The radial acceleration relation(RAR) and baryonic Tully-Fisher relation

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The radial acceleration relation is a natural consequence of the baryonic Tully-Fisher relation

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ABSTRACT

Galaxies covering several orders of magnitude in stellar mass and a variety of Hubble types have been shown to follow the "Radial Acceleration Relation" (RAR), a relationship between $g_{\rm obs}$, the observed circular acceleration of the galaxy, and $g_{\rm bar}$, the acceleration due to the total baryonic mass of the galaxy. For accelerations above 10^{10} m s^{-2}, $g_{\rm obs}$ traces $g_{\rm bar}$, asymptoting to the 1:1 line. Below this scale, there is a break in the relation such that $g_{\rm obs} \sim g_{\rm bar}^{1/2}$. We show that the RAR slope, scatter and the acceleration scale are all natural consequences of the well-known baryonic Tully-Fisher relation (BTFR). We further demonstrate that galaxies with a variety of baryonic and dark matter (DM) profiles and a wide range of dark halo and galaxy properties (well beyond those expected in CDM) lie on the RAR if we simply require that their rotation curves satisfy the BTFR. We explore conditions needed to break this degeneracy: sub-kpc resolved rotation curves inside of "cored" DM-dominated profiles and/or outside $\gg$ 100 kpc could lie on BTFR but deviate in the RAR, providing new constraints on DM.

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Fitting the Radial Acceleration Relation to Individual SPARC Galaxies

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ABSTRACT

Galaxies follow a tight radial acceleration relation (RAR): the acceleration observed at every radius correlates with that expected from the distribution of baryons. We use the Markov Chain Monte Carlo method to fit the mean RAR to 175 individual galaxies in the SPARC database, marginalizing over stellar mass-to-light ratio ($\Upsilon_\star$), galaxy distance, and disk inclination. Acceptable fits with astrophysically reasonable parameters are found for the vast majority of galaxies. The residuals around these fits have an rms scatter of only 0.057 dex ($\sim$13%). This is in agreement with the predictions of modified Newtonian dynamics (MOND). We further consider a generalized version of the RAR that, unlike MOND, permits galaxy-to-galaxy variation in the critical acceleration scale. The fits are not improved with this additional freedom: there is no credible indication of variation in the critical acceleration scale. The data are consistent with the action of a single effective force law. The apparent universality of the acceleration scale and the small residual scatter are key to understanding galaxies.

Key words. dark matter — galaxies: kinematics and dynamics — galaxies: spiral — galaxies: dwarf — galaxies: irregular

$$g_{\rm bar}(R) = (\Upsilon_{\rm disk} V_{\rm disk}^2 + \Upsilon_{\rm bul} V_{\rm bul}^2 + V_{\rm gas}^2)/R, \quad (1)$$

where $\Upsilon_{\rm disk}$ and $\Upsilon_{\rm bul}$ are the stellar mass-to-light ratios for the disk and bulge, respectively. Similarly, the observed acceleration can be calculated directly from the observed velocity $V_{\rm obs}$,

$$g_{\rm obs}(R) = \frac{V_{\rm obs}^2}{R}. \quad (2)$$

According to the RAR (McGaugh 2014; McGaugh et al. 2016; Lelli et al. 2017a), the expected total acceleration $g_{\rm tot}$ strongly correlates with that expected from baryonic distributions $g_{\rm bar}$,

- g_{bar} < g_{obs} at large radii

CDM: $g_{obs} = g_{tot} = g_{bar} + g_{DM}$

MOND

$$g_{tot}(R) = \frac{g_{bar}}{1 - e^{-\sqrt{g_{bar}/g_{\dagger}}}}, \tag{3}$$

where $g_{\dagger} = 1.20 \times 10^{-10}$ m s^{-2}. Thus, one can compare the ob-

- inner region: $g_{bar} >> g+$: $g_{tot} = g_{bar}$
- outer region: $g_{bar} << g+$: $g_{obs} \approx \sqrt{g_{bar}\, g_{\dagger}}$.

baryonic Tully-Fisher relation(BTFR)

$M_{\rm bar} = \mathscr{A} V_{\rm f}^4$, where $V_{\rm f}$ is (by definition) measured on the *flat* part of the rotation curve so $V_c(r) \approx V_{\rm f}$ over a large range of r. If we are

CDM:

- $M_{vir} = M_{200} = \rho R_{200}^{3}$
- $V_c^2/R = GM/R^2 \quad \Rightarrow V_c \propto R$

  Ω = const
- $M_{vir} \propto V^3$
- $f_b = M_{bar}/M_{vir}$ not a constant, $\propto M_{vir}^{1/3}$

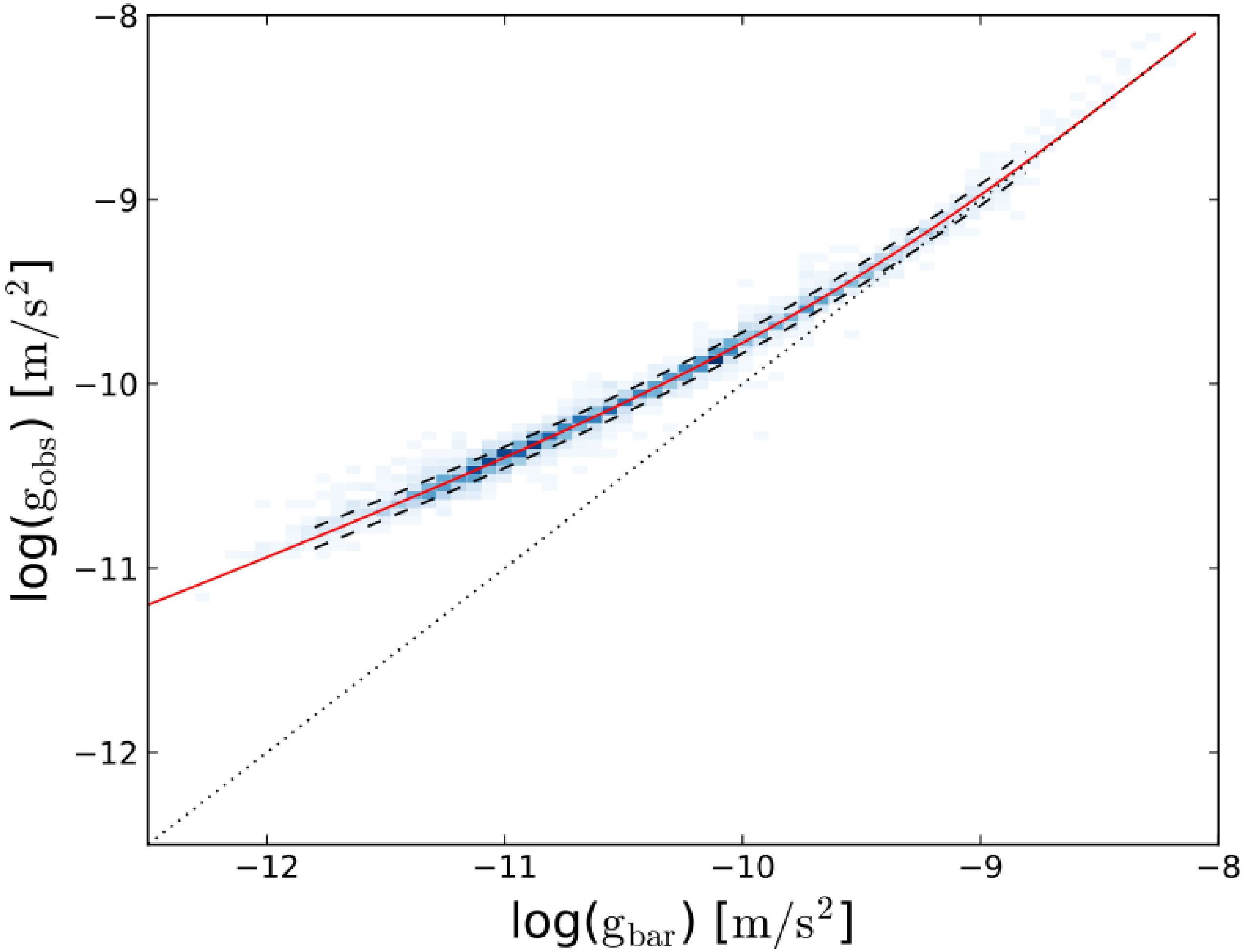
MOND

- outer region: $g_{bar} << g+$: $$g_{obs} \approx \sqrt{g_{bar}\, g_{\dagger}}.$$

  - $g_{obs} = V^2/R$
  - $g_{bar} = M_{bar}/R^2$

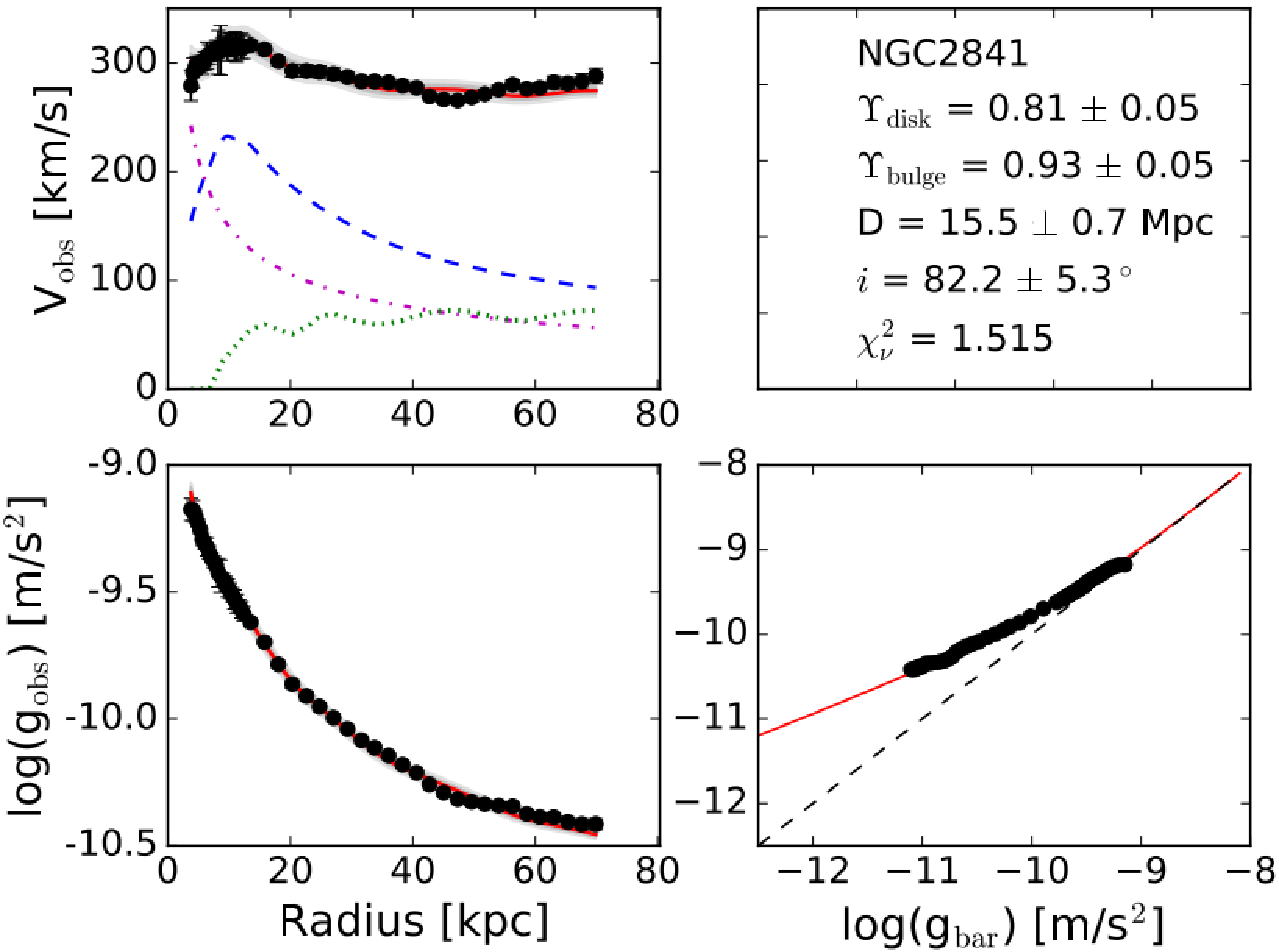
  - BTFR is natural conclusion of RAR(MOND)!

MOND VS CDM

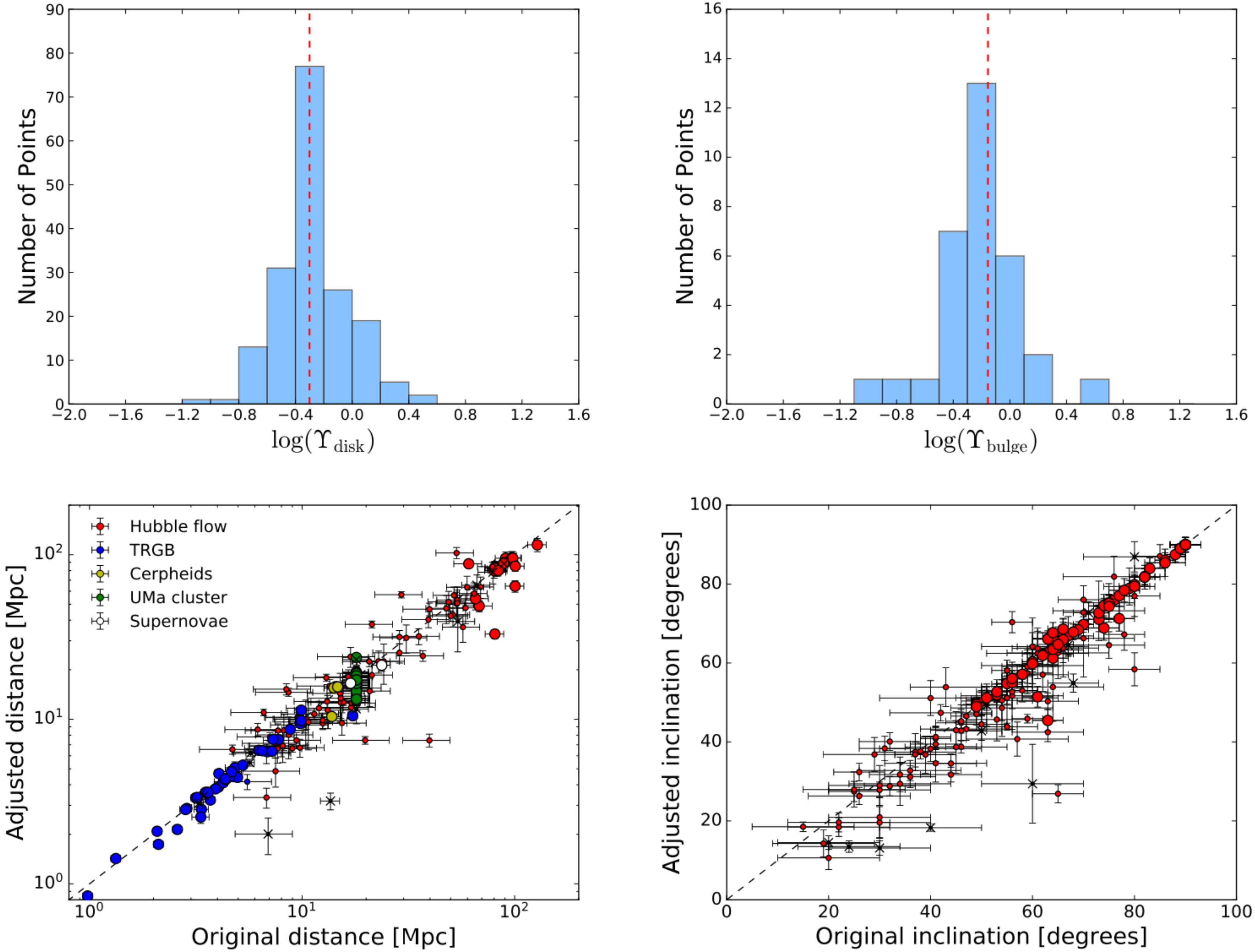


Caveats

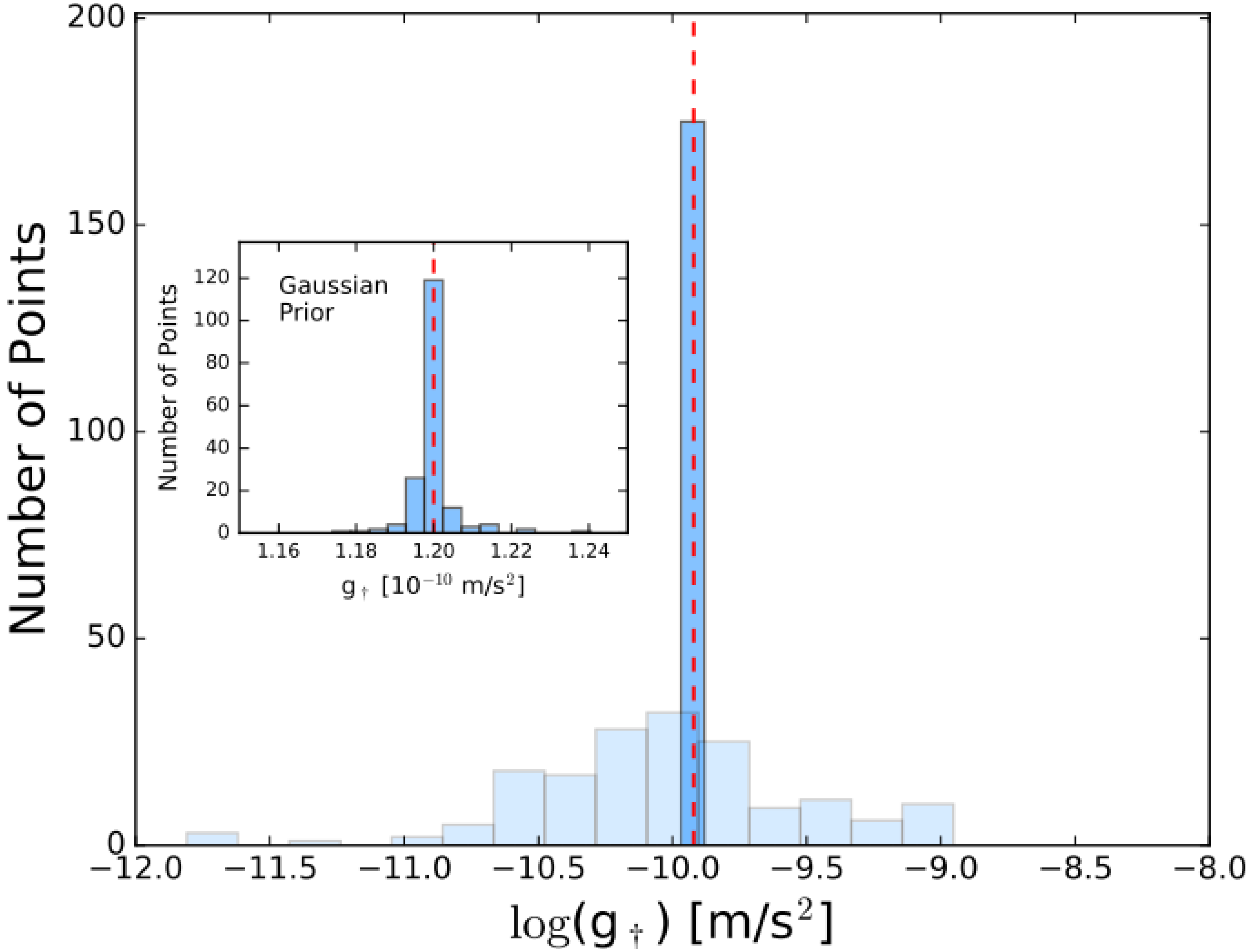
- g_{bar} (R)： Mass-to-light ratio, distance
- V(R): inclination effect: cos *i*
- g+: if free parameter, can the fitting being improved?



NGC2841
$\Upsilon_{\rm disk}$ = 0.81 ± 0.05
$\Upsilon_{\rm bulge}$ = 0.93 ± 0.05
D = 15.5 ± 0.7 Mpc
i = 82.2 ± 5.3 °
χ^2_ν = 1.515
$V_{\rm obs}$ [km/s]
Radius [kpc]
log($g_{\rm obs}$) [m/s^2]
log($g_{\rm bar}$) [m/s^2]



Number of Points
log(ϒdisk)
log(ϒbulge)
Adjusted distance [Mpc]
Original distance [Mpc]
Hubble flow
TRGB
Cerpheids
UMa cluster
Supernovae
Adjusted inclination [degrees]
Original inclination [degrees]



Number of Points
200
150
100
50
0
−12.0
−11.5
−11.0
−10.5
−10.0
−9.5
−9.0
−8.5
−8.0
log(g†) [m/s²]
Gaussian Prior
Number of Points
120
100
80
60
40
20
0
1.16
1.18
1.20
1.22
1.24
g† [10⁻¹⁰ m/s²]