Dark Matter and ISM in the THINGS galaxies

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ASTRON, Netherlands

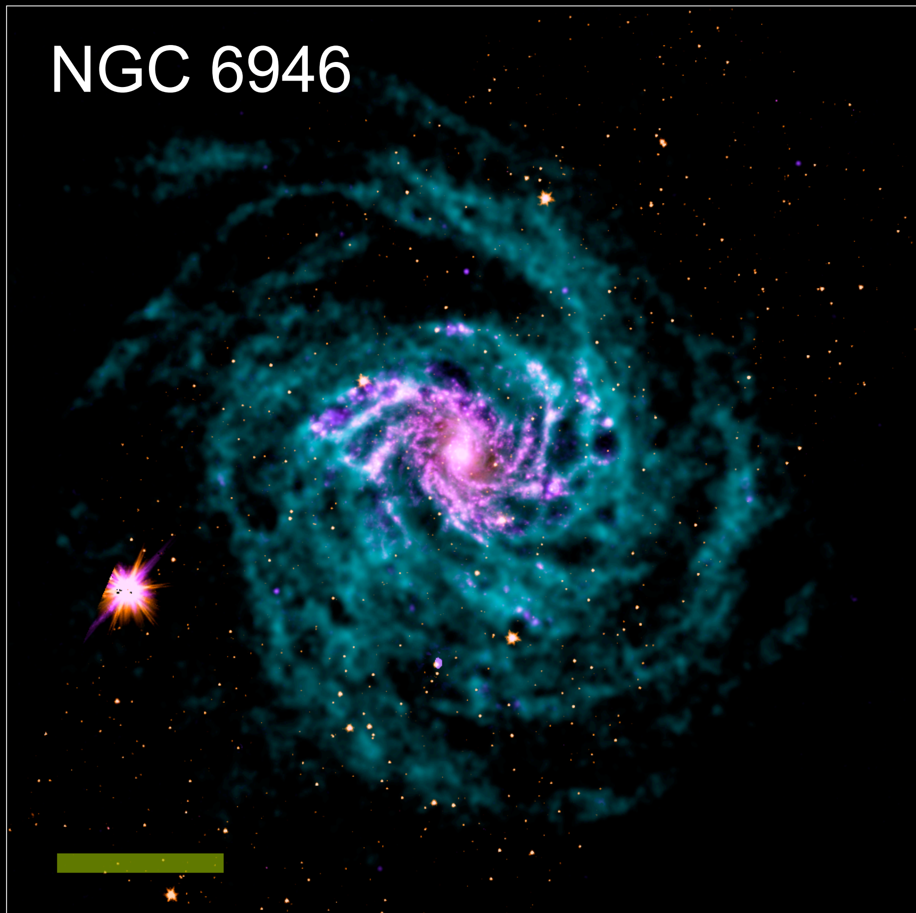
Green Bank, 1 April 2012

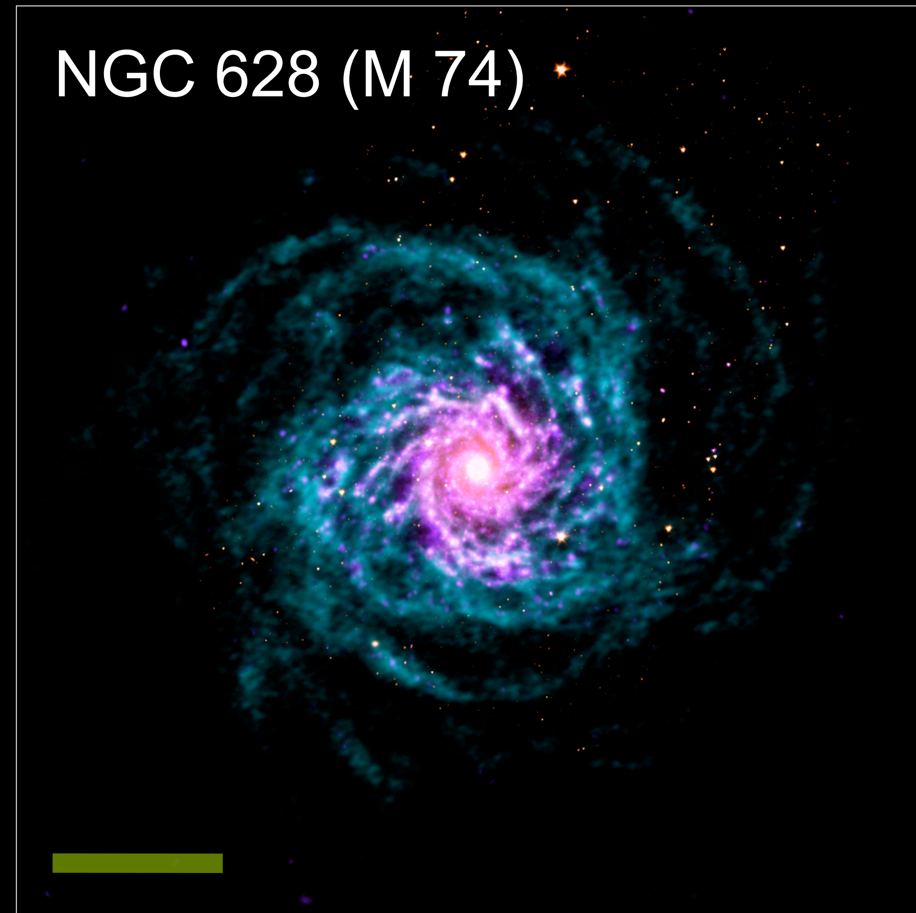
THINGS

- **T**he **HI N**earby **G**alaxy **S**urvey - Walter et al (2008)
- VLA B,C,D array of 34 nearby Sa-Irr galaxies
- distance 3-15 Mpc
- ~6” spatial (100-500 pc), 2-5 km/s velocity resolution
- overlap with SINGS (Spitzer) and GALEX NGS (UV)
- In progress: HERACLES CO observations (Leroy)


THINGS
The HI Nearby Galaxy Survey
NGC 2841
NGC 3621
NGC 7331
NGC 4826 (M64)
NGC 3198
NGC 6946
NGC 3184
NGC 925
NGC 3351 (M95)
NGC 5194 (M51)
NGC 5236 (M83)
NGC 3521
NGC 4214
NGC 2976
DDO 53
NGC 1569
M81dwB
M81dwA
NGC 2366
Our Galaxy
HI stars
IC 2574
NGC 4449
NGC 3627 (M66)
Holmberg II
NGC 7793
DDO 154
NGC 4736 (M94)
NGC 3077
Holmberg I
NGC 5055
NGC 2903
10 kpc
NGC 628 (M74)
NGC 5457 (M101)
NGC 3031 (M81)
NGC 2403
Data: Walter et al 2008
Milky Way HI map: Oort et al (1958)
Milky Way art: NASA/JPL, R. Hurt (SSC)

Spiral Galaxies in T*HI*NGS — The *HI* Nearby Galaxy Survey





‘Face-on’
Spiral Galaxies
in T*HI*NGS

scale:
10 kpc
30.000 light years

Color Coding:
Atomic Hydrogen (HI)
(Very Large Array)
Old stars
(Spitzer)
Star Formation
(Galex & Spitzer)

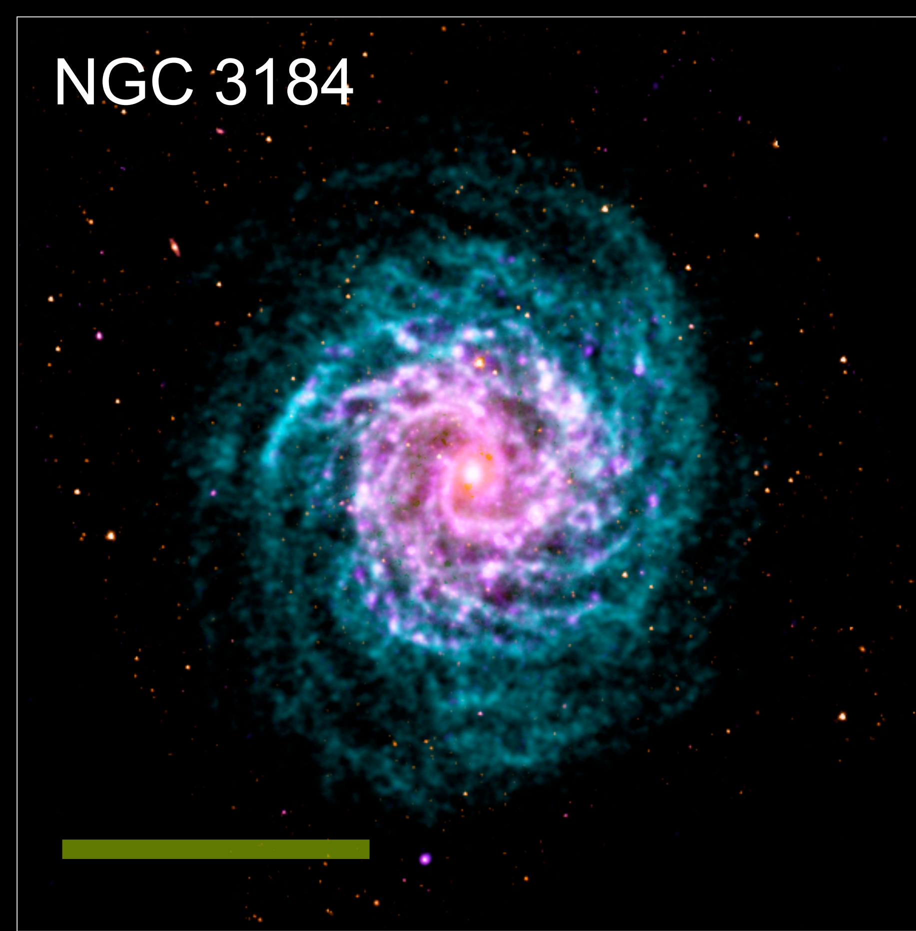
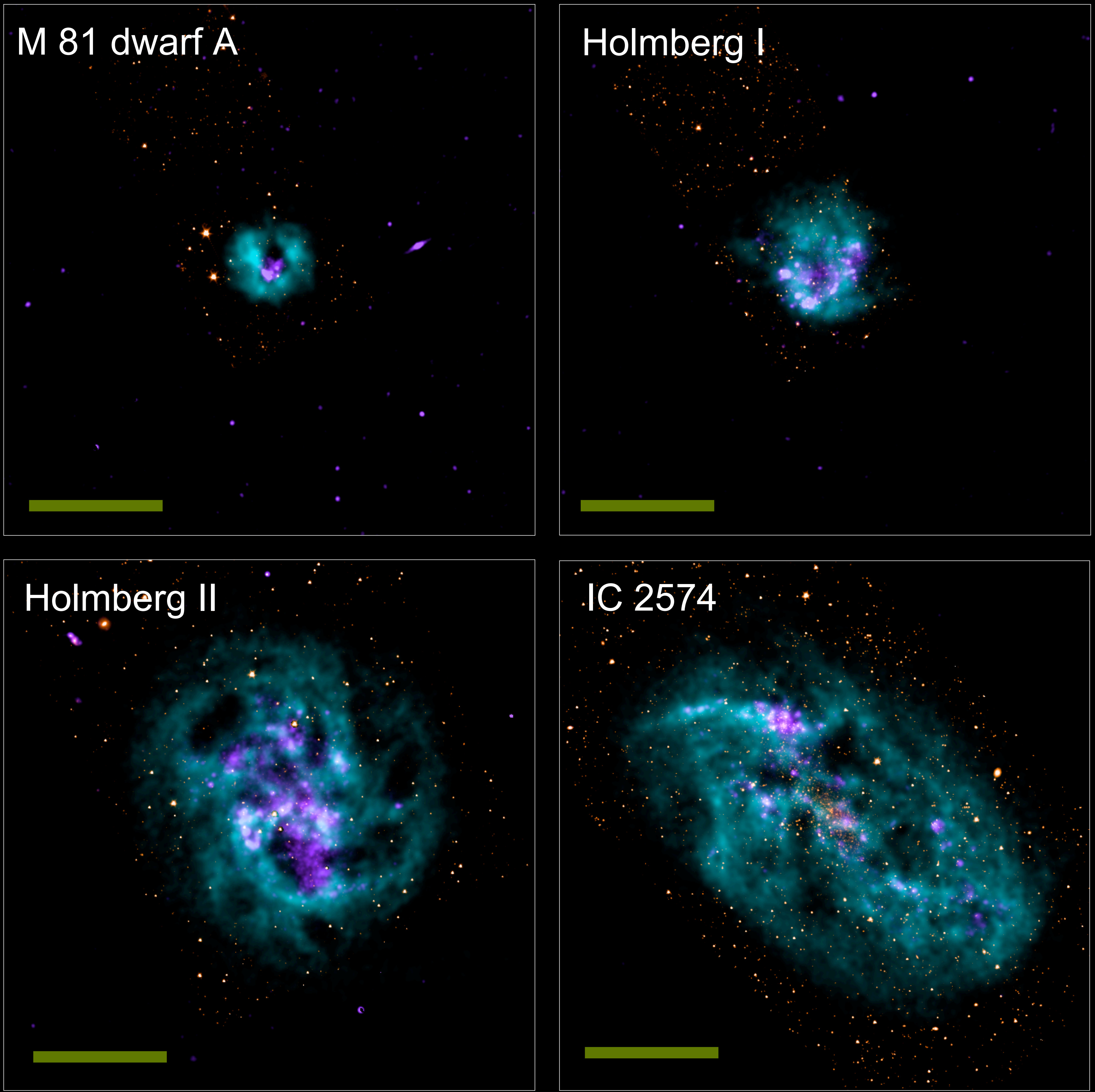


Image credits:
VLA THINGS: Walter et al.
Spitzer SINGS: Kennicutt et al.
Galex NGS: Gil de Paz et al.

Dwarf Galaxies in T*HI*NGS -- The *HI* Nearby Galaxy Survey



Dwarf Galaxies of the M81 group in T*HI*NGS

scale:
5 kpc
15.000 light years

color coding:

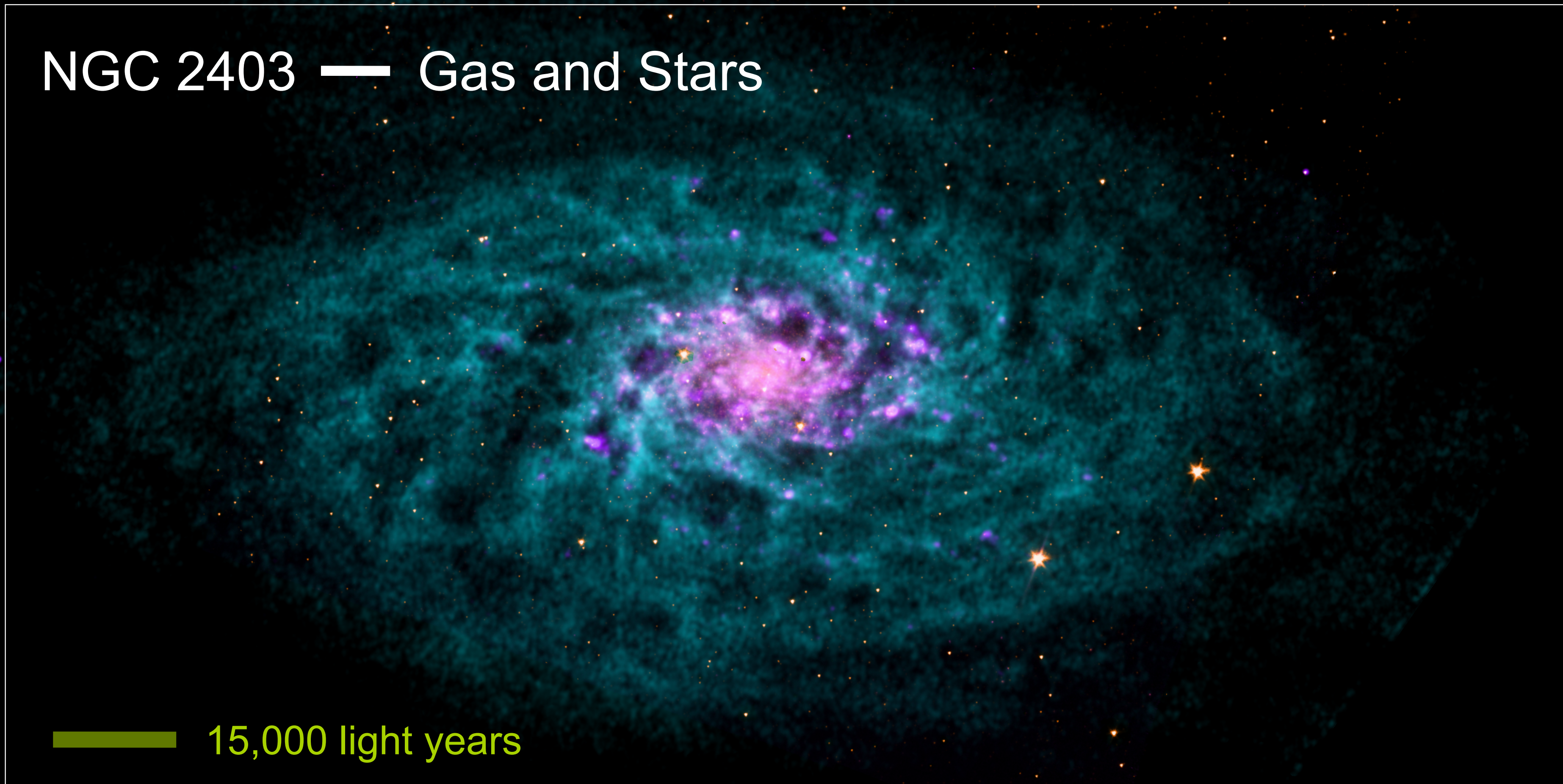
Atomic Hydrogen (HI)
(Very Large Array)

Old stars
(Spitzer)

Star Formation
(Galex & Spitzer)

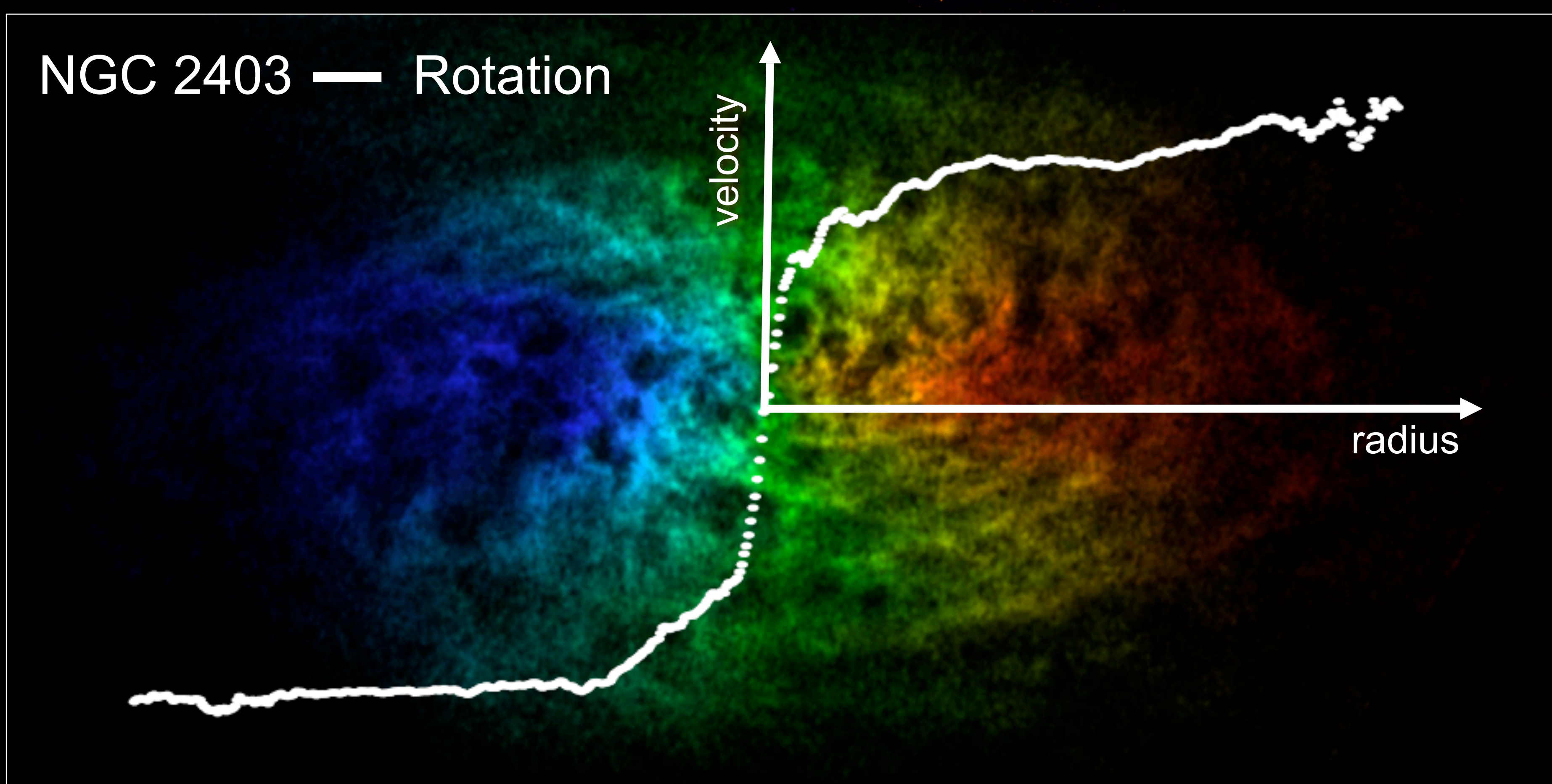
Image credits:
VLA THINGS: Walter et al.
Spitzer SINGS: Kennicutt et al.
Galex NGS: Gil de Paz et al.

Galaxy Dynamics in THINGS — The HI Nearby Galaxy Survey



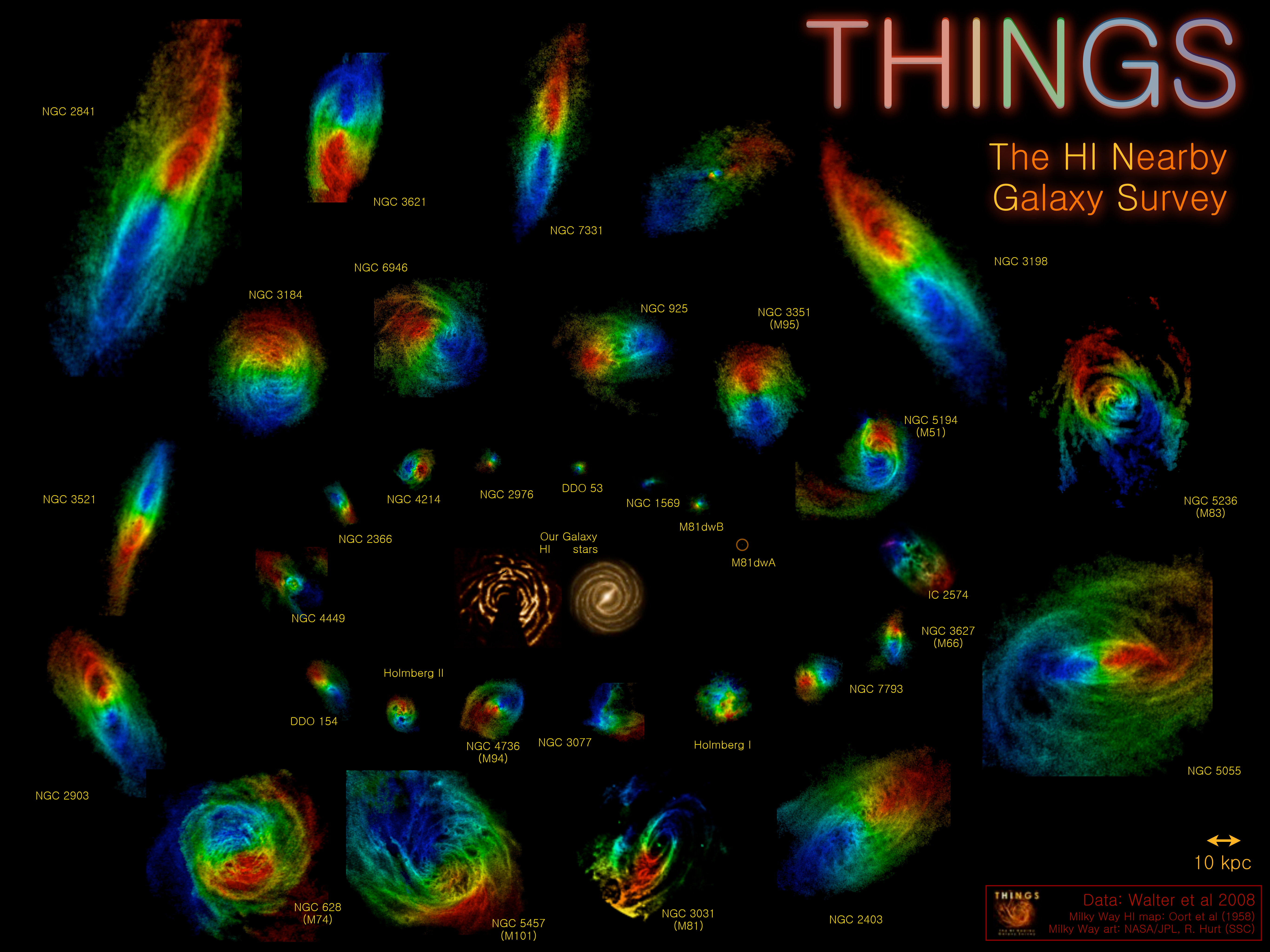
THINGS
The HI Nearby Galaxy Survey

Color Coding:
THINGS Atomic Hydrogen
(Very Large Array)
Old stars
(Spitzer Space Telescope)
Star Formation
(GALEX & Spitzer)



Color coding:
THINGS HI distribution:
Red-shifted (receding)
Blue-shifted (approaching)
Rotation Curve

Image credits:
VLA THINGS: Walter et al. 08
Spitzer SINGS: Kennicutt et al. 03
GALEX NGS: Gil de Paz et al. 07
Rotation Curve: de Blok et al. 08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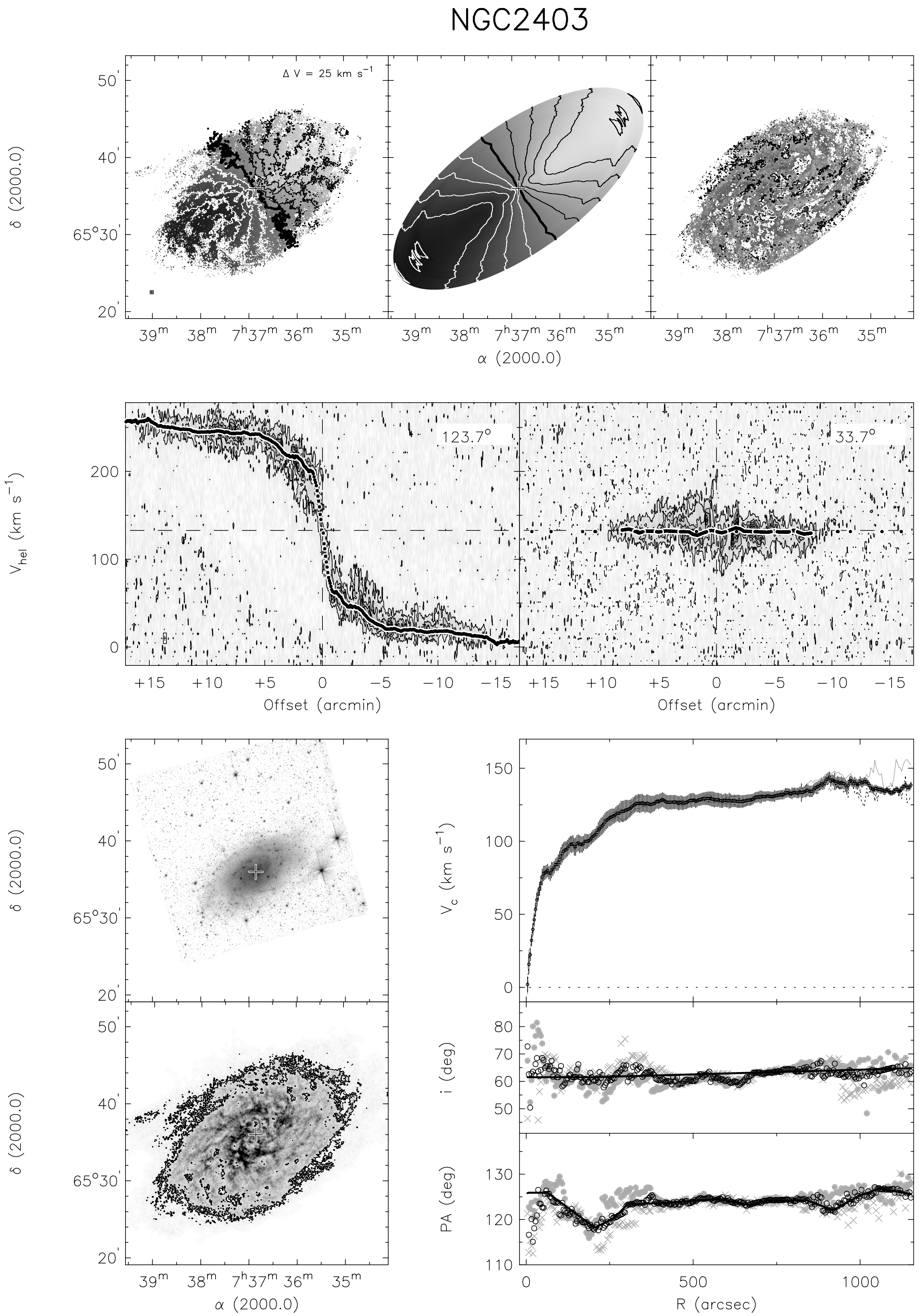
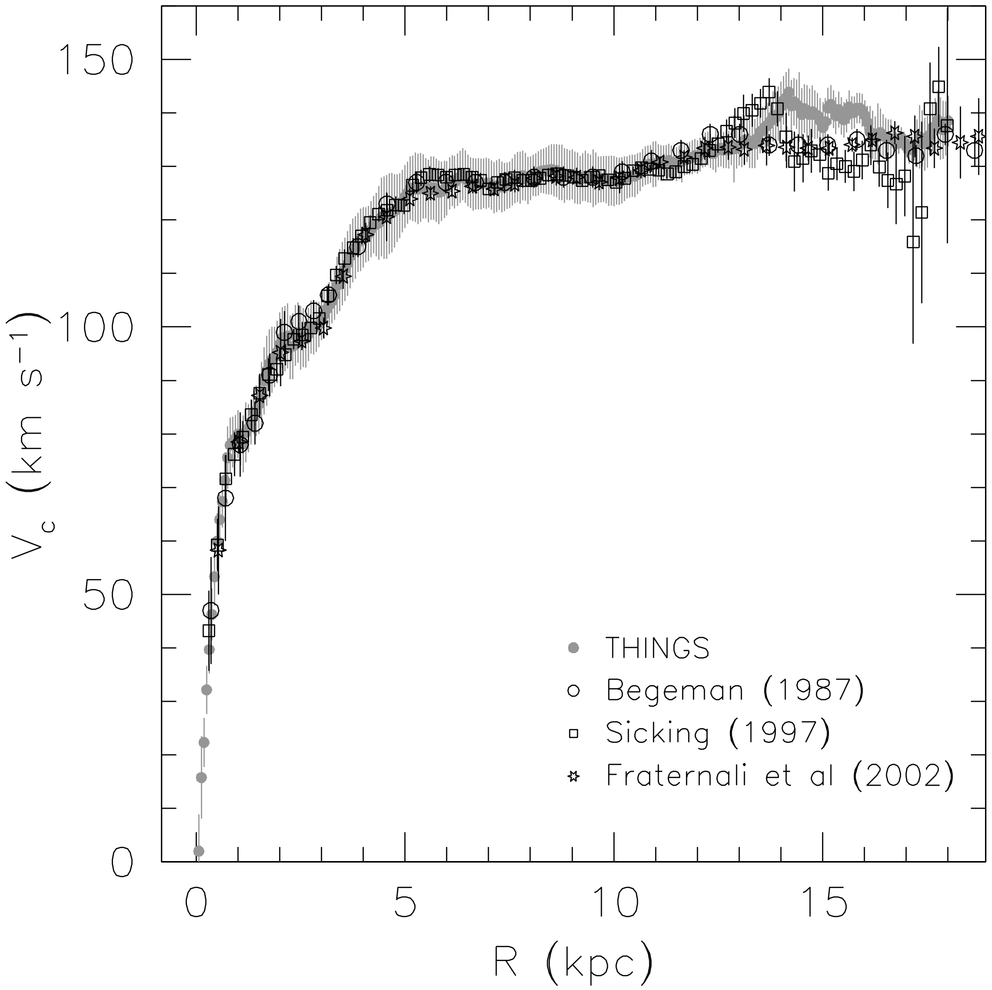
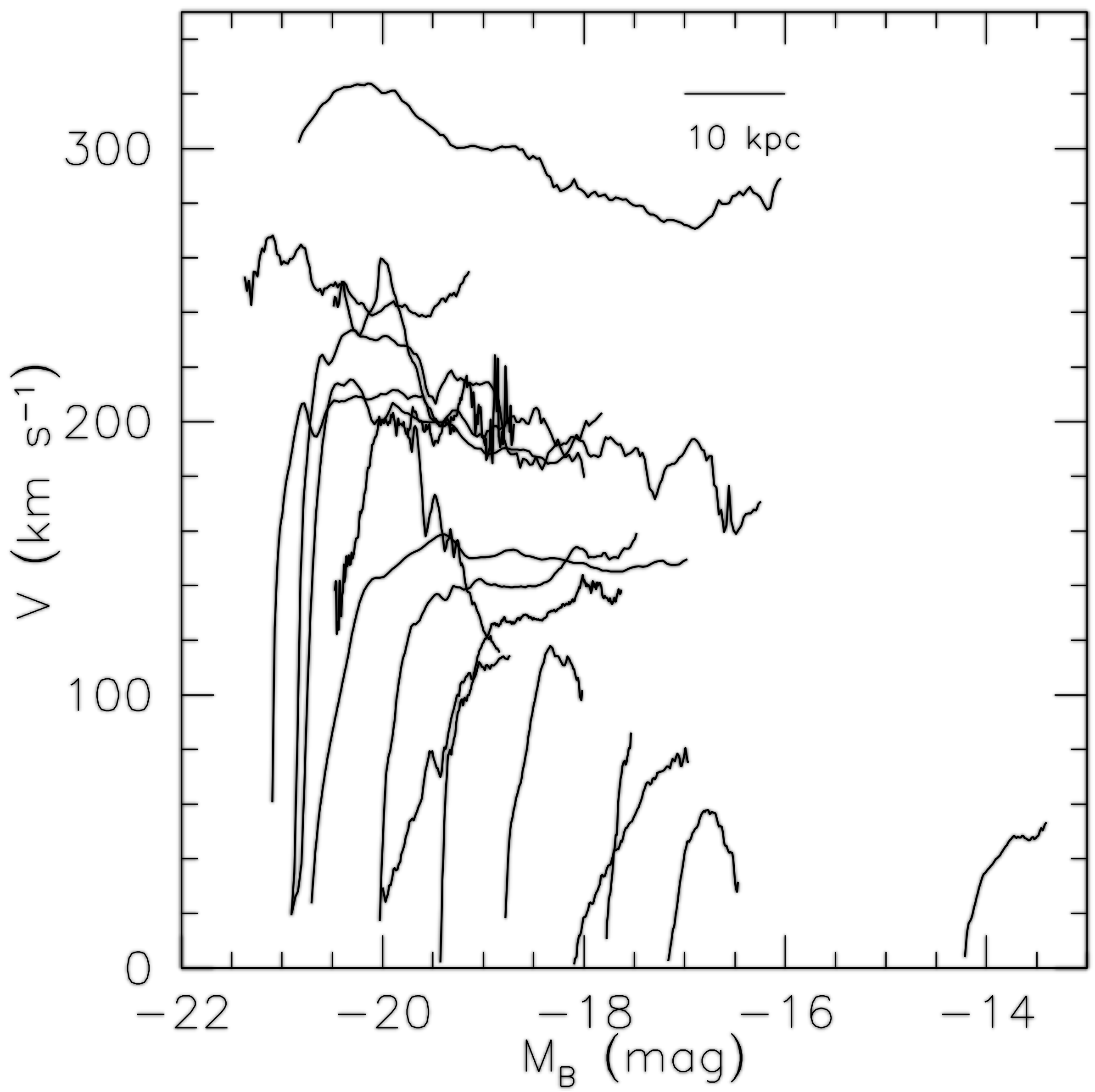
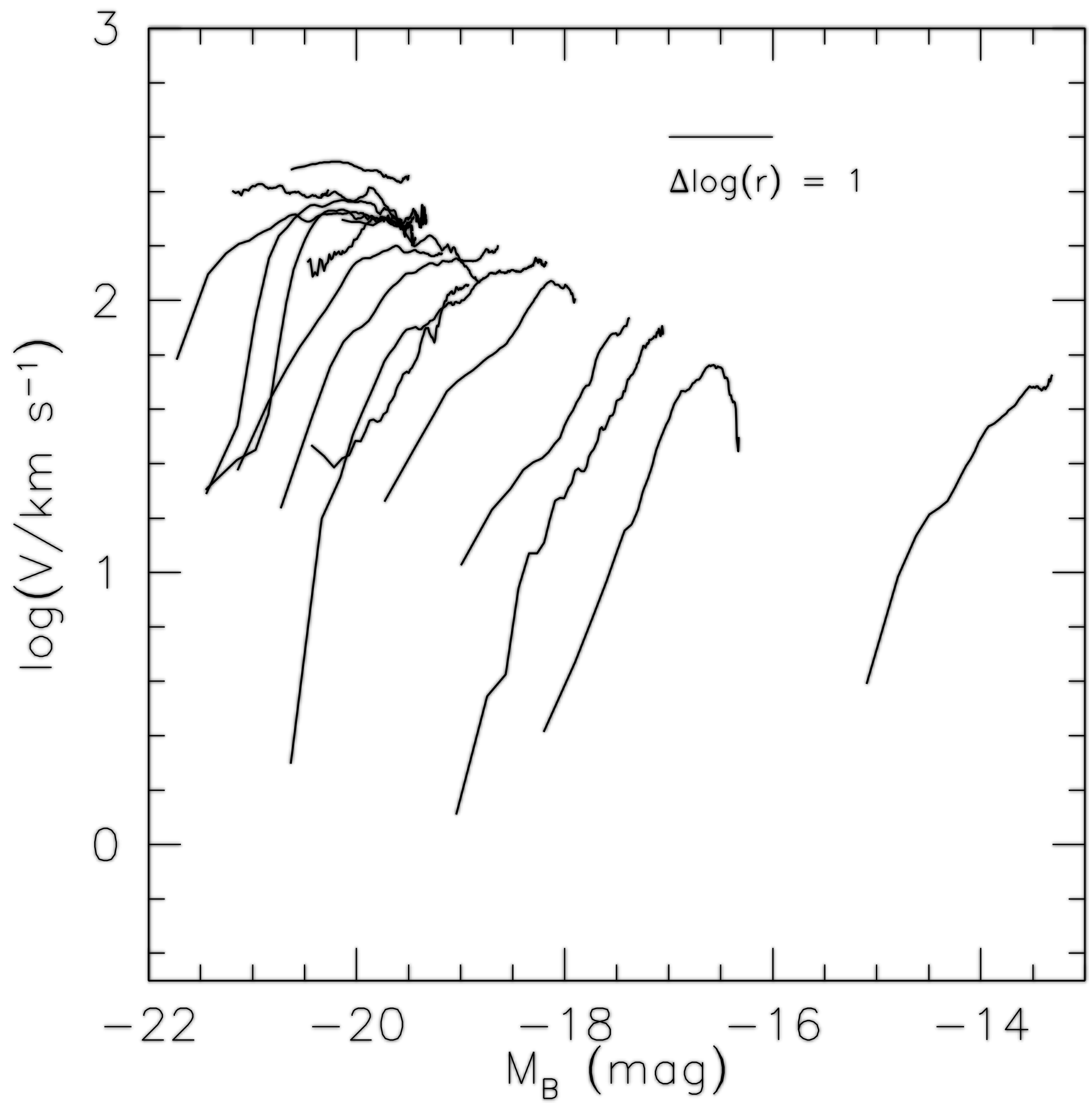




de Blok et al 2008

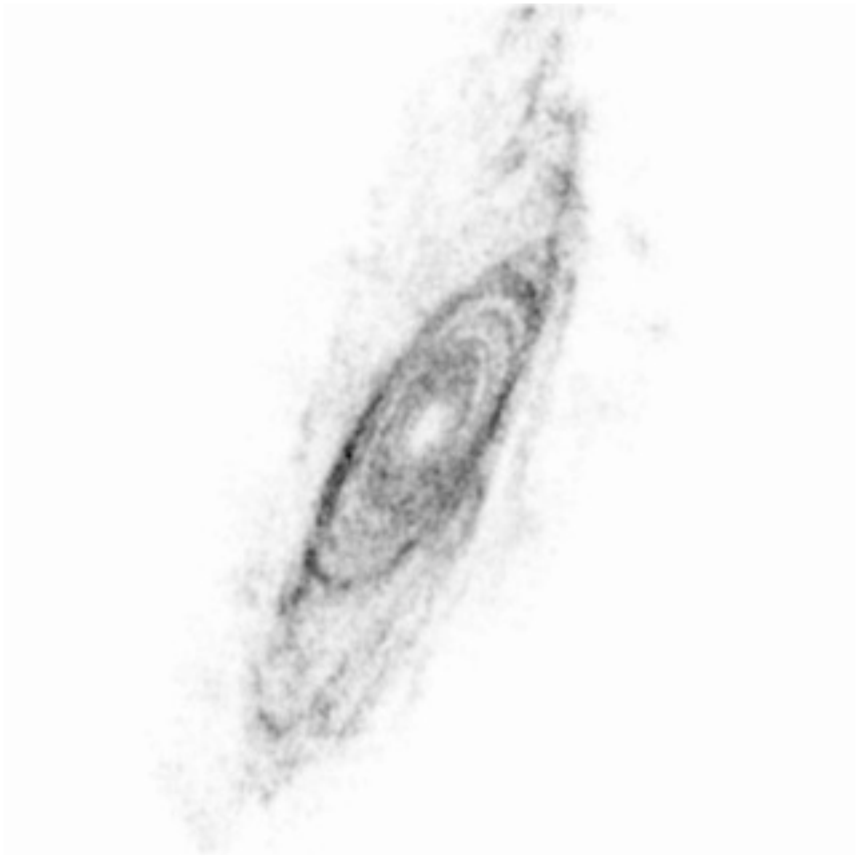
The THINGS Curves





de Blok et al 2008

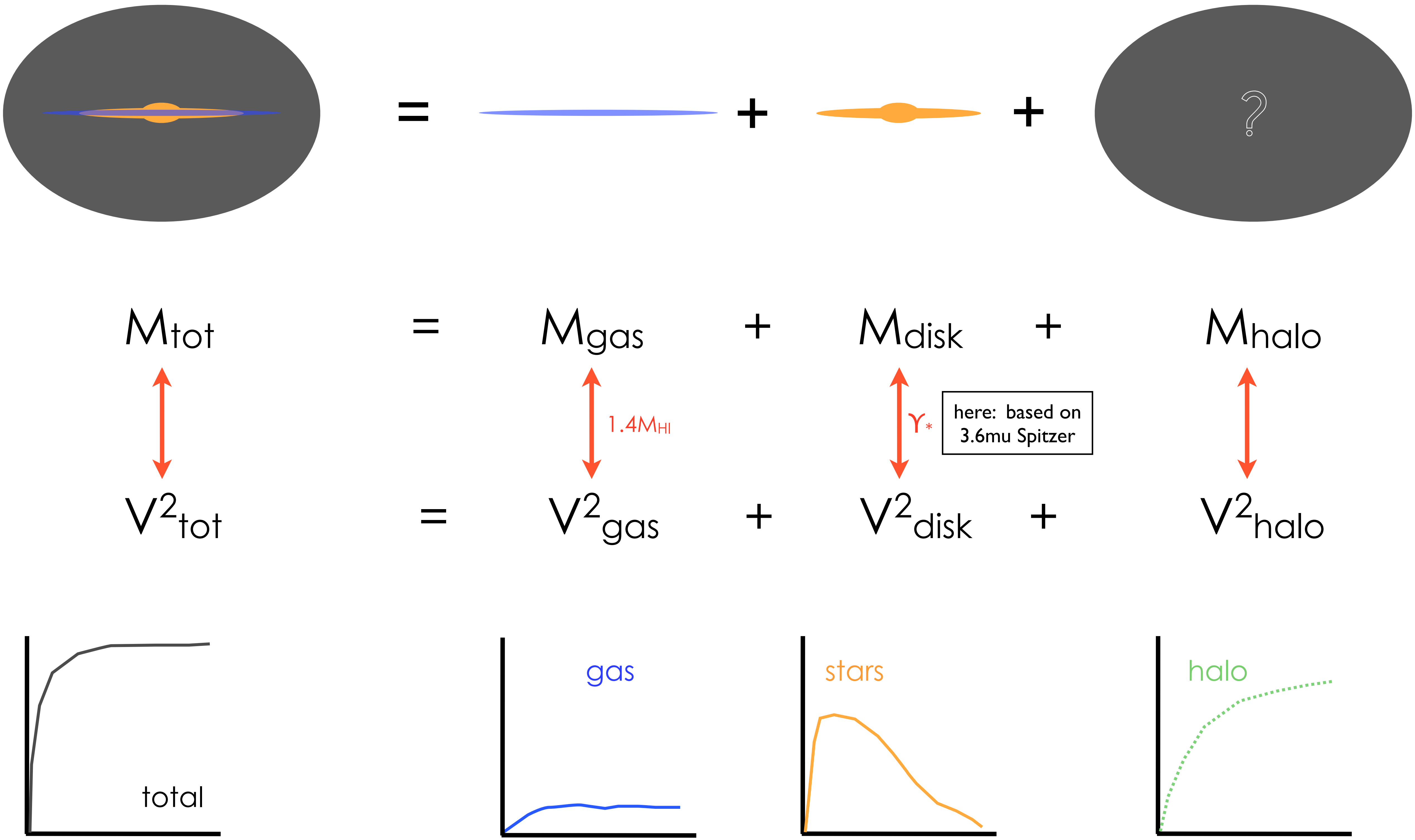
Tilted Rings



- Model galaxy with concentric rings with center (x,y) and systemic velocity V_{sys} each with their own i, PA, and V

$$\mathbf{V(x,y) = V_{sys} + V_C(R) \sin(i)\cos(\theta)}$$

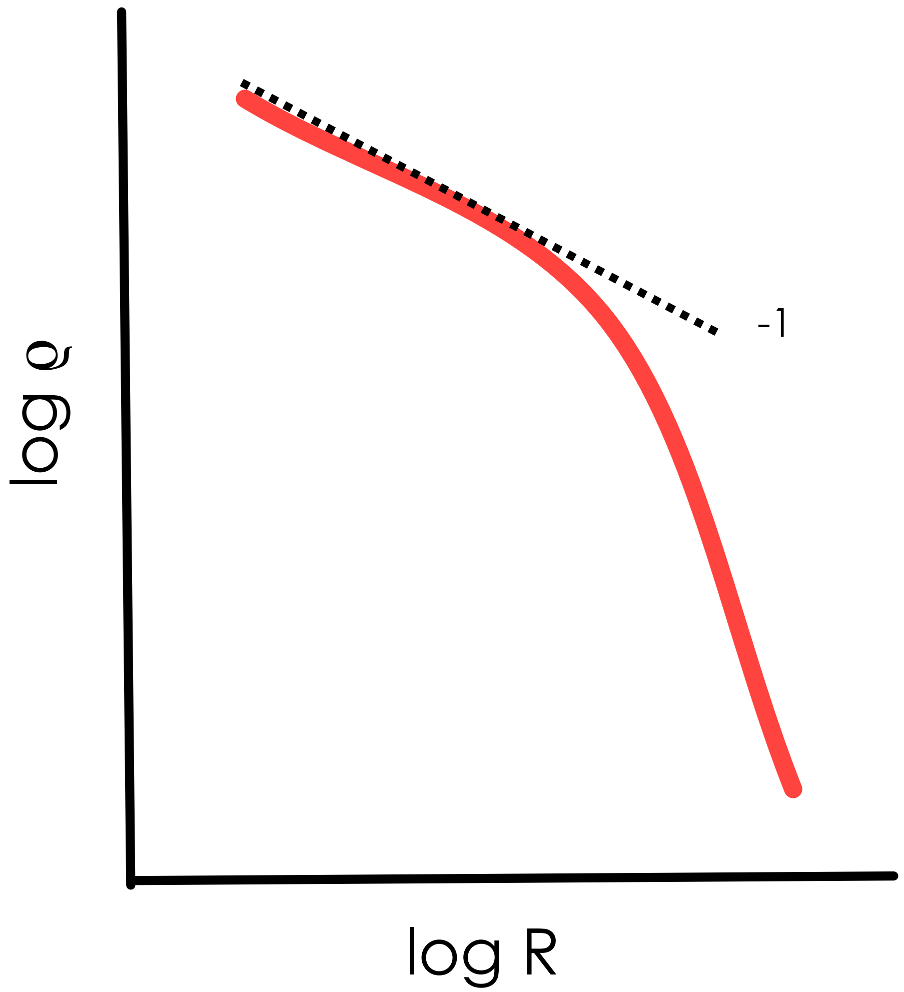
Mass Models



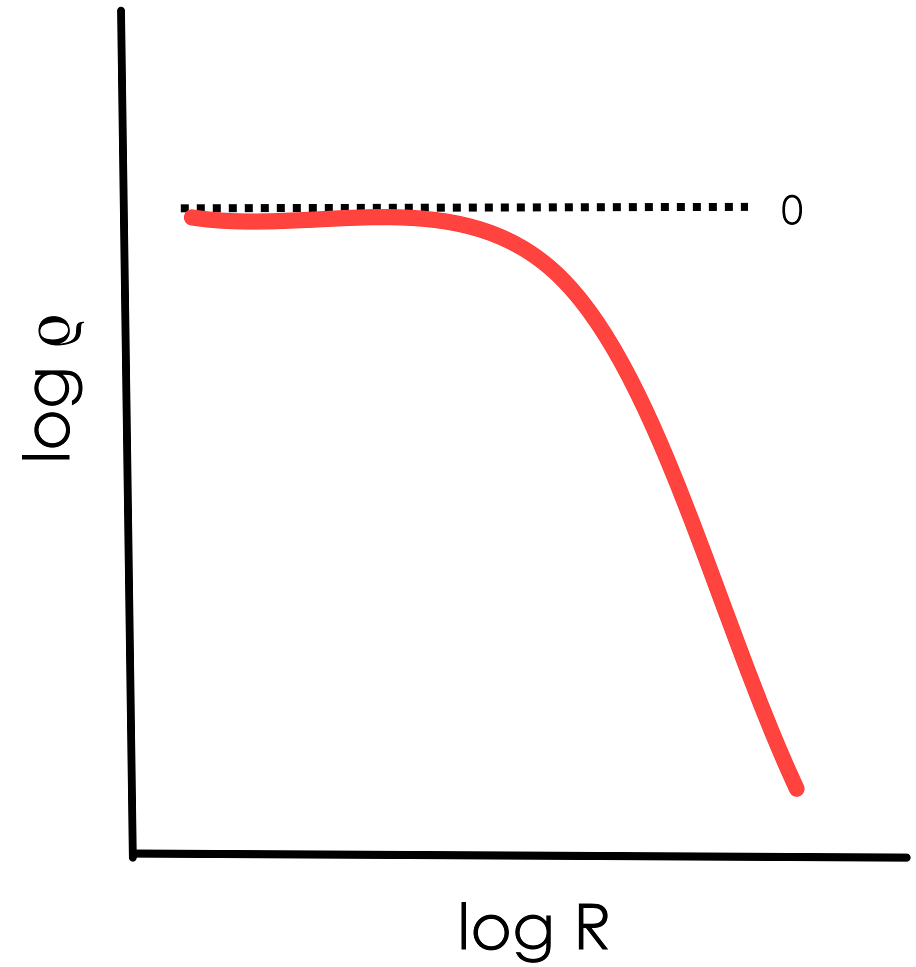
=
+
+
?
$M_{tot} = M_{gas} + M_{disk} + M_{halo}$
1.4M_{HI}
Υ_*
here: based on 3.6mu Spitzer
$V^2_{tot} = V^2_{gas} + V^2_{disk} + V^2_{halo}$
total
gas
stars
halo

Dark Matter Halo Models

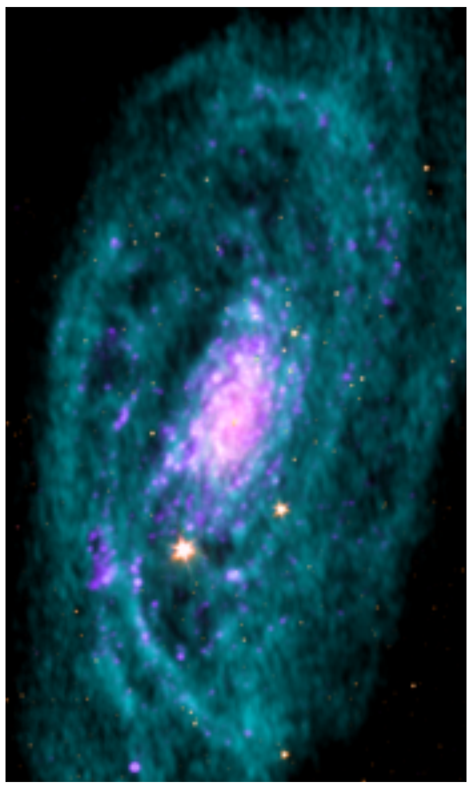
Cold Dark Matter (NFW)

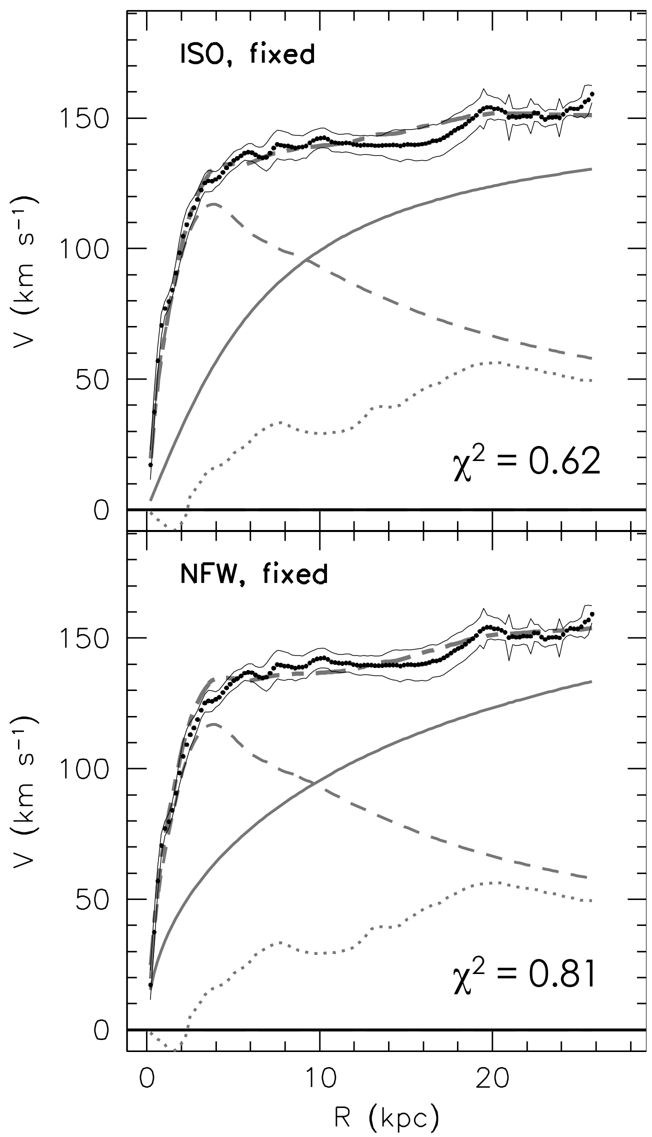


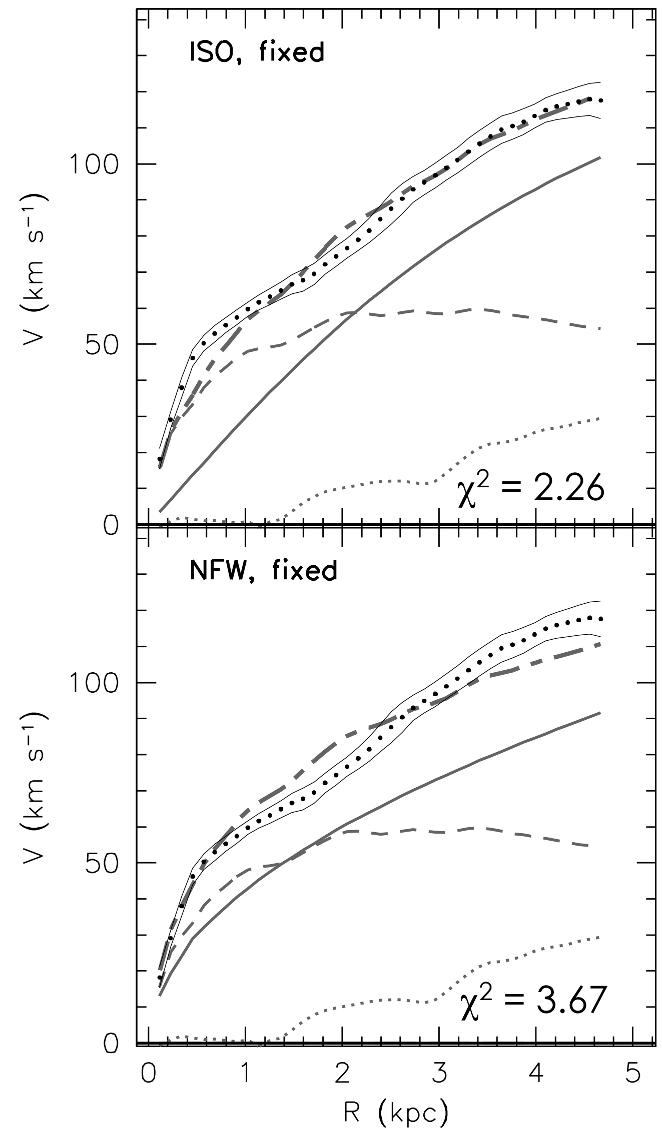
Empirical (ISO)

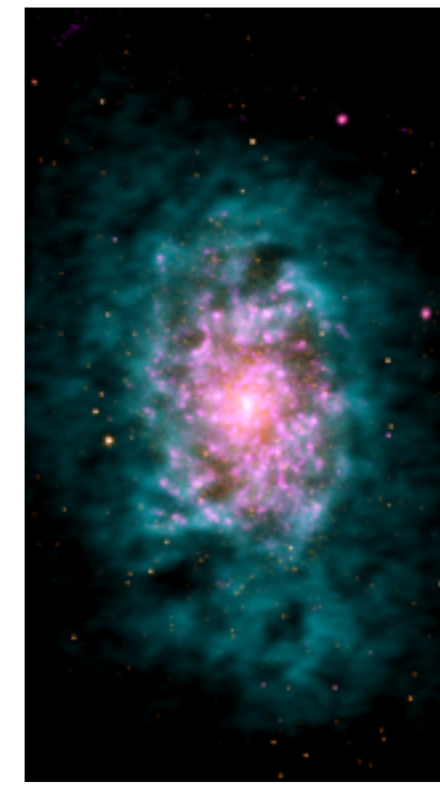


Examples



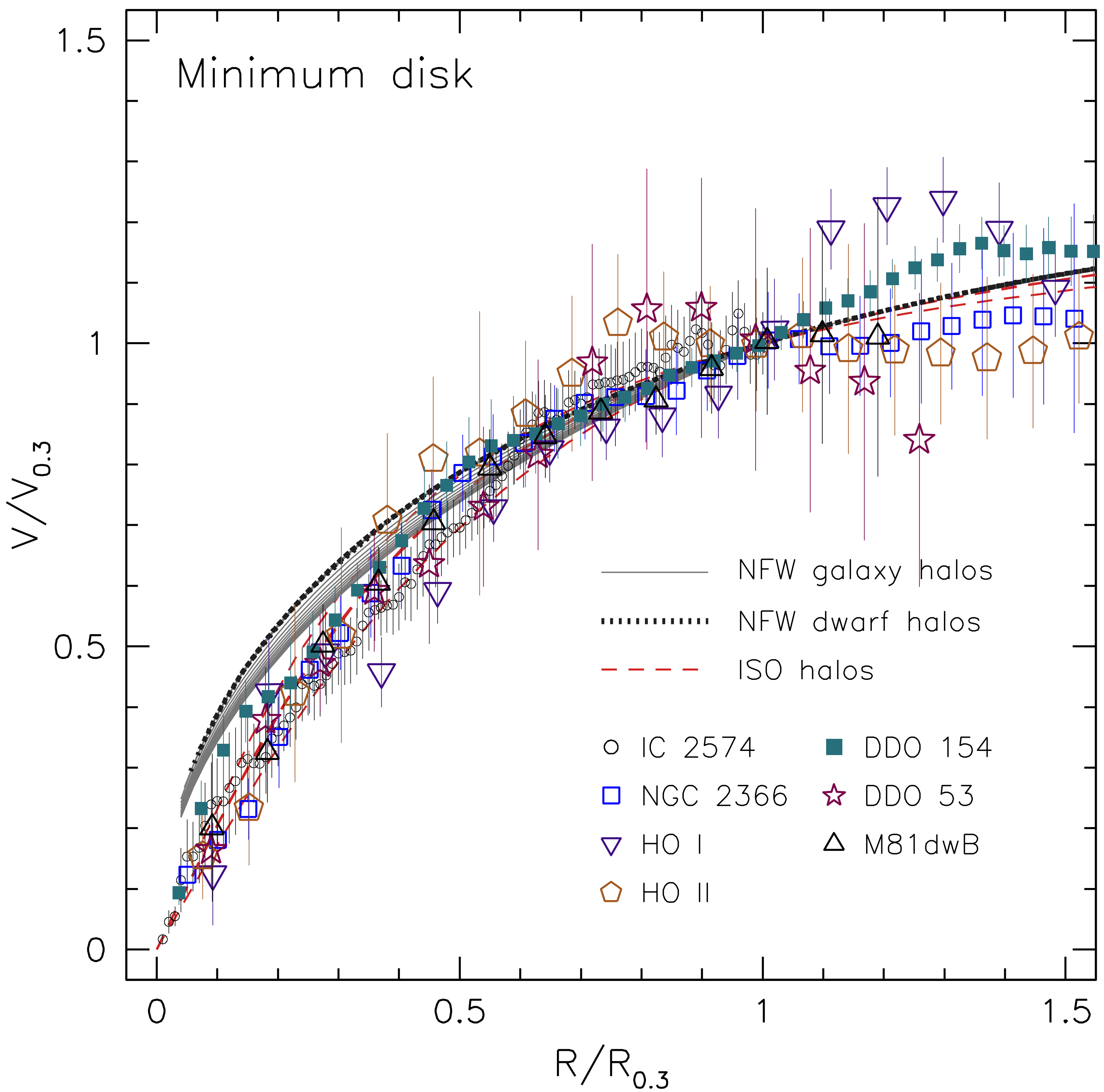






de Blok et al 2008

Rotation curve shape

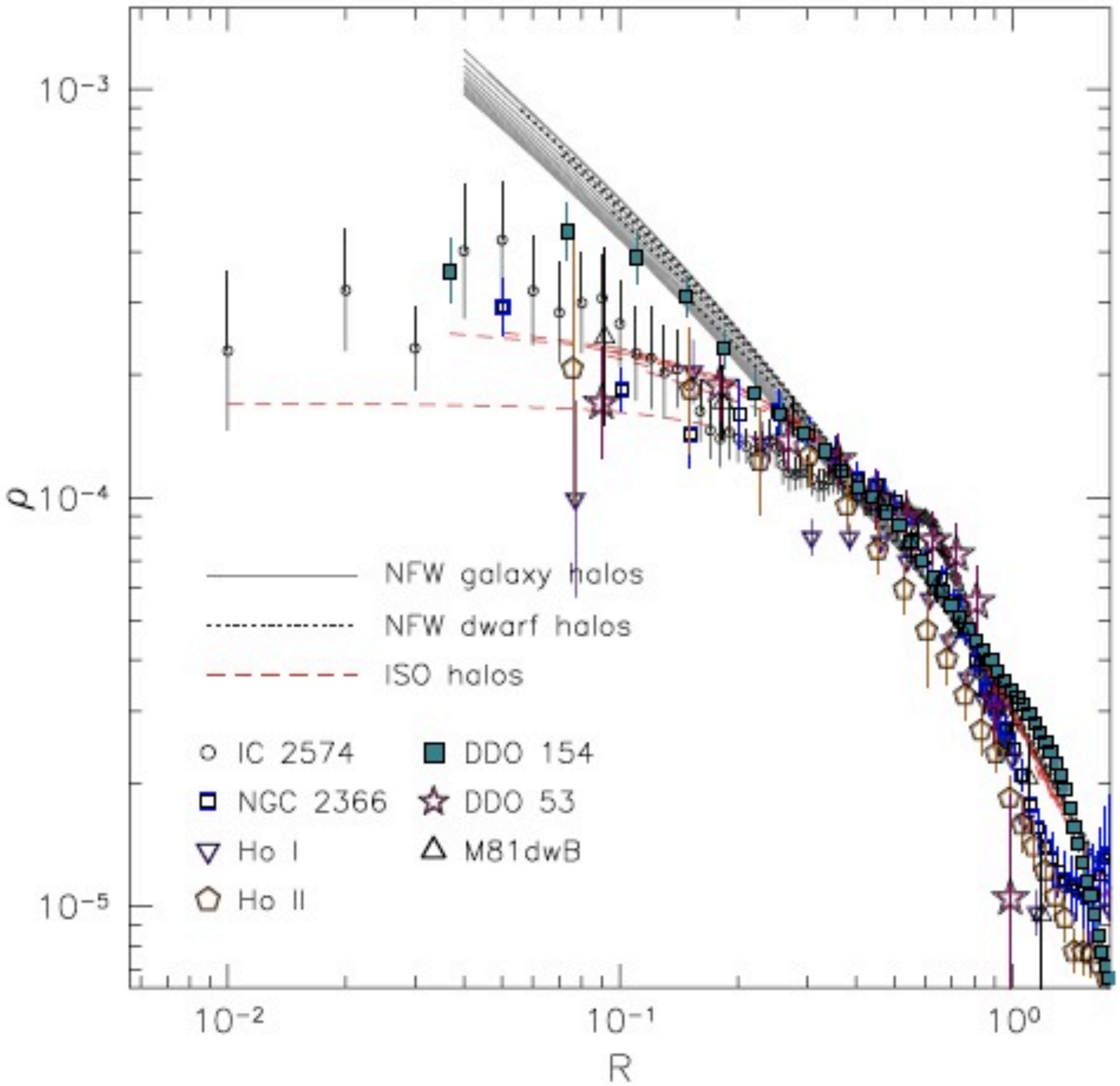


The rotation curves are scaled with respect to $V_{0.3}$ at $R_{0.3}$ where $d(\log V)/d(\log R) = 0.3$.

The scaled rotation curves rise too slowly to match the cuspy CDM halos.

Oh et al. (2011)

Slopes

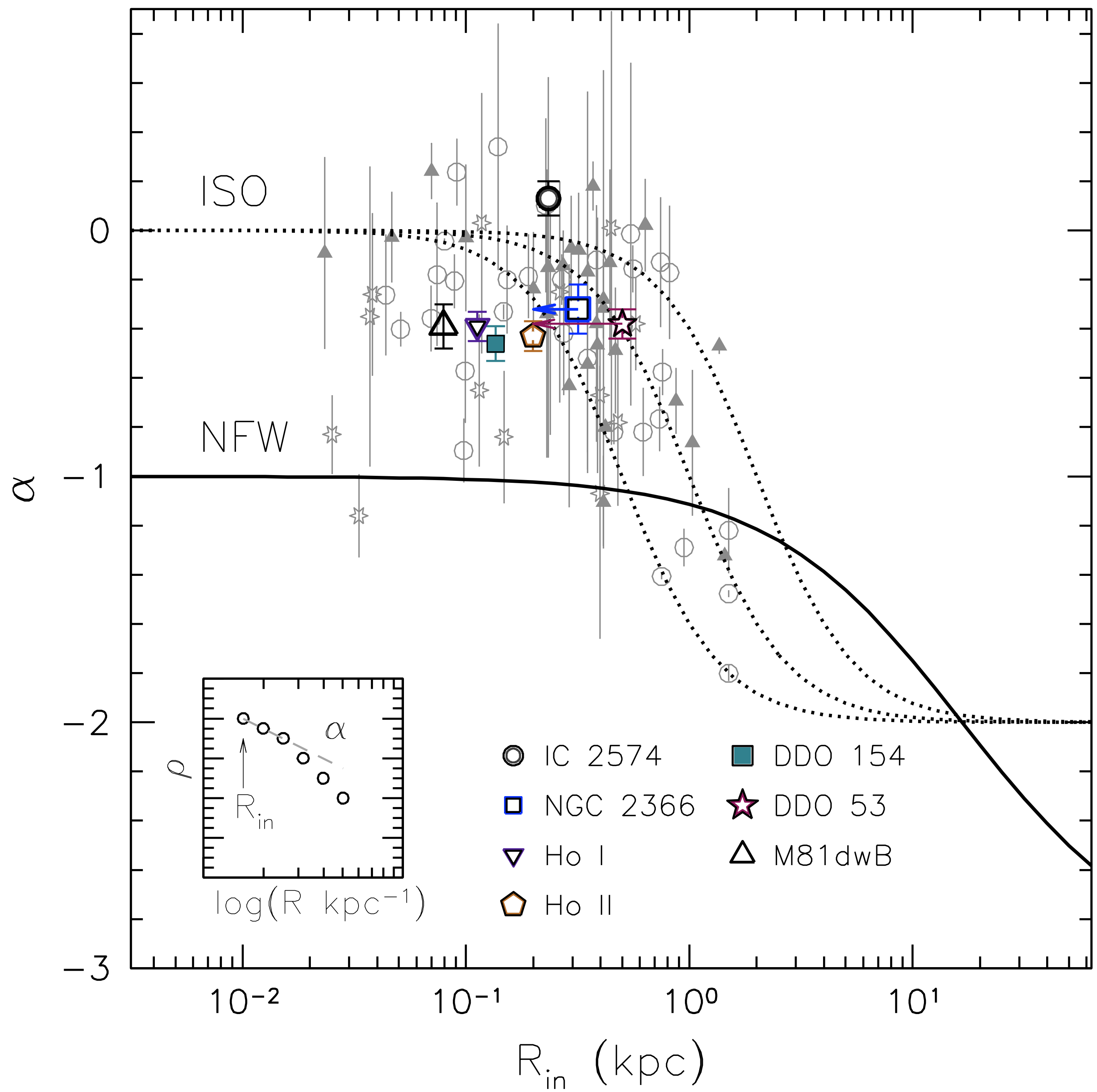


Mean value:
α = –0.29 ± 0.07.

Value found for LSB galaxies:
α = –0.2 ± 0.2, (de Blok et al 2001, 2002)

Oh et al. (2011)

Slopes



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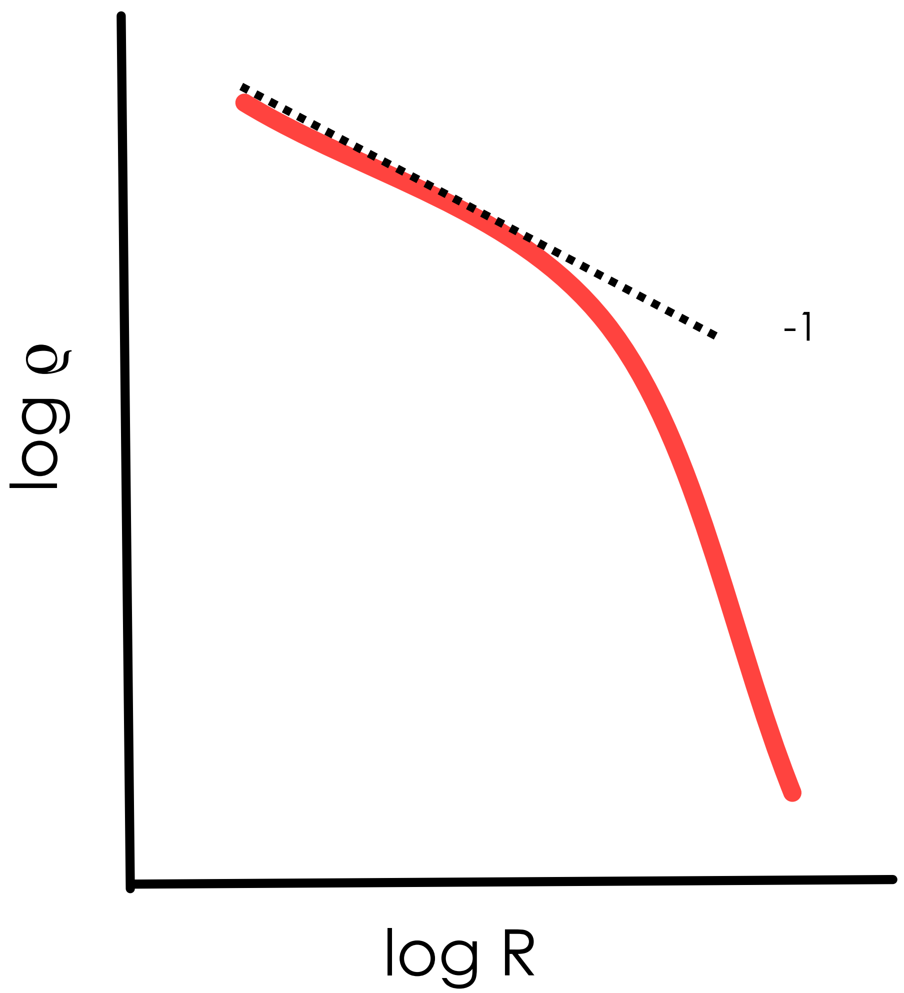
Dark Matter Halo Models

Cold Dark Matter (NFW)



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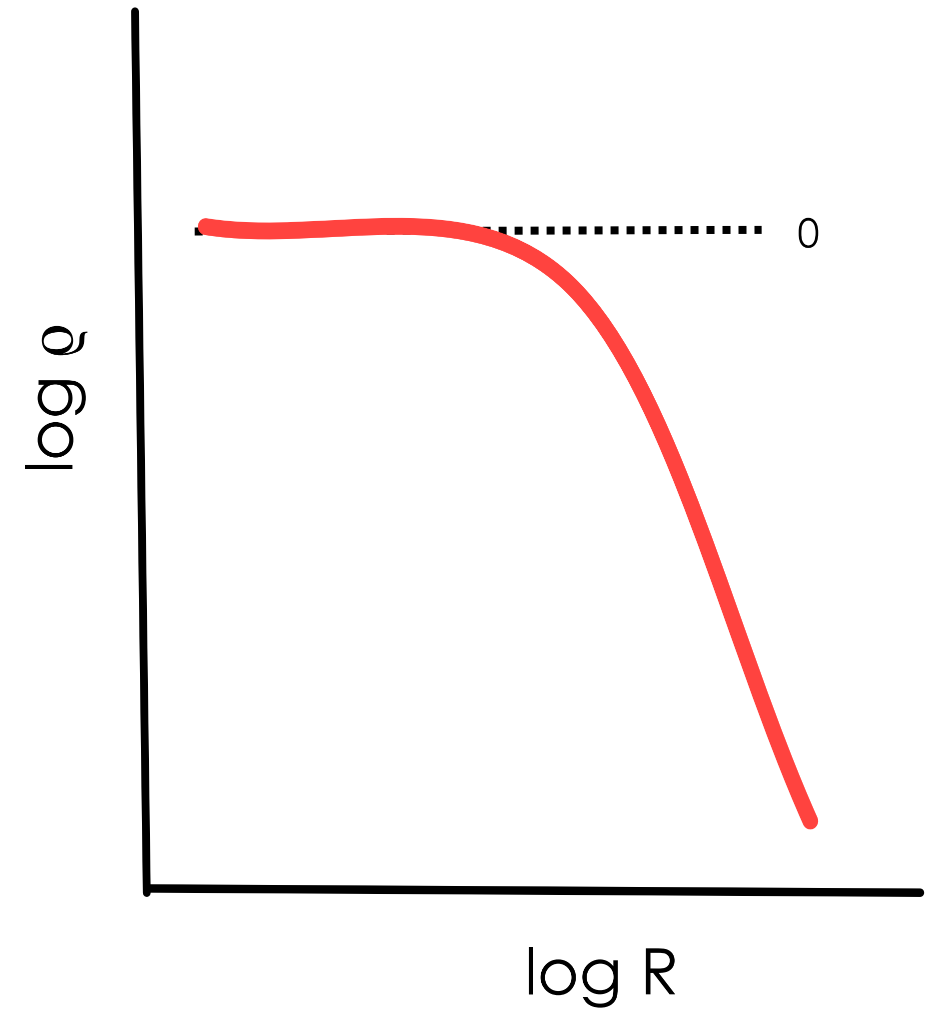
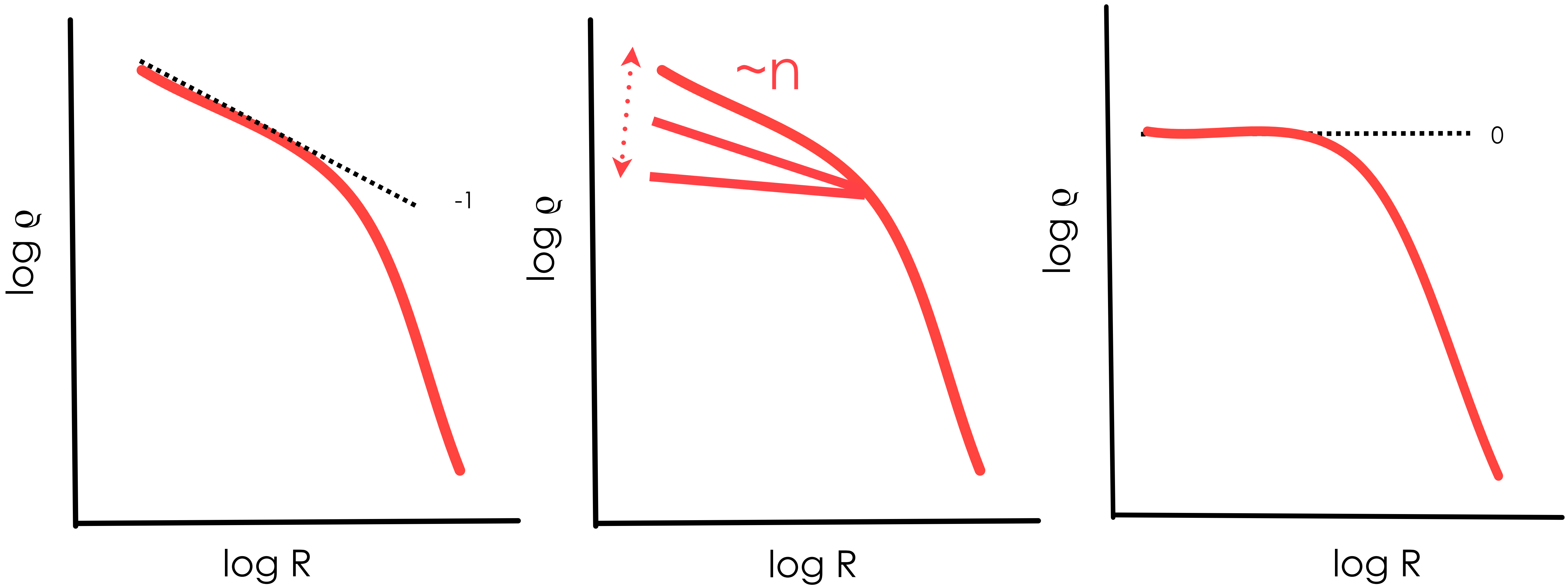


Dark Matter Halo Models

Cold Dark Matter (NFW) | **Einasto** | **Empirical (ISO)**



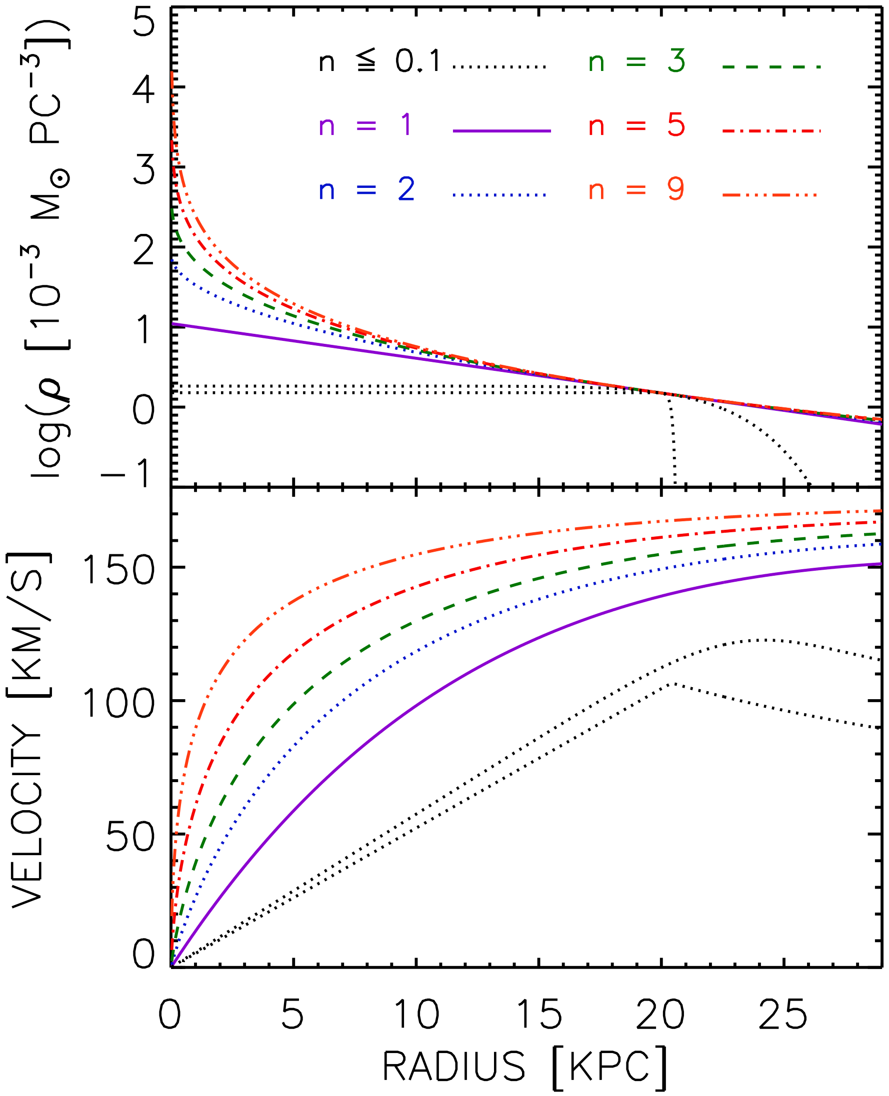
$$\rho_{\mathrm{E}}(r) = \rho_{-2}\,\exp\left\{-2n\left[\left(\frac{r}{r_{-2}}\right)^{1/n} - 1\right]\right\}$$

r_{-2} = radius where d(log ϱ)/d(log r) = -2; $\varrho_{-2} = \varrho(r_{-2})$

Einasto mass profile (Cardone et al 2005; Mamon and Łokas 2005)

The Einasto Halo

Index n regulates inner slope of density and rotation curve

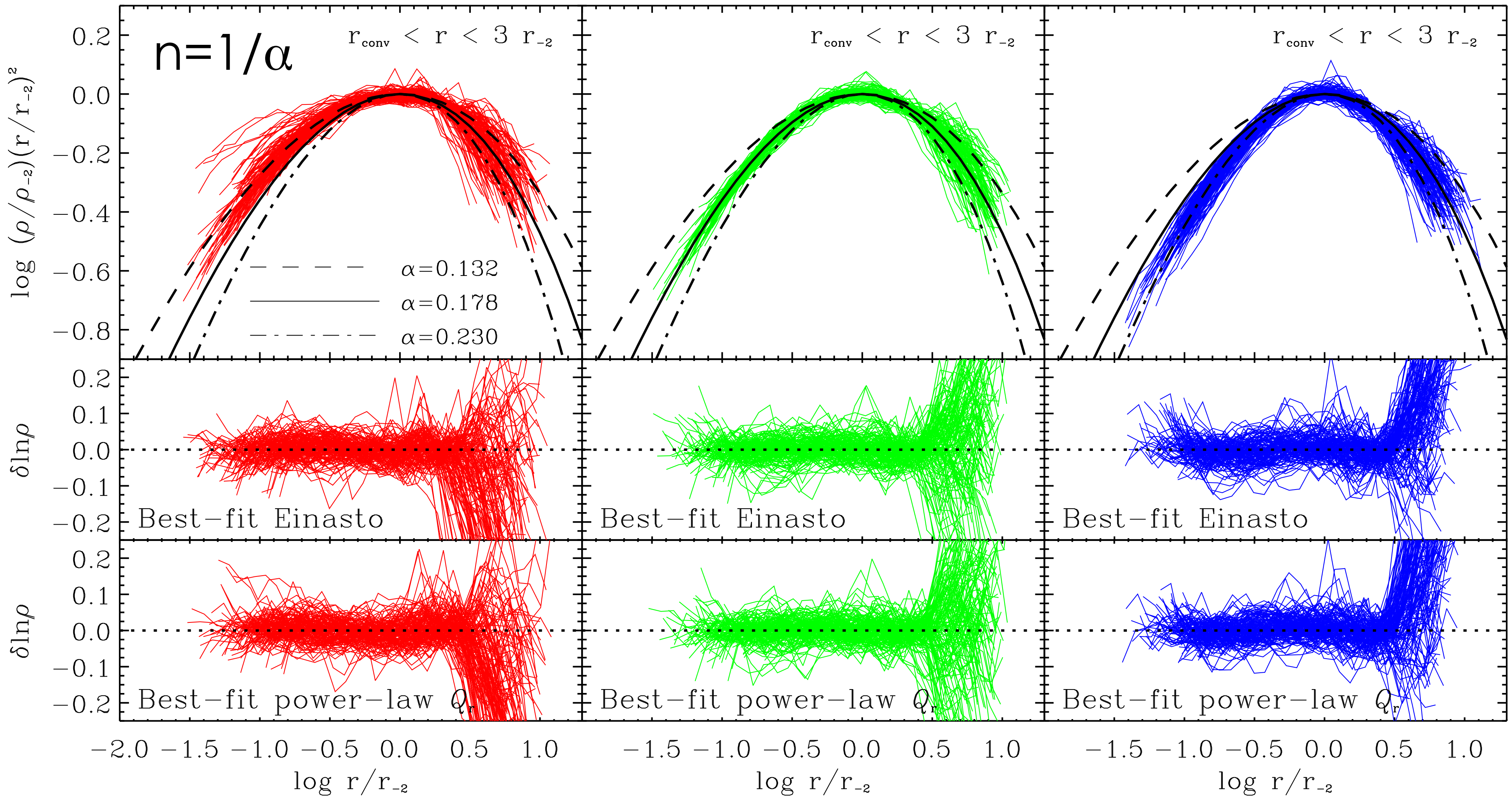


$$\rho_{\mathrm{E}}(r) = \rho_{-2}\, \exp\left\{-2n\left[\left(\frac{r}{r_{-2}}\right)^{1/n} - 1\right]\right\}$$

Chemin et al 2011

Einasto and CDM

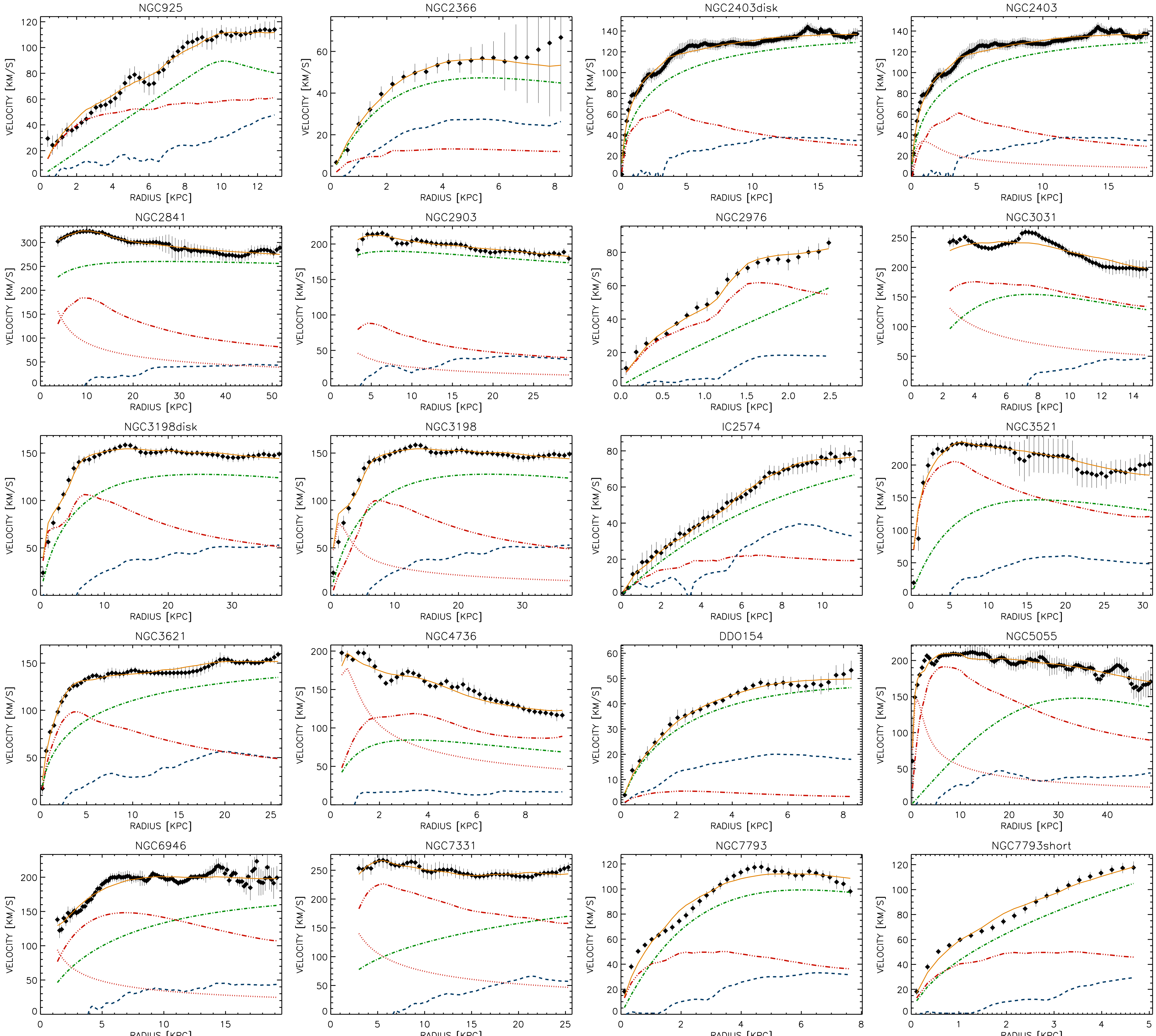
Einasto halo gives good description of CDM halos



Ludlow et al 2011

CDM halos yield fairly narrow range in n.
Navarro et al (2004): n = 6.2 ± 1.2.
Generally one finds 5 ≲ n ≲ 10

Einasto halo, Kroupa IMF, free n



Chemin et al 2011

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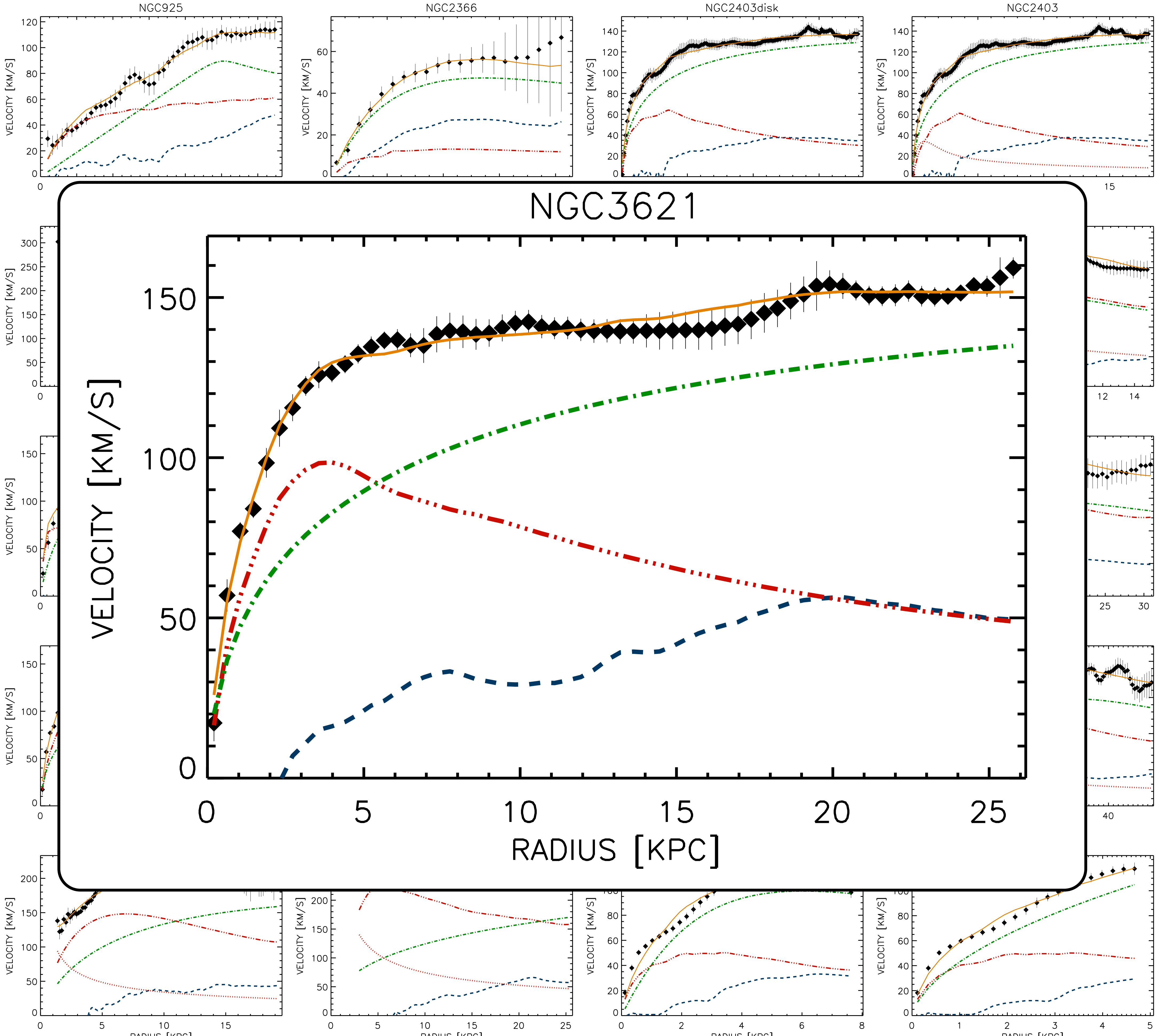
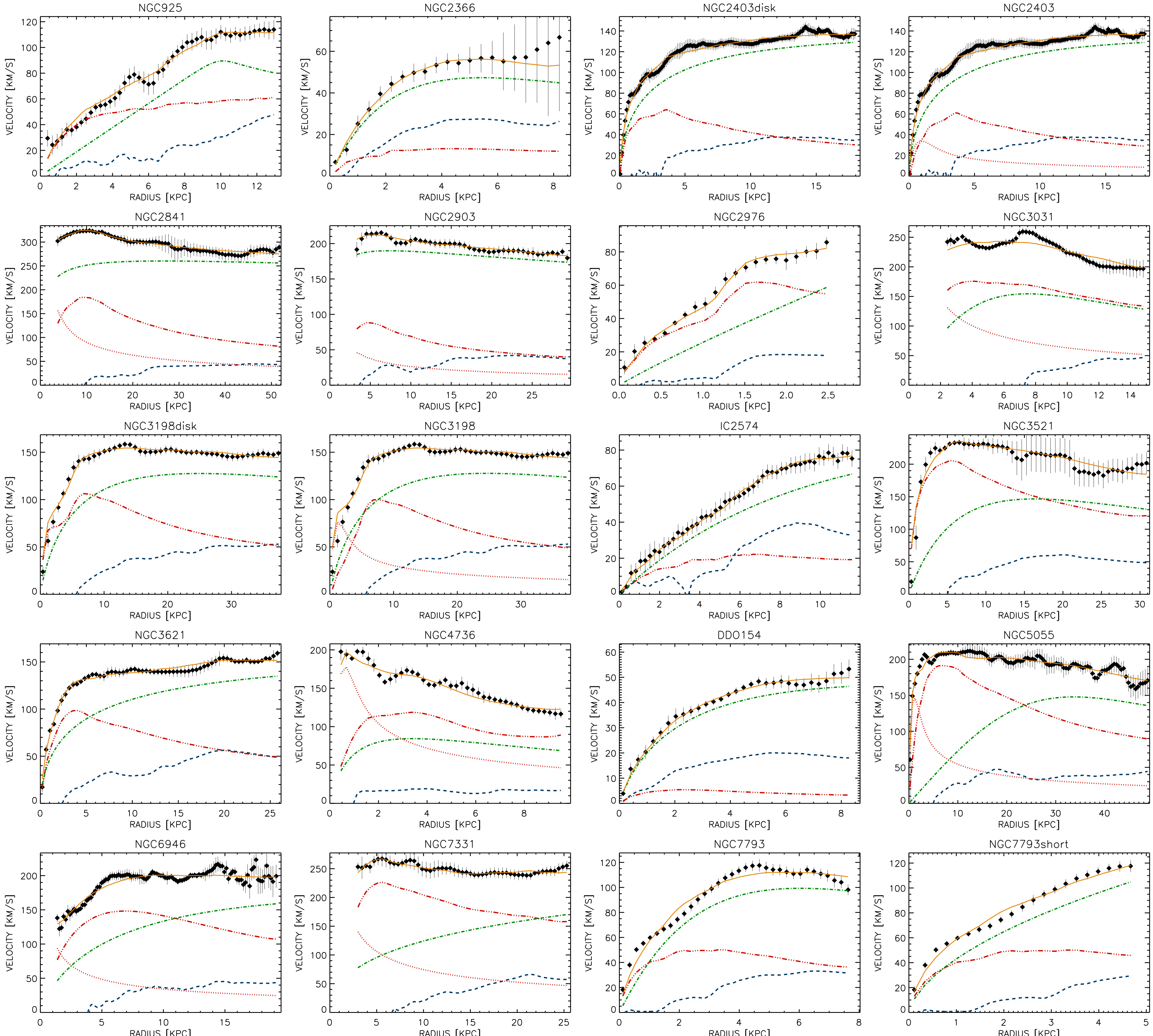


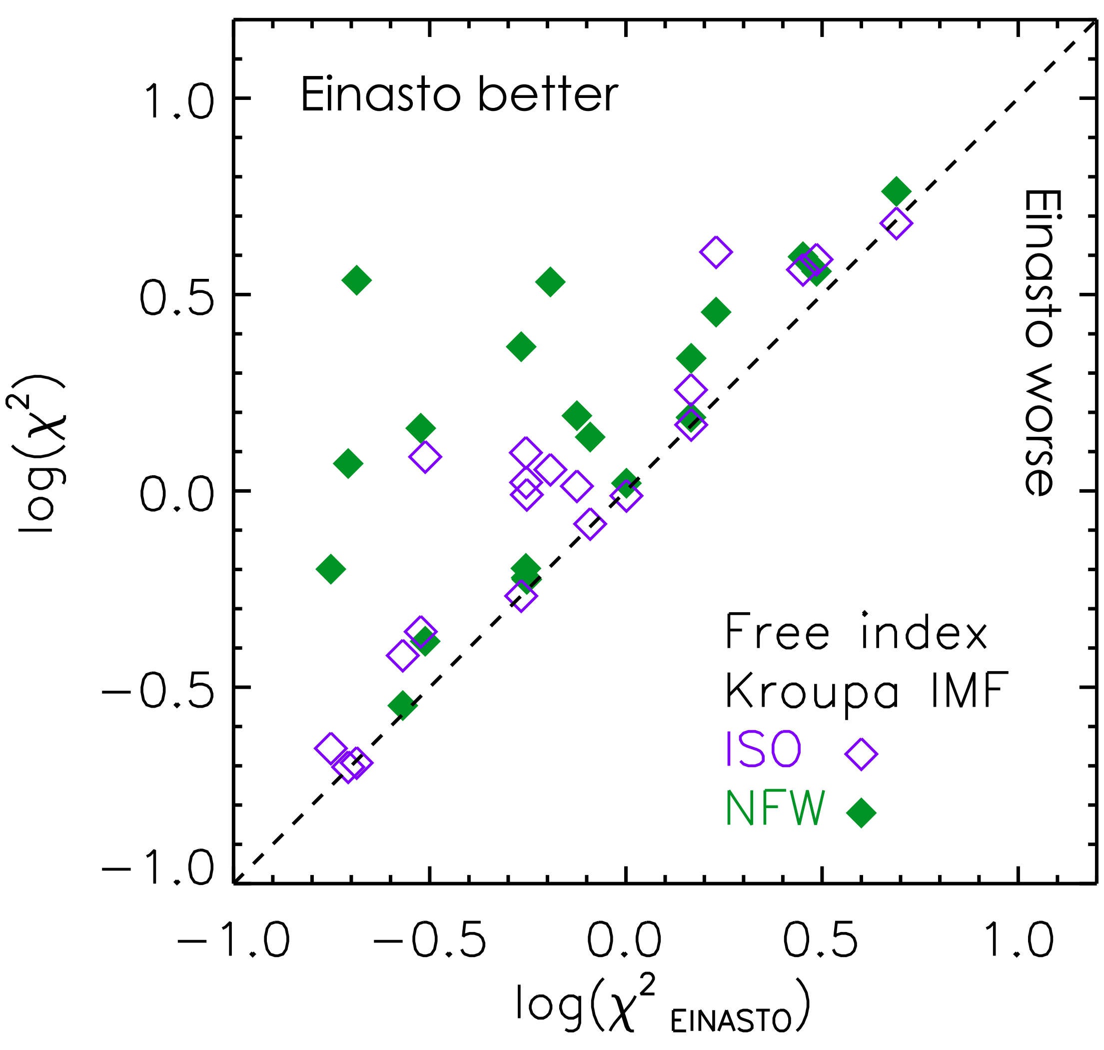
Chemin et al 2011

Einasto halo, Kroupa IMF, free n



Chemin et al 2011

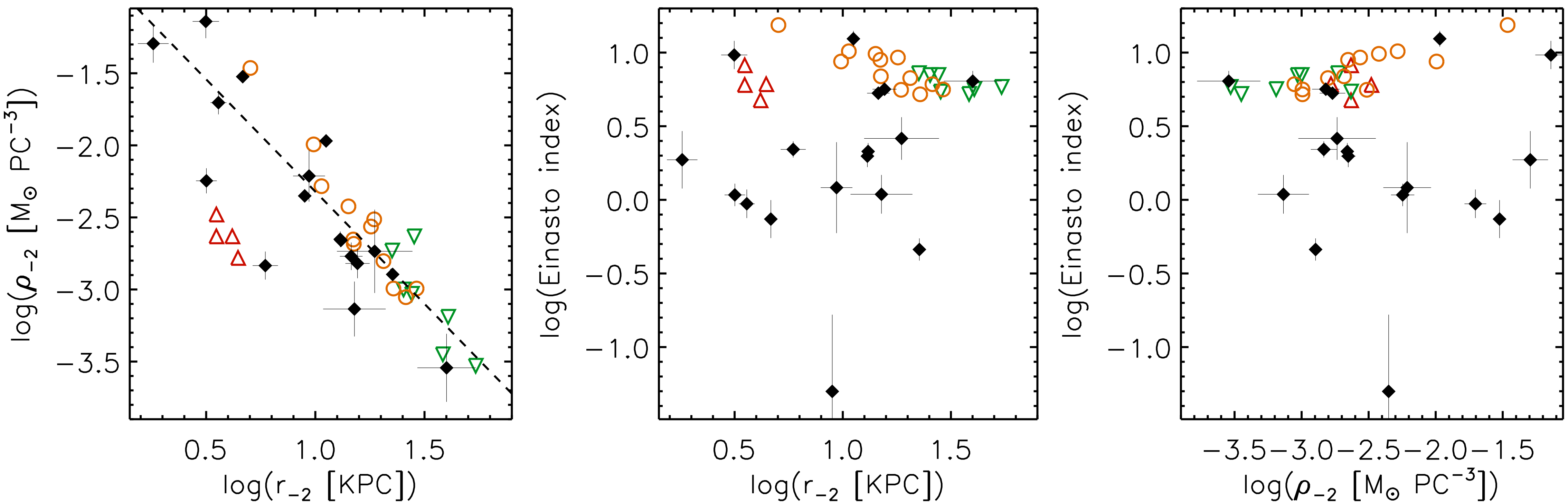
Comparison with ISO and NFW



Einasto halos provide better fits, also to observed rotation curves

Chemin et al 2011

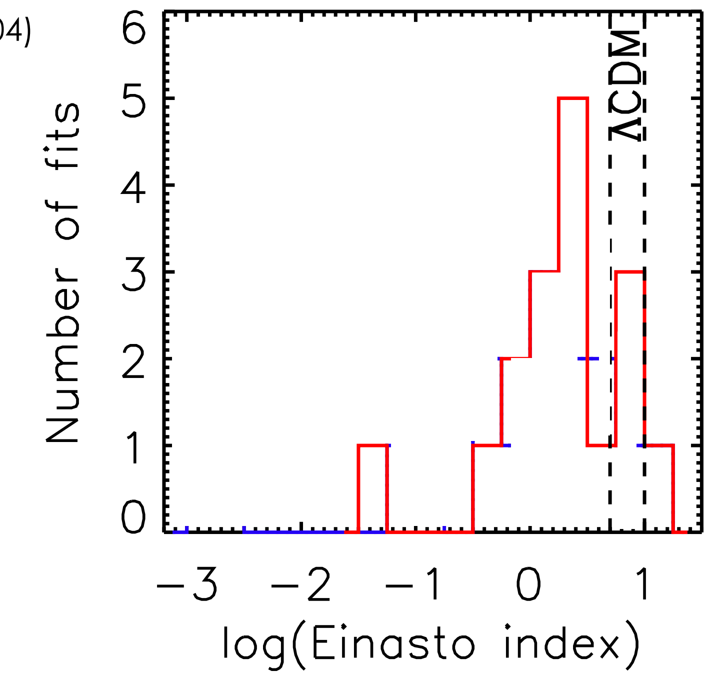
Einasto Halo Parameters



Kroupa IMF

- dwarf-sized halos (Navarro et al 2004)
- galaxy-sized halos (Navarro et al 2004)
- galaxy-sized halos with baryons (Tissera et al 2010)

degenerate fits not shown

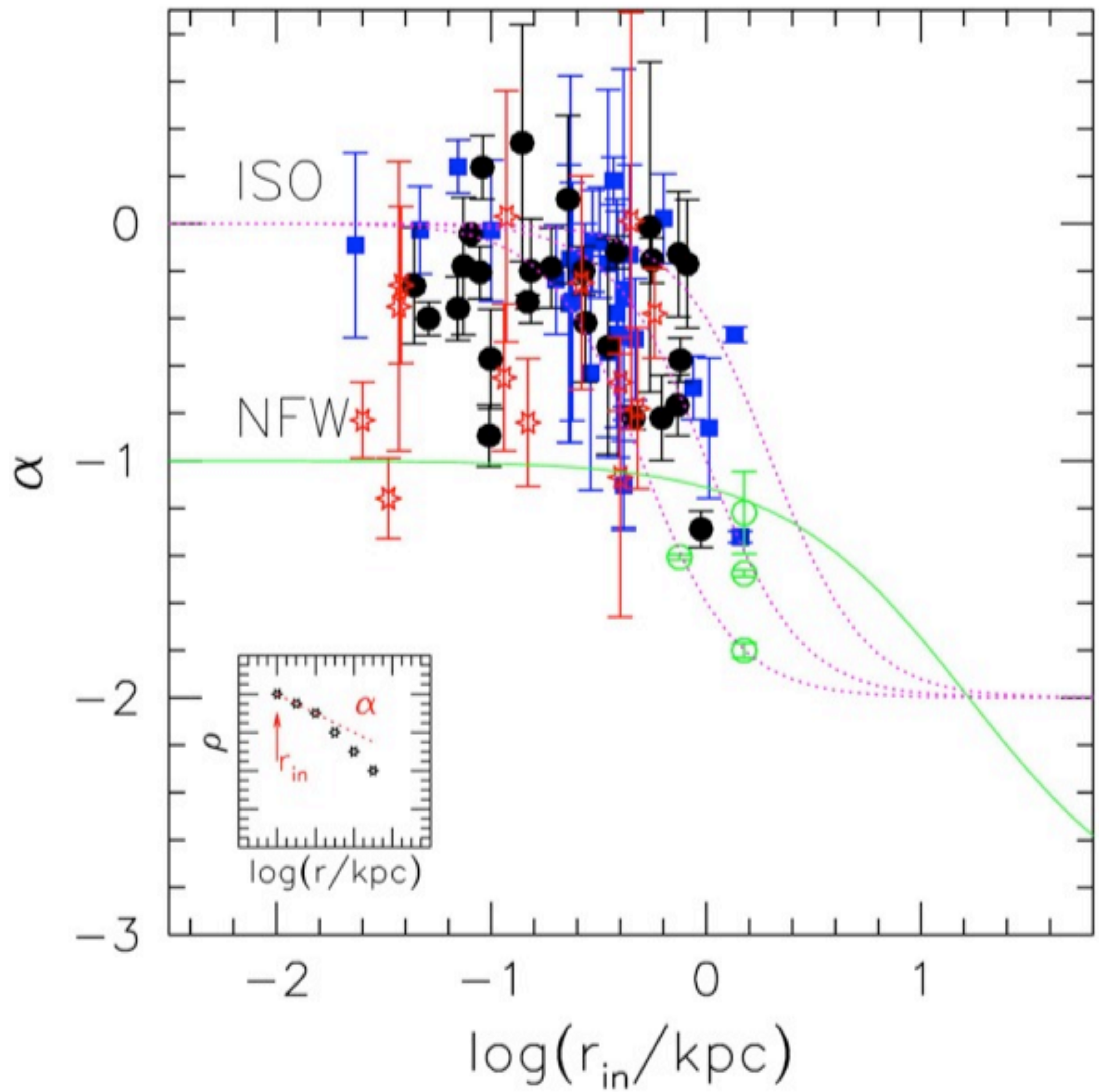


No single index or simple relation can describe observations

Observed indices smaller than simulations

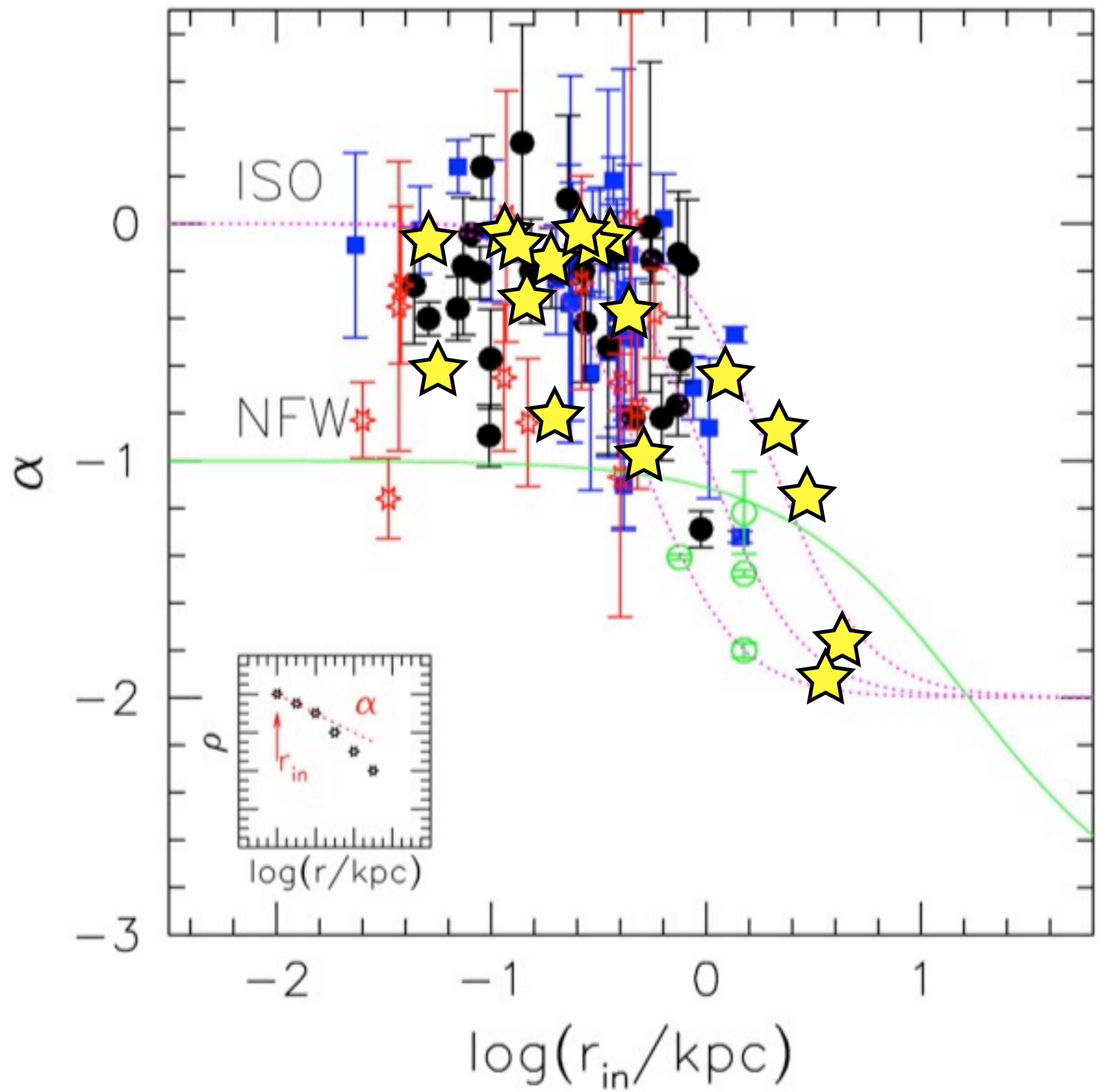
Chemin et al 2011

Einasto slope and resolution



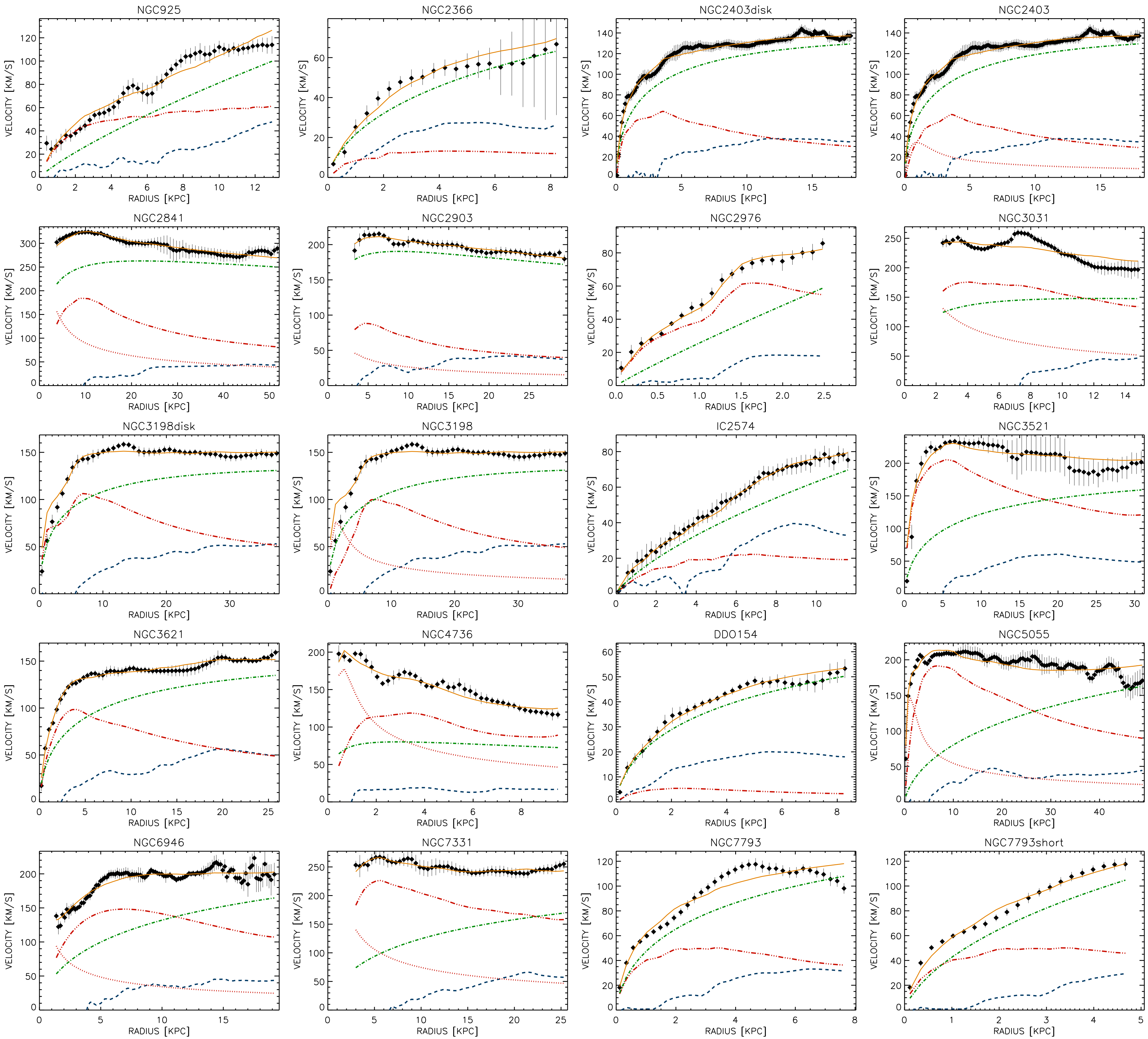
THINGS, Einasto halo, free n, Kroupa IMF

Einasto slope and resolution



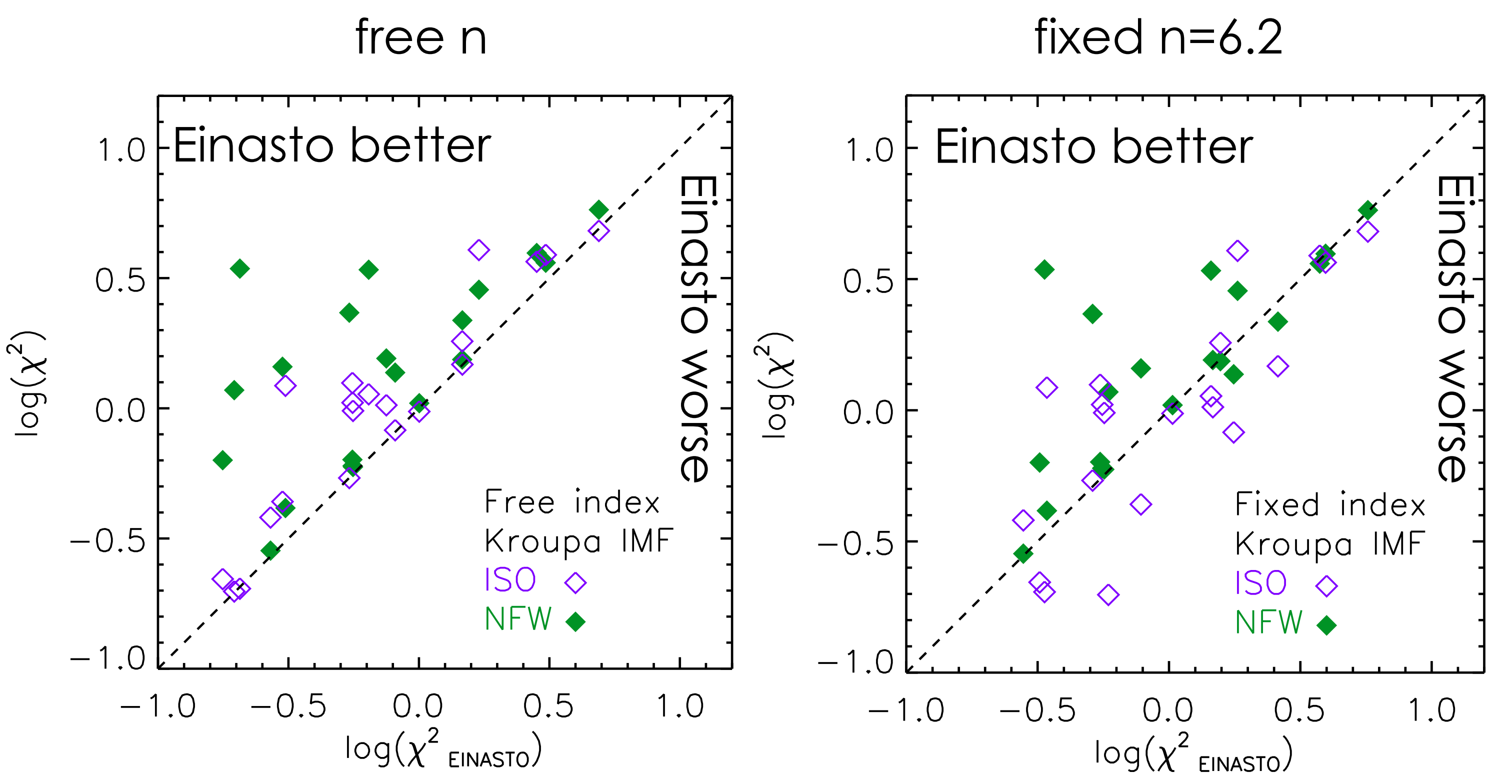
THINGS,
Einasto halo,
free n,
Kroupa IMF

Einasto halo, Kroupa IMF, n=6.2



Chemin et al 2011

Comparing free and fixed n



$$\rho_E(r) = \rho_{-2} \exp\left\{-2n\left[\left(\frac{r}{r_{-2}}\right)^{1/n} - 1\right]\right\}$$

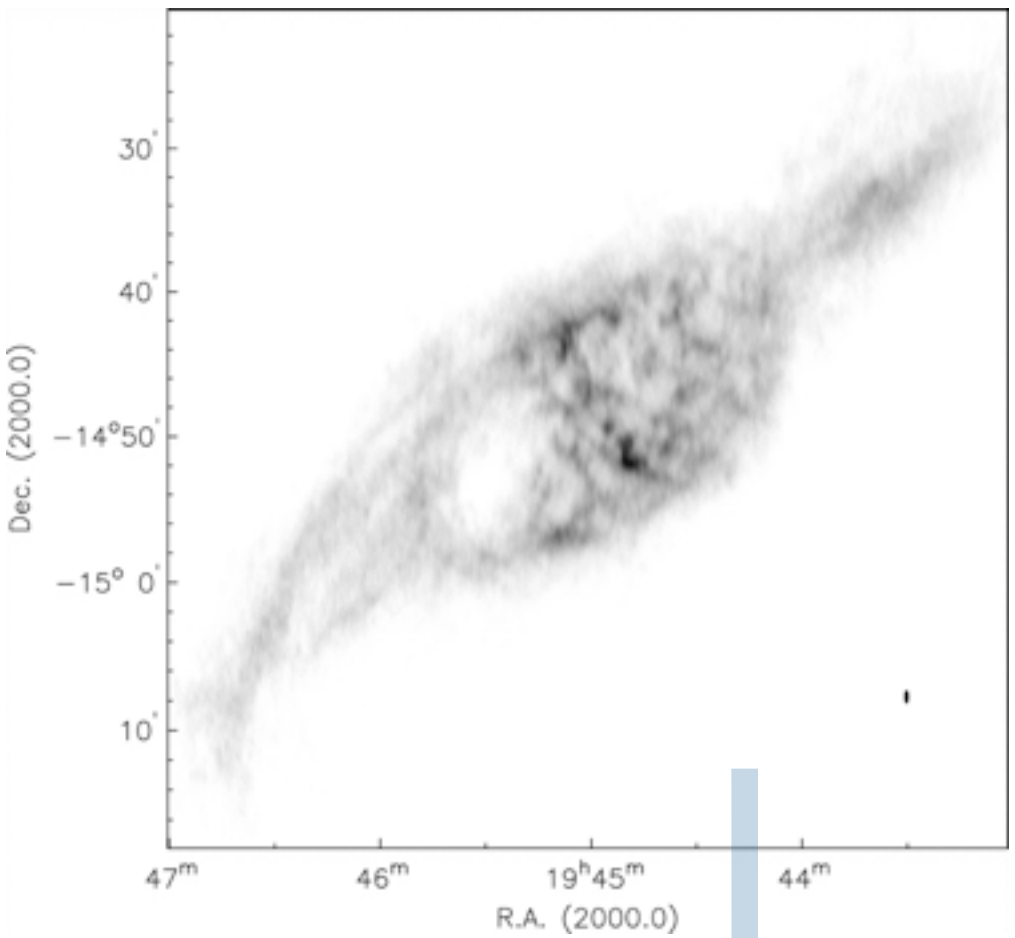
89% fixed index fits worse than free index
55% fixed index fits worse than ISO
80% fixed index fits better than NFW

Chemin et al 2011

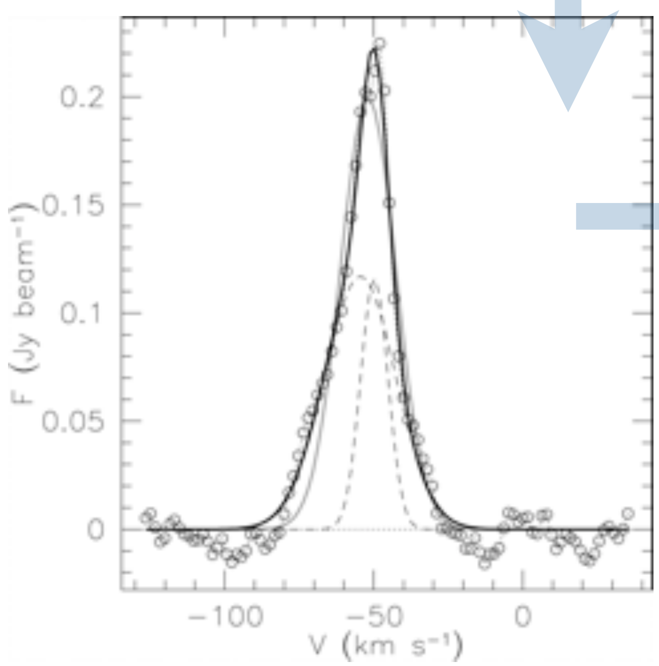
Einasto Results

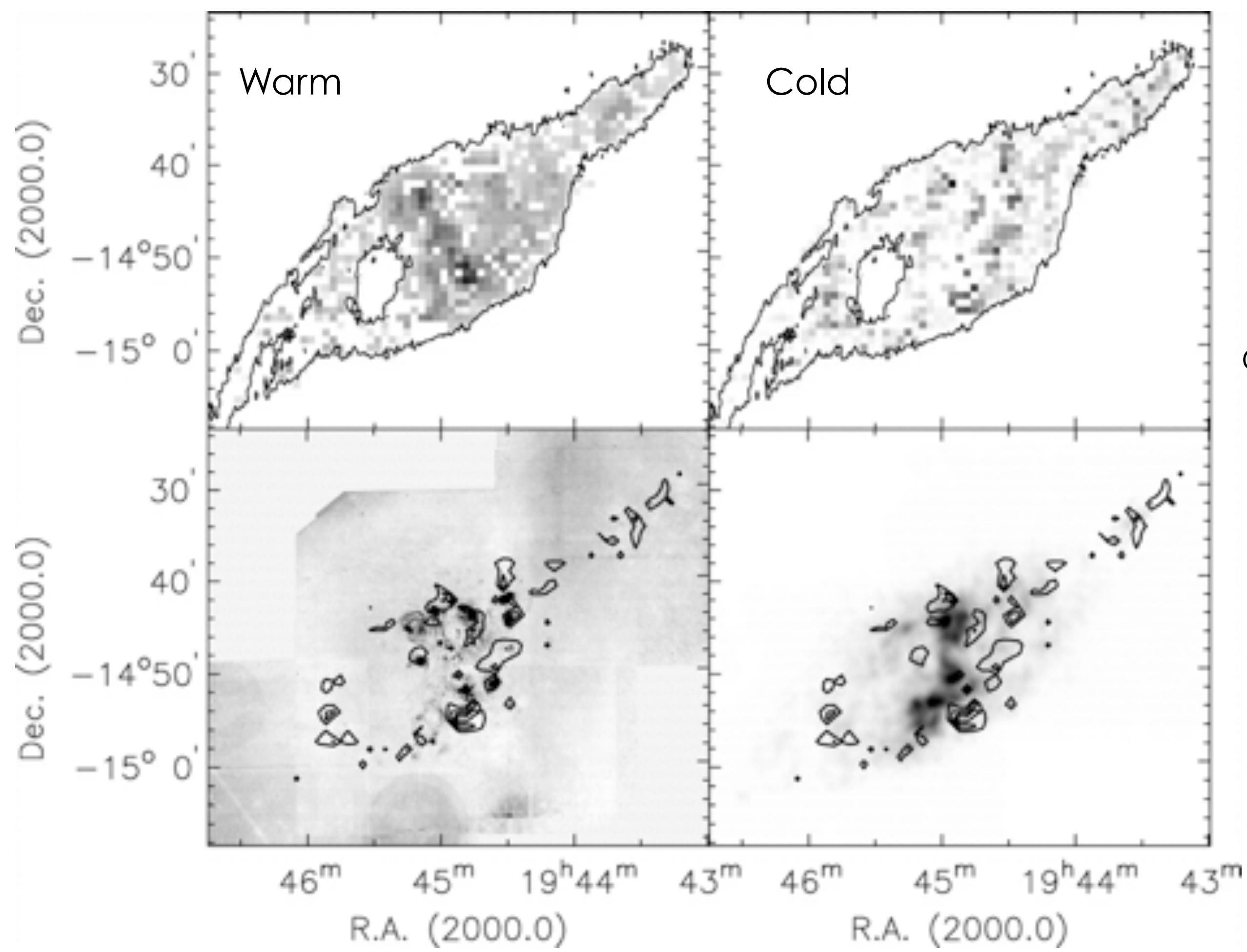
- Einasto fits better than ISO or NFW
- However, no unique n-value, no scaling between masses
- No universal Einasto halo in THINGS galaxies
- Typically smaller n-value than CDM halos. $n>4$ is rare
- To test: larger range in masses, more M/L* scenarios

Phases of the Neutral ISM



- Warm: T ~ 10^4 K
- Cold: T ~ few 100 K

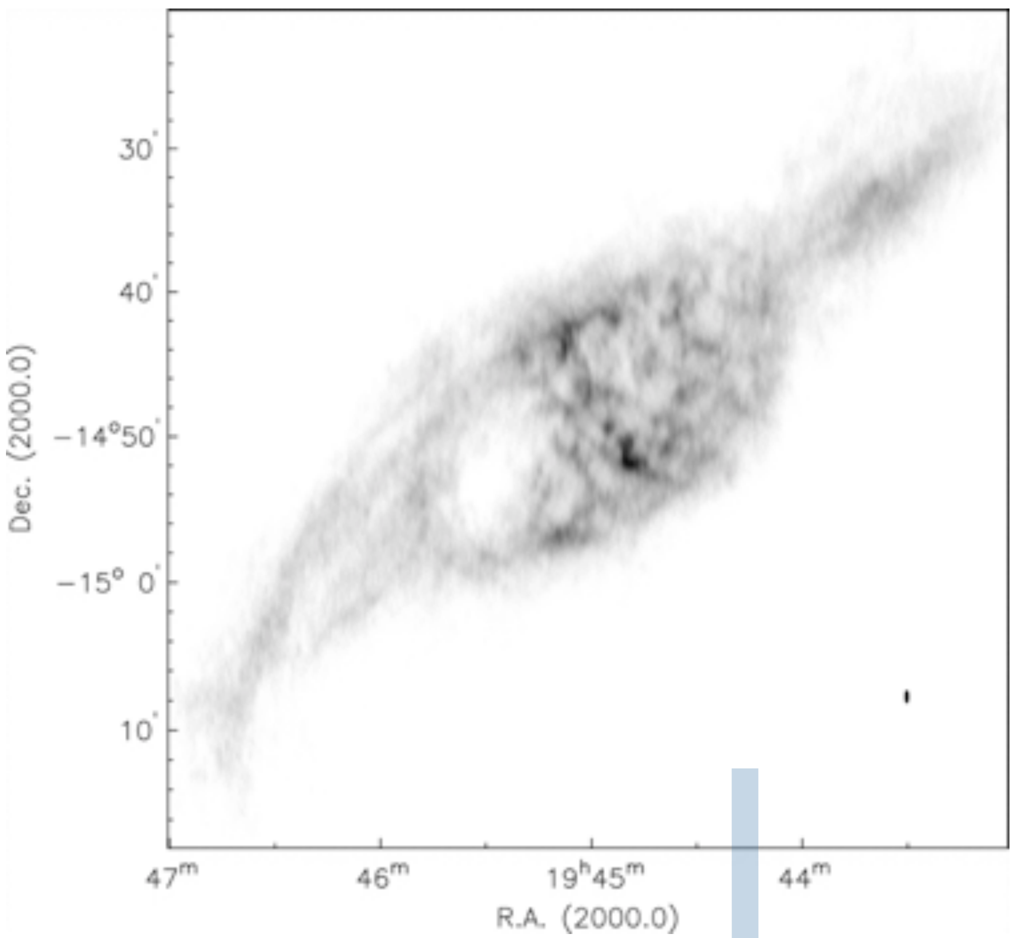


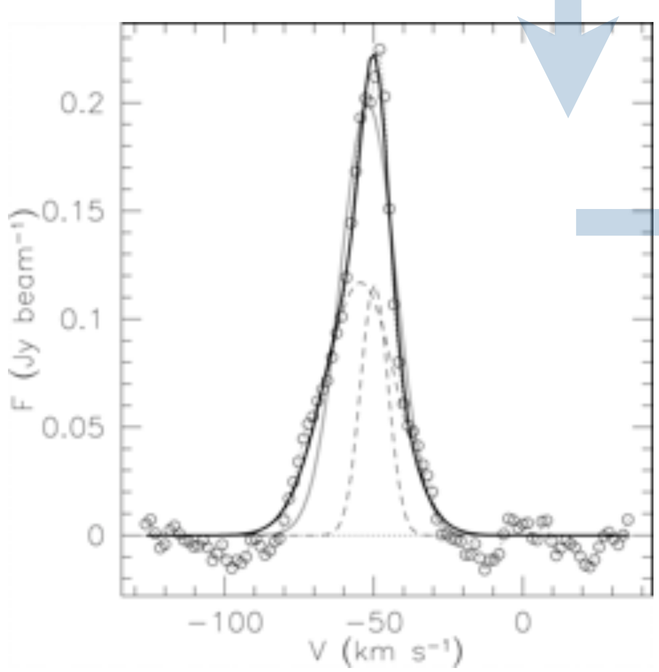


de Blok & Walter 2006a
also Young & Lo 1997, Braun 1997, etc

Input for star formation recipes and simulations

Phases of the Neutral ISM





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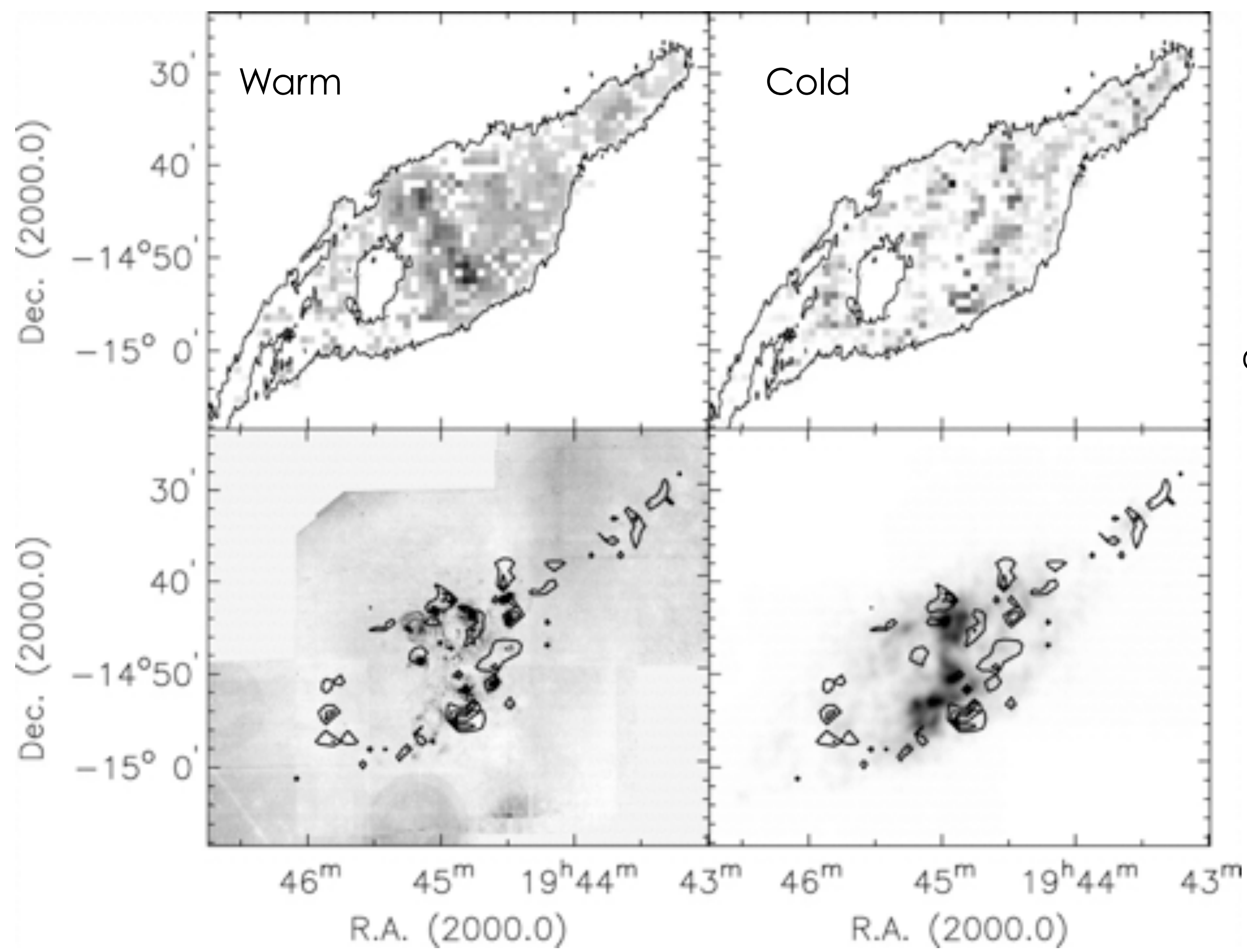

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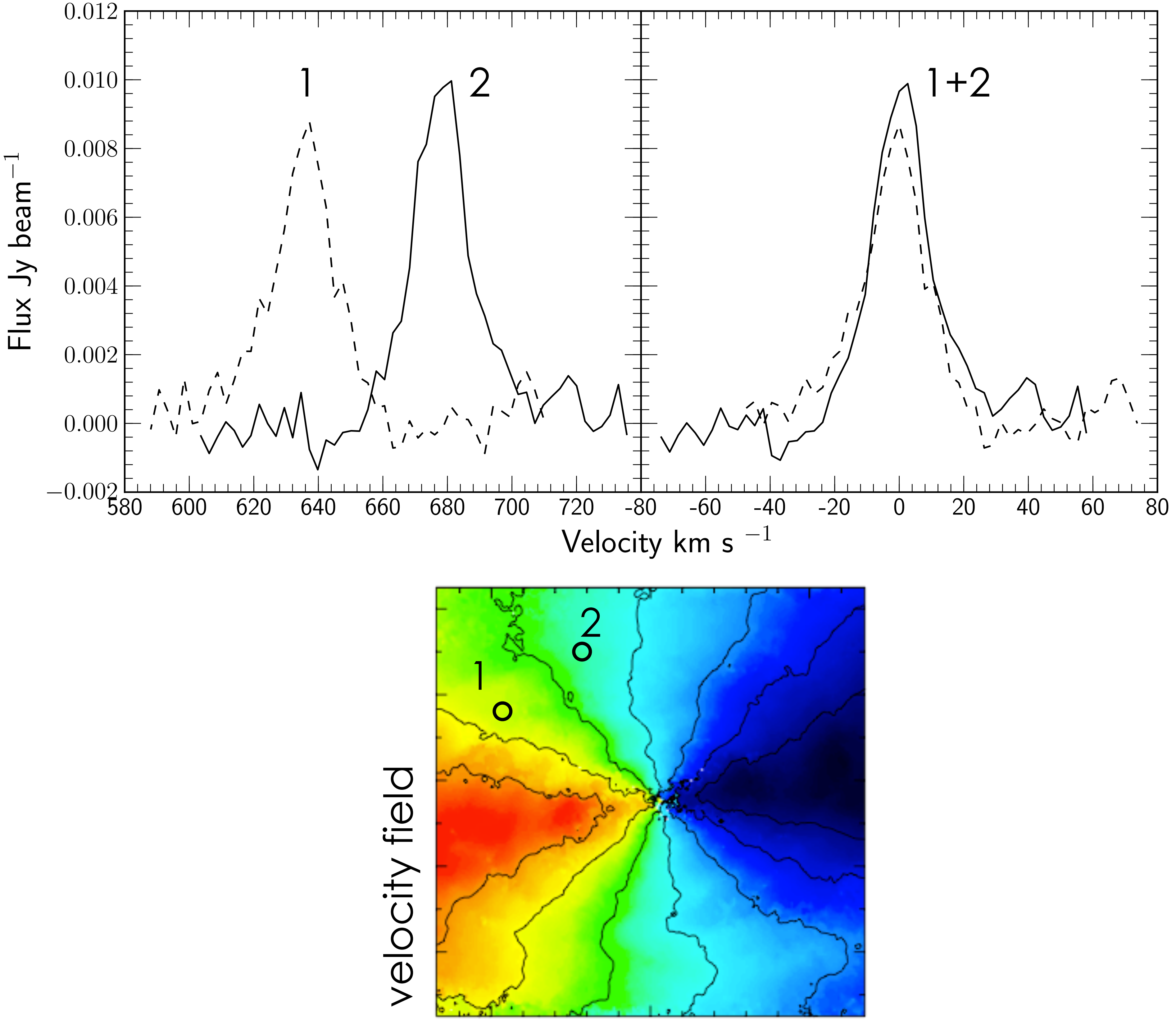
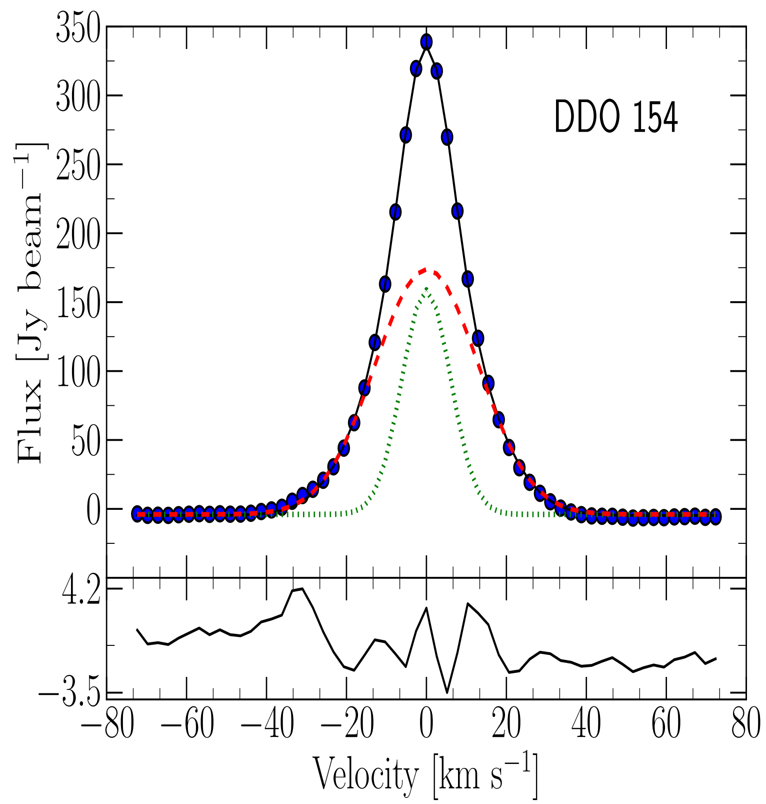
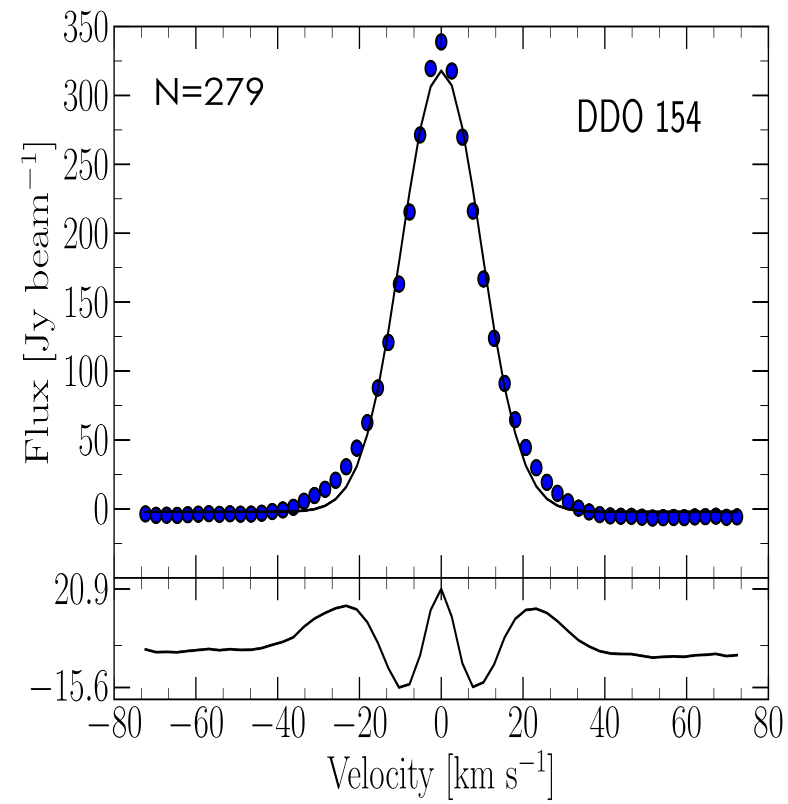
Input for star formation recipes and simulations

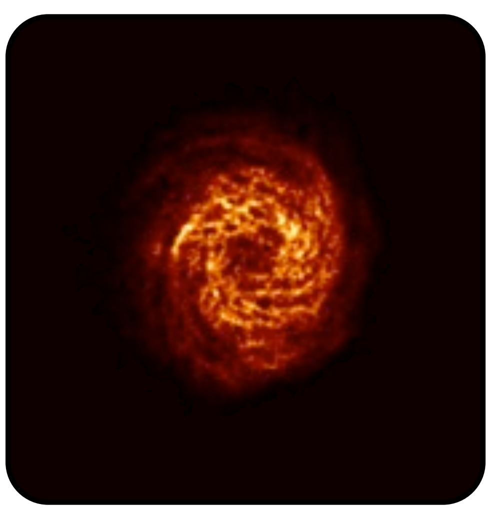
Shifting Profiles

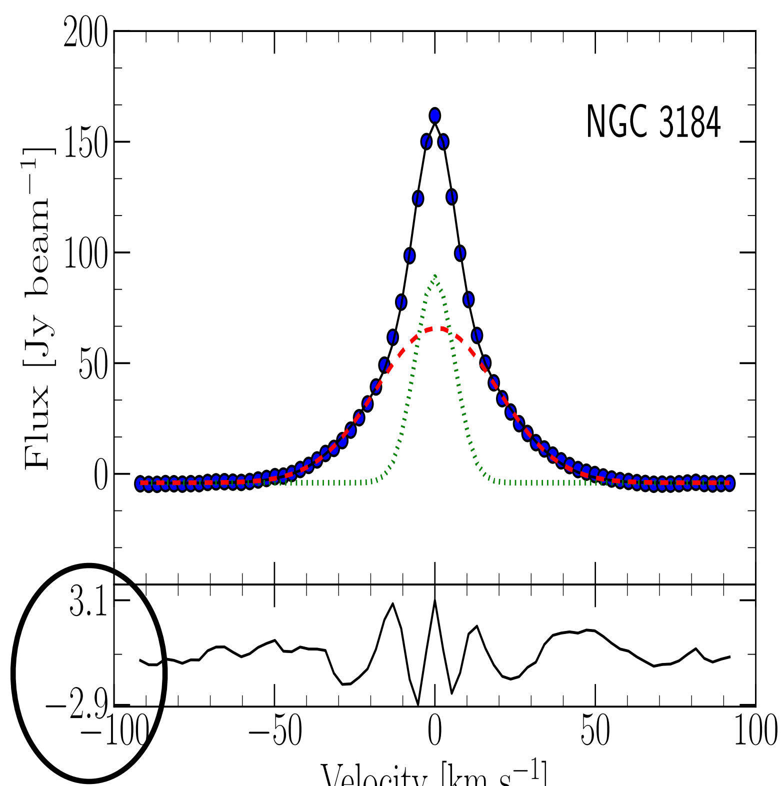


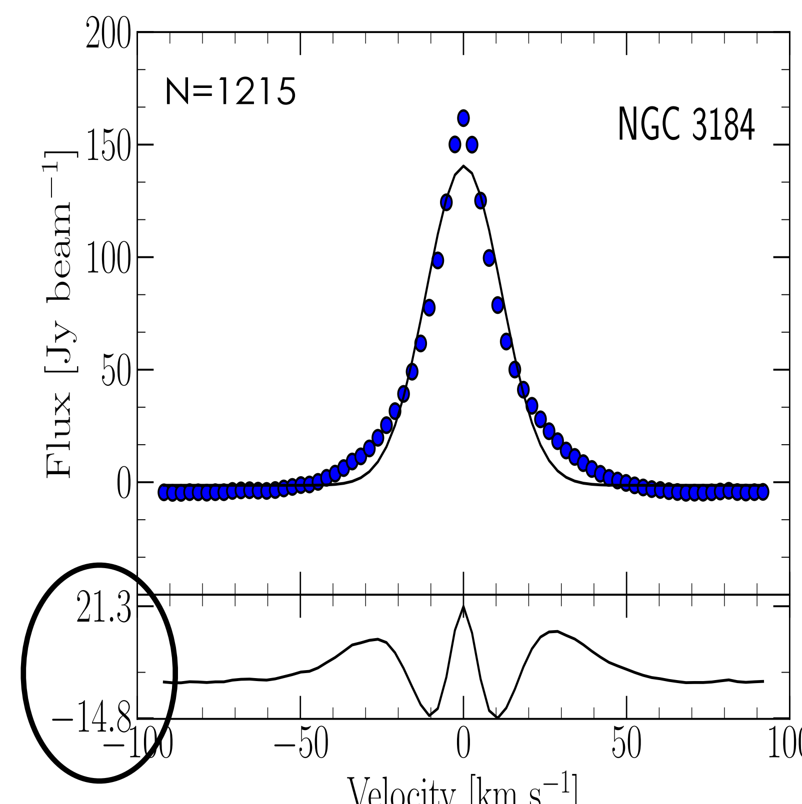
Super Profiles









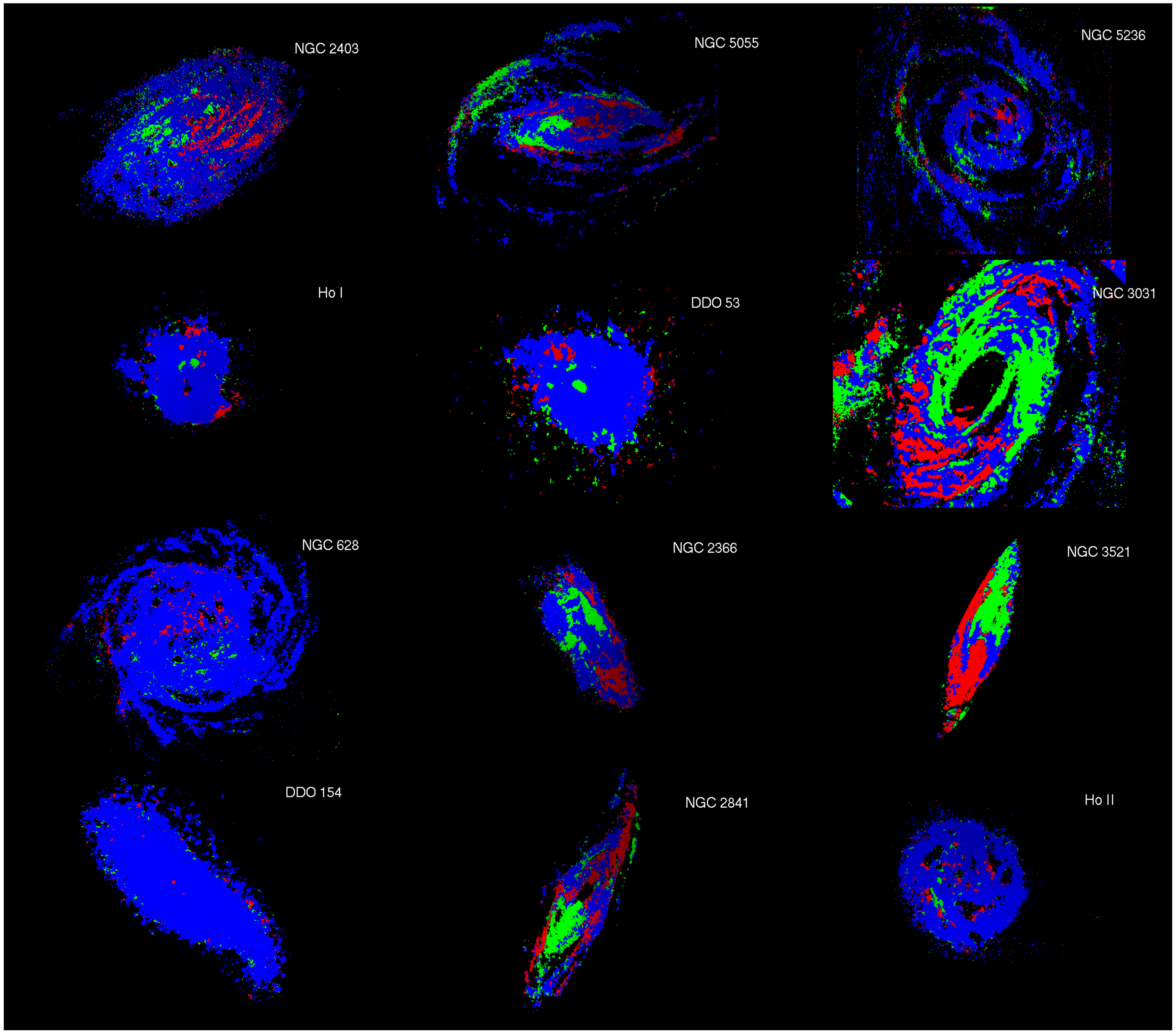


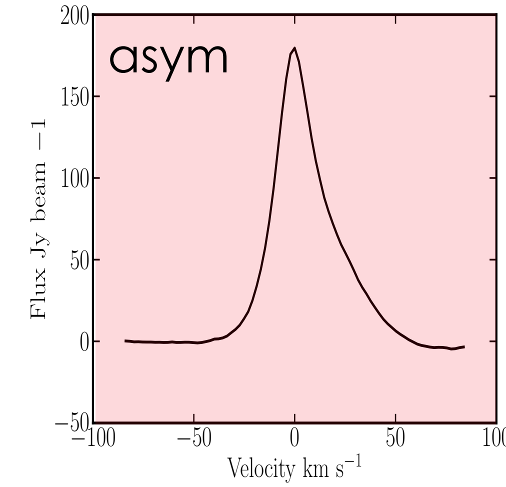
Injamasimanana et al (2012, in prep)

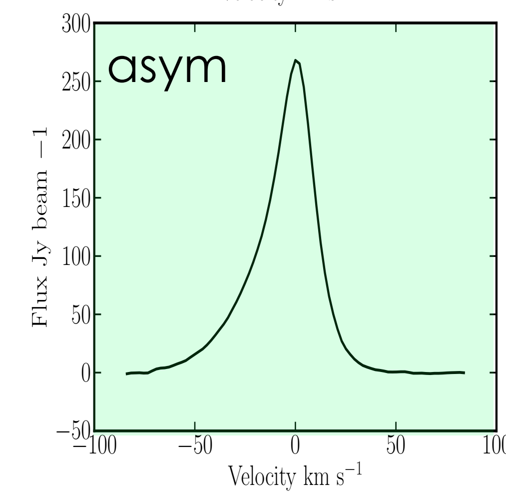
False Super Profiles

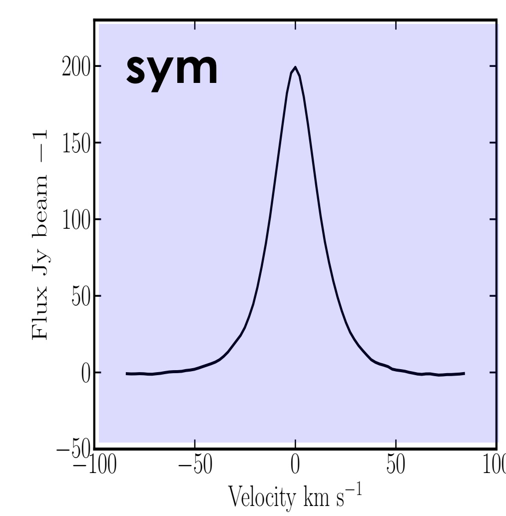
- Many ways to get a non-Gaussian super profile
  - Inclination effects
  - Thick, lagging component
  - Asymmetric input profiles
  - Inaccurate shuffling
  - Bulk motions (galaxy interaction, starburst)
- Tested and under control

Symmetrical Profiles





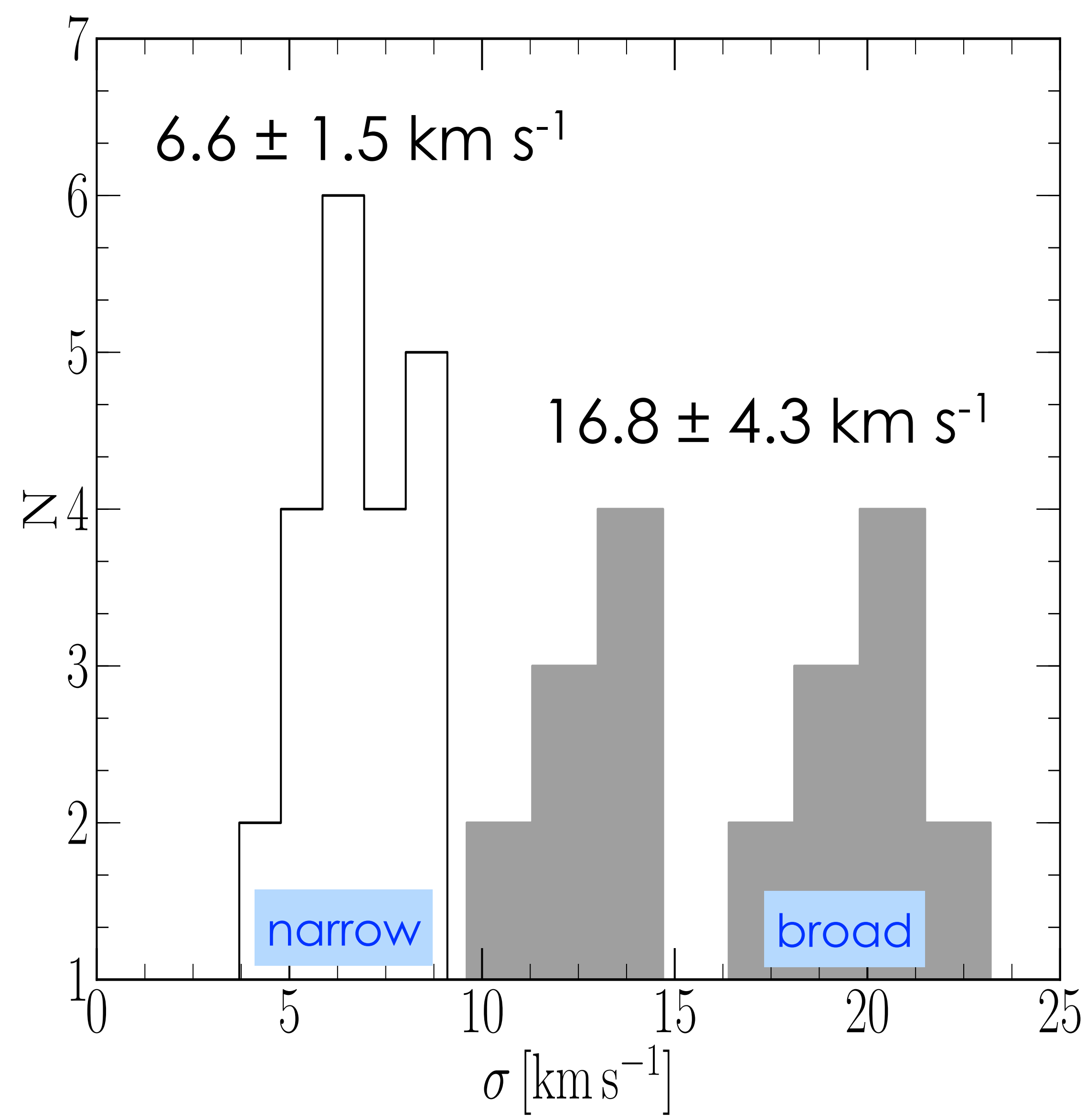




$|v_{Her3}-v_{IWM}| < 5$ km s^{-1} to identify symmetrical profiles

Injamasimanana et al (2012, in prep)

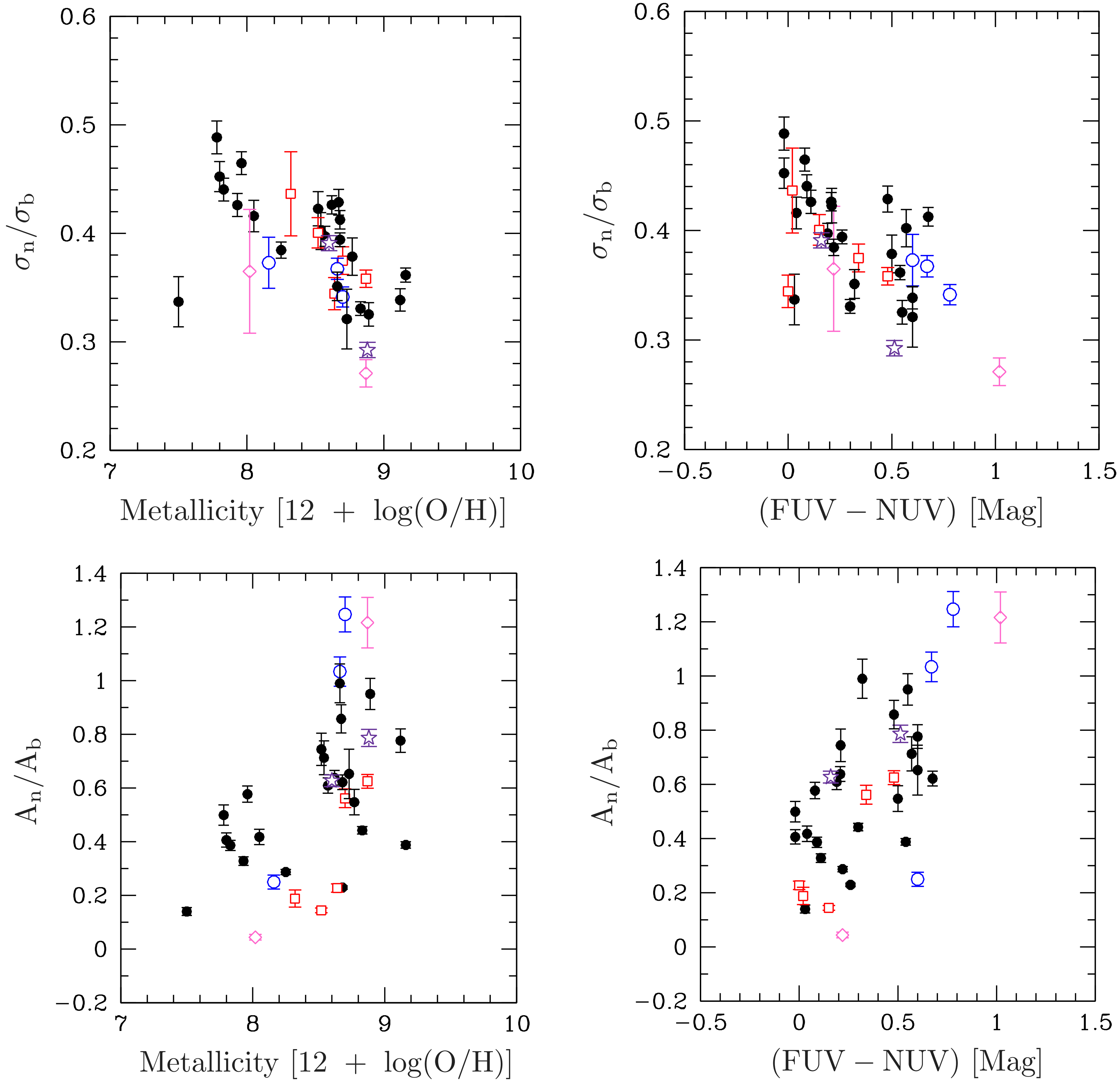
Dispersions



Clear detection of broad and narrow component

Injamasimanana et al (2012, in prep)

Global trends

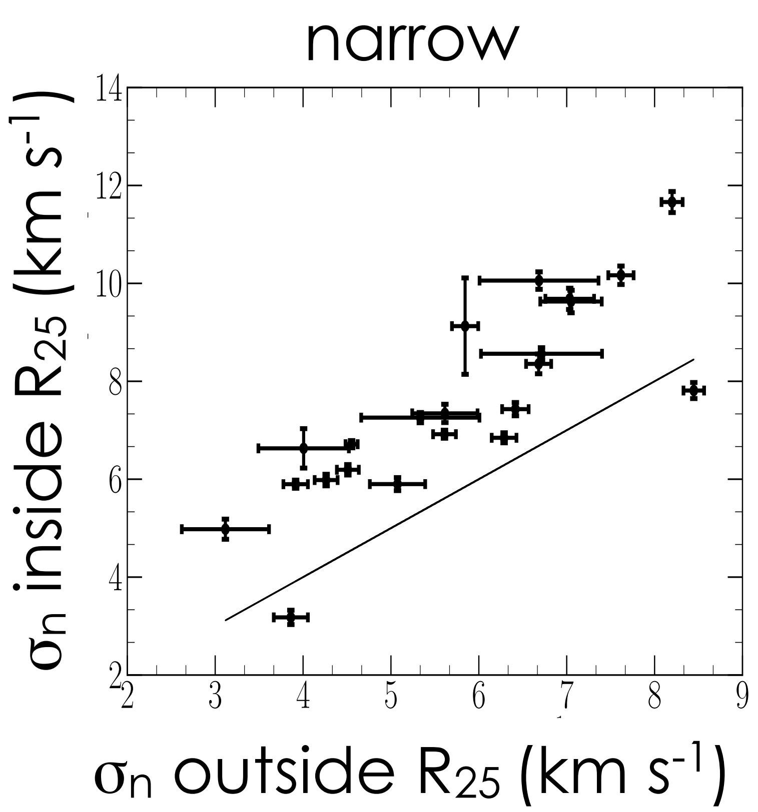


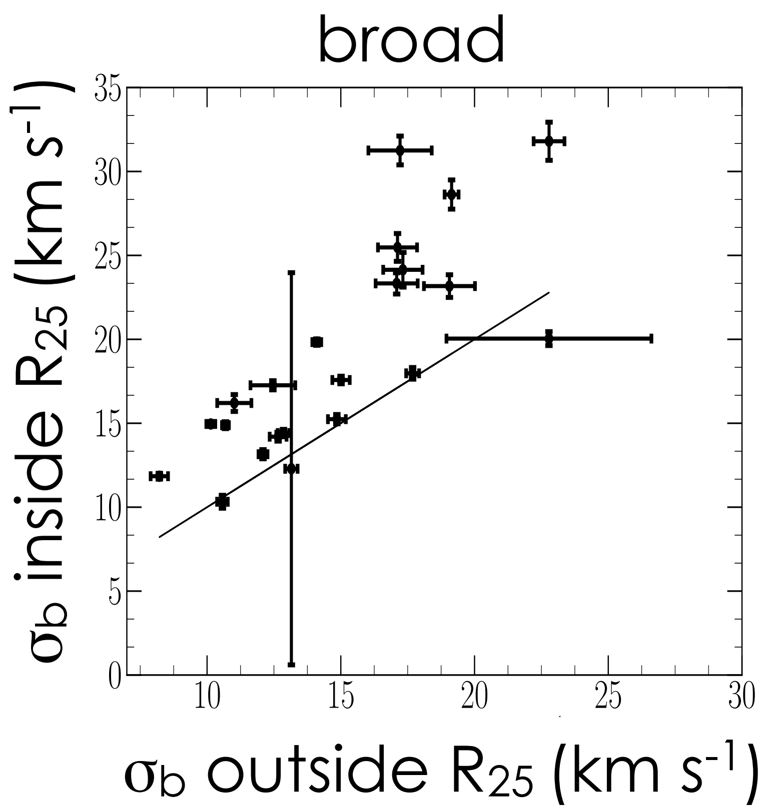
dispersion and mass ratios cold and warm components change with metallicity and luminosity

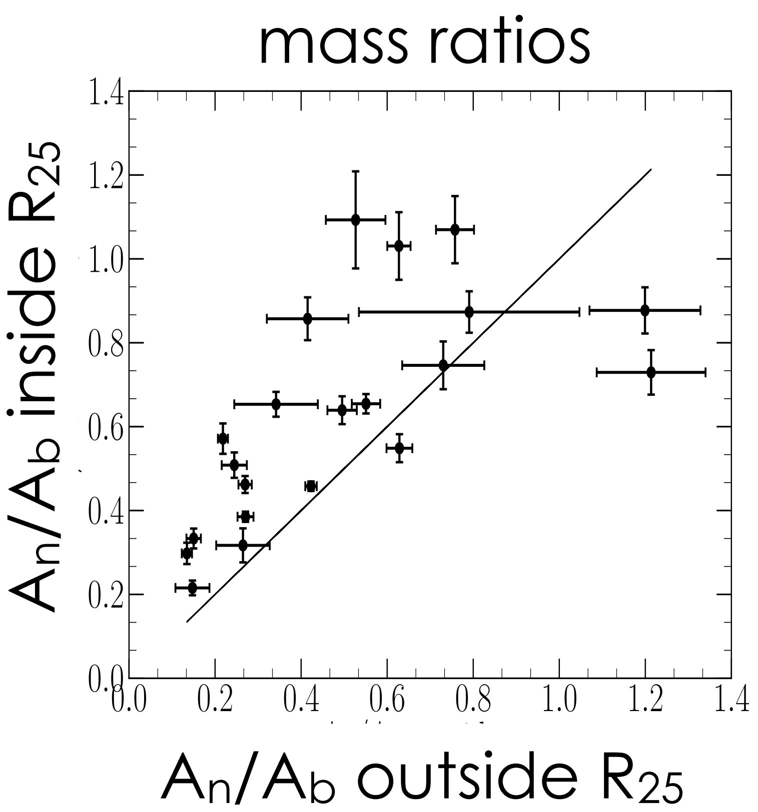
Ultimately link this back with SF?

Injamasimanana et al (2012, in prep)

Refining the profiles



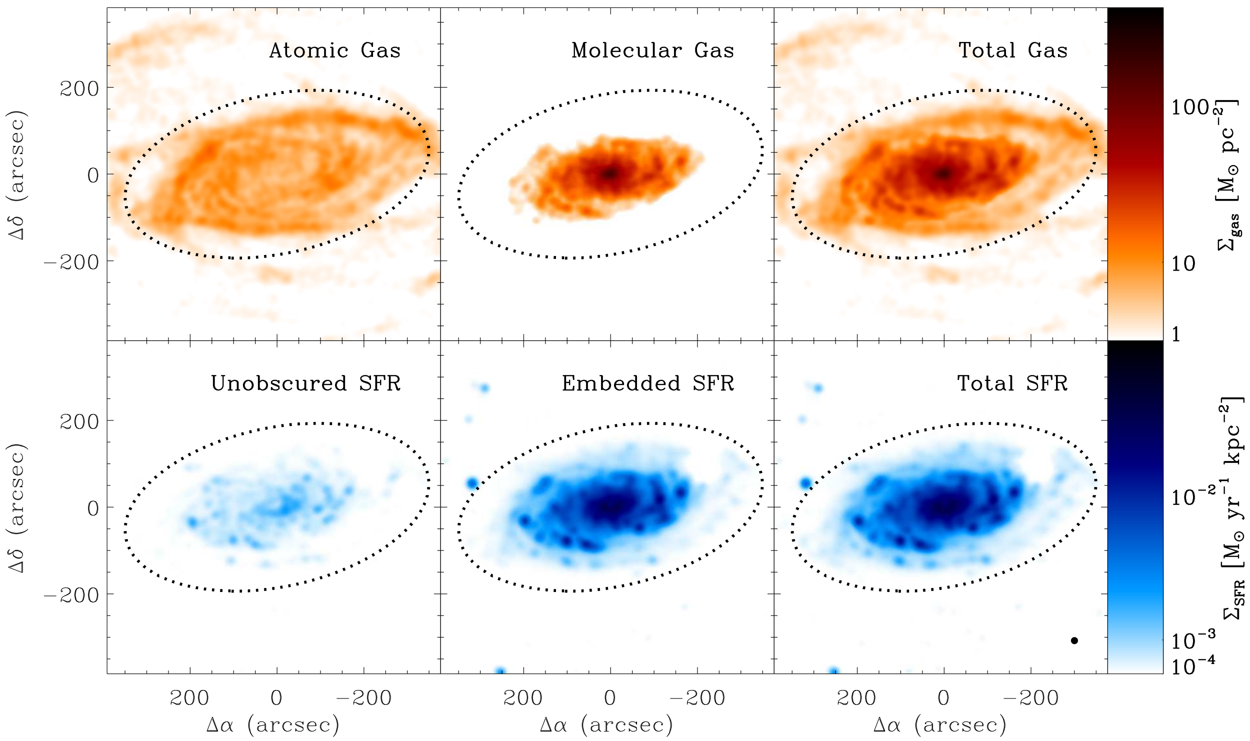


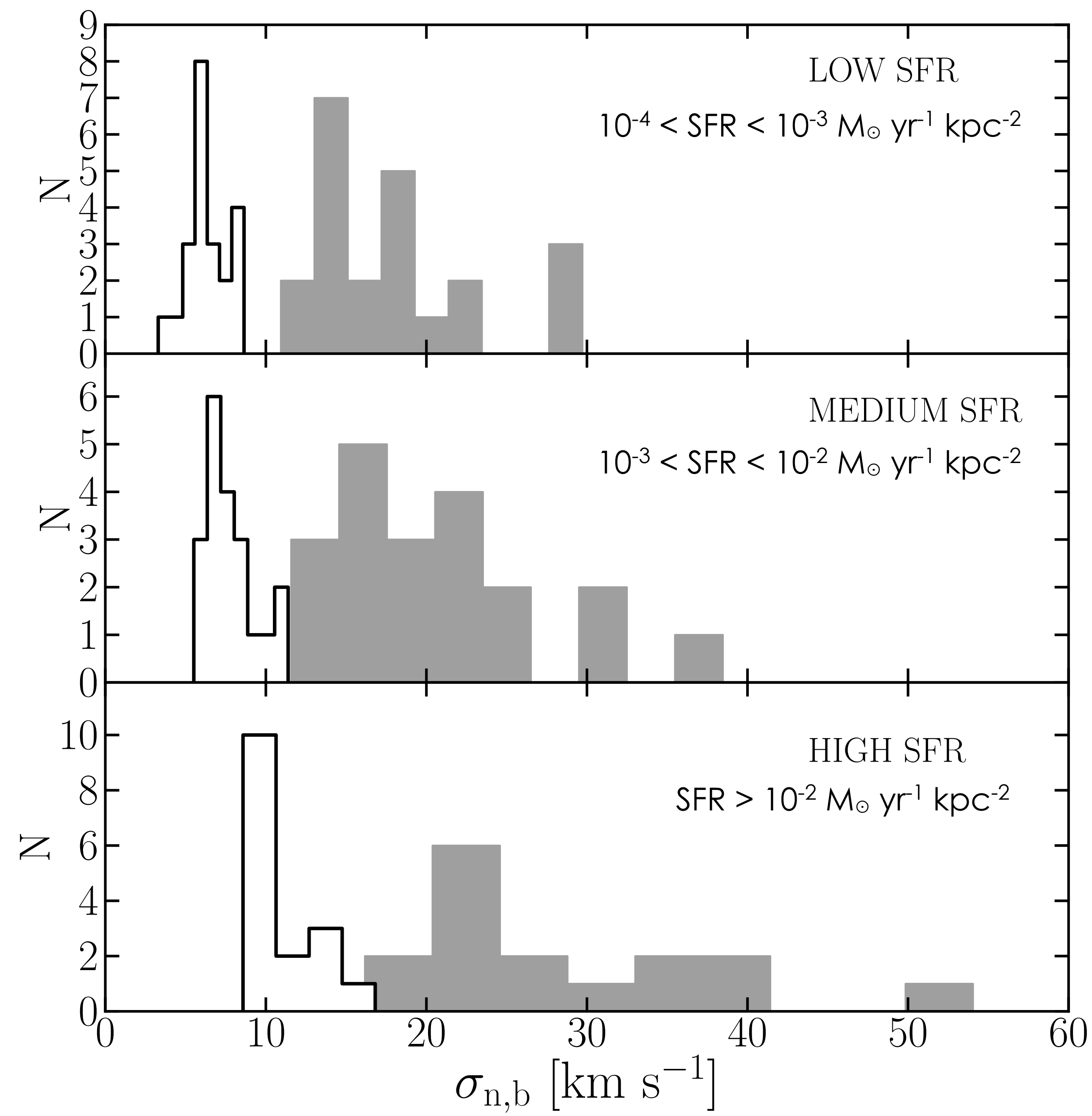


- Do properties change as a function of local environment?
- Create super profiles using masks
- Example: dispersions and mass ratios inside R_{25} (**high** star forming) and outside R_{25} (no or very **low** star formation)

Injamasimanana et al (2012, in prep)

Star formation rates





Define SFR masks using Leroy et al (2008) THINGS star formation rate maps (24μm Spitzer and GALEX FUX)

Injamasimanana et al (2012, in prep)

Super Profiles

- Can the cold HI be used as a proxy for molecular gas observations?
- Is there a H_2/cold HI factor?
- Input for numerical models

Summary

- Current high-resolution, multi-wavelength data sets are a goldmine for galaxy astro-physics
- Halos well fit by Einasto model with low n
- HI profiles show narrow and broad components
- Broad/narrow ratios seem related to SF