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# Recent results of Dark Matter direct detection experiments

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### a lively arena



#### trends

- reaching down for SUSY (bigger & cleaner detectors)
- testing DAMA result
- directionality, a cure for the neutrino floor?
- superheated liquids for SD interactions

### direct detection



expected rates



$$\mathcal{L}_{\text{eff}} = f_q \overline{\chi} \chi \overline{q} q + d_q \overline{\chi} \gamma^{\mu} \gamma^5 \chi \overline{q} \gamma_{\mu} \gamma^5 q + \dots$$
Scalar
Axial

#### expected rates



#### where



#### world wide race



## current direct DM searches

#### • Noble Liquid Detectors:

- PandaX, XENON100, XENON1T, LUX, LZ, (LXe TPC), XMASS
- ArDM, DarkSide, Deap...

#### Crystals

- ANAIS, CRESST, KIMS, CDMS, COGENT, DAMA/LIBRA, DM-ICE, SABRE...
- Superheated liquids:
- COUPP, PICASSO, PICO, SIMPLE, MOSCAB...
- Directional detectors:
- DMTPC, DRIFT, MIMAC, NEWAGE, CYGNUS-TPC...



Chanpreet Amole, IDM2016

## one or two signals?



#### one or two signals?



#### down to the limit



#### noble liquid detectors

- Either liquid argon or xenon (both excellent scintillators)
- Experiments
  - \* LNGS: DarkSide, XENON
  - Homestake: LUX, LZ
  - Jinping: PandaX
- The easiest scalable technology
- Masses now in the ton range

- More and more refined analysis techniques
  - \* PL, blinding, `salting'
- \* Similar stories of
  - increasing mass and
    - lowering the background
- calibrations become difficult with increasing mass
  - diffused sources
  - neutron guns

#### the wonders of double phase TPCs



#### ...and the power of discrimination



#### LUX@Sanford Lab (SD)

- 48 cm x 48 cm height dodecagonal cylinder.
- 250.9 kg LXe in active region
- 61 + 61 PMTs, top and bottom
- 332 live days
- Analysis complicated by changes in E-field because of charge accumulation on the walls
- Detector effectively divided in 16 independent detectors having uniform E-field



#### LUX most recent result



From arXiv 1608.07648v1

#### LUX's future:LZ

- LXe mass 10t,
- Active 7t
- fiducial 5.6t
- ~2020 start operations



## XENON100

- Longest running double phase Xe TPC (> 4 yrs)
- Well understood low background detector
- 224.6 days run -> best limit in 2012
- Now complete set of data being analysed
  - 477 days total, factor ~2 improvement on the limit
- Recently published results on
  - modulation
  - leptophilic dark matter
  - low-mass dark matter search



### XENON100



#### XENON100: Search for modulation effects in the 225 day run



E. Aprile et al. (XENON), Phys. Rev. Lett. 115, 091302 (2015)



Event Rate in 34 kg fiducial volume





#### XENON100: Search for modulation effects



E. Aprile et al. (XENON), Phys. Rev. Lett. 115, 091302 (2015)



- The phase (112±15) days (April 22) is not consistent with the SHM (June 2) at 2.5σ
- Analysis of the full combined dataset (477 days) ongoing

## leptophilic dark matter?

**DAMA/LIBRA result** interpretable with "leptophilic Dark Matter" in range of 2-6 keV

"Eur. Phys. J. C73 12 (2013) 2648, arXiv: 1308.5109"

DAMA/LIBRA modulation spectrum converted to Xe, assuming WIMP coupling to electrons to estimate expected signal in XENON100,

Exclusion of WIMP-electron couplings at ~4.4  $\sigma$ 

Science 349, 851 (2015)



#### the present&future, XENON1T



- + 3.5 tons
- + 2 tons active

 see Marco Garbini's talk later!

#### DarkSide @LNGS: liquid argon TPC

- Ar allows 1÷1.6×10 ^7 rejection factor for electron recoils, via PSD
- Currently DS-50 operating at LNGS
- Depleted Argon (extracted from mines)
- 50 kg fiducial, 153 kg total
- 30 ton B-loaded scintillator veto
- 1000 ton water Cherenkov veto
- Plan to build Dark Side 20k, 20 t fiducial mass, 30 t total.
  - Silicon PM readout
  - Impressive facilities









# crystals

### SABRE

Explore the annual modulation with more sensitive Nal crystals

- High purity crystals, 50 kg array
- Better sensitivity at low energies
- Active veto
- Target background 0.1-0.2 dru in 2-6 keV region (DAMA's about 1 dru)
- Gran Sasso + Australia site to check environmental effect and phase (if any)
- Collaboration of Australia, Italy, UK, USA





#### News & Events /

#### Stawell Underground Physics Laboratory construction to begin

#### 19 Jul, 2016

Construction is set to begin on the Stawell Underground Physics Laboratory (SUPL), which will establish the city as a regional centre for scientific excellence.

The building site, which is being constructed more than one kilometre underground in an existing gold mine, will create 19 construction jobs and 15 full time jobs.

The project is modelled on the Gran Sasso Underground Physics Laboratory in Italy which employs 200 particle physicists and hosts a visiting scientific community to 200 international physicists every year.

The Stawell laboratory – the first of its kind in the southern hemisphere – will be used to conduct research into a wide range of sensitive physics and biomedical experiments, including research into 'dark matter'.

It capitalises on existing infrastructure and creates an innovative new use for the gold mine that will create high value, skilled research jobs.

#### Francis Froborg's talk, IDM 2016





Photo: Mark Killmer http://www.symmetrymagazine.org/article/photowalk-winners-announced

## other Nal efforts

- ANAIS @ Canfranc, target mass of 112 kg operative in ~0.5 years
- DM-Ice (17 kg, South Pole) • + KIMS (100 kg, South Korea)=COSINE





Jay Hyun Jo, IDM 2016





#### superheated liquids (aka bubble chambers)



## COUPP-PICASSO-PICO

- bubble formation parameters can be tuned for complete insensitivity to electron recoils,
- 10<sup>10</sup> discrimination factor
- C<sub>3</sub>F<sub>8</sub> used (also CF<sub>3</sub> I, C<sub>4</sub> F<sub>10</sub> and C<sub>2</sub> CIF<sub>5</sub>)
- COUPP-PICASSO now united in the PICO collaboration
- PICO 60, world's largest, at SNOLAB
- Future projects: PICO-250 and 500





### a sparkling detector...



Acoustic readout and trigger

#### COUPP-PICASSO-PICO



PICO 2L [PRL 114, 231302 (2015)]

### MOSCAB

- Based as well on bubble nucleation technique, but with the `Geyser' twist
- Liquid is kept in the superheated state by cooling the vapour phase at a lower temperature than the liquid.
- The liquid is essentially constantly in superheated state, no need to cycle it.
- 40 kg detector will be deployed at Gran Sasso







### tracking detectors



### tracking detectors



# directionality may help when sitting on the neutrino floor



## directionality techniques

#### **Low-pressure TPCs**

DMTPC, MIMAC, NEWAGE, DRIFT, D3...

Emulsions Crystal Scintillators Columnar recombination Carbon nanotubes





15 keV Fluorine nucleus recoil

# directionality techniques

- \* Gas TPCs seems more promising
- Used CS<sub>2</sub>, CF<sub>4</sub>, O<sub>2</sub>, SF<sub>6...</sub>
- Readout with wires, GEMs. Micromegas, etc
- Modular structures to reach high masses







2015

N. Spooner, CYGNUS

### CYGNUS-TPC

- a multi site `galactic recoil observatory'
- few ton scale `easily' achievable
  - From N. Spooner, CYGNUS 2015:
    - something the size of ICARUS T600 would contain
       ~ 0.5 t Fluorine (SF6) @ 200 Torr



#### conclusions

- \* the field is extremely lively, challenging and competitive
- however no guaranteed discovery
- \* diversification of techniques in the last few years
- \* ...and finally we'll know for sure in a couple of years if there is ad annual modulation or not!