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Galaxies, Black Holes & Laboratories: Studies of interstellar medium materials in energetic environments

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Dust and gas in ULIRGs: Tracing Star Formation and Black Hole Growth at the Centers of the Ultraluminous Infrared Galaxies
Ithaca, NY, United States
June 19, 2006 through June 22, 2006

Galaxies, Black Holes & Laboratories:

Studies of interstellar medium materials in energetic environments

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and many others

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Dust and gas in ULIRGs, Cornell Univ., June 20, 2006

Motivation

Science Case

- Energetic feedback from supernovae & active black in galaxies
- Interstellar dust controls formation of stars & planets

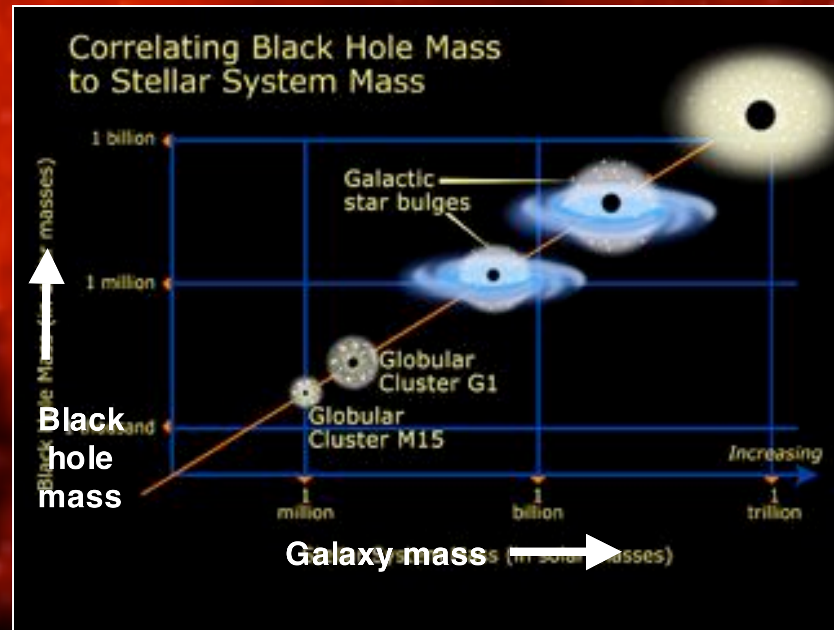
LLNL Assets

- High energy experimental and computational facilities, “astro-materials” expertise

Plan

- Two ISM dust types
- Two energy regimes
- Two dust grain morphologies
- Study processes where LLNL can uniquely contribute
  - Experimentally
  - Numerically

Galaxy Formation & Energetic Feedback



- Galaxies grow through merging, triggering collapse of interstellar clouds, star formation, supernovae
- Thermal pressure, and photon + particle (Cosmic Ray) densities 10 – 1000 x Milky Way

- Galaxy and central black hole masses fundamentally related
- Energy input from active black holes affects galaxy formation

Energetic feedback on interstellar medium (pressure, radiation & Cosmic Rays) key to understanding evolution of galaxies

Two types of ISM dust

Silicates -> Rocks

- Olivine’s, incl. Mg_2SiO_4 (forsterite)
- Other common minerals in the ISM, Interplanetary Dust Particles, Comets, Earth

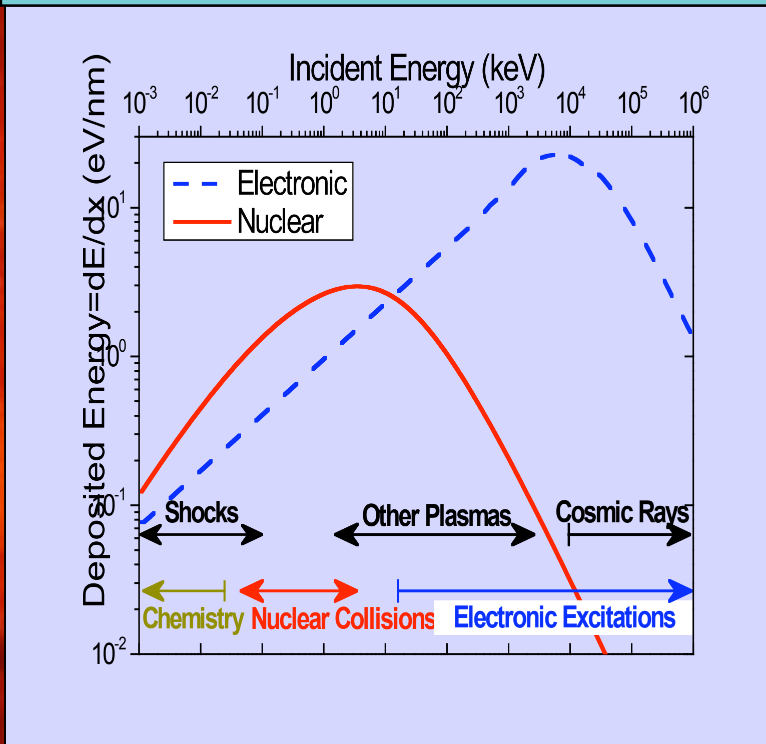
Carbonaceous -> Life

- Graphite, nano-diamonds
- Hydrogenated Amorphous Carbon
- Basis for more complex organic molecules, Life

- ISM materials condense out in stellar outflows & ejecta of superovae
- Mix silicate / carbon depends on type of star and evolutionary stage

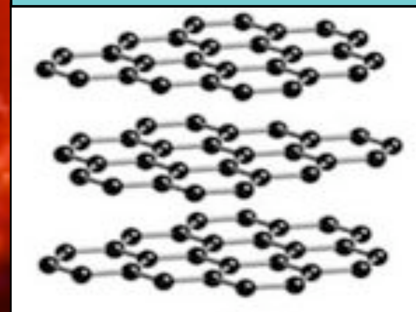
Two energy regimes & morphologies

Two energy deposition regimes



Two astrophysical regimes
Thermal: Shocks
Non-thermal: Cosmic Rays
Both occur in supernovae and jets

Two morphologies



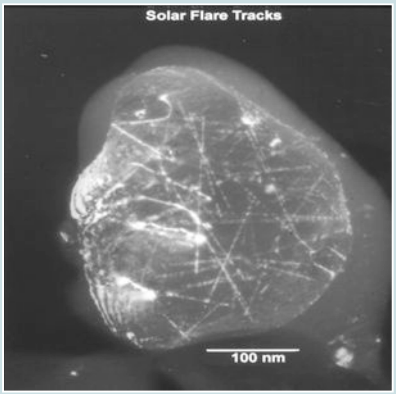
Graphite

Anthracite-Coal

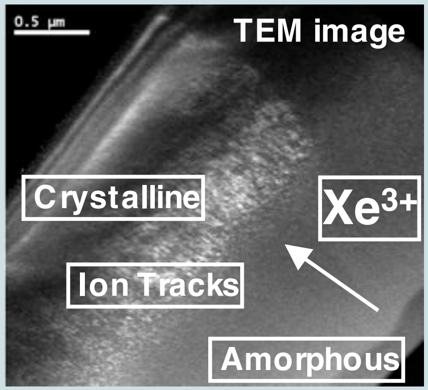
- Amorphization: Irradiate crystalline materials (silicates and carbonaceous) at high energies to see if caused by Cosmic Rays (E. Bringa - this meeting)
- Cover both nuclear (low) and electronic (high) energy regimes
  - Astrophysical shocks (100 km/s : 100 eV - 10 keV)
  - Cosmic Rays (low en. most abundant: 0.1 - 5 GeV)
  - Effects will be different: bond breaking vs. re-ordering (C-rings)

Can Cosmic Rays amorphize ISM silicate dust? E. Bringa - this meeting

2005 - LLNL Ion Beam



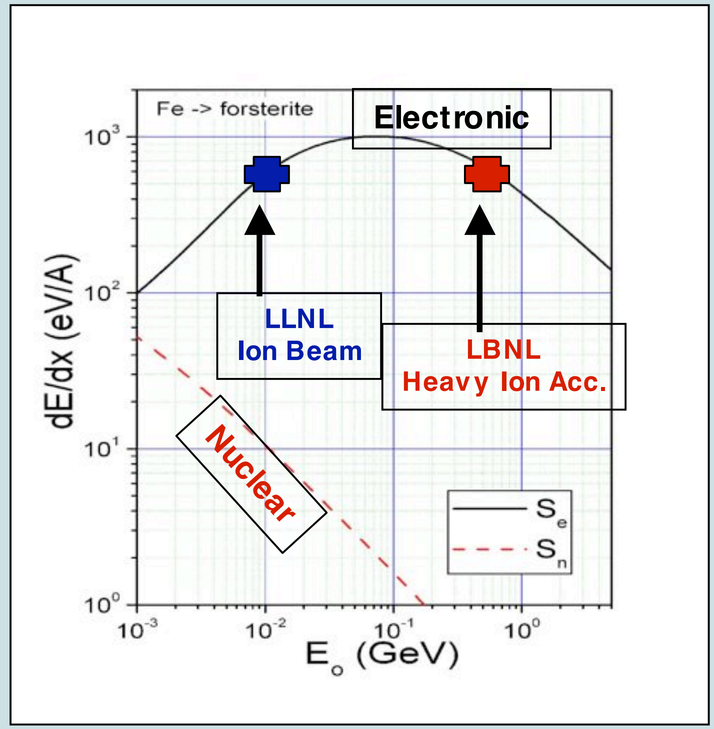
Observation
Bradley et al 1984



Experiment
Bringa et al 2006

- **ISM silicate dust grains, observed**
  - Crystalline in stellar outflows
  - Amorphous in dense ISM clouds
  - Possible reason: Cosmic rays
- **LLNL experiments:**
  - 10 MeV ions (Xe^{+++}) amorphize fosterite
  - dE/dx models then suggest low energy (100 - 500 MeV) Cosmic Ray Fe-ions will do this also, at fluences representative for our Galaxy

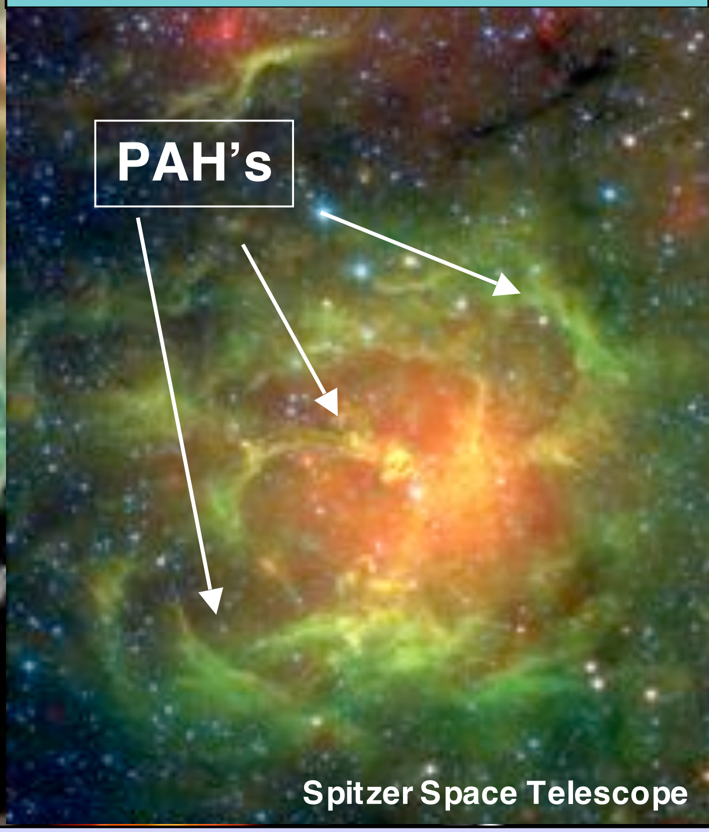
2006 - LBNL 88" Cyclotron



- **LBNL experiments (Feb 2006)**
  - 500 MeV Fe-ions
  - Galactic Cosmic Ray fluence
  - Results currently being analyzed

Lifecycles of hydrocarbons (C_mH_n), PAHs, and organic (H, C, N, O, S, P) molecules

ISM cloud: dust and gas

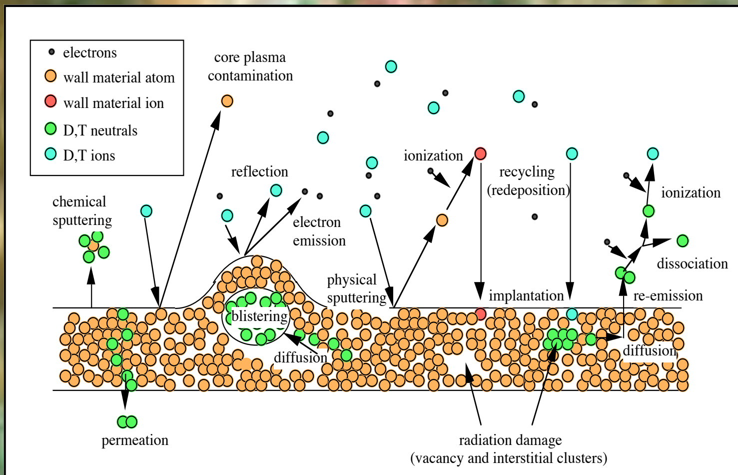


- **Polycyclic Aromatic Hydrocarbons**
  - **Ubiquitous around clouds**
  - **Easily destroyed by UV light**
  - **Must be replenished inside clouds**

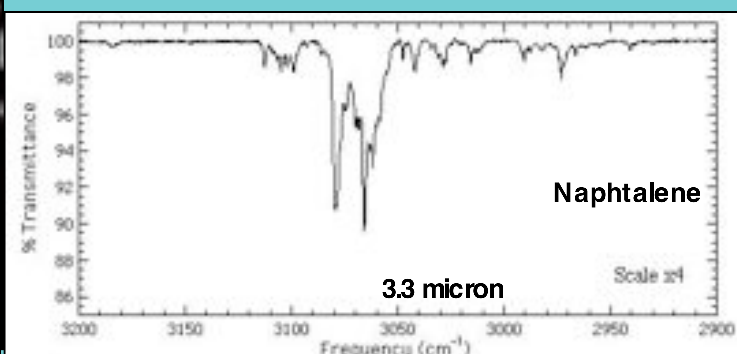
Possible Processes?

- **Gas phase chemistry**
  - **Big supply available**
  - **Energy source, efficiency?**
- **Chemistry changes induced in grains by energetic ions**
  - **Hot gas in shocks (keV ions)**
  - **Cosmic Rays (0.1 - 1 GeV most abundant)**
- **Regeneration due to grain-grain collisions in shocks**
  - **Supernovae**
  - **Active black holes**
  - **Colliding galaxies**

Previous and ongoing work on carbonaceous materials



Surface physics in Tokamaks
Bringa et al 2004

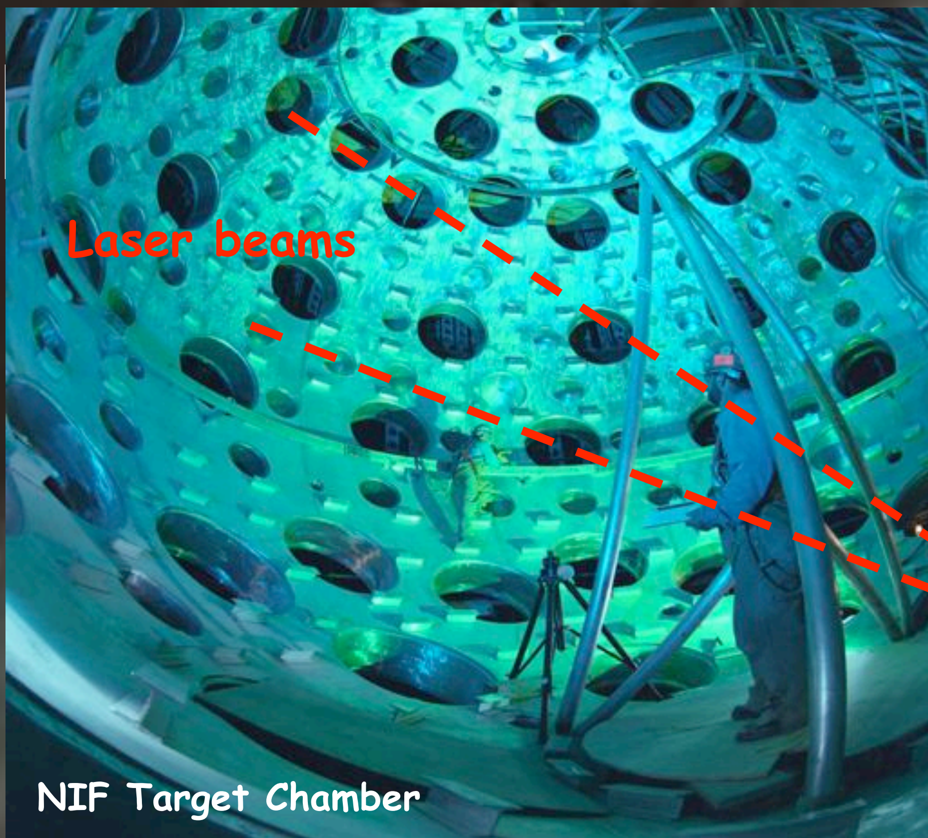


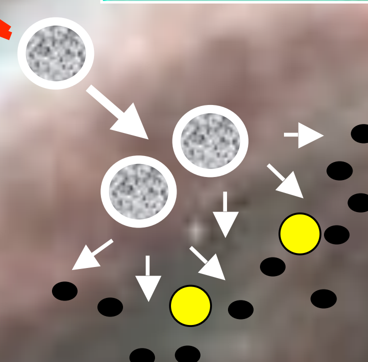
Laboratory IR spectra of PAHs
NASA / Ames Astrochemistry Lab
http://web99.arc.nasa.gov/~astrochm/pahdata/index.html

- **Graphite - Tokamak wall studies**
  - radiation damage, erosion
  - hydrocarbon contamination
  - high flux & not much on chemistry
    - overlap with LLNL interests
- **PAHs - NASA / Ames Astrobiology Inst.**
  - Formation & destruction of large numer of PAHs at low energies
  - IR spectroscopy of individual PAHs (large data base)
    - excellent resource for predicting astronomical spectra
- **Hydrogenated Amorphous Carbon**
  - low energy He^+ Cosmic Rays (Strazulla et al 2005)
  - no detailed chemistry (only IR spectr.)
    - apply new LLNL technology (Superconducting Tunnel Junction X-ray Spectrometer at the Advanced Light Source)

Laser dust dynamics experiments (?)

Astrophysics & Space Technology





Collisions compress, break up, melt dust grains:

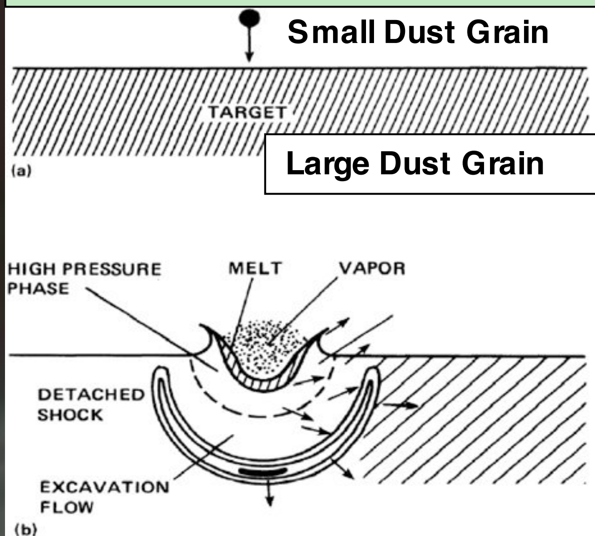
`nano-diamonds' & `black diamonds'

Laser dust dynamics experiments (?)

Astrophysics & Space Technology

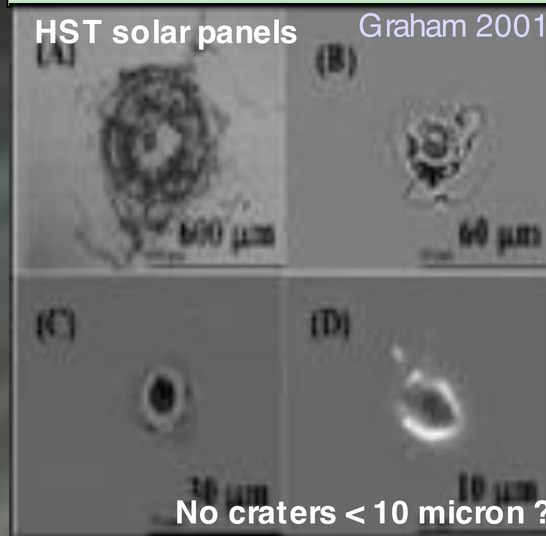
J. Hansen et al, LLNL

Astrophysics: Grain-grain collisions



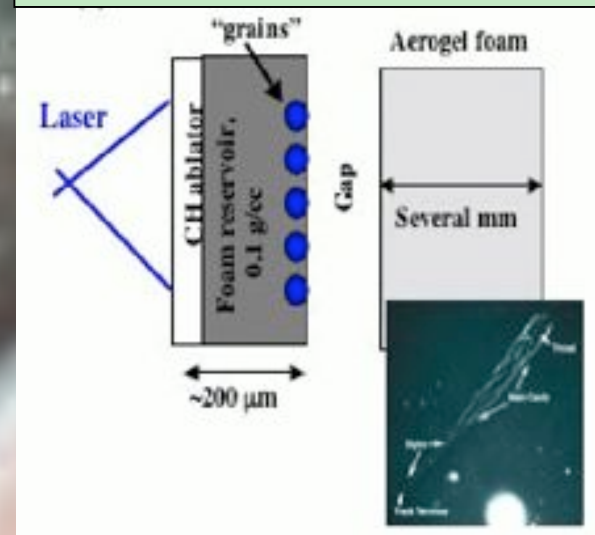
- Shocks accelerate grains to typical ~ 100 km/s
- Size distribution, structural changes (nano-diamonds ?)

Space Technology: Micrometeorite impacts



- Hypervelocity (> 1 km/s) impacts affect space hardware
- Cratering (impactors) not understood

Laser experiments & debris analysis



- Mbar pressures, picosec time, sub-micron particles
- Accelerate grains in foam (10 km/s possible)
- Catch in foam reservoir

Potentially new LLNL capability in extreme astro-materials science
Leverages LLNL expertise in lasers, debris analysis, simulations

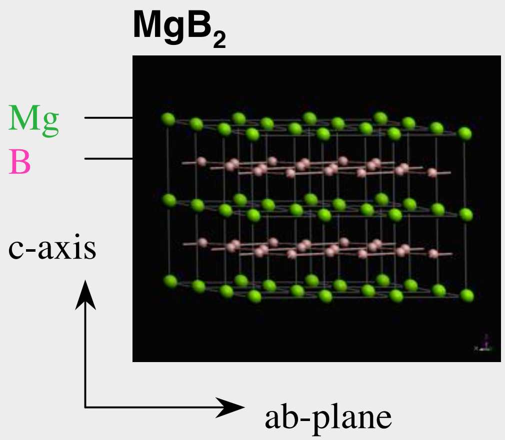
Conclusion

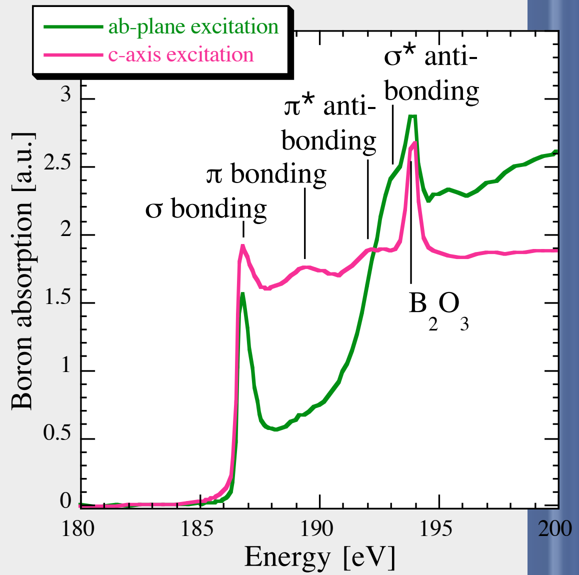
- **Compelling, broad scientific interest**
  - ISM dust, formation stars/planets/galaxies, energetic feedback
- **Spitzer, future IR telescopes**
  - ISM dust = new diagnostic
- **Advanced technologies**
  - Synergy between astrophysics & materials science (‘astro-materials science’)

STJ + Advanced Light Source:

New application to ISM astro-materials science

Superconducting Tunnel Junction
X-ray Spectrometer at the Advanced Light Source





- New LLNL developed technology
- More sensitive and higher spectral resolution (10 - 15 eV) than competing detectors
- Direct access to Advanced Light Source at LBNL (S. Friedrich- LLNL)

- Measuring small energy shifts allows characterization of chemical changes in materials after irradiation
- Has already been shown to work for graphite like material MgB_2
- New application for ISM 'astro-materials' science: measure C