ESCAPE

European Science Cluster of Astronomy & Particle physics ESFRI research Infrastructures

Towards a Dark Matter Test Science Project

Caterina Doglioni - Lund University

Input from: Antonio Boveia, Francesca Calore, Elena Cuoco, Kay Graf, Lukas Heinrich, Giovanni Lamanna, Samuel Meehan, Graeme Stewart, Pasquale Serpico, Vincent Poireau, Florian Reindl, Federica Petricca, iDMEu proponents

@CatDogLund, she/her

http://www.hep.lu.se/staff/doglioni/

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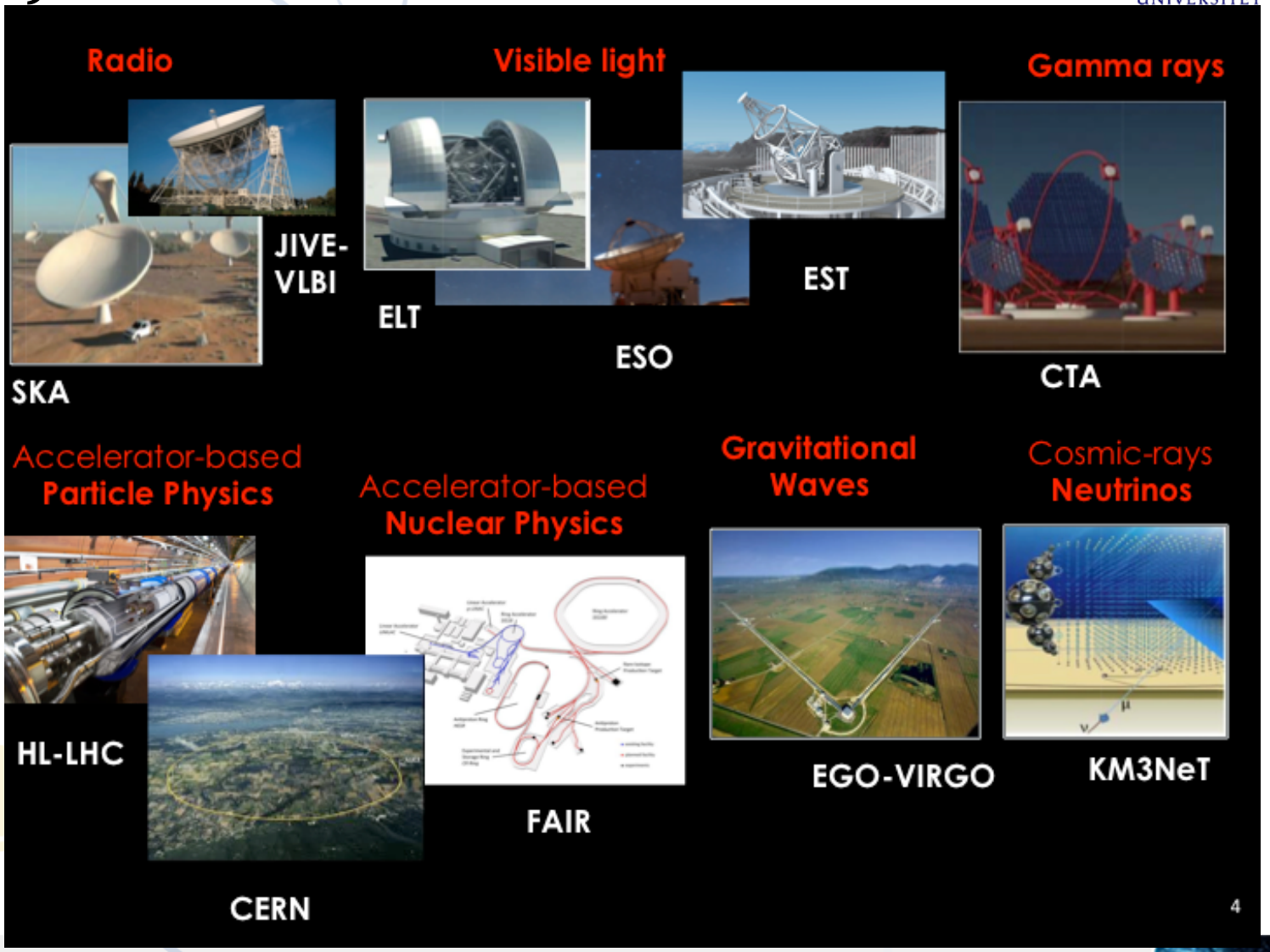
The ESCAPE Project

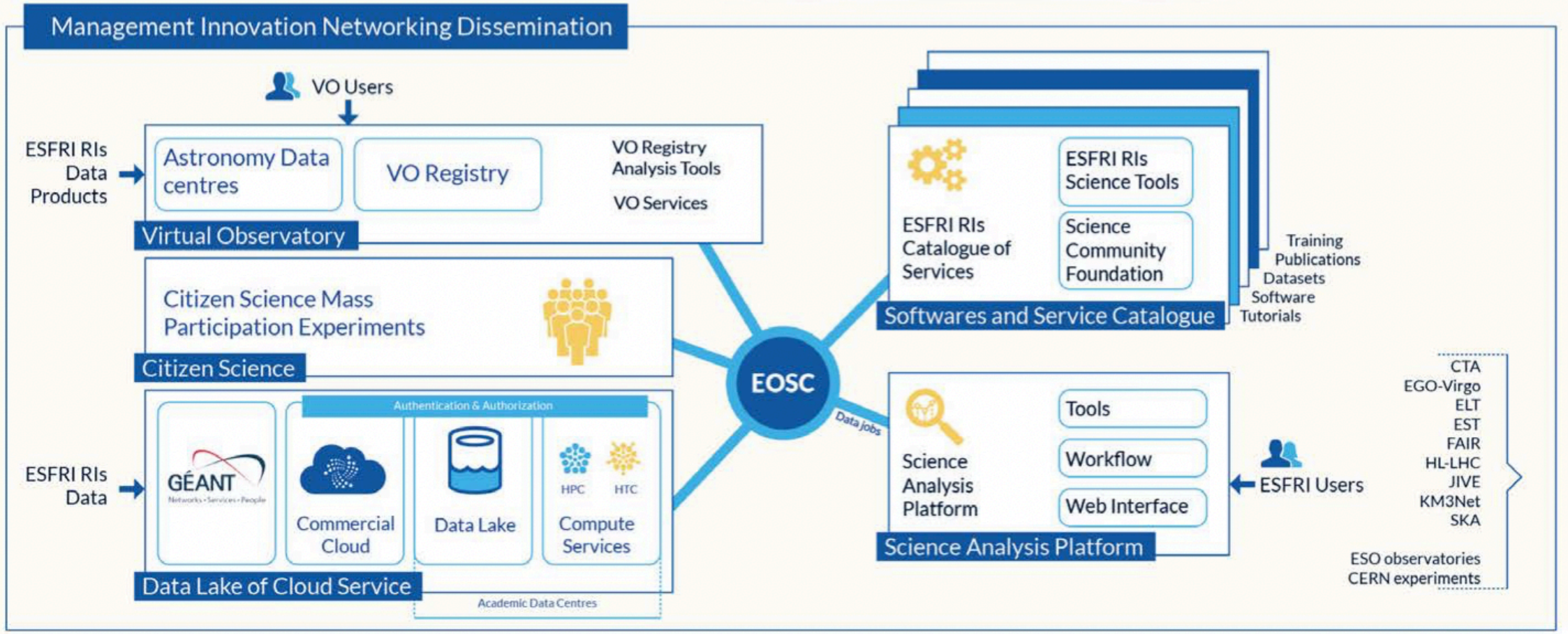
Slide from G. Lamanna

- ESCAPE builds and provides **services** to the scientific community of astrophysics and particle physics
- Profits from **complementary excellences** in data stewardship of the communities involved
  - e.g. Astronomy Virtual Observatory infrastructure
  - High Energy Physics expertise in exabyte-scale data management and large-scale distributed computing
- Fulfills the **need** of global, open access to data, long-term curation and sustainability of **observatories and facilities**



Services towards the European Open Science Cloud (EOSC)

Slide from G. Lamanna



The “Software Catalogue”: objectives

Open-source scientific Software and Service Repository (OSSR)

Slide from K. Graf

Aim: co-develop and expose the tools of the ESCAPE (ESF)RI projects in a repository under the EOSC catalogue of services

Objectives:

- continuous development, deployment, exposure and preservation of software/tools/services interoperability, software re-use and cross-fertilisation
- open innovation environment for open standards (workflows), common regulation and shared (novel) software for multi-messenger & multi-probe data

All objectives follow:

- a community-based approach
- the FAIR principles for open software/services and data

E-OSSR strives to:

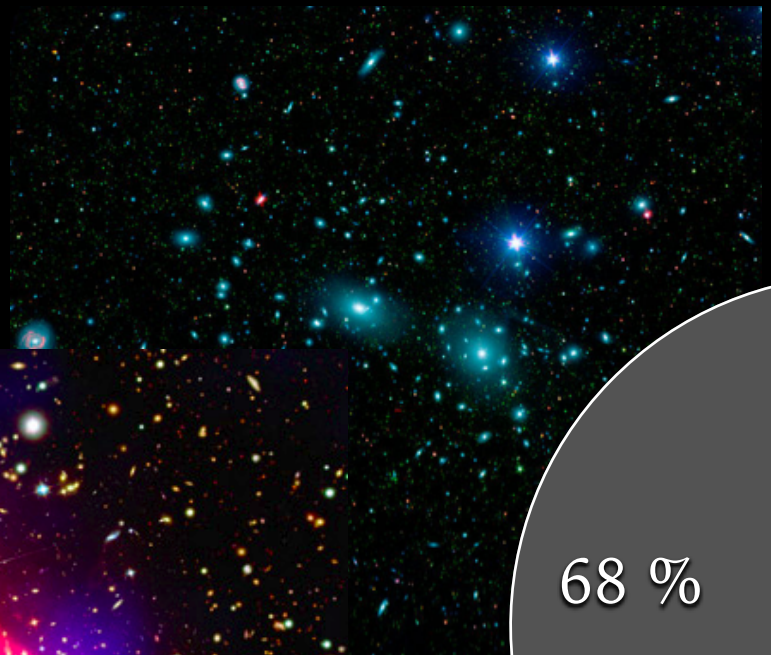
- establish a foundation to (co-)develop EOSC-ready software and services;
- expose them to users via the EOSC catalogue of services;

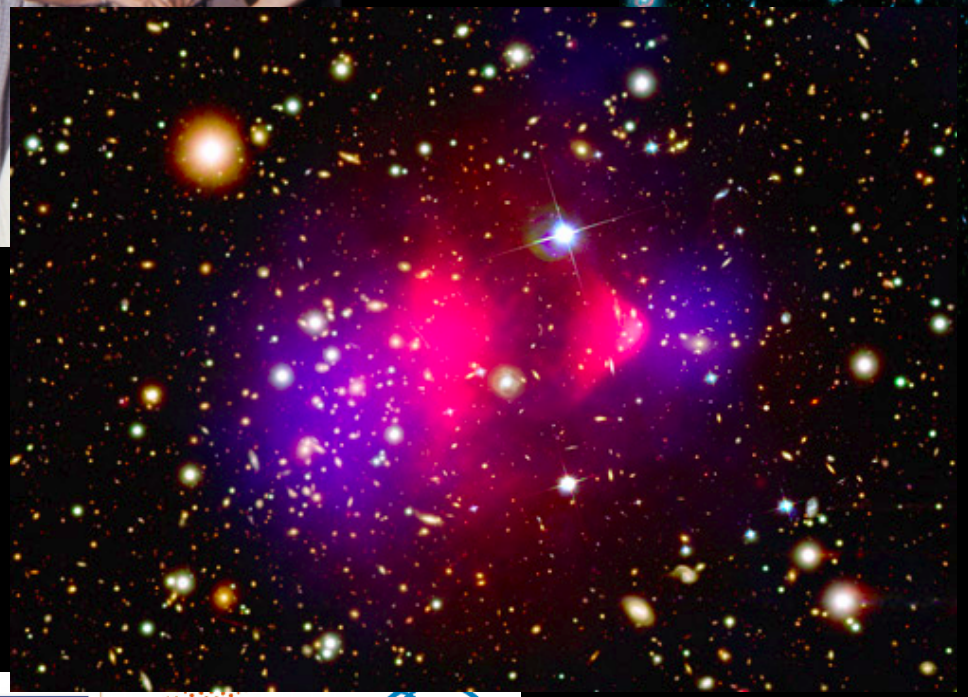
How/why Test Science Projects?

Slide from G. Lamanna

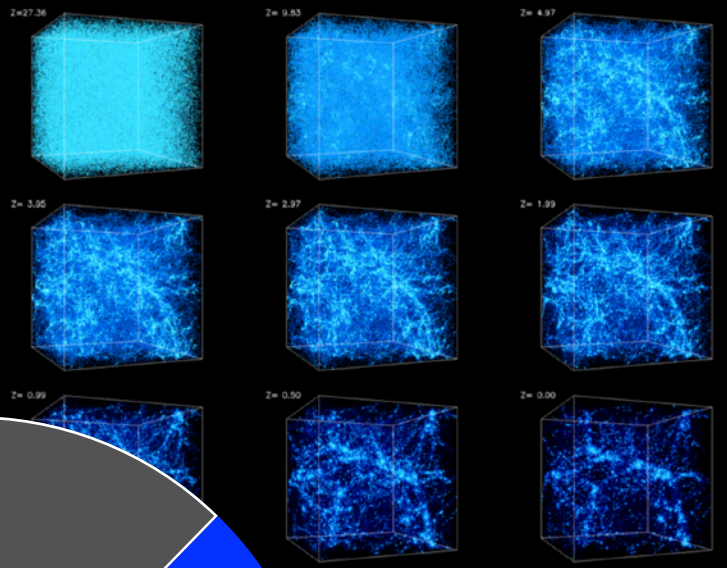
- Propose **Test Science Projects** to demonstrate multi-domain science integration across ESCAPE
- Involve researchers to demonstrate new cutting edge **open science capabilities**, making use of the services implemented within ESCAPE
  - researchers can give feedback on the capabilities delivered by ESCAPE
  - researchers can exploit synergies between the ESFRIs and among the scientific communities of Astrophysics/Astroparticle, accelerator-based Particle and Nuclear Physics
- Supported by consortia of EU member states research agencies and institutes within the **J**oint **E**CFA **N**uPECC **A**PPEC **A**ctivities (JENAA)

Dark matter as a science case

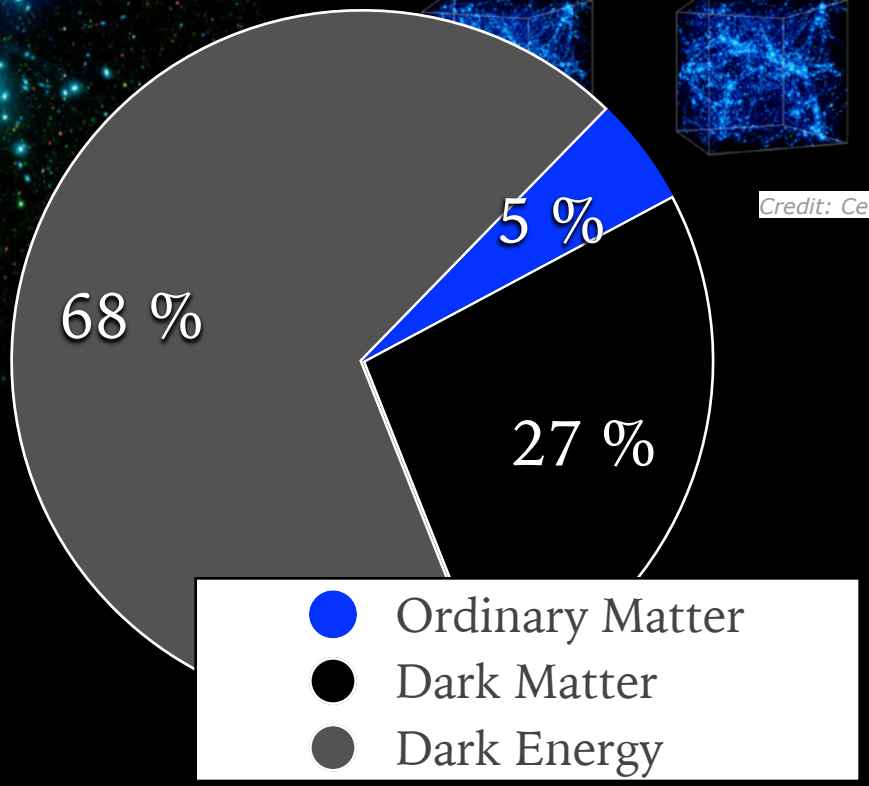




Credit: NASA, Carnegie Institution



Credit: Center for Cosmological Physics, A. Kravtsov



Different kinds of DM, and synergies

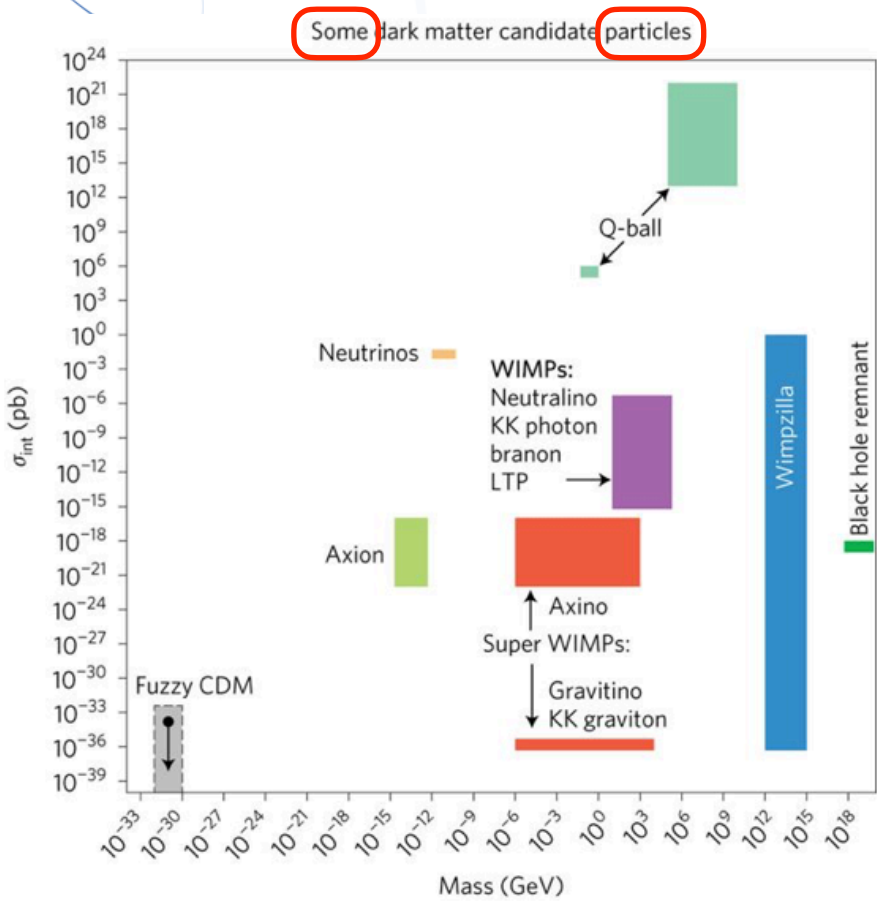
Many hypotheses for dark matter

→ many ways to detect it

→ many different experiments

→ many different data / workflow needs

→ many different data / result sharing policies



https://www.nature.com/articles/nphys4049
adapted from The Dark Matter Scientific Assessment Group

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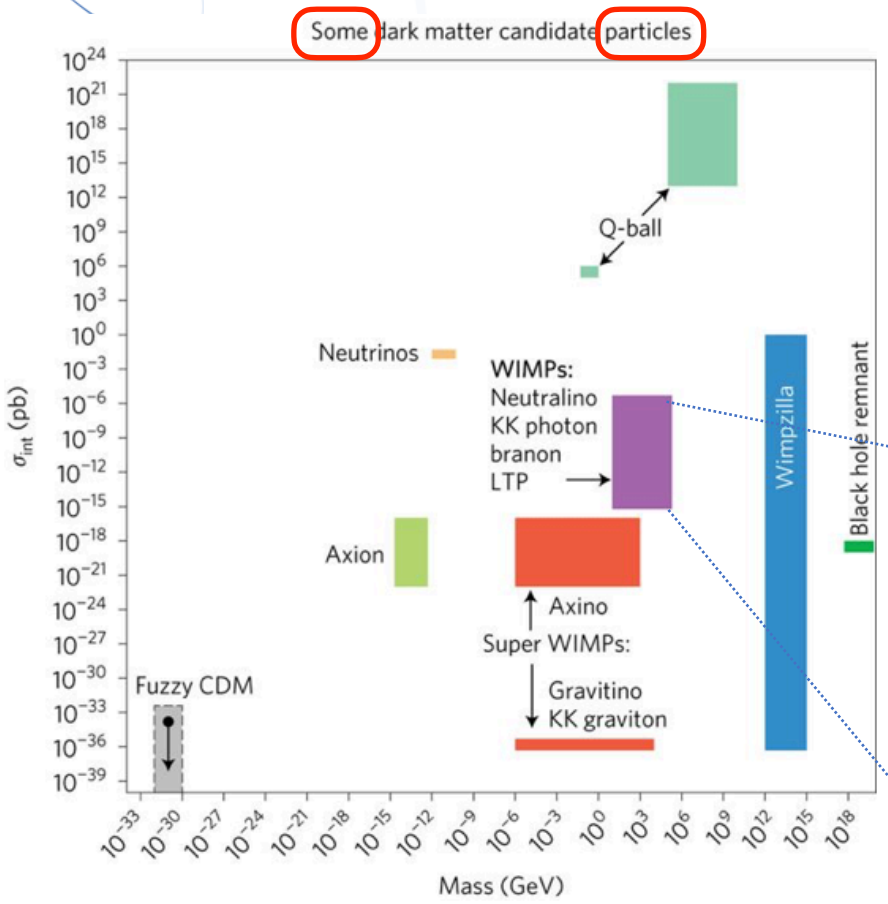
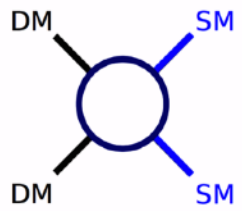
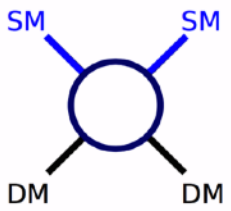


https://www.nature.com/articles/nphys4049
adapted from The Dark Matter Scientific Assessment Group

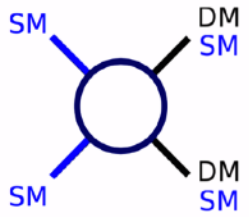
one of many models predicting **Weakly Interacting Massive Particles (WIMP)**



Indirect Detection

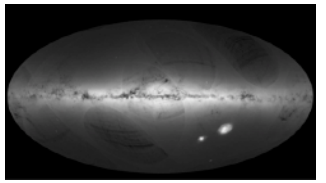


Direct Detection

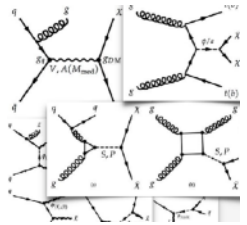


Colliders

Credit: ESA/Gaia/DPAC.



Astrophysics

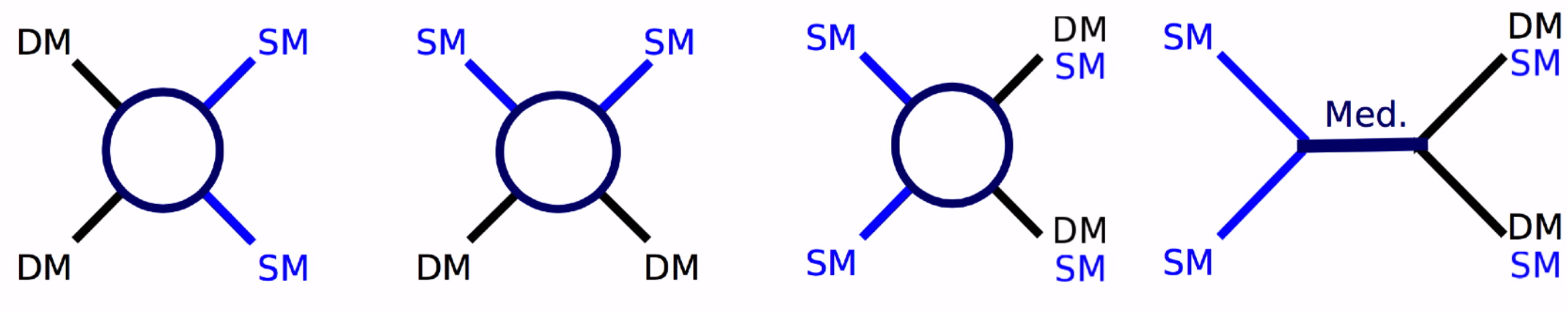


Theory

- Well studied models, established complementarity
- WIMP-like models not yet completely excluded
- In the following we will take WIMPs as an example, but we won't necessarily restrict our work to them

Dark matter complementarity

- DM discoveries need complementary experiments that involve DM with **cosmological origin** / can **produce DM**
  - Direct detection can **discover DM that interacts** inside the detector
  - Indirect detection can see **annihilating/decaying DM** through its decays
  - Accelerators/colliders can produce DM and **probe the dark interaction**



Indirect Detection | Direct Detection | Particle Accelerators (colliders & extracted beam lines)

- Work on “common language / common resources” (plots, scenarios, tools) ongoing in Snowmass / iDMEu JENAA EOI / many other communities

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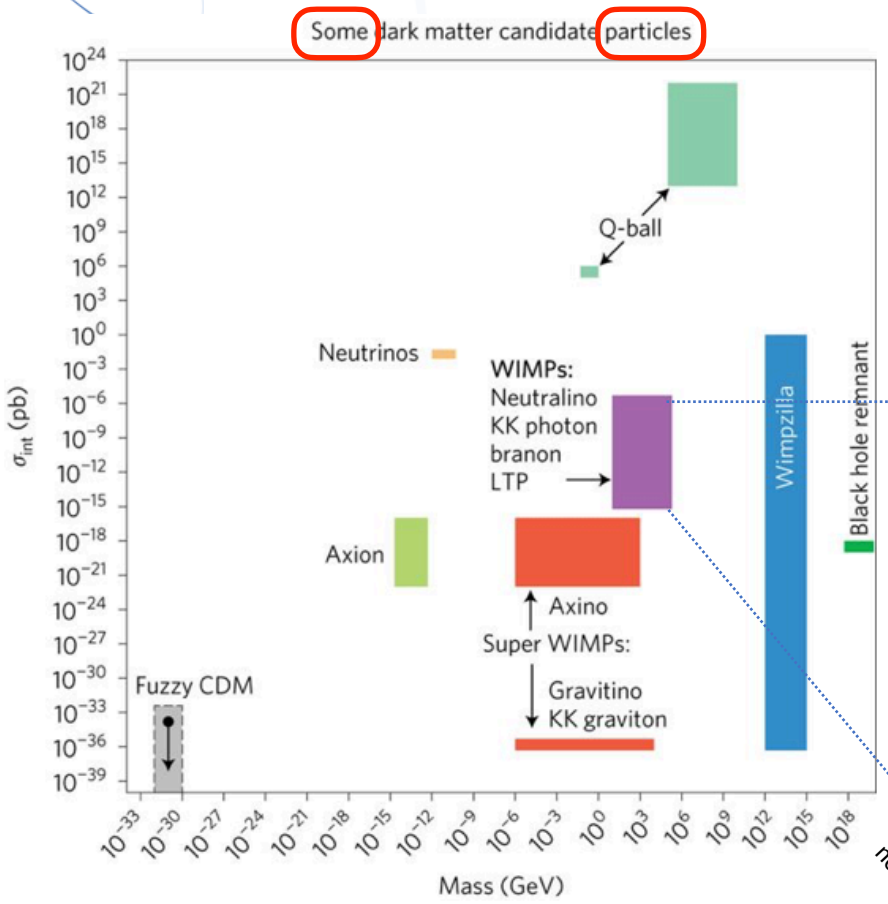

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for illustrative purposes
no 1:1 correspondence

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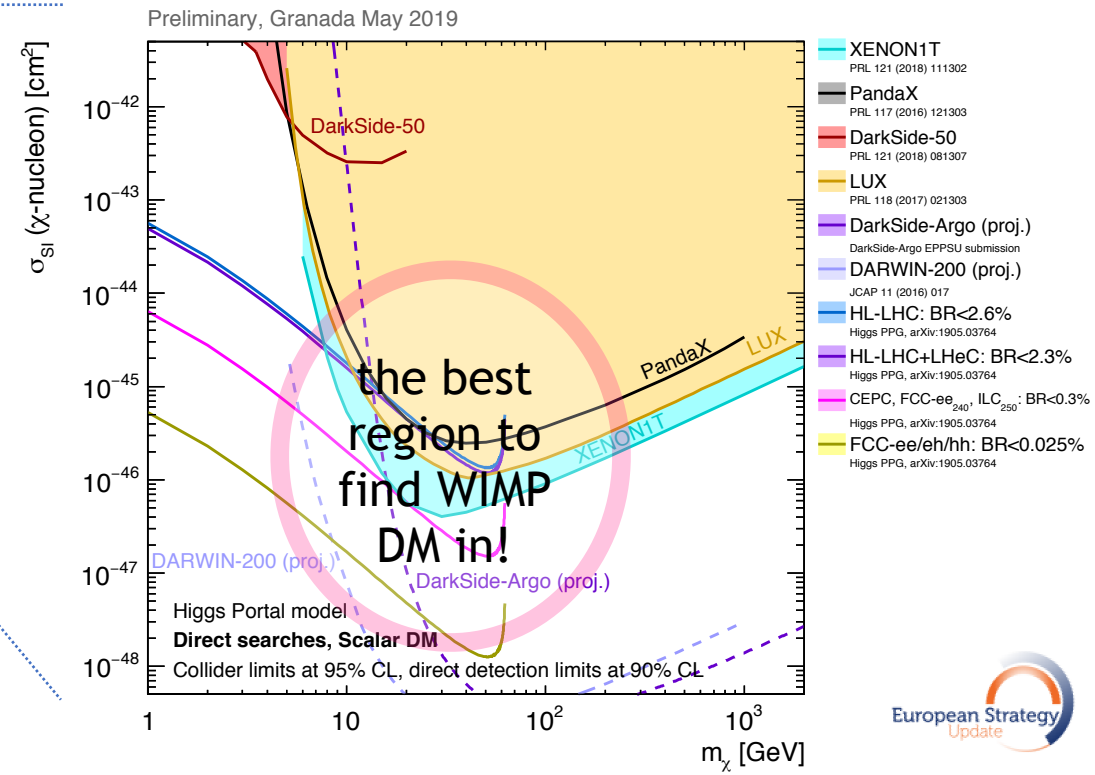
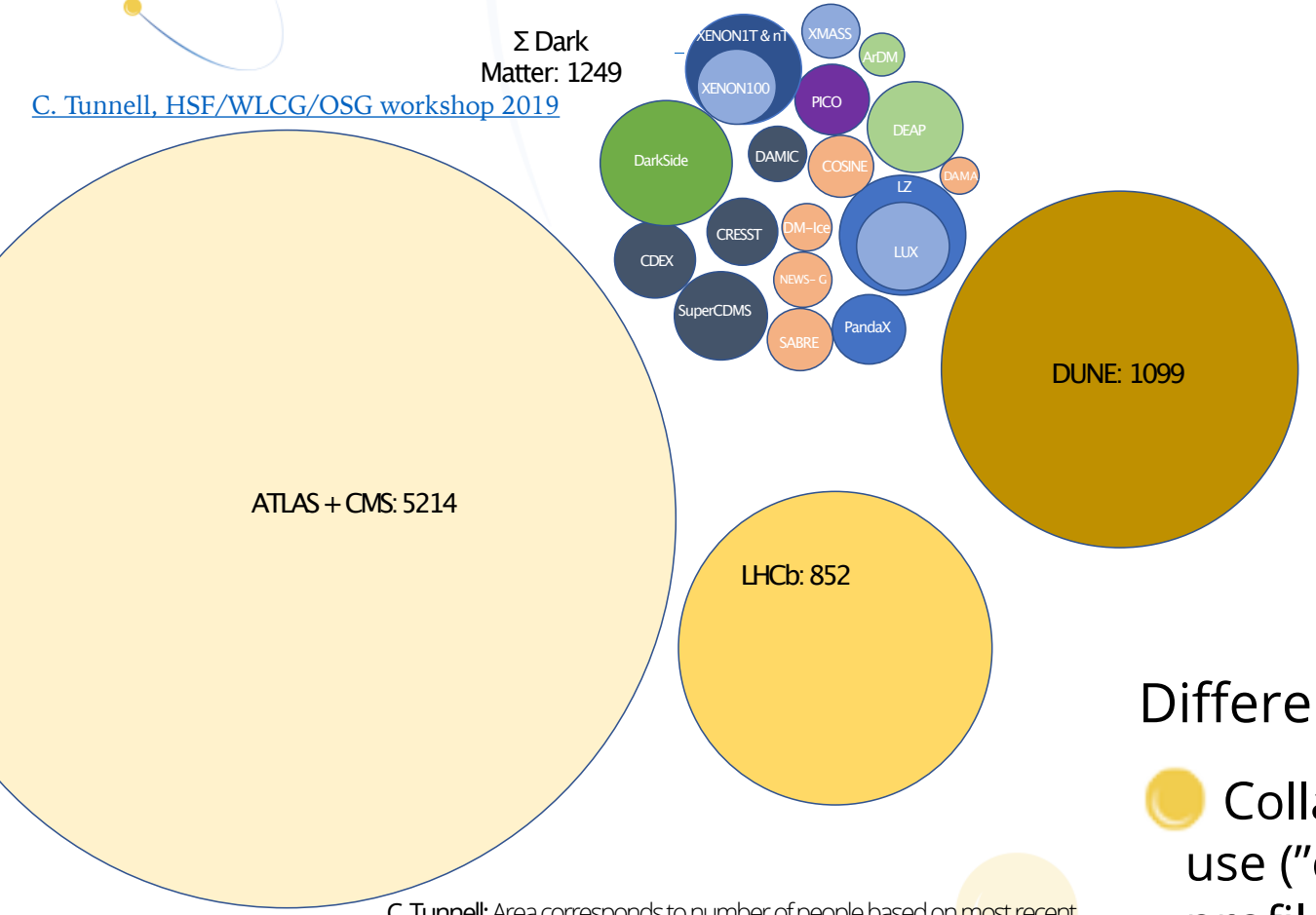


http://arxiv.org/abs/arXiv:1910.11775

Ca

Different kinds of (WIMP) DM communities



C. Tunnell, HSF/WLCG/OSG workshop 2019

C. Tunnell: Area corresponds to number of people based on most recent publication from any experiment that has published scientific papers in the last two years. This relied on Inspire-HEP. See gist for calculation notes. 16/ March/2019

Diagram only representing **collider and direct detection**

- Differences in collaboration variety and size
- Differences in data volumes:
  - Colliders: ”Big Data” volumes (>> PB)
  - DD: smaller data volumes (~TB/PB)
- Synergies in statistical analysis and interpretation of results

Different modus operandi for **indirect detection**

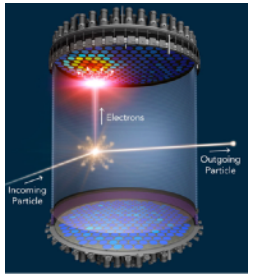
- Collaborations e.g. Fermi release data for general use (”observatory mode”), but also perform high-profile analyses themselves

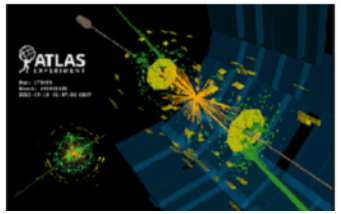
(Different) end-to-end WIMP analysis workflows

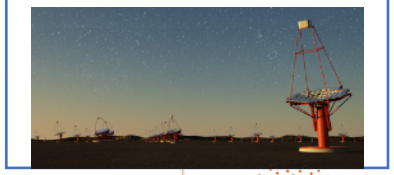
Simplified abstraction of workflows to fit in this slide, happy to receive feedback!

Generation & simulation of events

Experimental data







Credit: SLAC/LZ/ATLAS/CTA

Data **processing** (including reconstruction & calibration)

Analysis of events/ distributions (including background subtraction, background estimation, statistical analysis)

Interpretation of results

Combination of results with other searches/ experiments

Comparison of results with other searches / experiments

(Different) end-to-end WIMP analysis workflows

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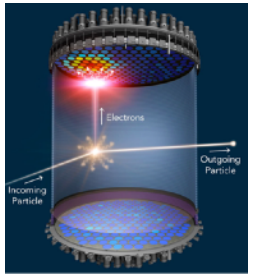

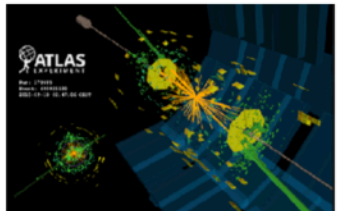

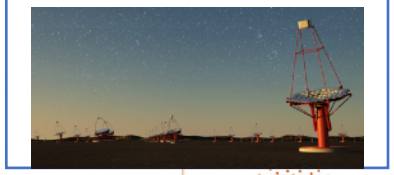

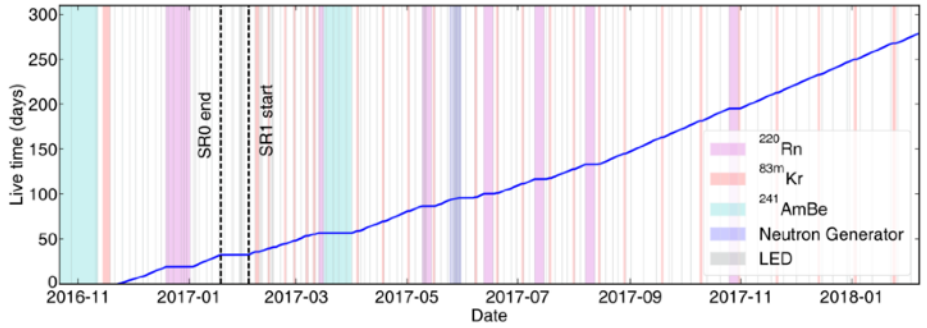

XENON 1T, PRD 100, 052014 (2019)

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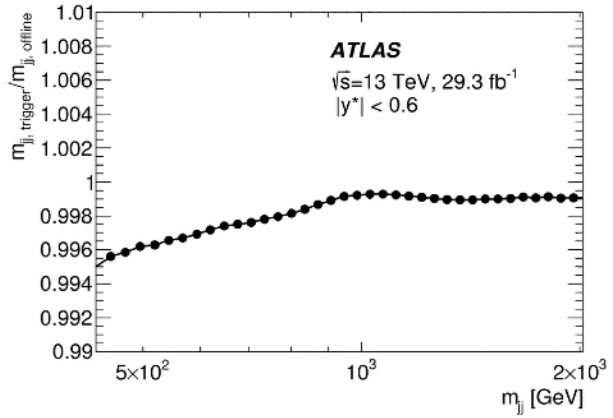

ATLAS, Phys. Rev. Lett. 121, 081801 (2018)

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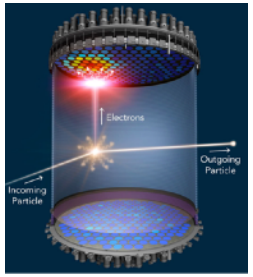

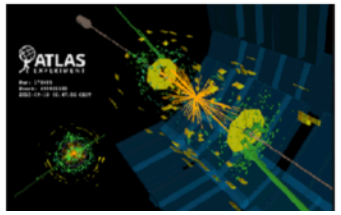

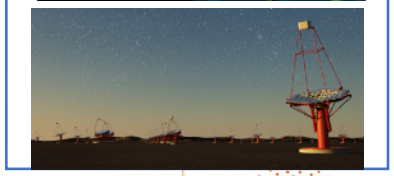

Credit: SLAC/LZ/ATLAS/CTA

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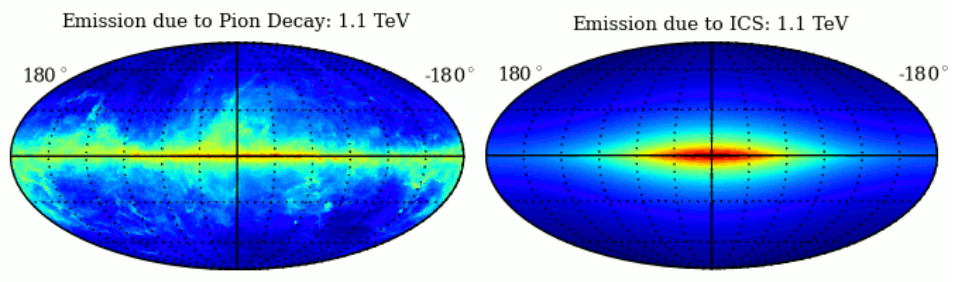
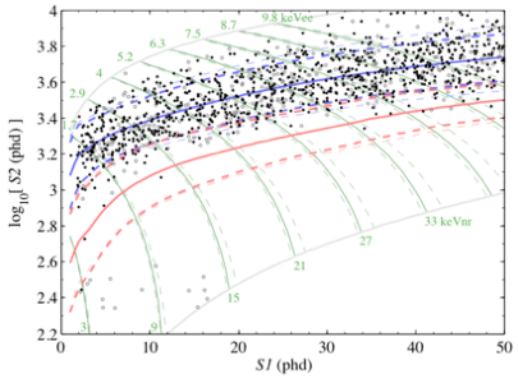


Credit: Galprop, HAWC website

Analysis of events/ distributions (including background subtraction, background estimation, statistical analysis)

PhystatDM, 2019

LUX, PRL. 118, 021303 (2017)



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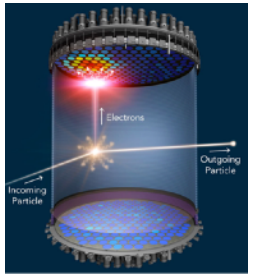

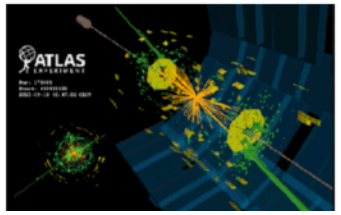

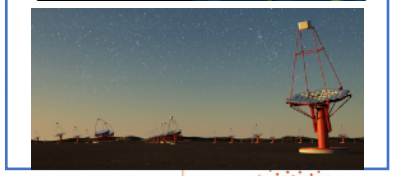

Credit: SLAC/LZ/ATLAS/CTA

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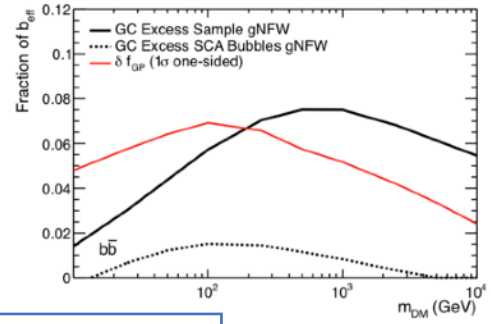
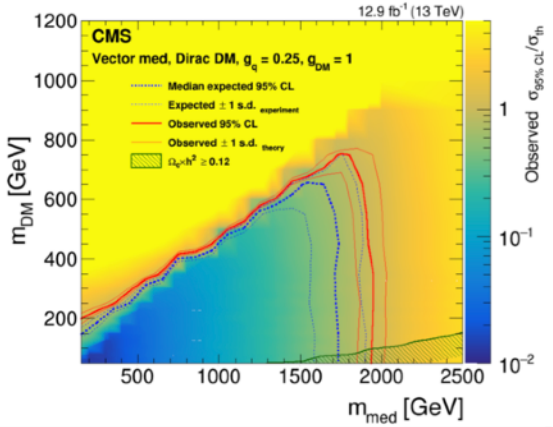
https://arxiv.org/abs/1704.03910





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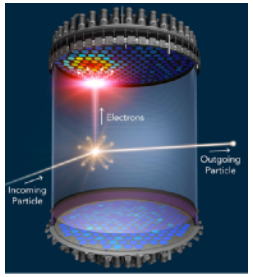

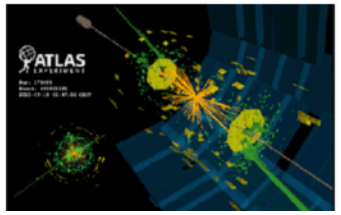

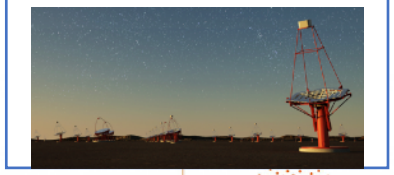

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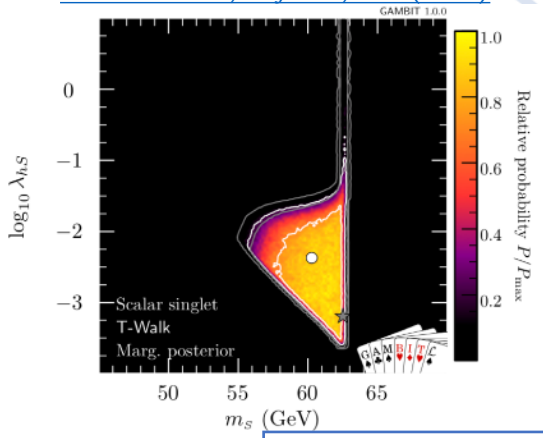
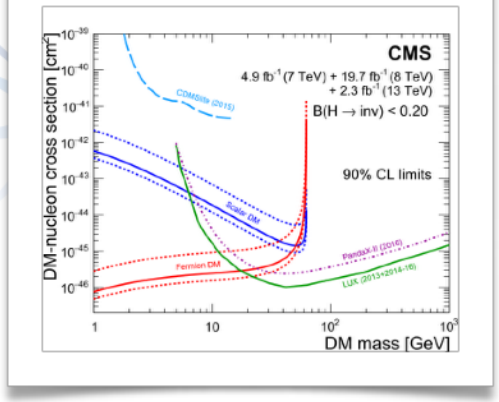
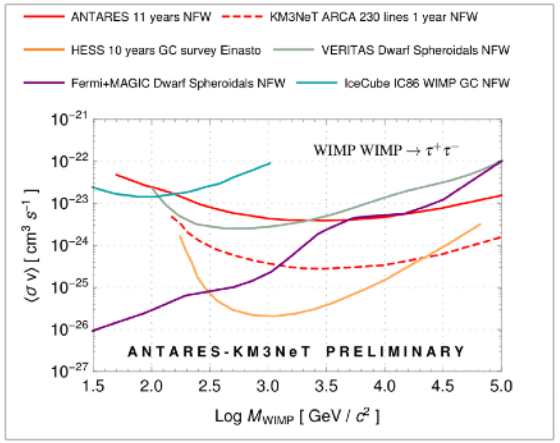
GAMBIT Coll., EPJC 77, 568 (2017)



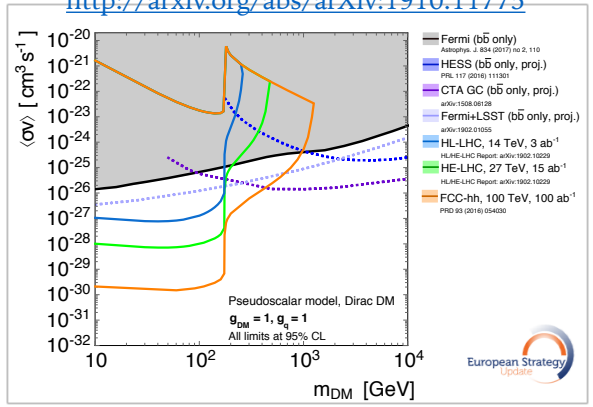
CMS, JHEP 02 (2017) 135





https://pos.sissa.it/358/552/pdf

http://arxiv.org/abs/arXiv:1910.11775



Interpretation of results

Combination of results with other searches/ experiments

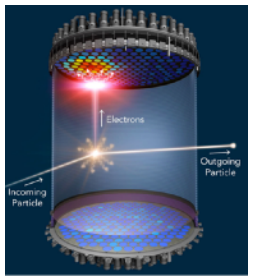
Comparison of results with other searches / experiments

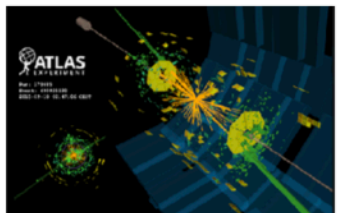
Challenges for Test Science Project

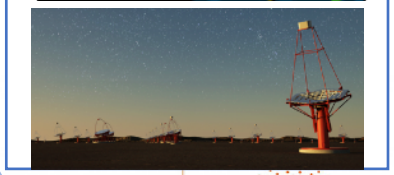
- Not possible to find a one-size-fits-all solution in either case...so work in parallel
- Idea (not original, see DANCE workshop): review what is done by various collaborations, finding points of contact

Generation & simulation of events

Experimental data







Credit: SLAC/LZ/ATLAS/CTA

Data sharing and data processing challenges

Data **processing** (including reconstruction & calibration)

e.g. RUCIO data management software shared across collaborations (e.g. LHC/DUNE/ ...), DIRAC analysis framework from LHCb being investigated by KM3Net

ESCAPE WP2, WP4, WP5

Data analysis, preservation and interpretation challenges

Analysis of events/ distributions (including background subtraction, background estimation, statistical analysis)

Interpretation of results

Combination of results with other searches/ experiments

V. Poireau et al.

Ongoing work between Fermi-LAT, HAWC, HESS, MAGIC & VERITAS GitHub, ICRC Proceedings

Comparison of results with other searches / experiments

ESCAPE WP3, WP5, WP6

Example: the ATLAS experiment perspective

for now: L. Heinrich, S. Meehan, K. Cranmer, C. Doglioni
open to others if interested!

Data sharing & processing

Follow updates to **CERN-wide data sharing policies** (http://opendata.cern.ch)

Benefit from **HEP Software Foundation** as platform to understand shared solutions for data processing challenges & interactions with ESCAPE software catalogue

Data analysis & interpretation

Start working on test ”generic DM search”:

data analysis & data preservation

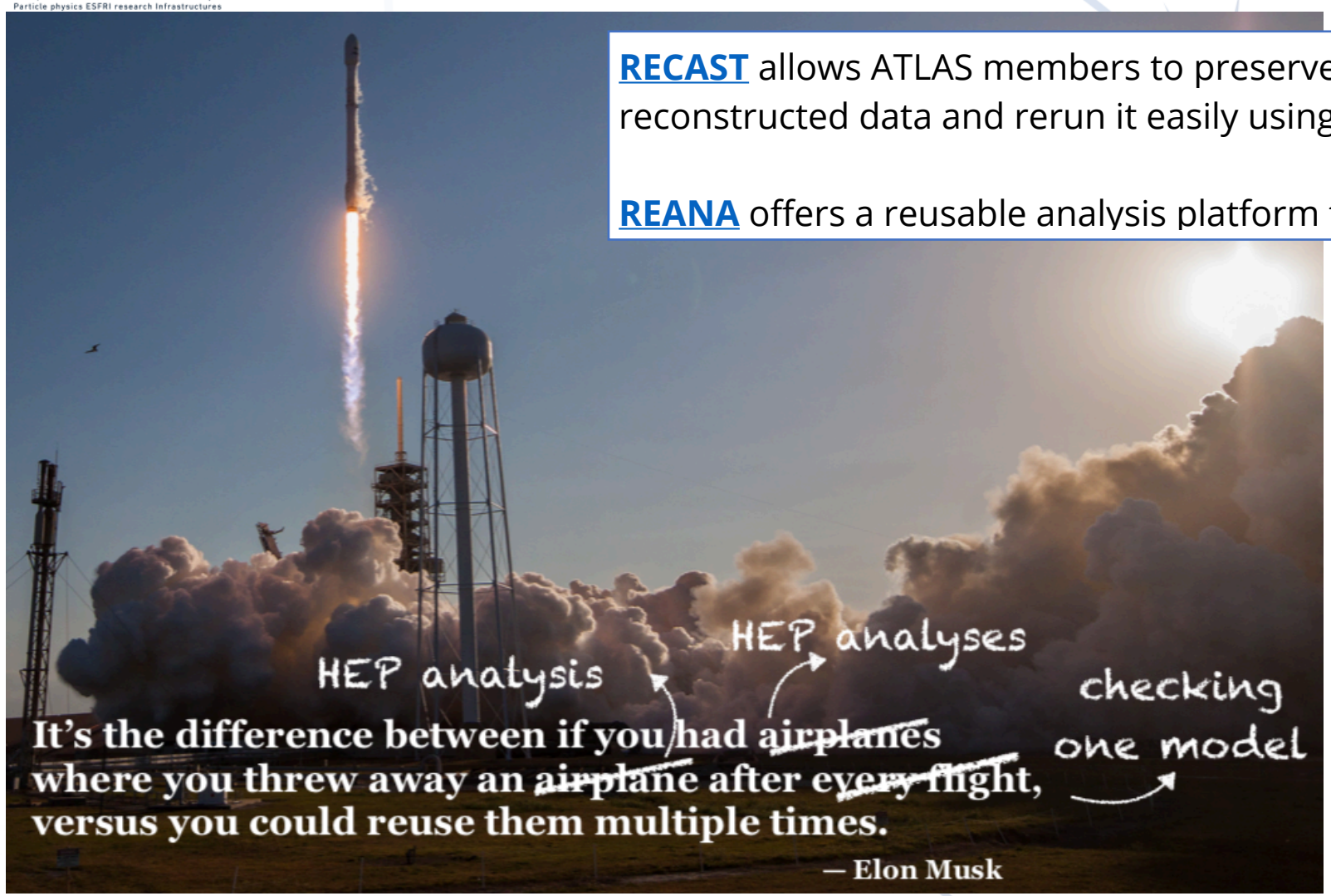
- Preserve workflow & analysis code with **RECAST** ATLAS Note, docs and **REANA**
  - Built around the idea of containerized workflows
- Preserve likelihood with **pyhf** Zenodo, docs
  - Discussions ongoing with **Fermi** data analysers

interpretation of results

- Deposit digitized data & likelihoods in **HEPData**
- Include LHC measurements with **CONTUR**
- Could use **GAMBIT** (& DDCalc) for combinations

The ideas behind RECAST / REANA

All HEP/CERN software is Open Source



RECAST allows ATLAS members to preserve the analysis pipeline starting from the reconstructed data and rerun it easily using different (DM) models

REANA offers a reusable analysis platform to run the RECAST pipelines (& more)

DM TSP for ATLAS:

1. implement a dark matter analysis pipeline in RECAST/REANA
   (see talk by L. Heinrich, Higgs Couplings talk by S. Meehan with RECAST in action)

2. adapt RECAST/REANA to work within ESCAPE/EOSC ecosystem
   (Data Lake, Software Catalogue, Science Analysis Platform)

3. produce results ready to be interpreted in different DM models

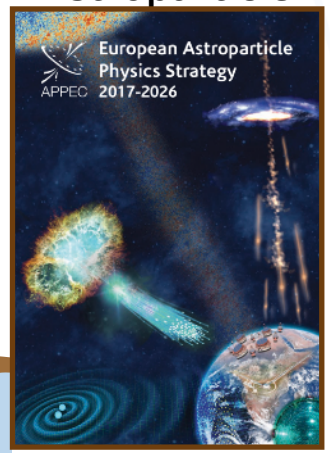
Lukas Heinrich's lightning talk @ S212

Foundations needed to exploit synergies

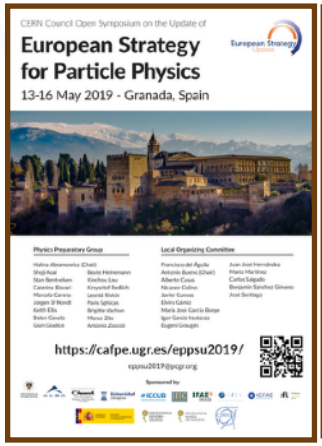
ESCAPE
European Science Cluster of Astronomy & Particle physics ESFRI research Infrastructures

LUNDS UNIVERSITET

APPEC Astroparticle



ECFA Particle



NuPECC Nuclear

Common theory ground

instrumentation (accelerators, beams, detectors, vacuum & cryogenics, control & automation...)

data acquisition, computing, data sharing & open science

HSF
HEP Software Foundation

ESCAPE
European Science Cluster of Astronomy & Particle physics ESFRI research Infrastructures

iris hep

& more...

EuCAPT

[Talk at EPS-HEP / ECFA session 2019](), [CERN EP Newsletter]()

European Research Council
Established by the European Commission

ATLAS EXPERIMENT

Synergistic initiatives following European Strategy Update

searches & interpretation

JENAS EoI: Initiative for Dark Matter in Europe and beyond: Towards facilitating communication and result sharing in the Dark Matter community (iDMEu)

https://indico.cern.ch/event/869195/
ESCAPE newsletter APPEC newsletter

build a discussion platform to facilitate collaboration of existing groups/efforts on **dark matter searches** and **interpretation**

*provides a discussion platform for the **comparison of common DM interpretations***

software & data

instrumentation (accelerators, beams, detectors, vacuum & cryogenics, control & automation...)

data acquisition, software, computing, data sharing & open science

Towards a Dark Matter Test Science Project

ESCAPE Progress Meeting, 2020

compare **end-to-end analysis workflows** for WIMP searches, towards their implementation in a common **Software Catalogue** and as input to the design of the **European Open Science Cloud**

*allows to **create experimental curves** by **example ESCAPE experiments,** comparing and contrasting analysis pipelines that use ESCAPE / EOSC tools*

More initiatives and links in backup slides

How to proceed towards a DM Test Science Project

- **DM Test Science Project**: ESCAPE/EOSC reaching out to researchers
  - Demonstrator of selected end-to-end pipelines for direct, indirect detection and collider searches for Dark Matter integrated in ESCAPE/EOSC infrastructure (in particular in software catalogue)
    - Will also include an outreach / citizen science component
  - We don't want to reinvent any wheels - aim to collect and test existing pipelines and workflows
  - Pipelines produce results that will help characterise discovery / constrain Dark Matter
    - Collaboration with the JENAA Expression of Intent iDMEu
- Currently in the process of **collecting information**
  - ESCAPE high-energy collider/ID experiments on board, ID combination work already ongoing
  - Seeking more input from non-ESCAPE & non-collider community: direct detection, astrophysics, theory…
  - …who in turn need more input from ESCAPE: communication is key!
- **Kick-off + regular discussions** once main players identified
  - This will start / be advertised in the next few weeks…stay tuned!

ESCAPE

European Science Cluster of Astronomy & Particle physics ESFRI research Infrastructures

Backup slides

@CatDogLund, she/her
http://www.hep.lu.se/staff/doglioni/

European Research Council
Established by the European Commission

ATLAS EXPERIMENT

ESCAPE - The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement n° 824064.

ESCAPE services

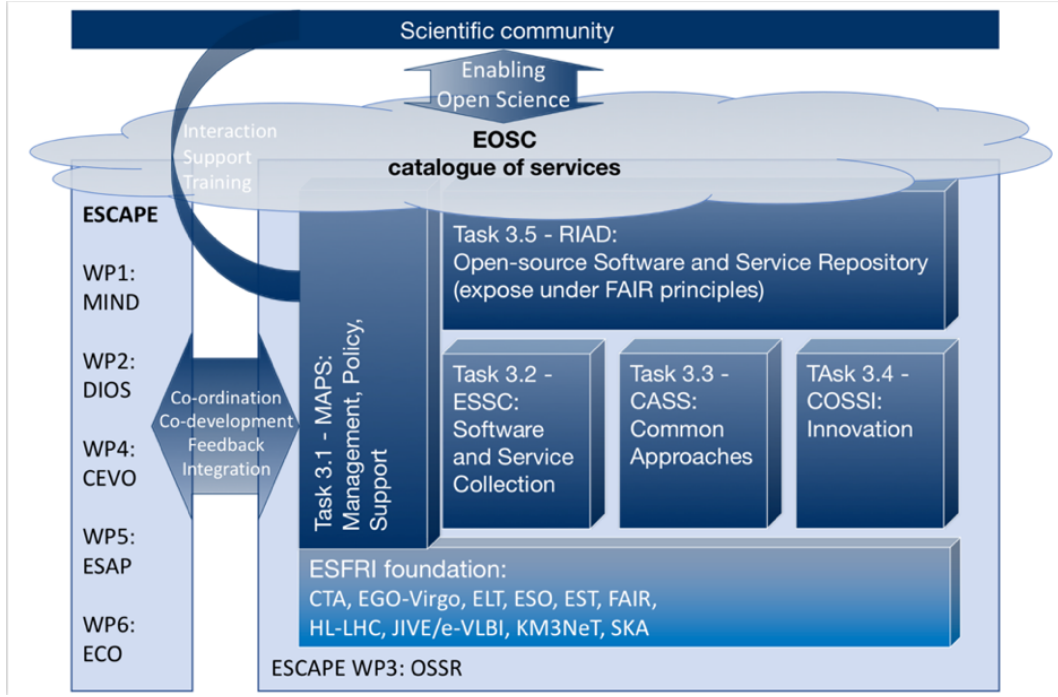
Slide from G. Lamanna

- **Data Lake**:
  - Build a scalable, federated, data infrastructure as the basis of open science for the ESFRI projects within ESCAPE. Enable connection to compute and storage resources.
- **Software Repository**:
  - Repository of "scientific software" as a major component of the “data” to be curated in EOSC. Implementation of a community-based approach for the continuous development of shared software and for training of researchers and data scientists.
- **Virtual Observatory**:
  - Extend FAIR standards, methods, tools of the Virtual Observatory to a broader scientific context; demonstrate EOSC ability to include existing platforms
- **Science Platforms**:
  - Flexible science platforms to enable the analysis of open access data
- **Citizen Science**:
  - Open gateway for citizen science on ESCAPE data archives and ESFRI community CS projects

ESCAPE software catalogue

Slide from K. Graf

OSSR Overview



ESFRI/RI	Institute/SME
CTA	CNRS-LAPP
CTA	CTAO
CTA	IFAE
CTA	MPG-MPIK
CTA	UCM
EGO-Virgo	EGO
ELT	HITS
EST	AIP
EST	NWO-I-CWI
EST	UNITOV
FAIR	GSI
HL-LHC, CERN	CERN
JIVE	JIVE
KM3NeT	CNRS-CPPM
KM3NeT	FAU
KM3NeT	INFN
KM3NeT	NWO-I-Nikhef
SKA	SKAO
SME	OROBIX
9 ESFRI / RI	**19 Partners**

Open questions and challenges

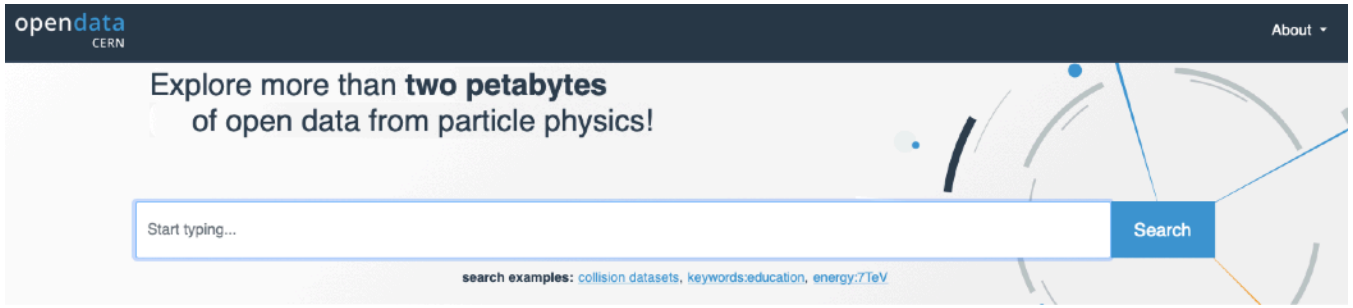
Collected from chats with members of DM community

- It is our duty as scientists to make our research FAIR
  - But do we (PIs) / the system (funding agencies) offer sufficient reward?
    - A concern of many: maintaining code is necessary but is often done on a voluntary basis
  - Need a healthy system of incentives coming from within the researcher community
- How can the DM community interface itself effectively with the Software Catalogue and the other ESCAPE WPs?
  - See dedicated discussion, and input from HEP Software Foundation
- How does ESCAPE interface itself with other entities that support/develop DM research / open science in astronomy and astrophysics?
  - E.g. ESA, http://www.esa.int/About_Us/Digital_Agenda/Open_Science
- How can ESCAPE reach out to researchers? (today's discussion)

Open pipelines @ ATLAS: HOWTO?

"Making data FAIR is relatively straightforward, but making FAIR data useful is difficult"

from a conversation with Stephen Serjeant, Hugh Dickinson



ATLAS: released partial dataset for educational purposes, may do mor (many "sociological" questions in a collaboration of 3000 people...)

Many different possible use cases, e.g.:

- **preserve** data & pipelines (RECAST/REANA - see HSF talk by L. Heinrich)
- **re-analyse** data with different pipelines
- **combine** data of different experiments
- **reinterpret** data for different DM models (pyhf / CONTUR / ... - see this document)

How to deploy *diverse* software on EOSC?

How to facilitate user participation (documentation, documentation, documentation)?

How to ensure lifetime of tools beyond "postdoc contracts"?

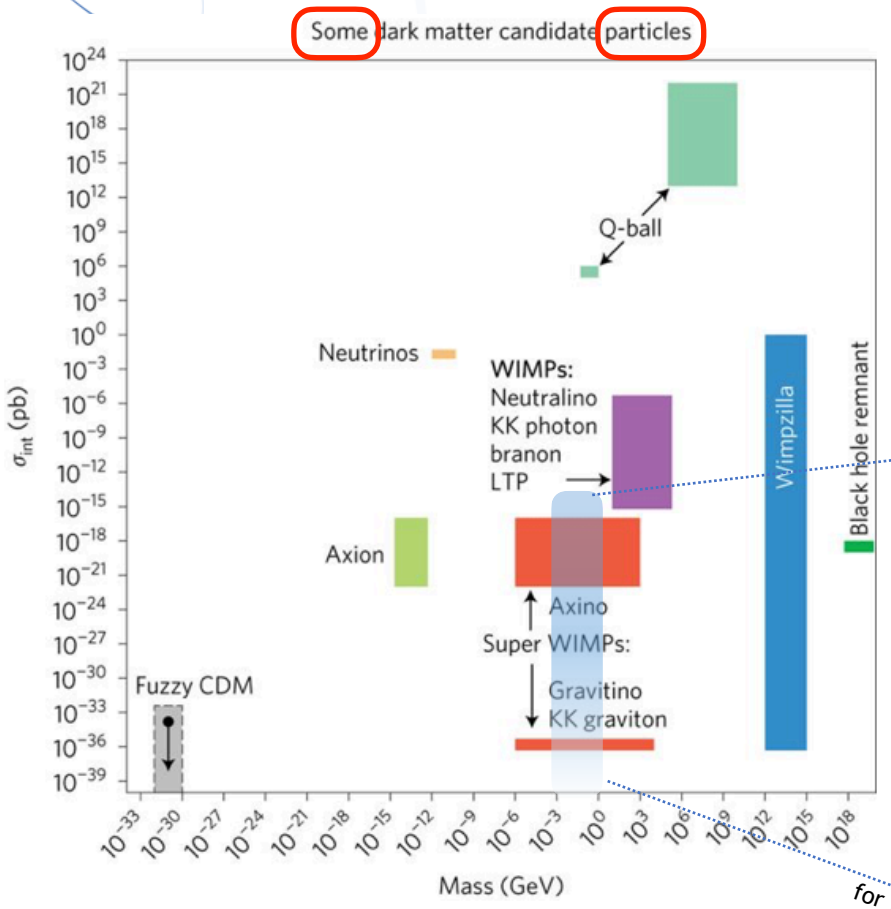
Initiative for Dark Matter in Europe and beyond

- Many DM discussions, from **Granada** to the **ApPEC-ECFA-NuPECC JENAS meeting** held in Orsay in October 2019
  - Talk on ESCAPE (G. Lamanna) in plenary programme
  - HEP Software Foundation meeting on possible software synergies

- JENAS prompted a new initiative centered around **dark matter:** https://indico.cern.ch/e/iDMEu, also featured in ESCAPE newsletter
  - *iDMEu* aiming to build a discussion platform to facilitate collaboration of existing groups/efforts
  - *Dark Matter Test Science Project* targeting data, software and tools sharing where necessary/useful
  - Points of contact between *iDMEu* and *TSP*:
    - participation of DM community to software catalogue
    - help with common repositories of data and final results (e.g. versioning)
      - e.g. DMTools, DM Limit Plotter

Different kinds of DM, and synergies

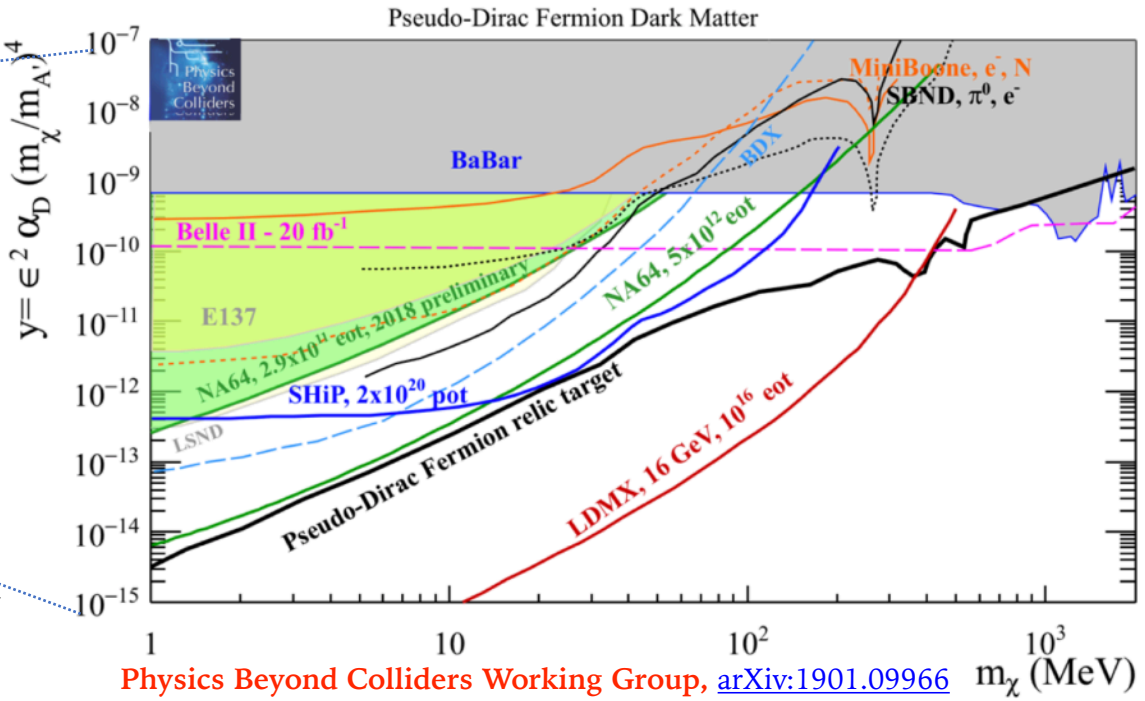
Many hypotheses for dark matter
→ many ways to detect it
→ many different experiments
→ many different data / result sharing policies
→ many different data / workflow needs



https://www.nature.com/articles/nphys4049
adapted from The Dark Matter Scientific Assessment Group

for illustrative purposes
no 1:1 correspondence

Dark photon portal model



Physics Beyond Colliders Working Group, arXiv:1901.09966

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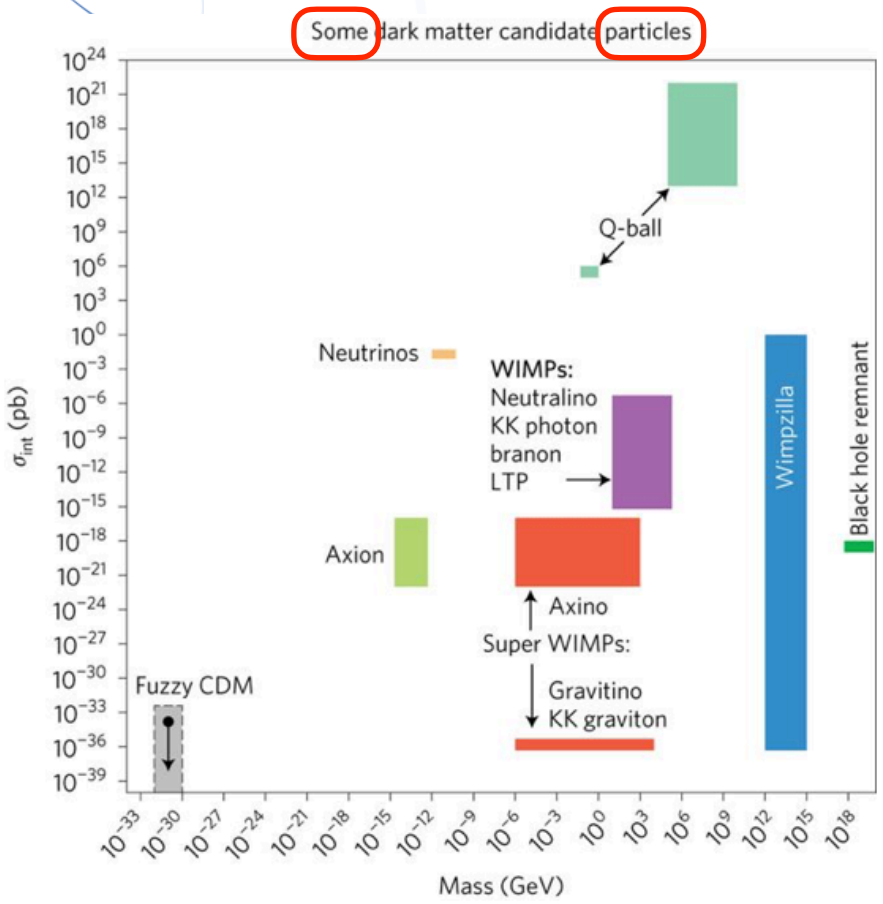

https://www.nature.com/articles/nphys4049
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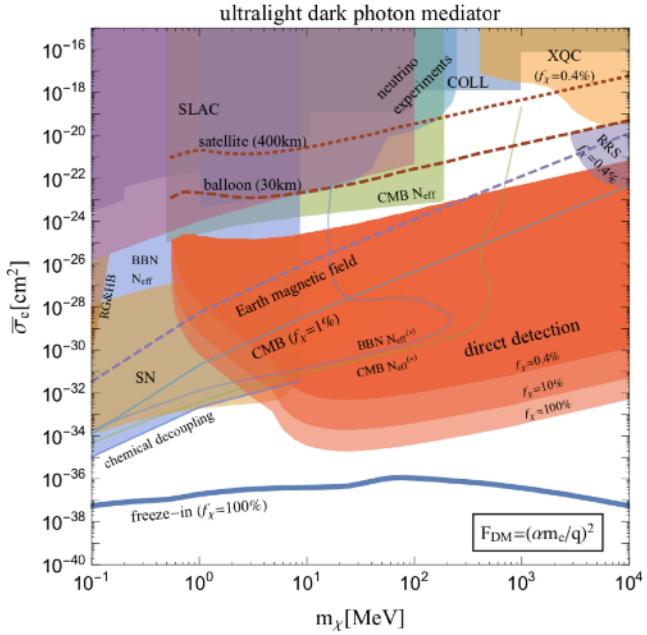
Constraints from astrophysics



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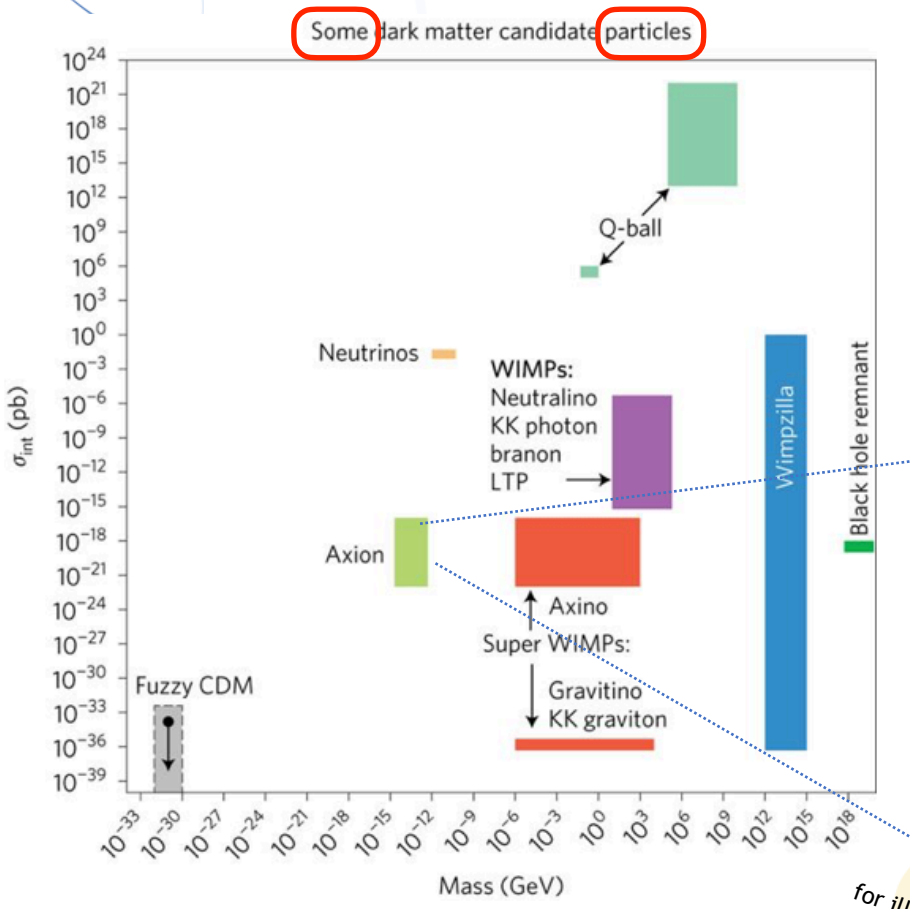

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for illustrative purposes
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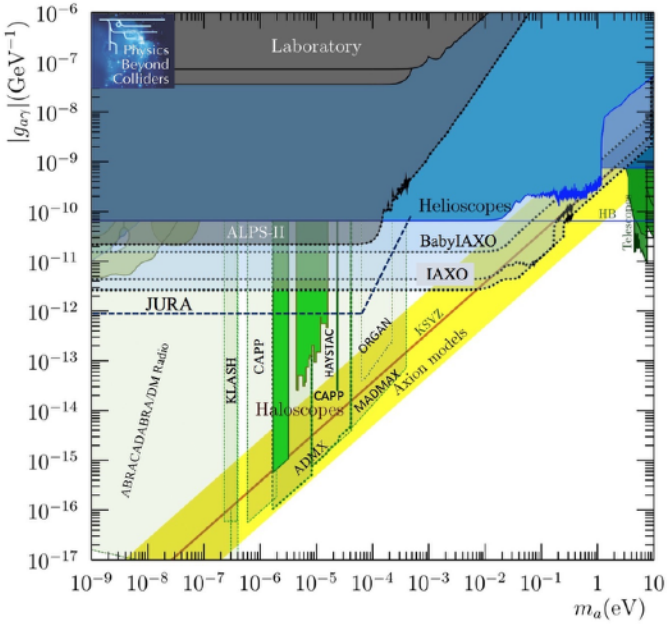
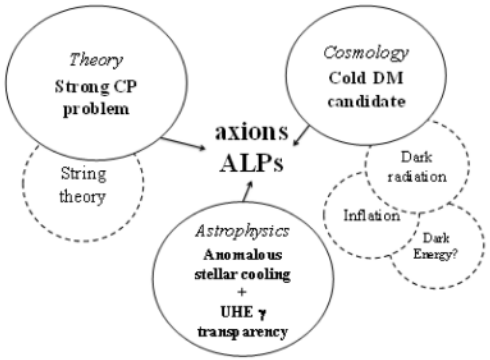
Axion models





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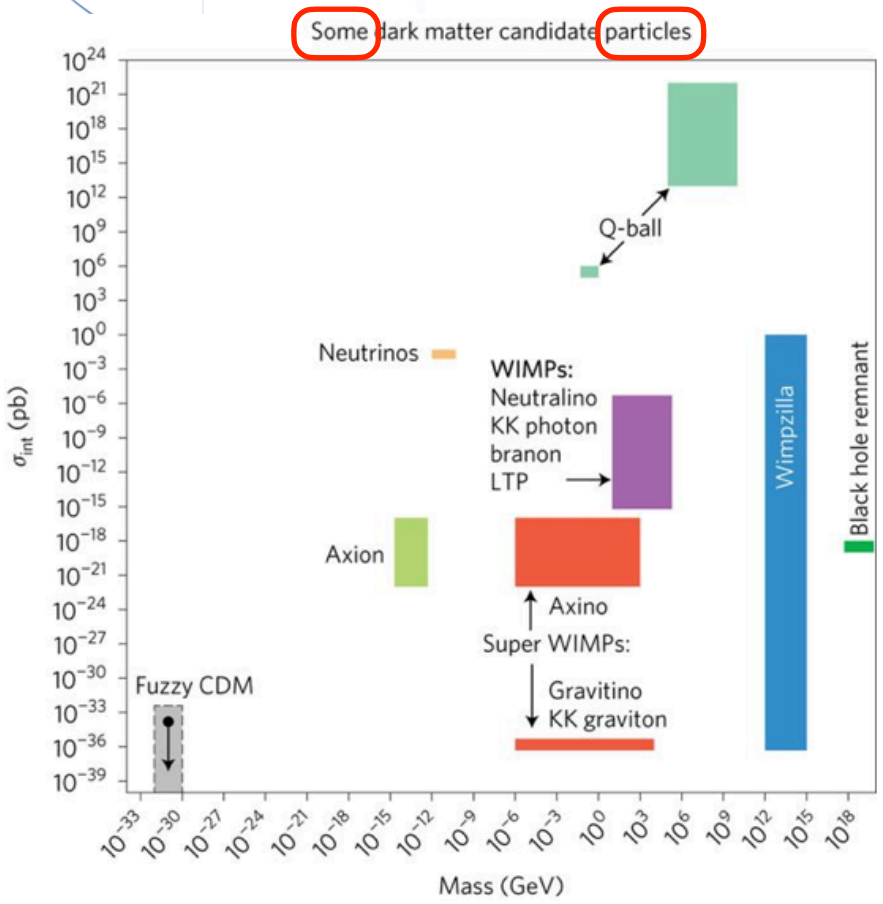

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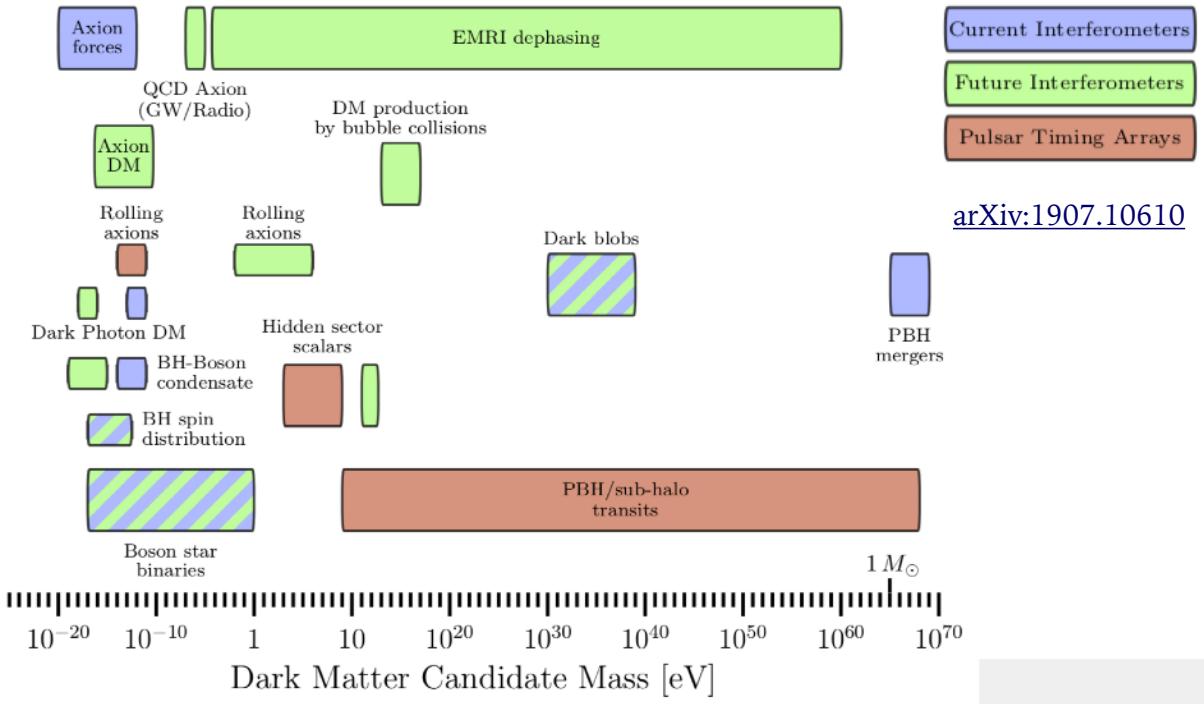
adapted from The Dark Matter Scientific Assessment Group

Models relevant for GW experiments



arXiv:1907.10610

Combination of ID results