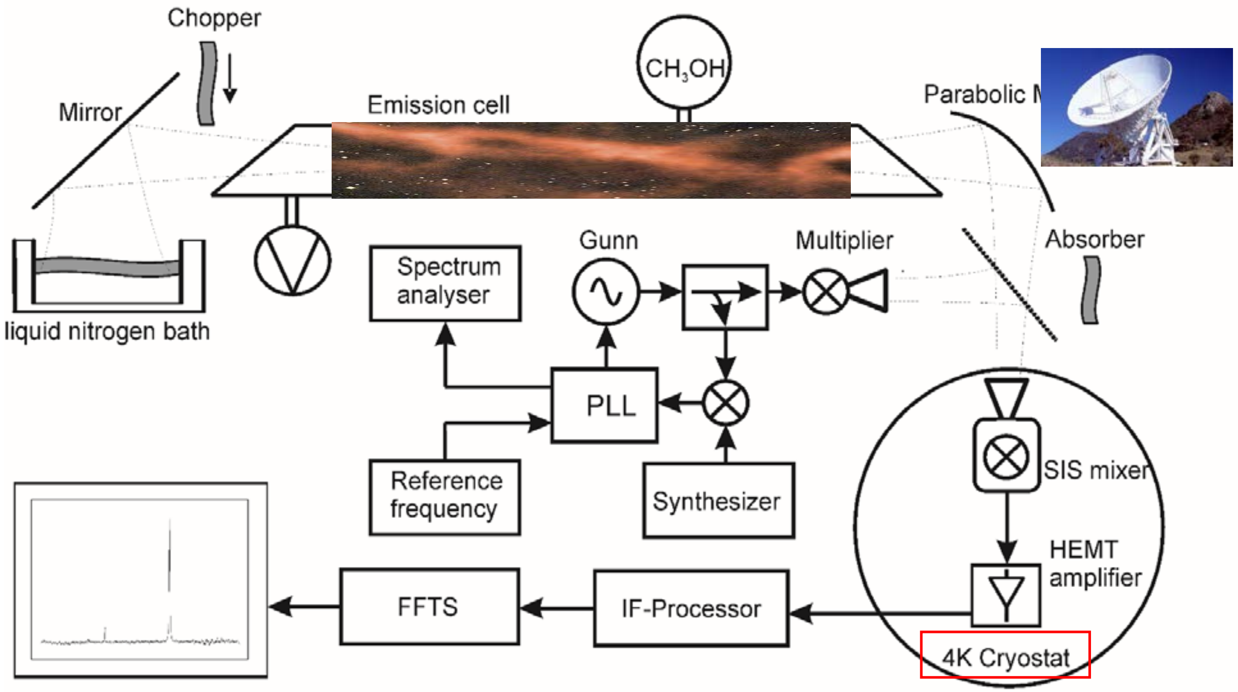
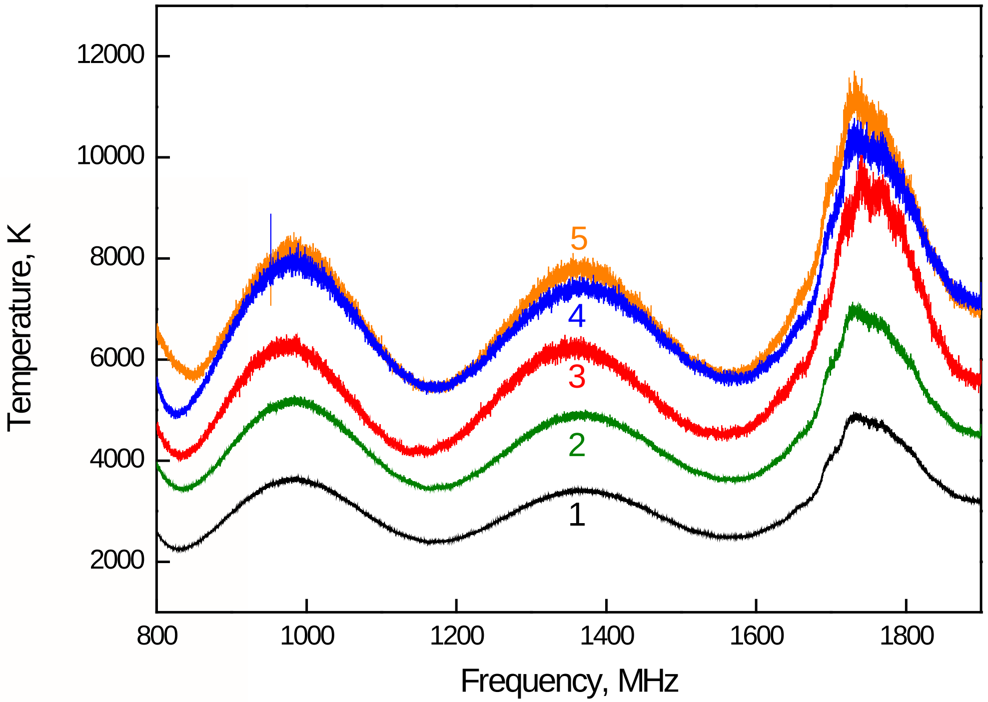
Radio Astronomy, Lecture 6

Grundlagen der Linienemission
HI
HI in Galaxien

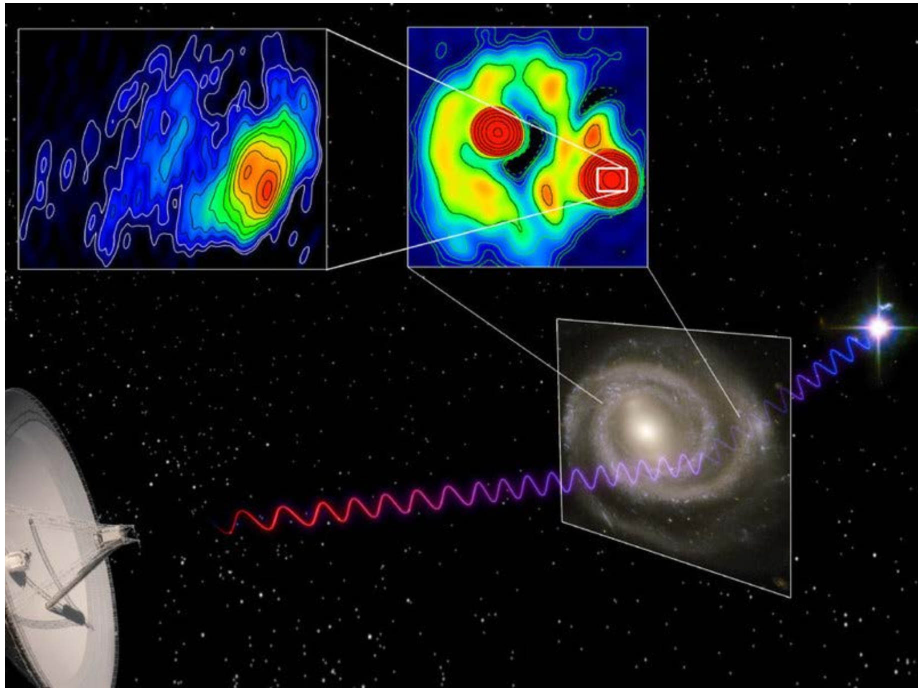




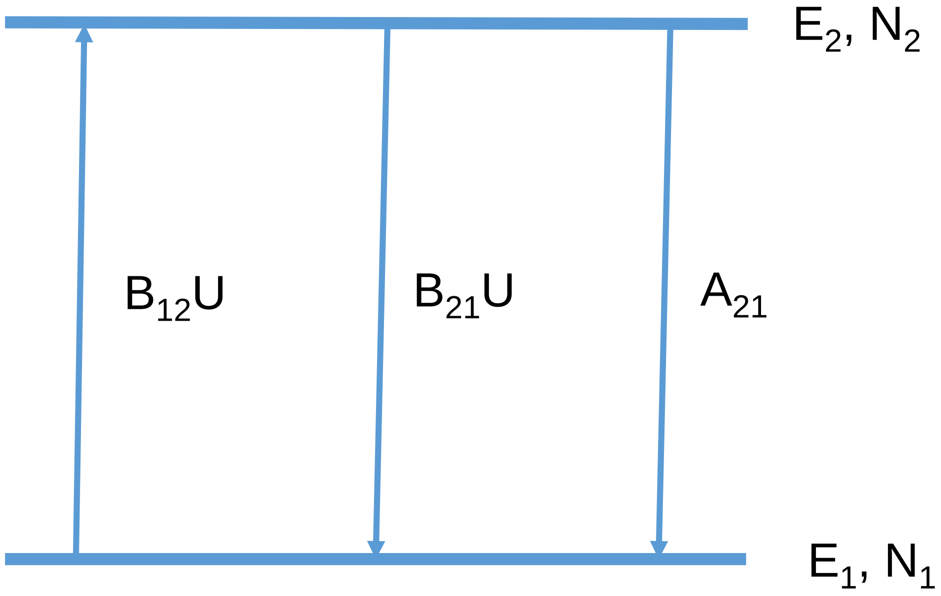
Receiver ***T_{rec}*** and system ***T_{sys}*** noise temperatures at the LO frequency of 804 GHz:
1) T_{rec} 2) T_{sys} including the emission cell without windows
3) T_{sys} including the evacuated cell and HDPE windows
4) T_{sys} including the evacuated cell and Teflon windows
5) T_{sys} including the cell and Teflon windows, the cell is filled with 1 bar of air

Absorption

Emission



The Einstein Coefficients



Thermodynamic equilibrium: $N_2 A_{21} + N_2 B_{21} \bar{U} = N_1 B_{12} \bar{U}$

Boltzmann distribution: $\frac{N_2}{N_1} = \frac{g_2}{g_1} \exp\left(-\frac{h\nu_0}{kT}\right)$

Planck function: $\bar{U} = \frac{4\pi}{c} B_\nu(T) = \frac{8\pi h\nu_0^3}{c^3} \frac{1}{\exp\left(\frac{h\nu_0}{kT}\right) - 1}$

↓

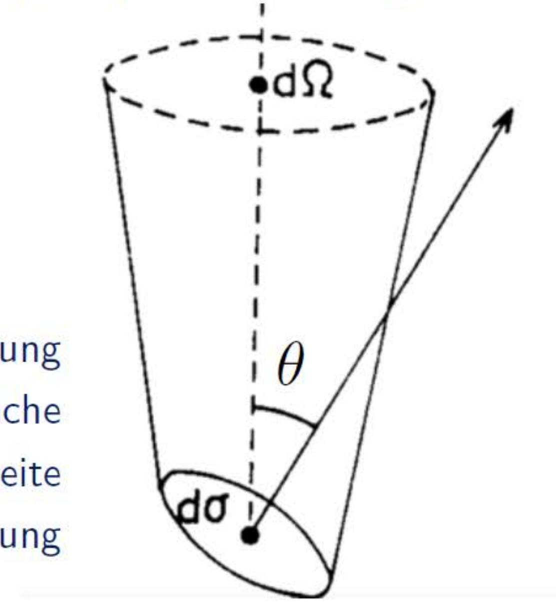
$$g_1 B_{12} = g_2 B_{21} \qquad A_{21} = \frac{8\pi h\nu_0^3}{c^3} B_{21}$$

Lecture 1

Definition “Intensität”

equivalent Flächenhelligkeit, engl. brightness, intensity, or specific intensity,

$$\frac{\mathrm{d}P_{\nu,\mathrm{rec}}}{\mathrm{d}\sigma\ \mathrm{d}\nu\ \mathrm{d}\Omega\ \cos\theta} =: I_\nu$$



$\mathrm{d}P_{\nu,\mathrm{rec}}$: registrierte Leistung

$\mathrm{d}\sigma$: infinitessimale Detektorfläche

$\mathrm{d}\nu$: infinitesimal Detektorbandbreite

$\mathrm{d}\theta$: Winkel Flächennormale Beob.-Richtung

- ‘Intensität’ ist Eigenschaft auf Sphäre um Detektor
  Entfernung der Quelle spielt keine Rolle

  z.B. Sonne hat eine Intensität von

$$1.8 \times 10^{-17}\,\mathrm{erg\,s^{-1}\,cm^{-2}\,Hz^{-1}\,sr^{-1}} \quad @\,100\,\mathrm{MHz}$$

- Energiedichte $u_\nu = \frac{1}{c} I_\nu$

Radiative transfer

$$\begin{aligned} \mathrm{d}I_{\nu-} &= -\kappa_\nu I_\nu \,\mathrm{d}s\,, \\ \mathrm{d}I_{\nu+} &= \varepsilon_\nu \,\mathrm{d}s\,, \end{aligned} \qquad \frac{\mathrm{d}I_\nu}{\mathrm{d}s} = -\kappa_\nu I_\nu + \varepsilon_\nu$$

Spontaneous emission:

$$\mathrm{d}E_\mathrm{e}(\nu) = h\nu_0 N_2 A_{21}\,\varphi_\mathrm{e}(\nu)\,\mathrm{d}V \frac{\mathrm{d}\Omega}{4\pi}\,\mathrm{d}\nu\,\mathrm{d}t$$

Absorbtion

$$\mathrm{d}E_\mathrm{a}(\nu) = h\nu_0 N_1 B_{12}\frac{4\pi}{c} I_\nu\,\varphi_\mathrm{a}(\nu)\,\mathrm{d}V \frac{\mathrm{d}\Omega}{4\pi}\,\mathrm{d}\nu\,\mathrm{d}t$$

Stimulated emission

$$\mathrm{d}E_\mathrm{s}(\nu) = h\nu_0 N_2 B_{21}\frac{4\pi}{c} I_\nu\,\varphi_\mathrm{e}(\nu)\,\mathrm{d}V \frac{\mathrm{d}\Omega}{4\pi}\,\mathrm{d}\nu\,\mathrm{d}t$$

$$\Downarrow$$

$$\frac{\mathrm{d}I_\nu}{\mathrm{d}s} = -\frac{h\nu_0}{c}(N_1 B_{12} - N_2 B_{21}) I_\nu\,\varphi(\nu) + \frac{h\nu_0}{4\pi} N_2 A_{21}\,\varphi(\nu)$$

k_v $\qquad\qquad$ ε_v

Dipole Transition Probabilities

Electric dipole: $d(t) = e\,x(t) = e\,x_0 \cos \omega t$

Magnetic dipole: $m(t) = m_0 \cos \omega t$

$$P(t) = \frac{2}{3} \frac{e^2 \dot{v}(t)^2}{c^3} \qquad \langle P \rangle = \frac{64\pi^4}{3\,c^3}\, \nu_{mn}^4 \left(\frac{e\,x_0}{2} \right)^2 \qquad \langle P \rangle = h\,\nu_{mn} A_{mn} \qquad \mu_{mn} = \frac{e\,x_0}{2}$$

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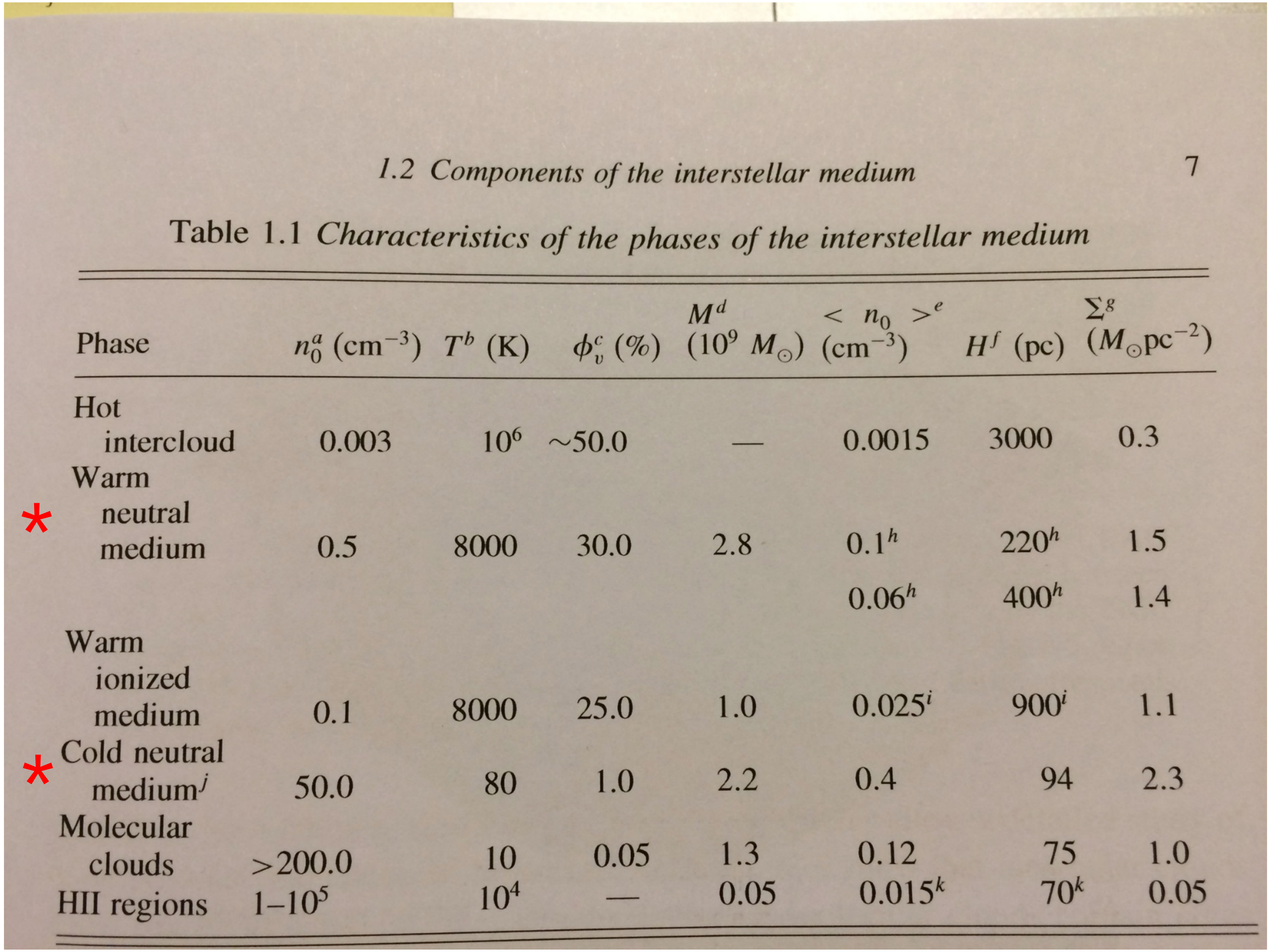
$$A_{mn} = \frac{64\pi^4}{3\,h\,c^3}\, \nu_{mn}^3 \, |\mu_{mn}|^2$$

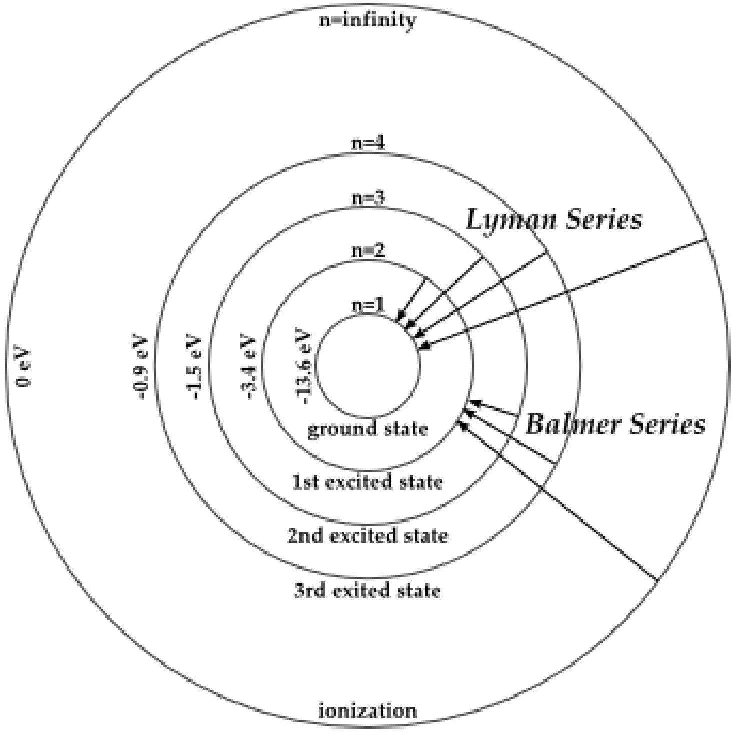
Line Radiation of Neutral Hydrogen



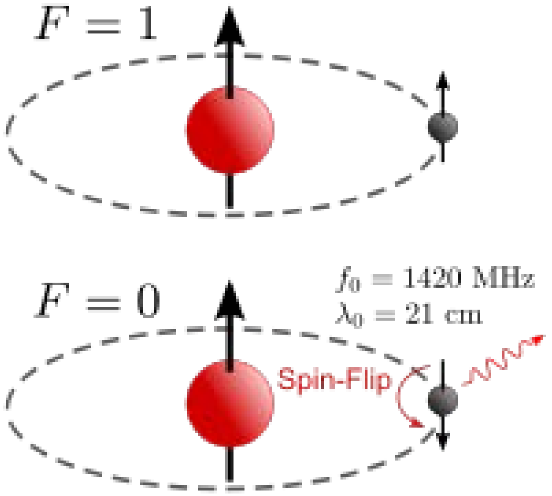
1.2 Components of the interstellar medium 7

Table 1.1 *Characteristics of the phases of the interstellar medium*

Phase	n_0^a (cm^{-3})	T^b (K)	ϕ_v^c (%)	M^d ($10^9\ M_\odot$)	$< n_0 >^e$ (cm^{-3})	H^f (pc)	Σ^g ($M_\odot$pc^{-2})
Hot intercloud	0.003	10^6	~50.0	—	0.0015	3000	0.3
* Warm neutral medium	0.5	8000	30.0	2.8	0.1^h	220^h	1.5
					0.06^h	400^h	1.4
Warm ionized medium	0.1	8000	25.0	1.0	0.025^i	900^i	1.1
* Cold neutral medium^j	50.0	80	1.0	2.2	0.4	94	2.3
Molecular clouds	>200.0	10	0.05	1.3	0.12	75	1.0
HII regions	1–10^5	10^4	—	0.05	0.015^k	70^k	0.05



n = 2 – 1, Lyα = 121 nm



F = 1 - 0, 21 cm

From magnetic dipole: $$A_{mn} = \frac{64\pi^4}{3hc^3} \nu_{mn}^3 |\mu_{mn}|^2$$

$\mu = he/2m_e c$ $A_{10} = 3 \times 10^{15}$ s^{-1}

radiative half-life $\tau_{1/2} = 1/A_{10} \approx 3 \times 10^{14}$ s $\approx 10^7$ yr

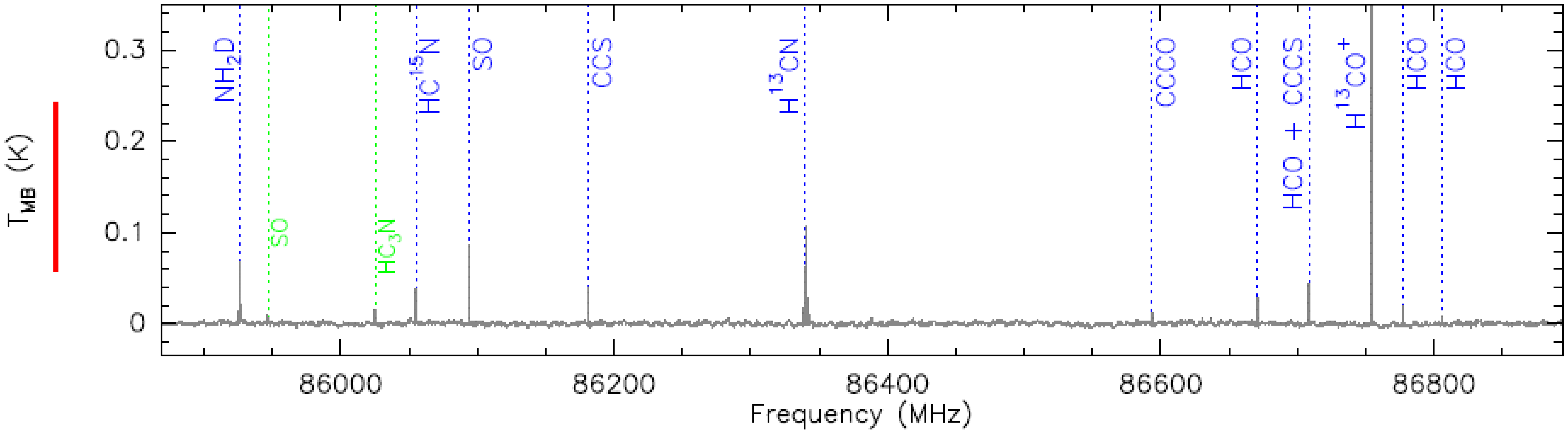
$$\frac{N_1}{N_0} = \frac{g_1}{g_0} \exp\left(-\frac{h\nu_{10}}{kT_s}\right) \text{ + Slide 6} \longrightarrow \kappa_\nu = \frac{3c^2}{32\pi} \frac{1}{\nu_{10}} A_{10} N_\mathrm{H} \frac{h}{kT_s} \varphi(\nu)$$

Doppler shift: $$\frac{\nu_{10} - \nu}{\nu_{10}} = \frac{v}{c}$$

Column density: $\frac{\mathcal{N}_\mathrm{H}}{\mathrm{cm}^{-2}} = \int_0^\infty \left(\frac{N_\mathrm{H}(s)}{\mathrm{cm}^{-3}}\right) \mathrm{d}\left(\frac{s}{\mathrm{cm}}\right)$

$$\frac{\mathcal{N}_\mathrm{H}}{\mathrm{cm}^{-2}} = 1.8224(3)\times 10^{18}\left(\frac{T_\mathrm{s}}{\mathrm{K}}\right)\int_{-\infty}^{\infty}\tau(v)\,\mathrm{d}\left(\frac{v}{\mathrm{km\,s^{-1}}}\right)$$

$$\tau = -\ln\left(1-\frac{T_\mathrm{L}}{T_\mathrm{s}-T_\mathrm{BG}}\right)$$



HI in External Galaxies

Density map + Rotation curve of a Galaxy

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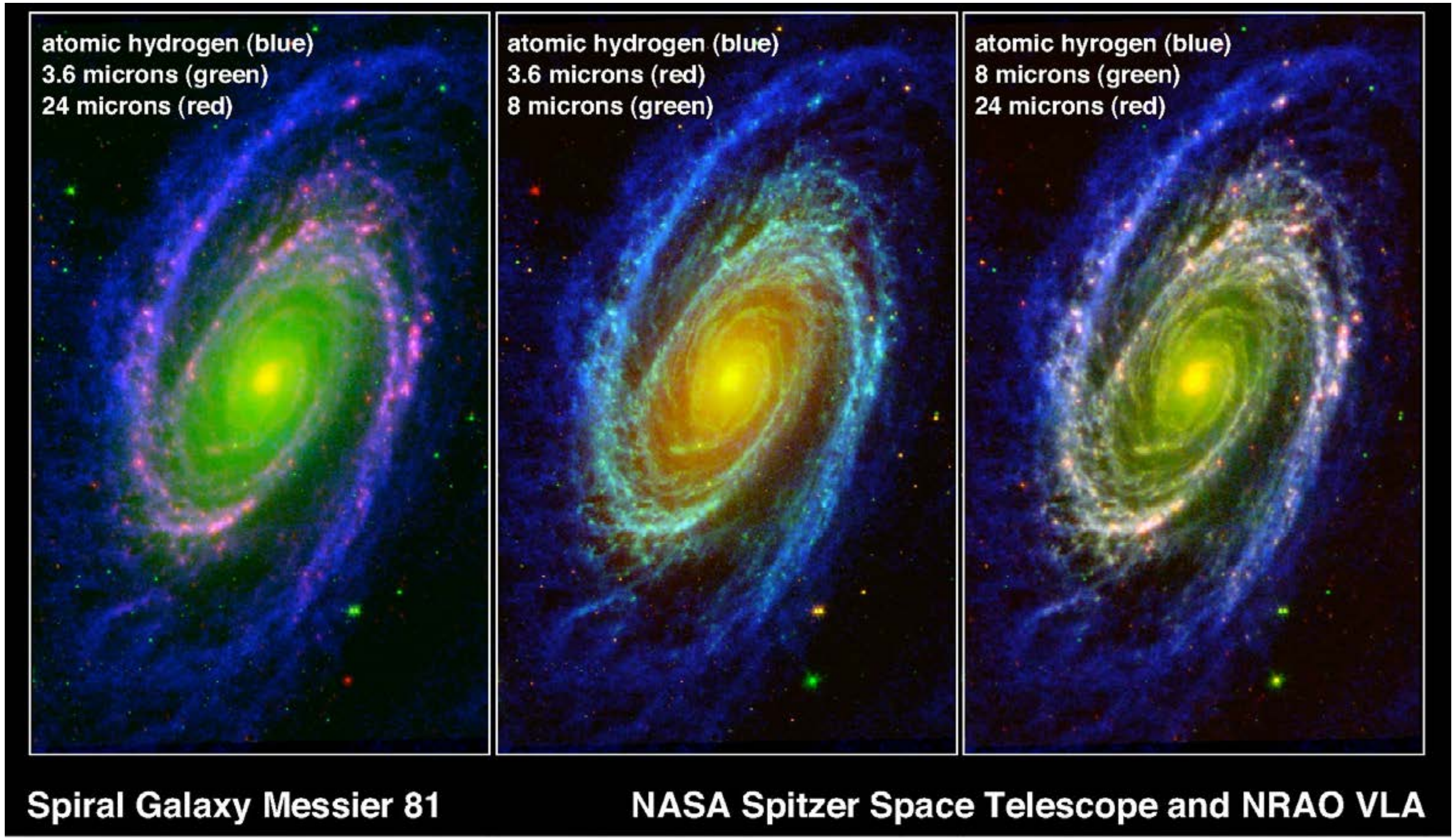
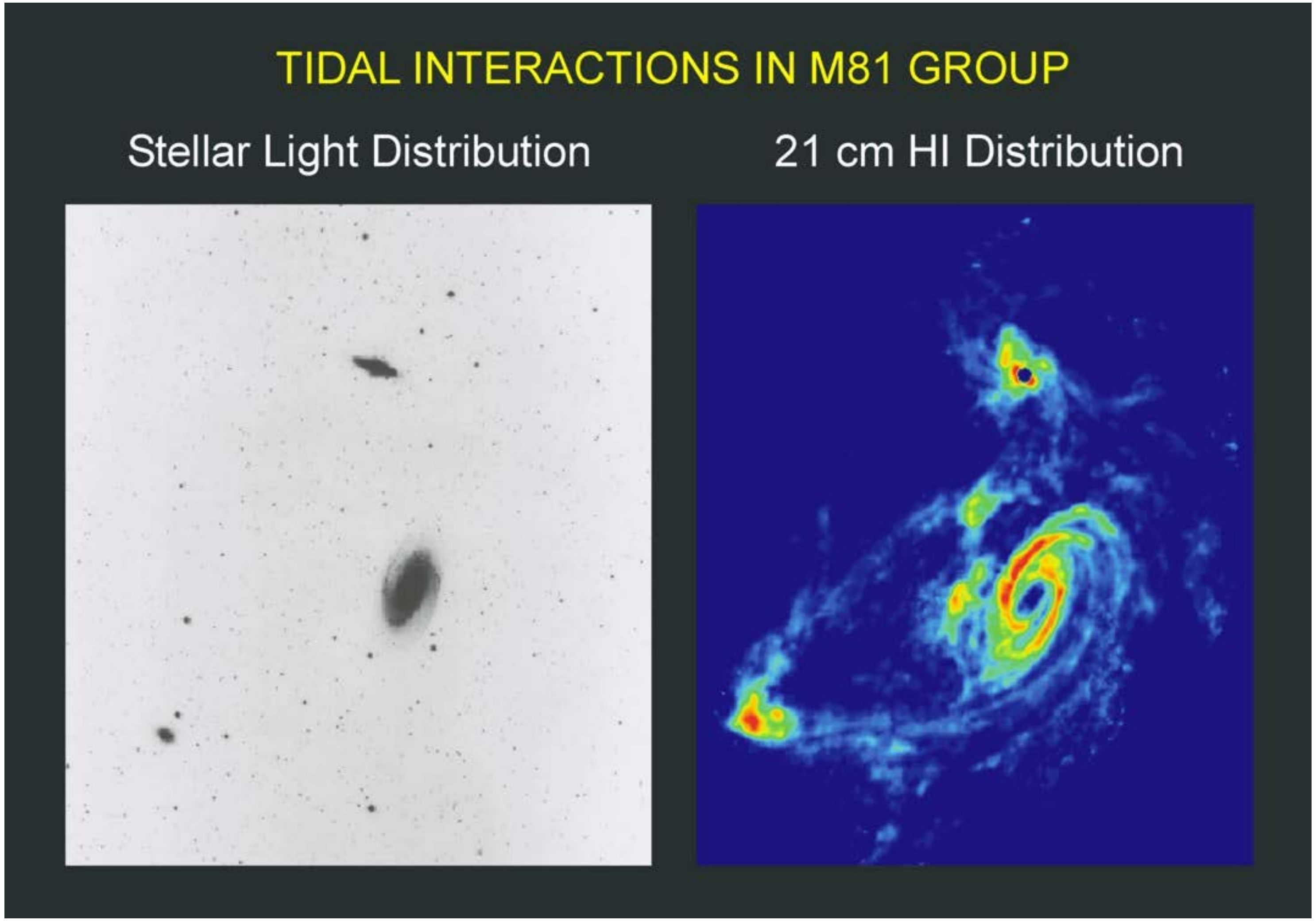
Galaxy structure and history



A high-resolution HI image of M81 made with the VLA for the THINGS survey compared with Spitzer mid-infrared emission.

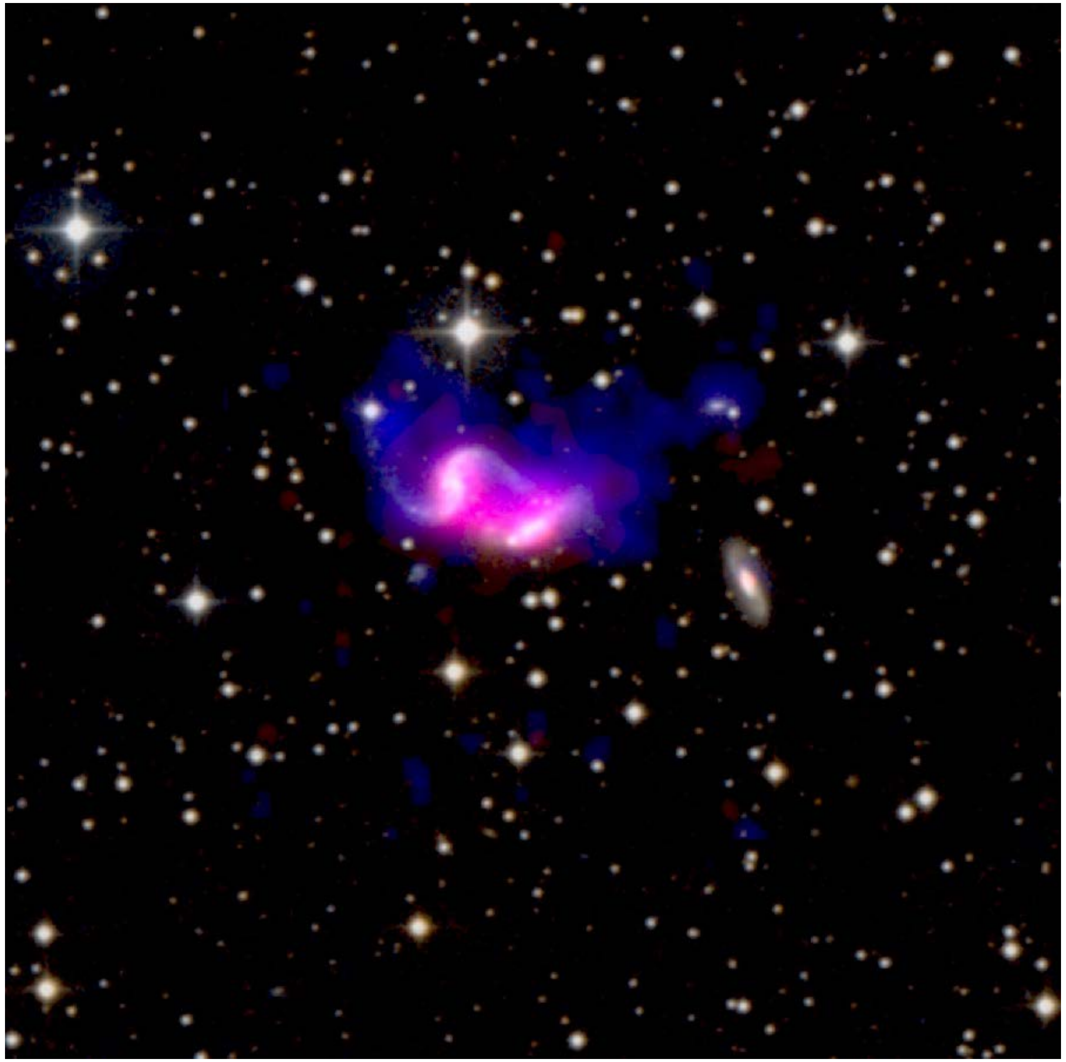


TIDAL INTERACTIONS IN M81 GROUP

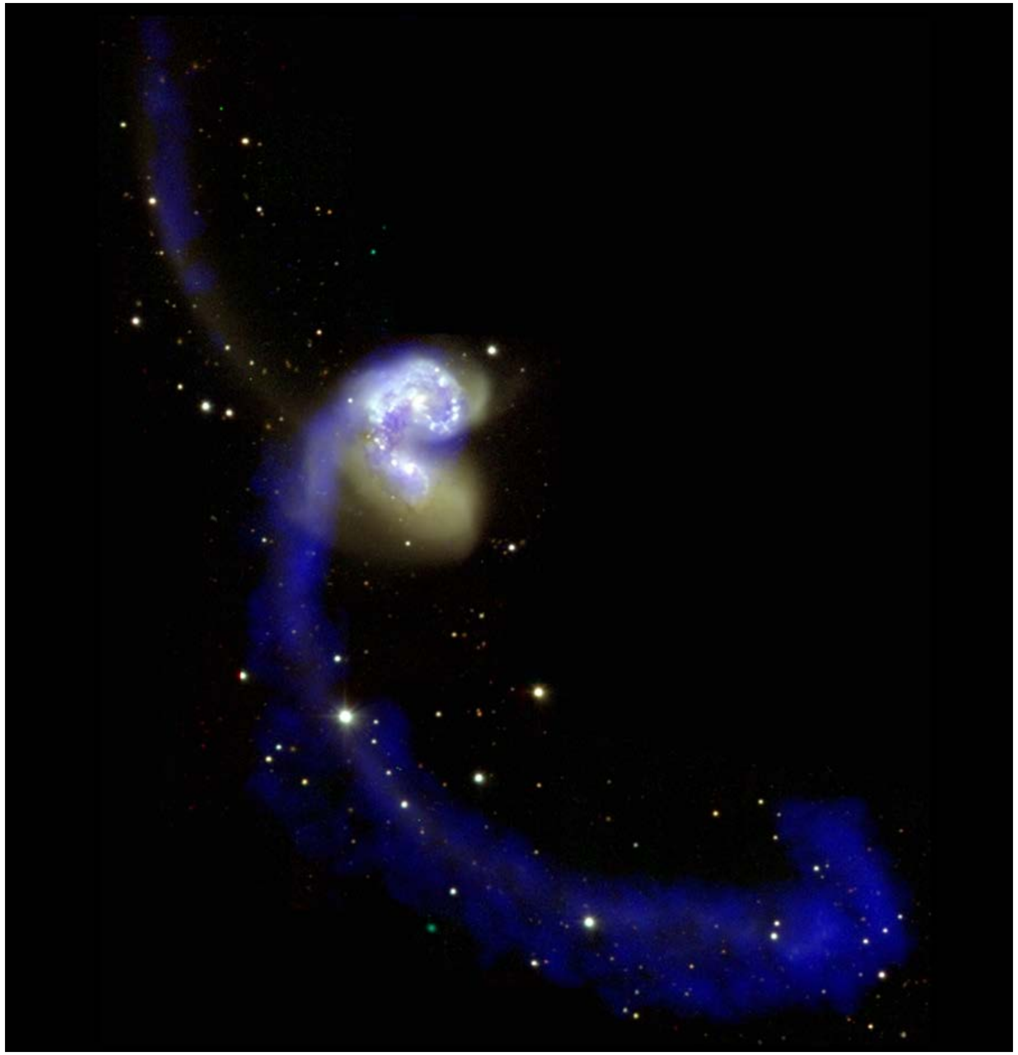
Stellar Light Distribution

21 cm HI Distribution

The streamers visible only in HI clearly demonstrate that the M81 group is an interacting system of galaxies.



The radio continuum (red) and HI (blue) images of the post-merger pair of galaxies UGC 813 and UGC 816 indicate that the disks of these two galaxies passed through each other about 50 million years ago.



Optical (white) and HI (blue) images of the strongly interacting galaxies NGC 4038 and NGC 4039. The velocity distributions of the long HI tidal tails provide strong constraints for computer models of the interaction history.