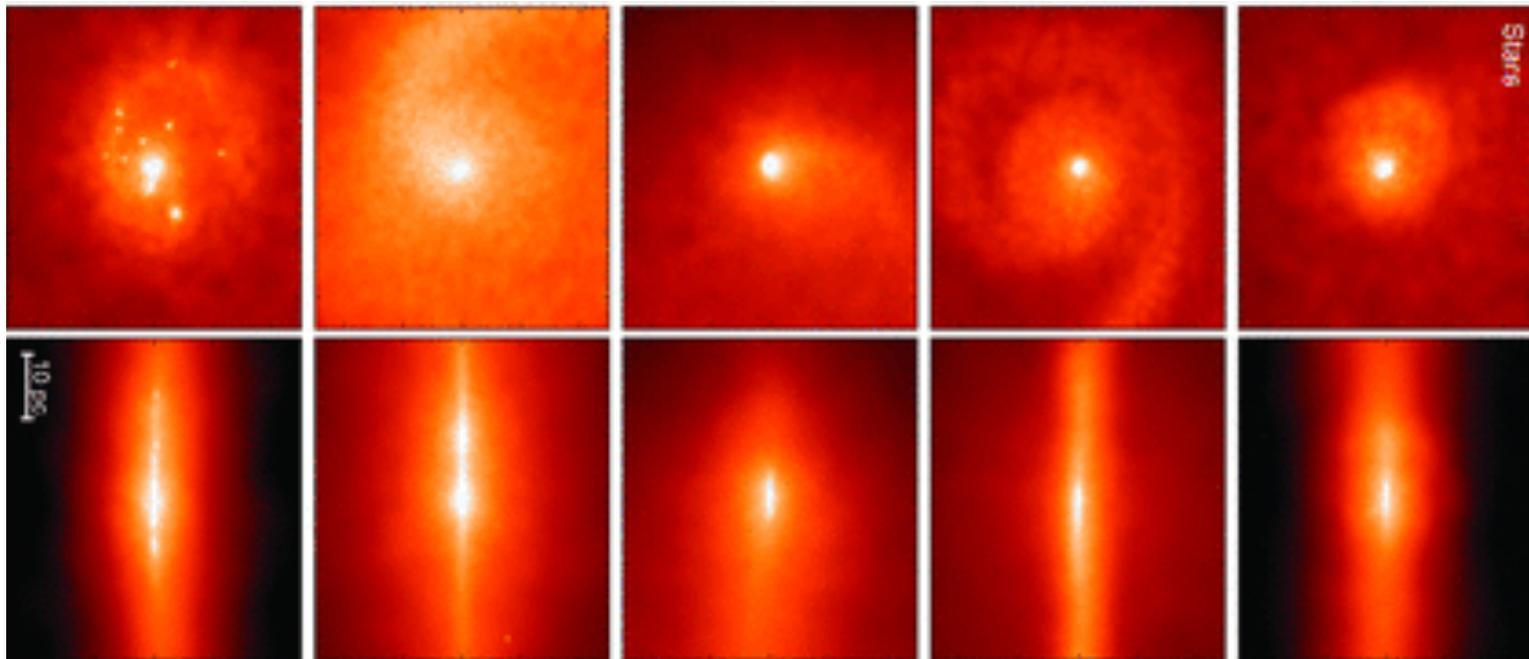


# Tremaine (1995); Peiris & Tremaine (2003) Disk Model



## Hopkins & Quataert (2010)

- Central gas accretion around BH generates “lopsided” stellar disks on  $\sim 10\text{pc}$  scales.
- Provides torques to transfer gas from larger scales.
- “Double Nuclei” may be a natural consequence of star formation around a BH.



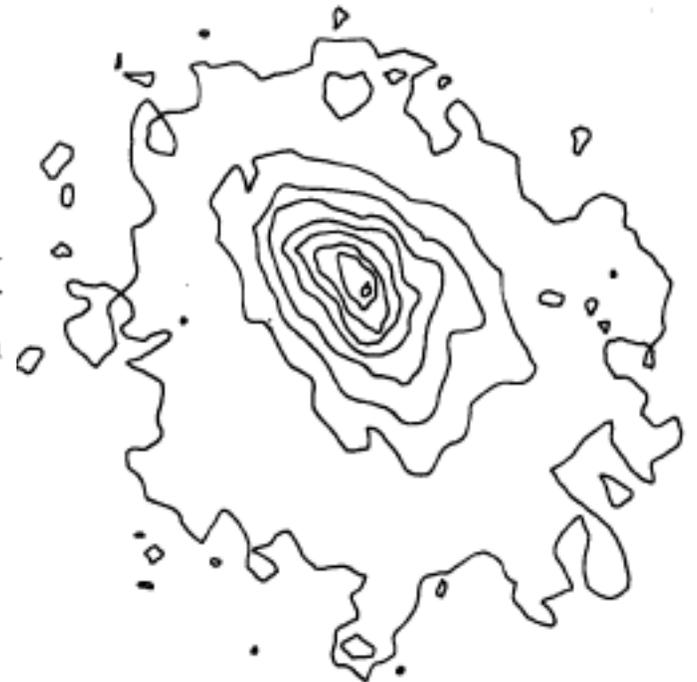
# Ground-based Detection of P3?

*Redman & Shirley (1937)*

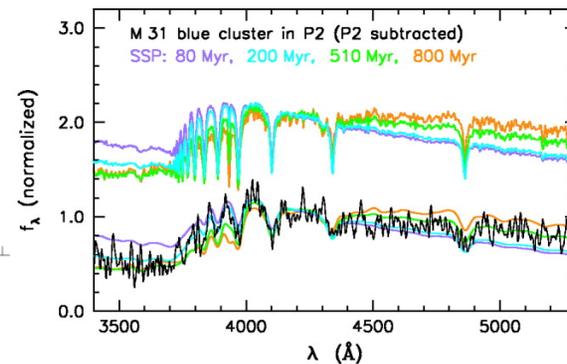
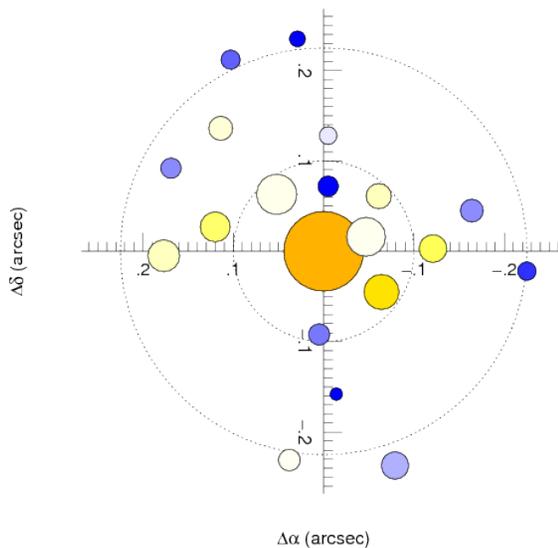
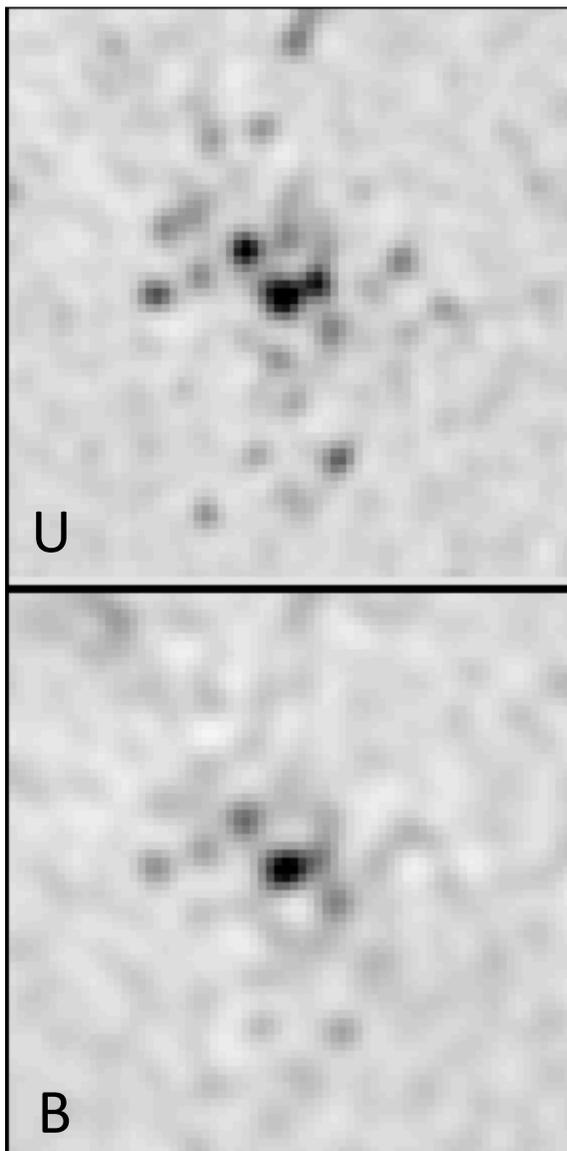
at the centre. We understand that unpublished Mt. Wilson material shows that the spectrum of the nucleus is of a peculiar dwarf A type. It seems likely that this is mainly produced by dwarf A stars, and if the average absolute magnitude of these is  $+1$ , the star density at the centre attains at least  $1000/(\text{parsec})^3$ .\* There is, however, a very steep fall of density outwards,

*Nieto et al. (1986)*

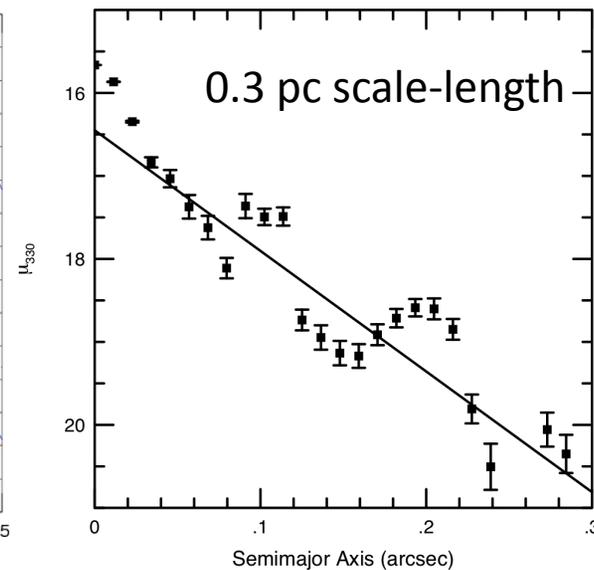
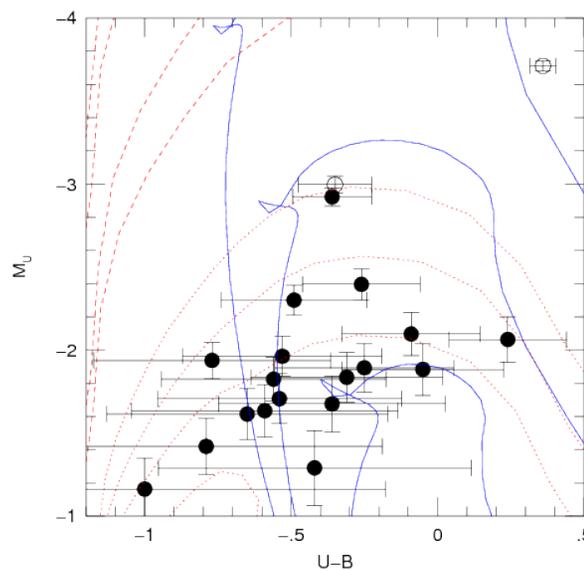
– An intensity profile more peaked in the  $U$  than in the  $r$  band (Kent, 1983) at the same resolution. This implies a central color gradient within the 4 central arcsec, which is at variance with previous observations.



# The Structure and Population of the P3 Cluster

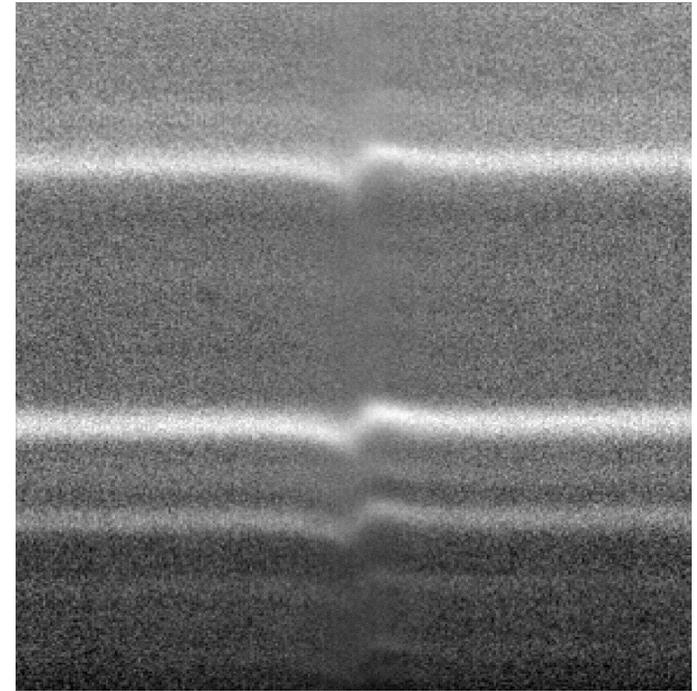


A0-type spectrum & SED



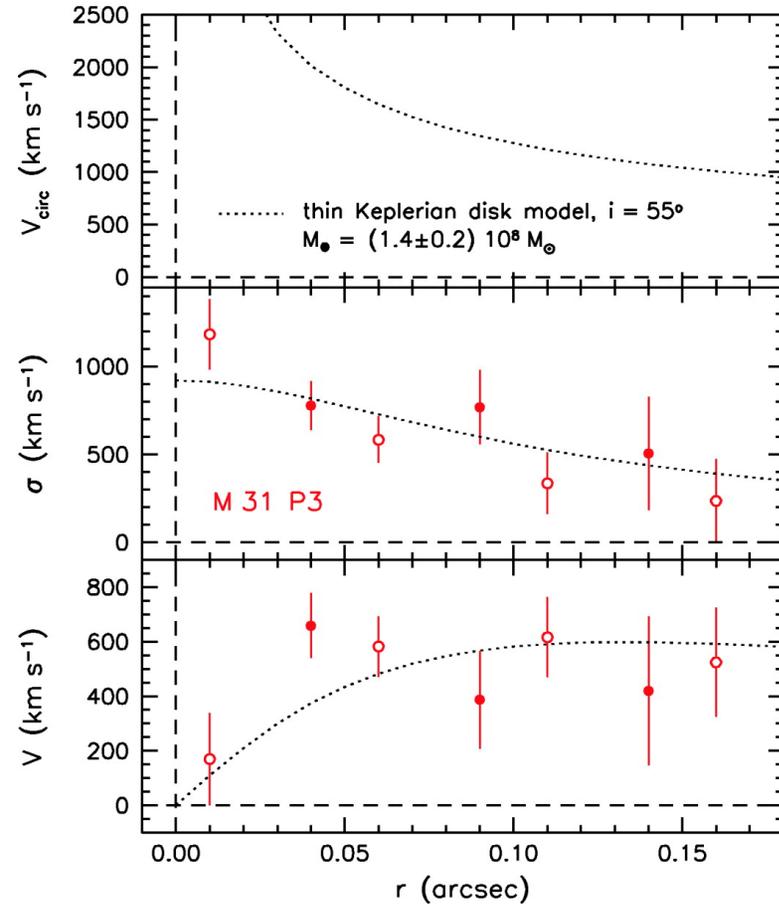
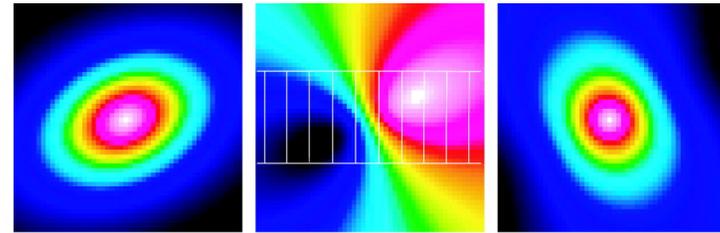
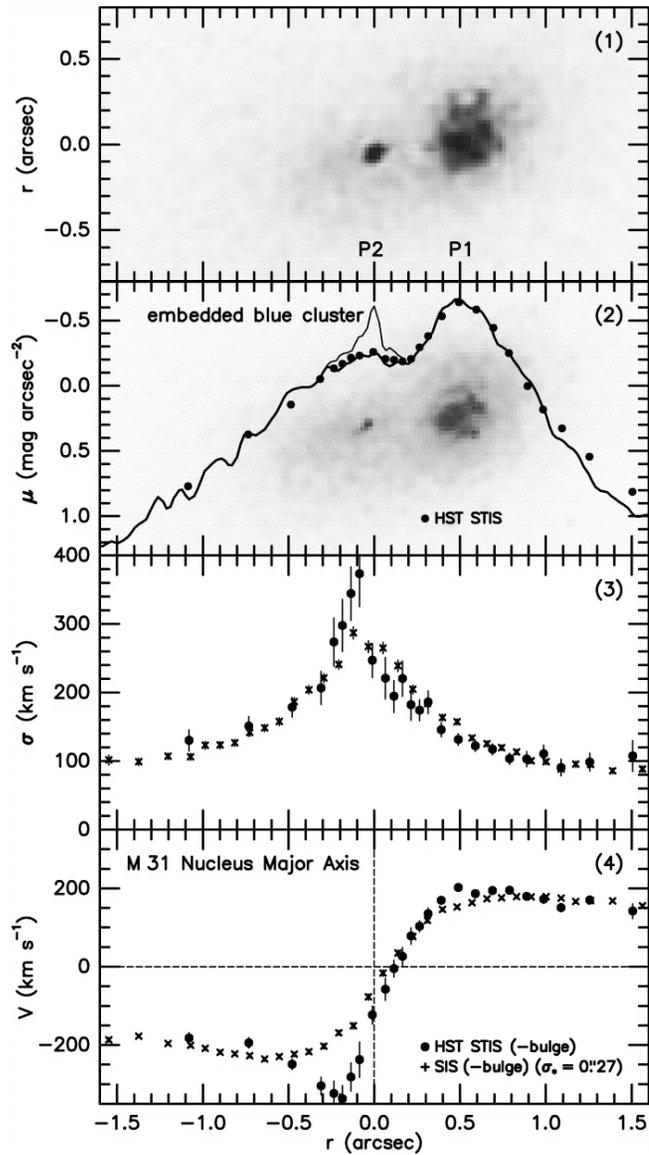
# The Supermassive Black Hole in M31

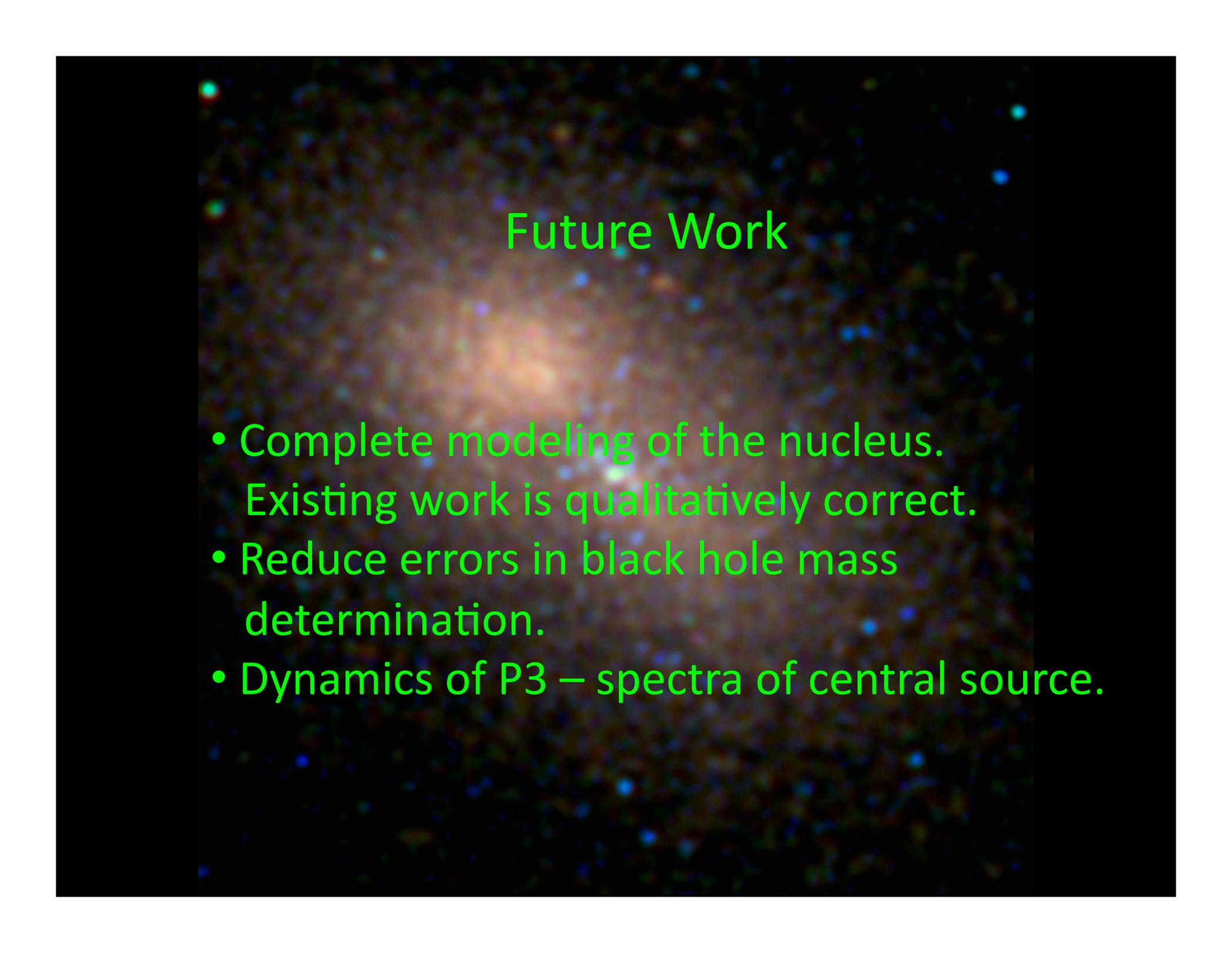
- Rapid rotation in the nucleus (Lallemand et al. 1960).
- Nucleus dynamical mass  $\sim 2 \times 10^8 M_{\odot}$  (Morton & Thuan 1973; Walker 1974)
- Dressler (1984)  $M_{\bullet} \sim 10^6 - 7 M_{\odot}$
- Dressler & Richstone (1988)  $M_{\bullet} \sim 5 \times 10^7 M_{\odot}$
- Kormendy (1988)  $M_{\bullet} \sim 10^6 - 7 M_{\odot}$
- Bacon et al. (1994)  $M_{\bullet} \sim 7 \times 10^7 M_{\odot}$
- Kormendy & Bender (1999)  $M_{\bullet} \sim 3 \times 10^7 M_{\odot}$
- Bacon et al. (2001)  $M_{\bullet} \sim 7 \times 10^7 M_{\odot}$
- Peiris & Tremaine (2003)  $M_{\bullet} \sim 1.0 \times 10^8 M_{\odot}$
- Salow & Statler (2004)  $M_{\bullet} \sim 6 \times 10^7 M_{\odot}$
- Bender et al. (2005)  $M_{\bullet} \sim 1.4 \times 10^8 M_{\odot}$
- $M_{\bullet}(\sigma)$  predicts  $M_{\bullet} \sim 5 \times 10^7 M_{\odot}$



Kormendy & Bender 1999

# Bender et al. (2005) Dynamics



The background of the slide is a deep space image of a galaxy. It features a bright, glowing central nucleus with a yellowish-orange hue, surrounded by a dense field of stars in various colors, including blue, white, and red. The overall appearance is that of a star-forming galaxy or a galaxy with a significant stellar population.

## Future Work

- Complete modeling of the nucleus.  
Existing work is qualitatively correct.
- Reduce errors in black hole mass determination.
- Dynamics of P3 – spectra of central source.