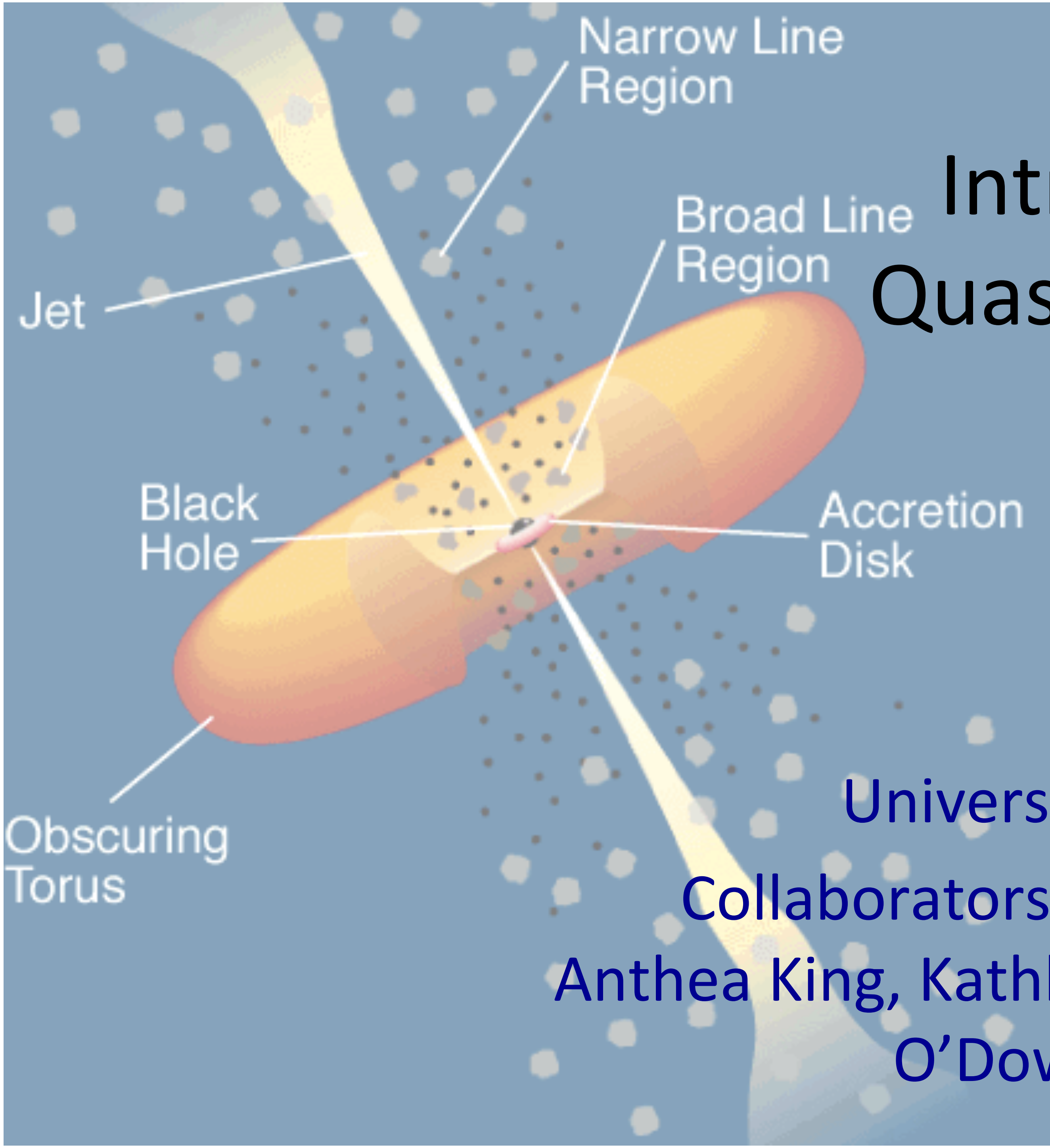
Introduction to Quasar Structure



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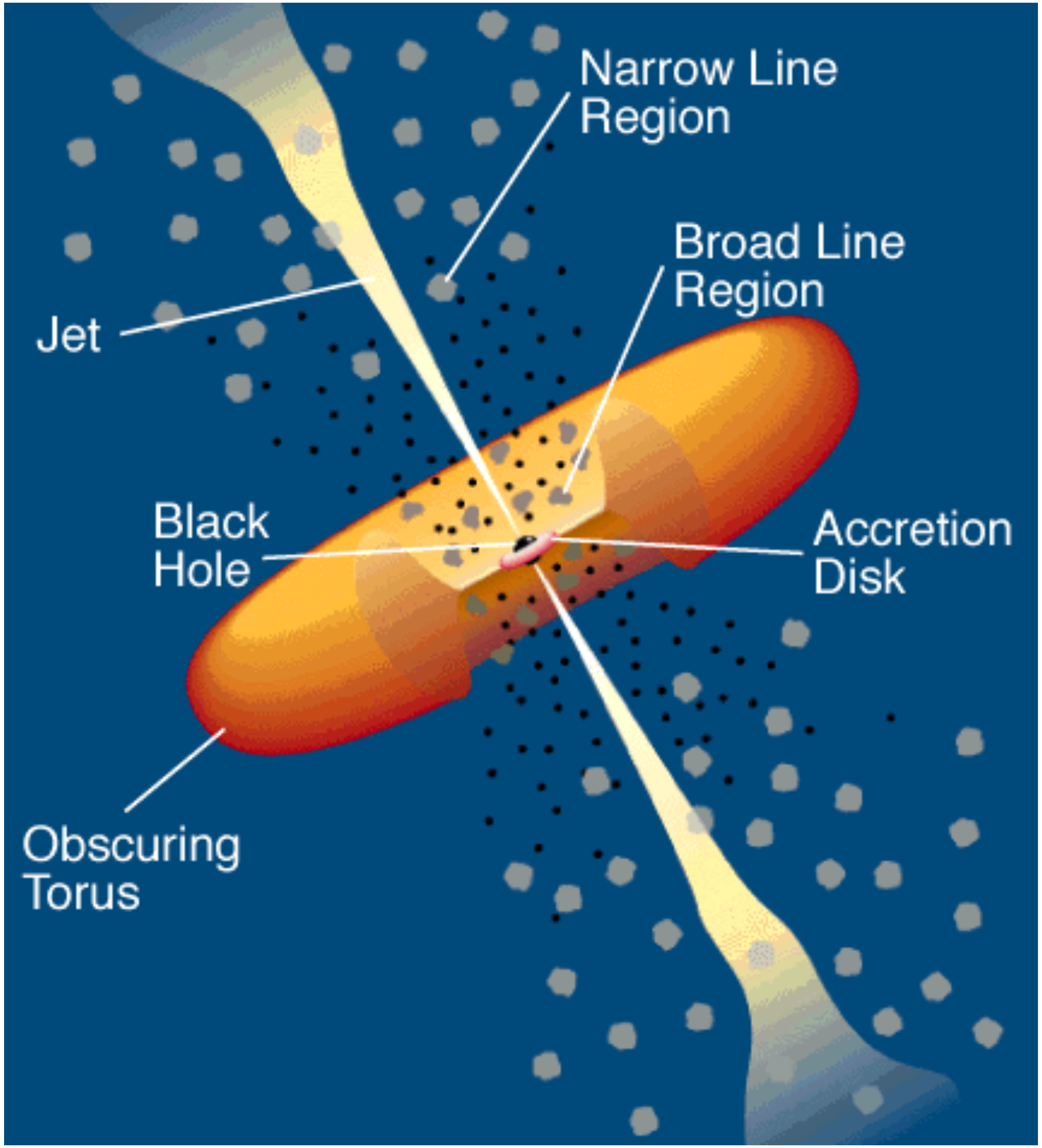
Part 1

- Current models of quasars
- Why lensing?

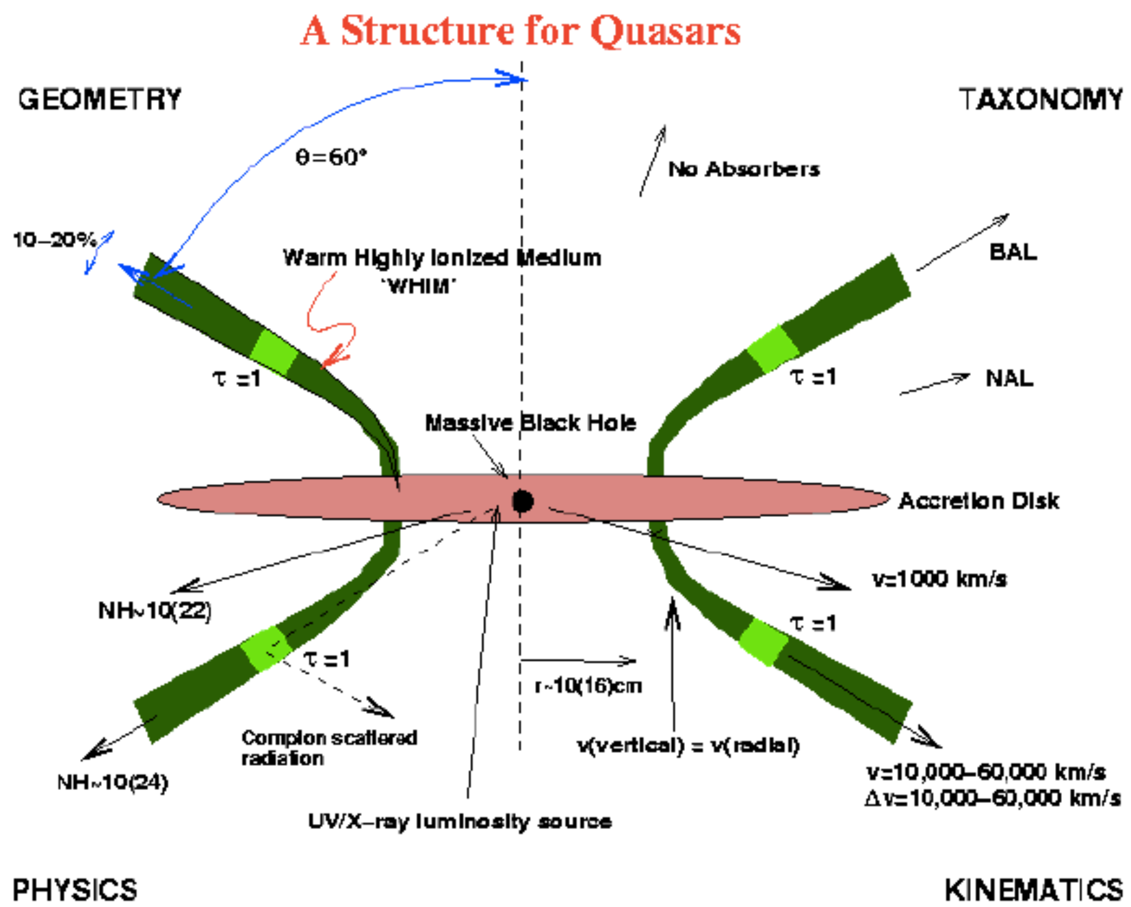
Part 2

- BALs: unique probes
- The accretion disk profile
- Can we determine angle-of-viewing?
- Summary



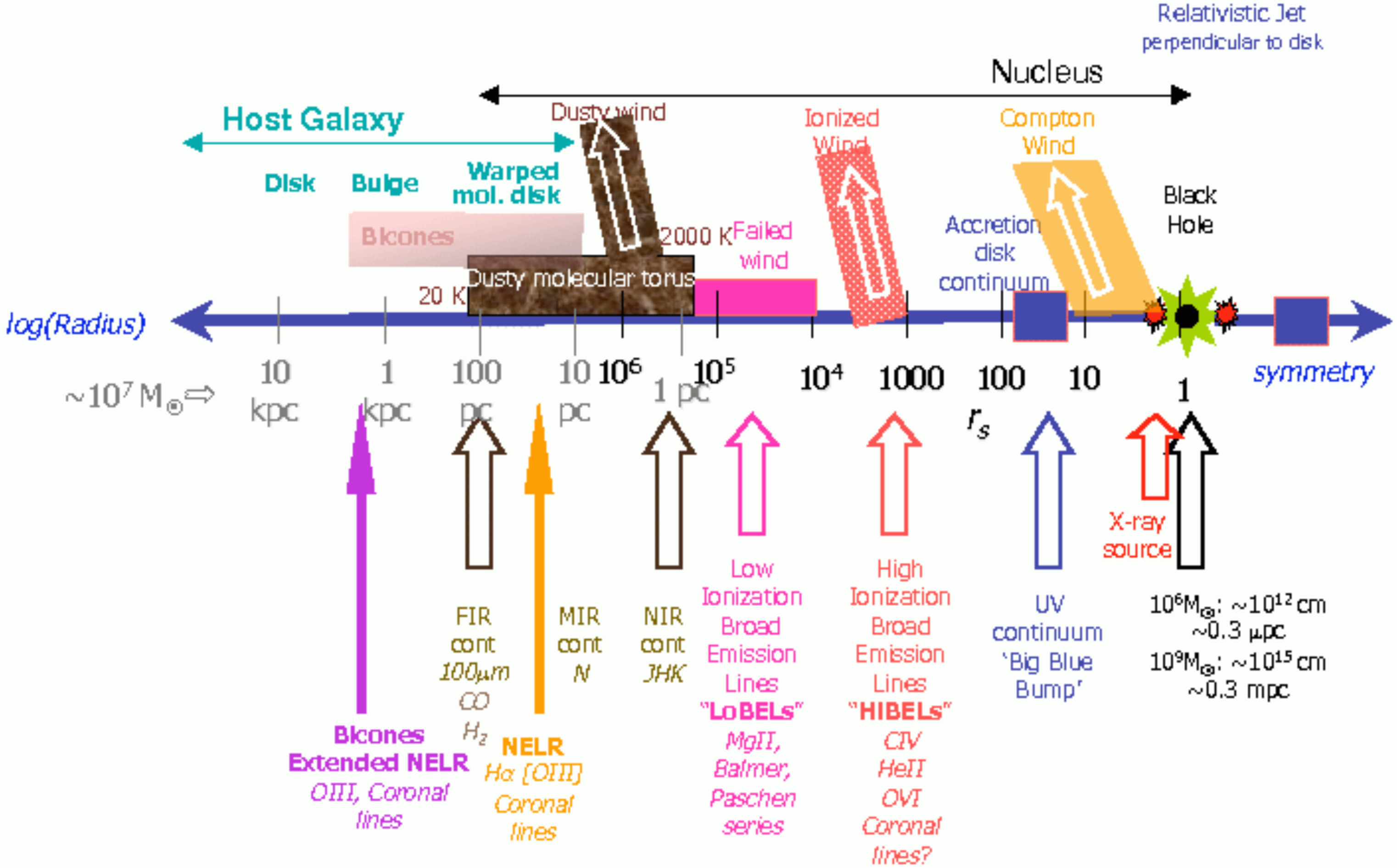
Urry & Padovani 2002

Seminal image, close to the mark



Elvis 2000 updated in 2004 (and various iterations on this theme)

Scale of Quasar/AGN Components



Martin Elvis, September 2007

Some observations to get started

- There have been over 20k papers published with quasar in the title and a further 30k referring to quasars in the abstract, but…
- we still have a poor understanding of what we are observing ie model for the inner region,
- due to the small scales, ~ micro-arcseconds

Why lensing?

position. For the same quasar, Corrigan *et al.*(1991) found weak evidence for colour changes in one image as a function of amplification. Such observations might provide information about the spectral profile of the continuum source. For the BAL quasar, 1413+117, Angonin *et al.*(1990) found evidence for differences in structure of the absorption troughs in different images. These might be due to either variability in the source or to differential amplification of different parts of the source.

Gravitational microlensing can resolve structure in extragalactic sources on much smaller scales than any other know technique, *i. e.*microarcsecond scales. However this is a telescope over which we have no control – we are not able to chose our sources, nor our microlenses. In particular, we cannot chose the mass distribution in the lens, and must work not only with the imperfect focus that a compact object provides, but usually with the complex network of caustics realised from an ensemble of compact objects. Deconvolution techniques for the light curves are still in their infancy. Nevertheless, signficant progress has been made, and we might expect that consistent monitoring of selected objects both by direct imaging and spectroscopy, might provide a wealth of information, particularly on the structure of quasars.

Webster 1994

The microlensing approach

- Optical depth to microlensing ~1 → caustic network
- Potential approaches (incomplete!):
  - Single epoch + macro-imaged spectral
  - Lightcurves, multi-band
  - Target-of-opportunity: caustic-crossings
  - Statistical populations: uniform angle-of-viewing
- Disk-wind model + opaque torus
- Opaque accretion disk → only view the forward side of the wind/disk
- KISS

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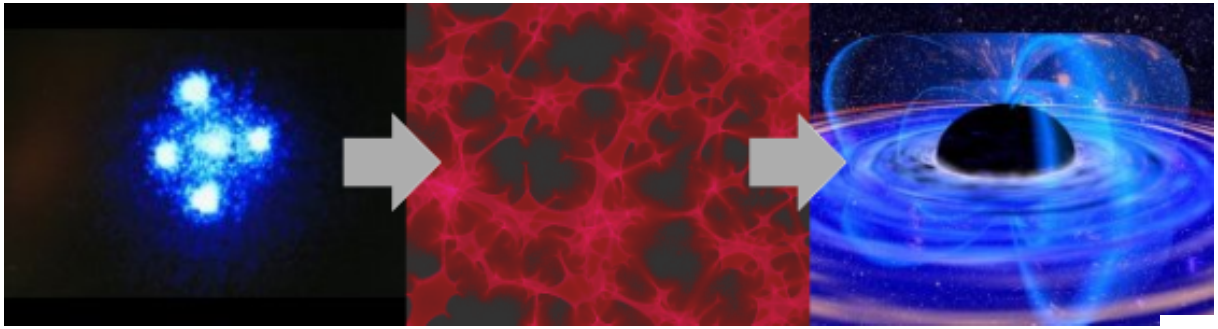
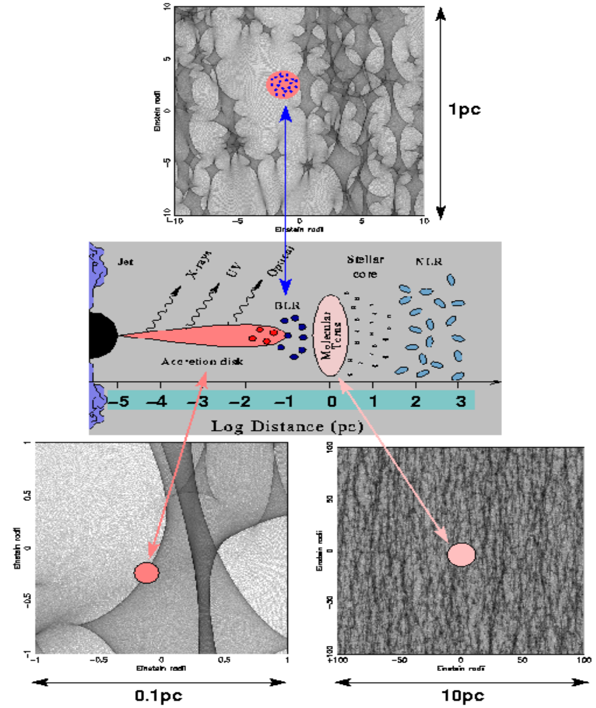
Peeling the onion

- Special classes of quasars provide insights:
- BALs, Anomalous....
- Axi-symmetric → direction matters
- Need all elements to resolve the structure

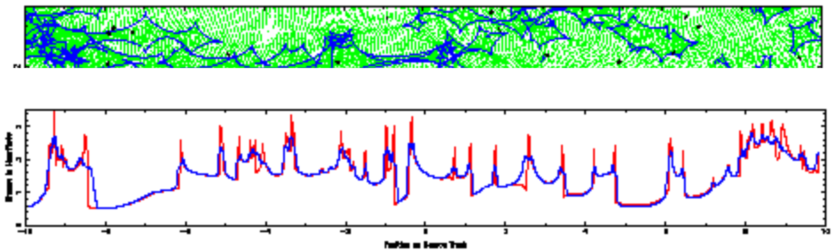


Key Elements

Gerlumph: microlensing simulations
Fluke&Vernardos

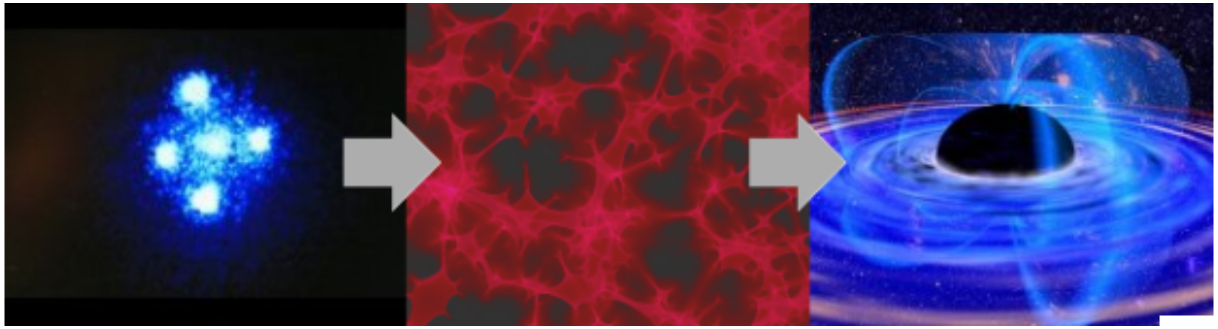


Lightcurves show variation on observable timescales



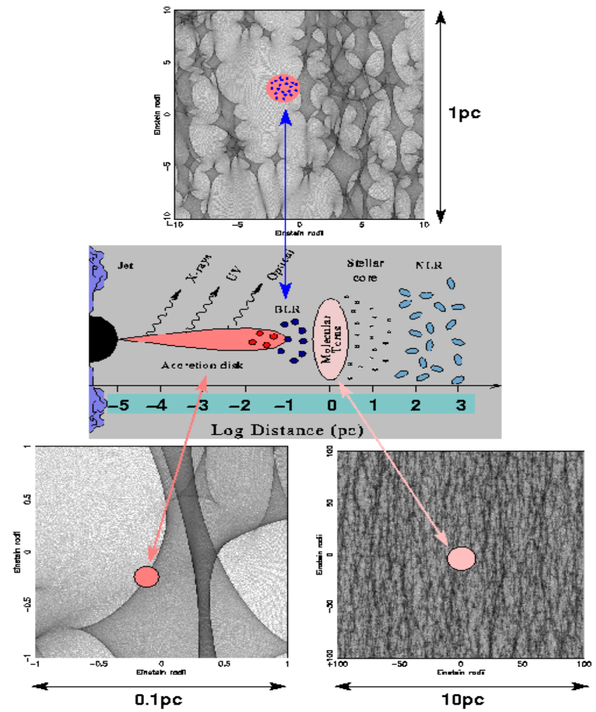
Different image scales show different magnification lightcurves

Key Elements

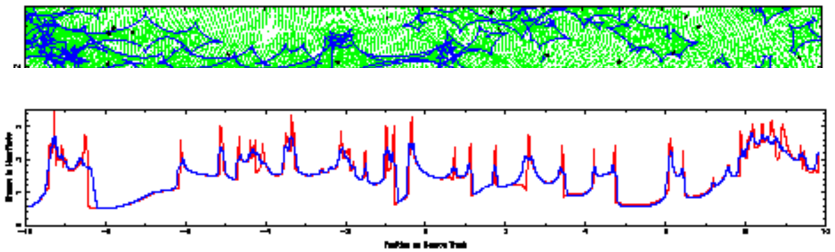


Gerlumph: microlensing simulations
Fluke&Vernardos

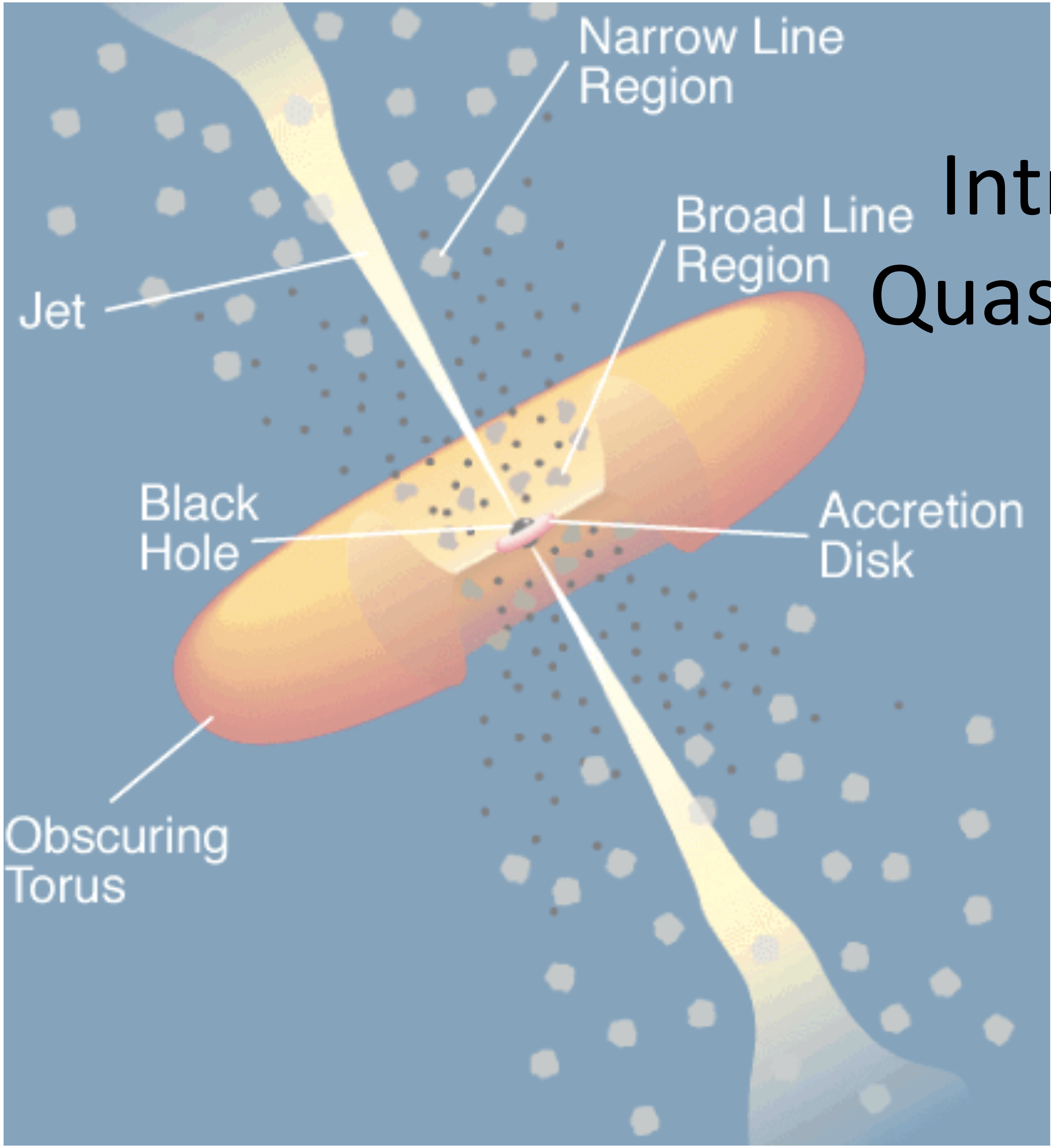
+ quasar models



Lightcurves show variation on observable timescales



Different image scales show different magnification lightcurves



Introduction to Quasar Structure

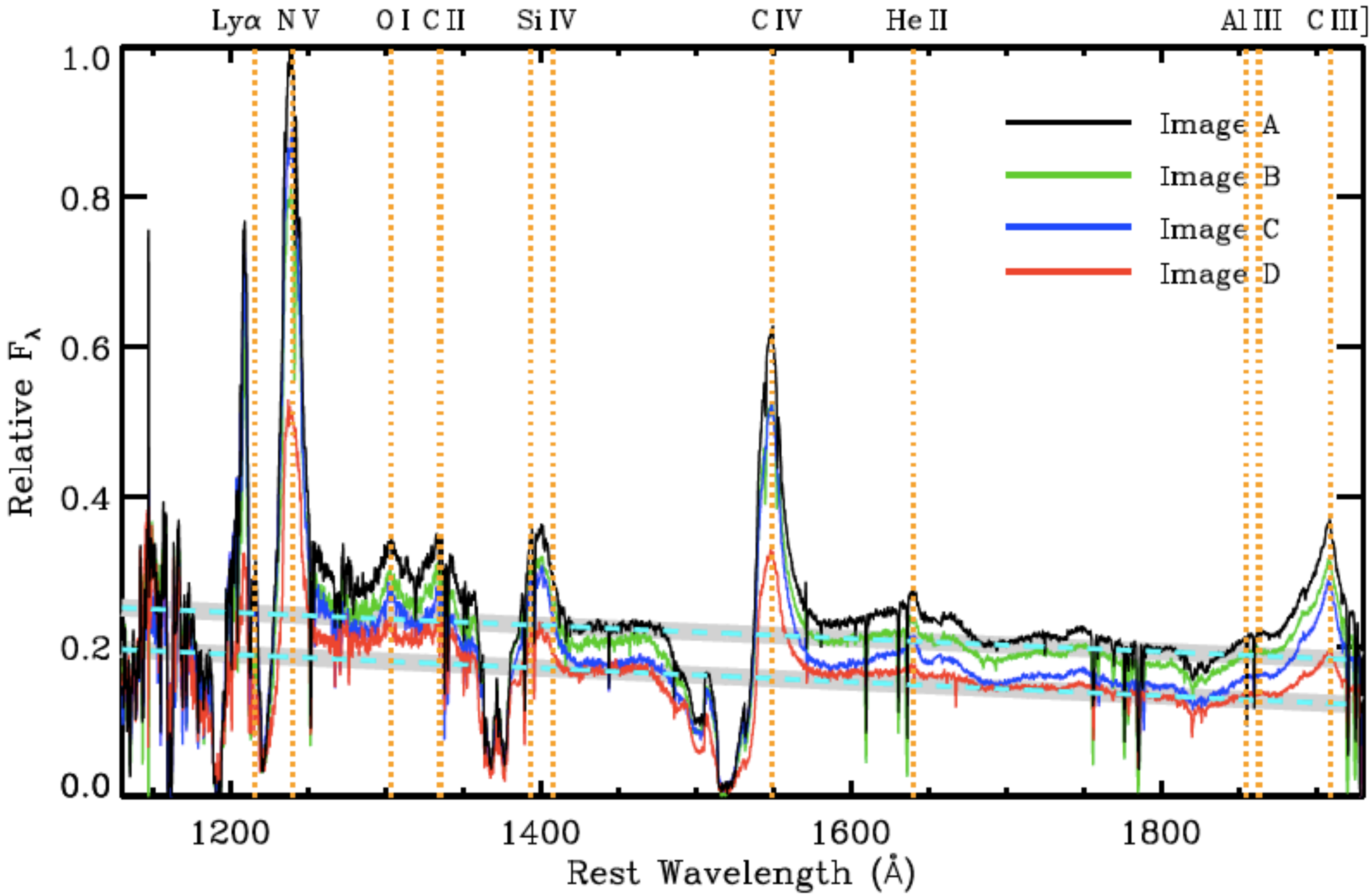
Part 2

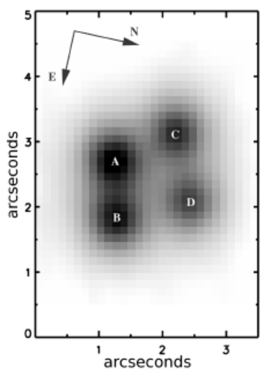
BALs: unique probes

Two experiments:

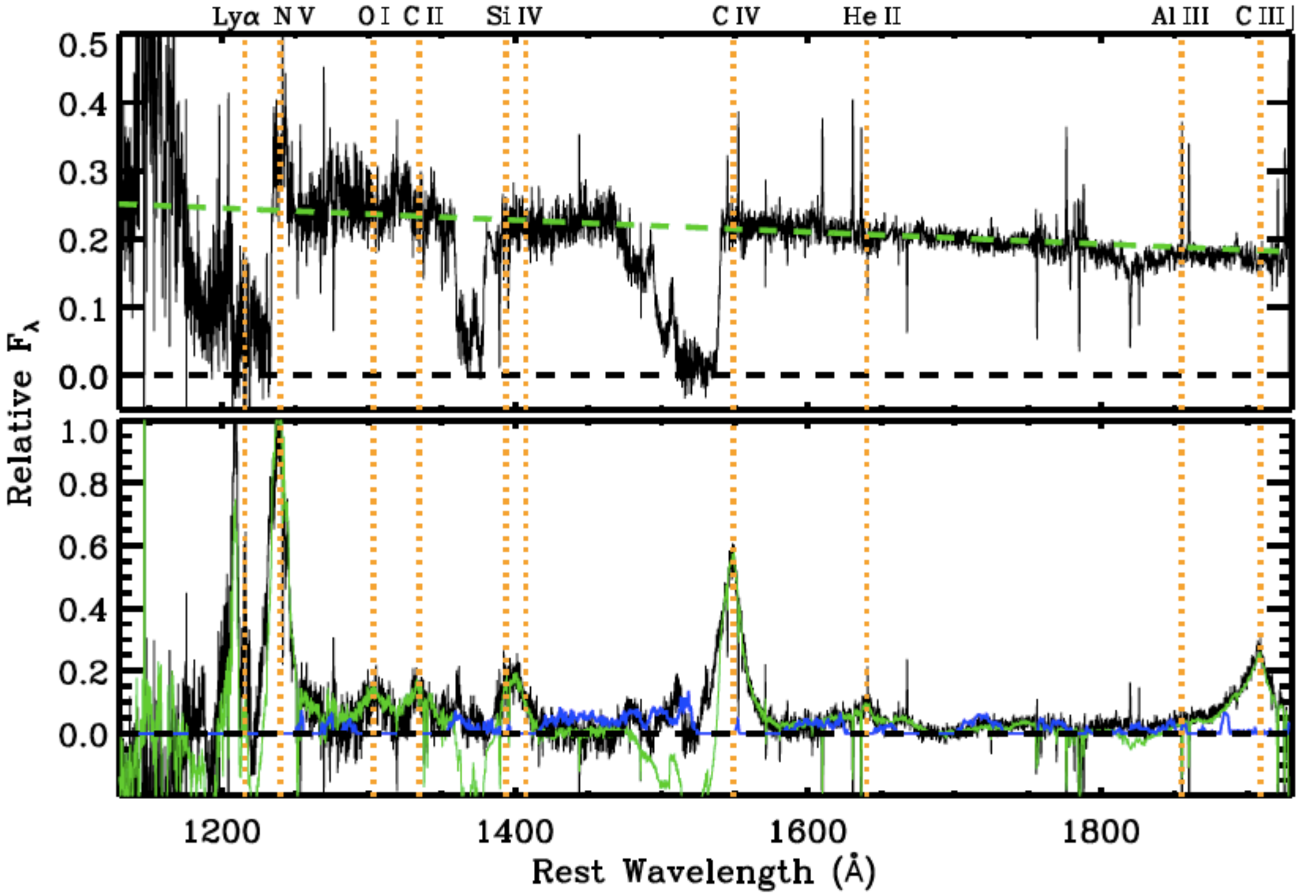
- H1413+117 using high resolution IFU spectra (O'Dowd+:2015)
- Statistical study using SDSS sample

  (Yong+: 2017)
- (Extended statistical follow-up)





BAL H1413 +117: very high quality Gemini GMOS IFU data



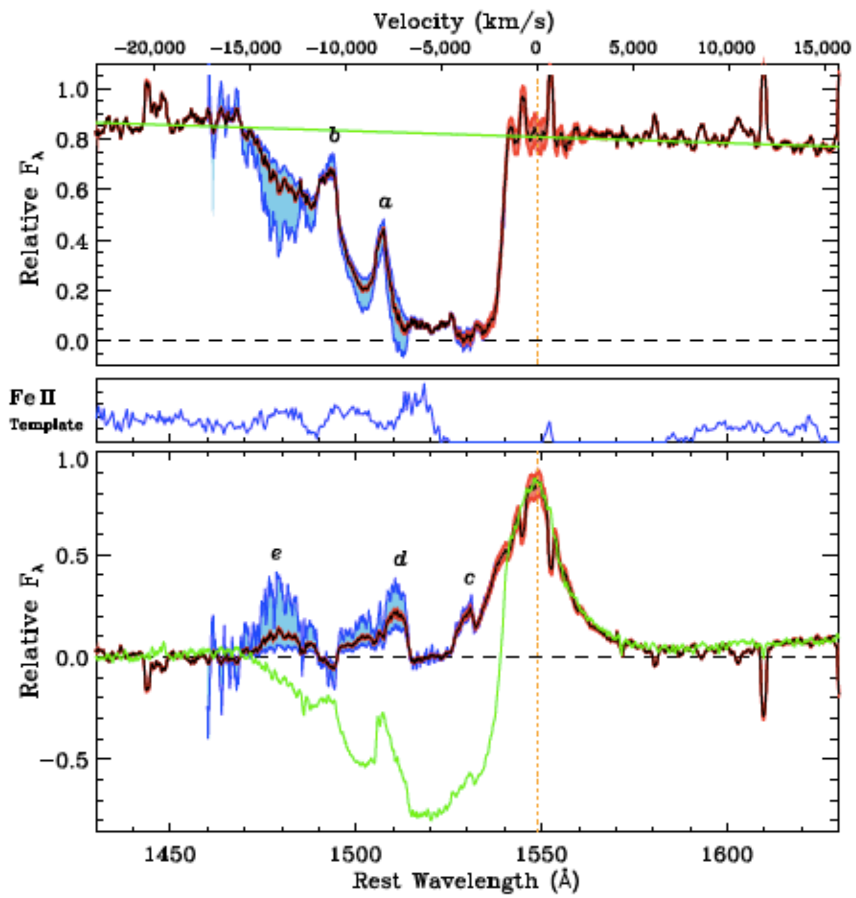
continuum

BELR

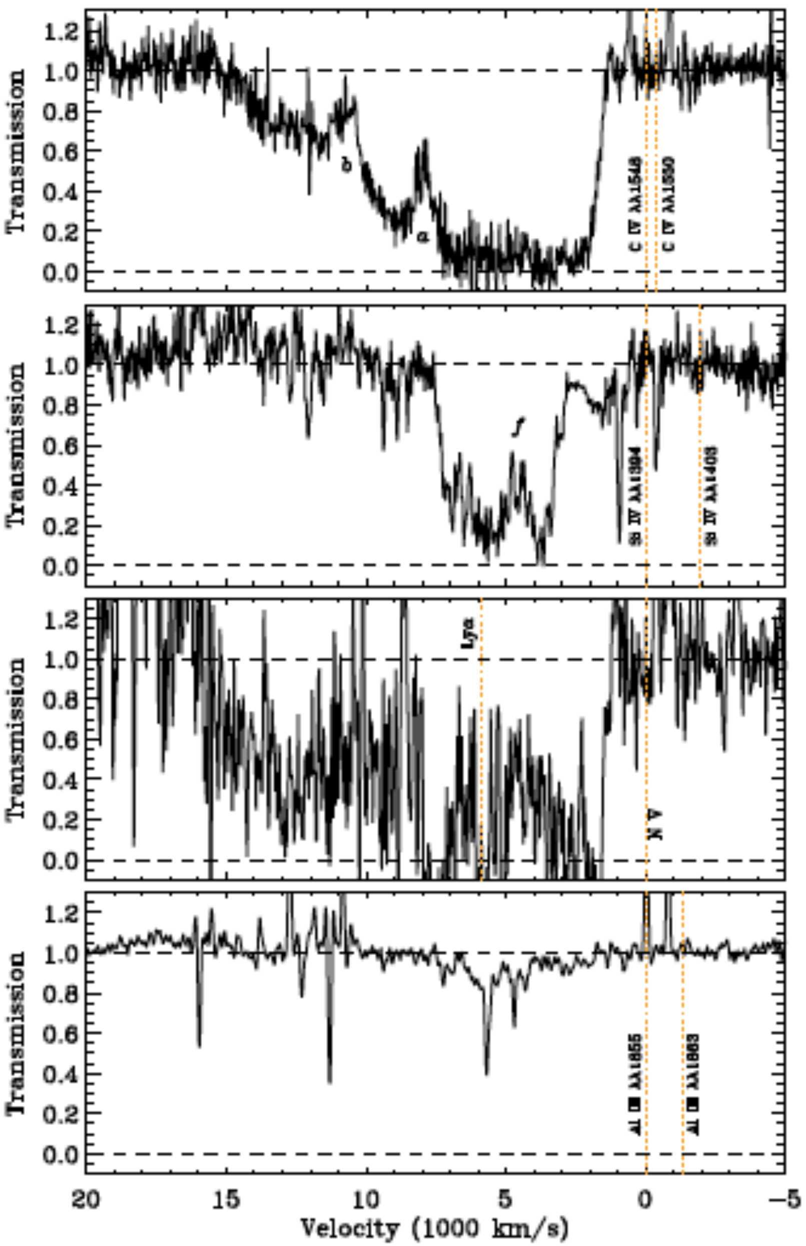
Deconvolve into continuum and line with different microlensing configurations

$$\mathbf{F}_1 = \mathbf{m}_{C,1}\mathbf{A}_C\mathbf{F}_C + \mathbf{m}_{L,1}\mathbf{A}_L\mathbf{F}_L$$

$$\mathbf{F}_2 = \mathbf{m}_{C,2}\mathbf{A}_C\mathbf{F}_C + \mathbf{m}_{L,2}\mathbf{A}_L\mathbf{F}_L$$



Blowup of CIV line and absorption trough – note the offset of absorption from the peak of emission and the rapid onset of that absorption



Absorption associated with lines of different ionisation and their relative offsets

BALs: what did we learn?

- The offset for CIV and NV is ~1500km/sec: this shows where the line-of-sight to the UV continuum intersects with the outflowing wind
- The strong absorption suggests a high covering factor at high velocities, ie large radii and wide spatial region
- The BAL absorption is clumpy

Modelling

- Yong MSc, 2015

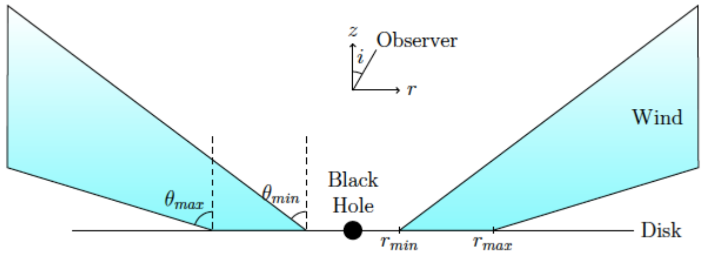
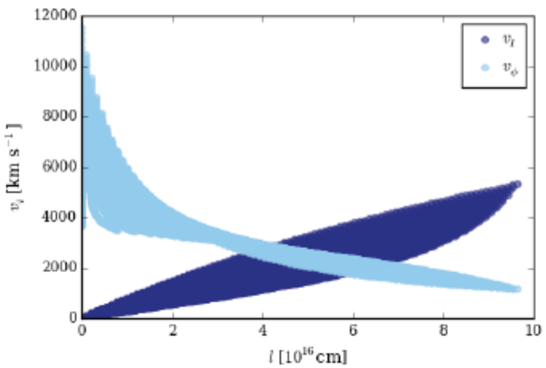
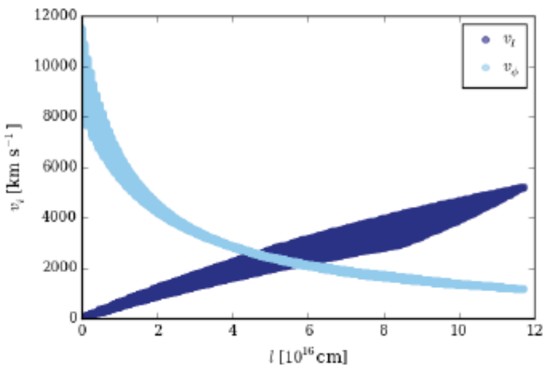
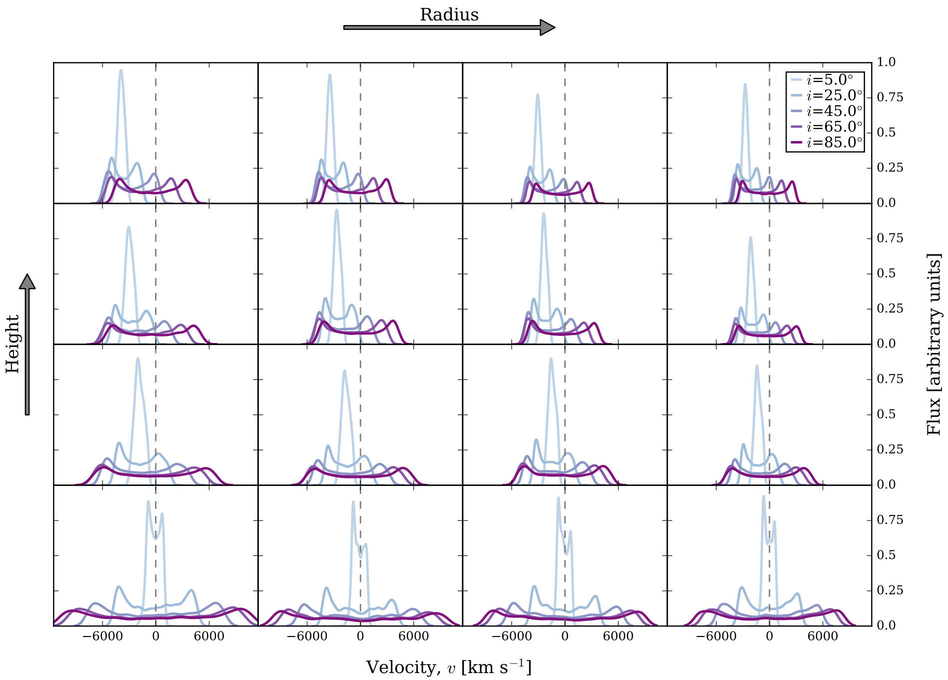


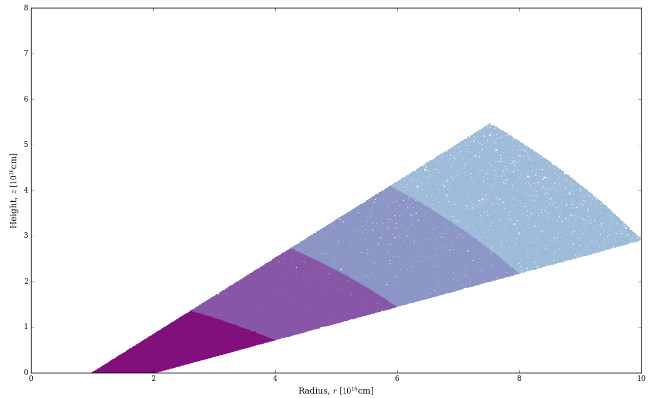
Figure 5.1: Cylindrical disk wind model.

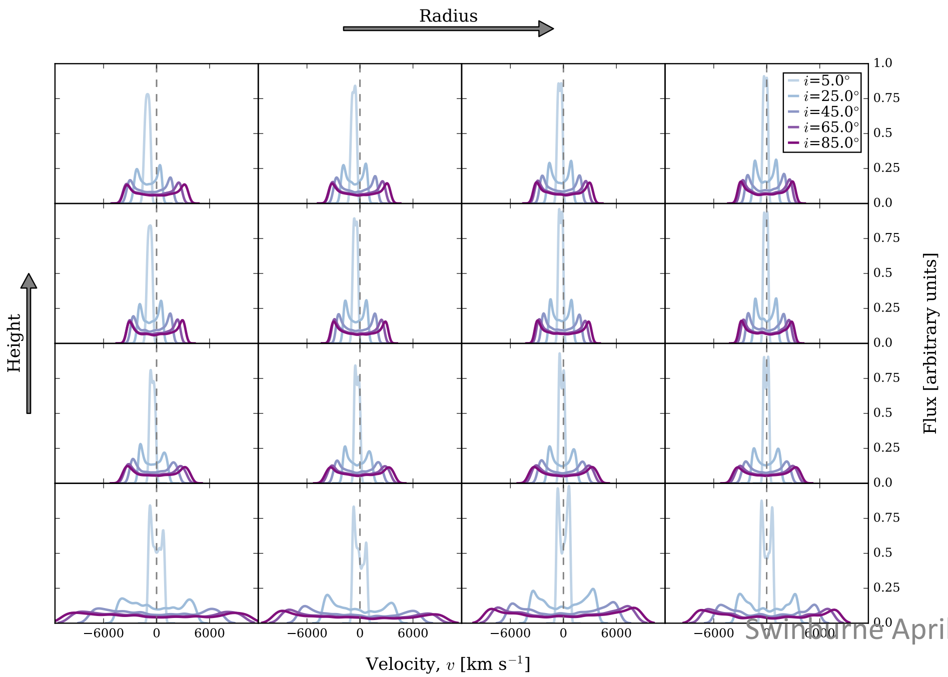

(a) M95 model


(b) E04 model

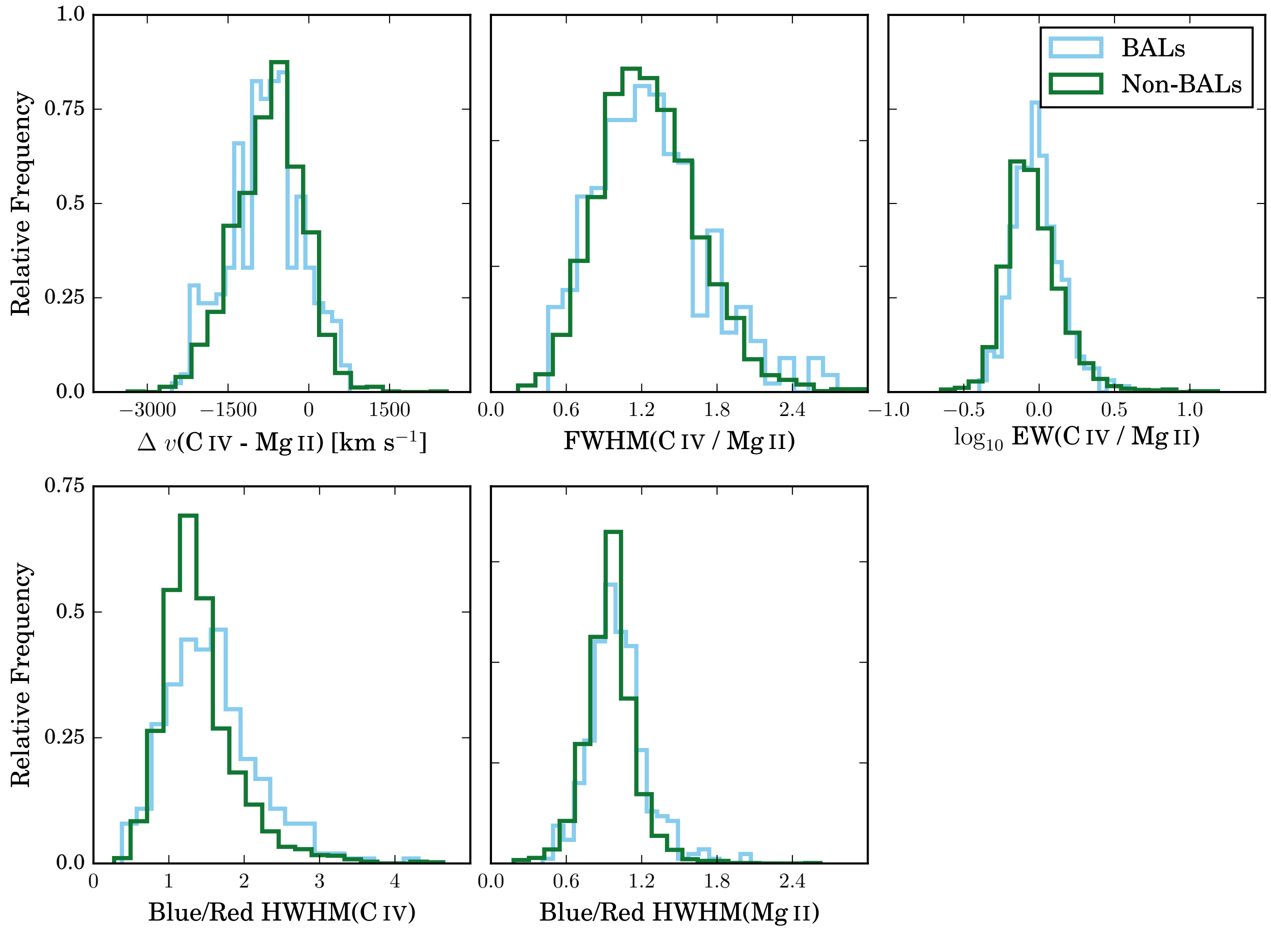
A dynamical model with M_{BH}, rotational and poloidal wind components, but no photoionisation. Emission ~ gas density.







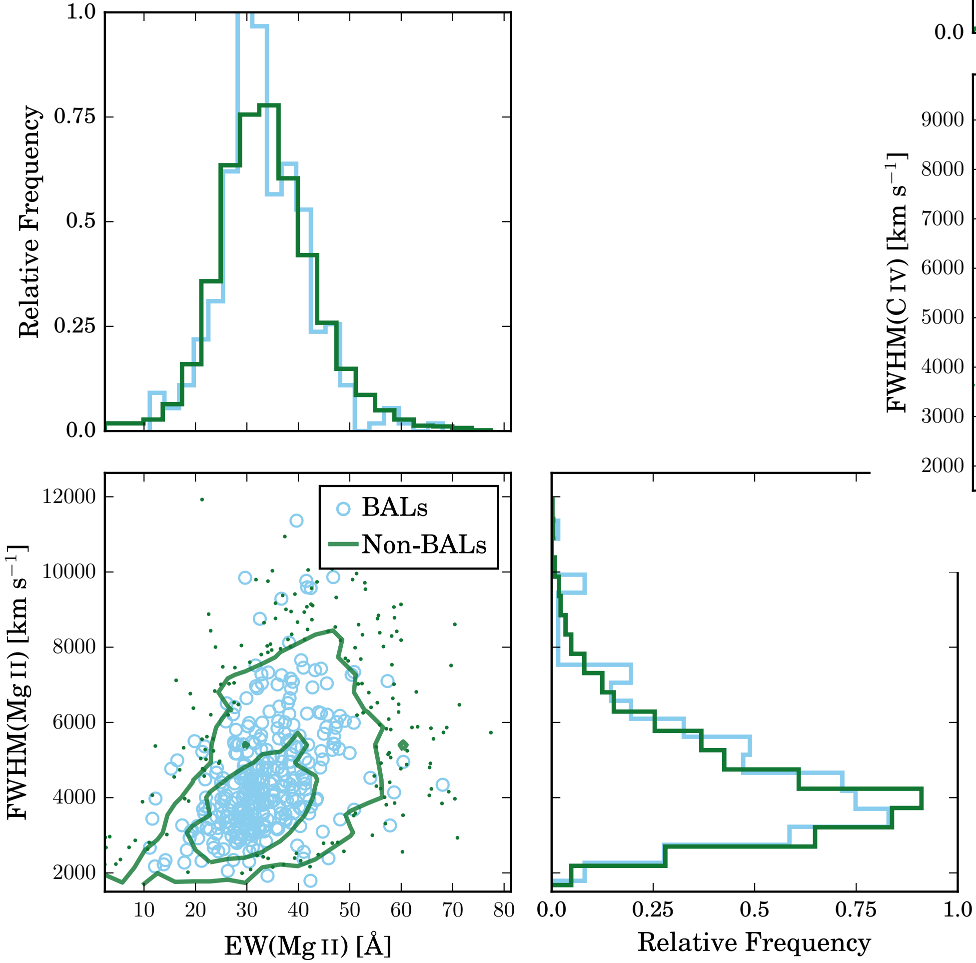
Velocity offsets → angle of viewing
FWHM → angle of viewing

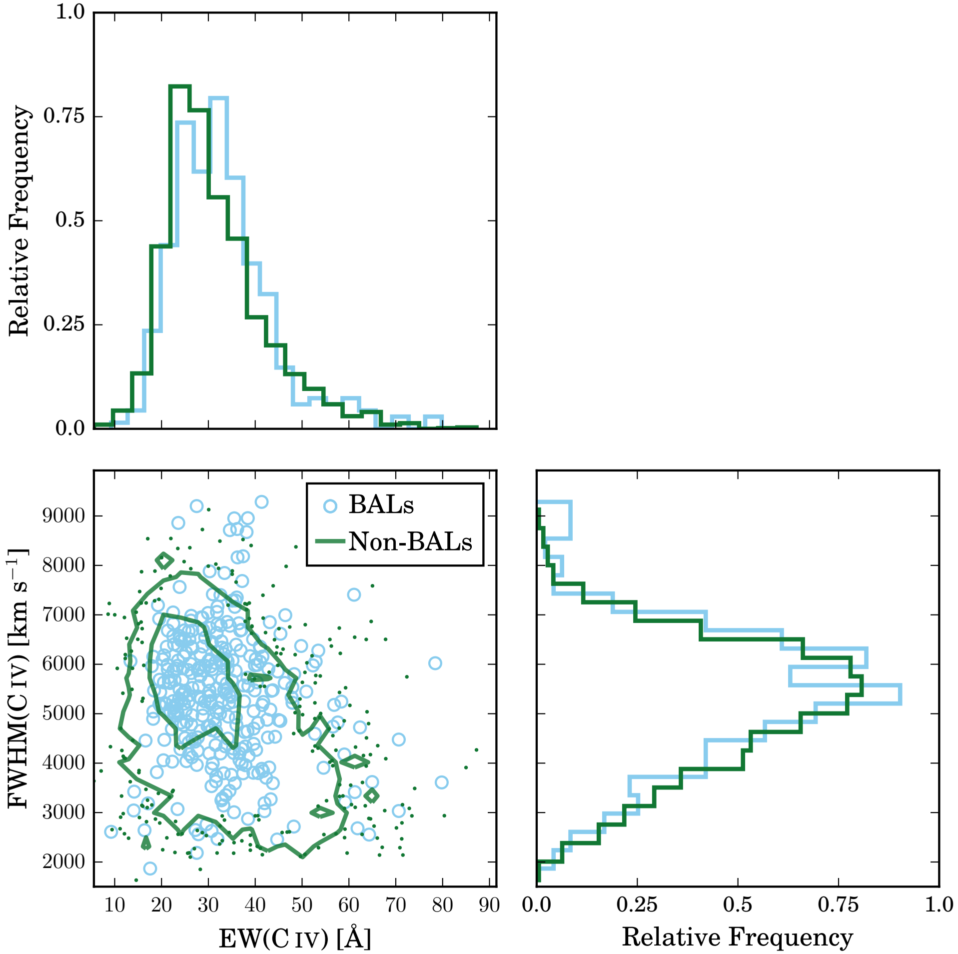


A complete SDSS sample of high S/N quasars in the redshift range 1.4<z<2.6 to include CIV and MgII - ~12% and ~0.5% absorption respectively.

- Note the similarities in distributions of different line parameters

Closer inspection reveals some trends; with less obvious interpretation





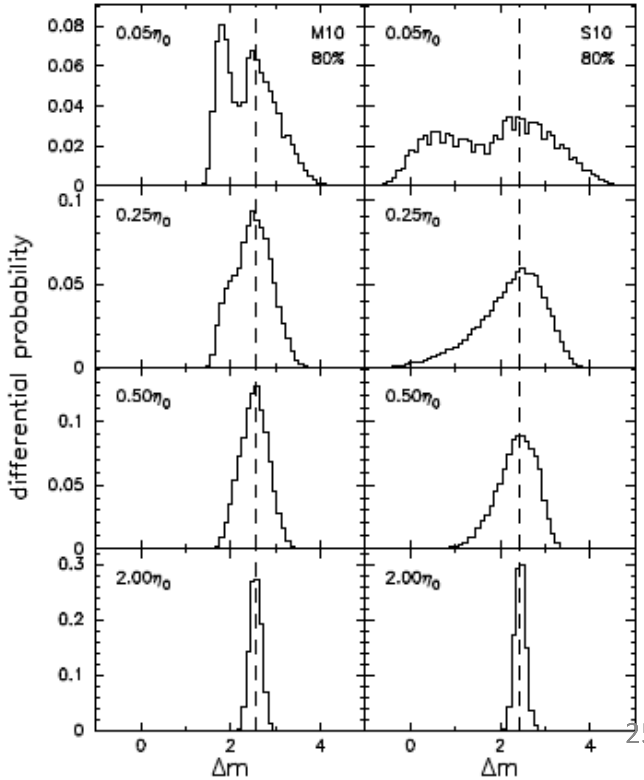
BALs: what did we learn? - 2

- Strong evidence for the disk-wind model
- We do not observe BALs along (very) different lines-of-sight ie they can be observed along any line-of-sight
- But not all lines-of-sight give a BAL
- Indeed different lines-of-sight give different sorts of BALs
- Velocity offsets measure the projected poloidal velocity ie outflow for a particular line
- A 'narrow' wind would give constrained FWHM, velocity offsets etc

→ the wind has a large opening angle, and variable optical depth

Accretion disk profile

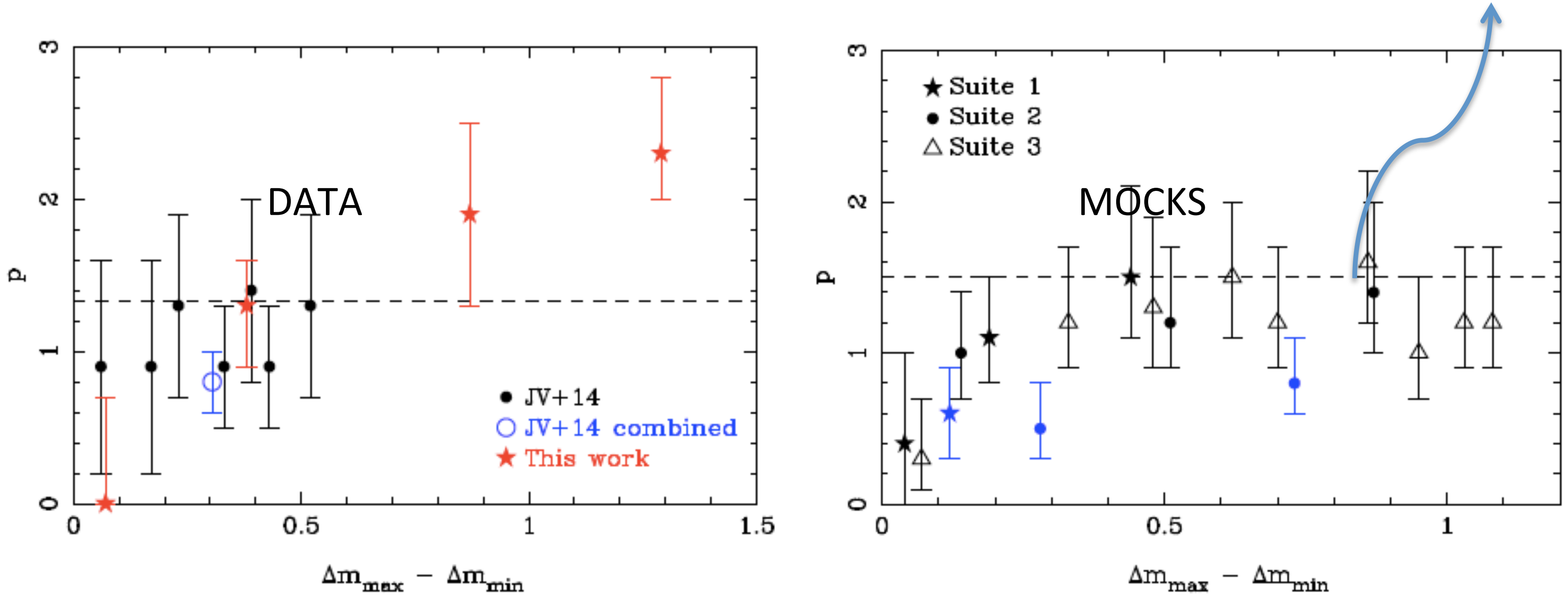
- Do we see an Shakua-Sunyaev disk profile?
- Size affects magnification (Bate+: 2007)
- Can we use single epoch
- Images to obtain profiles?
- Single epoch results all over the place
- New HST images → galaxy rings + new data



- New HST imaging – ~7 bandpasses
- 4 sources test ‘single epoch imaging’
- (others show Einstein rings)
- p=4/3 → SS disk
- Single epoch observations only valid if Δm is large

$$r = r_s \left(\frac{\lambda}{\lambda_0} \right)^p$$

input profile



Disk profiles: what we learned

- Ensembles with low Δm don't return valid measurements
- But high Δm's are valid
- One strong measurement, $p > 4/3$ → shallower temperature profile,
- and a larger accretion disk
- → we do not see an SS accretion disk with the continuum emission

Finally, angle-of viewing

Simple modeling suggests that angle-of-viewing affects

- Velocity offsets, +
- FWHM

- Can we use these correlations to measure angle-of-viewing?
- BLR velocities scale with $M_{BH,}$ angle-of-viewing, geometry
- Simple model: predicts obscuration by torus of ~40^o
- Difficult to test
- But sensible and consistent

Summary

- Data: high image, spectral and angular resolution
- (high cadence temporal datasets coming)
- Modeling sophistication – dynamics& kinematics + photoionisation
- Breaking degeneracies with lensing: microlensing networks now 'available'
- Much, much more to be done