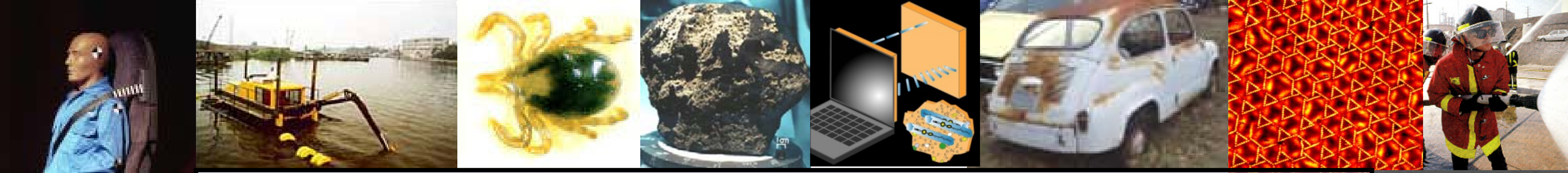
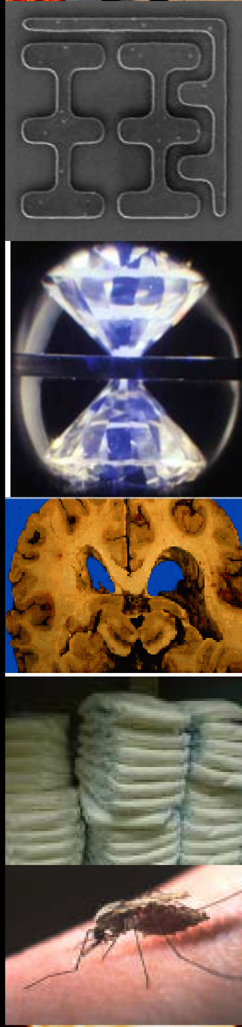


Light Source 101

With *many* thanks to Lisa Miller
Statistics by Kathy Nasta

Jean Jordan-Sweet
December 9, 2010



Outline

- The Facility
- The Users
- The Science

Brookhaven National Laboratory

National Synchrotron Light Source

Commissioned in 1982(VUV)-1984(X-ray) , built for ~$23M

What is a Synchrotron?

A synchrotron is a machine that produces tiny beams of very bright

LIGHT

by accelerating charged particles (electrons or positrons) around a “circular” track using magnetic fields

X-RAYS

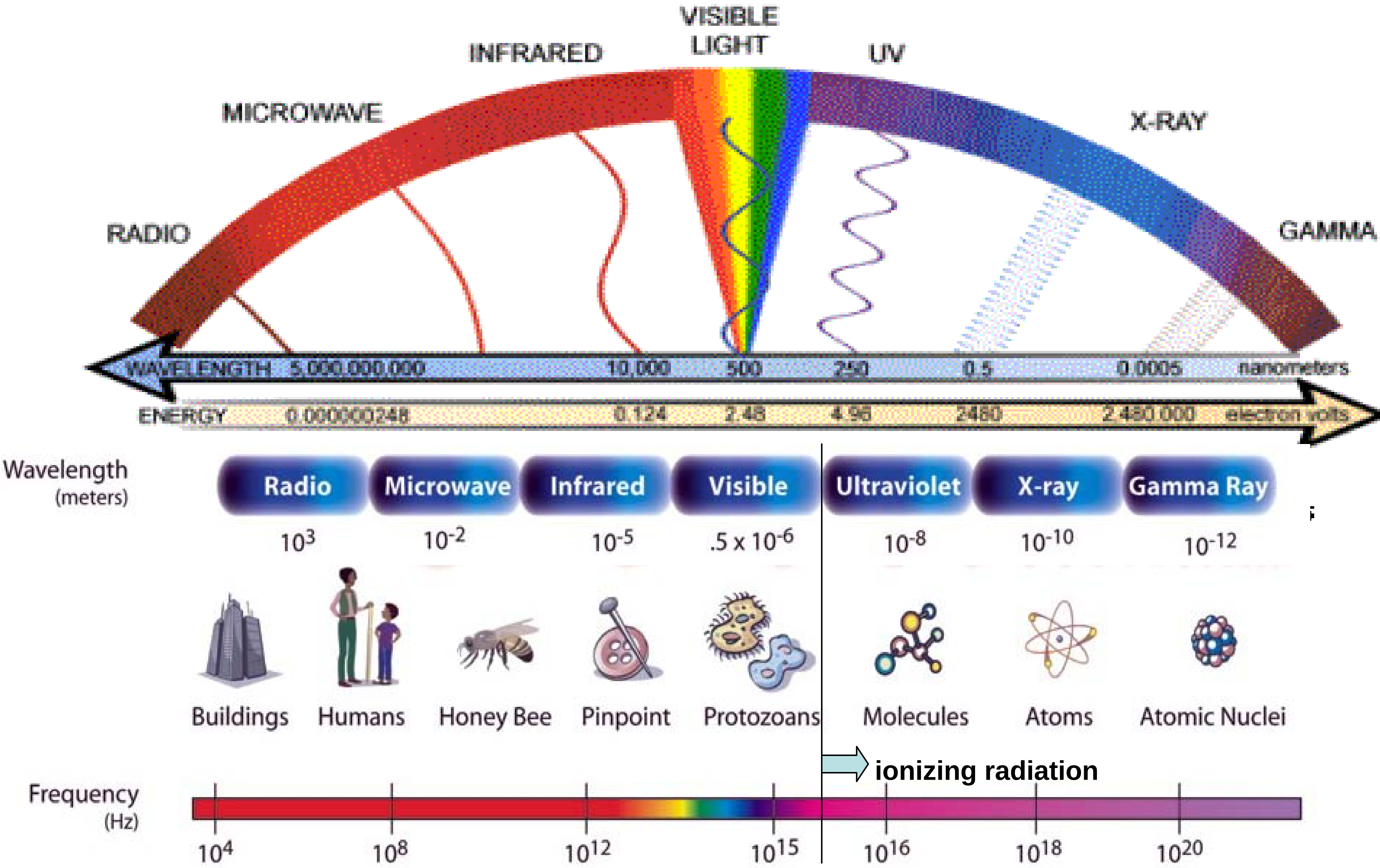
ULTRAVIOLET LIGHT

VISIBLE LIGHT

INFRARED LIGHT

MICROWAVES

The Electromagnetic Spectrum



ionizing radiation

Early Synchrotrons

- First particle accelerators (cyclotrons) were used to “split the atom”.
- First synchrotron was built in 1947 by General Electric.
- Synchrotron radiation was given off by these accelerators and was seen to be a nuisance.
- In the 1960’s it was realized that this would be a useful source of radiation – a new light source.

North American Synchrotrons

CLS- Saskatoon, CA
2.9 GeV

CHESS- Ithaca, NY
5.5 GeV

ALS- Berkeley, CA
1.9 GeV

NSLS- Upton, NY
0.75 and 2.8 GeV

SRC- Stoughton, WI
0.8 – 1.0 GeV

APS- Argonne, IL
6.8 GeV

NSLS-II- Upton, NY
3.0 GeV

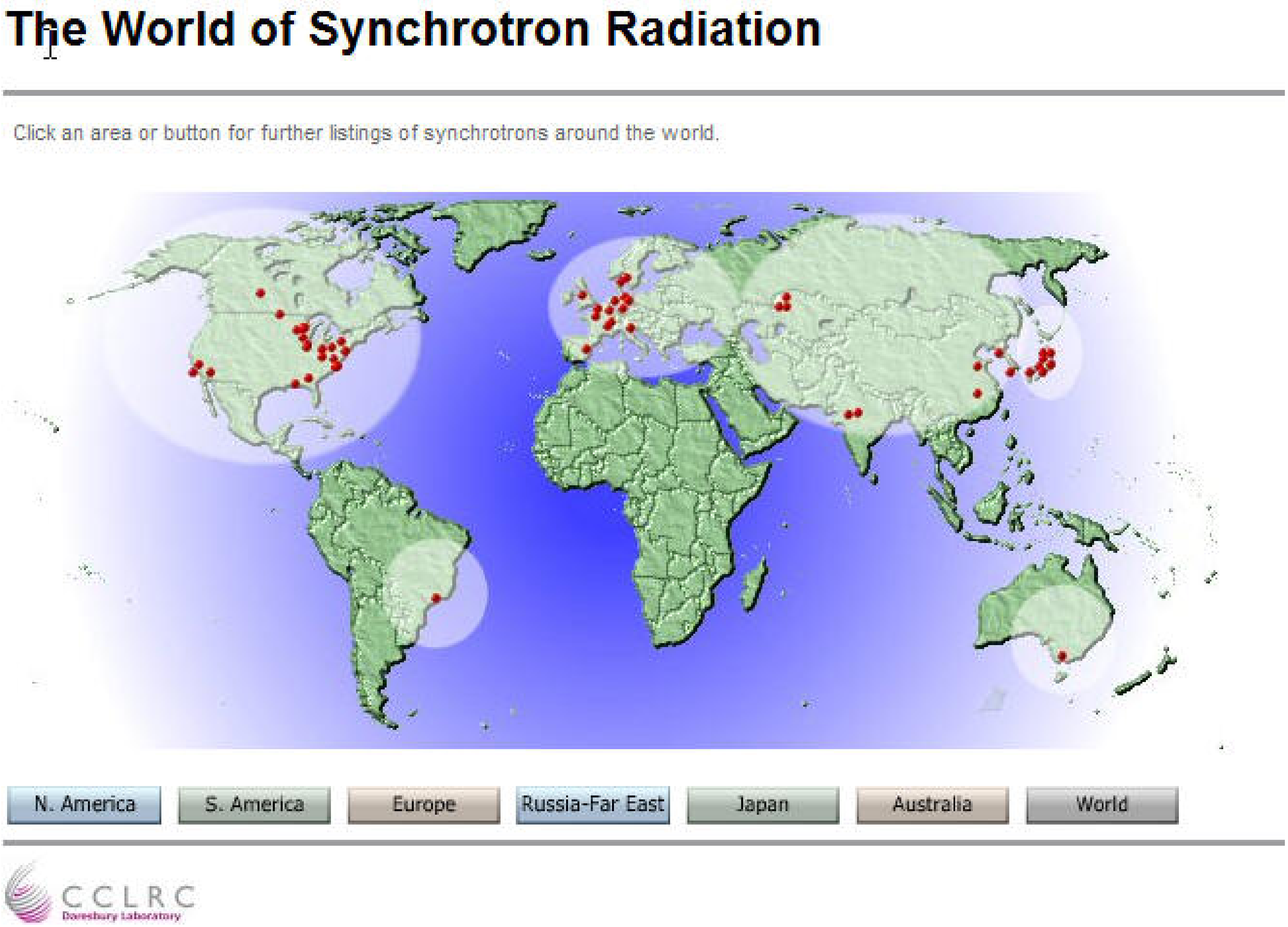
SSRL- Stanford, CA
3.0 GeV

CAMD- Baton Rouge, LA
1.3 – 1.5 GeV

SURF-III- Gaithersburg, MD
0.386 GeV

4 are operated by the U.S. DOE

1st → 2nd → 3rd generations



The World of Synchrotron Radiation

Click an area or button for further listings of synchrotrons around the world.

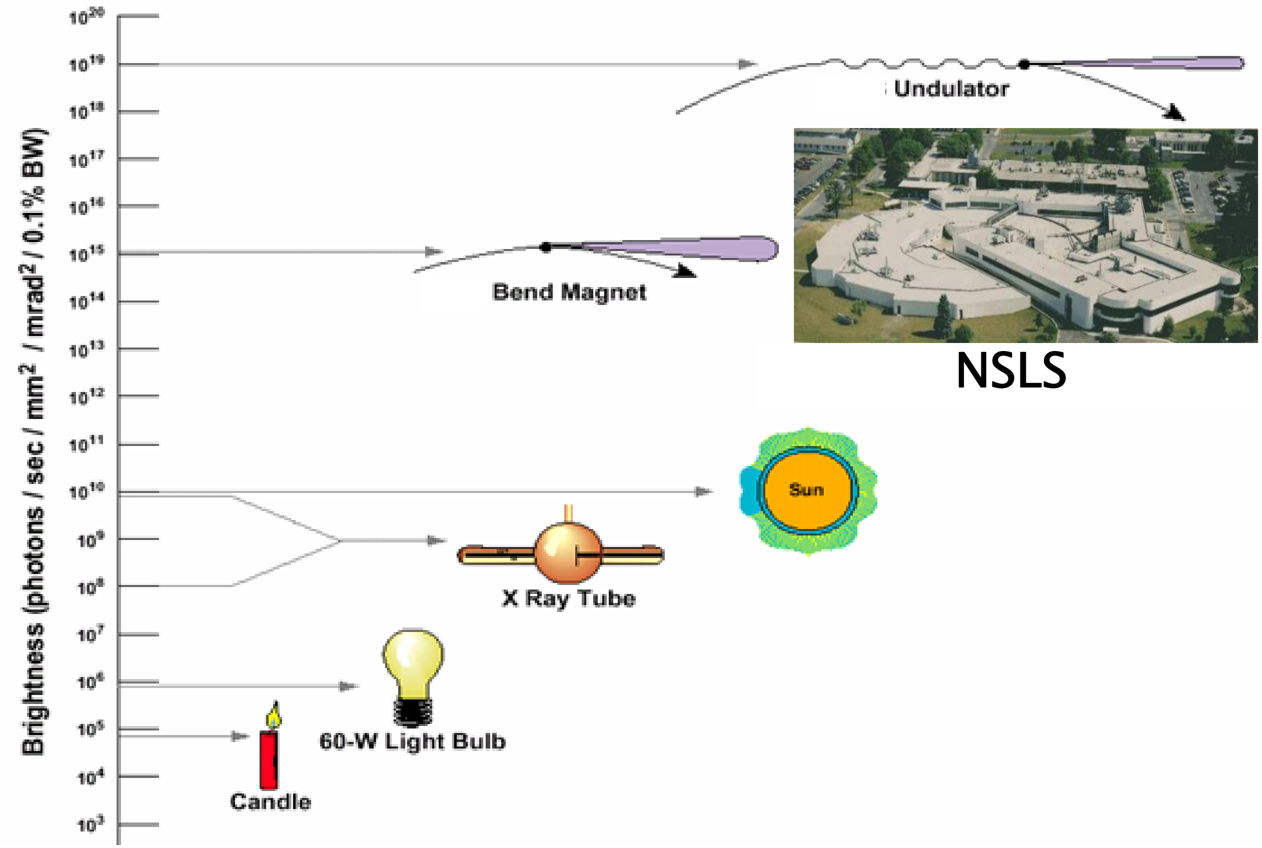
http://srs.dl.ac.uk/srworld/world_sr.html

Properties of Synchrotron Light

- **Broad band** – a wide energy range of photons is available (tunable)
- **Polarized** – this minimizes background scattering, improves sensitivity and enables measurement of circular dichroism
- **Pulsed** – the electron bunches produce nanosecond light pulses, enabling process kinetics to be followed and ‘movies’ of reactions to be made.

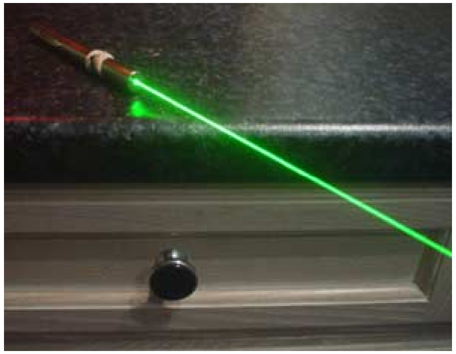
Properties of Synchrotron Light

Brightness – many orders of magnitude brighter than conventional sources, enabling quick experiments on small samples.

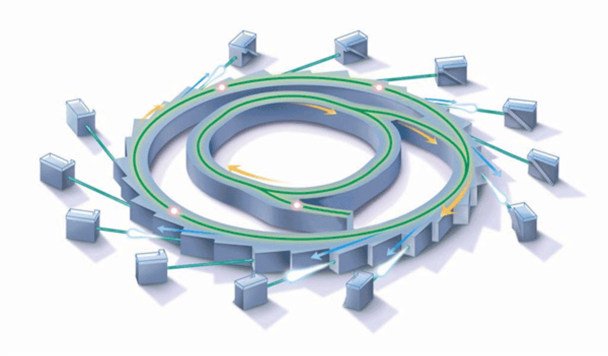


The BRIGHTNESS of Synchrotron Light

100 Watts / 1000000 mm^2 (1 m^2) =
0.0001 Watts / mm^2

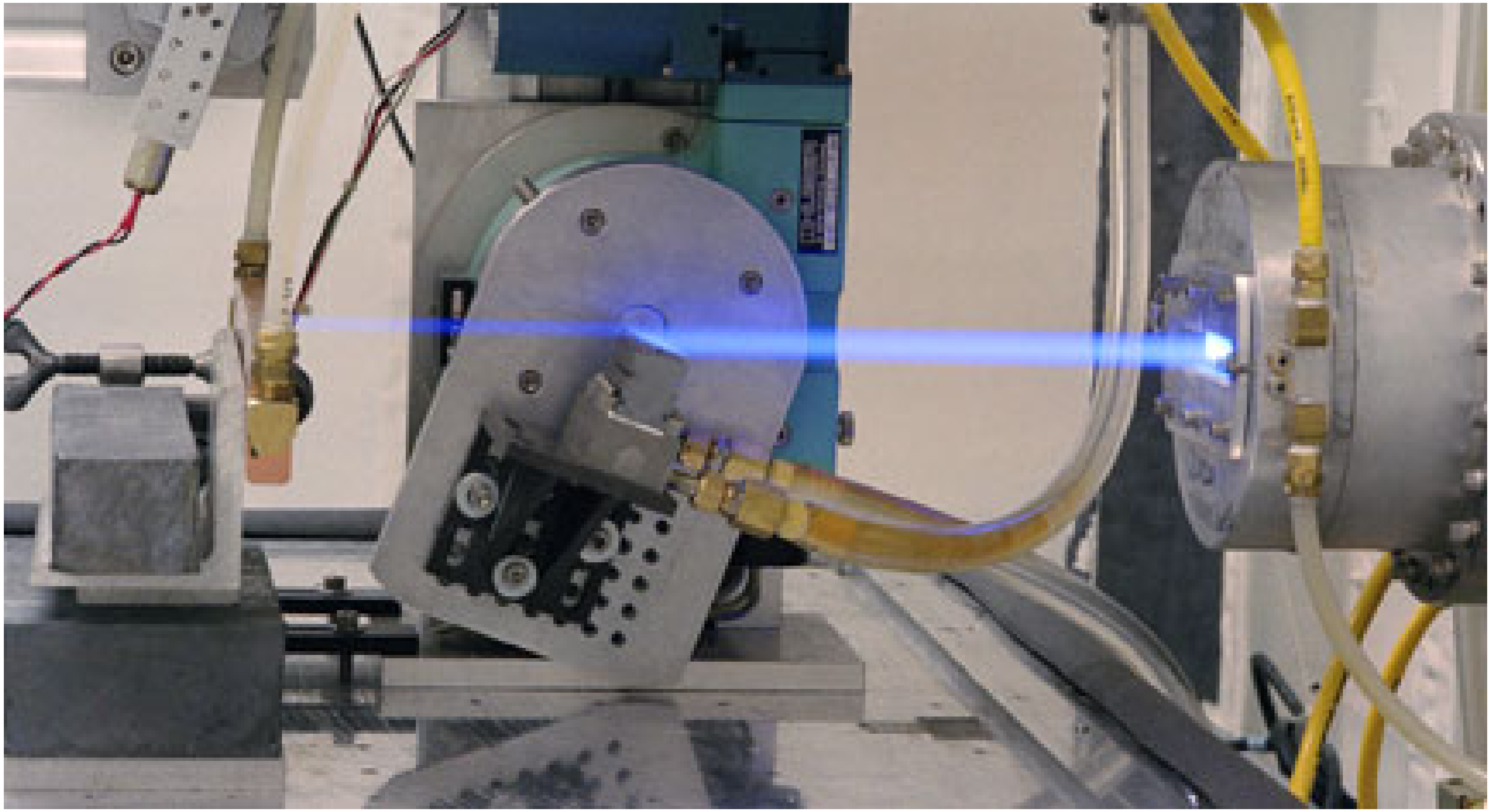


0.005 Watts / 1 mm^2 =
0.005 Watts / mm^2



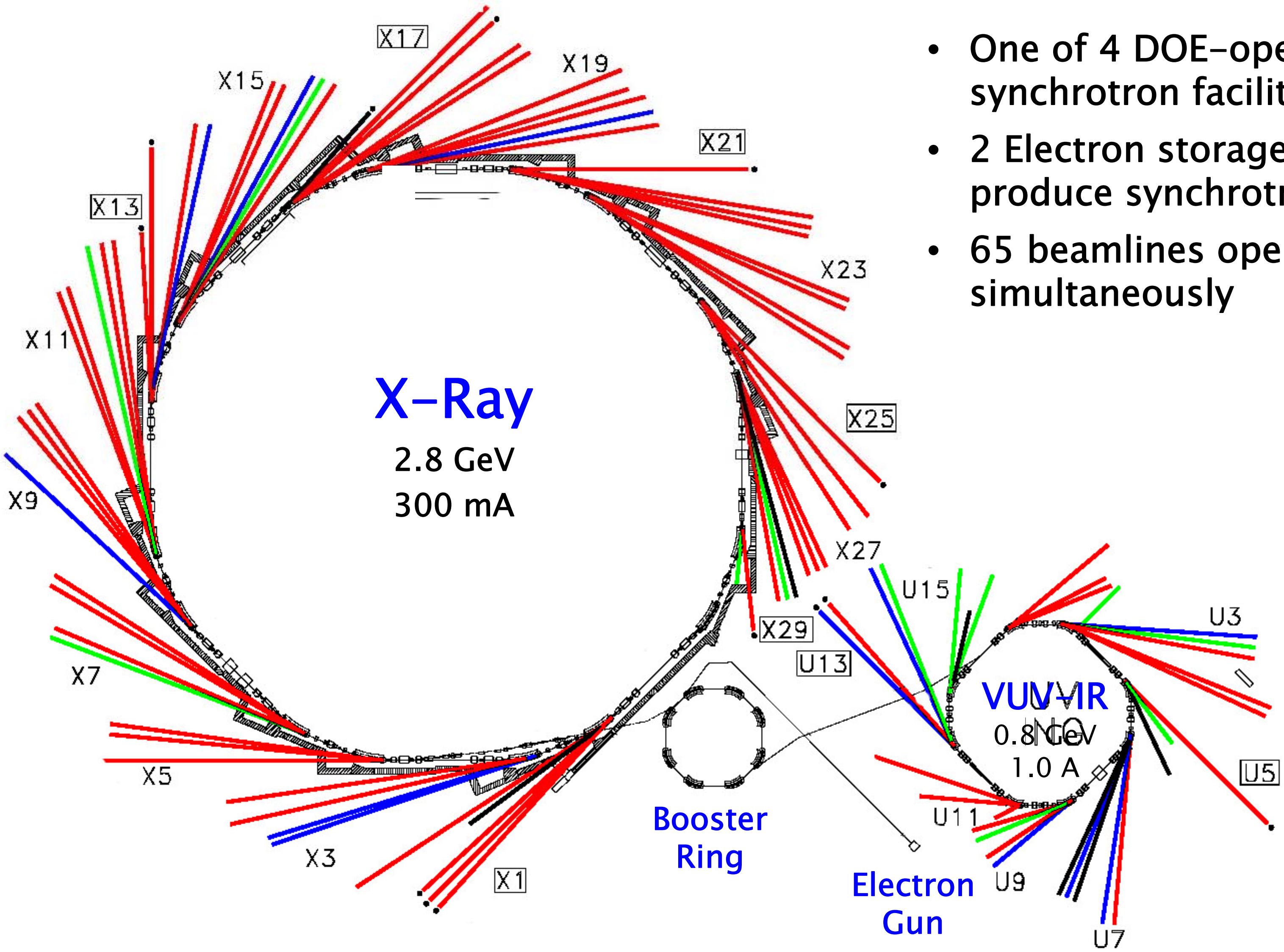
30 Watts / 0.01 mm^2 =
3000 Watts / mm^2

This is Synchrotron Light



(actually it’s air (nitrogen) that has been excited by x-ray light)

How Do We Make Synchrotron Light?



- One of 4 DOE-operated synchrotron facilities
- 2 Electron storage rings that produce synchrotron light
- 65 beamlines operate simultaneously

Building a Synchrotron 101

1) Take evacuated beam pipe

ADD:

2) Bends (dipoles) to form e-beam trajectory (& as SR sources)

3) Quadrupole magnets to focus e-beam transversely

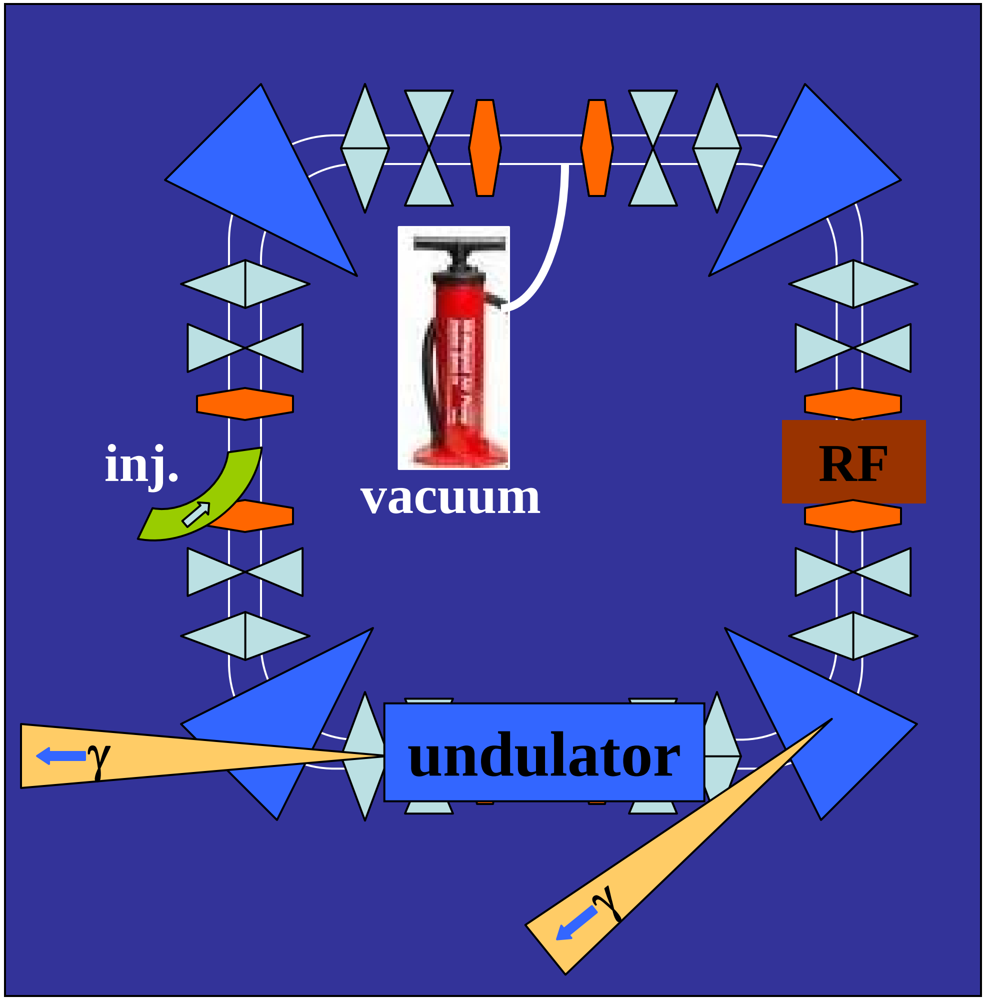
4) Sextupoles for achromatic focusing

5) RF to make up for energy loss; also provides longitudinal focusing (bunching)

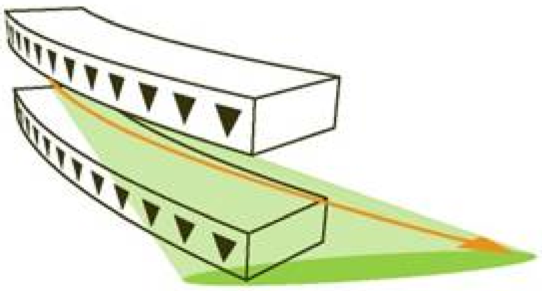
6) Injection system

7) IDs into avail. straight sections

8) Beamlines to deliver photons to the Users



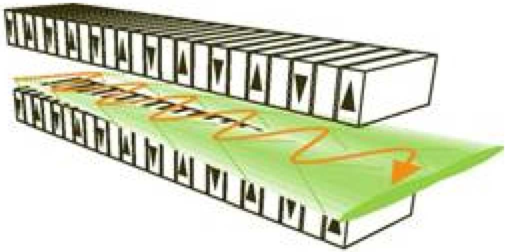
Types of Light-Generating Sources

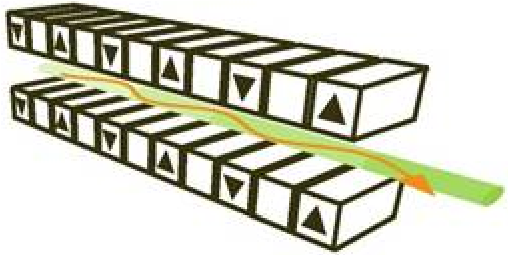


Bending magnet

- Sweeping searchlight
- At each deflection of the electron path a beam of radiation is produced

Insertion devices: inserted into "straight sections" of the ring and produce higher intensity of light





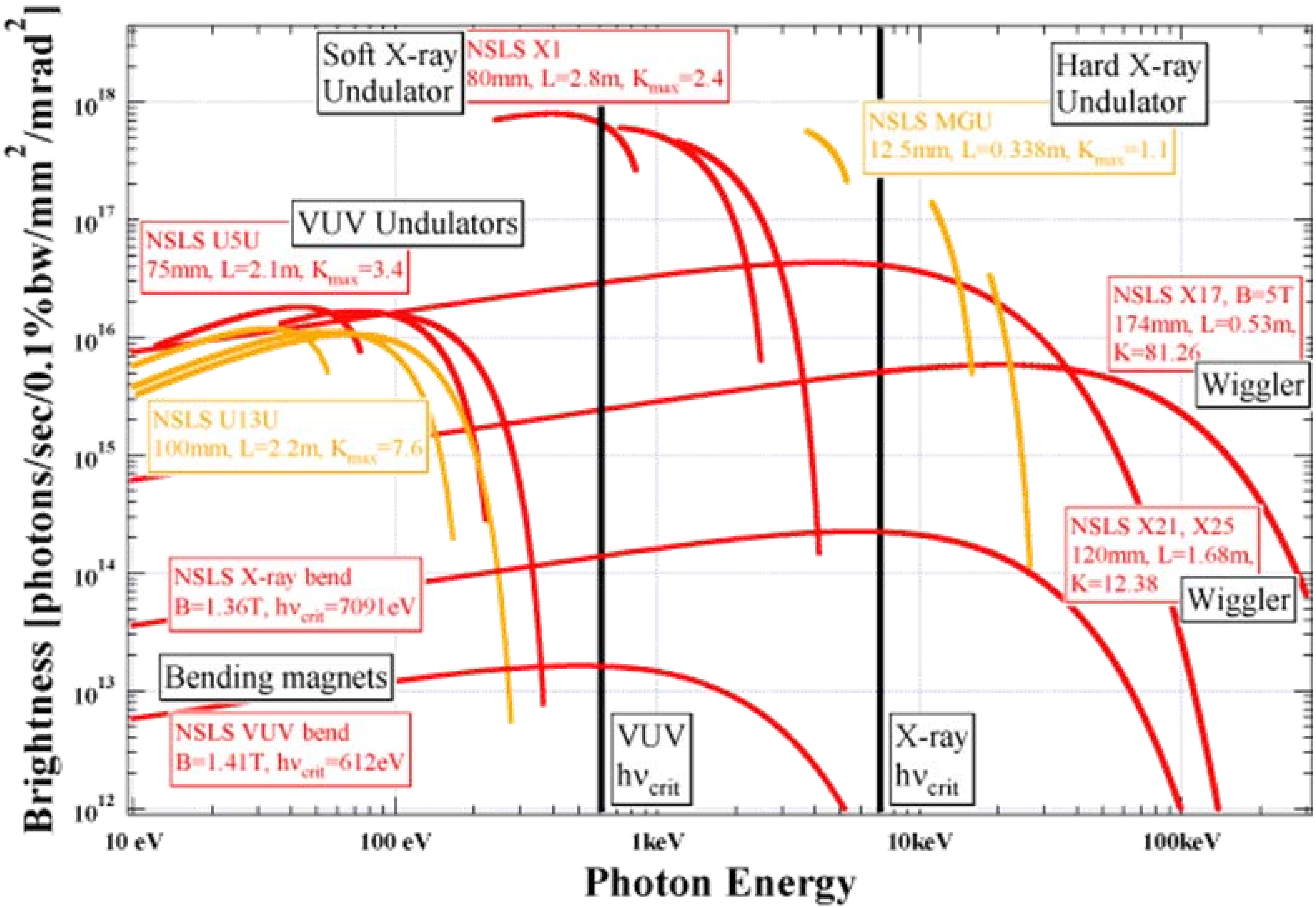
Wiggler

- Beams emitted at each pole reinforce each other and appear as a broad beam of incoherent light

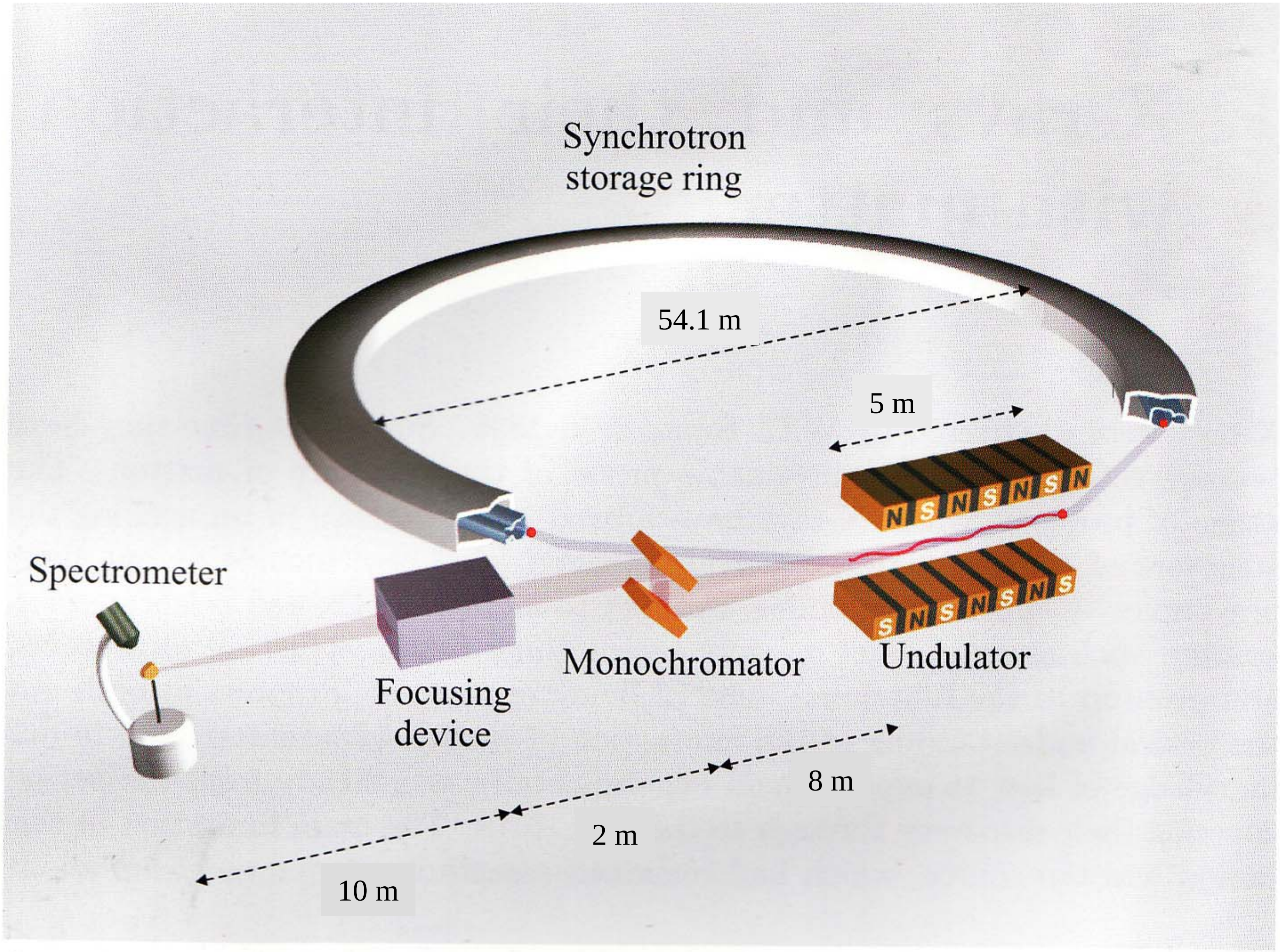
Undulator

- Produces a very narrow beam of coherent light, amplified by up to 10,000x

Source output



Typical Beamline



modified from Als-Nielsen and McMorrow, *Elements of Modern X-Ray Physics*

Outline

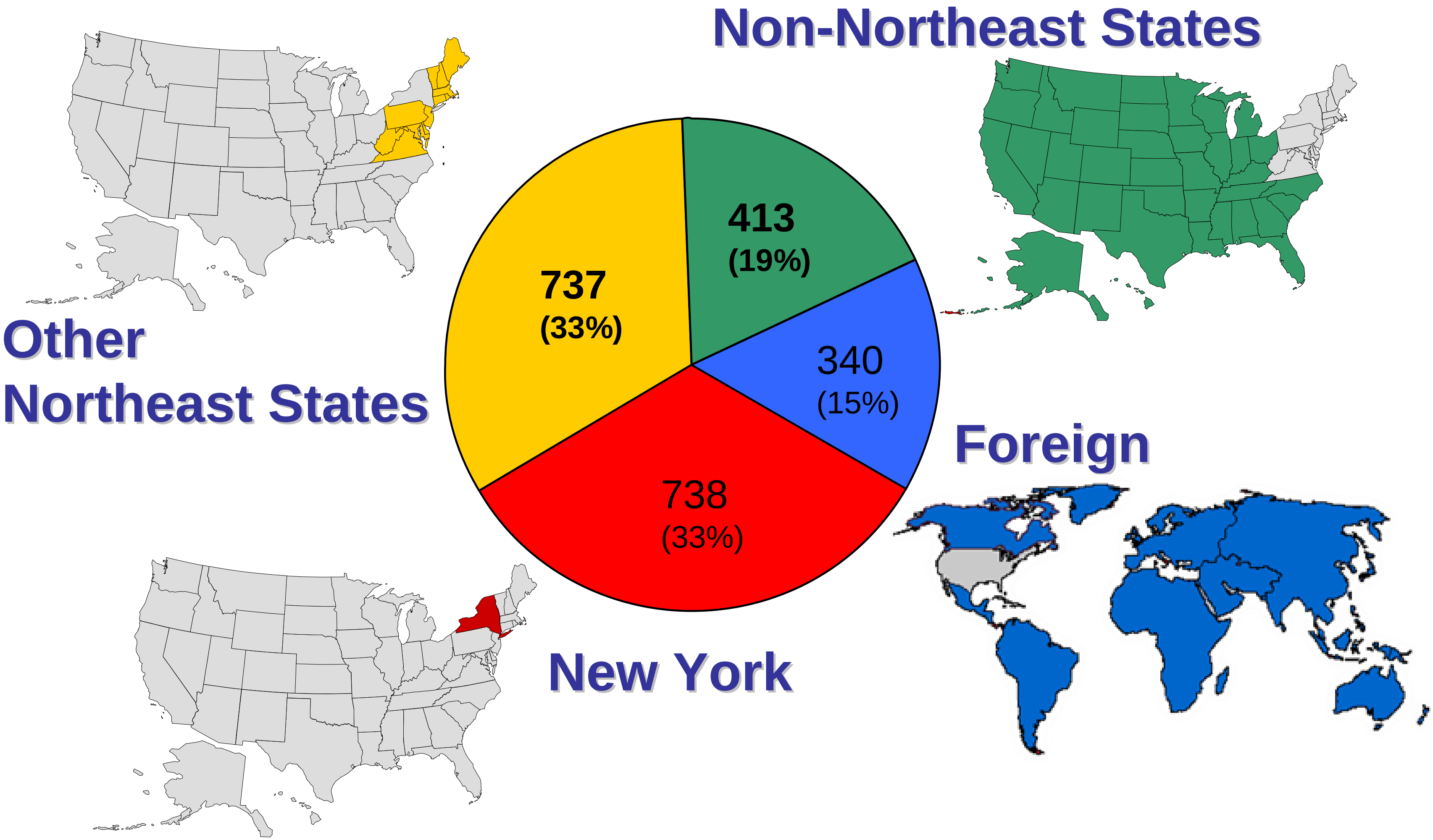
- The Facility
- The Users
- The Science

- Facility operates 24 hours/day, 7 days/week, ~10 months/year
- >2200 users per year (~1/3 are new users)
- Typical stay is 2-4 days (onsite housing)

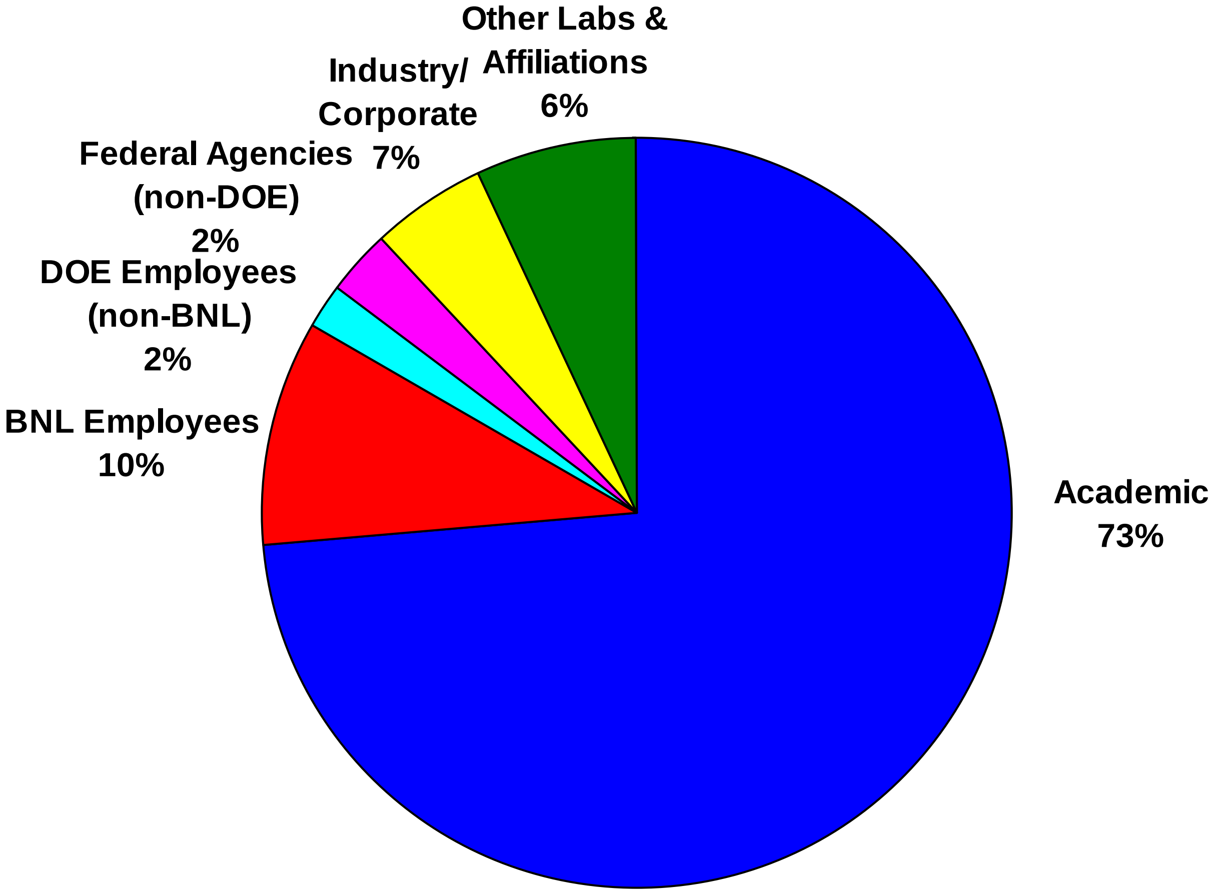
How to Get Beamtime

- Scheduled in three 4-month cycles
- User access via 2 primary mechanisms:
  - General User Proposals: peer-reviewed proposal system
  - Participating Research Teams (75%)
- Some proprietary research is done (full cost-recovery rate, ~$100/hr)

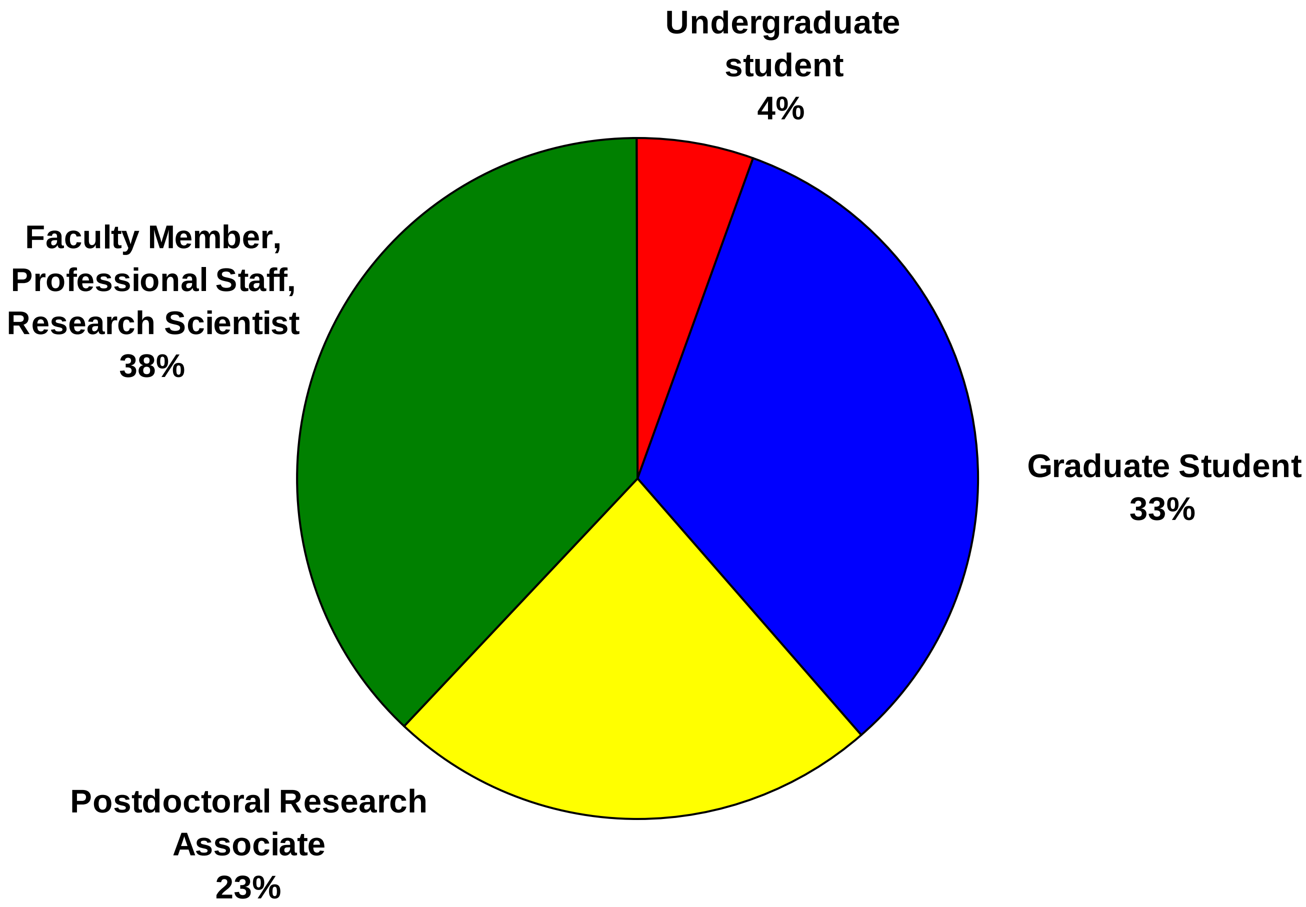
NSLS User Distribution
FY 2010



NSLS Users by Research Institution FY 2010

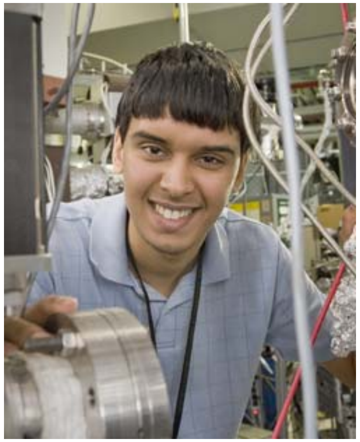


NSLS Users by Employment Level
FY 2010



- A large number of students and postdocs work at NSLS

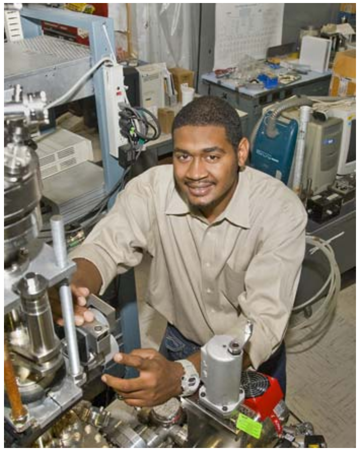
Student Research



Bishnu Panigrahi
college student
"heavy metal transport in plants"
Sayville, NY

Ashley Jones
college student
"Arsenic toxicity in the kidney"
Saginaw, MI

Megan Bourassa
PhD student
"metal homeostasis in ALS"
Phoenix, AZ



Jeff Ambrose
college student
"nitrogen fixation in soils"
New Orleans, LA

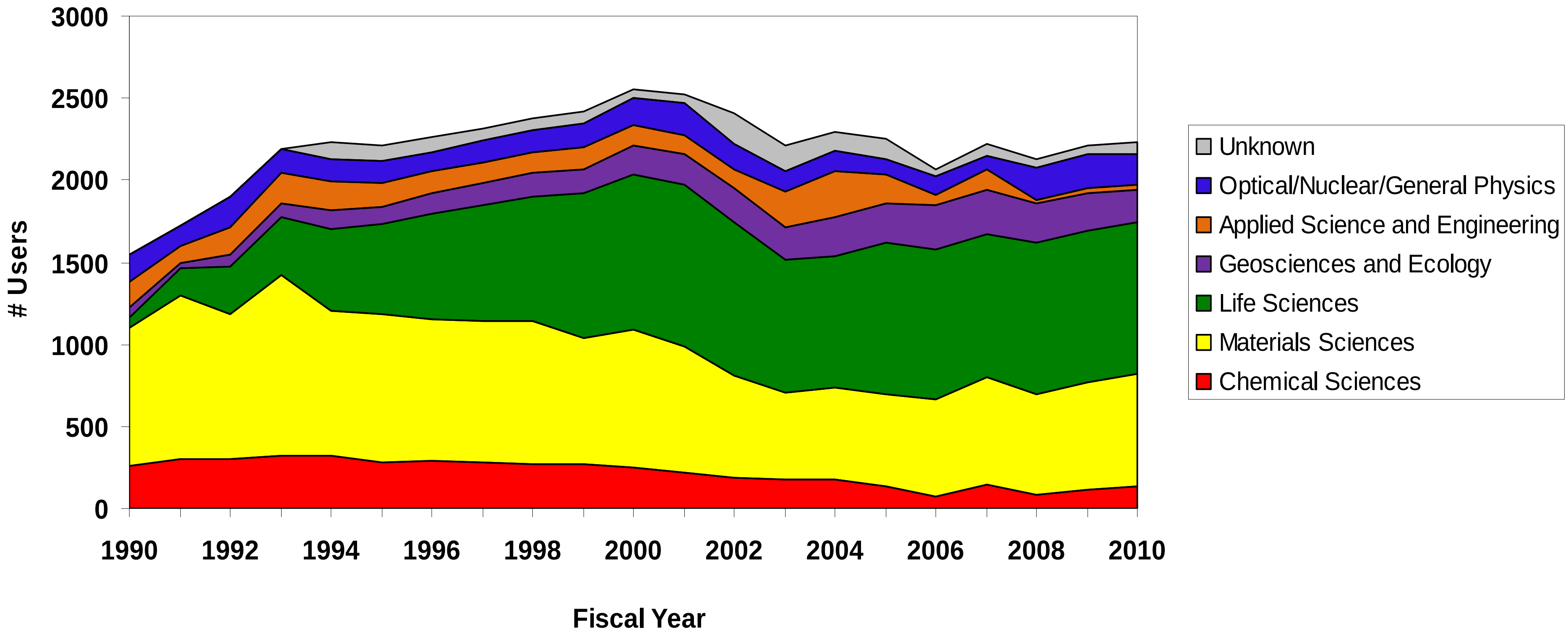
Matt Engel
PhD student
"protein structure in hepatitis C virus"
Stony Brook, NY

Andreana Leskovjan
PhD student
"metal uptake in Alzheimer's disease"
Tampa, FL

Alvin Acerbo
PhD student
"improving imaging resolution"
The Netherlands

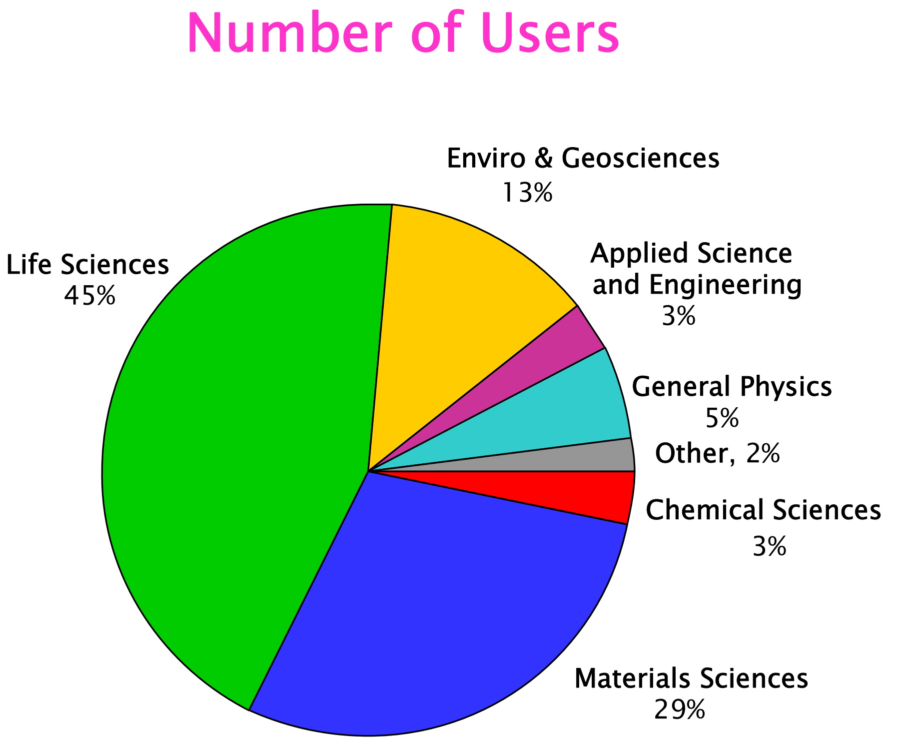
Shirin Mortazavi
college student
"unique methods to crystallize proteins"
Bellport, NY

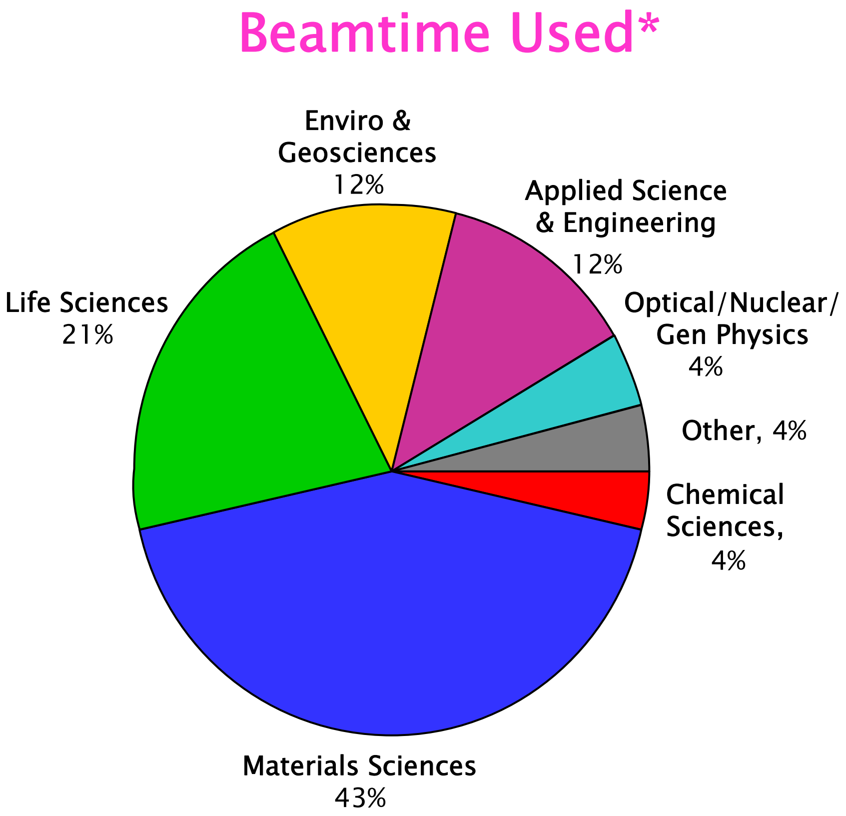
NSLS User Community



- 2228 scientists in FY 2010
- >400 academic, industrial, government institutions
- ~750 new users register each year
- Strongest growth in life sciences
- Largest groups are materials and life sciences

Beamtime Used by Field of Research



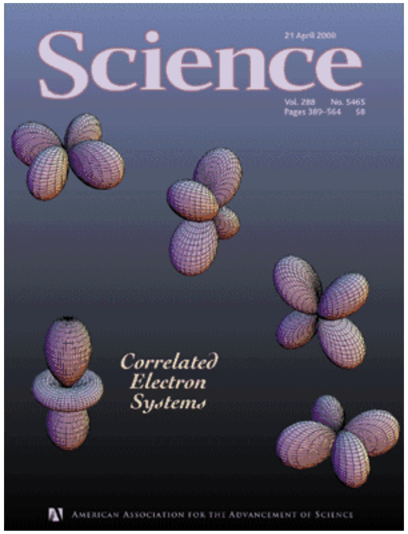


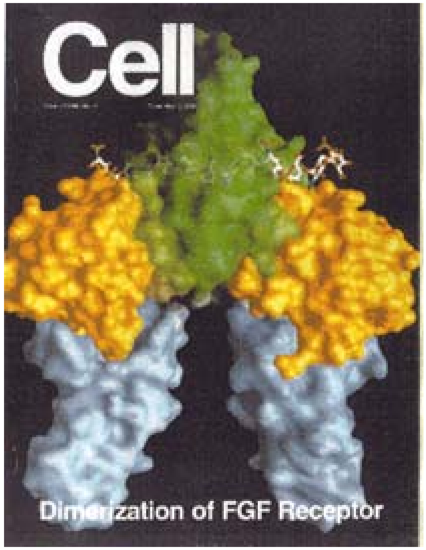
- More life science users, shorter beamtime, high-throughput
- Materials science experiments are more complicated, time-consuming

FY 2006

NSLS Publications

- almost 1000 publications per year
- > 200 publications in premier journals



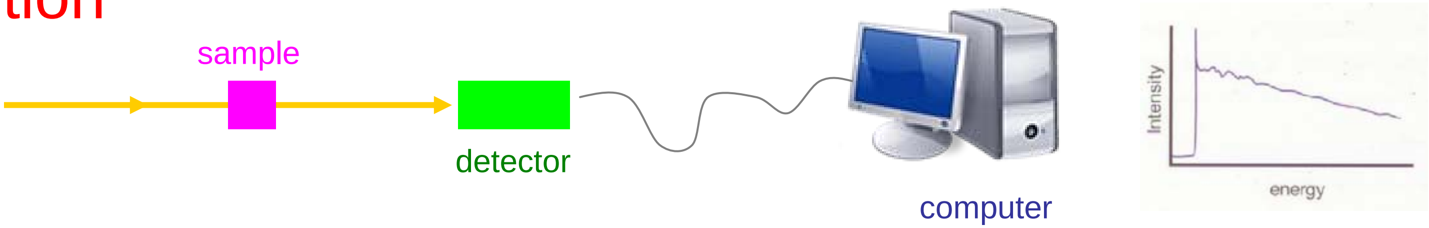


Outline

- The Facility
- The Users
- The Science

What do we do with Synchrotron Light?

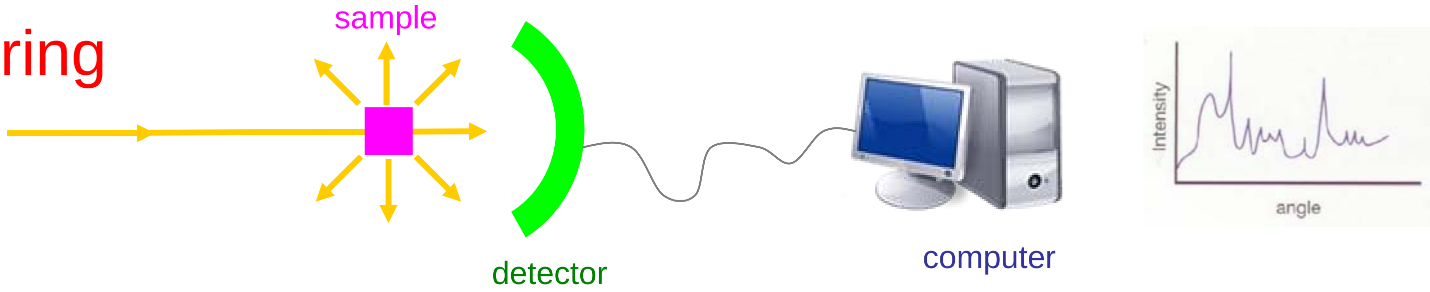
Absorption


sample

detector

computer

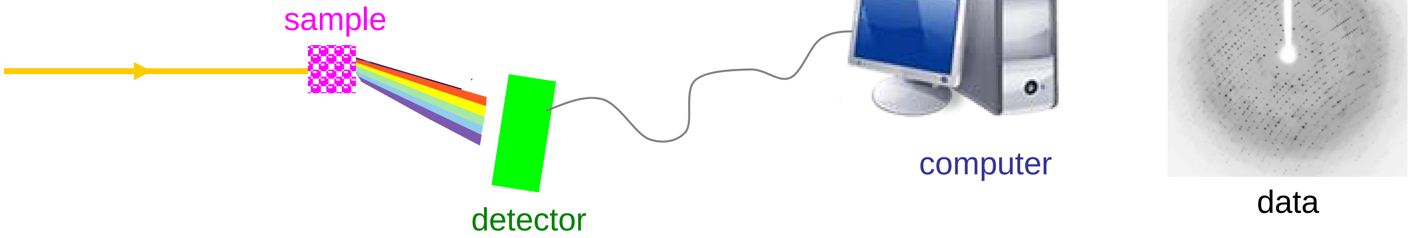
Scattering


sample

detector

computer

Diffraction


sample

detector

computer

data

Major Synchrotron Techniques

SPECTROSCOPY

- Infrared spectroscopy
- Photoelectron spectroscopy
- X-ray absorption spectroscopy
- X-ray emission spectroscopy

DIFFRACTION/SCATTERING

- Protein crystallography
- Small molecule crystallography
- Powder diffraction
- Small-angle x-ray scattering
- X-ray microdiffraction
- High momentum resolution x-ray scattering

IMAGING

- Infrared microspectroscopy
- Soft X-ray scanning microscopy
- Hard X-ray microprobe
- X-ray microtomography
- Diffraction-enhance imaging

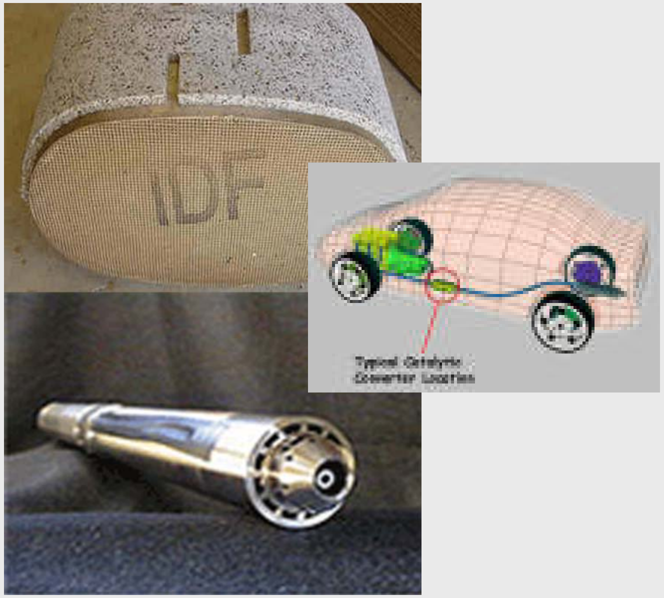
OTHER

- Micro-machining
- X-ray footprinting

Chemistry

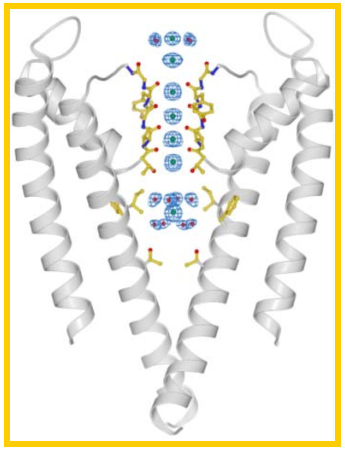
Corrosion

Rechargeable
batteries



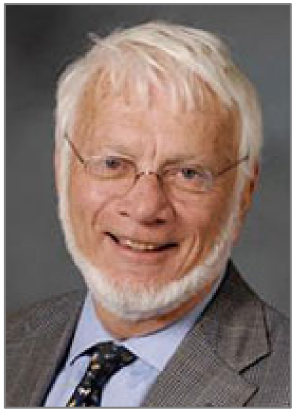
Catalytic converters

2003 and 2009 Nobel Prizes in Chemistry

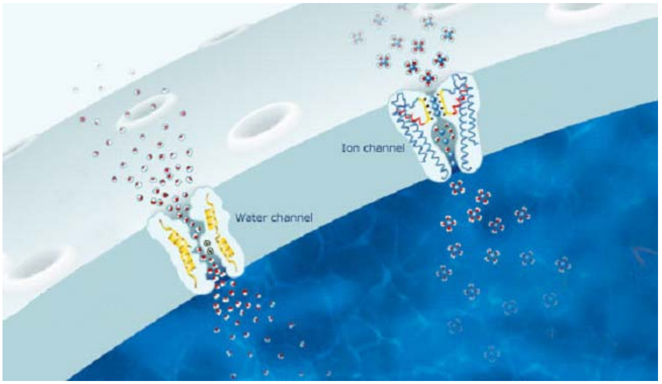


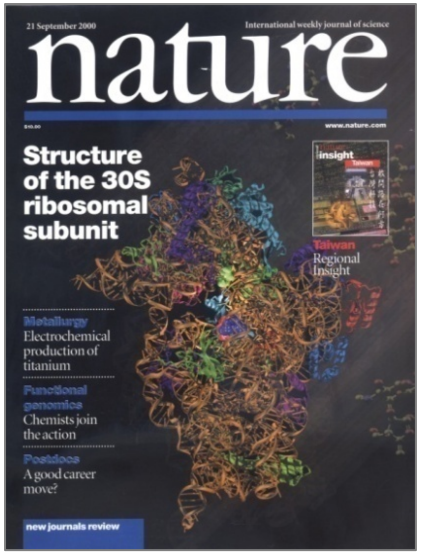
Rod MacKinnon

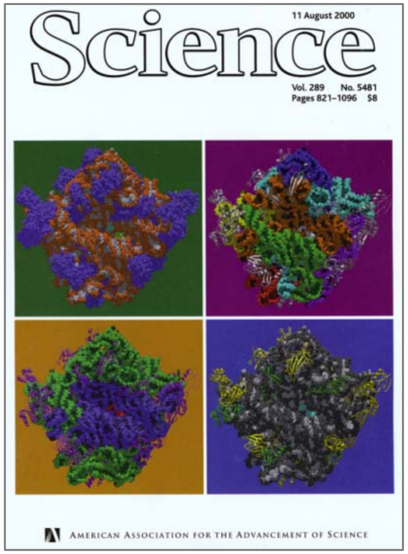
Venkatraman
Ramakrishnan



Thomas Steitz

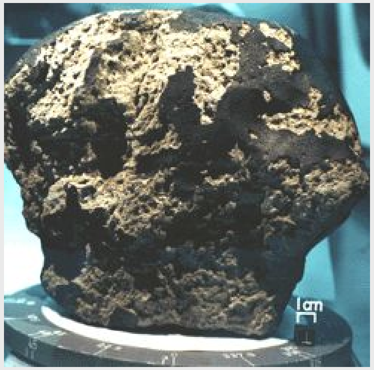






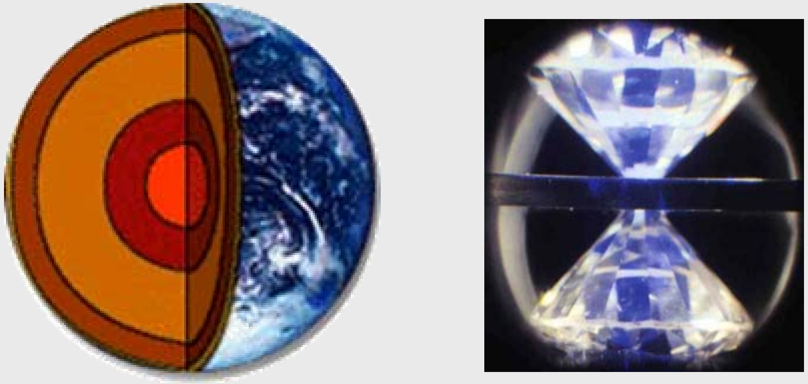
Geology and Environmental Science

Environmental cleanup



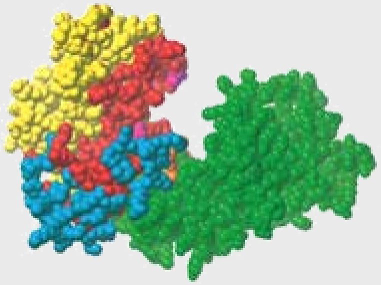
Mars meteorites

Space dust



Earth's core

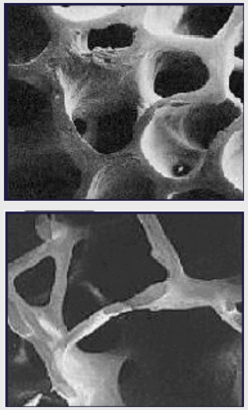
Biology and Medicine

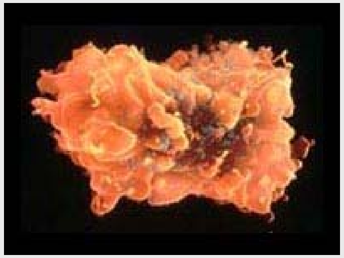

Anthrax


Malaria


Lyme's disease


Arthritis


Osteoporosis

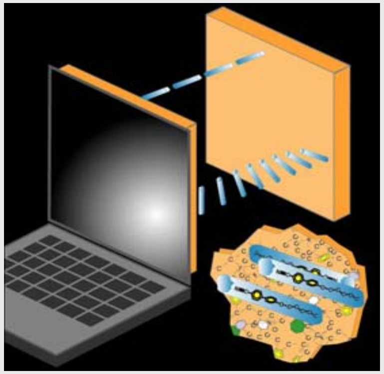

HIV


Alzheimer's disease

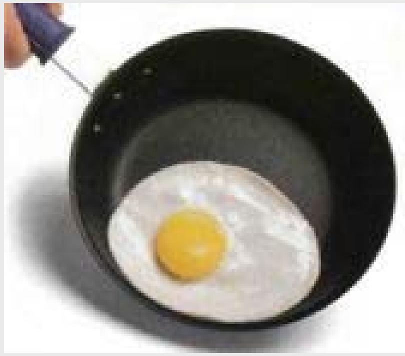
Physics and Materials Science

Data storage

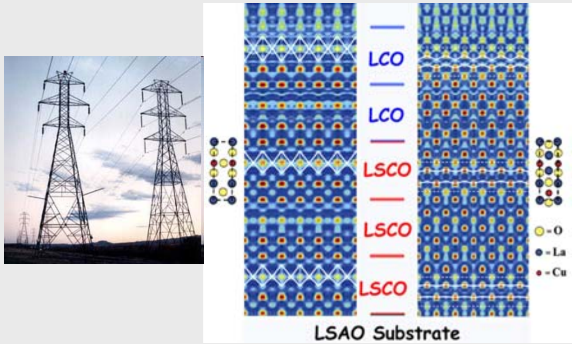
Improved polymers



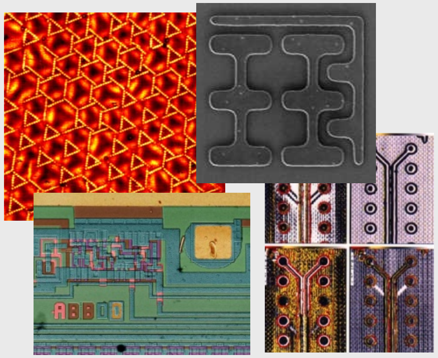
Liquid crystal displays



Nonstick coatings



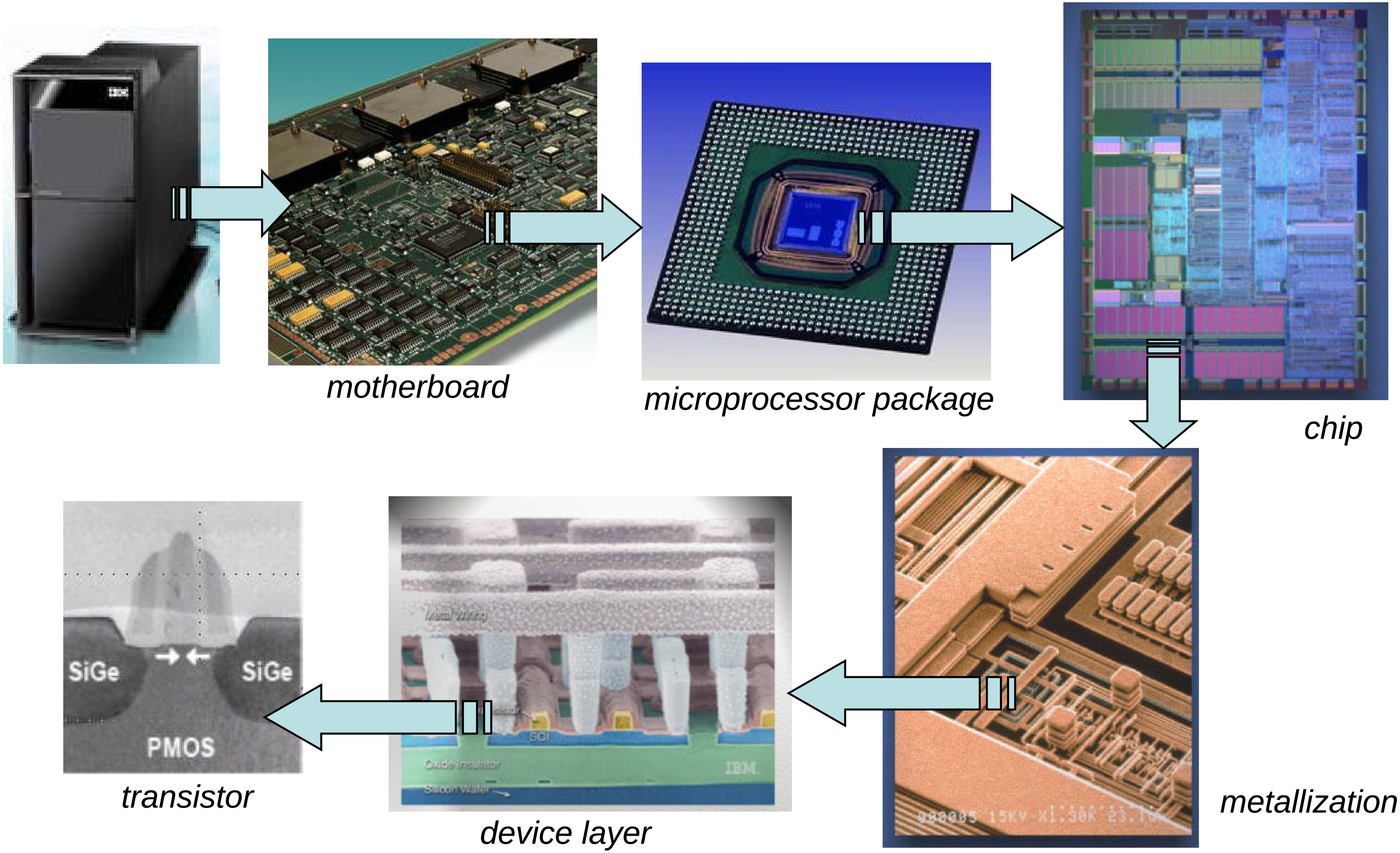
Exotic inorganics



Nanomaterials

IBM and collaborators at NSLS

Computer hardware



motherboard

microprocessor package

chip

metallization

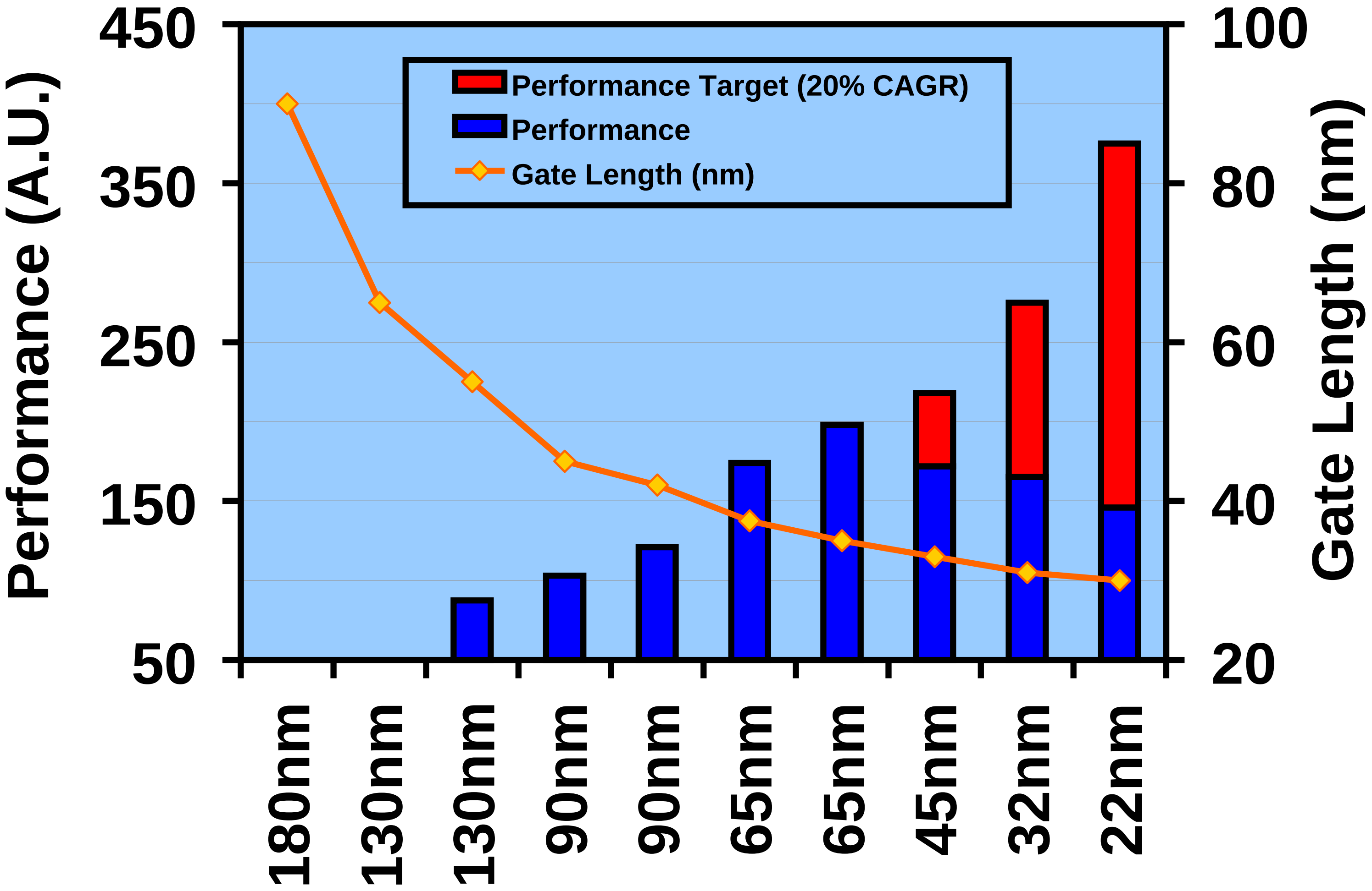
device layer

transistor

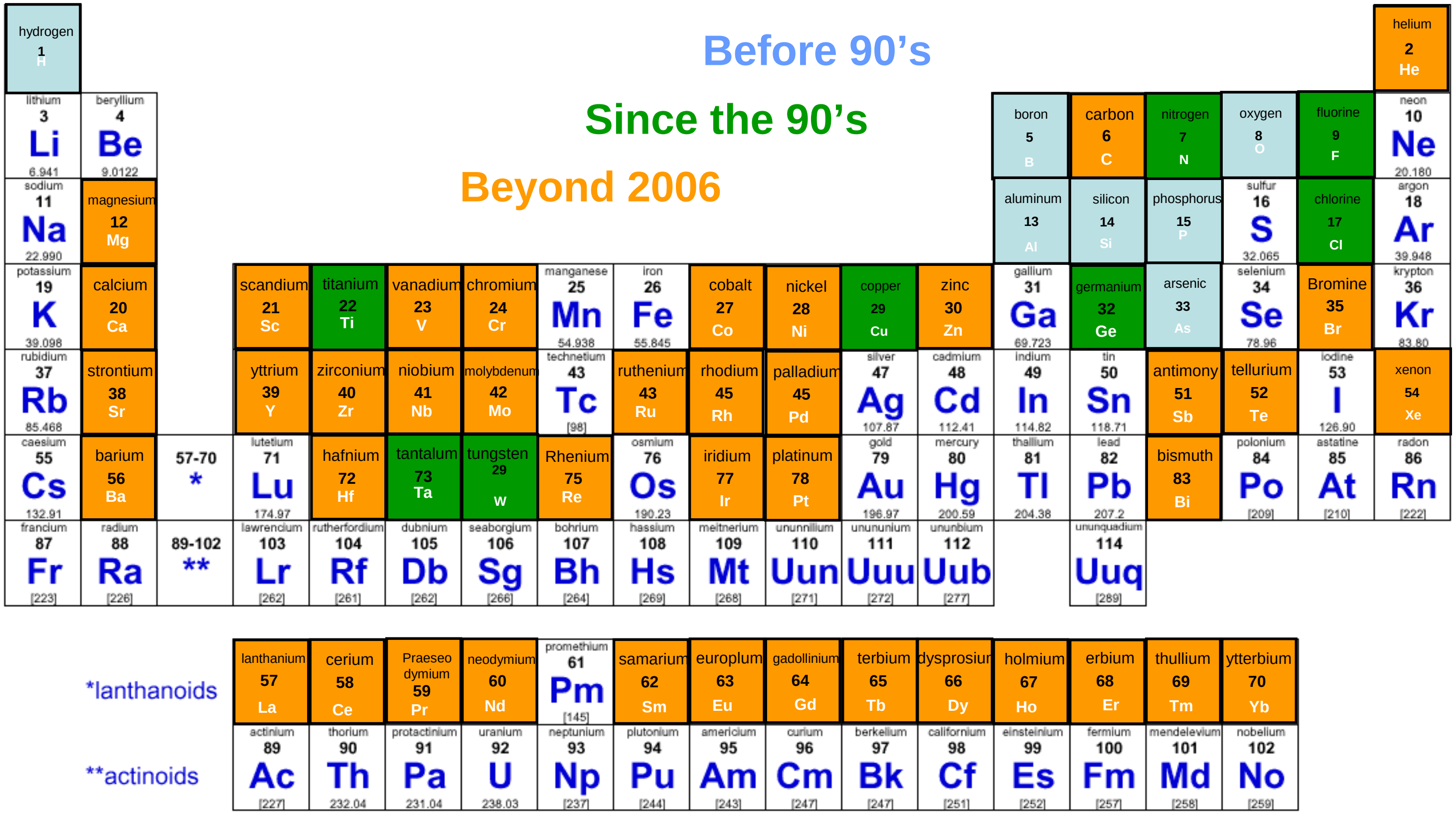
http://www-03.ibm.com/press/us/en

Faster, Smaller, Cheaper

With every generation beyond 45nm, performance scaling is becoming increasingly difficult and will require new performance-enhancing elements



“We are not just shrinking lithography and buying the next-best stepper. Everything in the last five years has included changes in basic materials and process engineering, whether it’s strain engineering, embedded silicon germanium in our SoI, our Airgap technology, our high-k metal gate—these are fundamental R&D, not just shrinking.” ***Tom Reeves*** *VP of semiconductor and technology services at IBM* , interview in *Electronic News*, 6/19/2007



Before 90’s

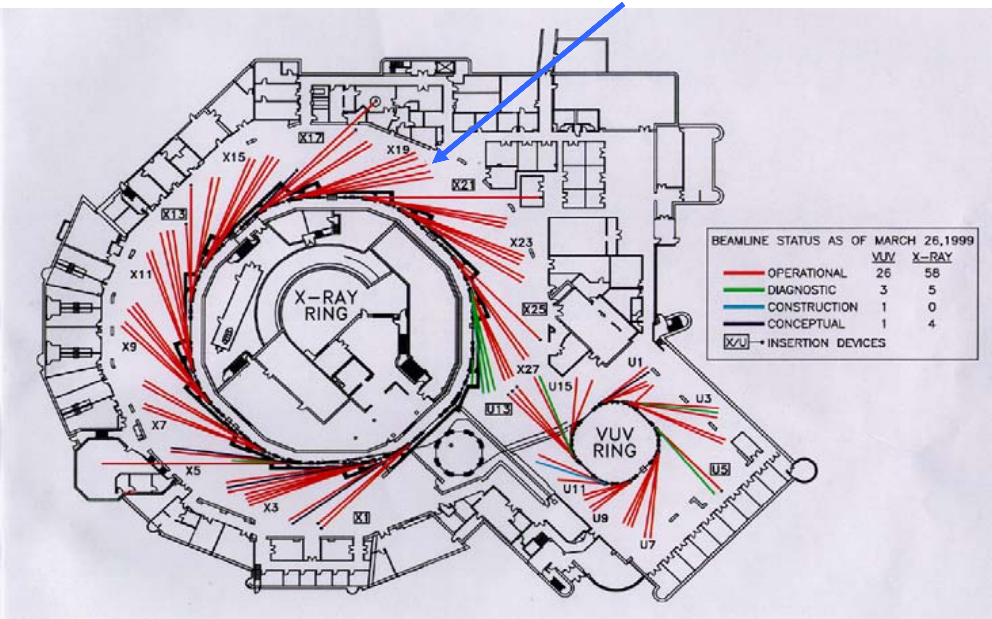
Since the 90’s

Beyond 2006

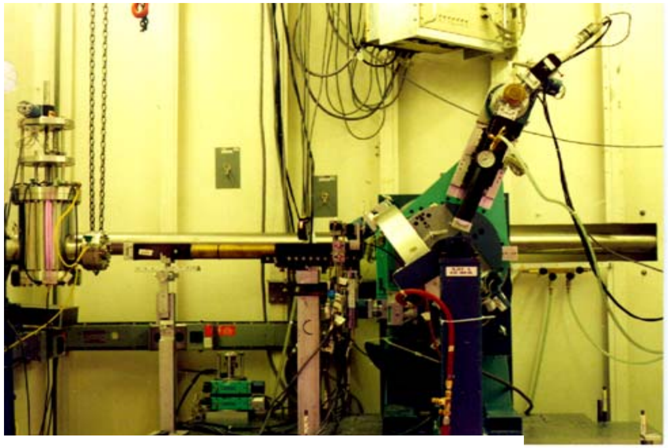
hydrogen 1 H																		helium 2 He
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B	carbon 6 C	nitrogen 7 N	oxygen 8 O	fluorine 9 F	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg												aluminum 13 Al	silicon 14 Si	phosphorus 15 P	sulfur 16 S 32.065	chlorine 17 Cl	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca		scandium 21 Sc	titanium 22 Ti	vanadium 23 V	chromium 24 Cr	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co	nickel 28 Ni	copper 29 Cu	zinc 30 Zn	gallium 31 Ga 69.723	germanium 32 Ge	arsenic 33 As	selenium 34 Se 78.96	Bromine 35 Br	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr		yttrium 39 Y	zirconium 40 Zr	niobium 41 Nb	molybdenum 42 Mo	technetium 43 Tc [98]	ruthenium 43 Ru	rhodium 45 Rh	palladium 45 Pd	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb	tellurium 52 Te	iodine 53 I 126.90	xenon 54 Xe
caesium 55 Cs 132.91	barium 56 Ba	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf	tantalum 73 Ta	tungsten 29 W	Rhenium 75 Re	osmium 76 Os 190.23	iridium 77 Ir	platinum 78 Pt	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				
*lanthanoids			lanthanium 57 La	cerium 58 Ce	Praeseo dymium 59 Pr	neodymium 60 Nd	promethium 61 Pm [145]	samarium 62 Sm	europlum 63 Eu	gadollinium 64 Gd	terbium 65 Tb	dysprosium 66 Dy	holmium 67 Ho	erbium 68 Er	thullium 69 Tm	ytterbium 70 Yb		
**actinoids			actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]		

Why IBM comes to the NSLS:

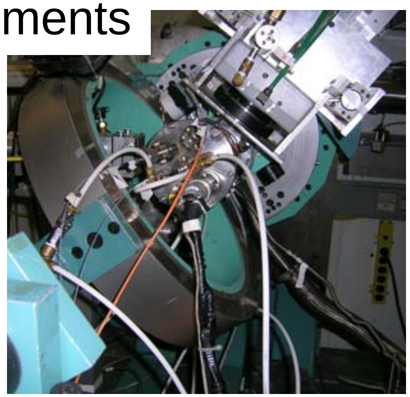
IBM scientists travel to the NSLS to use x-rays to look at the arrangement of atoms in crystalline materials. The x-rays can tell us the type of crystal, if it is under stress, or if it is unstable during heating or reacts with other materials. We can also use x-rays to measure the thickness of films, how rough they are, and their "texture".



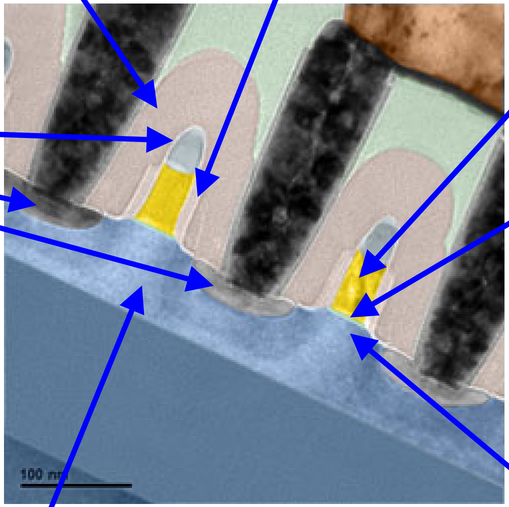
IBM's X20 beamlines



beamline instruments



FEOL materials and challenges



http://www-03.ibm.com/press/us/en/
photos.wss?rN=26&topic=6

strain liner
Si_3N_4-based
strain
interface quality

gate liner
Si_3N_4/SiO_2
interface quality

metal gate
TiN, W, metallic cmpds
work function
low resistance
thermal stability

metal silicides
Ni(M)Si
contact resistance
interface quality
shorts to gate
stability
texture

gate dielectric
HfO_2, La_2O_3, ZrO_2, others
high dielectric constant
interface quality
equivalent thickness
amorphous
leakage current

SOI
Si, SiGe, Ge
crystal quality
interface smoothness
capacitance

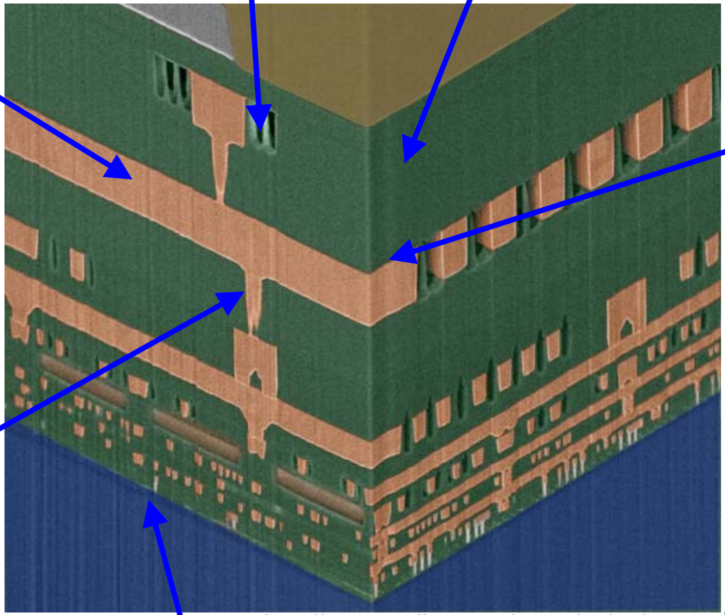
carrier channel
Si, SiGe, Ge
dopant profile
strain
stability
interface quality

BEOL / MOL materials and challenges

metallization
Cu, alloys
low resistance
TDDB
interface quality
plating conditions
seeding
self-annealing
electromigration

dielectric
air gap
formation
stability

dielectric
SiCOH, nanoglass, porogens
low dielectric constant
interface quality, pore size distribution,
mechanical strength



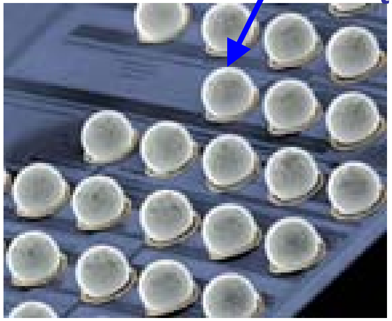
caps
CoWP, $SiC_xN_yH_z$
uniformity
barrier stability
stress

liners
Ti, Ta, TaN, TiN
uniformity
barrier stability
conformality

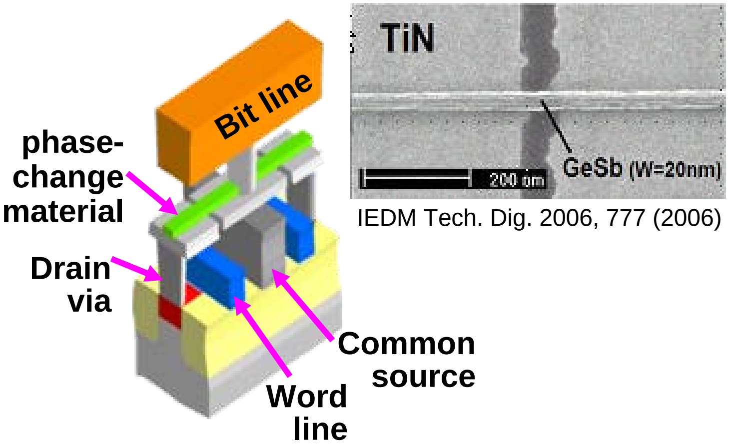
http://www-03.ibm.com/press/us/en/photos.wss?rN=36&topic=6

vias
W
low resistance
interface smoothness
conformal filling

solder
lead-free Sn-
uniformity
purity (radiation)
thermal stability



New devices, exotic materials

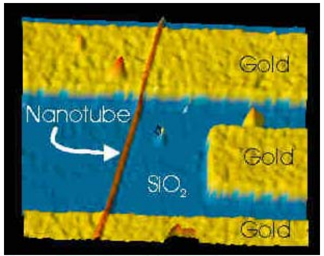


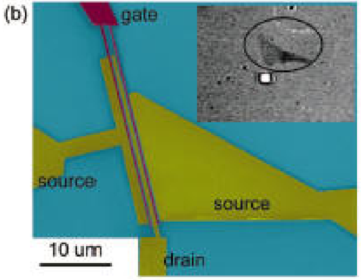
IEDM Tech. Dig. 2006, 777 (2006)

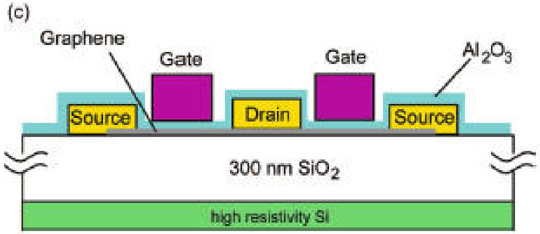
Phase-change memory

GeSb, GeSbTe, GeTe,others

- *crystallization Temp*
- *amorphization Temp*
- *resistance change*
- *transition speed*
- *scalability, cyclability*





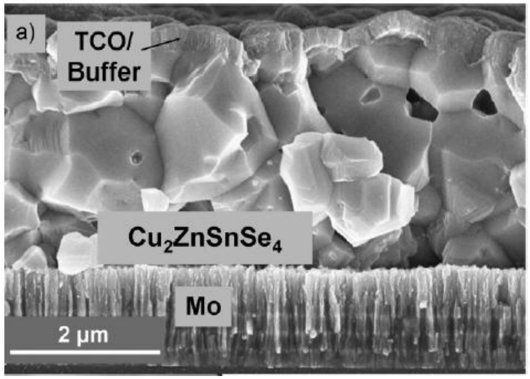


Nano Lett 9(1)422 (2009)

C-based transistors

graphene, CNT

- *switching speed*
- *carrier mobility*
- *manufacturability*



Adv. Mater. 22, E156, 2010

solar cells

CIGS, CZSSS, Si

- *ohmic contact*
- *efficiency*
- *low cost*
- *stability*
- *manufacturability*

The End