Quasars & Galaxy Evolution

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Quasars

…are accreting super-massive black holes (SMBH), with:

$L \sim 10^{46}$ to 10^{48} ergs/s

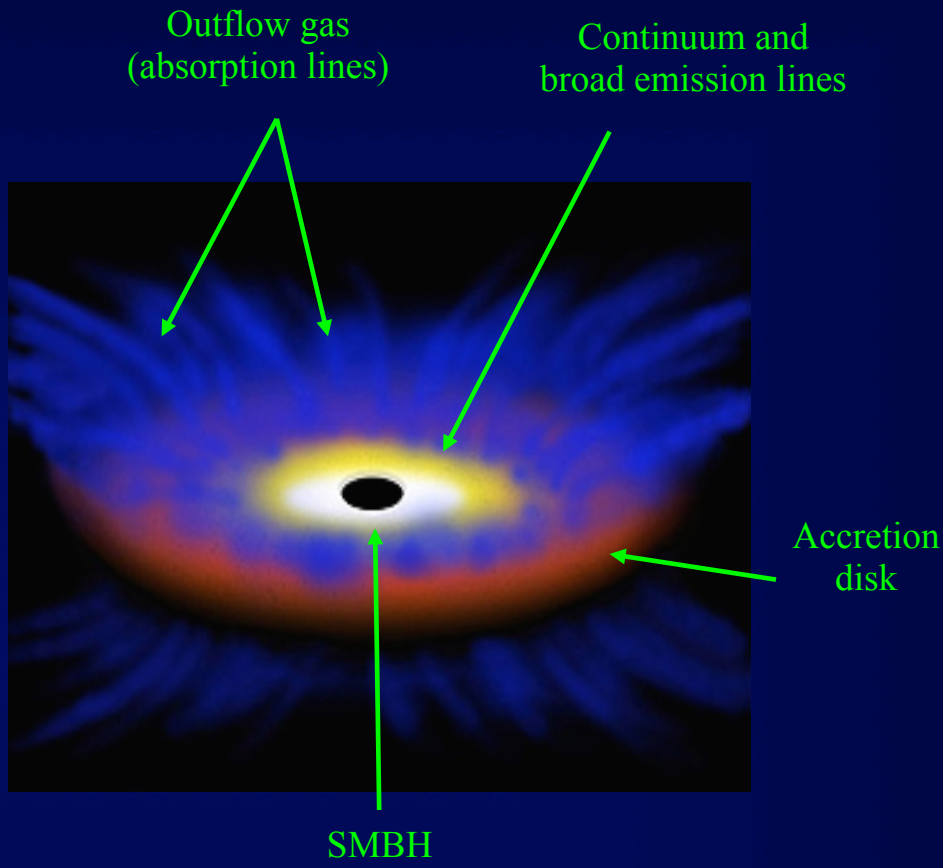
$R_{cont} < 0.01$ pc

$L \sim \eta \dot{M} c^2$

$\dot{M} \sim 0.6$ to 60 M_o/yr

$M_{BH} \sim 10^8$ to 10^{10} M_o

Quasars mark major short-lived episodes of SMBH growth, lasting just 10^7 - 10^8 yr.

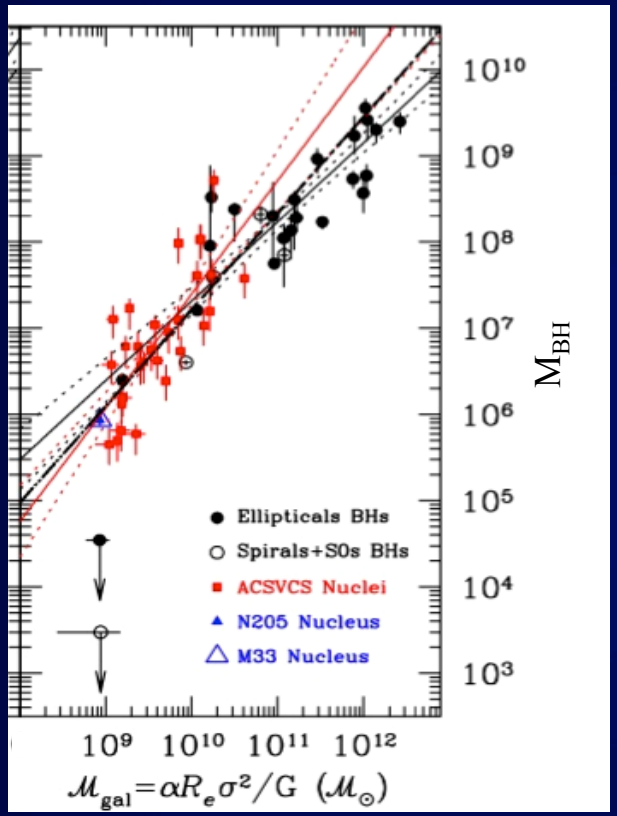


How are quasars related to galaxies?

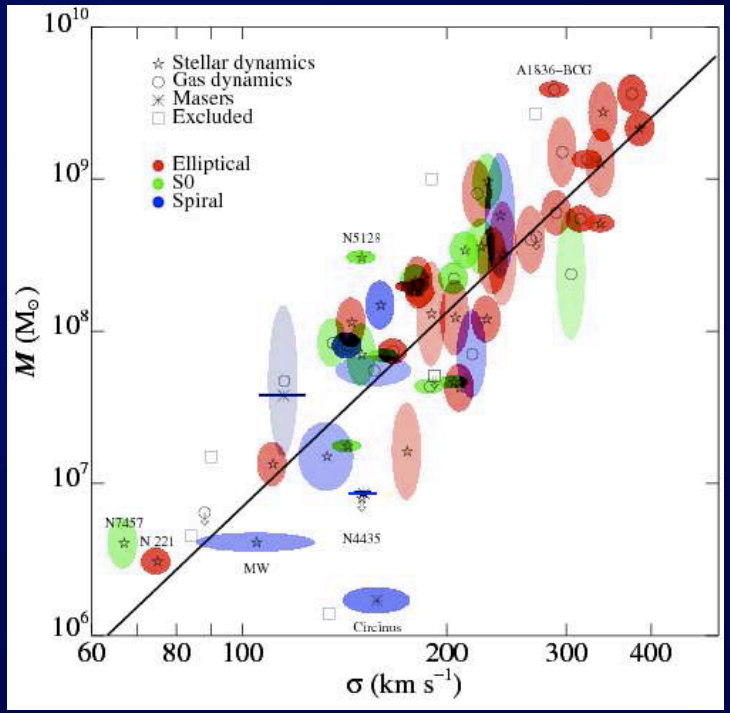
Quasars & Galaxies

SMBHs are byproducts of galactic spheroid formation.

Massive ellipticals were all quasar hosts, during the SMBH growth phase, at high redshifts.



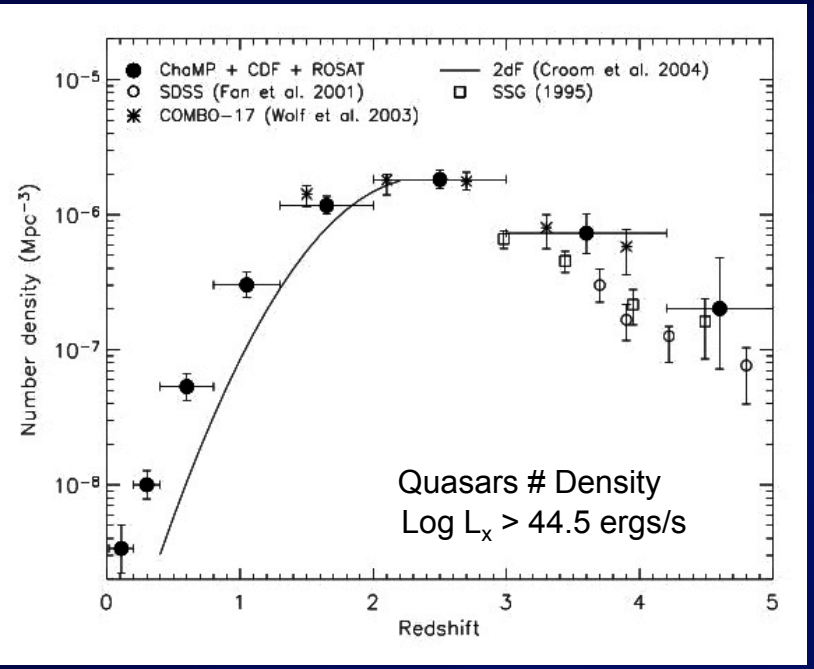
Super-Massive Black Holes (SMBHs) have ~0.2% of the host spheroid mass



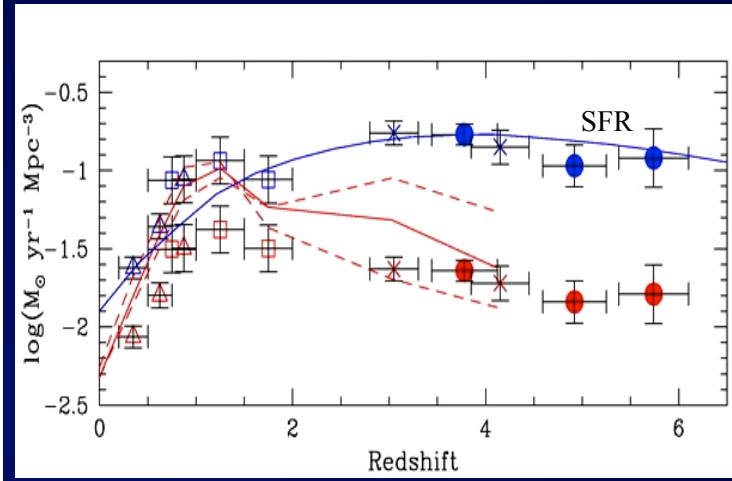
Ferrarese et al. 2006

Gultekin et al. 2009

Quasar & Galaxies

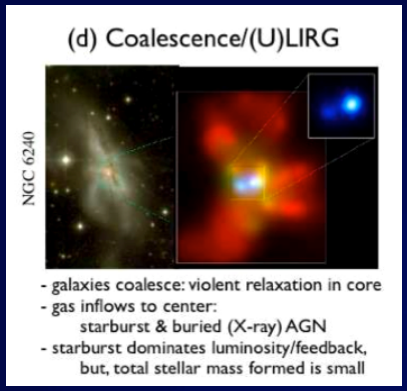


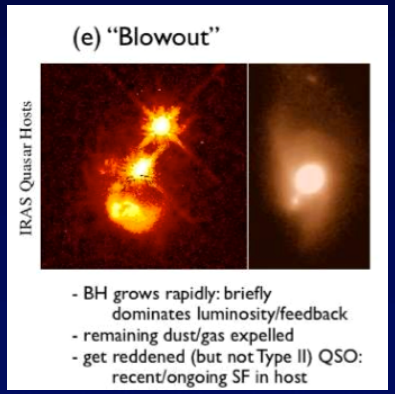
Silverman et al. 2005

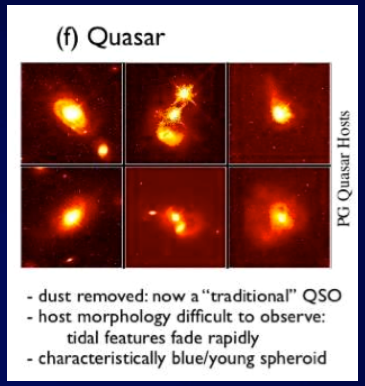


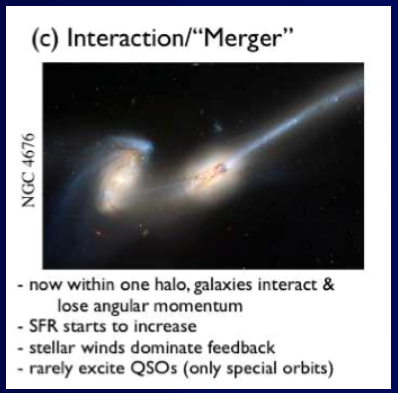
Giavalisco et al. 2003 + Merloni et al. 2004

The quasar epoch ~ coincides with the main period of star formation in massive spheroids/elliptical galaxies.









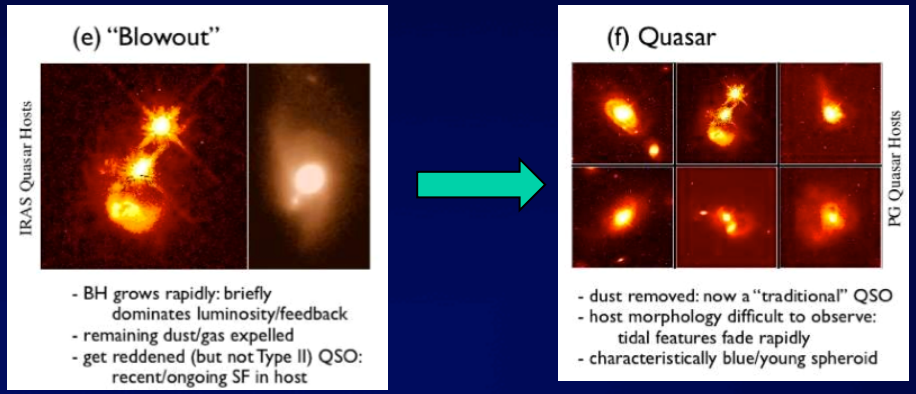
A plausible evolution scheme:

1) Gas-rich merger
2) ULIRG / starburst
3) Blowout of gas and dust
4) Visible quasar
5) Red & dead

Hopkins et al. 2008, Sanders et al. 1988

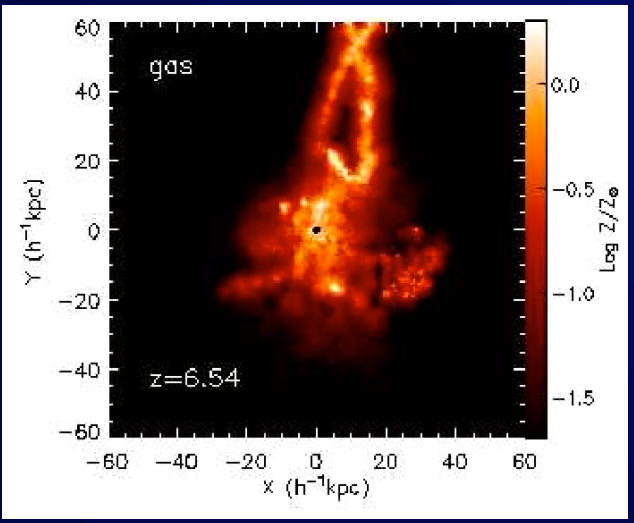
Quasars are bright continuum sources shinning thru this gas..

➔absorption lines!
➔ gas speeds, column densities, metallicities, constraints on models..



The blowouts and remnants of messy mergers *should* be metal rich at speeds < 1000 km/s

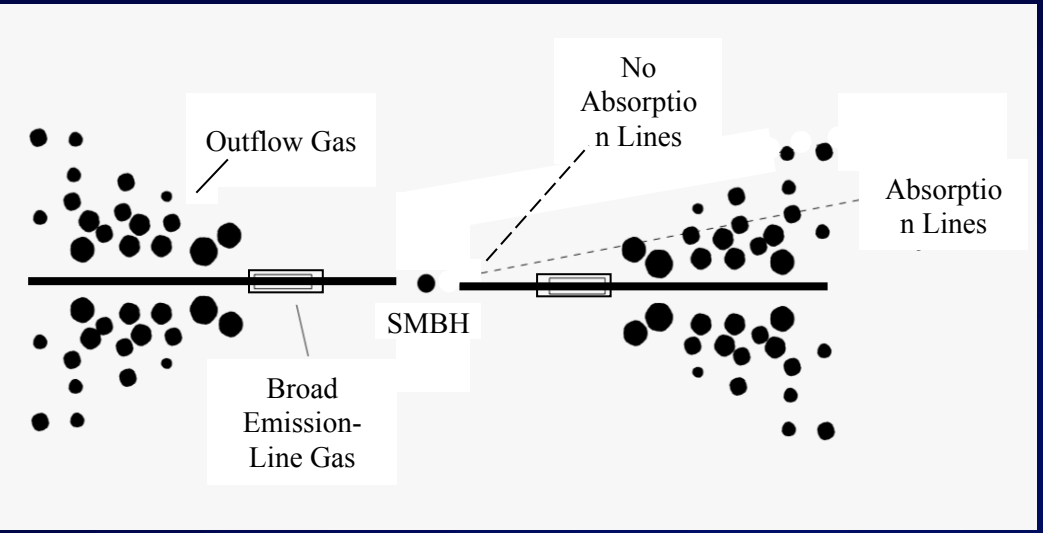
Narrow absorption lines (NALs)



Di Matteo et al. 2004

Topic 1: Use quasar NALs to measure the gaseous environs and test evolution models.

Metallicities constrain the amount of *prior*



Higher speed quasar winds are integral to the quasar/accretion phenomenon.

They might also drive galaxy-scale blowouts. In some models of galaxy formation,

e.g., to explain $M_{BH} \propto M_{gal}$

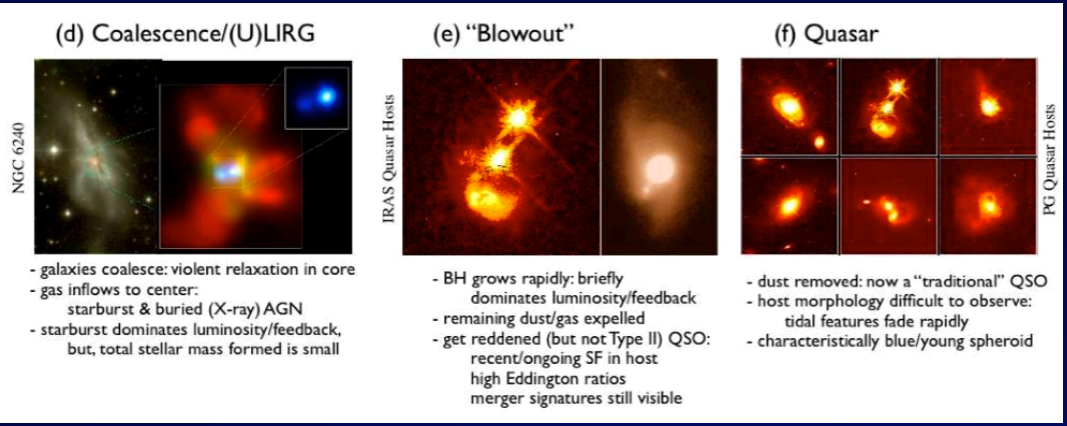
Quasar feedback halts SMBH growth and stops or inhibits star formation

Silk & Rees 1998, Kauffmann & Haehnelt 2000, Granato et al. 2004, Di Matteo et al. 2004, Hopkins et al. 2005-8, Springel et al. 2006, …

Topic 2:

Understand basic properties of quasar-driven ouflows (geometry, speeds, energetics, driving mechanisms, …).

How common are they? Do they evolve during quasar lifetimes? Are they energetically viable for feedback?



What is the relationship of quasars to galaxy assembly, star formation?

Other models invoke only secular processes in galaxies (not mergers) to fuel AGN and SF activity

This chronology makes predictions for the relation between quasars and star formation:

ULIRG → transition object → quasar

Red quasars?

Large L/L_{edd}?

Powerful outflows?

Topic 3:

Linking quasars to host galaxy evolution. Measure host properties and test evolution status using:

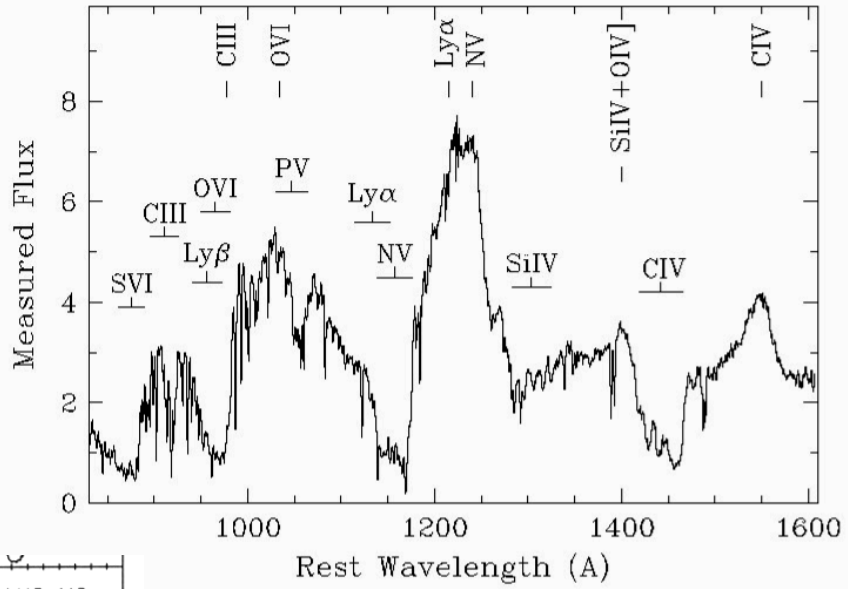
Sub-mm data to get SFRs, CO to measure molecular gas, multi-band images to get morphologies, age date stellar pops, merger status, cluster densities, masses..

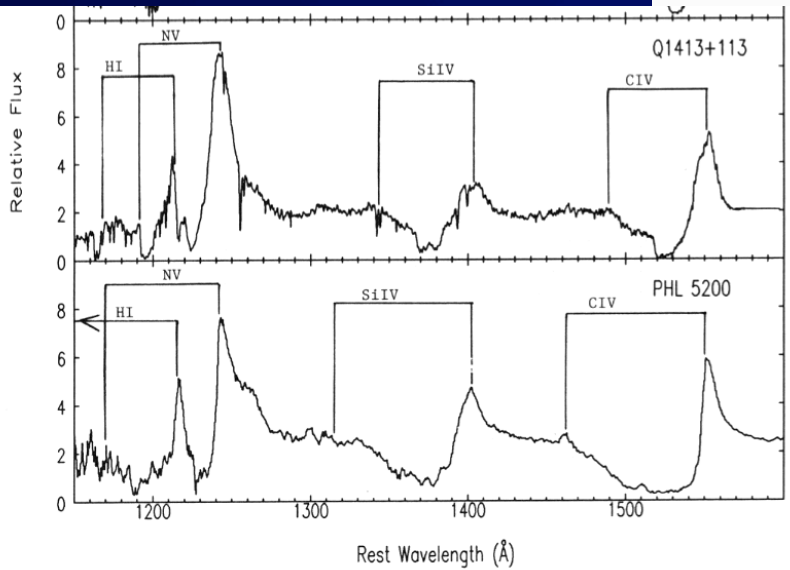
Obvious outflow lines:

Broad Absorption Lines (BALs)

Observed in 10-23% of optically-selected quasars

Probably present in all quasars with ~10-23% covering



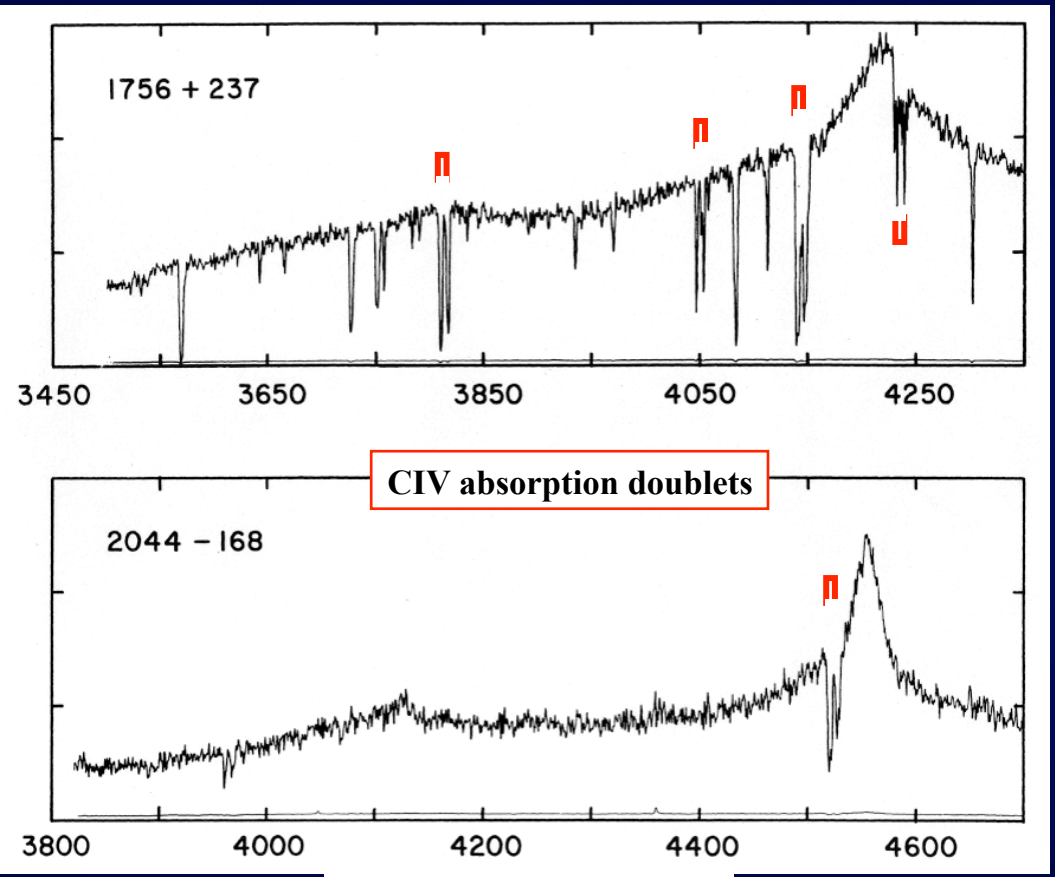


Launched from accretion disk

Measured flow speeds:
~5000 to >30,000 km/s

Possibly large mass loss rates,
with $\dot{M}_{out} \sim \dot{M}_{acc}$

Narrow Absorption Lines (NALs):



Foltz et al. 1986

Where do NALs form?

1) Quasar outflows

2) Intervening gas or galaxies

At $v < 1000$ km/s:

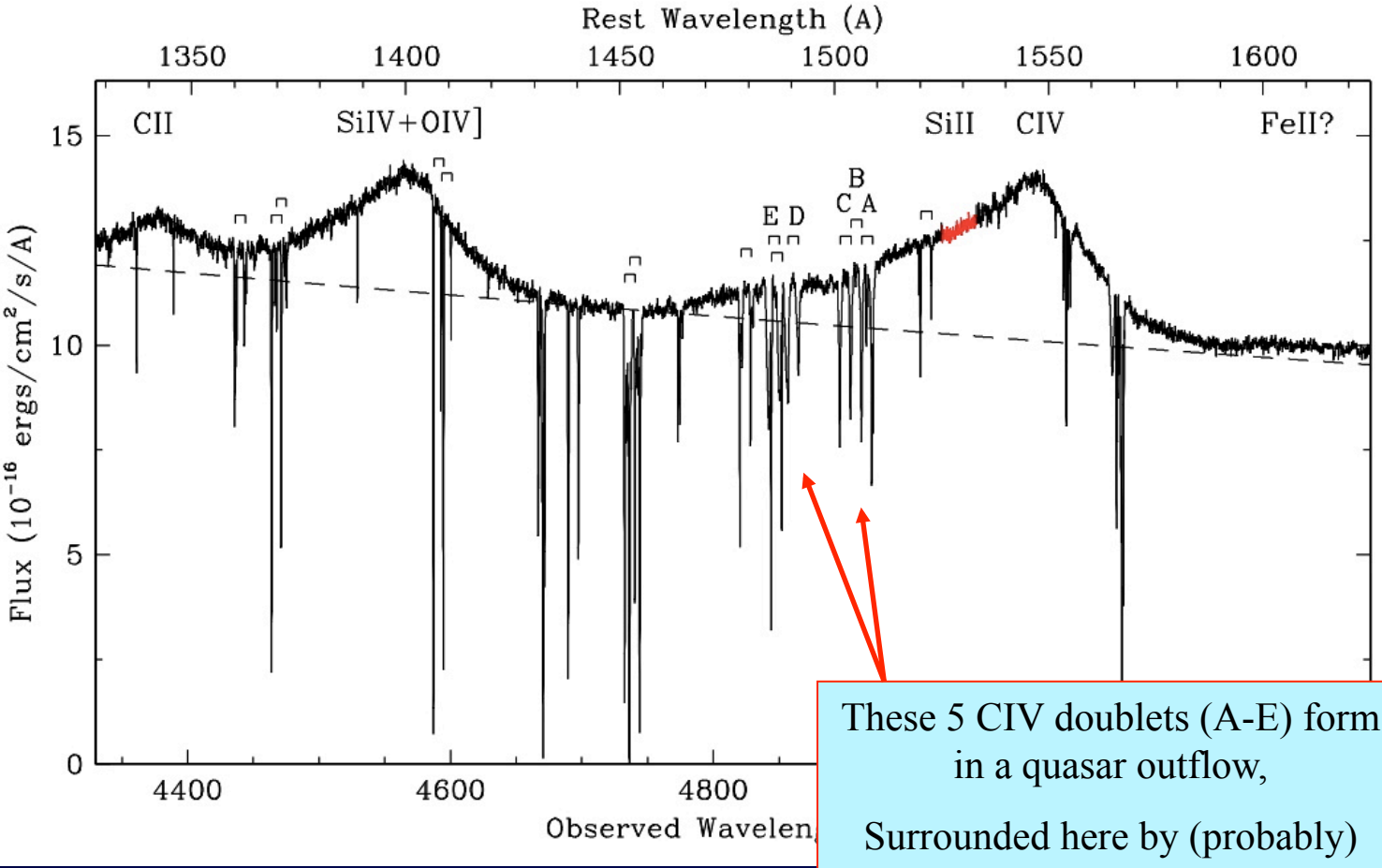
3) Mass-loaded quasar flows

4) Starburst-driven winds

5) Ambient halo gas

6) Merger remnants

Outflow NALs at 9700-14,000 km/s (in R~70,000 to 100,000 spectra, Keck, VLT)

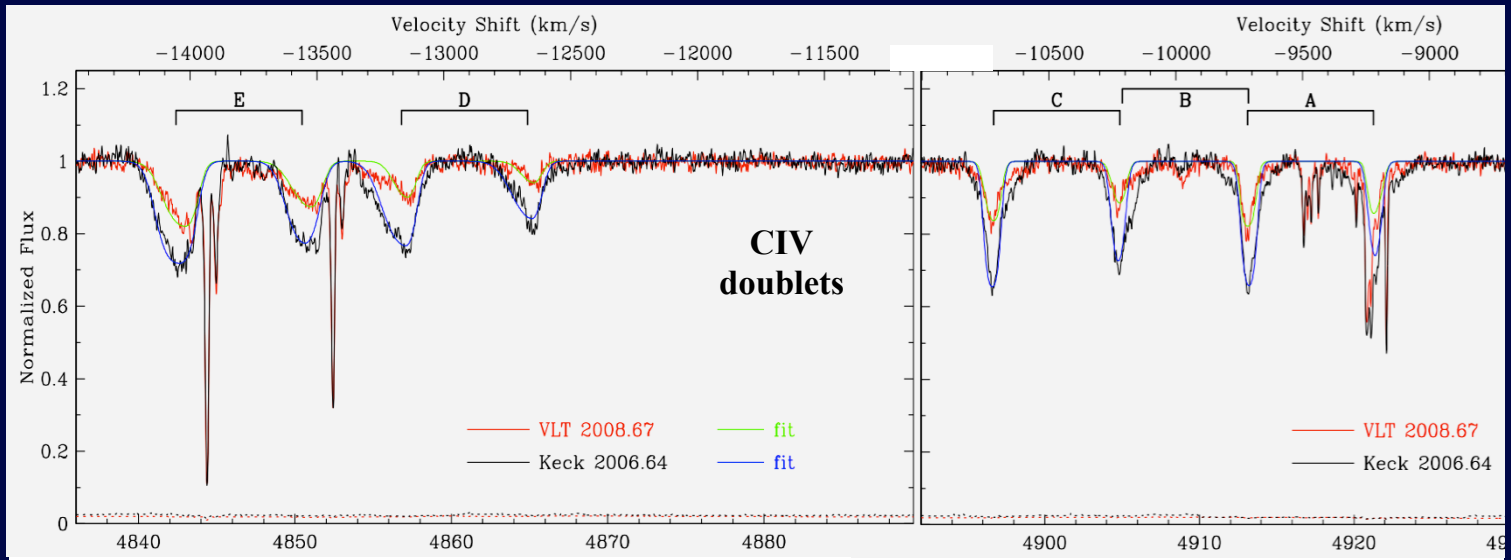


These 5 CIV doublets (A-E) form in a quasar outflow,

Surrounded here by (probably) unrelated intervening lines

QSO: z ~ 2.3, L ~ 8x10^{47} ergs/s, L/L$_E$ ~ 0.4

Hamann et al. 2011



Formation in a quasar-driven outflow confirmed by:

1) Line variability

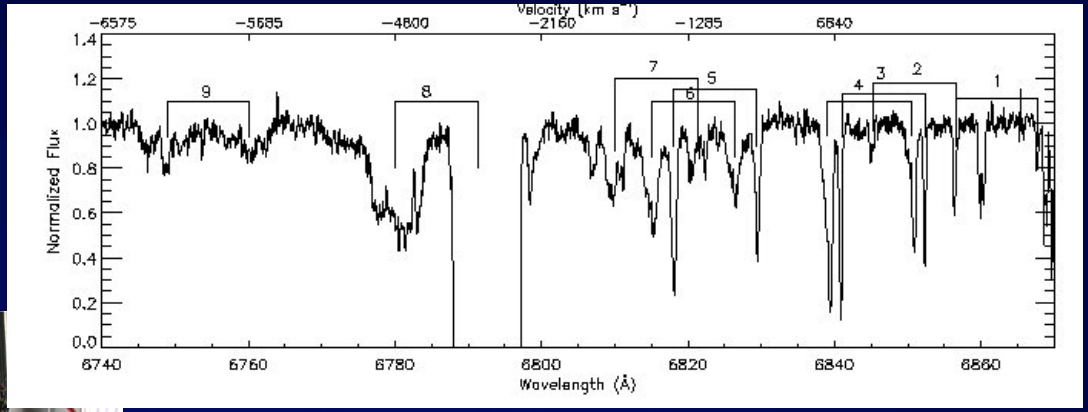
2) Smooth "broad" (very super-sonic) line profiles

3) Partial covering of the continuum source

➔ "Intrinsic" at speeds *much* too high for "environmental" gas.

Hamann et al. 2011

Simon et al. 2010, 11

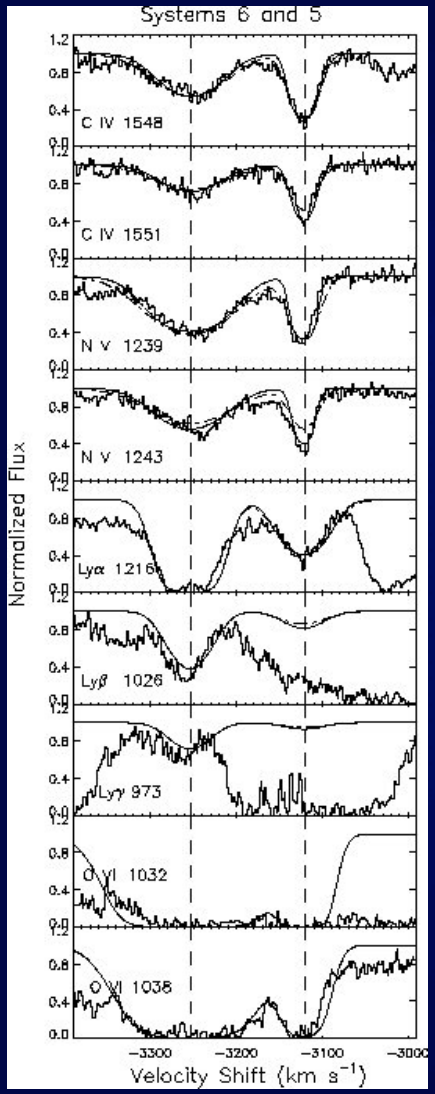


High resolution spectra of 24 high-z quasars,

Obtained at Keck, VLT, Magellan,

yield kinematics, column densities, ionization, abundances, crude locations

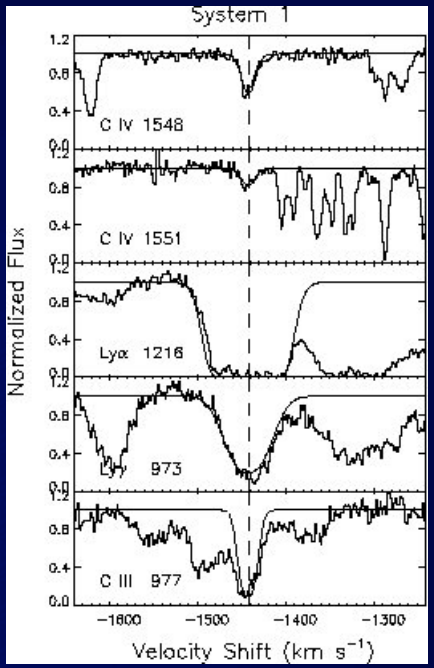
Plot above shows 9 CIV doublets in a quasar at redshift z ~ 3.4



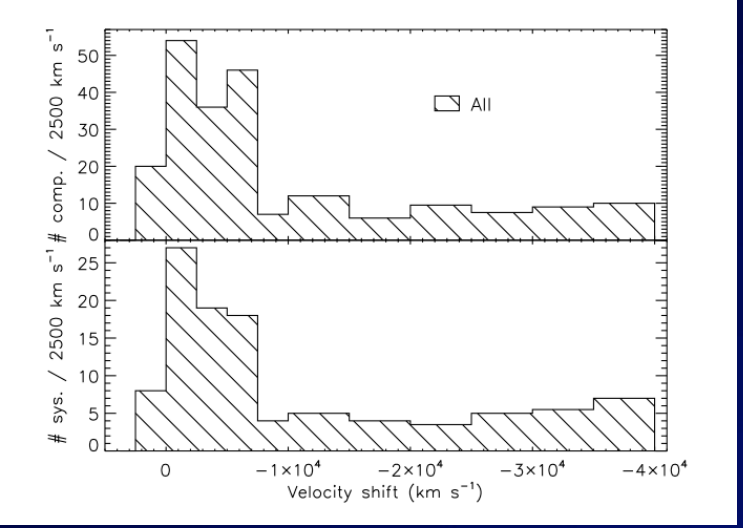
Kinematics, column densities, ionization, abundances., crude locations, …

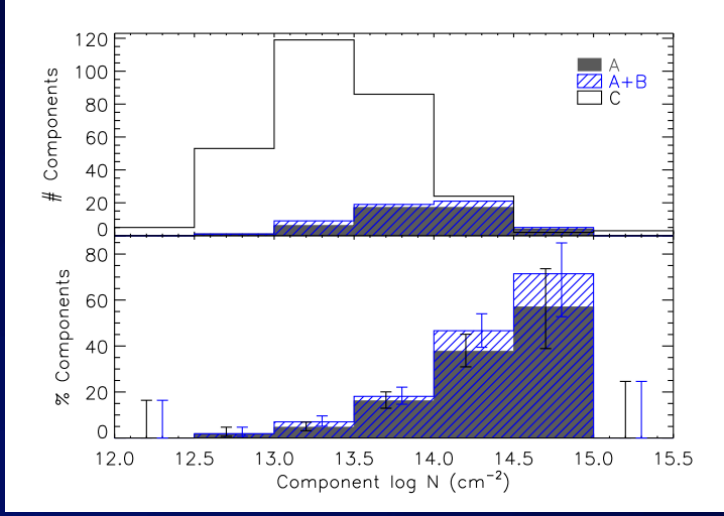
The absorbing gas in this z ~ 3.4 quasar is highly ionized, metal rich, probably ejected from the quasar/accretion disk at ~1500 to ~6000 km/s

Lots of star formation, before the quasar epoch, in at least the galactic nucleus.



Simon et al. 2010



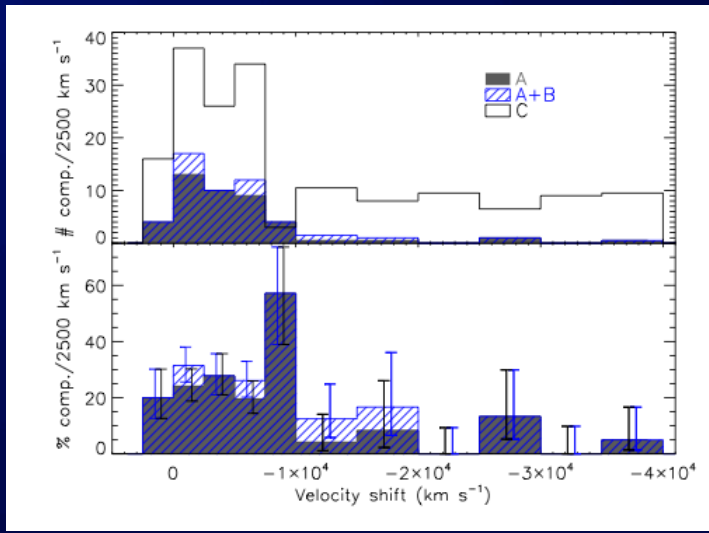


In a survey of 24 quasars and 271 CIV lines, Simon et al. 2010 found that:

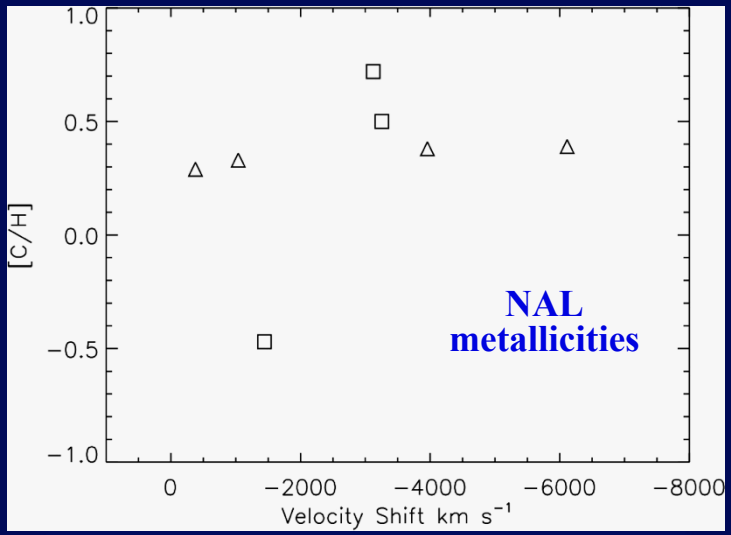
1) NALs are more common at low v shifts (near quasar redshift)

2) "Intrinsic" NALs (A+B) tend to be stronger

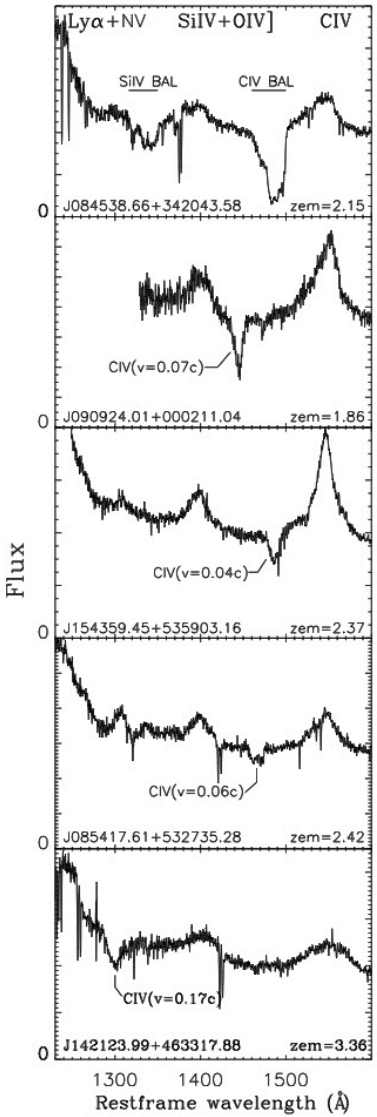
3) Intrinsic NALs appear at all v shifts (high speed outflows!)



NALs near the emission redshift often have Z ~ few Z_o even at redshifts > 4.



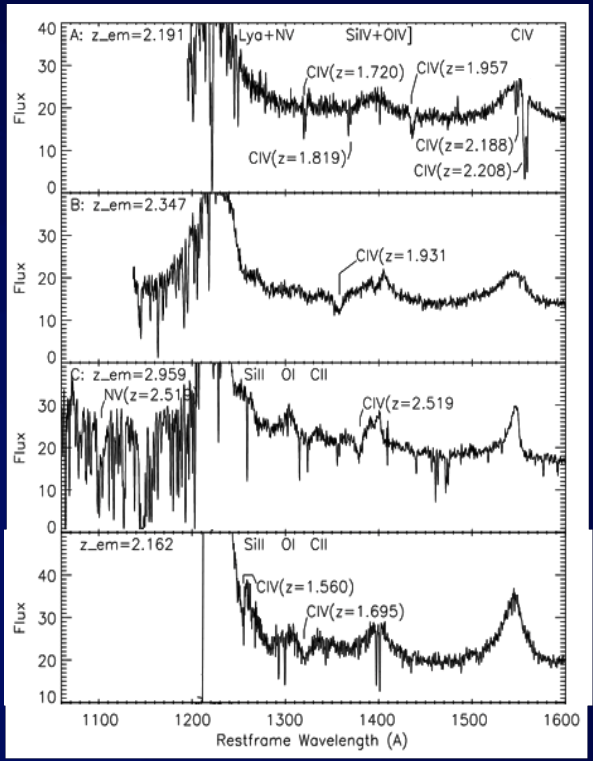
Simon et al. in prep.



There's a wide range of outflow features.

"mini-BALs" with v up to ~0.2c appear in ~10% of quasars

They might represent streams or blobs or filaments…



Rodriguez Hidalgo et al. in prep.

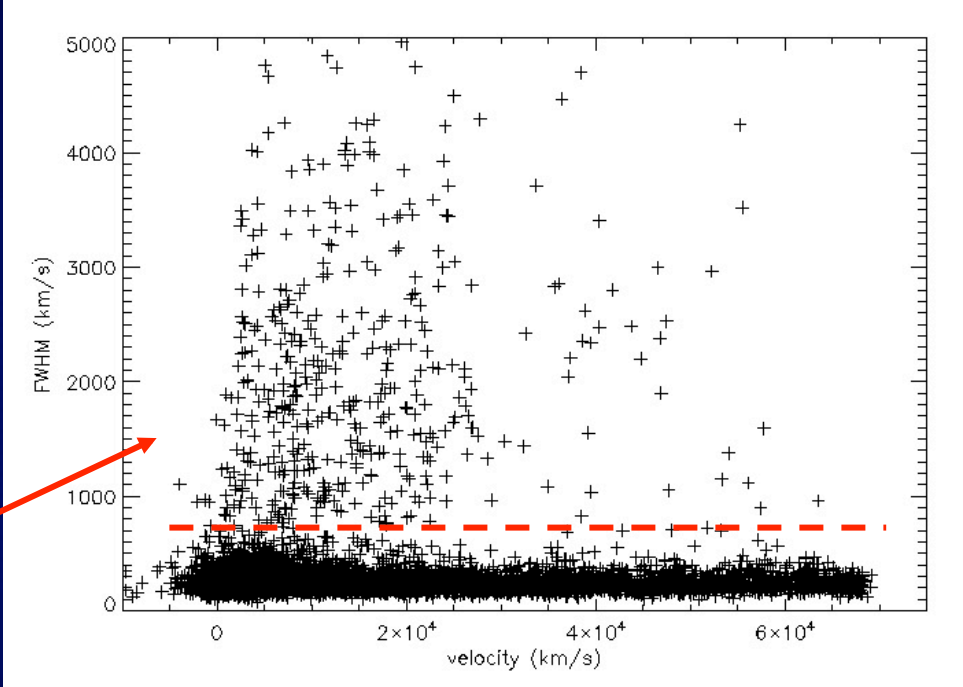
Rodriguez Hidalgo et al.

The first complete inventory of quasar outflow lines:

Measure all CIV λ1548,1551 absorption lines in ~2000 SDSS quasars.

Lines with large FWHM clearly form in outflows.

There are many varieties…

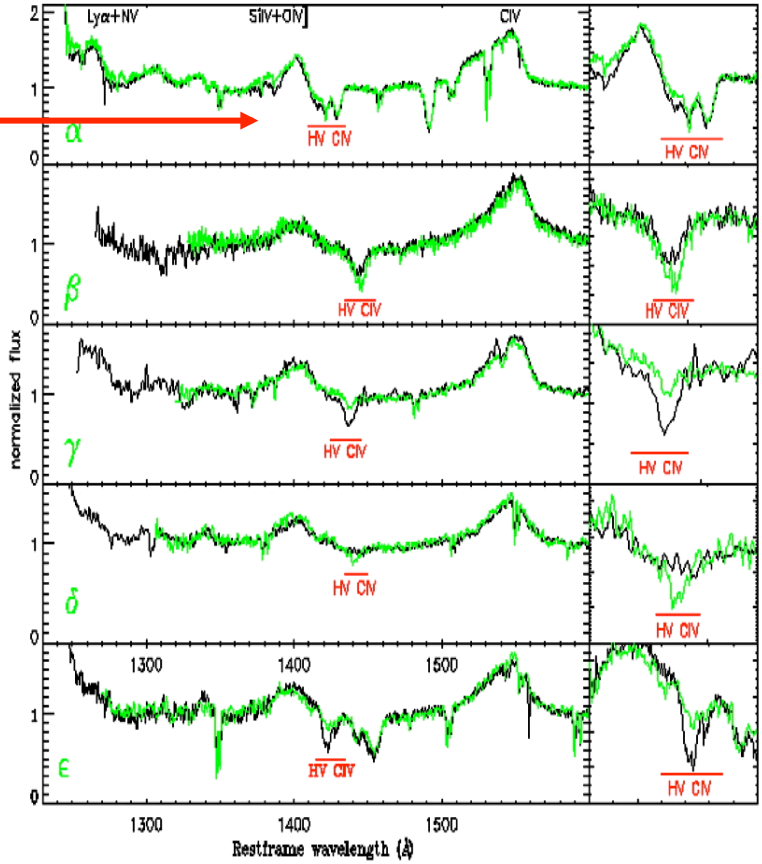


also Nestor et al. 2008

Sometimes there a many outflow lines in one quasar.

At least 50% of outflow lines vary in < 3 years (rest)

Variability trends tell us more about the sizes, locations, densities, dynamics, …, of flow "structures"

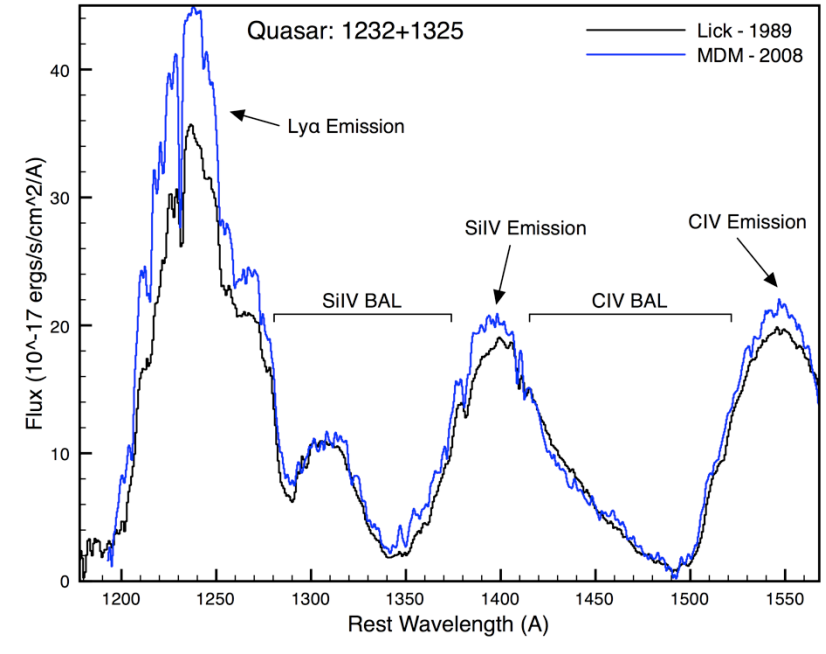


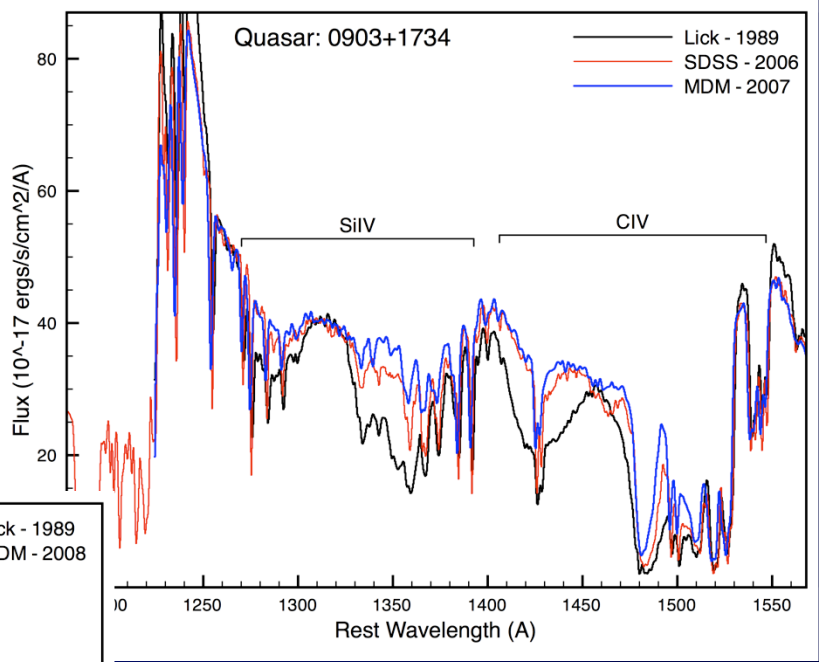
Rodriguez Hidalgo et al.

Capellupo et al. 2011

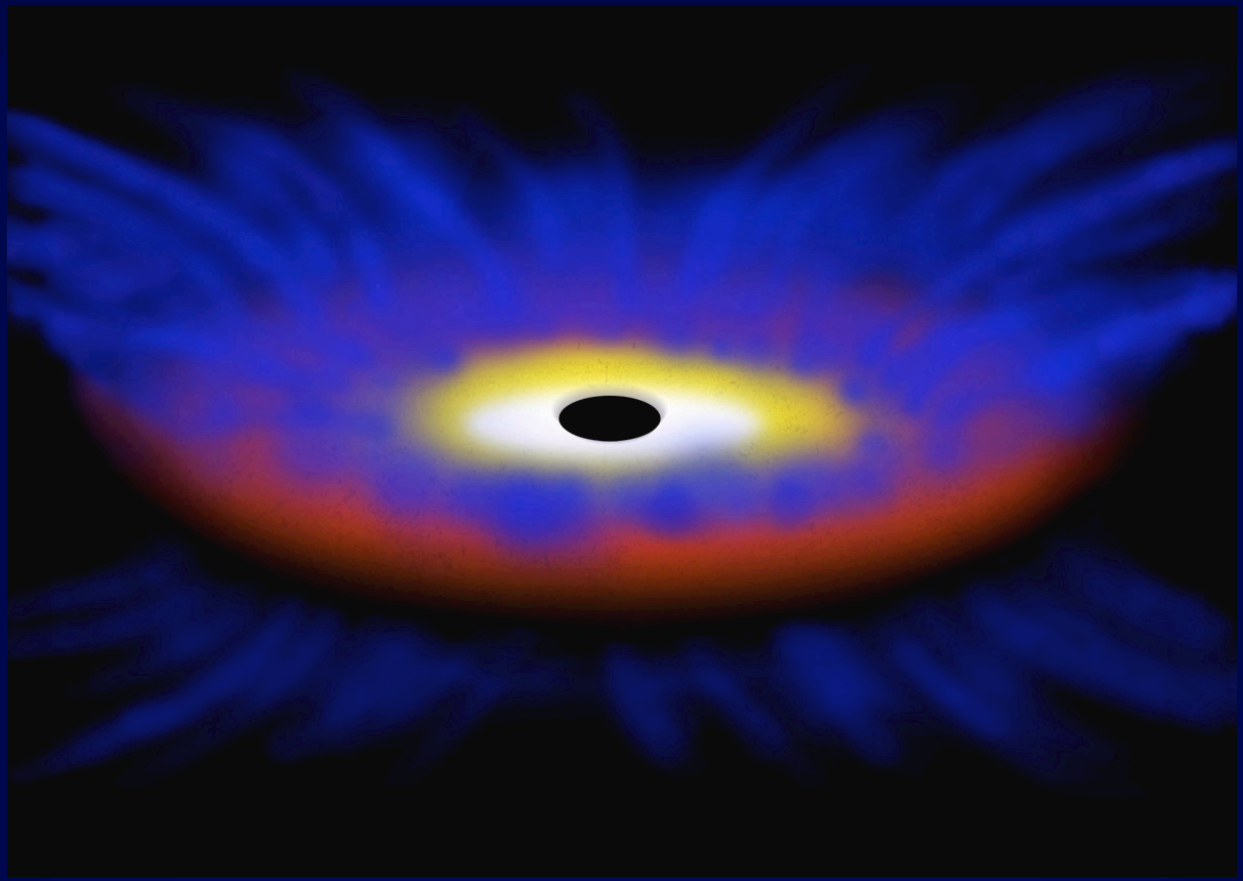
BALs can be complex and highly variable… or not…

Variabilities in different lines tell us about ionization, line saturation, column densities, …





Maybe the different outflow line types (BALs, mini-BALs, NALs) represent different evolutionary phases…?

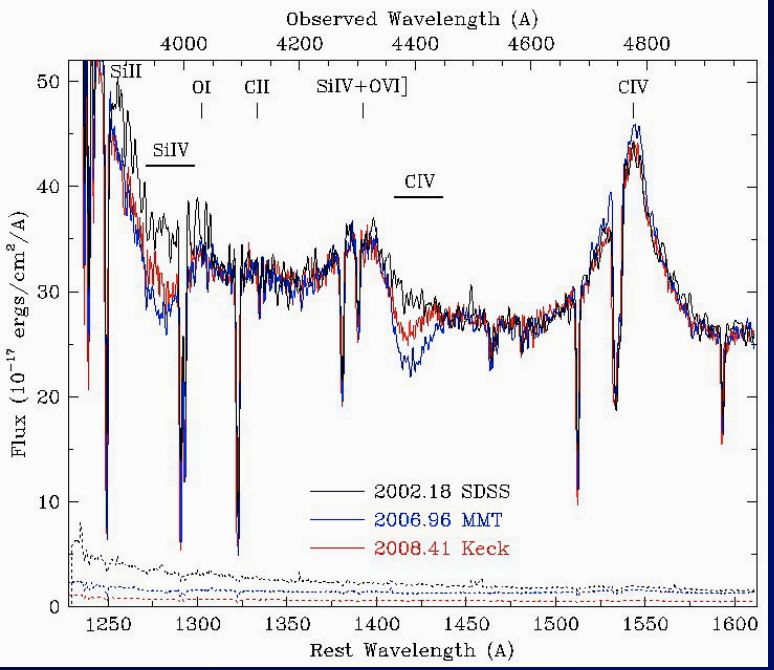


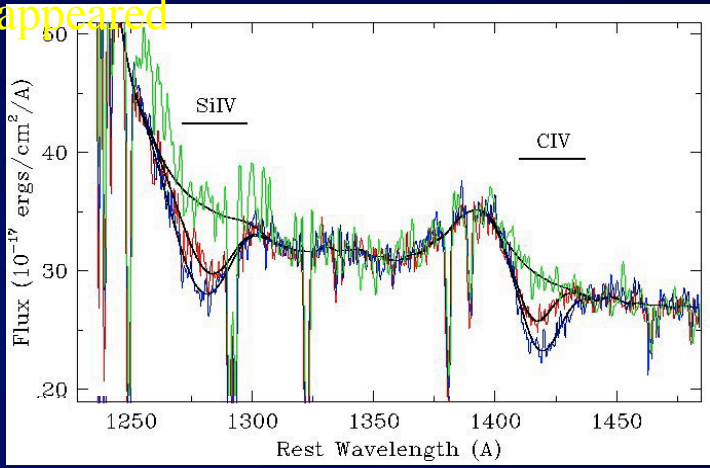
The outflows could be clumpy, filamentary, launched from a rotating disk.
(crossing times are < 1 year)

But they can also be remarkably stable - We do not see acceleration.

Emergence of a Quasar Outflow:

In this case, an outflow at
v ~ 26,000 km/s
appeared





Did a flow really "turn on" - the onset of an outflow evolution phase?

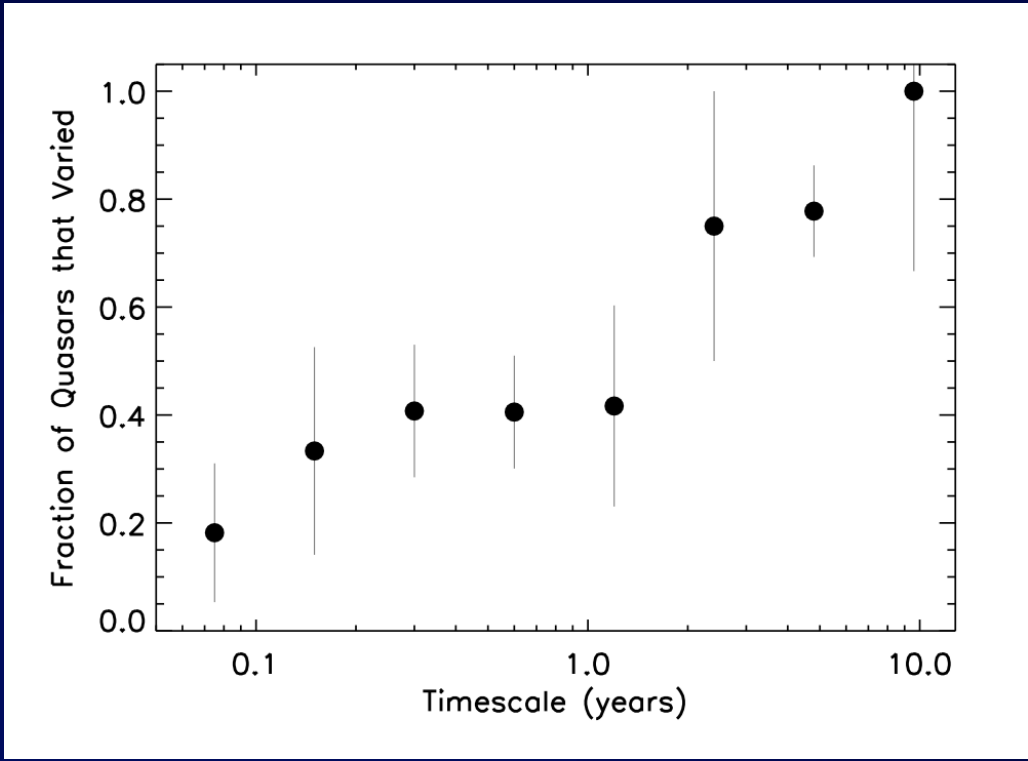
Or did an existing flow structure simply cross our line of sight?

We saw no acceleration! What will happen next? → It's GONE!

Hamann et al. 2008 (discovered by an undergrad - Kyle Kaplan)

Variability times are key to understanding the location, structure, size scales, transverse speeds, outflow energetics.

In spring 2010 we (Dan) sampled better the week-month time scales



Fraction of BAL quasars that varied vs. Δt

Capellupo et al.

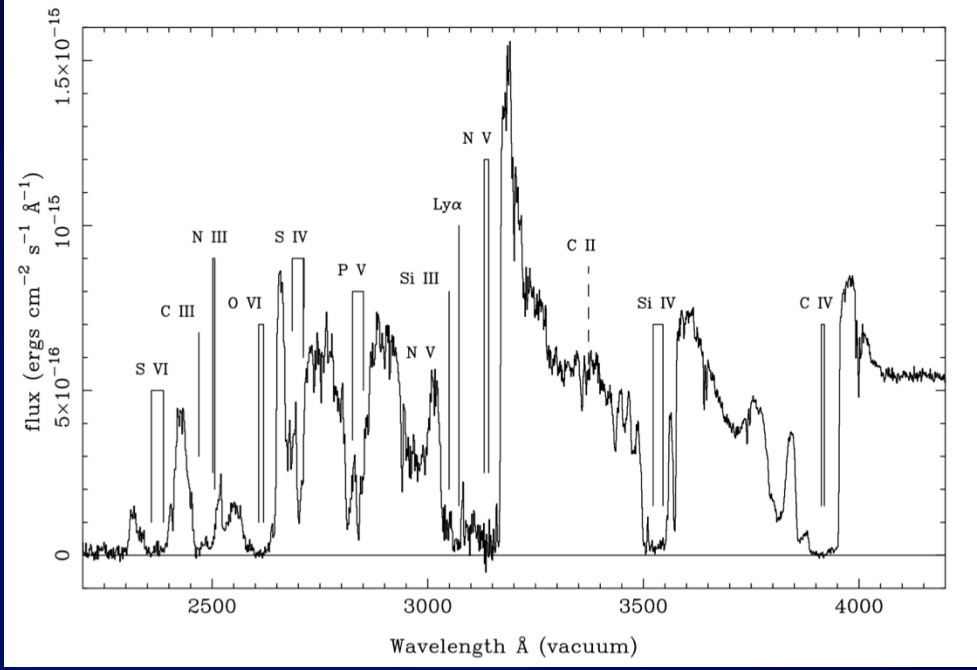
How massive are the flows?

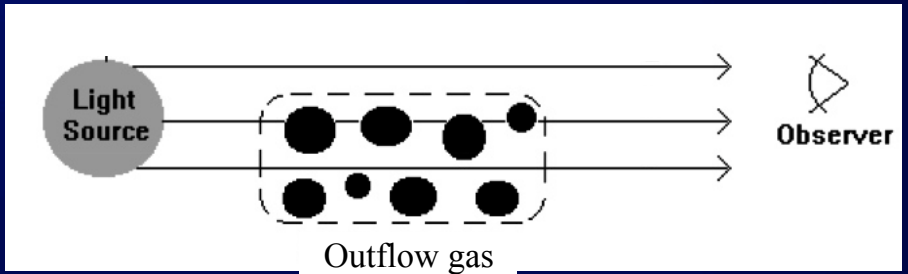
The lines can be saturated even if they are not "black"

because the absorber only partially covers the background light source

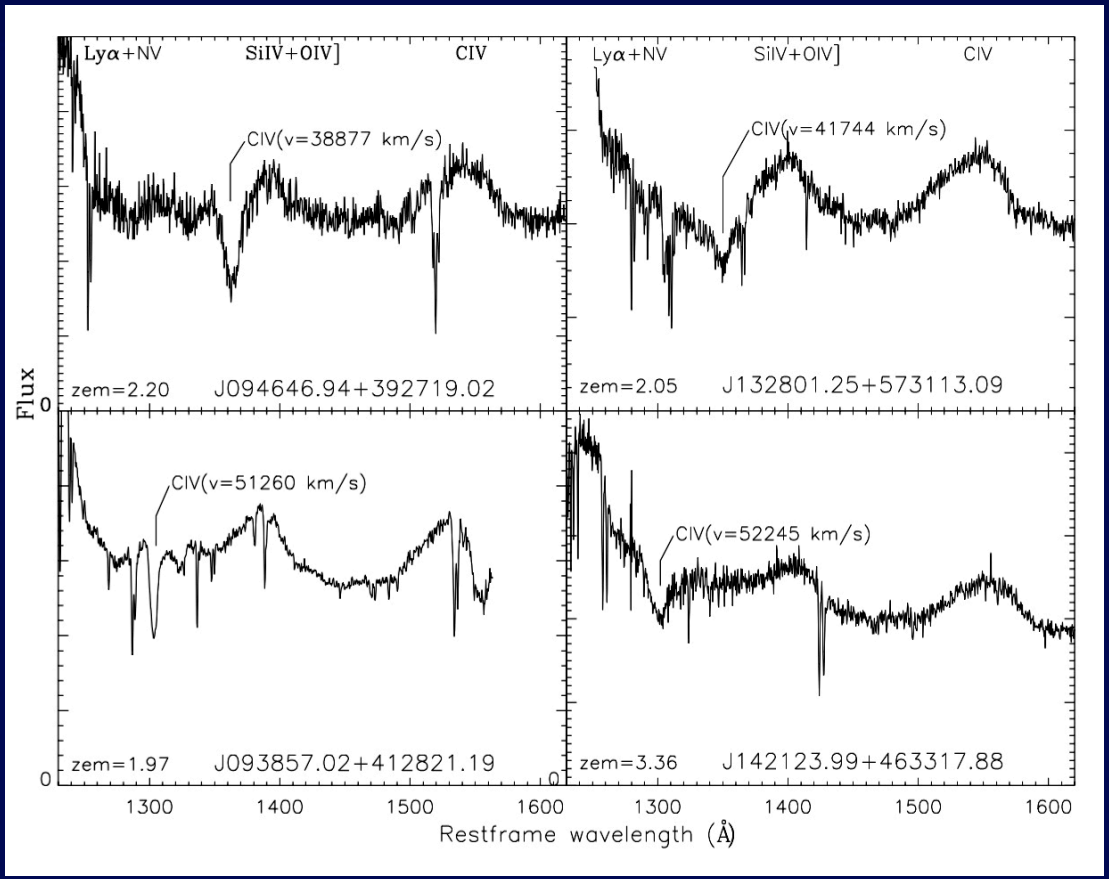
Approved HST-COS observations will look for low-abundance ions like PV and SIV

…to get total column densities, constrain the mass loss rates & KE yields

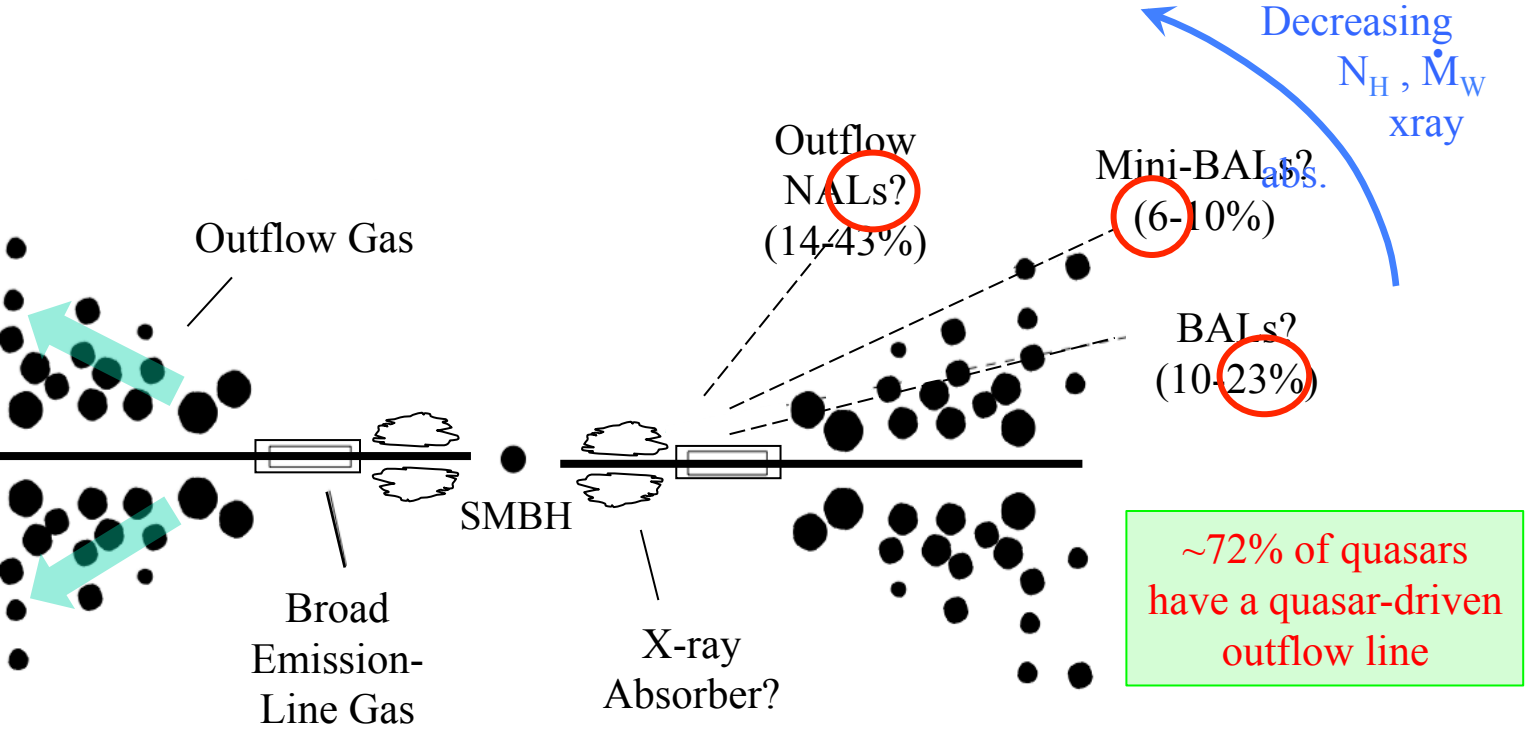




High velocity flows (v > 0.1c) present the biggest challenge to models.



Approved Chandra observations will measure the strength of X-ray absorption in 7 quasars with v > 0.1c outflows.

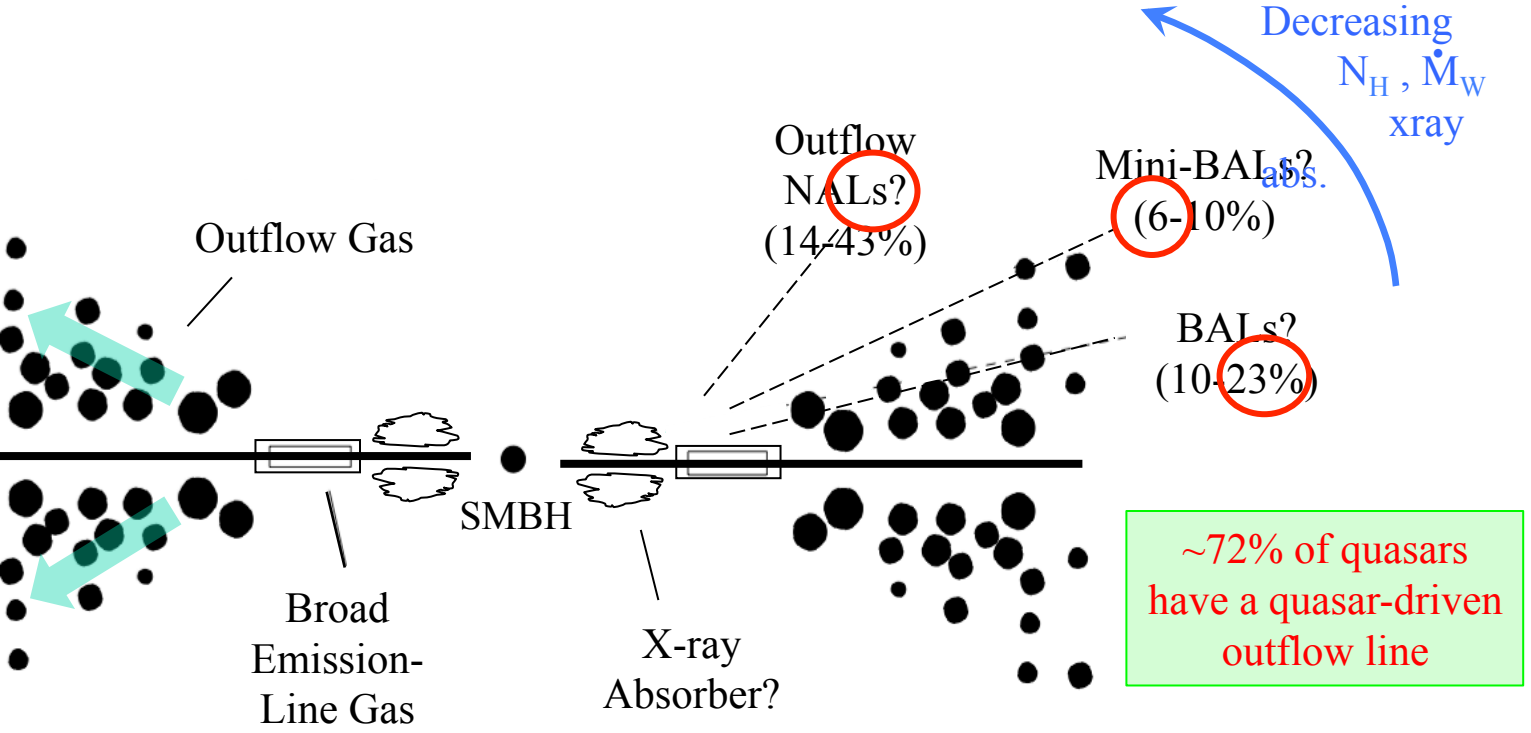


~72% of quasars have a quasar-driven outflow line

Is this geometry correct?

NALs: Simon et al. 2011, Nestor et al. 2008, Misawa et al. 2007

Mini-BALs: Rodriguez Hidalgo 2008 BALs: Hewett et al. 2003



Is this geometry correct?

Or is there evolution: FeLoBAL → BAL → mini-BAL → NAL ??

Low → High ionization (more → less reddening) ??

Do quasar outflows evolve with the host galaxy?

FeLoBALs (FeII, Low-ionization, BALs):

Very large column densities, enough to shield FeII

Probably very large mass loss rates, $\dot{M}_{out}$

Red colors, strong MIR and FIR emission (Farrah et al. 2007, 2010)

A powerful outflow phase driving a "blowout" in young quasars?

Merger → Starburst → Blowout → Quasar → Red & Dead

Are FeLoBAL quasars young?

What is their merger status? (NIR imaging, HST/WFC3)

Do they have large SFRs like ULIRGs? (sub-mm, APEX, SCUBA-2, ..)

Etc…