Laboratory X-ray astrophysics

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X-ray astrophysics laboratory

X-ray astrophysics

- Soft X-rays (~ 0.3-10 keV) probe energetic phenomena in a broad range of astrophysical objects
  - Accretion onto compact objects (black holes, neutron stars), and outflows associated with this process
  - Hot tenuous gas in the interstellar, intergalactic, and intracluster media (ISM, IGM, ICM)
  - Supernova remnants, many different kinds of stars, and more!
- Spectra in this energy range are rich – K-shell (1-n) transitions of abundant elements from Z=6 (C) to Z=26 (Fe), and L-shell (2-n) transitions of Fe

Observatories for x-ray spectroscopy

- Chandra and XMM-Newton have slitless grating spectrometers with resolving power up to ~ few hundred
- XRISM has the Resolve x-ray calorimeter, imaging with 1’ spatial resolution and 4.5 eV FWHM spectral resolution (R> 1000 at Fe K)
- Athena X-IFU (2030s) will have ~ order of magnitude better imaging resolution and ~ 2X better spectral resolution
- Other proposed missions provide even stronger capabilities, e.g. LEM (large FOV, < 2 keV, 1 eV FWHM), Arcus (R ~ few thousand gratings)

Laboratory X-ray astrophysics

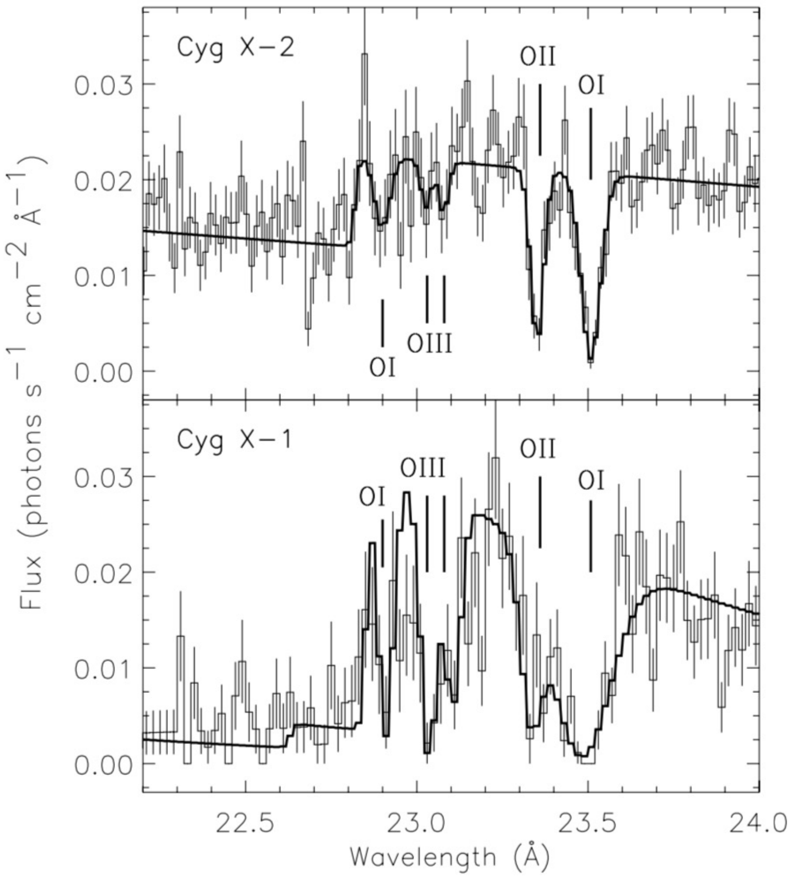
- Modeling x-ray spectra requires atomic data for highly charged ions
- Much of this data must be calculated
- The accuracy of the calculations is often limited
- We need to check how good theory is both to understand the quality of the data and to guide improvements in theory
- In some cases we can directly use the data we measure in the databases instead of relying on calculations
- Our group is involved in all of these activities (calculations, database curation, laboratory experiments)

Our group's experimental efforts

- Lawrence Livermore National Laboratory (LLNL) Electron Beam Ion Trap (EBIT) facility with GSFC x-ray calorimeter detector
- MPIK/Heidelberg portable EBIT deployed at synchrotron x-ray light sources
  - We are building a copy at GSFC that will be used in field campaigns at US light sources
- Clemson EBIT ion beam charge exchange experiments with GSFC x-ray calorimeter

Neutral oxygen in the ISM

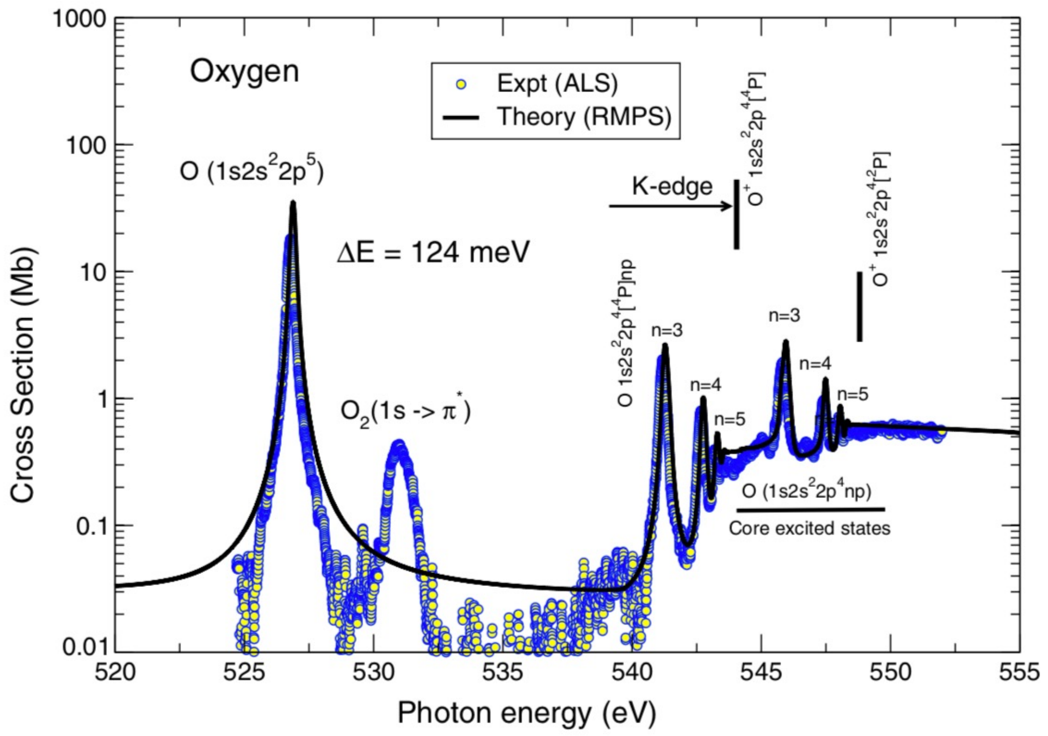
- Oxygen in the ISM has been studied extensively in the X-ray band The mean wavelength of Galactic O I is systematically shifted compared to laboratory measurements (Stolte+, McLaughlin+) by ~ 300 km/s!
- cf. Galactic escape velocity near us is 580±60 km/s
- There must be a large calibration error somewhere… but it can't be the astrophysical observatories



Juett+ 2004

Laboratory measurements of O I

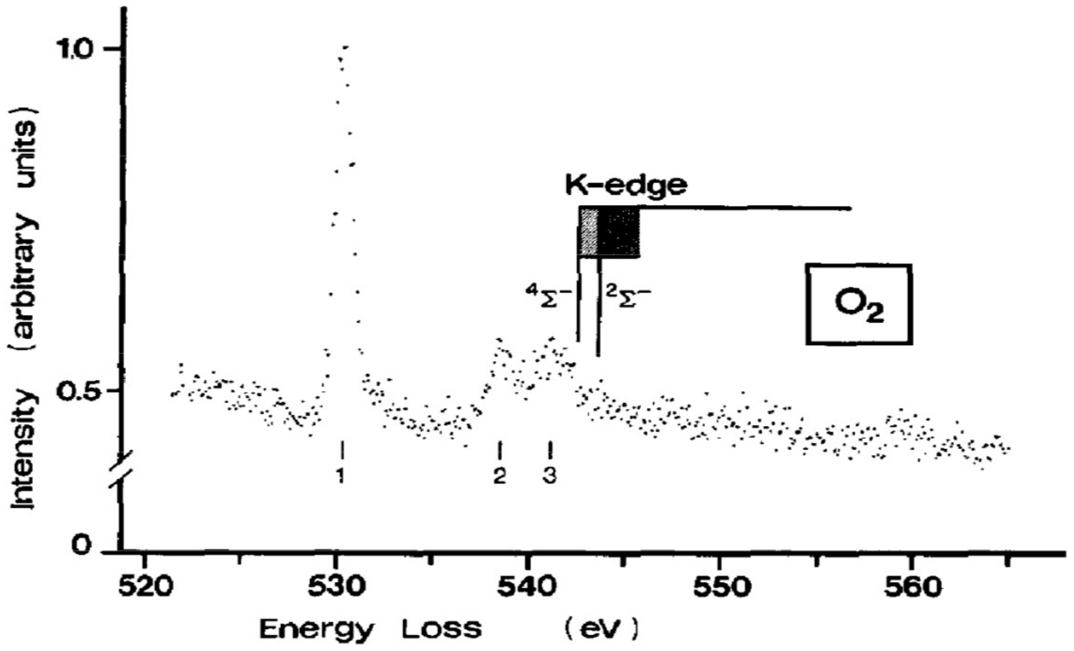
- Stolte+ 1999 measured O I at ALS synchrotron
- McLaughlin+ 2013 published a remeasurement from later ALS experiments
- Resolving power and statistics are great… but the instrument is calibrated against O_2. How was that calibrated?



McLaughlin+ 2013

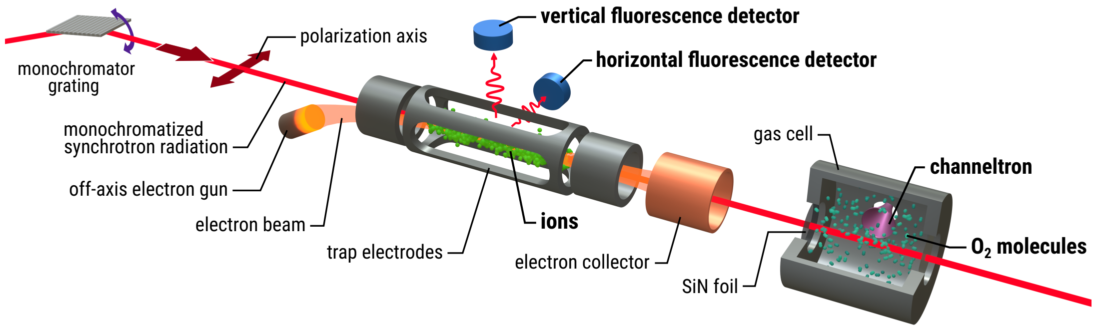
Calibration of O I measurements

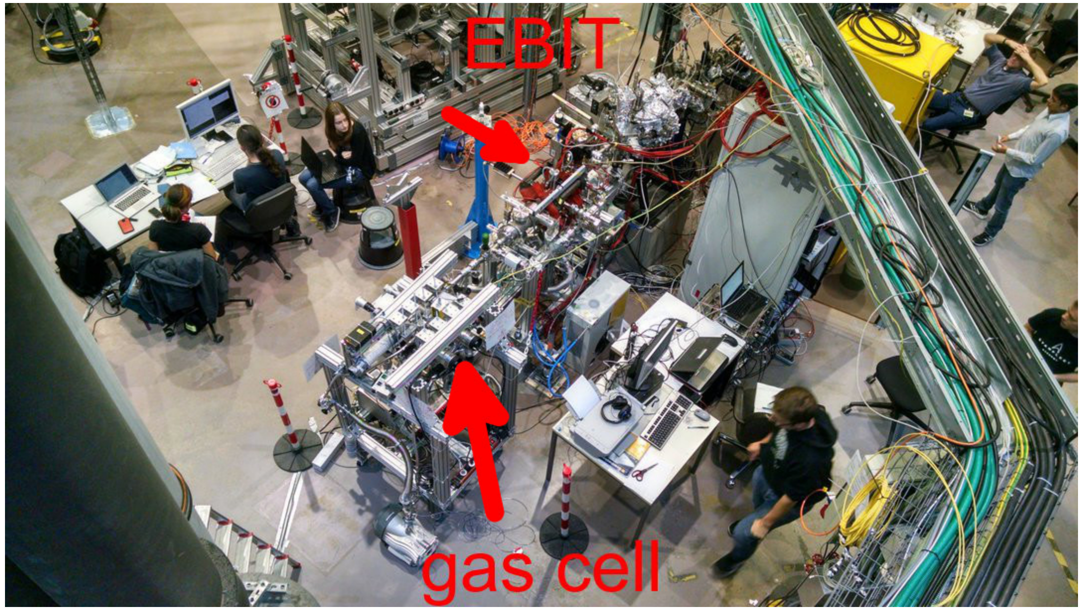
- Both Stolte+ 1999 and McLaughlin+ 2013 trace their O_2 calibration to electron energy loss spectroscopy (EELS) measurements
- All EELS measurements of O_2 trace their calibration to Wight+Brion 1974, which is based on an absolute calibration of an HV bias supply



Recalibration of the O2 spectrum at BESSY II

- Portable Polar-X EBIT developed at MPI-K Heidelberg used to trap He-like O VII and N VI ions for calibration (Micke+ 2018)
- Simple gas cell developed at GSFC to detect photoions from O_2

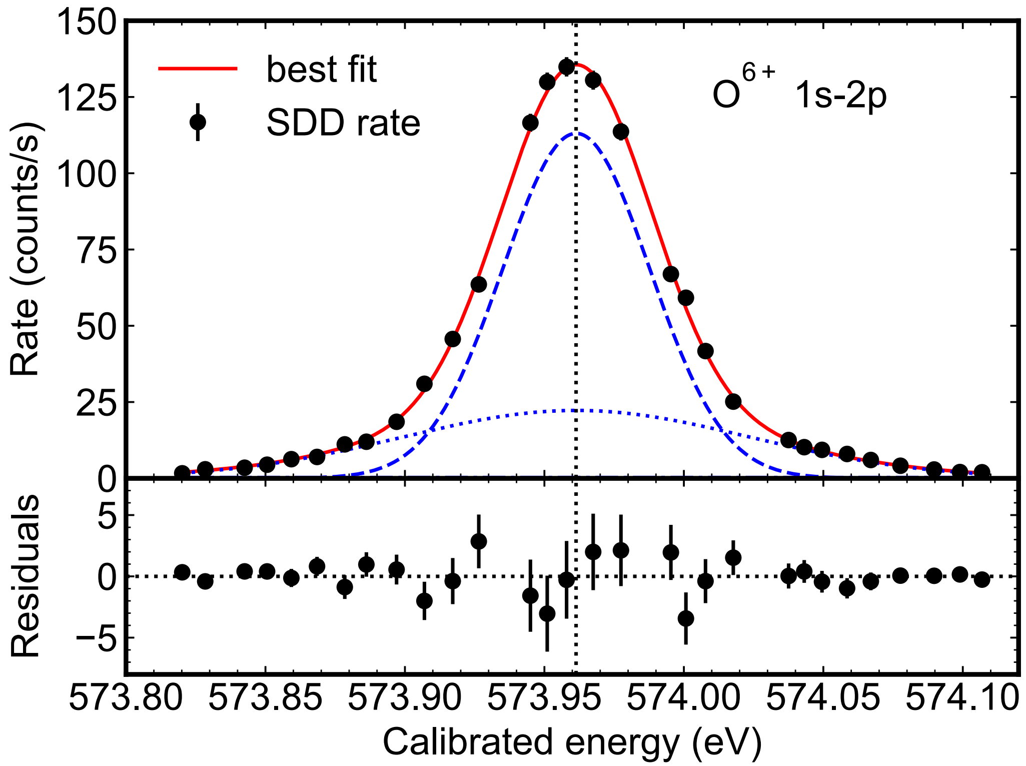




Leutenegger+ 2020

He-like ions are great for calibration

- Theoretical uncertainties on Rydberg series transition energies are on the order of 0.5 meV
- He-like ions are easy to generate with electron beam energies below the K-shell excitation threshold
- We were able to generate fluorescence count rates of 100s of Hz on resonance using the Polar-X EBIT at BESSY II, allowing calibrations at the meV level in scan times of minutes



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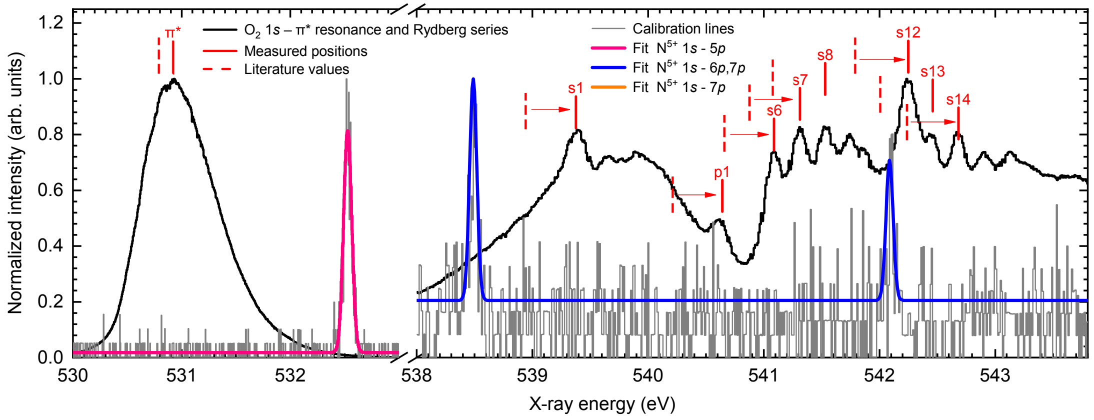
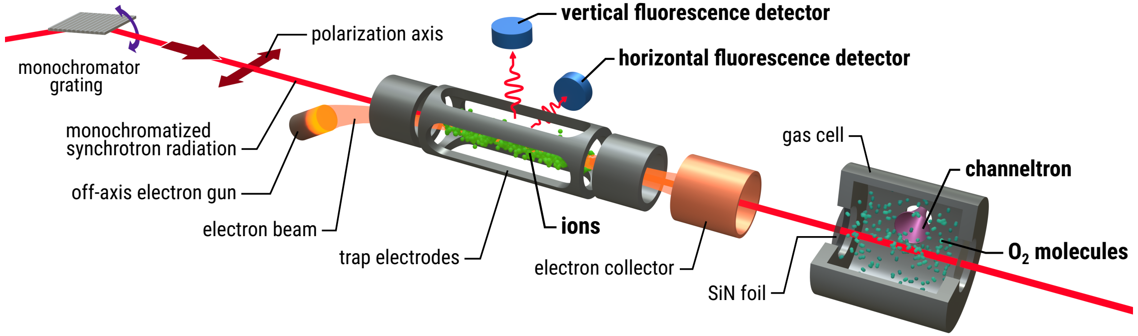
Recalibration of O_2

- Calibration shift of O_2 is 0.45 eV in the Rydberg series
- This completely resolves previous discrepancies for O I
- Precision achieved is 40 meV, limited by original O I measurements; this corresponds to 20 km/s!
- Precision achieved for O_2 is 8 meV; 1 meV achievable





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Opportunities for collaboration

- Students are welcome to get involved in any part of our laboratory astrophysics program
  - Theoretical calculations using Flexible Atomic Code, etc.
  - A variety of laboratory experiments, both onsite at GSFC and at our partner institutions (LLNL, MPIK/Heidelberg, Clemson, field campaigns at synchrotrons)
  - Database curation (Kronos charge exchange, XSTAR photoionization) and correspondence with other database maintainers (ATOMDB, SPEX)

Thanks for your attention!

- Contact me at:
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- Collaborators:
  - NASA/GSFC: S. Porter, J. Adams, S. Smith, R. Cumbee, C. Shah, R. Rahin, G. Grell, R. Kosarzycki
  - LLNL: G. Brown, M. Eckart, N. Hell, A. Fairchild
  - MPIK: J.R. Crespo Lopéz-Urrutia, M. Togawa, M. Botz, J. Danisch, J. Goes
  - Clemson: J. Marler, C. Sosolik, P. Johnson
  - Auburn: M. Fogle, S. Bromley
  - Remeis/Erlangen: J. Wilms, J. Stierhof
  - Many many more!