

Learning to Invert Solar Flares with RADYN Physics

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with C. Osborne and L. Fletcher



@rh1210



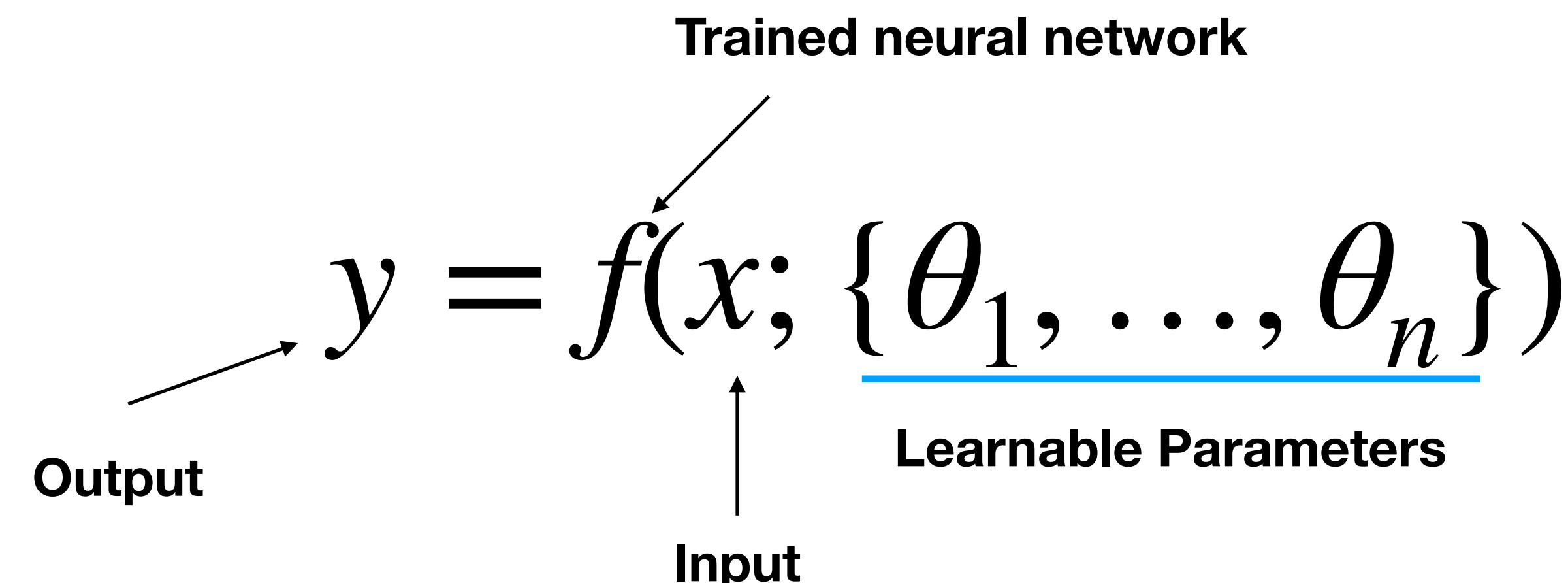
rhero12



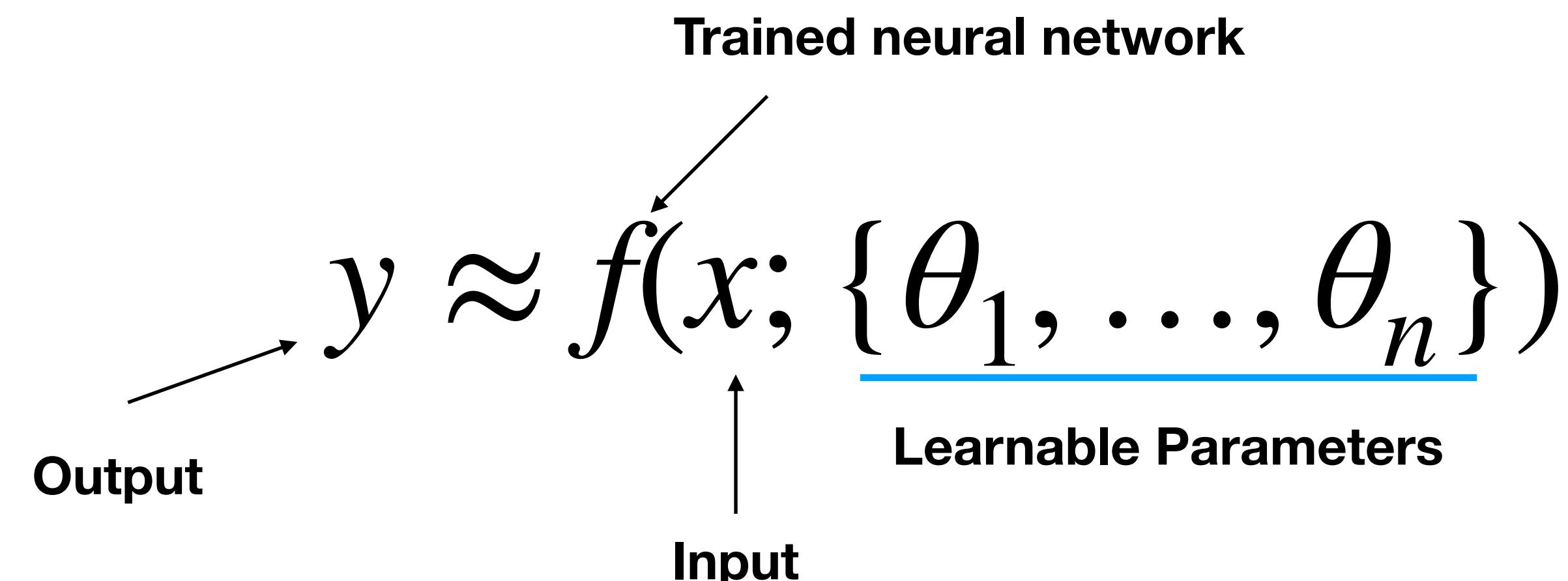
http://bit.ly/john_ESPOS_2020



- Machine learning the process of using statistical techniques to give computers the ability to learn how to perform a specific task *without* being explicitly programmed
- Deep neural networks are very good function approximators (Cybenko 1989, Lu et al. 2017)
 - processes that can be expressed by well-defined functions can be learned by a deep neural network

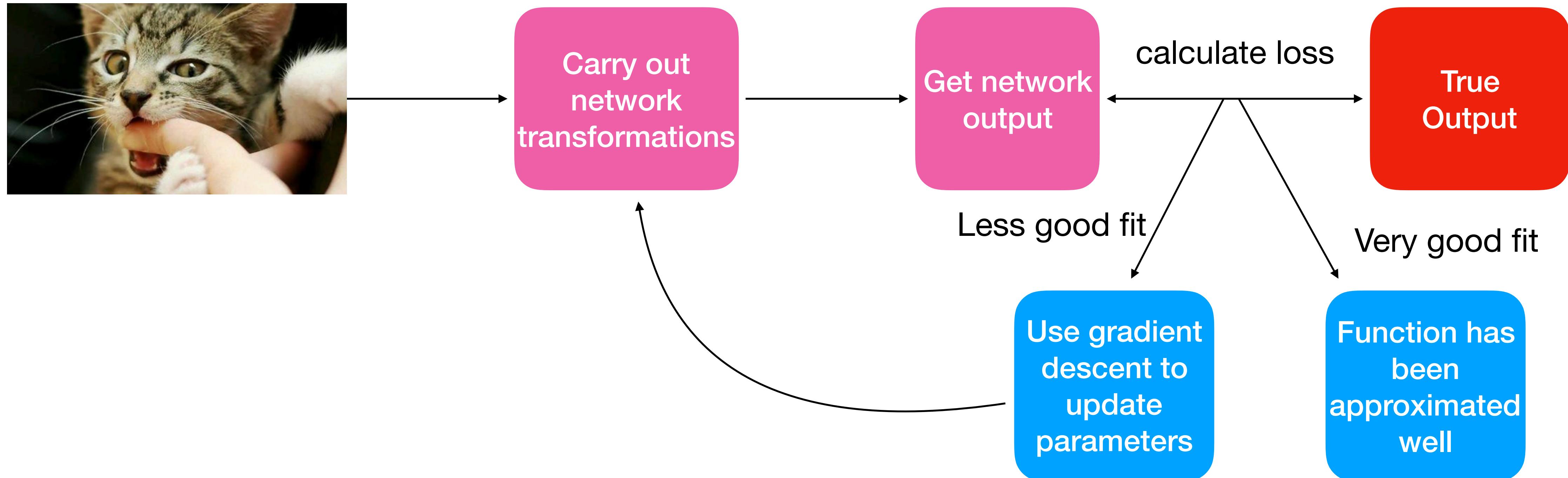


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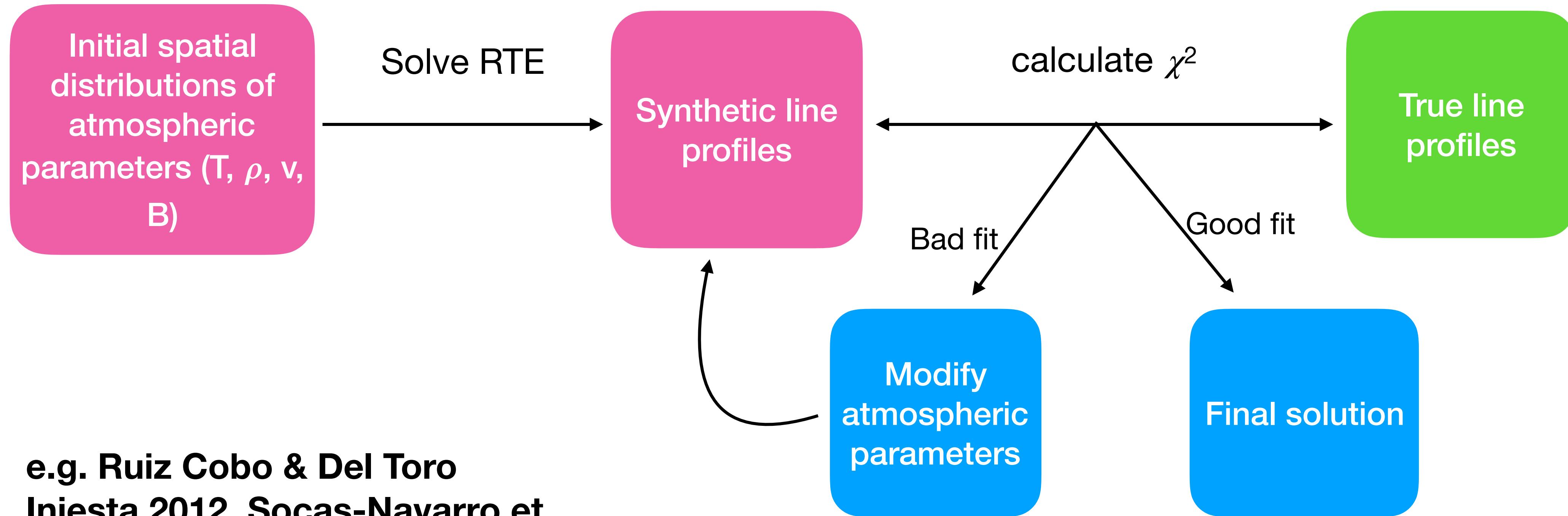
Deep Learning:

Training



Inversions:

Forward Modelling



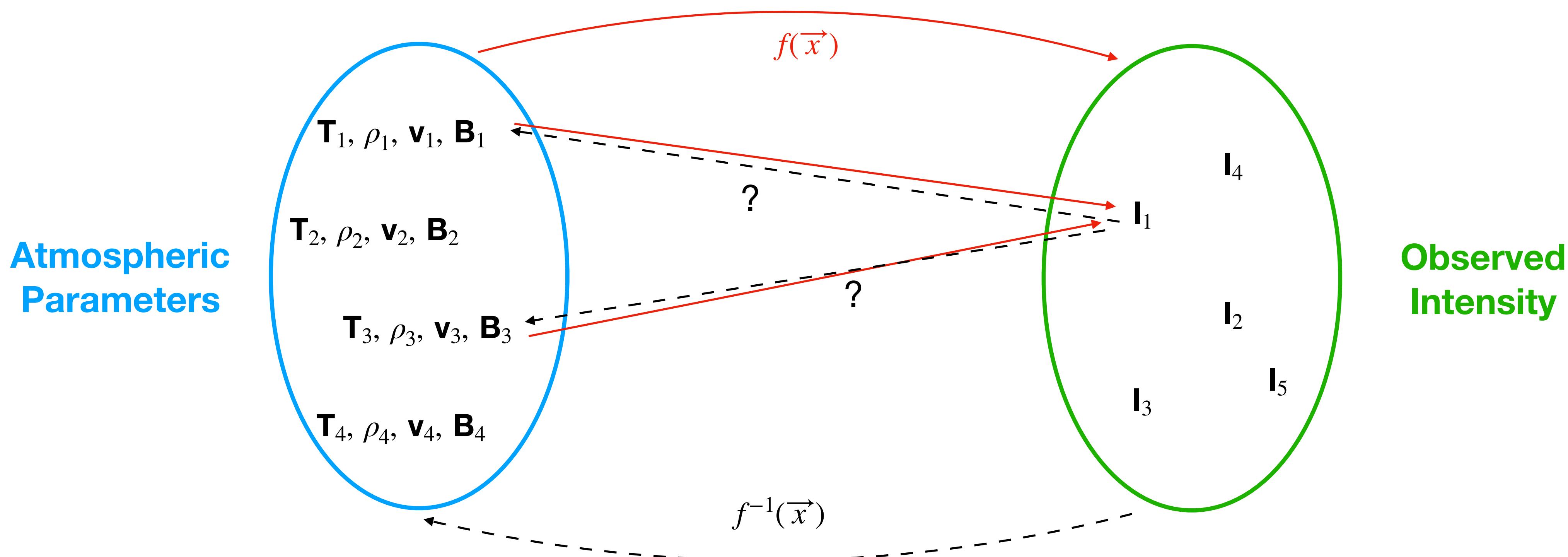
e.g. Ruiz Cobo & Del Toro
Iniesta 2012, Socas-Navarro et
al. 2000, Skumanich & Lites
1987, Asensio Ramos+ 2008,
de la Cruz Rodriguez+ 2019



Inversions:

Ambiguities

- Inversions, however, are not well-defined functions
 - there are many combinations of atmospheric parameters that can produce the same line profiles
 - there is information lost about the physics in the forward process



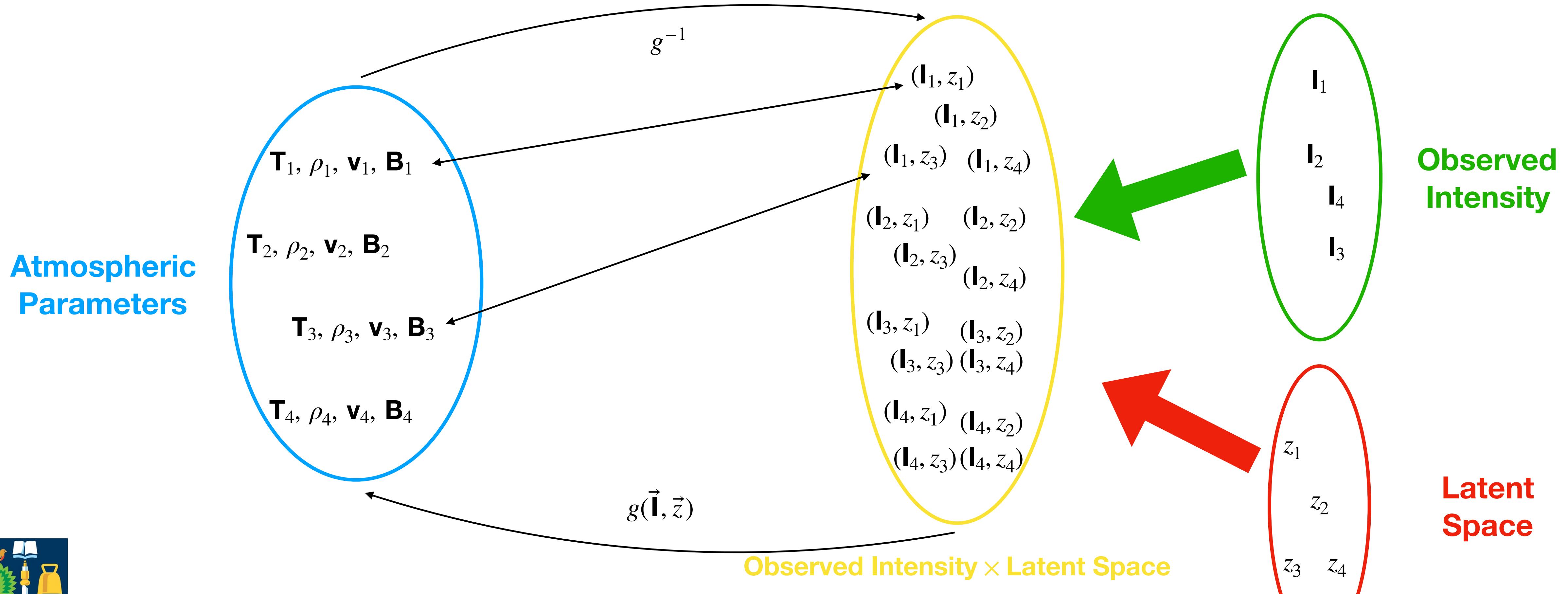
Cannot be modelled with traditional deep learning



Inversions:

Ambiguities

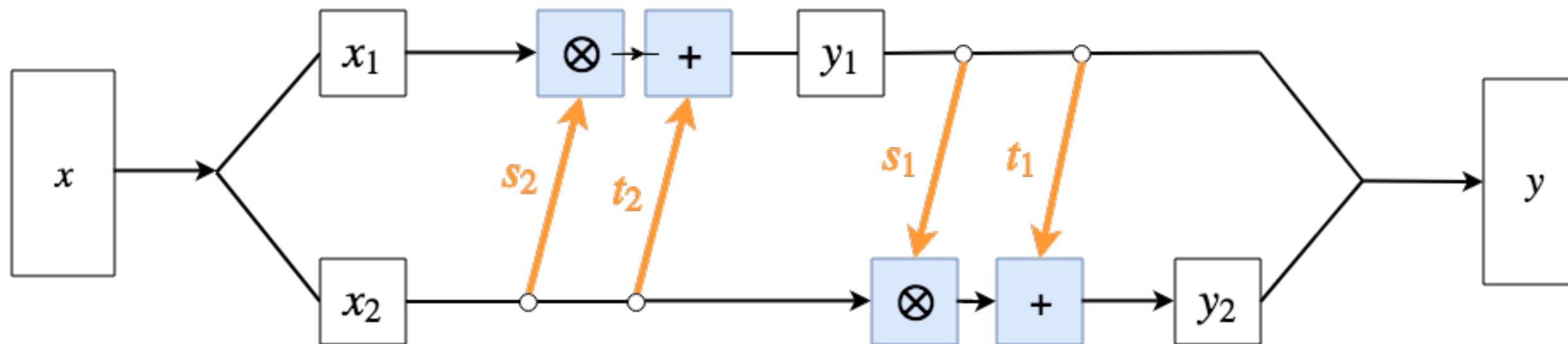
- How do we formulate the inverse process in such a way as to make it well-defined?
 - Introduce a latent space, z , which contains the information lost in the forward process



VIA VERITAS VITA

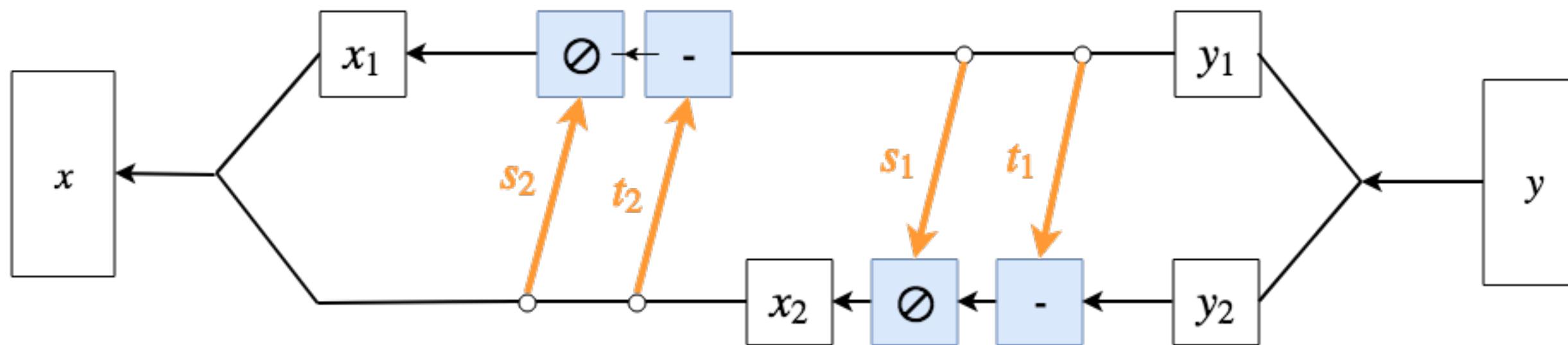
Invertible Neural Networks:

Affine-Coupling Layers



$$y_1 = x_1 \otimes \exp(s_2(x_2)) + t_2(x_2)$$

$$y_2 = x_2 \otimes \exp(s_1(y_1)) + t_1(y_1)$$



$$x_2 = (y_2 - t_1(y_1)) \otimes \exp(s_1(y_1))$$

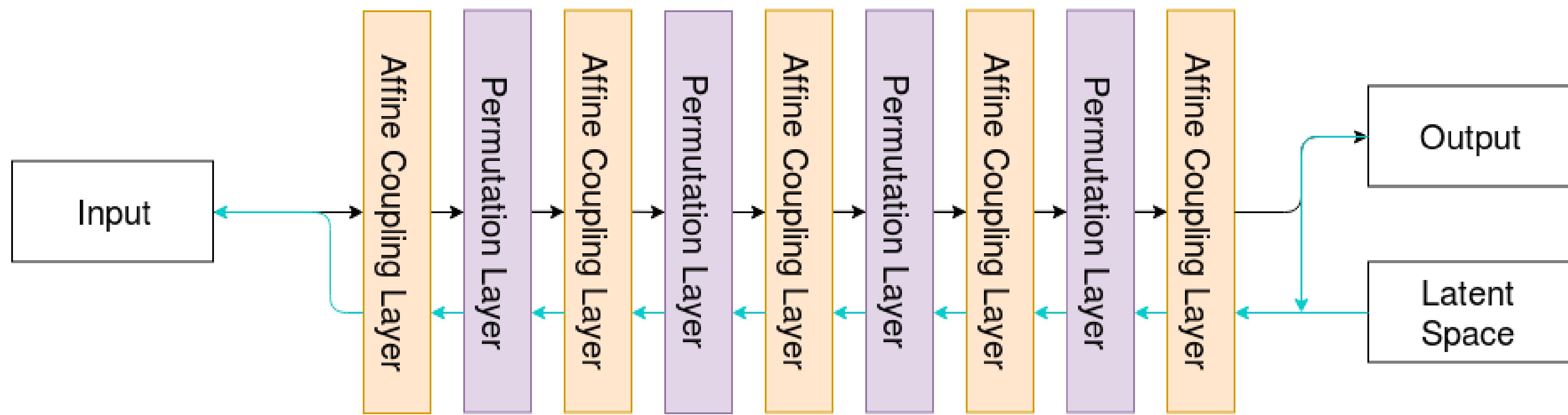
$$x_1 = (y_1 - t_2(x_2)) \otimes \exp(s_2(x_2))$$

See Dinh+ 2014, 2017 & Ardizzone 2018 for more details



Invertible Neural Networks:

Architecture

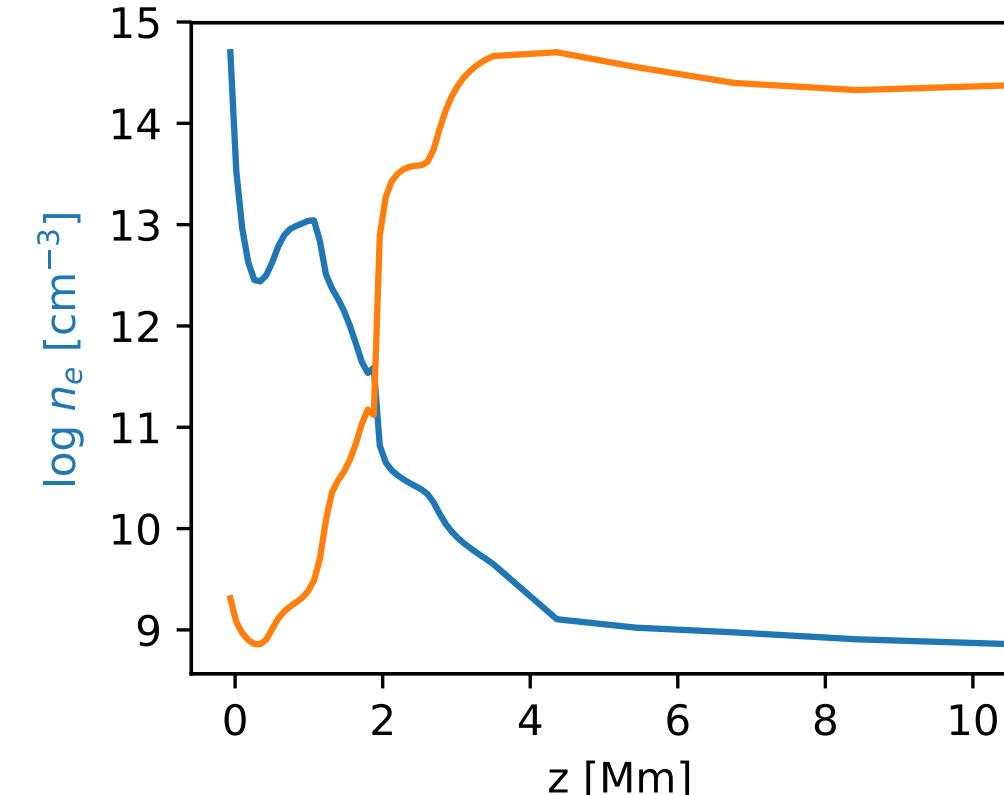


- We use the F-CHROMA RADYN grid for training data
 - available here: <https://star.pst.qub.ac.uk/wiki/doku.php/public/solarmodels/start>
- Each simulation has 500 timesteps
- We extract H α and Ca II $\lambda 8542$ line profiles as well as temperature, velocity and density profiles from each timestep of each simulation
- This gives us >40000 pairs of spectral lines to learn our inversions from
- Each pair of lines has corresponding atmospheric parameters
- Using any less than 2 lines doesn't work

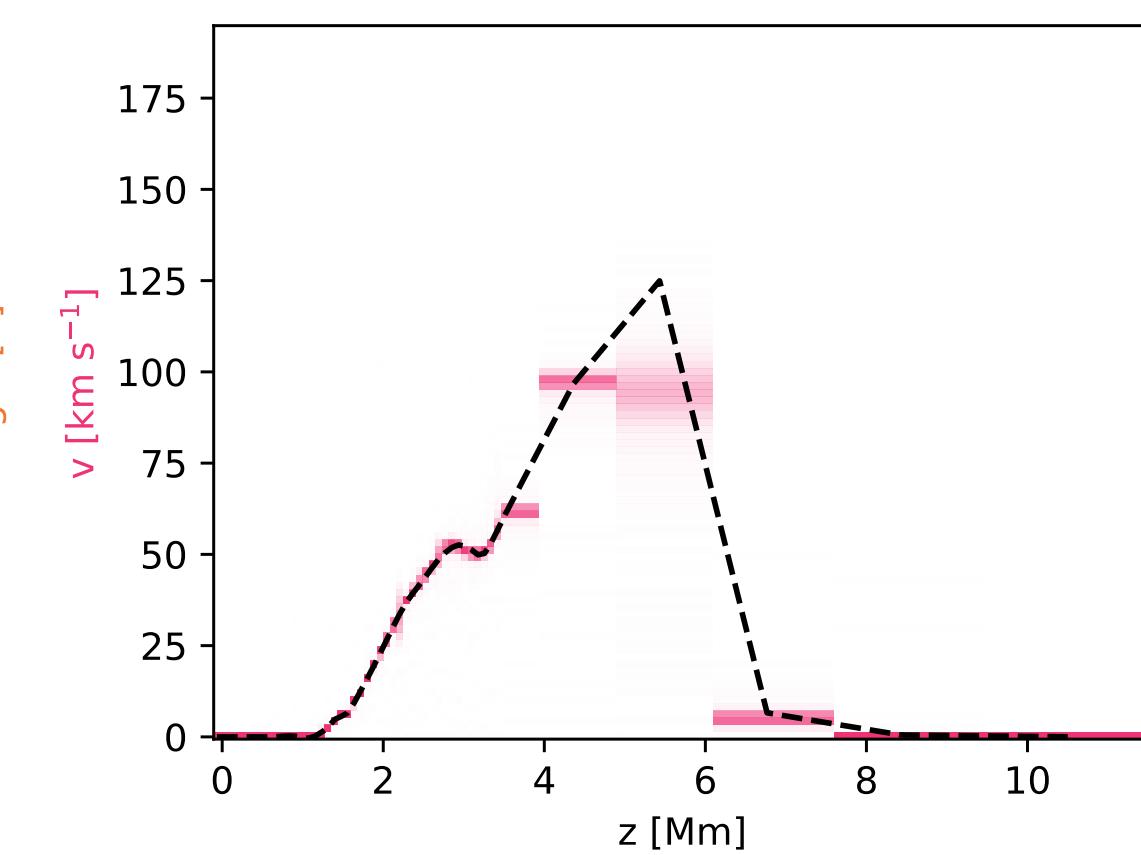
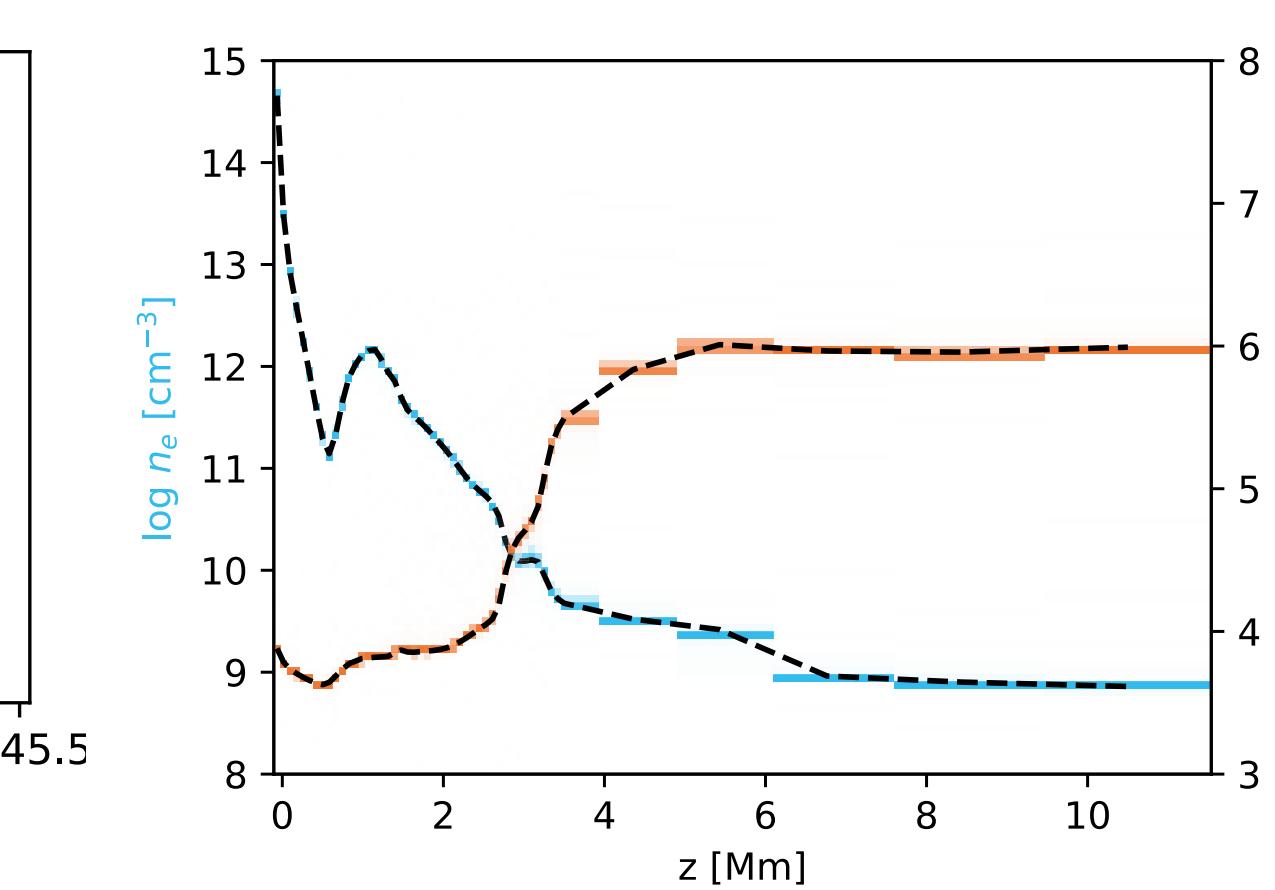
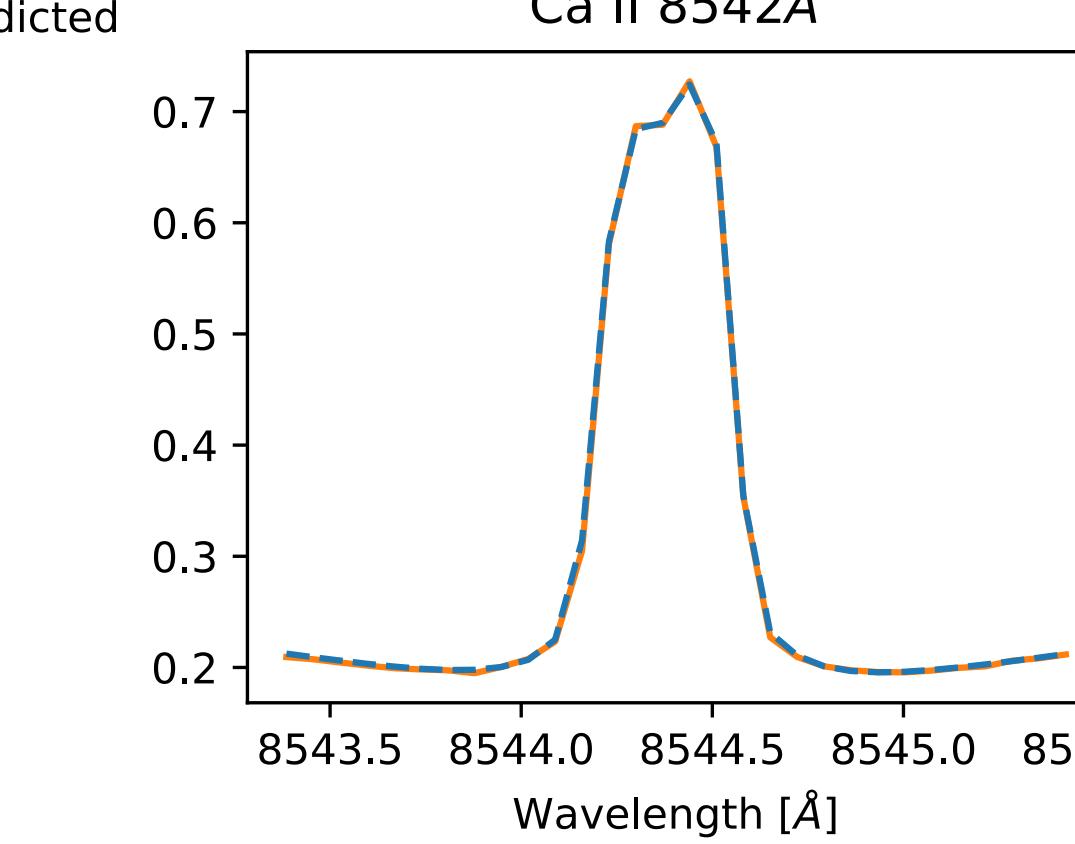
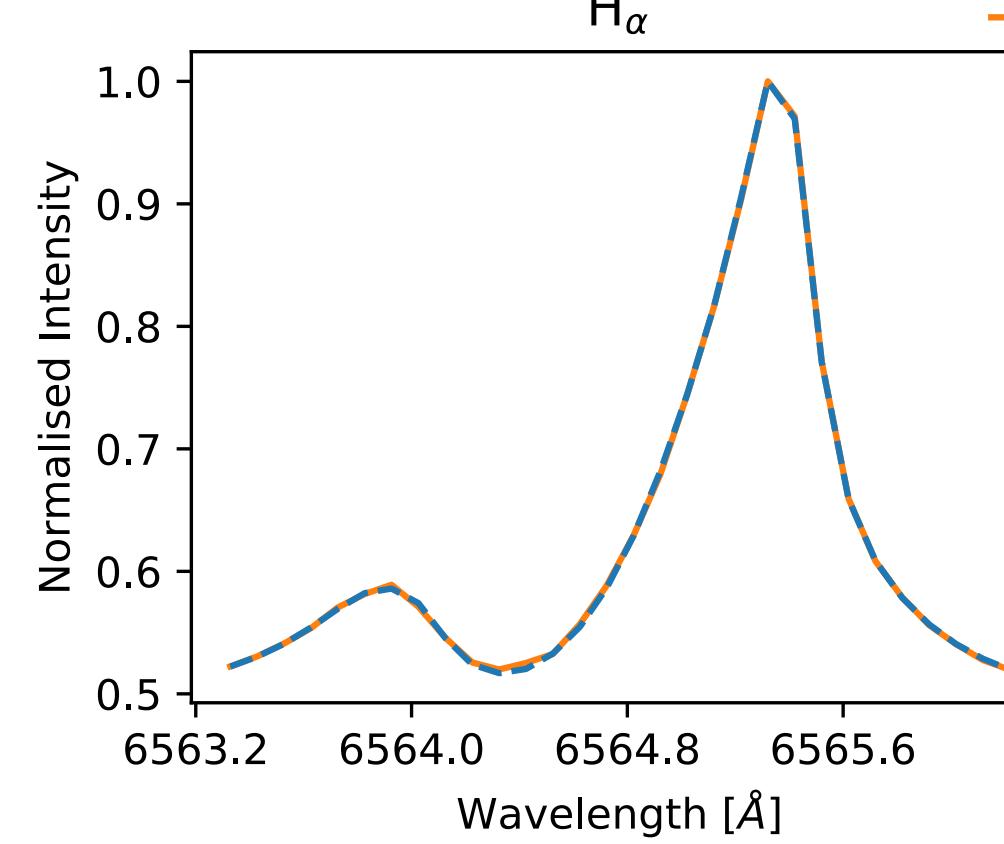
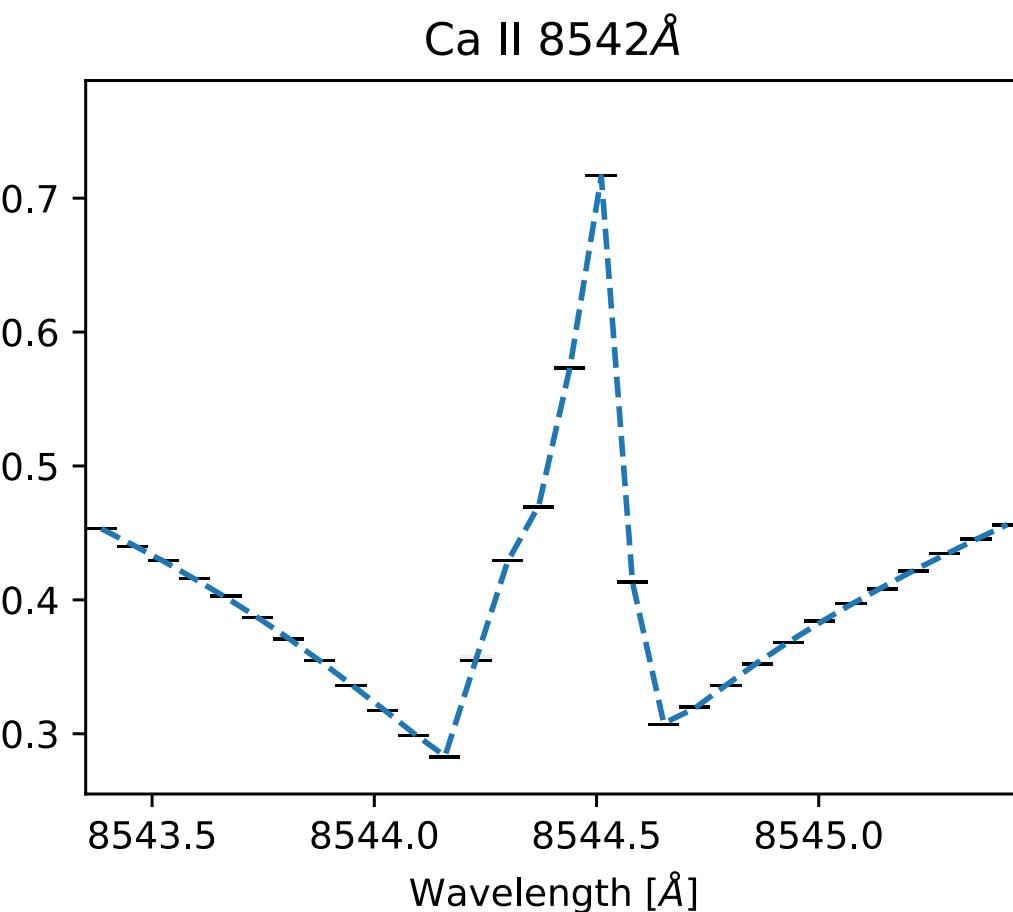
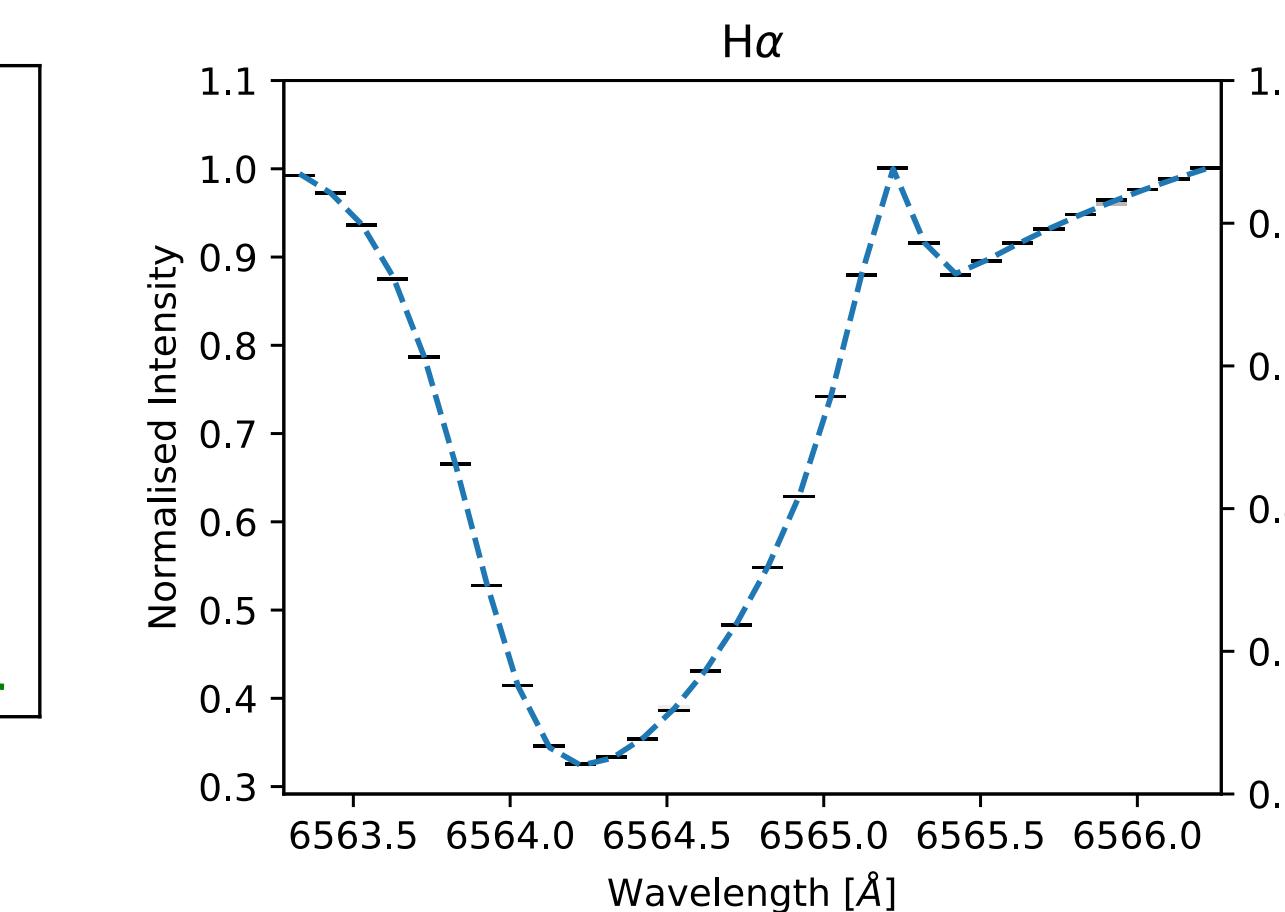
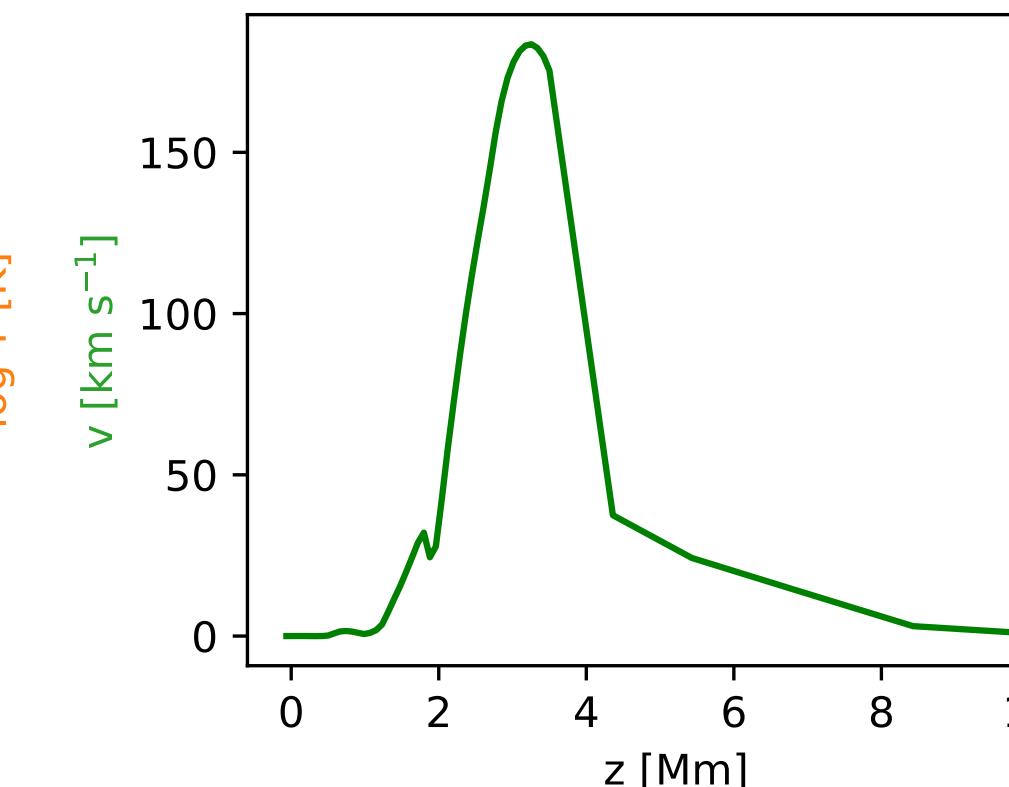


RADYNVERSION:

Validation



— Ground Truth
— Predicted



Forward Model Test

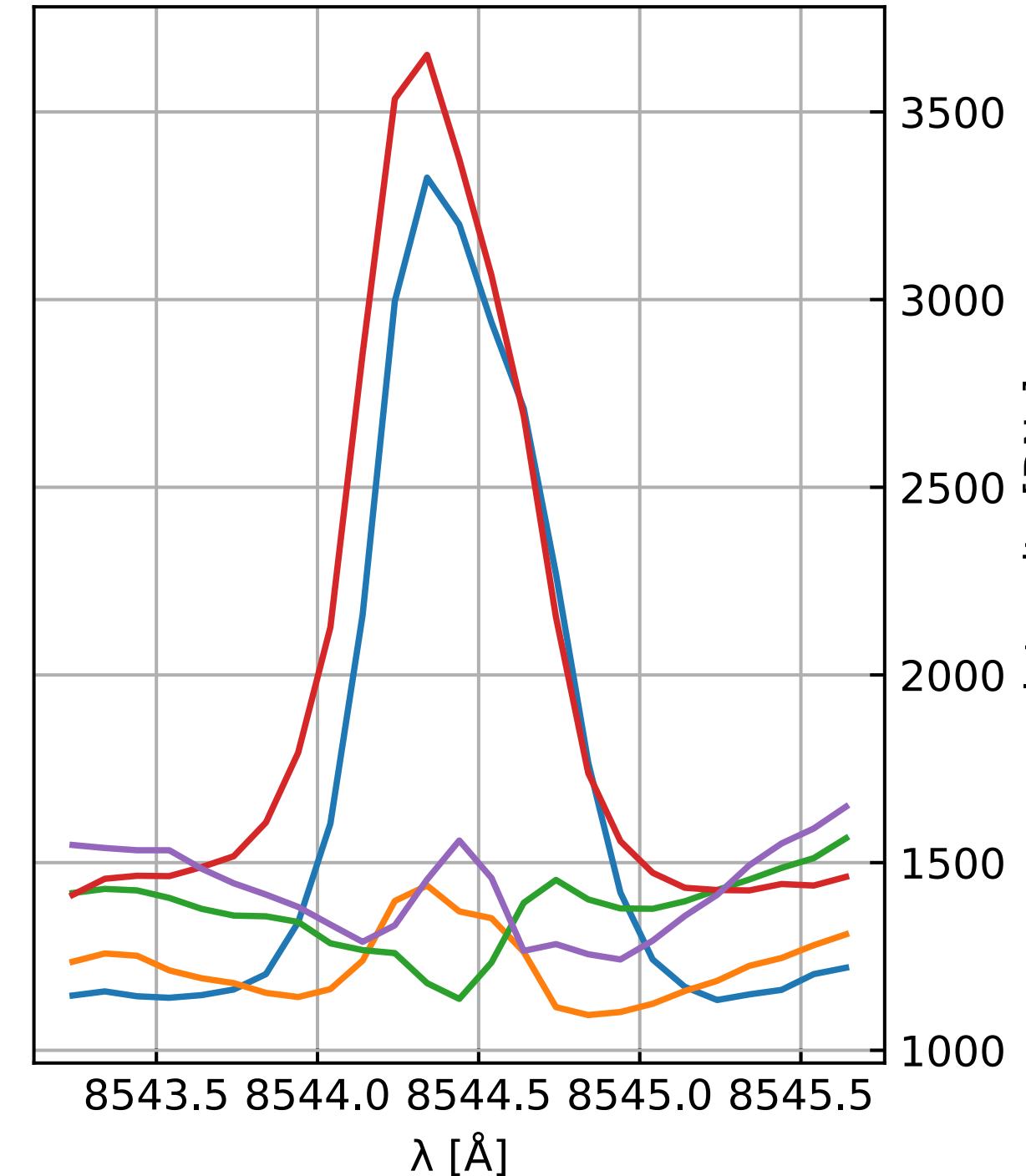
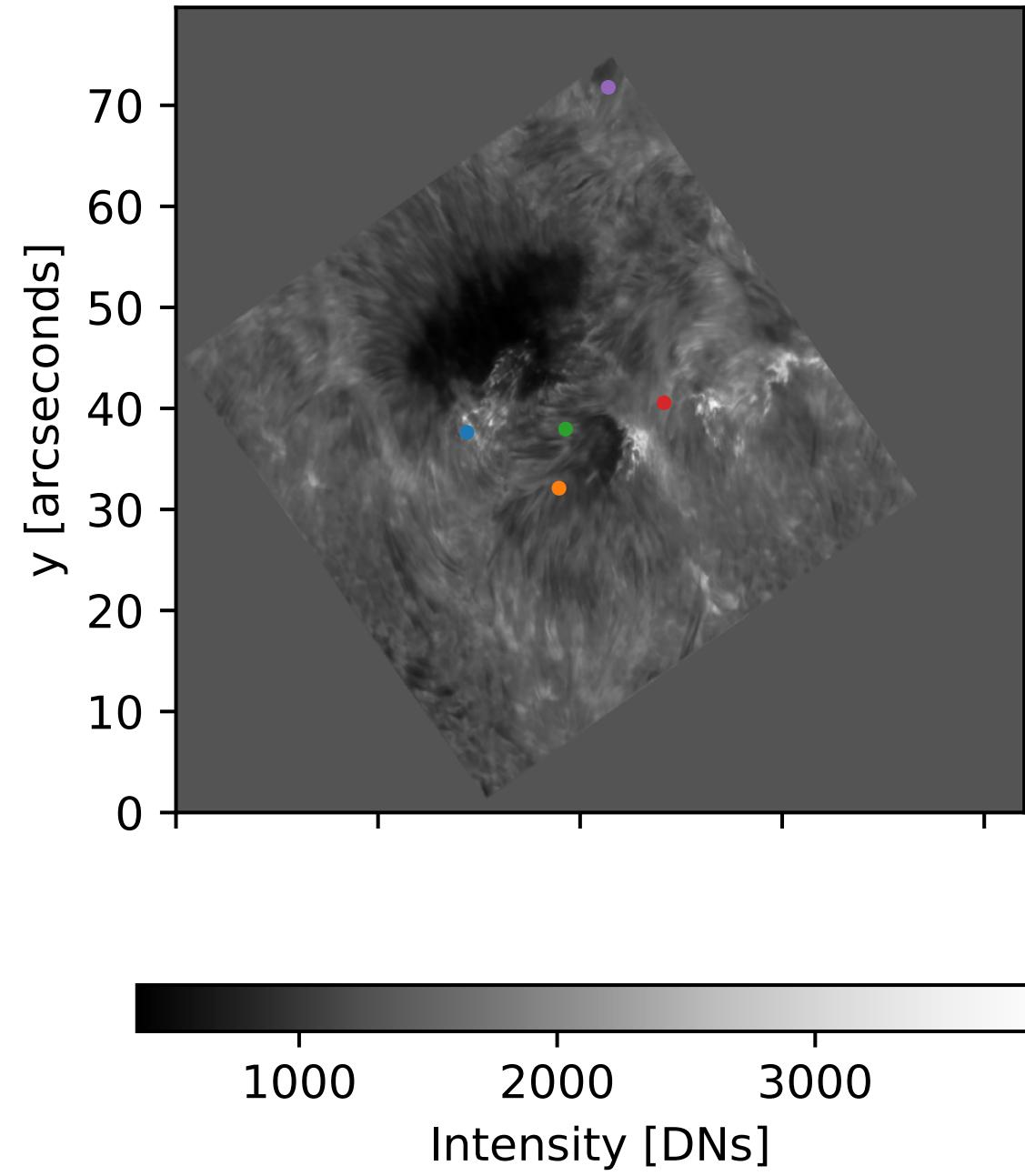
Inversion Test



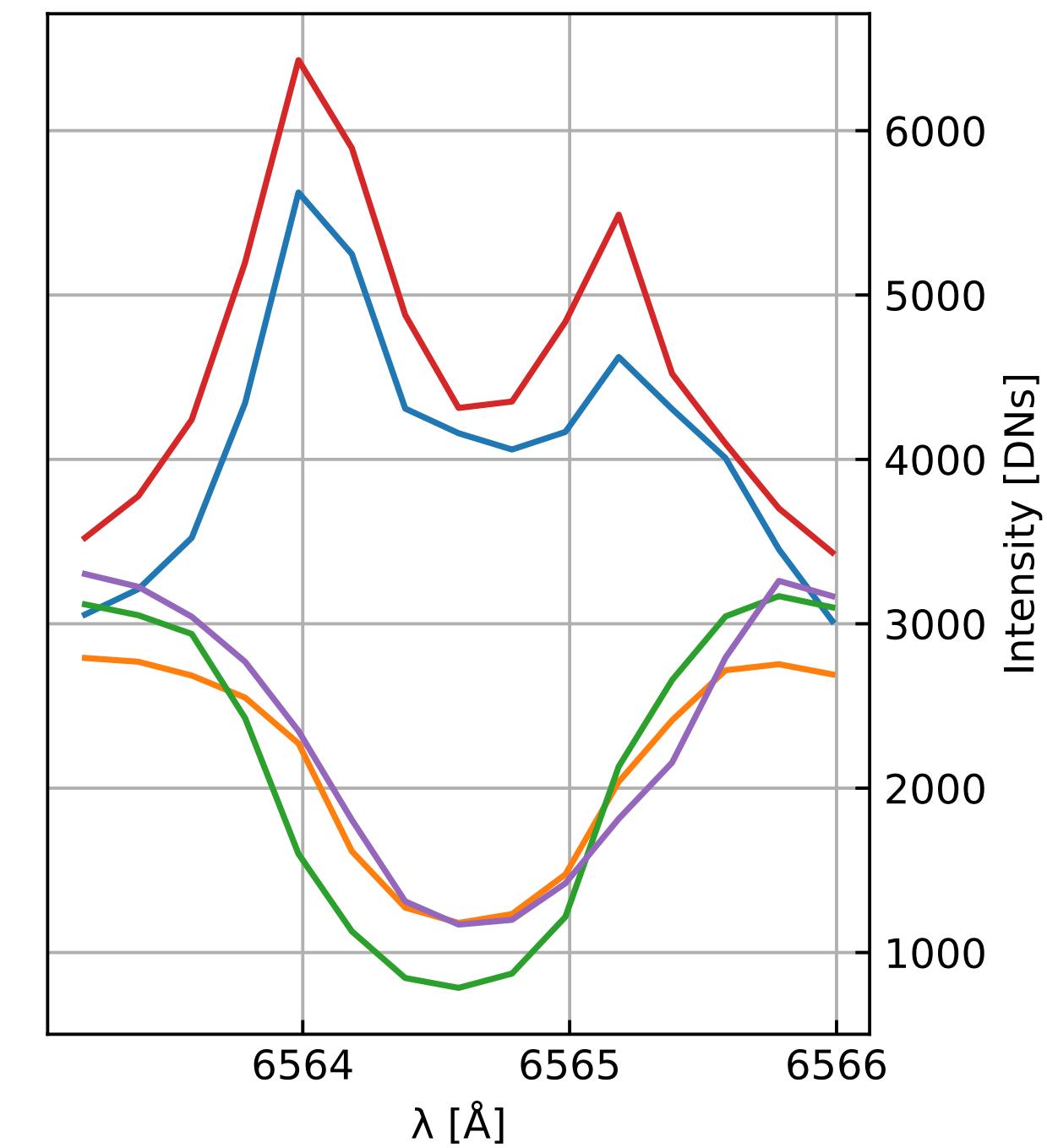
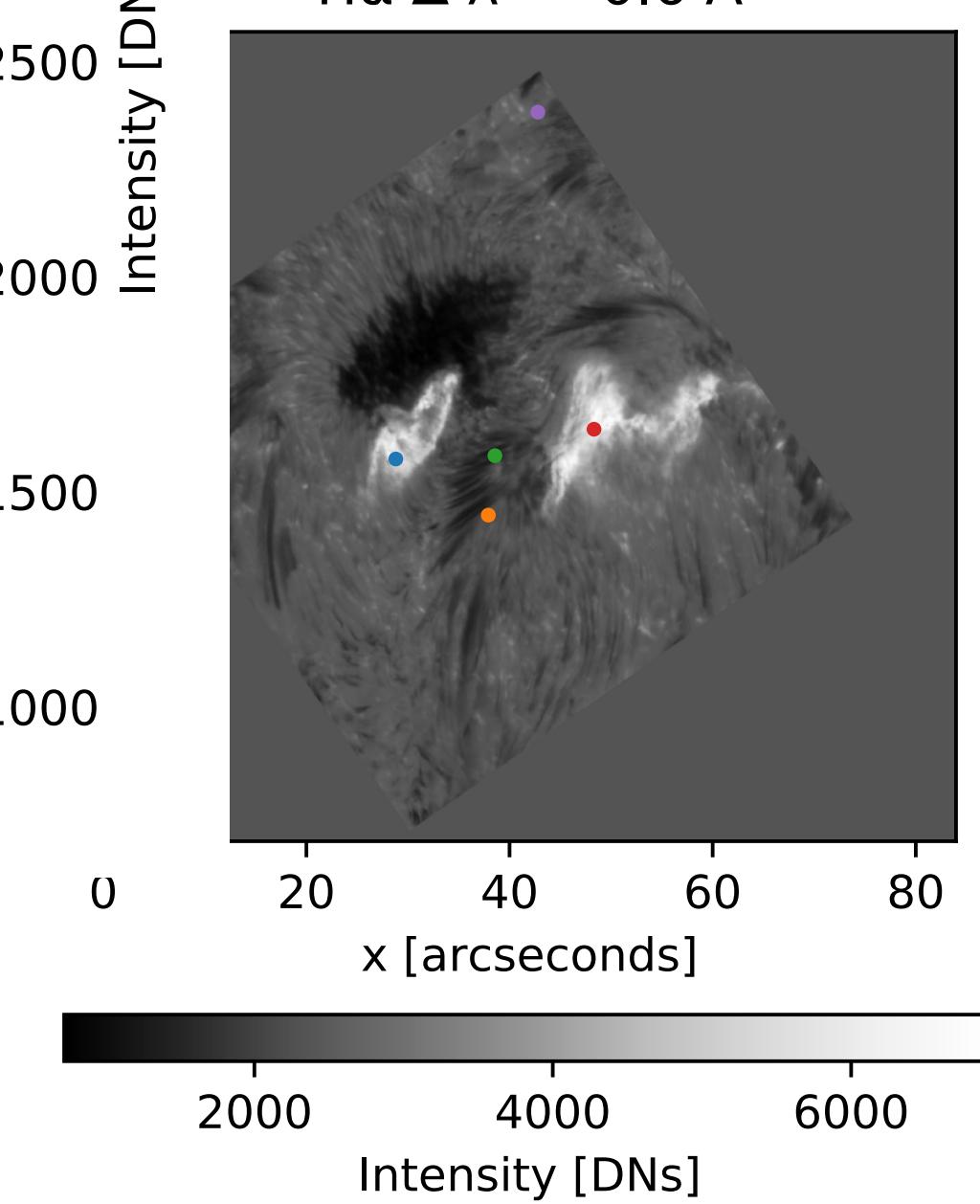
RADYNVERSION:

Application to Real Data

Ca II $\lambda 8542 \Delta \lambda = 0.4 \text{ \AA}$

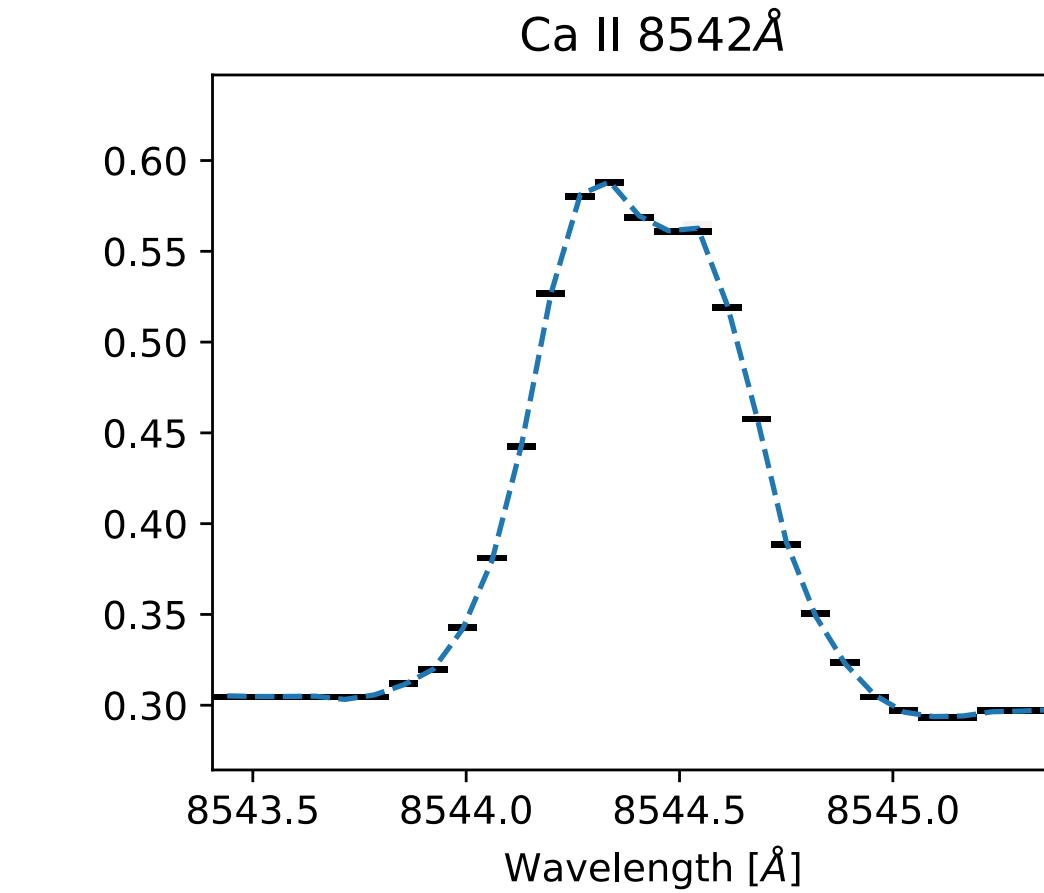
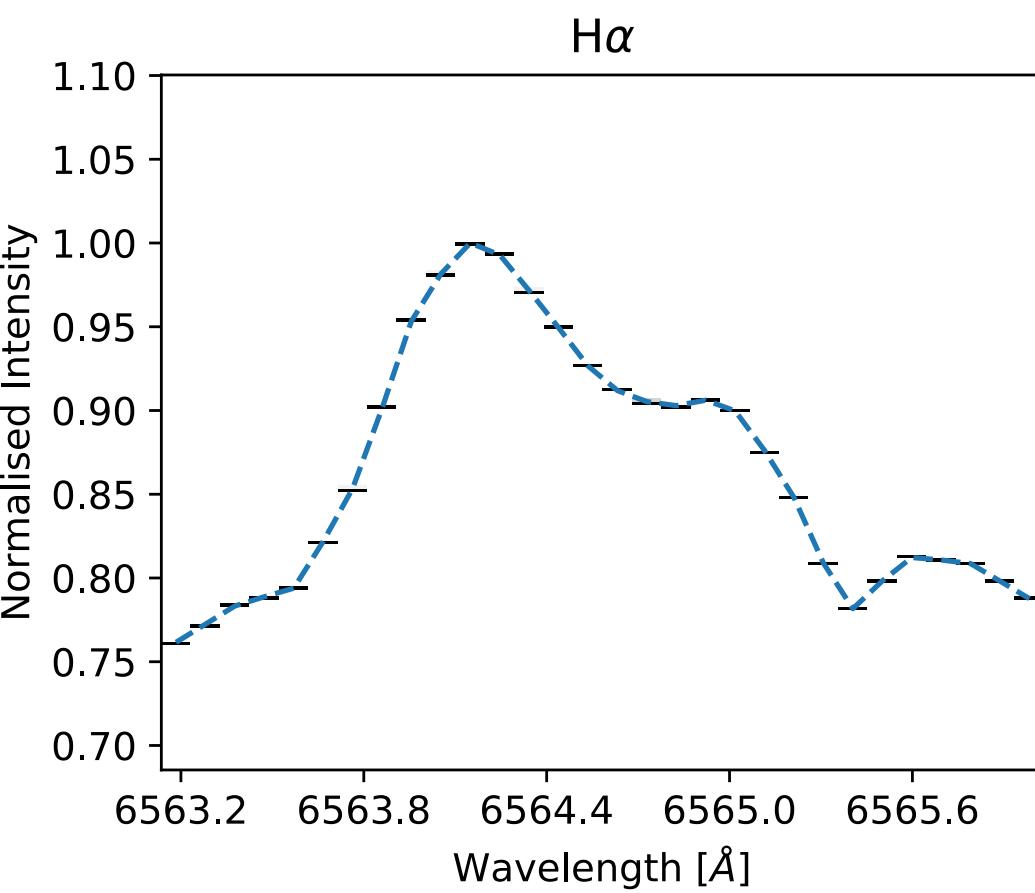
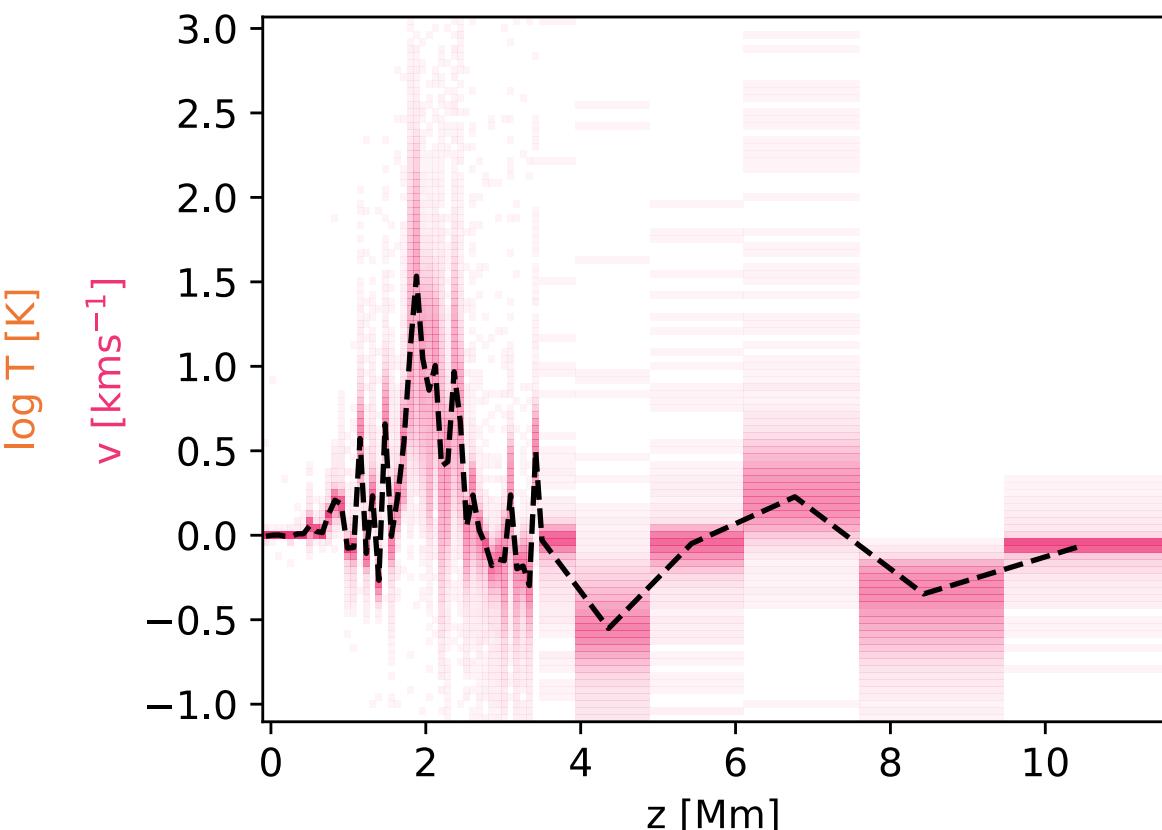
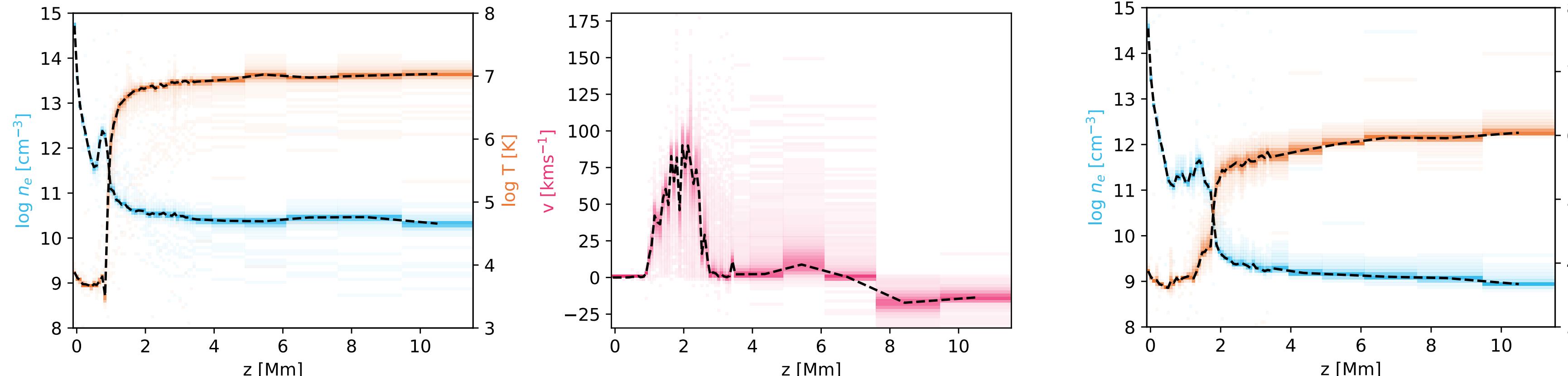
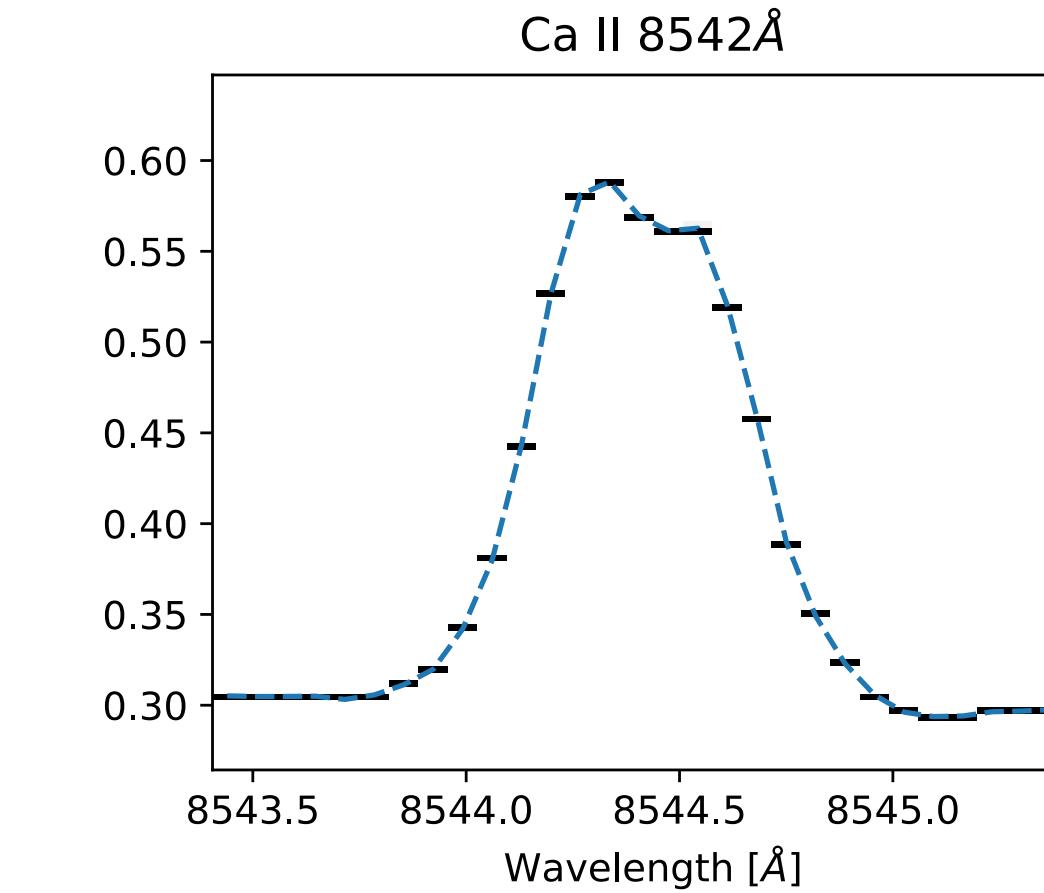
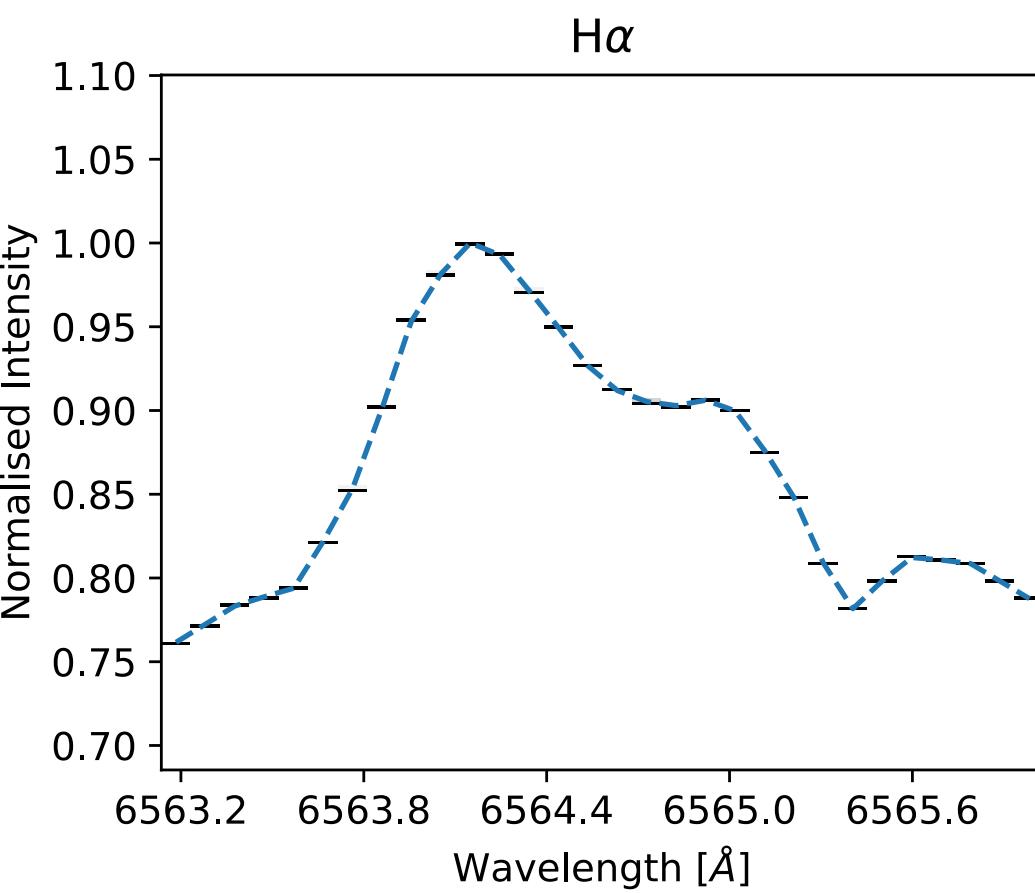
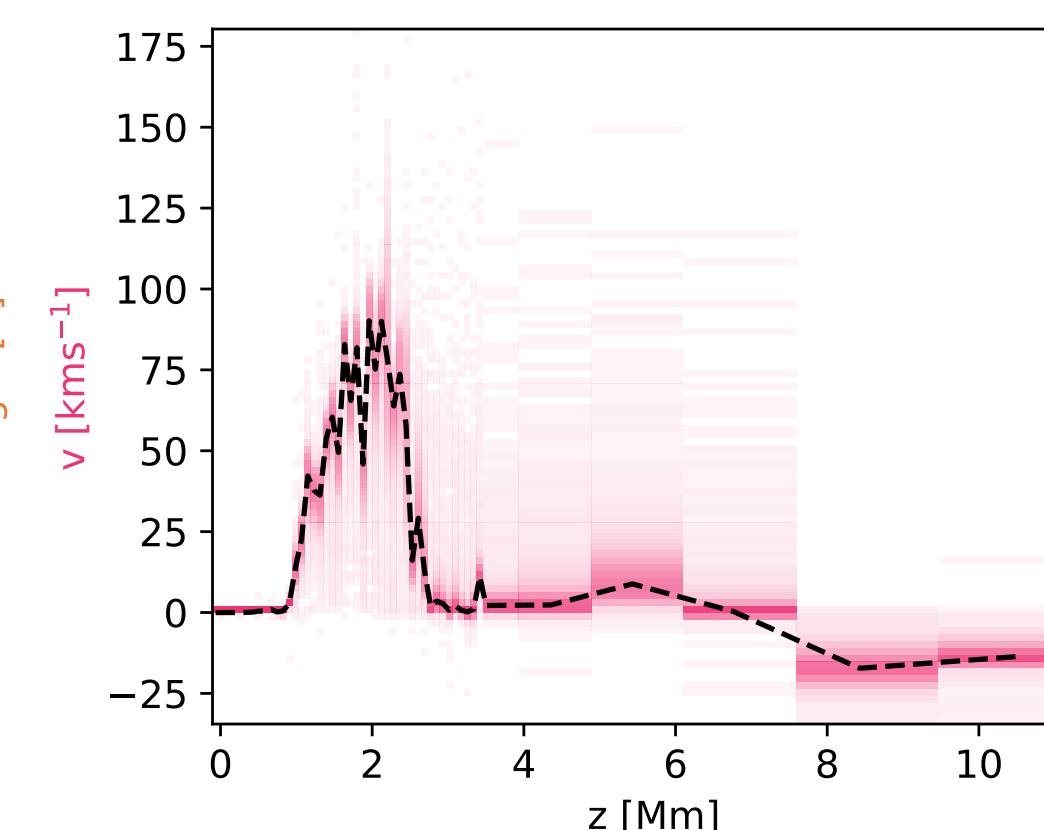
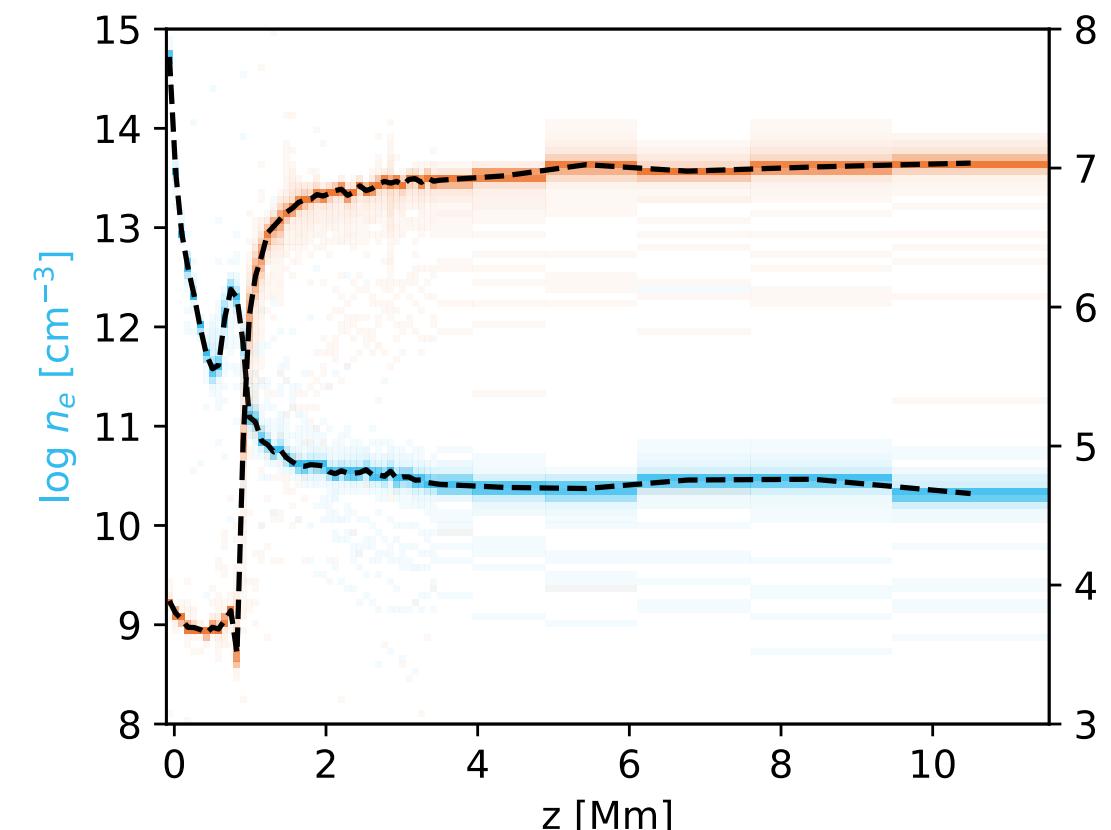


H $\alpha \Delta \lambda = -0.6 \text{ \AA}$



RADYNVERSION:

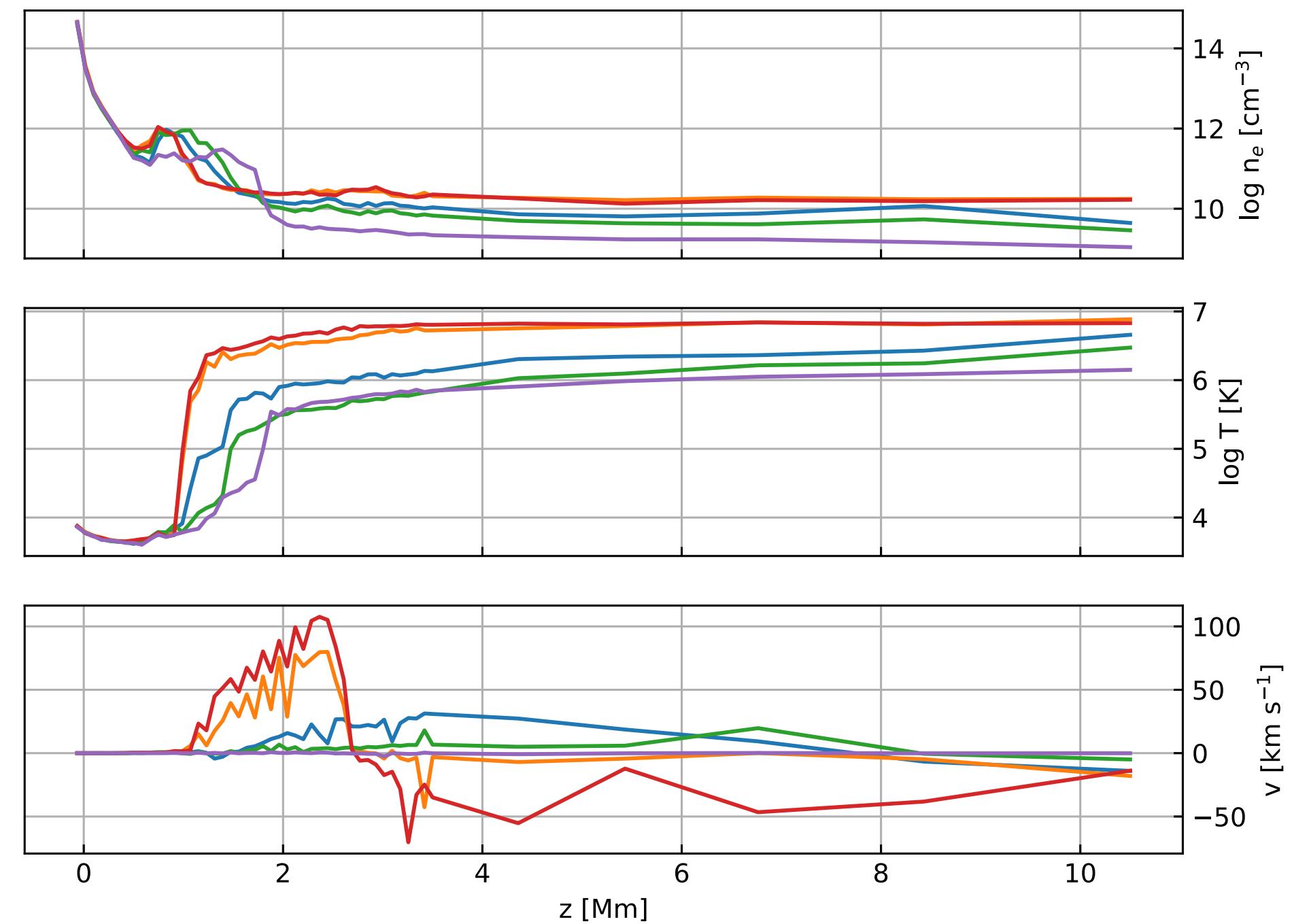
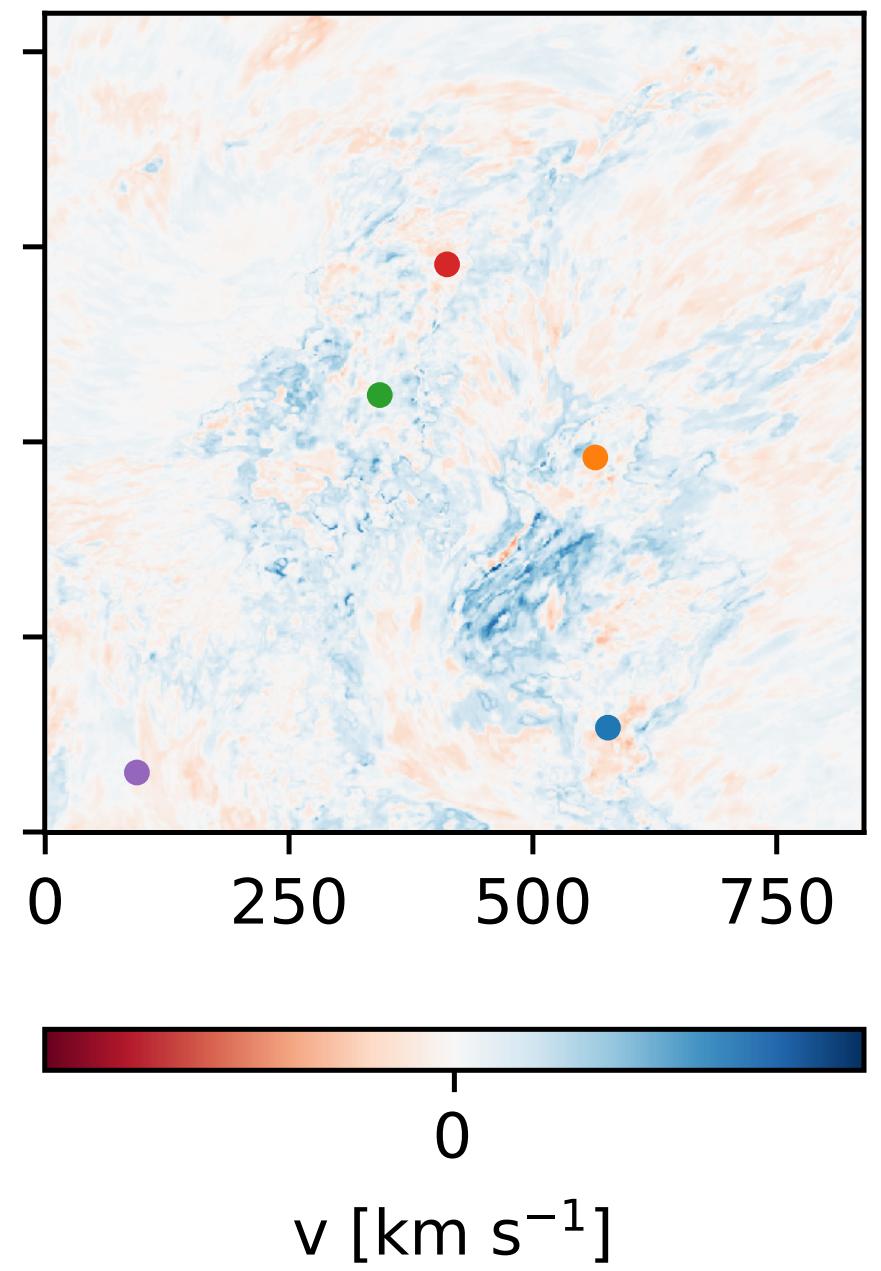
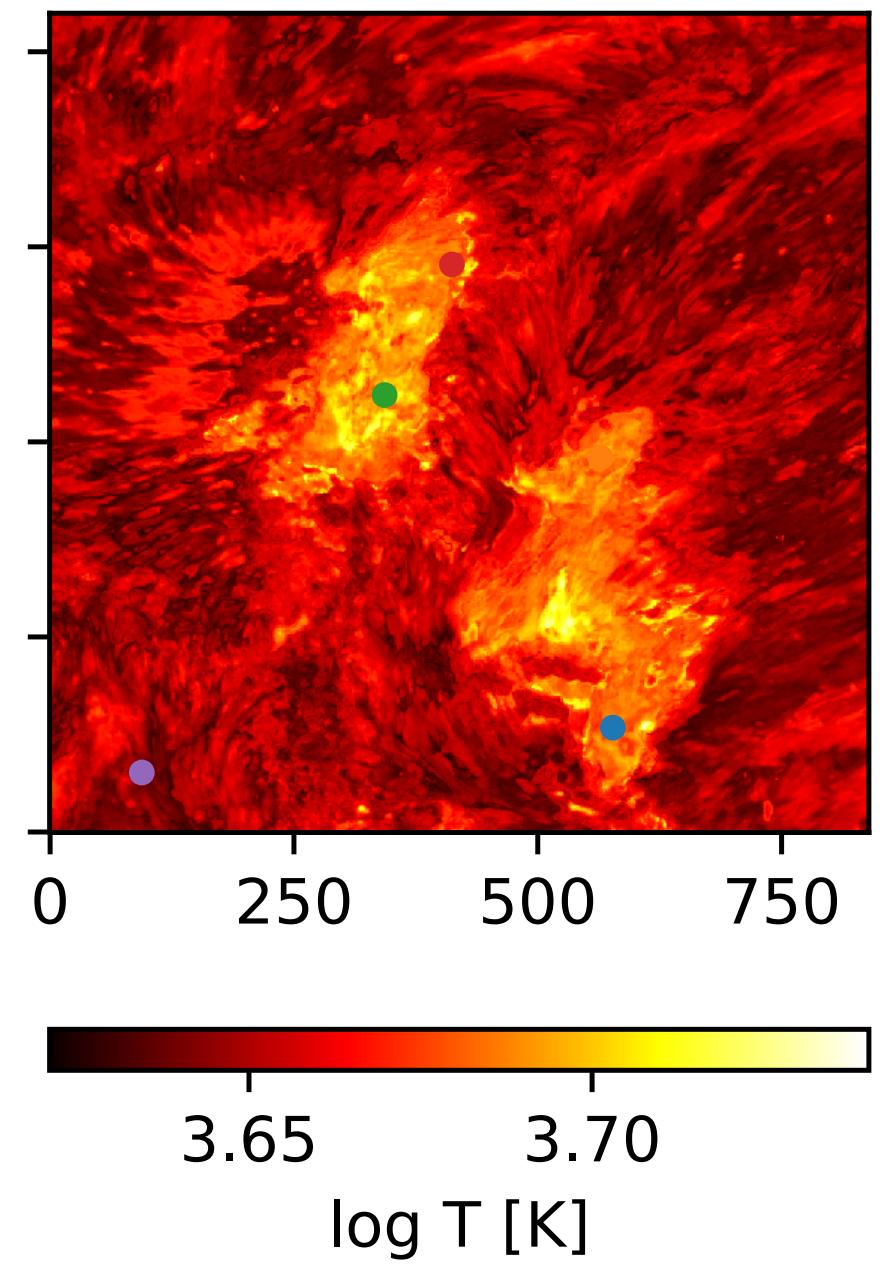
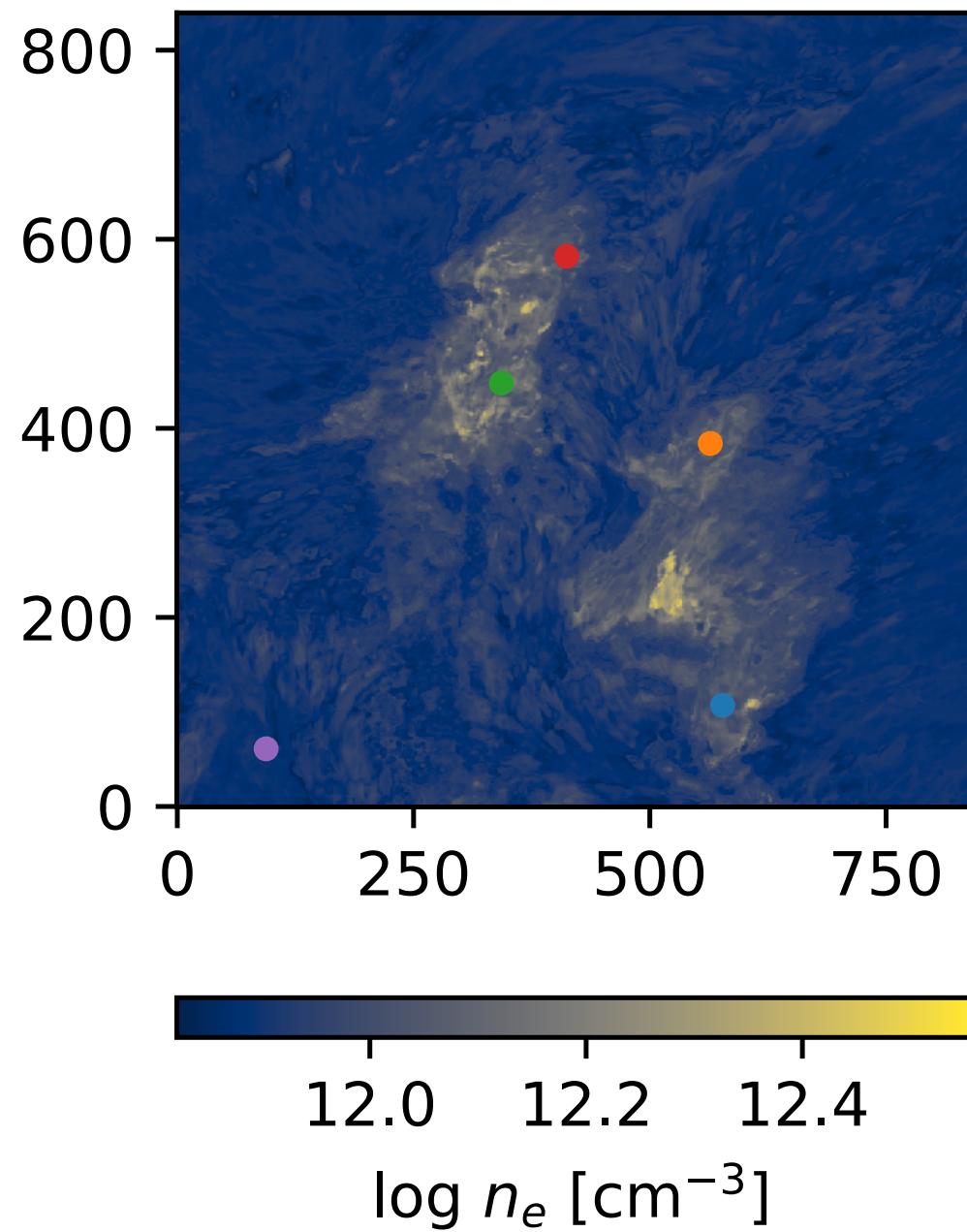
Single Pixel Inversions



RADYNVERSION:

Whole Image Inversions 1

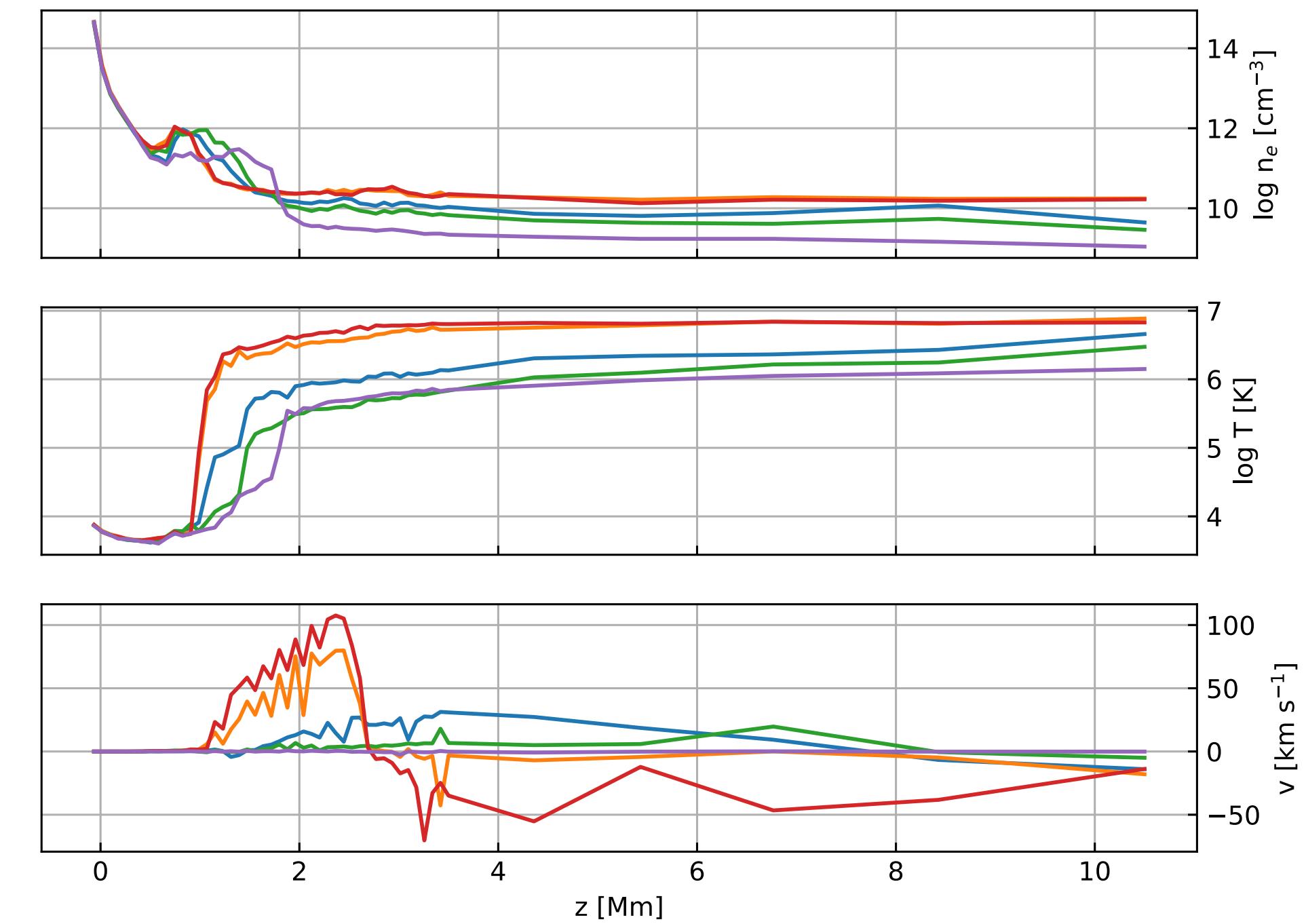
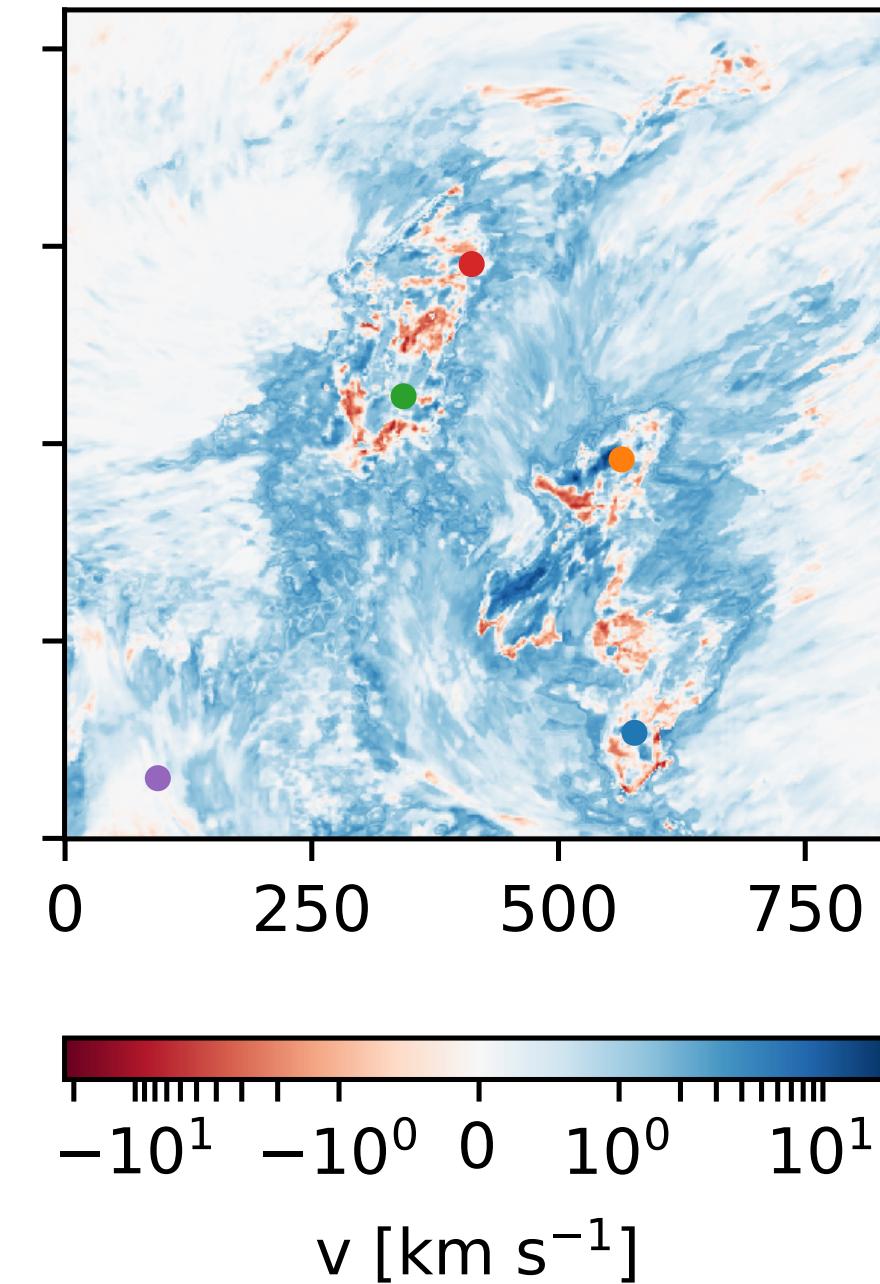
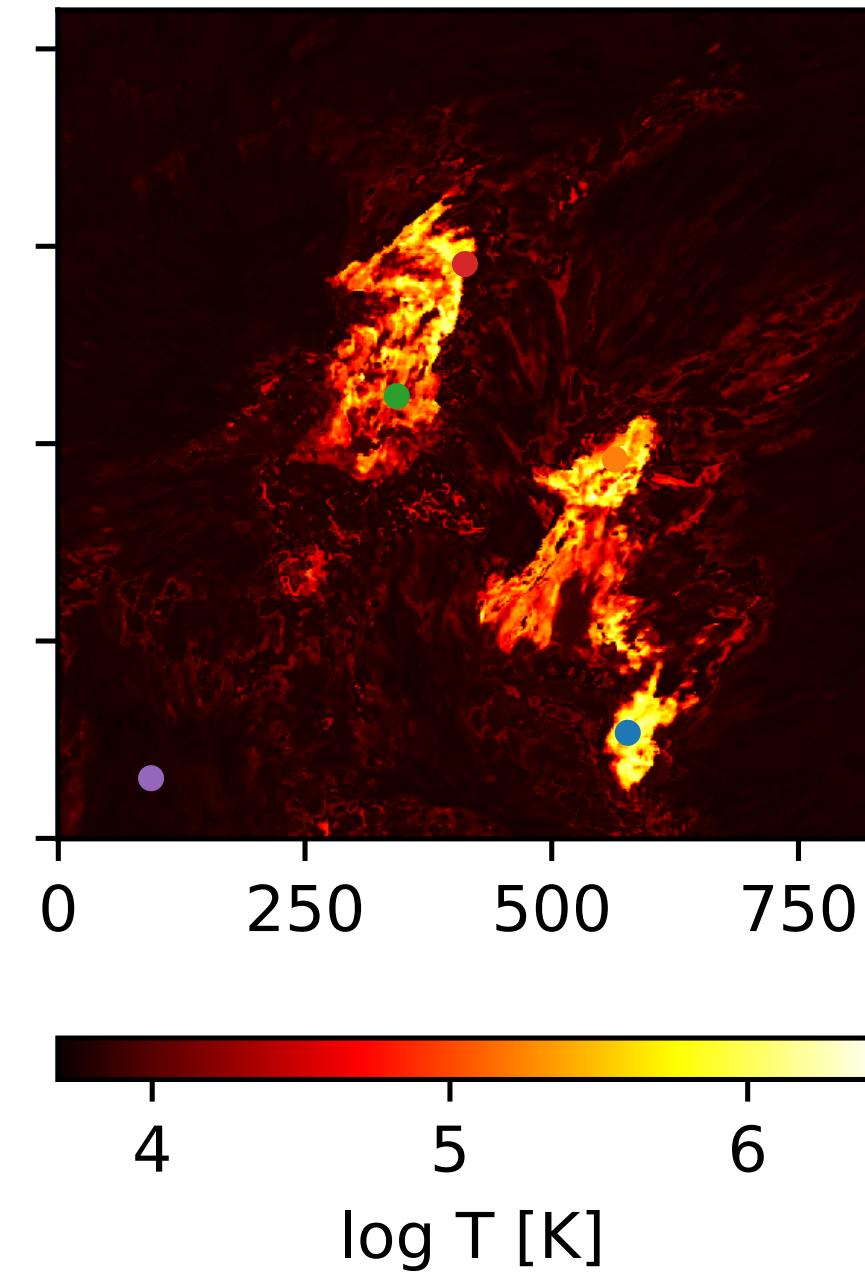
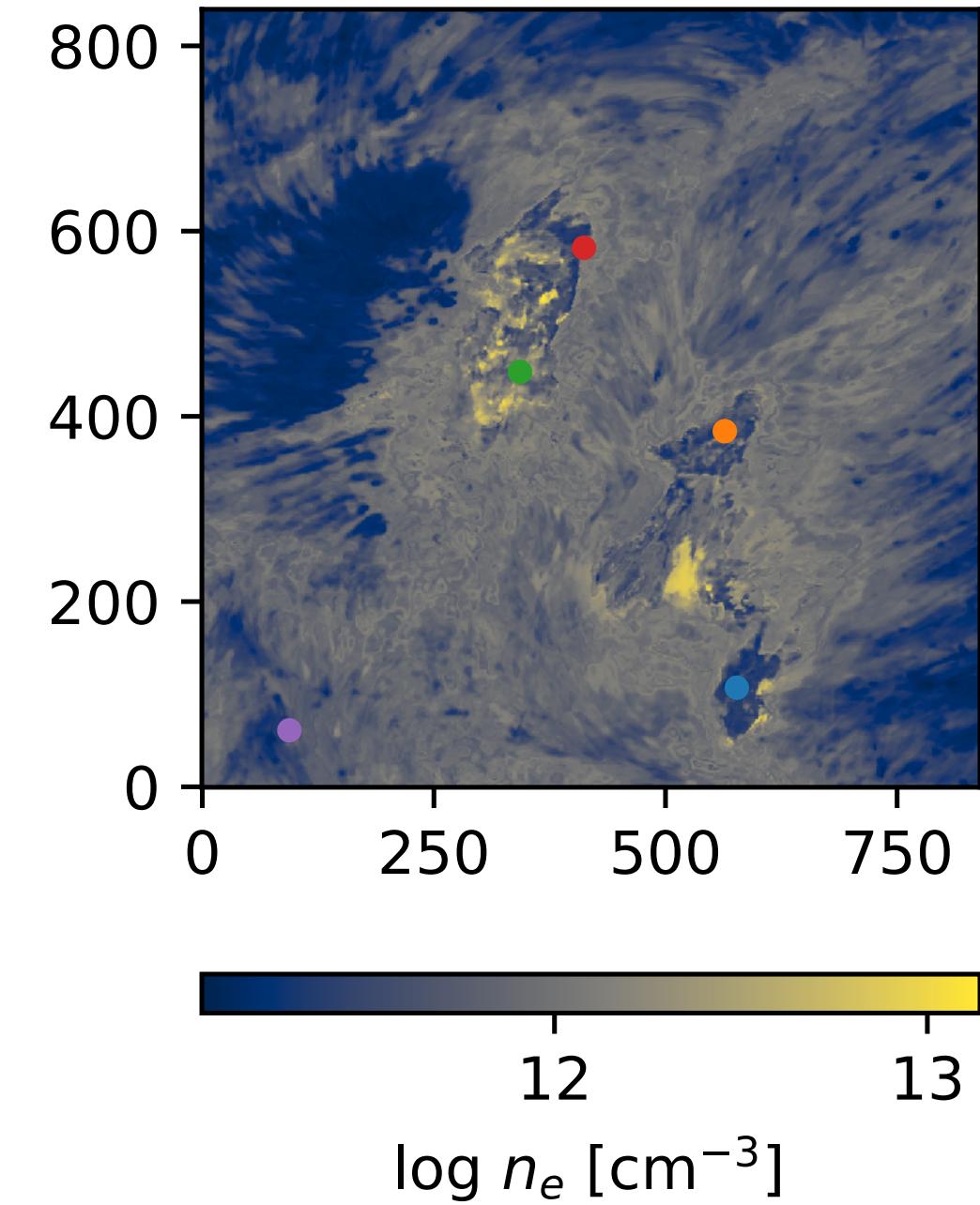
17:10:41 $z = 0.34\text{Mm}$



RADYNVERSION:

Whole Image Inversions 2

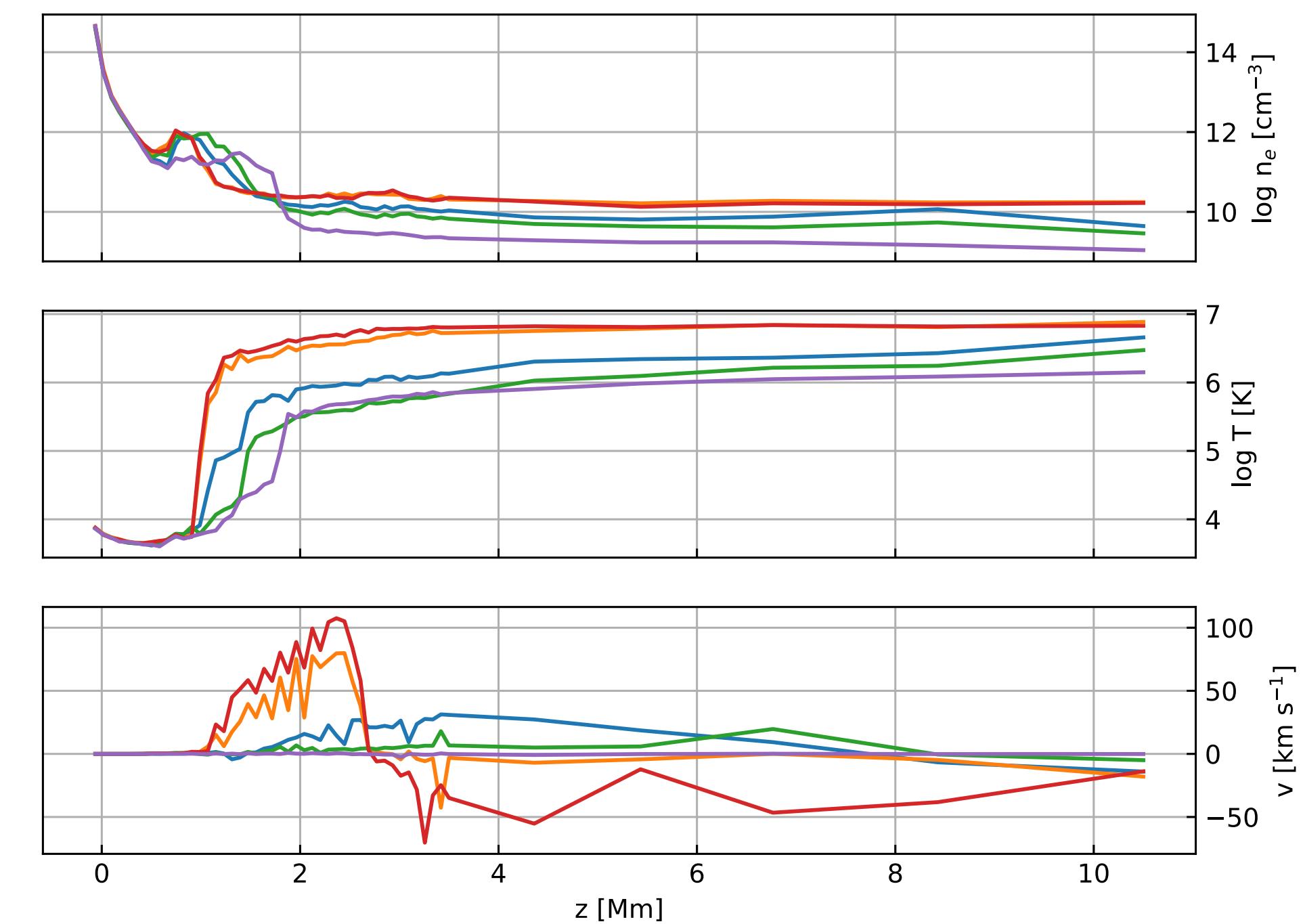
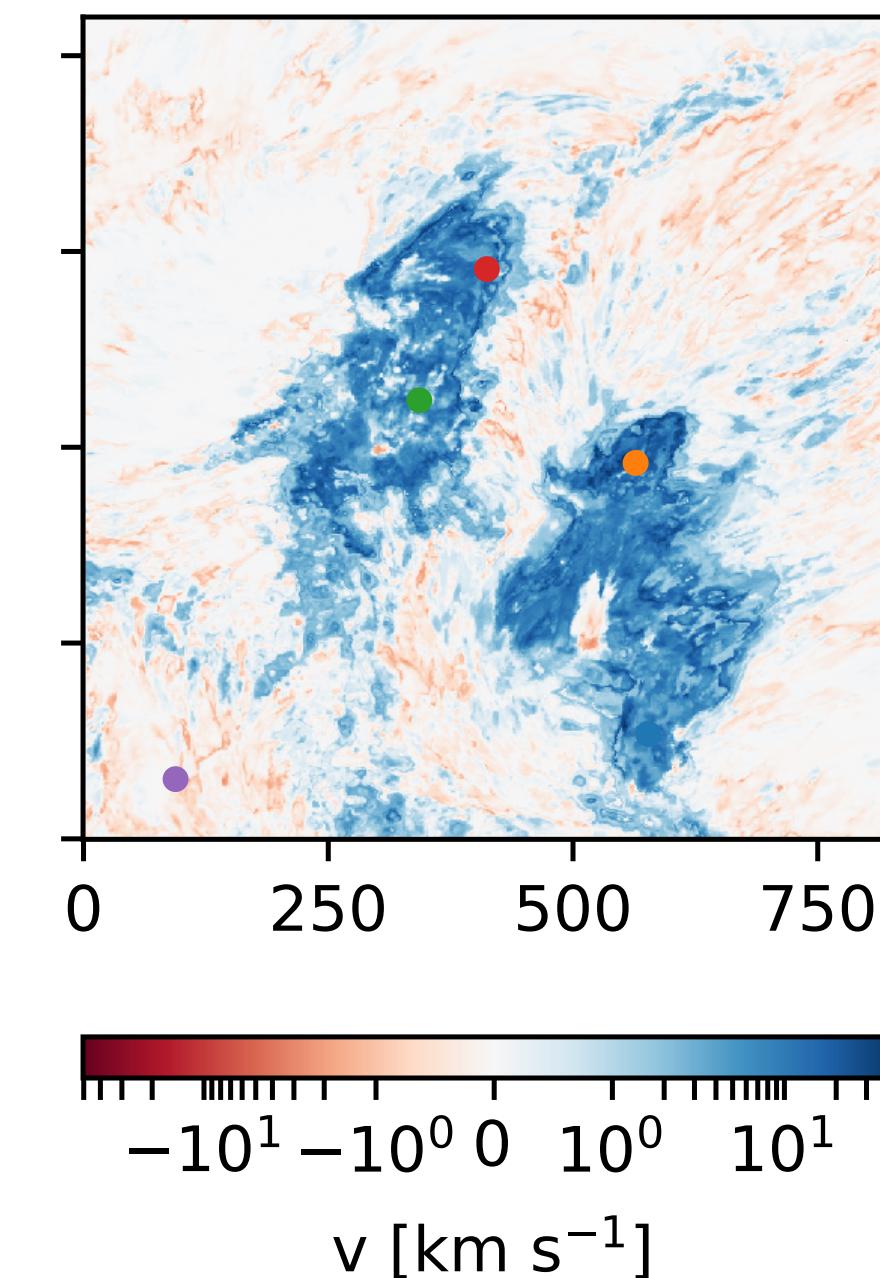
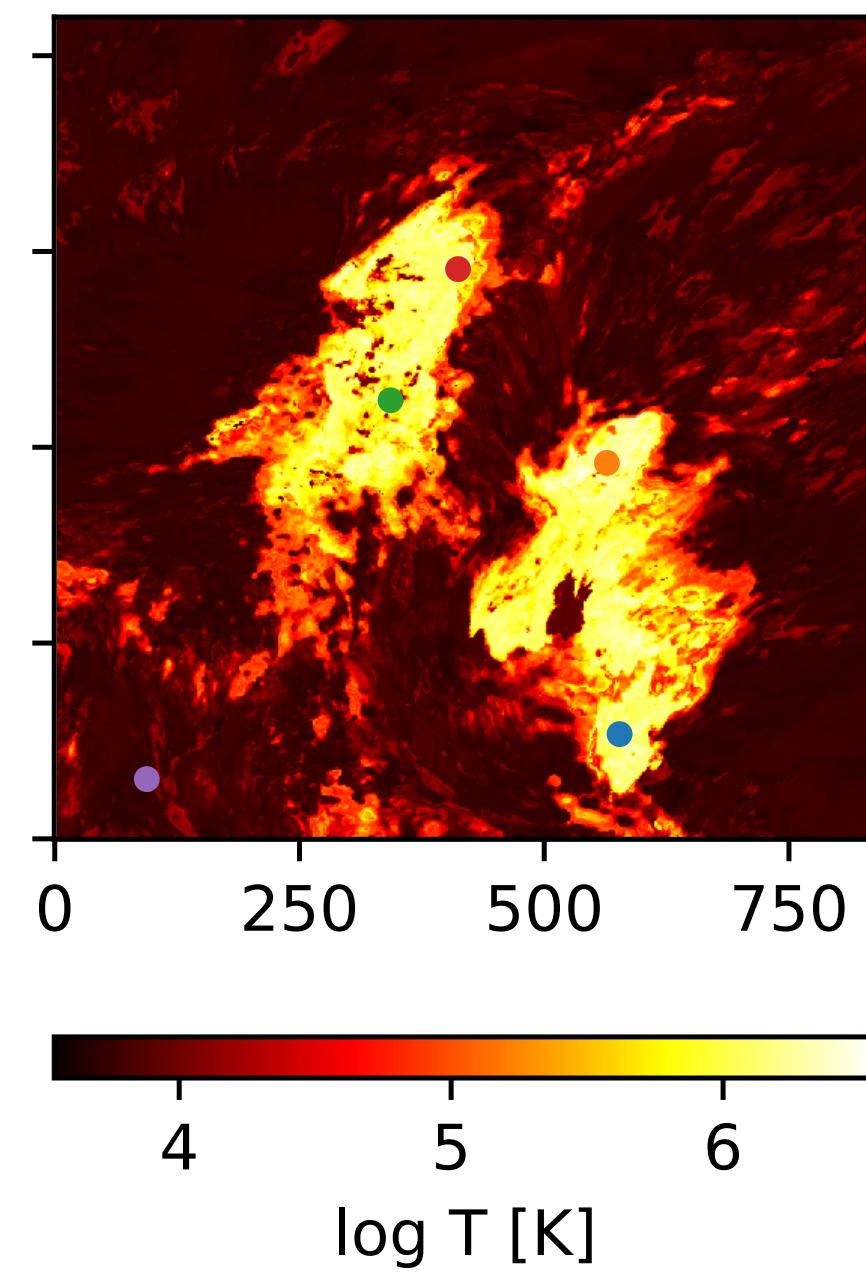
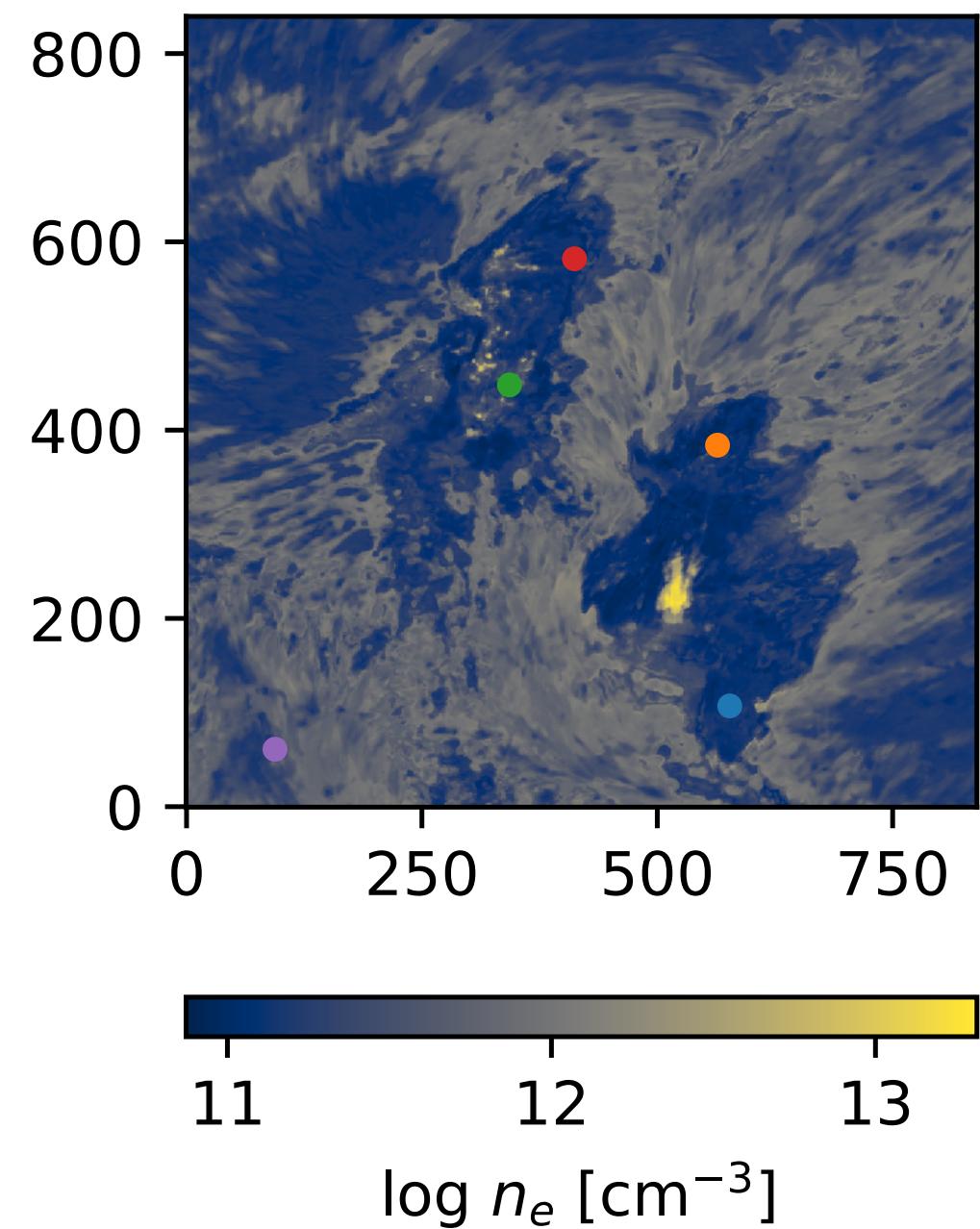
17:10:41 $z = 0.91\text{Mm}$



RADYNVERSION:

Whole Image Inversions 3

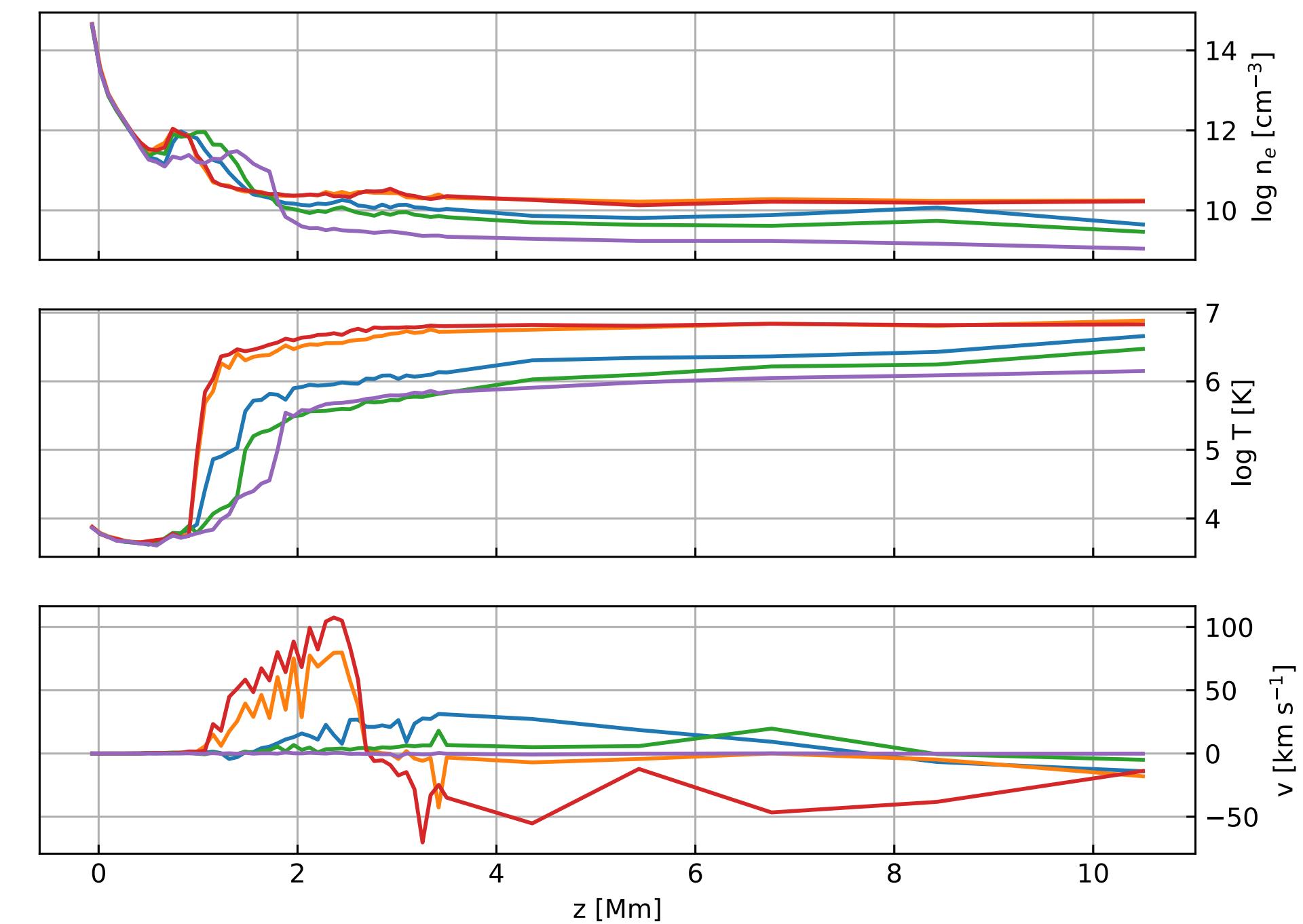
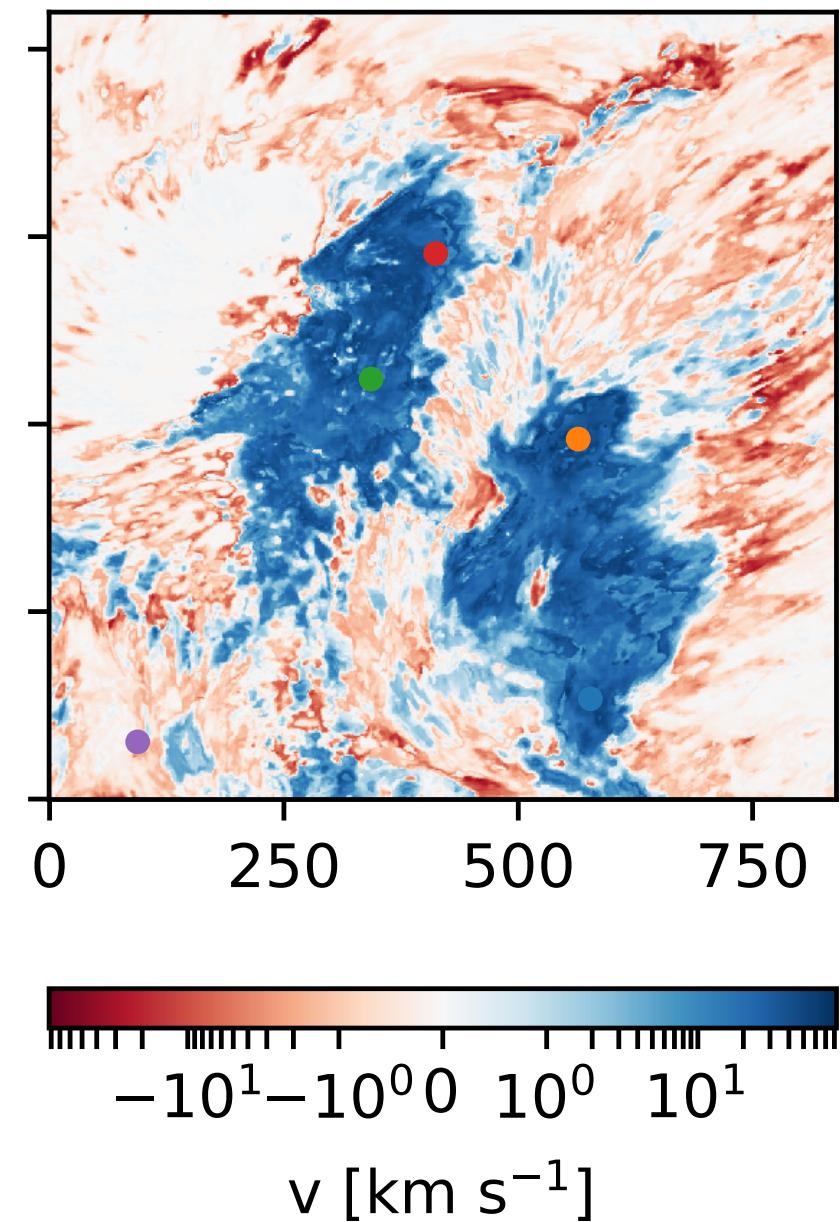
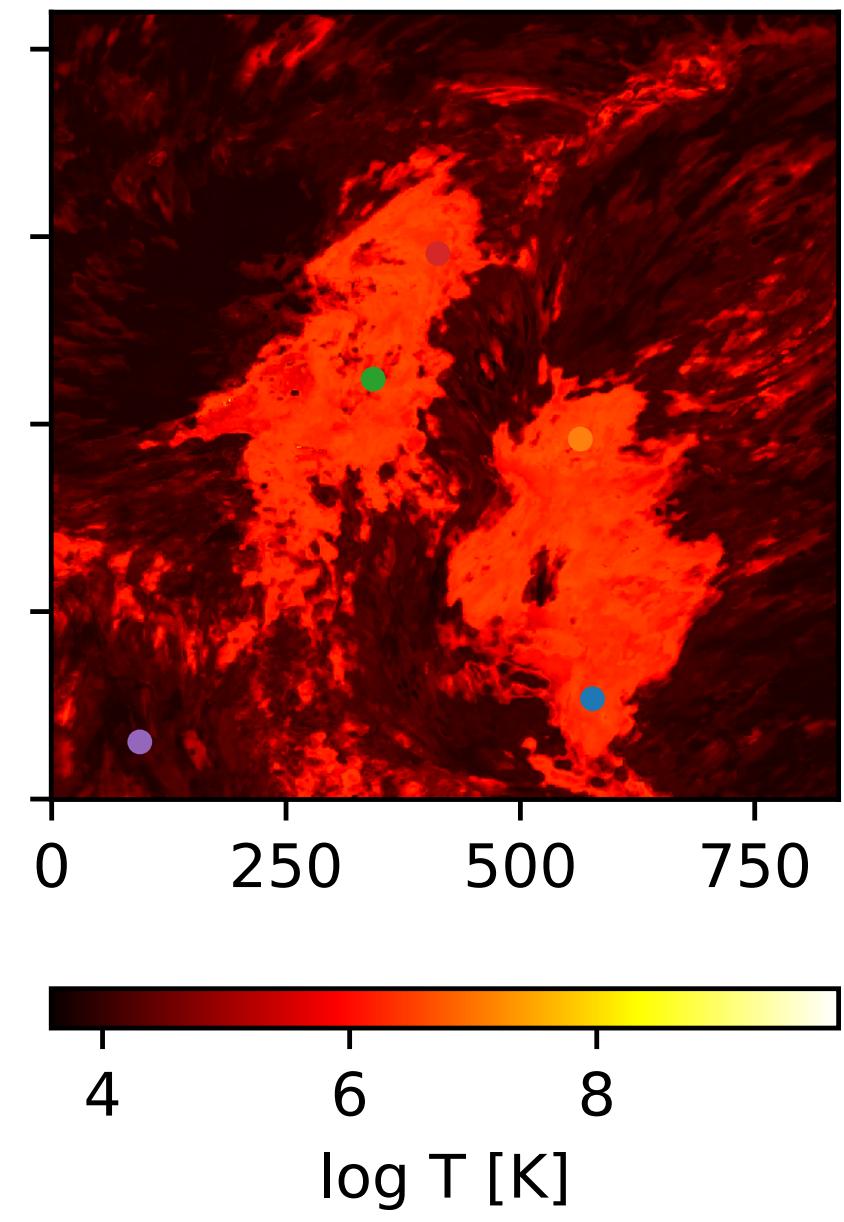
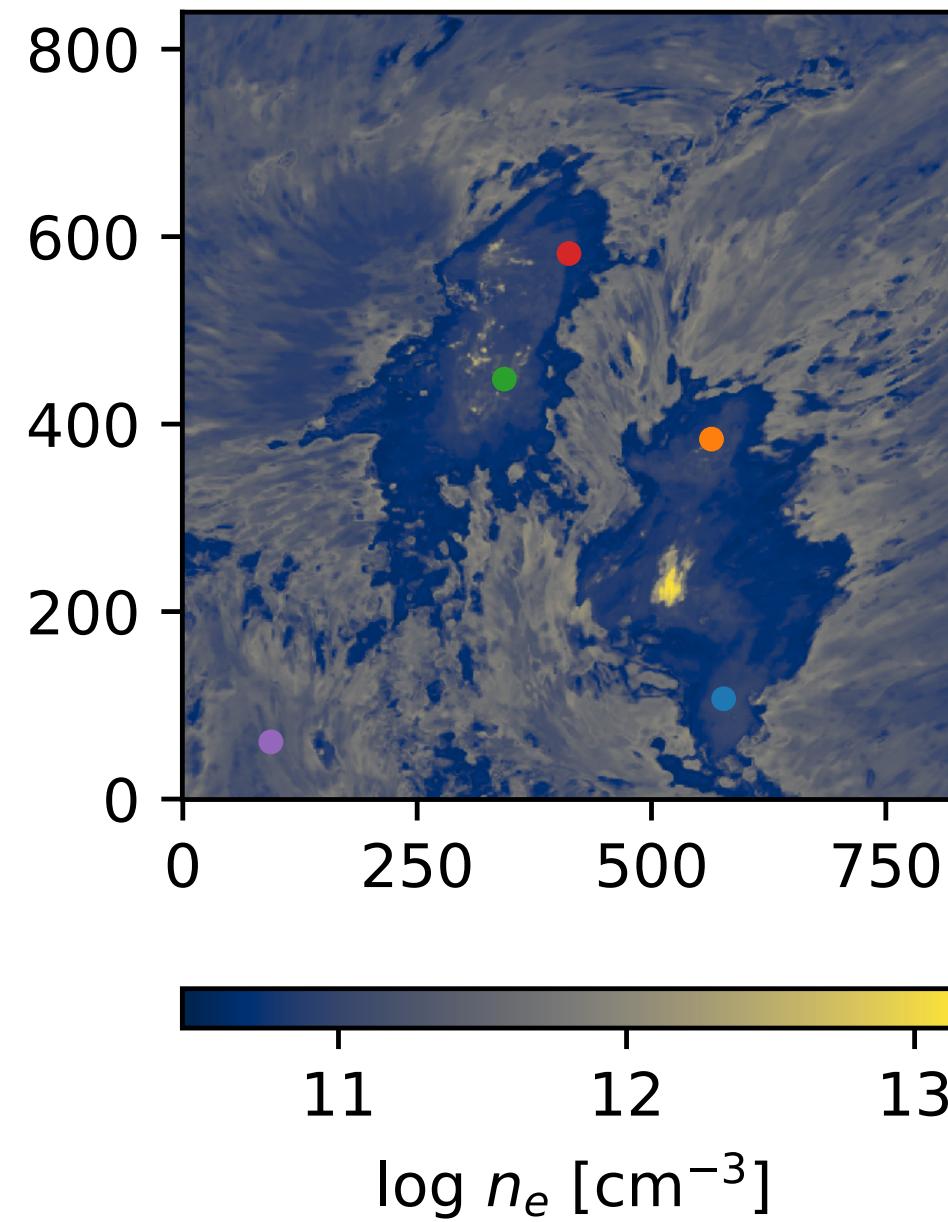
17:10:41 $z = 0.99\text{Mm}$



RADYNVERSION:

Whole Image Inversions 4

17:10:41 $z = 1.23\text{Mm}$



- There is a lot of inverted data and a lot we can do with it (pls help)



- The inverted atmospheres do not seem ridiculous for what we think is happening
- This method of inversion is useful for speed and ability to define confidence intervals
- Upper atmosphere will be better constrained with multi-wavelength obs. but this is hard to coordinate
- We will hopefully include a magnetic field soon because that's probably important

