Astro 406
Lecture 8
Sept. 13, 2013

Announcements:

- **PS 2 due now**
- **PS 3 available, due next Friday**
- Guest cosmologist today: Prof. Charles Gammie
  Dept. Chair, and expert on black hole feeding

Last time: exploring the Milky Way
grammatical aside: we live in the **G**alaxy $\equiv$ Milky Way
...everything else is just a **g**alaxy

- Herschel, Kapteyn: star counts $\rightarrow$ we are near MW center
- Shapley: globular clusters $\rightarrow$ we are far from MW center

Q: how did Shapley show this?
Q: how do we reconcile these results?

Interstellar Dust

interstellar matter mostly gas, but about 1% of mass is **dust**

`www: interplanetary dust`

microscopic: size $\sim 1\mu = 1000nm$

strongly absorbs light with $\lambda \sim r$

$\rightarrow$ visible, some IR blocked– "in fog"

but more transparent when $\lambda \gg r$ and $\lambda \ll r$

e.g., far-IR, radio, γ-ray

`www: Barnard 68 at different wavelengths`

Also note:

absorption $\rightarrow$ more to picture than meets eye

$\rightarrow$ scale of MW goes up!

$\rightarrow$ Hershel confused by "fog" of dust: we are not at the center!

Cosmic Revolutions

Copernican Revolution I: Copernicus, 17th Century

we're one typical planet among many

not center of solar system

Copernican Revolution II: Shapley, earth 20th Century

we're one typical star among many

not center of Milky Way Galaxy

... stay tuned for more...

Celestial Sphere: Coordinate Systems

points on the *sky* specified by 2 coordinates on celestial sphere
points in 3-D space need distance as well

Equatorial Coordinates: based on Earth spin $\vec{S}$
north celestial pole = direction of $\vec{S}$
points: RA = α, dec = δ

`www: S&G equatorial coordinate diagram`

Q: why is this system useful?
Q: why is this system inconvenient for Galactic studies?
Q: what would be a better choice?

equatorial system great for practical observations
since celestial sphere moves with Earth spin
but not conveniently aligned relative to Galaxy

Galactic Coordinates: cover sky, based on Galactic plane
angles: Galactic *longitude* ℓ, *latitude* b
`www: S&G Galactic coordinate diagram`
Galactic center coordinates: $(\ell, b)_{\text{MW center}} = (0, 0)$

`www: Galactic coordinates in projection`
Q: which directions wraparound? which don't?

N. gal. pole: gal pole in N hemisphere
Q: $(\ell, b)_{\text{N gal pole}} = ?$

Galactic cylindrical coords ("Galactocentric")

cylindrical system $\vec{r} = (R, \phi, z)$

- coordinate center $R = 0$ at MW Center
  "Galactocentric distance"

- azimuth origin $\phi = 0$ towards us

- $z = 0$ in midplane

`www: S&G diagram`

all points at Sun's distance: $R = R_\odot \sim 8$ kpc
with 1 kpc = 1000 pc
"solar circle/cylinder"

Mapping the Milky Way (and Beyond): Data vs Theory

Eternal problem in Astronomy: sky is 2-dimensional
$\Rightarrow$ sky coords (RA,dec) or (ℓ, b) only have 2 entries
without distance info, images & maps are "cosmic roadkill"

but real space is 3-dimensional (at least!)

- 3-D objects/systems projected onto plane of sky
- always going from 2-D observation to 3-D model

Q: how to definitively go between the two?
Q: what if you can't–other strategies?

Mapping the Milky Way: Gas

detect gas by EM emission and/or absorption
prefer: wavelengths at which galaxy is nearly transparent
$\rightarrow \lambda \neq$ visible

hydrogen most abundant in the Solar system, other stars
H $>$ 90% of all atoms *by number*, $\gtrsim$ 70% by mass
$\Rightarrow$ expect H most abundant in the interstellar medium

gaseous H can be

- molecular: H-H diatomic pairs
  requires low T, high density *Q: why?*
- atomic: single neutral atoms
  requires $T \lesssim 100,000$ K
- ionized: free, unbound e, p
  requires high T and/or ionizing (UV) photons

Q: How can we observe each phase?

In Search of Interstellar Hydrogen: Atomic Form

D'oh!
neutral, atomic hydrogen (H I): usually in ground state $n = 1$
$\rightarrow$ no/few transitions to $n > 1$
$\rightarrow$ no/few optical emission or absorption photons
$\Rightarrow$ optically invisible!

Woo hoo!
H in ground state has 2 spin states: hyperfine splitting

$$n = 1 \left\langle \begin{array}{ll} & e\uparrow \quad p\uparrow \\ \Delta E & \\ & e\downarrow \quad p\uparrow \end{array} \right. \tag{1}$$

$$\begin{aligned} \Delta E &= 5.9 \times 10^{-6} \text{ eV} \\ \Rightarrow \lambda &= hc/\Delta E = \boxed{21 \text{ cm}}, \nu = 1420 \text{ MHz} \end{aligned}$$

Q: what kind of light has $\lambda = 21$ cm?

interstellar H atoms collide inelastically
collision energy drives H $\rightarrow$ excited state $e\uparrow \quad p\uparrow$

after $\sim few \times 10^6$ yr, de-excite
"spin-flip" down to ground state
$\rightarrow$ emit 21-cm radiation

21 cm = radio: photons not absorbed by dust!

Q: what kind of telescope needed to see this signal?

iClicker: The Sky at 21 Centimeters

we map the whole sky at 21 cm, i.e., in *neutral hydrogen* and display the results in Galactic coordinates

Vote your conscience!

What will the neutral H sky pattern look like?

A H found over all sky, mildly concentrated in midplane

B H very tightly concentrated in midplane

C H in poles only; plane is "zone of avoidance" for H

D none of the above

`www: 21-cm sky`

Q: implications for 3-D neutral H distribution?

Neutral Atomic Hydrogen: H I

★ on sky: thin band in Galactic plane
can see warping at longitudes $\ell \gtrsim 90°$

★ in 3-D: atomic H in thin layer in disk midplane
disk has some warping

Q: where is the H seen in emission out of plane?