Variability Constraints on Quasar Broad Absorption Line Outflows

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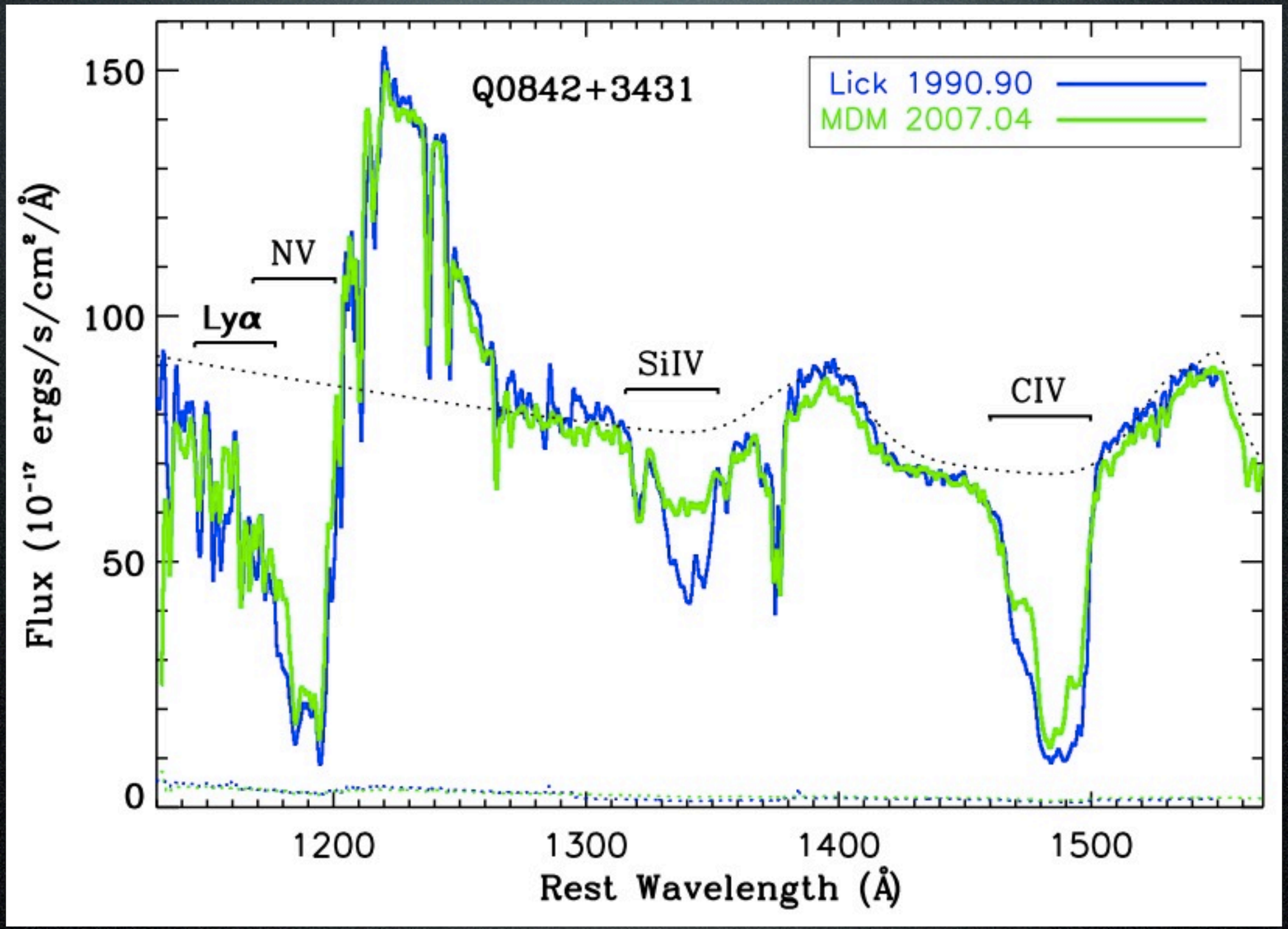
Tom Barlow, Jules Halpern

AGN Winds in Charleston
October 16, 2011


Q0842+3431
Lick 1990.90
MDM 2007.04
Lyα
NV
SiIV
CIV
Flux (10⁻¹⁷ ergs/s/cm²/Å)
150
100
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1200
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Rest Wavelength (Å)

BAL Variability

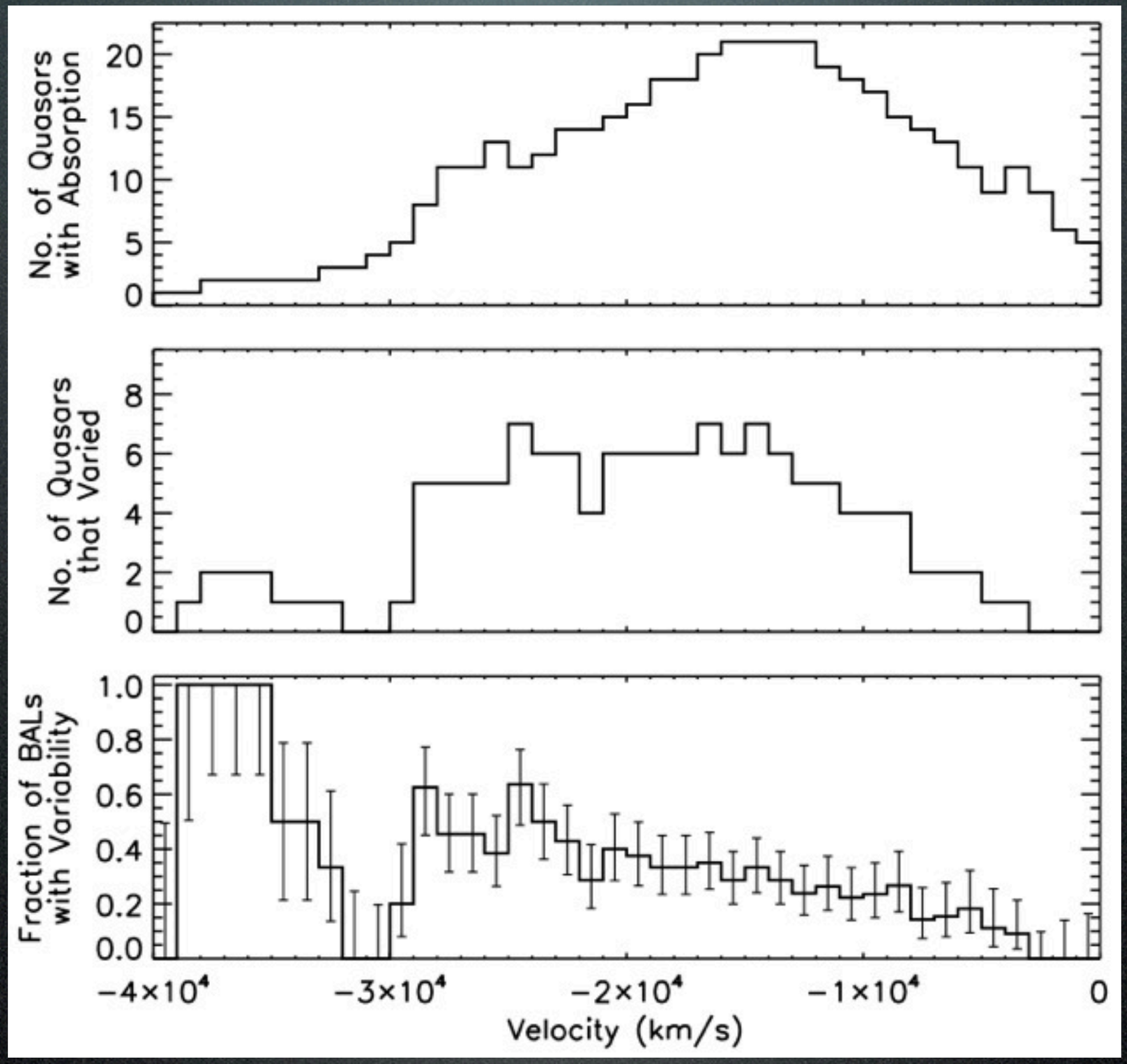
- Provide important constraints on outflows:
  - Short-term variability can put constraints on distance from SMBH and size of outflow structures
  - Long-term variability allows us to estimate lifetimes and gain insight on homogeneity and stability of outflows
- Previous work:
  - Short-term studies (23-29 objects, ≲1 yr timescales) - e.g. Barlow (1993), Lundgren et al (2007)
  - Long-term study (2-4 epochs) -Gibson (2008,2010)

Quasar Sample

1. Fiducial sample of BALQSOs from Barlow (1993) observed with Lick 3m
   - $1.2 < z_{em} < 2.9$, $L \sim 10^{46}$-10^{47} ergs/s
2. Obtain new spectra with MDM 2.4m, KPNO 2.1m (23 BALQSOs)
3. Obtain spectra from SDSS (8 BALQSOs)
4. We currently have 163 spectra of 24 BALQSOs across time-scales from ~1 week to 8 years

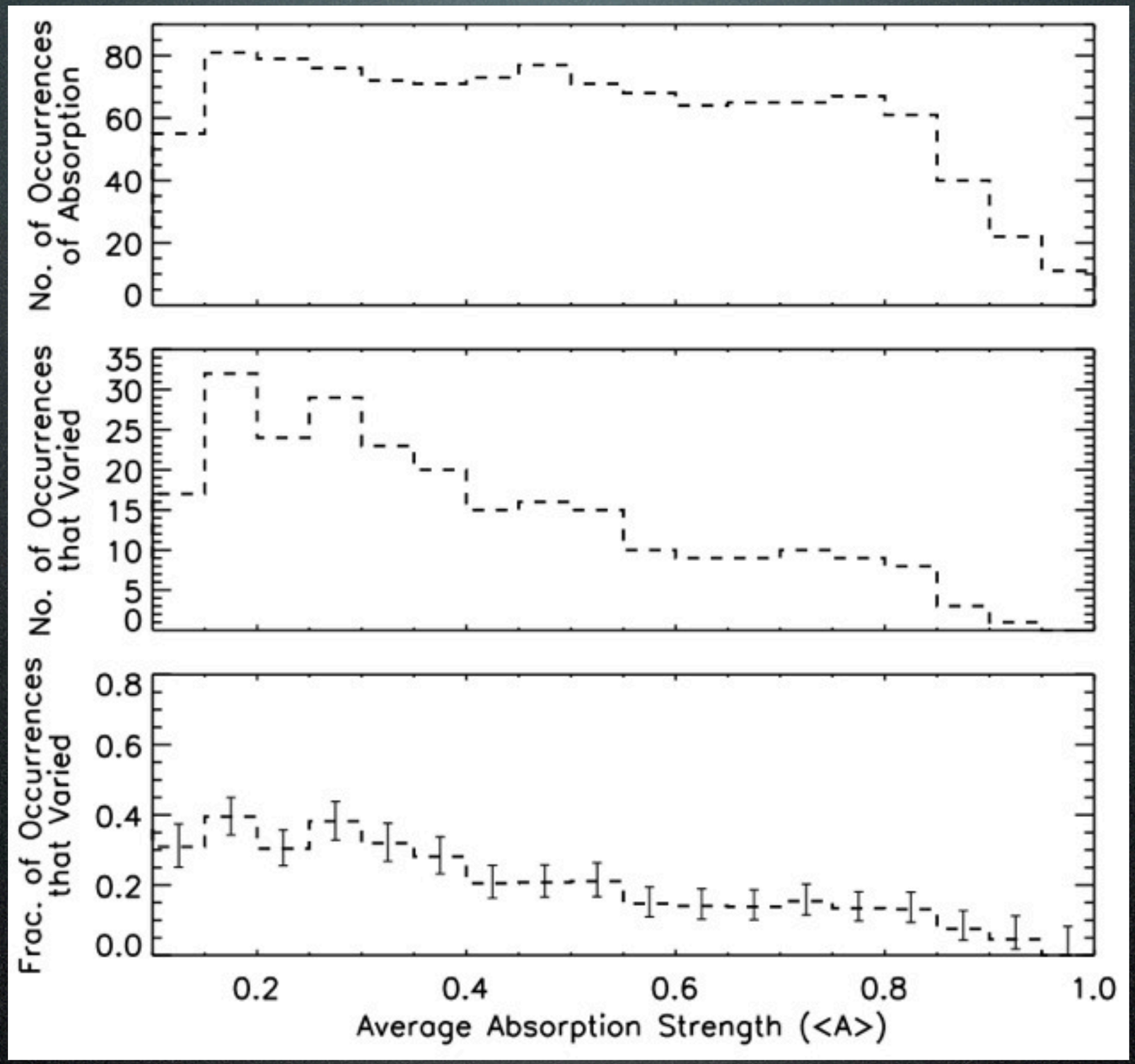
Measuring Variability

- Define the regions of BAL absorption based on balnicity (BI) definition --> absorption must be >10% below continuum across 2000 km/s
- In order to classify as “variable,” the variation must be at least 1200 km/s wide and the flux difference >4σ
- Instead of using EW, which would dilute changes in strength, we define a measure (A), where A is the fraction of normalized continuum flux removed by absorption within a specified velocity interval (~1200 km/s wide bins)



Variability vs Outflow Velocity

Capellupo et al., 2011, MNRAS



Variability vs Absorption Depth

Capellupo et al., 2011, MNRAS

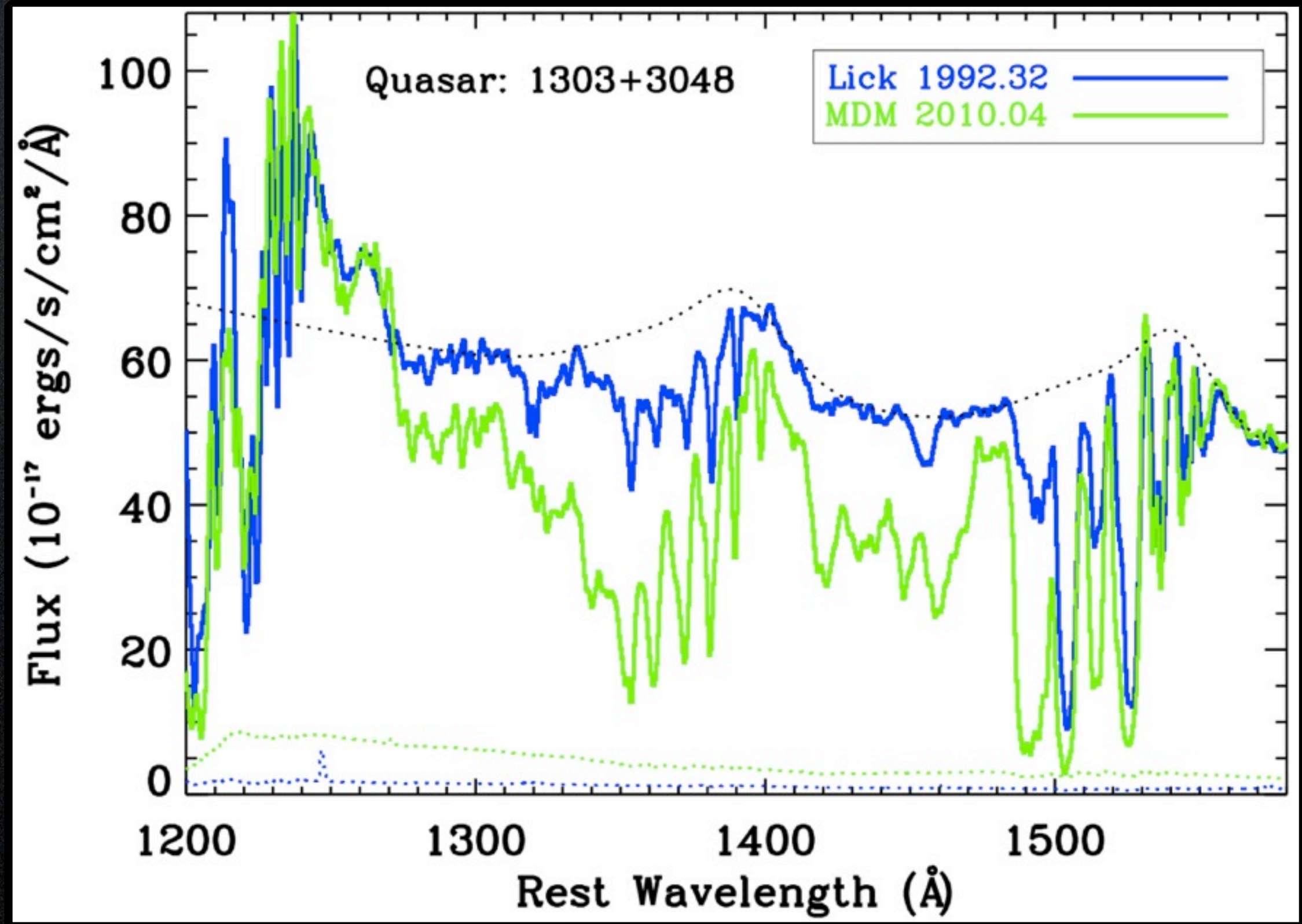
Causes of Variability

- What is causing the Variability?
  - Change in ionization
  - Change in covering factor - moving clouds

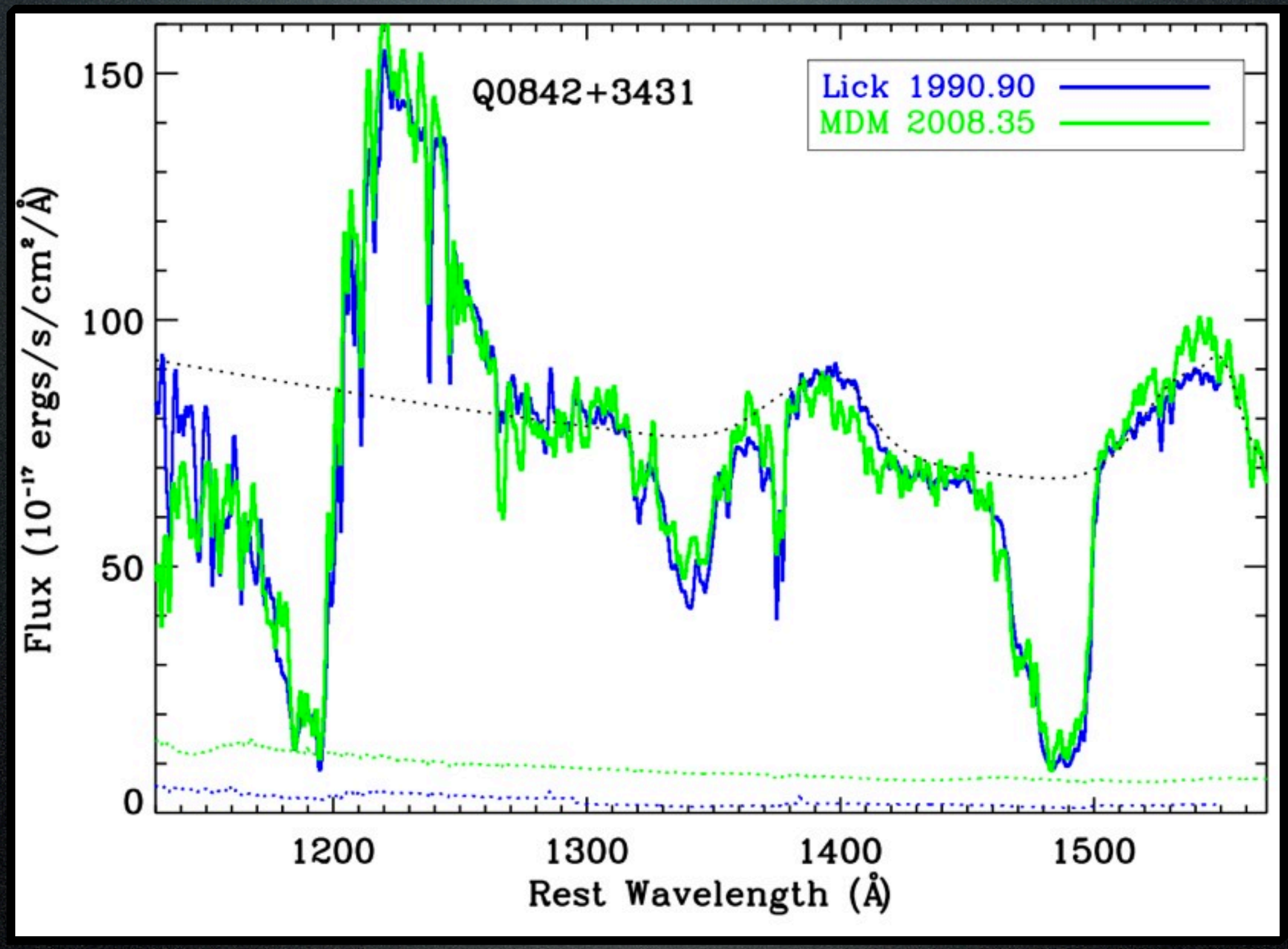
- One way to investigate this:
  - SiIV BALs - how do they vary compared to the CIV BALs?

CIV vs SiIV

- When looking at outflow speeds <20,000 km/s in our long-term subsample:
  - 31% (6/19) had CIV variability
  - 47% (9/19) had SiIV variability
- Half of the SiIV variable regions have no corresponding CIV variability
- All regions of CIV variability have corresponding SiIV variability, except for one tentative case
- SiIV variability always occurs in the same sense as CIV variability



Capellupo et al., submitted



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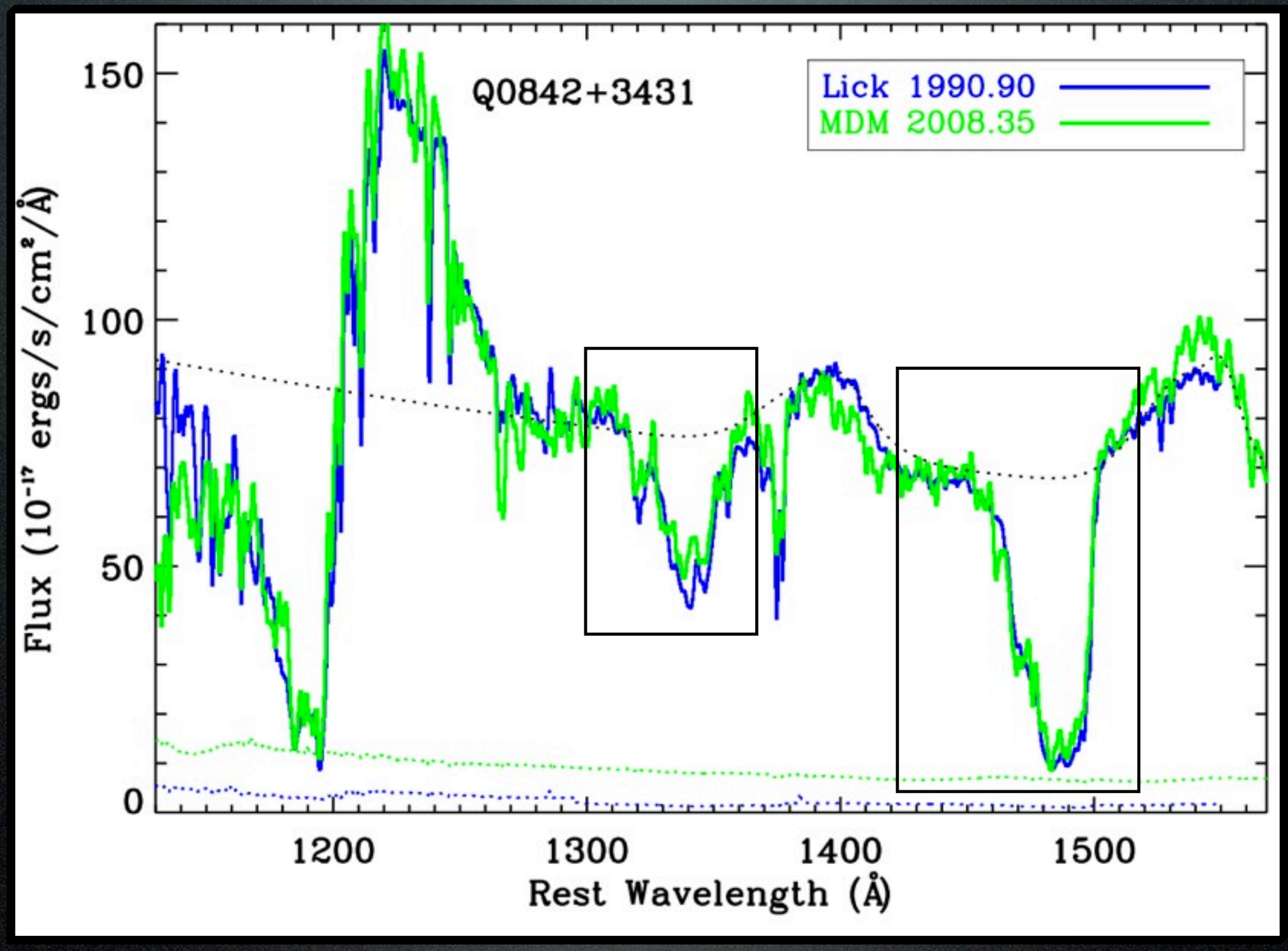

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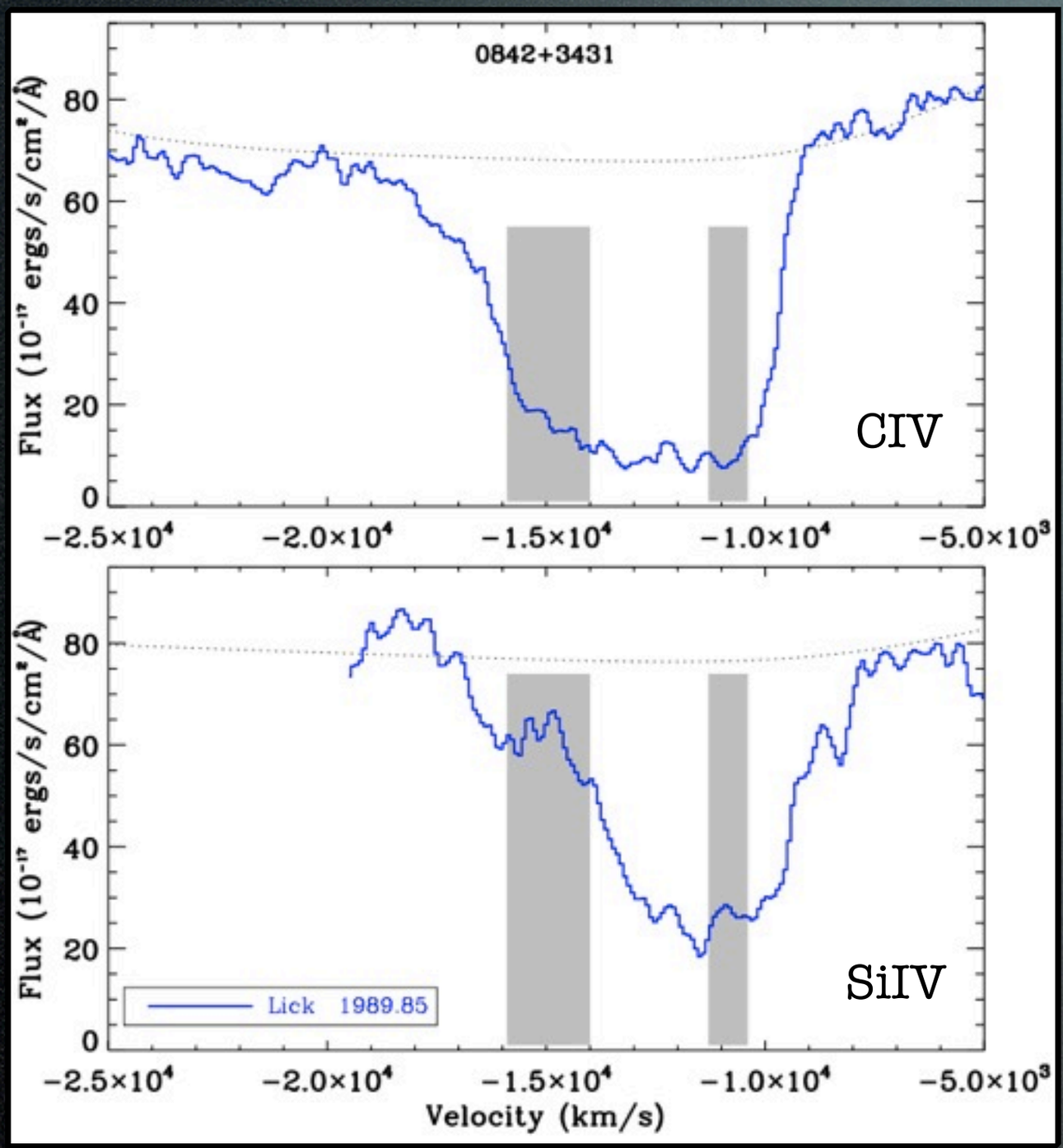
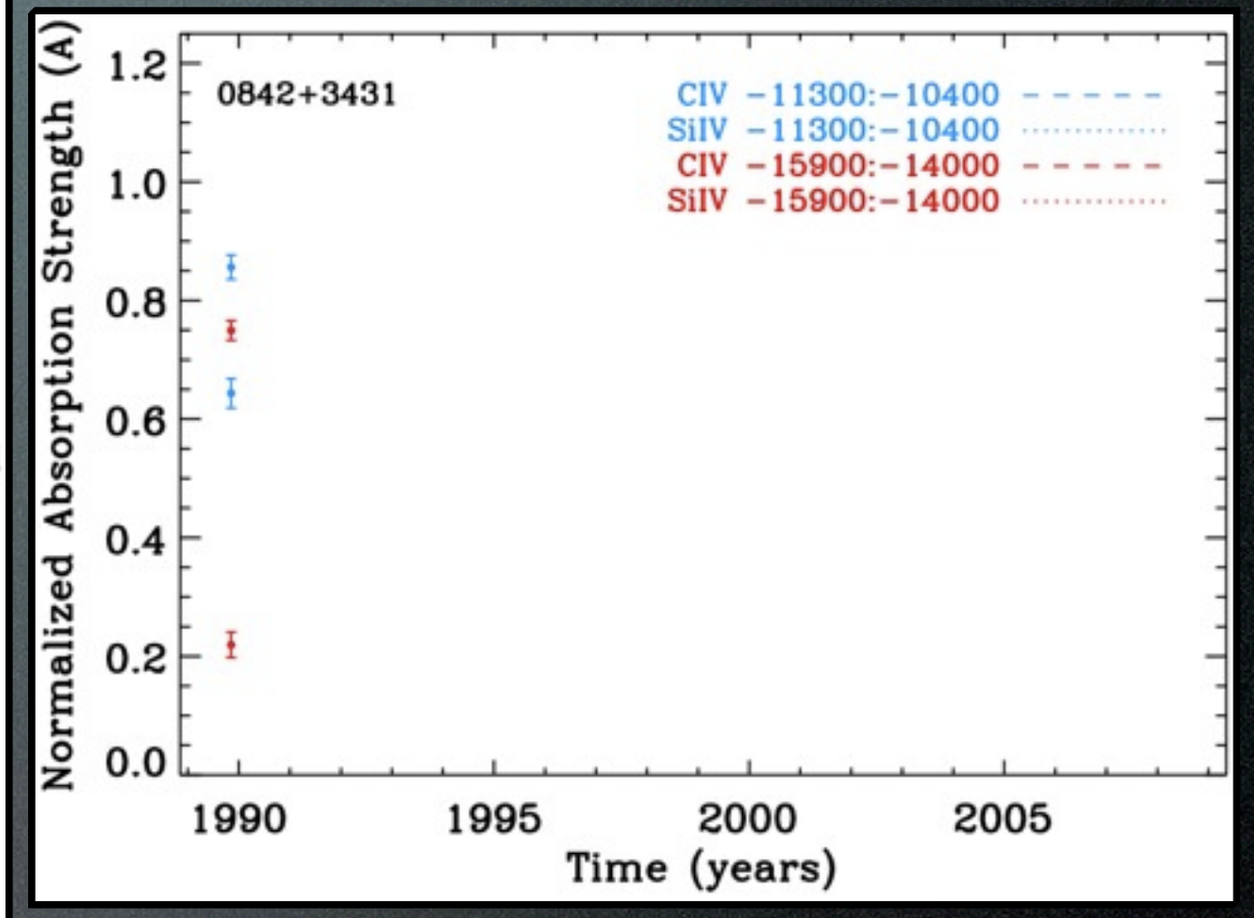
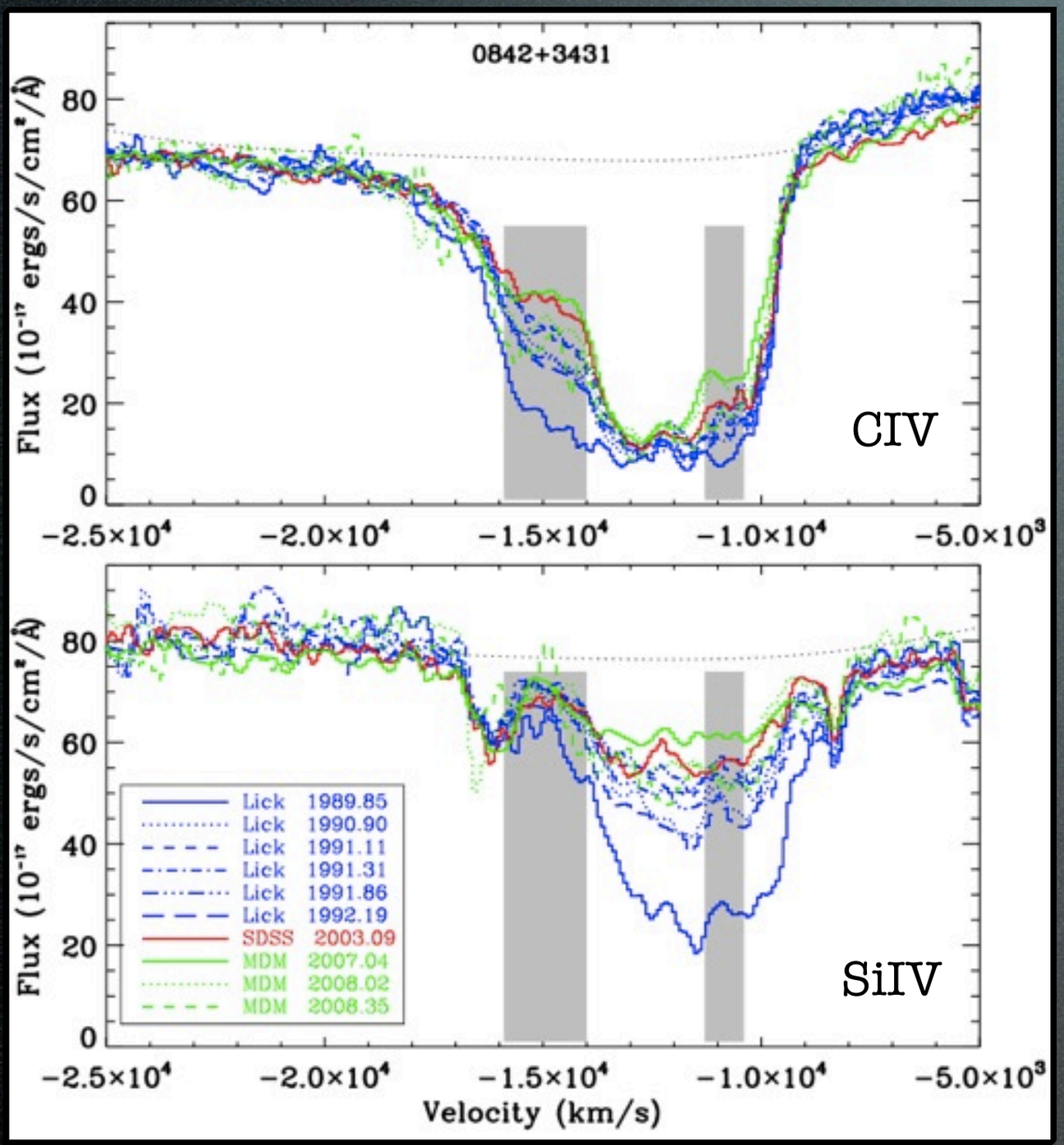
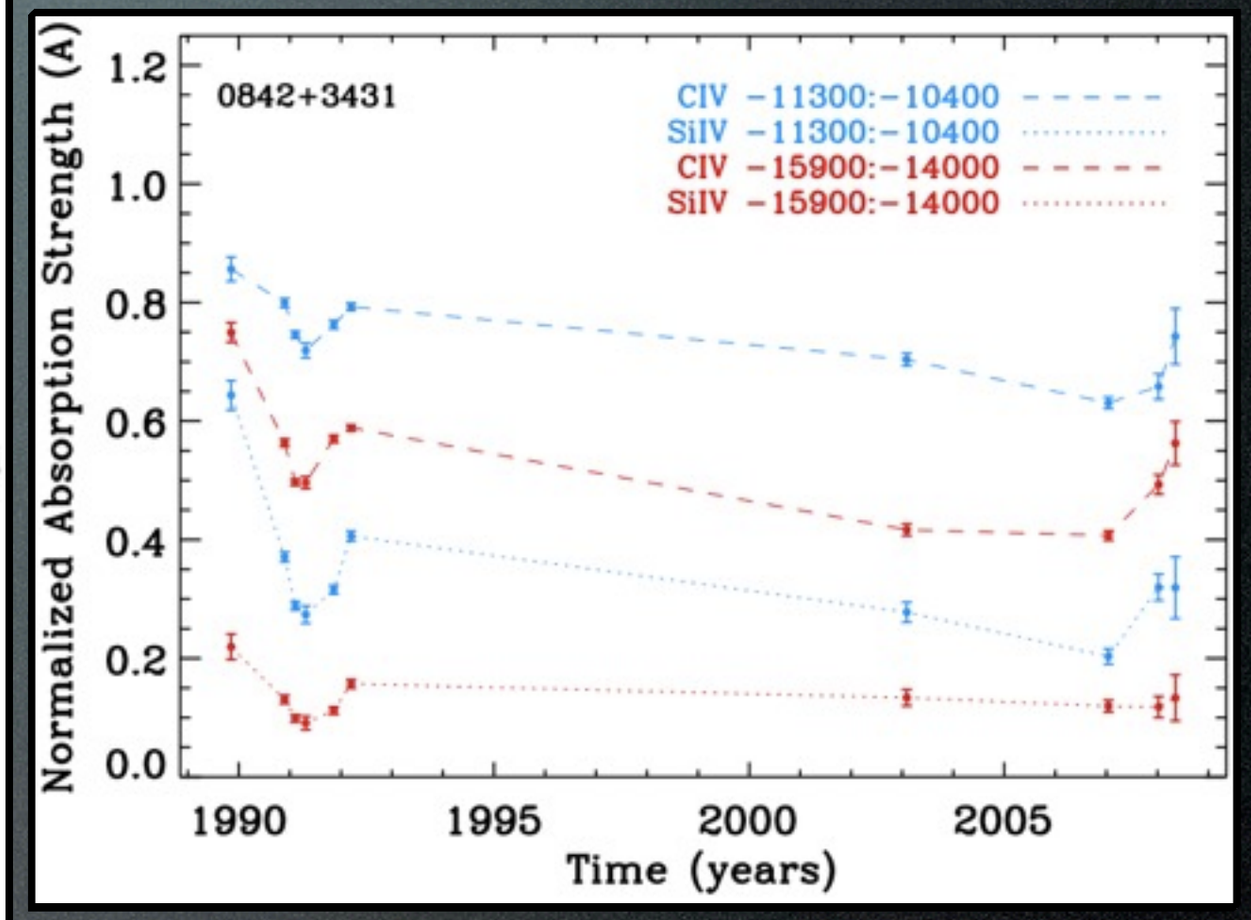


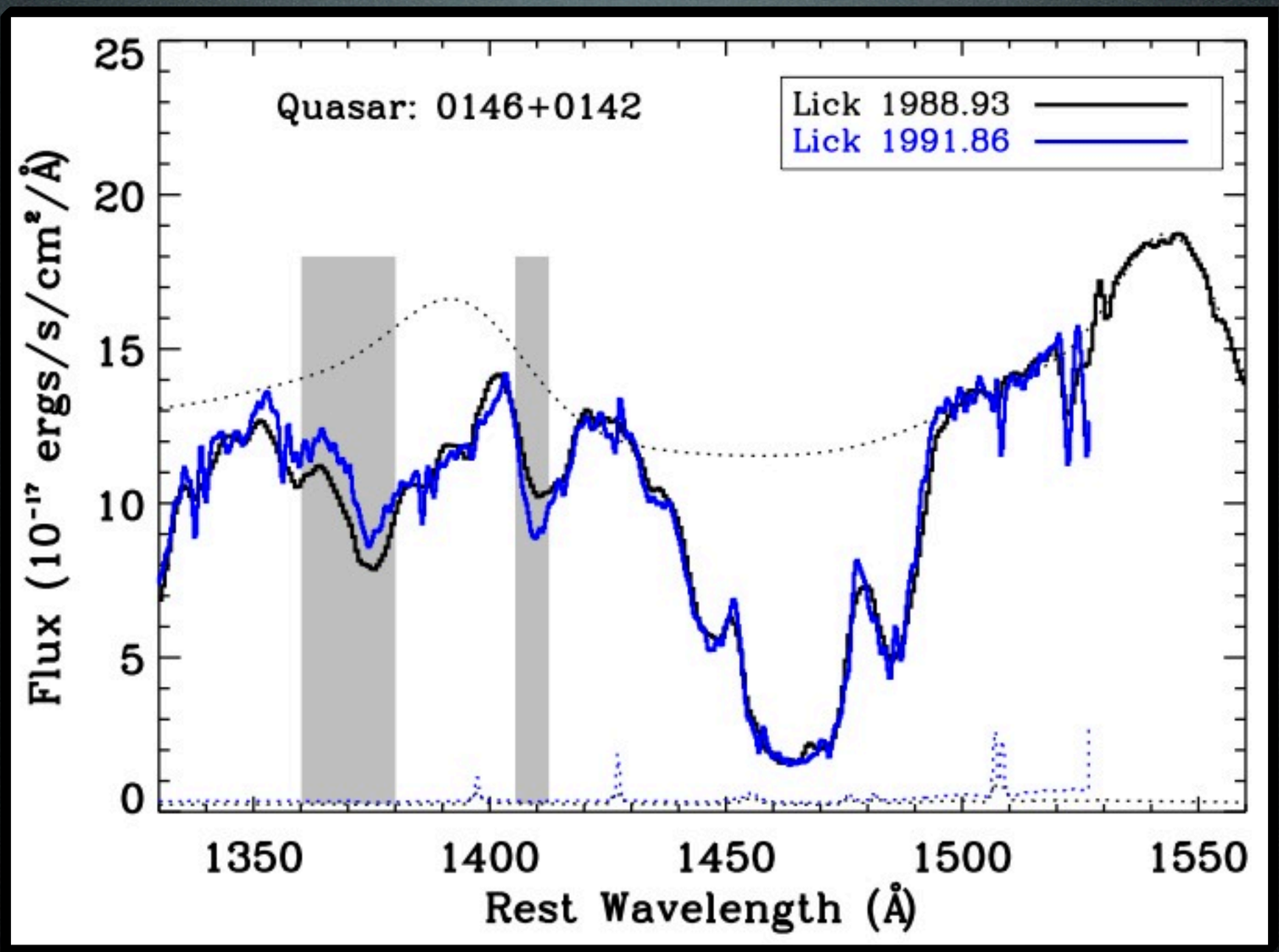


Capellupo et al., submitted



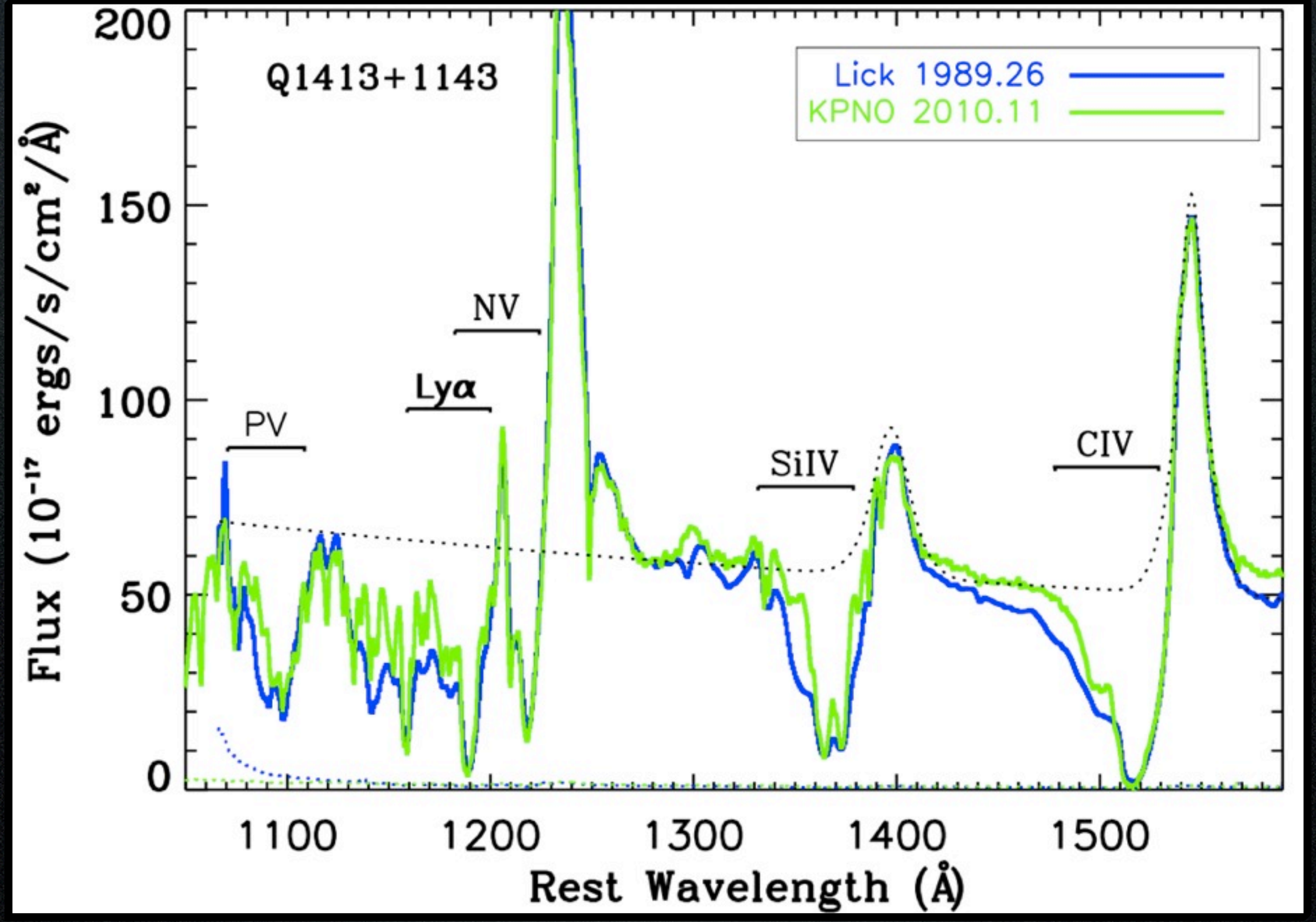


Capellupo et al., submitted



Capellupo et al., submitted

Lundgren et al (2007); Gibson (2008, 2010) - favor moving clouds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KPNO 2010.11
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Lyα
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SiIV
CIV
Flux (10⁻¹⁷ ergs/s/cm²/Å)
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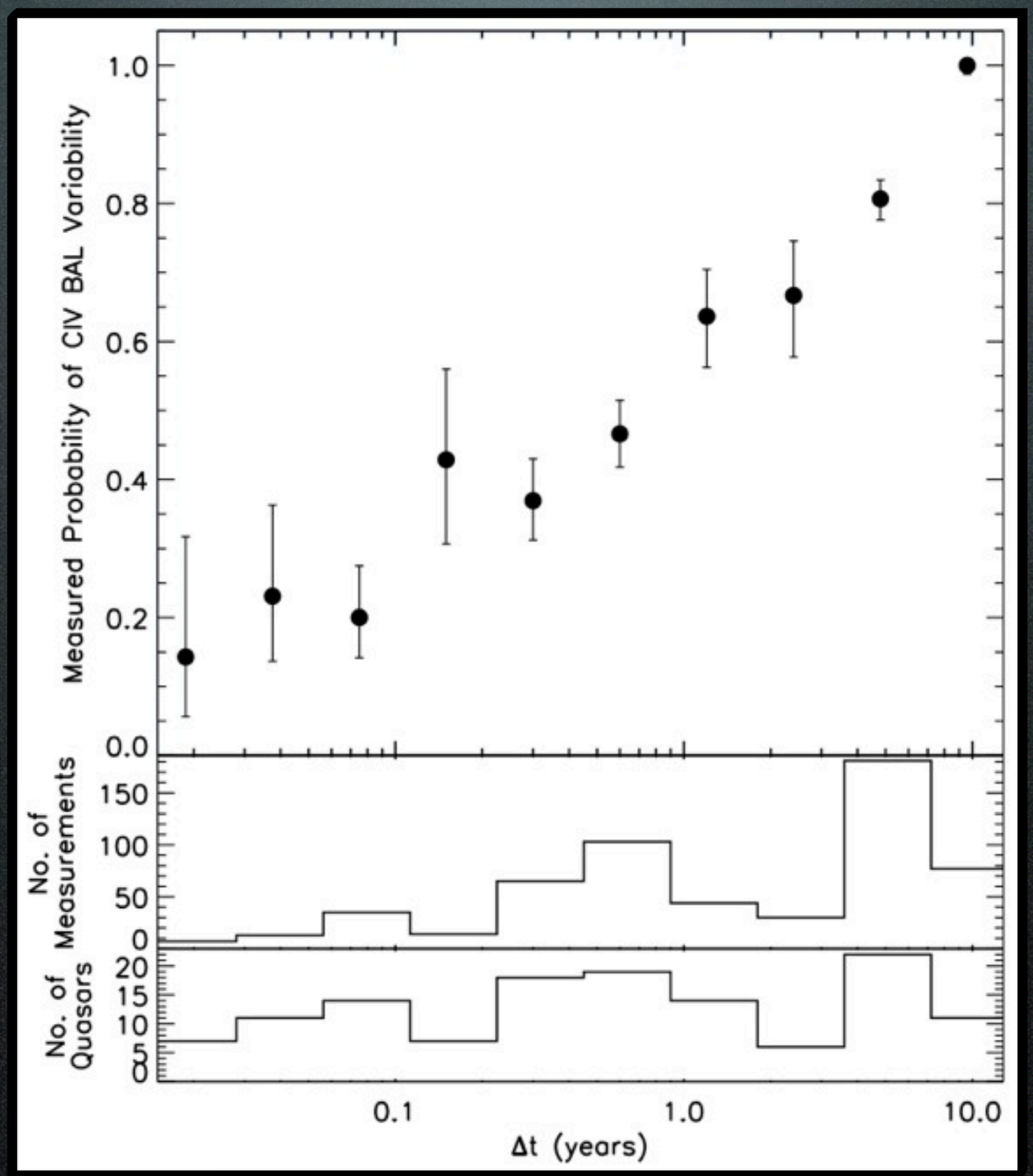
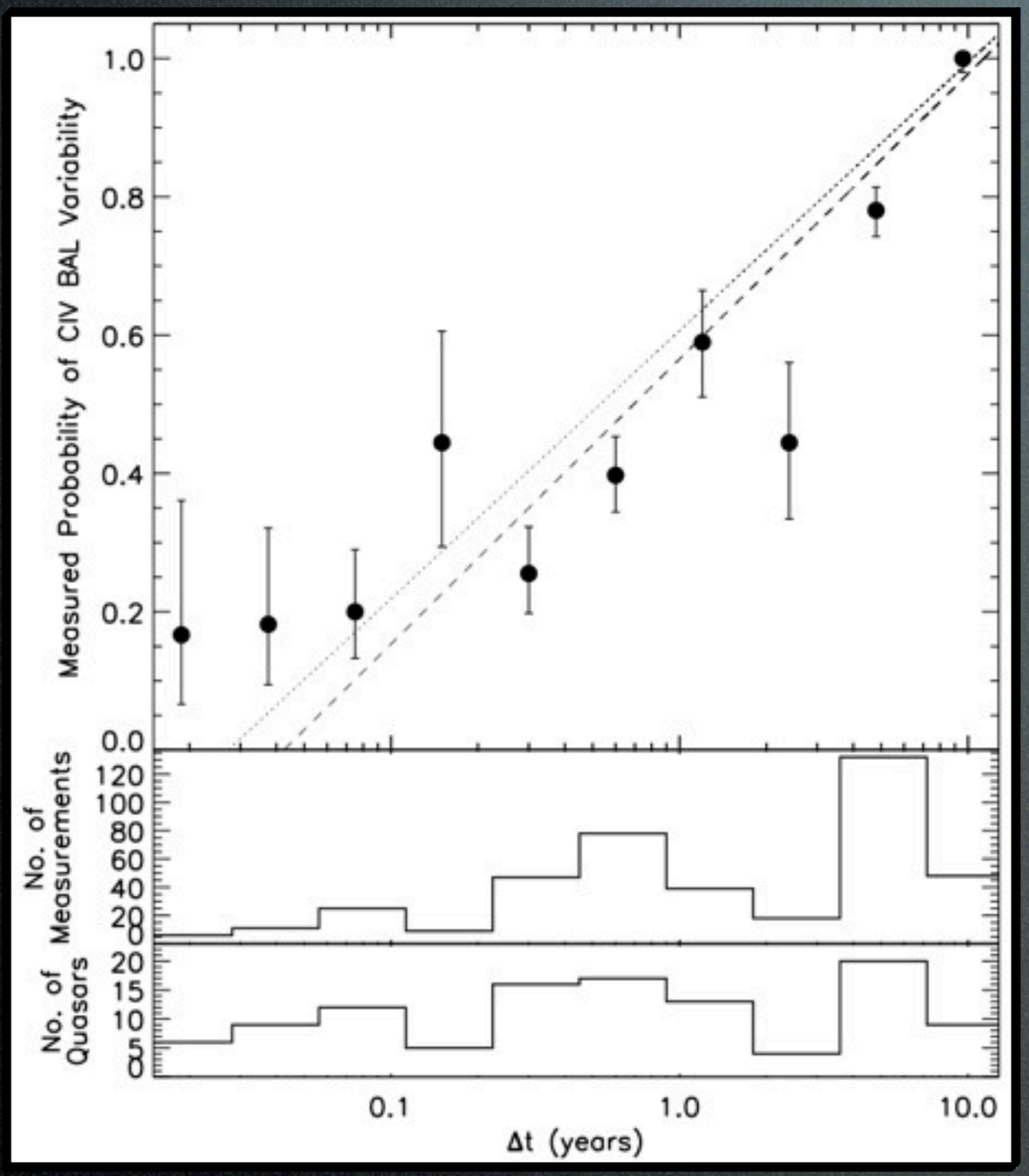
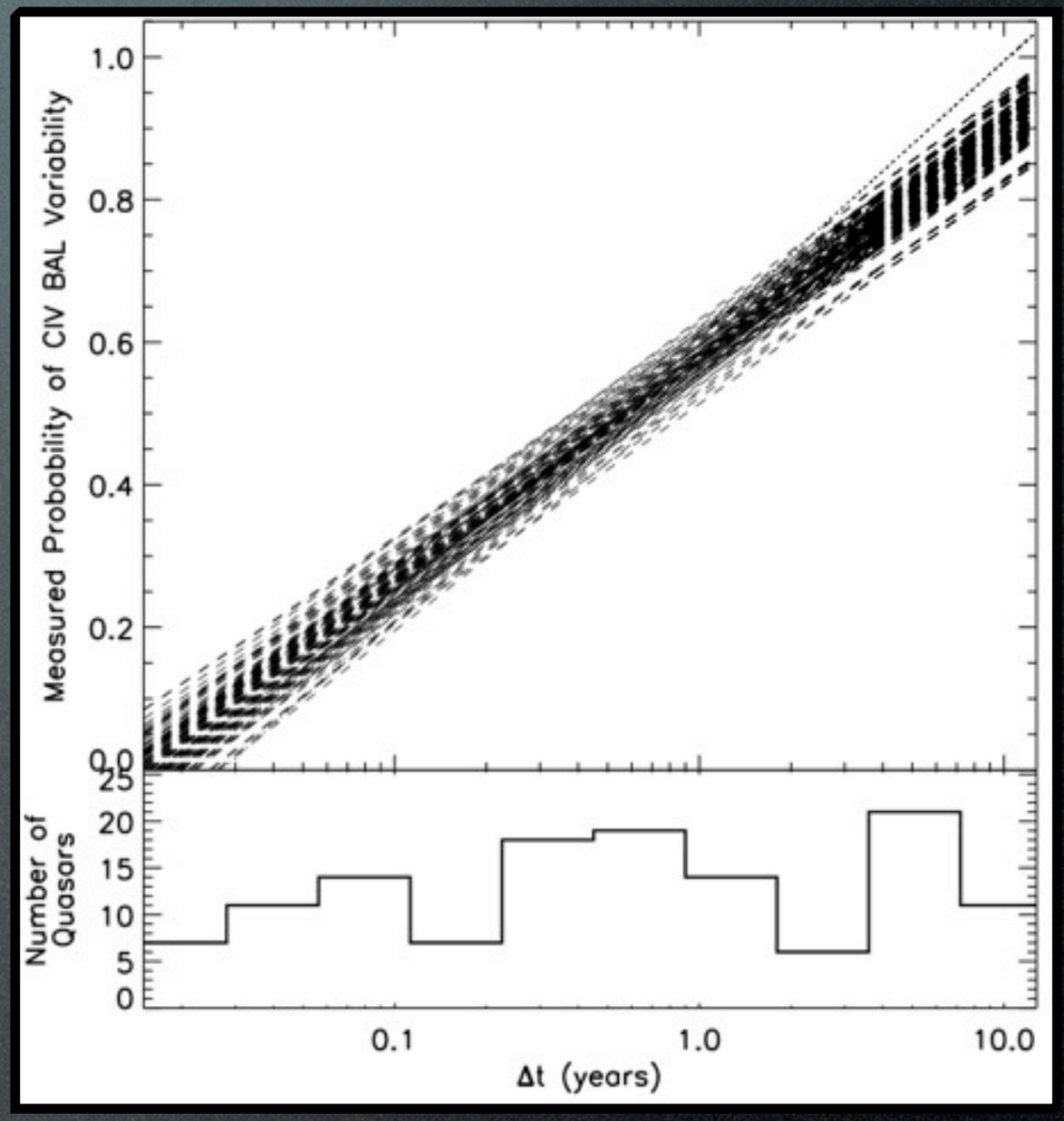


Variability Time-Scales

Capellupo et al., in prep



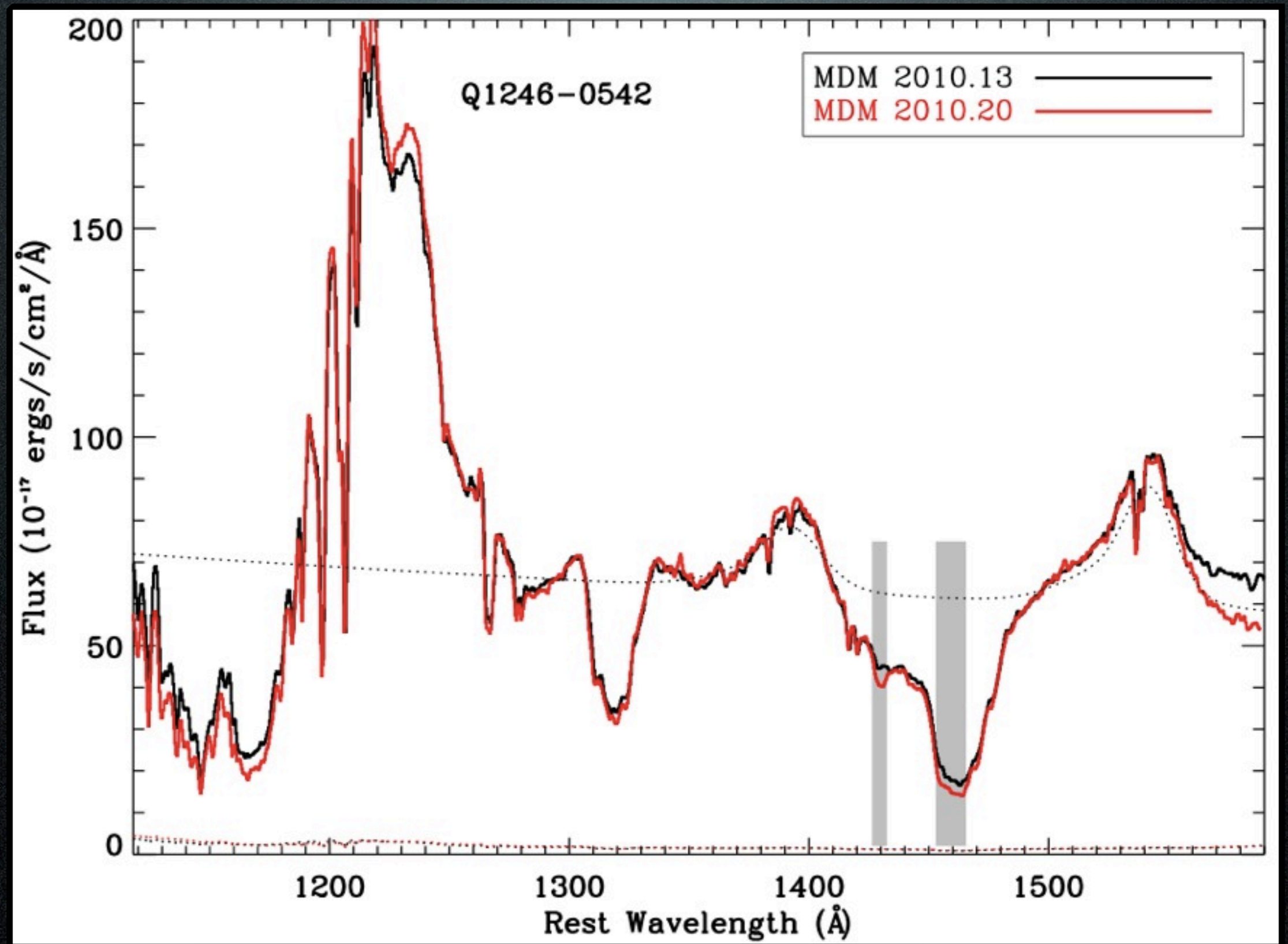


Variability Time-Scales

Capellupo et al., in prep

Time-scales of Variability

- Adding more epochs increases variability fraction from 65% in long-term 2-epoch analysis to 88% overall
- How long do you have to wait to see variability?
  - 57% varied at ≲0.5yr
  - 70% varied at ≲1 yr
  - 78% varied at ≲2 yr
  - 88% varied over our entire time interval of ~8yr


Q1246−0542
MDM 2010.13
MDM 2010.20
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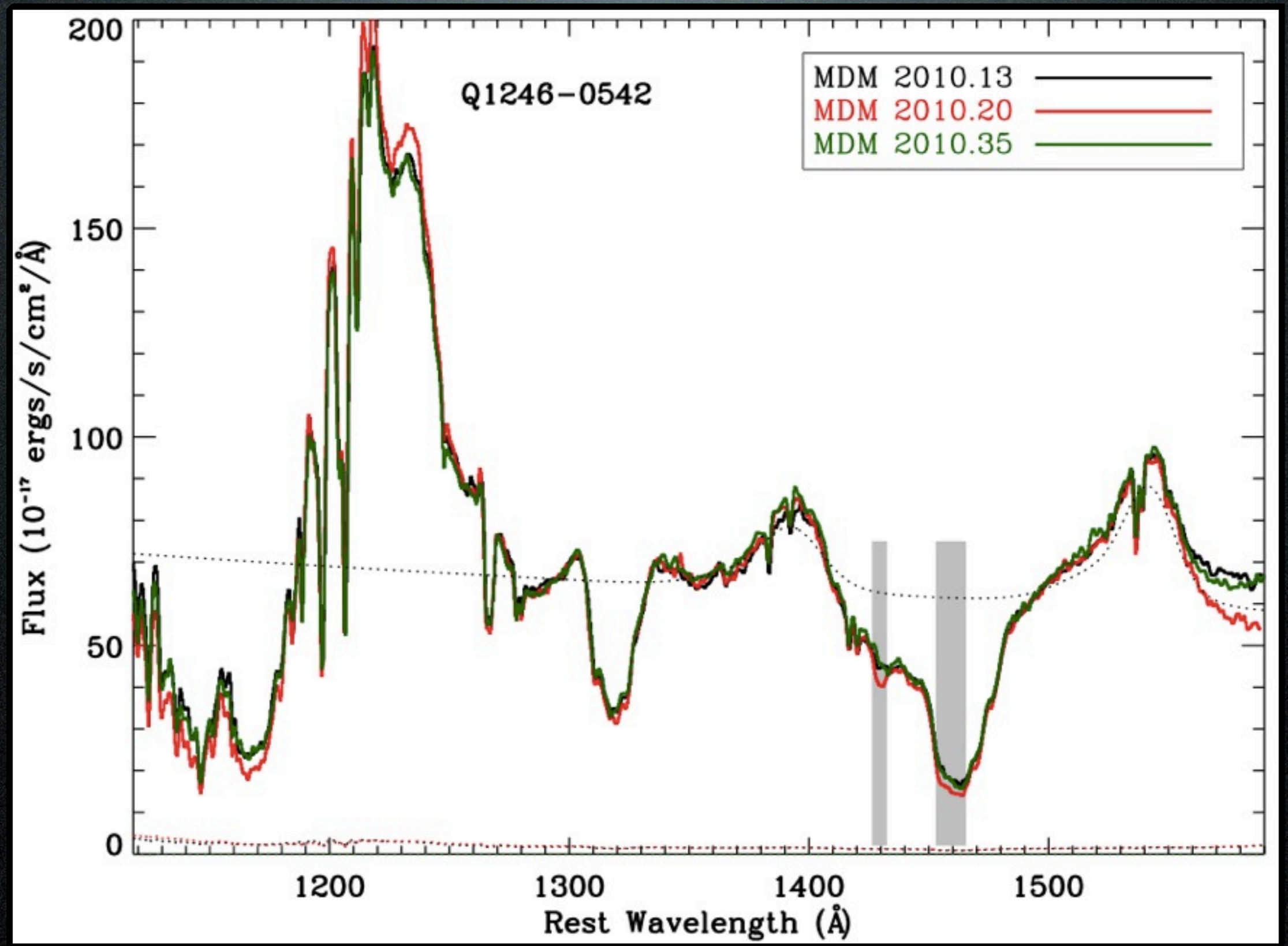
Rest Wavelength (Å)


Q1246−0542
MDM 2010.13
MDM 2010.20
MDM 2010.35
Flux (10⁻¹⁷ ergs/s/cm²/Å)
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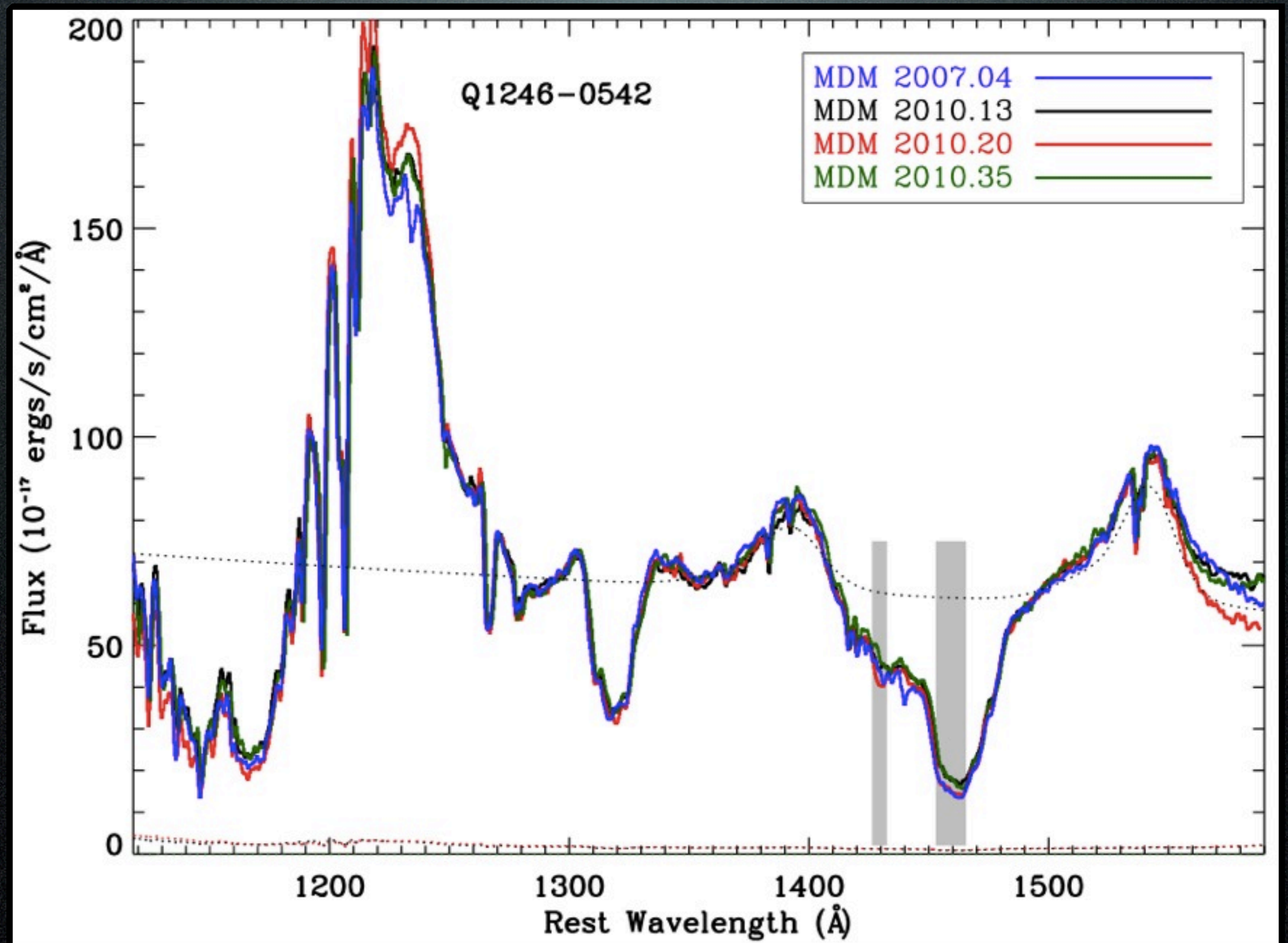
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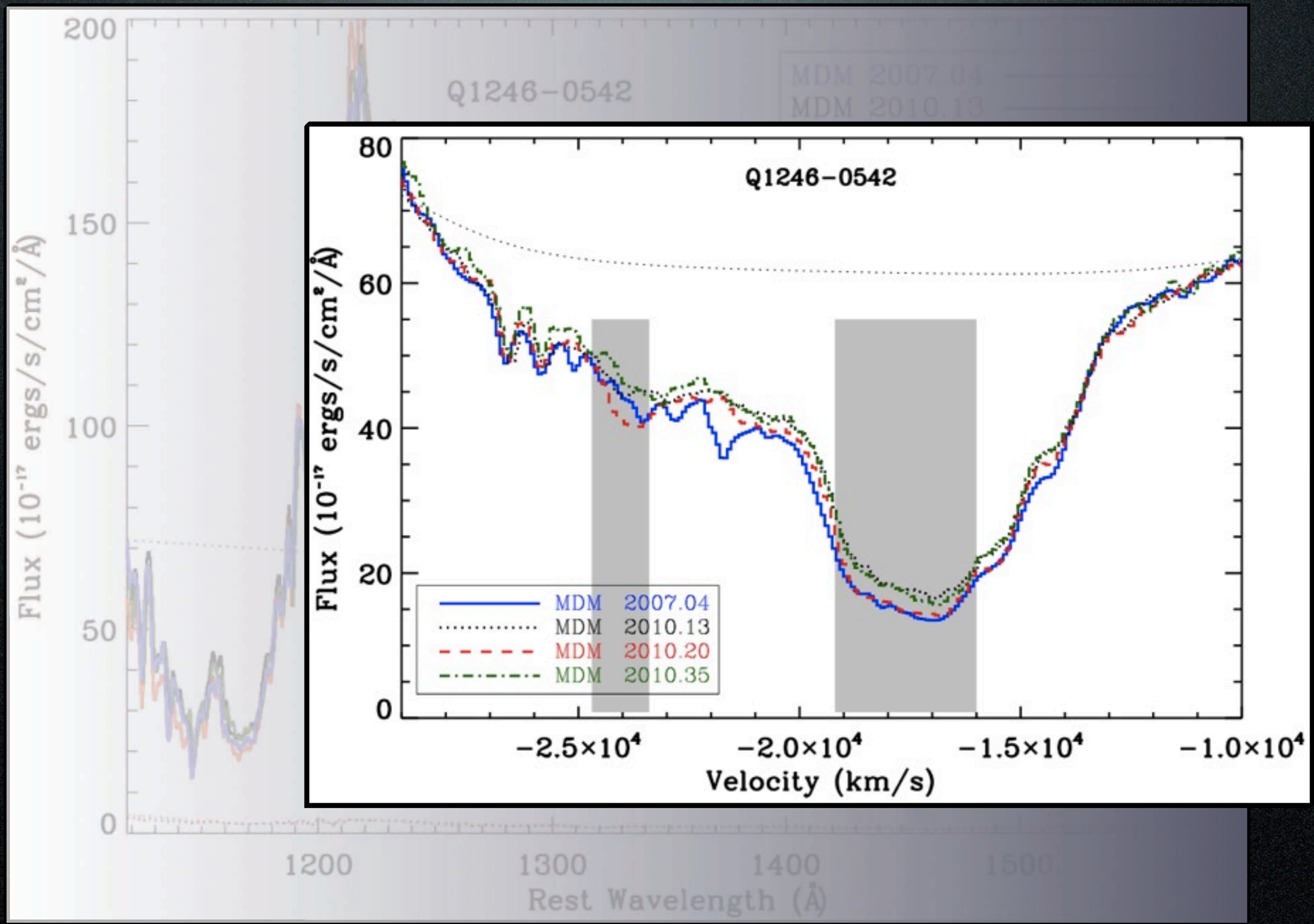
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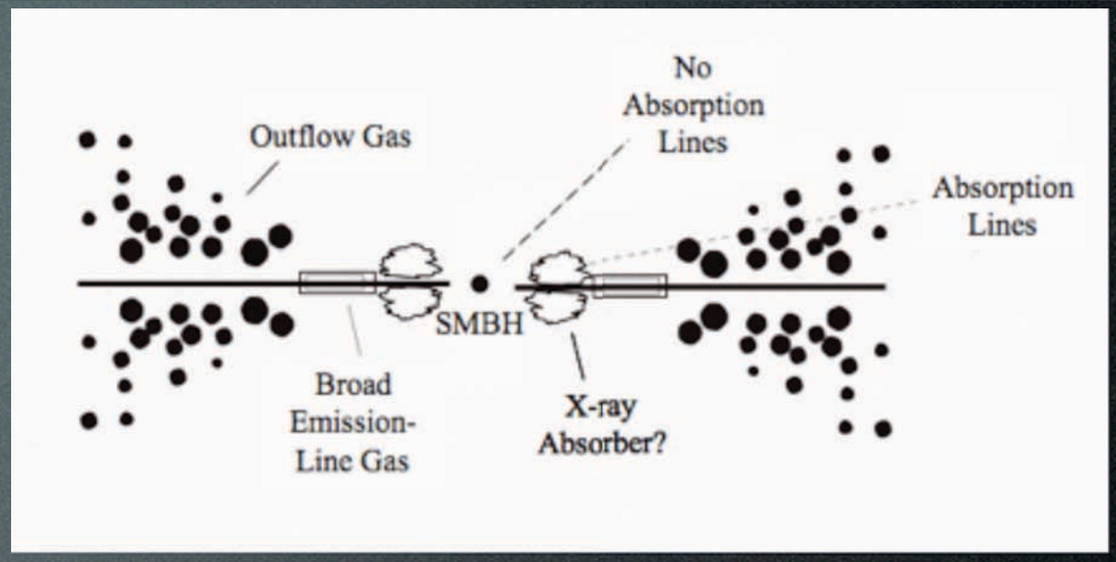
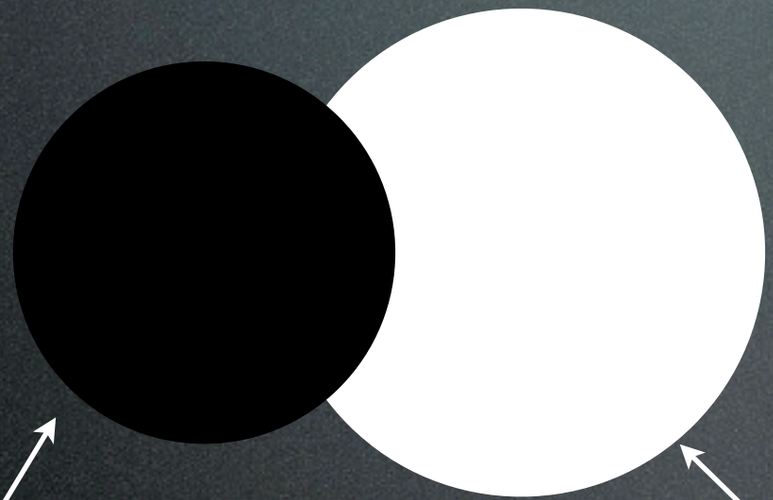
Rest Wavelength (Å)
Q1246−0542
MDM 2007.04
MDM 2010.13
MDM 2010.20
MDM 2010.35
Velocity (km/s)

Moving Cloud Scenario

Crossing Disks



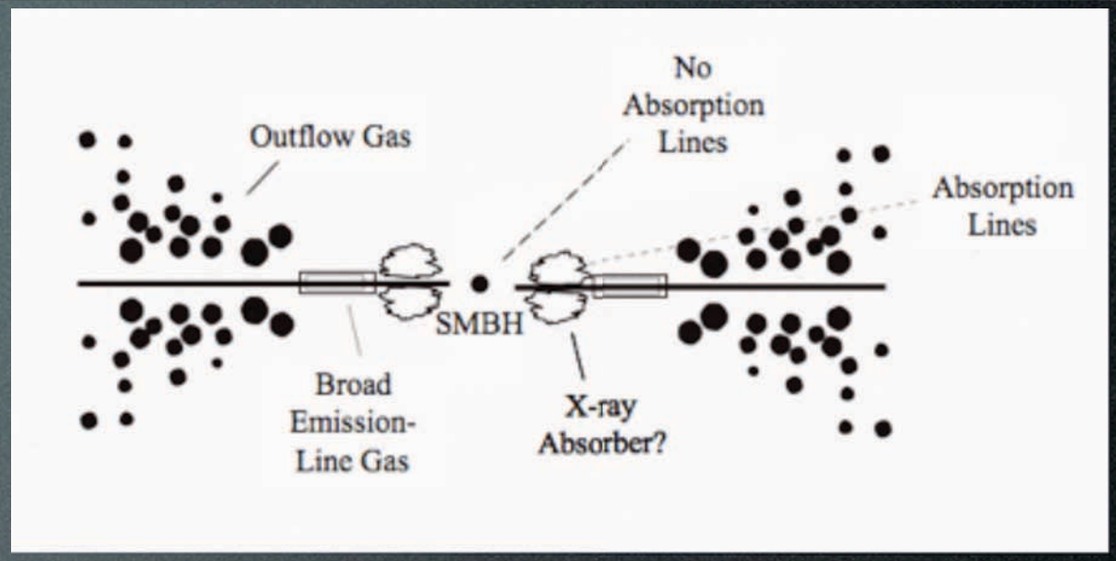


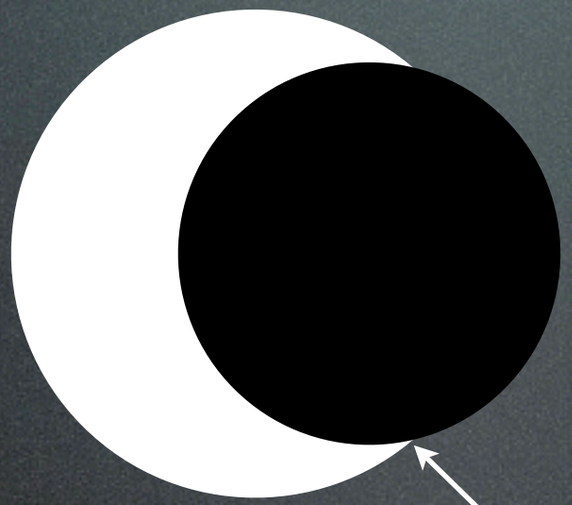
Moving Cloud

Continuum Source

Moving Cloud Scenario

Crossing Disks





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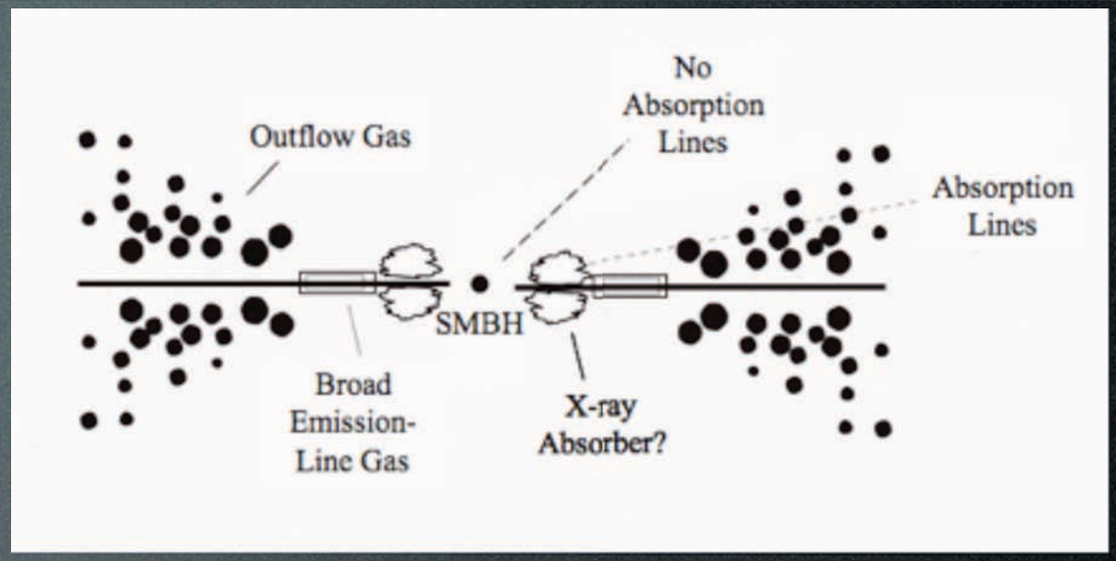
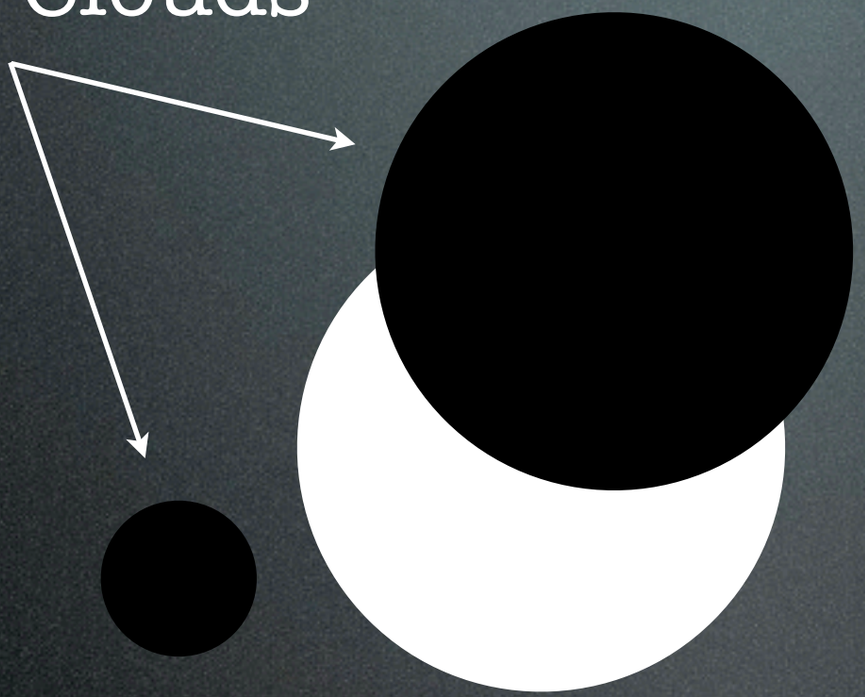


Multiple Clouds



Continuum Source

Multiple clouds?
e.g., Hall et al. 2007

Moving Cloud Scenario

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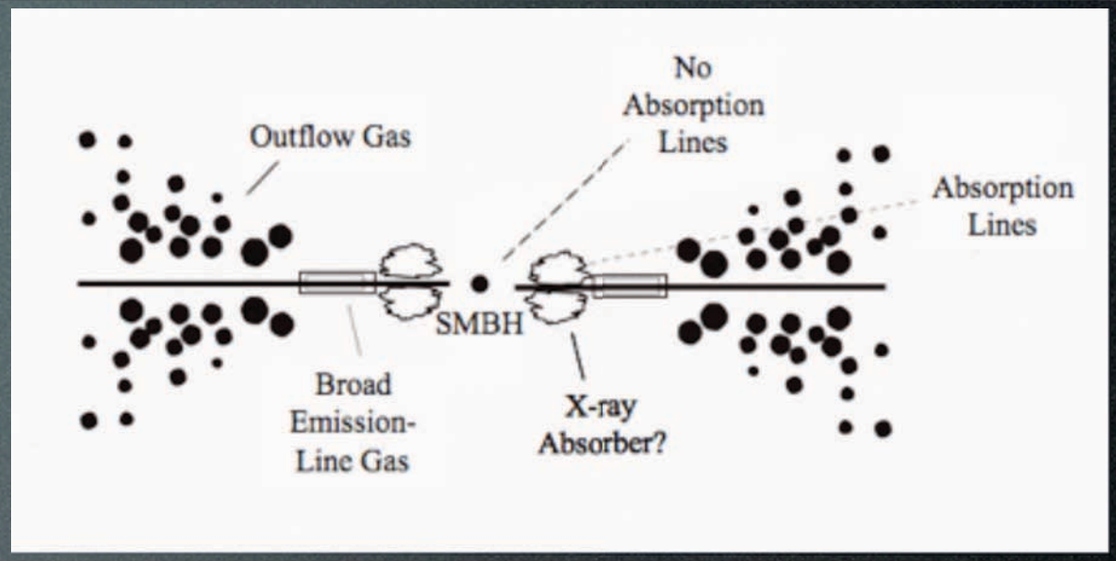

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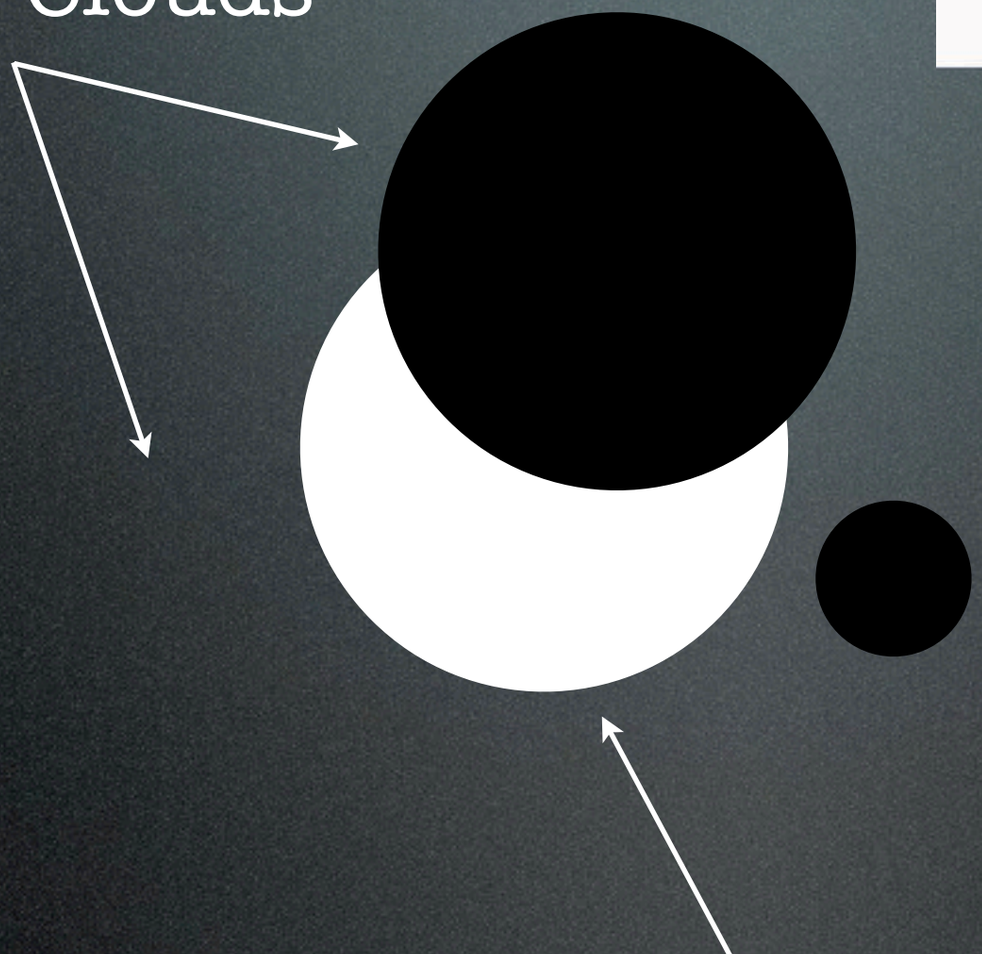
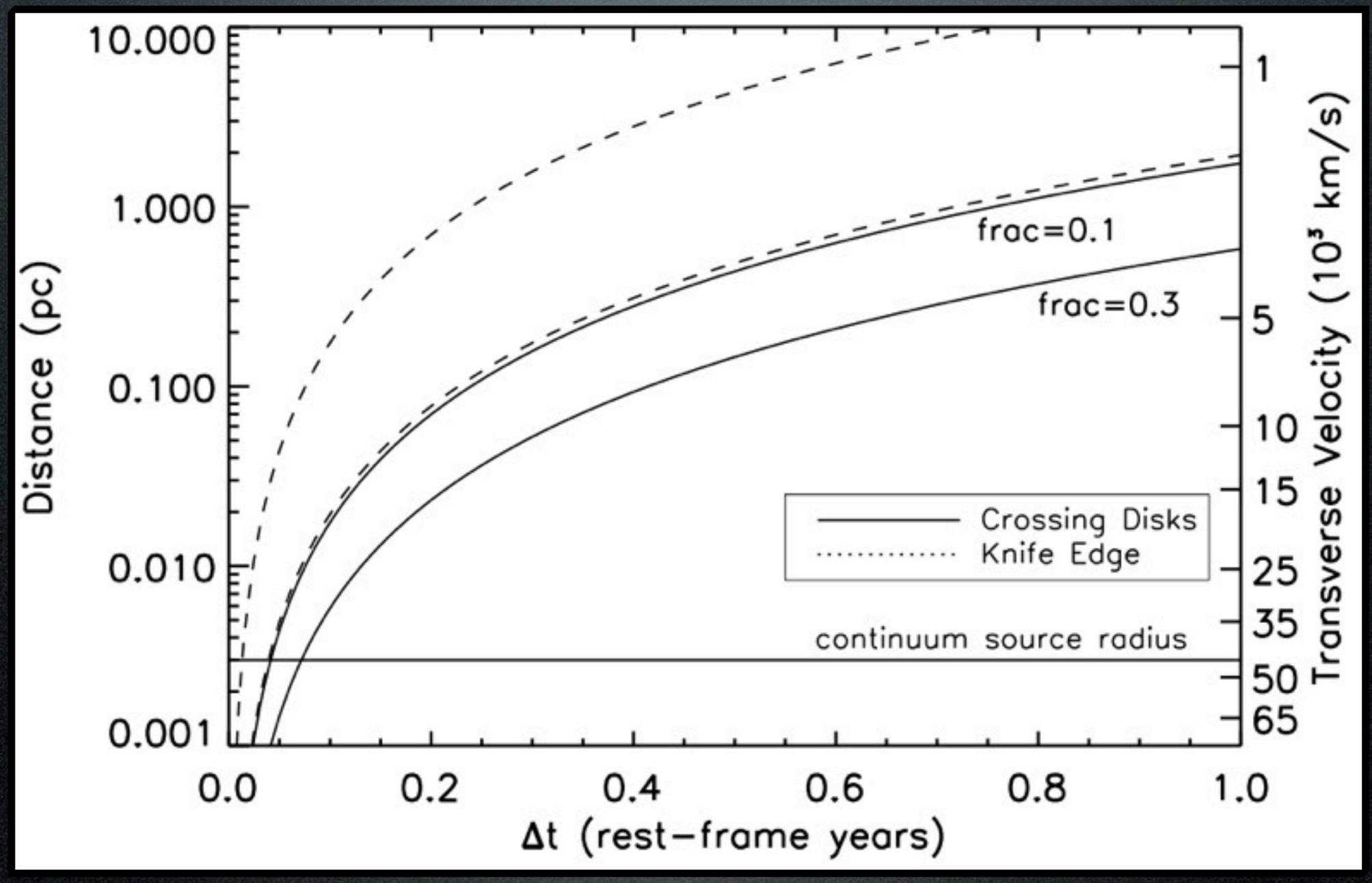


Multiple clouds?
e.g., Hall et al. 2007

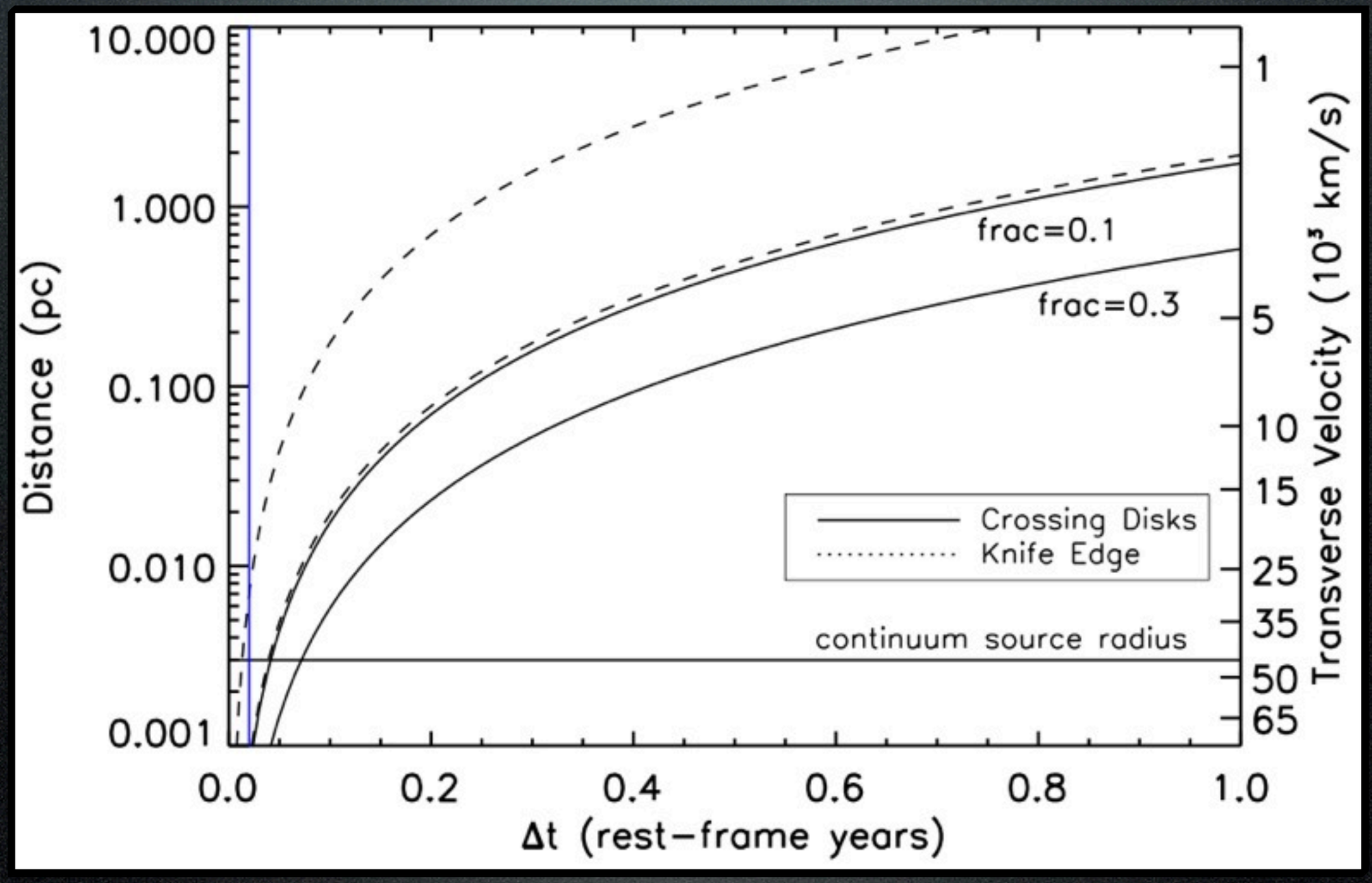
Constraints on Location of Gas

- Average bolometric luminosity for our sample: ~7×10^{46} ergs/s
- Characteristic diameter for continuum region at 1550 Å: $D_{1550} \sim 0.006$ pc
- Characteristic diameter for CIV BEL region: $D_{CIV} \sim 0.3$ pc
- Derive transverse speed based on an absorbing disc crossing continuum region
- Then, assume transverse speed ~ Keplerian rotation speed

Constraints on Location of Gas

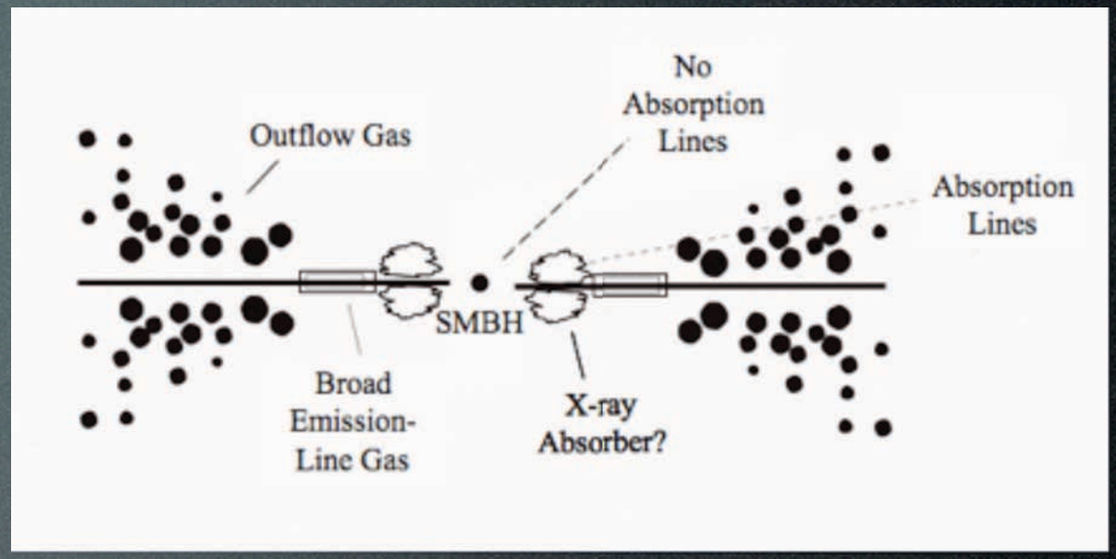


Constraints on Location of Gas



Moving Cloud Scenario

Knife Edge



Moving Cloud

Continuum Source

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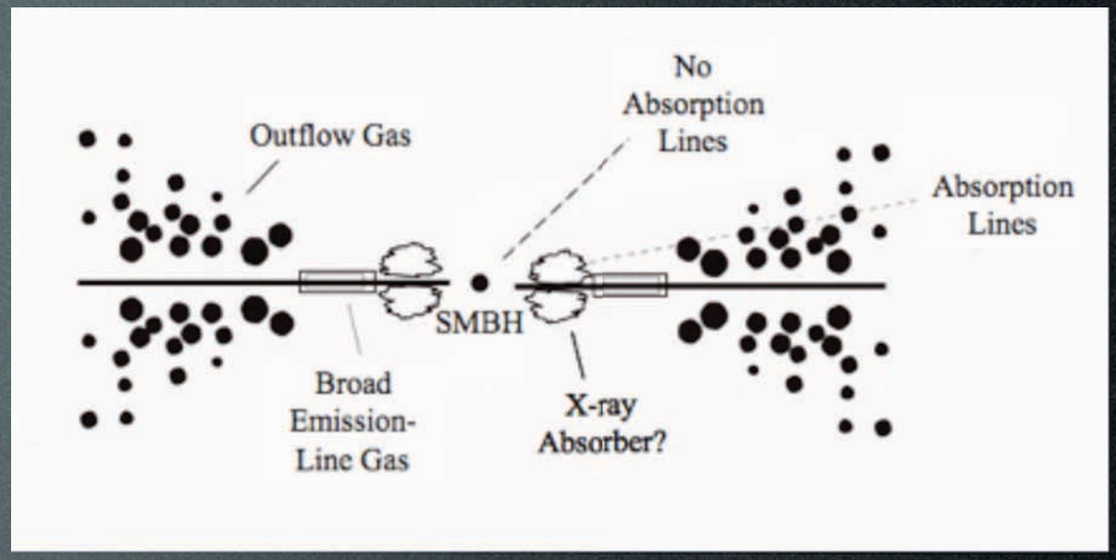

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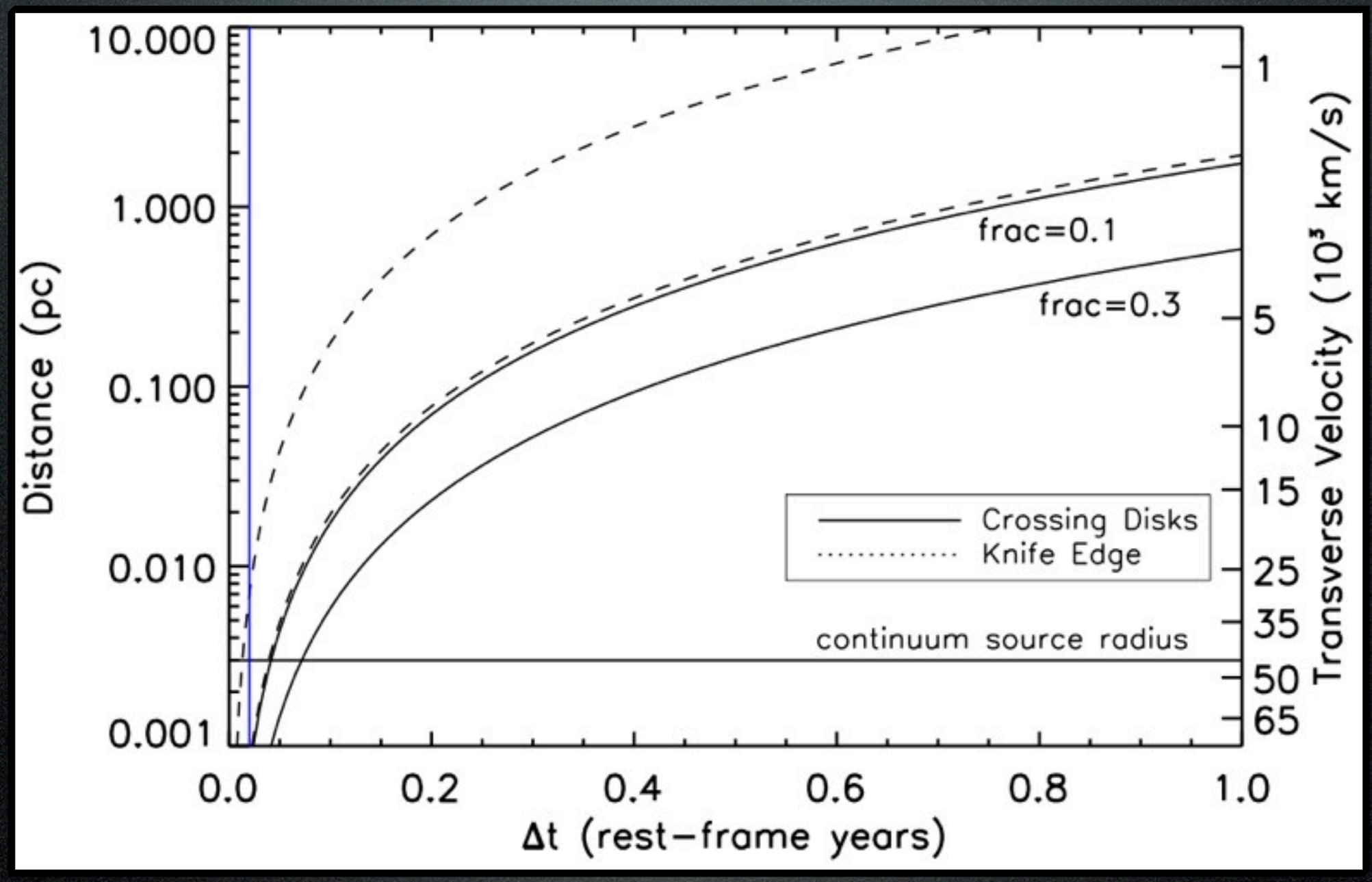

Constraints on Location of Gas

- For variability over $\Delta t \sim 7$ days, distance ~ 0.007 pc
  - For $U \propto L/(n \times r^2)$, at this distance, $n \sim 10^{15}$ cm^{-3}
- Hall et al. 2011 does not assume Keplerian orbit:
  - For Δt = 0.6 to 5 yr, transverse velocity between 2600 and 22,000 km/s, distance = 1.7 to 14 pc
- If variability in Q1246 was 10% change --> diameter of gas cloud ~0.002 pc

PV BALs with HST

- Using data from HST, we will look at bluer lines than SiIV and CIV, such as OVI and PV, in a sample of mini-BALs and BALs
- P is **much** less abundant than C (assuming solar abundances)
  - Therefore, if a PV BAL is detected, that indicates CIV and SiIV are very saturated and therefore, very high column densities ($N_H \gtrsim 10^{22}$ cm^{-2}, Hamann 1998)
- Derive constraints on ionization and column density in the flows --> estimate viability of BAL outflows as feedback mechanism

Summary

- Variability occurs more often at higher velocities and in shallower (portions of) absorption troughs
- BAL variability usually occurs in only portions of BAL troughs
- SiIV is more variable than CIV; they vary in same sense
- Including more epochs increases variability fraction
- Variability over ~week to month time-scales possibly constrains location of gas to sub-parsec distances from central source