Emission coefficient for line emission

Einstein coefficient (orpc)

eq 9.8:

$$j_\nu = \frac{n_j A_{ji} h\nu}{4\pi} \phi(\nu)$$

density of atoms w/e⁻ in level j

e.g Gaussian

eg eq 9.1

most commonly

- challenge b/c lots of uncertainties
  (see list section 9.4)

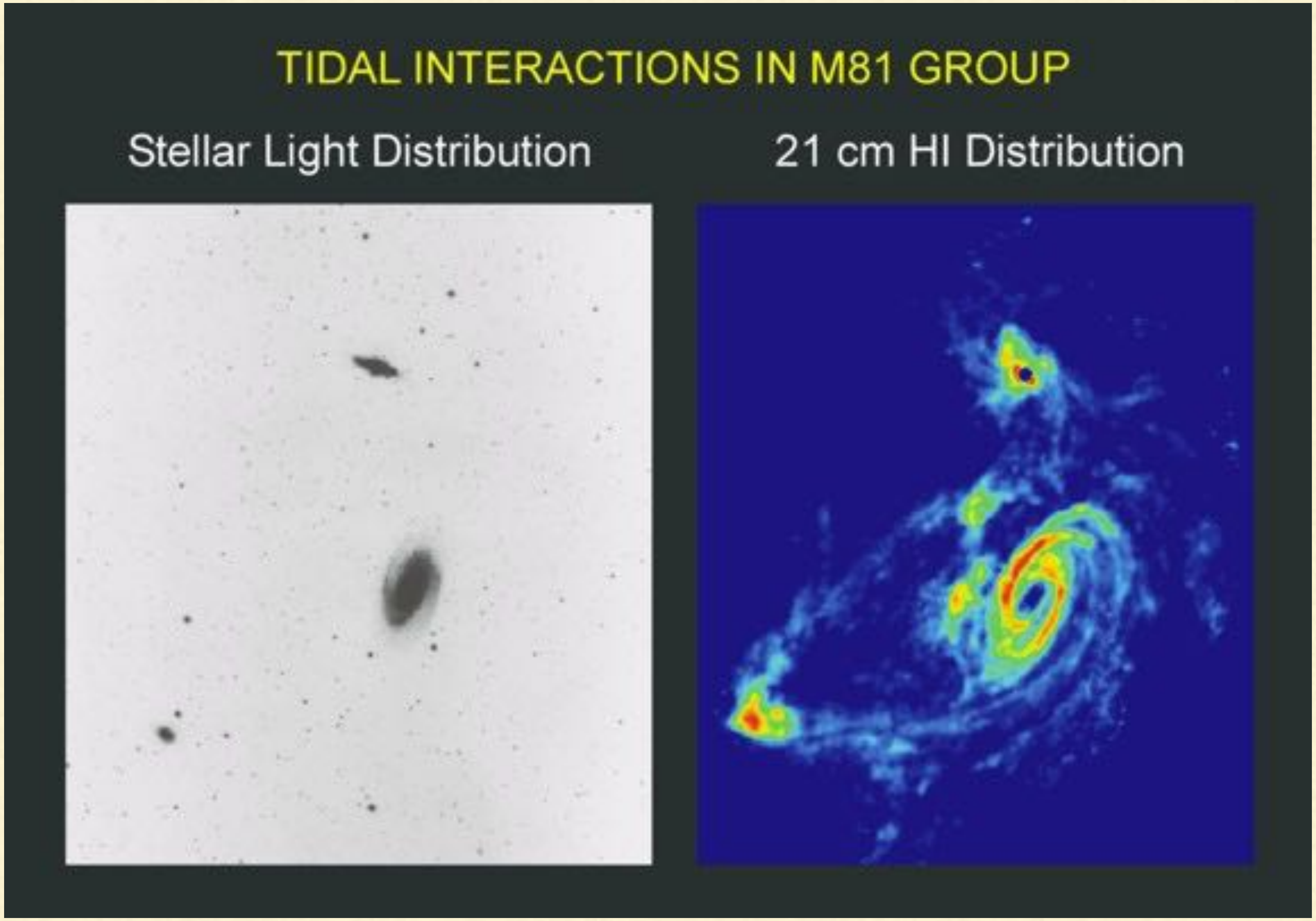
can simplify w/o compromising result too much

3 cases

- radio recombination lines (RRLs)
- optical recombination lines (Balmer)
- λ21cm neutral hydrogen line

- spin flip transition
- collisionally excited ⇒ LTE, Boltzmann eq 3.23
- bypasses extinction
- everywhere & loads of it
- Learnt loads
  e.g. (see 307)
  - tidal interactions
- rotation ⇒ DM
- large scale structures

Here, use it to measure HI mass

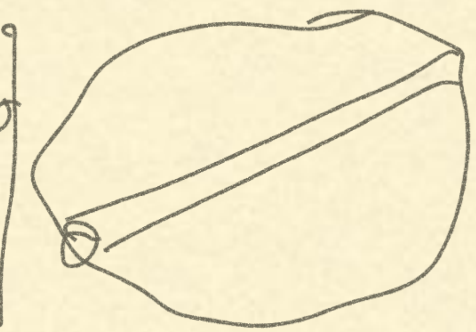


Need introduce column density

definition $N_{HI} \equiv \int_l n_{HI}\, dl \quad [\mathrm{cm}^{-2}]$ eq 9.22

Number density integrated over line-of-sight

can use in $\tau_\nu = \sigma_\nu \int_l n_1\, dl = \left[\frac{n_1}{n_{HI}} = \frac{1}{4}, \text{eq } 9.20\right]$



$= \frac{1}{4}\sigma_\nu \int_l n_{HI}\, dl = \frac{1}{4}\sigma_\nu N_{HI}$ (eq 9.21) (σ_ν = effective cross-section eq 9.23)

$\Rightarrow \ldots \Rightarrow$

$$N_{HI} = 3.85 \cdot 10^{14}\, T_S \int \tau_\nu\, d\nu$$ ($\tau_\nu \ll 1$, eq 9.25)

T_S = spin temperature, can assume = kinetic temp T (when line is in LTE) when $\tau_\nu \ll 1$ $T_B(v) = T_S \tau_v$ eq 6.33

$\Rightarrow N_{HI} = 1{,}82 \cdot 10^{18}\, T_S \int \tau_v \, dv$ eq. 9.26

velocity

iso freq

$\Rightarrow N_{HI} = 1{,}82 \cdot 10^{18} \int_v T_B(v)\, dv$ $[\mathrm{cm}^{-2}]$

km/s

if optically thick line at vel v $\Rightarrow T_B(v) = T_S$ (eq 6.32)

cannot evaluate N then (cannot see far enough into cloud)

eq 9.29: $M_{HI} = 2.36 \cdot 10^5 D^2 \int_v f_v \, dv$

$M_\odot$

Mpc

Jy km/s

f_v = total flux density at some velocity

D = distance

Ex 9.4 ngc 2903

$\tau_\nu \ll 1$, $\Omega_s = 1.8 \cdot 10^{-5}$ sr

$\int I_\nu \, dv = 0.0458$ Jy/beam km/s

beam : $\Omega_b = 5.21 \cdot 10^{-9}$ sr

$M_{tot} \simeq 1.6 \cdot 10^{11} M_\odot$

$\int I_\nu \, dv = 8.79 \cdot 10^{-17}$ erg/s/cm²/Hz/sr km/s

use R-J eq 4.6 $\Rightarrow$ $\int_v T_B \, dv = 142$ K km/s

$B_\nu(T) = \frac{2\nu kT}{c^2}$

$\Rightarrow$ [9.28] $\Rightarrow$ $N_{HI} = 2.58 \cdot 10^{20}$ /cm²

multiply N with source area $\Rightarrow$ total # of HI atoms

eq B.2 : $\sigma_s = r^2 \Omega_s$ [r = distance = 86 Mpc] $\Rightarrow \sigma = 1.27 \cdot 10^{46}$ cm² ☆

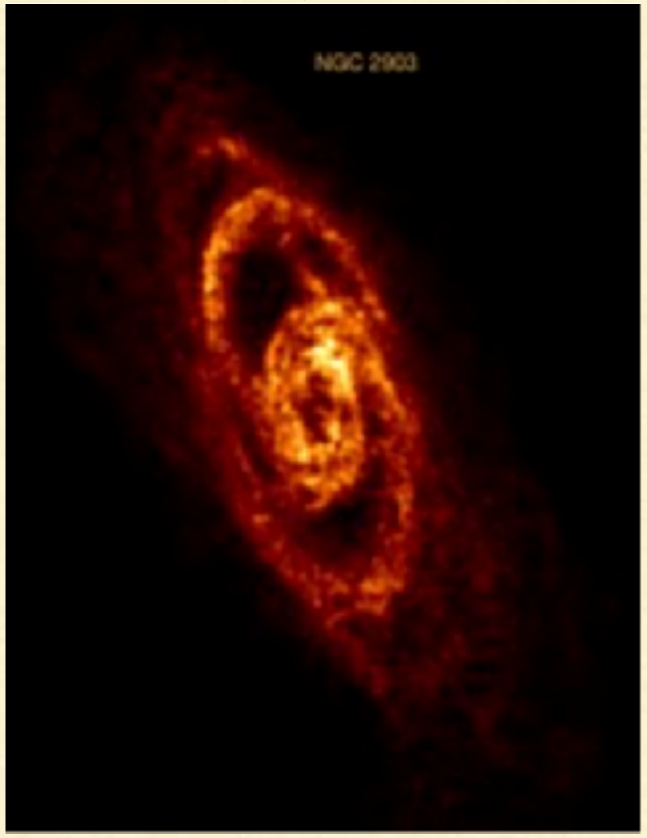
☆ $N = N_{HI} \cdot \sigma_s = 3.27 \cdot 10^{66}$ = total # of HI atoms

× mass of 1 HI atom, divide by $M_\odot$

$\Rightarrow M_{HI} = 2.7 \cdot 10^9 M_\odot$

fraction HI mass 2% of total

HI ✓ from THINGS



Optical recombination lines (9.4.2) $\tau_\nu \ll 1$

Balmer lines observed in optical

Only need know # of particles in n_j to use eq 9.8 (expression for j_ν)

effective recombination coeff see table 9.4

$$\Rightarrow \ldots \Rightarrow \int_\nu j_\nu \, d\nu = \frac{1}{4\pi} h\nu_{ji} \alpha_{ji} n_e n_i \simeq \frac{1}{4\pi} h\nu_{ji} \alpha_{ji} n_e^2$$

use 6.12 with 9.13

freq of line centre

e- & ion densities, set to equal

$\propto$ density

$$\Rightarrow \ldots \Rightarrow \int_\nu I_\nu \, d\nu = \frac{1}{4\pi} h\nu_{ji} \alpha_{ji} n_e^2 l = 2.46 \cdot 10^{17} h\nu_{ji} \alpha_{ji} \, EM$$

intensity over the line

$\propto$ temp

$\left[\frac{pc}{cm^6}\right]$

Table 9.4. Effective recombination coefficients[a]

$\alpha_{j,i}$ (cm^3 s^{-1})	Temperature (K) 5 000	10 000	20 000
$\alpha_{3,2}$ (H α)	2.21×10^{-13}	1.17×10^{-13}	5.97×10^{-14}
$\alpha_{4,2}$ (H β)	5.41×10^{-14}	3.03×10^{-14}	1.61×10^{-14}

[a] Case B recombination has been assumed (see Sect. 9.4.2). H α values are from Ref. [160] and H β values are from Ref. [115]. For the latter reference, means for the densities, 10^2 and 10^4 cm^{-3} are given.

↑ wellknown, for any 2 lines in an atom, EM is the same

$$\frac{\int_\nu I_\nu d\nu \ (j\to i)}{\int I_\nu d\nu \ (k\to m)} = \frac{\nu_{ji}\,\alpha_{ji}}{\nu_{km}\,\alpha_{km}} \quad \alpha \text{ Temp}$$

Ex Hα & Hβ

$$\frac{\nu_{32}\,\alpha_{32}}{\nu_{4-2}\,\alpha_{42}} = \left[\begin{matrix}\text{table C.1}\\ \text{table 9.4}\end{matrix}\right] = \frac{486.132}{656.288}\cdot\frac{1{,}17\cdot 10^{-13}}{3{,}03\cdot 10^{-14}}$$

$$= 2{,}86$$

Assume HII region
T = 10^4 K