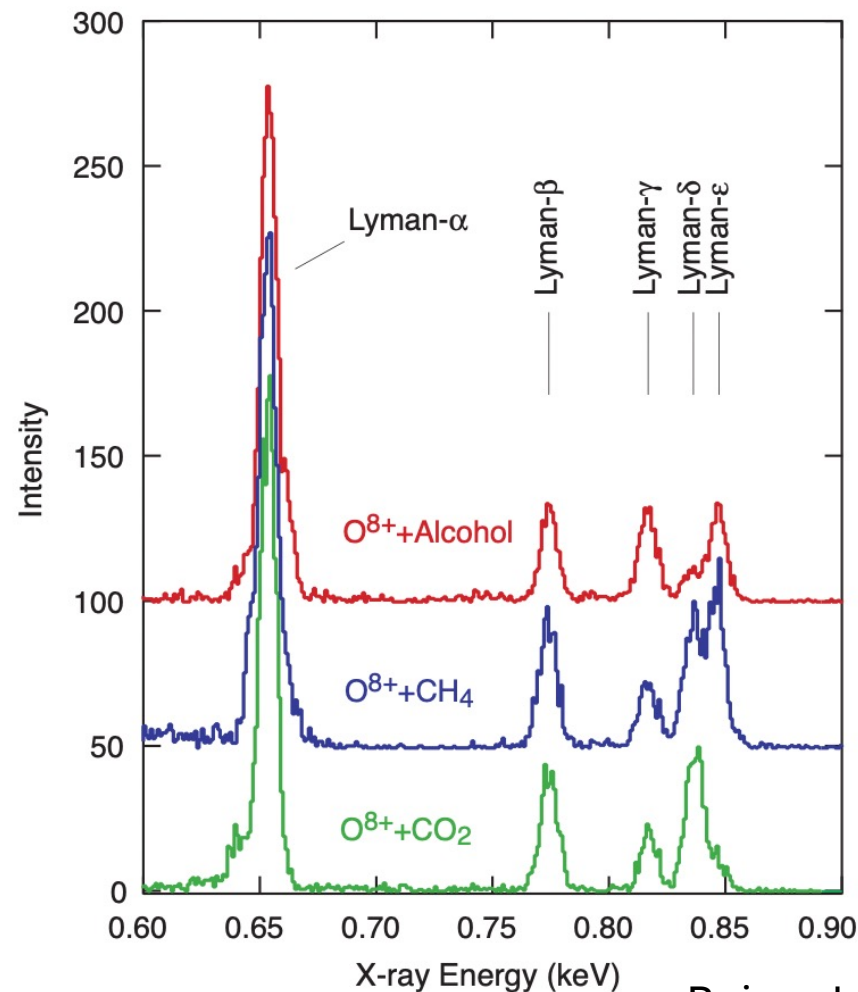
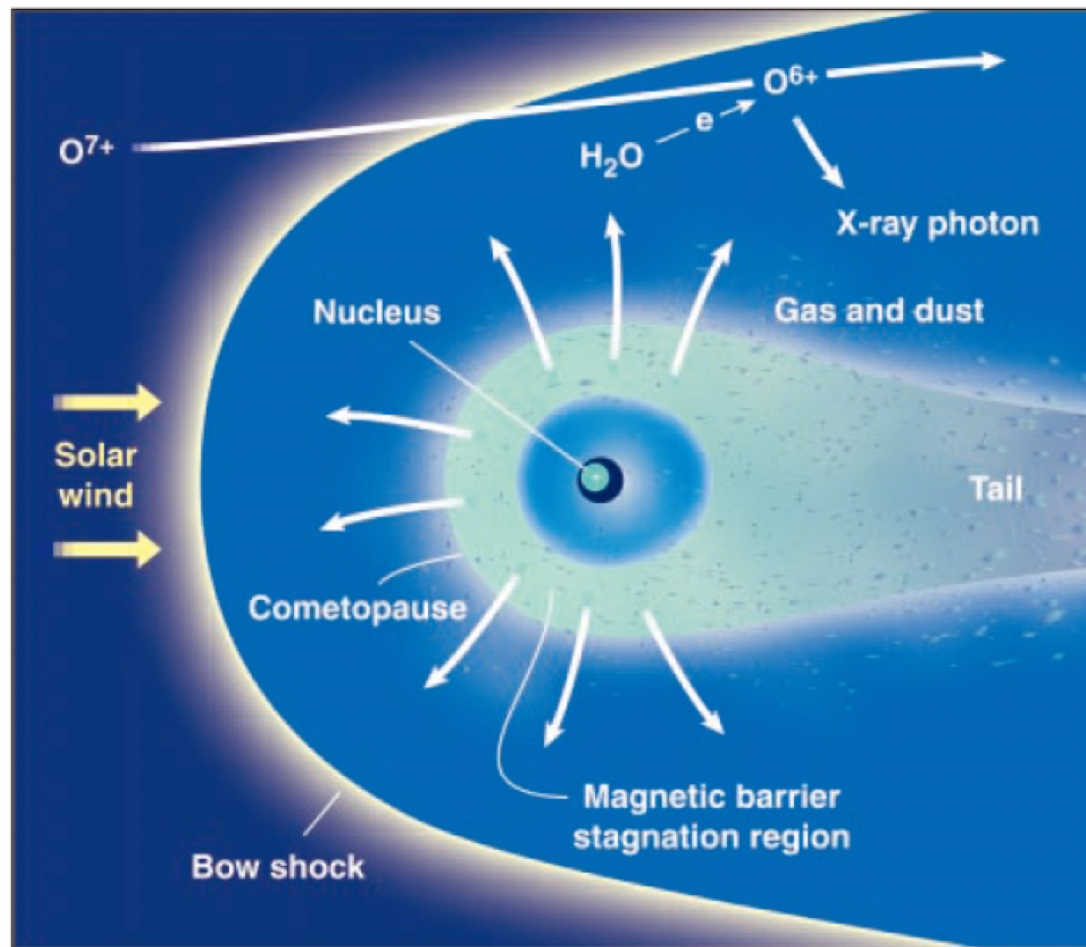


# Charge exchange model in SPEX

- Need for an (accurate) charge exchange model
- Current status and applications
- Challenges and potential solutions
- EBIT-TES campaign: first photon

Liyi Gu (SRON)

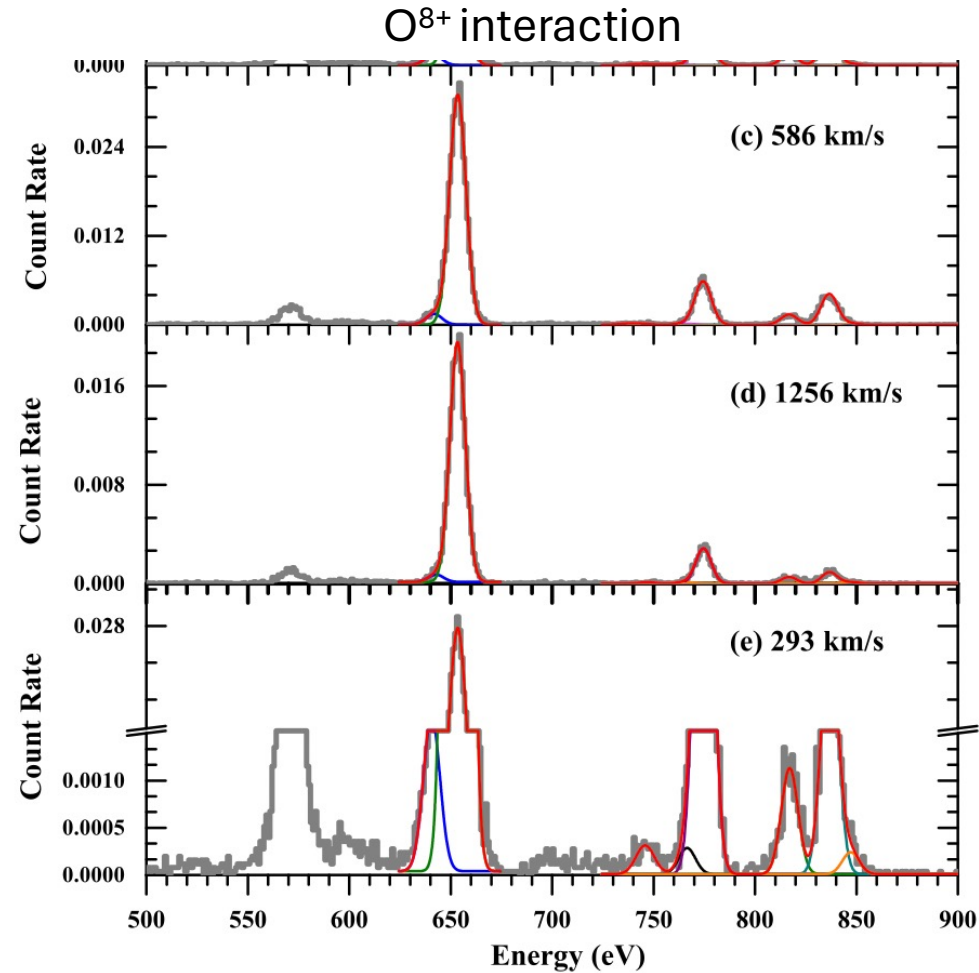
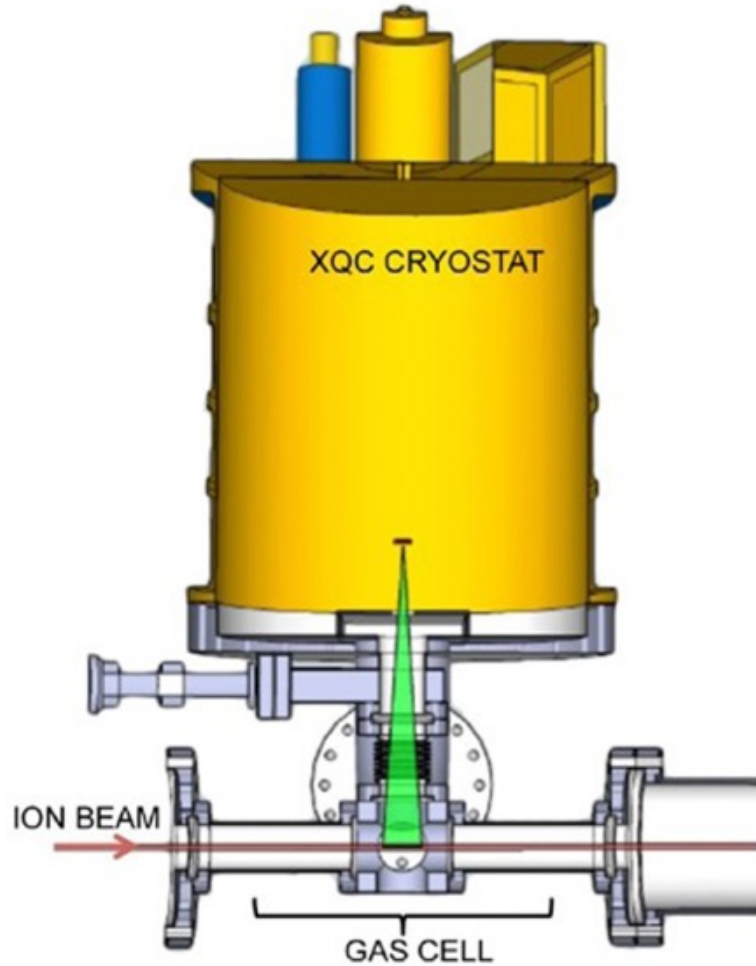
# Need for CX model: coupled with the advent of X-ray spectrometer



Beiersdofer + 2003

A Resolve-level instrument with an accurate model could constrain chemical composition in comet/planet atmosphere

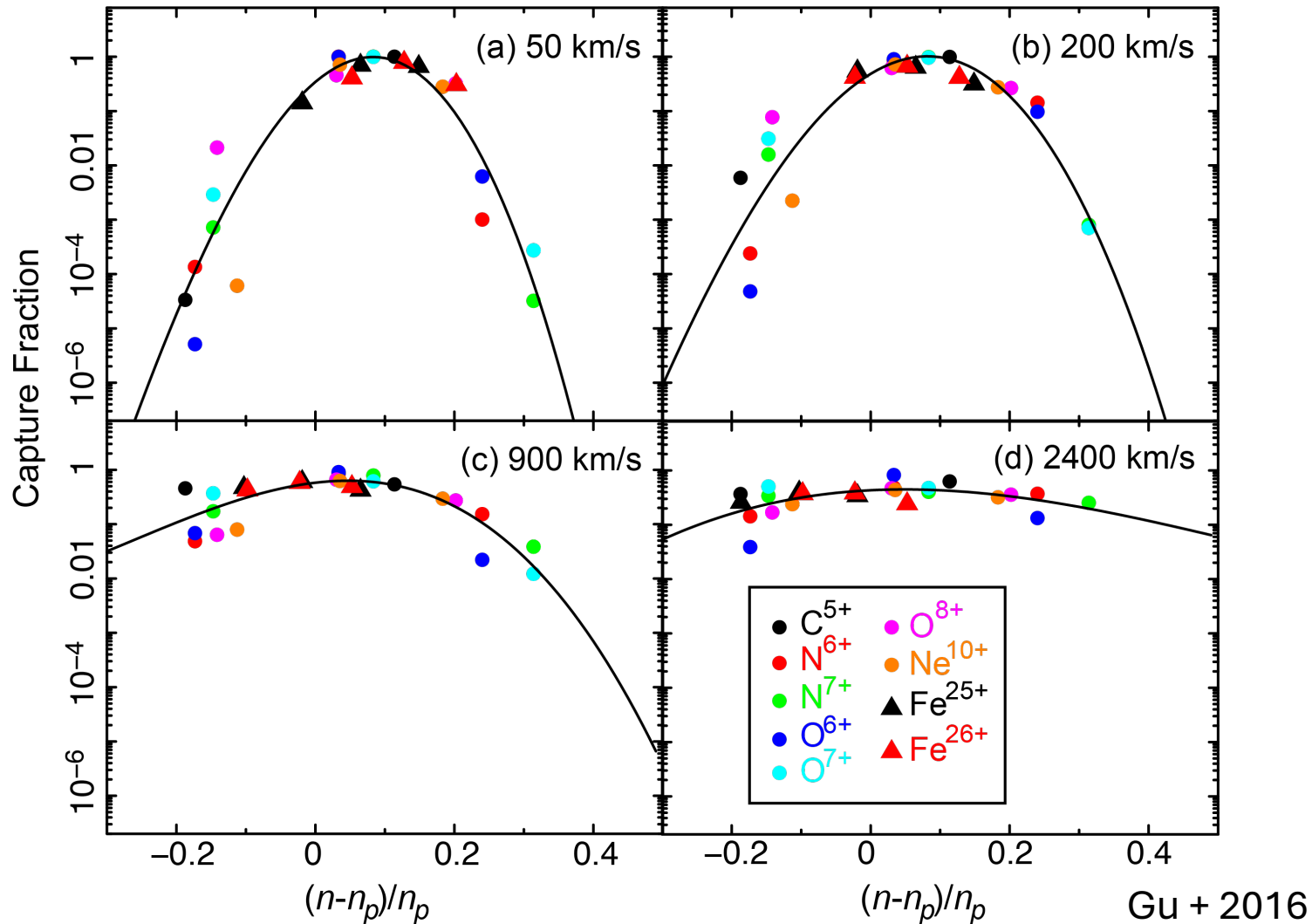
Need for CX model: coupled with the advent of X-ray spectrometer



Seely + 2017

... And constrain velocity in the wind-cloud interaction

# SPEX CX: cross sections



- Single capture,  $n$  up to 16 (H-, He- up to B-), 10 for rest
- Individual calculations (QMOCC, AOCC etc) when available
- Kronos database (MCLZ, P. Stancil+)
- Gu+2016 empirical scaling based on laboratory data

Level population and cascade solved with the SPEX engine

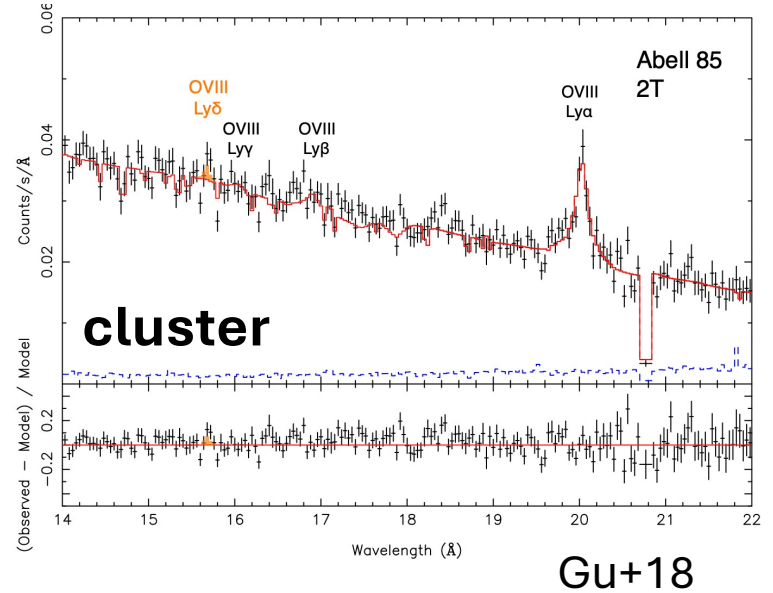
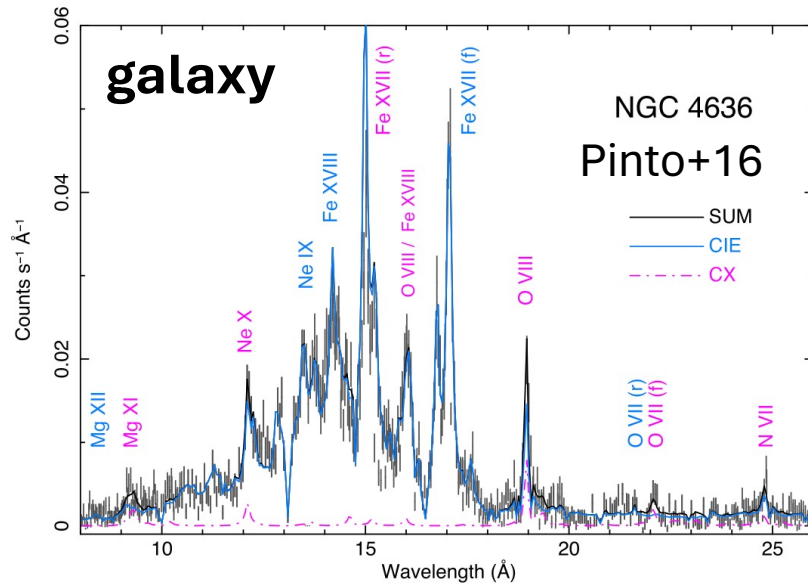
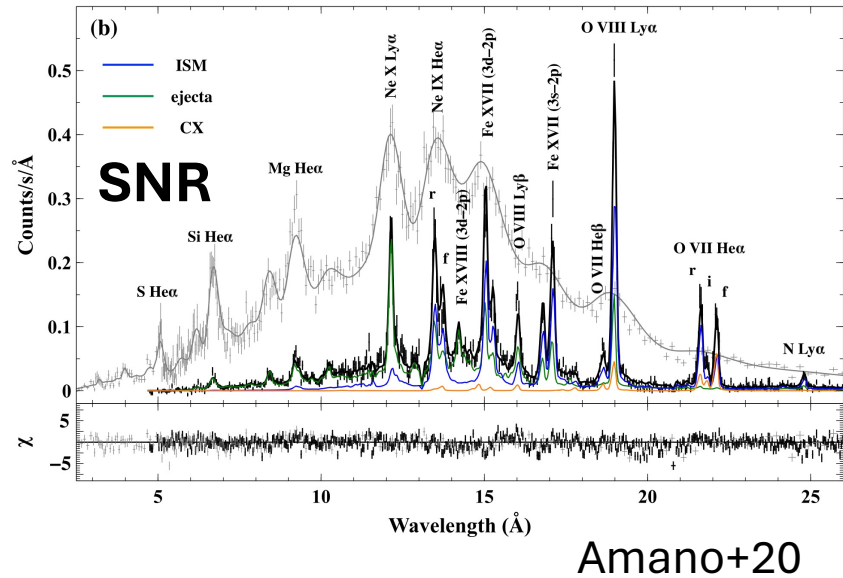
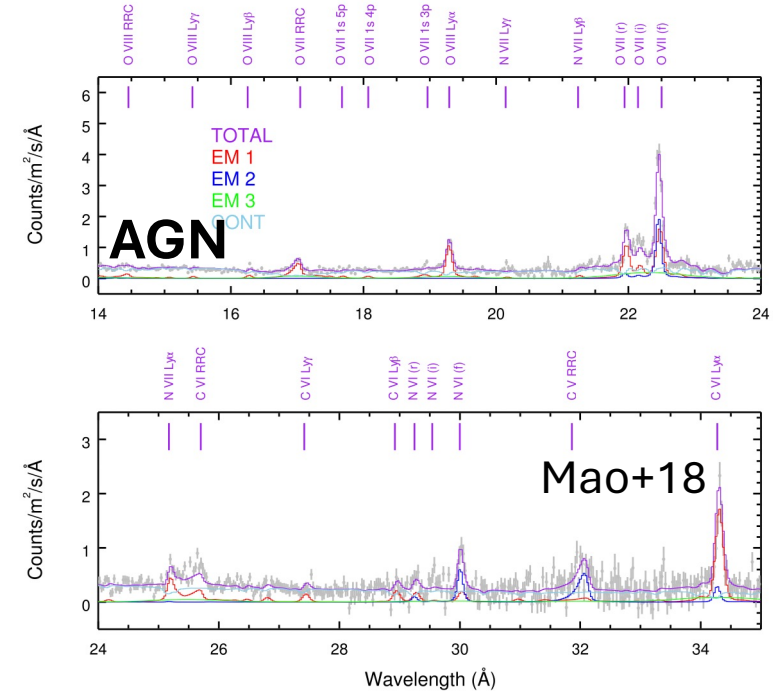
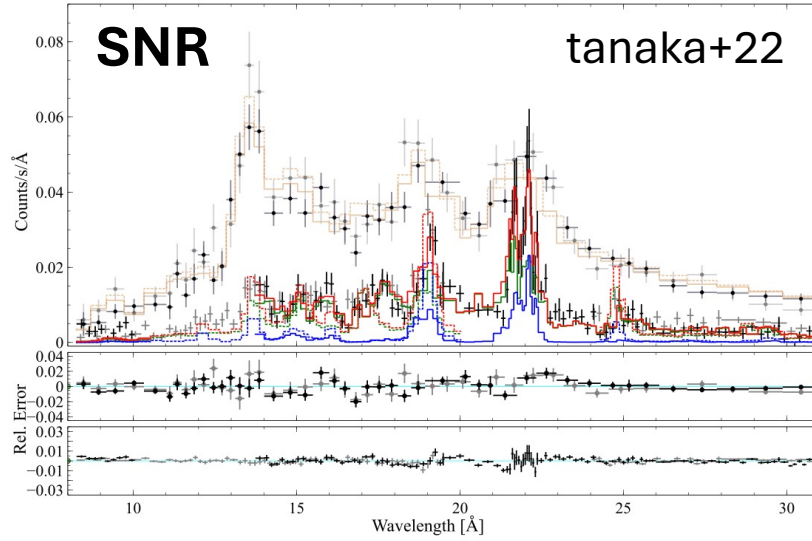
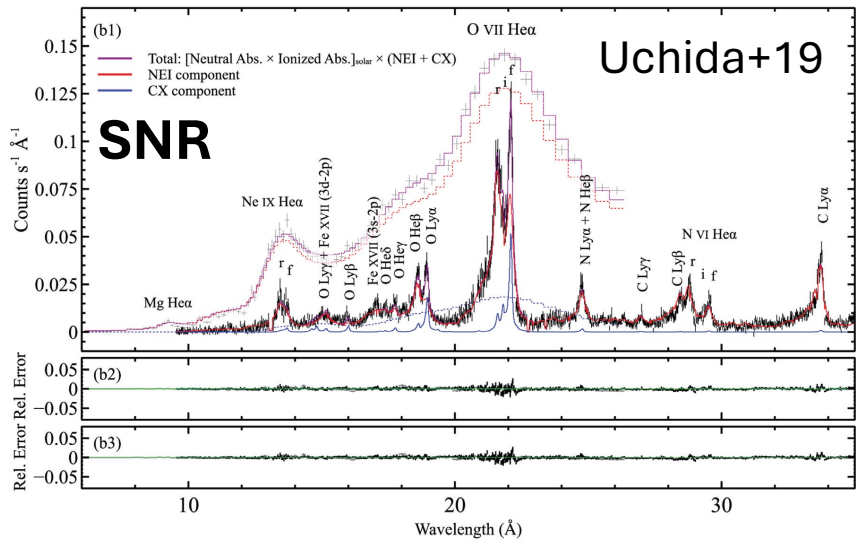
Gu + 2016

# SPEX CX: design

- Hot plasma at interface: collisional ionization equilibrium set by “t” parameter
  - Crude assumption. Probably recombining
- Cold matter: molecular forms (CO/CO<sub>2</sub>/H<sub>2</sub>O...) incorporated, soon available
- multi-temperature/DEM (“sig”)
- Both single- and multiple- collisions (switch with ”op”)
- Collision with thermal Doppler velocity, or kinetic motion (switch ”mode”)
- flux calculated from ion concentration (“t” and abundances), emission measure (“norm”), and collision velocity (“zv”)
- Line ratio set by collision velocity (“zv”), and *l*-distribution (“wt”)



# Applications of SPEX CX



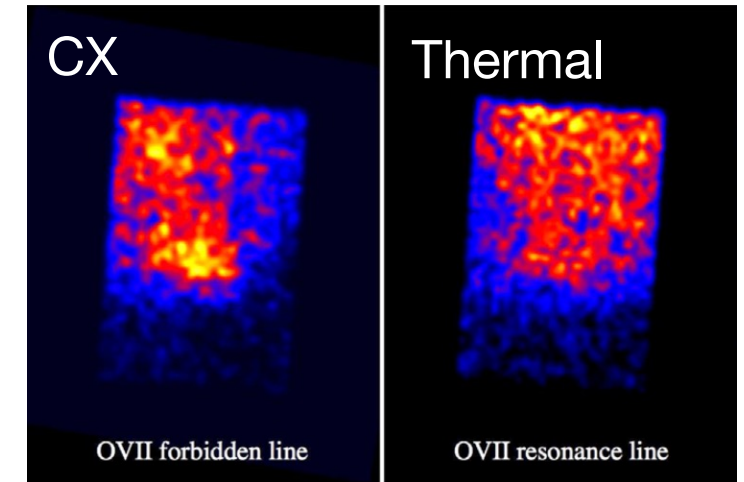
# Diagnostics using SPEX-CX

- Collision speed (line shift, ratio)
- Hot wind state and composition (line intensity)
- 2-D interaction structure (imaging spectroscopy, Katsuda talk)
- Neutral mass and species (line intensity and ratio)

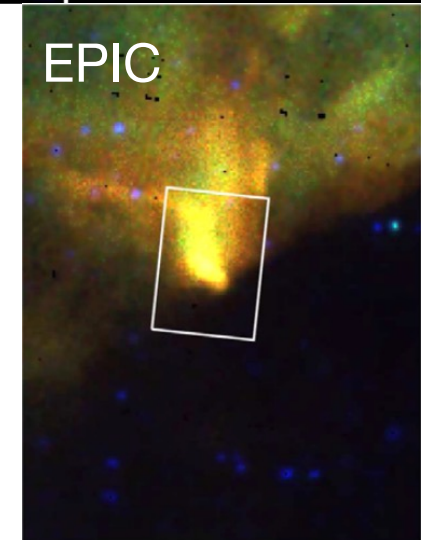
## Relevant plasma physics questions:

- Mass-loading of neutral into hot gas? (Lallement talk)
- Will it cool the hot gas significantly?
- Will it be multi-phase?
- Will the secondary (energetic) neutrals introduce instability?
- Will it affect gas dynamics?
- Will it alter the abundance of hot gas by ionizing neutrals?

RGS monochromatic (Uchida+19)

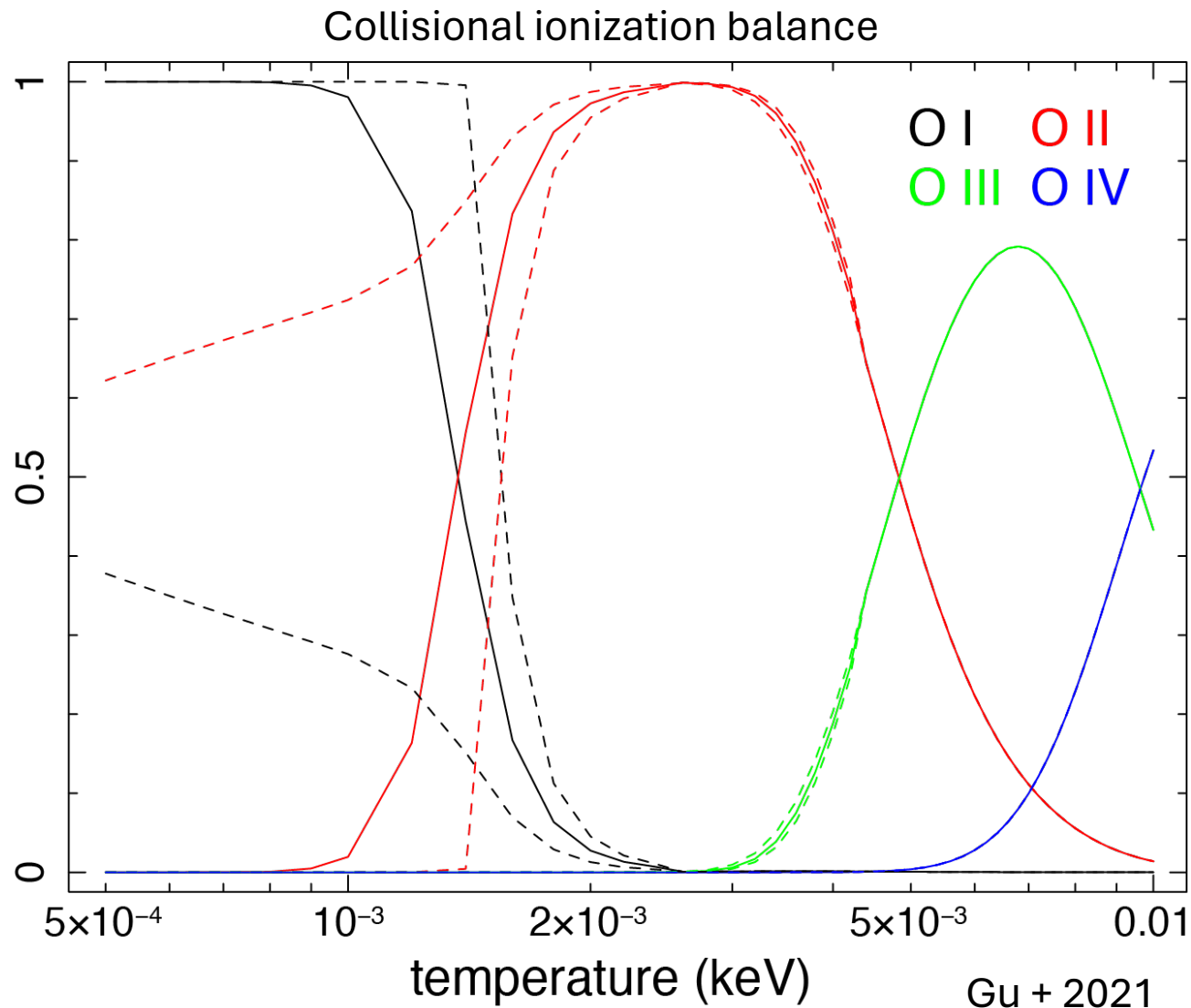


Mapping  
interaction  
in Cygnus  
Loop SNR



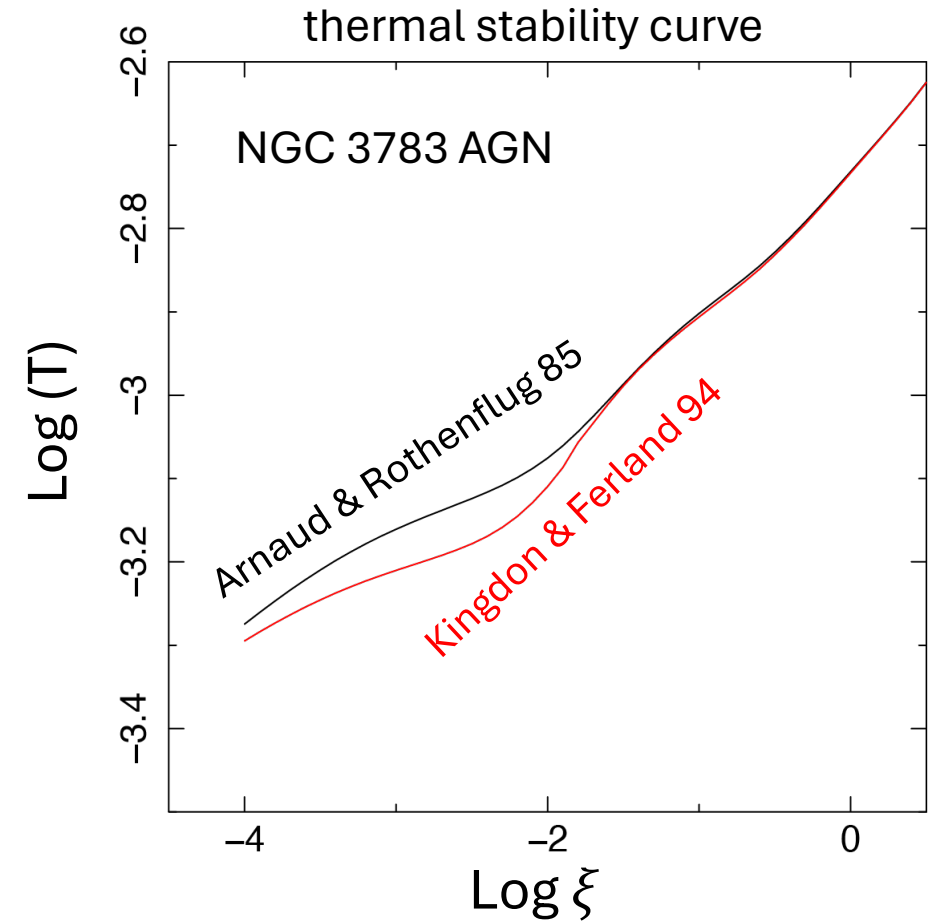


# CX rates needed for ion concentration



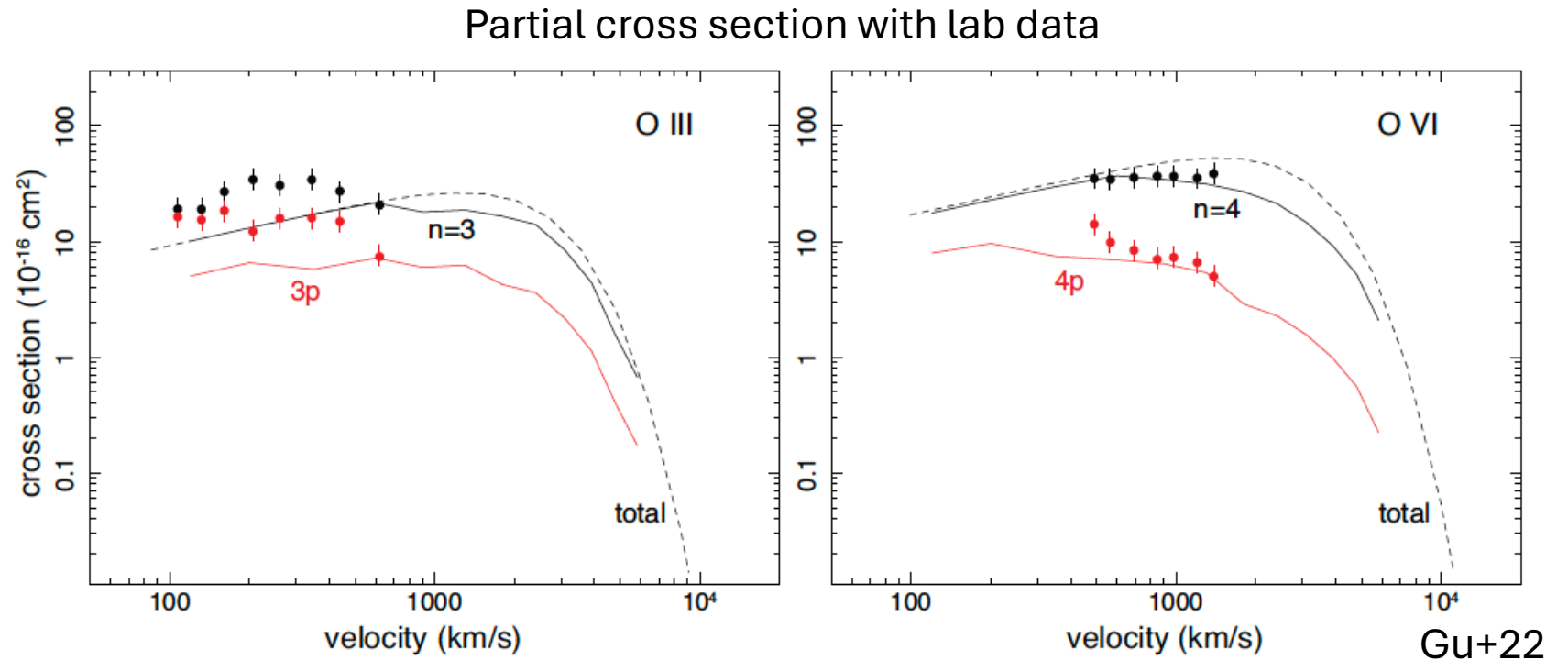
Dashed: CX recombination +/- 50%

- affect balance at low temperature
- Even more important for photoionization



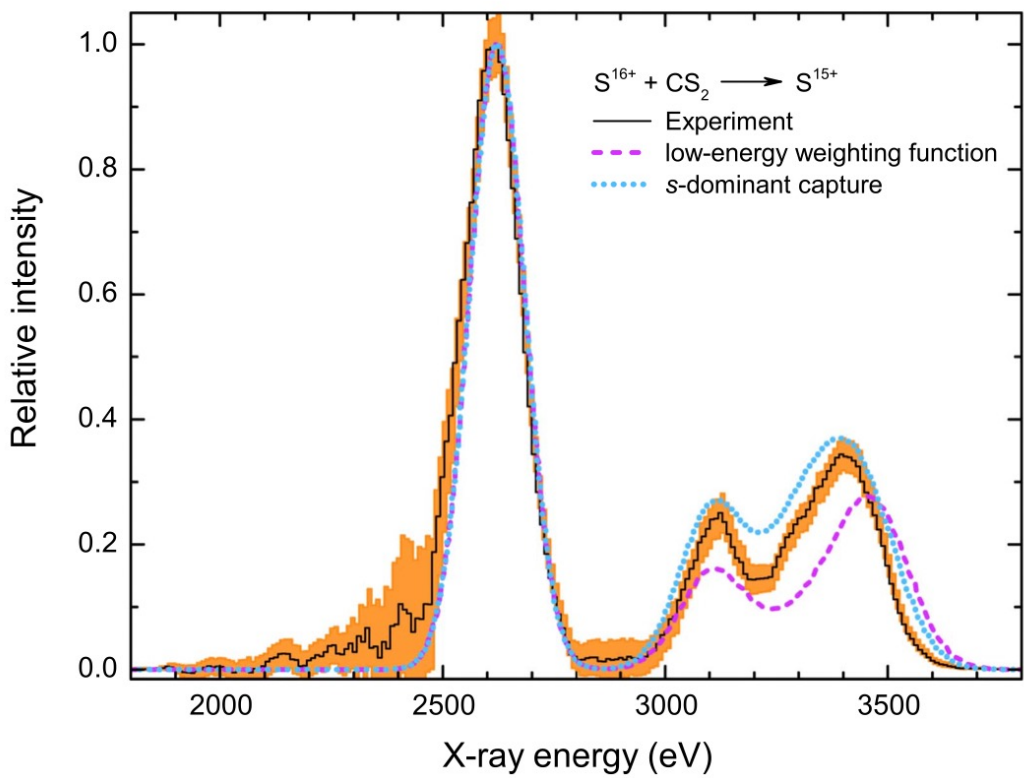
# Current challenges

- Assumption of ionization balance might not precisely reflect the true state at the interface.
- Thermal instability not well understood
- Level-resolved cross sections/line emissivities are uncertain by 50%
- Double capture
- CX with dust



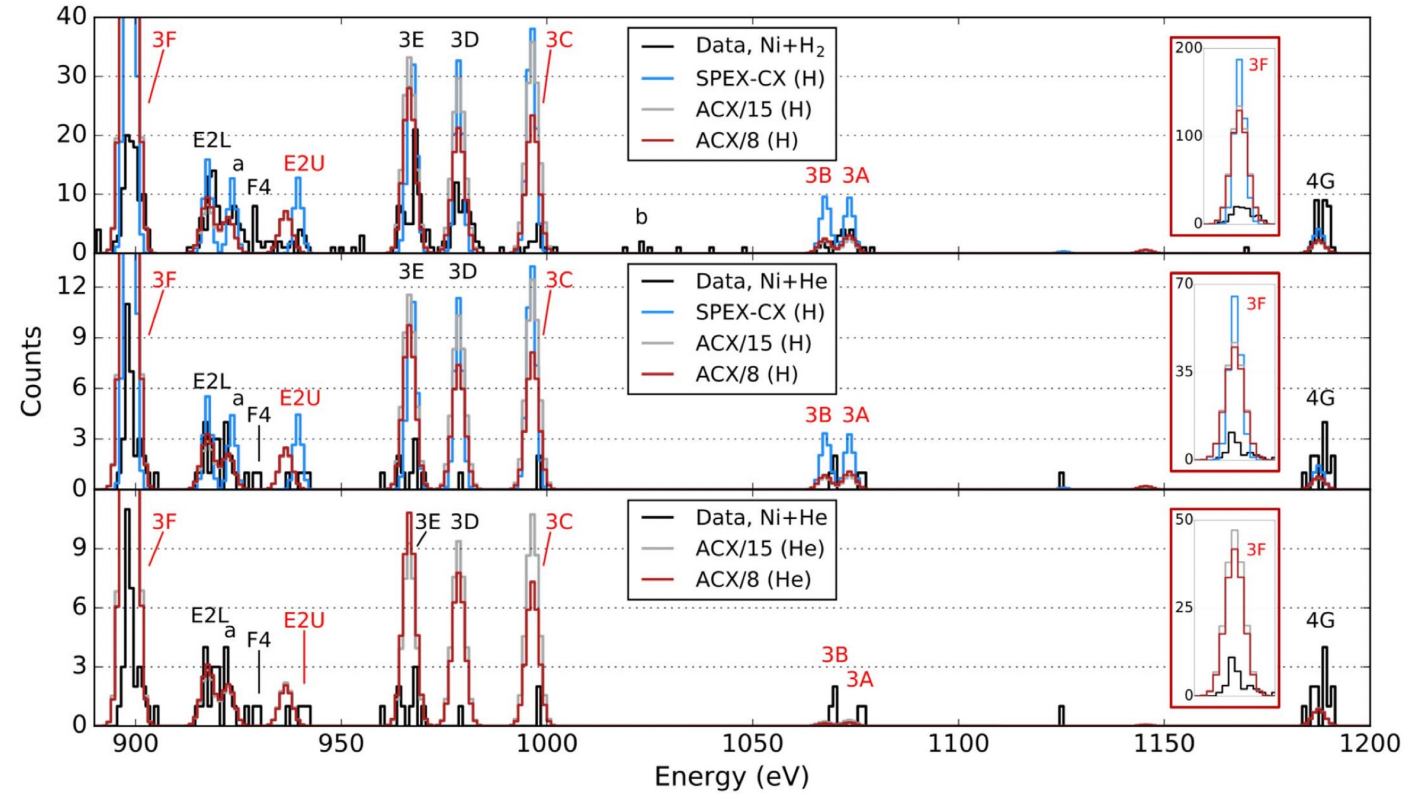
# Comparison with lab X-ray data

Shah+2016



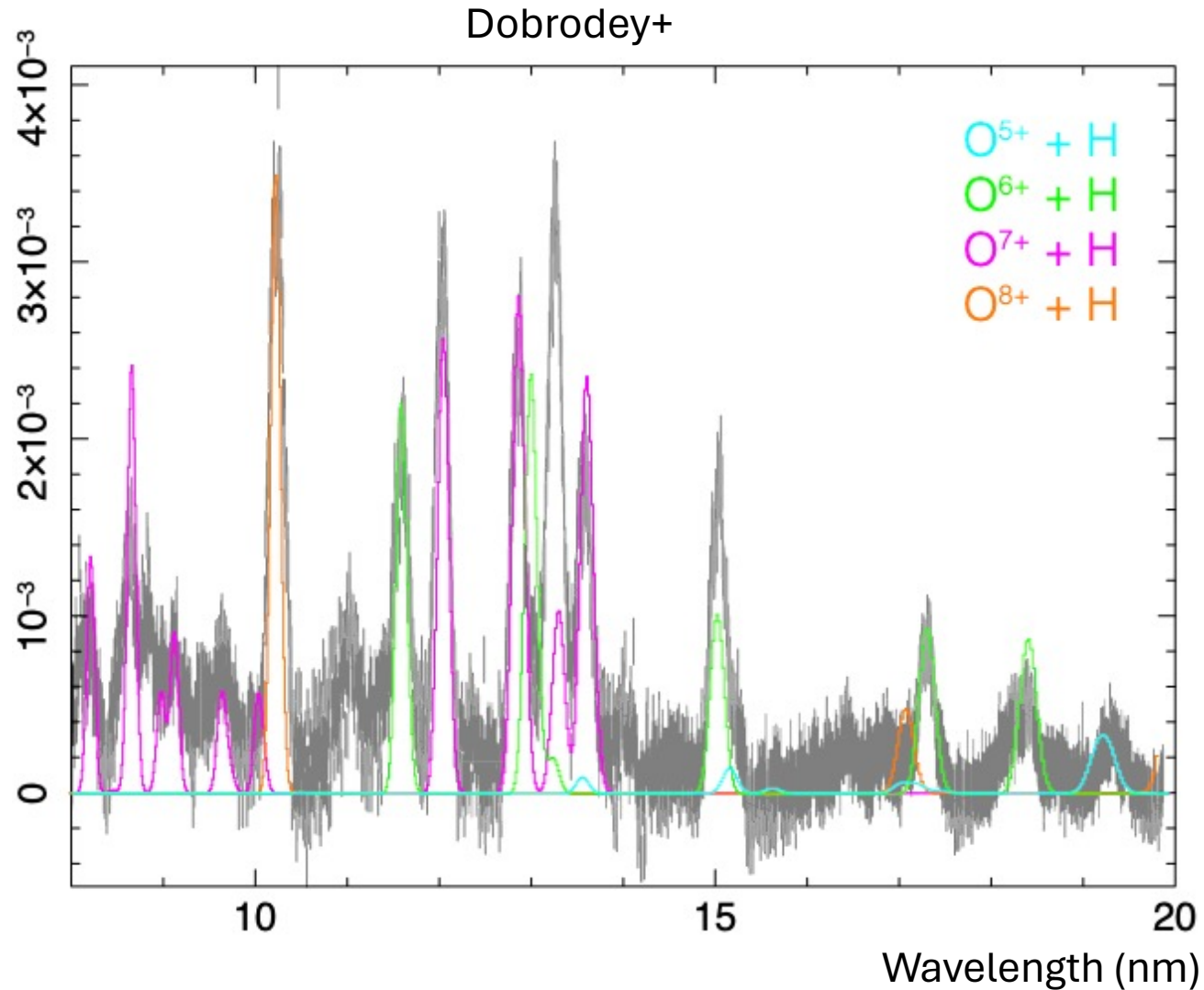
- FlashEBIT
- Magnetically trapped sulfur interacting with neutrals
- Demonstration of 3.5 keV sulfur line

Betancourt-Martinez+2018



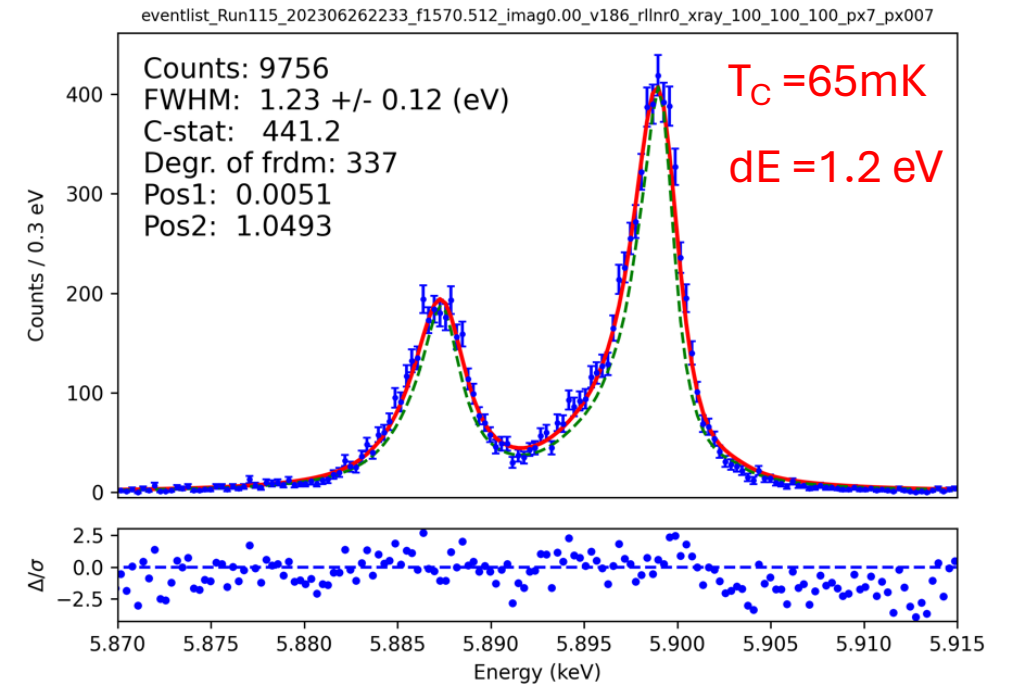
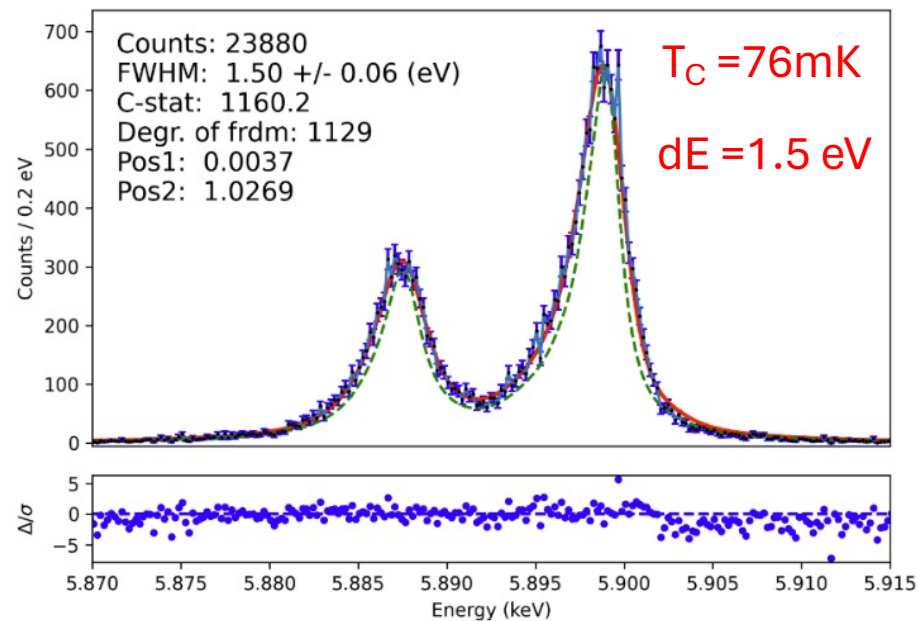
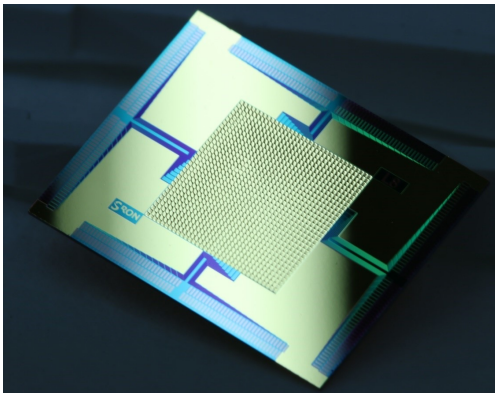
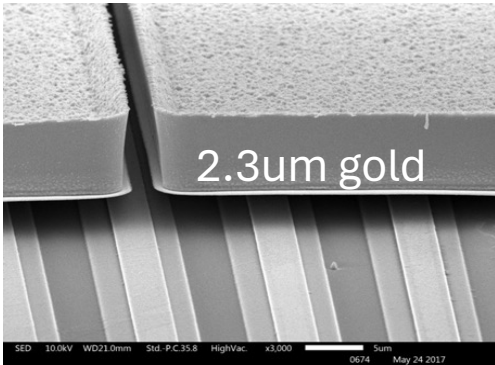
- EBIT-I (Leutenegger talk)
- Ni<sup>19+</sup> interacting with H<sub>2</sub> and He
- Capture into n=11 while model predicts n=10

# Comparison with lab EUV data

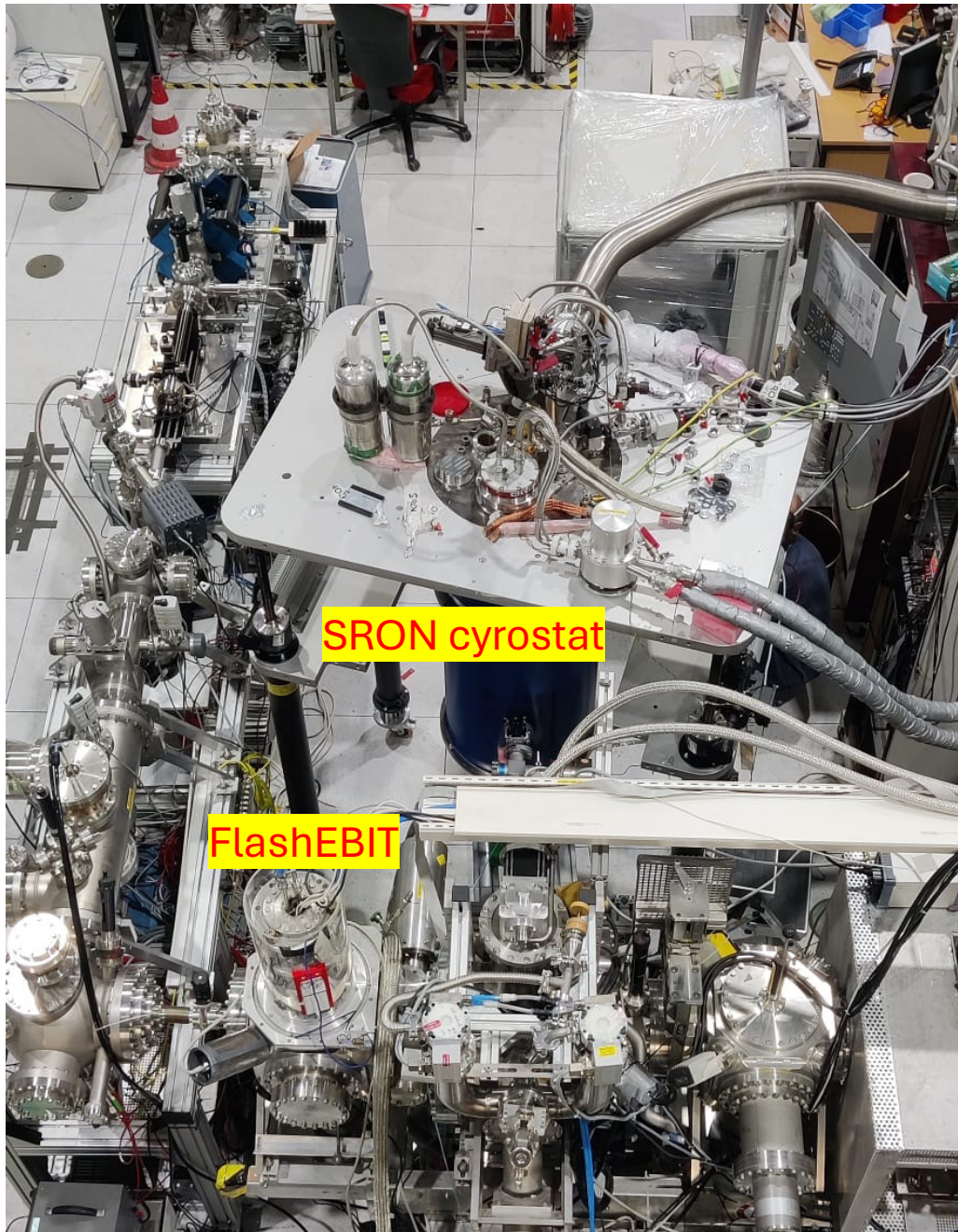


- FlashEBIT, EUV grating
- Oxygen ions interacting with  $H_2O$
- SPEX-CX reproduce most of the lines except for the O VI peak at 13.3 nm

# Status of SRON TES microcalorimeter



- Existing TES calorimeter optimize for NewAthena X-IFU like mission has been produced with typical single pixel energy resolution of **1.5 eV @ 6 keV**
- Energy resolution of **1.2 eV @ 6 keV** with large absorber is achieved in 2023 by lowering critical temperature.



# SRON TES at MPIK EBIT

- Joint SRON-IRAP-MPIK project
- X-IFU like setup (test array) was transported early June to Heidelberg
- Works reasonably in a harsh environment
- 2-channel x 35 pixel readout, total FWHM  $\sim 2.2$  eV stable
- Aim for high resolution on a cryogenic EBIT
- Expect first light later this month
- Plan  $\geq$  one year TES+EBIT run

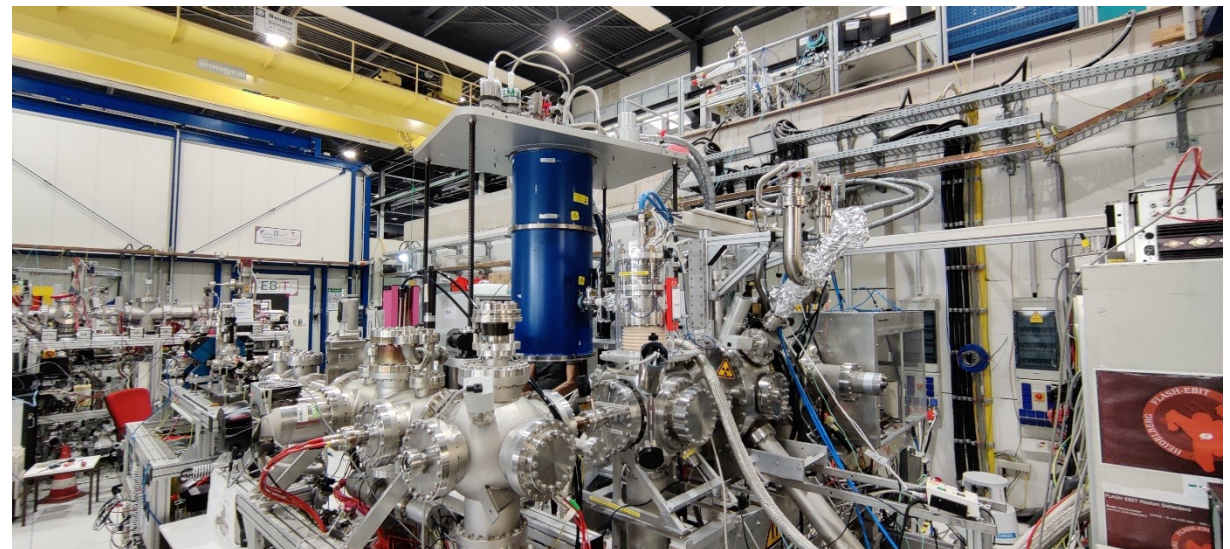
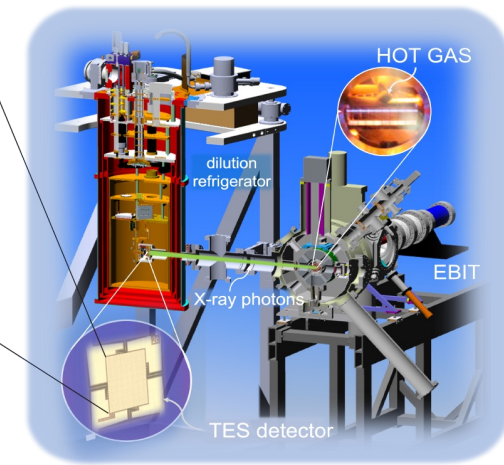
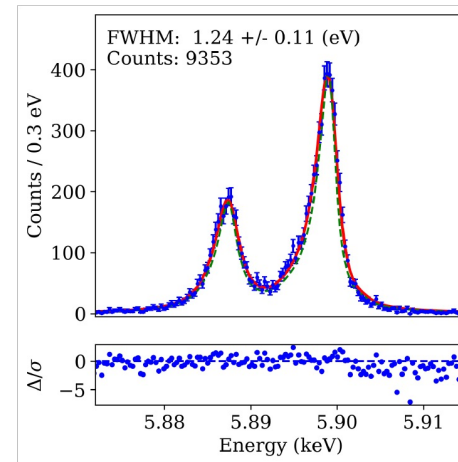
# Dedicated TES array and expected results

- Low critical temperature array has been fabricated at SRON. Will join the campaign later this year.

- ~ **1 eV** single pixel resolution

- Expected outcome:

- Full catalog of K- and L- transitions  
Fe, Mg, Si, S, Ar, Ca, Cr, Mn, Ni
- Spectroscopy of fine structure  
and QED test
- response to XRISM requests
- High-Z and fusion plasma simulation
- NewAthena X-IFU calibration



## Ending remarks

- The advent of high-resolution X-ray spectrometers necessitates accurate CX models
- SPEX-CX will incorporate new update from Kronos database (P. Stancil talk)
- Many applications so far, more expected with XRISM (L. Gu next talk)
- Laboratory calibration with EBIT, Coltrims, etc
- SRON TES detector integrated to a large EBIT at Heidelberg, for period ~ year(s)
- For any idea/request, feel free to chat with me