UMass Physics Faculty:
Laura Cadonati, Andrea Pocar

Targets:
Gravitational Waves,
Solar and Supernova Neutrinos, Dark Matter

Experiments:
LIGO, Borexino, DarkSide/MAX
LIGO: Laser Interferometer Gravitational-wave Observatory

A New Sense for the Universe

Gravitational Waves will give a non electromagnetic view of the universe, and open a new spectrum for observation.

This will be complementary information, as different from what we know as hearing is from seeing.

Gravitational Wave Astronomy
The LIGO Observatory

Strain

\[ h = \frac{\Delta L}{L} \]

Initial LIGO goal: measure difference in length to one part in \(10^{21}\), or \(10^{-18}\) m
Status of LIGO

- **Initial LIGO**
  - All interferometers at design sensitivity: S5 run, one year of coincidence data
  - Null results already astrophysically interesting, pose meaningful constraints on:
    - Individual objects and events
    - Source populations (real or theorized)
    - Total energy density in GWs

- **Advanced LIGO**: will look at 100 more galaxies, expected to transition field to observational astronomy within the next 5 years!
Probing Astrophysics Frontiers With Gravitational Wave Bursts

- “Bursts” of gravitational waves (supernovae, colliding black holes)
- Study instrumental and environmental noise transient, vetoes
- Interface data analysis and instrument
The Borexino Solar Neutrino Experiment

http://borex.lngs.infn.it/
http://physics.princeton.edu/borexino/
Neutrinos

Neutrinos are fundamental particles which interact very weakly with matter (no electric charge, no strong force)

Neutrinos are the second most abundant particles in the universe, after photons

Not in Standard Model: Neutrinos are massive and oscillate (flavor mix)

What is the flavor content of each neutrino?
What is the absolute neutrino mass scale?
Are neutrinos their own antiparticles?
4p → He⁴ + 2e⁺ + 2νₑ + 26.7MeV

Solar neutrinos, produced with electronic flavor, oscillate
survival probability is energy dependent
Borexino can measure the whole spectrum at once
(data since May 2007)
Borexino @ UMass

Data Analysis, in close collaboration with other groups

- precision measurement of $^7$Be neutrinos
- solar neutrino spectroscopy: $^8$B, pep, CNO neutrinos
- antineutrinos (from the Earth, nuclear reactor and the sky)
- supernova neutrinos
- GEANT4 simulations
- refinement of reconstruction and analysis algorithms
- muon-related physics

L. Cadonati, A. Pocar - Introduction To Research, Physics Department, UMass Amherst - January 28, 2011
DarkSide and MAX: Searching for Dark Matter

observations indicate that only 
\(~4\%\) of the energy density in the
universe is in the form of regular
matter (protons, electrons, 
photons, neutrinos)

\(~22\%\) of the unknown (dark)
universe appears to be massive, ie
subject to gravity

it is possible that such dark
matter is made of non-relativistic
weakly interacting massive
particles: WIMPs

Link to cosmology, astrophysics, particle and nuclear physics
DarkSide/MAX experiments

- two newly-formed collaborations with a long-term experimental program to build large experiments for detecting WIMPs (Weakly Interacting Massive Particles)

- WIMPs might be detected when they scatter on nuclei (via the weak force), which then recoil leaving ionization along their tracks

- Darkside: a two-phase depleted argon time projection chamber (TPC) with an active target of 50 kg, to be completed in the next couple of years (featuring innovative background-discrimination strategies)

- MAX (Multi-ton Argon and Xenon TPCs): 5 ton depleted argon + 2.5 ton xenon dual-phase TPCs to be run together
2-phase TPC in Action

- gaseous Ar/Xe
- liquid Ar/Xe
- transparent vessel (optional)
- photodetectors
- fiducial volume boundary
2-phase TPC in Action

- **Multiplication field** (~3 kV/cm)
- **Field-shaping rings**
- **Drift field** (~1 kV/cm)
- **Extraction and acceleration grids**
2-phase TPC in Action

primary scintillation photons emitted and detected (S1)

WIMP Scatter deposits energy in FV
2-phase TPC in Action

secondary photons emitted by multiplication in gas region (S2)

ionized electrons drifted to gas region
DarkSide @ UMass

New Research Area

Planned activities:

- Participate in the design and assembly phase of the Darkside-50 detector
- Geant4 detector simulations
- Study of scintillation and suitable light detectors in liquid argon
- Calibration and data analysis
- Work on a 10 kg prototype currently being upgraded at Princeton to be deployed in Gran Sasso Summer ’11
Neutrino Physics @ UMass

**Particle Astrophysics**

Solar neutrinos (Borexino experiment)
WIMP dark matter (Darkide experiment)

(faculty: Laura Cadonati, Andrea Pocar)

http://borex.lngs.infn.it/
http://people.umass.edu/egpa/Home.html

**Nuclear Physics**

Neutrino-less double beta decay: EXO experiment

(faculty: Krishna Kumar, Andrea Pocar)

http://www-project.slac.stanford.edu/exo/
http://www.umass.edu/exo
Double beta decay: EXO

extremely rare decay in which a nucleus simultaneously emits two electrons

- neutrinos are their own antiparticles
- violation of lepton number
- measurement of the absolute \( v_m \) mass
- relevant to particle physics and cosmology

New physics?

- standard second order weak process
- exciting possibility of a non-standard \( 0\nu\beta\beta \) process

sensitivity to \( \geq 10^{25} \) y lifetimes:
- ultra-low background
- underground location
- large source mass
EXO-200: $^{136}$Xe

detect the 2 electrons (ionization + scintillation)

$^{136}$Xe $\rightarrow$ $^{136}$Ba$^{++}$ + $2e^-$ (+ $2\nu_e$)

200 kg Xe (80% $^{136}$ isotope)
time projection chamber (TPC) detector
3D reconstruction of events + energy

EXO-200 is now running and collecting data!
salt mine in New Mexico (WIPP site)

design sensitivity for $0\nu\beta\beta$ lifetime: $6 \times 10^{25}$ years
EXO: a future ton scale experiment

the EXO collaboration is already planning a ton-scale $^{136}\text{Xe}$ experiment, using a bold idea to suppress backgrounds:

plan to tag the barium ion appearance in coincidence via optical spectroscopy:

$^{136}\text{Xe} \rightarrow ^{136}\text{Ba}^{++} + 2e^- (+ 2\nu_e)$

- requires high efficiency single ion detection
- sensitivity for $0\nu\beta\beta$ lifetime up to $\sim 10^{28}$ years! ($m_\nu \sim 10$ meV)

- plenty of R&D required in the coming few years
- offers a rare mix of experimental nuclear/particle physics and AMO + ion physics techniques
- UMass getting actively involved (lots of lab work available)
EXO at UMass

Krishna Kumar, Andrea Pocar (faculty)
Tim Daniels (postdoc)
David Wright (visiting scientist)
Adam Blomberg (grad student)
Tyler DeMarco ('11), Chris Dunay ('12),
Cameron Mackeen ('13), Kelly Malone ('13),
Alexa Villaume ('12) (ug students)

activities:

- EXO-200 data analysis (for the coming 4-5 years)
  - participate in EXO-200 operations at WIPP
    (includes regular shifts WIPP)
  - EXO-200 calibration campaigns
  - work on the EXO-200 muon detector

- Monte Carlo simulations (EXO-200 and future larger EXO experiment)

- EXO lab at UMass (for various aspects of EXO R&D):
  - scintillation detection in LXe (and LAr for Darkside)
    - tagged Ba ion source and studies of ion survival in LXe