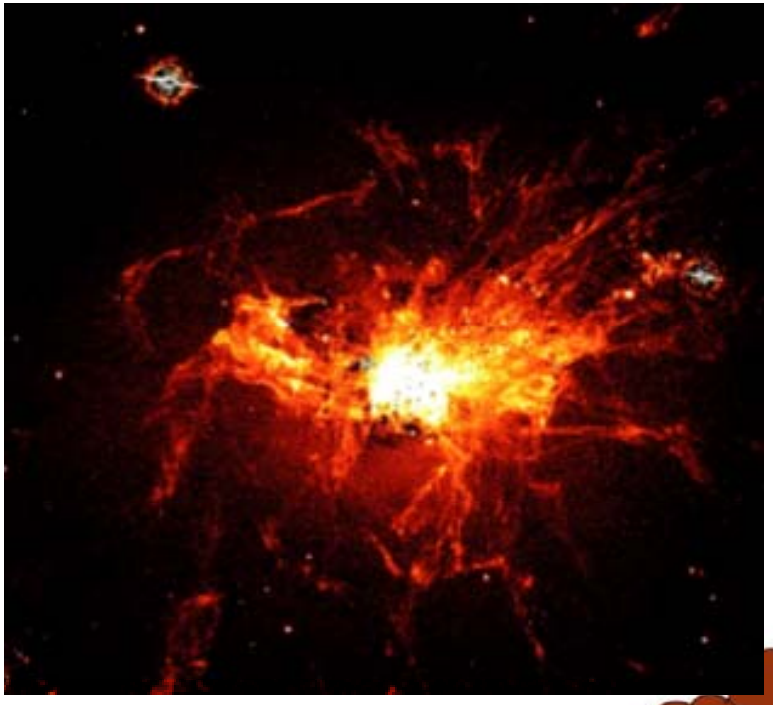
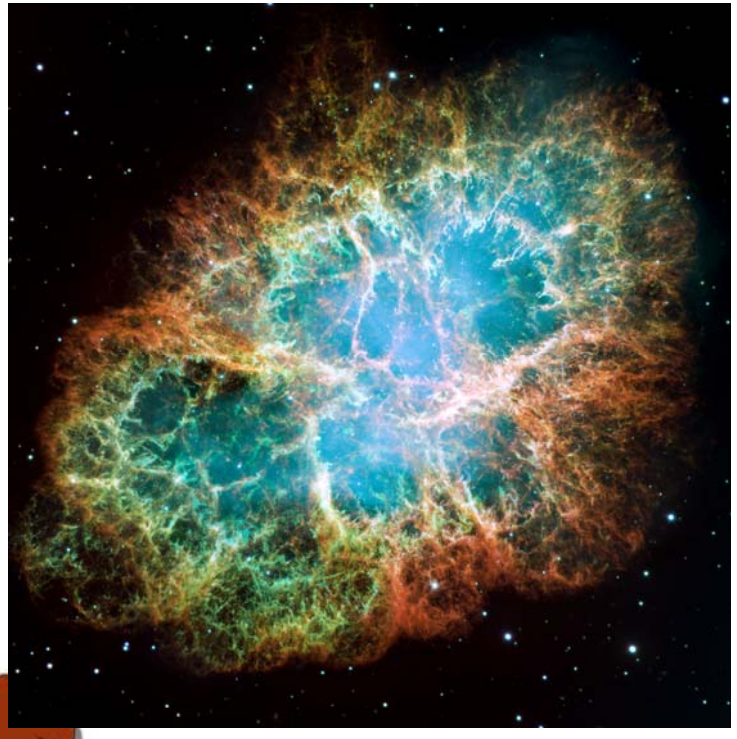
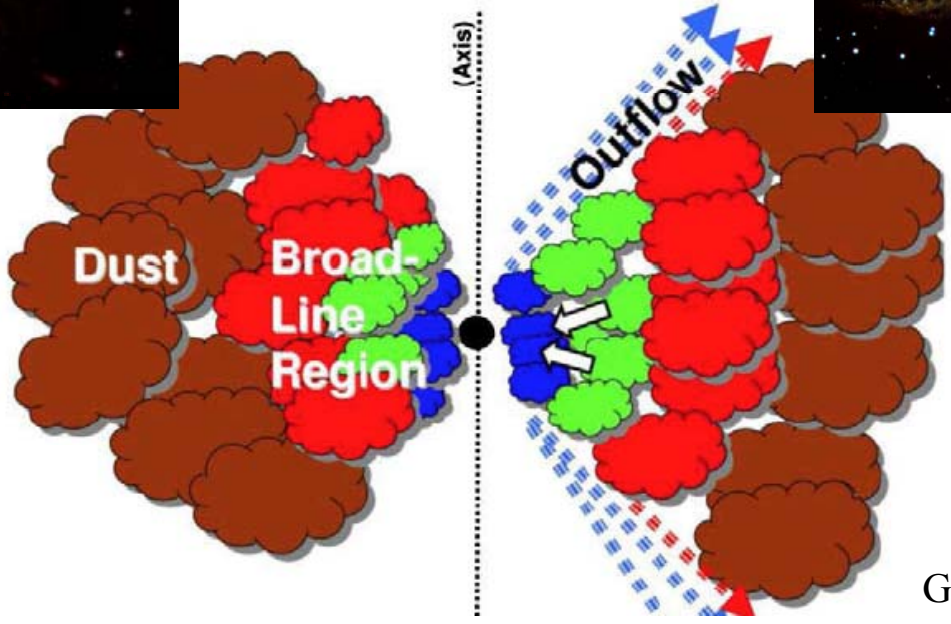
Implications of strong H_2 emission in astronomical environments



Fabian+08

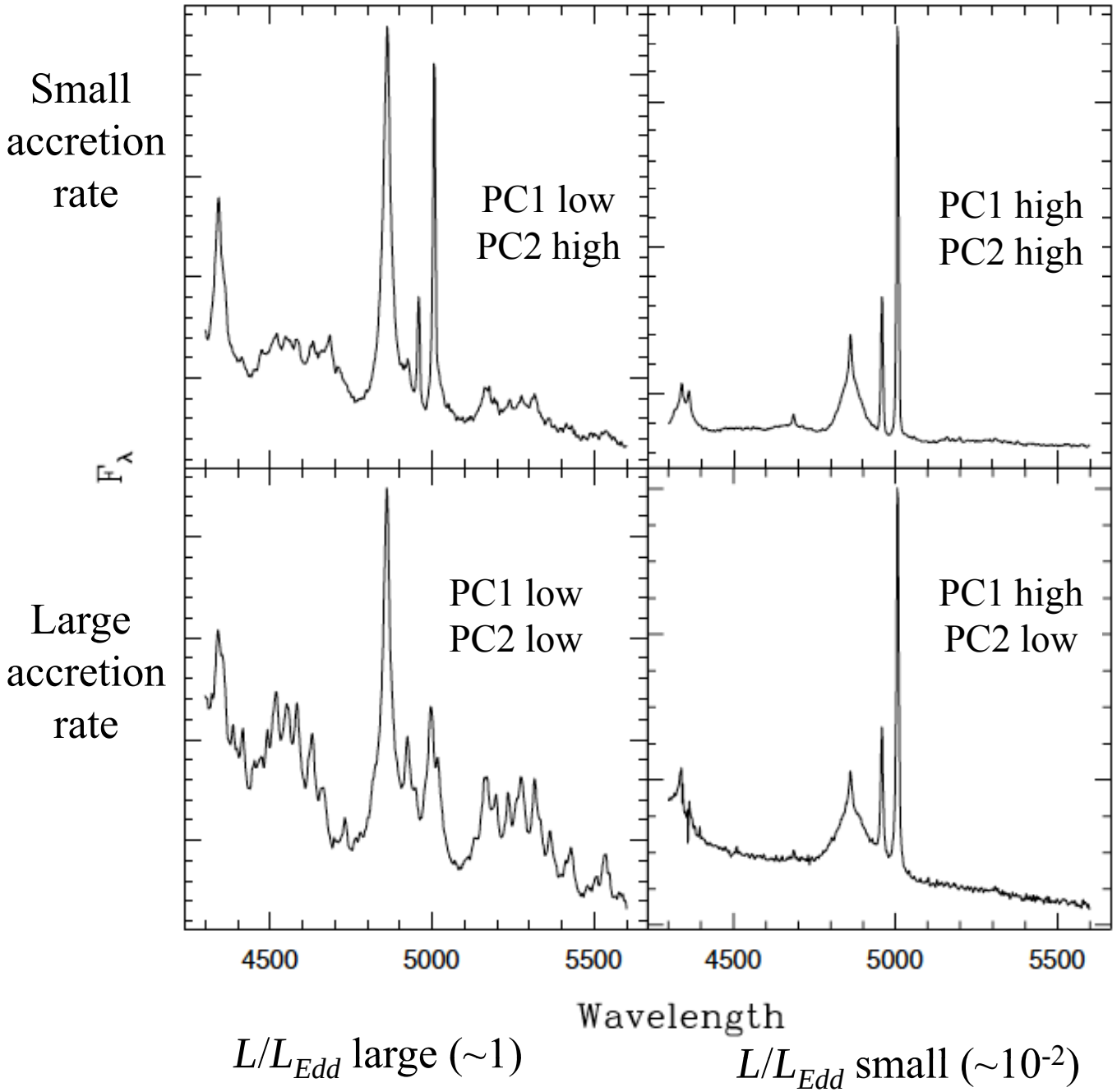


STScI

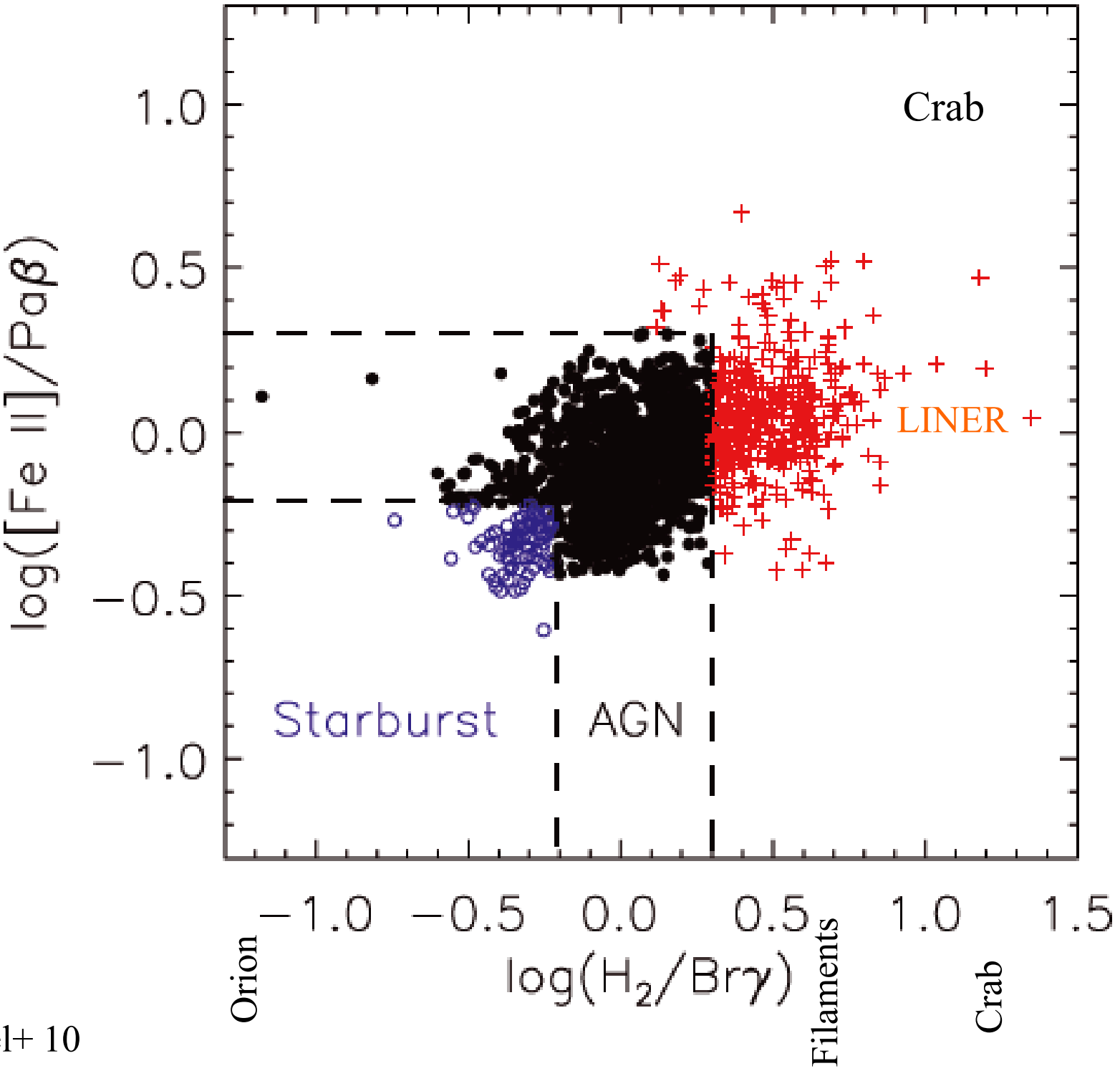


Gaskell+08

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



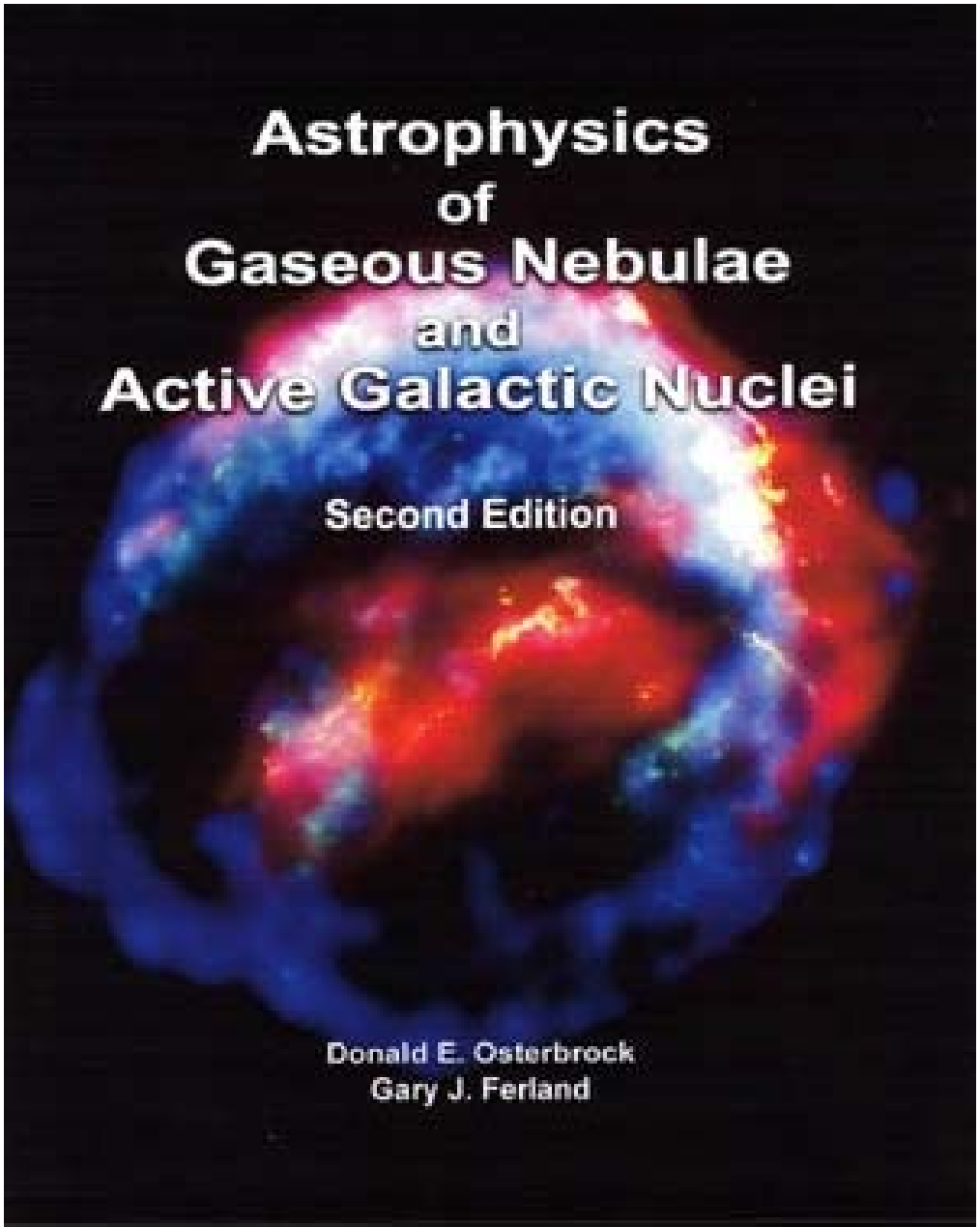
Boroson 2002, ApJ, 565, 78

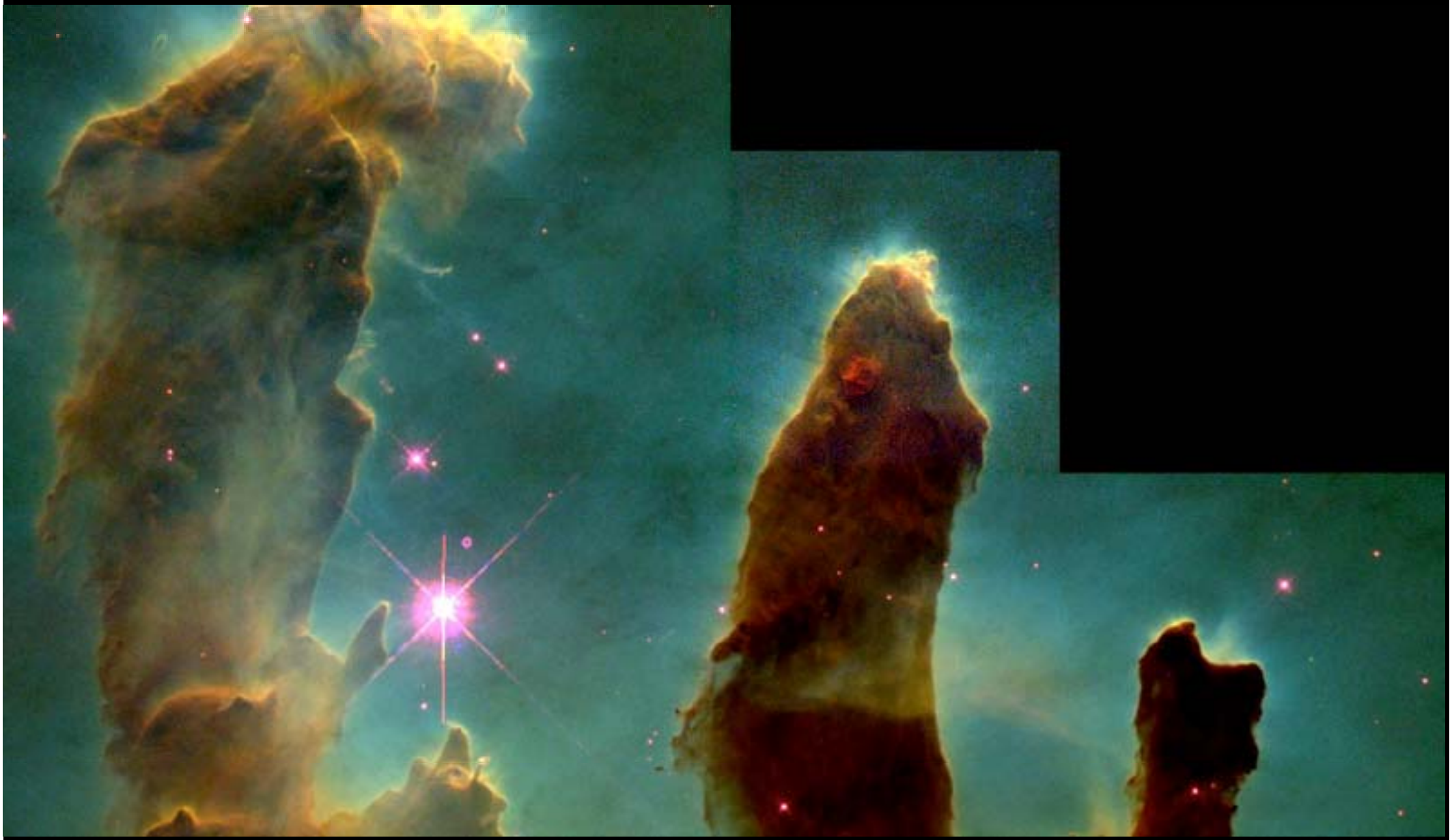

Crab
LINER
Starburst
AGN
Orion
Filaments
Crab
log([Fe II]/Paβ)
log(H2/Brγ)
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
1.5

Riffel+ 10

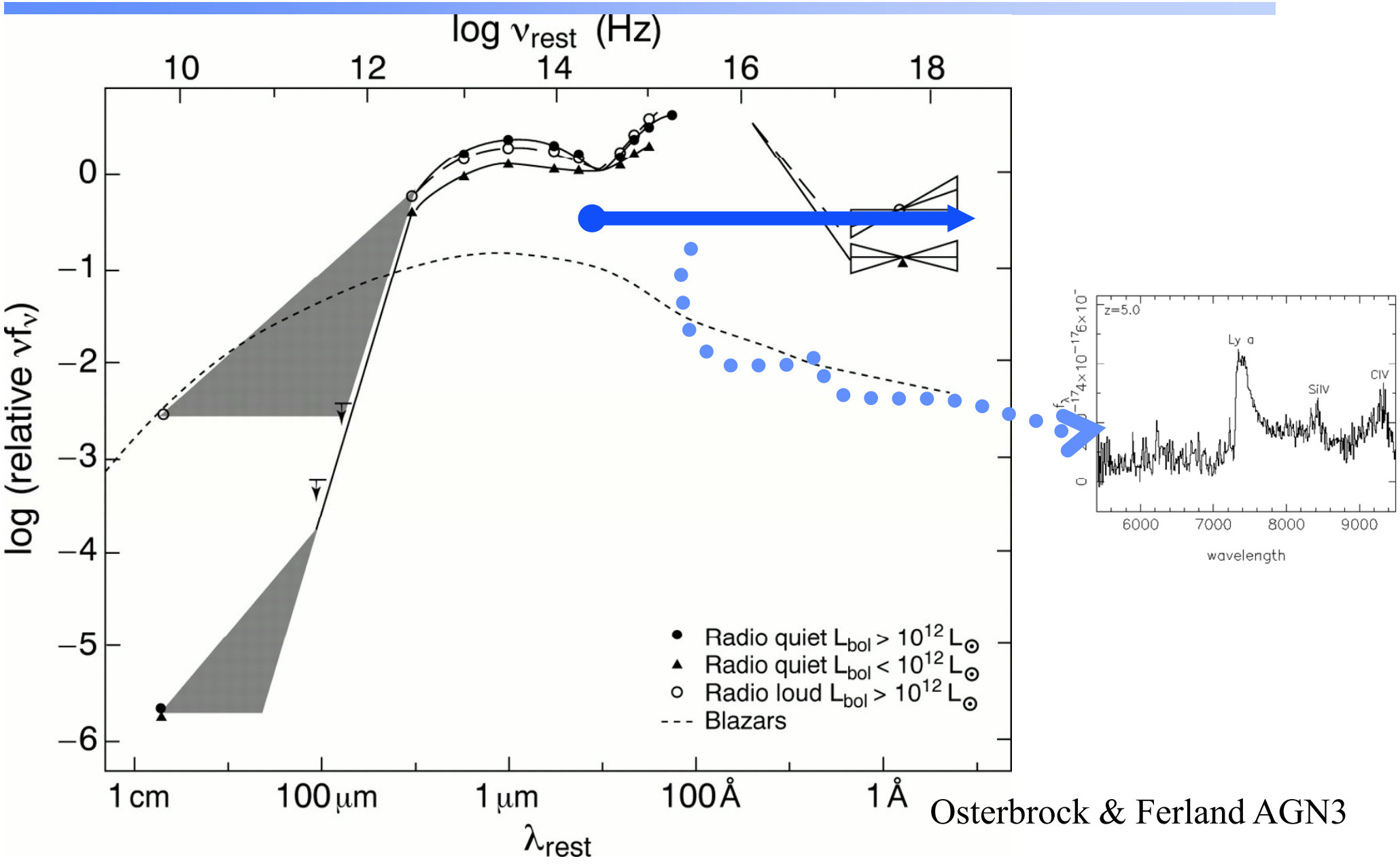
Spectrum of a non-equilibrium gas

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

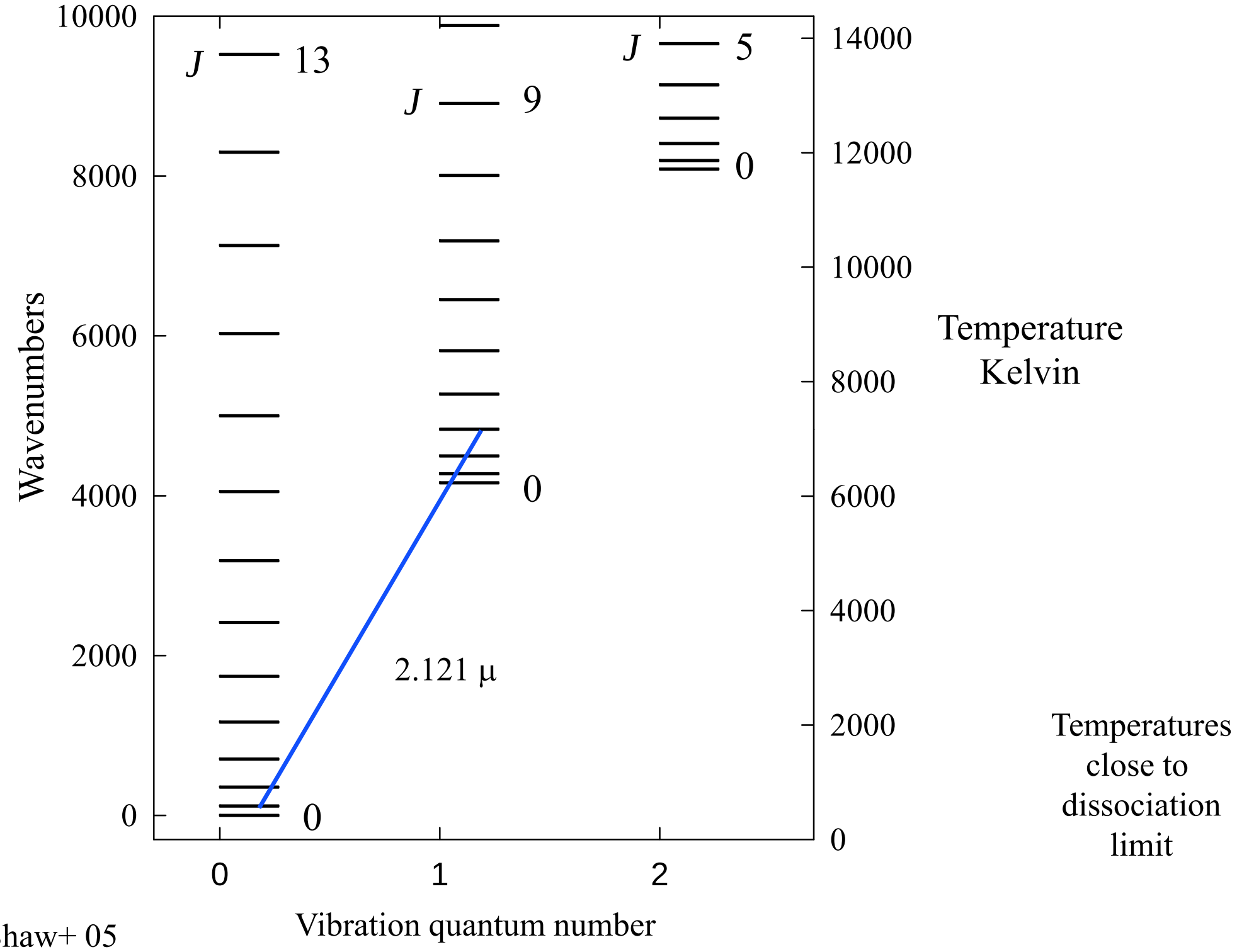




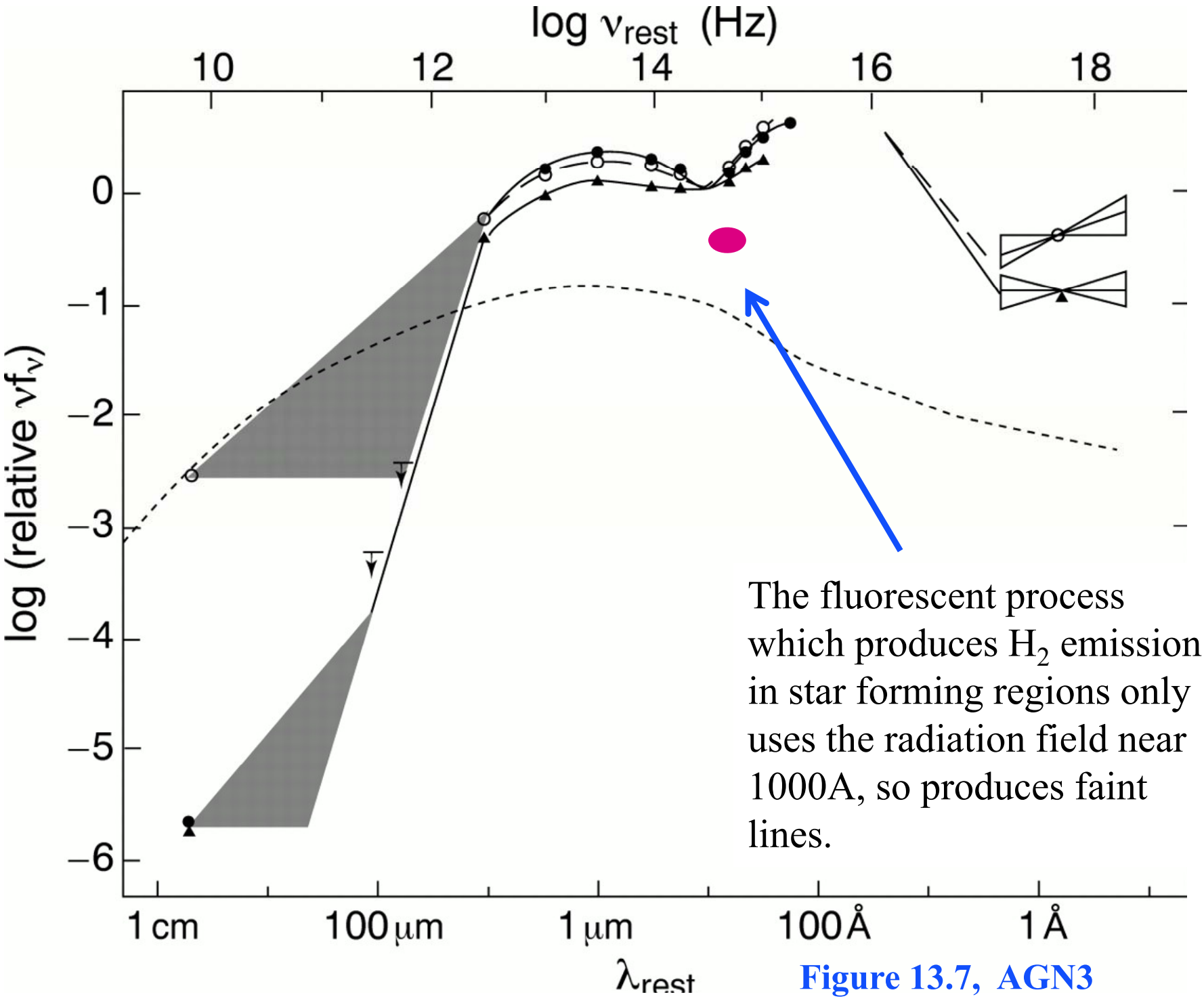
Continuum → H I lines



Osterbrock & Ferland AGN3

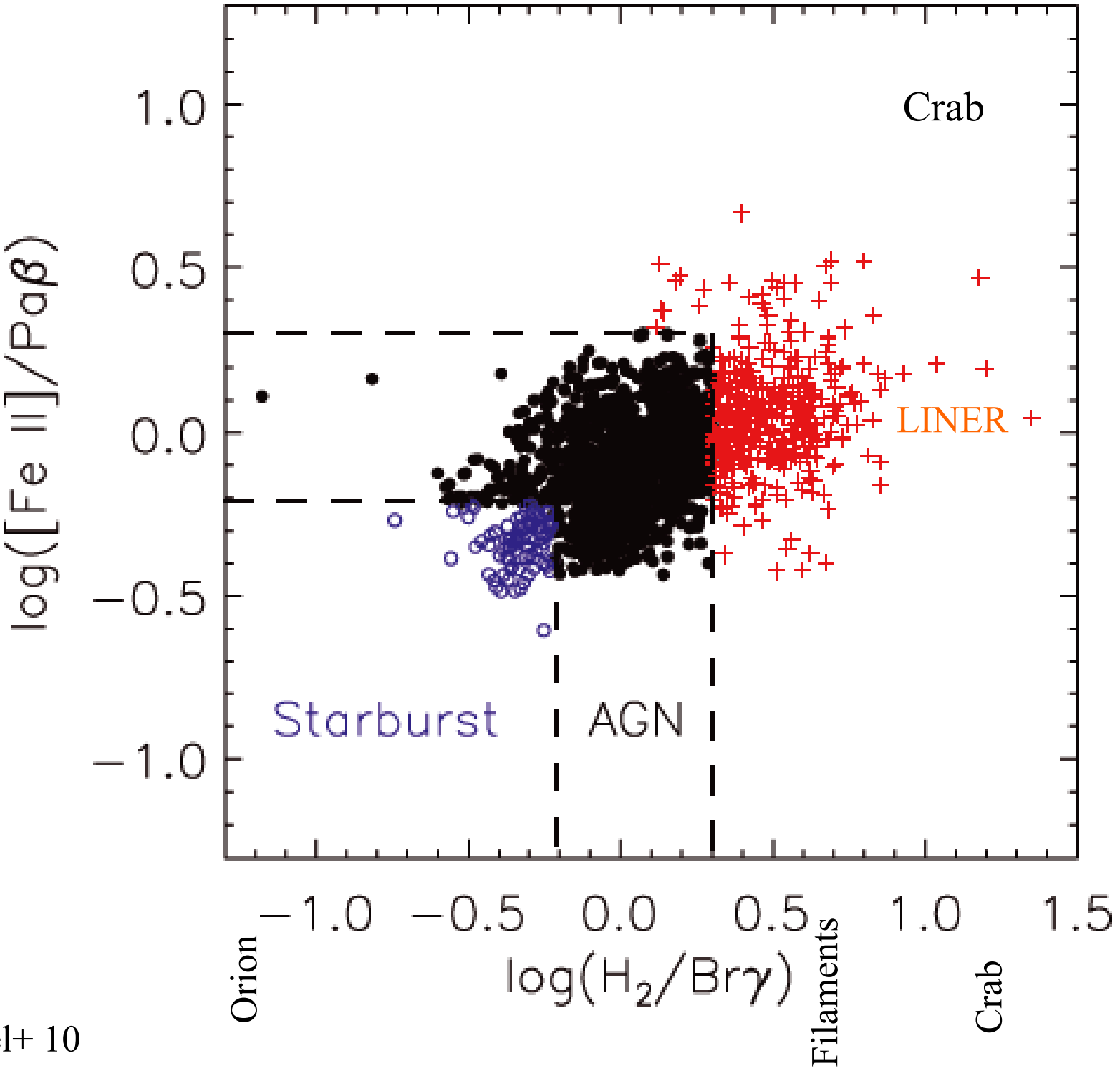

10000
8000
6000
4000
2000
0
Wavenumbers
J 13
J 9
J 5
0
0
0
2.121 μ
14000
12000
10000
8000
6000
4000
2000
0
Temperature
Kelvin
Temperatures
close to
dissociation
limit
0
1
2
Vibration quantum number

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


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

Independent energy sources unlikely

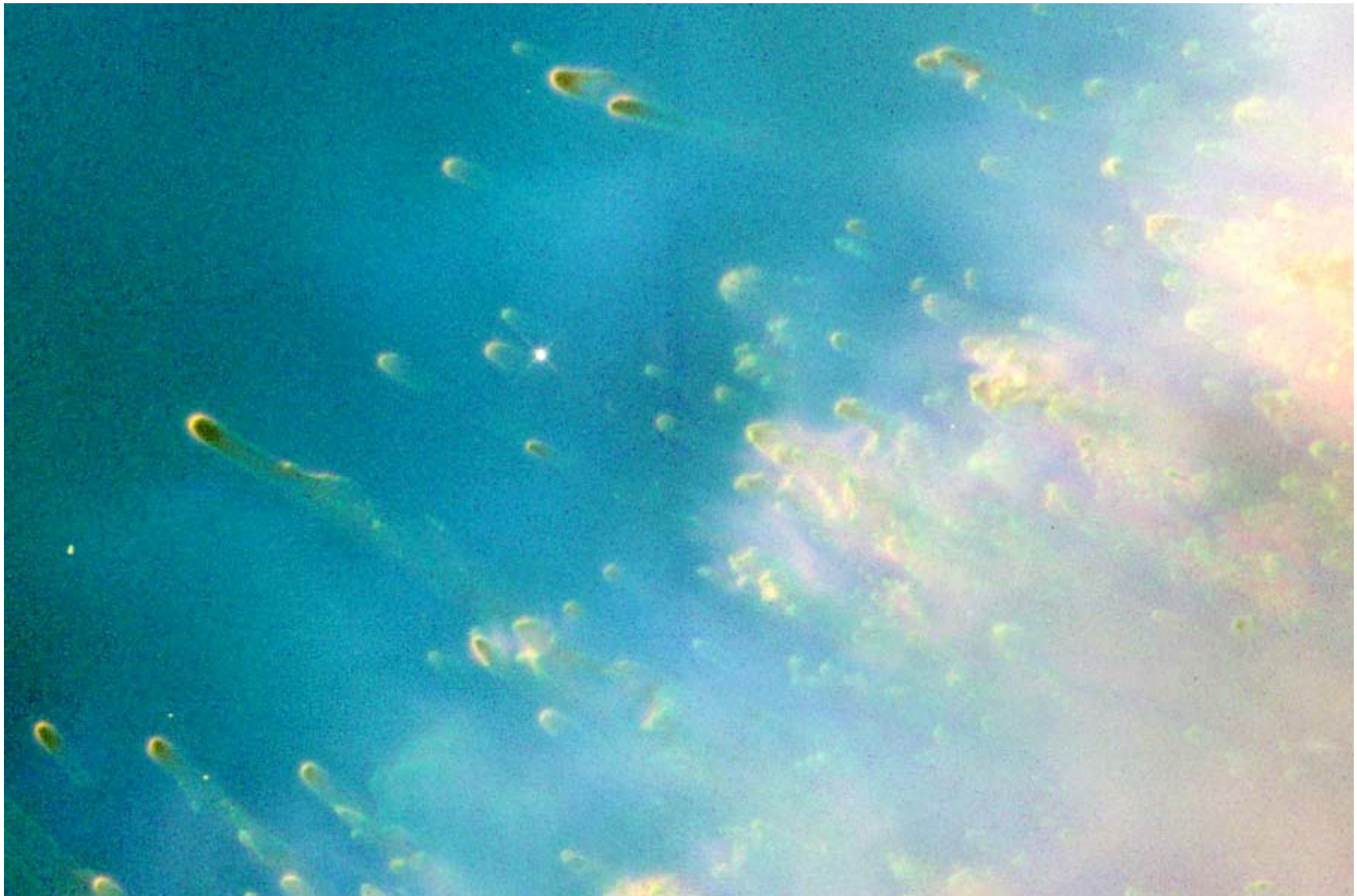
Object	Heating erg cm^{-2} s^{-1}	
	Radiative	Collisional
Earth	1 400 000	5.8
Supernova remnant	0.0028	7.9

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

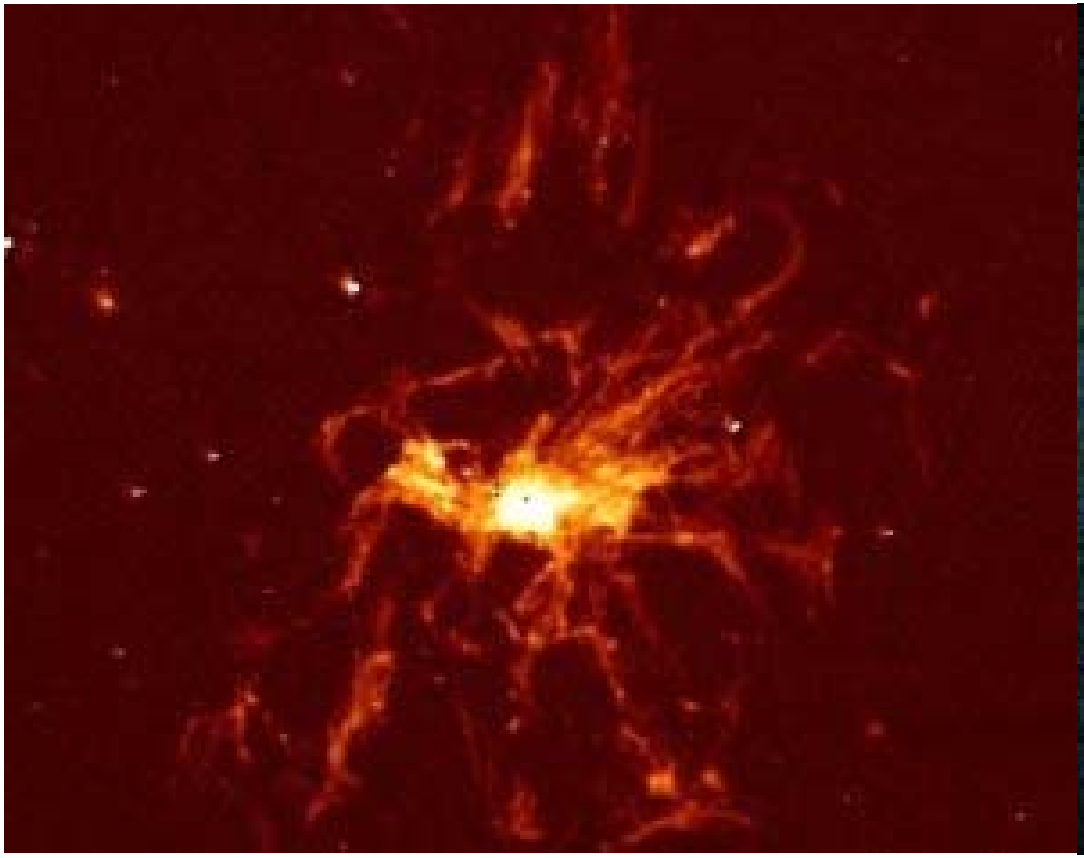
Advective flow of H_2 into H^+ region

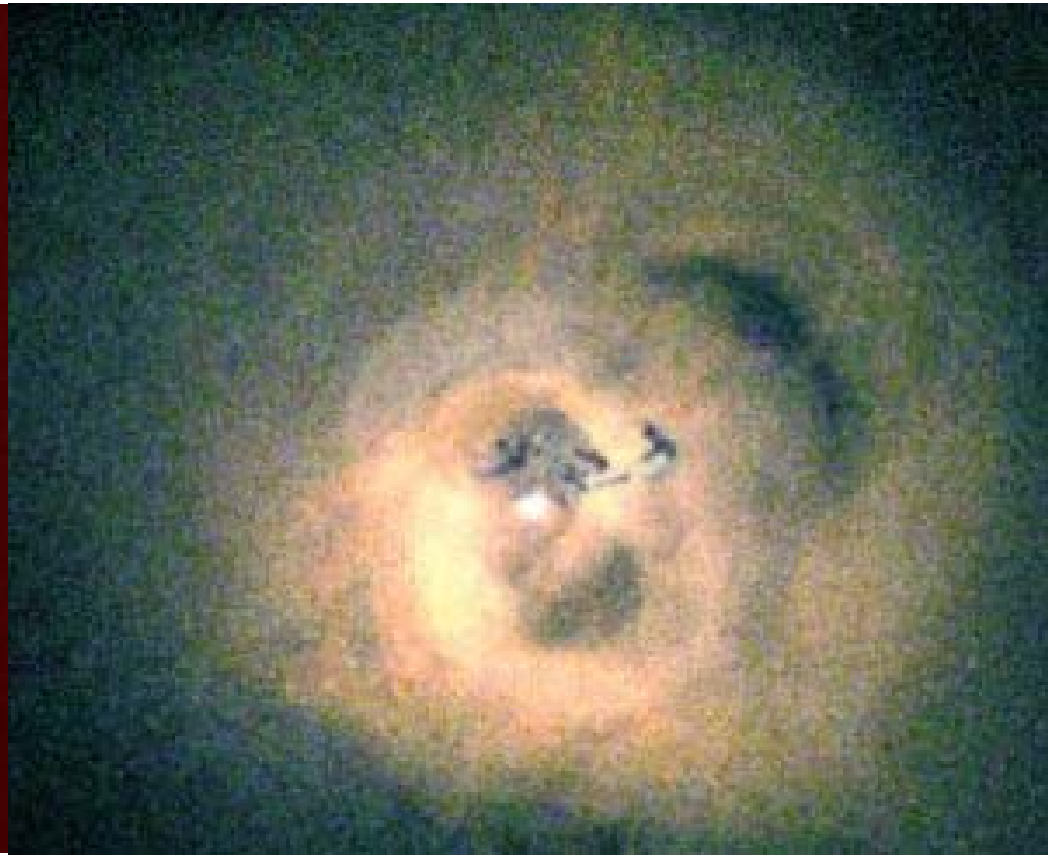
- Henney+ 07



Cool core cluster filaments

- **Thermal particles from surrounding hot gas**

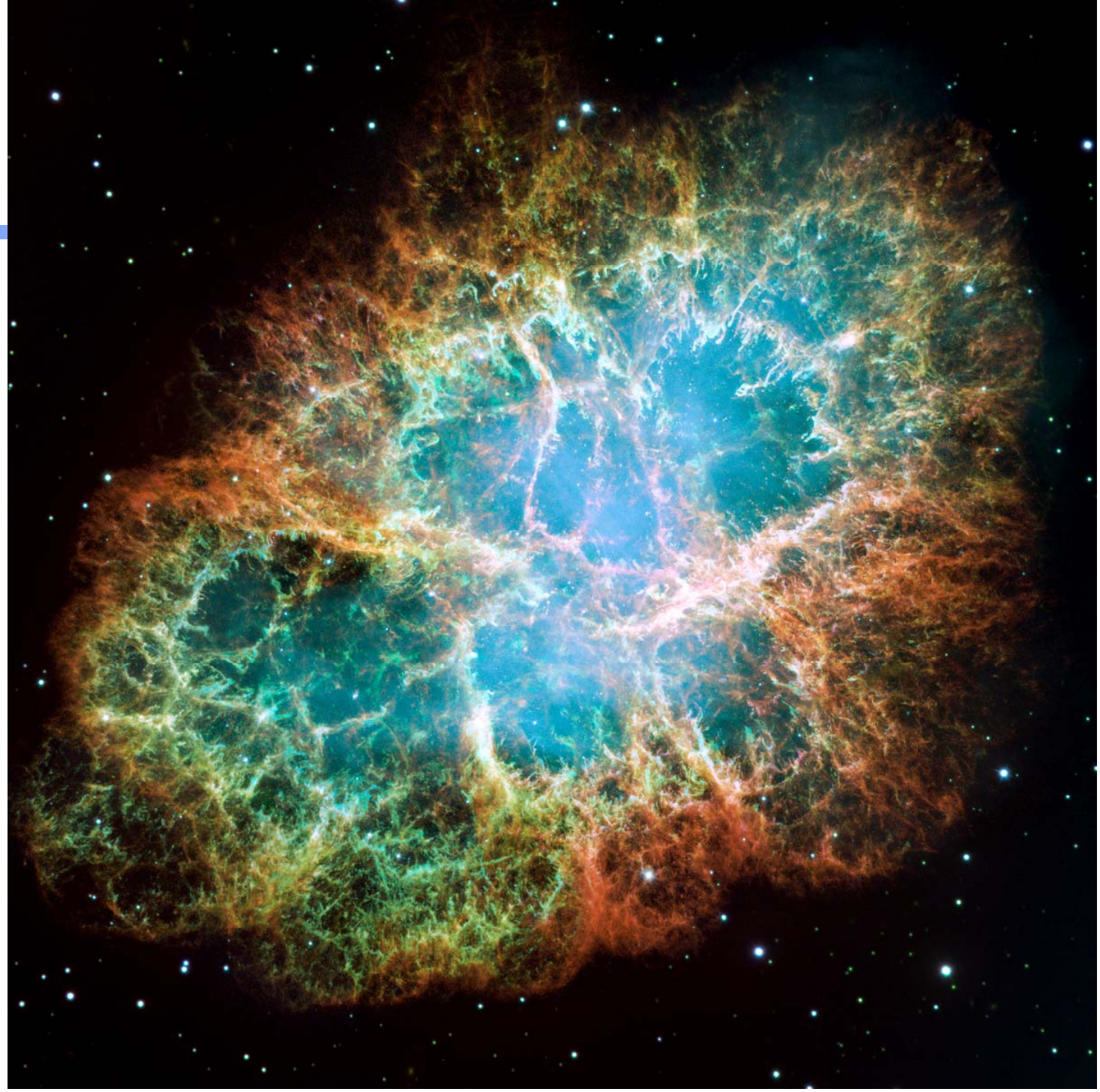


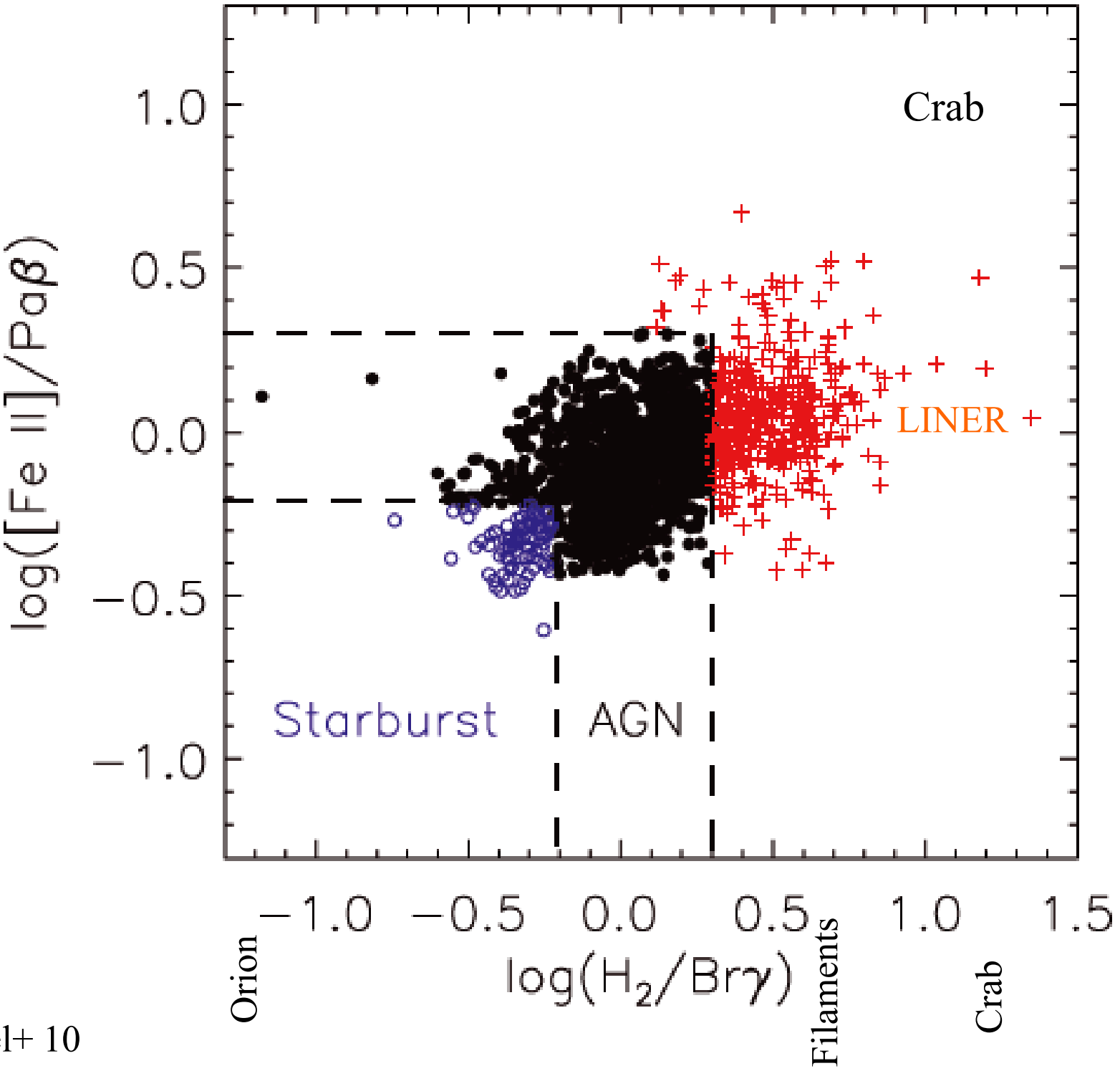


– Johnstone+ 07, Ferland+ 08, 09, Fabian+ 11

The Crab

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

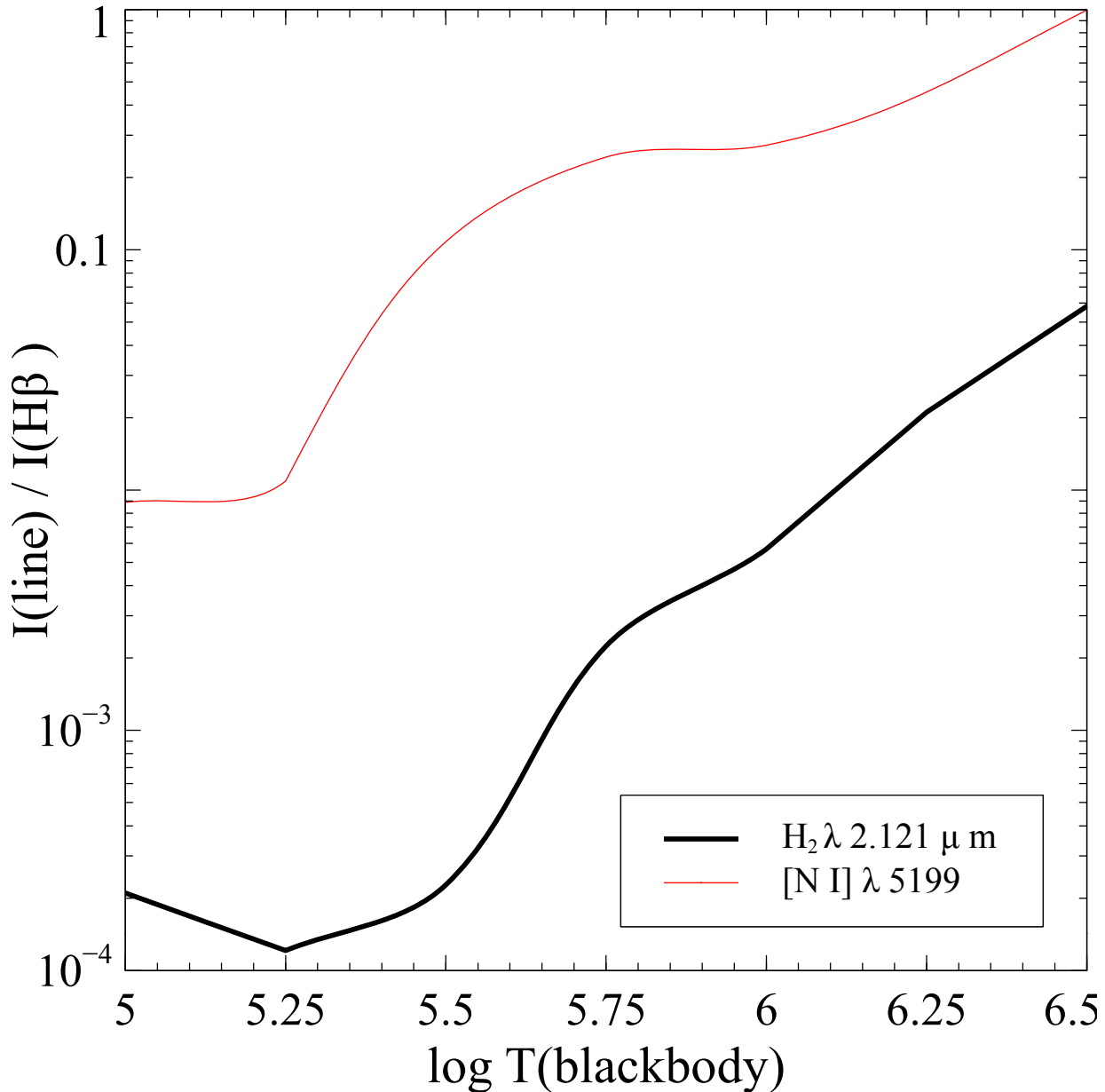


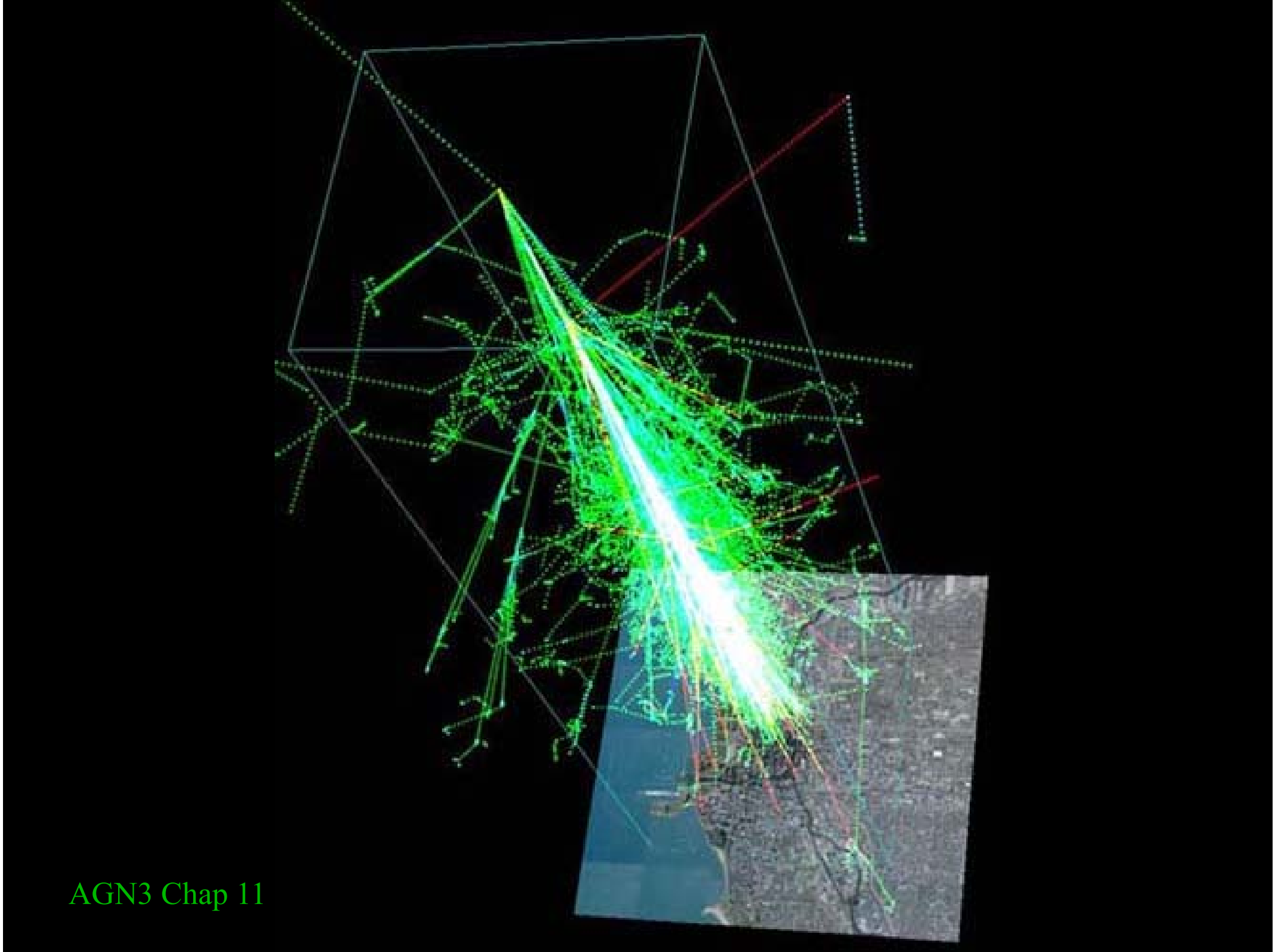

Crab
LINER
Starburst
AGN
Orion
Filaments
Crab
log([Fe II]/Paβ)
log(H2/Brγ)
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
1.5

Riffel+ 10

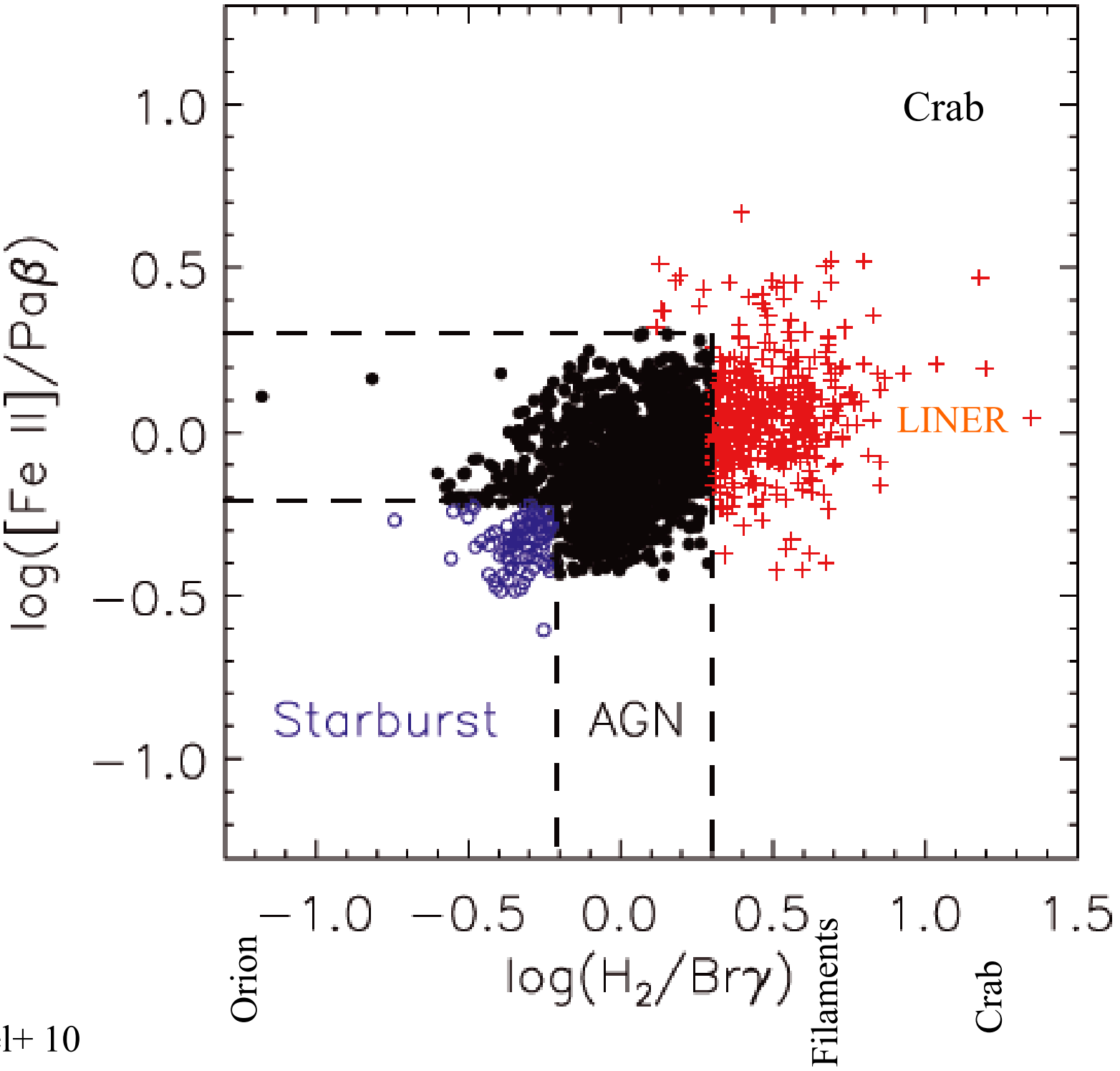
Effects of SED

- **Energetic photons entering molecular regions**





AGN3 Chap 11


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

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?**