Supernova Remnants

Post-genitors of Supernova

Balmer Dominated Shocks in Type 1a Supernovae Remnants

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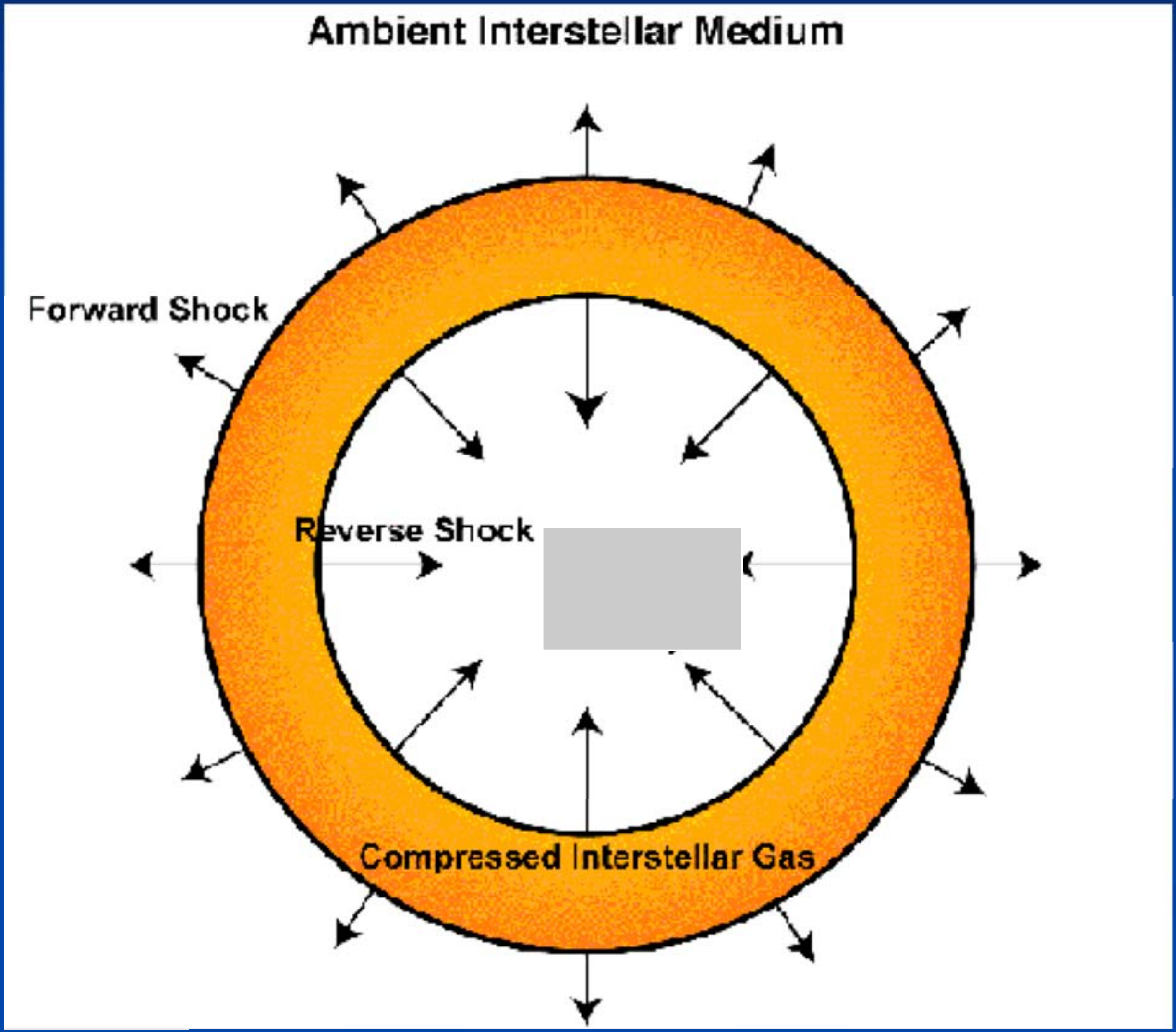
Type 1A SNR- Balmer Filaments

- Remnants
  - CSM interactions?
  - CSM structure?

- Balmer Line Filaments
  - Modeling = CSM Interaction
  - Observations = CSM Structure

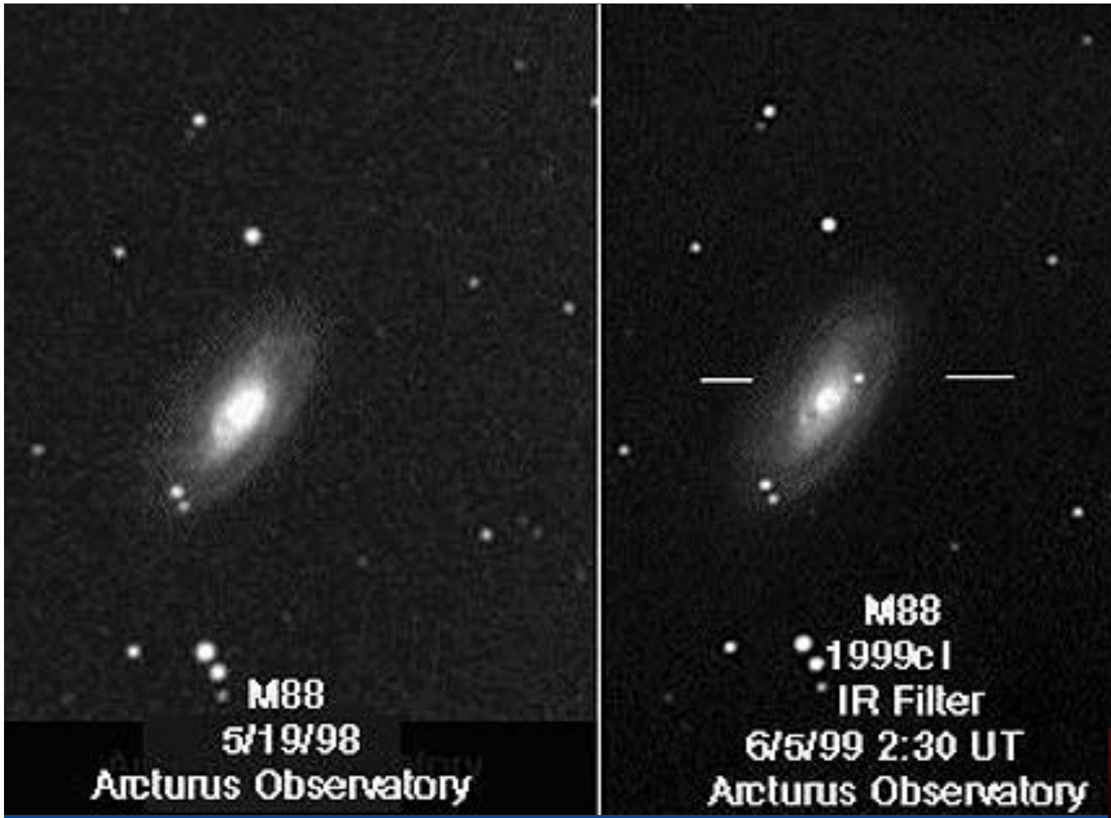
- What we have gleaned from SNRs

Basic SNR Structure

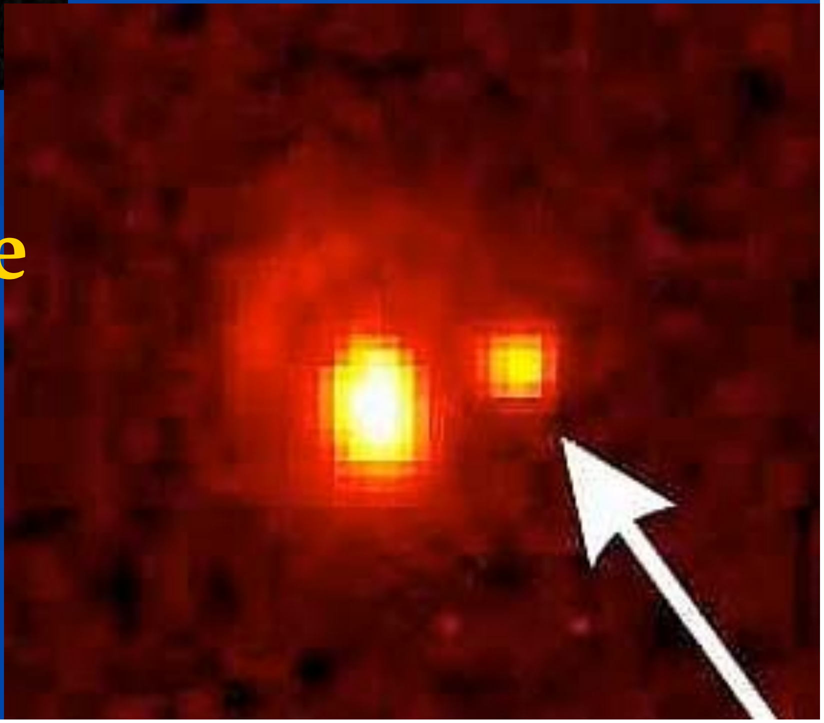


Remnants-A Summary

- 256 know galactic supernova remnants ranging in age from 300-10,000 years
- 27 LMC/SMC Supernova Remnants (SNR)
- Compared with the number of Supernova found of ~3700 since 1006 a rate of ~300/year currently (Blondin's talk last week)
- So in about 100 years the SNR community will be the place to be…

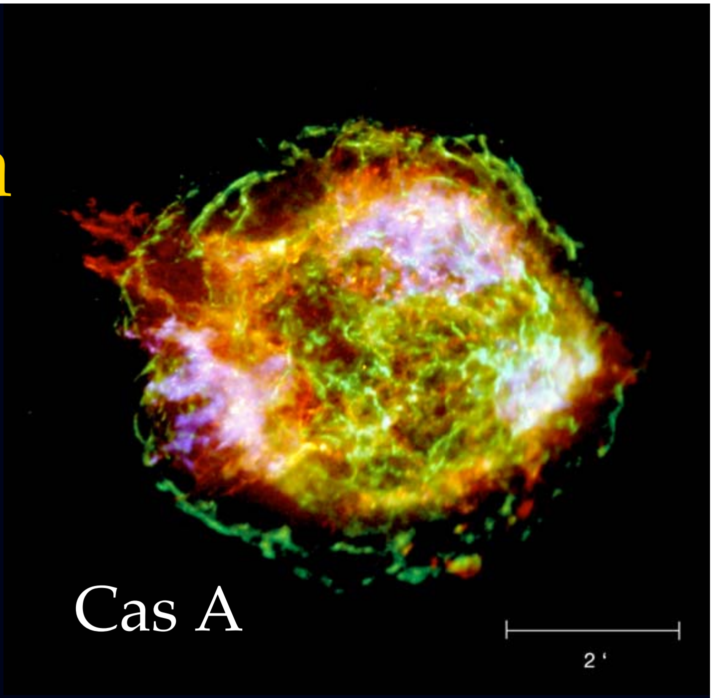


Observations of Supernovae

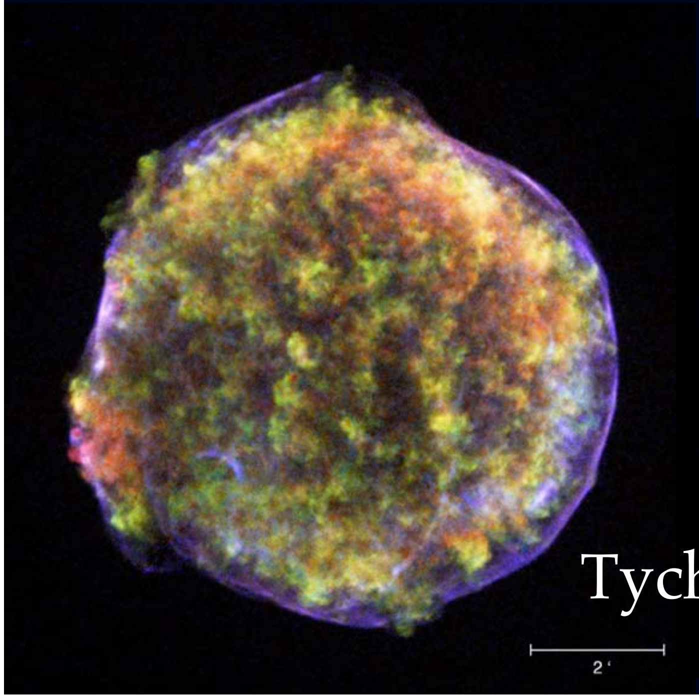


Supernova Remnants

The Crab

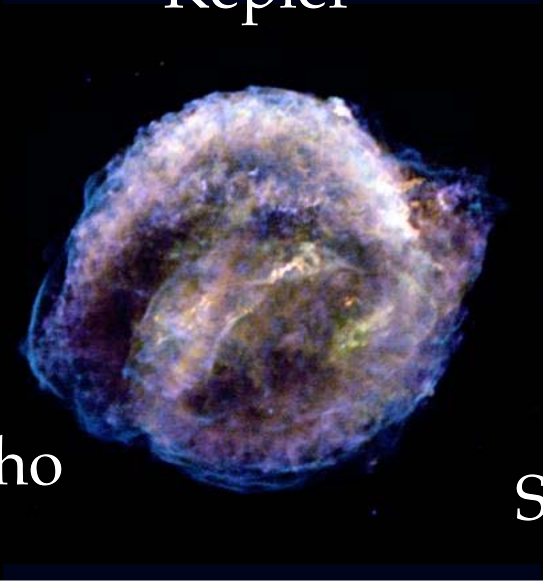


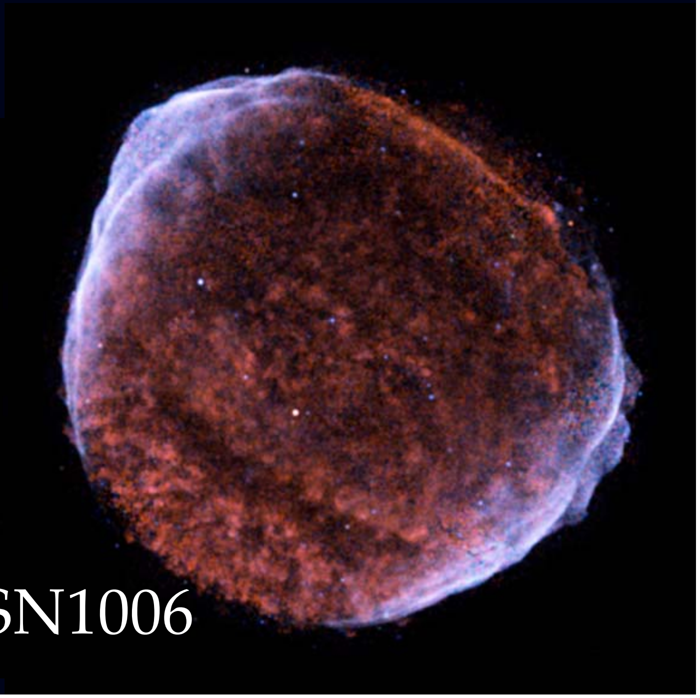
Cas A



Tycho

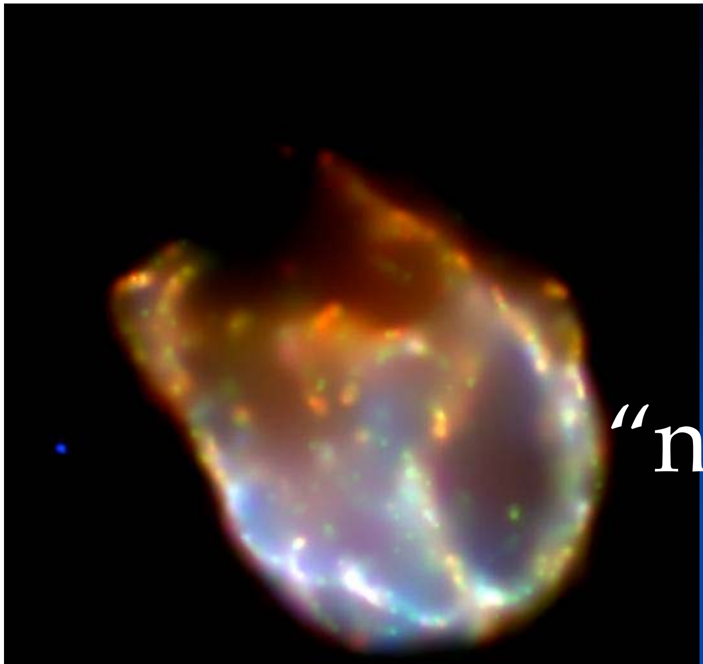
Kepler





SN1006

The “non- spherical” remnants



SNR 0525-69.6

DEM L71

G029.7-00.2

G041.1-00.3

G189.1+03.0

Why Study SNR?

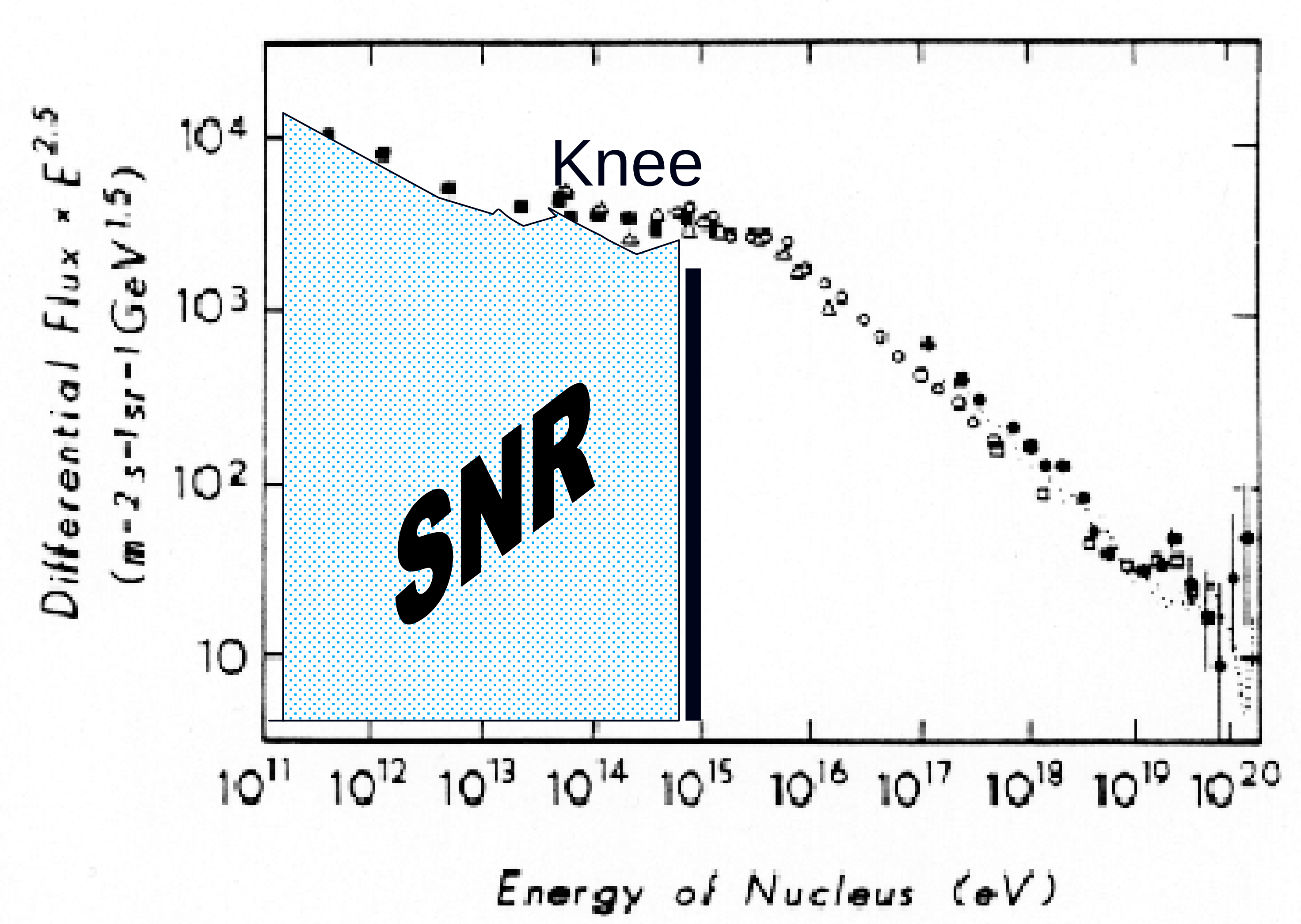
Cosmic Ray Factories

ISM interactions

ISM structure

Shock Physics

Cosmic Rays



Spectrum from http://imagine.gsfc.nasa.gov/docs/teachers/hera/xray_intro.html

ISM interaction/structure

- Can obtain temperatures and densities
- Infer the structure of the ISM
- Magnetic field information from shock physics
- Waves/Instabilities- RT, KH, RM ….

Can we really see the CMS?

Or How long before the CSM becomes the ISM?

When does the CSM lose the signature of the progenitor:

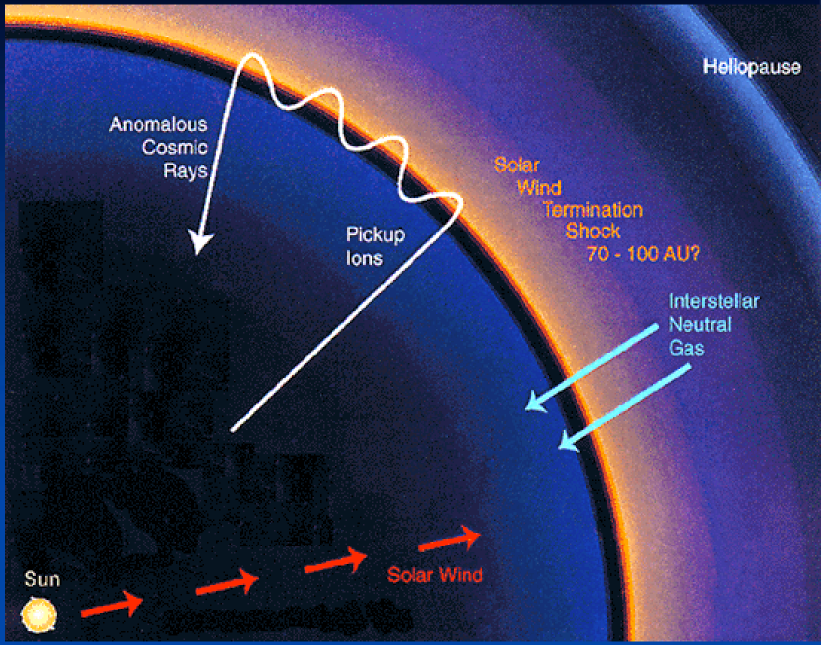
Take a single degenerate case - WD + MS

(following Wood-Vasey and Sokoloski 2006)

- Assume a wind that creates a cavity with a r~1.5 x10^{15} cm
- This will “relax”, meaning that the wind will equilibrate to the mean ISM value in t=4 x 10^5 years

So if the SN explosion goes off within 40,000 years of the end of accretion and the evolution of the remnant takes on the order of 100 years there is a chance to “see” signatures of the CSM from the remnant interaction

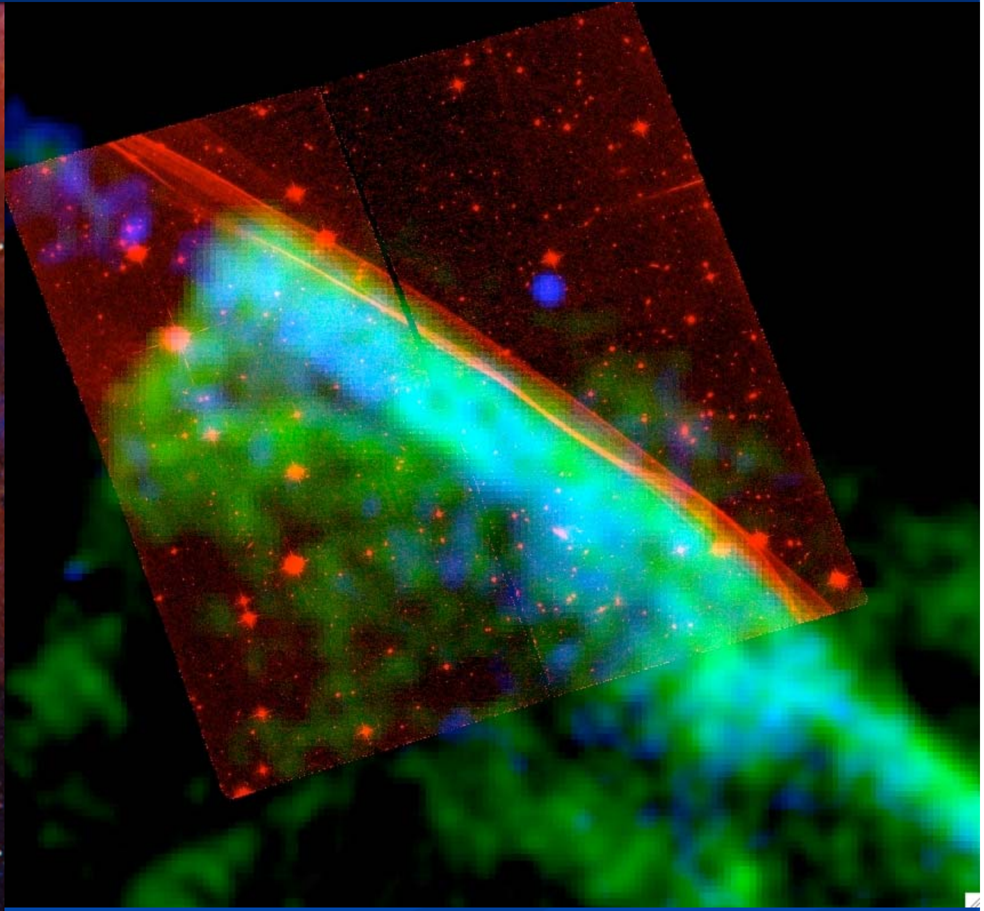
Neutrals as a Diagnostic in the ISM



- Pre-shock conditions
- Possible shock precursor
- Interpretation of ion spectral line
- Energetic Neutral Atoms (ENA)
  - Detected at Jupiter by Cassini
  - Neutrals carry away a significant fraction of energy and mass from the magnetosphere of the planets
- Pickup Ions
  - Local interstellar neutrals enter heliosphere unaffected by magnetic field
  - Source of anomalous cosmic rays

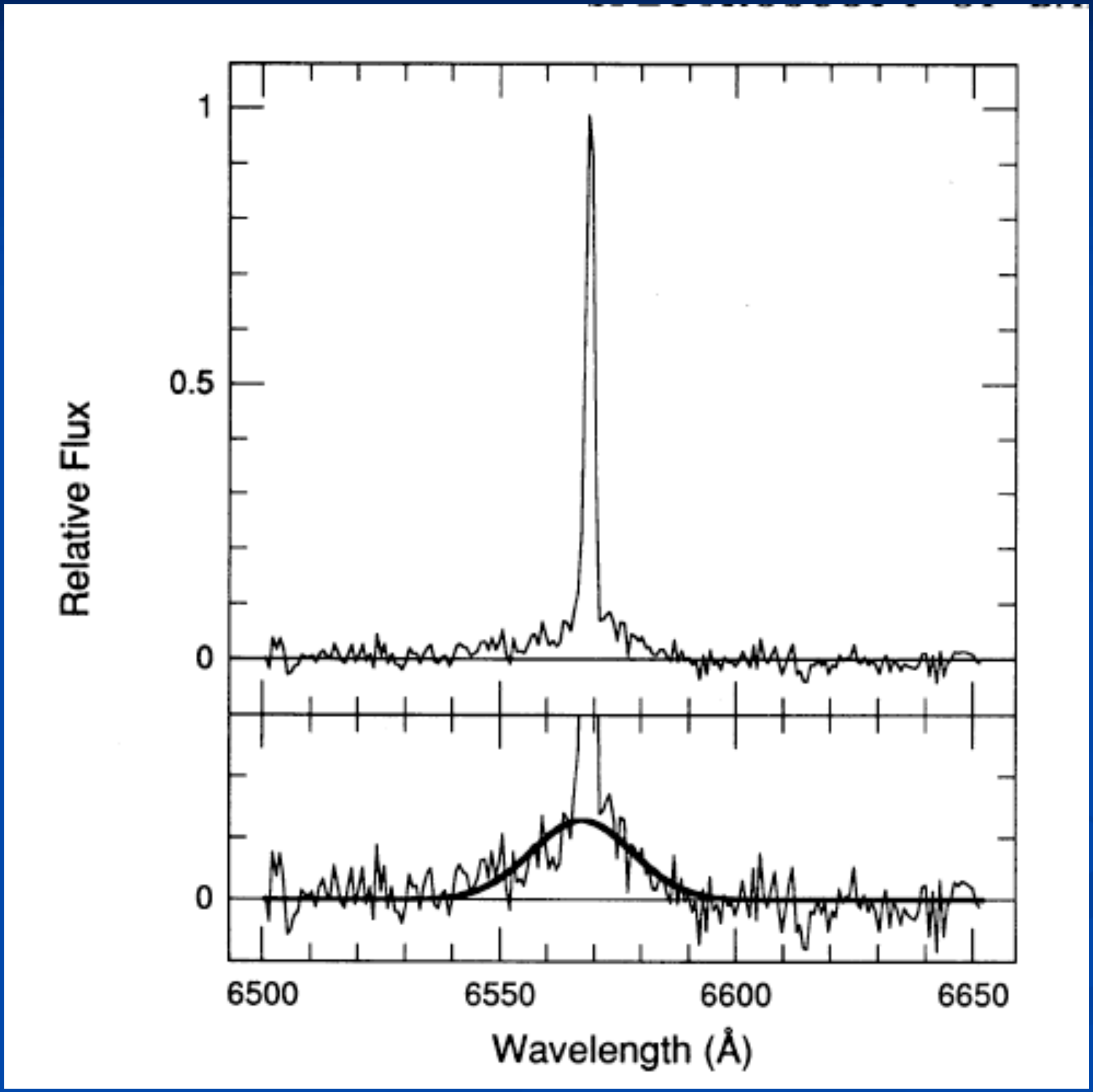
Balmer Dominated Filaments

Cygnus Loop



Composite: X-ray & H-α
SN1006 (Raymond et al. 2007)

Spectra of Balmer Dominated Filament



Smith, Raymond, & Laming (1994) ApJ

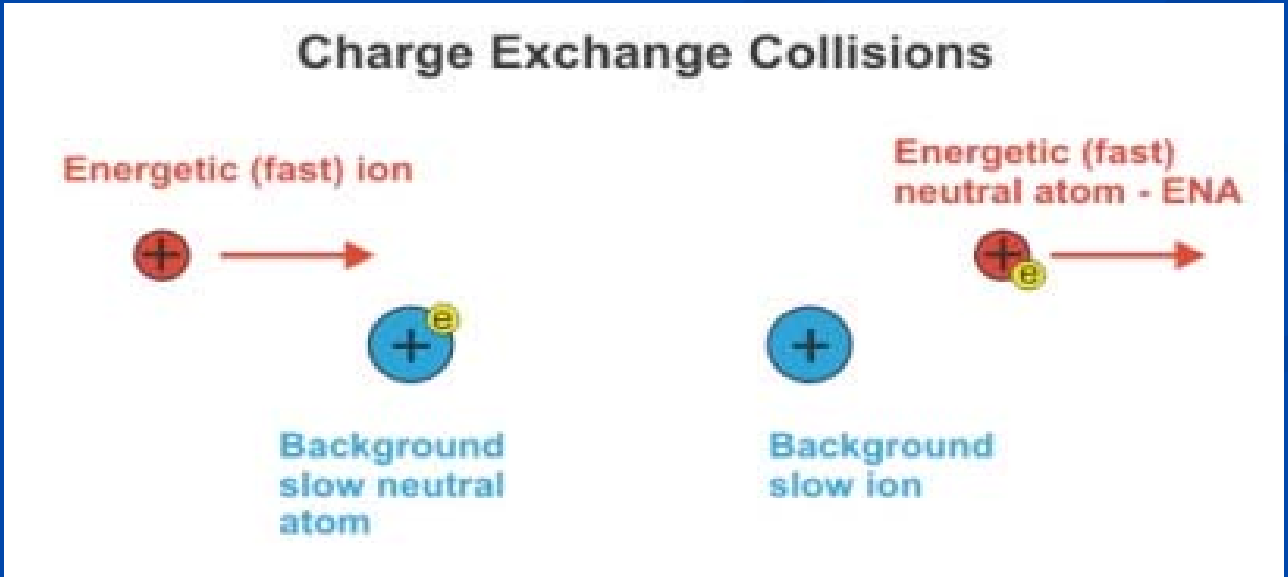
How you get a broad and narrow H-α?

BROAD COMPONENT

- 2 steps:
  - Downstream proton charge transfers with a neutral hydrogen to make a fast neutral hydrogen and a slow proton
  - The fast neutral is excited by a proton or an electron
- Emission is Doppler shifted by the velocity of the fast neutral

NARROW COMPONENT

- Upstream neutral excited by a proton or electron
- Emitted at rest wavelength



Atomic Physics behind it all

- Chevalier and Raymond (1978) & Chevalier, Kirshner, and Raymond (1980) proposed a method for studying neutrals based on the 2 components of the H-alpha lines.

$$\frac{I(\mathrm{broad})}{I(\mathrm{narrow})} \approx \frac{\langle \sigma_x v \rangle_s}{6\langle \sigma_i v \rangle_f}\left[1 + g_\alpha\left(1 + \frac{\langle \sigma_x v \rangle_f}{\langle \sigma_i v \rangle_f}\right)\right]$$

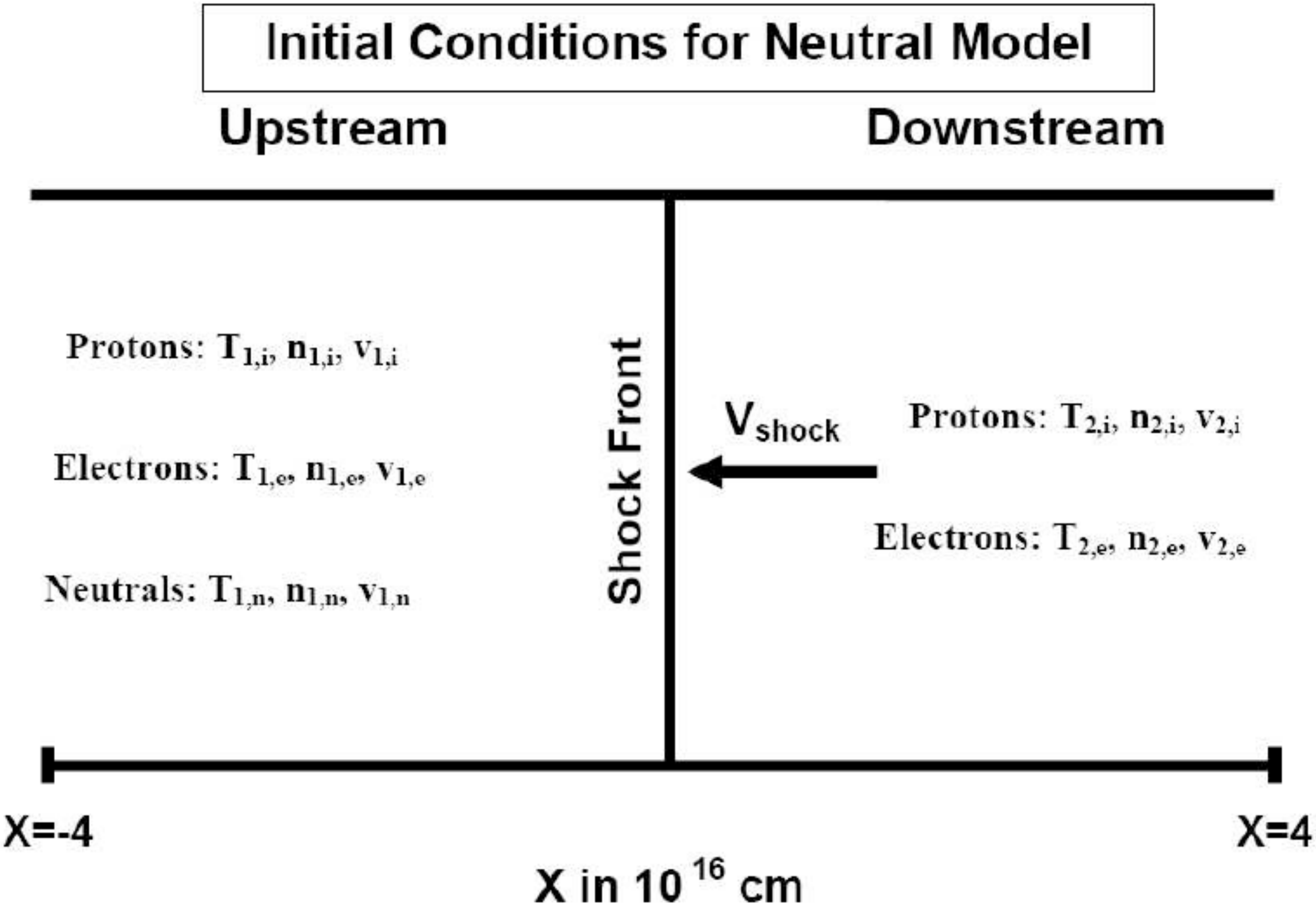
Observations of neutrals

There are several ways neutrals play a role in the observations of SNR. For example, FWHM of Broad H-α component depends on neutral fraction. This broad to narrow ratio, I_{broad}/I_{narrow} indicates the sharing of heating between atomic species. The neutral fraction also effects other diagnostic lines such as HeI/HeII. Neutrals are also thought to be a possible candidate to create a pre-cursor to shock.

Remnant	I_{broad}/I_{Narrow}
Tycho (Smith et al 1991)	1.08
SN1006	0.73
0519-69.0 (Smith et al 1991)	0.8
0548-70.4 (Smith et al 1991)	1.1

From the table at the right, heating in the fastest SNR shocks is not equal for each atomic species.

Monte Carlo neutral model setup



Initial Conditions for Neutral Model

Upstream

Protons: $T_{1,i}$, $n_{1,i}$, $v_{1,i}$

Electrons: $T_{1,e}$, $n_{1,e}$, $v_{1,e}$

Neutrals: $T_{1,n}$, $n_{1,n}$, $v_{1,n}$

Shock Front

Downstream

V_{shock}

Protons: $T_{2,i}$, $n_{2,i}$, $v_{2,i}$

Electrons: $T_{2,e}$, $n_{2,e}$, $v_{2,e}$

X=-4

X=4

X in 10^{16} cm

Monte Carlo model parameters

Variables

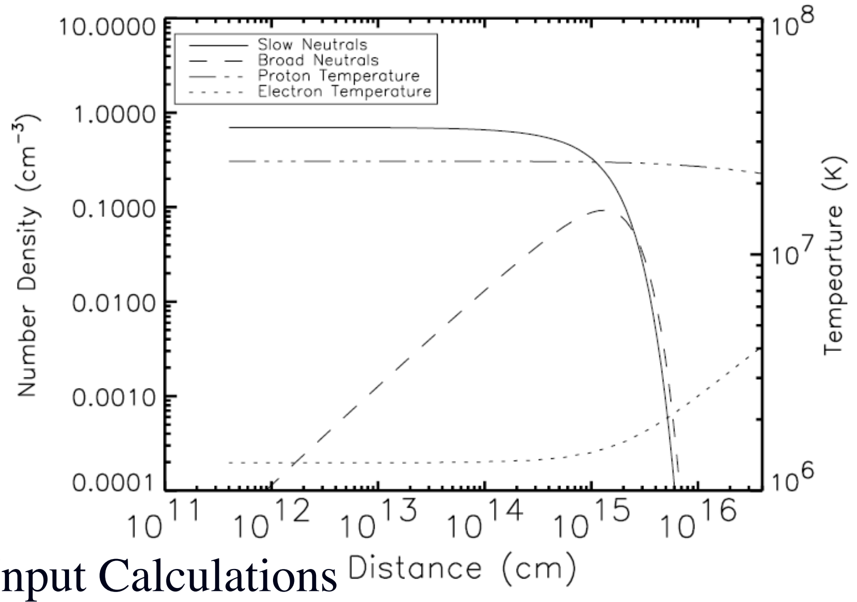
- Neutral fraction (1-90%)
- Magnetic orientation (0,45,90)
- Shock speed (300-3000 km/sec)
- T_e/T_p (0.1, 0.5, 0.9)

Atomic Interactions

- Charge transfer

$$H(slow) + p(fast) \rightarrow H(fast) + p(slow)$$

- Excitation
- Ionization

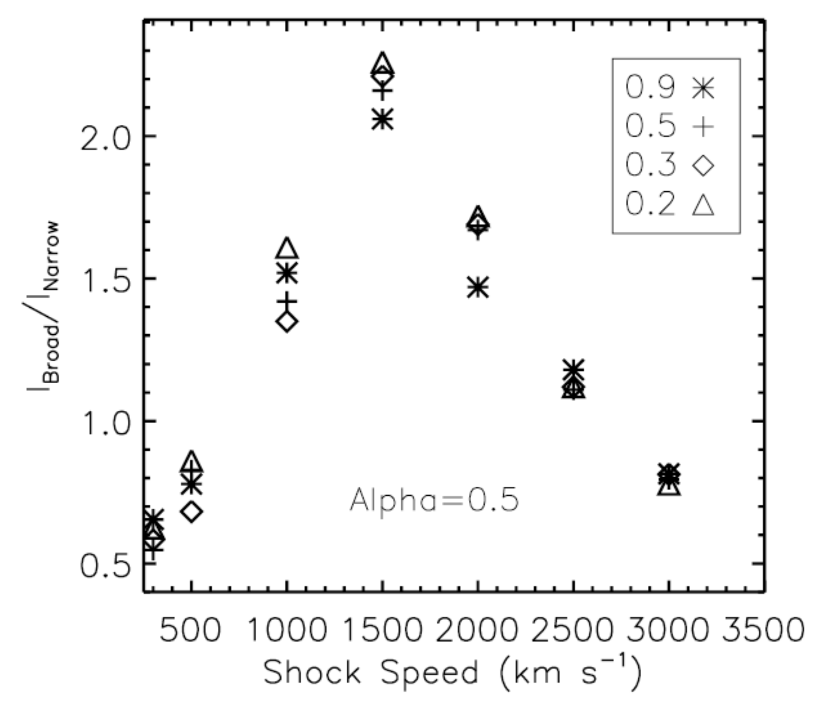


Input Calculations

Low-Hybrid Wave Heating

- Current "stylish" wave heating
- Heat goes preferentially to electrons, then transfers to protons via Coulomb collisions
- Heating occurs if $V_{Alfven} < v_{gyro}$

Predicted I_{broad}/I_{narrow}



Variations based on

- $T_e/T_p=\alpha$
- Shock Speed
- Magnetic Angle

Smaller variations based on neutral fraction

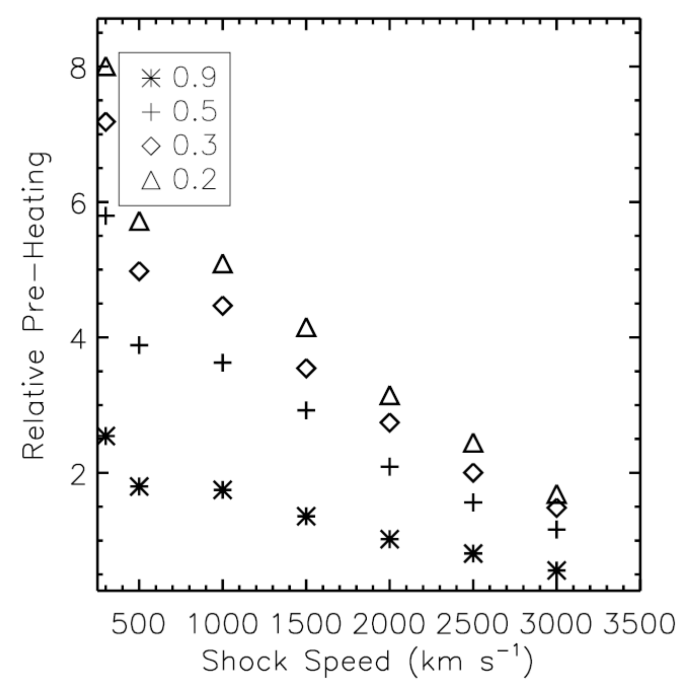
Using the I_b/I_n ratio from the previous results, we can predict the magnetic angle of the shock

For SN 1006 ratio of 0.73 and the shock speed ~2800 km/sec, the parallel shock model fits the data as expected!

Comparison of Model to I_{broad}/I_{narrow} Observed in Supernova

Remnant	Code Result	Obs. Ratio
Tycho (Smith et al 1991)	1.04-2.4	1.08
SN1006	0.47-1.1	0.73
0519-69.0 (Smith et al 1991)	1.0-1.4	0.8
0548-70.4 (Smith et al 1991)	1.0-1.4	1.1

Precursor heating

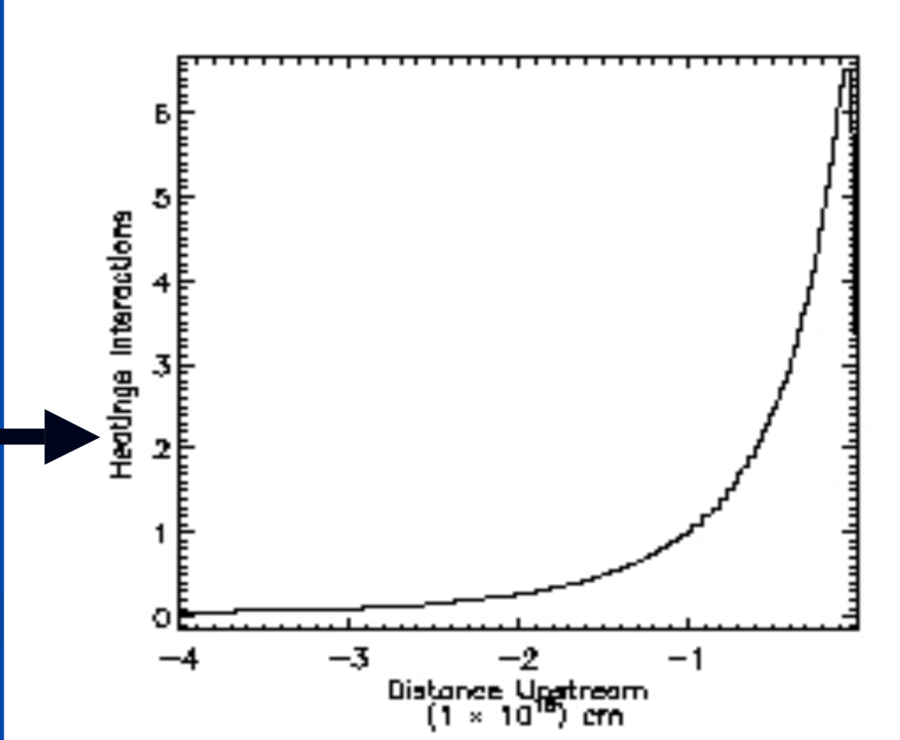


Depends on

- Shock speed
- Neutral fraction

60K increase versus the MK temperatures – no effect on the pre-shock area

Precursor extends to only one mean free path behind the shock



Neutral conclusions

- Neutrals are NOT a strong precursor to the shock
- The broad to narrow intensity ratio is highly dependant on velocity and temperature equilibration (or lack thereof)
- Neutral fraction has a decreased effect as the shock velocity increases-could be explained by the fall off of the charge exchange cross section with increasing shock speed as seen in Heng & McCray (2006, ApJ)

Balmer Filaments as Structure Probes

SN1006-Balmer Filament

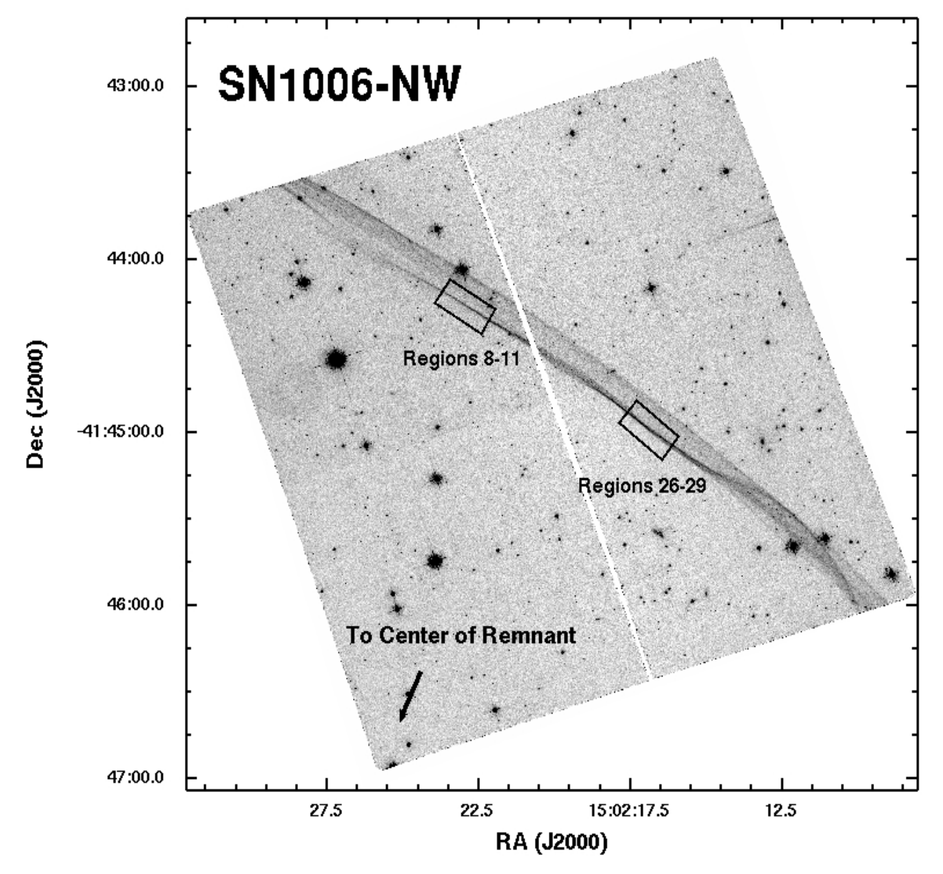
(Raymond et al. Astro-ph 0701311)

- Northwest region of the filament

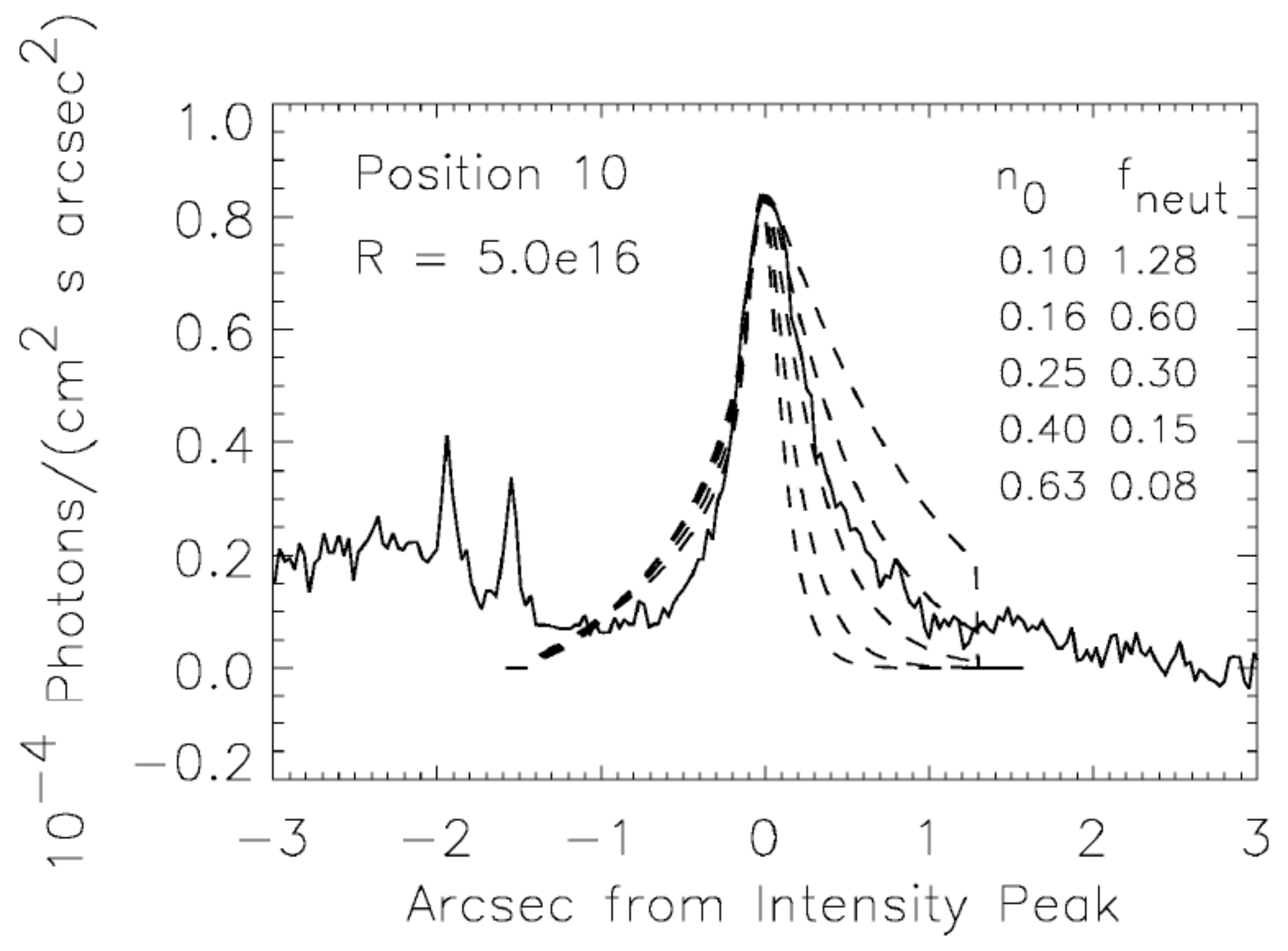
  From past observations:

  - Thermal x-ray emission

    (Long et al. 2003, ApJ, 586, 1162)
  - Low density ISM ~0.25 cm^{-3}
  - Ejecta knots are present nearby the HST observation- these knots have been observed in X-rays (Chandra)



Extent of Balmer filament



Thickness of emission region~1/preshock density

Structure of the Balmer Filament

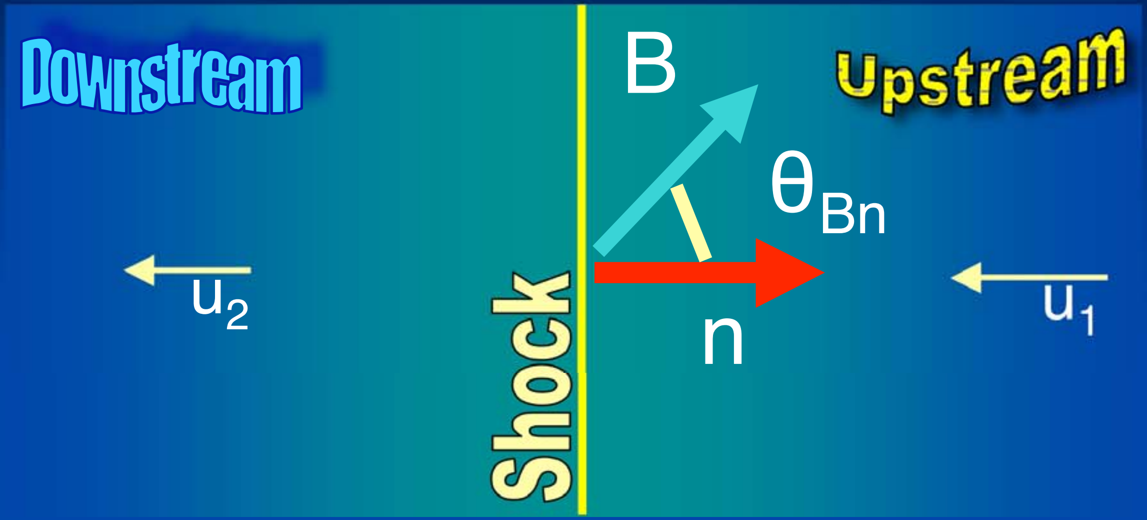
- Radius of curvature of the ripples<<Length of filament
- Filament Length=7′ or 4 pc long (100 times the ripple length)
- Ripples length scales can be accounted for with general ISM turbulence
- However, the amplitude of the ripples is higher than a Kolmogorov spectrum of density fluctuations
- Small width of the narrow component of the filament means no room for precursors!

SNR Balmer filament clues to SNe

Balmer width and structure--Structure of the ISM/CSM surrounding the explosion

Temperature , density of ISM---how much energy is deposited pre-explosion

Shocks overview



- Behavior governed by Rankine-Hugoniot conditions
  - $\rho_1 u_1 = \rho_2 u_2$ (mass)
  - $\rho_1 u_1^2 + P_1 = \rho_2 u_2^2 + P_2$ (momentum)
  - $\frac{1}{2} u_1^2 + h_1 = \frac{1}{2} u_2^2 + h_2$ (energy)

Heating in collisionless shocks

- Shock heating based on many factors:
  1. v_{shock}: shock speed
  2. θ_{Bn}: magnetic field angle to shock normal
  3. β: ratio of thermal and magnetic pressure
  4. M_A: Alfvenic mach number
  5. Mass to charge ratio
  6. Plasma waves/instabilities
  7. Equilibration between species: T_e/T_p
  8. Environment –density, abundances, neutral fraction

Heating studies

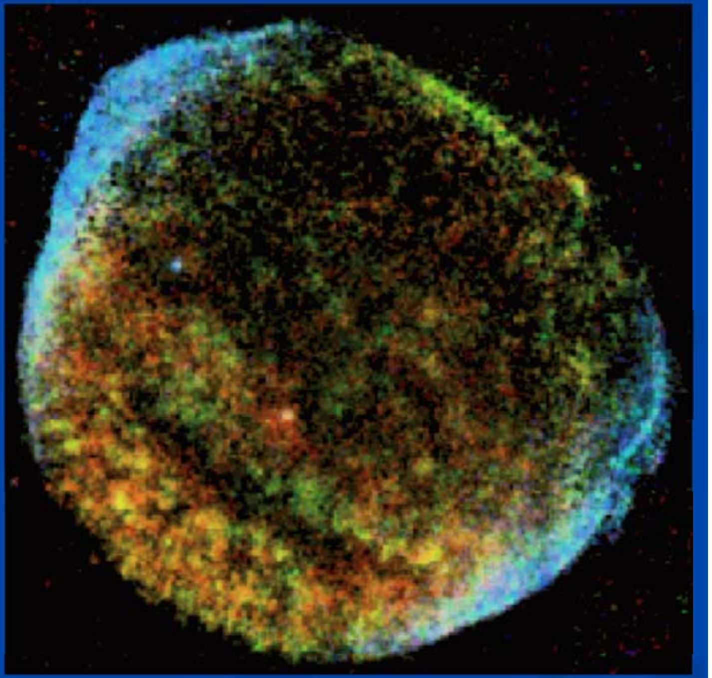
- Ions studied seem to vary by shock
  - Mass proportional heating in Supernova Remnant (SNR)
  - Greater than mass proportional heating in Interplanetary shocks
- What about electrons?
  - Mass difference
  - Can have a very different temperature
  - Long et al. 2003 found in SN1006 an electron temperature <1.2keV but a proton temperature of 16keV
  - Temperature difference allows the fluid to separate effectively into two streams leading to instabilities and further variation in the phenomena the streams experience
- What about neutrals? They exist pre-shock and could contribute to precursor heating
- What about heavier ions? (not protons)

Diagnosing shocks with spectral lines

- Lyman-β (1025 Å)
  - Broad component proportional to the amount of proton heating
  - Centers on post-shock ionic velocities
  - Created by collisional excitation of protons
  - Produces ~30% of the H-α signal
- Oxygen VI (1032,1037 Å)
  - Broadening ~ kinetic temperature of the oxygen

Heating in SN1006

- From the widths of the Gaussian fits of the oxygen lines, $T_{OVI} = 1.5 \pm 0.3 \times 10^9$ K in the post shock region. Proton post shock temperature of 1×10^8 K
  - **This is LESS than mass proportional heating!**
- Widths of C IV, O VI, He II ion lines in SN 1006 indicate negligible ion-ion equilibration (Laming et al. 1996, Vink et al. 2003, Ghavamian et al 2002)
  - **LESS than Mass proportional Heating!**
- Density measurements indicate that the NW is at least 4 times as dense as the NE region



ROSAT HRI composite image of SN1006

Summary for heavy ion heating

- Shock heating often has a strong M/Q dependence
- Velocity dependant
- Perpendicular shocks impart a larger fraction of energy to heavies
- The heating rate does not depend on Mach number, but upstream proton β
- T_e/T_p show shocks far from equilibrium