

Mapping the Clumpy Structures within Submillimeter Galaxies using LGS-A0 Spectroscopy

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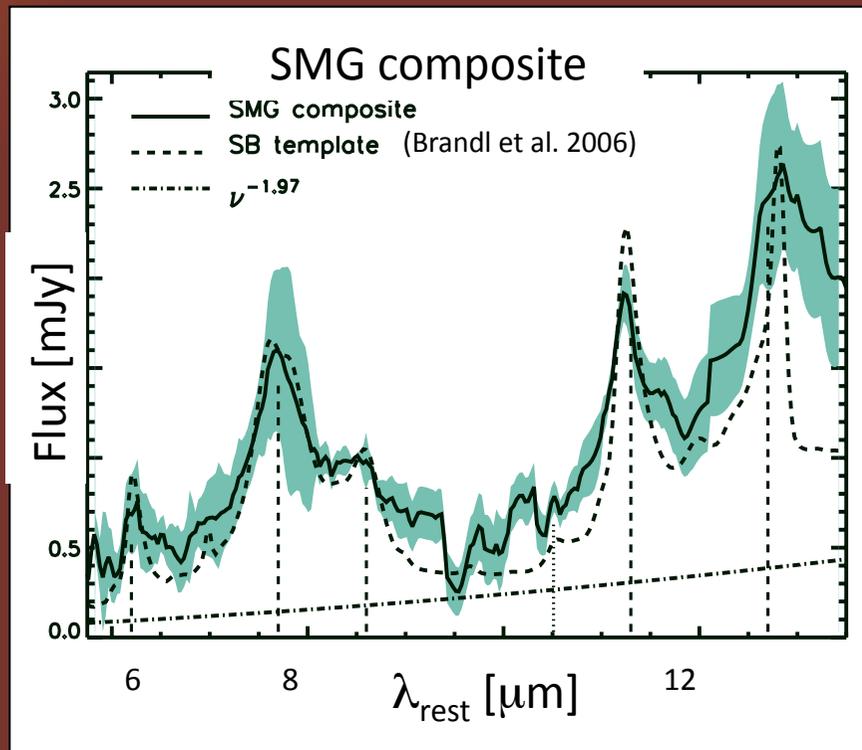
Carnegie Observatories, Pasadena



*Andrew Blain, Mark Swinbank, Ian Smail,
Rob Ivison, Scott Chapman*

SMGs in the “big picture”

- Observationally-defined population of strong submm emitters
- ~100s detections abound with SCUBA, MAMBO, Bolocam, AzTEC
- $M_* \sim 10^{11} M_\odot$ (e.g., Hainline+10), $SFRs \sim 10^2 - 10^3 M_\odot/\text{yr}$
- Progenitors of today’s most massive galaxies (e.g. Lilly+99)
- AGN signatures in opt / near-IR / X-ray (Chapman+05; Swinbank+04; Alexander+05, +08)



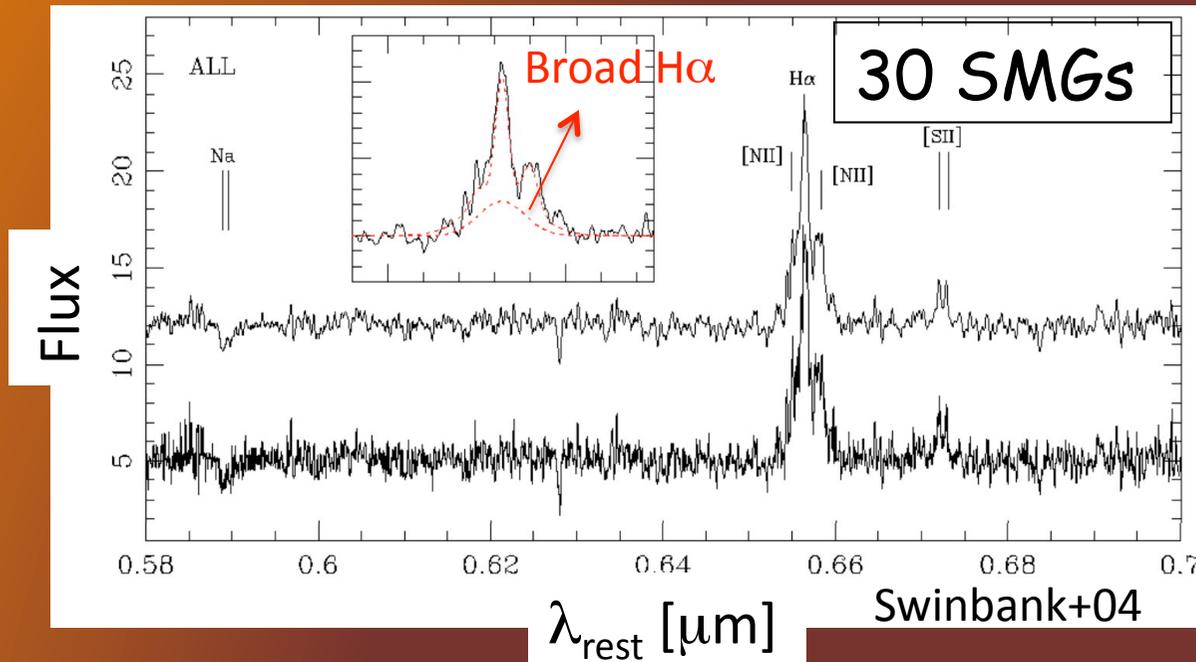
→ Starburst and AGN coexist!

Menéndez-Delmestre+09

also: Lutz+05,
Menéndez-Delmestre+07,
Valiante+07, Pope+08

Near-IR AGN signatures in SMGs

- The width of H α can be used to derive dynamical masses and SFRs



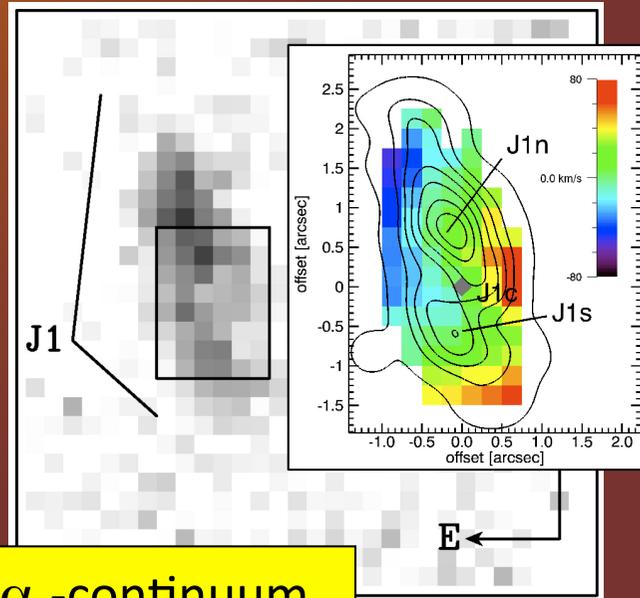
- But the H α line can be enhanced by the high-velocity gas in the broad-line region close to the central AGN
- Attempts have been made to disentangle the AGN contribution by including a broad component... difficult

With no spatially-resolved information, it is difficult to disentangle AGN-contribution.

IFU view of SMGs

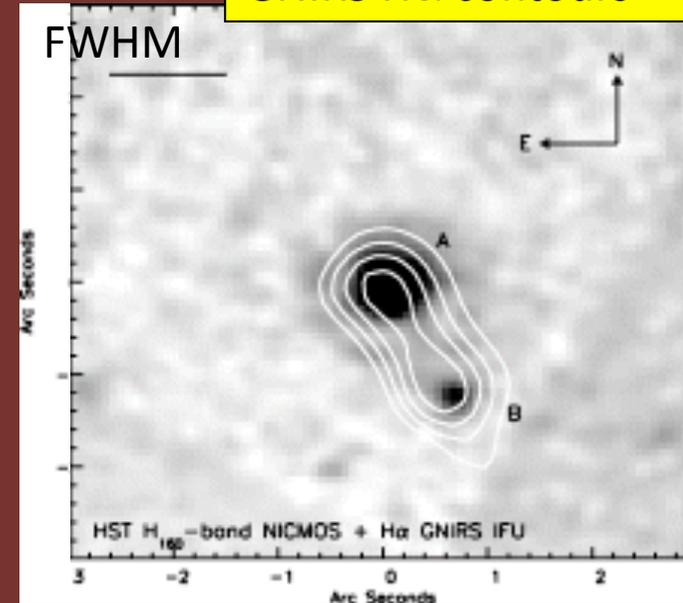
(seeing-limited, unaided by Adaptive Optics)

SPIFFI H α view
of SMM J14011 @
 $z=2.565$ (Tecza+04)
Inset: H α
Velocity map
(Nesvabda+07)



H α -continuum

NICMOS H-band,
GNIRS H α contours



GNIRS observations of SMM
J030227 @ $z=1.407$
(Swinbank+06)

- A handful of SMGs have been observed with IFU instruments
- Although with modest resolution, these observations already reveal H α sub-structure

AO-aided Integral Field Spectroscopy with Keck/OSIRIS

- OSIRIS =

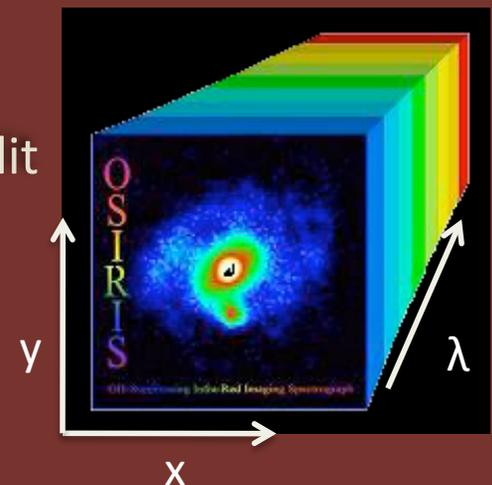
“OH-Suppressing IR Imaging Spectrograph”

- lenslet-based
- designed to be used with Laser Guide Star Adaptive Optics (LGS-AO)
- sub-arcsec resolution
- FOV = $4.8 \times 6.4''$, $2.4 \times 3.2''$ ($0.1''$, $0.05''$ /lenslet)
- $R \sim 3400$ ($\sim 6 \text{ \AA}$ @ $2 \mu\text{m}$)

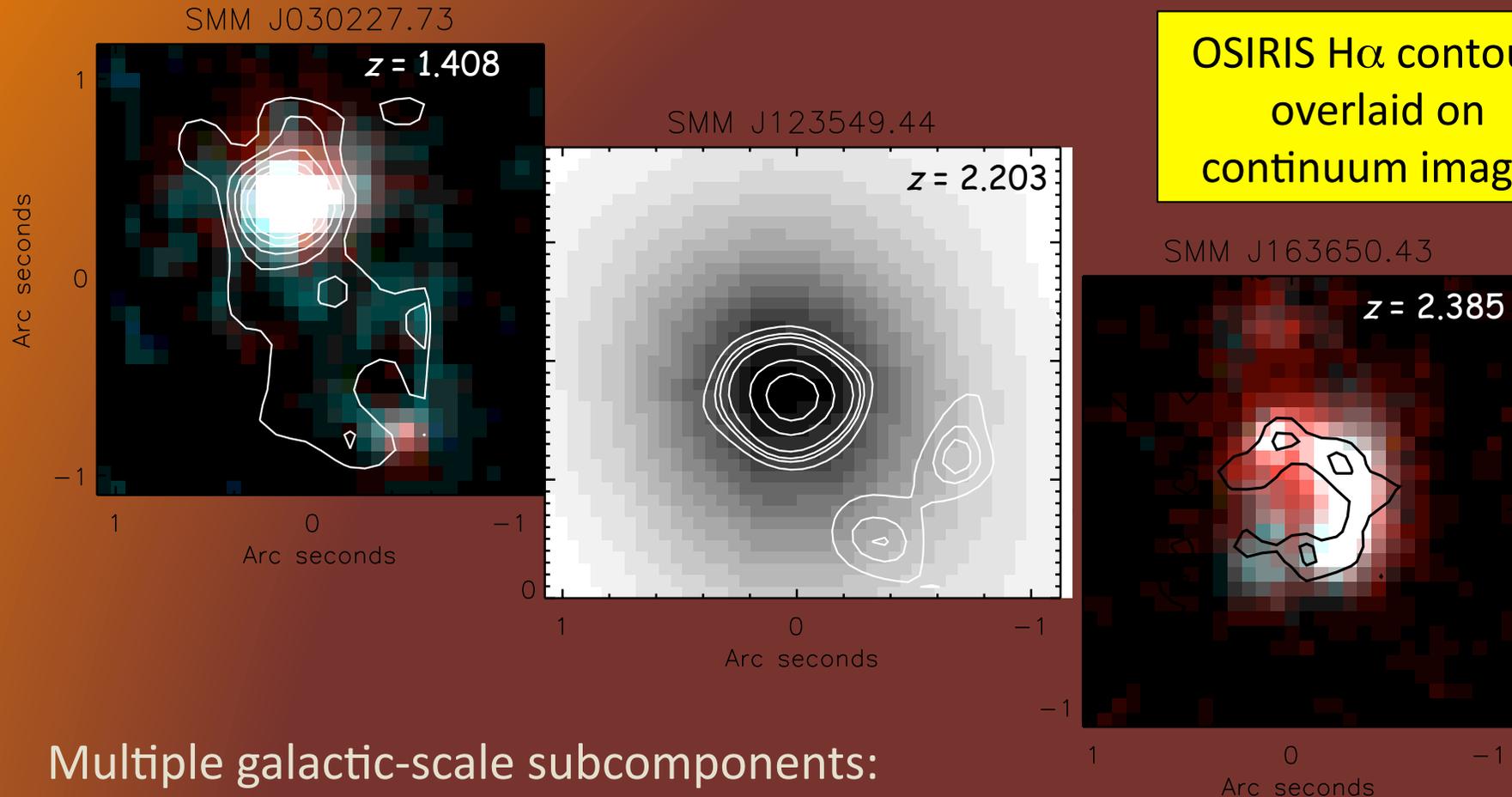
~10x the non-AO resolution
→ down to kpc-scale!!

- Our sample: SMGs with bright $H\alpha$ (from longslit spectroscopy) to optimize detection

- 3 SMGs within $1.4 < z < 2.4$
- ~3 hours of integration time / source

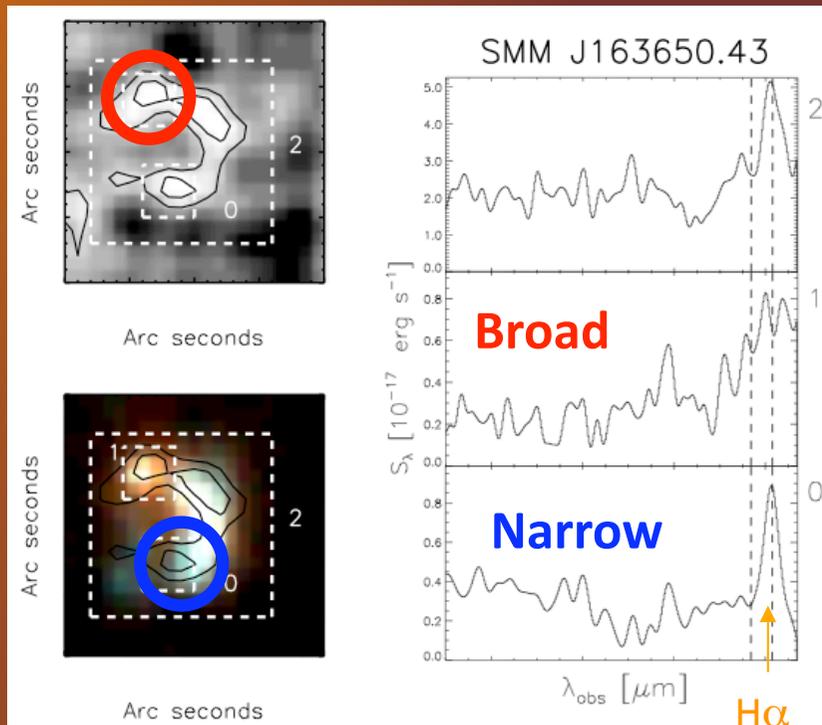


OSIRIS view of SMGs



- Multiple galactic-scale subcomponents:
 - Point sources + spatially-extended emission
- H α emission spreads over $\sim 1\text{--}2''$ ($\sim 8\text{--}16$ kpc at $z \sim 2$)
 - Compare to local ULIRGs ~ 1 kpc (e.g., Charmandaris et al. 2002)

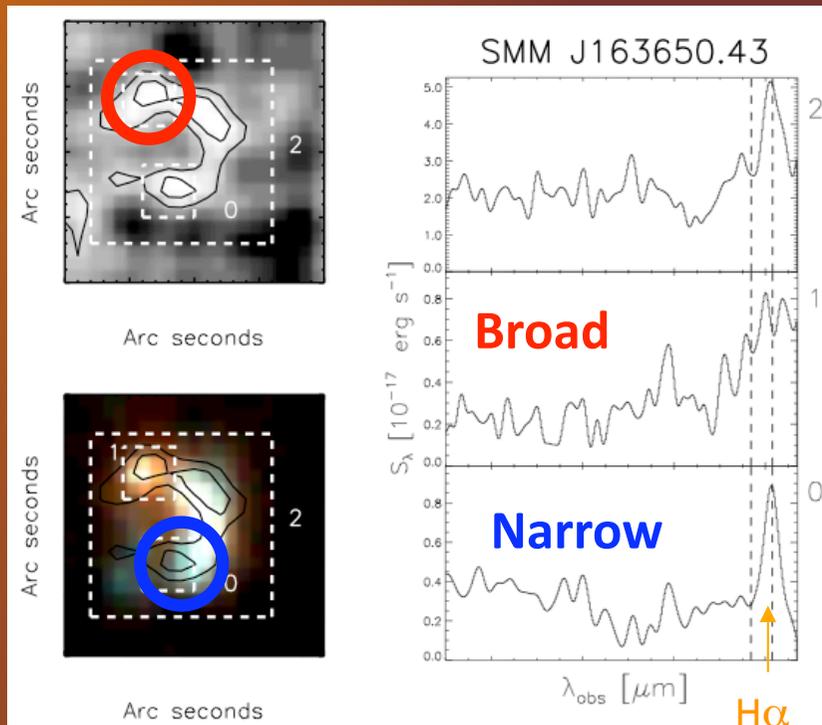
Spatial distinction between AGN and Extended SF



- Separation between spatial and spectral info:
 - Broad H α -- AGN (FWHM~2600 km/s)
 - Narrow H α -- Star-formation (FWHM~475 km/s)

With OSIRIS, we can spatially distinguish between AGN and star-forming regions

Spatial distinction between AGN and Extended SF

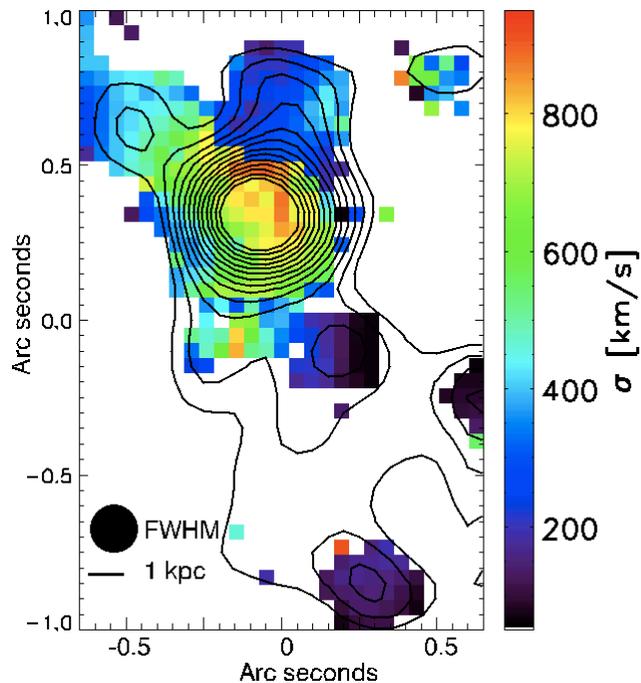


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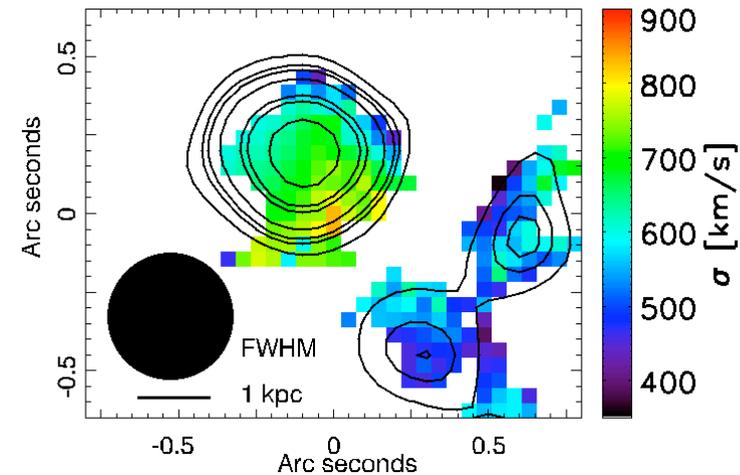
With OSIRIS, we can spatially distinguish between AGN and star-forming regions

Spatial distinction between AGN and Extended SF

SMM J030227.73



SMM J123549.44



With OSIRIS, we can spatially distinguish between AGN and star-forming regions

Dynamics of SMGs

- No evidence for ordered rotation, as would be associated to a disk and such as are found in:

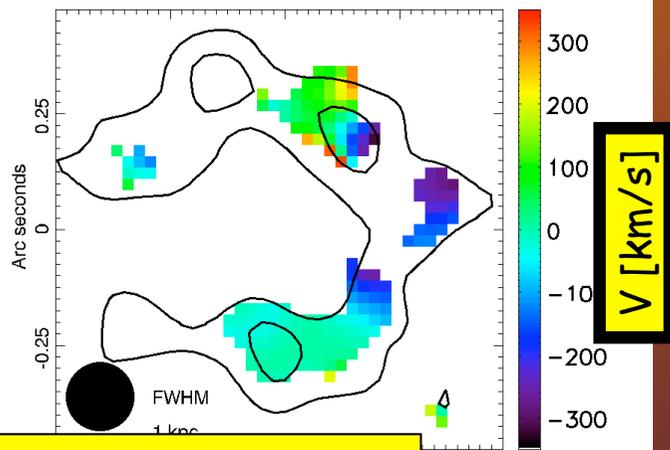
- Select massive LBGs (Law, Förster-Schreiber)
- VIMOS/VLT galaxies at $z \sim 1.5$ (Lemoine-Busserole+10)

- We find velocity offsets between different sub-components (\sim few \times 100 km/s)

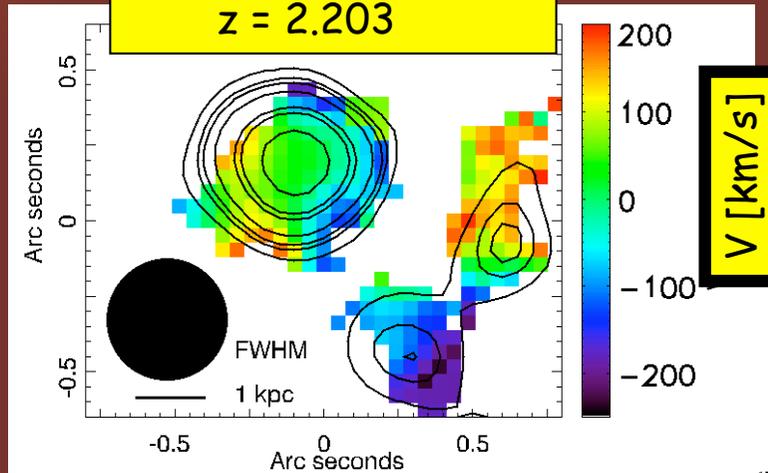
Merger?

- Merger scenario in agreement with SMGs' disturbed morphologies

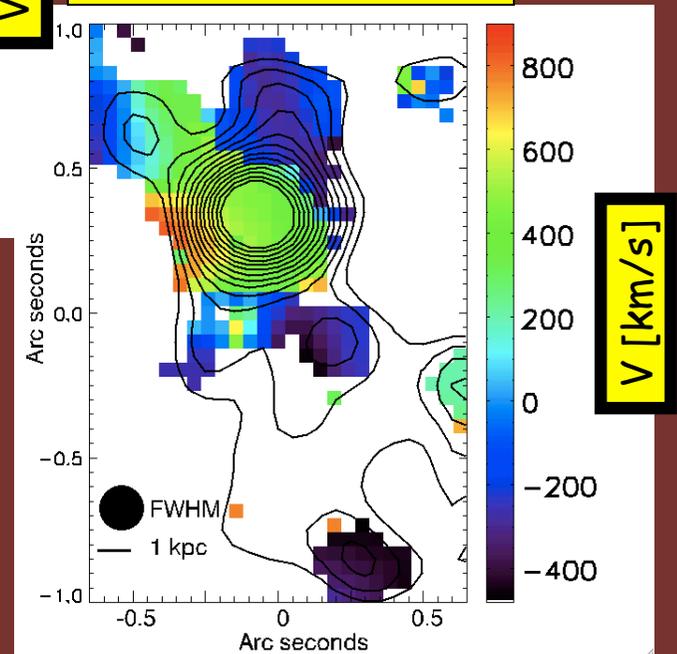
SMM J163650.43
 $z = 2.385$



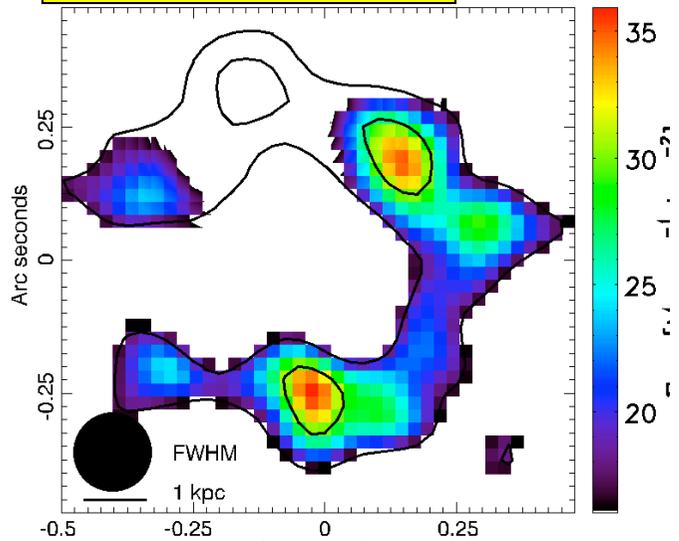
SMM J123549.44
 $z = 2.203$



SMM J030227.73
 $z = 1.408$

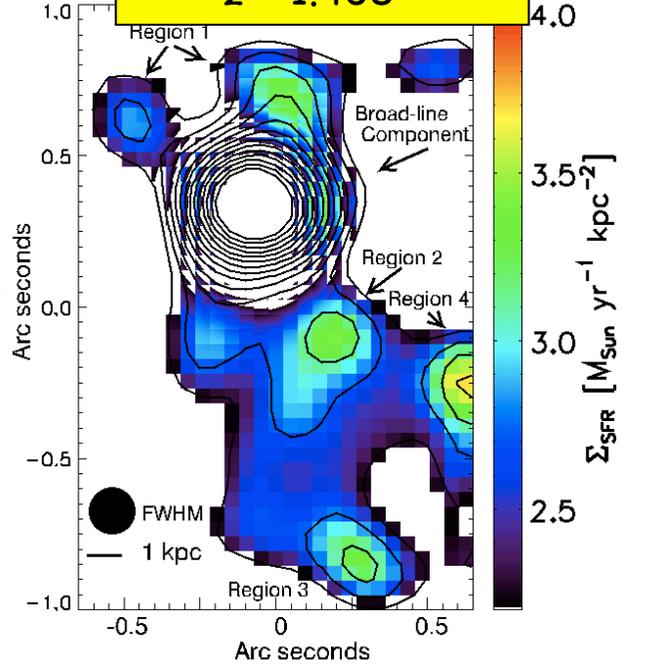


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Σ_{SFR} from H α maps

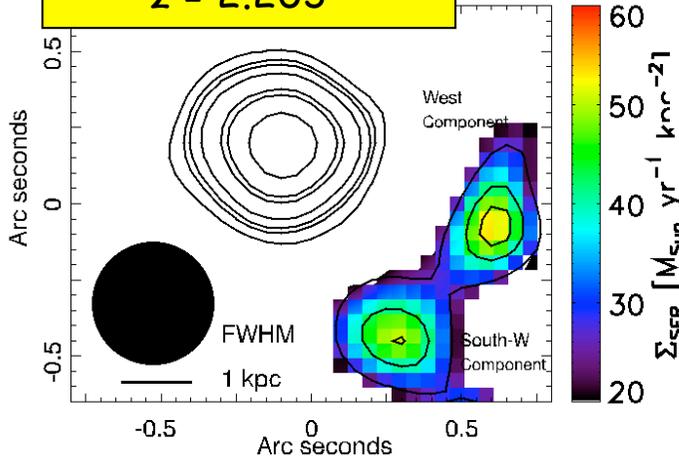
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Star-formation in multiple ~ 1 kpc "clumps"

- 1-25% H α contribution per clump
 - $\Sigma_{\text{SFR}} \sim 10\text{-}150 \text{ M}_{\odot} \text{ yr}^{-1} \text{ kpc}^{-2}$
- (extinction-corrected based on SMG mean Balmer decrement; Takata+06)

SMM J123549.44
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- Compare to: (Kennicutt+98)
 - Normal spirals: $\langle \Sigma_{\text{SFR}} \rangle \sim 0\text{-}0.1$
 - Local SBs: $\langle \Sigma_{\text{SFR}} \rangle \sim 1\text{-}100$

SMGs harbor SF activity similar to local starbursts, but on larger spatial scales, reflecting their large luminosities and total SFRs.

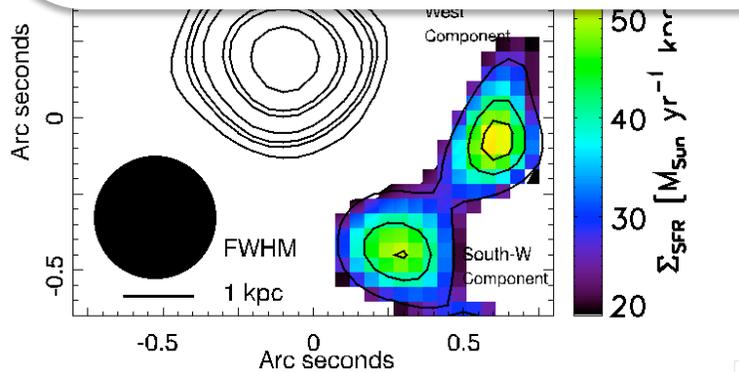
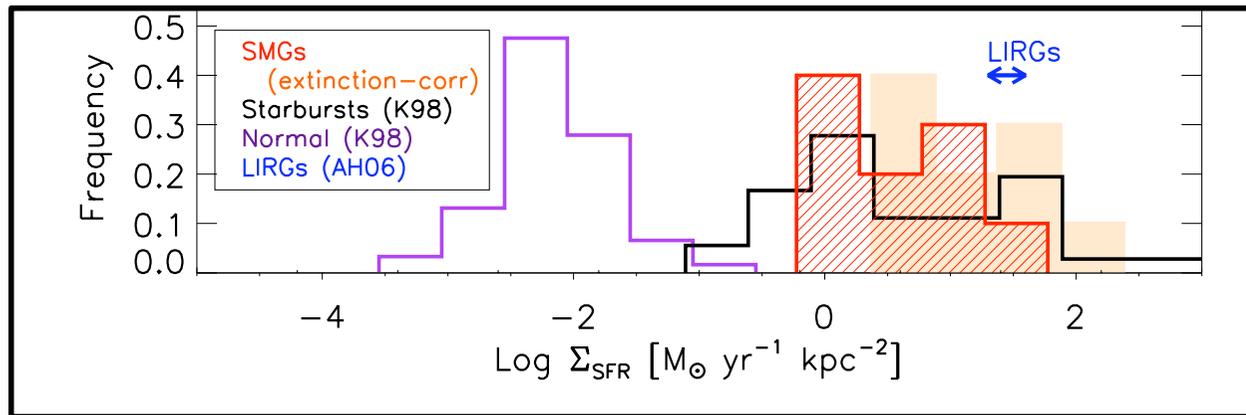
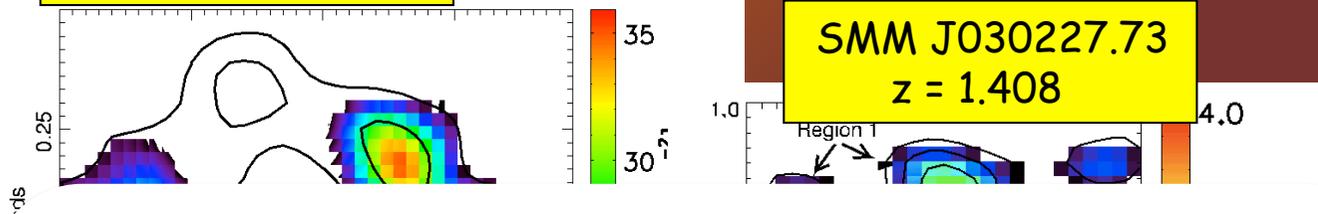
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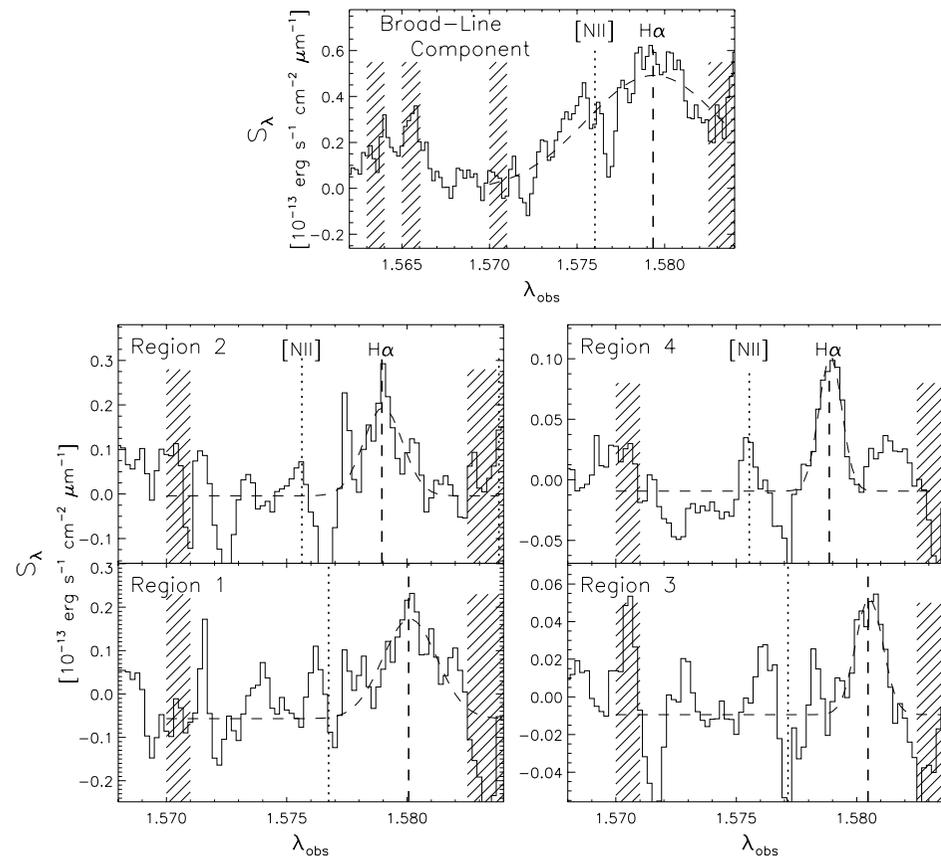
Main Results

From the first IFU observations of SMGs aided by Laser Guide Star Adaptive Optics:

- AGN signatures complicate interpretation of long-slit SMG spectra
- With OSIRIS, we spatially distinguish compact, broad- $H\alpha$ AGN and more extended narrow- $H\alpha$ stellar emission coming from kpc-scale clumps, asymmetrically distributed around the AGN and each contributing 1-25% of the total clump-integrated $H\alpha$ emission
- Even eliminating AGN contribution, SMGs remain starbursting monsters, with Σ_{SFR} similar to starbursts and luminous infrared galaxies
- We find no evidence for ordered rotation, but velocity offsets ($\sim \text{few} \times 100$ km/s, suggesting that these SMGs do not represent regular potential well structures}, but are more likely in an advanced merging phase..
- We find that SMGs display large (as opposed to “compact”) $H\alpha$ spatial extensions $\sim 1-1.5''$ ($\sim 8-12$ kpc).

SMGs are not simple high-z analogs of local ULIRGs or nuclear starbursts, but instead they appear to have star formation distributed across a far larger region than the $\sim 1-2$ kpc nuclear bursts in local ULIRGs.

SMG clump spectra



SMM J030227