MIRI SPECTROSCOPY OF THE EPOCH OF GALAXY ASSEMBLY

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(On behalf of the MIRI EC high-z group)

OUTLINE

MIRI SPECTROSCOPY. A NEW WINDOW INTO THE HIGH-Z UNIVERSE

MIRI & REIONIZATION EPOCH. FIRST IONIZATION SOURCES

- Hα emitters at z ~ 7-10. Metal-poor vs. Metal-free

MIRI & GALAXY ASSEMBLY. DUSTY STAR-FORMING GALAXIES (DSFGs)

- Obscured AGNs. Prospects of direct detection
- Tracing obscured (extended -Σ_{SFR}-) star formation
- Synergy with ALMA. KS-law at high-z

MIRI. JWST MID-INFRARED INSTRUMENT

Table 1: Observing Modes for the MIRI Instrument on *Webb*

Mode	Wavelength (microns)	Pixel Size/Resolving Power	Field of View
Imaging	5.0–28	0.11 arcsec	1.23 × 1.88 arcmin
Single Slit Spectroscopy	5.0–~14	$\lambda/\Delta\lambda$ = ~100 at 7.5 microns	0.6 × 5.5 arcsec slit
IFU Spectroscopy	5.0–7.7	$\lambda/\Delta\lambda$ = 3500	3.0 × 3.9 arcsec
	7.7–11.9	$\lambda/\Delta\lambda$ = 2800	3.5 × 4.4 arcsec
	11.9–18.3	$\lambda/\Delta\lambda$ = 2700	5.2 × 6.2 arcsec
	18.3–28.8	$\lambda/\Delta\lambda$ = 2200	6.2 × 7.7 arcsec
Coronagraphy	10.65	0.11 arcsec	24 × 24 arcsec
	11.4	0.11 arcsec	24 × 24 arcsec
	15.5	0.11 arcsec	24 × 24 arcsec
	23	0.11 arcsec	30 × 30 arcsec

Single target / Not affected by slit losses

Spectroscopy (10σ, 10 ksec): ~10^{-20} to ~6×10^{-17} Watt/m^2 (x10-100 Spitzer)

MIRI detailed description: Wright+, Rieke+, Wells+, Glasse+, Kendrew+, Boccaletti+, Bouchet+, Ressler+, Gordon+, 2015, PASP 127

MIRI. A UNIQUE WINDOW FOR THE STUDY OF HIGH-Z GALAXIES

First mid-IR instrument combining many new & unique capabilities:

- Continuous coverage 5-28 um
  REST-FRAME RANGE: 0.6um < λ < 6um

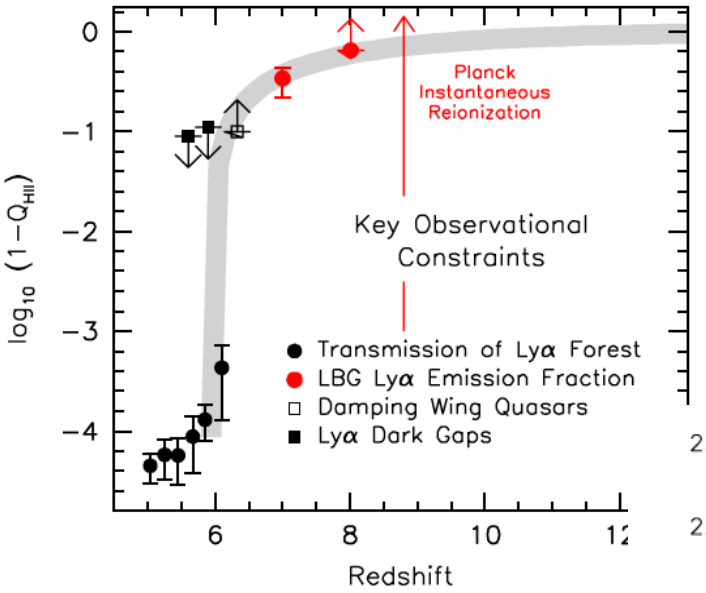
- Sub-arcsec imaging (x6 better than IRAC/Spitzer)
- Spatially resolved, sub-arcsec (0.2”- 0.6” pixel) 2D spectroscopy
  PHYSICAL SCALES ~ 1-2 kpc for z > 1.0

- Spectral resolution of R ~3000 (x5 HR IRS/Spitzer)
  KINEMATICS: velocity structures ~100 km s^{-1}

- Sensitivity x10-100 better than Spitzer
  GALAXIES: fainter (z < 3) and higher redshifts (z>3)

KEY FOR DETAILED PHYSICS OF BIRTH & ASSEMBLY OF GALAXIES

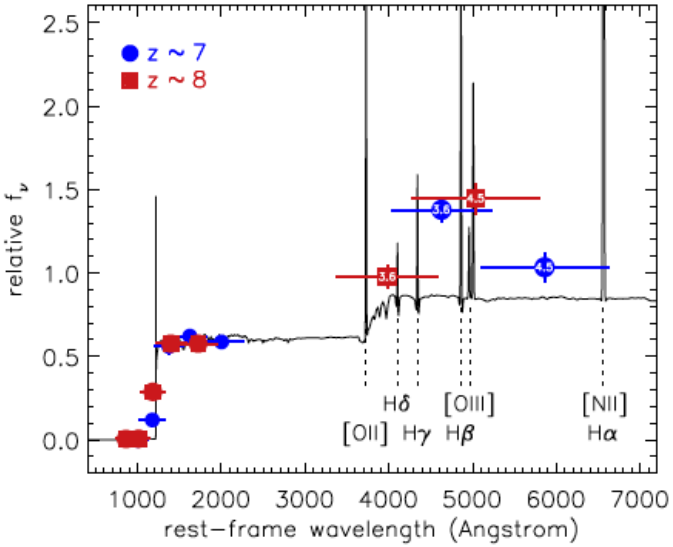
REIONIZATION. PREDICTED STRONG EMISSION LINES @ Z~7-8



Bouwens et al. 2015, ApJ, 811

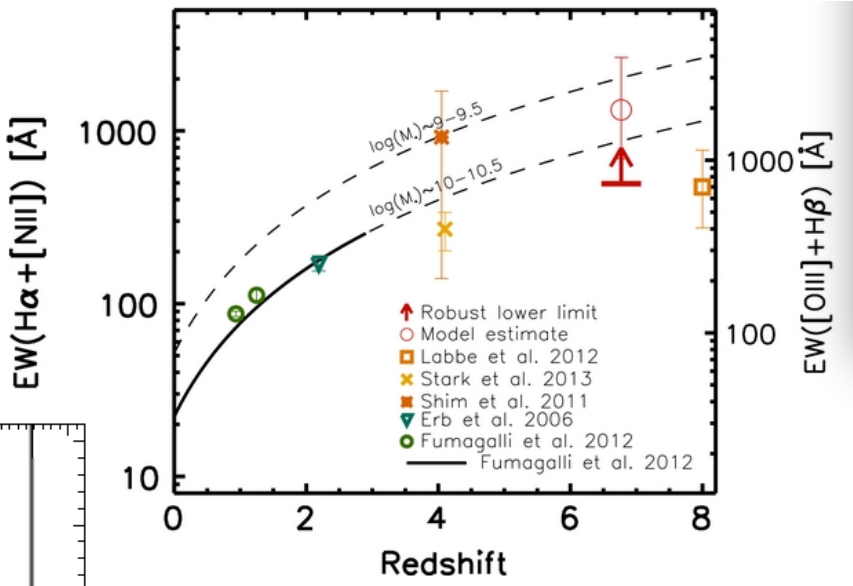
Z_ri = 8.8 (+1.3, -1.2)

Reionization mostly between
Z~10 to Z~6



Labbé et al. 2013

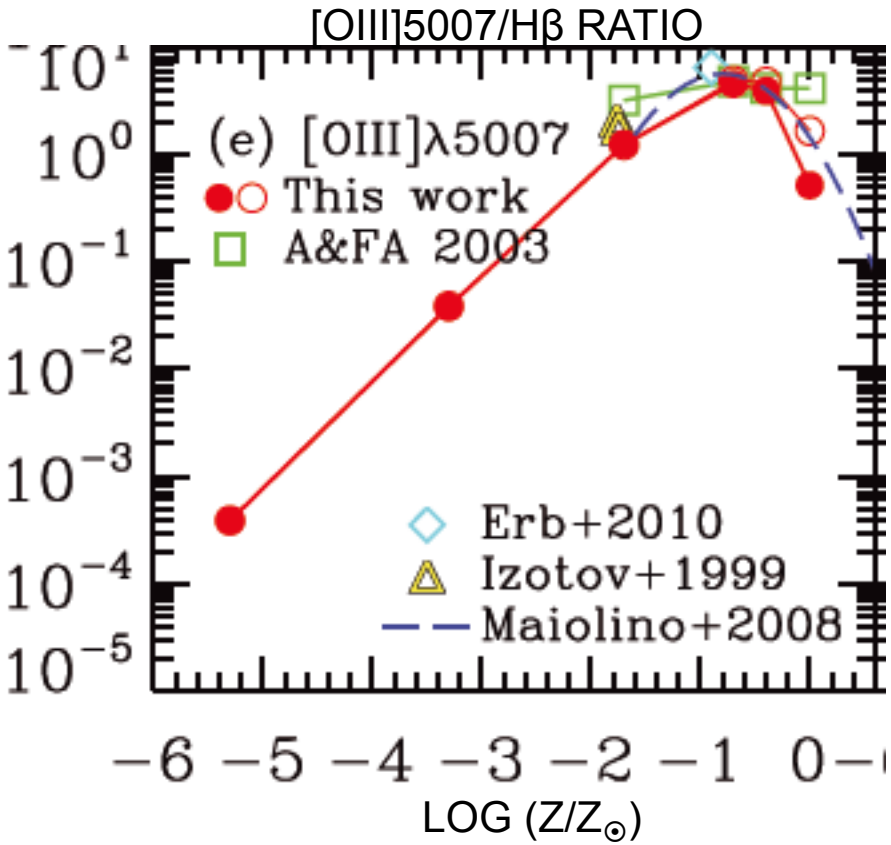
EW(Hα) = 430Å
EW (Hβ + [OIII]) = 670Å
A_V = 0.4

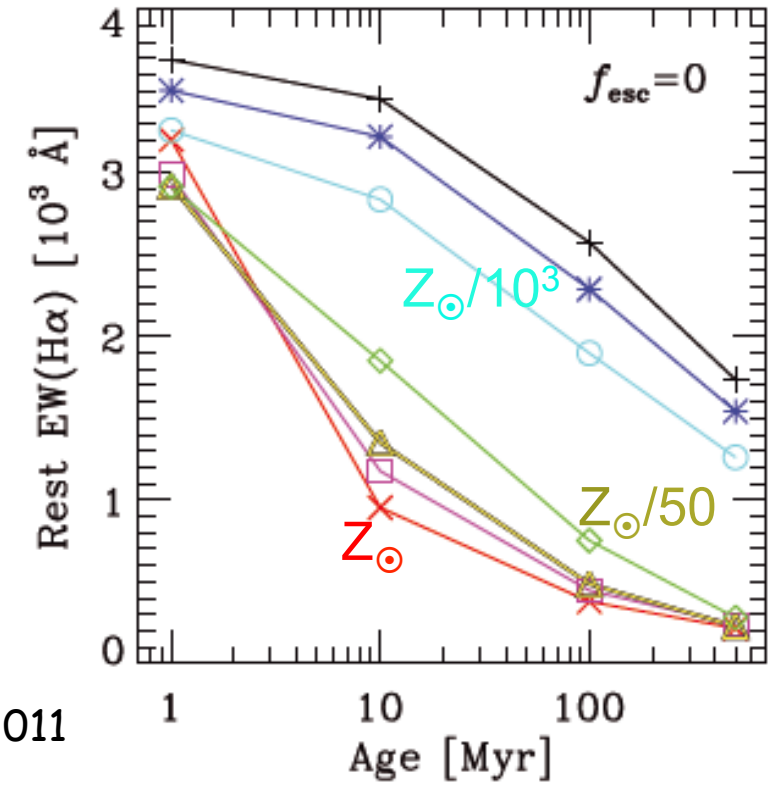


Smit et al. 2014

$EW(H\alpha) \propto (1+Z)^{1.8}$

REIONIZATION SOURCES. EMISSION LINES & METALLICITY





Inoue 2011

METAL-POOR (>$Z_\odot$/50)

Hα ~ [OIII]5007 ~ 3xHβ

EW(Hα) ~1500Å for ~10 Myr

[OII]3727 ~ 0.3xHβ

Hα/[OIII] ~1

(NEARLY-) METAL-FREE (< $Z_\odot$/100)

Hα/Hβ ~ 3 / [OIII]5007/Hβ < 0.6

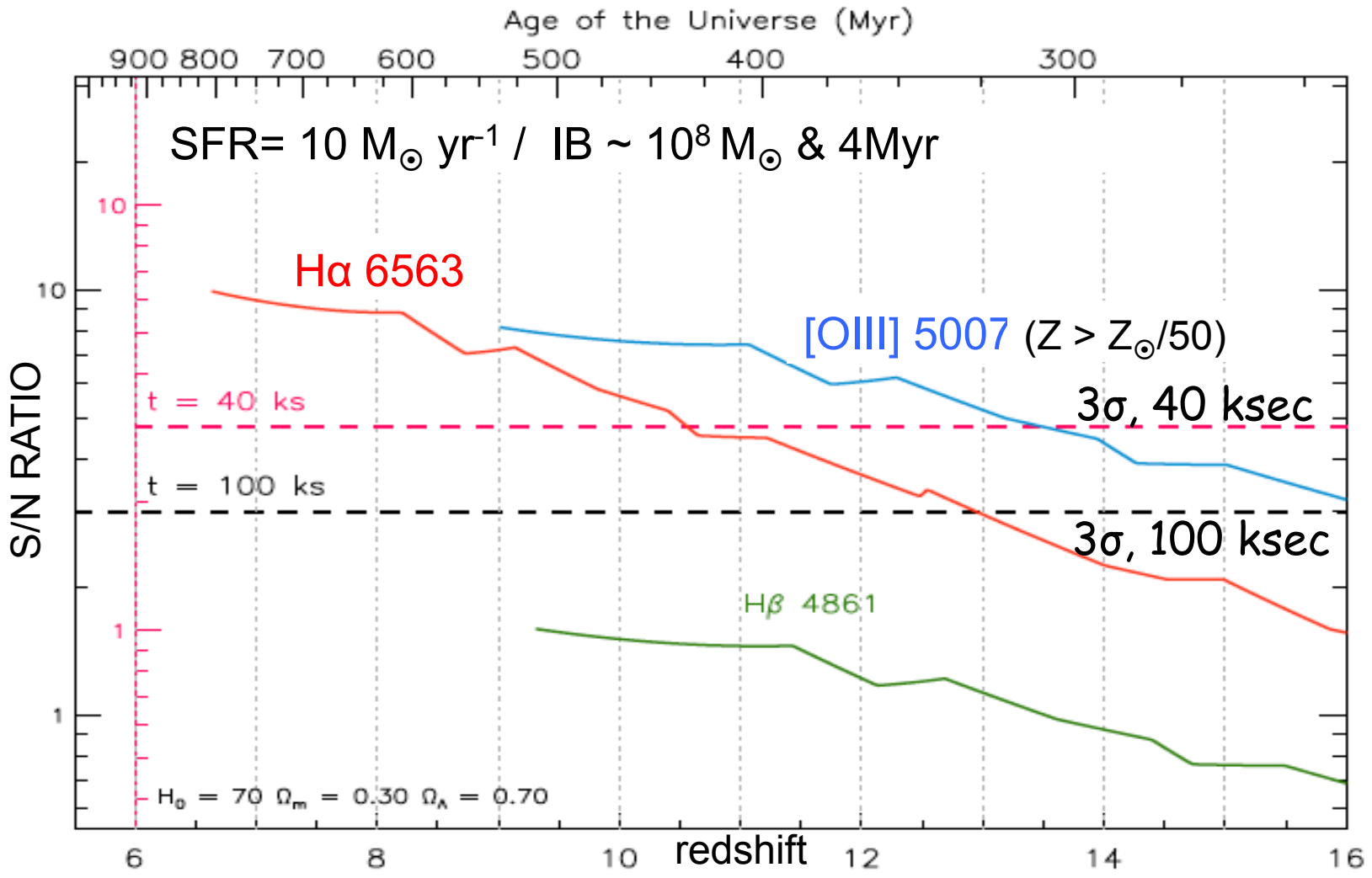
EW(Hα) >2000Å for ~10 Myr

[OII]3727 < 0.1xHβ

Hα/[OIII] > 5

MIRI SPECTROSCOPY OF REIONIZATION SOURCES

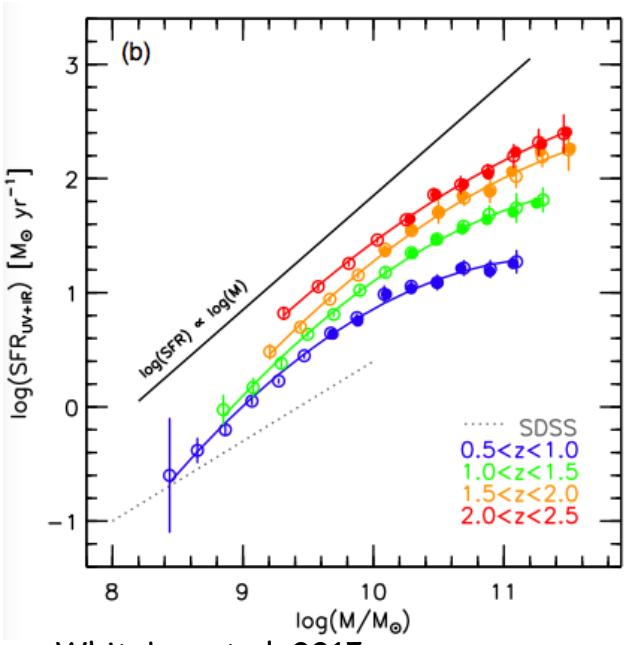
Only JWST instrument able to trace Hα beyond z > 6.7 & [OIII]5007 @ z > 9



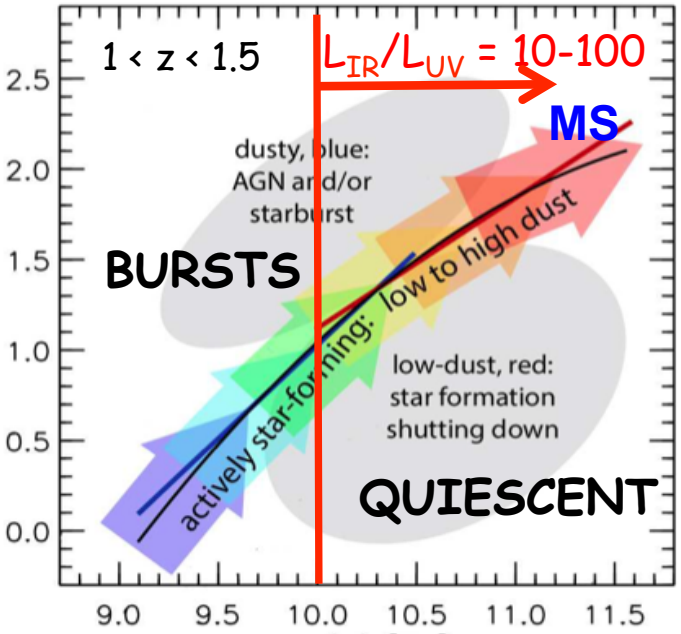
Hα & [ÒIII] detectable (> 3σ) in bright metal-poor sources

Potential to identify bright (nearly-) metal free ionizing sources @ Z ~ 9-10

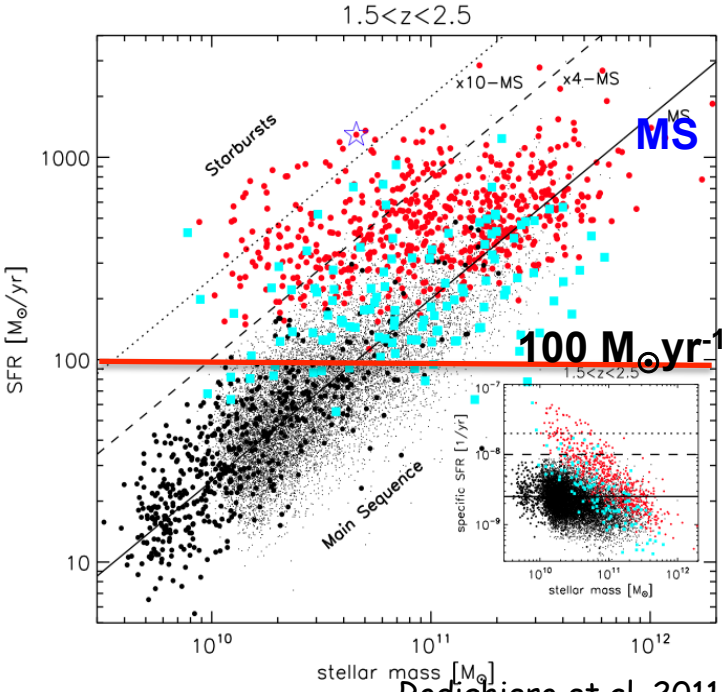
GALAXY FORMATION. THE DUSTY STAR FORMING PHASE



Whitaker et al. 2015



Whitaker et al. 2012



Rodighiero et al. 2011

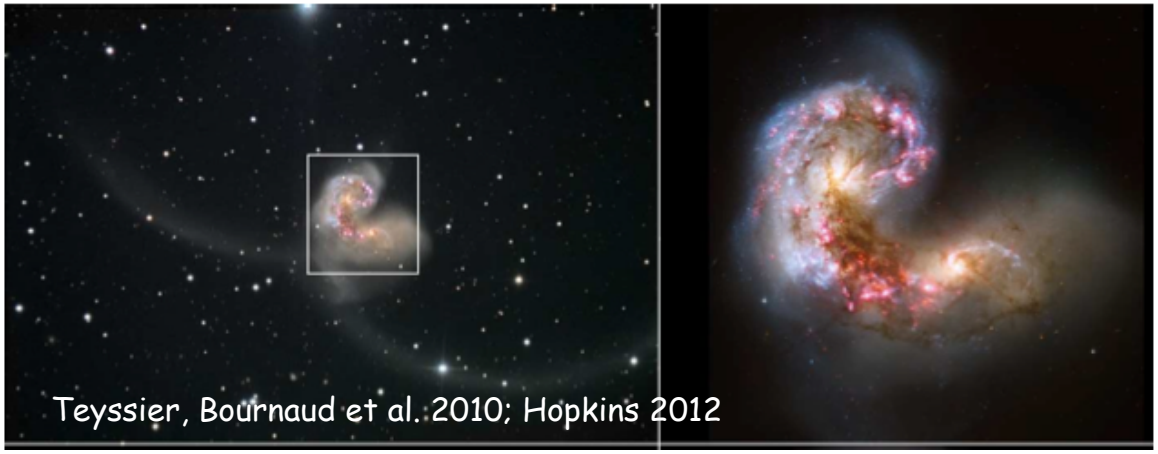
SF GALAXIES FORM A MAIN-SEQUENCE (MS)
SFR OF MS GALAXIES INCREASES ~ x10-100 FROM Z~0 TO Z~3

HIGH-Z STARBURSTS, ABOVE-MS, SFR >> 100 $M_\odot$ yr^{-1}

M> 10^{10} $M_\odot$ MS SF GALAXIES → DUSTY, IR-DOMINATED LUMINOSITY (DSFGs)

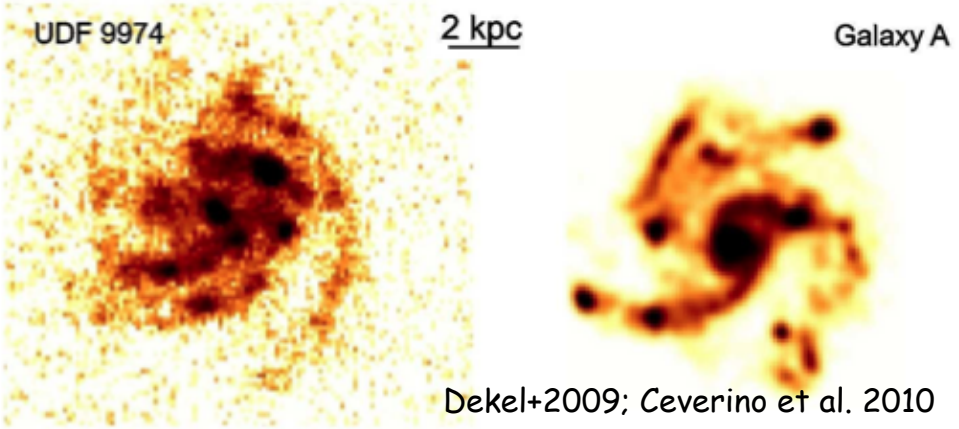
GALAXY ASSEMBLY. FORMATION SCENARIOS

ABOVE-MS SF GALAXIES: MERGERS OF GAS-RICH SYSTEMS?



Compact sizes: ~ 2 kpc radius
No rotational pattern: $V/\sigma < 1$
Caotic motions/radial flows, shocks
Starbursts: SFR >> 100 $M_\odot\ yr^{-1}$
sSFR < 1 Gyr^{-1}

MS SF GALAXIES: CONTINUOUS GAS ACCRETION IN LARGE DISKS?



Extended sizes: ~ 5-10 kpc radius
Turbulent rotating disks: $V/\sigma > 1$
Clumpy (kpc-size) SF regions
Steady SFR ~ 10-100 $M_\odot\ yr^{-1}$
sSFR ~ 1 Gyr^{-1}

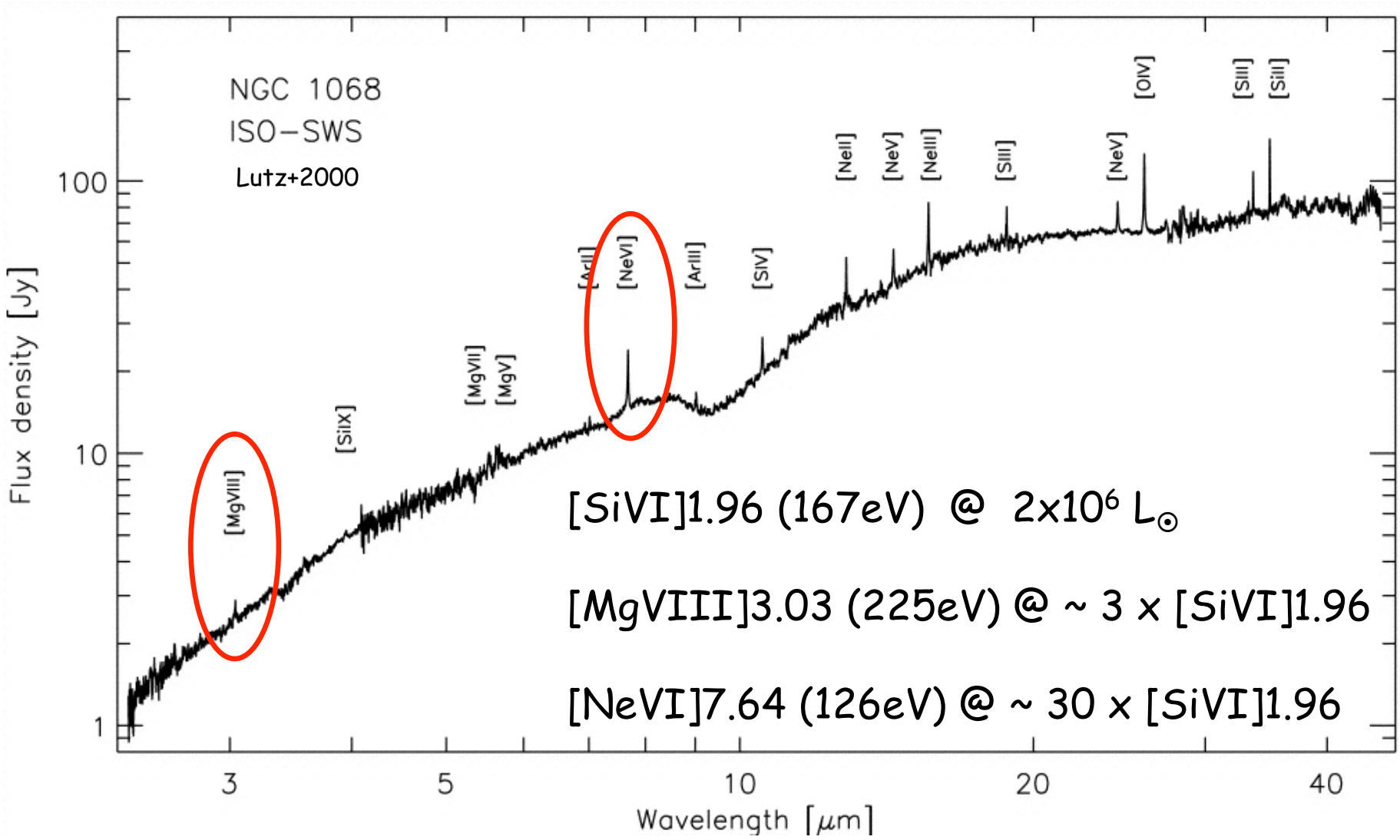
EARLY PHASES (Z~2-6) OF GALAXY ASSEMBLY. DETAILED PHYSICAL PROCESSES

NEED SENSITIVE HIGH ANGULAR RESOLUTION 2D (~1 kpc) IR (+OPTICAL) SPECTRA ON PROTOTYPES OF THE DIFFERENT CLASSES OF HIGH-Z GALAXIES

- Presence of obscured AGN & SF. Luminosity contribution?
- SF: KS-law? Clumpyness? Sizes? Distribution? Gas fraction?
- Flows: SF or AGN related? Quenching? Outflows/inflows?
- Kinematics: Mdyn? Thin/thick disks, mergers, turbulence, shocks?

MIRI MRS

OBSCURED AGNS. IR CORONAL LINES

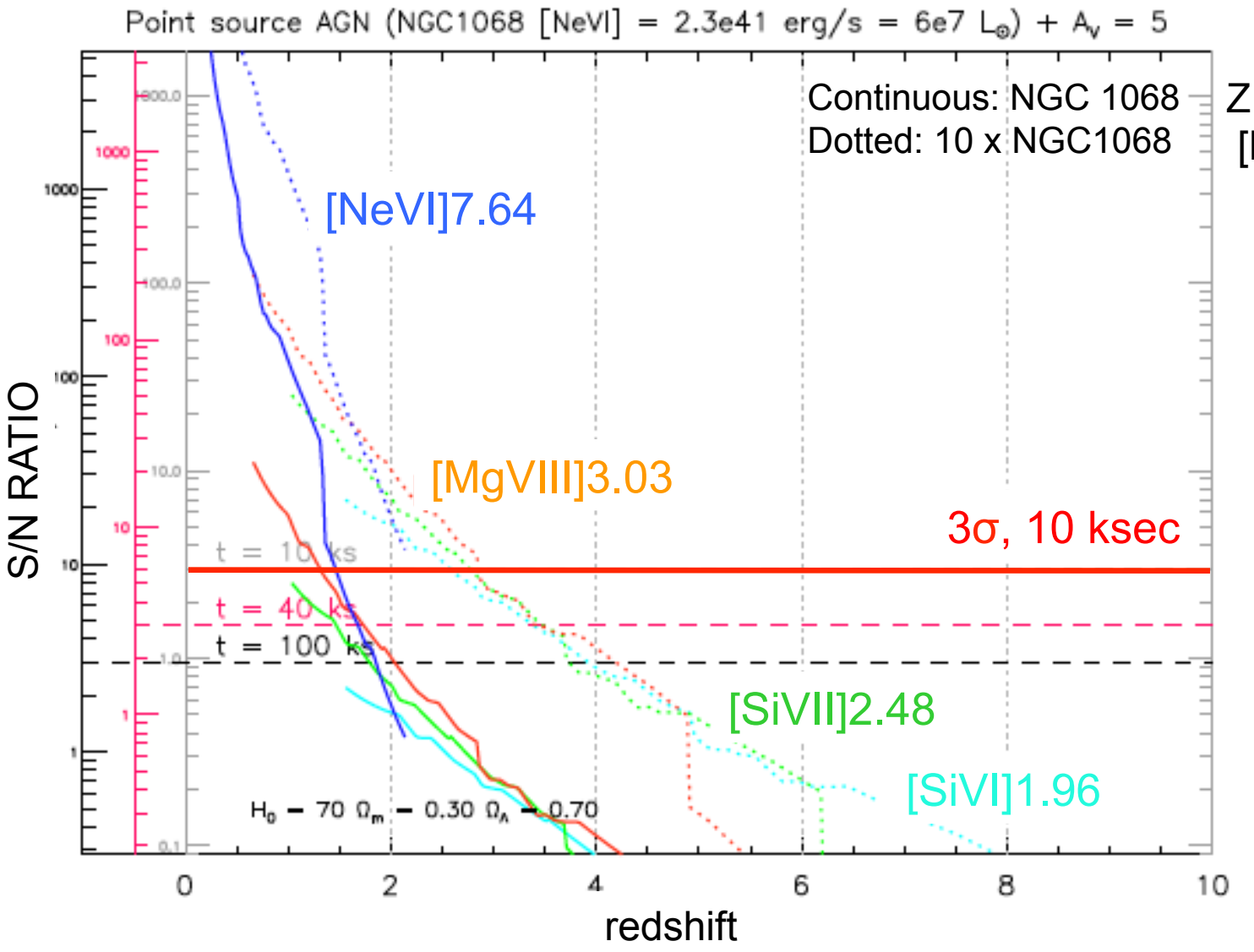


[SiVI]1.96 (167eV) @ $2 \times 10^6 L_\odot$

[MgVIII]3.03 (225eV) @ ~ 3 x [SiVI]1.96

[NeVI]7.64 (126eV) @ ~ 30 x [SiVI]1.96

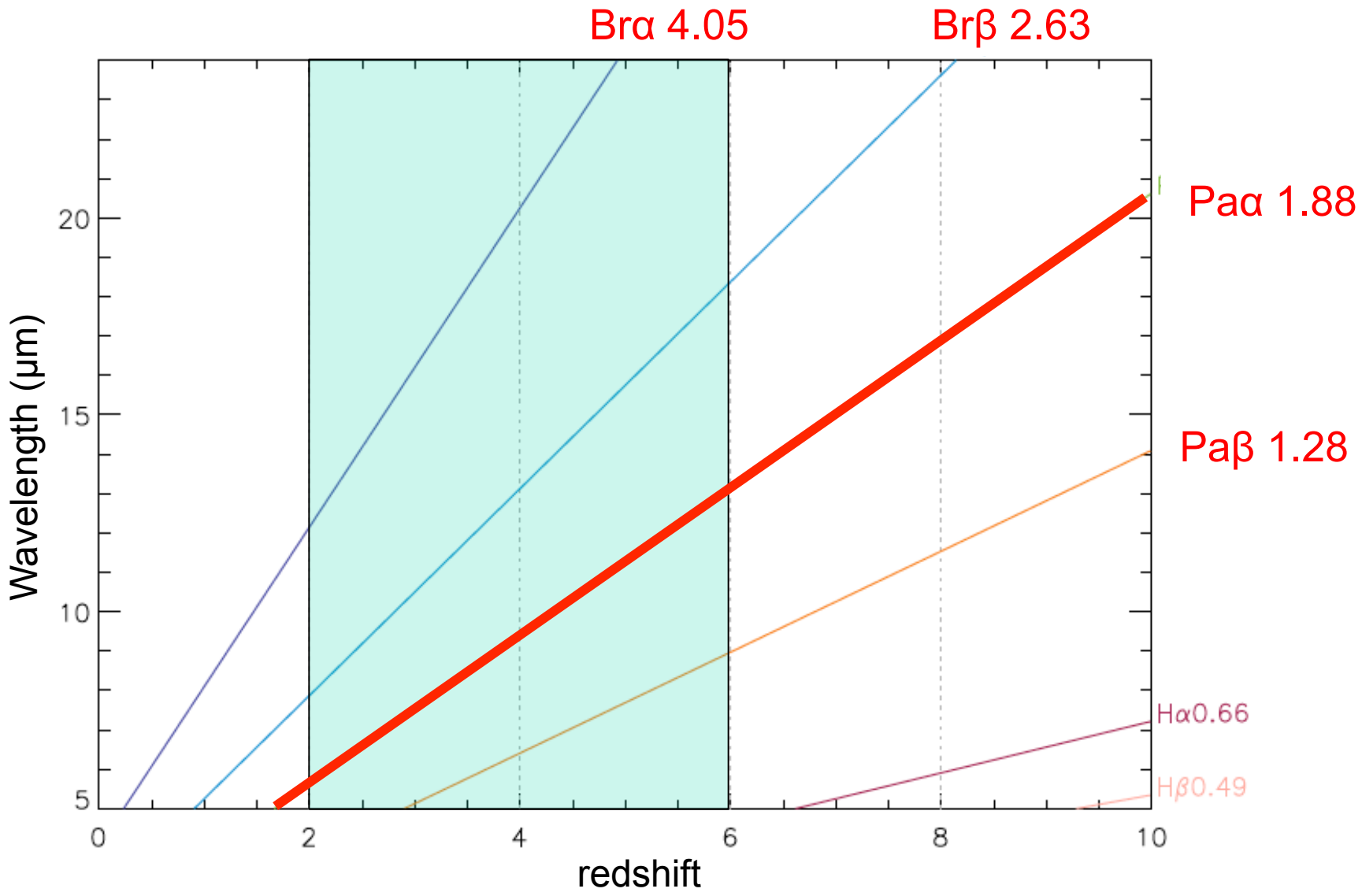
MIRI. DETECTION OF HIGH-Z OBSCURED AGNS



Z < 3:
[NeVI]7.64 & [MgVIII]3.03

DETECTION (>5σ) OF OBSCURED AGN WITH L(AGN)> 10 x L(NGC1068) @ z < 3

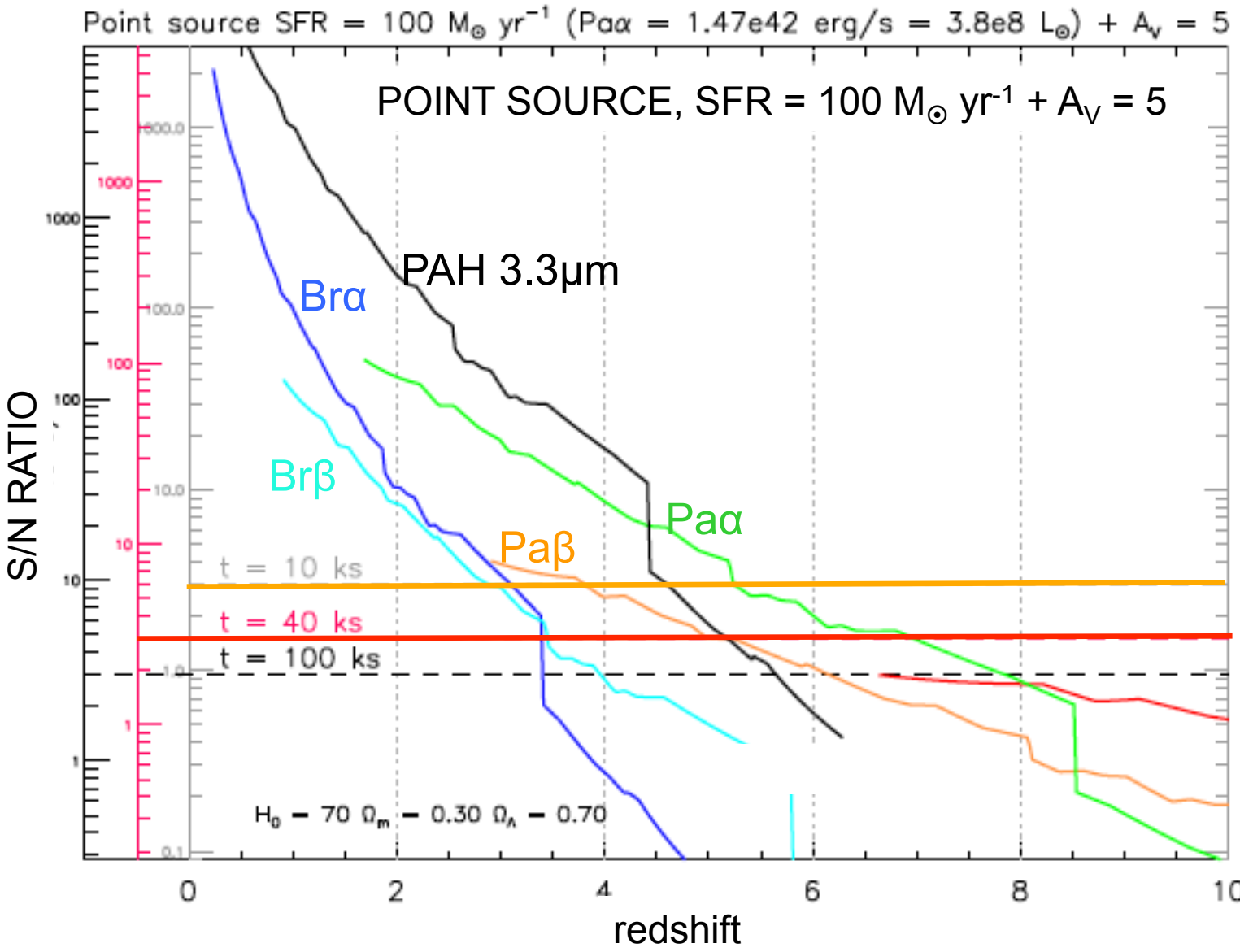
OBSCURED STAR FORMATION. IONIZED GAS TRACERS



Continuous coverage of Paα (strongest near-IR line) @ Z ≥ 1.7

Several hydrogen lines within MIRI range for Z ~2 to 6

TRACING STAR FORMATION IN HIGH-Z DSFGs



MS-SFG:
SFR_{MS} ~ 100 $M_{\odot}$/ yr^{-1}

(ABOVE-) MS-SFG:
SFR ~4-10 x SFR_{MS}

3σ, 10 ksec
3σ, 40 ksec

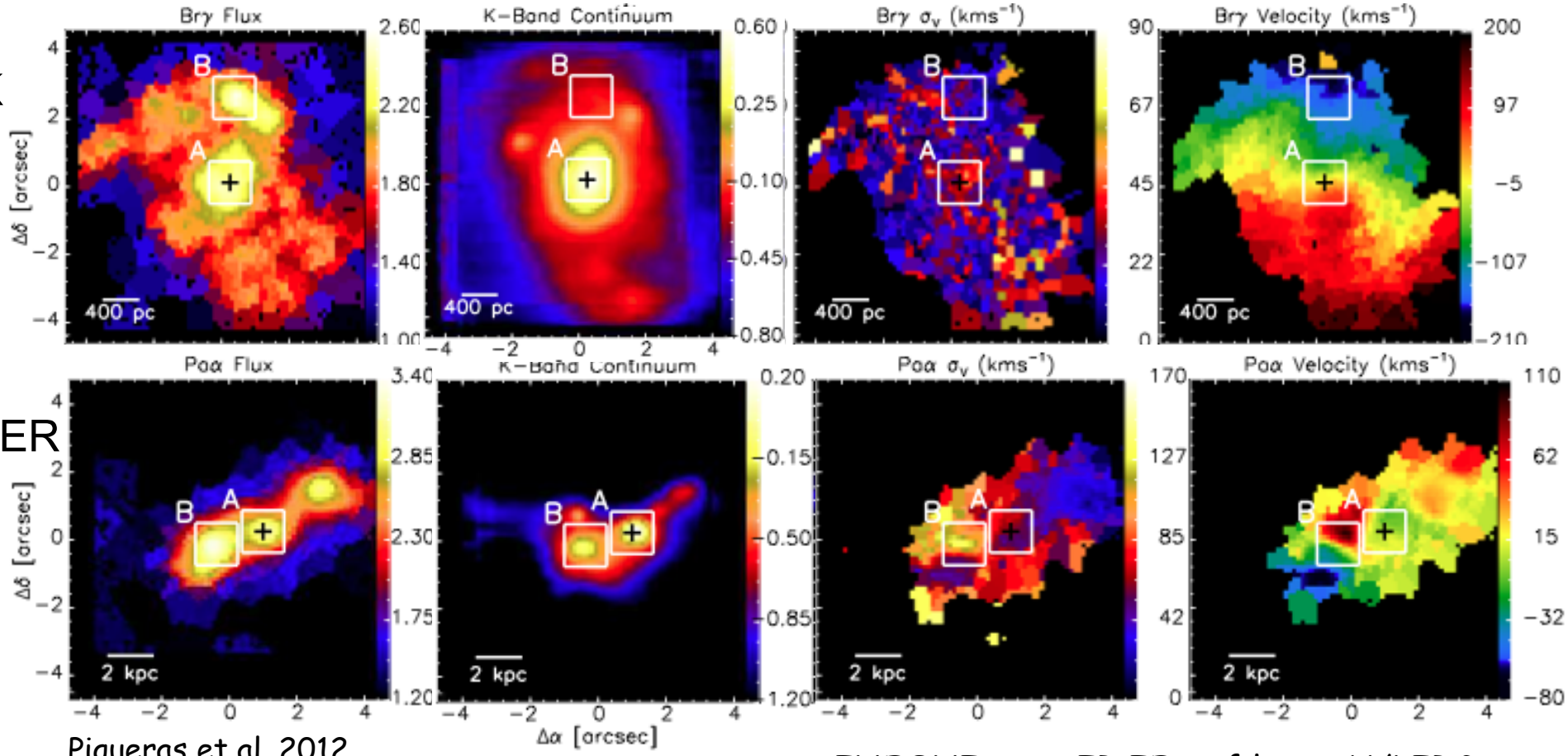
Caveat: assumed unresolved lines

SIGNIFICANT DETECTION (> 5σ) OF (ABOVE-) MS DSFGs IN < 10 HOURS

IONIZED GAS STRUCTURE & KINEMATICS in DSFGS @ Z ~2 TO 6

DISK

MERGER

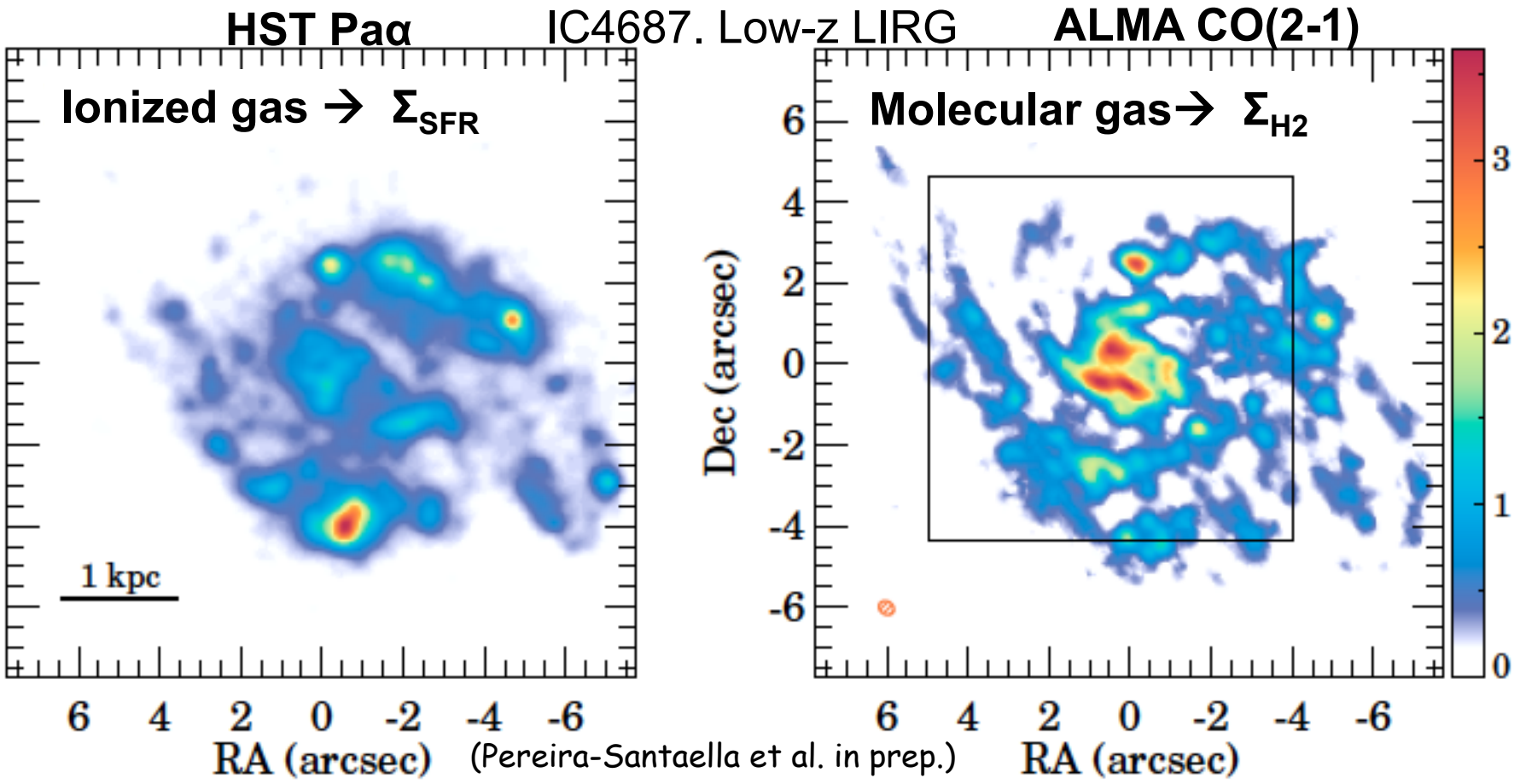


Piqueras et al. 2012

VLT SINFONI near-IR IFS of low-z U/LIRGs

KPC-SCALE 2D SF & KINEMATIC STRUCTURE OF MASSIVE DSFGS @ Z ~2-6

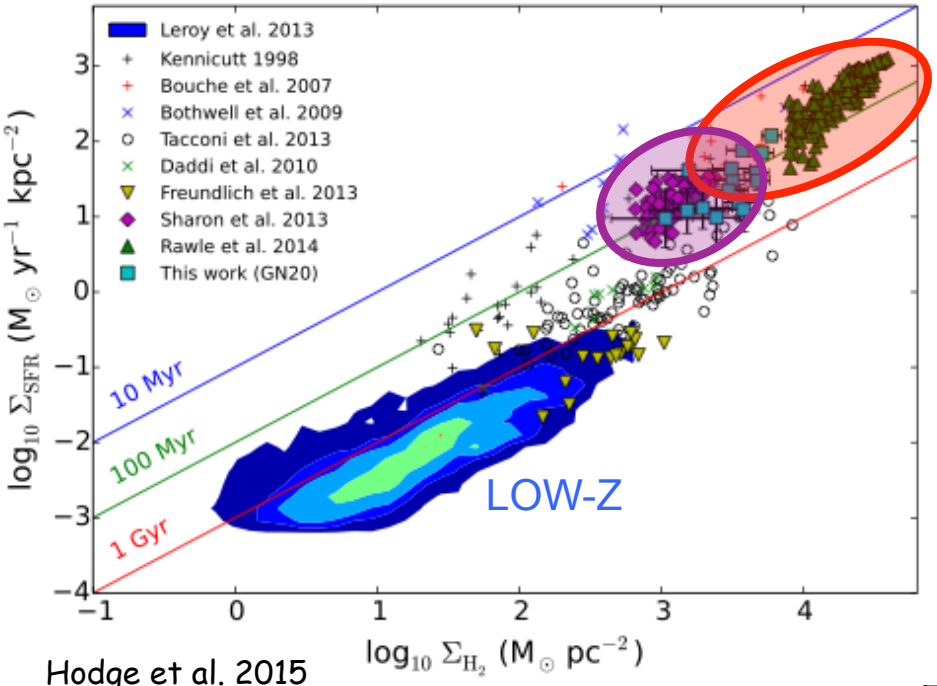
MIRI SYNERGY WITH ALMA: KS-LAW IN DSFGs @ Z ~2 TO 6



(Pereira-Santaella et al. in prep.)

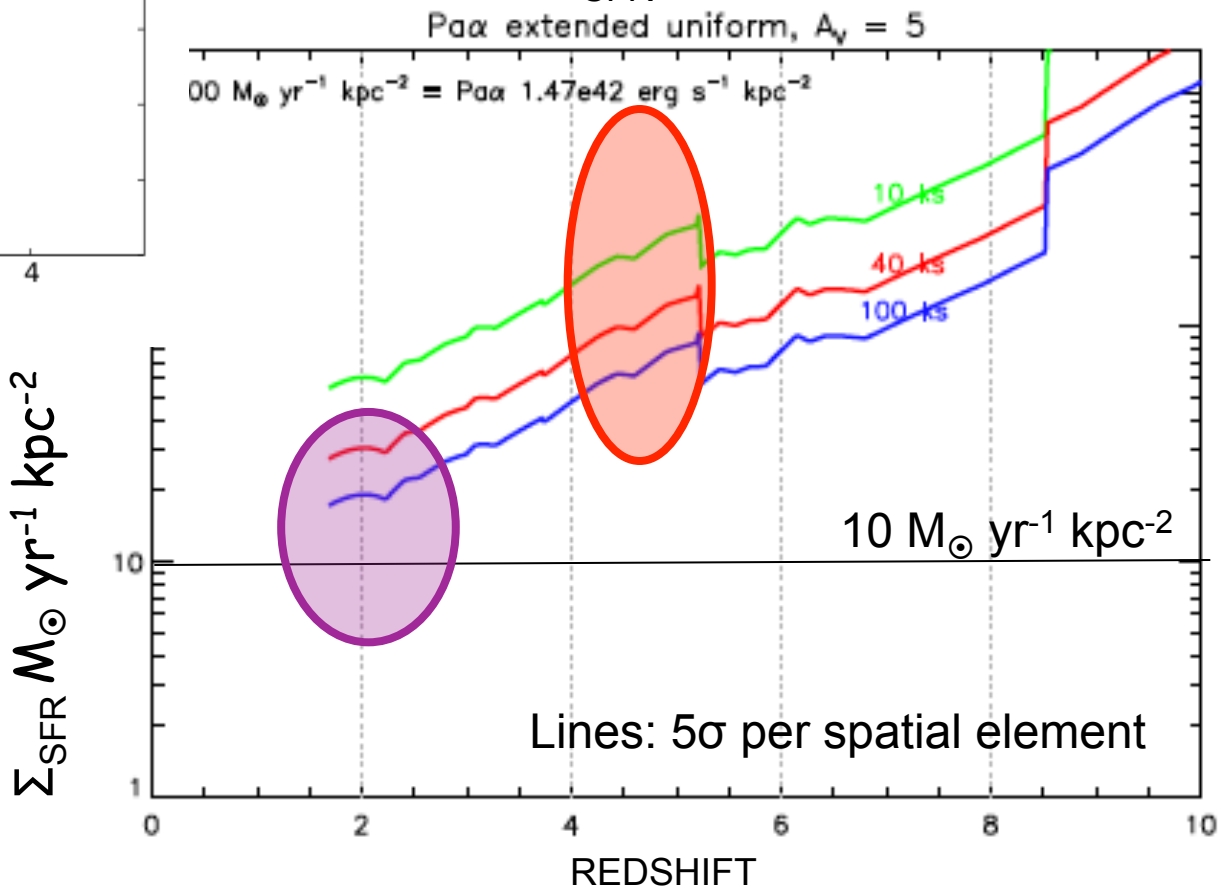
KS-LAW (Σ_{SFR} – Σ_{H2}) @ KPC-SCALES IN MASSIVE DSFG @ Z~2-6

DSFGs. EXTENDED SOURCES



Hodge et al. 2015

MIRI MRS / Σ_{SFR} traced with Paα



KPC-SCALE STUDIES OF EXTENDED MASSIVE DSFGS WITH $\Sigma_{SFR} > 10\ M_\odot\ yr^{-1}\ kpc^{-2}$

SUMMARY

MIRI BRINGS UNIQUE CAPABILITIES FOR THE STUDY OF HIGH-Z GALAXIES

- Rest-frame near-IR coverage: low extinction + rich spectral features
- 2D (sub-)arcsec spectroscopy: spatially resolved kpc-scales
- Medium spectral resolution : velocity structures ~100 km s^{-1}
- High sensitivity: 10-100 better than Spitzer

REIONIZATION OBJECTS (Universe 4%-7% present age; z > 6.7)

- Bright Hα emitters. SFR, metal-poor versus (nearly-) metal-free
- QSOs: black hole masses

GALAXY ASSEMBLY (Universe 8%-50% present age; 1< z <6)

- The dusty IR-luminous phase of massive star-forming galaxies
- Obscured AGN and SF. Extended SF and SF laws (+ ALMA)
- Kinematics