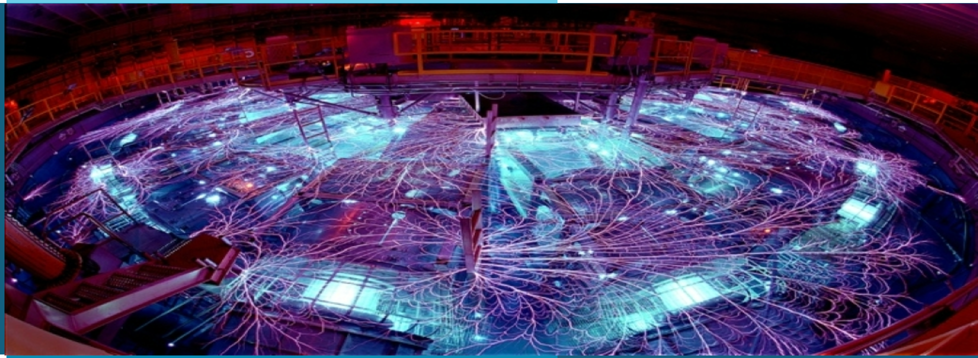
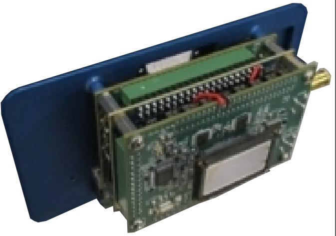
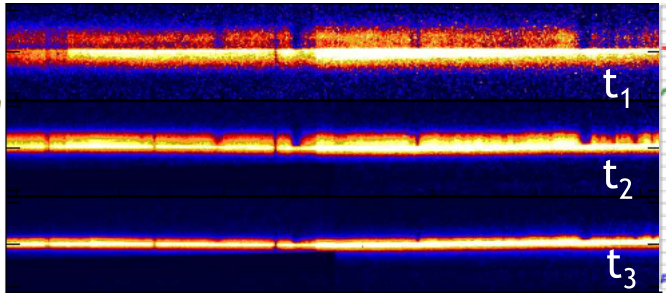
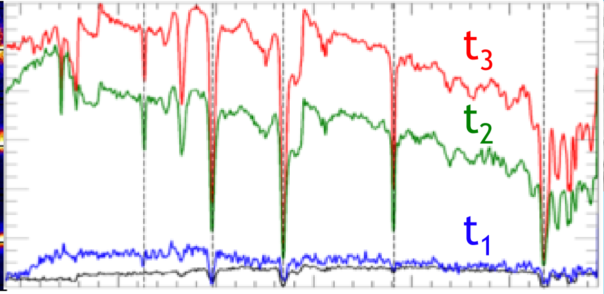
SAND2020-12517C

Z opacity sample evolution using time-resolved spectroscopy with a gated hybrid CMOS detector









G. P. Loisel, J. E. Bailey, T. Nagayama, G. S. Dunham, P. D. Gard, G. A. Rochau, A. P. Colombo, A. D. Edens, Q. Looker, M. W. Kimmel, J. W. Stahoviak, J. L. Porter

Sandia National Laboratories, New Mexico

62[nd] APS-DPP meeting
Nov 10[th] 2020

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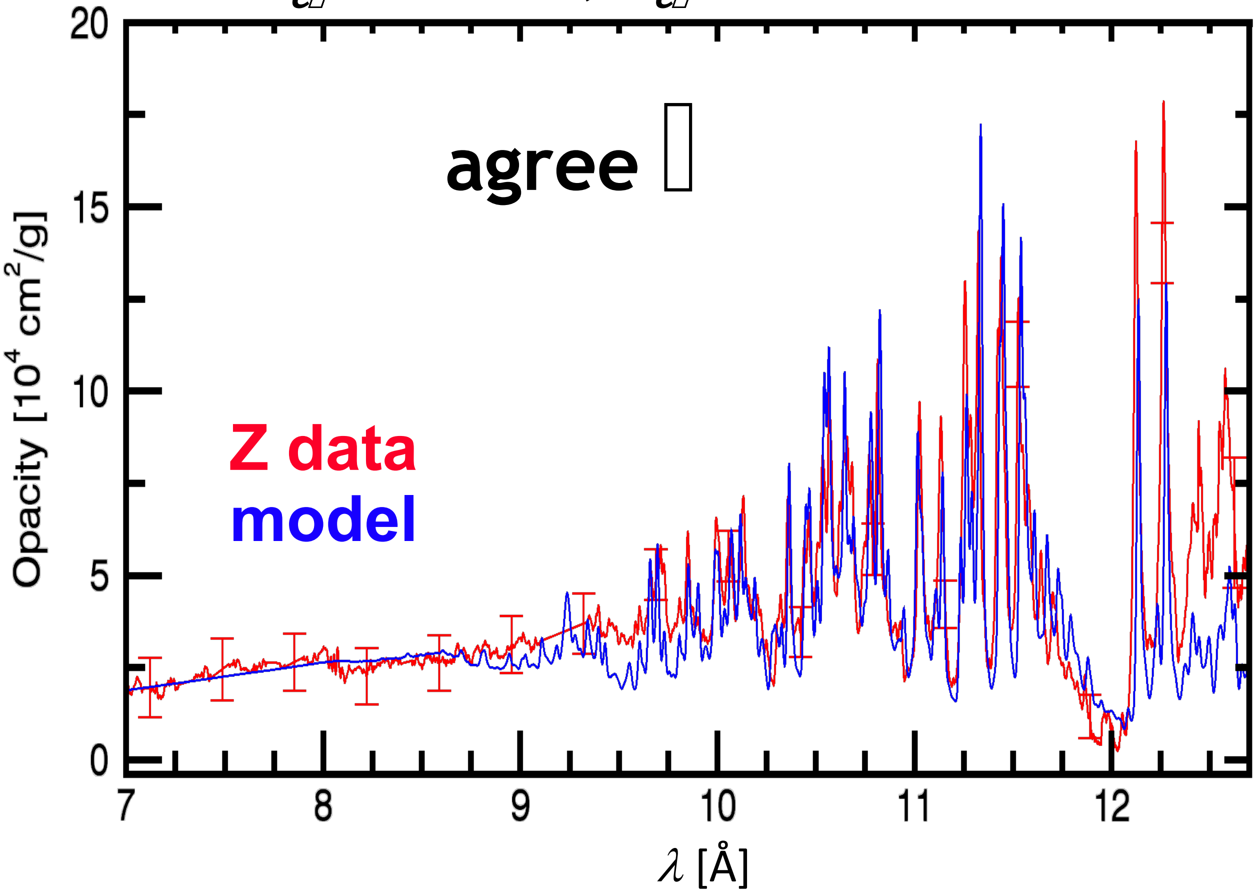
Fe opacity measurements at solar interior conditions don’t agree with predictions

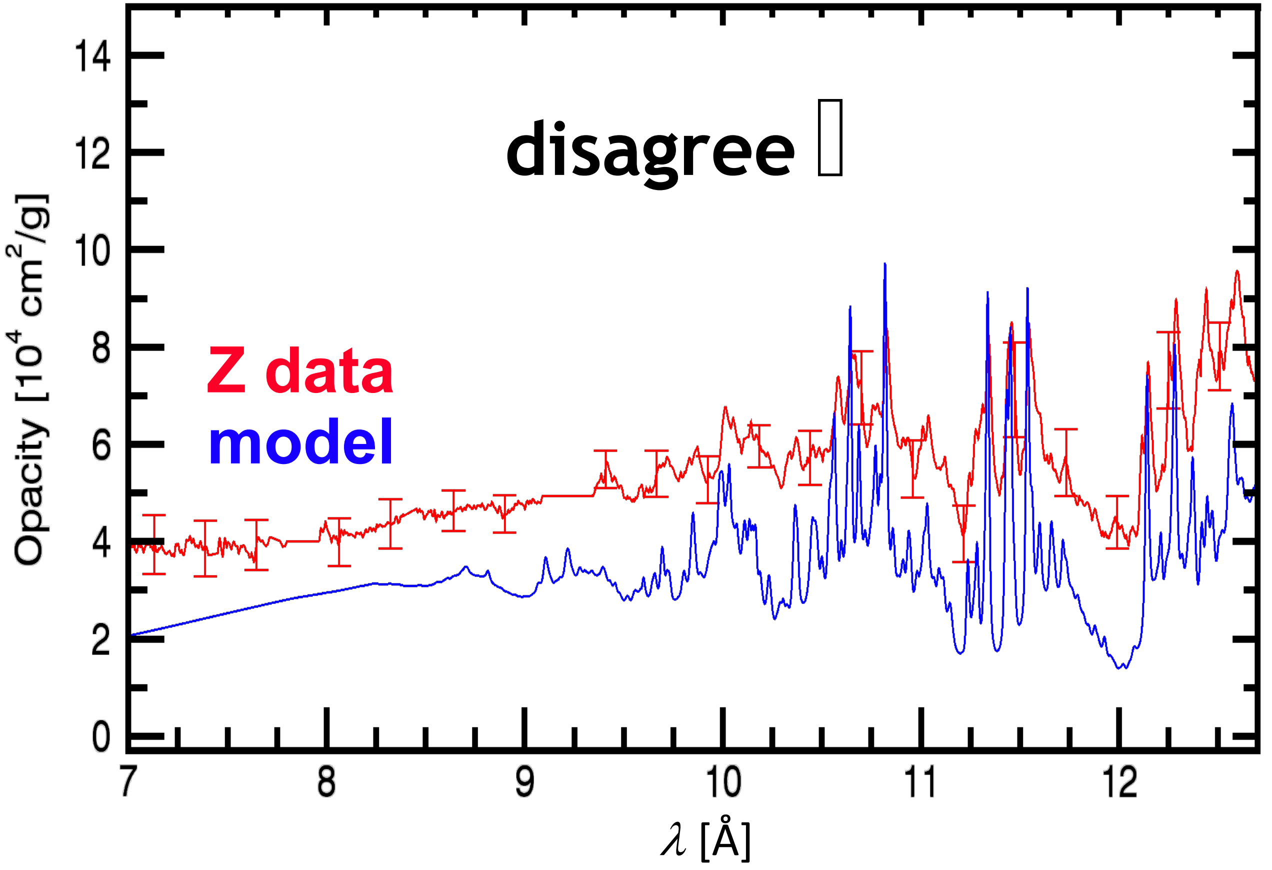
Anchor 1

T_e = 156 eV, n_e = 6.9×10^{21} cm^{-3}



Anchor 2 ~ solar

T_e = 182 eV, n_e = 3.1×10^{22} cm^{-3}

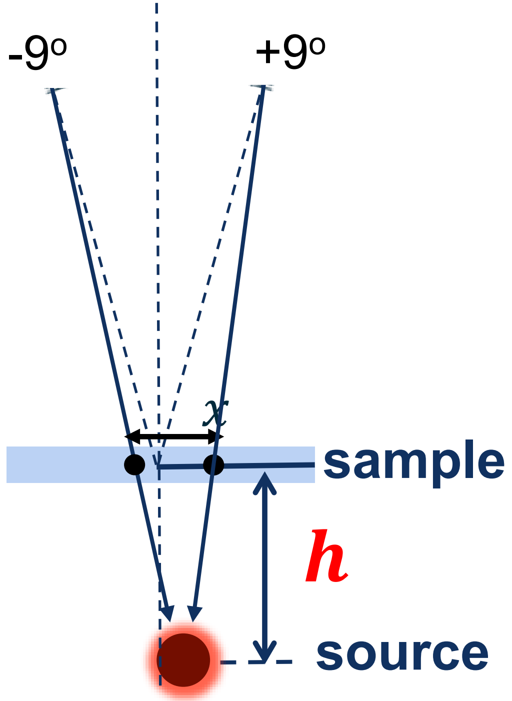


Despite careful scrutiny and experiment execution, could the measurements be flawed?

Nagayama et al., *PRL*, **122** (2019), Bailey *et al.*, *Nature*, **517**, (2015), Bailey *et al.*, *PRL*, **99** (2007)

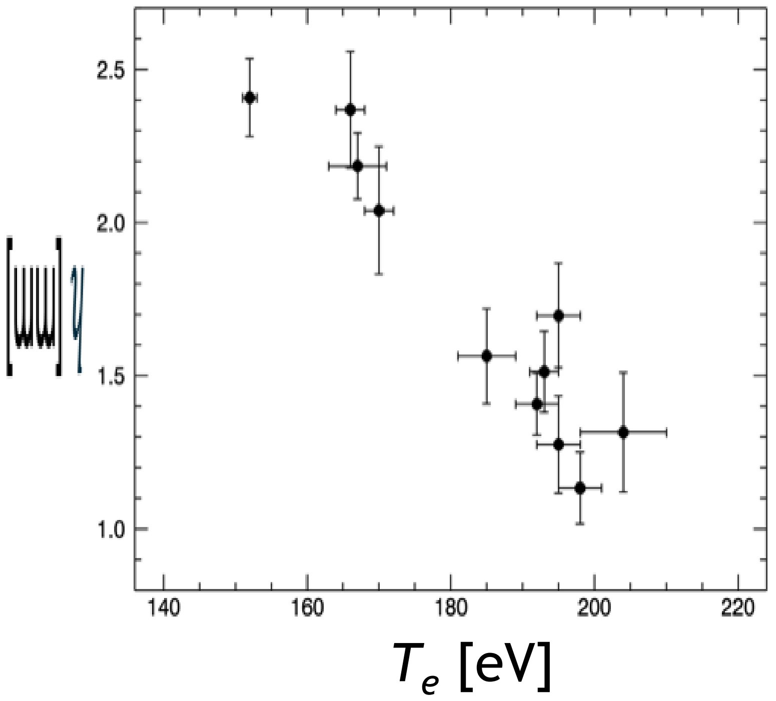
The experiment picture is forged from measurements and measurements-constrained simulations

parallax → h

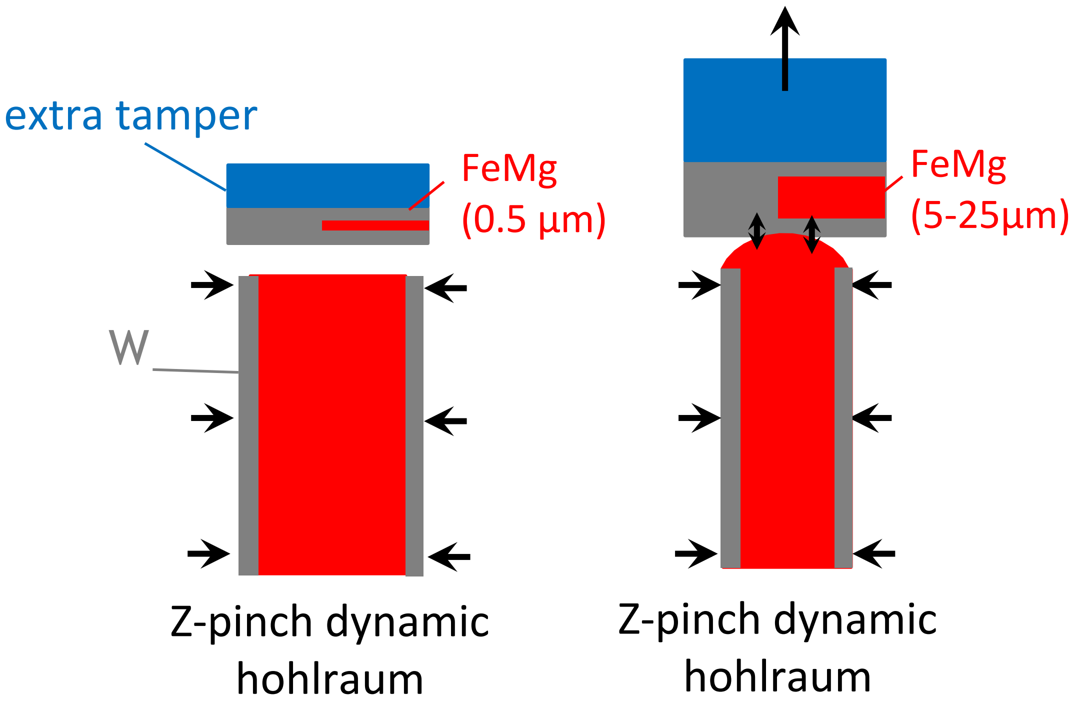


$$h = \frac{x}{2 \tan 9^{\circ}}$$

T_e = anticorrelation vs h



n_e : The sample heats → expands



Expansion =
1) top tamper thickness
2) plasma pressure
3) potential preheat

<u>Our current picture:</u>

1. Temperature drops when sample moves up
2. Density continuously drops due to sample expansion

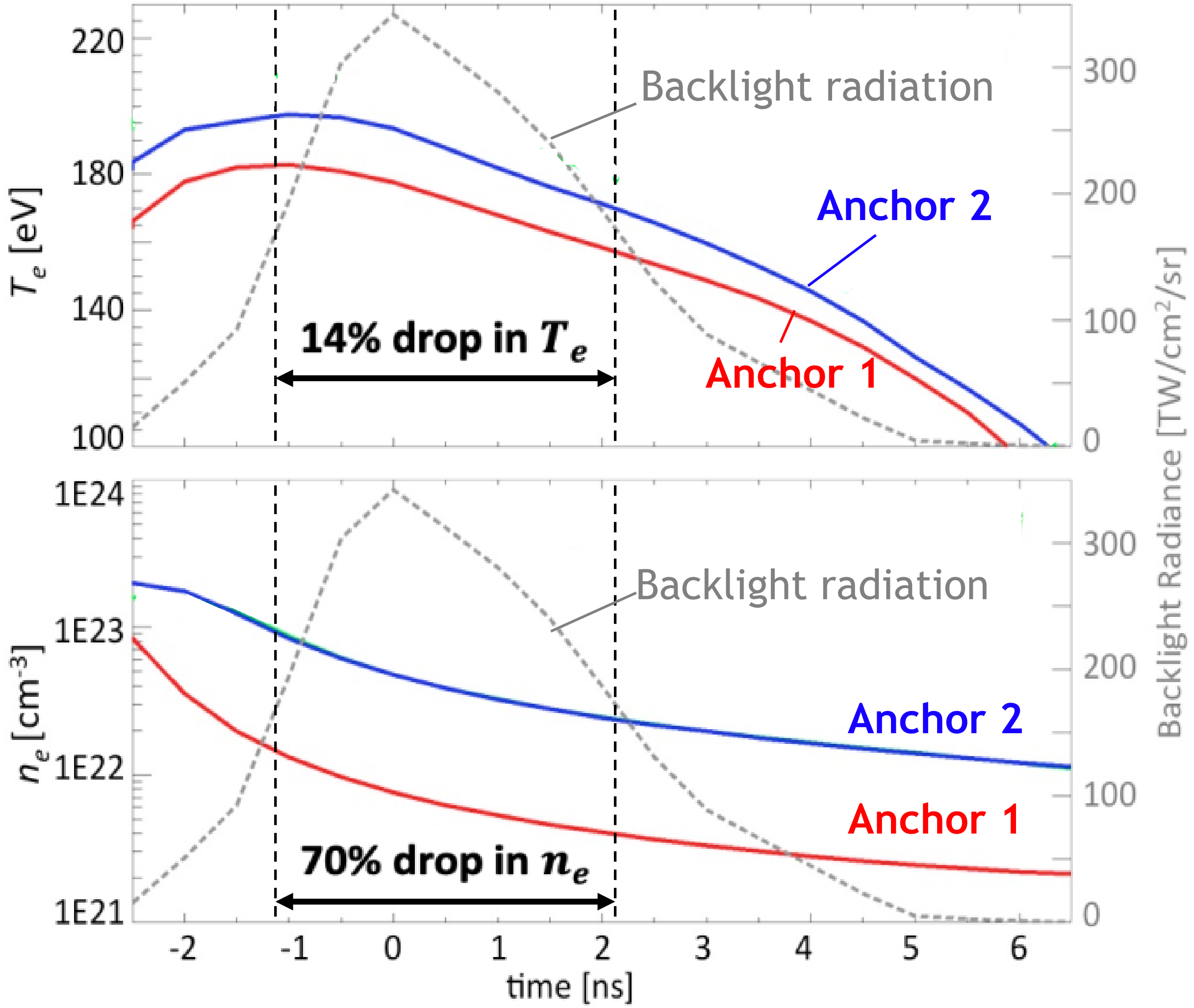
➢ These effects are modulated by the tamper thickness

Nagayama *et al.*, *PRE*, **93** (2016), *MacFarlane *et al.*, *JQSRT*, **99** (2006) & MacFarlane *et al.*, *PRE*, **72** (2005)

Sample evolution is predicted from calibrated-simulations[1]

Temperature T_e vs time

Density n_e vs time



- Predicted temporal gradients in T_e , n_e over the backlight duration are concerning
- Yet, effect on published opacity was found negligible[2]

[1]Nagayama *et al.*, *PRE*, **93**, (2016), MacFarlane *et al.*, *JQSRT*, **99** (2006), *PRE*, **72** (2005) , [2]Nagayama *et al.*, *PRE*, **95** (2017)

Time-resolved measurements can also augment the outcomes of the opacity research on Z

- **Testbed for radiation-hydrodynamics simulations**

- **Evaluate proposed model refinements that address the model-data discrepancies**
  - → line broadening
  - → 2-photon absorption
  - → excited states distribution

- **Better understanding of how opacity experiments work**
  - → better control of sample conditions
  - → reach higher T_e, n_e

- **Increase efficiency of absolute opacity measurements**
  - → multiple opacity measurements over different T_e, n_e within a single experiment

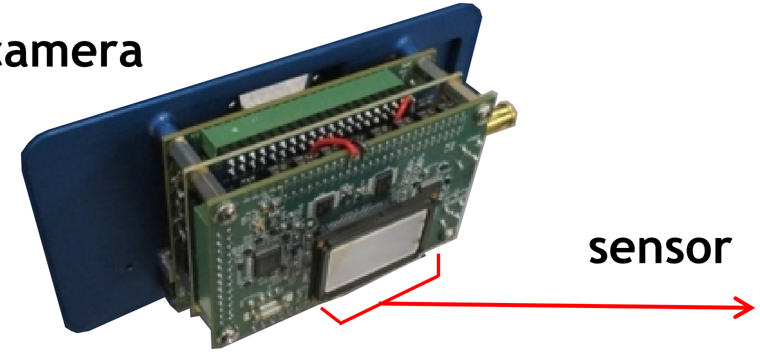
➢ **First goal: assess the opacity sample evolution with time-gated measurements**

The ultrafast single-line-of-sight UXI[1] detector is used to record time-gated absorption spectra

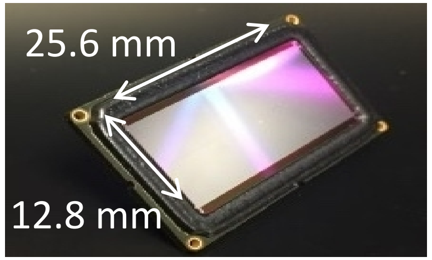
Requirements

- Accurate Mg ***line*** transmission measured
  - high S/N spectra
  - linear photon intensity
  - enough spectral resolution
  - avoid line saturation
  - reproducibility
- Multiple time-steps to observe actual evolution
- Line transmission model

UXI camera



sensor



1024x512 25-µm pixels

[1]**U**XI=**U**ltra-fast **X**-ray **I**mager: Claus *et al.*, *Proc. SPIE*, **9591**, (2015), *Proc. SPIE*, **10390**, (2017), [2]Looker *et al.*, *RSI*, **91**, 043502 (2020)

The ultrafast single-line-of-sight UXI[1] detector is used to record time-gated absorption spectra

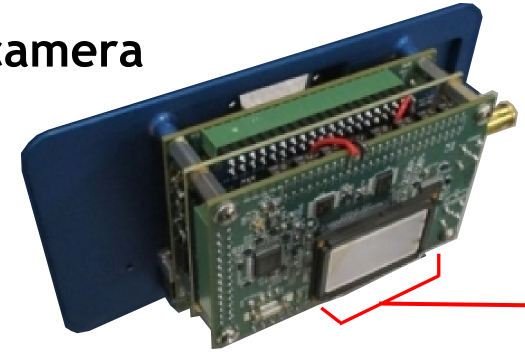
Requirements

- Accurate Mg ***line*** transmission measured
  - high S/N spectra →
  - linear photon intensity →
  - enough spectral resolution →
  - avoid line saturation
  - reproducibility
- Multiple time-steps to observe actual evolution →
- Line transmission model

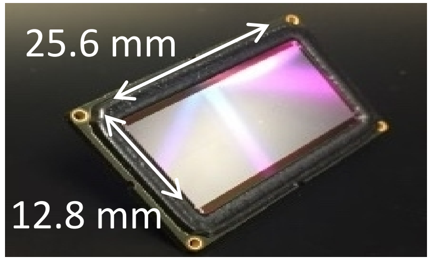
UXI benefits:

- High single photon, soft x-ray response. Absolutely calibrated for the slit pattern[2]
- Very good linearity[2] **<3%**
- Pixel size → **λ/δλ = 1100-1200** (~7mÅ)
- Highly uniform response[2] ~**2%**
- Time-resolution = **1.9 ns** adequate to collect 5 or 6 frames /camera /exp

UXI camera



sensor



1024x512 25-μm pixels

➢ **Meets requirements to obtain the sample condition evolution**

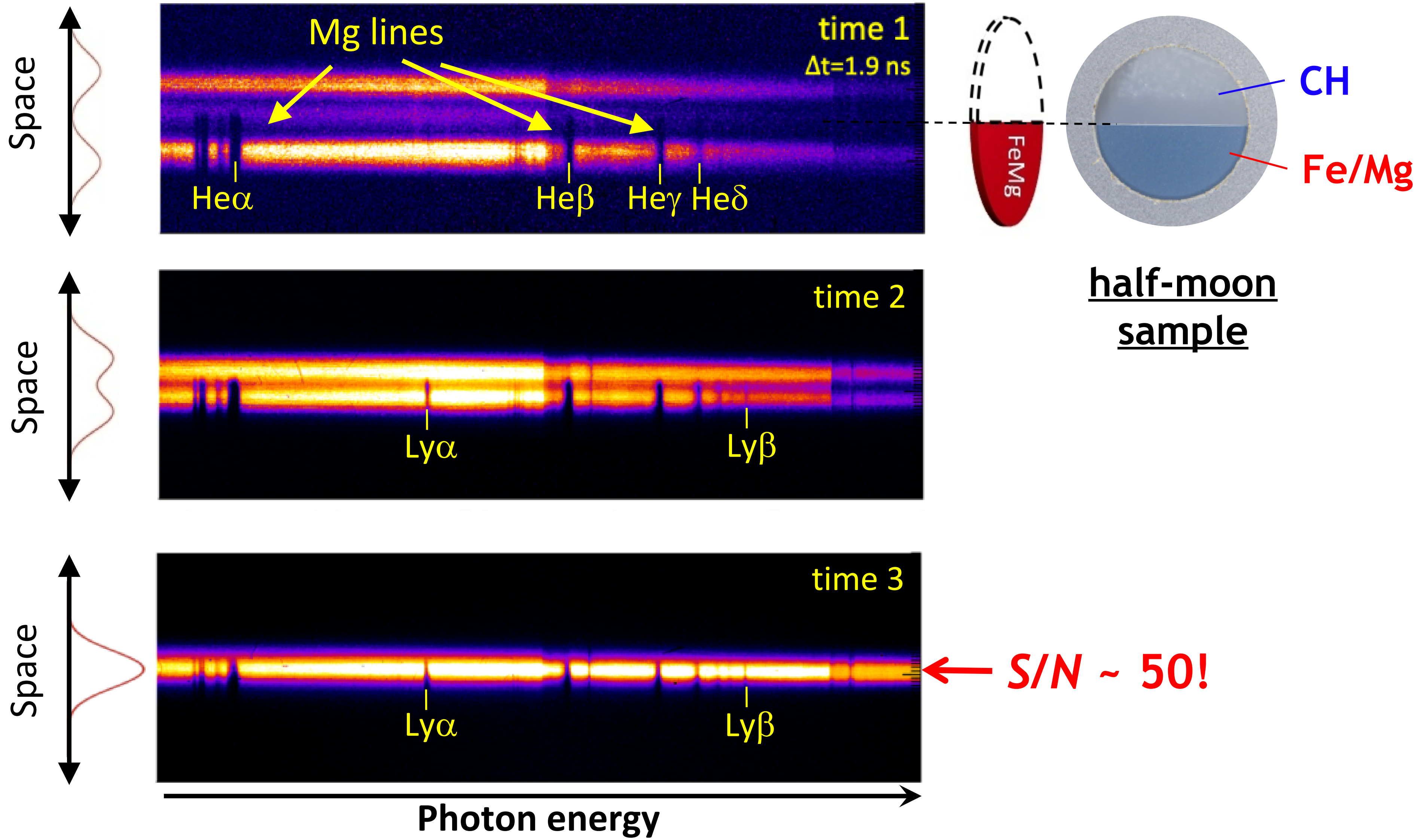
[1]**U**XI=**U**ltra-fast **X**-ray **I**mager: Claus *et al.*, *Proc. SPIE*, **9591**, (2015), *Proc. SPIE*, **10390**, (2017), [2]Looker *et al.*, *RSI*, **91**, 043502 (2020)

Our first goal is to measure the sample conditions evolution using Mg K-shell absorption

Images are:
time-resolved
1D space-resolved
spectrally-resolved

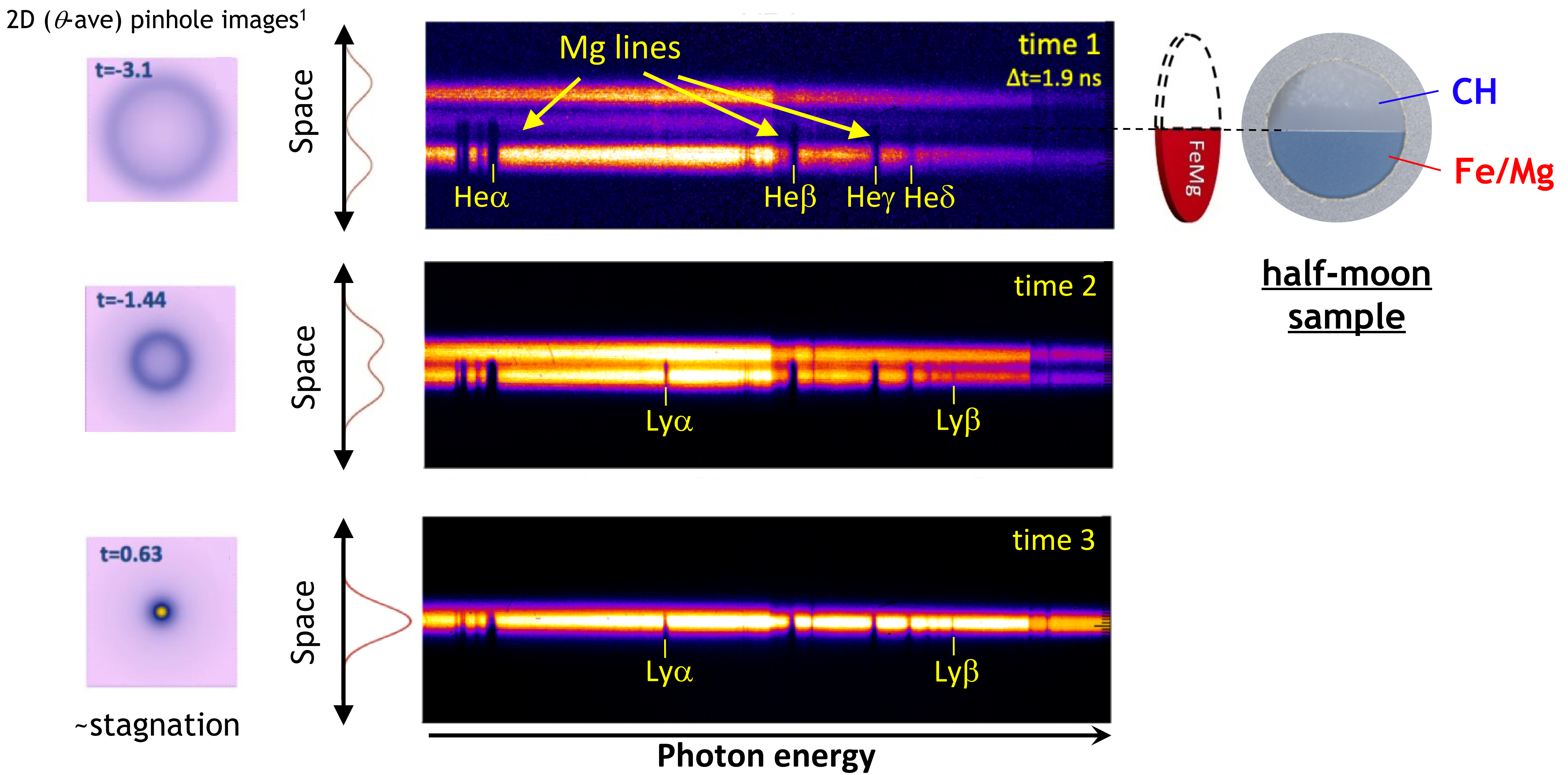
He-like = Mg +10
→ Heα, Heβ, Heg …

H-like = Mg +11
→ Lyα, Lyβ



➢ **Positions can be exactly registered frame-to-frame since UXI = single line-of-sight**

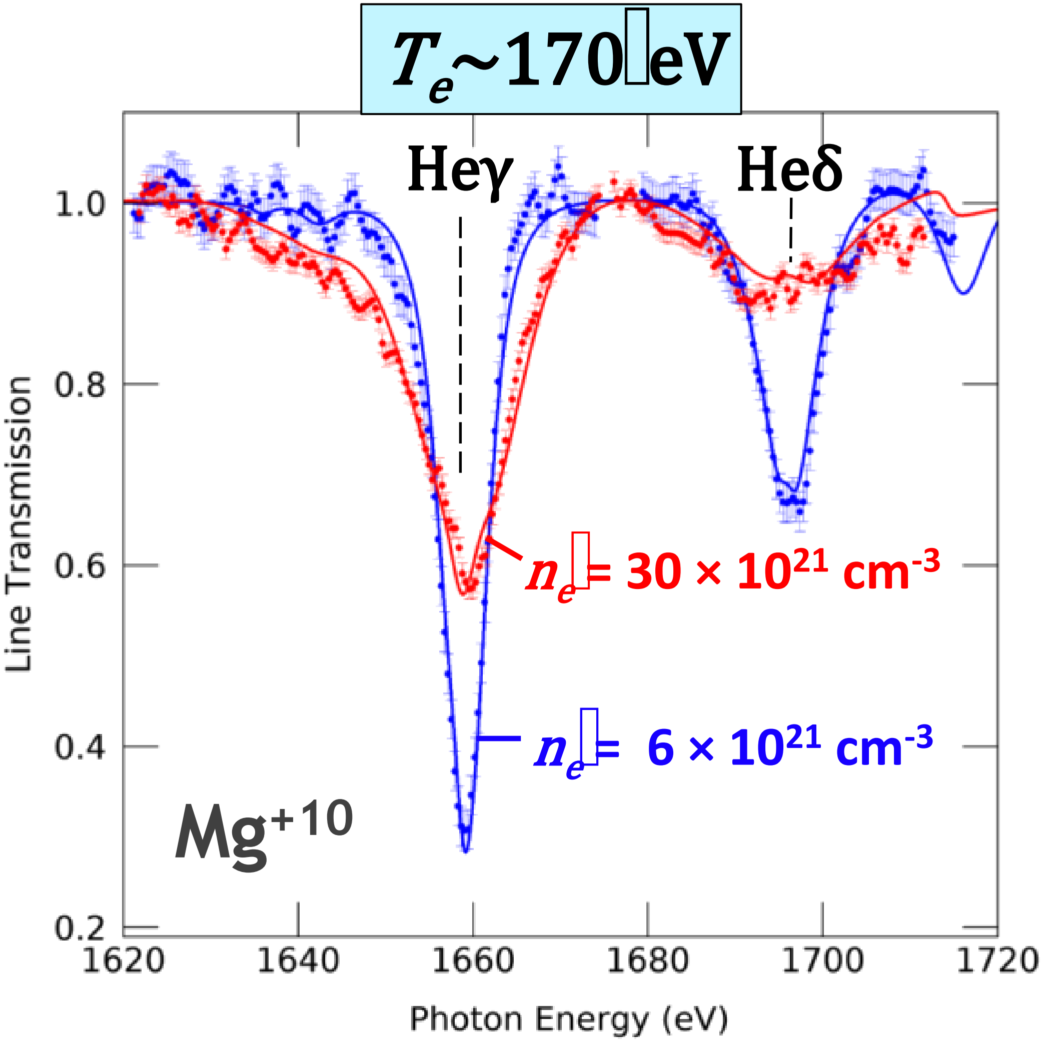
Our first goal is to measure the sample conditions evolution using Mg K-shell absorption

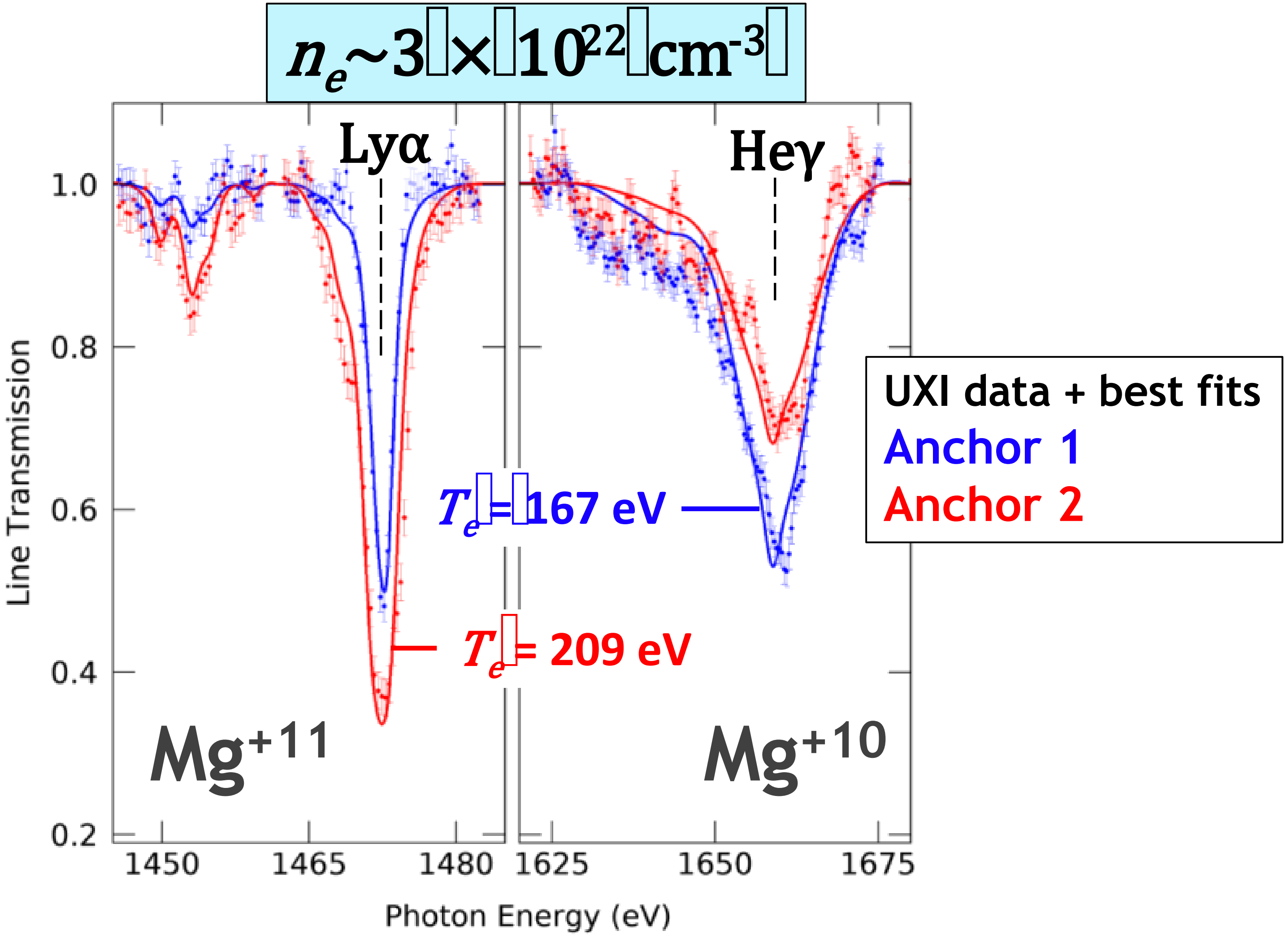


➢ **The reproducible (320 km/s ± 8%) radiating shock is used to cross-time datasets[1]**

[1]G. Rochau *et al.*, *PRL*, 100 (2008)

Conditions were obtained for both anchor 1 & 2 conditions



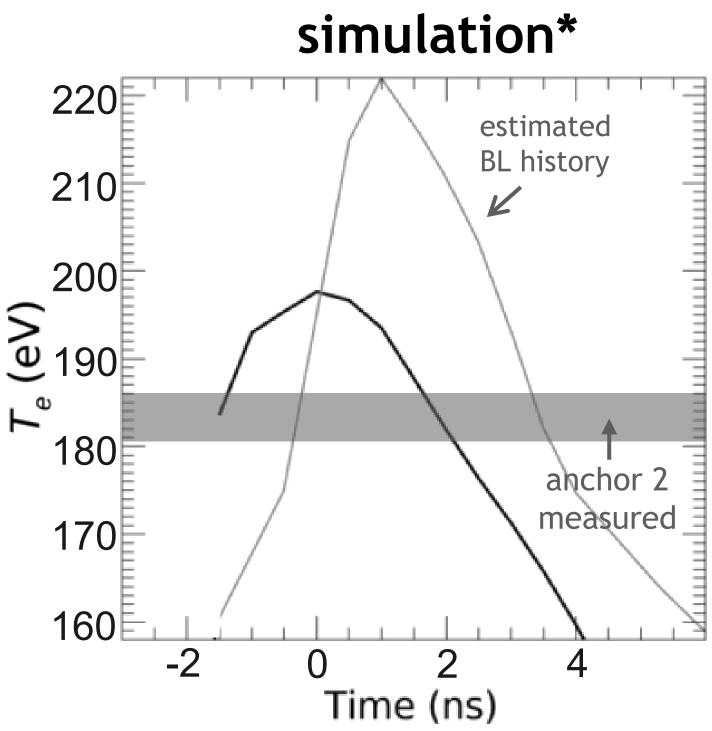


- He-like lines broadened by n_e
- H / He ratios increase with T_e at fixed n_e

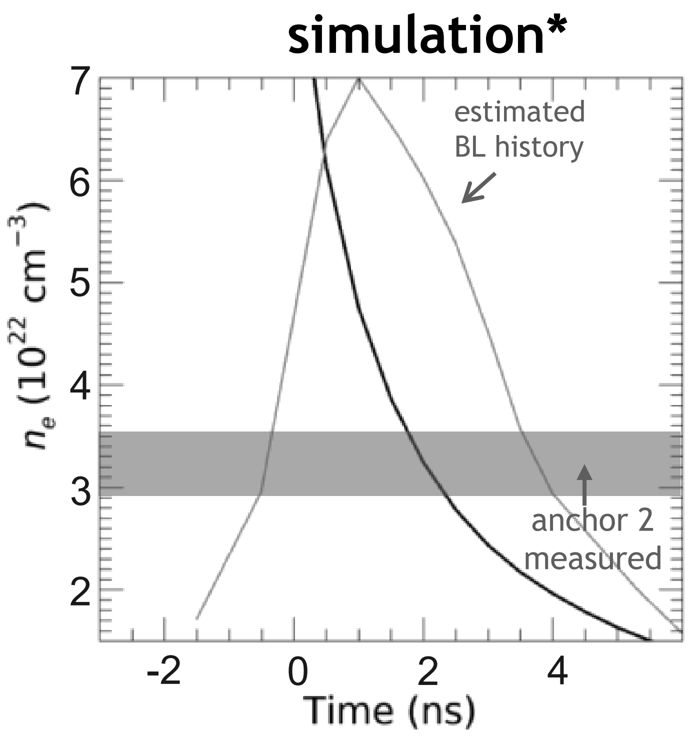
Nagayama et al., *PoP*, **95**, (2014), Bailey et al., *RSI*, **79**, (2008)

Simulations predict T_e , n_e evolution trends for anchor 2 Fe

Temperature T_e

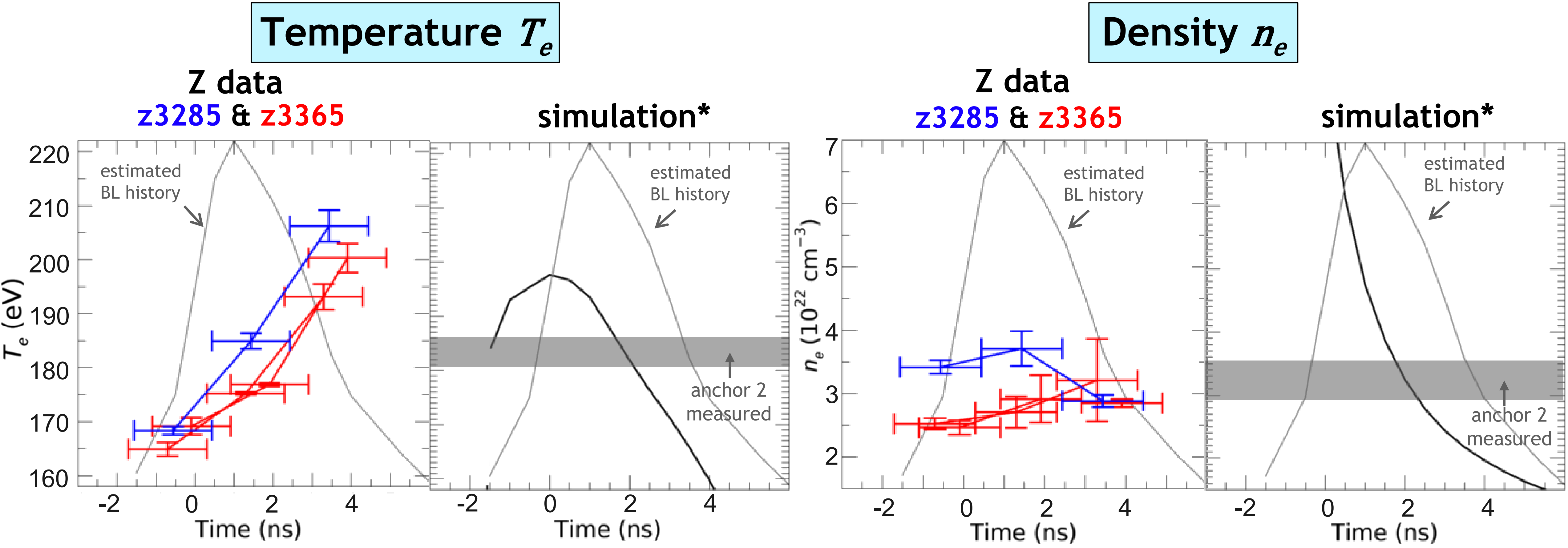


Density n_e



*Nagayama *et al.*, *PRE*, **93** (2016)

Anchor 2 Fe conditions evolution trends disagree with simulation predictions



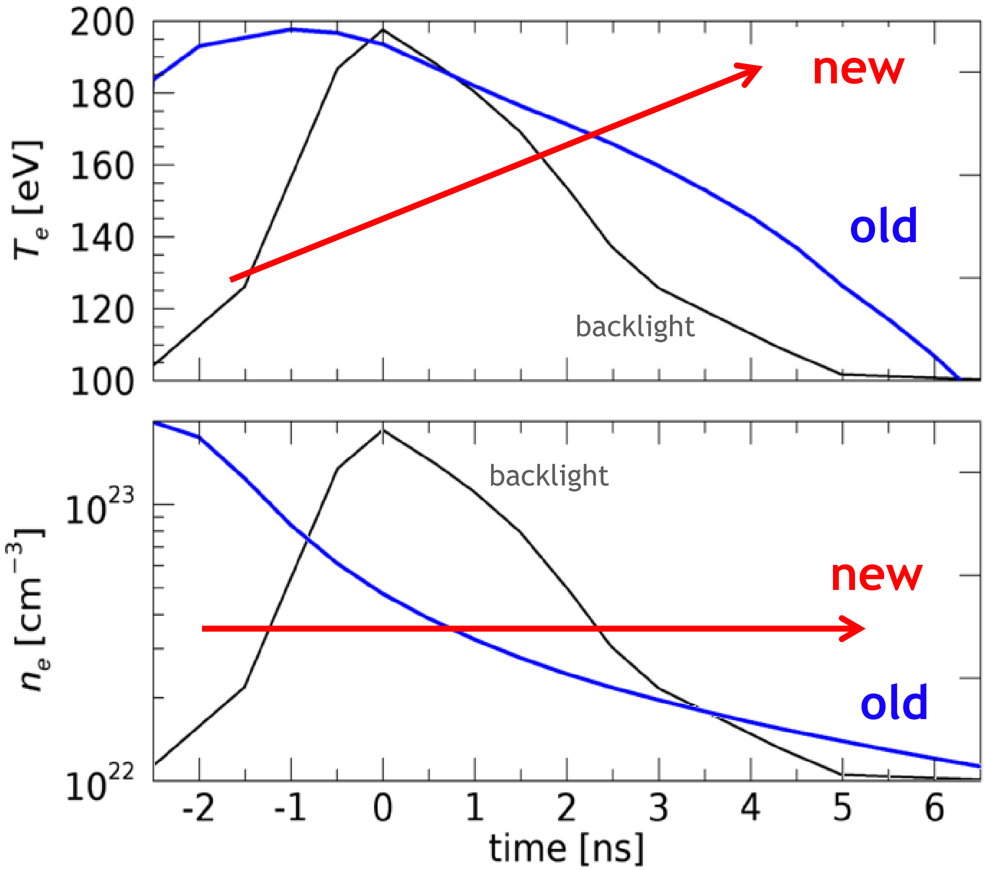
- ➢ **Conditions agree between two shots and two cameras**
- ➢ **If confirmed, these results mean we need to revisit our understanding of how the experiment works**
- ➢ **Investigate the effect of such variation on the time-integrating film opacity measurements**

*Nagayama *et al.*, *PRE*, **93** (2016)

Our current picture of how the experiment works is challenged

Temperature T_e

Density n_e



1) **Temperature keeps increasing:**
- Is sample and source moving closer together?
- Are heating/cooling rates off?

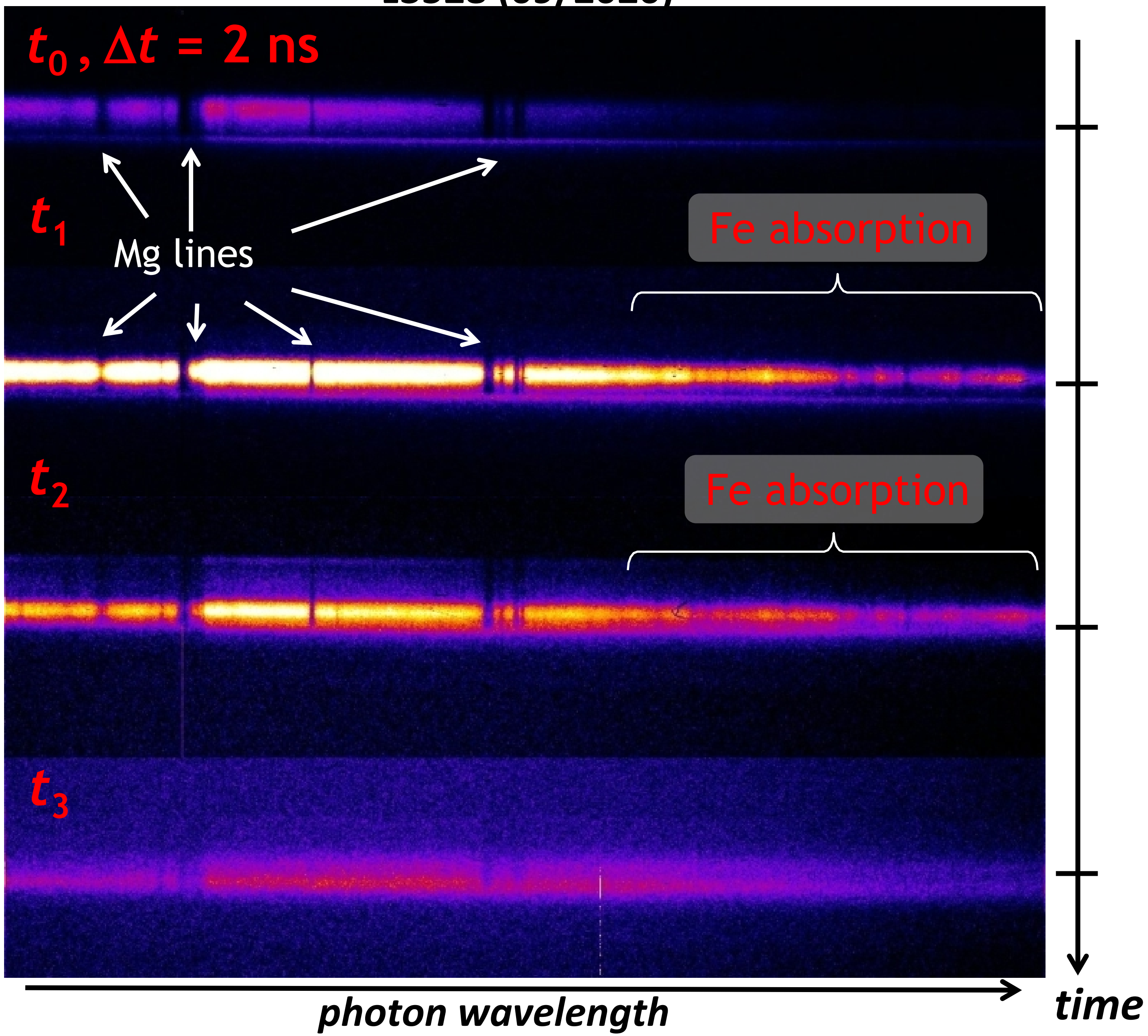
2) **Density low at early times and mostly constant:**
- Is there significant preheat that allows for early expansion?
- Is source plasma pushing on sample?

➢ **We can now re-evaluate the impact of temporal gradients**

➢ **We can start devising experiments and studies that can test these hypotheses**

We are poised to measure time-resolved absolute Fe opacity

z3528 (09/2020)



- First time-resolved Fe absorption observed in Sept 2020

Summary: Fast, time-gated measurements augment the opacity science effort on Z

- **The opacity community is struggling with the high temperature/density iron opacity discrepancy**
  → Further experimental scrutiny is prescribed

- **Calibrated-simulations help understand how the experiment works**
  → How accurate is our picture?

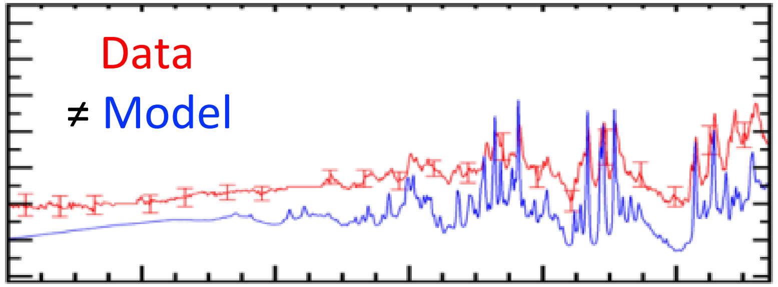
- **Time-integration effects appear unlikely, but cannot be precluded without data**
  → Measure $T_e(t)$, $n_e(t)$ of an Fe/Mg opacity sample

- **Ultra-fast X-ray Imager successfully fielded on Z**
  → First time-resolved Mg K-shell absorption obtained

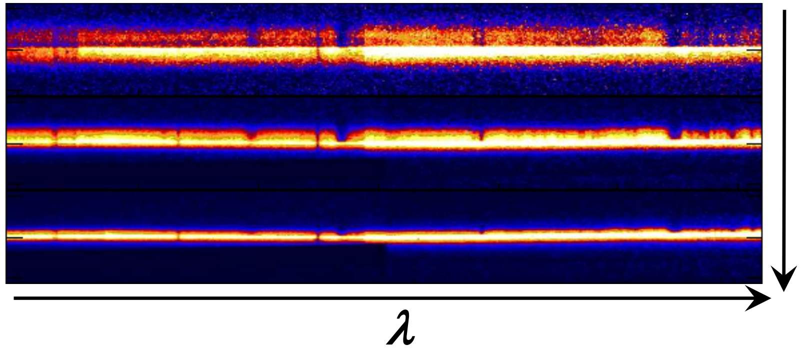
- **First assessment of anchor 1 and 2 Fe sample evolution calls for refining the Z experiment picture**

→ Time resolved measurements increase the understanding of the Z opacity platform and test time-integration effects.

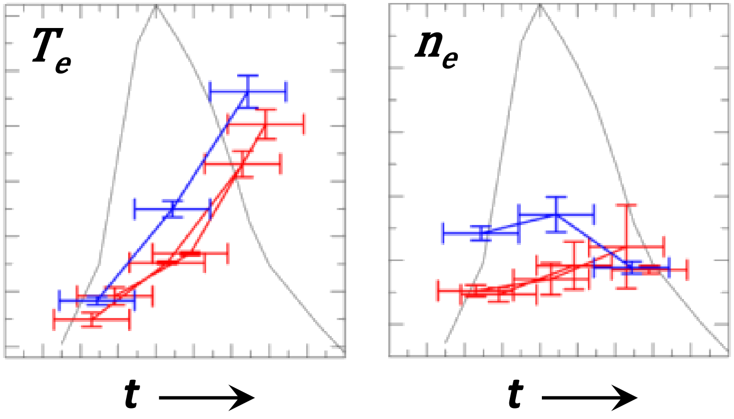
Anchor 2 Fe opacity



Time-gated images

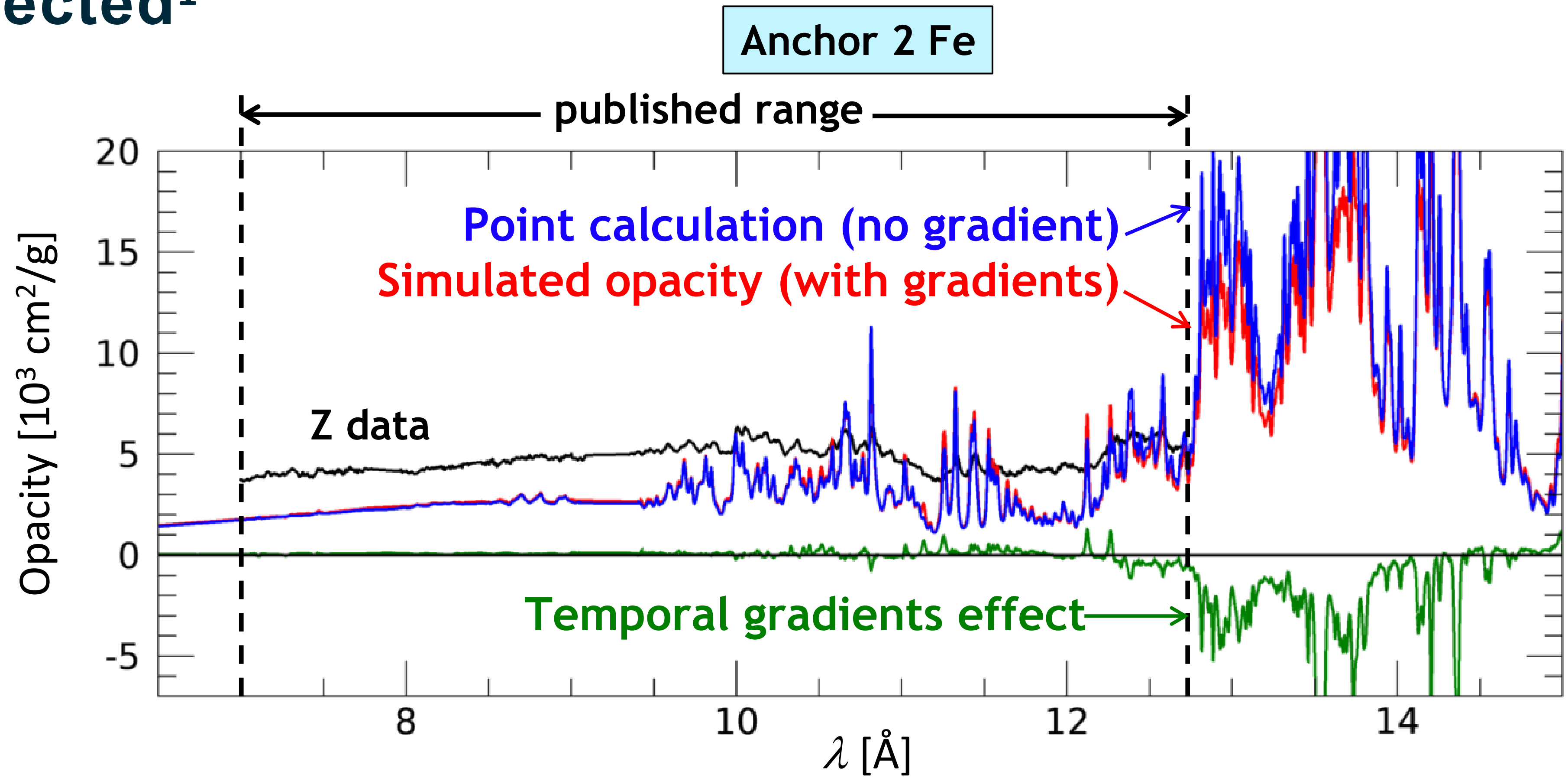


Anchor 2 Fe



Extra slides

Yet, post-processed simulations predict spectrum is unaffected[1]



- **But are the simulations accurate?**
- **Temporal gradients cannot be precluded without experimental evidence**

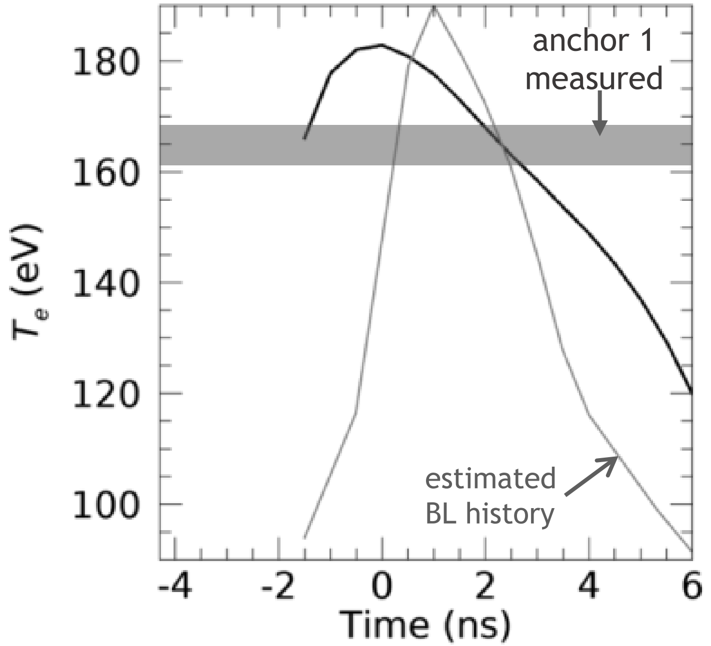
[1]Nagayama *et al.*, *PRE*, **95** (2017), MacFarlane *et al.*, *HEDP*, **3** (2007)

Simulations predict T_e , n_e evolution trends for anchor 1 Fe

Temperature T_e

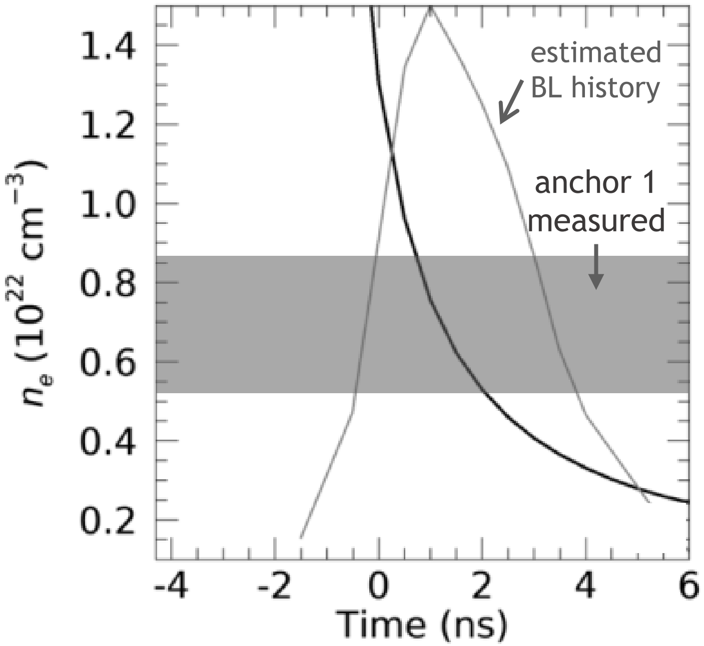
Z data

simulation*



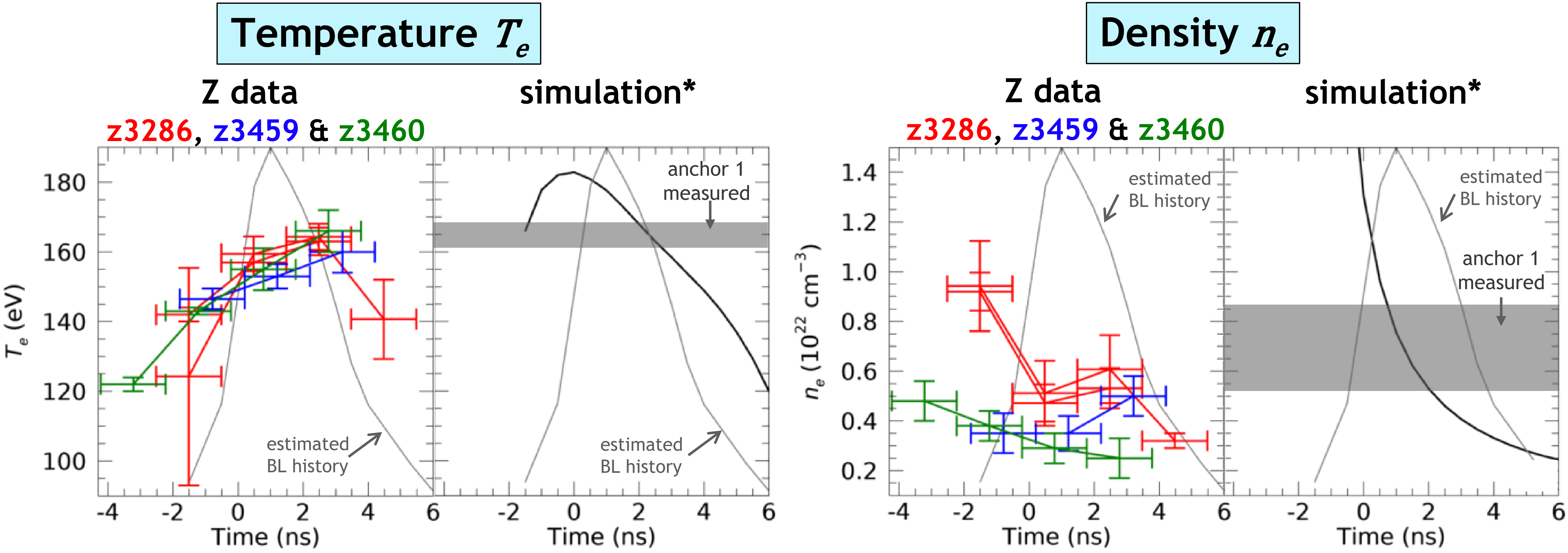
Density n_e

simulation*



*Nagayama *et al.*, *PRE*, **93** (2016)

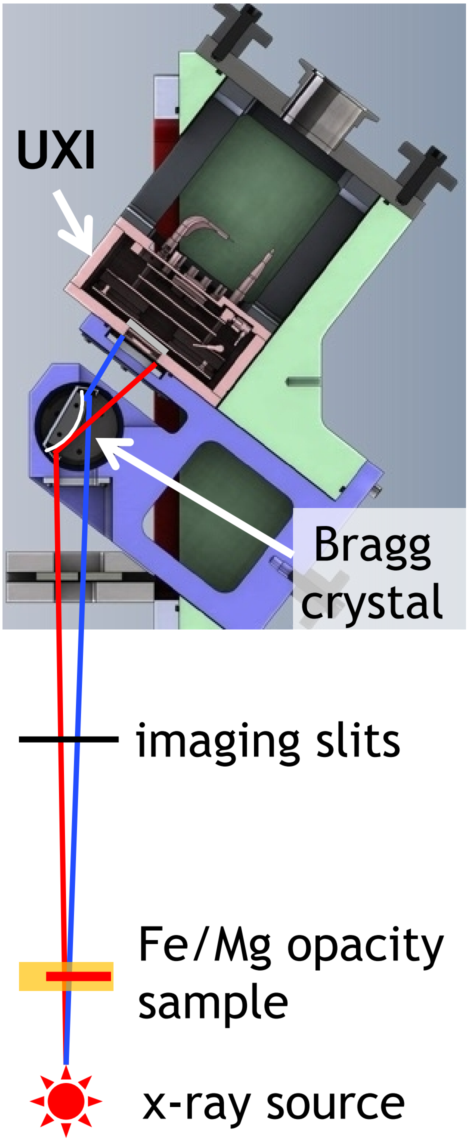
Anchor 1 Fe evolution shows interesting comparison with predictions

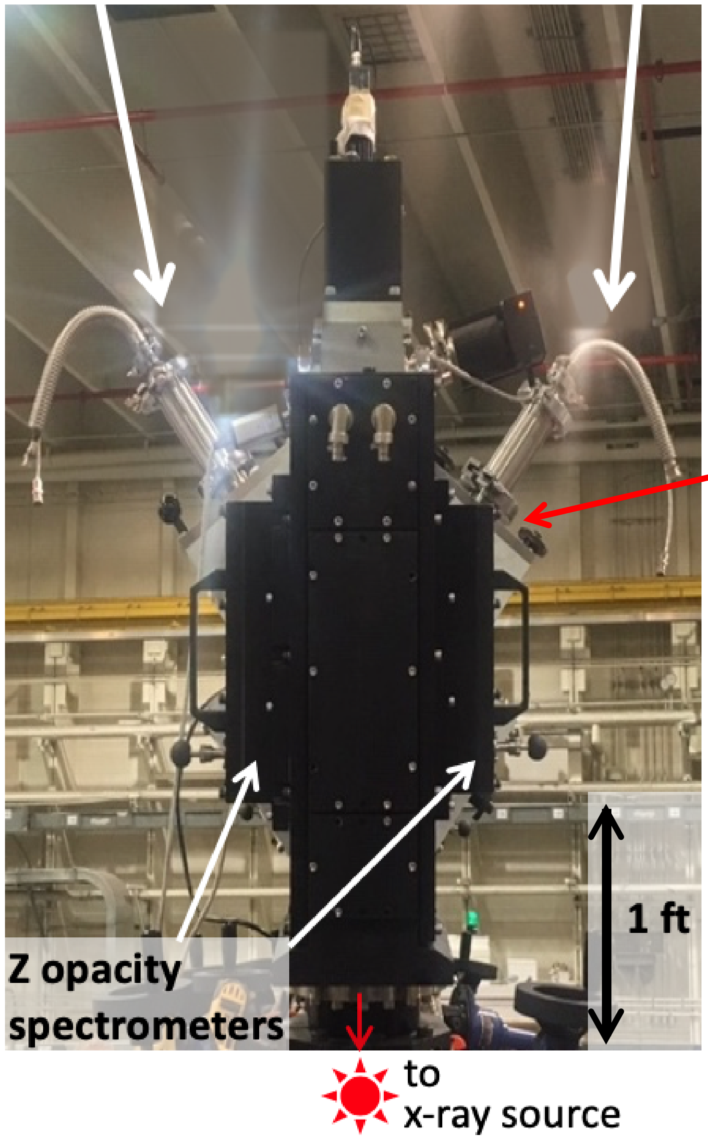


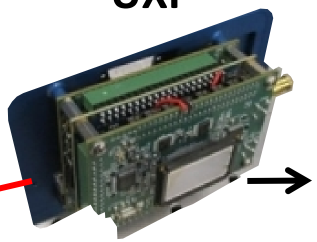
- ➢ Time-resolved conditions are consistent with film-recorded conditions
- ➢ Convolve simulation results with the UXI gates for better comparison
- ➢ Improve cross-timing of simulations with data

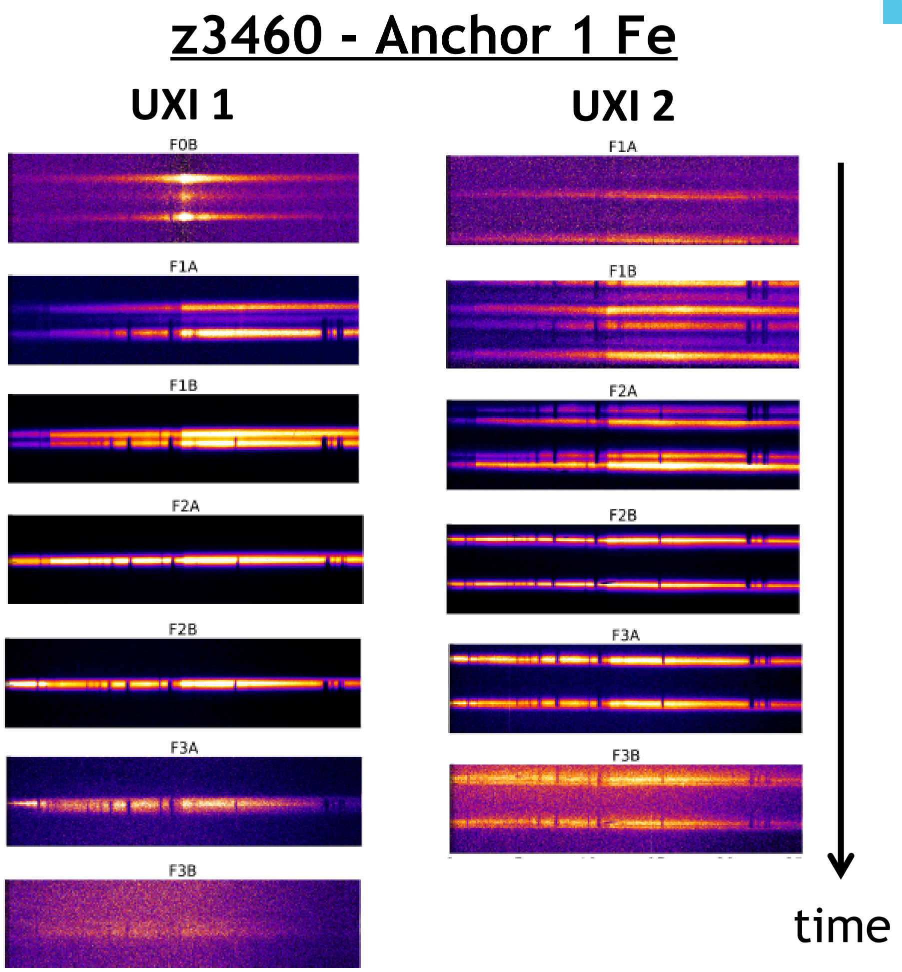
*Nagayama *et al.*, *PRE*, **93** (2016)

UXI detector successfully fielded in Z opacity spectrometers





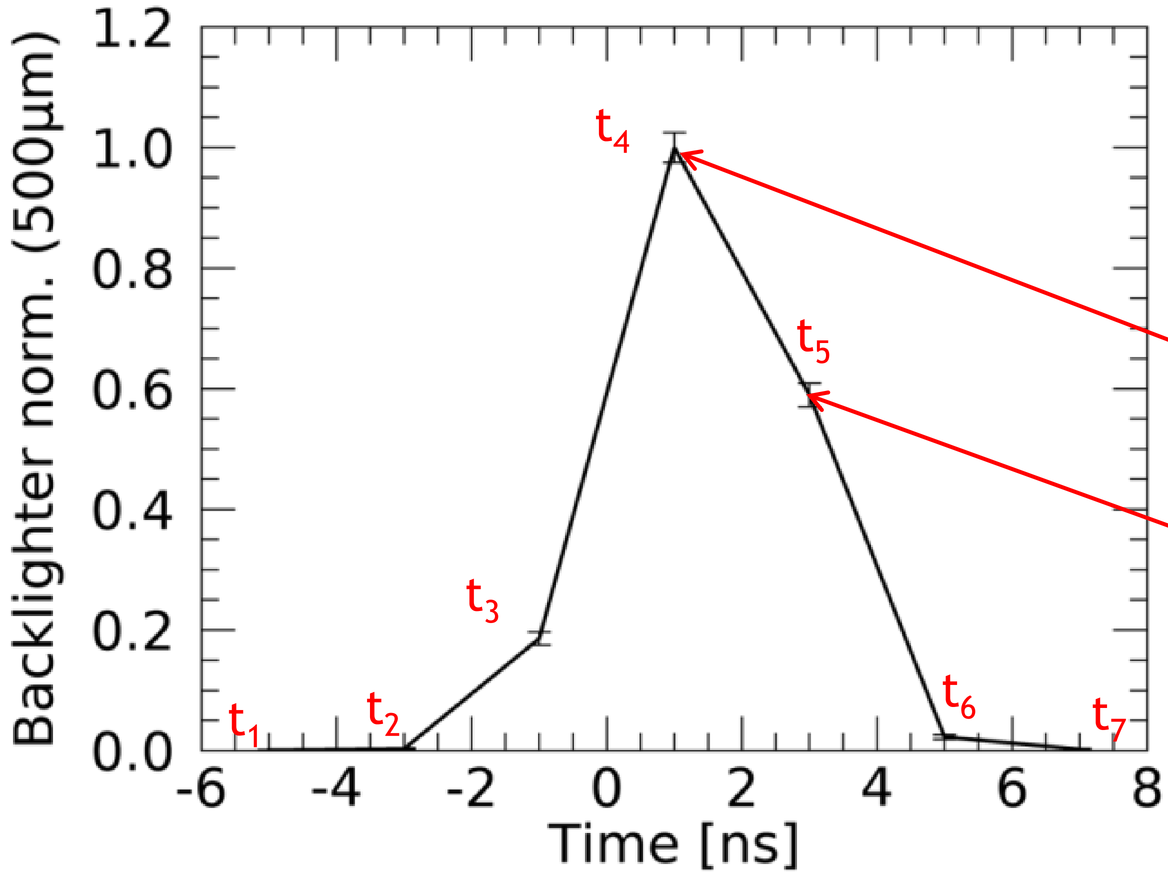




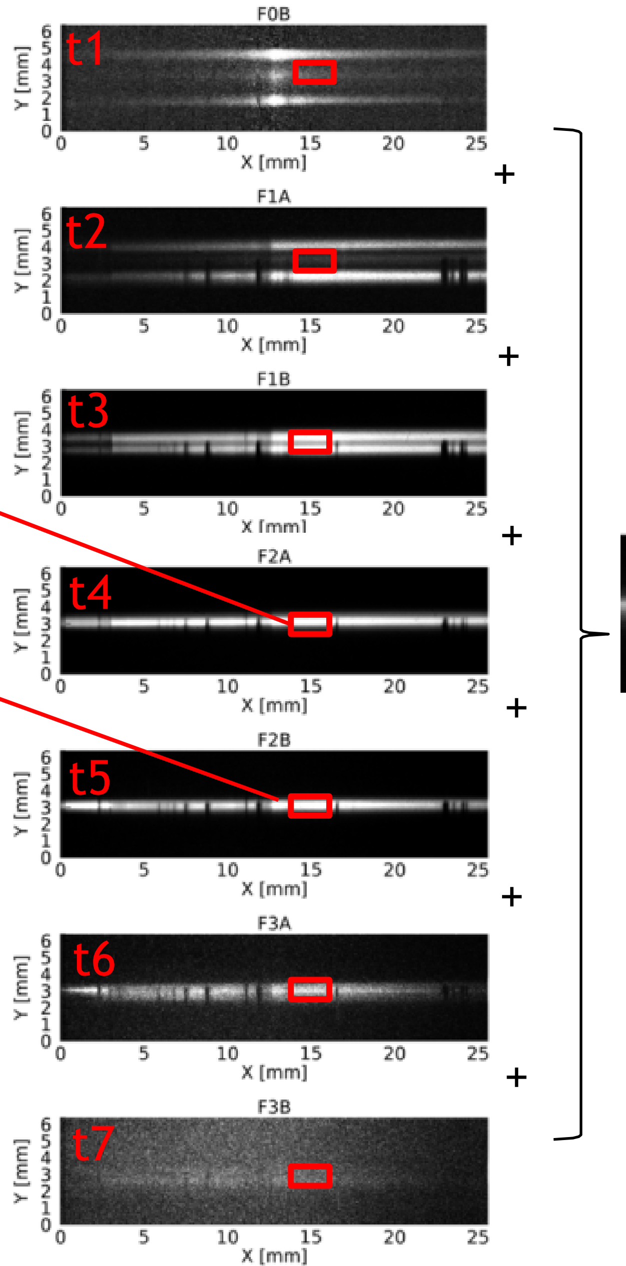
- Average of 8 frames per shot, with max of 13 frames on a single shot with 2 UXI cameras.

Time-gradients effect on film-recorded opacity measurements needs to be assessed

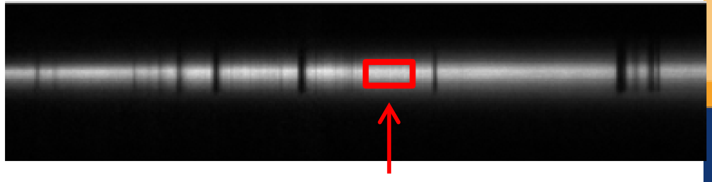
Backlighter time-history on UXI



z3460 - UXI



addition =
z3460 - film data



area in film-data analysis

UXI sees a lot more of the sample evolution than film data!
→ Conditions have to be properly weighted to make a comparison with film data