US Federal Cancer Moonshot: *One Year Later*

Jerry S.H. Lee, Ph.D.

Health Sciences Director

Deputy Director, Center for Strategic Scientific Initiatives (CSSI)
Joint Executive for Data Integration, Center for Biomedical Informatics and Information Technology (CBIIT)

Office of the Director, National Cancer Institute (NCI), National Institutes of Health (NIH)

Dimitri Kusnezov, Ph.D.

Chief Scientist

National Nuclear Security Administration
Department of Energy

Frontiers of Predictive Oncology and Computing II

October 17th, 2017

10/17/16

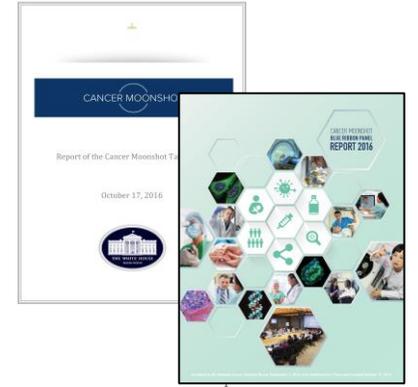Joined NCI
Center for Strategic
Scientific Initiatives
(CSSI)

Transitioned to
Deputy Director, CSSI

NCI Alliance for
Nanotechnology
in Cancer

CENTER for
STRATEGIC
SCIENTIFIC INITIATIVES

06　**08**　**09**　**10**　**16**

2005　　　　　　　　　　　　　　　　　　　**2018**

IMAT
Innovative Molecular Analysis Technologies

PHYSICAL SCIENCES
in ONCOLOGY

THE CANCER GENOME ATLAS

Official
*"Other Duties
As Assigned"*

NCI Center for
Global Health

Center for
Cancer Genomics

CBIIT

*J*oint*E*xecutive*D*ata*I*ntegration

Served as Deputy Director for
Cancer Research and Technology
WH Cancer Moonshot Task Force

4/14/16

WH OSTP/NSTC

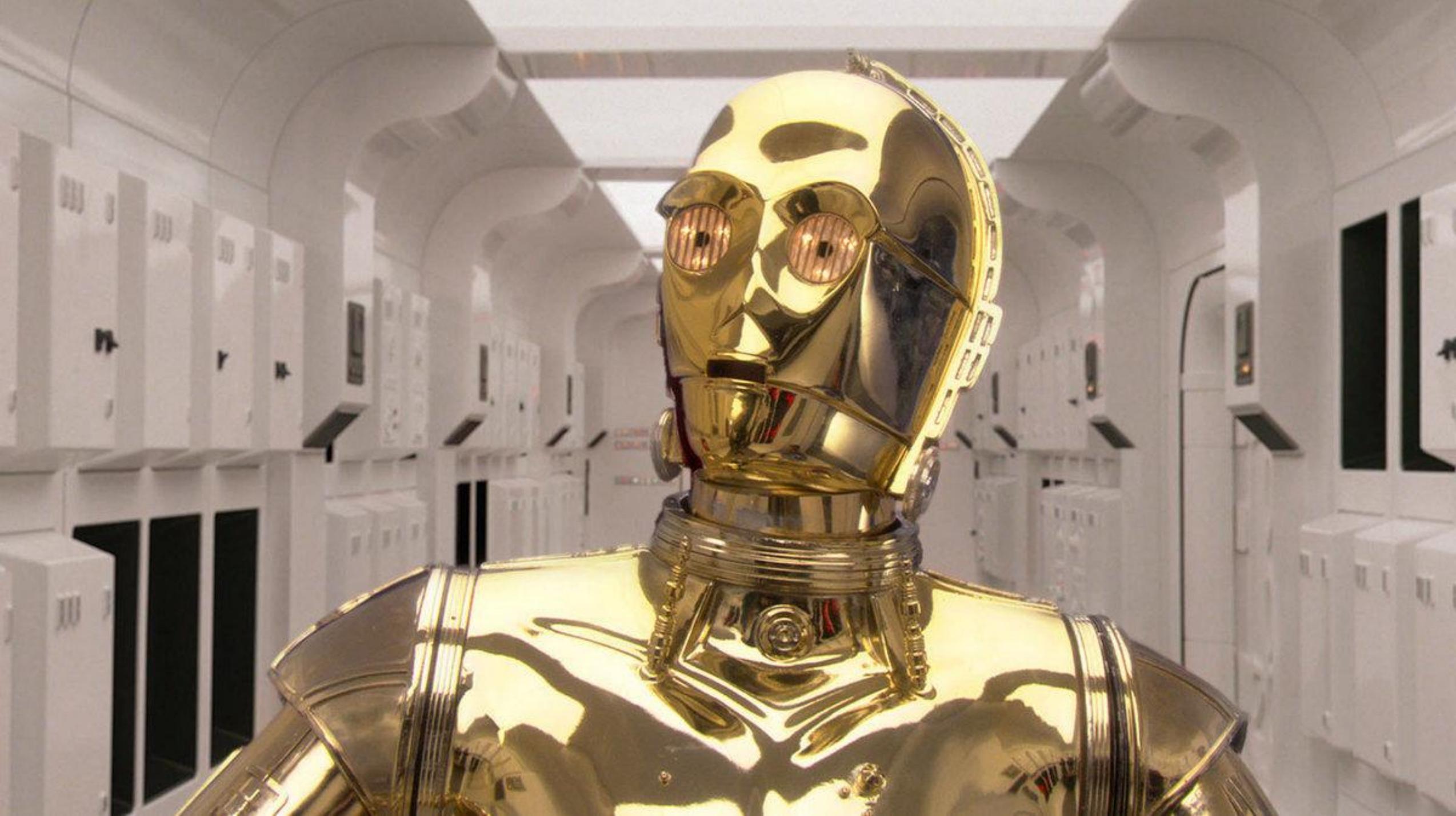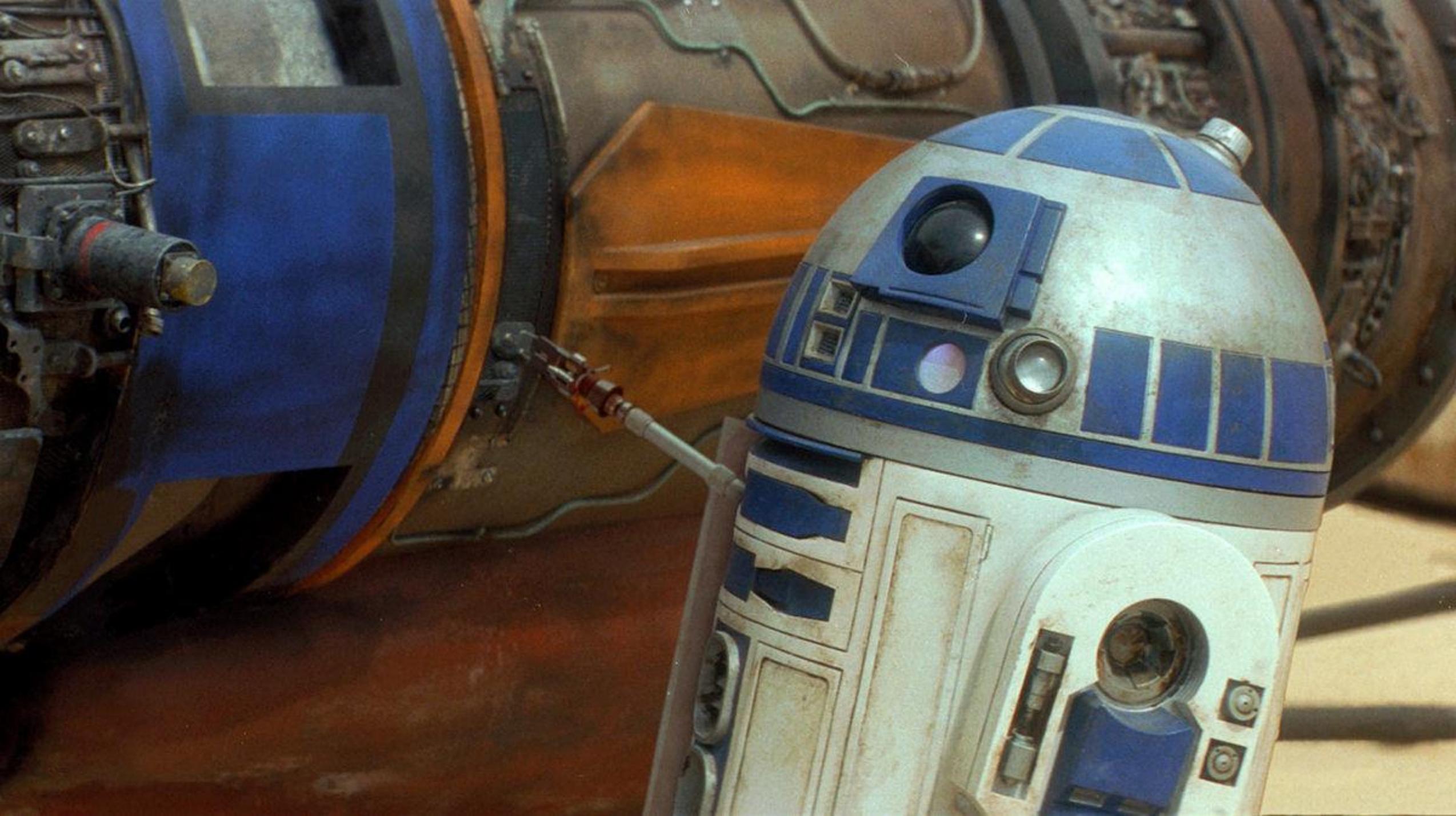*Machine Learning and Artificial Intelligence*
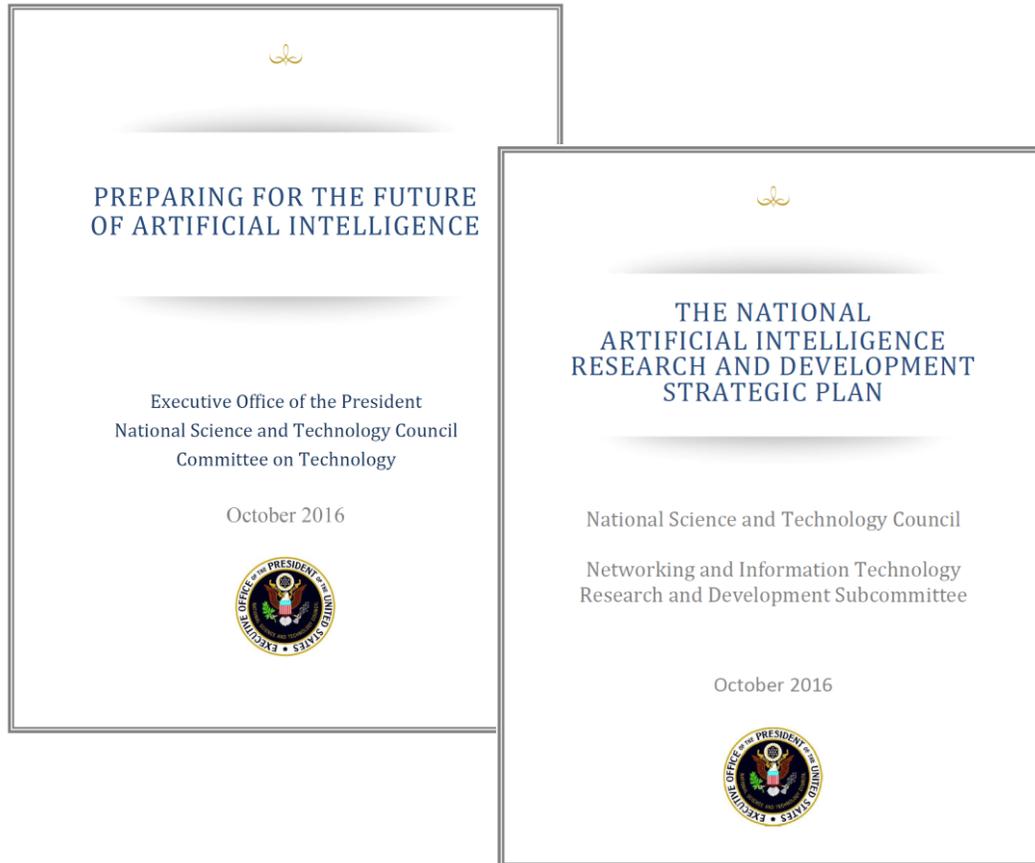
WH OVP/NCI

Cancer Moonshot

"…an **advantage** of **machine learning** is that it can be used even in cases where it is **infeasible** or **difficult** to write down <u>**explicit**</u> <u>**rules**</u> to **solve** a problem…"

2017

1,688,780

new cases of cancer in the U.S.

600,920

projected deaths due to cancer in the U.S.
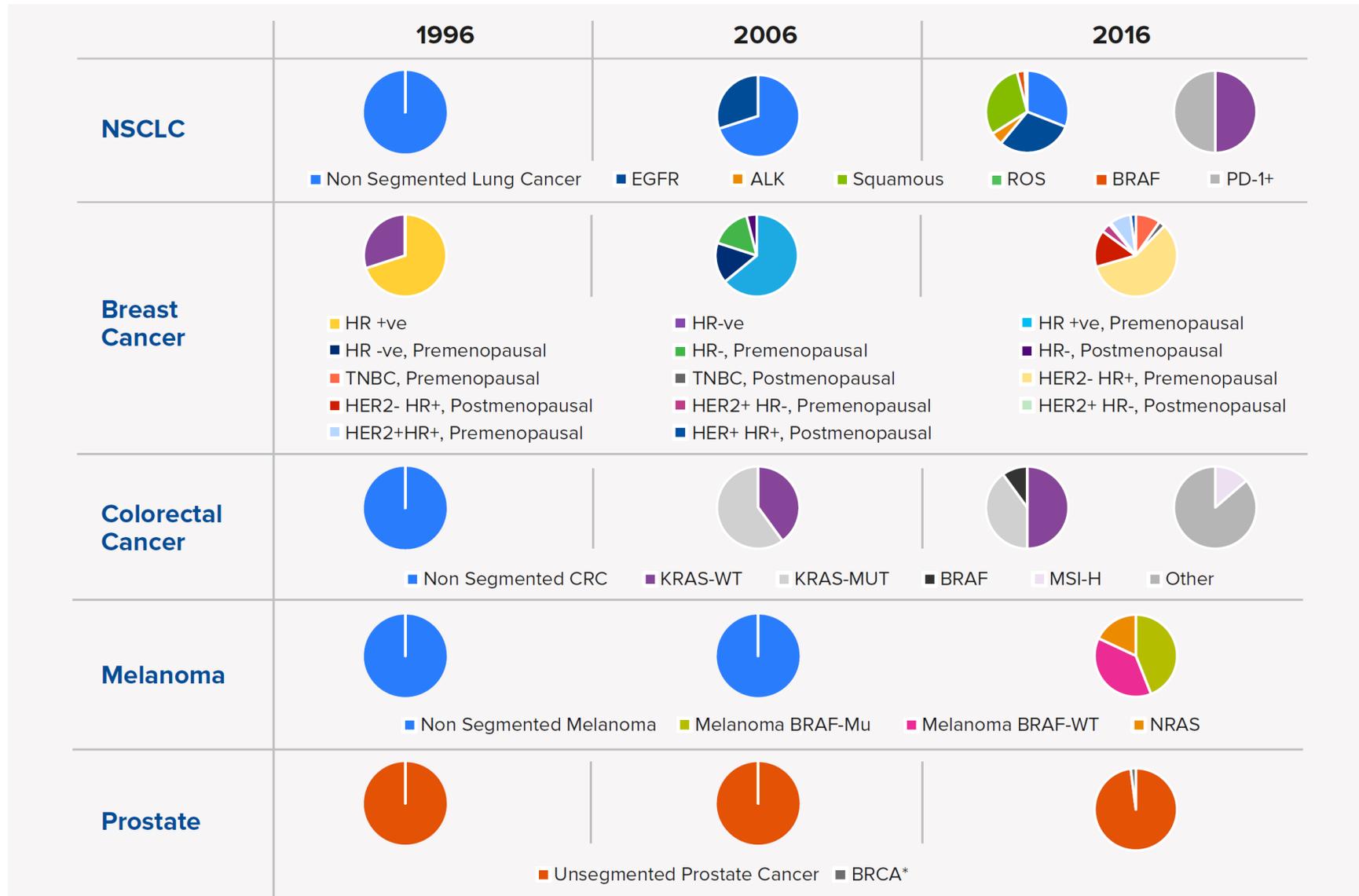
2017

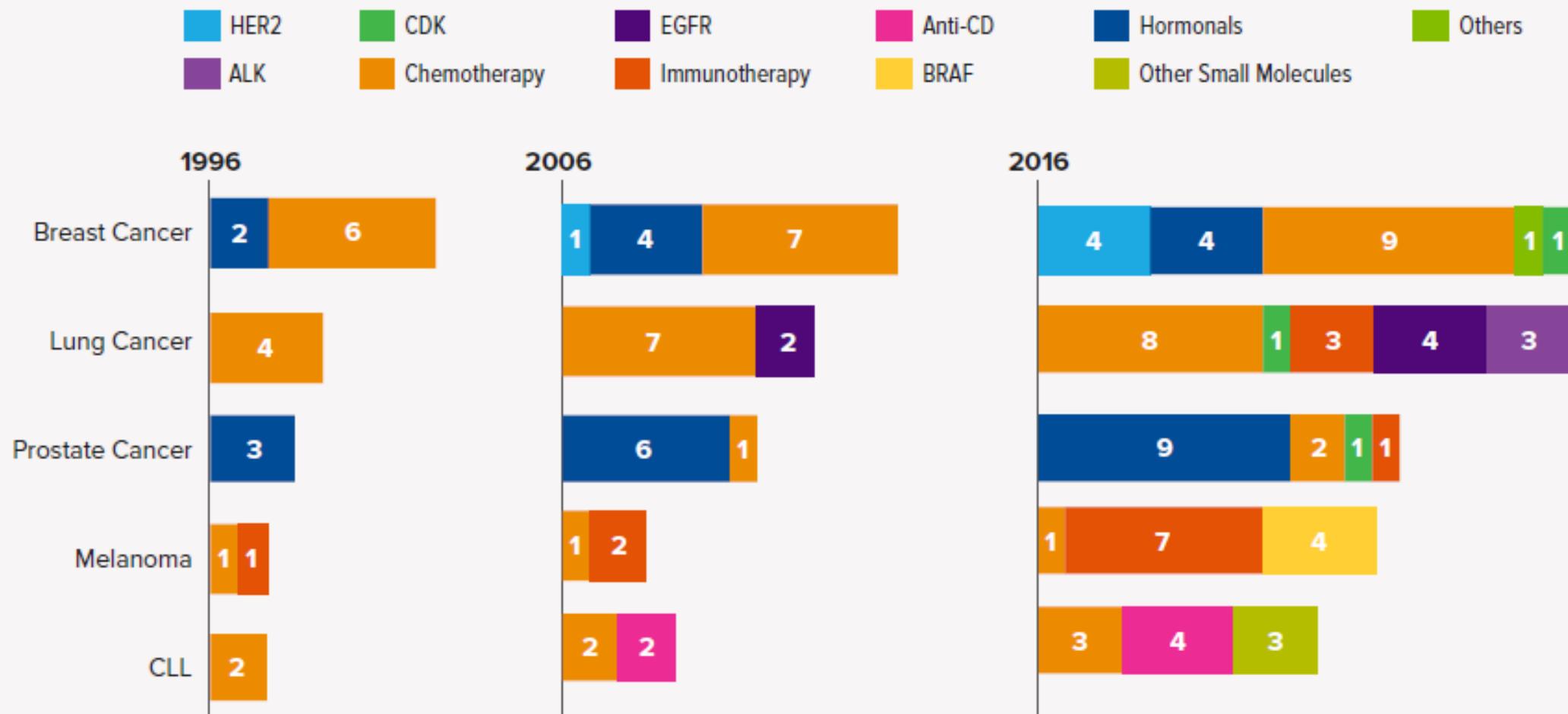# 15,533,220

cancer survivors in the U.S.

"…to apply machine learning, a practitioner starts with **a historical data set**, which the practitioner divides into a ***training set*** and a ***test set***…"

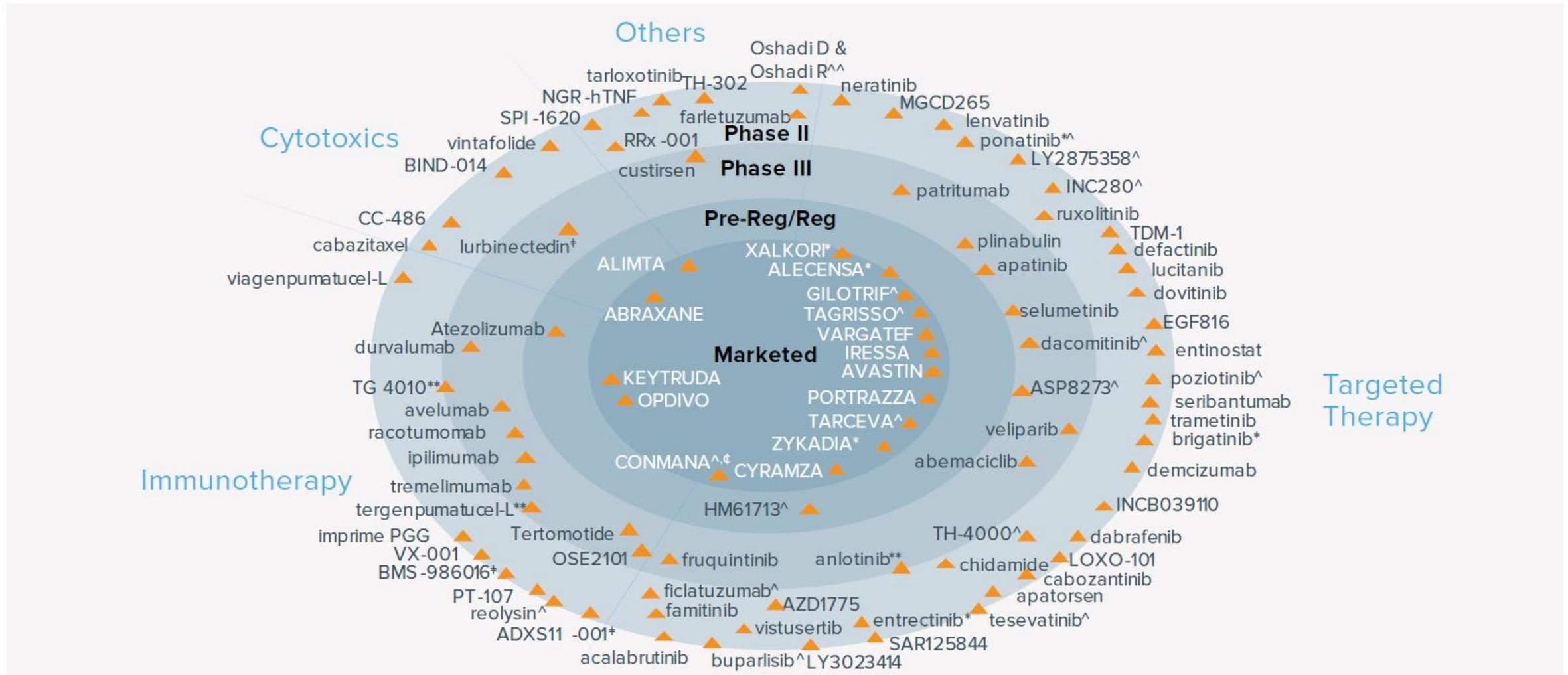# Cancer has been progressively redefined over the past 20 years

	1996	2006	2016

NSCLC

■ Non Segmented Lung Cancer   ■ EGFR   ■ ALK   ■ Squamous   ■ ROS   ■ BRAF   ■ PD-1+

Breast Cancer

■ HR +ve   ■ HR-ve   ■ HR +ve, Premenopausal
■ HR -ve, Premenopausal   ■ HR-, Premenopausal   ■ HR-, Postmenopausal
■ TNBC, Premenopausal   ■ TNBC, Postmenopausal   ■ HER2- HR+, Premenopausal
■ HER2- HR+, Postmenopausal   ■ HER2+ HR-, Premenopausal   ■ HER2+ HR-, Postmenopausal
■ HER2+HR+, Premenopausal   ■ HER+ HR+, Postmenopausal

Colorectal Cancer

■ Non Segmented CRC   ■ KRAS-WT   ■ KRAS-MUT   ■ BRAF   ■ MSI-H   ■ Other

Melanoma

■ Non Segmented Melanoma   ■ Melanoma BRAF-Mu   ■ Melanoma BRAF-WT   ■ NRAS

Prostate

■ Unsegmented Prostate Cancer   ■ BRCA*

Number of Treatment Options over Time for Selected Tumors (1996–2016)

Legend: HER2, CDK, EGFR, Anti-CD, Hormonals, Others, ALK, Chemotherapy, Immunotherapy, BRAF, Other Small Molecules

1996

- Breast Cancer: Hormonals 2, Chemotherapy 6
- Lung Cancer: Chemotherapy 4
- Prostate Cancer: Hormonals 3
- Melanoma: Chemotherapy 1, Immunotherapy 1
- CLL: Chemotherapy 2

2006

- Breast Cancer: HER2 1, Hormonals 4, Chemotherapy 7
- Lung Cancer: Chemotherapy 7, EGFR 2
- Prostate Cancer: Hormonals 6, Chemotherapy 1
- Melanoma: Chemotherapy 1, Immunotherapy 2
- CLL: Chemotherapy 2, Anti-CD 2

2016

- Breast Cancer: HER2 4, Hormonals 4, Chemotherapy 9, Other Small Molecules 1, CDK 1
- Lung Cancer: Chemotherapy 8, Others 1, Immunotherapy 3, EGFR 4, ALK 3
- Prostate Cancer: Hormonals 9, Chemotherapy 2, CDK 1, Immunotherapy 1
- Melanoma: Chemotherapy 1, Immunotherapy 7, BRAF 4
- CLL: Chemotherapy 3, Anti-CD 4, Other Small Molecules 3

Melanoma: 44 on deck for 2017

Chart 5: Key In–Market and Investigational Agents for Melanoma

Others

MORAB -004 APN301 Reolysin^
Hiltonol
TLPLDC^
HF10 + IPI
Dorgenmeltucel-L^
DC Vaccine^
TC-DC Vaccine^
RTA 408
MK-2206
IL -12 gene therapy
FANG Vaccine^
Provecta^
L19 -IL2
POL -103A^
Coxsackievirus A21
Astuprotimut-r^

SYLATRON
M-VAX* PROLEUKIN
Nintedanib
TEMODAR ⁰⁰ MUFORAN *
AMG 232
IMLYGIC^ TAFINLAR +
Palbociclib*
INTRON-A MEKINIST
TAFINLAR
PLX3397 + Pembrolizumab
Nab-paclitaxel
Marketed MEKINIST
Binimetinib*
Evofosfamide
OPDIVO COTELLIC +
Pazopanib
CDX-011 YERVOY + ZELBORAF
Encorafenib
Bevacizumab*
OPDIVO ZELBORAF
Axitinib
Denileukin diftitox
KEYTRUDA
Masitinib
Pimasertib*
Epacadostat *
YERVOY
GSK -2141795*
Lenvatinib
Pre-Reg/Reg
Nilotinib
Phase III
Ganitumab + Binimetinib
Immunotherapy
Sunitinib
Tremelimumab
Phase II
Ganetespib *
Durvalumab*
Pidilizumab
LN-144

Cytotoxics

Targeted
Therapy

Lung Cancer: 76 on deck for 2017

Chart 4: Key In-Market and Investigational Agents for NSCLC

Treatment Landscape for a Newly Diagnosed Metastatic NSCLC Patient

2006

			First Line		Second Line
Histological Testing	**Squamous cell carcinoma**			Chemotherapy	Chemotherapy
	Non-squamous cell carcinoma	Biomarker testing		Gefitinib	Chemotherapy
			EGFR+ve	Erlotinib	
			EGFR+ve	Bevacizumab based therapies	Chemotherapy
			263	Chemotherapy	Erlotinib

Indicates segments requiring histological testing

Indicates segments requiring biomarker testing

Treatment Landscape for a Newly Diagnosed Metastatic NSCLC Patient

2016

		First Line			Second Line	Third Line	Fourth Line
Squamous cell carcinoma		Chemotherapy			Afatinib	Chemotherapy	Chemotherapy
		Portrazza			Nivolumab		

Histological Testing

Non-squamous cell carcinoma

Biomarker testing	EGFR+ve	Gefitinib	EGFR790M testing	Positive	Osimertinib	Chemo	Chemotherapy
		Erlotinib			Chemo	Atezolizumab	
						Nivolumab	
				Negative	Chemo	Pembrolizumab*	
					Erlotinib		
					Pembrolizumab*		

Biomarker testing	ALK+ve		Crizotinib	Alectinib	Chemotherapy	Chemotherapy
				Ceritinib	Atezolizumab	
				Chemotherapy	Nivolumab	
				Crizotinib	Alectinib	
				Chemo	Ceritinib	
				Pembrolizumab*	Pembrolizumab*	

| Biomarker testing | PD-L1+ | Pembrolizumab | Nivolumab | Chemotherapy | Chemotherapy |
| | | | Atezolizumab | | |

Biomarker testing	EGFR-ve/ ALK-ve/PD1-ve	Bevacizumab -based therapies	Ramucirumab -based therapies		
		Chemotherapy	Erlotinib		
		nab paclitxel	Chemotherapy		

$?
Outcome?

Indicates segments requiring histological testing

Indicates segments requiring biomarker testing

"…it is of critical national importance that we …**double the _rate_ of progress** in the **fight against cancer**- and _**put ourselves on a path**_ to achieve in just **5 years** research and treatment **gains** that **otherwise might take a decade** or more…"

NCI Center for Strategic Scientific Initiatives (CSSI): Concept Shop

Director
Douglas R. Lowy, MD

Deputy Director
Jerry S.H. Lee, PhD

Associate Director
Sean E. Hanlon, PhD

Mission

"…to create and uniquely implement exploratory programs focused on the development and integration of advanced technologies, **trans-disciplinary approaches, infrastructures, and standards**, to accelerate the **creation and broad deployment** of **data, knowledge, and tools** to empower the **entire cancer research continuum** in better understanding and leveraging knowledge of the cancer biology space **for patient benefit**…"

2003, 2007, 2011, 2013, 2014, 2017　　**2005, 2010, 2015**　　**2008, 2013***　　**2011, 2014**

2004, 2008, 2014　　**2005, 2008**　　**2010**

Dates indicate approval(s) by NCI Board of Scientific Advisors; *Program moved to NCI Division of Cancer Biology

Translational from basic science to human studies
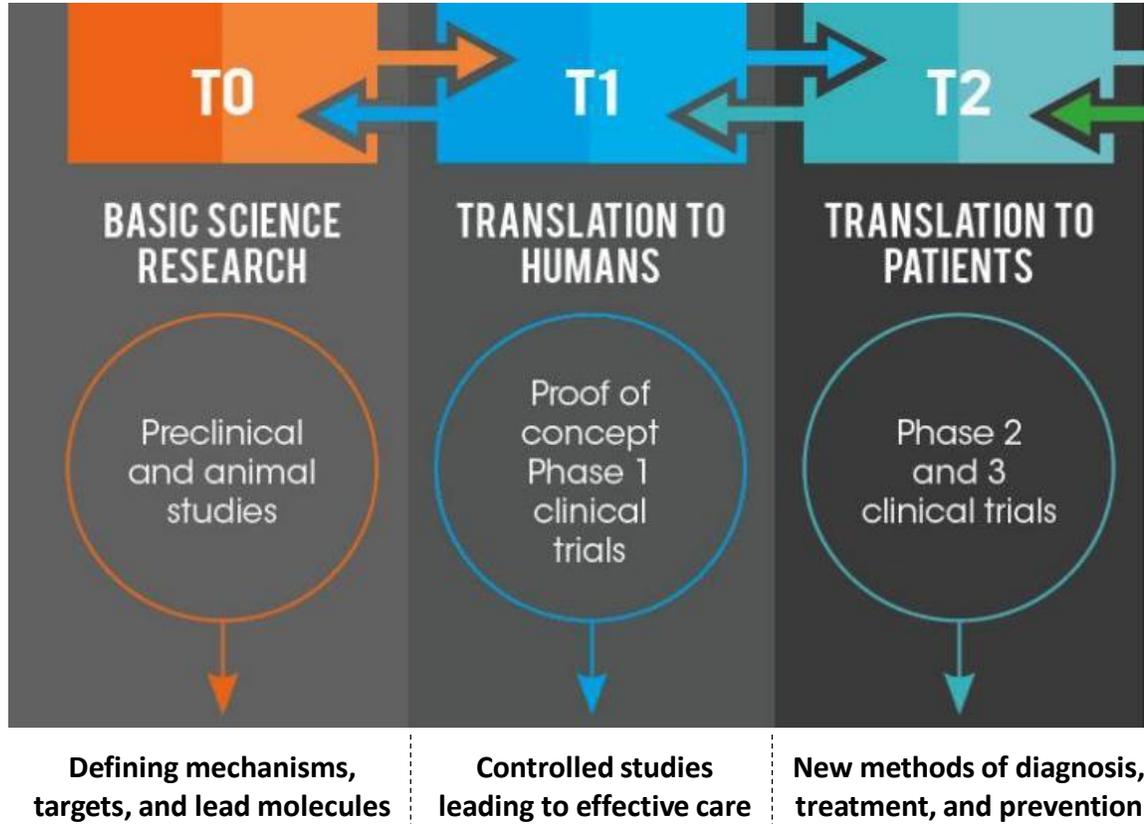
Translational of new interventions into the clinic and health decision making

T0 — BASIC SCIENCE RESEARCH — Preclinical and animal studies — Defining mechanisms, targets, and lead molecules

T1 — TRANSLATION TO HUMANS — Proof of concept Phase 1 clinical trials — Controlled studies leading to effective care

T2 — TRANSLATION TO PATIENTS — Phase 2 and 3 clinical trials — New methods of diagnosis, treatment, and prevention

T3 — TRANSLATION TO PRACTICE — Phase 4 clinical trials and clinical outcomes research — Delivery of recommended and timely care to the right patient

T4 — TRANSLATION TO COMMUNITY — Population-level outcomes research — True Benefit to society

"The working group recommends the initiation of a **bold** technology-based project: *Human Cancer Genome Project*."

- National Cancer Advisory Board (NCAB) Working Group on Biomedical Technology, **February 16, 2005**

Science

An Open Letter to Cancer Researchers

"…the unstated goal of the HCGP is to ***accelerate*** **the discovery of cures for cancers**. The question we need to answer is not whether the information generated will be useful, but whether, **if given $1.5 billion in "new" cancer money, would the HCGP be the** <u>best application</u> **of that money toward the goal of cancer cures**…"

– Oct 21, 2005

First Pass at Cancer Genome Reveals Complex Landscape

"…to conduct this mini–cancer-genome project, a **29-person** team, resequenced…**11** breast cancer samples and **11** colon cancer samples…then winnowed out more than **99%** of the mutations by **removing errors**…and **changes that didn't alter a protein**.

…this yielded a total of 189 "candidate" cancer genes. Although some are familiar…most had **never been found mutated** in cancer before. The results…are a **'treasure trove'**…

…the relatively small number of new genes **common to the tumors** reinforces concerns about [NIH] The Cancer Genome Atlas…

…despite such doubts, the atlas project gets under way next week. NIH will announce the three cancers to be studied in the pilot phase…the project is on an **extremely aggressive timeline**…"

04/20/2016
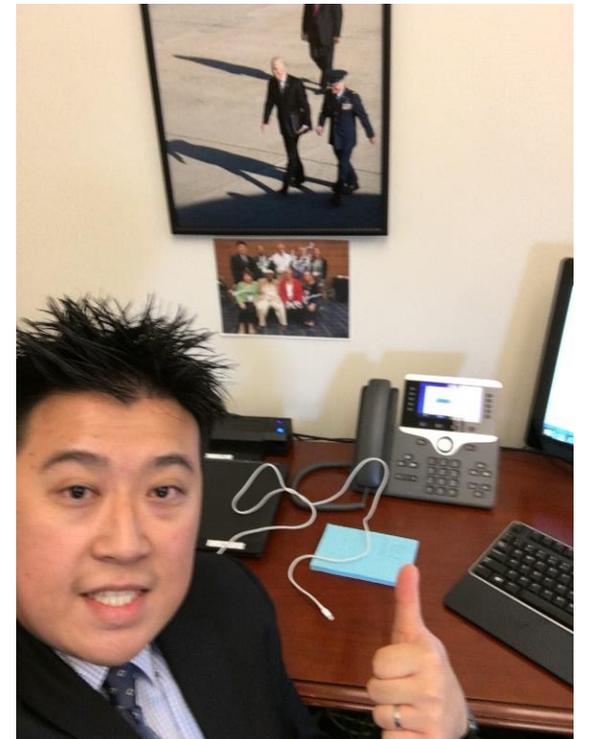
2016

Goals of the Initiative:

- **Accelerate progress in cancer, including prevention & screening**
  - **From cutting edge basic research to wider uptake of standard of care**
- **Encourage greater cooperation and collaboration**
  - **Within and between academia, government, and private sector**
- **Enhance data sharing**

(From Presidential Memo 2016)

October 17, 2016

"…established, within the Office of the Vice President, a **White House Cancer Moonshot Task Force**, which will focus on making the **most of Federal investments**, **targeted incentives**, **private sector efforts** from **industry and philanthropy**, **patient engagement initiatives**, and other mechanisms to support cancer research and enable progress in treatment and care…"

"…a **Blue Ribbon Panel**… will provide **expert advice on the vision, proposed scientific goals, and implementation** of the National Cancer Moonshot….the Panel will provide an **intensive examination** of the **opportunities** and **impediments** in **cancer research**…initial findings and recommendations of the Panel will be reported to the National Cancer Advisory Board that will provide **final recommendations to the NCI Director**…"

STRATEGIC GOALS

Catalyze New Scientific Breakthroughs

Unleash the Power of Data

Accelerate Bringing New Therapies to Patients

Strengthen Prevention and Diagnosis

Improve Patient Access and Care

IMPLEMENTATION PATH

FEDERAL

PUBLIC-PRIVATE COLLABORATION

PRIVATE/ NON-PROFIT

2/1/2016

10/17/2016

Make a **decade's** worth of progress in **cancer prevention, diagnosis, treatment, and care** – ultimately to end cancer **as we know it.**

June 29, 2016

- **38** announcements
  - 12 public sector
  - 26 private sector

Oct 17, 2016

- **36** announcements
  - 8 public sector
  - 28 private sector
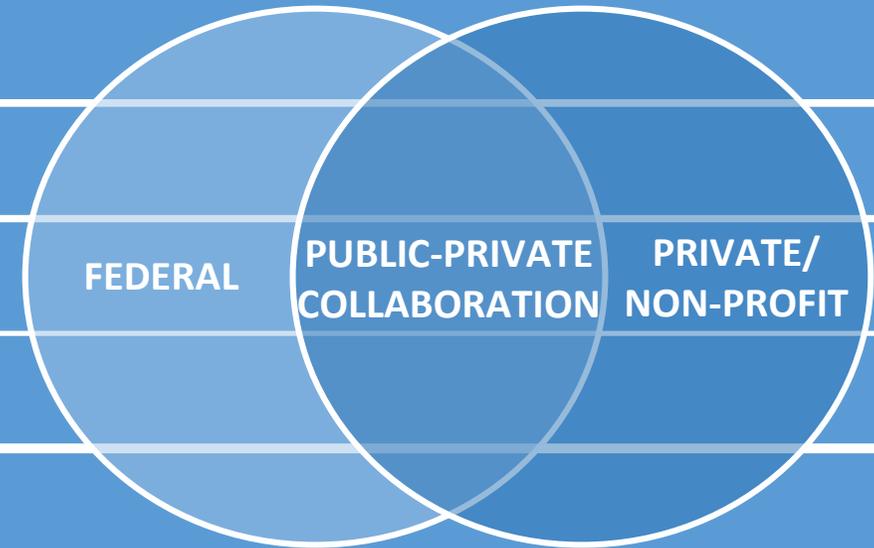
Cancer Moonshot Data & Technology Team

Co-Chairs: Dimitri Kusnezov (DOE), DJ Patil (OSTP), and Jerry Lee (OVP)

Members:

- John Scott **(DoD)**
- Craig Shriver **(DoD)**
- Cheryll Thomas **(CDC)**
- Frances Babcock **(CDC)**
- Teeb Al-Samarrai **(DOE)**
- Sean Khozin **(FDA)**
- Alexandra Pelletier **(PIF)**
- Maya Mechenbier **(OMB)**
- Henry Rodriguez **(NCI)**

- Karen Cone **(NSF)**
- Michael Kelley **(VA)**
- Louis Fiore **(VA)**
- Warren Kibbe **(NCI)**
- Betsy Hsu **(NCI)**
- Niall Brennan **(CMS)**
- Thomas Beach **(USPTO)**
- Claudia Williams **(OSTP)**
- Vikrum Aiyer **(USPTO)**

- Tom Kalil **(OSTP)**
- Kathy Hudson **(NIH)**
- Dina Paltoo **(NIH)**
- Al Bonnema **(DoD)**
- Michael Balint **(PIF)**
- Kara DeFrias **(OVP)**
- Greg Pappas **(FDA)**
- Erin Szulman **(OSTP)**
- Paula Jacobs **(NCI)**

Cancer Data and Tech Track
Face-to-Face
(9/9/16)

Cancer Data and Tech Track
Face-to-Face
(11/18/16)

Bubble size = estimated size of available dataset
Note: Representative selection of landscape, not all inclusive

- Available datasets, size known
- Available datasets, size unknown
- Dataset in development
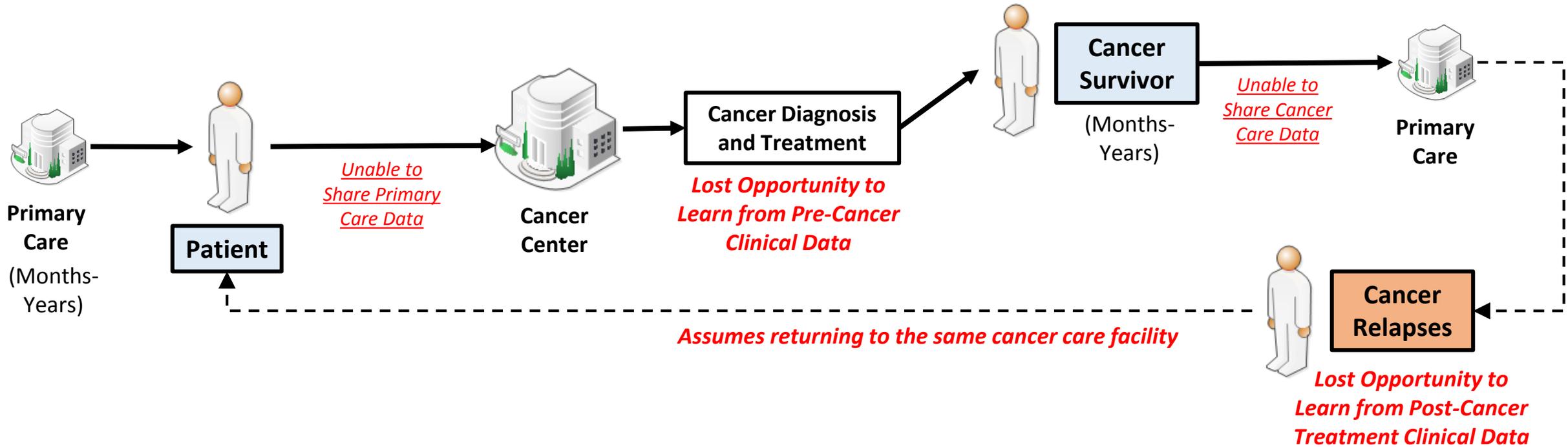- Available datasets that comprise multiple smaller datasets
- Portals that are currently active/utilized in the public domain

Opportunity exists to generate publicly available longitudinal data to drive understanding of genetic mutations and find Precision Medicine cures

*Datasets have potential to include longitudinal data in the future
**Public/private information not available
***Serves as a portal also, has potential to include longitudinal data in the future

1. FoundationCore's pediatric cancer data has been made public

HARVARD BUSINESS SCHOOL
Kraft Precision Medicine Accelerator

Without a National Learning Healthcare System for Cancer

Primary Care

(Months-Years)

Patient

Unable to Share Primary Care Data

Cancer Center

Cancer Diagnosis and Treatment

Lost Opportunity to Learn from Pre-Cancer Clinical Data

Cancer Survivor

(Months-Years)

Unable to Share Cancer Care Data

Primary Care

Assumes returning to the same cancer care facility

Cancer Relapses

Lost Opportunity to Learn from Post-Cancer Treatment Clinical Data

Vision:

Enable the creation of a *Learning Healthcare System for Cancer,* where as a nation we learn from the *contributed knowledge* and experience of *every cancer patient*. As part of the Cancer Moonshot, we want to *unleash the power of data* to enhance, improve, and inform the journey of every cancer patient from the *point of diagnosis through survivorship*.

Priorities Areas and Ongoing Activities

➢ **Priority Area A: Enabling a seamless data environment**   **[If you build it…]**

  ▪ DOE-MVP CHAMPION and NCI GDC (and C's)

➢ **Priority Area B: Unlocking science through open computational and storage platforms**   **[Make it easy AND relevant to use…]**

  ▪ NCI-DOE, ATOM, APOLLO, CDC-FDA NLP

➢ **Priority Area C: Workforce development using open and connected data**   **[They will come…]**

  ▪ NCI-VA BD-STEP

GDC Content

Current

- ❖ TCGA   11,353 cases
- ❖ TARGET   3,178 cases

Coming soon

- ❖ Foundation Medicine   18,000 cases
- ❖ Cancer studies in dbGAP   ~4,000 cases

Planned (1-3 years)

- ❖ NCI-MATCH   ~3,000 cases
- ❖ Clinical Trial Sequencing Program   ~3,000 cases
- ❖ Cancer Driver Discovery Program   ~5,000 cases
- ❖ Human Cancer Model Initiative   ~1,000 cases
- ❖ APOLLO – VA-DoD   ~8,000 cases

~56,000 cases

GDC

NIH NATIONAL CANCER INSTITUTE
Genomic Data Commons

Current

❖ TCGA   11,353 cases
❖ TARGET   3,178 cases

Coming soon

❖ Foundation Medicine   18,000 cases
❖ Cancer studies in dbGaP   ~4,000 cases
❖ Multiple Myeloma RF   ~1,000 cases
❖ AACR GENIE   59,000 cases

Planned (1-3 years)

❖ NCI-MATCH   ~3,000 cases
❖ Clinical Trial Sequencing Program   ~3,000 cases
❖ NCI-CPTAC   ~1,000 cases
❖ Cancer Driver Discovery Program   ~5,000 cases
❖ Human Cancer Models Initiative   ~1,000 cases
❖ **APOLLO – VA and DoD**   **~8,000 cases**

~117,000 cases
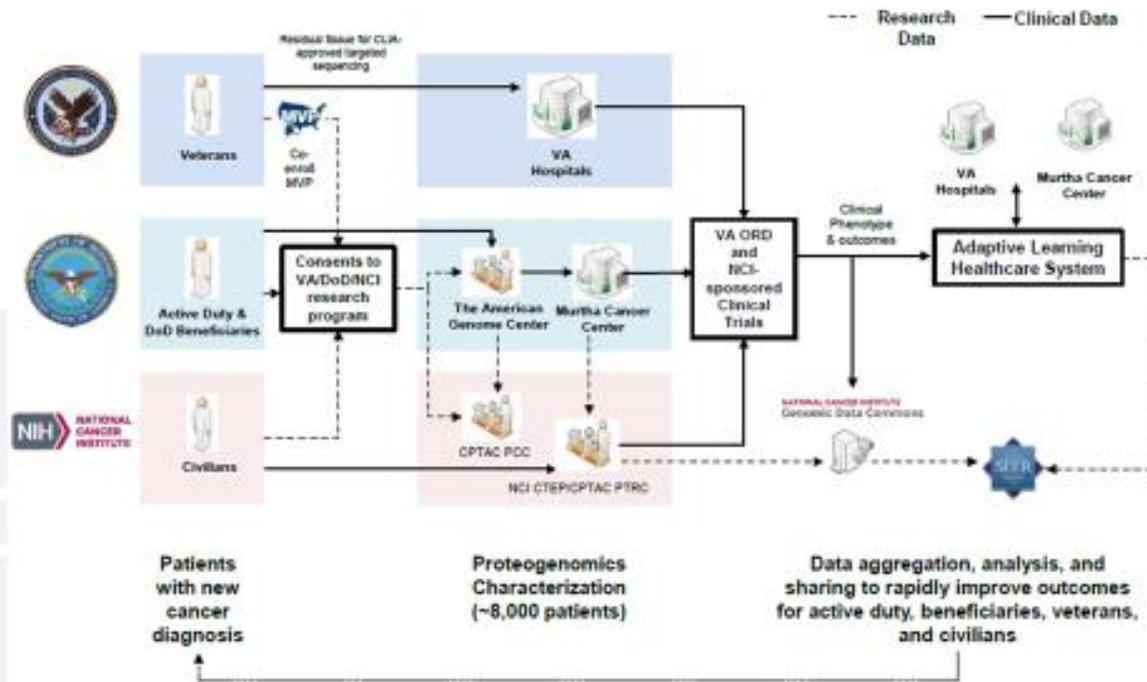
Col. Craig Shriver, MD

"…to apply machine learning, a practitioner starts with **a historical data set**, which the practitioner divides into a **_training set_** and a **_test set_**…"

2006-2015: A Decade of Illuminating the Underlying Causes of **Primary Untreated Tumors**

The Cancer Genome Atlas

CLINICAL **PROTEOMIC** TUMOR ANALYSIS CONSORTIUM

CANCER IMAGING ARCHIVE

(12,000+ patient tumors and increasing)

Primary tumor (Localized)
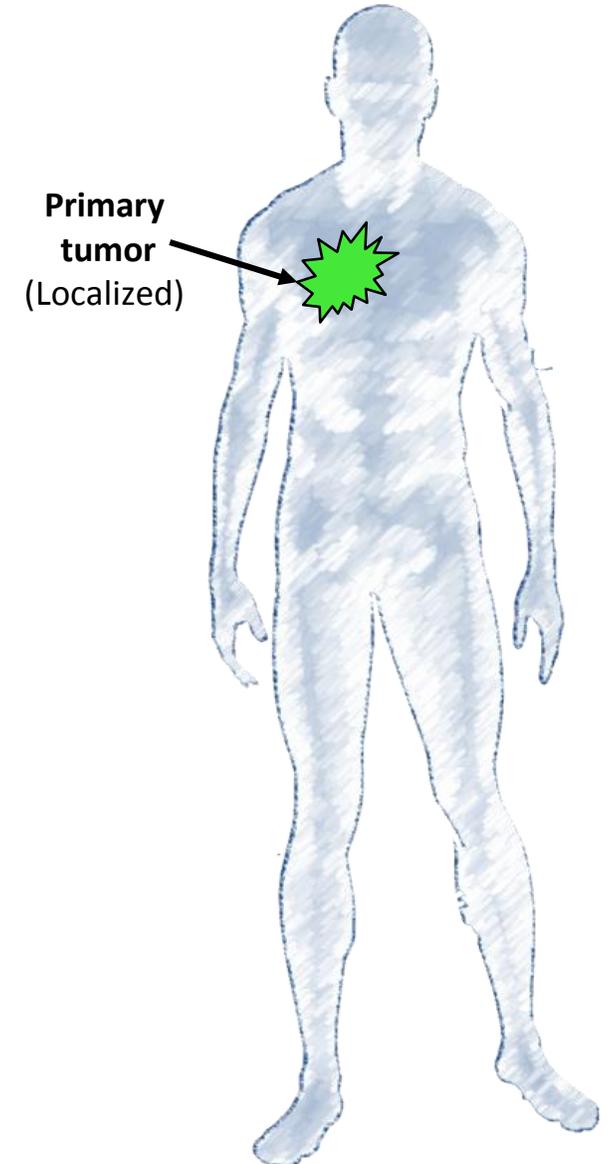
Central Dogma of Biology
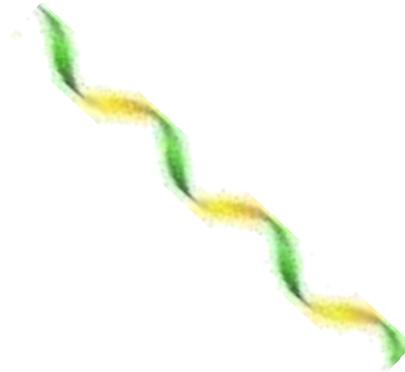
DNA → **RNA** → **Protein**

The Cancer Genome Atlas

Re-writing Central Dogma (2016)
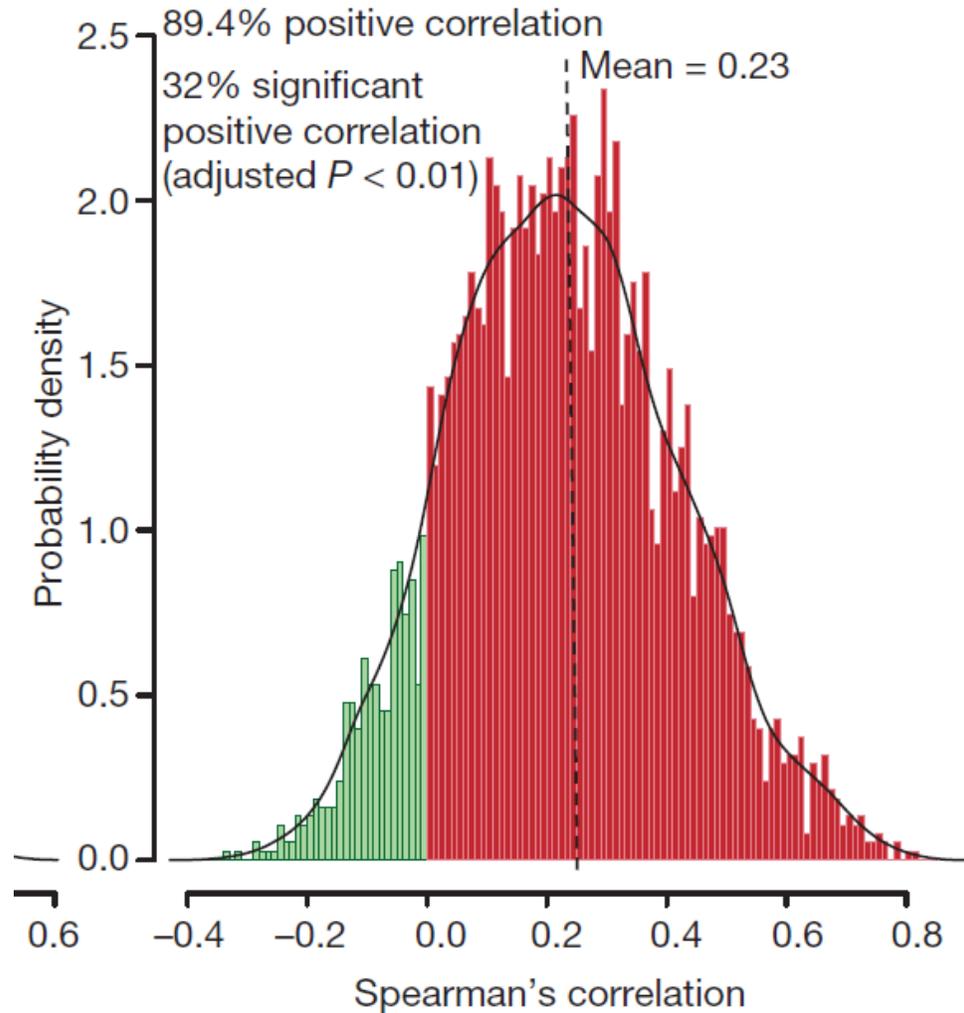
On average across 375 tumor samples, **_ONLY_ 33%** of DNA/RNA predicted cancer protein abundance

Zhang, B. et. al. Proteogenomic characterization of human colon and rectal cancer. *Nature*. 2014 Jul 20

"…there is great potential for **new insights** to come from the **combined analysis of cancer proteomic and genomic data**, as proteomic data can **now reproducibly provide information** about protein levels and activities that are *difficult or impossible to infer from genomic data alone*…"

Douglas R. Lowy, MD
Acting Director of the National Cancer Institute, National Institutes of Health

HOME   ABOUT US   SHARE YOUR DATA   ACCESS THE ARCHIVE   RESEARCH ACTIVITIES   HELP

XConfluence   Spaces ▾   🔍 [search]   ▾ Log in

The Cancer Imaging Archive (TCIA) Public Access

🔊 Blog

SPACE SHORTCUTS

📄 How-to articles

📄 Troubleshooting articles

CHILD PAGES

📄 Research Projects

└ CPTAC Imaging Proteomics

Pages / Wiki / Research Projects 📎   Tools ▾

CPTAC Imaging Proteomics

Created by jfreymann, last modified by cjaffe on Sep 15, 2015

Background

NCI has announced resources for the Clinical Proteomic Tumor Analysis Consortium (CPTAC) (http://proteomics.cancer.gov/) aimed at integrating proteomic research with genomics to produce a more unified understanding of tumor biology. As the CPTAC available tissue donor resources begin to ramp up, a number of legacy TCGA genetic-focused cases -- CPTAC analyzed -- have diagnostic images already accessible on The Cancer Imaging Archive (TCIA).

The NCI Cancer Imaging Program organized these CPTAC specific cases as an opportunity for researchers to explore what such combined research resources might offer. They consist of 28 ovarian (TCGA-OV) and 14 breast (TCGA-BRCA) cases. Those imaging cases are easily downloadable from TCIA using the drop-down Tool-menu entry "shared lists" under the separate names of: "CPTAC Breast Analyzed" and "CPTAC OV Analyzed". The images of those grouped cases can be down-loaded by entering the afore-mentioned "shared lists" names on https://public.cancerimagingarchive.net/ncia/searchCustomList.jsf Their individual case-matched CPTAC Proteomic Analysis Data is down-loadable from: https://cptac-data-portal.georgetown.edu/cptacPublic/ Moreover, the case specific Clinical Data that matches each of those TCIA archived image cases are attached here as XLS sheets.

Image Downloads

Type "CPTAC Breast Analyzed" into the Image Search "Tools" drop-down menu item called "Shared List"

Type "CPTAC OV Analyzed" into the Image Search "Tools" drop-down menu item called "Shared List"

2009

The Cancer Genome Atlas
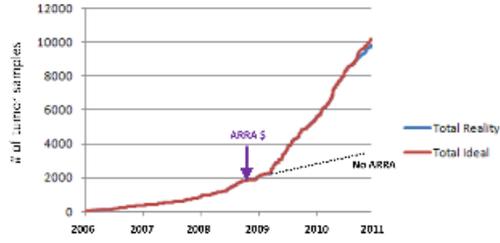
"…we must **increase** research and patient **data** sharing…imagine what we could do with **global sets** of patient data to represent the great **international diversity** of populations, of people, and of cancers…"

Vice President Biden, Vatican, April 2016

2016

CLINICAL **PROTEOMIC** TUMOR ANALYSIS CONSORTIUM
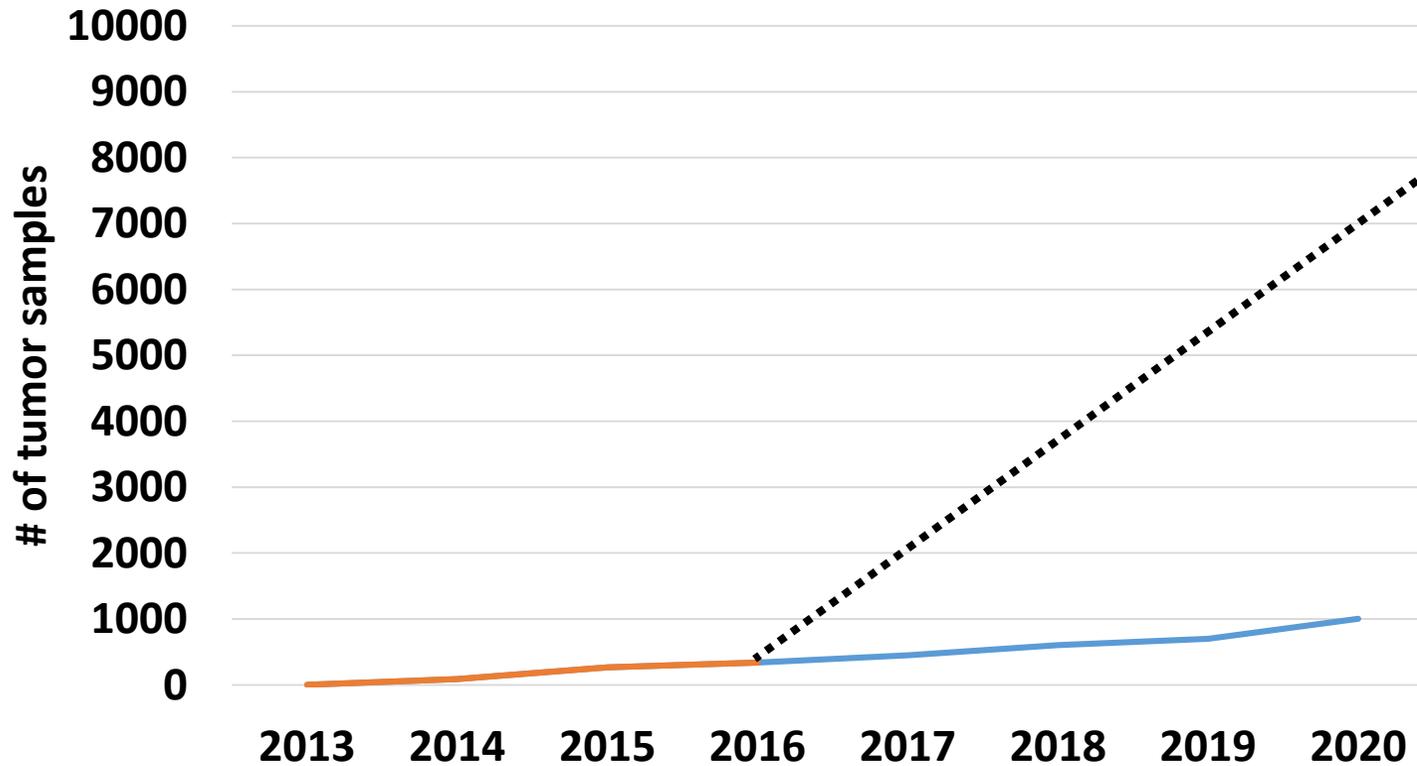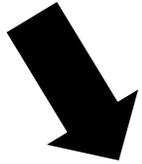
Moonshot?
(Agency and International Collaborations)

— **Projected**

— **Reality**

# of tumor samples

10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0

2013 2014 2015 2016 2017 2018 2019 2020

Col. Craig Shriver, MD

Jennifer Lee, MD

Henry Rodriguez, PhD, MBA

APOLLO Network Follow
Applied Proteogenomics OrganizationaL Learning and Outcomes
Jul 1 · 3 min read

APOLLO Network #CanServe Cancer Patients through Collaboration

https://medium.com/cancer-moonshot/

Applied Proteogenomics OrganizationaL Learning and Outcomes

APOLLO Leadership Meeting
August 29, 2016

Patients with new or recurrent cancer diagnosis

Proteogenomics Characterization (~8,000 patients)

Data aggregation, analysis, and sharing to rapidly improve outcomes for active duty, beneficiaries, veterans, and civilians
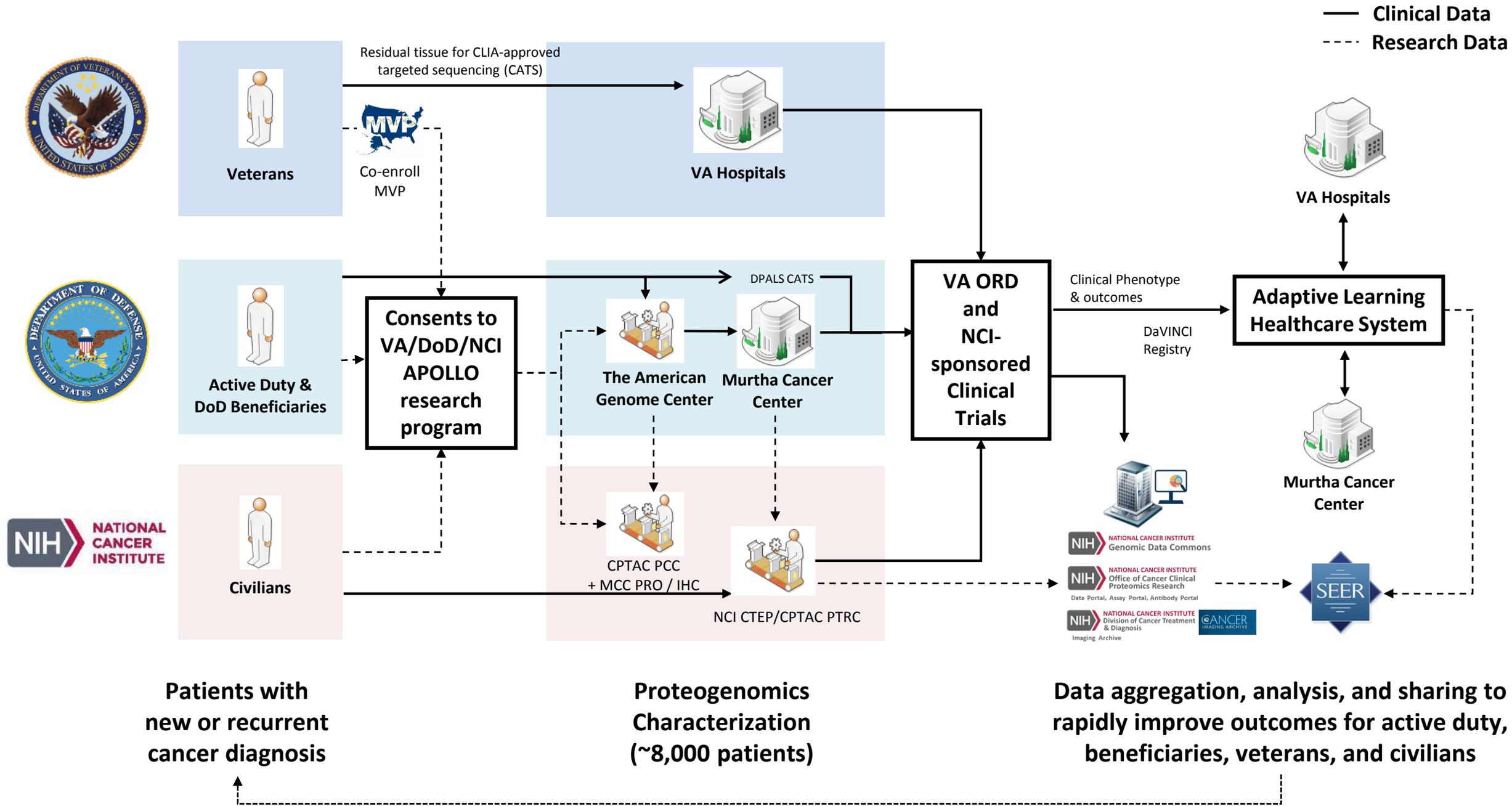
APOLLO – *A*pplied *P*roteogenomics *O*rganizationa*L* *L*earning and *O*utcomes consortium
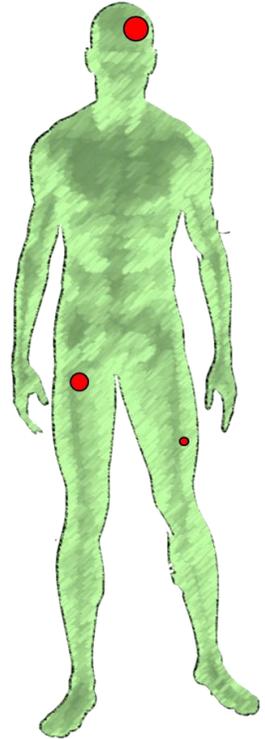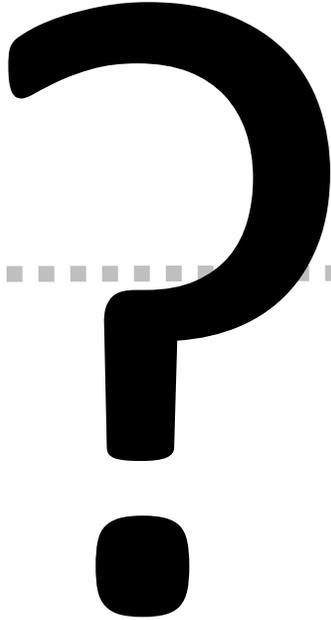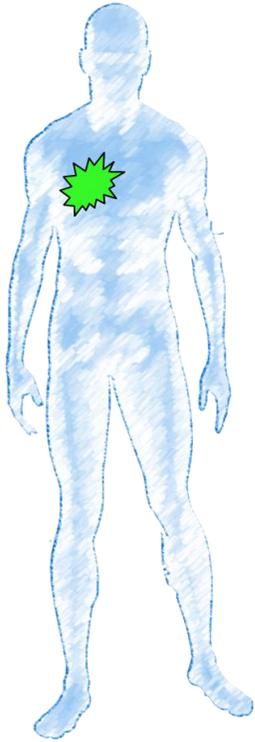
The Cancer Genome Atlas

CLINICAL PROTEOMIC
TUMOR ANALYSIS CONSORTIUM

NATIONAL CANCER INSTITUTE
NCI-MATCH CLINICAL TRIAL

The Cancer Genome Atlas

CLINICAL PROTEOMIC TUMOR ANALYSIS CONSORTIUM

VISTA CPRS

MVP

MILLENNIUM COHORT STUDY

NATIONAL CANCER INSTITUTE
NCI-MATCH CLINICAL TRIAL

CANCER IMAGING ARCHIVE

SEER
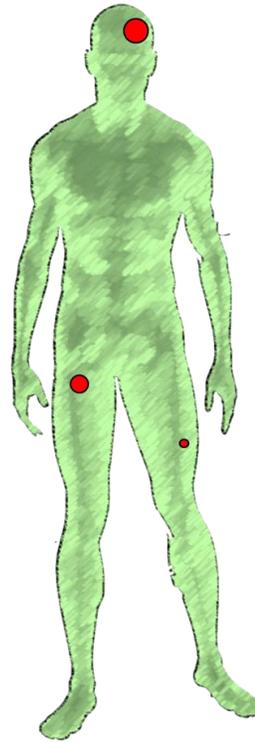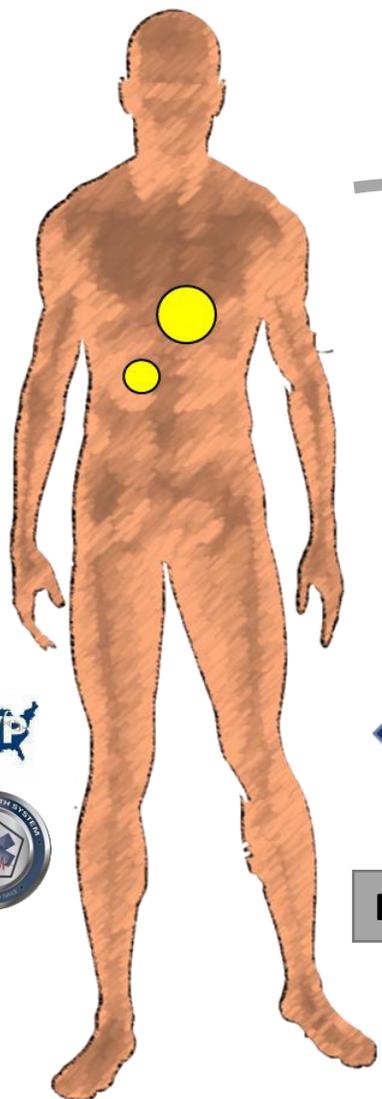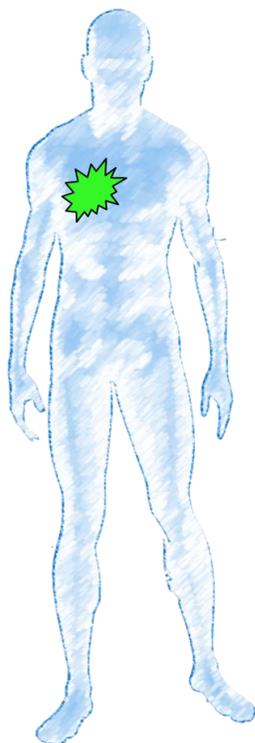
DAVINCI
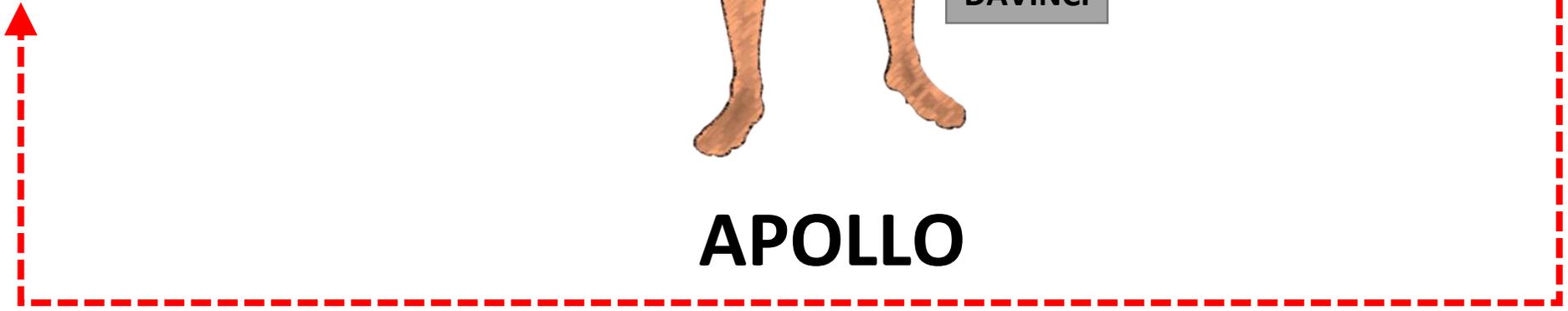
APOLLO

A NCI-DoD-VA Proteogenomic Translational Initiative

T1 CLINICAL STUDIES T2 CLINICAL TRIALS T3 CLINICAL PRACTICE T4 INTERNATIONAL ADOPTION & ASSESSMENT

APOLLO Network

The **A**pplied **P**roteogenomics **O**rganizationa**L** **L**earning and **O**utcomes (APOLLO) network is a collaboration between NCI, the Department of Defense (DoD), and the Department of Veterans Affairs (VA) to incorporate proteogenomics into patient care as a way of looking beyond the genome, to the activity and expression of the proteins that the genome encodes. The emerging field of proteogenomics aims to better predict how patients will respond to therapy by screening their tumors for both genetic abnormalities and protein information, an approach that has been made possible in recent years due to advances in proteomic technology.

The data will be derived from DoD and VA clinical trials and health care system databases and include a full set of medical images, including CT and MRI scans, obtained before and during treatment. Each set of noninvasive images can be connected to the patient's genomic, proteomic, and clinical data.

The data will be curated and made available publicly through the Genomic Data Commons, Proteomic Data Portal, and Cancer Imaging Archive (imaging data). Using all of the data available (analytical, invasive, noninvasive, and clinical) will enable researchers to study the relationships among these data, validate results, and develop predictive and prognostic models to improve patient care.

https://proteomics.cancer.gov/programs/apollo-network

7/17/2016

"…**proteogenomics**, which is -- as I used a metaphor -- it's like the **genes** are the **full roster** of a **basketball team**….but the winning strategy comes from finding out who their starting lineup is. The **proteins** are the **starters** you're going to play against -- the five you are going to **have to defend against**

I'm pleased to say, Mr. Prime Minister, that we've signed three memorandums of understanding between our two nations …we're going to be able to **share patient histories**, *proteogenomics* and **clinical phenotypes data** -- data on various proteins and genetic characteristics of almost *60,000 patients* in Australia and the United States with full privacy protections…

And I predict that you're going to see this repeated around the world."

- Vice President Biden, Australia

9/19/2016

The Cancer Moonshot Follow
The official Medium account of the Vice President's Cancer Moonshot. Notes may be archived: http://wh.go...
Sep 23, 2016 · 5 min read

A Global Effort to End Cancer as We Know It

https://tinyurl.com/zr955sr

International Cancer Proteogenome Consortium

University of Victoria
McGill University
Leibniz Institute for Analytical Sciences
Fudan University
Shanghai Institute of Materia Medica, CAS
Lund University
Chang Gung University
Korea Institute of Science and Technology
University of Manchester, and University of Dundee
National Cancer Center Japan
U.S. National Cancer Institute (CPTAC)
Academia Sinica
Macquarie University
University of British Columbia
Swiss Federal Institute of Technology – Zurich
Children's Medical Research Institute
Bioplatforms Australia
Garvan Institute of Medical Research

9 MOUs
11 international teams
20+ institutions

Henry Rodriguez, PhD, MBA

9/16/2017

http://proteomics.cancer.gov

NCI Proteomic Data Commons

Proteogenomics Data Generation
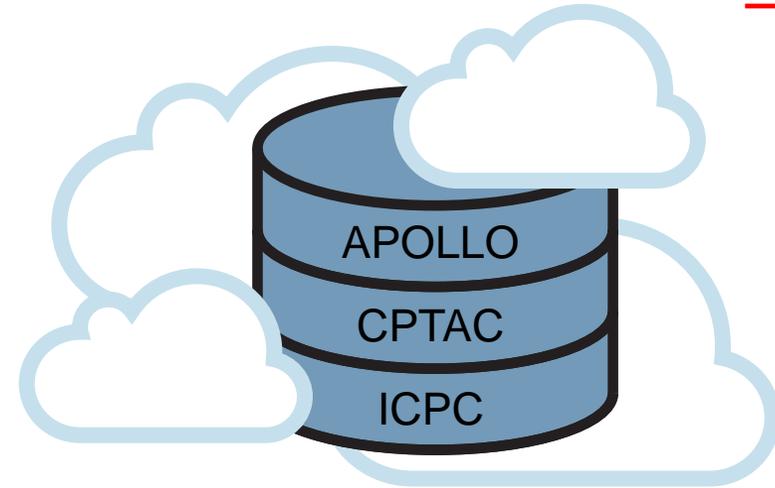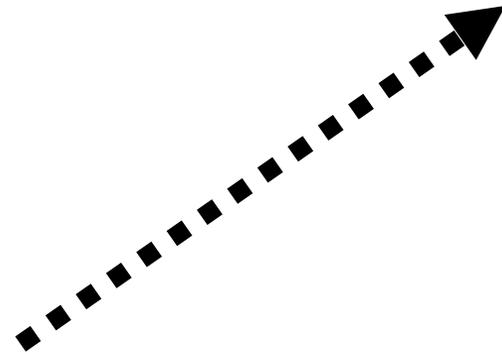
Proteomic Data Commons

APOLLO

CPTAC

ICPC

Izumi Hinkson, PhD

SFTP site

Internal Jamboree

Research Community

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01001001
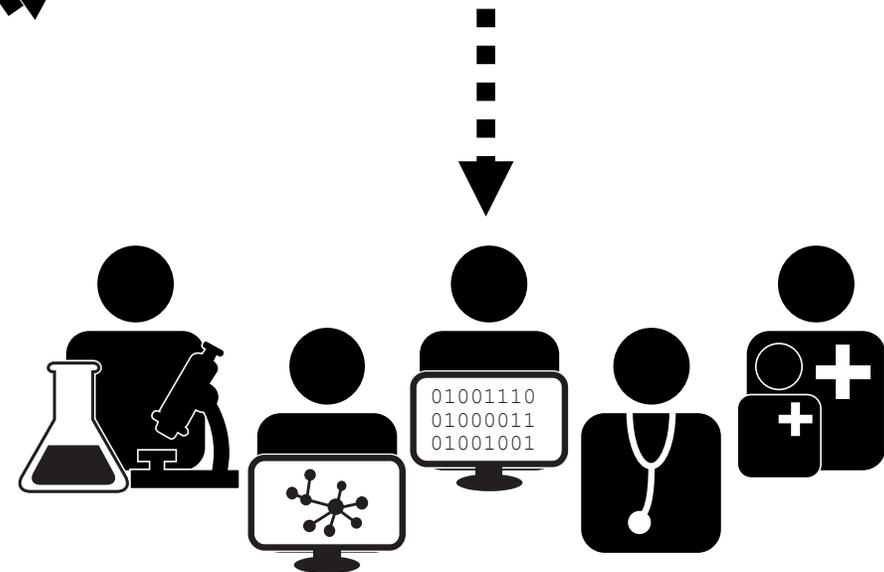
International Cancer Proteogenome Consortium

The International Cancer Proteogenome Consortium (ICPC), is a voluntary scientific organization that provides a forum for collaboration among some of the world's leading cancer and proteogenomic research centers. Catalyzed by the effort of the Beau Biden Cancer Moonshot[SM] to encourage international cooperation and investments among nations in cancer research and care, as well as new efforts in precision medicine, the International Cancer Proteogenome Consortium (ICPC) was launched in late 2016. The ICPC brings together more than a dozen countries to study the application of proteogenomic analysis in predicting cancer treatment success and to share data and results with researchers worldwide, hastening progress for patients.

https://proteomics.cancer.gov/programs/
international-cancer-proteogenome-consortium

- **Australia**
  Team: Macquarie University, Children's Medical Research Institute, Garvan Institute of Medical Research, and Bioplatforms Australia Ltd.
  Cancer focus: all cancer types, including sarcoma, colorectal cancer, melanoma, childhood cancers

- **Canada/Germany**
  Team: McGill University, University of Victoria, University of British Columbia, and Leibniz Institute for Analytical Sciences
  Cancer focus: lung cancer, breast cancer, colorectal cancer, melanoma, cancers in adolescents and young adults

- **China**
  Team: Shanghai Institute of Materia Medica, Chinese Academy of Science, and Fudan University
  Cancer focus: liver cancer and other frequent cancer types in Chinese population

- **Japan**
  Team: National Cancer Center Japan
  Cancer focus: TBD

- **South Korea**
  Team: Korea Institute of Science and Technology
  Cancer focus: lung cancer (adenocarcinoma)

  Team: Korea University
  Cancer focus: gastric cancer, pancreatic ductal adenocarcinoma

- **Sweden**
  Team: Lund University
  Cancer focus: melanoma

- **Switzerland**
  Team: ETH Zürich
  Cancer focus: prostate cancer, melanoma

- **Taiwan**
  Team: Academia Sinica
  Cancer focus: lung cancer, breast cancer

  Team: Chang Gung University
  Cancer focus: oral squamous cell carcinoma, colorectal cancer

- **United Kingdom**
  Team: University of Manchester and University of Dundee
  Cancer focus: esophageal cancer, prostate cancer

- **United States**
  Team: NCI Clinical Proteomic Tumor Analysis Consortium
  Cancer focus: (potentially) glioblastoma multiforme, lung adenocarcinoma, lung squamous cell carcinoma, pancreatic ductal adenocarcinoma, clear cell kidney carcinoma, cutaneous melanoma, head and neck squamous cell carcinoma, sarcomas, uterine corpus endometrial carcinoma, acute myeloid leukemia
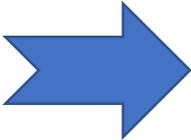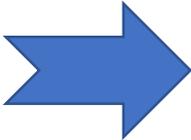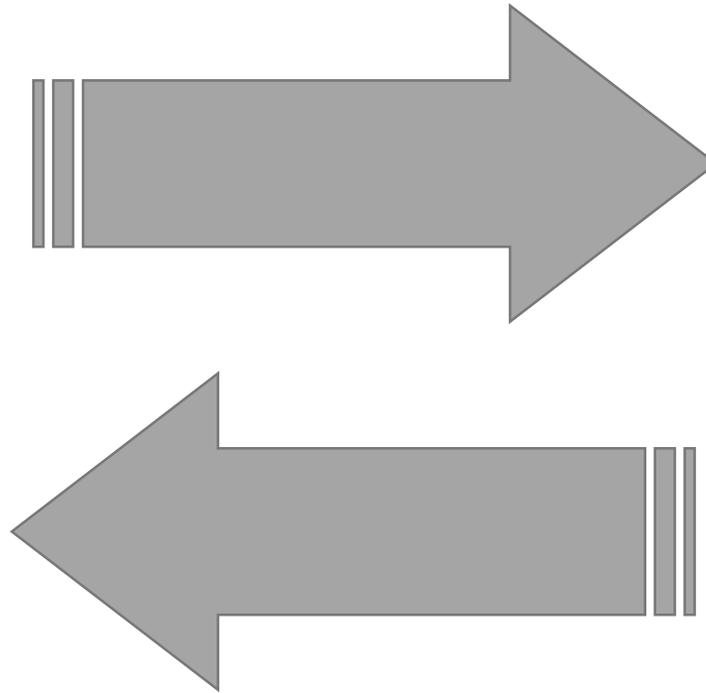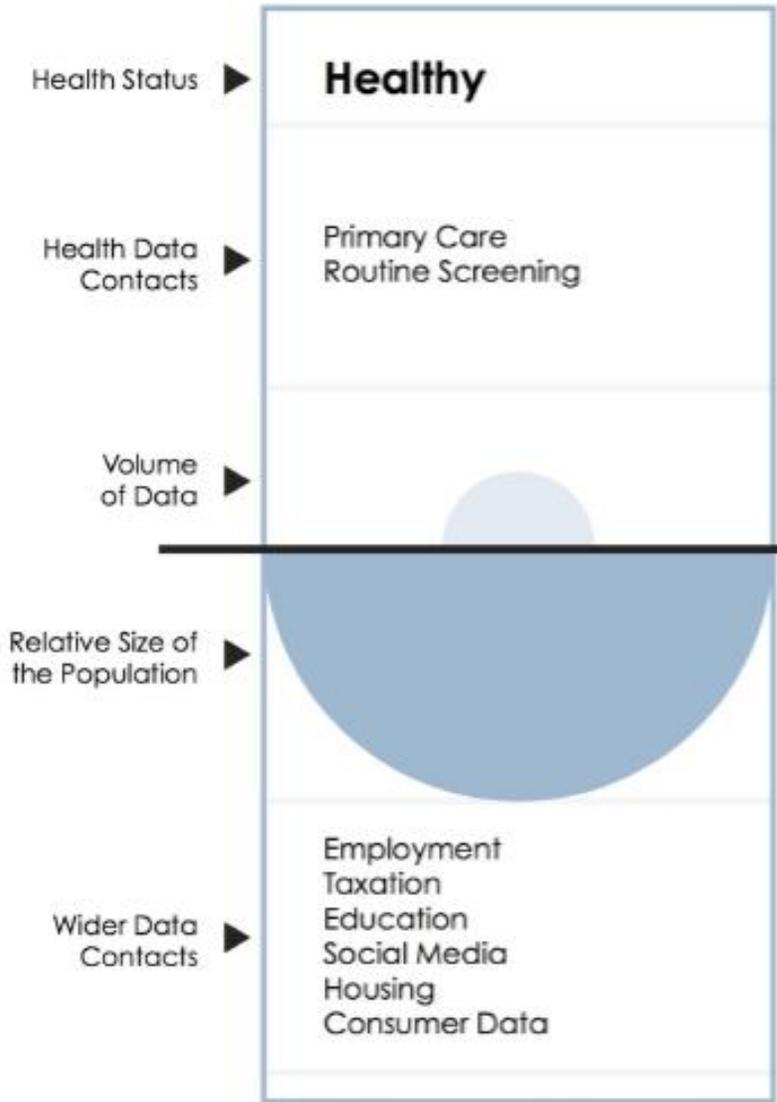
Henry Rodriguez, PhD, MBA

Precision Health

2001

2010

1 million healthy genomes

2015

Precision Health

Healthy

Health Status ▶

Health Data
Contacts ▶ Primary Care
Routine Screening

Volume
of Data ▶

Relative Size of
the Population ▶

Wider Data
Contacts ▶ Employment
Taxation
Education
Social Media
Housing
Consumer Data

Precision Oncology

Disease

Primary Care
Emergency Care
Inpatient Hospital
Clinical Test Results
Disease Registry
Residential Social Care

Social Care
Pension

Denny and Steventon. *BMJ,* 2015

Precision Health — Reality — Precision Oncology

	Healthy	Morbidity	Multi-morbidity	Disease
Health Status ▶	Healthy	Morbidity	Multi-morbidity	Disease
Health Data Contacts ▶	Primary Care Routine Screening	Primary Care Outpatient Records Clinical Test Results Disease Registry	Primary Care Emergency Care Inpatient Hospital Clinical Test Results Disease Registry	Primary Care Emergency Care Inpatient Hospital Clinical Test Results Disease Registry Residential Social Care
Volume of Data ▶				
Relative Size of the Population ▶				
Wider Data Contacts ▶	Employment Taxation Education Social Media Housing Consumer Data	Hospital Employment Taxation Education Social Media Housing Consumer Data	Social Care Social Security Pension Social Media Housing Consumer Data	Social Care Pension

Denny and Steventon. *BMJ,* 2015

DOE continues to work on the Moonshot Themes

▶ Some areas we can continue to build because we got pretty far down the road

▶ Others did not get far enough or were just too hard in the given time (eg payer data...)

    ▶ More agencies were partnering than the Cures Act recognized

▶ Drive efforts with the priorities of the new administration

    ▶ Aligning with Next Generation Supercomputing

    ▶ Building on our internet backbone

    ▶ Supporting US Veterans

    ▶ ...

Use potential attractors as a strategy to draw in broader thinking and resources

- Force the enterprise to rethink traditional paradigms by challenging them with qualitatively new classes of prediction and a richness of data

  - DOE-NCI Pilots: mid 2015
  - GSK "ATOM" Oct 2017
  - DOE-VA: early 2016
  - Government of Norway

- Use the qualities of data to change how we think of many of our

  traditional approaches from architectures to UQ to codes to …

- Align with where next economic drivers could provide most amplification

- Use Codesign as a philosophy

- Bring in DOE's multiphysics labs: ANL, LANL, LLNL, ORNL, *PNNL, SNL*

- Use Esnet

- Fund from multiple sources: DOE, VA, NCI; Exascale funding for CANDLE

- Vendors: IBM, Intel, GE, Nvidia…

- Use legislative support: 21st Century CURES Act
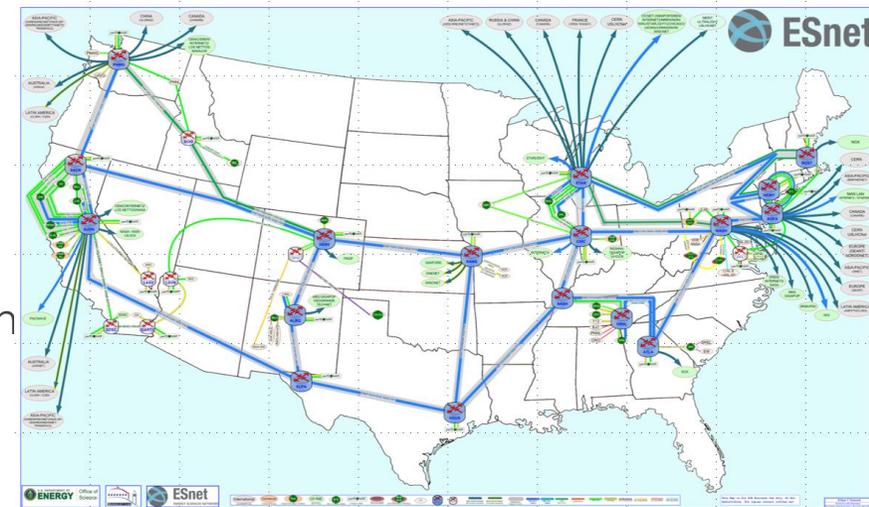
Robinson Pino (2016)

Some early successes under President Trump. Currently on DOE's web page...

The Department of Veterans Affairs (VA) and the Department of Energy (DOE) are partnering to drive technology innovation and transform health care delivery for Veterans. The partnership brings together VA's unparalleled and vast array of healthcare and genomic data with DOE's world class high performance computing (HPC), artificial intelligence and data analytics. By combining expertise, we can push the frontiers of data analytics, next-generation computing, precision health, genomic sciences, and health care delivery. This partnership supports:

- Innovation tied to design and development of DOE's next generation supercomputing that will merge Big Data (BD), Artificial Intelligence (AI) and High-Performance Computing (HPC) as well as innovation in population science using complex health system and genomic data for knowledge generation.
- Better Healthcare via using supercomputing to inform when and how to treat our Veterans to improve outcomes and reduce cost.
- Better Science via a cadre of researchers and clinicians who specialize in healthcare with the DOE experts in HPC, AI &BD.
- Better Government via interagency collaborations bringing to bear the full capabilities and expertise within and public private partnerships.

The starting point for the DOE-VA partnership is MVP CHAMPION (Million Veterans Program Computational Health Analytics for Medical Precision to Improve Outcomes Now). Under MVP CHAMPION, VA and DOE will establish a scientific computing environment that will not only house

More Info

- Find
Progra

- Cont
Inform
free at

ENERGY.GOV   SCIENCE & INNOVATION   ENERGY ECONOMY   SECURITY & SAFETY   SAVE ENERGY, SAVE MONEY

Our Mission

The National Labs

Million Veteran Program
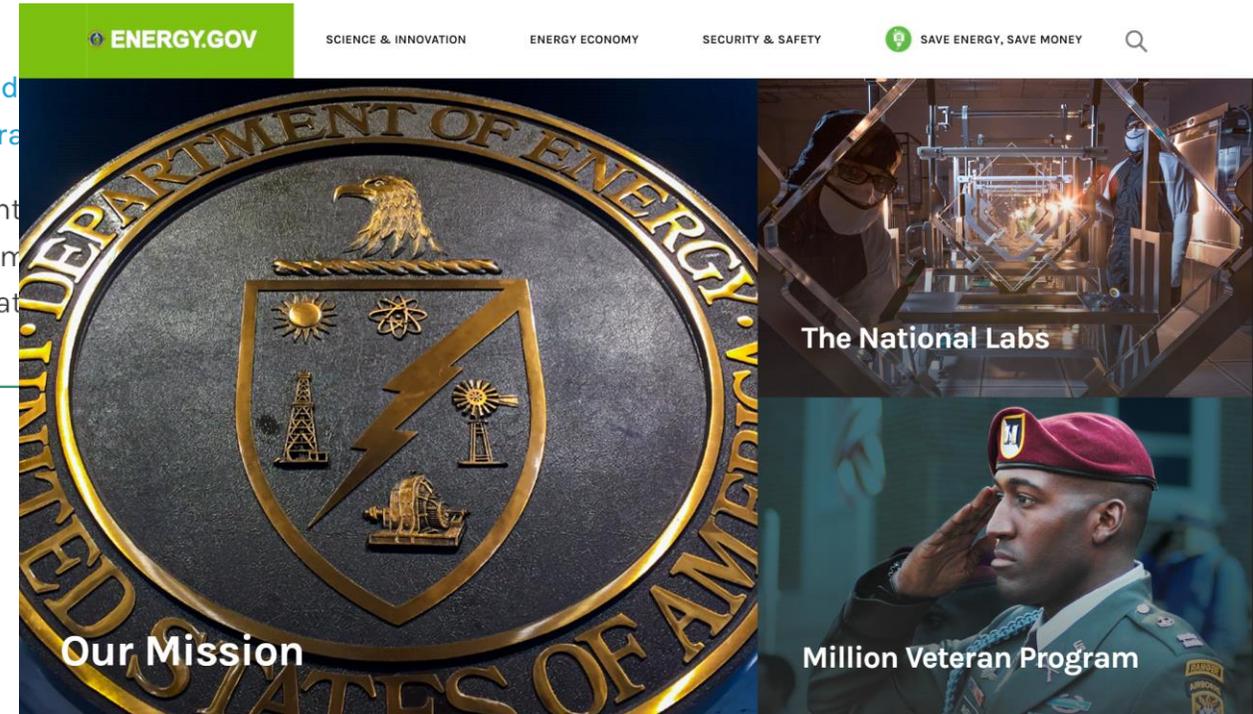
VA-DOE Scientific Data Connection
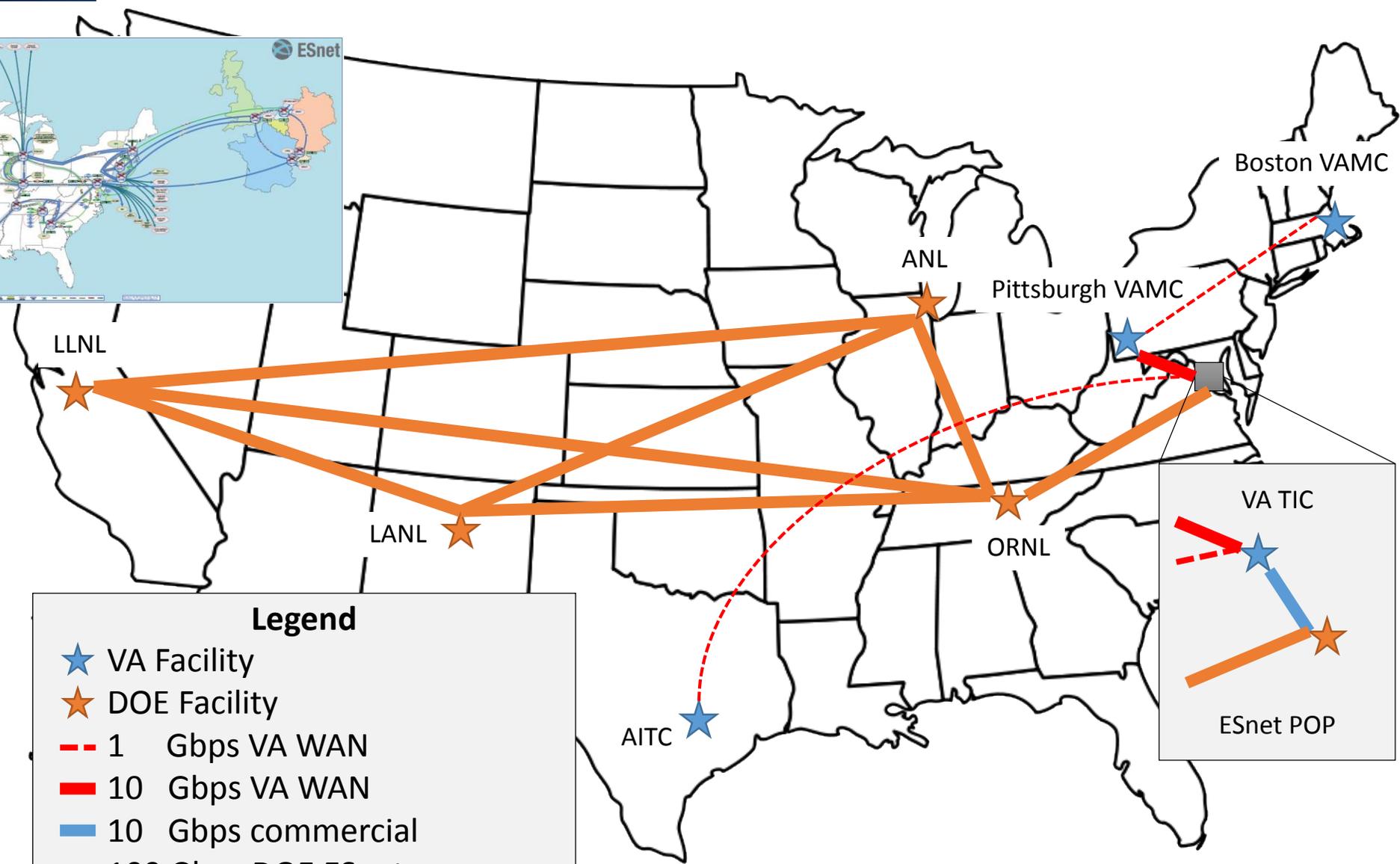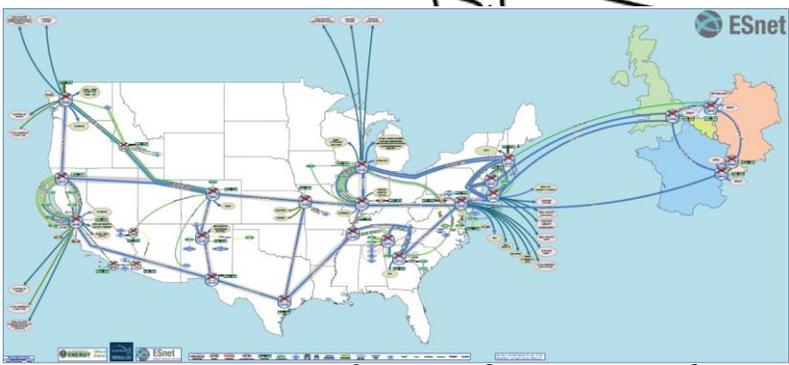
Legend
- ⭐ VA Facility
- ⭐ DOE Facility
- - - - 1 Gbps VA WAN
- ▬▬ 10 Gbps VA WAN
- ▬▬ 10 Gbps commercial
- ▬▬ 100 Gbps DOE ESnet

Boston VAMC
Pittsburgh VAMC
ANL
LLNL
LANL
ORNL
AITC
VA TIC
ESnet POP

Upgrading to a 400Gbps network...

This is a time of rapid technological change in computing
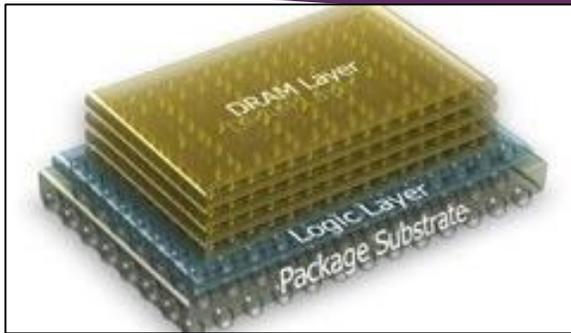
Memory intensive architectures

Neuromorphic learning systems
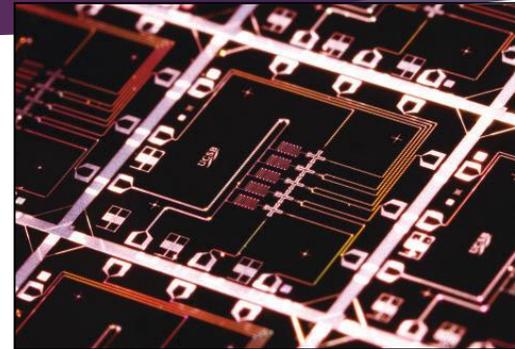
Quantum information systems

We're entering the era of heterogeneous computing. The architecture will be configured to match the computing needs of the application.

DOE is using this data as an accelerator for next generation technologies in high performance computing

Cloud-based systems

- Data sharing
- Distributed analytics
- Remote tool deployment
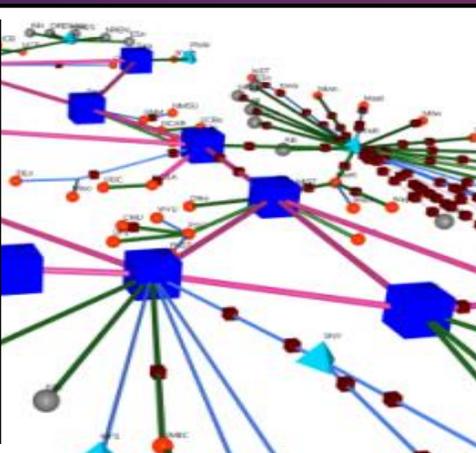
High-Performance Supercomputers

- Physics-based molecular simulation
- Path to Exascale
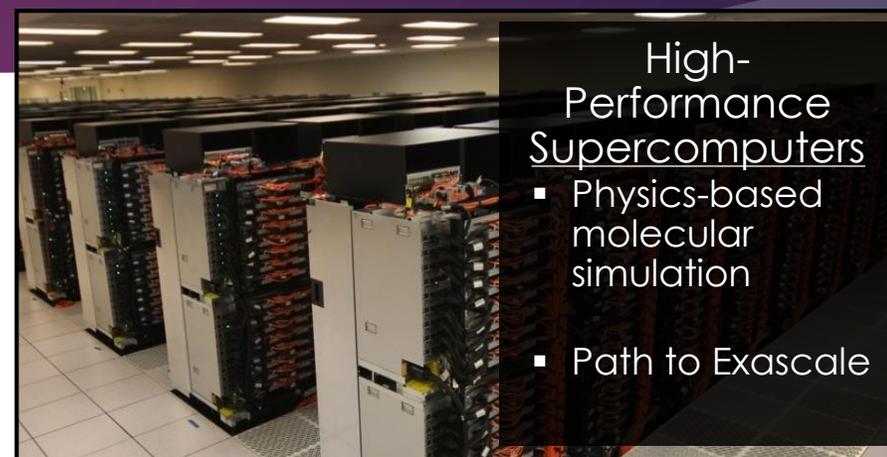
Memory-intensive systems

- Fast genomic analysis
- Network analytics
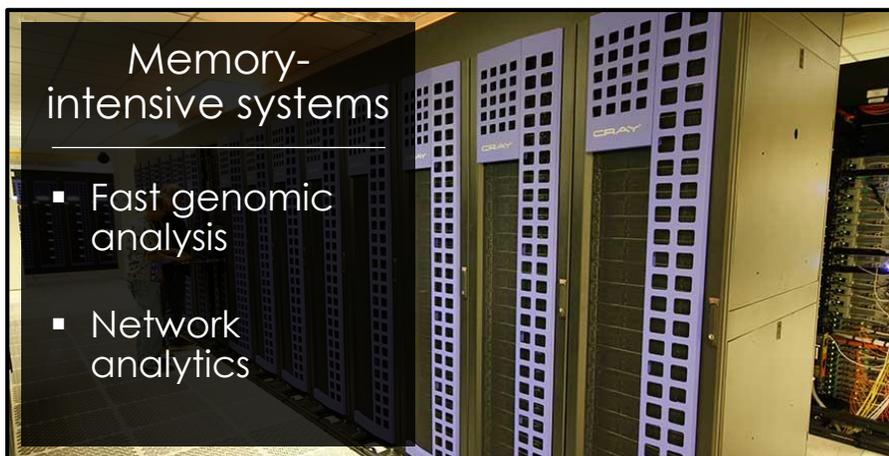
Neuro-synaptic processors

- Deep machine learning analytics
- Clinical data stream processing

Data Shared in Public Domain

NIH: GDC

cBioPortal

NIH: TARGET

NIH: CGCI

NIH: TCGA

AACR GENIE

MMRF MMGI

MMRF CoMMpass

FoundationCore[1]

I-SPY 1 Trial

Broad: TumorPortal

Precision Medicine Initiative – Cohort Program

GEO

AmbryShare*

CCC***

Affymetrix Human GeneAtlas

Point-in-time Data

Longitudinal Data

100,000 Genome Project

ICGC

MSKCC: IMPACT

CLL Study**

I-SPY 2 Trial

NCBI: dbGaP

Million Veteran Program

ORIEN*

Human Longevity Knowledgebase

Dana-Farber: Profile

ASH Myeloma

Strata

Geisinger & Regeneron: Genomic Sequencing Study

Prostate Cancer Foundation – Catch Trial

Lung-MAP Trial

OPN

TRACERx Trial

Data Shared among Partners Only

Bubble size = estimated size of available dataset
Note: Representative selection of landscape, not all inclusive

- Available datasets, size known
- Available datasets, size unknown
- Dataset in development
- Available datasets that comprise multiple smaller datasets
- Portals that are currently active/utilized in the public domain

Opportunity exists to generate publicly available longitudinal data to drive understanding of genetic mutations and find Precision Medicine cures

*Datasets have potential to include longitudinal data in the future
**Public/private information not available
***Serves as a portal also, has potential to include longitudinal data in the future

1. FoundationCore's pediatric cancer data has been made public

HARVARD BUSINESS SCHOOL
Kraft Precision Medicine Accelerator

Oncology Precision Medicine Data Landscape:
December 2016 Update
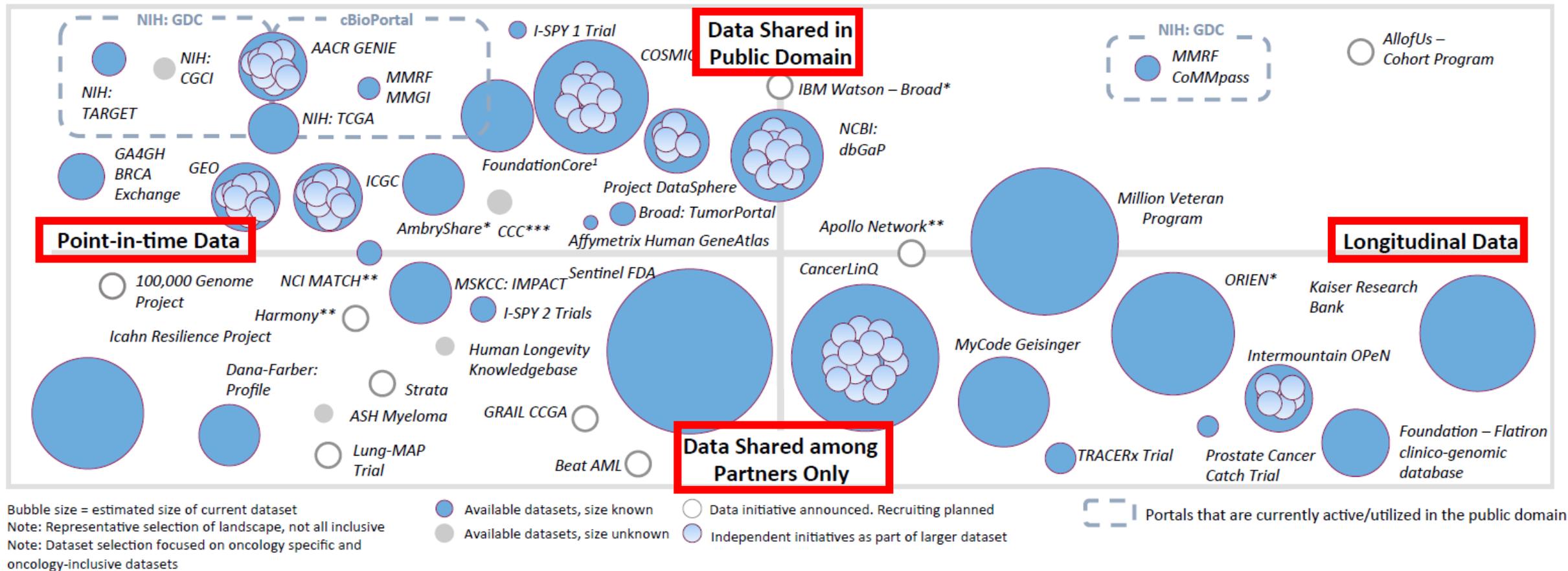
Opportunity exists to generate publicly available longitudinal data to drive understanding of genetic mutations and find Precision Medicine cures

*Datasets have potential to include longitudinal data in the future
**Public/private information not available
***Serves as a portal also, has potential to include longitudinal data in the future

1. FoundationCore's pediatric cancer data has been made public
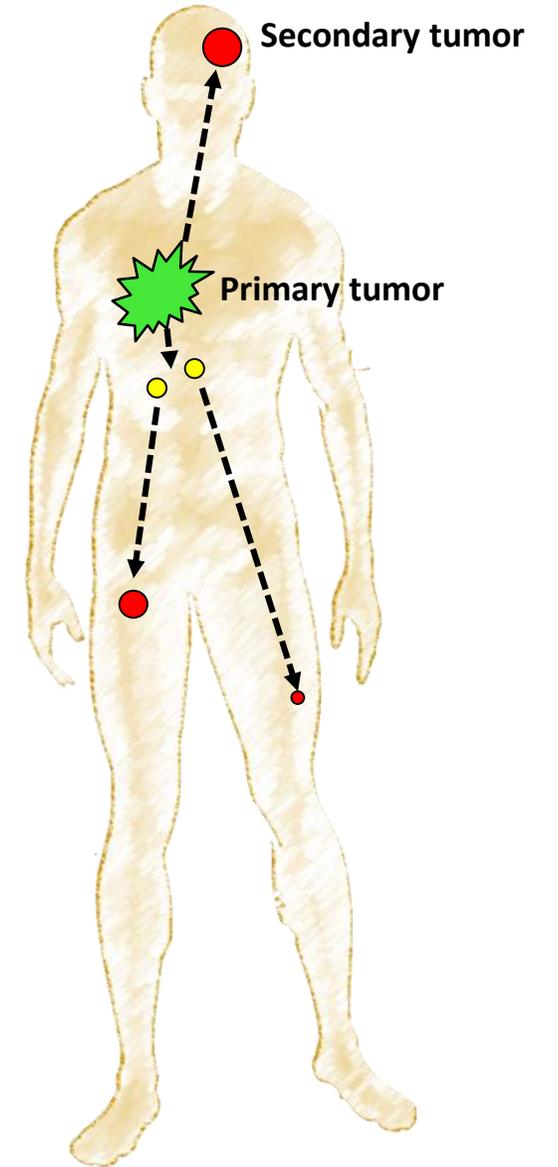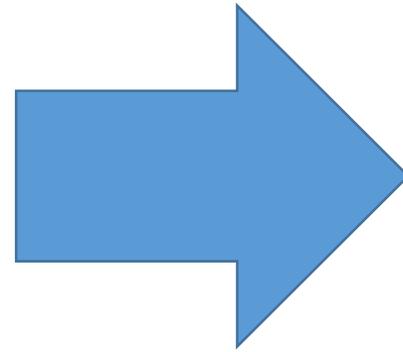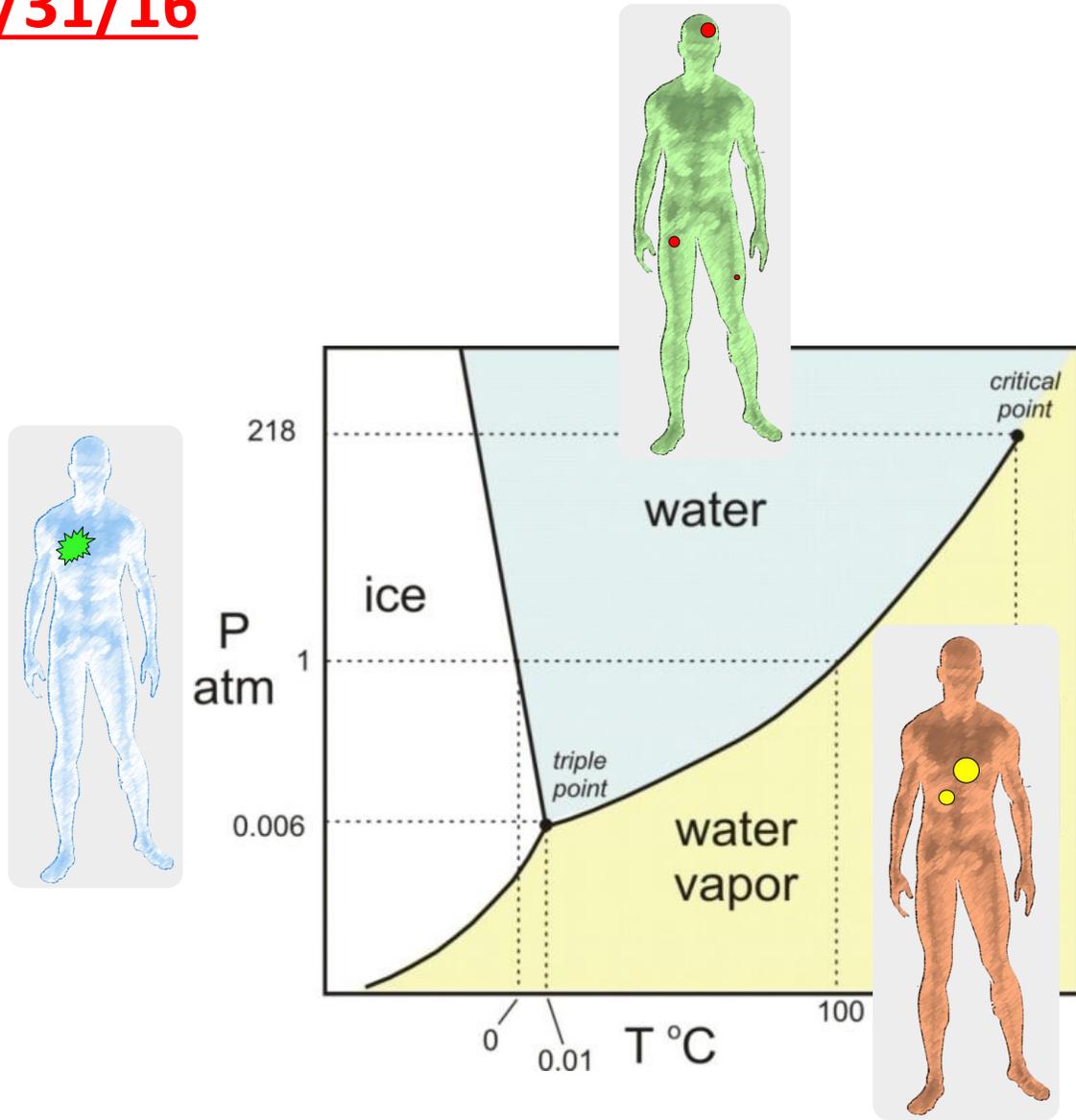
Finding the Right "Needle" at the Right "Time" of Disease
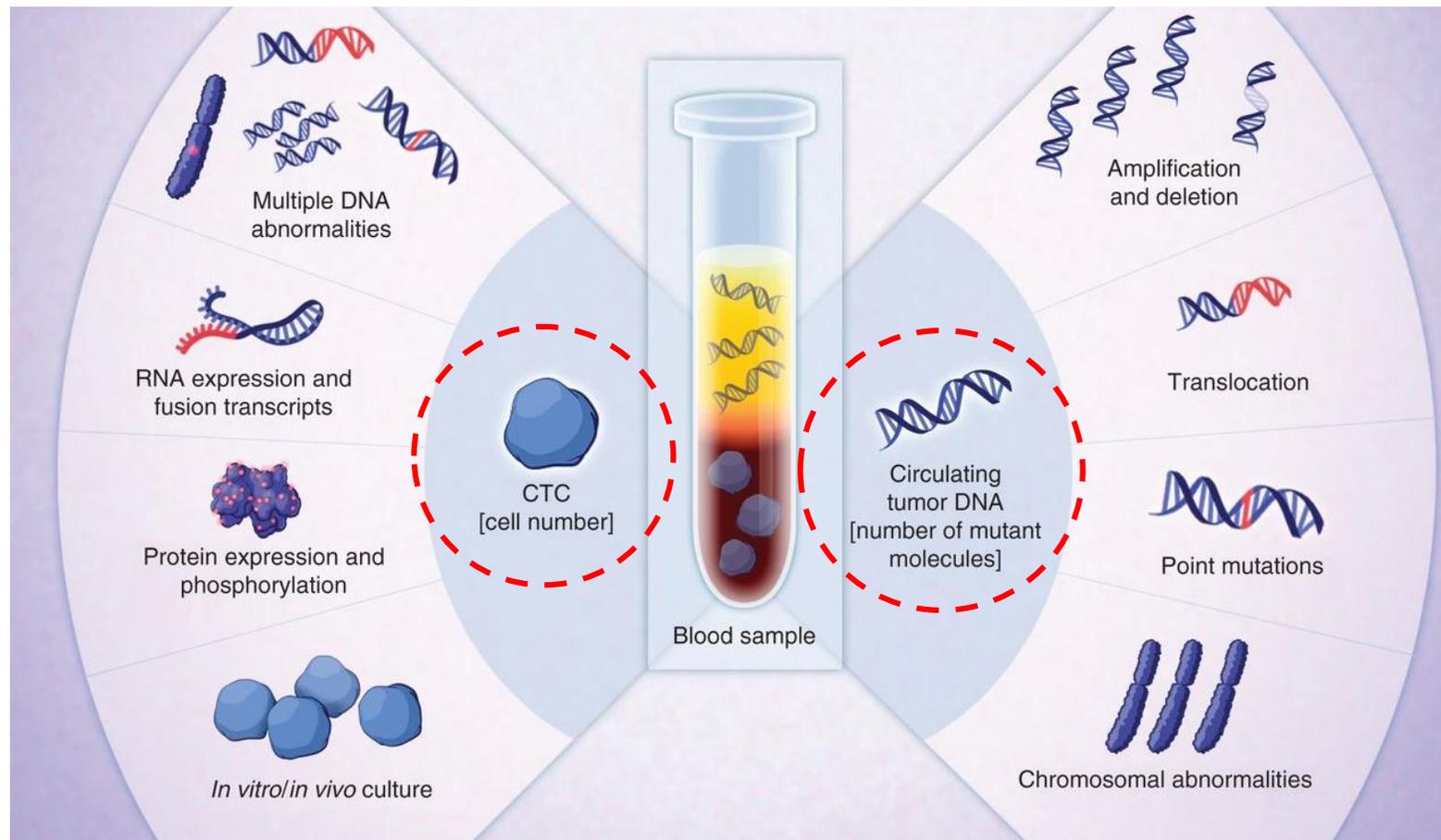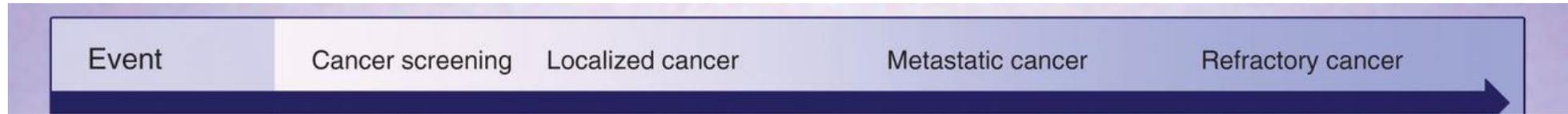
Sources of Circulating "Needles" (Normal and Cancer Patients)

Bone Marrow
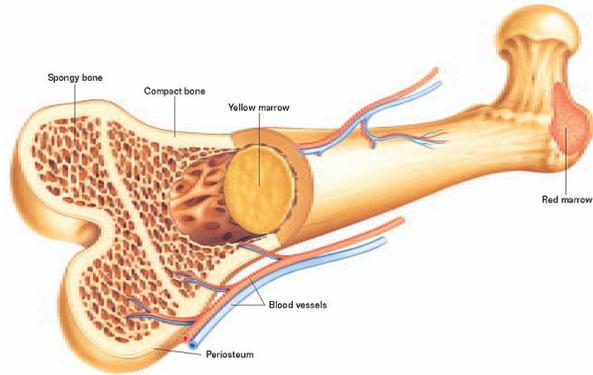
GI Tract
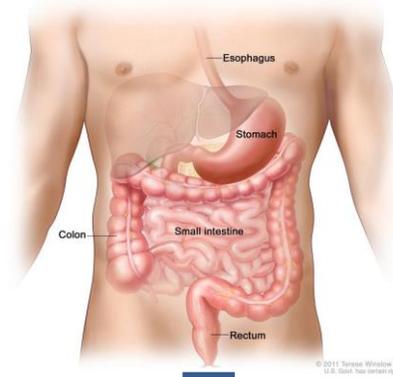
Skin
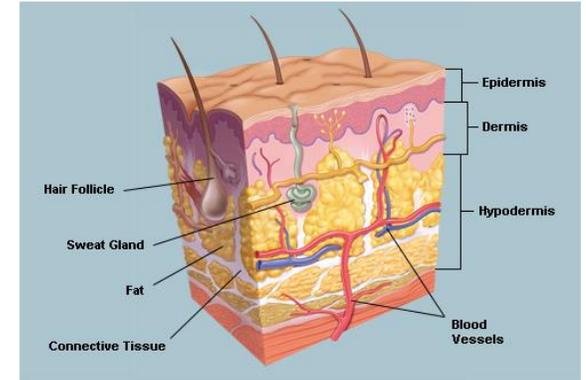
Tumor
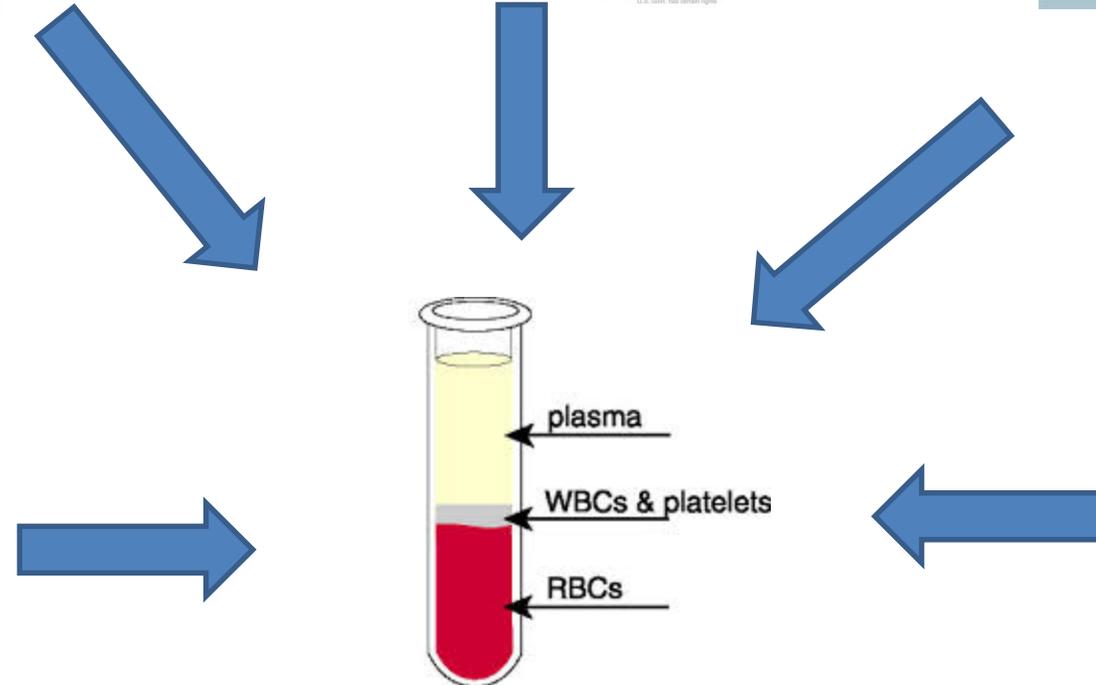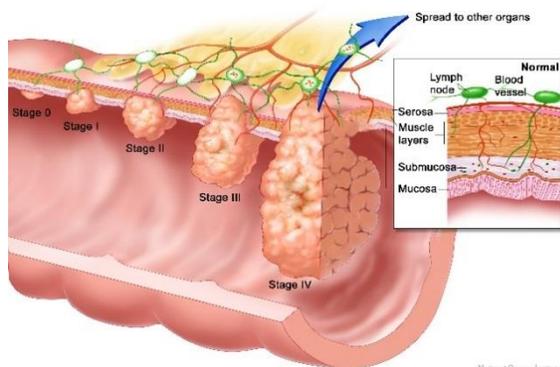
Fetal DNA

May 3rd, 2016

The FNIH Launches New Project to Evaluate the Effectiveness of Liquid Biopsies as Biomarkers in Colorectal Cancer Patients

Press Releases

Announcements

Press Contact

May 3, 2016 — The Foundation for the National Institutes of Health (FNIH) Biomarkers Consortium is launching a research partnership to determine whether liquid biopsies can be used instead of traditional solid tumor biopsies for diagnosing and monitoring metastatic colorectal cancer. According to the American Cancer Society, metastatic colorectal cancer is the third leading cause of cancer death in the United States.

Peter Kuhn, PhD, of the University of Southern California (USC), will lead the project team for "High Definition Single Cell Analysis of Blood and Tissue Biopsies in Patients with Colorectal Cancer Undergoing Hepatic Metastasectomy" (HD-SCA). The team is comprised of experts from the National Cancer Institute, the U.S. Food and Drug Administration, USC, Scripps Clinic, Baylor College of Medicine, Mayo Clinic and four sponsoring pharmaceutical companies.

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FNIH on Twitter

The Genome: Unlocking Life's Code

June 29th, 2016

Briefing Room

Your Weekly Address

Speeches & Remarks

Press Briefings

Statements & Releases

White House Schedule

Presidential Actions

  Executive Orders

  Presidential Memoranda

  Proclamations

Legislation

  Pending Legislation

  Signed Legislation

The White House
Office of the Press Secretary

For Immediate Release   June 28, 2016

FACT SHEET: At Cancer Moonshot Summit, Vice President Biden Announces New Actions to Accelerate Progress Toward Ending Cancer As We Know It

WASHINGTON, D.C. – Today, the Cancer Moonshot is hosting a summit at Howard University, in Washington, D.C. as part of a national day of action that also includes more than 270 events in

CANCER RESEARCH UK   Let's beat

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Home › About us › Cancer news › Science blog › Our Moonshot pledge to accelerate research on detecting early signs of cancer

Our Moonshot pledge to accelerate research on detecting early signs of cancer

Category: Science blog   June 29, 2016   Henry Scowcroft

Credit: emretok/Flickr via CC-BY 2.0

Popular posts

Most read today   Most discussed

Don't believe the hype – 10 persistent cancer myths debunked

Cannabis, cannabinoids and cancer – the evidence so far

Processed meat and cancer – what you need to know

Featured topics

Cancer controversies

Clinical trials

Breast cancer

In January 2016, US President Barack Obama announced a new effort to accelerate progress against cancer. Headed up by Obama's Vice President Joe Biden, The Cancer Moonshot initiative aims to double the rate of new discovery, achieving "a decade's worth of progress in five years".
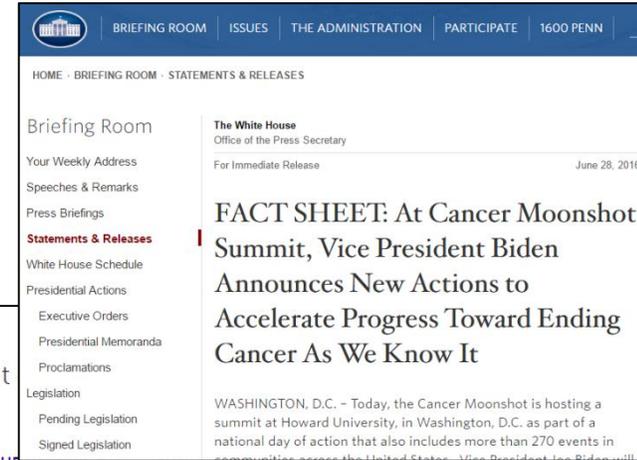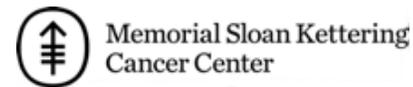
Search the blog

https://medium.com/cancer-moonshot/blood-profiling-atlas-in-cancer

12/2/2016

Analytical matrix (serum, plasma); Collection tube; effect of storage, time, temperature; Processing and handling of specimen
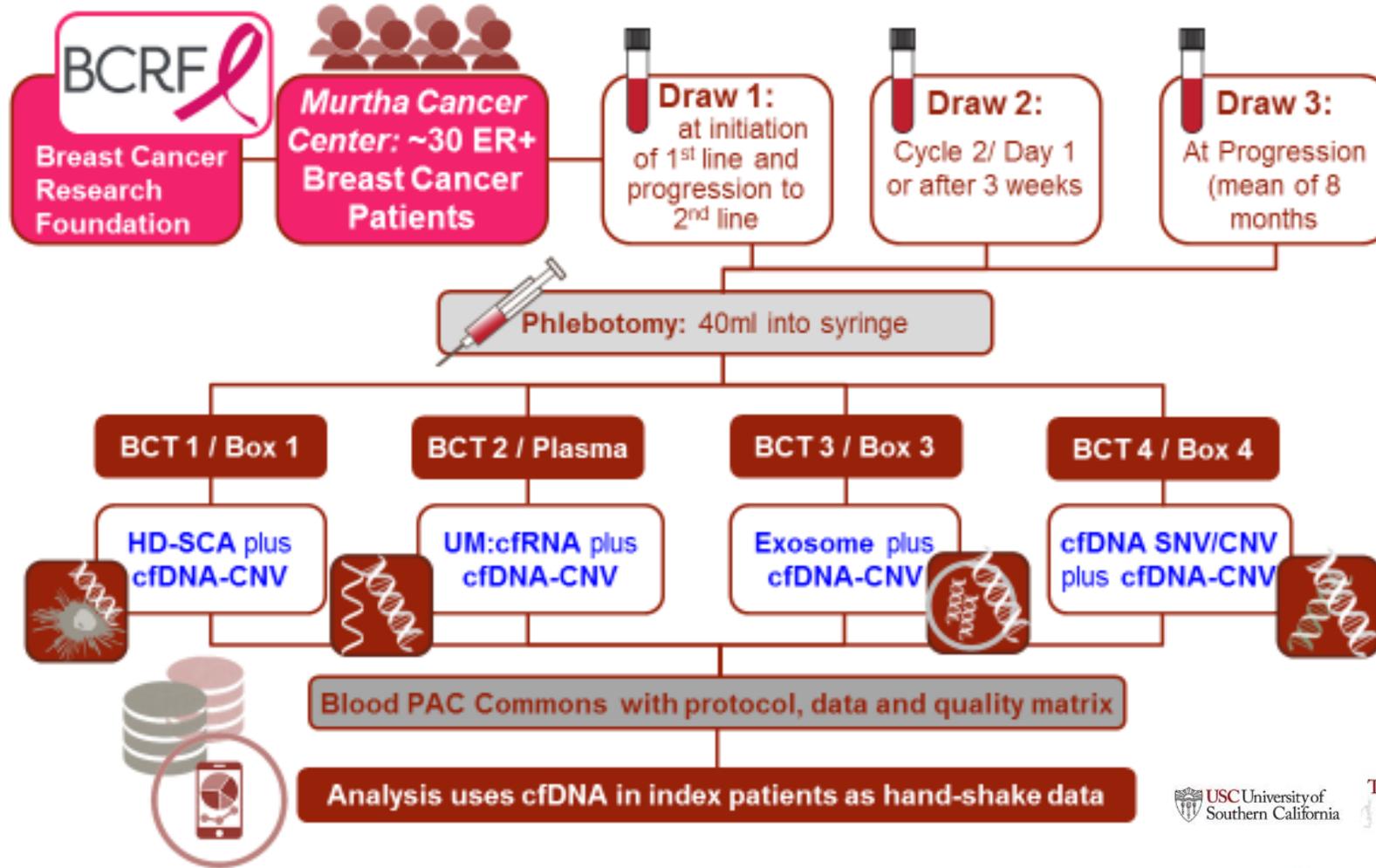
Adequate test performance characteristics in the laboratory setting

Test results track clinical conditions

Test use results in improved clinical outcome for patient

Pre-Analytical Data/SOP → Analytic validation → Clinical validation → Clinical utility

	Analytic validation	Clinical validation		Clinical utility
Pfizer		X	Breast and Lung	X
USC	X	X	Breast	
AstraZeneca	X	X	Breast	
Novartis	X		N/A	
U. Mich	X	X	Solid Tumors	X
Epic Sciences	X	X	Prostate	
Foundation Medicine	X	X	Unknown	
Genentech	X	X	Unknown	X (CTC only)
Guardant Health	X	X	Lung	X
MSKCC	X	X	Metastatic Prostate	X
PGDx	X	X	Unknown	
Thermo Fisher	X	X	Unknown	
Provista	X	X	Breast	
Genomic Health	X	X	Unknown	
CytoLumina	X	X	Prostate	
Indivumed	X	X	Unknown	

http://bloodpac.org

Lauren Leiman
Executive Director
lauren@bloodpac.org

BloodPAC
BLOOD PROFILING ● ATLAS IN CANCER
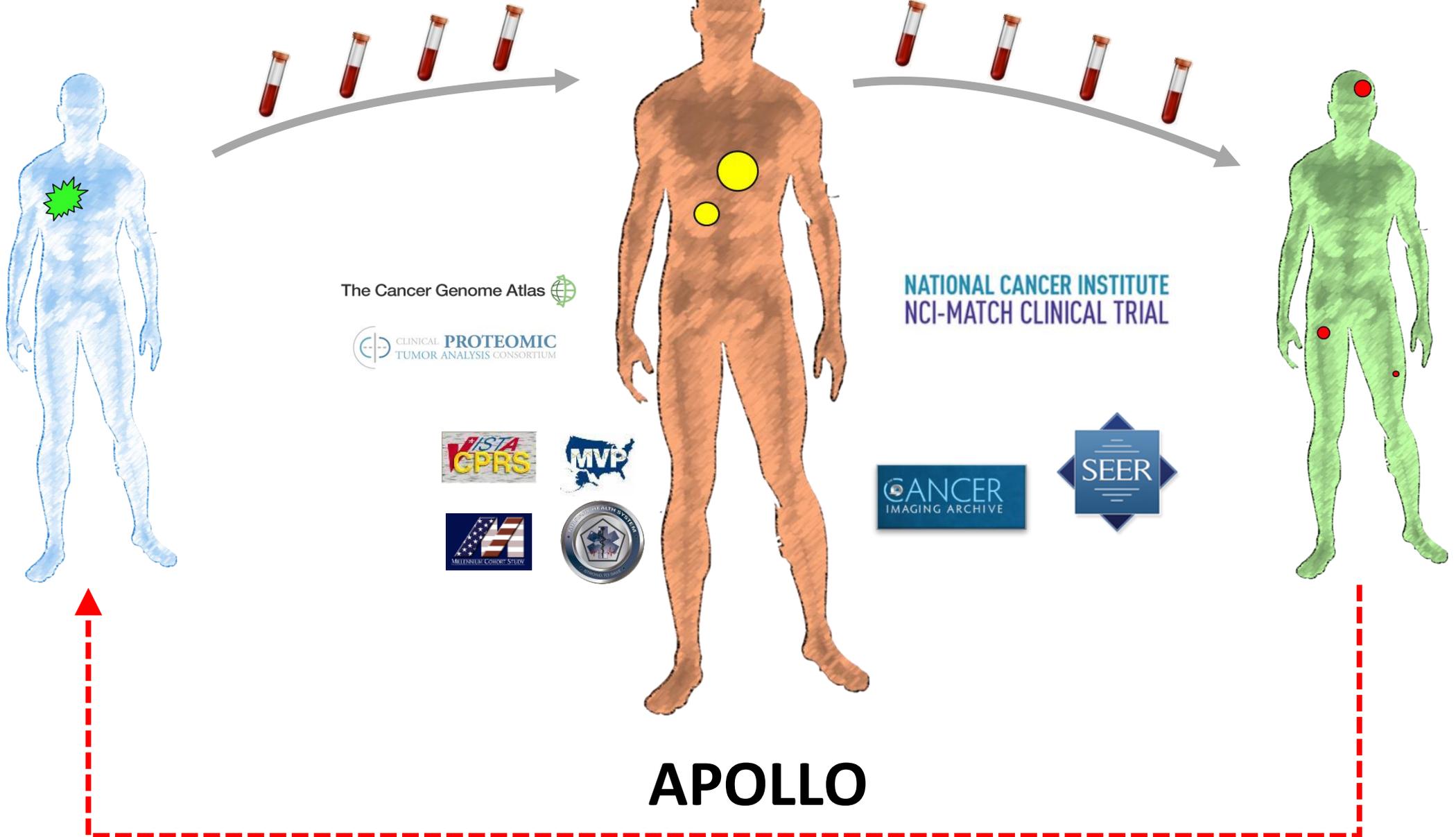
The Cancer Genome Atlas

CLINICAL PROTEOMIC
TUMOR ANALYSIS CONSORTIUM

NATIONAL CANCER INSTITUTE
NCI-MATCH CLINICAL TRIAL

CANCER IMAGING ARCHIVE

SEER

APOLLO

National Cancer Data Ecosystem

Genomic Data Commons

Imaging Data Commons

Data Standards
Validation and Harmonization

Blood Profiling Atlas Commons

Proteomics Data Commons

Clinical Data Commons (Cohorts / Indiv.)

SEER (Populations)

CancerBase

Researchers   Institutions   Clinicians   Patients

Data Contributors and Consumers

Modified from Abernethy et. al. *JCO* 2010

Treatment Landscape for a Newly Diagnosed Metastatic NSCLC Patient

2006

			First Line	Second Line
Squamous cell carcinoma			Chemotherapy	Chemotherapy
Non-squamous cell carcinoma	Biomarker testing		Gefitinib	Chemotherapy
		EGFR+ve	Erlotinib	
		EGFR+ve	Bevacizumab based therapies	Chemotherapy
		263	Chemotherapy	Erlotinib

Histological Testing

Indicates segments requiring histological testing

Indicates segments requiring biomarker testing

Treatment Landscape for a Newly Diagnosed Metastatic NSCLC Patient

2016

		First Line			Second Line	Third Line	Fourth Line
Squamous cell carcinoma		Chemotherapy			Afatinib	Chemotherapy	Chemotherapy
		Portrazza			Nivolumab		

Histological Testing

Non-squamous cell carcinoma

Biomarker testing	EGFR+ve	Gefitinib	Erlotinib	EGFR790M testing	Positive	Osimertinib	Chemo	Chemotherapy
						Chemo	Atezolizumab	
							Nivolumab	
					Negative	Chemo	Pembrolizumab*	
						Erlotinib		
						Pembrolizumab*		

Biomarker testing	ALK+ve		Crizotinib		Alectinib	Chemotherapy	Chemotherapy
					Ceritinib	Atezolizumab	
					Chemotherapy	Nivolumab	
					Crizotinib	Alectinib	
					Chemo	Ceritinib	
					Pembrolizumab*	Pembrolizumab*	

Biomarker testing	PD-L1+	Pembrolizumab		Nivolumab		
				Atezolizumab		

Biomarker testing	EGFR-ve/ ALK-ve/PD1-ve	Bevacizumab -based therapies	Ramucirumab -based therapies	Chemotherapy	Chemotherapy
		Chemotherapy	Erlotinib		
		nab paclitxel	Chemotherapy		

$? Outcome?

Source: Drugs@FDA, Mar 2017; NCCN Guidelines, nccn.org, Mar 2017

Indicates segments requiring histological testing   Indicates segments requiring biomarker testing

Technology timeline:

AOL Instant Messenger
5/1/1997

WinAMP(mp3)
4/21/1997

802.11b WiFi
9/16/1999
(~3 yrs old)

iPod (10GB max)
10/23/2001
(~4 yrs old)

iTunes Music Store
4/28/2003
(~6 yrs old)

YouTube
4/23/2005
(~8 yrs old)

twitter
7/15/2006
(~9 yrs old)

facebook
9/26/2006
(~9 yrs old)

iPhone (EDGE, 16 GB max)
1/9/2007
(~10 yrs old)

Gmail
2/7/2007

iPhone 3G (16 GB max)
7/11/2008
(~11 yrs old)

iPad (EDGE, 64 GB max)
4/3/2010
(~13 yrs old)

UberX
7/1/2012
(~15 yrs old)

iPhone5 (LTE, 128 GB max)
9/12/2012
(~15 yrs old)

Google Baseline
7/14/2014
(~17 yrs old)

Apple ResearchKit
3/9/2015
(~18 yrs old)

HTC VR Headset
4/5/2016
(~19 yrs old)
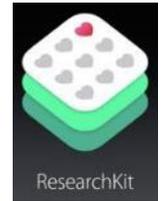
AI beats human at Go
AlphaGo
3/15/2016
(~19 yrs old)

Next Gen

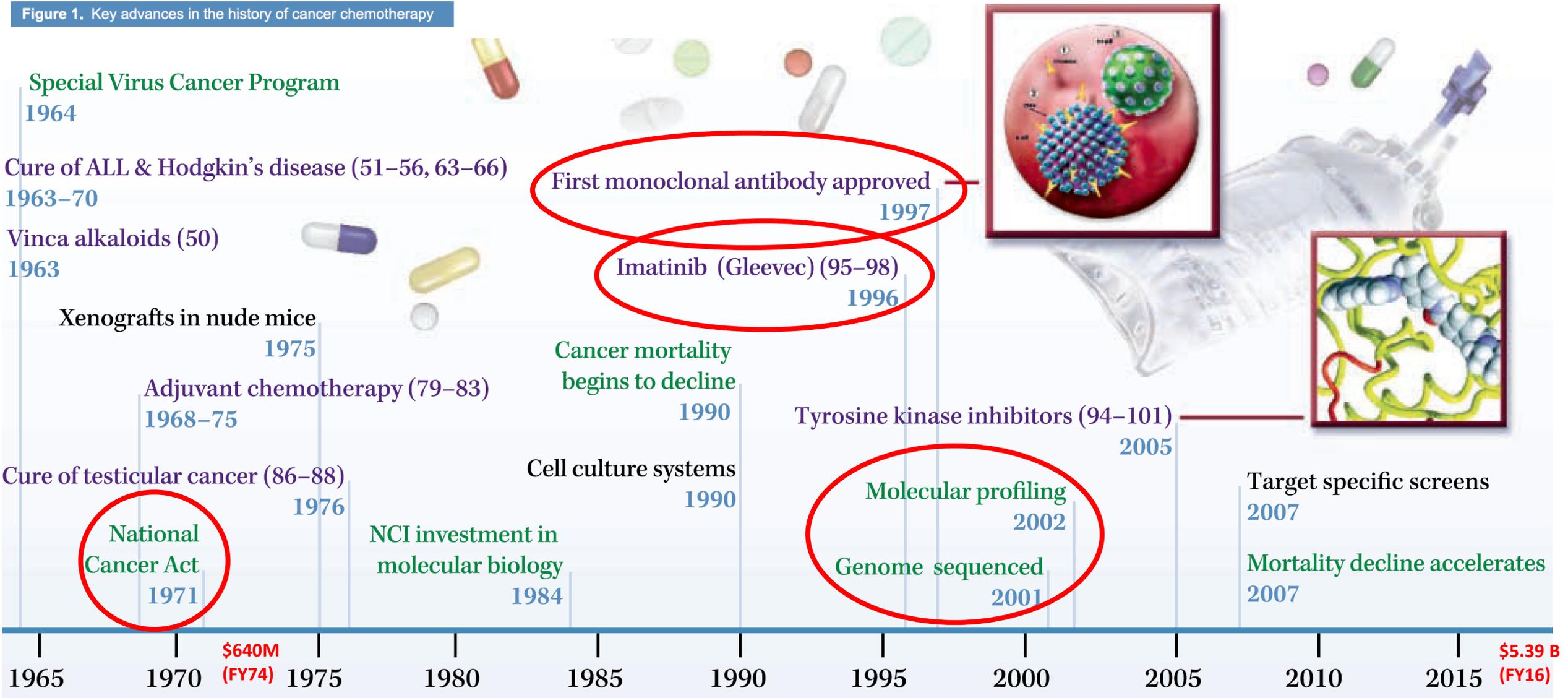1997   2002   2007   2012   2017

A History of Cancer Chemotherapy

Vincent T. DeVita, Jr. and Edward Chu

Yale Cancer Center, Yale University School of Medicine, New Haven Connecticut

Figure 1. Key advances in the history of cancer chemotherapy

Special Virus Cancer Program
1964

Cure of ALL & Hodgkin's disease (51–56, 63–66)
1963–70

Vinca alkaloids (50)
1963

Xenografts in nude mice
1975

Adjuvant chemotherapy (79–83)
1968–75

Cure of testicular cancer (86–88)
1976

National Cancer Act
1971

NCI investment in molecular biology
1984

Cancer mortality begins to decline
1990

Cell culture systems
1990

First monoclonal antibody approved
1997

Imatinib (Gleevec) (95–98)
1996

Tyrosine kinase inhibitors (94–101)
2005

Molecular profiling
2002

Genome sequenced
2001

Target specific screens
2007

Mortality decline accelerates
2007

$640M (FY74)

$5.39 B (FY16)

1965   1970   1975   1980   1985   1990   1995   2000   2005   2010   2015

Big Data Scientist Training Enhancement Program (BD-STEP)

2017 Potential Partners:

Graduates of BD-STEP would:

- have skillsets to perform next-generation **patient-centered outcomes research** by manipulating and analyzing large-scale, multi-element, patient data sets to **develop novel disease signatures or unique performance-based clinical benchmarks**

- have an understanding of real-time, performance-driven health care delivery in the VA systems

Connie Lee, VHA/EES   **Michelle Berny-Lang, NCI**

BD-STEP Sites and Fellows: 2016-2017

NCI-CPTAC DREAM
Proteogenomics Challenge

DREAM CHALLENGES
powered by Sage Bionetworks

Development of a Natural Language Processing (NLP) Workbench Web Service

- Two Year Project (July 2016 – September 2018)

- **Project Goals:**

  - Develop a Natural Language Processing (NLP) Workbench that utilizes Web Services for **analyzing unstructured clinical information**

  - Pilots for use in **cancer registries** and safety surveillance domains

  - Code cancer data items to **nationally adopted coding systems** (ICD-O-3)

  - Collect data from at least **four national laboratories** for the following primary cancer sites (**Breast, Lung, Prostate, Colorectal**)

    - **125 cases per cancer site** from each laboratory for a total of at least **2,000 cases**.

  - Double annotation will be completed by certified tumor registrars with a master reviewer
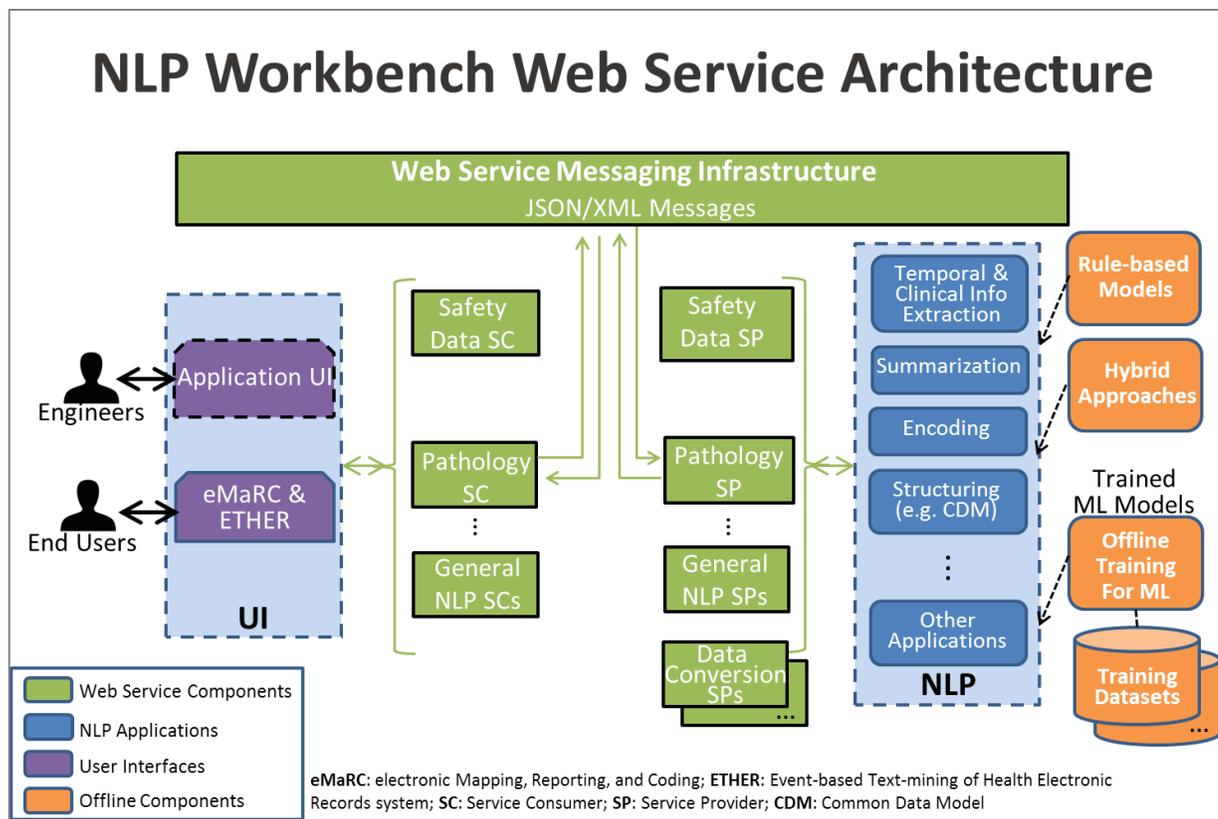
NLPWorkbench@cdc.gov

Sandy Jones (CDC) SFT1@cdc.gov

NLP Workbench Web Service Dos and Don'ts

- **Will include processes with demonstrated efficiency** - *is more than a collection of general NLP components and workflows*

- **Will cover certain needs** - *cannot be the panacea for all problems*

- **Will describe the process for the generation of annotated datasets**

- **Intend to incorporate only <u>open-source solutions</u> equipped to support the project objectives** and *will not endorse ANY existing solution*

NLP Workbench Web Service Architecture

Web Service Messaging Infrastructure
JSON/XML Messages

Engineers — Application UI
End Users — eMaRC & ETHER

UI

Safety Data SC
Pathology SC
⋮
General NLP SCs

Safety Data SP
Pathology SP
⋮
General NLP SPs
Data Conversion SPs ...

Temporal & Clinical Info Extraction
Summarization
Encoding
Structuring (e.g. CDM)
⋮
Other Applications

NLP

Rule-based Models
Hybrid Approaches

Trained ML Models
Offline Training For ML

Training Datasets ...

- Web Service Components
- NLP Applications
- User Interfaces
- Offline Components

eMaRC: electronic Mapping, Reporting, and Coding; ETHER: Event-based Text-mining of Health Electronic Records system; SC: Service Consumer; SP: Service Provider; CDM: Common Data Model

WORKSHOP December 18, 2017

The NEW ENGLAND JOURNAL of MEDICINE

			Funding for NIH Innovative Research Initiatives under the Cures Act.*			

Fiscal Year	BRAIN	PMI	Cancer Moonshot	Regenerative Medicine
		millions of $		
2017	10	40	300	2
2018	86	100	300	10
2019	115	186	400	10
2020	140	149	195	8
2021	100	109	195	
2022	152	150	194	
2023	450	419	216	
2024	172	235		
2025	91	36		
2026	195	31		
10-Yr total	1,511	1,455	1,800	30

* BRAIN denotes Brain Research through Advancing Innovative Neurotechnologies, and PMI Precision Medicine Initiative.

Hudson et. al. *NEJM* 2017

Updated: Oct 2nd, 2017

Currently **24** opportunities addressing broadly BRP recommendations

Please check back regularly as additional Funding Opportunity Announcements are posted.

https://www.cancer.gov/research/key-initiatives/moonshot-cancer-initiative/funding

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Development

Cancer Moonshot Data and Technology Team: Enabling a National Learning Healthcare System for Cancer to Unleash the Power of Data

Elizabeth R. Hsu, Juli D. Klemm, Anthony R. Kerlavage, Dimitri Kusnezov, Warren A. Kibbe ✉

Accepted manuscript online: 31 January 2017   Full publication history

DOI: 10.1002/cpt.636   View/save citation

Cited by (Cros

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Macroscopy

CMS

Centers for Medicare & Medicaid Services' Oncology Care Model: Delivering Higher Value Cancer Care

LK Mortimer, LM Strawbridge, EW Lukens, A Bassano, PH Conway, RM Kline ✉

First published: 18 April 2017   Full publication history

DOI: 10.1002/cpt.638   View/save citation

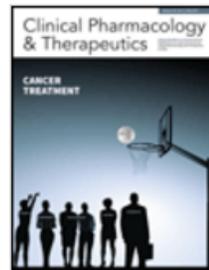Cited by (CrossRef): 0 articles   Check for updates   Citation tools ▼

Charting a Course for Precision Oncology

D Kusnezov[1] and J Paragas[2]

DOE

Clinical Pharmacology & Therapeutics

Volume 101: Cancer Treatment

May 2017
Pages 543–695

http://ascpt.onlinelibrary.wiley.com/hub/issue/10.1002/cpt.v101.5/

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Commentary

Drug Development, Trial Design, and Endpoints in Oncology: Adapting to Rapidly Changing Science

GM Blumenthal ✉, KB Goldberg, R Pazdur

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Collaboration to Accelerate Proteogenomics Cancer Care: The Department of Veterans Affairs, Department of Defense, and the National Cancer Institute's Applied Proteogenomics OrganizationaL and Learning (APOLLO) Network

L.D. Fiore, H. Rodriguez, C.D. Shriver

Accepted manuscript online: 10 February 2017   Full publication history

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Commentary

Data Sharing, Clinical Trials, and Biomarkers in Precision Oncology: Challenges, Opportunities, and Programs at the Department of Veterans Affairs

LD Fiore ✉, MT Brophy, RE Ferguson, C Shannon, SJ Turek, K Pierce-Murray, S Ajjarapu, GD Huang, CSE Lee, PW Lavori

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Jerry S.H. Lee, PhD
jerry.lee@nih.gov

@jleePSOC