Astro 596/496 NPA
Lecture 2
Aug. 26, 2009

Announcements:
- Pick up: Syllabus, handy abundance table
- PF 1 due Fri. Sept. 2, $\leq$12noon
- ASTR 596/496 APA: The Art and Practice of Astronomy begins today, 4 pm, here

Last time: overview

Now: begin content

Program Notes: ASTR 596/496 NPA Bugs/Features

- notes online–but come to class!
  some people find it convenient to print 4 pages/sheet

- class $\in$ diverse backgrounds: ask questions!

- Socratic questions

- typos/sign errors
  Dirac story
  please report errors in lectures and problem sets

Slices of the Cosmic Pie

We want to use physics to understand the nature
and history of cosmic matter

To place in context:
(looking ahead to results we haven't derived)
Q: what are the main components of the universe today?
Q: which is the dominant component, and by how much?

`www: Cosmic Pie Chart`

Observables for Nuclear and Particle Astrophysics

To be a science: must have empirical evidence
$\longrightarrow$ need observable data to reveal/test cosmic matter history

Seek observables which:
- probe nature of cosmic constituents
- reveal history of cosmic matter

$\star$ *indicate nuke/particle interactions have taken place.*

Q: What are some?
(no peeking at notes)

Q: Compare observables list to cosmic pie chart. Comments?

Observables for Nuclear and Particle Astrophysics

Observable	Example
direct matter detection	cosmic rays
neutrinos	solar, supernova neutrinos
high-energy photons	X-rays, γ-rays
abundances: elemental & isotopic	Sun, Galactic stars
dark matter	direct detection, annihilation prod
dark energy	cosmic acceleration

Note: the dominant cosmic components today
are the *hardest* to track observationally!

will look at all observables
but central to both nuclear and particle astrophysics:
the baryonic universe

Baryons: Praise Them or Bury Them?

recall: **baryon** $\rightarrow$ proton, neutron $\rightarrow$ nuclei $\rightarrow$ atoms
...formal definition to come...

baryons are tiny fraction of cosmic matter today
and an even smaller fraction of total cosmic mass-energy

and (at least some) baryons are not exotic
with (fairly) well-understood physics

Q: so why would a particle astrophysicist study cosmic baryons?

In Defense of Baryons

⋆ because we know much about baryonic physics
  ▷ both micro (particle, nuclear, atomic)
  ▷ and macro (hydrodynamics, condensed matter)
  baryons show how particle properties are manifest
  in cosmo/astro context
  ⇒ good training for dark matter, dark energy

⋆ lessons:
  ▷ detailed picture of how baryonic microphysics determines cosmic properties and shapes cosmic events
  ▷ see how unexpected and complex phenomena emerge

⋆ we are baryons!
  baryonic history is our history!

Abundances

Central Baryonic Observable: Abundances

a key tracer of cosmic particle history
and *the* key tracer of cosmic nuclear history
is baryonic *composition* $\Rightarrow$**abundances**

Q: where can we measure abundances?

Observable Abundances

Sun, solar system
MW Galaxy: stars, ISM, cosmic rays
External galaxies: ISM, stars
Intergalactic medium at high, low redshift

Solar System Abundances: “Rosetta Stone”

`www: SS mass fractions`
`www: SS isotopic abundances`

Q: what strikes you?

Solar System Abundances: Trends

- impressive scale – abundance variation by 12 decades!
- zig-zag
- dropoff towards high masses
- peaks, esp iron, also in very heavy elements (Pt, Pb)
- dip: LiBeB

...Will unpack this by the end of the course

Q: where measured?

Where measured?

Sun

- photosphere
- only **elemental** abundances
  (sum over isotopes) *Q: why?*

Meteors

- most primitive: carbonaceous chondrites
- much more precise abundances, and get **isotope** info
- but only measure "refractory" elts (condense readily)
  can't measure "volatile" (gaseous/hard to condense)
    e.g., H, He, C, N, O, Ne, Ar

Q: so how can we put both on same scale?

Q: what is physical significance of SS abs?

Solar Abundances: Physical Significance

Strictly:

SS abundances $\Rightarrow$ matter at Sun birth

record of all nuclear processing and mixing of that material

Broadly:

Sun $\sim$ typical Pop I (Milky Way disk) star

$\Rightarrow$ expect similar patterns in nearby disk stars

Practically:

serve as benchmark, fiducial standard

(much as Sun is a standard, e.g., $L_\odot$ and $M_\odot$)

Quantifying Abundances

see Arnett, Ch. 1

composition quantified via

abundance $\equiv$ ratio of species i to some standard

usually "species" $=$ element or isotope

in choosing how to quantify:

want abundance *changes* to

reflect nuclear/high-energy transformations, but

to be invariant under compression

Q: why?

consider a sample of (bayronic) matter

- (total) mass density: ρ
- mass density of species i: ρ_i
- number density of species i: n_i

note: $\sum_i \rho_i = \rho$

$\rho_i = m_i n_i$, $m_i =$ mass of one nucleus/atom

these quantify sample composition

but: not good as abundance measures

Q: why?

Q: what would be better?

compression invariance $\Rightarrow$ take *ratio*
of density to density of conserved quantity:

- mass density (if non-relativistic)
- baryon number density n_B

again: "baryon" $=$ proton or neutron
a nucleus with N neutrons, Z protons
has **baryon number** $A = N + Z$
and baryon number density $n_{B,i} = A_i n_i$

Useful (theoretical) abundance measures of species i:
mass fraction: $\boxed{X_i = \rho_i/\rho}$
mole fraction: $\boxed{Y_i = n_i/n_B}$

note: traditional astronomers mass fraction shorthand:

$X_{\mathrm{H}} = X$

$X_{\mathrm{He}} = Y$

$X_{\mathrm{other}} = Z$ *"metallicity"*

e.g., famous "metals" like C, N, O, ...

normalization: $X + Y + Z = 1$

observe/infer: solar system value

$X_\odot \simeq 0.70$, $Y_\odot \simeq 0.28$, $Z_\odot \simeq 0.02$

but for astrophysical sources,

can't directly measure n_i or ρ_i

Q: what do we measure?

direct astrophysical composition observables: **spectra**
from emission/absorption lines, measure column densities
$N_i \simeq \int_{\rm mfp} n_i \; d\ell$

observers report ratios $N_i/N_j \simeq n_i/n_j$
Q: what assumed in $\simeq$?

usually normalize to H (most abundant)
$\mathcal{A}_i/\mathrm{H} \equiv N_i/N_{\rm H} \simeq n_i/n_{\rm H}$
e.g., solar system mean $(\mathrm{Fe/H})_\odot = 3.2 \times 10^{-5}$

For SS isotopes: arbitrarily normalize to Si (10^6)
as in your handy table of abundances
`www: SS abs plot`