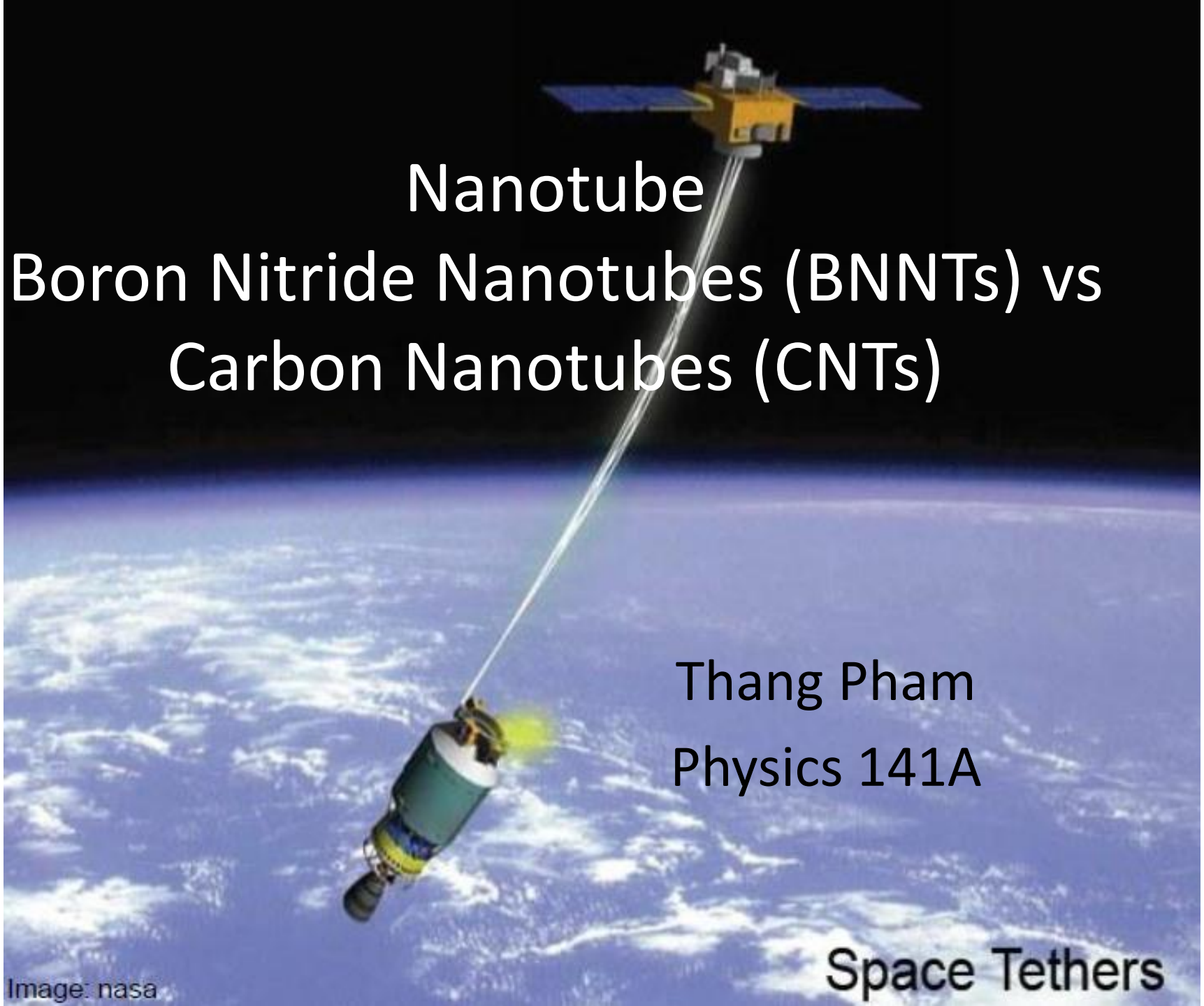
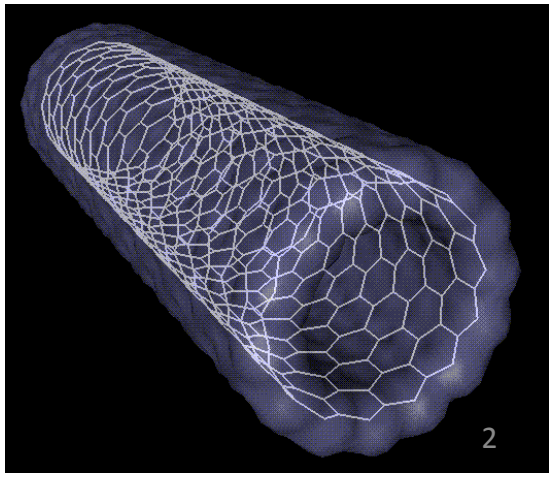
Nanotube
Boron Nitride Nanotubes (BNNTs) vs Carbon Nanotubes (CNTs)

Thang Pham
Physics 141A



Outline

1. Crystal structures of Nanotubes (NTs)
2. Physics Properties: BNNTs vs CNTs
3. What make BNNTs special?
    - 3.1 Neutron Absorption: BNNTs
    - 3.2 Giant Stark Effect (GSE): BNNT
4. Future



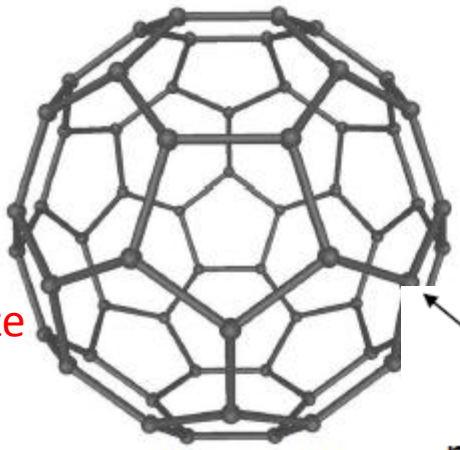
Nanotech.blogspot.com

0. What's wrong with CNTs ???

Forms (Allotropes) of Carbon

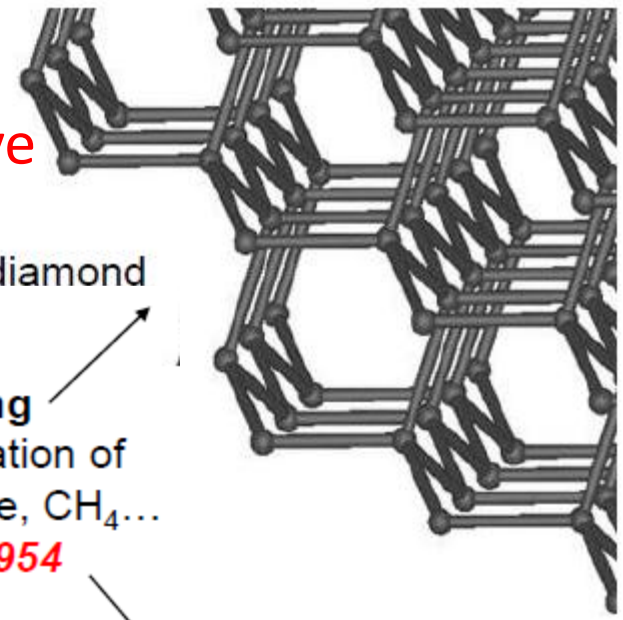
Expensive

Nobel Prize 1996



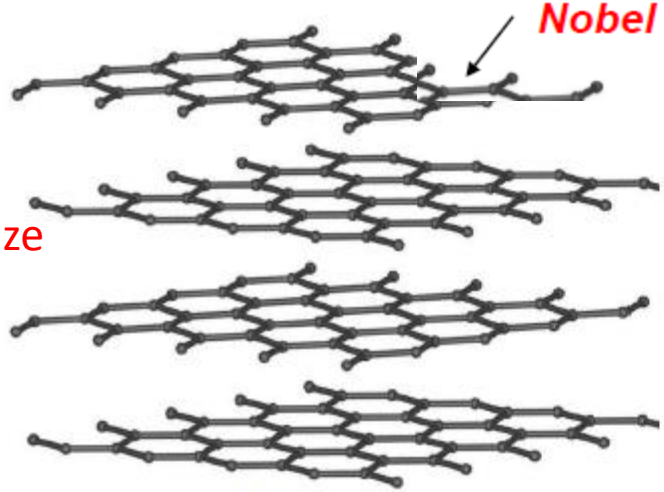
buckyball

diamond

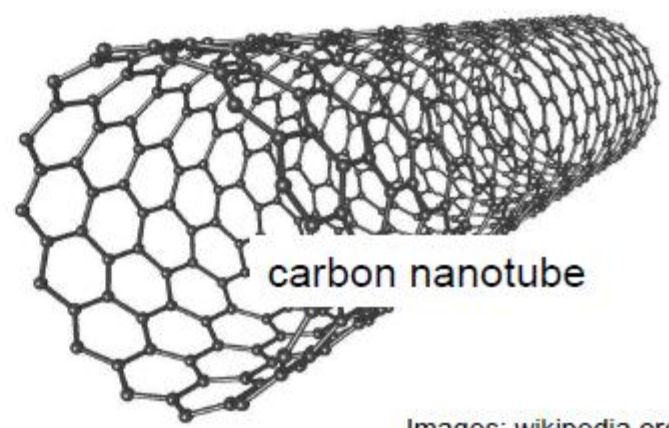


Linus Pauling
proposed hybridization of sp bonds in methane, CH_4…
Nobel Prize 1954

Nobel Prize 2010



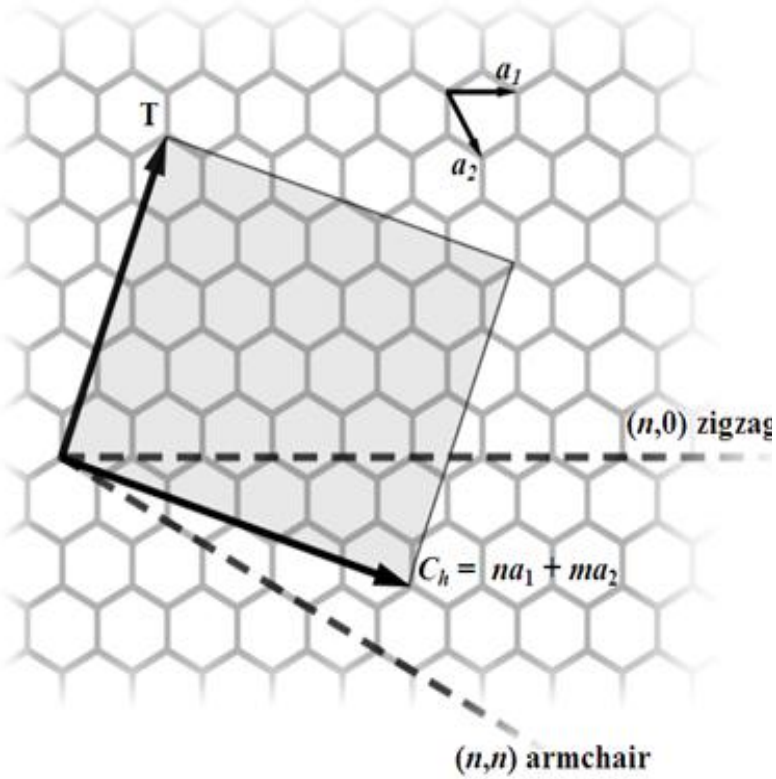
graphite

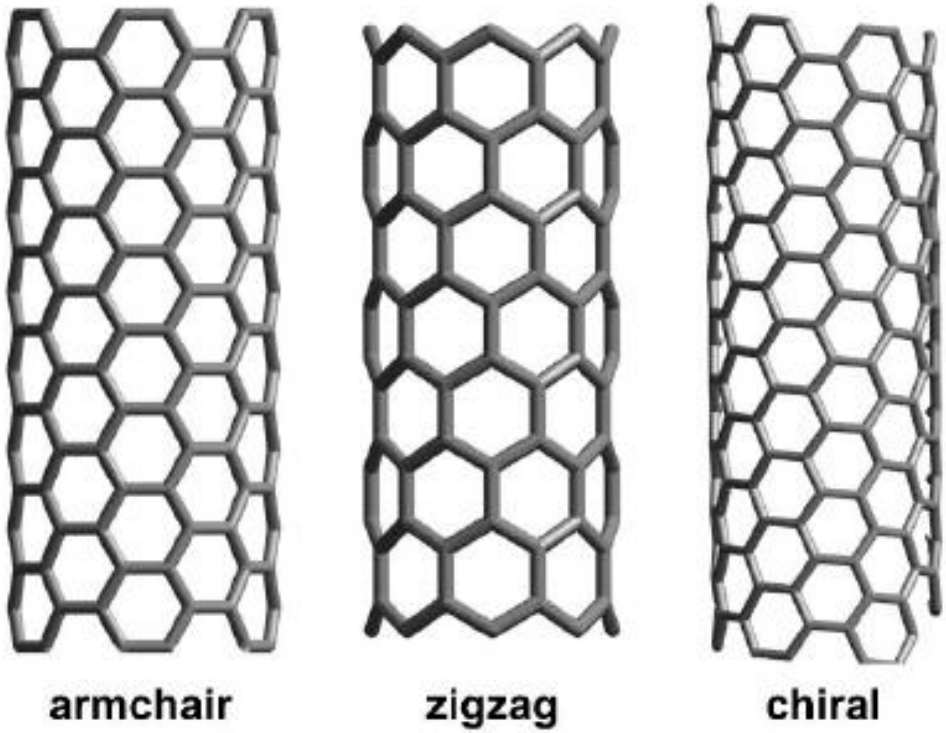


carbon nanotube

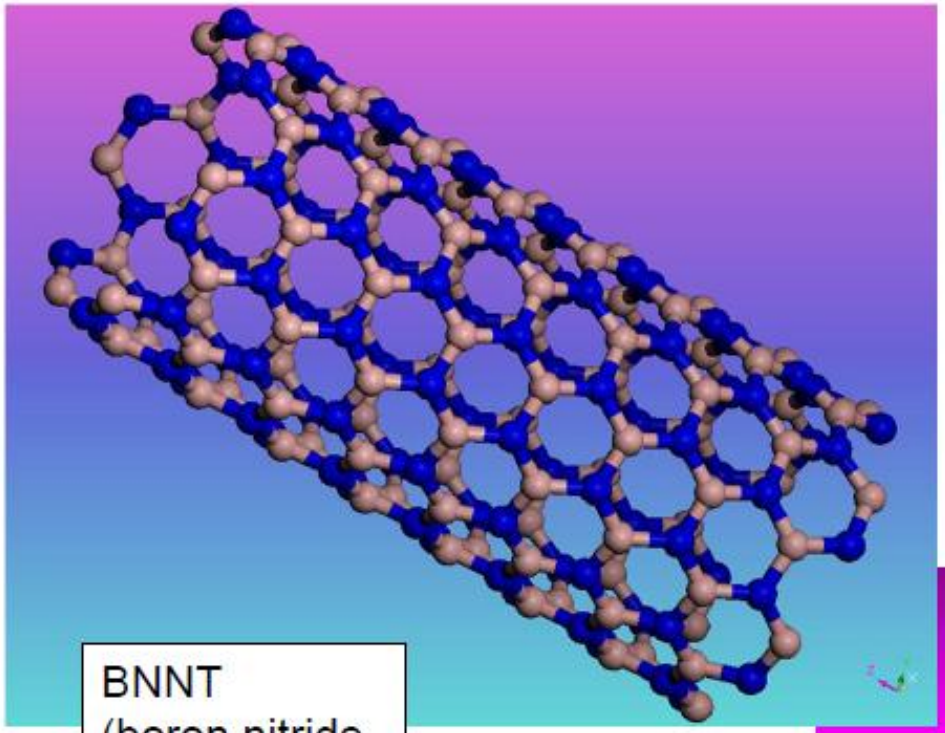
Images: wikipedia.org

1. Crystal Structures



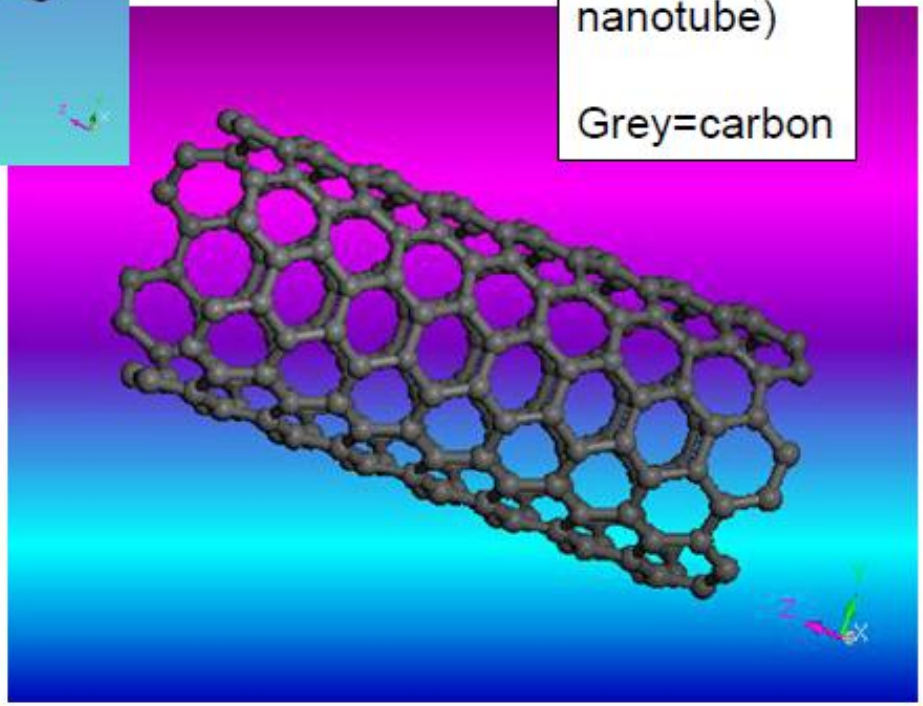


Wikipedia/CNTs



BNNT
(boron nitride
nanotube)

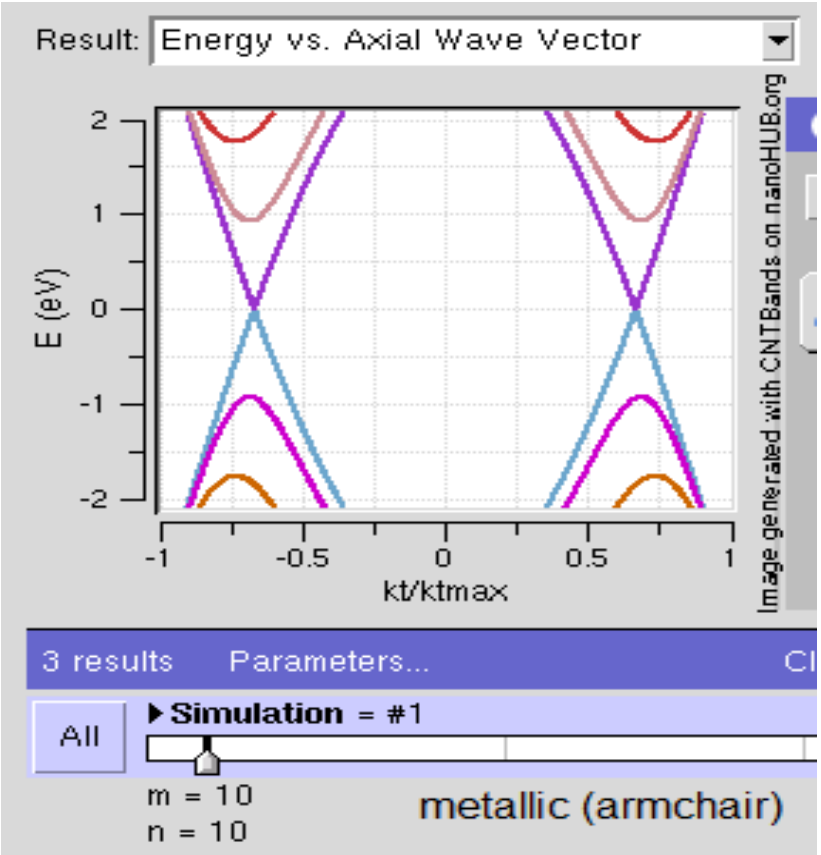
Blue=boron
Grey=nitrogen



CNT
(carbon
nanotube)

Grey=carbon

images: www.computenano.com



CNT Band Structures

Rules?

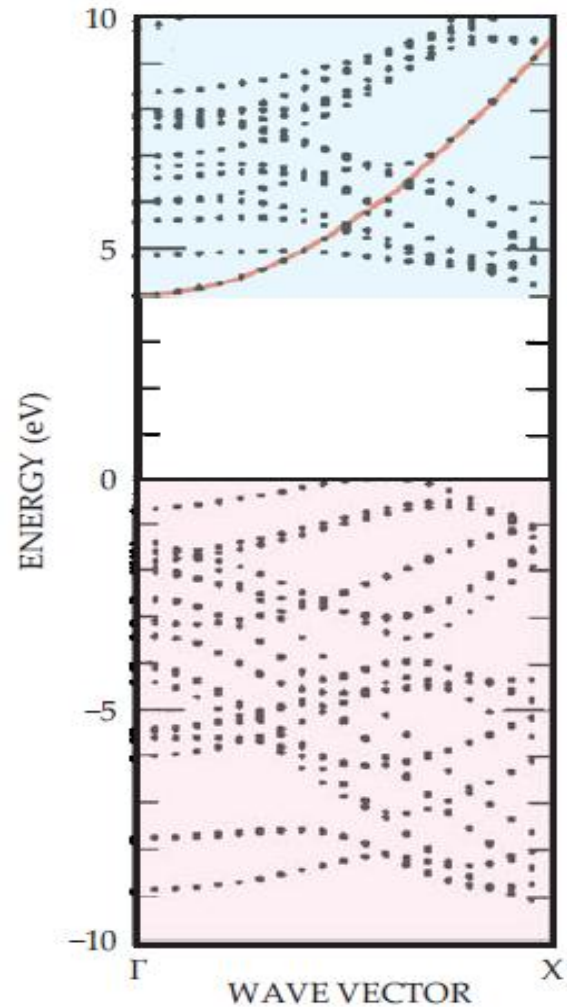
n = *m*: metallic

n − *m* is a multiple of 3: semiconducting with a very small band gap

Otherwise: moderate semiconductor

Exception?

Source: wikipedia/CNT



BNNT Band Structures

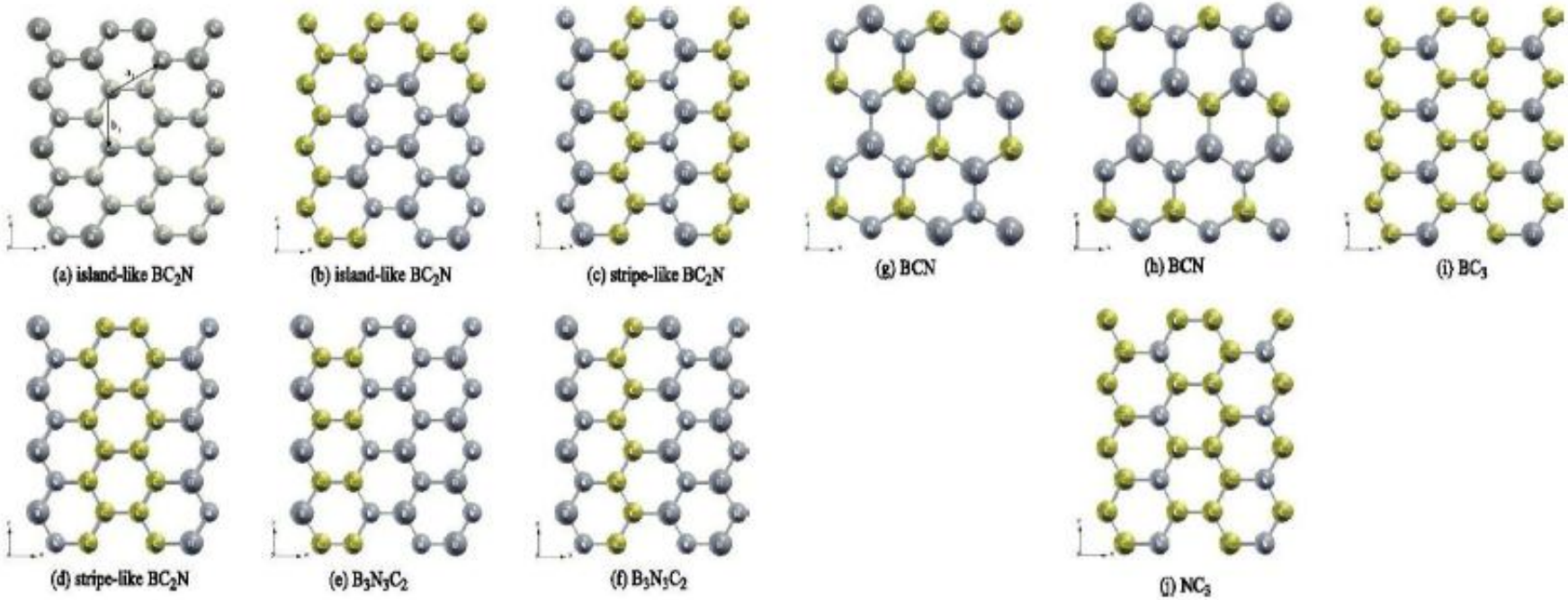
Insulator (Wide band gap semiconductor)

Eg = 5.5 eV

Source: Physics Today

Band Gap Tuning 1

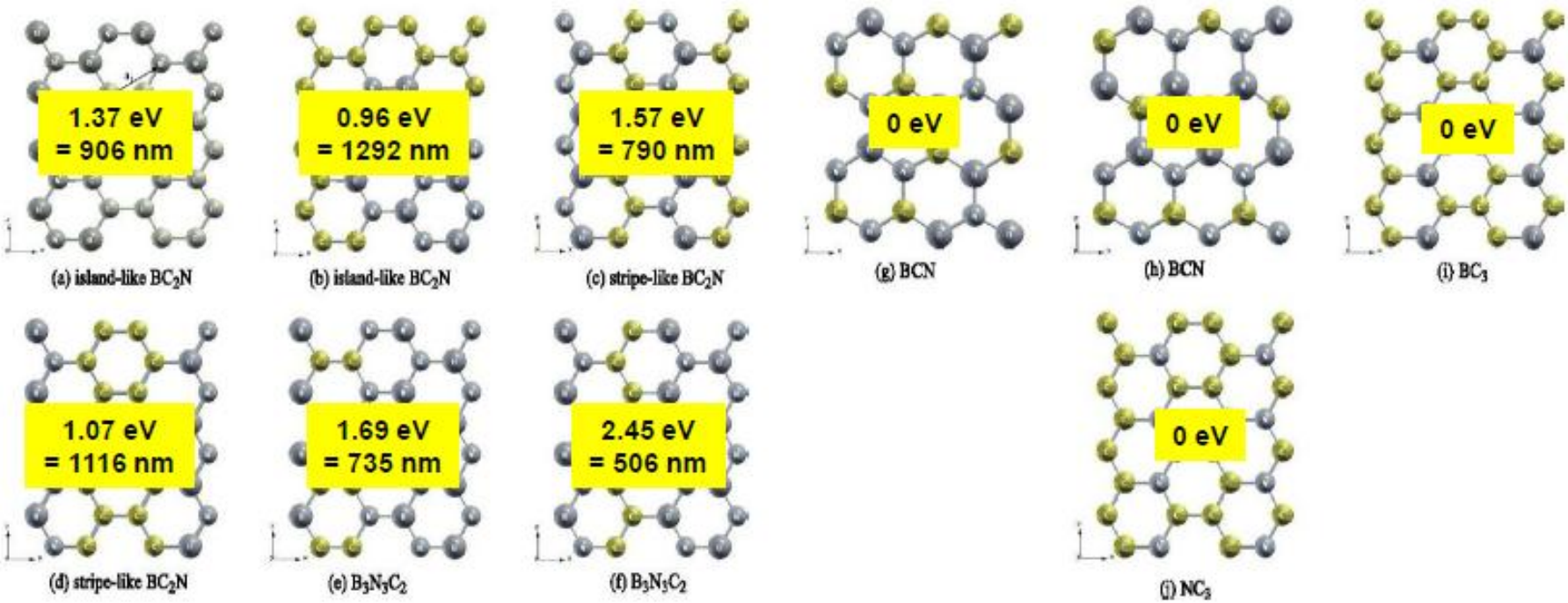
Possible Combinations of $B_xC_yN_z$



S. Azevedo and R. de Paiva 2006 Europhys. Lett. 75 126

Band Gap Tuning 1

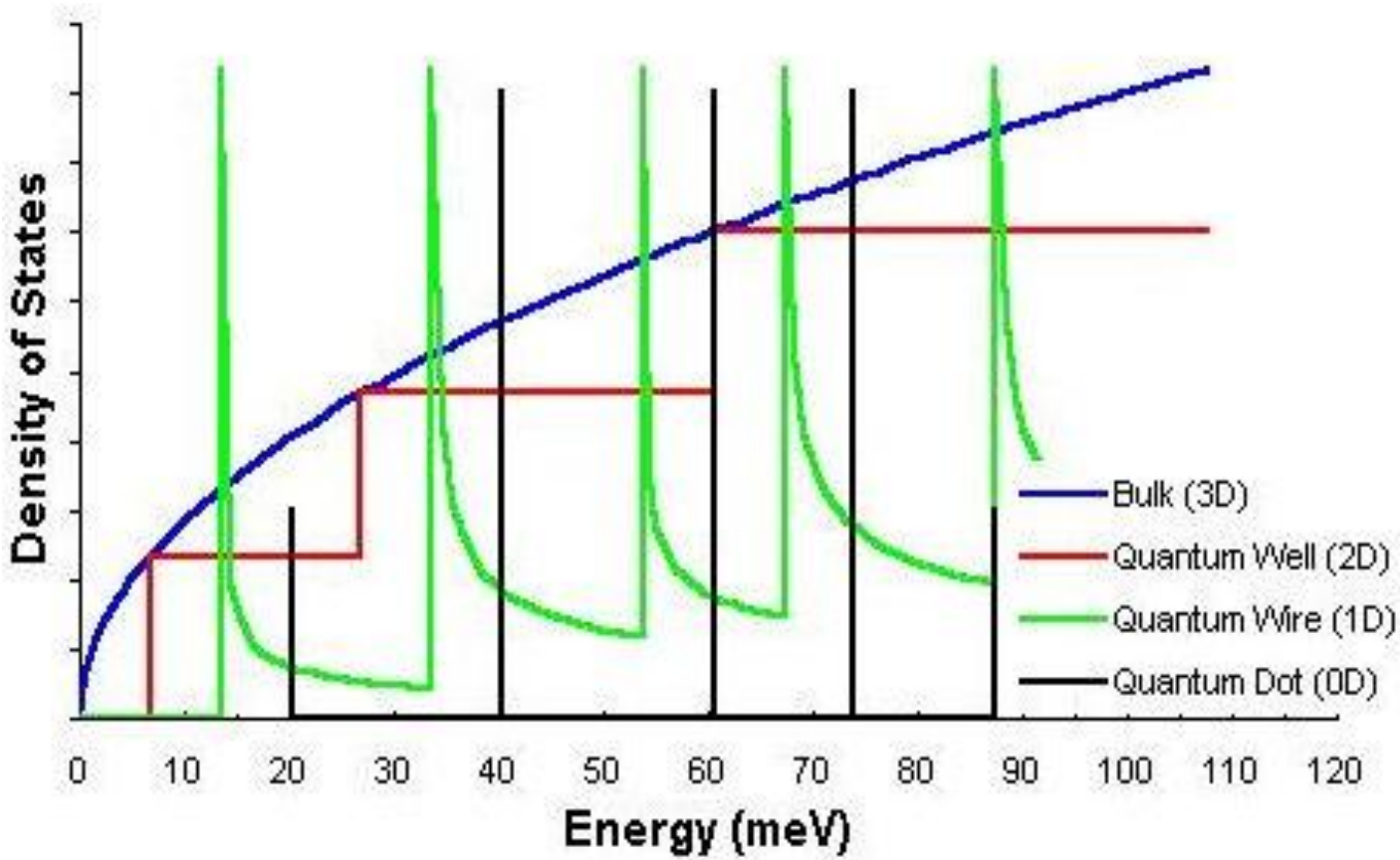
Possible Combinations of $B_xC_yN_z$



calculated band gaps

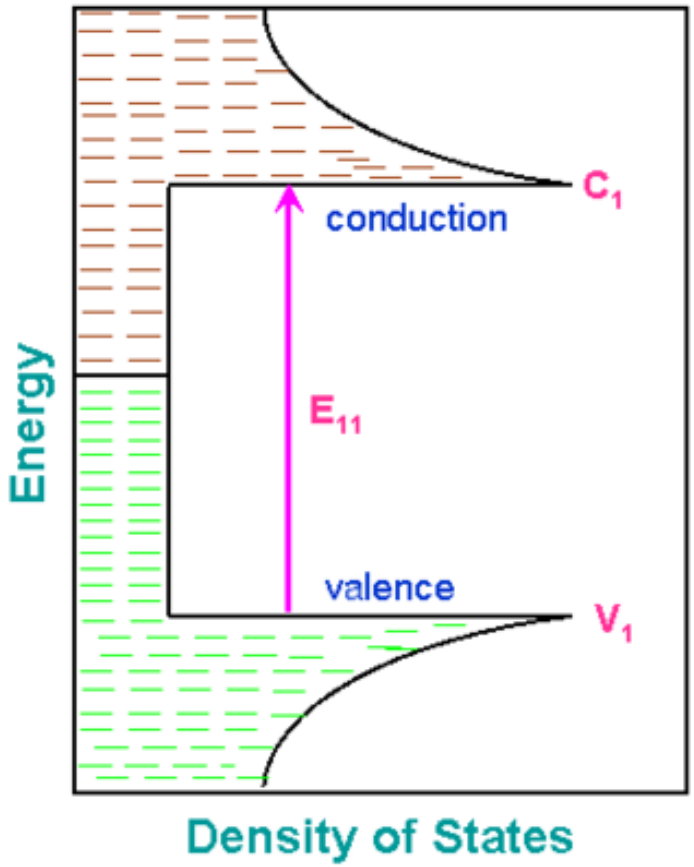
S. Azevedo and R. de Paiva 2006 Europhys. Lett. 75 126

2. Physical Properties



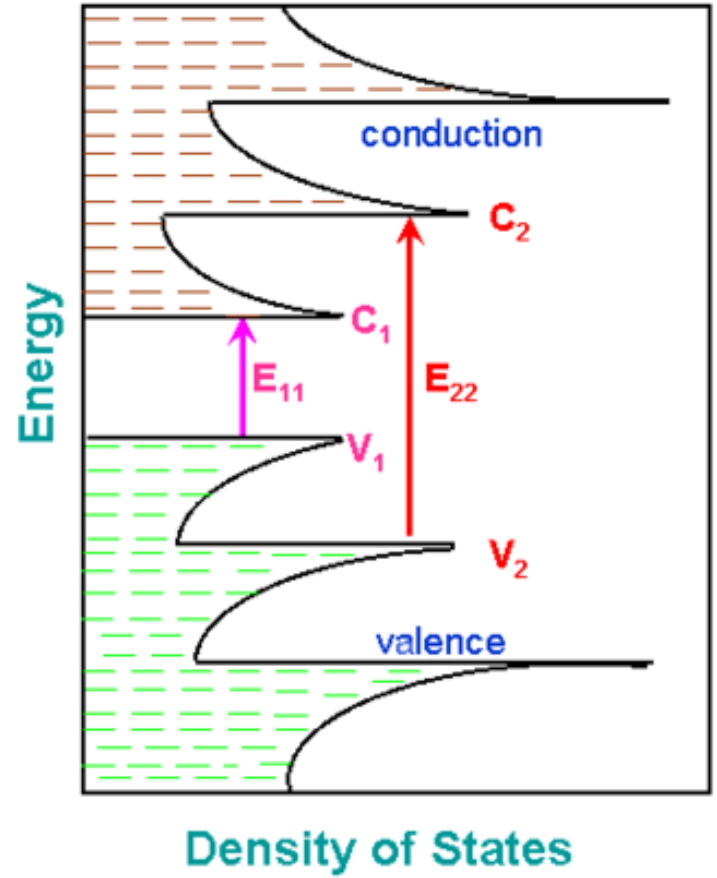
DOS (E) is proportional to $E^{-1/2}$

Source: Wikipedia/CNTs



Metallic SWNT

$v_1 \rightarrow c_1$ corresponds to the "first van Hove" optical transition



Semiconducting SWNT

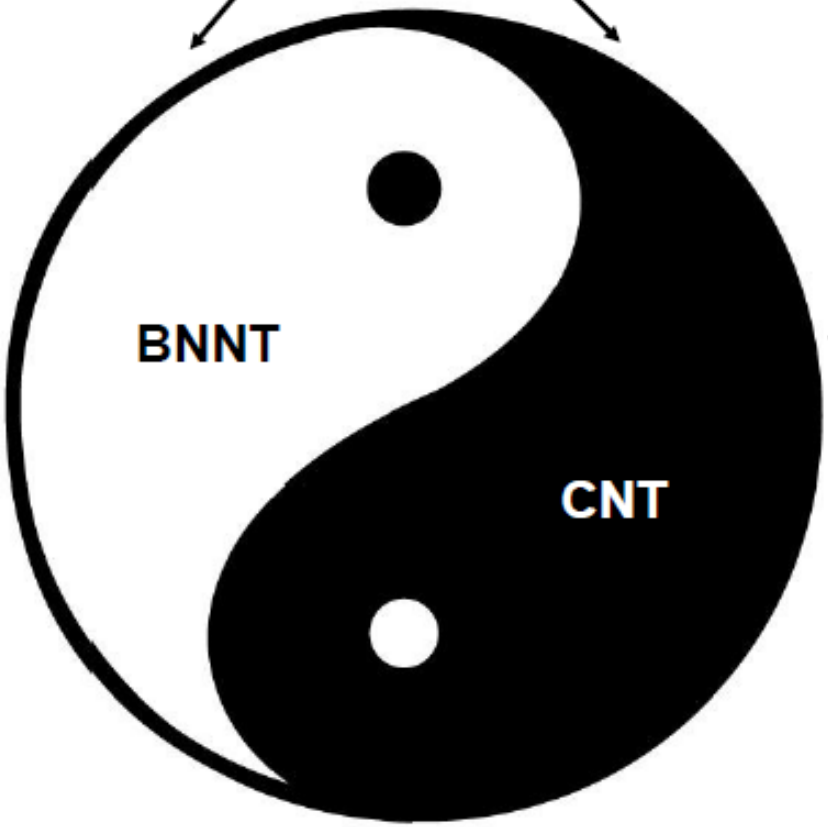
$v_2 \rightarrow c_2$ corresponds to the "second van Hove" optical transition

Source: Wikipedia/CNTs

The Yin-Yang of Nanotubes

Sp2 bond,
Strength,
Stiffness,
Aspect Ratio
Thermal Conductivity,

White,
High temperature,
Electrical Insulator



Black,
Lower temperature,
Electrical Conductor

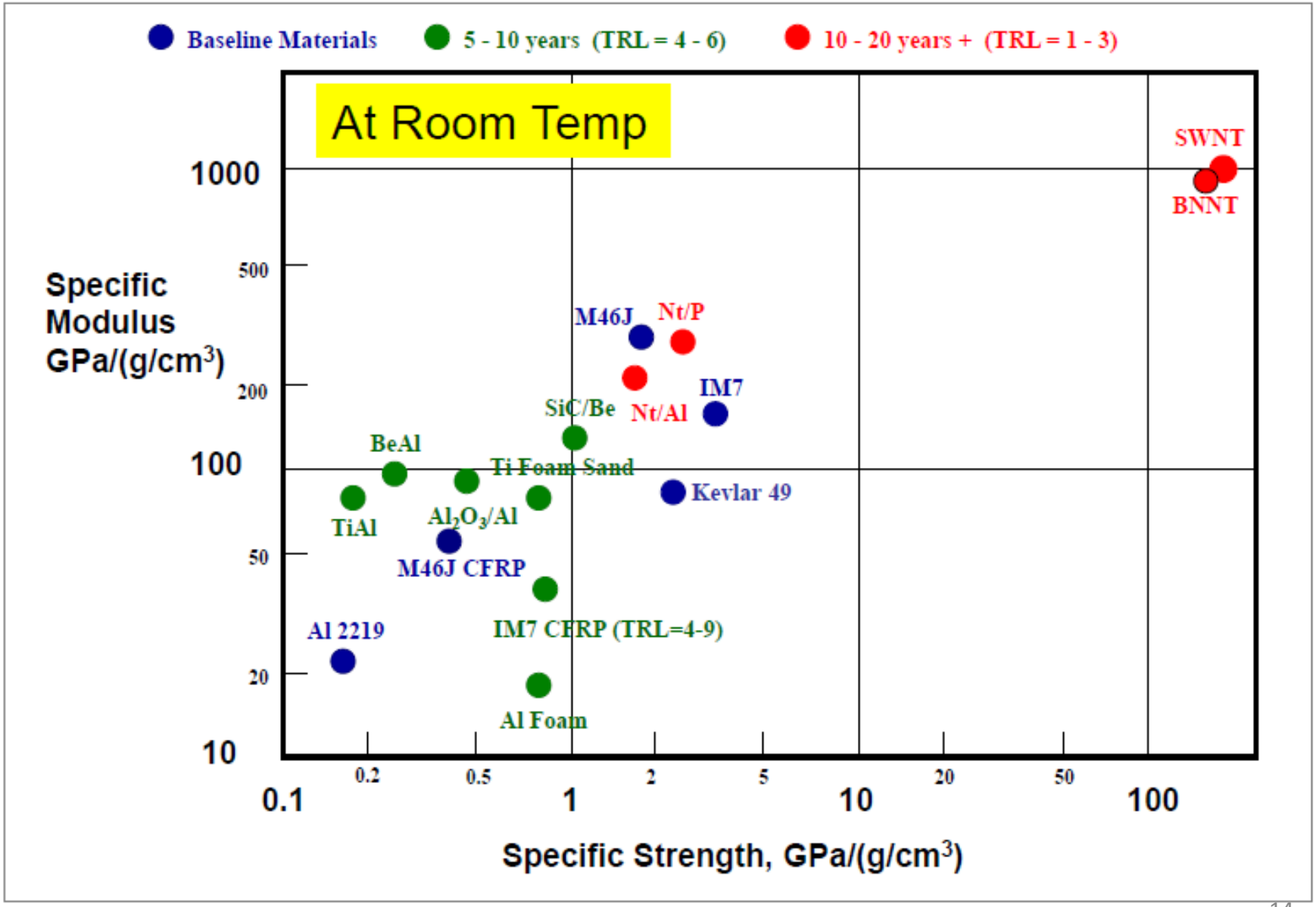
Source: NASA Langley Research

Comparison of Material Properties, CNT v BNNT

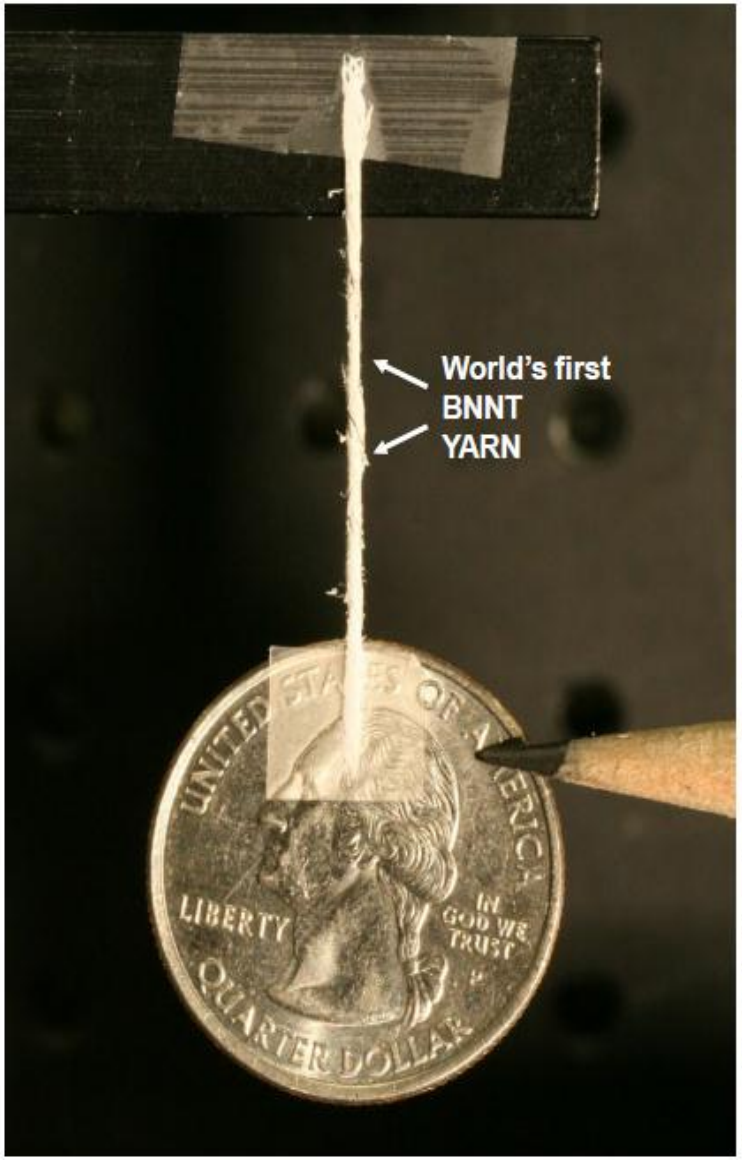
	Carbon nanotubes	Boron nitride nanotubes
Electrical properties	Metallic or semiconducting	Always semiconducting (about 5.5 eV band gap)
Mechanical properties (Young's modulus)	1.33 TPa	1.18 TPa
Thermal conductivity	60 – 40,000 W/mK	~ 3000 W/mK (Cu = 400 W/mK)
Thermal oxidation resistance	Stable up to 300–400°C in air	Stable up to 800°C in air
Neutron scattering cross-section	C = 0.0035	B = 767 (B^{10} ~ 3800) N = 1.9 Excellent radiation shielding
Polarity	Covalent bond (No dipole)	Permanent dipole **Piezoelectric** (0.25–0.4 C/m^2)
Surface morphology	Smooth	Corrugated
Color	Black	Gray
Coefficient_of Thermal Expansion	-1×10^{-6}	-1×10^{-6}

3. What make BNNTs ideal materials for space applications?

Very strong and light materials



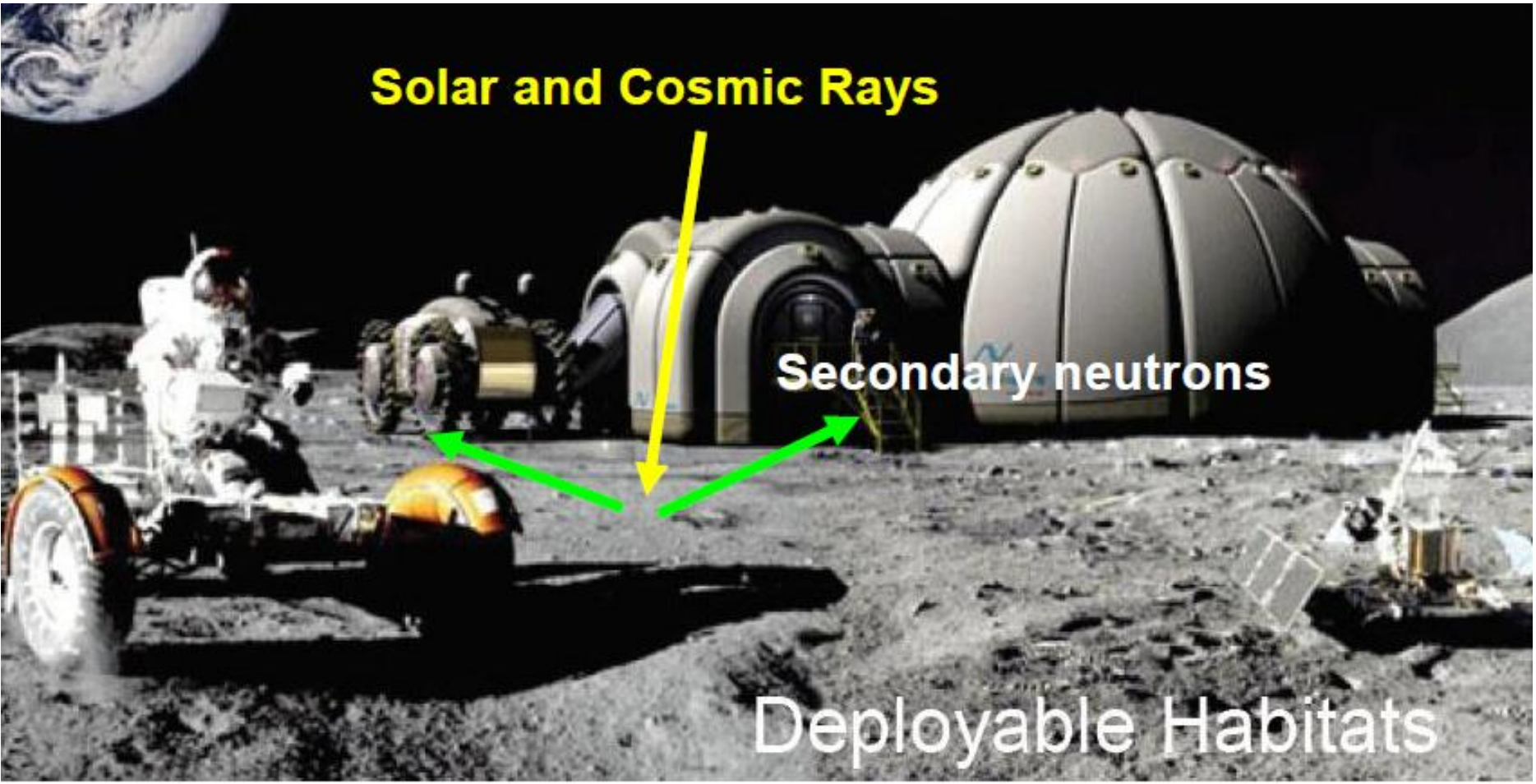
Based on: Charlie E. Harris, M. J. Shuart, H. Gray, NASA/TM-2002-211664



(From: M. W. Smith et al, Nanotechnology, 20, 505604 (2009))

Source: NASA Langley Research Center + National Institute of Aerospace

Neutron (and UV) absorption: protect the crew and equipment

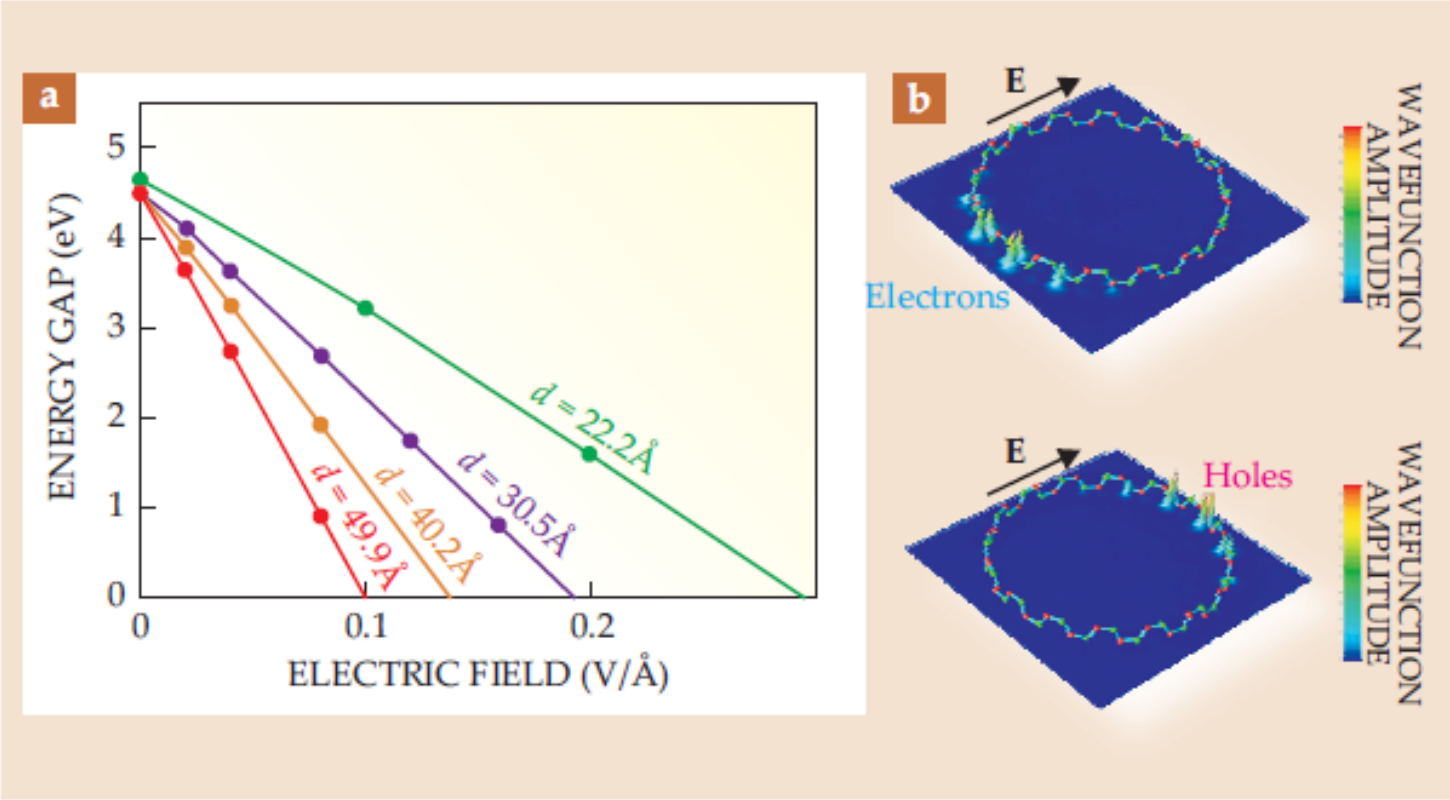


Neutron (and UV) absorption: protect the crew and equipment

Material	Atomic mass	Density (g/cm^3)	Neutron Scatter Cross Sections	Neutron Absorption Cross-sections (barns)
Hydrogen	1.01	gas	82.02	0.33
Boron	10.81	Boron nitride ("BN") (2.27); BNNT (1.37)	5.24	710 (^{10}B: 3835)
Carbon	12.01	1.8–3.5	5.55	0.0035
Nitrogen	14.01	gas	11.51	1.9
Oxygen	16.00	gas	4.23	0.00019
Aluminum	26.98	2.7	1.50	0.231
Titanium	47.87	4.54	4.35	5.0
Lead	207.2	11.34	11.12	0.17

Source: NIST

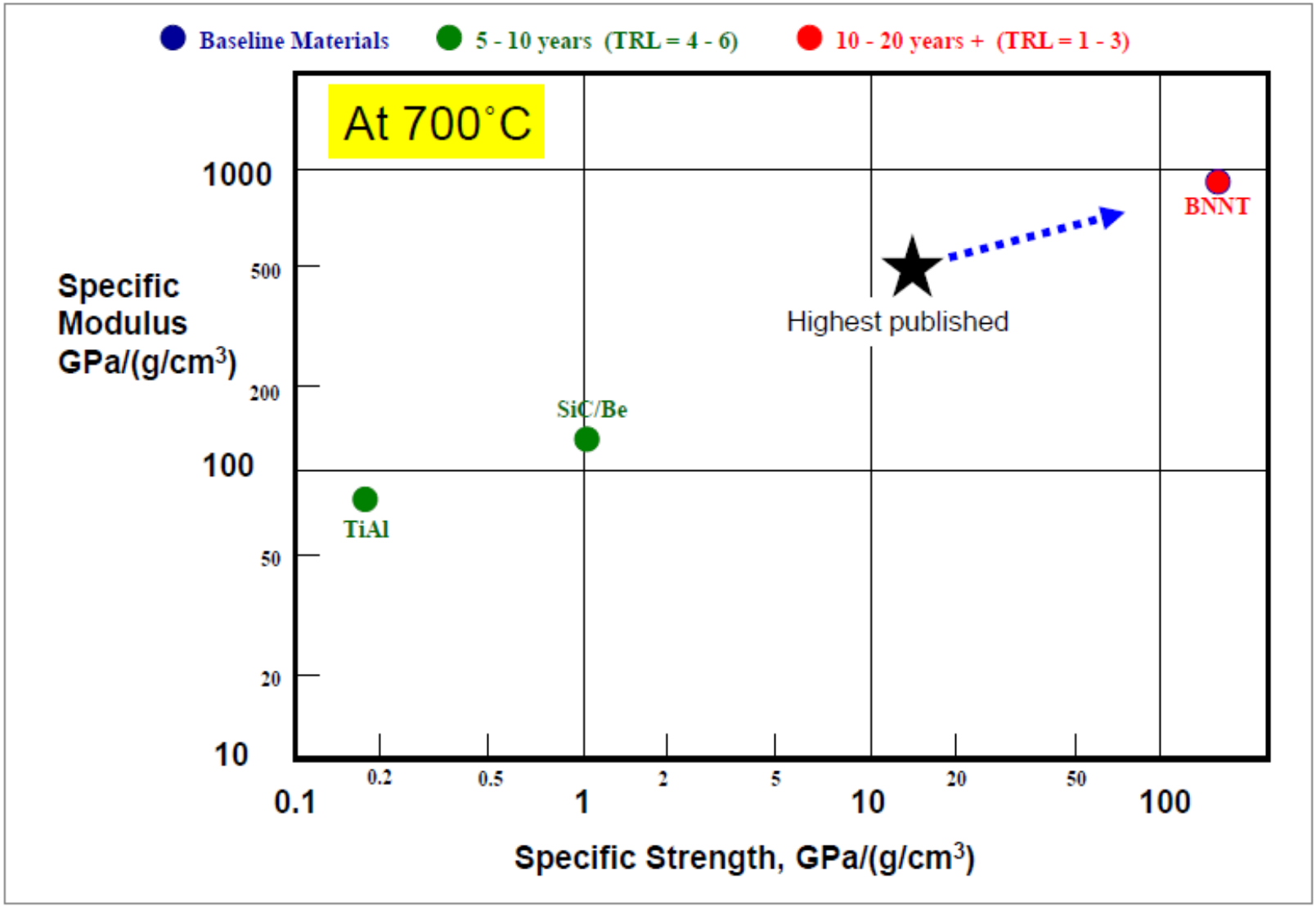
Giant Stark Effect (GSE): BNNTs



Band Gap Tuning 2! → Photovoltaics

Source: Physics Today

Mechanical Properties Revised at high T



★ Wei, et al., Tensile Tests on Individual Multi-Wall Boron Nitride Nanotubes, *Advanced Materials*, V 22, 43, p 4895, 2010

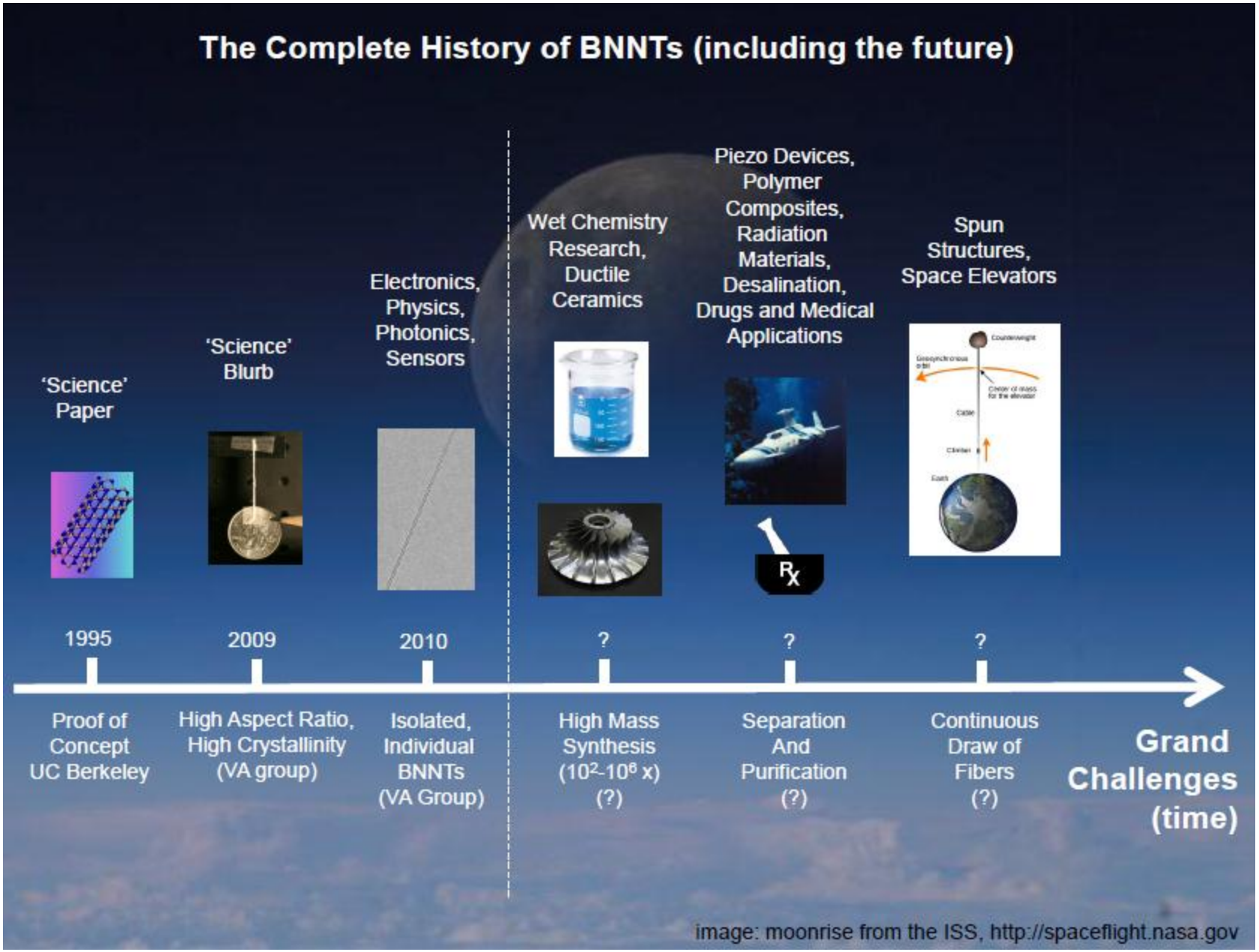

The Complete History of BNNTs (including the future)
'Science' Paper
'Science' Blurb
Electronics, Physics, Photonics, Sensors
Wet Chemistry Research, Ductile Ceramics
Piezo Devices, Polymer Composites, Radiation Materials, Desalination, Drugs and Medical Applications
Spun Structures, Space Elevators
1995
2009
2010
?
?
?
Proof of Concept UC Berkeley
High Aspect Ratio, High Crystallinity (VA group)
Isolated, Individual BNNTs (VA Group)
High Mass Synthesis (10^2-10^6 x) (?)
Separation And Purification (?)
Continuous Draw of Fibers (?)
Grand Challenges (time)
image: moonrise from the ISS, http://spaceflight.nasa.gov

Image: science.discovery.com

"…(the nanotube is) the strongest fiber that you can make out of anything, ***ever***."

~ (the late) Prof. Richard Smalley
Nobel Prize, Chemistry, 1996

image: moonrise from the ISS, http://spaceflight.nasa.gov

Conclusion

- 1D nanostructures
- Metal, semiconductors, band gap tuning
- High (Young) modulus, thermal oxidation temperature, neutron absorption
- Promising materials for aerospace
- What's wrong with CNTs and BNNTs

→ structure control, mass production

Thank you for your attention!

Q & A