Astro 501: Radiative Processes
Lecture 25
October 26, 2018

Announcements:

- **Problem Set 7** due now
- **Problem Set 8** due next Friday

Last time: the physics and astrophysics of line shapes

Q: why not a delta function? what about energy conservation?

Q: sources of broadening?

Q: lineshapes in astrophysical applications?

Linewidths

naïvely: in transition $u \rightarrow \ell$, *energy conservation* requires
$h\nu = E_u - E_\ell \equiv h_{u\ell}$, so $\phi_{\mathrm{naive}}(\nu) = \delta(\nu - \nu_{u\ell})$: *zero width!*

But real observed linewidths are nonzero, for several reasons

- *intrinsic width*
quantum effect, due to nonzero transition rate $\Gamma = 1/\tau$
and energy-time uncertainty principle $\Delta E \ \Delta t \gtrsim \hbar/2$

- *thermal broadening*
thermal motion of absorbers $\rightarrow$ Doppler shifts

- *collisional broadening*
absorber collisions add to transition probability

Collisional Linewidth

if particle densities are high, atomic collisions are rapid
and can drive transitions $u \leftrightarrow \ell$

thus there is a nonzero collision rate $\Gamma_{\rm coll}$ per atom
where $\Gamma_{\rm coll} = n \; \sigma_{\rm coll} v$

heuristically: this decreases excited state lifetimes
and thus adds to energy uncertainty

so total transition rate includes both $\Gamma_{\rm int}$ and $\Gamma_{\rm coll}$:
$\rightarrow$ collisions add damping, which depends on
photospheric density and temperature via $\Gamma_{\rm coll}$

thus collisional broadening measures density and temperature
thus also know as "pressure broadening"

Q: effect of collisions on lineshape?

recall: atomic transition $u \to \ell$ has

$$\sigma_{u\ell}(\nu) = \pi e^2/m_e c \; f_{u\ell} \; \phi_{u\ell}(\nu) = B_{\text{classical}} \; f_{u\ell} \; \phi(\nu) \tag{1}$$

without collisions, intrinsic profile shape that is *Lorentzian*

$$\phi_{u\ell}^{\text{intrinsic}}(\nu) = \frac{4\Gamma_{u\ell}}{16\pi^2(\nu - \nu_{u\ell})^2 + \Gamma_{u\ell}^2}$$

full width at half-maximum: $(\Delta\nu)_{\text{FWHM}} = \Gamma_{u\ell}/2\pi$
set by intrinsic level de-excitation rate $\Gamma_{u\ell}$

With collisions: $\Gamma_{\text{coll}} = n \; \sigma_{\text{coll}} \; v$
still a Lorentzian profile, but with effective transition rate to

$$\frac{\Gamma_{u\ell}}{2} = \frac{\Gamma_{u\ell}^{\text{intrinsic}}}{2} + \Gamma_{\text{coll}} \tag{2}$$

`www: solar Hα line`

Awesome Example: Classifying Stars

Q: how can spectra determine stellar (photosphere) T?

`www: spectra of main sequence (dwarf) stars`
Q: many lines are strongest in middle of sequency–why?

`www: white dwarf spectrum`
`www: O star spectrum`
Q: similar temperatures, why different?

Q: at fixed T, how can spectrum distinguish main sequence vs giant stars?

Q: which of the above requires distance to star?
Q: what stellar properties do require distance?

Awesome Example: Classifying Stars

to a good approximation, stellar spectra are:

- blackbody = Planck form, at photospheric T
- with lines (often many!) due to photospheric absorption

Star Type: *OBAFGKMLT*

a sequence in *temperature*; Sun is G2V

"early types" hotter than Sun: *OBAF*

"late types" solar and cooler: *GKMLT*

main sequence spectra: lines very temperature sensitive

Balmer H lines: weak→strong→weak for types O→A→M

- O stars $T > 30,000$ K: most H is ionized
- A stars $T \sim 10,000$ K: most H neutral, but $n = 2$ populated
- M stars $T \sim 4000$ K: H neutral, tiny $n = 2$ population

Stellar Luminosity Class: I, II, III, IV, V
determined by shapes of strong lines at fixed spectral type
i.e., at (nearly) fixed temperature
V: line wings broader than intrinsic damping width
I: no additional broadening

physically: damping wings sensitive to *pressure broadening*
i.e., by collision rate $\Gamma_{\rm coll} = n\sigma_{\rm coll}v$
at fixed T, this corresponds to different *density* and pressure
but hydrostatic equilibrium: $\nabla P = \rho\vec{g} = G\rho M/R^2$
linewidth set by pressure $\rightarrow$ set by stellar *radius* R

Class I: supergiant
Class II: bright giants
Class III: normal ("red" giants)
Class IV: subgiants
Class V: main sequence (non-giants = "dwarfs"); Sun is G2V

Absorption Lines: Probing the Depths

so far: focused on absorption line *shape*
but important information also in line *depth*
below the continuum level

Q: what is needed to measure line depth?
Q: in high-resolution spectra, what sets line depth at each ν*?*
Q: as absorber density increases, effect on line?

absorption cross section (line oscillator strength) generally known
`www: online databases`
Q: given this, what quantitative information does line depth give?