Karín Menéndez-Delmestre

An IFU View of Extreme Starbursts at z~2 – the Case of Submm Galaxies

Ultra-luminous infrared galaxies (ULIRGs) are locally rare, but appear to dominate the co-moving energy density at z>2. Many are optically-faint, dust-obscured galaxies that have been identified only recently by the detection of their thermal dust emission redshifted into the submillimeter wavelengths. These submm galaxies (SMGs) have been popular candidates to be progenitors of the most massive galaxies at z~0. With colossal ULIRG-like luminosities that translate into unusually high SFRs (~100-1000 Msun/yr), SMGs could build the stellar bulk of a massive galaxy in under a few hundred million years. However, the predominance of AGN signatures in these SMGs shows that star formation and AGN activity coexist in these objects, implying that we are witnessing the coupled growth of the stellar spheroid and a central SMBH.

We have undertaken the first integral-field spectroscopic observations aided with adaptive optics (AO) of SMGs. With the OSIRIS integral field unit (IFU), designed to be used with the Keck Laser Guide Star Adaptive Optics (LGS-AO) system, we investigate the distribution of Hα line emission in 3 SMGs at 1.4<z<2.4. LGS-AO allows us to probe down to kpc-scale spatial resolutions, up to 10 times more resolved than what prior seeing-limited observations had been able to achieve. The exquisite resolution provided by LGS-AO allows us to spatially distinguish between AGN and star-forming regions as revealed by differences in Hα spectral properties and to uncover velocity offsets (~few x 100 km/s) between individual galactic-scale sub-components. We find that, after an estimated correction for extinction based on typical Balmer decrements for SMGs, their high SFR surface densities are similar to local extremes like ULIRGs and starbursts. However, their spatial extensions stretch beyond >8 kpc, suggesting that SMGs may be undergoing such intense star-forming activity on significantly larger spatial scales than extreme local environments, which are typically concentrated in ~1-2kpc.

An IFU view of extreme starbursts at z≈2: the case of sub-mm galaxies

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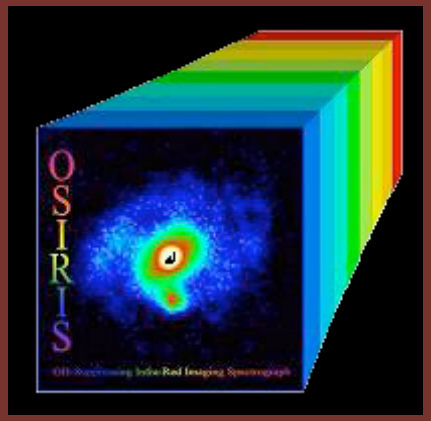


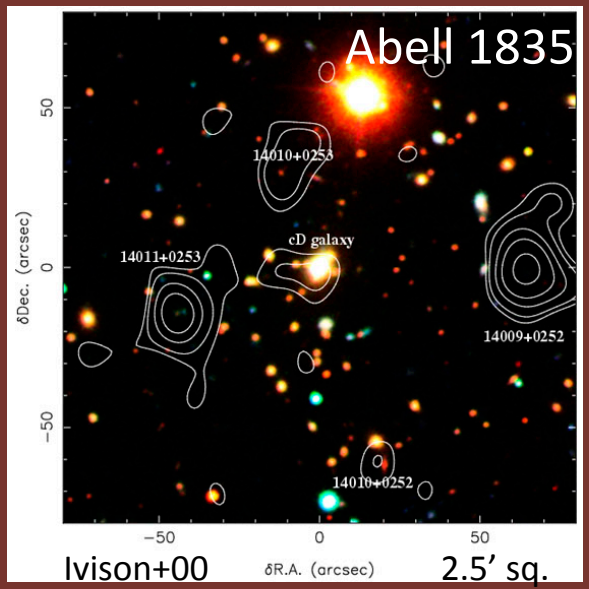
Andrew Blain, Mark Swinbank, Ian Smail,

Rob Ivison, Scott Chapman

SMGs in the "big picture"

- Observationally-defined population of strong submm emitters
- ~100s detections abound with SCUBA, MAMBO, Bolocam, AzTEC
- Challenge to identify redshifts

A deep submm image



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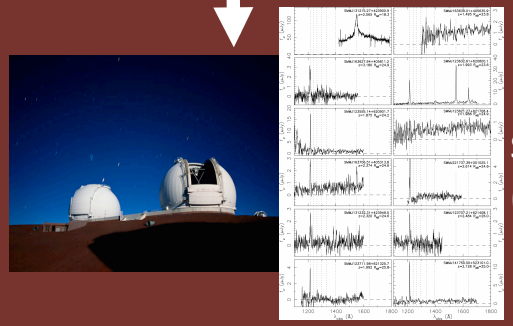
  - ~70% are μJy radio sources, a **radio-identified** sample
- $M_* \sim 10^{11} M_\odot$ (e.g., Hainline+10), SFRs~10^2 - 10^3 $M_\odot$/yr
- Progenitors of today's most massive galaxies (e.g. Lilly+99)

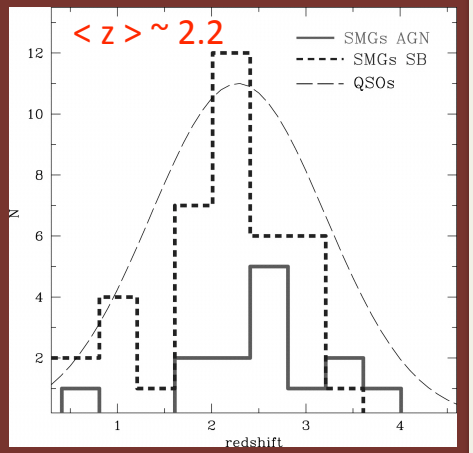
Building the radio-identified sample of SMGs:

SCUBA detection:
~13" spatial resolution

VLA radio counterparts (Ivison+98+02)



UV-based spectroscopic-*z* (LRIS-B, Keck)



Chapman+05

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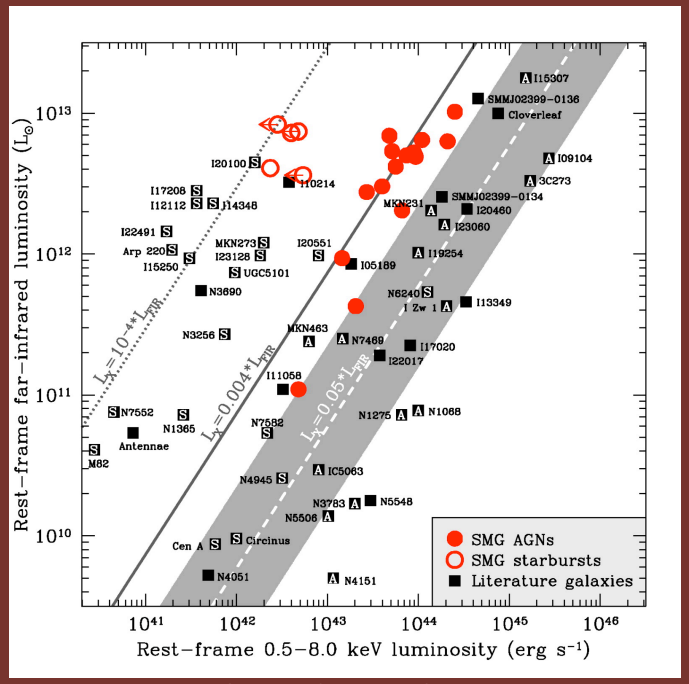
- AGN signatures in opt / near-IR / X-ray (Chapman+05; Swinbank+04; Alexander+05, +08, MD+07,+09)



Alexander et al. 2005

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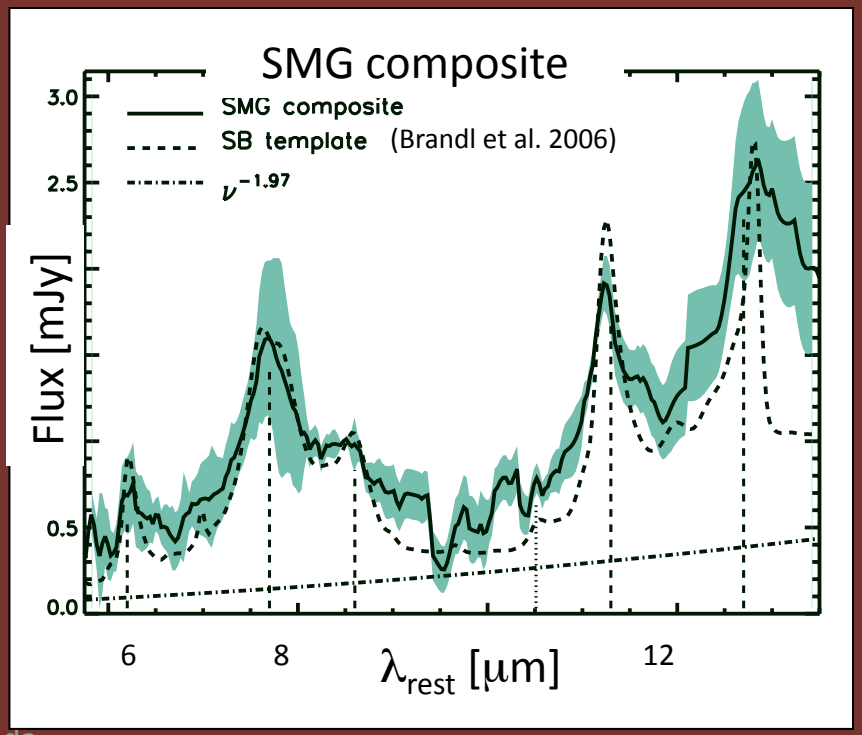
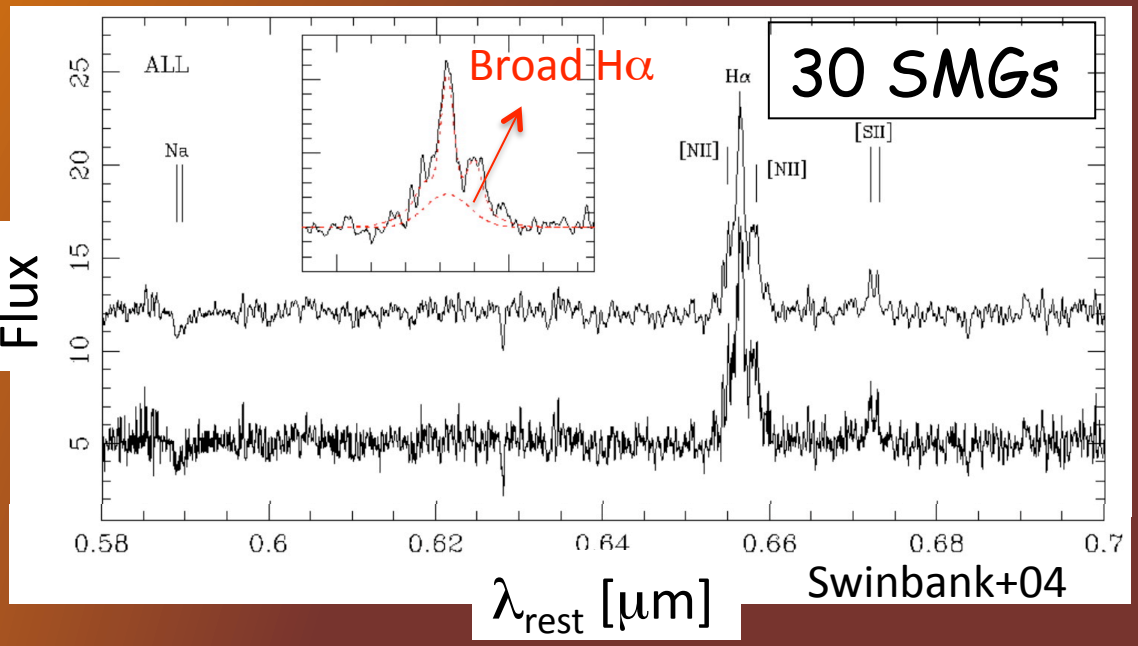


Menéndez-Delmestre+09

Near-IR AGN signatures in SMGs

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



- But the Hα 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

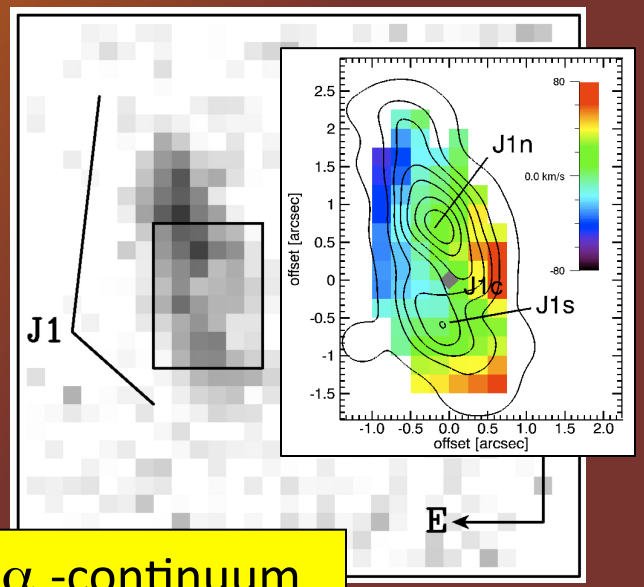
With no spatially-resolved information, it is difficult to disentangle AGN-contribution.

IFU view of SMGs

(seeing-limited, unaided by Adaptive Optics)

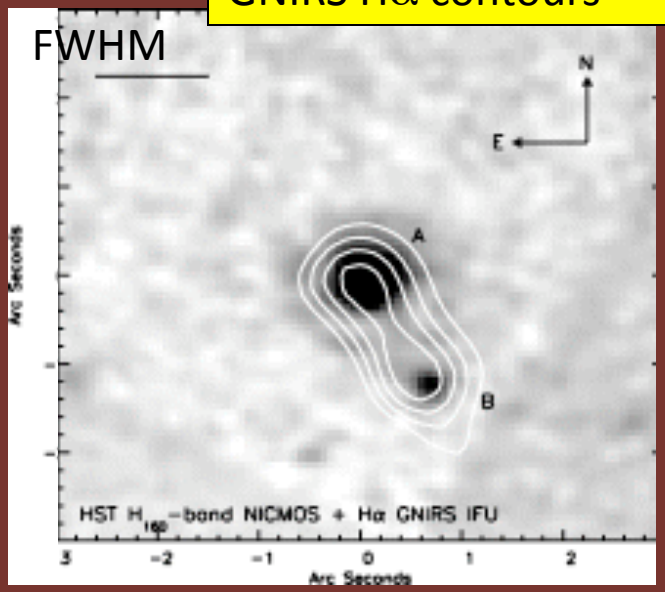
SPIFFI Hα view of SMM J14011 @ z=2.565 (Tecza+04)

Inset: Hα Velocity map (Nesvabda+07)



Hα -continuum

NICMOS H-band, GNIRS Hα 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 Hα sub-structure

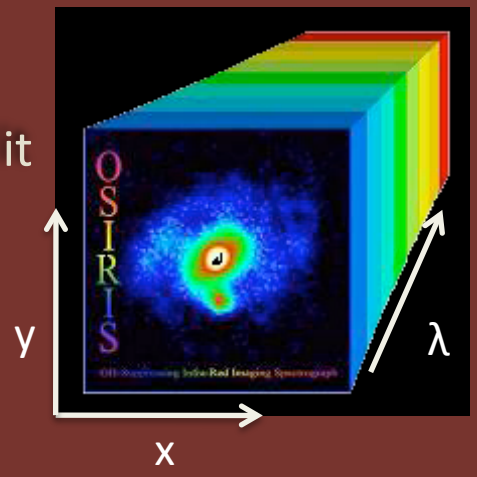
AO-aided Integral Field Spectroscopy with Keck/OSIRIS

- OSIRIS =

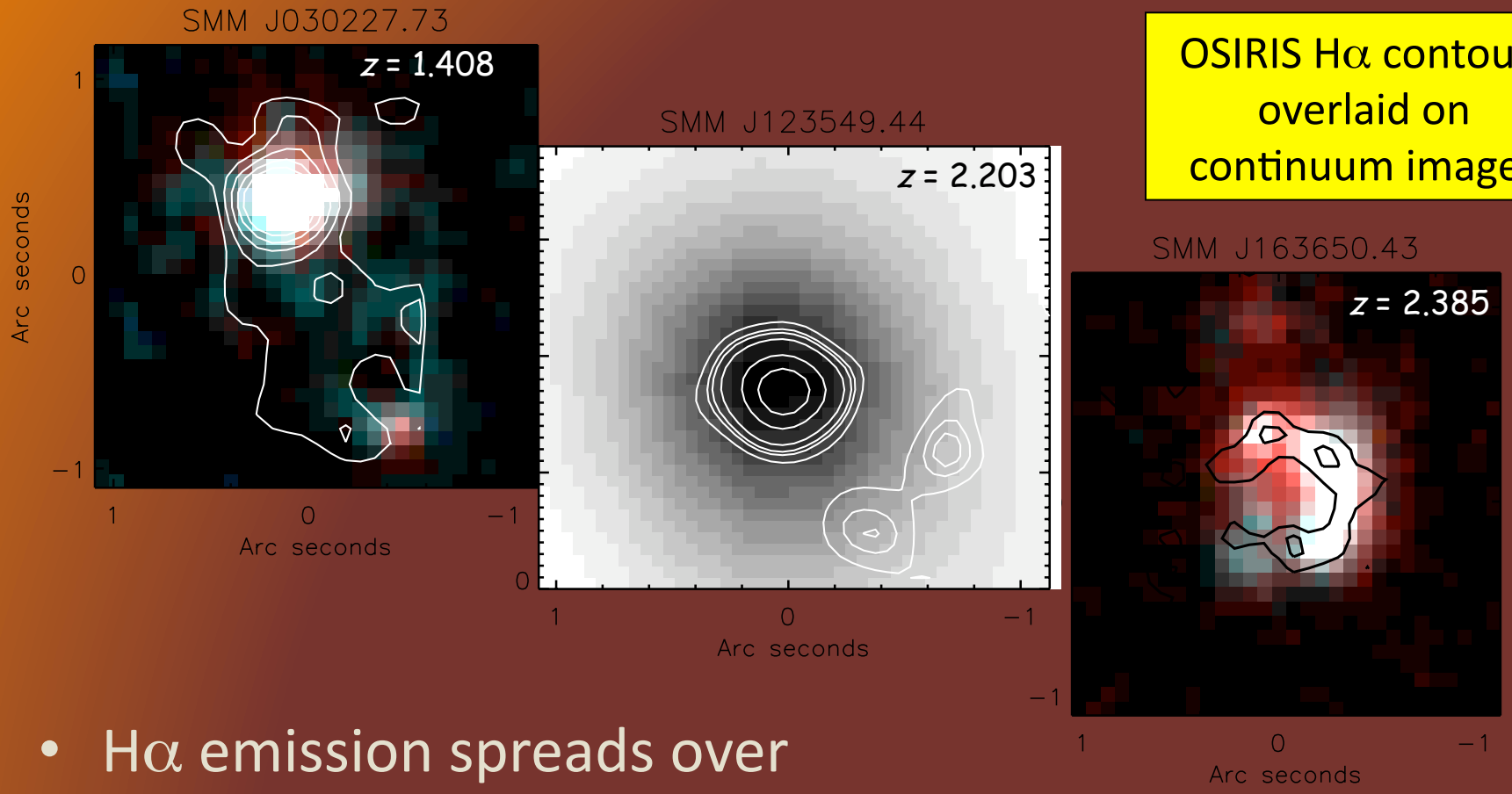
  "OH-Suppressing IR Imaging Spectrograph"
  - lenslet-based
  - designed to be used with Laser Guide Star Adaptive Optics (LGS-AO)
  - sub-arcsec resolution
  - FOV = 4.8 x 6.4", 2.4 x 3.2" (0.1", 0.05"/lenslet)
  - R~3400 (~6 Å @ 2 μm)

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

- Our sample: SMGs with bright Hα (from longslit spectroscopy) to optimize detection
  - 3 SMGs within 1.4 <z < 2.4
  - ~3 hours of integration time / source



OSIRIS view of SMGs

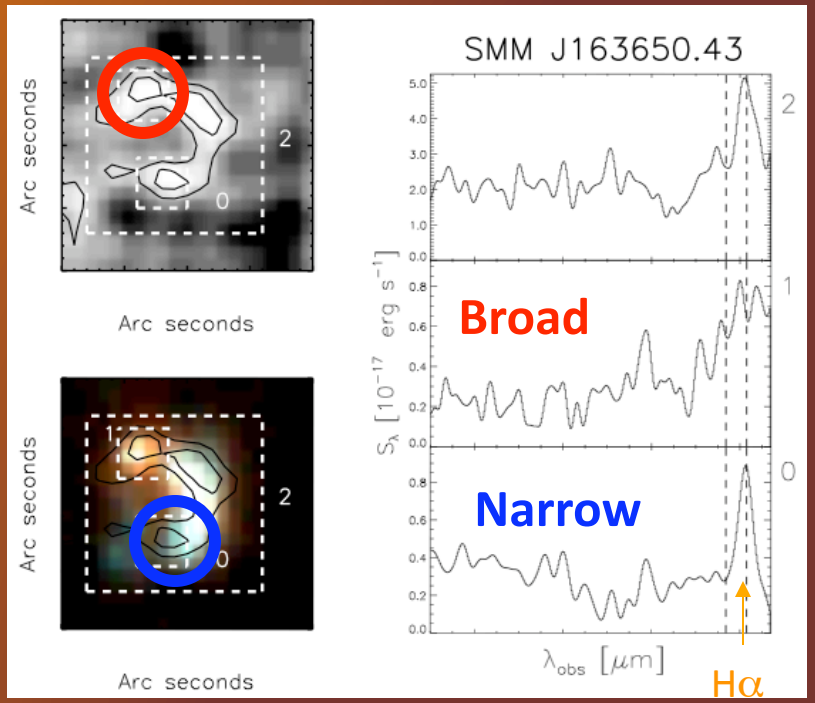


OSIRIS Hα contours overlaid on continuum images

- Hα emission spreads over ≳1-1.5" (≳ 8-12 kpc at z~2)

Multiple galactic-scale sub-components in SMGs

Spatial distinction between AGN and Extended SF

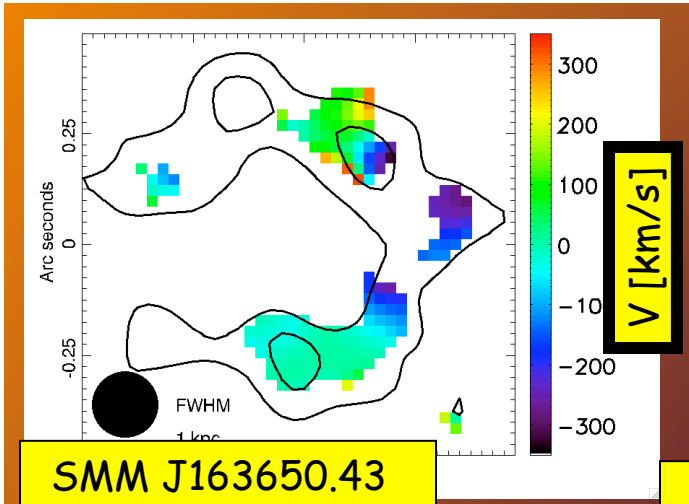


- Separation between spatial and spectral info:
  - Broad Hα -- AGN (FWHM~2400 km/s)
  - Narrow Hα (FWHM~475 km/s) -- Star-formation

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

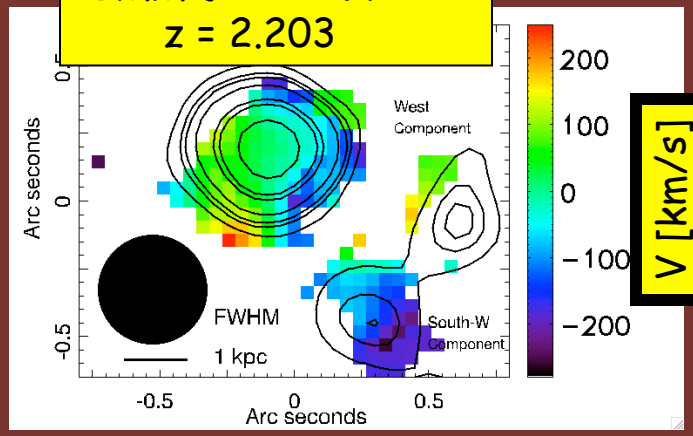
Dynamics of SMGs

- 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~1.5 (Lemoine-Busserole+10)

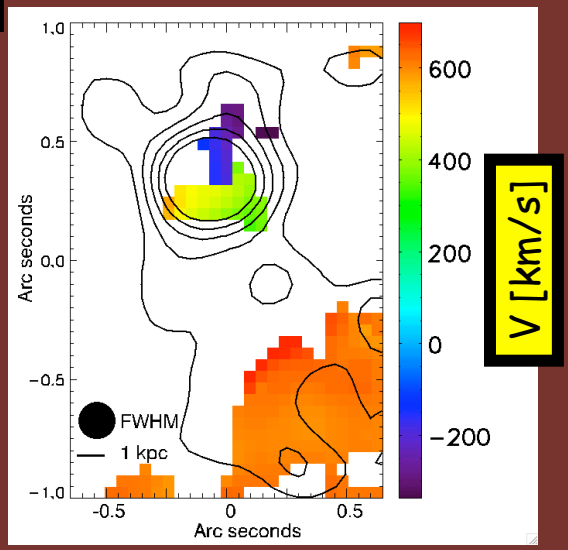


SMM J163650.43
z = 2.385

SMM J123549.44
z = 2.203



SMM J030227.73
z = 1.408



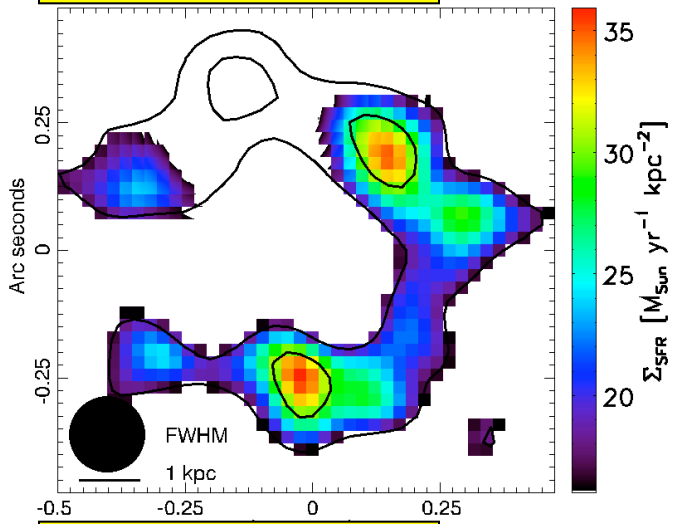
- We find velocity offsets between different sub-components (~ few x 100 km/s)

Merger?

- Merger scenario in agreement with SMGs' disturbed morphologies

Σ_{SFR} from Hα maps

SMM J163650.43
z = 2.385



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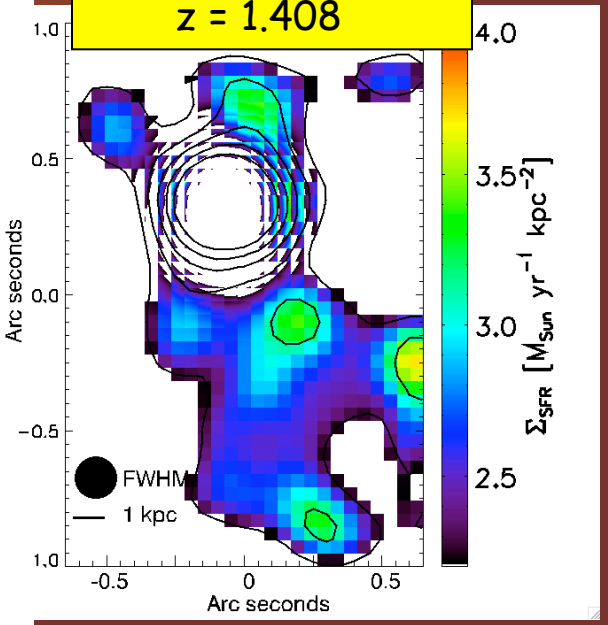

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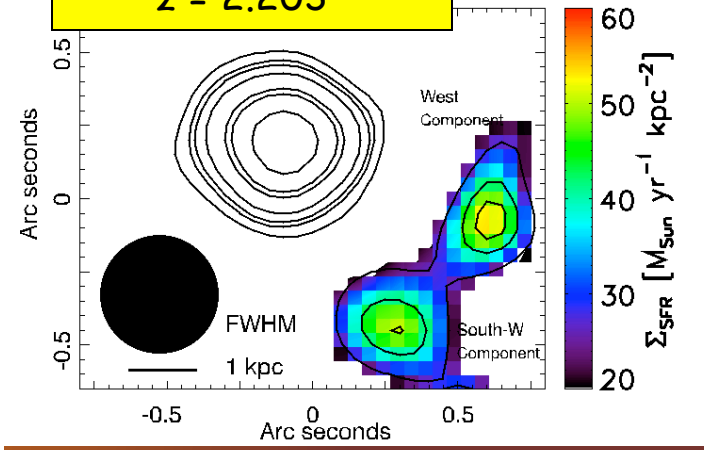

Star-formation in multiple ~1 kpc "clumps"

- Σ_{SFR} ~ 10-100 $M_{\odot} yr^{-1} kpc^{-2}$

(extinction-corrected based on SMG mean Balmer decrement; Takata+06)

- Compare to: (Kennicutt+98)
  - Normal spirals: $<\Sigma_{SFR}>$~0-0.1
  - Local SBs: $<\Sigma_{SFR}>$~1-100
  - LBGs: $<\Sigma_{SFR}>$~2.9 (Erb+06); $(\Sigma_{SFR})_{peak}$ ~10-25 (Law+07)

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

Main Results

From the first 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- Hα AGN and more extended narrow-Hα stellar emission coming from kpc-scale clumps.
- Even eliminating AGN contribution, SMGs remain starbursting monsters
- We find no evidence for ordered rotation, but velocity offsets (~ *few* x 100 km/s) could indicate ongoing merger activity between sub-components.
- We find that SMGs display large (as opposed to "compact") Hα spatial extensions ~1-1.5" (~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 ~1-2 kpc nuclear bursts in local ULIRGs.