



A Conference in honour of Bob Fosbury

Infrared Spectroscopy of Active Galaxies

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ESO (Emeritus)



Overview

- Historical introduction to [CII]156 μ m and other far infrared fine structure lines
- Near infrared spectroscopy of galaxies at ESO
 - Nuclear starbursts
 - Coronal lines in AGN
 - High z galaxies
- Mid- Far Infrared spectroscopy of galaxies from space at with ESA's ISO
 - AGN line profiles
 - Starburst vs AGN luminosity in (U)LIRGS
 - Nuclear UV SEDs from infrared emission line spectra
 - Brief update of SPITZER & Herschel



IR Fine Structure lines in the ISM

(Moorwood, A: 1966, The temperature of interstellar gas clouds in regions of neutral hydrogen, unpublished UCL Undergraduate Thesis supervised by M. Seaton who first suggested that far IR FS lines could be the dominant source of ISM cooling in 1955!)

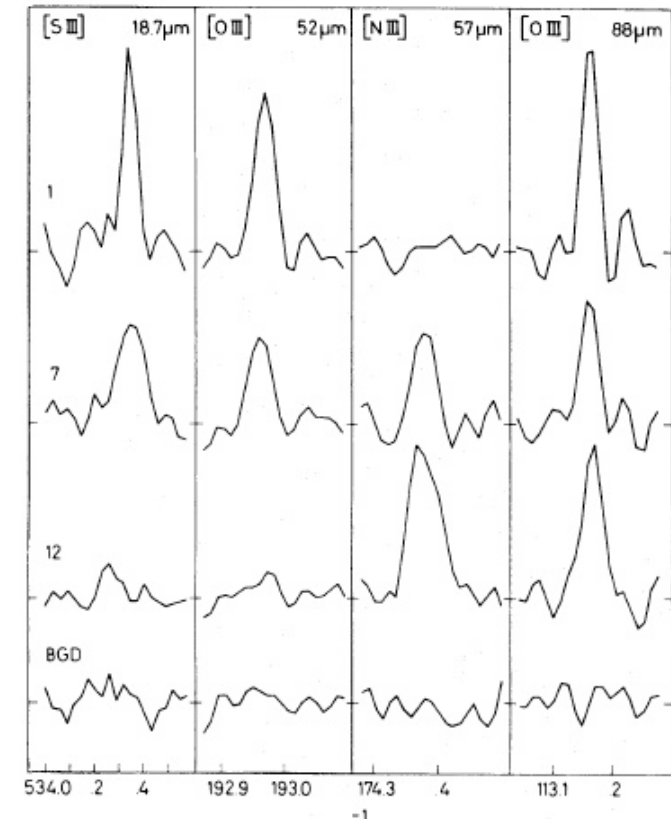
- The observed 21cm line radio emission from clouds of neutral H is consistent with
 - Heating to $\sim 3000\text{K}$ by cloud - cloud collisions (Kahn model)
 - Interpretation of the measured 21 cm temperature of $\sim 125\text{K}$ as the harmonic mean temperature
 - Cooling predominantly by the [CII](156 μm), [CaII] (34 μm) and other fine structure lines excited by H - ion collisions.
 - ❖ possibly by H₂ below 100K

Join UCL newly formed IR astronomy balloon group to measure the [CII] line for PhD thesis ?

Detection of far IR fine structure lines of [SIII]18.7 μ m; [OIII] 52&88 μ m; [NIII]57 μ m with the ESTEC/Meudon Michelson on the KAO



M17



Moorwood, A. F. M.; Baluteau, J.-P.;
Anderegg, M. et al; 1980, Ap.J., 238 ,
565

The UCL/ESA hunt for far infrared fine structure lines with balloon and aircraft borne telescopes

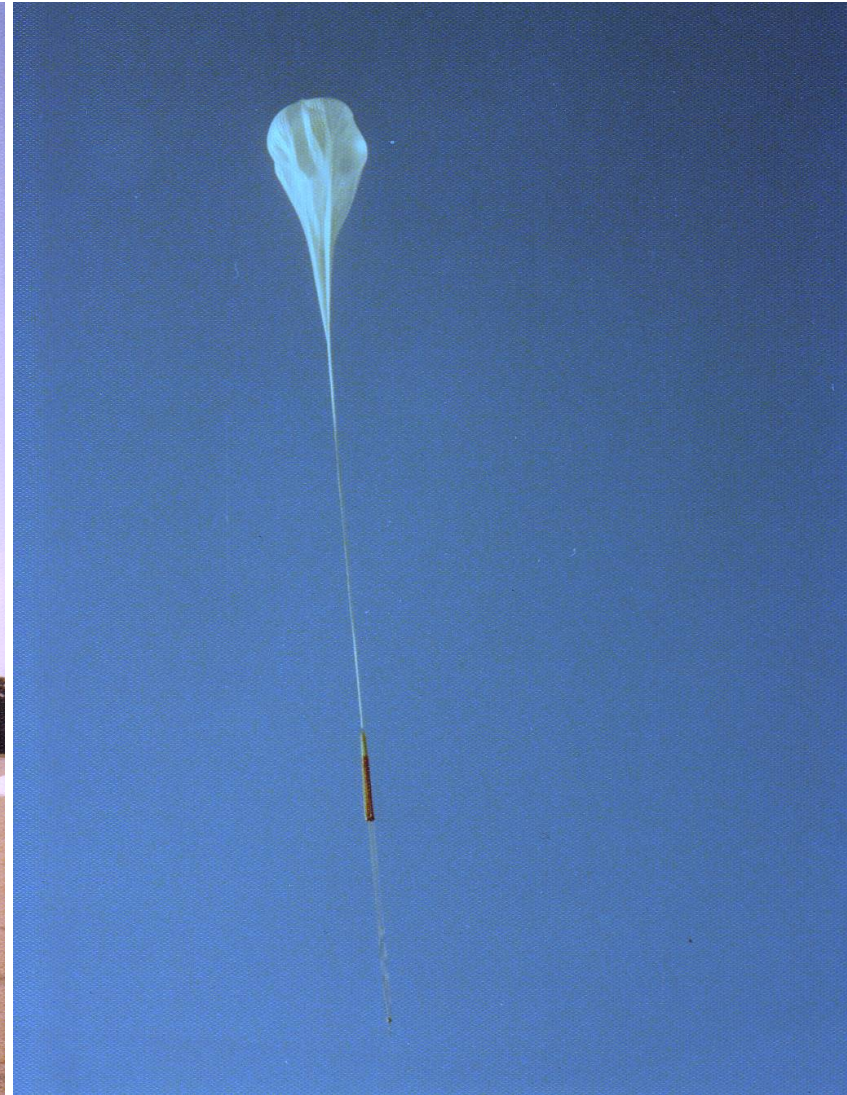
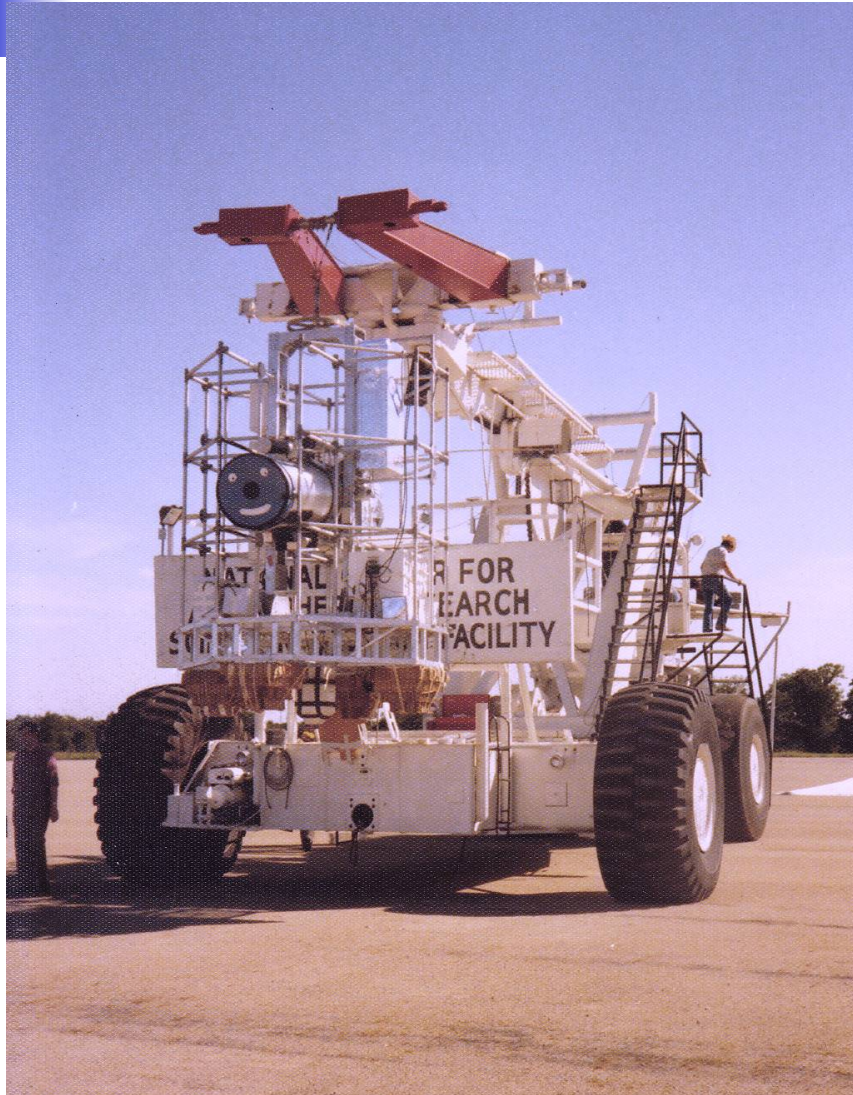
Maiden 1976 flight of UCL
60cm telescope + ESTEC
Michelson from Palestine Texas

- Battery failed during ascent
- Parachute failed during descent
- Police alerted by a bemused fisherman about half buried alien spaceship on an island in the Mississippi

Time to switch to
groundbased astronomy?



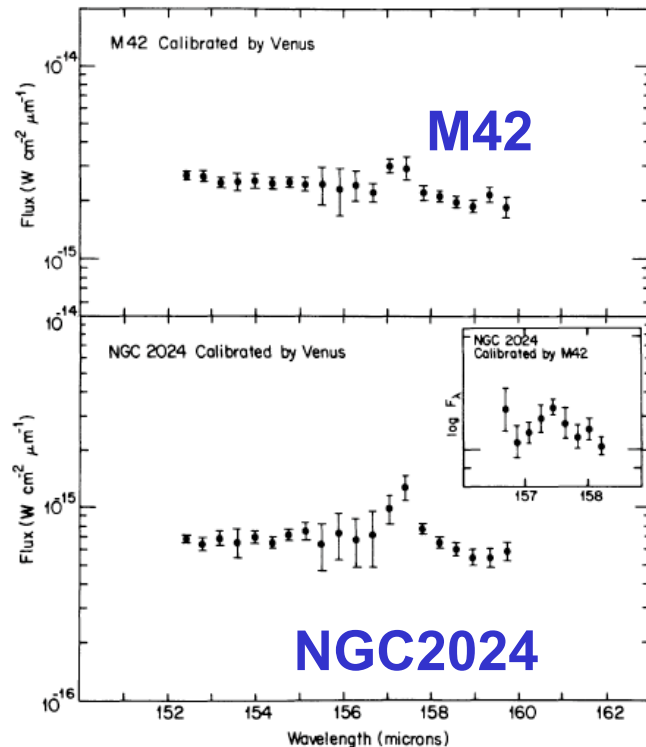
**Far IR spectroscopy of HII regions with ESTEC/Meudon
Michelson on 60cm UCL balloon-borne telescope in 1978**
(with Jennings et al. at UCL, P. Salinari, M. Anderegg)



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1st detection of [CII](157 μ m) from Lear Jet



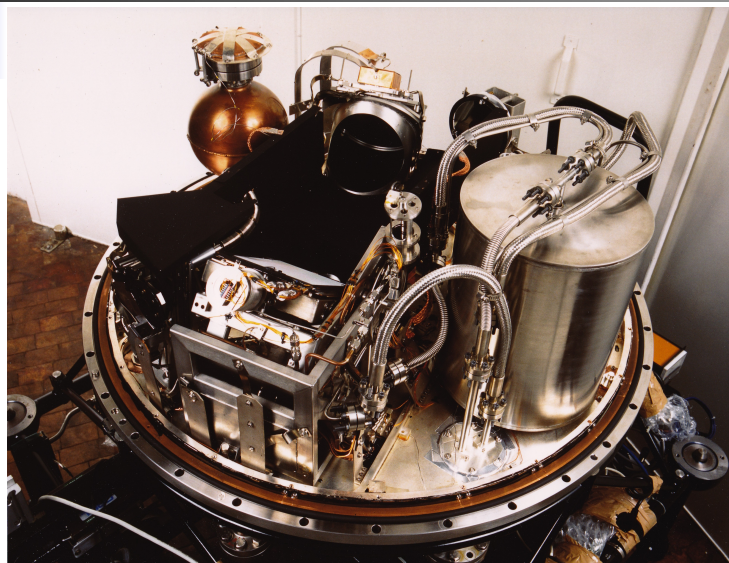
R. Russel, G. Melnick, G. Gull, M. Harwit: 1980, ApJ, 240, L103

Emission from HII regions - not low density HI clouds

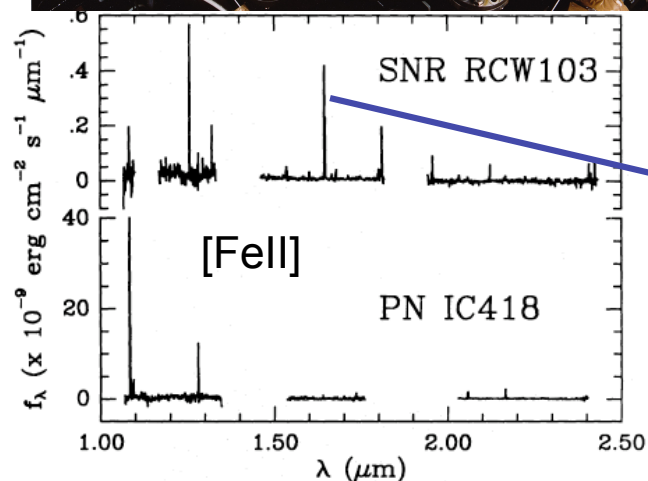
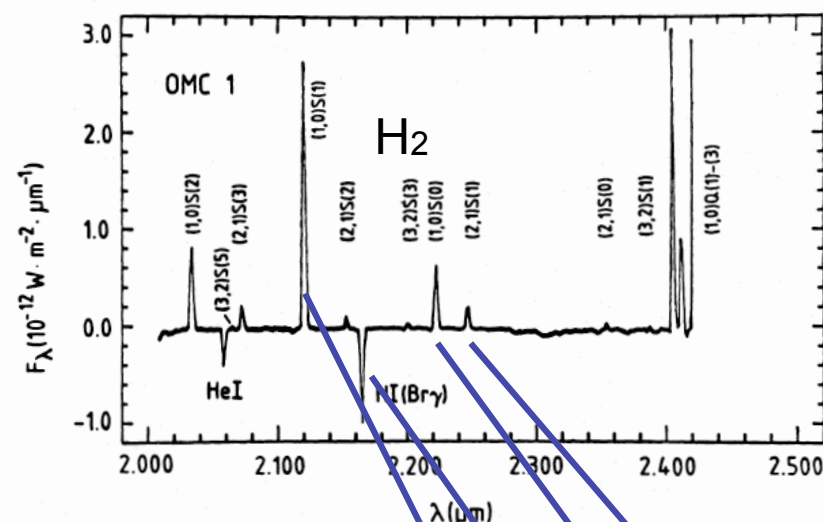
The [CII] industry!

- COBE (brightest diffuse line), KAO (nearby galaxies), ISO (ULIRGS)
- APEX (Maiolino, BOB) high z galaxies
- Herschel, LIRGS+
- ALMA for detection of milky way galaxies up to $z \sim 3$ and ULIRGS at $z > 8$ galaxies with band 5 (if implemented) ?

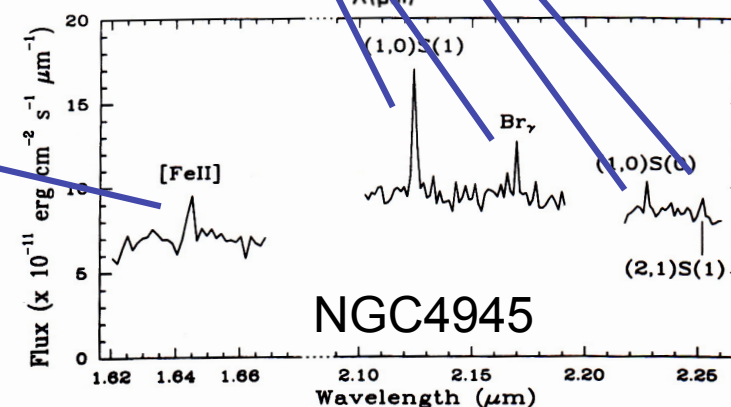
IRSPEC spectroscopy of ~ 40 starburst galaxies/AGN & templates of molecular clouds, HII regions PN and SNR



Oliva, E, Moorwood, A.F.M., 1988,
A&A., 197, 261



E. Oliva, A.F.M. Moorwood and I.J.
Danziger, 1990, A&A, 249, 453

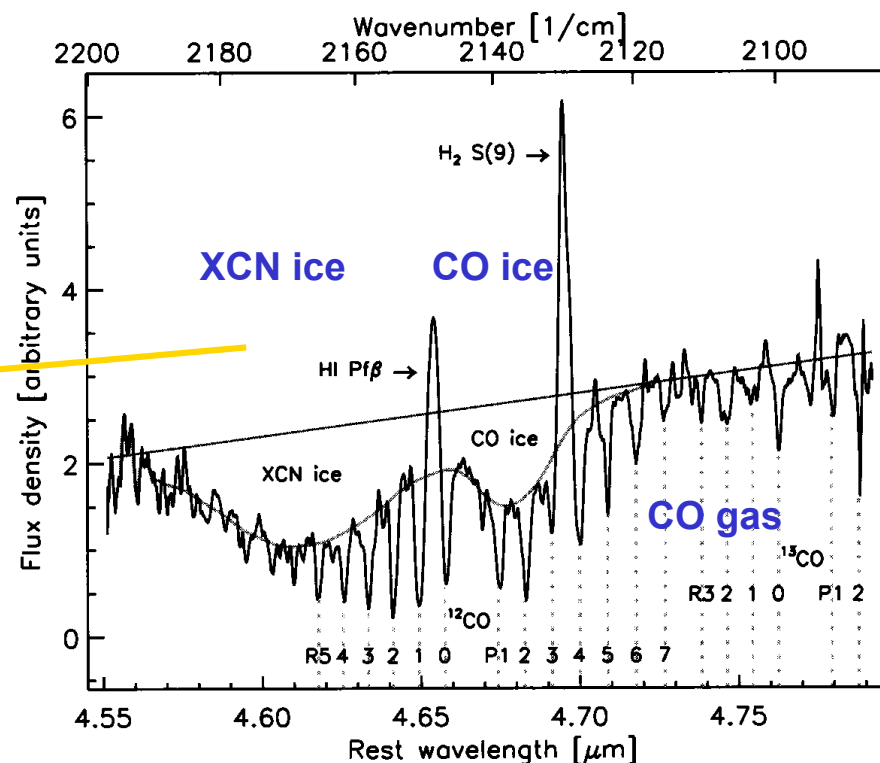
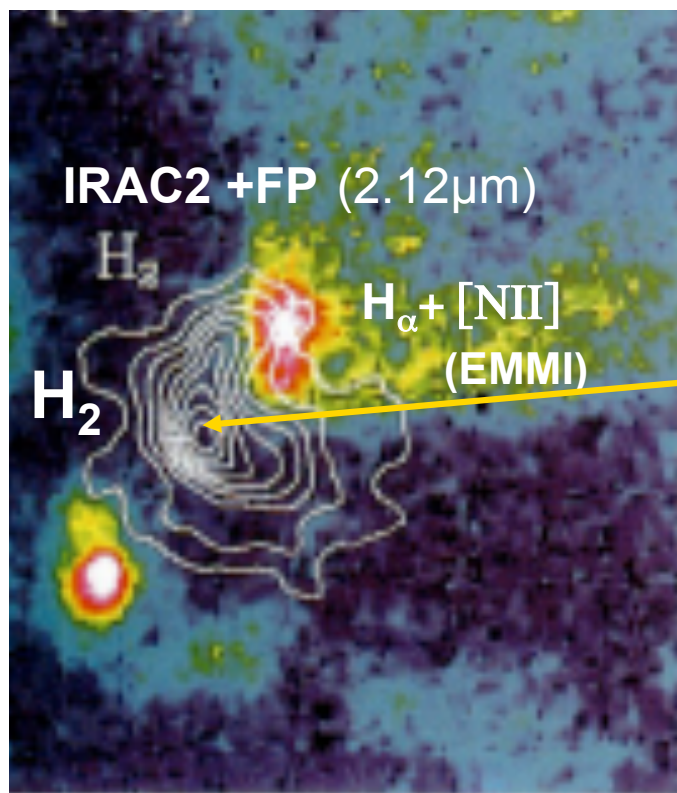


Moorwood, A & Oliva, E.,
1988, A&A, 203,278

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IRAC2 & ISAAC/VLT spectroscopy of molecules towards the highly obscured ($A_V \sim 2500$) hard x-ray AGN in NGC4945



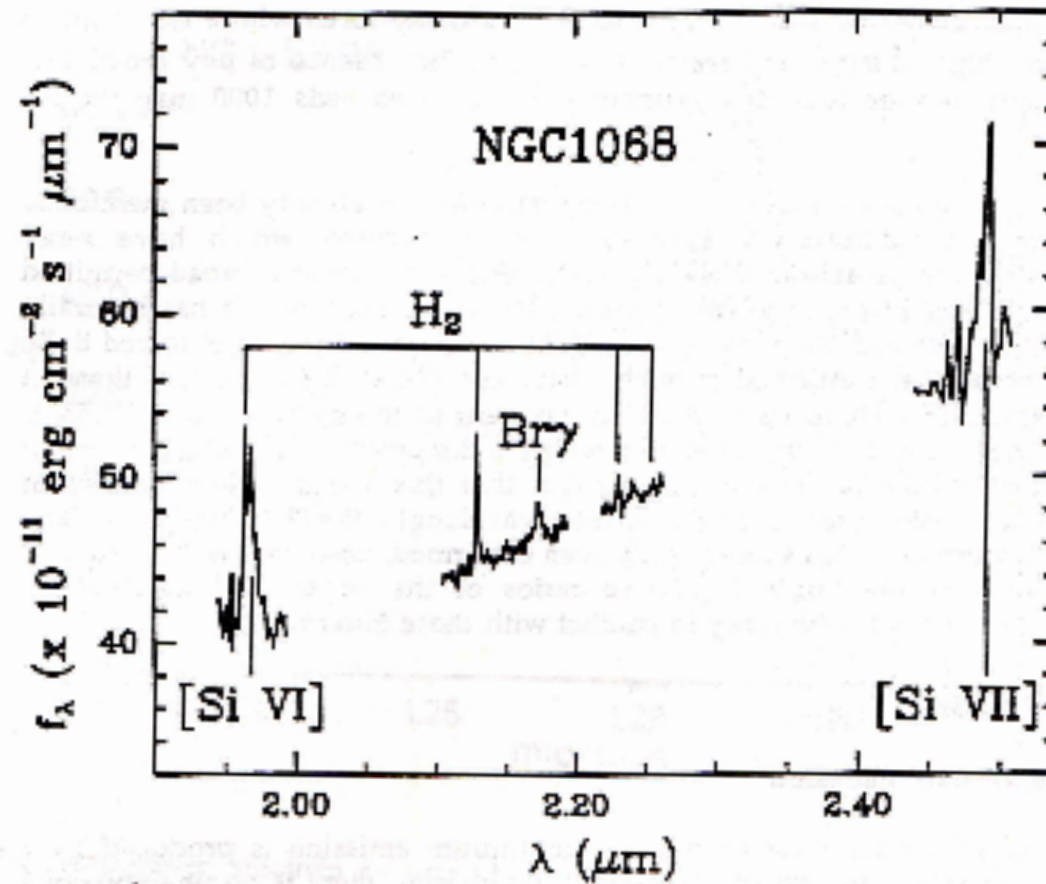
A.F.M. Moorwood, P.P. van der Werf, J.K. Kotilainen, A. Marconi, E.Oliva. 1996, A&A, 308, L1

Galaxies Near and Far, May 2011

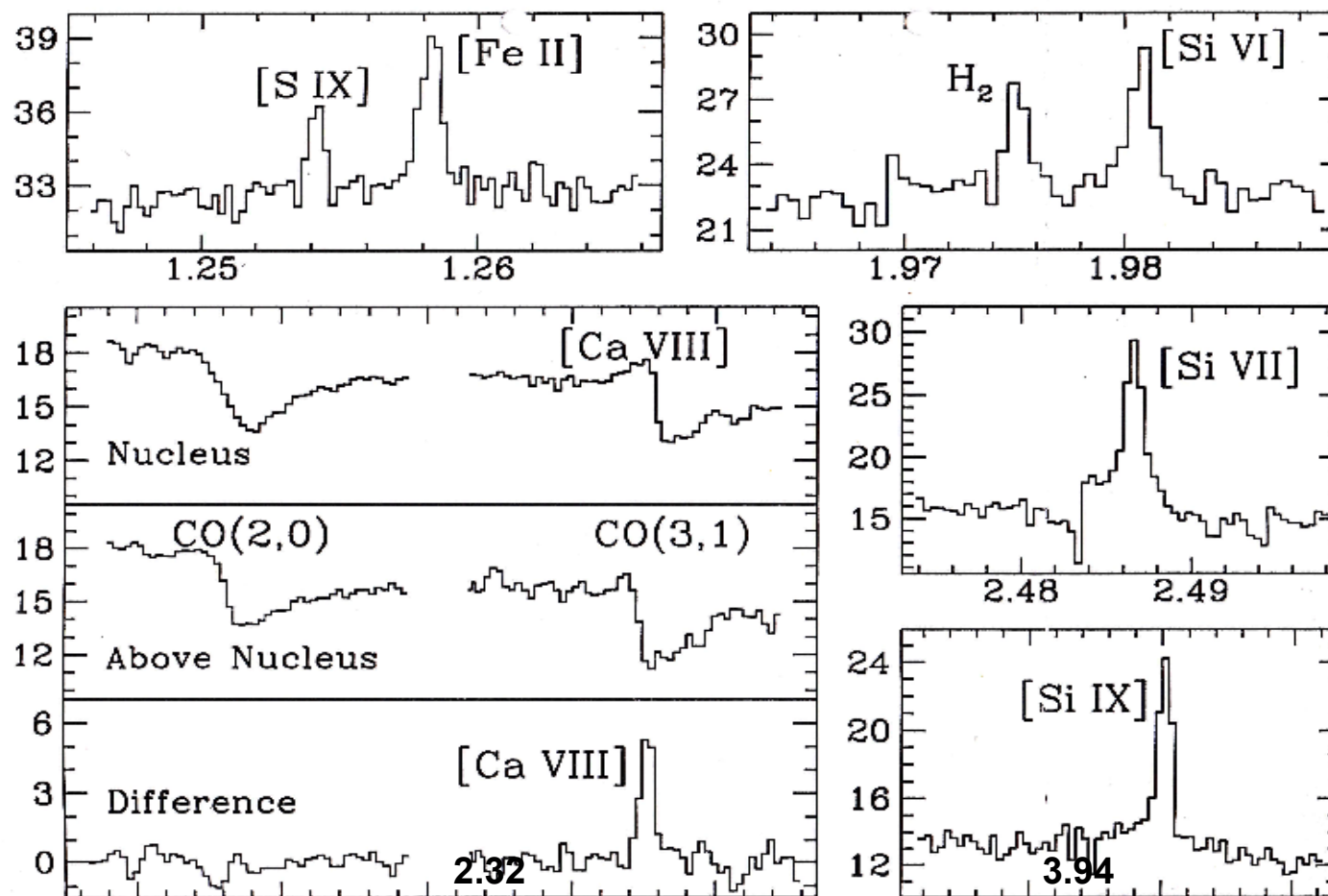
(H.Spoon, A. Moorwood, K. Pontoppidan, J.Cami, J.Kregel, D.Lutz, A.Tielens: 2003, A&A, 402, 499

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Discovery of Infrared [SiVI, VII] coronal lines in NGC 1068
with IRSPEC (Oliva, E., Moorwood, A.F.M.: 1990, Ap.J., 348, L5)



More infrared [S IX], [Si VI, VII, IX], [Ca VIII] Coronal lines in the Circinus galaxy



E.Oliva, M. Salvati, A.F.M. Moorwood, A. Marconi: 1994, A&A, 288, 457

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Blueshifts and asymmetries of high excitation optical lines in AGN

- AGN emission lines show asymmetries and blueshifts relative to the systemic velocity which increase with ionization potential

(Grandi, S.A: 1977, BAAS and Ap.J., 215, 446; Heckman, T.M. et al: 1981, Ap.J., 247, 403; Pelat, D., Alloin, D., Fosbury, R.A.E.: 1981, MNRAS, 195, 787; Penston, M.V., Fosbury, R.A.E et al. 1984, MNRAS, 208, 347)

- Highly (photo) ionized gas near to nucleus.
Blueshifts due to

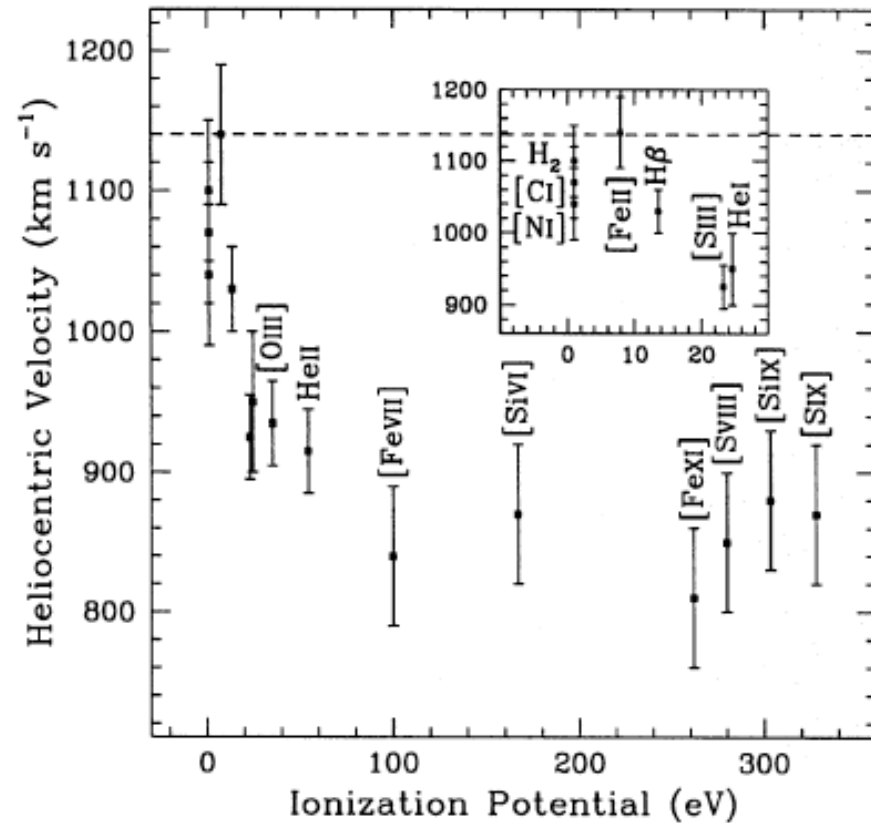
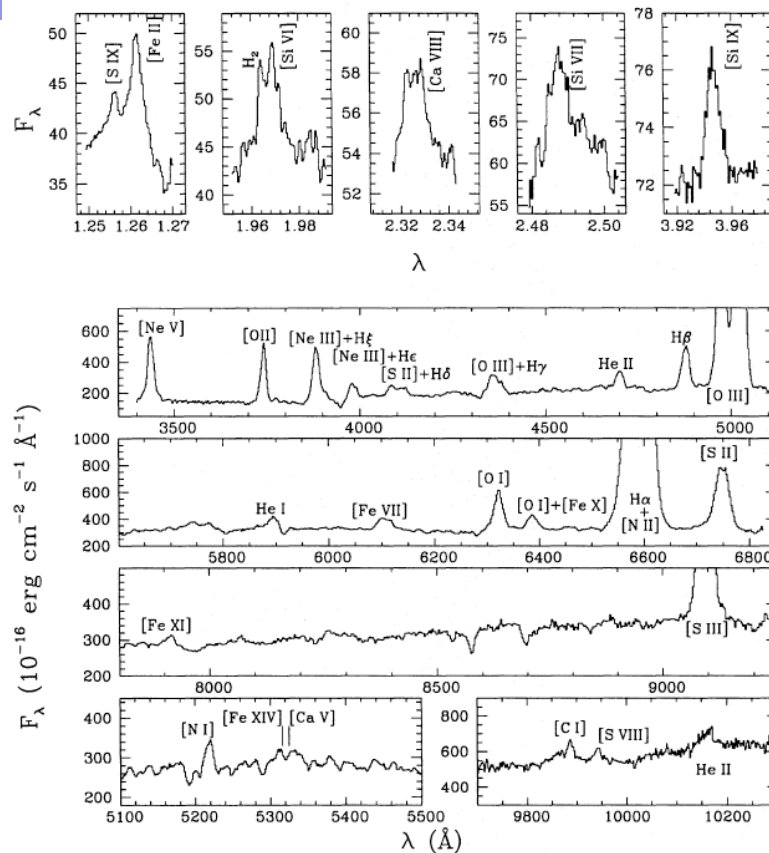
- Decelerating outflow - highest ionization species closest to nucleus experience fastest outflow - ionized clouds embedded in dusty medium which absorbs part of redshifted emission

- redshifted gas partially obscured by small (~few pc) optically thick absorber (molecular torus?)

or

- Infalling clouds where far inner side of clouds less obscured by dust within the ionized clouds

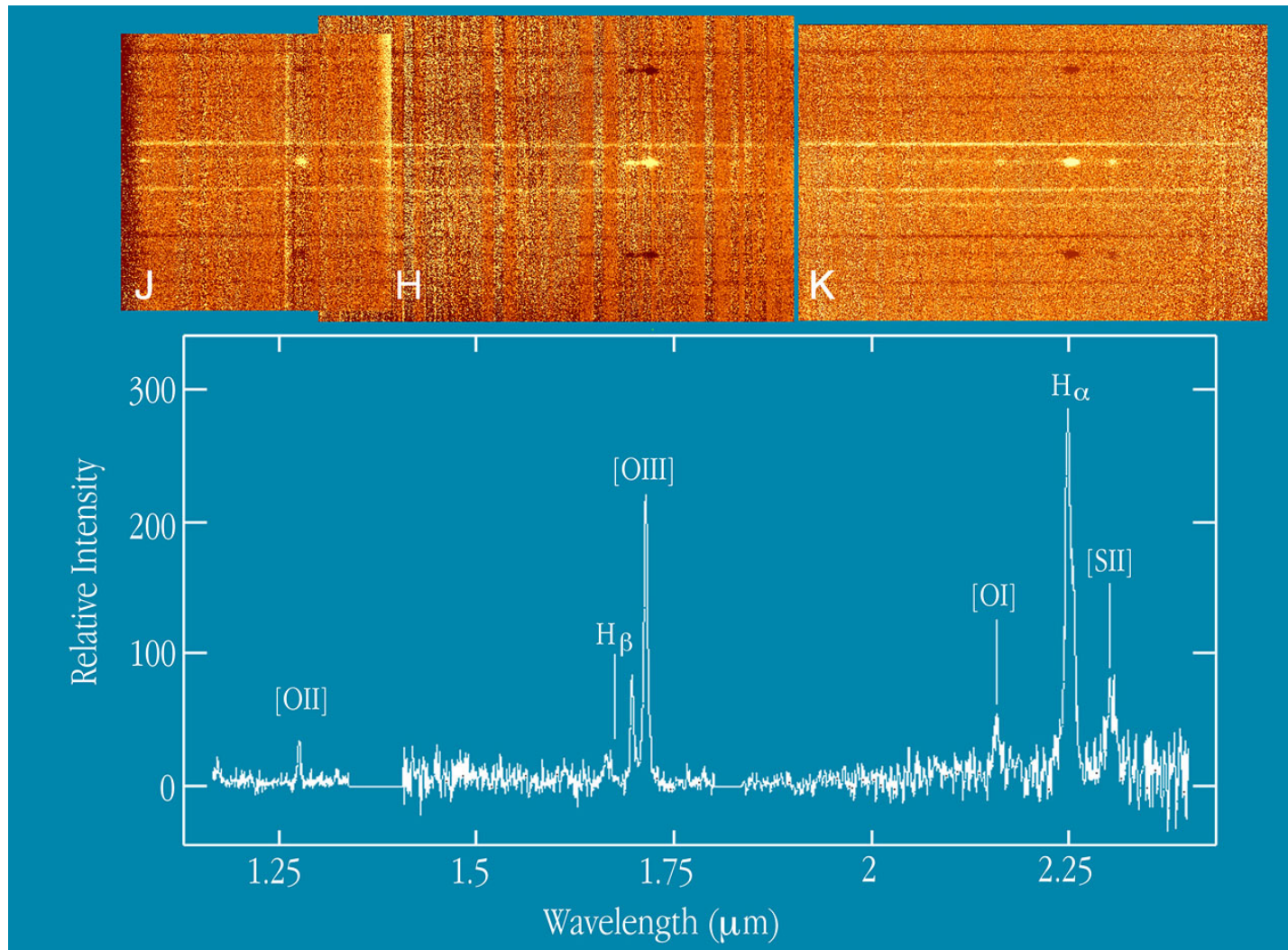
Visible and infrared coronal lines in NGC1068



A. Marconi, P.P. van der Werf, A.F.M. Moorwood, E.Oliva 1996,,A&A,315, 355

■ Blueshifts are dependent on ionization potential but
NOT wavelength ruling out distributed dust extinction models

ISAAC 1-2.5 μm spectrum of MRC0406-244 at $z = 2.4$



What's at the end of the rainbow?



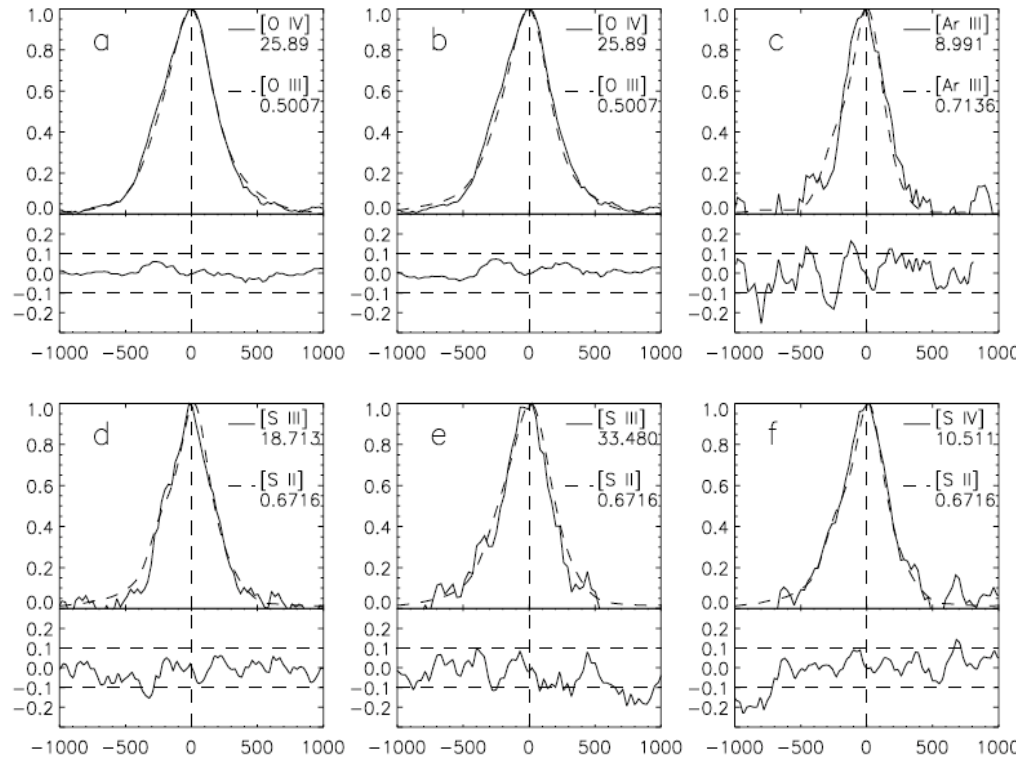
ISO



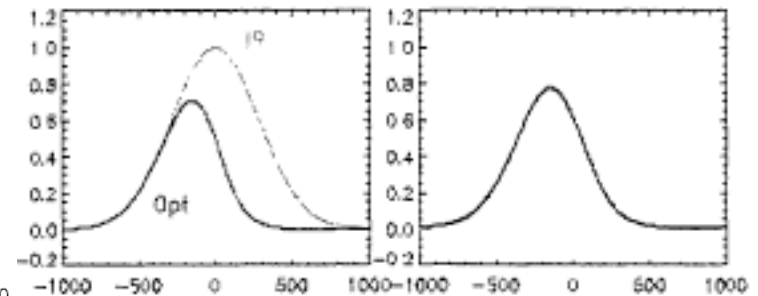
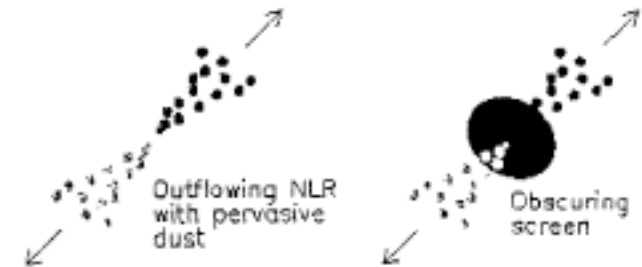
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Profiles of visible and mid-IR lines in NGC4151



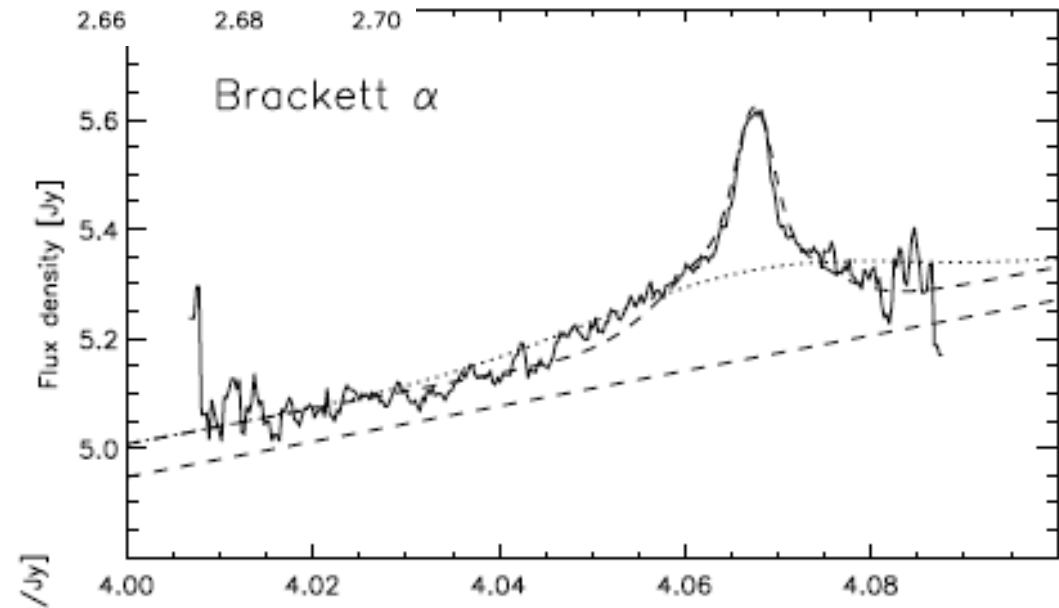
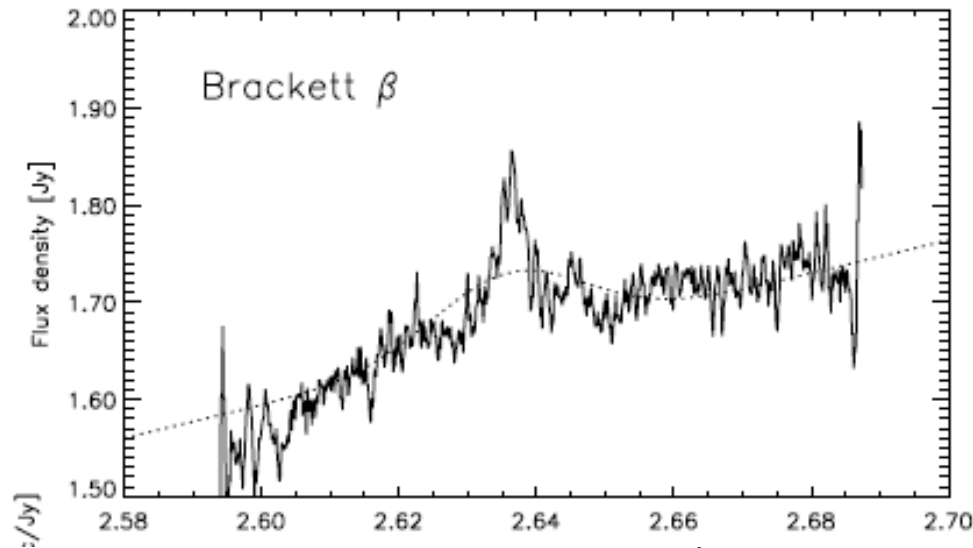
E. Sturm et al. 1999, Ap.J., 512,



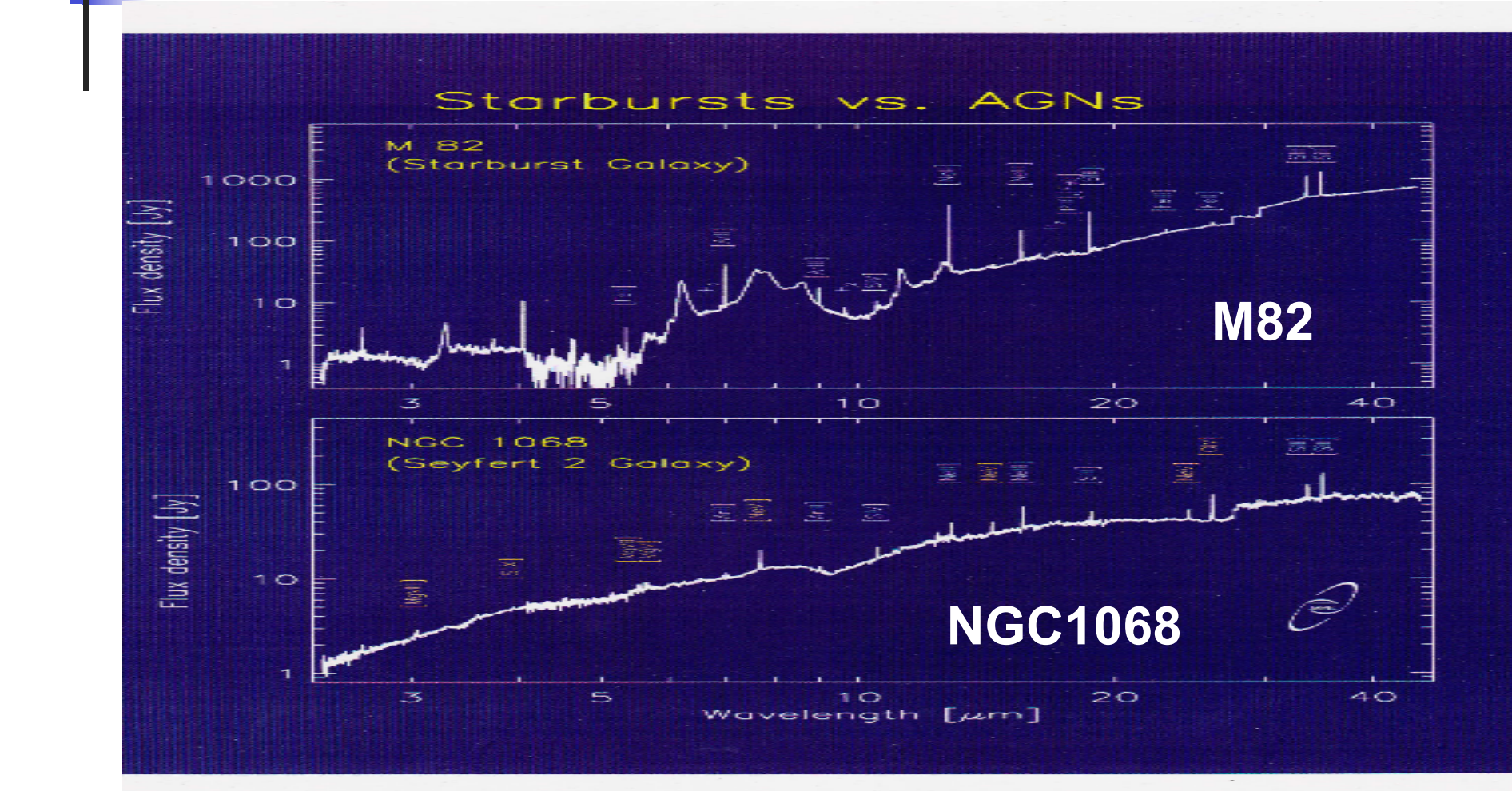
Identical profiles of [OIV](25.9 μ m)/[OIII](0.5 μ m); [ArIII](8.99 μ m)/[ArII](0.71 μ m); [SIII](18.7 μ m)/[SII](0.67 μ m); [SIV](10.5 μ m)/[SII](0.67 μ m)

Obscuring screen $\sim 0.7''$, possibly molecular disc/torus

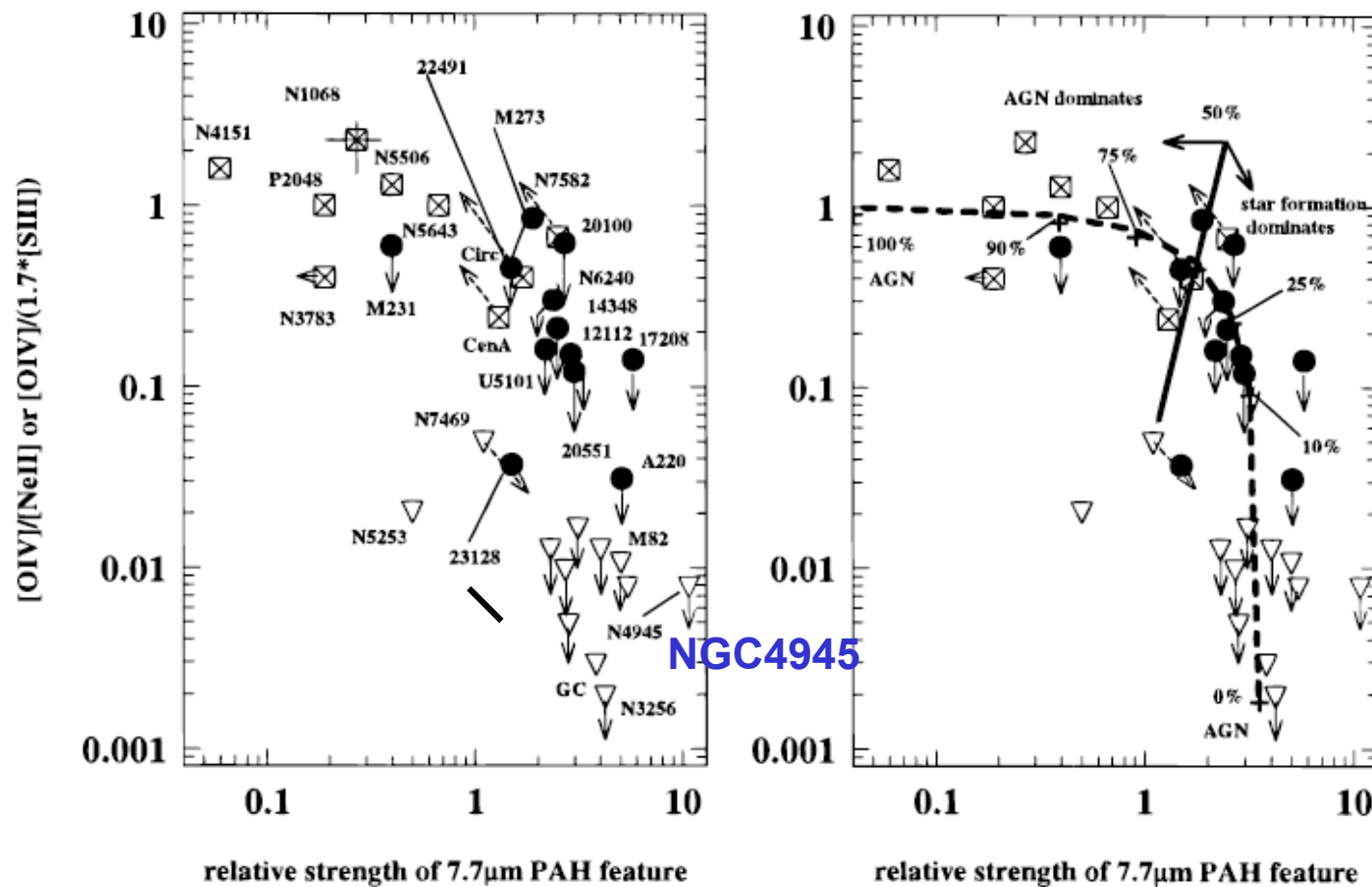
Search for broad H infrared recombination lines in NGC1068



D. Lutz, R. Genzel, E. Sturm, L. Tacconi,
E. Wieprecht, T. Alexander, H. Netzer,
A. Sternberg, **A.F.M. Moorwood**,
R.A.E. Fosbury, K. Fricke, S.J.
Wagner, A. Quirrenbach, H. Awaki and
K.Y. Low: 2000, ApJ., 530, 733.....



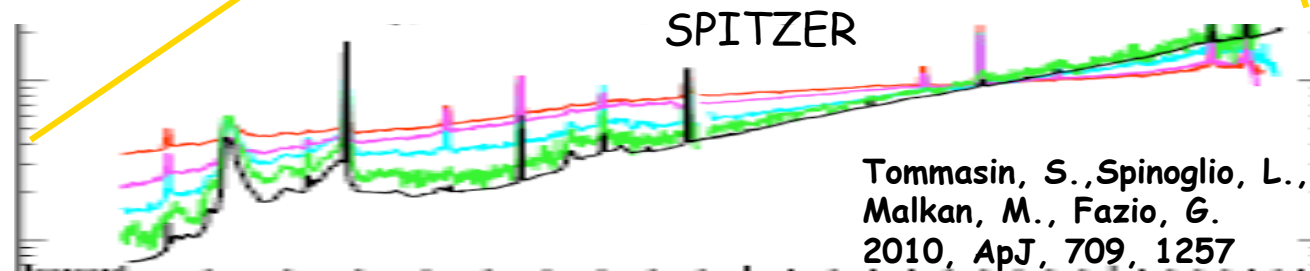
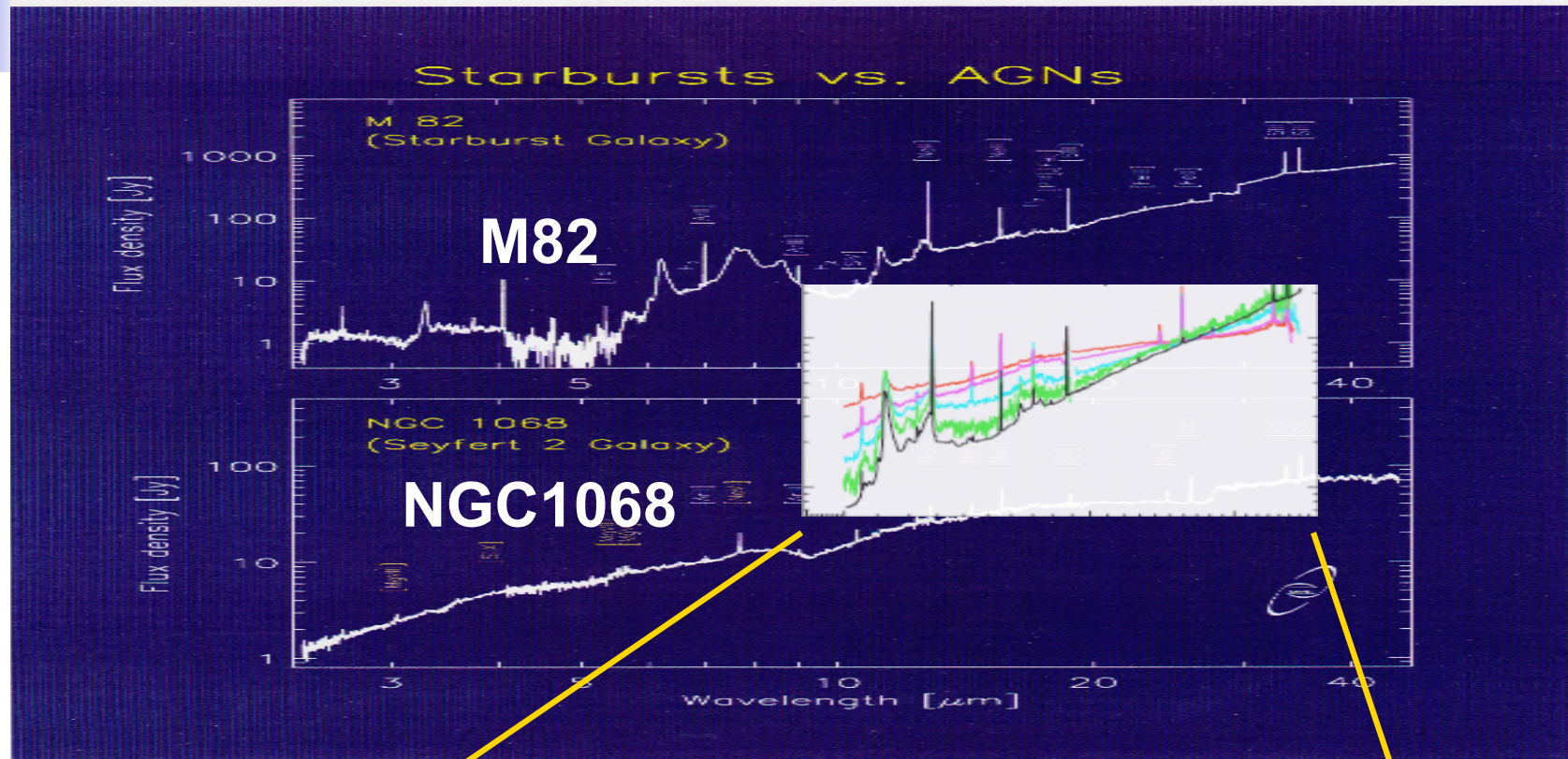
Starbursts vs AGNs Powering ULIRGS - ISO



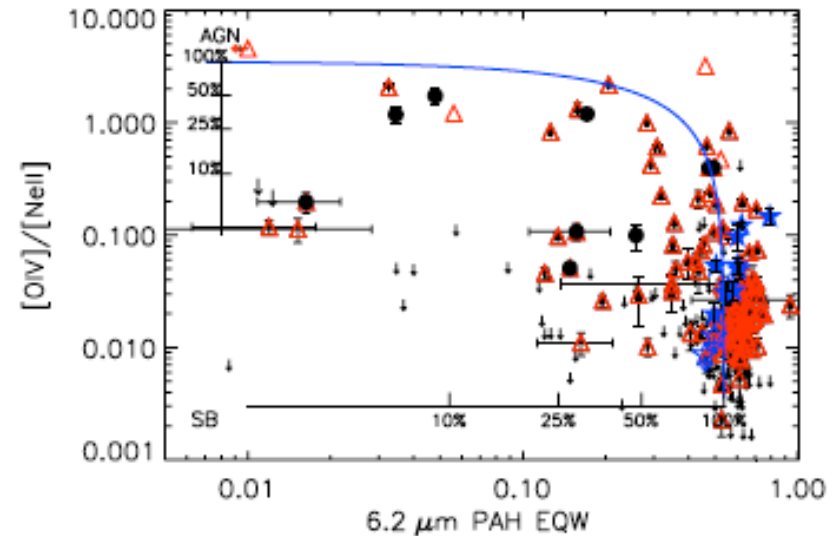
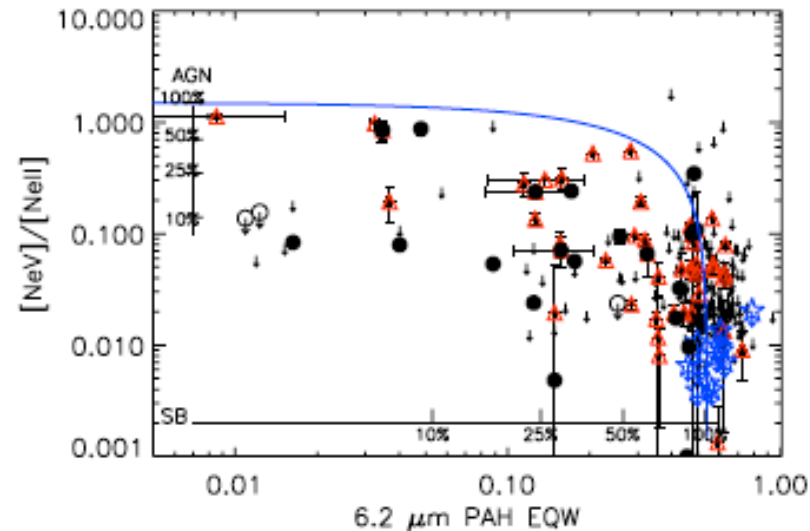
> 50% L provided by AGN in $3/15 = 20\%$

Genzel et al., 1998, Ap. J., 498, 579

ISO 2.5-40 μ m SWS spectra of starburst galaxies and AGN



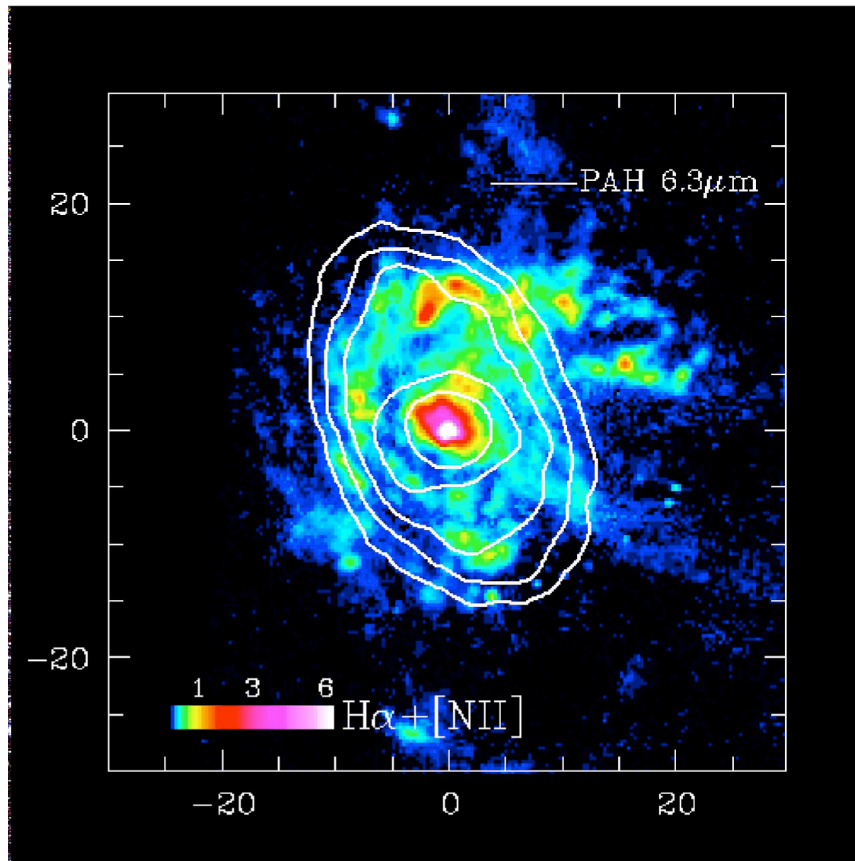
Starbursts vs AGN Powering LIRGS - SPITZER



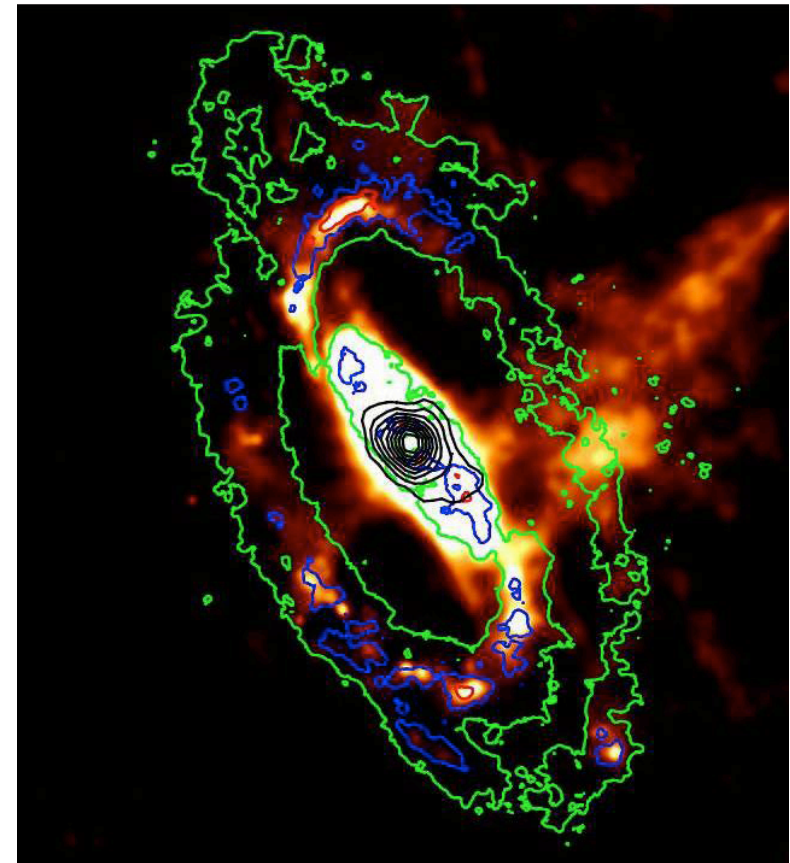
- SAMPLE OF 248 LIRGS - AGN in 18% (>50% L in 10%), integrated contribution is 12% L

Petric et al., 2011, ApJ., 730, 28

The CIRCINUS galaxy (closest S2 + starburst + H₂O masers)

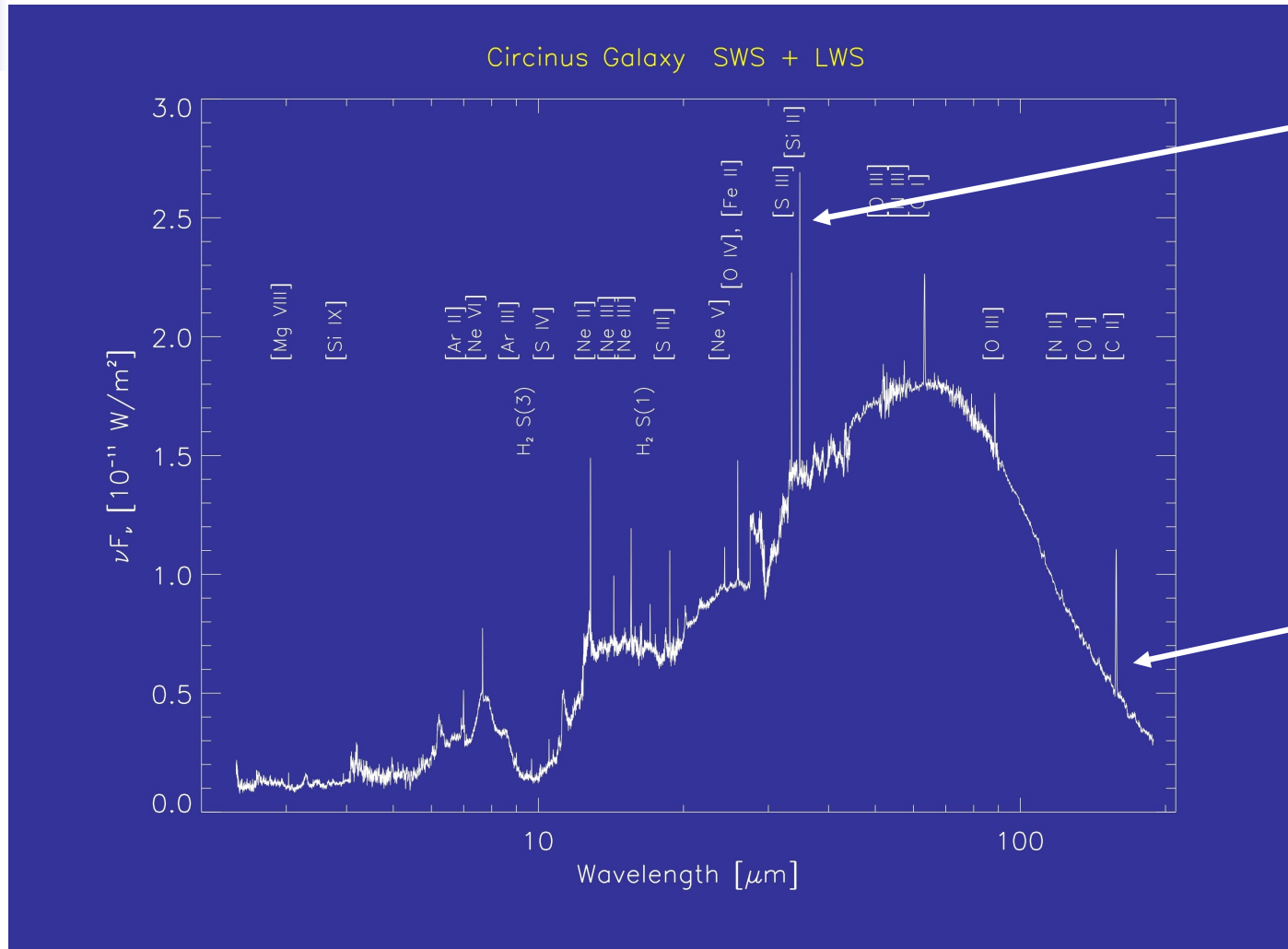


Moorwood, 1999



**8μm Spitzer image +
HI Contours (Bi-Quing For)**

ISO 2.5-200 μ m spectrum of CIRCINUS



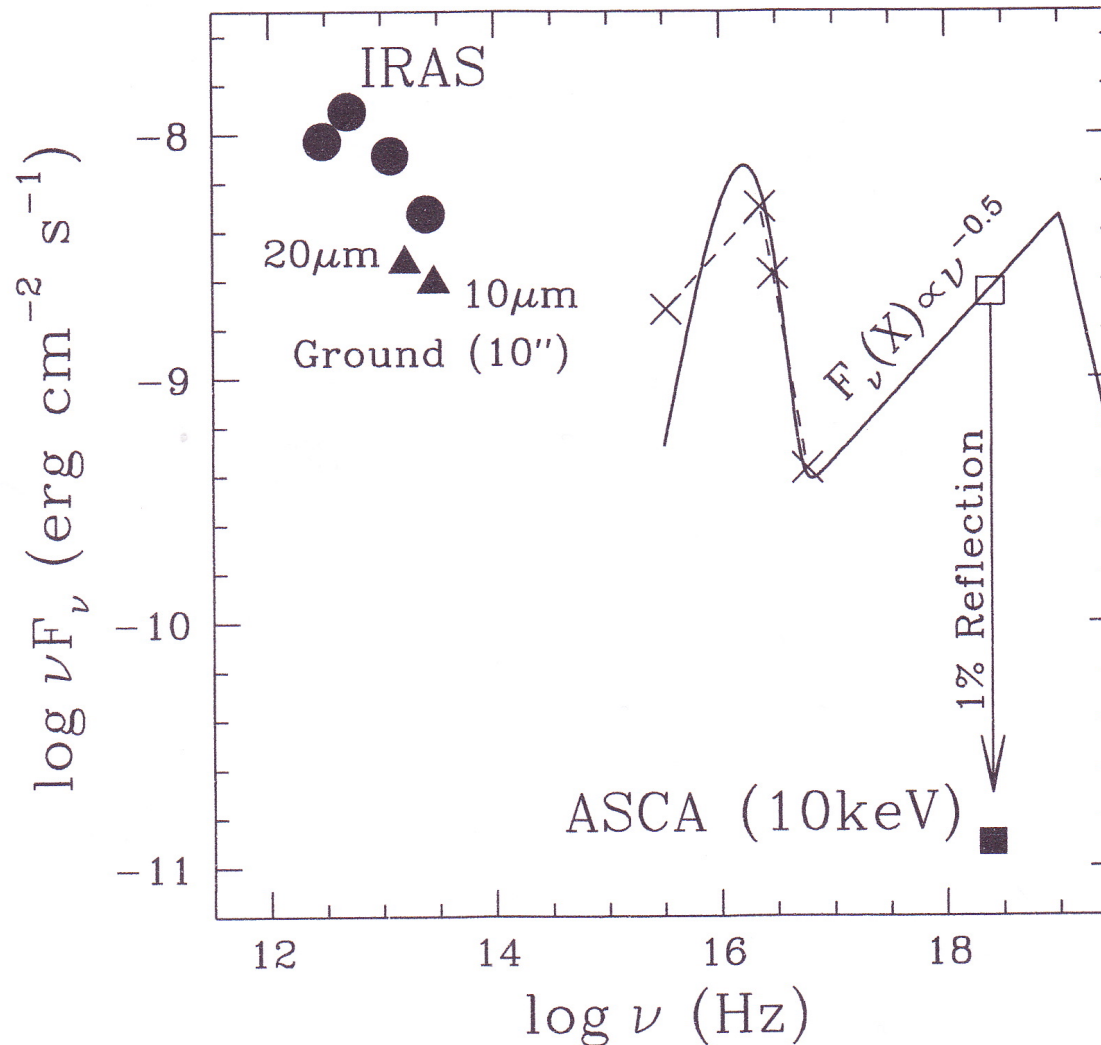
(Moorwood. A, 1998, The Universe as
seen by ISO, ESA SP427, 825)

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Herschel

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Deducing the obscured far UV ionizing continuum of the Circinus galaxy from ISO/SWS 2.5-45 μ m spectroscopy



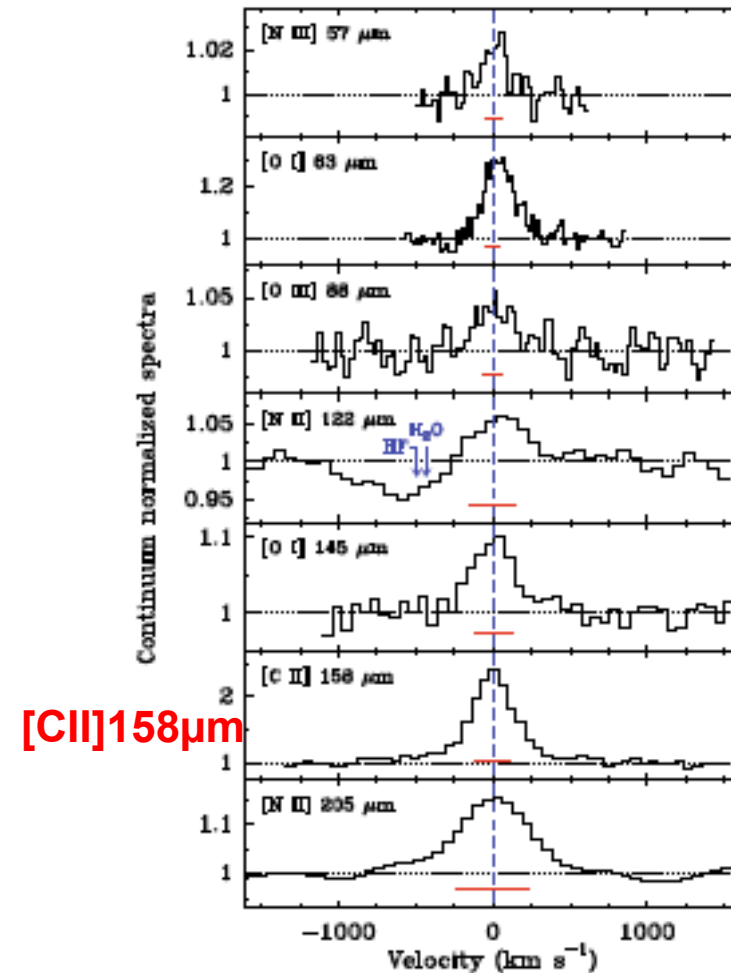
Moorwood, A.F.M., Lutz, D.; Oliva, E.; Marconi, A.; Netzer, H.; Genzel, R.; Sturm, E.; de Graauw. T:1996, A&A, 315, L109

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Far IR spectroscopy with Herschel

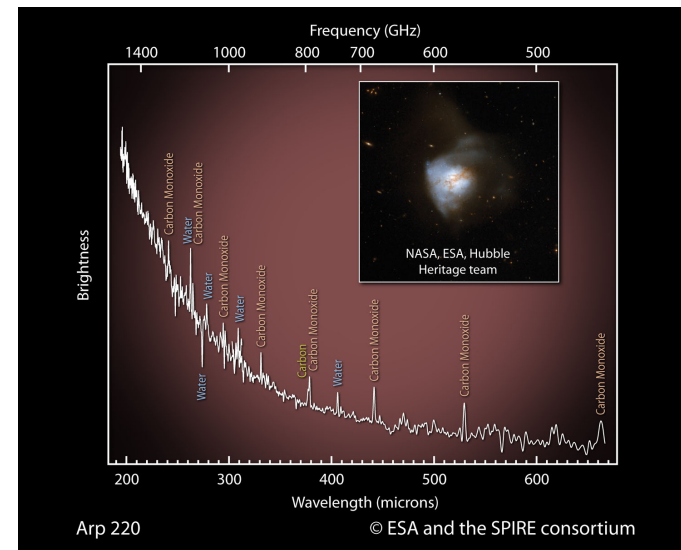
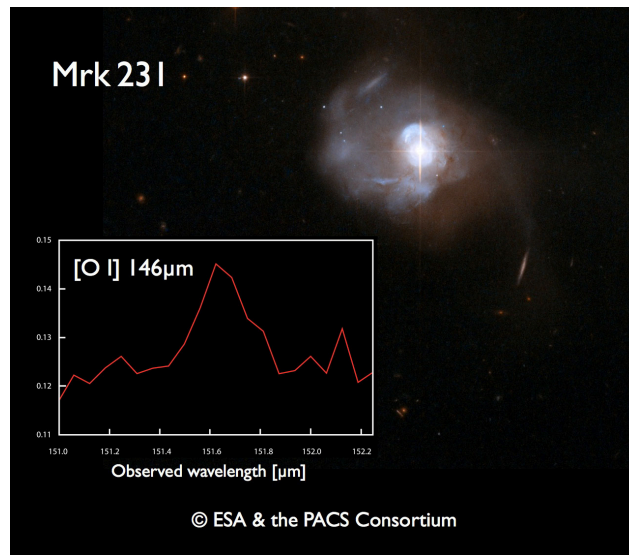
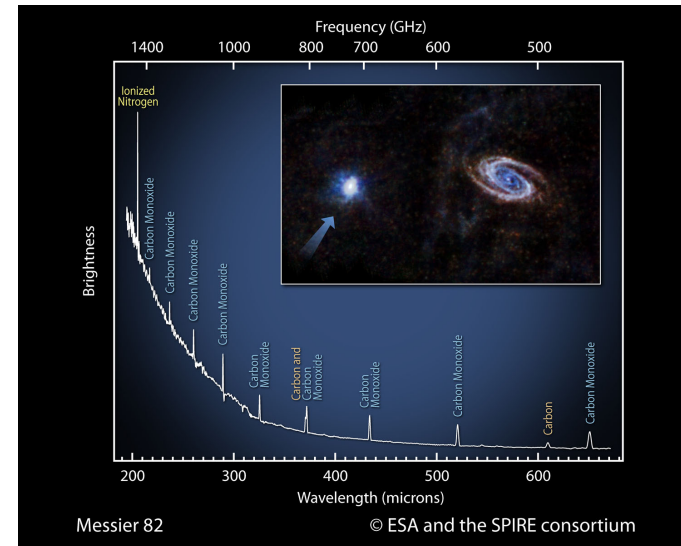
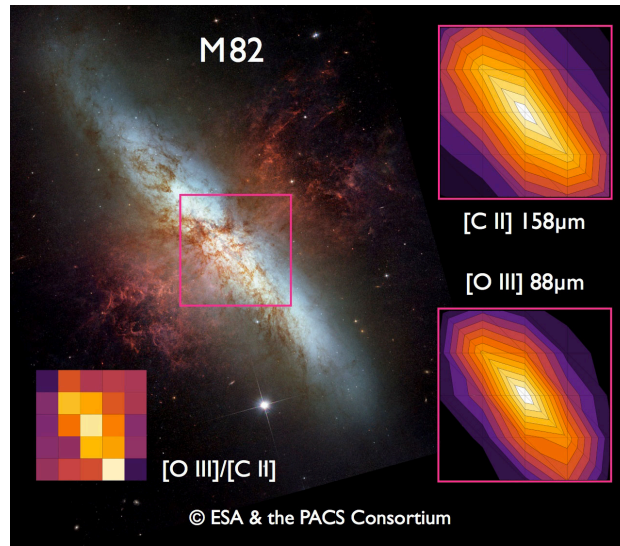
M231



Deficit 10-100 c.f lower L

Fischer et al. 2010, A&A, 518, L41
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Herschel spectra of M82, M231 and Arp 220





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