Evidence for Dark Matter in the Universe

F. Zwicky
Studies clusters of galaxies 1933

Concludes that there is missing mass holding cluster together

Galaxies found to have large rotational velocities at large distances from center 1950's - 1970's

Galaxies have dark matter (not made of protons and neutrons); x-rays and weak gravity lensing * confirm this

Cosmic microwave background implies \( \Omega_{\text{total}} \approx 1 \)
Many other observations give \( \Omega_{\text{dark matter}} \approx (0.3 - 0.4) \)

Universe is accelerating due to dark energy \( \Omega_{\text{dark energy}} \approx (0.6 - 0.7) \) 1998-2002

Super Symmetric Dark Matter

$\Omega h^2$ can be computed reliably

0. Few % accuracy
0. Matches measured errors of $\Omega_{cdm}$

\[ \checkmark \]
TABLE I. Liquid Xenon as a WIMP Detector

1. Large mass available - up to tons. (10 Tons)
   - Atomic mass: 131.29
   - Density: 3.057 gm/cm$^3$
   - $W_i$ value (eV/pair) 15.6 eV
   - No long-lived isotopes of xenon

2. Drift velocity: 1.7 mm/μs @ 250V/cm field
   - Decay time: 2 ns → 27 ns

3. Light yield > NaI, but intrinsic scintillator (no doping)

   ⇒ Excimer process very well understood

   First excimer laser was liquid xenon in 1970!

   Well Understood
**Properties of Liquid Xenon**

Liquid Xenon Scintillation Mechanism

- Nuclear/ Electron Recoil
- Excitation
  - Xe$^+$
  - + Xe
- Ionization
  - Xe$^+$
  - + e$^-$ - 45 ns
- Recombination
  - Xe$^{2+}$
- Xe$^-$ + Xe

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**Principle Tests Setup**

- PMT
- Die Chamber
- Source
- Grounded Grid
- Anode Wire Frame

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**Very Fast Signals**

- Pulse Time Discrimination (ZEPLIN II)

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**H. Wang, ZEPLIN II IV, UCLA**

Feb 22, 2002
Proportional scintillation vs field

Single phase 99.8% rejection

Xenon Two-Phase Prototype Detector
Background and recoil separation

Gamma (122 keV)
Minimum Ionization (backgrounds)

Secondary Scintillation

Gamma recoil

Primary Scintillation

Heavy Ionization (recoil signal)

Feb. 22, 2002

H. WANG, ZEPLIN II/IV, UCLA

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Feb. 22, 2002

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Xenon outs WIMPs

Dark-matter detector could pin down the Universe’s missing mass.
1 May 2002

PHILIP BALL

Researchers in London are building a cheap dark-matter detector that should be able to spot the exotic particles called WIMPs that are suspected of hiding most of the Universe’s missing mass. A prototype of the detector has just shown, for the first time, that it can spot something as close to a WIMP as it’s possible to produce in the lab.

WIMP stands for ‘weakly interacting massive particle’. If WIMPs exist at all, they are thought to be highly compared to the protons and neutrons in an atomic nucleus, but to barely interact with these components of normal matter.

Physicists believe that WIMPs make up as much as 90% of the total mass of the Universe. Astronomers can’t see this matter – hence its ‘dark’ moniker – but they can see its gravitational effects on the way the stars and gas in galaxies rotate.

Even if billions of WIMPs are streaming through our bodies, they don’t have any effect. So WIMP-hunting could be a frustrating affair – like trying to fish for prawns using the net from a football goal.

Several experiments are currently going to great lengths in the search for WIMPs. The problem is that detectors capable of WIMP-spotting will probably pick up other cosmic particles, too, including the WIMP signal. Cosmic rays – high-energy particles of normal matter from space – and radioactive emissions would also register.

To shield a WIMP-detector from cosmic rays, it must be placed deep underground. The UK Dark Matter Collaboration (UKDMC) houses detectors at a depth of 1,100 metres in a salt mine in Yorkshire. Another array in Italy is buried in a tunnel beneath a
Installation Underground

Xe Purification: 
Oxysorb and pumping on solid Xe
Xe capture (beer barrels)

S3 Fiducial Volume Cut
Project normalized amplitudes of each phototube onto plane

Trigger on one photo-electron in any pmt
Noise events
Single pmt events
Double pmt events
Bulk events
Turret events

Si vs Si cut
No hint of a signal

Preliminary Limits
Construction in Progress

Field shaping rings are made out of pure Oxygen-free copper.

The largest PTFE piece is being machined at the UCLA Physics department machine shop.

Final setup to be placed in lead shield.
The Search for Dark Matter Using Liquid Xenon and Other Detectors

R&D for ZEPLIN IV 2004

1) DAMA
   Liquid Xenon 7 kg
   Enriched Xenon
   No discrimination

2) ZEPLIN III
   6 kg of
   Highly Discriminating
   IC Liquid Xenon - High Ei
   + ULDME
   Field to observe primary ionization

3) XENON
   Test detector for
   Eventual 1 ton detector
   Discrimination (2 Phase +)

4) XMAS
   LARGE Liquid Xenon
   Detector for Solar Neutrinos and DM Search

Other Liquid Xenon Detectors

Phasor Line
Liquid
Pressure Sensor Amplifier

Pressures Sensor Amplifier

Jan 22, 2002

David Cline, UCLA (KITP New Cosmology 8-21-02)
Xenon discriminating detector

- Available in Large Quantities  $\Rightarrow 10^{ton}$
- High Atomic Number ($Z_{Xe} = 54$, $\sigma_{WIMP-Nucleon} \propto A^2$)
- High Density ($\sim 3g/cm^3$ liquid)
- High Light (175nm) & Ionization Yield
- Can be Highly Purified
  - long light attenuation length ($\sim m$)
  - long free electron life time ($\sim 5ms$)
- Gamma & Recoil signal Discrimination
- Easy to Scale up to Large Volume $\Rightarrow 30$ton $\Rightarrow 1$ton
- No Long Lived Radioactive Isotopes

Feb. 22, 2002

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