Characterizing Interstellar Dust with Chandra in the Next Decade

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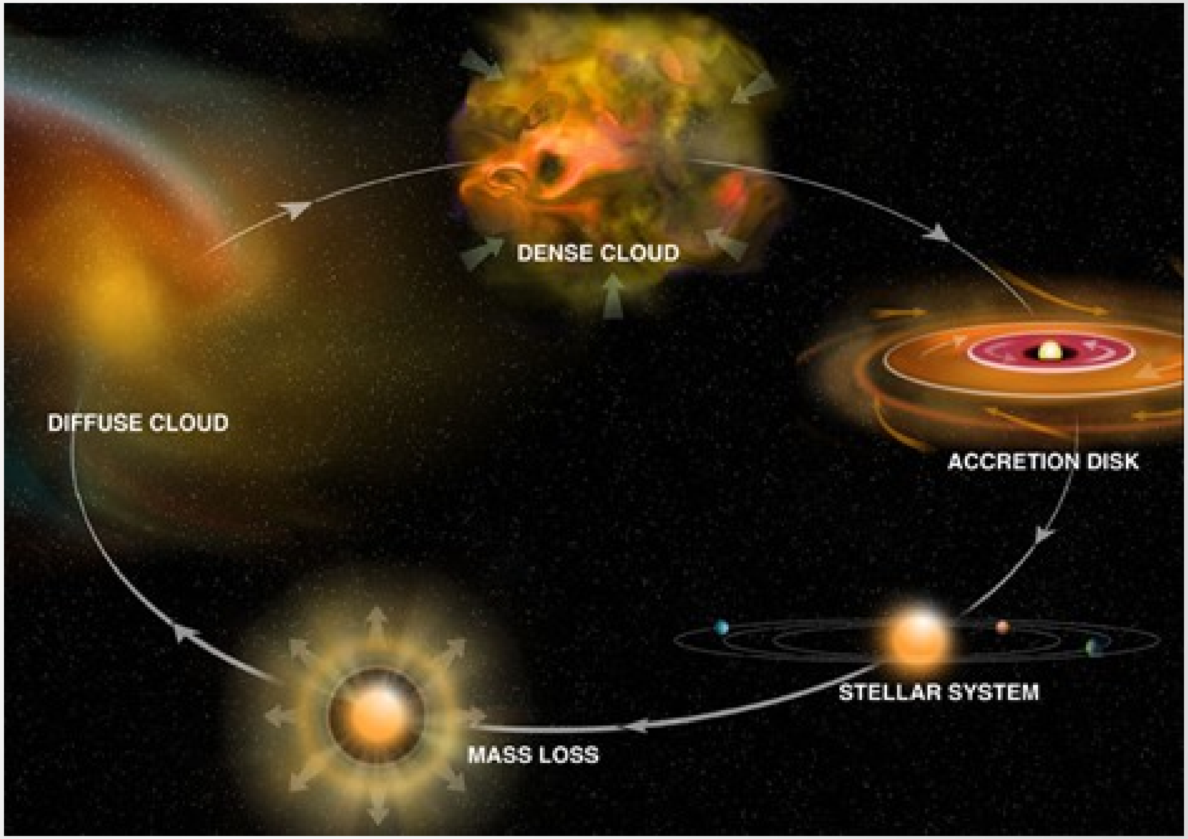
The life cycle of dust in the universe

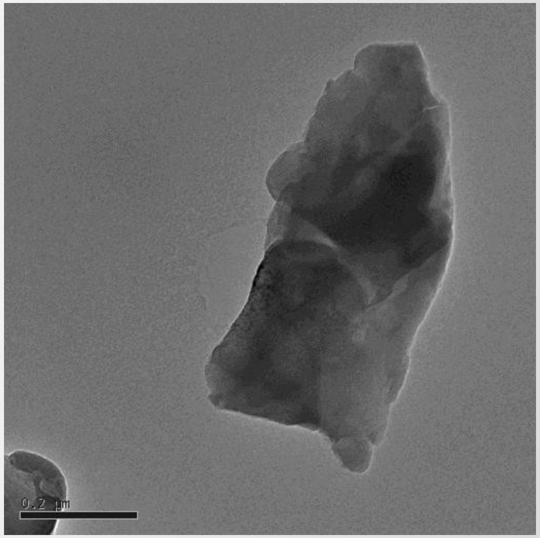
Dust has an important role in the processes that drive the evolution of the Interstellar Medium (ISM)



What kind of dust do we find in the ISM?

What is the chemical composition of interstellar dust in the ISM?

Major dust forming elements are: C,N,O, Mg, Si and Fe (and possibly S)



Silicate dust grain

- **Silicates**
- Hydrogenated Amorphous Carbon
- Interstellar ices
  (CO, H_2O, NH_3, CH_4, CO_2 etc.)
- Graphite
- Sulfide minerals: FeS, FeS_2, MnS (?)

Observing Dust

Dust has been extensively studied between wavelength ranges: radio to far UV

Open questions:

- **Chemical composition of dust unclear:** Where is the iron? 90% depleted! Might be in silicates. Also large uncertainties for: O, S, and C
- **Structure of dust**: How is dust produced and destroyed? What is the ratio of amorphous and crystalline dust?

X-rays can provide an answer!

the study of interstellar dust

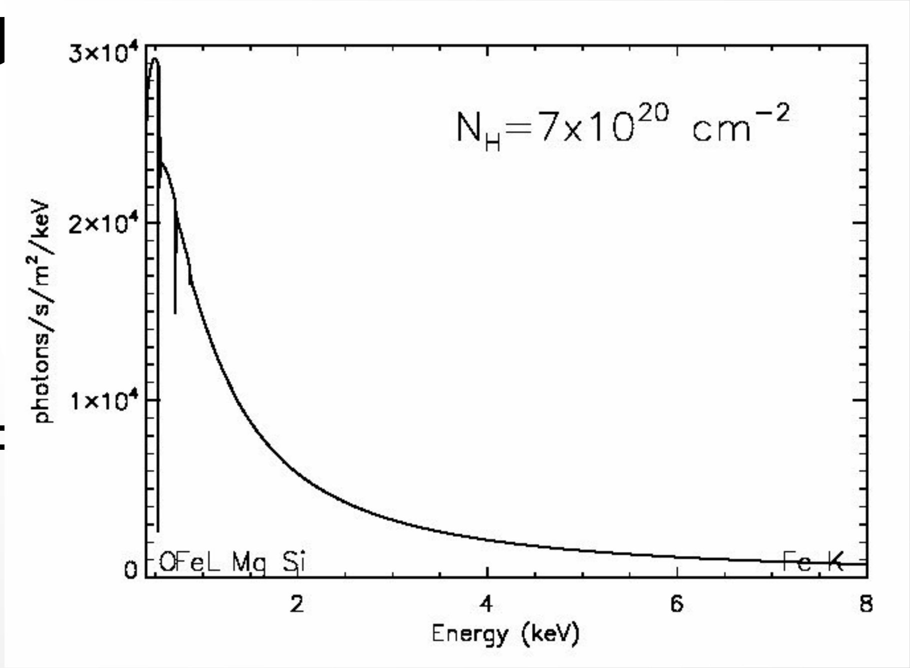
- **X-rays are sensitive to a wide range of column densities; makes it possible to analyze dust content in various regions**

the study of interstellar dust

- X-rays are sensitive to a wide range of column densities; makes it possible to analyze dust content in various regions
  Depending on the environment we can observe different edg

Diffuse regions: O and Fe
$N_H \sim 2x10^{21} cm^{-2}$

Dense regions: Si, Mg, S, F
$N_H \sim 2.5x10^{22} cm^{-2}$



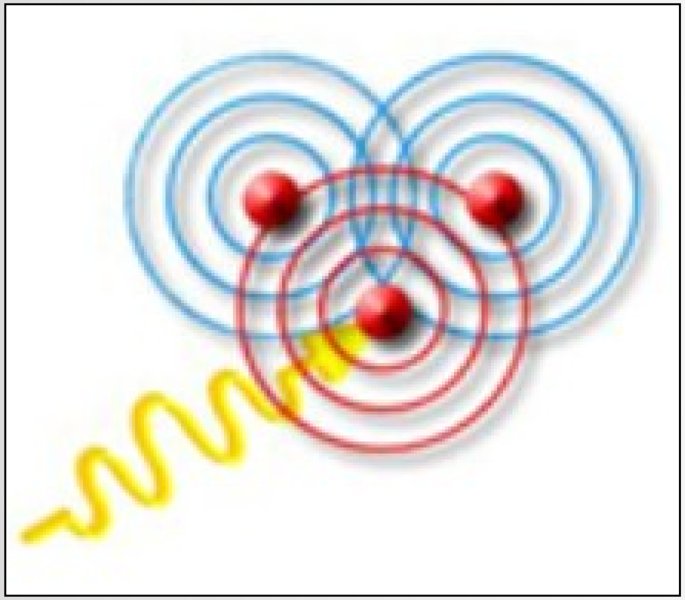
the study of interstellar dust

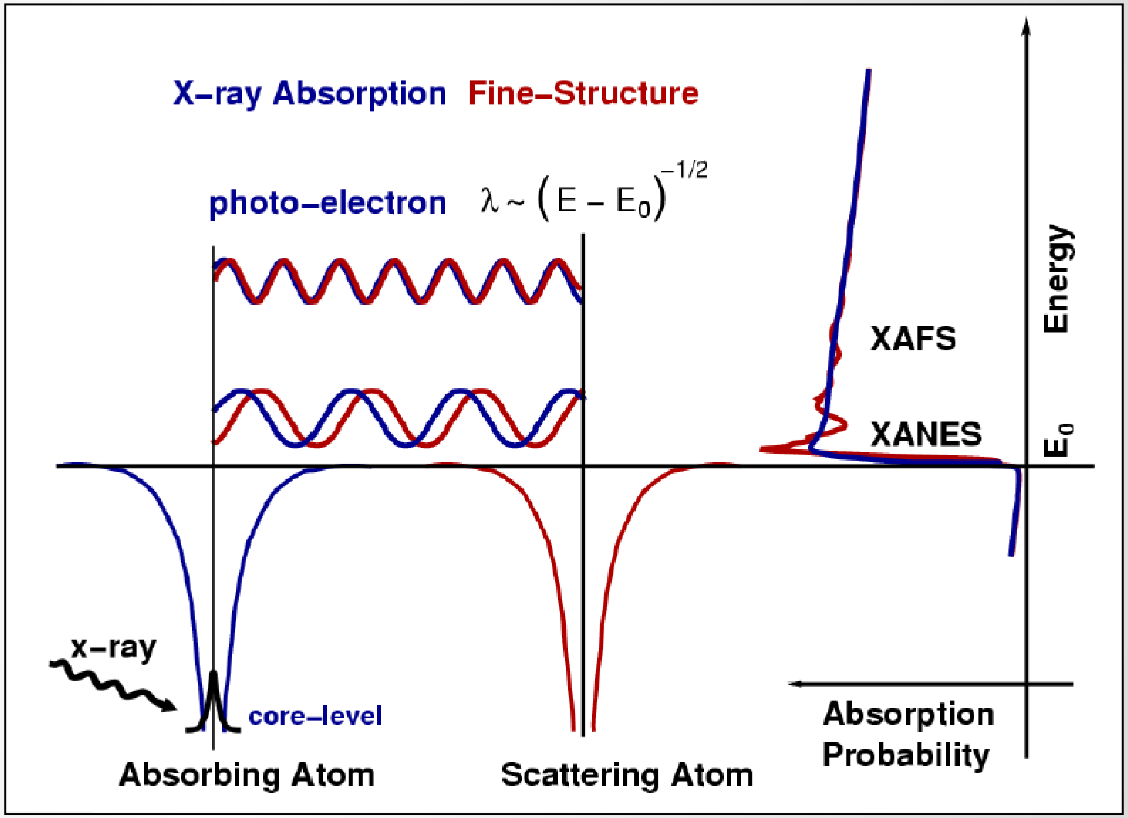
- X-rays are sensitive to a wide range of column densities; makes it possible to analyze dust content in various regions
- **Measuring non blended absorption features in the soft X-rays of O, Mg, Si and Fe**

the study of interstellar dust

- X-rays are sensitive to a wide range of column densities; makes it possible to analyze dust content in various regions
- Measuring non blended absorption features in the soft X-rays of O, Mg, Si and Fe
- **Absorption of both gas and dust can be measured simultaneously**

structures (XAFS) to characterize ID





Modified from *Fundamentals of XAFS* by Mathew Newville

Models:
Filling the gaps

Few lab measurements available of X-ray edges interesting for astronomy

We need to expand the database

The DUSTLAB project:

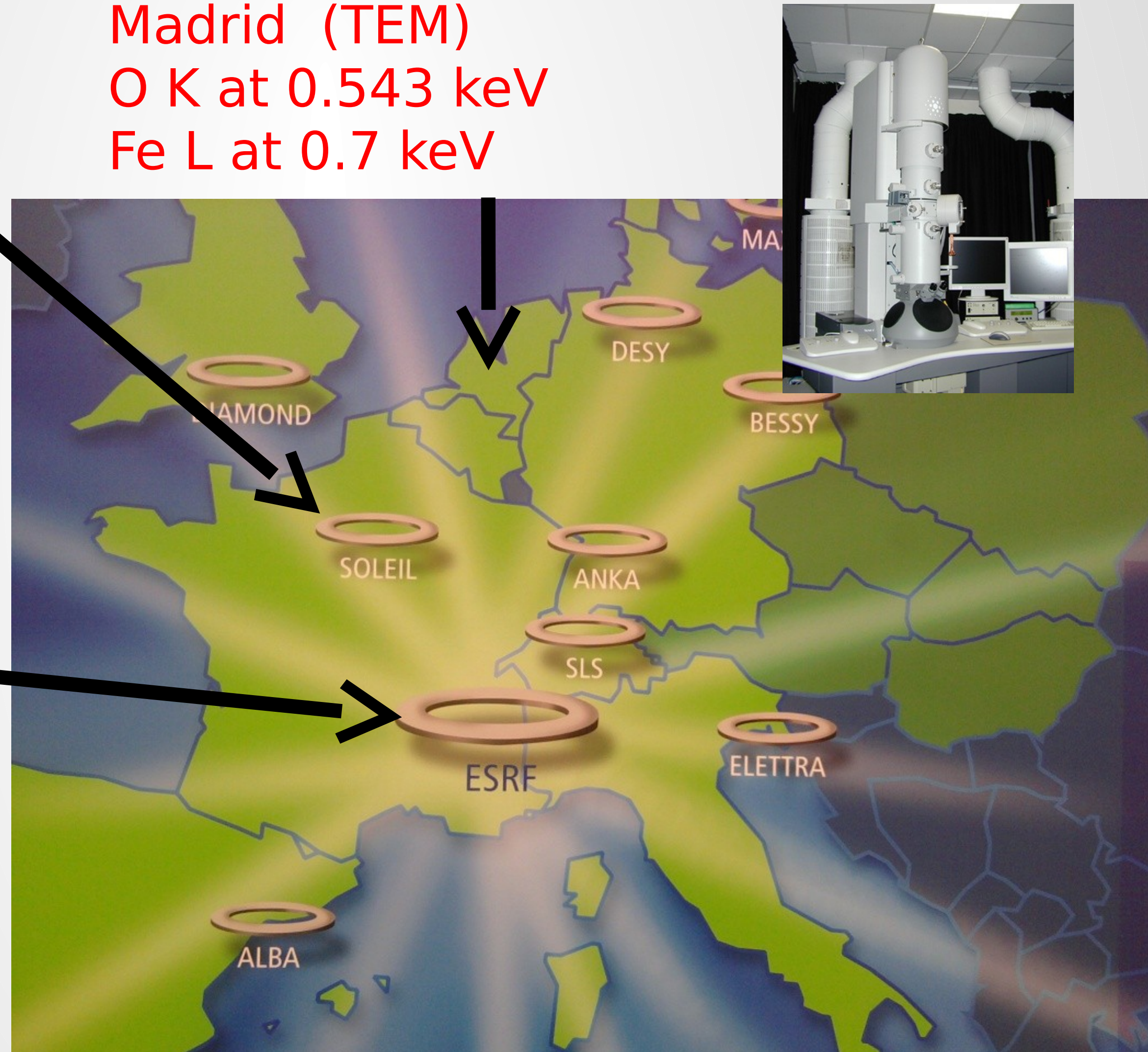
(Costantini, De Vries 2013)

- Collect relevant dust samples (e.g. silicates and sulfates)
- Measure relevant edges (**O, Fe, Mg, Si, S**)
- Implement into fitting X-ray

Laboratory data

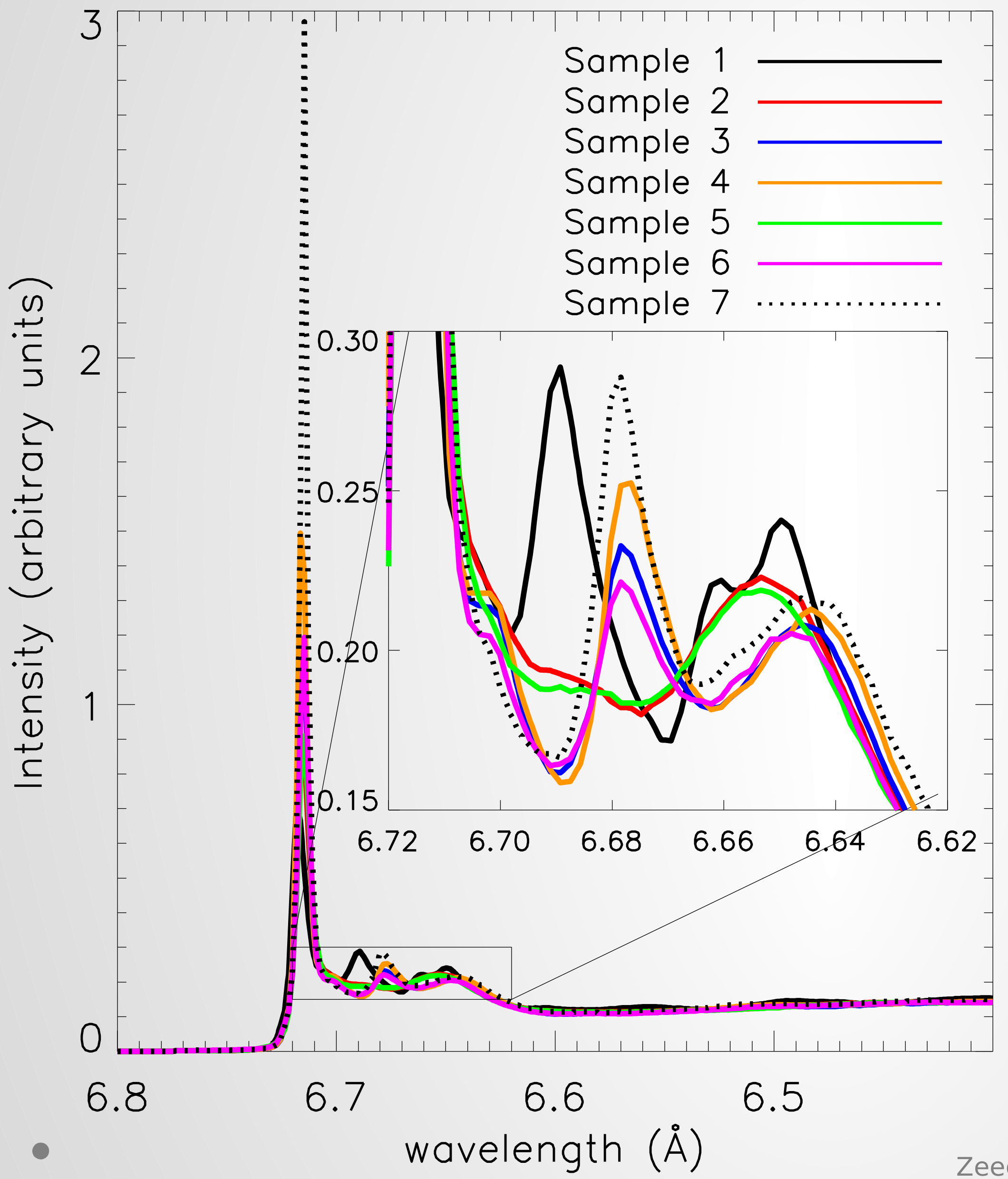
LUCIA
Mg K at 1.3 keV
Si K at 1.84 keV

Electron Microscope Utrecht (EMU),
Madrid (TEM)
O K at 0.543 keV
Fe L at 0.7 keV



DUBBLE
Fe K at 7.11
keV

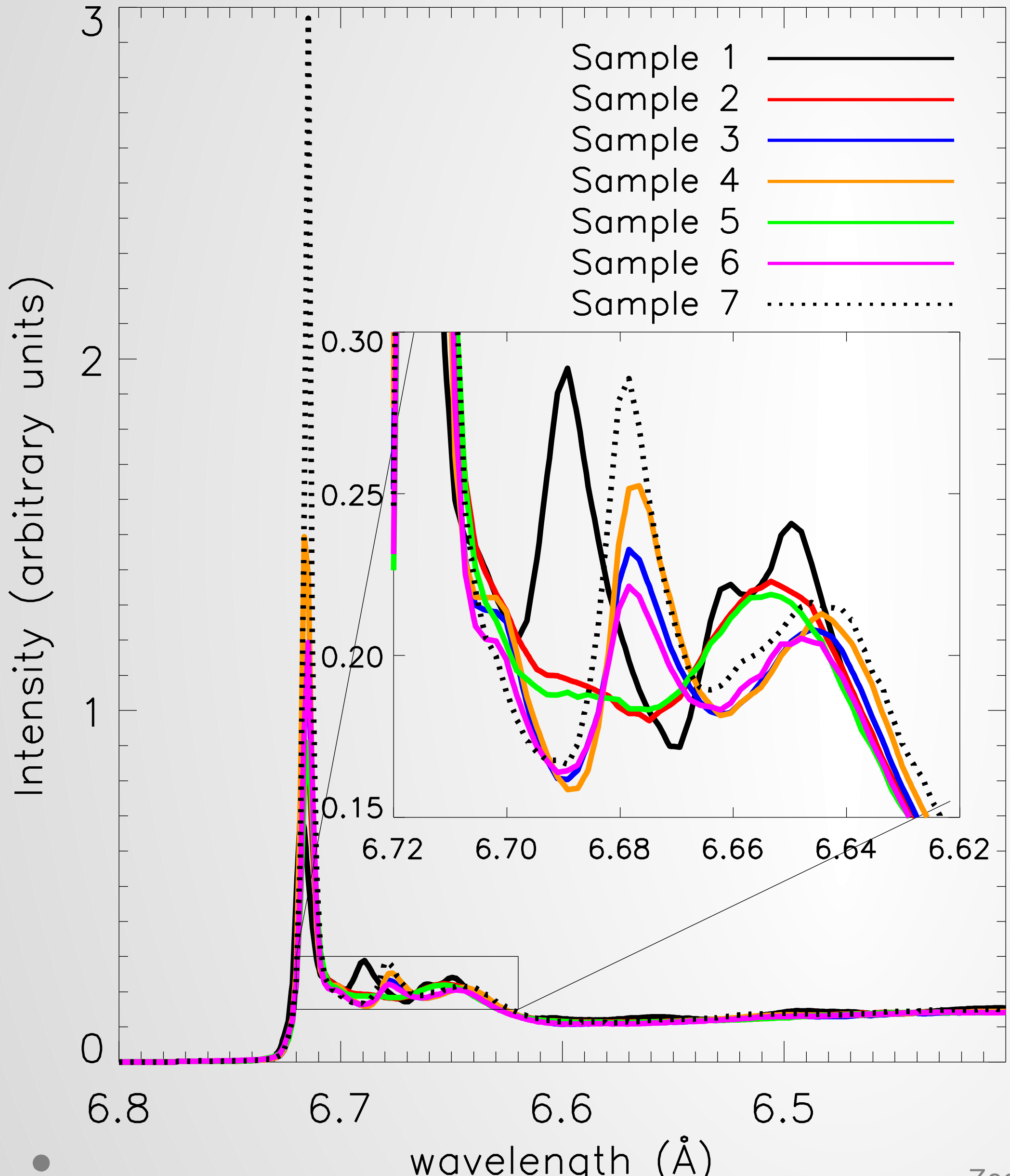
Absorption profiles: Si K-edge



Sample
1. Olivine ($Mg_{1.56}Fe_{0.4}Si_{0.91}O_4$)
2. Pyroxene (amorphous) ($Mg_{0.9}Fe_{0.1}SiO_3$)
3. Pyroxene ($Mg_{0.9}Fe_{0.1}SiO_3$
4. Enstatite ($MgSiO_3$)
5. Pyroxene (amorphous) ($Mg_{0.6}Fe_{0.4}SiO_3$)
6. Pyroxene ($Mg_{0.6}Fe_{0.4}SiO_3$)
7. Hyperstene ($Mg_{1.502}Fe_{0.498}Si_2O_6$)

Zeegers, Costantini et al 2016 (submitted)

Absorption profiles: Si K-edge



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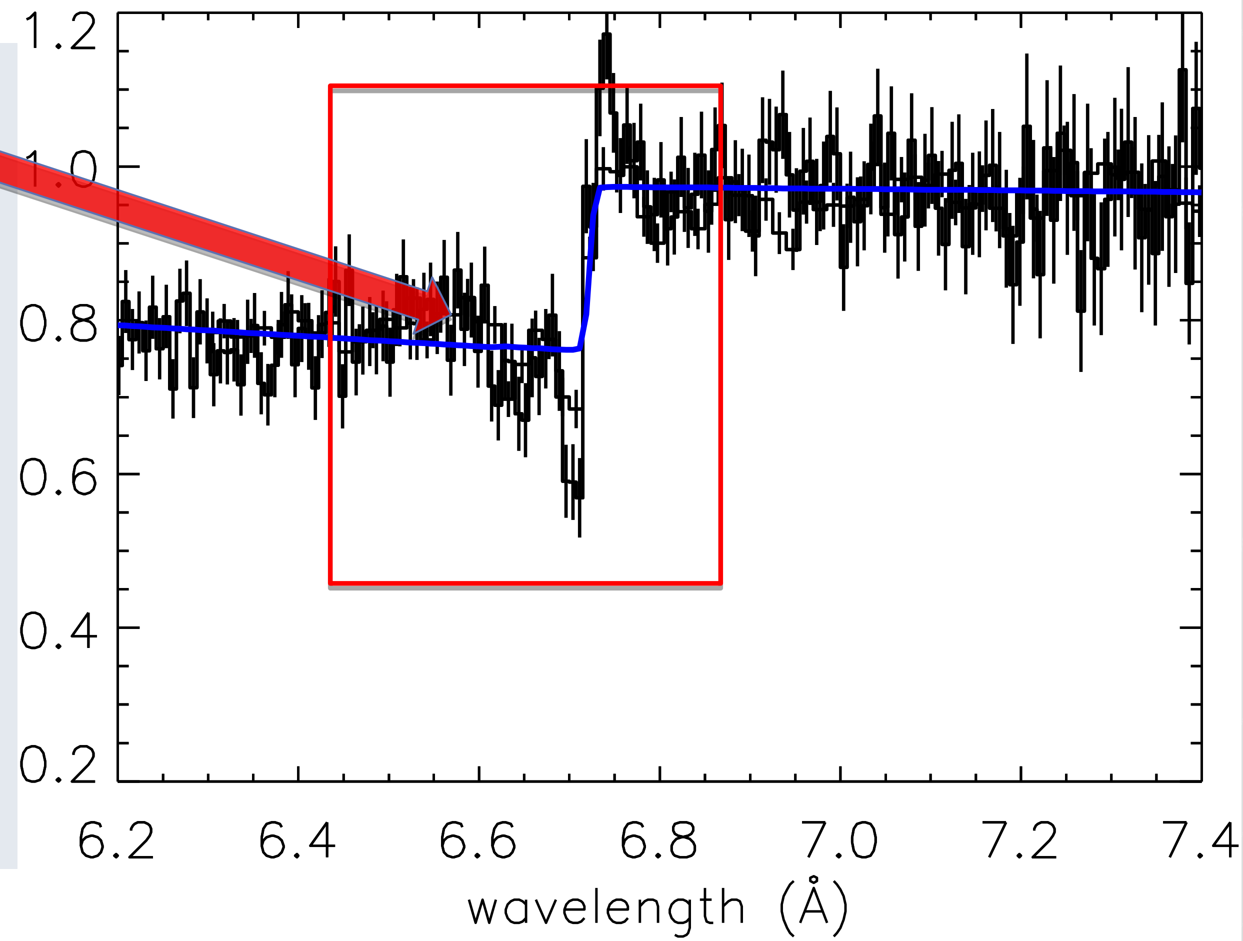
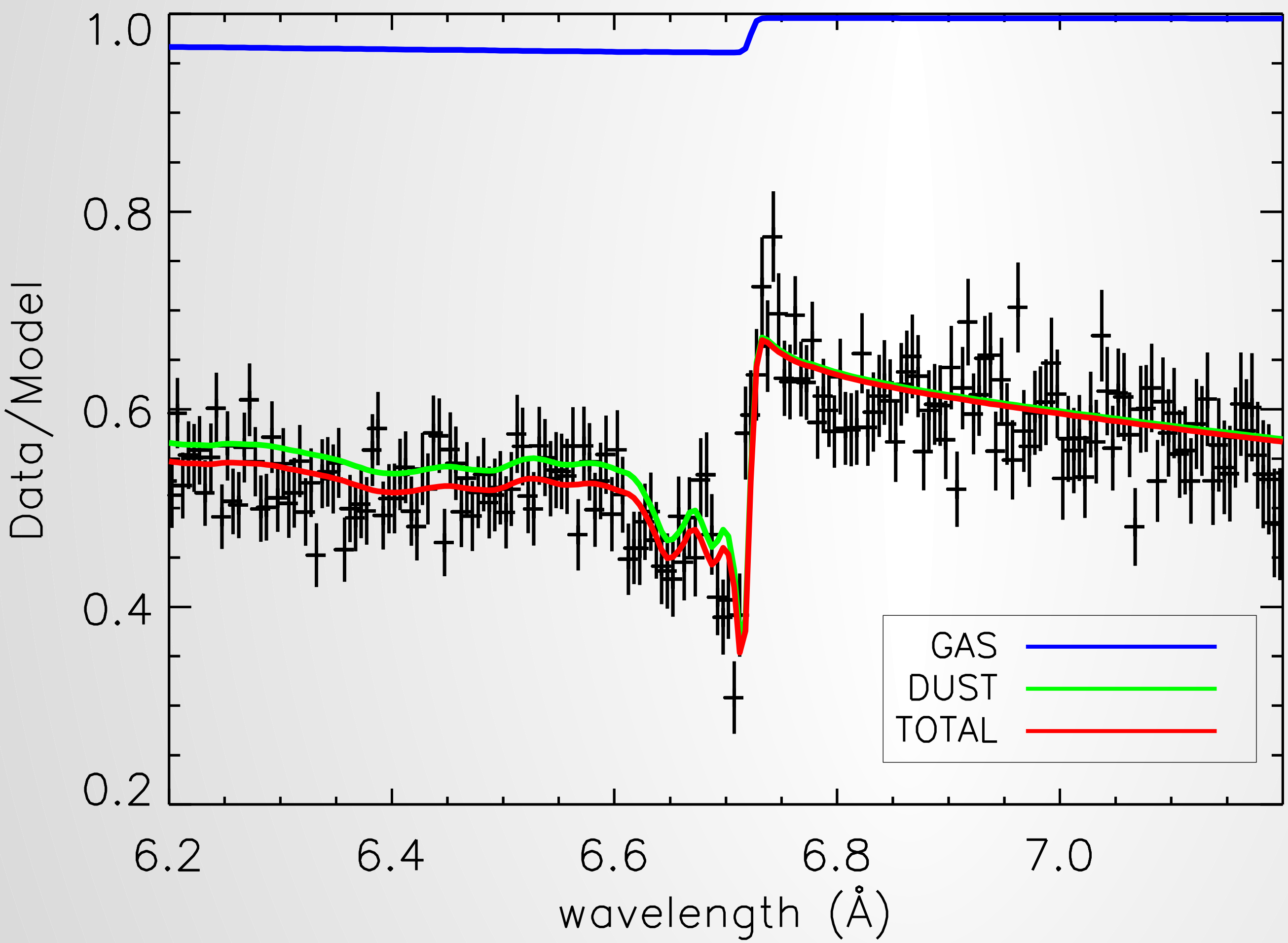
Observing dust in the X-rays

XAFS provide a unique fingerprint of Interstellar Dust



- Lee 05,09 Costantini 12, pinto 10,13

Test case: Si K-edge of X-ray binary GX 5-1



data fit to Chandra data of the X-ray binary **GX5-1**

Column density:

$N_H = 3.52 \times 10^{22}\ cm^{-2}$

Best fit:

Mix of amorphous Pyroxene

($Mg_{0.6}Fe_{0.4}SiO_3$)

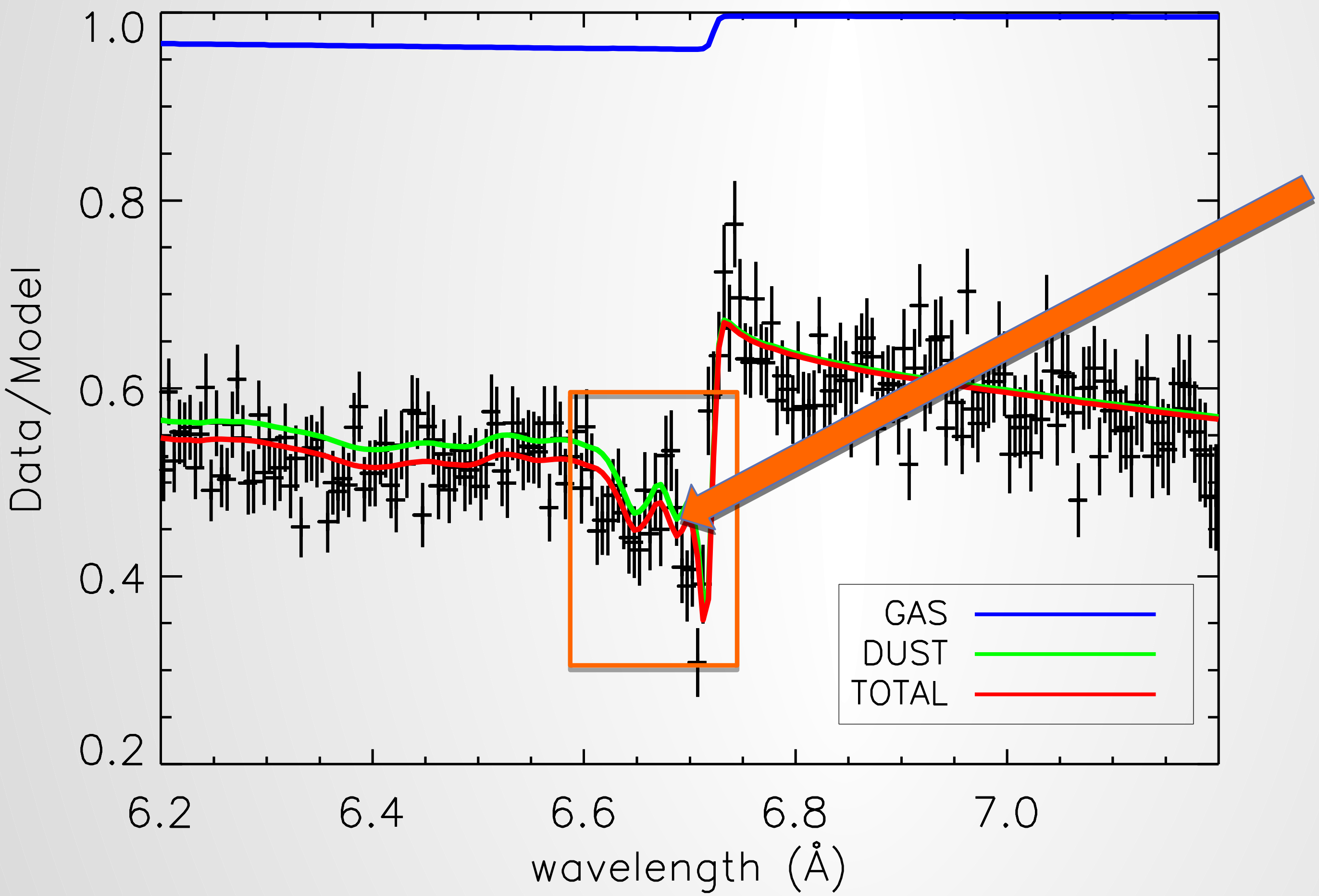
and

crystalline olivine

($Mg_{1.56}Fe_{0.4}Si_{0.91}O_4$)

- Zeegers, Costantini et al 2016 (submitted)

crystalline vs amorphous dust



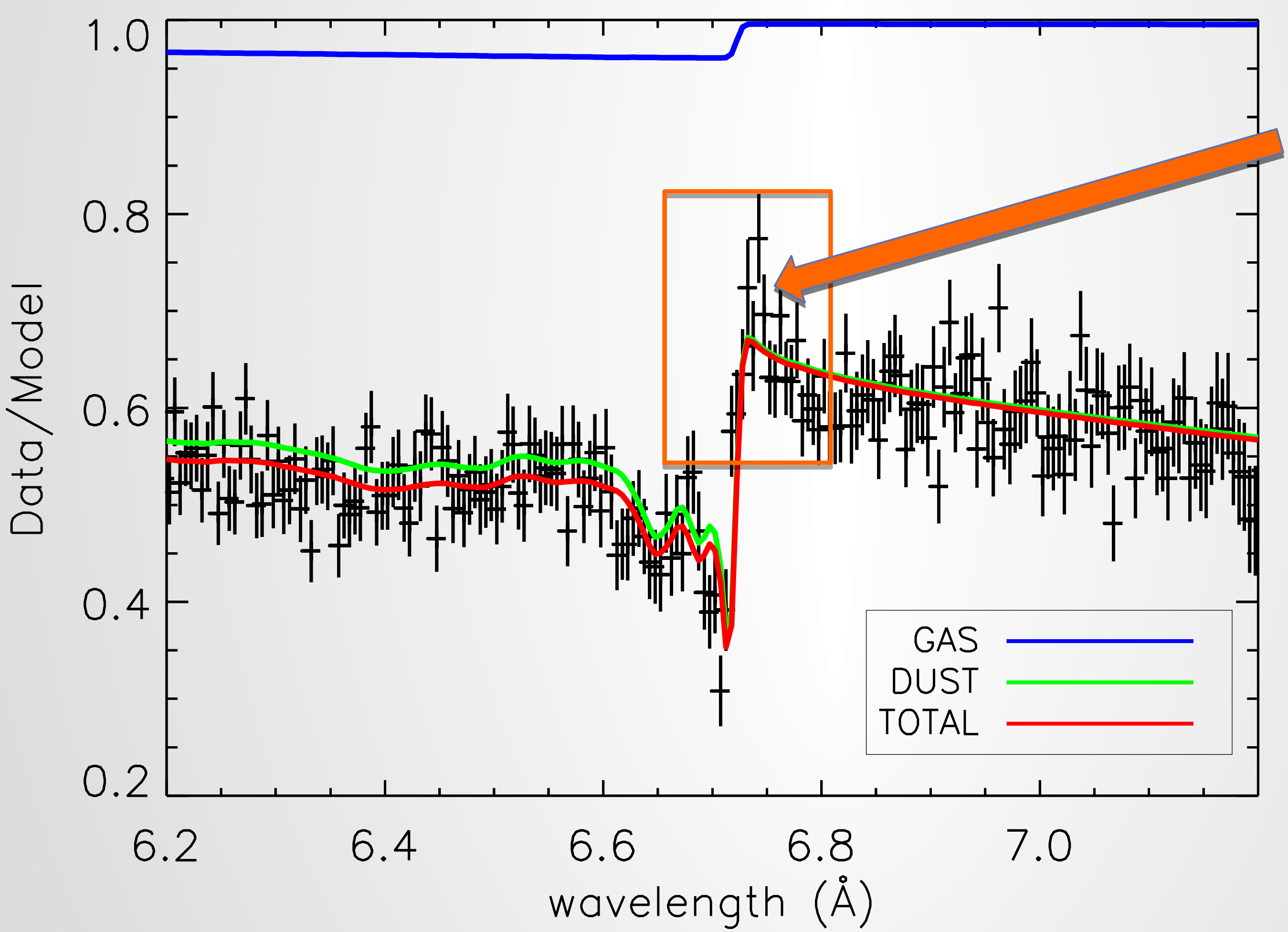
Sharp XAFS features indicate crystalline dust

We find >70% of crystalline dust

- Special environment with freshly produced dust?
- Do we understand the dust structure?

Zeegers, Costantini et al 2016 (submitted)

Scattering feature

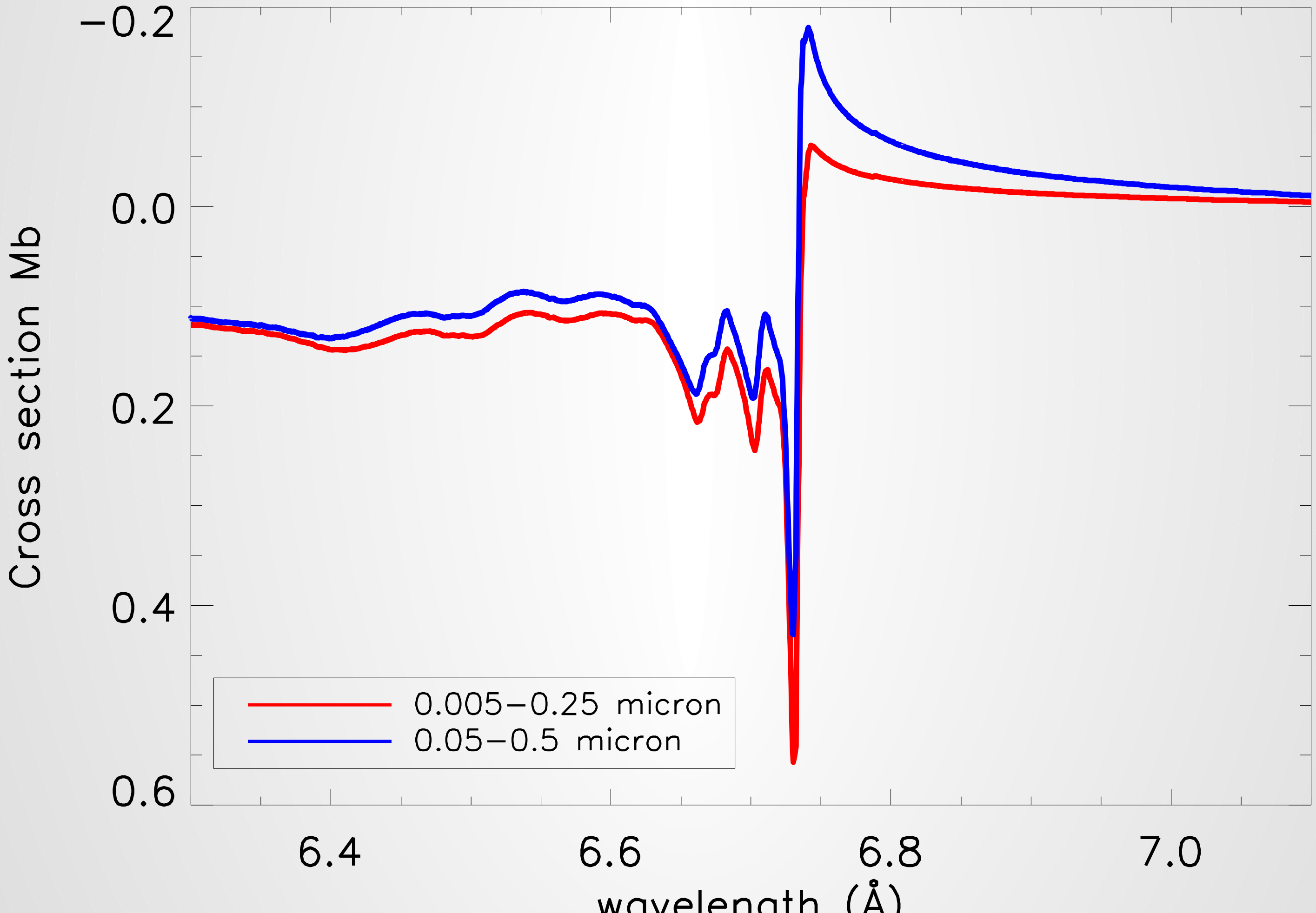


Peak arises due to scattering (Hoffman and Draine 2016)

Depends mainly on the particle size of the dust grains

Zeegers, Costantini et al 2016 (submitted)

Large particles along the line of sight?



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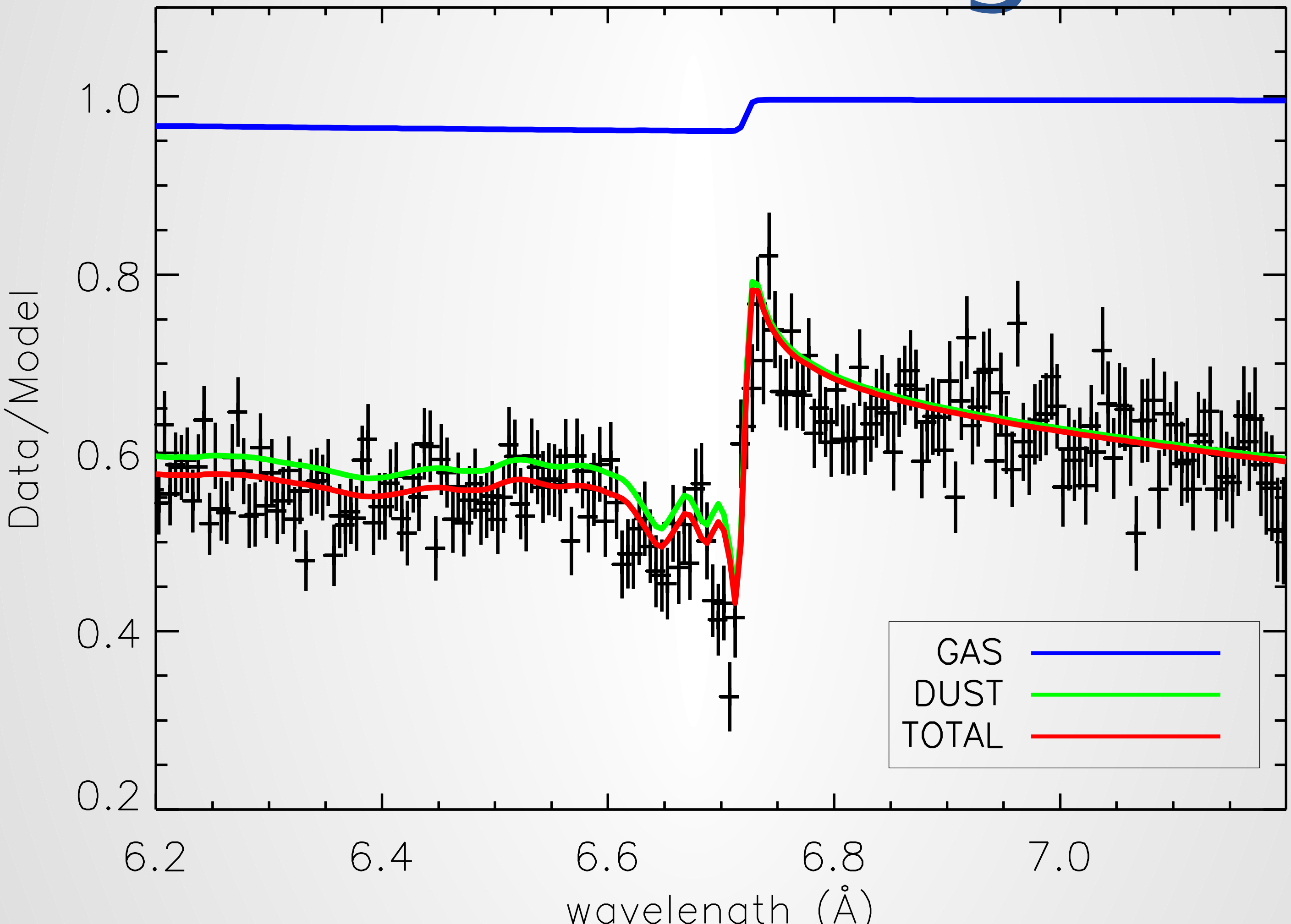
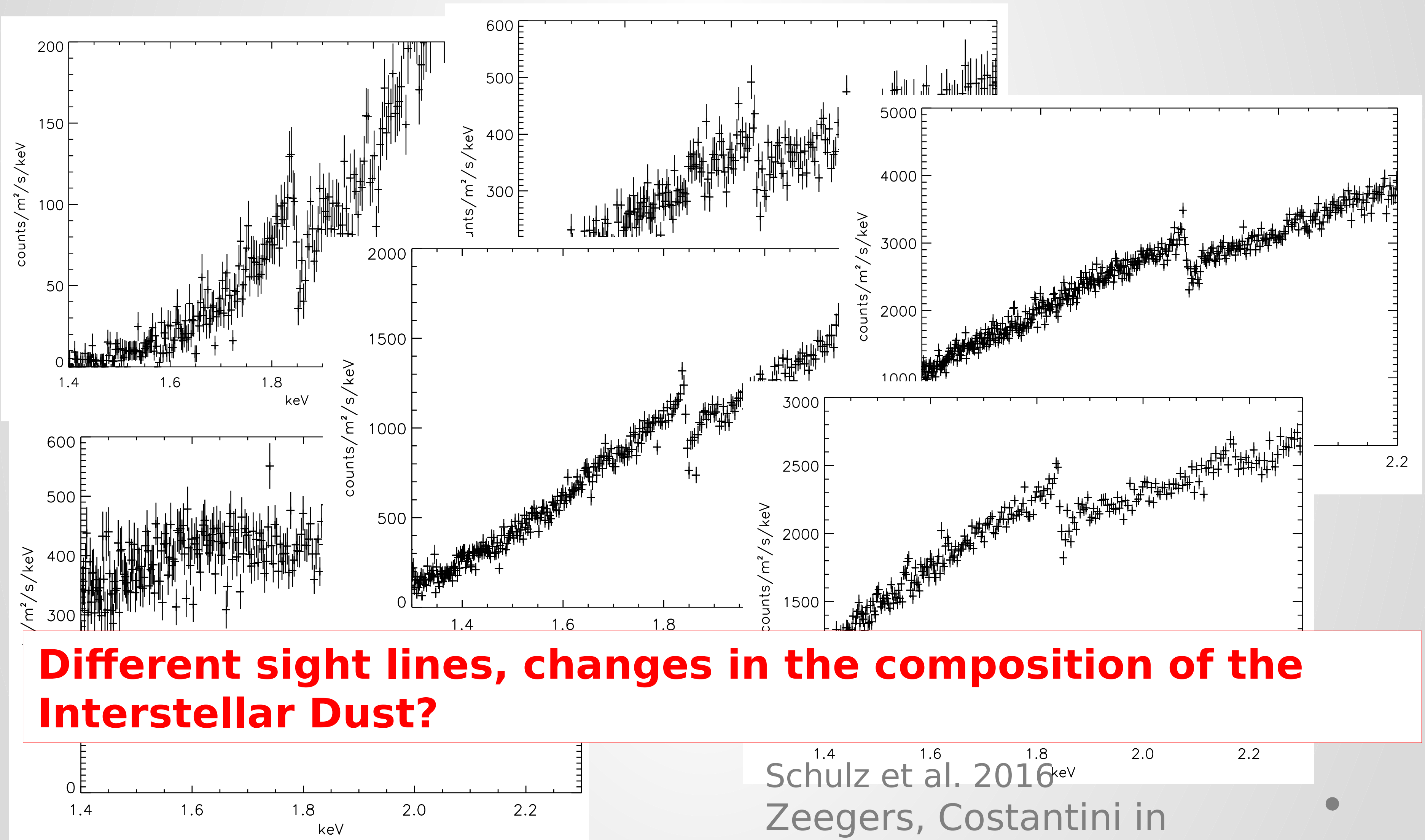


Different dust size distributions necessary to fit scattering features

Zeegers, Costantini et al 2016 (submitted)

spectra other X-ray binaries



Different sight lines, changes in the composition of the Interstellar Dust?

Schulz et al. 2016
Zeegers, Costantini in prep

The Next Decade...

Chandra has a huge potential in solving the major open question about interstellar dust.

New lab measurements of the X-ray edges will play an essential part!