HerCULES
Herschel Comprehensive (U)LIRG Emission Survey

Paul van der Werf
Leiden Observatory

ESAC
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Credits!

- Data processing: Trevor Fulton
  Kate Isaak
  Adam Rykala

- Modeling: Rowin Meijerink
  Marco Spaans
  Edo Loenen
  Eduardo Gonzalez-Alfonso
  Axel Weiß

NB: data taking December 13
data processing December 14-17
modeling December 18
this talk December 19
HerCULES in a nutshell

HerCULES will uniformly and statistically measure the neutral gas cooling lines in a flux-limited sample of (U)LIRGs.

Sample:
- all IRAS RBGS ULIRGs with $S_{60} > 12.19$ Jy (6 sources)
- all IRAS RBGS LIRGs with $S_{60} > 16.8$ Jy (23 sources)

Observations:
- SPIRE/FTS full high-resolution scans: 200 to 670 μm at $R \approx 600$, covering CO 5–4 to 13–12 and [CI] (+ other lines?)
- PACS line scans of [CII] and both [OI] lines
- All targets observed to same (expected) S/N
- Extended sources observed at several positions
Who is HerCULES?

Paul van der Werf (Leiden; PI)
Susanne Aalto (Onsala)
Peter Ade (Cardiff)
Lee Armus (Spitzer SC)
Vassilis Charmandaris (Crete)
Kalliopi Dasyra (CEA)
Aaron Evans (Stony Brook)
Jackie Fischer (NRL)
Yu Gao (Purple Mountain)
Eduardo Gonzalez-Alfonso (Henares)
Thomas Greve (MPIA)
Rolf Güsten (MPIfR)
Andy Harris (U Maryland)
Chris Henkel (MPIfR)
Kate Isaak (Cardiff)
Frank Israel (Leiden)
Carsten Kramer (Cologne)
Edo Loenen (Leiden)
Steve Lord (NASA Herschel SC)

Jesus Martín-Pintado (Madrid)
Joe Mazzarella (IPAC)
Rowin Meijerink (Leiden)
David Naylor (Lethbridge)
Padelis Papadopoulos (Bonn)
Sabine Philipp (DLR)
Adam Rykala (Cardiff)
Dave Sanders (U Hawaii)
Giorgio Savini (Cardiff)
Howard Smith (CfA)
Marco Spaans (Groningen)
Luigi Spinoglio (Rome)
Gordon Stacey (Cornell)
Sylvain Veilleux (U Maryland)
Cat Vlahakis (Leiden)
Fabian Walter (MPIA)
Axel Weiss (MPIfR)
Martina Wiedner (Paris)
Manolis Xilouris (Athens)
Aims of HerCULES

- develop use of the CO rotational ladder as a diagnostic
- inventory of neutral gas cooling
- statistically robust approach
- low-z benchmark for future ALMA observations
PDRs vs. XDRs

- Identical incident energy densities give very different CO spectra
- Very high J CO lines are unique XDR tracers
- Need full coverage of CO ladder in real galaxies

(Spaans & Meijerink 2008)
Cooling budget in Mrk231

- CO cooling from the dense phase approaches [C II] cooling
- Consistent with dense PDRs
- Solution to the [C II] problem
- Full understanding crucial in ALMA era
A local benchmark for high-z galaxies

- Even in ALMA era, often limited spatial resolution on very high z galaxies, but many lines available
- HerCULES will provide an empirical framework for interpreting these data.

(Walter, Weiß et al.)
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<th>log($L_{IR}/L_\odot$)</th>
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HerCULES SDP

- 1 target observed in SDP: Mrk231 (SPIRE/FTS only)
- 18 lines detected at good S/N
- FTS sensitivity better than expected by factor 2
The bottom line

- CO lines in Mrk231 require PDR (low-J lines) + XDR (high-J lines)

- Modeling CO lines enables separation of starburst and AGN contribution to $L_{IR}$
Mrk231
SPIRE
FTS

unidentified lines?
Mrk231 CO excitation

$^{12}\text{CO}$ flux density Mrk231

- Solomon 97
- Downes 98
- Papadopoulos 07

Weiß, yesterday
Mrk231 PDR/XDR separation

Quantitative separation of starburst and AGN as power source!

(Meijerink, Spaans & Loenen, yesterday)
Water lines

- All water lines are in emission

- Water lines IR-pumped, provides constraints on the continuum as well as on emitting medium

- Best-fitting model:
  - warm component: $T=100$ K, $R=100$ pc (56% of $L_{\text{IR}}$)
  - cool component: $T=47$ K, $R=350$ pc (22% of $L_{\text{IR}}$)
  - $M(H_2)_{\text{warm}} \approx 0.1 \, M(H_2)_{\text{cool}}$
  - emitting gas and dust mixed

(Gonzalez-Alfonso, yesterday)
To be done

- Improved FTS processing to get to thermal noise
- Modeling extreme PDR to reproduce maximum number of CO lines
- Verify and identify unidentified lines
- Go really deep with the FTS on a number of targets
- Compare/coordinate with PACS
- Follow-up H₂O lines (and others?) with HIFI
Conclusions

- CO lines in Mrk231 require PDR (low-J lines) + XDR (high-J)
- Modeling CO lines enables separation of starburst and AGN contribution to $L_{\text{IR}}$
- New template for high-z galaxies including H$_2$O lines!
- Water lines IR-pumped, helps constrain physical models
- 7 unidentified lines?
- Stay tuned for more!