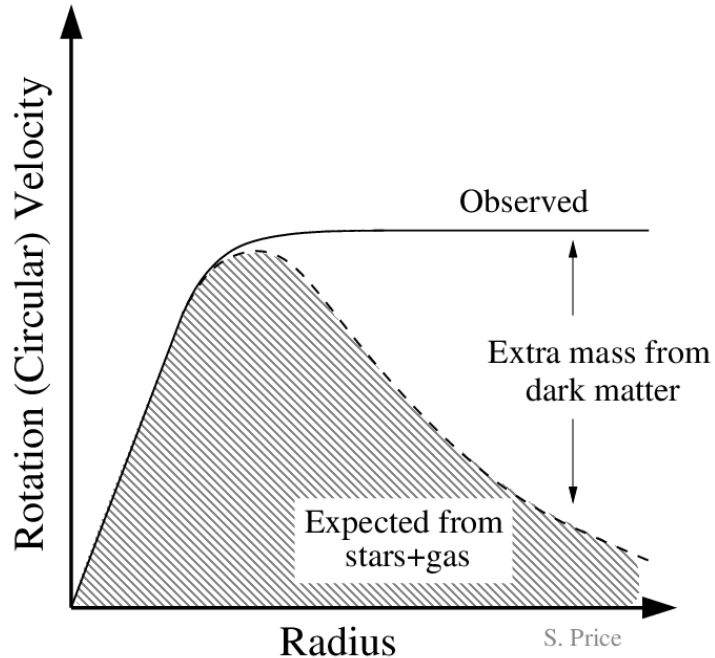# Unveiling Dark Matter:
## -Evidence From Rotation Curve (M31 Galaxy)

Mason Gingery, Ben Walker, Tong Wang

# Motivation (Dark Matter)

- Difference between expected and observed rotation velocity

- Unknown matter in universe
  - Doesn't emit/reflect light
  - Invisible

$$v = \sqrt{\frac{GM}{r}}$$

Given the equation above, we would expect the graph to look like this



Graph labeled: Rotation (Circular) Velocity vs. Radius, showing "Observed", "Extra mass from dark matter", and "Expected from stars+gas". S. Price

Andromeda
(M31 Galaxy)

# Methods (Coding)

- Step One: Calculate the rotation velocity by
  - the central black hole
  - Bulge
  - Disk

- Step Two: Compared the total rotation velocity with observed velocity
- Step Three: Compute the contribution of dark matter to the rotation velocity

$$v = \sqrt{\frac{GM}{r}}$$

# Methods (Coding)

$$v = \sqrt{\dfrac{GM}{r}}$$

```python
def calc_orbital_velocity(mass, radius):
    return np.sqrt((ac.G * mass) / radius)
```

| radius | mass_bhole | mass_disk | mass_bulge |
|---|---|---|---|
| 5.7 | 3e+07 | 3.7e+09 solMass | 2.2e+10 |
| 6.8 | 3e+07 | 5.3e+09 solMass | 2.2e+10 |
| 8 | 3e+07 | 7.2e+09 solMass | 2.2e+10 |
| 9.1 | 3e+07 | 9.4e+09 solMass | 2.2e+10 |
| 10 | 3e+07 | 1.2e+10 solMass | 2.2e+10 |
| 11 | 3e+07 | 1.5e+10 solMass | 2.2e+10 |
| 12 | 3e+07 | 1.8e+10 solMass | 2.2e+10 |
| 14 | 3e+07 | 2.1e+10 solMass | 2.2e+10 |

| radius | vel_bhloe | vel_bulge | vel_disk | observed |
|---|---|---|---|---|
| 5.7 | 4.8 km / s | 1.3e+02 km / s | 53 km / s | 2.4e+02 |
| 6.8 | 4.4 km / s | 1.2e+02 km / s | 58 km / s | 2.4e+02 |
| 8 | 4 km / s | 1.1e+02 km / s | 63 km / s | 2.5e+02 |
| 9.1 | 3.8 km / s | 1e+02 km / s | 67 km / s | 2.6e+02 |
| 10 | 3.6 km / s | 95 km / s | 71 km / s | 2.6e+02 |
| 11 | 3.4 km / s | 90 km / s | 75 km / s | 2.6e+02 |
| 12 | 3.2 km / s | 86 km / s | 78 km / s | 2.5e+02 |

```python
for i, radius in enumerate(dis):
    rad = radius * 1000 * u.parsec
    orb_vel = calc_orbital_velocity(mass,rad)
```

# Results
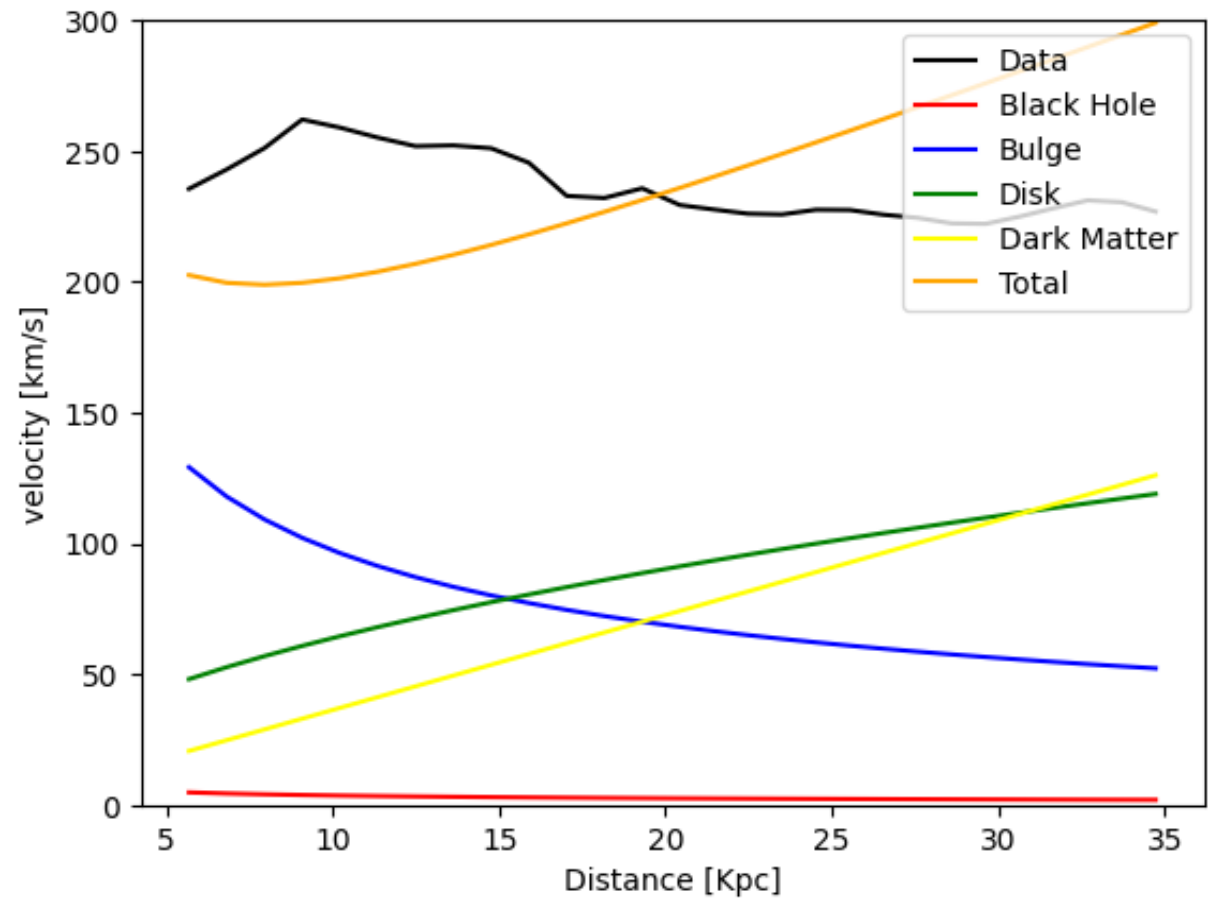


- Gap between observed rotation velocity and rotation velocity by central black hole, bulge and disk

- Proof of contribution of dark matter to rotation velocity

# Conclusion

Why do rotation curves imply that dark matter exists?

Flat rotation curves imply that there is much more mass in the galaxy than expected.

The galaxy is spinning too fast to stay together, so the galaxy should not be stable.

This implies that there must be mass that we can't see.

# References

1. Carignan, C., Chemin, L., Huchtmeier, W. K., & Lockman, F. J. (2006). The extended Hi rotation curve and mass distribution of M31. *The Astrophysical Journal*, *641*(2). https://doi.org/10.1086/503869

2. *M31*. M31 Fact Sheet - StarDate's Black Hole Encyclopedia (n.d.). http://blackholes.stardate.org/objects/factsheet-M31.html