Submillimeter Galaxies at z~2
with Keck/OSIRIS Laser-guide Star Adaptive Optics Spectroscopy

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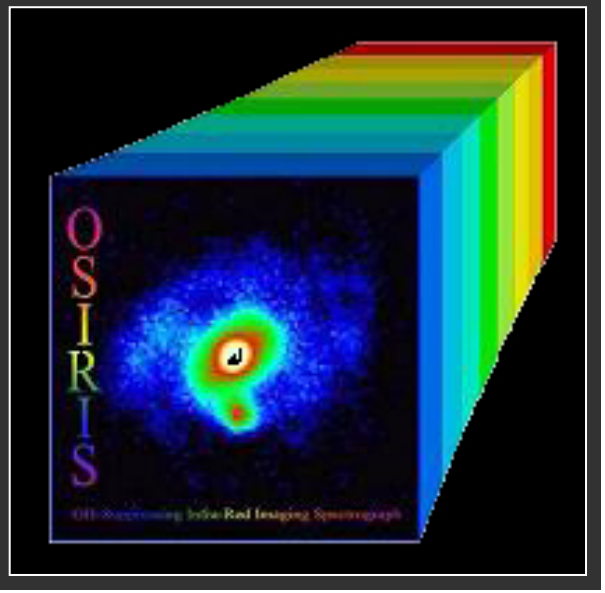
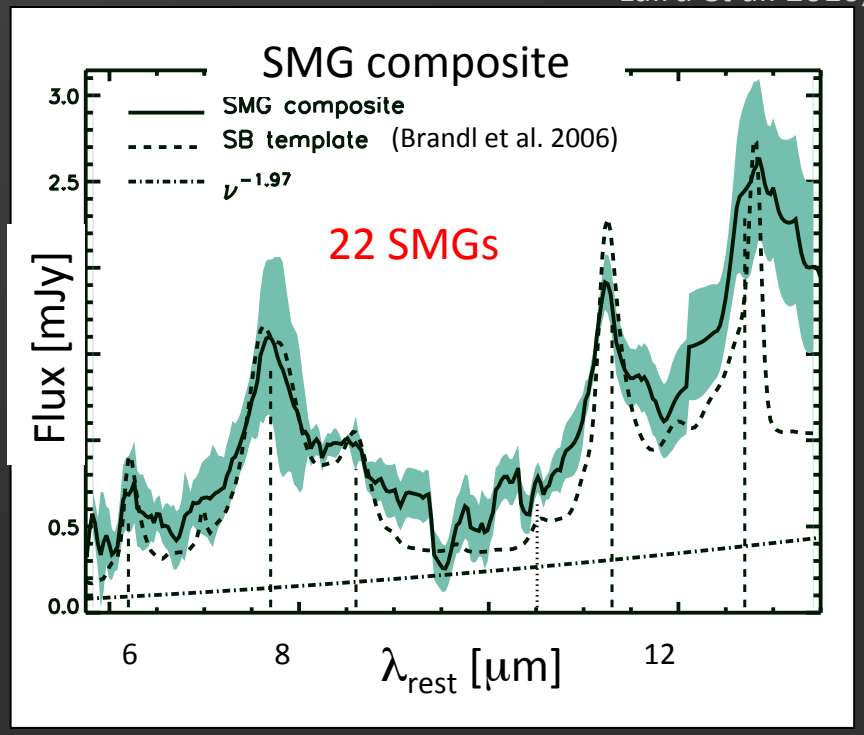


Menéndez-Delmestre et al. 2013, ApJ, 767, 151

SMGs in the "big picture"

- Observationally-defined population of strong submm emitters
- At first, "SCUBA galaxies", now hundreds of detections abound with different instruments.
- $M_* \sim 10^{11} M_\odot$ (e.g., Hainline+10), SFRs$\sim 10^2 - 10^3\ M_\odot$/yr (Chapman+05, Swinbank+04)
- 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, Laird et al. 2010; Georgantopolous+11; Johnson+13)



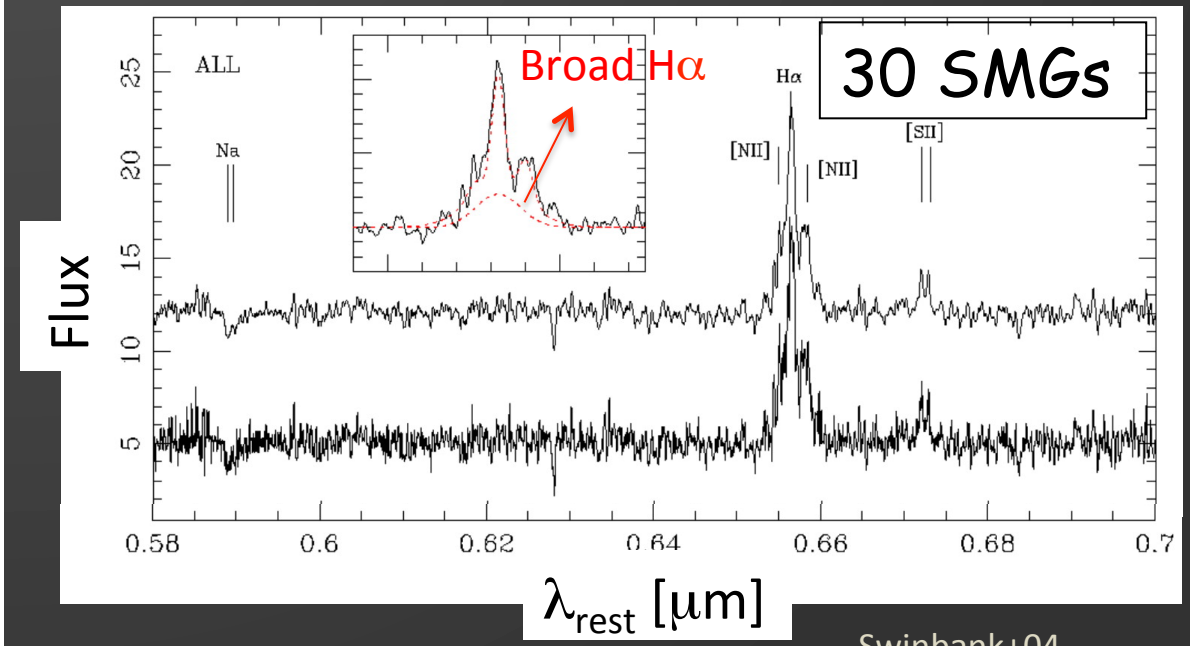
→ Starburst and AGN coexist!

Menéndez-Delmestre+09

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

Near-IR AGN signatures in SMGs

- Hα line properties can be used to derive dynamical masses and SFRs



Swinbank+04

- But AGN presence may pollute Hα line

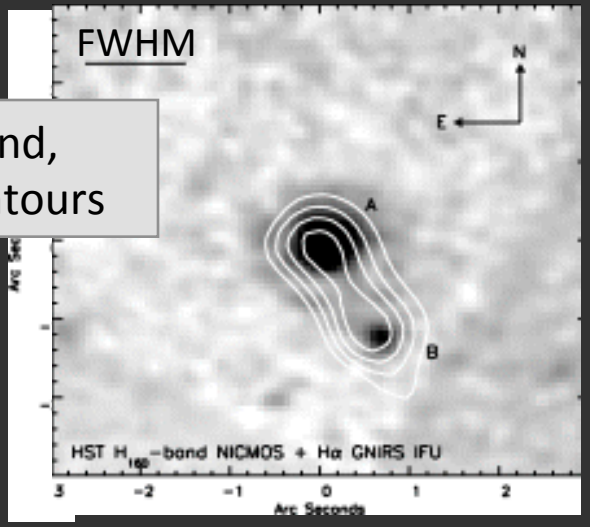
→ Presence of broad Hα lines in SMGs

- 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)

- A handful of SMGs have been observed with IFU instruments

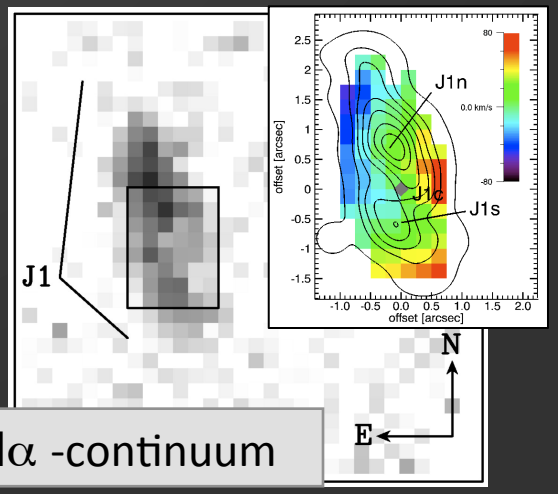


NICMOS H-band, GNIRS Hα contours

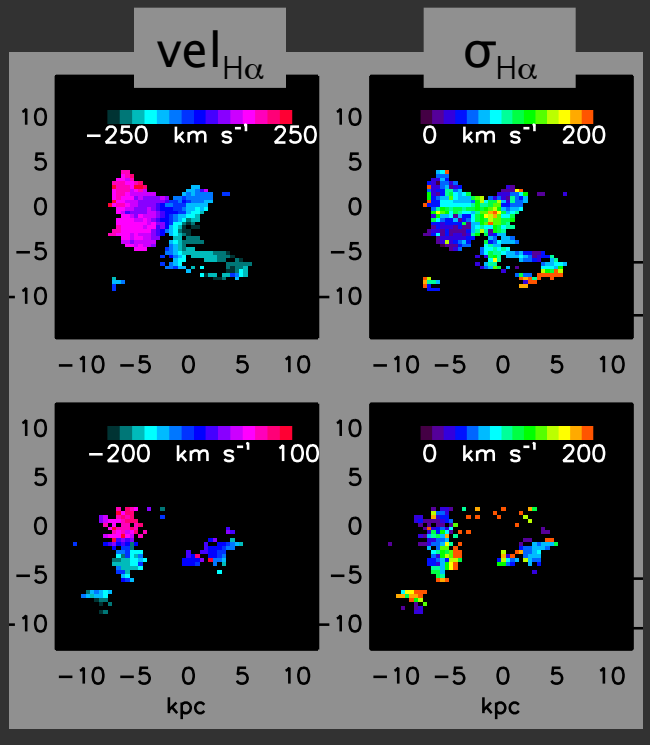
GNIRS observations of SMM J030227 @ z=1.407 (Swinbank+06)

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

Inset: Hα Velocity map (Nesvabda+07)



Hα -continuum

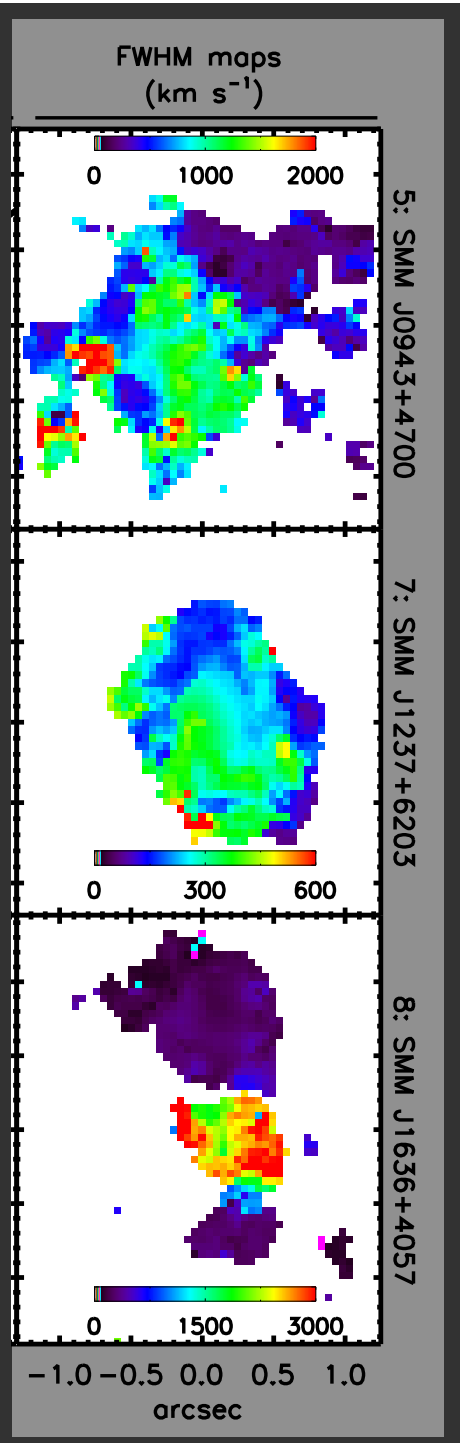


From Gemini/NIFS + VLT/SINFONI Hα IFU view of 9 SMGs at 2.0 < *z* < 2.7 (Alaghband-Zadeh+12)

IFU view of SMGs
(seeing-limited)

- A handful of SMGs have been observed with IFU instruments
- [OIII] emission in AGN-dominated SMGs (Harrison+12)
  - tracing AGN outflows
- Although with modest resolution, these observations already reveal Hα (and [OIII]) sub-structure
- Prominence of multiple galactic-scale subcomponents

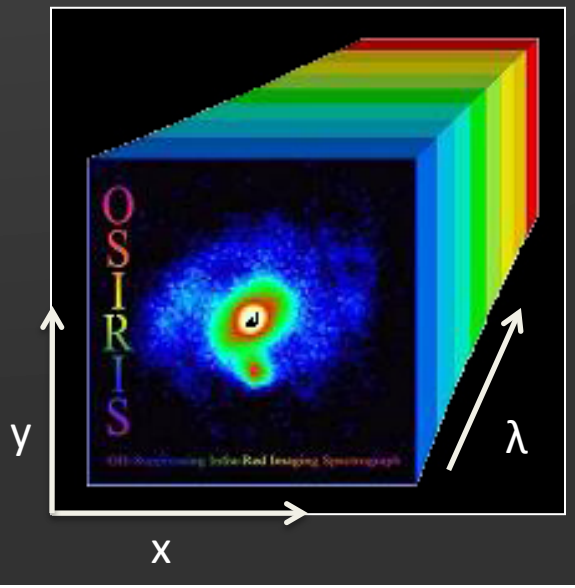
From Gemini/NIFS + VLT/SINFONI
[OIII] IFU view of 8 AGN-dominated SMGs at
$1.4 < z < 3.4$ (Harrison+12)

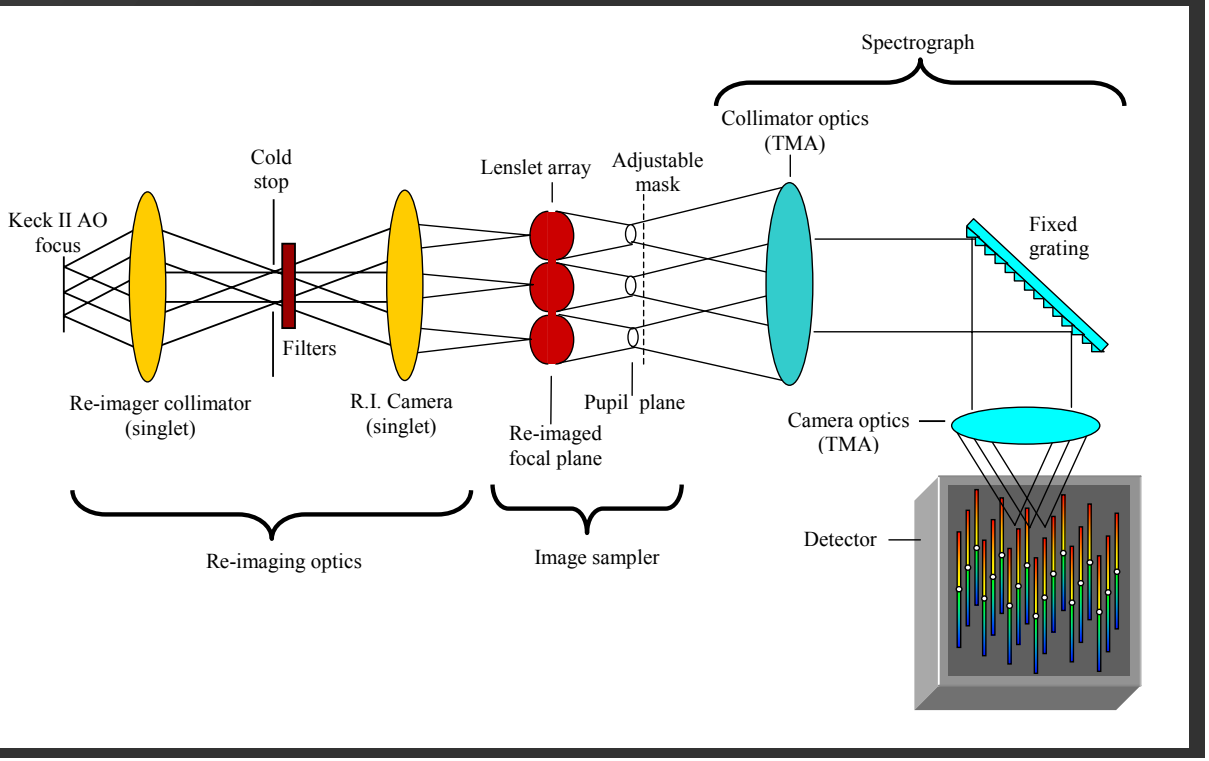


AO-aided Integral Field Spectroscopy with Keck/OSIRIS

"OH-Suppressing IR Imaging Spectrograph"

- lenslet-based spectrograph
- designed to be used with Laser Guide Star Adaptive Optics (LGS-AO)





Our Study

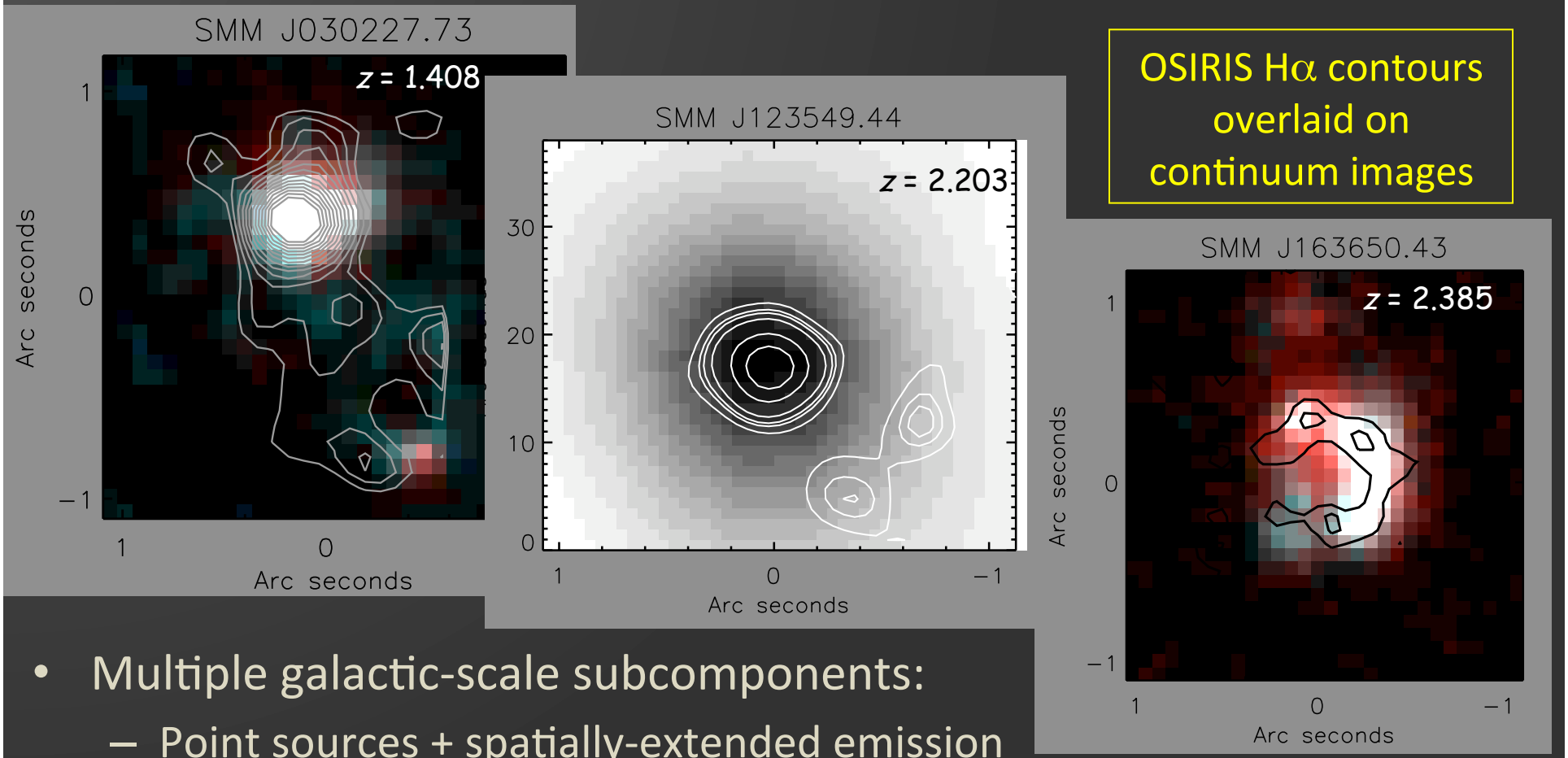
- Our sample: SMGs with bright Hα (from longslit spectroscopy; Swinbank+04) to optimize detection
  - 3 SMGs within 1.4 <z < 2.4
  - ~3 hours of integration time / source

- With LGS-AO OSIRIS…
  - sub-arcsec resolution

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

  - FOV = 4.8 x 6.4”, 2.4 x 3.2” (0.1”, 0.05”/lenslet)
  - R~3400 (~6 Å @ 2 μm)

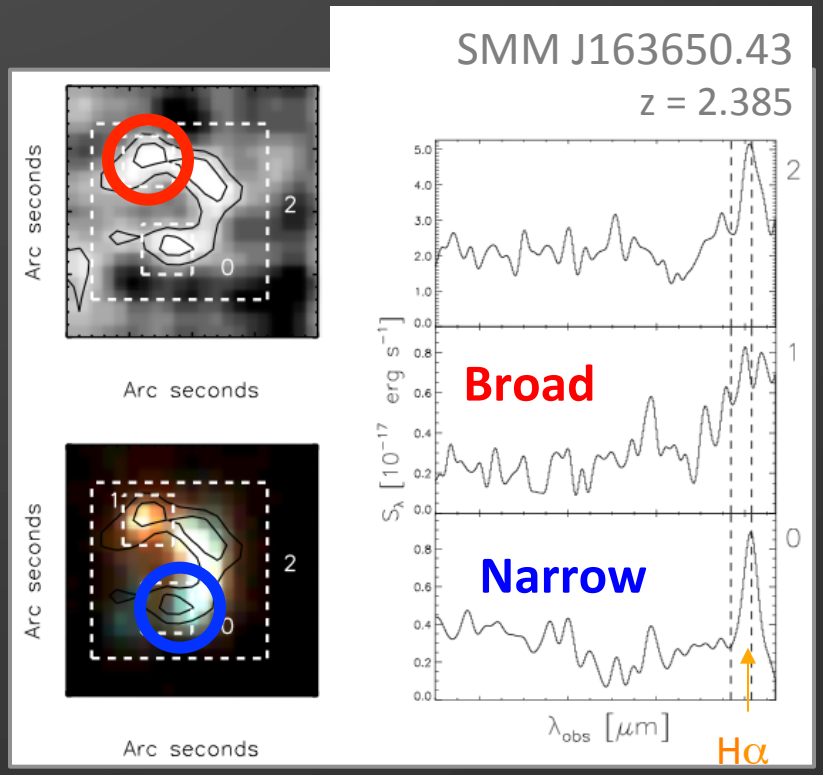
OSIRIS view of SMGs



OSIRIS Hα contours overlaid on continuum images

- Multiple galactic-scale subcomponents:
  - Point sources + spatially-extended emission
- Hα emission spreads over ~1-2" (~8-16 kpc at z~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 Hα →AGN (FWHM~2600 km/s)

    coincident with broad [OIII]

    (Gemini/NIFS; Harrison+12)
  - Narrow Hα → Star-formation (FWHM~400 km/s)

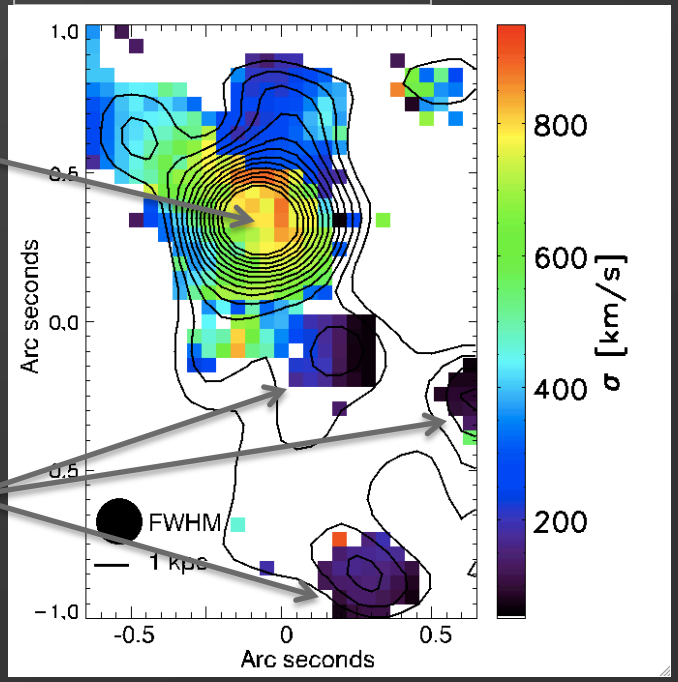
With OSIRIS, we can spatially distinguish between AGN and star-forming regions

Spatial distinction between AGN and Extended SF

SMM J030227.73
z = 1.408

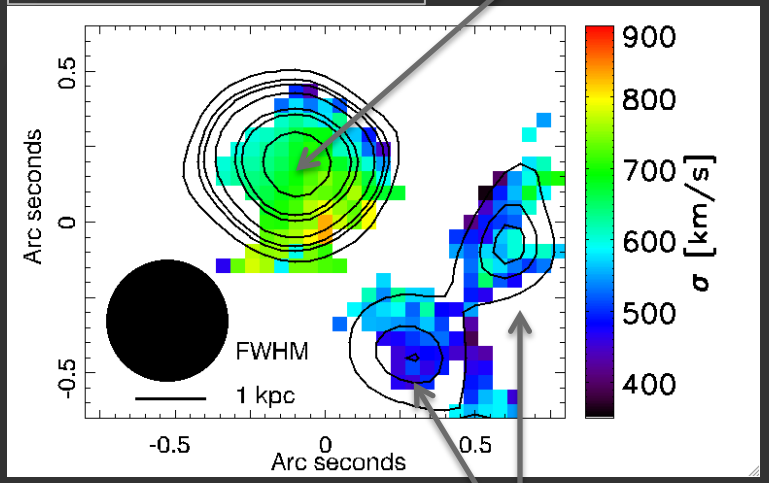
FWHM$_{H\alpha}$
> 2000 km/s

FWHM$_{H\alpha}$
< 400 km/s



SMM J123549.44
z= 2.203

FWHM$_{H\alpha}$
> 1200 km/s



FWHM$_{H\alpha}$ ~ 500-800 km/s

→ Narrow-Hα emission is divided into multiple clumps unresolved on ~ 1 – 2 kpc scales, asymmetrically distributed around the AGN.

Spatial distinction between AGN and Extended SF

- Clump dynamical masses:

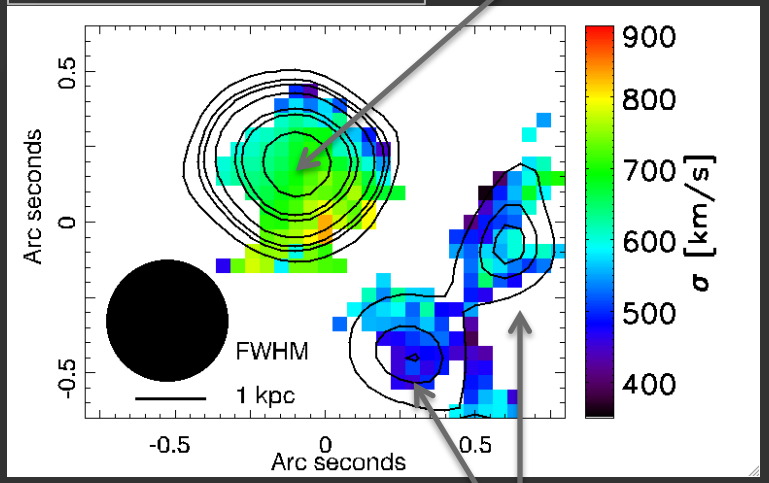
  M_{clumps} ~ 1–30 × 10^9 $M_\odot$

- Compared to the optically-selected z~2 star-forming galaxies:
  - M_{clumps} ~ 0.1–8 × 10^9 $M_\odot$

    (Förster Schreiber+11)
  - M_{clumps} ~ 10^8 - 10^{10} $M_\odot$

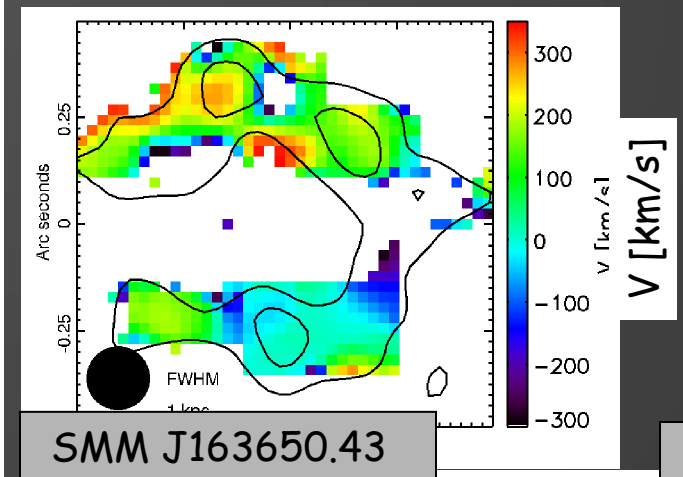
    (Guo+12)

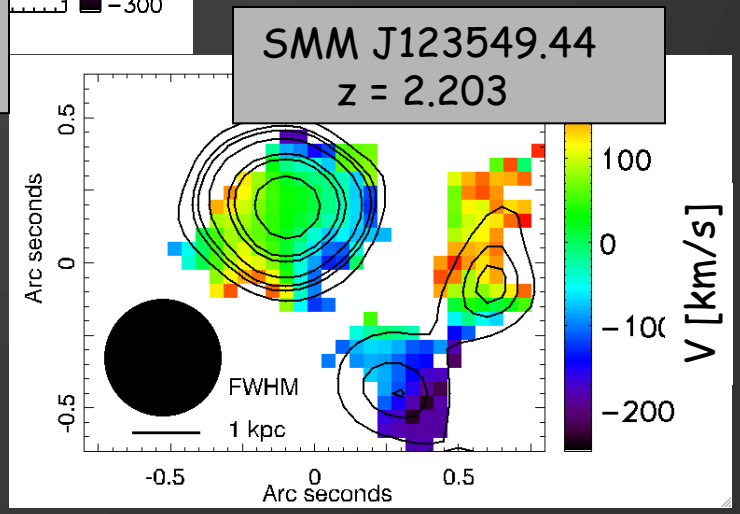
SMM J123549.44
z= 2.203

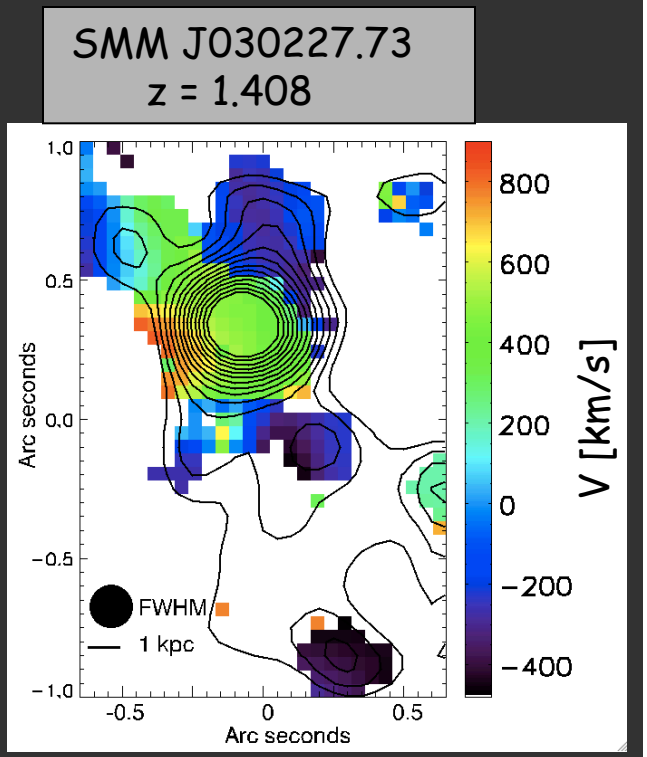


Dynamics of SMGs

- No evidence for ordered rotation, as have been found in massive LBGs (Law, Förster-Schreiber)
- We find velocity offsets between different sub-components (~ few x 100 km/s)







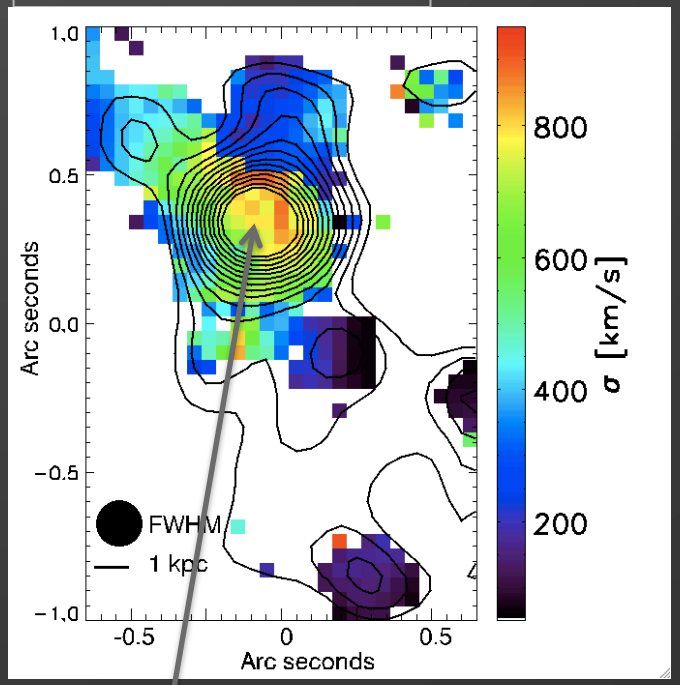
- In agreement with average projected separation of ~8 kpc and velocity offsets ~200± 100 km/s (Alaghband-Zadeh+12)

Mergers?

→ Merger scenario in agreement with SMGs' disturbed morphologies (Swinbank+2010)

Removing the AGN from Hα maps

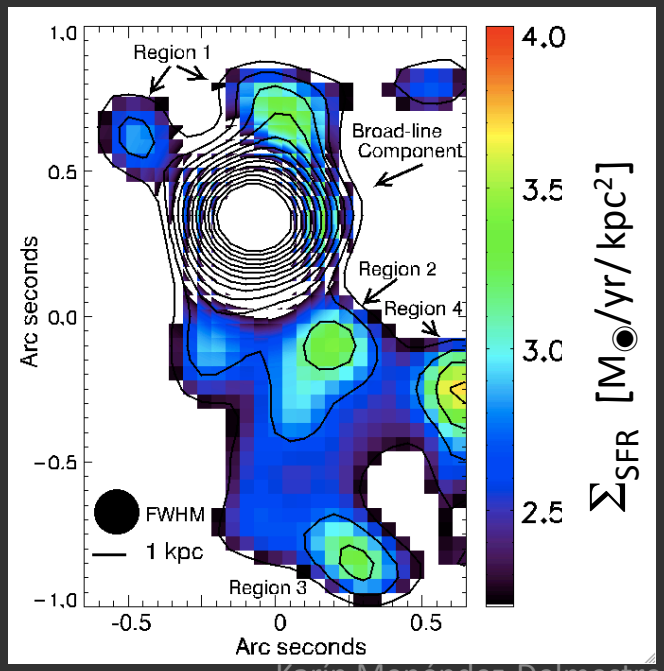
SMM J030227.73
z = 1.408



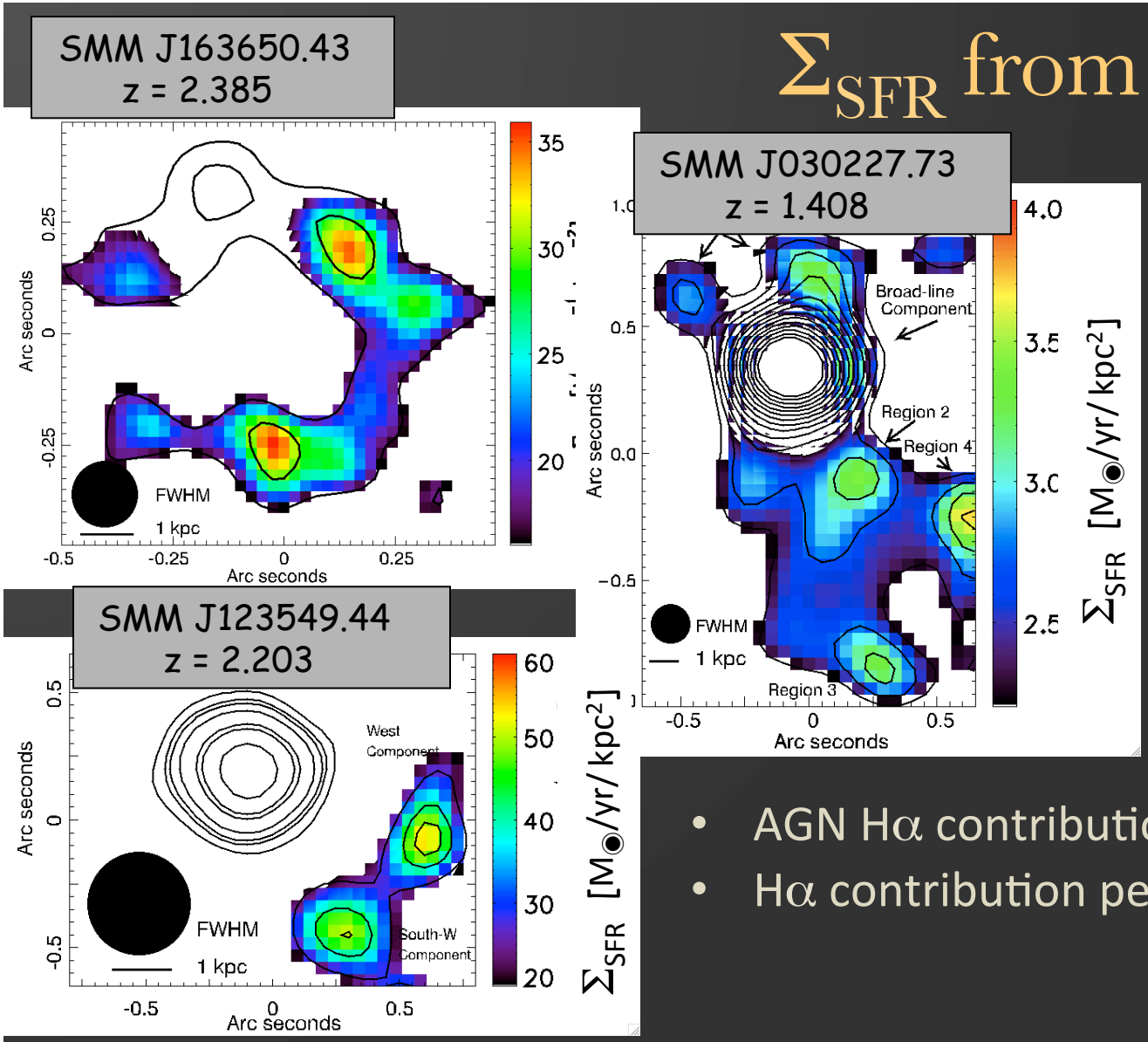
$FWHM_{H\alpha}$
> 2000 km/s

- We rely on a target-specific PSF determined from peak-up imaging of the TT-star to subtract the AGN contribution
- important to minimize the spread of emission beyond the AO-corrected PSF that may escape the immediate regions of these high-S/N regions of emission.

→ PSF subtraction removes AGN contamination from SFR surface density maps!



Σ_{SFR} from Hα maps

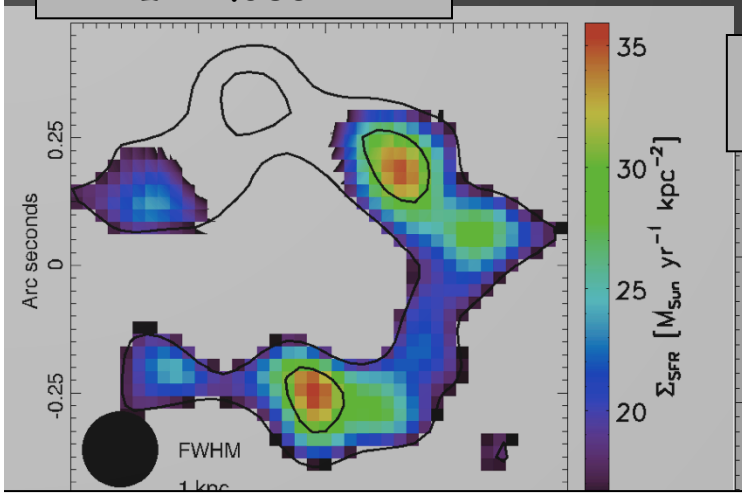


Star-formation in multiple ~1-2 kpc "clumps"

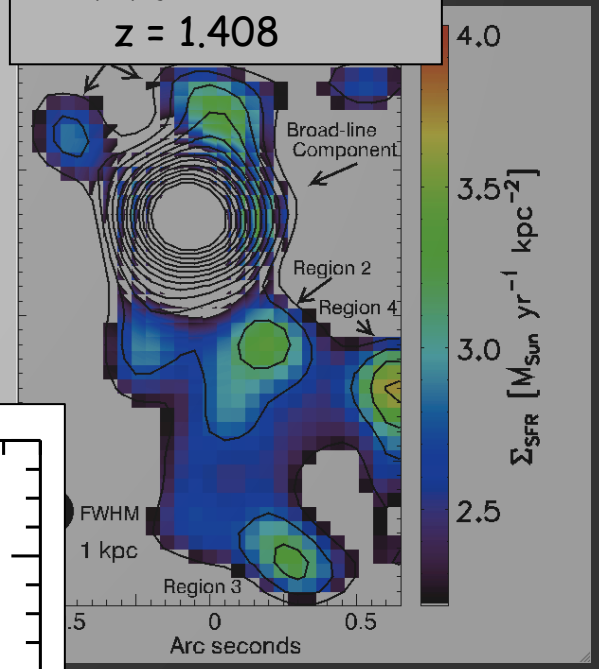
- AGN Hα contribution up to 90%
- Hα contribution per clump: ~1-30%

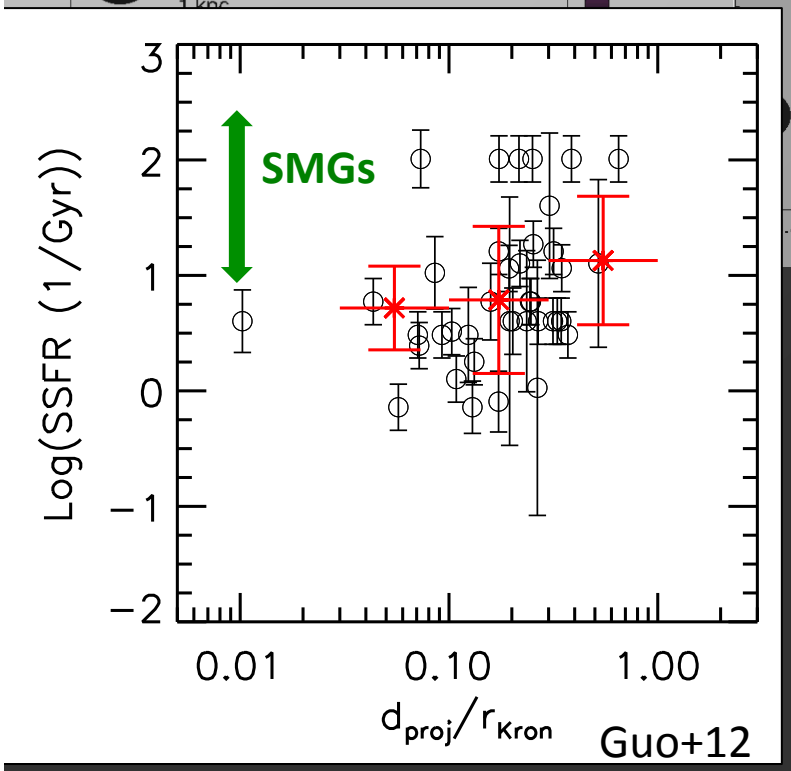
Σ_{SFR} from Hα maps

SMM J163650.43
z = 2.385



SMM J030227.73
z = 1.408





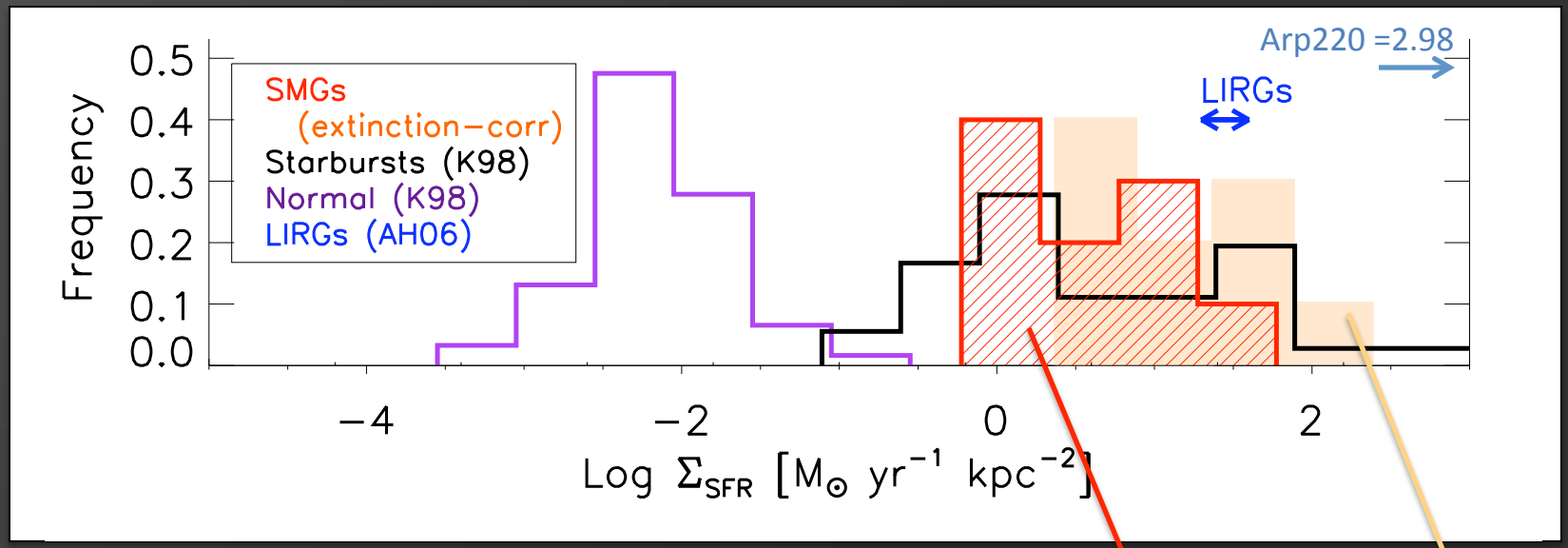
Star-formation in multiple ~1-2 kpc "clumps"

- AGN Hα contribution up to 90%
- Hα contribution per clump: ~1-30%

  → $sSFR_{clump}$ ~8 – 250 Gyr^{-1}

- Compare to optically-selected SF-ing clumps at z~2 (Guo+12)

Σ_{SFR} from Hα maps



- Compare to:
  - Normal spirals: $<\Sigma_{SFR}>$~0-0.1
  - Local SBs: $<\Sigma_{SFR}>$~1-100 (Kennicutt+98)

    log Σ_{SFR}(M82) =1.48 → Σ_{SFR} ~ 30
  - Low-z LIRGs (Alonso-Herrero+2006)

Σ_{SFR} : 1-50 $M_\odot$/yr/kpc²

Σ_{SFR} : 4-200 $M_\odot$/yr/kpc²

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

SMGs harbor SF activity similar to local starbursts (but on larger spatial scales)

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

- AGN signatures complicate interpretation of SMG spectra
- With OSIRIS, we spatially distinguish compact, broad- Hα and more extended narrow-Hα emission, likely associated to AGN and star-forming activity, respectively.
- Even eliminating AGN contribution, SMGs retain very high SFRs, with Σ_{SFR} similar to local starbursts and low-z luminous infrared galaxies
- We find that SMGs display large Hα spatial extensions:

  ~1-1.5" (~8-12 kpc) → extended starbursts (not main sequence!)
- The asymmetric distribution of multiple ~1-2 kpc star-forming clumps together with the lack of ordered rotation suggests that these systems do not represent regular potential well structures, but are more likely in an advanced merging phase → ALMA will tell!

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