Dark Matter In Inner Part of NGC 628

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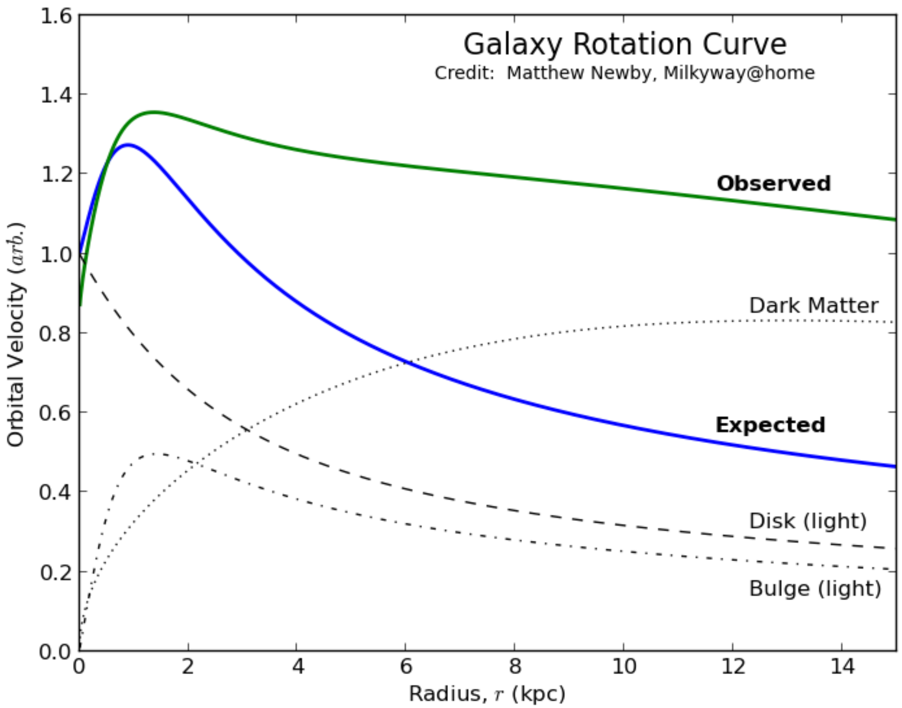
Introduction

Galaxy Rotation Curve Problem

- Kepler's laws: $\mathrm{v} \propto \frac{1}{\sqrt{\mathrm{r}}}$
  - where v is orbital velocity, and r is radius.
- Observed: $\mathrm{v} \approx \text{constant}$
- Dark Matter
  - can't be observed directly
  - study it is by gravity currently



Source: https://milkyway.cs.rpi.edu/milkyway/science.php

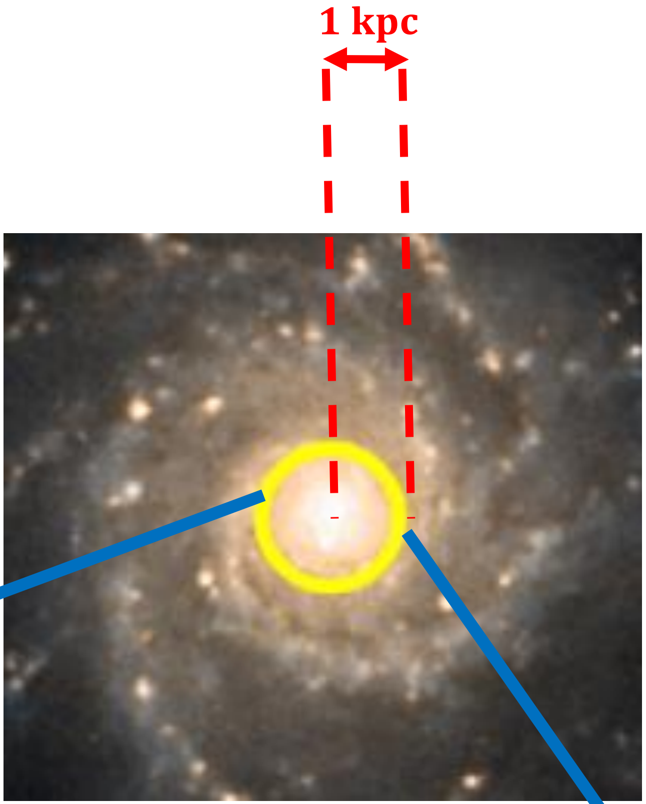
Dark Matter Candidates

- WIMP (Weakly Interacting Massive Particles)
  - hypothetical particles
- MACHOs (MAssive Compact Halo Objects)
  - dim objects with $\mathrm{M} < 1\mathrm{M}_{\odot}$
  - e.g. brown dwarfs, white dwarfs, black holes
- Axions
  - hypothetical elementary particles
  - tiny mass: 10^{-6} to 10^{-2} $\mathrm{eV/c^2}$
- Compare to WIMP and MACHOs, Axions assemble less in the inner part of galaxies.

About My Project and Data

Goal

- Look into the inner part of NGC 628.
- Find out the dynamical mass composition.
- Estimate the proportion of dark matter.

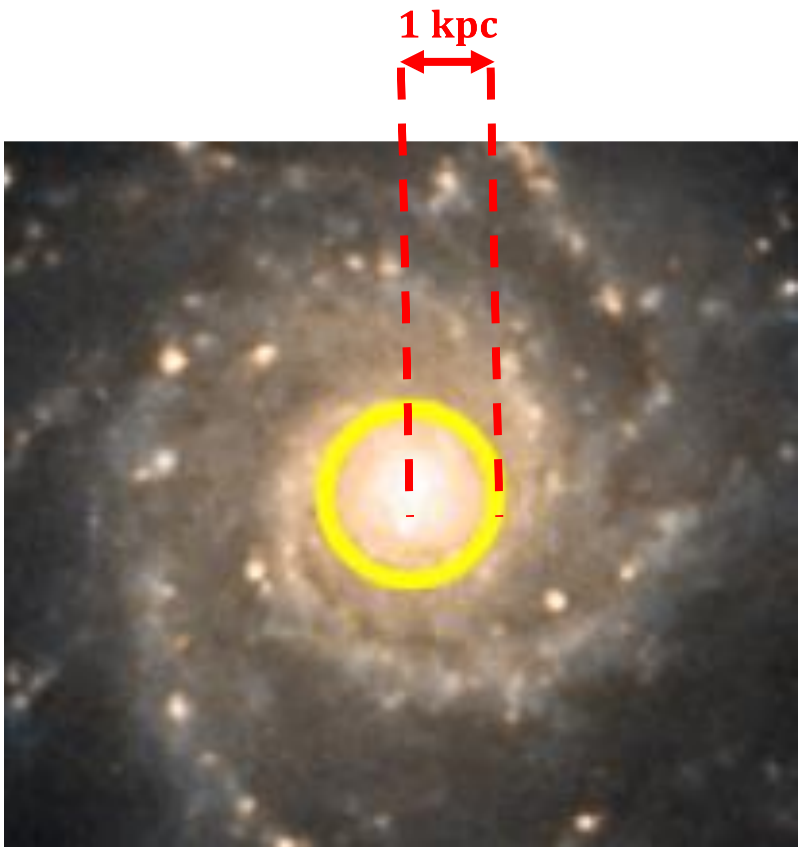


Source: https://almascience.nao.ac.jp/aq/

$$M_{\text{dynamical}} = M_{\text{molecular}} + M_{\text{atomic}} + M_{\text{stellar}} + M_{\text{dust}} + M_{\text{black hole}} + M_{\text{dark matter}}$$

Data Selection

- ALMA Archive
- Project Code:
  - 2013.1.00532.S
- Tracing Molecule:
  - CO(1-0),
  - rest frequency ~115.27 GHz
- Spectral window:
  - 114.516 GHz (central frequency)

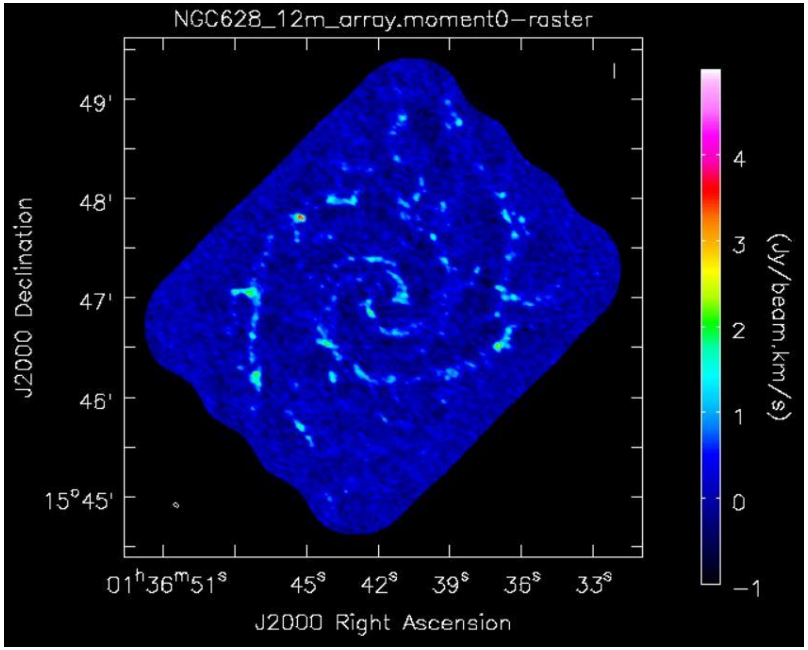


Source: https://almascience.nao.ac.jp/aq/

Data Feathering

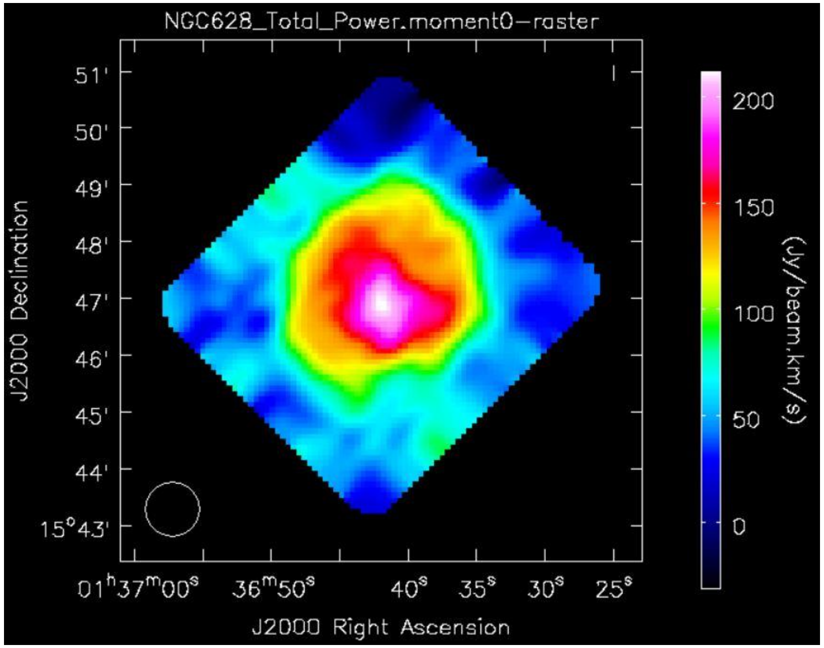
- 12m Array
  - Resolution: $3.35'' \times 2.03''$

Moment0 Map



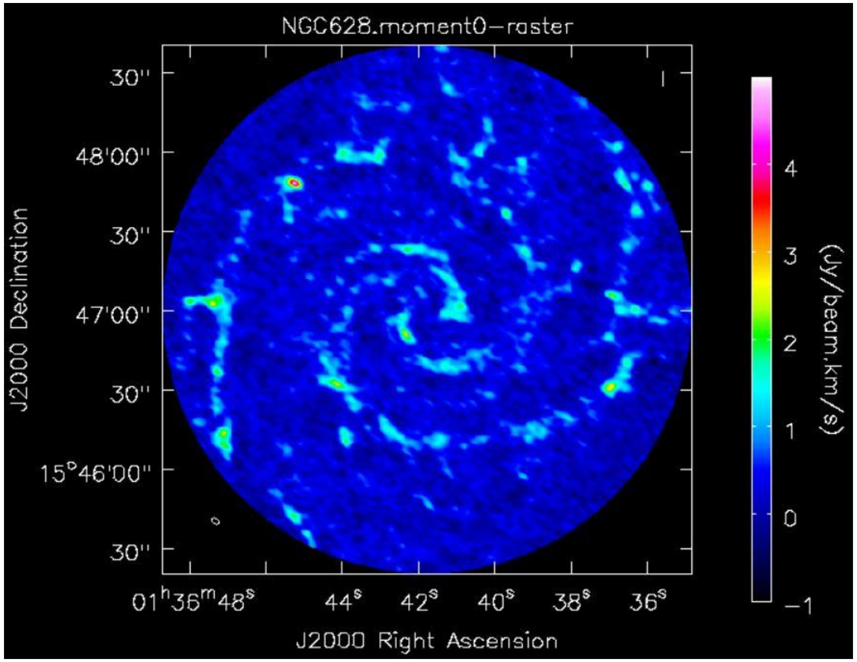
- Total Power Array
  - Resolution: $56.71'' \times 56.71''$

Moment0 Map

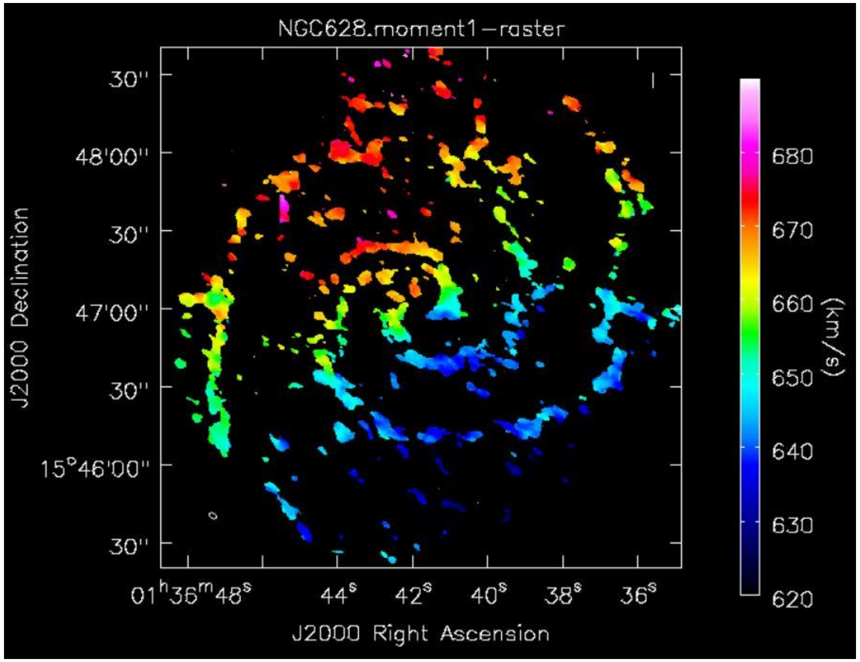


Moment0 and Moment1 Map
(12m Array & TP Array)

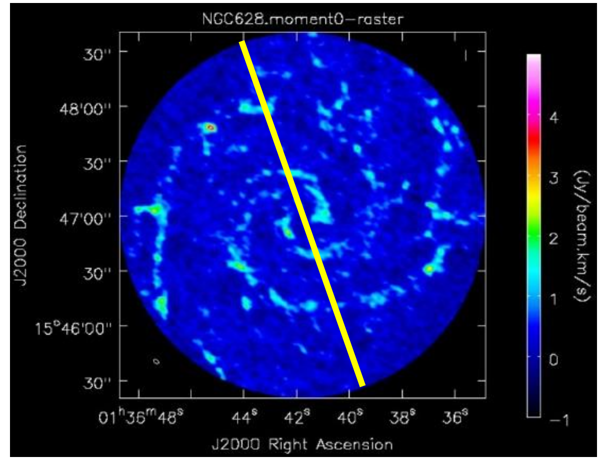
Moment0 Map



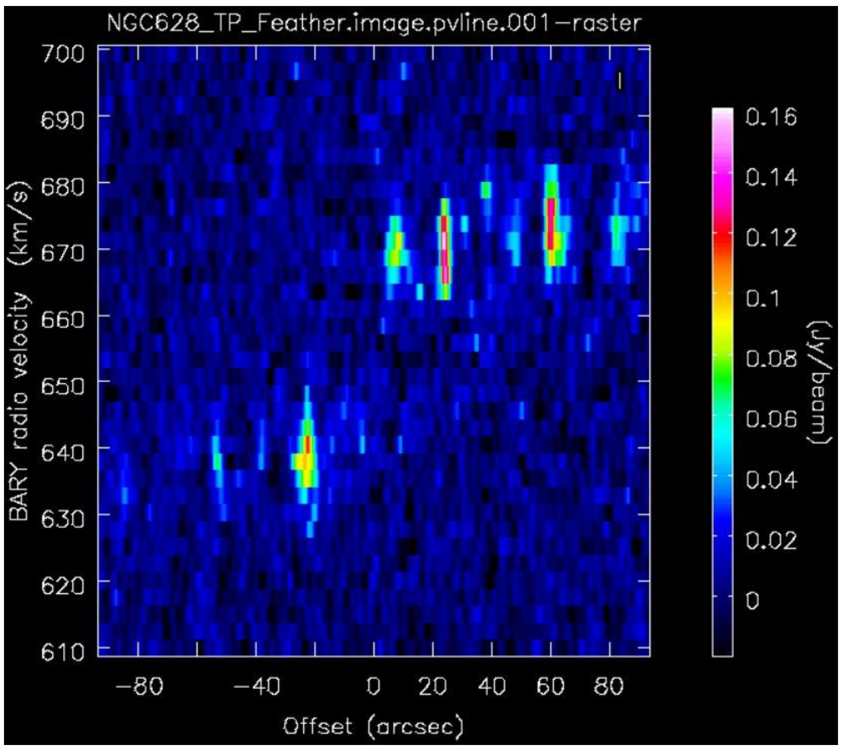
Moment1 Map

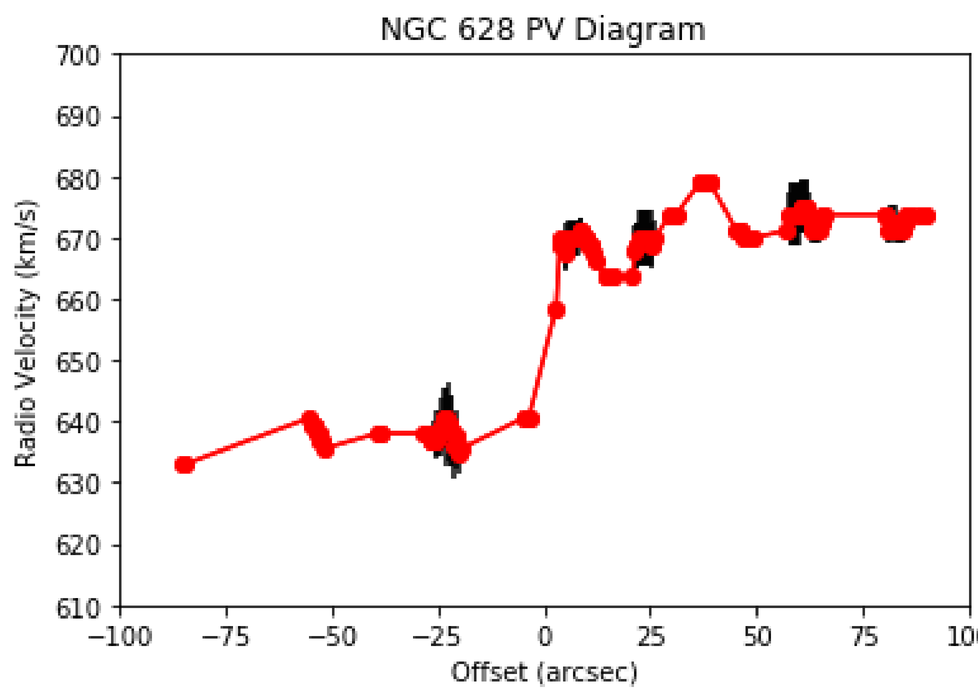


PV Diagram
(12m Array & TP Array)



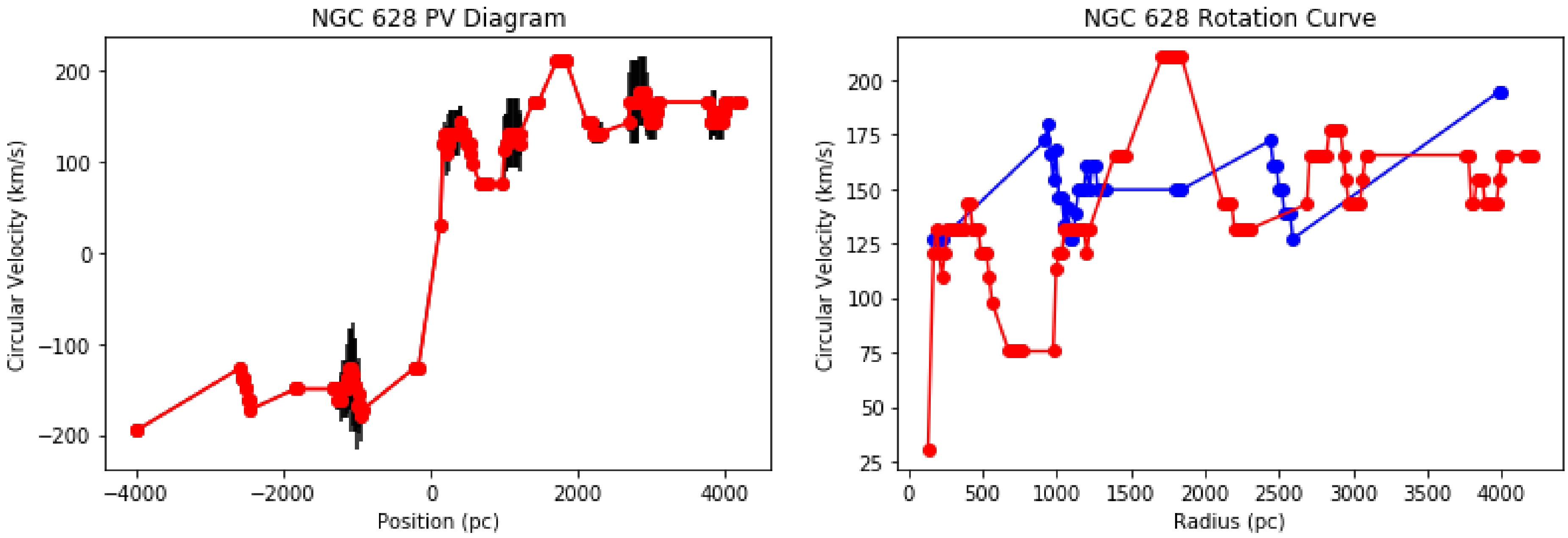
Center:
01:36:41.772
15.47.00.460
Position Angle: 19°





Select pixels with fluxdensity ≥ 0.03 Jy/beam

PV Diagram



Recessional Velocity = 655km/s
Inclination Angel = 6.5°

Select pixels with fluxdensity ≥ 0.03 Jy/beam

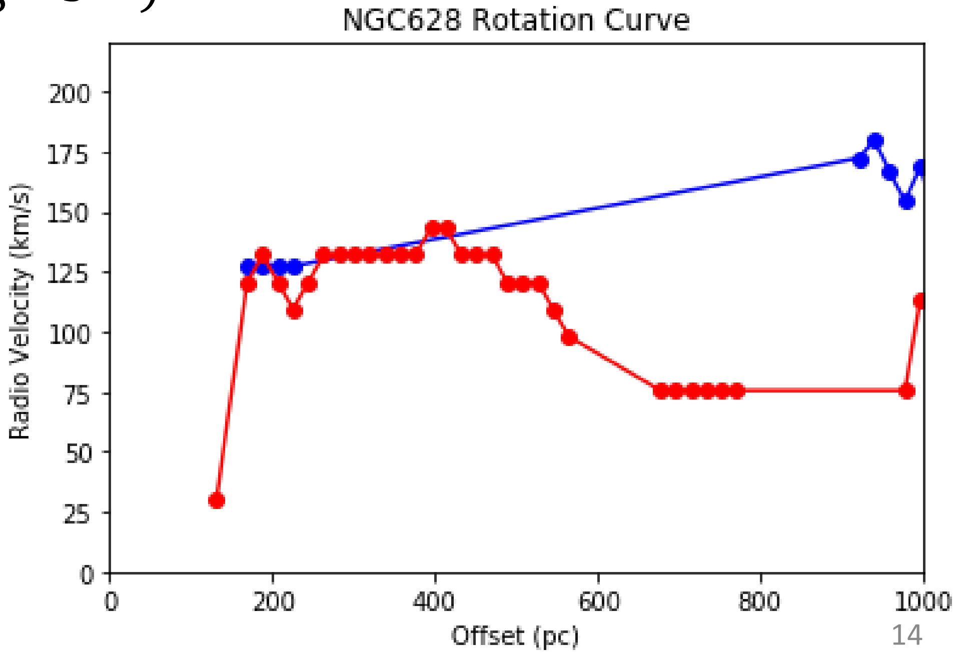
Mass Estimation In the Inner Part of NGC 628

Selected Region: Region Within 1 kpc Centered On NGC 628

Estimation of Dynamical Mass

- $M_{dyn} = \frac{{V_{circ}}^2 R}{G}$
  - $V_{circ} \approx 130$ (km/s)
  - $R = 1000$ (pc)
  - $G = 6.67 \times 10^{-11}$ ($m^3 kg^{-1} s^{-2}$)

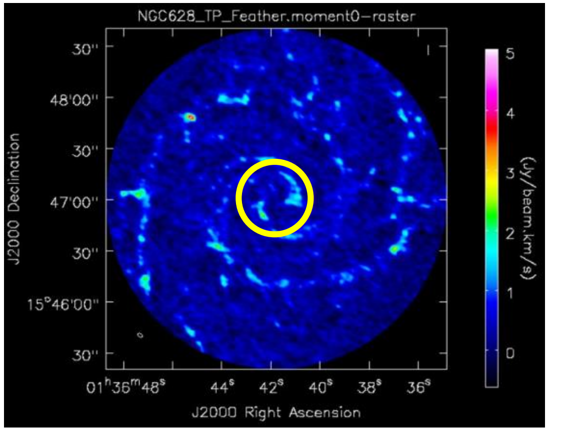
$M_{dyn} \approx 4.0 \times 10^9\ M_{\odot}$



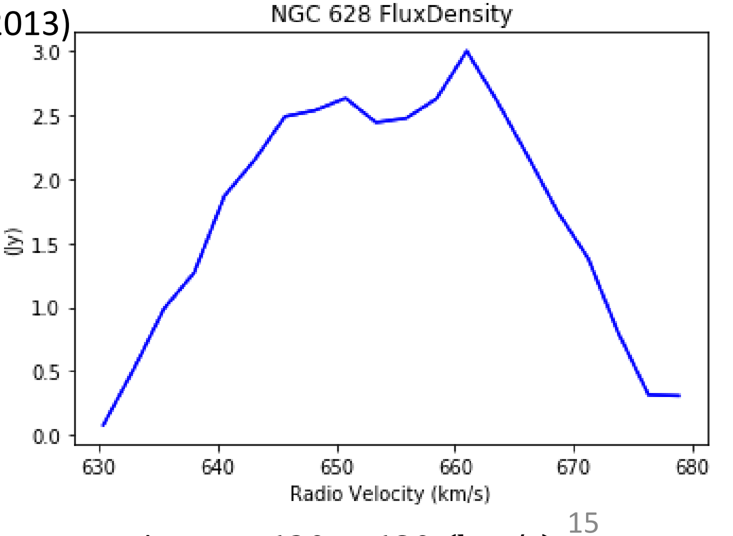
Estimation of Molecular Gas Mass

- $M_{H_2} = 1.2 \times 10^4 \times D^2 \times S_{CO(1-0)} \times \frac{X_{CO}}{3\times10^{20}}$
- $M_{mol} = 1.36 \times M_{H_2}$ (An–Li TSAI et al. 2009)

- $D \approx 9$ Mpc (Jiayi Sun, 2018)
- $S_{CO(1-0)} \approx 87.80$ (Jy km s^{-1})
- $X_{CO} = 2 \times 10^{20}$ (cm^{-2}/(K km s^{-1})) (Bolatto et al. 2013)



$$M_{mol} \approx 7.7 \times 10^7\ M_\odot$$



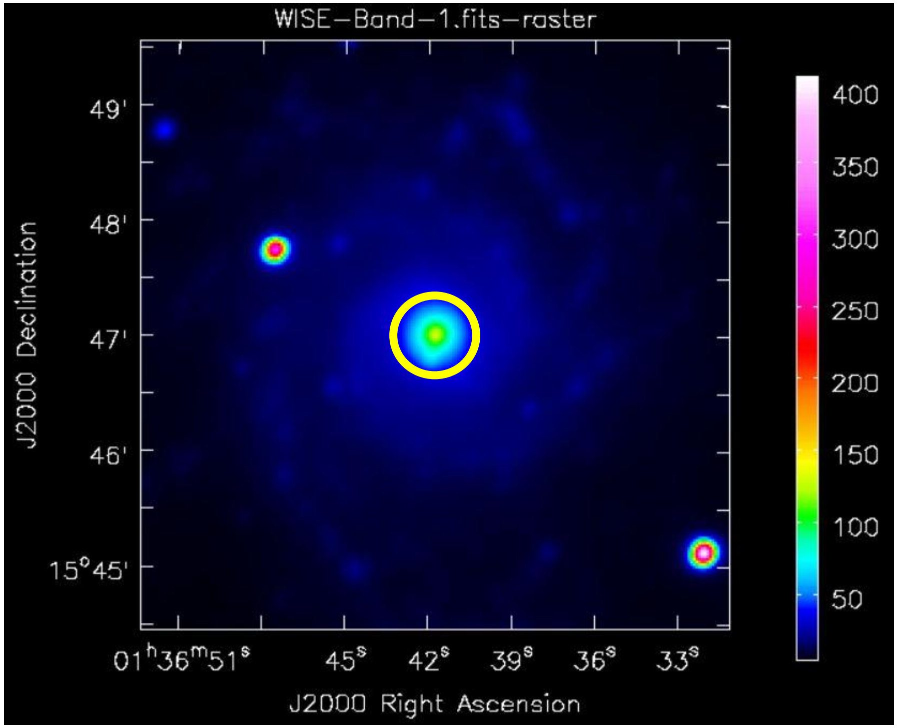
Selected area: a circle with radius 1000 pc

Integral range: 630 ~ 680 (km/s)

Estimation of Stellar Mass

- Wide-field Infrared Survey Explorer (WISE)
  - Band 1 (central frequency: 3.4 μm)
  - coadd_id: 0234p151_ac51
- DN-to-Jy conv. (Cutri et al. 2012)
  - $\mathrm{Jy/DN} = 1.935 \times 10^{-6}$
- $\log\left(\frac{M_*}{M_\odot}\right) = 1.08\log\left(\frac{\nu L_\nu}{L_\odot}\right)$
  - XQ Wen et al. (2013)

$$M_* \approx 9.3 \times 10^8\ M_\odot$$



Source: WISE data from NASA/IPAC Infrared Science Archive

Selected area: a circle with radius 1000 pc

Estimation of Black Hole Mass
(Dong & De Robertis, 2006)

- $\log(\frac{M_{BH}}{M_{\odot}}) = 6.7$

$$M_{BH} \approx 5.0 \times 10^{6}\ M_{\odot}$$

Estimation of Atomic Gas Mass
(R. Auld et al, 2018)

- Telescope
  - Arecibo L-band Feed Array (ALFA)
  - Arecibo Galaxy Environment Survey (AGES)
- Field of view
  - total region of NGC 628

$$\boxed{\mathrm{M_{HI}} \approx 9.1 \pm 0.1 \times 10^{8}\ \mathrm{M_{\odot}}}$$

Overestimated for 1 kpc

Estimation of Dust Mass

(G. Aniano et.al, 2012)

- Telescope
  - Spitzer and Herschel
- Field of view
  - a circle with radius of 9.4 kpc

$$\mathrm{M_d} \approx 2.9 \pm 0.4 \times 10^7\ \mathrm{M_\odot}$$

Overestimated for 1 kpc

Estimation of Dark Matter Mass

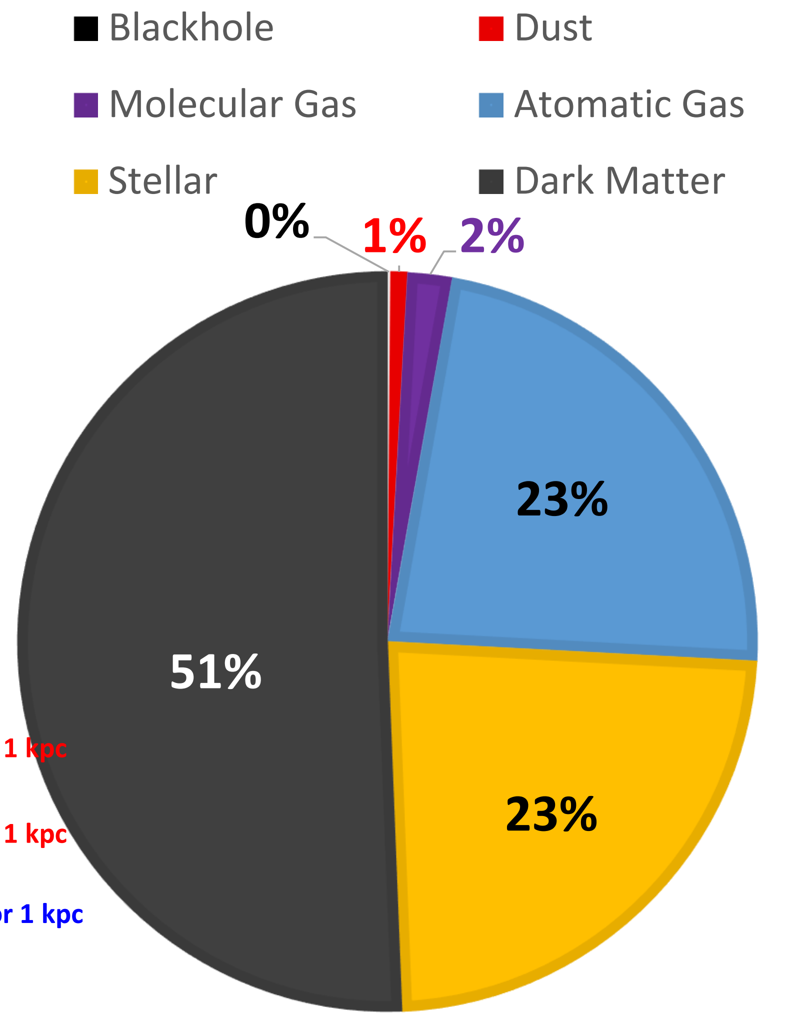
Mass Composition In 1 kpc Region of NGC 628		
$M_{dynamical}$ ($M_\odot$)	4.0×10^9	
$M_{molecular}$ ($M_\odot$)	7.7×10^7	
$M_{stellar}$ ($M_\odot$)	9.3×10^8	
$M_{black\ hole}$ ($M_\odot$)	5.0×10^6	
M_{atomic} ($M_\odot$)	9.1×10^8	Overestimated for 1 kpc
M_{dust} ($M_\odot$)	2.9×10^7	Overestimated for 1 kpc
$M_{dark\ matter}$ ($M_\odot$)	2.1×10^9	Underestimated for 1 kpc

$$M_{dynamical} = M_{molecular} + M_{stellar} + M_{black\ hole} + M_{atomic} + M_{dust} + M_{dark\ matter}$$

Summary

Mass Composition In 1 kpc Region of NGC 628	
$M_{dynamical}$ $(M_\odot)$	4.0×10^9
$M_{molecular}$ $(M_\odot)$	7.7×10^7
$M_{stellar}$ $(M_\odot)$	9.3×10^8
$M_{black\ hole}$ $(M_\odot)$	5.0×10^6
M_{atomic} $(M_\odot)$	9.1×10^8 Overestimated for 1 kpc
M_{dust} $(M_\odot)$	2.9×10^7 Overestimated for 1 kpc
$M_{dark\ matter}$ $(M_\odot)$	2.1×10^9 Underestimated for 1 kpc

NGC 628 MASS COMPOSITION IN 1000 PC



$$M_{dynamical} = M_{molecular} + M_{stellar} + M_{black\ hole} + M_{atomic} + M_{dust} + M_{dark\ matter}$$

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Thanks For Your Listening.