SUPERWINDS FROM MASSIVE STAR-FORMING CLUMPS AT Z~2

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(see Genzel et al. 2011 - arxiv:1011.5360 and Newman et al. in prep)

Abstract

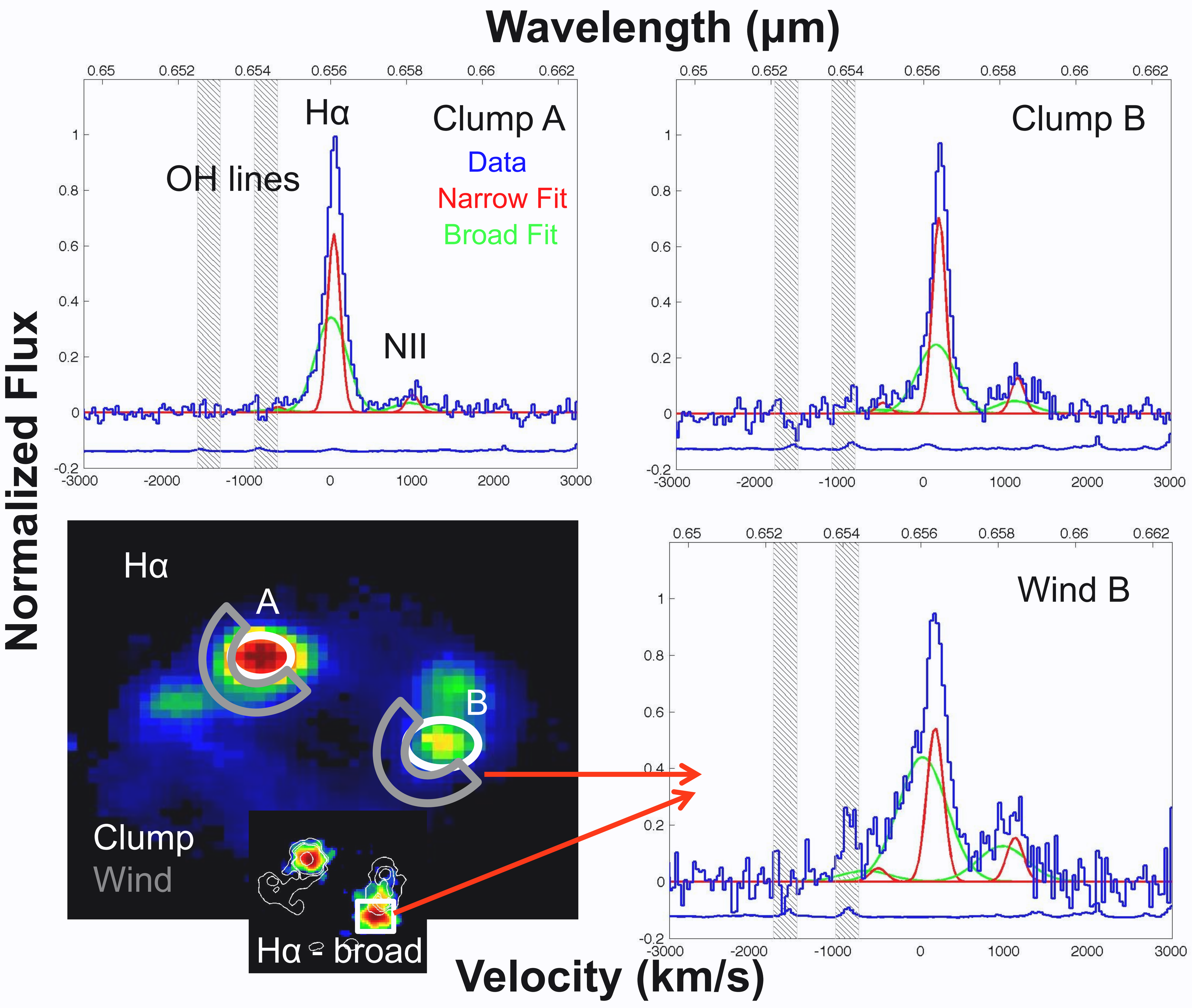
We have obtained high-resolution data of the z~2 ring-like, clumpy star-forming galaxy ZC406690 using the VLT/SINFONI with AO. We find broad, blueshifted Hα emission line wings in the spectra of its massive, star-forming clumps and even broader wings (up to 70% of the total Ha flux) in regions spatially offset from the clumps by ~ 2 kpc. The broad emission seems to originate from large-scale outflows with mass outflow rates from individual clumps that are several times the SFR of the clumps. The mass and energy in the winds coming from individual clumps (M_w ~ 1-3x10^8 $M_\odot$ and E_w ~ 3x10^{56} – 10^{57} erg) is comparable to that from entire local starburst galaxies. We find local electron densities of 300-1800 cm^{-3} in and around the clumps, and column densities of 1200-8000 $M_\odot/pc^2$. We calculate an ionization parameter for the clumps of 6x10^7 – 10^8 cm/s, based on both the SFR and the O_{32} ratio. In addition, based on emission line ratio diagnostics and photoionization and shock models, we find that the emission from the clumps is due to a combination of photoionization from the star-forming regions and shocks generated in the outflowing component. Based on the ionization parameter, density and SFR, the clumps, which are situated in a ring and are offset from the center of the galaxy, seem to resemble nuclear starburst regions of local ULIRGs and LIRGs. These new observations help us to better understand how these clumps, which are very common in z~2 SFGs, interact with their environment through massive, energetic outflows and evolve with the galaxy.

Introduction – Superwinds at High-z

- **Galactic-scale outflows are ubiquitous** in local starburst galaxies and perhaps as well in most high-redshift star-forming galaxies (Heckman et al. 1990, Steidel et al. 1996, Pettini et al. 2000). They regulate star formation through feedback, inject enriched material into the IGM and are perhaps responsible for the evolution of the SFR over time as a function of galaxy mass known as galaxy downsizing.
- We observed ZC406690 at the ESO VLT with SINFONI adaptive optics assisted observations, revealing that it is a **rotating, clumpy ring** with M_* ~ 4 x 10^{10} $M_\odot$, and M_{gas} ~ 2x10^{11} $M_\odot$. We observed broad, blue-shifted Hα emission line wings centered on the star-forming clumps and estimated the wind **mass outflow rate** from the clumps using the broad Hα component as **1-6 x SFR**.
- We found that with such powerful outflows, some of the clumps will be **disrupted before they can migrate inwards** by dynamical friction to form a central bulge (in as soon as a few 100 Myrs). Understanding the fate of these massive, star-forming clumps which are quite common in z~1-3 SFGs will inform our understanding of the formation of bulges and other structures within galaxies.

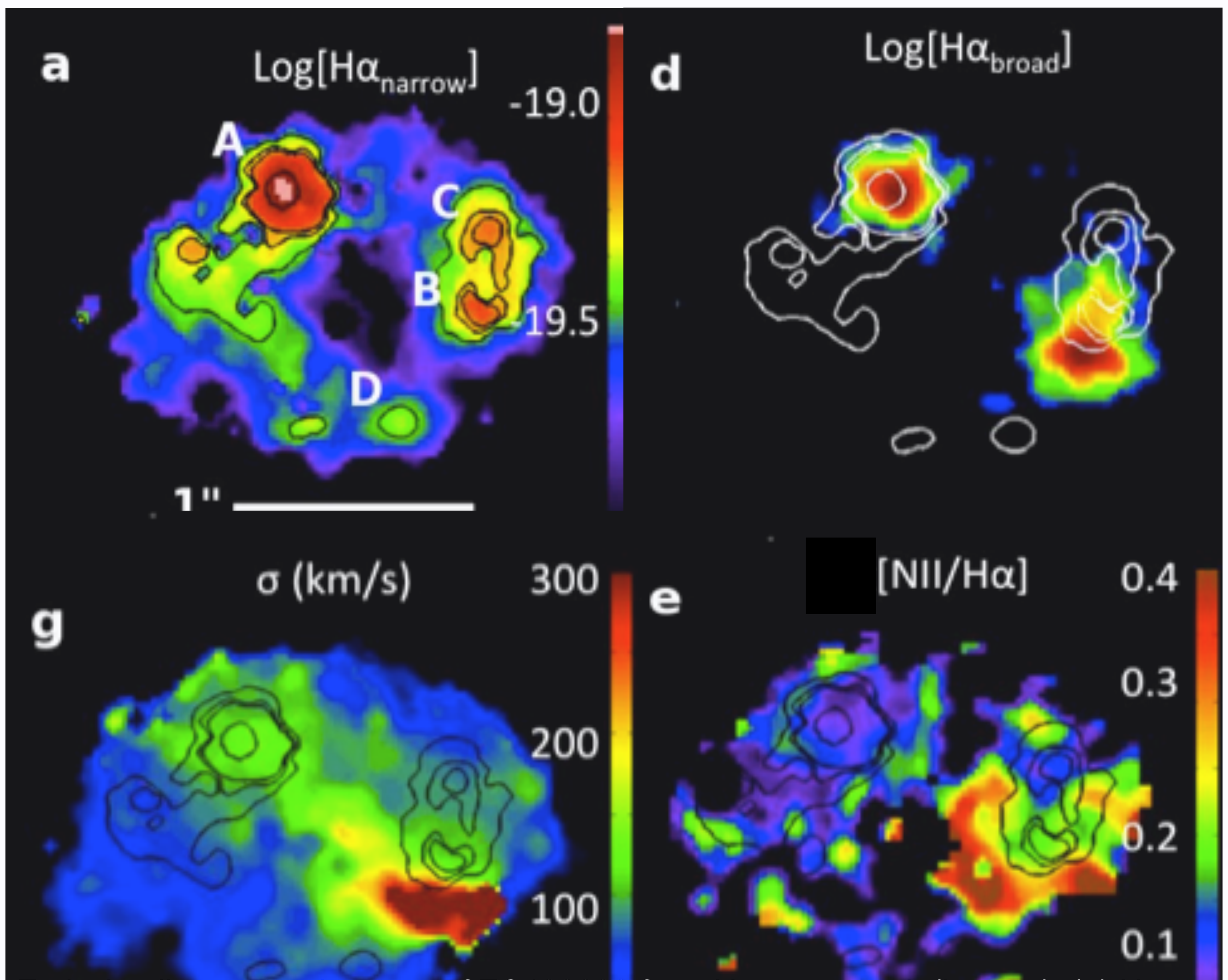
Direct Detection of Superwinds from Star-forming Clumps

We observe broad, blue-shifted Hα emission lines from the spectra of the clumps and the surrounding (wind) regions, which dominate the broad Hα emission. Based on two-component gaussian fits to the emission lines, we find that the broad components account for 45-70% of the total Hα flux from the clump and wind regions.

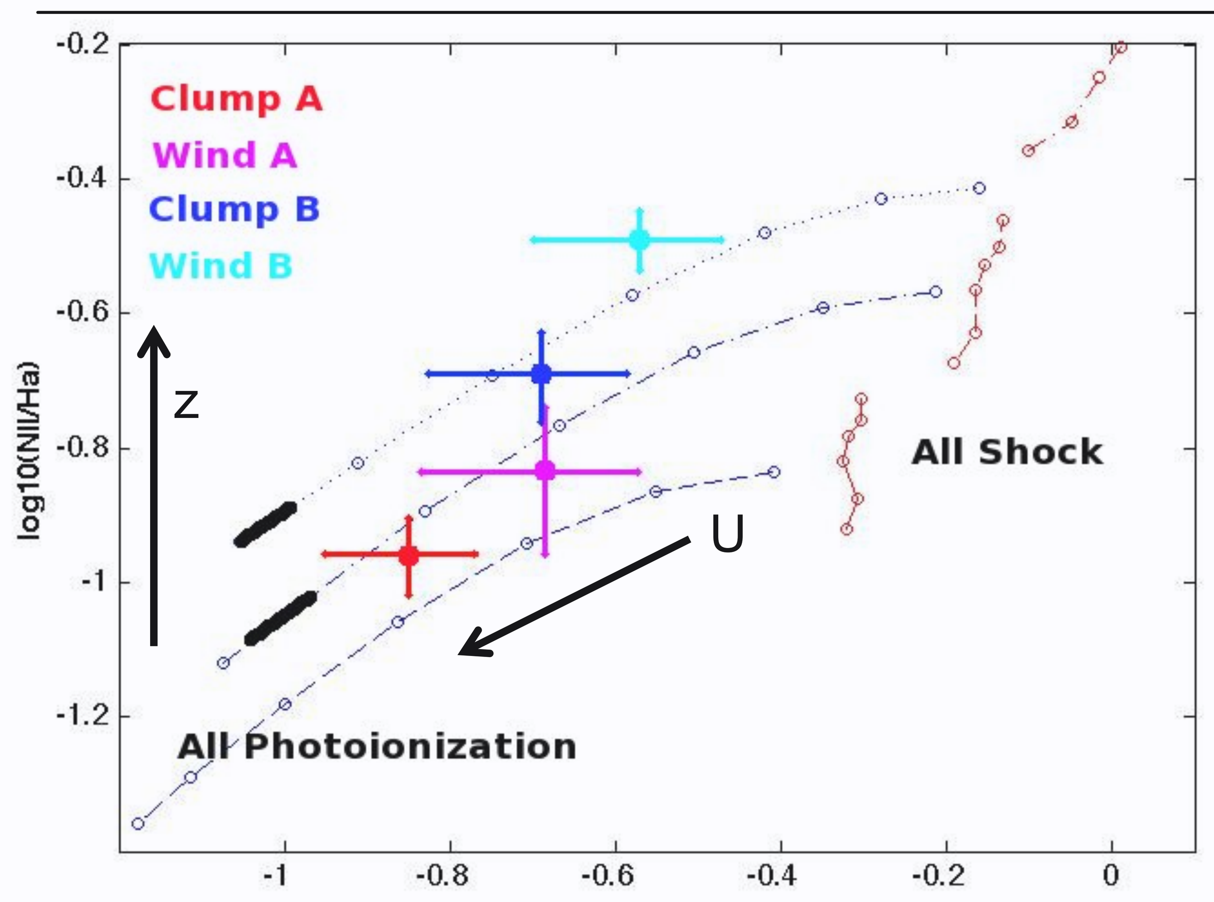


Effects of Superwinds on their Environment

Broad Hα emission is spatially correlated with larger [NII]/Hα and [SII]/Hα ratios, which are shock indicators.



Emission line and ratio maps of ZC406690 from Newman et al. (in prep): (a) Narrow Hα component, (d) Broad Hα component, (e) [NII]/Hα (g) velocity dispersion



Red lines = shock model

Blue lines = photoionization model, with dots as varying ionization parameter (U)

Thick black lines = observed U for the clumps

- Comparing our data (color points) to photoionization and shock models from Rich et al. (2011), we find that the wind regions have higher shock ratios than their clumps.
- Fitting these ionization parameters and emission line ratios to Rich et al.'s models for $Z_\odot$, we find shock contributions to the total Hα emission of 5%, 15%, 15-20% and 20-40% for clump A, wind A, clump B, and wind B.

Summary

- **Broad emission** around clump B is from an **outflowing component.**
- Broad Hα regions (around clumps A and B) have **elevated [NII]/Hα (~ 0.2-0.3) and [SII]/Hα (~ 0.2) ratios**, indicating shocks.
- **Some shock component is required** in the outflows to fit the observed ionization parameter (~6x10^7 – 10^8 cm/s) and models.
- **Shocks could inject energy** back into the disk, contributing to large observed σ (50-100 km/s) of this and other z~2 star-forming galaxies.
- **The density, SFR and ionization parameter of the clumps is similar to those of local starburst regions.**

Forster Schreiber et al. (2009) ApJ 706, 1364. -- Genzel, R., Newman, S. et al. (2011) ApJ 733, 101. Heckman, T., Armus, L. and Miley, G. (1990) ApJ Supp Ser 74, 833. -- Mancini, C. et al. (2011) submitted. Newman et al. in prep. -- Pettini, M. et al. (2000) ApJ 528, 96. -- Rich, J. et al. (2011) ApJ 734, 87. Steidel, C. et al. (1996) ApJL 462, L17.

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