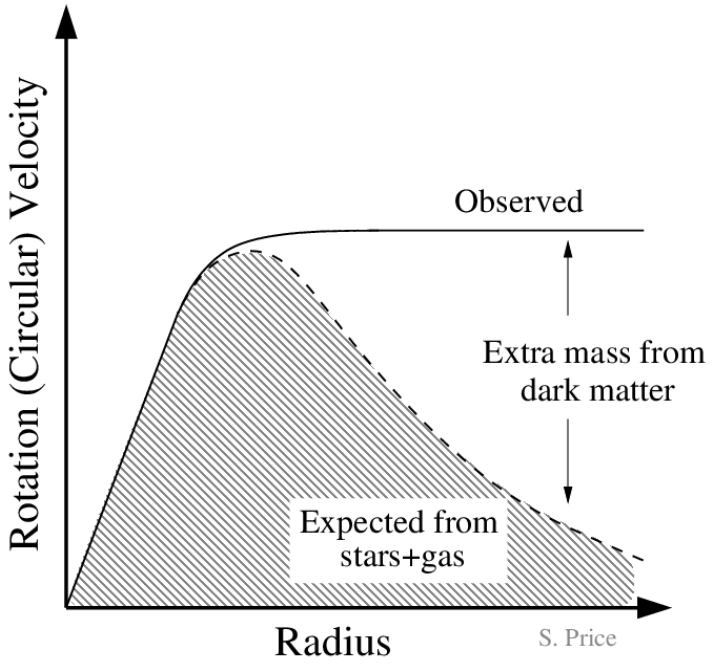
Unveiling Dark Matter:
-Evidence From Rotation Curve (M31 Galaxy)

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

Andromeda (M31 Galaxy)

Methods (Coding)

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

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

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

Methods (Coding)

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

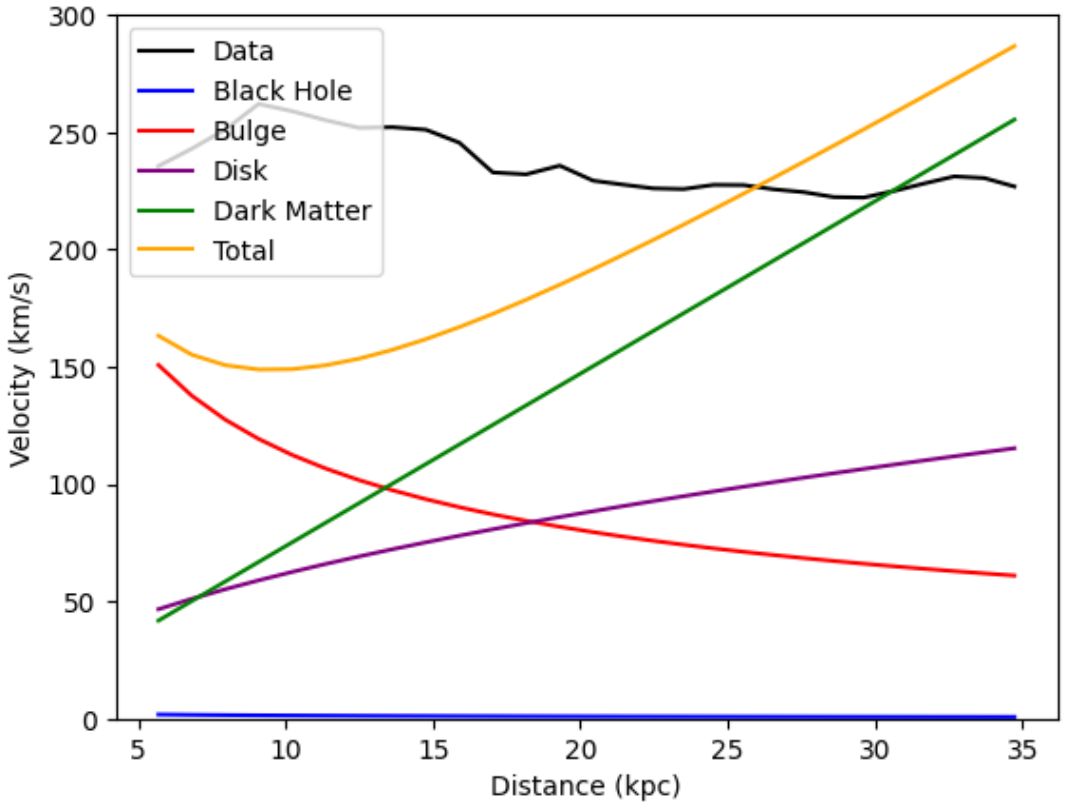
```
def calc_orbital_velocity(mass, radius):
  return np.sqrt((ac.G * mass) / radius)
```

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

```
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.