Galactic Structure

Galactic Structure

- Stars
  - DISK THIN and older, less massive THICK disk
  - BULGE and/or BAR
- Gas
  - atomic gas (HI)
    - in diffuse clouds, more extended than stars
  - molecular gas (H_2)
    - in dense clouds. Follows stars, spiral arms
  - hot, ionized gas (HII)
    - low mass, low density, large volume
- Dust
    - mostly in spiral arms & molecular clouds

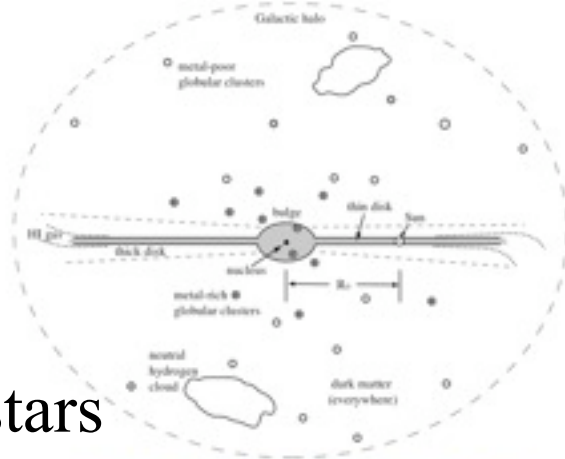


Fig 1.8 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Galactic Coordinates

from solar system

from Galactic Center

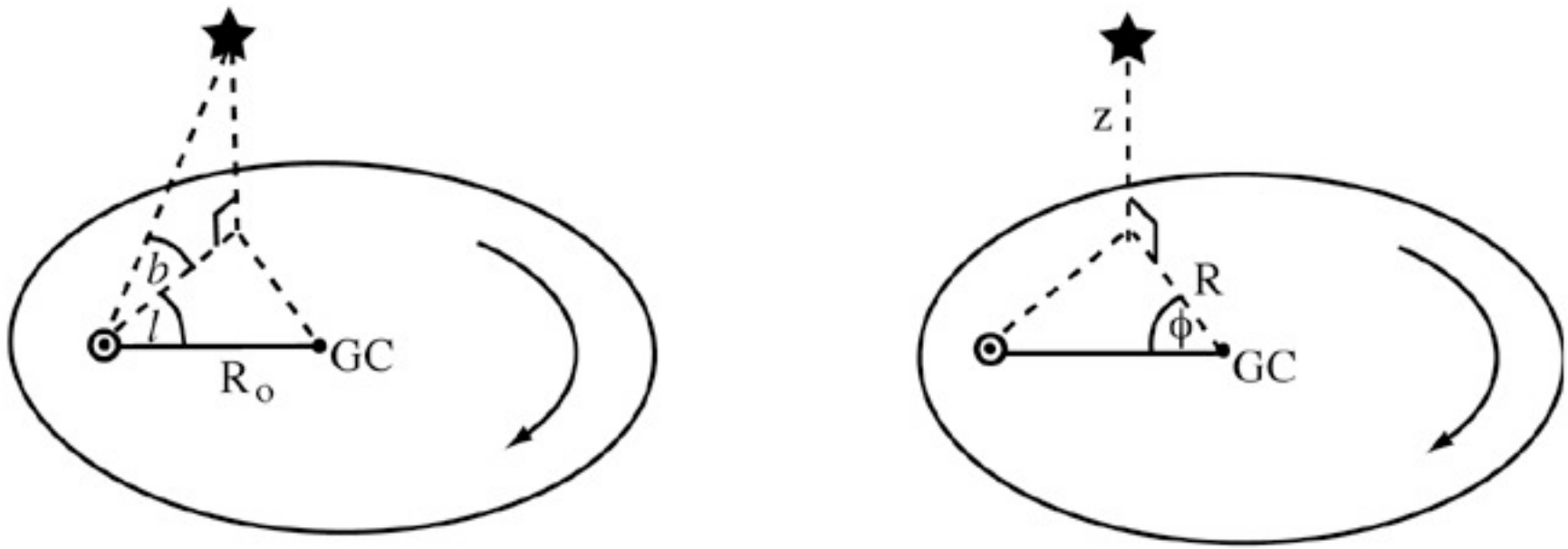


Fig 1.10 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

longitude & latitude

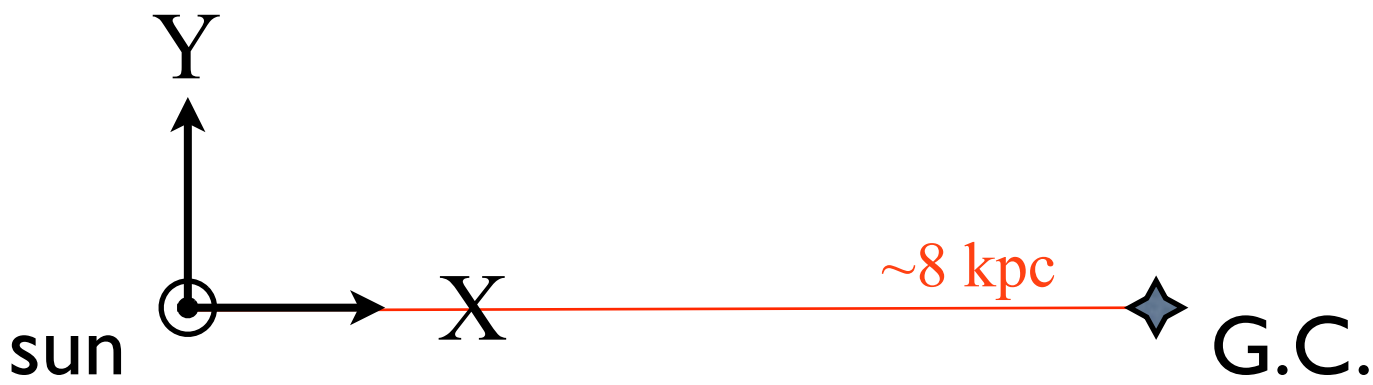
ℓ, b

R, ϕ, z

Galactic Coordinates

Cartesian coordinates centered on solar system

Could also center on G.C. - beware sign conventions



X, Y, Z:

X points towards the Galactic Center

Y points in direction of the sun's orbital motion

Z is perpendicular to the Galactic Plane

U, V, W are velocities in these directions

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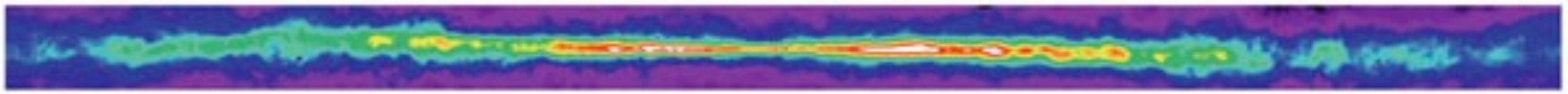
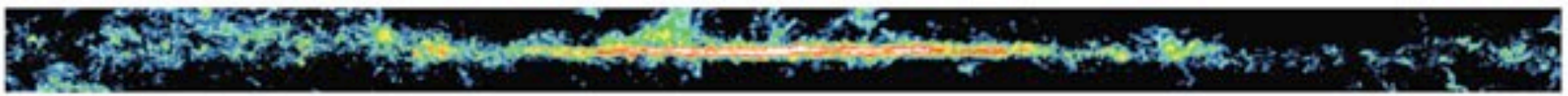
Milky Way Gas and Dust

radio (21 cm)
HI gas



a 21-cm radio emission from atomic hydrogen gas.

radio (CO)
molecular gas



b Radio emission from carbon monoxide reveals molecular clouds.

far-IR
dust

c Infrared (60–100 μm) emission from interstellar dust.

near-IR
stars

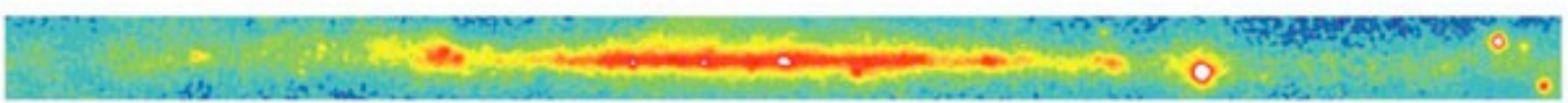
d Infrared (1–4 μm) emission from stars that penetrates most interstellar material.

Optical
stars & dust

e Visible light emitted by stars is scattered and absorbed by dust.

X-ray
hot gas

f X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).



g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

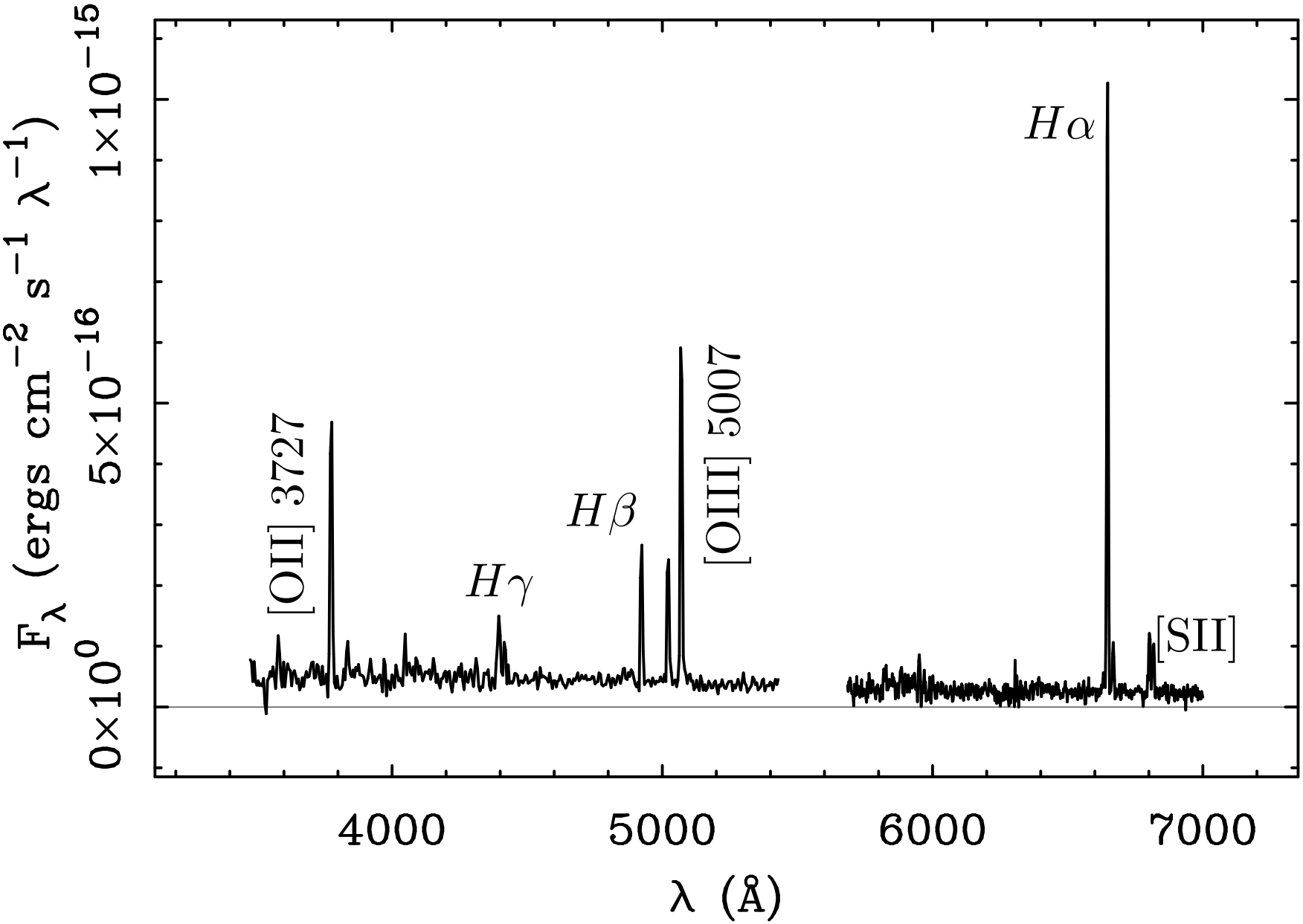
Emission lines from interstellar gas

- Gas emits photons corresponding to specific atomic or molecular transitions
- Excitation methods:
  - photoionization
  - collisional excitation $\quad k_B T \approx h\nu$
  - shocks
- Note that ISM densities are very low
  - typically $\quad 1 \text{ to } 1000 \text{ cm}^{-3}$
  - we breathe $\quad \sim 10^{22} \text{ cm}^{-3}$

Nomenclature

- Neutral — O — OI
- Singly ionized — O^{+} — OII
- Doubly ionized — O^{++} — OIII
  - etc
- e.g., [OIII] 5007
  - is the line emitted by doubly ionized oxygen at 5007 Å ("Nebulium")

HII region in UGC 1230

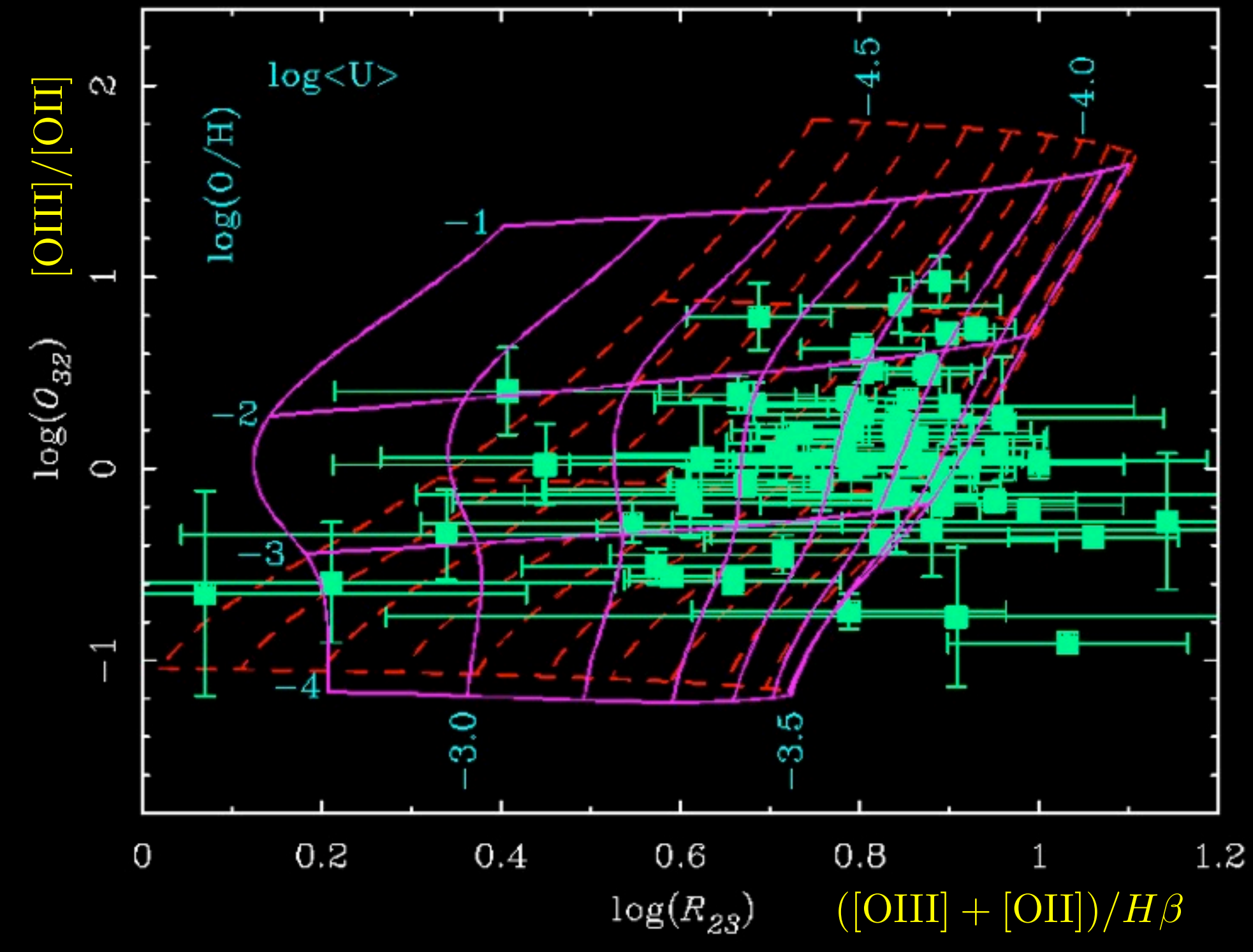


Nomenclature

atomic lines seen from ionized gas (e.g., HII regions)

- Permitted lines e.g., $\mathrm{H}\alpha$
  - occur rapidly
- Forbidden lines e.g., [OIII] 5007
  - occur slowly (by atomic standards)
  - can only happen when collision time is very long.
  - Only happens in near vacuum of space.

line strengths contain information about physical conditions



Nomenclature

molecular lines seen from molecular gas (e.g., H_2 clouds)

- rotational and vibrational states
  - e.g., CO $J = 1 \rightarrow 0$ 2.6 mm
    $J = 2 \rightarrow 1$ 1.3 mm

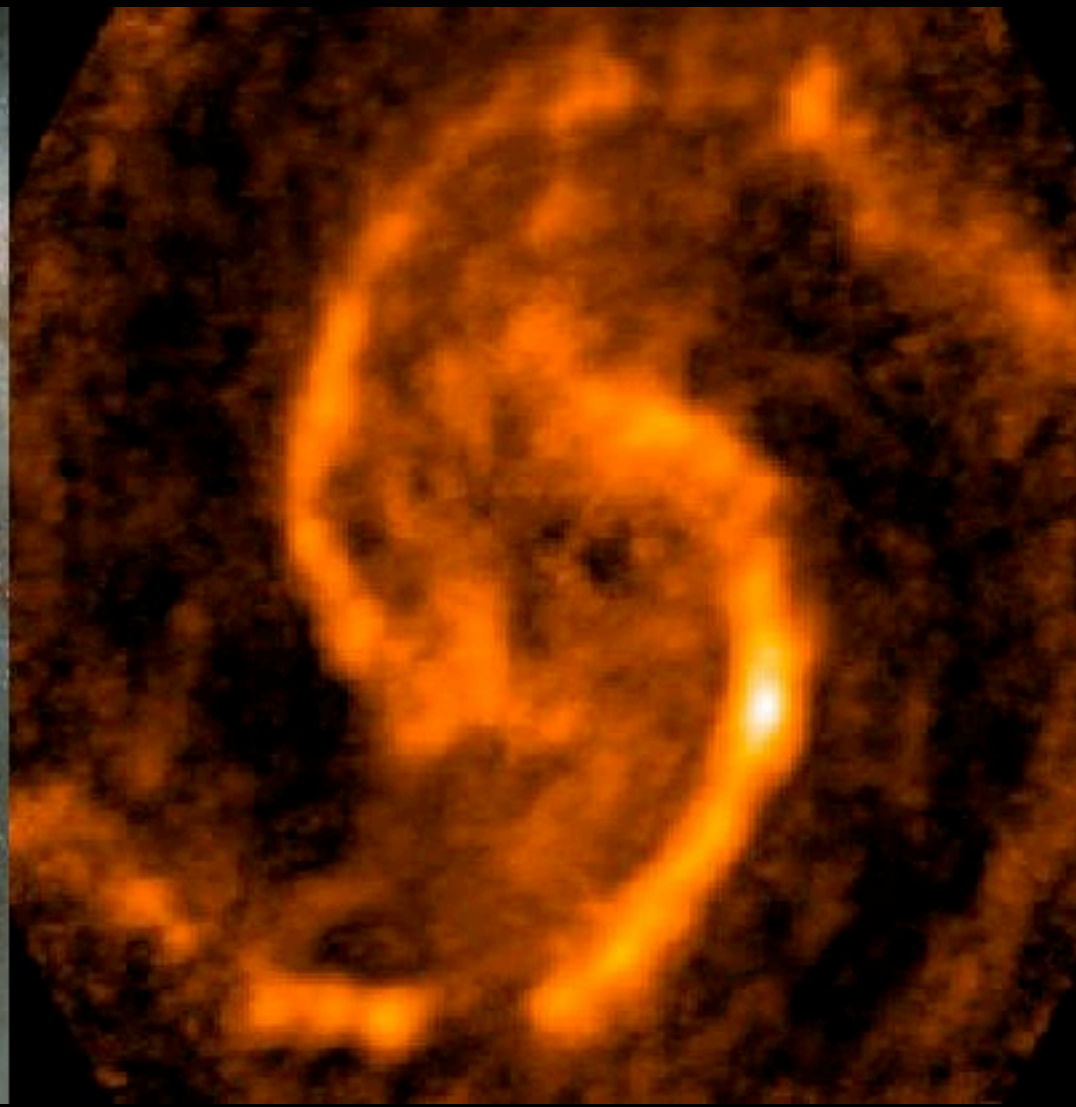
Atomic lines seen from atomic gas (e.g., HI clouds)

- hyperfine spin-flip transition
  - e.g., HI 21 cm

M51

stars

CO



Nomenclature

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Atomic lines seen from atomic gas (e.g., HI clouds)

- hyperfine spin-flip transition
  - e.g., HI 21 cm

NGC 2403

Oosterloo et al.

stars

HI

optical
broad band
BVR

radio
21 cm
spin-flip line of atomic H

Dust emission in IR

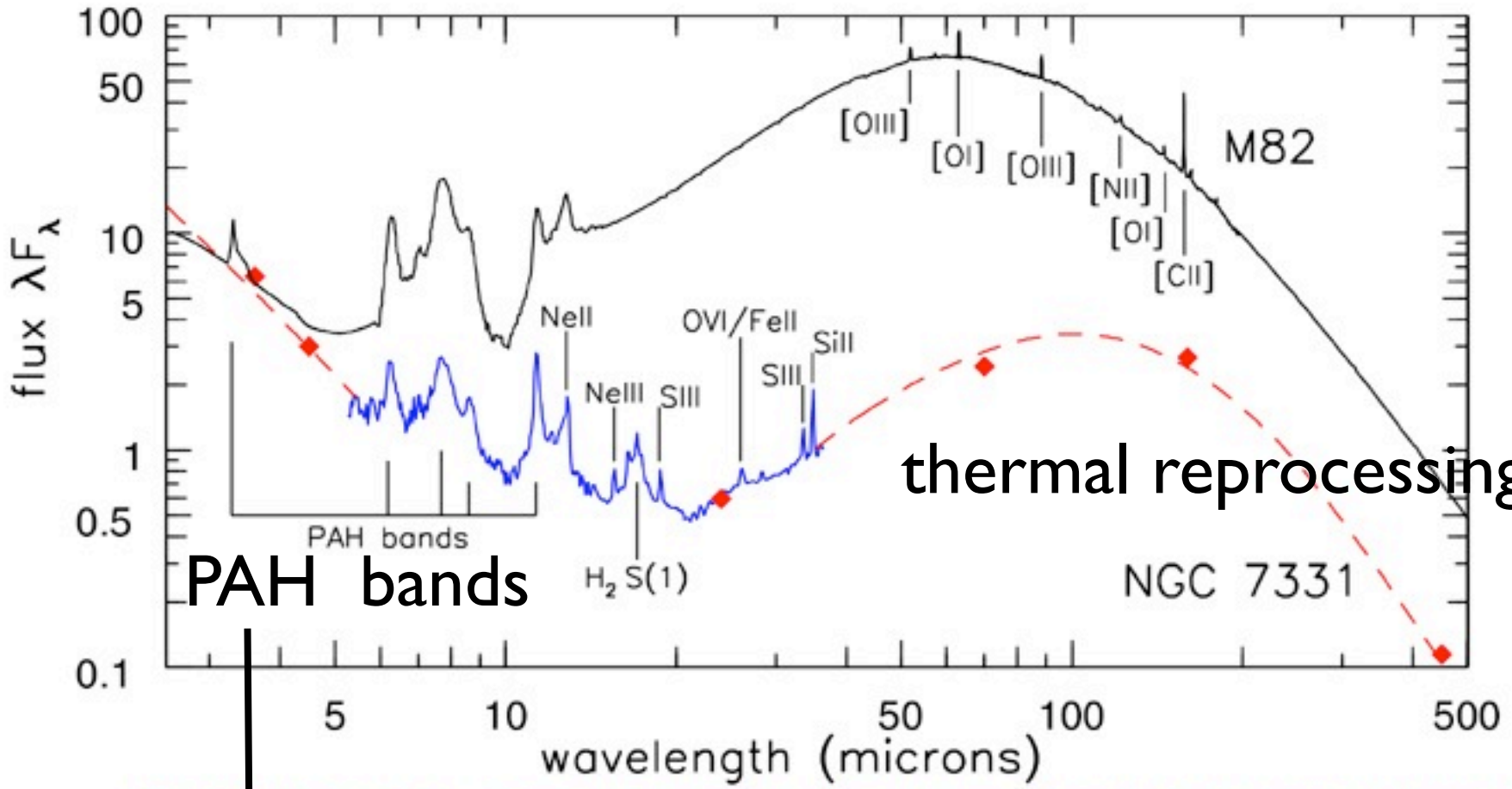
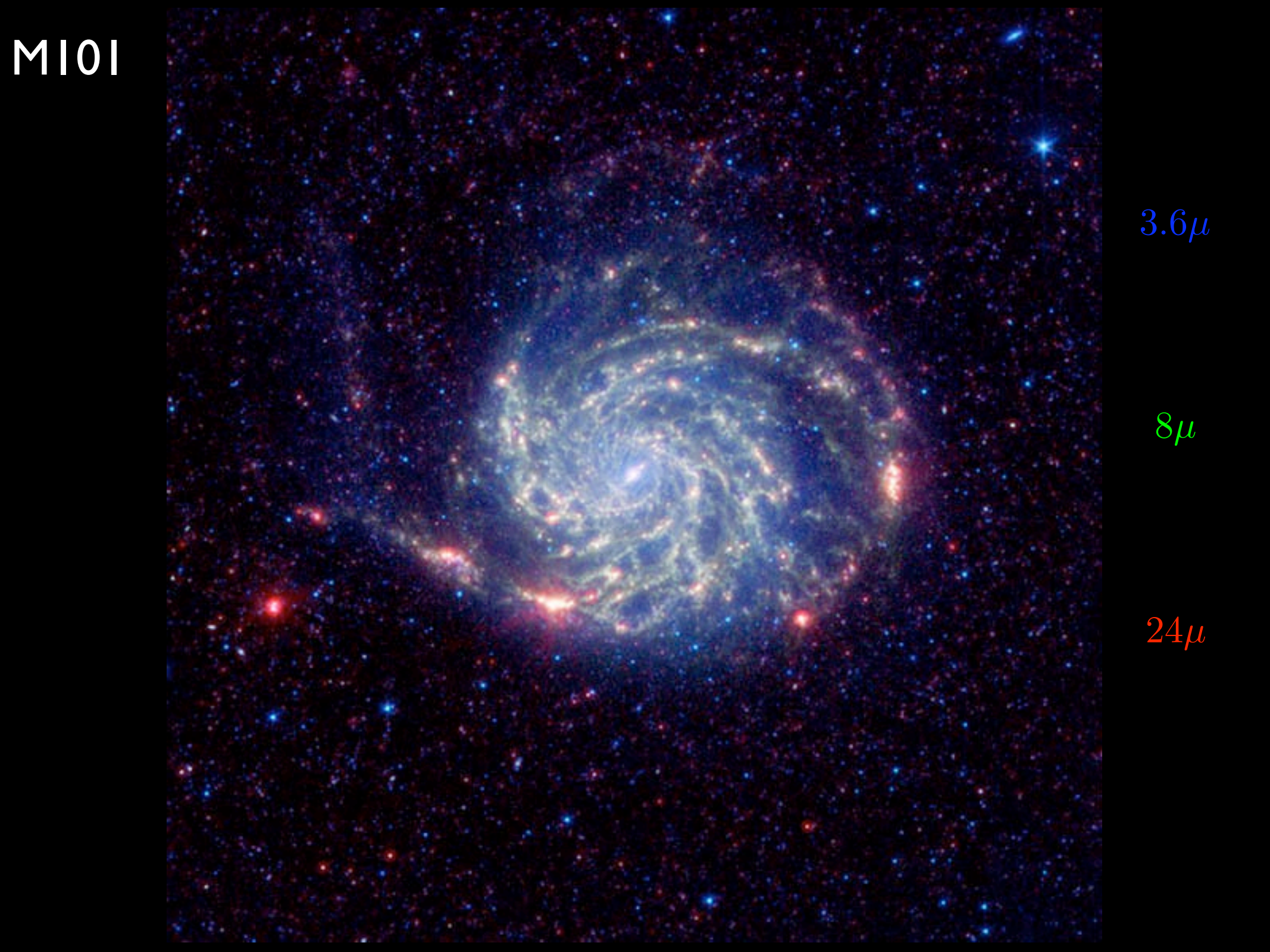


Fig 2.24 (Smith et al., Lagache) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

thermal reprocessing

PAH bands

Polycyclic Aromatic Hydrocarbons

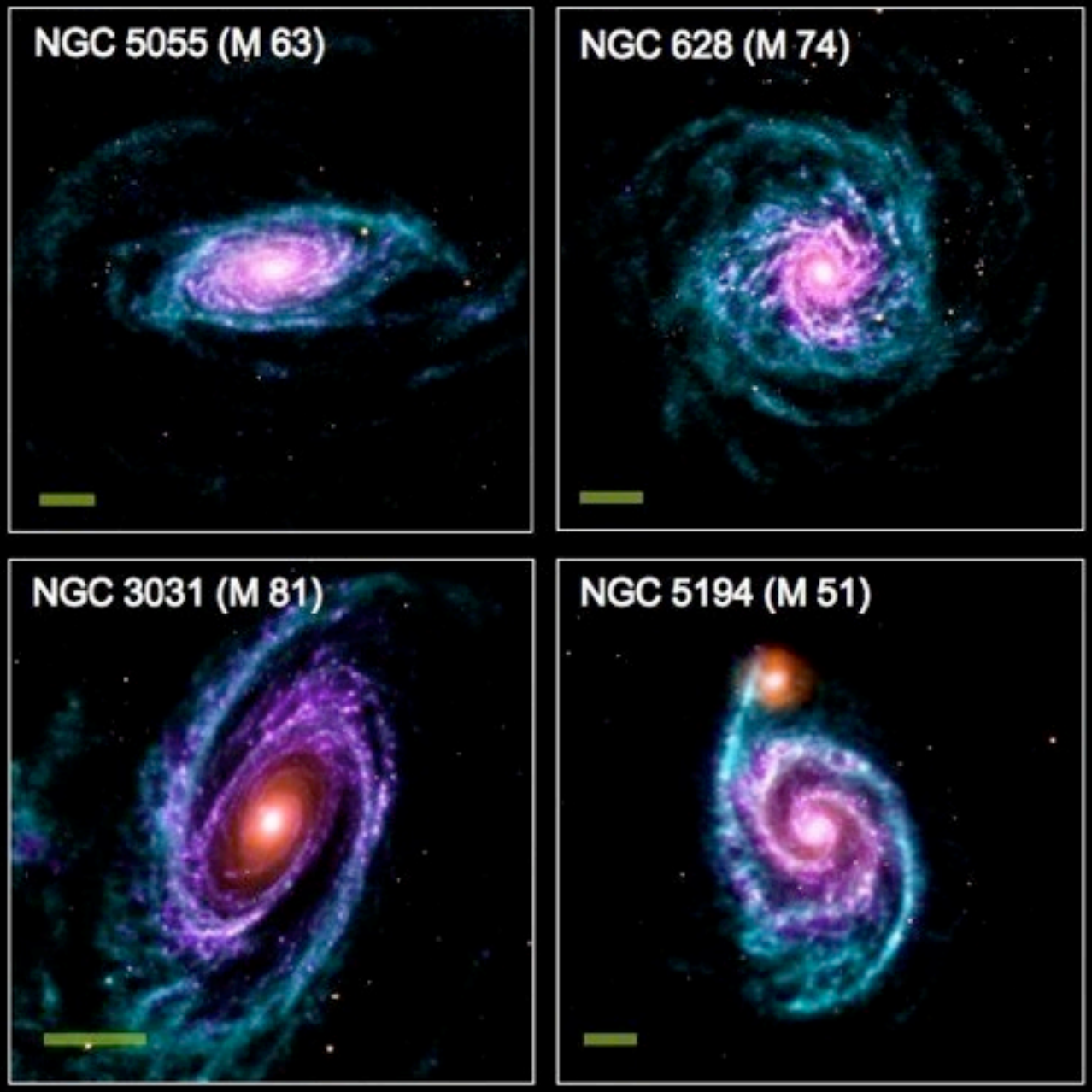

M101
3.6μ
8μ
24μ

Spiral Galaxies in THINGS — The HI Nearby Galaxy Survey

HI

stars

SF (UV & dust)



THINGS

The HI Nearby Galaxy Survey

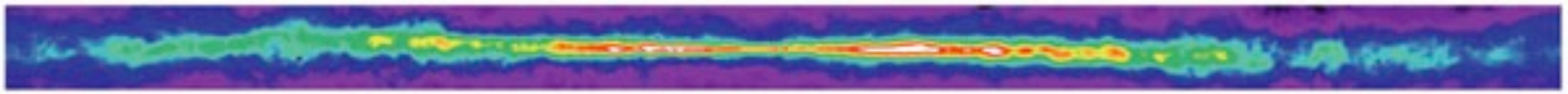
color coding:
THINGS Atomic Hydrogen
(Very Large Array)
Old stars
(Spitzer Space Telescope)
Star Formation
(GALEX & Spitzer)

scale:
15,000 light years

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

Milky Way Gas and Dust

radio (21 cm)
HI gas



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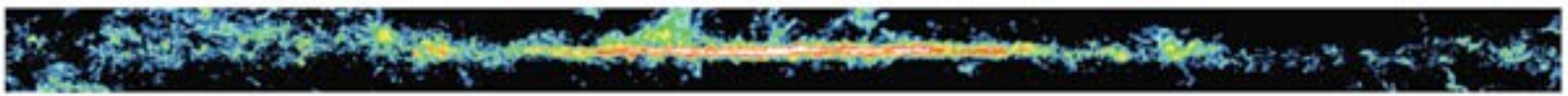

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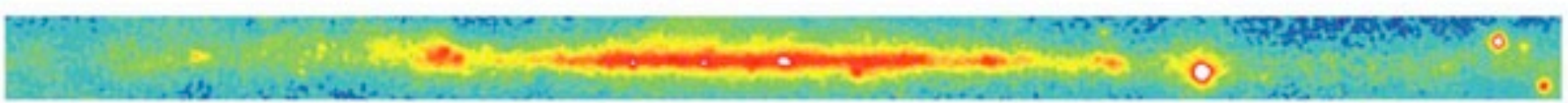


g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

MW as seen by COBE

Binney et al

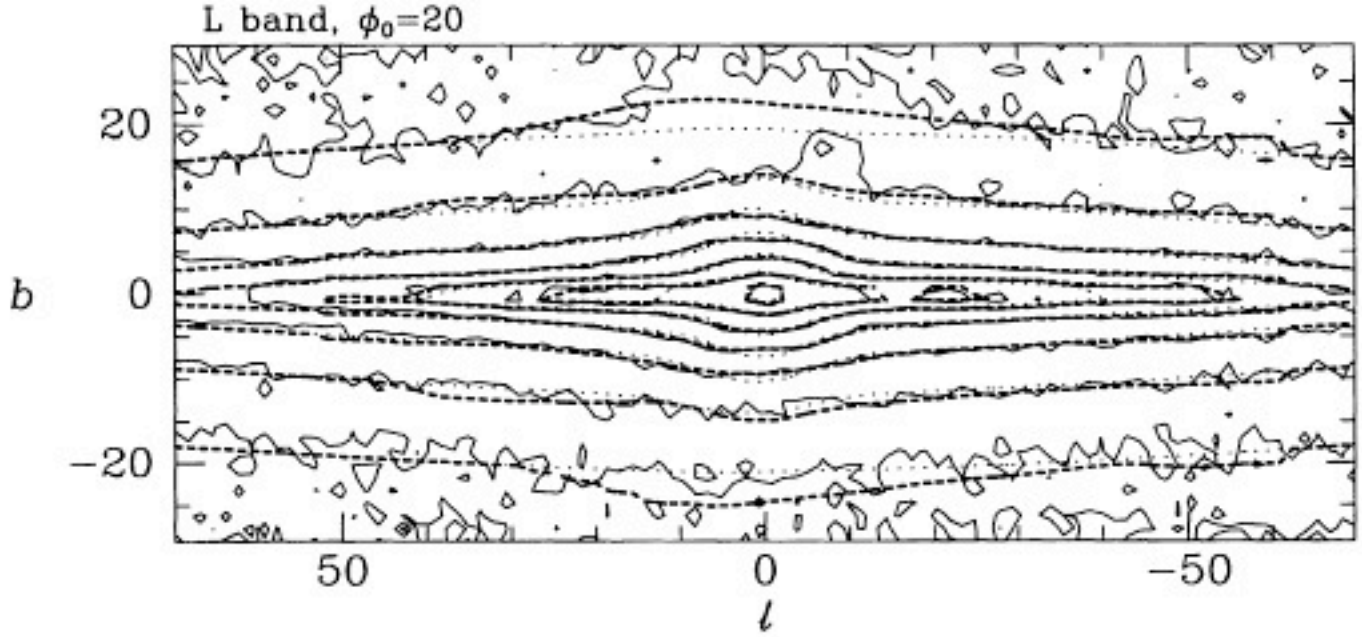
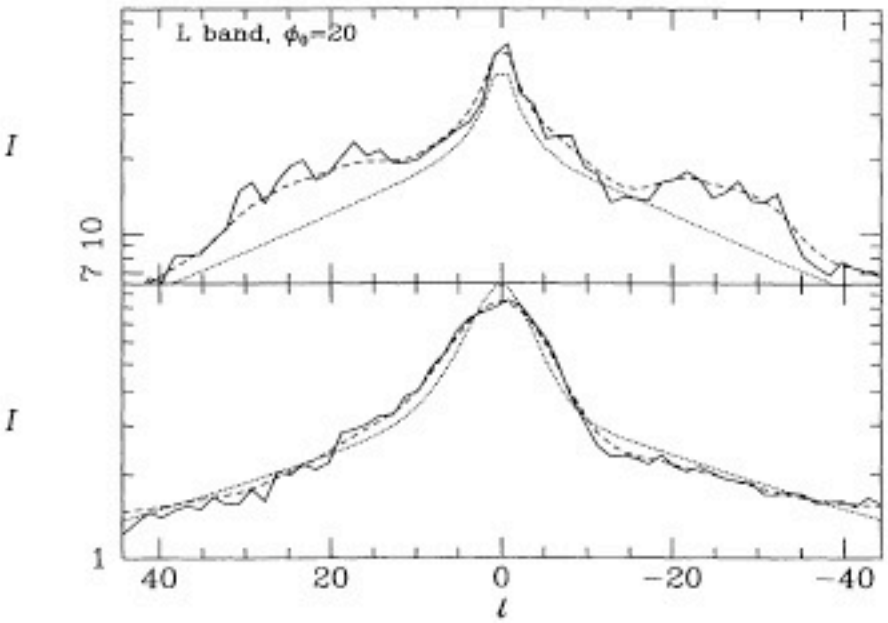


Figure 1. The fit between data (full contours) and model (thick dashed contours) that is obtained after five iterations of the Richardson–Lucy algorithm under the assumption that $\phi_0 = 20°$. The dotted contours show the initial analytic fit of equation (1). Contours are spaced by 1 mag. The Sun–centre line is assumed to lie 0.1 above the plane.



inferred by Kent et al. (1991) from Infrared Telescope data. At higher latitudes the iterations make smaller changes, but these include successfully modelling significant asymmetry in latitude at $|l| \lesssim 10°$. In fact, this figure shows that the final model fits the data nearly as well as any smooth model could, and that the remaining residuals are associated with small-scale structure which it is not appropriate to model at this stage.

The fit plotted in Figs 1 and 2 was obtained under the assumption that the Sun–centre line lies 0.1 above the assumed symmetry plane of the Galaxy. That is, the Sun has been assumed to lie 14 pc above the plane. Fig. 3 compares the residuals (model – data) that one obtains for this case with those that one obtains when the Sun is located within the plane (bottom panel) or 28 pc above the plane (top panel). Whereas in the bottom panel positive residuals tend to occur at $b > 0$, in the top panel they occur at $b < 0$. From the fact that in the middle panel positive and negative residuals show no

The Exponential Disk

- Stars in the disk of the Milky Way and other spiral galaxies have an azimuthally averaged radial surface density profile that is reasonably well approximated as an
- EXPONENTIAL DISK

$$\Sigma(r) = \Sigma_0 e^{-r/R_d}$$

  - Σ_0 = Central Surface Density
  - R_d = Radial Scale Length

radial gas distribution

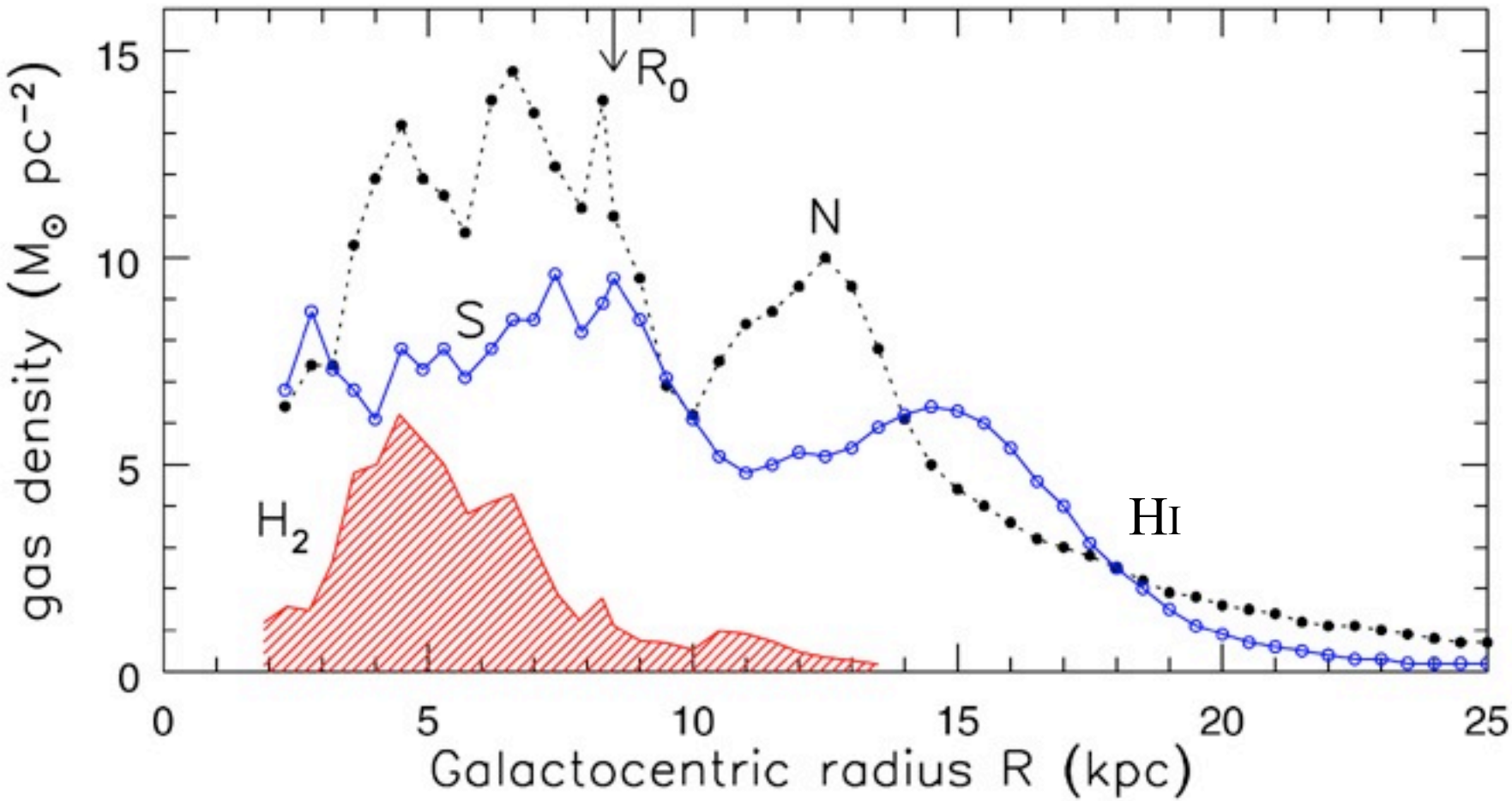
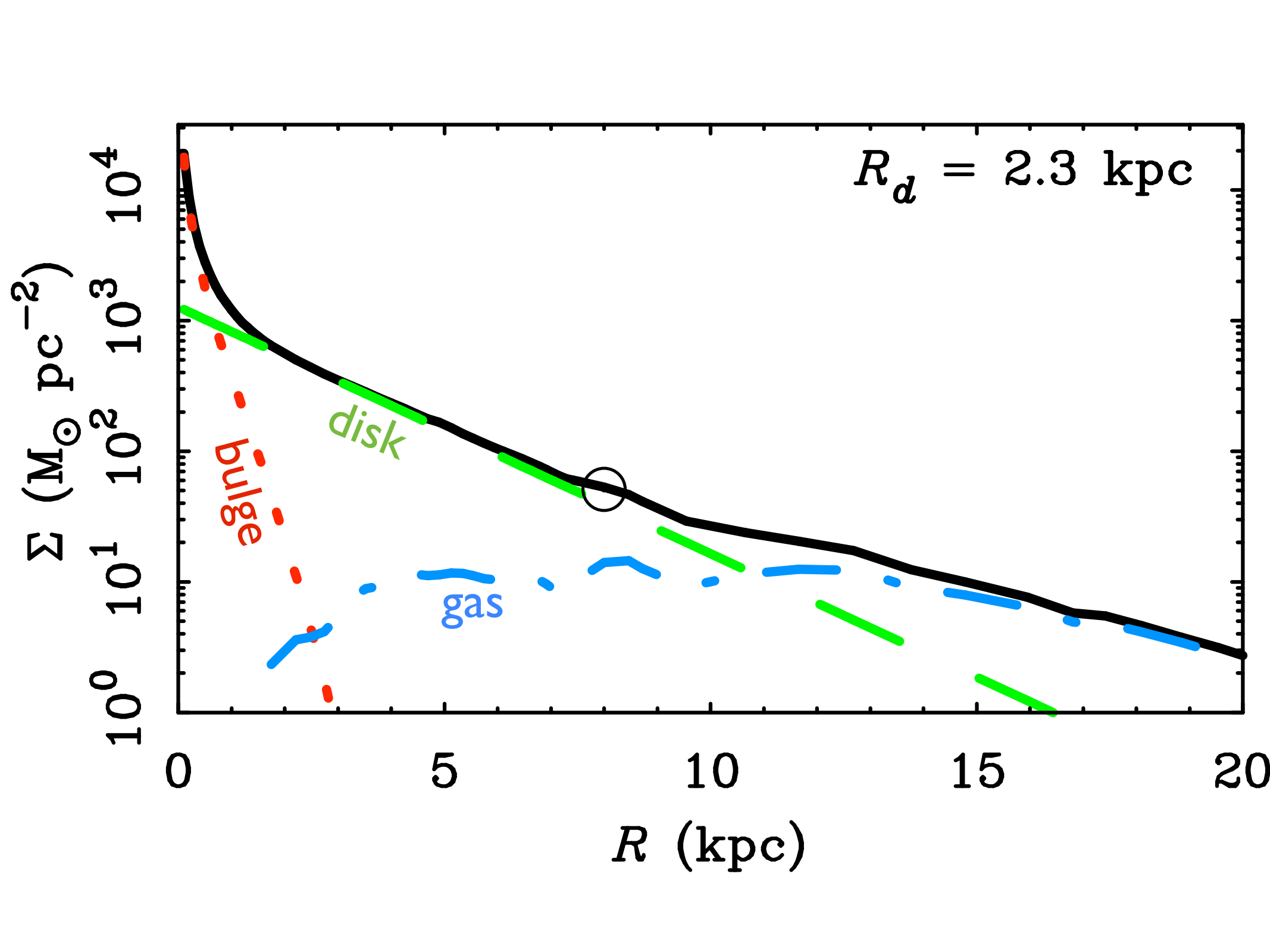
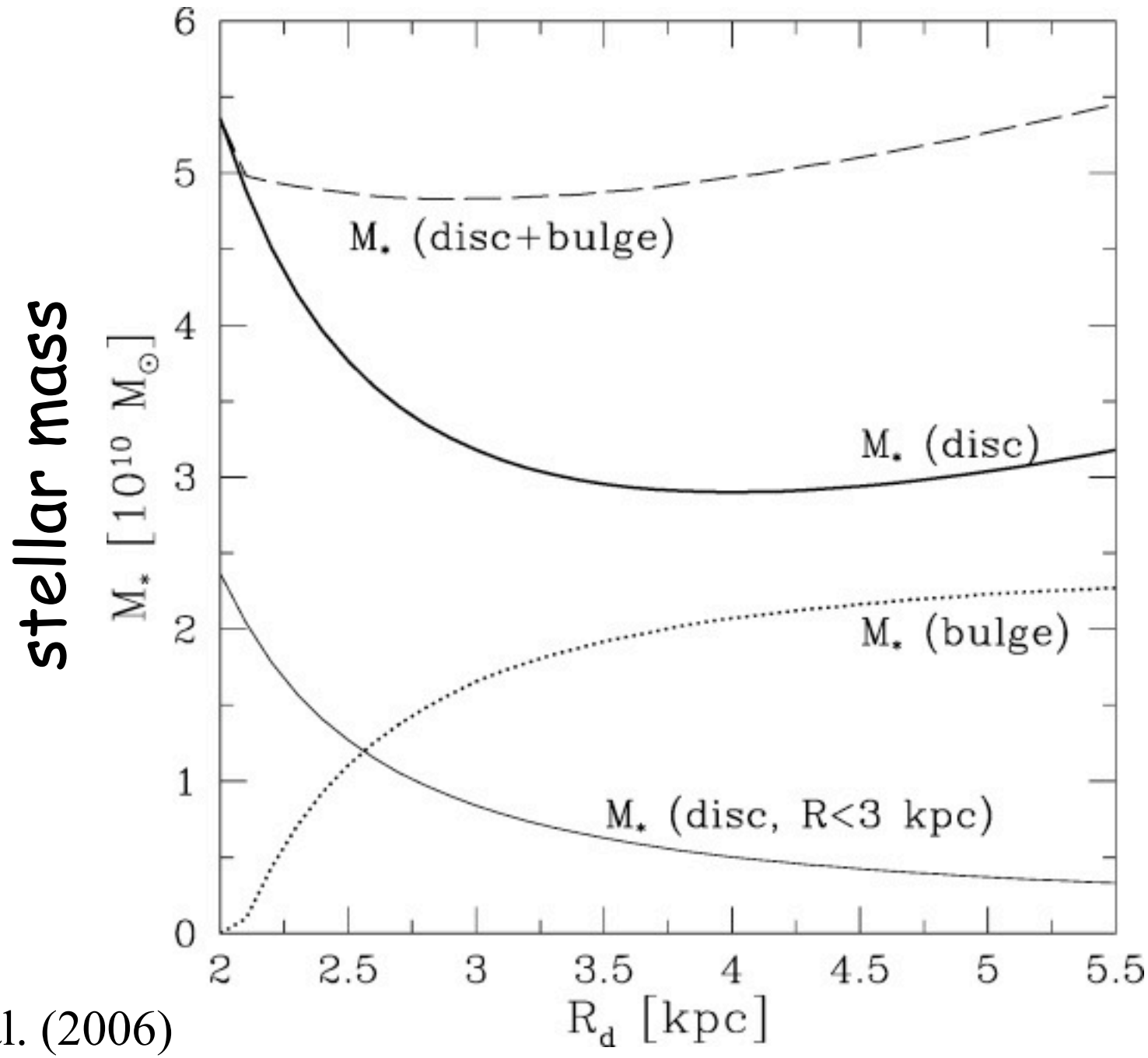


Fig 2.22 (Burton, Dame) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

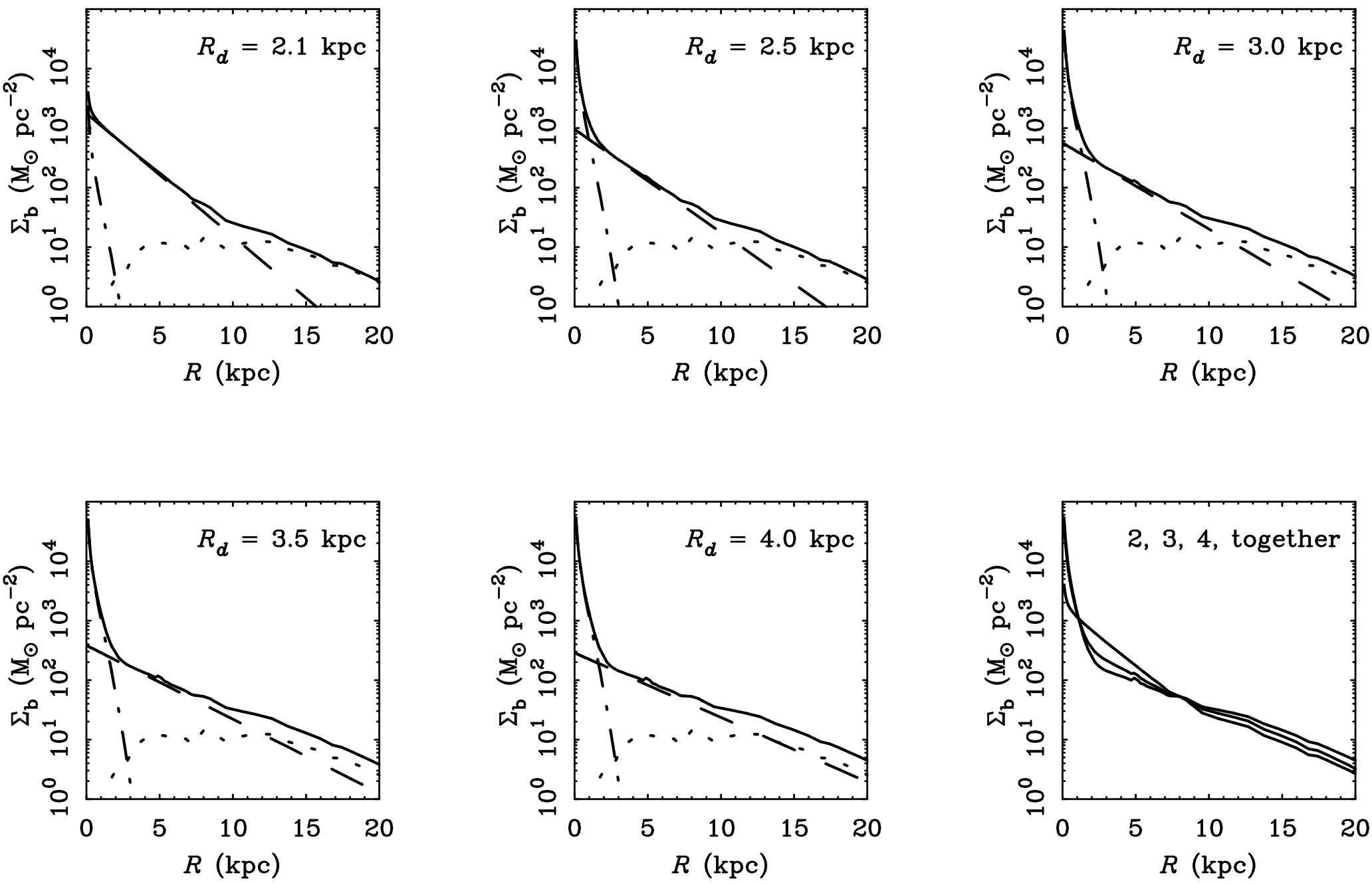
HI more extended than stars,
not really exponential


R_d = 2.3 kpc
bulge
disk
gas
Σ ($M_\odot$ pc^{-2})
10^0
10^1
10^2
10^3
10^4
0
5
10
15
20
R (kpc)

MW bulge-disk relation



Flynn et al. (2006)


R_d = 2.1 kpc
R_d = 2.5 kpc
R_d = 3.0 kpc
R_d = 3.5 kpc
R_d = 4.0 kpc
2, 3, 4, together
Σ_b ($M_\odot$ pc^{-2})
10^0 10^1 10^2 10^3 10^4
0 5 10 15 20
R (kpc)