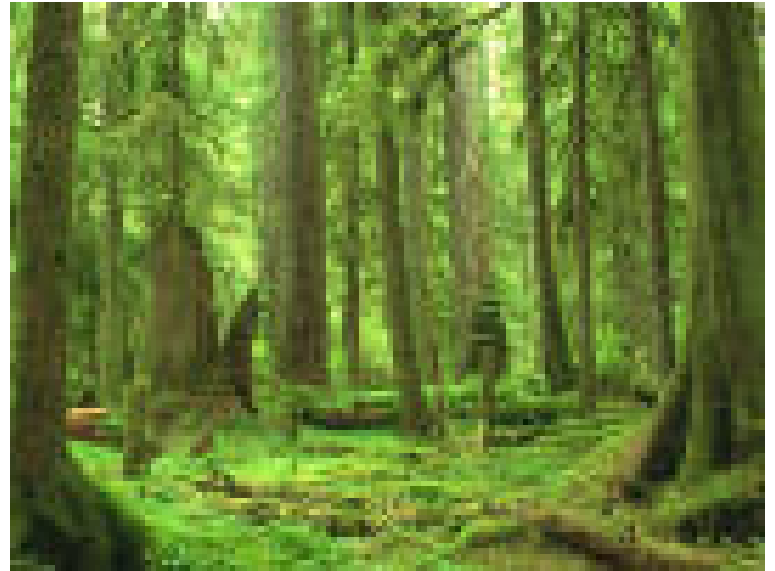


Measuring Small Scale Structure in the Lyman Alpha Forest



With Gravitational
Microlensing

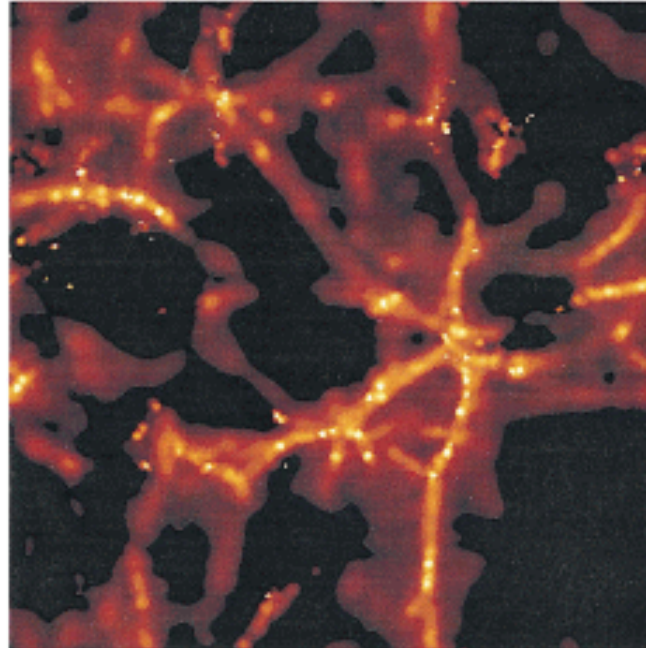
Brendon Brewer

Supervisor: Dr Geraint Lewis

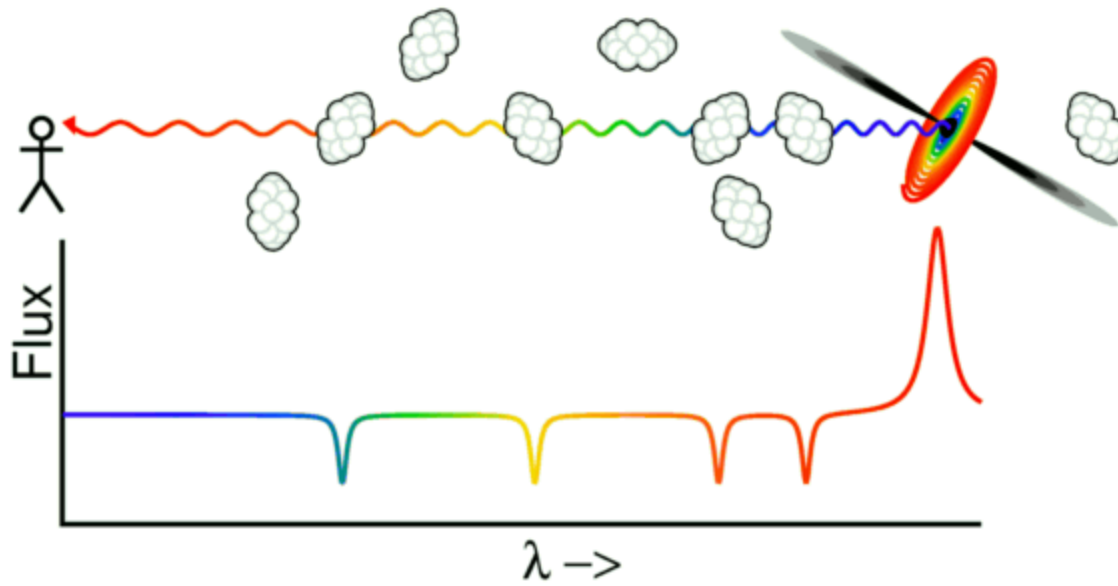


The Lyman Alpha Forest

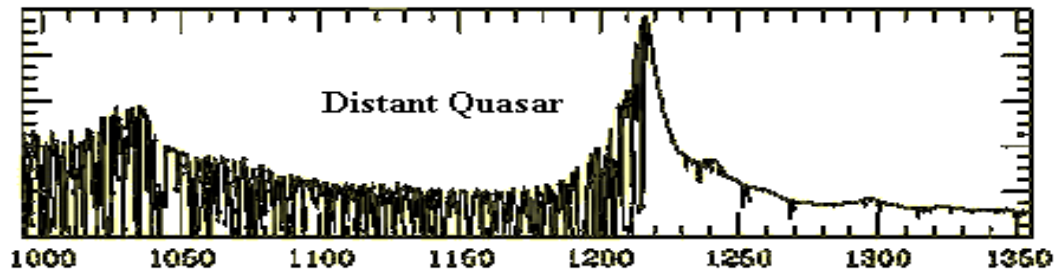
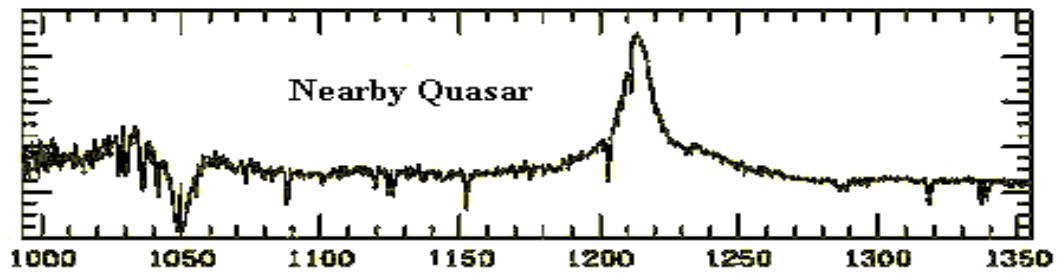
- Lyman Alpha is a transition between the $n=1$ and $n=2$ states of atomic hydrogen
- Atomic hydrogen exists in the universe – intergalactic medium. Large scale structure of the gas is related to cosmology, dark matter etc...



Dave R., Hernquist L., Katz N.,
Weinberg D.~H., 1999, ApJ,
511, 521



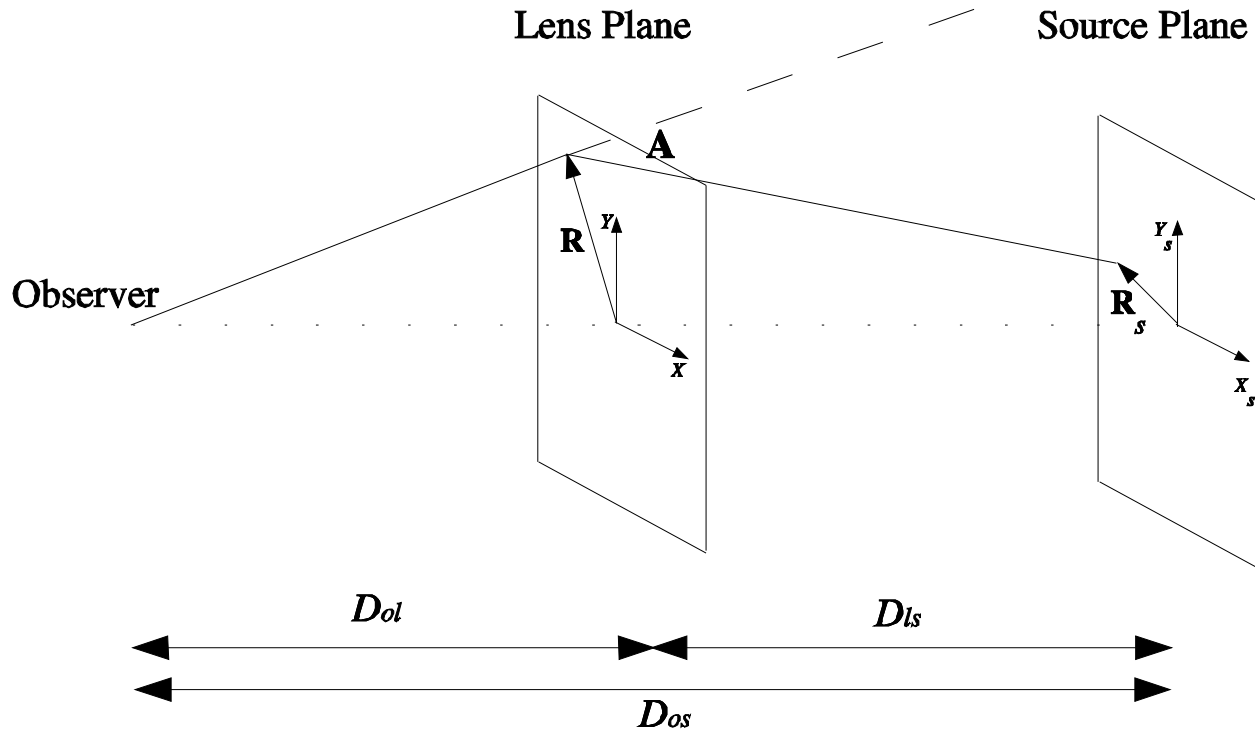
<http://www.astro.ucla.edu/~wright/Lyman-alpha-forest.html>



A real one...

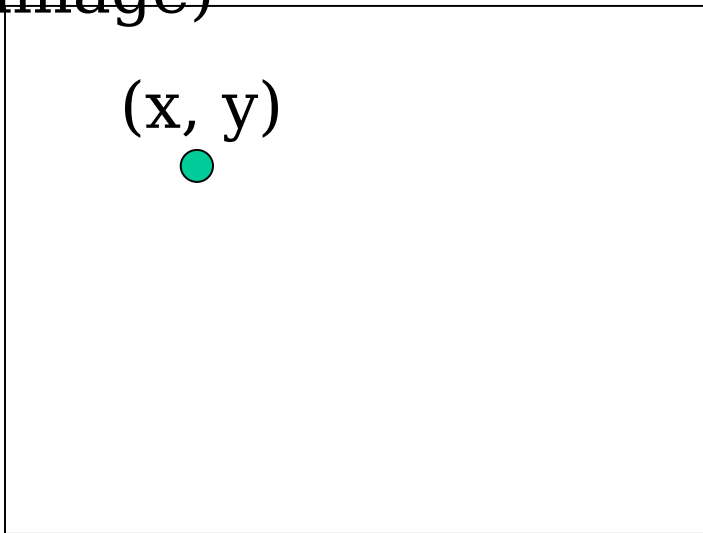
Gravitational Lensing

- Bending of Light by Massive Object
- Deflection Angle due to point mass $\sim 1/r$

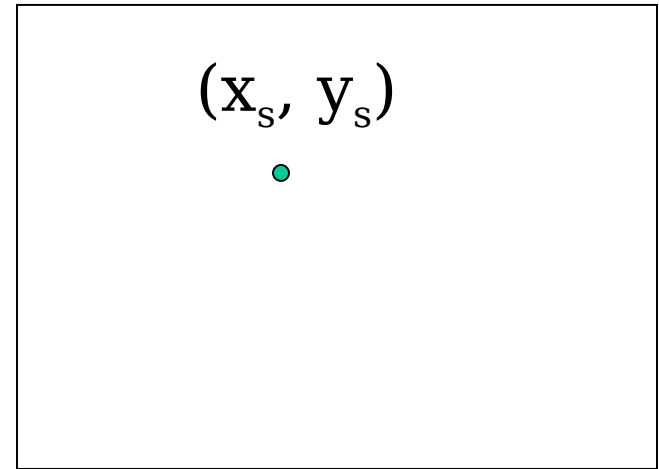


Source Plane, Lens Plane

Image plane (observed image)

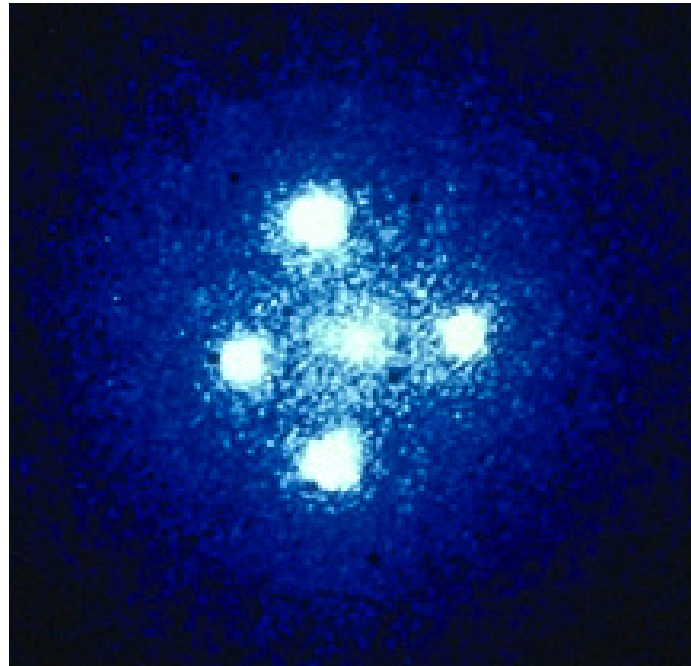


Source plane (undistorted image)



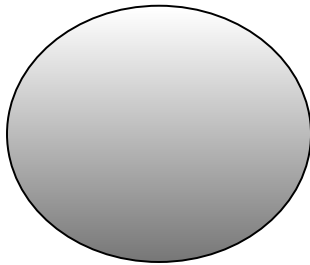
All the lens does is take a point from what the image would have been like, and moves it somewhere else. (In general not a one to one mapping – this leads to multiple imaging).

Real Example



QSO
2237+0305

Micro lensing of a Quasar by a Galaxy



A smooth matter
model of the galaxy
will give multiple
imaging like that
observed in QSO
2237+0305



But galaxies aren't
really smooth. They
have stars in them.
This leads to an
additional effect...

Microlensing

- Lens doesn't have to be very massive – eg individual stars, compact dark matter
- The deflection angles are very small (way below detection limits – micro arc seconds, hence the name). An image of the quasar is actually made up of tiny 'micro-images'.
- However, changes in magnification can occur as the source moves behind the lens.

Magnification Maps

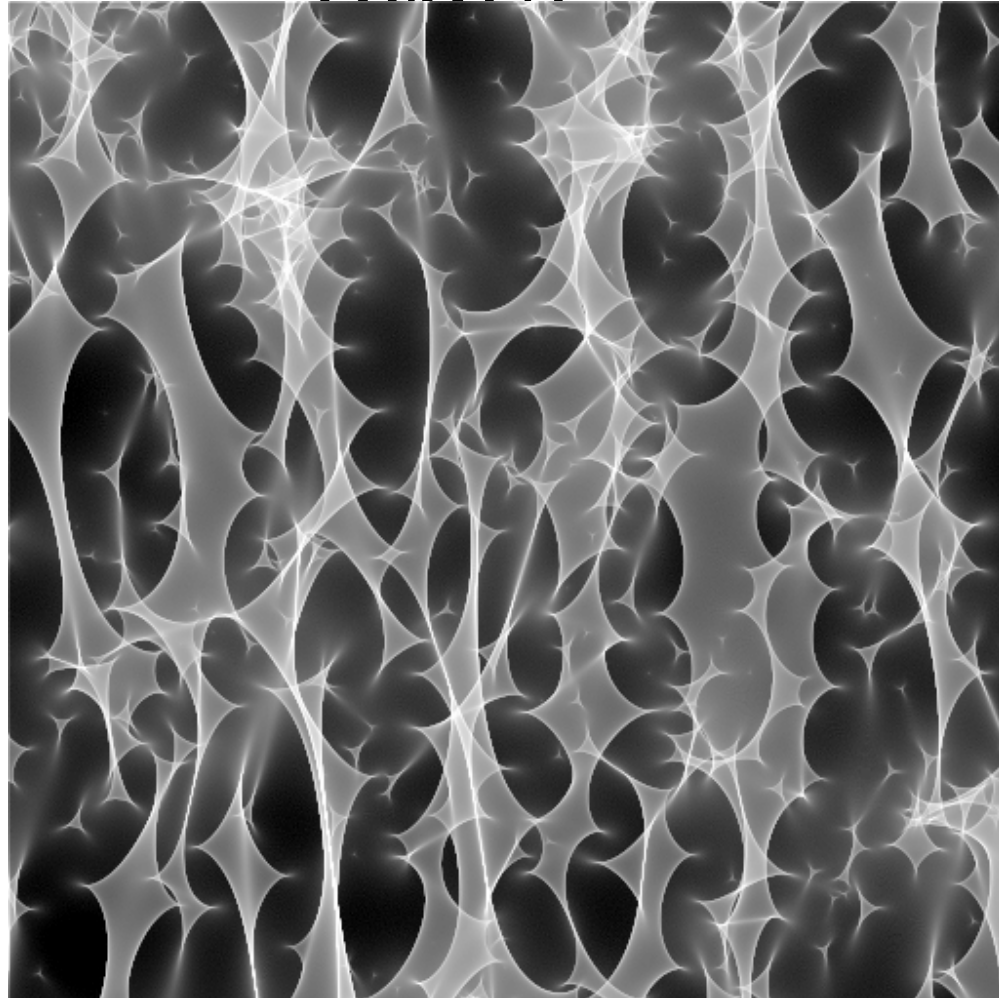
- Surface brightness is conserved
- The area of a small part of an image can be changed by the lensing.
- This leads to a change in the brightness of the source – but it depends on where the source is.
- Magnification expressed as a function of source plane position is called a magnification map.
- Jargon: There exist curves in the source plane, on which the magnification is infinite. These are called *caustics*.

Backwards Ray Tracing Method

- Many rays (about 10^9) are fired from the observer to the lens plane, a uniform distribution in the lens plane
- Calculate deflection angles due to ~ 2000 stars (plus external shear, the effect due to the rest of the galaxy), keep track of where they land in the source plane
- Areas where a lot of rays land are the bright regions of the magnification map – a source positioned there would be brightened. Ray tracing movie...

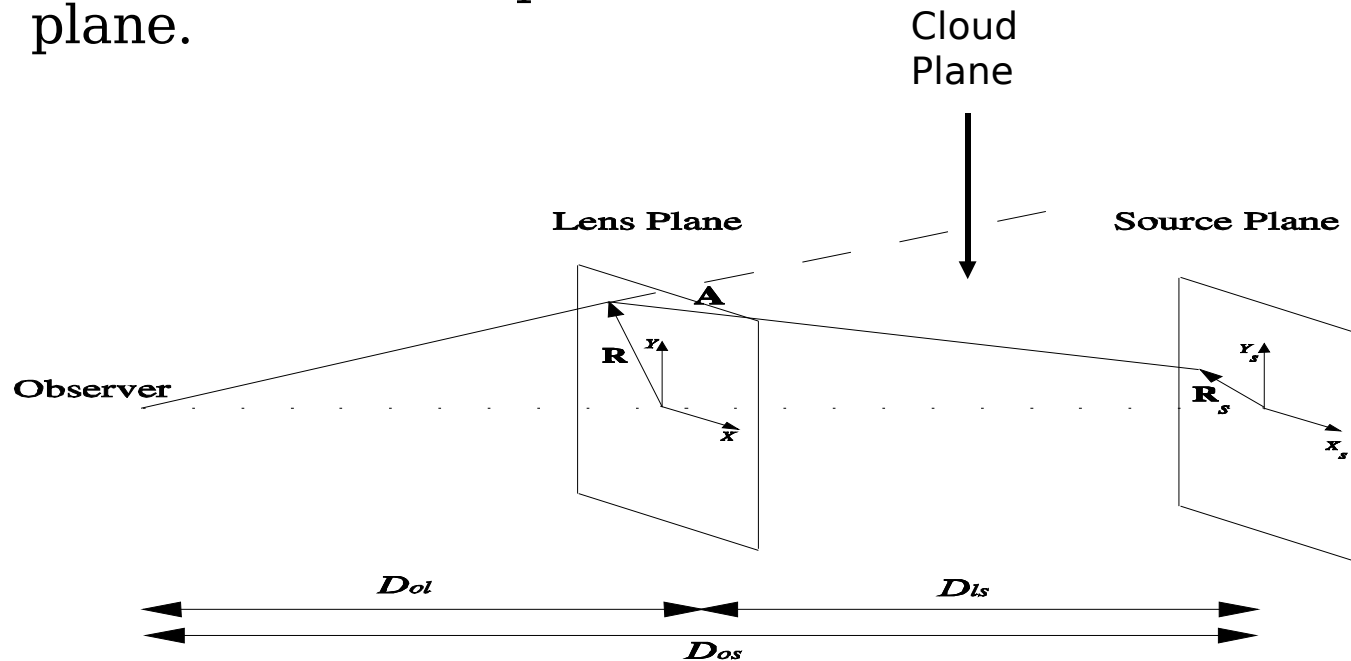
Magnification Map due to Lots of Stars

Too much
informatio
n!



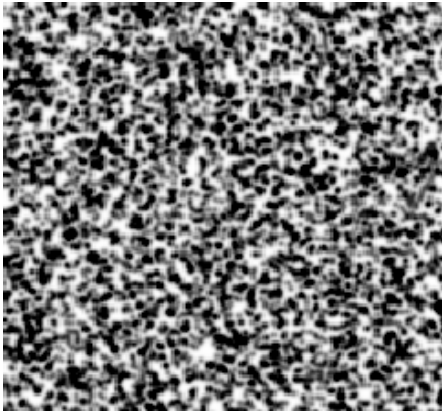
Absorption Clouds

- Put absorbers in between the source and the lens. This is a model for one absorption line of the Ly α forest. Put them in the “cloud plane”.
- Position described by a distance parameter λ . $\lambda=0 \rightarrow$ clouds at the lens plane, $\lambda=1 \rightarrow$ clouds at source plane.

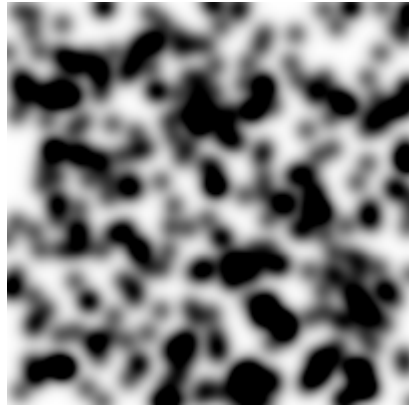


- Get two magnification maps – one for absorbed wavelengths and the other for non-absorbed wavelengths. Absorbed ray tracing movie...
- Therefore the strength of LyA forest lines (relative to continuum) changes as the quasar moves across the source plane.
- Want to see how these variations depend on the size of the absorbing clouds.

Three Different Cloud Sizes



0.005
pc



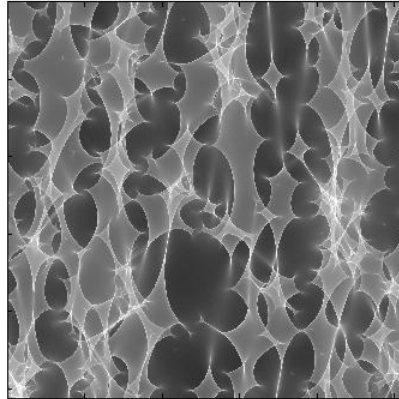
0.02 pc



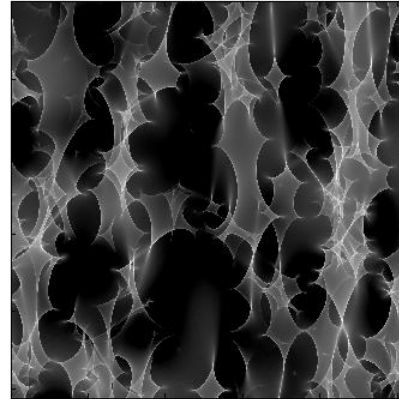
0.1 pc

Line Strength Map

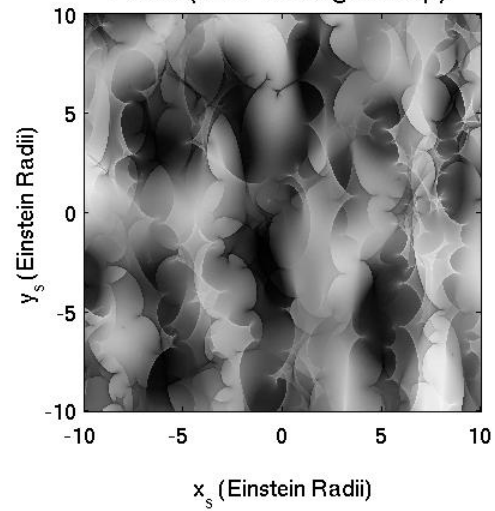
Unabsorbed



Absorbed

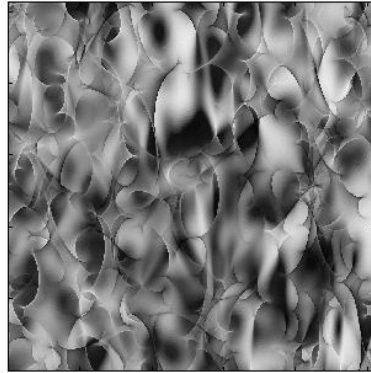


Ratio (Line Strength Map)

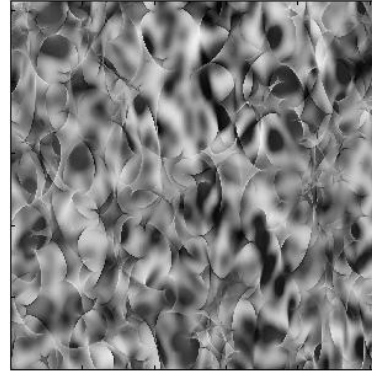


Line Strength Maps (Small Clouds)

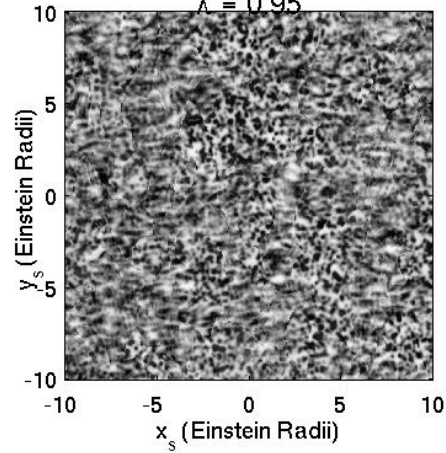
$\lambda = 0.2$



$\lambda = 0.5$

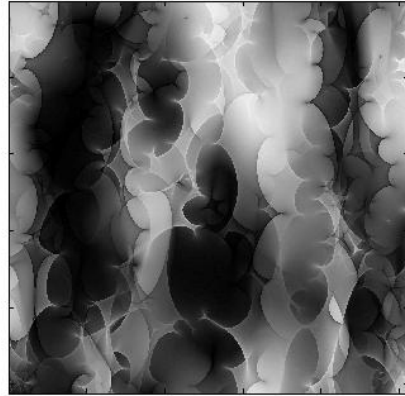


$\lambda = 0.95$

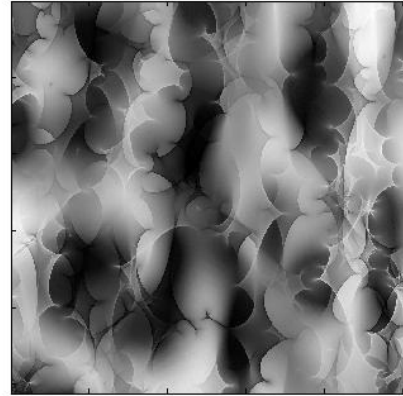


Line Strength Maps (Medium Clouds)

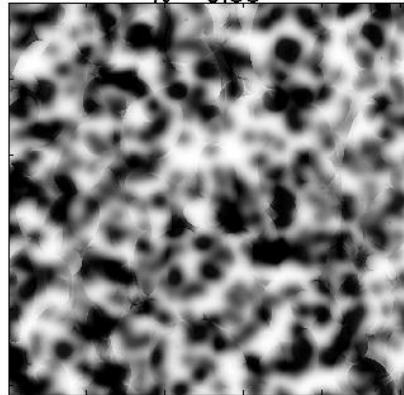
$\lambda = 0.2$



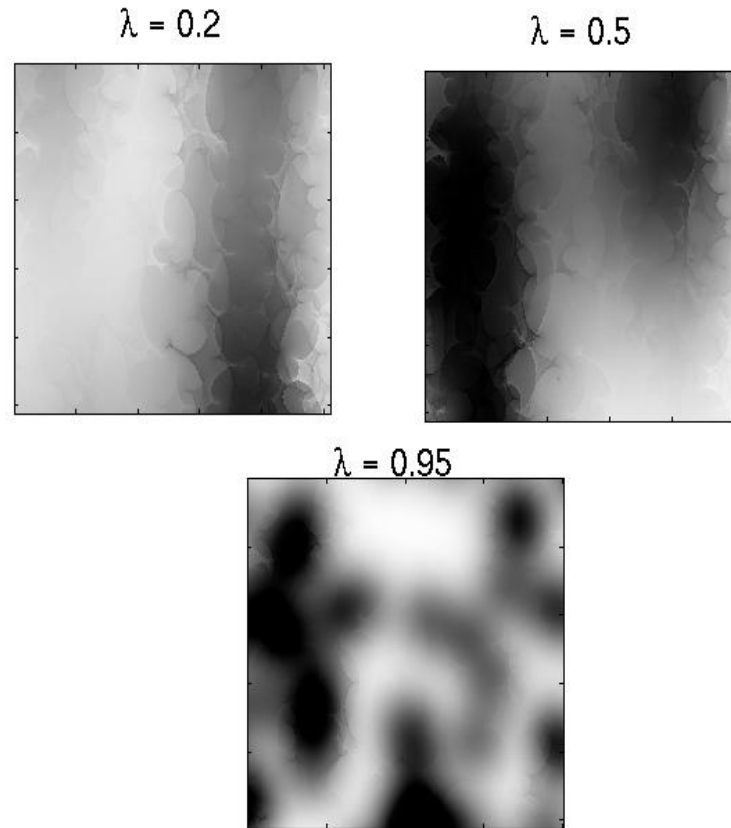
$\lambda = 0.5$

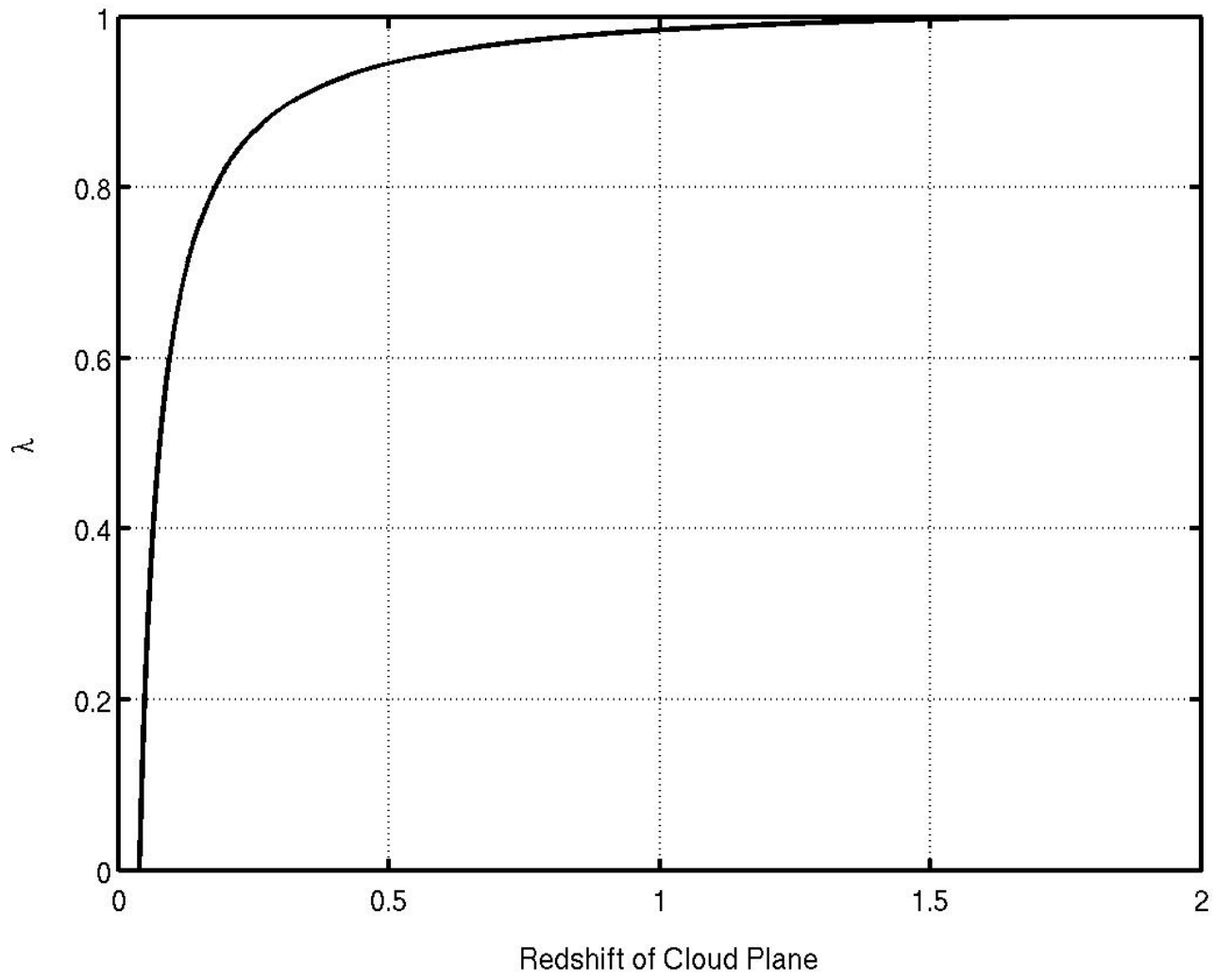


$\lambda = 0.95$



Line Strength Maps (Large Clouds)





Ways to measure this

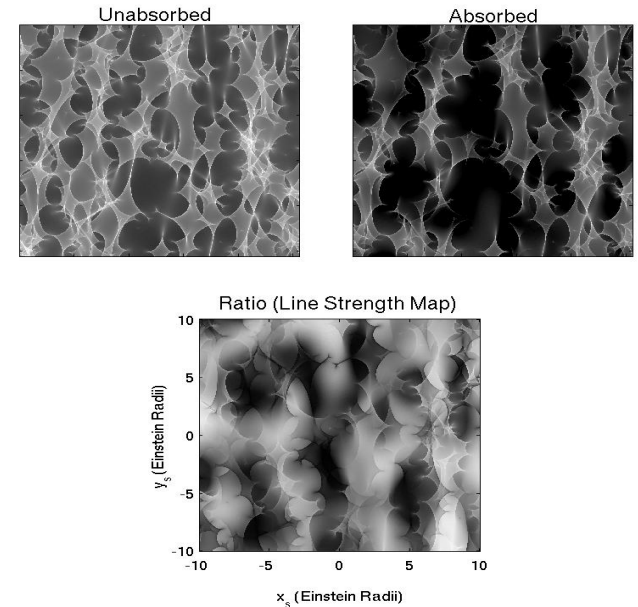
- Two possible ways to measure this – long term spectroscopic monitoring to measure typical timescale for line strength variations. Shorter timescales are associated with smaller clouds and clouds closer to the source.
- Or short term monitoring during caustic crossings. Note that sudden brightness changes are accompanied by line strength changes.

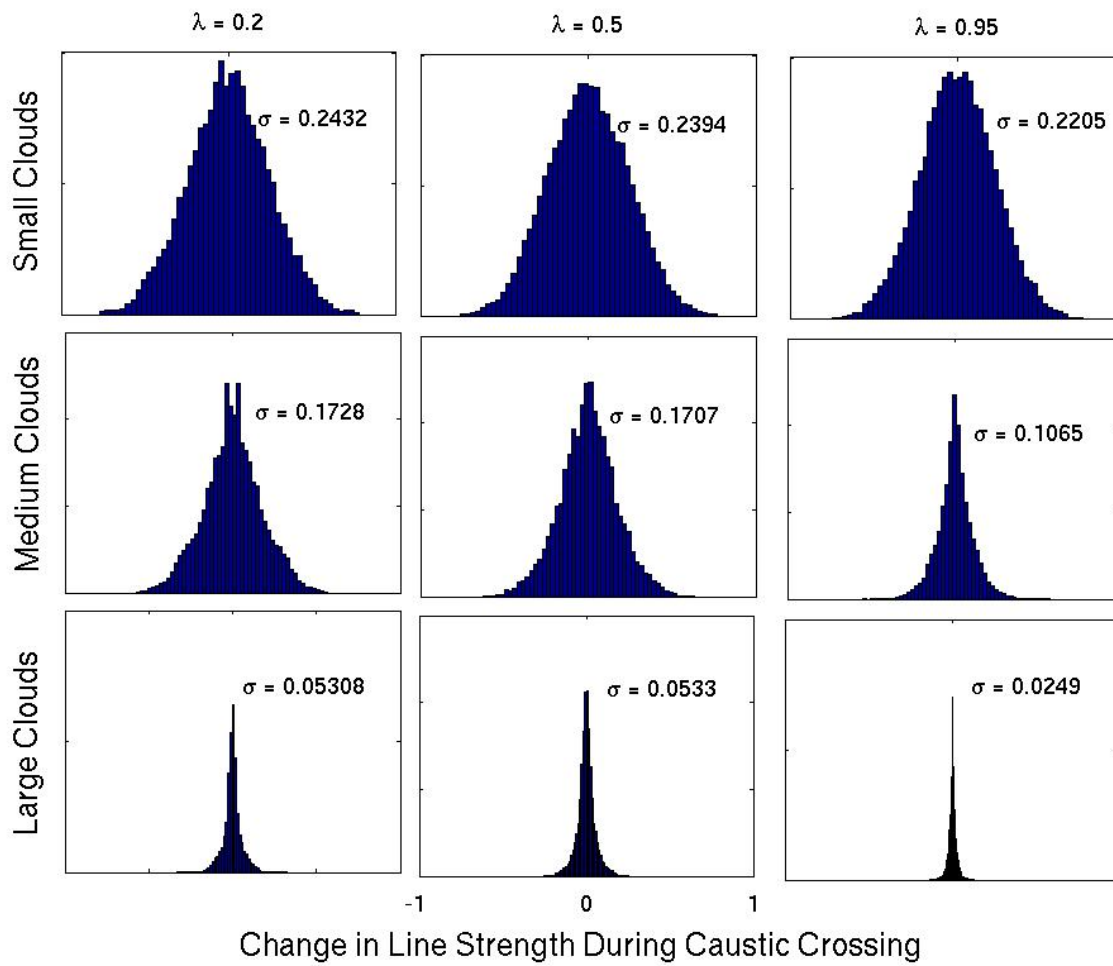
What happens to the line strength during a caustic crossing?

-I selected pairs of nearby points in the source plane at random

-A caustic crossing was defined as being a pair of points for which the continuum brightness changes by more than 1 magnitude between the two points

- Made histograms of the corresponding line strength changes at caustic crossings





Conclusions

- If the Lyman Alpha Forest gas is not smooth on the small scale (< 0.1 pc), the Lyman alpha forest absorption lines in a microlensed quasar will vary in strength with time.
- During caustic crossings, sudden brightness changes would be accompanied by sudden line strength changes.
- Could be measured by spectral monitoring of an image of Q2237+0305.

The End

Paper

“Probing Sub-parsec
Structure in the Lyman
Alpha Forest with
Gravitational
Microlensing”, B.J.
Brewer and G.F. Lewis,
2004, accepted to
MNRAS

astro-ph/0410138

