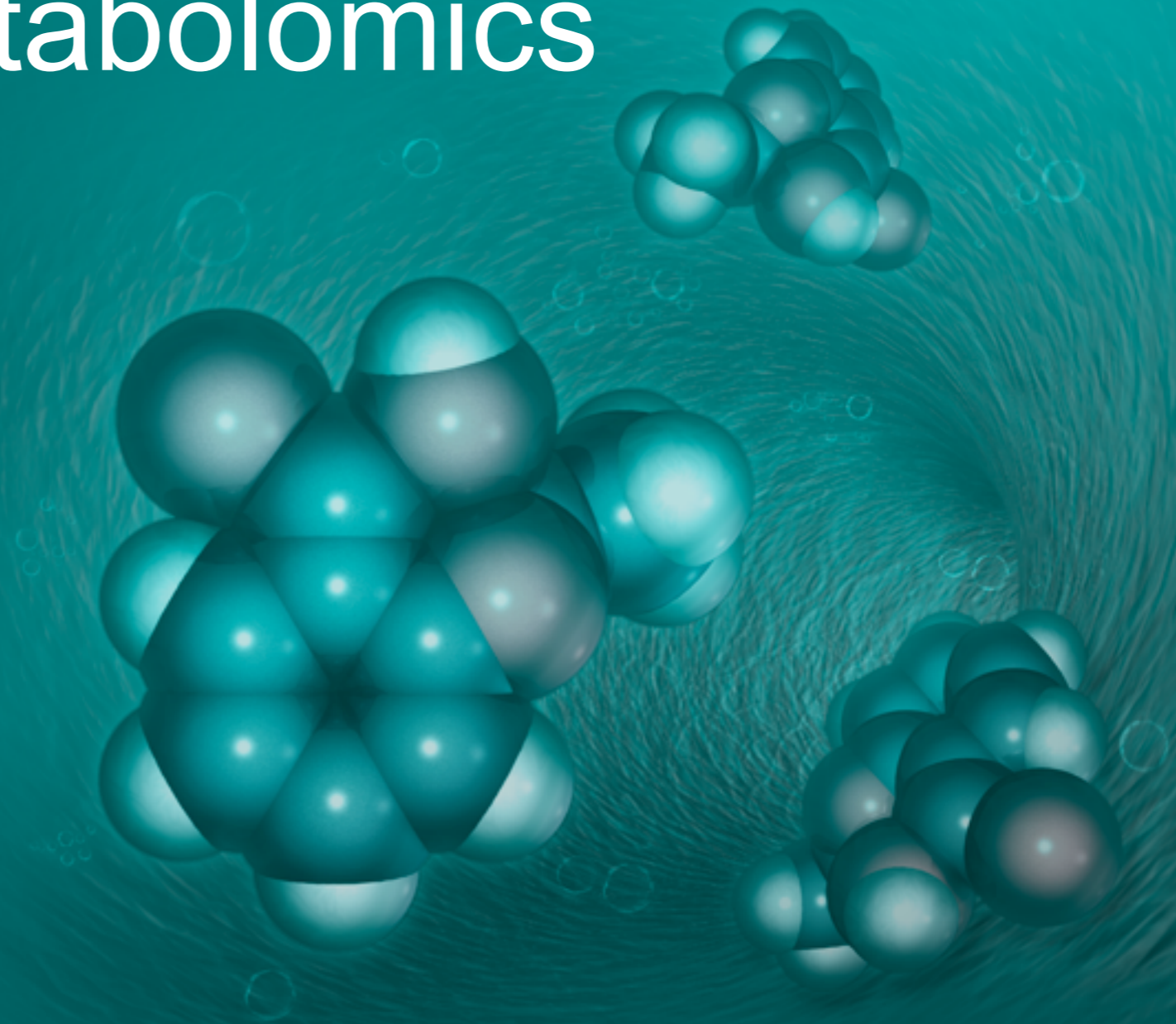


# Developing an Efficient Infrastructure, Standards and Data-Flow for Metabolomics

Christoph Steinbeck

European Bioinformatics Institute  
(EMBL-EBI)



# Developing an Efficient Infrastructure, Standards and Data-Flow for Metabolomics

Slides on  
<http://www.slideshare.net/csteinbeck>

Christoph Steinbeck

European Bioinformatics Institute  
(EMBL-EBI)

**The**

# **European Bioinformatics Institute**

**(EBI)**



The

# European Bioinformatics Institute

(EBI)



# The European Bioinformatics Institute (EBI)



# The European Bioinformatics Institute (EBI)



# The European Molecular Biology Laboratory (EMBL)

A basic research  
institute funded by  
public research  
monies from 20  
member states.



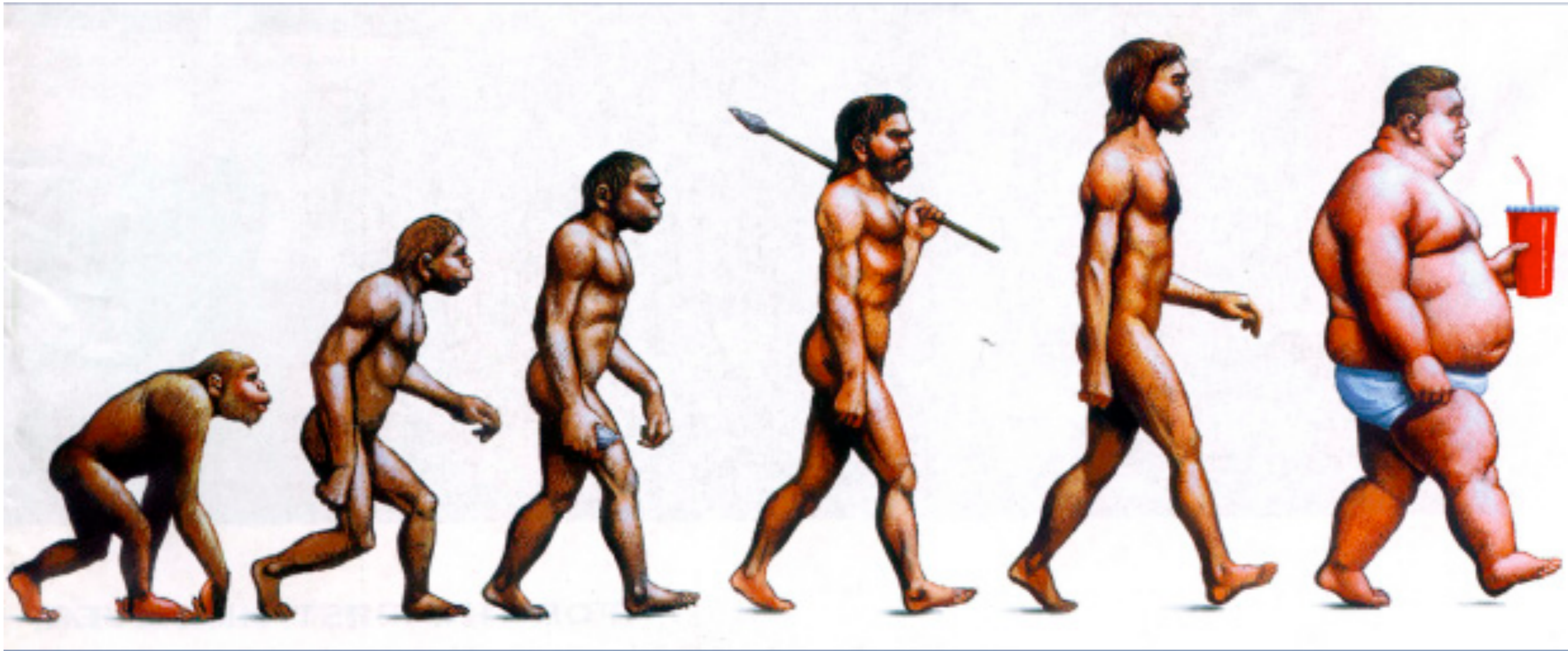
# Post Genomic Era

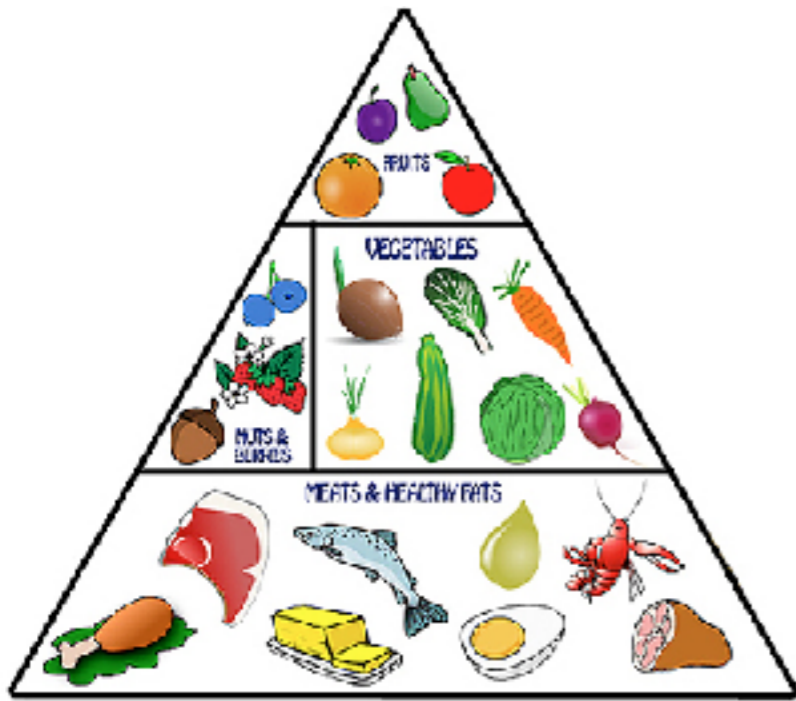
[O]ur understanding of the human genome has changed in the most fundamental ways. The small number of genes -- some 30,000 -- supports the notion that we are not hard wired. We now know the notion that one gene leads to one protein, and perhaps one disease, is false.

Craig Venter, June 2001



# Understanding Phenotypes





Nutrition



Disease



Exercise

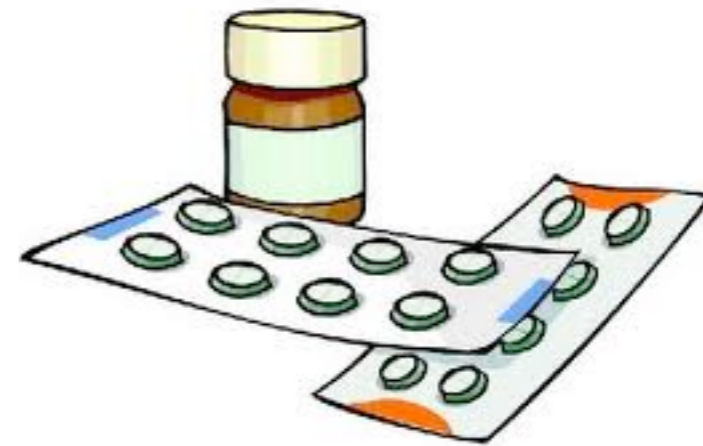
# Phenome/ Exposome



Age



Environment



Drugs

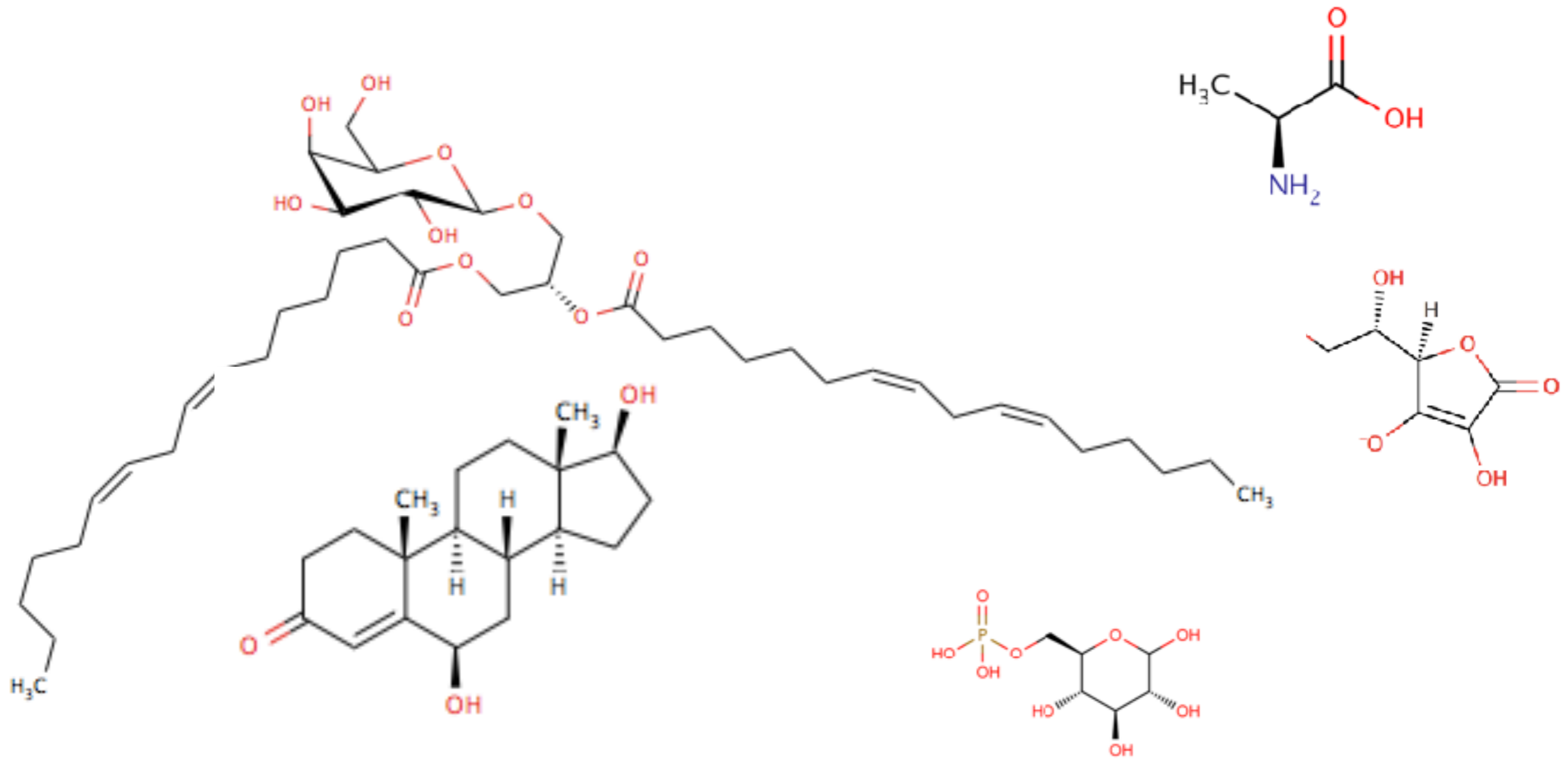
# Reaction times following external change

- Genetics (decades, centuries...)
- Epigenetics (days, month, years,...)
- Gene Expression (hours)
- Metabolism (seconds)

**The Metabolome  
is the most accessible and  
dynamically changing  
Molecular Phenotype**

# Metabolites:


## Small molecules in biological organisms



# Metabolomics

Measures **occurrence** and **concentrations** of many small molecules (**metabolites**) in an organism at once.

# Metabolomics uses a wide-range of analytical techniques



Nuclear Magnetic Resonance  
(NMR)

A photograph of a laboratory setting featuring a large, white, cylindrical Nuclear Magnetic Resonance (NMR) spectrometer. The machine is mounted on a grey base and has various tubes and cables connected to it. To the left of the machine is a silver metal ladder. In the background, there is a wooden table with various laboratory equipment and a computer monitor. The image is framed with a white, torn-edge border.



Mass Spec

A photograph of a laboratory setting featuring a mass spectrometer. The machine is white and has a control panel with a small screen and buttons. To the left of the machine is a computer monitor displaying a software interface. The image is framed with a white, torn-edge border.

# Phenome Centres popping up all over the world

- London
- Birmingham
- Shanghai
- NIH RCMRCs
- ...



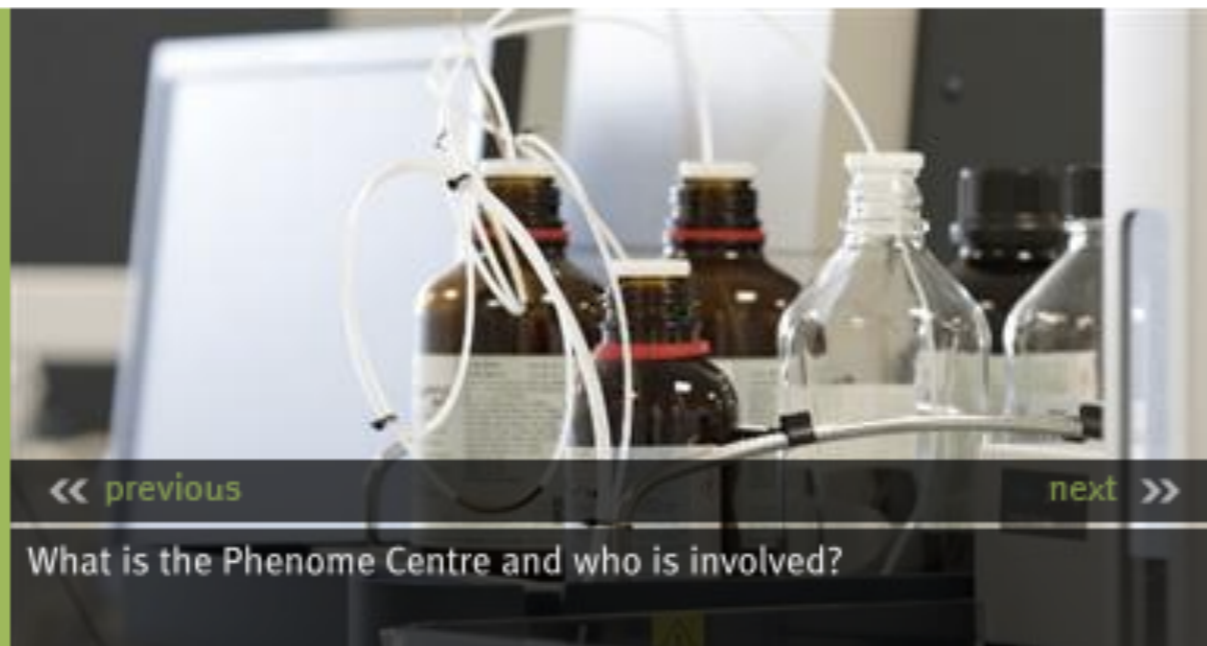


# MRC-NIHR National Phenome Centre

[About the centre](#) | [Access to facilities](#) | [FAQs](#) | [Latest news](#)

## welcome

MRC and NIHR funded and led by Imperial College London and King's College London, the National Phenome Centre will deliver broad access to a world-class capability in **metabolic phenotyping**.



[→ Back to Department of Surgery and Cancer](#)

### Staff related links

- [→ Professor Jeremy K Nicholson](#)  
(Director of the National Phenome Centre)
- [→ Dr Anthony C Dona](#)  
(NMR Manager)
- [→ Mr Matthew R Lewis](#)  
(Mass Spectrometry Manager)
- [→ Miss Lynn Maslen](#)  
(Centre Manager)
- [→ Dr Jake TM Pearce](#)  
(Informatics Manager)
- [→ Dr Rachel J Shaw](#)  
(Head of Science Operations and Analytics)

### News stories

- [→ New centre will decipher roles of nature and nurture in human health](#)
- [→ National phenome research facility to open at Imperial](#)

[Health legacy for London 2012](#)

- > 100,000 patient samples / year
  - > Several PetaBytes/year
- => ExaBytes of human data at moderate scale-up



**PROFESSOR JEREMY NICHOLSON**

DIRECTOR OF MRC-NIHR PHENOME CENTRE AND HEAD OF DEPARTMENT OF SURGERY AND CANCER, IMPERIAL COLLEGE LONDON

→ [Dr Rachel J Shaw](#)  
(Head of Science Operations and Analytics)

## News stories

- [New centre will decipher roles of nature and nurture in human health](#)
- [National phenome research facility to open at Imperial](#)

[Health legacy for London 2012](#)

**How do you make sense  
of all that data?**

Share them

-

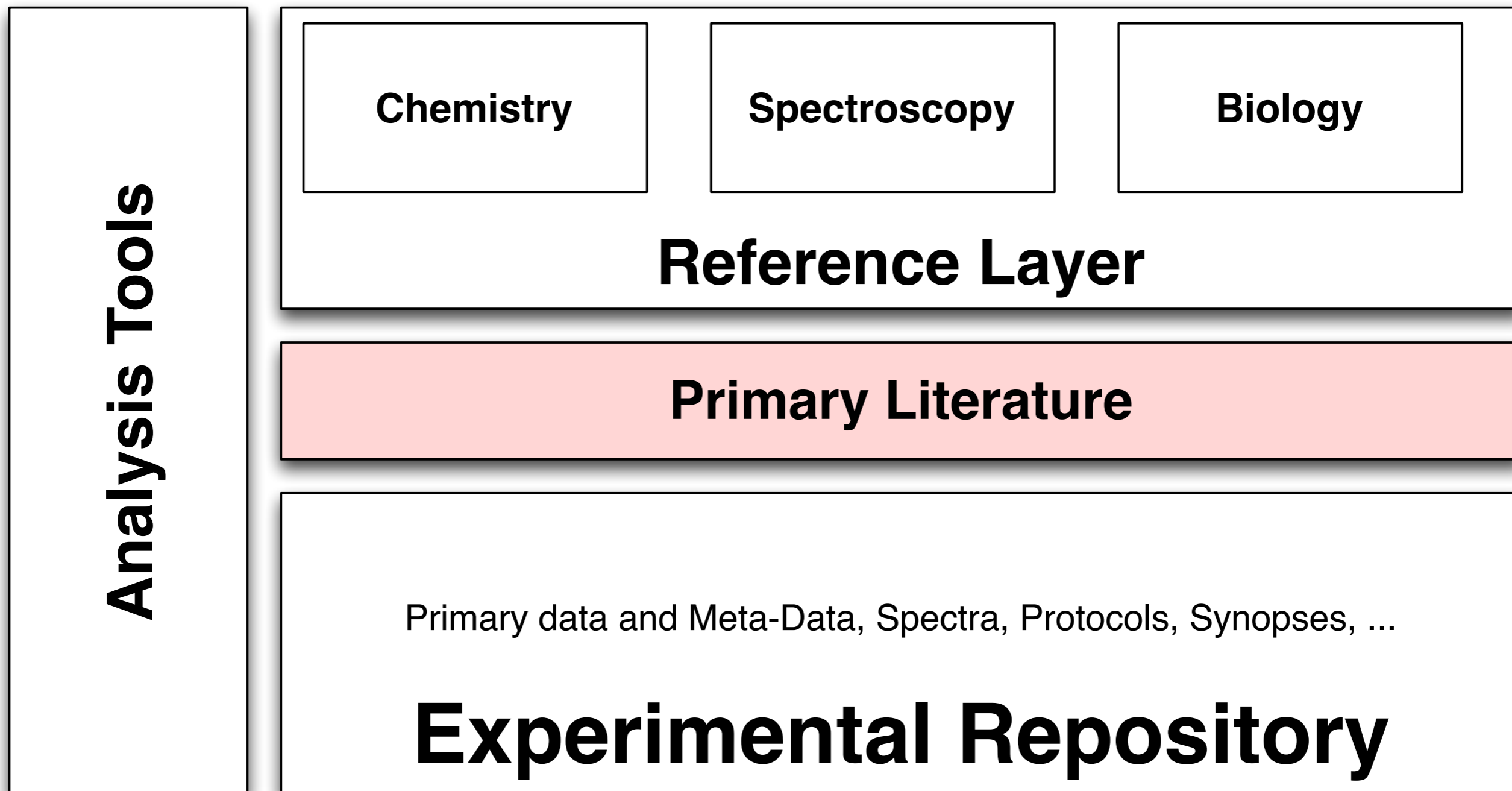
Free and Open

<http://www.ebi.ac.uk/metabolights>

# MetaboLights

open-access, cross-species, cross-application,  
long-term supported

# MetaboLights Database





# Metabolic differences in ripening of *Solanum lycopersicum* 'Ailsa Craig' and three monogenic mutants

[Stephan Beisken](#), [Mark Earll](#), [Charles Baxter](#), [David Portwood](#), [Zsuzsanna Ament](#), [Aniko Kende](#), [Charlie Hodgman](#), [Graham Seymour](#), [Rebecca Smith](#), [Paul Fraser](#), [Mark Seymour](#), [Reza M. Salek](#) & [Christoph Steinbeck](#)

[Affiliations](#) | [Contributions](#) | [Corresponding authors](#)

*Scientific Data* 1, Article number: 140029 | doi:10.1038/sdata.2014.29

Received 10 April 2014 | Accepted 06 August 2014 | Published online 16 September 2014

PDF | ISA tab | Citation | Reprints | Rights & permissions | Article metrics

## Abstract

[Abstract](#) • [Background & Summary](#) • [Methods](#) • [Data Records](#) • [Technical Validation](#) • [Usage Notes](#) • [Additional information](#) • [References](#) • [Data Citations](#) • [Acknowledgements](#) • [Author information](#)

Application of mass spectrometry enables the detection of metabolic differences between groups of related organisms. Differences in the metabolic fingerprints of wild-type *Solanum lycopersicum* and three monogenic mutants, *ripening inhibitor (rin)*, *non-ripening (nor)* and *Colourless non-ripening*

## About *Scientific Data*

*Scientific Data* is an open-access, peer-reviewed publication for descriptions of scientifically valuable datasets. Our primary article-type, the **Data Descriptor**, is designed to make your data more discoverable, interpretable and reusable.

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## Associated Links

*Mol. Inf.* | Article

[MassCascade: Visual Programming for LC-MS Data Processing in Metabolomics](#)  
by [Stephan Beisken et al](#)

*Bioinformatics* | Article

[ProteoWizard: open source software for rapid proteomics tools development](#)  
by [D. Kessner et al](#)

[Submit manuscript](#) ▶

MetaboLights &gt; Search

**Search results**

Filter your results

Type ↓

- 
- study
- 
- 
- compound

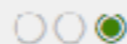
Technology ↓Organism ↓Organism Part ↓Validations Status Details ↓[+ Show more data from EMBL-EBI](#)

15 results, showing 1 to 10

Page 1 of 2

**A metabolomics approach to unravel the regulating role of phytohormones towards carotenoid metabolism in *tomato* fruit. (Zeaxanthin metabolism)**

Validations Status



Release date:

31-Aug-2014

Organism

- Solanum lycopersicum

Study Factors

- Phytohormones
- Carotenoids

Study identifier

[MTBLS107](#)

Total Study size

1.64GB

Submitted by

[Lieven van Meulebroek](#) **A metabolomics approach to unravel the regulating role of phytohormones towards carotenoid metabolism in *tomato* fruit. (alpha-carotene metabolism)**

Validations Status



Release date:

31-Aug-2014

Organism

- Solanum lycopersicum

Study Factors

- Phytohormones

Study identifier

[MTBLS109](#)

Total Study size

1.67GB

Submitted by

[Lieven van Meulebroek](#)

[www.ebi.ac.uk/metabolights](http://www.ebi.ac.uk/metabolights)  
([metabolights.org](http://metabolights.org), [metabolights.eu](http://metabolights.eu))



# MTBLS36: Metabolic differences in ripening of *Solanum lycopersicum* 'Ailsa Craig' and three monogenic mutants

Authors: Paul Fraser , Graham Seymour , Charlie Hodgman , Mark Seymour , Aniko Kende , Dave Portwood , Charles Baxter , Stephan Beisken , Mark Earl

Submitted: 07-Feb-2014 , Release date: 07-Feb-2014 , Update date: 02-Jun-2016

Submitted by: [Stephan Beisken](#) | Study status: Public

[Share Study](#)

## Study Description

[View Metabolites](#) [Download Study files](#)

Application of mass spectrometry enables the detection of metabolic differences between groups of related organisms. Differences in the metabolic fingerprints of wild-type *Solanum lycopersicum* and three monogenic mutants, ripening inhibitor (rin), non-ripening (nor) and Colourless non-ripening (Cnr), of tomato are captured with regard to ripening behaviour. A high-resolution tandem mass spectrometry system coupled to liquid chromatography produced a time series of the ripening behaviour at discrete intervals with a focus on changes post-anthesis. Internal standards and quality controls were used to ensure system stability. The raw data of the samples and reference compounds including study protocols have been deposited in the open metabolomics database MetaboLights via the metadata annotation tool Isatab to enable efficient re-use of the datasets, such as in metabolomics cross-study comparisons or data fusion exercises.

Study Design Description

Protocols

Samples

Assay

Study Files

Study Validation

Pathways

Organism(s)

*Solanum lycopersicum*

blank

Study Design Description

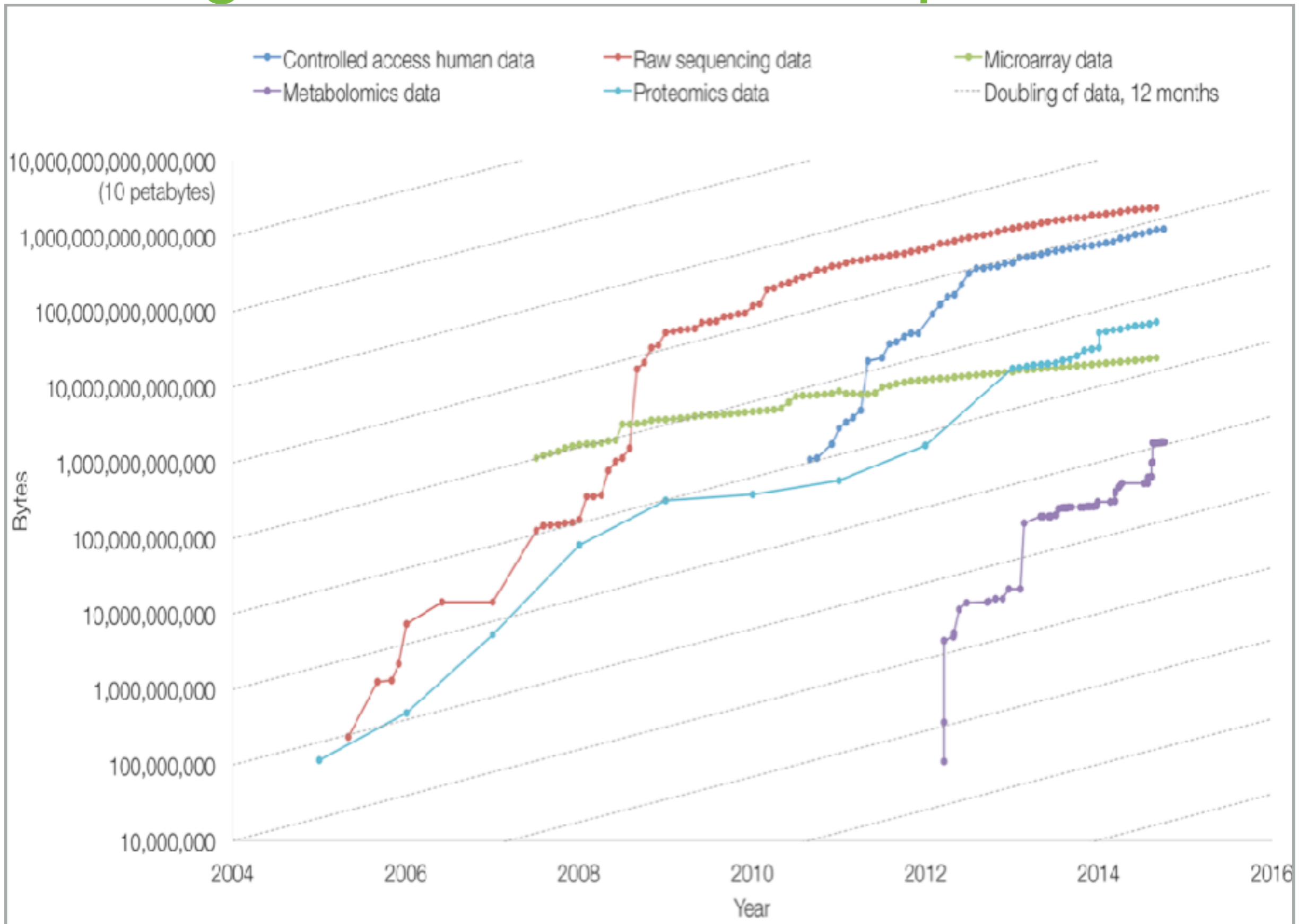
GO:leaf development

CHMO:ultra-performance liquid chromatography-mass spectrometry

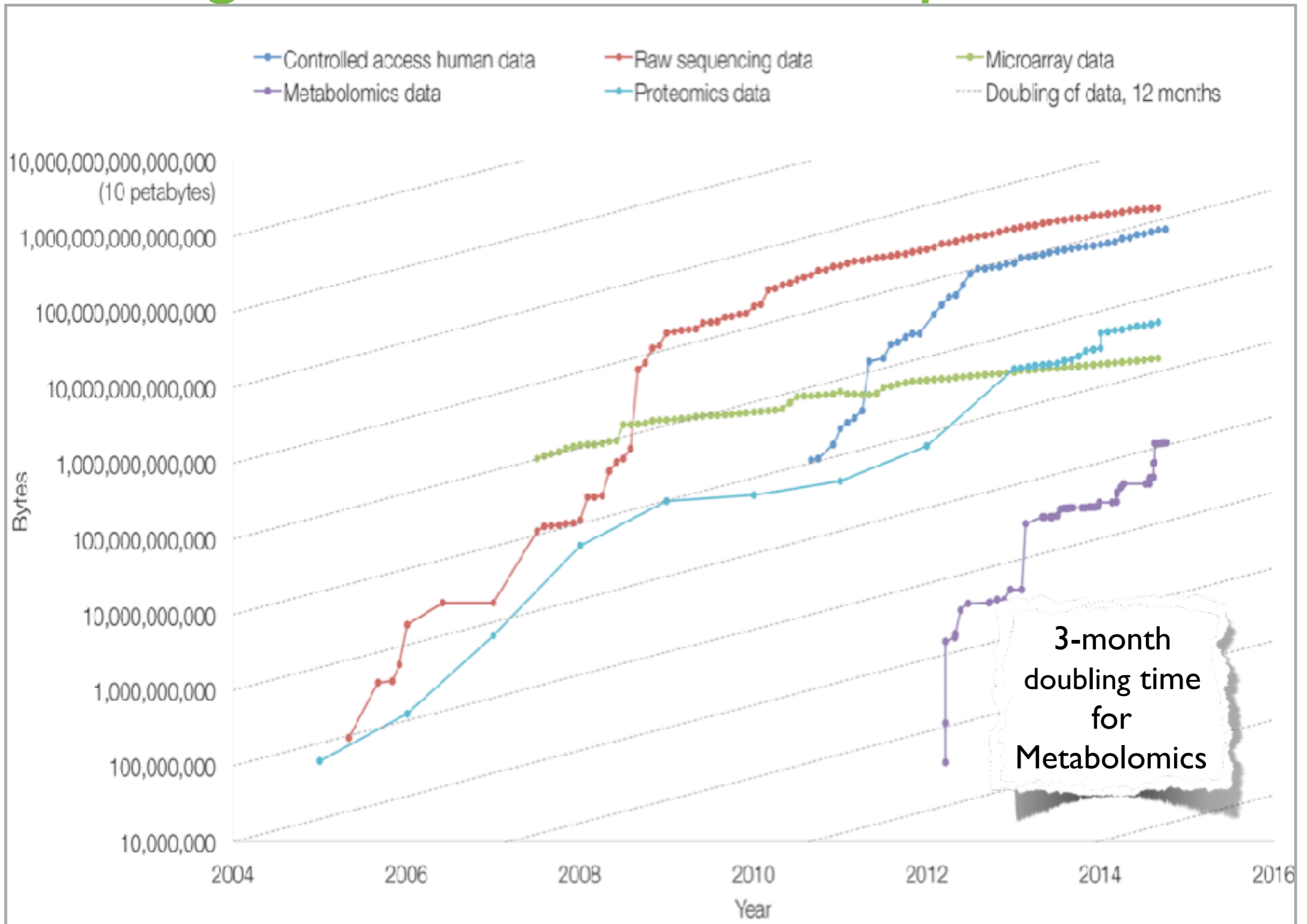
CHMO:tandem mass spectrometry

[www.ebi.ac.uk/metabolights](http://www.ebi.ac.uk/metabolights)  
([metabolights.org](http://metabolights.org), [metabolights.eu](http://metabolights.eu))

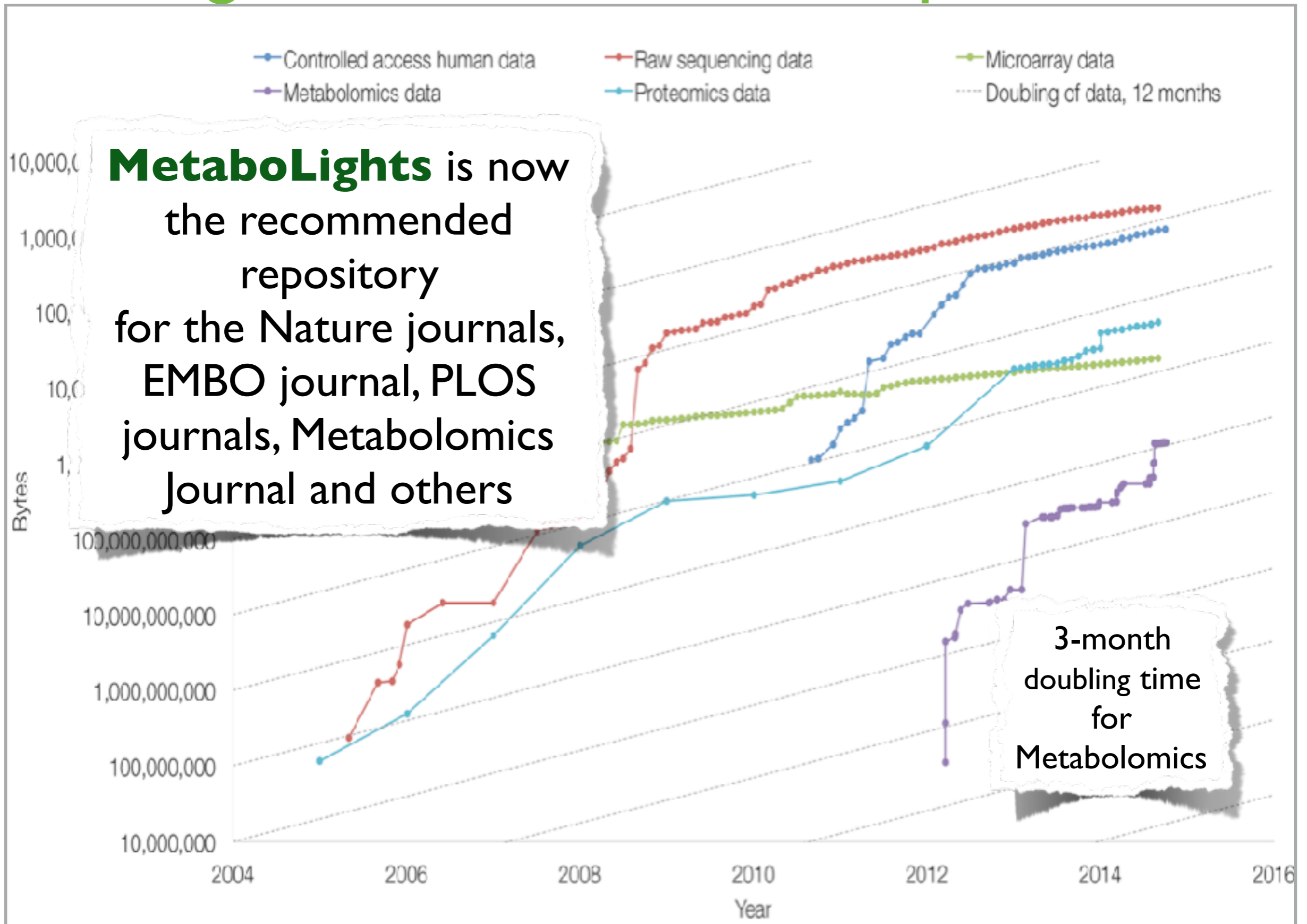
# Data growth in EBI data repositories

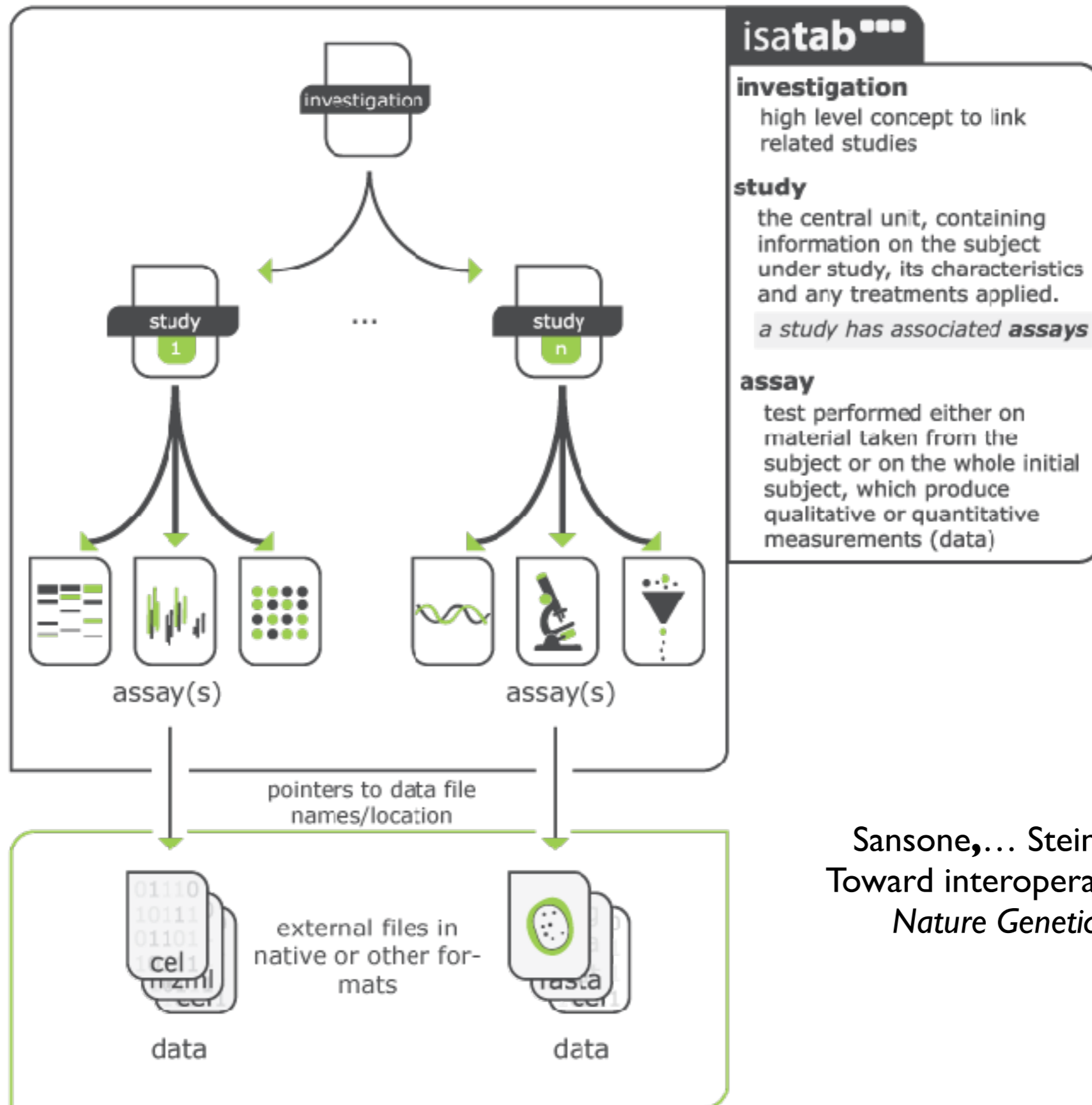


# Data growth in EBI data repositories



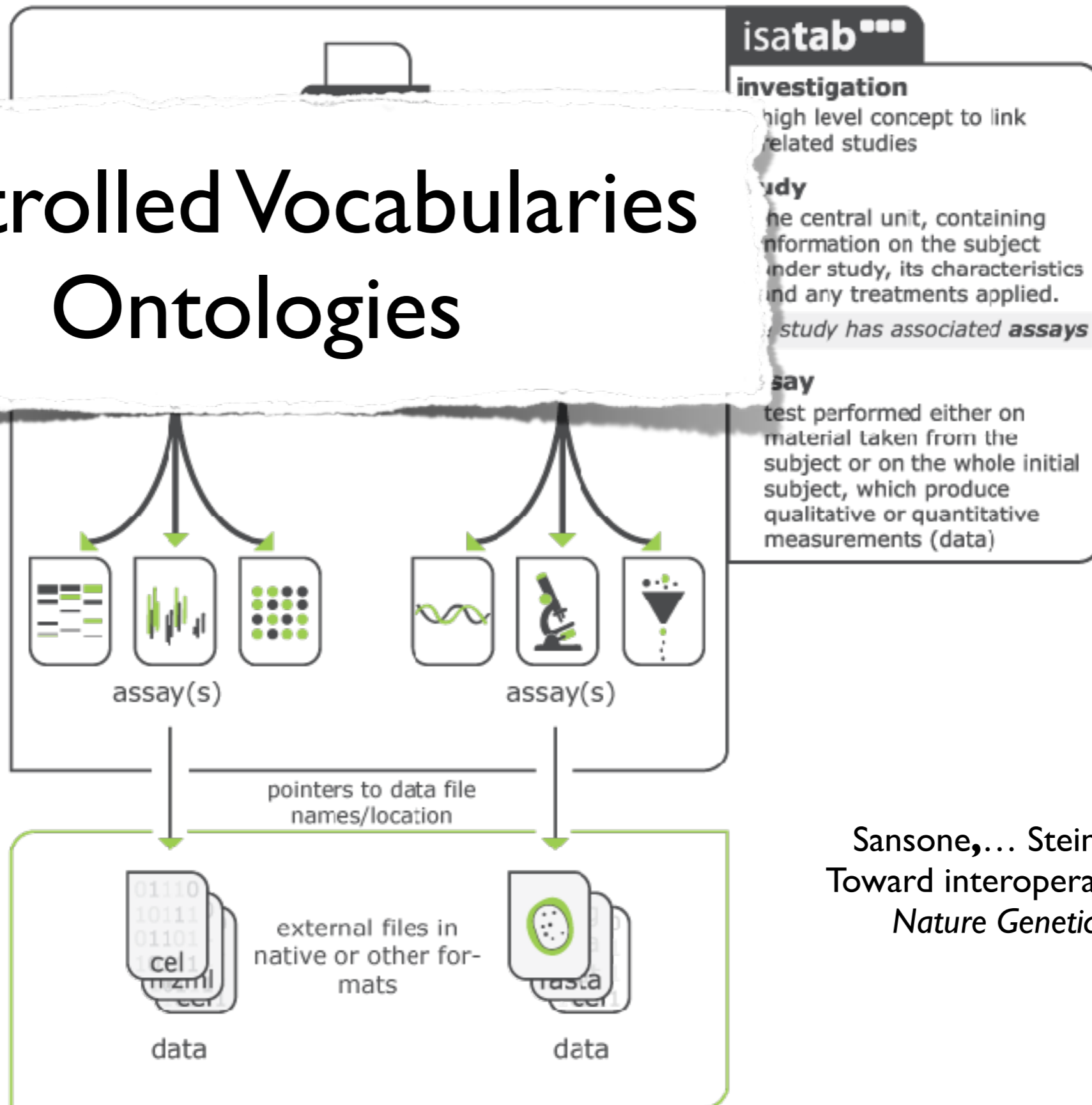
# Data growth in EBI data repositories





Sansone, ... Steinbeck et al. (2012)  
Toward interoperable bioscience data.  
*Nature Genetics*, 44, 121–126.

# Controlled Vocabularies Ontologies



Sansone, ... Steinbeck et al. (2012)  
Toward interoperable bioscience data.  
*Nature Genetics*, 44, 121–126.

# Controlled Vocabularies Ontologies

isatab<sup>™</sup>

## Investigation

high level concept to link related studies

## Study

the central unit, containing information on the subject under study, its characteristics and any treatments applied.

*study has associated assays*

## Assay

test performed either on material taken from the subject or on the whole initial subject, which produce qualitative or quantitative measurements (data)

# Minimum Information Standards

names/location



external files in native or other formats

data




data

Sansone, ... Steinbeck et al. (2012)  
Toward interoperable bioscience data.  
*Nature Genetics*, 44, 121–126.

## STUDY ASSAYS

+ add new assay(s)


VIEW X

metabolite profiling  
NMR spectroscopy  
Bruker  
e\_live\_mtbl1\_nmr\_metaboli...

## STUDY DESIGN DESCRIPTORS

+ add a new design column

Field Name	● design	● design	● design	● design	● design	● design
Study Design Type	NCIT:Metabolo...	NCIT:Diabetes...	NCIT:Metaboic...	NCIT:Human S...	Urine global pr...	OBI:NMR spect...

+ New field to design descrip

## STUDY PUBLICATIONS

+ add a new publication column

🔍 search for publication

Field Name	● publication
Study PubMed ID	17190852
Study Publication DOI	http://dx.doi.or...
Study Publication Author List	Salek RM, Magu...
Study Publication Title	A metabolomic...
Study Publication Status	Published

## STUDY FACTORS

+ add a new factor column

👉 select from previous factors...

Field Name	● factor	● factor
Study Factor Name	Gender	Metabolic synd...
Study Factor Type	NCIT:Gender	Mellitus, Type 2

## STUDY PROTOCOLS

+ add a new protocol column

👉 select from previous protocols...

Field Name	● protoco	● protocol	● protocol	● protocol	● protocol	● protocol	● protoco
Study Protocol Name	Sample collecti...	Extraction	NMR sample	NMR spectrosc...	NMR assay	Data transform...	Metabolite iden...
Study Protocol Type	Sample collecti...	Extraction	NMR sample	NMR spectrosc...	NMR assay	Data transform...	Metabolite iden...
Study Protocol Description	For the human...		Aliquots of 400...	The spectra of...	A 1D NOESY pr...	Spectra were o...	Assignments w...
Study Protocol URL						http://www.spc...	

+ New field to factor descrip

🔍 search ontologies
🕒 view history
📄 term definition

Recommended Ontologies
  All Ontologies

Search for: diabetes type 2
🔍 search

- MEDLINEPLUS - MedlinePlus Health Topics
- MESH - Medical Subject Headings
  - 📄 MESH:Diabetes Mellitus, Type 2
- NATPRO - Natural Products Ontology
- NCIT - National Cancer Institute Thesaurus
- NDFRT - National Drug File - Reference Terminology
- NIFSTD - Neuroscience Information Framework (NIF) Sta
- OMIM - Online Mendelian Inheritance in Man

👇 filter
🔍 search

Selected term. (You can also enter freetext here): MESH:Diabetes Mellitus, Type 2
🔍 Select Ontology Term

**Term name:** Diabetes Mellitus, Type 2

**Service Provider:** BioPortal

**Source:**  
http://data.bioontology.org/ontologies/MESH

**definition:** A subclass of DIABETES MELLITUS that is not INSULIN-responsive or dependent (NIDDM). It is characterized initially by INSULIN RESISTANCE and HYPERINSULINEMIA; and eventually by GLUCOSE INTOLERANCE; HYPERGLYCEMIA; and overt diabetes. Type II diabetes mellitus is no longer considered a disease eventually found in adult patients seldom.

[View in resource.](#)



# Controlled Vocabularies Ontologies

## STUDY ASSAYS

+ add new assay(s)

metabolite profiling  
NMR spectroscopy  
Bruker  
e\_live\_mtbl1\_rms\_metaboli...

## STUDY DESIGN DESCRIPTORS

+ add a new design column

Field Name	design	design	design	design	design	design
Study Design Type	NCIT:Metabolo...	NCIT:Diabetes...	NCIT:Metabo ic...	NCIT:Human S...	Urine global pr...	OBI:NMR spect...

+ New field to design descrip

## STUDY PUBLICATIONS

+ add a new publication column

search for publication

Field Name	publication
Study PubMed ID	17190857
Study Publication DOI	http://dx.doi.or...
Study Publication Author List	Salek RM, Magu...
Study Publication Title	A metabolomic...
Study Publication Status	Published

## STUDY FACTORS

+ add a new factor column

select from previous factors...

Field Name	factor	factor
Study Factor Name	Gender	Metabolic synd...
Study Factor Type	NCIT:Gender	Mellitus, Type 2

## STUDY PROTOCOLS

+ add a new protocol column

select from previous protocols...

Field Name	protocol	protocol	protocol	protocol	protocol	protocol	protocol
Study Protocol Name	Sample collecti...	Extraction	NMR sample	NMR spectrosc...	NMR assay	Data transform...	Metabolite iden...
Study Protocol Type	Sample collecti...	Extraction	NMR sample	NMR spectrosc...	NMR assay	Data transform...	Metabolite iden...
Study Protocol Description	For the human...		Aliquots of 400...	The spectra of...	A 1D NOESY pr...	Spectra were o...	Assignments w...
Study Protocol URL						http://www.scc...	

search ontologies view history term definition

Recommended Ontologies  All Ontologies

Search for: diabetes type 2 search

- MEDLINEPLUS - MedlinePlus Health Topics
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  - MESH:Diabetes Mellitus, Type 2
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- OMIM - Online Mendelian Inheritance in Man

filter

Selected term. (You can also enter freetext here): MESH:Diabetes Mellitus, Type 2 Select Ontology Term

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Service Provider: BioPortal  
Source: http://data.bioontology.org/ontologies/MESH  
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+ New field to factor descrip

# Controlled Vocabularies Ontologies

## STUDY ASSAYS

+ add new assay(s)

metabolite profiling	NMR spectroscopy	Bruker	e_live_mtbl1_mrs_metaboli...
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## STUDY DESIGN DESCRIPTORS

+ add a new design column

Field Name	design	design	design	design	design	design
Study Design Type	NCIT:Metabolo...	NCIT:Diabetes ..	NCIT:Metabo ic..	NCIT:Human S...	Urine global pr...	OBI:NMR spect...

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+ add a new factor column

select from previous factors...

Field Name	factor	factor
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Study Factor Type	NCIT:Gender	Mellitus, Type 2

## STUDY PROTOCOLS

+ add a new protocol column

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Field Name	protocol	protocol	protocol	protocol	protocol	protocol	protocol
Study Protocol Name	Sample collecti...	Extraction	NMR sample	NMR spectrosc...	NMR assay	Data transform...	Metabolite iden...
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Study Protocol URL						http://www.scc...	

search ontologies

view history

term definition

Recommended Ontologies  All Ontologies

Search for: diabetes type 2

search

MEDLINEPLUS - MedlinePlus Health Topics

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Selected term. (You can also enter freetext here): MESH:Diabetes Mellitus, Type 2

Select Ontology Term

+ New field to factor descrip



Metabome analysis of *Drosophila melanogaster* during embryogenesis (Normalized data)

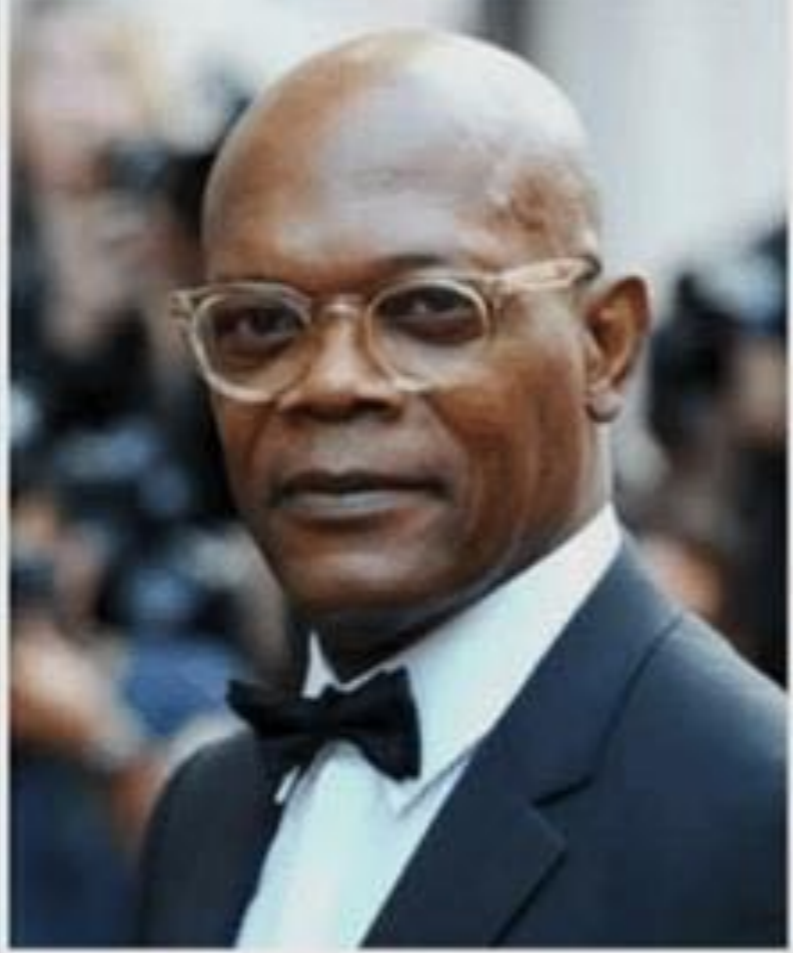
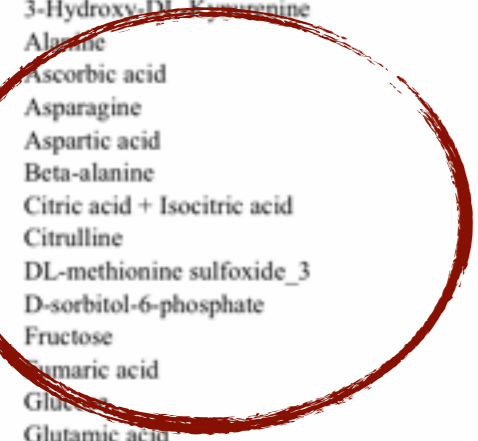
Compound_Name	0-2 Hrs AEL			2-4 Hrs AEL			4-6 Hrs AEL			6-8 Hrs AEL			8-10 Hrs AEL			10-12 Hrs AEL		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
2-Aminoethanol	0,7136056	0,6639233	0,726679	0,9094056	1,0639767	0,7451021	0,9178169	1,0385232	1,19182	0,9939918	1, <a href="#">1234241</a>	1,2878722	0,8004048	0,9580137	0,9992593	0,7263508	0,6553381	0,67140
3-Hydroxy-DL-Kynurenine	0,0000235	0,0000351	0,0000233	0,0000373	0,0000245	0,0000374	0,0000229	0,0000394	0,0000237	0,0000355	0,0101692	0,0000232	0,0207445	0,0208783	0,0208217	0,0579032	0,0414156	0,04111
Alanine	2,363344	2,4497882	1,9587284	1,8722018	1,0662766	0,6440171	2,0857126	1,4572888	2,3298619	2,6077837	2,4392098	2,8881375	1,8675234	1,4842899	1,4012411	1,195396	1,4318903	1,46094
Ascorbic acid	<a href="#">0,1742054</a>	0,2231896	0,3207919	0,3018765	0,2822338	0,2607638	0,2942426	0,2191213	0,2031219	0,2672933	0,2936285	0,3311912	0,2242365	0,2837459	0,2847014	0,2675374	0,2801292	0,22740
Asparagine	0,2596146	<a href="#">0,1878781</a>	0,2500357	0,3638829	0,2940516	<a href="#">0,1365858</a>	0,4239728	0,3791345	0,3946629	0,3926397	0,3827761	0,3737659	0,2760786	0,3199353	0,2984643	0,3166928	0,2773605	0,22935
Aspartic acid	2,5798803	2,4030774	2,8316859	2,447597	2,0606399	0,9712436	1,4519626	1,4632552	1,5804861	<a href="#">1,1286807</a>	1,3629721	<a href="#">1,1160588</a>	0,9130334	1,0623508	<a href="#">1,1029786</a>	<a href="#">1,1415617</a>	0,8067474	0,8458
Beta-alanine	<a href="#">0,1164733</a>	<a href="#">0,1550048</a>	<a href="#">0,1132455</a>	0,0276766	0,0323768	0,0243359	0,0327494	0,0260449	0,0281522	0,0307903	0,0338734	0,0361165	0,0333167	0,0346692	0,0332905	0,0503103	0,0474079	0,05802
Citric acid + Isocitric acid	<a href="#">0,1435768</a>	<a href="#">0,1338495</a>	<a href="#">0,1382322</a>	<a href="#">0,1447501</a>	<a href="#">0,1940281</a>	<a href="#">0,1945939</a>	<a href="#">0,1507612</a>	0,2011104	0,2036384	<a href="#">0,1987895</a>	0,2535048	0,2737135	0,2408268	0,2633844	0,2703533	0,4862541	0,4130157	0,28826
Citrulline	0,0051612	0,0054029	0,000035	0,0000249	0,0051871	0,0000374	0,0053875	0,0047238	0,0071576	0,0044803	0,000025	0,0085433	0,0000237	0,0072113	0,0077476	0,0090883	0,0000364	0,00815
DL-methionine sulfoxide_3	0,0761757	0,0747659	<a href="#">0,1201906</a>	<a href="#">0,1040812</a>	0,0727024	0,044619	0,0897841	0,0818787	0,0778425	0,0972834	0,0799754	<a href="#">0,1404203</a>	0,0968965	<a href="#">0,1045275</a>	<a href="#">0,1178397</a>	0,0971362	0,0895483	0,09805
D-sorbitol-6-phosphate	0,0331591	0,0229037	0,0259568	0,0325133	0,0202164	0,0189092	0,0464403	0,0283229	0,0329408	0,0426172	0,0232573	0,024848	0,0322811	0,0666123	0,0590467	0,0278436	0,0329669	0,05613
Fructose	0,0357368	0,0378288	0,0272182	0,0177792	0,0153198	0,0180837	0,0148006	0,0161174	0,0318275	0,0184333	0,0180633	0,0409066	0,0196142	0,0175175	0,0148006	0,0216353	0,0199754	0,01657
Fumaric acid	0,076414	0,0652904	0,0754844	0,0828494	0,0808654	0,0689362	0,0951171	0,0791569	0,0843231	0,0890573	0,0732563	0,0971853	0,0633816	0,0832684	0,0797502	0,0648435	0,0675744	0,07338
Glucose	0,7095361	0,5501533	0,3852236	0,3958675	0,4300395	0,5119795	0,4364624	0,685828	1,077795	0,6110588	0,9580169	1,2995462	0,6419494	0,6274609	0,6495449	1,0113695	0,7301603	<a href="#">1,11278</a>
Glutamic acid	2,0733097	1,6586608	1,8448216	2,0897297	1,6947575	1,0507528	2,2268974	1,9954899	2,0936122	2,4679364	2,394036	2,3079013	2,0712817	1,9599238	1,9720245	2,2101846	1,7210747	1,59026
Glutamine	0,5190086	0,2506308	0,2472681	0,4561196	0,2828118	0,0265633	0,3861026	0,2251665	<a href="#">0,1178161</a>	0,2938935	<a href="#">0,1877676</a>	0,0855201	0,2978794	<a href="#">0,1707982</a>	<a href="#">0,1518017</a>	0,2946971	<a href="#">0,1818956</a>	<a href="#">0,10691</a>
Glycine	1,7810008	1,4730983	1,8368889	1,9962893	1,6745931	1,4580617	<a href="#">2,1797718</a>	<a href="#">2,1153823</a>	2,3938079	2,5752434	2,6031826	3,2281646	2,3314653	2,573754	2,5209802	2,6694634	2,5251384	2,33180
Histidine	0,3774268	0,4440374	0,4657245	0,4321071	0,4423467	<a href="#">0,1707564</a>	0,502182	0,4811016	0,5250455	0,4564915	0,5461333	0,5972302	0,4196568	0,5020673	0,4843953	0,6355165	0,5016179	0,47748
Hypoxanthine	0,0000353	0,0000234	0,000035	0,0000249	0,0000367	0,0000249	0,0000344	0,0000263	0,0000356	0,0000237	0,0000375	0,0162815	0,0087316	0,008656	0,0076611	0,0091564	0,0000364	0,01433
Inosine	0,0374169	0,0513301	0,0588208	0,0492288	0,052275	0,0459741	0,0573186	0,0598509	0,0659944	0,0525845	0,065181	0,0885407	0,0381573	0,0502101	0,0524347	0,0395848	0,04006	0,03827
Inositol	0,0581028	0,0488099	0,043908	0,0253438	0,0192958	0,0209933	0,0431545	0,0441444	0,0509549	0,0719802	0,0815473	0,0946194	0,0647515	0,0843685	0,0833011	0,076145	0,0862398	0,07272
Isoleucine	0,2533648	0,2613839	0,2826754	0,2588686	<a href="#">0,1907158</a>	<a href="#">0,1716318</a>	0,3045073	0,2662669	0,4020253	0,3254359	0,3900108	0,3993988	0,280073	0,3296491	0,298643	0,3016375	0,26372	0,31692
Kynurenine	<a href="#">0,1482142</a>	0,136279	<a href="#">0,1379933</a>	<a href="#">0,1259786</a>	<a href="#">0,1367097</a>	0,0680577	<a href="#">0,1166155</a>	<a href="#">0,1283834</a>	<a href="#">0,1496495</a>	<a href="#">0,1048344</a>	<a href="#">0,1427187</a>	<a href="#">0,1542229</a>	0,0648846	0,0877958	0,0869184	0,0621707	0,0467438	0,04132
Leucine	0,5676777	0,5872688	0,6962387	0,5493921	0,3976597	0,3254446	0,5511283	0,5485723	0,7769521	0,6271054	0,8605283	0,8285109	0,5581725	0,6086046	0,5921815	0,5624558	0,5067277	0,597
Lysine	0,6329632	0,6274365	0,6948958	0,6080672	0,4948297	0,3056569	0,5080311	0,4460694	0,5594914	0,5073111	0,551196	0,661699	0,3873669	0,4037326	0,3895967	0,4562115	0,3974345	0,39716
Malic acid	<a href="#">1,1577921</a>	1,0512629	<a href="#">1,1652814</a>	1,2874752	1,2939721	<a href="#">1,1154523</a>	1,2448634	1,2908391	1,2723759	1,3066265	<a href="#">1,1989087</a>	1,5737636	1,0068557	<a href="#">1,1022516</a>	<a href="#">1,1419068</a>	<a href="#">1,1379496</a>	<a href="#">1,1301572</a>	1,03128
Maltose	0,0000235	0,0000351	0,0000233	0,0000373	0,0135948	0,0000249	0,0205952	0,0236616	0,0244889	0,0248502	0,0301013	0,0385926	0,0248869	0,032611	0,0343368	0,046562	0,0321815	0,02807
Mannose	0,0082773	0,007733	0,0081337	0,0000373	0,0000245	0,0000374	0,0000229	0,0000394	0,0080719	0,0096445	0,008666	0,0213902	0,0111756	0,0093269	0,0094395	0,0082512	0,008567	0,01122
Methionine	<a href="#">0,1294733</a>	<a href="#">0,1299932</a>	<a href="#">0,1459377</a>	<a href="#">0,1445168</a>	<a href="#">0,1004181</a>	0,0571171	<a href="#">0,1210339</a>	0,104495	0,139743	<a href="#">0,1316952</a>	<a href="#">0,1411718</a>	<a href="#">0,1403624</a>	0,0970917	0,0966059	0,0980383	0,0896057	0,0825279	0,08395
N-Acetyl-L-Aspartic acid	0,0182848	0,0215647	0,0251265	0,0297575	0,0355789	0,0454694	<a href="#">0,1479858</a>	<a href="#">0,1674359</a>	<a href="#">0,1896143</a>	0,3170706	0,3295207	0,3787037	0,3408597	0,4243207	0,4018464	0,4292759	0,3979621	0,29799
Nicotinic acid	0,0000235	0,0000351	0,0000233	0,0000373	0,0000245	0,0000374	0,0000229	0,0000394	0,0060502	0,0068995	0,0092379	0,0135332	0,0075658	0,0106356	0,0114744	0,0097465	0,0093433	0,01227
O-Phosphoethanolamine	0,7271293	0,7444868	0,6974565	0,5828976	0,6160085	0,4499123	0,5055079	0,5565012	0,5446093	0,4583896	0,4360472	0,5631786	0,3282165	0,3777254	0,387899	0,3325001	0,3151704	0,28484
Ornithine	0,0278567	0,0319728	0,0351946	0,0319068	0,0251343	0,0203983	0,0268716	0,0270179	0,0387832	0,0248827	0,0333827	0,0320563	0,0221145	0,0203071	0,0228883	0,025585	0,0243484	0,02730
Pantothenate	0,0458472	0,0321277	0,0467659	0,0500779	0,0298719	0,0339307	0,0464891	0,0390722	0,03482	0,0485958	0,0384642	0,0568348	0,043646	0,0442681	0,0476702	0,0440509	0,054956	0,04036
Phenylalanine	<a href="#">0,1208106</a>	<a href="#">0,1103289</a>	<a href="#">0,1290264</a>	<a href="#">0,1292757</a>	0,0870037	0,0641419	<a href="#">0,1418987</a>	0,12054	<a href="#">0,1746015</a>	0,2175426	0,2562081	0,2400905	0,2115608	0,2251579	0,2320303	0,2277993	0,2014617	0,20625
Phosphate	<a href="#">2,1021227</a>	2,3602229	2,4228128	2,4130588	2,3395247	<a href="#">2,1381528</a>	2,3808613	2,5360282	2,7689485	2,3196675	2,61353	<a href="#">3,1324707</a>	<a href="#">2,1033586</a>	2,8506181	2,8885907	2,2688	2,6162969	2,58775
Proline	0,6139192	0,6455688	0,646816	0,4294166	0,327196	<a href="#">0,1750616</a>	0,4371075	0,3991999	0,6127144	0,4582682	0,6519066	0,6014237	0,4407061	0,5154048	0,470494	0,6519253	0,4923079	0,6262
Pyroglutamic acid	0,9224207	1,3461456	1,605224	0,9991446	1,3001012	1,23892	0,7554836	1,282667	1,8359047	0,8301027	1,39918	<a href="#">2,1683758</a>	0,8012185	1,4523559	1,7574176	1,2427298	1,4145168	1,59045
Serine	0,2437604	0,2473739	0,3018444	0,2137145	<a href="#">0,1581005</a>	<a href="#">0,1125801</a>	0,2976059	0,2521942	0,36828	0,3053147	0,3609908	0,3840642	0,2119277	0,2485659	0,2380832	<a href="#">0,1708552</a>	<a href="#">0,1524556</a>	<a href="#">0,18497</a>
Sorbose	0,0555016	0,0669101	0,0484643	0,0334713	0,0282754	0,0313171	0,0277977	0,0280106	0,0504235	0,0372693	0,0372954	0,0637621	0,0308046	0,0286789	0,0269956	0,0421924	0,0341405	0,02937

Metabome analysis of *Drosophila melanogaster* during embryogenesis (Normalized data)

Compound_Name	0-2 Hrs AEL			2-4 Hrs AEL			4-6 Hrs AEL			6-8 Hrs AEL			8-10 Hrs AEL			10-12 Hrs AEL		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
2-Aminoethanol	0,7136056	0,6639233	0,726679	0,9094056	1,0639767	0,7451021	0,9178169	1,0385232	1,19182	0,9939918	1,1234241	1,2878722	0,8004048	0,9580137	0,9992593	0,7263508	0,6553381	0,67140
3-Hydroxy-DL-Kynurenine	0,0000235	0,0000351	0,0000233	0,0000373	0,0000245	0,0000374	0,0000229	0,0000394	0,0000237	0,0000355	0,0101692	0,0000232	0,0207445	0,0208783	0,0208217	0,0579032	0,0414156	0,04111
Alanine	2,363344	2,4497882	1,9587284	1,8722018	1,0662766	0,6440171	2,0857126	1,4572888	2,3298619	2,6077837	2,4392098	2,8881375	1,8675234	1,4842899	1,4012411	1,195396	1,4318903	1,46094
Ascorbic acid	<u>0,1742054</u>	0,2231896	0,3207919	0,3018765	0,2822338	0,2607638	0,2942426	0,2191213	0,2031219	0,2672933	0,2936285	0,3311912	0,2242365	0,2837459	0,2847014	0,2675374	0,2801292	0,22740
Asparagine	0,2596146	<u>0,1878781</u>	0,2500357	0,3638829	0,2940516	<u>0,1365858</u>	0,4239728	0,3791345	0,3946629	0,3926397	0,3827761	0,3737659	0,2760786	0,3199353	0,2984643	0,3166928	0,2773605	0,22935
Aspartic acid	2,5798803	2,4030774	2,8316859	2,447597	2,0606399	0,9712436	1,4519626	1,4632552	1,5804861	<u>1,1286807</u>	1,3629721	<u>1,1160588</u>	0,9130334	1,0623508	<u>1,1029786</u>	<u>1,1415617</u>	0,8067474	0,8458
Beta-alanine	<u>0,1164733</u>	<u>0,1550048</u>	<u>0,1132455</u>	0,0276766	0,0323768	0,0243359	0,0327494	0,0260449	0,0281522	0,0307903	0,0338734	0,0361165	0,0333167	0,0346692	0,0332905	0,0503103	0,0474079	0,05802
Citric acid + Isocitric acid	<u>0,1435768</u>	<u>0,1338495</u>	<u>0,1382322</u>	<u>0,1447501</u>	<u>0,1940281</u>	<u>0,1945939</u>	<u>0,1507612</u>	0,2011104	0,2036384	<u>0,1987895</u>	0,2535048	0,2737135	0,2408268	0,2633844	0,2703533	0,4862541	0,4130157	0,28826
Citrulline	0,0051612	0,0054029	0,000035	0,0000249	0,0051871	0,0000374	0,0053875	0,0047238	0,0071576	0,0044803	0,000025	0,0085433	0,0000237	0,0072113	0,0077476	0,0090883	0,0000364	0,00815
DL-methionine sulfoxide_3	0,0761757	0,0747659	<u>0,1201906</u>	<u>0,1040812</u>	0,0727024	0,044619	0,0897841	0,0818787	0,0778425	0,0972834	0,0799754	<u>0,1404203</u>	0,0968965	<u>0,1045275</u>	<u>0,1178397</u>	0,0971362	0,0895483	0,09805
D-sorbitol-6-phosphate	0,0331591	0,0229037	0,0259568	0,0325133	0,0202164	0,0189092	0,0464403	0,0283229	0,0329408	0,0426172	0,0232573	0,024848	0,0322811	0,0666123	0,0590467	0,0278436	0,0329669	0,05613
Fructose	0,0357368	0,0378288	0,0272182	0,0177792	0,0153198	0,0180837	0,0148006	0,0161174	0,0318275	0,0184333	0,0180633	0,0409066	0,0196142	0,0175175	0,0148006	0,0216353	0,0199754	0,01657
Fumaric acid	0,076414	0,0652904	0,0754844	0,0828494	0,0808654	0,0689362	0,0951171	0,0791569	0,0843231	0,0890573	0,0732563	0,0971853	0,0633816	0,0832684	0,0797502	0,0648435	0,0675744	0,07338
Glucose	0,7095361	0,5501533	0,3852236	0,3958675	0,4300395	0,5119795	0,4364624	0,685828	1,077795	0,6110588	0,9580169	1,2995462	0,6419494	0,6274609	0,6495449	1,0113695	0,7301603	<u>1,11278</u>
Glutamic acid	2,0733097	1,6586608	1,8448216	2,0897297	1,6947575	1,0507528	2,2268974	1,9954899	2,0936122	2,4679364	2,394036	2,3079013	2,0712817	1,9599238	1,9720245	2,2101846	1,7210747	1,59026
Glutamine	0,5190086	0,2506308	0,2472681	0,4561196	0,2828118	0,0265633	0,3861026	0,2251665	<u>0,1178161</u>	0,2938935	<u>0,1877676</u>	0,0855201	0,2978794	<u>0,1707982</u>	<u>0,1518017</u>	0,2946971	<u>0,1818956</u>	<u>0,10691</u>
Glycine	1,7810008	1,4730983	1,8368889	1,9962893	1,6745931	1,4580617	<u>2,1797718</u>	<u>2,1153823</u>	2,3938079	2,5752434	2,6031826	3,2281646	2,3314653	2,573754	2,5209802	2,6694634	2,5251384	2,33180
Histidine	0,3774268	0,4440374	0,4657245	0,4321071	0,4423467	<u>0,1707564</u>	0,502182	0,4811016	0,5250455	0,4564915	0,5461333	0,5972302	0,4196568	0,5020673	0,4843953	0,6355165	0,5016179	0,47748
Hypoxanthine	0,0000353	0,0000234	0,000035	0,0000249	0,0000367	0,0000249	0,0000344	0,0000263	0,0000356	0,0000237	0,0000375	0,0162815	0,0087316	0,008656	0,0076611	0,0091564	0,0000364	0,01430
Inosine	0,0374169	0,0513301	0,0588208	0,0492288	0,052275	0,0459741	0,0573186	0,0598509	0,0659944	0,0525845	0,065181	0,0885407	0,0381573	0,0502101	0,0524347	0,0395848	0,04006	0,03827
Inositol	0,0581028	0,0488099	0,043908	0,0253438	0,0192958	0,0209933	0,0431545	0,0441444	0,0509549	0,0719802	0,0815473	0,0946194	0,0647515	0,0843685	0,0833011	0,076145	0,0862398	0,07272
Isoleucine	0,2533648	0,2613839	0,2826754	0,2588686	<u>0,1907158</u>	<u>0,1716318</u>	0,3045073	0,2662669	0,4020253	0,3254359	0,3900108	0,3993988	0,280073	0,3296491	0,298643	0,3016375	0,26372	0,31692
Kynurenine	<u>0,1482142</u>	0,136279	<u>0,1379933</u>	<u>0,1259786</u>	<u>0,1367097</u>	0,0680577	<u>0,1166155</u>	<u>0,1283834</u>	<u>0,1496495</u>	<u>0,1048344</u>	<u>0,1427187</u>	<u>0,1542229</u>	0,0648846	0,0877958	0,0869184	0,0621707	0,0467438	0,04132
Leucine	0,5676777	0,5872688	0,6962387	0,5493921	0,3976597	0,3254446	0,5511283	0,5485723	0,7769521	0,6271054	0,8605283	0,8285109	0,5581725	0,6086046	0,5921815	0,5624558	0,5067277	0,597
Lysine	0,6329632	0,6274365	0,6948958	0,6080672	0,4948297	0,3056569	0,5080311	0,4460694	0,5594914	0,5073111	0,551196	0,661699	0,3873669	0,4037326	0,3895967	0,4562115	0,3974345	0,39716
Malic acid	<u>1,1577921</u>	1,0512629	<u>1,1652814</u>	1,2874752	1,2939721	<u>1,1154523</u>	1,2448634	1,2908391	1,2723759	1,3066265	<u>1,1989087</u>	1,5737636	1,0068557	<u>1,1022516</u>	<u>1,1419068</u>	<u>1,1379496</u>	<u>1,1301572</u>	1,03128
Maltose	0,0000235	0,0000351	0,0000233	0,0000373	0,0135948	0,0000249	0,0205952	0,0236616	0,0244889	0,0248502	0,0301013	0,0385926	0,0248869	0,032611	0,0343368	0,046562	0,0321815	0,02807
Mannose	0,0082773	0,007733	0,0081337	0,0000373	0,0000245	0,0000374	0,0000229	0,0000394	0,0080719	0,0096445	0,008666	0,0213902	0,0111756	0,0093269	0,0094395	0,0082512	0,008567	0,01122
Methionine	<u>0,1294733</u>	<u>0,1299932</u>	<u>0,1459377</u>	<u>0,1445168</u>	<u>0,1004181</u>	0,0571171	<u>0,1210339</u>	0,104495	0,139743	<u>0,1316952</u>	<u>0,1411718</u>	<u>0,1403624</u>	0,0970917	0,0966059	0,0980383	0,0896057	0,0825279	0,08395
N-Acetyl-L-Aspartic acid	0,0182848	0,0215647	0,0251265	0,0297575	0,0355789	0,0454694	<u>0,1479858</u>	<u>0,1674359</u>	<u>0,1896143</u>	0,3170706	0,3295207	0,3787037	0,3408597	0,4243207	0,4018464	0,4292759	0,3979621	0,29799
Nicotinic acid	0,0000235	0,0000351	0,0000233	0,0000373	0,0000245	0,0000374	0,0000229	0,0000394	0,0060502	0,0068995	0,0092379	0,0135332	0,0075658	0,0106356	0,0114744	0,0097465	0,0093433	0,01227
O-Phosphoethanolamine	0,7271293	0,7444868	0,6974565	0,5828976	0,6160085	0,4499123	0,5055079	0,5565012	0,5446093	0,4583896	0,4360472	0,5631786	0,3282165	0,3777254	0,387899	0,3325001	0,3151704	0,28484
Omithine	0,0278567	0,0319728	0,0351946	0,0319068	0,0251343	0,0203983	0,0268716	0,0270179	0,0387832	0,0248827	0,0333827	0,0320563	0,0221145	0,0203071	0,0228883	0,025585	0,0243484	0,02730
Pantothenate	0,0458472	0,0321277	0,0467659	0,0500779	0,0298719	0,0339307	0,0464891	0,0390722	0,03482	0,0485958	0,0384642	0,0568348	0,043646	0,0442681	0,0476702	0,0440509	0,054956	0,04036
Phenylalanine	<u>0,1208106</u>	<u>0,1103289</u>	<u>0,1290264</u>	<u>0,1292757</u>	0,0870037	0,0641419	<u>0,1418987</u>	0,12054	<u>0,1746015</u>	0,2175426	0,2562081	0,2400905	0,2115608	0,2251579	0,2320303	0,2277993	0,2014617	0,20625
Phosphate	<u>2,1021227</u>	2,3602229	2,4228128	2,4130588	2,3395247	<u>2,1381528</u>	2,3808613	2,5360282	2,7689485	2,3196675	2,61353	<u>3,1324707</u>	<u>2,1033586</u>	2,8506181	2,8885907	2,2688	2,6162969	2,58775
Proline	0,6139192	0,6455688	0,646816	0,4294166	0,327196	<u>0,1750616</u>	0,4371075	0,3991999	0,6127144	0,4582682	0,6519066	0,6014237	0,4407061	0,5154048	0,470494	0,6519253	0,4923079	0,6262
Pyroglutamic acid	0,9224207	1,3461456	1,605224	0,9991446	1,3001012	1,23892	0,7554836	1,282667	1,8359047	0,8301027	1,39918	<u>2,1683758</u>	0,8012185	1,4523559	1,7574176	1,2427298	1,4145168	1,59045
Serine	0,2437604	0,2473739	0,3018444	0,2137145	<u>0,1581005</u>	<u>0,1125801</u>	0,2976059	0,2521942	0,36828	0,3053147	0,3609908	0,3840642	0,2119277	0,2485659	0,2380832	<u>0,1708552</u>	<u>0,1524556</u>	<u>0,18497</u>
Sorbose	0,0555016	0,0669101	0,0484643	0,0334713	0,0282754	0,0313171	0,0277977	0,0280106	0,0504235	0,0372693	0,0372954	0,0637621	0,0308046	0,0286789	0,0269956	0,0421924	0,0341405	0,02937
Succinic acid(or aldehyde)	<u>0,1976778</u>	<u>0,1681202</u>	<u>0,1338944</u>	<u>0,1604764</u>	<u>0,1247114</u>	<u>0,1225705</u>	<u>0,1800843</u>	<u>0,1558549</u>	0,194578	0,2								

Metabome analysis of *Drosophila melanogaster* during embryogenesis (Normalized data)

Compound_Name	0-2 Hrs AEL			2-4 Hrs AEL			4-6 Hrs AEL			6-8 Hrs AEL			8-10 Hrs AEL			10-12 Hrs AEL		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
2-Aminoethanol	0,7136056	0,6639233	0,726679	0,9094056	1,0639767	0,7451021	0,9178169	1,0385232	1,19182	0,9939918	1,1234241	1,2878722	0,8004048	0,9580137	0,9992593	0,7263508	0,6553381	0,67140
3-Hydroxy-DL-Kynurenine	0,0000235	0,0000351	0,0000233	0,0000373	0,0000245	0,0000374	0,0000229	0,0000394	0,0000237	0,0000355	0,0101692	0,0000232	0,0207445	0,0208783	0,0208217	0,0579032	0,0414156	0,04111
Alanine	2,363344	2,4497882	1,9587284	1,8722018	1,0662766	0,6440171	2,0857126	1,4572888	2,3298619	2,6077837	2,4392098	2,8881375	1,8675234	1,4842899	1,4012411	1,195396	1,4318903	1,46094
Ascorbic acid	0,1742054	0,2231896	0,3207919	0,3018765	0,2822338	0,2607638	0,2942426	0,2191213	0,2031219	0,2672933	0,2936285	0,3311912	0,2242365	0,2837459	0,2847014	0,2675374	0,2801292	0,22740
Asparagine	0,2596146	0,1878781	0,2500357	0,3638829	0,2940516	0,1365858	0,4239728	0,3791345	0,3946629	0,3926397	0,3827761	0,3737659	0,2760786	0,3199353	0,2984643	0,3166928	0,2773605	0,22935
Aspartic acid	2,5798803	2,4030774	2,8316859	2,447597	2,0606399	0,9712436	1,4519626	1,4632552	1,5804861	1,1286807	1,3629721	1,1160588	0,9130334	1,0623508	1,1029786	1,1415617	0,8067474	0,8458
Beta-alanine	0,11647															0,0503103	0,0474079	0,05802
Citric acid + Isocitric acid	0,14357															0,4862541	0,4130157	0,28826
Citrulline	0,00516															0,0090883	0,0000364	0,00815
DL-methionine sulfoxide_3	0,07617															0,0971362	0,0895483	0,09805
D-sorbitol-6-phosphate	0,03315															0,0278436	0,0329669	0,05613
Fructose	0,03573															0,0216353	0,0199754	0,01657
Fumaric acid	0,0764															0,0648435	0,0675744	0,07338
Glucose	0,70953															1,0113695	0,7301603	1,11278
Glutamic acid	2,07330															2,2101846	1,7210747	1,59026
Glutamine	0,51900															0,2946971	0,1818956	0,10691
Glycine	1,78100															2,6694634	2,5251384	2,33180
Histidine	0,37742															0,6355165	0,5016179	0,47748
Hypoxanthine	0,00003															0,0091564	0,0000364	0,01430
Inosine	0,03741															0,0395848	0,04006	0,03827
Inositol	0,05810															0,076145	0,0862398	0,07272
Isoleucine	0,25336															0,3016375	0,26372	0,31692
Kynurenine	0,14821															0,0621707	0,0467438	0,04132
Leucine	0,56767															0,5624558	0,5067277	0,597
Lysine	0,63296															0,4562115	0,3974345	0,39716
Malic acid	1,15779															1,1379496	1,1301572	1,03128
Maltose	0,00002															0,046562	0,0321815	0,02807
Mannose	0,00827															0,0082512	0,008567	0,01122
Methionine	0,12947															0,0896057	0,0825279	0,08395
N-Acetyl-L-Aspartic acid	0,01828															0,4292759	0,3979621	0,29799
Nicotinic acid	0,00002															0,0097465	0,0093433	0,01273
O-Phosphoethanolamine	0,72712															0,3325001	0,3151704	0,28484
Ornithine	0,02785															0,025585	0,0243484	0,02730
Pantothenate	0,04584															0,0440509	0,054956	0,04036
Phenylalanine	0,12081															0,2277993	0,2014617	0,20625
Phosphate	2,10212															2,2688	2,6162969	2,58775
Proline	0,61391															0,6519253	0,4923079	0,6262
Pyroglutamic acid	0,92242															1,2427298	1,4145168	1,59045
Serine	0,24376															0,1708552	0,1524556	0,18497
Sorbose	0,05550															0,0421924	0,0341405	0,02937
Succinic acid(or aldehyde)	0,19767															0,1987016	0,2607845	0,28138
Threonine	0,10382															0,1344823	0,1132871	0,12386
Trehalose	0,2796473	0,0606068	0,1240332	0,1027748	0,0951209	0,1421869	0,1571007	0,2980184	0,2677091	0,5881808	0,8818292	0,6328081	1,5325015	1,7071206	1,9402558	2,7016369	2,5383997	2,42417
Tryptophan	0,1328337	0,1070515	0,1009809	0,1235152	0,0998706	0,0589395	0,1478654	0,1455593	0,189353	0,2062872	0,2200753	0,2440638	0,1606893	0,1871974	0,1914102	0,1870824	0,164513	0,1582
Tyrosine	0,6595429	0,5325356	0,5656363	0,6376878	0,5319195	0,3749202	0,7384121	0,7224414	0,8138561	0,8614112	0,906274	0,9404516	0,766517	0,7817572	0,8193581	1,0111085	0,8782975	0,77605
Uracil	0,0000353	0,0052333	0,0049321	0,0000249	0,0000367	0,0047507	0,0000229	0,0000394	0,0000237	0,0210095	0,0000375	0,031897	0,0218541	0,0181884	0,0211128	0,0120647	0,019748	0,01852
Urea	0,0851062	0,1193629	0,0888794	0,0387435	0,1168267	0,0855869	0,0395131	0,1034201	0,0775011	0,0294726	0,102742	0,0955085	0,0277511	0,0822891	0,063984	0,1276384	0,0537854	0,0749
Uric acid	0,0000235	0,0000351	0,0052205	0,0000249	0,0000367	0,0000249	0,0000344	0,0000263	0,0000356	0,0109919	0,0153788	0,0179178	0,0235554	0,0371264	0,0332703	0,0548785	0,0452457	0,06609
Valine	0,533012	0,5327782	0,681326	0,5291058	0,3475592	0,3136941	0,5153941	0,4835769	0,7305127	0,7080165	0,8629503	0,8821369	0,6322858	0,7283555	0,685441	0,7615518	0,6722779	0,7230
Xylitol	0,0000235	0,0000351	0,0046466	0,004535	0,0000245	0,0000374	0,005356	0,0000263	0,0079621	0,0098962	0,0086035	0,0218188	0,008344	0,008526	0,0082232	0,0000227	0,0078331	0,00847



Samuel-L-Jackson



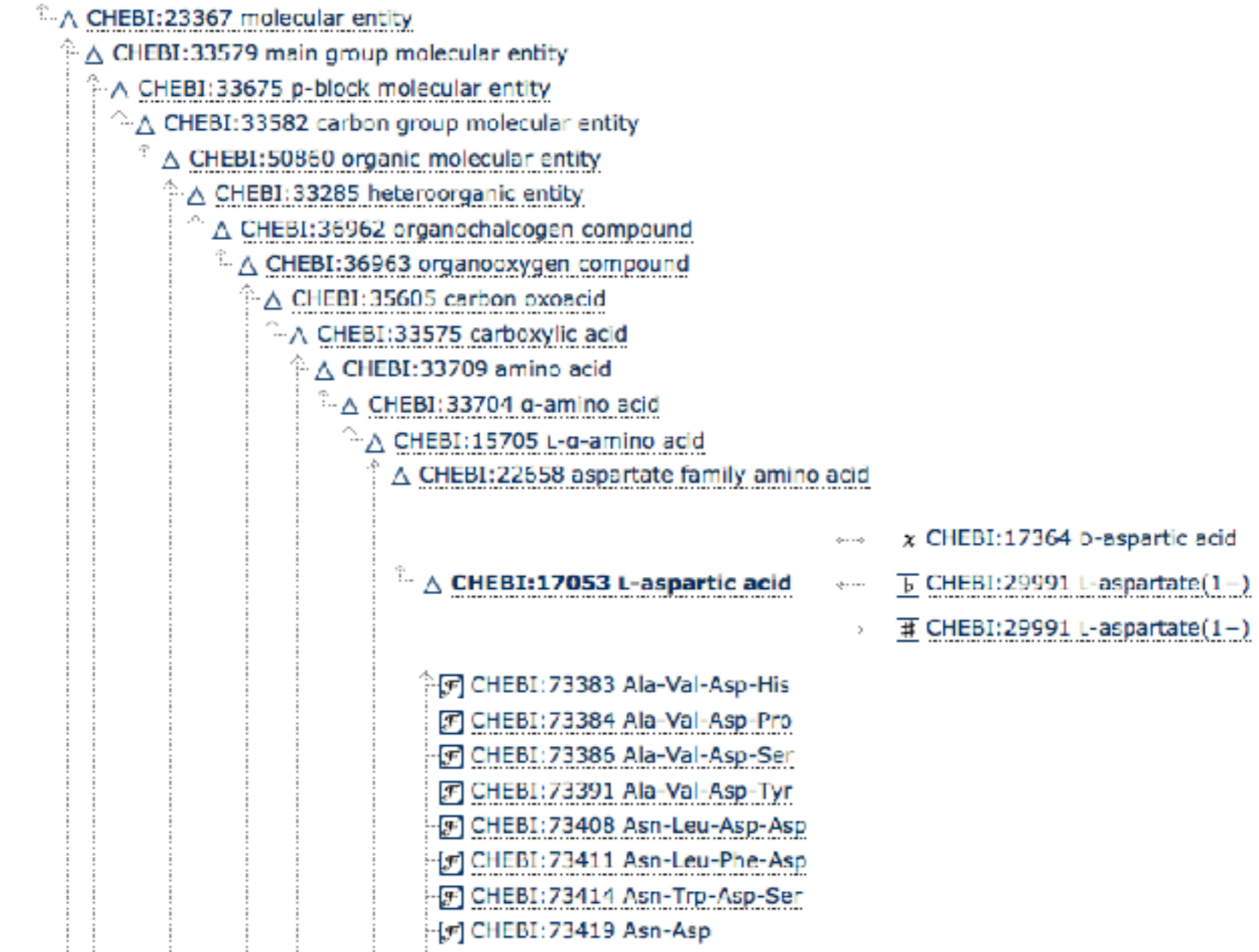
Samuel-D-Jackson

Metabome analysis of *Drosophila melanogaster* during embryogenesis (Normalized data)

Compound_Name	0-2 Hrs AEL			2-4 Hrs AEL			4-6 Hrs AEL			6-8 Hrs AEL			8-10 Hrs AEL			10-12 Hrs AEL		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
2-Aminoethanol	0,7136056	0,6639233	0,726679	0,9094056	1,0639767	0,7451021	0,9178169	1,0385232	1,19182	0,9939918	1,1234241	1,2878722	0,8004048	0,9580137	0,9992593	0,7263508	0,6553381	0,67140
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Alanine	2,363344	2,4497882	1,9587284	1,8722018	1,0662766	0,6440171	2,0857126	1,4572888	2,3298619	2,6077837	2,4392098	2,8881375	1,8675234	1,4842899	1,4012411	1,195396	1,4318903	1,46094
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- Asparagine
- Aspartic acid
- Beta-alanine
- Citric acid + Isocitric acid
- Citrulline
- DL-methionine sulfoxide\_3
- D-sorbitol-6-phosphate
- Fructose
- Glutamic acid
- Glutamine
- Glycine
- Histidine
- Hypoxanthine
- Inosine
- Inositol
- Isoleucine
- Kynurenine
- Leucine
- Lysine
- Malic acid
- Maltose
- Mannose
- Methionine
- N-Acetyl-L-Aspartic acid
- Nicotinic acid
- O-Phosphoethanolamine
- Ornithine
- Pantothenate
- Phenylalanine
- Phosphate
- Proline
- Pyroglutamic acid
- Serine
- Sorbose
- Succinic acid(or aldehyde)
- Threonine
- Trehalose
- Tryptophan
- Tyrosine
- Uracil
- Urea
- Uric acid
- Valine
- Xylitol

CHEBI:24431 chemical entity



Relationship Types

- is a
- has part
- is conjugate base of
- is conjugate acid of
- is tautomer of
- is enantiomer of
- has functional parent
- has parent hydride
- is substituent group from
- has role

Status

- Checked
- Unchecked

Urea	0,0851062	0,1193629	0,0888794	0,0387435	0,1168267	0,0855869	0,0395131	0,1034201	0,0775011	0,0294726	0,102742	0,0955085	0,0277511	0,0822891	0,0639984	0,1226384	0,0537854	0,0749
Uric acid	0,0000235	0,0000351	0,0052205	0,0000249	0,0000367	0,0000249	0,0000344	0,0000263	0,0000356	0,0109919	0,0153788	0,0179178	0,0235554	0,0371264	0,0332703	0,0548785	0,0452457	0,06609
Valine	0,533012	0,5327782	0,681326	0,5291058	0,3475592	0,3136941	0,5153941	0,4835769	0,7305127	0,7080165	0,8629503	0,8821369	0,6322858	0,7283555	0,685441	0,7615518	0,6722779	0,7230
Xylitol	0,0000235	0,0000351	0,0046466	0,004535	0,0000245	0,0000374	0,005356	0,0000263	0,0079621	0,0098962	0,0086035	0,0218188	0,008344	0,008526	0,0082232	0,0000227	0,0078331	0,00847

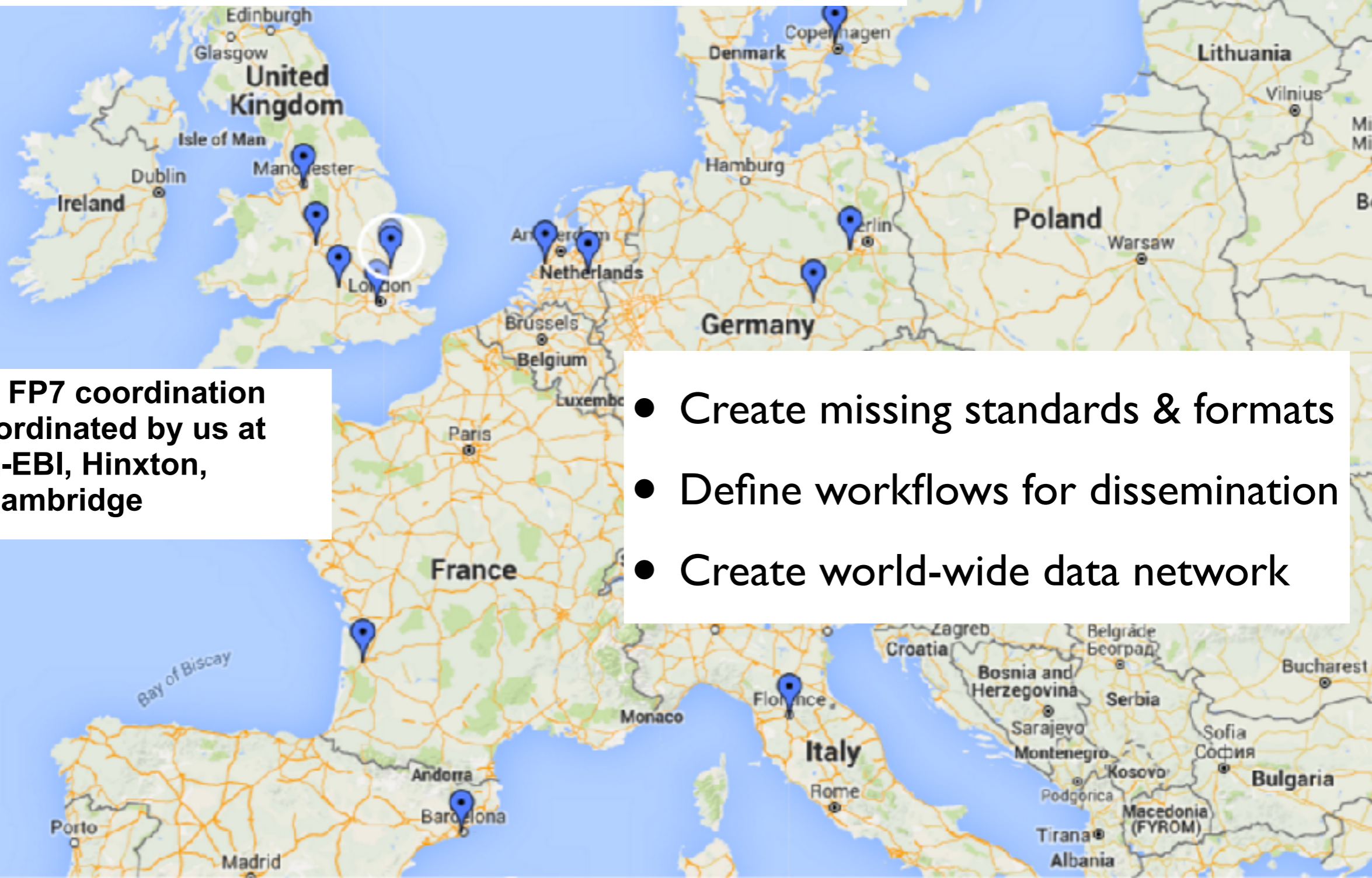
**Global Standards**  
and  
**Data Exchange**  
in  
**Metabolomics**

# COSMOS

Cordination of Standards in MetabolOmicS

European FP7 coordination  
action coordinated by us at  
EMBL-EBI, Hinxton,  
Cambridge

- Create missing standards & formats
- Define workflows for dissemination
- Create world-wide data network





# MetabolomeXchange 2014

- Global network for exchange and discoverability of metabolomics data
- Includes study as well as reference data



# MetabolomeXchange

An international data aggregation and notification service for metabolomics.

 Search:

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## Browse

Datasets are stored in external data repositories independent of MetabolomeXchange. Use this browse option to zoom in on a specific data provider. It will give you direct access to the repository itself and the meta-data of the provider.

[Learn more...](#)



## Subscribe

RSS is used to allow users to be notified of new or updated datasets. On several pages you will see the orange RSS icon that allows you to subscribe to the feed using your own preferred reader.

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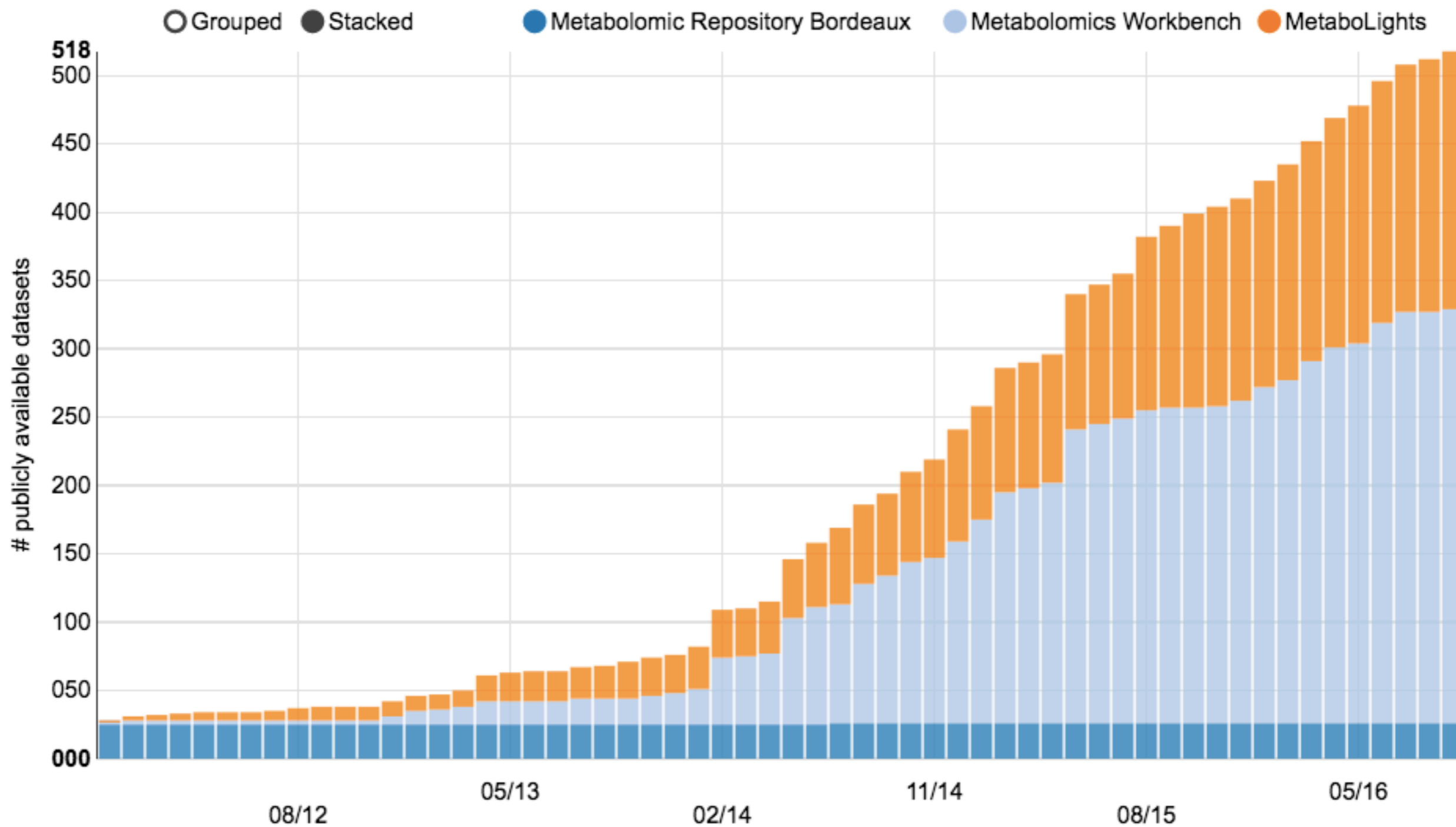
## API

The primary objective of MetabolomeXchange is to improve and encourage the exchange of Metabolomics data. One of the ways we do this is to provide an API (Application Programmable Interface). Providing a single point of entry when searching for Metabolomics data sets.

[Learn more...](#)



# Stats



# The MetaboLights Reference Layer





• 8.7 mio eukaryotic species on earth (+- 1.3mio)

- 
- 8.7 mio eukaryotic species on earth (+- 1.3mio)
  - 1.2 mio species identified and classified

- 
- 8.7 mio eukaryotic species on earth (+- 1.3mio)
  - 1.2 mio species identified and classified
  - 3000 - 4000 complete species genomes sequenced



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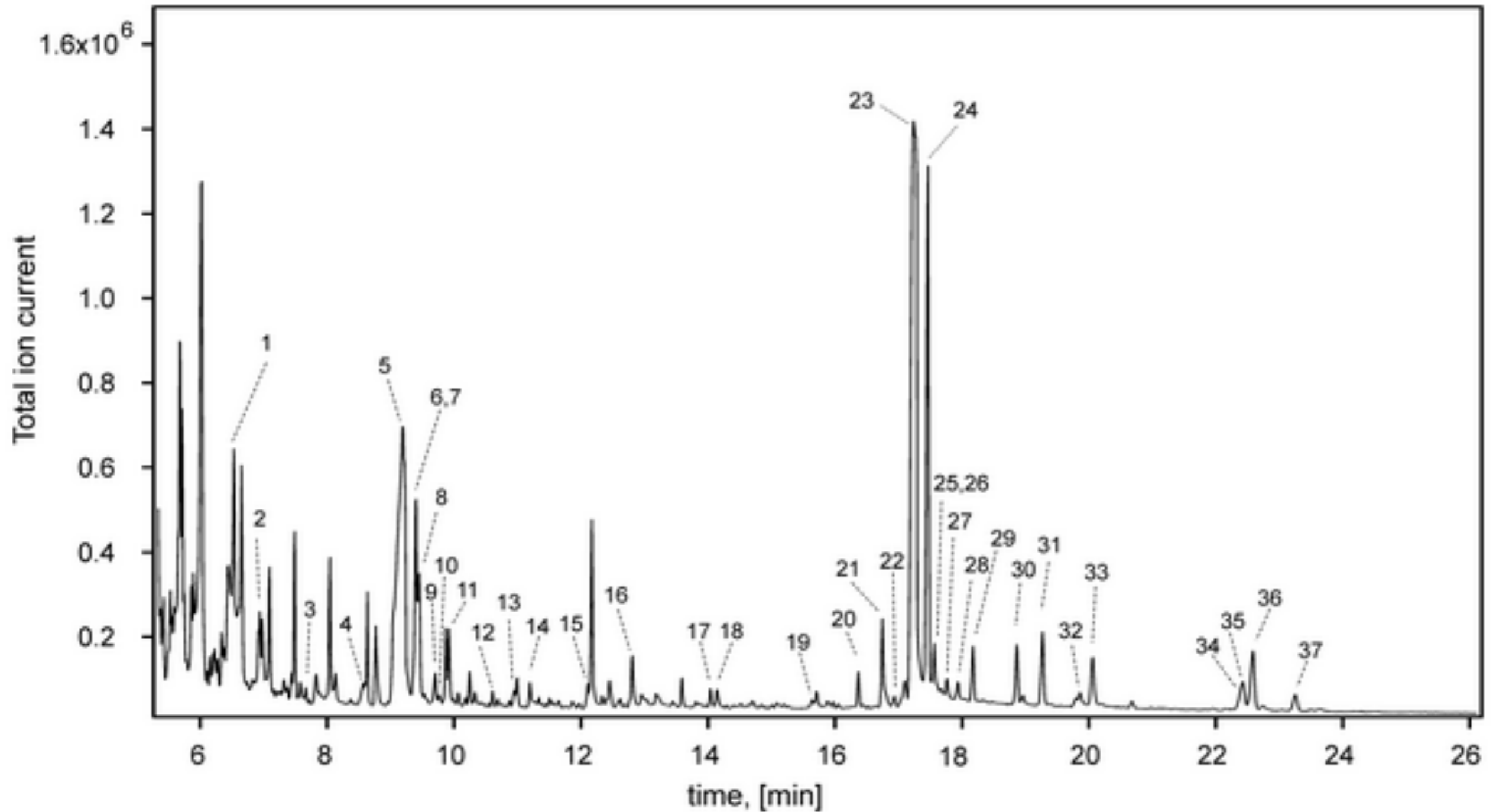
- 
- 8.7 mio eukaryotic species on earth (+- 1.3mio)
  - 1.2 mio species identified and classified
  - 3000 - 4000 complete species genomes sequenced

What about completed metabolomes?

- 
- 8.7 mio eukaryotic species on earth (+- 1.3mio)
  - 1.2 mio species identified and classified
  - 3000 - 4000 complete species genomes sequenced

What about completed metabolomes?

# Typical total ion chromatogram of serum from a healthy subject.



Psychogios N, Hau DD, Peng J, Guo AC, Mandal R, et al. (2011) The Human Serum Metabolome. PLoS ONE 6(2): e16957. doi:10.1371/journal.pone.0016957  
<http://journals.plos.org/plosone/article?id=info:doi/10.1371/journal.pone.0016957>

There are **known knowns**; there are things we know we know.

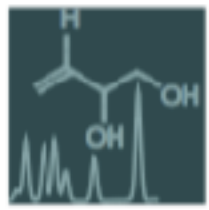
We also know there are **known unknowns**; that is to say, we know there are some things we do not know.

But there are also **unknown unknowns** – the ones we don't know we don't know.

— [United States Secretary of Defense](#),

[Donald Rumsfeld](#)





*Communication*

# **The Time Is Right to Focus on Model Organism Metabolomes**

**Arthur S. Edison <sup>1</sup>, Robert D. Hall <sup>2</sup>, Christophe Junot <sup>3</sup>, Peter D. Karp <sup>4</sup>, Irwin J. Kurland <sup>5</sup>, Robert Mistrik <sup>6</sup>, Laura K. Reed <sup>7</sup>, Kazuki Saito <sup>8</sup>, Reza M. Salek <sup>9</sup>, Christoph Steinbeck <sup>9</sup>, Lloyd W. Sumner <sup>10</sup> and Mark R. Viant <sup>11,\*</sup>**

Building upon extensive genomics research, we argue that the time is now right to focus intensively on model organism metabolomes. We propose a grand challenge for metabolomics studies of model organisms: to identify and map all metabolites onto metabolic pathways, to develop quantitative metabolic models for model organisms, and to relate organism metabolic pathways within the context of evolutionary metabolomics, *i.e.*, phylometabolomics. These efforts should focus on a series of established model organisms in microbial, animal and plant research.

**Species Metabolomes are  
being assembled on the fly  
right now through data  
sharing in Metabolomics**

# Repository Entry

MetaboLights > Study

Submitted ✓

In curation ✓

In review ✓

Public ✓

## MTBLS288: Identification of Conserved and Diverse Metabolic Shifts during Rice Grain Development (GC-MS assay)

Authors: [Shi Jianxin](#) , [Hu Chaoyang](#)

Submitted: 30-Nov-2015 , Release date: 03-May-2016 , Update date: 03-May-2016

[Share Study](#)

Submitted by: [Chaoyang HU](#) | Study status: Public

### Study Description

[View Metabolites Assay](#) [Download Study files](#)

Here we investigated the dynamic metabolic changes along the rice grain development of two japonica and two indica cultivars using non-targeted metabolomics approach, in which we successfully identified 214 metabolites. Principal component and clustering analysis revealed both cultivar and developmental stage dependent metabolic changes in rice grains. Generally, the stage specific metabolic kinetics corresponded well to the physiological status of the developing grains, and some of metabolic changes in developing grain of monocot rice are common with those of dicot Arabidopsis and tomato, while others show rice specific patterns.

See study MTBLS286 and MYTBL287 for the LG-MS pos and neg assays respectively for this study.

[Study Design Description](#) [Protocols](#) [Samples](#) **[Assay](#)** [Study Files](#) [Study Validation](#) ✓ [Pathways](#)



# Repository Entry

## Metabolites

Show  entries

Search:

Metabolite identification ↓	Chemical formula ↑	Species ↑	Smiles ↑	InChI ↑
<a href="#">5-Oxoproline (Pyroglutamate) (CHEBI:16010)</a>	C5H7NO3	Oryza sativa	<chem>OC(=O)C1CCC(=O)N1</chem>	InChI=1S/C5H7NO3/c7-4-2-1-3(6-4)5(8)9/h3H,1-2H2,(H,6,7)(H,8,9)
<a href="#">Adenine (CHEBI:16708)</a>	C5H5N5	Oryza sativa	<chem>C1=NC2=C(N1)C(=NC=N2)N</chem>	InChI=1S/C5H5N5/c6-4-3-5(9-1-7-3)10-2-8-4/h1-2H,(H3,6,7,8,9,10)
<a href="#">Alanine (CHEBI:16449)</a>	C3H7NO2	Oryza sativa	<chem>CCOC(=O)N</chem>	InChI=1S/C3H7NO2/c1-2-6-3(4)5/h2H2,1H3,(H2,4,5)
<a href="#">Arginine (CHEBI:29016)</a>	C6H14N4O2	Oryza sativa	<chem>C(CC(C(=O)O)N)CN=C(N)N</chem>	InChI=1S/C6H14N4O2/c7-4(5(11)12)2-1-3-10-6(8)9/h4H,1-3,7H2,(H,11,12)(H4,8,9,10)
<a href="#">Benzoate (CHEBI:30746)</a>	C7H6O2	Oryza sativa	<chem>OC(=O)c1ccccc1</chem>	InChI=1S/C7H6O2/c8-7(9)6-4-2-1-3-5-6/h1-5H,(H,8,9)
<a href="#">Beta-Alanine (CHEBI:16958)</a>	C3H7NO2	Oryza sativa	<chem>C(CN)C(=O)O</chem>	InChI=1S/C3H7NO2/c4-2-1-3(5)6/h1-2,4H2,(H,5,6)
<a href="#">Dehydroascorbate (CHEBI:17242)</a>	C6H6O6	Oryza sativa	<chem>OCC(O)C1OC(=O)C(=O)C1=O</chem>	InChI=1S/C6H6O6/c7-1-2(8)5-3(9)4(10)6(11)12-5/h2,5,7-8H,1H2
<a href="#">Fructose (CHEBI:28757)</a>	C6H12O6	Oryza sativa		
<a href="#">Fumarate</a>	C4H4O4	Oryza sativa	<chem>OC(=O)C=CC(O)=O</chem>	InChI=1S/C4H4O4/c5-3(6)1-2-4(7)8/h1-2H,(H,5,6)

# Reference Layer

MetaboLights > Species search

## Species selection page

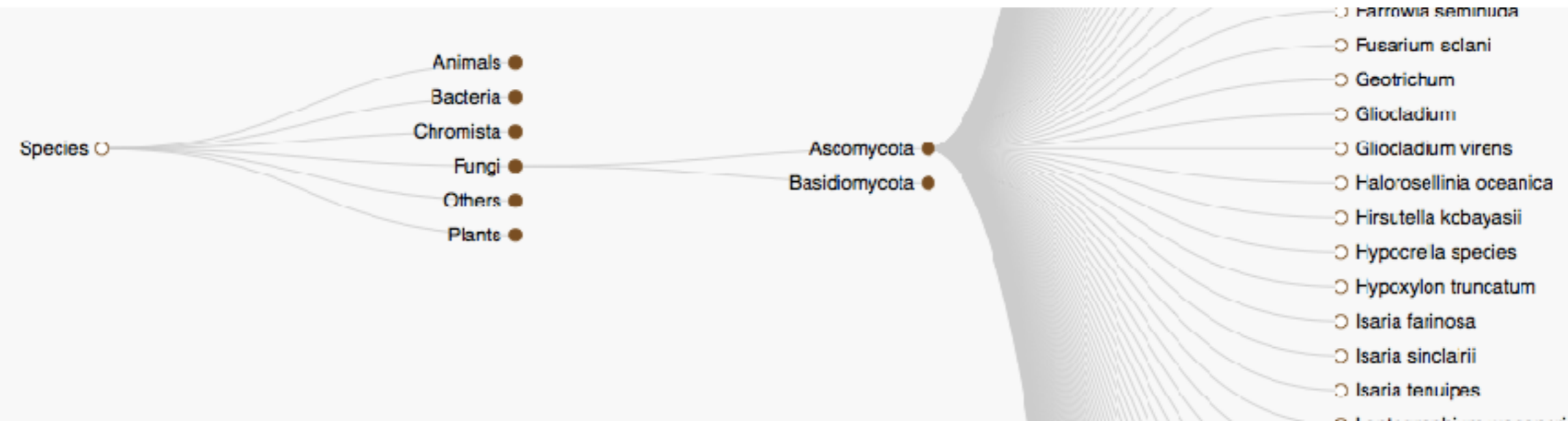
See below for some direct links to some common model organisms and a wider list of all the organisms we have information about.

### Model organisms

- [Homo sapiens \(Human\)](#)
- [Mus musculus \(Mouse\)](#)
- [Arabidopsis thaliana \(thale cress\)](#)
- [E. coli](#)
- [Saccharomyces cerevisiae \(Baker's yeast\)](#)
- [Caenorhabditis elegans](#)

### Taxonomy Search

### Taxonomy Browser (1593 species)



## Filter your results

### Type

compound

### Compound features

- Species  
 Pathways  
 Reactions  
 NMR  
 MS

### Technology

- mass spectrometry  
 NMR spectroscopy

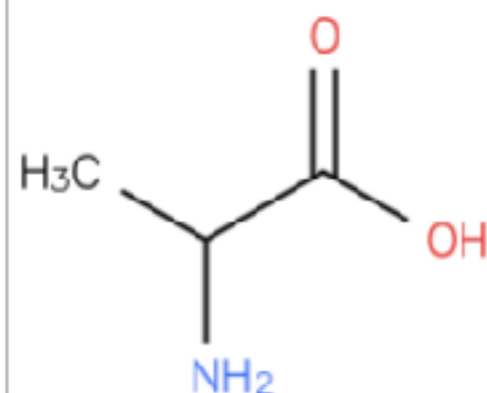
### Organism

Find your Organism

- Caenorhabditis elegans*  
 *Homo sapiens*  
 *Mus musculus*  
 *Saccharomyces cerevisiae*  
 *Escherichia coli*  
 *Vitis vinifera*  
 reference compound  
 *Arabidopsis thaliana*  
 *Daphnia magna*  
 *Chaetomium globosum*  
 *Streptomyces* species  
 *Mycoplasma genitalium*  
 *Salmonella typhimurium*  
 *Rubia yunnanensis*  
 *Centella asiatica*  
 *Cordyceps sinensis*

15 results, showing 1 to 10

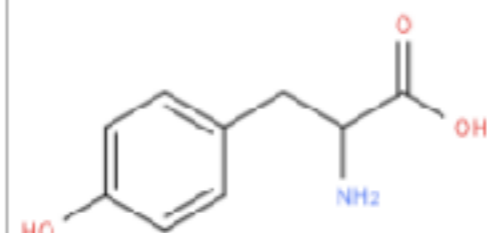
Page 1 of 2



alanine (MTBLC16449)

An alpha-amino acid that consists of propionic acid bearing an amino substituent at position 2.

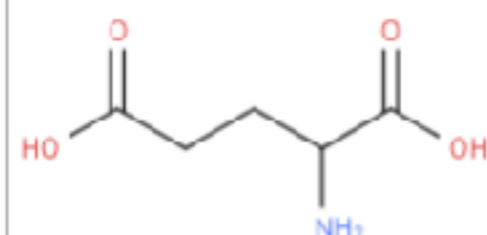
**Identified in** [CHEBI:16449](#) , [MTBLS20](#) , [MTBLS8](#) , [MTBLS3](#) , [MTBLS1](#)



tyrosine (MTBLC18186)

An alpha-amino acid that is phenylalanine bearing a hydroxy substituent at position 4 on the phenyl ring.

**Identified in** [MTBLS3](#) , [CHEBI:18186](#) , [MTBLS55](#) , [MTBLS1](#) , [MTBLS8](#)



glutamic acid (MTBLC18237)

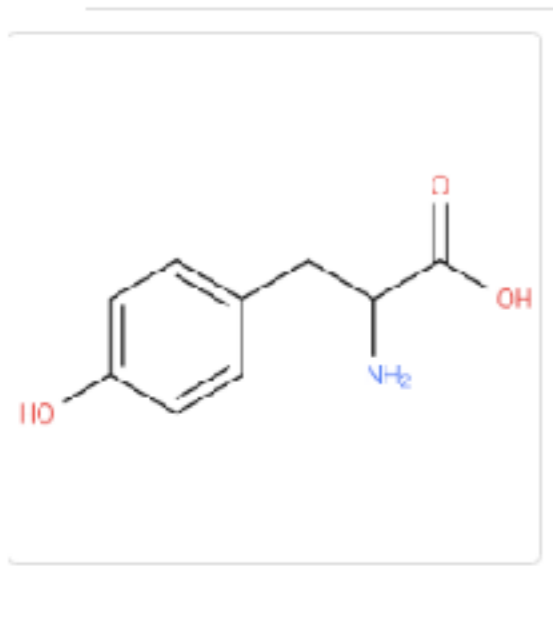
An alpha-amino acid that is glutaric acid bearing a single amino substituent at position 2.

**Identified in** [MTBLS8](#) , [MTBLS3](#) , [MTBLS29](#) , [MTBLS36](#) , [MTBLS1](#) , [CHEBI:18237](#)

# Tyrosine

MTBLC18186

2D 3D



tyrosine - (CHEBI:18186)

BETA

Upload Reference Spectra

Chemistry Biology NMR spectra MS spectra Literature

DEFINITION

An alpha-amino acid that is phenylalanine bearing a hydroxy substituent at position 4 on the phenyl ring.

Chemical Properties

Synonyms

External links

Chemical Properties

Property	Value
InChIKey	OUYCCASQSFEME-UHFFFAOYSA-N
InChI	InChI=1S/C9H11NO3/c10-8(9(12)13)5-6-1-3-7(11)4-2-6/h1-4,8,11H,5,10H2,(H,12,13)
Formula	C9H11NO3
Molecular Weight	181.18889
Exact Mass	181.07389



Search

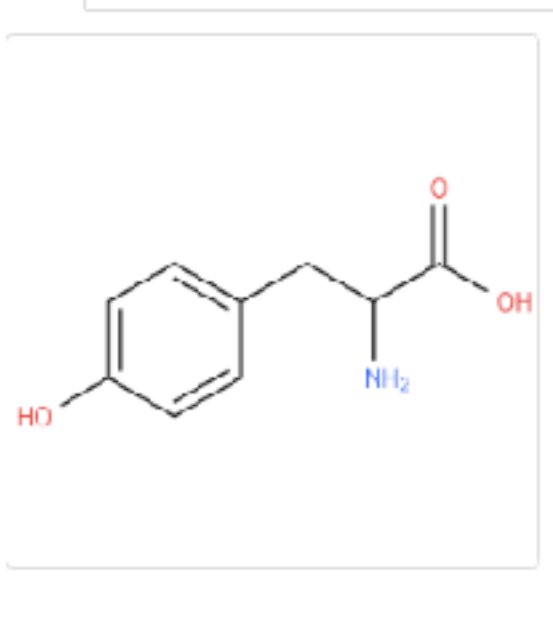
Examples: alanine, Homo sapiens, urine, MTBL51

[MetaboLights](#) > [Compound page](#)

## Tyrosine

MTBLC18186

2D 3D



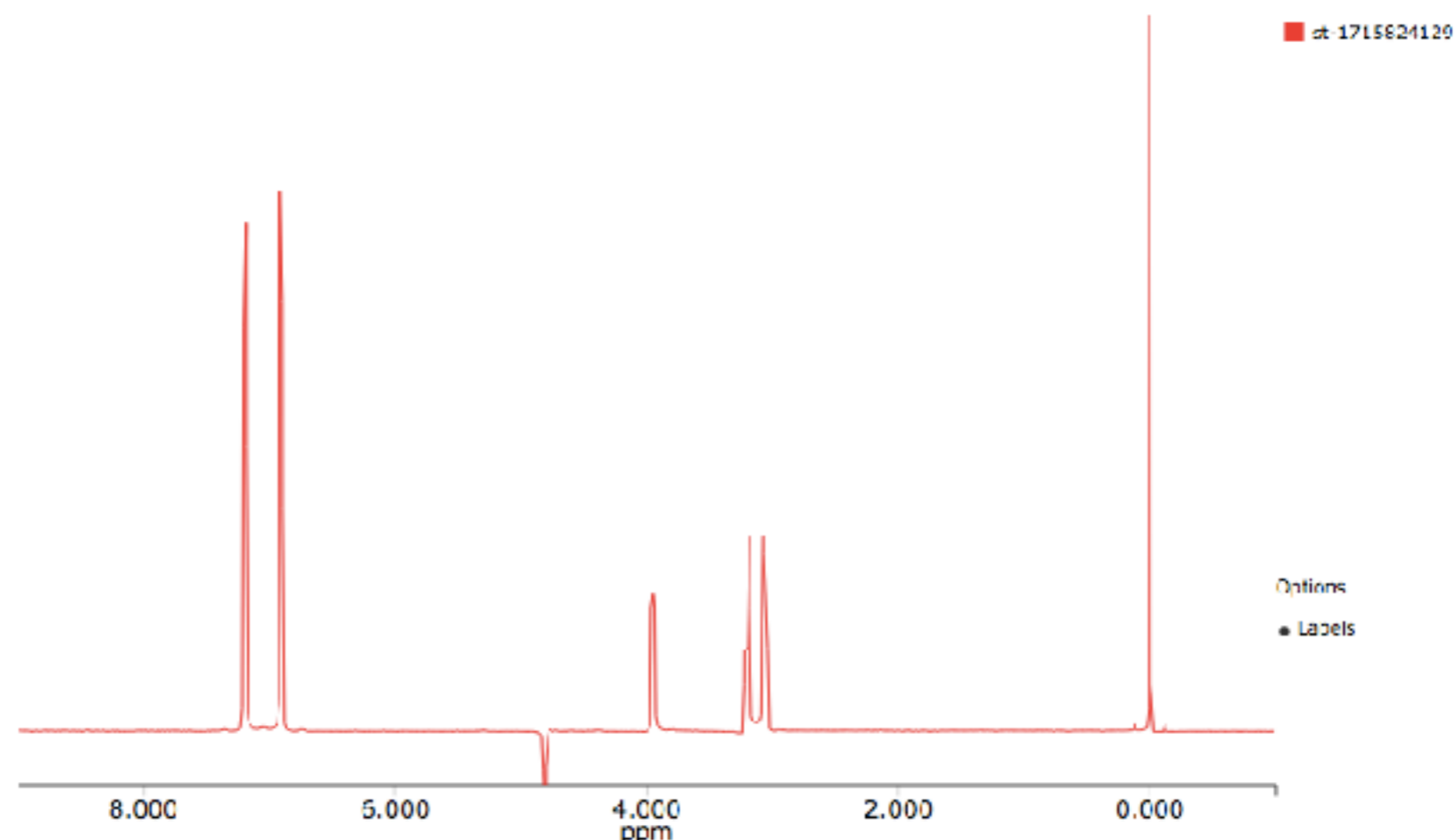
tyrosine - (CHEBI:18186)

[BETA](#)

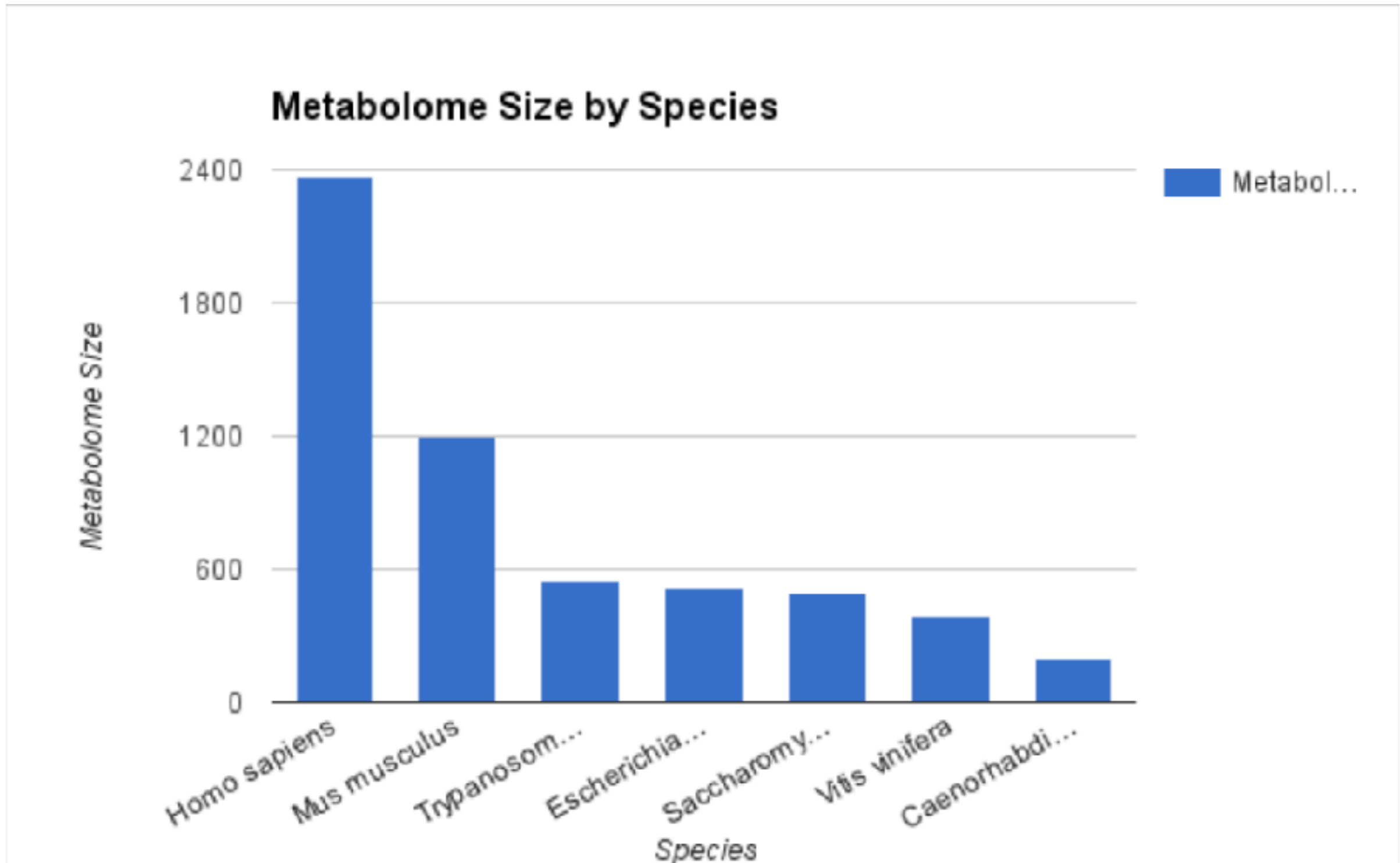
[Upload Reference Spectra](#)

[Chemistry](#) [Biology](#) [NMR spectra](#) [MS spectra](#) [Literature](#)

- BML (D:3316) - 1H 500 MHz, WS(NOESY Presat), pH:7.0, PD=10.0s, EA=30 degree
- BML (D:3320) - 1H 500 MHz, WS(Excitation Sculpting), pH:7.0, PD=0.75s, EA=90 degree
- BML (D:3327) - 1H 500 MHz, WS(Excitation Sculpting), pH:7.4, PD=3.0s, EA=60 degree
- BML (D:3313) - 1H 500 MHz, WS(Excitation Sculpting), pH:7.0, PD=10.0s, EA=30 degree



# 7 most annotated metabolomes in MetaboLights





# Training

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## EMBO Practical Course on Metabolomics Bioinformatics for Life Scientists

### Venue:

European Bioinformatics Institute, CB10 1SD  
United Kingdom  
See map: [Google Maps](#)

**Date:** Monday, February 16, 2015 - Friday, February 20, 2015

### Organizers:

Laura Emery , EMBL-EBI, UK  
Roza Salek , EMBL-EBI & Cambridge University, UK  
Christoph Steinbeck , EMBL-EBI, UK

**Participation:** Open application with selection



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- [Workshops for schools](#)



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[Overview](#) | [Programme](#) |

## Overview

Details of the course (programme, trainers and the cost) are yet to be confirmed and are subject to funding arrangements. If you would like to see details of similar courses from previous years please take a look at:

<http://www.ebi.ac.uk/training/past-courses-held-emb-ebi>

If you would like to register your interest in this course and be the first to hear of any updates please send us an email using the following link: [Keep me posted](#)

The background of the slide features a large, semi-circular seal of the Friedrich-Schiller-Universität Jena. The seal is rendered in a light blue color against a dark blue background. It depicts a bearded man wearing a crown and a fur-trimmed robe, likely representing a historical figure associated with the university. The Latin inscription around the seal reads: "CHR: MARCHIO: MISNI: IOHAN: COEPIT: DOCERE".

Friedrich-Schiller-Universität Jena

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# Funding and Collaborators

**UK Research Councils (BBSRC, MRC)**

**European Commission**

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Improving health through nutrition research





Slides on  
<http://www.slideshare.net/csteinbeck>

Thank you!



[Metabolights-help@ebi.ac.uk](mailto:Metabolights-help@ebi.ac.uk)