



<https://idr.openmicroscopy.org>

# The Image Data Resource (IDR): a scalable resource for FAIR biological imaging data


*OME Team*

University of Dundee




@openmicroscopy, @IDRNews








idr.openmicroscopy.org





CELL - IDR   TISSUE - IDR

ABOUT ▾   SUBMISSIONS ▾

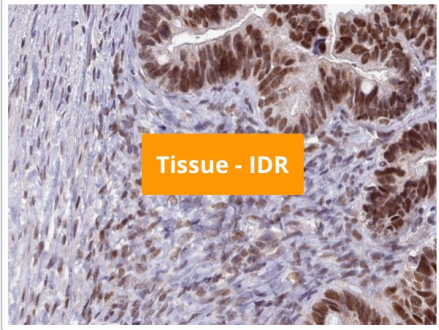
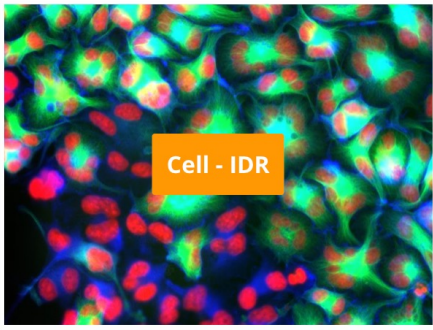
## Welcome to IDR

The Image Data Resource (IDR) is a public repository of image datasets from published scientific studies, where the community can submit, search and access high-quality bio-image data.

Search by:

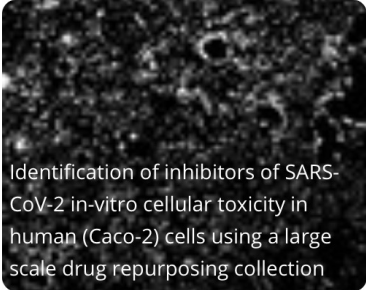
Name (IDR number) ▾

Type to filter values...



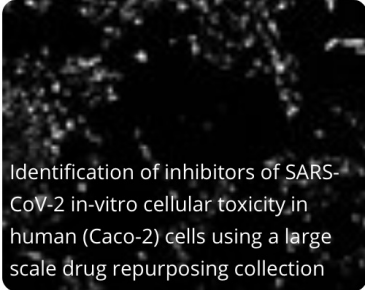
### Most Recent (10)

idr0094B Ellinger B et al.



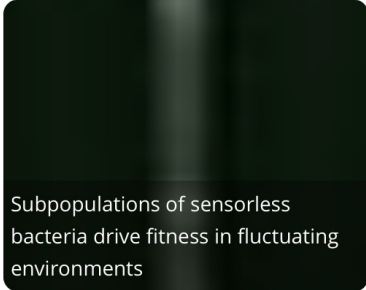
Identification of inhibitors of SARS-CoV-2 in-vitro cellular toxicity in human (Caco-2) cells using a large scale drug repurposing collection

idr0094A Ellinger B et al.



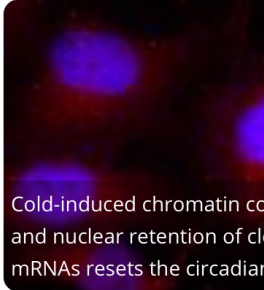
Identification of inhibitors of SARS-CoV-2 in-vitro cellular toxicity in human (Caco-2) cells using a large scale drug repurposing collection

idr0091A Julou T et al.




Subpopulations of sensorless bacteria drive fitness in fluctuating environments

idr0089B Fischl H et al.







Cold-induced chromatin compaction and nuclear retention of circadian mRNAs resets the circadian clock





idr.openmicroscopy.org





CELL - IDR    TISSUE - IDR

ABOUT ▾    SUBMISSIONS ▾

## Welcome to IDR

The Image Data Resource (IDR) is a public repository of image datasets from published scientific studies, where the community can submit, search and access high-quality bio-image data.

Search by:

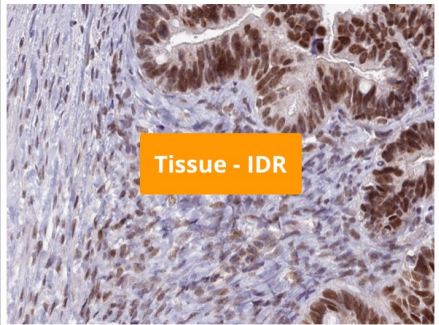
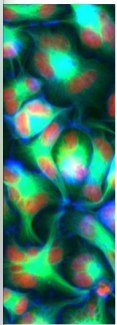
Study Attributes

☒ Name (IDR number)  
☐ Imaging Method  
☐ License  
☐ Organism  
☐ Publication Authors  
☐ Publication Title  
☐ Screen Technology Type  
☐ Screen Type  
☐ Study Type

Image Attributes

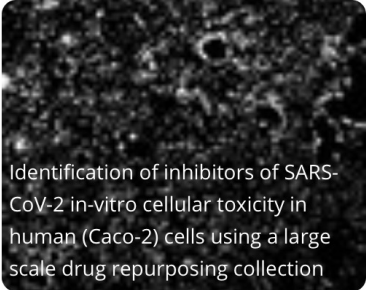
☐ Antibody  
☐ Cell Lines  
☐ Compound  
☐ Gene  
☐ Phenotype  
☐ siRNA

Type to filter values...



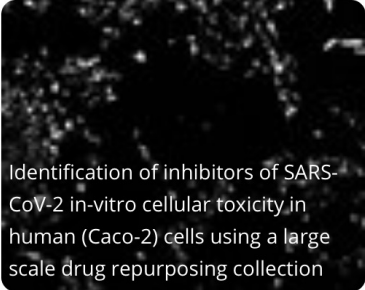
### Most Recent (10)

idr0094B Ellinger B et al.



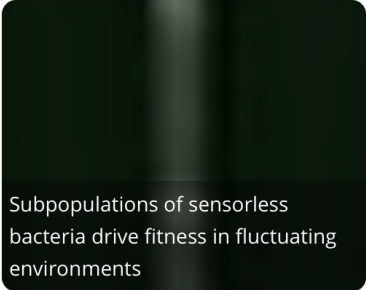
Identification of inhibitors of SARS-CoV-2 in-vitro cellular toxicity in human (Caco-2) cells using a large scale drug repurposing collection

idr0094A Ellinger B et al.



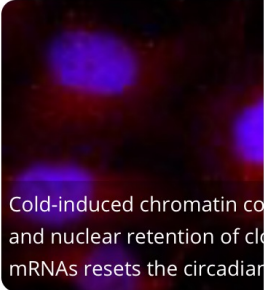
Identification of inhibitors of SARS-CoV-2 in-vitro cellular toxicity in human (Caco-2) cells using a large scale drug repurposing collection

idr0091A Julou T et al.



Subpopulations of sensorless bacteria drive fitness in fluctuating environments

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**Findable** – Original image data cross-linked from publication by DOI



**Accessible** – Metadata retrievable, open API



**Interoperable** – Uses common defined vocabularies

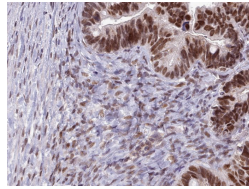


**Reusable** – Licensed (CC0 or CC BY 4.0), provenance included

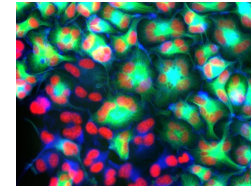


# Reference datasets

## Biological Domains

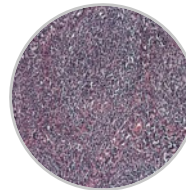
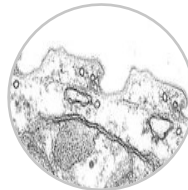
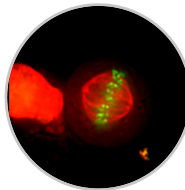
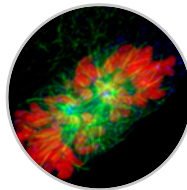
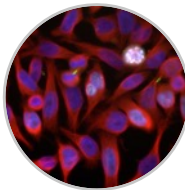


Tissue

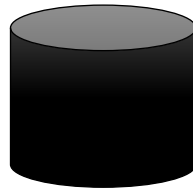


Cell

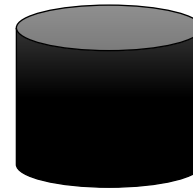
## Imaging Modalities



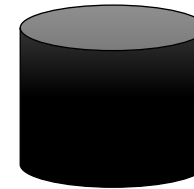
## Biomolecular Resources



Genes



Compounds



Cell Lines

## Controlled Vocabularies



Phenotypes



Ground Truth

<https://idr.openmicroscopy.org/about/submission.html>



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**January 2022**

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Raw data size	307 TB
Image files	30 M
5D Images	12 M
2D Planes	105 M
Organisms	15
Genes	89 K
Antibodies	11 K
Compounds	40 K

---



**>85 cross-published studies**



**cross-referenced via  
accessions and DOIs**

A high-content RNAi screen reveals multiple roles for long noncoding...

**Data availability**




A reporting summary for this article is available as a [Supplementary Information file](#). Sequencing data are available in the ArrayExpress database (<http://www.ebi.ac.uk/arrayexpress>) with the accession codes [E-MTAB-7432](#) (RNA-seq), [E-MTAB-7418](#) (CHART-seq) and [E-MTAB-7419](#) (CUT&RUN). The imaging data have been submitted to the Image Data Resource (<https://idr.openmicroscopy.org>) under IDR accession number [idr0056](#). The source data

↑ ↓

**IDR** CELL - IDR ISSUE - IDR ABOUT SUBMISSIONS

Search by: Name (IDR number)

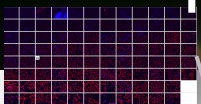
Found 3 studies with Name: **idr0056**

Study ID	Author	Thumbnail Image
idr0056C	Stojic L et al.	
idr0056B	Stojic L et al.	
idr0056A	Stojic L et al.	

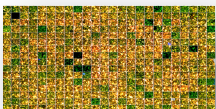
A long noncoding RNA regulates microtubule behaviour during mitosis



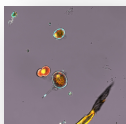
# The IDR @ EMBL-EBI Embassy



Gene Product  
Targeting HCS



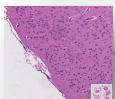
Genetic HCS



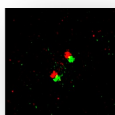
Geographic HCS



Chemical HCS



Histopathology



3D-Sim



Super-resolution

Webclient

idr.openmicroscopy.org/webclient/?show=well-976041

IDR Studies Genes Phenotypes Cell Lines siRNAs Antibodies Compounds Organisms Help

demo

Explore Tags Shares

Demo data

- idr0001-grami-sysgro/screenA 192
- idr0002-heriche-condensation/screenA 12
- idr0003-breker-plasticity/screenA 85
- idr0004-thorpe-rad52/screenA 47
- idr0005-toret-adhesion/screenA 141
- idr0005-toret-adhesion/screenB 18
- idr0006-long-nuclearbodies/screenA 169
- idr0007-srikumar-sumo/screenA 12
- idr0008-rohn-actinome/screenA 58
- idr0008-rohn-actinome/screenB 11
- idr0009-simpson-secretion/screenA 364
- idr0009-simpson-secretion/screenB 70
- idr0010-doi-dnadamage/screenA 148
- idr0011-le
- idr0011-ledesmaferandez/screenC 4
- idr0011-le
- idr0011-le
- idr0012-fuchs-cellmorph/screenA 58
- idr0013-neumann-mitochek/screenA 510
- idr0013-neumann-mitochek/screenB 28
- idr0015-UNKNOWN-taracoans/screenA 84
- idr0016-wawer-bioactivecompoundprofiling/screenA 375
- idr0017-breinig-drugscreen/screenA 36
- idr0018-neff-histopathology/experimentA 248
- idr0019-sero-nfkappab/screenA 7
- idr0020-ban-cthog/screenA 4
- idr0021-lawo-pericentriolmaterial/experimentA 10
- idr0023-szymborska-nucleopore/experimentA 55
- idr0025-stadler-proteinatlase/screenA 3
- idr0026-weigelin-immunotherapy/experimentA 18
- idr0027-dickerson-chromatin/experimentA 8
- idr0028-pascualvargas-rhogtpases
- idr0028-pascualvargas-rhogtpases/screenA 4
- idr0028-pascualvargas-rhogtpases/screenB 4
- idr0028-pascualvargas-rhogtpases/screenC 4
- idr0028-pascualvargas-rhogtpases/screenD 4
- idr0030-sero-yap/screenA 10
- idr0032-yang-meristem/experimentA 115
- idr0033-rohban-pathways/screenA 12
- idr0034-kilpinen-hipsci/screenA 29

Integrated studies

41757 [Well K7, Field 1]

Image ID: 3230268  
Well ID: 1315357  
Owner: Demo User

Well Details

Acquisition Date: 2016-08-20  
Import Date: 2016-08-20  
Dimensions (XY): 1080 x 1080  
Pixels Type: uint16  
Pixels Size (XYZ): 0.66 x 0.66 x -  
(µm)  
Z-sections/Timepoints: 1 x 1  
Channels: Hoechst, ERSyto, ERSytoBleed, Phalloidin, Mito  
ROI Count: 0

Attributes

Gene

Added by: Demo User  
Gene Identifier: 331  
Gene Symbol: 331

ORF

Added by: Demo User  
ORF Identifier: 331

ORF supplementary

Added by: Demo User  
ORF Sequence: GGTCGTAT...  
ORF Comments: >ccsbBroad304\_05835Open Reading Frame at 66.1557

Tables

INFO

Plate: 5965  
Well: 1315357  
Well Number: 247  
Characteristics (Organism): Homo sapiens  
Term Source 1: NCBITaxon  
REF:  
Term Source 1: NCBITaxon\_9606  
Accession:  
Characteristics U2OS [Cell Line]:  
Term Source 2: EFO  
REF:  
Term Source 2: EFO\_0002869  
Accession:  
ORF Identifier: ccsbBroad304\_05835

Thumbnails (of 5D Images)

Experimental  
metadata

Biomolecular  
annotations

Analysis  
results



Cross-data  
browsing



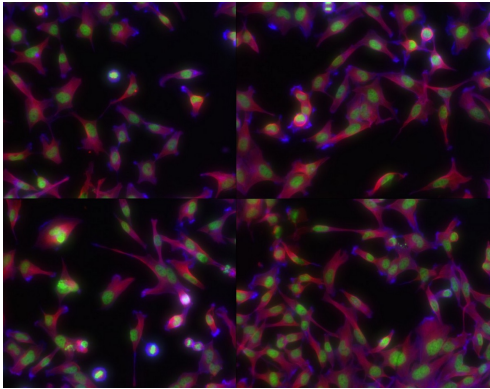
Cloud  
analysis



Download  
(local analysis)



# Linked Metadata



idr0012

OMERO Public

Studies Genes Phenotypes Cell Lines siRNAs Antibodies

Type Gene Symbol... Match case Add filter

Gene 1

- ASH2L (326) 6
  - idr0022-koedoot-cellmigration/screenA (288) 8
  - idr0006-fong-nuclearbodies/screenA (16) 1
  - idr0009-simpson-secretion/screenA (12) 6
  - idr0013-neumann-mitocheck/screenA (6) 3
  - idr0012-fuchs-cellmorph/screenA (2) 1
    - HT28 2
      - HT28 [Well G13, Field 1]
      - HT28 [Well G13, Field 2]
  - idr0010-doil-dnamage/screenA (2) 1

Two small thumbnail images of cell morphology are shown next to the 'Add filter' button.

Attributes 8

### Cell Lines

Added by: Public data

Cell Line	HeLa
-----------	------

### Gene

Added by: Public data

Gene Identifier	9070
Gene Symbol	ASH2L

### Phenotype

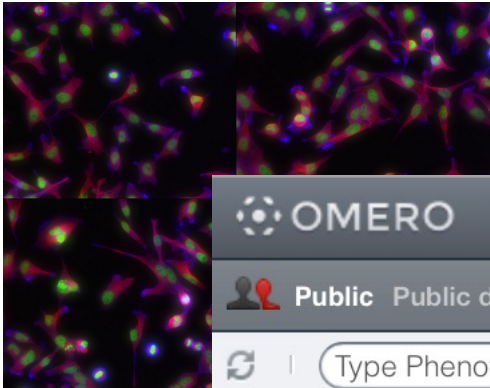
Added by: Public data

Phenotype	<u>elongated cells</u>
Phenotype Term Name	elongated cell phenotype
Phenotype Term Accession	CMPO_0000077

Red arrows indicate the link between the 'elongated cells' phenotype in the OMERO interface and the 'elongated cells' phenotype in the public data table. Another red arrow points from the 'elongated cells' phenotype in the public data table to the 'elongated cells' phenotype in the OMERO interface.



# Linked Metadata



id

OMERO Studies Genes Phenotypes

Public Public data

Type Gene Symbol...

Gene 1

- ASH2L (326) 6
- idr0022-koedoot-cellmigration/screenA
- idr0006-fong-nuclearbodies/screenA (1)
- idr0009-simpson-secretion/screenA (12)
- idr0013-neumann-mitochek/screenA (6) 3
- idr0012-fuchs-cellmorph/screenA (2) 1
  - HT28 2
    - HT28 [Well G13, Field 1]
    - HT28 [Well G13, Field 2]
- idr0010-doil-dnamage/screenA (2) 1

OMERO Studies Genes Phenotypes Cell Lines

Public Public data

Type Phenotype...

Match case ?

Phenotype 1

- CMPO\_0000077 (20872) 8
  - idr0028-pascualvargas-rhogtpases/screenD (3920) 4
  - idr0028-pascualvargas-rhogtpases/screenA (3808) 4
  - idr0028-pascualvargas-rhogtpases/screenC (3220) 4
  - idr0033-rohban-pathways/screenA (2916) 12
  - idr0028-pascualvargas-rhogtpases/screenB (2856) 4
  - idr0001-graml-sysgro/screenA (2788) 122
  - idr0008-rohn-actinome/screenB (1098) 10
  - idr0012-fuchs-cellmorph/screenA (266) 55

Attributes 8

## Cell Lines

Added by: Public data

Cell Line

HeLa

9070

ASH2L

elongated cells

elongated cell phenotype

CMPO\_0000077

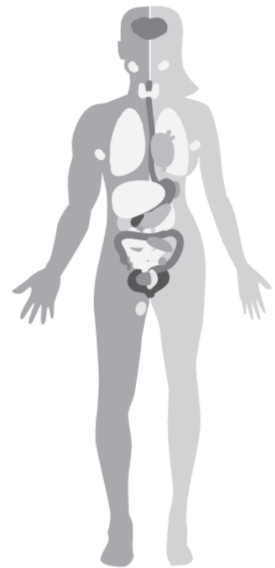


# Ontologies

Organism	NCBITaxon <a href="https://www.ncbi.nlm.nih.gov/taxonomy">https://www.ncbi.nlm.nih.gov/taxonomy</a>
Study Type	Experimental Factor Ontology (EFO) <a href="https://www.ebi.ac.uk/efo/">https://www.ebi.ac.uk/efo/</a>
Screen Type (HCS)	Experimental Factor Ontology (EFO) <a href="https://www.ebi.ac.uk/efo/">https://www.ebi.ac.uk/efo/</a>
Screen Technology Type (HCS)	Experimental Factor Ontology (EFO) <a href="https://www.ebi.ac.uk/efo/">https://www.ebi.ac.uk/efo/</a>
Library Type (HCS)	Experimental Factor Ontology (EFO) <a href="https://www.ebi.ac.uk/efo/">https://www.ebi.ac.uk/efo/</a>
Protocol	Experimental Factor Ontology (EFO) <a href="https://www.ebi.ac.uk/efo/">https://www.ebi.ac.uk/efo/</a>
Imaging Method	Biological Imaging Methods Ontology (FBbi) <a href="https://www.ebi.ac.uk/ols/ontologies/fbbi">https://www.ebi.ac.uk/ols/ontologies/fbbi</a>
Phenotype	Cellular Microscopy Phenotype Ontology (CMPO) <a href="https://www.ebi.ac.uk/cmpo/">https://www.ebi.ac.uk/cmpo/</a>
Clinical/Pathology	SNOMED CT <a href="https://bioportal.bioontology.org/ontologies/SNOMEDCT">https://bioportal.bioontology.org/ontologies/SNOMEDCT</a>
Compounds	PubChem <a href="https://pubchem.ncbi.nlm.nih.gov/">https://pubchem.ncbi.nlm.nih.gov/</a>



# Tissue Data: Human Protein Atlas



RNA expression (TPM)<sup>1</sup> Protein expression (score)<sup>1</sup>

Brain

Endocrine tissues

Bone marrow & immune system

Muscle tissues

Public

Explore Tags Shares Add filter

125920\_A\_7\_1.tif  
125920\_A\_7\_2.tif  
125920\_A\_7\_4.tif  
125920\_A\_7\_5.tif  
125920\_A\_7\_6.tif  
**125920\_A\_7\_8.tif**  
125920\_A\_8\_1.tif  
125920\_A\_8\_2.tif  
125920\_A\_8\_3.tif  
125920\_A\_8\_4.tif  
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125920\_B\_1\_3.tif  
125920\_B\_1\_5.tif  
125920\_B\_1\_6.tif  
125920\_B\_1\_7.tif  
125920\_B\_2\_1.tif

Cerebral cortex  
Lymph node

Zoom:

OMERO File ROIs Help 125920\_A\_7\_8.tif

Dimensions (XY): 3000 x 3000  
Pixels Type: uint8  
Pixels Size (XYZ) (μm): -  
Z-sections/Timepoints: 1 x 1  
Channels: 0, 1, 2  
ROI Count: 0

Attributes 6

**Antibody**  
Added by: Public data  
Antibody Identifier: CAB058686

**Antibody supplementary**  
Added by: Public data  
Dilution Factor: 1:1000  
Retrieval Method: HIER pH6  
Human Protein Atlas version: v18

**Gene**  
Added by: Public data  
Gene Identifier: ENSG00000148516

Tables





[EMPIAR home](#) | 
 [Deposition](#) | 
 [REST API](#) | 
 [FAQ](#) | 
 [About EMPIAR](#) | 
 [Policies](#) | 
 [Feedback](#) | 
 [Share](#)

Attributes 1

Publication DOI

Release Date

License

Copyright

Data Publisher

Data DOI

EMPIAR Accession

Annotation File

## EMPIAR-10404

### SARS-CoV-2 productively infects human gut enterocytes

#### Publication:

SARS-CoV-2 productively infects human gut enterocytes

[Lamers MM](#) , 
 [Beumer J](#) , 
 [van der Vaart J](#) , 
 [Knoops K](#) , 
 [Puschhof J](#), 
 [Breugem T](#), 
 [Ravelli RBG](#) , 
 [van Schayck JP](#) , 
 [Mykytyn AZ](#), 
 [Duimel HQ](#), 
 [van Donselaar E](#), 
 [Riesebosch S](#), 
 [Kuijpers HJH](#), 
 [Schipper D](#), 
 [van de Wetering WJ](#), 
 [de Graaf M](#), 
 [Koopmans M](#) , 
 [Cuppen E](#) , 
 [Peters PJ](#), 
 [Haagmans B](#) , 
 [Clevers H](#) 

*Science*

DOI: [10.1126/science.abc1669](https://doi.org/10.1126/science.abc1669)

#### Related IDR entry:

##### Deposited:

[idr0083](#)

##### Released:

2020-04-30

##### Last modified:

2020-05-01

##### Dataset size:

2020-05-01

##### Dataset DOI:

66.5 GB

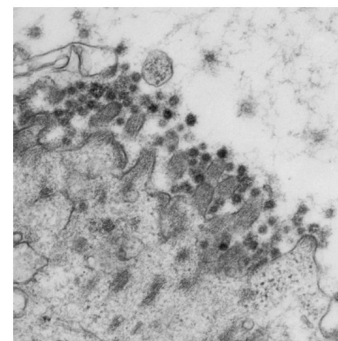
##### Experimental metadata:

[10.6019/EMPIAR-10404](https://doi.org/10.6019/EMPIAR-10404)

[Download xml](#)

#### Contains:

stitched maps



## Quick links

[EMDB](#)

[PDBe](#)

[BioImage Archive](#)

[EMPIAR Quick tour](#)

[Statistics](#)

[Re-use case study](#)

[EMPIAR@PDBj](#)

## EMPIAR citations


[Cryo-EM structure of the potassium-chloride cotransporter KCC4 in lipid nanodiscs.](#)

[Reid MS, Kern DM, Brohawn SG. \(2020\)](#)

[Development of basic building blocks](#)




# Open cloud and open analytics

 jupyter ARP2-3Complex Last Checkpoint: 09/08/2017 (autosaved)

Control Panel Logout

File Edit View Insert Cell Kernel Widgets Help

Not Trusted OMERO Python 2



## Query IDR for Phenotypes

```
In [4]: session = create_http_session(idr_url.value)
organism = org_sel.value
idr_base_url = idr_url.value

[query_genes_dataframe, screen_to_phenotype_dictionary] = get_phenotypes_for_genelist(idr_base_url, session, go_gene_li
display(HTML(query_genes_dataframe.to_html( escape=False)))
```

[=====] 100.0% ...Iterating through gene list

	Entrez	Ensembl	Key	Value	PhenotypeName	PhenotypeAccession	ScreenIds
ARPC2	[10109]	[ENSG00000163466]	GeneName	ARPC2	[decreased cell numbers, geometric cell phenot...	[CMPO_0000274, CMPO_0000299, CMPO_0000276, CMP...	[206, 206, 206, 206, 206, 206, 206, ...]
ARPC1A	[10552]	[ENSG00000241685]	GeneName	ARPC1A	[strong decrease in rate of protein secretion]	[CMPO_0000319]	[251]
ARPC5L	[81873]	[ENSG00000136950]	GeneName	ARPC5L	[increased actin localised to the nucleus, elo...	[CMPO_0000261, CMPO_0000287, CMPO_0000288, CMP...	[206, 206, 206, 206, 206, 206, 206, ...]
ACTR3C	[653857]	[ENSG00000106526]	EnsemblID	ENSG00000106526	[cell death phenotype, mitosis delayed phenoty...	[CMPO_0000305, CMPO_0000348, CMPO_0000307, CMP...	[1101, 1101, 1101, 1101, 1101, 1101, 1101]
ACTR3B	[57180]	[ENSG00000133627]	GeneName	ACTR3B	[binuclear cell phenotype]	[CMPO_0000213]	[1101]
HEL-68	[10552]	[ENSG00000241685]	EnsemblID	ENSG00000241685	[strong decrease in rate of protein secretion]	[CMPO_0000319]	[251]
ARPC4	[10093]	[ENSG00000241553]	GeneName	ARPC4	[mild decrease in rate of protein secretion]	[CMPO_0000318]	[251]
ACTR3	[10096]	[ENSG00000115091]	GeneName	ACTR3	[strong decrease in rate of protein secretion,...	[CMPO_0000319, CMPO_0000319]	[251, 803]

<https://github.com/IDR/idr-notebooks>



<https://github.com/IDR/idr-notebooks> can be launched in [MyBinder](#), just click the badge

## idr-notebooks



 jupyter

Files Running Clusters

Select items to perform actions on them.

<input type="checkbox"/>	0	<input type="checkbox"/>	/
<input type="checkbox"/>		<input type="checkbox"/>	binder
<input type="checkbox"/>		<input type="checkbox"/>	docker
<input type="checkbox"/>		<input type="checkbox"/>	includes
<input type="checkbox"/>		<input type="checkbox"/>	omero
<input type="checkbox"/>		<input type="checkbox"/>	CalculateSharpness.ipynb
<input type="checkbox"/>		<input type="checkbox"/>	Figure_1_Sampling_of_Phenotypes.ipynb
<input type="checkbox"/>		<input type="checkbox"/>	GeneNetwork.ipynb
<input type="checkbox"/>		<input type="checkbox"/>	GenesToPhenotypes.ipynb
<input type="checkbox"/>		<input type="checkbox"/>	Getting_Started.ipynb

<https://github.com/ome/omero-guide-fiji>  
<https://github.com/ome/omero-guide-cellprofiler>  
<https://github.com/ome/omero-guide-python>

...

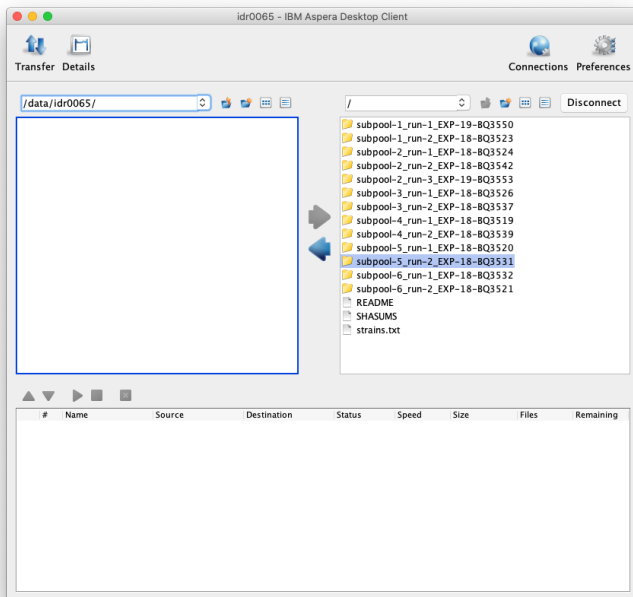
contain IDR-specific notebooks too !



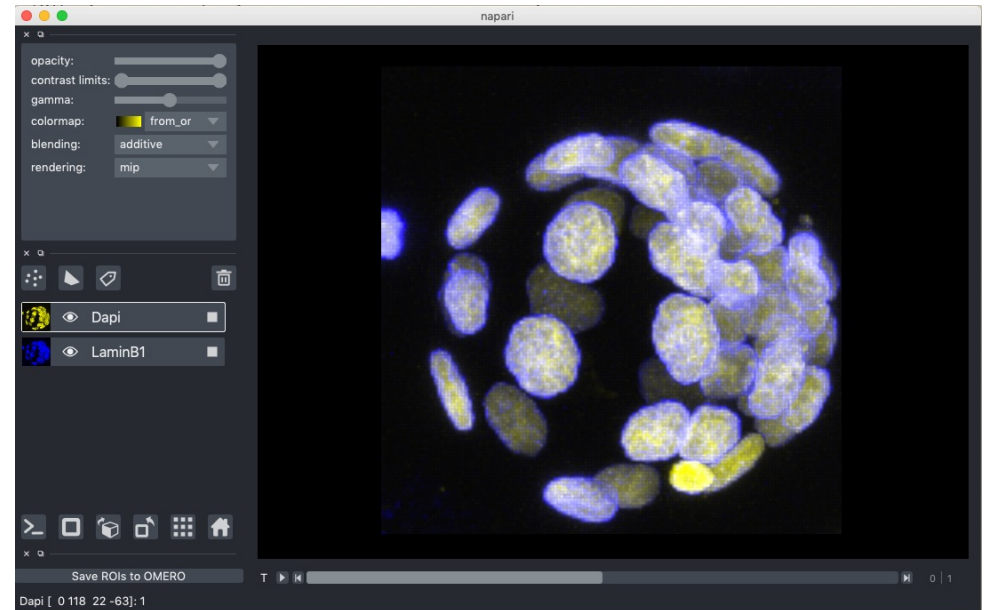
# Redesigning data access for re-analysis

*From file download*

*... to scalable remote data access*



**Aspera**



**Zarr + napari**

<https://idr.openmicroscopy.org/about/download.html>



Publicly available, curated studies...  
submitted by the community...  
in a searchable, scalable platform...  
that links metadata ...  
and enables reanalysis ...  
that can be deployed by others.

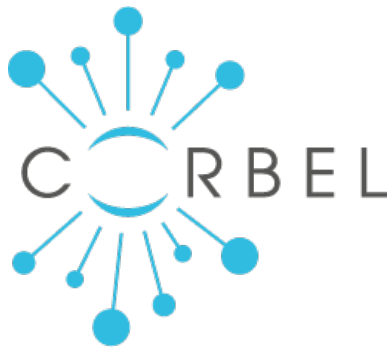


# Thanks to the funders



Biotechnology and  
Biological Sciences  
Research Council

Chan  
Zuckerberg  
Initiative 



GLOBAL  
BIOIMAGING  
growing collaboration

MULTI  
MOT 





# Thanks to the IDR Team



OME



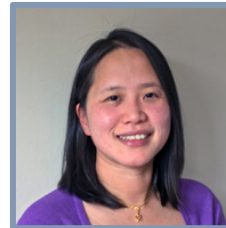
**Jason  
Swedlow**



**Sebastien  
Besson**



**Dominik  
Lindner**



**Frances  
Wong**



**Josh  
Moore**



**Jean-Marie  
Burel**



**Petr  
Walczysko**



**Will  
Moore**



**David  
Gault**



**Alvis  
Brazma**



**Ugis  
Sarkans**



## **Past members**

**Eleanor Willams  
Simon Li  
Simone Leo  
Gabry Rustici  
Ola Tarkowska  
Balaji Ramalingam  
Riad Gozim  
Mark Carroll  
Rafael Carazo-Salas  
Balint Antal  
Anatole Chessel  
Simon Jupp  
Tony Burdett**



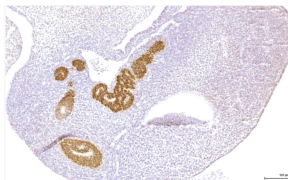
## Which diabetes related genes are expressed in the pancreas?



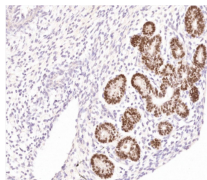
**IDR MULTIMICS API**



### Images linked to gene PDX1



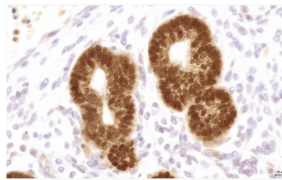
CS16



CS21



9PCW



15PCW

Developmental stage

TISSUE = "Pancreas"  
DISEASE = "diabetes"

Genes  
found

WFS1 VEGFA TCF7L2 TBC1D4 SOD2 SLC30A8 PTPN22 **PDX1**  
MIA3 KCNJ11 IRS2 IRS1 INSR INS IGF2BP2 IER3IP1  
HNF4A HNF1B HMGAI HFE GPD2 GCK ENPP1 EIF2AK3  
DNAJC3 CEL CAPN10 APPL1 AKT2 ABCC8

```
query.add_constraint('proteinAtlasExpression.tissue.name', '=', TISSUE)
query.add_constraint('proteinAtlasExpression.level', 'ONE OF', ['Median', 'High'])
query.add_constraint('organism.name', '=', 'Homo sapiens')
query.add_constraint('disease.name', 'CONTAINS', DISEASE)

<BinaryConstraint: Gene.disease.name CONTAINS diabetes>

Collect the genes

upin_tissue = list()
for row in query.rows():
    upin_tissue.append(row['symbol'])
unique = set(upin_tissue)
genes = sorted(genes, reverse=True)
```

### Search for images in IDR associated to the genes found in Humanmine

From the list of genes found using the intermine API, we are now looking in [Image Data Resource](#) for studies linked to those genes and with tissue as a Sample Type.

```
TYPE = "gene"
SAMPLE TYPE = "tissue"
EXPRESSION_KEY = "Expression Pattern Description"
EXPRESSION = "Islets" # "Brain"
KEYS = ('phenotype':
        ('Phenotype',
         'Phenotype Term Name',
         'Phenotype Term Accession',
         'Phenotype Term Accession URL',
         ))
```

```
projects = list()
for gene in genes:
    qs1 = {'key': TYPE, 'value': gene}
    url1 = URL.format(**qs1)
    json = session.get(url1).json()
    for m in json['maps']:
        qs2 = {'key': TYPE, 'value': gene}
        url2 = SCREENS_PROJECTS_URL.format(**qs2)
        json = session.get(url2).json()
        for p in json['projects']:
            value = find_type("project", p['id'])
            if value > -1:
                projects.append(value)
```

idr0070, Kerwin et al, *Journal of Anatomy* DOI: 10.1111/j.1469-7580.2010.01290.x