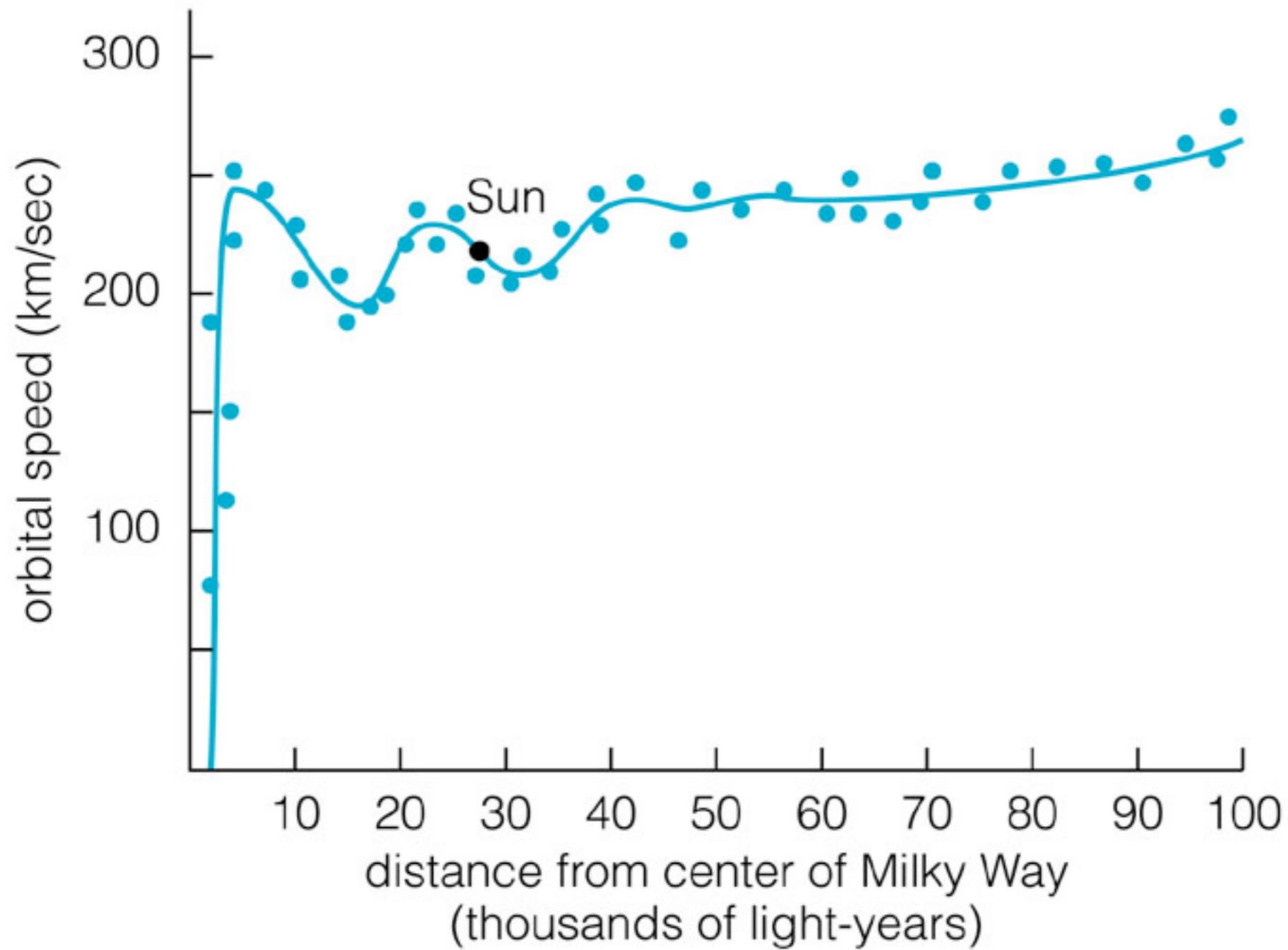


composite of the entire Milky Way

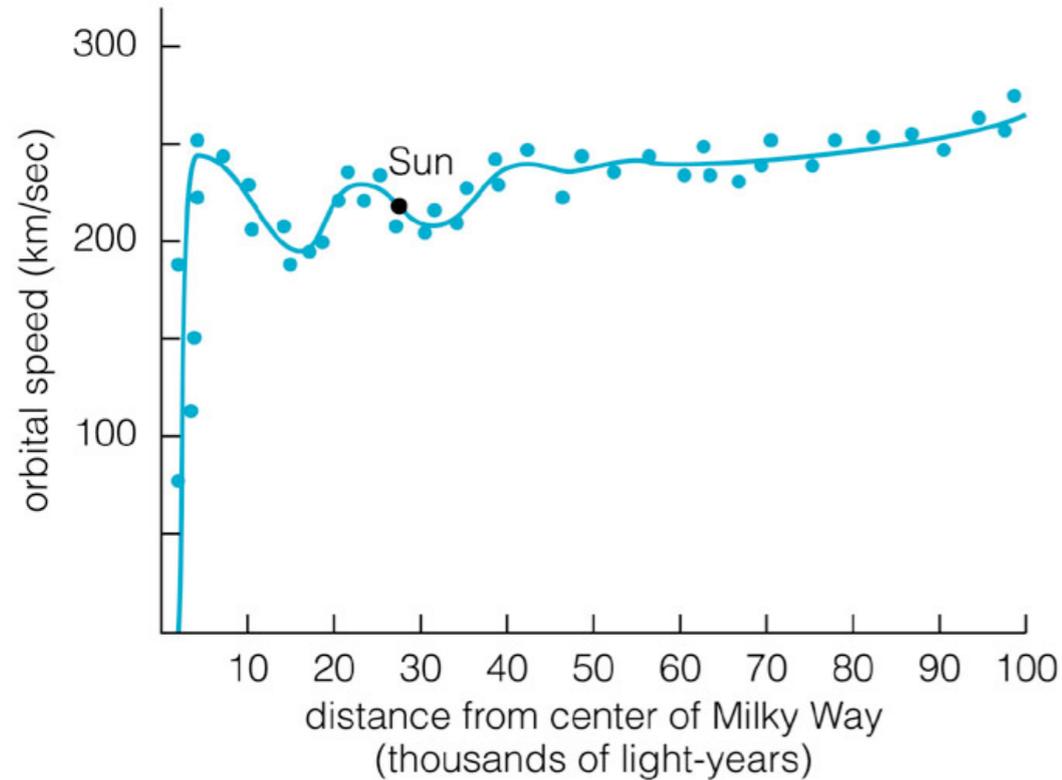
ground-based images, but pasted together to look like an external view



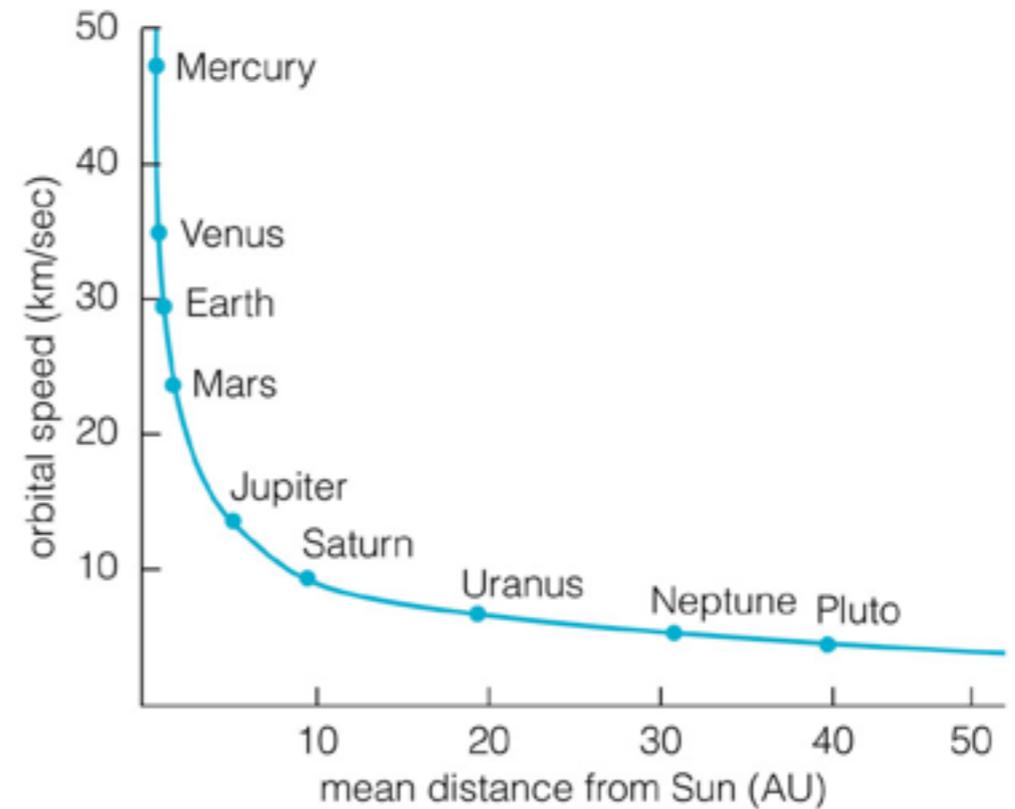
The rotation curve for our Milky Way



Orbital speed as a function of distance (a “rotation curve”)



Copyright © 2004 Pearson Education, publishing as Addison Wesley.



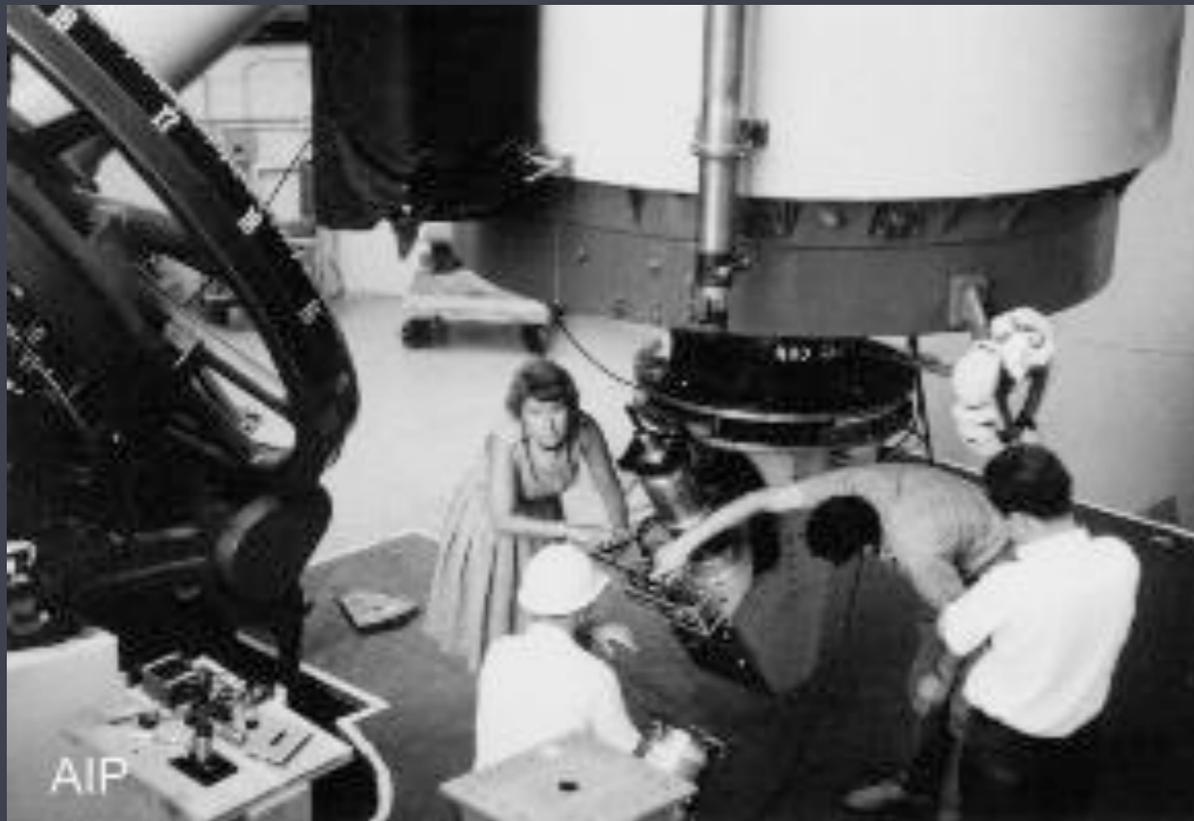
Copyright © 2004 Pearson Education, publishing as Addison Wesley.

Milky Way Galaxy

Solar System

Vera Rubin,
discoverer of
dark matter in
galaxies



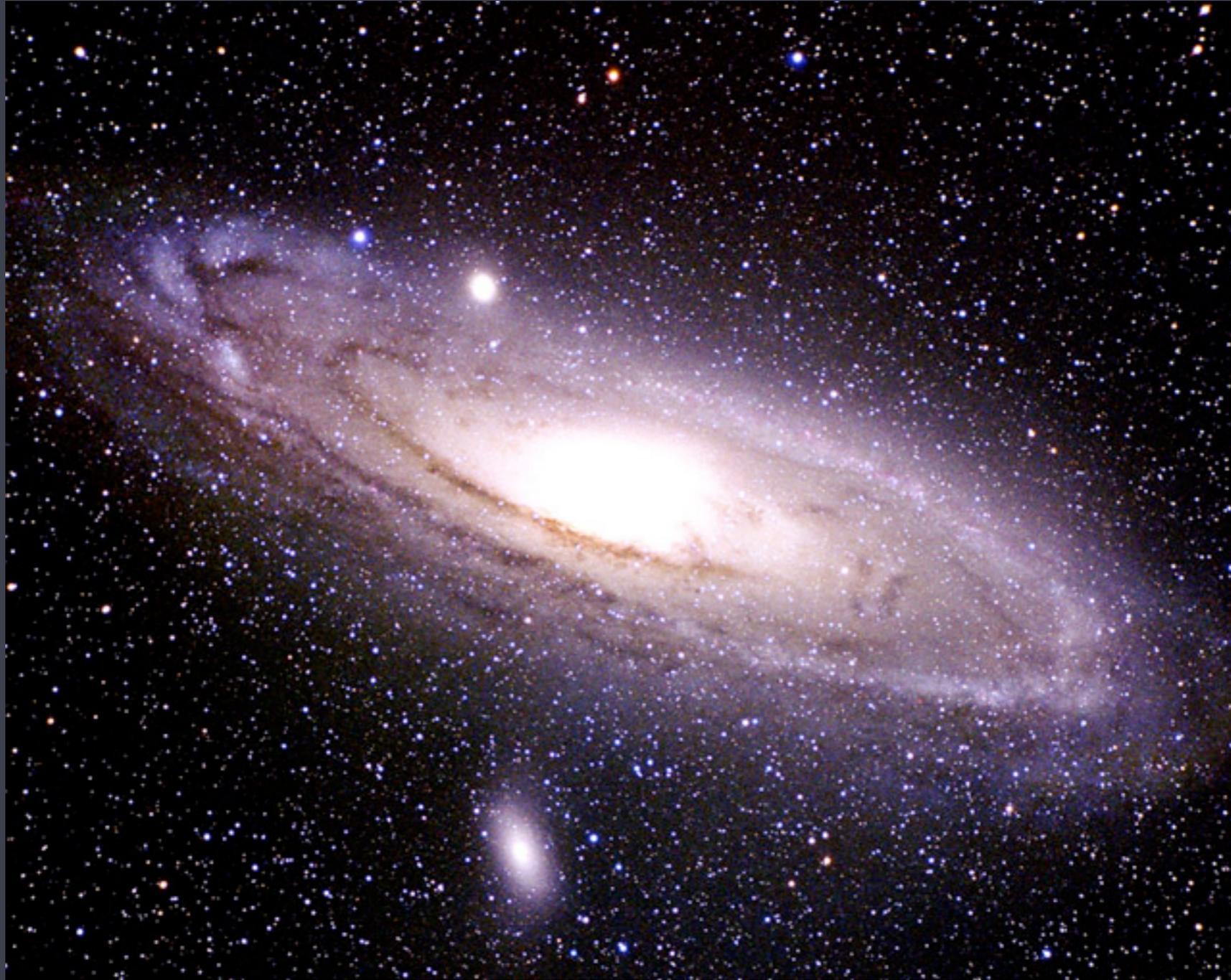


Vera Rubin at Lowell
Observatory...



and at Palomar
Observatory in 1965

M31, the Andromeda galaxy



M3 I, the Andromeda galaxy

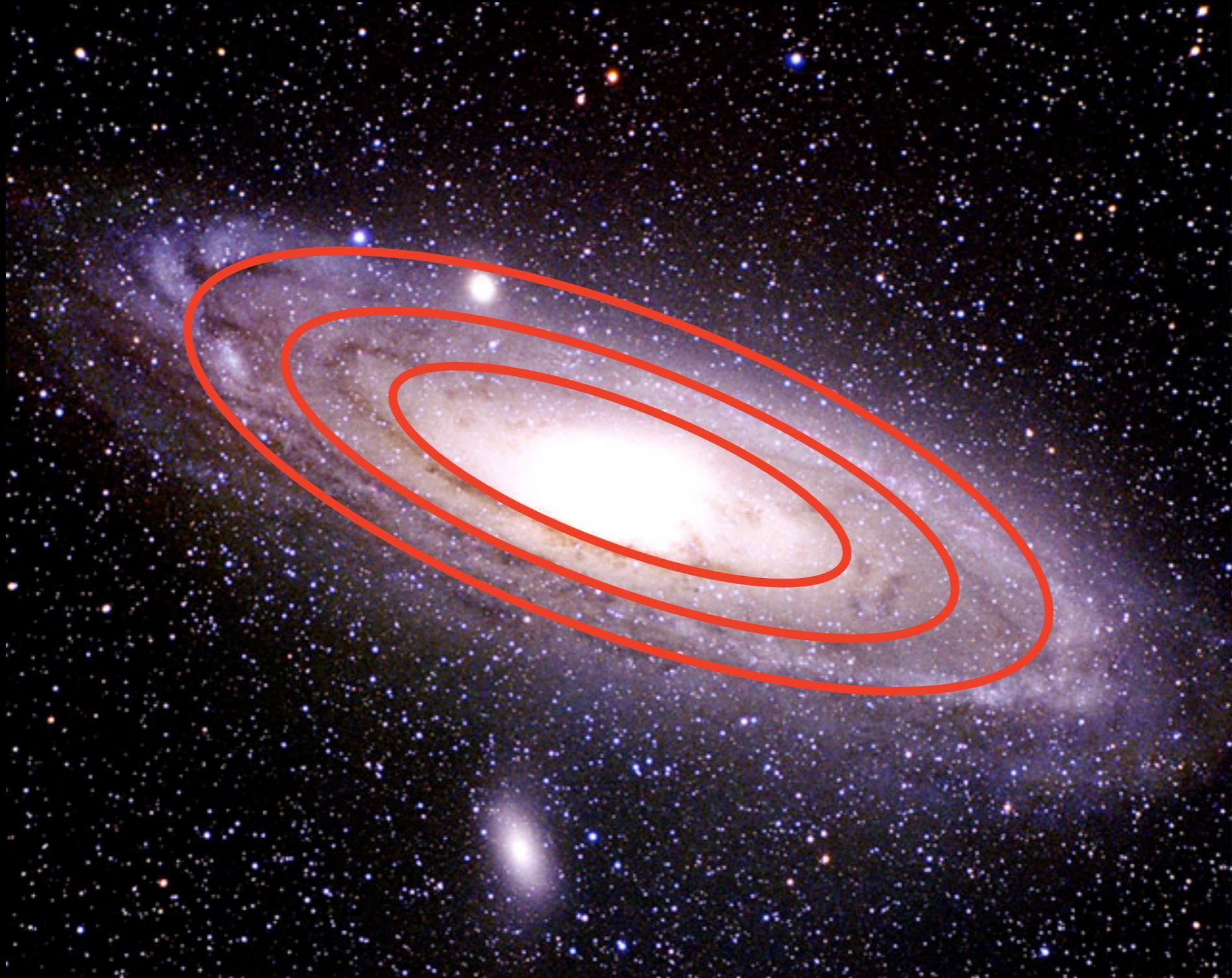
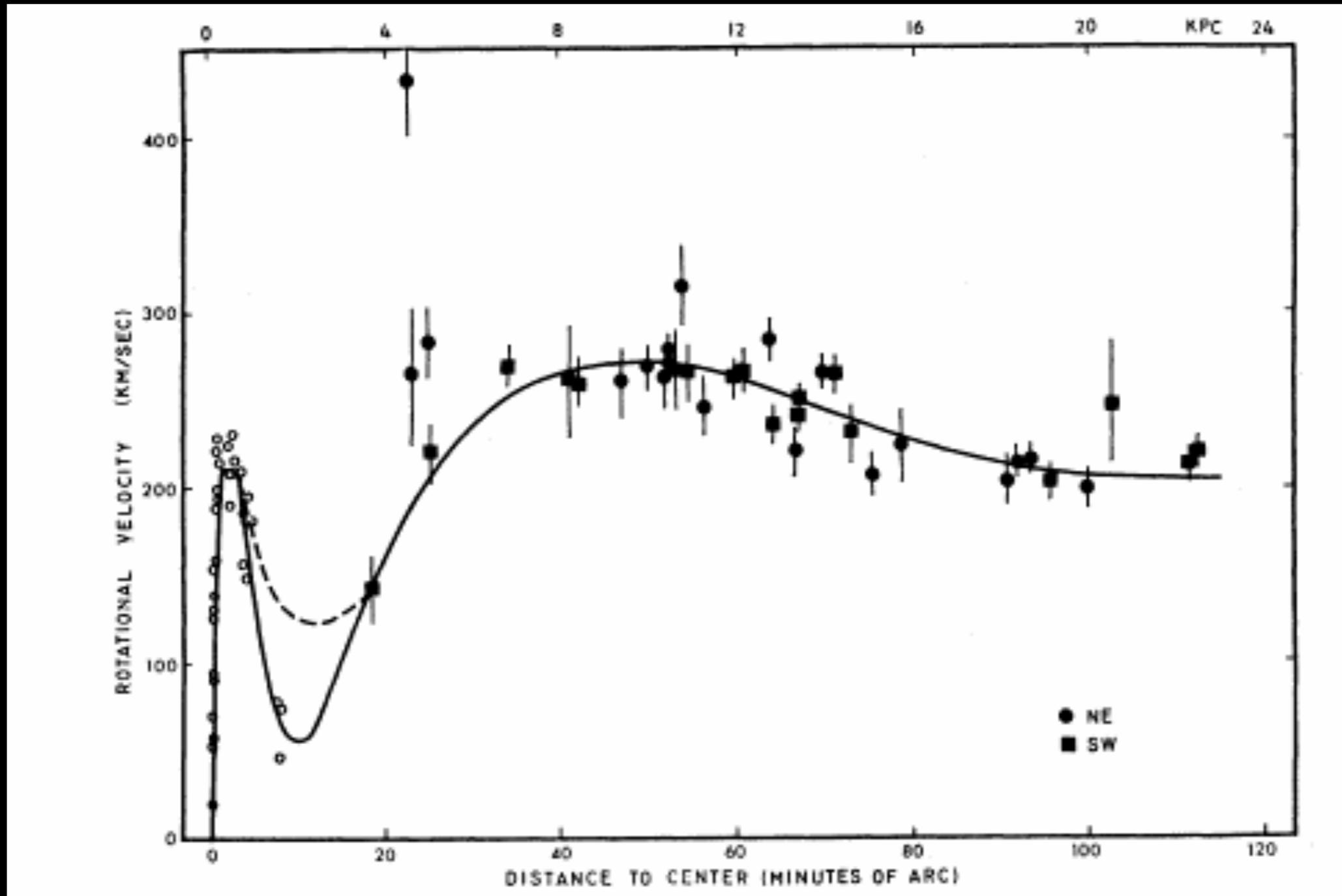


Image credit & copyright: Jason Ware

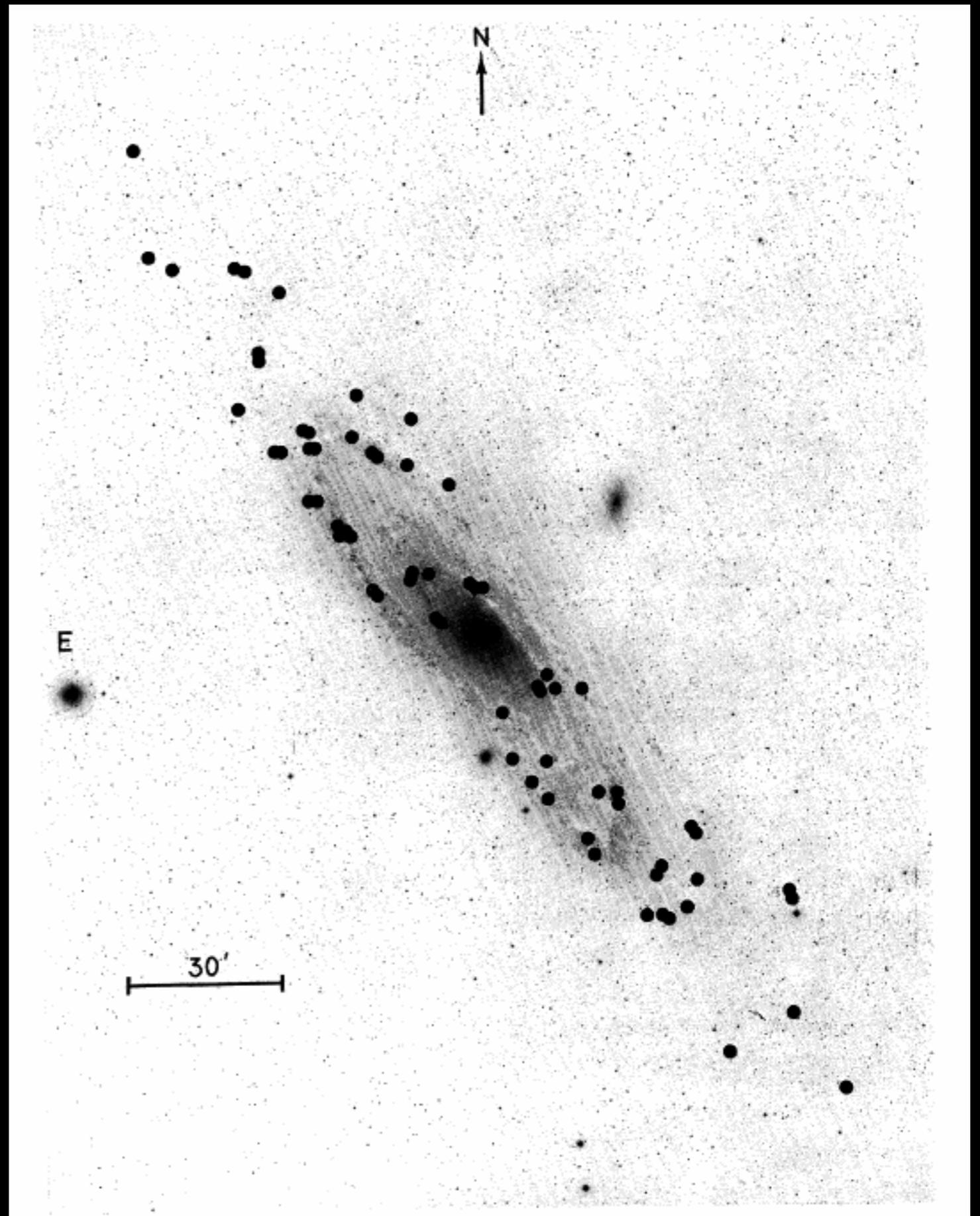
The rotation speed of stars and gas in Andromeda, as a function of distance from the center

Rotation speed (km/s) \uparrow

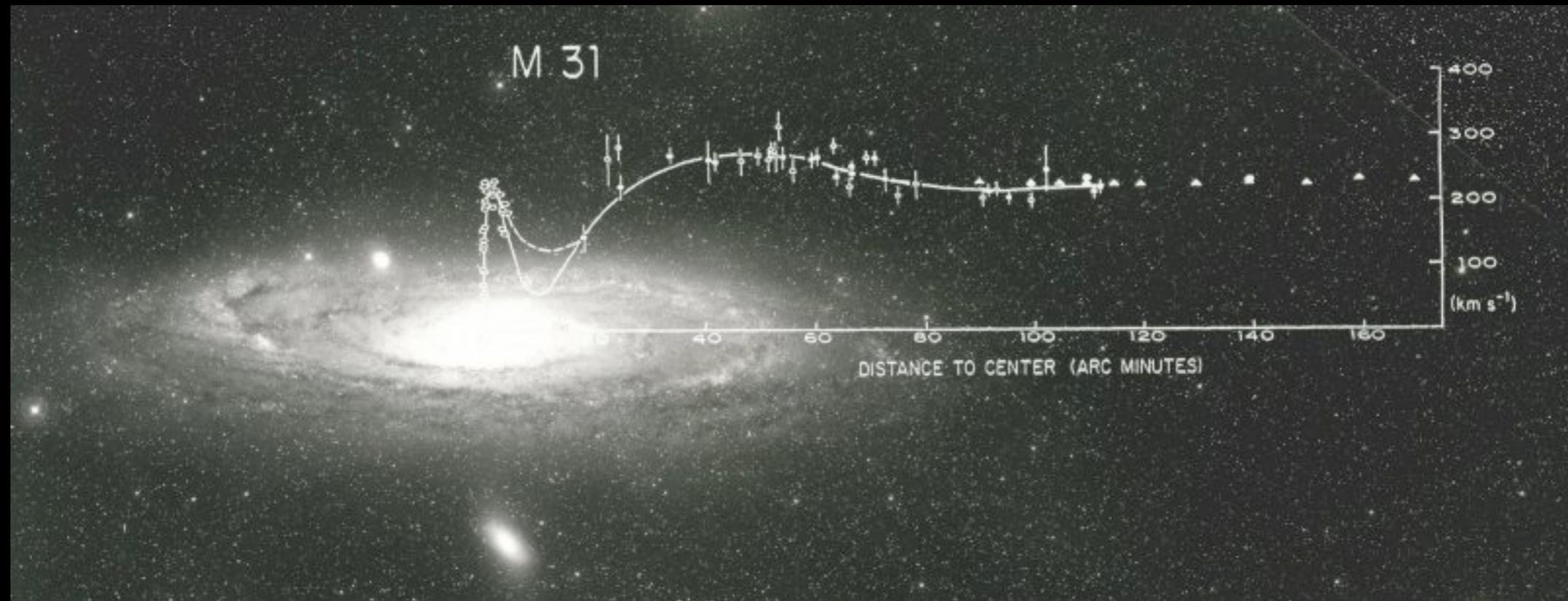


Distance from galaxy center \rightarrow

Positions of the rotational velocity measurements



The rotation speed is constant well beyond the visible edge of the galaxy!



This indicates a large amount of unseen mass, or *dark matter*

Rotation curves of other spiral galaxies, also showing the presence of dark matter

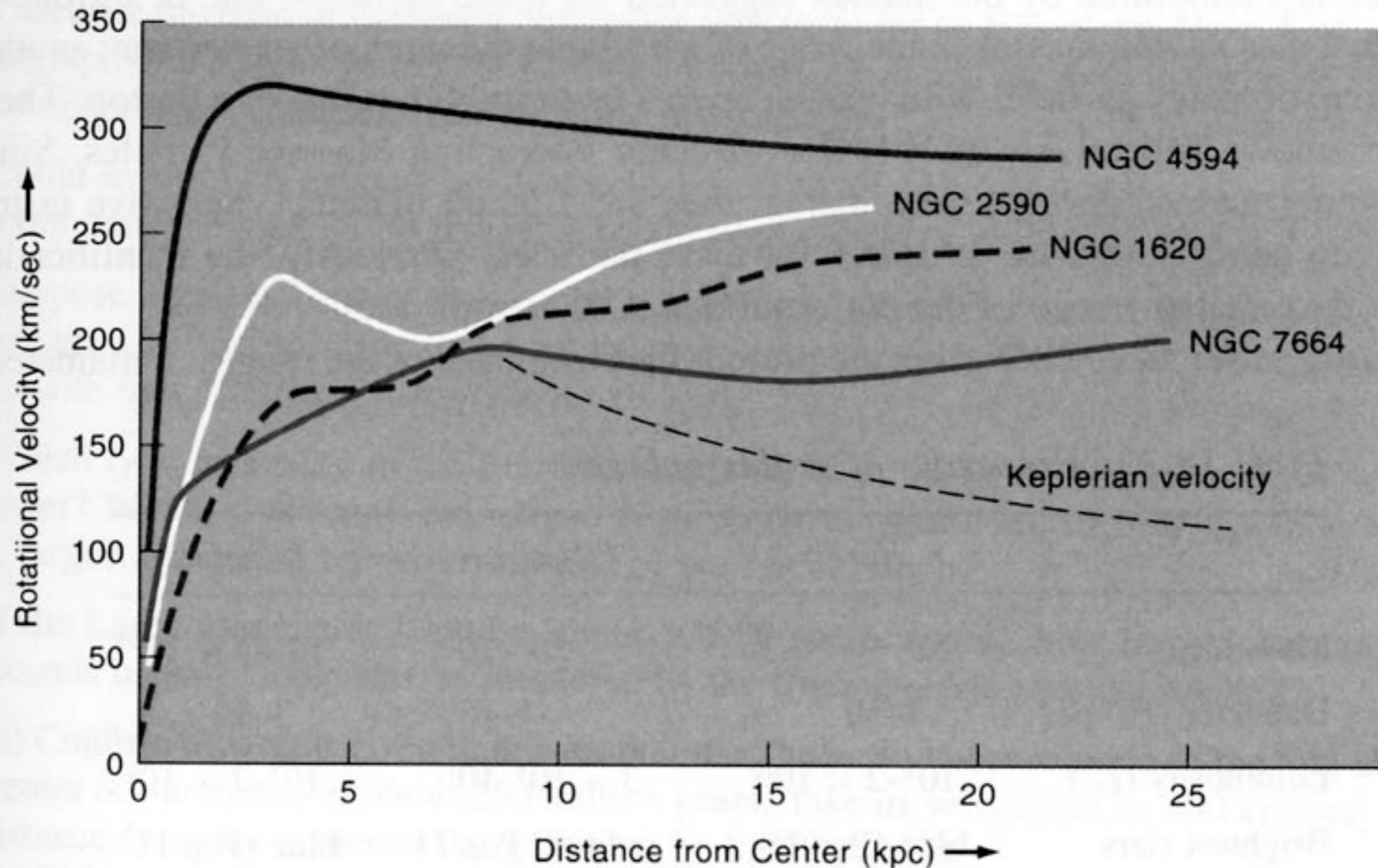
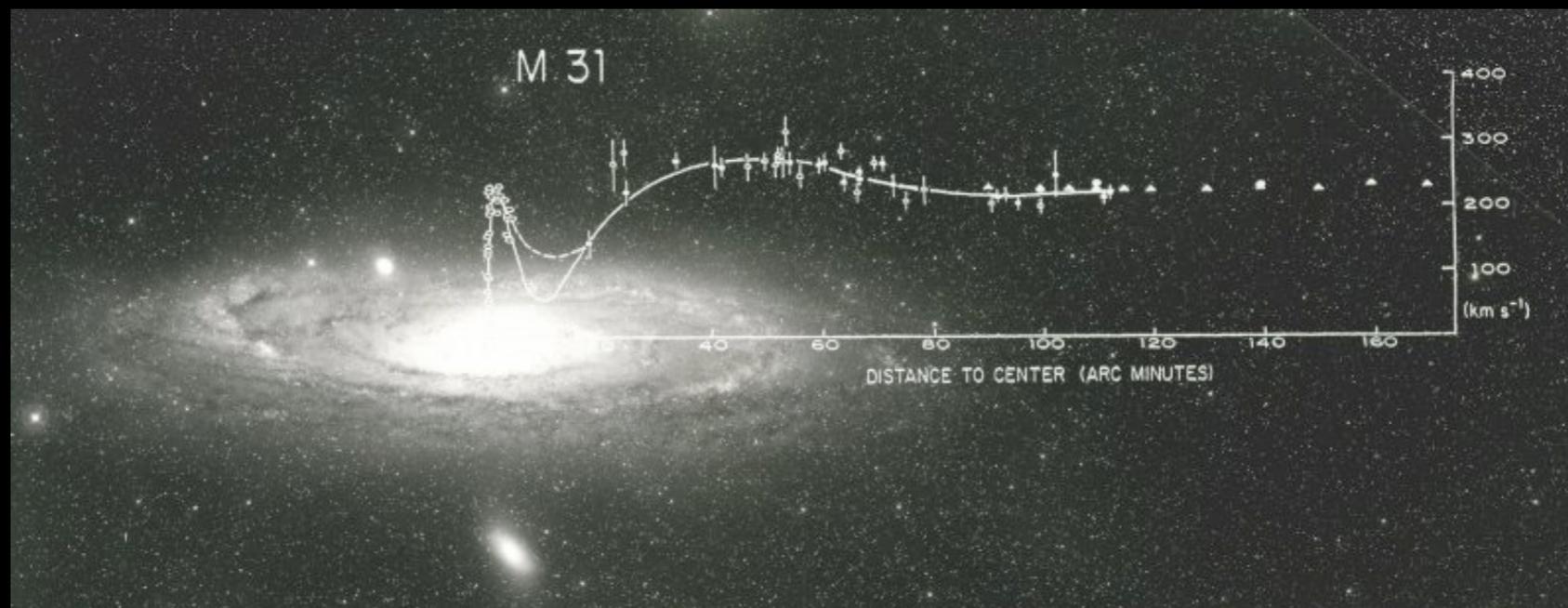


Figure 18.12. Curves of rotational velocity at increasing distances from the centers of four spiral galaxies. The velocities remain roughly flat instead of becoming smaller with greater distances from the center, as would be expected if most of the mass were located in and near the central bulge. The expected decrease, labeled “Keplerian velocity,” is shown for NGC 7664. Contrast this with the observed velocity.

Stars and gas on the edges of spiral galaxies orbit much faster than they would if they only felt the gravity of the other stars in the galaxy

There isn't just more mass than the starlight we see can account for, but that mass is distributed differently than the stars

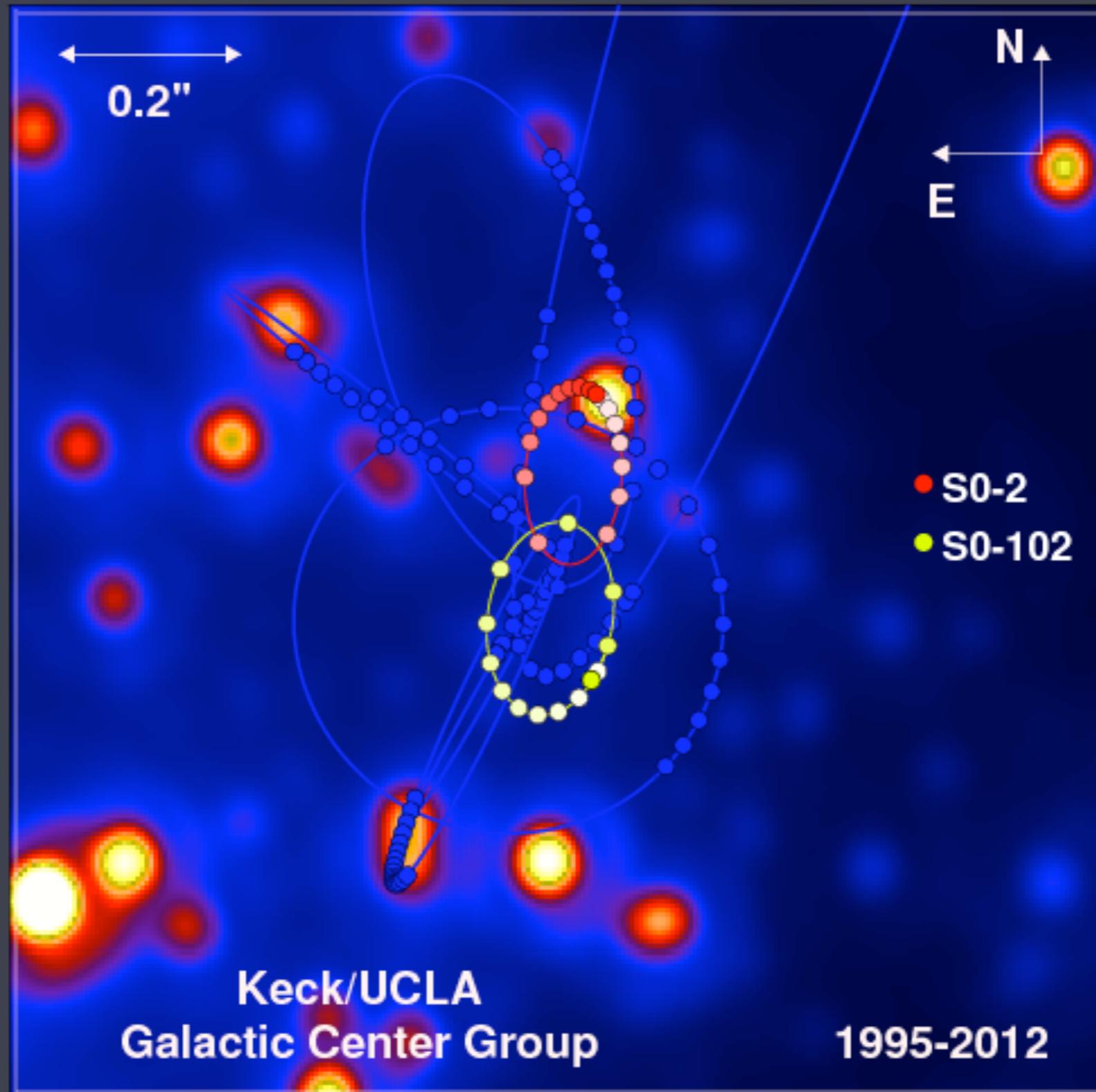


Most of the mass in spiral galaxies is not
stars (or gas, dust)

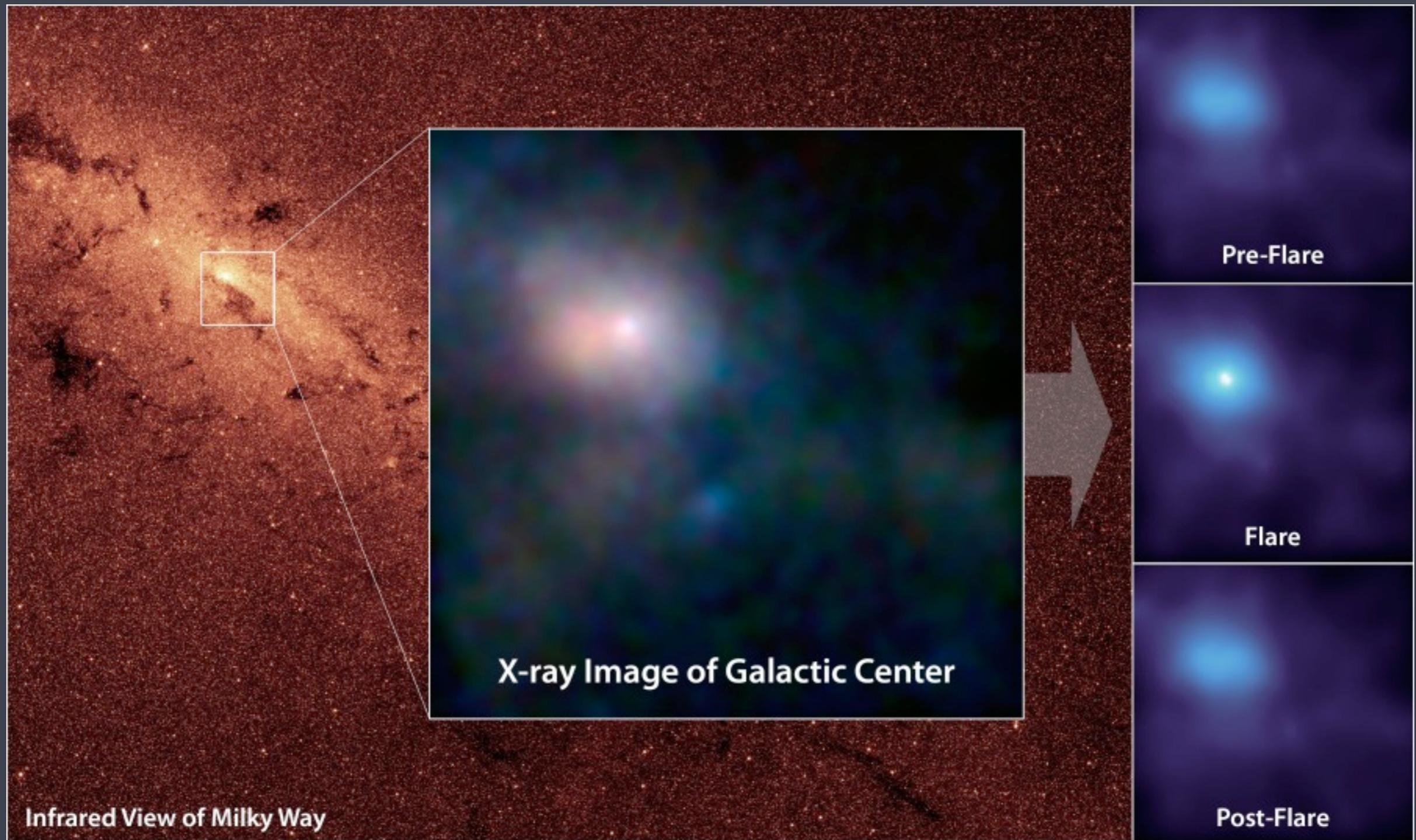
It is 80 to 90% dark matter

and that dark matter is much less
centrally concentrated than the stars
(and starlight) are

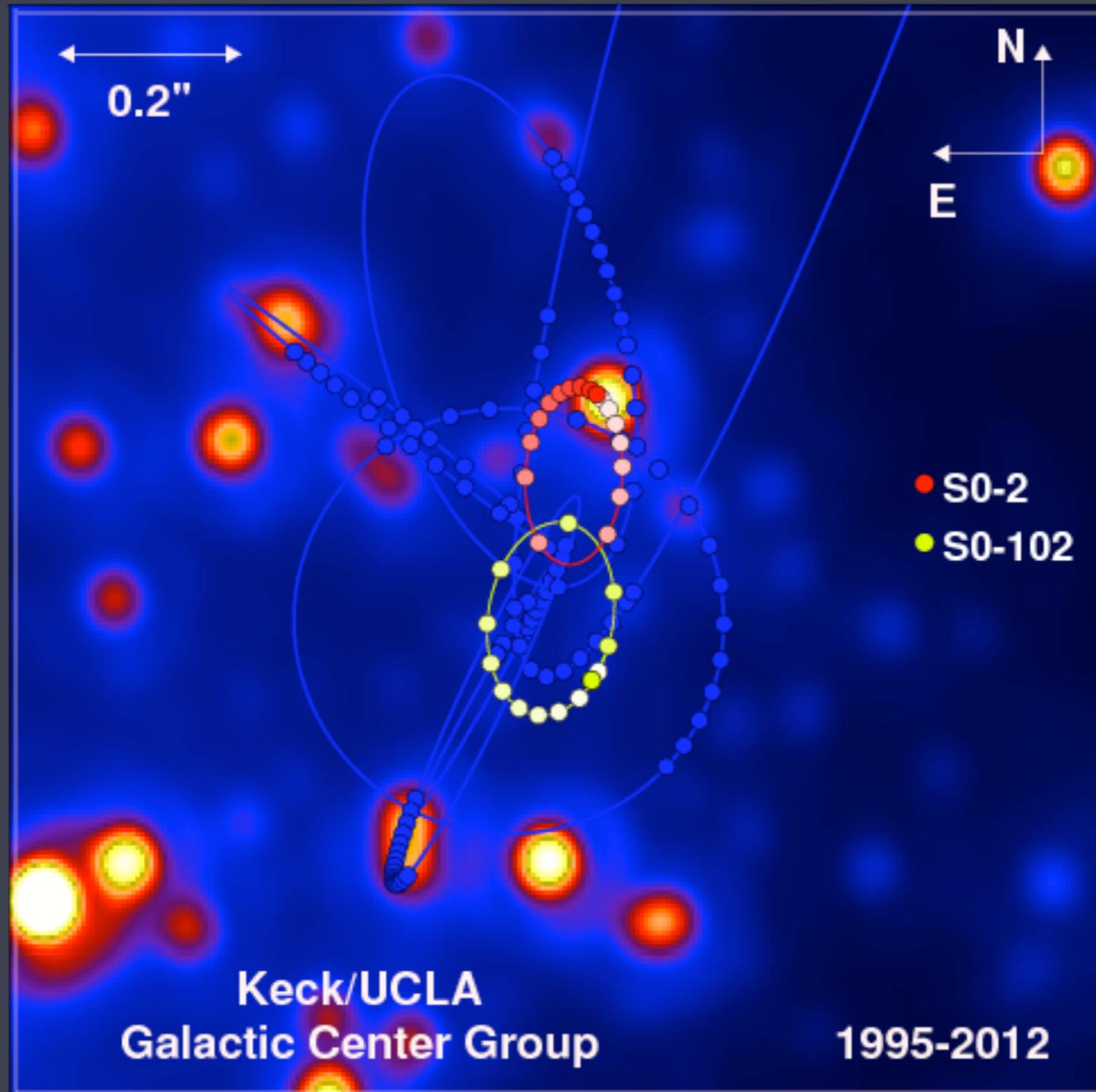
The most prominent single object in the Milky Way...is the Black Hole at the Galactic Center



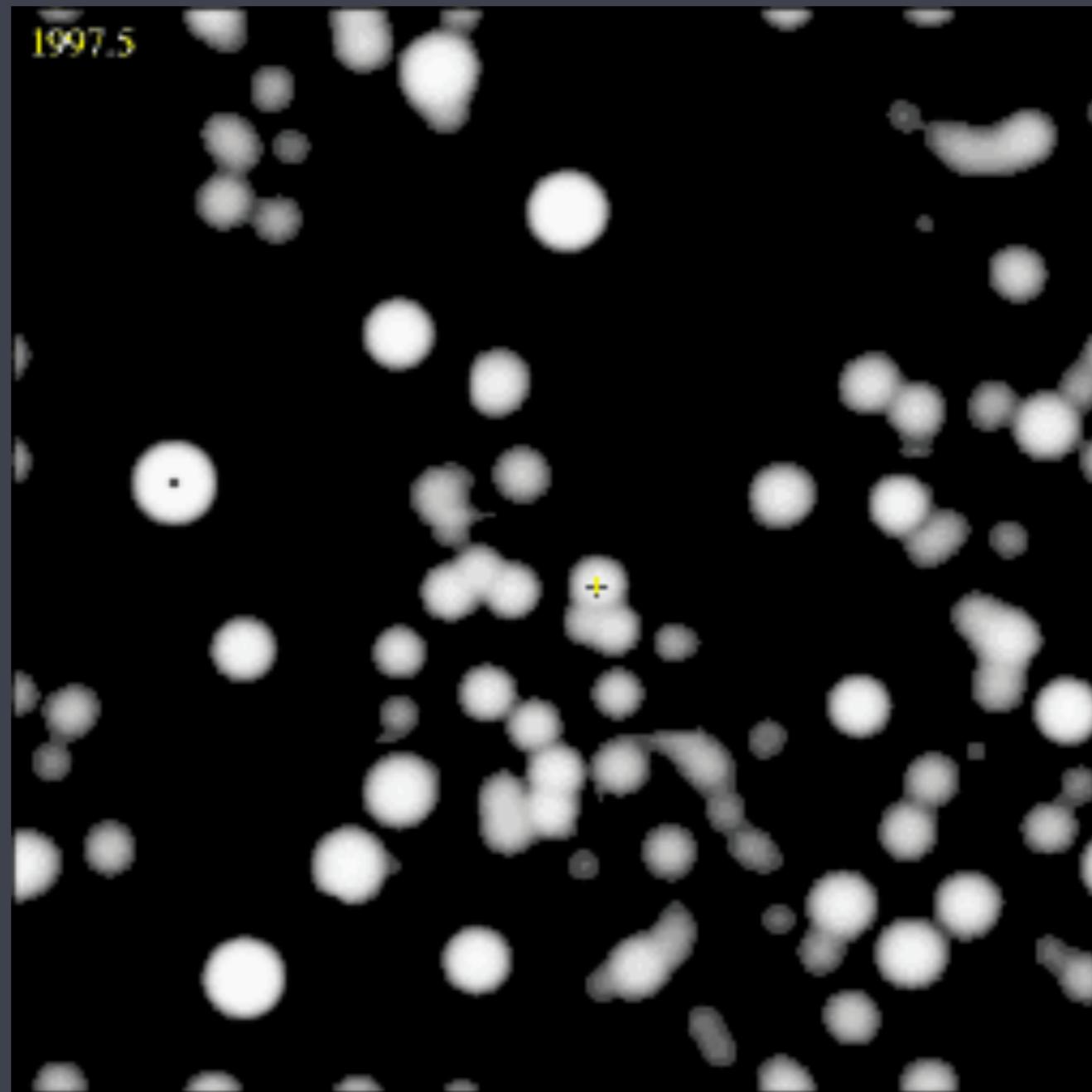
Black Hole at the center of the Milky Way: X-ray flares



stars orbiting the Galactic center



8-year time-lapse



<http://apod.nasa.gov/apod/ap001220.html>



Wide-Field Radio Image of the Galactic Center

$\lambda = 90 \text{ cm}$

(Kassim, LaRosa, Lazio, & Hyman 1999)

Galactic Center (long-wavelength radio)

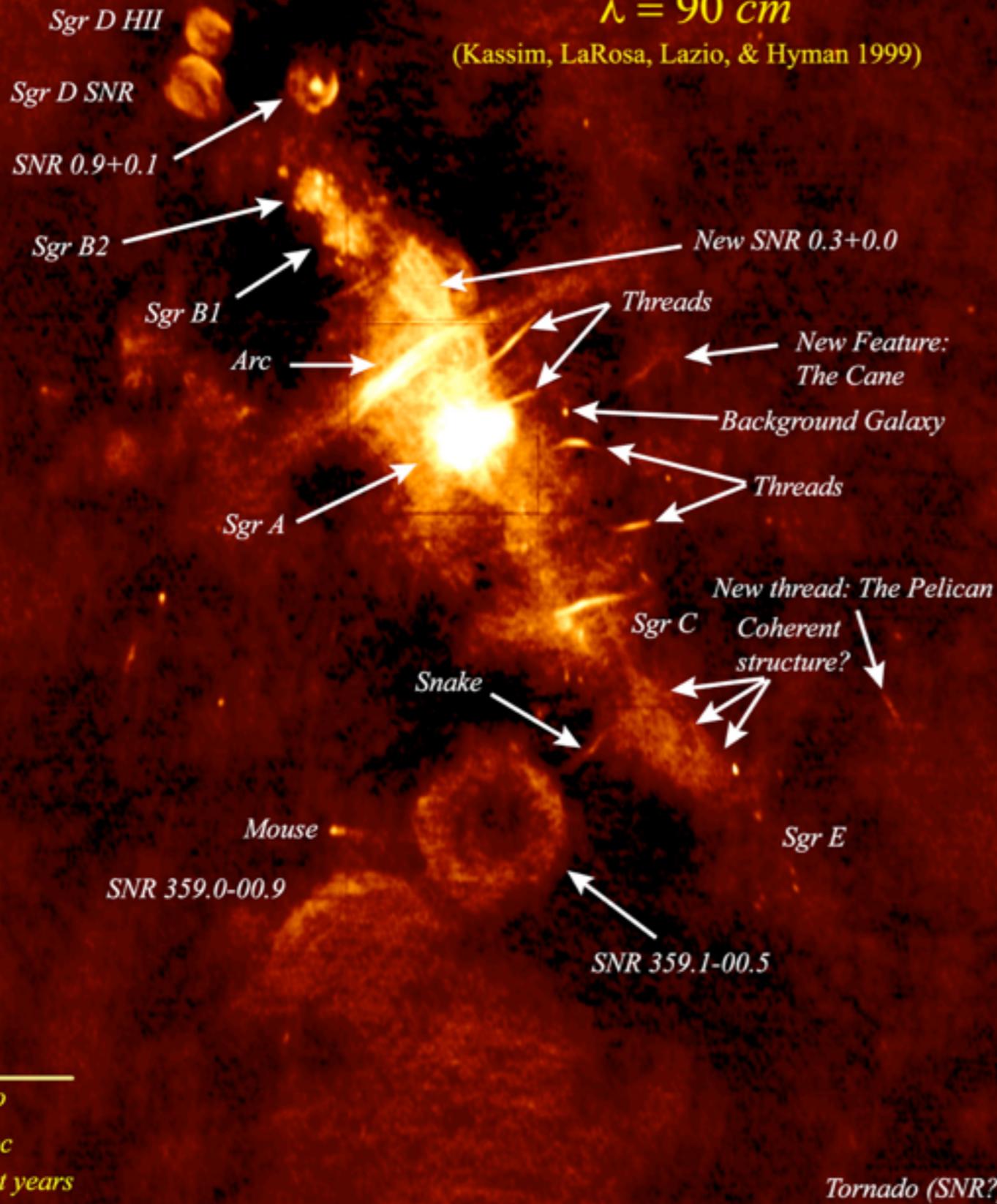


Image processing at the Naval Research Laboratory using DoD High Performance Computing Resources
 Produced by N.E. Kassim, D.S. Briggs, T.J.W. Lazio, T.N. LaRosa, J. Imamura, & S.D. Hyman
 Original data from the NRAO Very Large Array courtesy of A. Pedlar, K. Anantharamiah, M. Goss, & R. Ekers