Astro 596/496 NPA
Lecture 1
Jan. 14, 2019

Announcements:

- Welcome!
- Pick up Syllabus
- ASTR 496 NPA students: Pick up Syllabus Addendum

Today's Agenda

⋆ Introductions
⋆ Overview and Appetizer
⋆ Course Mechanics: ASTR 596 NPA, ASTR 496 NPA

Nuclear and Particle Astrophysics: Overview

We are in the middle of a golden age
for nuclear and particle astrophysics

Objective:
to understand the nature, and history of cosmic matter
(both visible and dark)
in terms of microphysical processes

Present status: turning point
dawn of **multimessenger astrophysics** *Q: what's that?*
recent spectacular successes but also null results: deep puzzles

Whirlwind Tour: Preview of Coming Attractions

Gravitational Wave Astronomy and the Heaviest Elements

1915: Einstein publishes **General Relativity** – relativsitic gravity

- gravity intimately liked with spacetime
- predicts gravitational radiation

August 14, 2015: **gravity waves detected** by LIGO

- confirms Einstein prediction
- witness *binary black hole merger*
- but (probably?) no electromagnetic signal *Q: is this a surprise?*

September 16, 2017: **EM signal coincident with gravity waves**

- **gamma ray burst** detected, **kilonova** imaged in host galaxy
- source: *binary neutron star merger*
- radiation from ejected neutron star matter
  likely points to production of heaviest elements: **r-process!**

The Poor Person's Accelerator

Major theme:

> the Universe is the poor man's accelerator
> –Y. Zel'dovich

Q: meaning?

Central Example (We Hope!): Dark Matter

- both baryonic *and* non-baryonic
  Q: what's a baryon?
- in fact: most cosmic matter is non-baryonic!
  Q: why is this a big deal?
- in fact: non-baryonic dark matter likely WIMPs

Q: meaning?

Weakly Interacting Massive Particles
here: weak $\Rightarrow$ scale of weak interaction
$\rightarrow$ particle masses $m_{\text{wimp}}c^2 \sim 1\text{TeV} = 10^{12}$ eV
Q: compare: electron, proton mass?

The Search is On!
- direct detection of local dark matter
  `www: UK DM search`
  `www: CDMS`
- indirect detection: astrophysical
  Q: how could dark *matter give photons?*
- `www: TeV gammas from Galactic center`
- `www: positron signal from Galactic center`

current situation unclear: disputed claims of signal!
what is clear: in next 5–10 years will either
★ hit jackpot, or
★ challenge/rule out deeply held, well-tested theories.

Big Bang Nucleosynthesis

WIMPS: origin $t \lesssim$ picoseconds
move on to $t = 1$ sec: U fusion reactor/thermonuclear bomb

Big bang nuke (BBN):
first example of particle astrophysics connection
cartoon: D in QSOALS–QSO, cloud, observer
`www: D lines (O'Meara 2001)`
Q: what does this tell you?

BBN deeply connected with cosmic microwave background (CMB)
`www: CMB power spectrum`
will see: BBN-CMB comparison $\Rightarrow$ triumph and crisis

Messengers Beyond Photons: Neutrinos

Barely there but at the heart of it all!

Solar Neutrinos
`www: Neutrino Sun`

Atmospheric Neutrinos
`www: IceCube Experiment`, `www: IceCube Sky: atmospheric neutrinos`

Supernova Neutrinos
`www: SN1987A discovery image`

Terrestrial Neutrinos
`www: geoneutrino simulated map`

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Cosmological Neutrinos (CNB)
tell me if you know how to detect these!

Stellar Nuclesynthesis: Supernovae

supernova explosions produce most of the diversity of heavy elements
will look at in detail
`www: Cassiopeia A element map`

life requires supernovae—but not too close!
`www: NearbySN page`

Messengers Beyond Photons: Cosmic Rays

`www:` *Fermi* `gamma-ray sky`
in Galactic coordinates *Q: meaning?*
Q: features?

`www: cosmic-ray shower`

`www: Auger sky--cosmic ray astronomy?`

The History of Cosmic Matter

`www: HDF`

traces cosmic star formation history

Tying it all together: Galactic/cosmic chemical evolution

will see how solar system, Galactic matter is a symphony of nucleosynthesis

integrating big bang, supernovae, low-mass stars

`www: circle of life`

Laboratory Tools

just as Universe is accelerator (astro $\rightarrow$ particle)
also particle $\rightarrow$ astro connection
then accelerators act as **telescopes** probing early U

Q: where is the most powerful accelerator on the Earth?

Q: what's the runner-up?

Large Hadronic Collider (LHC)
at CERN Laboratory, Geneva Switzerland
pp collision energies ≈ 10 TeV

$p\bar{p}$ collision energies ≈ 1 TeV
`www: Tevatron`

Main Course Goals

- Get a sense of the **variety** and **excitement** of the field
  both nuke astro and particle astro

  To do this: I choose **breadth** over depth
  "short attention span" astrophysics

- Get familiarity with what is known, unknown, and boundary:
  frontier areas where breakthroughs are happening

- Understand how to use **nuke/particle tools**
  in other research areas (e.g., *yours*)
  e.g.: abundances, neutrinos, γ-rays, cosmic rays
  encode past and present history, energetics of matter
  applications in galaxy formation, star formation, particle physics

Syllabus

ASTR 496PC Addendum to Syllabus