

# Dark matter in low-mass dwarf galaxies

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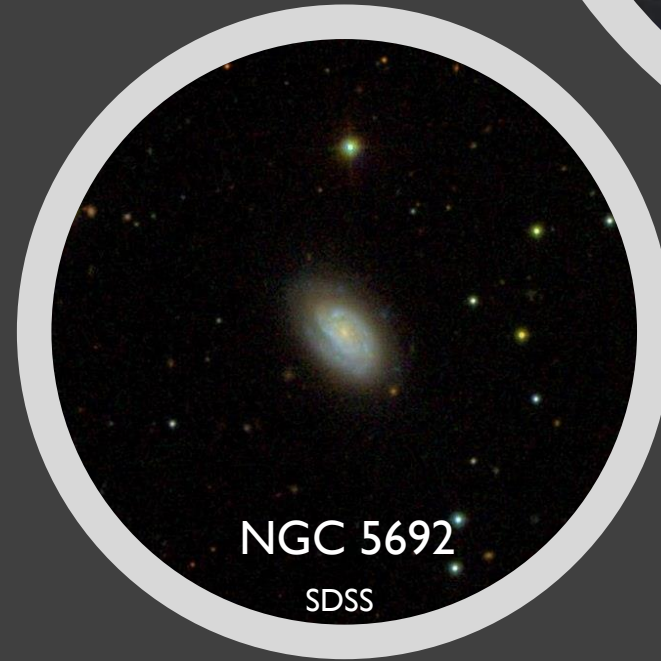
# Galaxies

- Groups of stars, gas, dust, and dark matter
- Held together by gravity
- They Rotate!



# Dwarf Galaxies

- Most abundant, low luminosity, low mass, small size
  - NGC 4451 ~ 16,304 ly in diameter
  - Milky Way ~ 100,000 ly in diameter
- Hard to spot
- Dominated by dark matter



NGC 5692

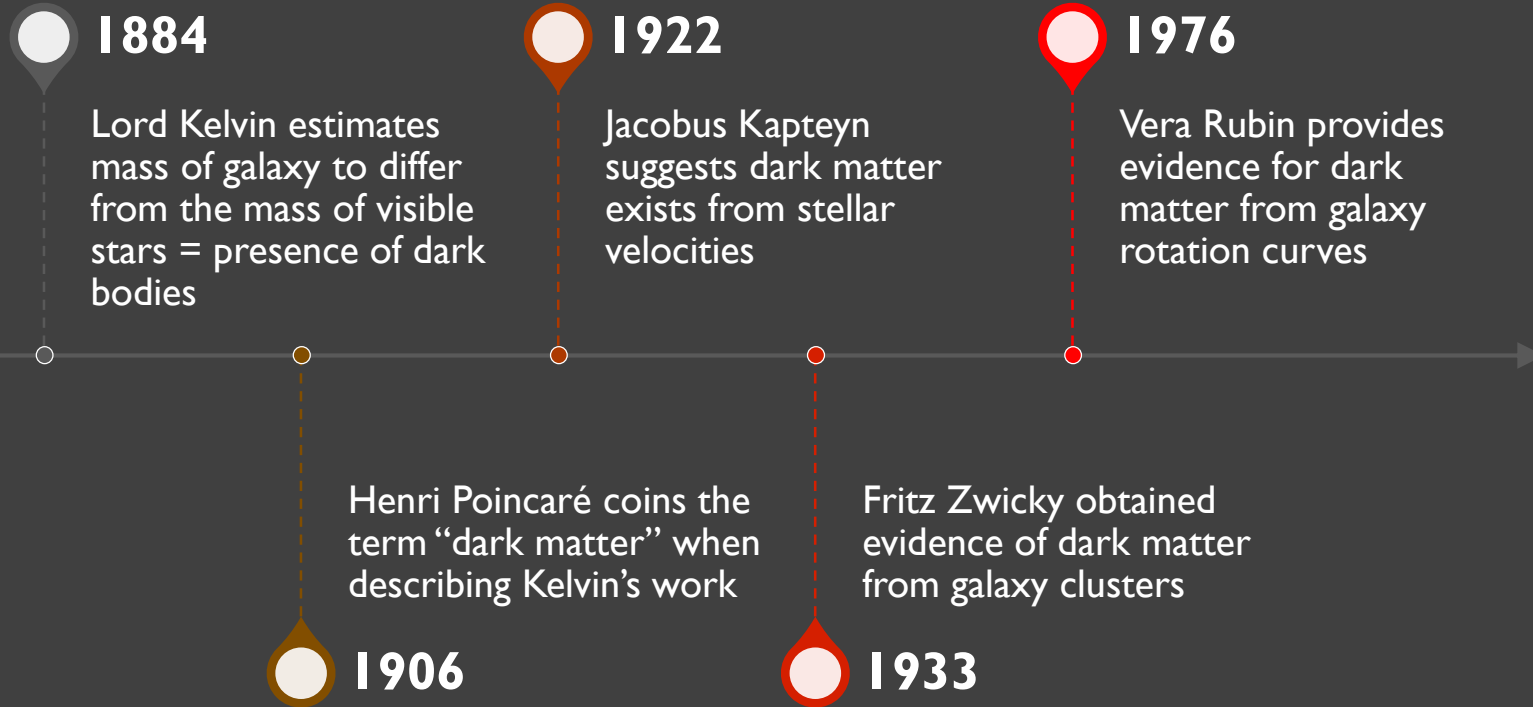
SDSS



NGC 6106

SDSS

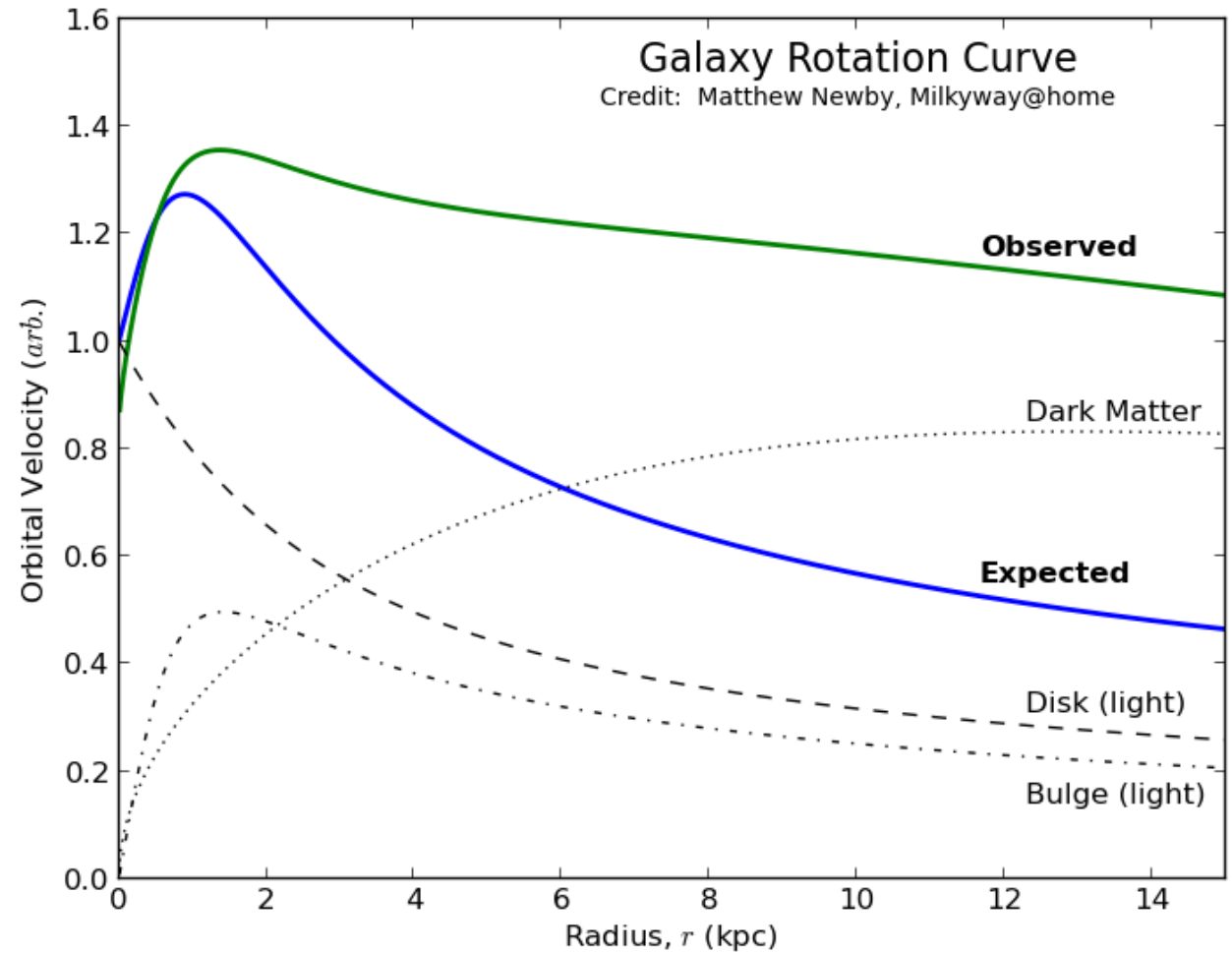
# Dark Matter History

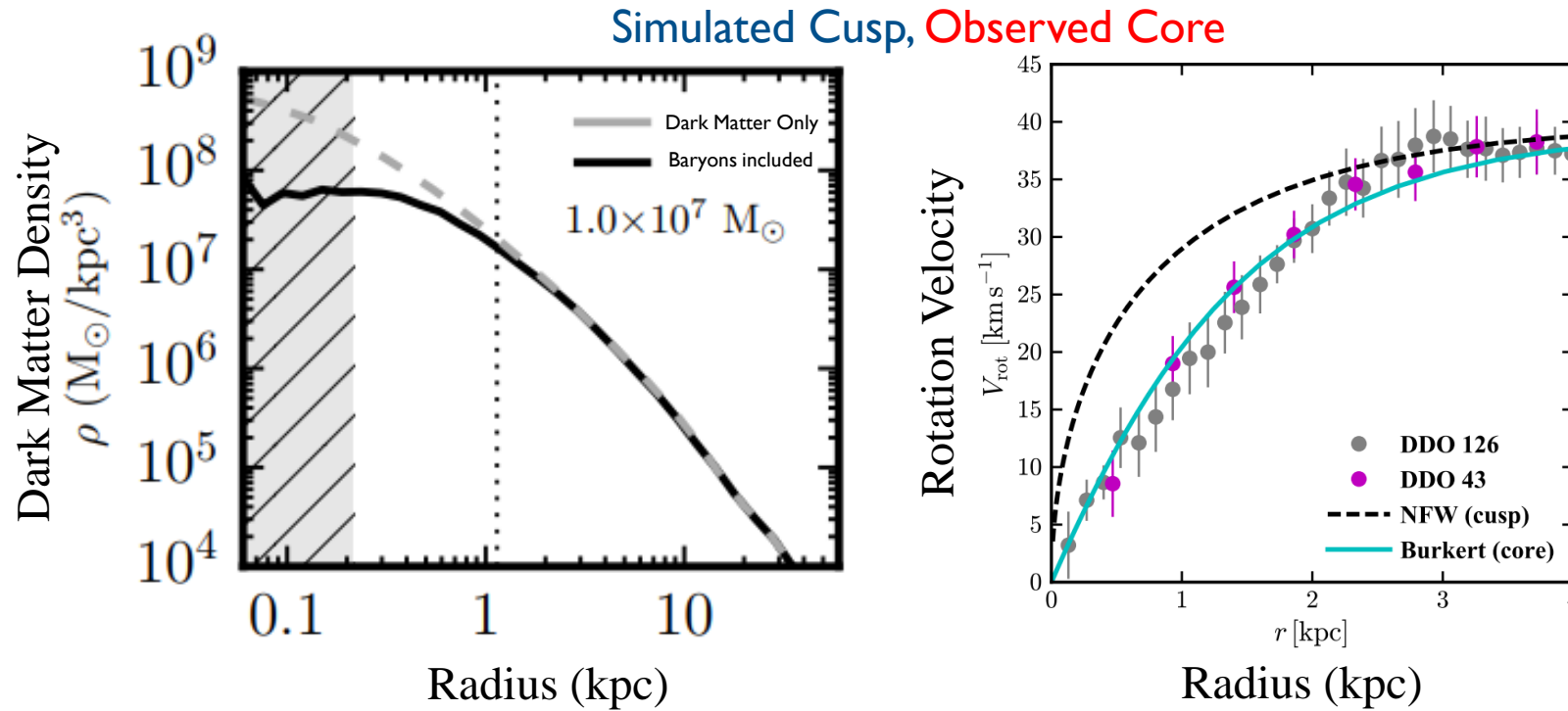


(Carnegie Institution of Washington  
via Associated Press)

# Dark Matter

- Expected velocity from observed mass
- But larger velocity observed
- Must be more unseen mass
- Dark matter: only known to interact with gravity





$$\rho \propto \left(\frac{v}{r}\right)^2$$

Adapted from Bullock & Boylan-Kolchin et al. 2017

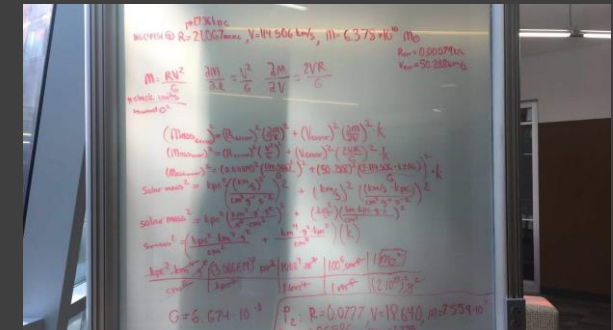
## Core-Cusp Problem

### Possible Causes:

- Dark matter functions differently than we understand
- Baryonic physics

# Chronology and My role

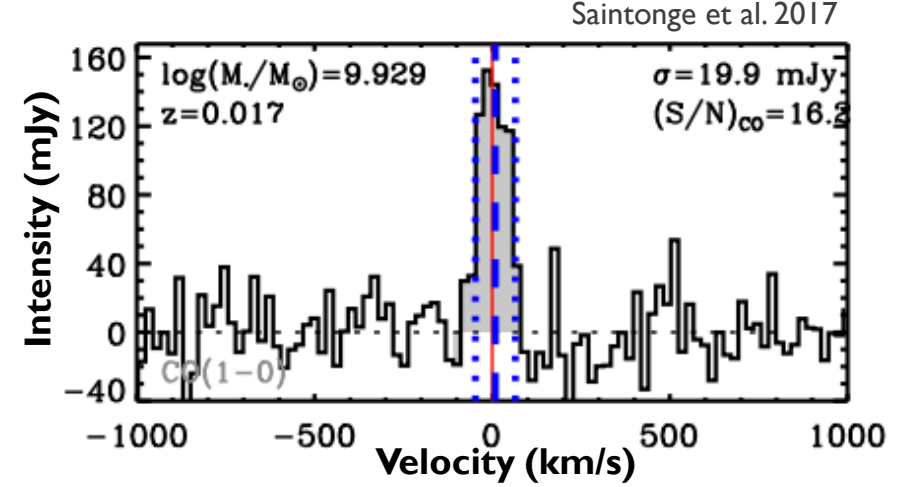
1. Setup, astronomy & scientific python overview
2. Plot CO velocity fields and rotation curves
3. Read papers, compare CO data to H $\alpha$  data, cleanup code
4. Determine error to CO rotation curves using Monte Carlo method, find dynamical mass
5. Compare rotation curve geometric parameters between datasets, find inner slope of dark matter density and dark matter rotational velocity
6. Start final presentation and paper, fix error on fits, plot comparisons between observed and simulated data, compare dark matter concentrations to other galaxy parameters
7. Finalize graphs and code, write presentation
8. Finish presentation and poster



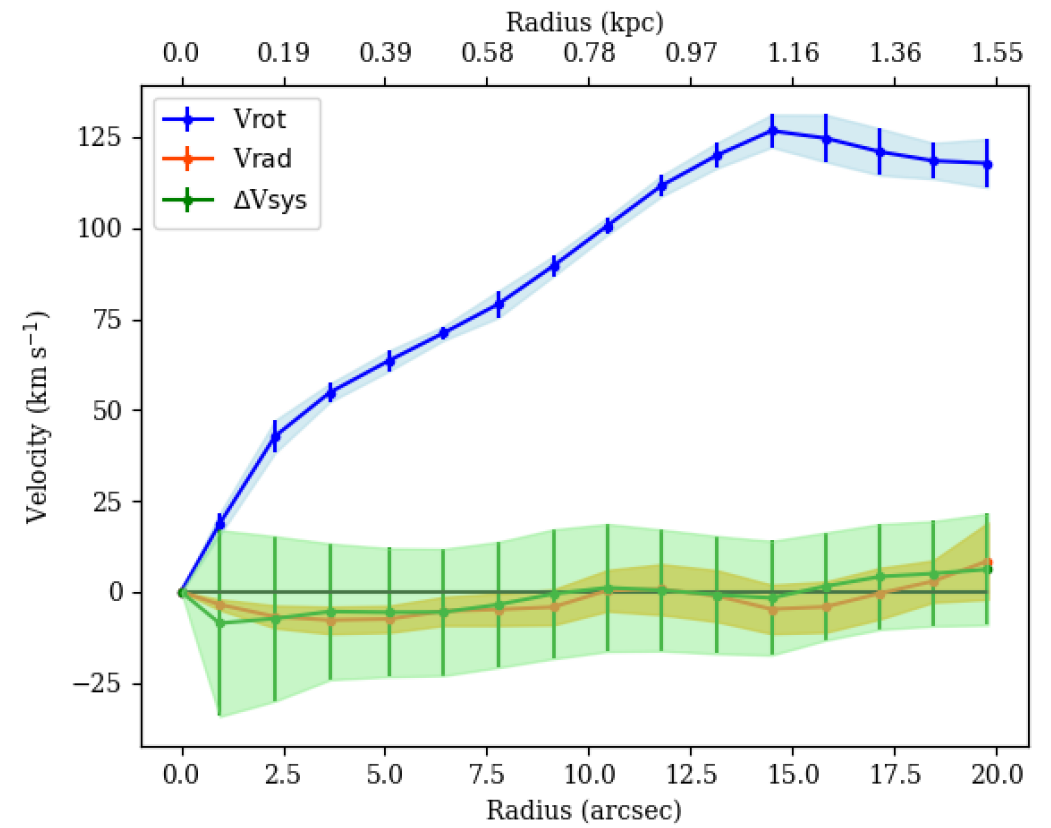
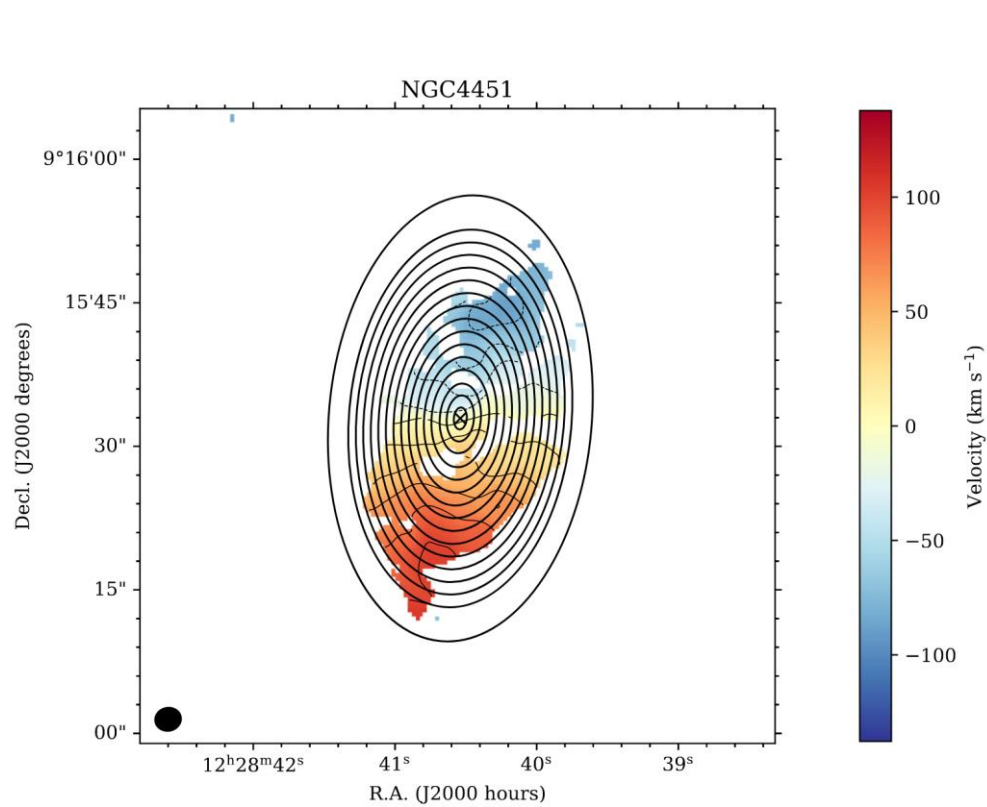


# Data

- ALMA
- Carbon Monoxide (CO)
- Measuring the spectrum: amount of light emitted by that molecule at different frequencies



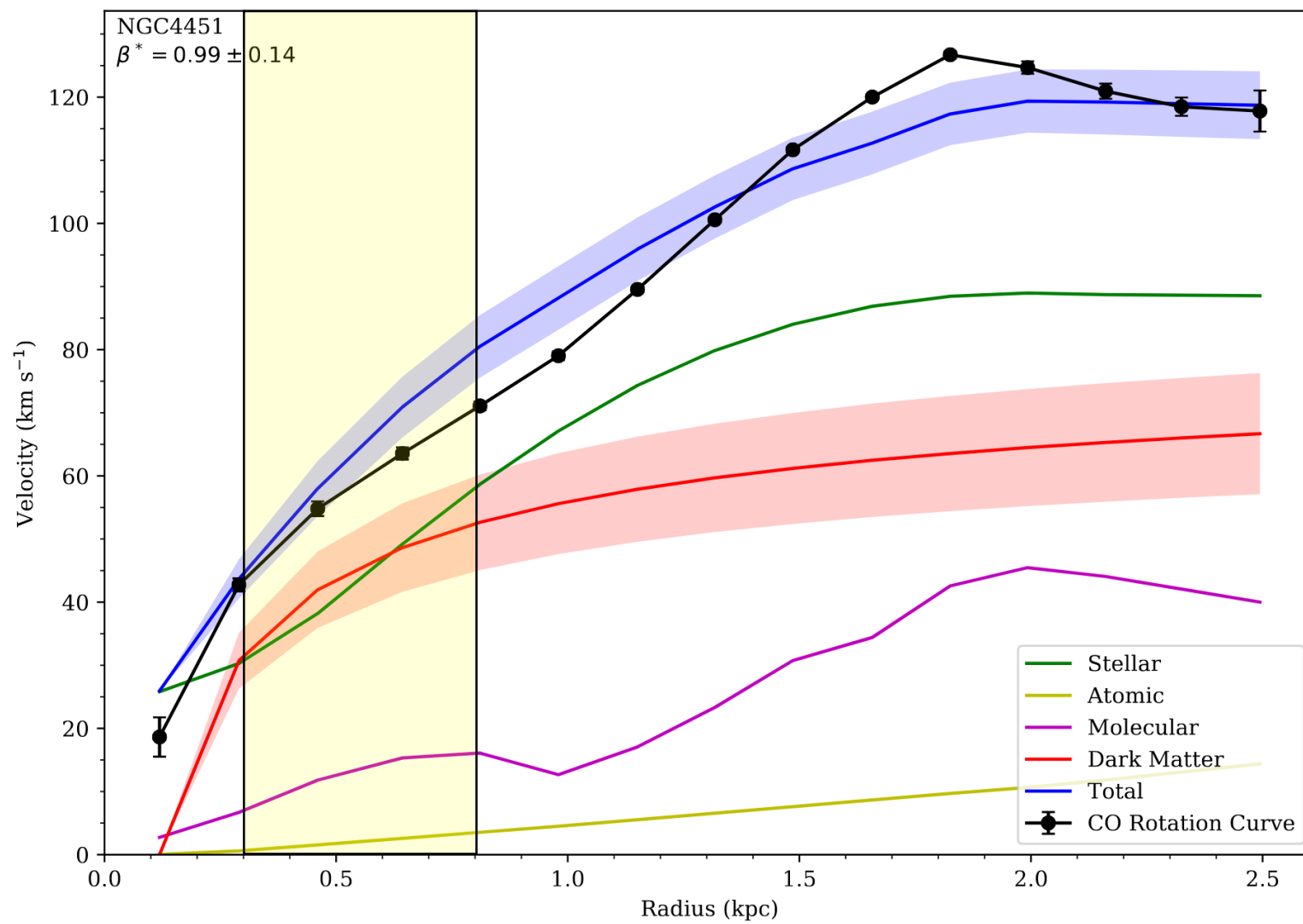


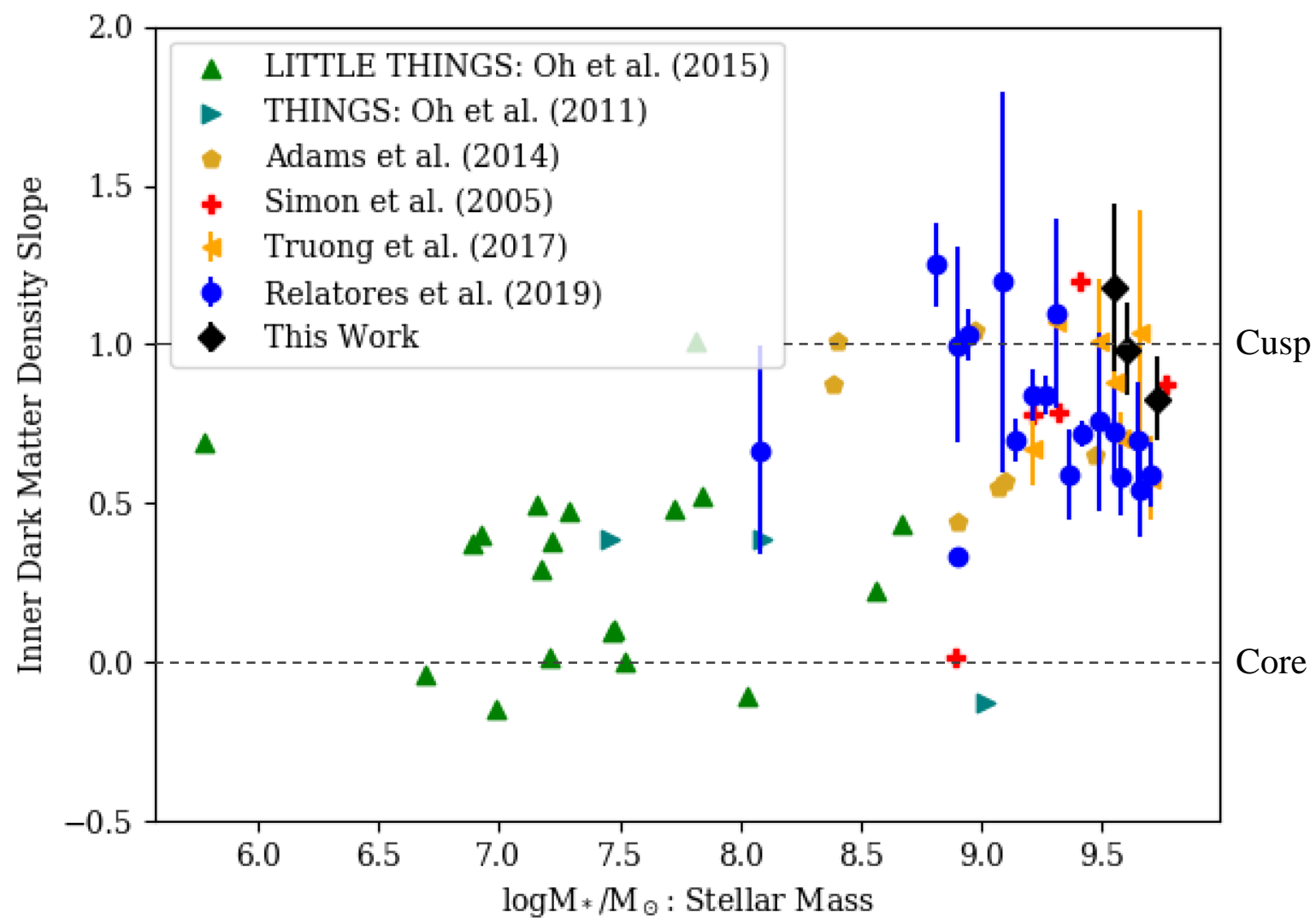


# Velocity Fields and Rotation Curves

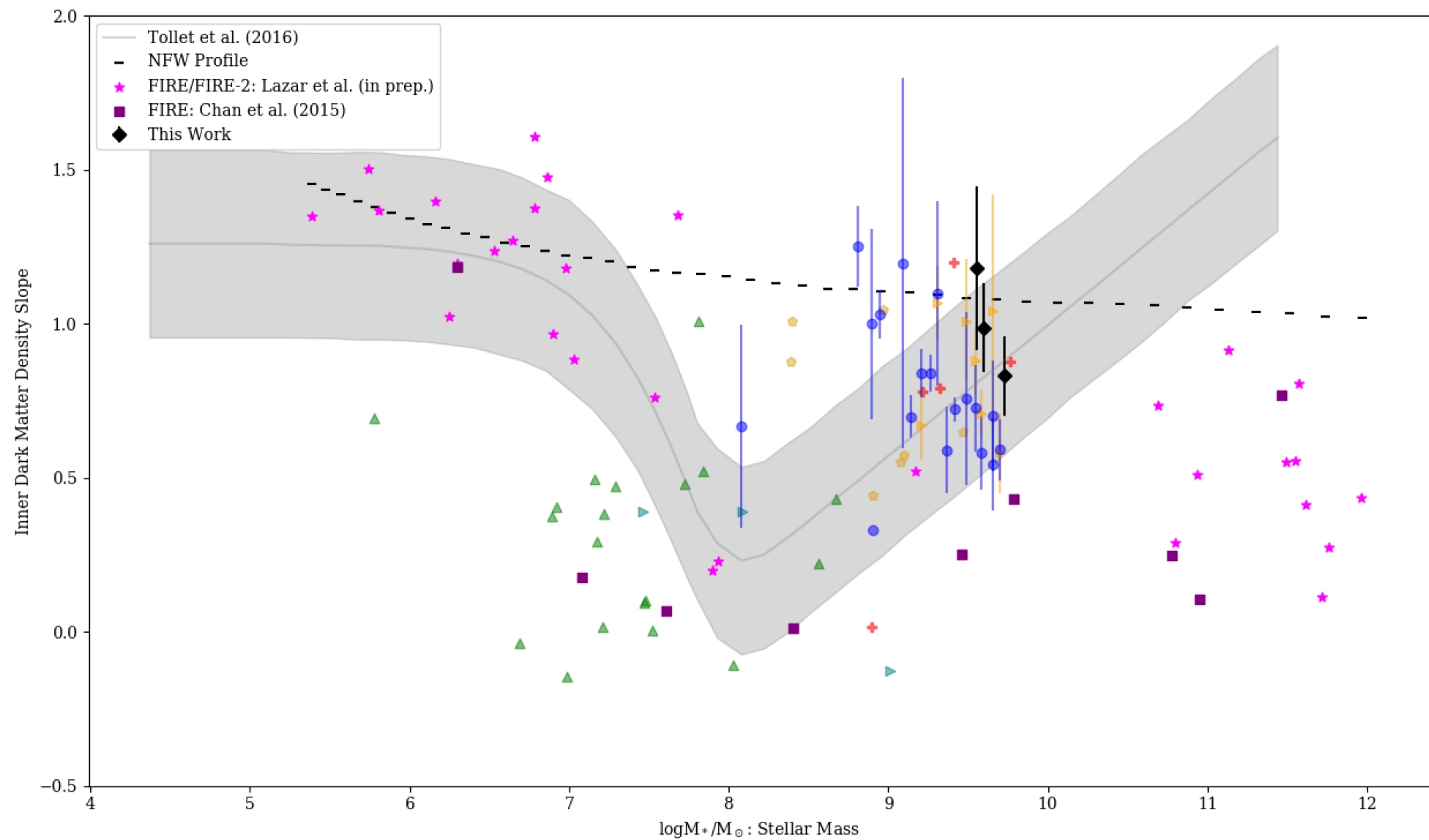
# Dynamical Mass & its Breakdown

$$M = \frac{R v_{rot}^2}{G}$$









## Lessons Learned & Mistakes Made

```
WARNING: VerifyWarning: Card 'RESTFREQ' is not FITS standard (invalid value string: '1.15271e+11'). Fixed 'RESTFREQ' card to meet the FITS standard. [astropy.io.fits.verify]
WARNING: VerifyWarning: Note: astropy.io.fits uses zero-based indexing. [astropy.io.fits.verify]
Traceback (most recent call last):
  File "fittingwrapper.py", line 127, in <module>
    R, eR, Vrot, eVrot, Vrad, eVrad, dVsys, edVsys, chisq, chisqr = fit_tilted_rings(gal,vheader, vfield, evfield, RA+1, Dec+changeDec, PA+changePA, Inc+changeInc, Vsys+changeVsys)
  File "/thurston2/lcooke/research/ALMADwarfCORotCurves/scripts/FitTiltedRings.py", line 315, in fit_tilted_rings
    r_rings = get_rings(vel_list, PA, inc, Vsys, bmaj)
  File "/thurston2/lcooke/research/ALMADwarfCORotCurves/scripts/FitTiltedRings.py", line 132, in get_rings
    this_max_r = np.max(r_thisring)
  File "/n/astromake/opt/python/anaconda3/lib/python3.6/site-packages/numpy/core/fromnumeric.py", line 2505, in amax
    initial=initial)
  File "/n/astromake/opt/python/anaconda3/lib/python3.6/site-packages/numpy/core/fromnumeric.py", line 86, in _wrapreduction
    return ufunc.reduce(obj, axis, dtype, out, **passkwargs)
ValueError: zero-size array to reduction operation maximum which has no identity
thurston%
```

- Sign and unit errors

- Always ask if you are unsure

- Keep track of where your data is coming from

Rich Text

Recompile

# Future Work

Decompose mass of galaxies where we have robust rotation curves

Paper

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n{Introduction}

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CO Rotation Curves and Dark Matter

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ABSTRACT

Abstract

1. INTRODUCTION

2. OBSERVATIONS AND DATA REDUCTION

2.1. Sample Selection

The initial galaxy sample selection is described by Truong et al. (2017), who observed these galaxies at CO J=1–0(1–0) with the Combined Array for Millimeter-wave Astronomy (CARMA). Of the initially selected 26 galaxies, 14 are detected with sufficient SNR to derive rotation curves. The remaining 12 were followed up with new, more sensitive CO observations using the Atacama Large Millimeter-wave Array (ALMA). Of the selected 13 galaxies, 11 are observed with the sufficient signal to produce velocity fields. Our final sample consists of 6 dwarf galaxies with a high enough SNR to produce rotation curves.

2.2. CO Observations

The CO observations were taken with ALMA as part of project number 2015.1.00820.S (P.L. Brühl).

2.3. CO Data Reduction

2.4. H<sub>2</sub> Data

H<sub>2</sub> data was taken using the Palomar Cosmic Web Imager (PCWI) integral field spectrograph on the Hale 5 m telescope at the Palomar Observatory. Full details of the obser-



# Acknowledgements

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Astronomy Department
- Dr. Hannah Krug



**UMD**  
**ASTRO** 



Dark matter  
distribution is  
affected by feedback



Simulations agree  
best with  
observations when  
baryonic physics are  
included



Core-Cusp problem  
in dwarf galaxies  
may be explained  
with baryonic  
physics

# Conclusions