Infrastructure and strategies for precision medicine: leukemias, solid tumors and beyond

Olli Kallioniemi

Director of the Science for Life Laboratory
Professor of Molecular Precision Medicine, Karolinska Institutet

FIMM

SciLifeLab

University of Helsinki
Institute for Molecular
Medicine Finland, FIMM
Helsinki, Finland
2008-

Karolinska Institutet
Dept. of Oncology and Pathology
Molecular Precision Medicine
Stockholm, Sweden
2016-

National center for molecular life sciences

SciLifeLab

KTH VETENSKAP OCH KONST

Karolinska Institutet

SciLifeLab

Stockholm University

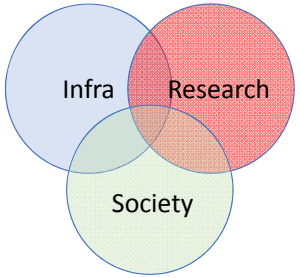
UPPSALA UNIVERSITET

40 national facilities
1200 scientists
700 publications
3073 projects

i) Unique and enabling infrastructures for national life science research

ii) Collaborative research among scientists across universities

iii) Translation towards lasting societal benefits



SciLifeLab TECHNOLOGIES & SERVICES RESEARCH EDUCATION COLLABORATION DATA

National center for molecular life sciences

SciLifeLab

- Genomics
- Bioinformatics
- Proteomics
- Metabolomics
- Bioimaging and Molecular Structure
- Single Cell Biology
- Chemical Biology and Genome Engineering
- Diagnostics
- Drug Discovery

270 MSEK/y for national infrastructure
170 MSEK/y for University research @ SciLifeLab
1019 MSEK/y external grants to the community

Microfluidic processors for single-cell analysis

Super-resolution Cryo-based electron microscopes

Hiseq-Xten /NovaSeq for next-gen DNA/RNA sequencing

SciLifeLab as a national infrastructure

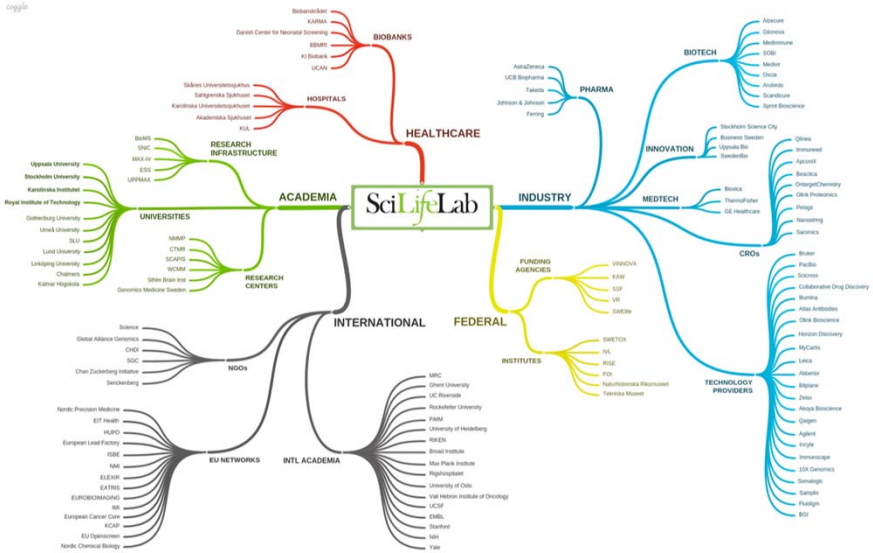
One of the three main research infrastructures in Sweden, along with MAX-IV and ESS, the only one in Life Science

Motivation for a national SciLifeLab infrastructure

- Progress in (life) science is dependent on cutting-edge, expensive infrastructure
- Healthcare and life science industry need access to scientific infrastructure and expertise
- Acquisition, professional operation, dynamic renewal of the infrastructure is a major challenge for individual universities
- Not all universities (in a small country) can have world-class infrastructures in all fields of life science

=> Collaboration

=> Enabling systematic, comprehensive, holistic understanding of life



Infrastructure organization with 41 facilities

SciLifeLab

Genomics

National Genomics Infrastructure S, U
Ancient DNA U
Diagnostics Development G, Lu, S, U
Eukaryotic Single Cell Genomics S
Microbial Single Cell Genomics U
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

Proteomics

Plasma Profiling S
Autoimmunity Profiling S
PLA Proteomics U
Chemical Proteomics and Proteogenomics S
Single Cell Proteomics U
Protein Science Facility S
Cell Profiling S
Mass Cytometry Li, S
Clinical Biomarkers U
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

Metabolomics

Swedish Metabolomics Centre Um
Swedish NMR Centre G, Um
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

Single Cell Biology

Eukaryotic Single Cell Genomics S
Microbial Single Cell Genomics U
Mass Cytometry Li, S
Single Cell Proteomics U
PLA Proteomics U
Cell Profiling S
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

Bioimaging and Molecular Structure

Advanced Light Microscopy S
Cryo-EM S, Um
Cell Profiling S
Swedish NMR Centre G, Um
PLA Proteomics U
Protein Science Facility S
BioImage Informatics U
Fluoroscence Correlation Spectroscopy S
Fluoroscence Tissue Profiling S
Tissue Profiling U
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

Chemical Biology and Genome Engineering

Chemical Biology Consortium Sweden S, Um
Swedish NMR Centre G, Um
Chemical Proteomics and Proteogenomics S
High Throughput Genome Engineering S
Genome Engineering Zebrafish U
Protein Science Facility S
PLA Proteomics U
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

Drug Discovery

Drug Discovery and Development Lu, S, U
Chemical Biology Consortium Sweden S, Um
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

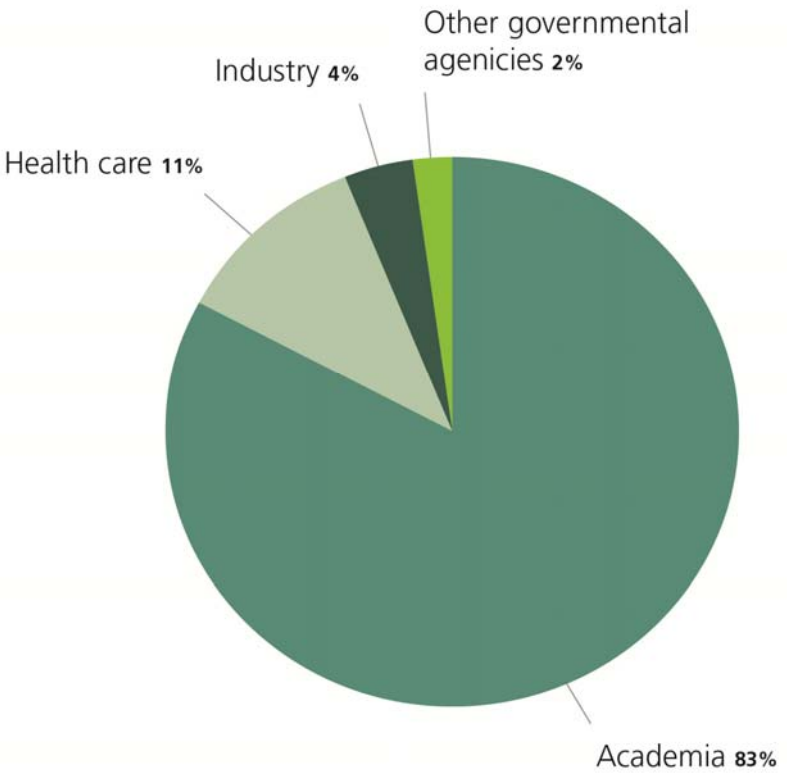
Diagnostics

Diagnostics Development G, Lu, S, U
National Genomics Infrastructure S, U
PLA Proteomics U
Plasma Profiling S
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um
Single Cell Proteomics U
Clinical Biomarkers U
National Bioinformatics Infrastructure G, Li, Lu, S, U, Um

Bioinformatics

National Bioinformatics Infrastructure G, Li, Lu, S, U, Um
BioImage Informatics U
Diagnostics Development G, Lu, S, U

G - Göteborg
Li - Linköping
Lu - Lund
S - Stockholm
U - Uppsala
Um - Umeå



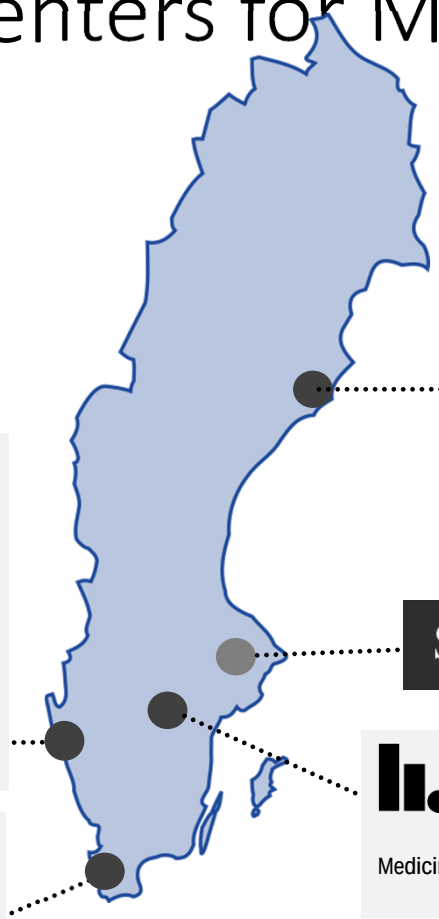
SciLifeLab Fellows' program: recruitment of young scientists

Career program aiming at strengthening Swedish research in Molecular Biosciences.
- International recruitment, attractive startup package
- Hosted initially (4+2 years) at SciLifeLab (proximity to research infrastructure)

International recruitment of young talent to Sweden: Wallenberg Centers for Molecular Medicine

National Molecular Medicine Fellows Program

Collaborative network for recruited fellows at SciLifeLab and young group leaders of the four **Wallenberg Centers for Molecular Medicine**.



Umeå University

Cancer
Infection biology
Metabolism/Diabetes
Neuroscience

SciLifeLab

LINKÖPING UNIVERSITY

Medicine-technology interface

Metabolism
Neuroscience
Inflammation
Cancer
Degenerative diseases

UNIVERSITY OF GOTHENBURG

Regenerative Medicine
Regeneration,
Replacement
Repair

LUND UNIVERSITY

Impact of SciLifeLab for diagnostics

SciLifeLab

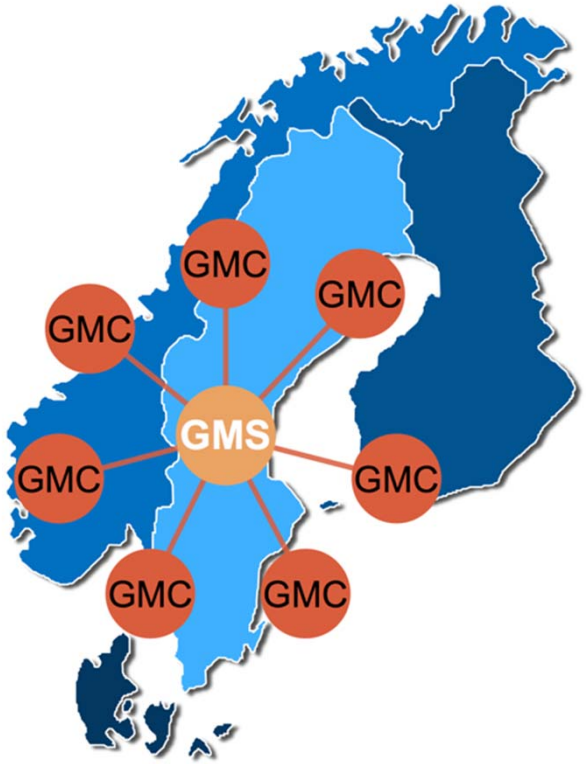
Testbed for new technologies & technology transitions in healthcare

SciLifeLab

Healthcare

GENOMIC MEDICINE SWEDEN

Richard Rosenquist Brandell
Karolinska Institutet
Thoas Fioretos
Lunds universitet



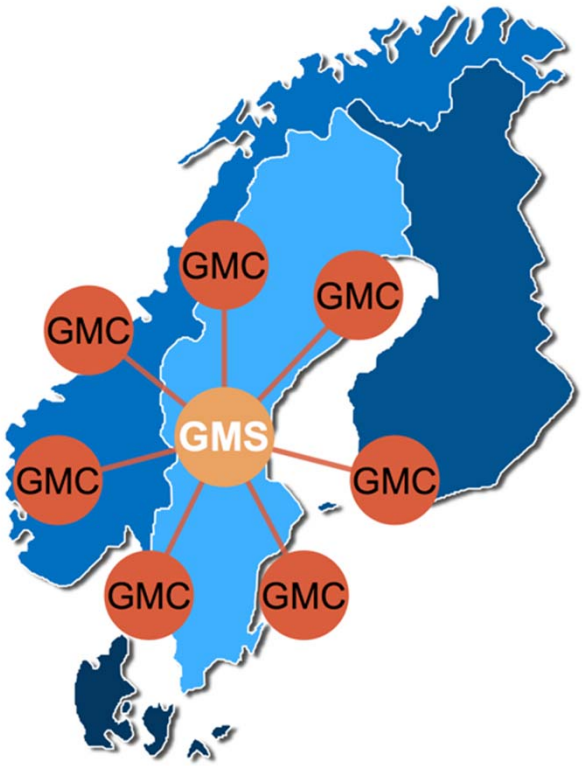
GMS

What is GMS aiming to achieve?

Through national coodination and collaboration, enable that all health care regions could offer to their patients:

- The best diagnosis – e.g. with the help of next-gen sequencing
- Precision medicin – right treatment to the right patient

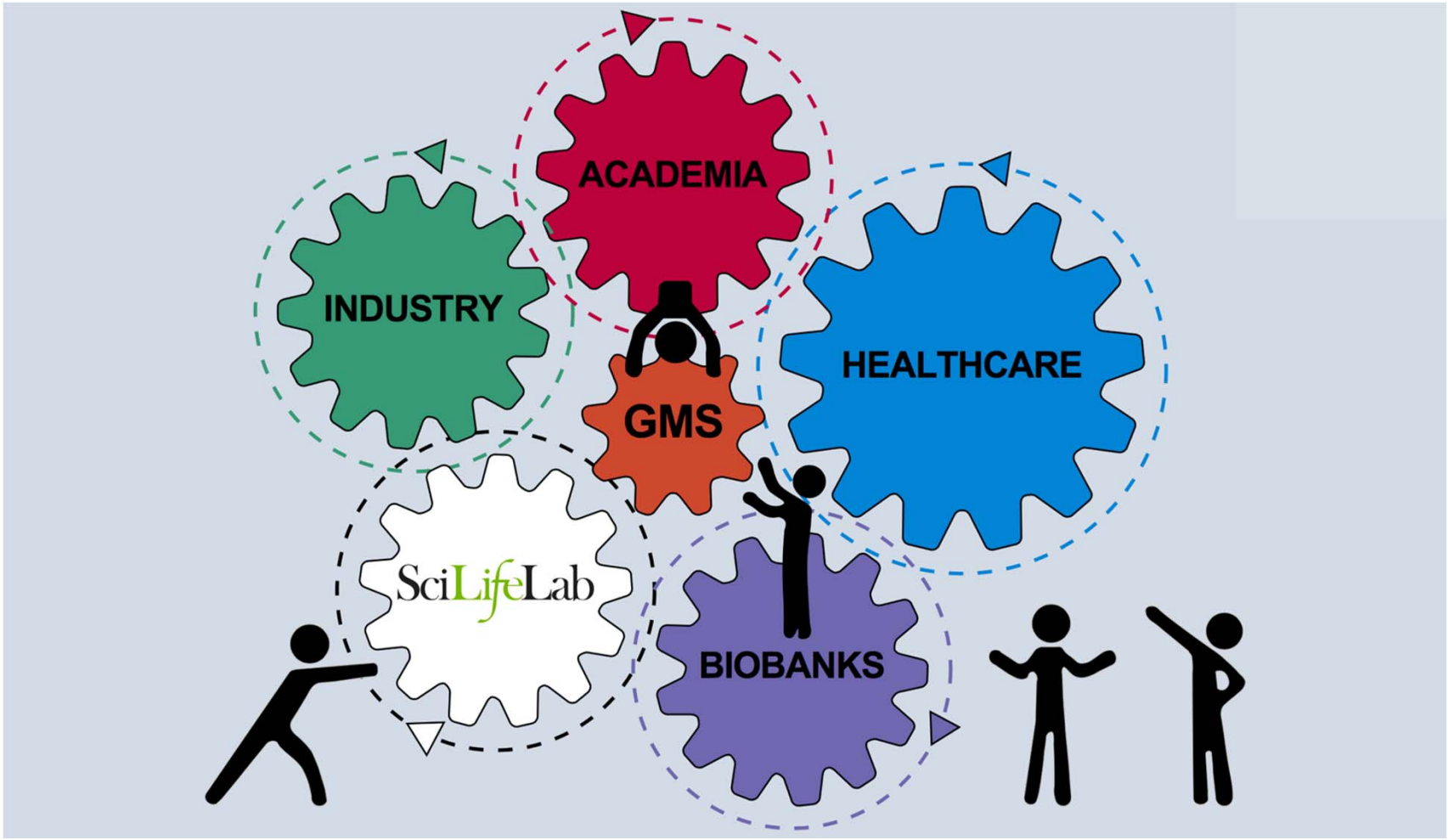
Strengthen Swedish research, innovation and industrial collaboration in precision medicine



GMS

Large national collaborative effort

GMS



How do we create an internationally leading infrastructure?

GMS

Build on existing national resources:

- Science for Life Laboratory
- Biobank Sverige
- Regional cancer centers
- Center for rare diseases
- National quality registers
- Clinical study groups in Sweden

SciLifeLab

NATIONELLA BIOBANKSRÅDET

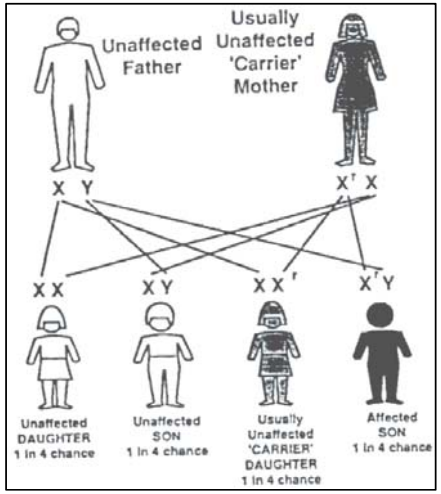
REGIONALA CANCERCENTRUM I SAMVERKAN

NFSD
NATIONELLA FUNKTIONEN SÄLLSYNTA DIAGNOSER

NATIONELLA KVALITETSREGISTER
Kunskap för bättre vård och omsorg

Kliniska Studier Sverige

GMS initial focus areas



Rare hereditary diseases

- Whole-genome sequencing
- >3 000 routine WGS for clinical genetics, molecular medicine, immunology
- >35% more diagnoses

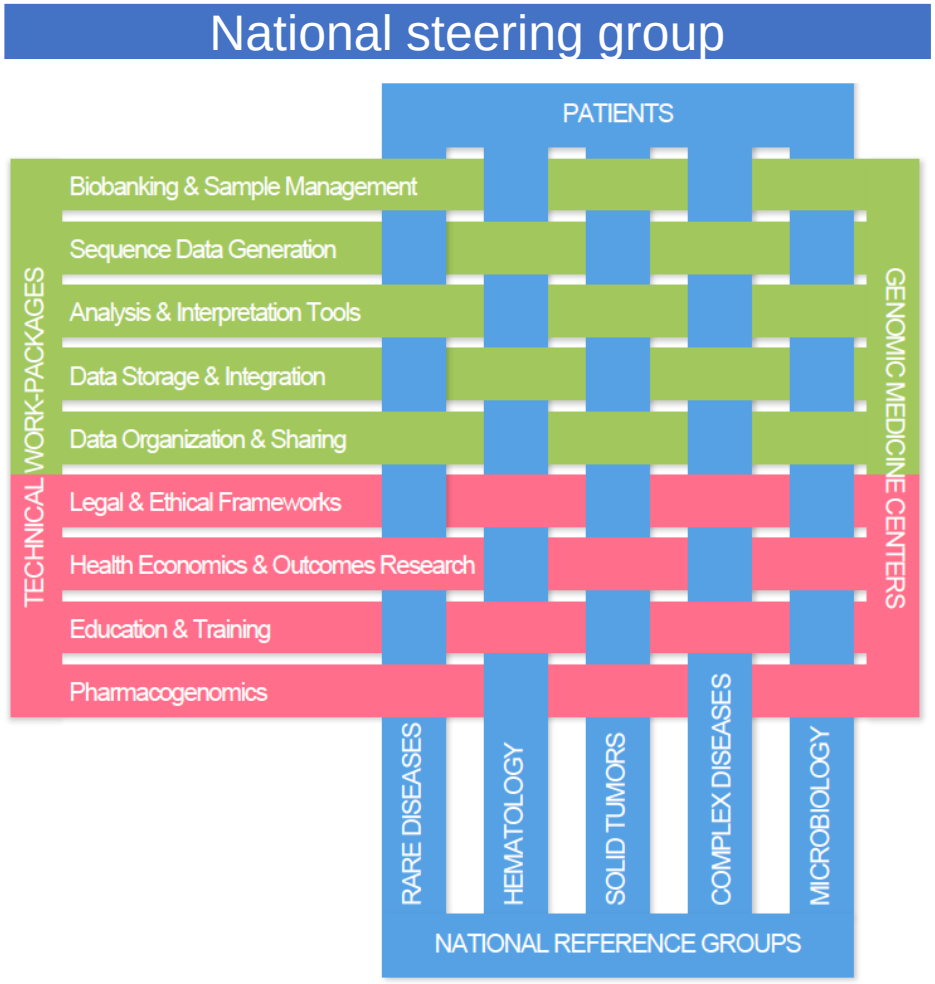
Cancer:

- Solid tumors and leukemias:
  - Gene panels
  - (RNA-sequancing)
  - (WGS)
- >5 000 routine tests already at clinical genetics and pathology

Status of GMS today

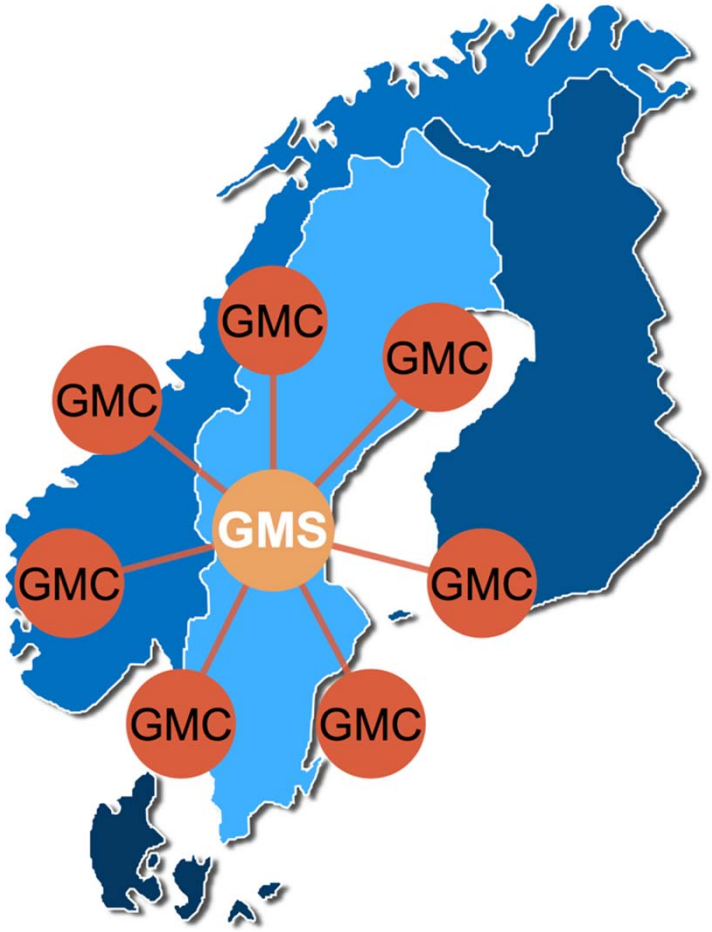
GMS

- Reference/working groups:
  - 5 reference groups
  - 5 technical working groups
  - 5 working groups for ELSI, health economy, education, pharmacogenetics, innovation
- Ca **300** people participate in the working groups
- Pilot projects underway for hereditary diseases, cancer and microbiology
- Regional genome medicine centers (GMCs) initiated



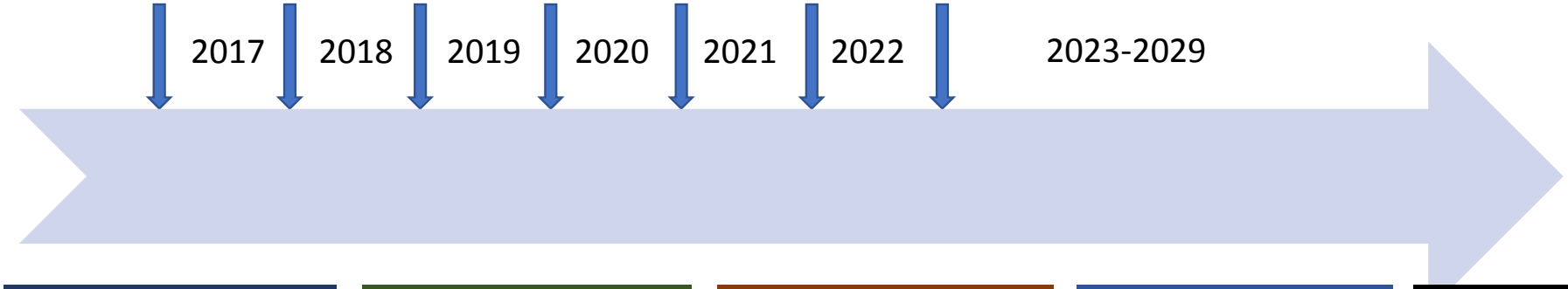
Genomic Medicine Centers

GMS



- Driven by university hospitals together with universities
- Representation from health care regions
- Work towards national coordination
- Competence from all parts of the chain e.g. technology, diagnostics, clinic
- Built on advanced molecular diagnostics
- Node for inclusion of clinical trials

Genomic Medicine Sweden – Time table



AP1 Organisation

- Nationell funktion
- Regionala GMCs
- Innovation och företagssamverkan

AP2 Informatik-plattform

- Data-processning
- Beslutsstöd
- Data-delning
- Datalagring

AP3 Diagnosrelaterade plattformar

- Sällsynta diagnoser
- Hematologi
- Solida tumörer
- Mikro-biologi
- Komplexa sjukdomar
- Farmakog enomik

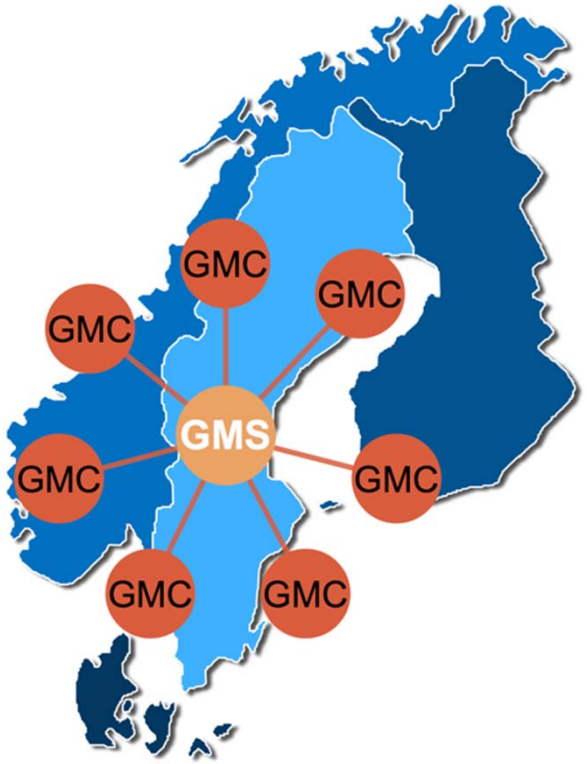
AP4 ELSI

AP5 Hälsoekonomi & kliniska resultat

AP6 Utbildning & kommunikation

GENOMIC MEDICINE SWEDEN

Richard Rosenquist Brandell
Karolinska Institutet
Thoas Fioretos
Lunds universitet



GMS

Real-time precision systems oncology

Precision cancer medicine

Precision systems medicine in hematological cancers

Precision systems medicine POC in solid tumors

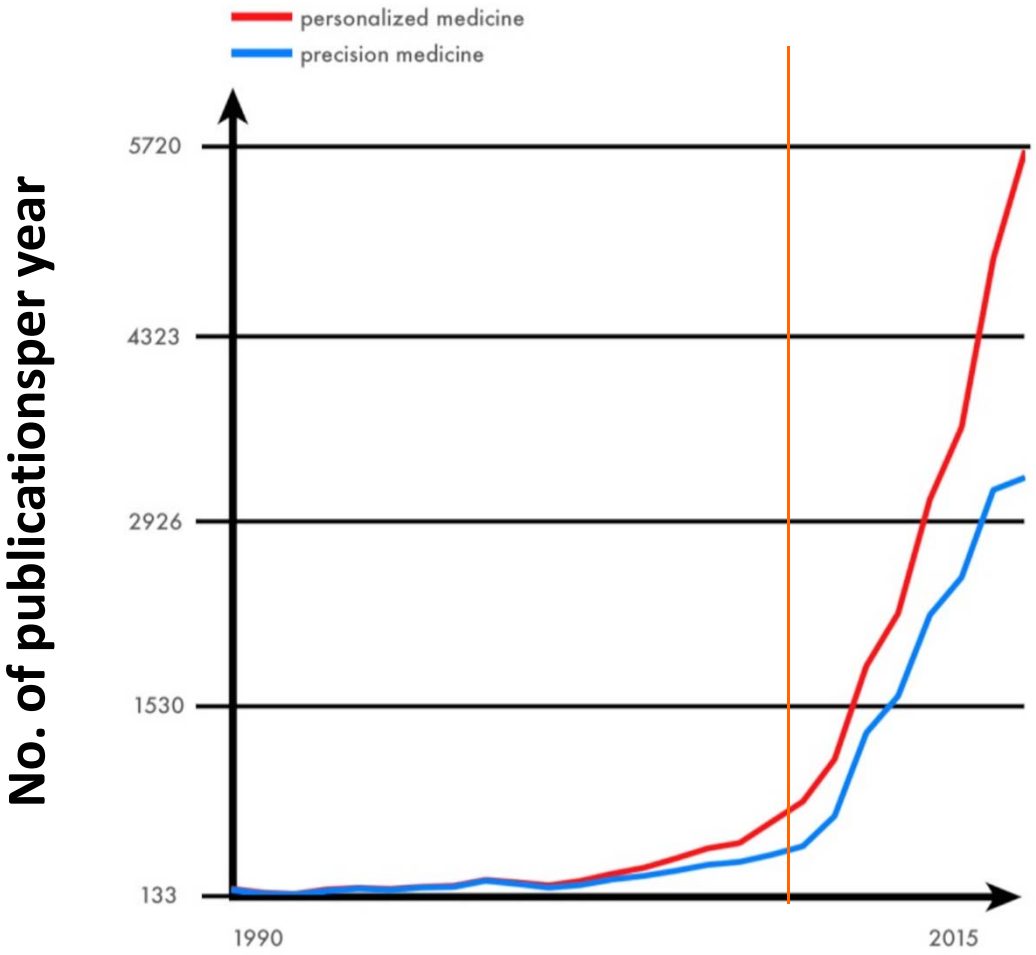
FIMM

SciLifeLab

University of Helsinki
Institute for Molecular
Medicine Finland, FIMM
Helsinki, Finland
2008-

Karolinska Institutet
Dept. of Oncology and Pathology
Molecular Precision Medicine
Stockholm, Sweden
2016-

Precision / personalized cancer care



<u>The grand challenges & opportunities in precision oncology:</u>

Better patient treatment

More effective cancer therapy for society (payers)

Improved success of cancer drug development

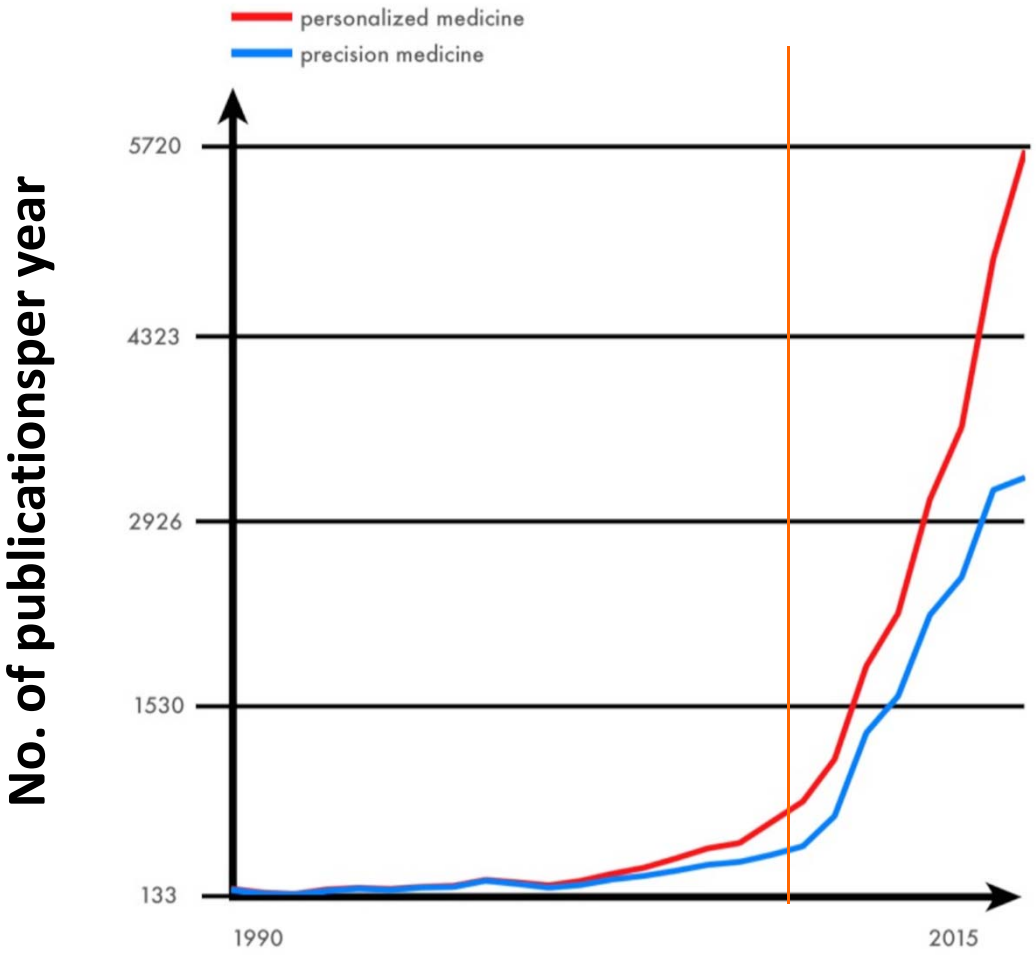
Drug repositioning, Combinations, Sequences

Prevention, early diagnosis, follow-up

FIMM

SciLifeLab

Precision / personalized cancer care



<u>Precision oncology does not change the fact that:</u>

Cancer is heterogeneous

Advanced cancer is hard or impossible to cure

Drug resistance arises to single targeted treatments

We need more and better and cheaper cancer drugs, combinations, sequential tx

Prevention is the best way to deal with cancer

FIMM

SciLifeLab

The Genetic Basis for Cancer Treatment Decisions

Janet E. Dancey,[1,2] Philippe L. Bedard,[3,4] Nicole Onetto,[1] and Thomas J. Hudson[1,5,6,*]

Table 1. Selected Genetic Markers and Their Application in Cancer Treatment

Genetic Marker	Application	Drug
BCR-ABL	Ph+ CML; Ph+ ALL	Imatinib, dasatinib, nilotinib
BCR-ABL/T315I	Resistance to anti-BCR-ABL agents	Imatinib, dasatinib, nilotinib
BRAF V600E	Metastatic melanoma	Vemurafenib
BRCA1/2	Metastatic ovarian cancer and breast cancer with BRCA 1/2 mutations	Olaparib, veliparib, iniparib
c-Kit	Kit (CD117)-positive malignant GIST	Imatinib
EGFR	Locally advanced, unresectable, or metastatic NSCLC	Erlotinib, gefitinib
EGFR T790M	Resistance to EGFR tyrosine kinase inhibitors in advanced NSCLC	Erlotinib, gefitinib
EML4-ALK	ALK kinase inhibitor for metastatic NSCLC with this fusion gene	Crizotinib
HER2 amplification	HER2-positive breast cancer or metastatic gastric or gastroesophageal junction adenocarcinoma	Trastuzumab
KRAS	Resistance to EGFR antibodies in metastatic colorectal cancer	Cetuximab, panitumumab
PML/RAR	Acute promyelocytic leukemia	ATRA, arsenic trioxide
TPMT	Deficiency is associated with increased risk of myelotoxicity	Mercaptopurine, azathioprine
UGT1A1	Homozygosity for UGT1A1*28 is associated with risk of toxicity	Irinotecan
DPD	Deficiency is associated with risk of severe toxicity	5-Fluorouracil

ATRA, all trans retinoic acid; Ph+, Philadelphia-positive chromosome; DPD, dihydropyrimine dehydrogenase; EGFR, epidermal growth factor receptor; EML4-ALK, echinoderm microtubule-associated protein-like 4 anaplastic lymphoma kinase; HER2, human epidermal growth receptor 2; GIST, gastrointestinal stromal tumors; ALL, acute lymphocytic leukemia; NSCLC, non-small cell lung cancer; TPMT, thiopurine S-methyltransferase.

Cell 148, February 3, 2012

SciLifeLab

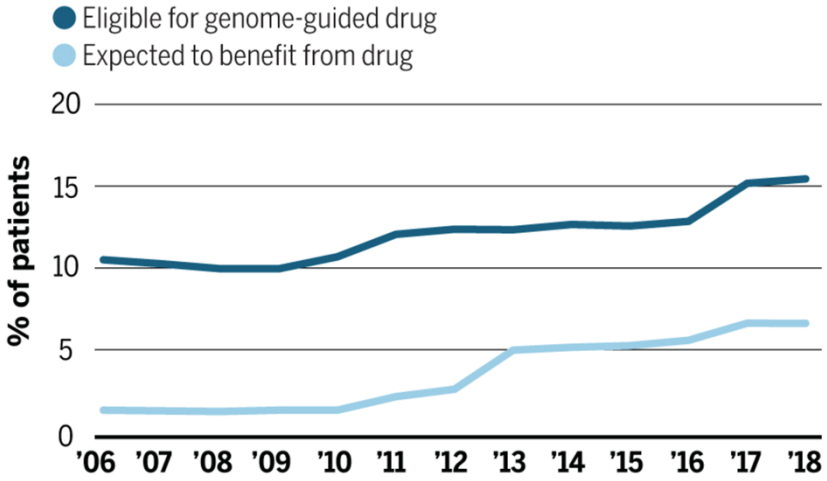
PERSPECTIVE

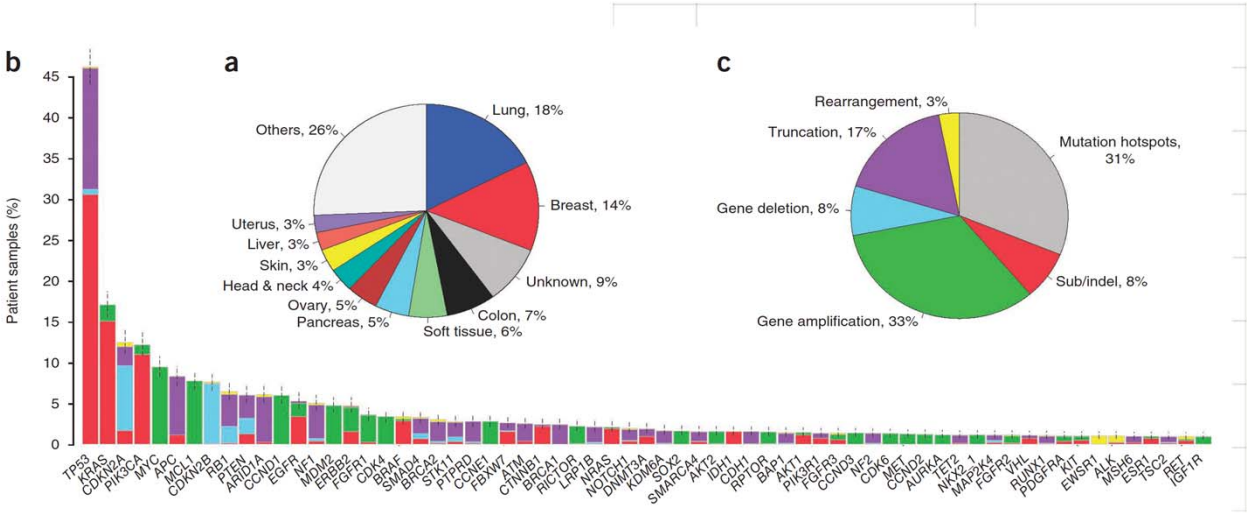
The precision–oncology illusion

Precision oncology has not been shown to work, and perhaps it never will, says **Vinay Prasad**.

A lucky few

The portion of U.S. advanced cancer patients who can be matched with a Food and Drug Administration–approved drug based on their tumor's genome is growing slowly, and only some will see their cancer shrink.





FIMM

SciLifeLab

PRECISION MEDICINE | OUTLOOK

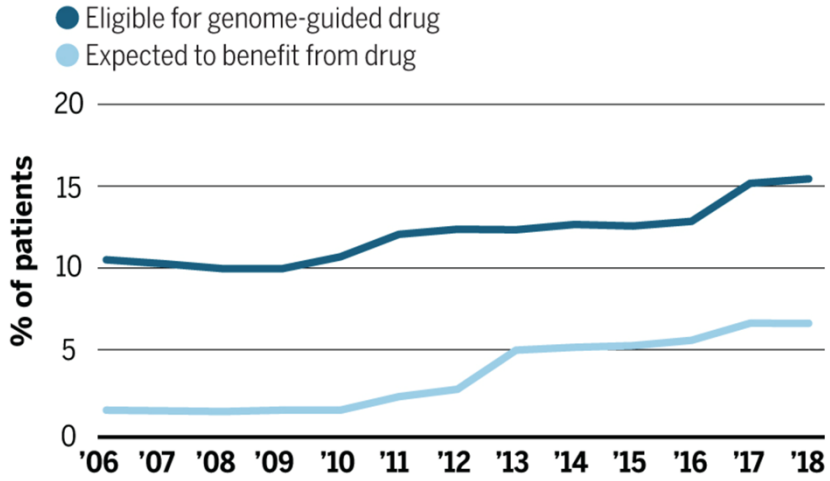
PERSPECTIVE

The precision–oncology illusion

Precision oncology has not been shown to work, and perhaps it never will, says **Vinay Prasad**.

A lucky few

The portion of U.S. advanced cancer patients who can be matched with a Food and Drug Administration–approved drug based on their tumor's genome is growing slowly, and only some will see their cancer shrink.



The NEW ENGLAND JOURNAL of MEDICINE

SOUNDING BOARD

Limits to Personalized Cancer Medicine

Ian F. Tannock, M.D., Ph.D., and John A. Hickman, D.Sc.

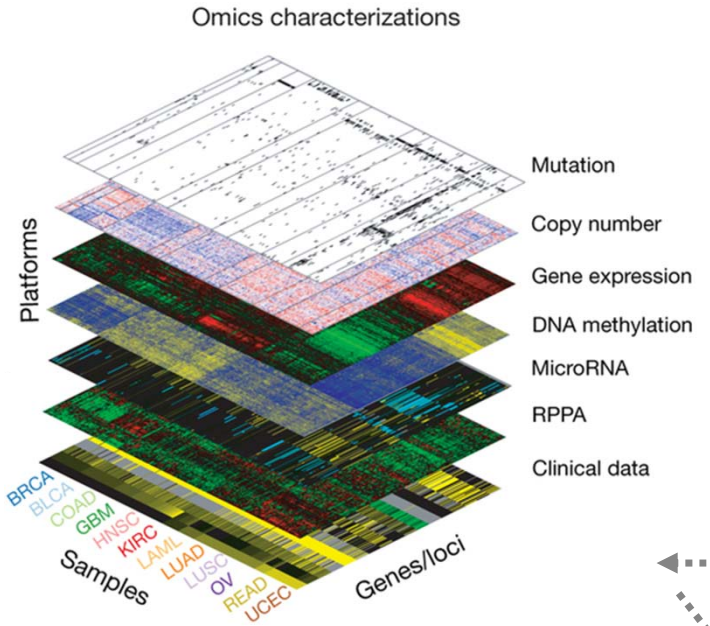
- Few patients eligible, few patients benefit outside of well-known drivers in specific cancers
- Small no. of available targeted drugs
- Limits to the impact of single targeted drugs, given cancer heterogeneity and redundancy of cell signaling
- Toxicity of combinations
- Lack of clinical evidence of benefits and increased costs to health care

FIMM

SciLifeLab

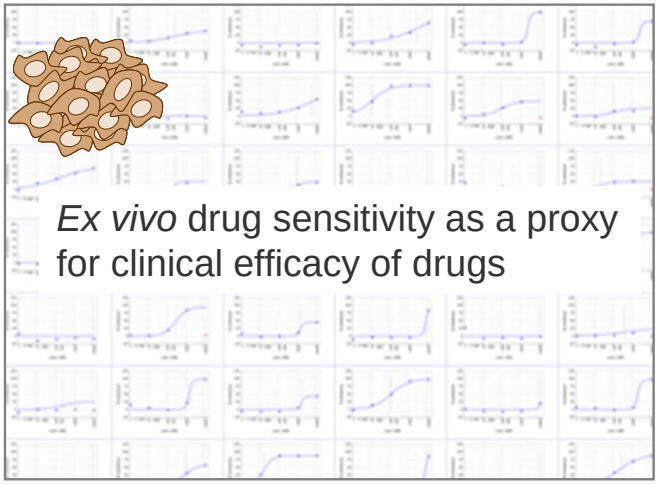
What more can Systems Medicine do?

Deep molecular profiling



TCGA Weinstein *et al.*,
Nature Genetics 45, 1113–1120, 2013

Deep functional profiling of PDCs



Pemovska T *et al.*, Cancer Disc 3:1416-1429, 2013
Yadav B *et al.*, Sci Rep 4:5193, 2014
Pemovska T *et al.*, Nature 7541:102-105, 2015
Saeed K *et al.*, Eur J Urol , May 5, *2017*
Ojamies P *et al.*, Leukemia, 31 Oct 31, *2017*
Malani D *et al.*, Leukemia, May 31, 2017

FIMM

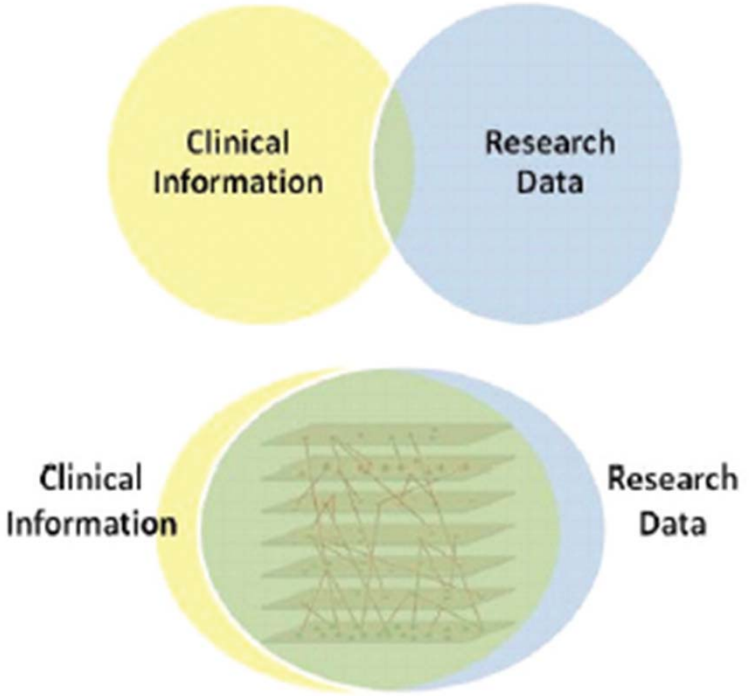
Clinical Precision Medicine

SciLifeLab

Real-time translation of systems biology/ systems medicine data

Usually translation of research to the clinic takes a decade or so

Can we provide systems biology information to the clinic that may help real-time with treatment decisions?

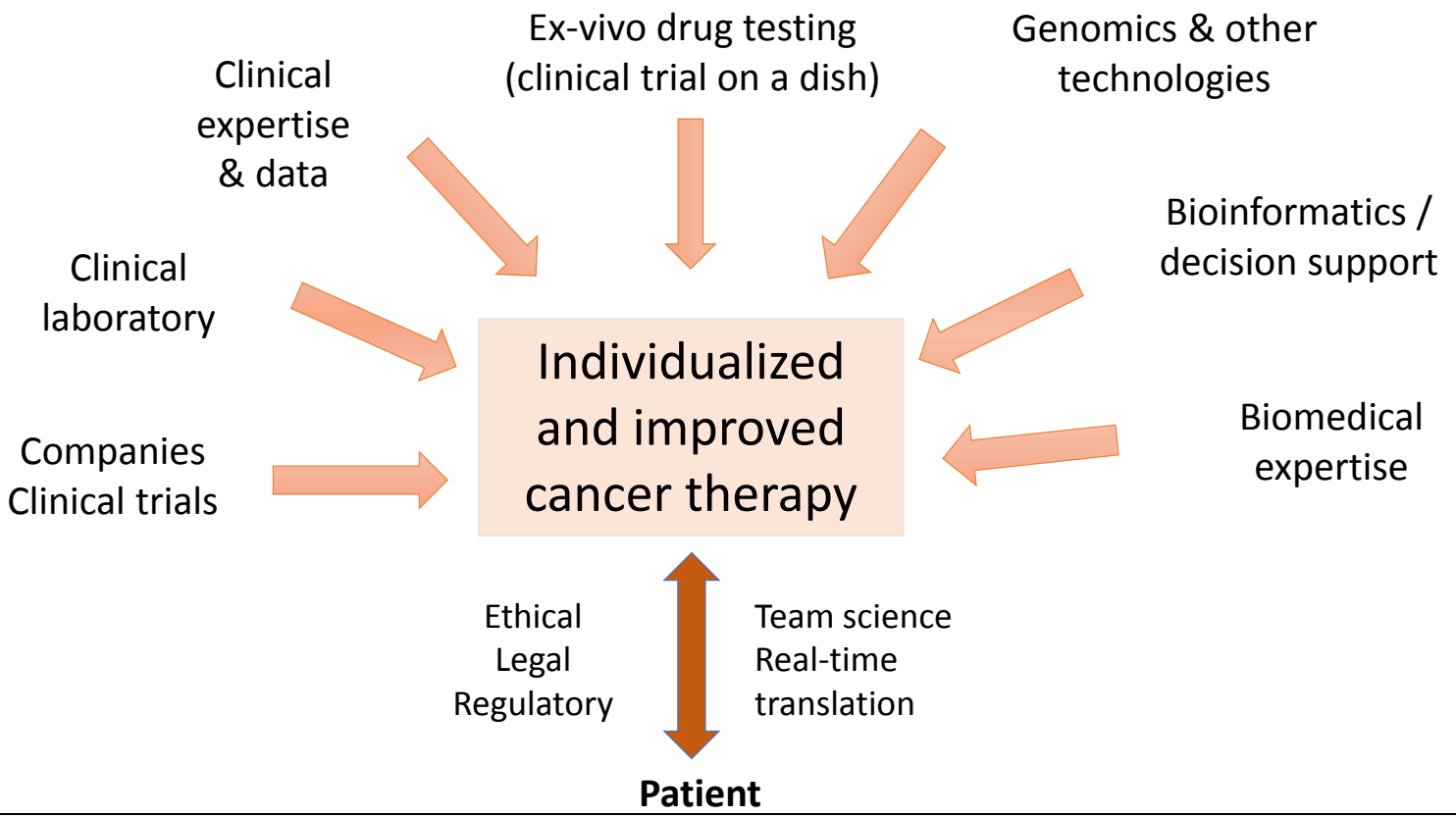


US National Academy of Sciences 2012

FIMM

SciLifeLab

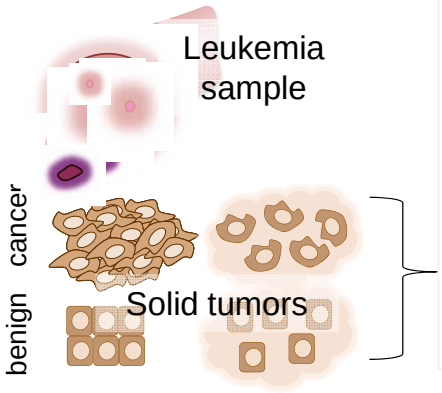
Elements assembled to take precision systems medicine to the clinical setting



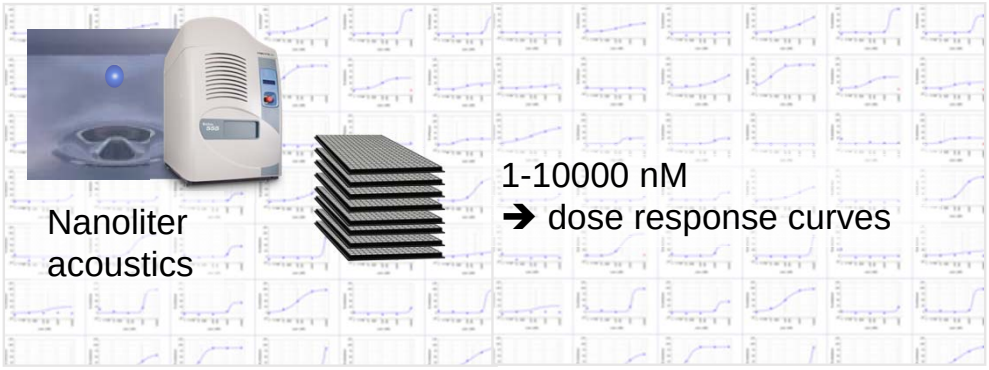
FIMM

SciLifeLab

Drug sensitivity and resistance profiling (DSRT) Platform: High-throughput, nanoliter-scale drug testing of patient-derived cells (PDCs)

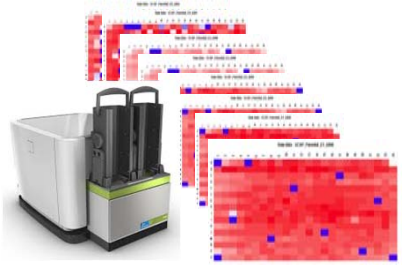


525 oncology drugs
149 approved drugs
376 investigational drugs
- conventional chemotherapeutics
- hormone therapy drugs
- kinase inhibitors
- epigenetic/differentiating drugs
- other targeted drugs
- immunosuppressants

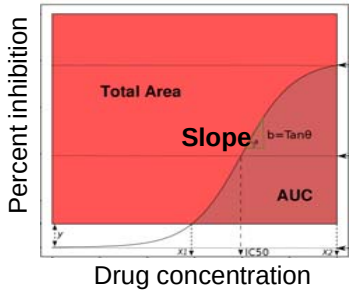


Fresh material, expansion, single cell suspension

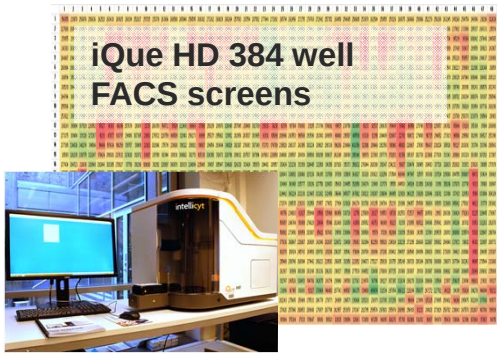
Viability / Toxicity by CellTiter-Glo / CellTox



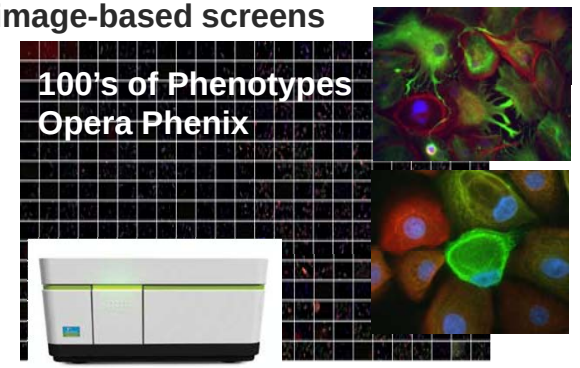
Drug Sensitivity Score (DSS)



Flow cytometry



High throughput high-content image-based screens

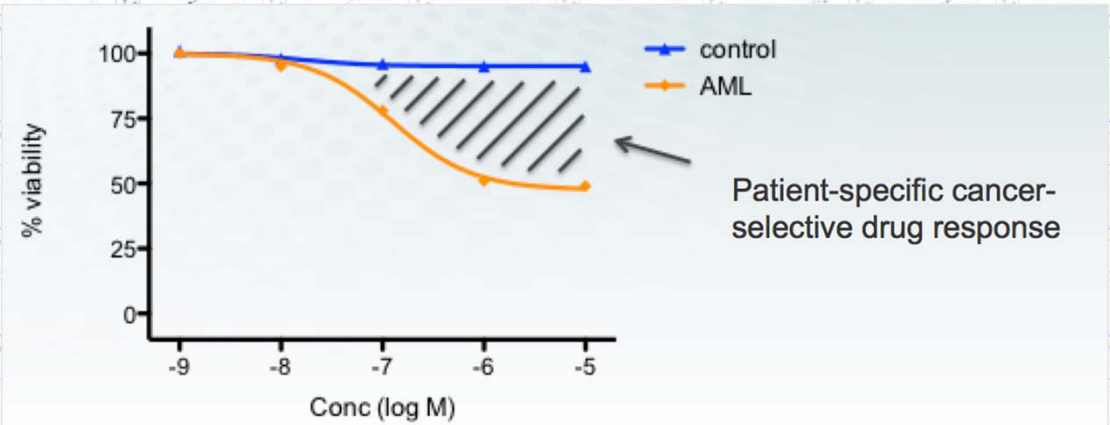


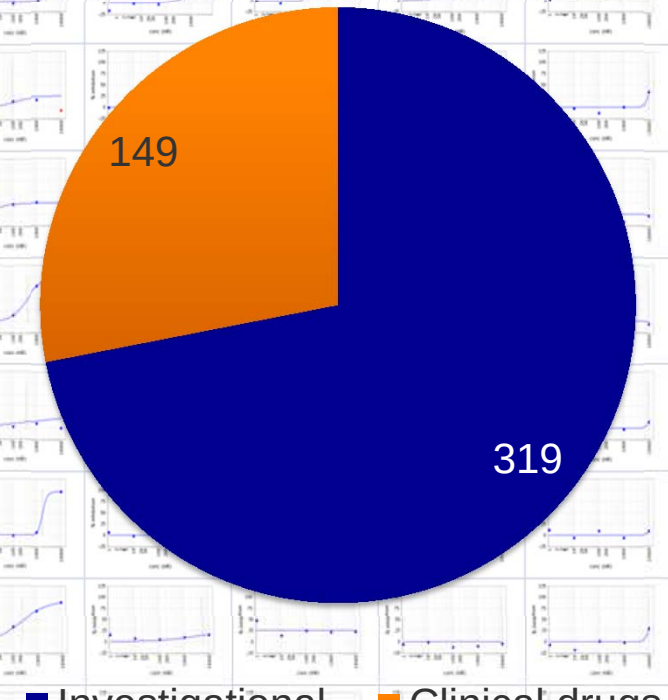
FIMM

SciLifeLab

Pharmacopeia-wide drug sensitivity and resistance testing with dose-response curves for each drug

Detailed dose-response curves
for all oncology drugs and many
emerging cancer compounds
for individual patient cell samples



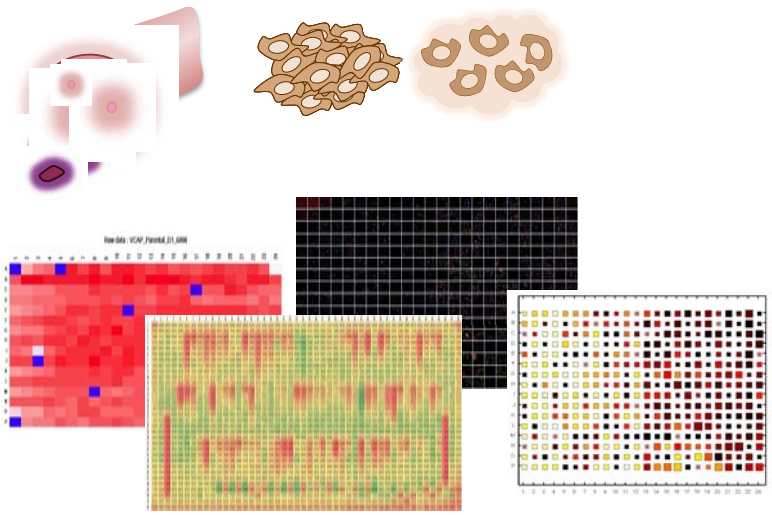


FIMM

SciLifeLab

Pharmacopeia-wide drug sensitivity and resistance testing (DSRT) of patients' cancer cells: data analysis

Drug testing of patients' cells *ex vivo*



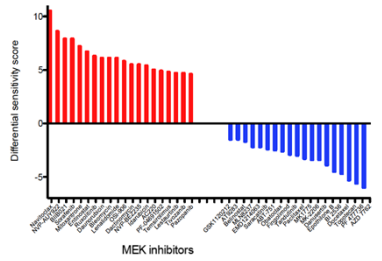
Comparative efficacy data for 540 drugs

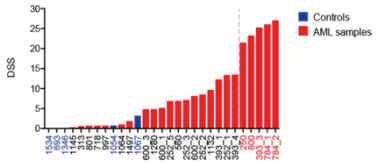
Comparing different drugs in one patient

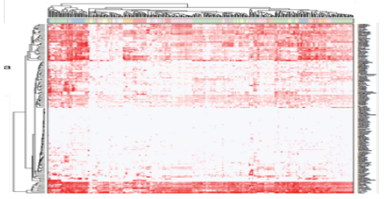
Comparing the same drug across different patients

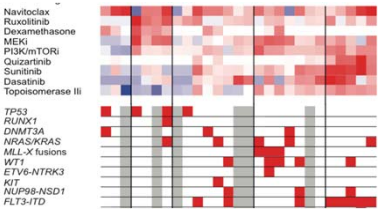
Cross- comparing drugs and patients

Identification of response biomarkers





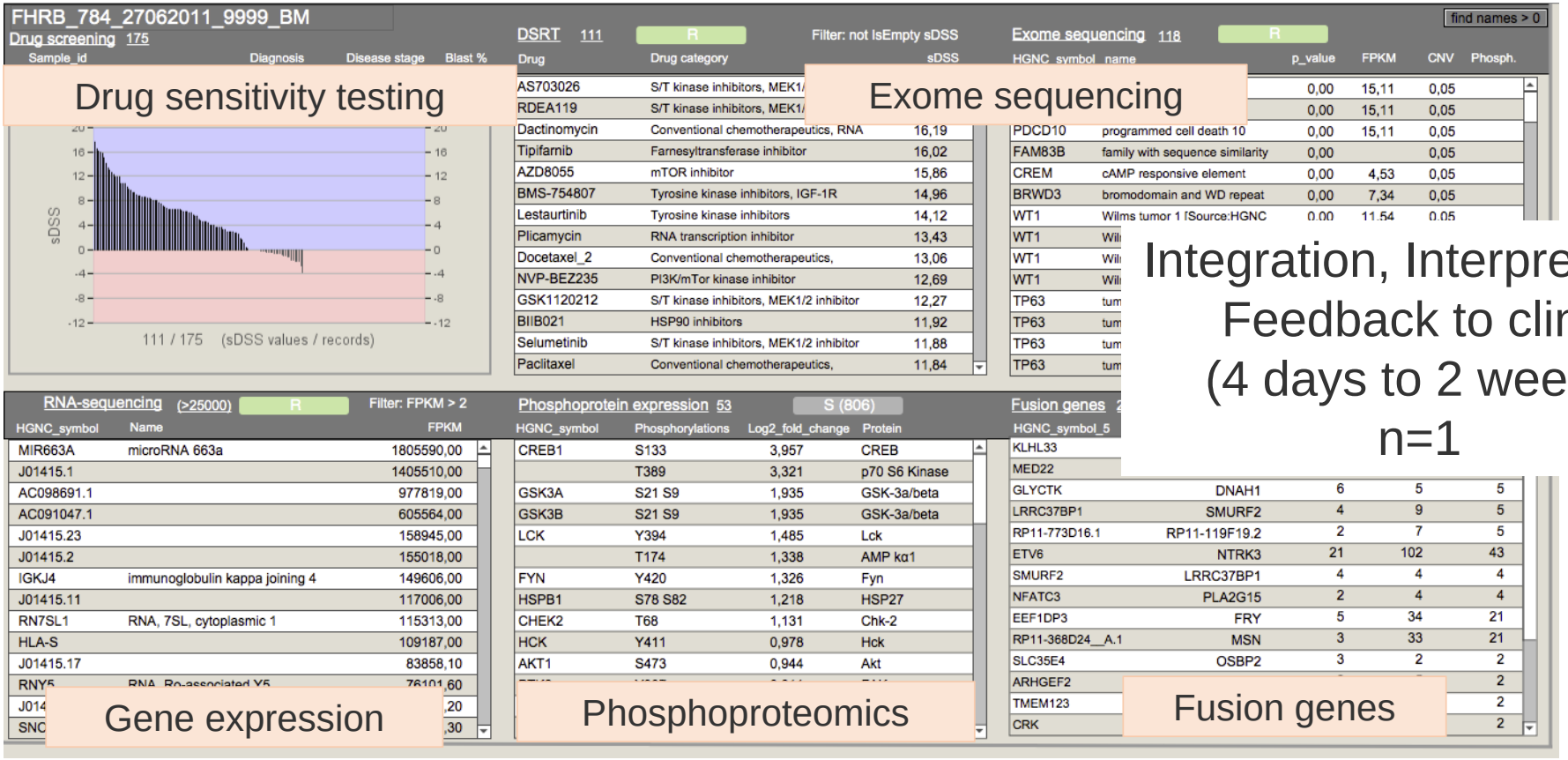




FIMM

SciLifeLab

Big data management, integration and rapid interpretation needed to give real-time feedback to the clinic



Drug sensitivity testing

Exome sequencing

Integration, Interpretation
Feedback to clinic
(4 days to 2 weeks)
n=1

Gene expression

Phosphoproteomics

Fusion genes

FIMM

SciLifeLab

CANCER DISCOVERY

search

Advanced Sear

Home About Articles For Authors Alerts News

Research Articles

Individualized Systems Medicine Strategy to Tailor Treatments for Patients with Chemorefractory Acute Myeloid Leukemia

Tea Pemovska, Mika Kontro, Bhagwan Yadav, Henrik Edgren, Samuli Eldfors, Agnieszka Szwajda, Henrikki Almusa, Maxim M. Bespalov, Pekka Ellonen, Erkki Elonen, Bjørn T. Gjertsen, Riikka Karjalainen, Evgeny Kulesskiy, Sonja Lagström, Anna Lehto, Maija Lepistö, Tuija Lundán, Muntasir Mamun Majumder, Jesus M. Lopez Marti, Pirkko Mattila, Astrid Murumägi, Satu Mustjoki, Aino Palva, Alun Parsons, Tero Pirttinen, Maria E. Rämet, Minna Suvela, Laura Turunen, Imre Västrik, Maija Wolf, Jonathan Knowles, Tero Aittokallio, Caroline A. Heckman, Kimmo Porkka, Olli Kallioniemi, and Krister Wennerberg

DOI: 10.1158/2159-8290.CD-13-0350 Published December 2013

Image-based ex-vivo drug screening for patients with aggressive haematological malignancies: interim results from a single-arm, open-label, pilot study

Berend Snijder, Gregory I Vladimer*, Nikolaus Krall, Katsuhiro Miura, Ann-Sofie Schmolke, Christoph Kornauth, Oscar Lopez de la Fuente, Hye-Soo Choi, Emiel van der Kouwe, Sinan Gültekin, Lukas Kazianka, Johannes W Bigenzahn, Gregor Hoermann, Nicole Prutsch, Olaf Merkel, Anna Ringler, Monika Sabler, Georg Jeryczynski, Marius E Mayerhoefer, Ingrid Simonitsch-Klupp, Katharina Ocko, Franz Felberbauer‡, Leonhard Müllauer, Gerald W Prager, Belgin Korkmaz, Lukas Kenner, Wolfgang R Sperr, Robert Kralovics, Heinz Gisslinger, Peter Valent, Stefan Kubicek, Ulrich Jäger, Philipp B Staber†, Giulio Superti-Furga†*

Chemogenomic Landscape of *RUNX1*-mutated AML Reveals Importance of *RUNX1* Allele Dosage in Genetics and Glucocorticoid Sensitivity

Laura Simon[1], Vincent-Philippe Lavallée[1,2], Marie-Eve Bordeleau[1], Jana Krosl[1], Irène Baccelli[1], Geneviève Boucher[1], Bernhard Lehnertz[1], Jalila Chagraoui[1], Tara MacRae[1], Réjean Ruel[1], Yves Chantigny[1], Sébastien Lemieux[1,3], Anne Marinier[1,4] Josée Hébert[1,2,5,6], and Guy Sauvageau[1,2,5,6]

Molecularly targeted drug combinations demonstrate selective effectiveness for myeloid- and lymphoid-derived hematologic malignancies

Stephen E. Kurtz[a], Christopher A. Eide[a,b], Andy Kaempf[c], Vishesh Khanna[a,b], Samantha L. Savage[a], Angela Rofelty[a], Isabel English[a], Hibery Ho[a], Ravi Pandya[d], William J. Bolosky[d], Hoifung Poon[d], Michael W. Deininger[e], Robert Collins[f], Ronan T. Swords[g], Justin Watts[g], Daniel A. Pollyea[h], Bruno C. Medeiros[i], Elie Traer[a], Cristina E. Tognon[a], Motomi Mori[c,j], Brian J. Druker[a,b,1], and Jeffrey W. Tyner[k,1]

ELSEVIER

Leukemia Research

journal homepage: www.elsevier.com/locate/leukres

Research paper

Ex-vivo sensitivity profiling to guide clinical decision making in acute myeloid leukemia: A pilot study

Ronan T. Swords[a,1], Diana Azzam[b,c,d,1], Hassan Al-Ali[d,e,f,g,1], Ines Lohse[b,c,d,1], Claude-Henry Volmar[b,c,d], Justin M. Watts[a], Aymee Perez[a], Ana Rodriguez[a], Fernando Vargas[a], Roy Elias[a], Francisco Vega[a], Arthur Zelent[a], Shaun P. Brothers[b,c,d], Taher Abbasi[h], Jonathan Trent[a], Shaukat Rangwala[i], Yehuda Deutsch[j], Eibhlin Conneally[k], Leylah Drusbosky[l], Christopher R. Cogle[l], Claes Wahlestedt[b,c,*]

Leukemia

Original Article | OPEN | Published: 11 November 2016

Mechanisms of resistance

Enhanced sensitivity to glucocorticoids in cytarabine-resistant AML

D Malani, A Murumägi, B Yadav, M Kontro, S Eldfors, A Kumar, R Karjalainen, M M Majumder, P Ojamies, T Pemovska, K Wennerberg, C Heckman, K Porkka, M Wolf, T Aittokallio & O Kallioniemi

Leukemia **31**, 1187–1195 (2017) | Download Citation

FIMM

SciLifeLab

nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio & Video | For Au

Research › Letters › Article

ARTICLE PREVIEW

view full access options ▸

NATURE | LETTER

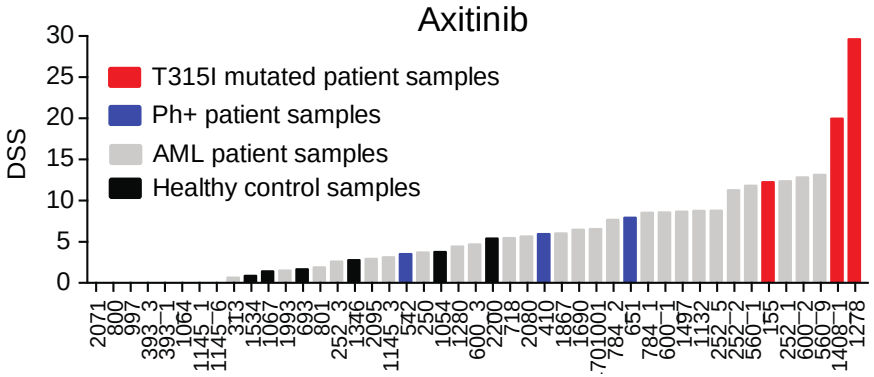
Axitinib effectively inhibits BCR-ABL1(T315I) with a distinct binding conformation

Tea Pemovska, Eric Johnson, Mika Kontro, Gretchen A. Repasky, Jeffrey Chen, Peter Wells, Ciarán N. Cronin, Michele McTigue, Olli Kallioniemi, Kimmo Porkka, Brion W. Murray & Krister Wennerberg

Affiliations | Contributions | Corresponding authors

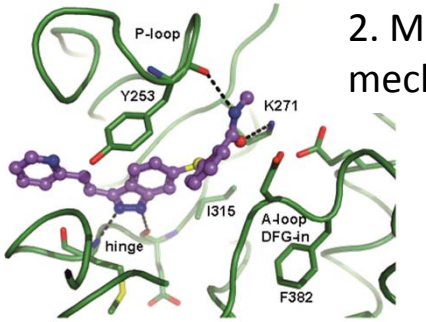
Nature (2015) | doi:10.1038/nature14119

Received 17 July 2014 | Accepted 26 November 2014 | Published online 09 February 2015



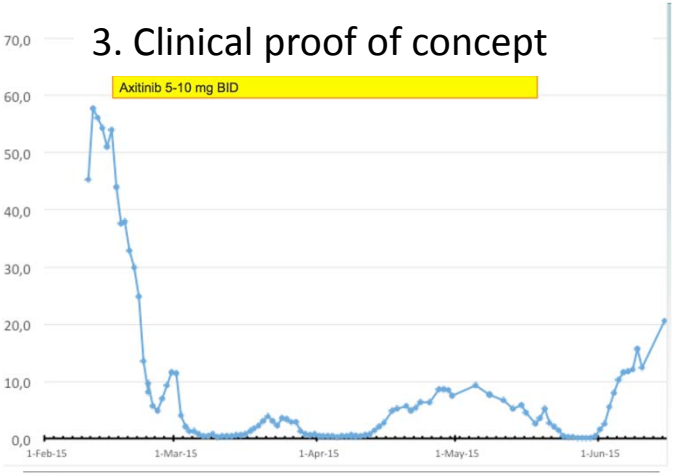
1. Drug efficacy in a subgroup ex-vivo:
   - T315I gate-keeper mutation in BCR-ABL
   - Resistance to ABL inhibitors

Kinase	Axitinib Kd (nM)
ABL1	36
ABL1(T315I)	**1.5**
ABL1(H396P)	20
ABL1(M351T)	36
ABL1(E255K)	63
ABL1(Y253F)	230
ABL1(F317I)	800
VEGFR2	**5.9**



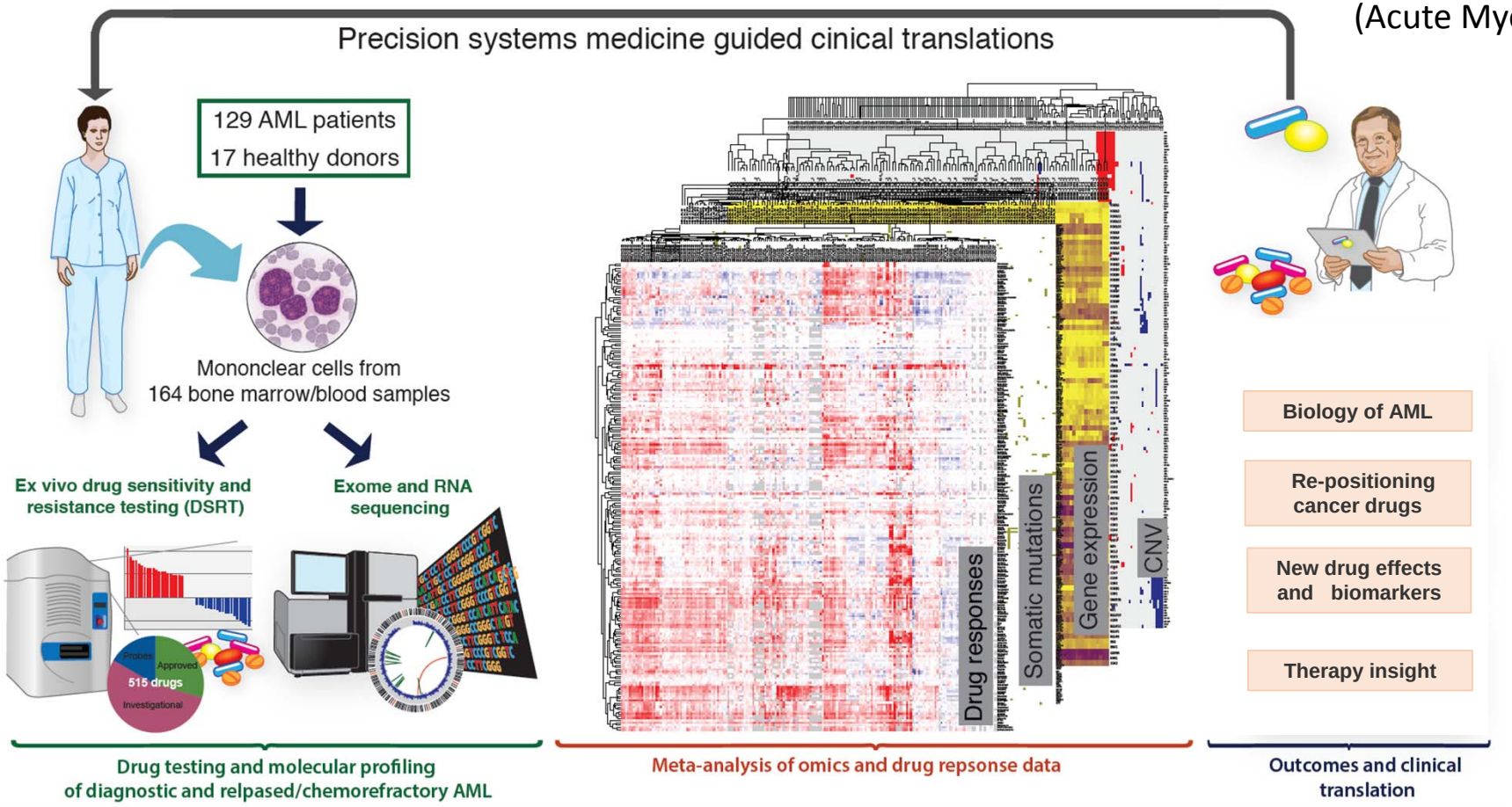
2. Molecular mechanisms

3. Clinical proof of concept



Individualized Systems Medicine study of 164 consecutive AML samples

(Acute Myeloid Leukemia)



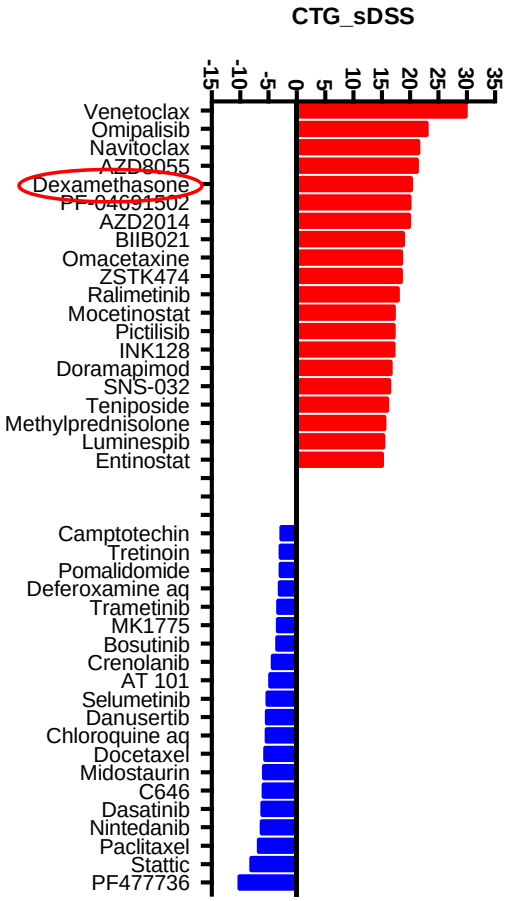
FIMM

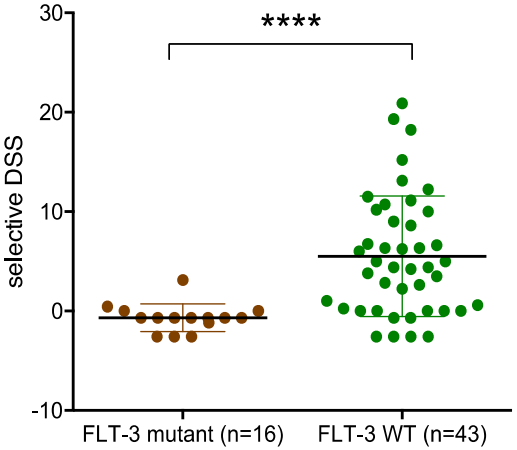
SciLifeLab

some conclusions in AML

so far...

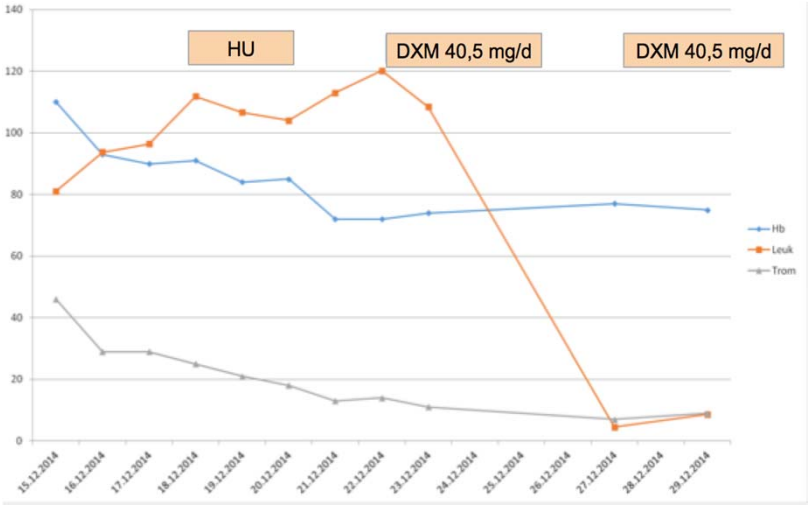
Opportunities to reposition existing cancer drugs
In biomarker-defined subgroups





Subgroup responding to glucocorticoids

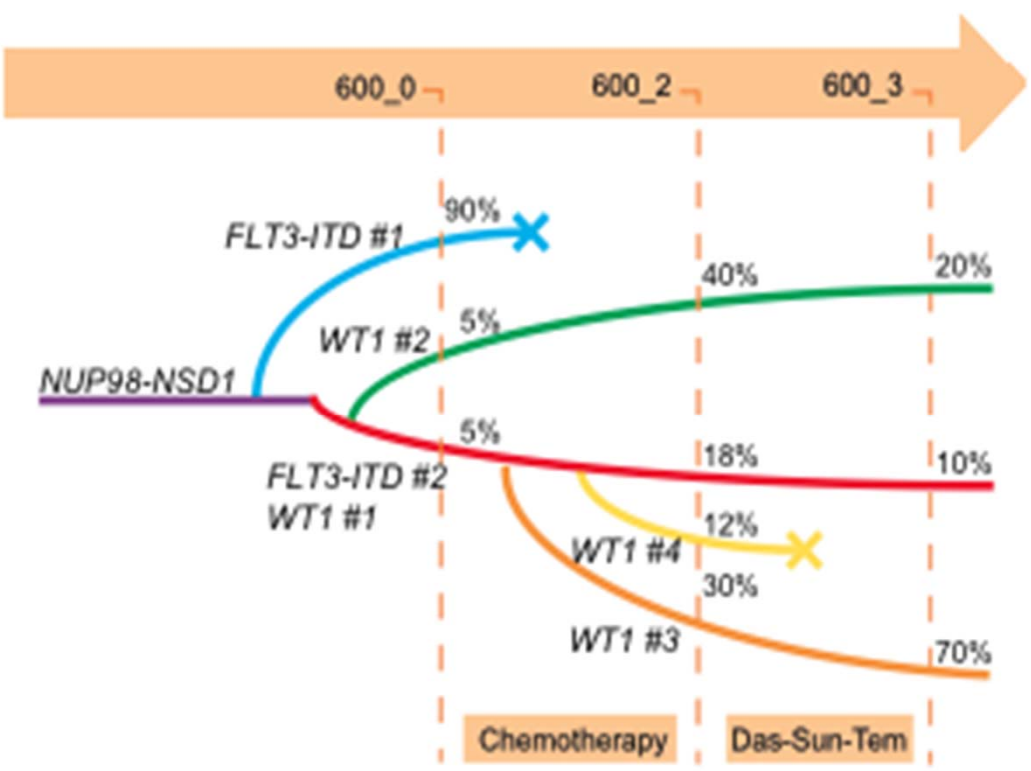
Clinical Proof of concept:

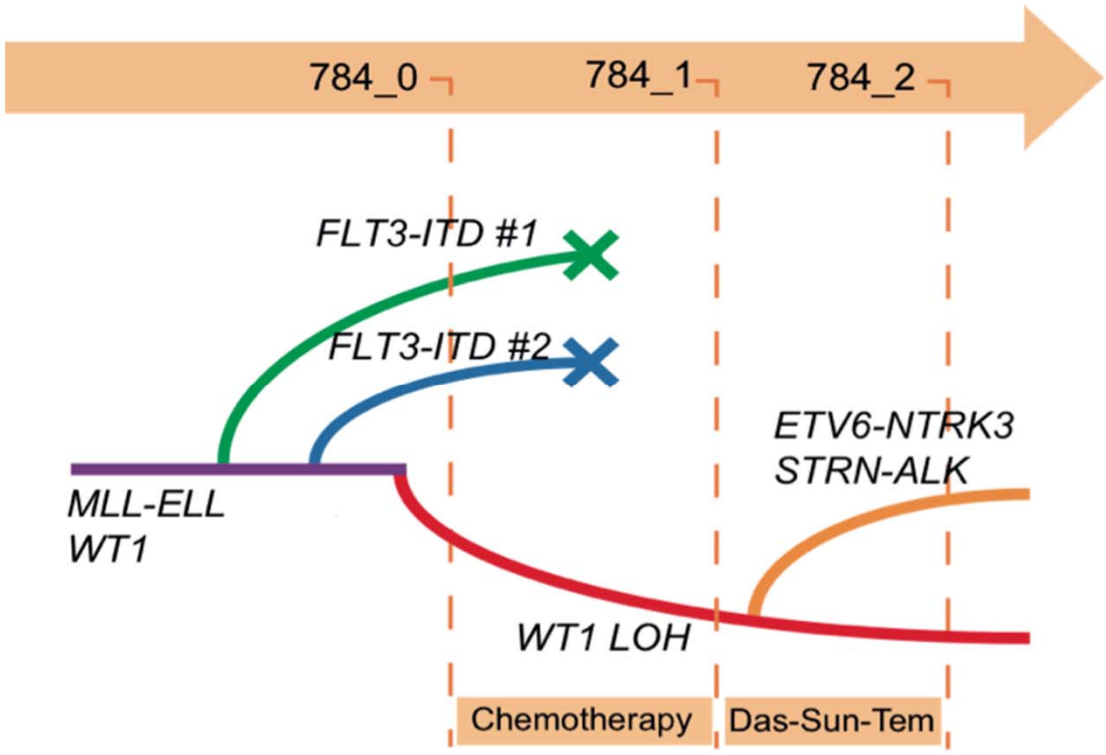


FIMM

SciLifeLab

AML therapies in patients often eliminate cancer subclones, but new clones emerge and cause resistance and relapse

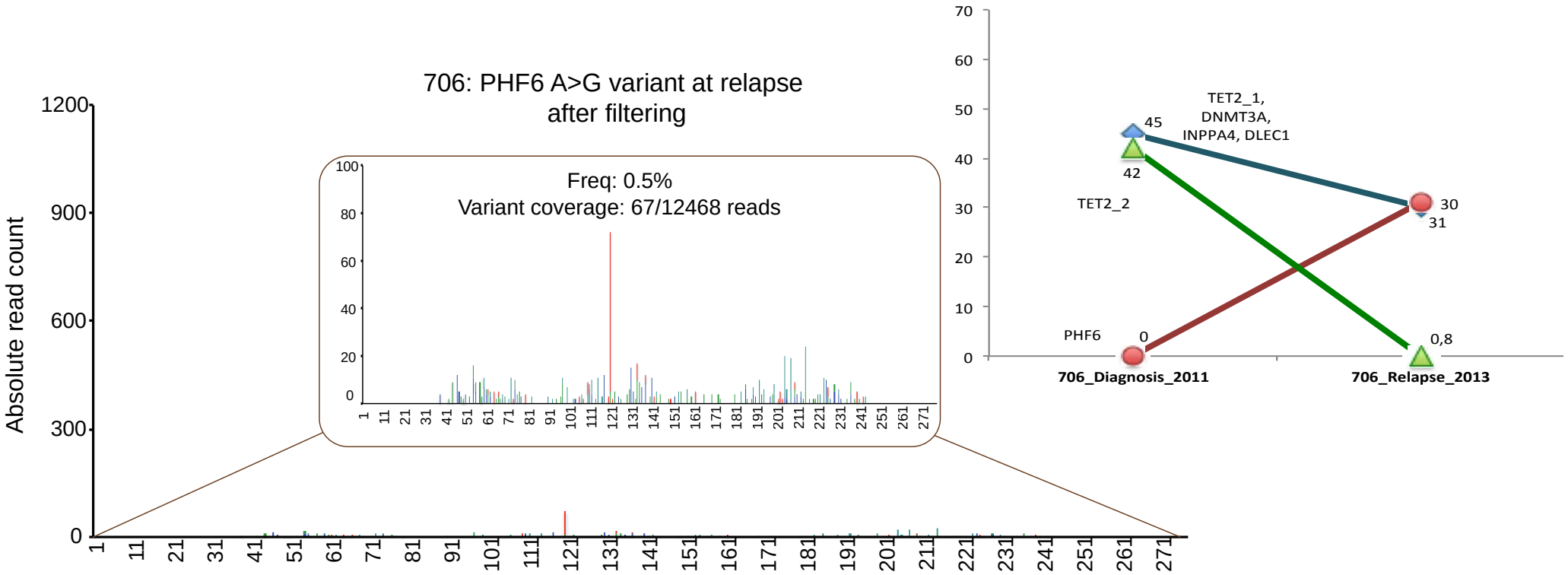




FIMM

SciLifeLab

Drug-resistance arises from pre-existing rare cell variants



16 relapse-associated mutations identified before treatment (at frequencies of 0,54-2%) that were not detected by exome sequencing

What next?

Refinement and consistency of the functional assays and cell models

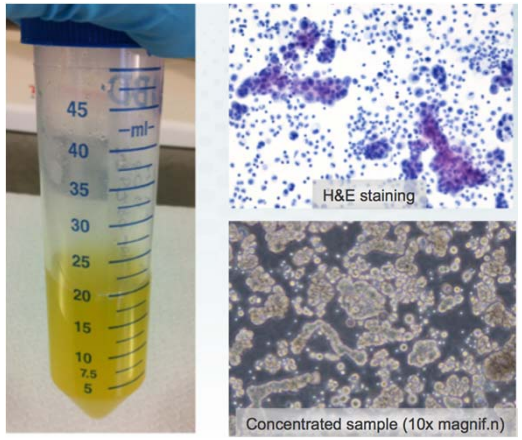
Clinical trials based on systems medicine (and ex-vivo drug sensitivity / trial on a dish) in a pan-Nordic / pan-EU / global setting

Precision systems medicine POCs in solid tumors (ovarian cancer)

FIMM

SciLifeLab

Precision Systems Cancer Medicine: Ovarian cancer

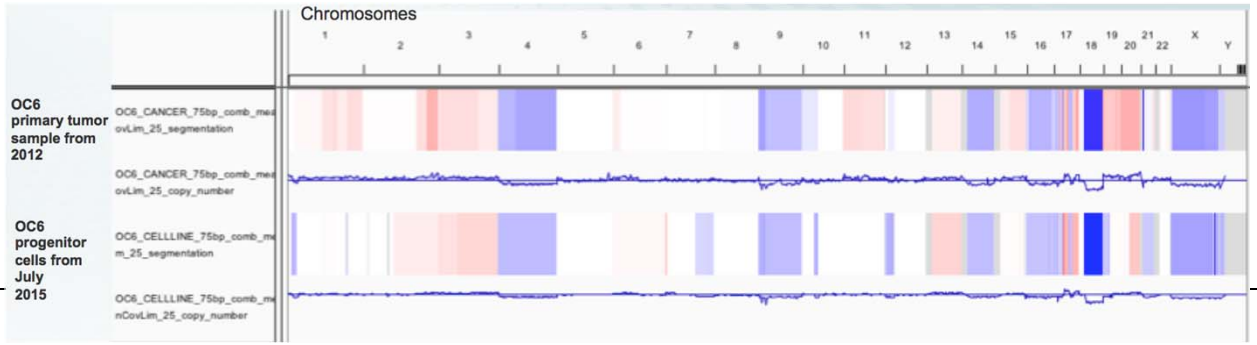


Astrid Murumägi, Ralf Butzov *et al.,*

Progenitor cells isolated from ovarian cancer ascites for functional drug testing

Excellent representation of genomics between conditionally reprogrammed cells *ex vivo* and patient's primary tumor

Both Primary tumor sample from 2012 (FFPE) and conditionally reprogrammed cells carry **KRAS (G12V) hotspot mutation** and **TP53 (S215N) mutation**



FIMM

SciLifeLab

Acknowledgements

Collaborators & PIs @ FIMM:
- Kimmo Porkka
- Satu Mustjoki
- Caroline Heckman
- Krister Wennerberg
- Tero Aittokallio
- Jing Tang
- FIMM TC Platforms

Collaborators / SciLifeLab/KI:
- Sören Lehman
- Janne Lehtiö
- Thomas Helleday
- Yudi Pawitan
- SciLifeLab platforms

AML 2.0 data team:
Disha Malani
Ashwini Kumar
Bhagwan Yadav

Senior scientists: Päivi Östling, Vilja Pietiäinen, Teijo Pellinen, Astrid Murumägi, Brinton Seashore-Ludlow

Thank You for Your Attention!