

INFRARED  
SPECTROSCOPY OF  
GALAXIES

PAST, PRESENT, FUTURE  
**JD SMITH**  
UNIVERSITY OF TOLEDO



# BURNING QUESTIONS ABOUT GALAXIES IN THE UNIVERSE

- WHAT IS THE HISTORY OF METAL AND DUST PRODUCTION?
- WHAT IS THE RELATIVE IMPORTANCE OF ACCRETION VS. STAR FORMATION?
- HOW ARE GAS, DUST AND STARS ARRANGED IN GALAXIES (AND WHY)?

# FIRST (MIR, EXTRAGALACTIC, SPECTROSCOPIC) LIGHT

OBSERVATIONS OF M82 AND NGC 253 AT 8-13 MICRONS

F. C. GILLETT

Kitt Peak National Observatory\*

D. E. KLEINMANN AND E. L. WRIGHT

Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory

AND

R. W. CAPPS

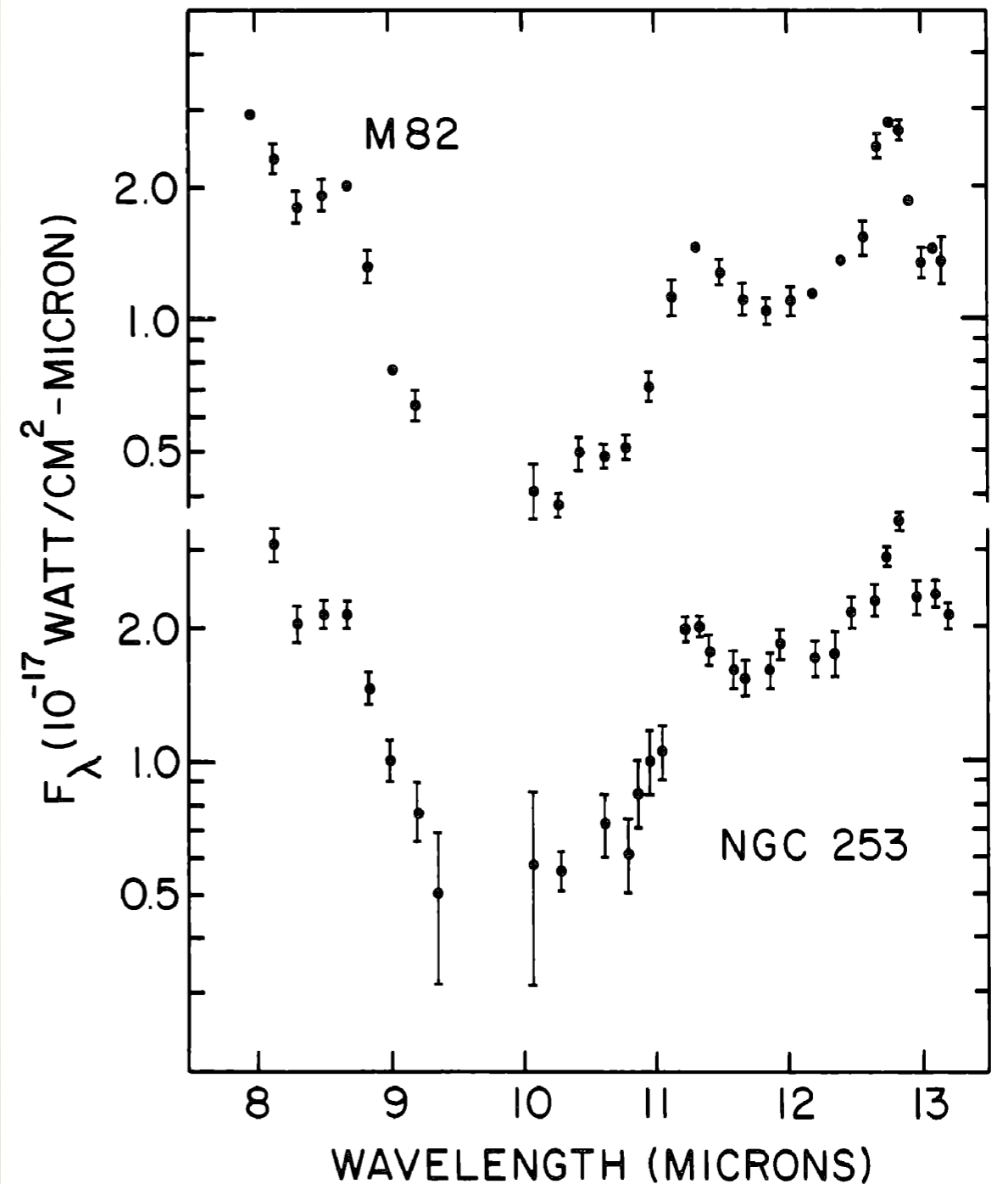
Kitt Peak National Observatory,\* and Steward Observatory

*Received 1975 January 27; revised 1975 February 26*

$\lambda/\Delta\lambda \sim 50$

KPNO 2.1 M,  
COOLED FILTER WHEEL  
SPECTROMETER

GILLETT ET AL., 1975





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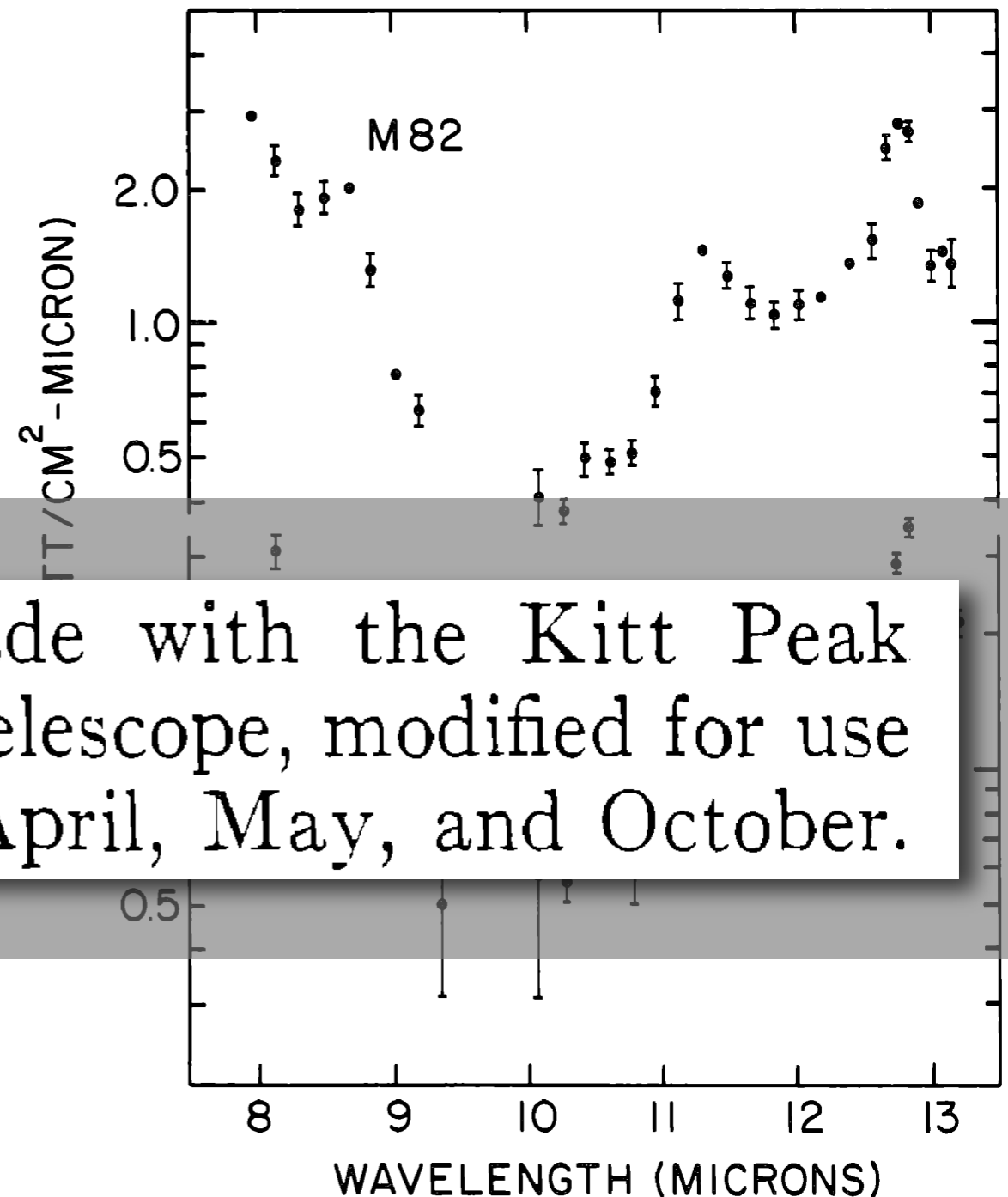
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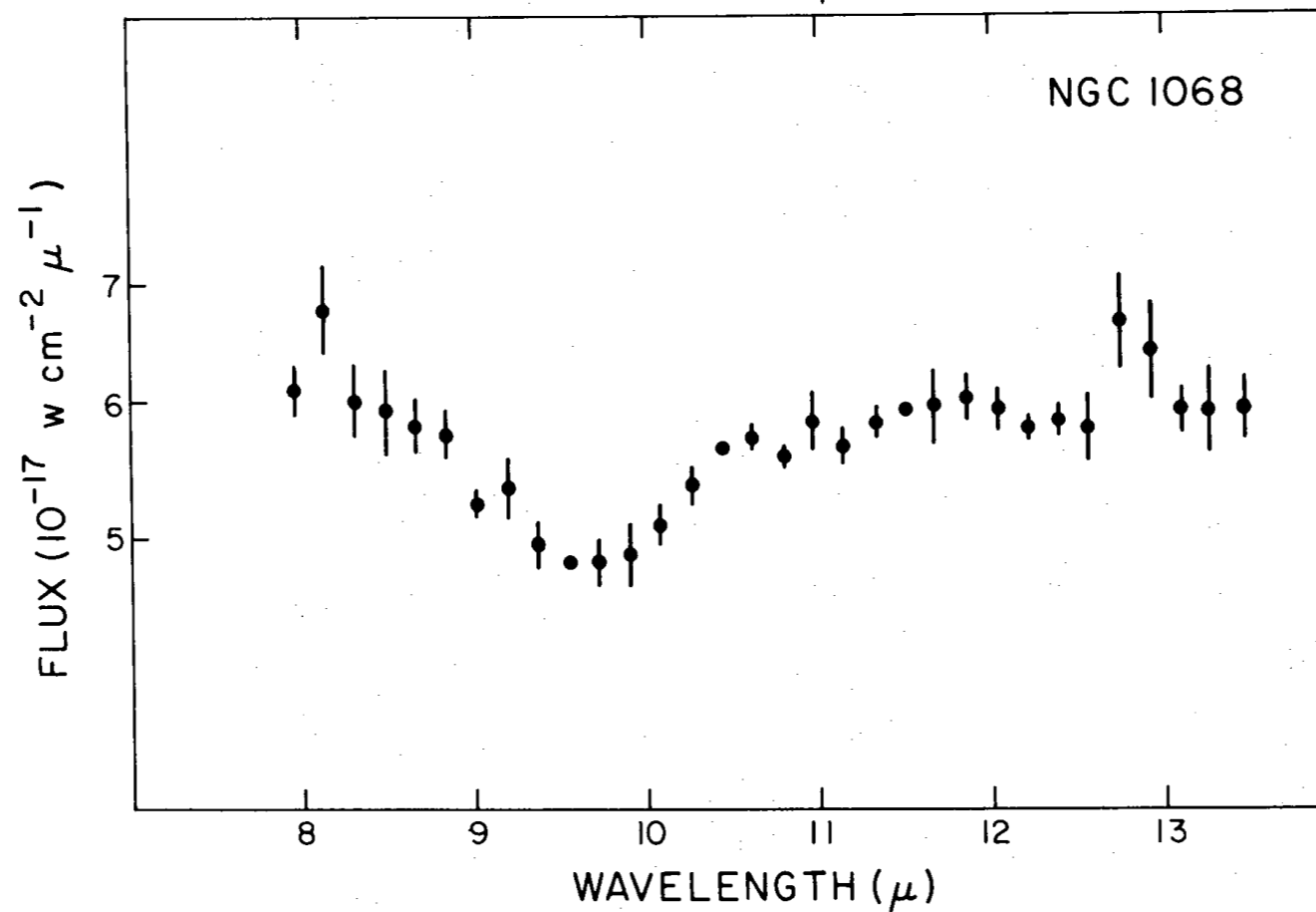


The observations were made with the Kitt Peak National Observatory 2.1-m telescope, modified for use in the infrared, during 1974 April, May, and October.

GILLETT ET AL., 1975



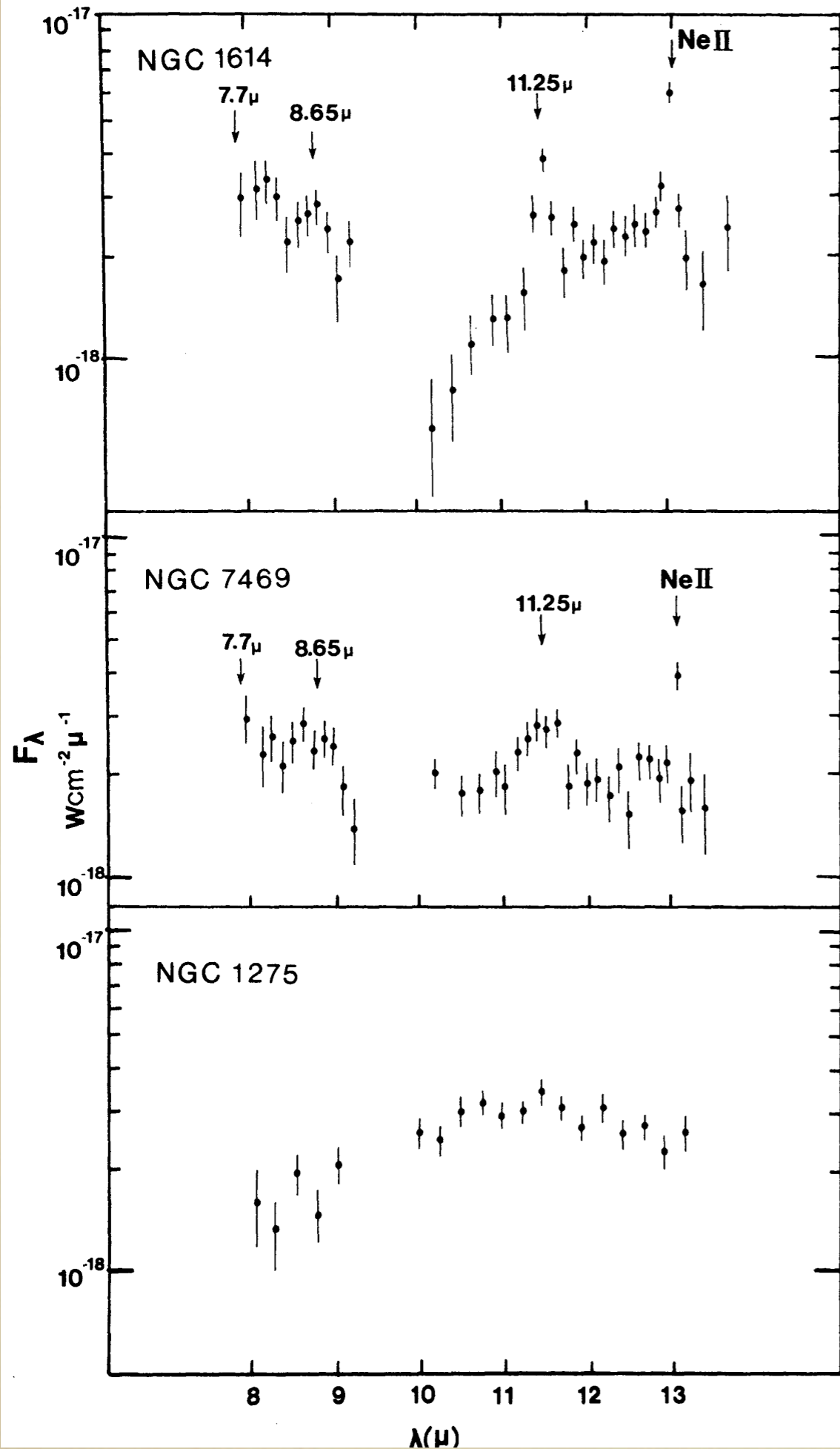
## 8–13 $\mu$ SPECTROPHOTOMETRY OF NGC 1068



All of the models require a “silicate” absorption

KLEINMANN, GILLETT, AND WRIGHT, 1976





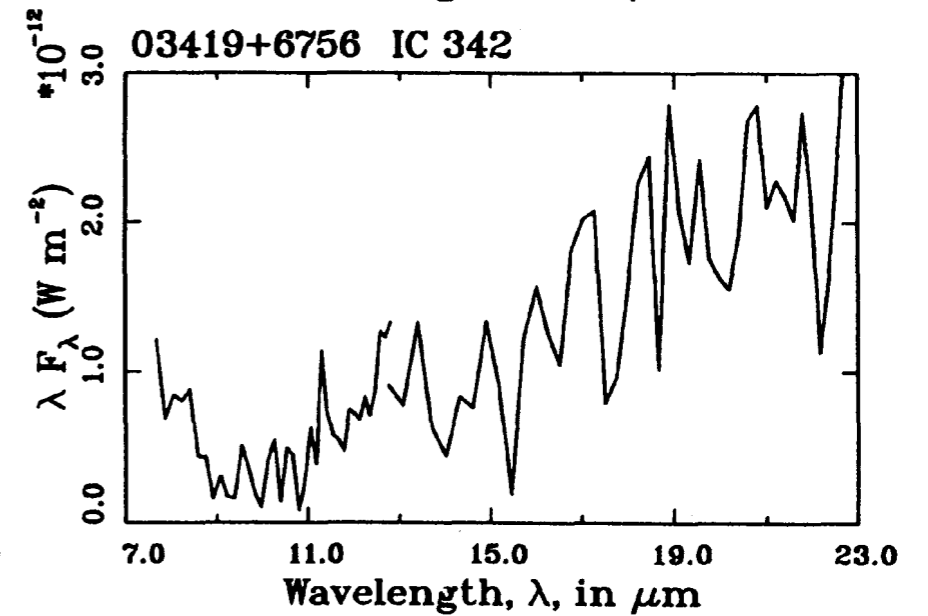
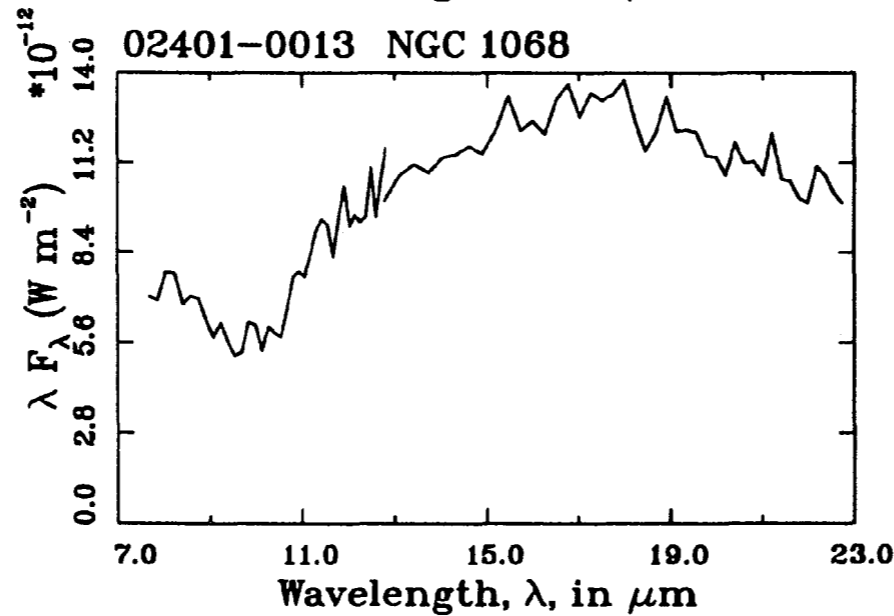
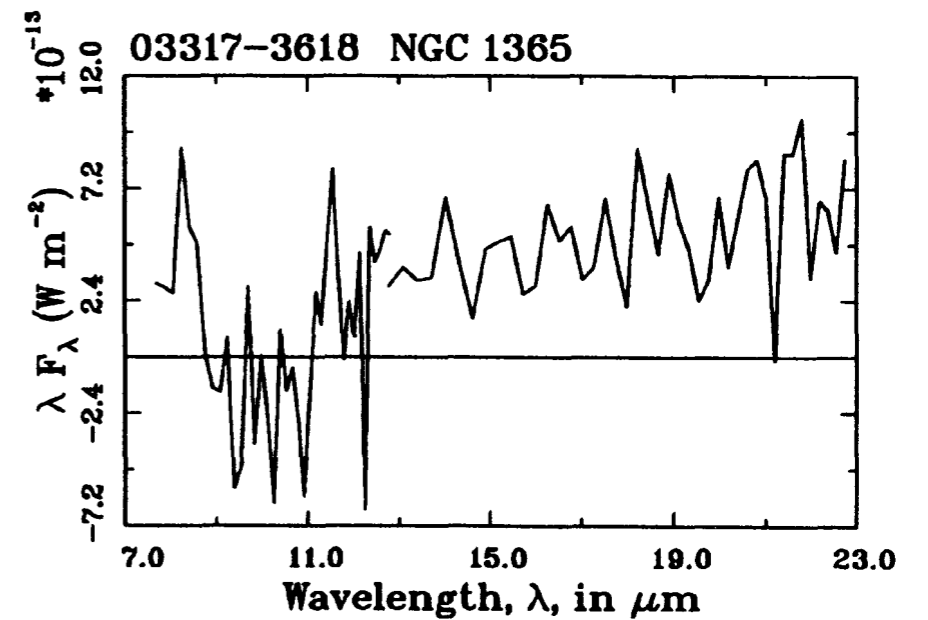
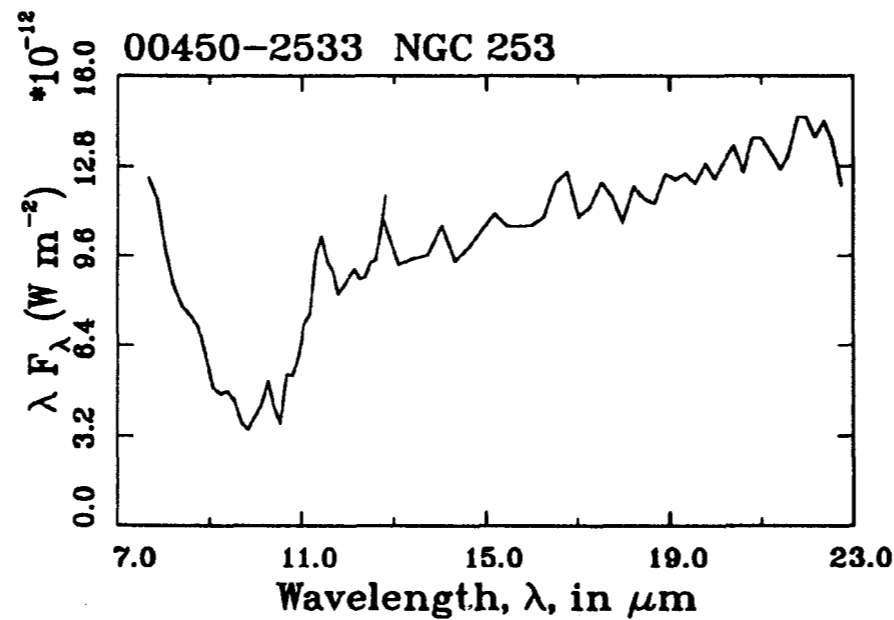
$\lambda/\Delta\lambda \sim 100$   
 UKIRT,  
 UCL SPECTROMETER

AITKEN, ROCHE,  
 AND PHILLIPS, 1981



# ALONG CAME IRAS

**LRS:  
8-22 $\mu$ M  
SLITLESS  
GRISM, 5  
PIXELS!**

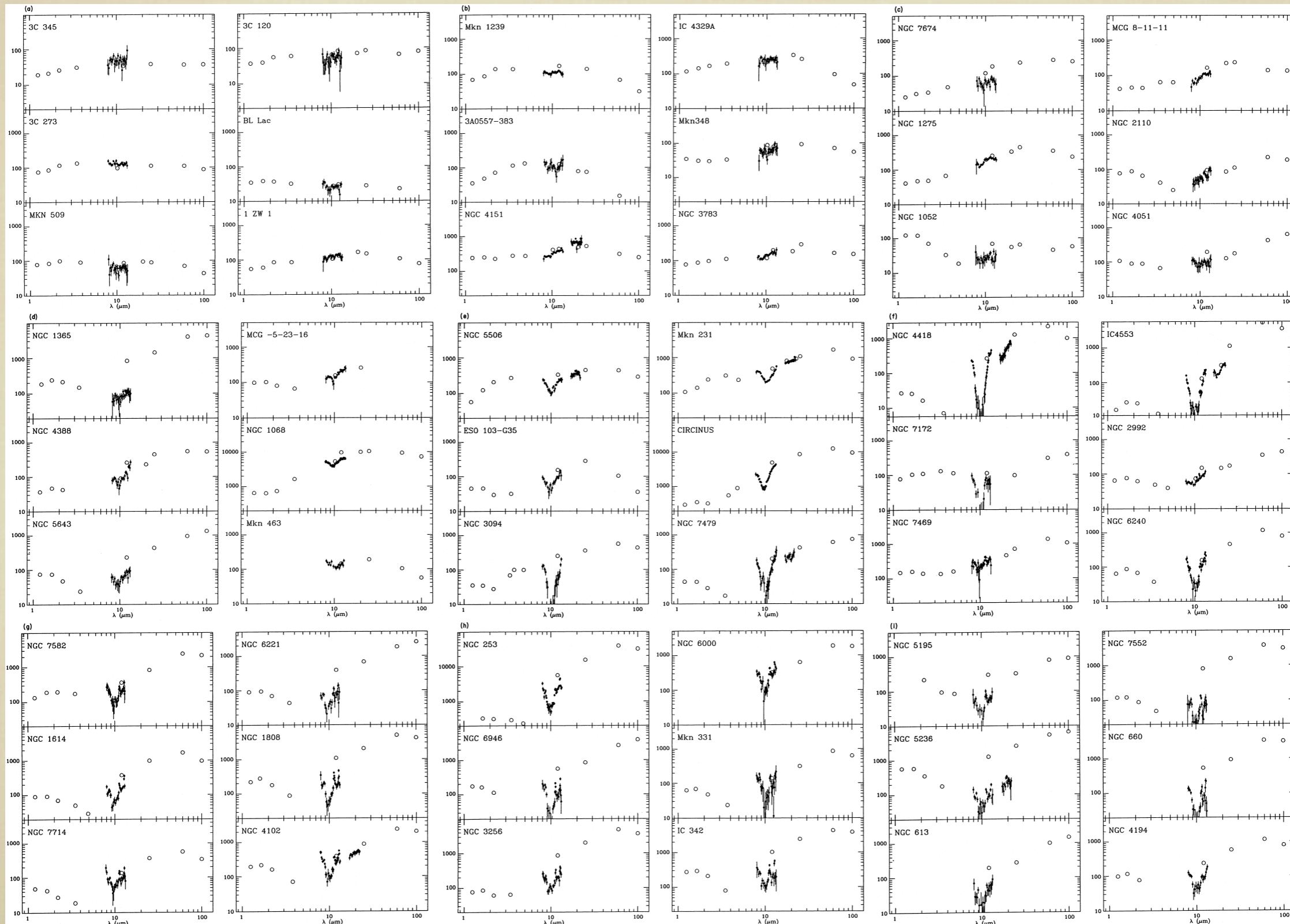


**COHEN & VOLK, 1989**

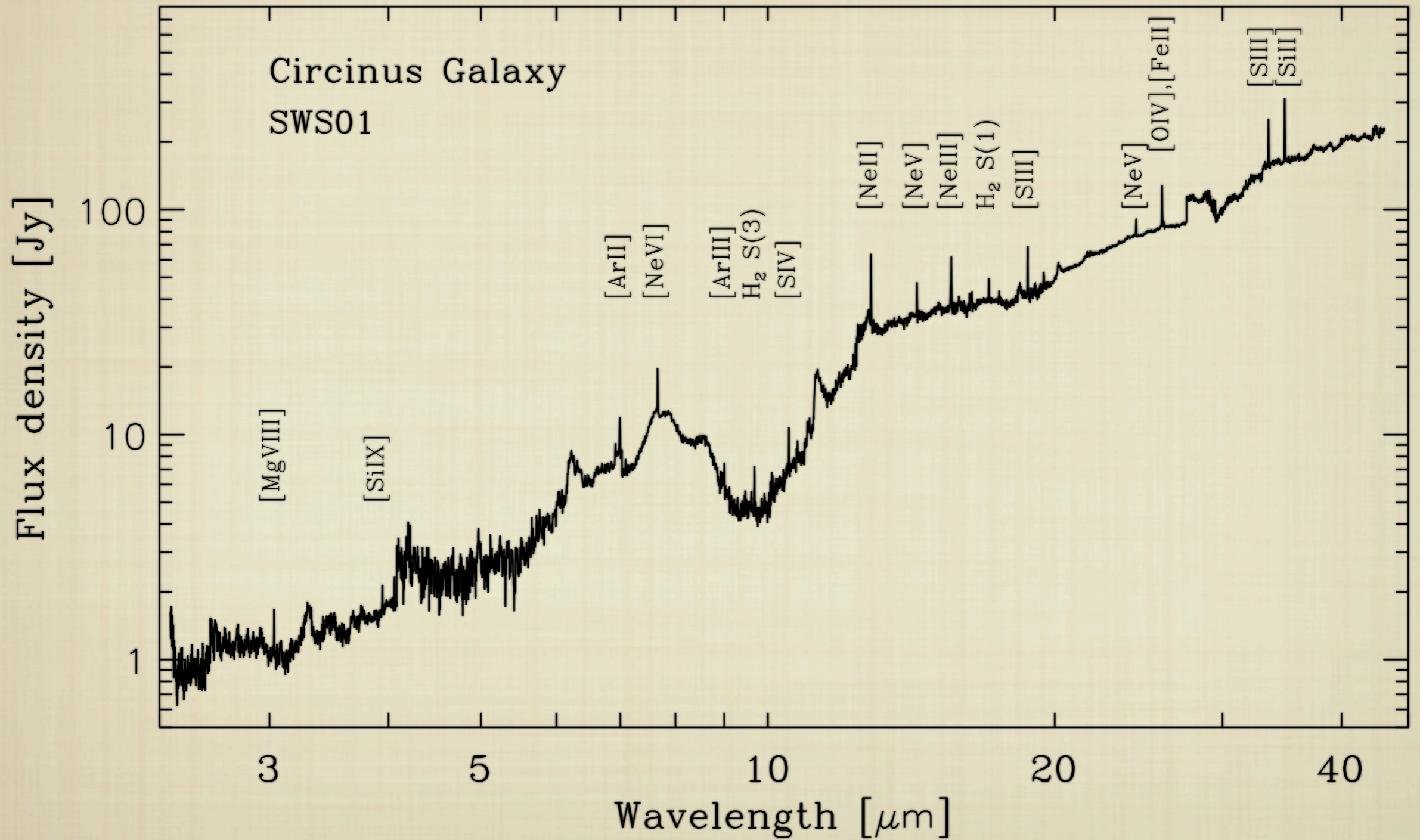


# ALONG CAME IRAS

ROCHE ET AL., 1991



# ISO: A SEA CHANGE

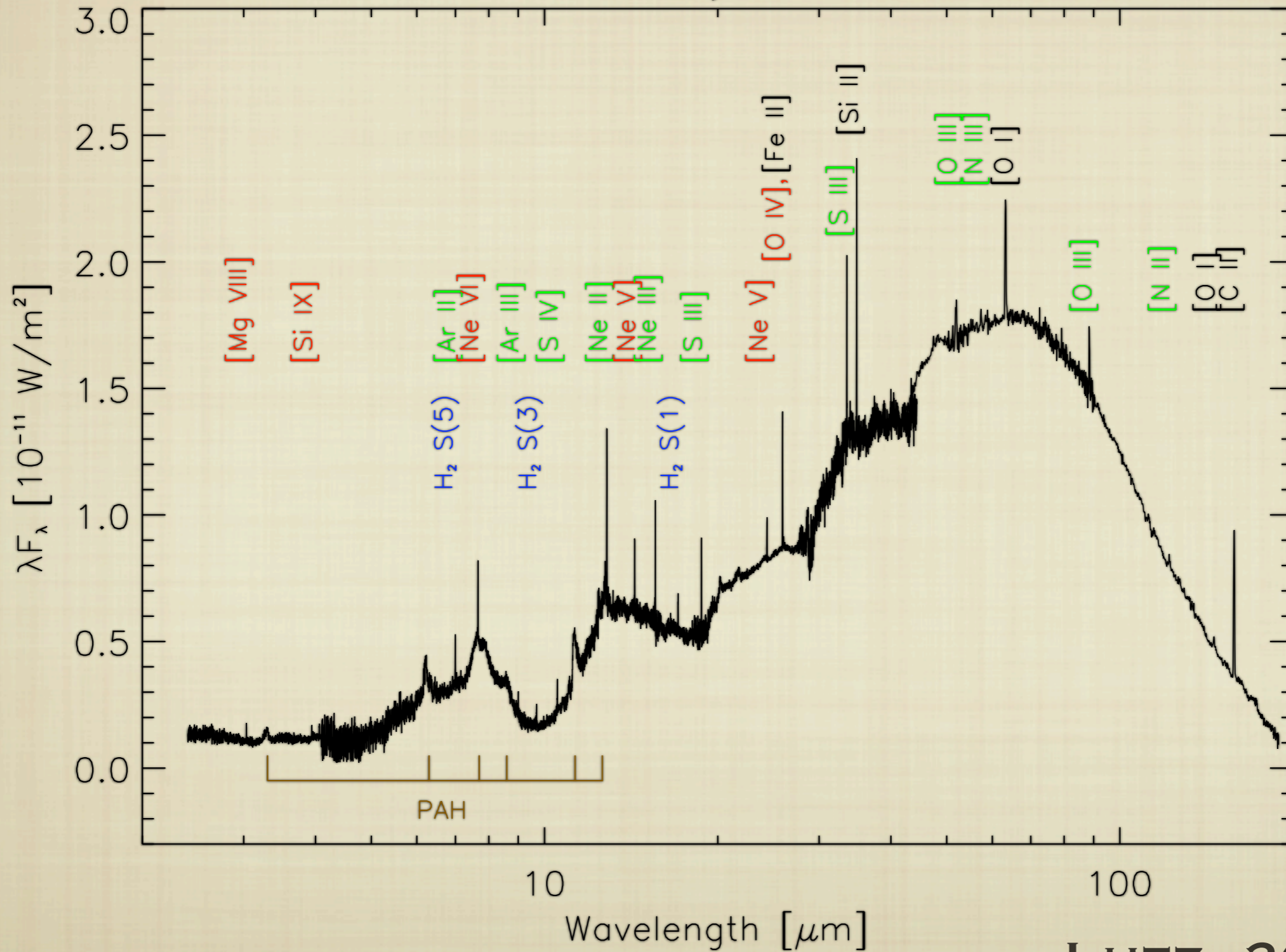


MOORWOOD ET AL., 1996



# ISO: A SEA CHANGE

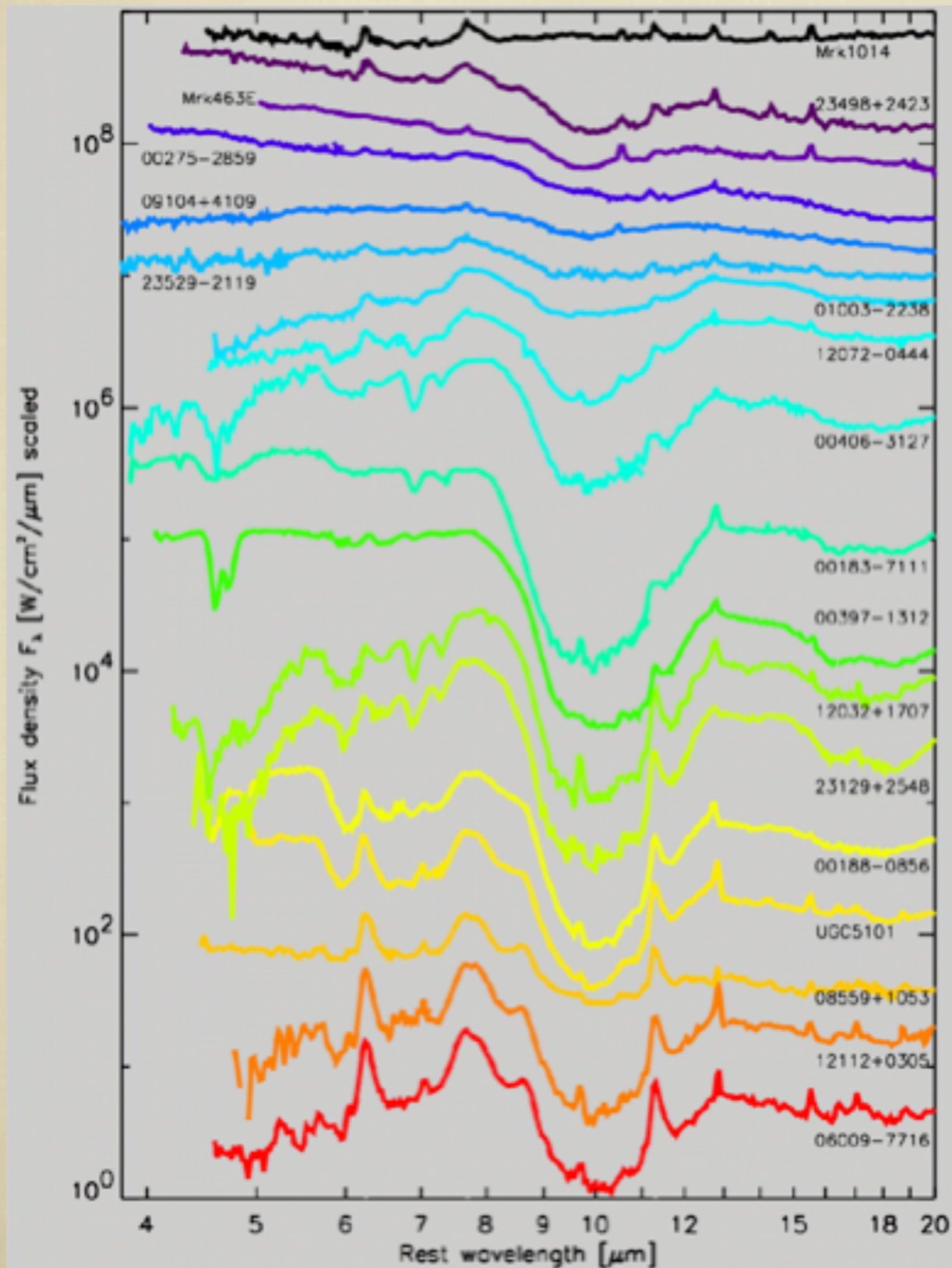
Circinus Galaxy SWS + LWS



LUTZ, 2001



# SPITZER/IRS: CATHARSIS

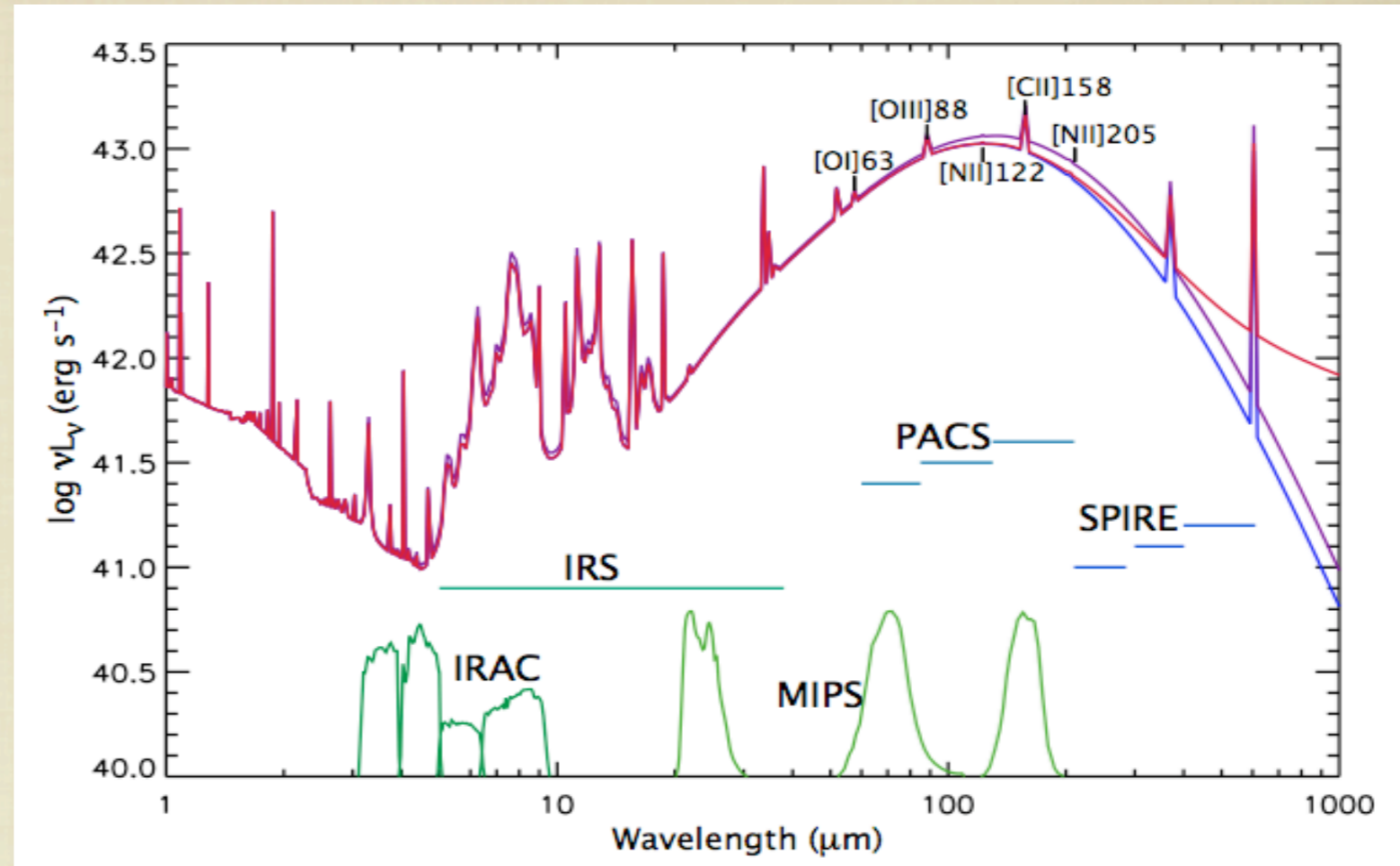


**SEE POSTERS:**  
**#2 K. DASYRA**  
**#4 P. OGLE**  
**#9 V. DESAI**  
**#10 J. RIGBY**



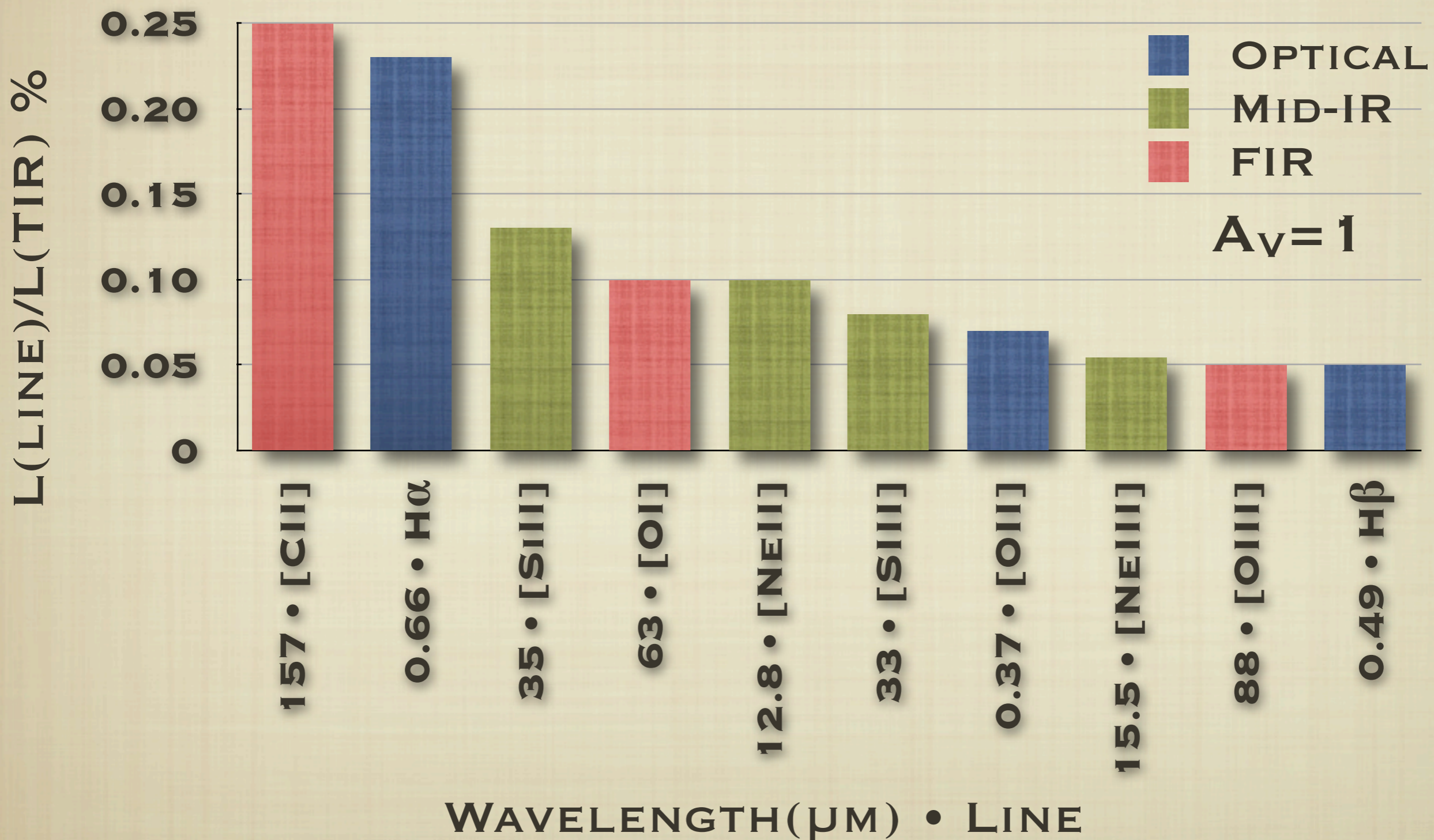
# THE RICH IR SPECTRA OF GALAXIES

- OLD STELLAR PHOTOSPHERES.
- STOCHASTICALLY HEATED GRAIN CONTINUUM.
- STRONG AROMATIC EMISSION BANDS.
- THERMAL DUST EMISSION.
- COOLING LINES OF HII REGIONS, PDRs, HIGH EXCITATION AGN ENVIRONMENTS: 5–150EV.



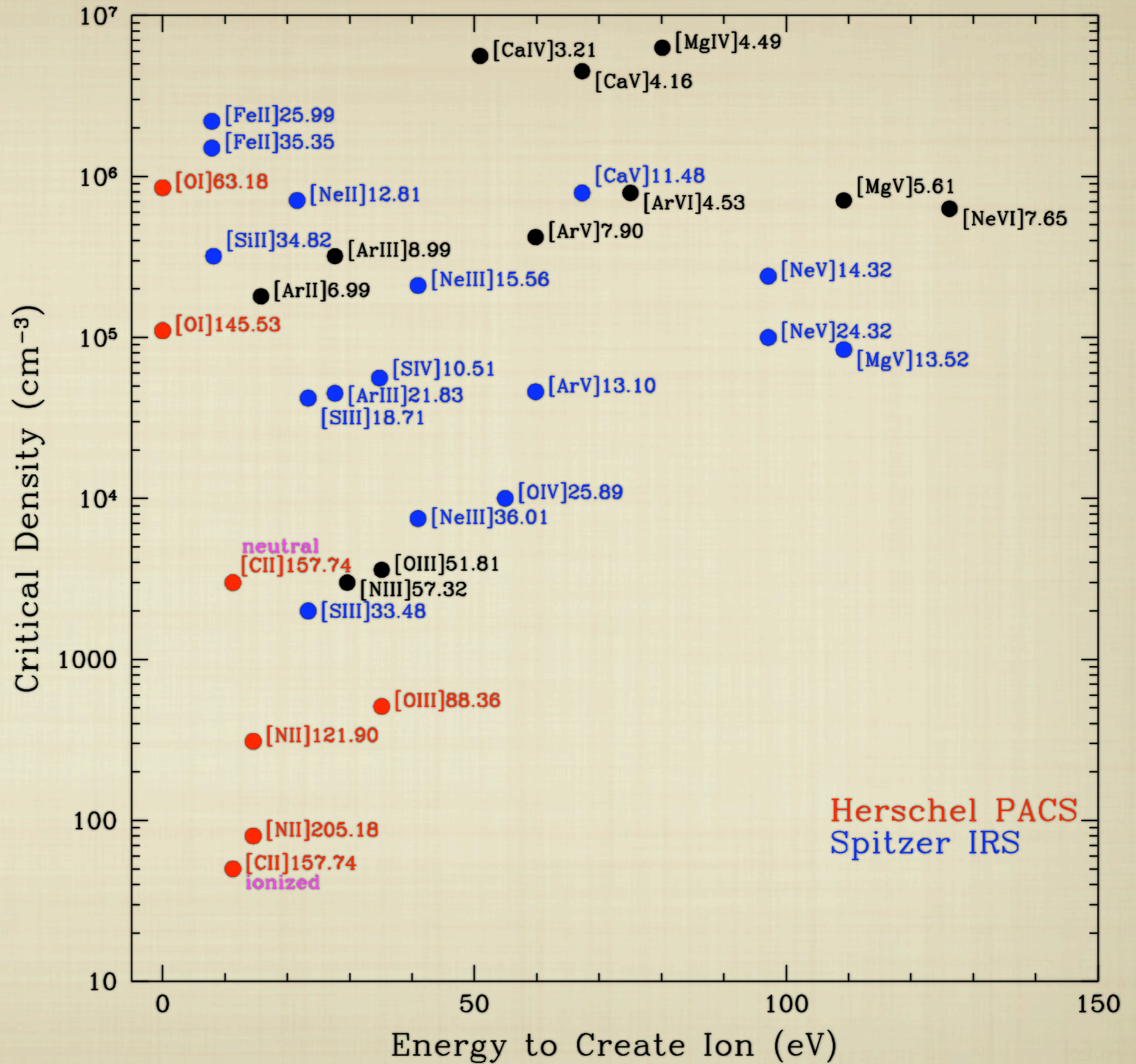


# THE TOP 10 MOST LUMINOUS EMISSION LINES OF STAR-FORMING GALAXIES





# EMISSION LINE ROADMAP

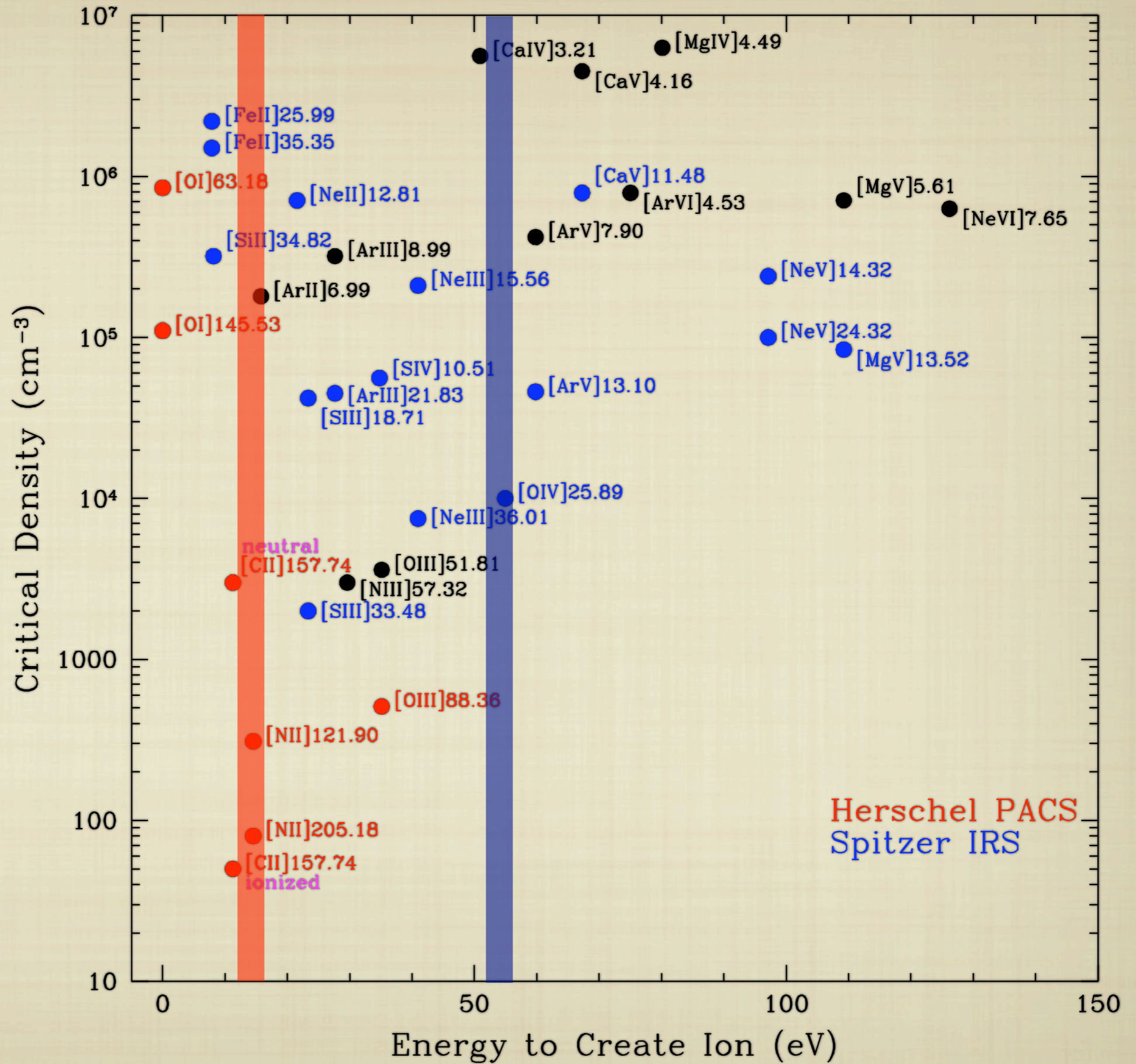




# EMISSION LINE ROADMAP

## H-LYMAN

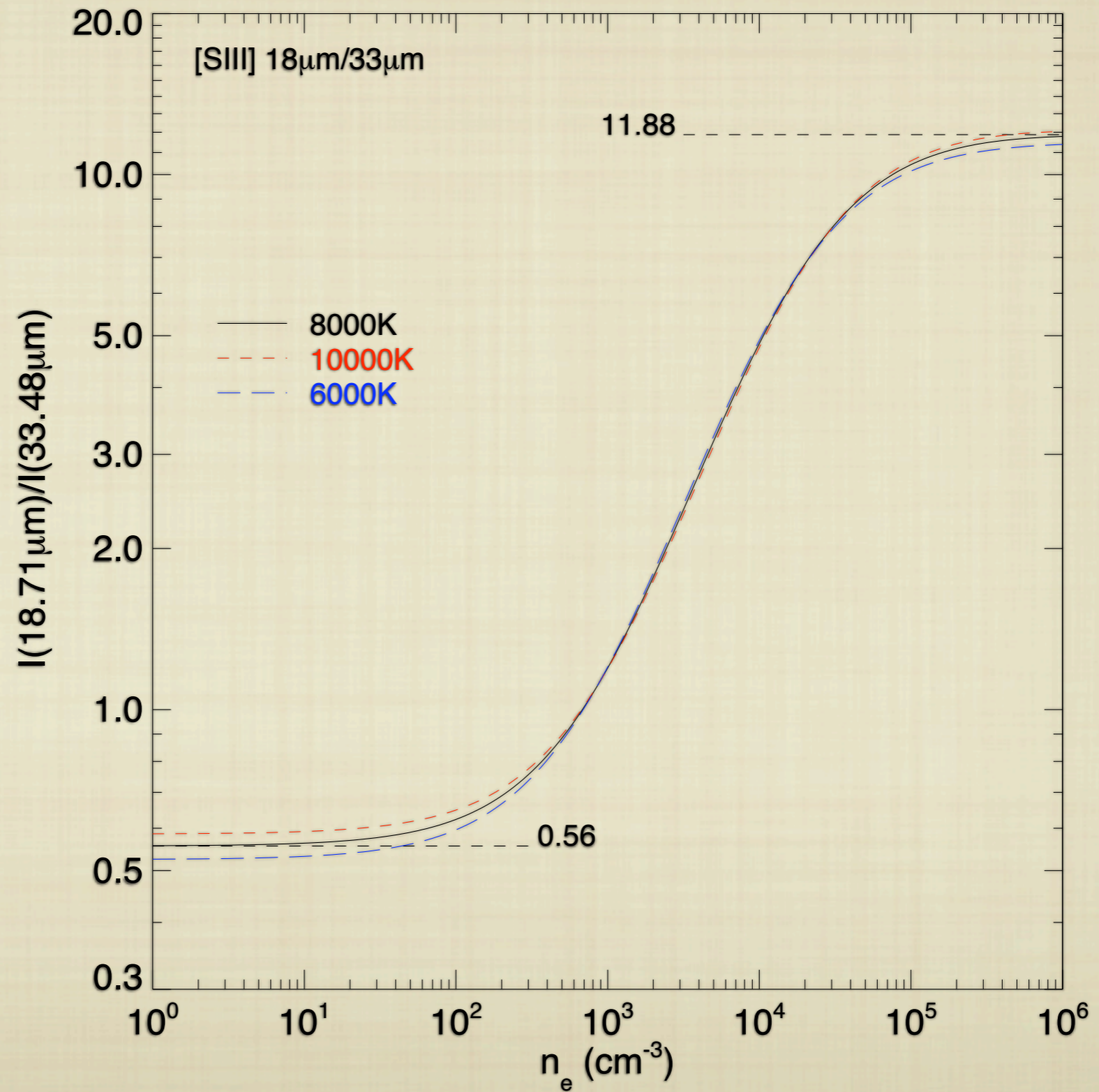
## HE-LYMAN





# DIAGNOSTICS

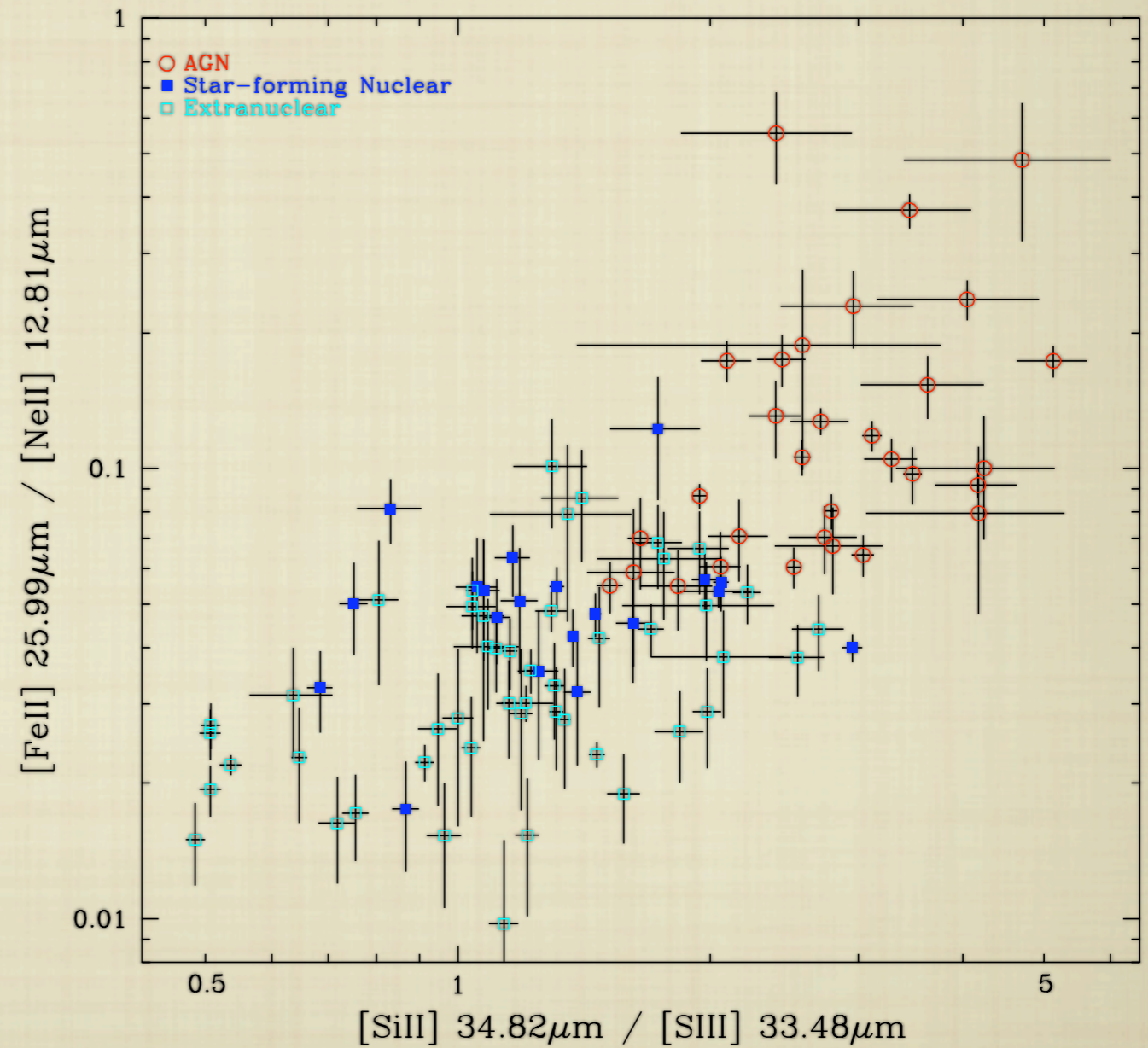
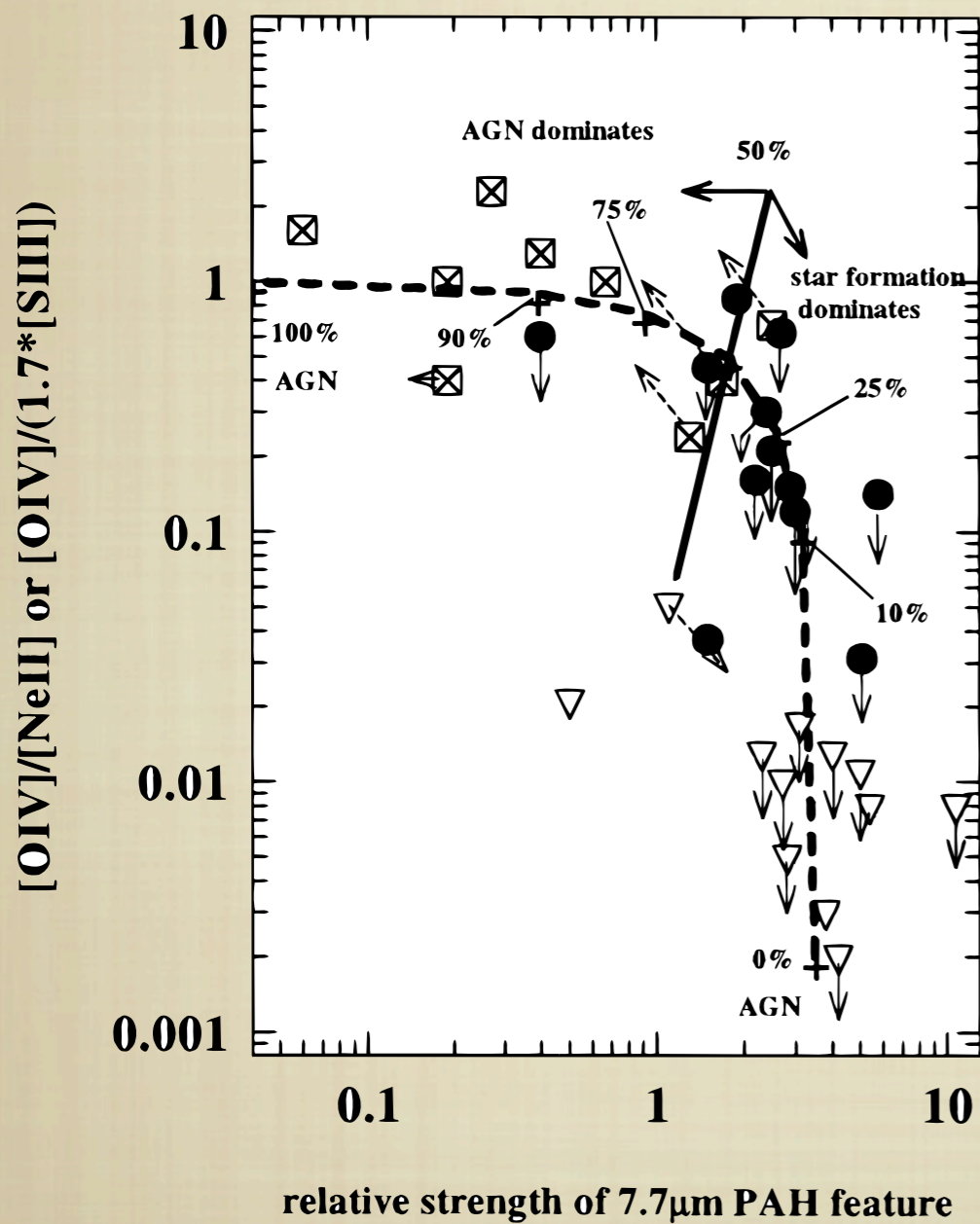
**GAS  
DENSITY**





# DIAGNOSTICS

## AGN VS. STARBURST



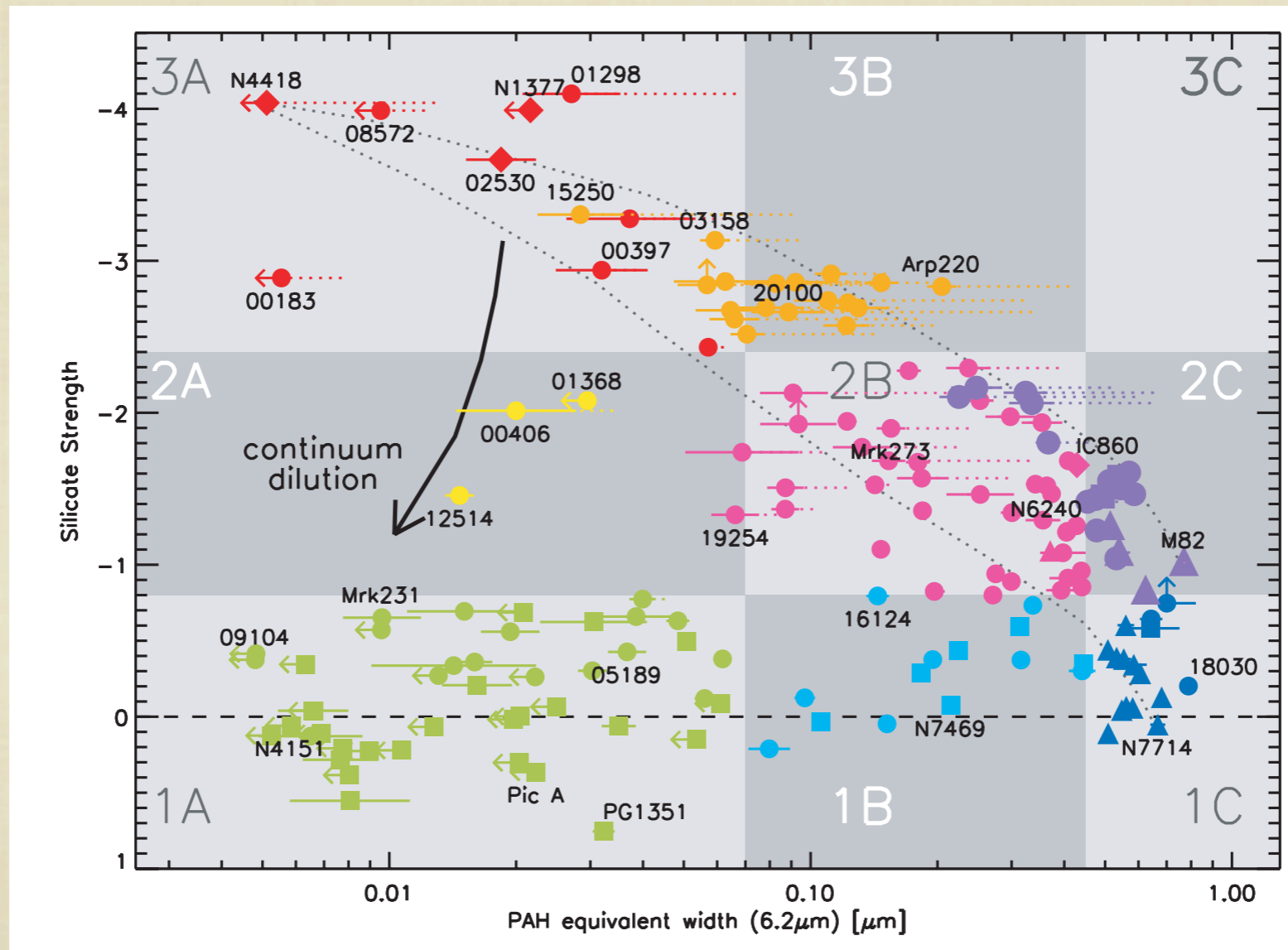
GENZEL ET AL., 1998

DALE ET AL., IN PREP



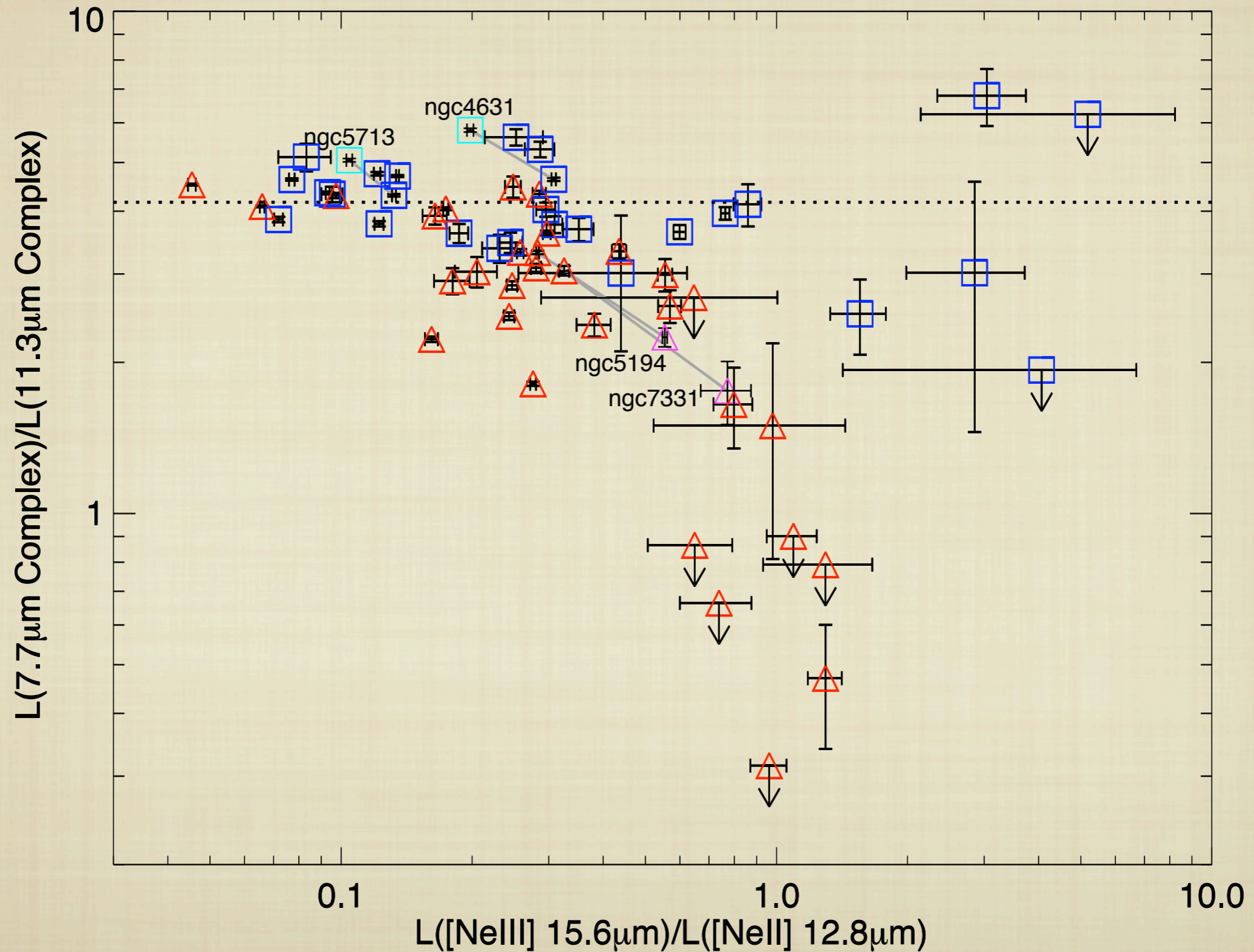
# DIAGNOSTICS

## AGN VS. STARBURST



SPOON ET AL., 2007

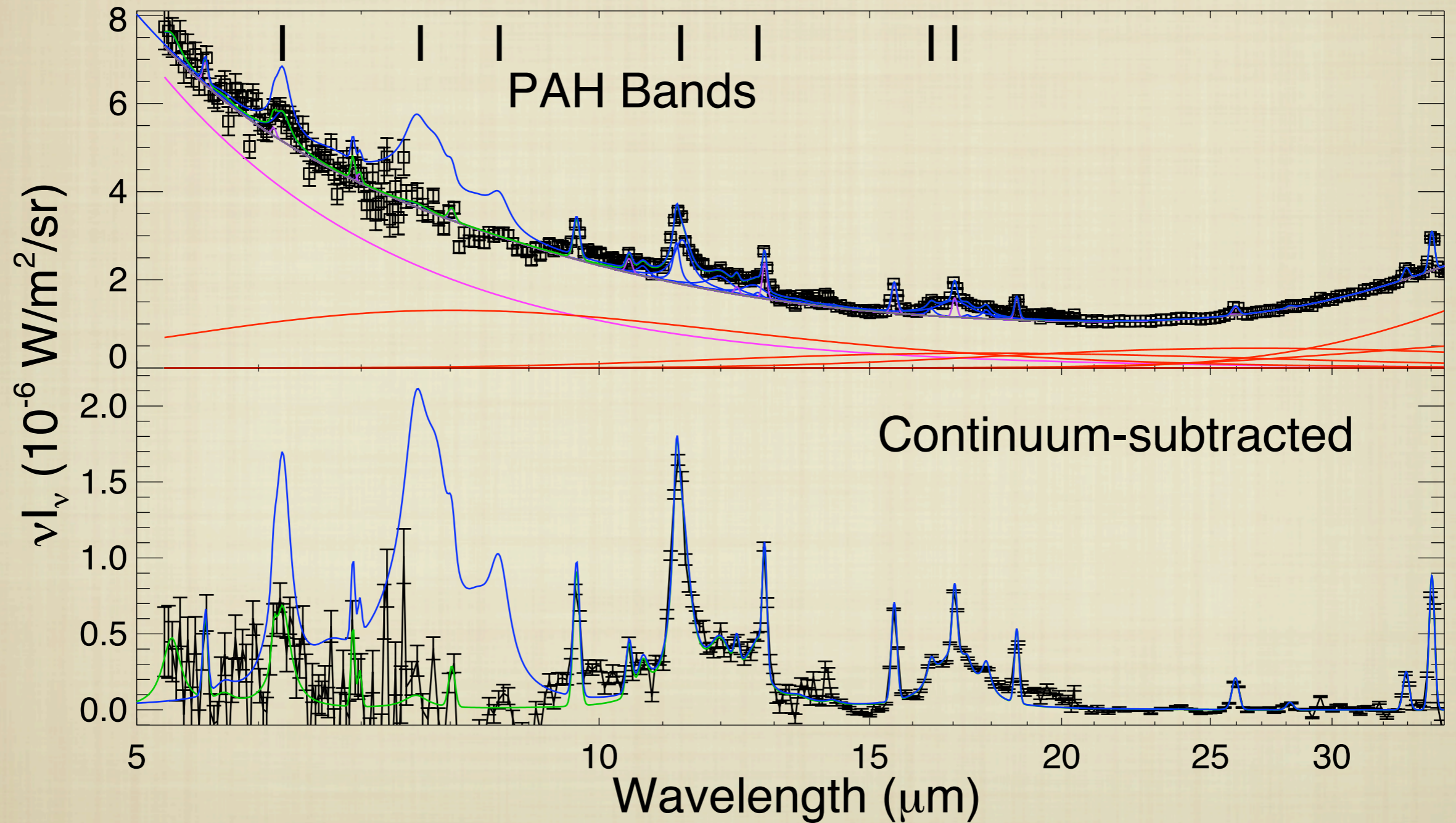
# PAH DIAGNOSTICS



SMITH ET AL, 2007



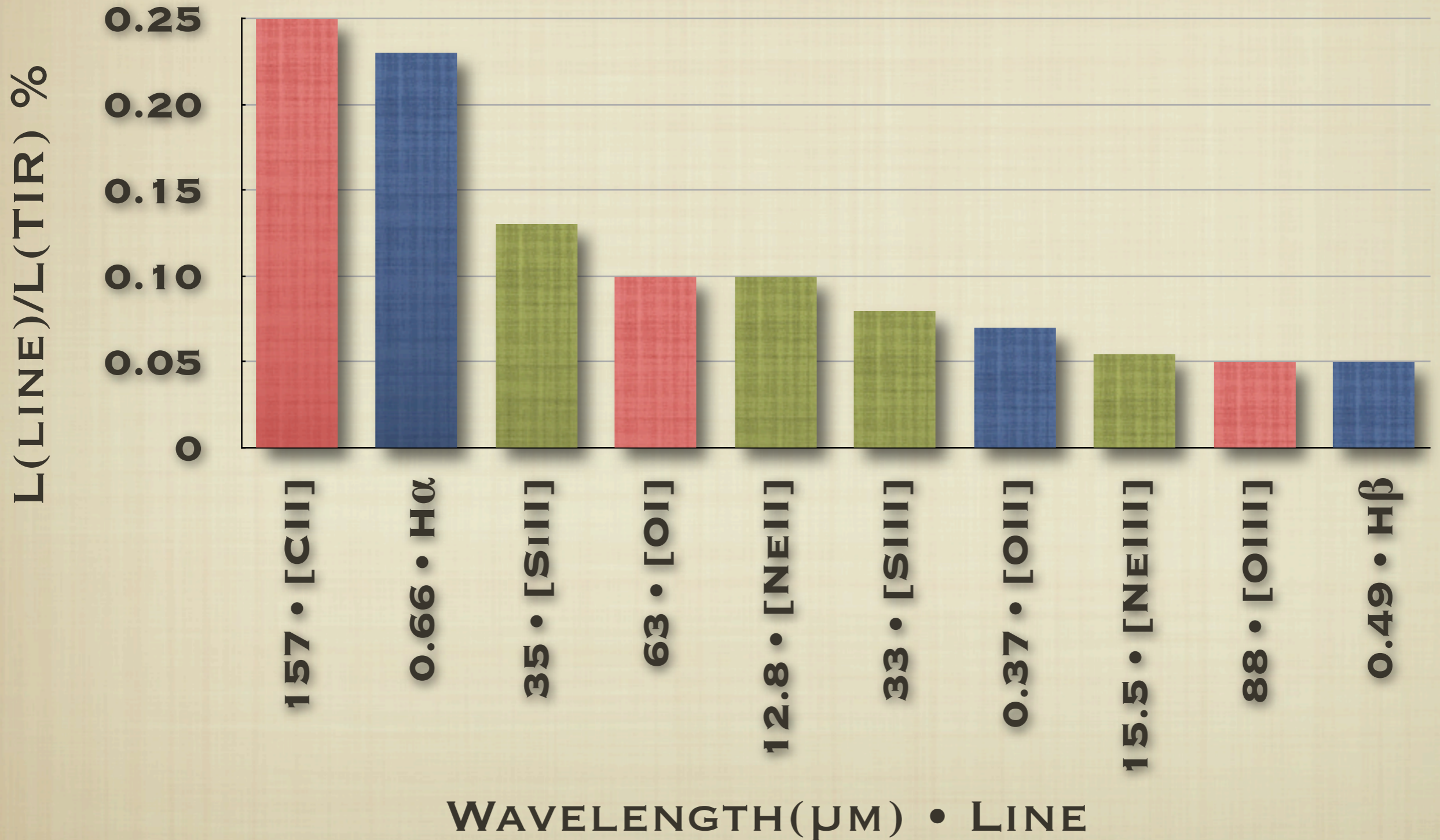
# PAH DIAGNOSTICS



SMITH ET AL, 2007

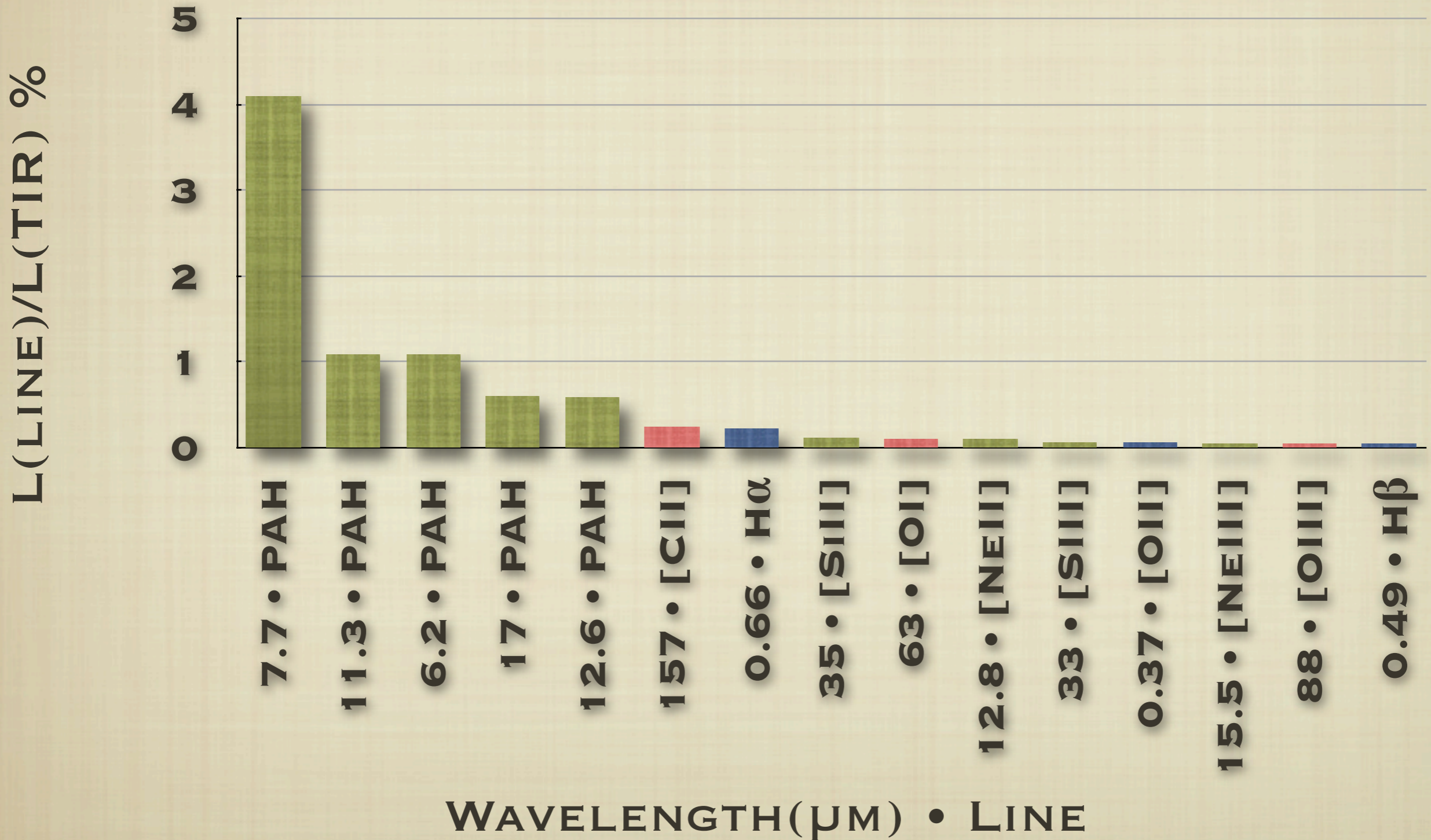


# KING PAH



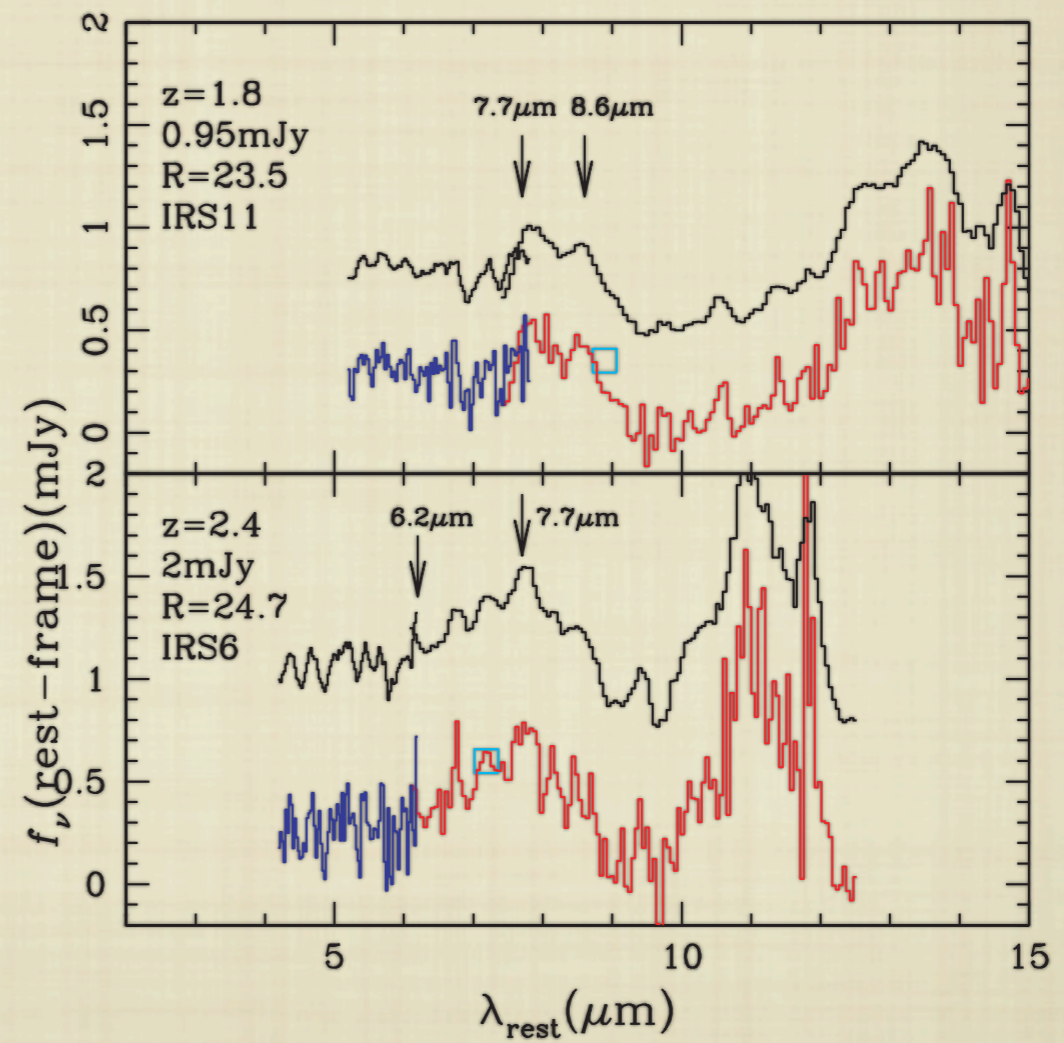
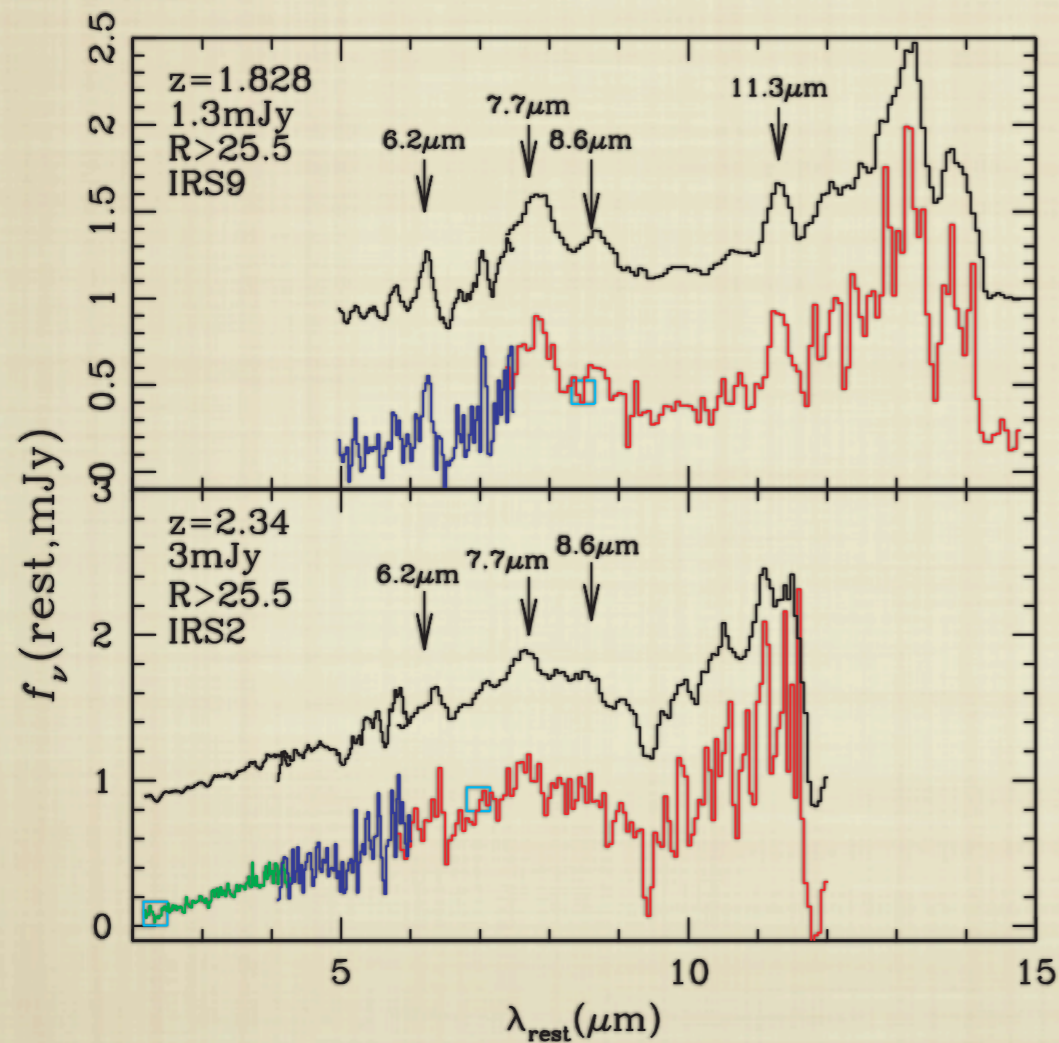


# KING PAH





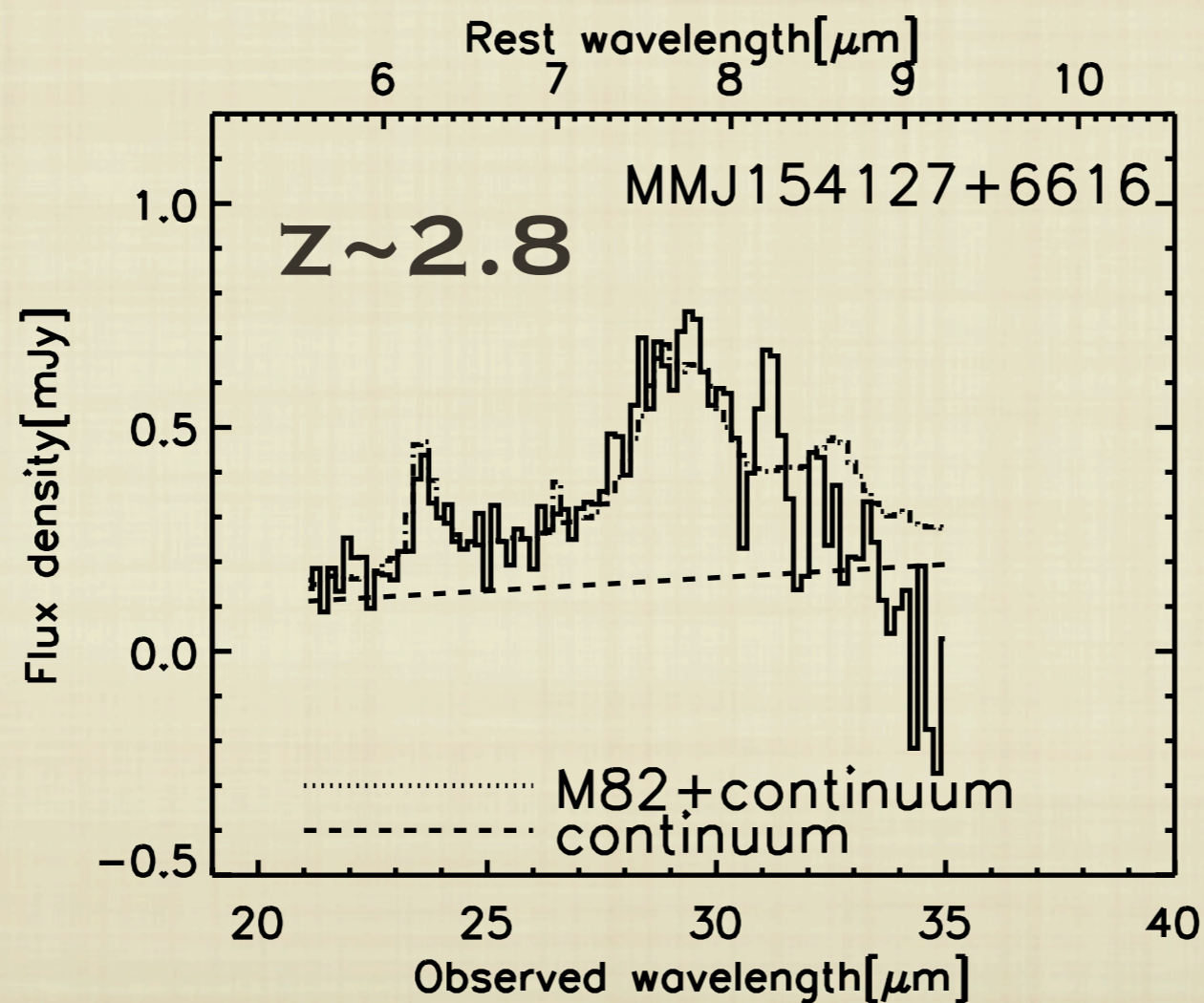
# I LOVE THE SMELL OF PAHS IN THE MORNING



YAN, 2005



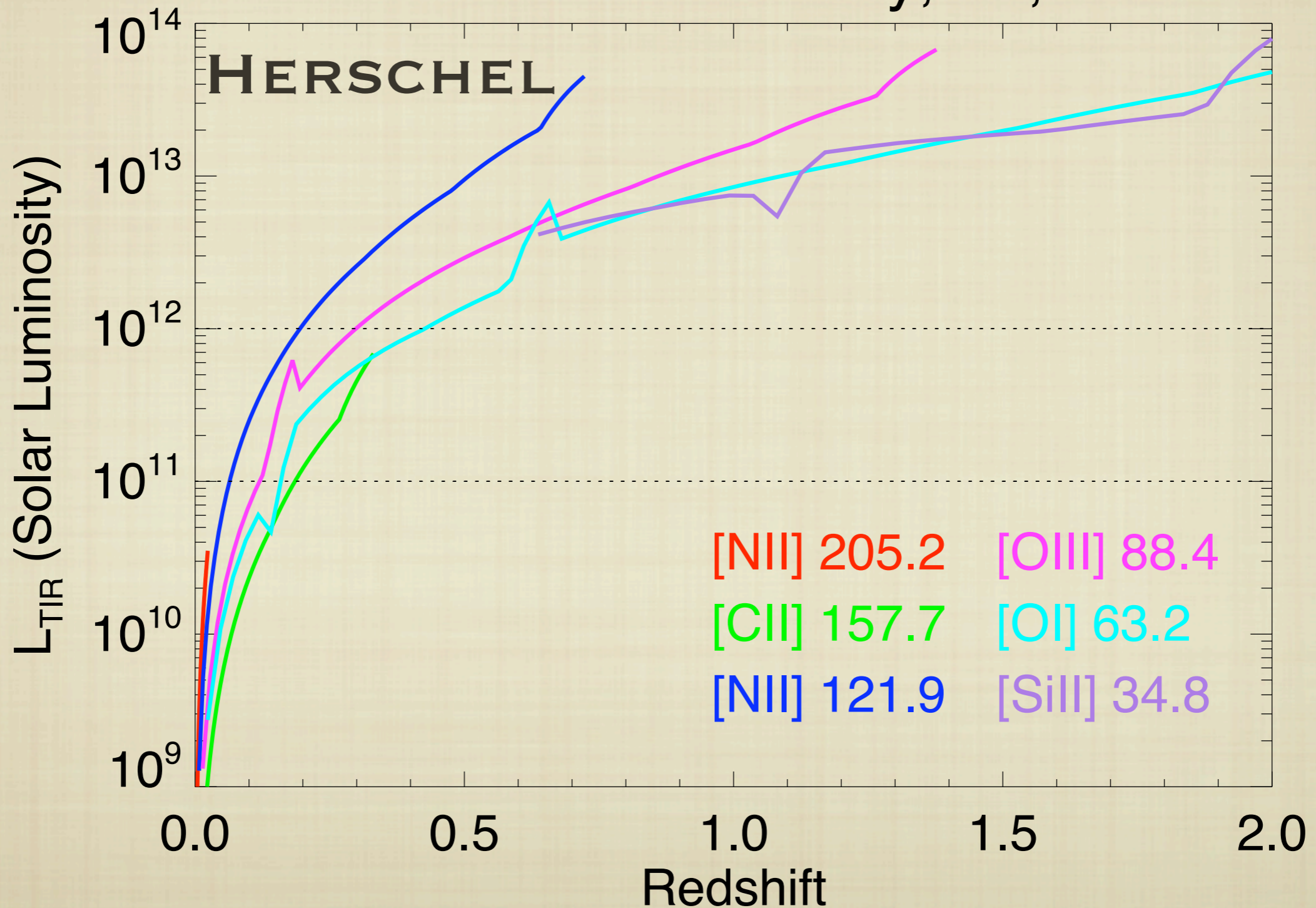
# I LOVE THE SMELL OF PAHS IN THE MORNING



VALIANTE ET AL, 2007

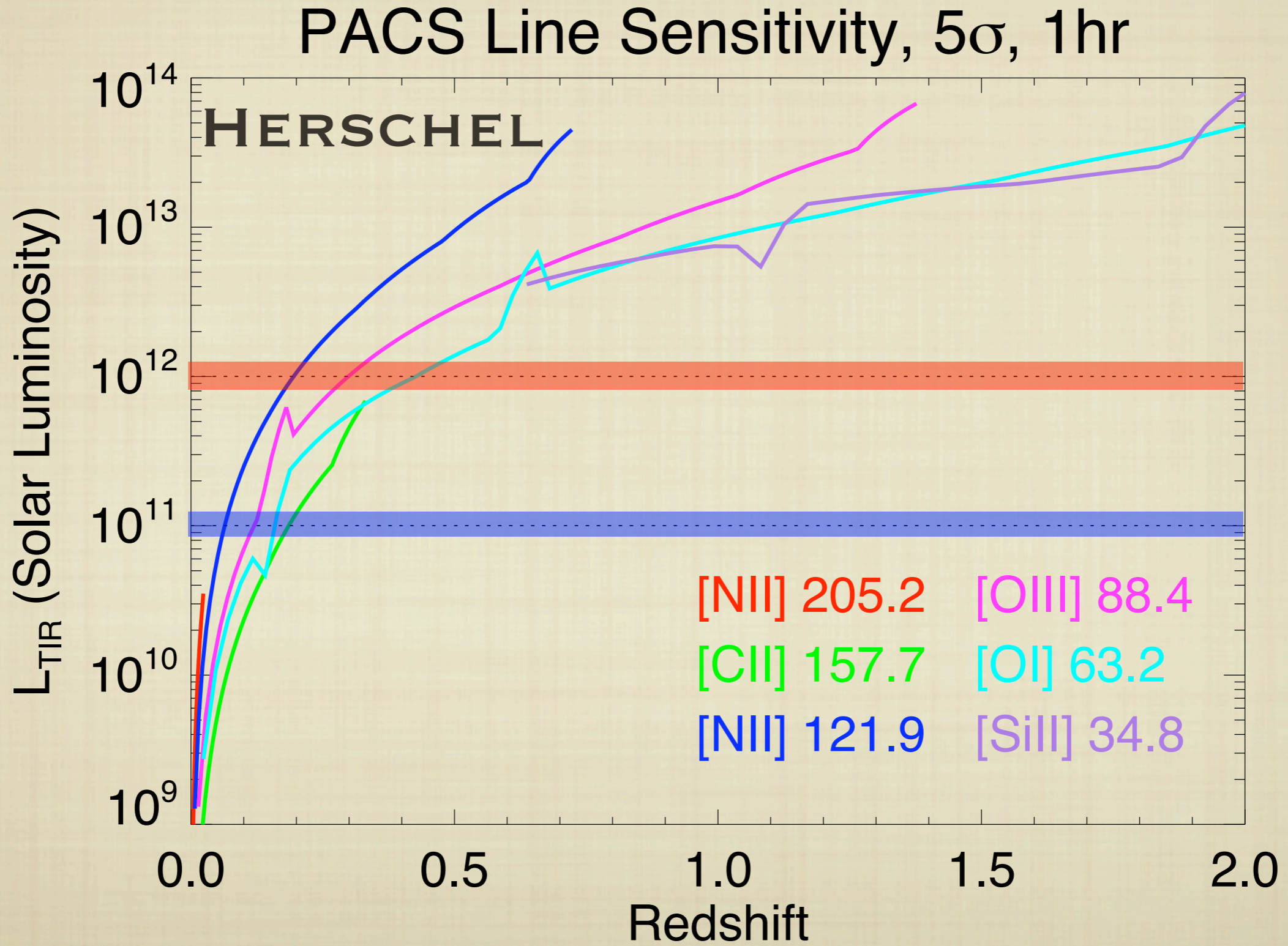
# THE DIAGNOSTICS DESERT

## PACS Line Sensitivity, $5\sigma$ , 1hr



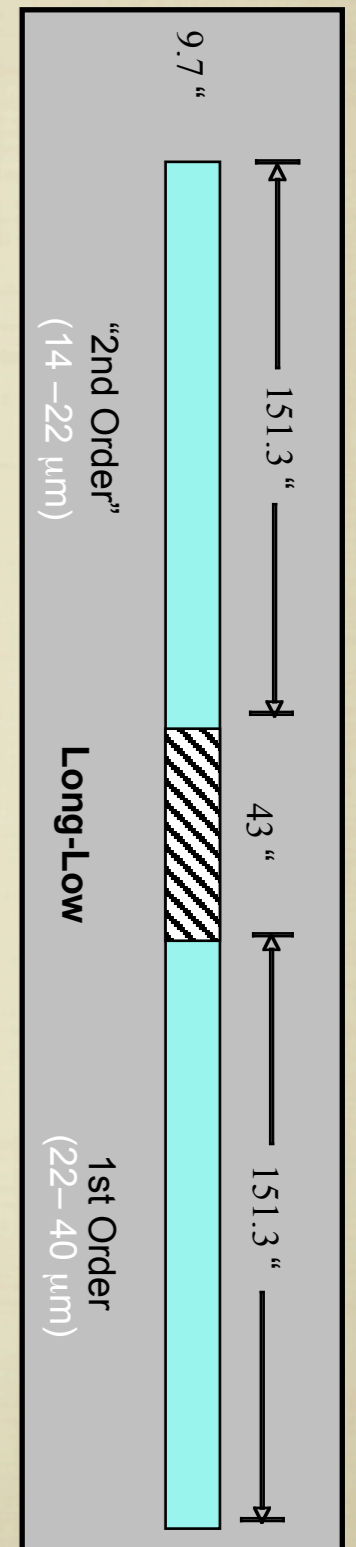


# THE DIAGNOSTICS DESERT

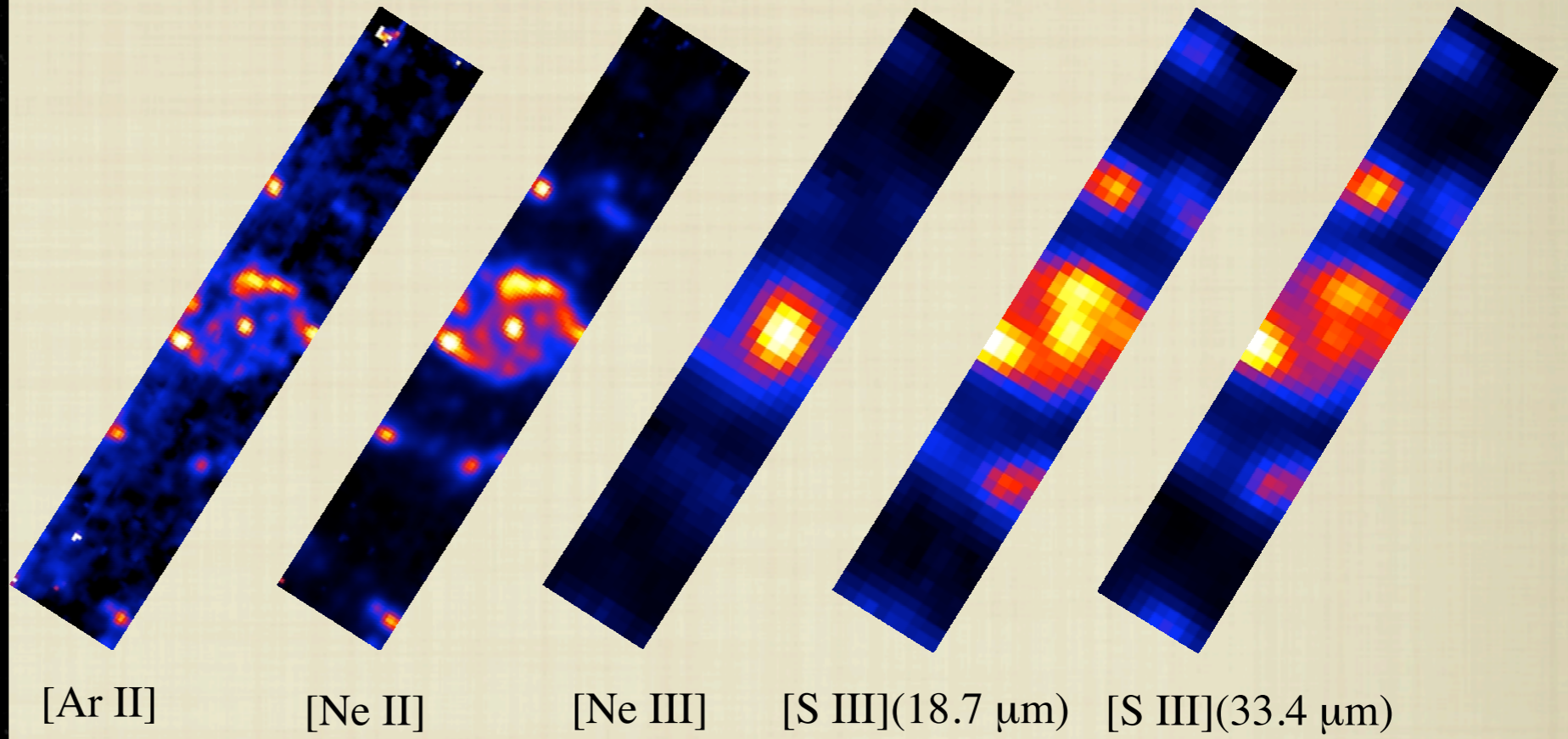
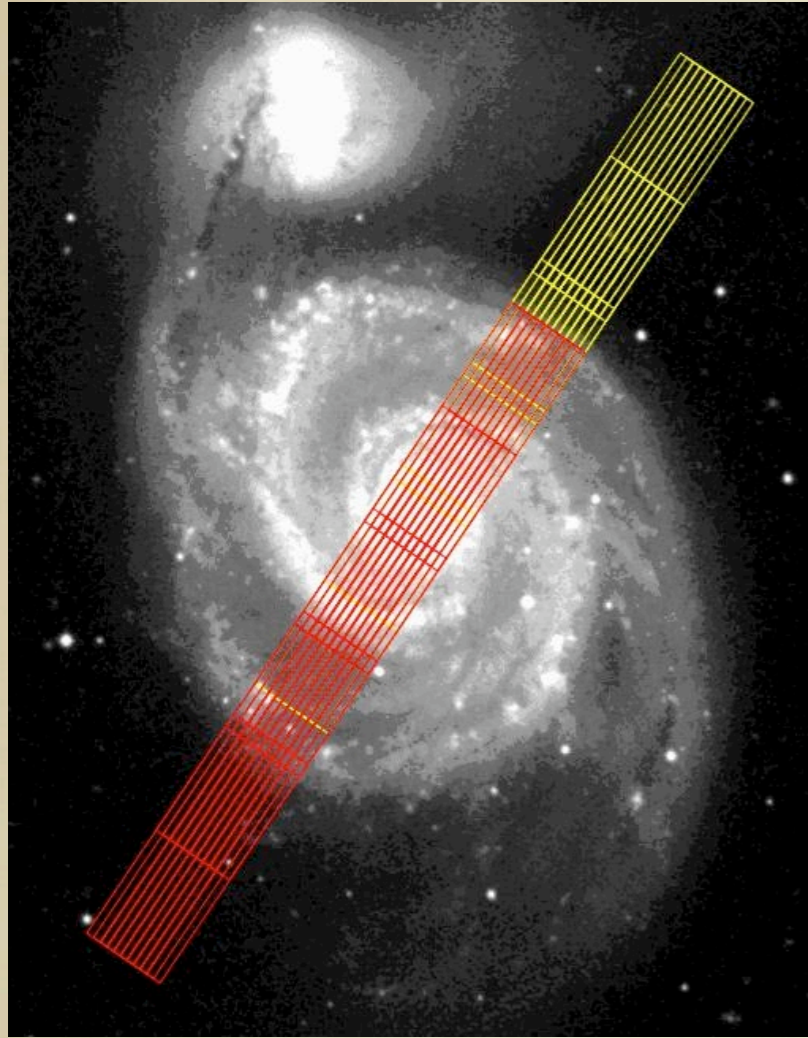


# THE HUMBLE LONG SLIT

- **STABLE BACKGROUND, IMAGING AND DETECTOR PERFORMANCE + SUB-SLIT WIDTH SPACECRAFT POINTING:**
  - **HIGH SPECTRAL MAPPING SPEED WITH LONG SLITS!**
- **SIMPLER OPTICS, SMALLER INSTRUMENT, EASIER TO CHARACTERIZE SLIT THROUGHPUT.**
- **SOME ADDITIONAL DATA COMPLEXITIES: EASILY HANDLED.**



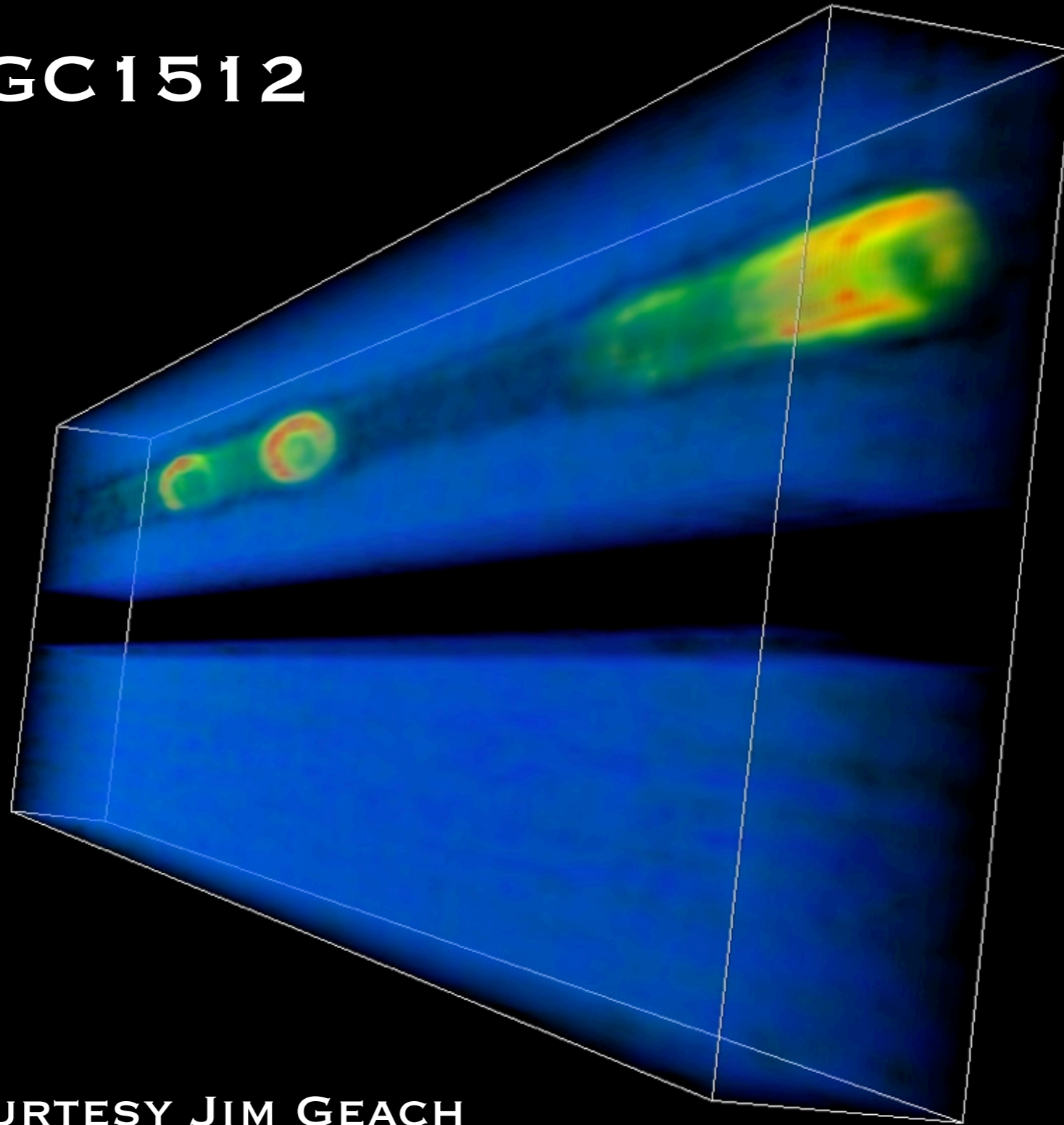




COURTESY G. BRUNNER



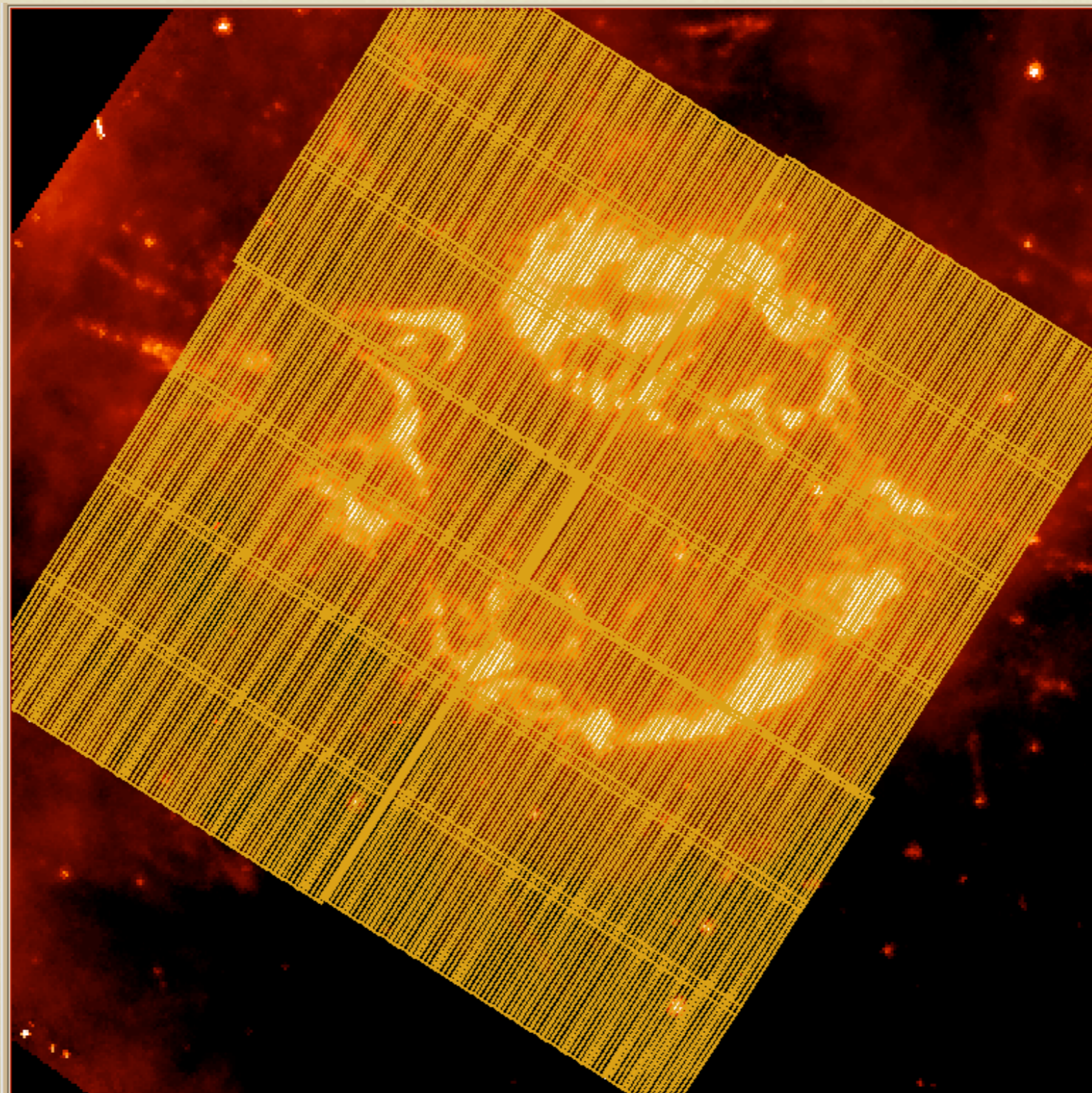
**NGC 1512**



**COURTESY JIM GEACH**

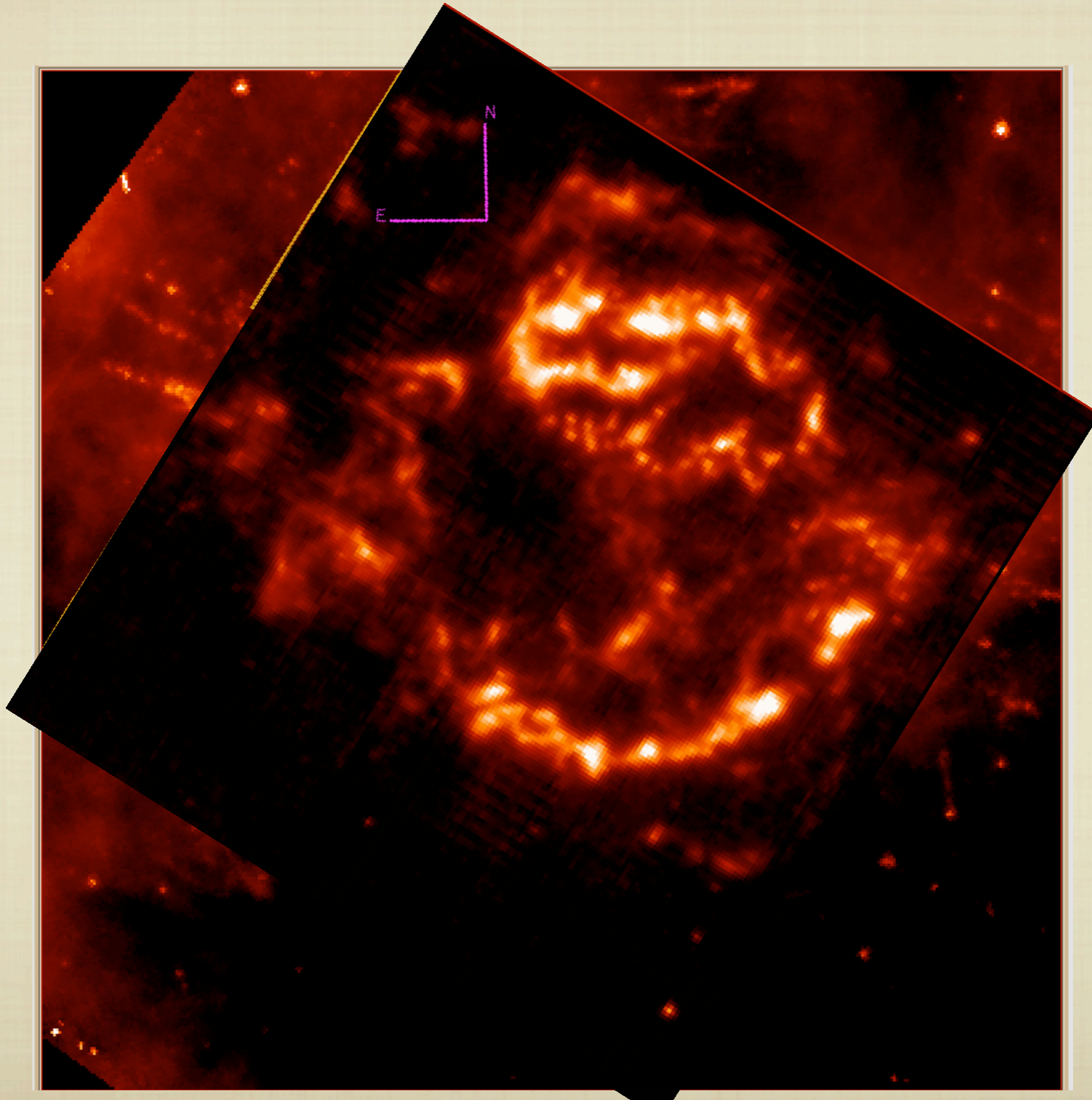


# SNR CASA



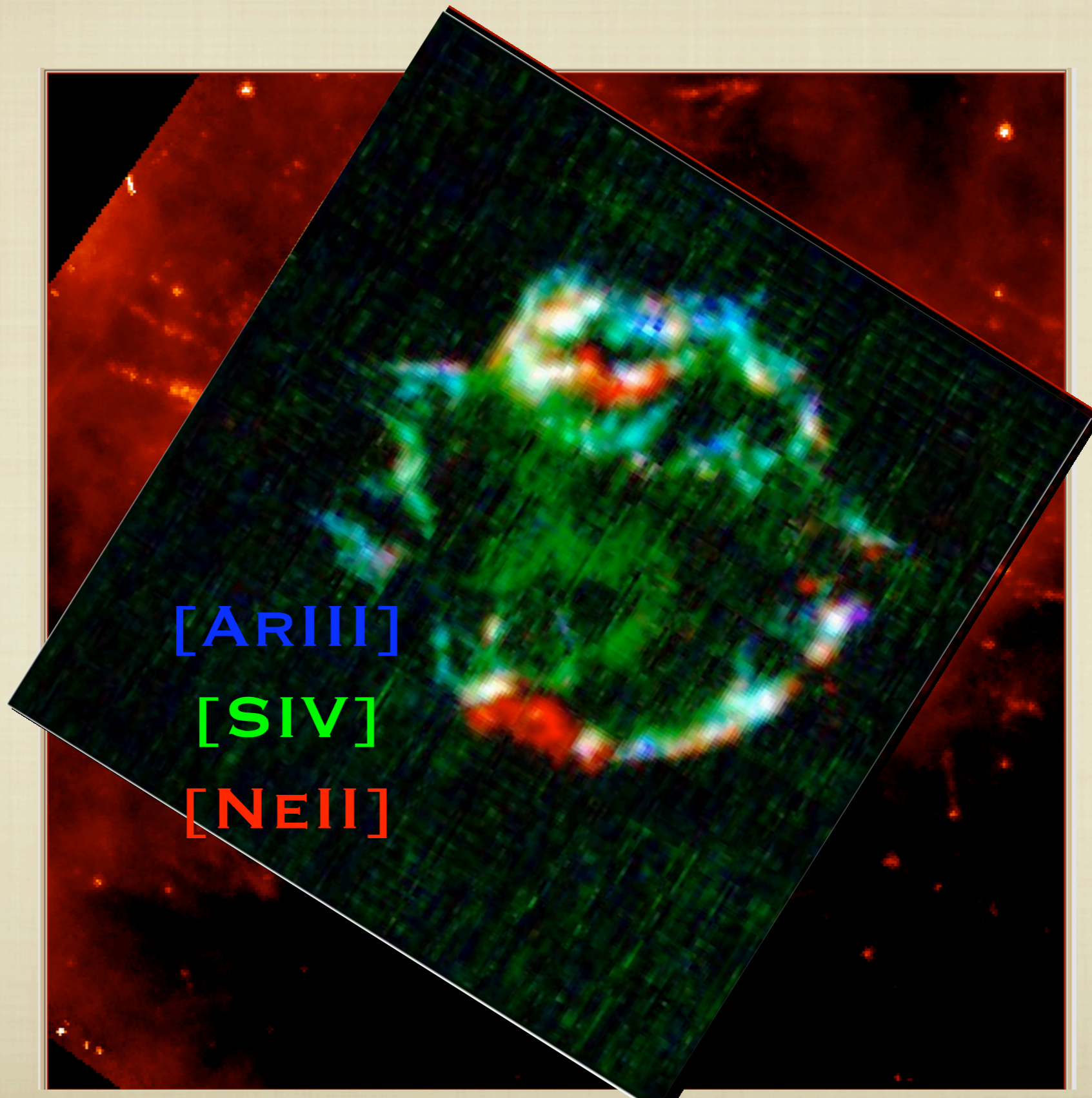


# SNR CASA





# SNR CASA





# ONWARD, UPWARD

- **INCREDIBLE DIAGNOSTIC POWER OF THE MID AND FAR-IR EMISSION OF GALAXIES, AS OF YET MINIMALLY EXPLOITED!**
- **PAH EMISSION: THE GIANT ELEPHANT IN THE ROOM.**
- **COLD, LARGE APERTURE, MODEST RESOLUTION SLITS: INCREDIBLE POWER FOR BOTH POINT-SOURCE AND MAPPING SURVEYS.**



