Gas outflow rates in galaxies using quasars

Nicolas Bouché (UCSB → 

Observatoire Midi-Pyrénées
University of Toulouse

W. Hohensee (Camarillo High, CA)
R. Vargas (Oak Lawn High, IL)
&
C. Martin(UCSB), G. Kacprzak (Swinburn), C. Churchill, J. Cooke (Swinburn)

Outflows: tools available

- Optical spectroscopy (NaD, Mg II) — Lehnert/Heckman, Martin C., Weiner, Rupke
- F-IR spectroscopy (OH) — Sturm et al. 2011
  - Ha emission — Genzel/ Newman 2012; Soto & Martin 2012(a,b)
  - Xray emission — Manon; Martin 2002

- (stack) Background galaxies — Steidel 2010, Bordoloi 2011; Rubin et al. 2010
- Background QSOs (OVI) — Tripp 2012; Tumlinson 2012
- Background QSOs (Mg II) — Bouché 2012, Gauthier 2012

Wind signatures

- Ubiquitous — Lehnert/Heckman 2000, Martin C. 2005, Weiner 2009, Rupke 2005, Shapley 2003 Rubin et al. 2011
- V wind ~ $SFR^{0.3}$ — Martin C. 2005
- Roughly *collimated* — Chen, Tremonti et al. 2010, Bouché et al. 2012 Bordoloi et al. 2011, Gauthier& Chen 2012
- Extends far ... — Steidel et al. 2010

$$\dot{M}_{\rm out}(b) = 0.41 {\rm M}_\odot\,{\rm yr}^{-1}\,\frac{\mu}{1.5}\,\frac{\Omega_w}{2}\,\frac{N_H(b)}{10^{19}{\rm cm}^2}\,\frac{V_{\rm out}}{200{\rm km\,s}^{-1}}\,\frac{b}{25\ {\rm kpc}}$$

Winds using background QSO

- Pros
  - Radial information
  - Can probe wind around *any* galaxy
- Cons:
  - Rare!
  - Can probe anything else (disk, accretion)

A dozen z=0.1 qso-galaxy pairs

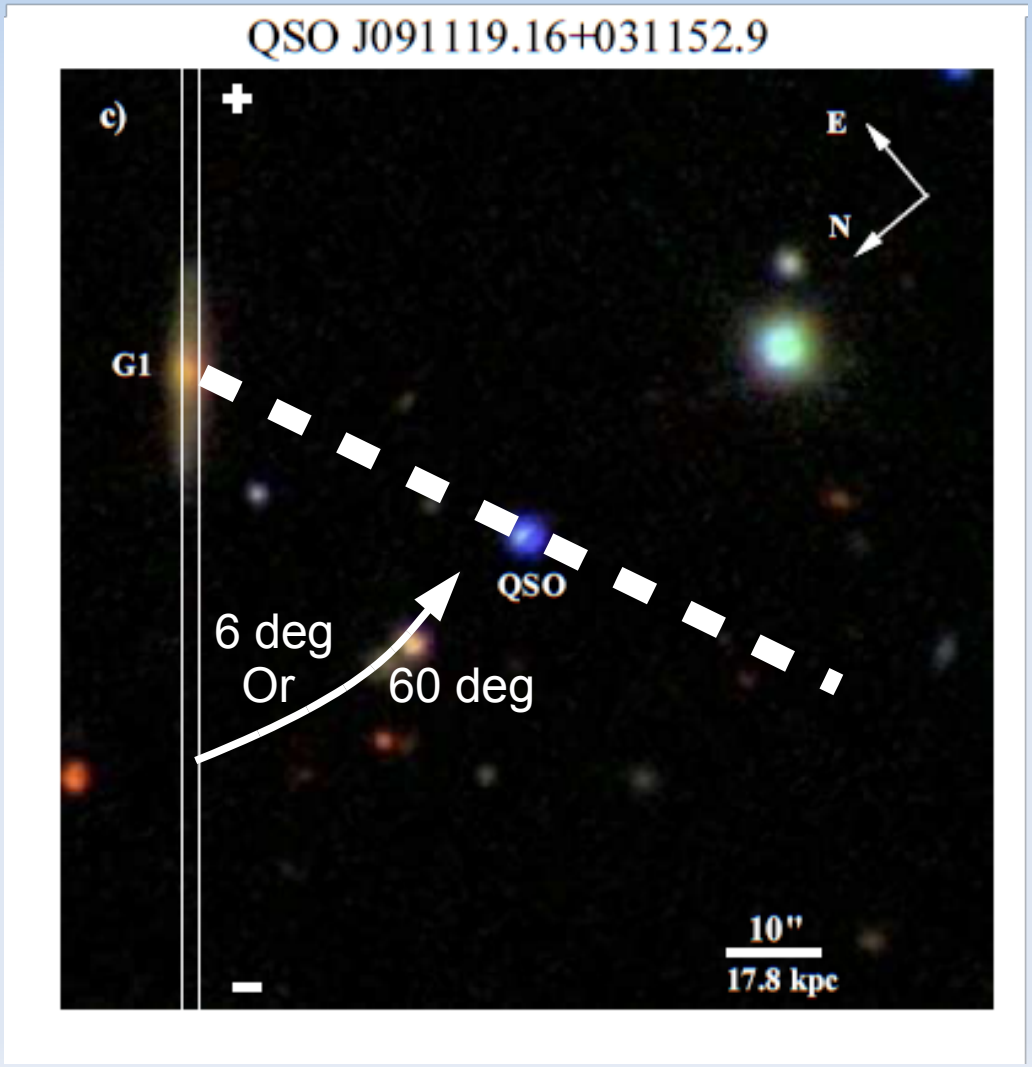
- SDSS Volume limited to **Mr -20.5**

  → redshift z< 0.12

- MgII available w/ LRIS

  → redshift z > 0.09

Kacprzak et al. 2011,
Barton & Cooke 2009



12 out of 30 pairs with MgII

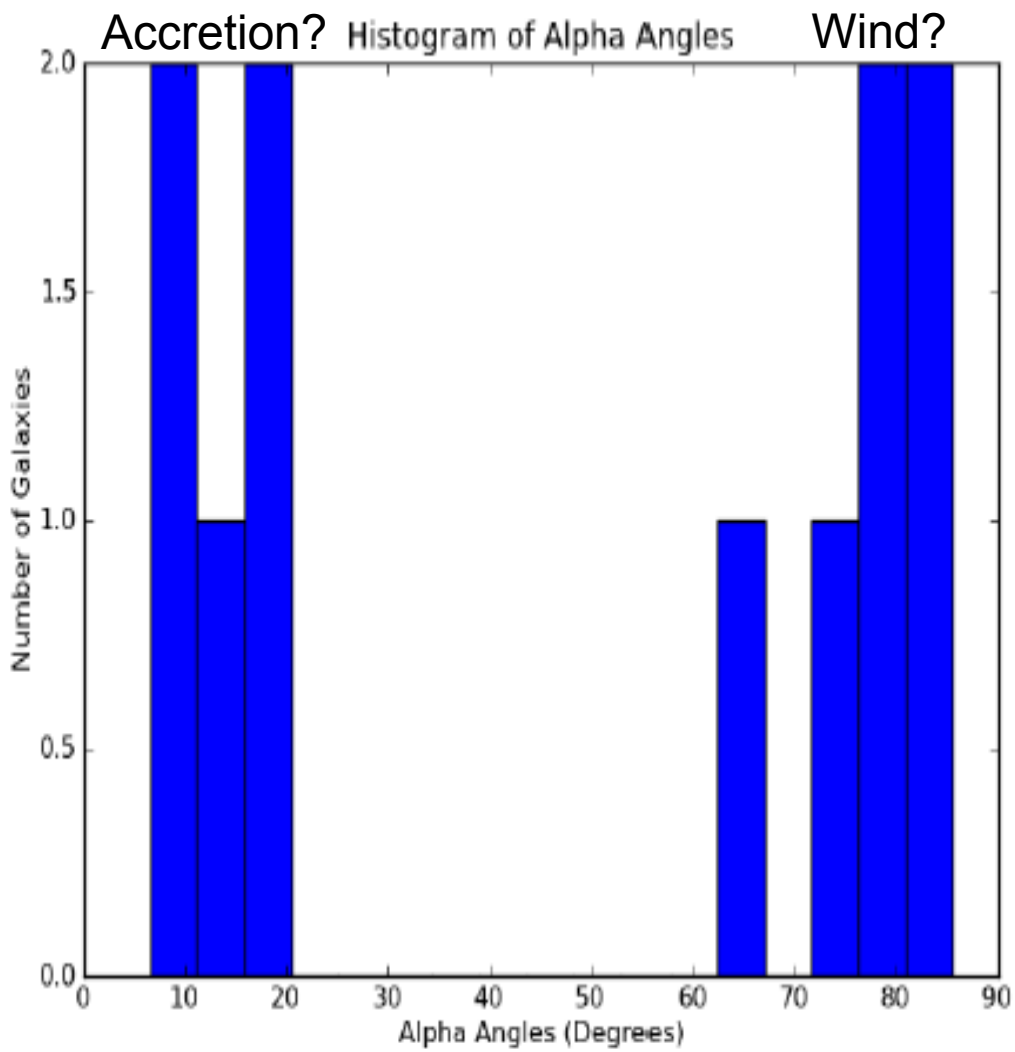
* with MgII kinematics

* with galaxy kinematics

Azimuthal distribution: MgII

Bouché et al. 2012, astro-ph/1110.5877

Accretion?



Wind?

<SFR> = 0.5 M/yr

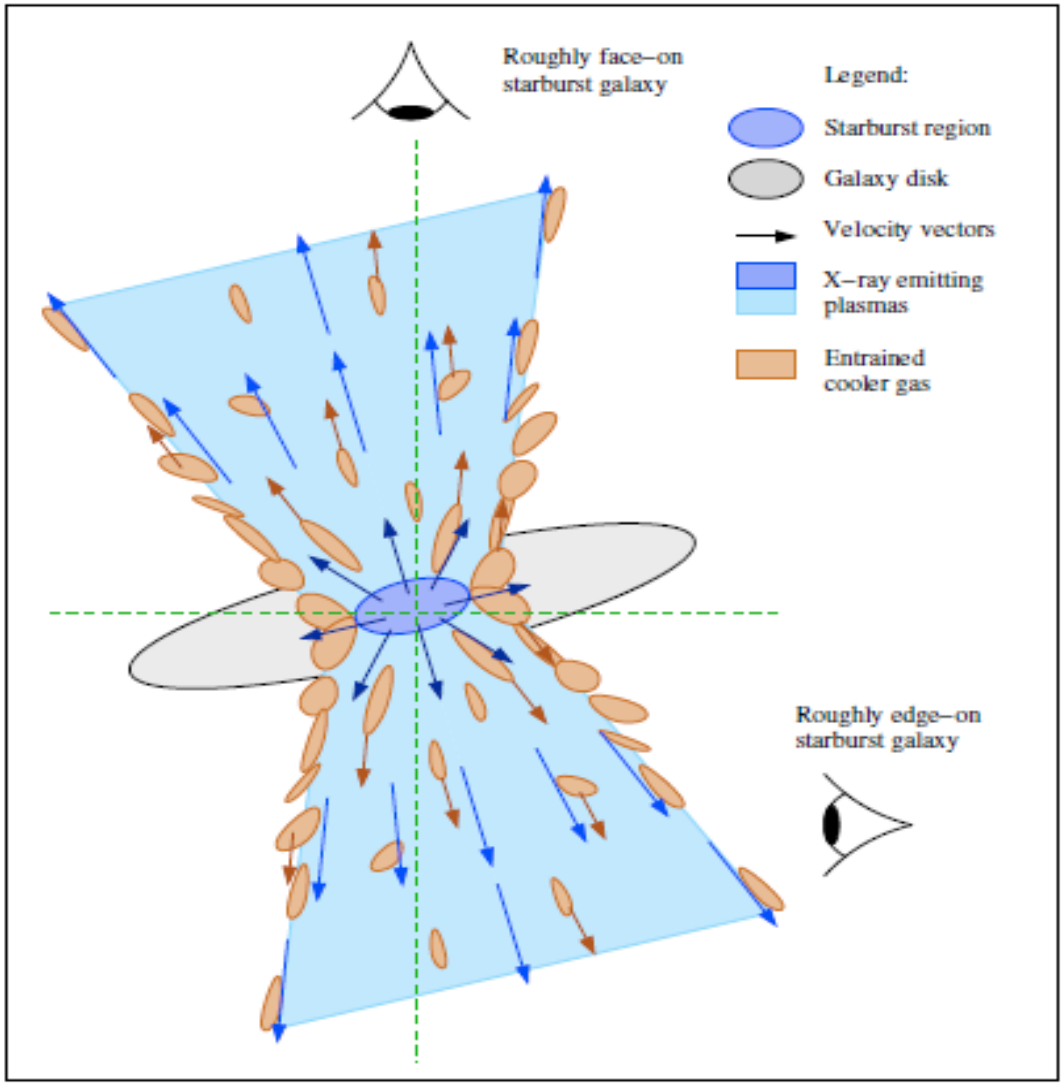
<SFR> = 2 M/yr

Not uniform at >3 sigma; confirmed in Kacprzak et al. 2012

Wind modeling with 1 parameter

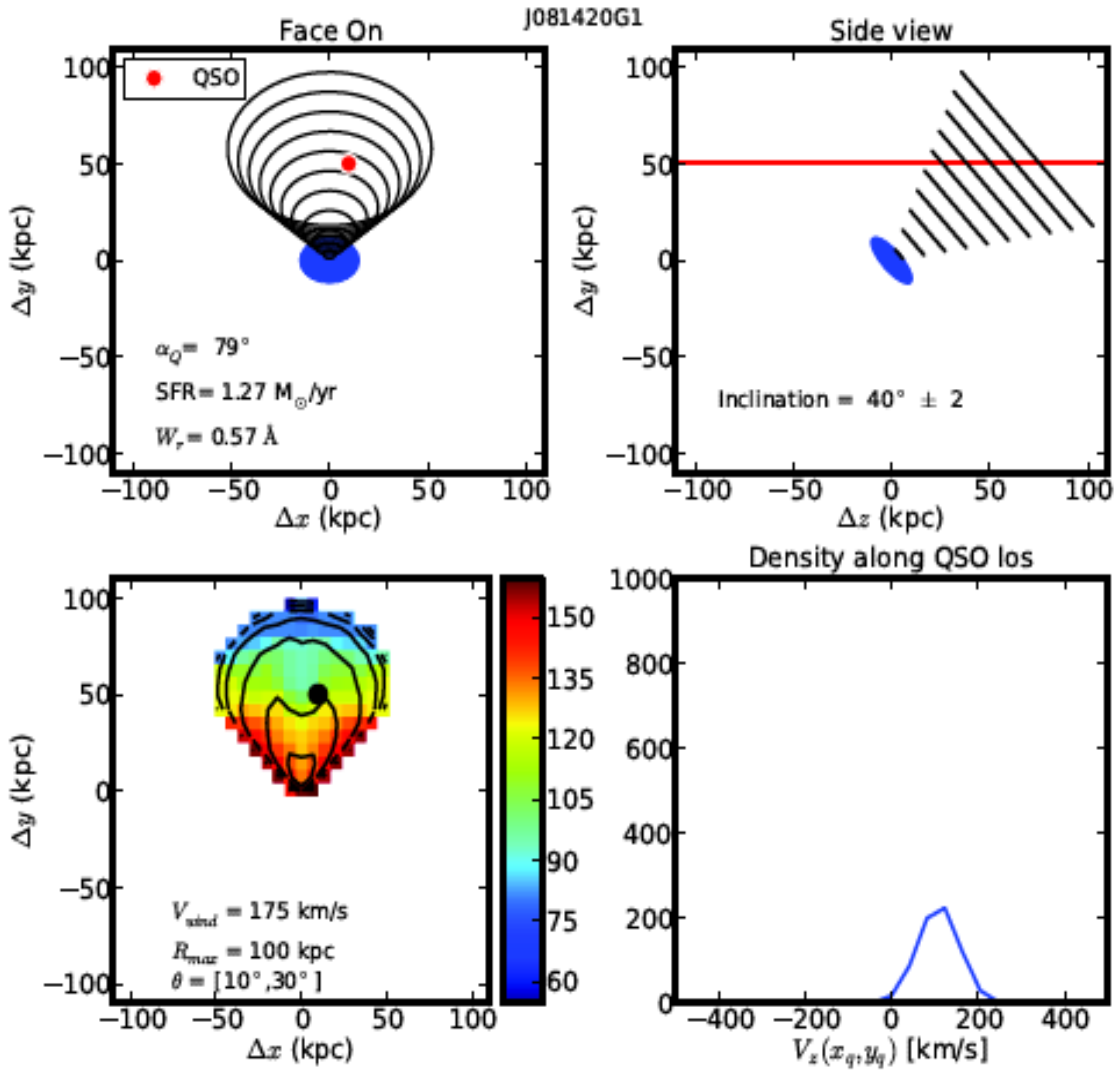
- Steady flow
- Mass conserved

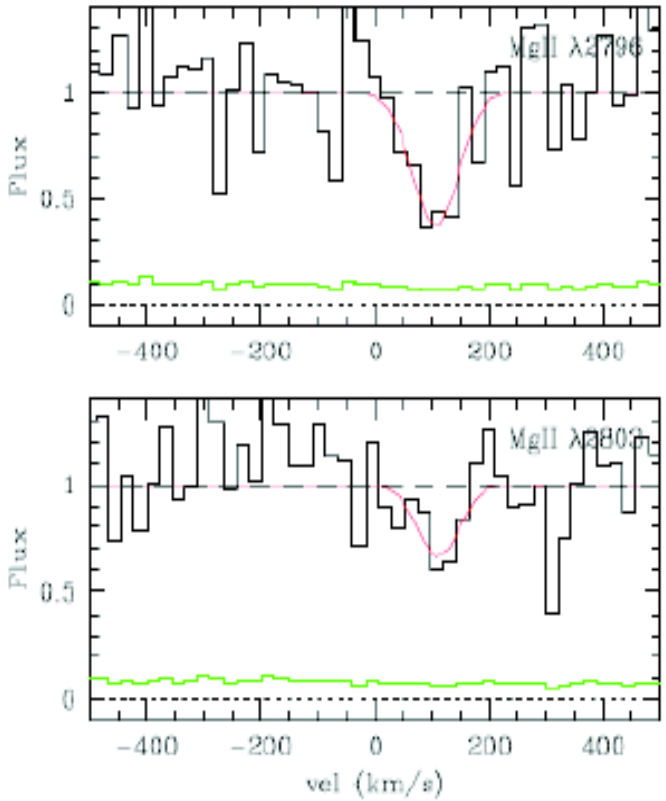
  $\rightarrow \rho \sim 1/r^2$
- Vwind ~ Cst



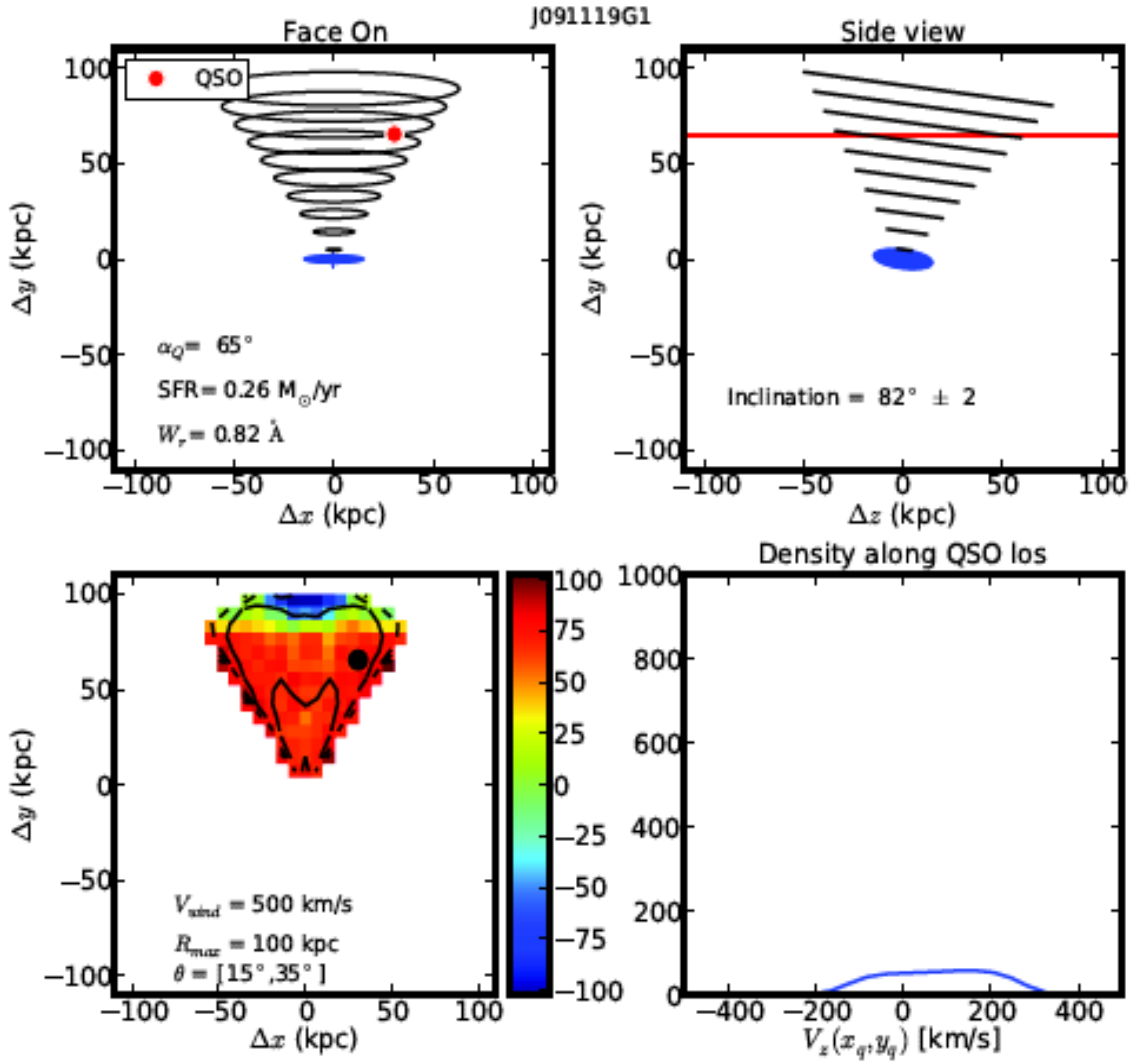
Strickland D.

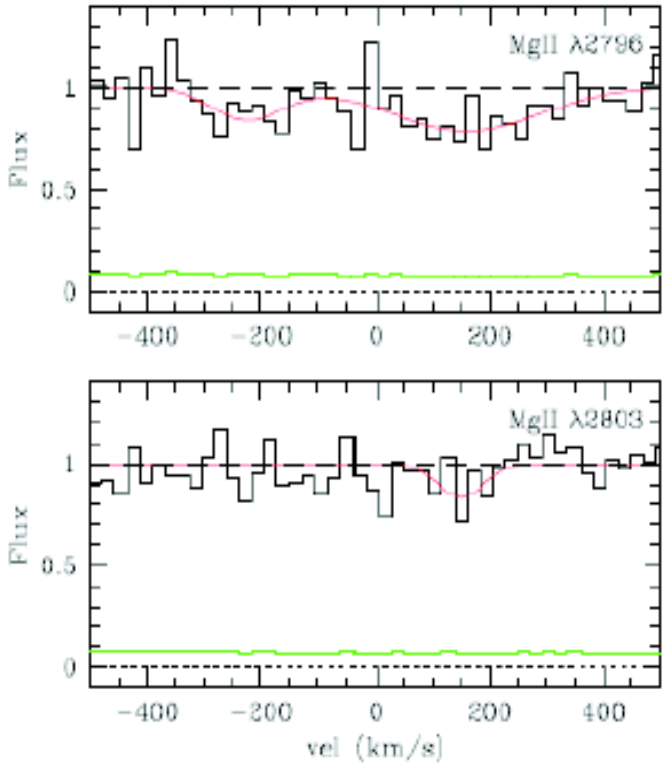
Wind modeling with 1 parameter



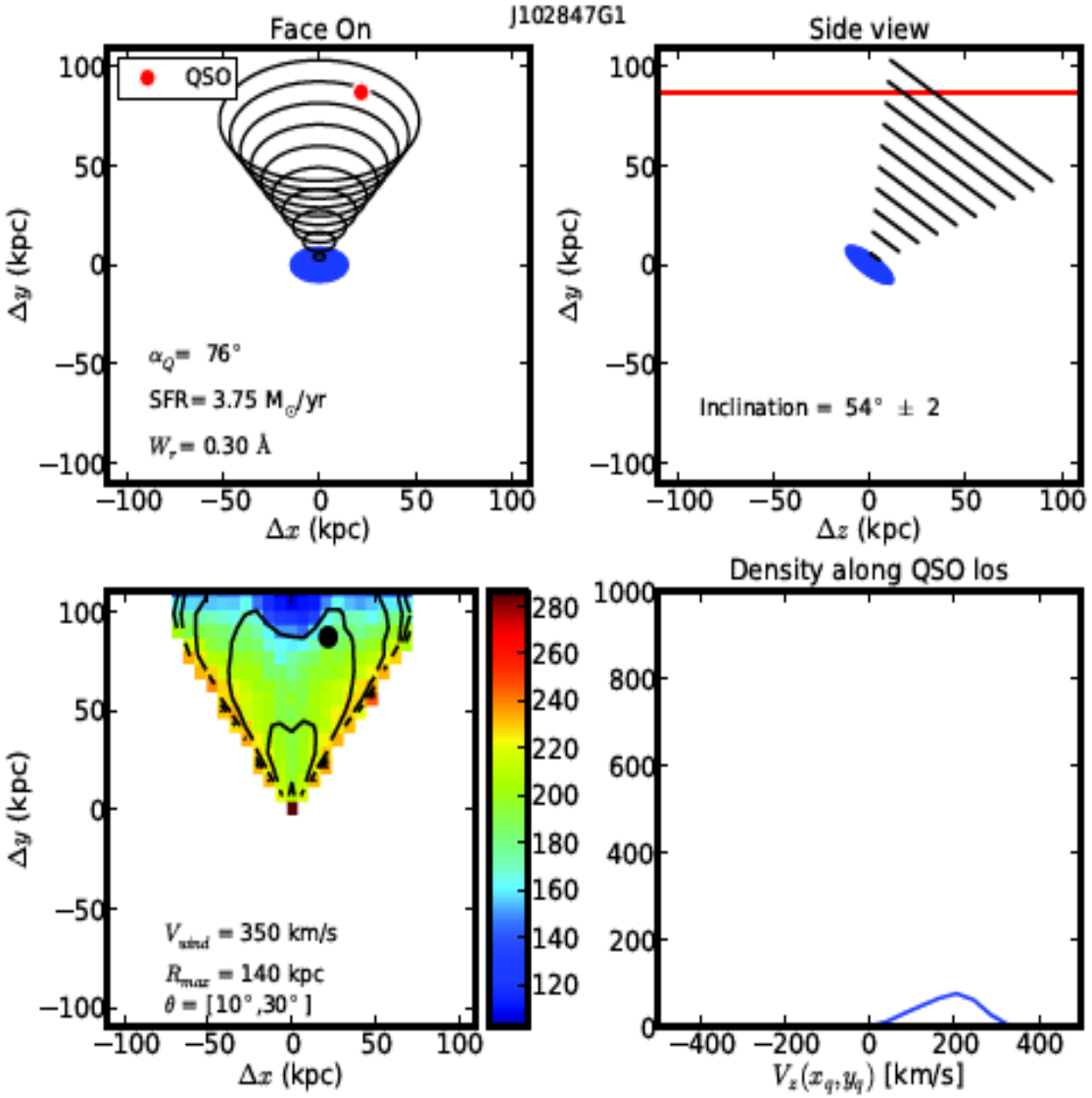


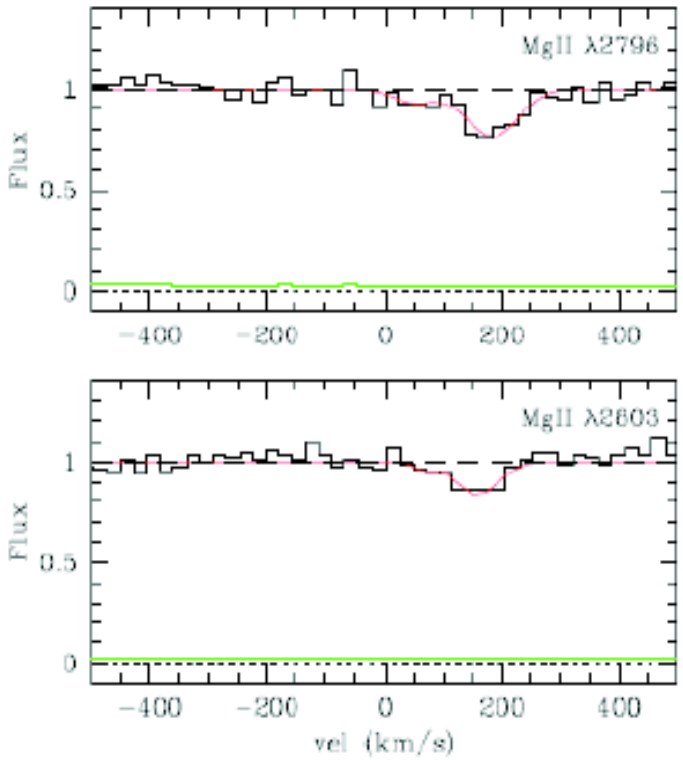
Wind modeling with 1 parameter





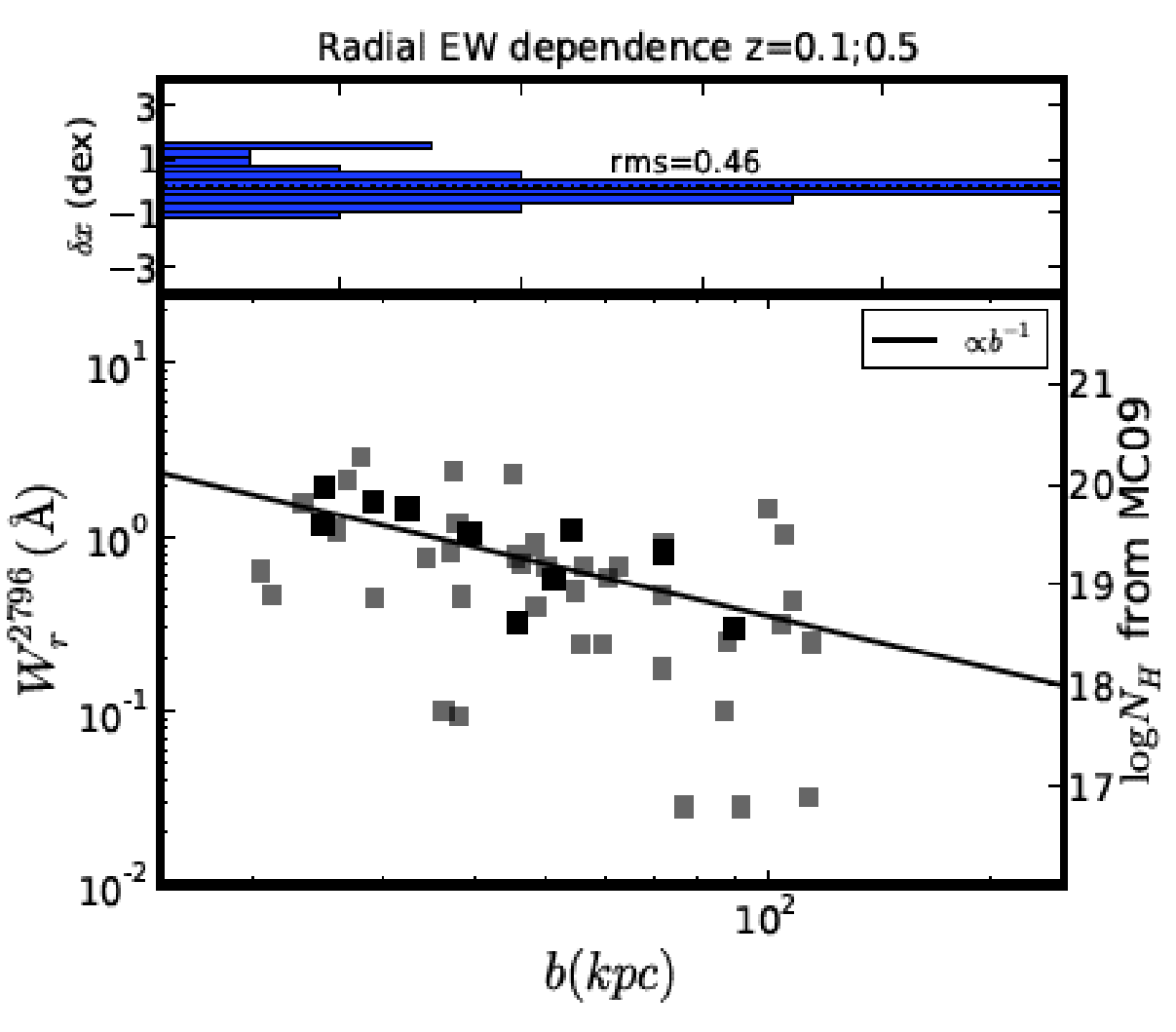
Wind modeling with 1 parameter

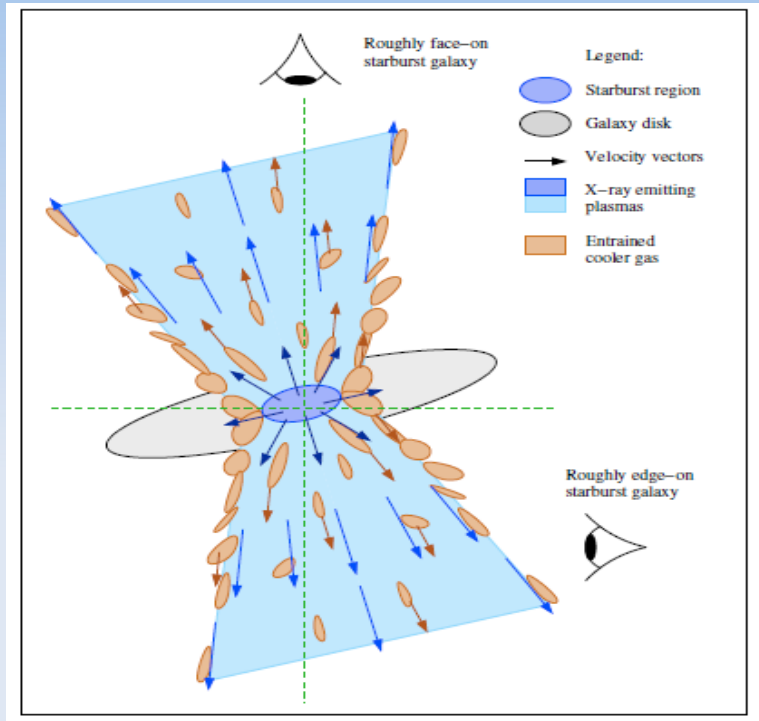




Radial dependence: all

- N(b) ~ 1/b



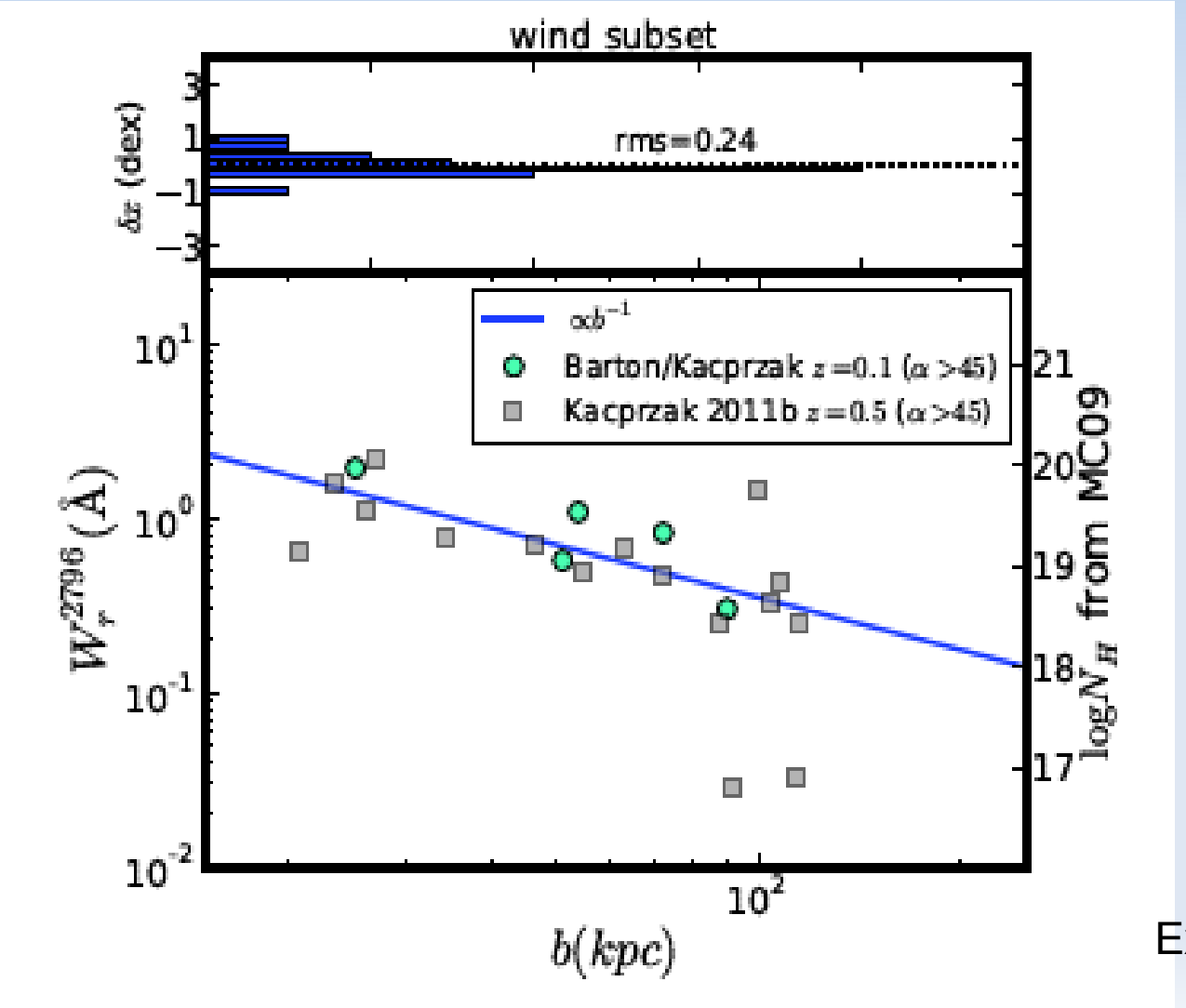


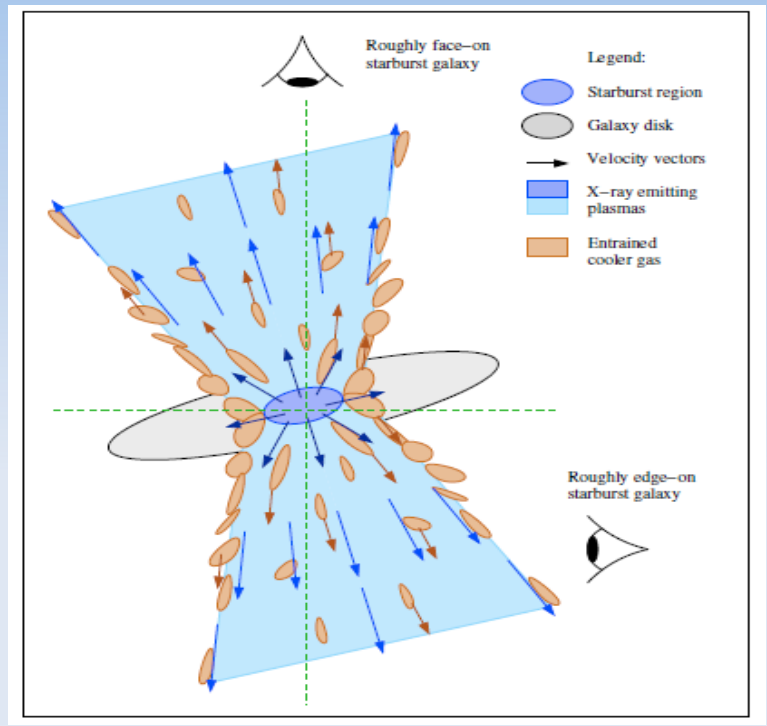
Lanzetta 1991; Steidel 1995, Chen HW 2010

Radial dependence: wind subset

Bouché et al. 2012, astro-ph/1110.5877

- N(b) ~ 1/b

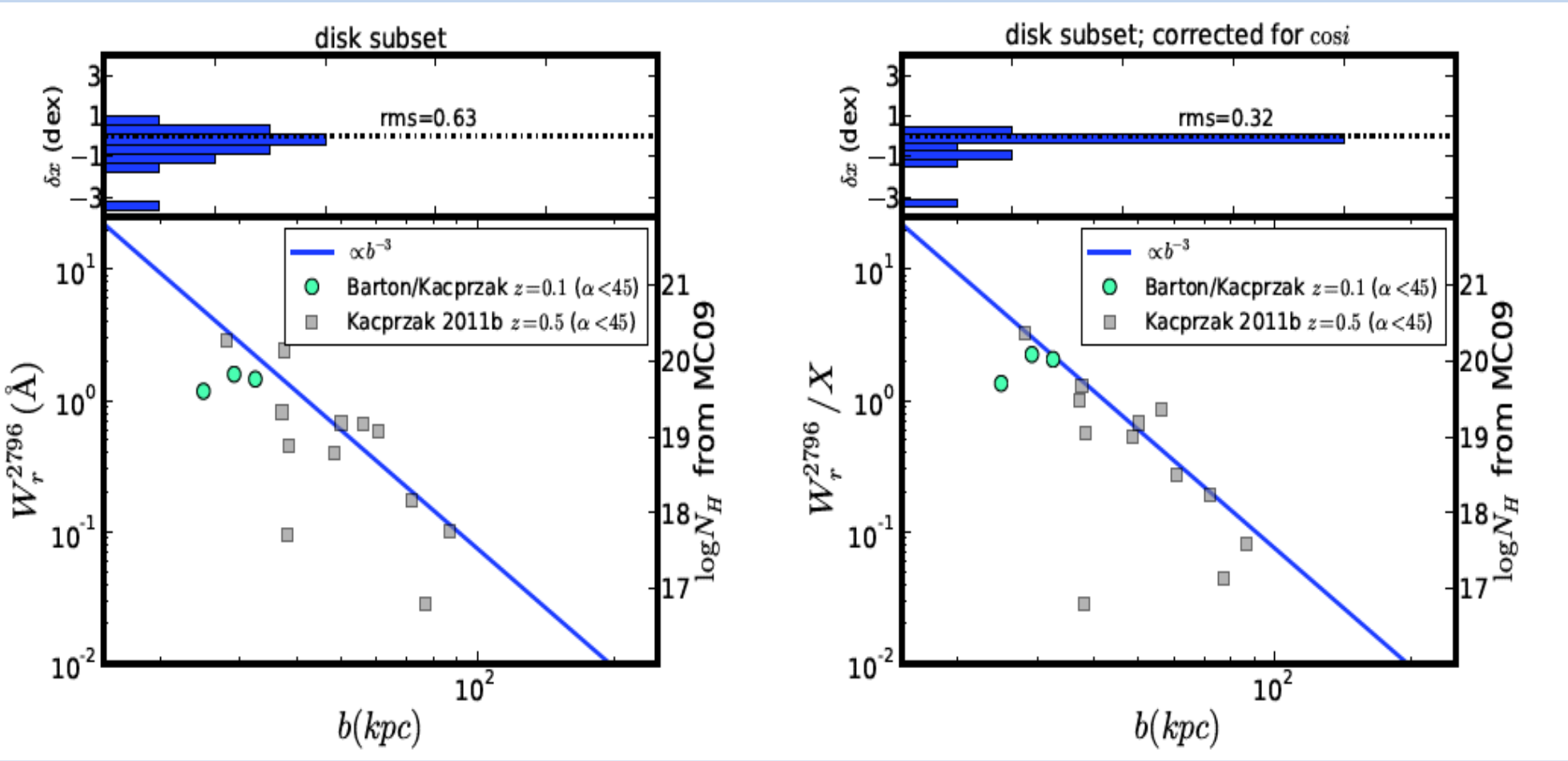




Explains the Chen SFR dependence!

Radial dependence: disk sub-set

- Scatter depends on inclination



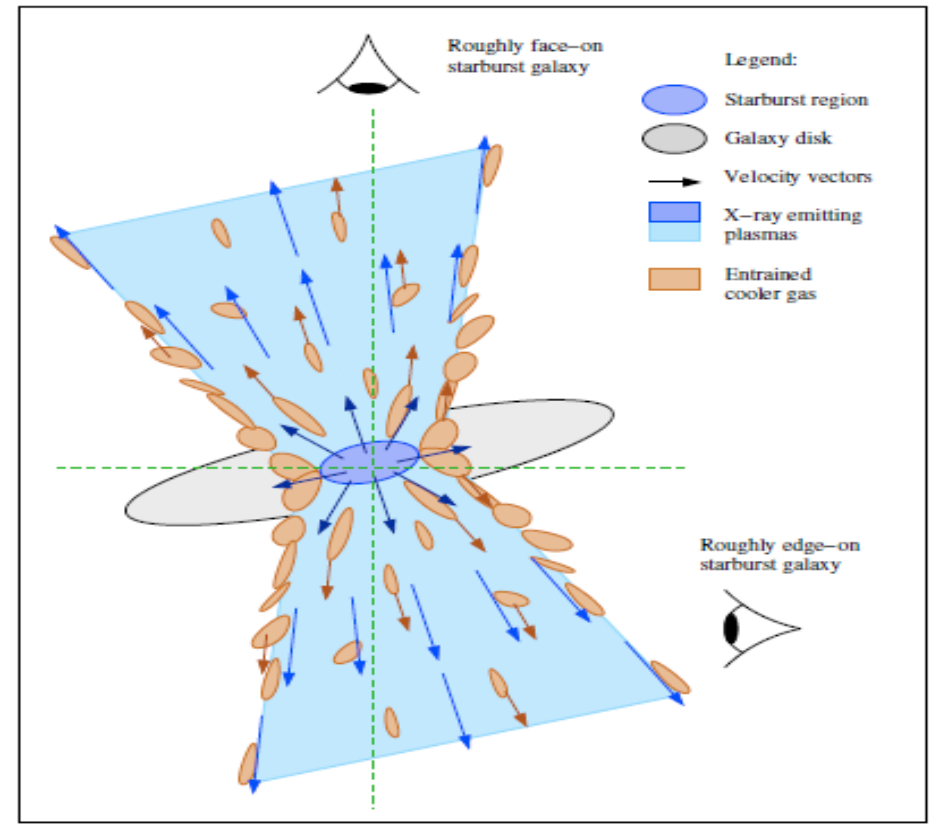
Explains the Kackrzak 2011 inclination dependence!

Winds using background QSOs

- Results:

Cone ~ +/- 30 deg
Radial ~ 1 / b
Vout ~ ½ Vesc

Mout/SFR ~ 2 or 3



$$\dot{M}_{\rm out}(b) = 0.41\ {\rm M}_\odot\,{\rm yr}^{-1}\,\frac{\mu}{1.5}\,\frac{\theta_{\rm max}}{30^\circ}\,\frac{N_H(b)}{10^{19}{\rm cm}^2}\,\frac{V_{\rm out}}{200\ {\rm km\,s}^{-1}}\,\frac{b}{25\ {\rm kpc}} \quad (4)$$

Bouché et al. 2012, astro-ph/1110.5877

astro-ph/1110.5877

Two birds with one stone

- QSOs: What are MgII absorbers?

Accretion?

Kacprzak 2011
Stewart K. 2011

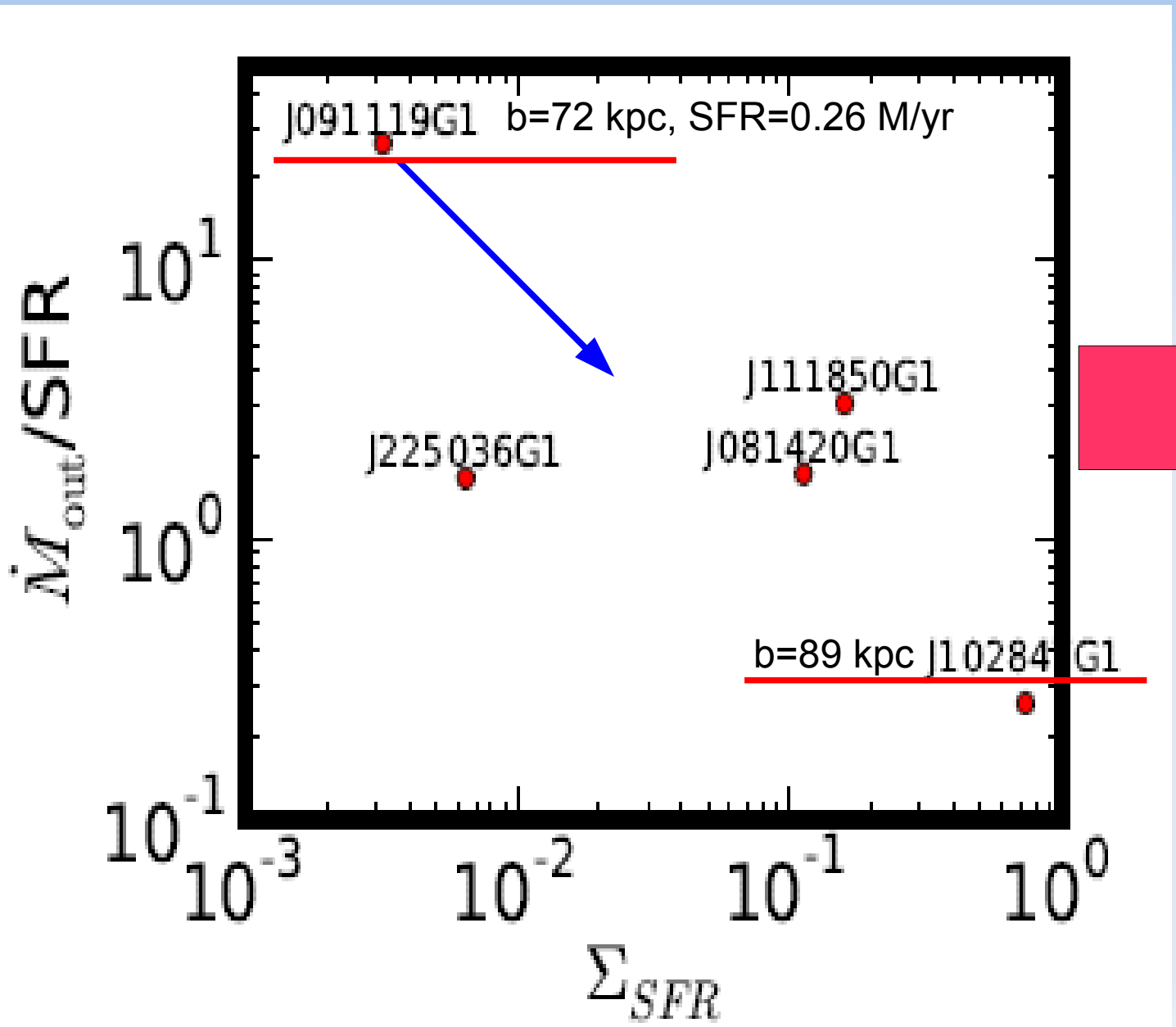
Winds

Bouché 2006
Bond 2001

- Galaxies: What are wind properties?
  - – tight scaling relation (1/b)
  - – tight constraints on loading factor:

Mout/SFR ~ 2 or 3

Loading Factor @ z=0.1



SINS z=2

Newman et al. 2012

Open issues:

Mass / Mout in the various components:

- Hot gas
- Warm Ionized, diffuse
- Warm Ionized, dense
- Cold, neutral