CO Emission from z~6 Quasars: Black Hole, Bulge and Dynamical Masses

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Radiative Transfer Modeling
- Chris Walker
- Romeel Davé

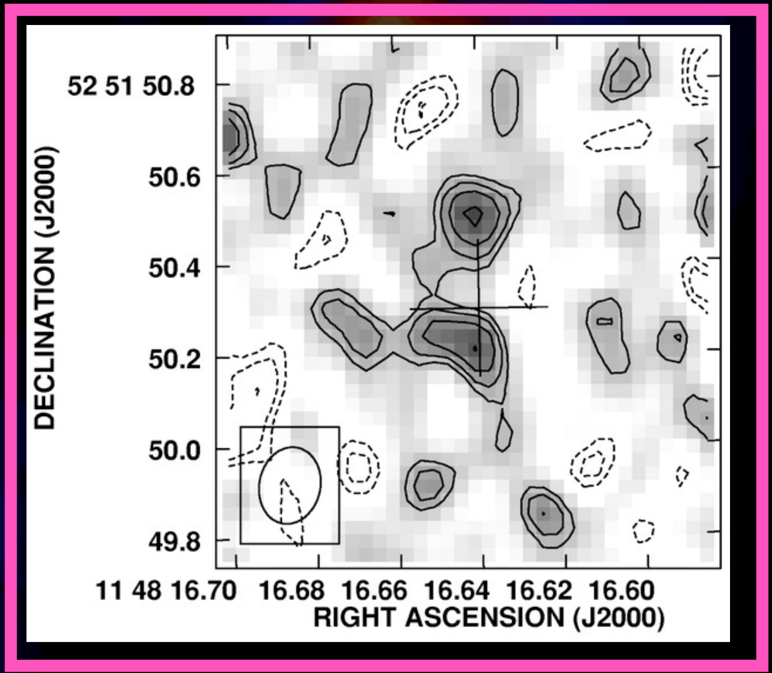
Cosmological/Hydrodynamic Modeling
- Yuexing Li
- T.J. Cox
- Lars Hernquist
- Philip Hopkins

CO in z=6.42 quasar J1148+5251

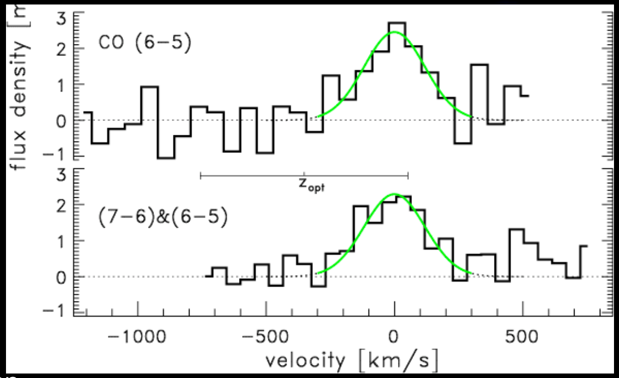
Quasars z~6

- CO Flux density peak at ~J=6
- SFR~3000 $M_\odot$/yr
- 2 component morphology
- H_2 mass=1x10^{10} $M_\odot$
- BH mass~10^9 $M_\odot$
  (Willott et al.)
- σ~120 km/s linewidth = 5X10^{10} $M_\odot$ dynamical mass
- (no 10^{12} $M_\odot$ bulge?)

$M_{BH} \approx 0.002 M_{star}$



Walter et al, 2004
Bertoldi et al. 2004

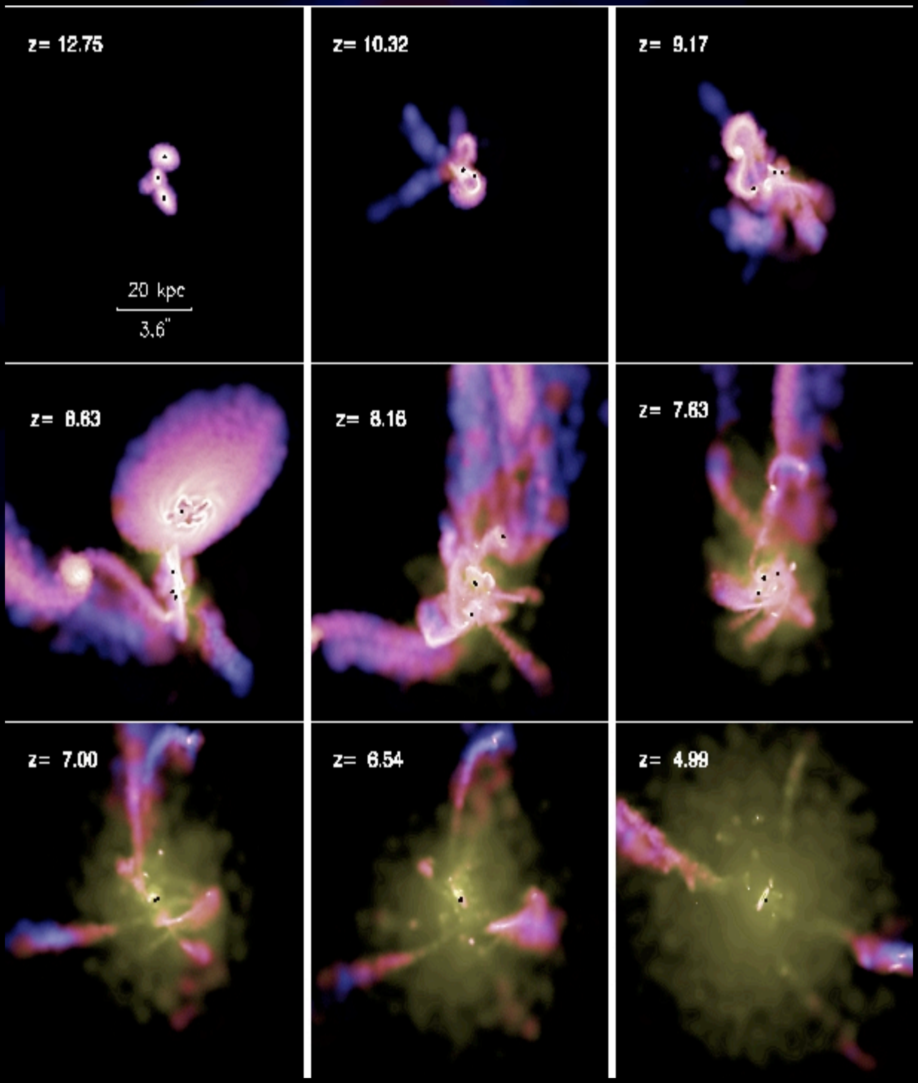


z~6 Quasar Formation Simulations

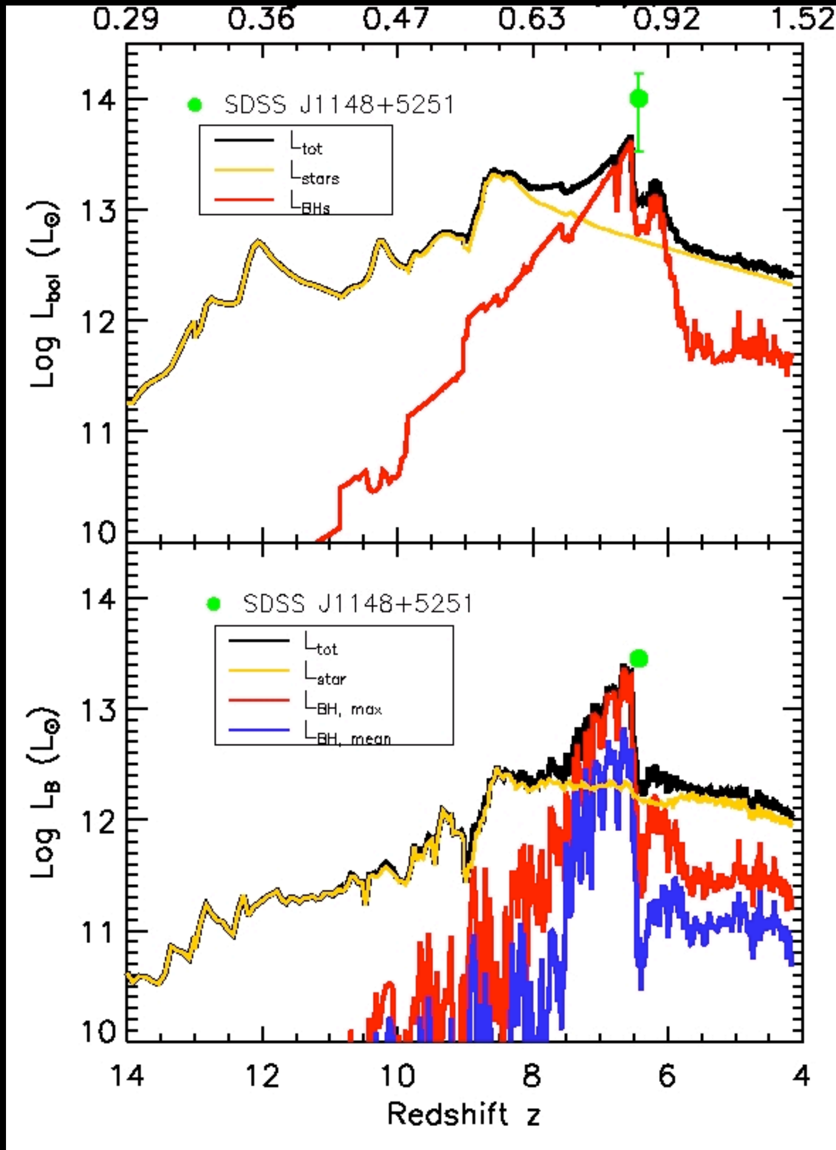
- Structure Formation models to identify most massive halo
- Resimulate most massive halos (10^{12}-$10^{13}M_{\odot}$ at z=6) to derive merger tree
- Hydrodynamically simulate galaxy mergers: GADGET-2
- 3 galaxies chosen for this study (10^{12}-$10^{13}M_{\odot}$ at z=6)

  Y. Li et al (2007a,b)

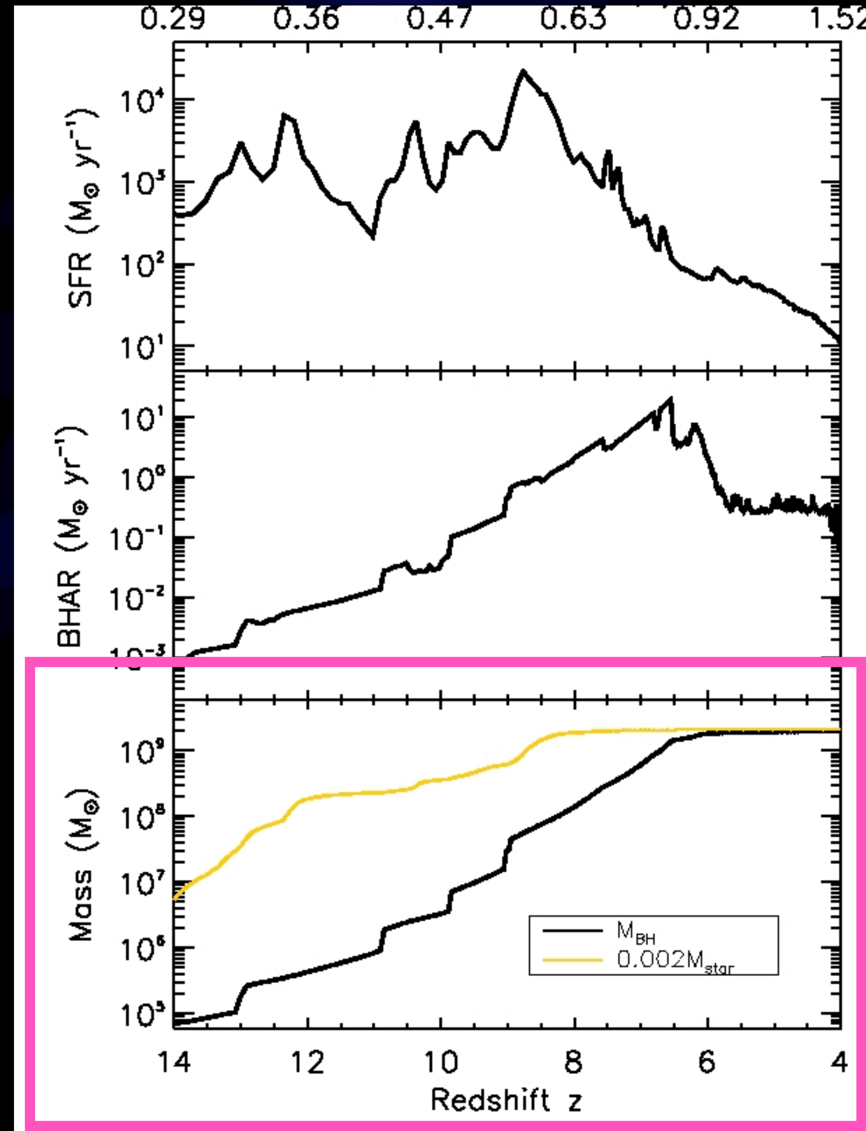
  Y. Li et al. in prep



z~6 Quasar



Li et al (2007a)



$M_{BH} \approx 0.002 M_{star}$

So why are the observed line widths so narrow?

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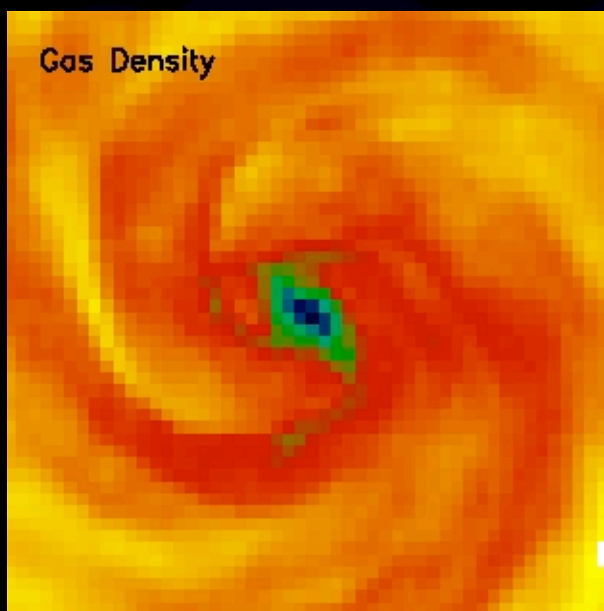
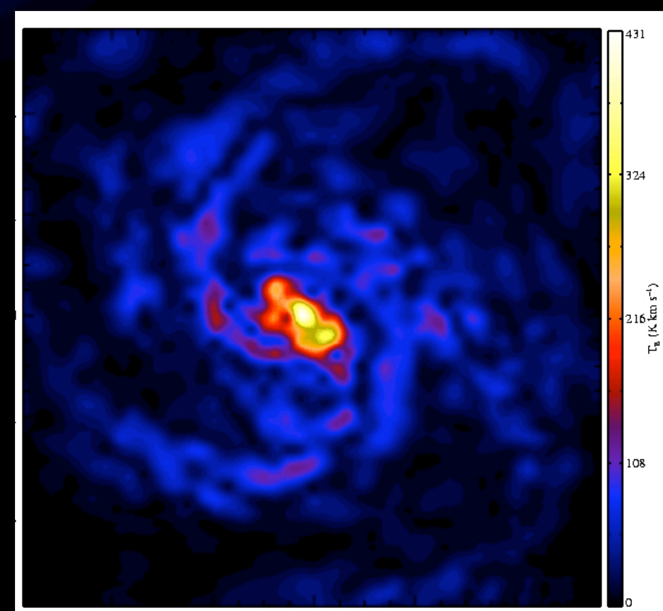
Aspen Winter Meeting 2008

Non-LTE Radiative Transfer

- 3D Monte Carlo code developed based on improved Bernes (1979) algorithm
- Benchmarked against Leiden non-LTE radiative transfer tests
- Sub-grid algorithm considering mass spectrum GMCs as SIS
- $M_{cloud}=10^4$-10^6 $M_\odot$, Galactic CO Abundance, 10 CO transitions, 10 million rays per iteration

Gas-rich Spiral Example CO J=1-0





Narayanan et al. 2007

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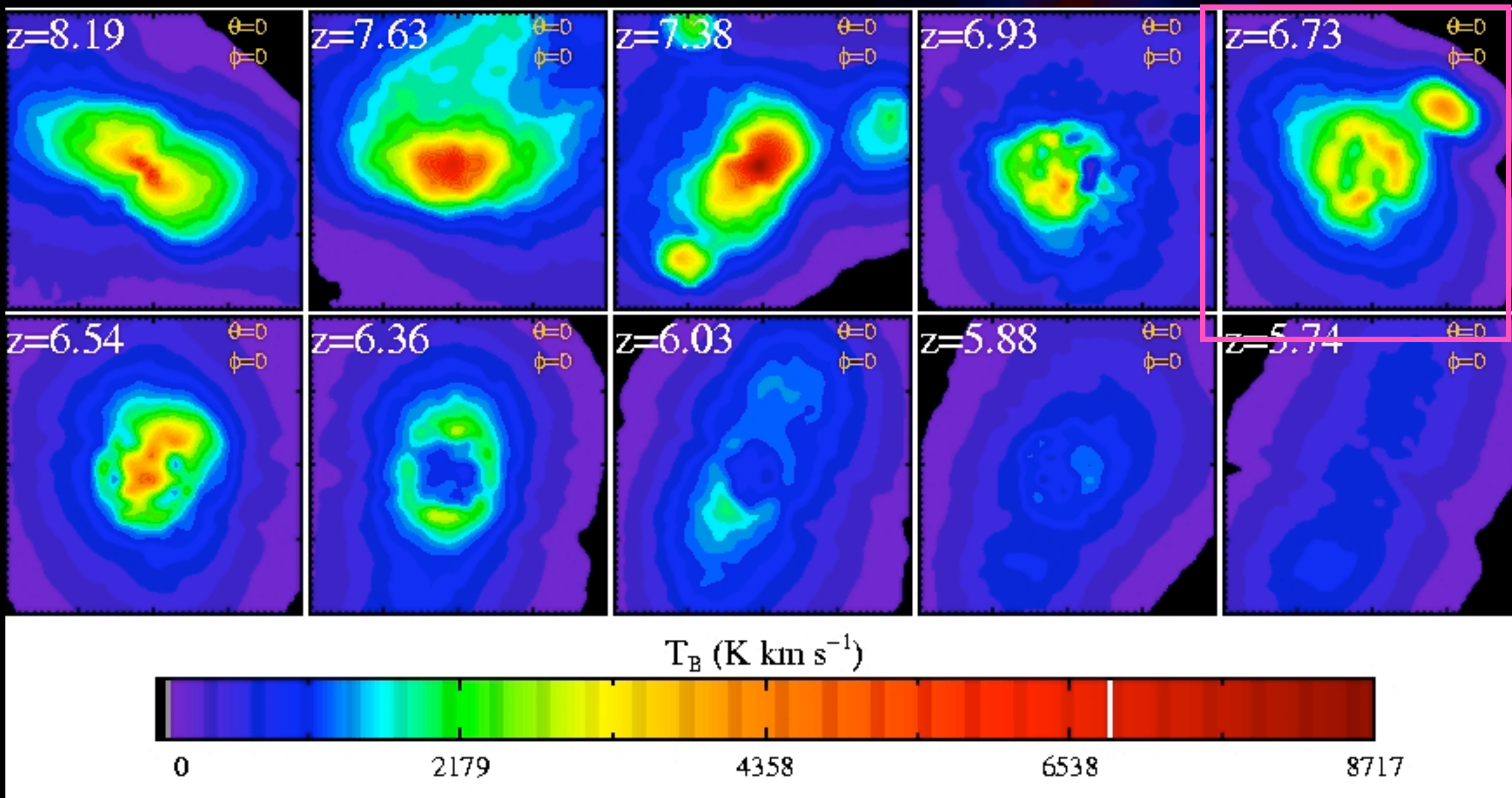
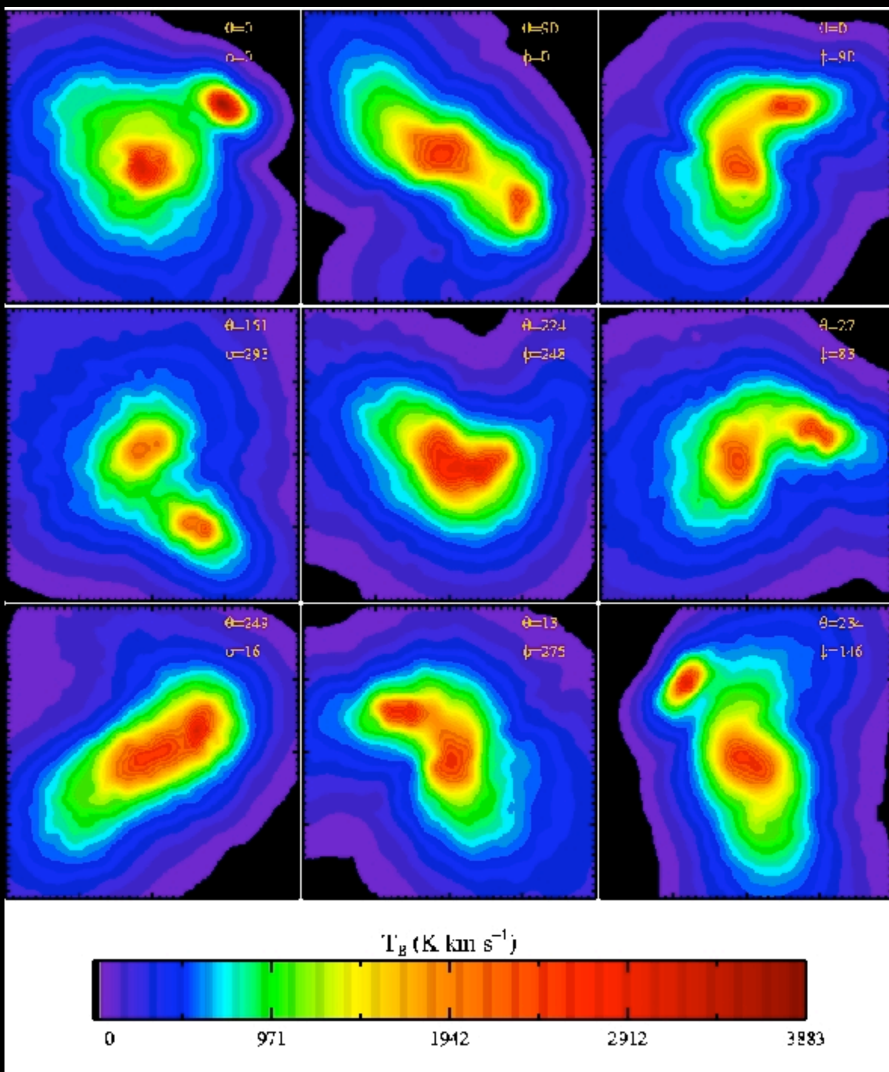
Simulated CO (J=1-0) Morphology



DN, Li et al. 2007

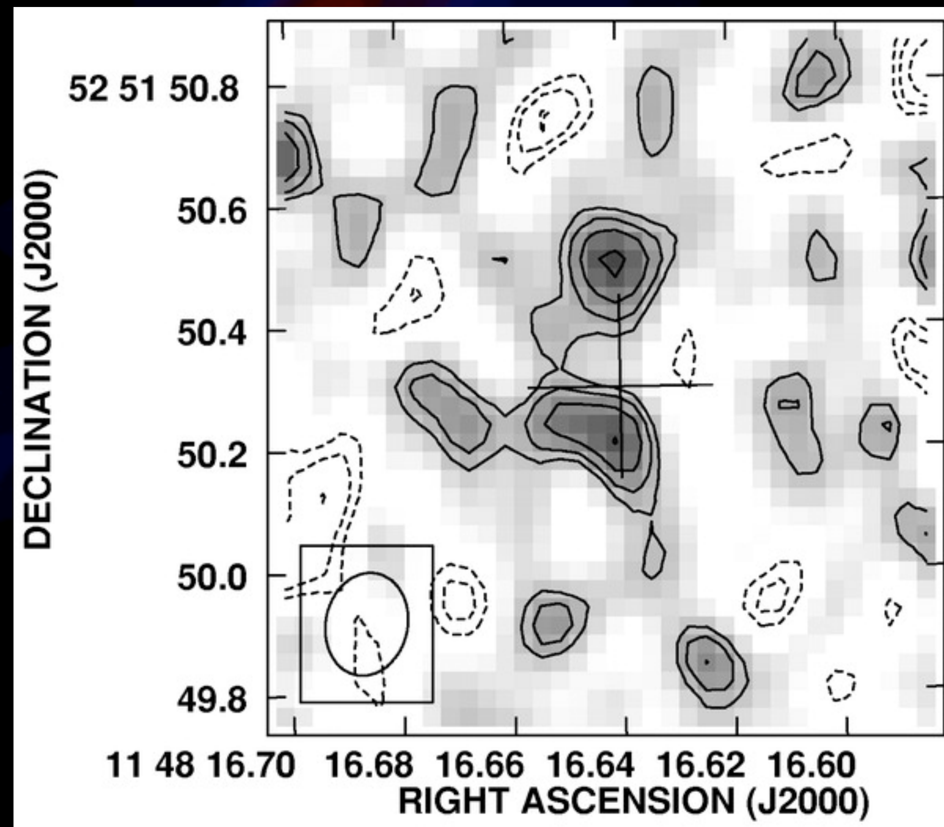
CO (J=3-2) Morphology - Good Correspondence with Observations

Simulations



Narayanan, Li, et al. 2007

Observations (VLA)

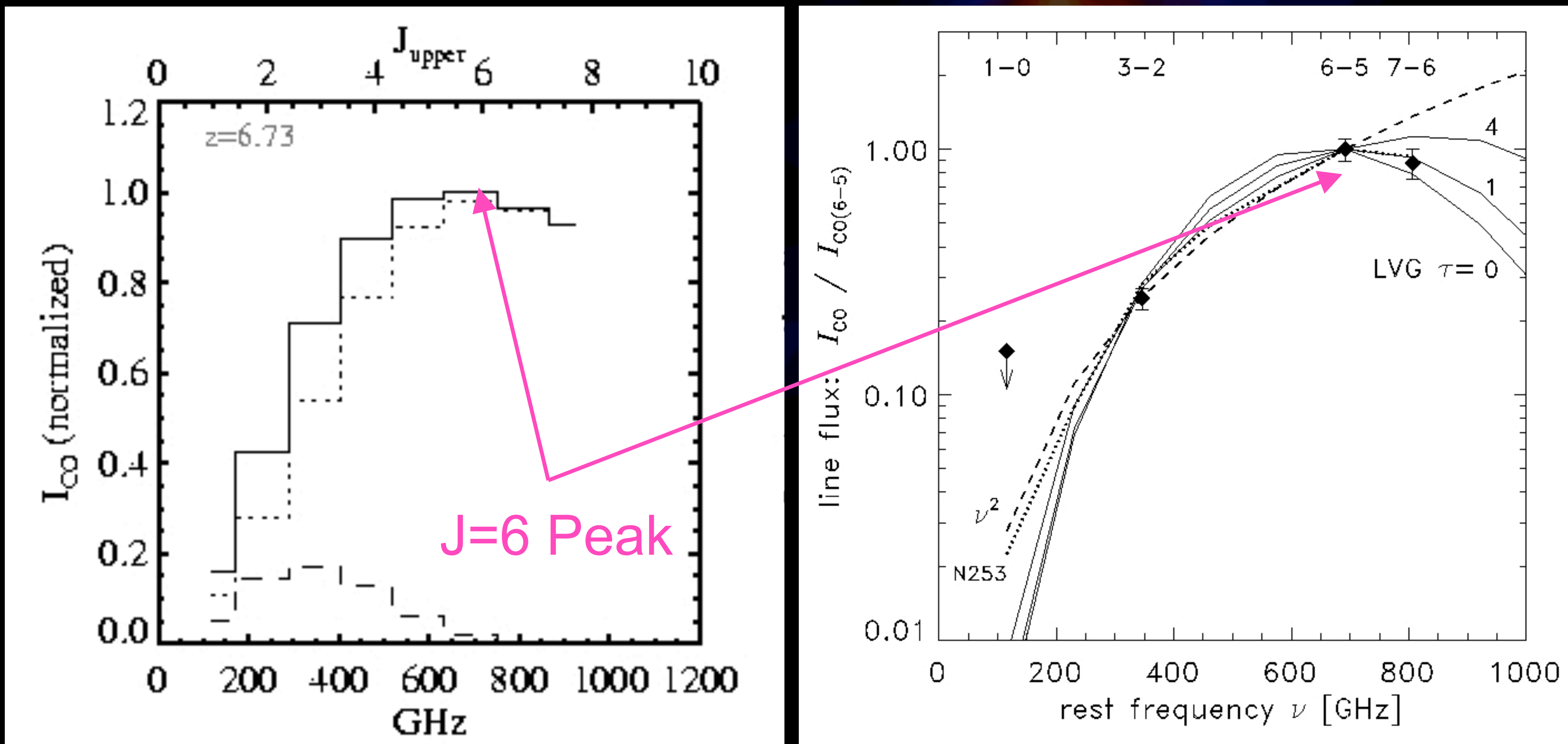


Walter et al. (2004)

CO Excitation: CO SEDs

Simulations

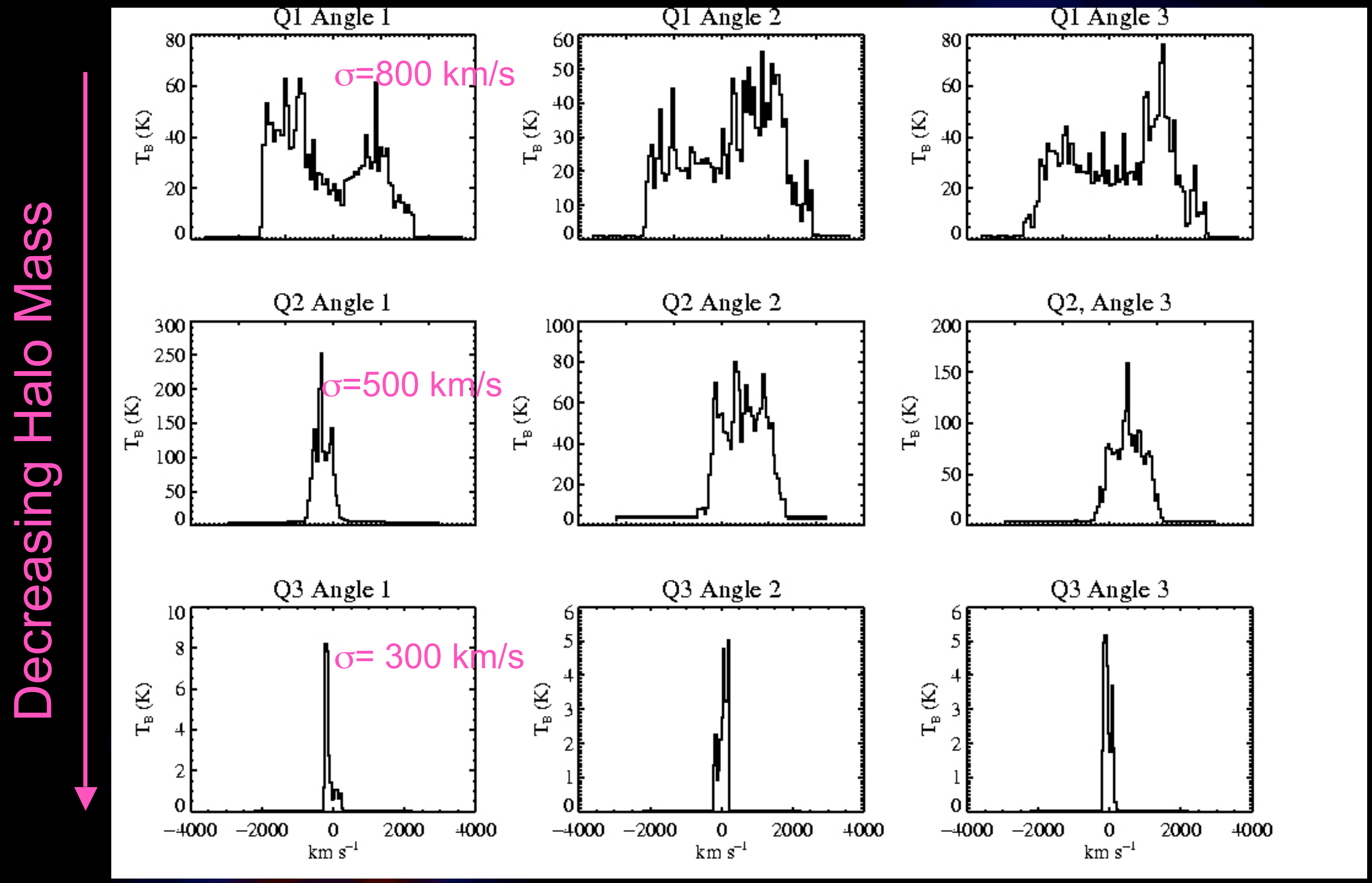
Observations



DN + (2007)

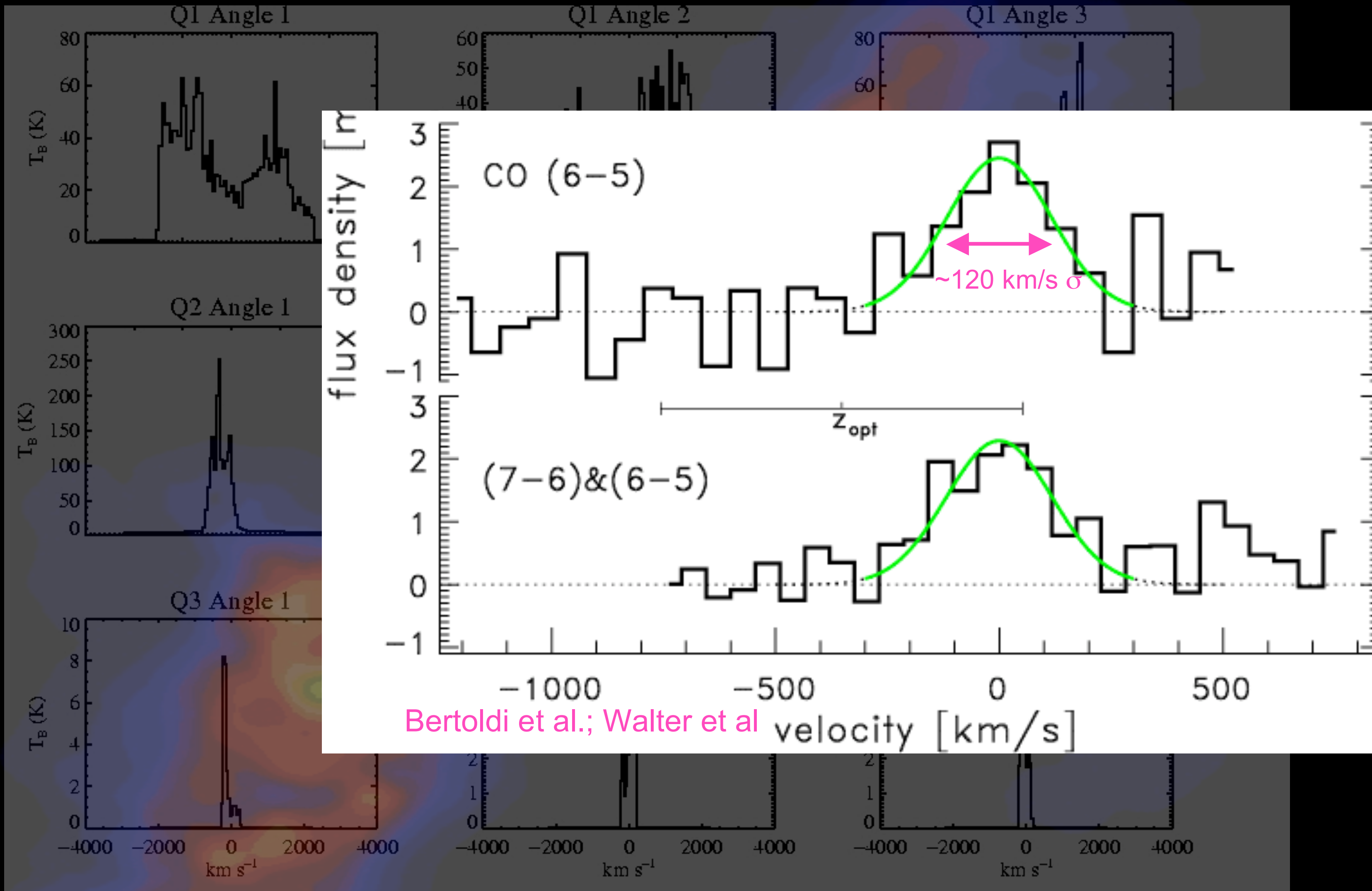
Bertoldi et al.(2004)

CO Emission Lines



Large virial velocities in massive halo (σ~300-800 km/s) manifested in large CO line widths

CO Emission Lines



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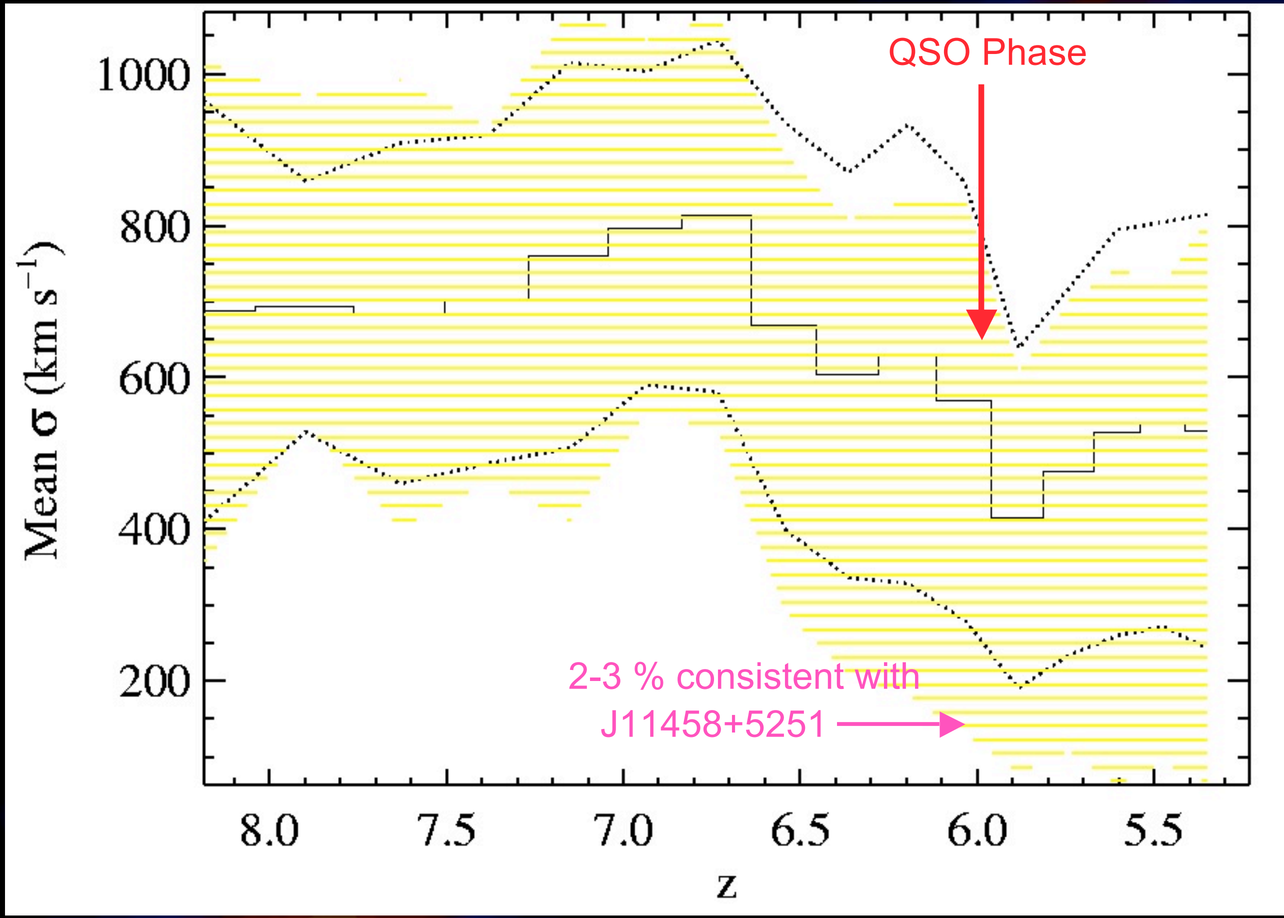
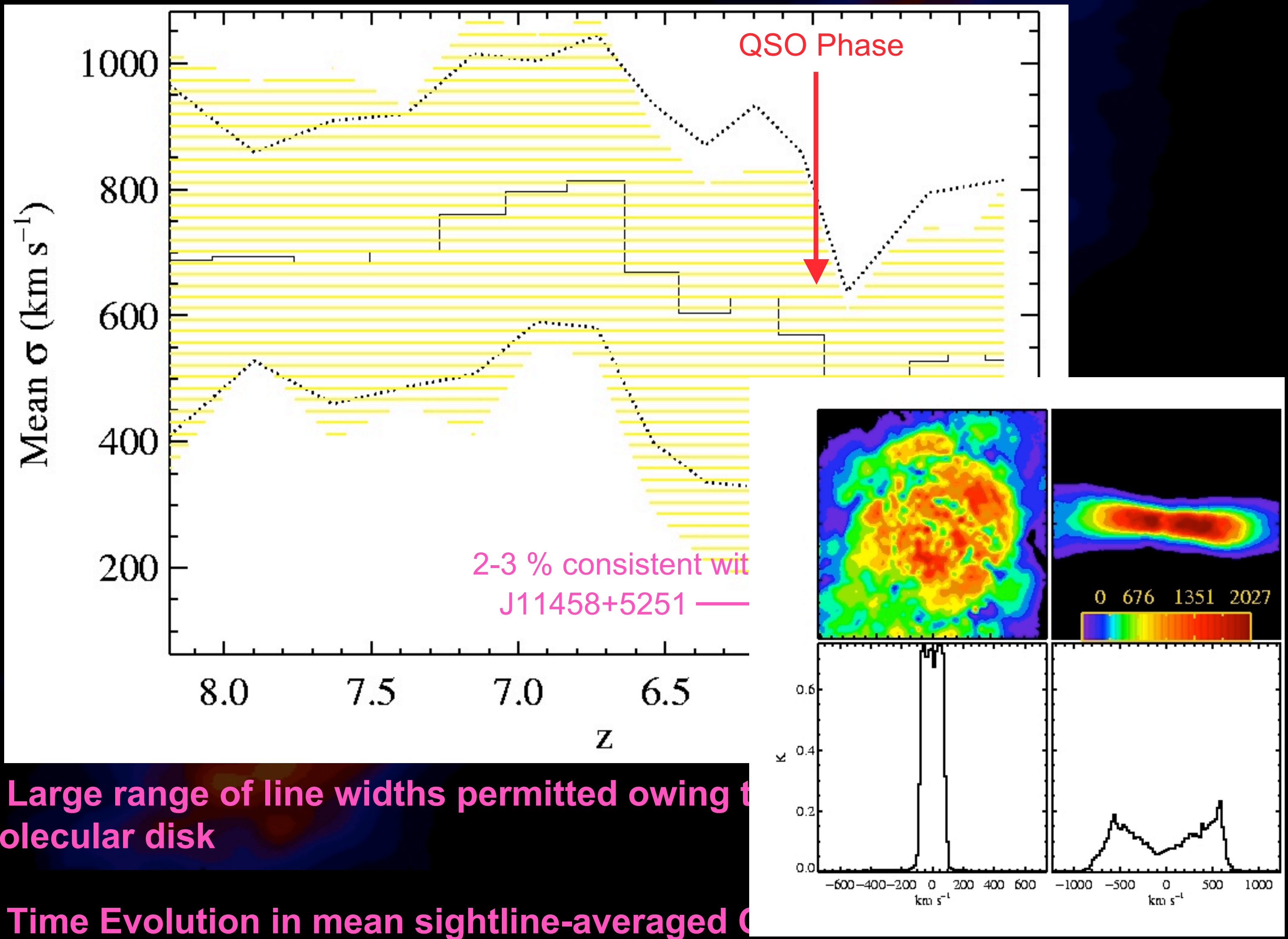
Sightline-Dependent CO Line Widths: Most Extreme Halo as an Example



1. Large range of line widths permitted owing to different viewing angles of molecular disk

2. Time Evolution in mean sightline-averaged CO line width

Sightline-Dependent CO Line Widths: Most Extreme Halo as an Example



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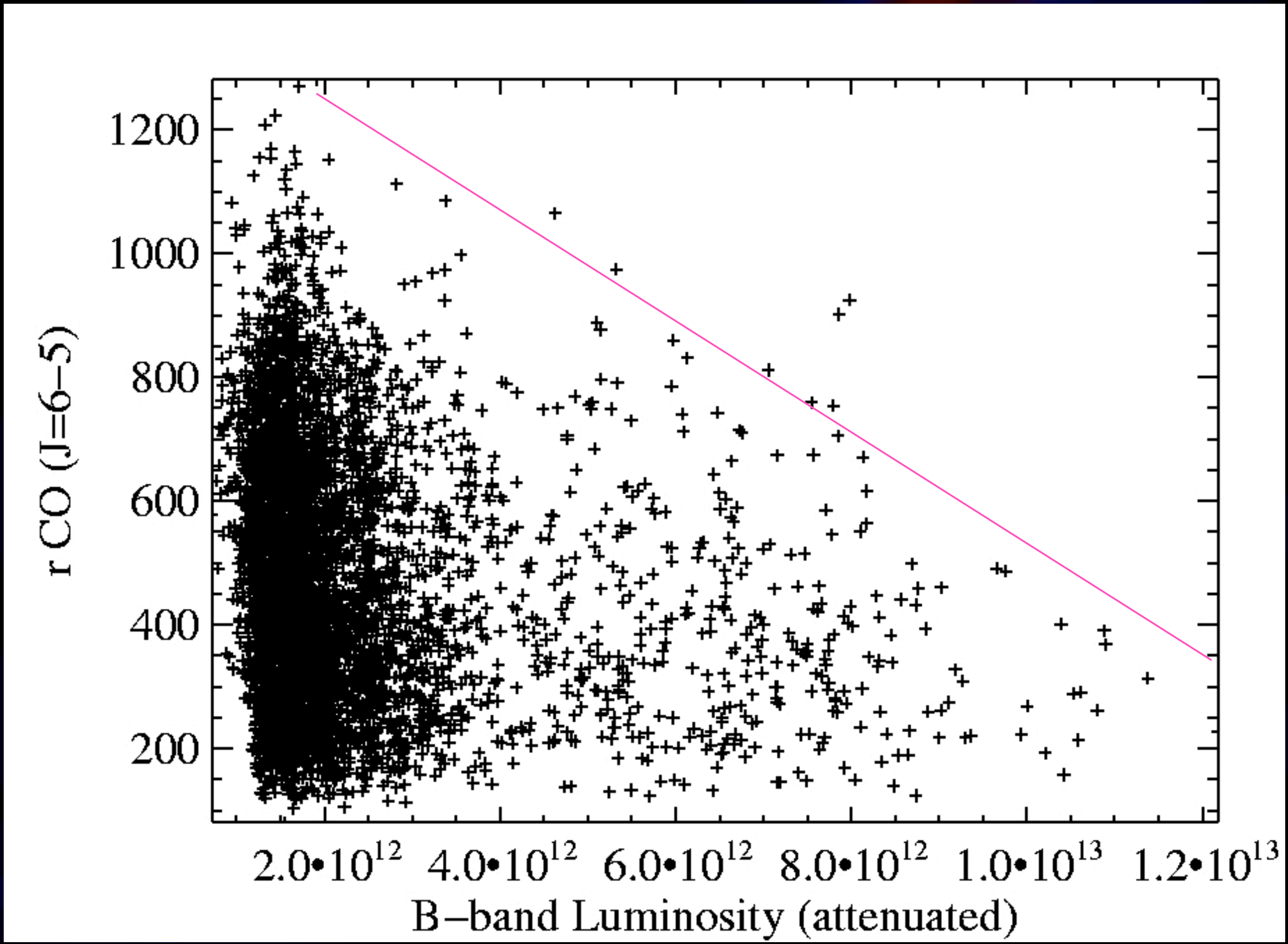
CO FWHM-QSO Luminosity Relation

Optically Luminous LOSs have small CO FWHMs because of molecular disk formation

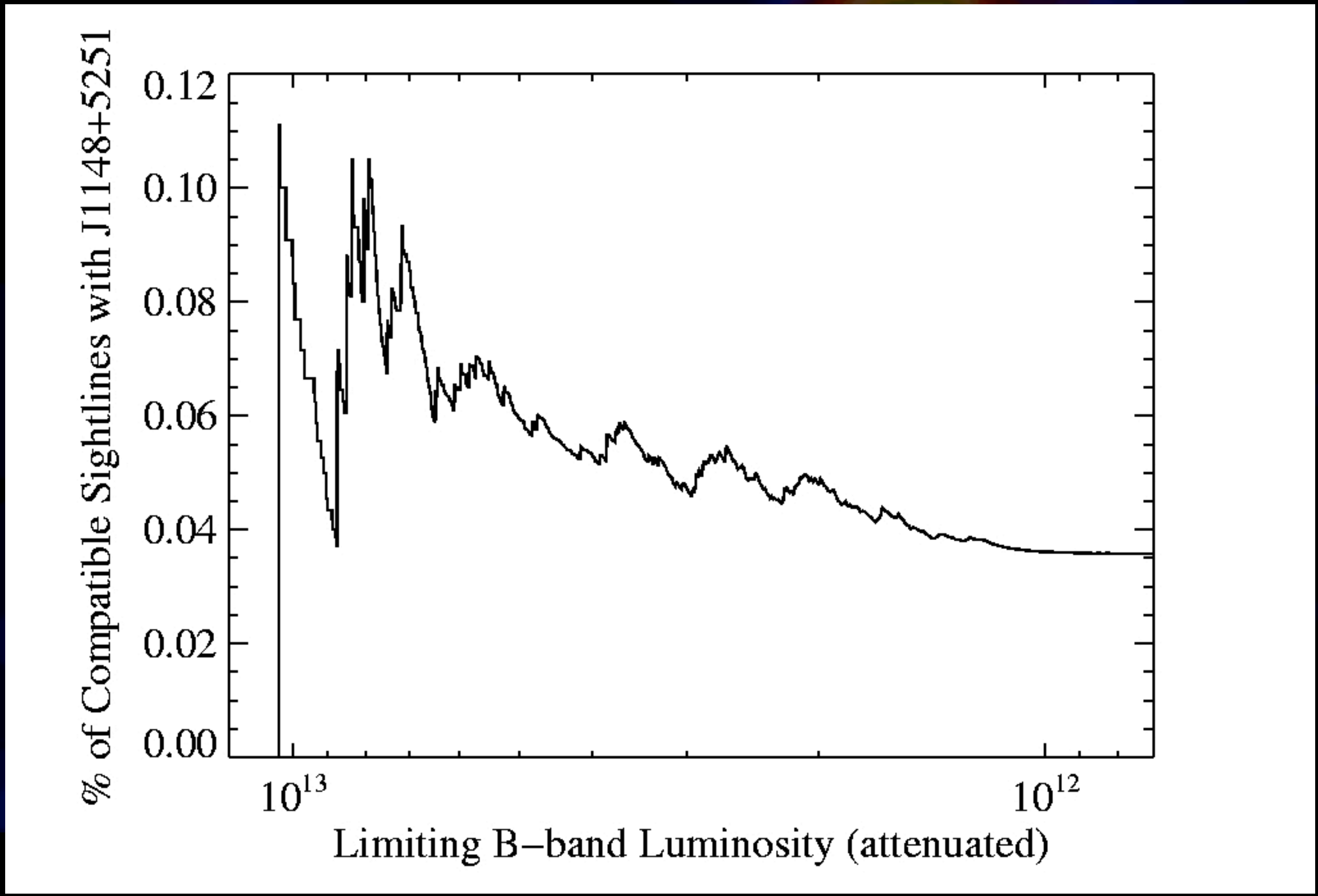


Narayanan et al. (2008)

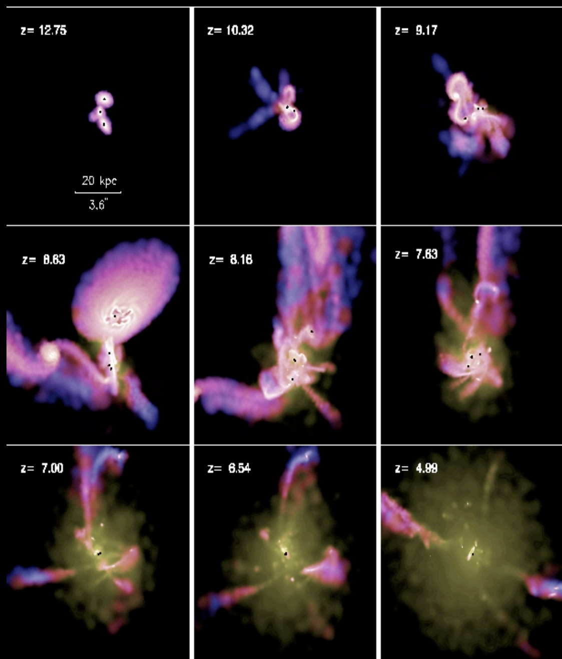
Selection Effect

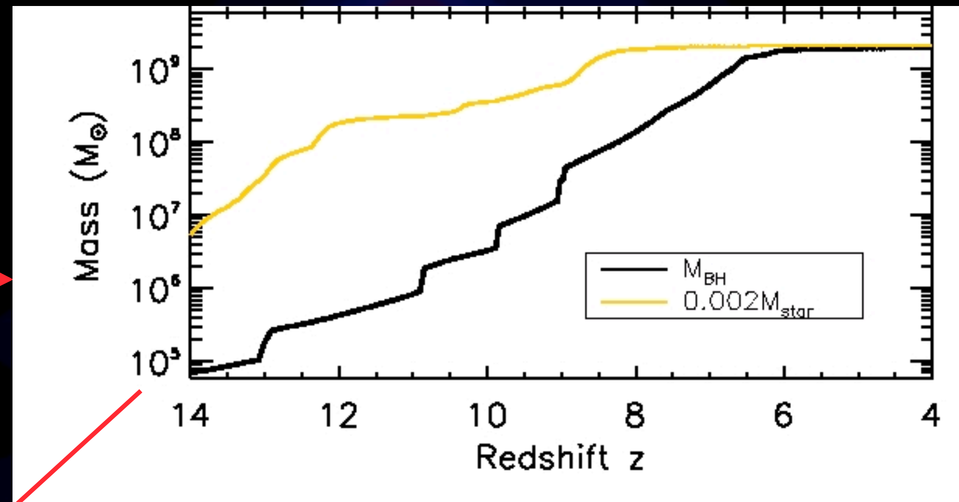
Highest B-band Luminosities have higher percentages of compatible sightlines because of selection effects:

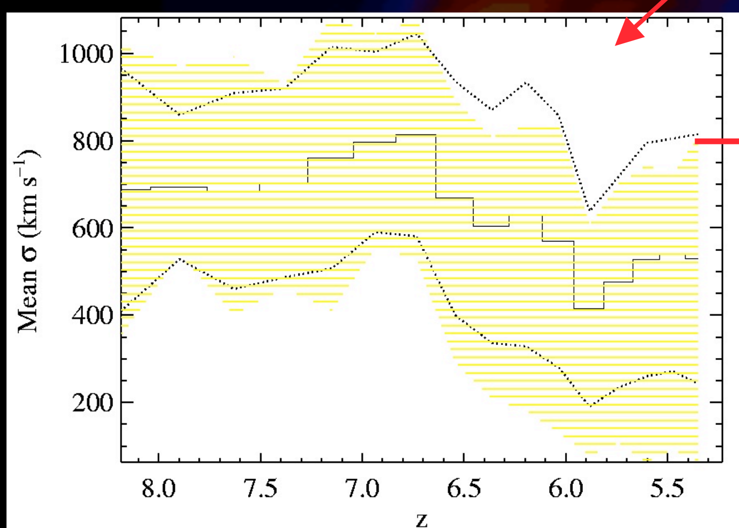
10-25% of sightlines compatible with observations
(Halo Mass Dependent)

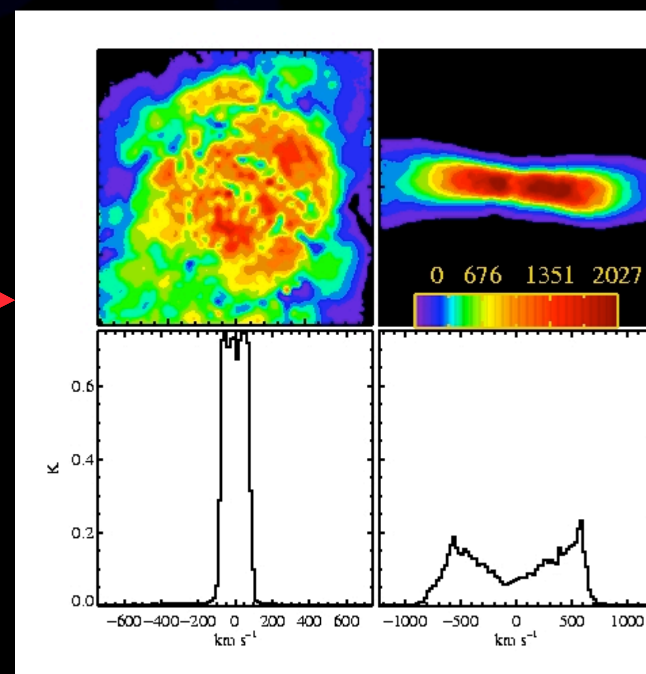


Observable Tests (How Have We Gotten Here?)









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Observable Tests:

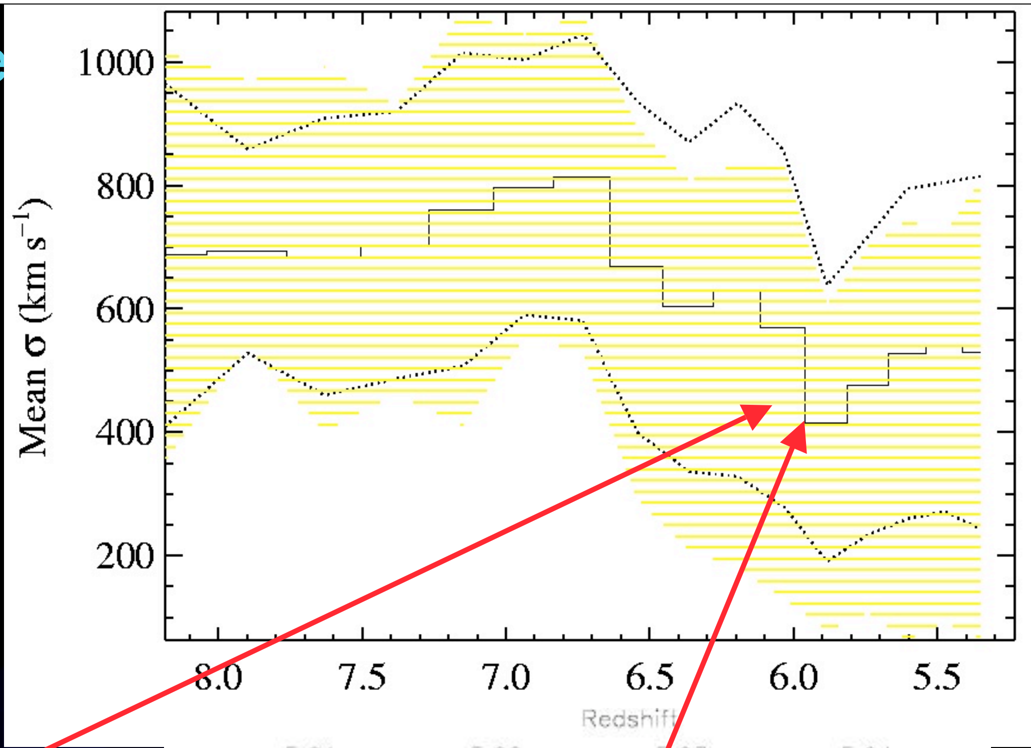
1. Line widths of future z~6 quasar detections (should be broad(er)!)

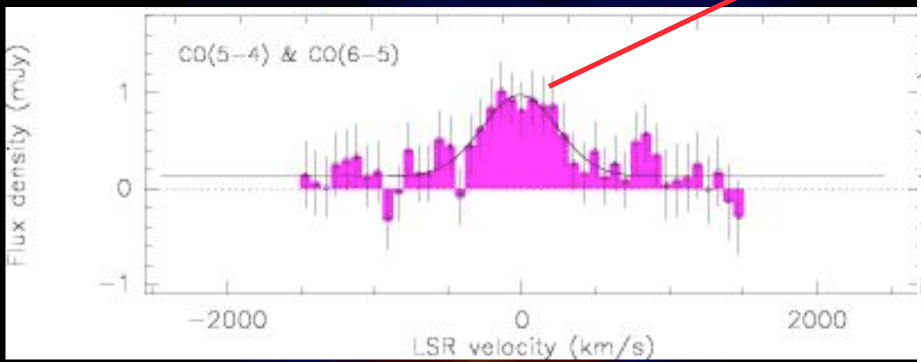
2. Line widths of galaxies and quasars which form in comparable 10^{12}-10^{13} $M_\odot$ halos at z~2 (SMGs, z=2 QSOs)

Obse

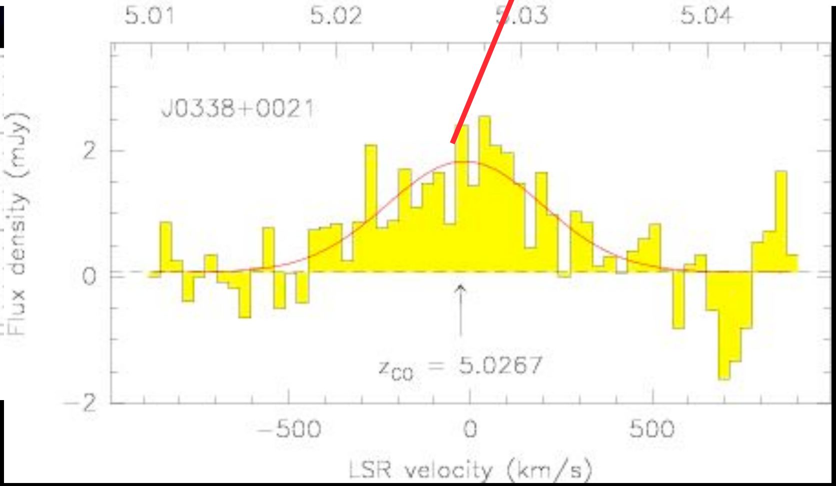
1. Line widths of lower luminosity z~6 quasars (should be broad(er)!)

2. Line widths of galaxies and quasars which form in comparable 10^{12}-10^{13} $M_\odot$ halos at z~2





Carilli et al. (2007)



Maiolino et al. (2007)

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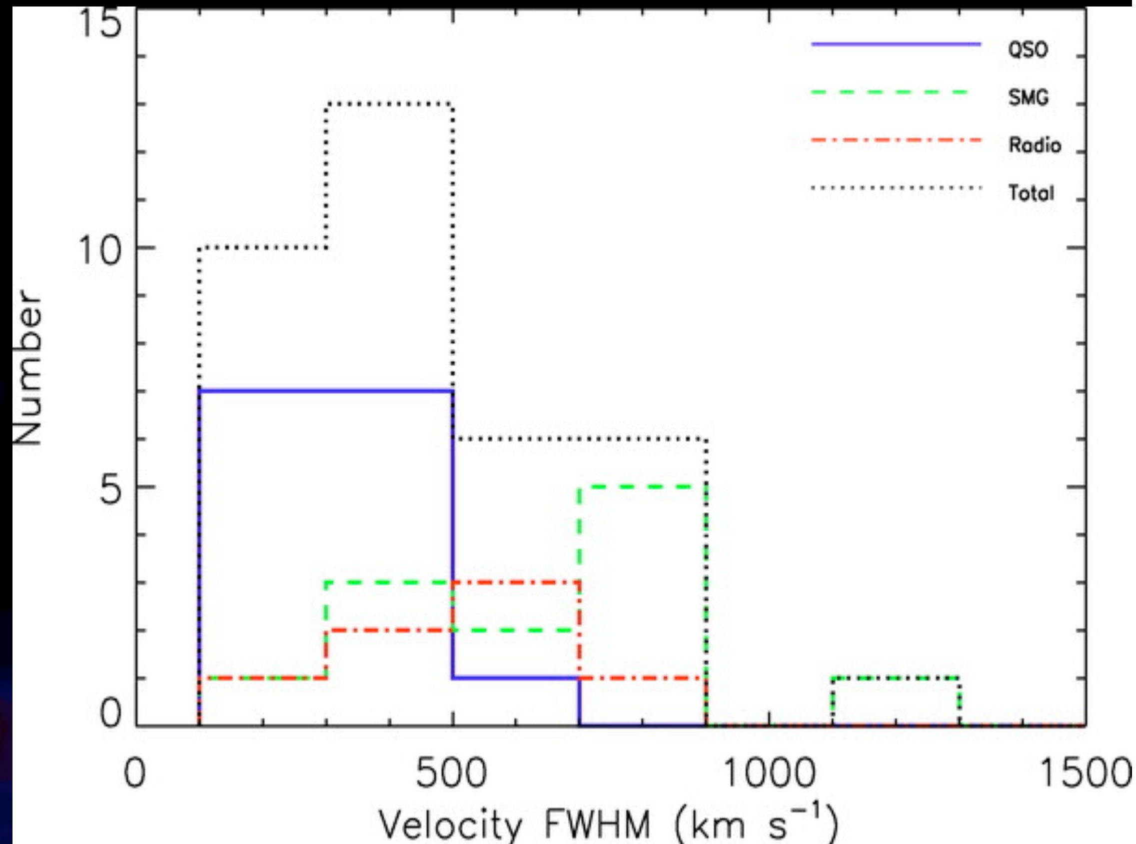
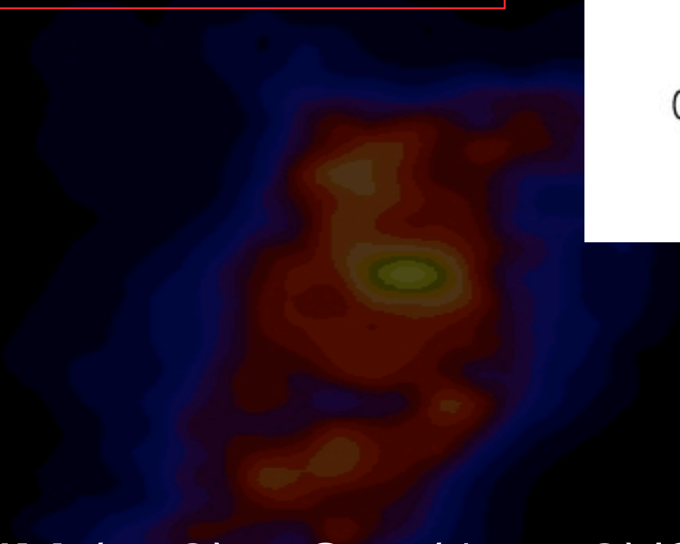


z~2: Carilli & Wang 2006



FWHM (z=2) = Sqrt(1+z=2)/Sqrt(1+z=6) * FWHM (z=6)

Observable Tests:

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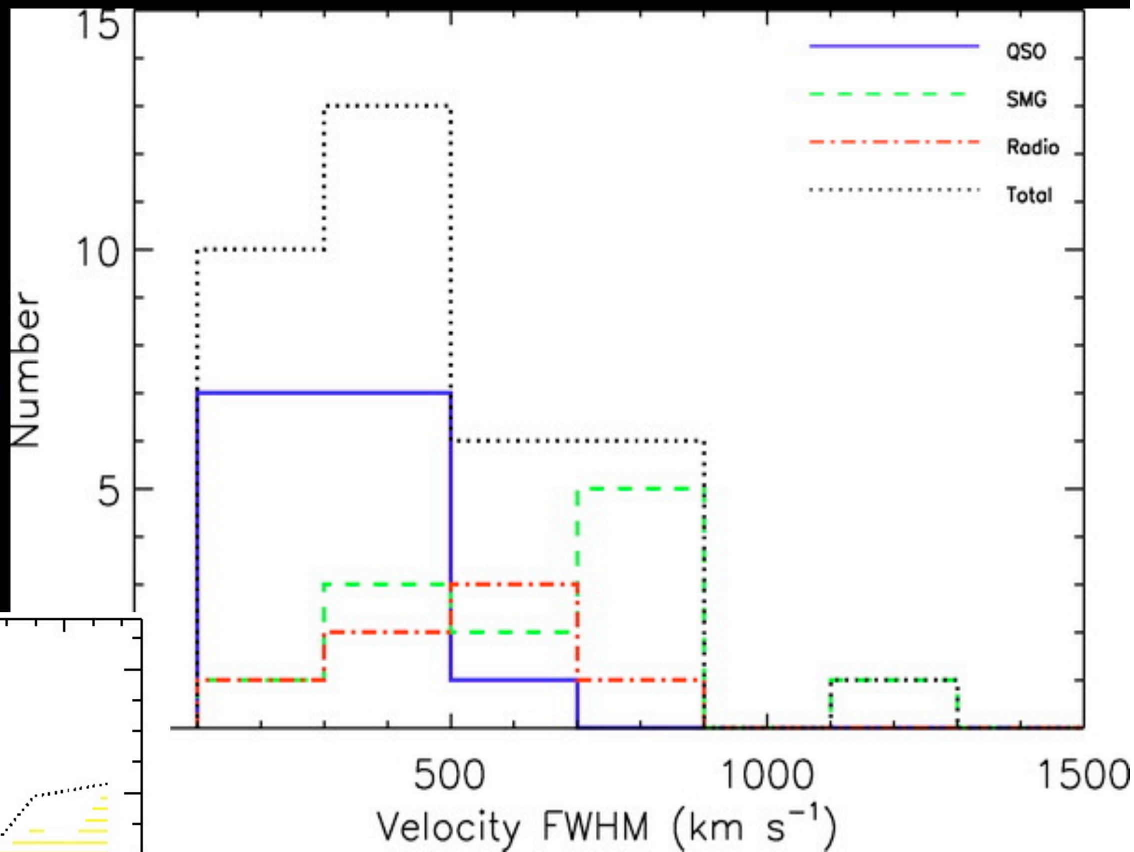

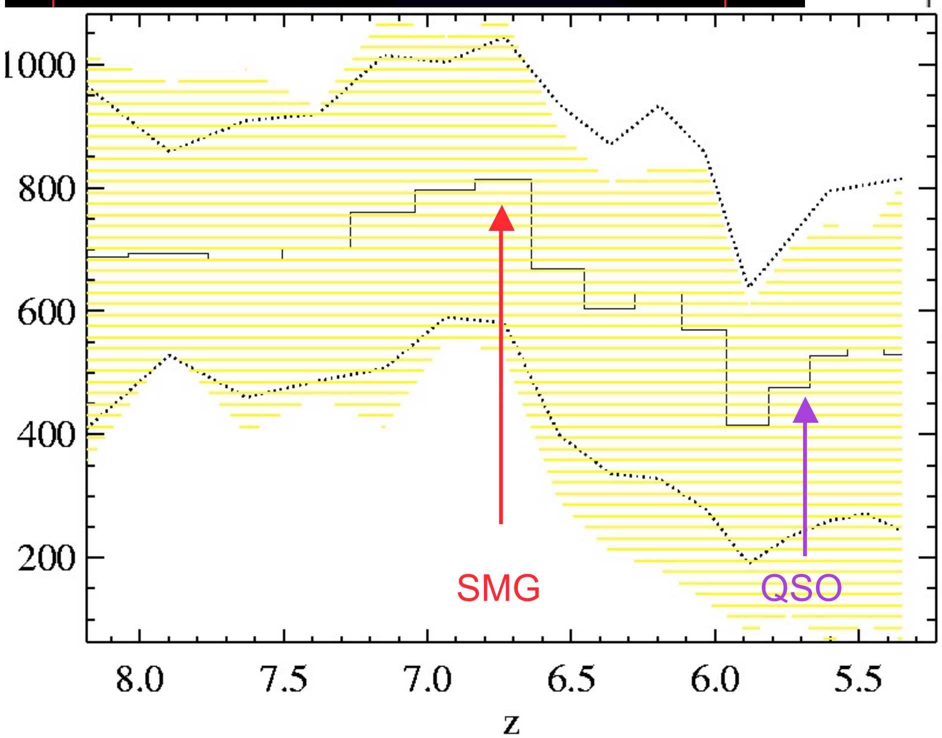

1. z~2 Quasar line widths natural with redshift evolution of potentials for 10^{12}-10^{13} $M_\odot$ halo

2. SMG line widths natural for temporal evolution of line widths in 10^{13} $M_\odot$ mergers at z~2

Conclusions

- Merger driven model for z~6 Quasar formation which lies on the present-day Magorrian relation well supported by simulated CO morphology and line widths

- CO emission line widths in first quasars predicted to have σ =300-500 km/s if qso's form in massive halos, consistent with virial velocity of halo

- Molecular Disk formation may bias optically selected quasars toward narrow CO line widths

- Linewidths of z~2 qso's and SMGs naturally explained in this model