INFRARED SPECTROSCOPY OF DUST IN GALAXIES

SPITZER'S LEGACY JD SMITH



THE FIVE STAGES OF ASTRONOMER'S REGARD OF DUST

ABSORPTION OF LIGHT IN THE GALACTIC SYSTEM By Robert J. Trumpler

For more than a century astronomers have interested themselves in the question: Is interstellar space perfectly transparent, or does light suffer an appreciable modification or loss of intensity when passing through the enormous spaces which separate us from the more remote celestial objects? Any effect

- 1. DISREGARD.
- 2. DISDAIN.
- **3.** ACCEPTANCE.

INTEREST: PHYSICS.
 INTEREST: TOOL.

DUST...

- ONLY <~1% OF THE GAS MASS IN A GALAXY.
- IS DISTRIBUTED HIGHLY NON-UNIFORMLY IN GALAXIES.
- **MUST BE CREATED.**
- EVOLVES AND IS DESTROYED.
- RESPONDS IN COMPLEX WAYS TO INPUT RADIATION (IONIZING AND OTHERWISE).

THE LIGHT BETWEEN: COSMIC BACKGROUND

Frequency v [GHz]



THE LIGHT BETWEEN: COSMIC BACKGROUND



THE EMBARRASSINGLY RICH INFRARED SPECTRUM OF GALAXIES

- OLD STELLAR PHOTOSPHERES.
- STOCHASTICALLY HEATED GRAIN CONTINUUM.
- STRONG AROMATIC EMISSION BANDS.



COURTESY: BRENT GROVES

- THERMAL DUST EMISSION.
- COOLING LINES OF HII REGIONS, PDRS, HIGH EXCITATION AGN ENVIRONMENTS: 5–150EV.

HISTORICAL INTERLUDE: IR SPECTROSCOPY OF GALAXIES

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

λ/Δλ~50 KPNO 2.1 M, COOLED FILTER WHEEL SPECTROMETER

GILLETT ET AL., 1975



THE HUMBLE PAH

- LARGE PLANAR AROMATIC MOLECULES (~10's–1000 CARBONS ATOMS, 10Å DIAMETER)
- VIBRATIONAL (C-C, C-H) EMISSION BANDS
 AT 3.3, 6.2, 7.7, 8.6, 11.3, 12.6, 17.1 μm,
 ... (UIB,AFE,AIB,...)



IS THE PAH SPECTRUM CONSTANT?

- PAH GRAINS ARE PHOTO-EXCITED BY SINGLE PHOTONS TO T>50-100K.
- RADIATION FIELD.
- UNIFORM IR EMISSION SPECTRUM.

"A DAY IN THE LIFE OF A SMALL GRAIN"



DRAINE, 2003







DRAINE & LI, 2001

PAH VARIATIONS: BY EYE







Sмітн, 2007

PAH VARIATIONS: BY EYE







Sмітн, 2007

THE INCREDIBLE PAH LUMINOSITY



 $L_{TIR} = L(3 - 1100 \mu M)$

THE TOP 10 MOST LUMINOUS (OBSERVED) EMISSION LINES OF STAR-FORMING GALAXIES



WAVELENGTH(µM) • LINE

KING PAH



WAVELENGTH(µM) • LINE

KING PAH



WAVELENGTH(µM) • LINE

DUST EMISSION AS A TOOL

PAH EMISSION IS ALREADY A POWER-TOOL OF CHOICE AT Z~2.

USED TO ESTABLISH (EVEN QUANTIFY) STAR-FORMATION.



THE FUTURE: PAH'S FIRST LIGHT







STAR-FORMATION VS. PAH EMISSION



CALZETTI, 2007

DUST IN AGN

COMPOSITE POWER SOURCES DOMINATE LOCAL ULIRGS



- HOT DUST, HEATED TO THE SUBLIMATION TEMPERATURE (~1500K).
- "ANOMALOUS" PROPERTIES (E(B-V)/N_H, A_V/N_H).
- X-RAY DOMINATED REGION (XDR) CAN BE QUITE LARGE: COULD IT DESTROY/EXCITE GRAINS?

X-RAY IRRADIATION OF INTERSTELLAR GRAINS

In this paper, we have embarked on the first fundamental physical study of grains heated transiently by X-rays. Our model provides two solid observational predictions: the infrared spectra of grains, even if they are superheated, should show a cutoff between 1 and 3 μ m; and X-ray–illuminated environments should exhibit no PAH emission. The first prediction may explain the universal 1 μ m minimum found in the PG quasars (Sanders et al. 1989), and the second agrees with the observed lack of PAH features in Seyfert galaxies (Aitken & Roche 1985). The IR spectra from X-ray–illuminated grains generally contain a Planckian

VOIT, 1991

- 5Å GRAINS: EVAPORATE QUICKLY
- 10Å GRAINS: PERSIST
- (XDR'S: PAH'S REQUIRED FOR ELECTRON HEATING)

PAHS IN AGN





LUTZ, 1997

PAHS IN AGN





LUTZ, 1997

DIFFICULTIES

HOST GALAXIES UNRESOLVED: CONTAMINATED DUST SIGNATURE.

SOLUTION: USE LOW-LUMINOSITY, NEARBY ANALOGS. Quasar With Host Galaxy HE1239-2426



QUASAR PAHS



Rest-frame wavelength (um)

SHI, 2007

A (WEAK) AGN IN MOST GALAXIES?



KEWLEY ET AL., 2006













SMITH, 2007

FOLLOWING THE ACTION



YANG, 2007

FOLLOWING THE ACTION



YANG, 2007

ISSUES & OPPORTUNITIES

DUST EMISSION: A (PRECISION) TOOL FOR STUDYING GALAXY EVOLUTION?

HOW DOES CHEMICAL ABUNDANCE CONTROL PAH EMISSION?

HOW DO AGN MODIFY (EXCITE?) PAH GRAINS? BUMP DESTROYERS?

AGN HEATED DUST VS. "TIRED" STARLIGHT?