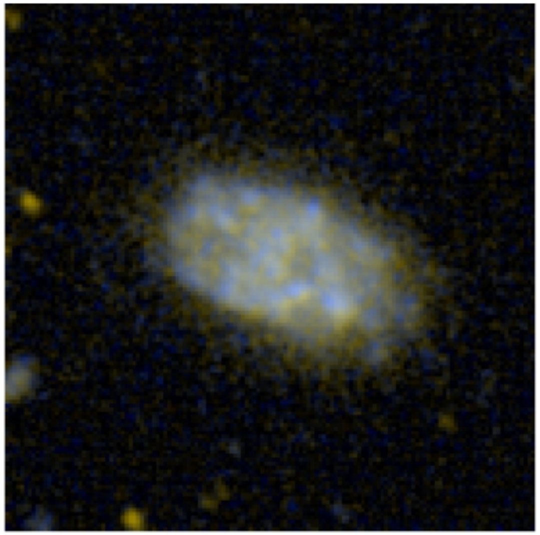
Cusped models not ruled out (in late type dwarfs)

Joshua J. Adams

Carnegie Observatories

April 13, 2012, Ringberg



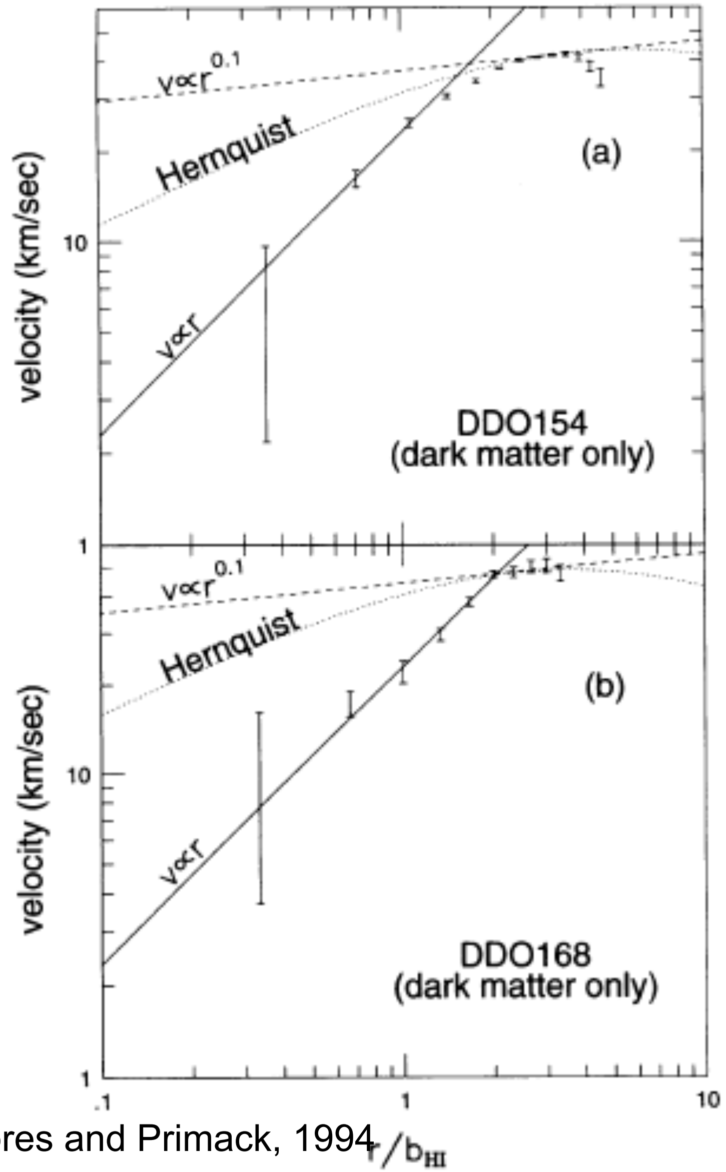
Project Collaborators:

Josh Simon, Karl Gebhardt, Guillermo A. Blanc, Maximilian H. Fabricius, Gary J. Hill, Jeremy D. Murphy, Remco C. E. van den Bosch, Glenn van de Ven

Talk Outline

- Short summary of past observational work
- Recent theoretical work
- The case of NGC 2976
- Preview of seven more late-type dwarfs

Work using gas tracers



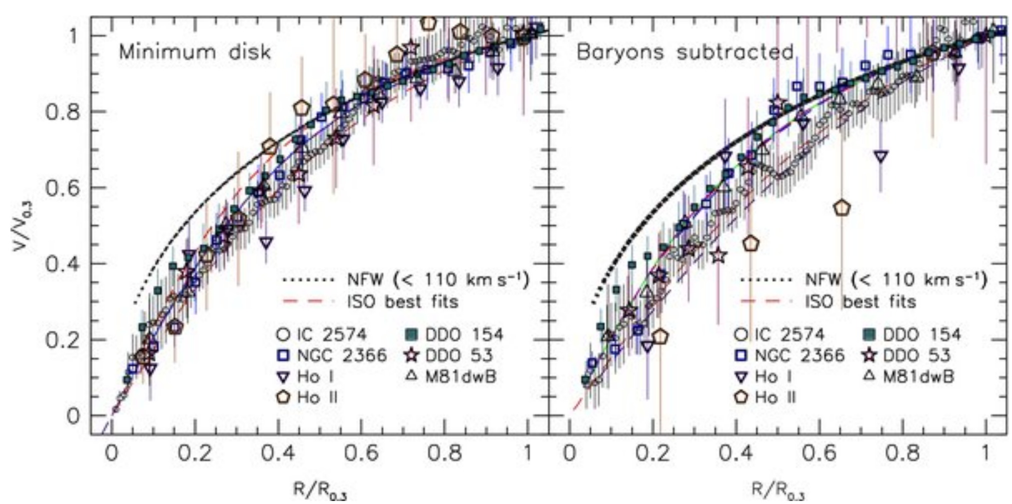
Flores and Primack, 1994

TABLE 3

LIMITS ON DARK MATTER DENSITY PROFILE SLOPES

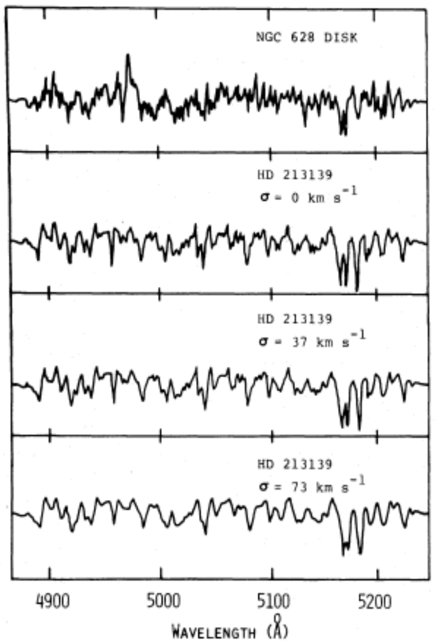
Galaxy	Maximum Disk α_{DM}	Minimum Disk α_{DM}
NGC 2976...........	0.01 ± 0.13	0.27 ± 0.09
NGC 4605...........	0.71 ± 0.06	0.90 ± 0.02
NGC 5949...........	0.79 ± 0.17	0.93 ± 0.04
NGC 5963...........	0.75 ± 0.10	1.41 ± 0.03
NGC 6689...........	0.43 ± 0.18	1.07 ± 0.06

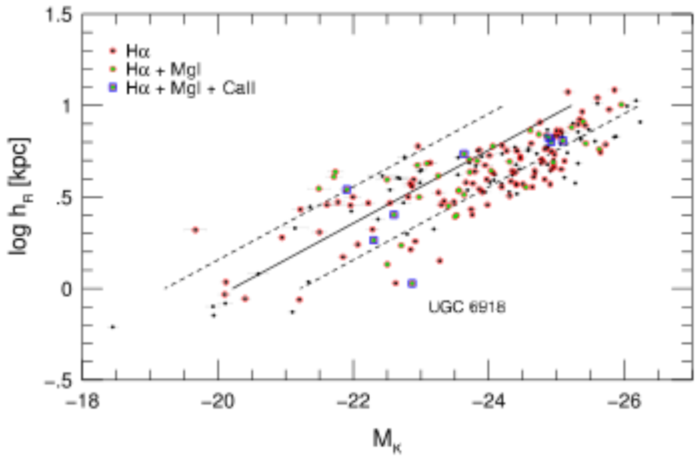
Simon et al., 2005

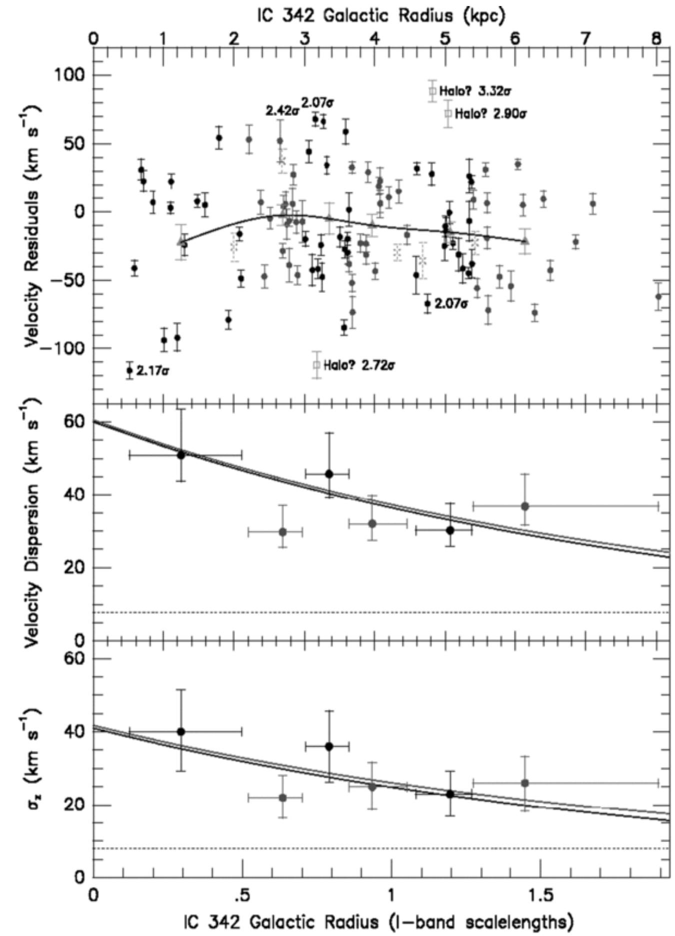


Oh et al., 2011a

Collisionless kinematic tracers







van der Kruit and Freeman, 1984

Bershady et al., 2010

Hermann and Ciardullo, 2009

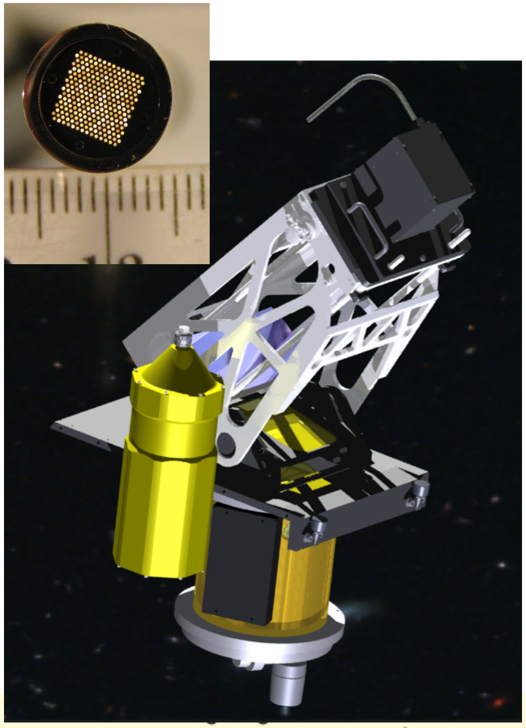
Most work uses the vertical isothermal sheet equilibrium equation to decompose the DM and baryons:

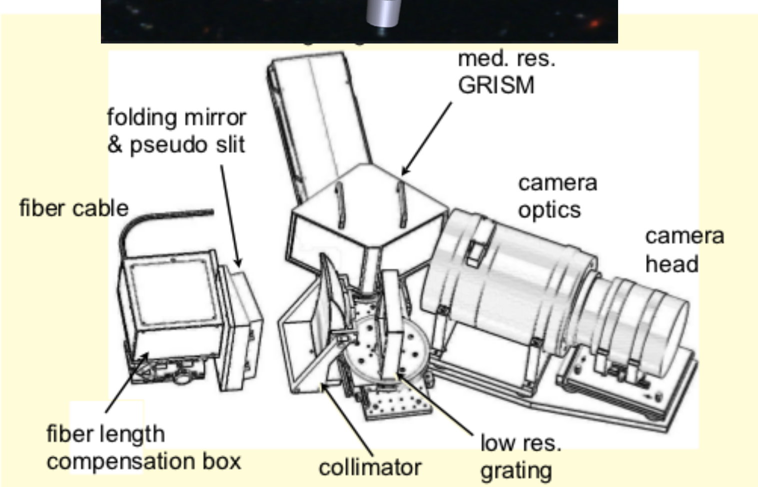
$\sigma_z^2(R)=KG\Sigma(R)h_z$

New SNe feedback simulations

Governato et al., 2009

VIRUS-P and VIRUS-W Properties

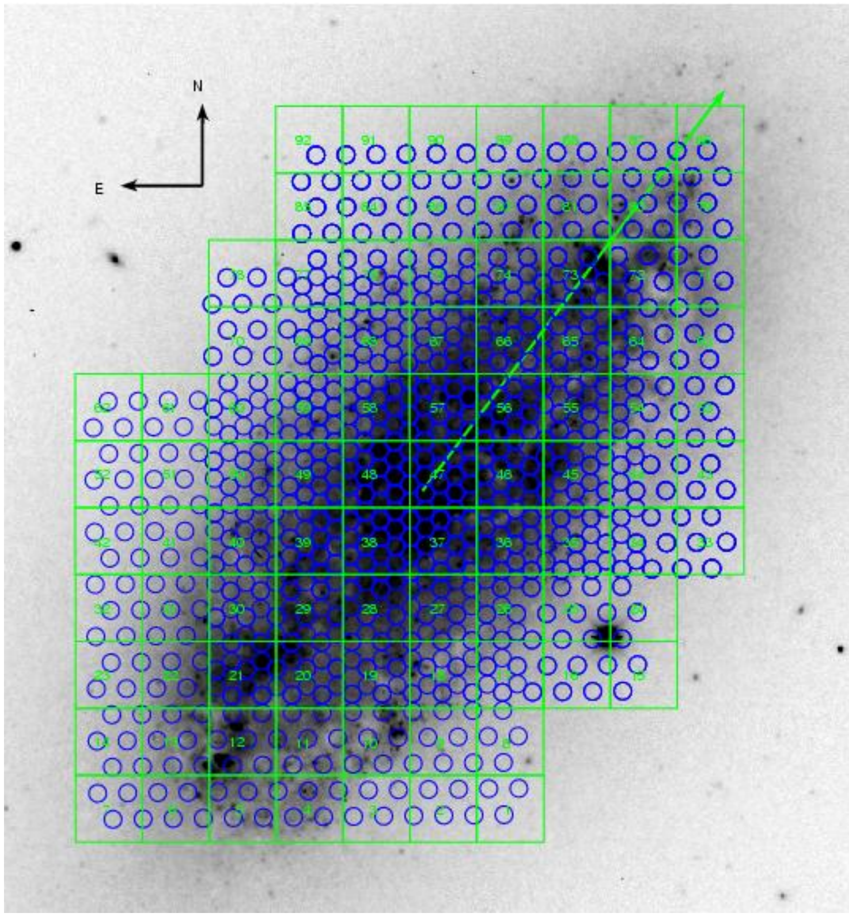




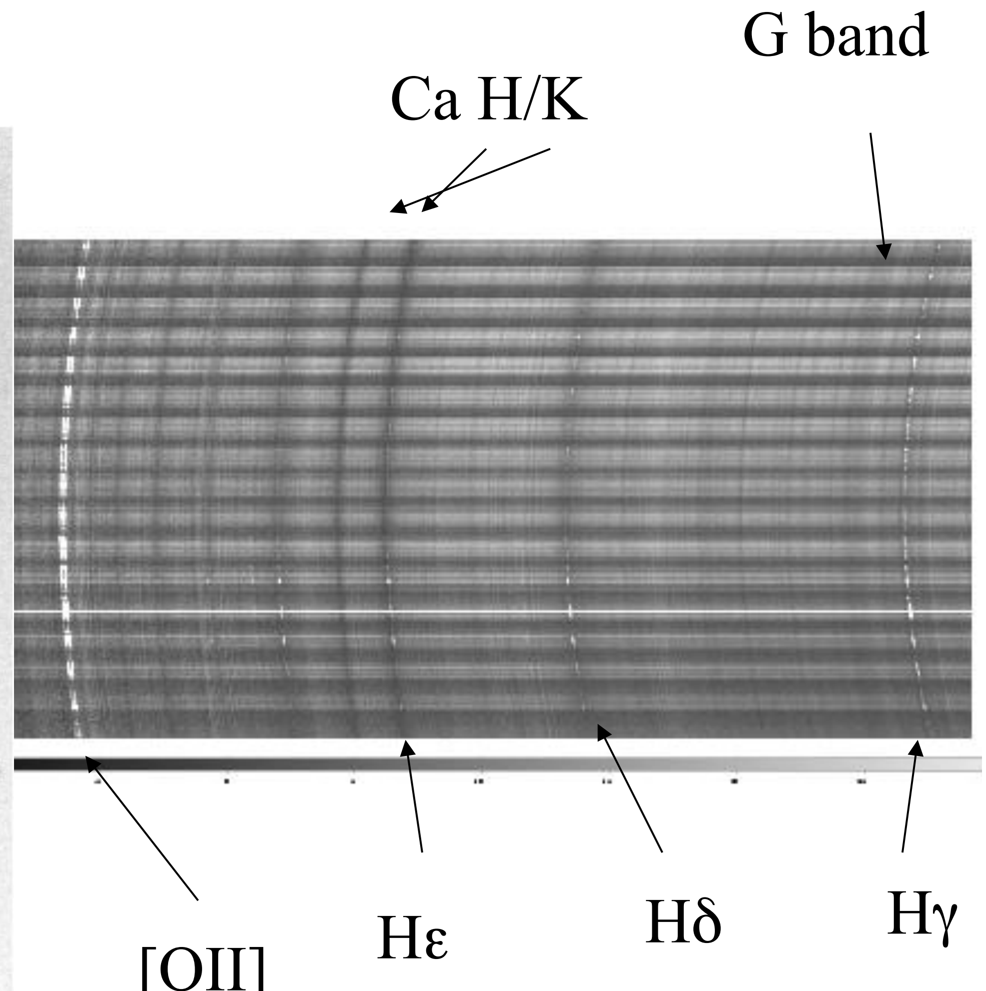
- VIRUS Prototype IFU
  - 1.'6x1.'6 FOV at HJST
  - Largest FOV of any existing IFU
  - 4.2" diameter fibers on sky
  - 3680-4400Å
  - R~2400 (σ_{inst}~50 km/s)

- VIRUS Wendelstein IFU
  - Made by Maximilian Fabricius (MPE)
  - 0.'9x1.'8 FOV at HJST
  - 3.1" diameter fibers
  - 4800-5400Å
  - R~8300 (σ_{inst}~18 km/s)

VIRUS-P data

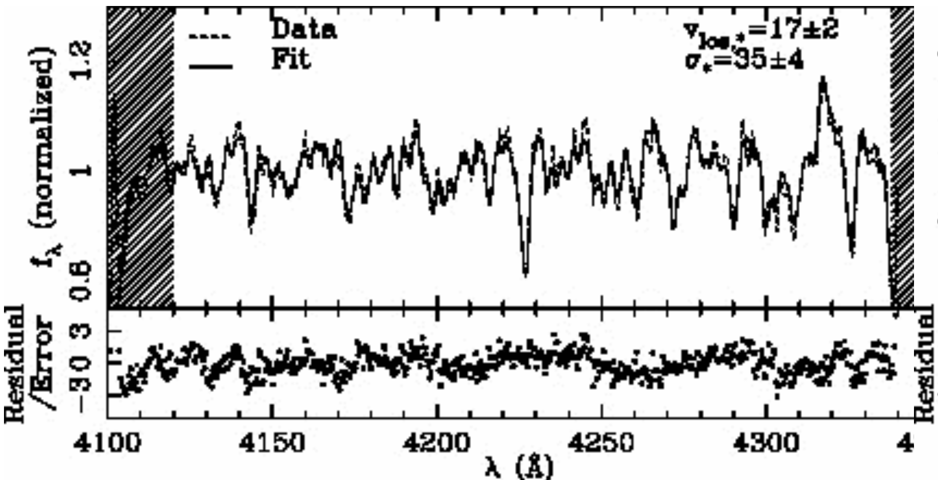


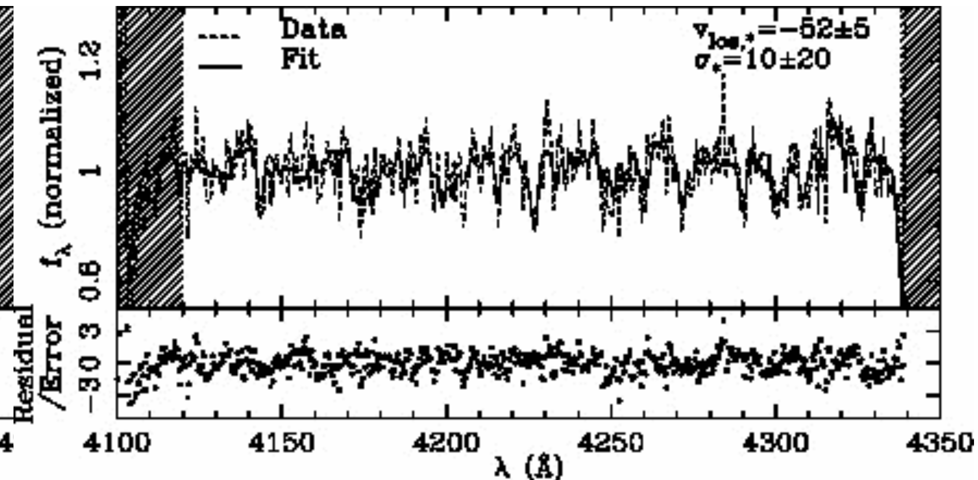
arrow=120” (2 kpc)

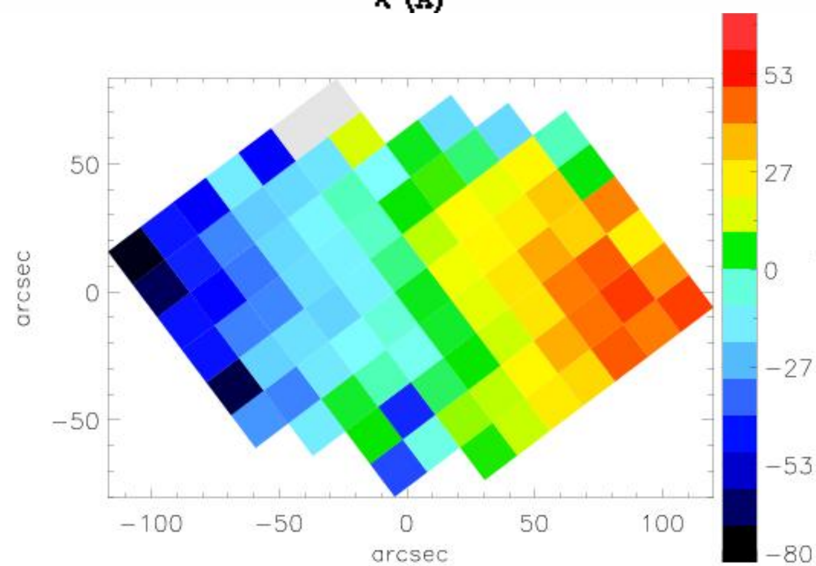


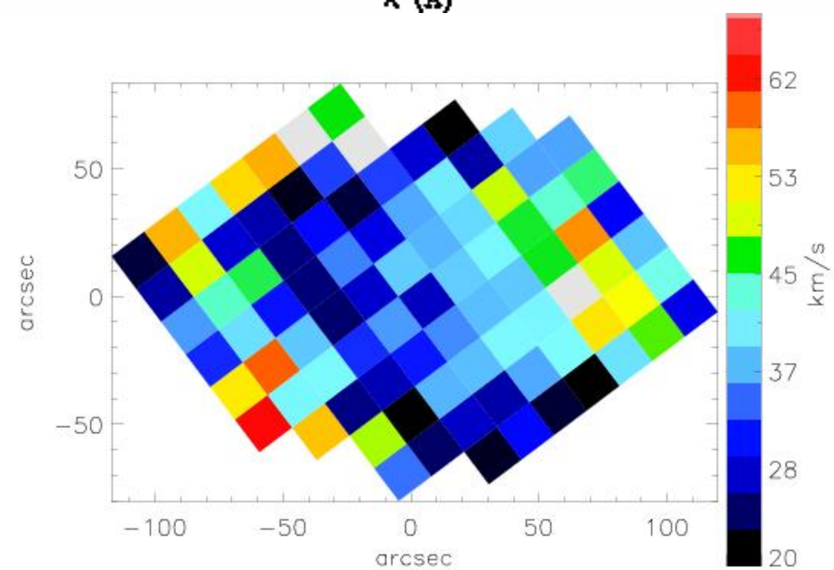
18 non-photometric hours

Data on NGC 2976









Adams et al., 2012

V_{los} map

σ map

Modeling parameters

Multiple Gaussian Expansion (MGE) and Jeans Anisotropic Modeling (JAM) by Cappellari

Fit power law for DM in NGC 2976. For new data am fitting full, generalized NFW.

Four well determined parameters fixed: α_0, δ_0, V_{sys}, d

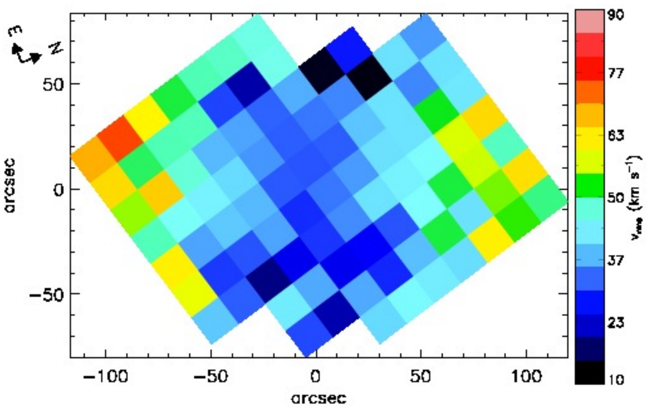
Five (or six) parameters fit: $\Upsilon_{*,R}$, i, β_z, α, ρ_0 (or M_{200}, c_{200})

Assuming: spherical DM halo, axisymmetry in baryons, cylindrical velocity ellipsoid coordinates

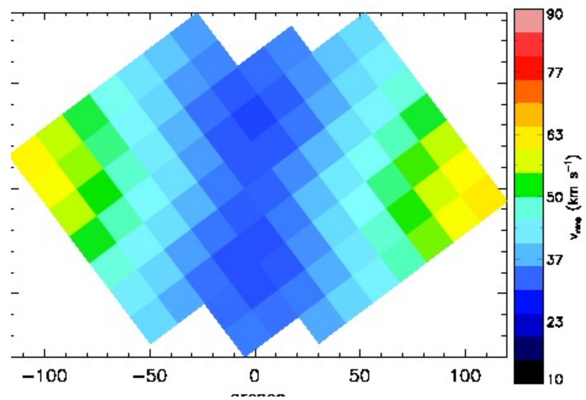
$$\frac{\rho(r)}{\rho_{crit}} = \frac{\delta_c}{(r/r_s)^{\alpha}(1+r/r_s)^{3-\alpha}}$$

JAM models and mass profiles

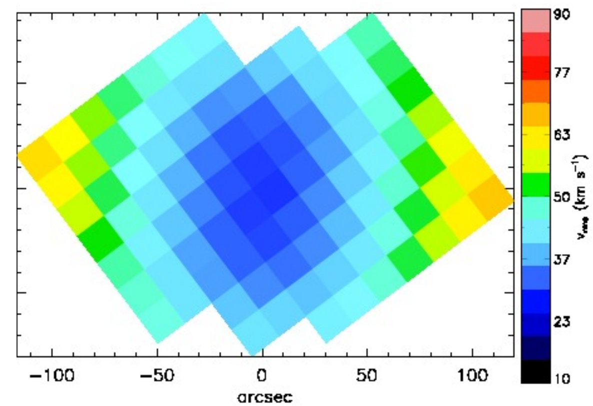
Data 2nd moment velocities

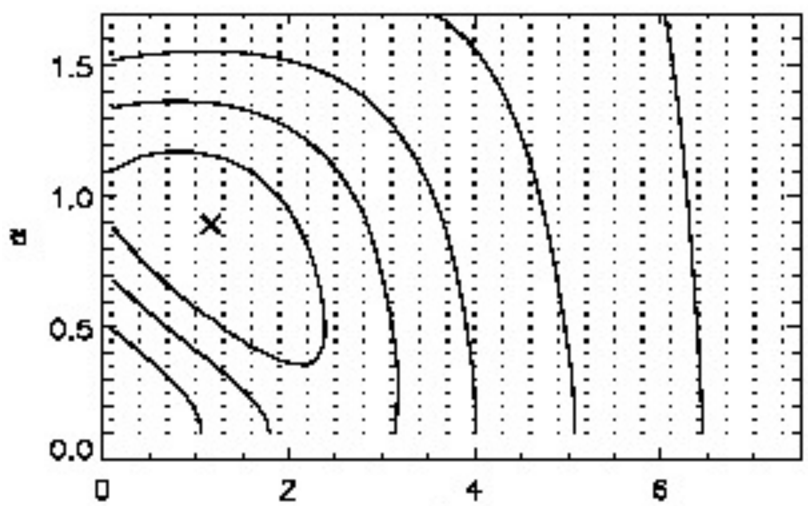


Best cuspy model



Best DM dominated,core model

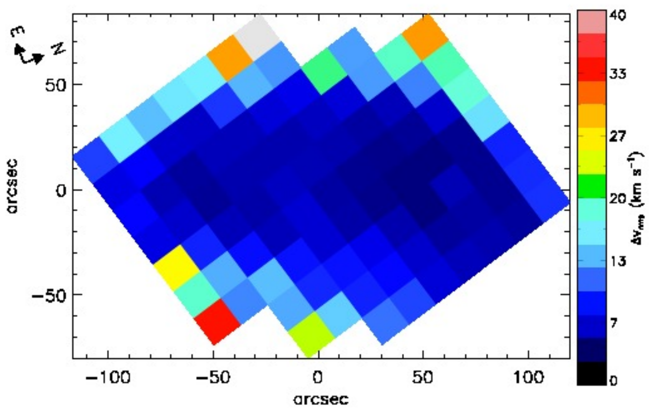




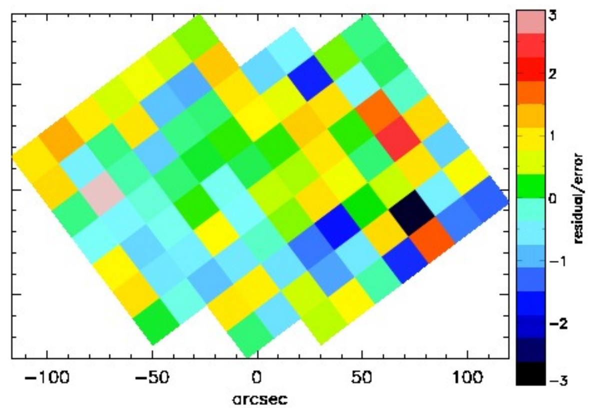
With likelihood of $\Upsilon_{*,R}$=1.1±0.8 based on SED fitting

JAM model residuals

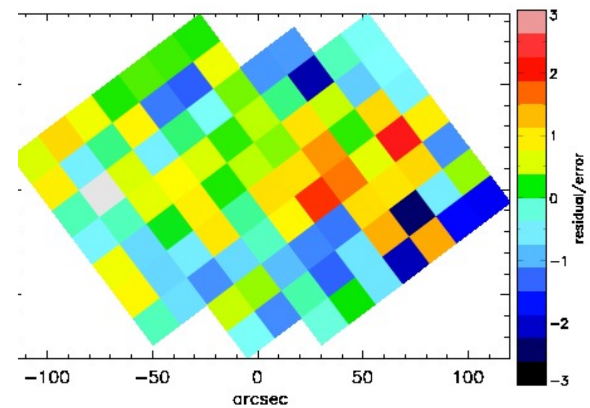
Data 2nd moment errors

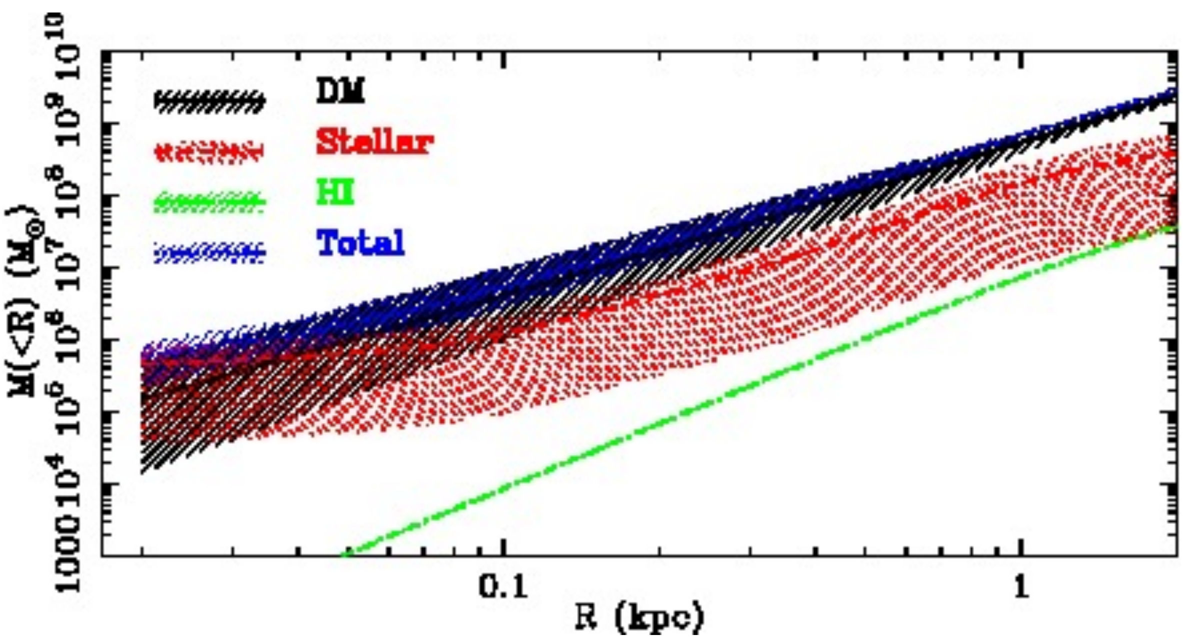


Cusp model residual

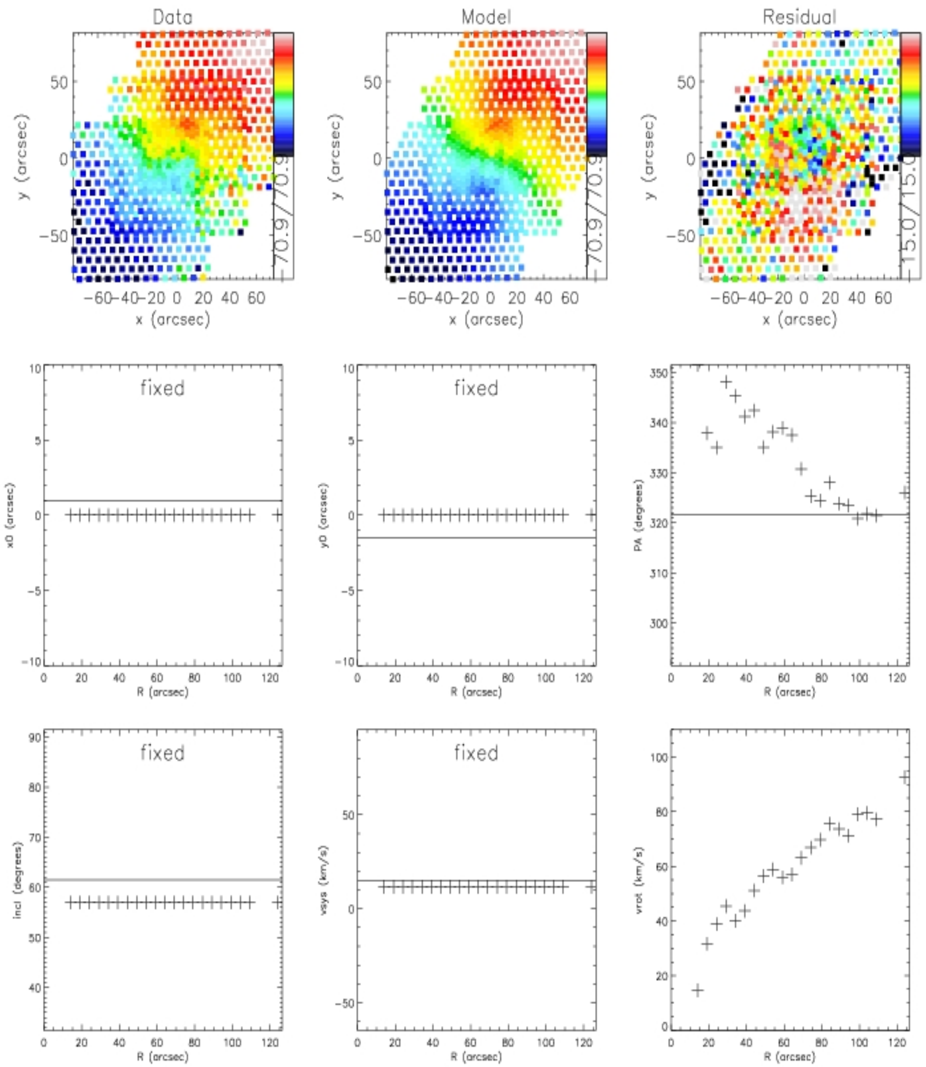


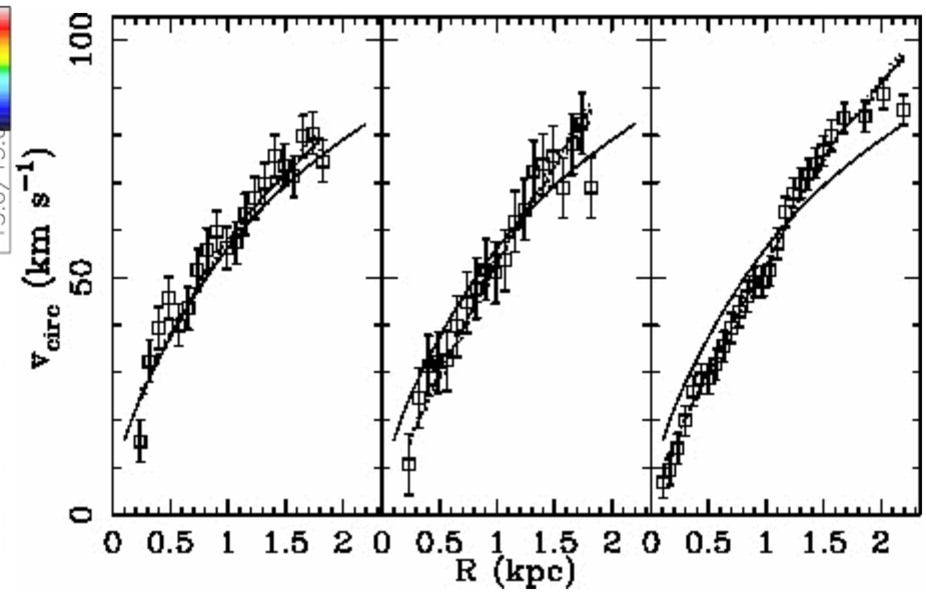
Core model residual





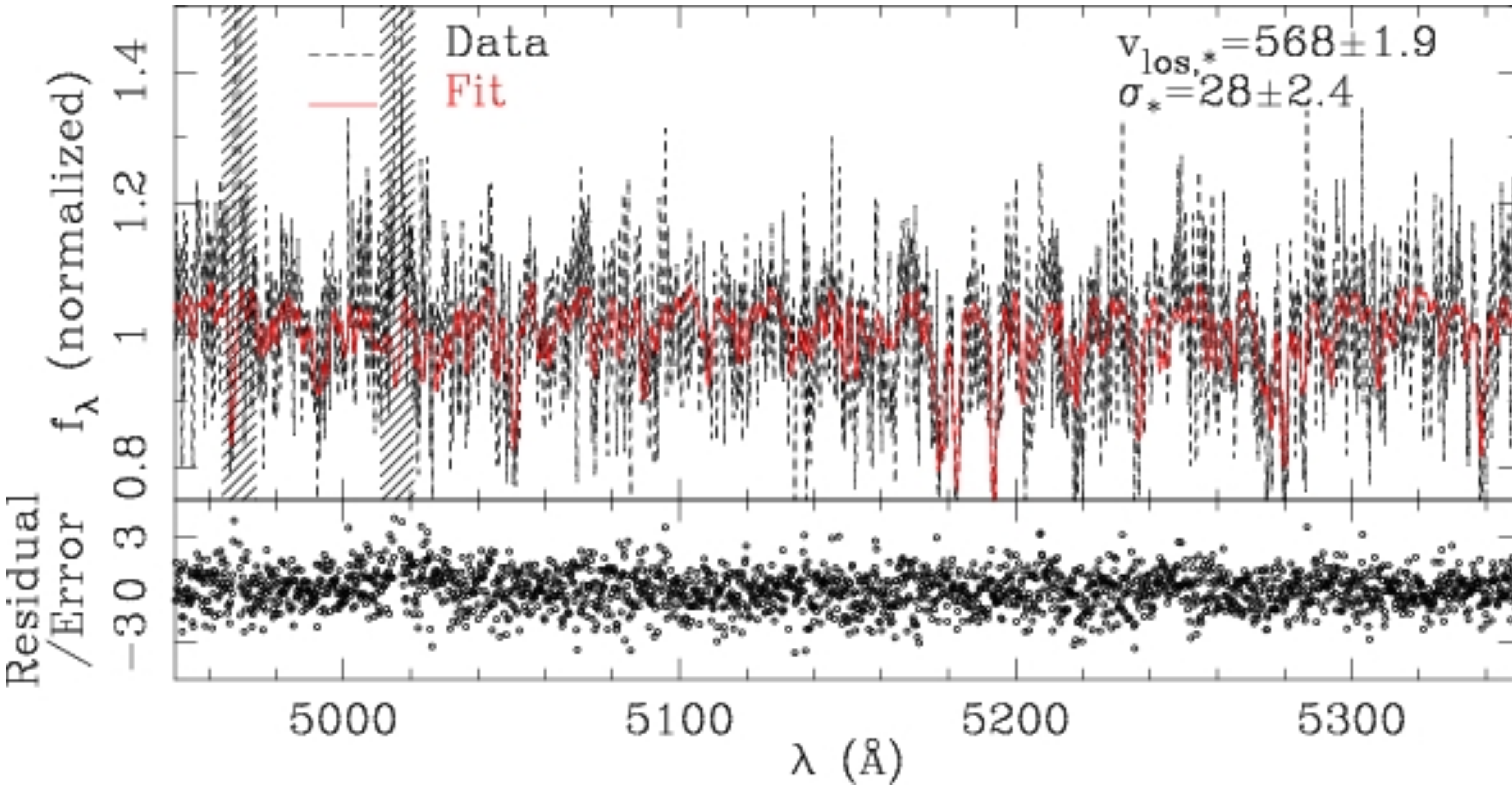
Reconciling the two tracers





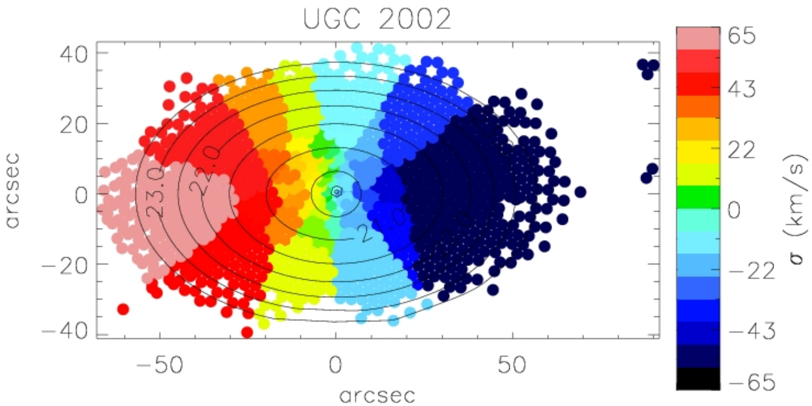
Solid line from best JAM model
Left: tilted ring with variable PA
Middle: harmonic decomp.
Right: Simon '03 data and harmonic decomposition

A VIRUS-W LOSVD

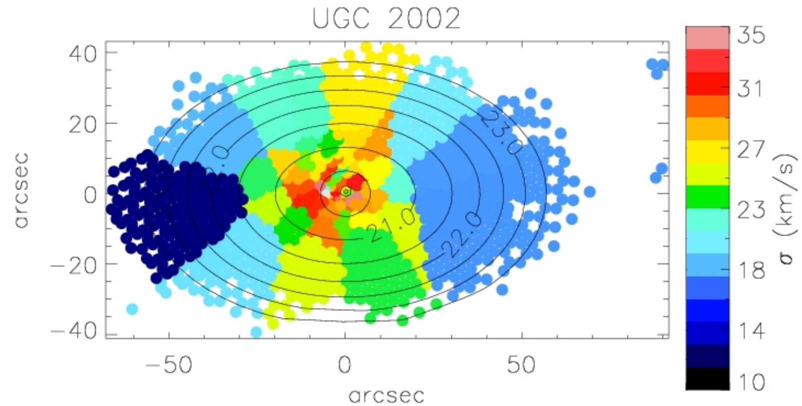


Essential to have K giants and hot (A or B) dwarfs to match EWs

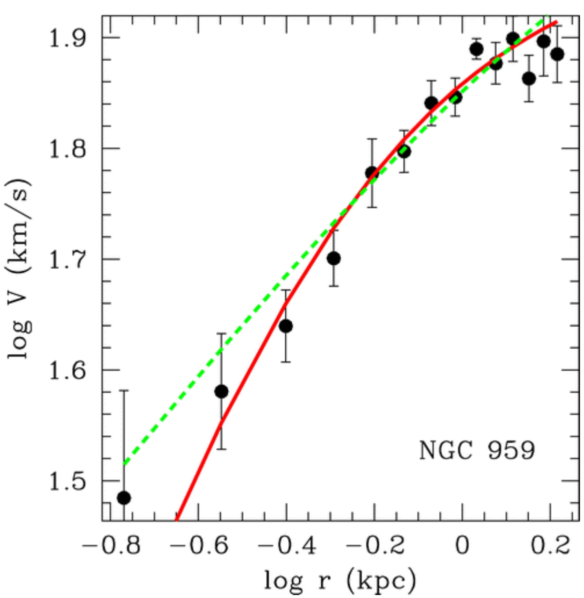
New VIRUS-W data on UGC 2002



V_{los}



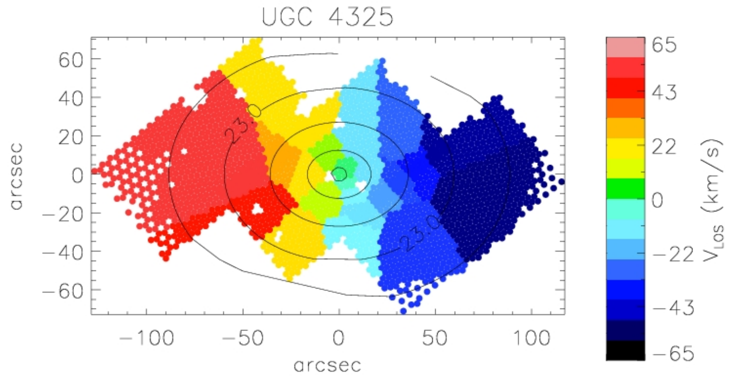
σ



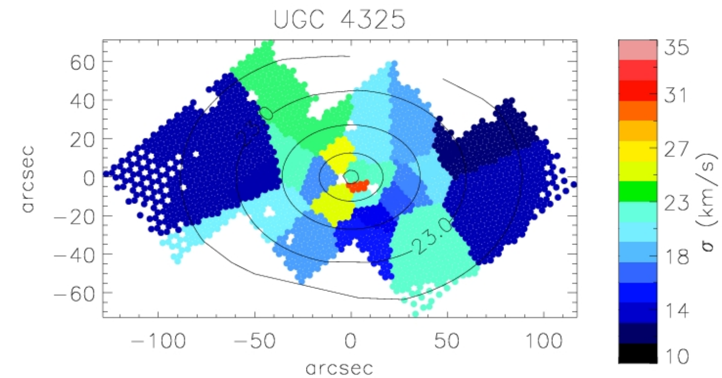
- Best fit DM halo with M_{200}=1.2E11 Msol, c_{200}=15, and α=1.0 (errors TBD)
- Our gas fits agree
- Best fitting cored model has M_{200}=3.2E13 Msol, c_{200}=25, and has very large residuals

Kuzio et al., 2008

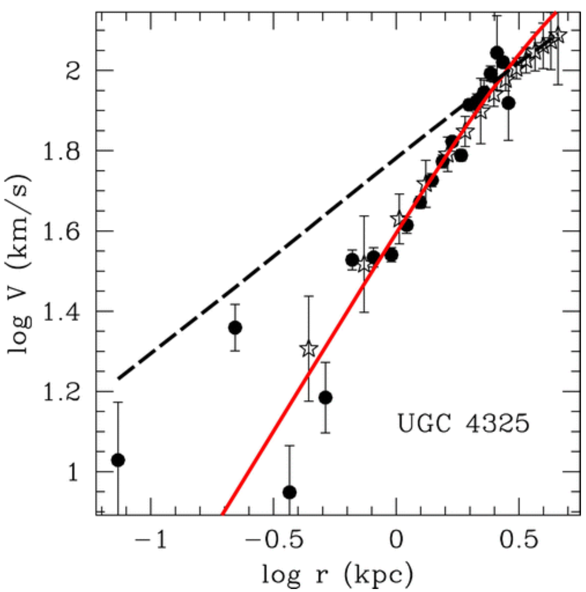
New VIRUS-W data on UGC 4325



V_{los}



σ

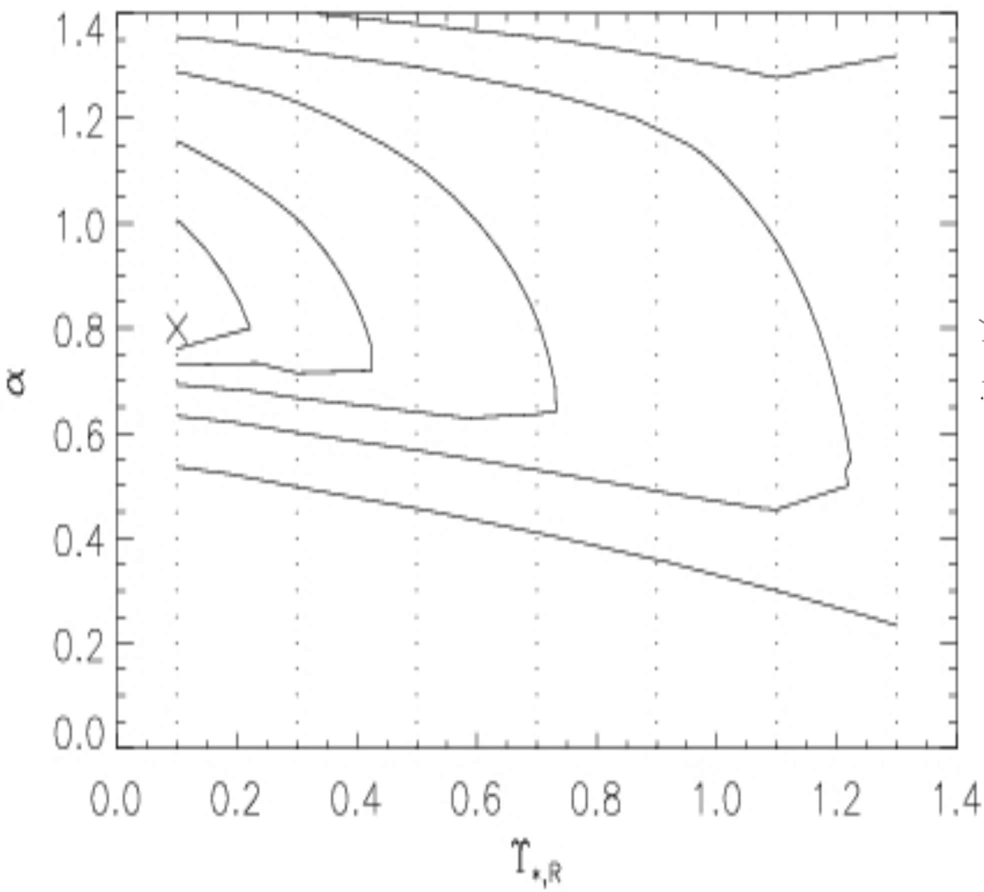


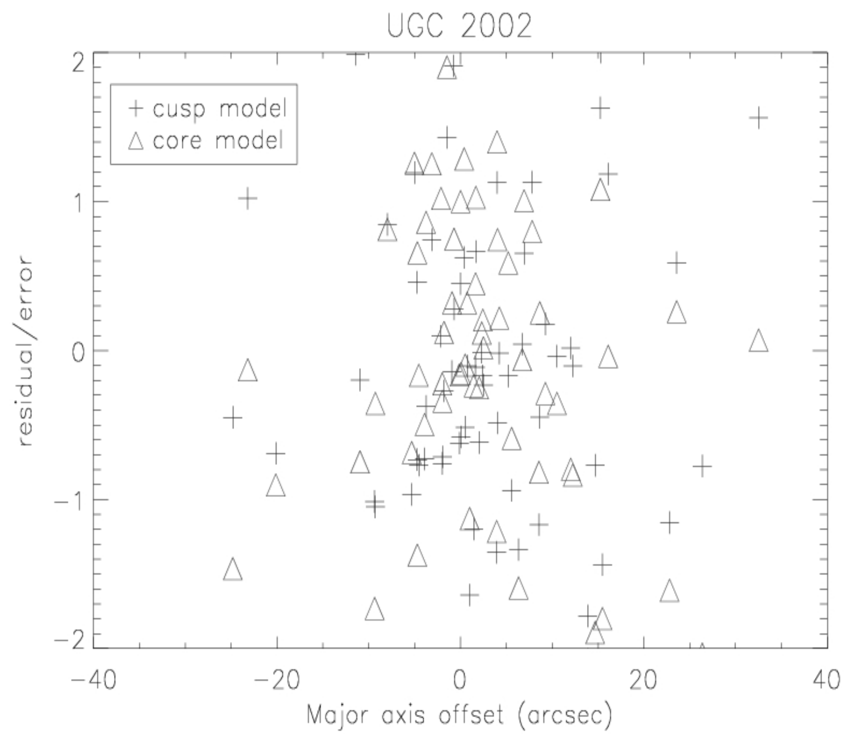
Kuzio et al., 2008

- Best fit DM halo with M_{200}=3.7E11 Msol, c_{200}=25, and α=0.0 (errors TBD)
- Our gas fits range from α=0.64-1.0
- Best fitting cuspy model has M_{200}=1.7E12 Msol, c_{200}=5, and only mildly worse residuals ($\Delta\chi^2$=1)

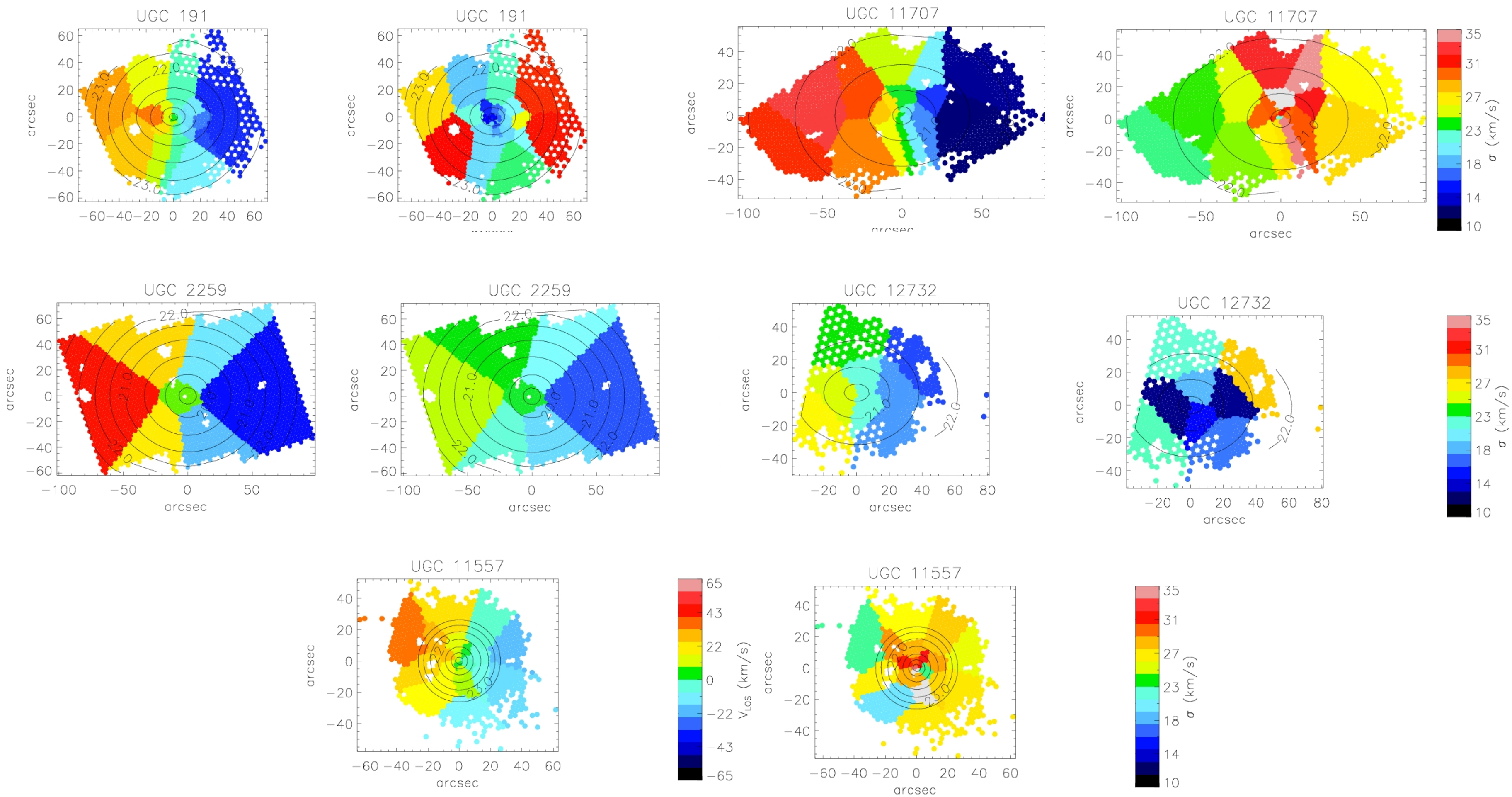
Parameter constraints

UGC 2002 (preliminary)





Five more kinematic maps



UGC 191, UGC 2259, UGC 11557, UGC 11707, UGC 12732

Summary

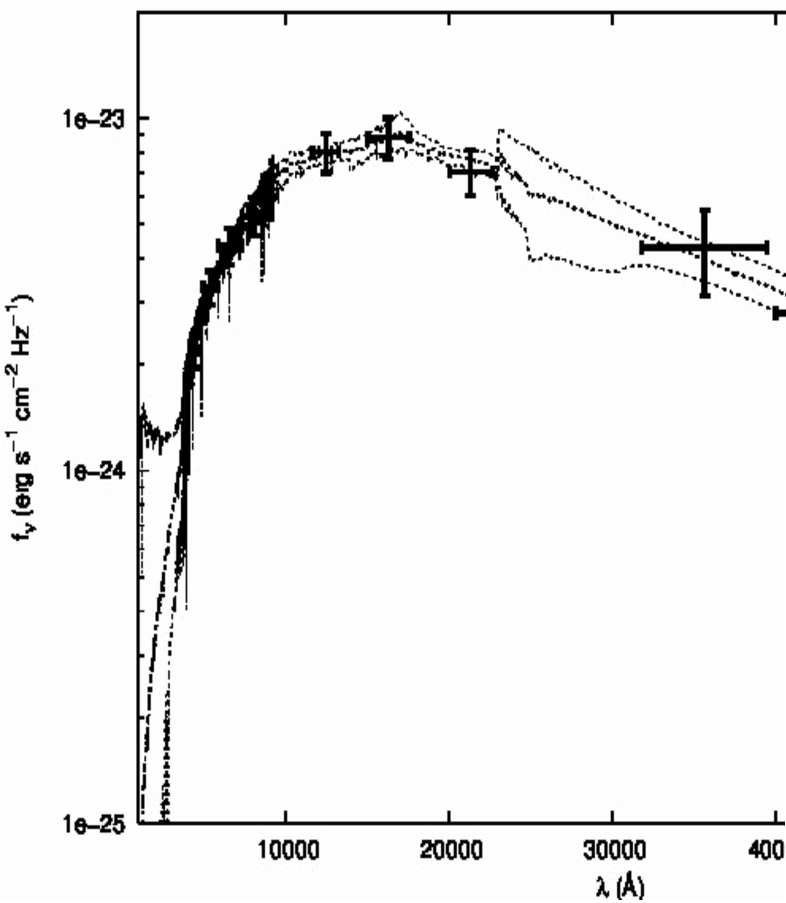
- The degeneracies, particularly between $\Upsilon_{*,R}$ and α, are often too strong to make a constraint by the kinematics alone in late-type dwarfs
- A loose stellar population fit to $\Upsilon_{*,R}$ suffices to give a constraint in NGC 2976
- The interpretation of the gas kinematics are subject to assumptions choices, but can be made compatible with the best stellar-kinematics-based mass model
- NGC 2976 is DM dominated at least down to 200 pc
- A cuspy DM halo is best, a core is excluded at 2σ
- A sample of 10 more late-type dwarfs is being gathered

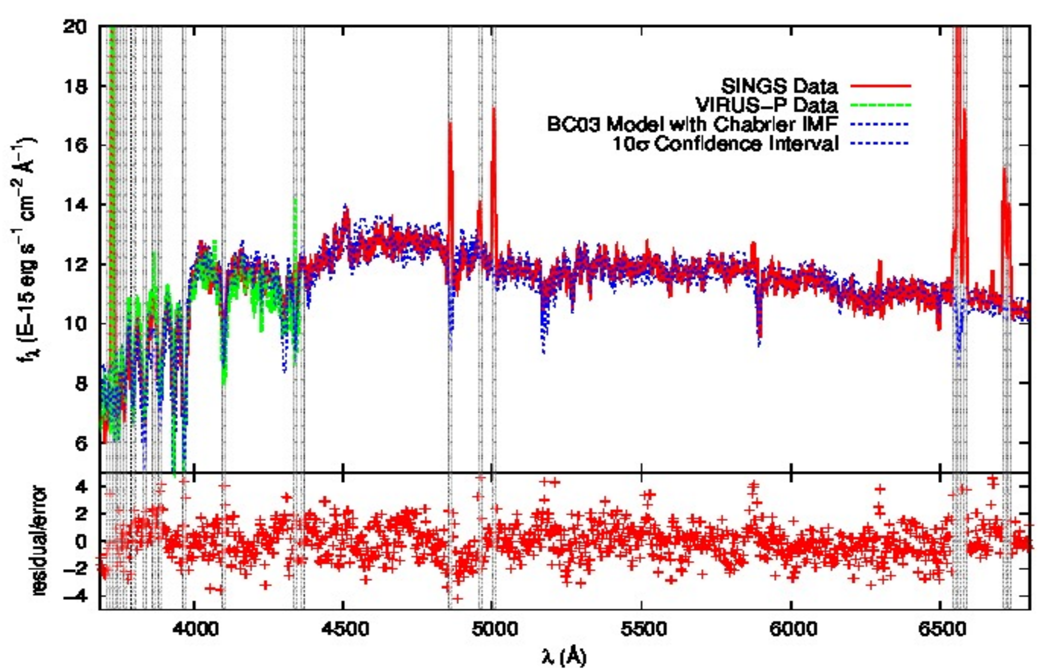
Extra slides

$\Upsilon_{*,R}$ Constraint

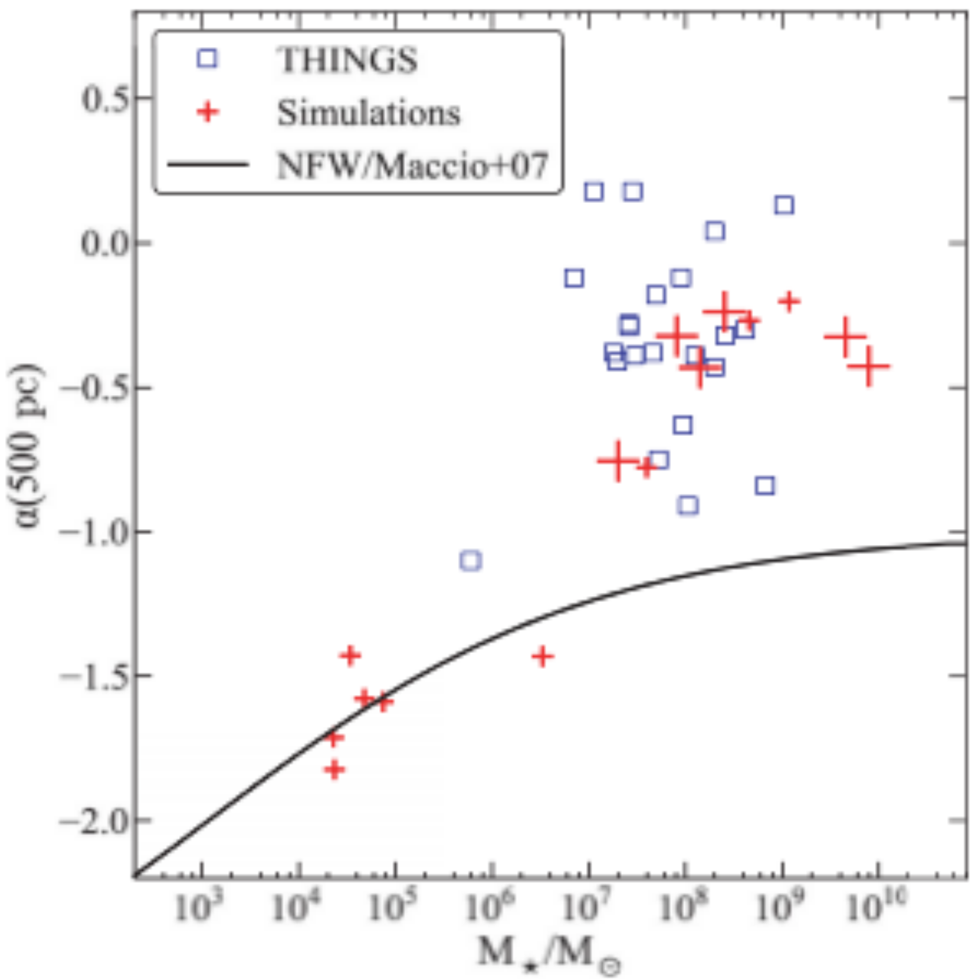
- Two stellar population fits
- Used the Tremonti et al. ('04) Z and SFH grids
- Used (BC03,BC07) and (Chabrier,Salpeter) IMFs
- Used Calzetti et al. '00 dust law
- Fit all two-population combinations
  - BC03 Salpeter: $\Upsilon_{*,R}$=1.23±0.52
  - BC03 Chabrier: $\Upsilon_{*,R}$=0.63±0.39
  - BC07 Salpeter: $\Upsilon_{*,R}$=1.42±0.42
  - BC07 Chabrier: $\Upsilon_{*,R}$=1.04±0.23
- Total is $\Upsilon_{*,R}$=1.1±0.80

$\Upsilon_{*,R}$ Constraint



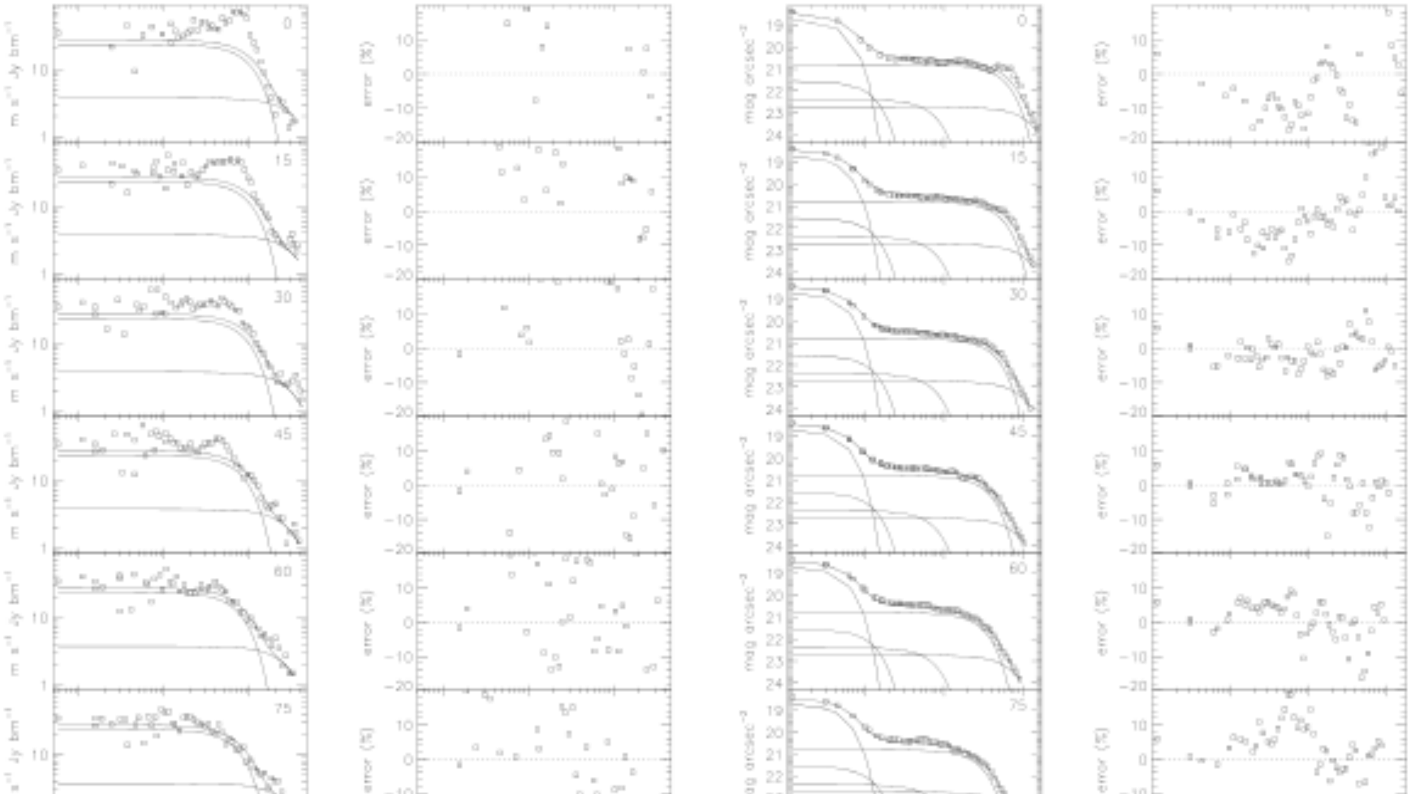


New SNe feedback simulations



Governato et al., 2012

MGE fit



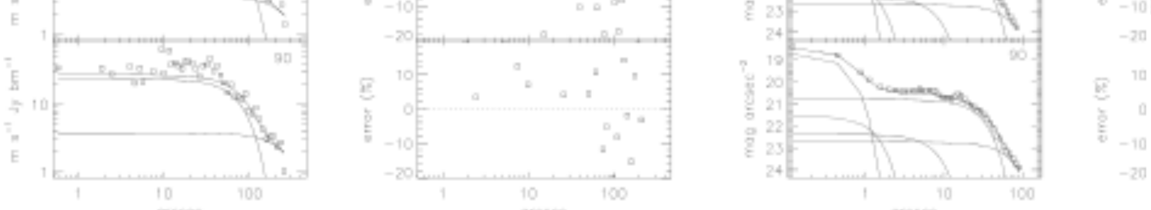
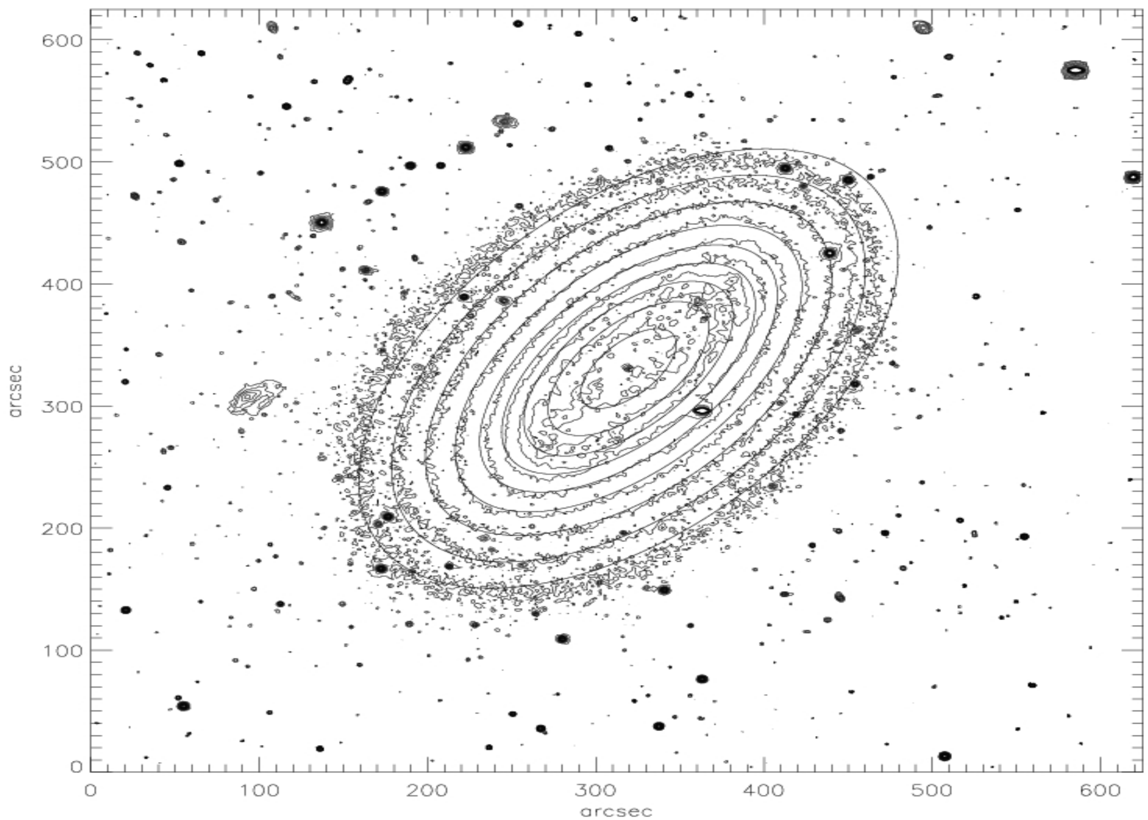


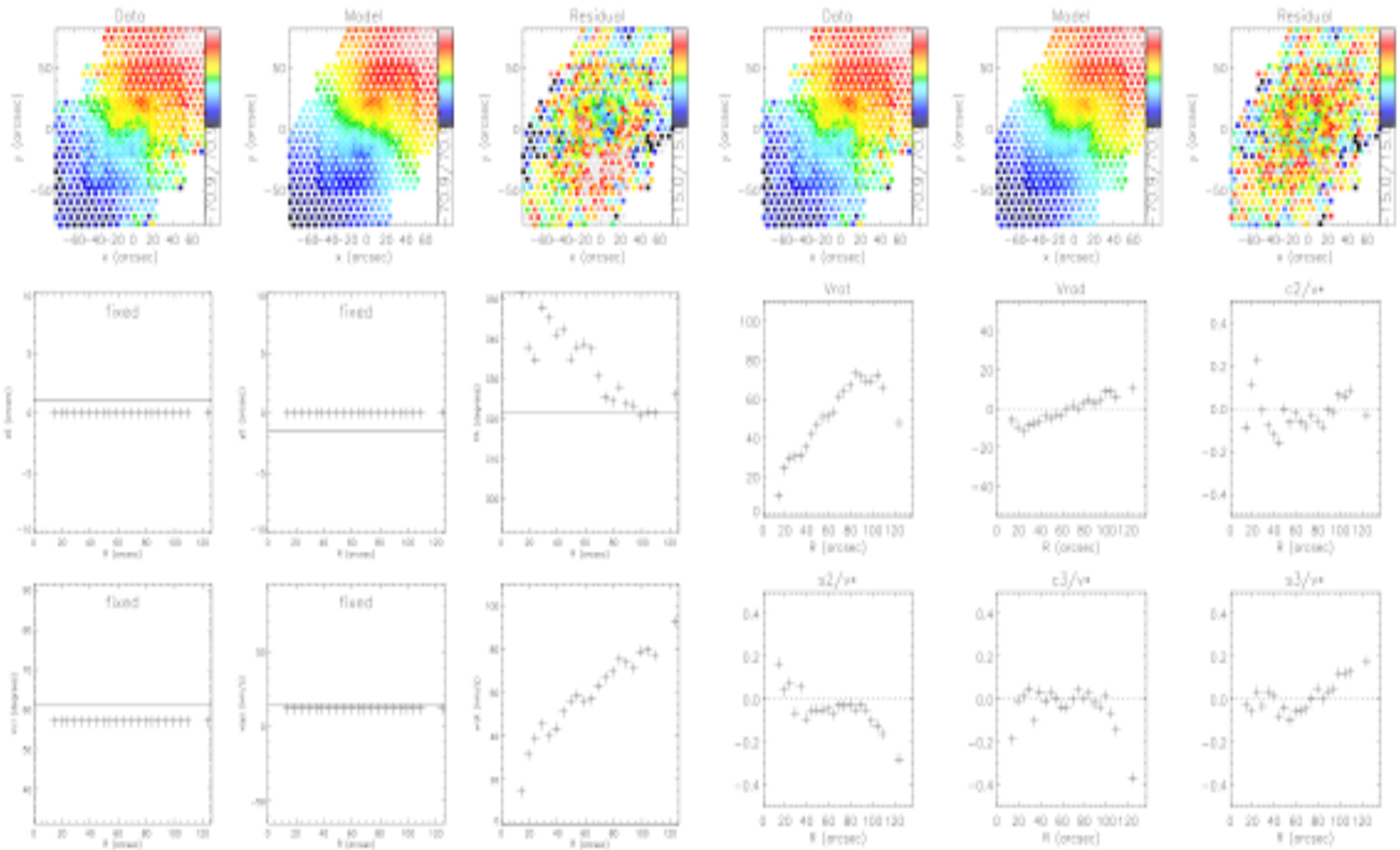
Table 4
Multi-Gaussian Expansion terms for NGC 2976

Component	Index (k)	$\Sigma_{0,k}$ ($M_\odot$ pc^{-2})	σ_k (arcsec)	q'_{k_*}
Stellar†	1	2298.3	0.28	1.00
	2	68.9	0.99	1.00
	3	27.8	6.36	1.00
	4	117.8	49.89	0.48
	5	19.6	108.26	0.54
HI	1	8.0	84.80	0.70
	2	1.3	291.13	0.75

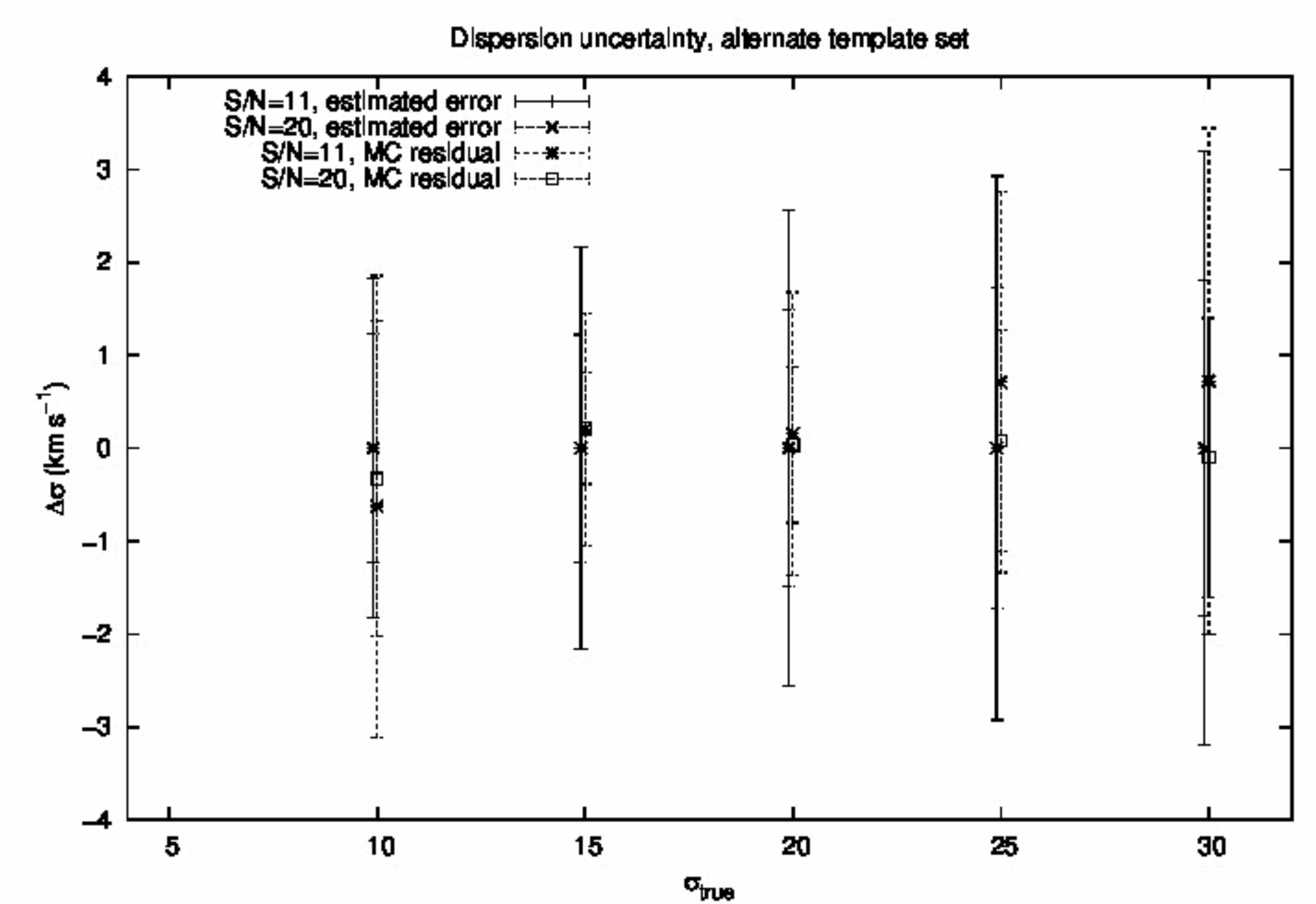
MGE fit



Gas fits


Data
Model
Residual
Data
Model
Residual
fixed
fixed
fixed
fixed
Vrot
Vrad
c2/v*
s2/v*
c3/v*
s3/v*
x (arcsec)
R (arcsec)

LOSVD template mismatch



- LOSVD parameters by maximum likelihood for Gaussian errors and direct, pixel space fitting
- Systematic error of empirical template mismatch test is well below 1 km/s