Modelling Disc Winds From X-ray Binaries

Daniel Baig

Supervisor: Dr James Matthews

With thanks to the PYTHON collaborators

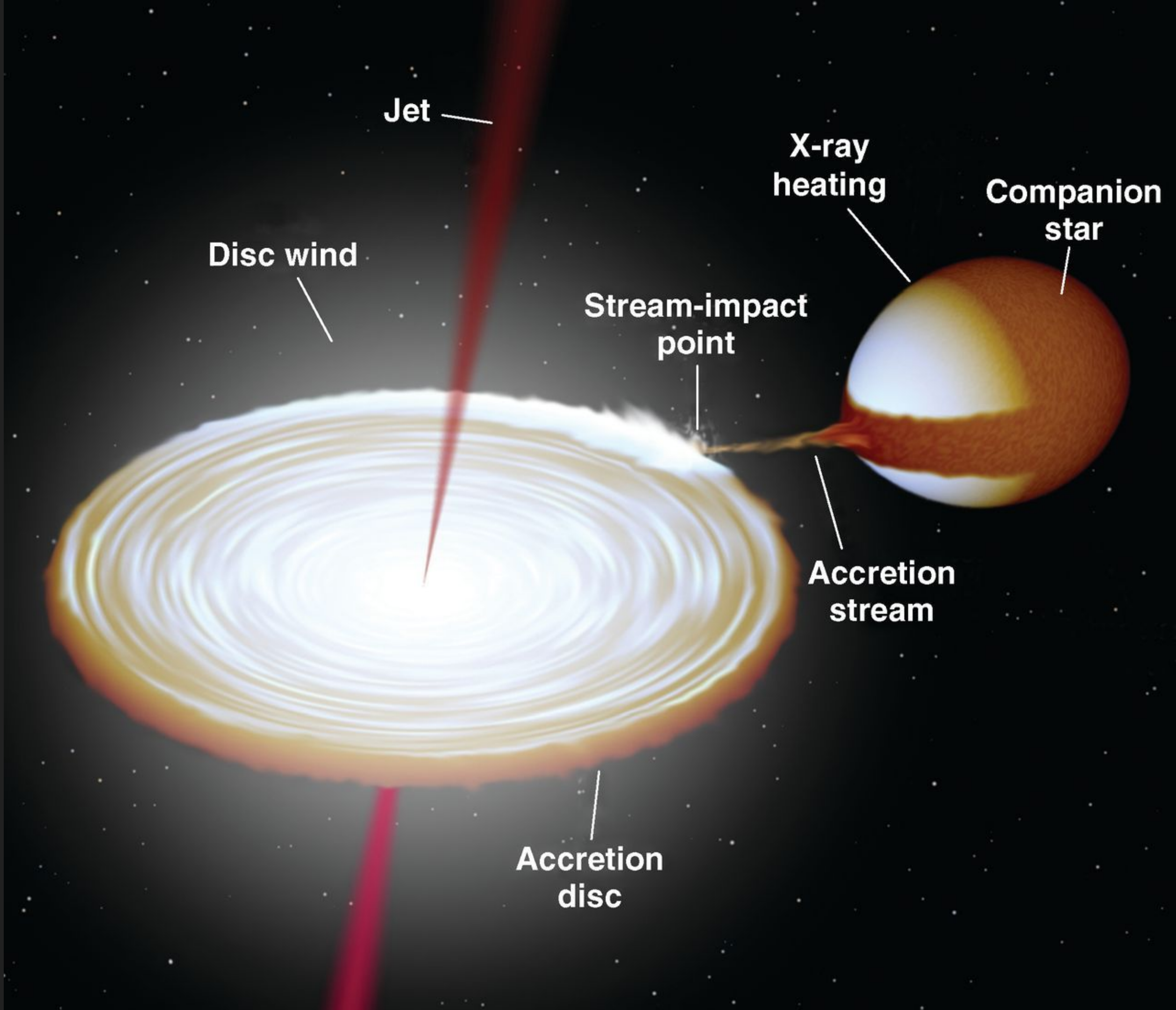
Introduction

- X-Ray Binaries -> Disc Winds -> P-Cygni Profiles.
- Simulation using the Monte Carlo radiative transfer code: PYTHON (not that one).
- Parameter file parameter space -> variable parameter space -> optical spectrum.
- Novel method for variable parameter space estimation using a Monte Carlo string minimisation method.

X-Ray Binaries

- Black hole accreting from companion star.
- Forms an accretion disc.
- Will only accrete if the volume of the companion star is sufficiently large for matter to be transferred to the other object.

Image produced with BinSim by Rob Hynes.



Disc Winds

- Accretion discs eject material due to thermal and/or magnetic processes.
- Disc winds carry away material (and angular momentum when magnetically driven).
- Identified by P-Cygni profiles in spectra.

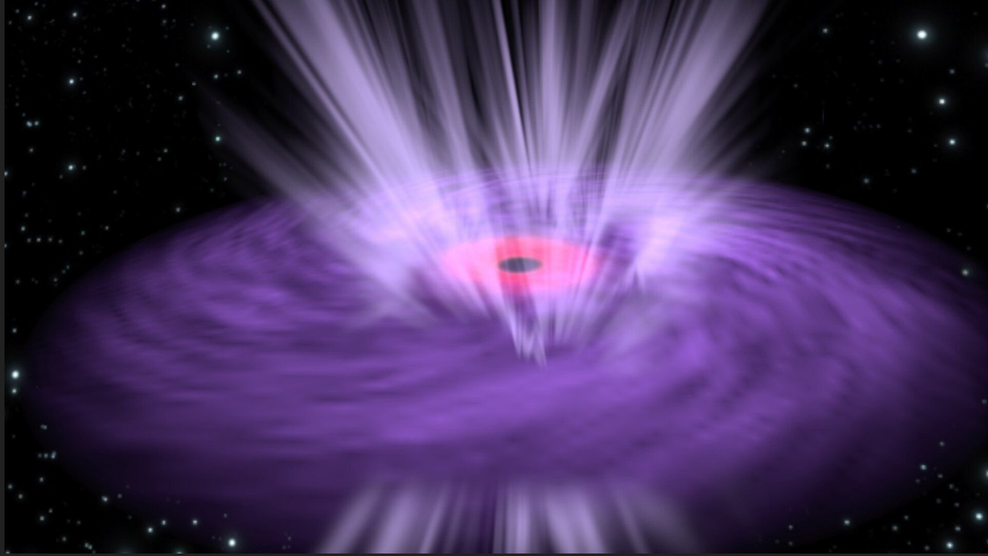


Image source: European Space Agency

P-Cygni Profiles

- Emission due to deexcitation and line emission.
- Blueshifted absorption.
- Have been seen in data for XRBs in the optical region, but not in simulations.

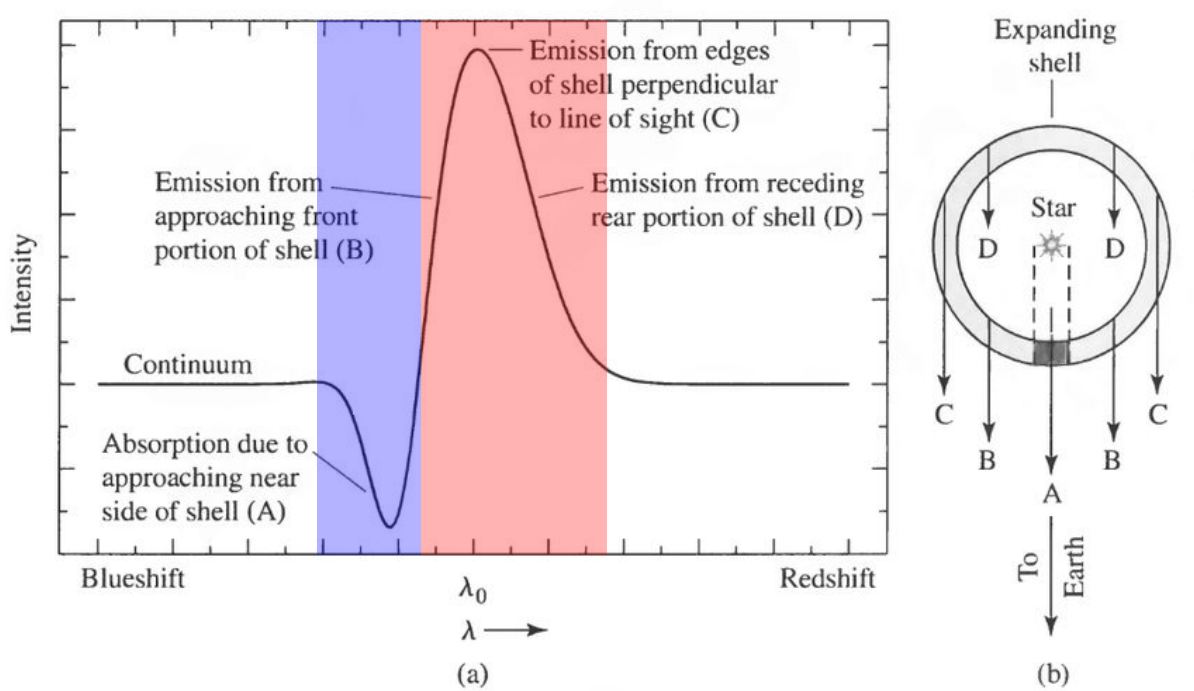


Image source: Kasai, E.K., 2013. *The type IA supernova rate in intermediate redshift galaxy clusters*

Motivation and Aims

- Simulate P-Cygni profiles as seen in observations of MAXI J1820 in the hard state.
- Explore the parameter file parameter space to find the region where P-Cygni profiles are possible (and physically feasible).

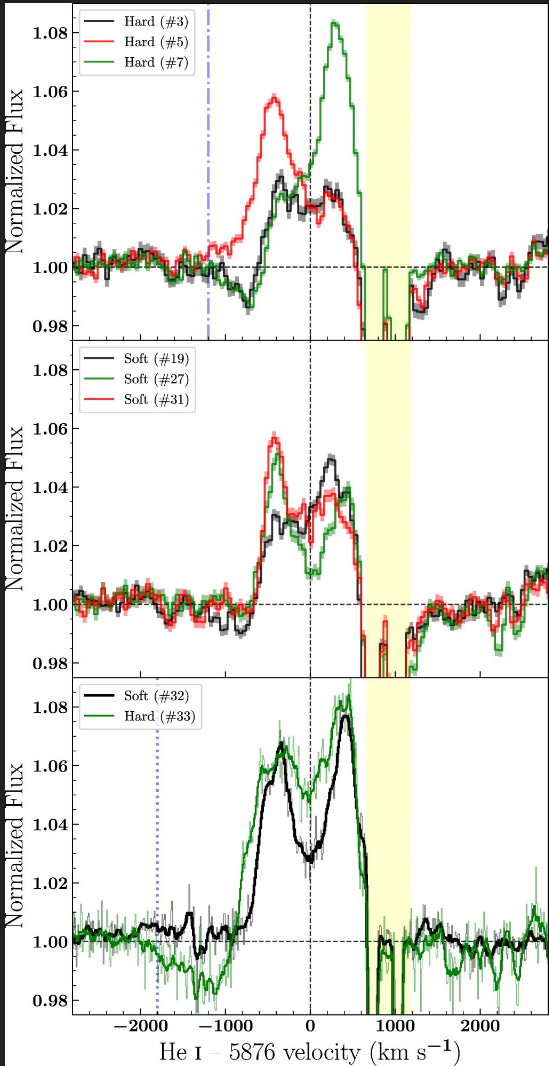


Image source: T. Muñoz-Darias et al. 2019 ApJL 879 L4

Geometry Setup.

- Set the sources of the photons, e.g. accretion disc, central source.
- Create a grid based on a coordinate system that takes advantage of the symmetry of the system, i.e., logarithmic cylindrical.
- Set initial matter distributions, velocities, temperatures etc.

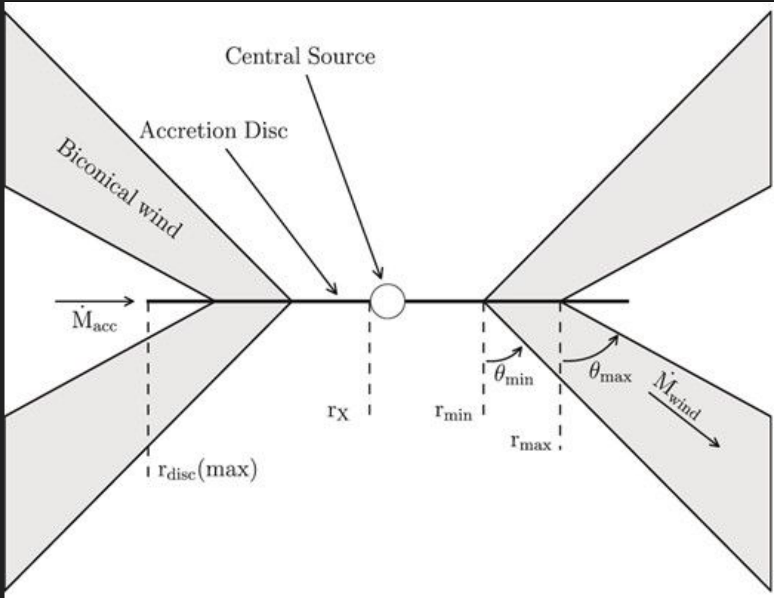
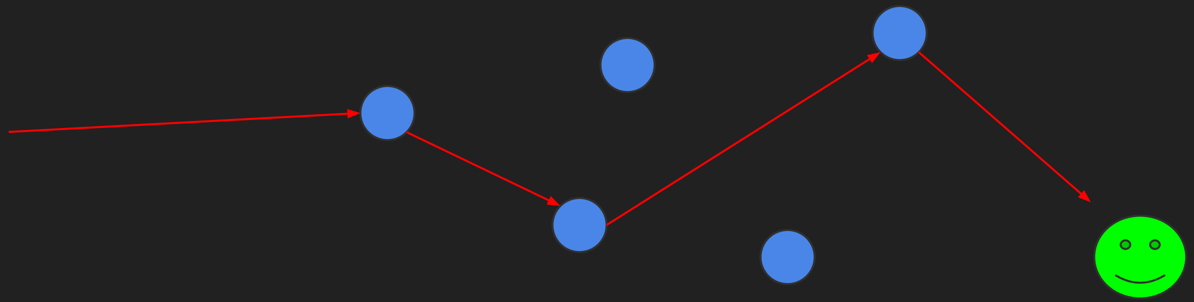


Image source: Matthews, J.H. et al. 2016. Testing quasar unification: radiative transfer in clumpy winds.

Radiative transfer procedure.

- Simulate many photons travelling through the system.
- Probability that it interacts with free or bound electrons and is scattered or absorbed.
- Photons eventually reach observer and contribute to a spectrum.



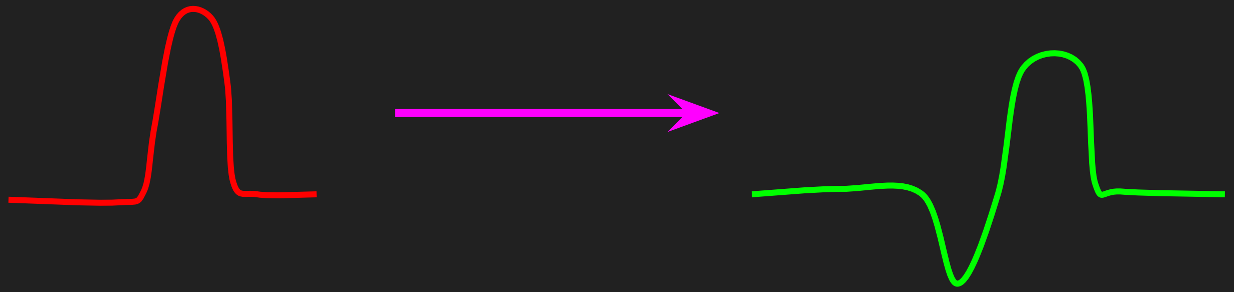
$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu$$

α_ν is the absorption coefficient and j_ν is the emission coefficient.

Rybicki, G.B. et al. 1991. Radiative processes in astrophysics.

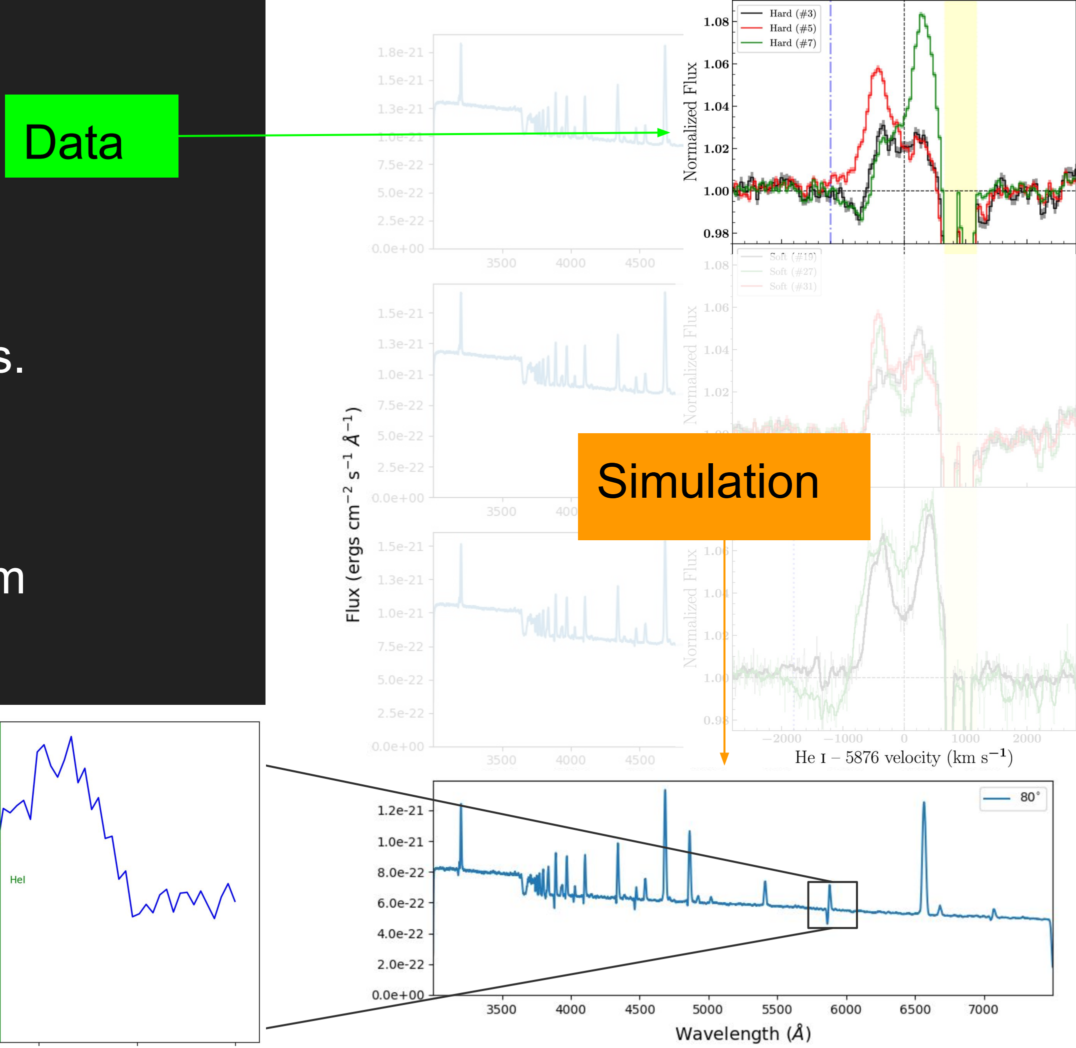
Method

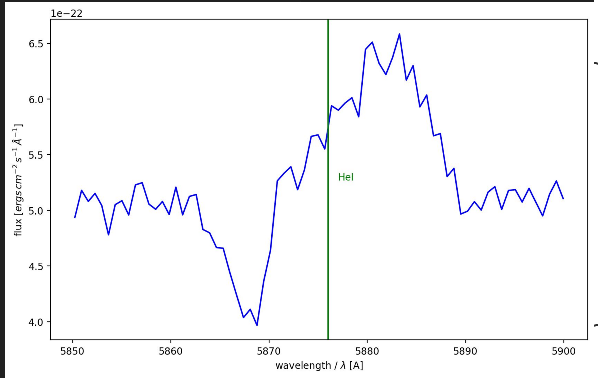
- Vary variables to find conditions of the system that produce P-Cygni profiles.
- Varying: mass loss rate, filling factor, acceleration length and acceleration exponent.
- Try to identify features in the variable parameter space that lead to P-Cygni profiles.



Results

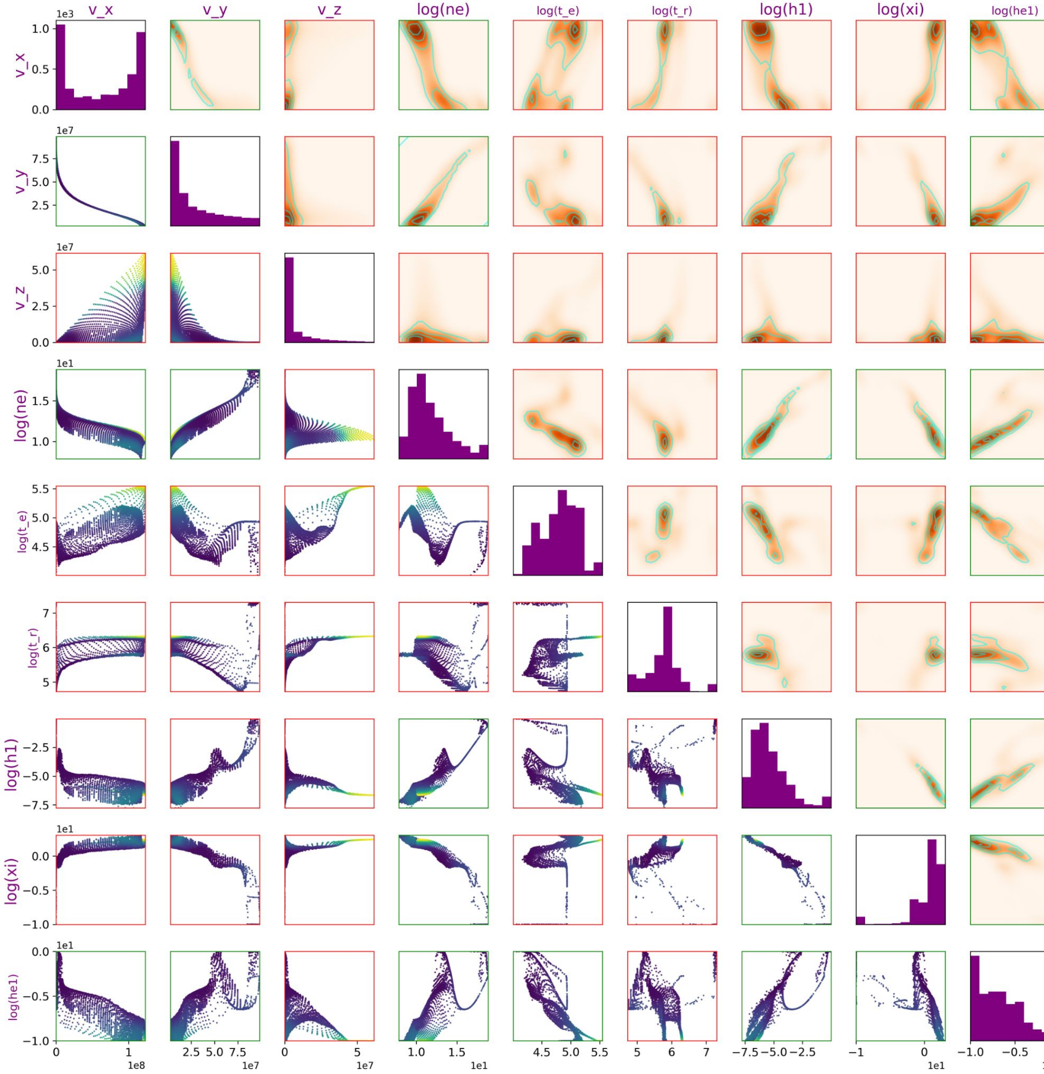
- Found P-Cygni profiles.
- But required extreme conditions.
  - Very clumpy.
  - Very high mass loss rate.
  - Slowly accelerating.
- So needs very out-of-equilibrium conditions.





Variable Parameter Space

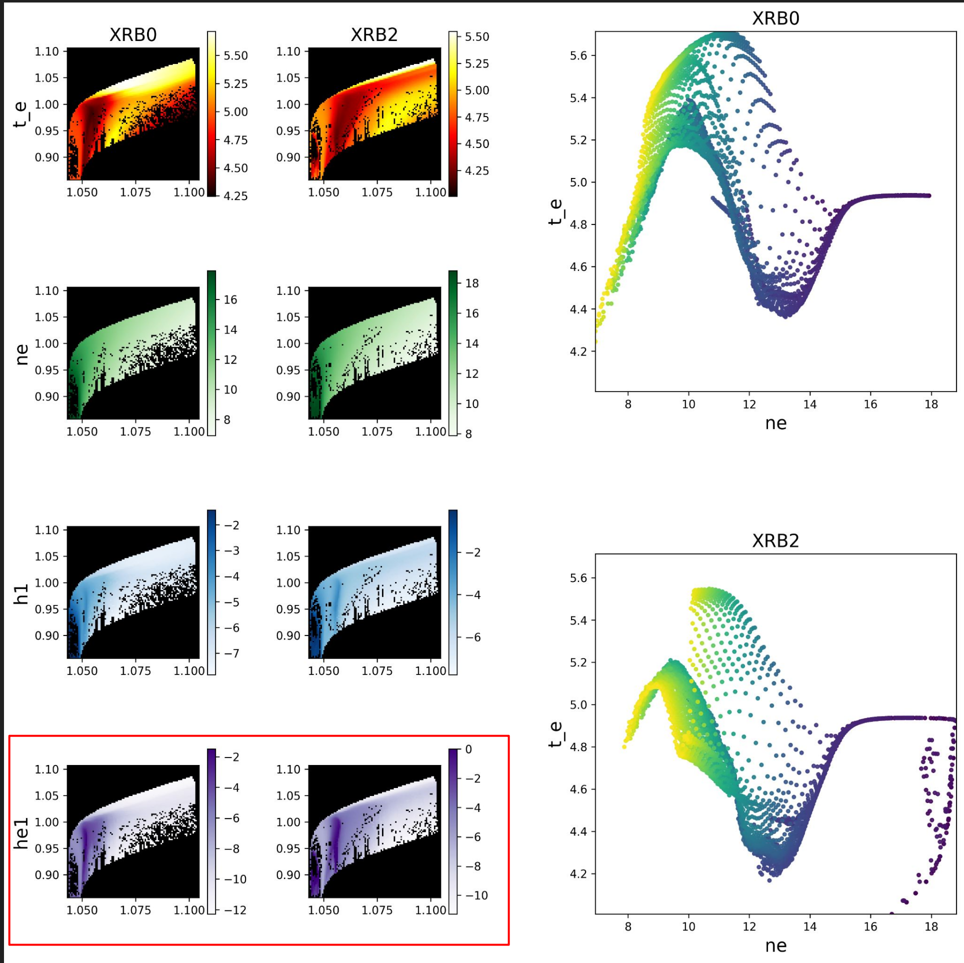
- Non-linear structure.
- Some identifiable features.
- Difficult to develop intuition about the system.



Variables in Physical Space

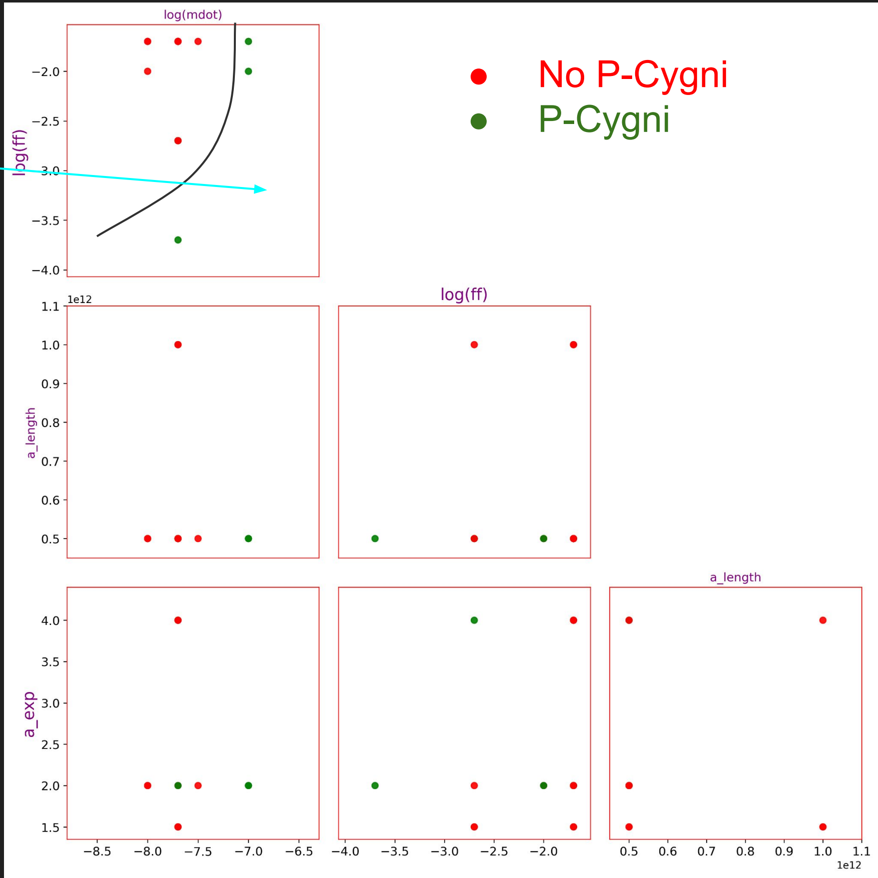
- XRB0: default
- XRB2: P-Cygni profile present

- Show common overall features.
- Finer structure leads to P-Cygni troughs.



Parameter File Parameter Space

- Few samples.
- Can identify part of P-Cygni region.



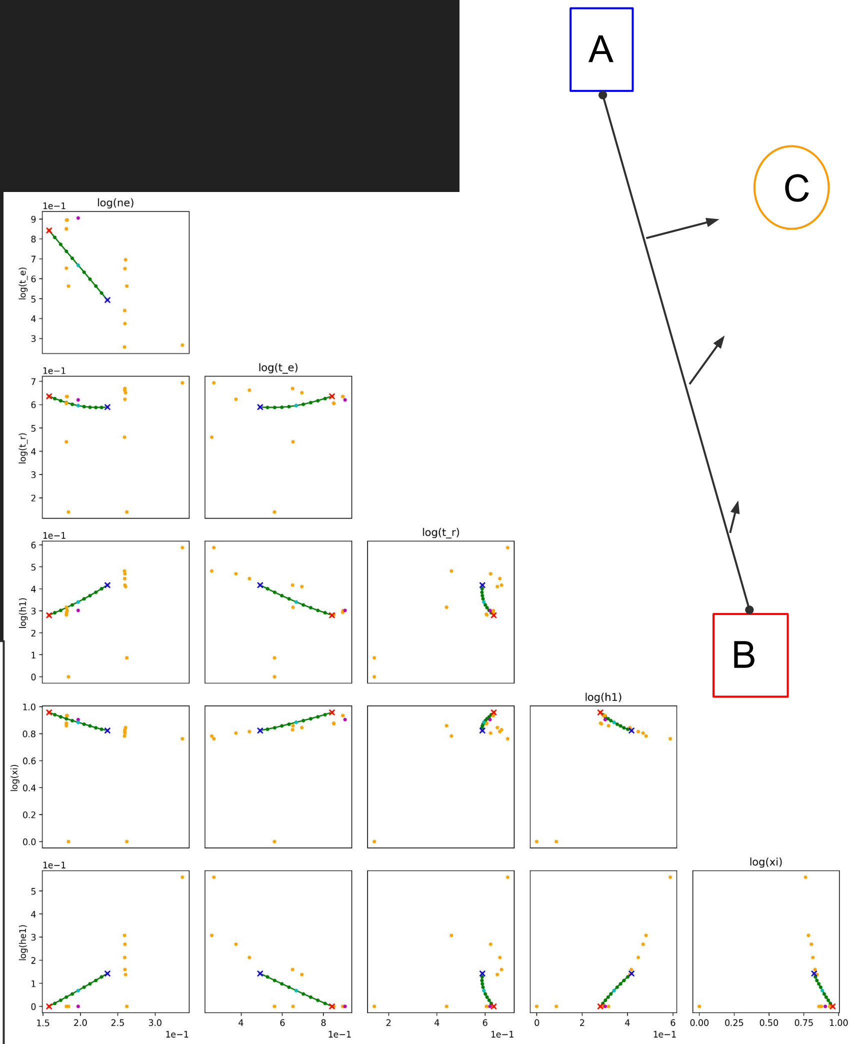
String Minimisation--a Parameter Space Emulator

String Minimisation - Theory

- Consider two points in the parameter file parameter space.
- How does the distribution of points in variable parameter space vary as you travel along a path from one to the other?

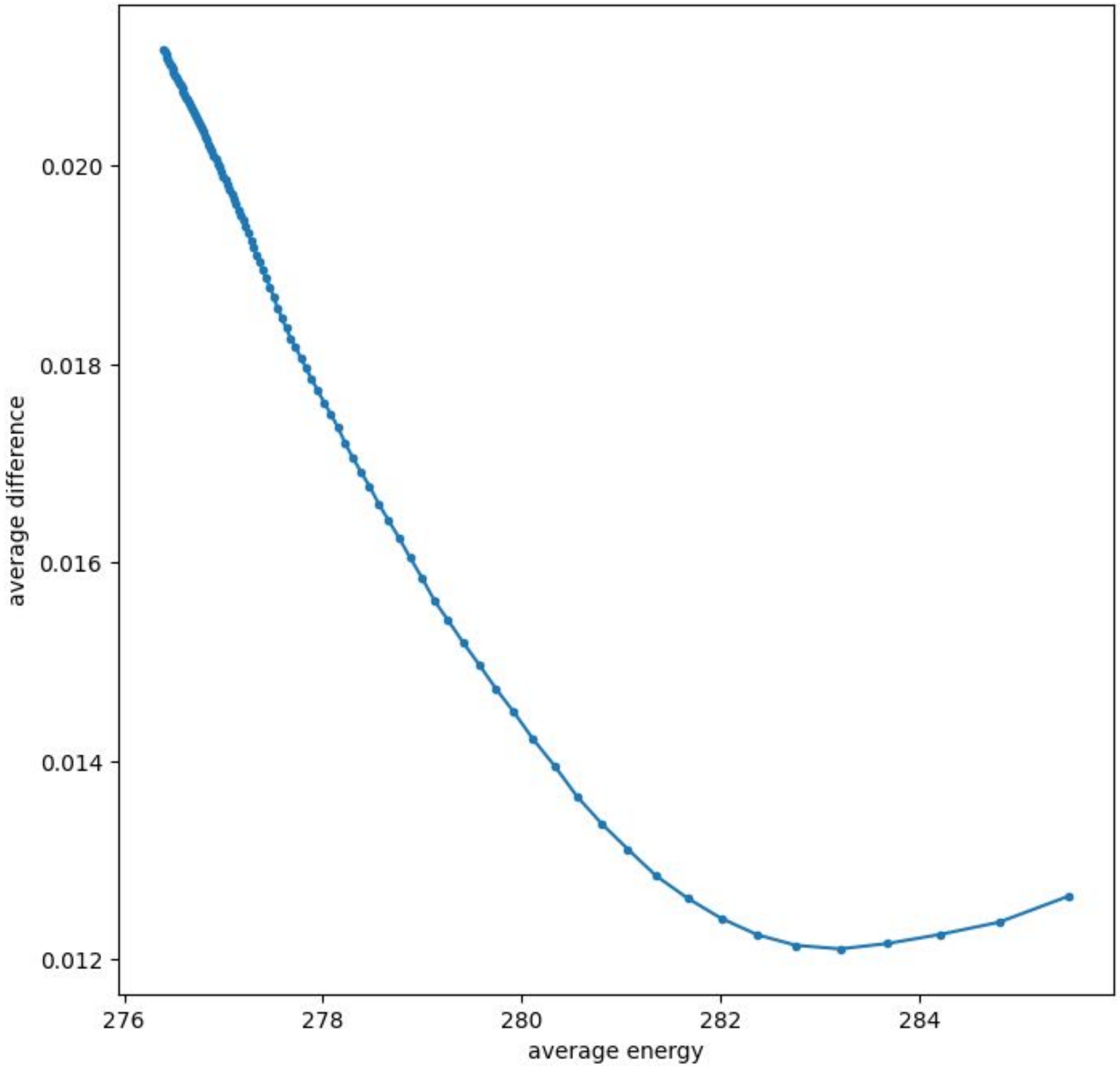
$$V = \sum_{i=0}^{n} \frac{\sigma(\delta_i)\sigma(r_i)}{\rho_i} + \tilde{k} \sum_{i=0}^{n-1} (|\underline{r}_{i+1} - \underline{r}_i| - l)^2$$

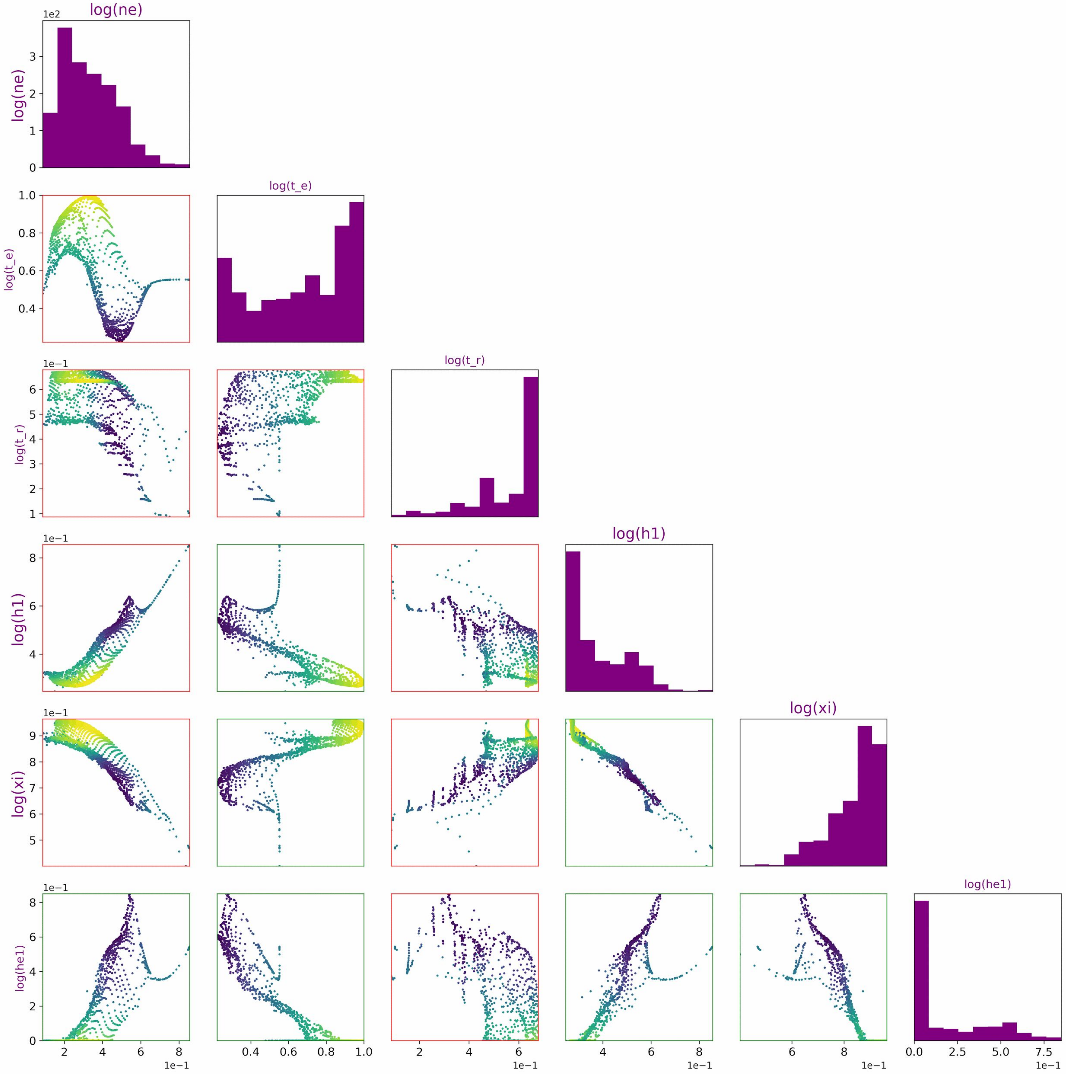
$$;\ \sigma(x) = \frac{2}{1+e^{-x}} - 1 \approx \frac{x}{1+x}\ ;\ x \geq 0$$



Results

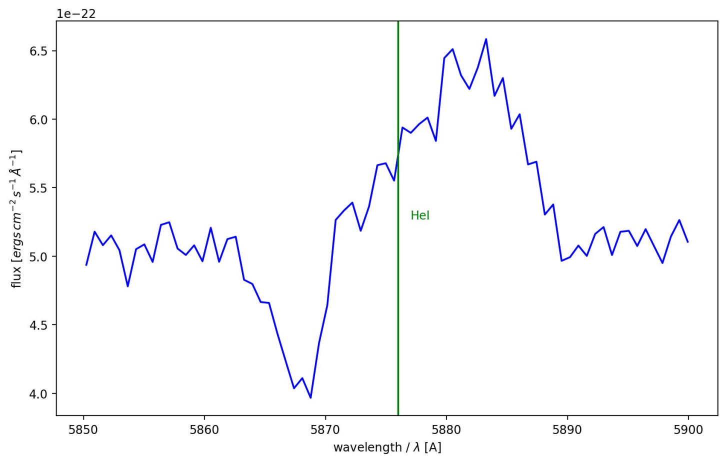
- Shows promising results--to an extent.
- Requires good tuning of the spring constant.
- Could potentially be used for parameter space searches in any field.

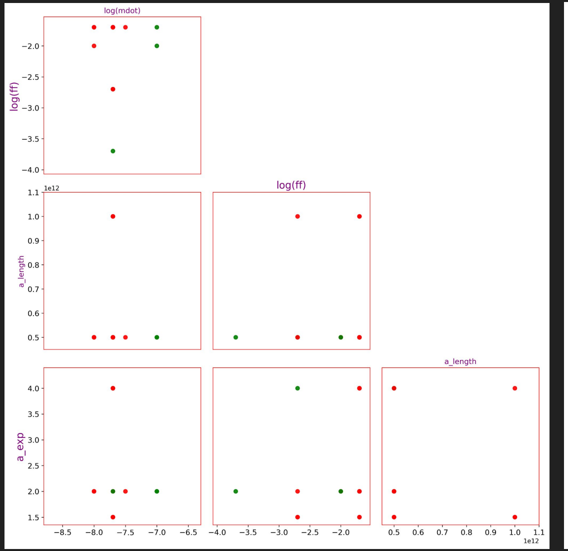


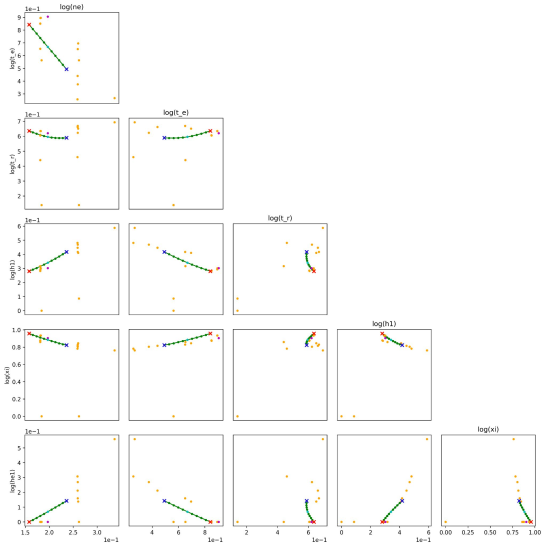

log(ne)
log(t_e)
log(t_r)
log(h1)
log(xi)
log(he1)
1e2
1e−1

Conclusion

- Found P-Cygni profiles.
- Found indications that they require extreme conditions.
- Suggests that the wind heavily influences the dynamics of the disc.
- Showed that the string minimisation technique has potential to be a useful tool.



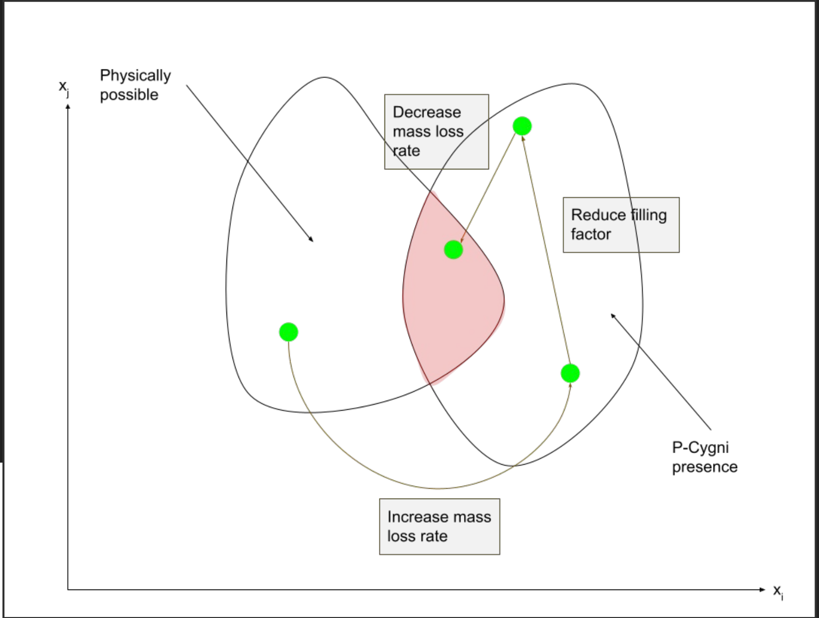




Future Work

- Continue the search for less extreme regions of parameter space that produce P-Cygni profiles.
- Adjust function of string minimisation potential.
- Determine the performance of the string method by assessing its ability to reproduce completely analytic multidimensional functions.

$$\underline{u} = f(\underline{x})\,;\;\; f : \mathbb{R}^n \to \mathbb{R}^m$$



Thank you for listening.