Everything You Wanted To Know About Shock-Excited Gas, But Were Afraid To Ask

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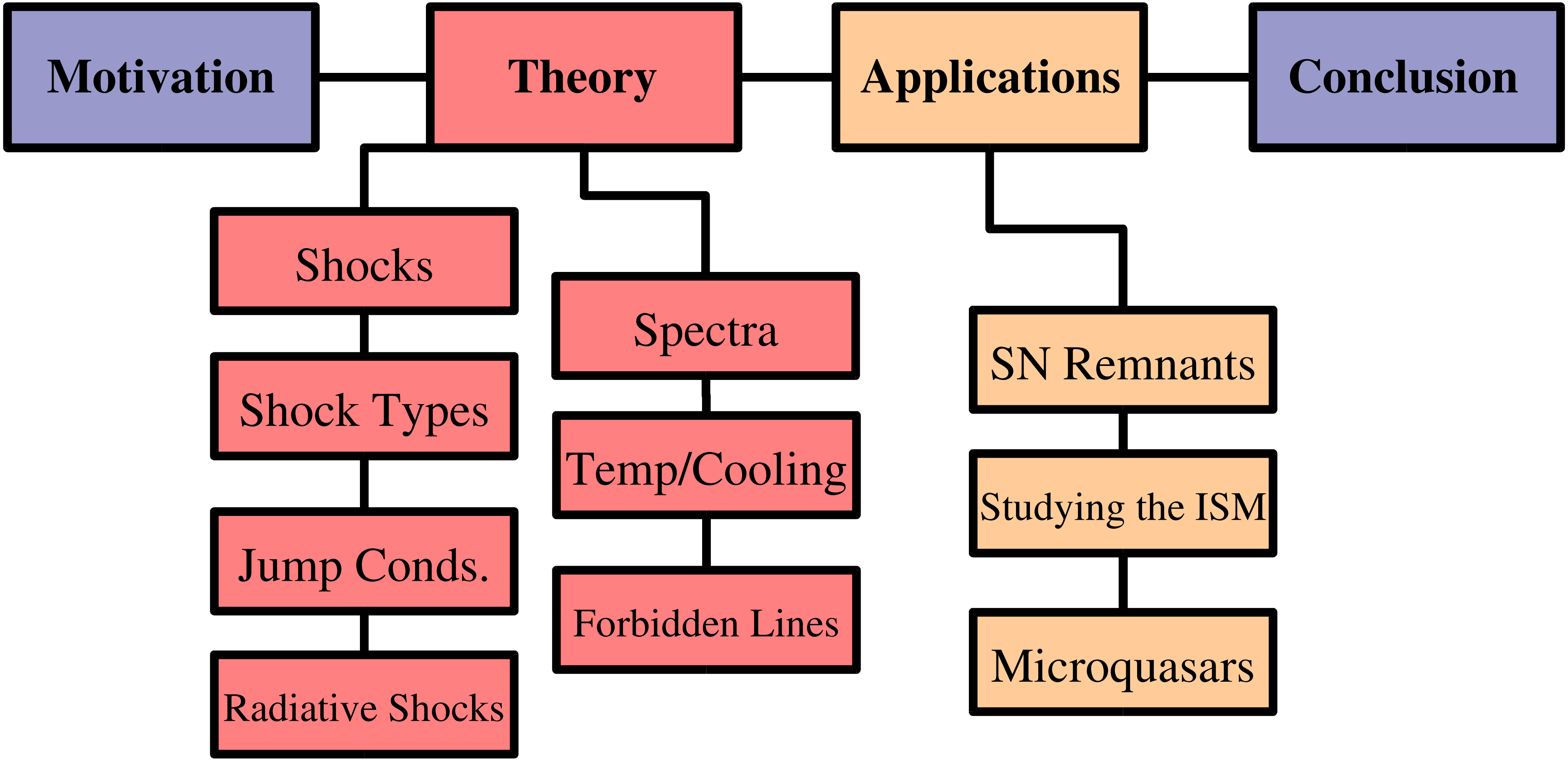
AY230 Fall 2008

Final Project

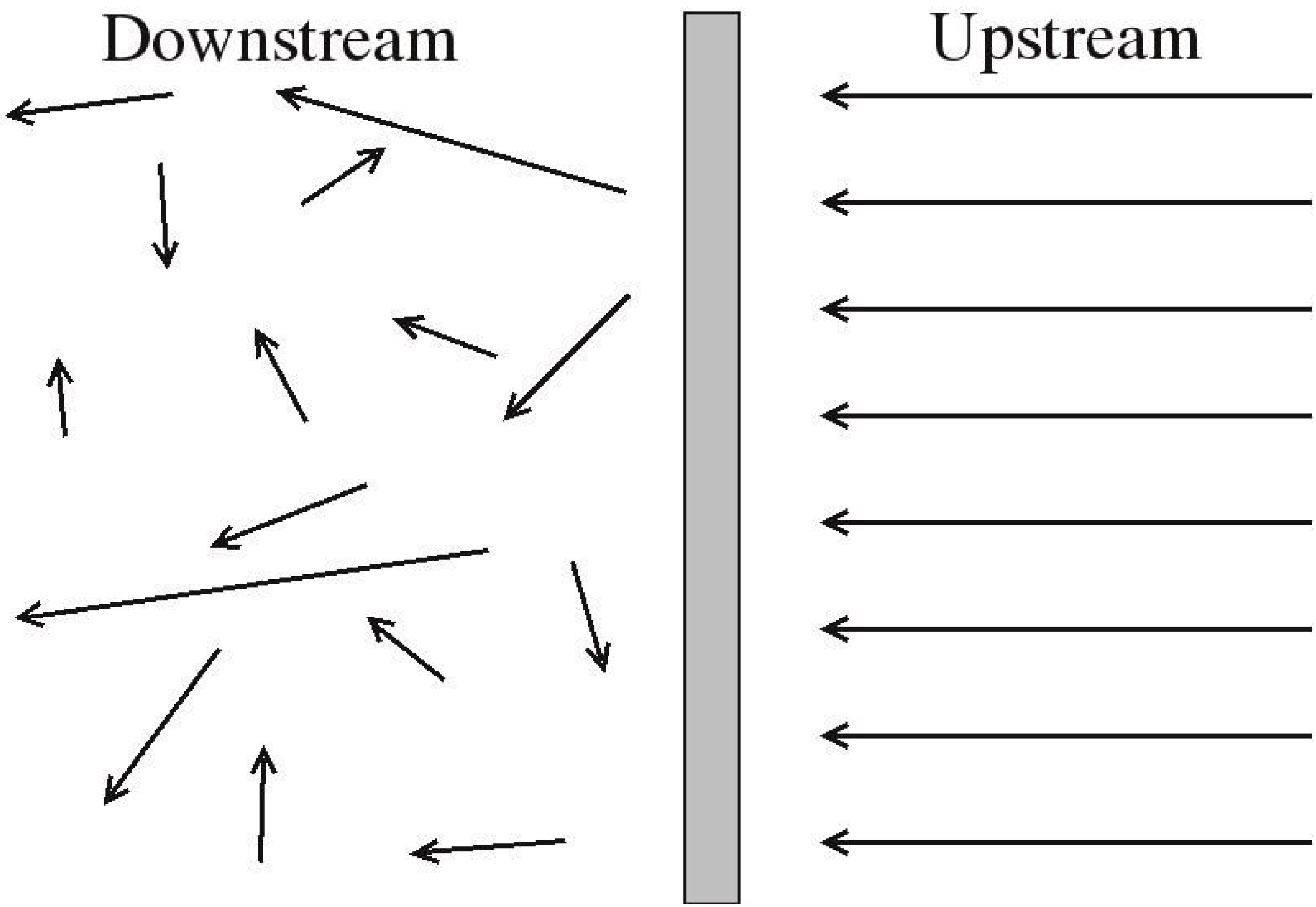
Talk Structure



Motivation

- Shocks are ubiquitous
- Microquasars: open questions
- Combines what we've learned in AY230

Theory

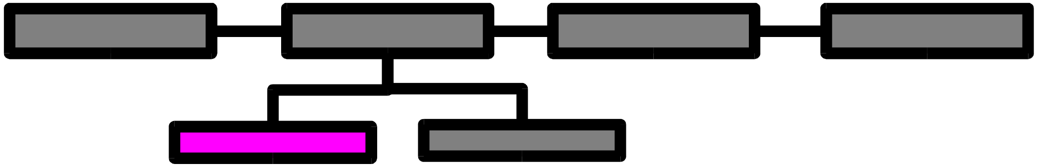


Theory: Definitions

$$C_s = \left(\frac{dP}{d\rho}\right)^{1/2} = \left(\frac{\gamma P}{\rho}\right)^{1/2}$$

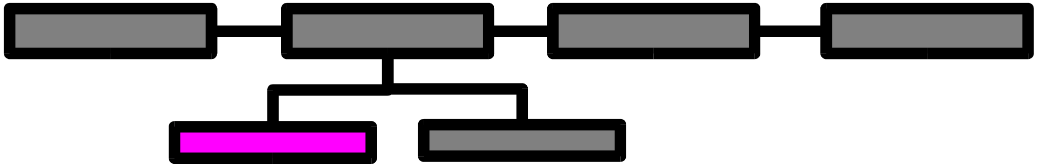
In the ISM, $C_s \approx 10$ km/s.

$$M = \frac{v_{s,u}}{C_{s,u}}$$



Theory: Shock Types

- C-shocks
  - Slow (< 50 km/s)
  - Low ionization fraction
  - Magnetohydrodynamics
- J-shocks
  - Fast
  - Just hydrodynamics



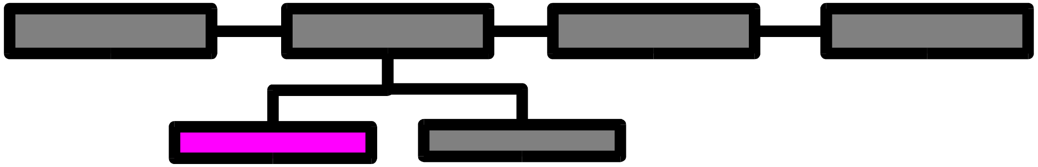
Theory: Jump Conditions

$$\rho_u v_u = \rho_d v_d$$

$$\rho_u v_u^2 + P_u = \rho_d v_d^2 + P_d$$

$$E_d - E_u = P_u v_u - P_d v_d$$

$$E = \rho v \left(\frac{1}{2} v^2 + \frac{u}{\rho} \right)$$



Theory: Jump Conditions

$$\frac{P_d}{P_u} = \frac{2\gamma}{\gamma+1}M^2 - \frac{\gamma-1}{\gamma+1}$$

$$\frac{\rho_u}{\rho_d} = \frac{\gamma-1}{\gamma+1} + \frac{2}{\gamma+1}\frac{1}{M^2}$$

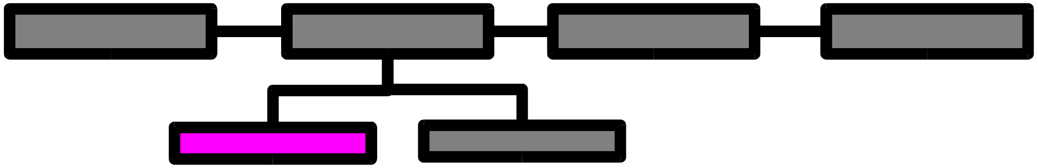
$$\gamma = \frac{5}{3}.$$

Theory: Jump Conditions

$$\frac{\rho_d}{\rho_u} = \frac{\gamma + 1}{\gamma - 1} = 4$$

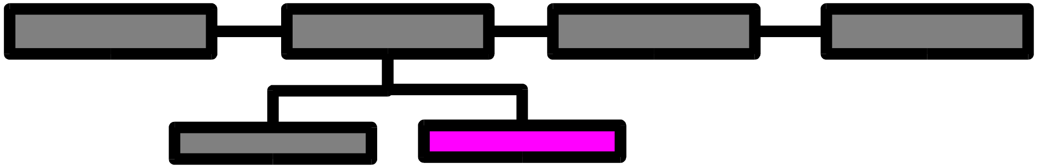
$$P_d = \frac{2}{\gamma + 1}\rho_u v_u^2 = \frac{3}{4}\rho_u v_u^2$$

$$T = 3.18 \times 10^5 \frac{(\text{shock velocity})^2}{10^4 \times \text{ particles per H nucleus}}\ \text{K}$$



Theory: Radiative Shocks?

$$N_{crit} \approx 2 \times 10^{17} \left(\frac{v_u}{100 \text{ km/s}} \right)^{4.2} \text{ cm}^{-2}$$



Theory: Spectra

- Collisional excitation = Forbidden lines

[7] There, particles suffer many collisions, leading the collisional ionization and electron recapture processes into equilibrium. Casting this in an equation, which we quote from Osterbrook [3], we see:

$$n(X^{+i})n_e q_{ion}(X^{+i},T) = n(X^{+i+1})n_e \alpha_G(X^{+i},T)\ \mathrm{cm}^{-3}\mathrm{s}^{-1} \quad (17)$$

The collisional ionization rate coefficient, q_{ion}, depends only on the electron temperature and the ion's collisional ionization cross section. It does not, however, depend on the electron density. This means that the post-shock temperature sets which ionization species get produced [3]. For typical

Theory: Spectra

- Completely dissociative shock

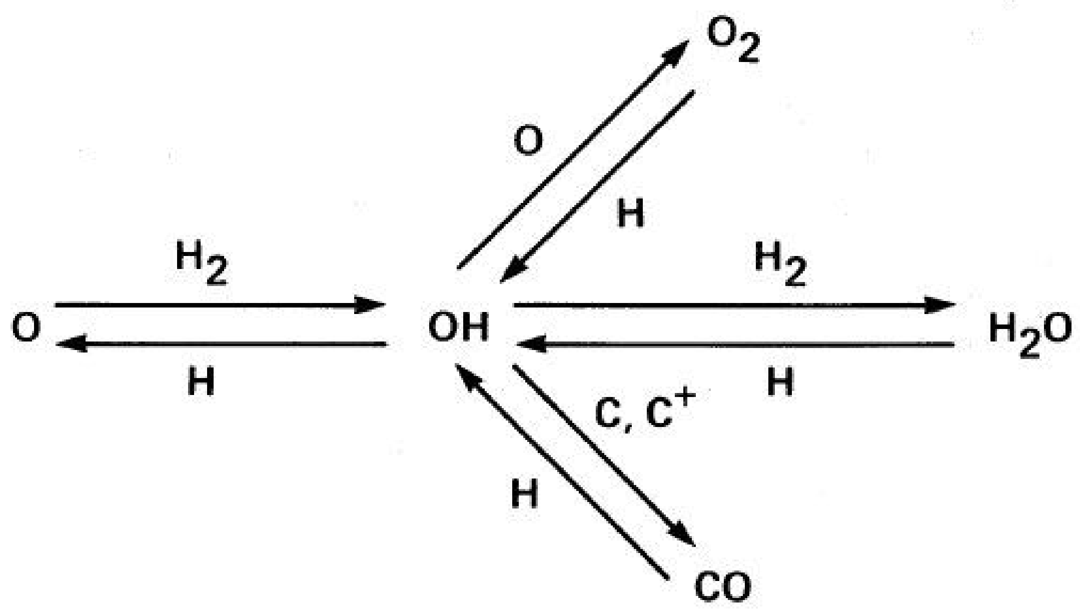
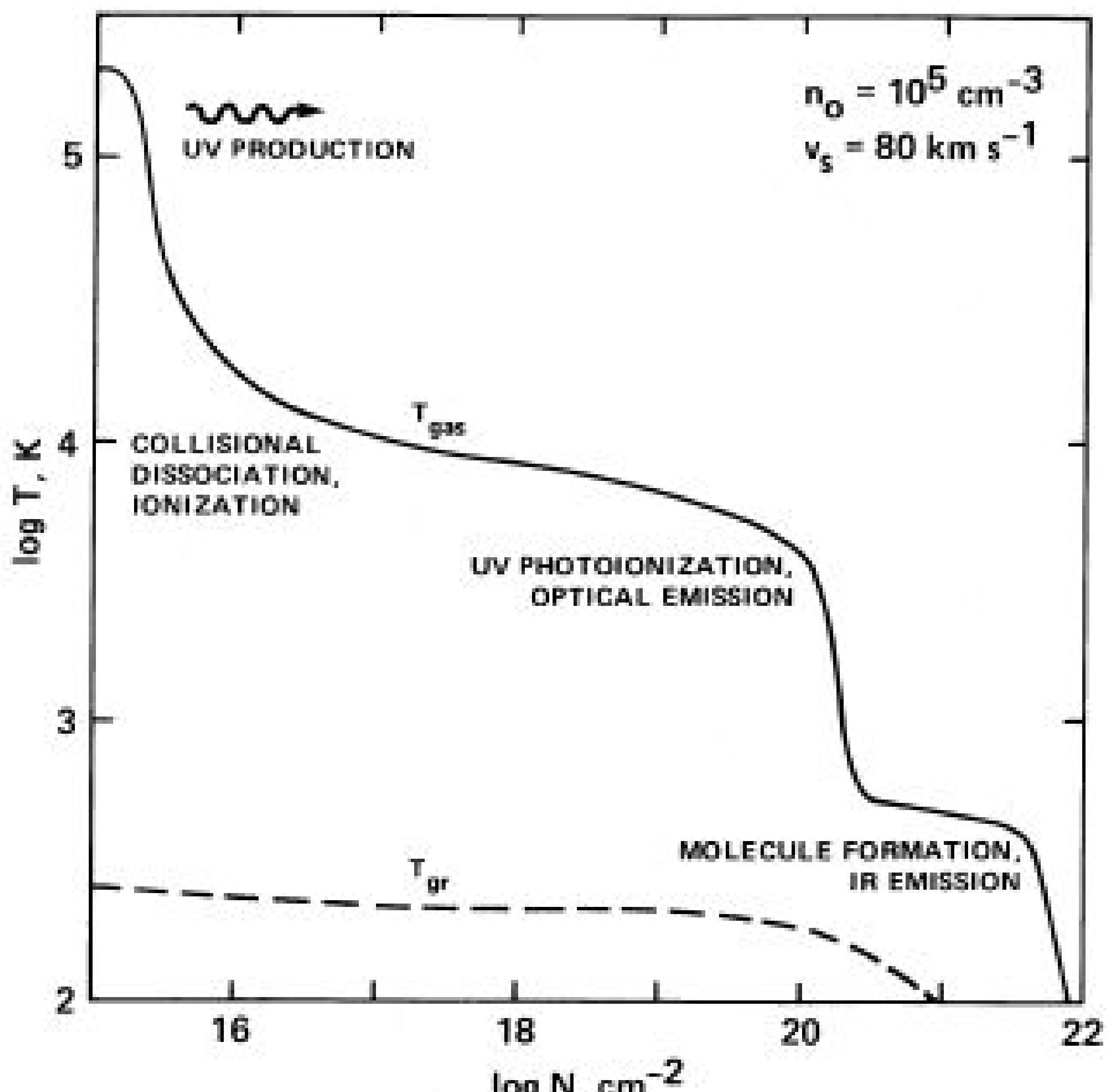


FIG. 2.—Fast neutral reactions with moderate activation energies or endothermicities dominate the oxygen chemistry in warm $T \gtrsim 300$ K postshock gas.

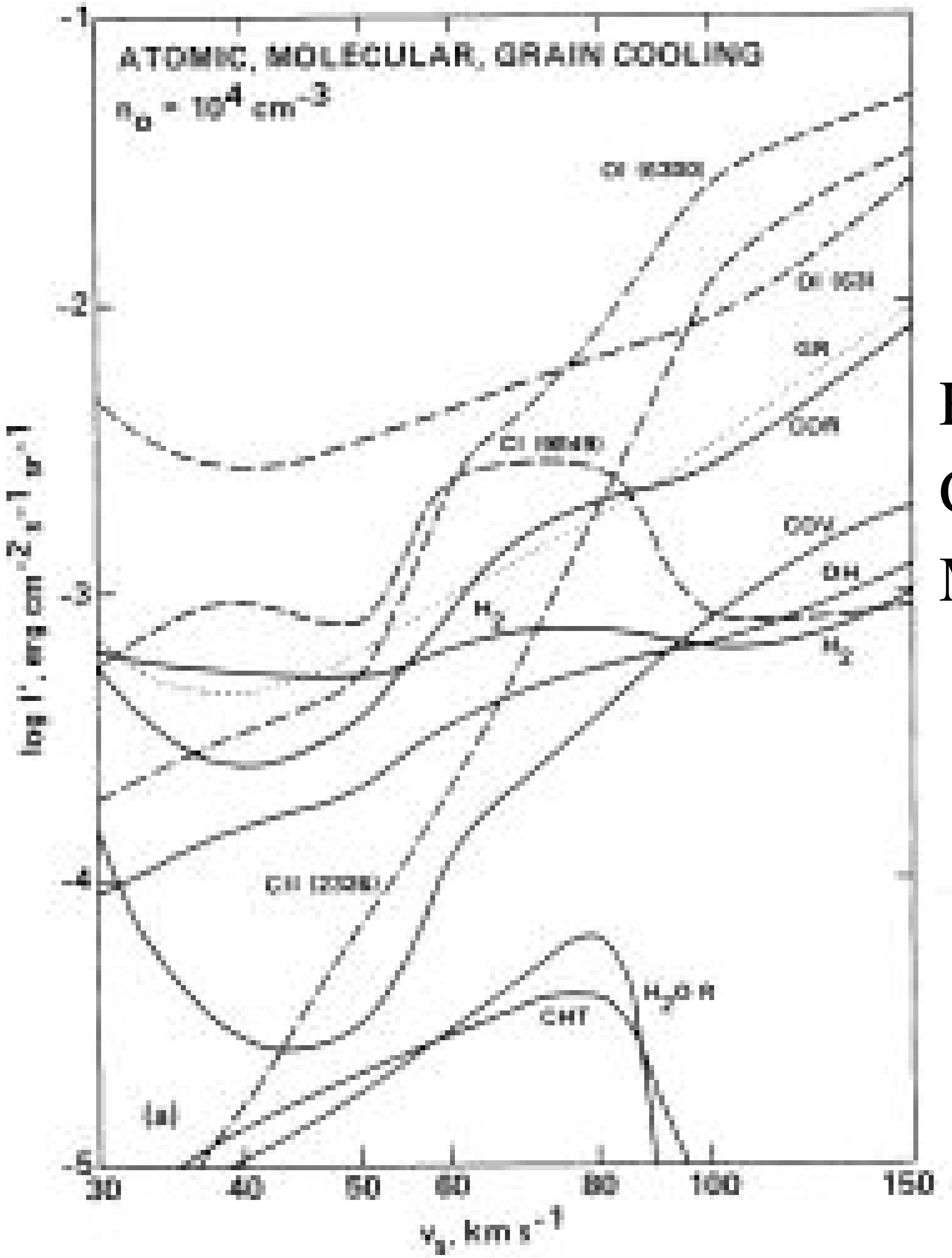
Hollenbach & McKee, 1989

Theory: Temperature Profile



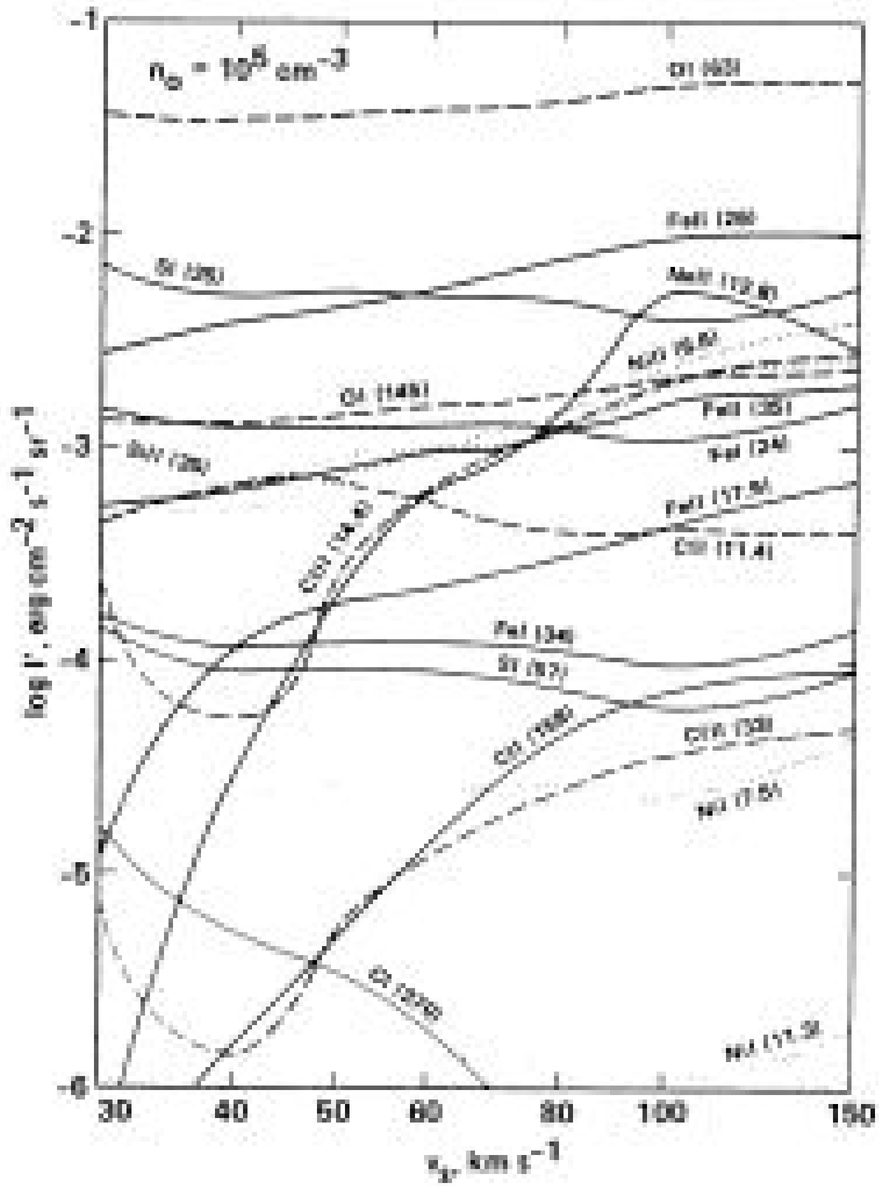
Hollenbach & McKee, 1989

Theory: Cooling Mechanisms



Hollenbach, Chernoff, and McKee 1989

Theory: Cooling Mechanisms

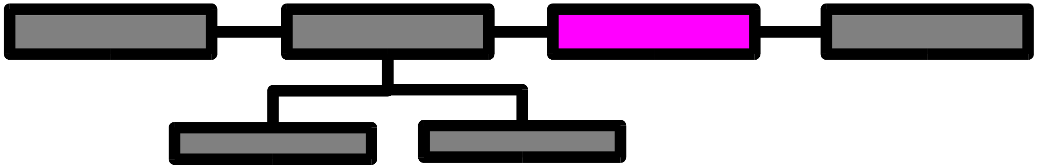


Hollenbach, Chernoff, and McKee 1989

Theory: Forbidden Lines

Ion	Wavelength (Angstroms)	Orion (photoionized)	Cas A (shock-heated)
$[OII]$	3727	1.47	1.28
$[OIII]$	4363	0.0139	0.22
$H\beta$	4861	1.00	1.00
$[OIII]$	4959	1.00	1.12
$[OIII]$	5007	3.02	3.38
$[OI]$	5577	0.00058	0.07
$[OI]$	6300	0.00012	0.31
$[NII]$	6583	0.596	2.98
$[SII]$	6717	0.0314	1.15

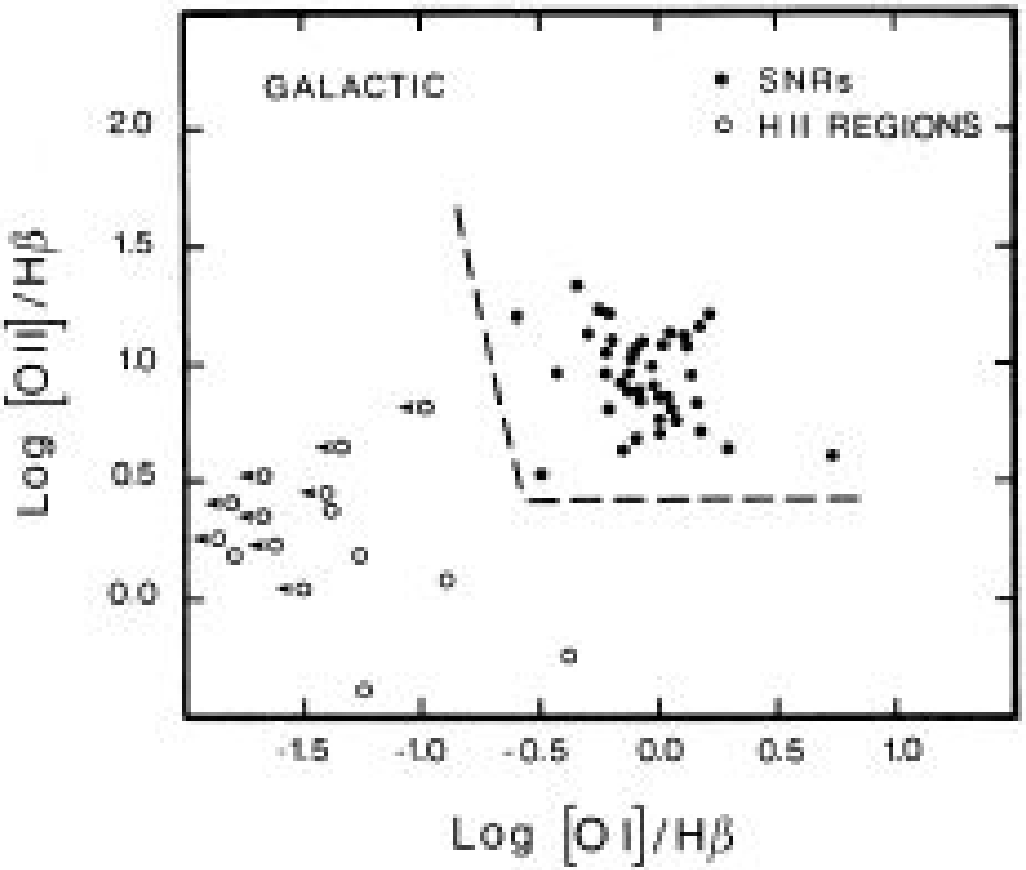
TABLE I: Table adapted from [3], showing the observed emission-line relative intensities in shock-heated and photoionized environments.



Applications: Shock Diagnostics

- Forbidden lines
- UV/Optical/IR strucAture
- Low-ionization metal species
  - Enhanced relative to H-alpha, H-beta
- Higher temperatures

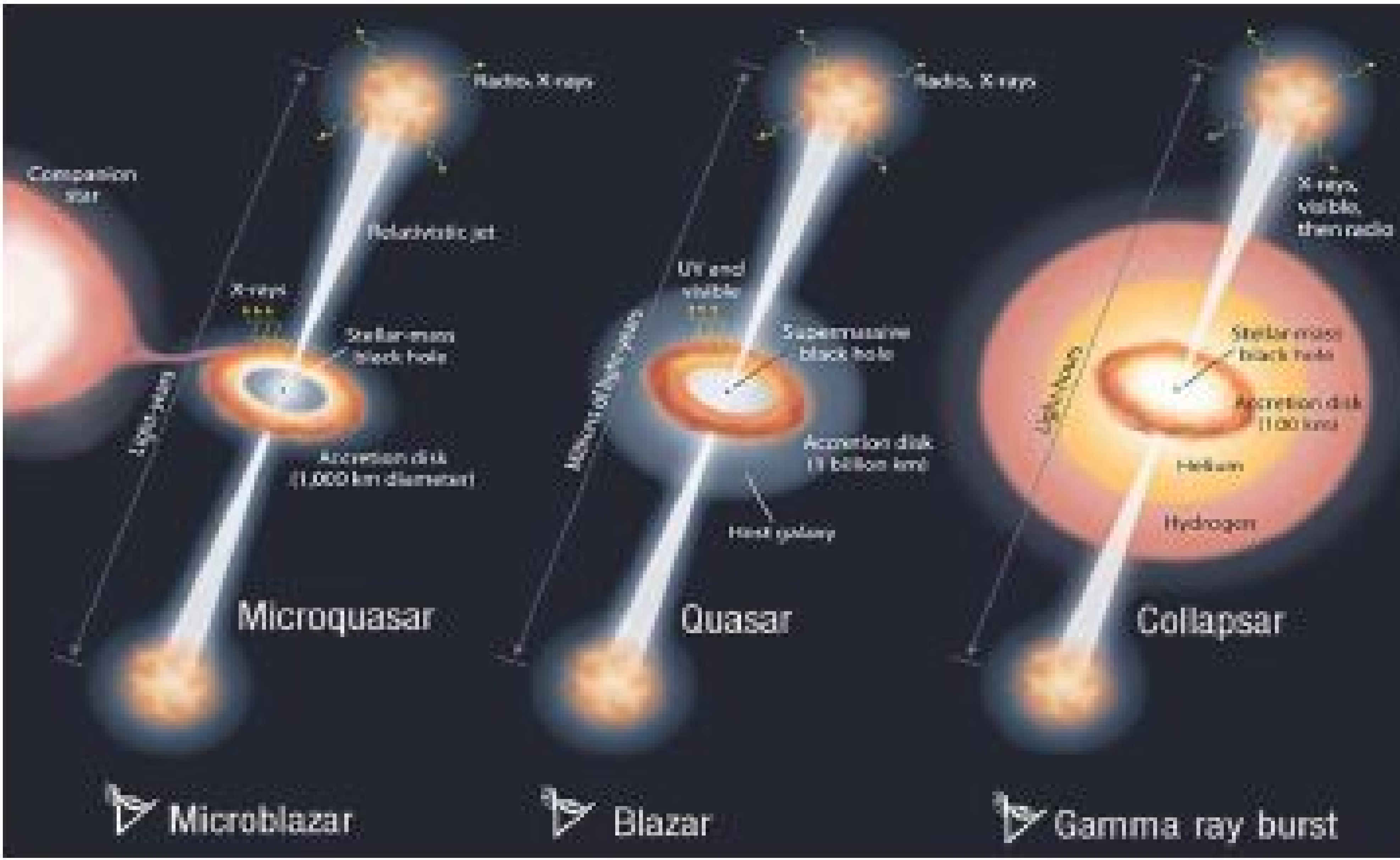
Applications: SN Remnants



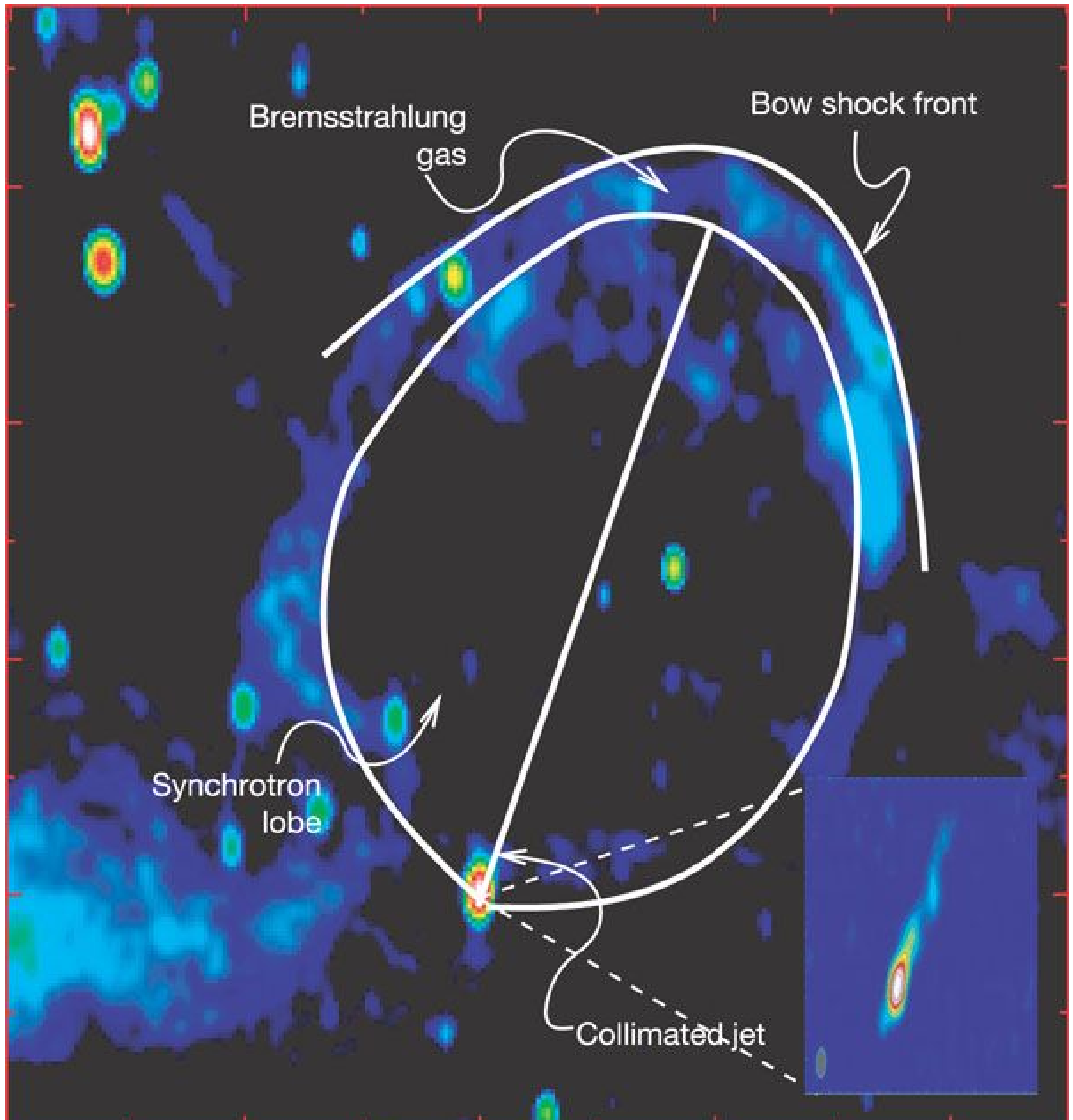
Fesen, Blair, and Kirshner, 1985

FIG. 3.—Extinction-corrected log ([O II]/Hβ) vs. log ([O I]/Hβ) for galactic supernova remnants (*dots*) and H II regions (*open circles*). The dashed line indicates the limit of observed ratio values for remnants. The figure illustrates the considerable difference for these emission-line ratios between remnants and H II regions.

Applications: Microquasars

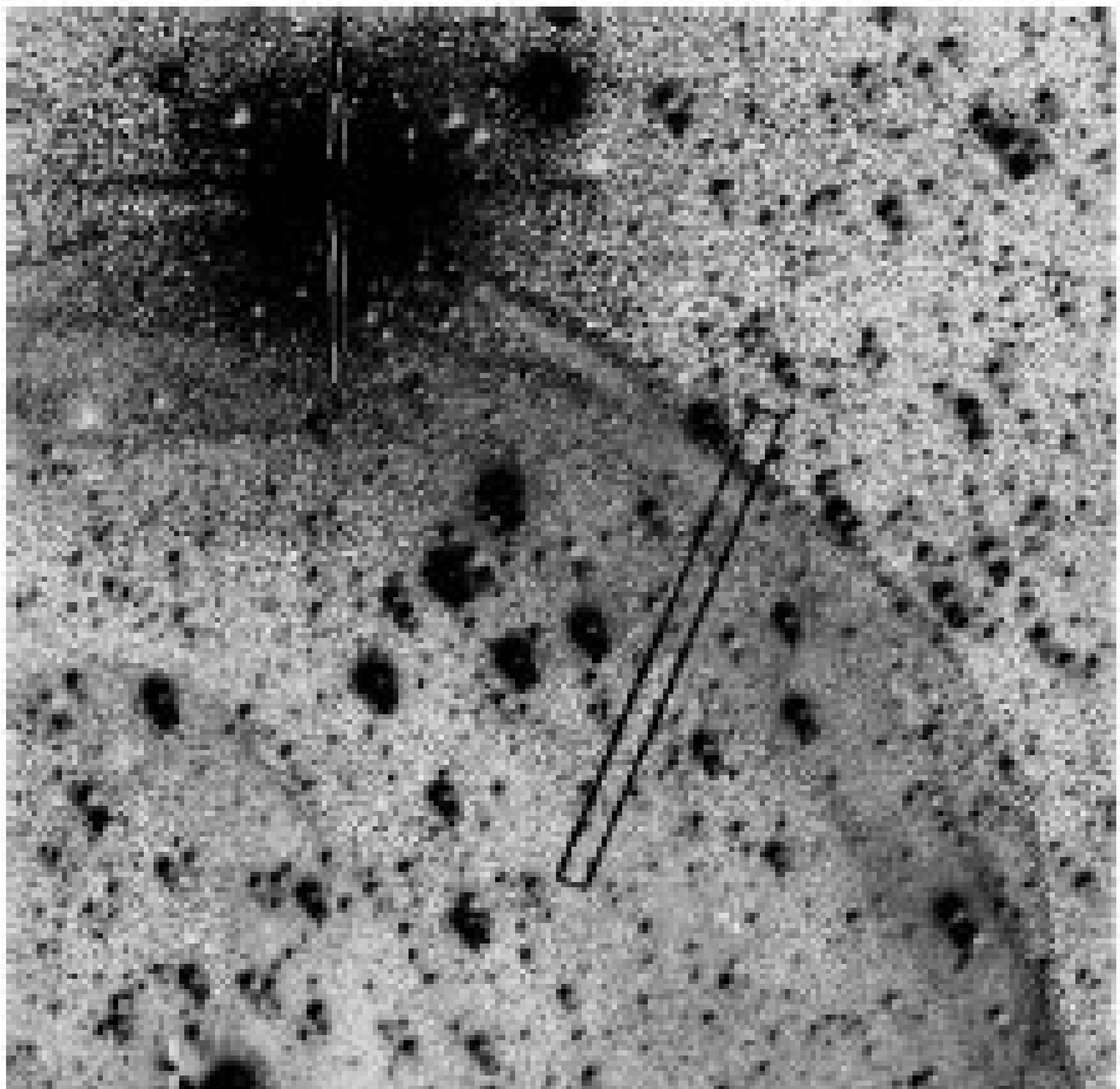


Applications: Microquasar Cygnus X-1



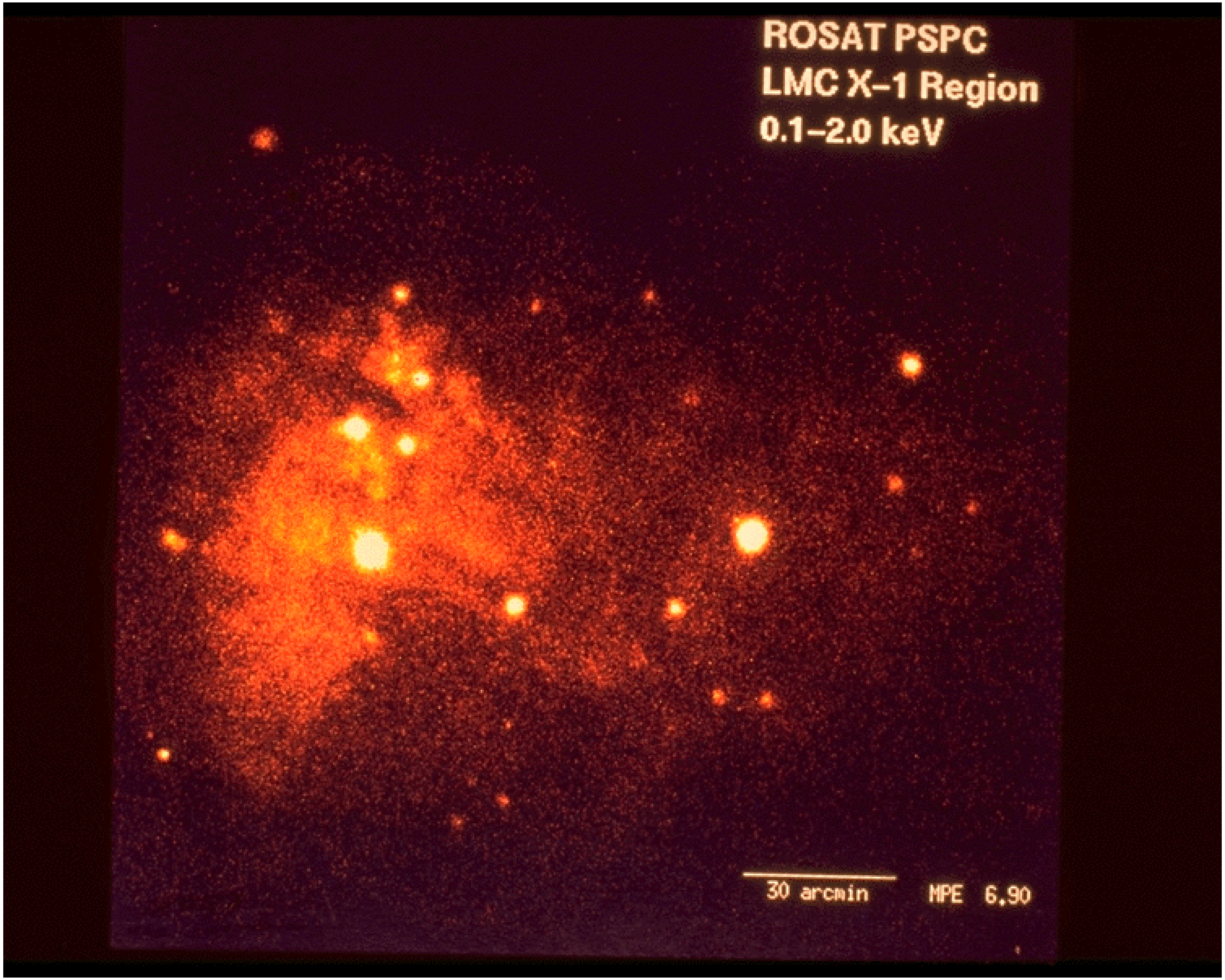
Gallo et. al.
2005

Applications: Microquasar Cygnus X-1

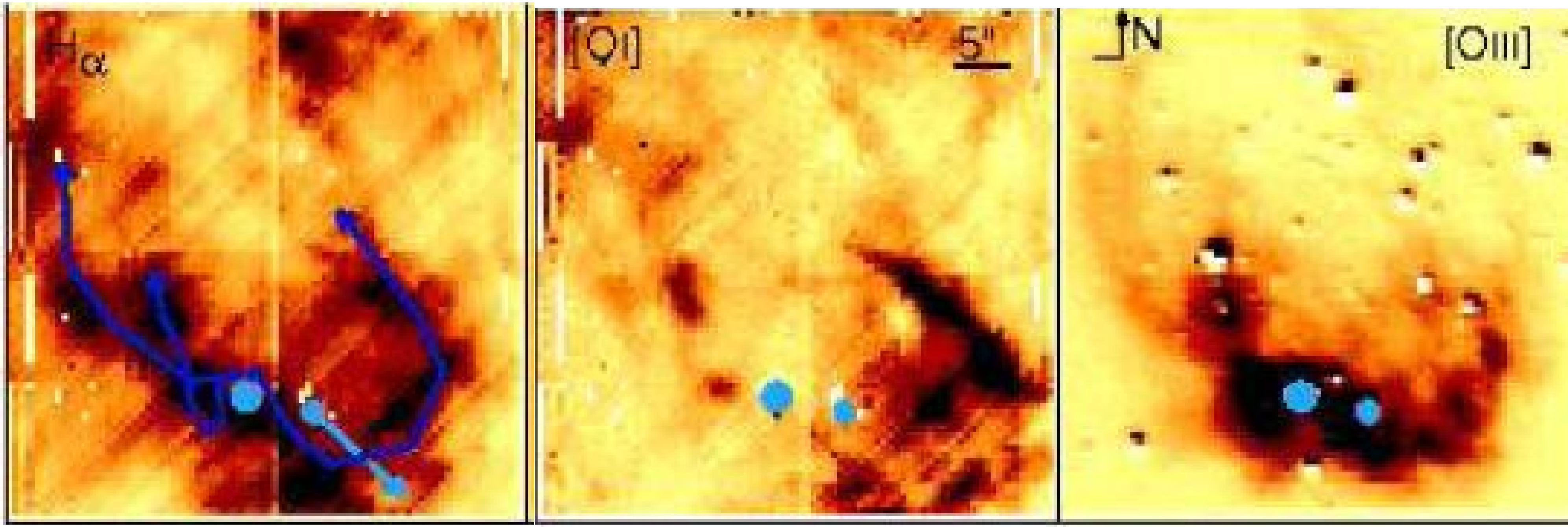


Russell et. al. 2007

Applications: Microquasar LMC X-1?



Applications: Microquasar LMC X-1?



Summary

- J-shocks: jump conditions
- Post-shock temperature profile
- Low-ionization metal species
- Collisional excitation = forbidden lines
- How to distinguish shocks from HII regions
- Examples
    - SN remnants
    - Microquasars
        - Cygnus X-1
        - LMC X-1