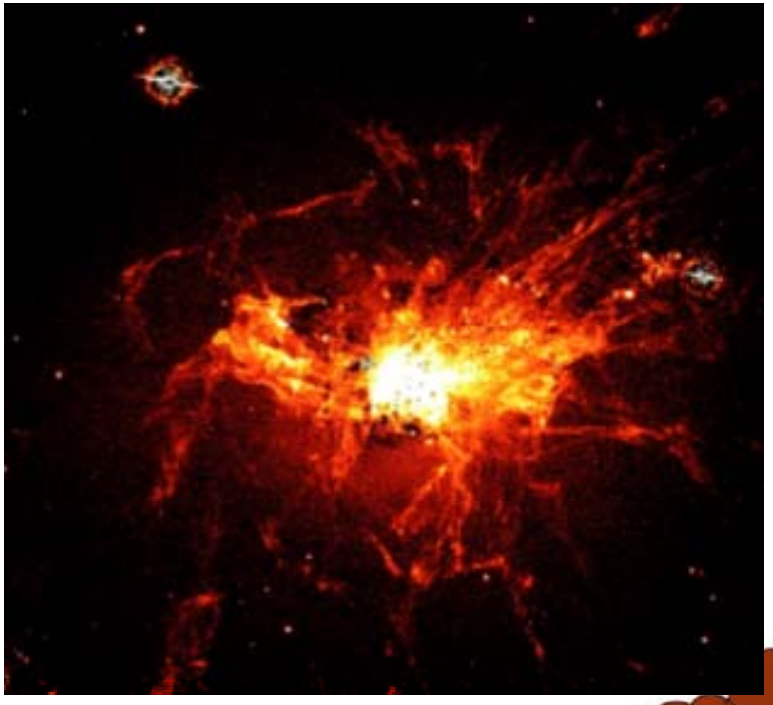
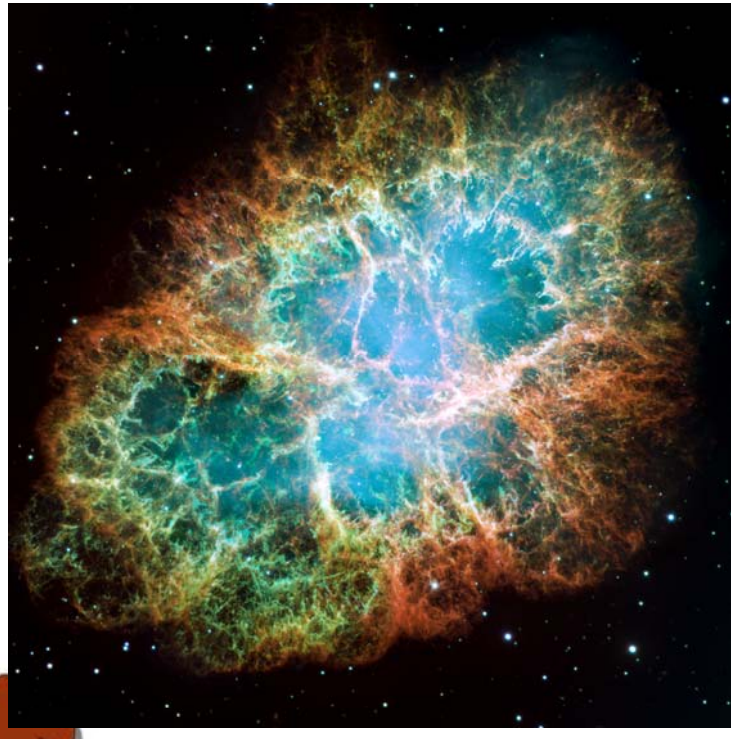
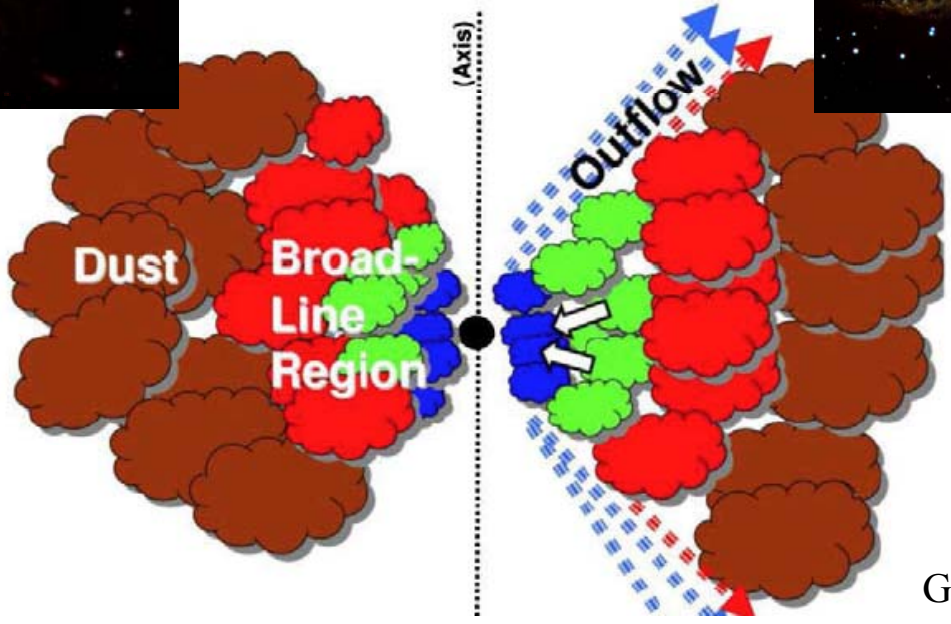
# Implications of strong $H_2$ emission in astronomical environments



Fabian+08

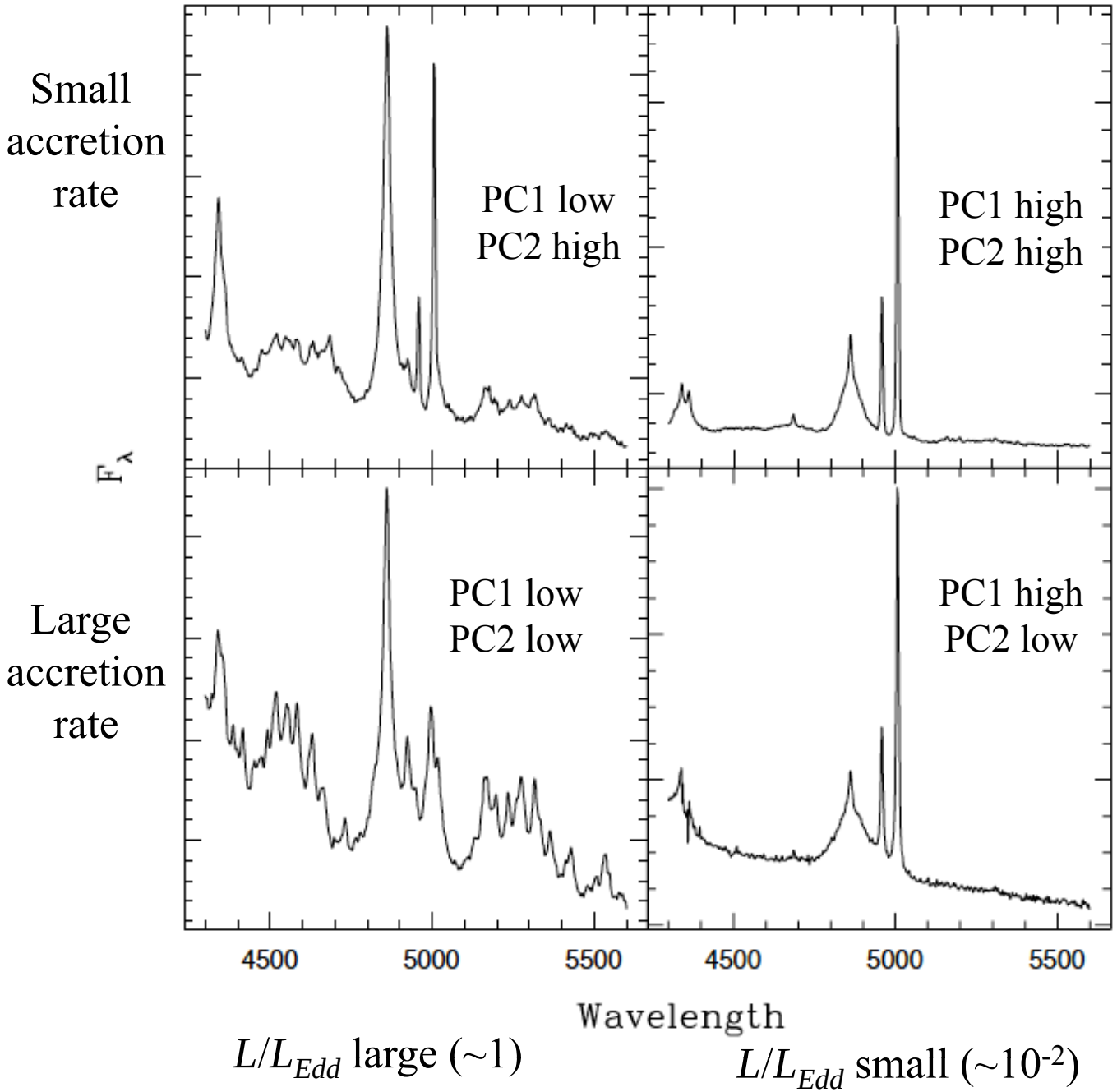


STScI

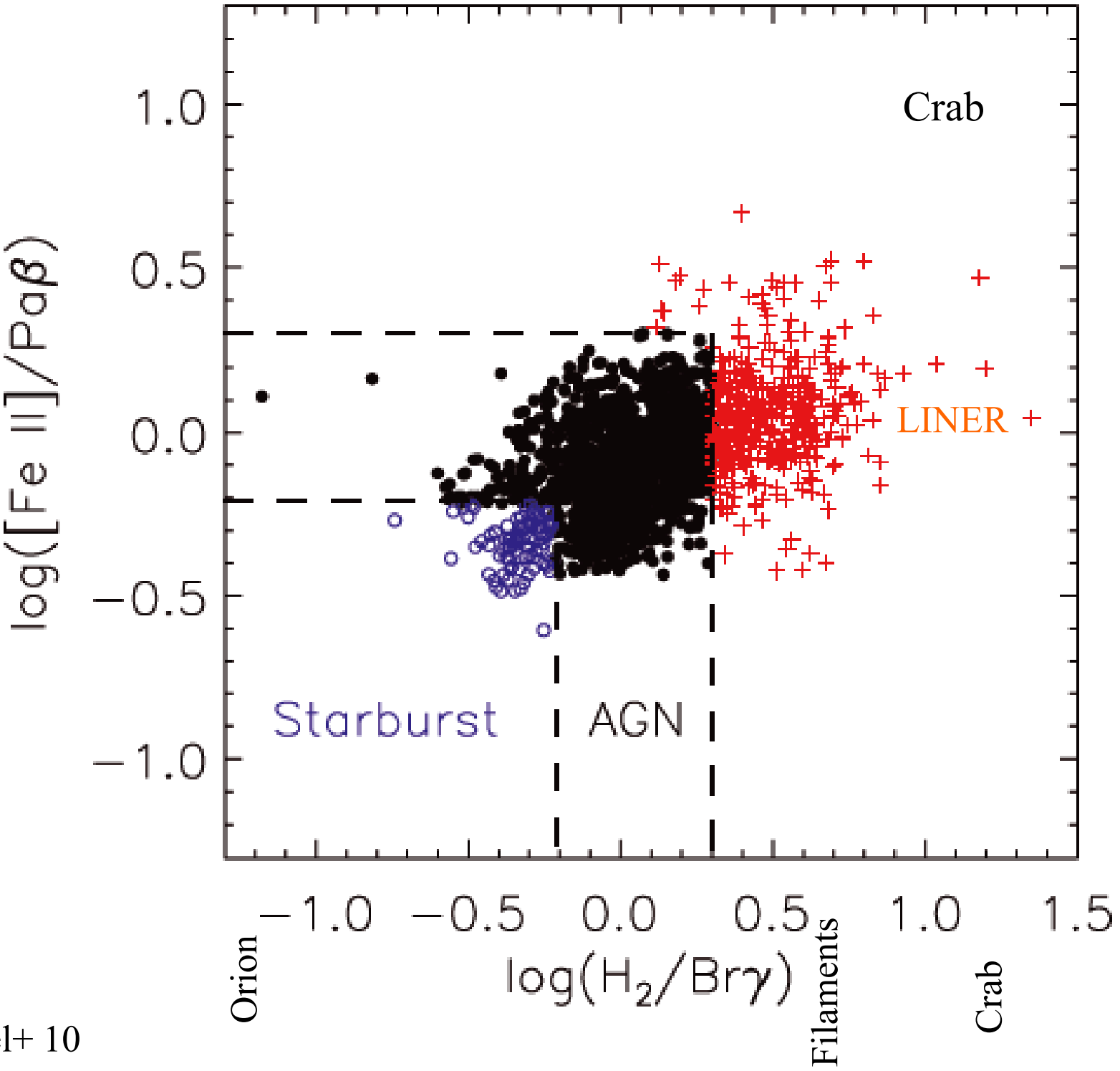



Gaskell+08

# Spectral dependence on accretion rate, $L/L_{Edd}$



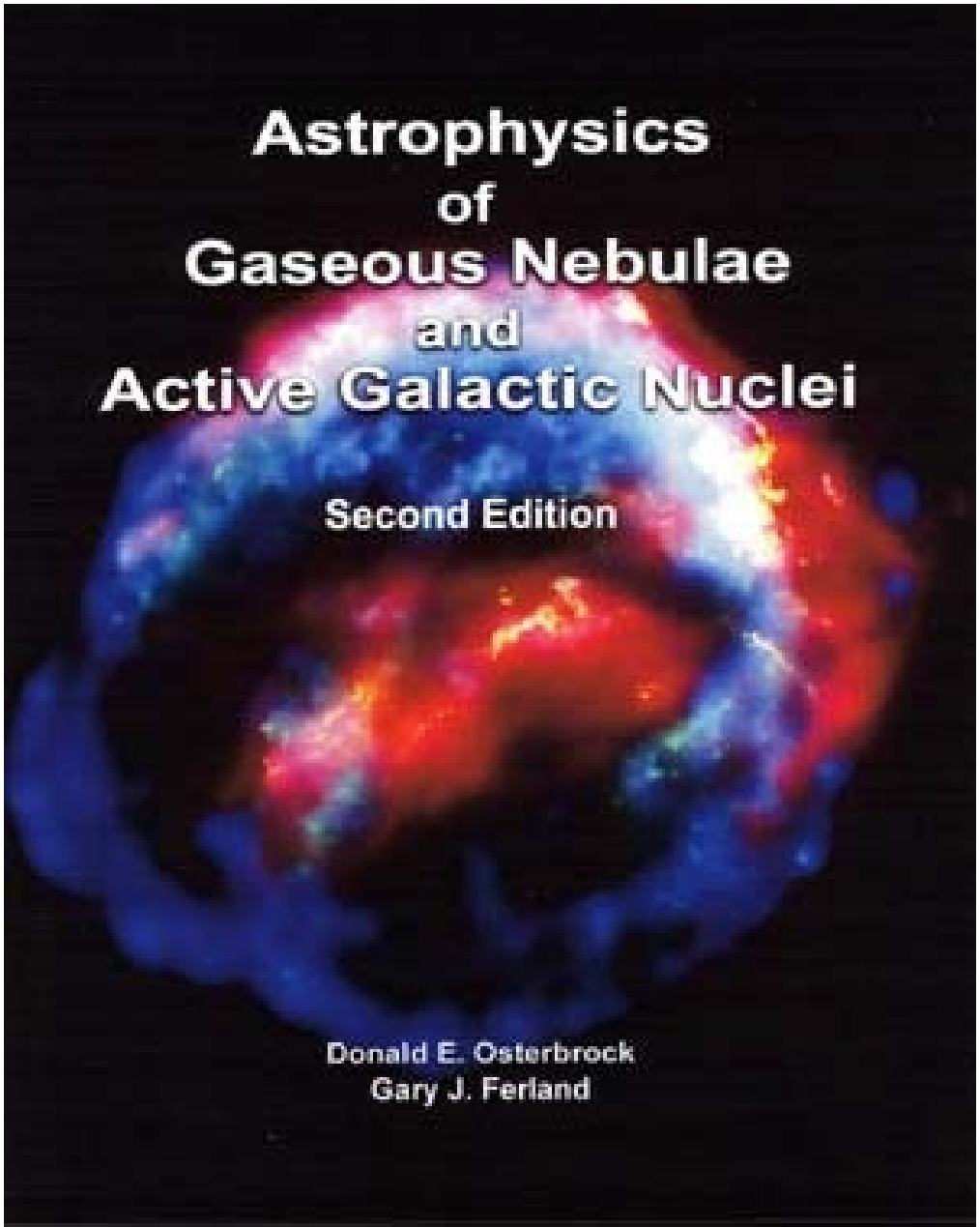

Boroson 2002, ApJ, 565, 78

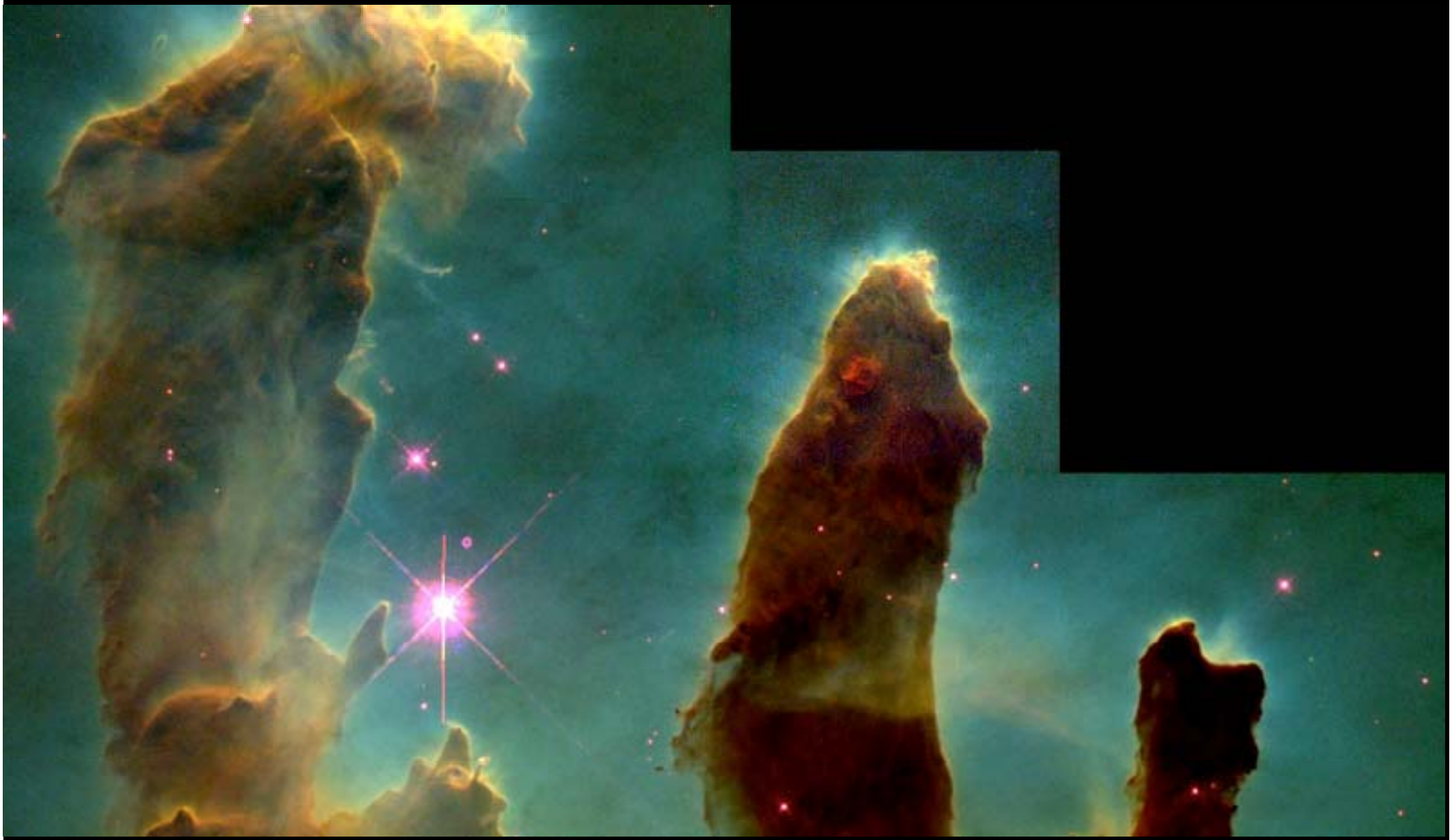

Crab
LINER
Starburst
AGN
Orion
Filaments
Crab
log([Fe II]/Paβ)
log(H2/Brγ)
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
1.5

Riffel+ 10

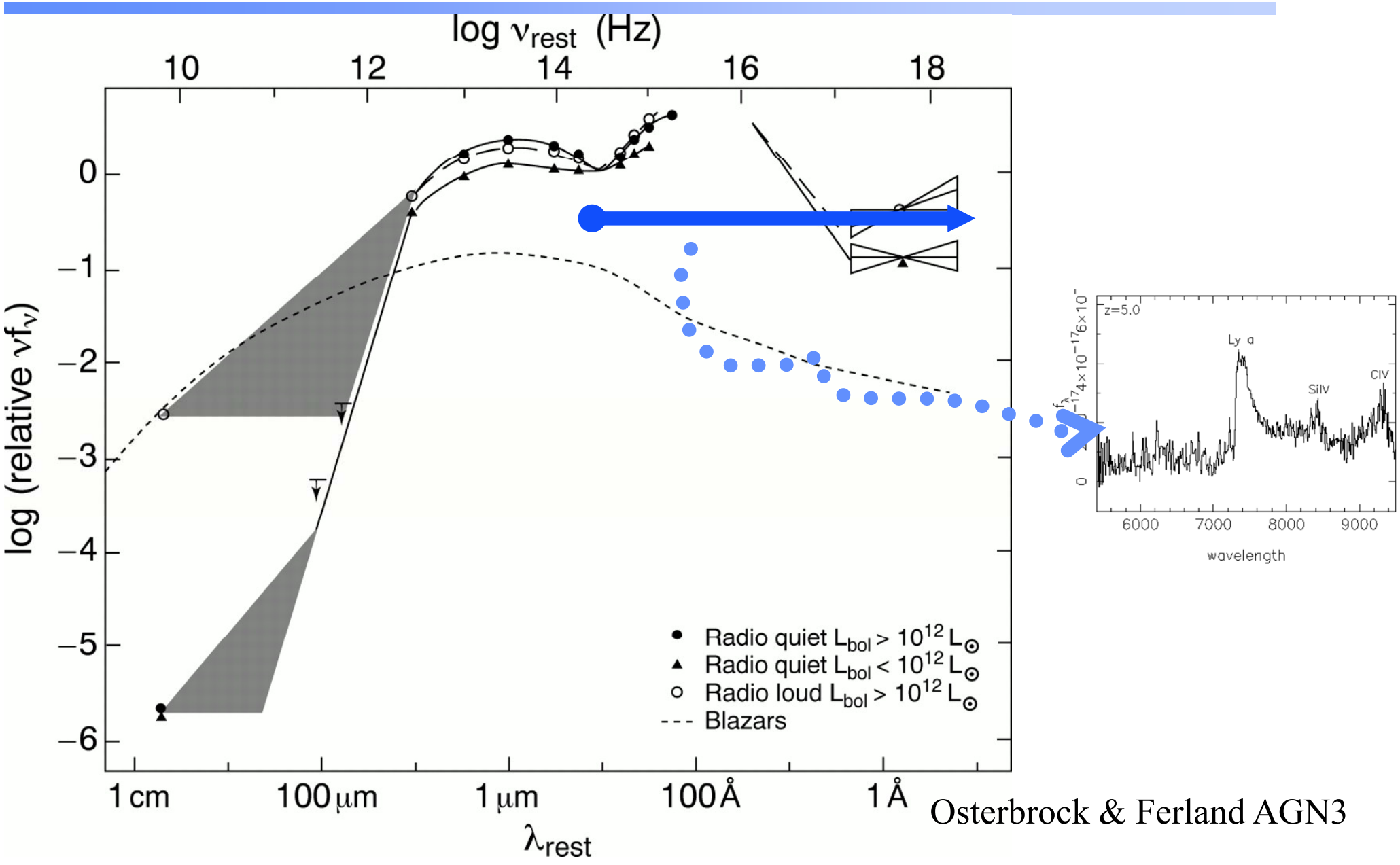
# Spectrum of a non-equilibrium gas

- **Treat microphysics in detail**
- **Energetic radiation & particles interact with gas**
  - ionization
- **Ejected electrons heats, excite & ionize gas**
- **Ionization drives chemistry**
- **Full spectrum predicted**

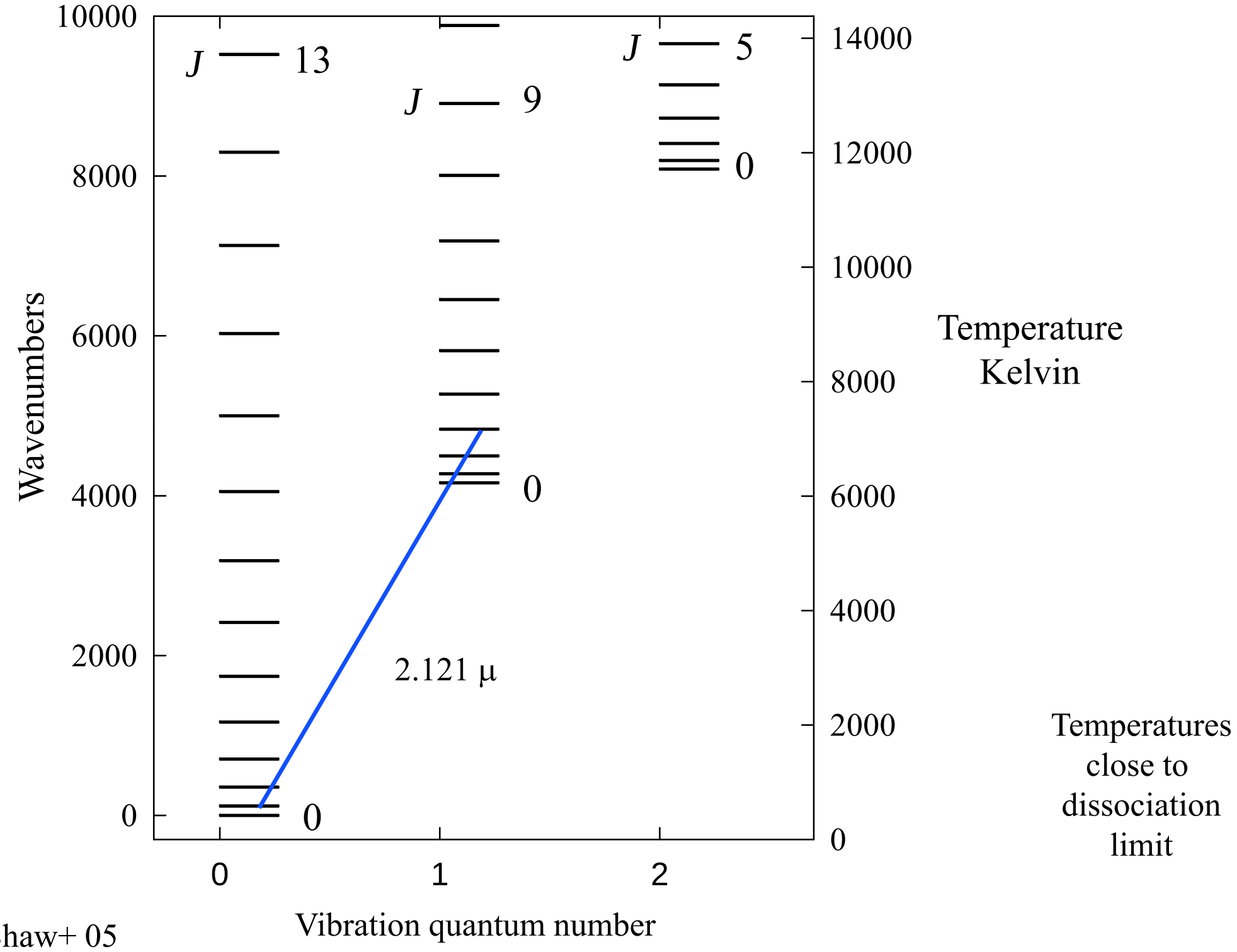




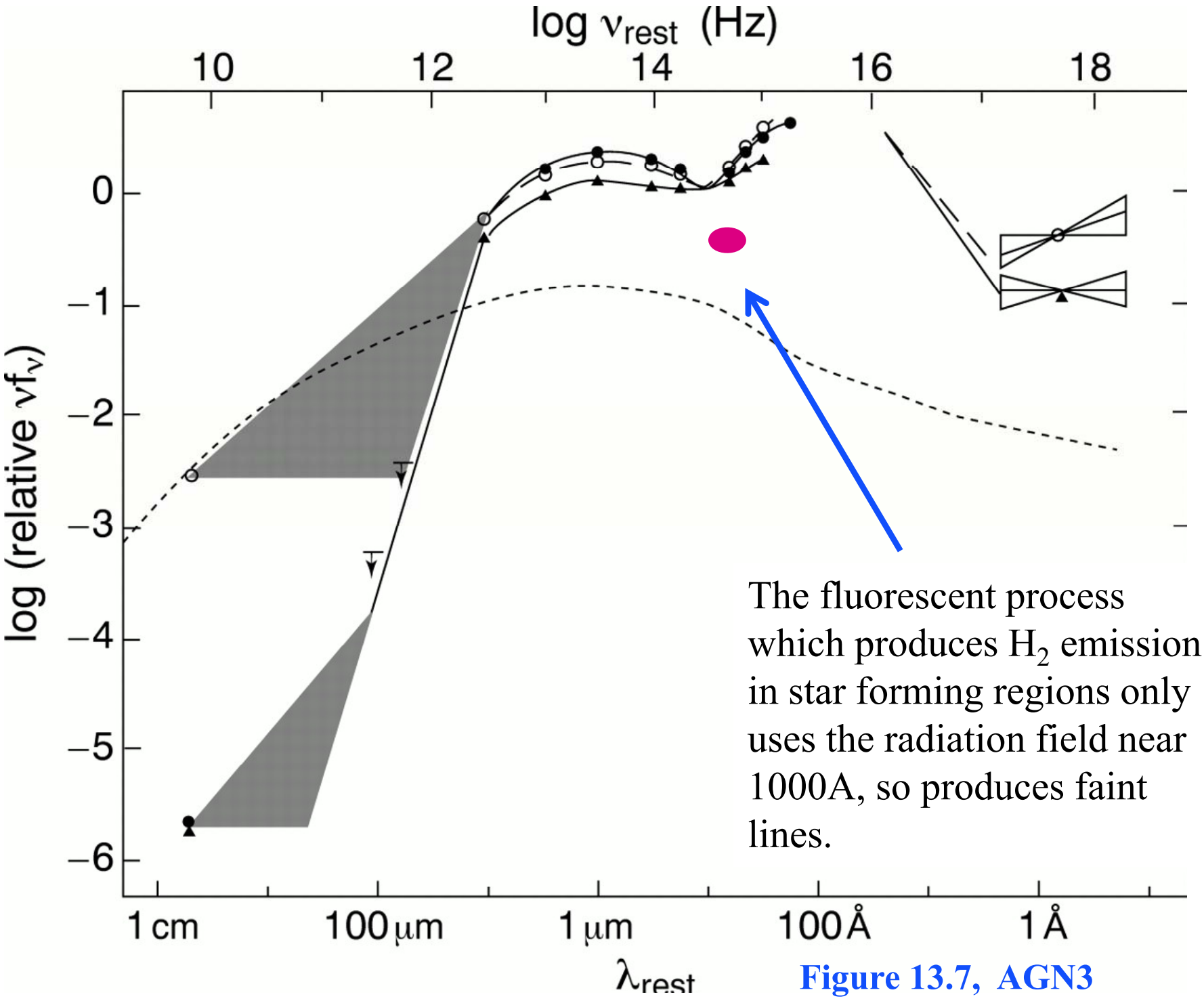
# Continuum → H I lines




Osterbrock & Ferland AGN3

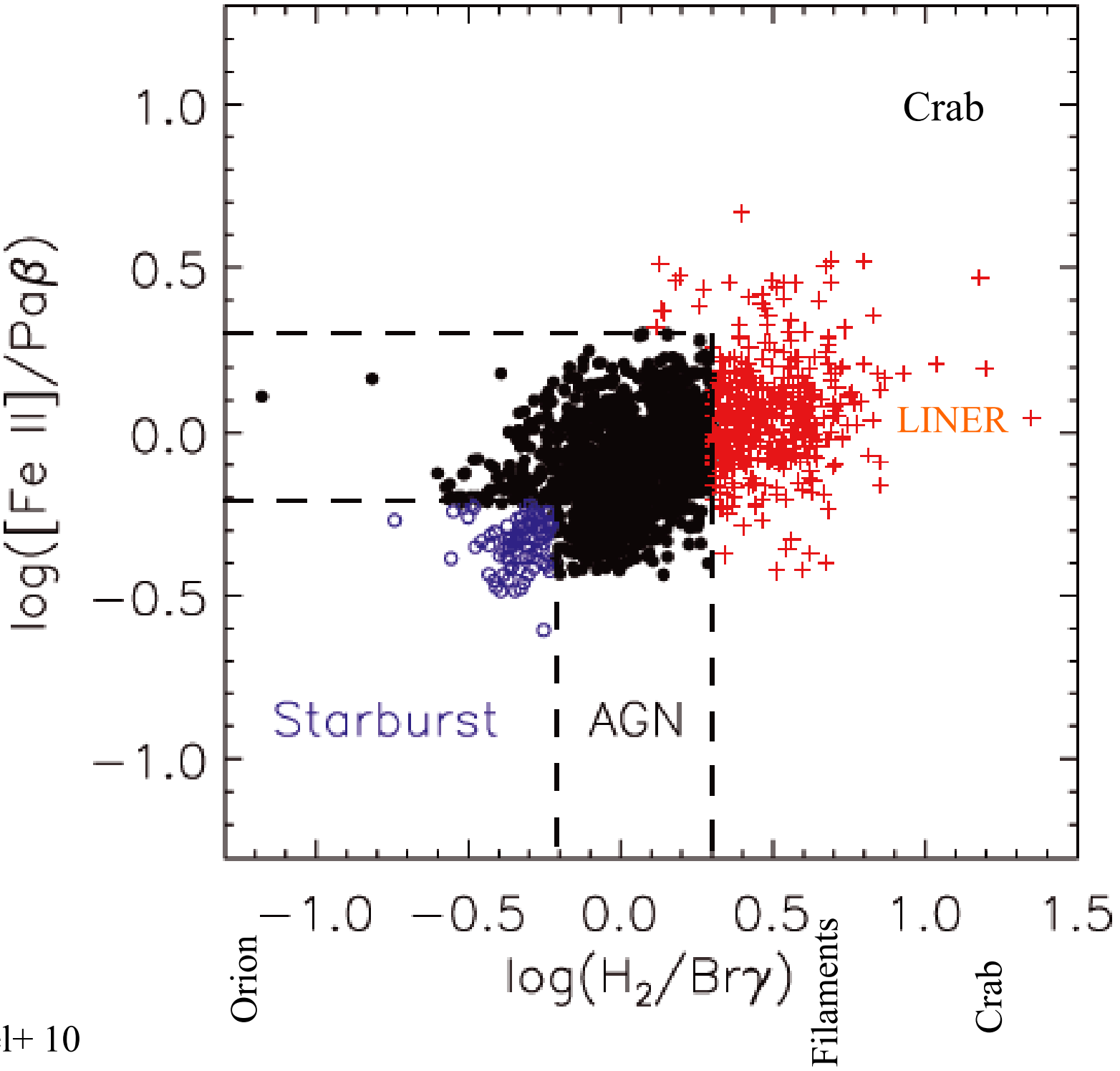

10000
8000
6000
4000
2000
0
Wavenumbers
J 13
J 9
J 5
0
0
0
2.121 μ
14000
12000
10000
8000
6000
4000
2000
0
Temperature
Kelvin
Temperatures
close to
dissociation
limit
0
1
2
Vibration quantum number

Shaw+ 05




The fluorescent process which produces $H_2$ emission in star forming regions only uses the radiation field near 1000A, so produces faint lines.

**Figure 13.7, AGN3**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Riffel+ 10

# Independent energy sources unlikely

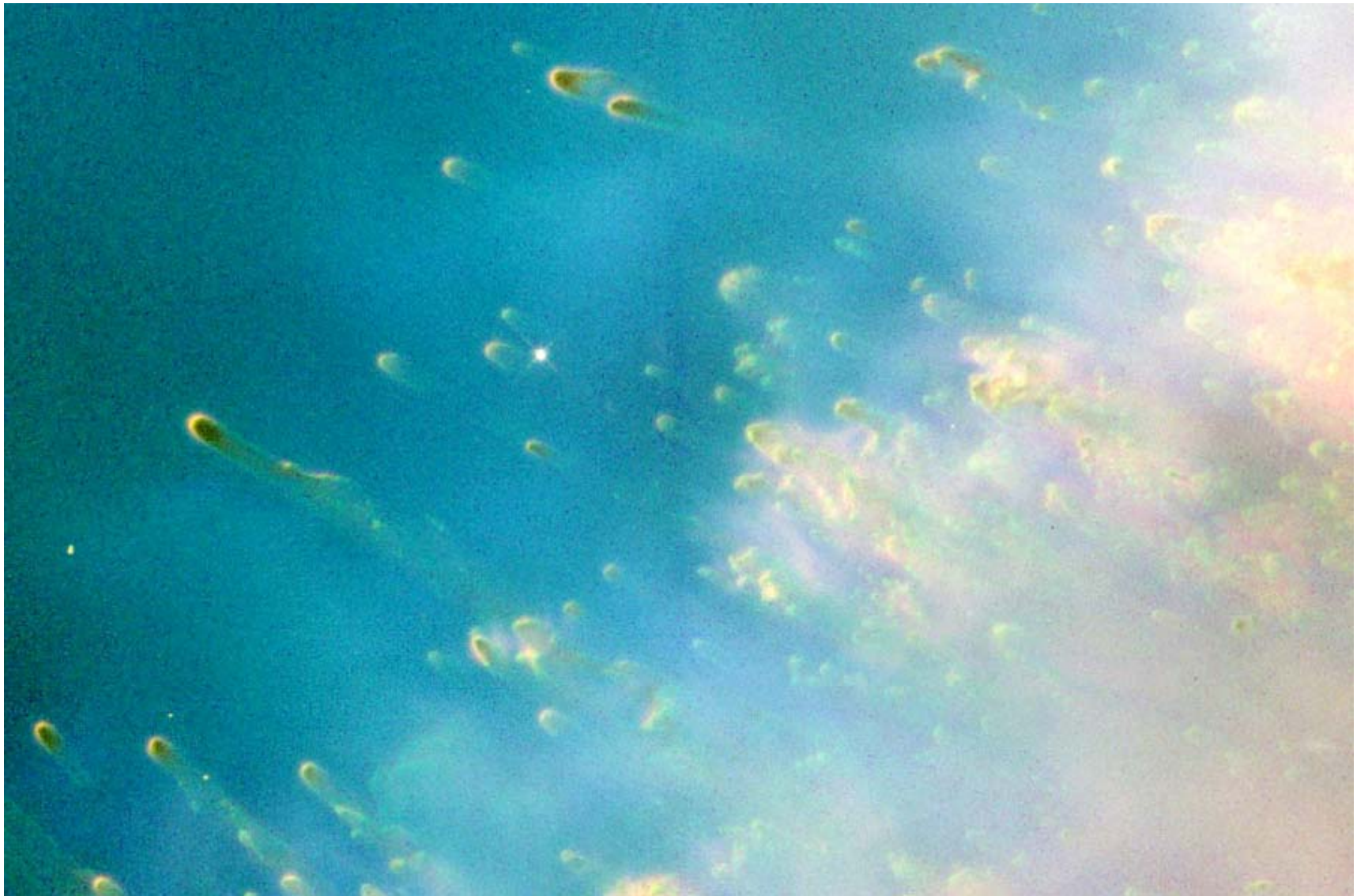
| Object | Heating erg $cm^{-2}$ $s^{-1}$ | |
|---|---|---|
| | Radiative | Collisional |
| Earth | 1 400 000 | 5.8 |
| Supernova remnant | 0.0028 | 7.9 |

# Four ways to produce strong ionic *and* $H_2$ emission

- Advection of molecular gas into hot ionized regions
- “extra heating” - heat deposition by shocks, dissipative MHD waves, etc
- Ionizing particles
- Very hard SED

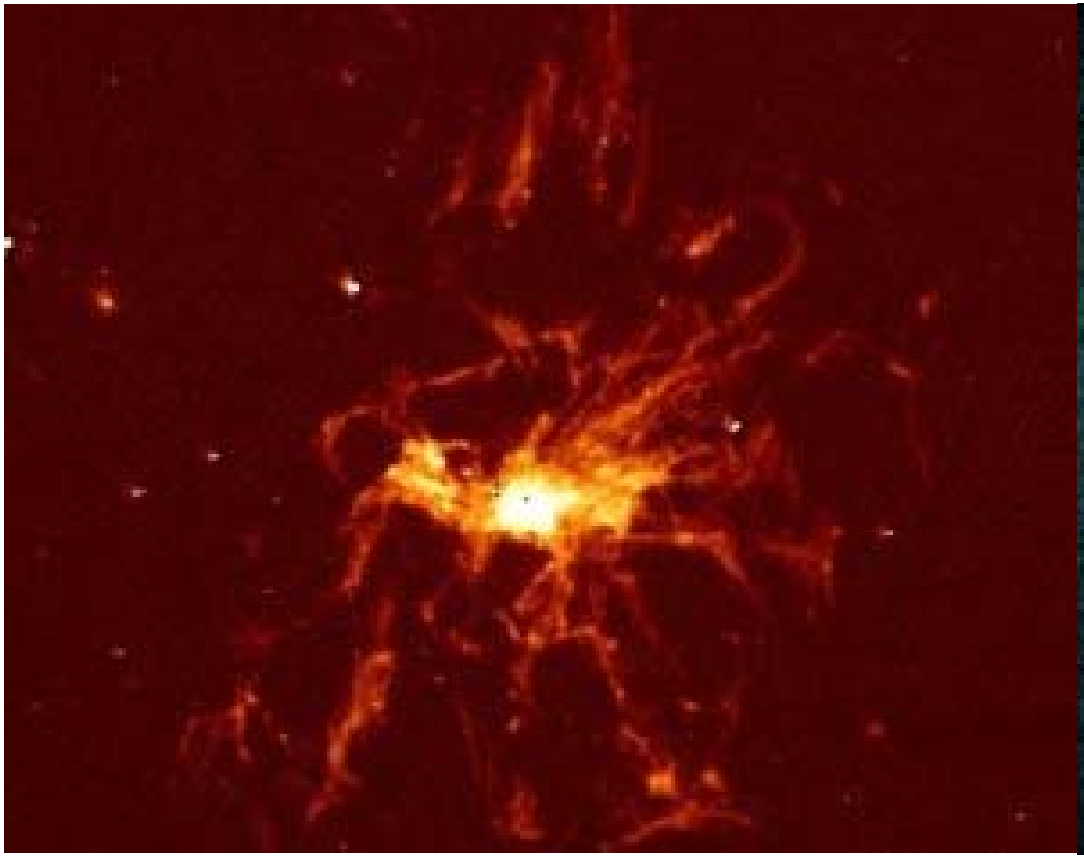
# Advective flow of $H_2$ into $H^+$ region

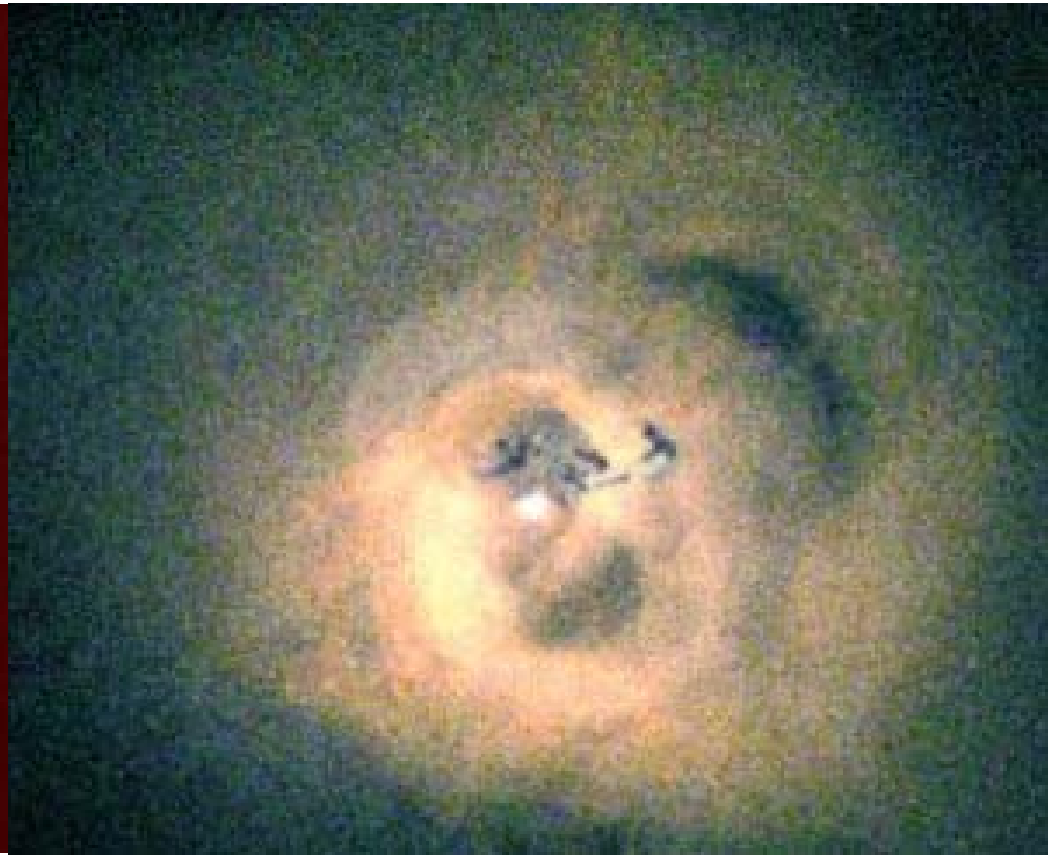
- Henney+ 07



# Cool core cluster filaments

- **Thermal particles from surrounding hot gas**

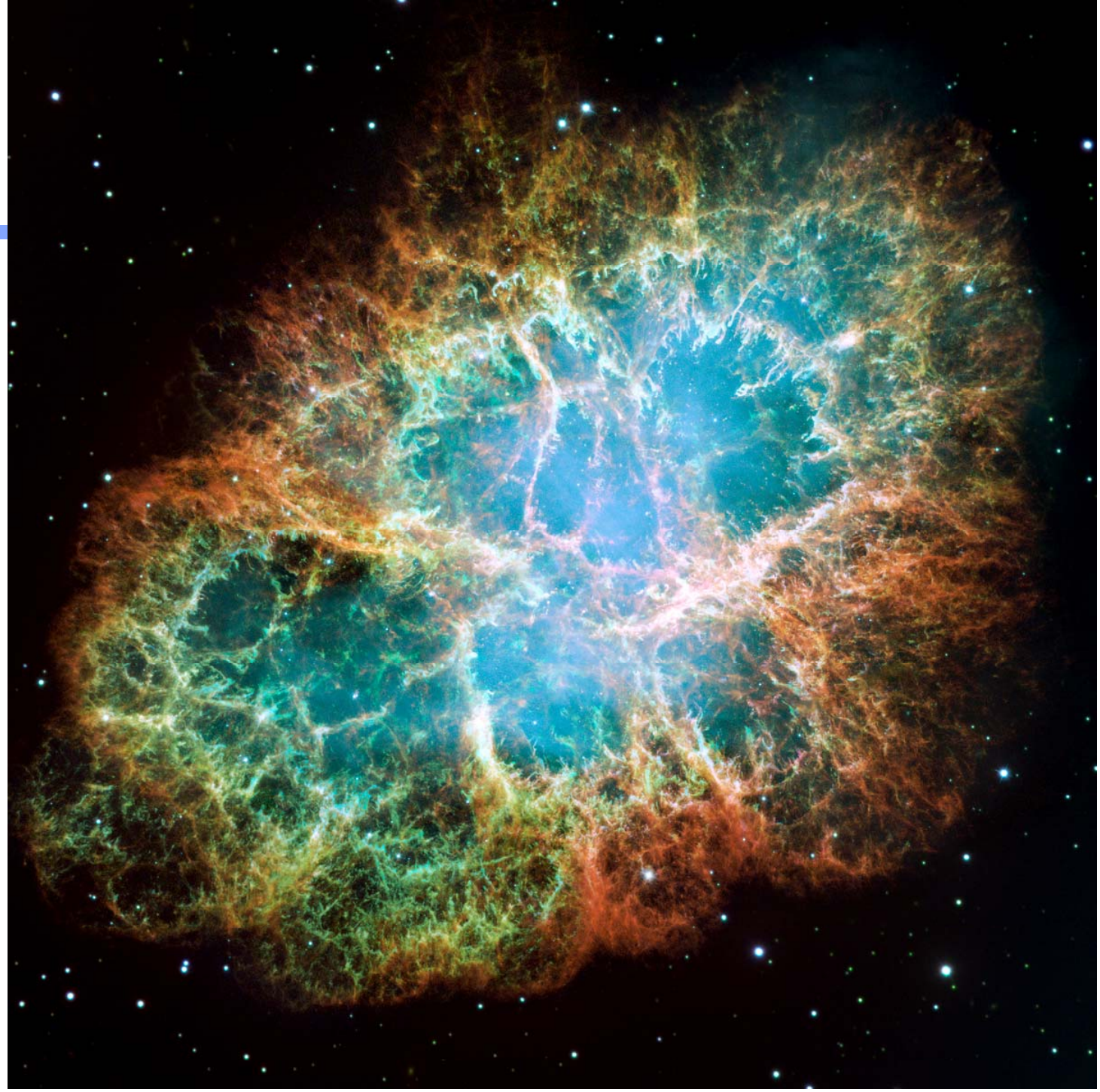


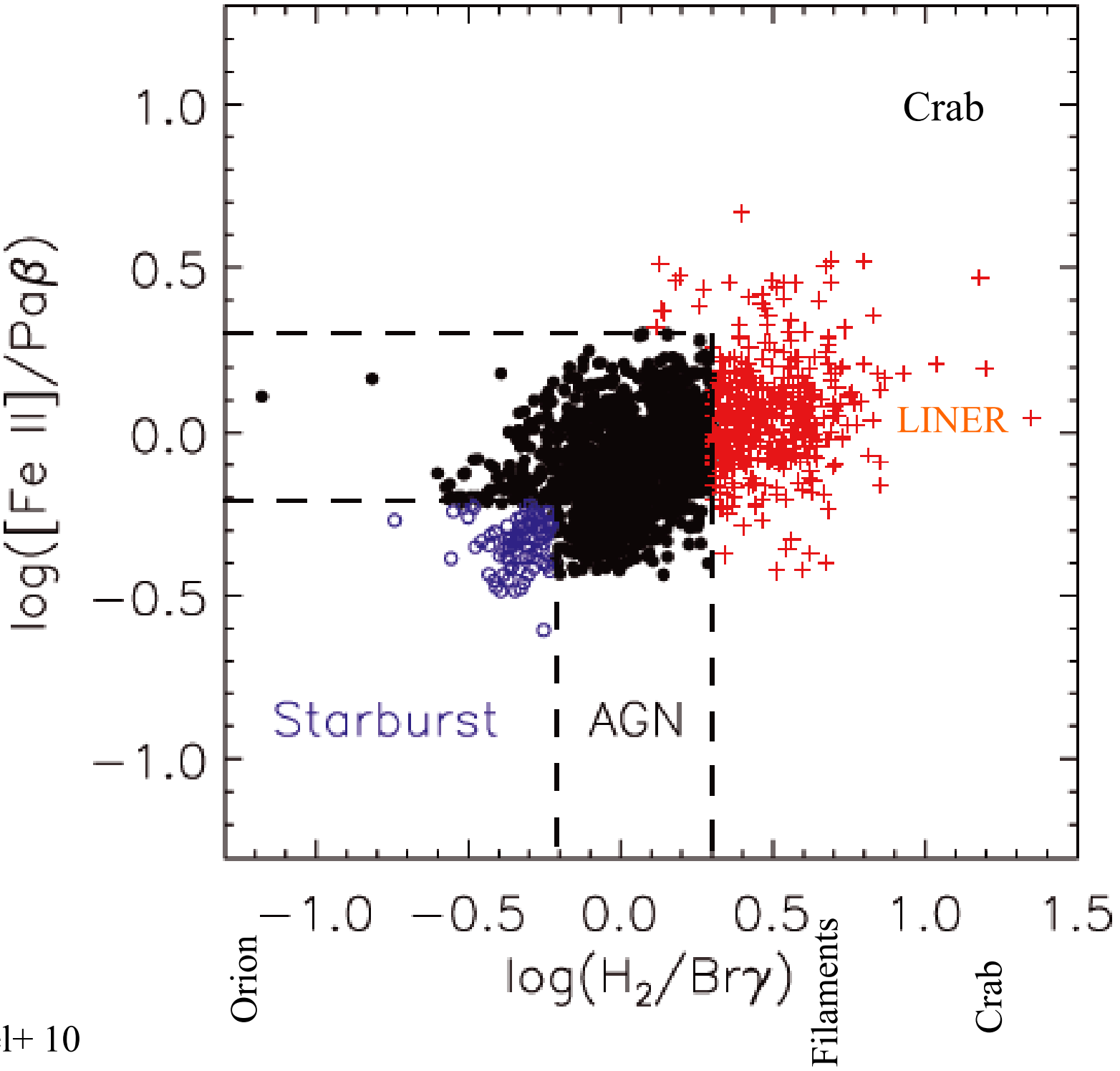


– Johnstone+ 07, Ferland+ 08, 09, Fabian+ 11

# The Crab

- Graham+ 90 hard photons or ionizing particles
- Lo+ 10, 11a 11b; $H_2$ is warm and abundant
- A photon-rich environment

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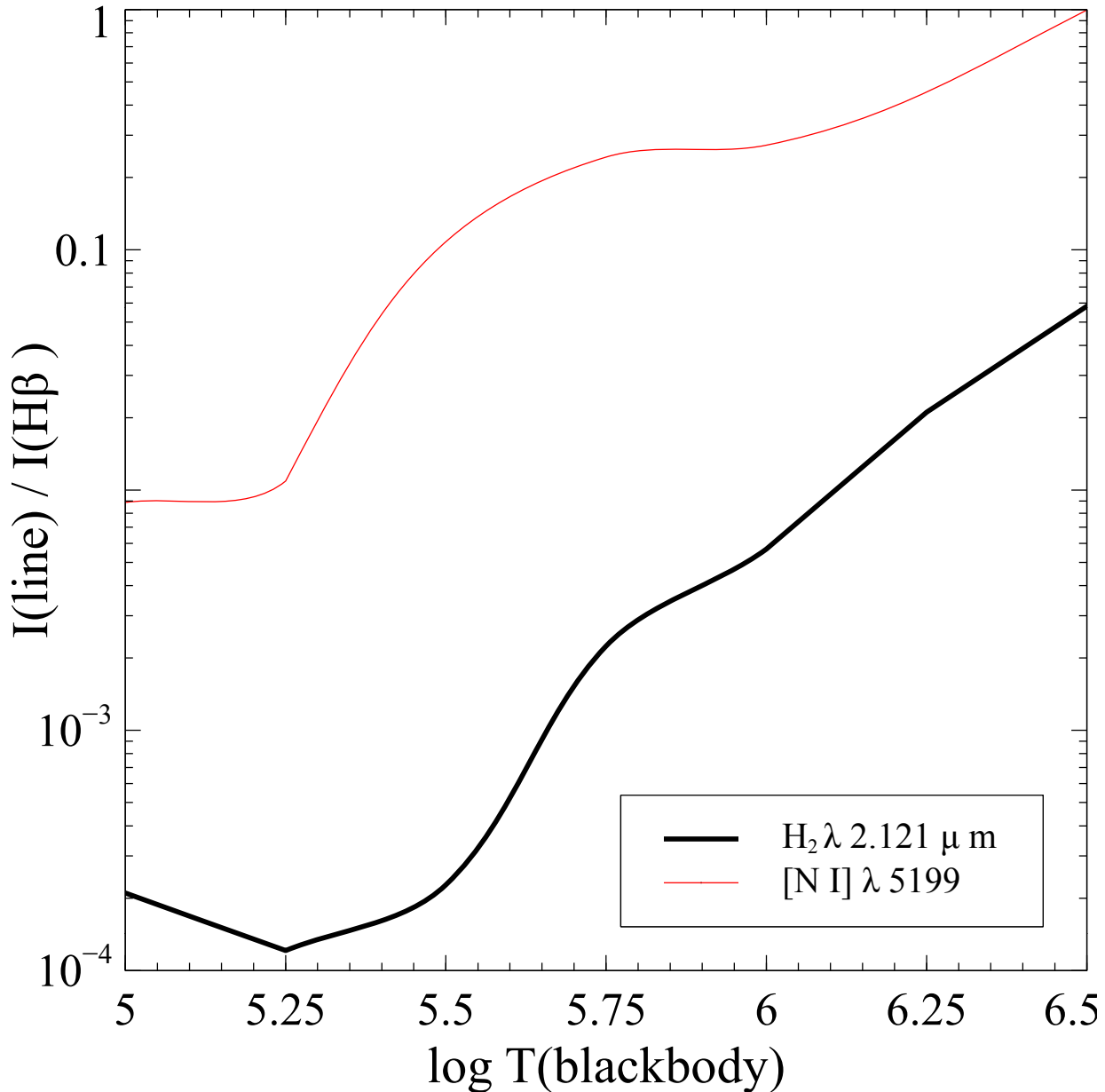
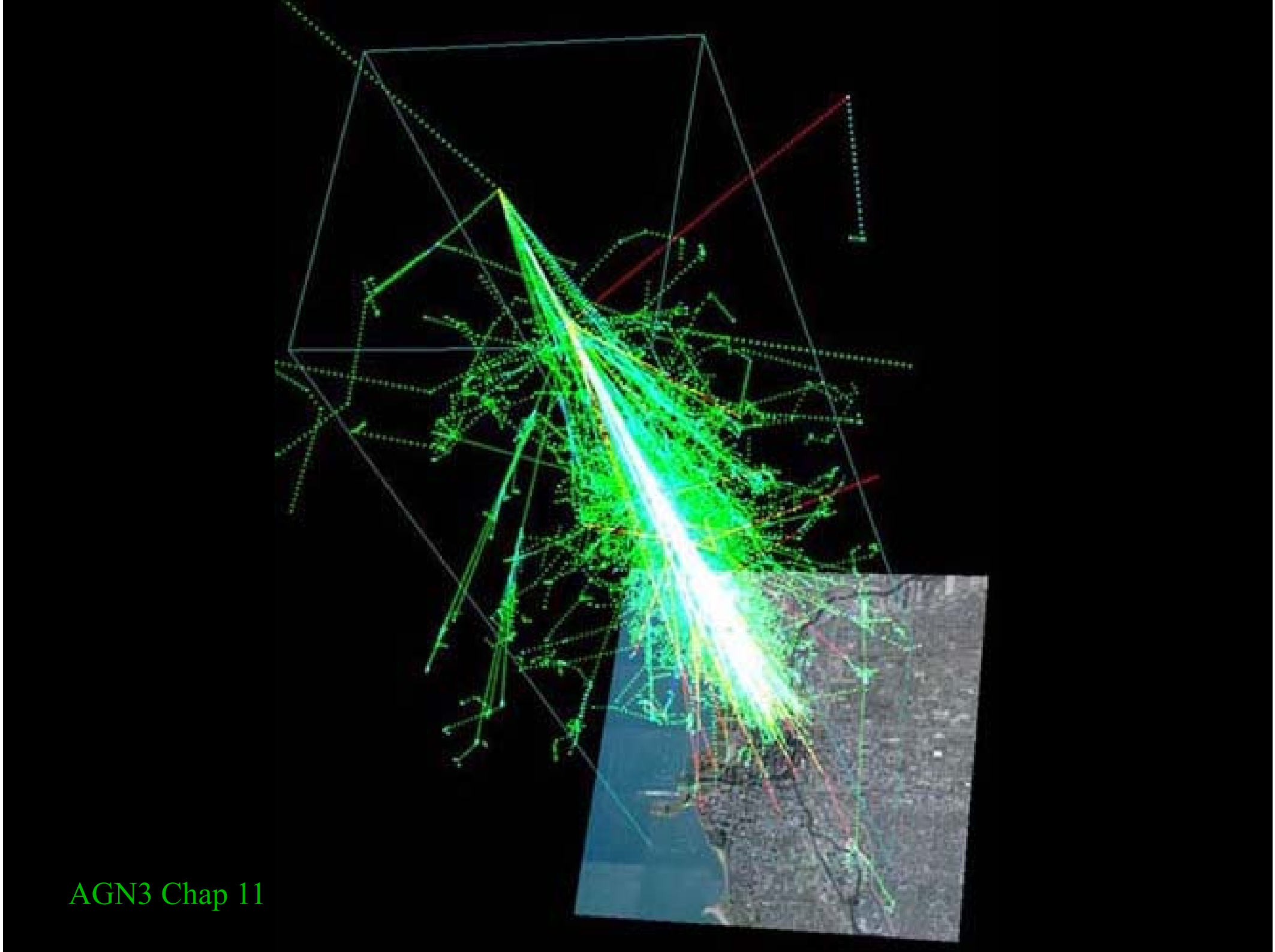
Riffel+ 10

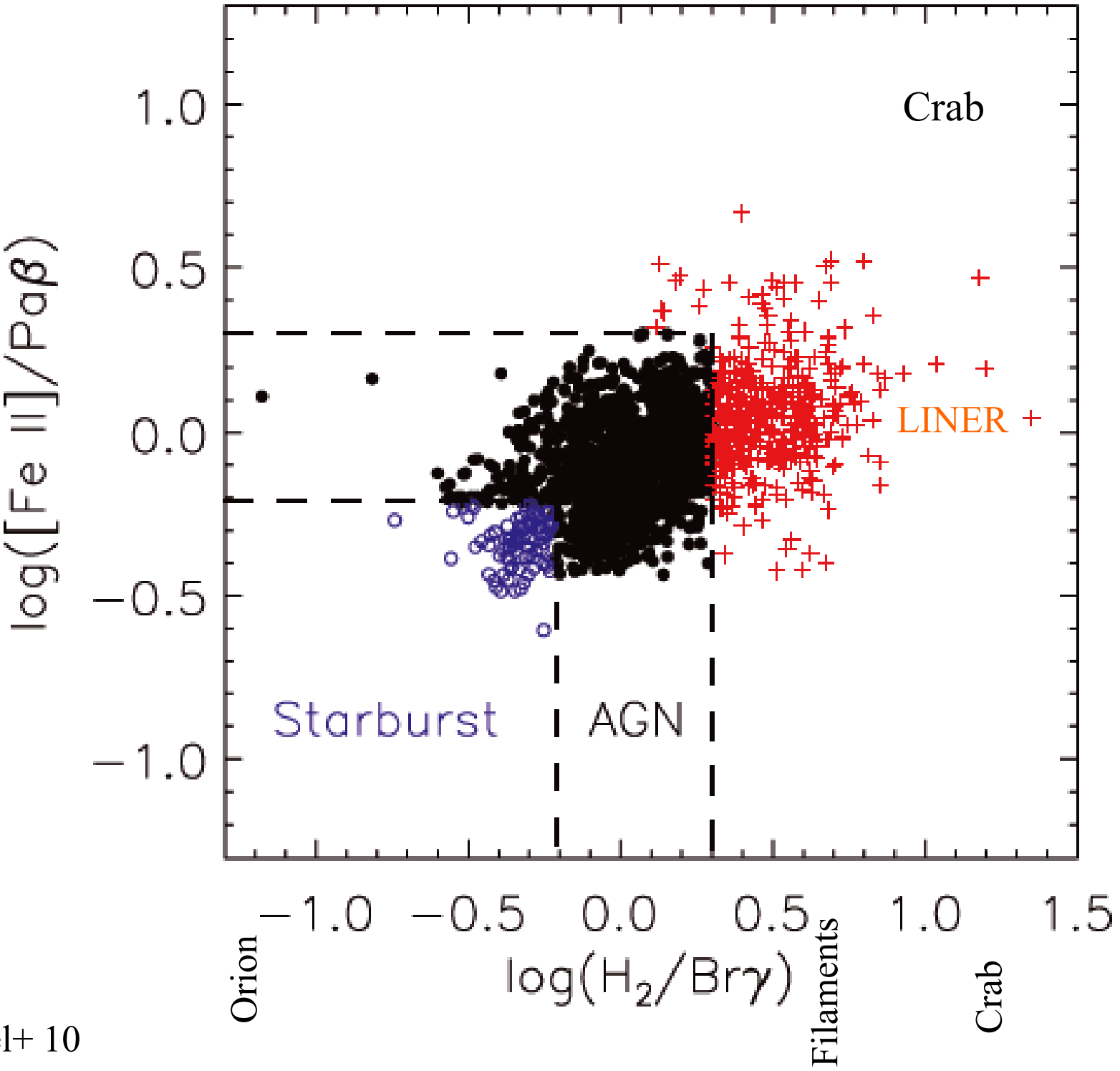
# Effects of SED

- **Energetic photons entering molecular regions**





AGN3 Chap 11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Riffel+ 10

# Progress so far

- **Helix $H_2$ results from rapid advective flow of $H_2$ into the $H^+$ region (Henney+ 07)**
- **Cool-core cluster filaments are photon starved, with $H_2$ (and optical) emission due to penetrating ionizing particles (Ferland+ 09, Fabian+ 11)**
- **The Crab Nebula is photon-rich, and has abundant ionizing particles. Photons sufficient?? (Lo+ 10, 11a, 11b).**
- **Is the Starburst/AGN/LINER sequence the hardening of the 100-500 eV SED?**