Rewards and Pitfalls of Interdisciplinary Research

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The Ohio State University

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National and Foreign Partners

The Aligarh Muslim University, India

And

The Ohio State University, USA

Disciplinary, Interdisciplinary, Multi-Disciplinary

- Global problems are generally **Multi-Disciplinary**
  - Climate change
  - Cancer research
  - Health and medicine
  - Data Analytics
  - Economic and Business Risk Management
  - Space exploration
- **Interdisciplinary ㅂ Interactive Disciplines**
  - Chemical physics, Biophysics, Astrophysics
  - Online digital communication and education
  - Nanotechnology
  - Search for extra-solar planets

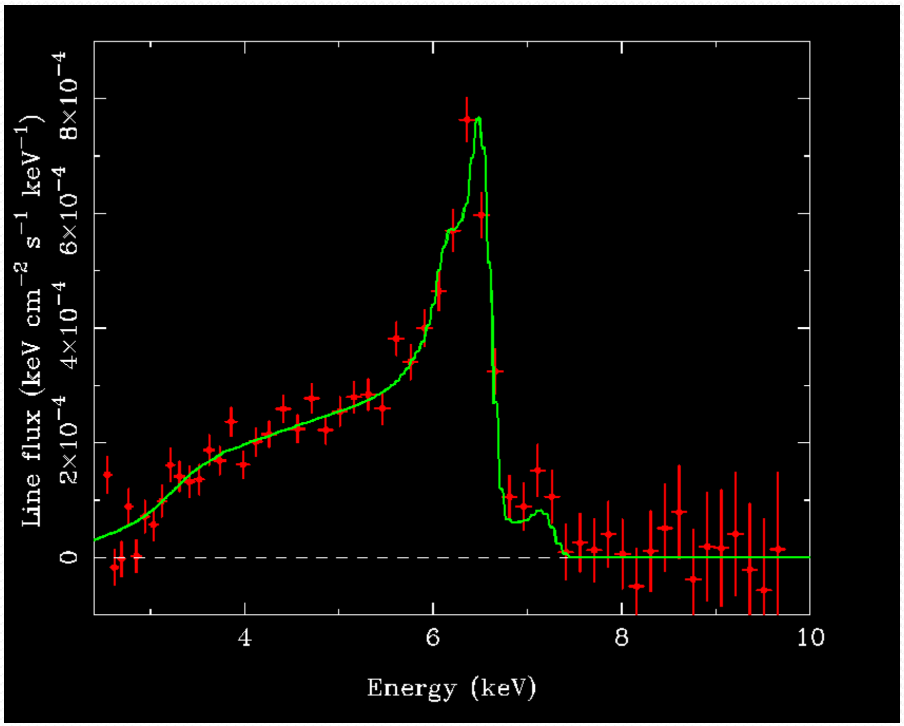
Black Holes

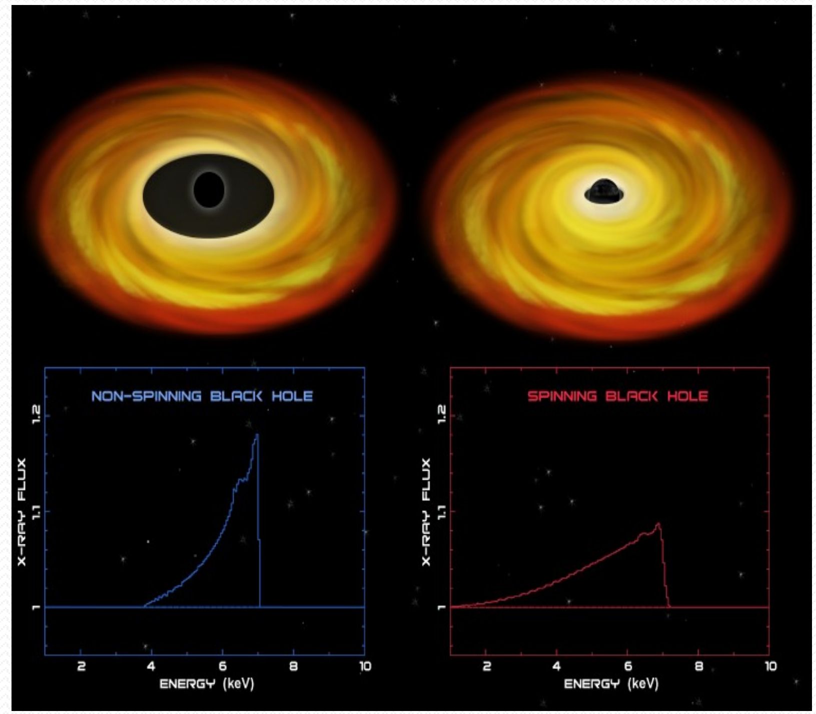
How do we know black holes exist ?

X-Ray Astronomy

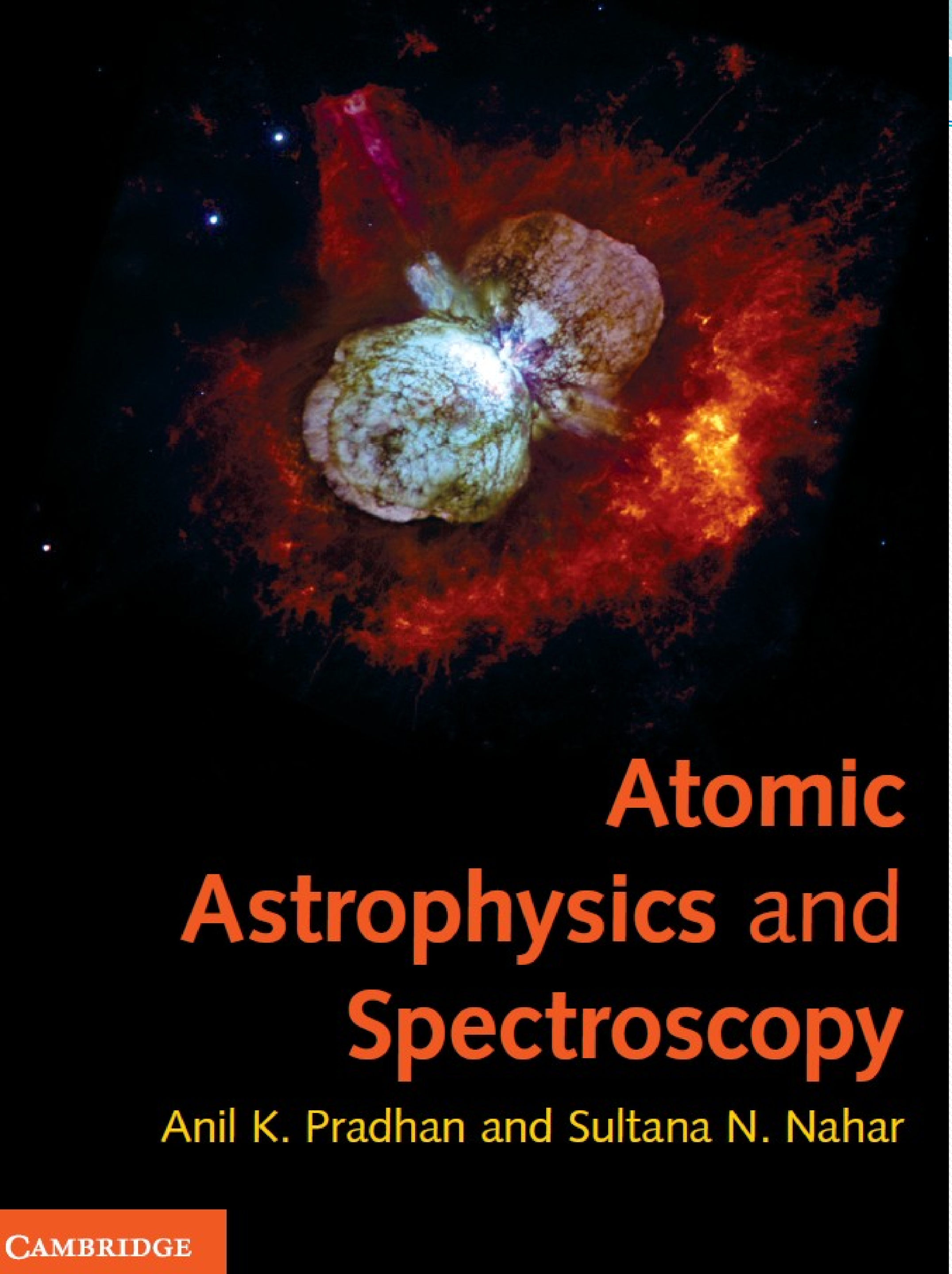
Relativistic Broadening of Iron Kα (6.4 keV)

2p ㅂ 1s transition array





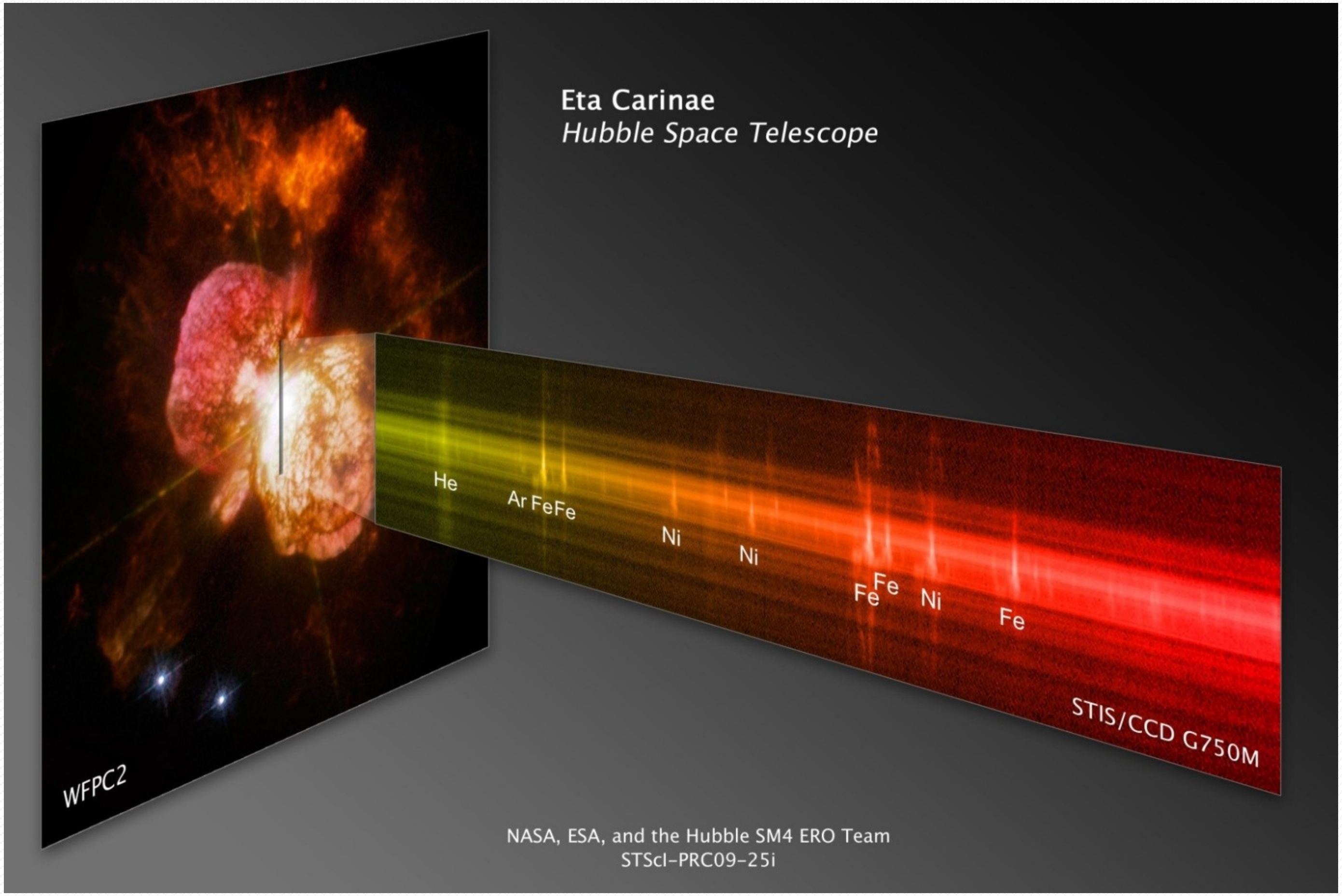
- Due to gravitational potential of the black hole photons lose energy
- Asymmetric broadening at decreasing photon energies < 6.4 keV



Eta Carinae Nebula
Massive Stellar Eruption

- Binary Star System
- Symbiotic Star
- ~100 M(Sun)
- ~1,000,000 L(Sun)
- Pre-supernova phase

Image + Spectrum



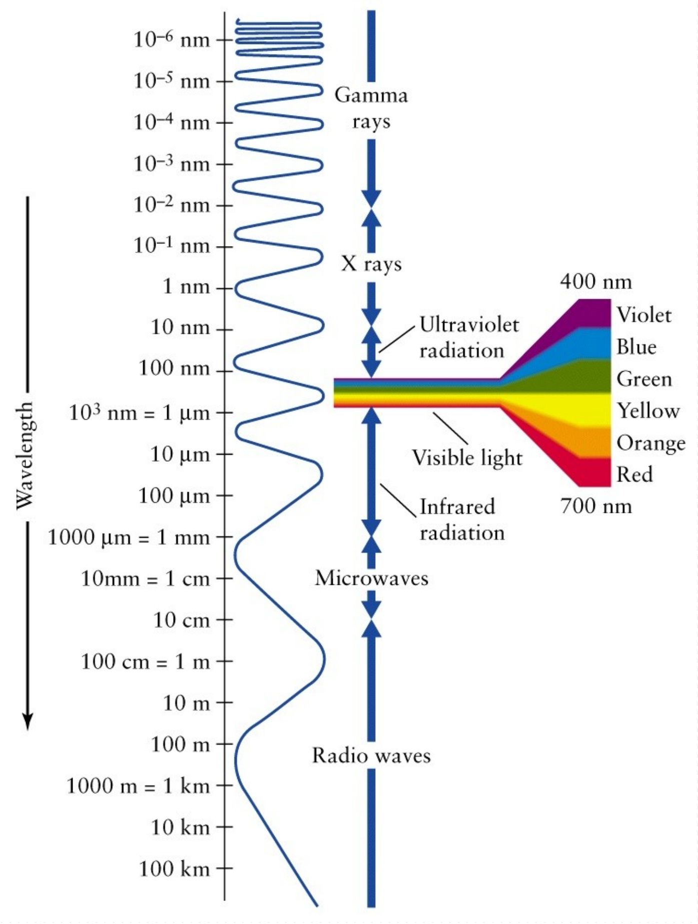
Imaging vs. Spectroscopy

- Imaging □ Pictures

- Spectroscopy □ Microscopic (or Nanoscopic) science of light and matter

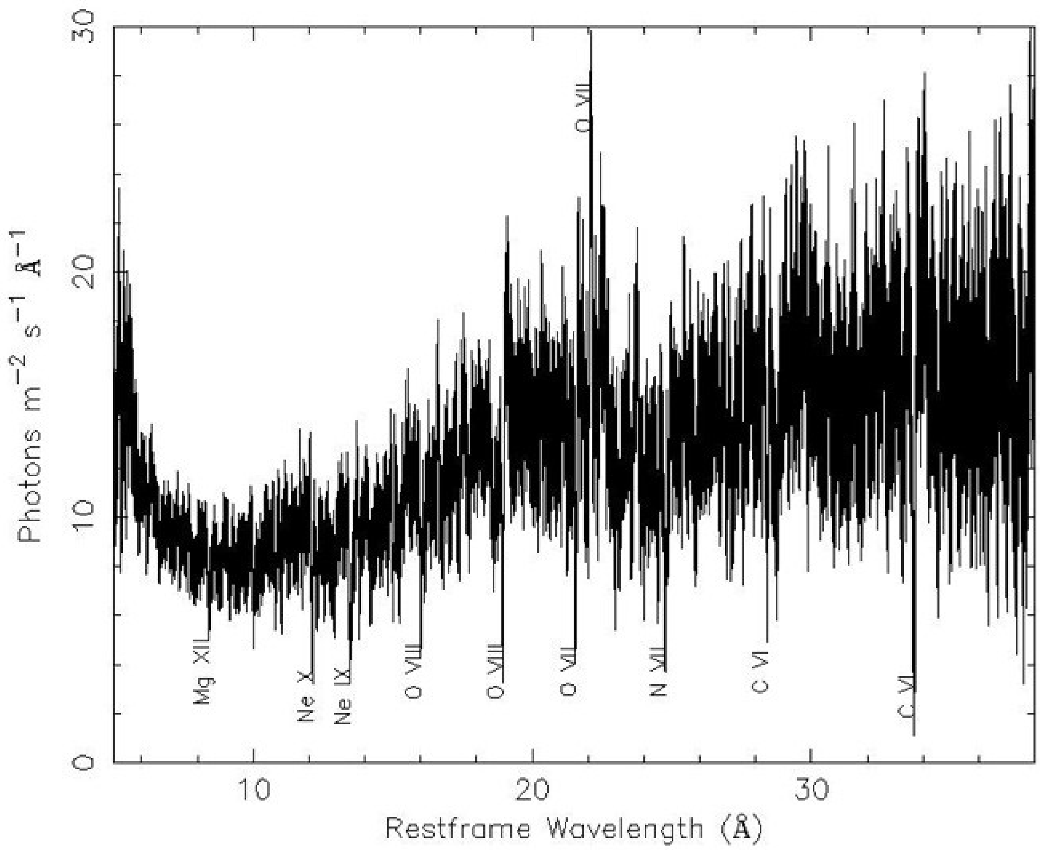
- Pictures are incomplete at best, and deceptive at worst

Light: Electromagnetic Spectrum From Gamma Rays to Radio



Gamma rays are the most energetic (highest frequency, shortest wavelength), radio waves are the least energetic.

Active Galactic Nucleus
NGC 5548, central region, spectral bar code



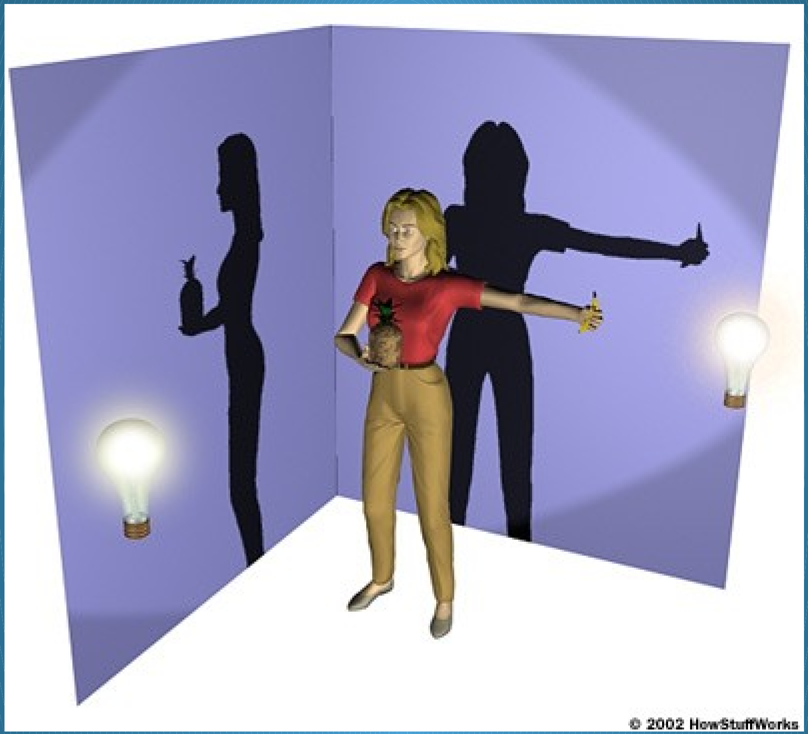
X-Rays in Medicine

CAT Scans (Computerized Tomography)

- **Full-body scans to detect cancer**
- **Great Idea !! ....??**
- **CAT scanners use high-energy X-rays with very high radiation dosages comparable to Hiroshima! -- NY Times (Sep. 6, 2004)**

"For a prime example of medical screening that has proliferated beyond reason, consider the alarming case of full-body computed tomography scans to detect cancer, cardiovascular disease and other conditions"

CATSCAN: Image Depends on Viewing Angle



Woman holding a pineapple if viewed from the right;
Or a banana if viewed from the front

N.B. The Image is formed by ABSORPTION not EMISSION, as in an X-ray

NEED 3D IMAGE ⇒ CATSCAN

Paradigm Change
X-Ray Imaging ▭ Spectroscopy

- Spectroscopy is far more powerful than imaging

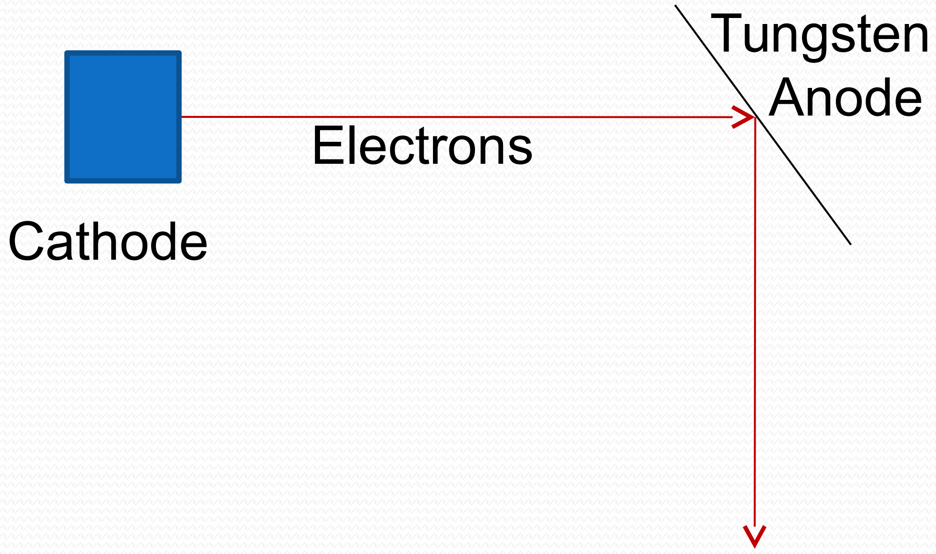
  "A spectrum is worth a thousand pictures"
- Every element or object in the Universe has

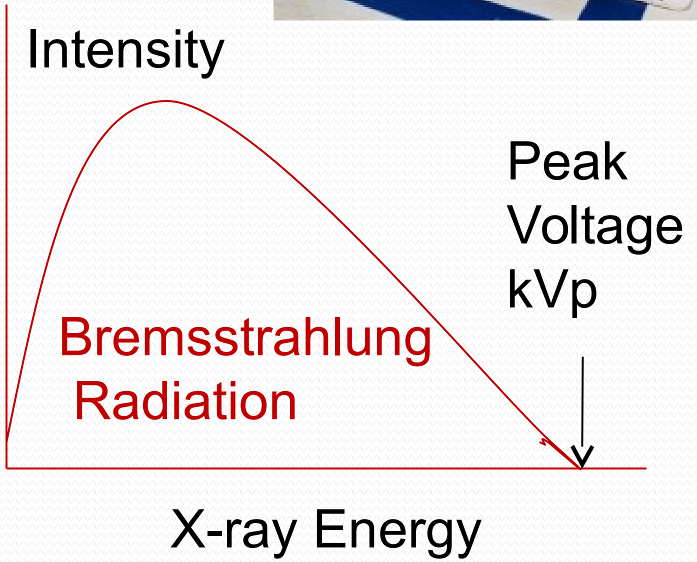
  unique spectral signature (like DNA)
- Absorption and emission of X-rays is highly efficient at resonant spectral energies in heavy element nanoparticles embedded in tumors
- Potentially useful in

  Imaging, diagnostics, and therapy

X-Ray Spectroscopy

- How are X-rays produced?
- Roentgen X-ray tube: Cathode + a





Problems With Traditional Broadband X-Ray Machines

Energies too low: insufficient penetration, too much absorption by intervening tissue

- Need Higher radiation dose

Energies too high: too much penetration, too little absorption or density contrast

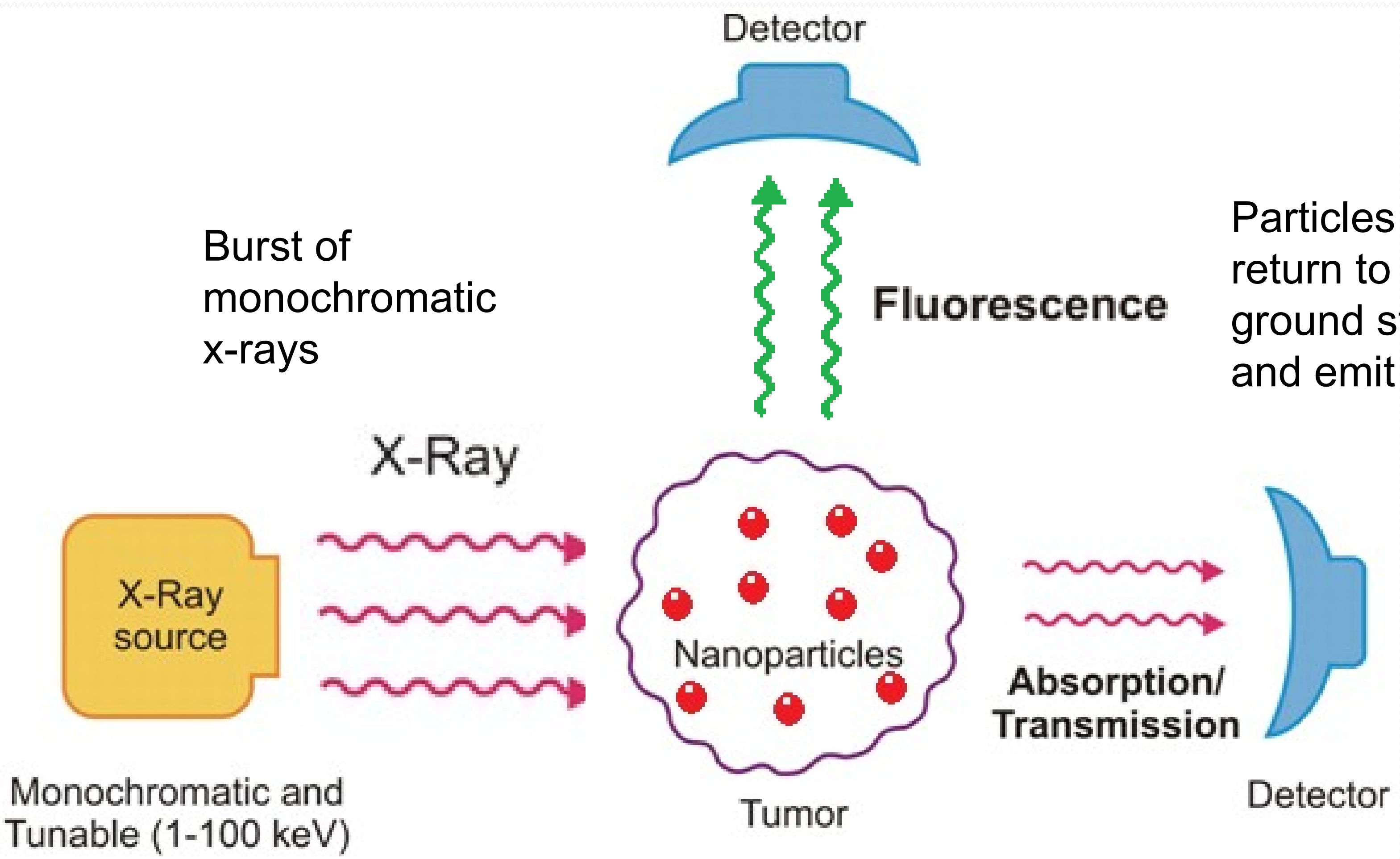
- Need Higher radiation dose

Need X-rays at energies “just right”

- **The Goldilocks Criterion:**

BROADBAND → MONOCHROMATIC

Therapy and Diagnostics (Theranostics)



Burst of monochromatic x-rays

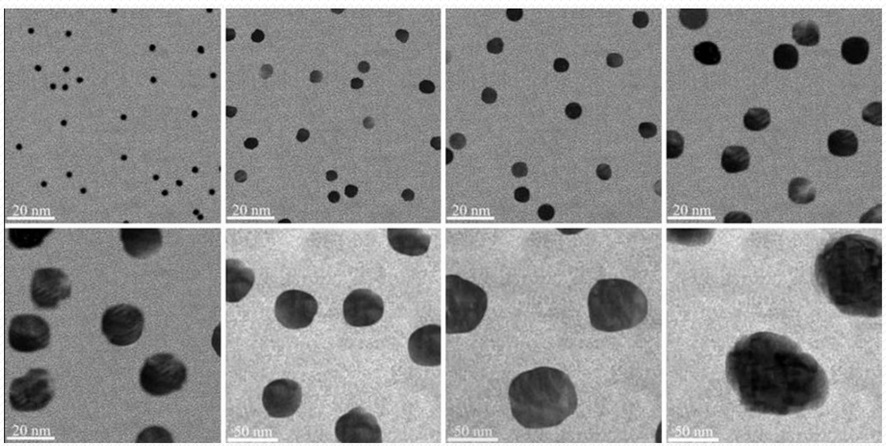
Particles return to the ground state and emit light

Particles absorb X-rays and excite/ionize

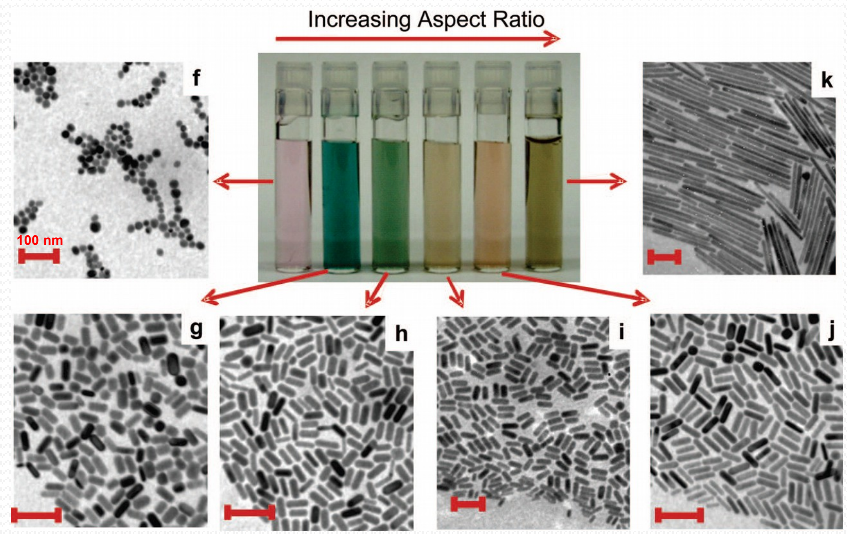
X-rays that are transmitted are detected

Nanobiotechnology: Gold Nano Particles (GNP)

GNPs with diameters of 3~100 nm



Gold nanorod with aspect ratio varies from 1.3~5



Well controlled size and shape of GNPs can be made relatively easy.

Nanoscale Res Lett (2009) 4:858–864
ACCOUNTS OF CHEMICAL RESEARCH (2008)1721-1730

NANOTECHNOLOGY

Gold Nanoparticles in Mice Tumor Irradiated with BROADBAND X-rays

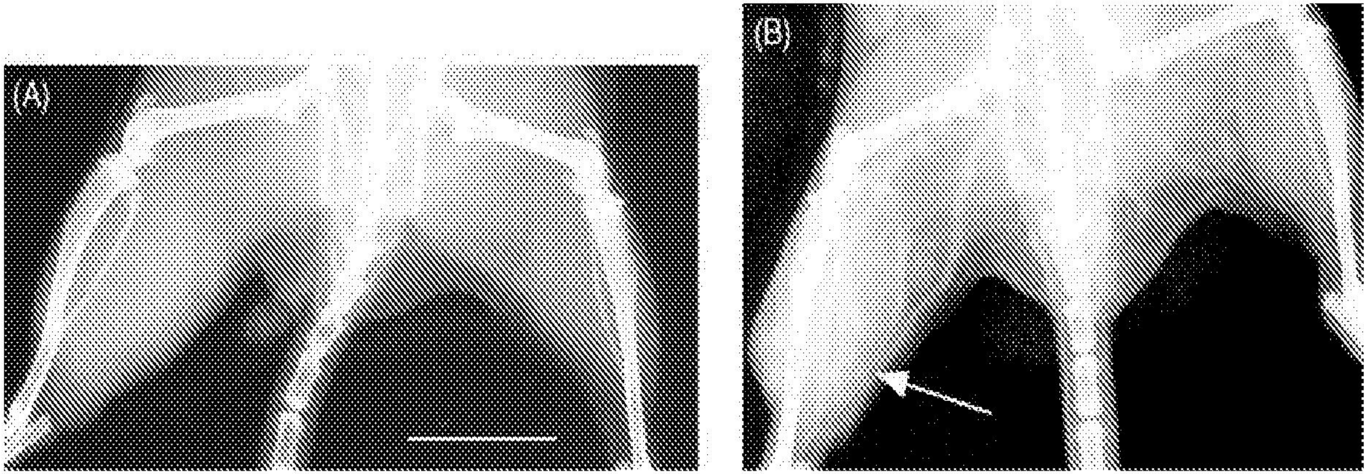


Figure 3. Radiographs of mouse hind legs before and after gold nanoparticle injection. (A) Before injection. (B) 2 min after i.v. gold injection (2.7 g Au/kg). Significant contrast (white) from the gold is seen in the leg with the tumour (arrow) compared with the normal contralateral leg. 6 s exposures at 22 kVp and 40 mA s. Bar = 1 cm.

Reduction in Tumor Size Following Gold Irraditaion with X-rays

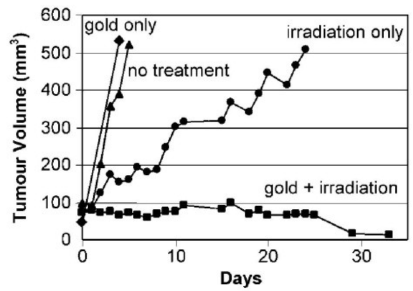


Figure 1. Average tumour volume after: (a) no treatment (triangles, $n = 12$); (b) gold only (diamonds, $n = 4$); (c) irradiation only (30 Gy, 250 kVp, circles, $n = 11$); (d) intravenous gold injection (1.35 g Au/kg) followed by irradiation (squares, $n = 10$).

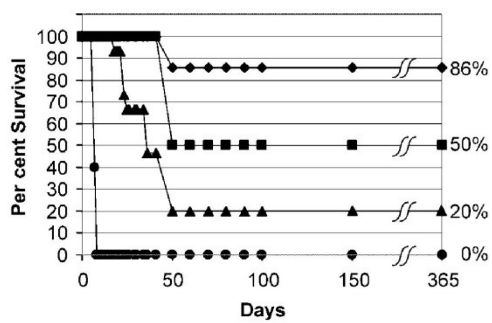


Figure 2. Graph of mice survival after various treatments of subcutaneous EMT-6 tumours. A gold dose response was evident. Circles: no treatment ($n = 17$), and gold only (1.35 g Au/kg, no irradiation), indistinguishable from no treatment ($n = 4$); triangles: irradiation only (26 Gy, 250 kVp), producing 20% long-term (>1 year) survival ($n = 15$); squares: irradiation after i.v. injection of 1.35 g Au/kg gold nanoparticles, 50% long-term survival ($n = 4$); diamonds: irradiation after 2.7 g Au/kg injection, producing 86% long-term survival ($n = 7$).

General issues:

1. Radiation dosage
2. Nanobiotechnology
3. Targeting & delivery

X-Ray Sources Output Spectra:

Broadband BX (a),

Quasi-Monochromatic (QX) with sharp spectral features (b-f) narrowband,

Monochromatic MX (g) From synchrotrons

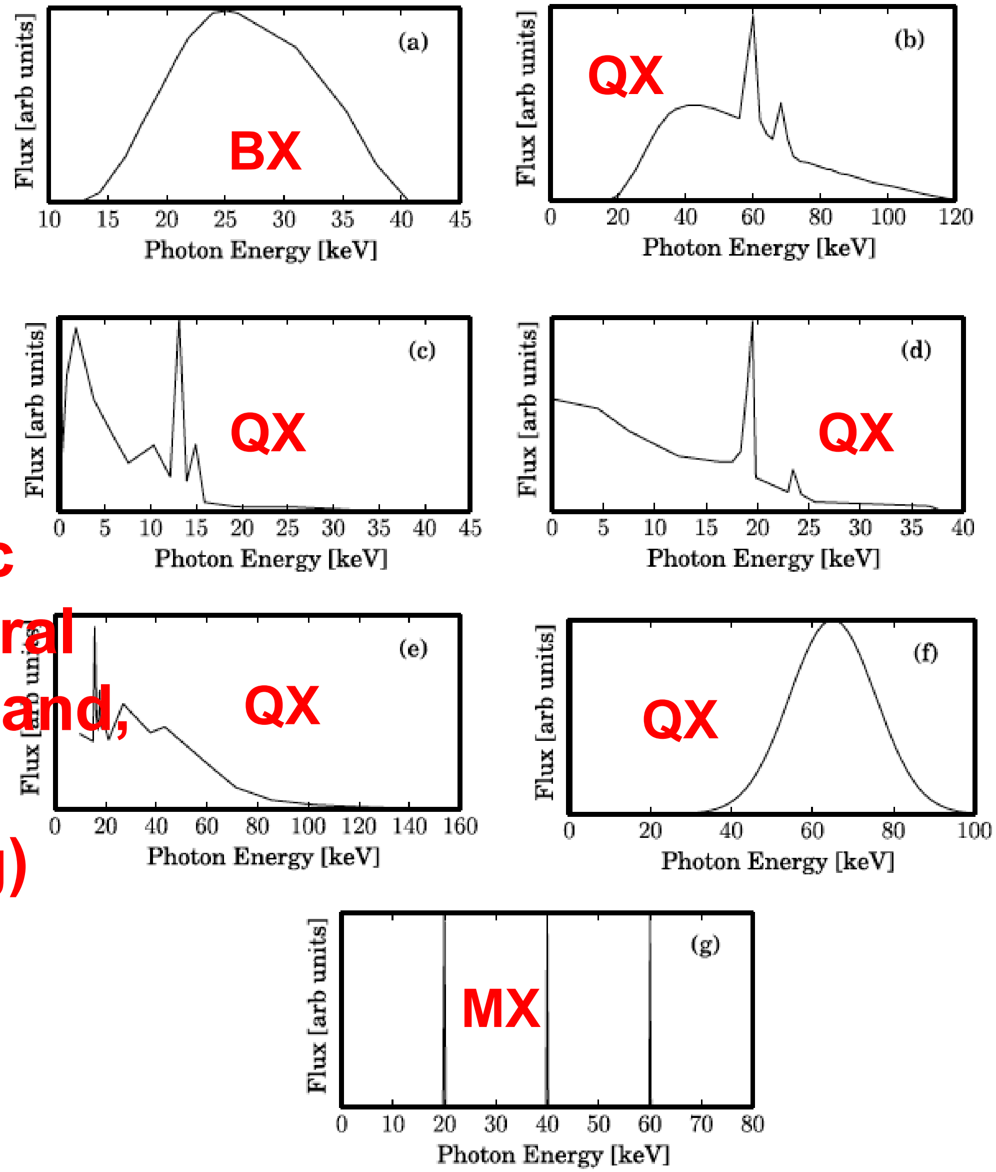


Figure 1. The eight spectra used in GEANT4 simulations—two broadband (BX), three quasi-monchromatic (QX), and three monochromatic (MX): (a) BX 40 kV, (b) BX 120 kV with tungsten target (CT Scan); (c) QX high-intensity laser with zirconium target with $K\alpha$ 15.7 keV, and (d) silver target with $K\alpha$ 22.0 keV; (e) QX broadband-to-monochromatic x-ray (B2MX) conversion of 150 kV source using zirconium target; (f) QX inverse Compton scattering; (g) MX 20, 40, 60 keV.

Westphal et al., J. Phys. Med. Biol. 2017

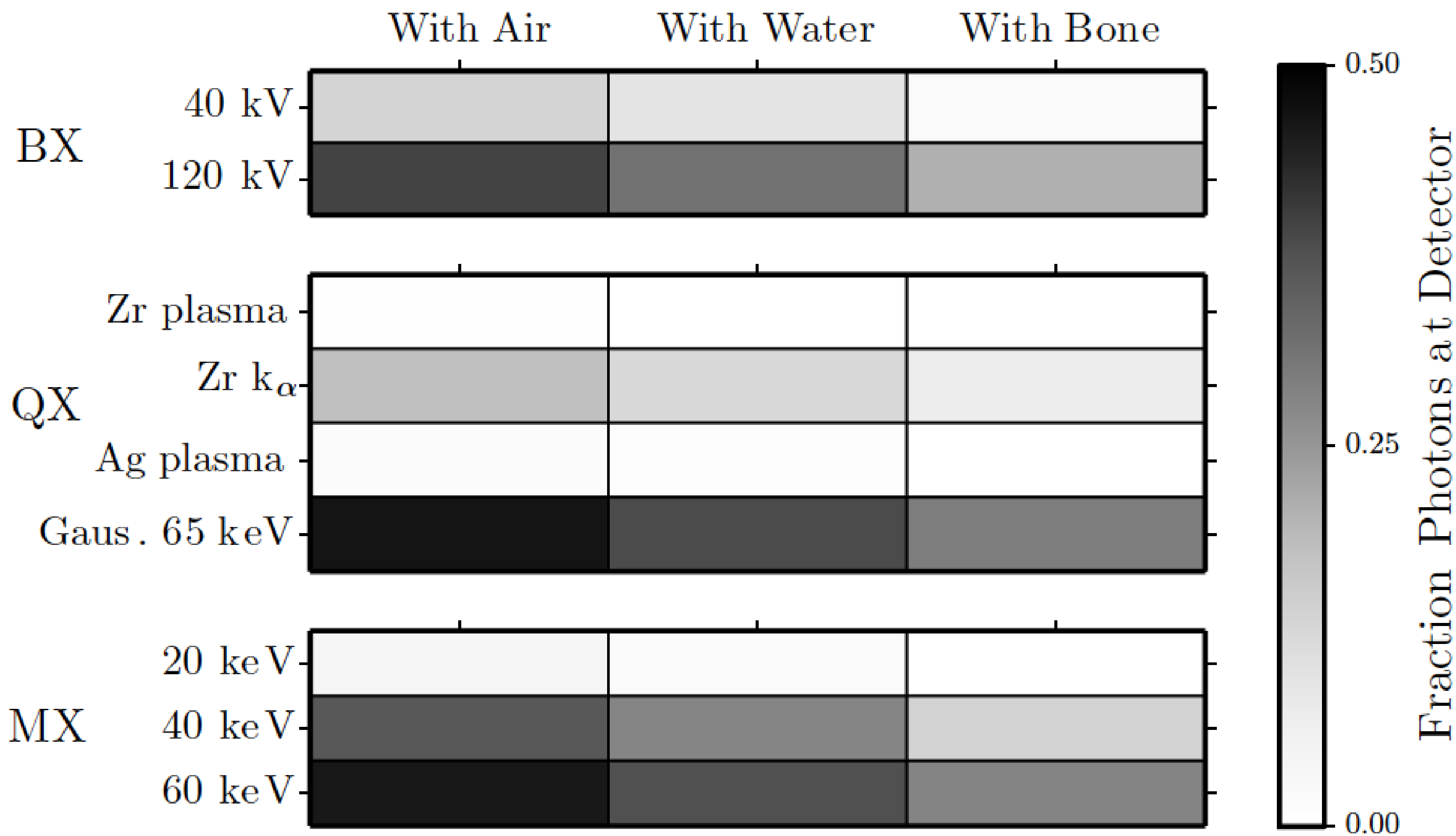
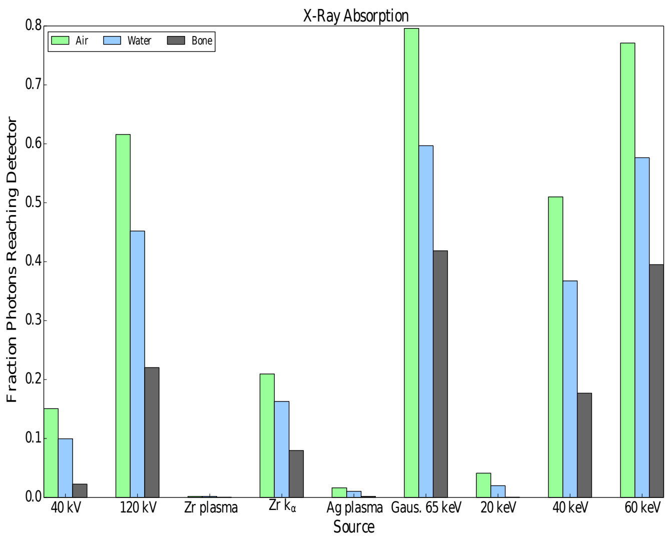
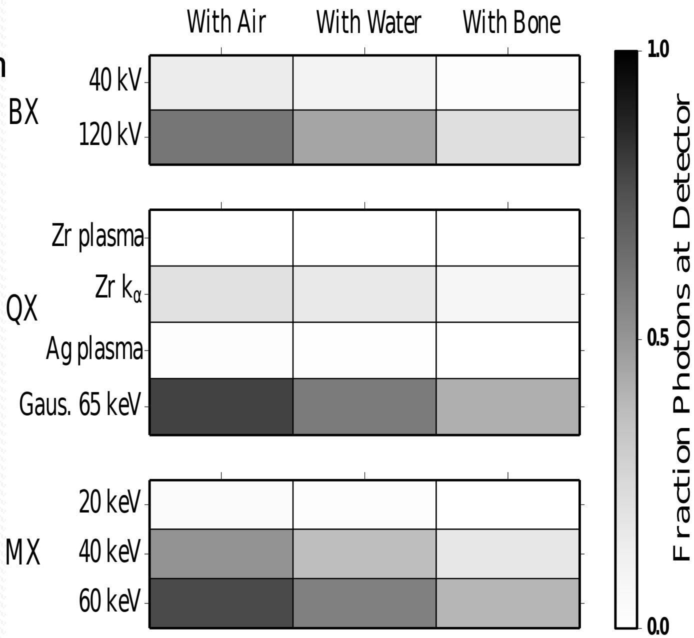


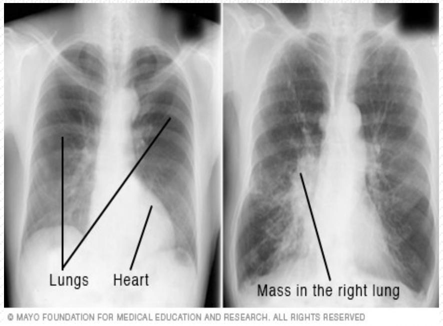
Figure 4. Rectangular phantom x-ray imaging contrast: simulated x-ray image using data from the bar plot above in figure 3. Darker sections indicate more photons reached the detector while lighter sections indicate fewer incident photons reaching the detector, corresponding to air and bone layers respectively. The QX 65 keV Gaussian input spectrum shows the best contrast, comparable to or better than the conventional 120 KV BX spectrum.

GEANT4: Monte Carlo Numerical testing variety of X-ray sources

Fraction Photons Penetrating Phantom







M.S. Westphal, *et al*. Broadband, monochromatic and quasi-monochromatic X-ray propagation in multi-Z media for imaging and diagnostics. *Physics in Medicine and Biology*, 62:6361–6378, 2017.

Nanobiophysics: Interactive Disciplines

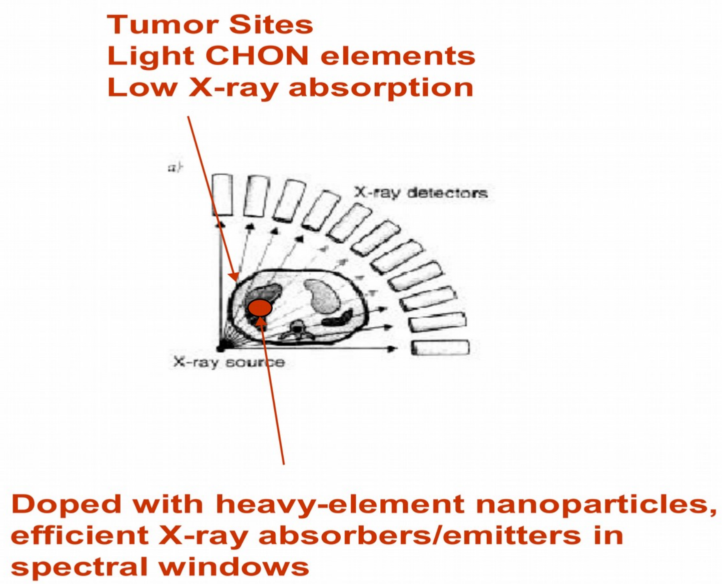
- Atomic and molecular physics and chemistry
- Nanobiotechnology using high-Z nanomoieties
- High-performance computing and modeling

  - High-precision quantum mechanical calculation of heavy atomic species: Bromine, Gadolinium, Platinum, Gold
  - Ohio Supercomputer Center

Interdisciplinary Research: **Rewards**

- Define and lead into new fields:
  - **Resonant Nano-Plasma Theranostics (RNPT)**
  - **Nanospectroscopy**

Nanospectroscopy – An example of potential application



Newsmedia Headlines (over 100)

- **Could Black Holes Help Treat Cancer Patients**? ***(Space.com)***
- **Astronomers reach for the stars to discover new cancer therapy *(Physics Inventions*)**
- **Astronomy Research Suggests Tumor Tools *(Cancer Discovery*)**
- **Researchers Study New Radiation Therapy for Cancer Employing *Resonant Nano-Plasma Theranostics (Nanomedicine)***

Ohio State University astronomers together with radiation oncologists and medical physicists are involved in developing a new radiation therapy that will be effective on tumor tissues, causing less damage to normal tissues.

Interdisciplinary Research: Pitfalls

- Team with expert collaborators across disciplines

    - Theoretical, computational, experimental programs

    - Sultana Nahar (Prof. of Astronomy), Yan Yu (Prof. of Radiation Oncology), Rolf Barth (Prof. of Pathology), Russ Pitzer (Prof. of Chemistry), Enam Chowdhury (Prof. of Physics), postdocs & students

- Seed funding to initiate

    - Large Interdisciplinary Grant from OSU

- Long lead time to establish (5-10 years)
- Proposals to multiple divisions in funding agencies

    - NIH, NSF, DOE, NASA, Local Sources,…………
    - Reviewed by disciplinary experts (doctors, physicists, chemists,…)

- Postdoc and student turnover and handover

Cautionary Lessons

- Interloper syndrome: Disciplinary skepticism
- A priori demonstration and results

  - Pathways to clinical translation to cancer treatment
  - Myriad details of future medical environment
  - Future developments in nanobiotechnology and X-ray sources
- Major projects require high-level support

  - Unsuccessful proposal to build and launch an Indo-US satellite for solar studies involving ISRO, PRL and several institutions in India and the US including OSU, NASA, NRL, Harvard, etc.

Summary

- Multi-disciplinary studies for important problems
  - -- Global warming
  - -- Cancer research
  - -- Energy sources
- Interdisciplinary effort essential for new science and technology
- Feedback to disciplinary advancement
- Support from established disciplinary collaborators
- High-level administrative and government support
- **www.astronomy.ohio-state.edu/~pradhan**