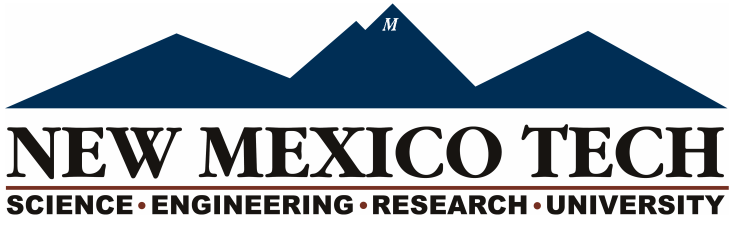
Dynamical Characterization of the First Galaxies

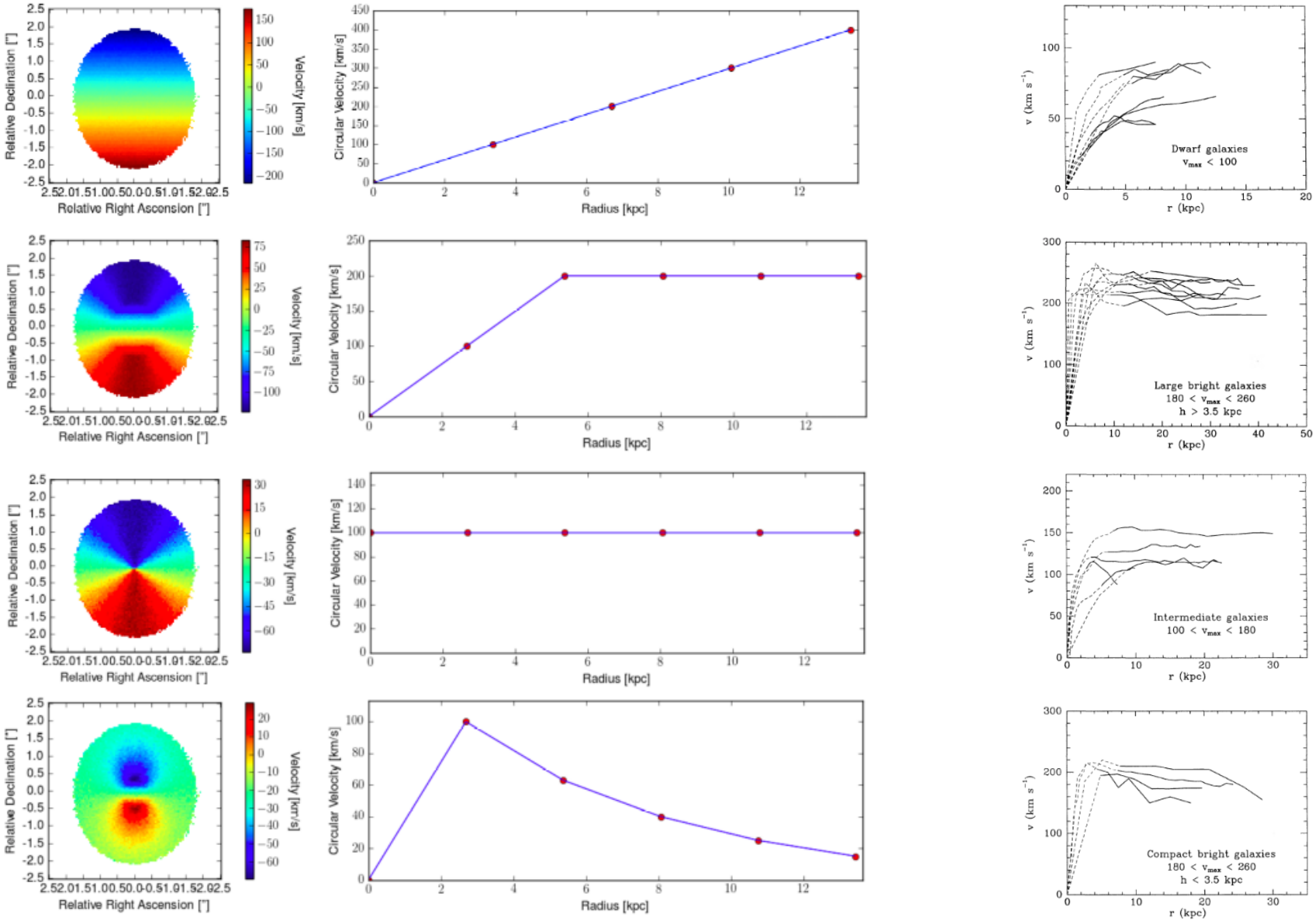
G. Jones[1,2], C. Carilli[2]

[1]NMT [2]NRAO

New Mexico Symposium, 2016



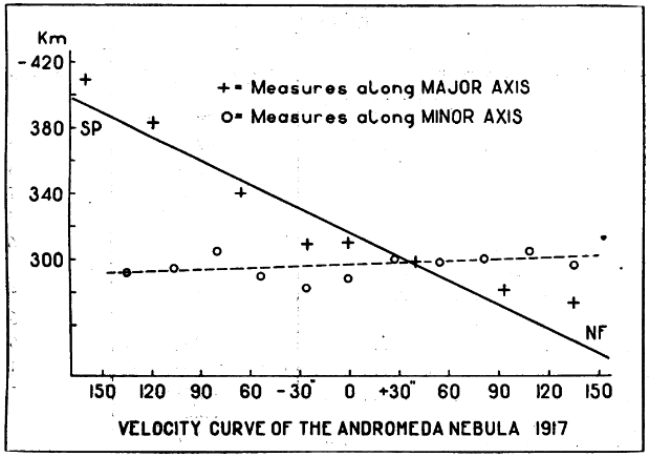
Velocity Fields & Rotation Curves



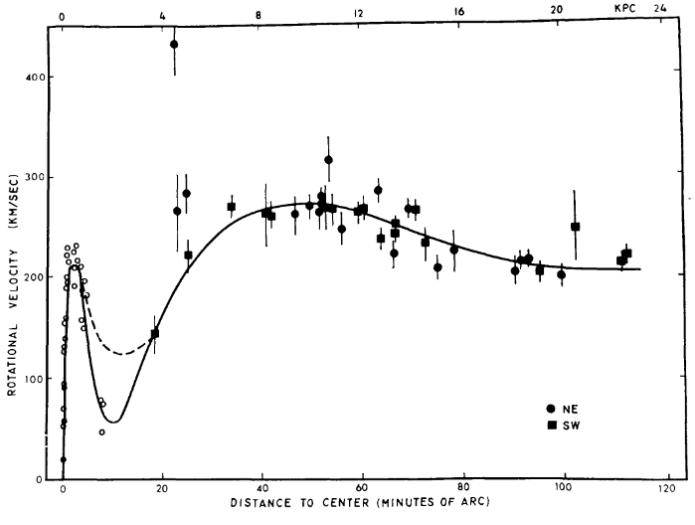
Casertano & van Gorkom (1991)

Past Work

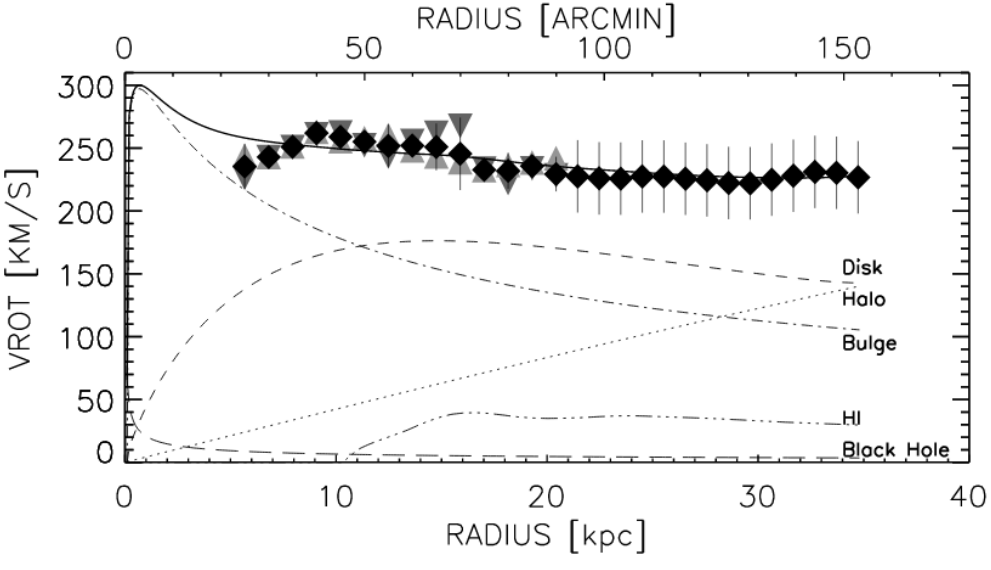
Pease (1918)



Line	Spatial Extent	Traces
HI	Large	Atomic
Hα	Compact	Ionized
CO	Medium	H_2
[CII]	Medium	Varied

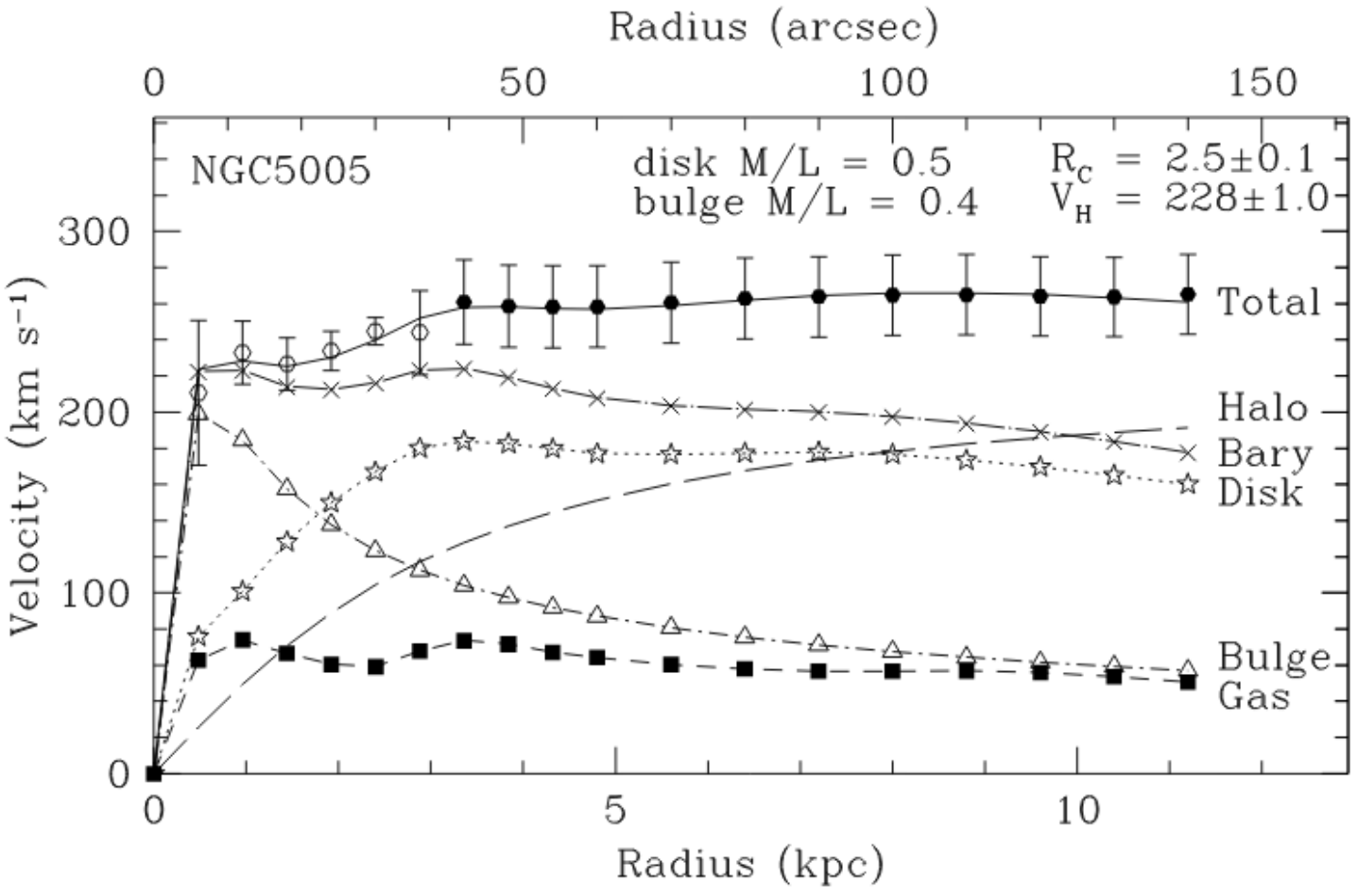


Rubin & Ford (1970)



Carignan et al. (2005)

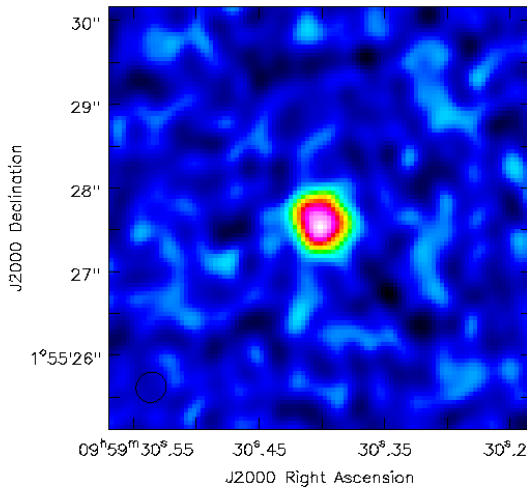
Rotation Curve Decomposition

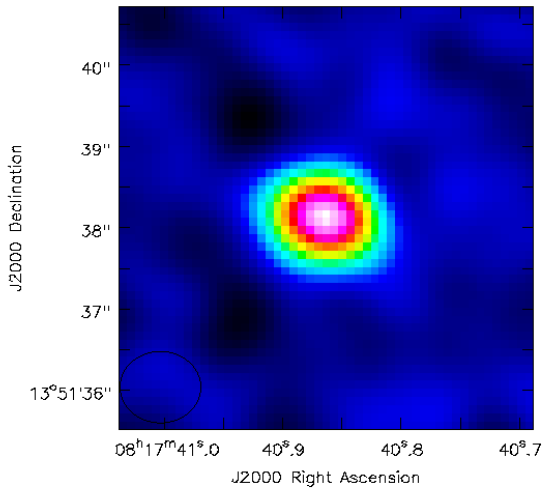


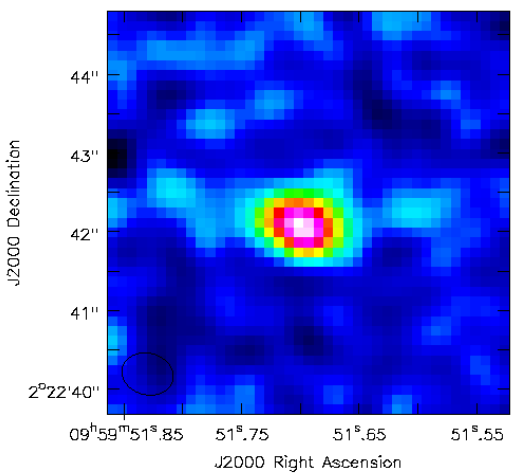
Richards et al. (2015)

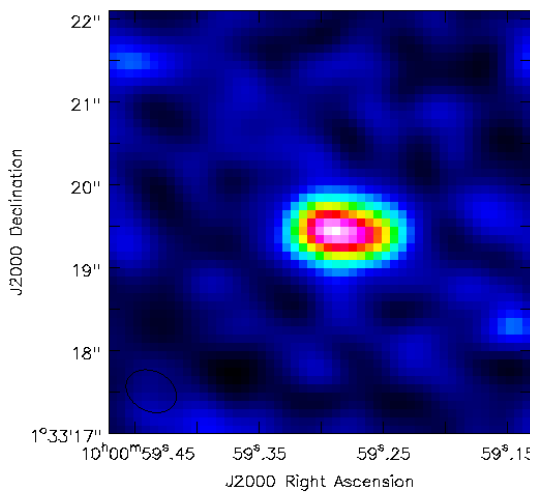
Overview

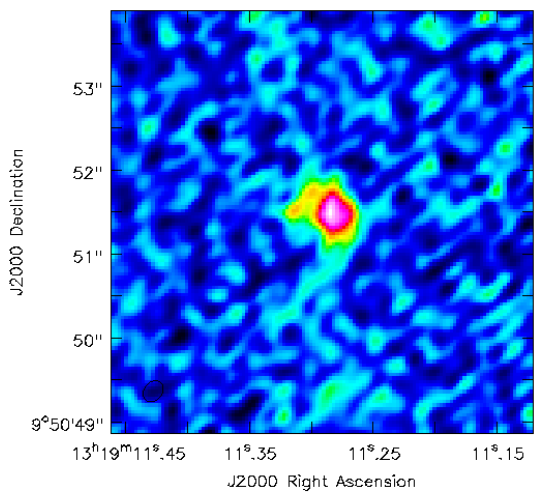
- Five Observations of [CII] with ALMA
- Cubes $\rightarrow$ velocity fields
- Tilted ring fitting
- Mass profiles and rotation curves











Sources

'Normal' Galaxies

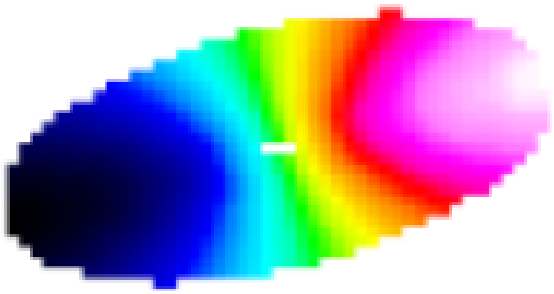
- HZ9 ($z = 5.54$) - LBG
  - Capak et al. (2015)
- HZ10 ($z = 5.65$) - LBG
  - Capak et al. (2015)
- ALMAJ0817-1351 (z=4.26) - DLA Host Galaxy
  - Neeleman et al. (in prep)

Starbursts

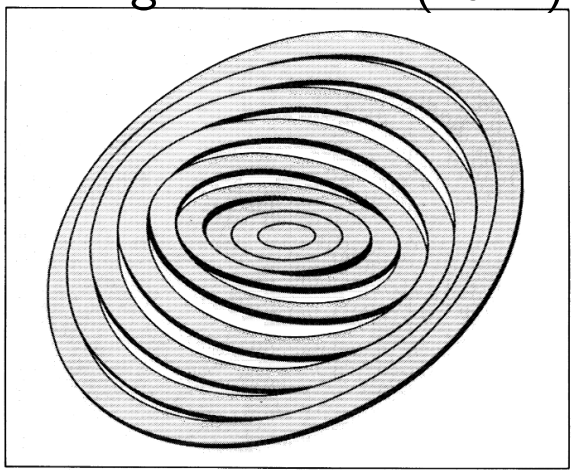
- ULAS J1319+0950 ($z = 6.13$) - QSO Host Galaxy
  - Shao et al. (in prep)
- AzTEC/C159 ($z = 4.56$) - SMG
  - Karim et al. (in prep)

General Approach

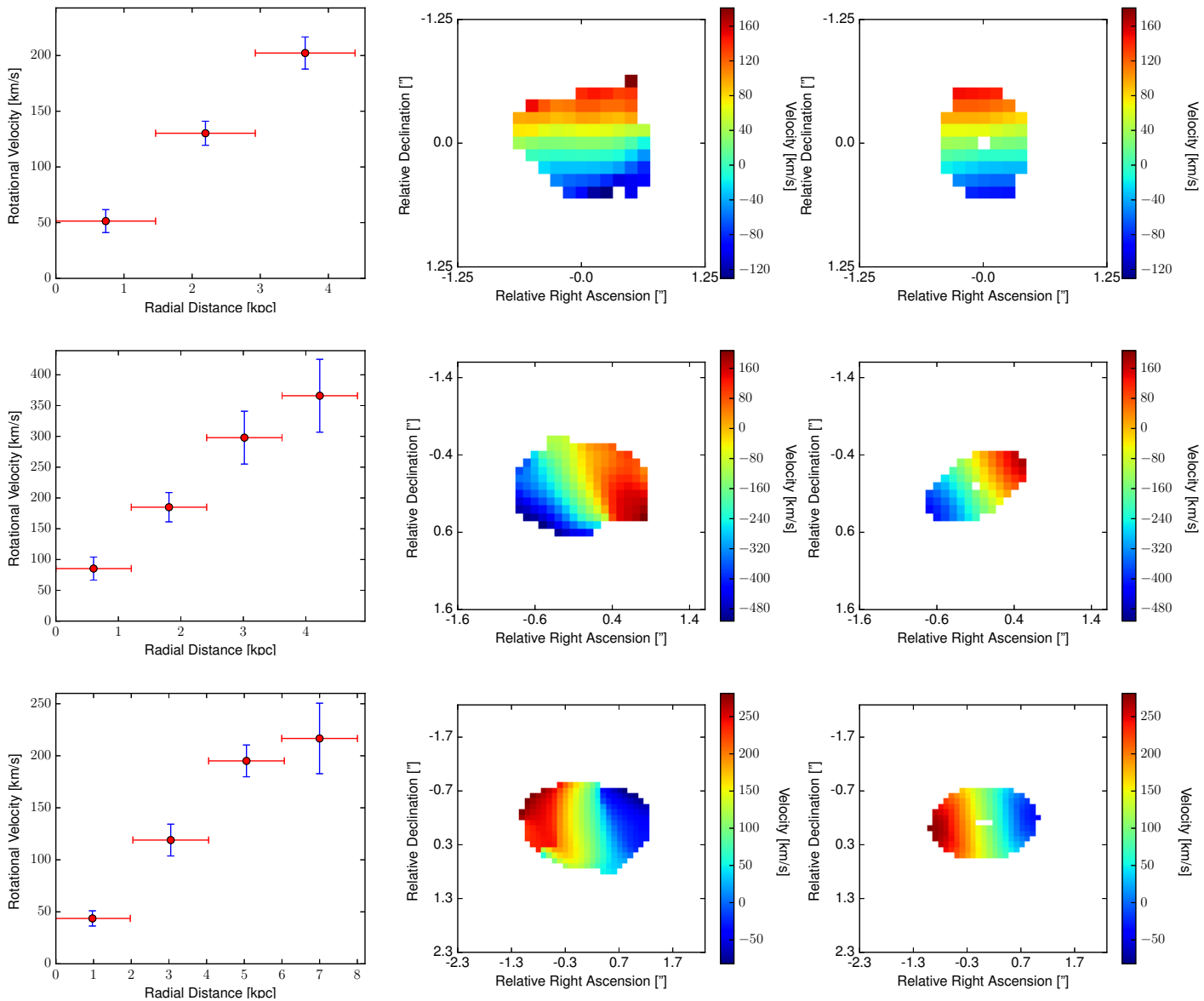
- AIPS XGAUS
  - ALMA [CII] data cube $\rightarrow$ velocity field
- GIPSY ROTCUR
  - Fits rings of radius R_i, width W
    - x_0, y_0, v_{sys}, position angle, inclination, v_c
  - Explored effects of initial estimates, ring widths
  - Produced rotation curves, physical parameters, mass profiles



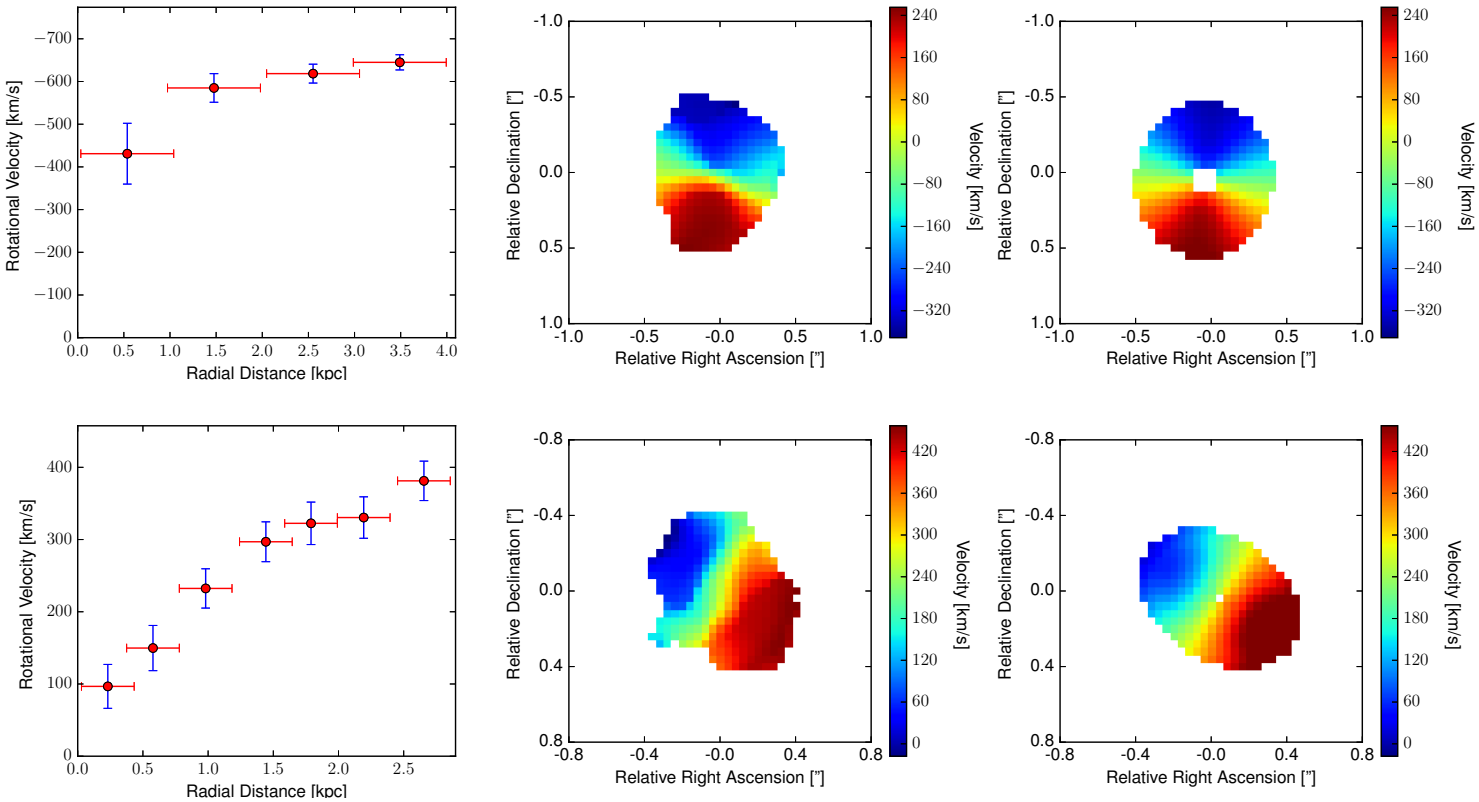
Rogstad et al. (1974)



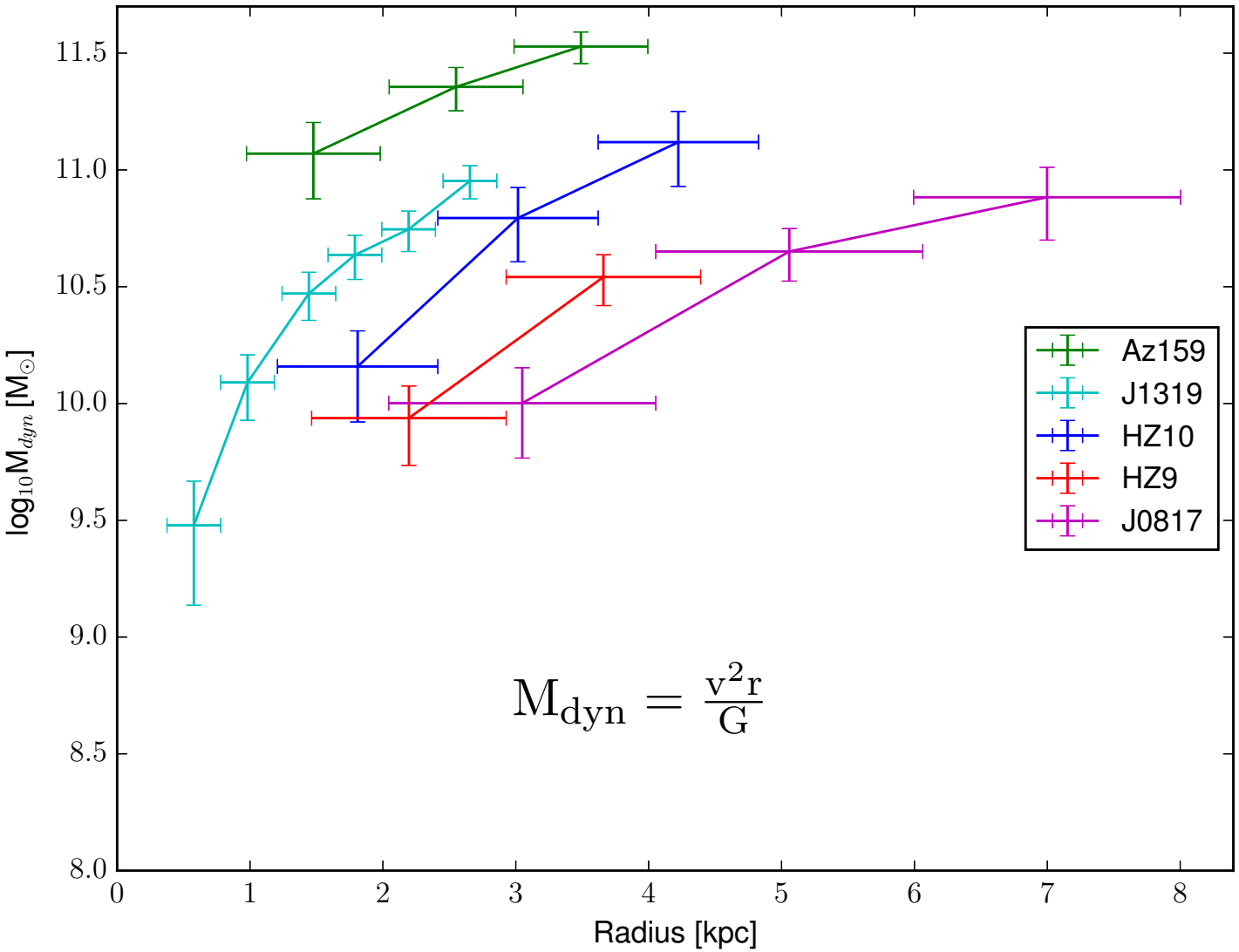
Rotation Curves



Rotation Curves



Mass Profiles

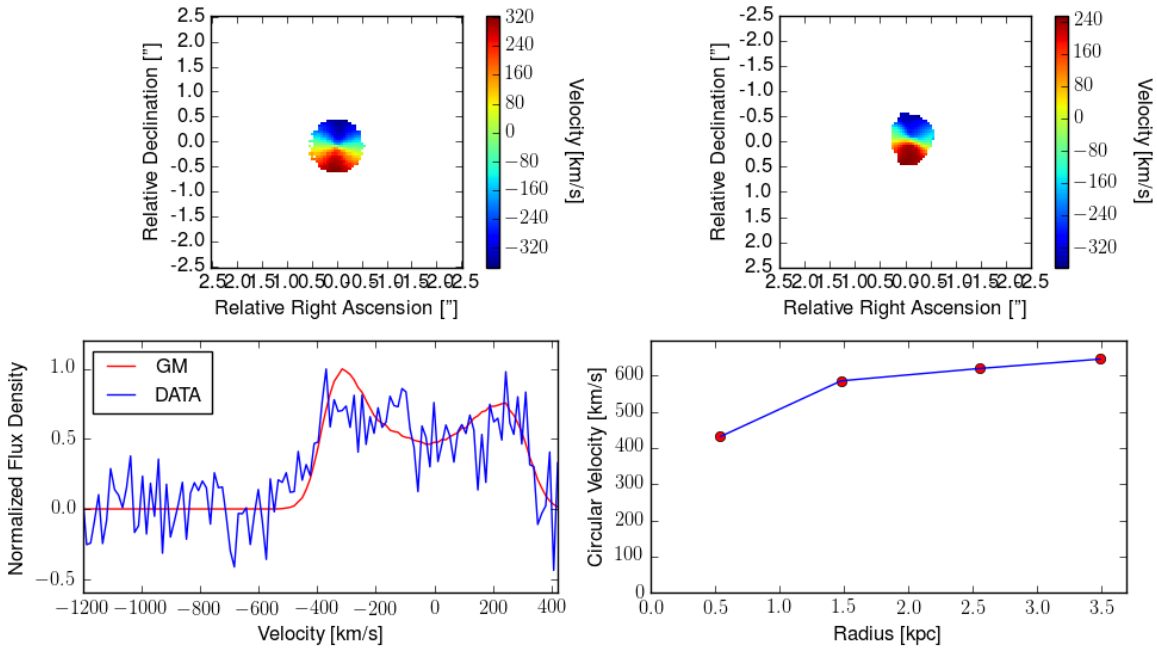


AzTEC/C159 Dark Matter

- $\mathrm{M_{dyn}} = \mathrm{M_{star}} + \mathrm{M_{gas}} + \mathrm{M_{dust}} + \mathrm{M_{DM}} + \cdots$
  - $\mathrm{M_{dyn}} = 10^{11.5 \pm 0.1}\,\mathrm{M_\odot}$
  - $\mathrm{M_{star}} = 10^{11.0}\,\mathrm{M_\odot}$ (Smolcic et al. 2015)
  - $\mathrm{M_{H_2}} = 10^{10.0}\,\mathrm{M_\odot}$ (Jiménez-Andrade et al., in prep)
  - $\mathrm{M_{dust}} = 10^{9}\,\mathrm{M_\odot}$ (Smolcic et al. 2015)
- So $\mathrm{M_{DM}} \lesssim 10^{11}\,\mathrm{M_\odot}$

Future Work

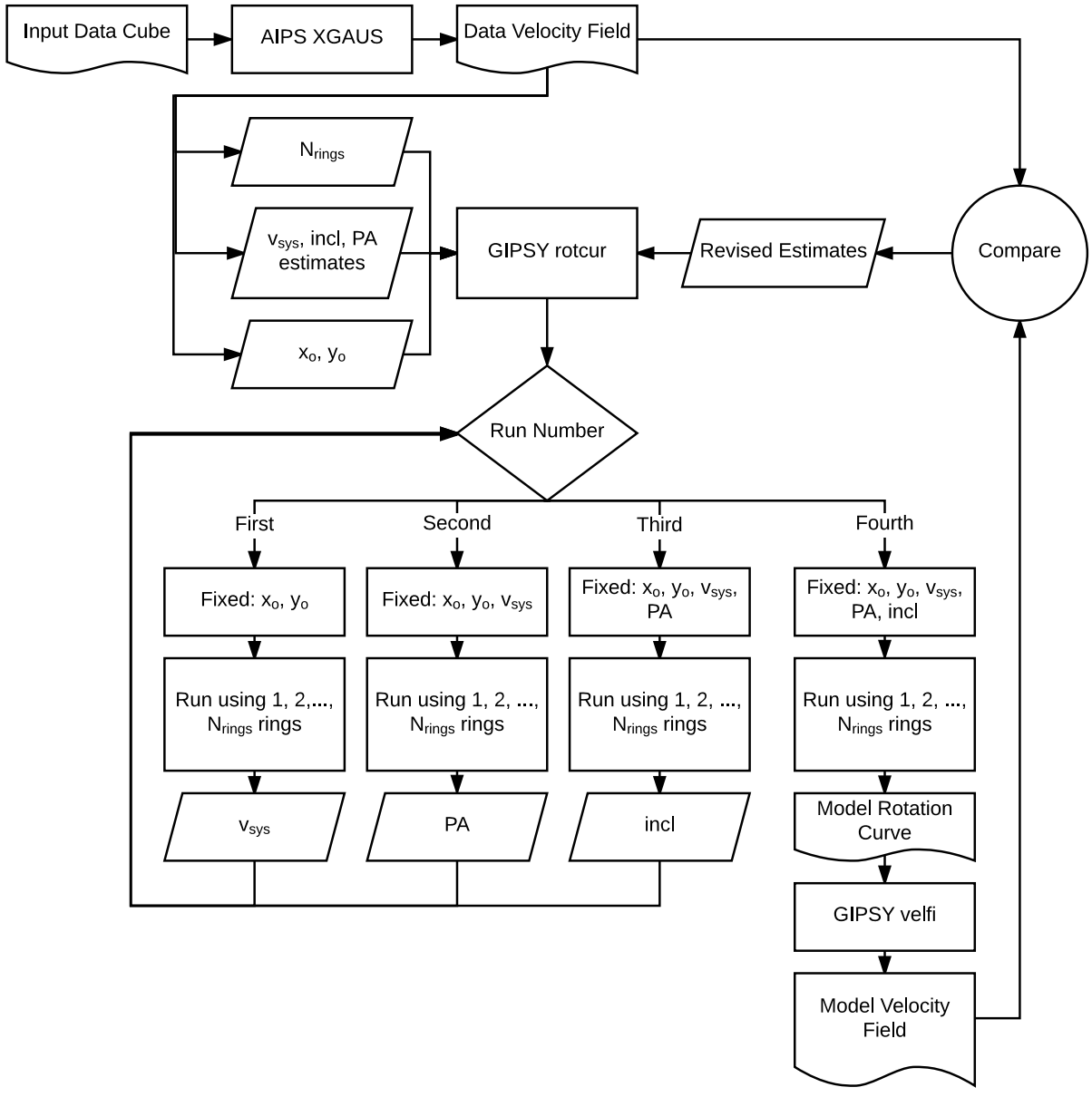
- Fit tilted rings to entire cube (Galmod)
  - z0, $\rho(r)$, beam smearing



Conclusions

- Fitted models to galaxies at $t_0 < 1.5\,\mathrm{Gyr}$
- Evidence for dark matter in AzTEC/C159
- Will expand to fitting full data cubes

Iterative ROTCUR Approach



Fitting Results

Source		z_{fit}	Position Angle [°]	Inclination [°]	RA	Dec	R_{max} [kpc]	v_{max} [km s^{-1}]
HZ9	RC1	5.5415(1)	11 ± 4	60 ± 8	9h59m51.701(8)s	$+02°22'42.1(1)''$		
	GAUS	5.5410(1)	84 ± 11	45 ± 9	9h59m51.685(8)s	$+02°22'42.1(1)''$		
	RC2	5.5417(3)	5 ± 6	42 ± 1	9h59m51.685(8)s	$+02°22'42.1(1)''$	3.7 ± 0.7	200 ± 15
HZ10	RC1	5.6533(3)	294 ± 5	62 ± 12	10h0m59.314(7)s	$+01°33'19.4(1)''$		
	GAUS	5.6541(5)	273 ± 4	70 ± 5	10h0m59.321(7)s	$+01°33'19.4(1)''$		
	RC2	5.6539(6)	300 ± 8	57 ± 6	10h0m59.314(7)s	$+01°33'19.4(1)''$	4.2 ± 0.6	365 ± 60
J1319	RC1	6.134(2)	244 ± 4	61 ± 10	13h19m11.293(3)s	$+09°50'51.40(4)''$		
	GAUS	6.134(2)	233 ± 11	53 ± 9	13h19m11.295(3)s	$+09°50'51.40(4)''$		
	RC2	6.134(2)	239 ± 1	44 ± 5	13h19m11.295(3)s	$+09°50'51.40(4)''$	2.7 ± 0.2	380 ± 30
Az159	RC1	4.5666(8)	354 ± 3	33 ± 11	9h59m30.415(3)s	$+01°55'27.54(5)''$		
	GAUS	4.5664(3)	27 ± 45	31 ± 21	9h59m30.415(3)s	$+01°55'27.59(5)''$		
	RC2	4.5662(3)	354 ± 1	28 ± 5	9h59m30.415(3)s	$+01°55'27.54(5)''$	3.5 ± 0.5	645 ± 20
J0817	RC1	4.260(1)	89 ± 9	44 ± 9	8h17m40.847(7)s	$+13°51'38.3(1)''$		
	GAUS	4.260(1)	62 ± 15	60 ± 23	8h17m40.854(7)s	$+13°51'38.2(1)''$		
	RC2	4.261(1)	98 ± 1	47 ± 2	8h17m40.854(7)s	$+13°51'38.2(1)''$	7 ± 1	220 ± 35

Assumptions

- $v_{exp} = 0$
- No warps
- Ring width=FWHM(minor axis of synthesized beam)/(2 – 3)

- Initial estimates from:
  - Gaussian fits
  - Early fitting results

$$V(x, y) = v_{sys} + v_c(r)\sin(incl)\cos(\theta) \quad (1)$$

$$\cos(\theta) = \frac{-(x - x_o)\sin(\phi) + (y - y_o)\cos(\phi)}{R} \quad (2)$$