# Some issues for spectroscopy on JET

## Part 1: $Z_{eff}$ data consistency in the past
## Part 2: Will reflection matter in the future?

K-D Zastrow

# Part 1: $Z_{eff}$ data consistency on JET

K-D Zastrow

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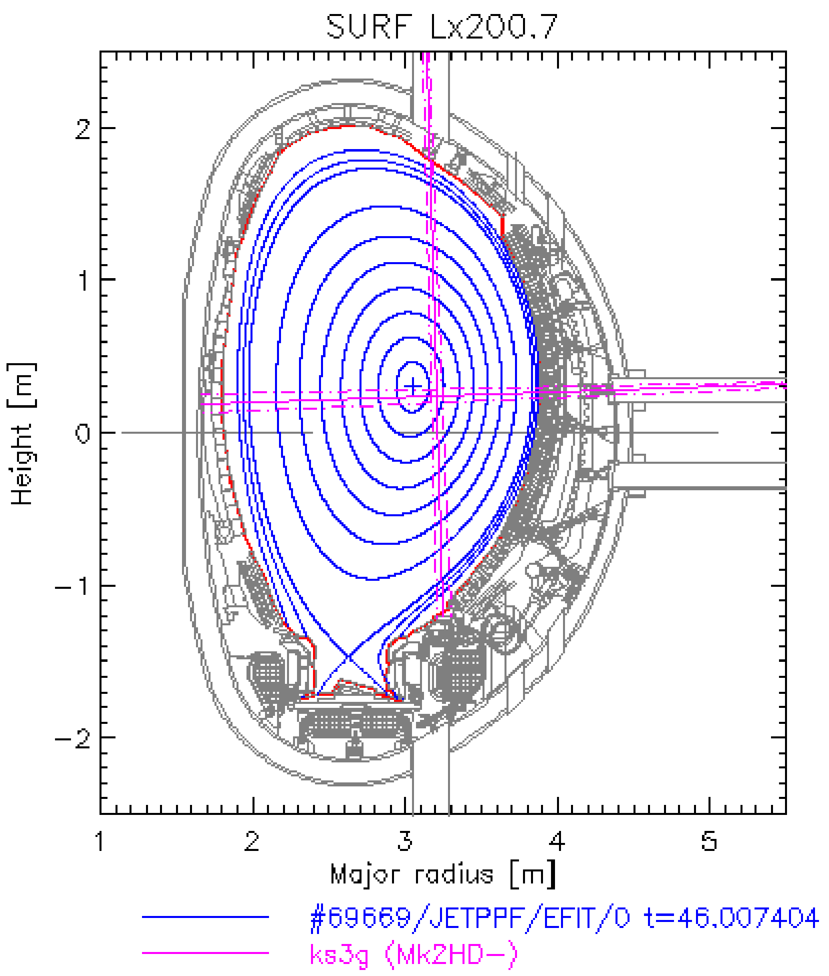
# JET Data consistency: $Z_{eff}$ and local impurities

- Fact #1: The ratio of raw bremsstrahlung measurements in horizontal and vertical lines of sight is not explained by mapping density and temperature along the lines of sight
- Fact #2: The average ratio of $Z_{eff}$ derived from bremsstrahlung measurements using the horizontal and vertical lines of sight in limiter phase and X-point phase are different
- Fact #3: The line average $Z_{eff}$ derived from bremsstrahlung measurements is typically larger than the prediction based on local measurements of carbon densities by core charge-exchange spectroscopy

# Visible Bremsstrahlung (VB)

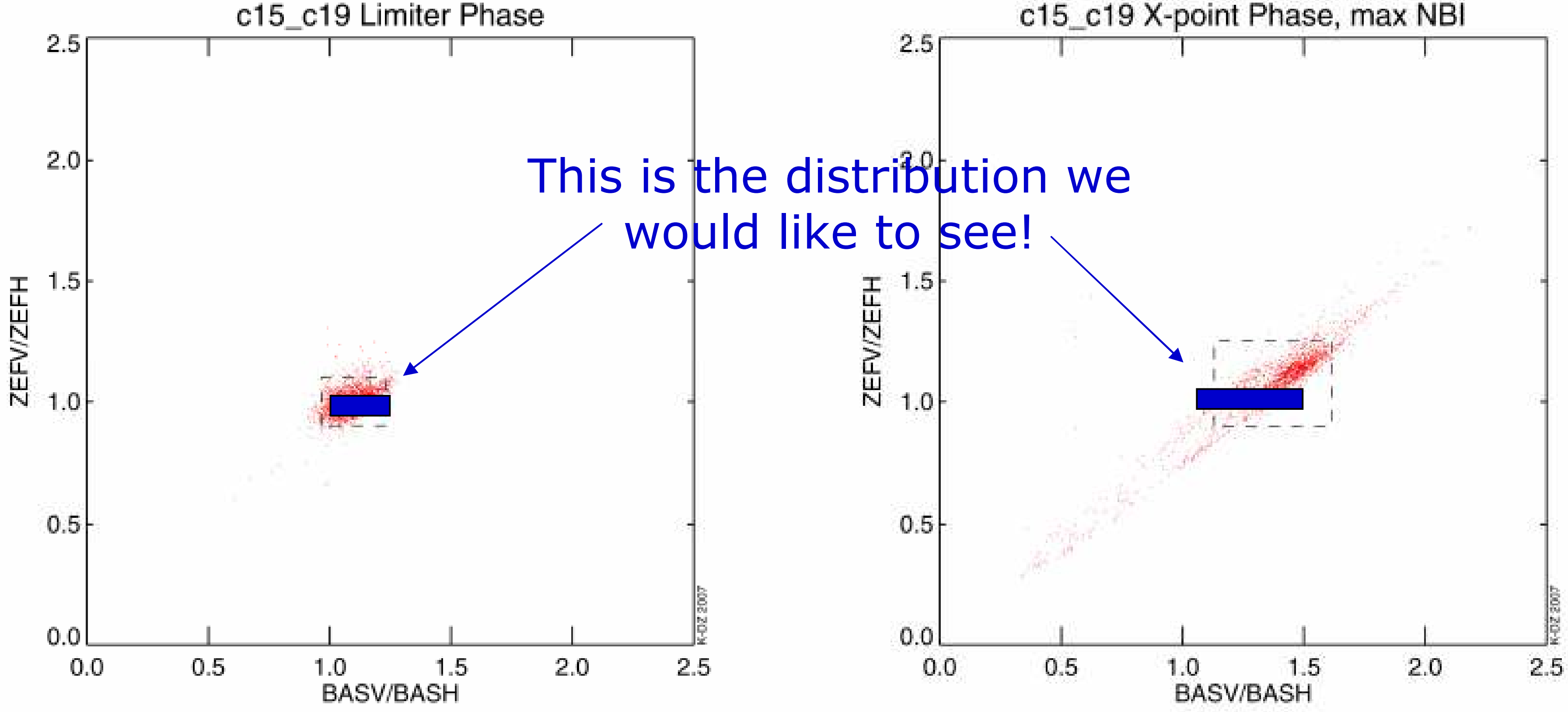



- Line average

$$I(\lambda)=g(\lambda)\int_{LOS}\frac{Z_{eff}(T_e)n_e^2}{\sqrt{T_e}}$$

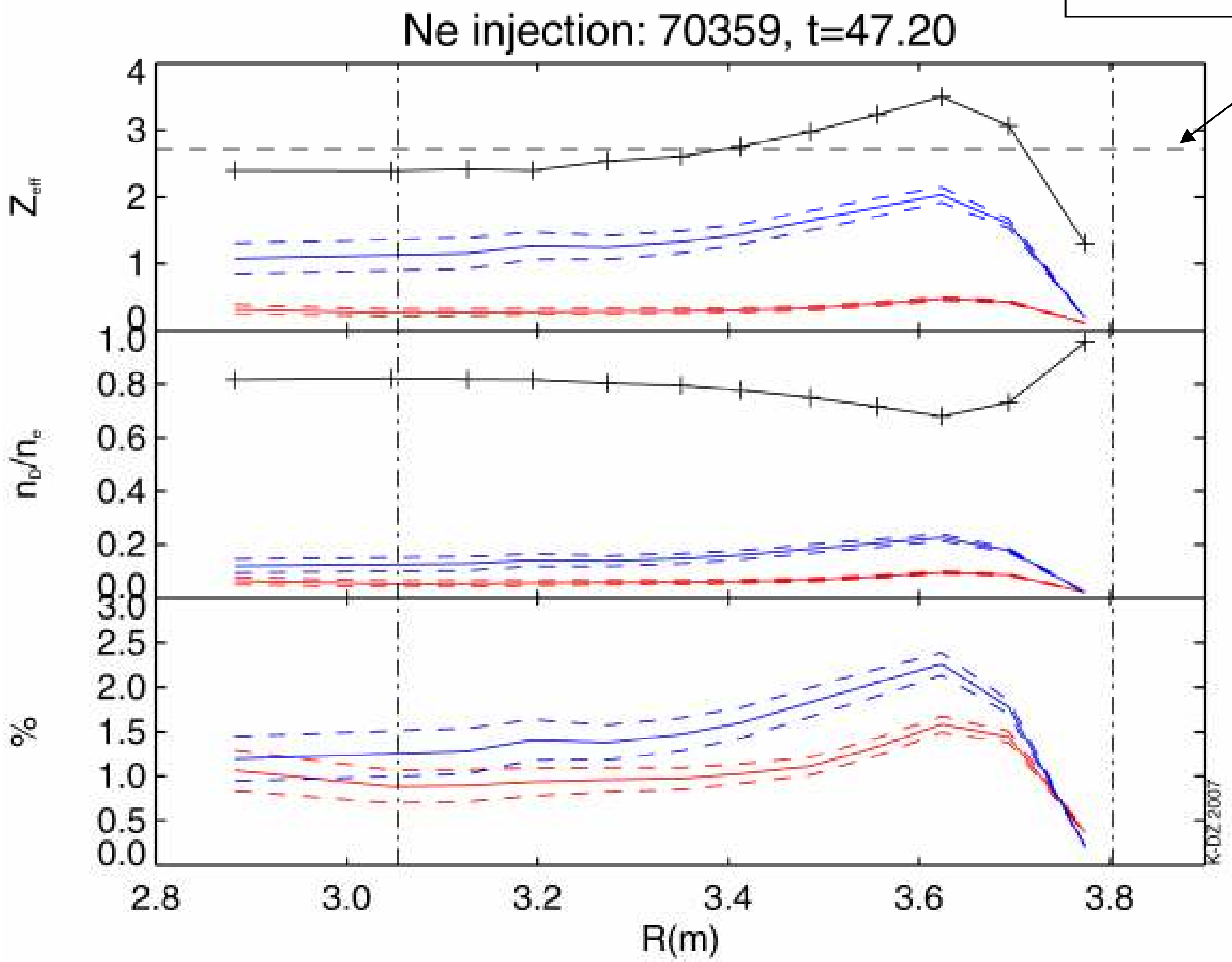
- Analysis
  - renormalise LIDAR $n_e$ to Interferometer at every time
  - map $n_e$ and $T_e$ profile along line-of-sight
  - calculate integral
  - Remove ELMs from measured signal
  - $Z_{eff}=I_{measured}/I_{calculated}$

# Bremstrahlung and $Z_{eff}$ Ratios




A large part of the physics that determines the ratio of the raw Bremsstrahlung is not included in the model used to derive $Z_{eff}$

# CXS: Local densities after Neon injection




Predicted $Z_{eff}$ from VB

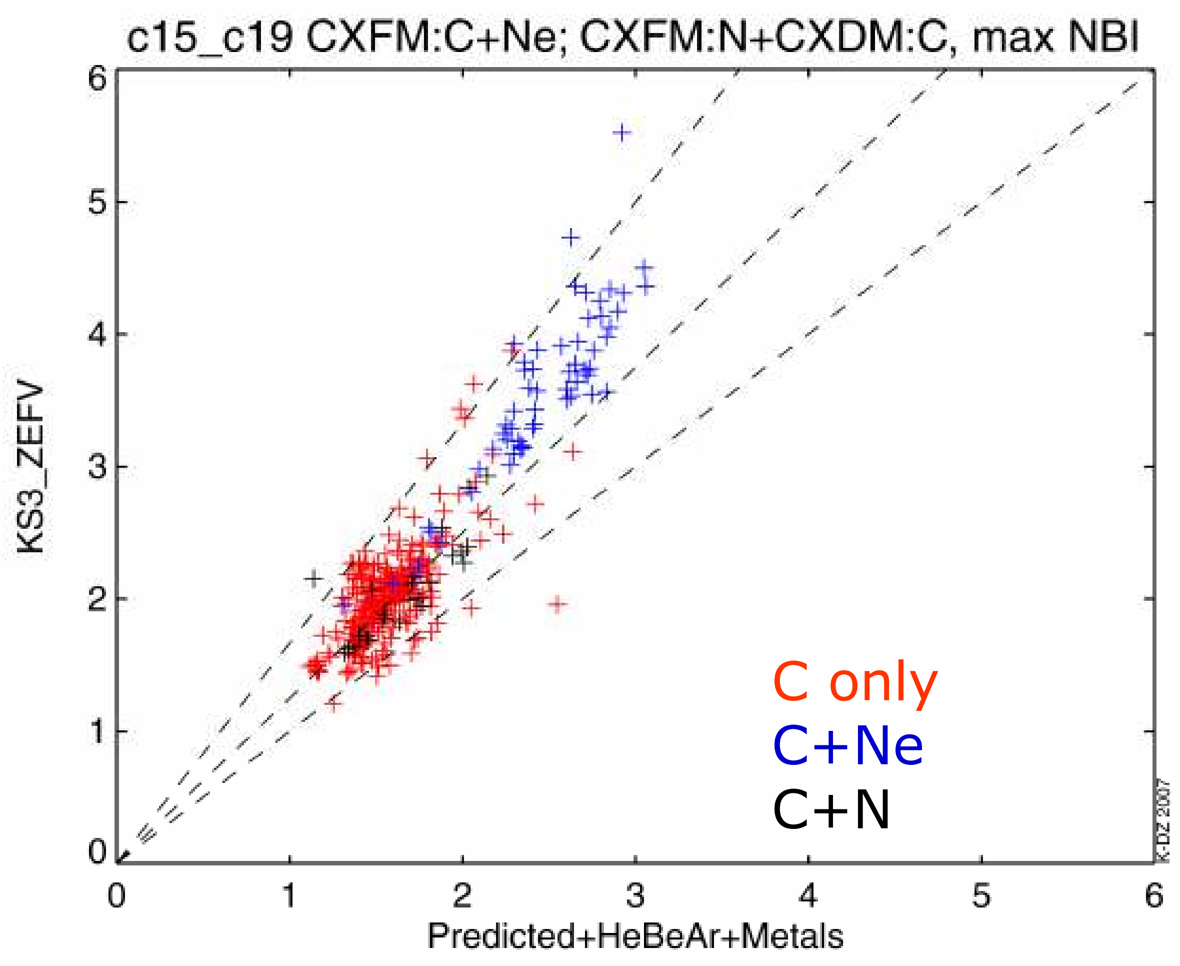
Total $Z_{eff}$ and contributions $\Delta Z_{eff}$ (C, Ne)

Total $n_D/n_e$ and contributions $-\Delta n_D/n_e$ (C, Ne)

Carbon concentration

Neon concentration

# Prediction of vertical VB (CX only)




Typically more VB signal seen than predicted. SOL Emission model missing?

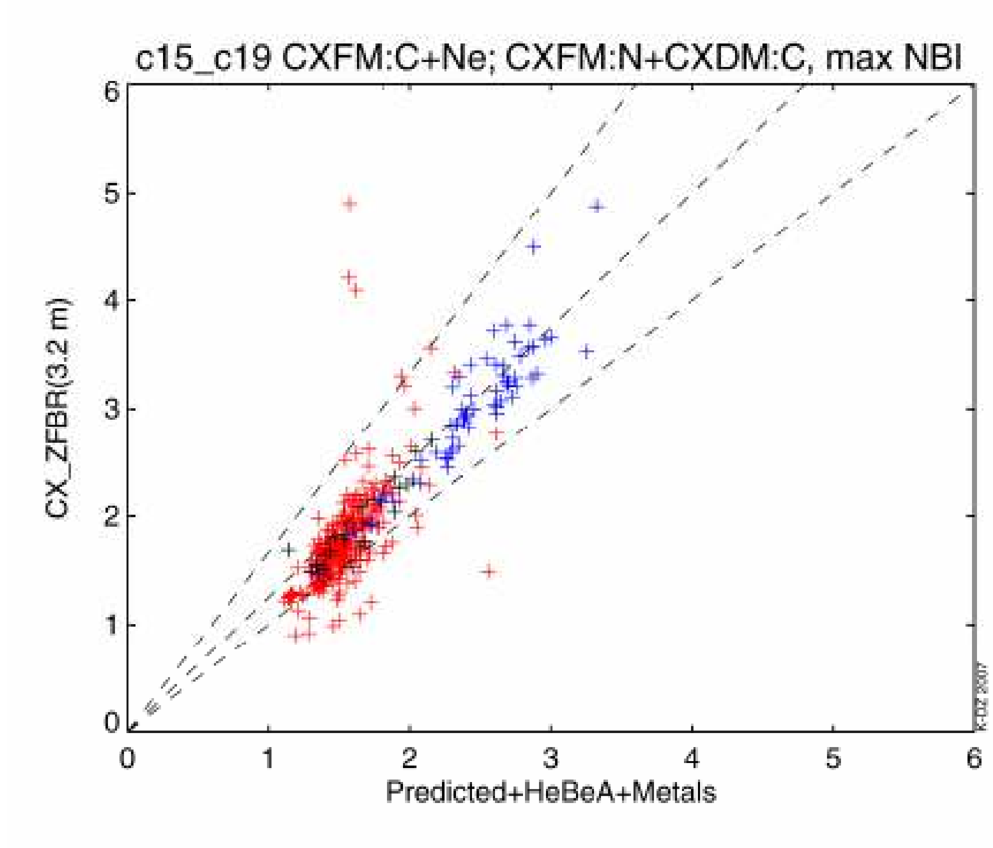
Argon and Metals from VUV "calibrated" on impurity transport experiments

He relative to D from influx

Be relative to C from influx

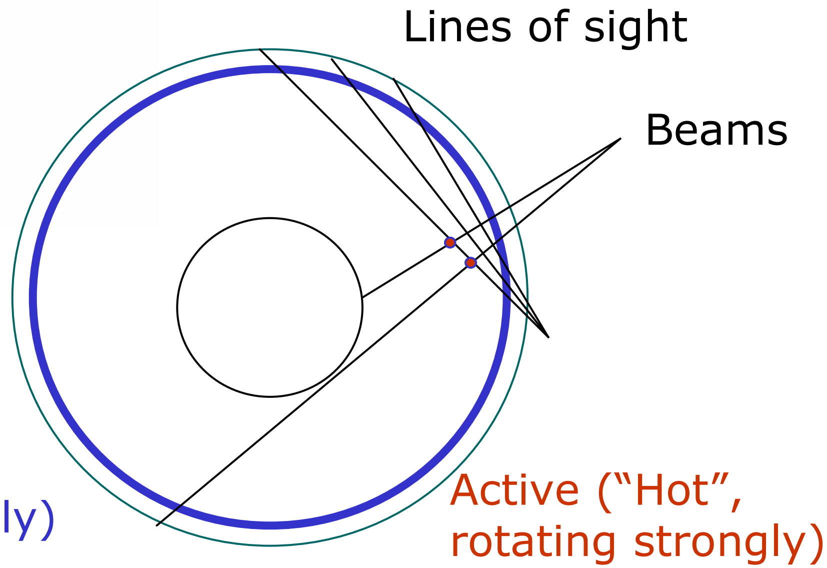
<u>Better, but not enough!</u>

# Prediction of continuum in CXS spectrum




More successful!

Central tangential line of sight has more weight in the core than vertical line of sight



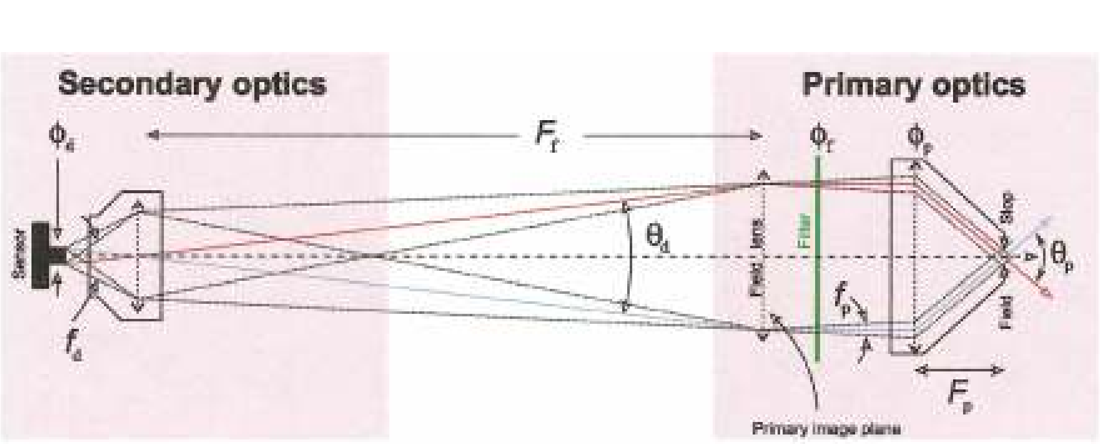

SOL Emission (not rotating) as wavelength reference

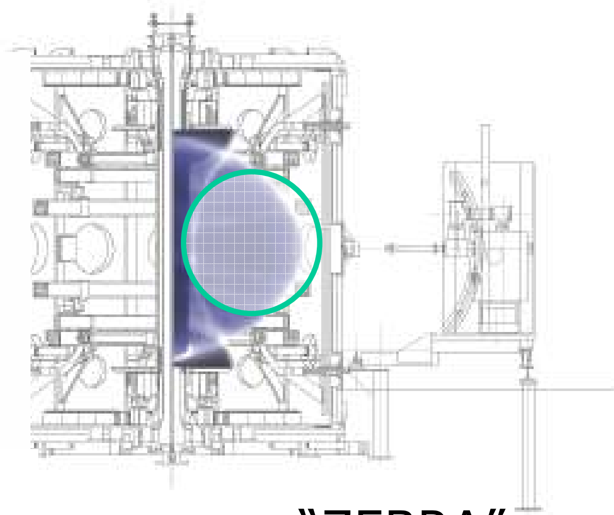
Passive ("Cold", rotating slowly)

# Potential systematic errors for impurity density

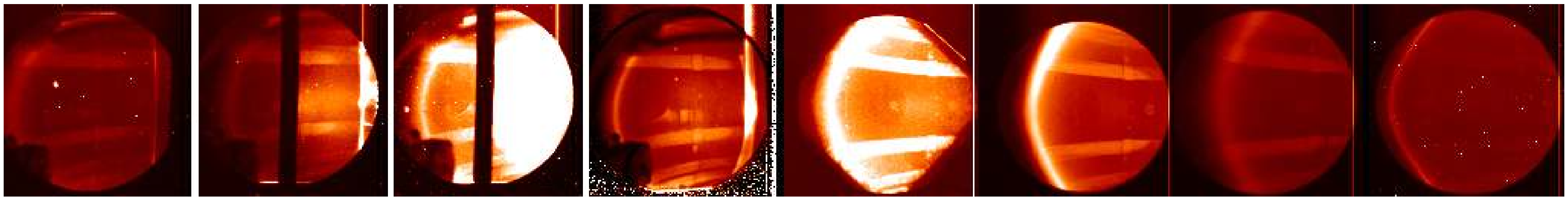
| | VB | CX |
|---|---|---|
| Measures | $Z_{eff}$ | C density (plus He, Be, N, Ne, Ar) |
| Sensitivity | $\sim Z_{eff}$ | $\sim(Z_{eff}-1)$ |
| Alignement | Weak dependence | Relative to beams |
| $n_e$ dependence | $\sim 1/n_e^2$ | $\sim n_e$ ish |
| Data quality | Poor for low $n_e$ | Poor for high $n_e$ |
| Assumption that can be wrong | Only continuum detected | Dominant impurities measured |
| Atomic physics | simple | complex |

# MAST: Imaging system for bremsstrahlung



"ZEBRA"



Because its an image, reflections can clearly be seen and treated (excluded) before inversion

Figures provided by A Patel, UKAEA

# MAST: Chord integrated and inverted signal

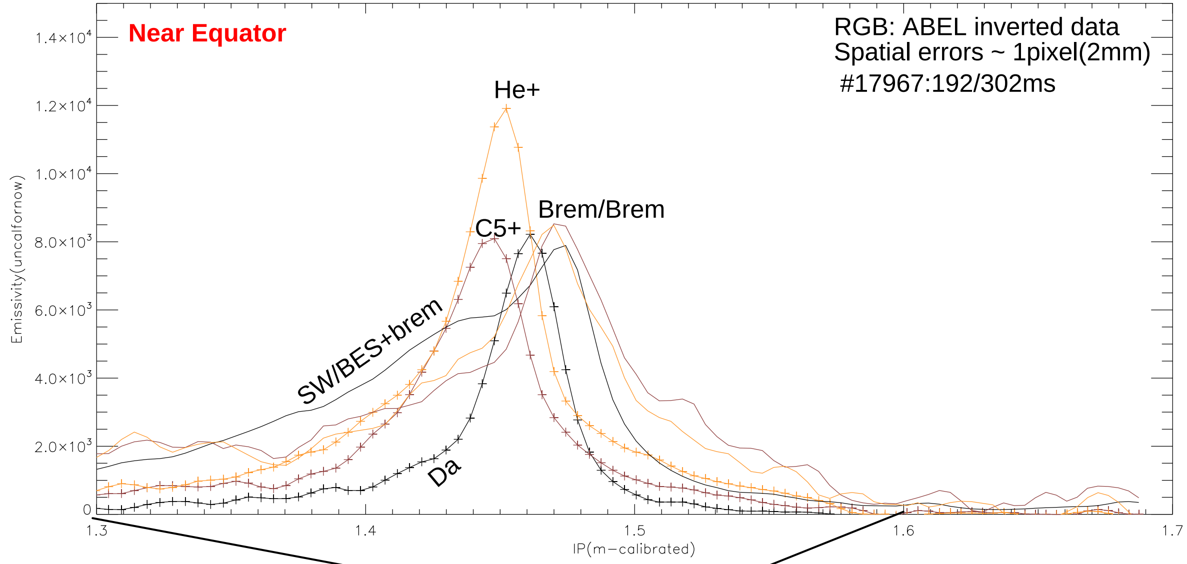
From co-axial filtered images

-Bremsstrahlung

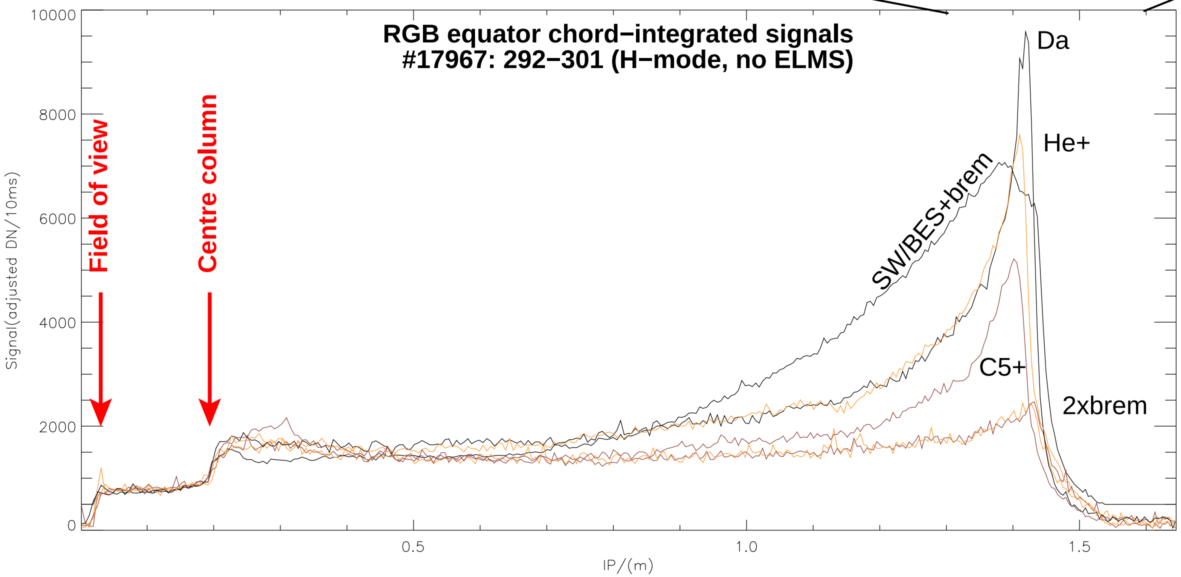
-C-CX, He-CX

-Dα

-Beam emission




"RGB"




"Bremsstrahlung" peak at larger radius than Dα

Does this happen on JET? Are we simply missing SOL emission in prediction?

Slide provided by A Patel, UKAEA

# Part 1: Summary of main findings

- $Z_{eff}$ from bremsstrahlung is generally larger than predicted because
  - Other impurities than carbon are present, which accounts for many of the outliers
  - There is more continuum near the edge than predicted
- There is strong evidence that the bulk carbon, neon and nitrogen concentrations from CXS are measured correctly
  - Good agreement with continuum measured by CXS for lines of sight that are strongly weighted to the core
  - These should therefore be used when the core dilution or resistivity is of interest (e.g. prediction of neutron yield)
- There is strong evidence that it is the local $Z_{eff}$ in the plasma periphery that is not described correctly
  - Poor agreement with continuum measured by CXS for lines of sight that are strongly weighted to the edge
  - Horizontal $Z_{eff}$ larger than vertical in Limiter phase, the other way round in X-point phase
  - It is therefore reasonable to modify these when the edge dilution or resistivity is of interest (e.g. edge barrier modelling)

# Part 2: Modelling the effect of reflection

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UKAEA Fusion Working in Europe

University of Strathclyde Glasgow

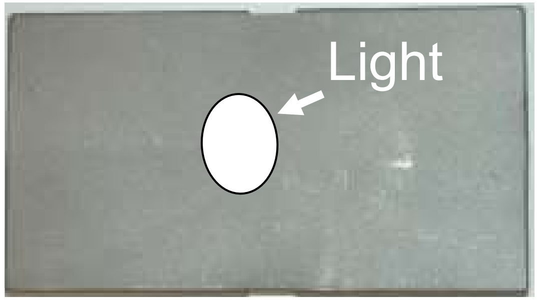
UNI BASEL

# On reflection

- Do we need to worry about reflection?
  - With JET now?
    - CFC tiles have very low reflectivity
    - But do we know how much the contribution from reflection actually is?
  - With JET with a metal wall (from 2010)
    - Need to have some idea if its important before we do the experiment
- Diagnostics potentially affected
  - Visible bremsstrahlung ($Z_{eff}$)
  - Erosion measurements from S/XB ratios
  - Addition of "volume average CX feature" to CX spectroscopy
  - …
- What can we do about it?
  - Evaluate reflection characteristics of JET tiles
  - Model the effect of reflection on spectroscopic signals, derive either "error bars" or "correction terms"

  - $\Rightarrow$ first steps towards this goal presented in this talk

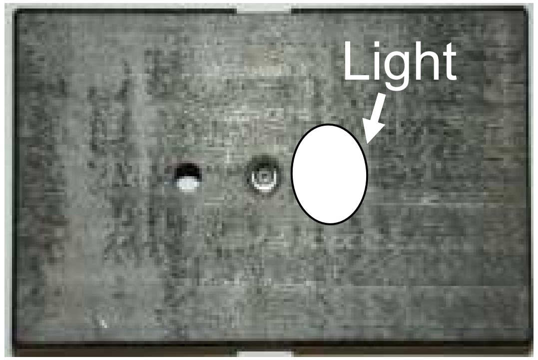
![EFDA JET logo] 
# Investigated samples for angular dependence



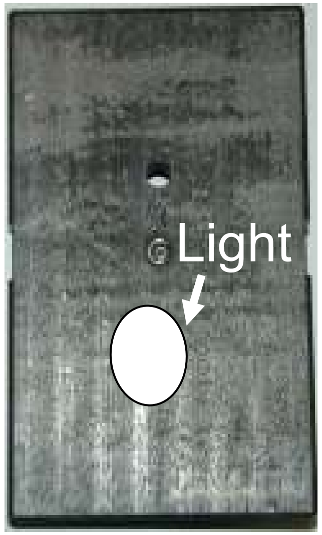

Inconel tile
Ni 74 / Cr 15 / Fe 7

Spectralon/ teflon (used as a reference)

- Due to the anisotropy of CFC, measurements made with 2 orientations




CFC inner wall cladding *called for measurement*
**Carbon //**

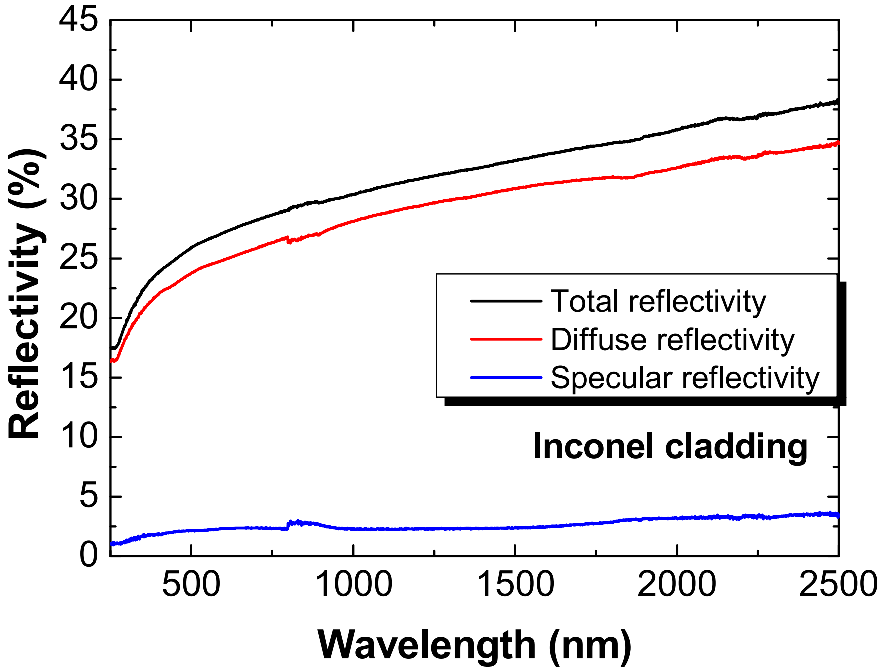


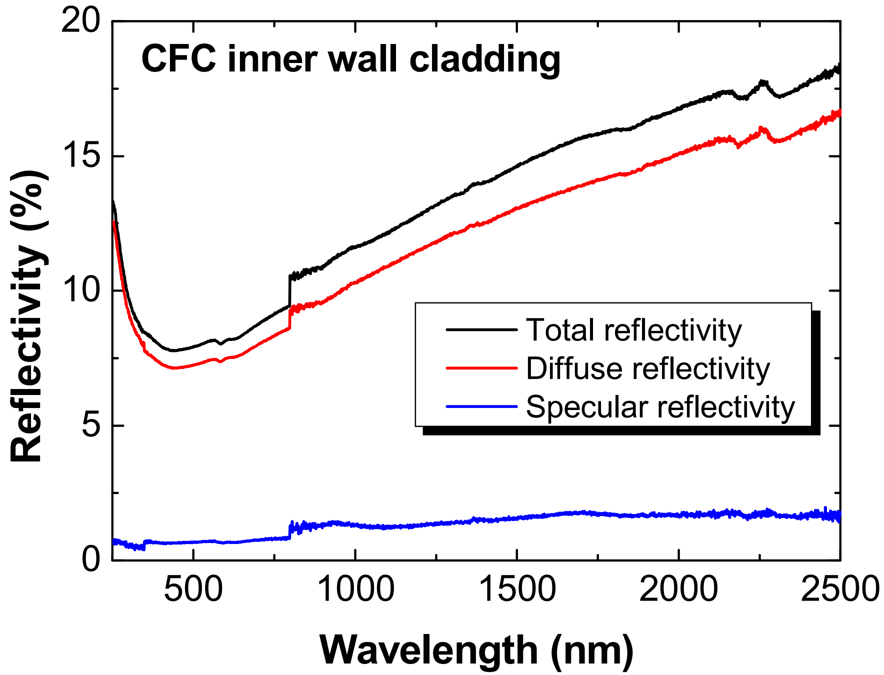

CFC inner wall cladding *called for measurement*
**Carbon ⊥**

Measurements impossible on the CFC guard limiter (geometry of the sample)

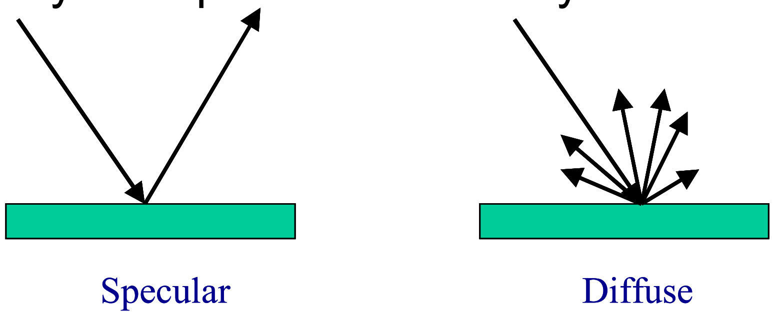
G de Temmerman, U Basel

# Total, specular and diffuse reflectivity



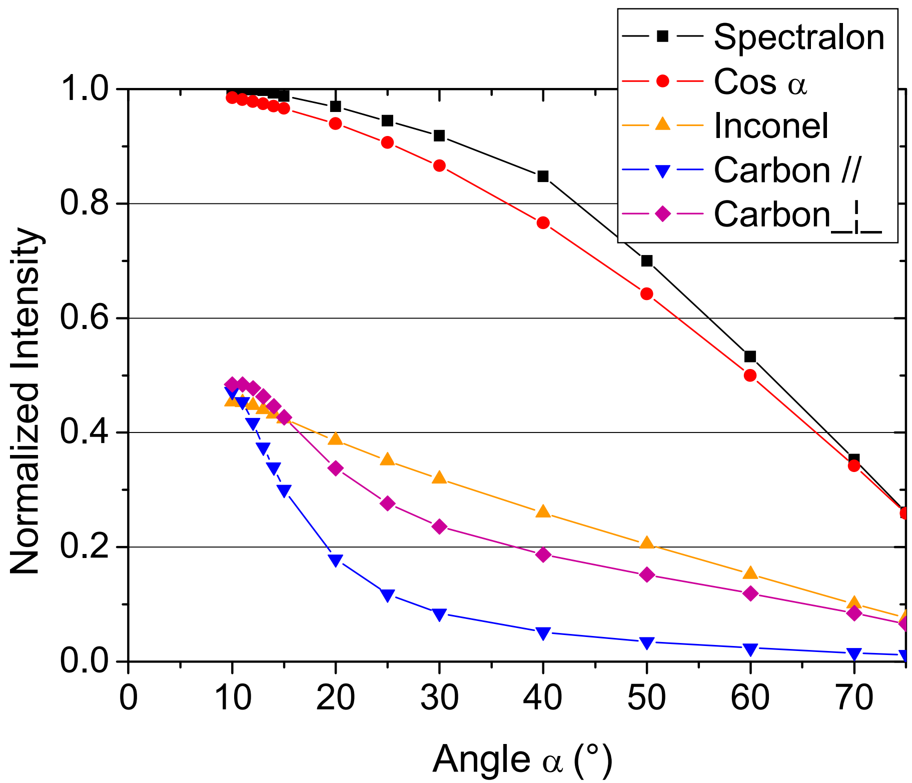

- Total reflectivity of Inconel much higher than CFC
- Very low specular reflectivity of the tiles due to high roughness

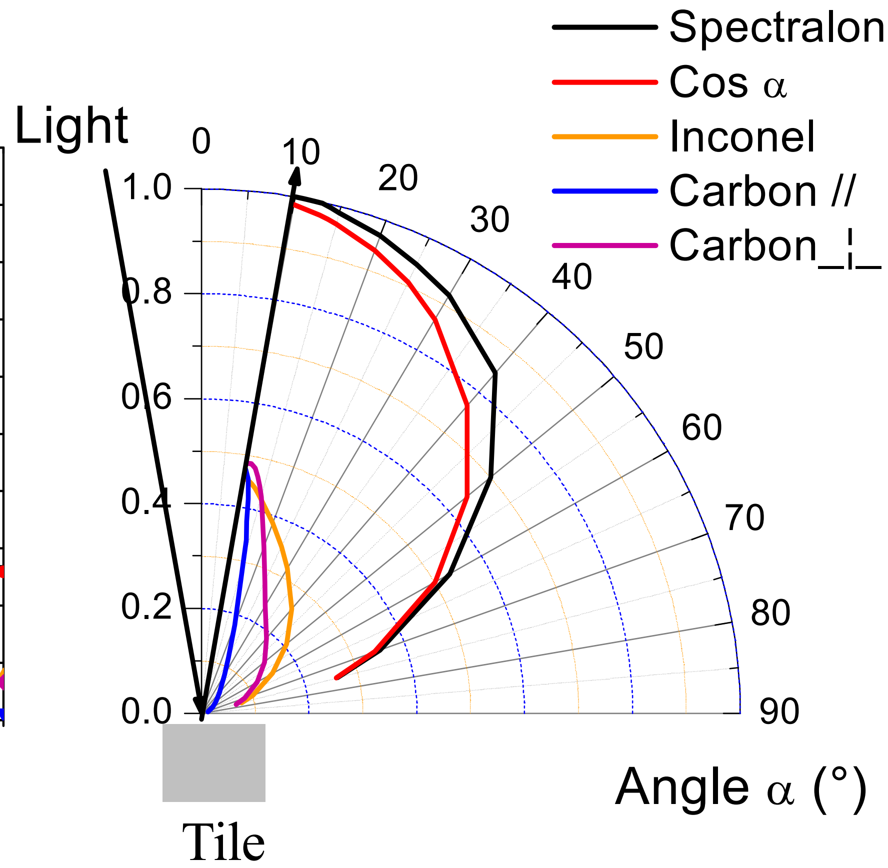



G de Temmerman, U Basel

# Results at 600 nm

Intensities for a given angle now normalized to the intensity measured for the spectralon at 10°

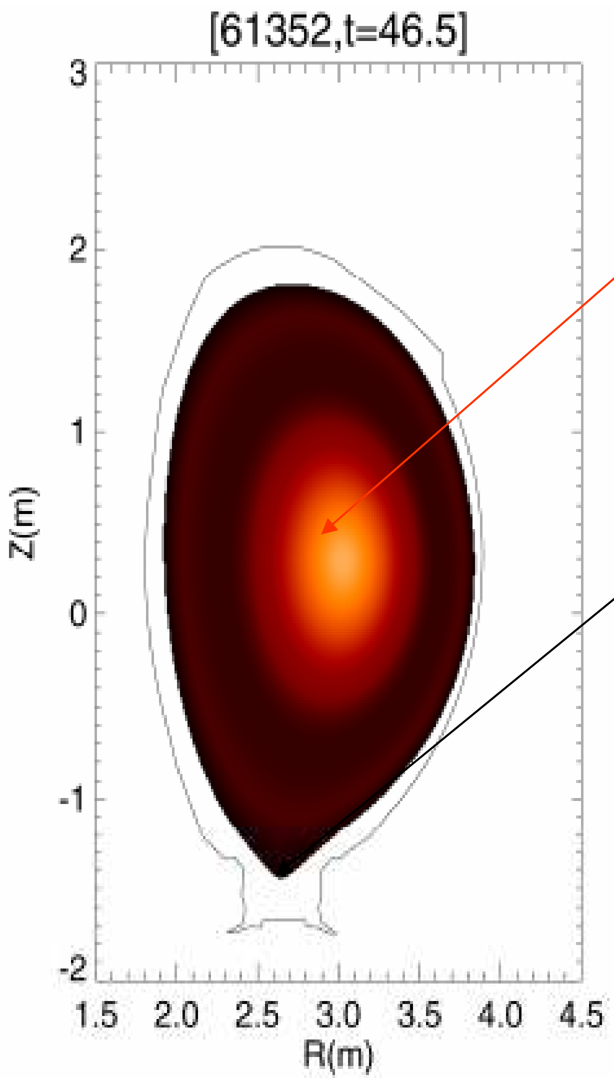



- Evolution for the Inconel seems more linear/ larger distribution
- Strong differences between the two orientations of the CFC tile

G de Temmerman, U Basel

# From 2D contours to simulated image




Flux surfaces from FLUSH

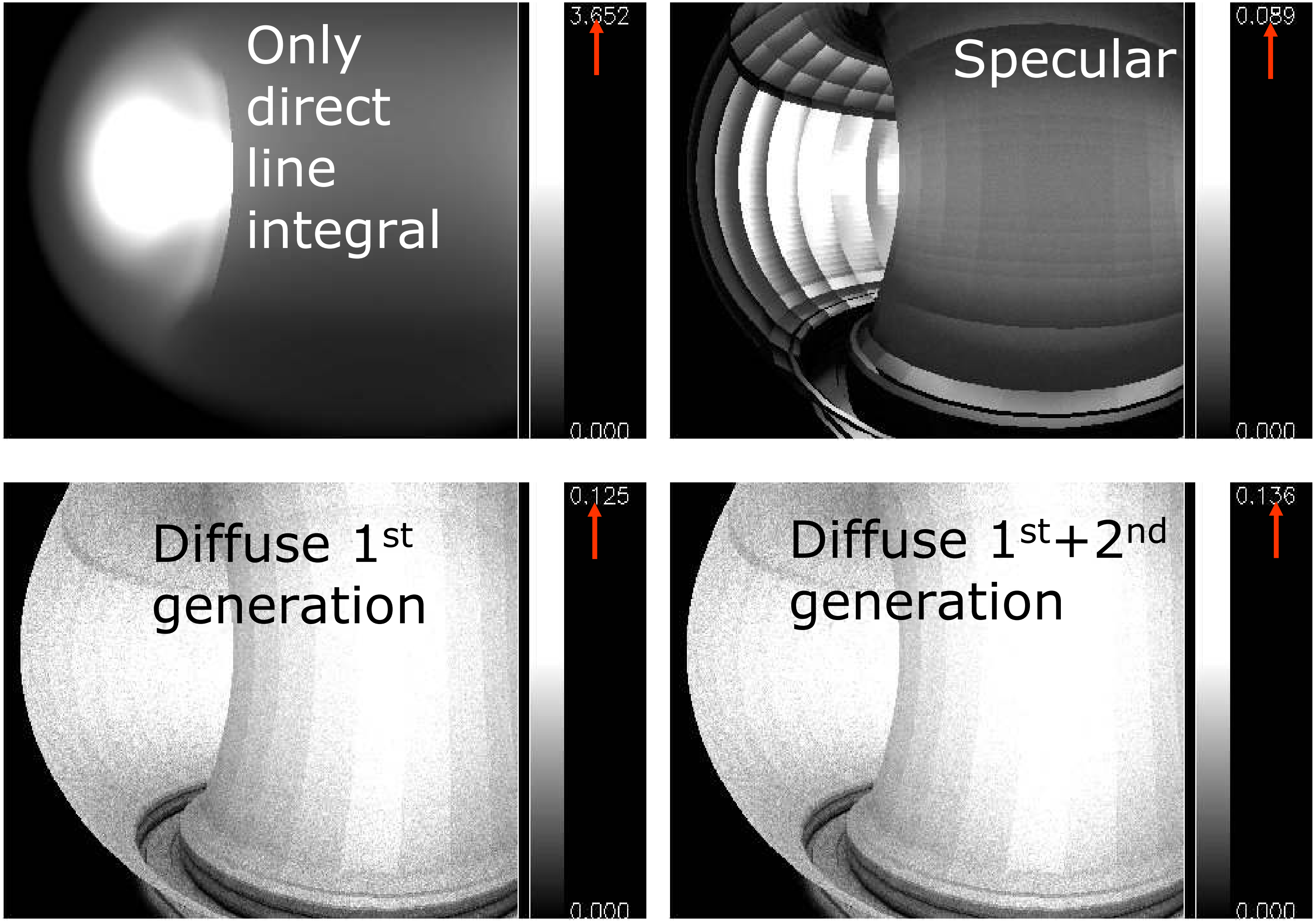
Emissivity constant on flux surfaces ~$n_e^2(\rho)/T_e^{1/2}(\rho)$

JET Limiter outline replicated 32 times toroidally to construct the "vessel" out of square tiles

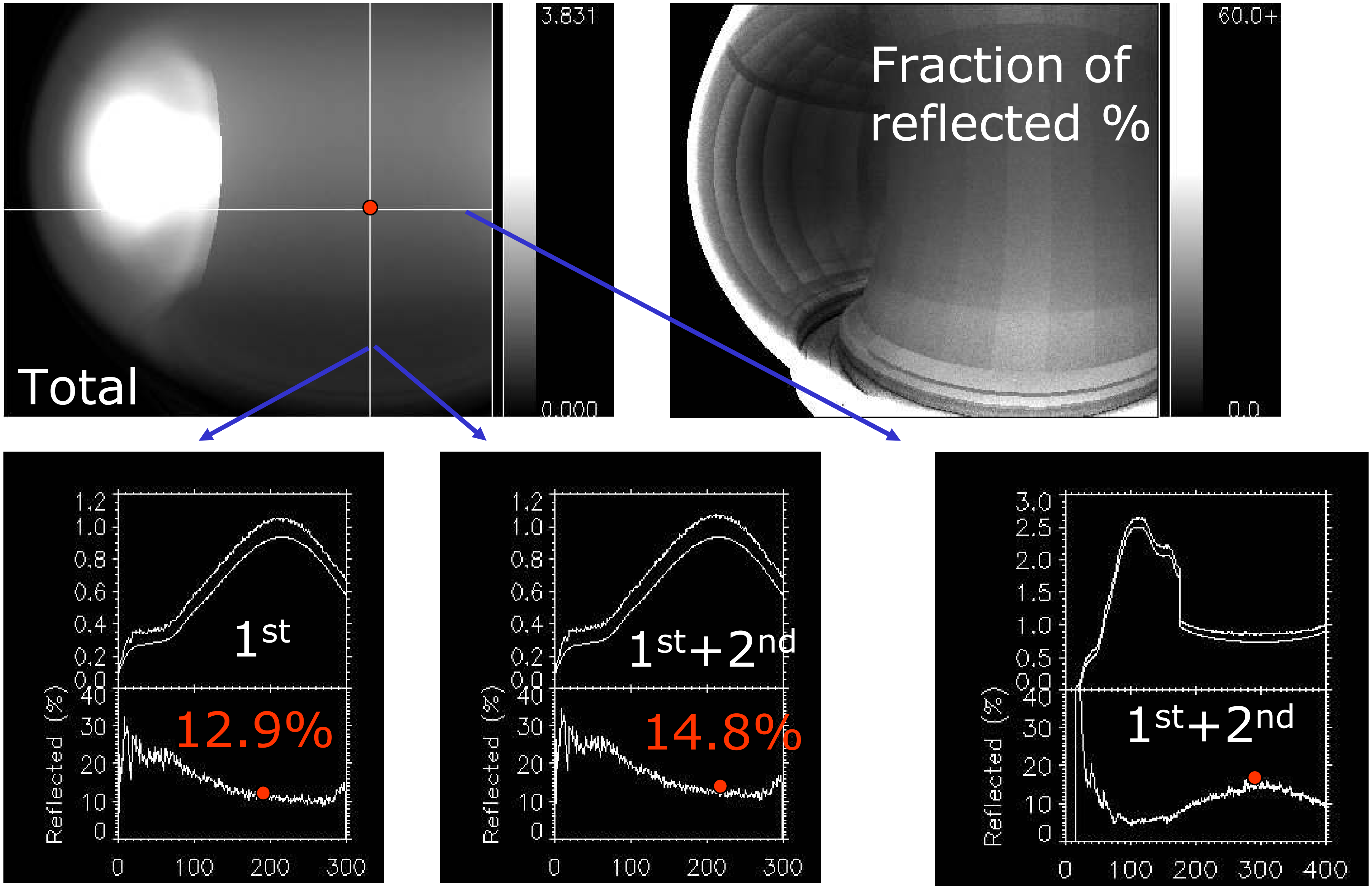
Each tile is then split into two triangles (total: 7104)

Same material everywhere, Inconel or CFC-parallel

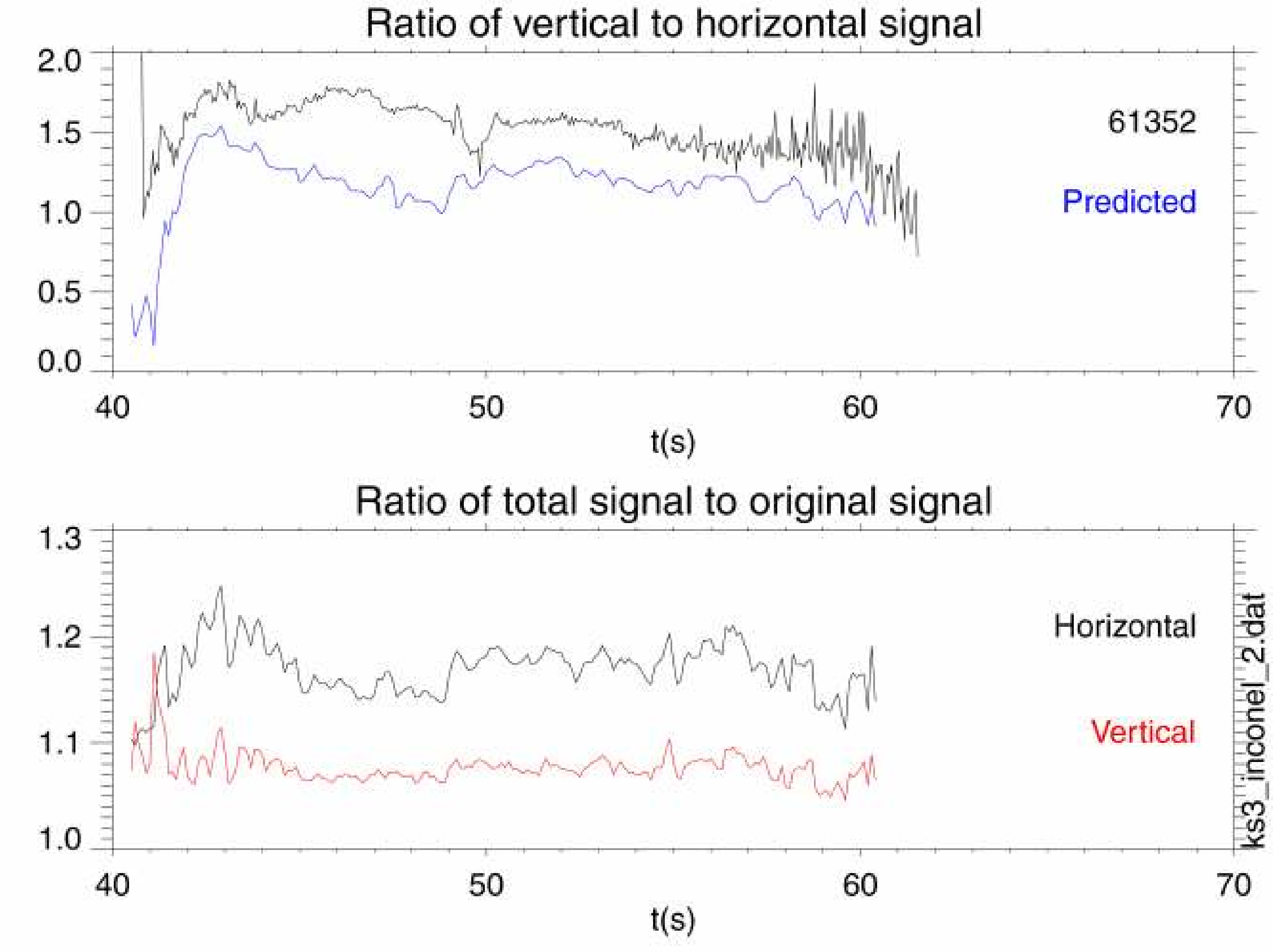
# Bremsstrahlung with Inconel wall (1)



# Bremsstrahlung with Inconel wall (2)



# Prediction for vertical bremsstrahlung signals




$N_{MC}$=1000 (2% error)

Only 1st generation

Calculated every 100 ms

3 CPU hours

+ 100 for 2nd generation

9.5 CPU hours

# Part 2: Summary of first impressions

- The fraction of reflected light in the total intensity depends on the geometry of the source as well as the geometry of the wall.
- The values found in the simulation for the two types of source are the same order as the total reflectivity measured in the lab on the sample tiles which is reassuring but no code verification (5-10% for CFC, 15-30% for Inconel)
- Verification! Are equations correct, and implemented correctly?
- For CFC, probably no need to worry about reflection, certainly no need to include 2$^{nd}$ generation, except where a diagnostic line of sight is almost perpendicular to the wall.
  - Ironically it is more important to have the correct wall in the model (and thus much more work) to do a good job with CFC.
- Also tile orientation matters with CFC, this has so far been ignored (don't know how to deal with this!)
- For Inconel, reflection is an important contribution, and 2$^{nd}$ generation should be included as well.

- What are the reflection characteristics of W and Be tiles?
- How will these evolve after exposure to plasma?