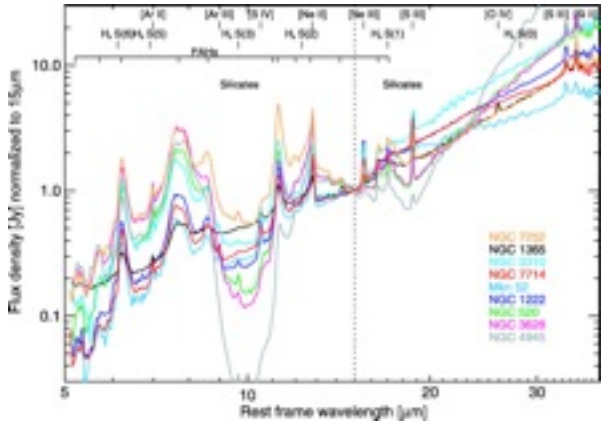
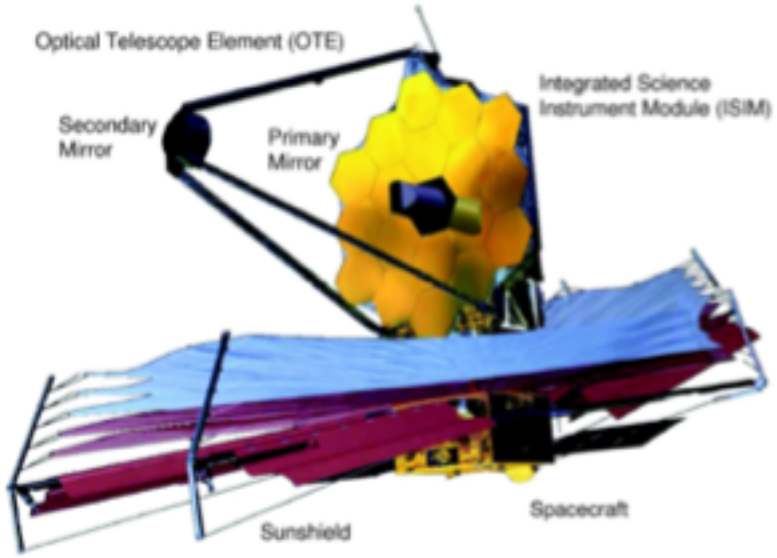
**L. Colina**

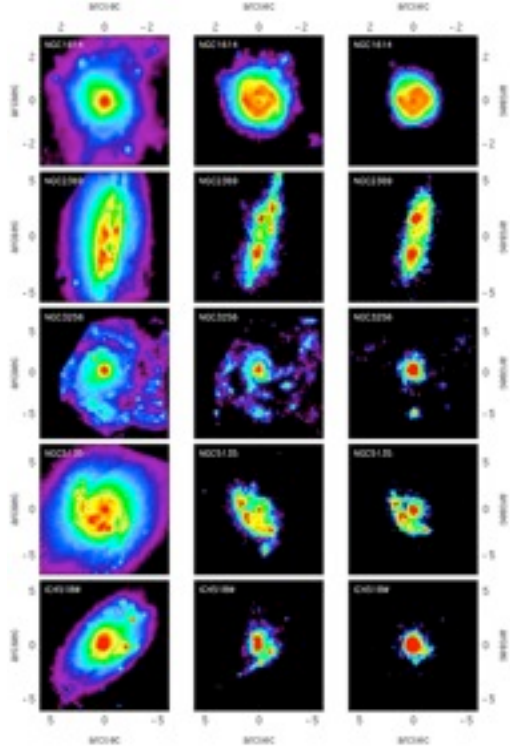
*Mid-IR JWST view of dusty starbursts near and far*

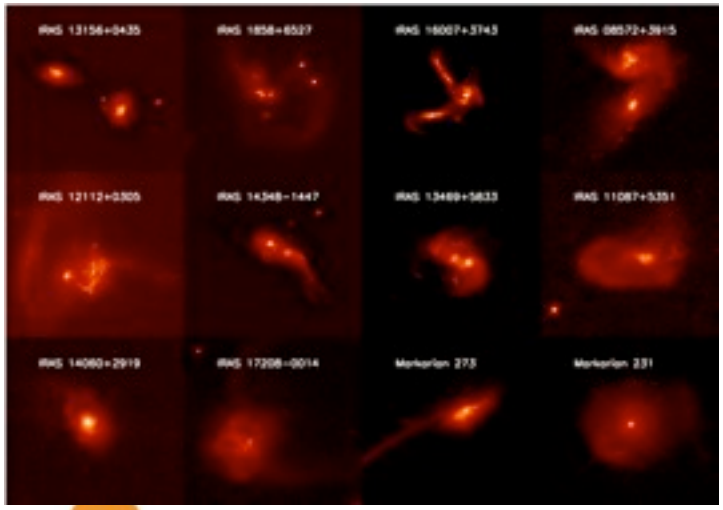
This talk will present MIRI, the Mid-IR imager and spectrograph for the JWST. MIRI will offer unique capabilities for the study of the dustiest and more extreme starbursts in the local Universe and at cosmological distances.

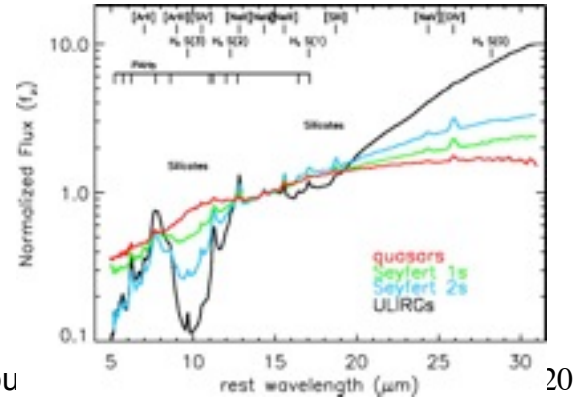
# MIRI/JWST VIEW OF DUSTY STARBURSTS NEAR & FAR







# JWST. BASIC FACTS

- NASA, ESA & CSA project

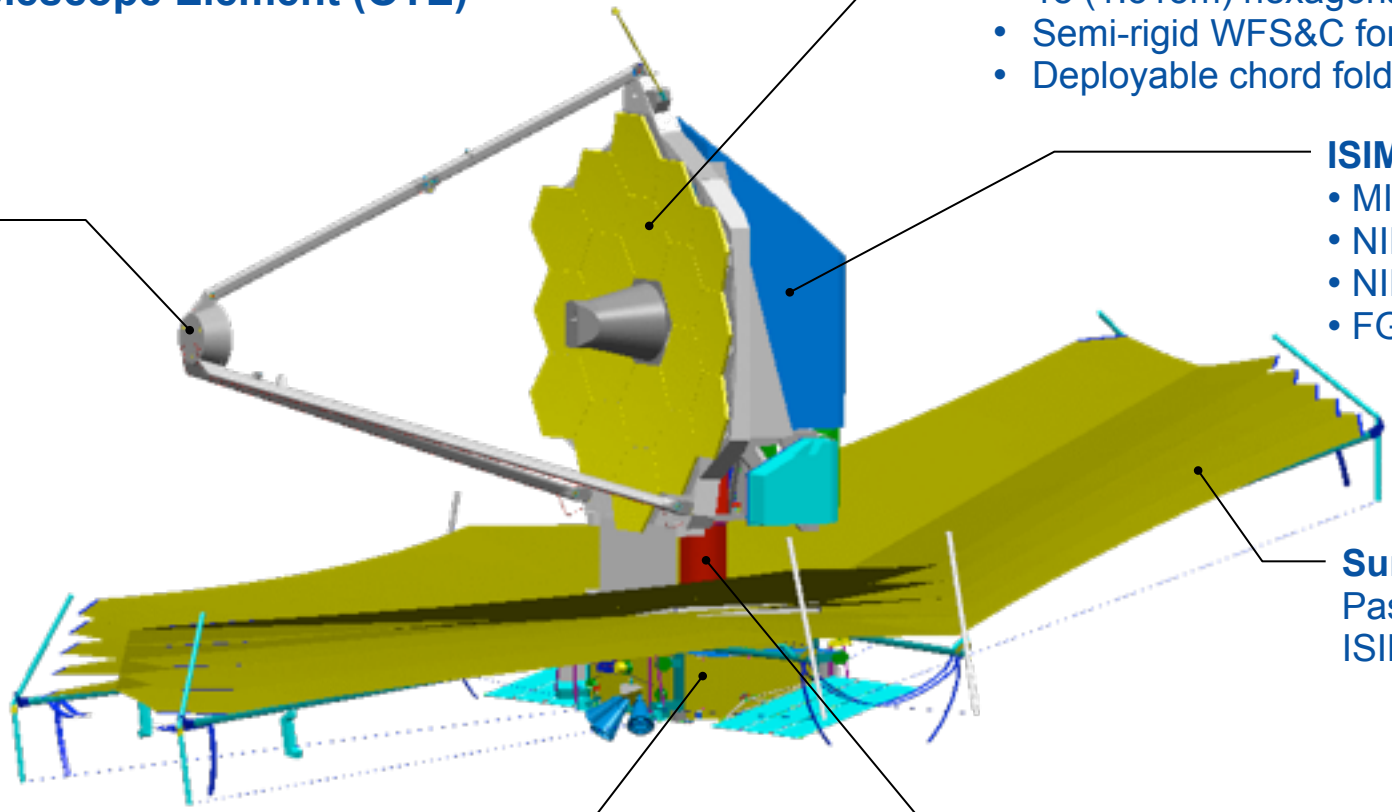
- Diameter of mirror: 6.5 m (HST: 2.4 m)
- Spectral range: 0.6 - 28 μm (HST: 0.1 y 2.5 μm)
- Angular resolution: 0.06"- 0.6"

- Orbit: 1.5 millions km (HST: 600 km).
- Low thermal background. Passive cooling at T of 40K

- Launch date: late 2014

# JWST. OBSERVATORY OVERVIEW

## Optical Telescope Element (OTE)



**Primary Mirror (PM)**
- 18 (1.315m) hexagonal segments
- Semi-rigid WFS&C for phasing
- Deployable chord fold

**ISIM**
- MIRI
- NIRSpec
- NIRCam
- FGS

**Secondary Mirror (SM)**

**Sunshield**
Passive cooling of ISIM/OTE to <40K

**Tower**

**Spacecraft Bus**

# JWST. OBSERVATORY OVERVIEW

**DIAMETER 6.5 m (18 segments); 22 X 10 m (sunshield); 6200 kgr (total mass)**

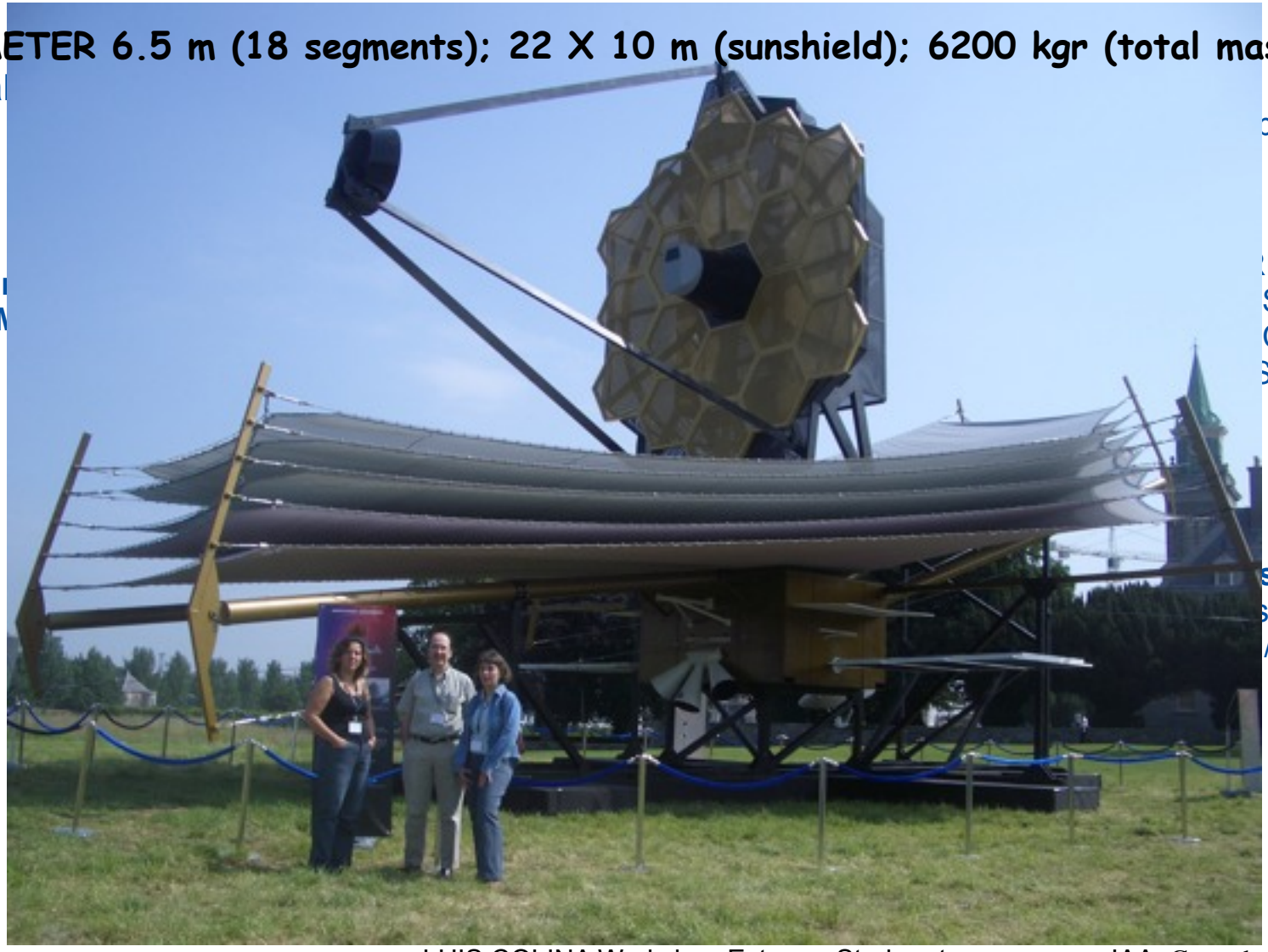
**Optica**

segments
phasing

**Secondar**
**Mirror (SM**

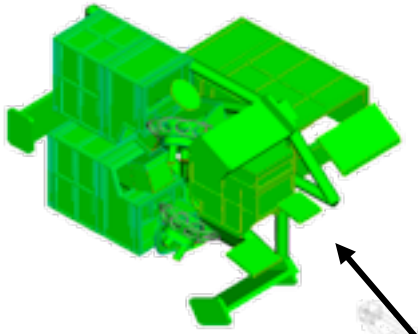
I
Spec
Cam
S

**shield**
sive cooling of
/OTE to <40K

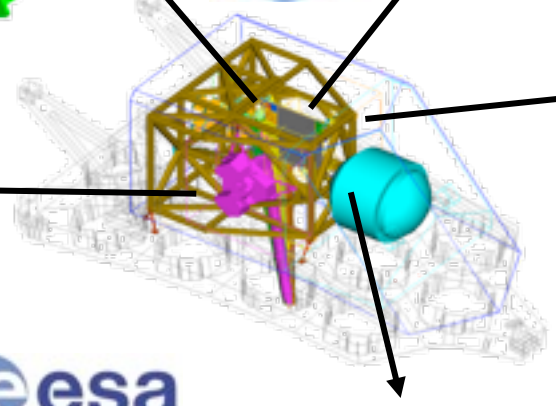


# JWST. SCIENCE INSTRUMENTS

Fine Guidance Sensor & Tunable Filter
- 1.2 to 4.8 μm operation
- Guide star acquisition & tracking
- Tunable filter imager
  2 (2048x2048)
  68mas pixels



Near Infrared Camera (NIRCam)
- 0.6 to 5 μm operation
- Wide Field Imaging
- Coronagraph imaging capability
- Supports WFS&C
- 2 (4096x4096) 31mas pixels
- 2 (2048x2048) 62mas pixels



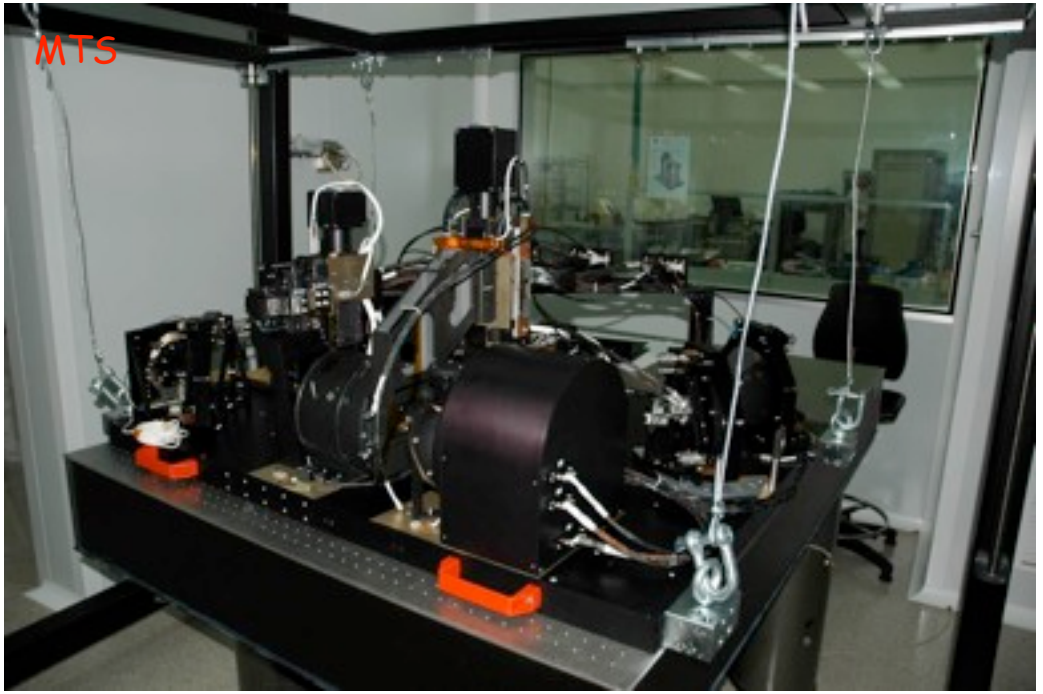
Near Infrared Spectrometer (NIRSpec)
- 0.6 to 5 μm operation
- Simultaneous Spectra of >100 objects
- λ/Δλ ~ 100 to 1000
- 2 (2048x2048) 100mas pixels

Mid Infrared Instrument (MIRI)
- 5 to 28 μm operation
- Science Discovery Space
- Imaging
  1 (1024x1024) 110mas pixels
- Spectroscopy
  2 (1024x1024) 200-470mas pixels

Solid Hydrogen Dewar
- Cools MIRI detectors to ~7K
- 5 year lifetime
- Studying Cryo-cooler

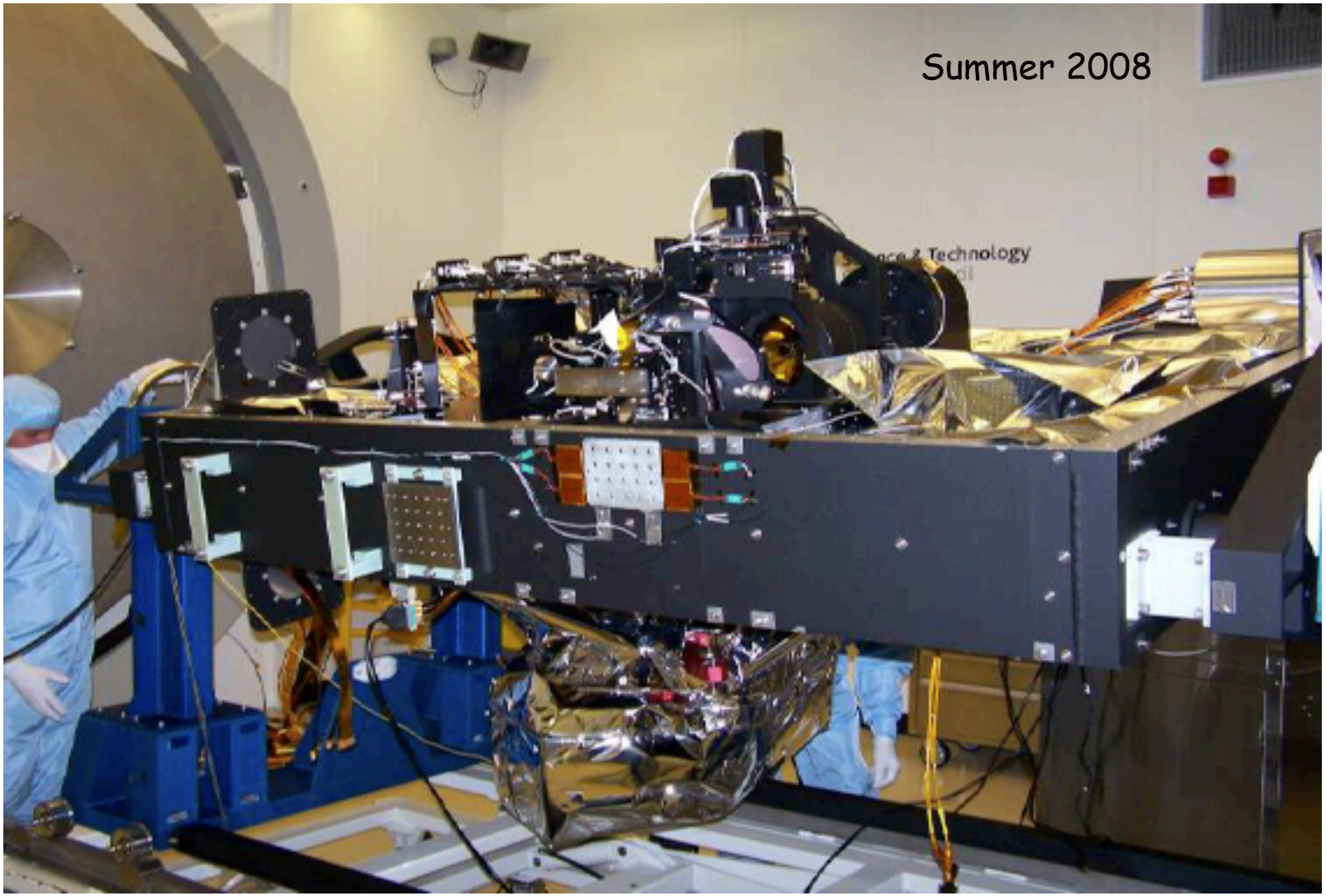
# MIRI. JWST MID-INFRARED INSTRUMENT


- Built by european consortium: 10 countries, 28 institutes
- PI: G. Wright, UK-ATC
- US contribution: detectors & cryocooler (JPL, UA, NASA)
- US PI: G. Rieke (U. Arizona)
- Spanish contribution: MIRI Telescope Simulator (INTA + CSIC)




Delivery of MIRI to NASA: summer 2011

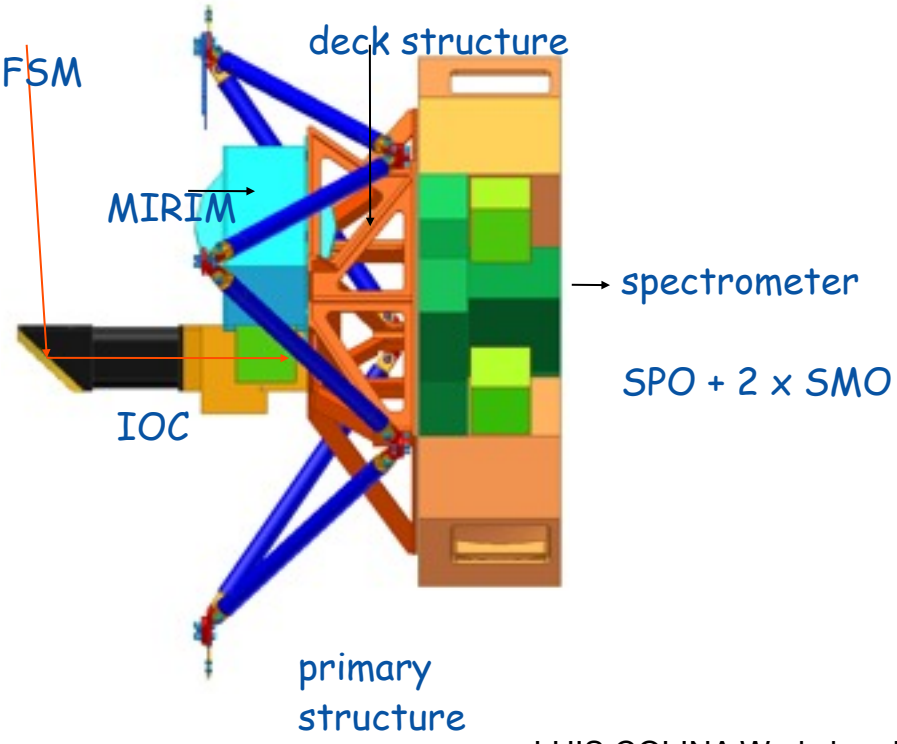
# MTS & MIRI VM. TEST BENCH at RAL

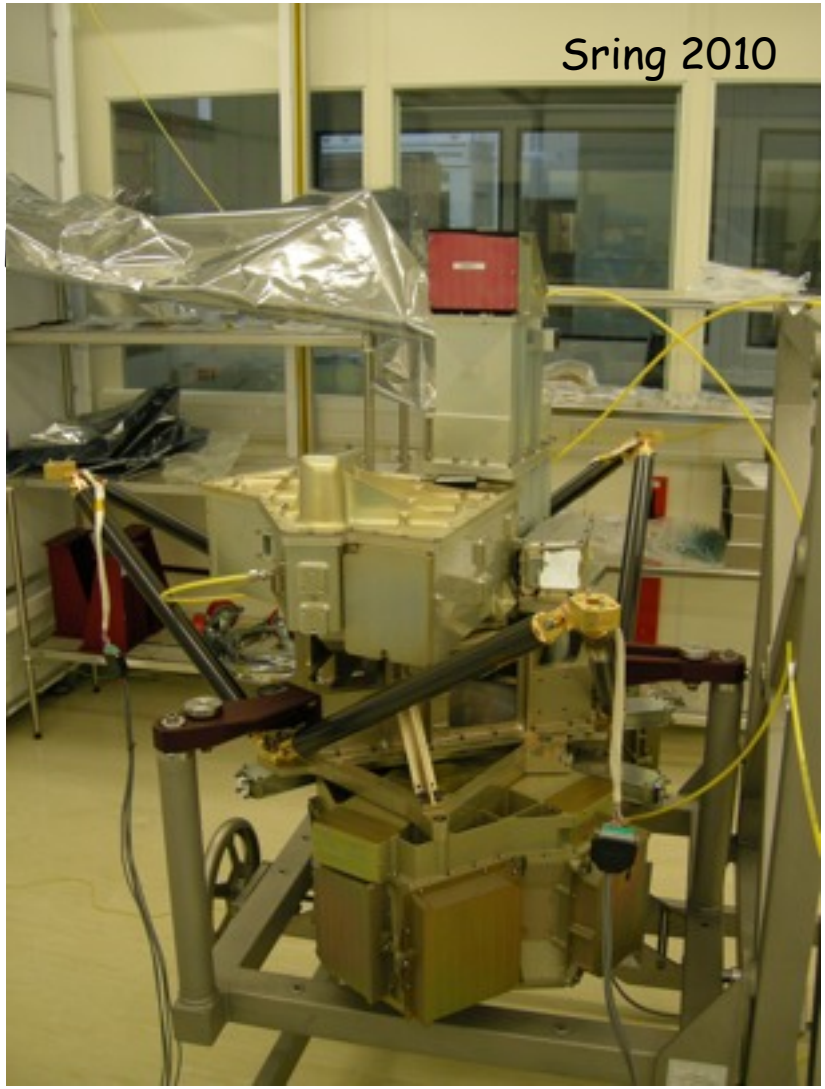


# MIRI. JWST MID-INFRARED INSTRUMENT

- Spectral range: 5 - 28 μm
- Two modules: imager and spectrograph

- Imager provides imaging, coronagraphy & long-slit
- Spectrograph provides integral field spectroscopy



# MIRI IMAGER

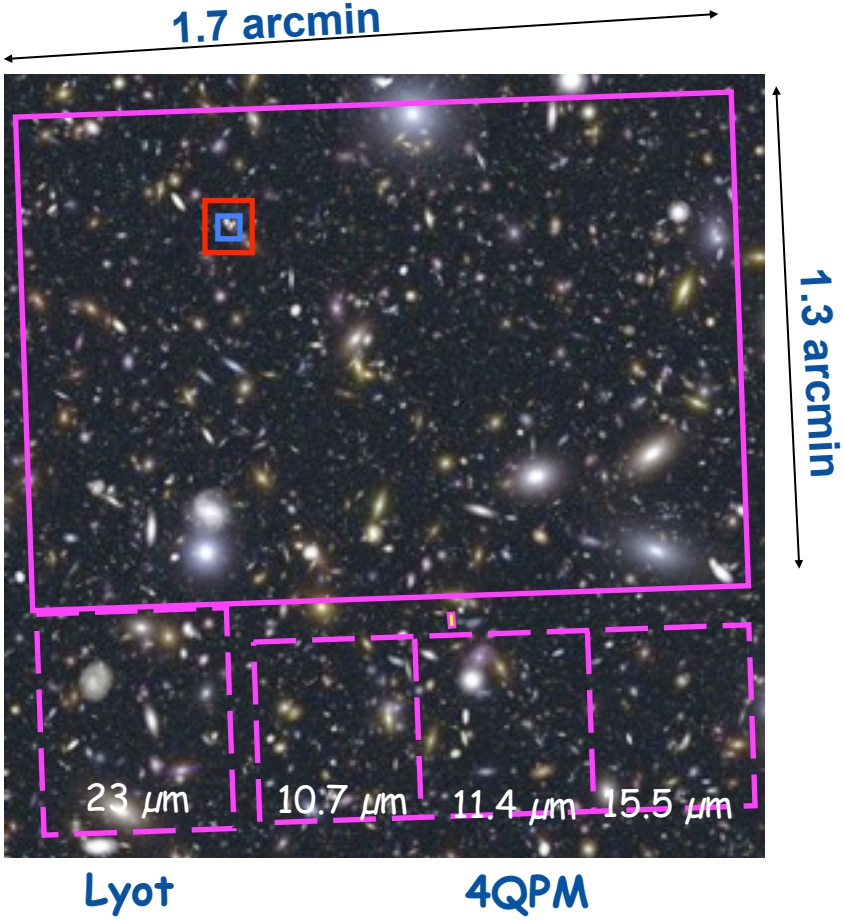



Table 12 MIRI filters

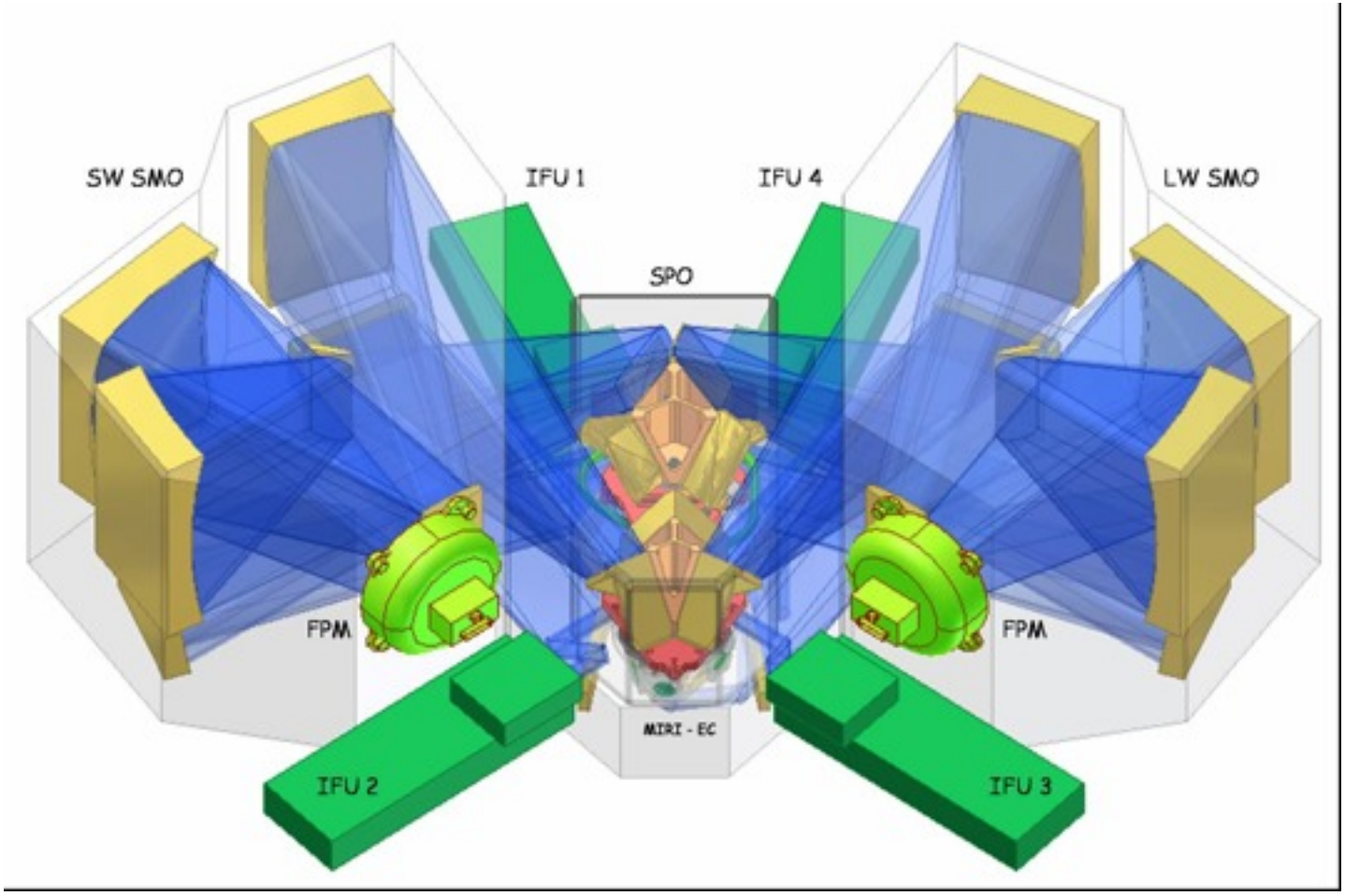
| | $\lambda_0$ ($\mu$m) | $\Delta\lambda$ ($\mu$m) | comment |
|---|---|---|---|
| B1 | 5.6 | 1.2 | Broad band |
| B2 | 7.7 | 2.2 | PAH, broad band |
| B3 | 10 | 2 | Silicate, broad band |
| I1 | 11.3 | 0.7 | PAH, broad band |
| I2 | 12.8 | 2.4 | Broad band |
| B4 | 15 | 3 | Broad band |
| I3 | 18 | 3 | Silicate, broad band |
| B5 | 21 | 5 | Broad band |
| B6 | 25.5 | ~4 | Broad band |
| B6' | 25.5 | ~4 | Redundant filter, risk reduction |
| ND# | neutral density | | Coronagraphic acquisition |
| NIR | near-IR, TBD | | Testing |
| | blackened blank | N/A | Darks |

## Low Resolution Spectrograph

5-14 μm spectral range
5" x 0.6" slit
R of 100-200

http://www.roe.ac.uk/ukatc/consortium/miri/index.html

# MIRI SPECTROGRAPH. IFS CONFIGURATION

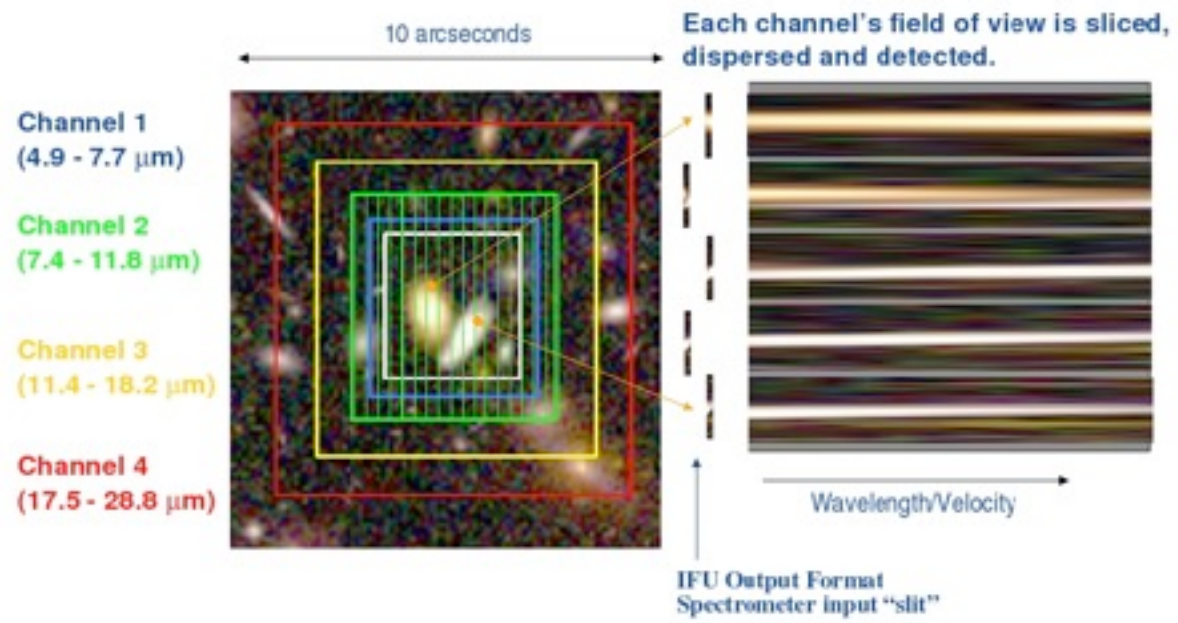



4 IFUs
1 SW + 1 LW spectrographs

4 simultaneous subspectral ranges

3 settings for full 5-28 um coverage

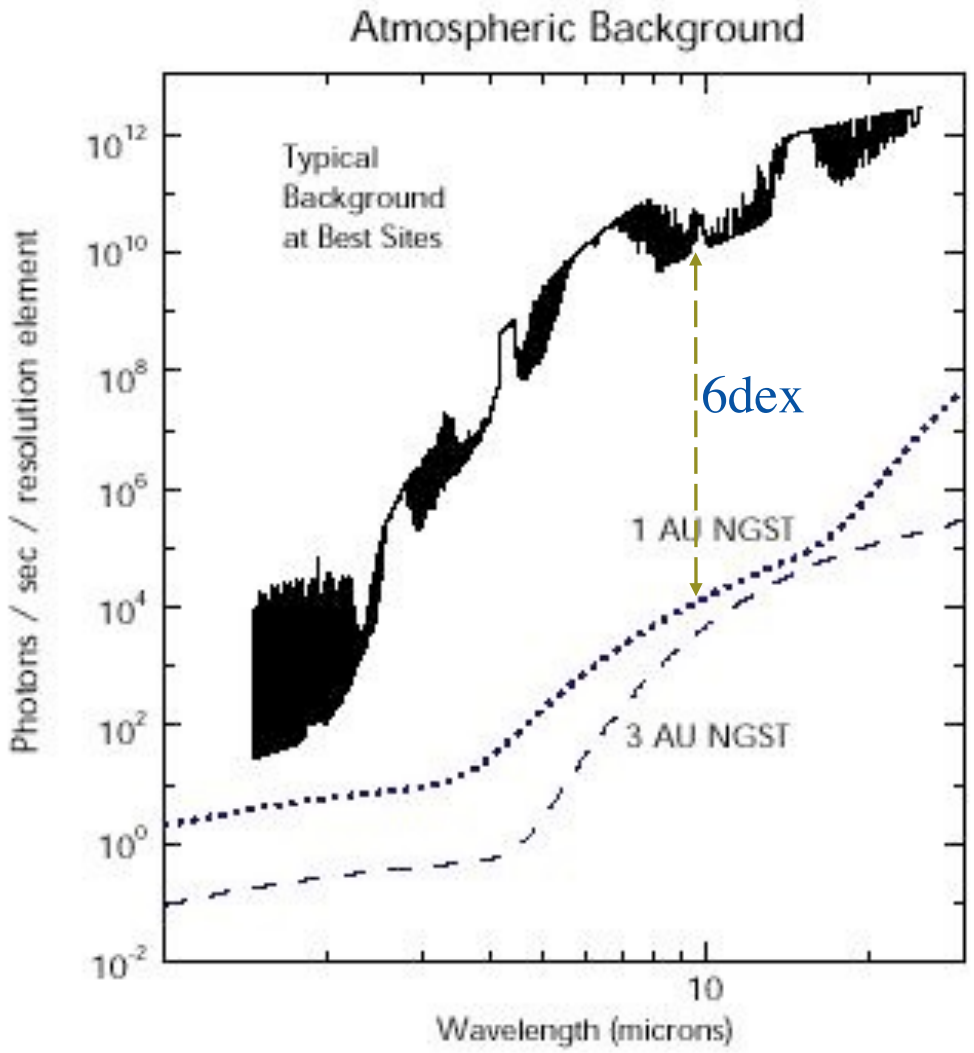
# MIRI IFS. CHARACTERISTICS




| Channel | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Number of Slices (N) | 21 | 17 | 16 | 12 |
| Wavelength range (μm) | 5.5 – 7.7 | 7.7 – 11.9 | 11.9 – 18.3 | 18.3 – 28.3 |
| Slice width<br>Pixel size (arcsec) | 0.176<br>0.196 | 0.277<br>0.196 | 0.387<br>0.245 | 0.645<br>0.273 |
| FoV (arcsec) | 3x 3.87 | 3.5x 4.42 | 5.2x 6.19 | 6.7x 7.73 |
| Resolving Power | 2400 - 3700 | 2400 - 3600 | 2400 - 3600 | 2000 - 2400 |

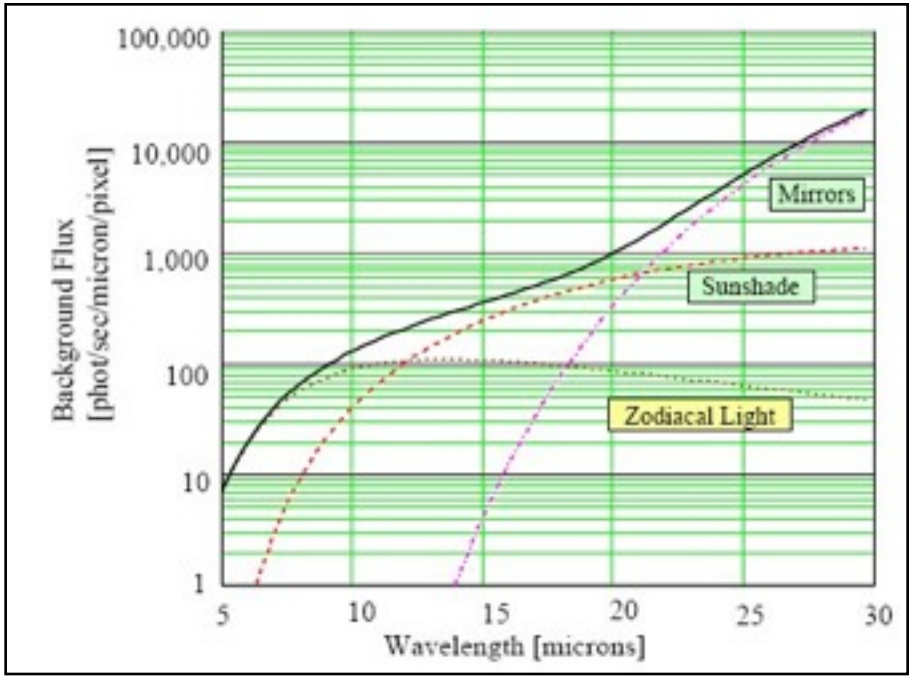
http://www.roe.ac.uk/ukatc/consortium/miri/index.html

# IR BACKGROUND. EARTH VS. SPACE




Earth: 220-300 K environment

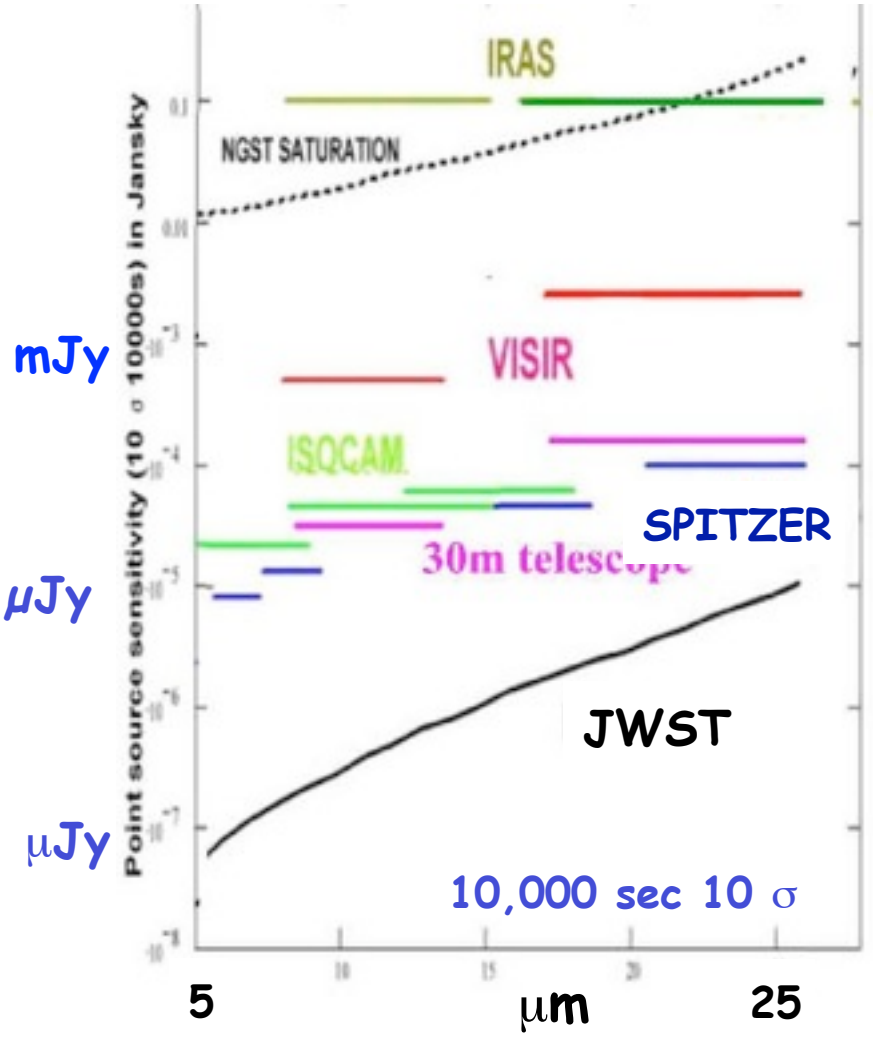
Space: 30-40 K environment




http://www.roe.ac.uk/ukatc/consortium/miri/index.html MIRI UK-ATC web page

# MIRI IMAGING SENSITIVITY

| Imager Filter | | Point source sensitivity (10 sigma in 10,000 sec) [micro-Jansky] | | |
|---|---|---|---|---|
| Wavelength [μm] | Passband [μm] | Requirement (FRD) | Design CBE | Margin |
| 5.6 | 1.2 | 0.18 | 0.13 | 28% |
| 7.7 | 2.2 | 0.27 | 0.22 | 19% |
| 10.0 | 2.0 | 0.70 | 0.54 | 23% |
| 11.3 | 0.7 | 1.66 | 1.33 | 20% |
| 12.8 | 2.4 | 1.33 | 0.99 | 26% |
| 15.0 | 3.0 | 1.77 | 1.28 | 28% |
| 18.0 | 3.0 | 4.32 | 3.18 | 26% |
| 21.0 | 5.0 | 8.63 | 7.13 | 17% |
| 25.5 | 4.0 | 28.3 | 28.3 | 0% |



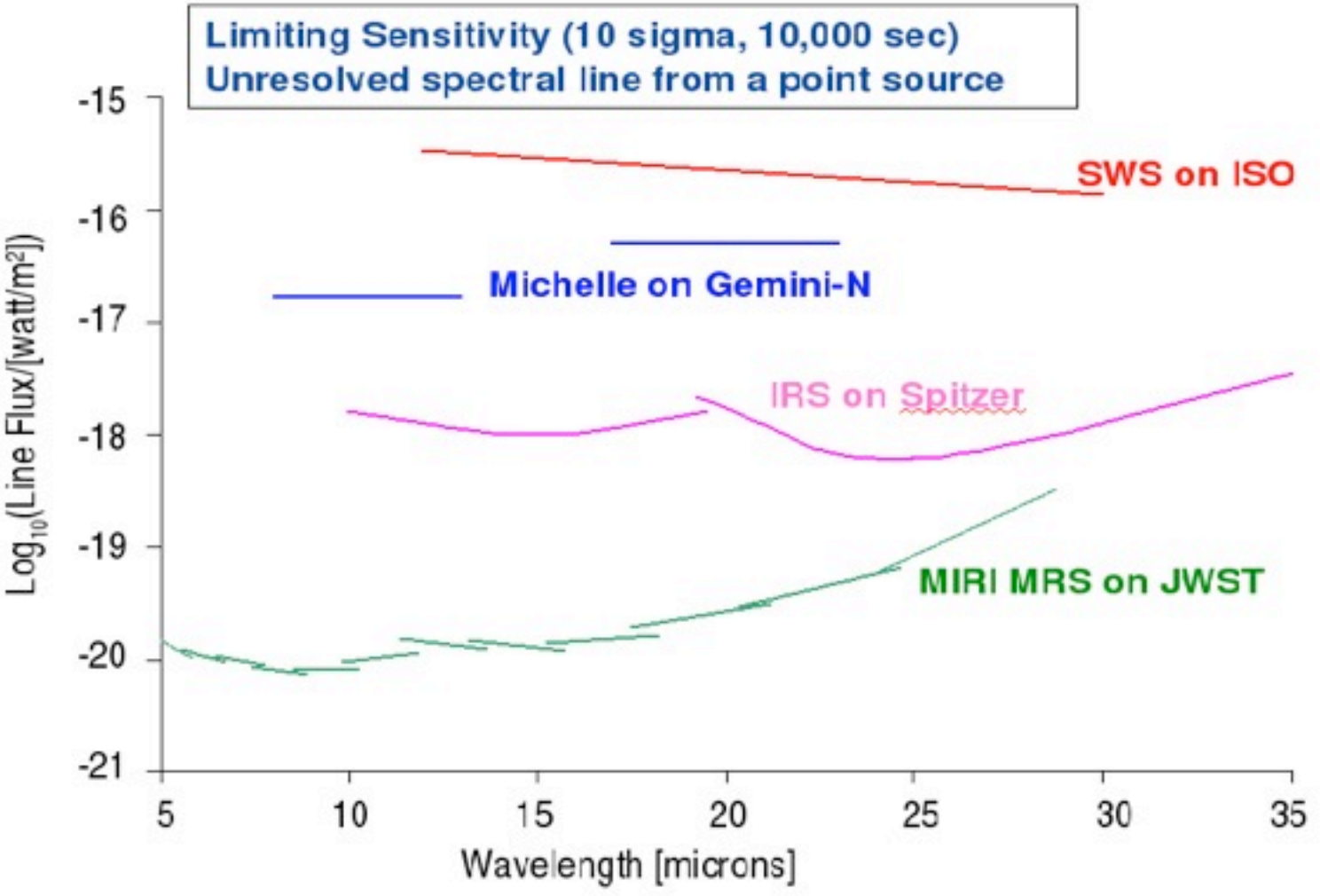

MIRI

~ $10^4$ deeper than VLT

~ 10-100 deeper than Spitzer

http://www.roe.ac.uk/ukatc/consortium/miri/index.html

# MIRI IFS SENSITIVITY



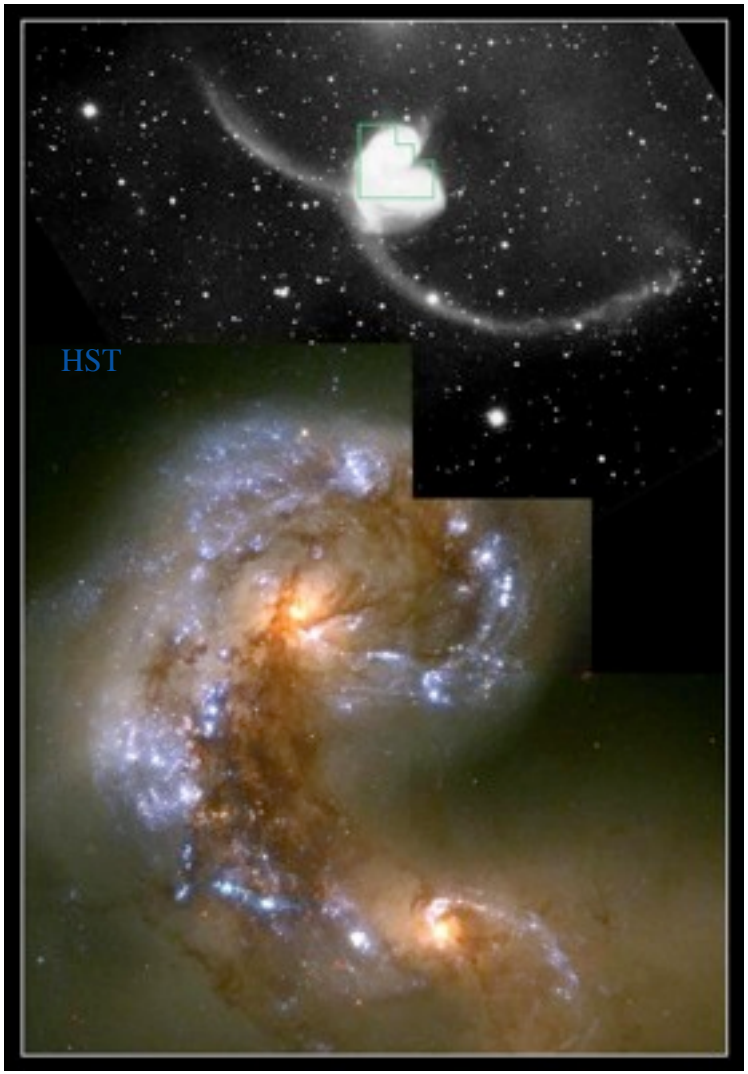

UK-ATC MIRI page

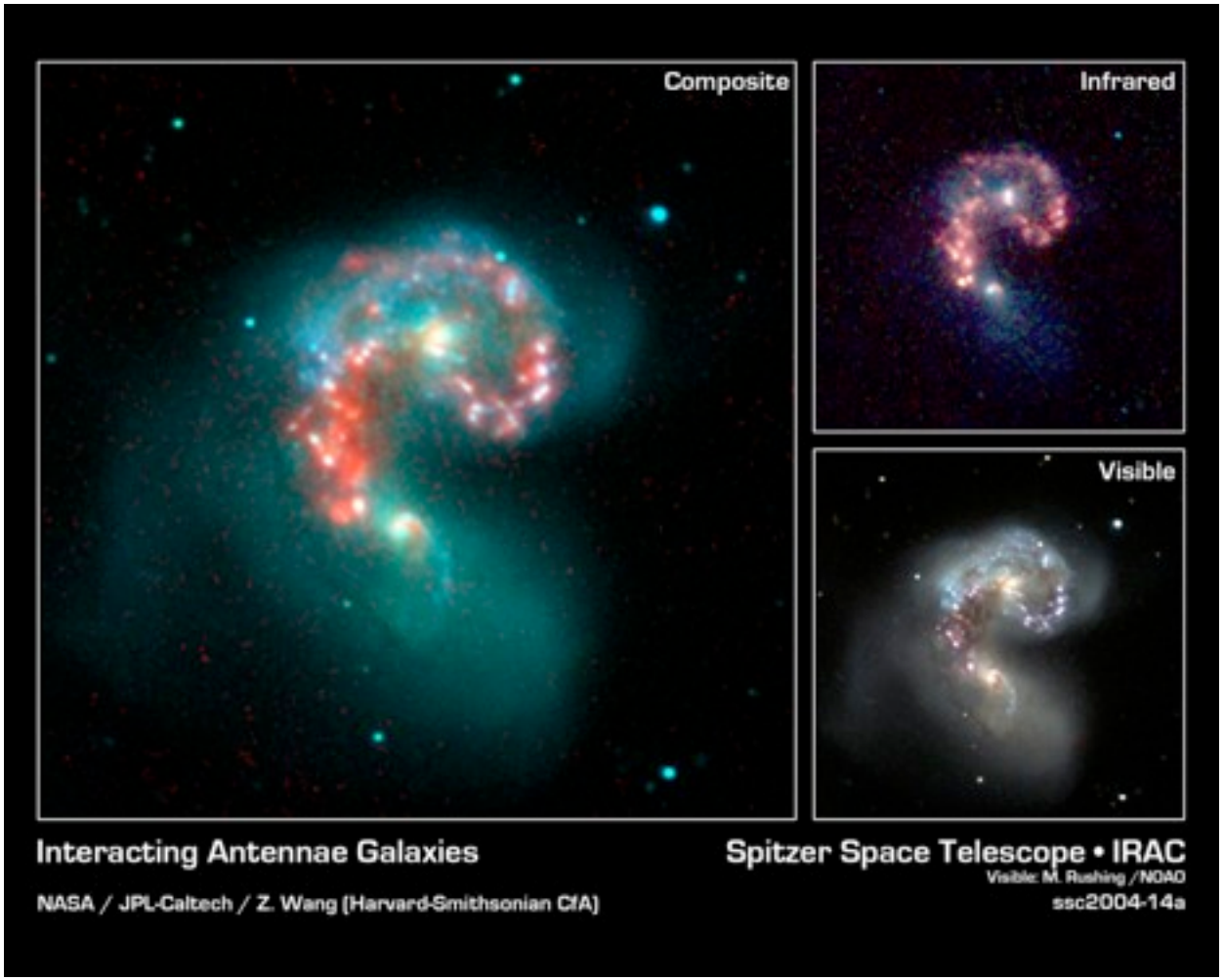
# MIRI vs Mid-IR INSTRUMENTS

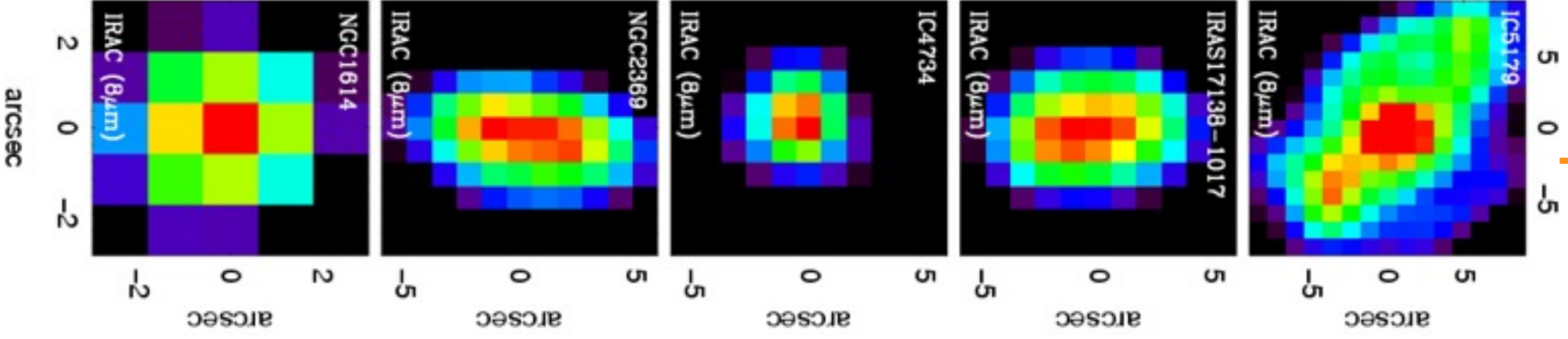
| TELESCOPE | Angular Resolution (arcsec) | Wavelength Range (μm) | Spectral Resolution (R) | Sensitivity |
|---|---|---|---|---|
| GTC<br>VLT | ~ 0.3 | 10 & 20 (windows) | 150 – 1000<br>350, 3000 & 25000 | 10^-4 |
| SPITZER | 1.7 - 2 | 5.2 - 38<br>9.9 – 37.2 | 50 – 120 (LR)<br>600 (HR) | 10^-1 to 10^-2 |
| JWST | 0.18 - 0.65 | 5 - 14<br>5 - 28 | ~ 70 – 200 (LR)<br>~ 3000 (HR) | 1 |

MIRI unique capabilities will produce a revolution in extragalactic science, in particular dust-obscured objects

# MIRI & PHYSICS OF LOW-Z STARBURTS



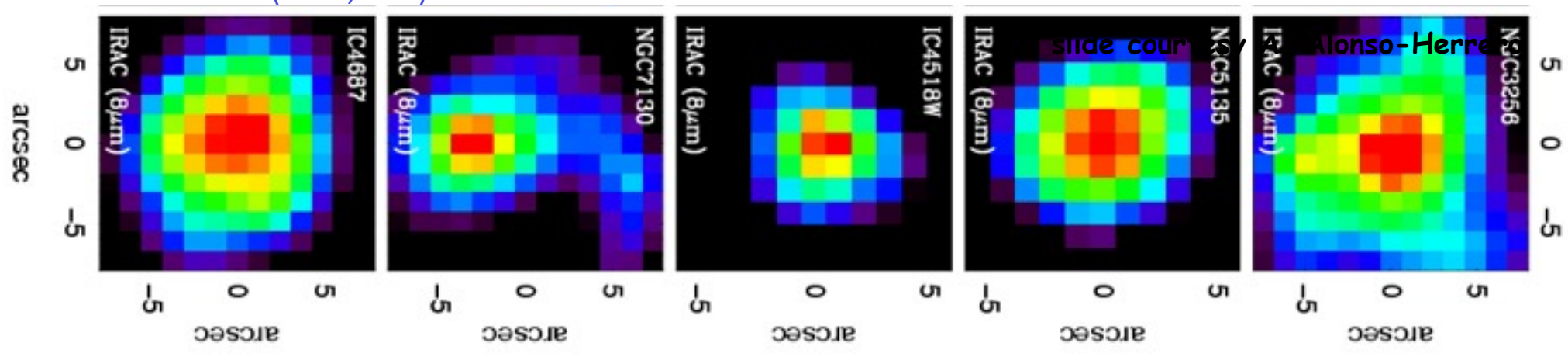



**Mid-IR imaging**

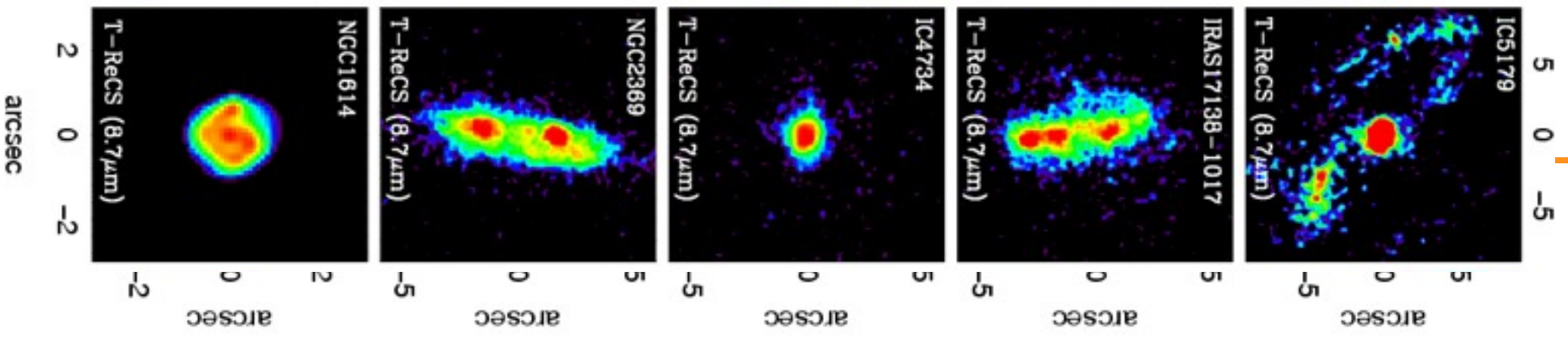
Resolution at distance of 30Mpc

- **IRAC/Spitzer = 450pc (galactic star forming rings, etc.)**
- **MIRI/JWST = TReCS/Gemini = 45 pc (nuclear dominated)**

Díaz-Santos (2008, PhD)




Slide courtesy of Alonso-Herrero

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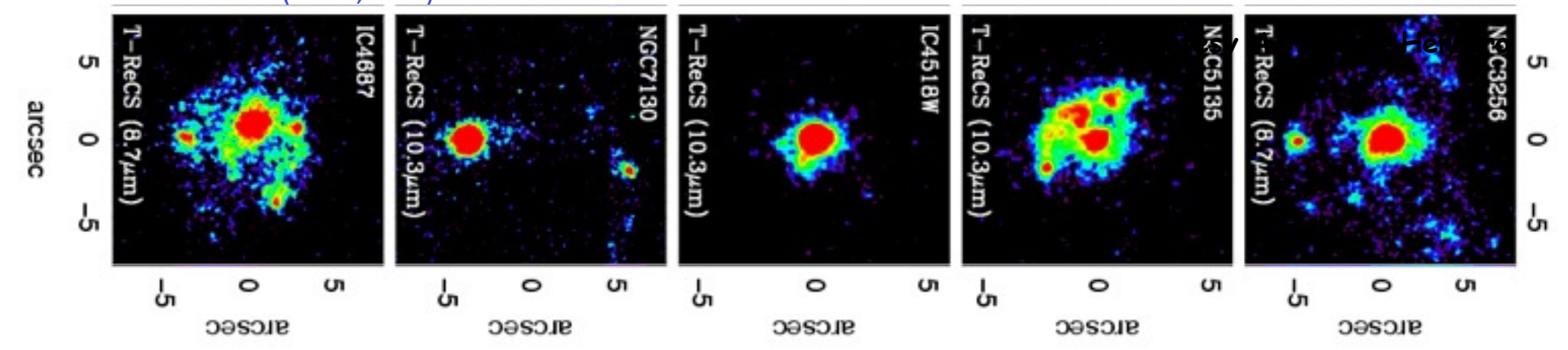
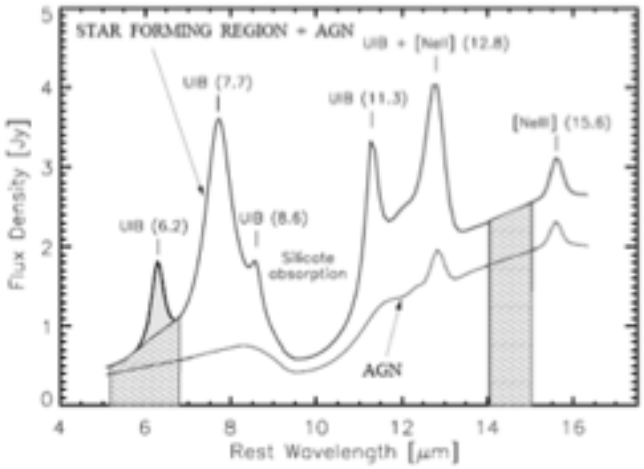
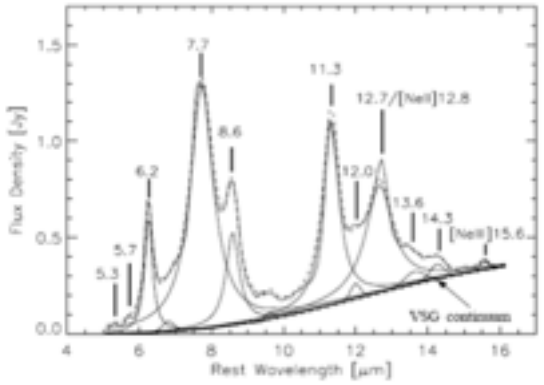
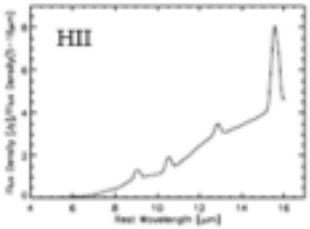


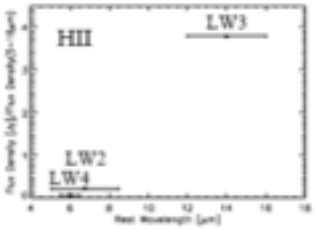
# MIRI IMAGING. AGNS & STARBURSTS PHOTOMETRY DIAGNOSTICS

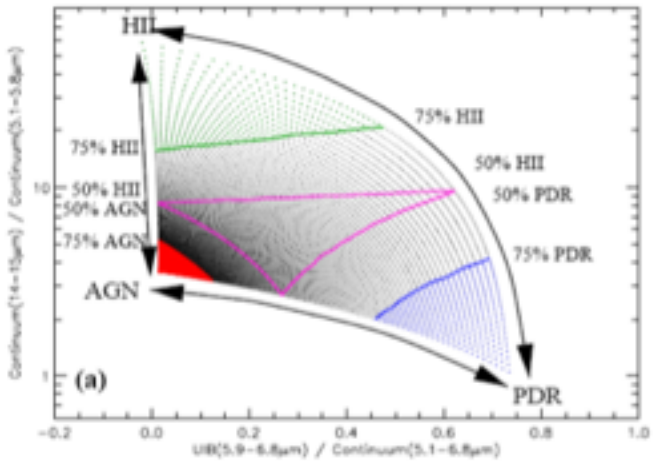


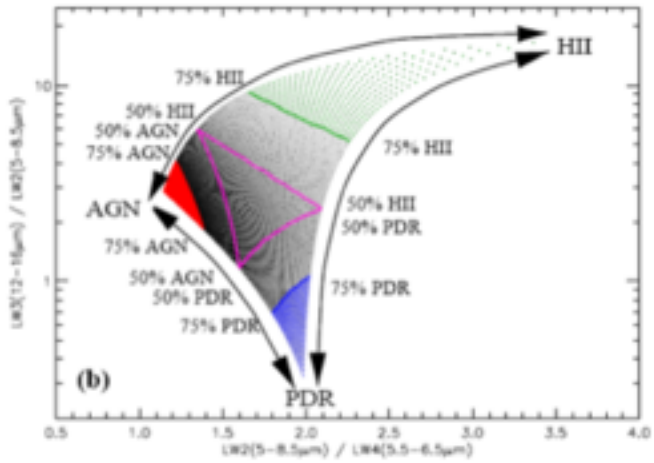



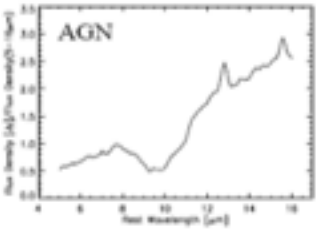

DIAGNOSTIC DIAGRAMS

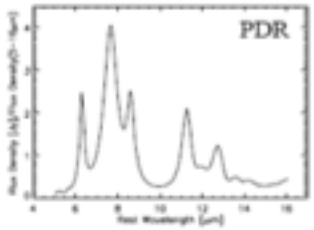


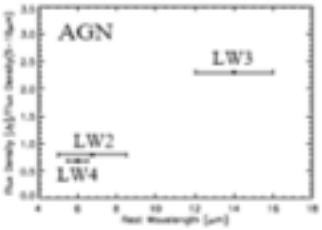



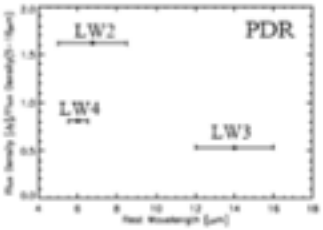



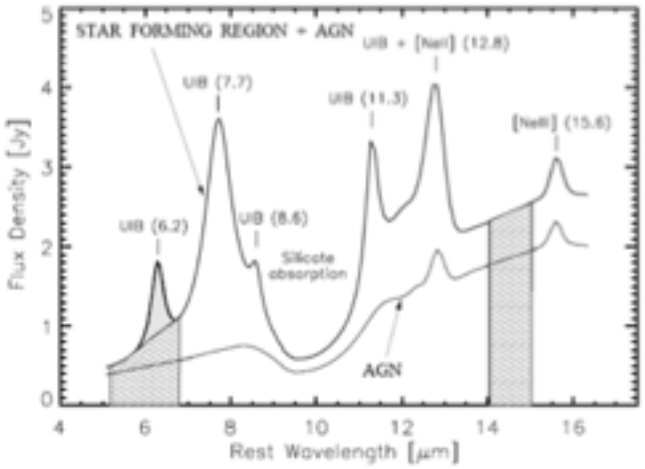



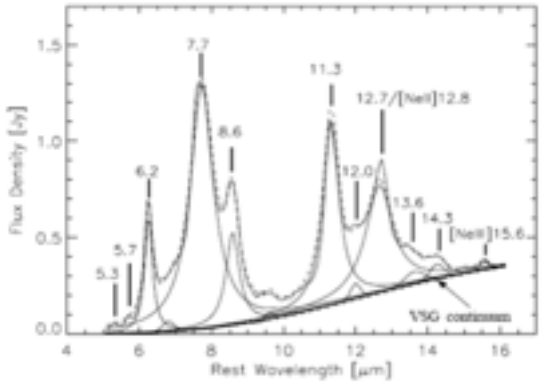




Laurent et al. 2000 ISO

# MIRI IMAGING. AGNS & STARBURSTS PHOTOMETRY DIAGNOSTICS



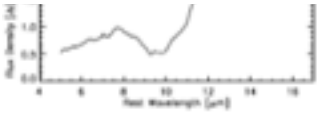



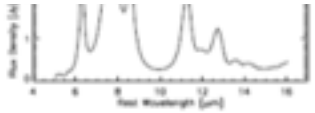

Sensitivity & sub-arcsec resolution opens window to investigate different constituents: AGN, starburst & host galaxy

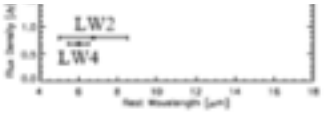


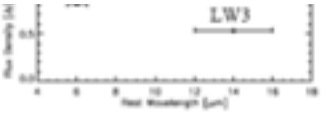
Table 12 MIRI filters

| | $\lambda_0$ ($\mu$m) | $\Delta\lambda$ ($\mu$m) | comment |
|---|---|---|---|
| B1 | 5.6 | 1.2 | Broad band |
| B2 | 7.7 | 2.2 | PAH, broad band |
| B3 | 10 | 2 | Silicate, broad band |
| I1 | 11.3 | 0.7 | PAH, broad band |
| I2 | 12.8 | 2.4 | Broad band |
| B4 | 15 | 3 | Broad band |
| I3 | 18 | 3 | Silicate, broad band |
| B5 | 21 | 5 | Broad band |
| B6 | 25.5 | ~4 | Broad band |
| B6' | 25.5 | ~4 | Redundant filter, risk reduction |
| ND# | neutral density | | Coronagraphic acquisition |
| NIR | near-IR, TBD | | Testing |
| | blackened blank | N/A | Darks |



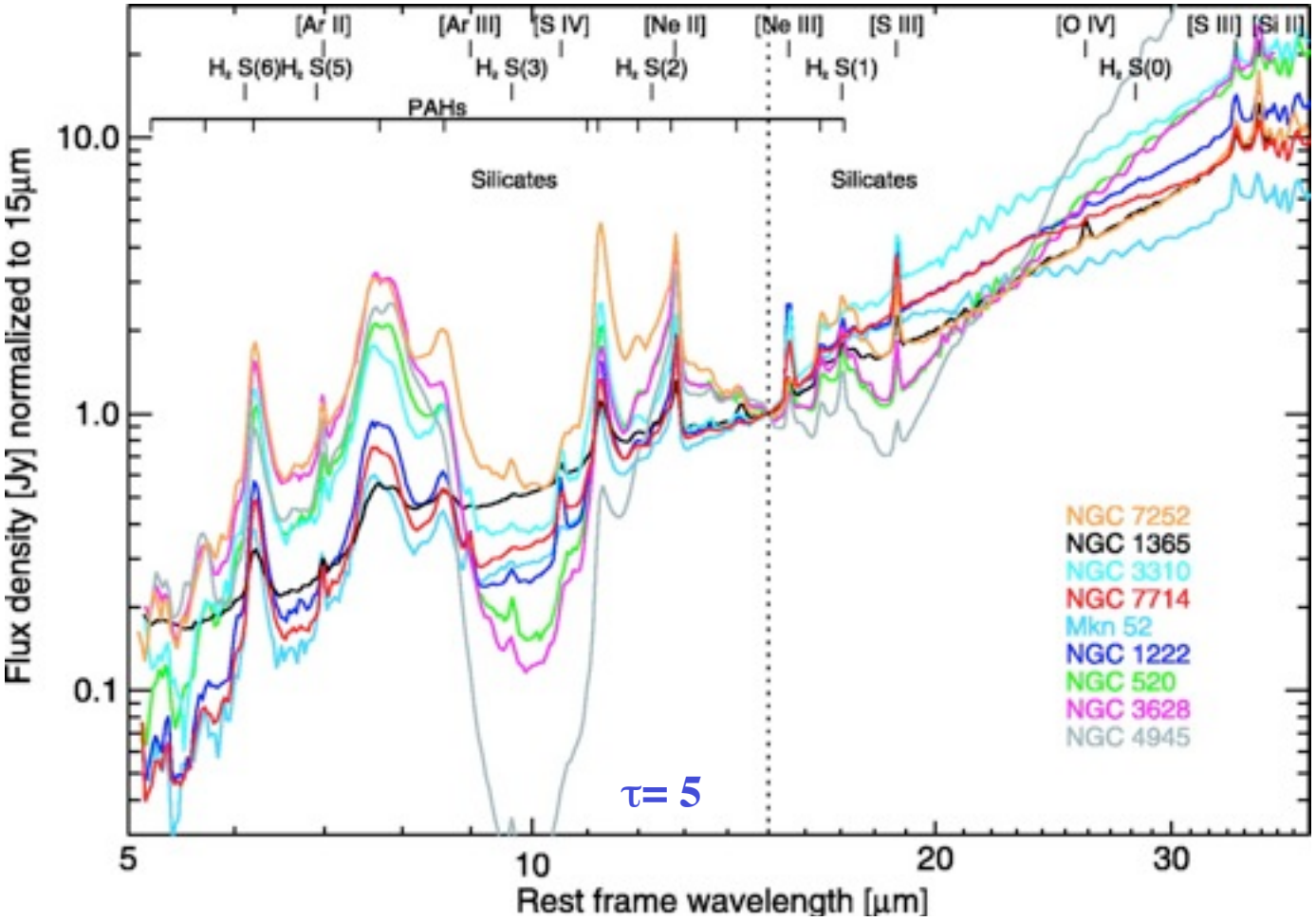





Laurent et al. 2000 ISO

# STARBURSTS: VARIETY OF IR SPECTRA




- Weak high excitation lines
- Strong low ionization lines
- Strong PAH

No absorption to heavily obscured starbursts

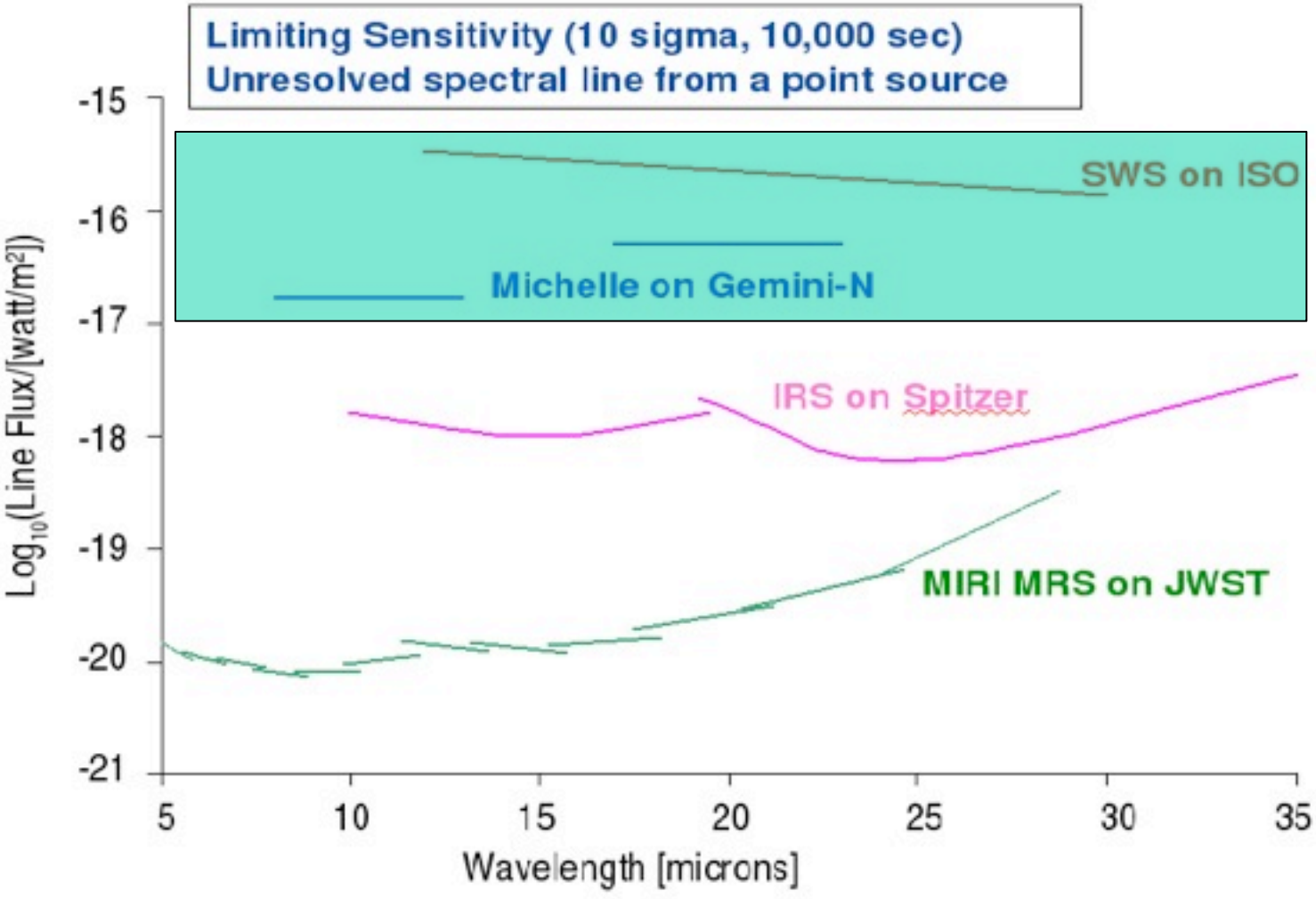
Brandl et al. 2006

# MID-IR EMISSION LINES. TRACERS OF IONIZATION MECHANISMS

| Emission Line | Wavelength | Ionization potential | Diagnostic |
|---|---|---|---|
| [FeII] | 25.99 micron | 7.9 eV | Density/SNRs |
| [OIV] | 25.89 micron | 54.9 eV | AGN presence? |
| [NeV] | 24.3 micron | 97.1 eV | AGN presence |
| [SIII] | 18.71 micron | 23.3 eV | Abundance |
| [NeIII] | 15.56 micron | 41.0 eV | Excitation + [NeII] |
| [Cl II] | 14.37 micron | 13.0 eV | Starformtaion |
| [NeV] | 14.32 micron | 97.1 eV | AGN presence |
| [NeII] | 12.81 micron | 21.6 eV | Excitation + [NeIII] |
| [SIV] | 10.54 micron | 34.8 eV | Excitation + [NeV] |
| [ArIII] | 8.99 micron | 27.6 eV | "ion. para. U" + [NeVI] |
| [NeVI] | 7.6 micron | 126.2 eV | AGN and "ion. para U" |
| [ArII] | 6.98 micron | 15.7 eV | Abundance |
| [FeII] | 5.34 micron | 7.9 eV | Density/SNRs |
| PAH features | Throughout range | | Starformation |
| H2 | Throughout range | | Starformation |

MIRI EC definition team

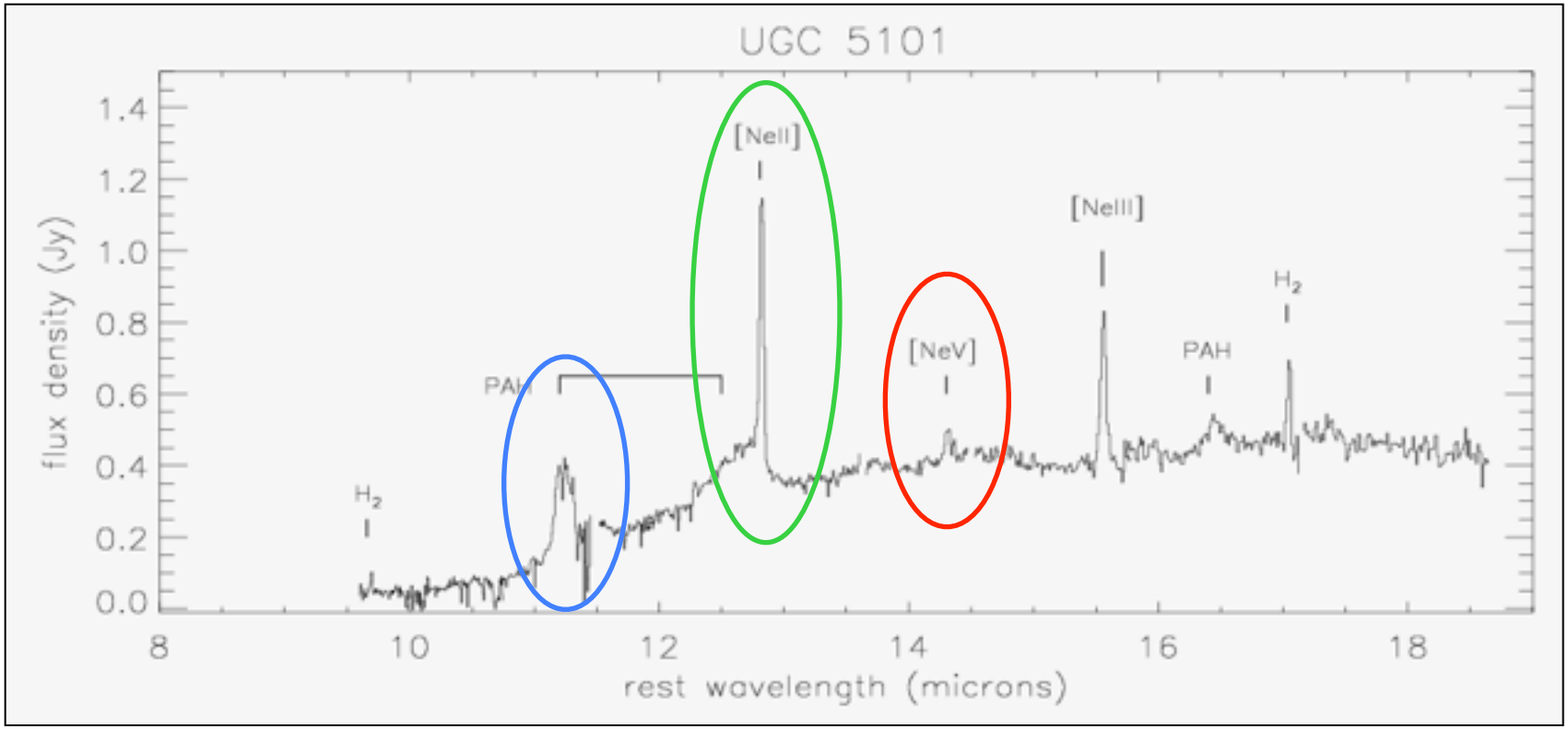
# MIRI IFS SENSITIVITY




Emission lines in Low-z AGNs & LIRGs

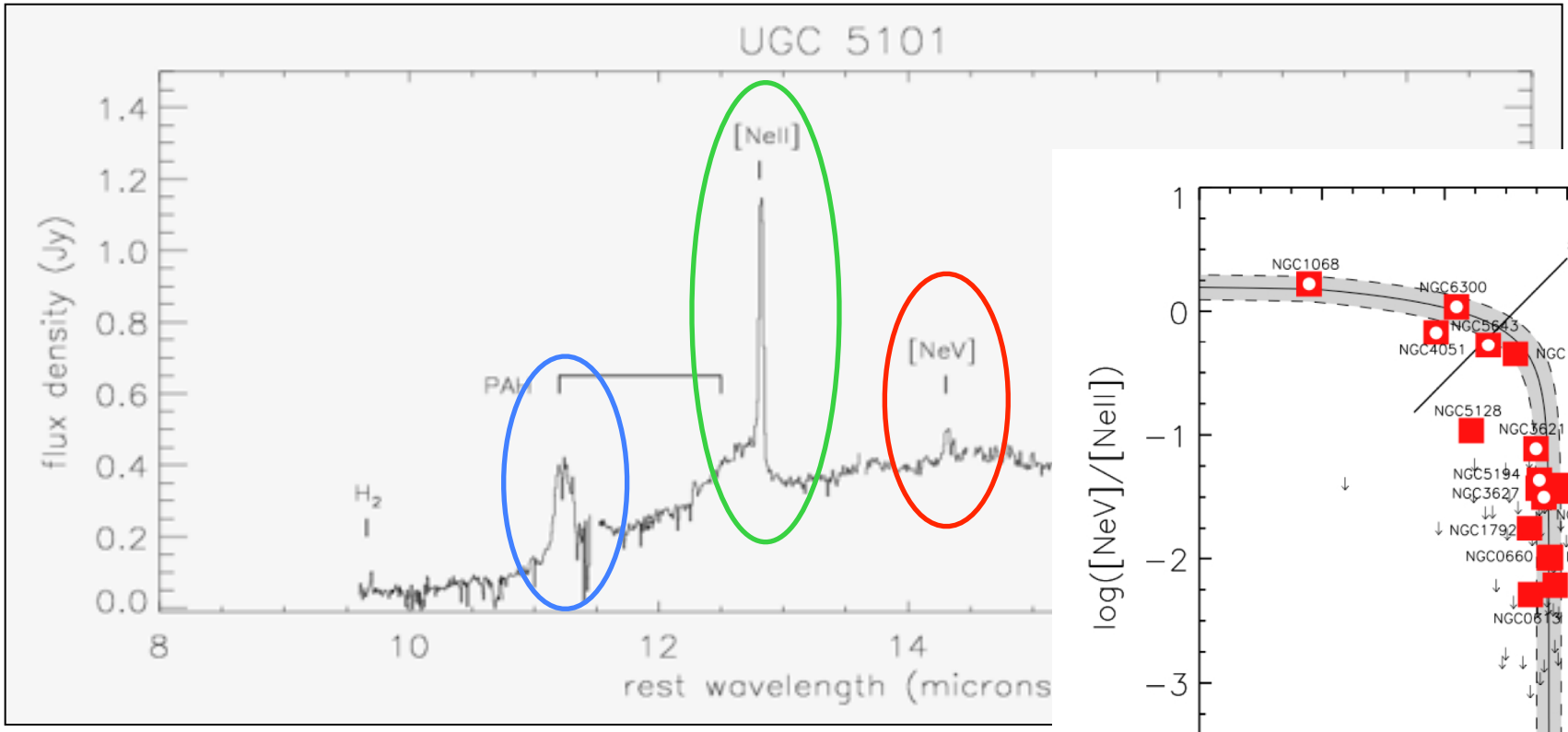
UK-ATC MIRI page

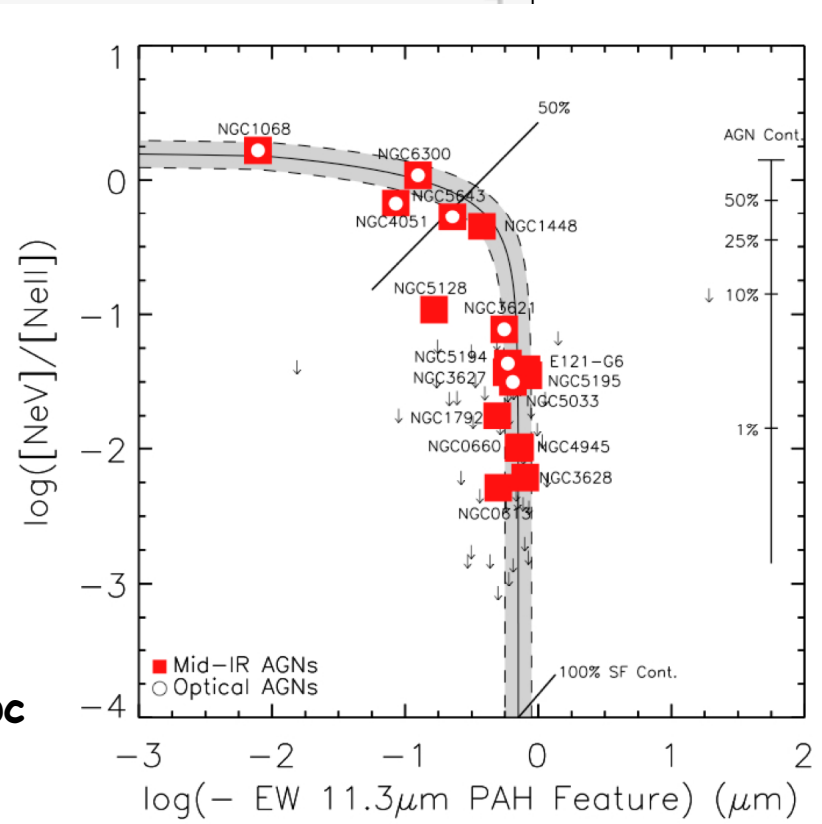
# AGN-STARBURST SPECTRAL DIAGNOSTICS




**Resolving scales of less than 100 pc**

# AGN-STARBURST SPECTRAL DIAGNOSTICS

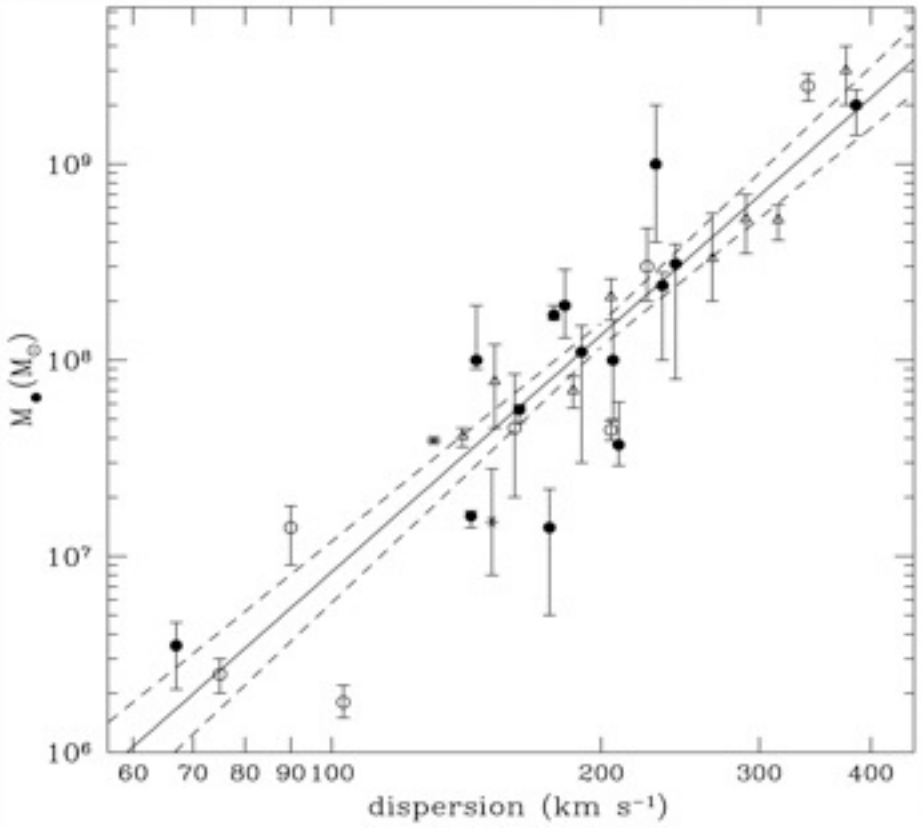



**Resolving scales of less than 100 pc**

Goulding & Alexander 2009

# WEIGHTING BLACK-HOLES IN DUSTY STARBURSTS & AGNS




$$r_h \sim GM_\bullet/\sigma^2 \sim 11.2\,(M_\bullet/10^8 M_\odot)/(\sigma/200\,\mathrm{km\ s^{-1}})^2\ \mathrm{pc}$$

**Sphere of influence of a $10^7$ $M_\odot$ BH at a distance of 10 Mpc is $R_{bh}$ = 0.4"**

Tremaine et al. (2002) stellar dynamics: circles

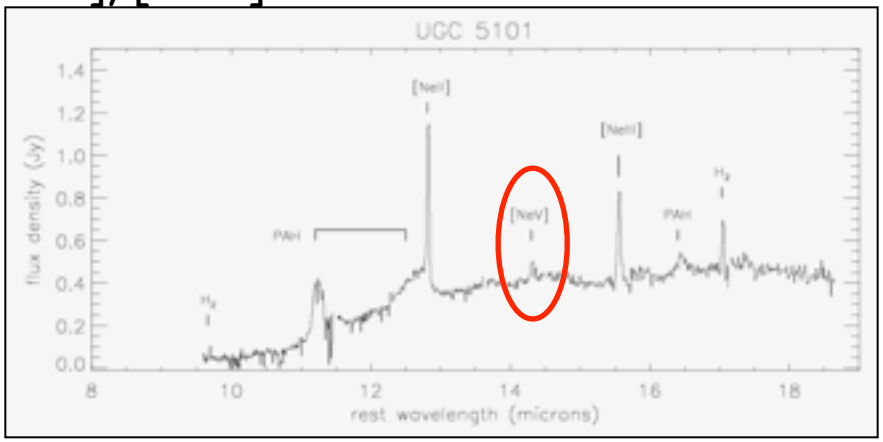
gas dynamics: triangles

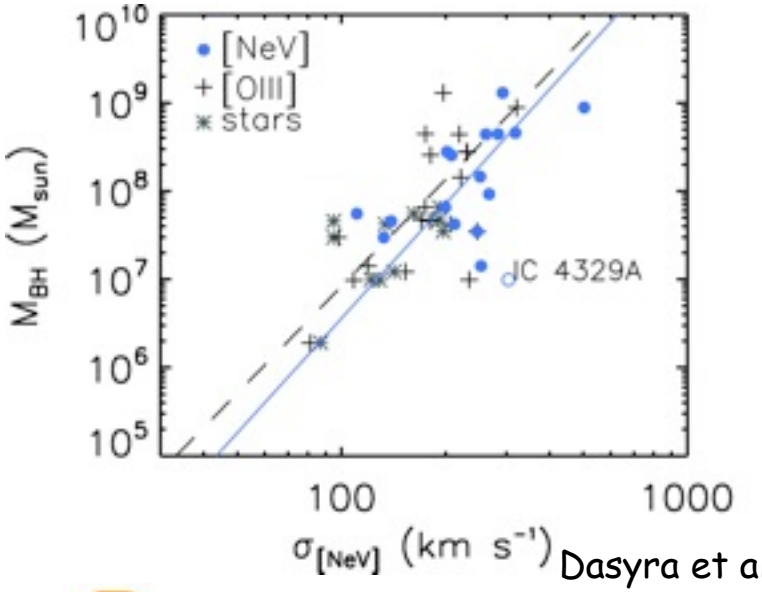
masers: asterisks

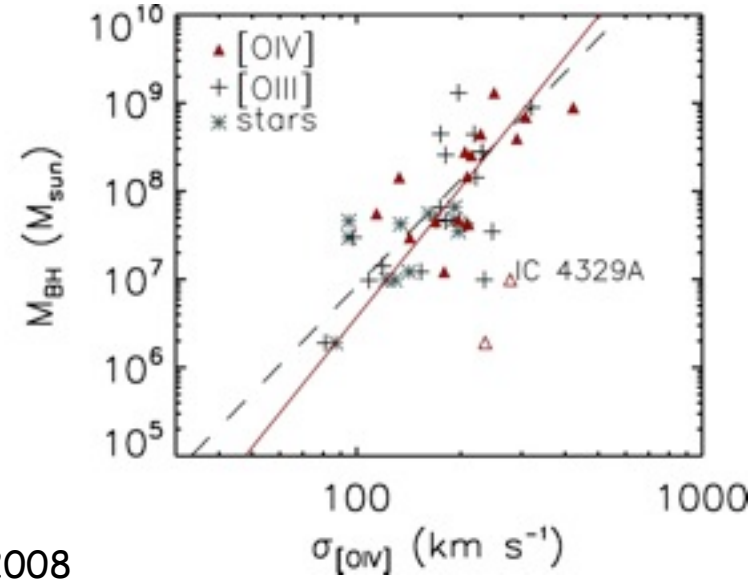
**IR lines**
**High angular resolution**
**Extinction minimized**

# WEIGHTING BLACK HOLES WITH HIGH EXCITATION LINE KINEMATICS

- Isolate hidden AGNs with high excitation lines: [NeV], [OIV]
- Black hole mass – velocity dispersion relations

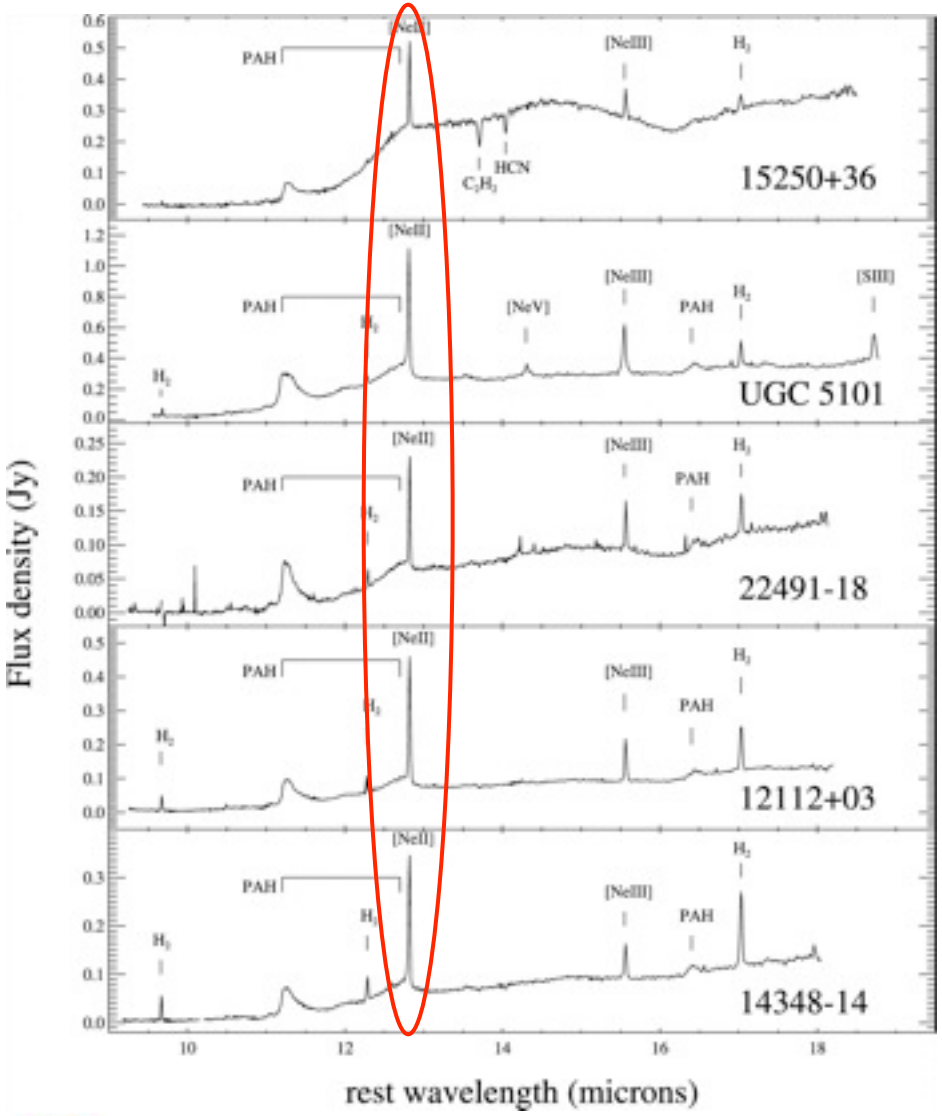


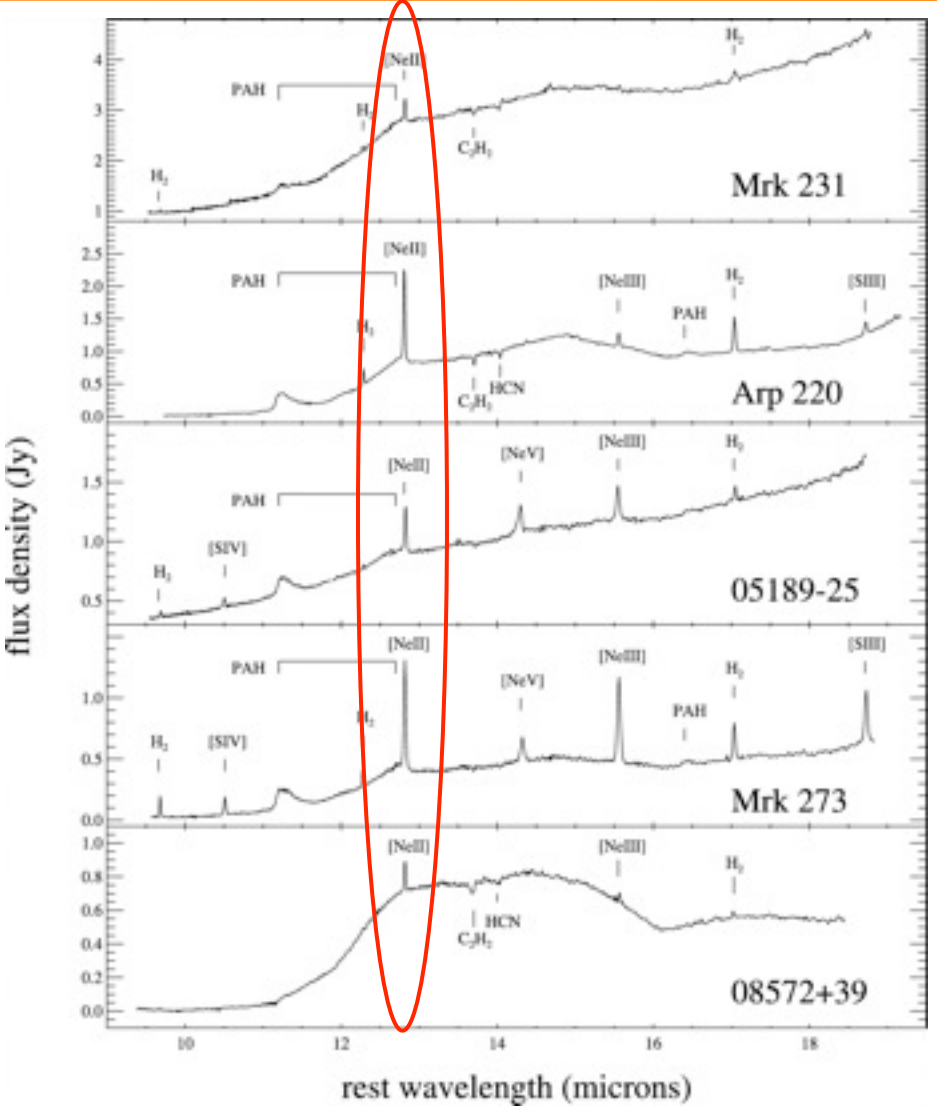




Dasyra et al. 2008

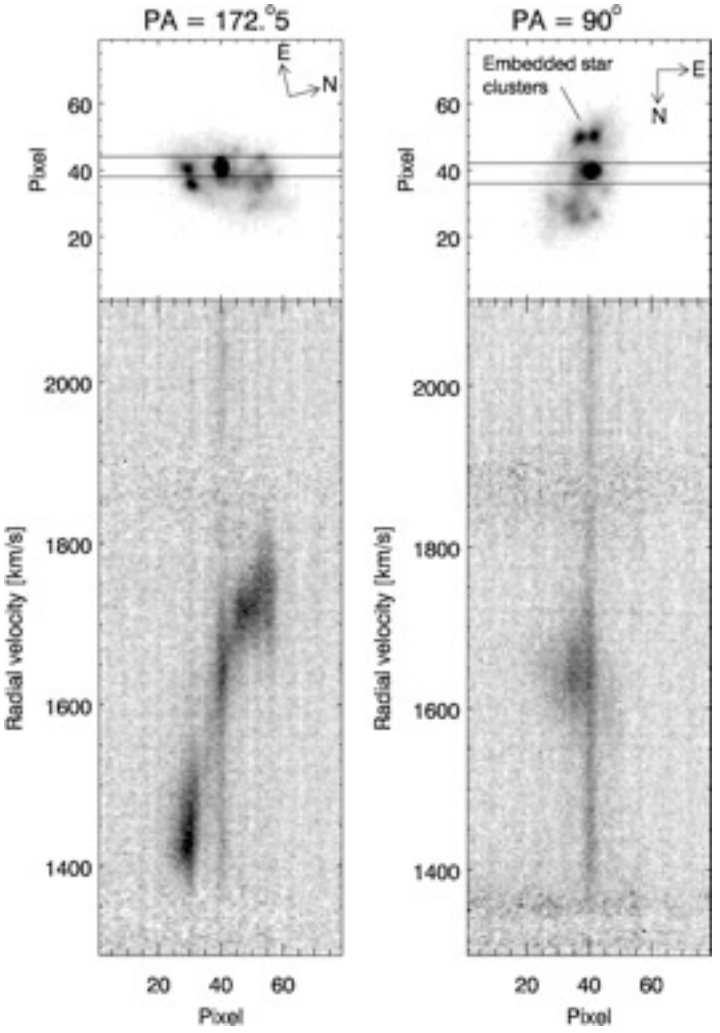
# WEIGHTING BLACK-HOLES. SPATIALLY RESOLVED [NEII]




Armus et al. 2006

# WEIGHTING BLACK-HOLES WITH [NeII]. NGC 7582



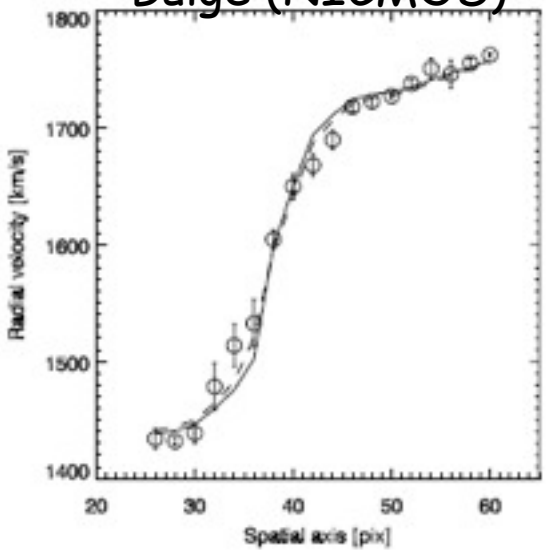

Wold et al. 2006

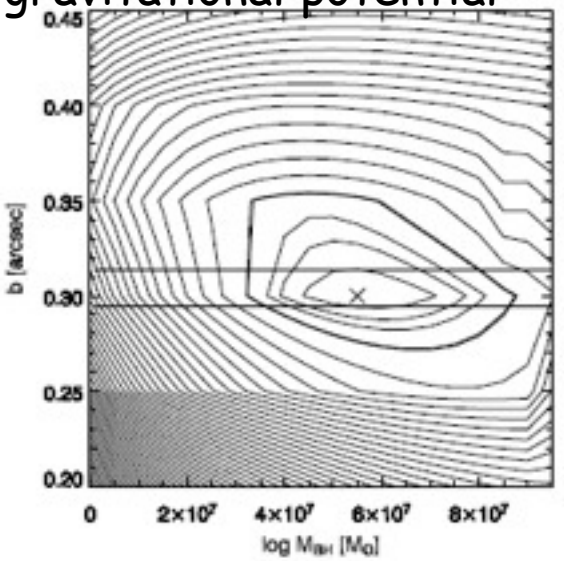
VISIR/VLT
[NeII]12.8μm/ R= 16000
0.4´´ = 40 pc

KEY ADVANTAGE

$A_{12.8\mu m} = 0.02\ A_V$
$= 0.1\ A_H$

Bulge (NICMOS) + BH gravitational potential

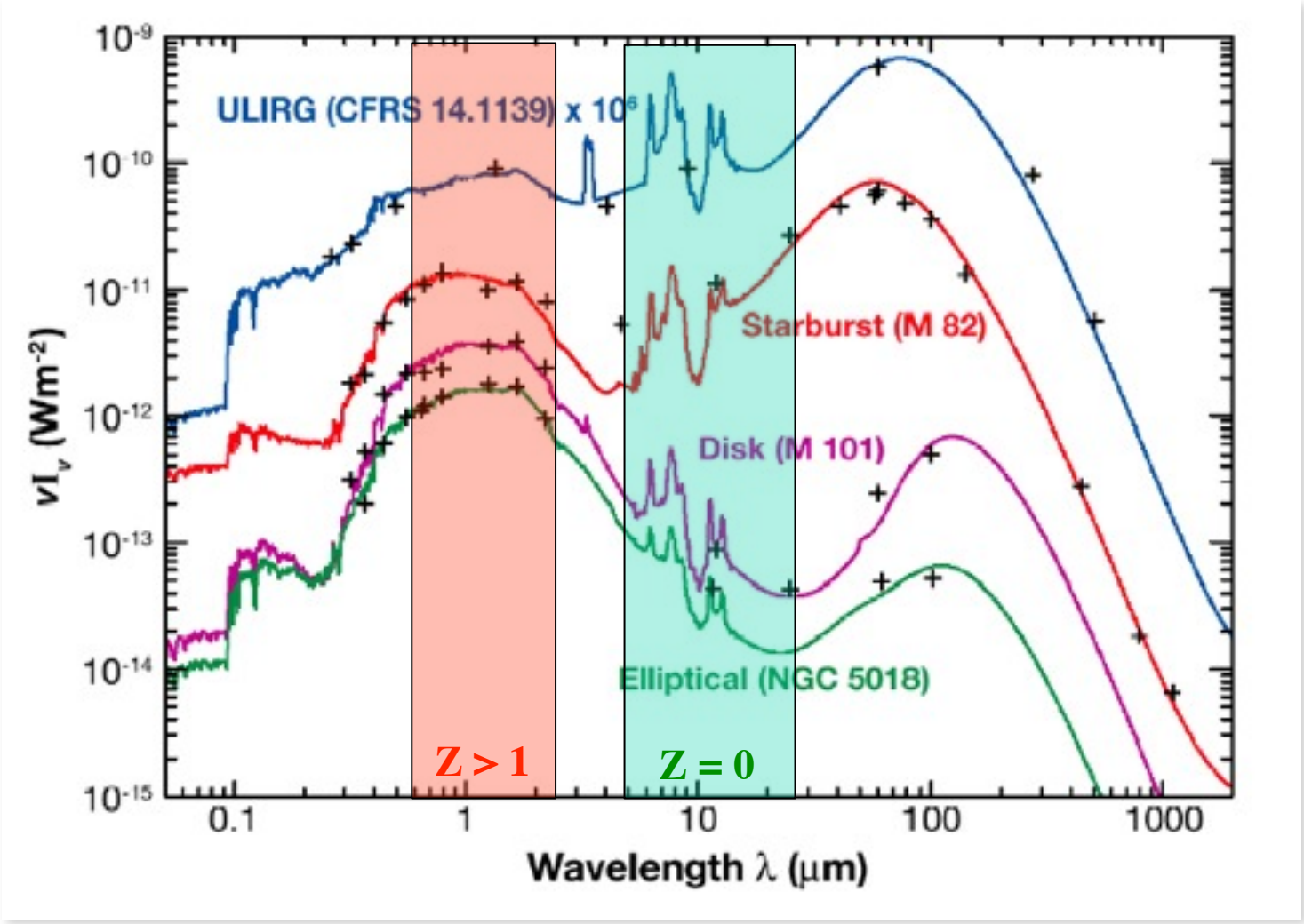



$M_{BH} = 5.5\ [3.6\text{-}8.1] \times 10^7\ M_\odot$

**FUTURE: MIRI IFS with R=3000**

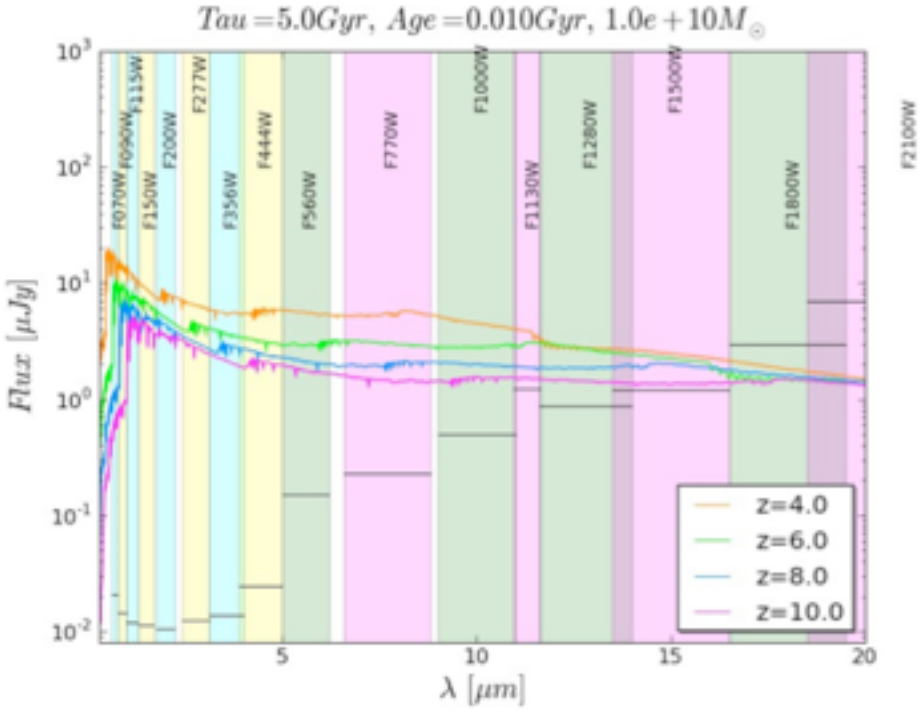
# MIRI & PHYSICS OF HIGH-Z STARBURSTS

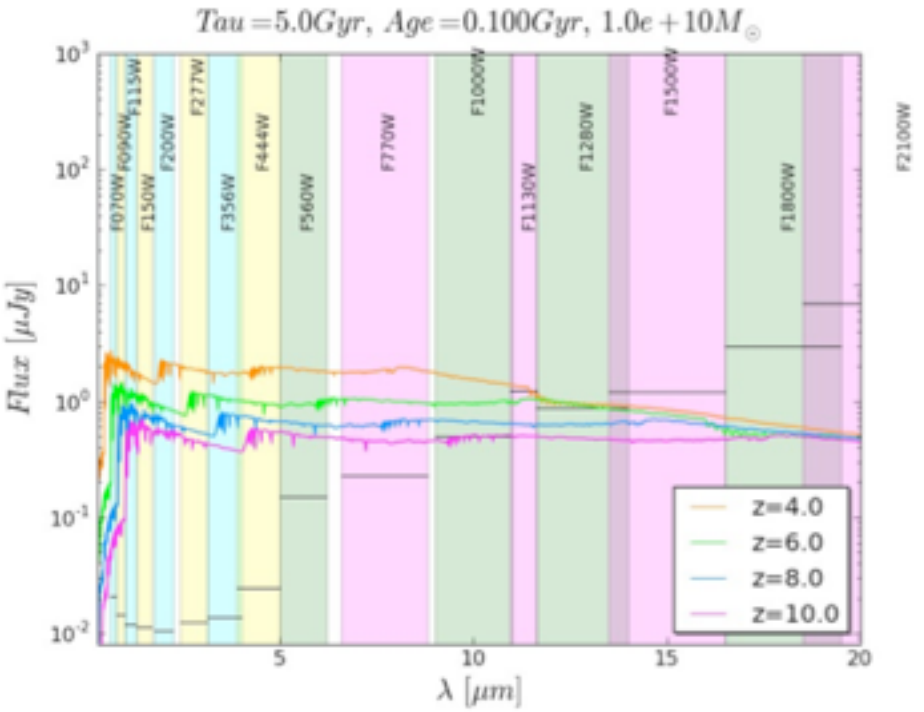



Near-IR (& optical) spectral features

Lagache et al. 2005, ARAA

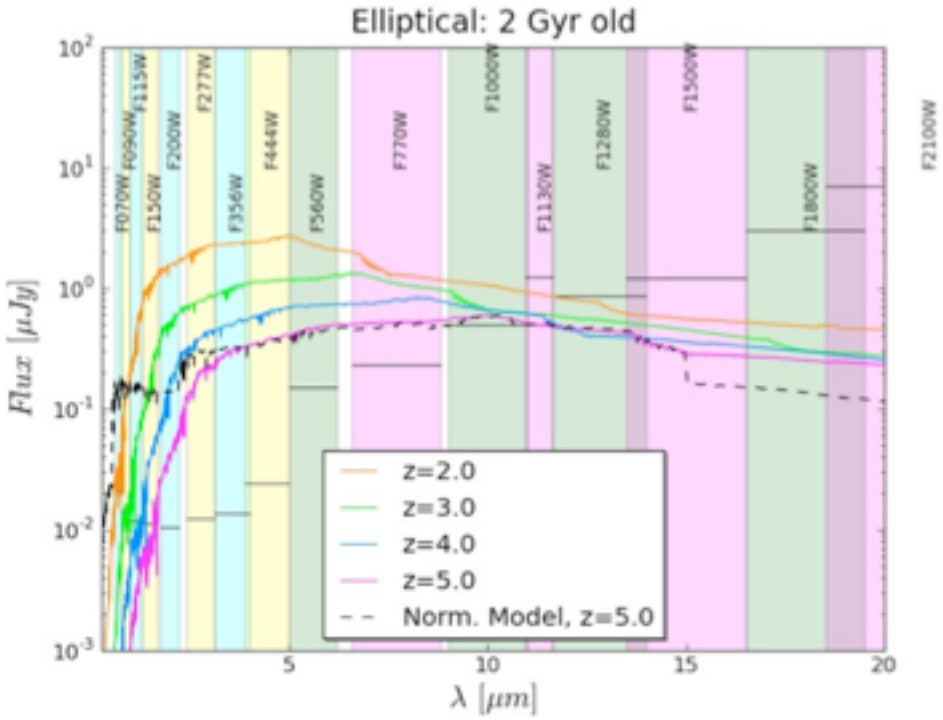
# HIGH-Z GALAXIES & MIRI IMAGING

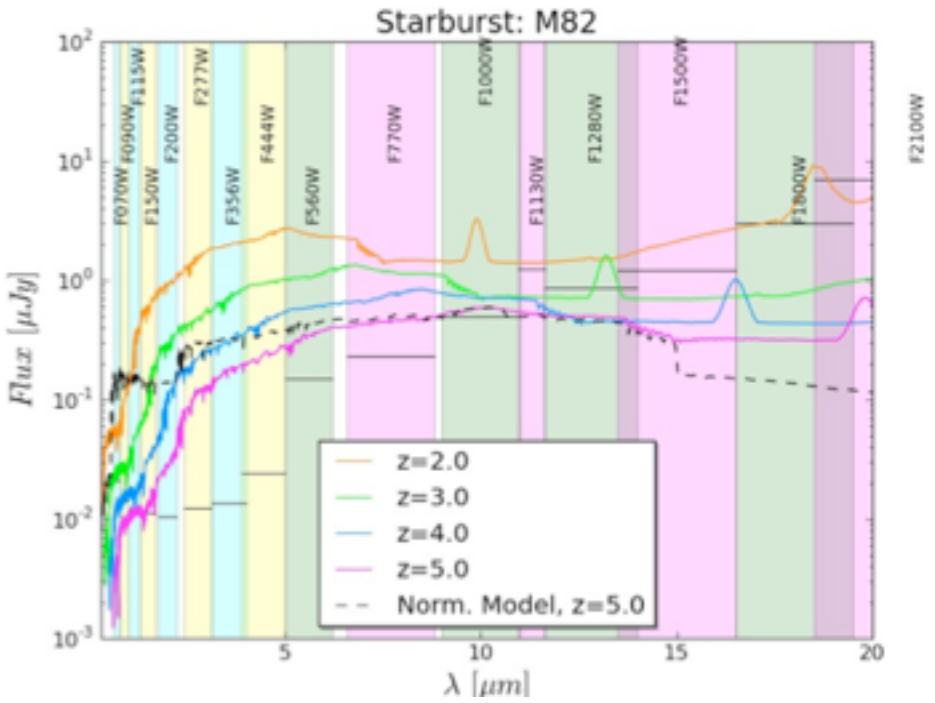



10 ksec, 10σ sensitivity; Azzollini et al.

# HIGH-Z GALAXIES & MIRI IMAGING

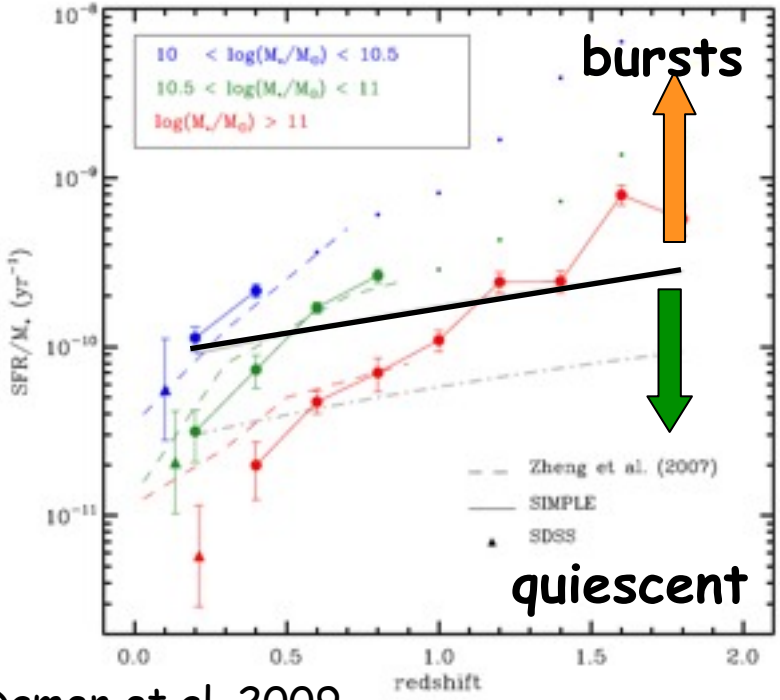



10 ksec, 10σ sensitivity; Azzollini et al.

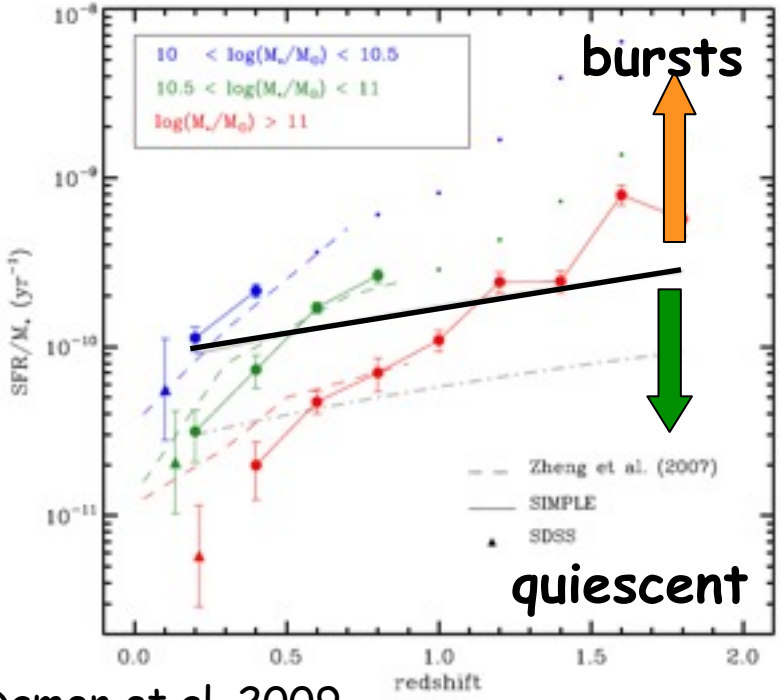
**MIRI: ABLE TO DETECT & RESOLVE STARBURSTS & GALAXIES AT Z > 2**

# STAR FORMATION & STELLAR MASS BUILDUP

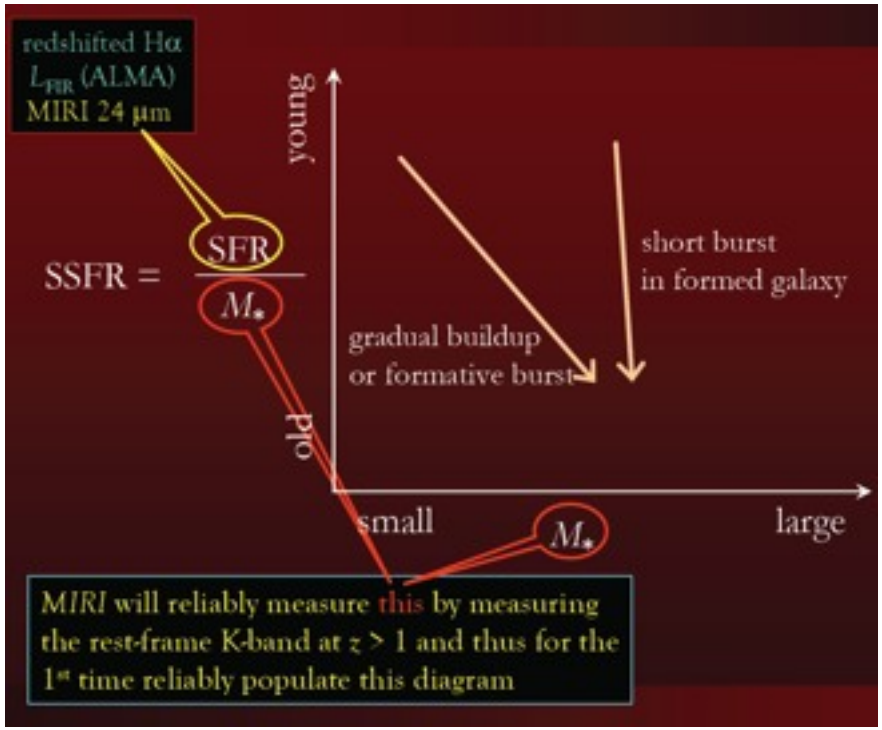



Damen et al. 2009

# STAR FORMATION & STELLAR MASS BUILDUP




Damen et al. 2009

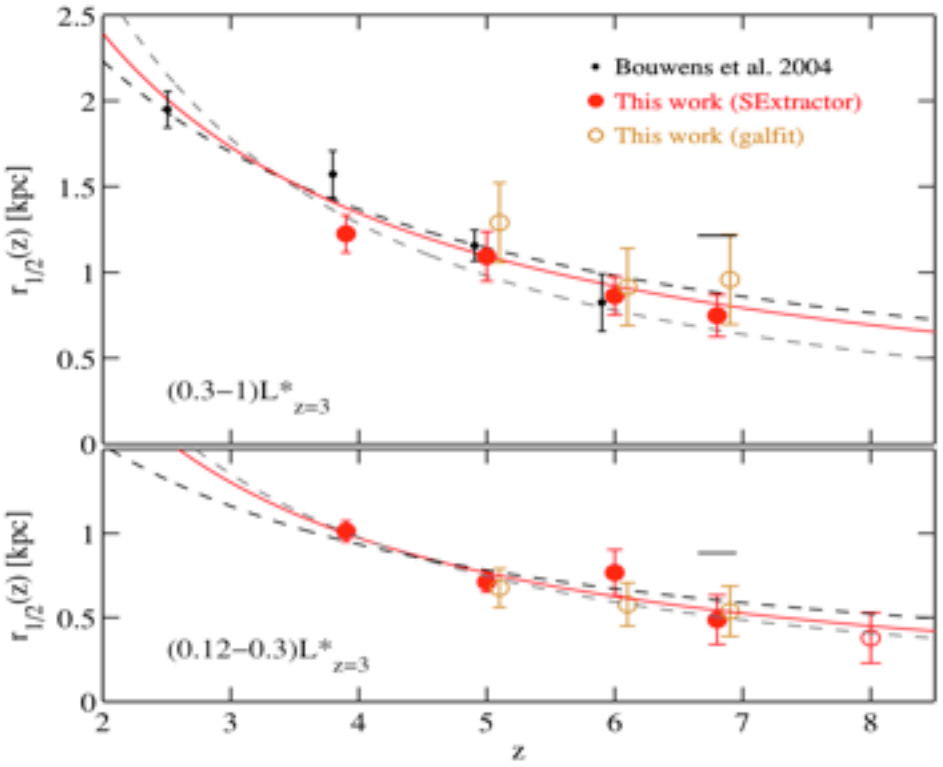



courtesy P. Van der Werf

**MIRI: REST-FRAME NIR IMAGING @ Z > 1**

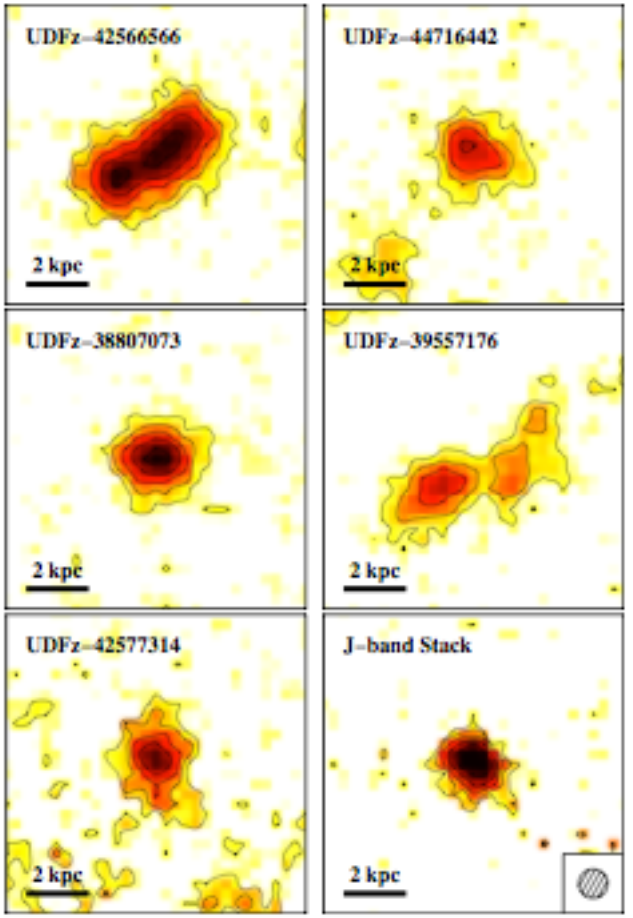
- **RELIABLE STELLAR MASSES OUT TO Z ≤ 8**

# SIZE & MORPHOLOGY EVOLUTION

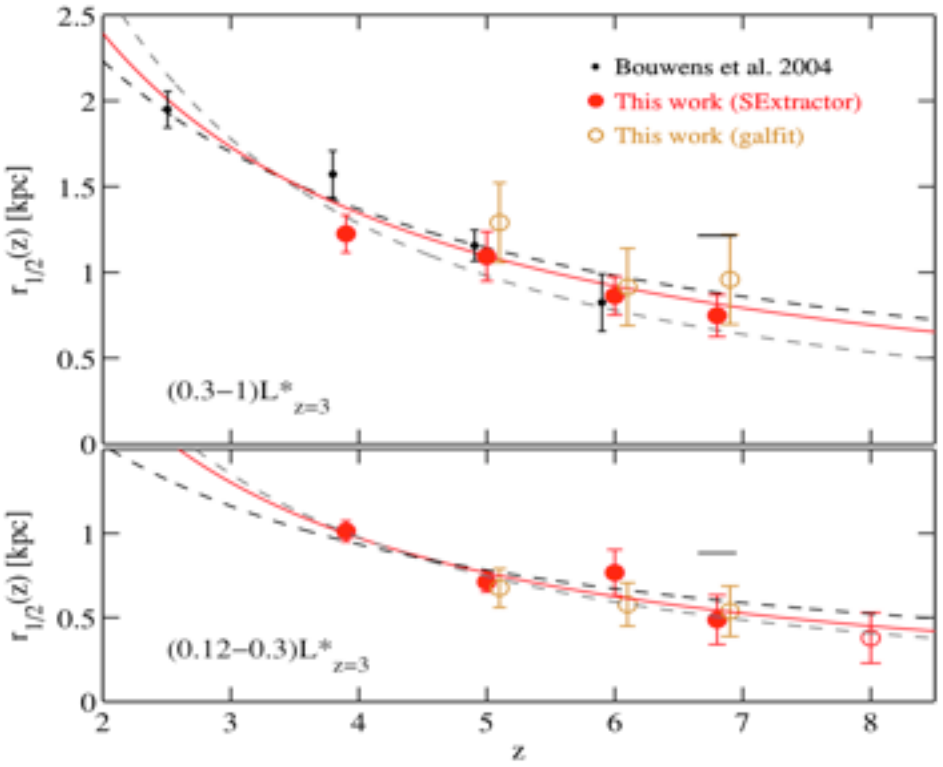



Oech et al. 2010

**WFPC3**
**UV-rest frame**
**Z = 6.8**

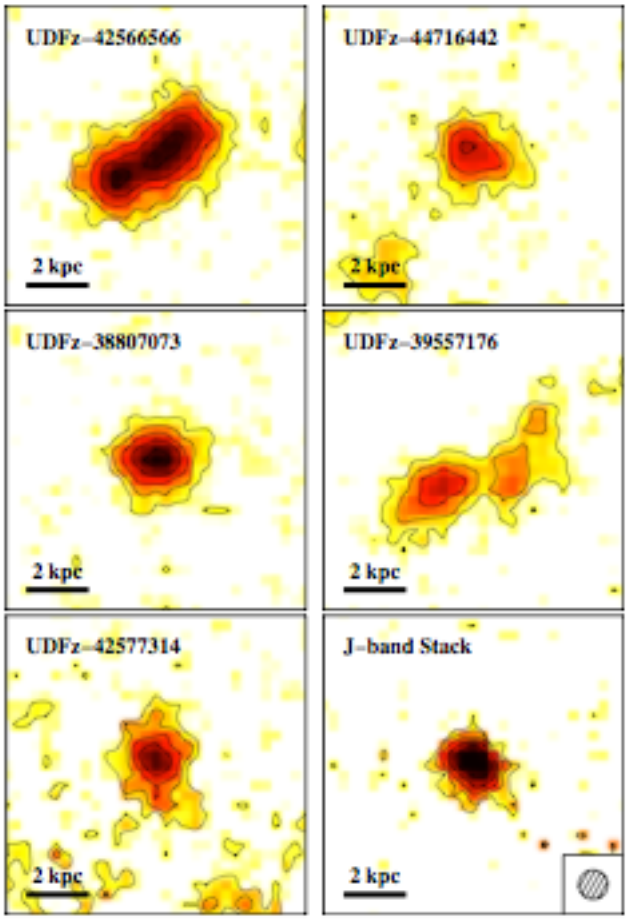


# SIZE & MORPHOLOGY EVOLUTION




Oech et al. 2010

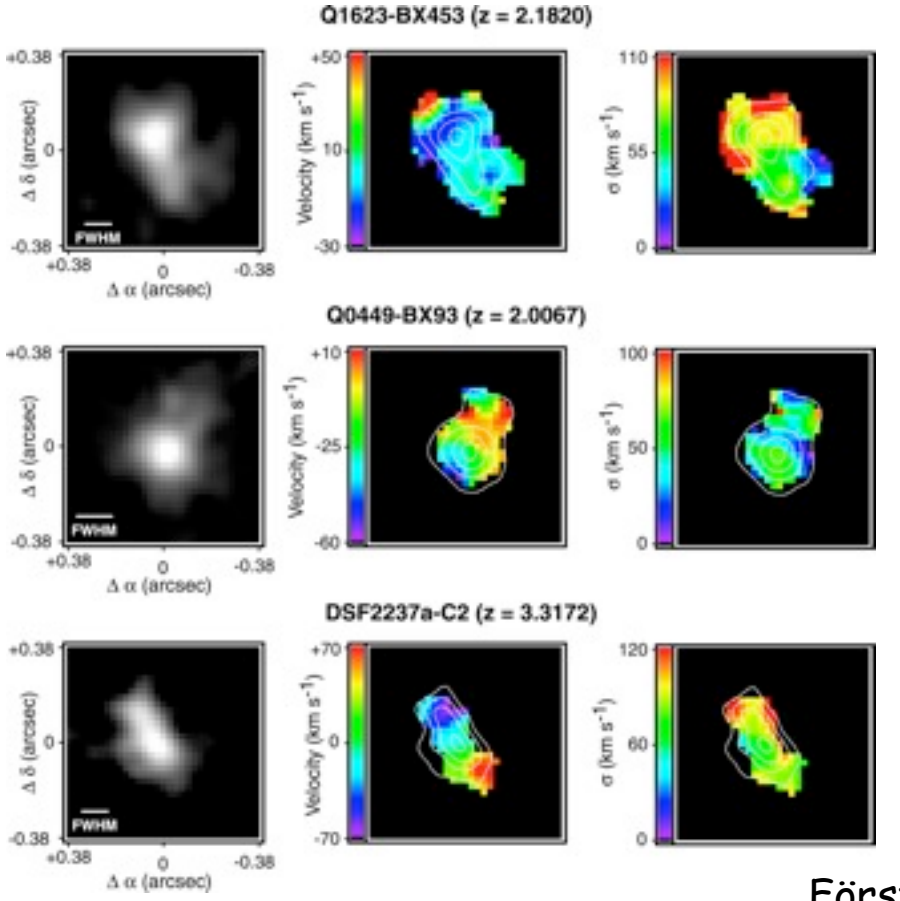
**WFPC3**
**UV-rest frame**
**Z = 6.8**



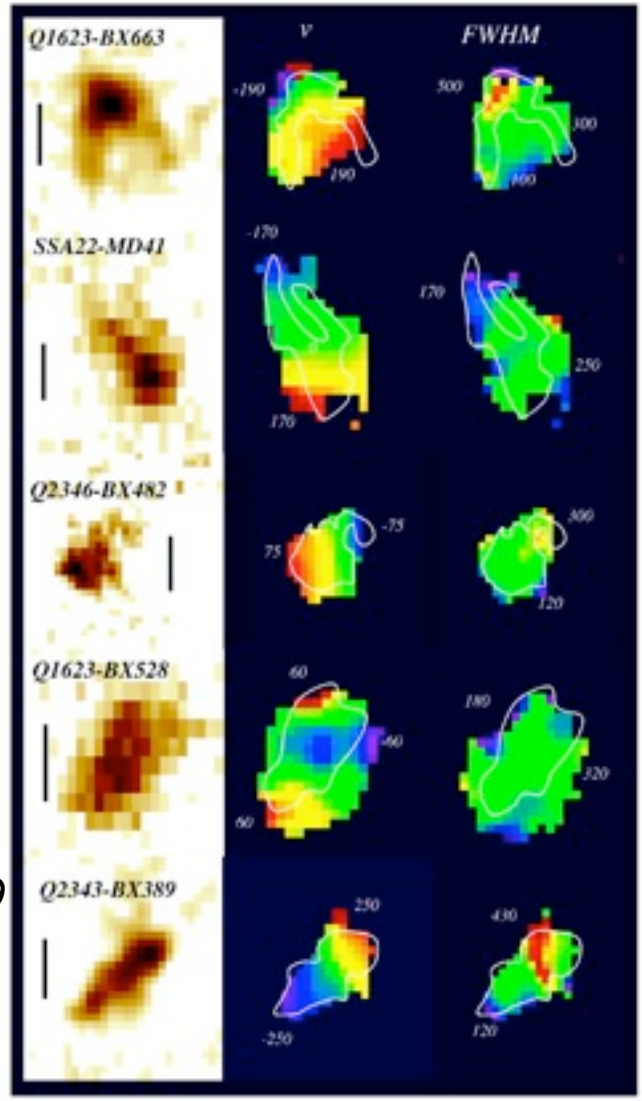

**MIRI: REST-FRAME KPC RESOLVED NIR IMAGING @ Z > 1**

## SIZE AND MORPHOLOGY EVOLUTION

# HIGH-Z STARBURSTS. STRUCTURE AND KINEMATICS

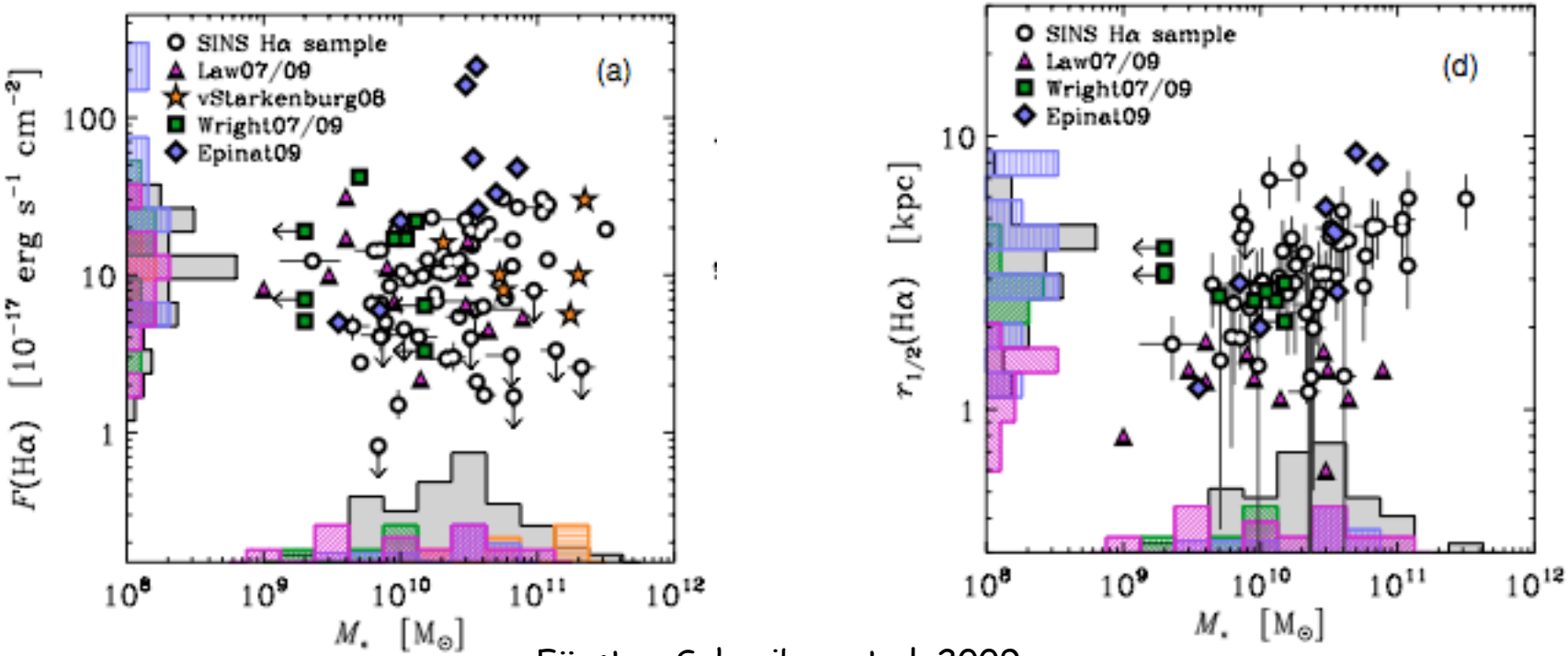



Law et al. 2007
KECK IFS; R= 3600
FWHM = 0.1 arcsec/ 1 kpc




Förster-Schreiber et al. 2009
VLT IFS
R = 3000 (H)-4000 (K)
FWHM = 0.5 arcsec/ 4 kpc

# HIGH-Z STARBURSTS. IFS RESULTS

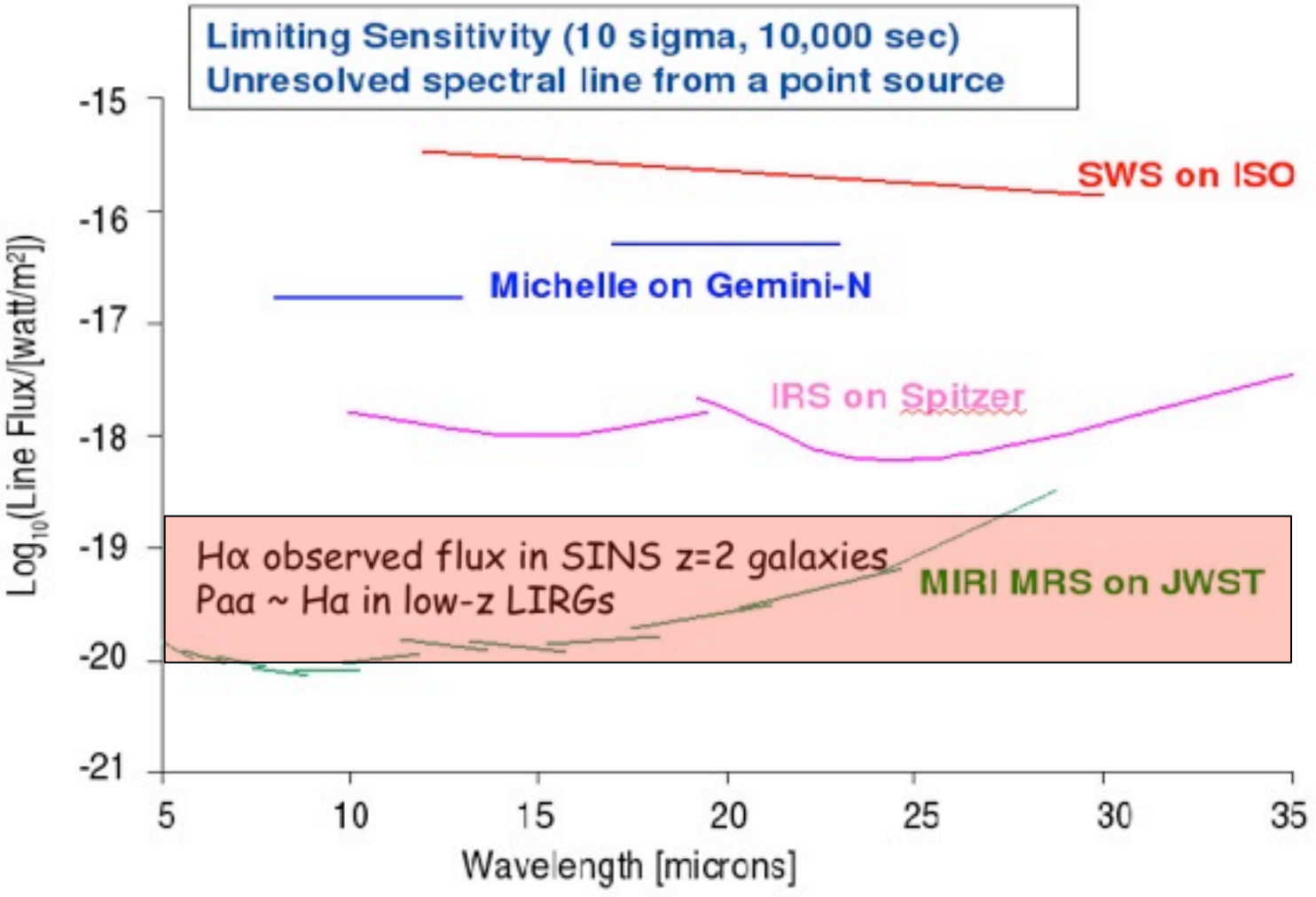



Förster-Schreiber et al. 2009
1.5 < z < 2.5 galaxy populations

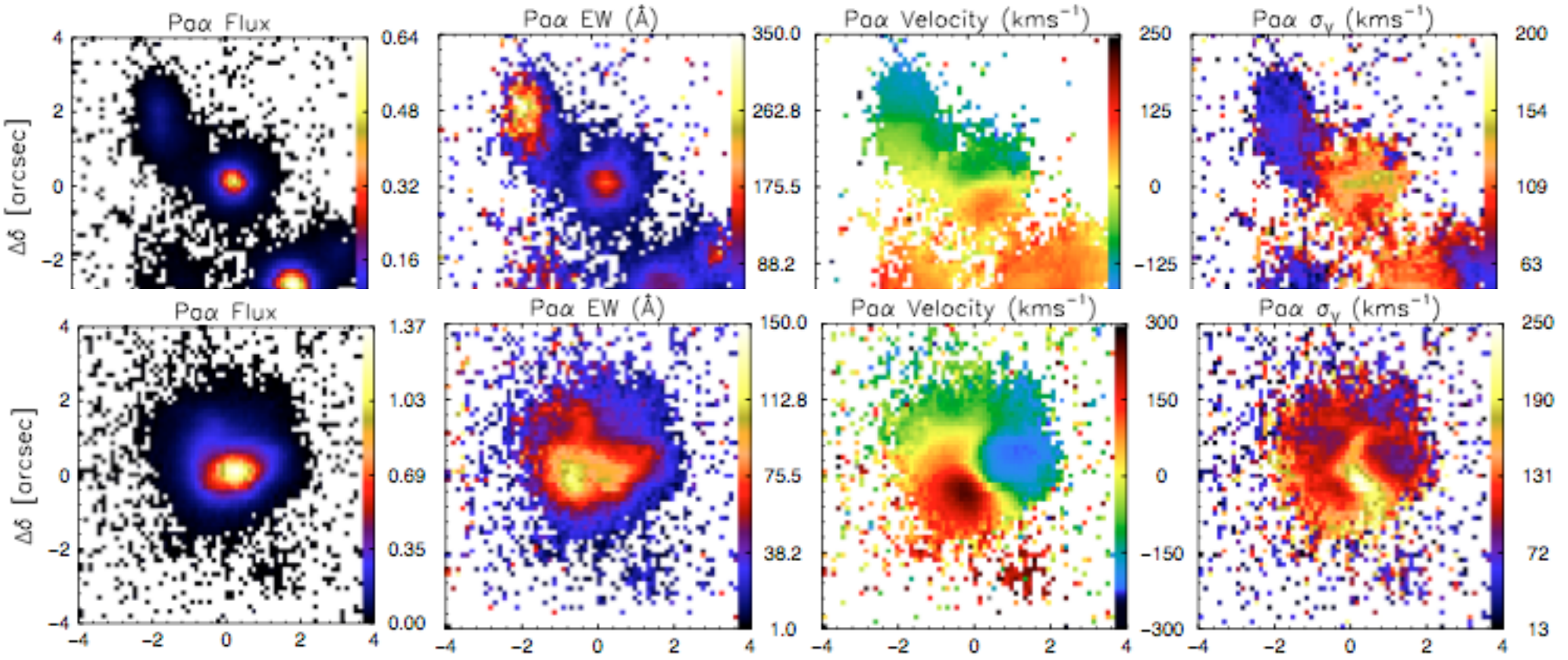
Strongest NIR line (Paα @ 1.87μm) within MIRI spectral range for z > 1.7

Low-z LIRGs: observed Paα flux similar to Hα due to internal extinction (Alonso-Herrero et al. 2006)

# HIGH-Z STARBURSTS. MIRI IFS



# Paα IFS OF HIGH-Z STARBURSTS. STRUCTURE AND KINEMATICS




Piqueras et al. in progress

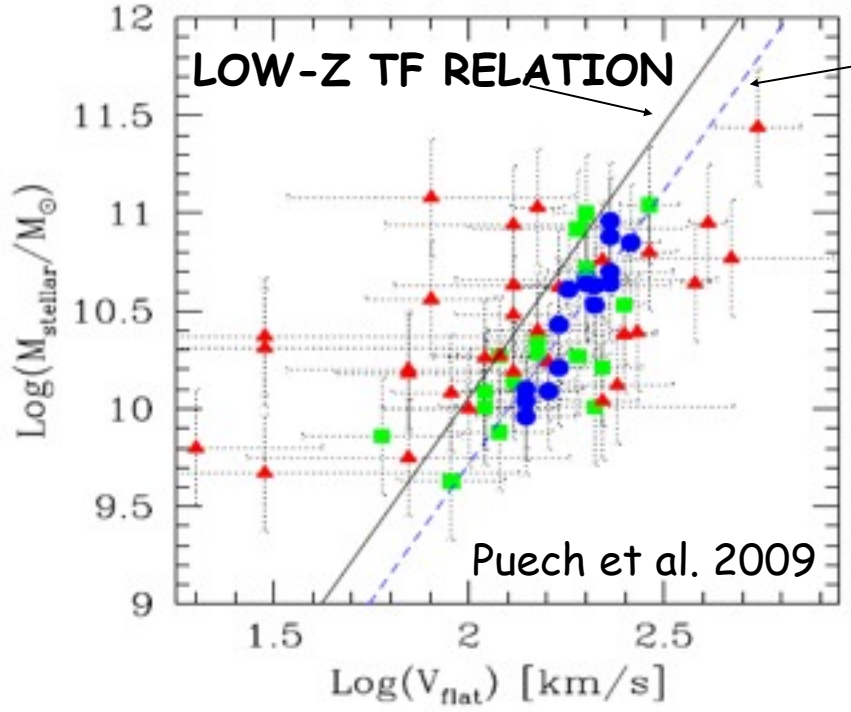
Low-z (U)LIRGs

VLT SINFONI near-IR IFS

R = 4000 (K)

FWHM ~ 1 kpc = MIRI IFS of high-z starbursts

# MIRI & EMERGENCE OF SCALING RELATIONS




ROTATING DISKS
PERTURBED ROTATORS
COMPLEX DYNAMICS

**MIRI:**

**Paα KPC-SCALE GAS KINEMATICS @ Z > 1 IN DUSTY STARBURSTS**
**NEAR-IR BASED STELLAR MASS**

- **from compact spheroidals to extended rotating disks and mergers**

# SUMMARY

- MIRI/JWST unique instrument for science of dusty starbursts at all redshifts:
  - Full 5 to 28 μm spectral range (imaging & spectroscopy)
  - Sub-arcsec angular resolution (similar to ground 8-10m class telescopes)
  - Extremely high sensitivity (10-100x better than Spitzer)

- Low-redshift starbursts & AGNs
  - Detailed physics of dust-enshrouded objects on scales of ≤ 100 pc, or less

- High-redshift galaxies & starbursts
  - Resolved near-IR stellar structure: stellar mass buildup, size & morphology evolution
  - Paα resolved kinematics on kpc scales: scaling relations & galaxy formation