

# Preliminaries

<https://people.nsl.msui.edu/~witek/Classes/PHY802/NuclPhys802-2016.html>

Instructor: Witold Nazarewicz and guest stars

TA: Terri Poxon-Pearson ([poxonpea@nsl.msui.edu](mailto:poxonpea@nsl.msui.edu))

## Recommended textbooks:

- *Nuclear Physics: Exploring the Heart of Matter* (2013)  
<http://www.nap.edu/catalog/13438/nuclear-physics-exploring-the-heart-of-matter>
- *2015 NSAC Long Range Plan: Reaching for the Horizon*  
[http://science.energy.gov/~media/np/nsac/pdf/2015LRP/2015\\_LRPNS\\_091815.pdf](http://science.energy.gov/~media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf)

## Requirements/grading criteria:

- Attendance and participation [40%]
- Answers to the problems [35%]
- Final presentation [25%; May 3, 2016] (PHY 802) or essay (PHY 492; tier II writing requirement) – based on 1-2 selected nuclear physics papers from Physical Review Letters, Science, or Nature. Consult <http://physics.aps.org/browse/>



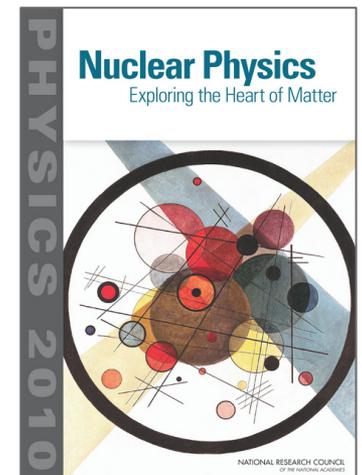
You will have one week to send your answers to Terri by 10am on Wednesday

## Focus:

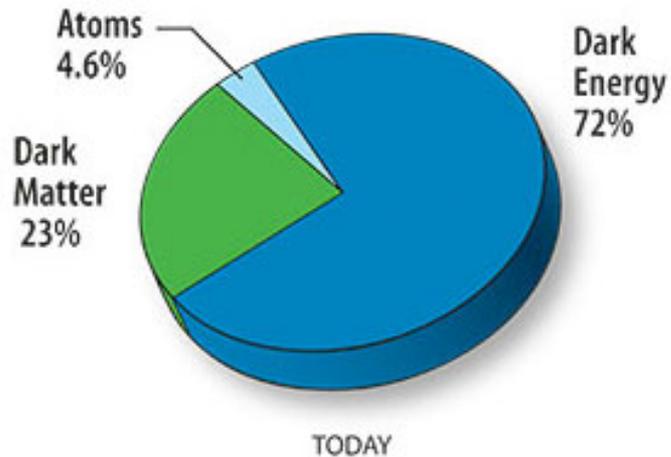
- Broadening and deepening students' knowledge and understanding
- Critical thinking; connecting the dots

“All the matter that makes up all the living organisms and ecosystems, planets and stars, throughout every galaxy in the universe, is made of atoms, and 99.9% of the mass of all the atoms in the (visible) universe comes from the nuclei at their centers which are over 10,000 times smaller in diameter than the atoms themselves”

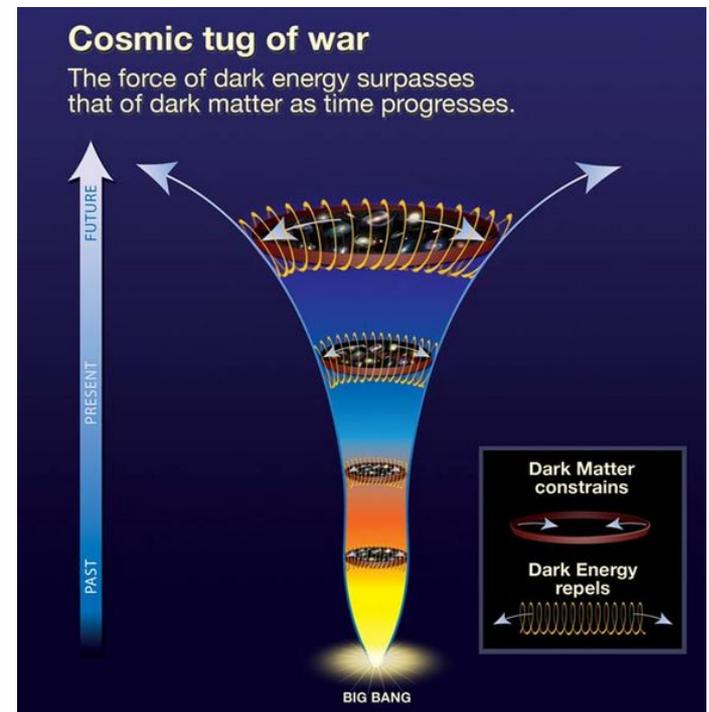
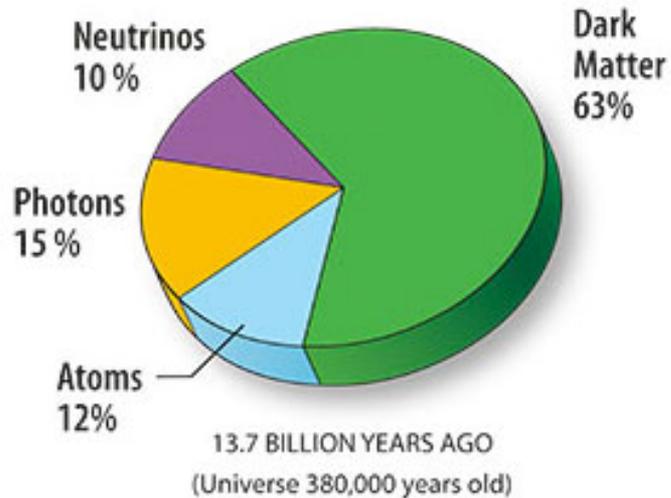
*NRC Decadal Study Report*



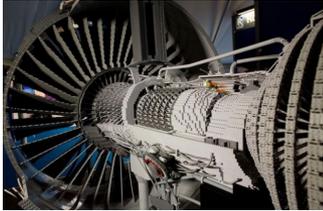
# But...



Dark matter and dark energy together make up some 96% of the universe



# The Quantum Ladder



Galaxy clusters  
Galaxies

Stars  
Planets

Living Organisms,  
Man-made Structures

Cells, Crystals,  
Materials

Molecules

Atoms

Nuclei

Quarks and  
Leptons

Elementary  
Particles  
(baryons, mesons)

???

Super-  
strings ?



macroscopic



subatomic



reduction



complexity

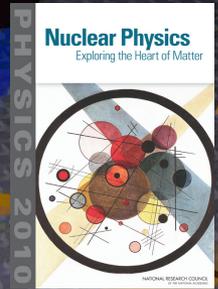
# The Scale of the Universe

<http://htwins.net/scale2/>

# The Nuclear Landscape and the Big Questions

- Where do nuclei and elements come from?
- How are nuclei made and organized?
- What are practical and scientific uses of nuclei?

Both experiment and theory answer these questions synergically



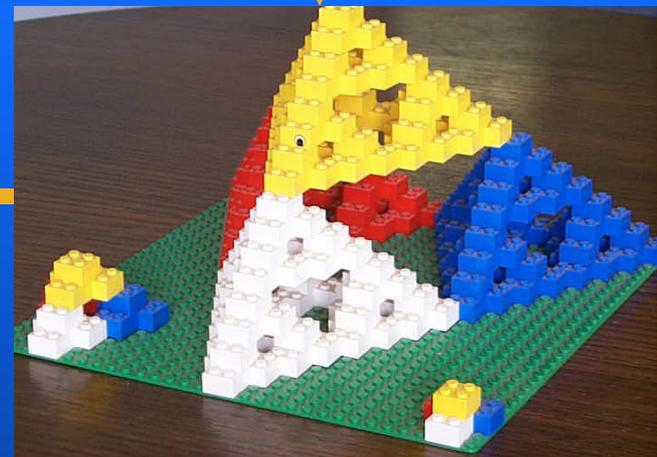
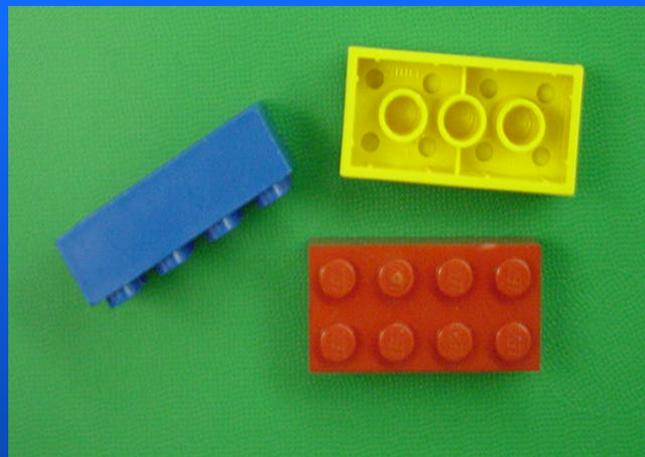
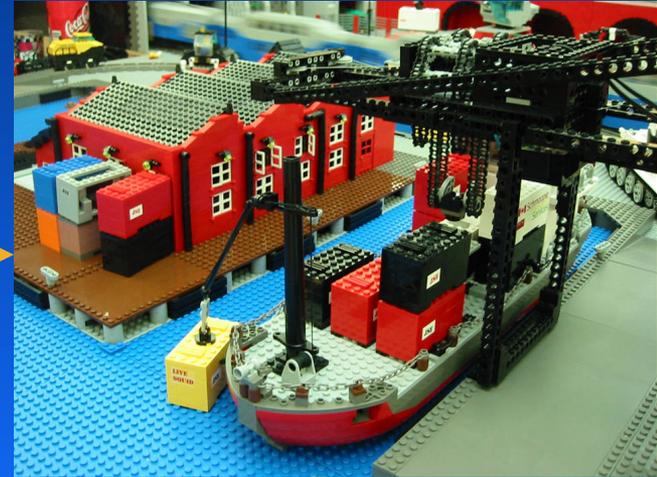
## TIMESCALE

➔ from QCD transition (color singlets formed; 10 ms after Big Bang) till today (13.8 billion years later)

## DISTANCE SCALE

➔ from  $10^{-15}$  m (proton's radius) to ~12 km (neutron star radius)

# The Lego Block Approach



Reduce the complex forms and materials to one (or a few) fundamental building blocks

# *Emergent Behavior*

The phenomenon of emergent order refers to this kind of organization, with the higher levels displaying new properties not evident at the lower levels. Unique properties of organized matter arise from how the parts are arranged and interact, properties that cannot be fully explained by breaking that order down into its component parts. You can't even describe the higher levels in terms of lower-level language.

Emergence in physics and mathematics is often used in a slightly different sense than biological systems. In physics, going from the micro to the macro doesn't necessarily result in great organization, but it does introduce new properties, often ushering in a new structure with it... Almost anything can be more than the sum of its parts!

## Examples:

friction, pressure, flow,  
superfluidity, ferromagnetism



Möbius strip: a surface with only one side and only one boundary component. (Try to cut it along the center line!)

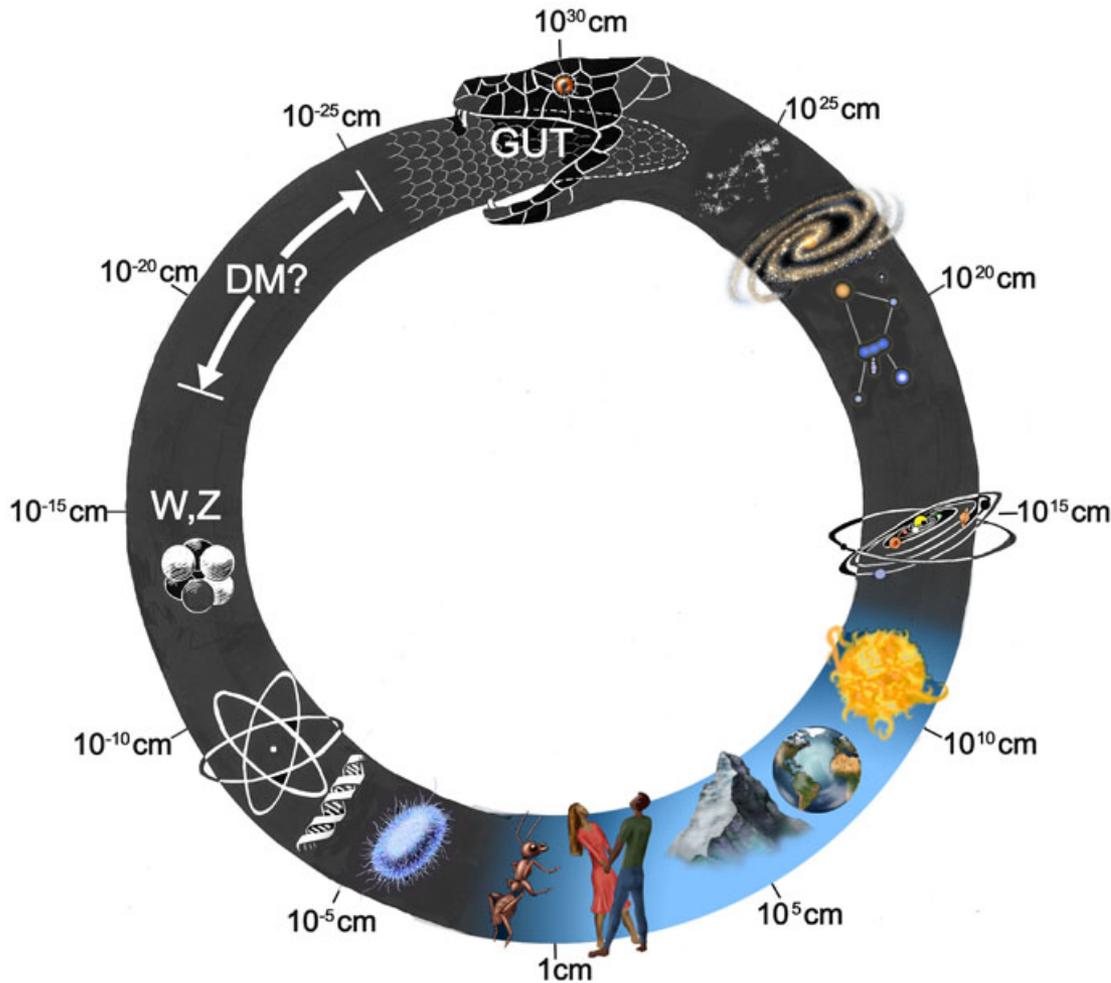
One of my favorite times in the academic year occurs in early spring when I give my class of extremely bright graduate students, who have mastered quantum mechanics but are otherwise unsuspecting and innocent, a take-home exam in which they are asked to deduce superfluidity from first principles. There is no doubt a special place in hell being reserved for me at this very moment for this mean trick, for the task is impossible. Superfluidity, like the fractional quantum Hall effect, is an emergent phenomenon – a low-energy collective effect of huge numbers of particles that cannot be deduced from the microscopic equations of motion in a rigorous way and that disappears completely when the system is taken apart<sup>A</sup>). There are prototypes for superfluids, of course, and students who memorize them have taken the first step down the long road to understanding the phenomenon, but these are all approximate and in the end not deductive at all, but fits to experiment. The students feel betrayed and hurt by this experience because they have been trained to think in reductionist terms and thus to believe that everything not amenable to such thinking is unimportant. But nature is much more heartless than I am, and those students who stay in physics long enough to seriously confront the experimental record eventually come to understand that the reductionist idea is wrong a great deal of the time, and perhaps always.

Robert B. Laughlin, Nobel Prize Lecture, December 8, 1998



Think of other examples of emergent phenomena in subatomic physics

# A unifying view



## *The Cosmic Uroboros*

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*The View from the Center of the Universe (2006)*

- Sheldon Glashow originally suggested this symbol, with the swallowing of the tail expressing his hope for a unification of the theories governing the largest and smallest scales
- Sixty orders of magnitude separate the very smallest from the very largest.
- The Cosmic Uroboros represents the universe as a continuity of vastly different size scales, of which the largest and smallest may be linked by gravity.
- There are connections between large and small: electromagnetic forces are most important from the scale of atoms to that of mountains; strong and weak forces govern both atomic nuclei and stars; cosmic inflation may have created the large-scale of the universe out of quantum-scale fluctuations.
- Few realize that the universe exists on all scales, everywhere, all the time. This is a truly extravagant thought.