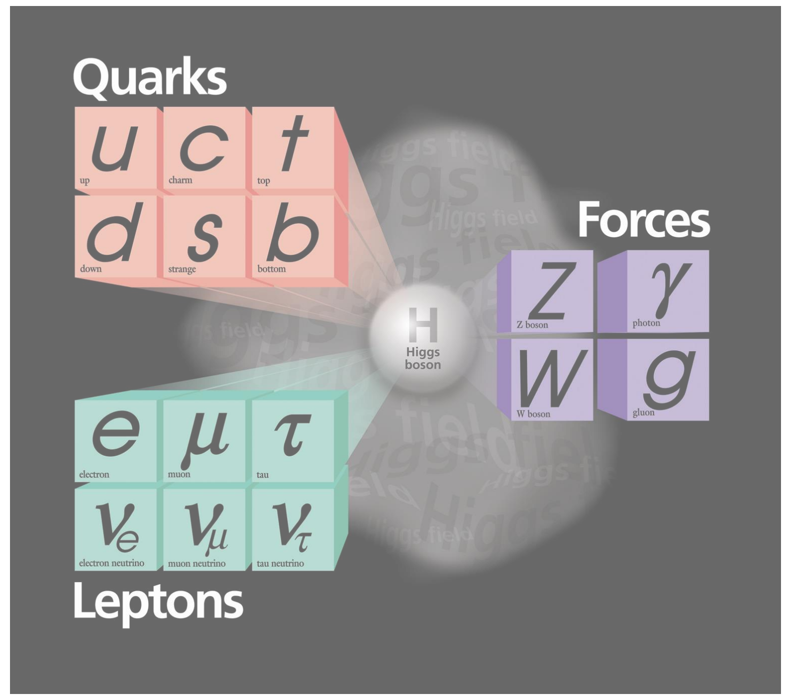
Dark matter and neutrino study with CYGNO: Computing model and data handling

G. Dho - SOSC 2024 Sixth International School on Open Science Cloud


Quarks
u c t
d s b
Forces
Z γ
W g
H Higgs boson
e μ τ
ν_e ν_μ ν_τ
Leptons
SM
Λ-CDM
GR
$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$

standard model (SM)/general relativity (GR)

- divergence - renormalization;
- gravity;
- dark matter;
- dark energy;
- neutrino masses;
- matter–antimatter asymmetry;
- the theory is composed of a mess of terms, stuck together.



$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

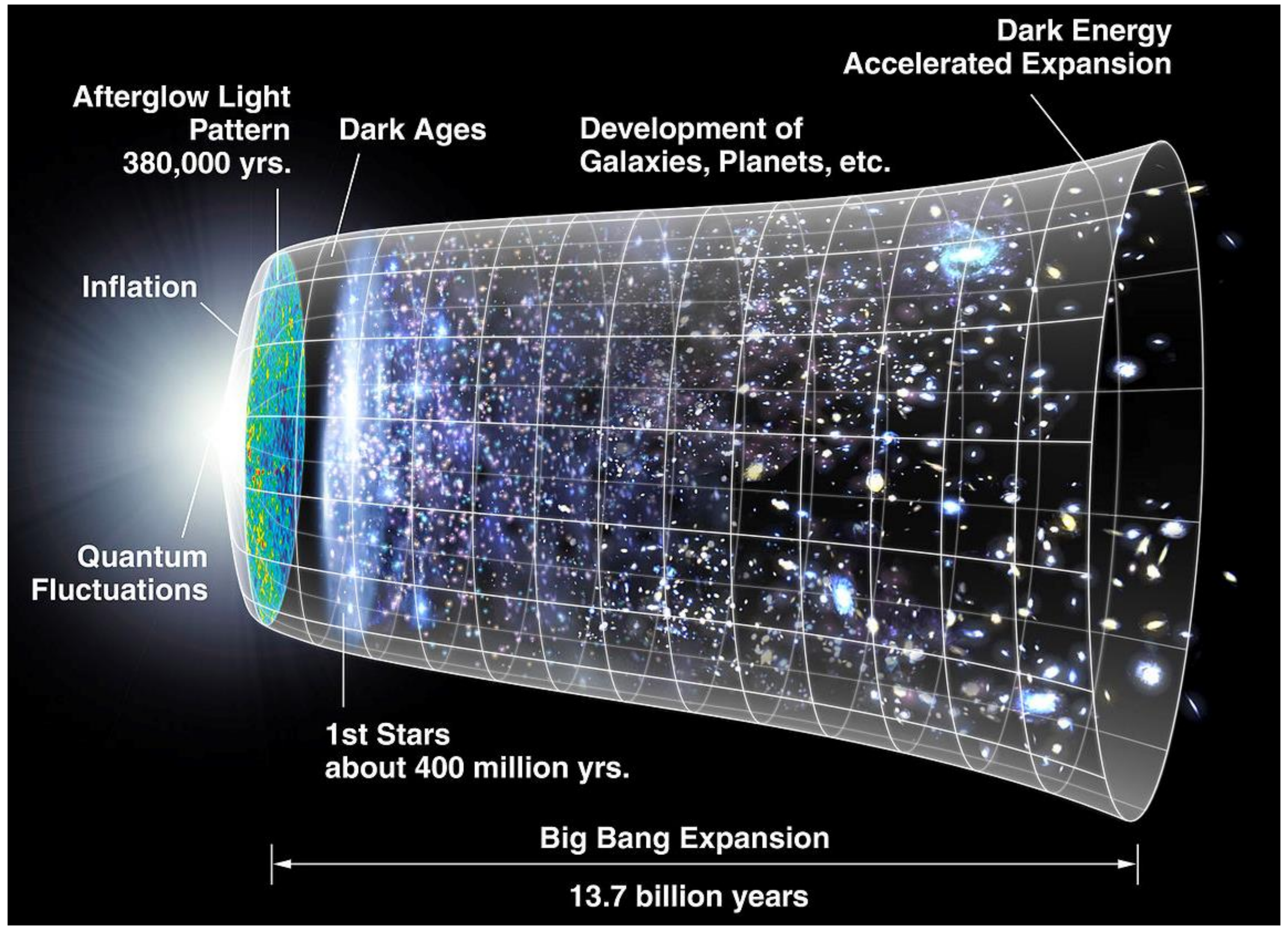
- quantisation of the space-time;
- dark energy …;
- dark matter …;
- the black hole/singularity
- the theory is elegant and with profound meaning as never probably happened in physics

cosmology (Λ-CDM)

origin and evolution of the universe, from the Big Bang to today and on into the future

time

- **The Planck epoch** - Time < 10^{-43} s - four fundamental forces were combined into a single, **unified force**.
- The universe **expands** - Time 10^{-43} - 10^{-36} s - **inflation** (exponential expiation) explaining why universe was so flat and uniform, **primordial black holes** could start to be formed
- The **elementary particles** are born - Time ~10^{-36} s - quarks were combined, forming **protons** and **neutrons**; **neutrinos** were able to escape this plasma of charged particles and began traveling freely through space, while photons continued to be trapped by the plasma. It could be that **dark matter** (WIMPs) was part of this plasma
- The first **nuclei** emerge - Time ~1 s to 3 min - **nucleosynthesis**: universe cooled enough for violent collisions to subside, **protons and neutrons clumped together into nuclei** of the light elements—hydrogen, helium and lithium
- The **cosmic microwave background** (CMB) becomes visible - Time 380,000 y - the particle soup had cooled enough for electrons to **bind to nuclei to form neutral atoms**; **photons** became free to traverse the universe
- The earliest **stars** - Time: ~100 million years
- Our **Sun** is born - Time: 9.2 billion years
- Today - Time: **13.8 billion years** - The universe is expanding at an increasing rate —> **dark energy**



fixing the amount of “components” expected to be observed in the universe today

But… prediction vs observation

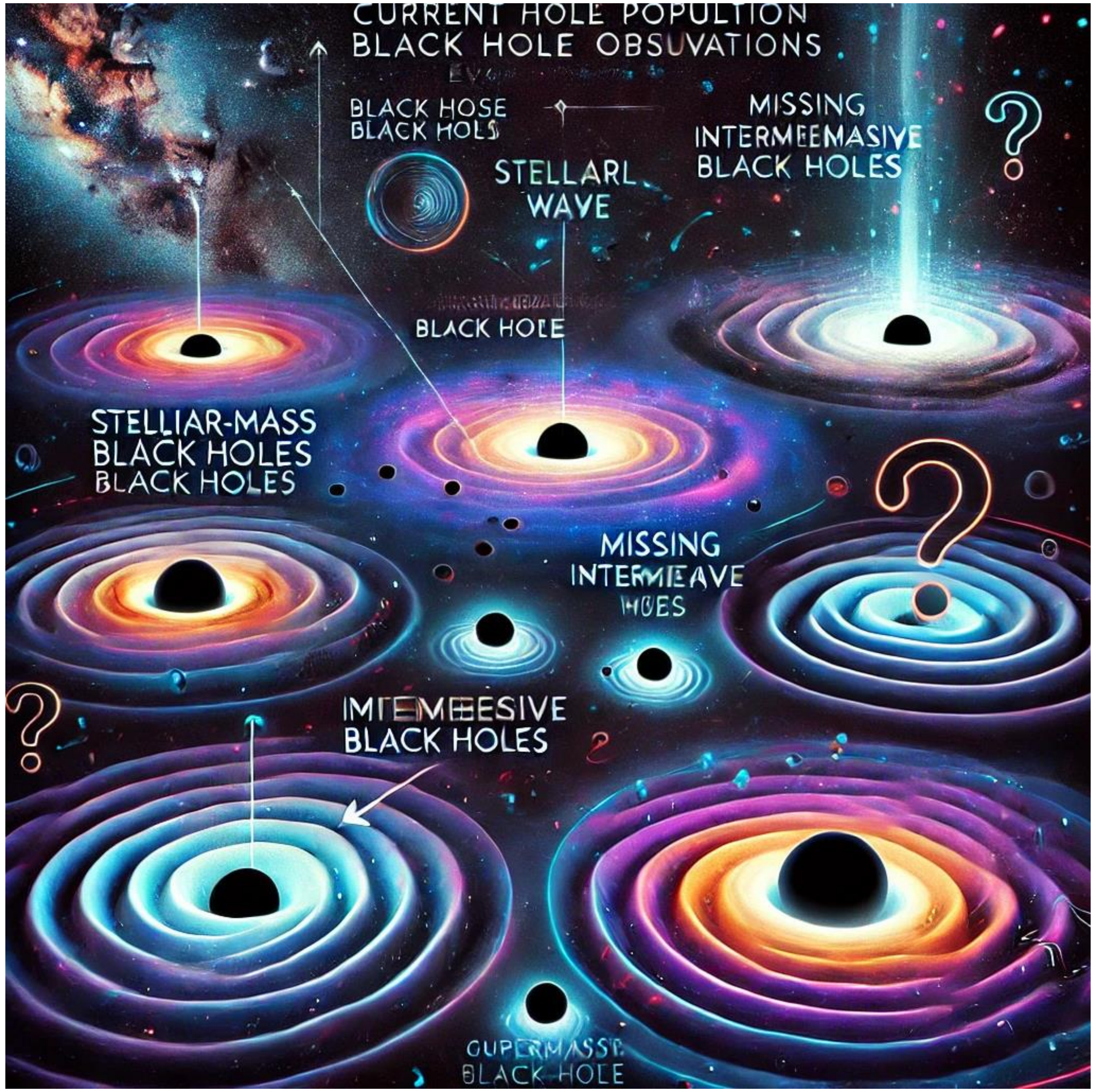
example of unexpected:

- the **distribution** of black hole **masses** in LIGO/Virgo detected compared to that predicted by stellar evolution theories.

- the observed **rate of black hole mergers** compared to the expected rate.

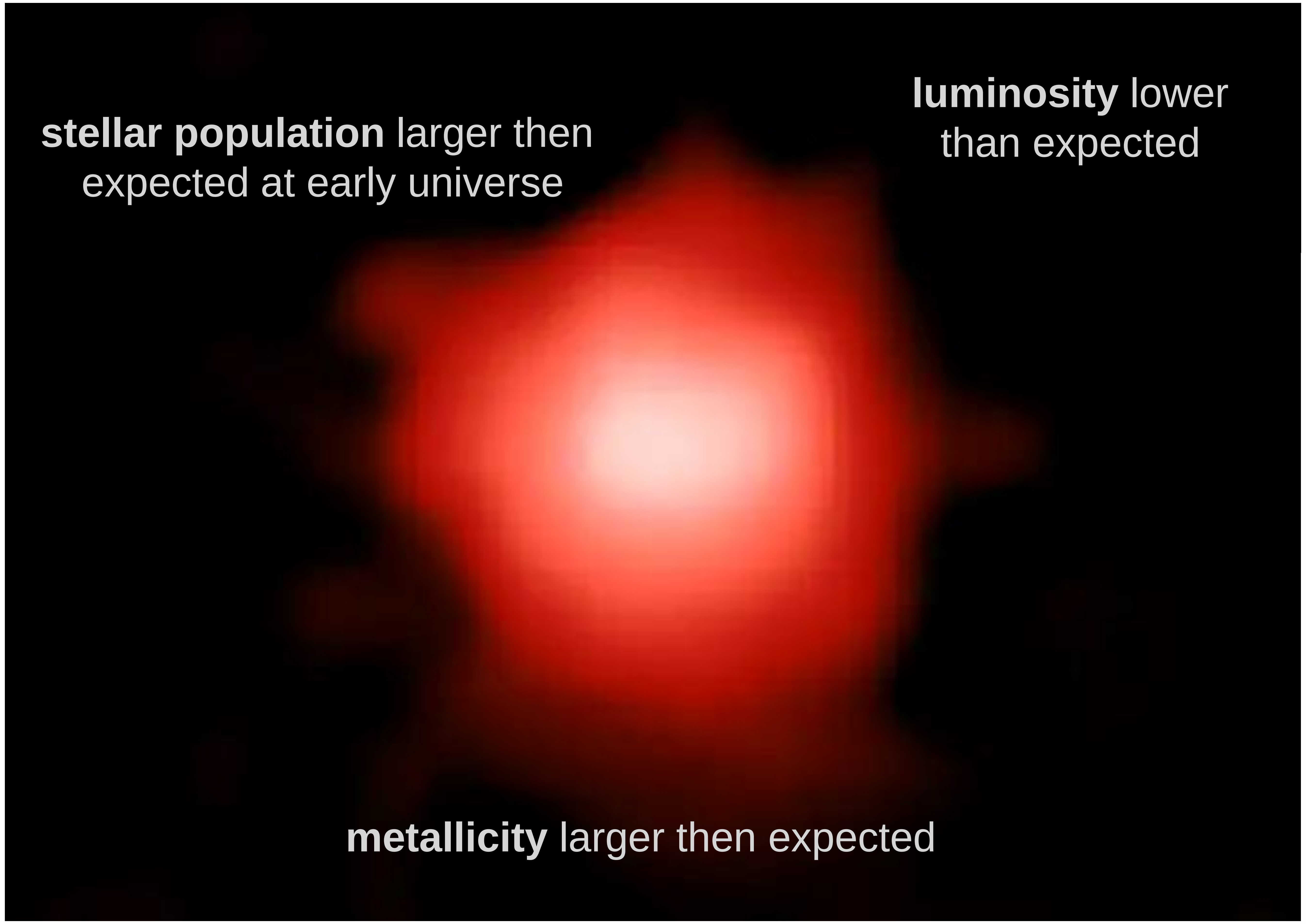
- the **growth of supermassive black holes** versus time in the early universe.

In general, the **higher the redshift, the greater the tension vs formation models**, especially in the case of **supermassive black holes that appear to grow too rapidly in the early universe.**



But… prediction vs observation

the JWST might have spotted a galaxy from 13.5 billion years ago, just 300 million years after the Big Bang



In the first Gyr:

#1 too many early/bright galaxies

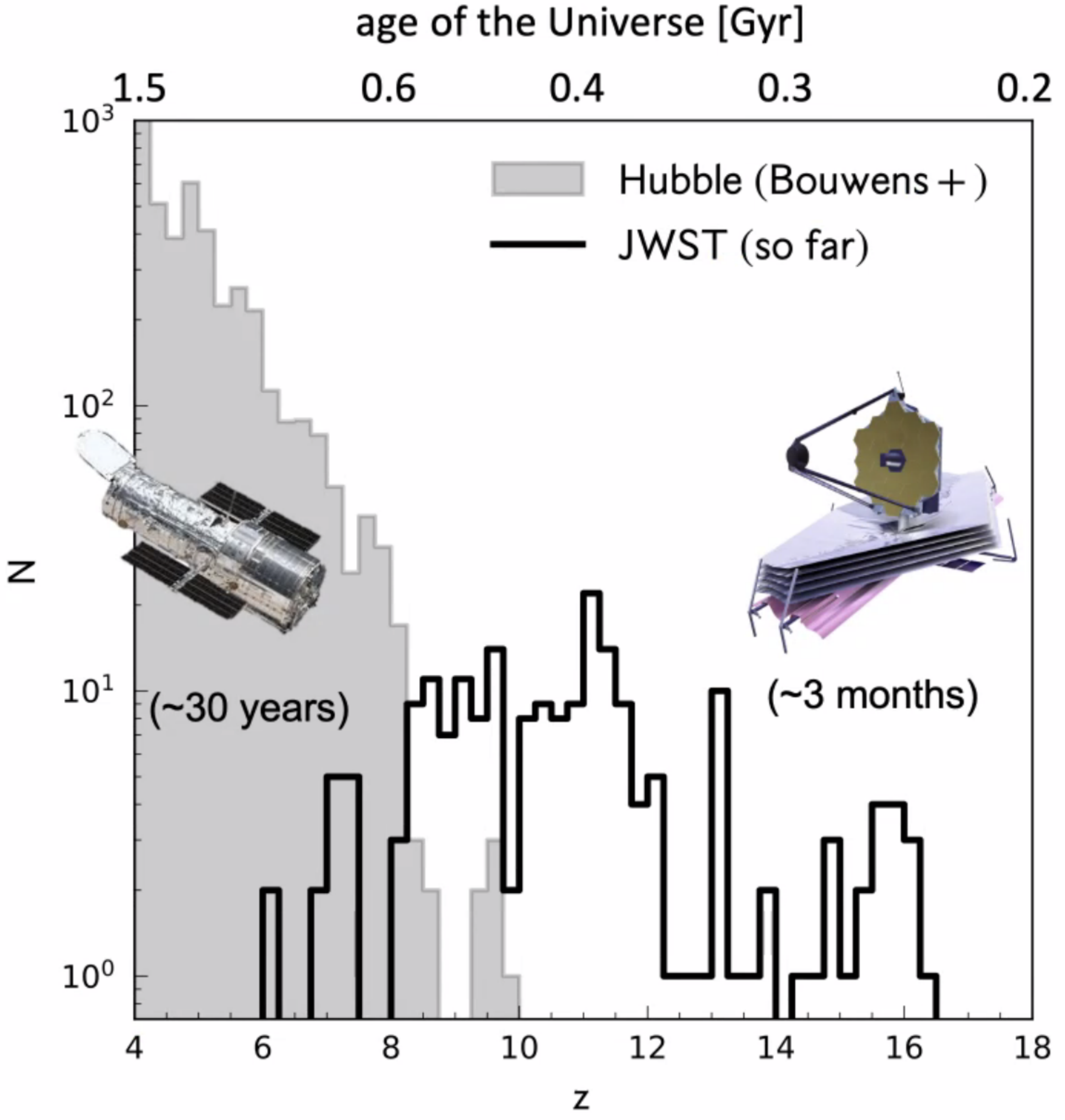
#2 that come in a variety of physical conditions,

#3 including passive galaxies already in place,

#4 a lot of AGN, with rapidly growing SMBH,

#5 galaxies that have already assembled a lot of mass,

#6 and a lot of disks



Paola Santini (INAF - Osservatorio Astronomico di Roma)
https://indico.gssi.it/event/529/

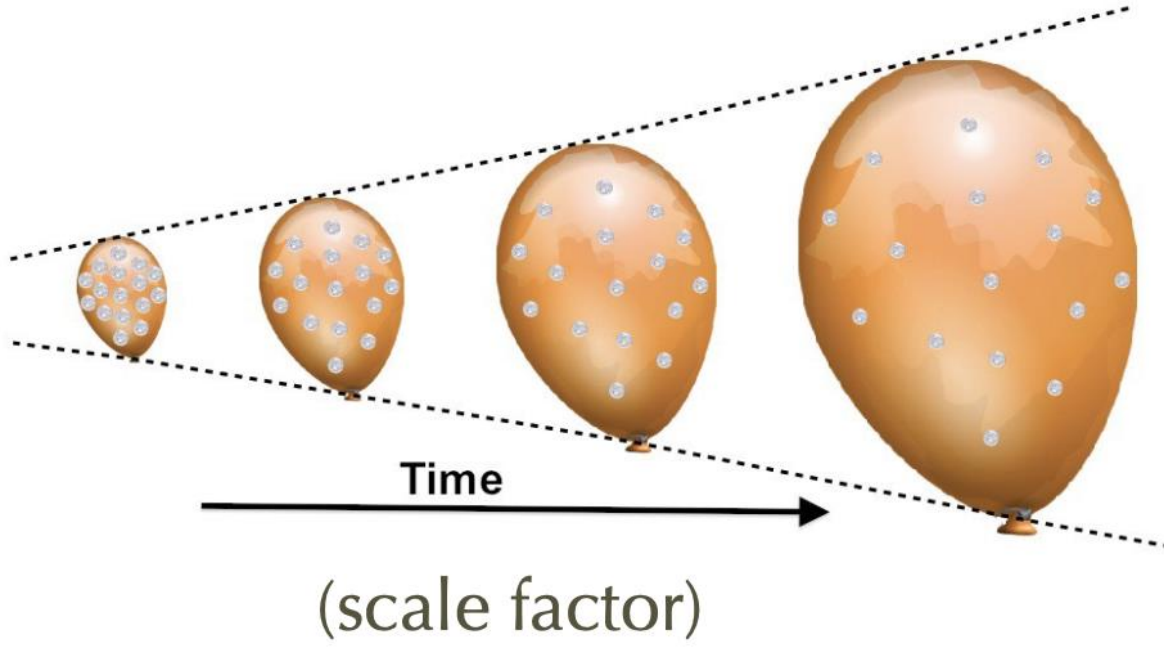
expansion vs gravitational collapse

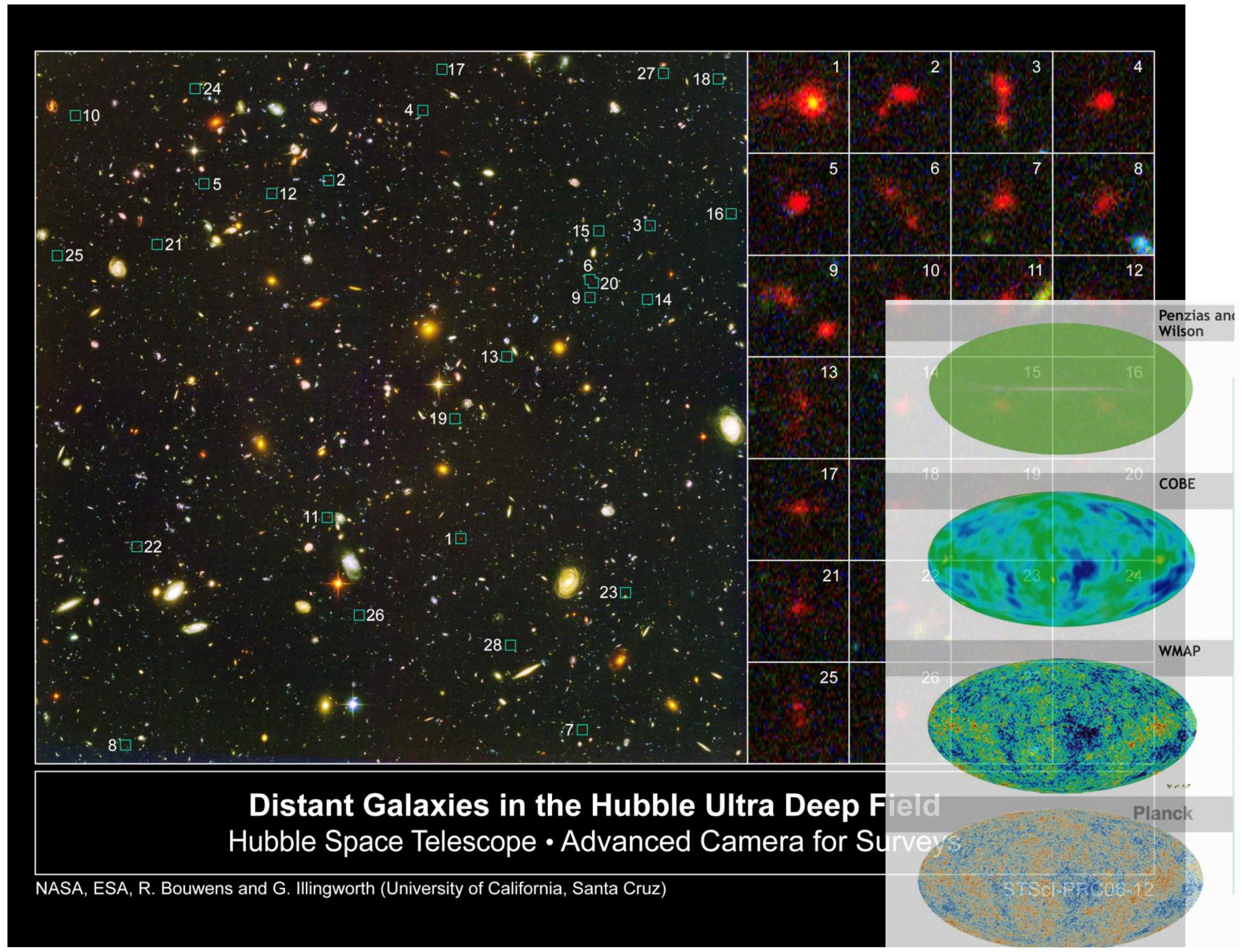
the dark energy: 68% of energy that we do not “understand”

space-time   matter

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

space-time
in expiation



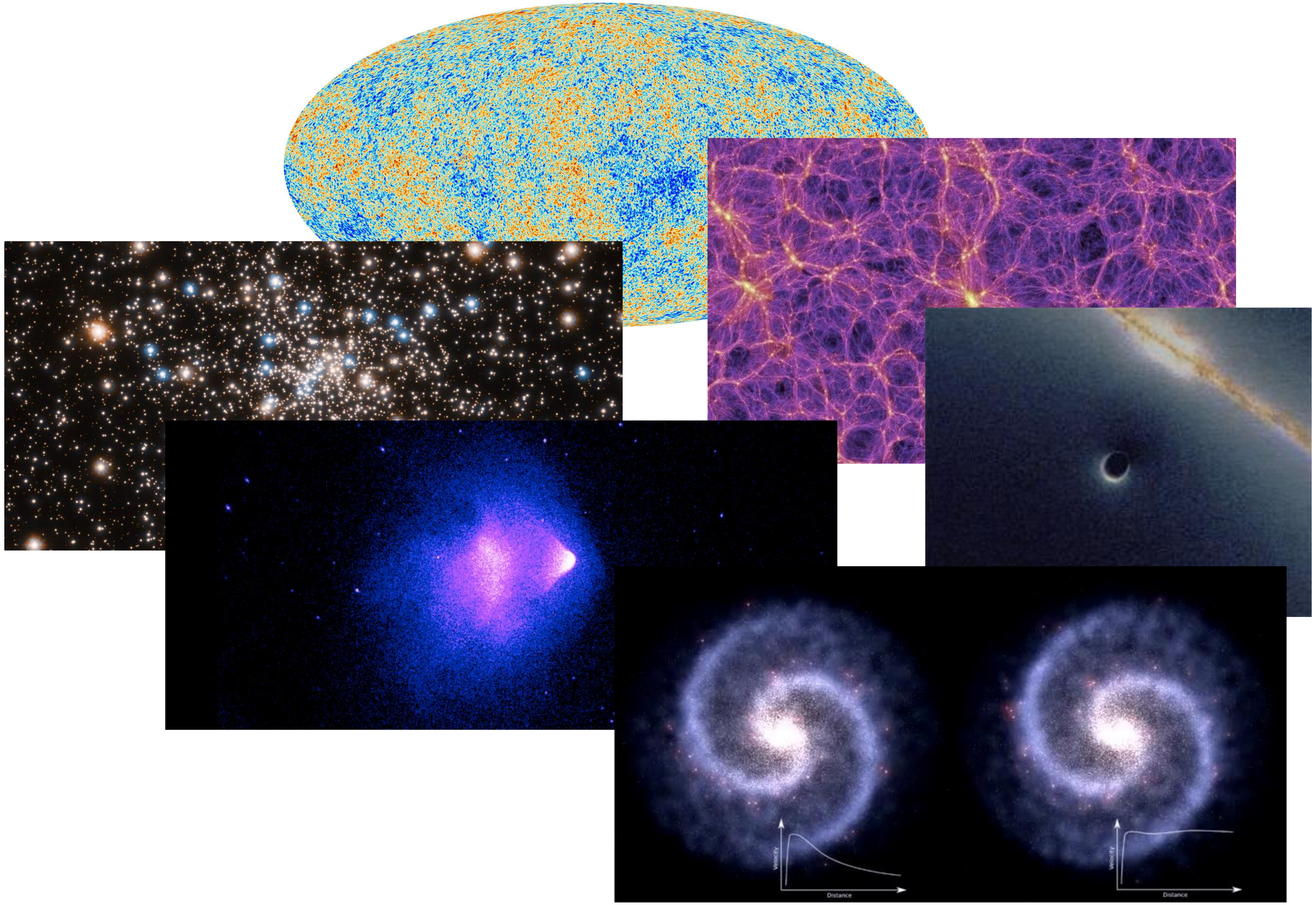


- **vacuum energy** coming from SM, E_{vacum} ~ 10^{120} times the needed one (Λ)
- **quintessence** just the fifth forces …
- **MOND** (Modified Newtonian dynamics), a modified theory of Gravity

dark matter footprint

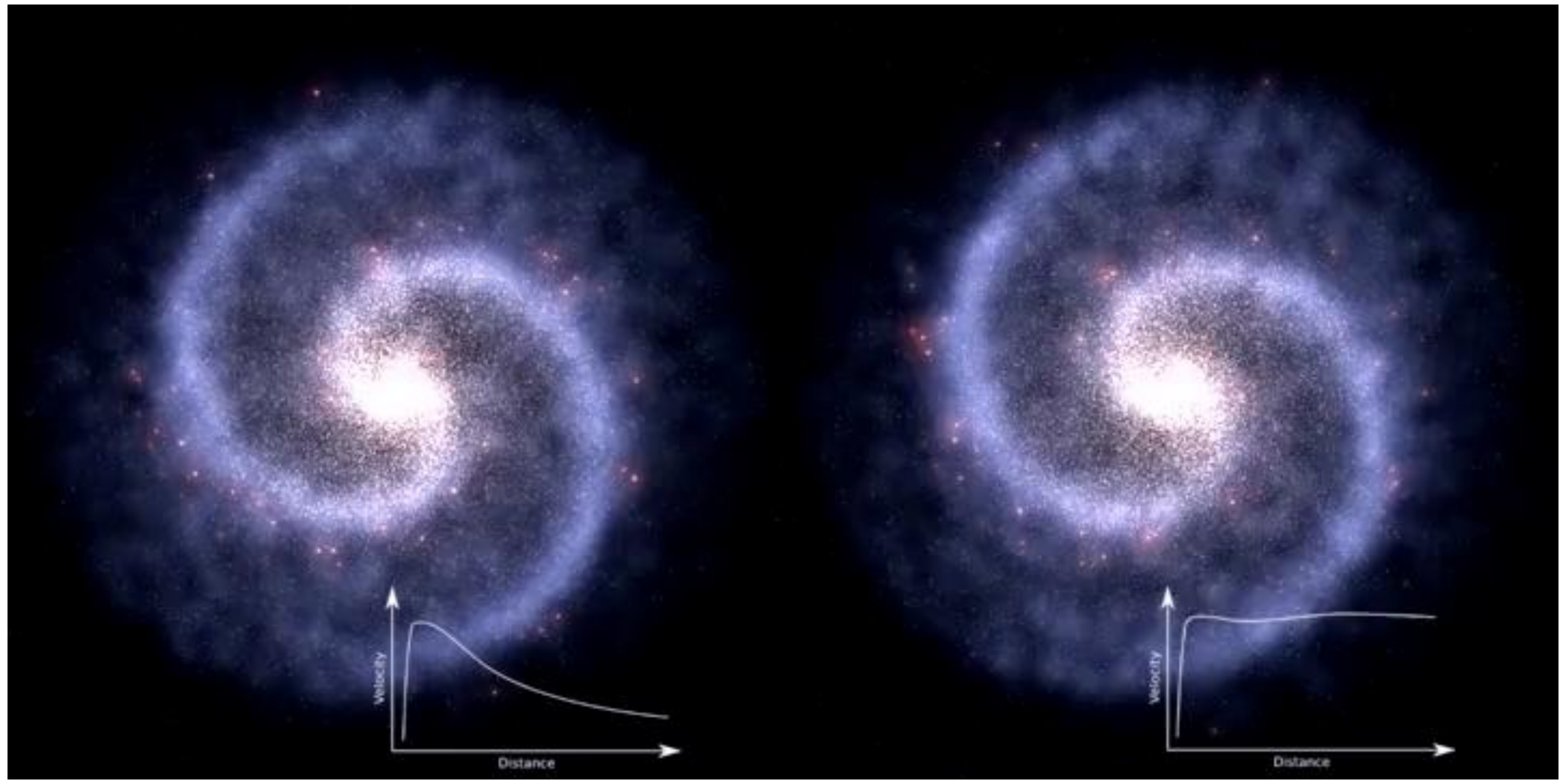
dark matter: the ~85% of the matter in the universe that we can’t “see”

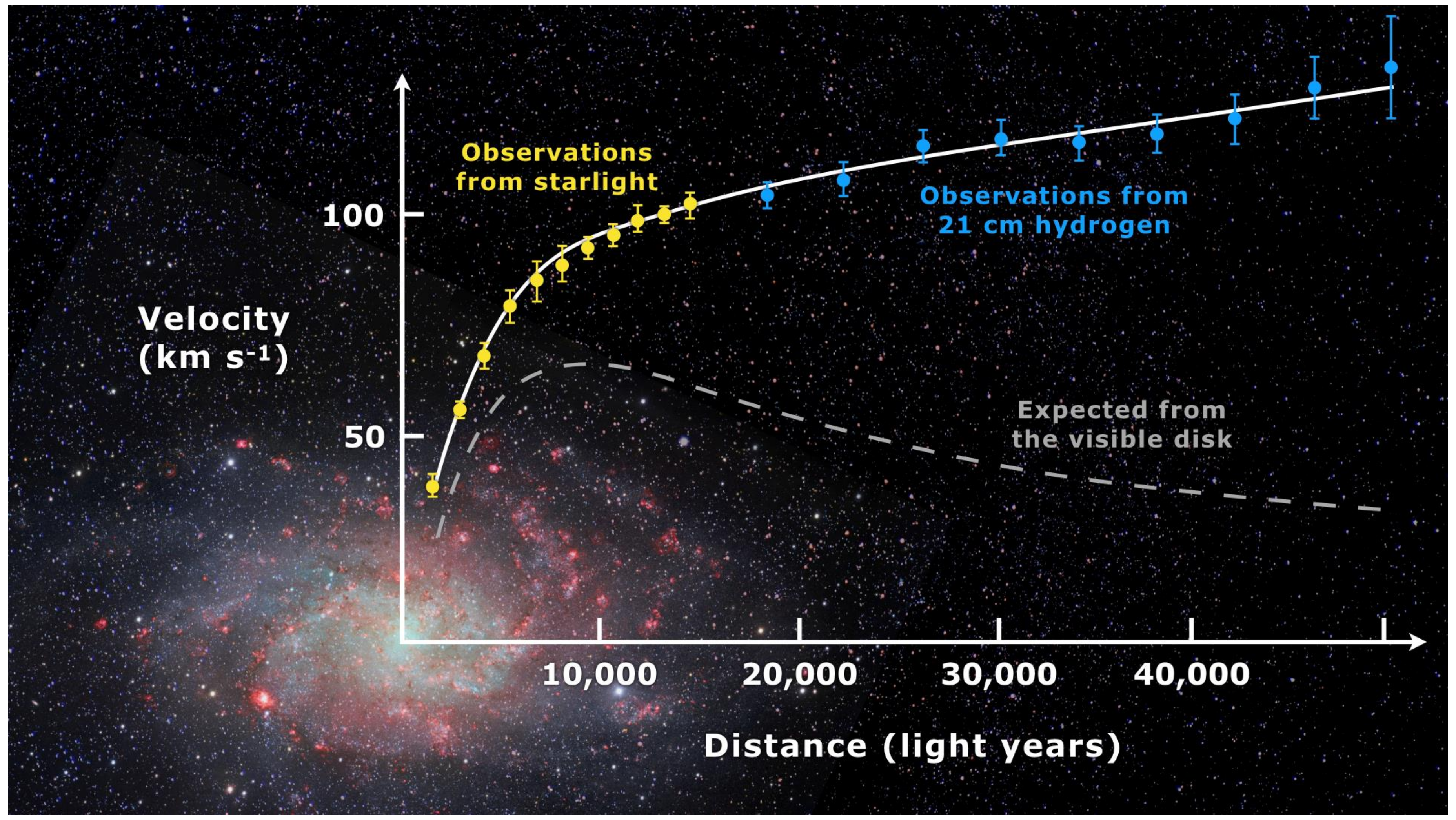
- Galaxy Rotation Curves
- Velocity Dispersions
- Galaxy Clusters
- Gravitational Lensing
- CMB - Cosmic Microwave Background
- Structure Formation
- Bullet Cluster
- Type Ia supernova distance measurements
- Sky surveys and baryon acoustic oscillations
- Redshift-space distortions
- Lyman-alpha forest



galaxy rotation curves

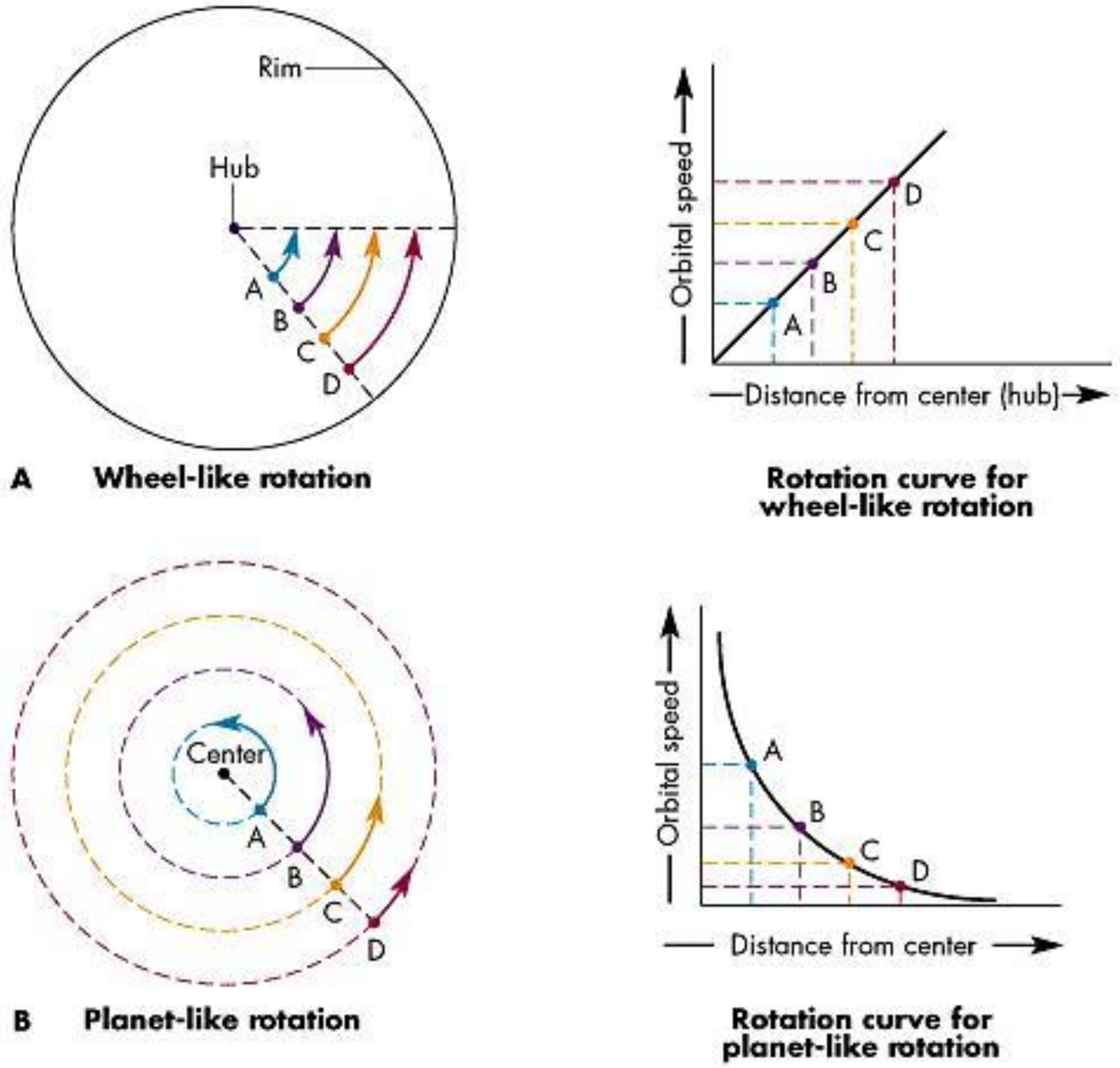
astronomical observables





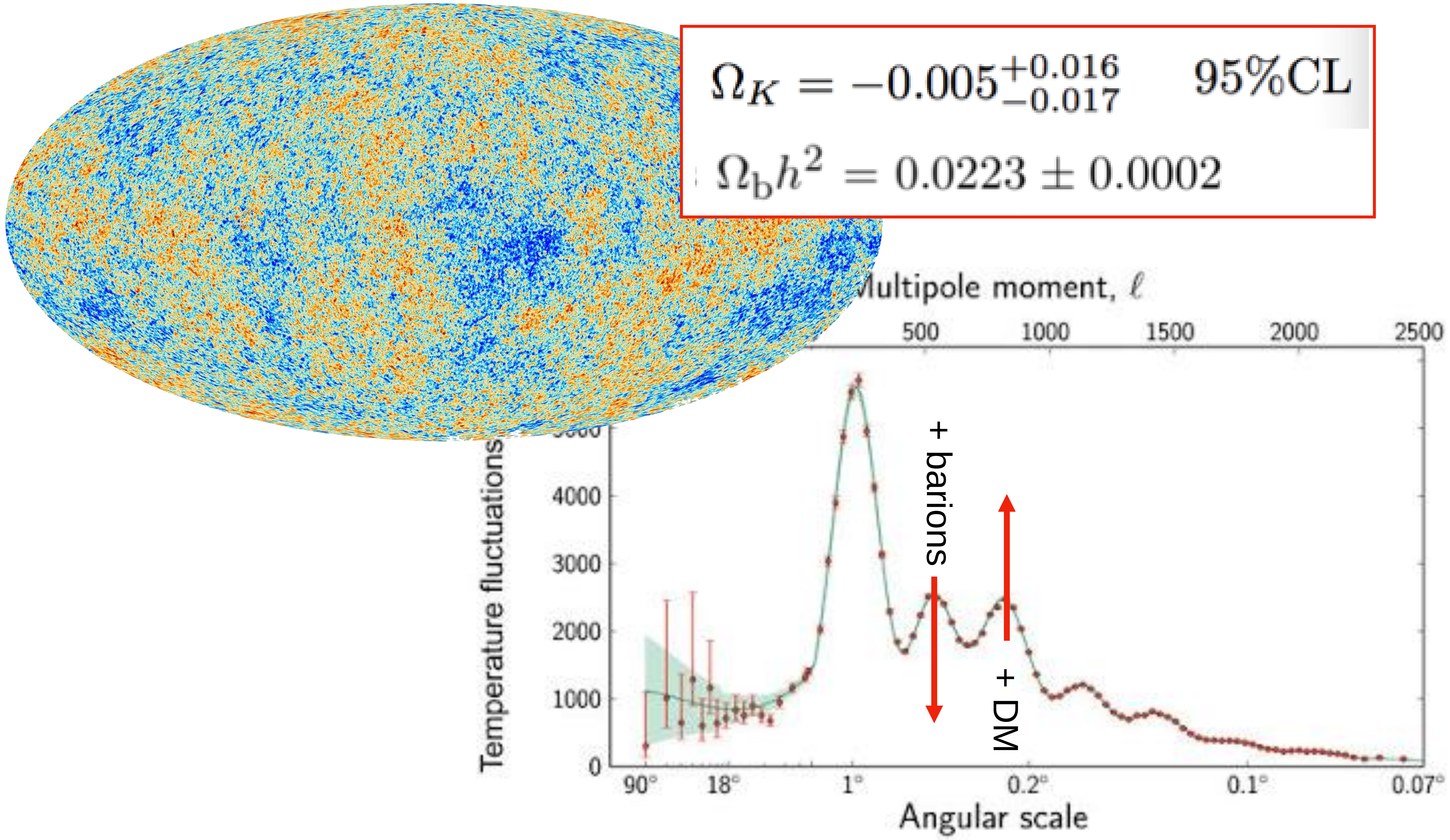
$$v = \sqrt{\frac{GM(r)}{r}}$$

Kepler's 3rd Law applied to Galaxy



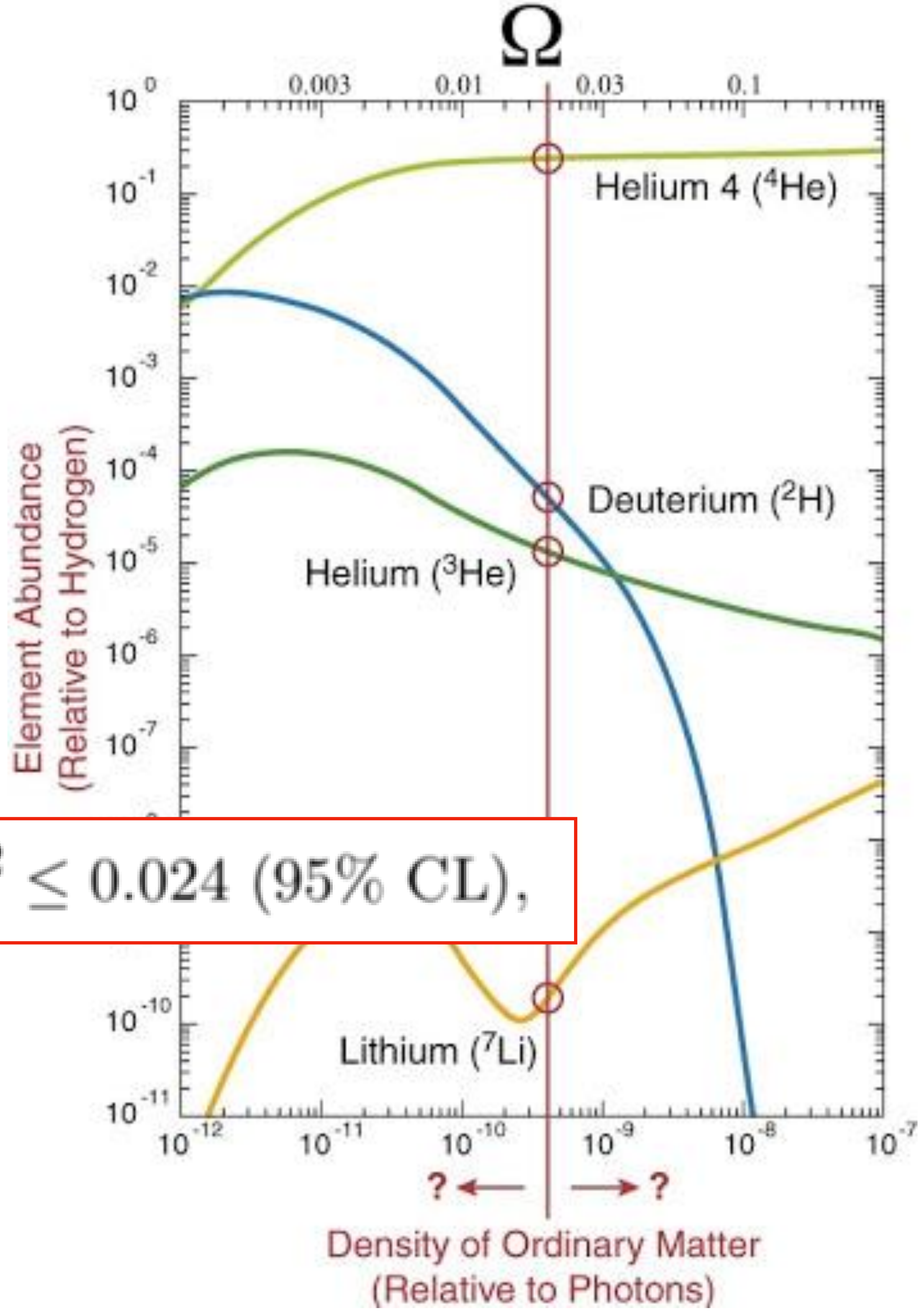
dark matter footprint

cosmological observables (ΛCDM)



$$\Omega_K = -0.005^{+0.016}_{-0.017} \quad 95\%\mathrm{CL}$$

$$\Omega_b h^2 = 0.0223 \pm 0.0002$$



$$0.021 \le \Omega_b h^2 \le 0.024 \ (95\% \ \mathrm{CL}),$$

CMB: The **temperature fluctuations** spectra of CMB depends on the interaction between gravity (to which both DM and baryonic matter contribute) and the pressure generated by the only baryonic matter

Big Bang Nucleosynthesis: The amount of **lightest chemical elements depends critically** on the conditions of the early universe, and in particular on the balance between **baryonic and non-baryonic matter**

it’s “just gravity”

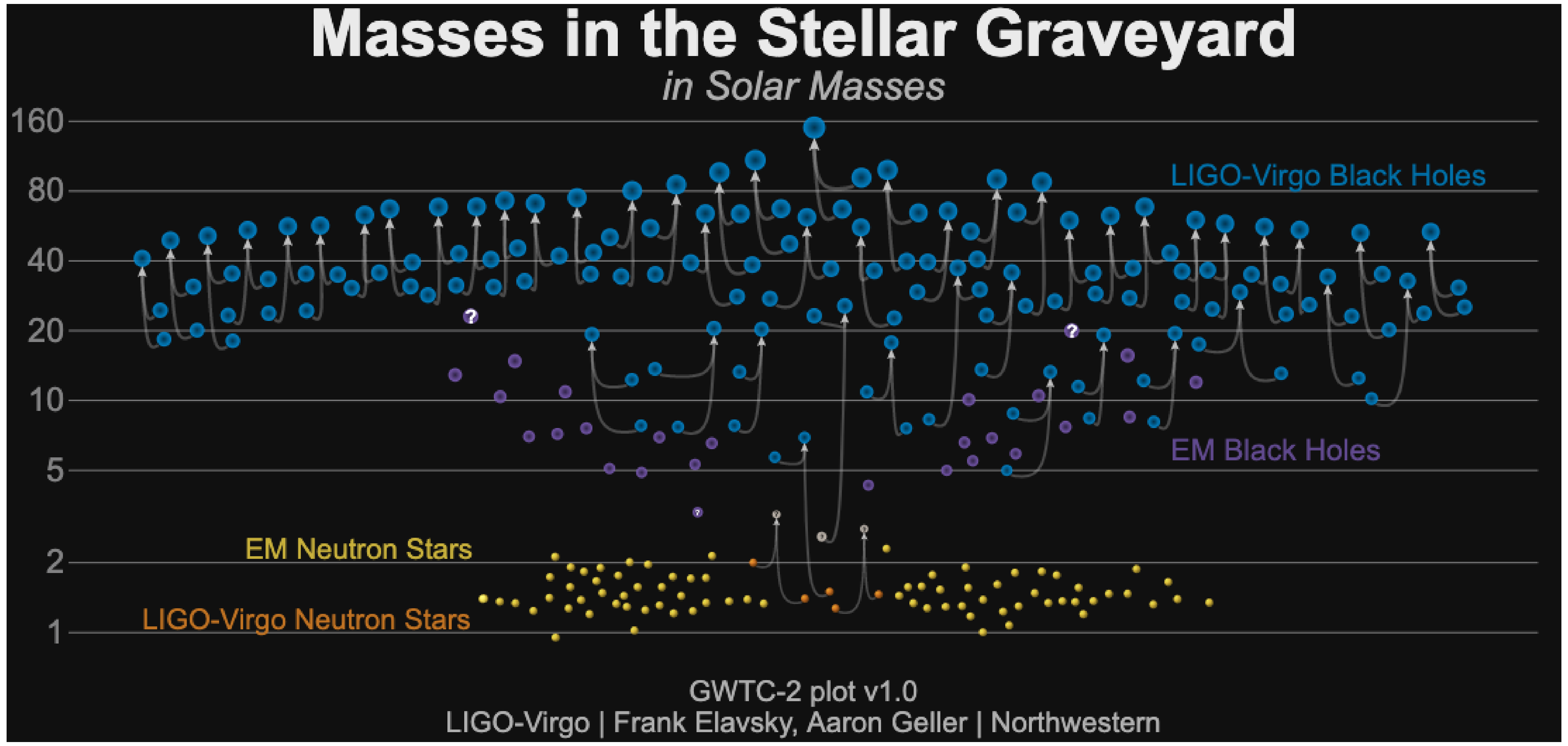
made of baryons

- **gas, dust, cold molecules, charged particle** in the galaxy halo —> any (radio emission) search failed.
- **astronomical candidates**:
  - planets and brown dwarfs (0.01-0.08 Mo)
  - fossils of white and black dwarf and neutron stars that brings to dark dwarf
  - MACHO
  - Primordial Black Holes (PBH)

up to now gravitational effect or cooling/accretion time is too long/short to ensure the proper abundance need.

it’s “just gravity”

the PBH an example…



The merger rate of primordial-black-hole binaries

Yacine Ali-Haïmoud,[1] Ely D. Kovetz,[2] and Marc Kamionkowski[2]

[1] *Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003, USA*

[2] *Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA*

(Dated: January 10, 2018)

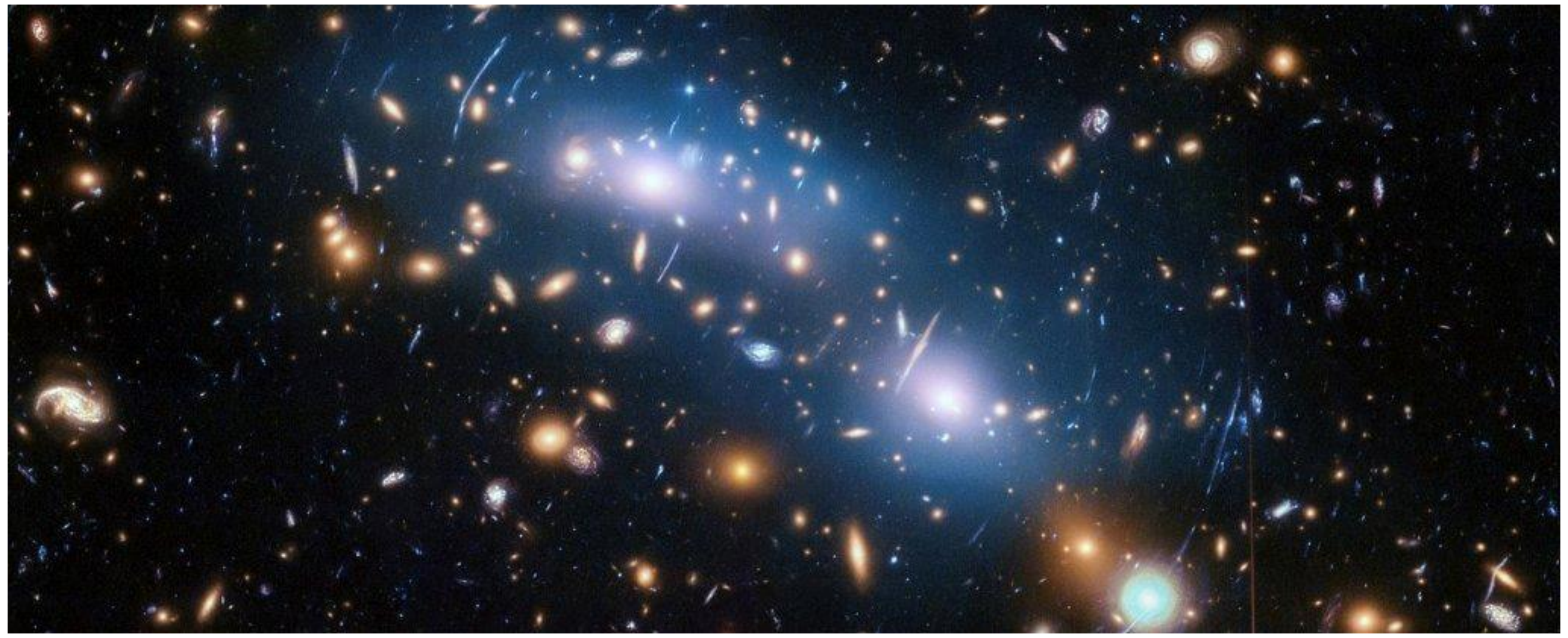
Primordial black holes (PBHs) have long been a candidate for the elusive dark matter (DM), and remain poorly constrained in the $\sim 20 - 100\ M_\odot$ mass range. PBH binaries were recently suggested as the possible source of LIGO’s first detections. In this paper, we thoroughly revisit existing estimates of the merger rate of PBH binaries. We compute the probability distribution of orbital parameters for PBH binaries formed in the early Universe, accounting for tidal torquing by all other PBHs, as well as standard large-scale adiabatic perturbations. We then check whether the orbital parameters of PBH binaries formed in the early Universe can be significantly affected between formation and merger. Our analytic estimates indicate that the tidal field of halos and interactions with other PBHs, as well as dynamical friction by unbound standard DM particles, do not do significant work on nor torque PBH binaries. We estimate the torque due to baryon accretion to be much weaker than previous calculations, albeit possibly large enough to significantly affect the eccentricity of typical PBH binaries. We also revisit the PBH-binary merger rate resulting from gravitational capture in present-day halos, accounting for Poisson fluctuations. If binaries formed in the early Universe survive to the present time, as suggested by our analytic estimates, they dominate the total PBH merger rate. Moreover, this merger rate would be orders of magnitude larger than LIGO’s current upper limits if PBHs make a significant fraction of the dark matter. As a consequence, LIGO would constrain $\sim 10 - 300\ M_\odot$ PBHs to constitute no more than $\sim 1\%$ of the dark matter. To make this conclusion fully robust, though, numerical study of several complex astrophysical processes – such as the formation of the first PBH halos and how they may affect PBH binaries, as well as the accretion of gas onto an extremely eccentric binary – is needed.

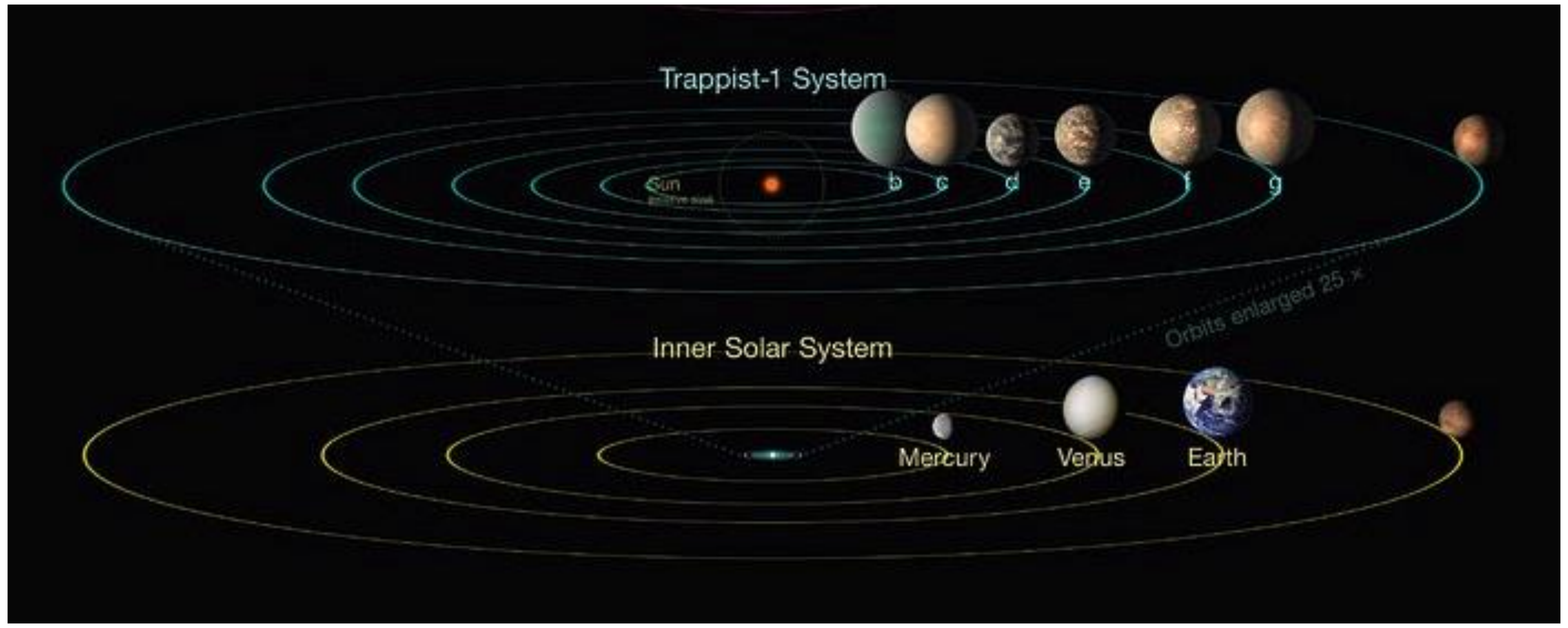
Until the discovery of gravitational waves by LIGO-Virgo collaboration, the **Black Holes (BH)** were identified only via **X Ray telescope (EM)**, and their mass was limited at about **20 solar masses**. LIGO-Virgo observed BHs match more **bigger and smaller** and if Primordial Black Holes (PBH) exist it could have these mass… Moreover, the merger rate would be **order of magnitude larger then LIGO-Virgo observed rate to justify dark matter**.

it’s another gravity

MOND…

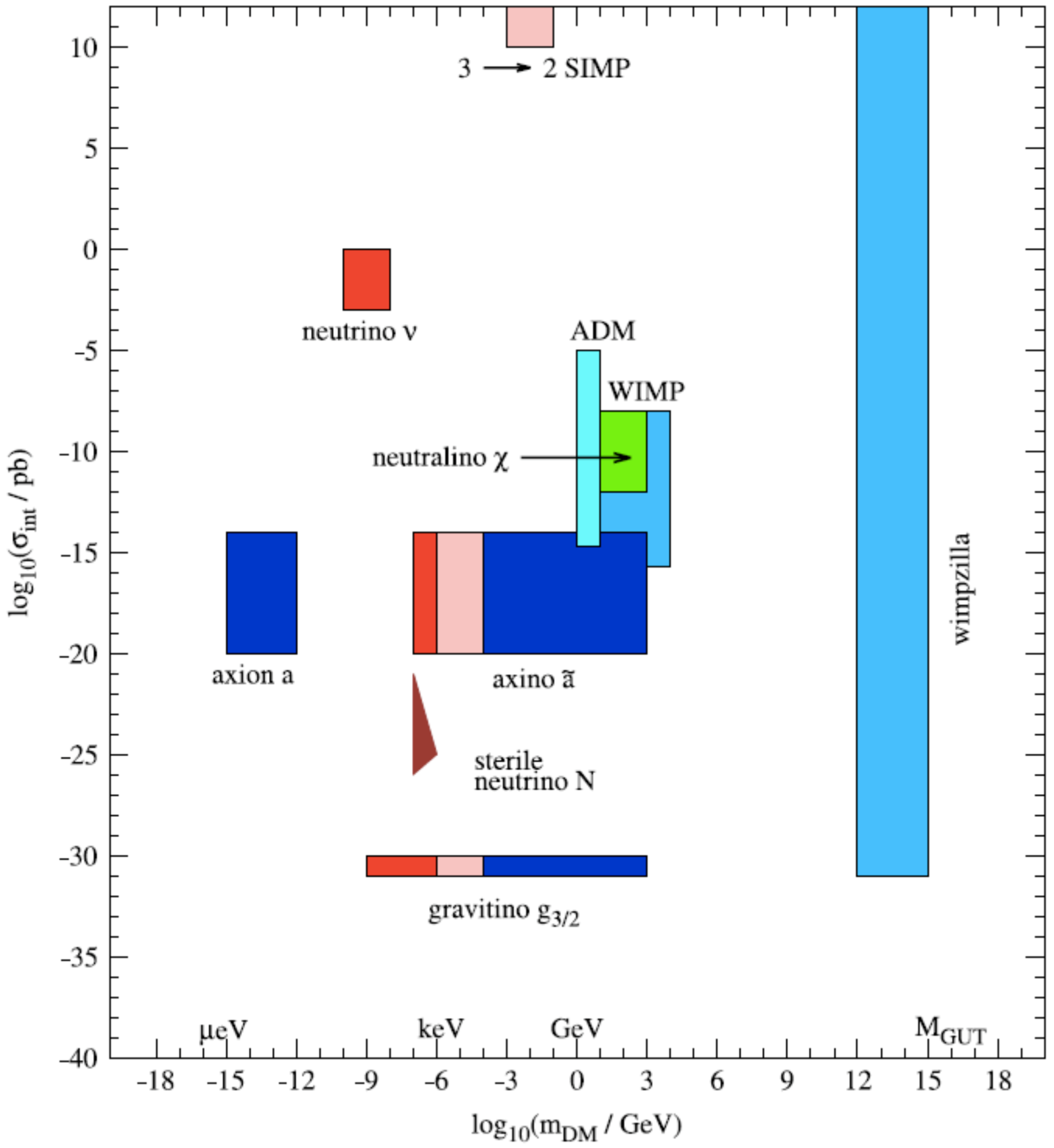
- General Relativity works fine but:
  - Quantum Field Theory calculations lead to higher-derivative corrections!
  - Quantum Field Theory in curved spacetime changes gravity at the early-epoch!
  - Why General Relativity and not any other theory?
  - **Solar System tests maybe passed by number of modified gravity**

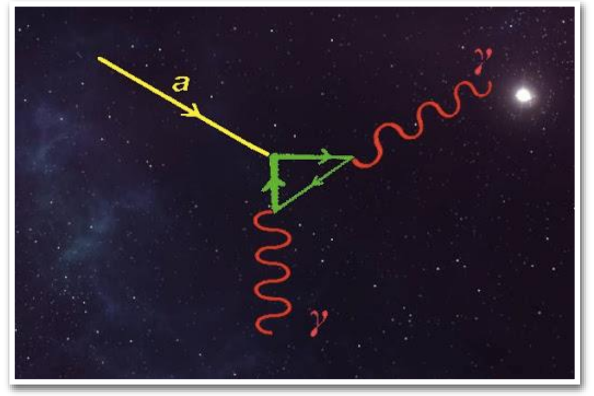


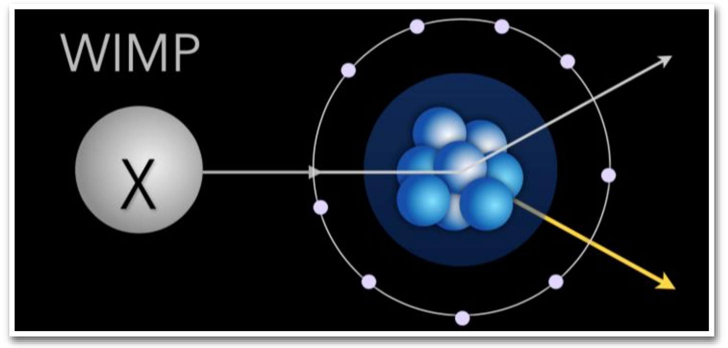


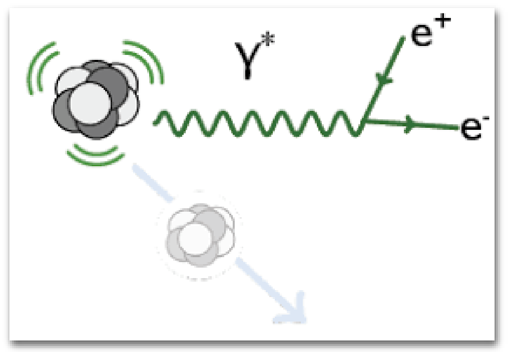
it's another particle…

- it must have **mass** to interact with gravity
- it must be **stable** to explain today abundance (T>>10^{17} sec) and possibly relic from the early universe
- it must be **neutral** with no **electromagnetic** interaction
- it must be **cold**, not too warm (like neutrino) to not escape from mass cluster (p/m<<1 at CMB formation)
    - —>
- it could be **axions**, particles with mass of 10^{-3}-10^{-5} eV, no charge, no spin, needed to solve the not observed CP violation in strong interaction.
- it could be **WIMPs**, particles with mass of 10^{9}-10^{12} eV, weakly interacting, motivated by SUSY and "**freeze out** miracle" that predict the relic abundance starting form the weak force cross section properties.
- it could be **gravitino**, **sterile neutrino** (~keV), **dark photons** (~ GeV)
- it could be **WIMPzillas** with mass of 10^{-21}-10^{-28} eV produced at the beginning of the universe due to the large energy available at that epoch









Dark Matter properties and detection

the WIMPs production and detection

Early Universe "freeze out" miracle

1) In the hot, early Universe DM WIMP is in thermal equilibrium with SM particles

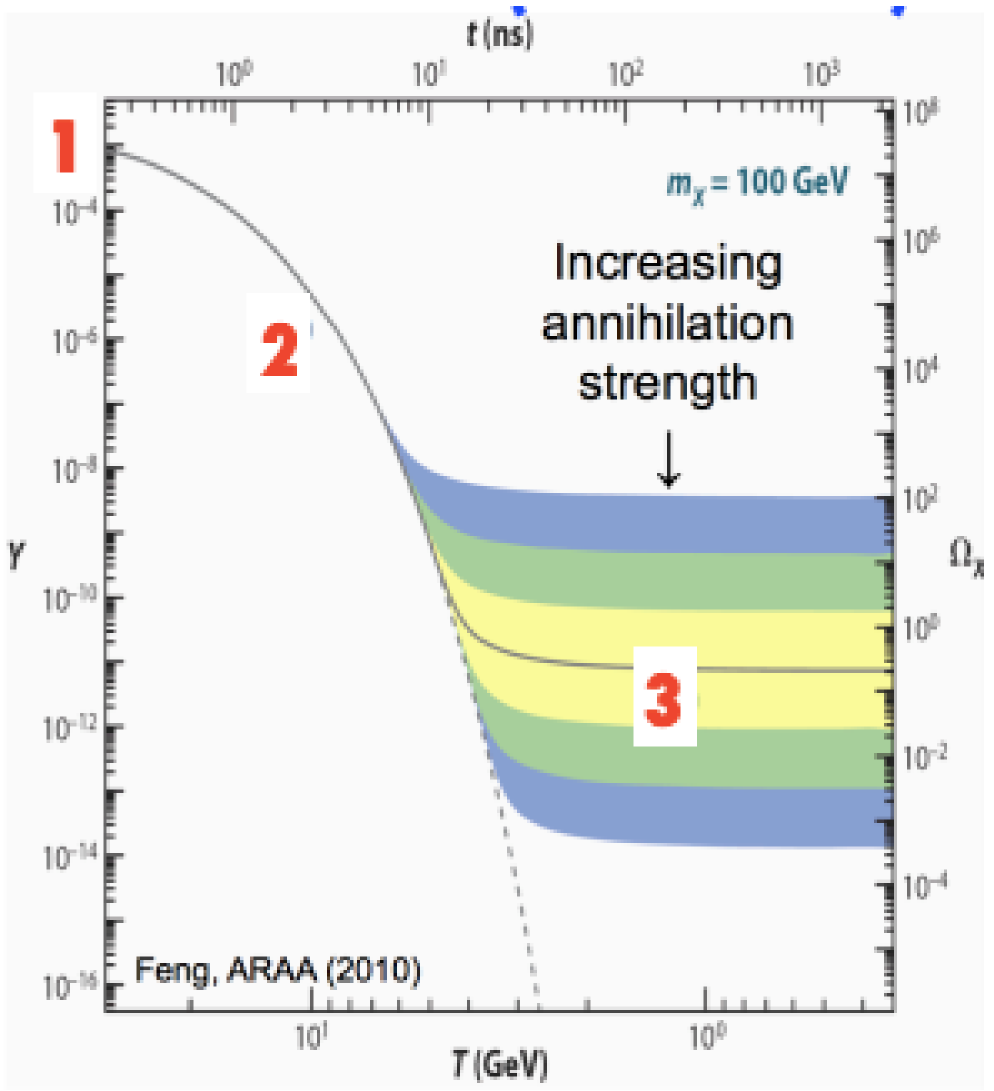
$$XX \leftrightarrow \bar{q}q$$

2) When the Universe starts to cool down, DM decouples from SM particles

$$XX \rightleftarrows \bar{q}q$$

3) When the Universe starts to expand, DM today relic density is determined

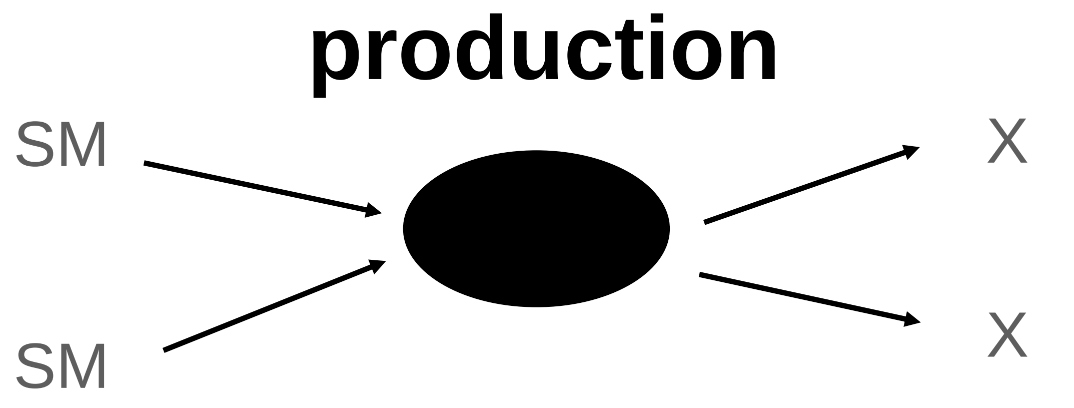
$$XX \not\rightleftarrows \bar{q}q$$

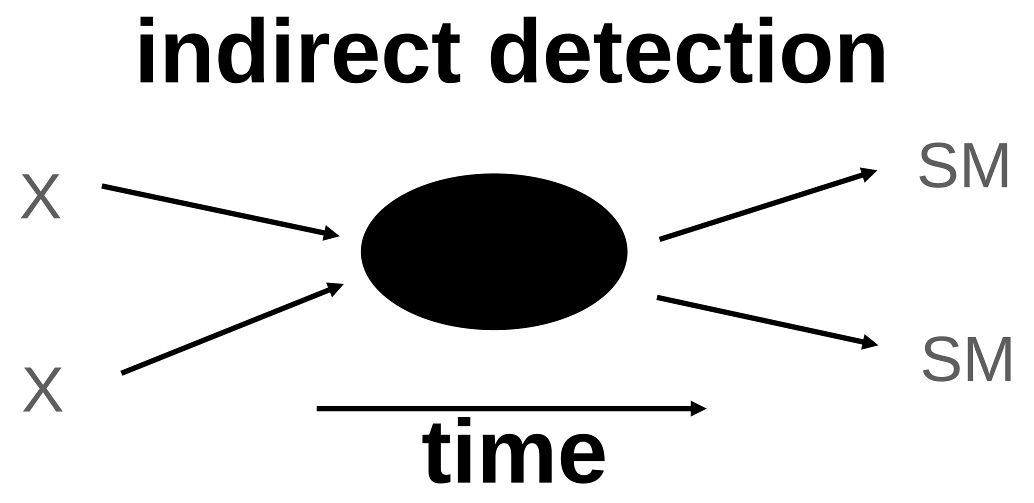


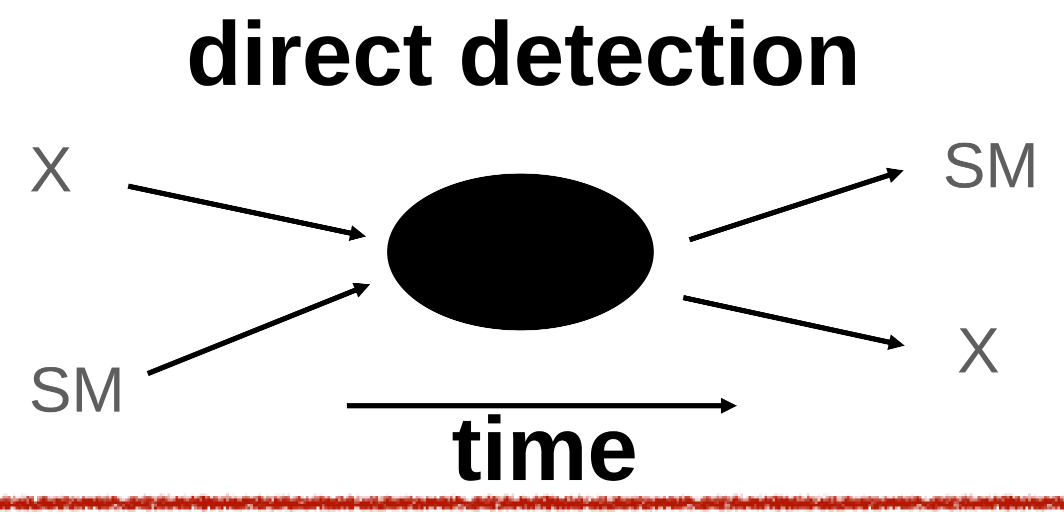
In order to reproduce the measured DM relic density, WIMP cross section and mass must be of the order of the weak scale

WIMP miracle

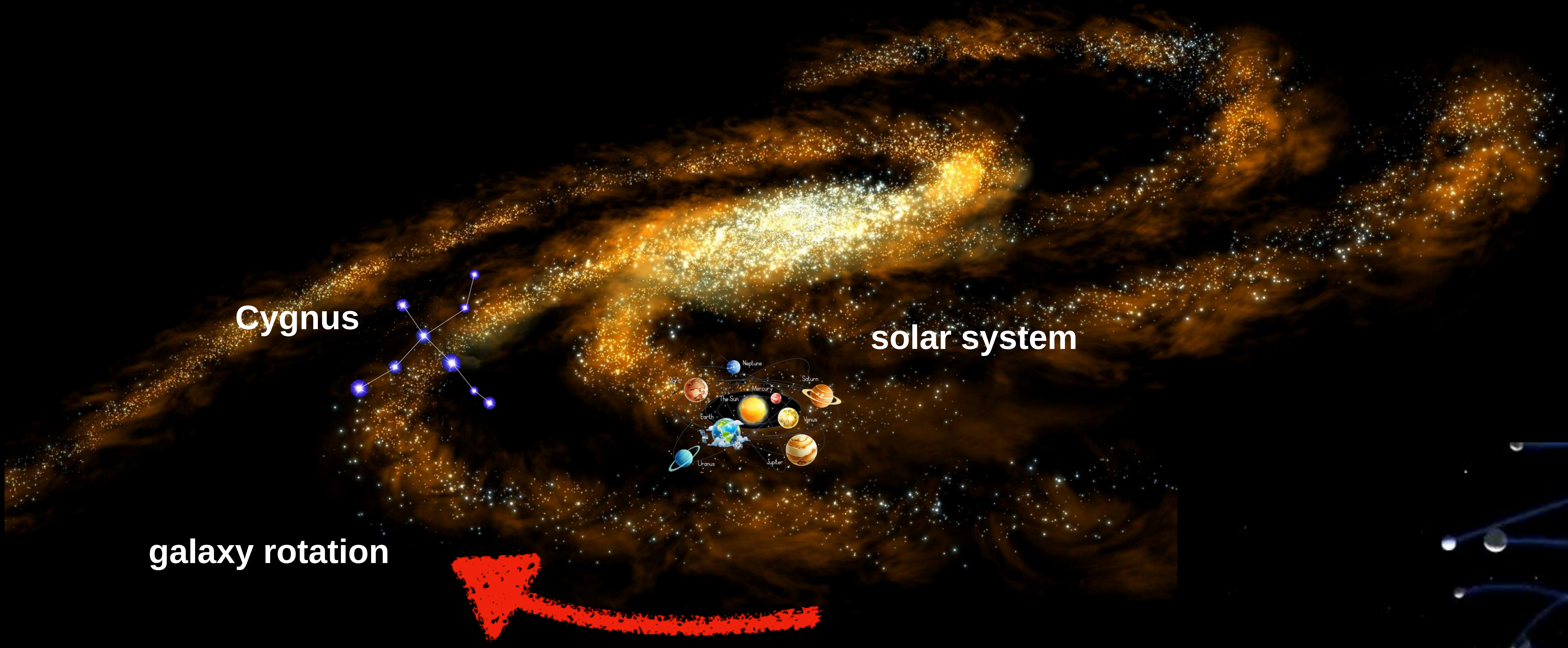
$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$







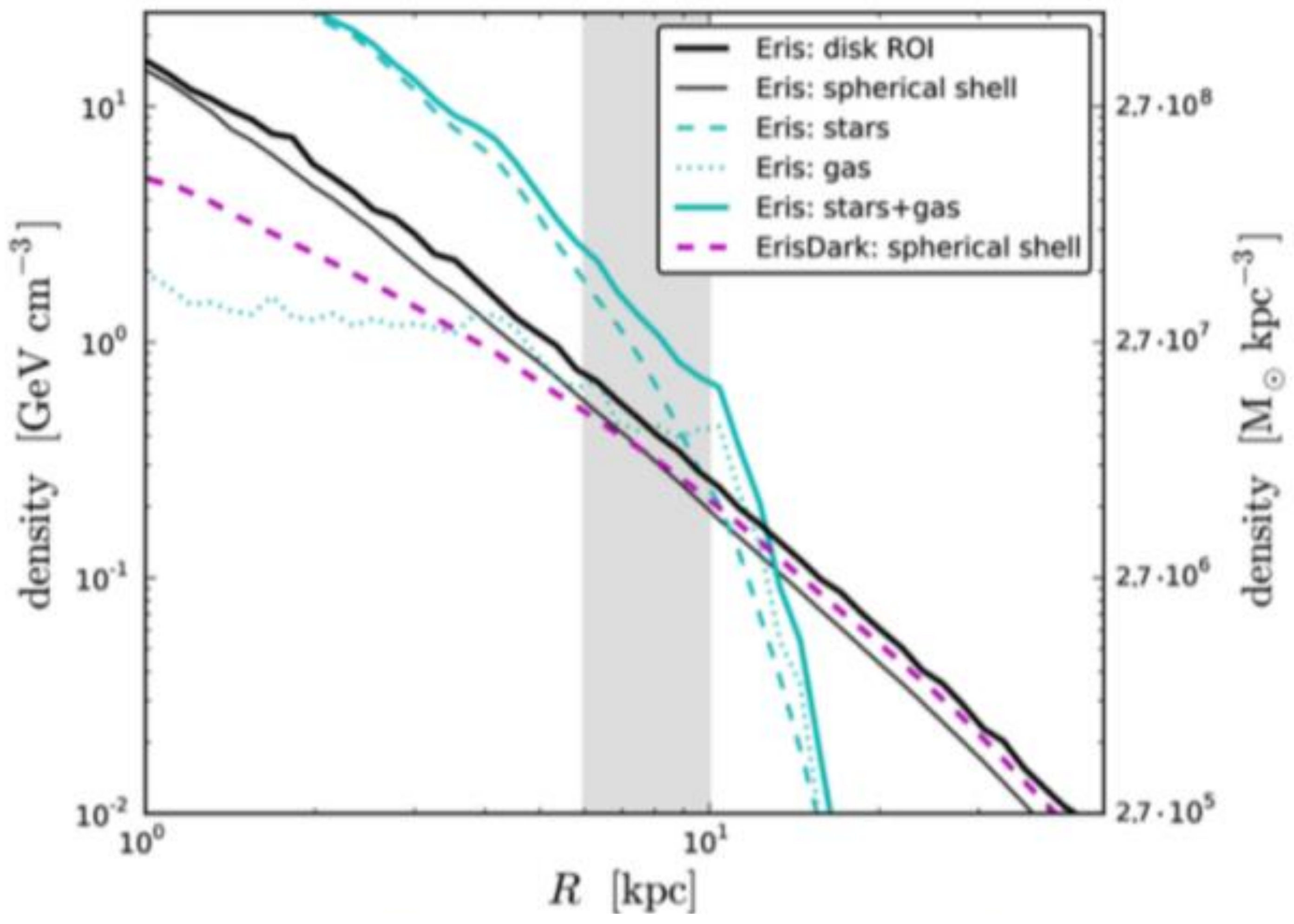
the dark matter when living on the earth

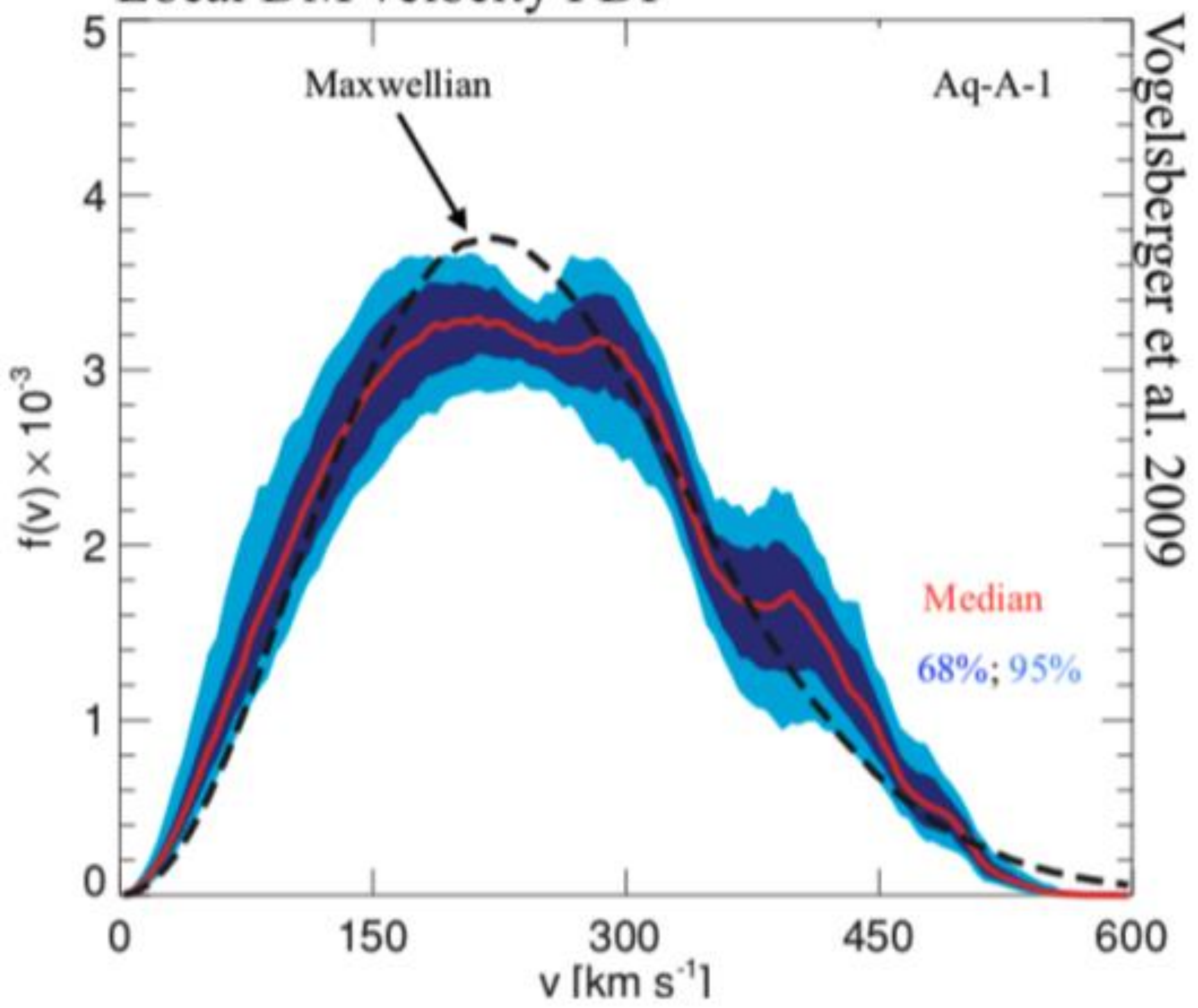


the WIMPs direct search properties

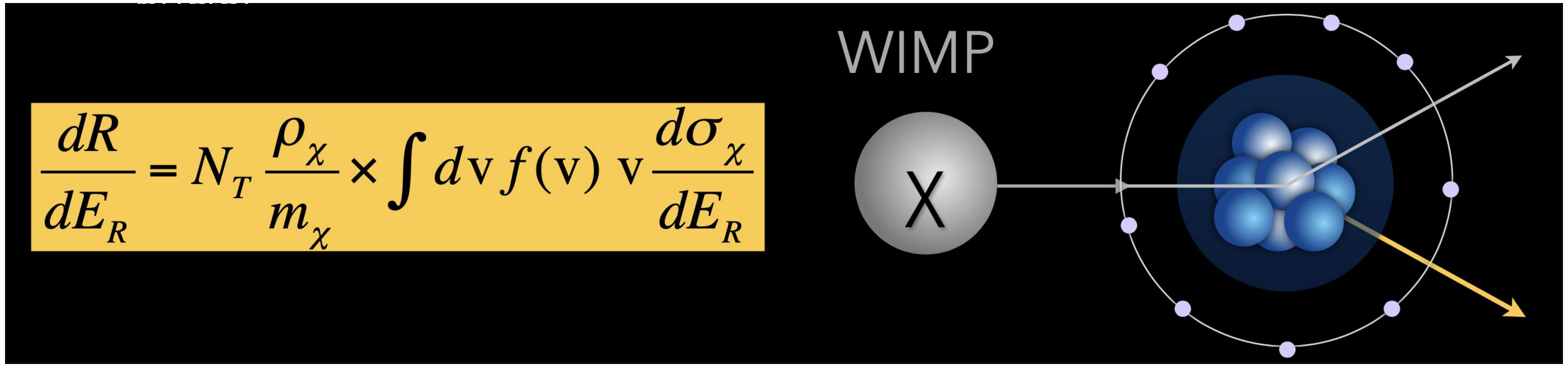
and constraint…

https://arxiv.org/pdf/1404.1938.pdf





χN →χN elastic scattering off nuclei E ≈ 1÷100 keV

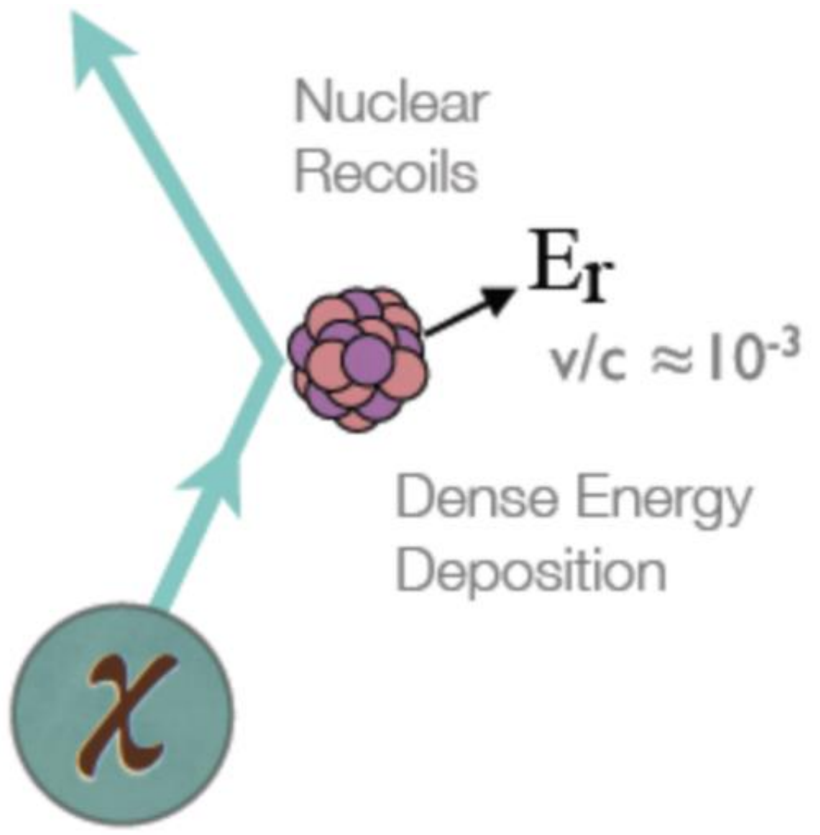


$$\frac{dR}{dE_R} = N_T \frac{\rho_\chi}{m_\chi} \times \int d\mathrm{v}\, f(\mathrm{v})\, \mathrm{v} \frac{d\sigma_\chi}{dE_R}$$

v~ 220 km/s, ρ_x ~ 0.3 GeV cm^{-3} DM density in the Milky Way,
σ cross section (SD and SI), m_x ~ 1-100 GeV DM mass

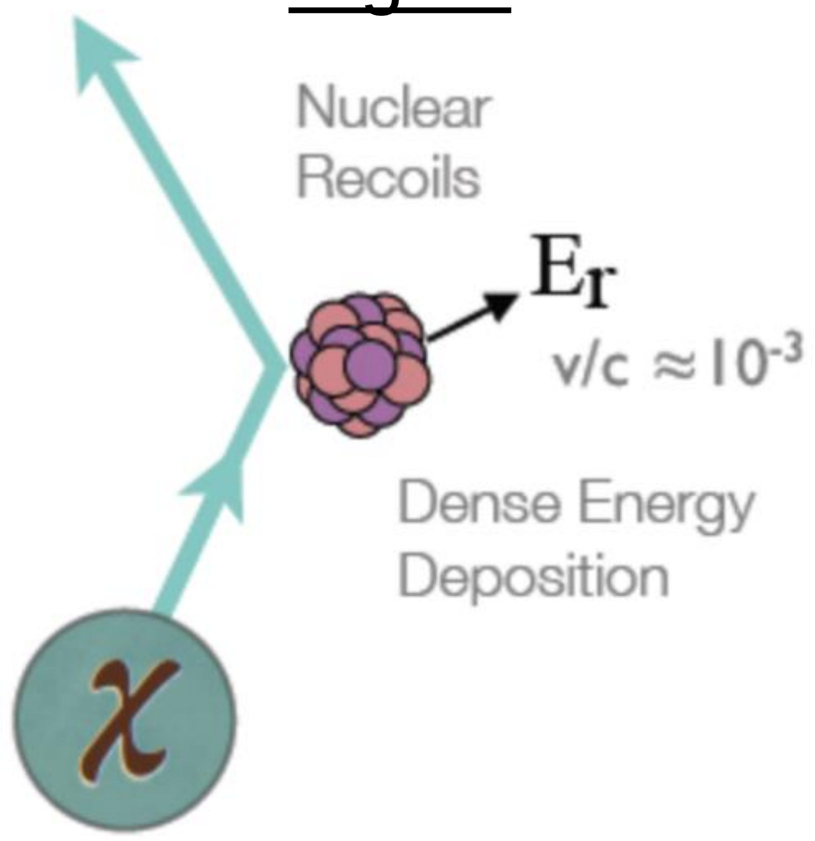
detector requirements:

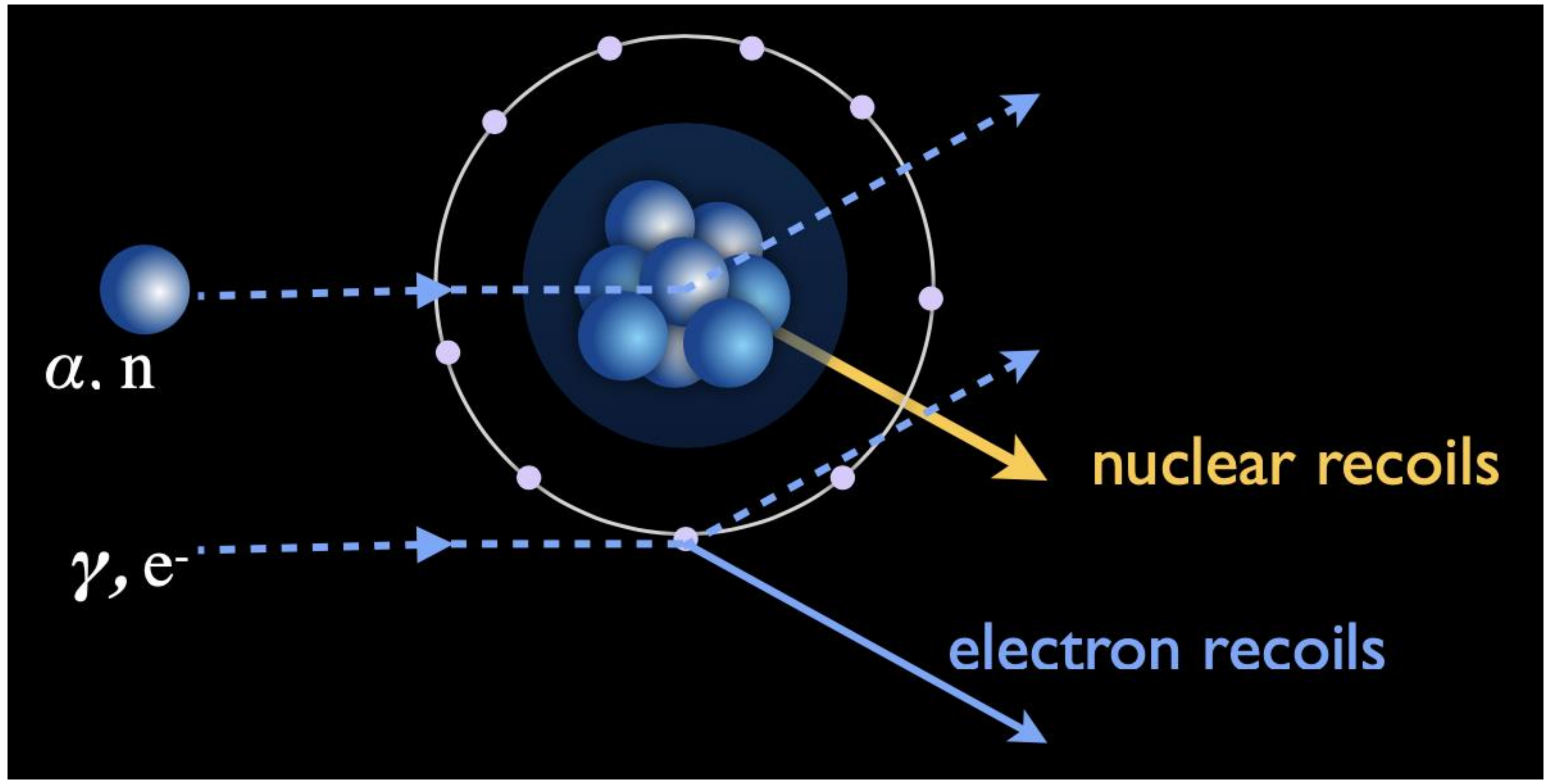
- large mass;
- long exposure;
- low energy threshold



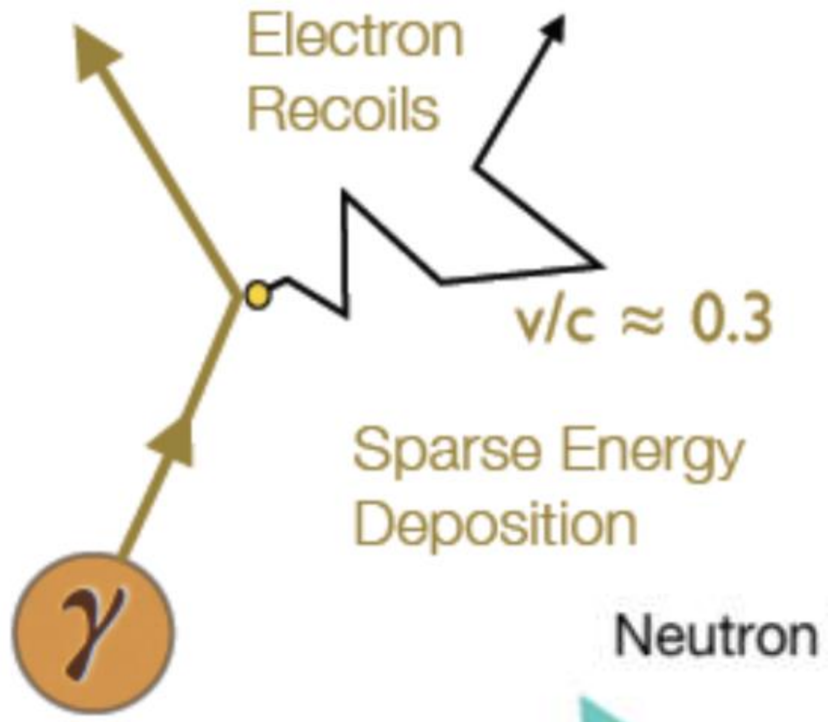
background

Signal

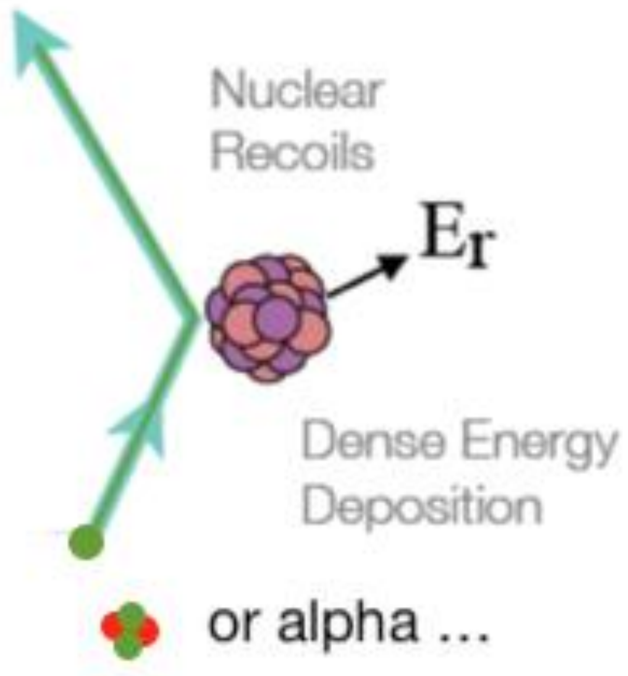


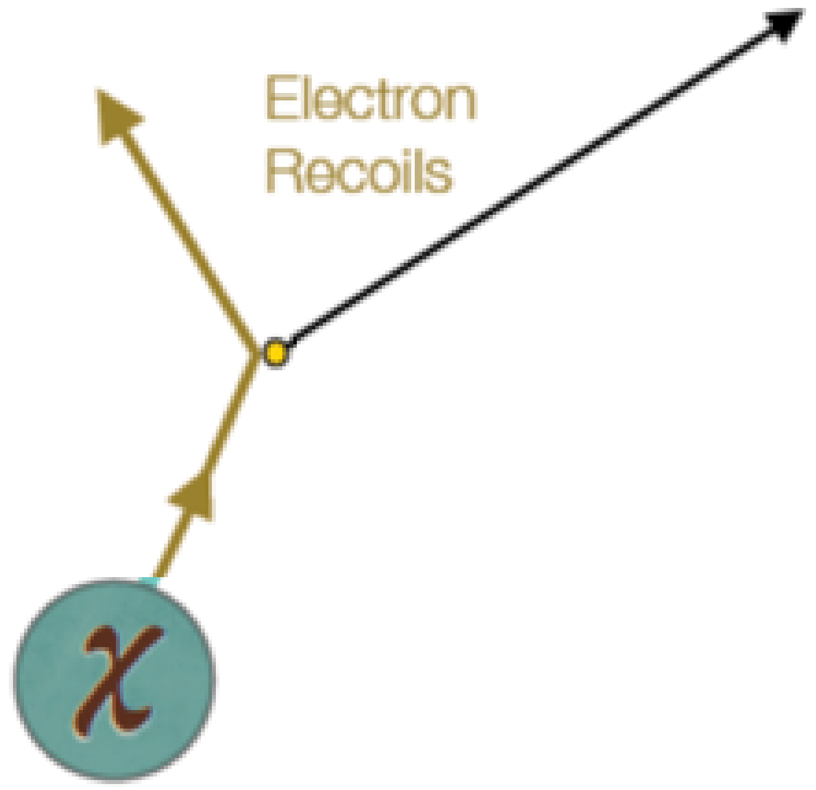


Background

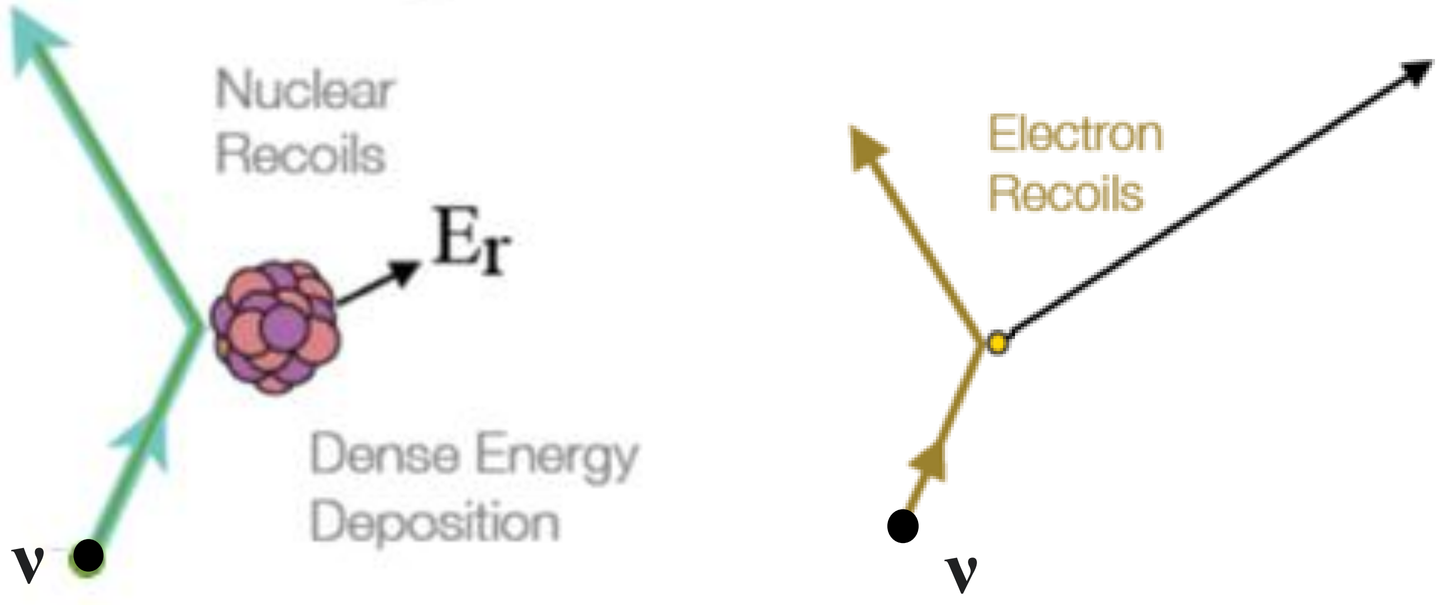


Neutron background

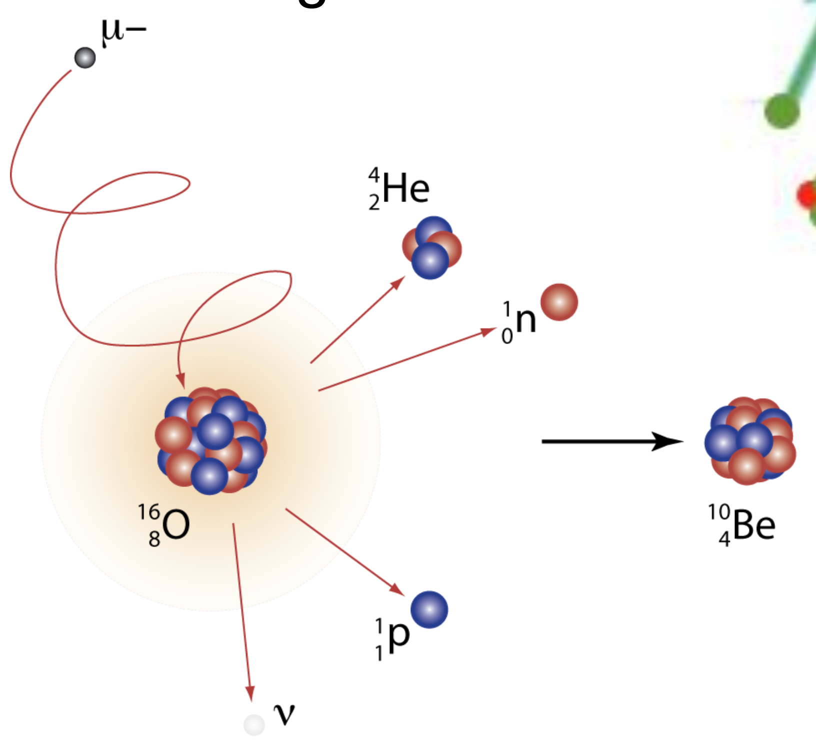




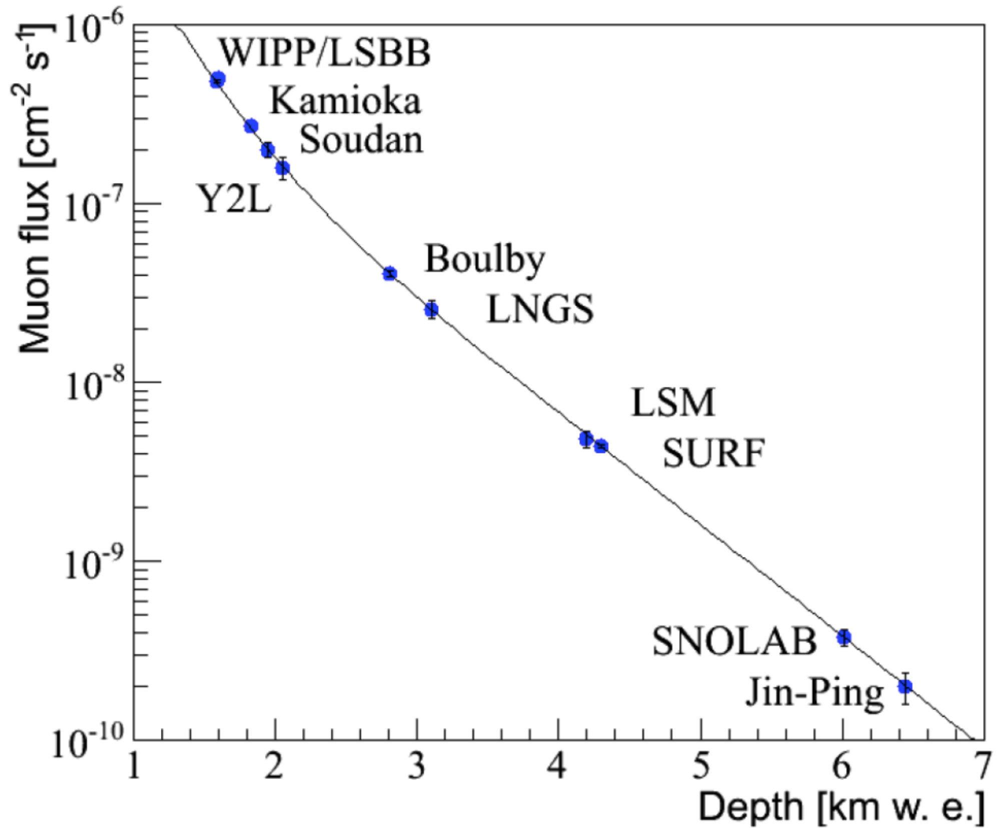
Signal <—> Background

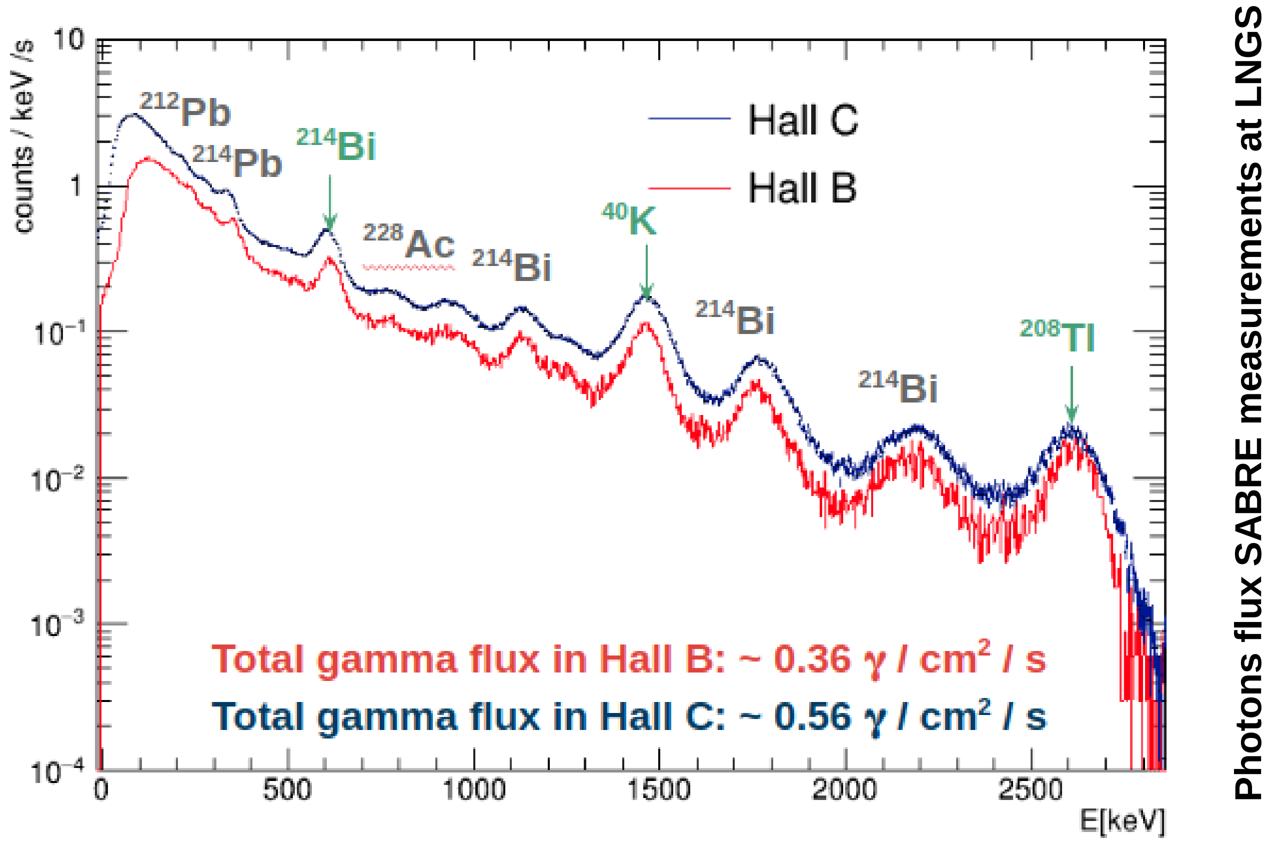


muons background

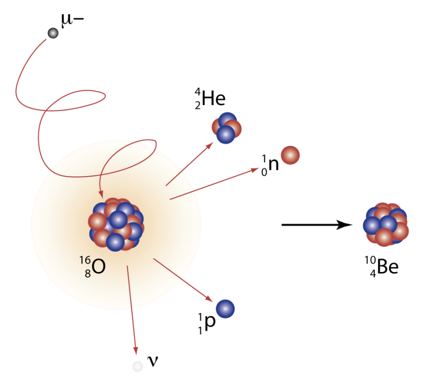


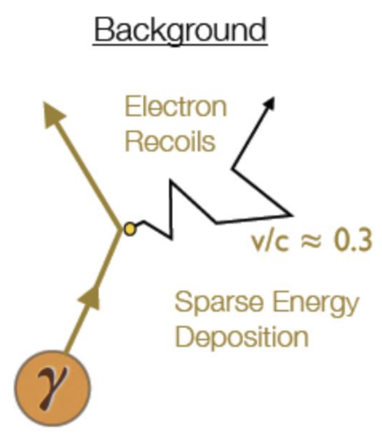
external background

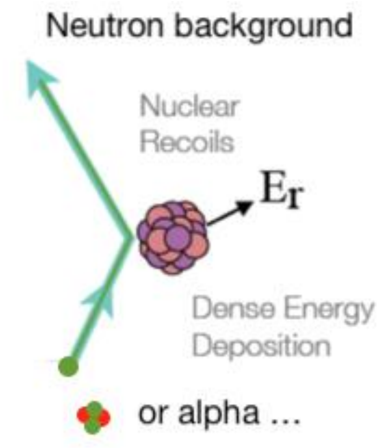




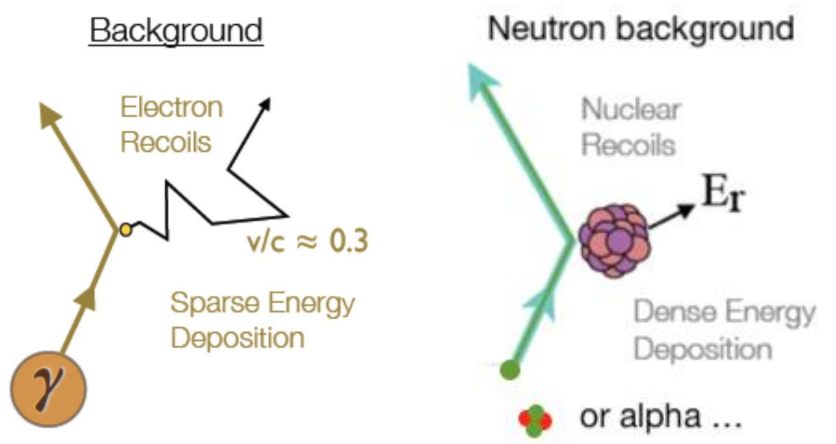
- **muons** (cosmic)
  - underground lab
- **gamma** (natural radioactivity)
  - *passive shielding*
  - material selection
  - detector discrimination
- **neutrons** (natural radioactivity and [...]ic induced)
  - underground lab
  - *passive and active shielding*
  - materiale selection low U, Th contamination
- **neutrinos**
  - **ultimate dealbreaker** (coherent nucleus scattering and elastic electron scattering) **neutrino fog**



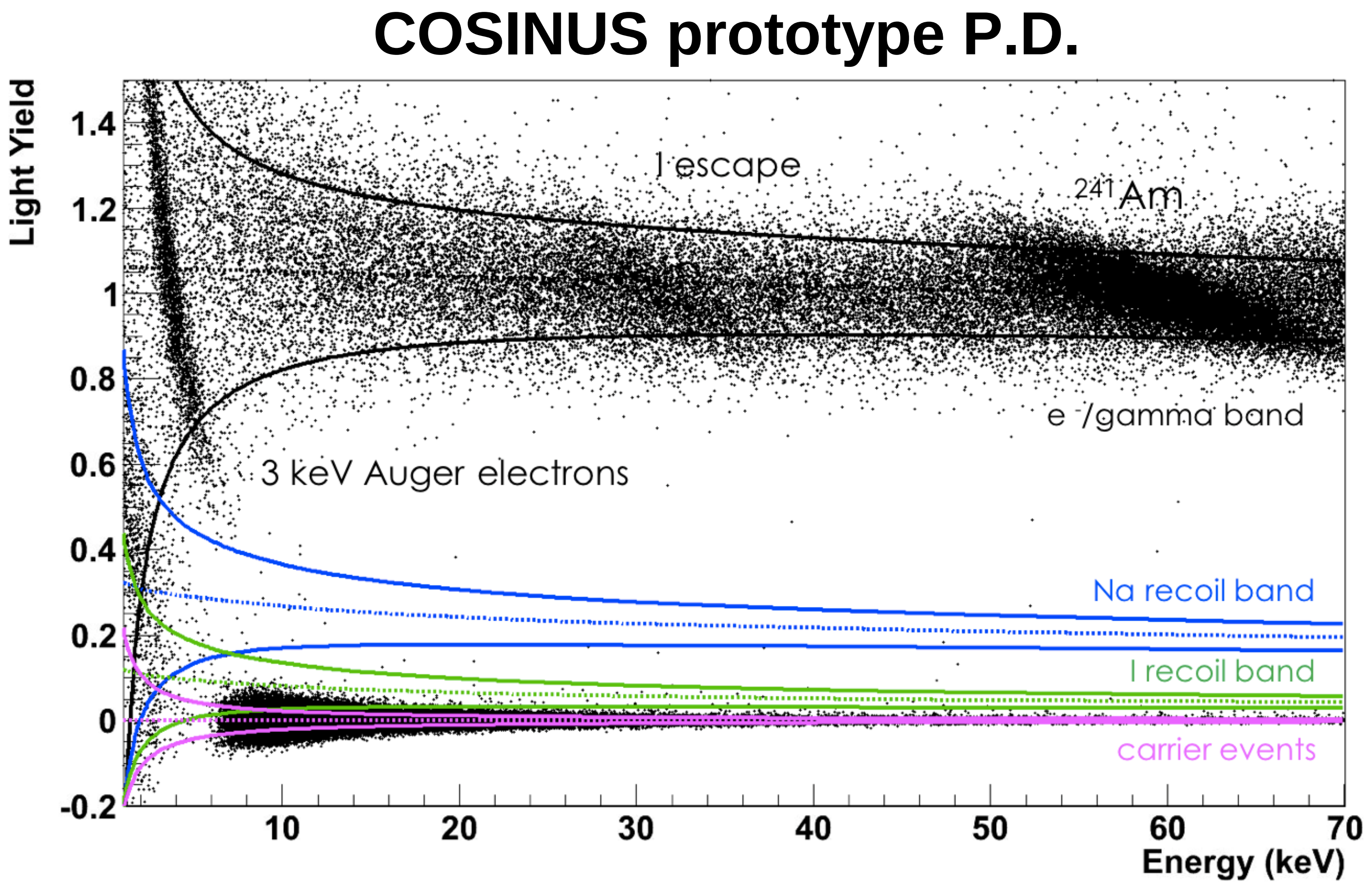


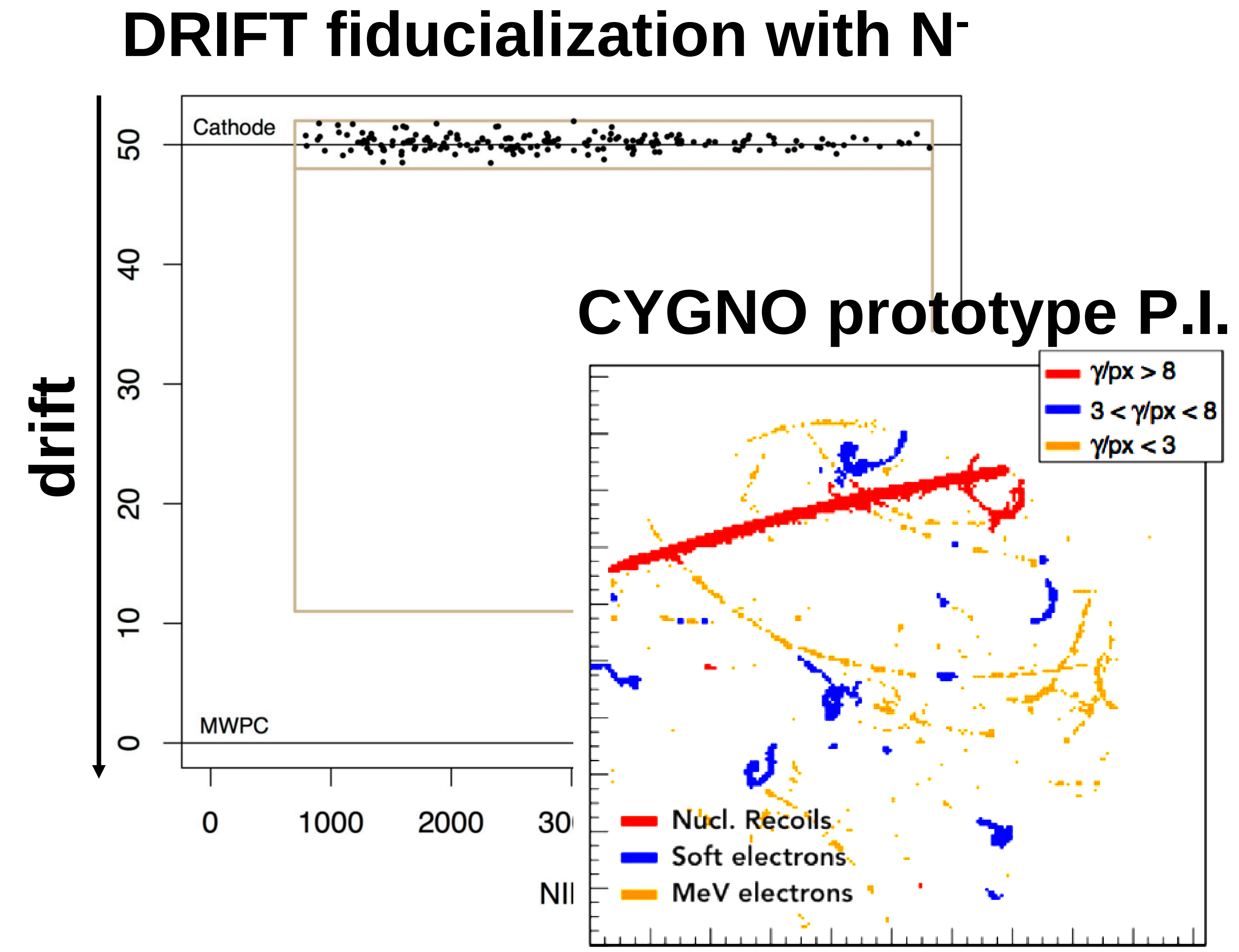


internal background



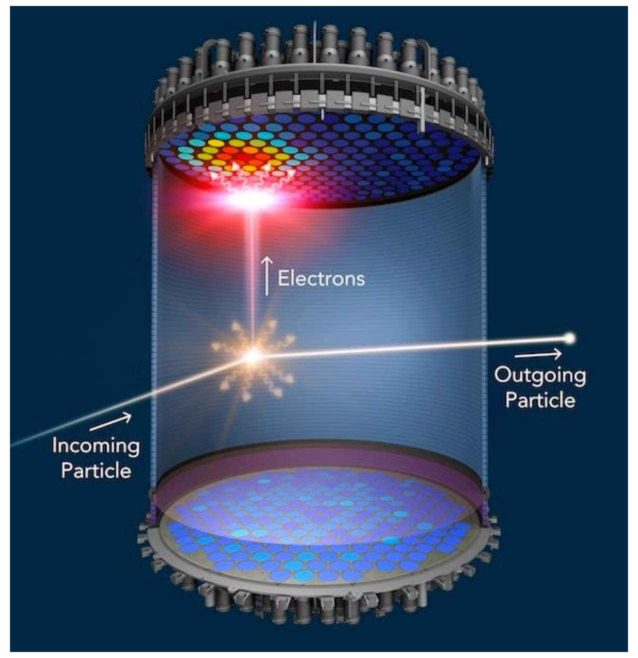
- **Solid** (hight purity powder or melts with intrinsic low background)
  - cosmogenic activation, removed by underground production
  - residual surface α or β-decay removed, by **discrimination**
  - readout (PMTs)
- **Liquid**
  - ^{85}Kr and Radon, removed by cryogenic cycle and liquid **filtering**
  - Argon: ^{39}Ar and ^{42}Ar, Xenon: ^{136}Xe
  - readout (PMTs, SIPM, ecc)
  - residual surface α or β-decay, removed by **fiducialization**
- **Gas**
  - Radon, removed by gas **filtering**
  - residual surface (mainly from readout) α or β-decay, removed by **discrimination and fiducialization** (*)
  - readout (PMTS, SIPM, Camera!), removed by fiducialization

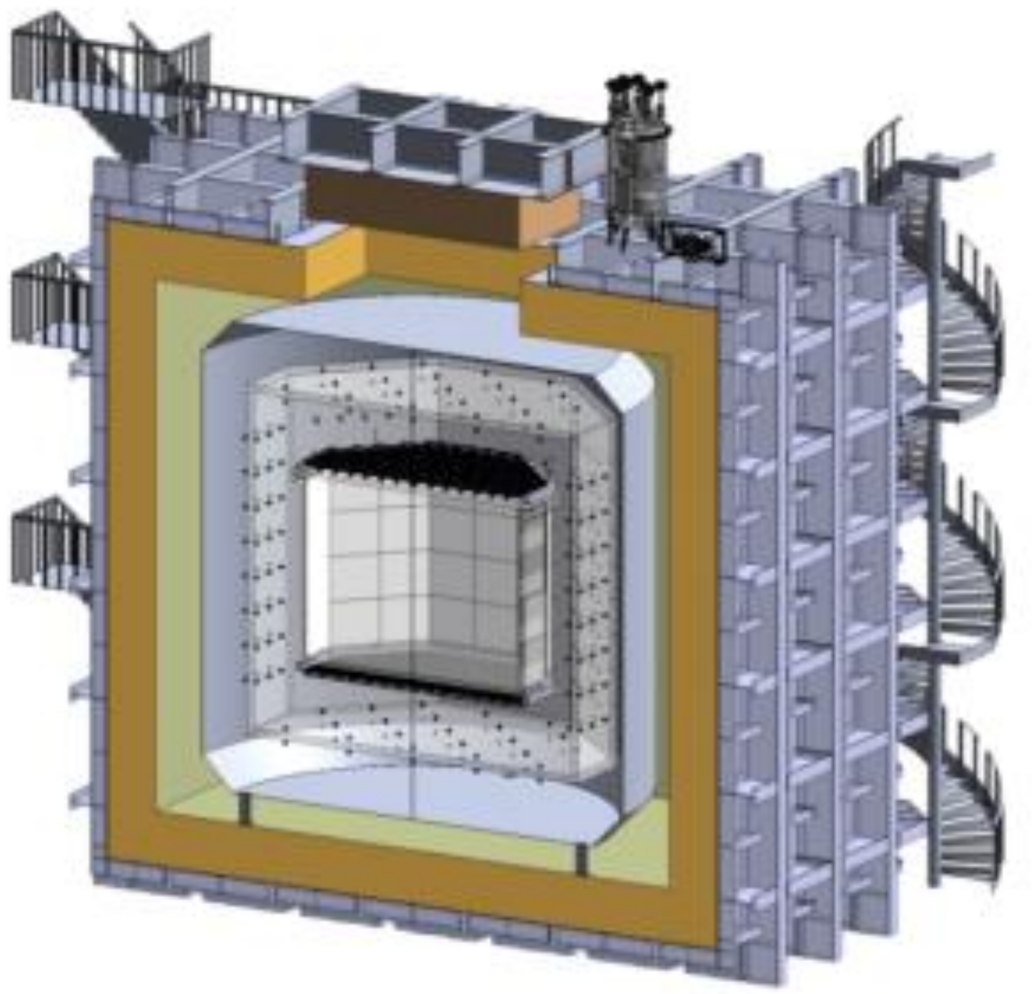




(*) with some constraint on longitudinal fiducialization (see next)

detector requirements

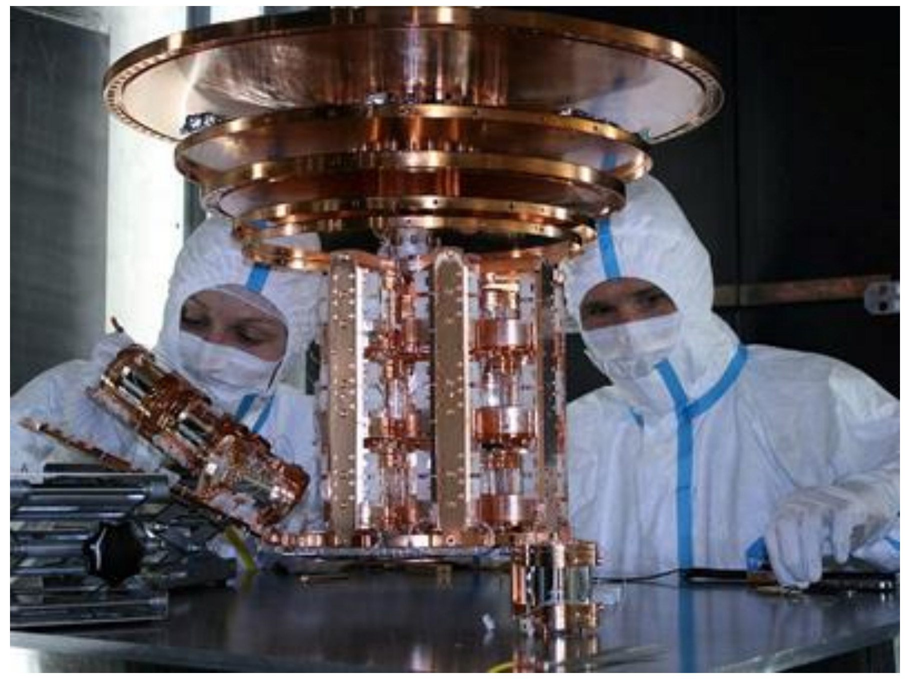


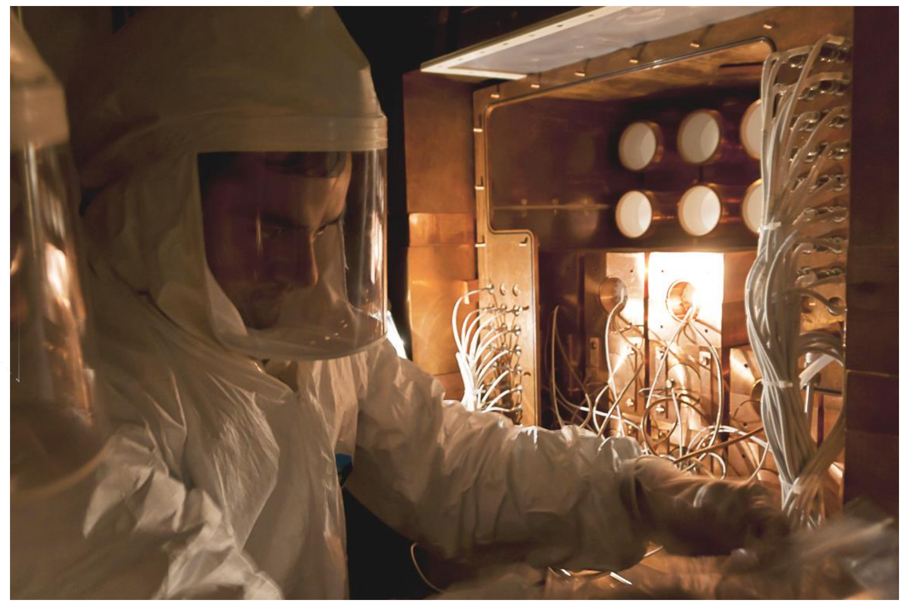


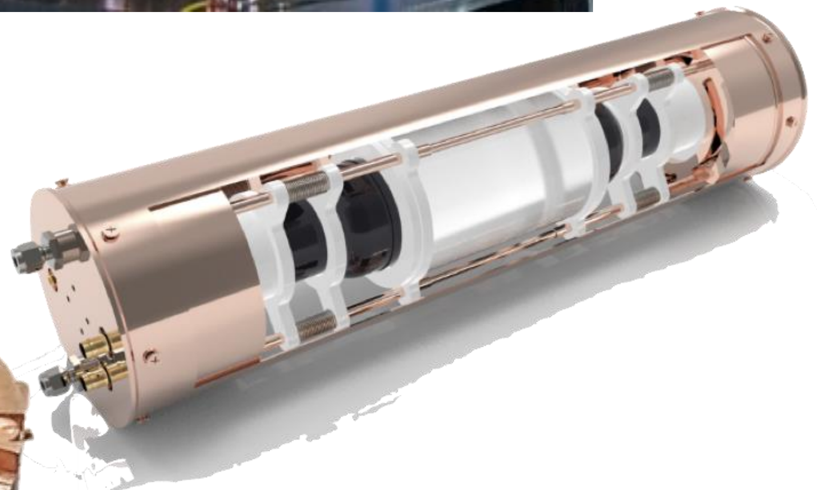
detector requirements:

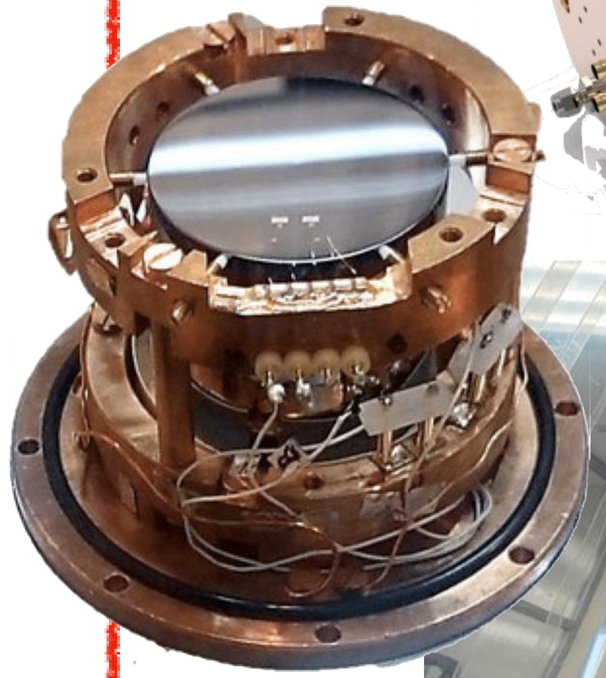
- large detector **mass**;
- long exposure and **stability**;
- very low energy **threshold**;
- ultra-low **radioactive** background;
- very high background **discrimination**
- **calibration**
- DM identification:
  - nuclear recoil **shape** Weak
  - seasonal **modulation** Weak alone
  - **directionality** Strong

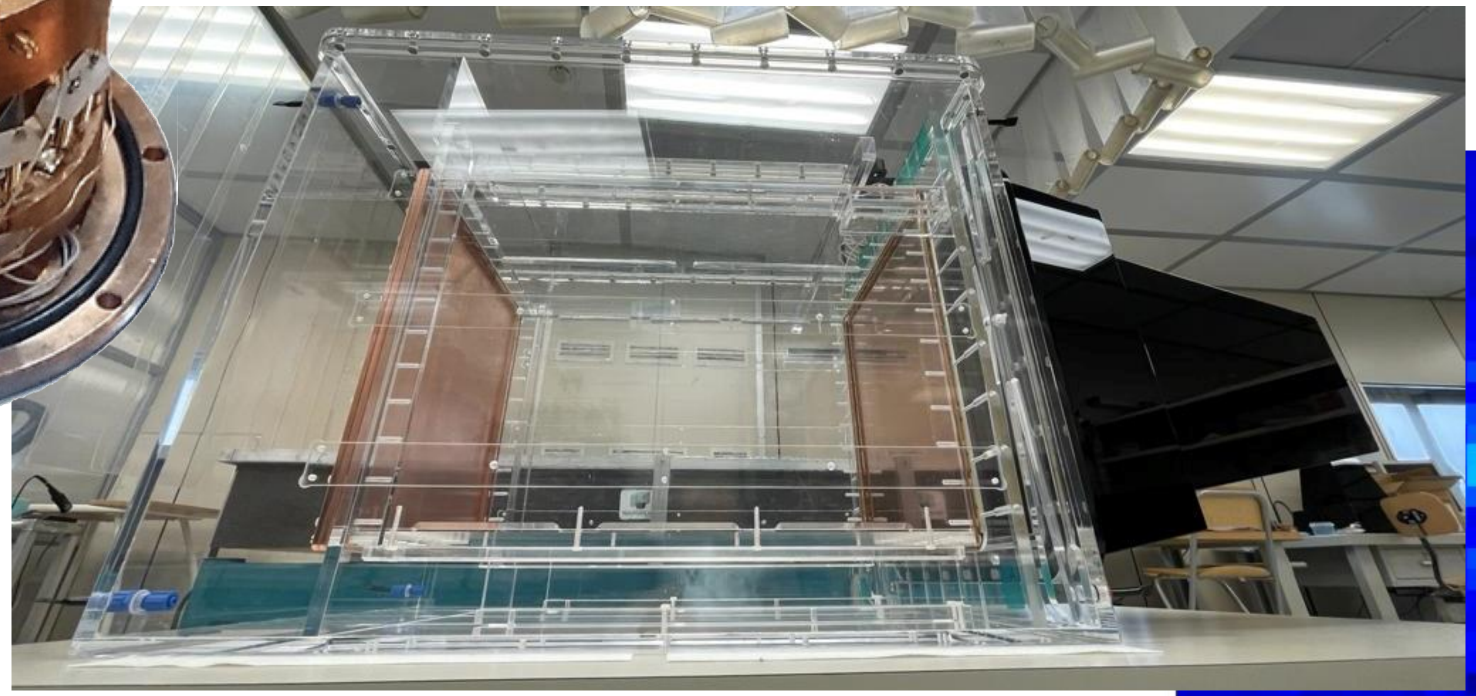
Astronomy possible only with directionality

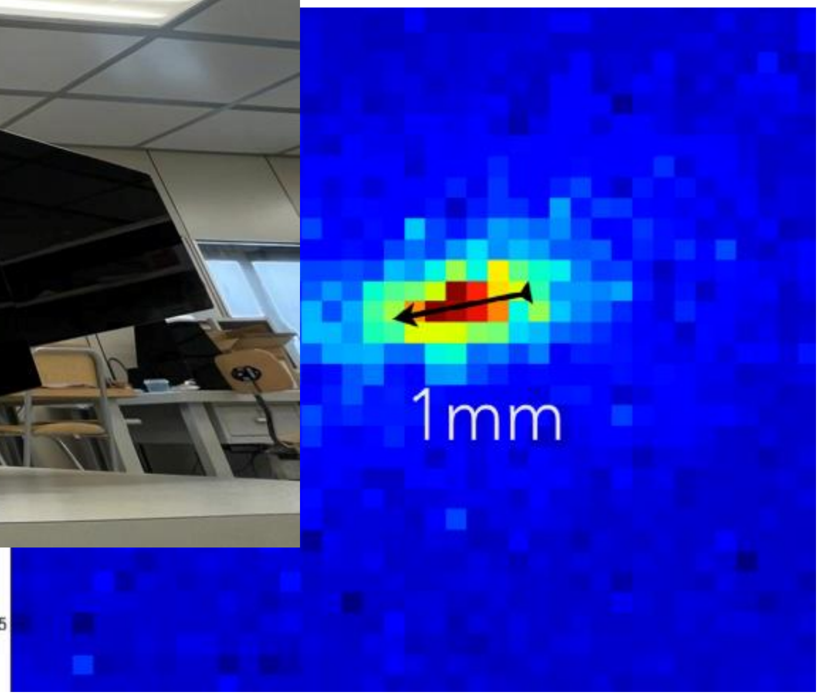








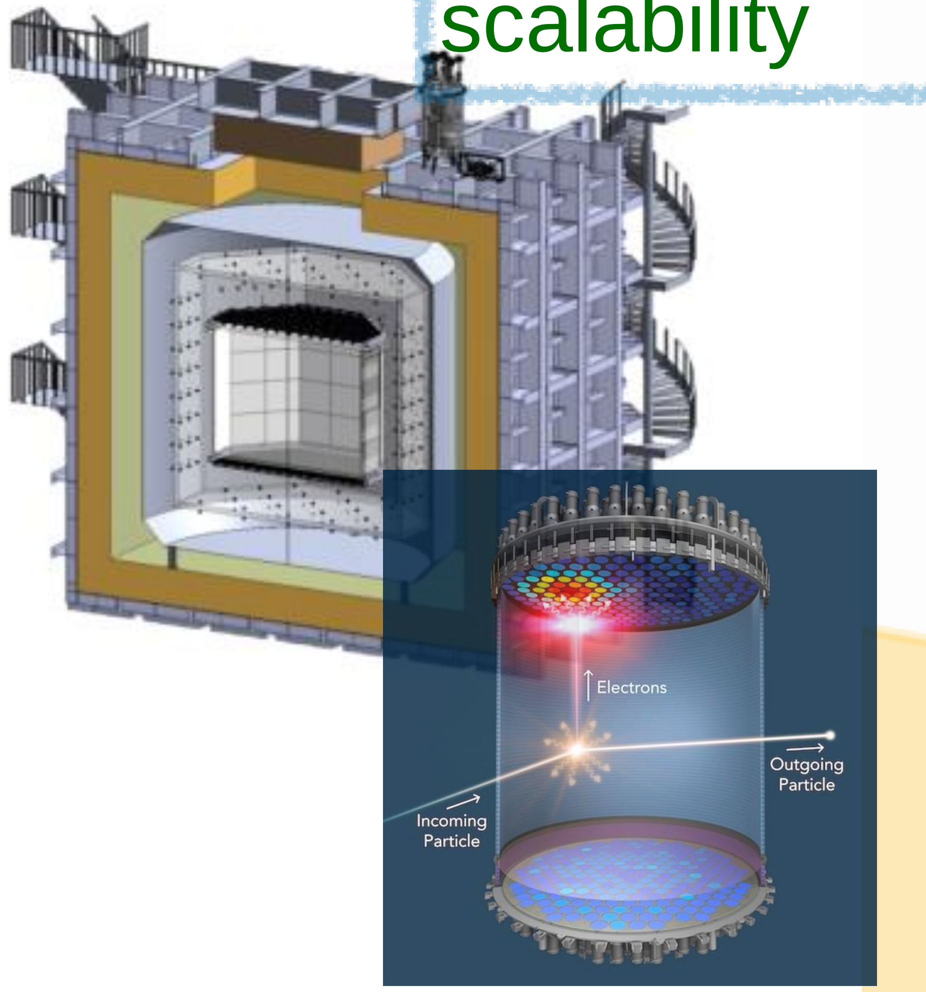


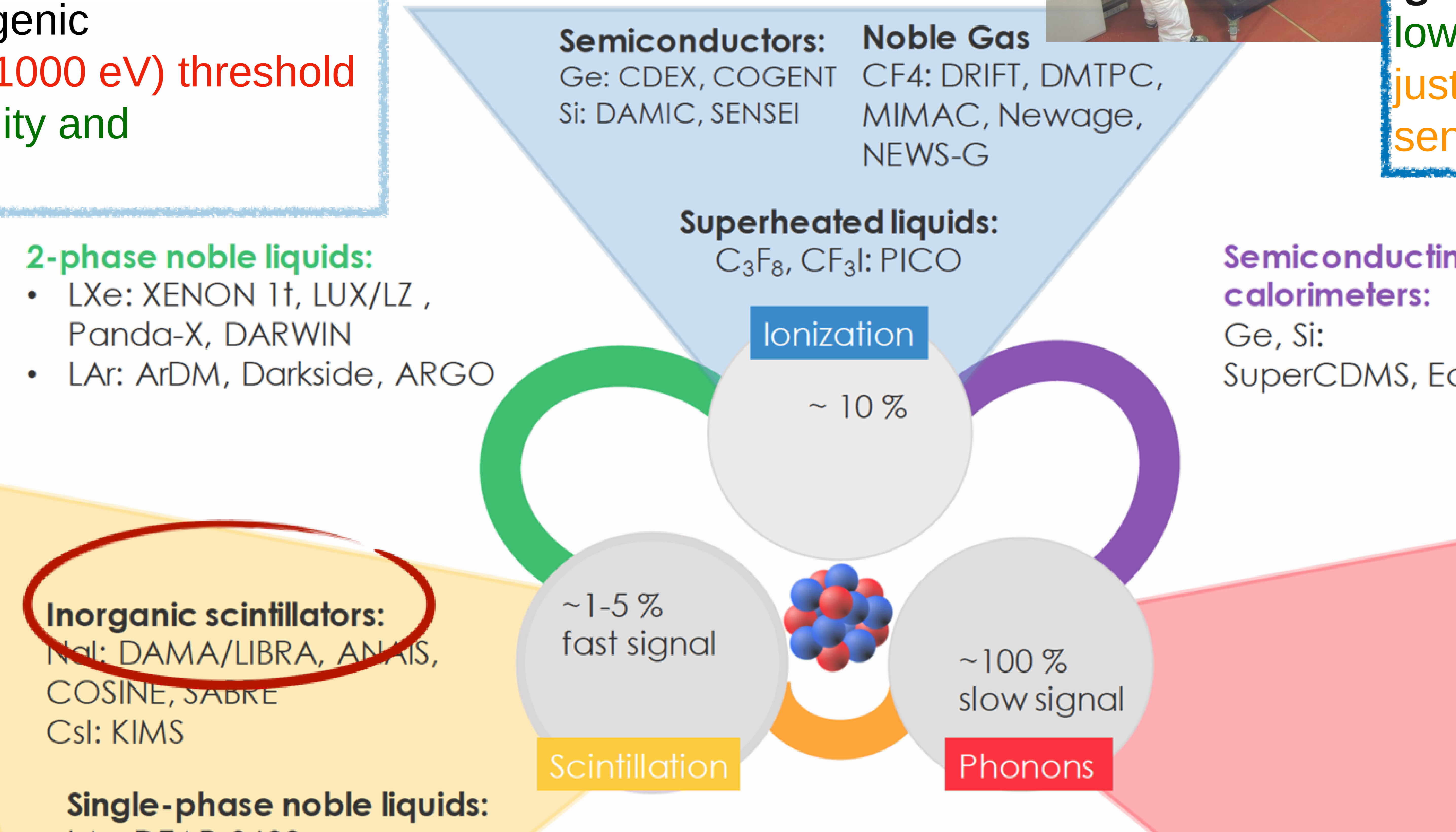


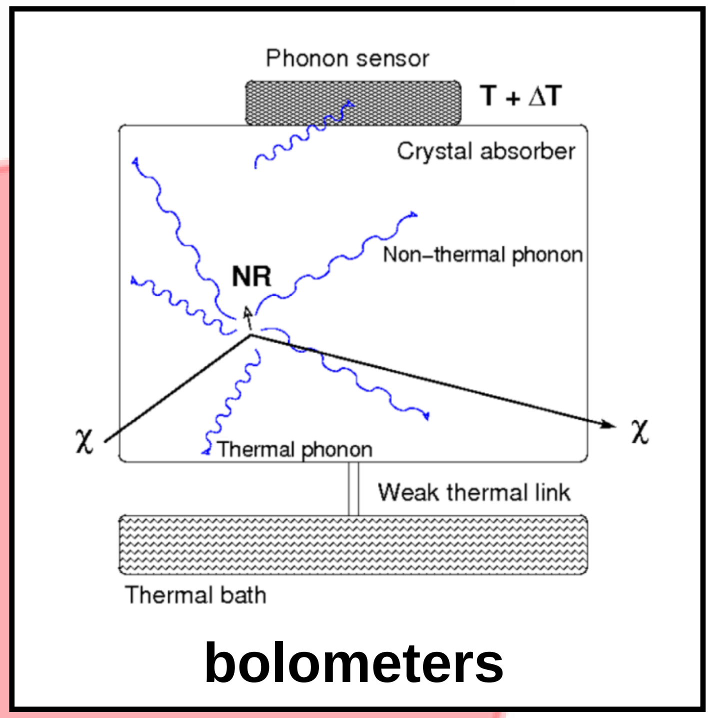
detector technology

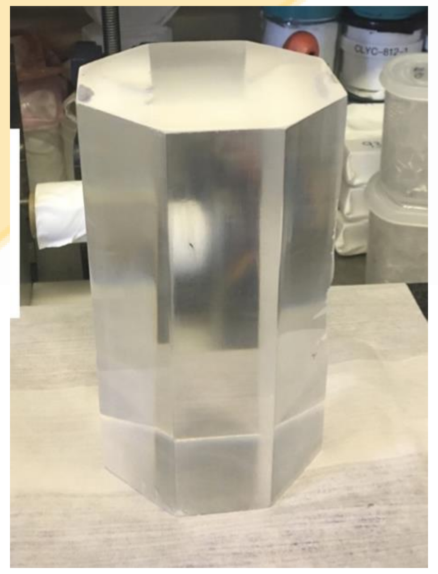
gaseous
low (O 100 eV) threshold
just some ideas to increase sensitivity and scalability

liquid, cryogenic
medium (O 1000 eV) threshold
high sensibility and scalability





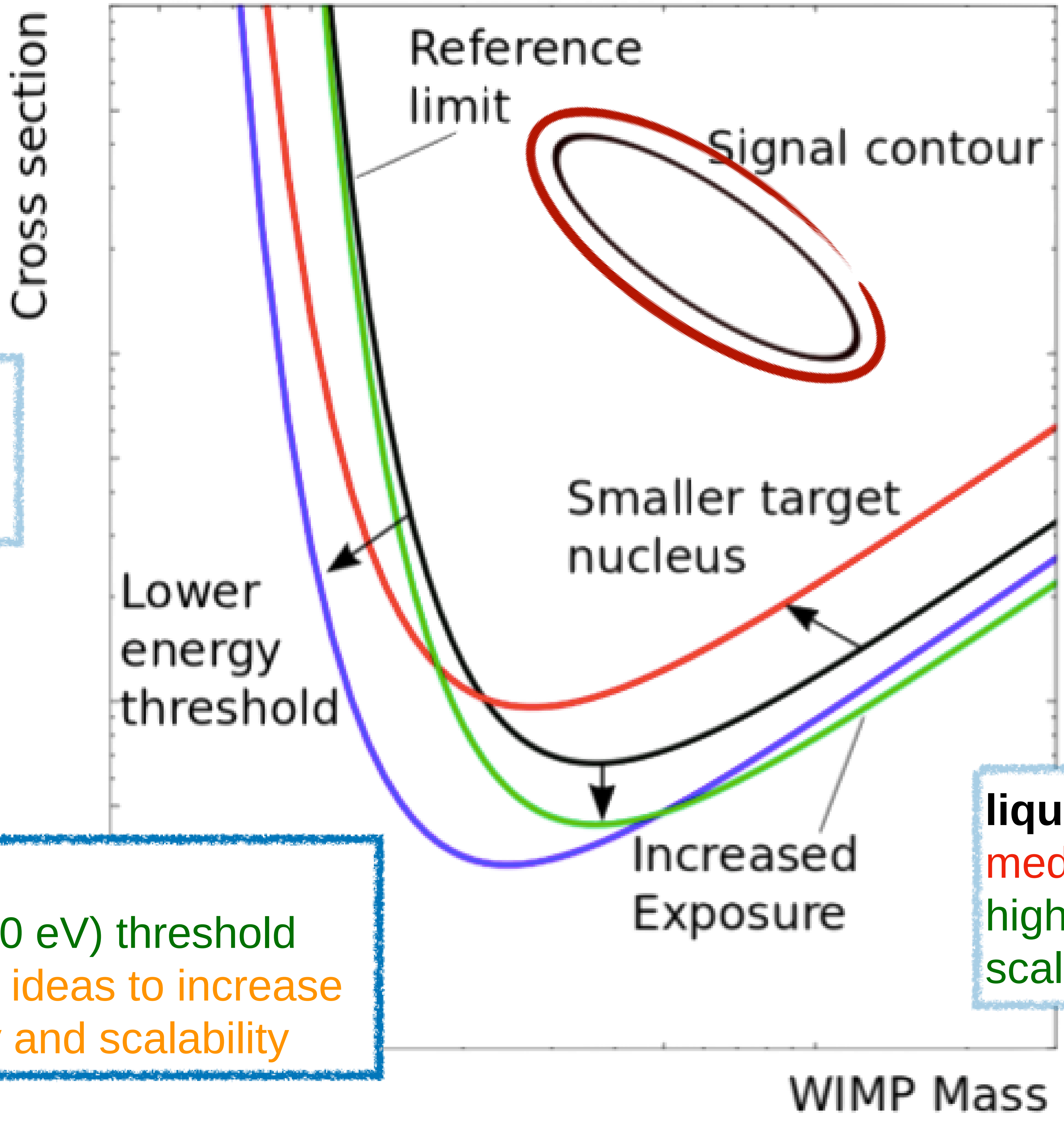




solid, cryogenic
very low (O 10 eV) threshold
limited mass and scalability

detector sensitivity characteristics

solid, cryogenic
very low (O 10 eV) threshold
limited mass and scalability

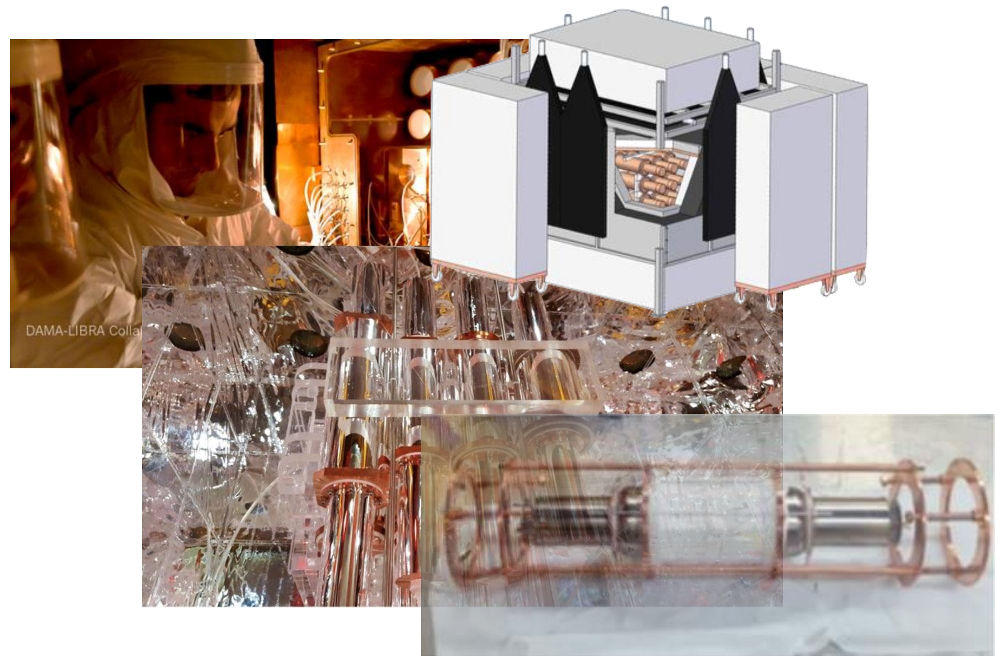


gaseous
low (O 100 eV) threshold
just some ideas to increase sensitivity and scalability

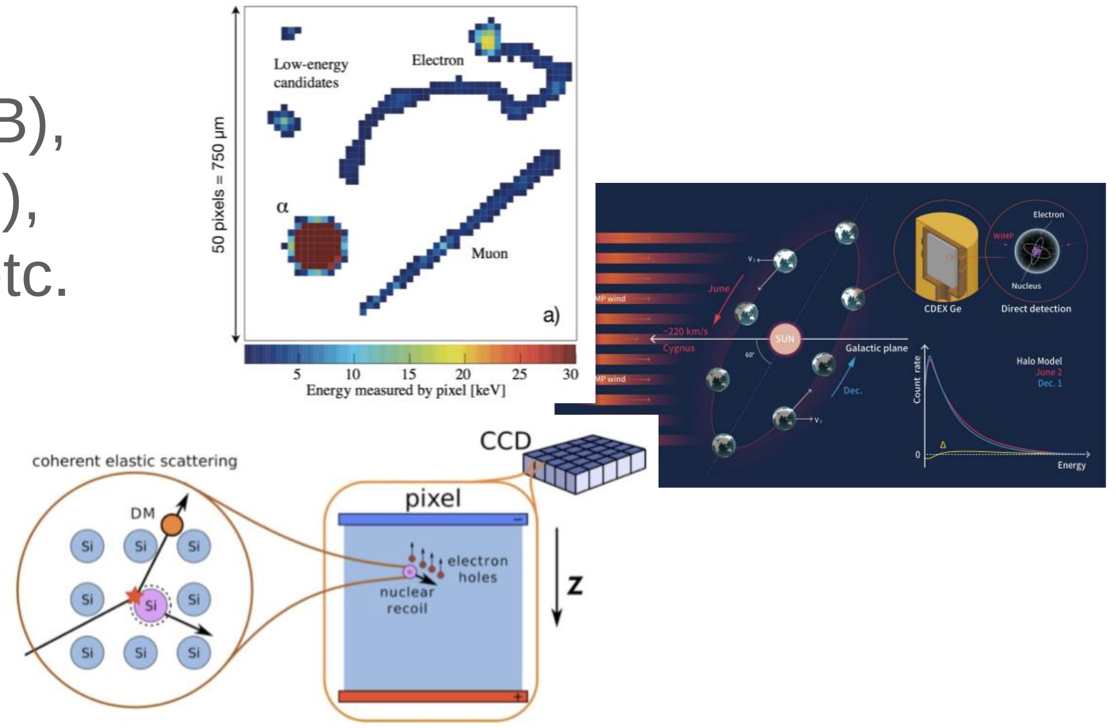
liquid, cryogenic
medium (O 1000 eV) threshold
high sensibility and scalability

dark matter scenario

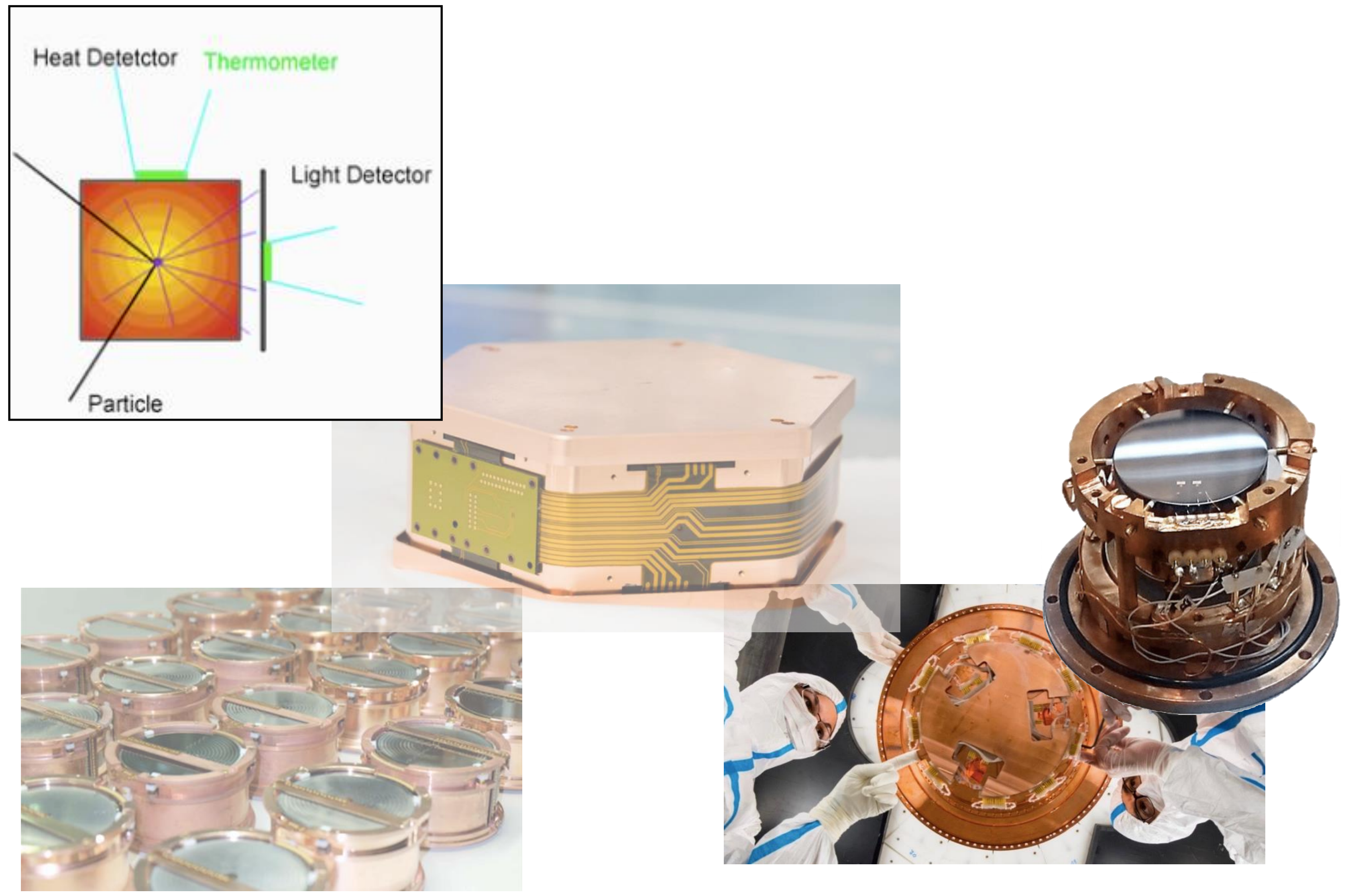
solid —> crystals —> gases —> liquid



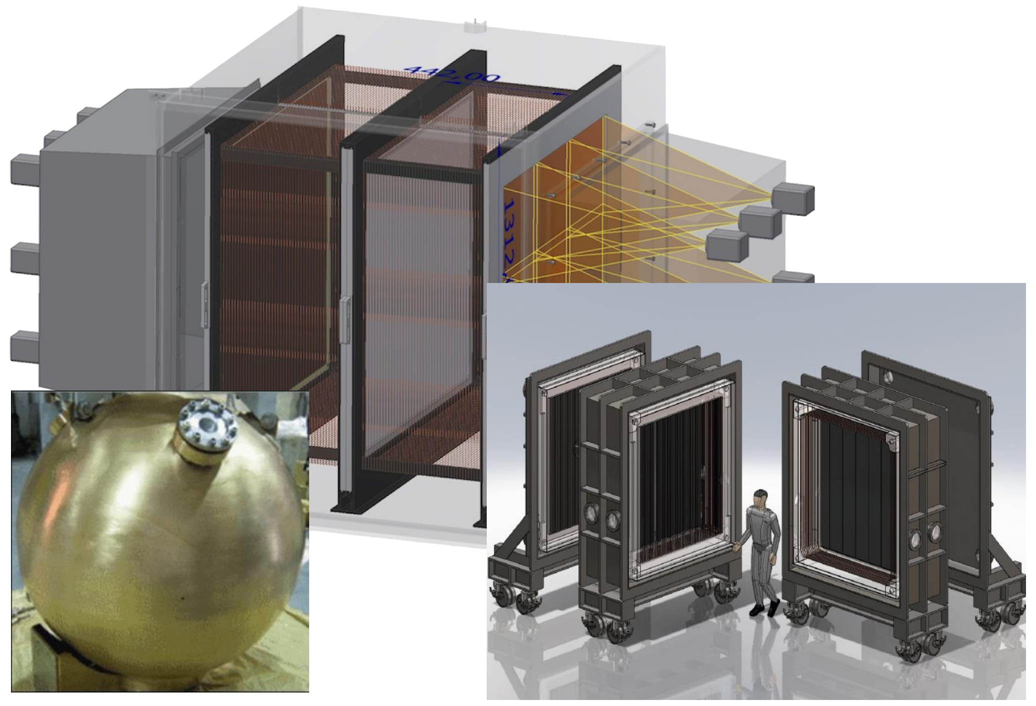
DAMIC (SNOLAB),
DAMIC-M (LSM),
CDEX (CJPL), etc.

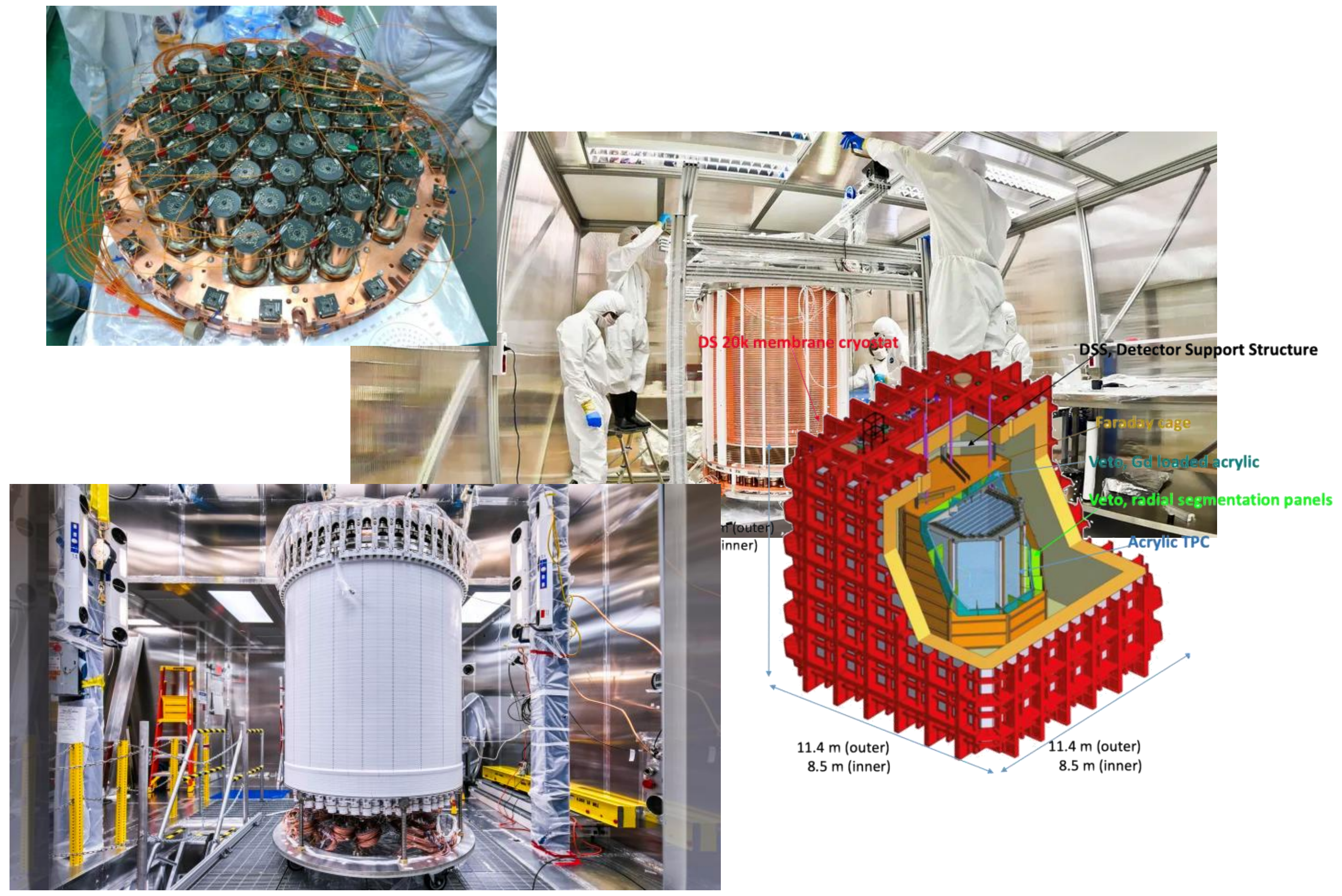


DAMA (LNGS), COSINE (Korea),
SABRE (LNGS/LSC), ANAIS (LSM), etc



DRIFT (Bulby), CYGNO (LNGS),
TREX (LSC), NEWS-G (SNOLAB), etc



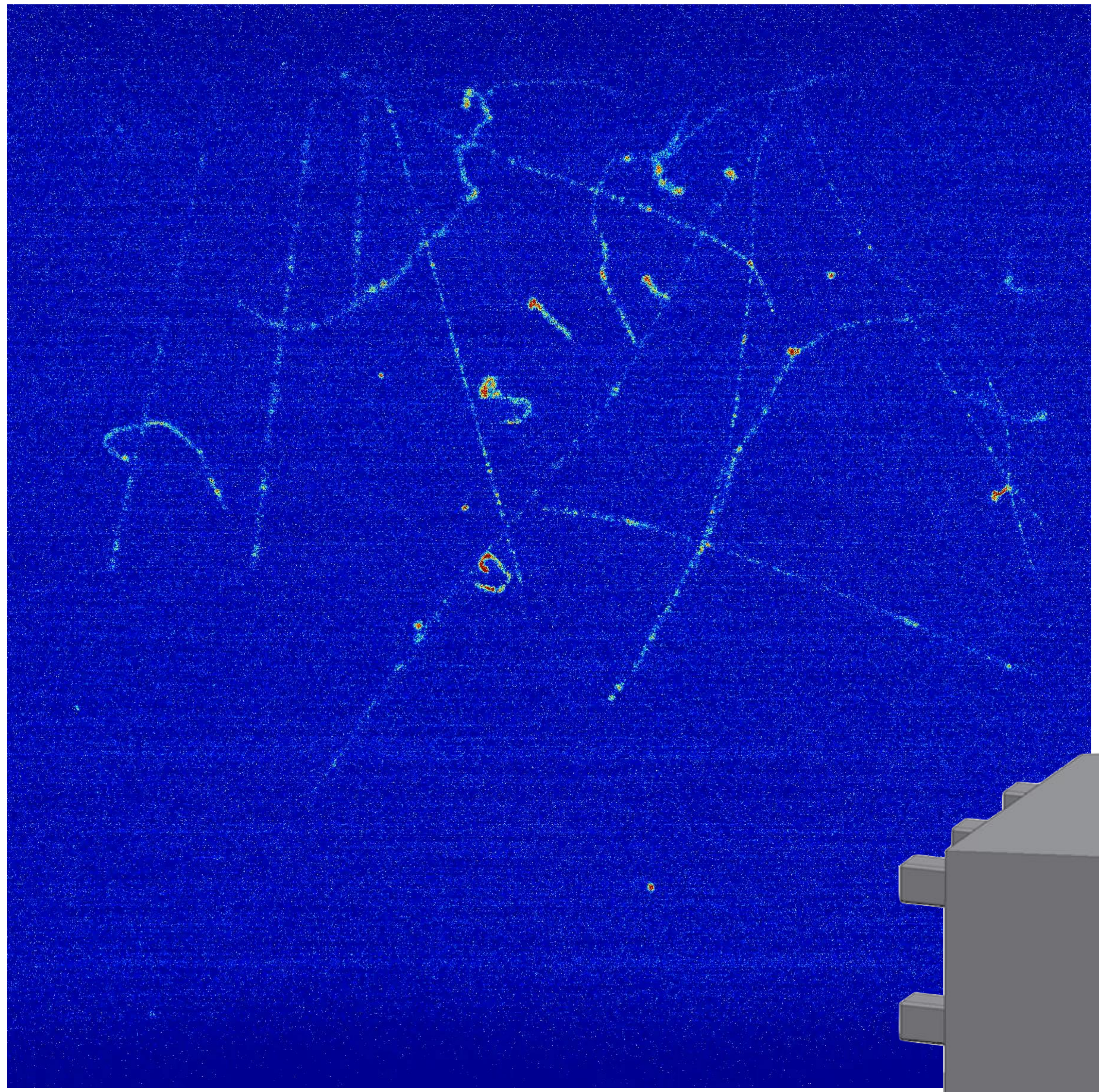


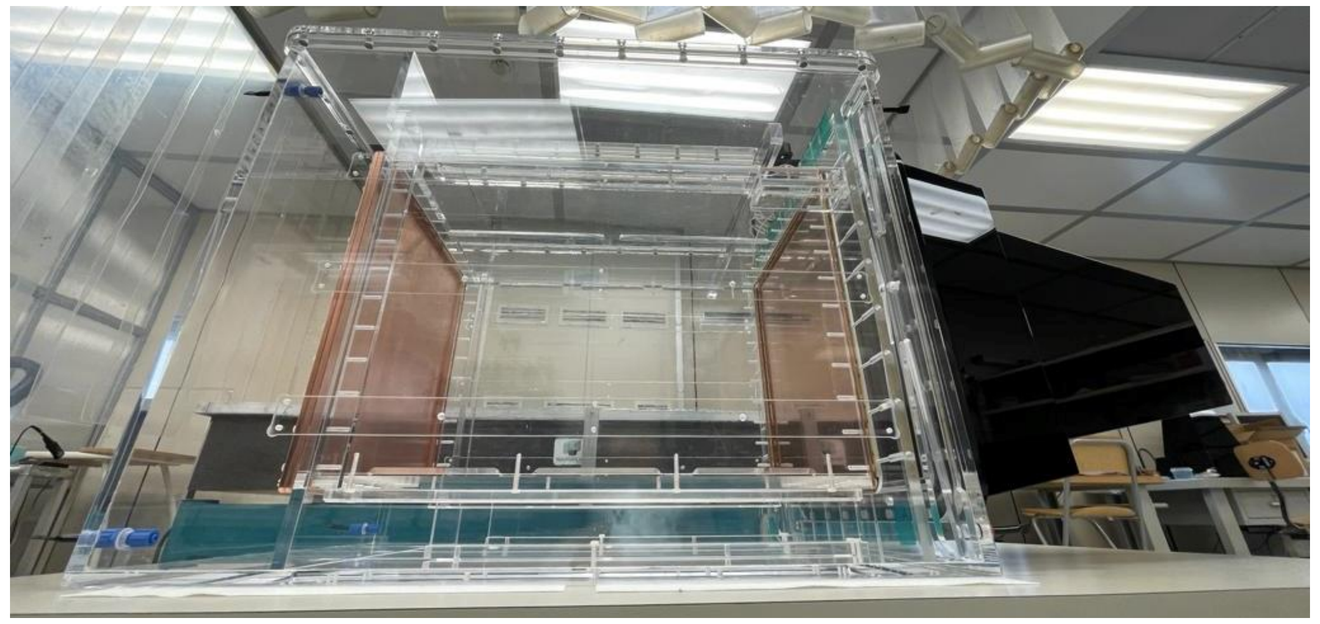
SuperCDMS (SNOLAB), EDELWEISS (LSM), CREST,
COSINUS (LNGS), etc

LUX (SNOLAB), XENON (LNGS),
DARKSIDE (LNGS), PANDAX (CJPL), etc.

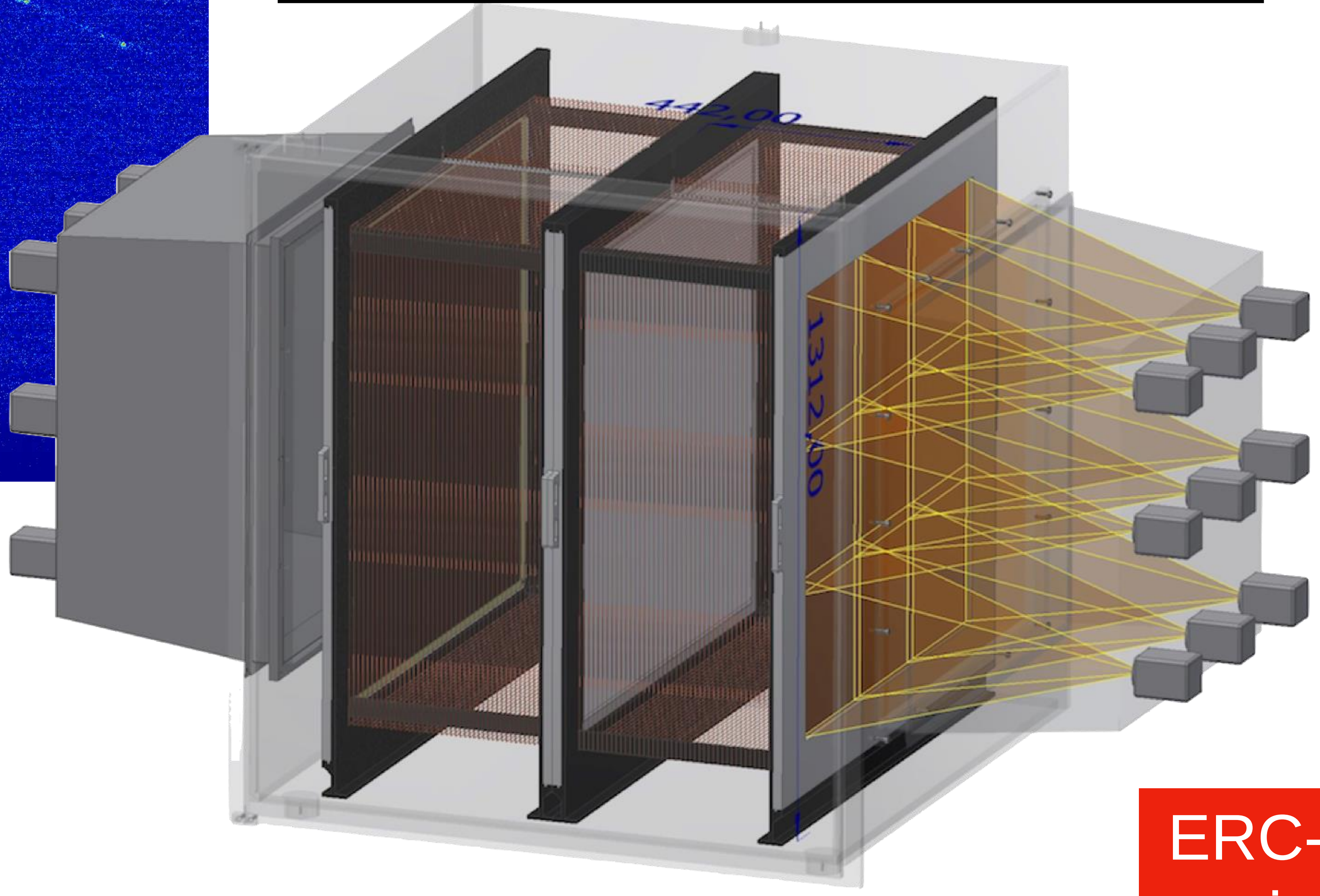
0.1 1 10 **dark matter mass threshold (GeV)**

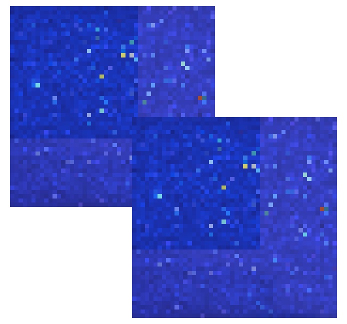
CYGNO & optical read out



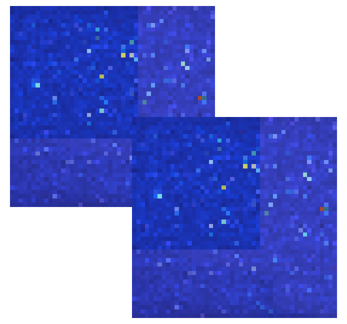


10^7 **readout** channels + time signals
18 cameras monitoring 330*330 mm
each with **150 μm resolution** and a
sensitivity of ~ **1 ph / 2 eV** released in gas



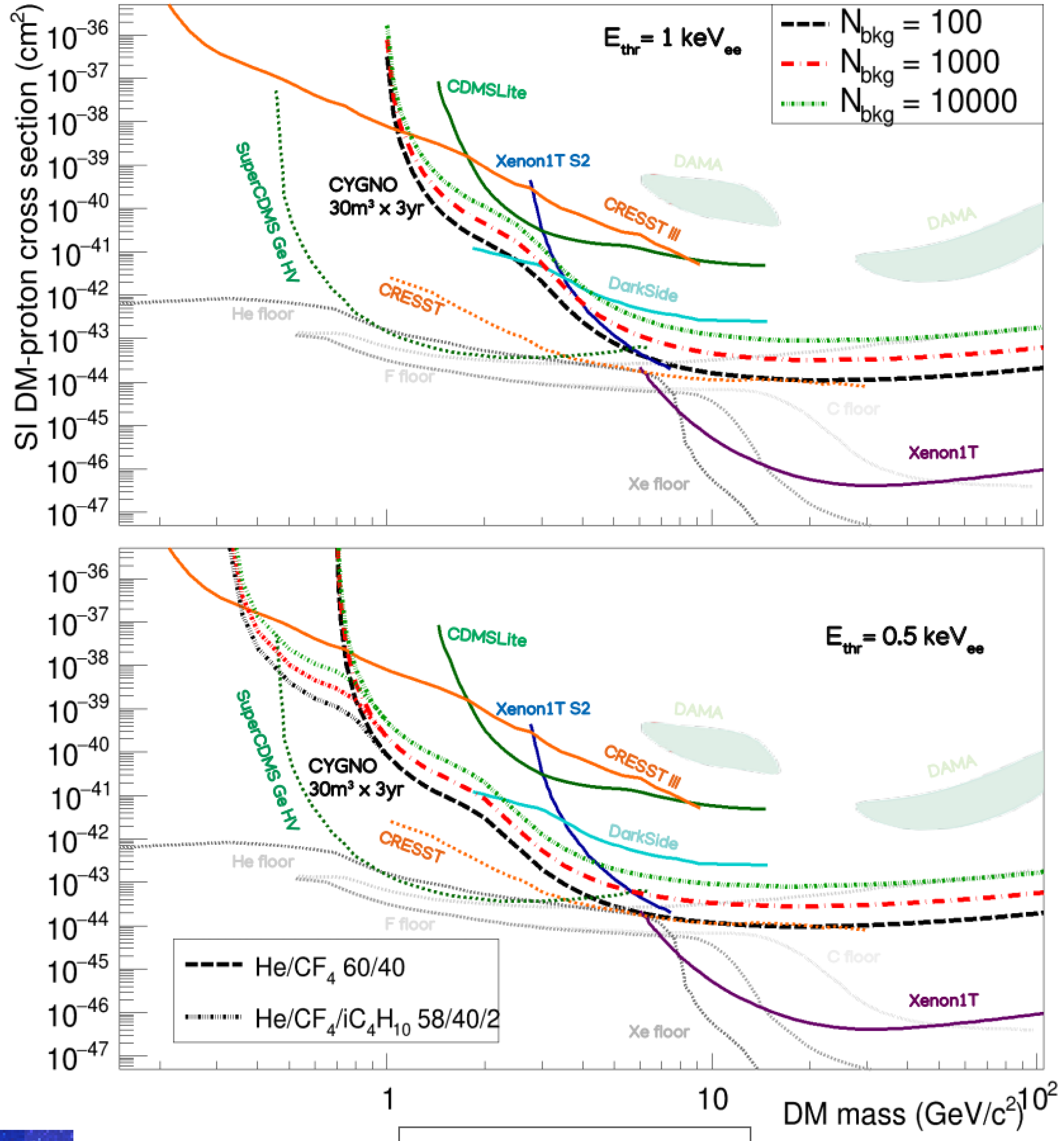


x N …



x N …

CYGNO 1 m^3 of HeCF4 60/40
(H, He light target, F target and quenching/light production)



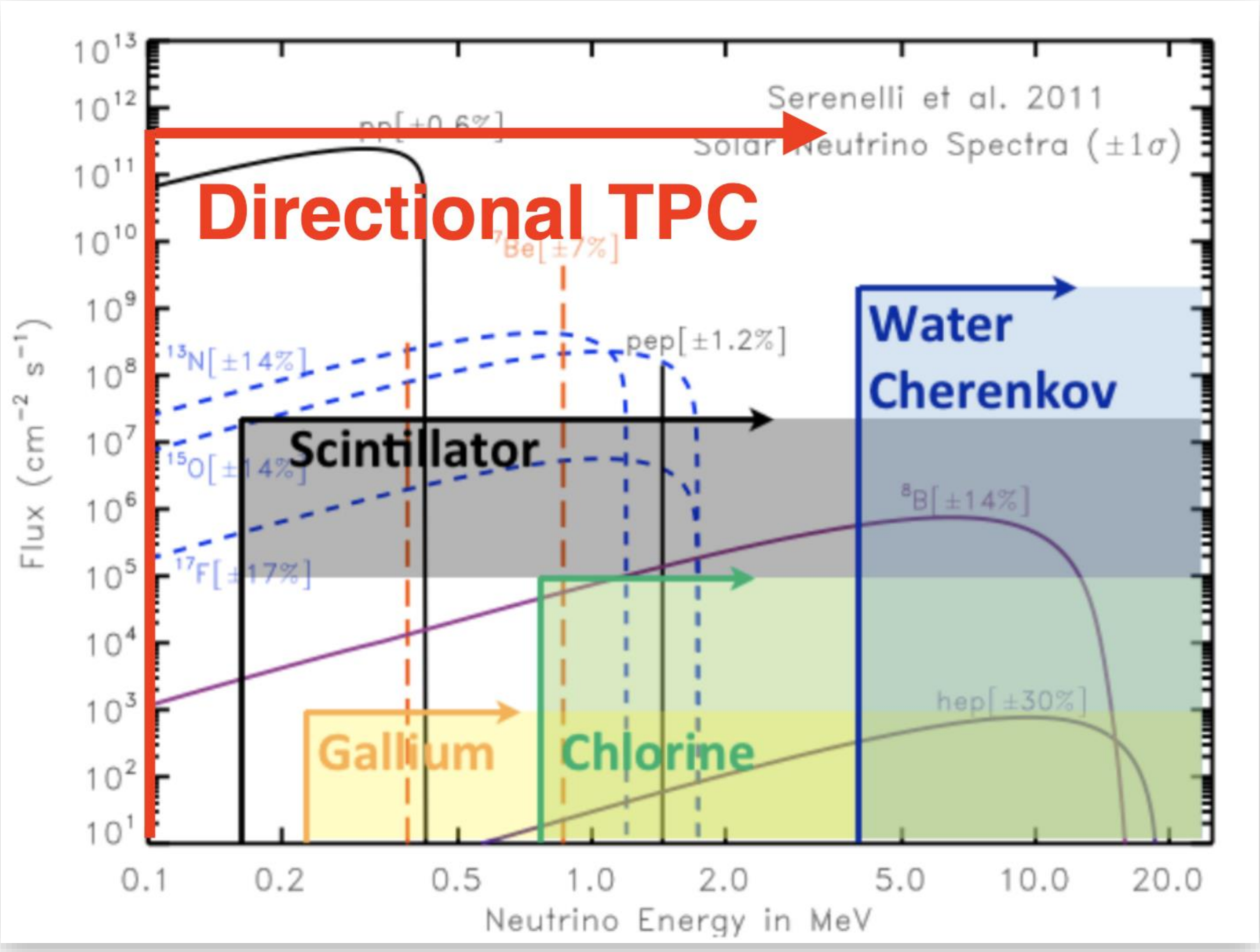
1 keVee
2.15 keV per l'He
3.12 keV per il C
3.75 keV per il F

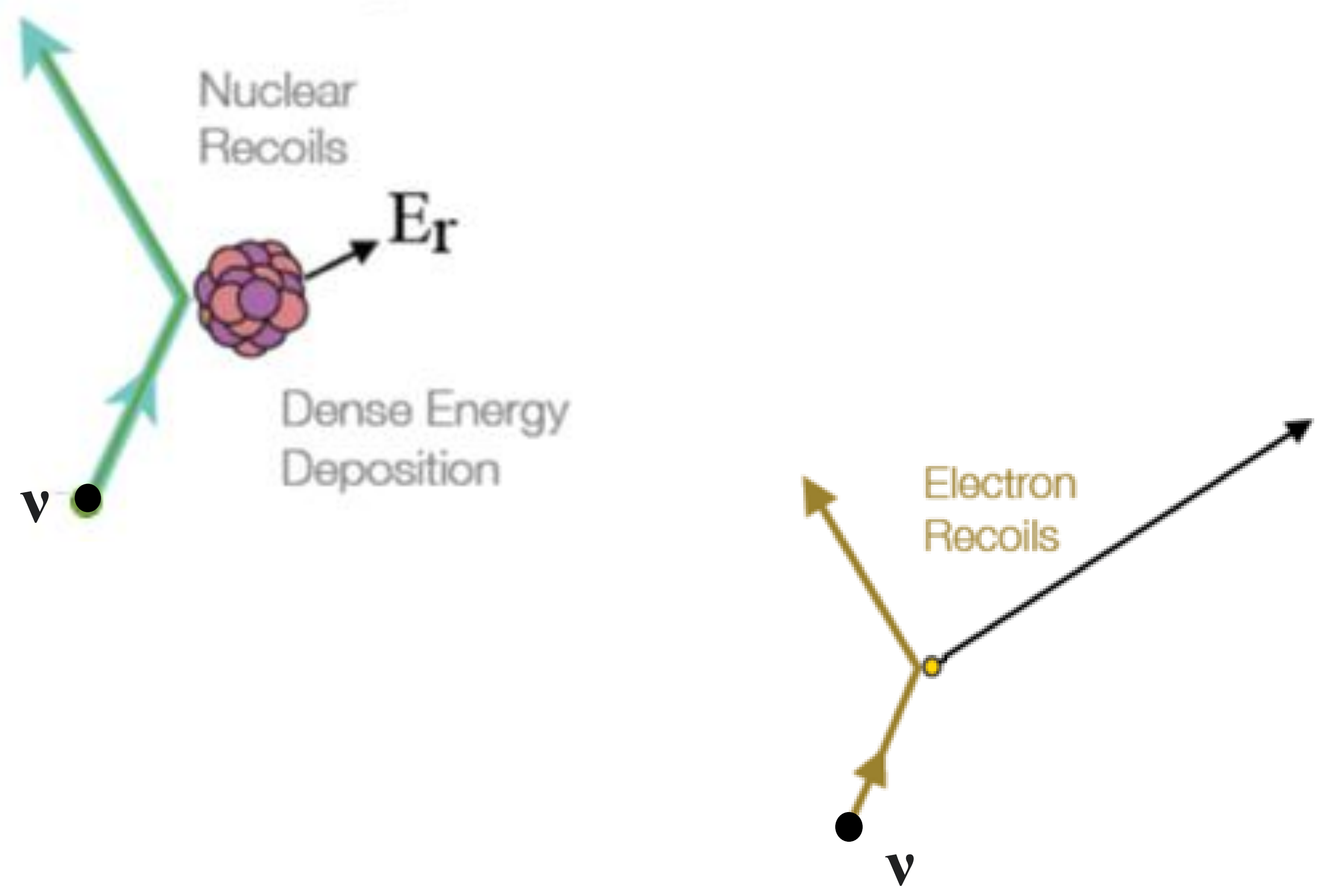
ERC-INITIUM R&D on negative ion for 3D reconstruction

neutrino ultimate limit

elastic electron scattering

gassous
low (O 100 eV) threshold
just some ideas to increase sensitivity and scalability





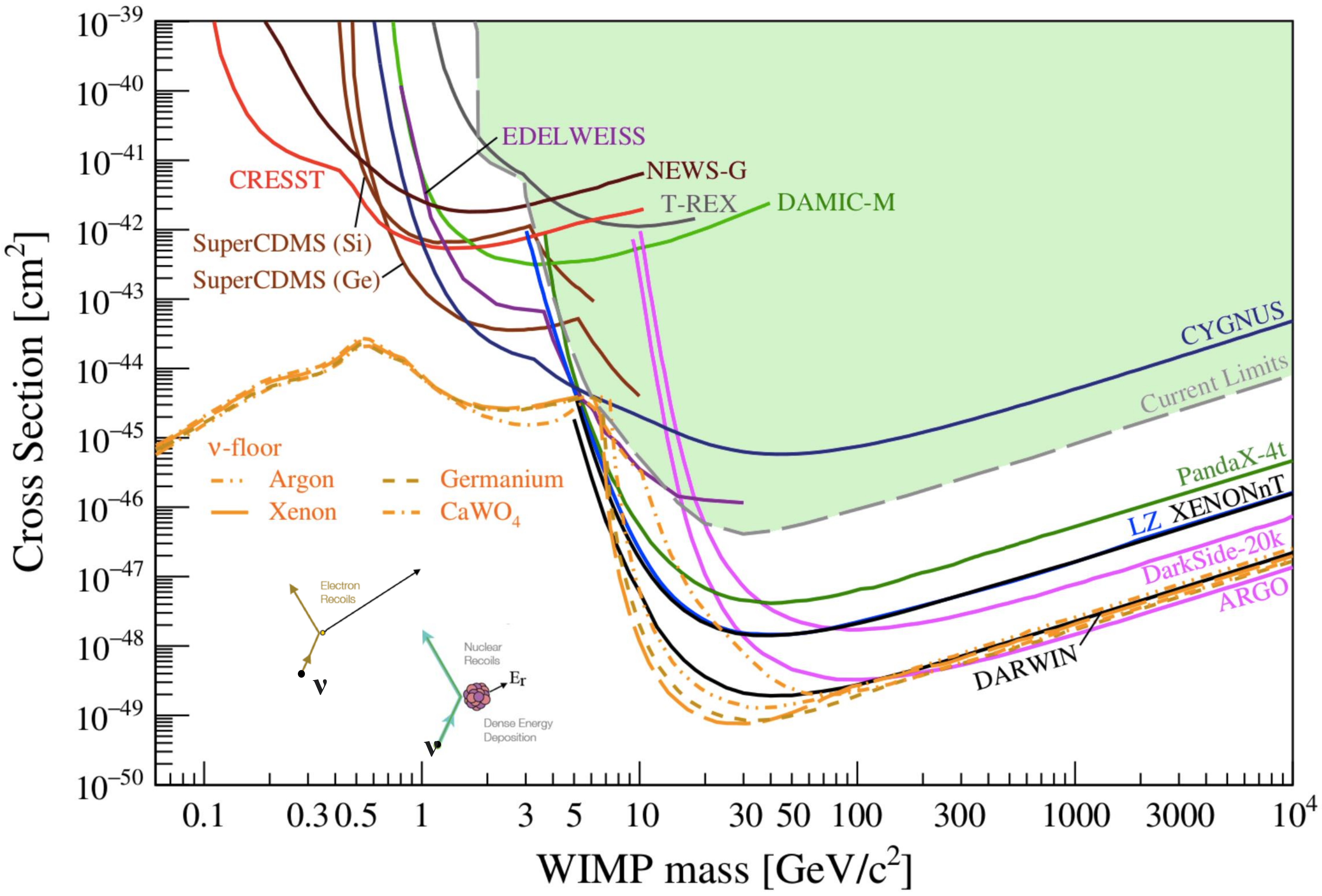
For 1 m³ of He:CF₄ 60:40 with 20 keV threshold

$$R = N_e \cdot \int_{E_{min}}^{E_{max}} w(E)\varphi_{ppI}(E)\sigma(E)dE \qquad R = 2.9 \cdot 10^{-8}\,\frac{events}{s \cdot m^3} = 0.9\,\frac{events}{y \cdot m^3}$$

~ 30 events/year in CYGNO30

where we are going…

APPEC Dark Matter Report 2021 (to be published) submitted to APPEC for final approval

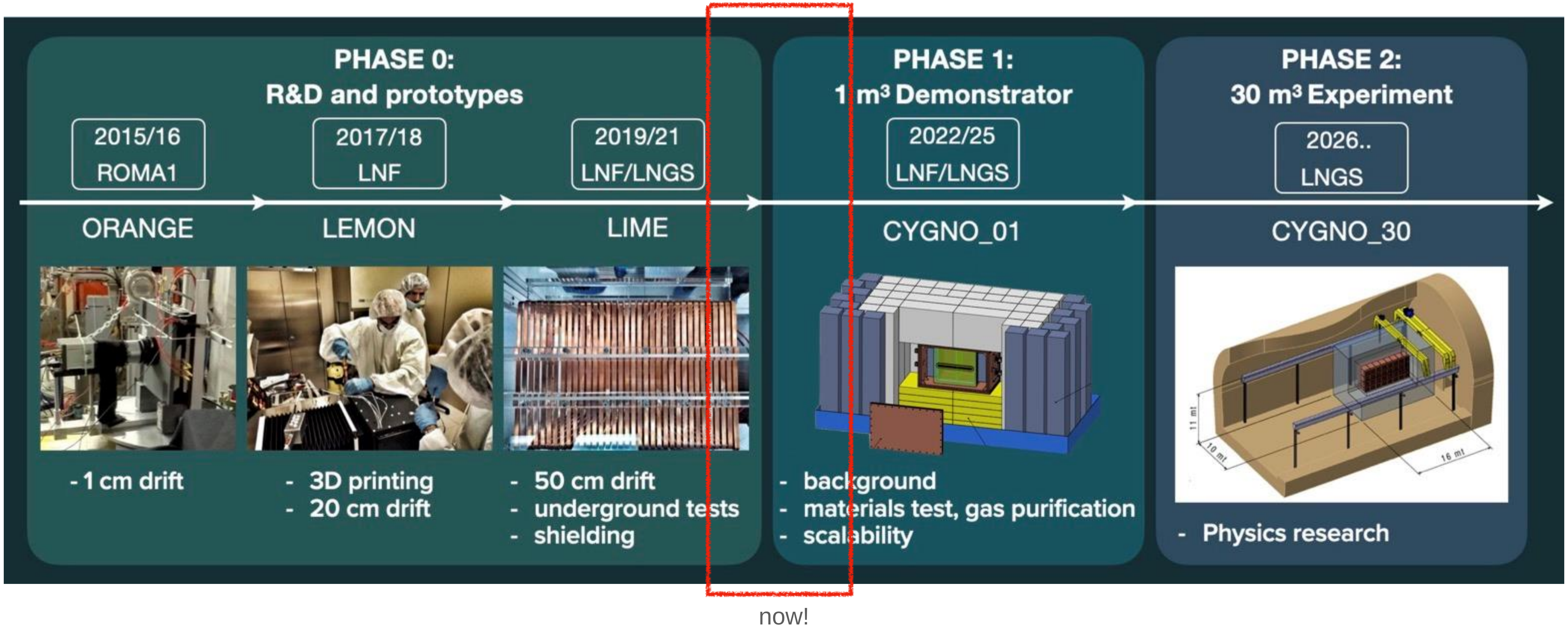


CYGNO Computing Model

why (scientific objective)

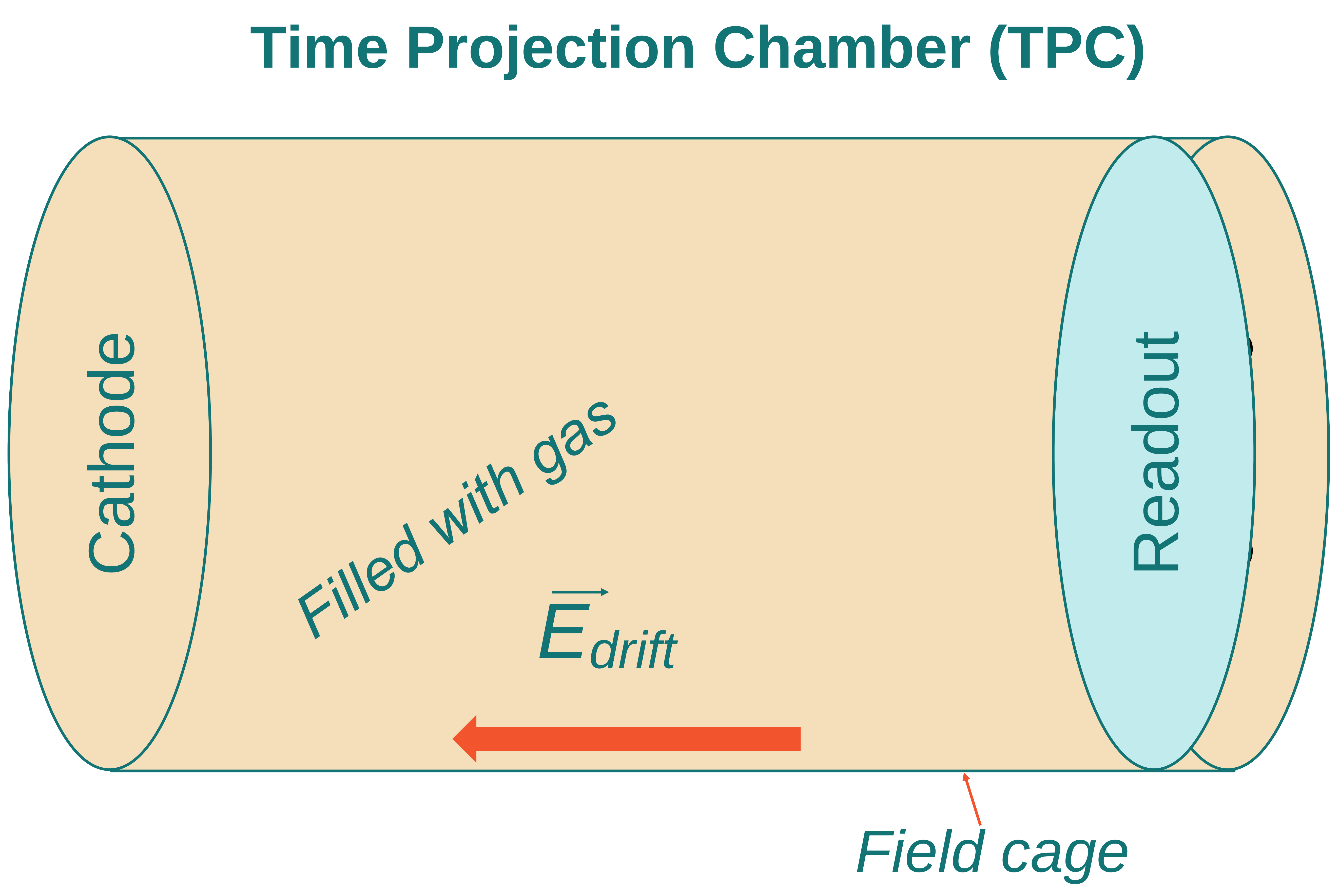
CYGNO a large TPC for dark matter and neutrino study

exploiting the progress in **commercial scientific Active Pixel Sensors (APS)** based on CMOS technology to realise a large **gaseous Time Projection Chamber** (TPC) for **Dark Matter and Solar neutrino search**.



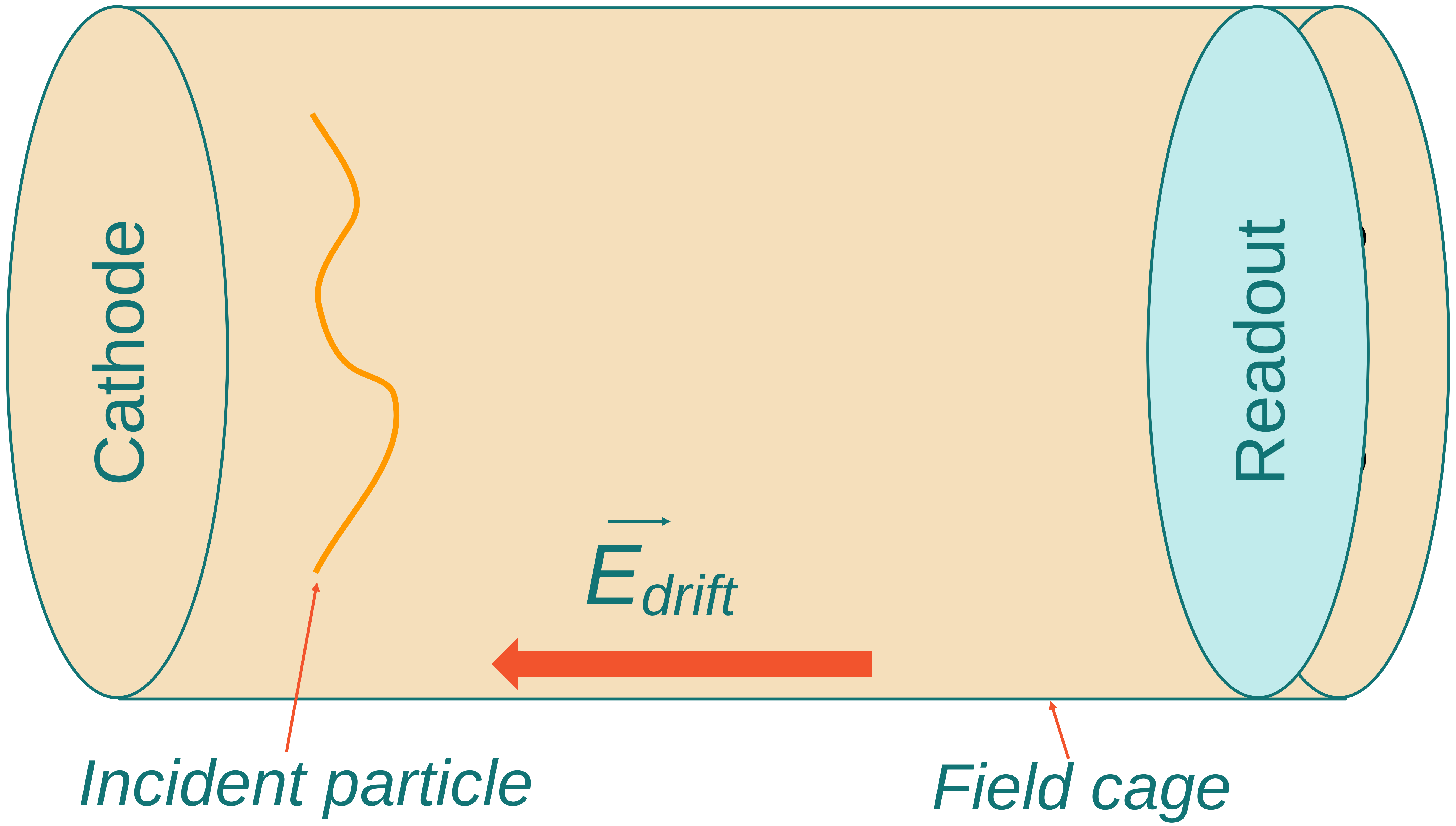
low-energy (1–100 keV) nuclear recoils
10^5 beta/gamme rejection

TPC Detector in a nutshell



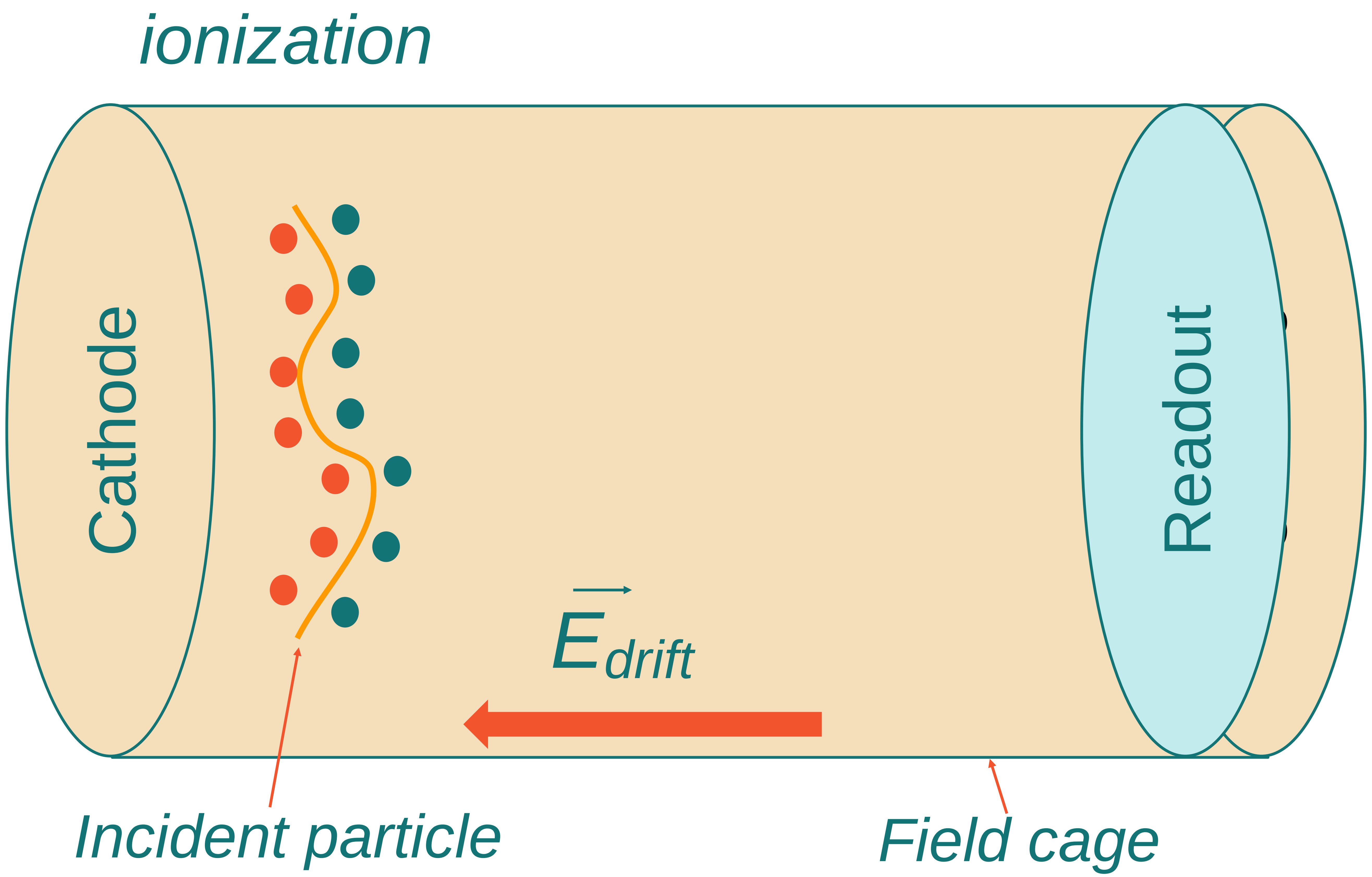
A TCP is costituited by a vessel filled with gas or liquid (Ar, Xe, He:CF_4 in CYGNO case) where an electric field is applied (hundreds of V/cm)

TPC Detector in a nutshell



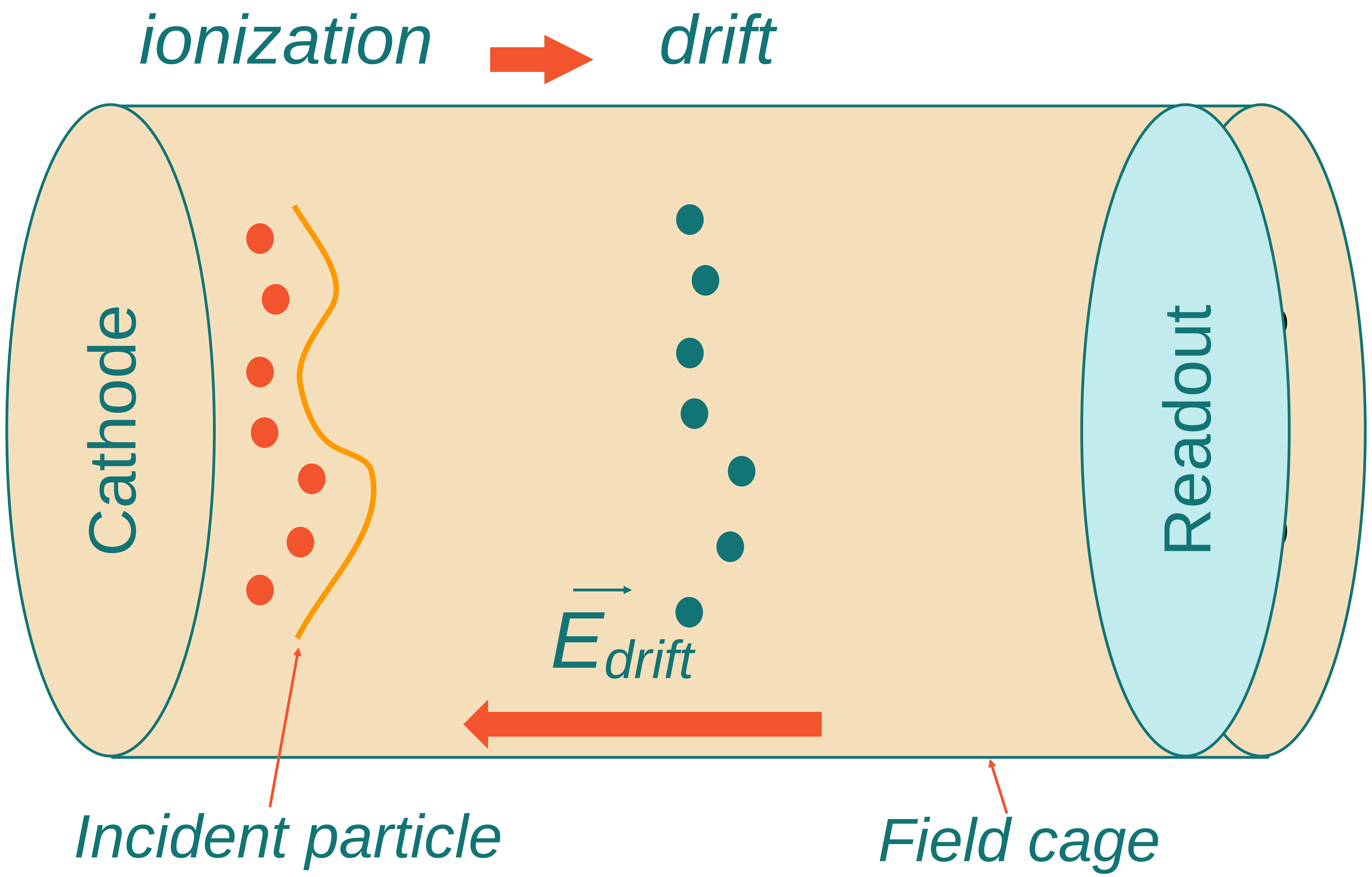
when a charged particle pass through the gas, there is a known probability to ionise the gas and …

TPC Detector in a nutshell



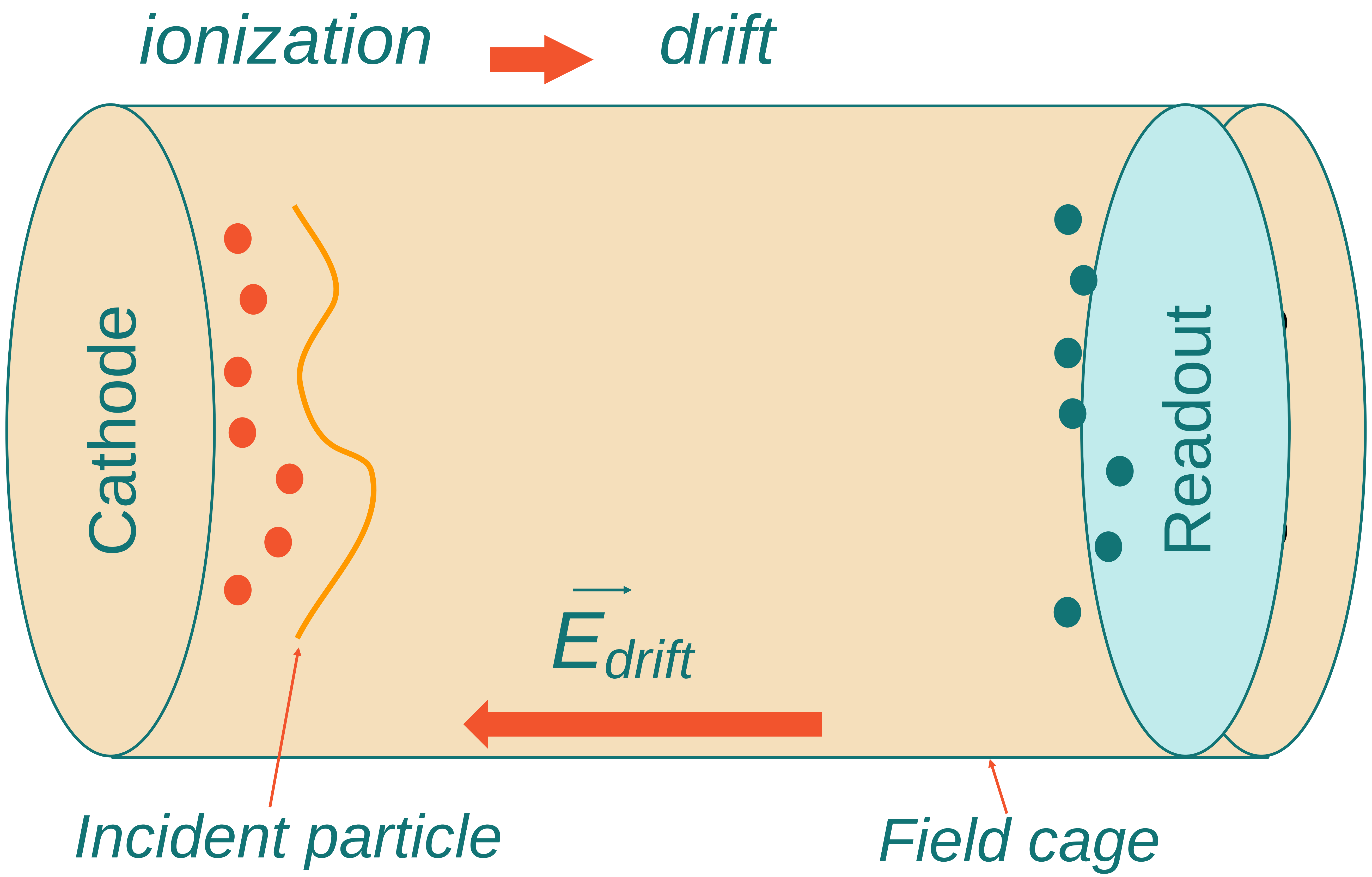
… produce free ions and electrons that …

TPC Detector in a nutshell



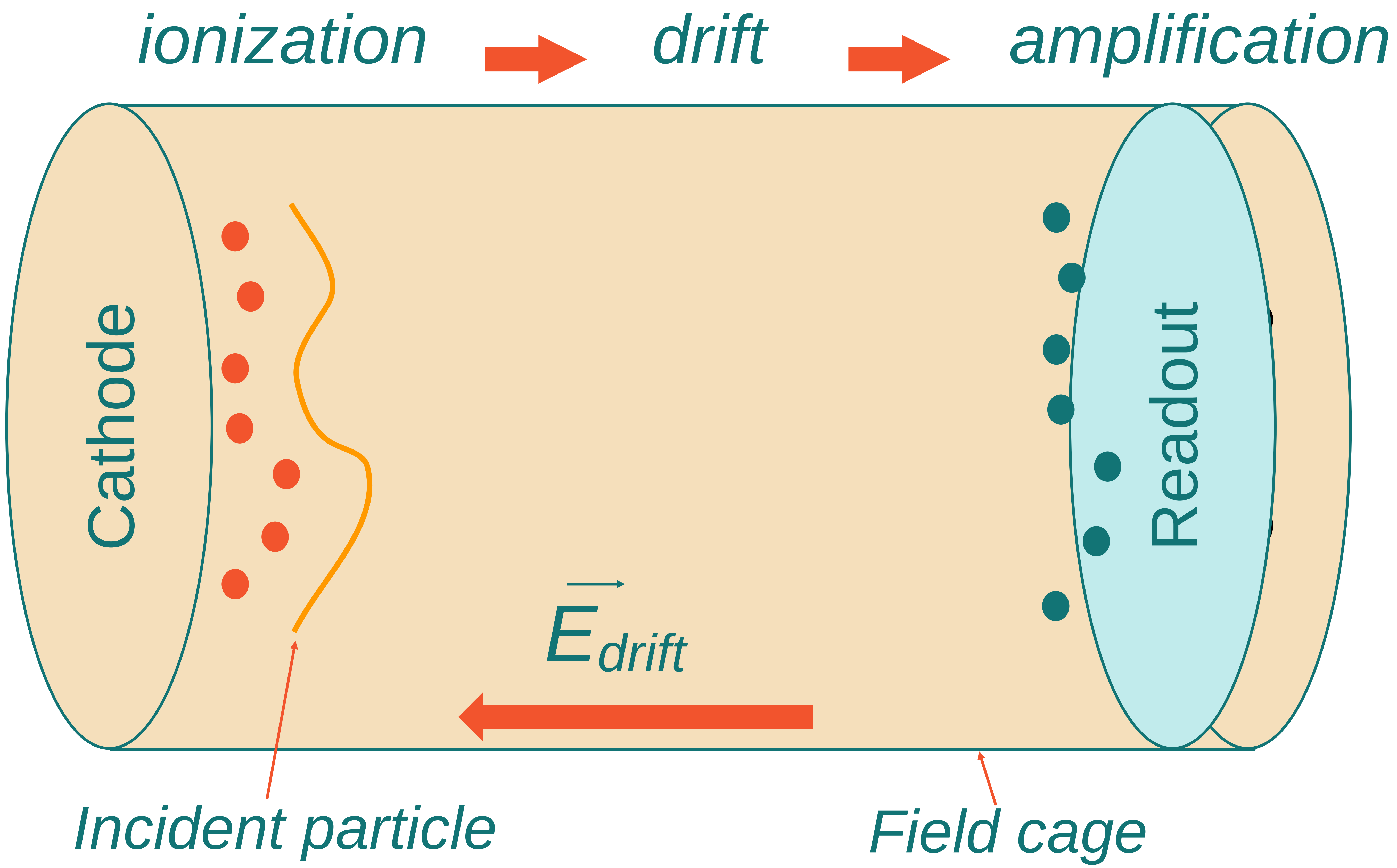
… start to drift in the direction of the anode and the cathode where …

TPC Detector in a nutshell



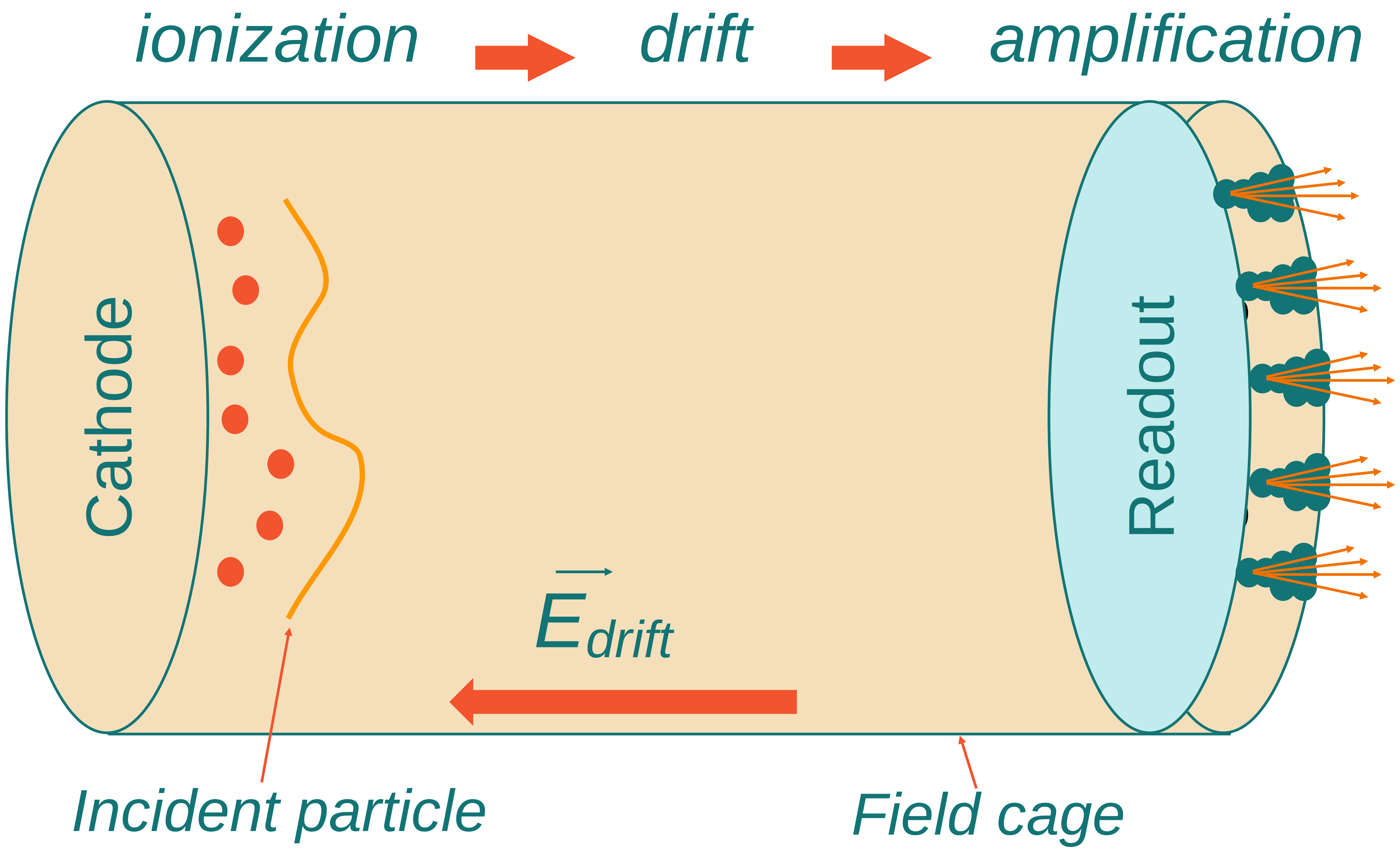
… a readout device is placed.

TPC Detector in a nutshell



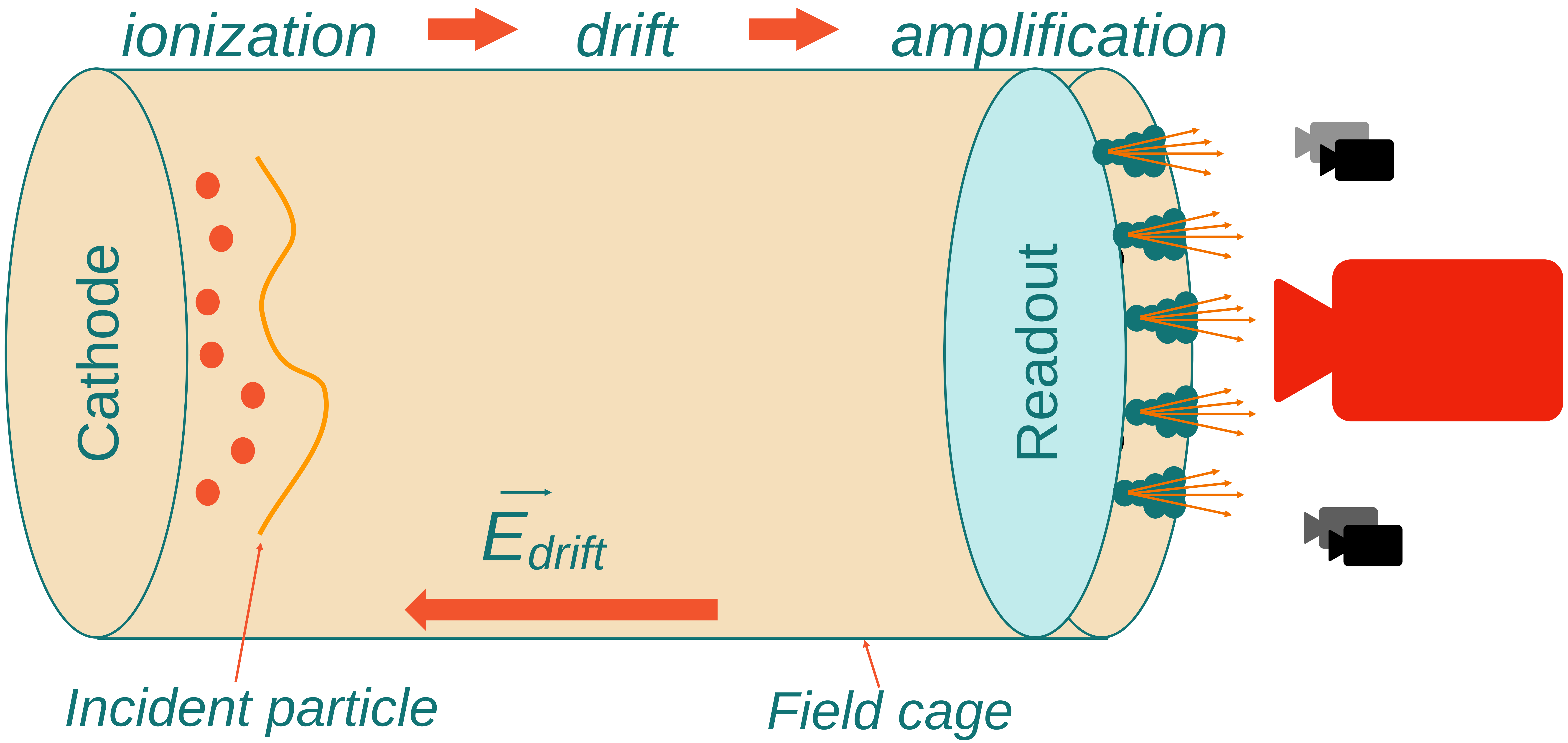
In CYGNO gas TCP an amplification process by means of triple **Gas Electron Multiplier** (GEM) and produce an avalanche of electrons …

TPC Detector in a nutshell



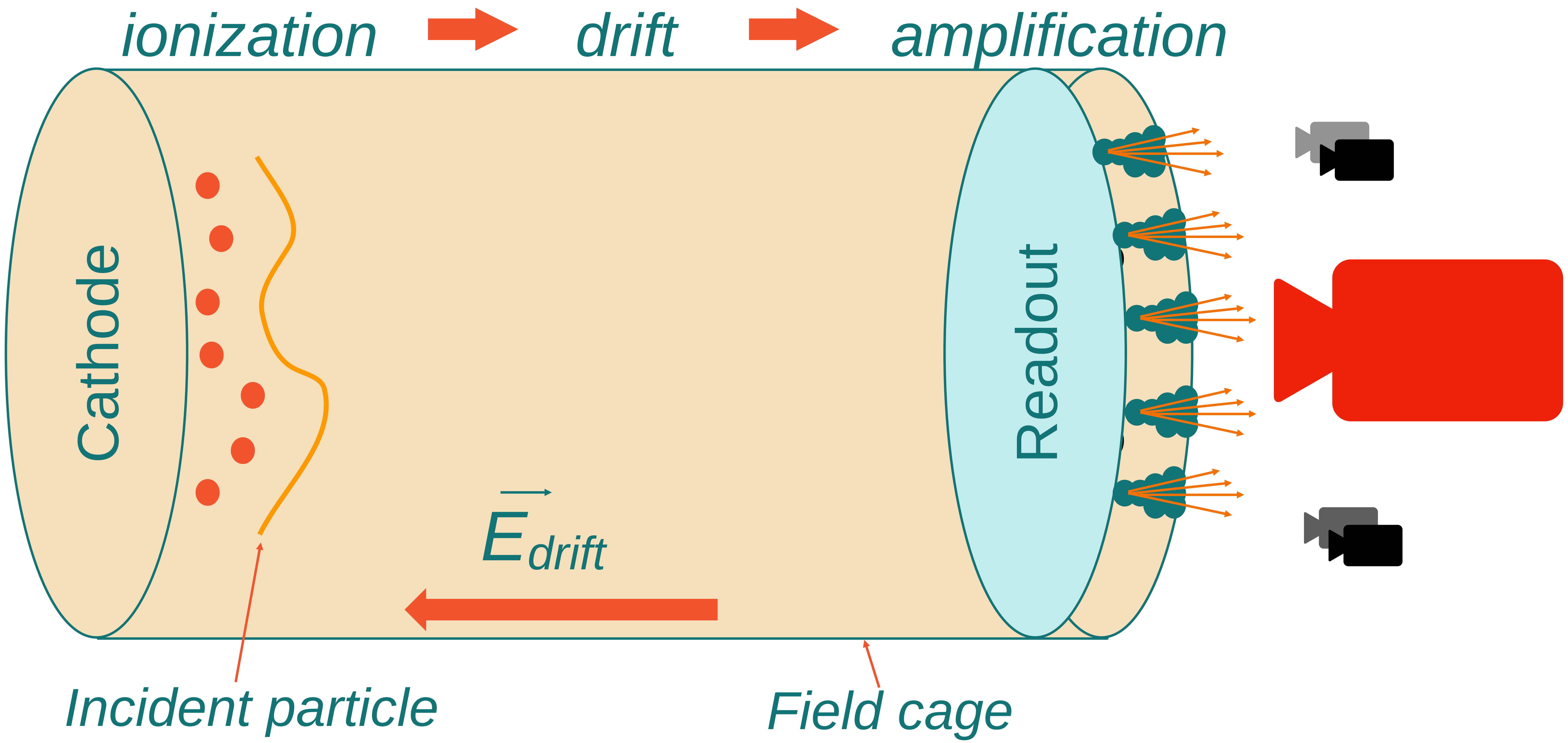
… that generate photons with an efficiency ~ 7% in HeCF4 gas mixture.

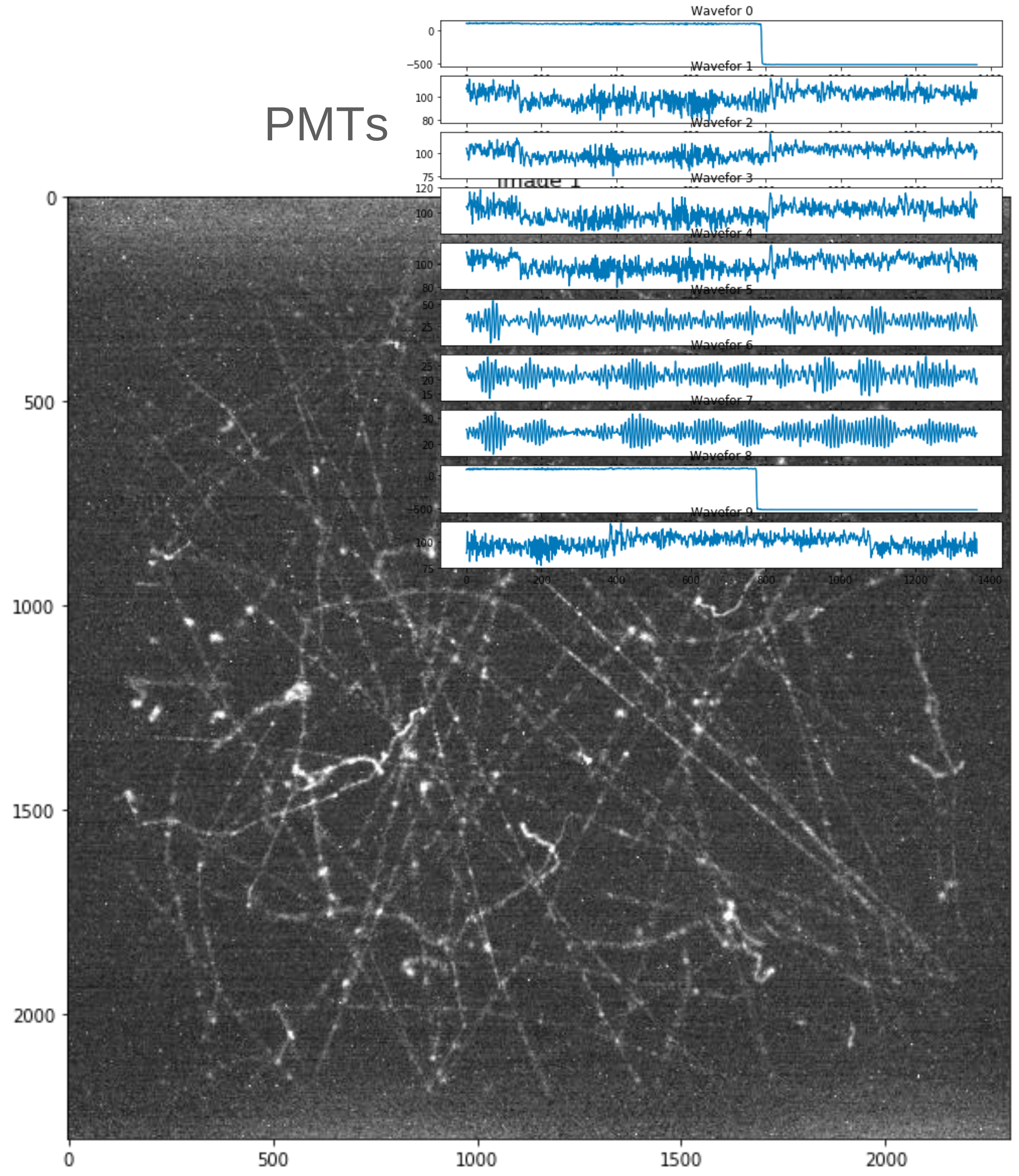
optical readout in a nutshell



an **sCMOS** camera 2304×2304 resolution, 0.7 electrons rms and **PMTs** for the time shape longitudinal evolution

optical readout in a nutshell

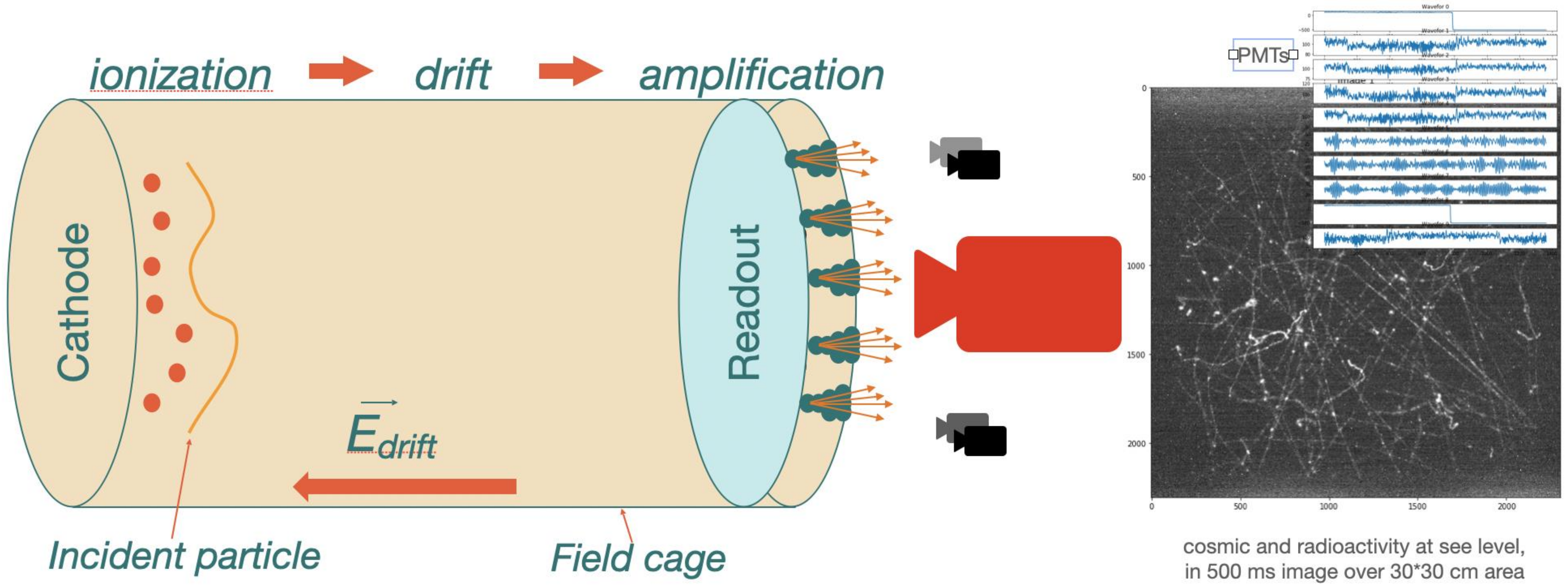




cosmic and radioactivity at see level,
in 500 ms image over 30*30 cm area

CYGNO prototype under test at LNGS

validating montecarlo expectation and testing HW/SW



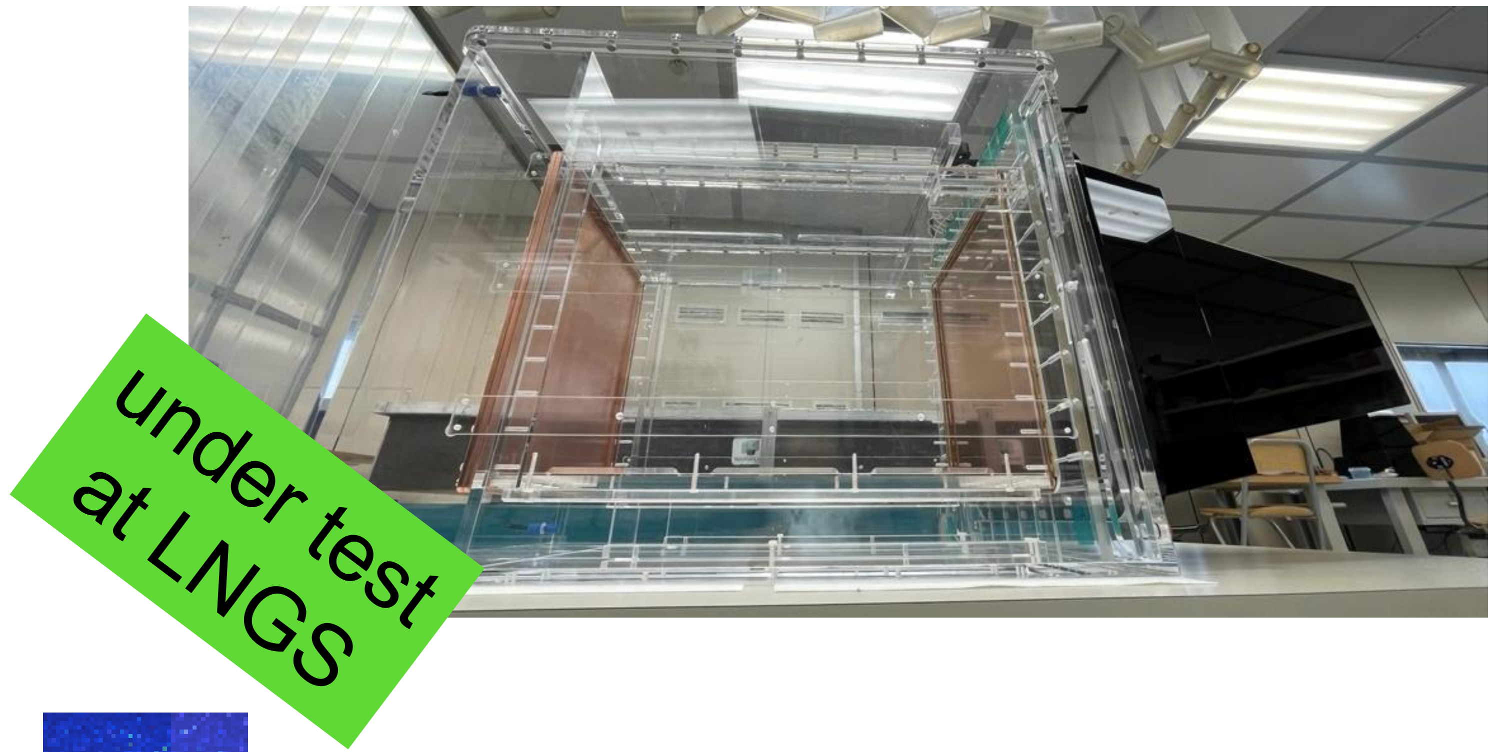
cosmic and radioactivity at see level,
in 500 ms image over 30*30 cm area

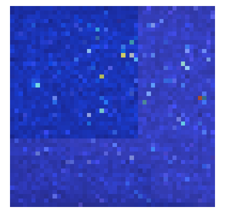
- testing data taking, calibration and reconstruction, and analysis algorithms
- comparing data and monte-carlo full simulation
- validating ancillary system like gas system, DAQ, computing infrastructure

CYGNO project objective

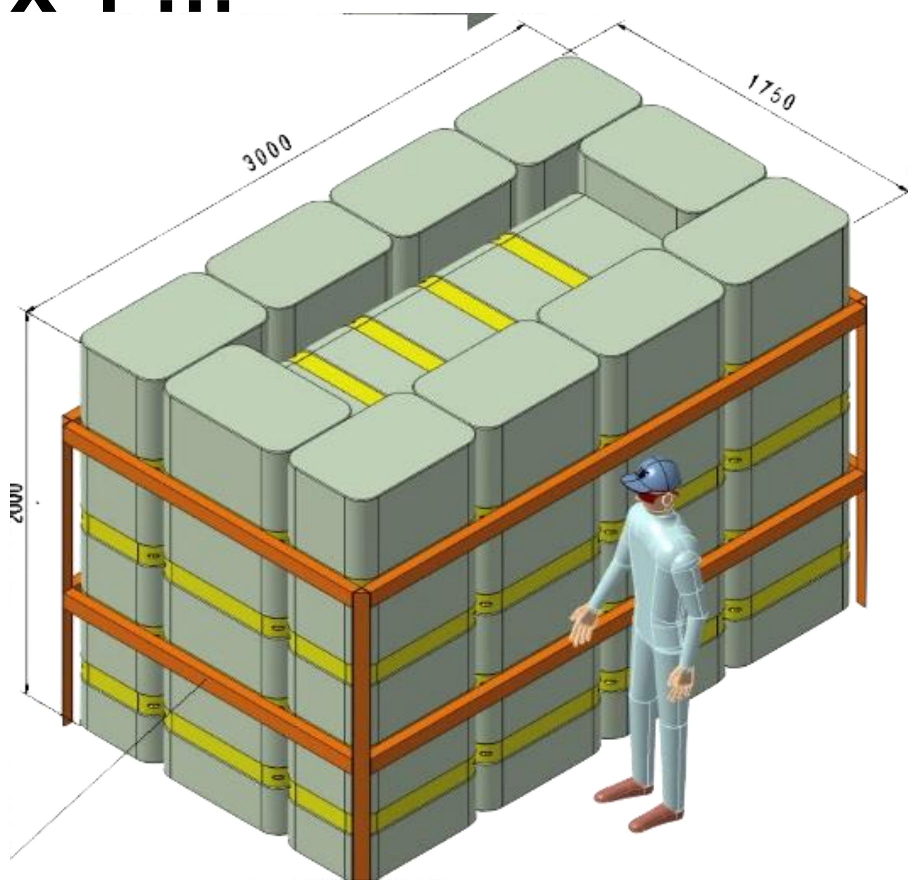
demonstrate the technique and …

LIME





x 1 …

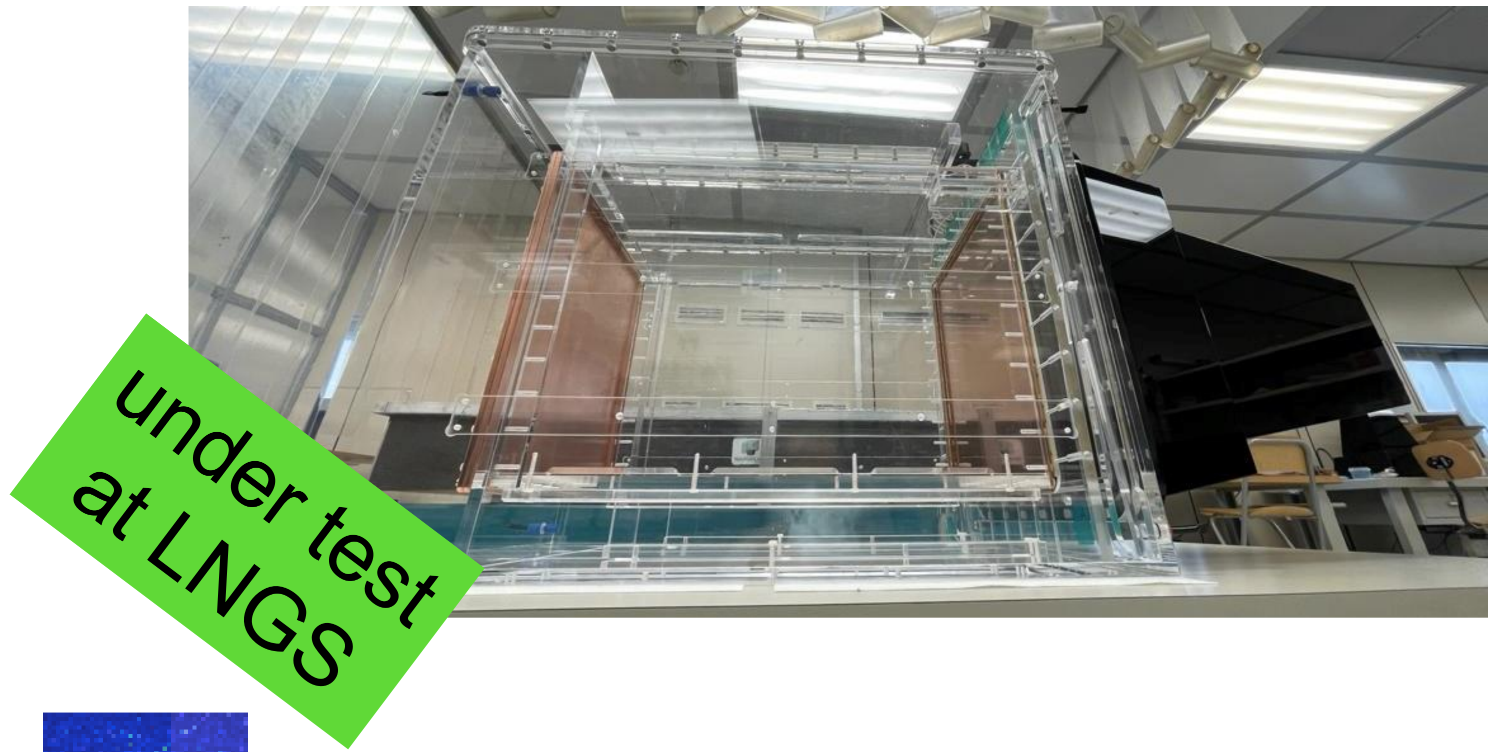


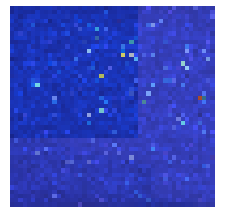
5*10 litres, 1 camera
10 MB/event 0.9 Hz

CYGNO project objective

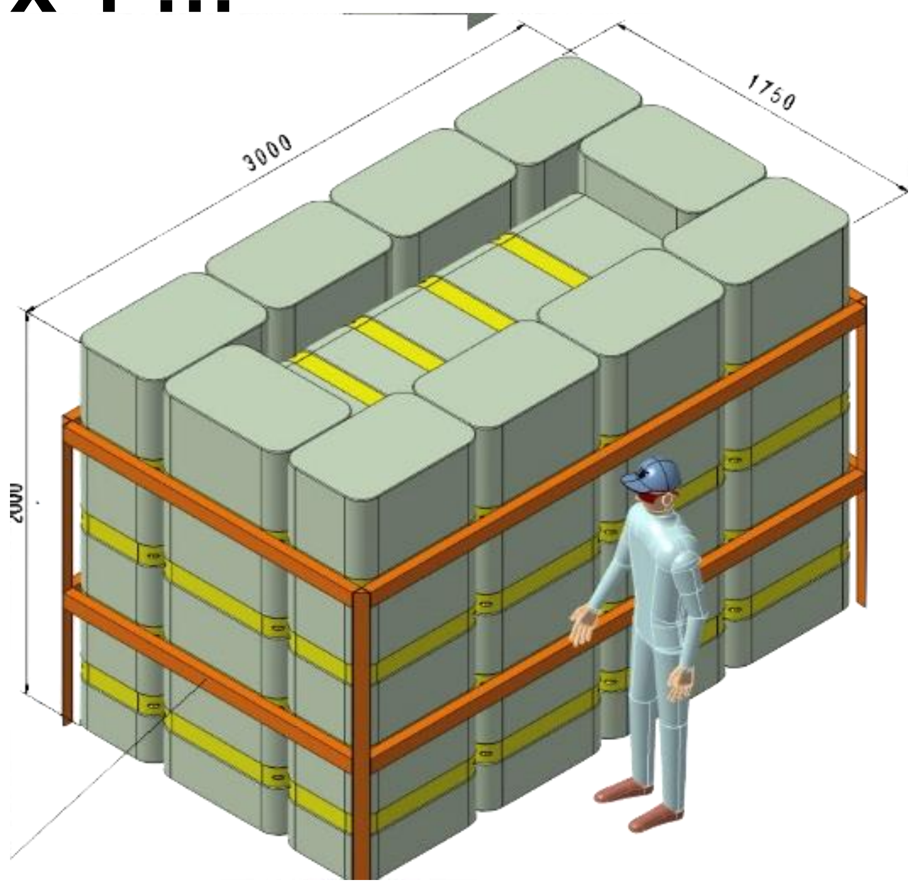
demonstrate the technique and feasibility of …

LIME



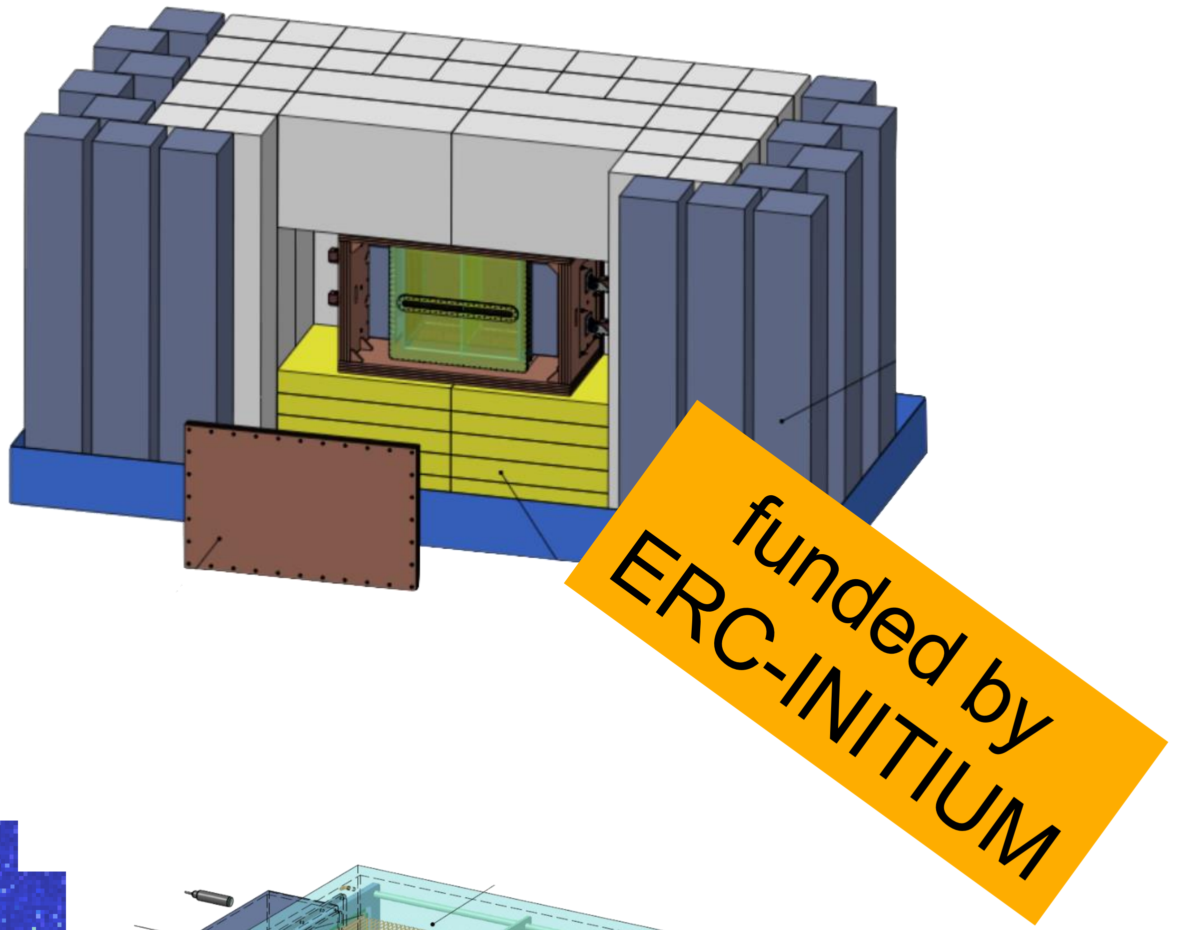


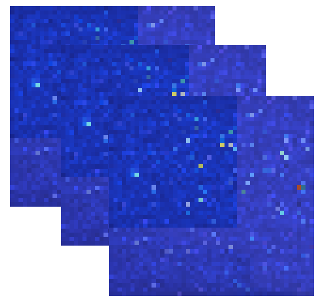
x 1 …



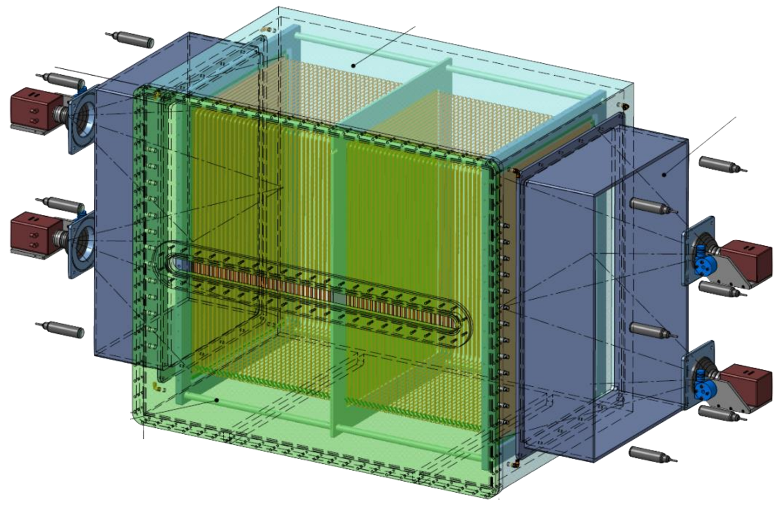
5*10 litres, 1 camera
10 MB/event 0.9 Hz

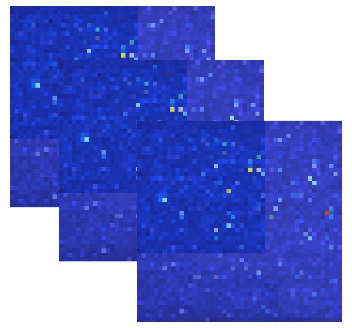
CYGN04





x 3 …





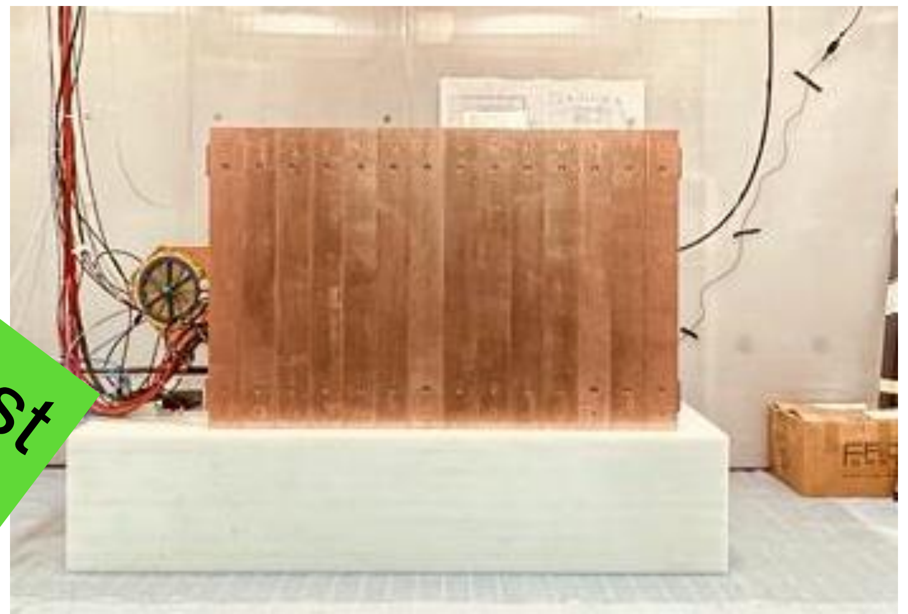
x 3 …

4*10^2 litres, 4 cameras
110 MB/event (Hz ?)

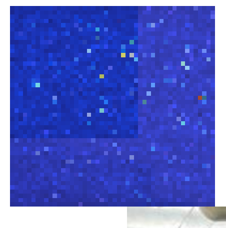
CYGNO project objective

demonstrate the technique and feasibility of large scale detector

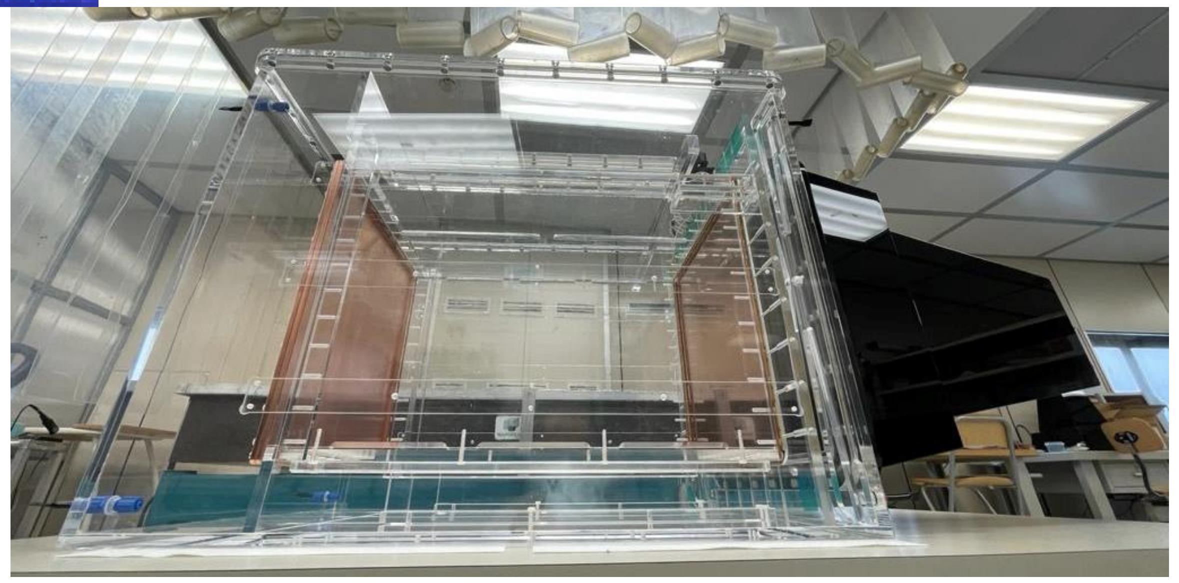
prototype



under test at LNGS

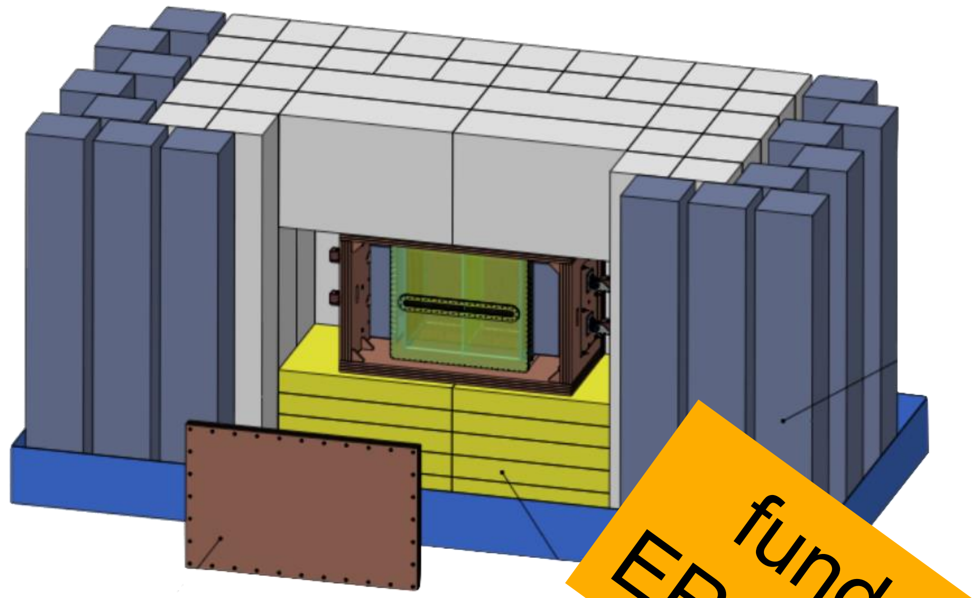


x 1 …

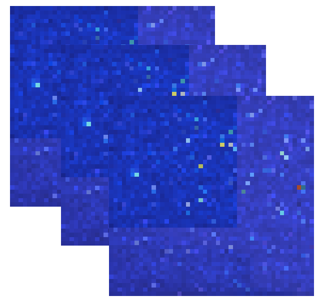


5*10 litres, 1 camera
10 MB/event 0.9 Hz

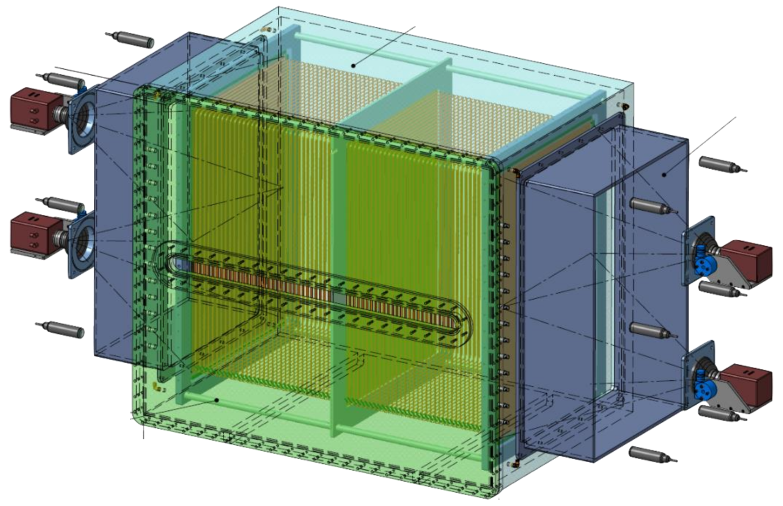
CYGN04

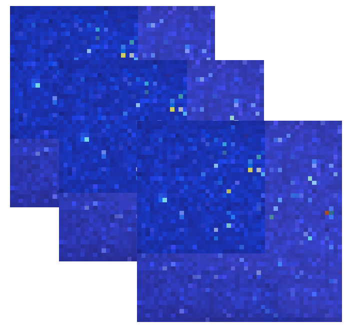


funded by ERC-INITIUM



x 3 …

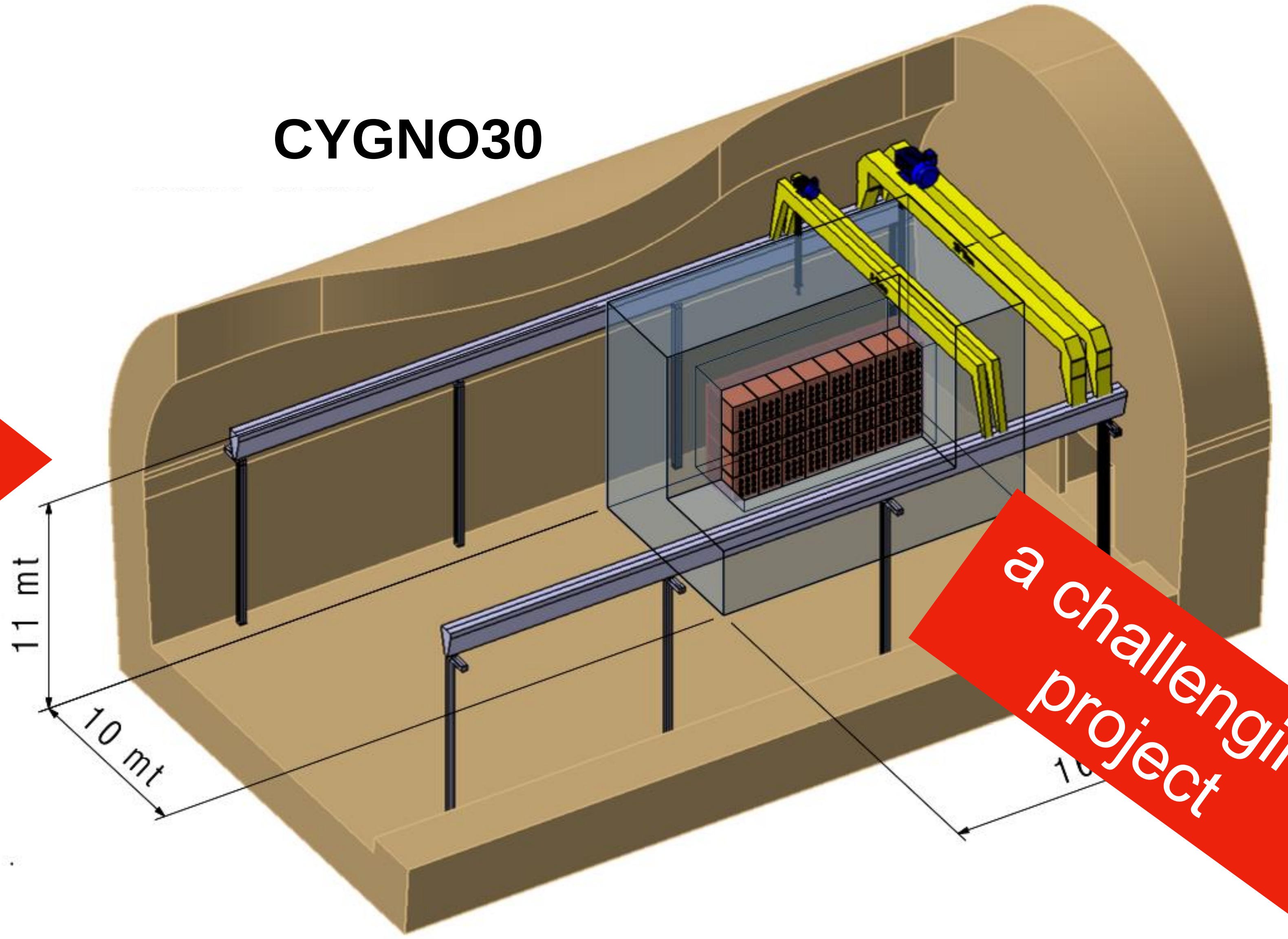




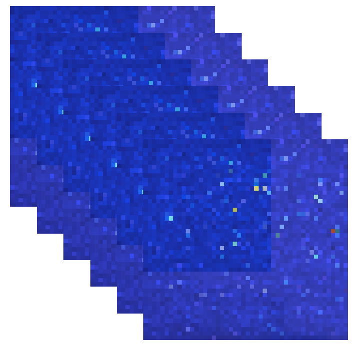
x 3 …

4*10^2 litres, 6 cameras
110 MB/event (Hz ?)

CYGNO30



a challenging project



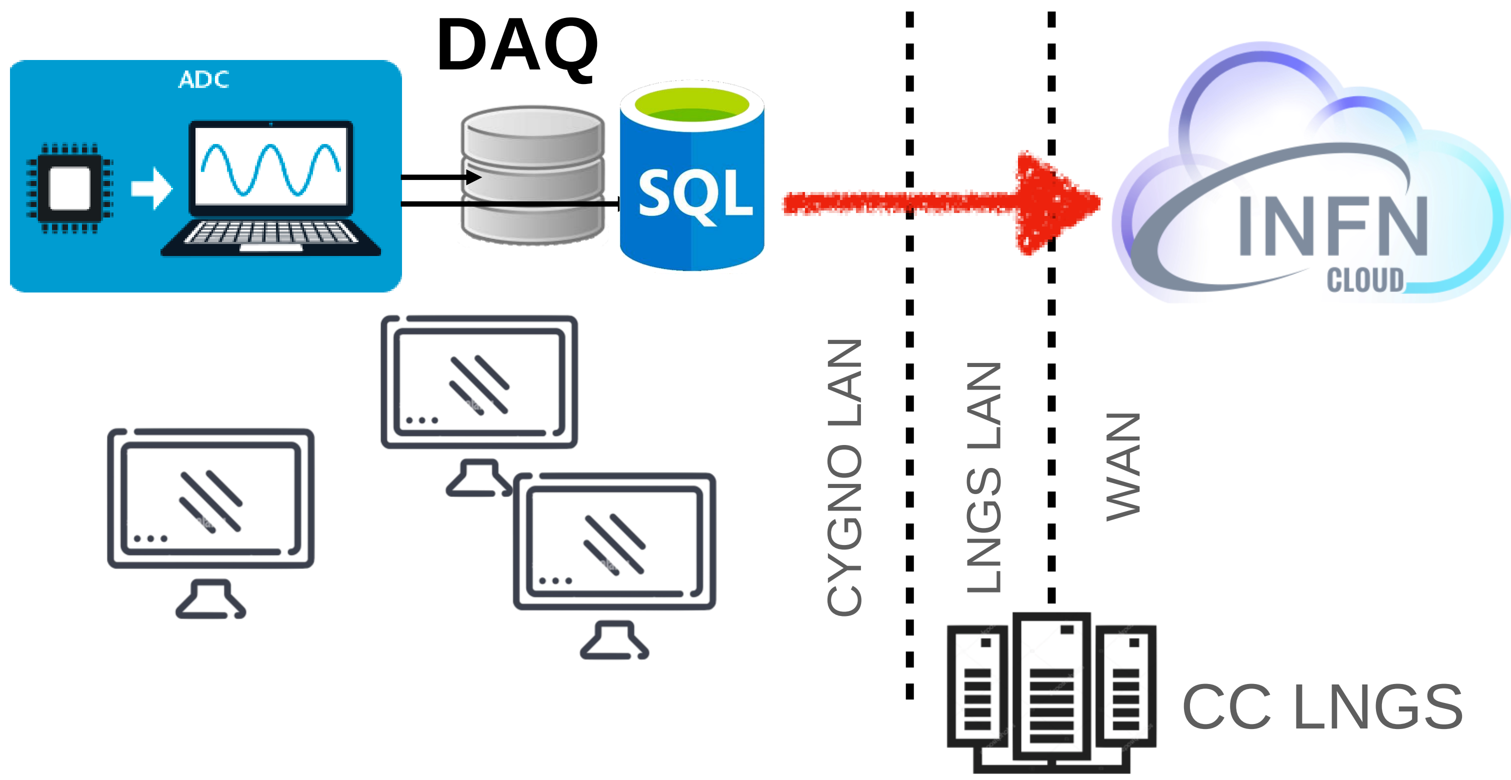
x N …

3*10^4 litres, > 100 cameras
2 GB/event (Hz ?)

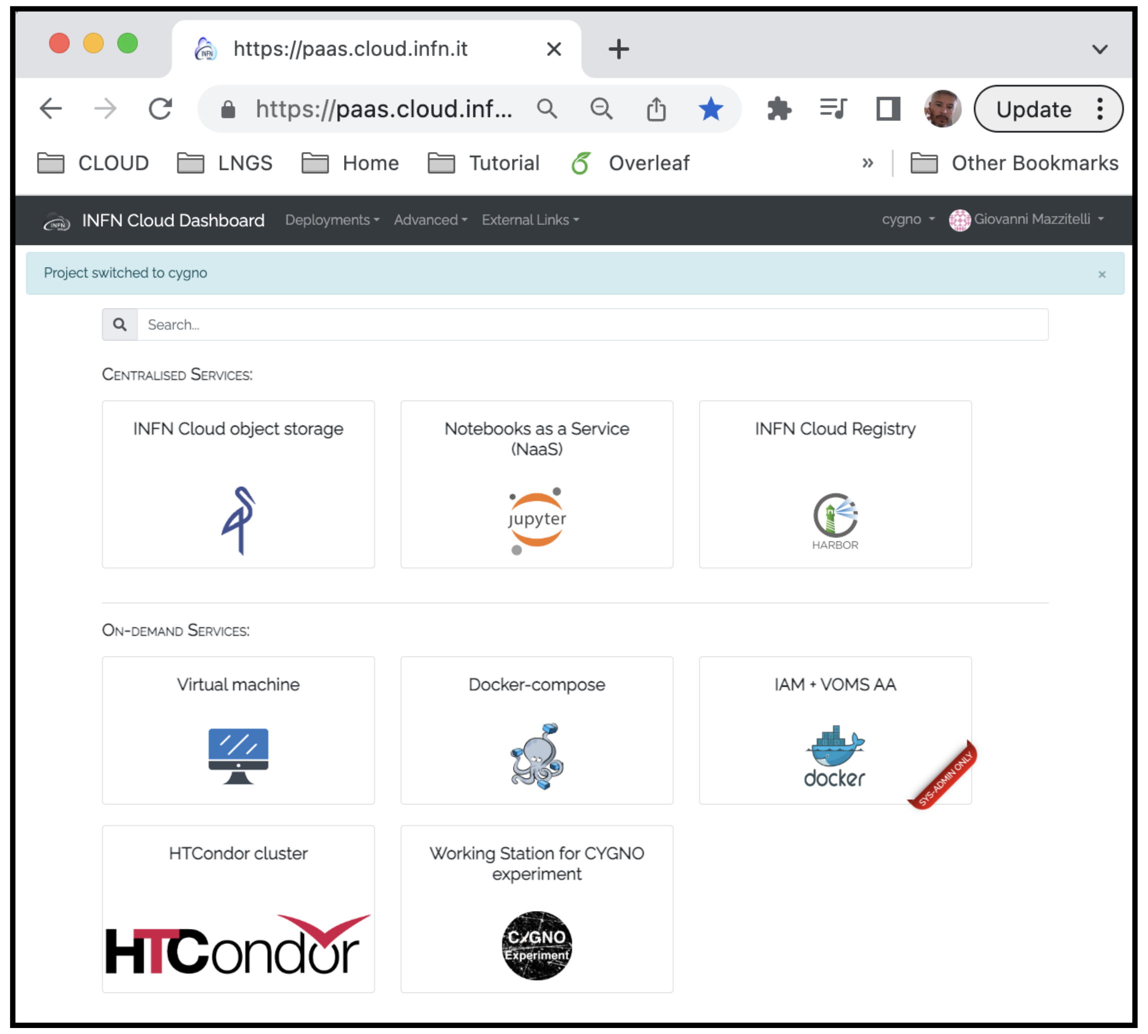
the INFN-Cloud infrastructure

data management and online data validation and qualification

- the CYGNO project is hosted in the **underground laboratory of LNGS** where it is recommended to have only the **minimum setup** necessary to collect data on a local buffer
- many experiments in the past decide to host their computing infrastructure in **CC of LNGS**
- In 2020 started the **INFN-Cloud project**, offering many services at PaaS/SaaS level, optimal to host our computing model, ensuring the characteristics of scalability, safety, reliability etc.
- in collaboration with the INFN-Cloud we **integrate and develop a sets of tools** for data management, analysis and simulation available at **user level** and accessible and exploitable to all the CYGNO international collaborators



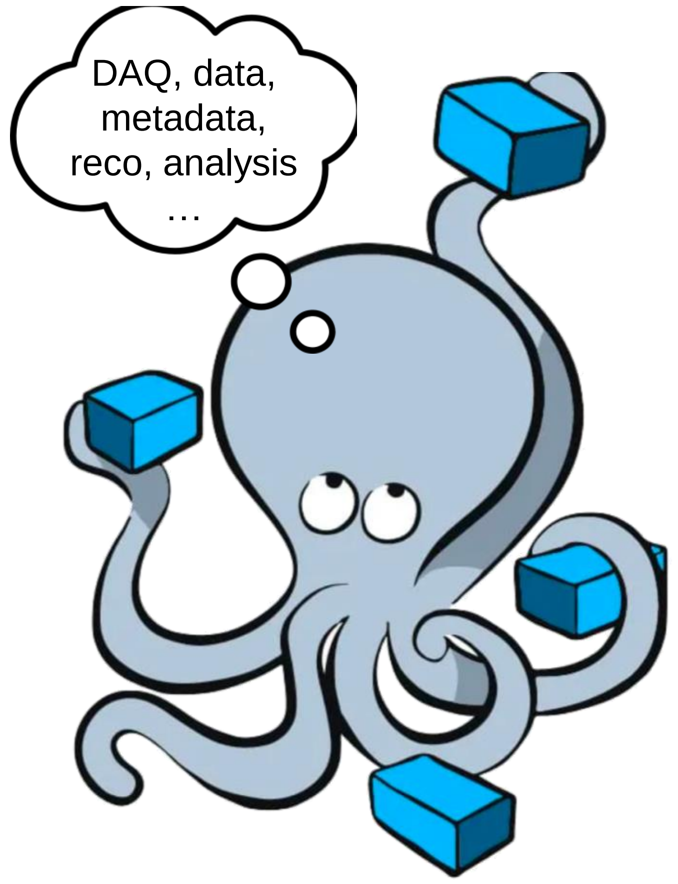
CYGNO-INFN cloud dashboard



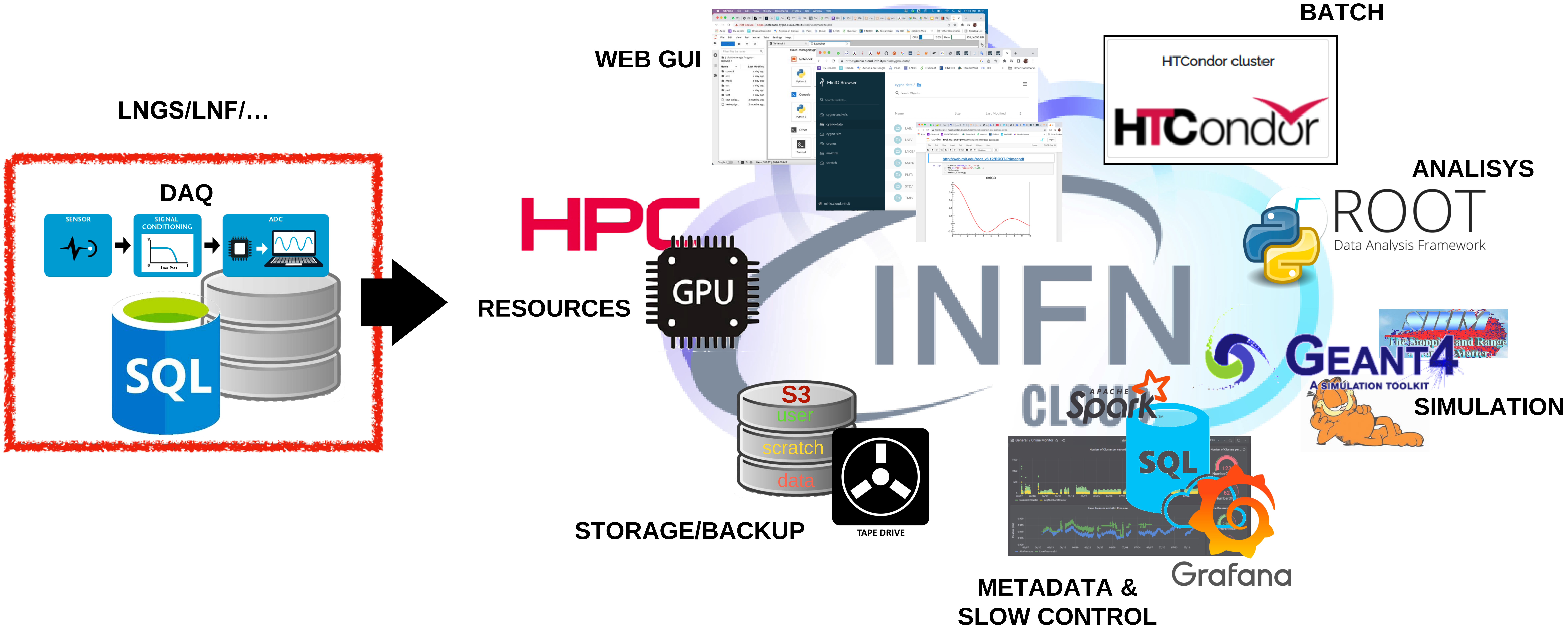
the middleware CYGNO project

data management and online data validation and qualification

- experiment **data management**;
- experiment front end **metadata** production and management;
- slow/fast remote **experiment monitor** without access to LAN DAQ (shift workers from all over the world);
- online data **reconstruction** and **pre-analysis**;
- online data **validation** and **qualification**;
- high level/back end metadata production and management, **alarms and warnings** dispatcher also via discord experiment channel.

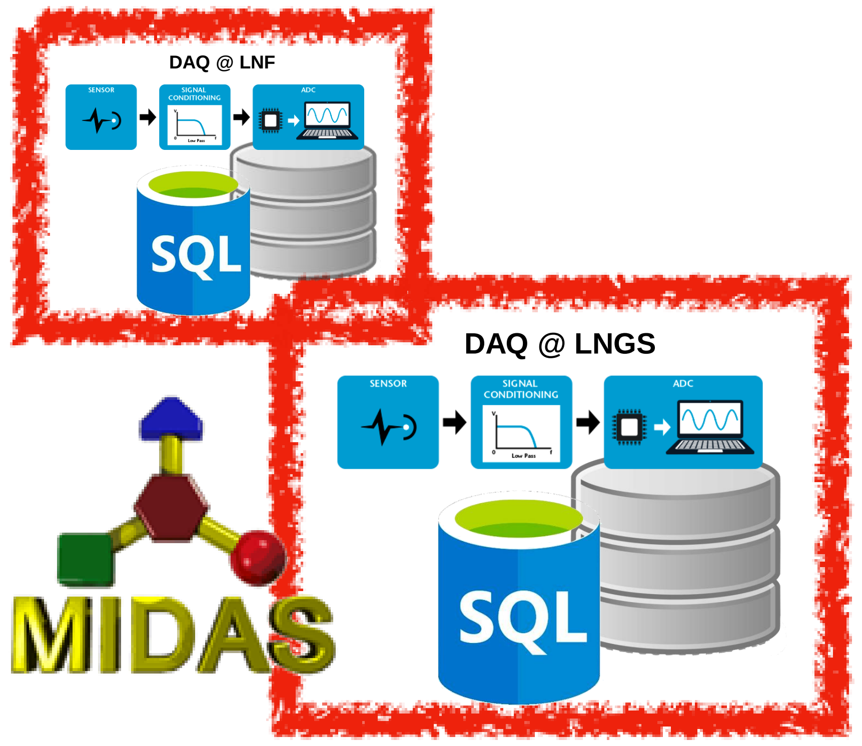


CYGNO… computing model



logical units, “composed” services

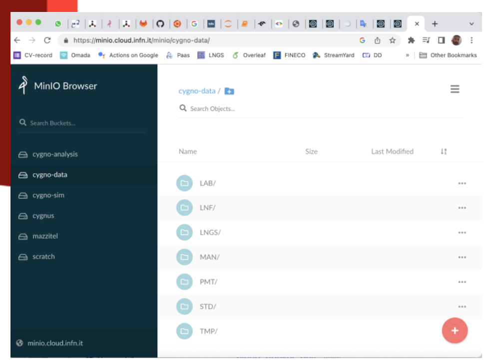
test and
development
setup at LNF



production
setup at LNGS

Mariadb replica
for metadata
sql.cygno.cloud.infn.it

S3 storage
minio.cloud.infn.it

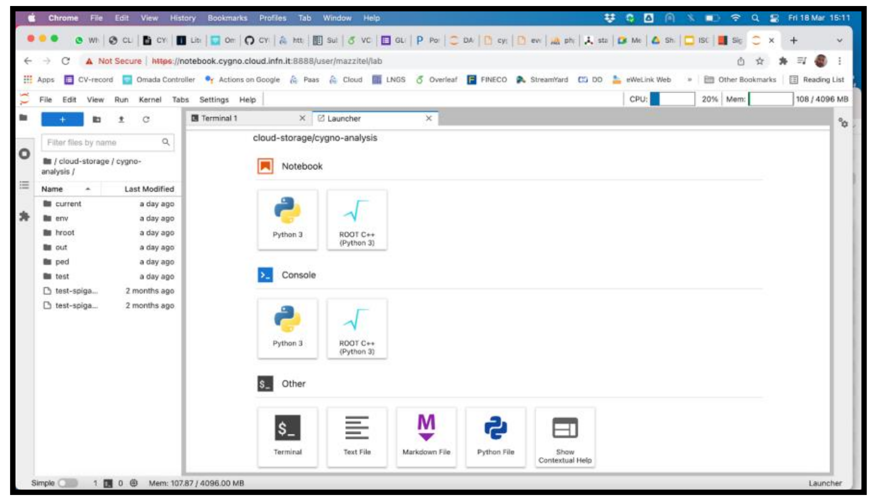


messaging
kafka.cygno.cloud.infn.it

Identity and Access Management
iam.cloud.infn.it

data and metadata monitor
grafana.cygno.cloud.infn.it

analysis and simulation
web interfaces
notebook01.cygno.cloud.infn.it
notebook02.cygno.cloud.infn.it



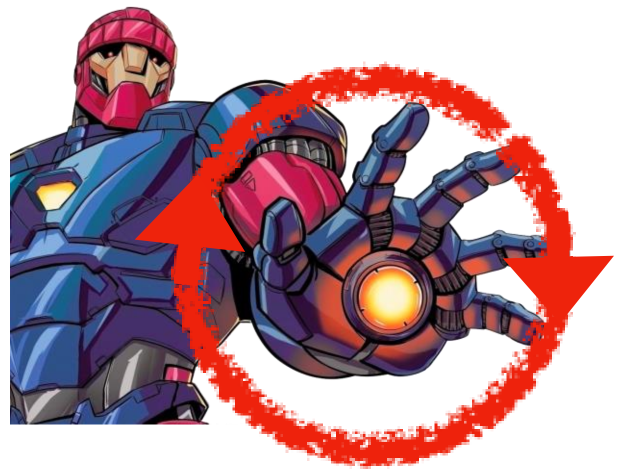
batch queues
condor01.cygno.cloud.infn.it
condor02.cygno.cloud.infn.it

HTCondor cluster

backup
tape.cygno.cloud.infn.it

TAPE DRIVE

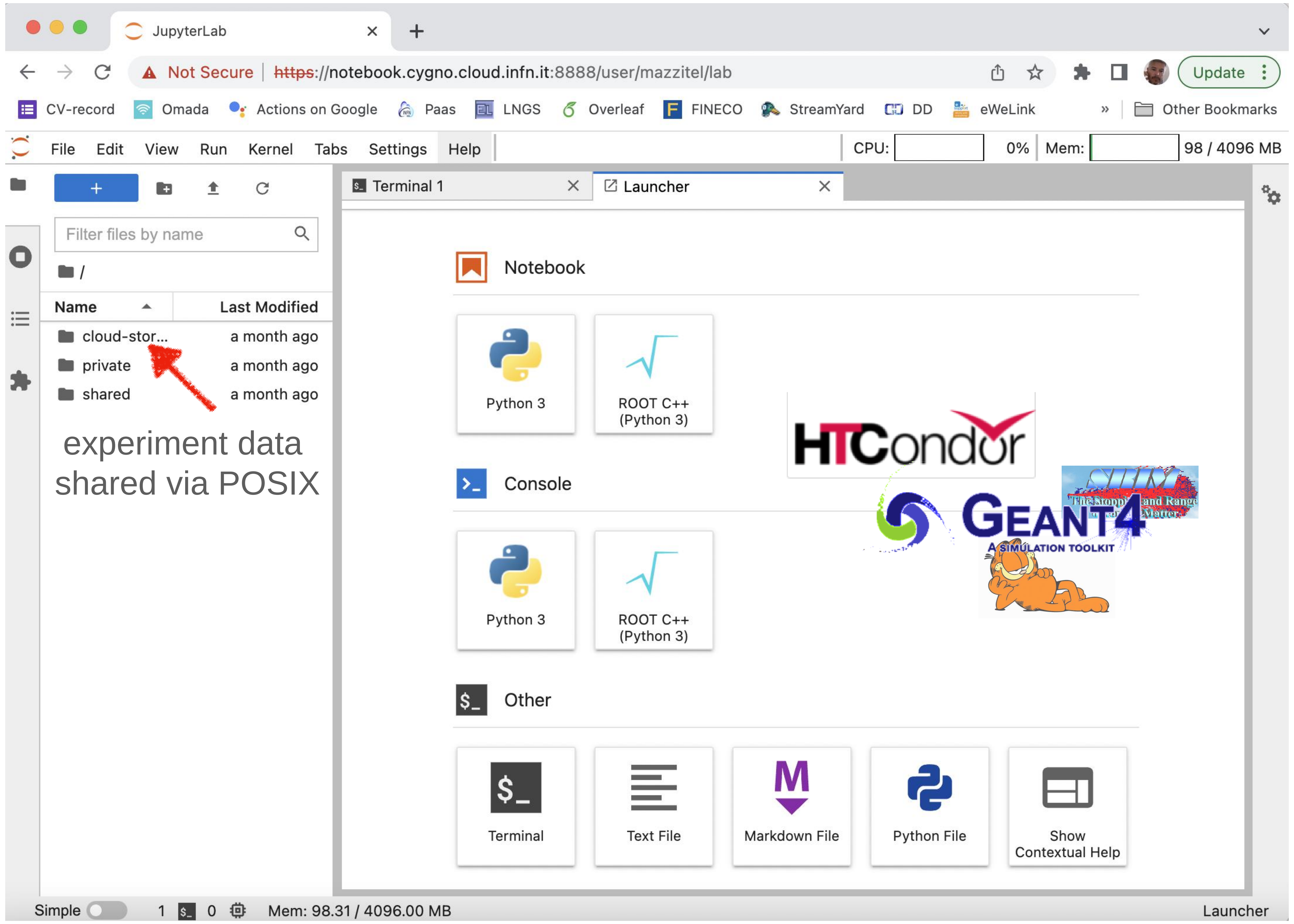
pre analysis and data quality
sentinel.cygno.cloud.infn.it



the user interface and services

multi-user platform integrated with INDIGO IAM authentication and authorisation, batch system, analysis and simulation software

- the tool is based on “**Dynamic On Demand Analysis Service (DODAS)**” project that allows the integration of cloud storage for persistence services with **analysis** (python/root/ecc) and **simulation software** (GEANT/GARFILD/ecc).
- **notebooks/consoles** for scripting in python and root; **terminals; editor; data access via POSIX** (FUSE simulated)
- **batch system on demand**: from the interface the experiment HTCondor queues can be reach to submit and control job
- **user interface** and **work node** software running on the queues is managed by the experiment and can be easily update on user request.



WHAT NEXT → integrate **CVMFS:** scalable, reliable and low-maintenance **software distribution** service

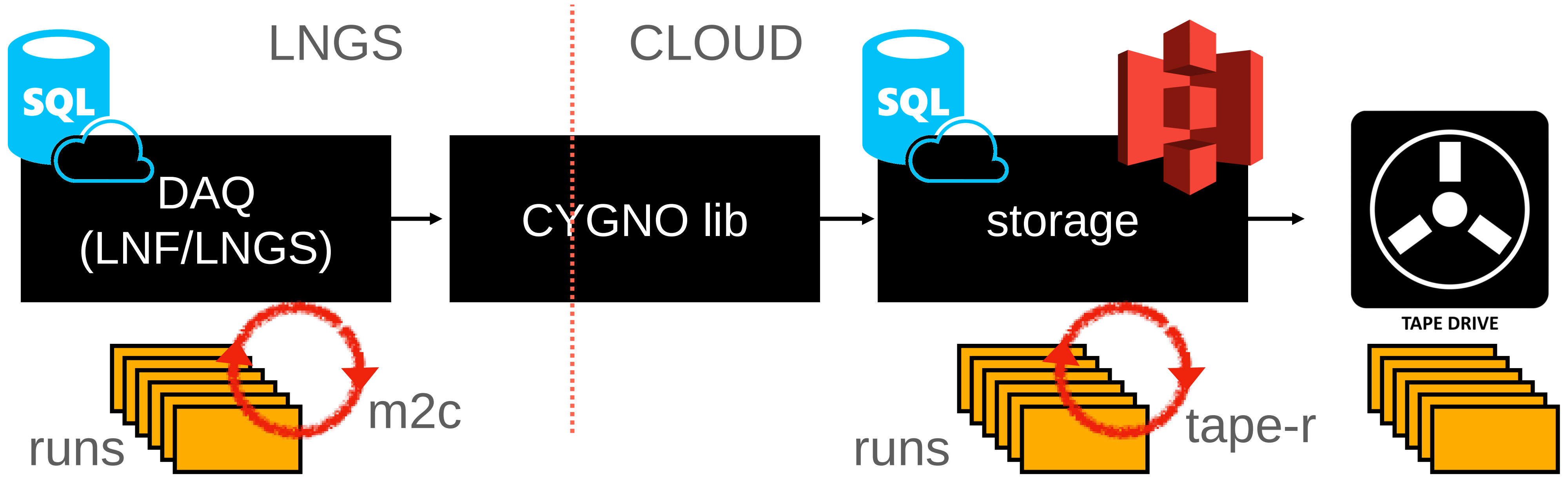
data management

the "tape-r"

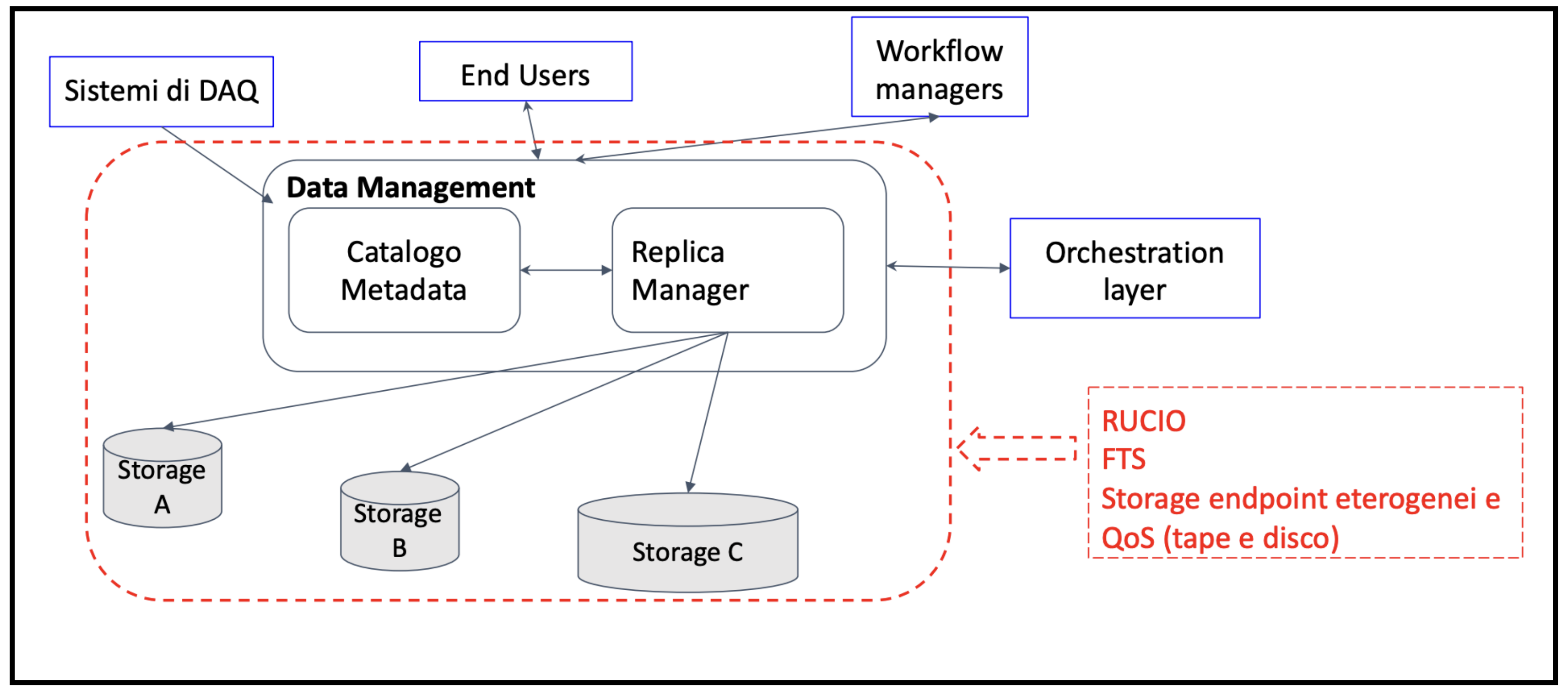
- data by means **m2c process**, bunched in runs, are copied on **S3 object storage**, as well as **metadata**, locally stored and replicated on cloud MariaDB;
- a few second after the run is closed, it is available for **full reconstruction** on the cloud HTcondor queue and can be **downloaded** with various tools (web, rest api, POSIX, ecc);
- the **"tape-r" process** replicate **data** on tape and update **metadata** of the run status**;**
- TAPE **@CNAF token-based access** in the next future is going to be integrated in **RUCIO** as cloud services for more complete and generalised data management system

TAPE DRIVE

data replica dashboard



WHAT NEXT



data reconstruction pipeline

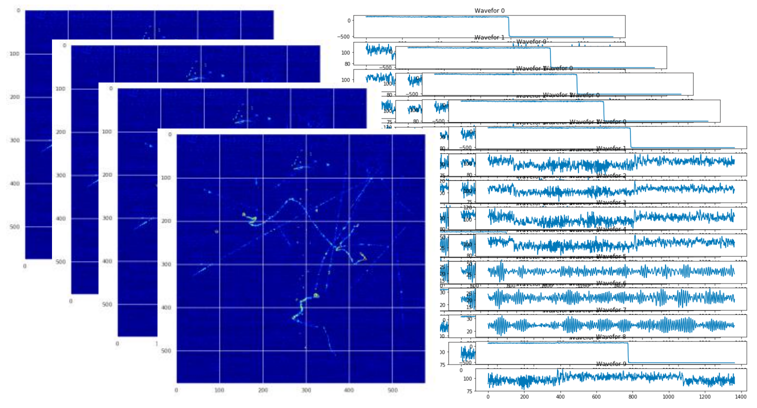
offline/online process

data preparation
zero suppression
noise filters
optical corrections

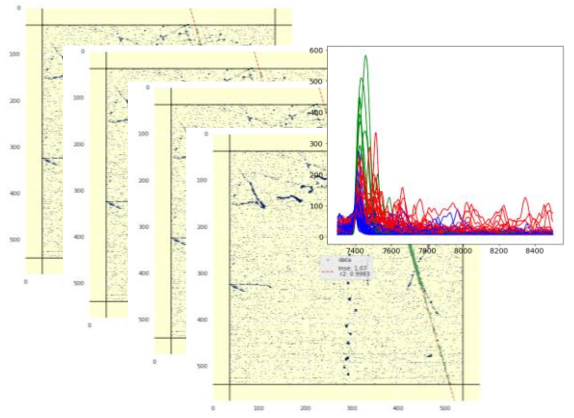
reconstruction
clustering &
superclustering
PMT info evaluation

sCMOS images

PMT waveforms

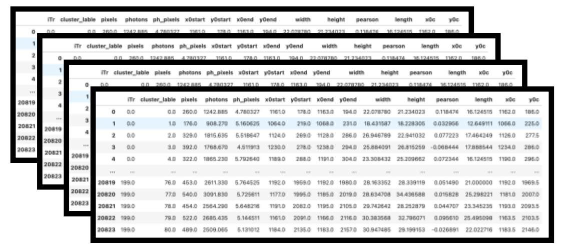


RAW events
calibration source, radioactivity,
cosmic rays, Dark Matter wind…



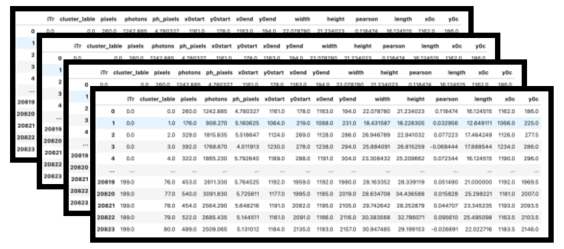
data "hits"

EVENTs data sets



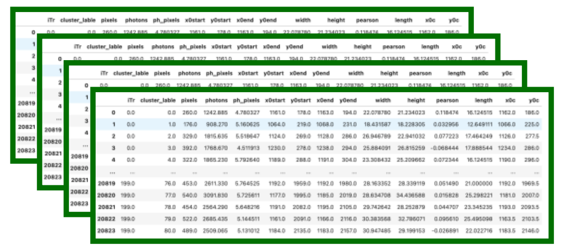
clusters features
PMTs features

multi-EVENTs data sets



post-processing
calibrations
high-level analysis

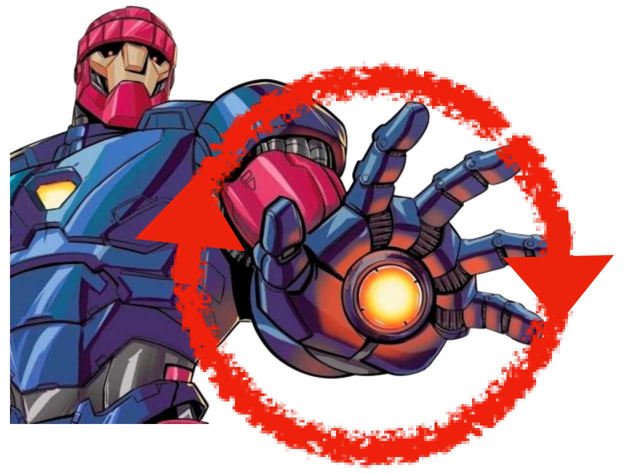
calibrated data sets



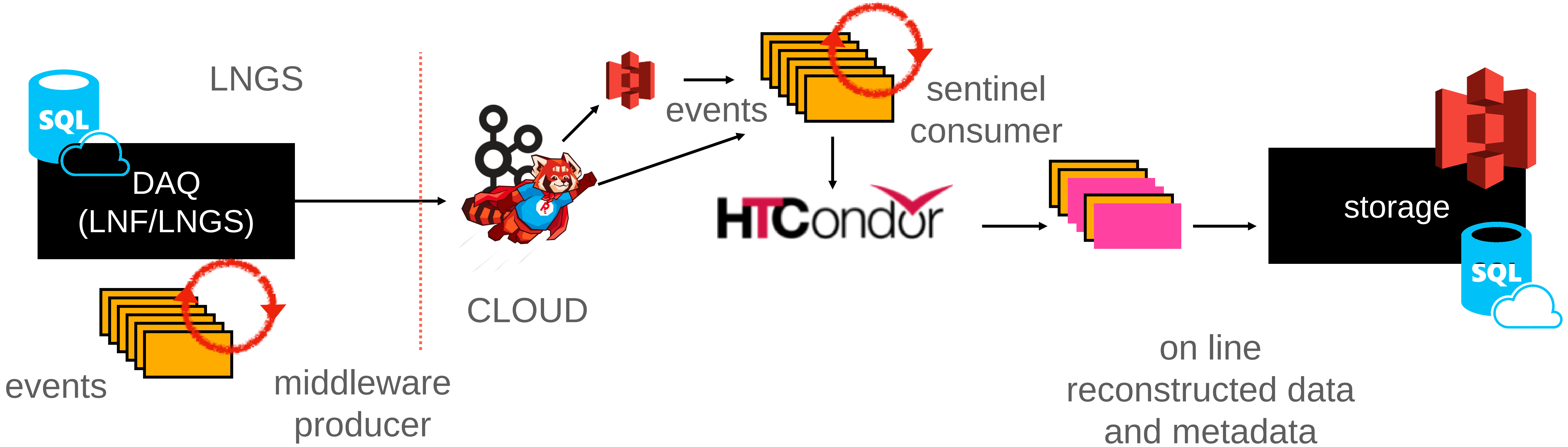
user analysis
physical outcomes

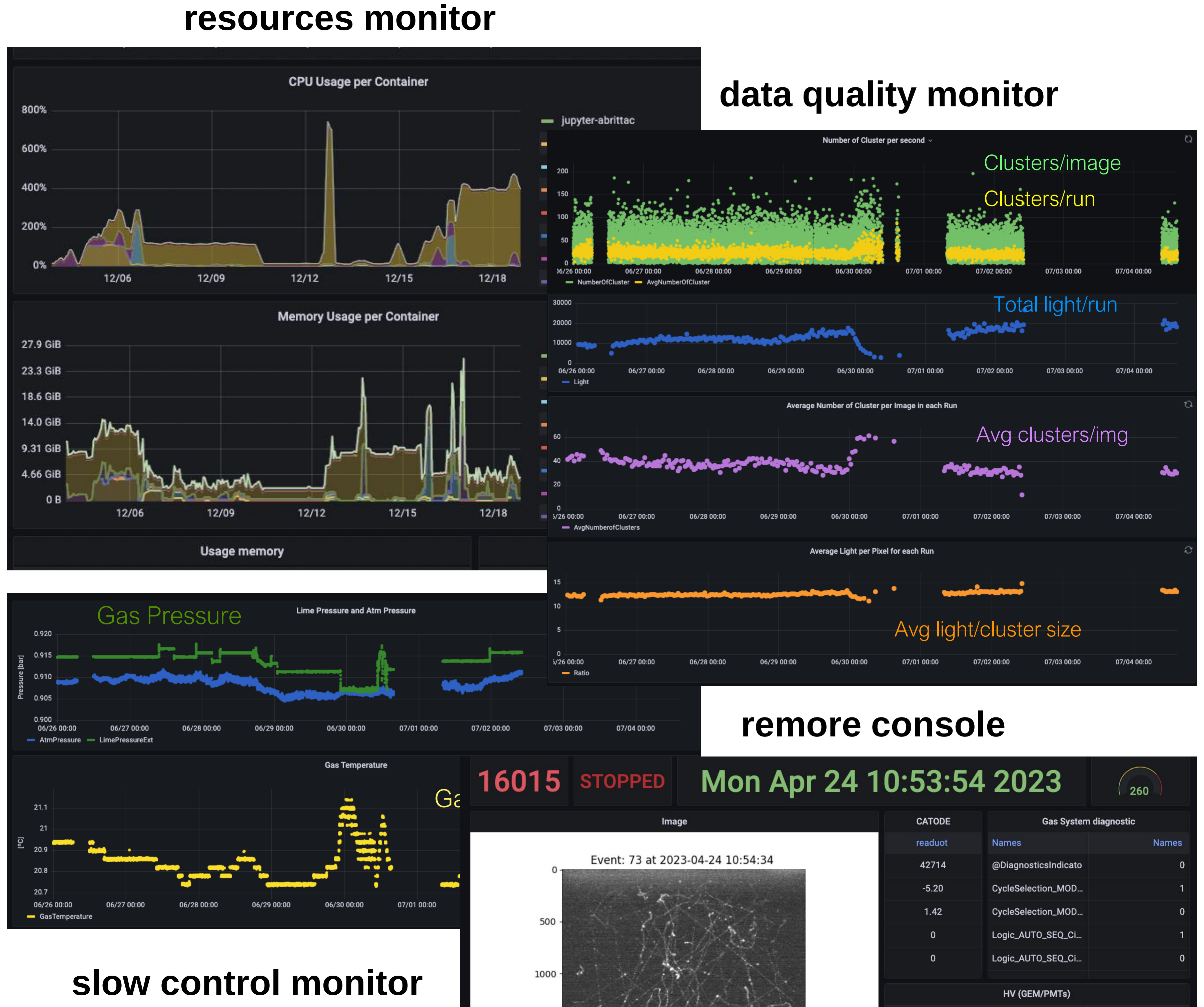
noise filter: median filter
optical correction: vignetting, optical distortion
superclustering: Geodesic Active Contour (GAC)

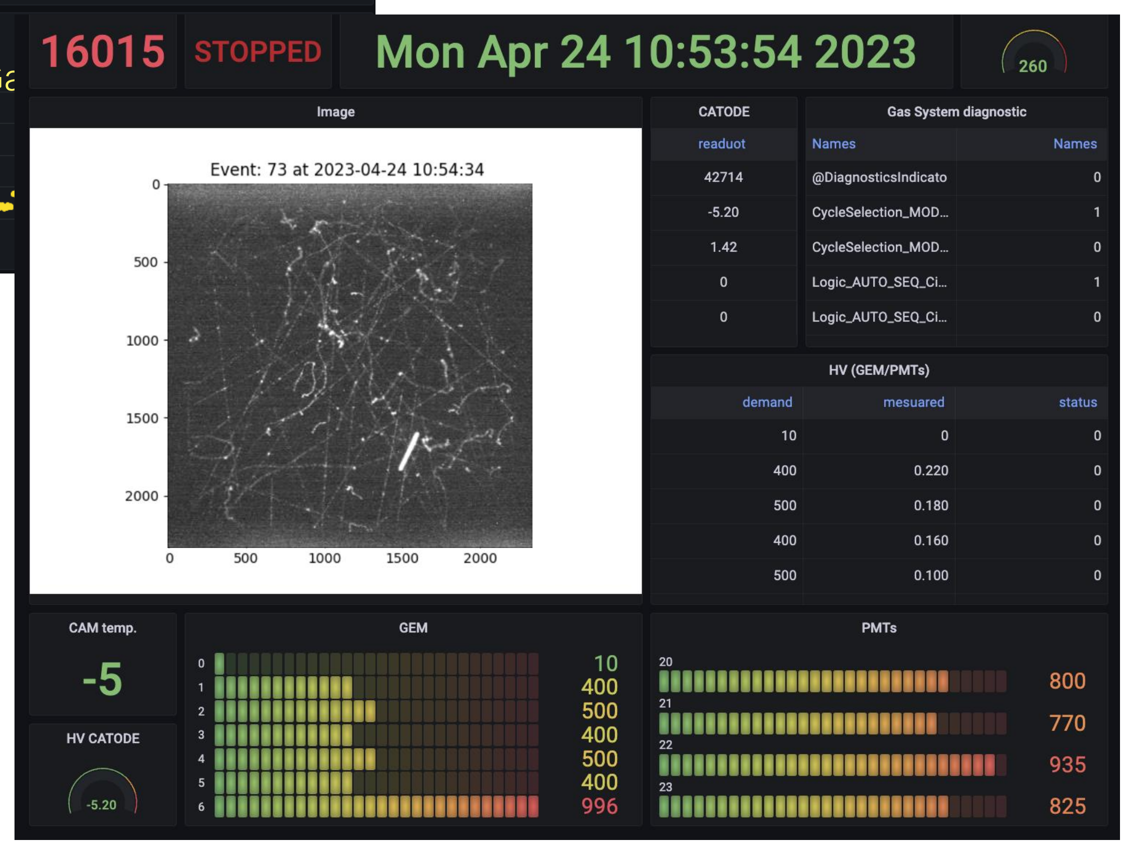
online data reconstruction



the “sentinel” - Data Transformation Service (DTS)



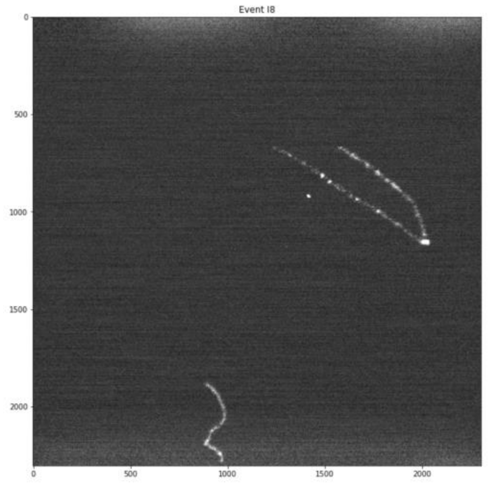


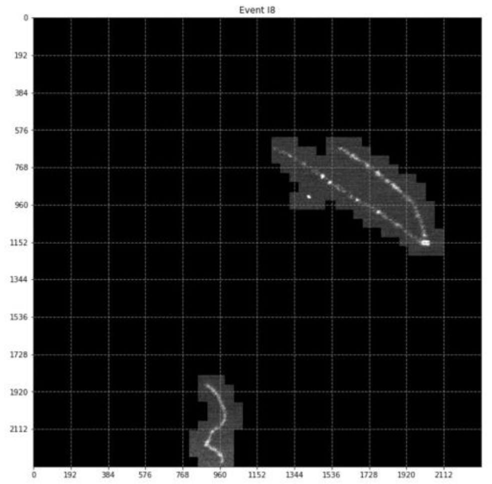


- parallel to run data management, sigle events are send to cloud by means of **kafka producer**
- the **sentinel** process consume data **parallelising the events reconstruction** on the HTCondor queues
- data and metadata are the stored and **presented** for on line motoring

WHAT NEXT

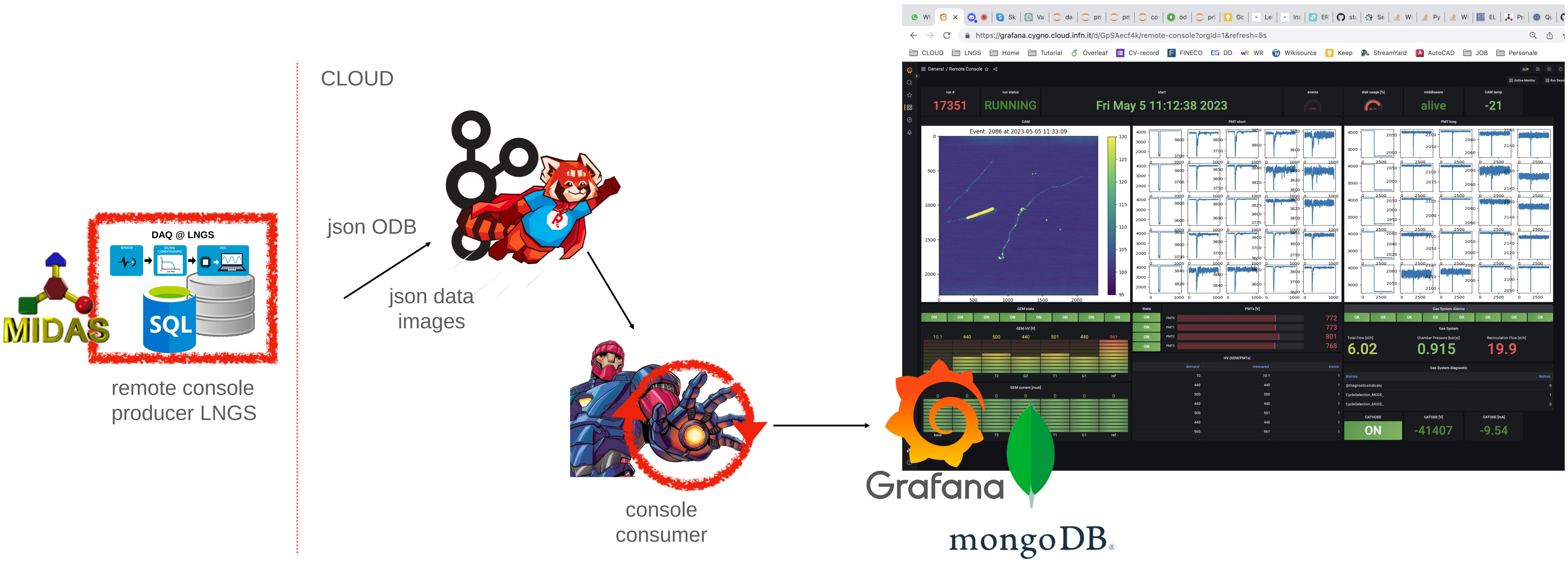
optimise/scale architecture to completely be able to provide online reconstruction
implement **data compression** (triggerless ML/GPU algorithms are under study)





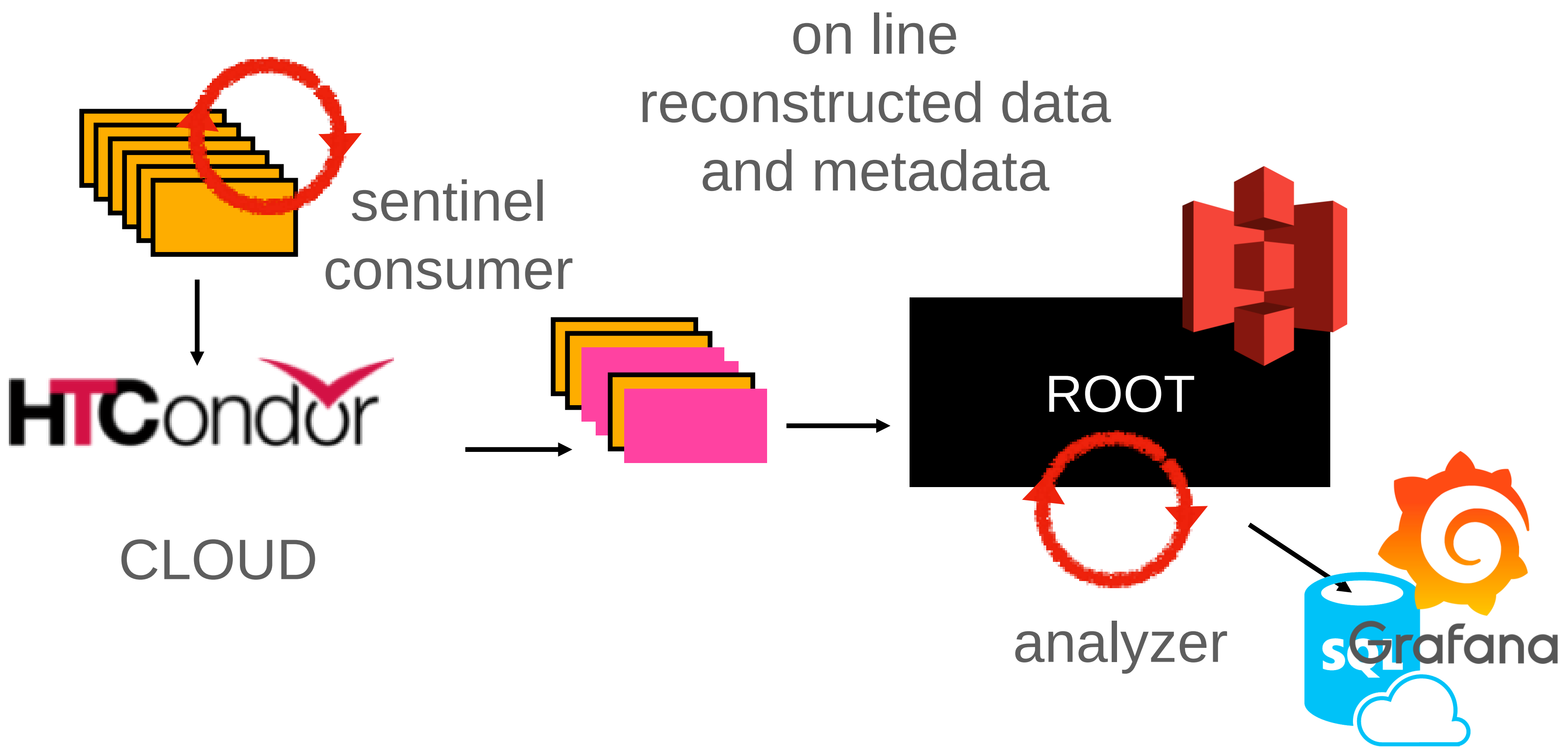
online experiment monitoring

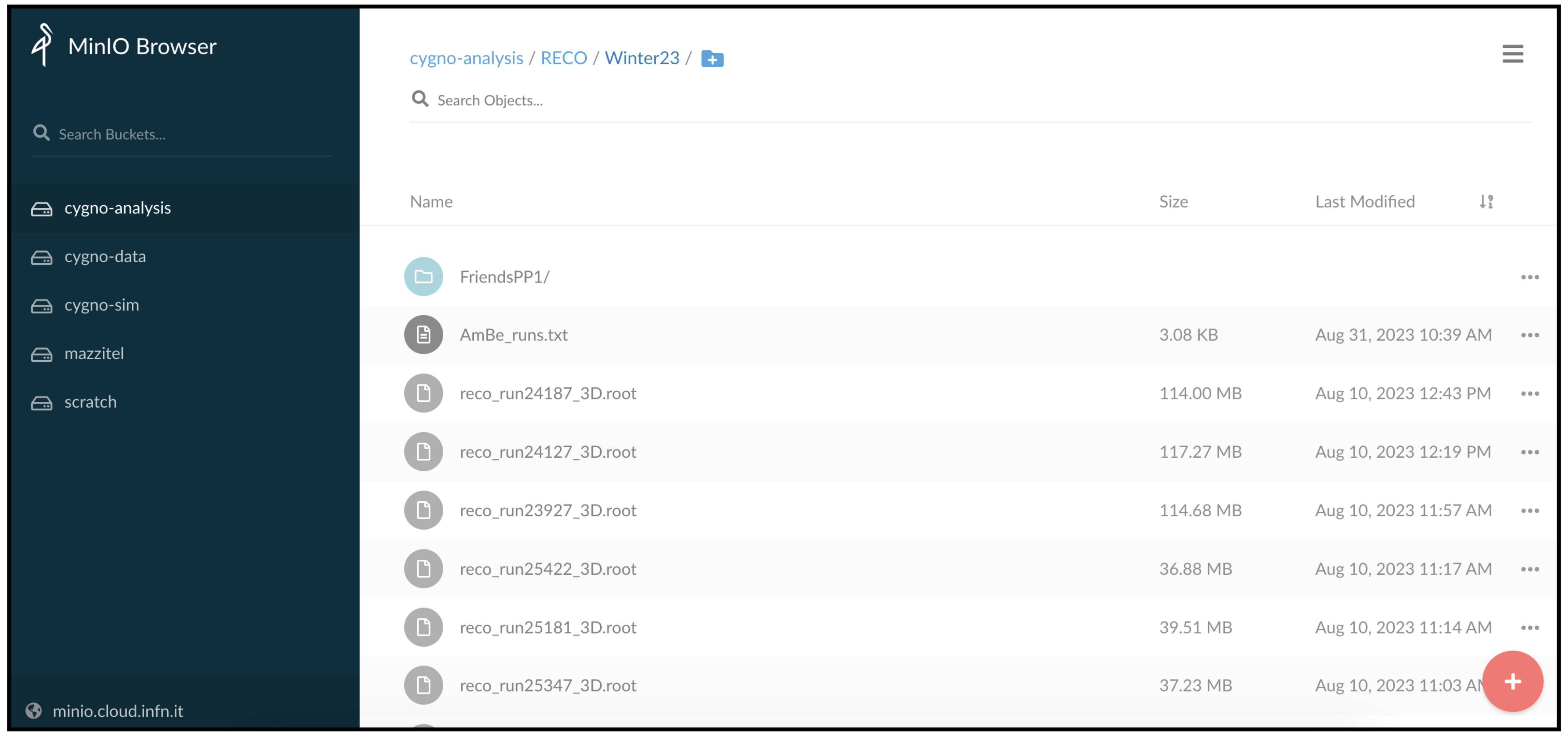
the r-console



online data analysis

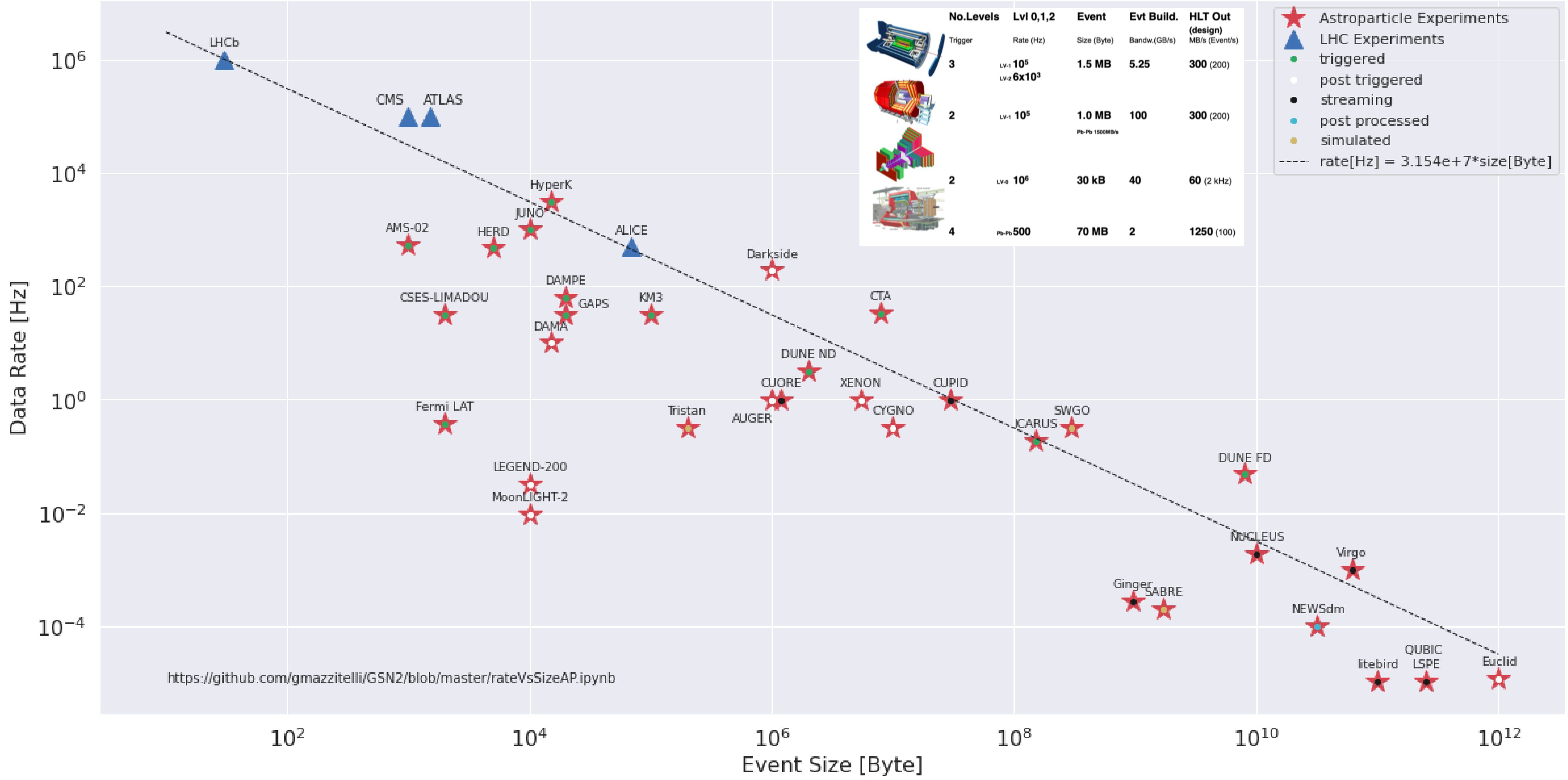
analyser - DTS





astroparticle experiments

exploiting CYGNO experience



bigger rather then faster!

astroparticle experiments are characterised by having a **different throughput** respect to typical HEP experiments, anyhow following a scaling law that underline how are anyway demanding in the overall process.

astroparticle experiments features:

- **unique** and **unrepeatable** data (ex. ultra high cosmic events) constraint on uptime/dead-time
- data could be acquired in **difficult and extreme conditions** (ex. space, under water ice, etc) conditioning the possibility of interventions and changes in the setup
- **templates and montecarlo** are needed not only to evaluates systematic but also to identify “candidates” of events. (ex OG, cosmic ray shower, etc) with large request of computing resources
- for many experiment data need to often to be **re-calibrated and reconstructed many times** with discontinuity and peak in the usage of computing resources

conclusion

- our current model of the Universe, based on the Standard Model (SM), General Relativity (GR), and Lambda Cold Dark Matter (LCDM), is facing more tensions and unresolved questions today than in the past.
- dark matter is one of these unresolved questions: it probably exists as a particle, and we may likely discover it in future detectors with lower thresholds and larger mass ranges.
- CYGNO project started, and a **technical run** is on going to test all the needs for the full **demonstrator** starting in 2025. if successful a **full scale detector** for physics will follow, who's characteristics will be challenging also from the computing point of view;
- a setup based on the **INFN-Cloud** of full **computing services and data handling tools** for CYGNO experiment has been setup, is **running and show appropriate performance**
- the CYGNO use case is one of the seed that can be easily **generalised** to develop the **computing model of many small/medium experiments** in the astroparticle Italian community, reducing resources requests, costs, energy and environments impact, improving security, ecc. ecc.