Galaxy Evolution as seen by PACS

E. Sturm
(MPE)
for the SHINING and PEP Teams
Talk by J. Fischer
(Session 8a, Wednesday, 14:00)
Current deep far-infrared data (4’x4’ cutout in UDF region)

Resolved into individually detected sources:
~75% @ 100μm
~75% @ 160μm
The cosmic infrared background resolved

Berta+10,11 Magnelli+13

the contribution of different redshift bins to the CIB, i.e. the fraction of CIB emitted at different cosmic epochs:

At 160 μm half of the resolved CIB originates at z>1
The main sequence of star formation

Star formation rate vs Stellar mass

- Outliers
- Main sequence
- Passive galaxies

Brinchmann+04, Noeske+07, Daddi+07, Elbaz+07, Peng+10, Rodighiero+10, ...
The main sequence of star formation

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Star formation rate vs. Stellar mass

Outliers
Main sequence
Passive galaxies

Z=0

Brinchmann+04, Noeske+07, Daddi+07, Elbaz+07, Peng+10, Rodighiero+10, …
The main sequence of star formation

What controls the position of a galaxy in the SFR-M_* plane?

- Are there different modes of star formation?
  e.g. Gas fractions?
  Star formation efficiencies?

- What is the role of mergers as opposed to secular evolution?

- What different galaxy properties do the different populations in this plane reflect (e.g. sizes, morphology, dust temperature, etc.)?

- What is the role of AGN?
  e.g. Co-evolution?
  Feedback?
  Quenching?

Brinchmann+04, Noeske+07, Daddi+07, Elbaz+07, Peng+10, Rodighiero+10, …
A morphological `main sequence'

Dust temperatures

Elbaz+ 2011, Magdis+ 2012b, Magnelli+ 2013a

- high redshift starbursts above the main sequence show increased dust temperatures
- dust temperature can be expressed as a function of main sequence offset with less scatter and less redshift dependence compared to expressing temperature as a function of IR luminosity.
Galaxies on and above the MS: the “[C II] deficit”

Graciá Carpio+ 2011
Galaxies on and above the MS: the “[C II] deficit”

Objects above MS: enhanced SFE in warm and compact ISM

Talk by J. Graciá Carpio (Session 15, Friday, 10:20)
Poster by A. Contursi (P09, Session A)

Graciá Carpio+ 2011
AGN feedback: Herschel (molecular outflows)

Well studied lensed z=2.29 HLIRG (Sy2) Coeval star formation & AGN
Differential magnification AGN/Host \( \approx 3 \)

Keck: Graham & Liu 95
NICMOS: Evans +99

IRAS F10214+4724
Well studied lensed z=2.29 HLIRG (Sy2) Coeval star formation & AGN
Differential magnification AGN/Host \( \approx 3 \)

MIPS J142824.0+352619

- A hyperluminous "Monster": Extreme Starburst at z=1.325
- no AGN signatures
- Lensed by foreground z\( \approx 1 \) elliptical
AGN feedback: Herschel (molecular outflows)

[\text{O III}] 51.8 \mu m

Sturm+ 2010

Galaxy Evolution as seen by PACS

The Universe Explored by Herschel, ESLAB 2013

12 hours

1.5 hours

Sturm+ 2010
The Luminosity of a ULIRG but the SFE of a normal starforming galaxy.

ULIRG / Merger - like

Sturm+ 2010
High-J CO - A new probe of warm and dense molecular gas

Spaans & Meijerink 2008

Walter & Carilli 2008
The CO Line-SED of NGC1068 from J=0 ...40

SPIRE (Spinoglio +2012)

Galaxy Evolution as seen by PACS

The Universe Explored by Herschel, ESLAB 2013

E. Sturm
The CO Line-SED of NGC1068 from J=0 ...40

- PDR from SF ring (r=1.1kpc), excited by FUV from young stars in the galactic arms
- XDR from CND (r=150 kpc), excited by X-rays from AGN
- XDR from CND (r=150 kpc), excited by X-rays from AGN
- XDR from infalling clump (r=40 pc), excited by X-rays from AGN (or shock from jet interaction) or clumpy cloud torus?

Galaxy Evolution as seen by PACS
High-J CO - A new probe of warm and dense molecular gas

Talk by A. Poglitsch
(Session 10a, Thursday, 10:40)
The role of AGN: co-evolution?
The role of AGN: co-evolution?

L(SF)

L(AGN)

Talk by D. Rosario
(Session 14, Friday, 09:20)

Rosario+ 2012, 2013
Mrk 231

$\Delta v \sim 1,170 \text{ km/s}$

P-Cygni profile with blue-shifted absorption and red-shifted emission

Fischer + 2010

The role of AGN: feedback / quenching?
Galaxy Evolution as seen by PACS

Veilleux+ 2013
Gonzalez Alfonso+ 2012, 2013 in press
Spoon+ 2013

The Universe Explored by Herschel, ESLAB 2013

Talk by M. Melendez
(Session 8a, Wednesday, 14:20)
• Mass loss rates up to \( \sim 1000 \, M_\odot/\text{yr} \sim 5 - 10 \times \text{SFR} \)

• These ULIRG winds will totally expel the cold gas reservoir in the nuclei in about \( 10^6 - 10^8 \) yrs, therefore halting the star-formation activity on the same timescale.

Sturm+ 2011
What drives these outflows?

**Mrk 231** (Sturm+ 2011, González-Alfonso+ 2013 in press):

- **Mass outflow rate:** \( \dot{M} \sim 1000 \, M_\odot \, \text{yr}^{-1} \)
- **Mass loading factor:** \( \dot{M} / \text{SFR} \sim 10 \)
- **Momentum flux:** \( \dot{M} v \sim 13 \, L_{\text{AGN}} / c \) (with \( L_{\text{AGN}} = 2.8 \times 10^{12} \, L_\odot \))
- **Mechanical luminosity:** \( 0.5 \, \dot{M} v^2 = 6 \times 10^{10} \, L_\odot \) (2% of \( L_{\text{AGN}} \))
- **Depletion time:** \( M_{\text{gas}} / \dot{M} : \sim 10 \, \text{Myr} \)

E.g. DeBuhr, Quataert & Ma 2012:

3D SPH simulations of the AGN Wind feedback plus radiation pressure feedback

Momentum flux: \( \dot{p} \sim \tau \, L / c \),

with \( \tau \sim 5-10 \) needed to explain the \( M_{\text{BH}} - \sigma \) relation

ram pressure: \( \tau < 1 \) \( \rightarrow \) energy trapping

Depletion time (\( M_{\text{gas}} / \dot{M} \)) : \( \sim 10 \, \text{Myr} \)
Galaxy Evolution as seen by PACS

(a) IRAS F08572+3915 (10 arcsec)

(b) IRAS F08572+3915 (cen pix)

(c) $-1200 < v (\text{km/s}) < 400$

(d) $4500 < v (\text{km/s}) < 1100$

(e) Cione+ in prep

(f) $100-200$
Galaxy Evolution as seen by PACS

(a) IRAS F08572+3915 (10 arcsec)

(c) $-1200 < v (\text{km/s}) < -400$

(d) $4600 < v (\text{km/s}) < 11000$

(e) $v [\text{km/s}]$

IRAS F08572+3915
$z=0.058210$

$119 \mu \text{m}$

$79 \mu \text{m}$

$65 \mu \text{m}$

$\uparrow \text{OH} \uparrow$

$\uparrow ^{18}\text{OH} \uparrow$

$\text{H}_2\text{O} \quad 4_{23} - 3_{12} \quad \text{H}_2\text{O} \quad 6_{15} - 5_{24} \quad \uparrow \text{OH} \uparrow$

$\text{H}_2\text{O}$
SUMMARY

Different modes of star formation:
- merger-like, higher SFE vs.
- smooth accretion, normal SFE

A morphological main sequence

Role of AGN / Co-Evolution:
Secular evolution more important at high z

Role of AGN / Feedback & Quenching:
“Caught-in-the-act” negative feedback from radiation driven, molecular outflows in AGN-dominated ULIRGs
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“Caught-in-the-act” negative feedback from radiation driven, molecular outflows in AGN-dominated ULIRGs

Secular evolution more important at high z