

Observations of CR precursors in SNRs

Discovery of a Narrow (10^{16} cm) Precursor in Tycho:
A CR Precursor?

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Introduction

- Diffusive shock acceleration requires a precursor in which particles scatter back and forth between the shock jump and MHD turbulence (e.g., Blandford and Eichler, 1987)

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- Diffusive shock acceleration requires a precursor in which particles scatter back and forth between the shock jump and MHD turbulence (e.g., Blandford and Eichler, 1987)
- Dissipation of the turbulence will heat and accelerate the gas in a precursor.

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I. Balmer-dominated filaments in SNRs

II. Evidence of CR precursor from observations of Balmer-dominated filaments.

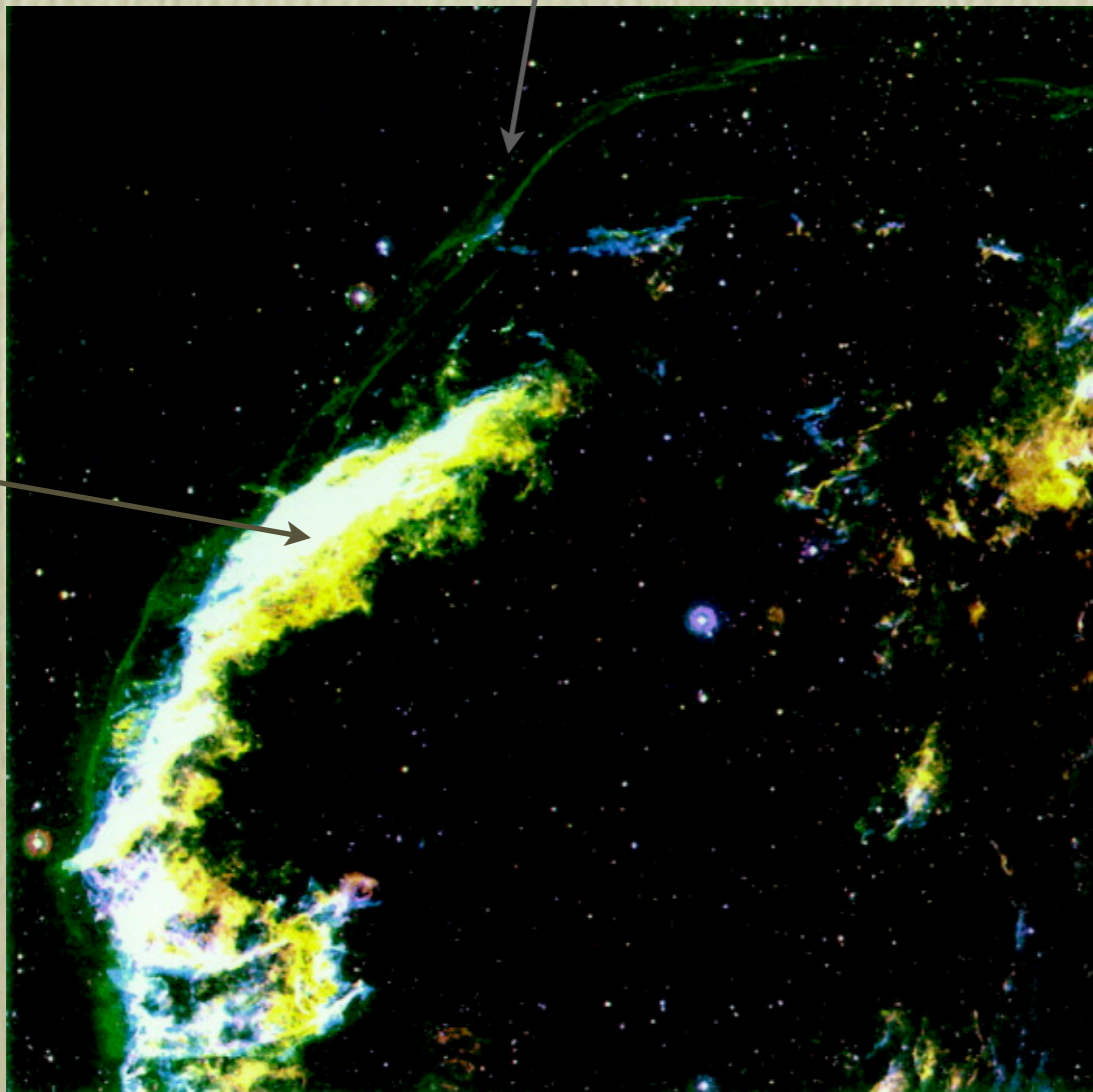
III. The case of Tycho :

Discovery of Narrow Precursor in Tycho

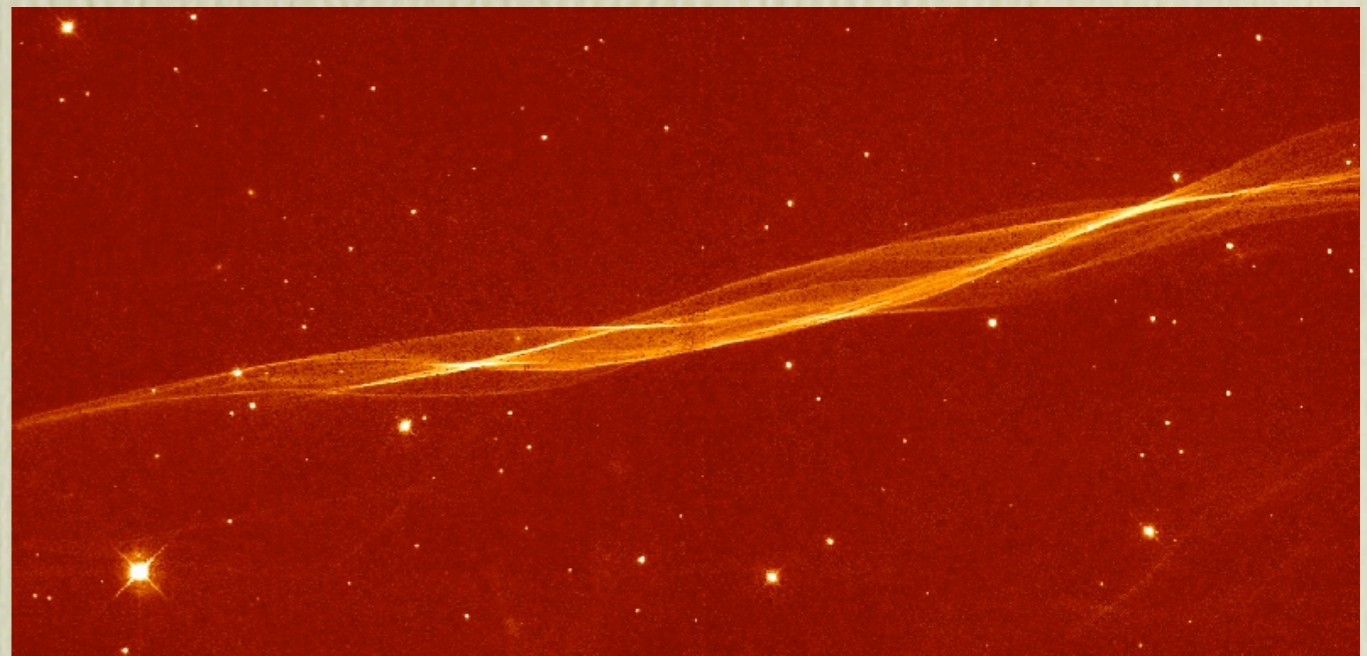
Balmer-dominated filament

- A faint optical filament whose spectrum is dominated by hydrogen Balmer lines.

Radiative filament



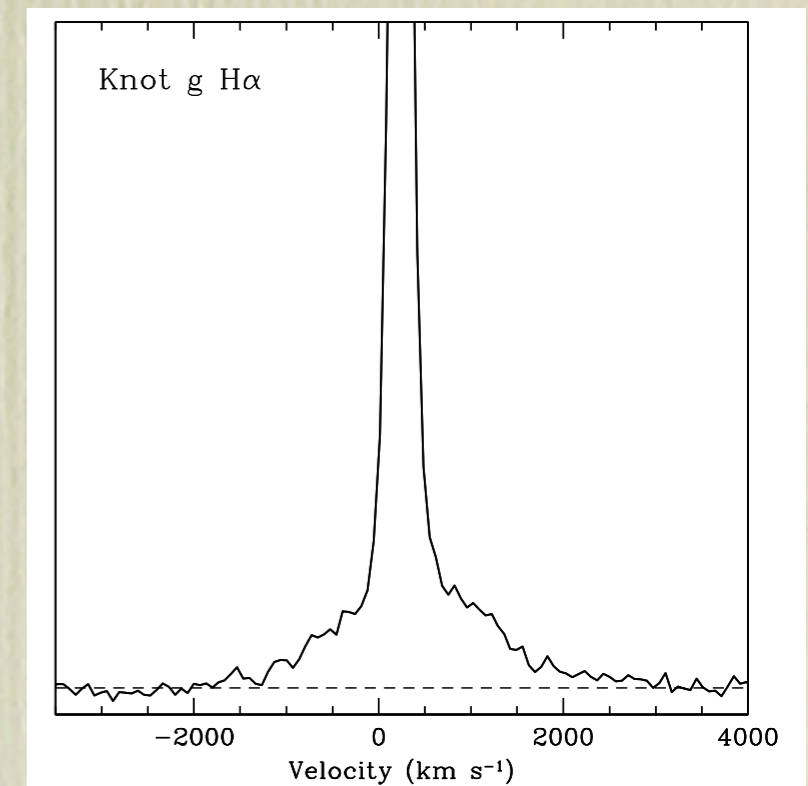
Cygnus Loop : SII(R), Ha(G), OIII(B)



HST image of Balmer-dominated filaments

Balmer-dominated filament

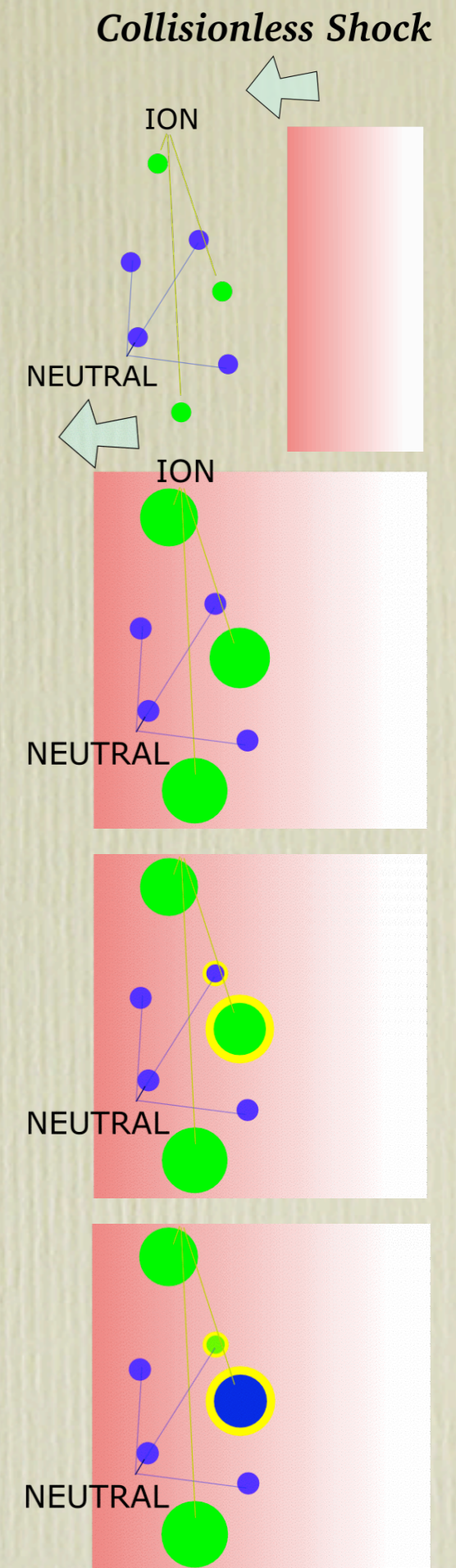
- found in **young SNRs** ($V_s > 1000 \text{ km/s}$)
 - ◆ Tycho, Kepler, SN1006 etc.
- Ha line profile shows two distinct components : **narrow** ($\sim 40 \text{ km/s}$) & **broad** ($\sim V_s$)
- represents a **non-radiative shock into a partially neutral medium.**



Theory of Non-radiative Shock into a Partially Neutral Medium

- As the shock is collisionless, a neutral atom passing through the shock is not affected by electromagnetic fields at the shock transition.
- Some atoms retain their pre-shock velocity distribution, giving a narrow line profile component characteristic of the pre-shock temperature.
- Other atoms undergo charge transfer with post-shock protons, giving a broad component whose line width is controlled by (and comparable to) to the shock speed

● Cold Ion ● Hot Ion
● Cold Neutral ● Hot Neutral



The **narrow** component should show characteristics of the **pre-shock** gas

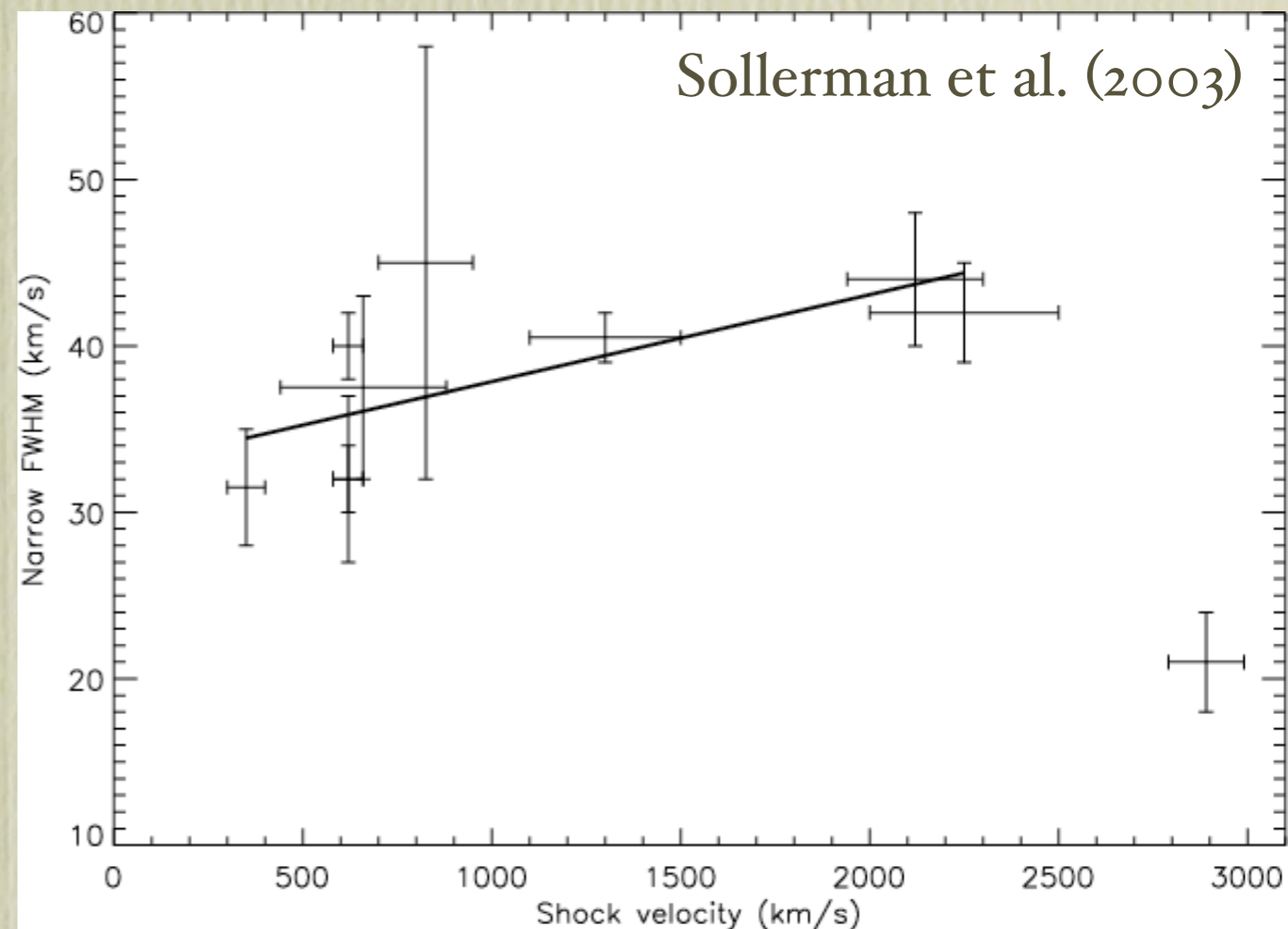
And if there is a CR precursor,
the narrow component will represent
this gas in the precursor which is heated
and accelerated.



Broadening & Doppler Shift

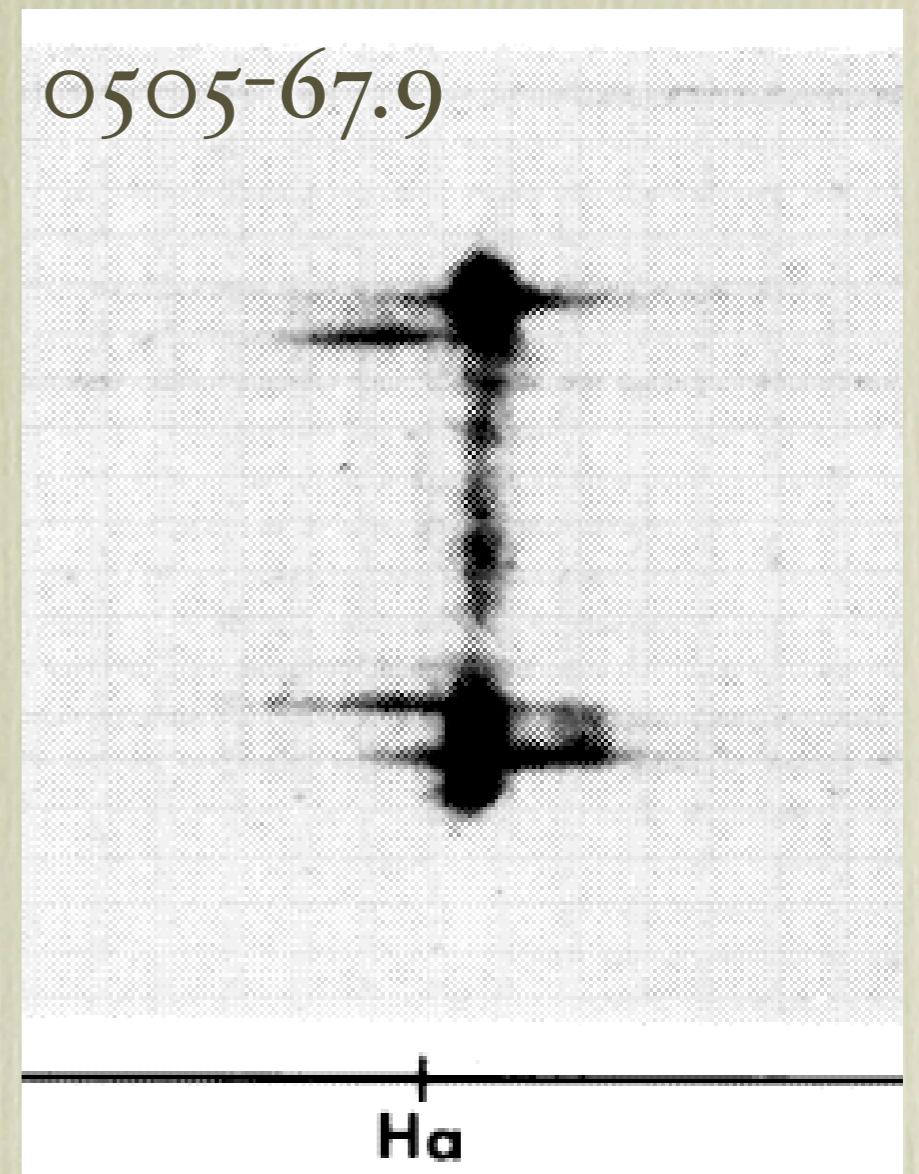
Broadening

- $\sim 40\text{km/s}$ for most SNRs observed (e.g., Sollerman et al, 2001)
- corresponds to $T=40,000\text{K}$. No neutral hydrogen expected.
- heated in a narrow (CR) precursor?



Doppler Shift

- Long-slit observation of LMC SNRs (Smith et al. 1994) do not show doppler shift.
- Gas acceleration in the precursor (~ 10 km/s) is proposed for Tycho (Lee et al, 2004).

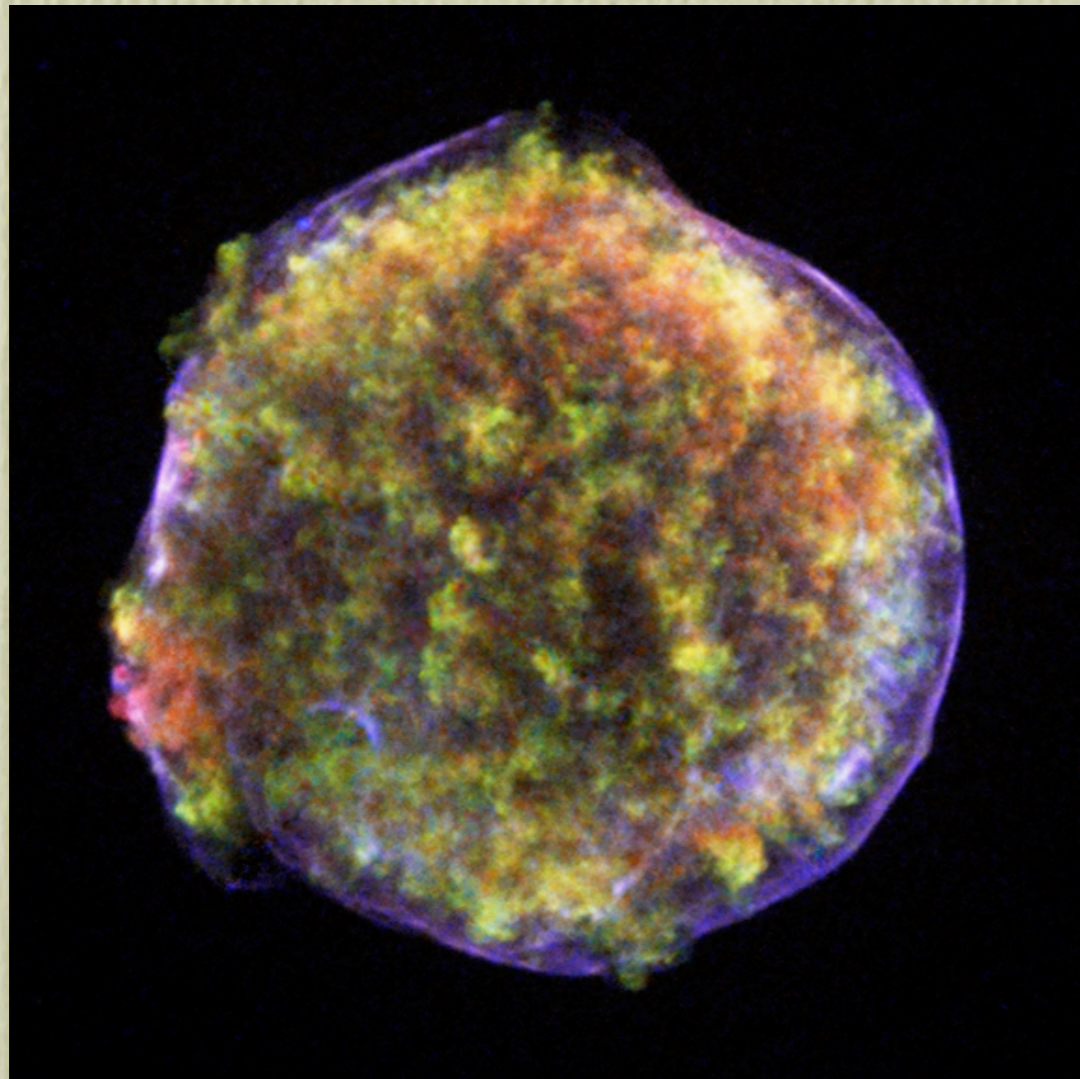


Some indications of CR precursor.

H α profile from CR precursor only
is observed.

Comparison w/ unperturbed medium
has not been possible.

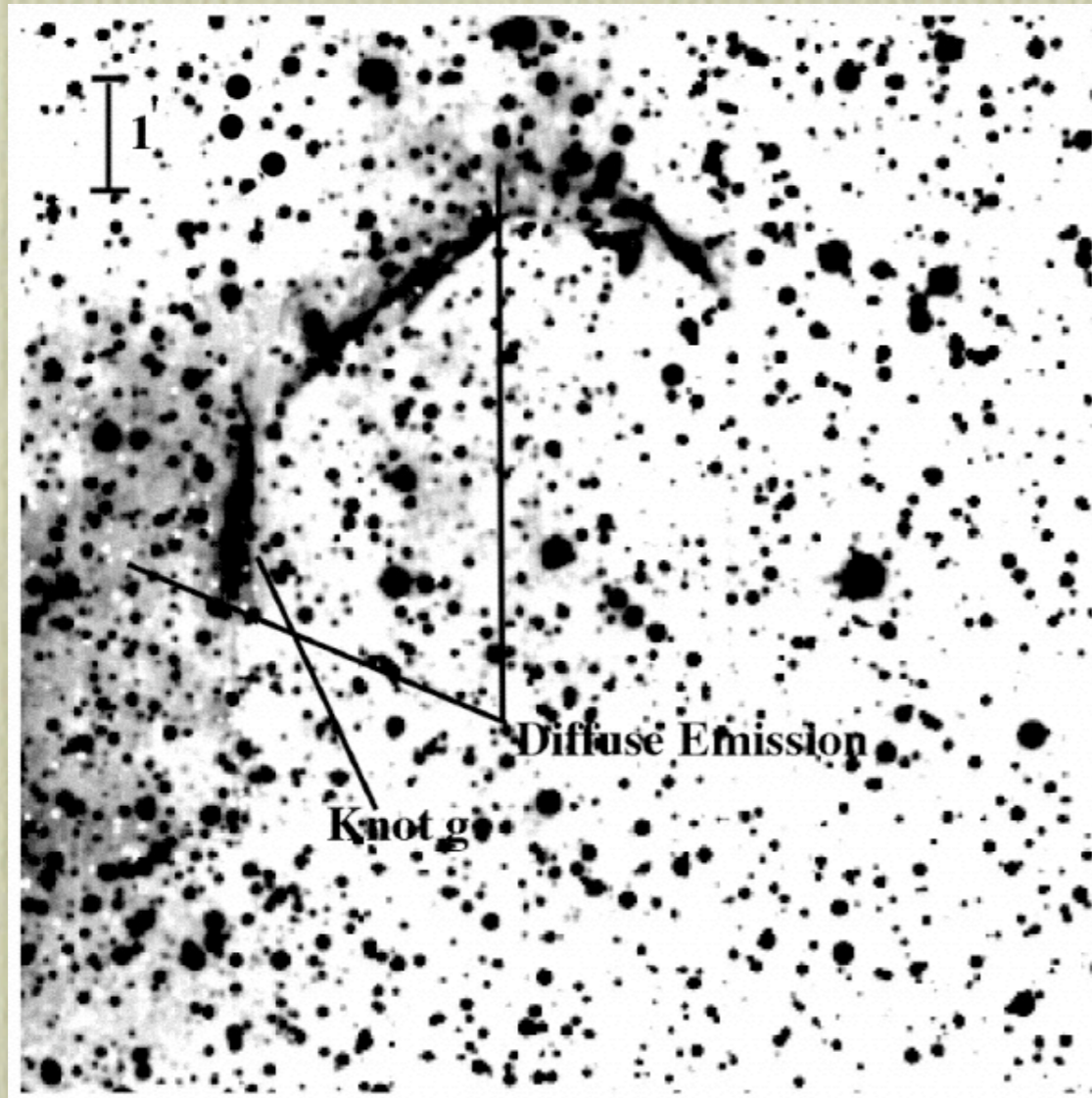
Tycho



Tycho in X-ray

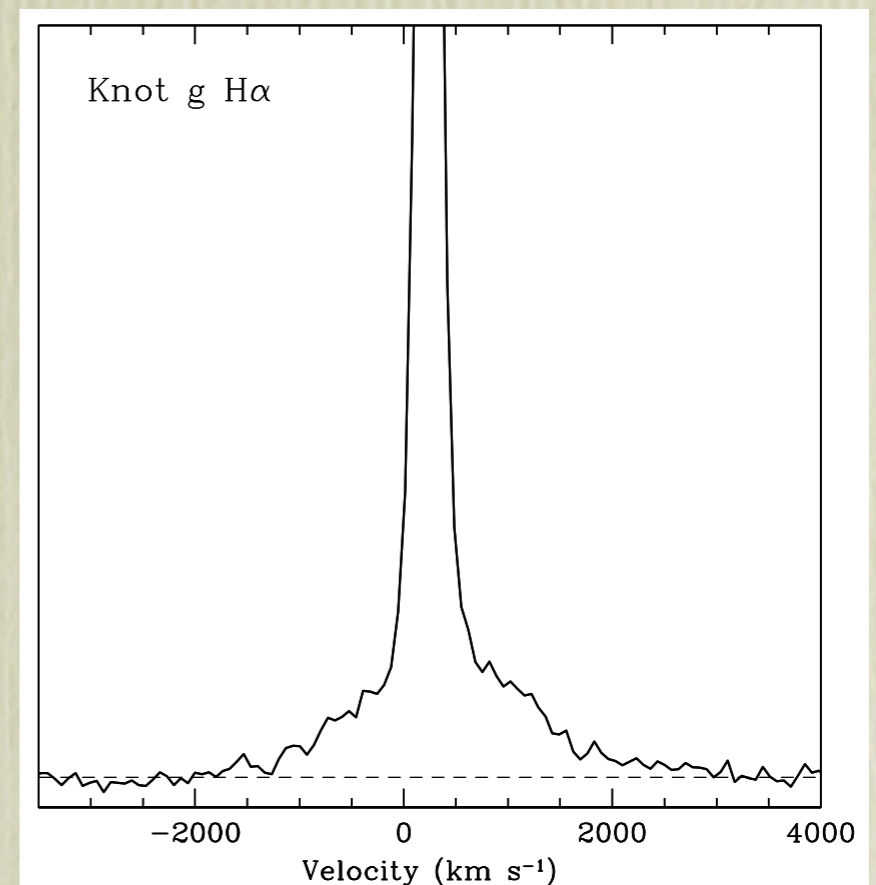
- A remnant of Type Ia supernova that occurred in the year 1572 (Baade, 1945)
- Distance ~ 2.3 kpc
- $V_s \sim 2,000$ km/s

H α profile

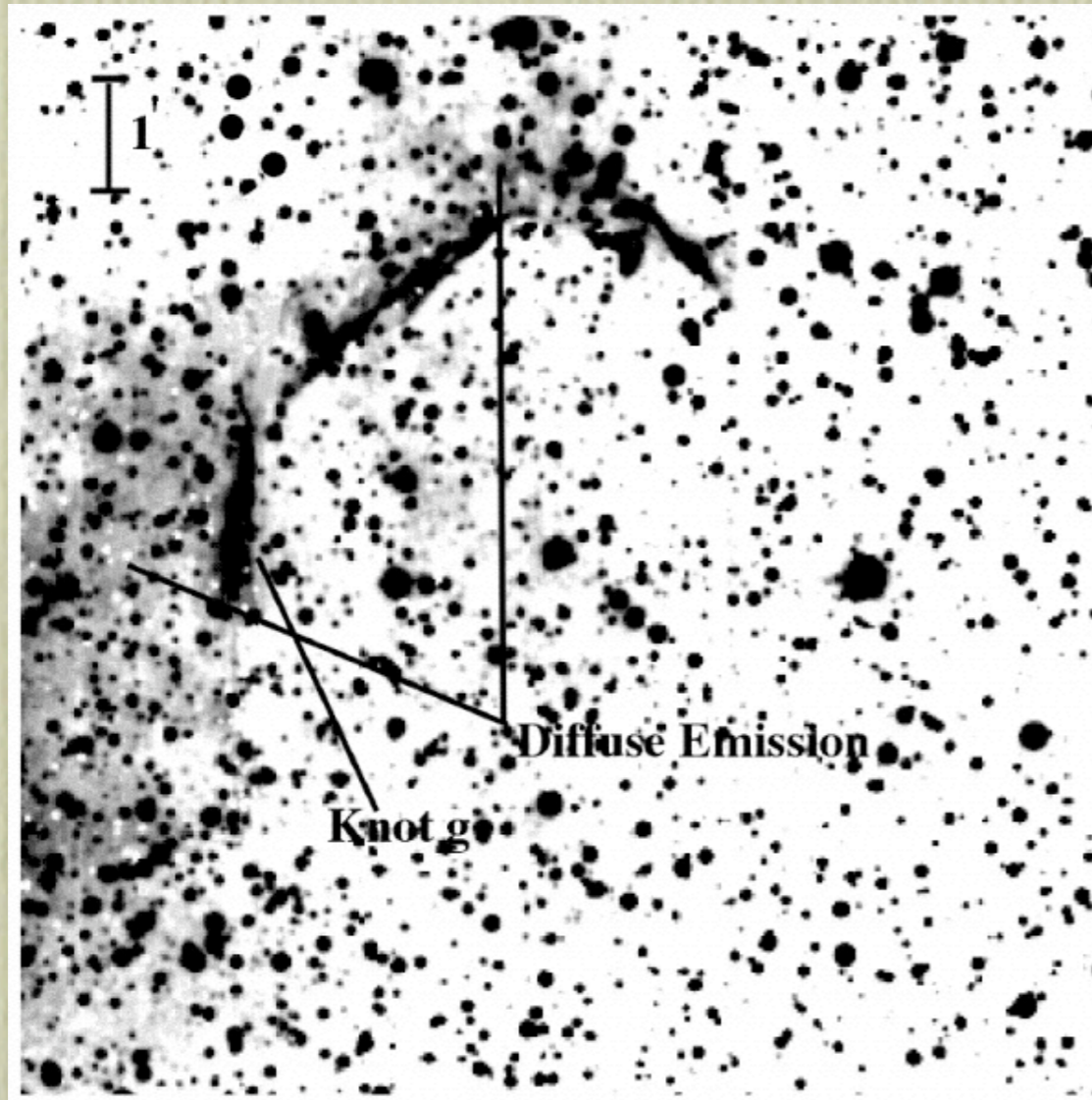


Tycho in H α
(Ghavamian et al, 2000)

- Narrow ~ 40 km/s
- Broad $\sim 2,000$ km/s



Photoionization Precursor



Tycho in Ha
(Ghavamian et al, 2000)

- Existence of Photo-Ionization Precursor (PIP, Ghavamian et al, 2000)
- Weak Ha emission (~ 1 pc)
- Ionized by HeII emission from postshock gas
- $T \sim 12,000$ K

PIP vs. Knot g

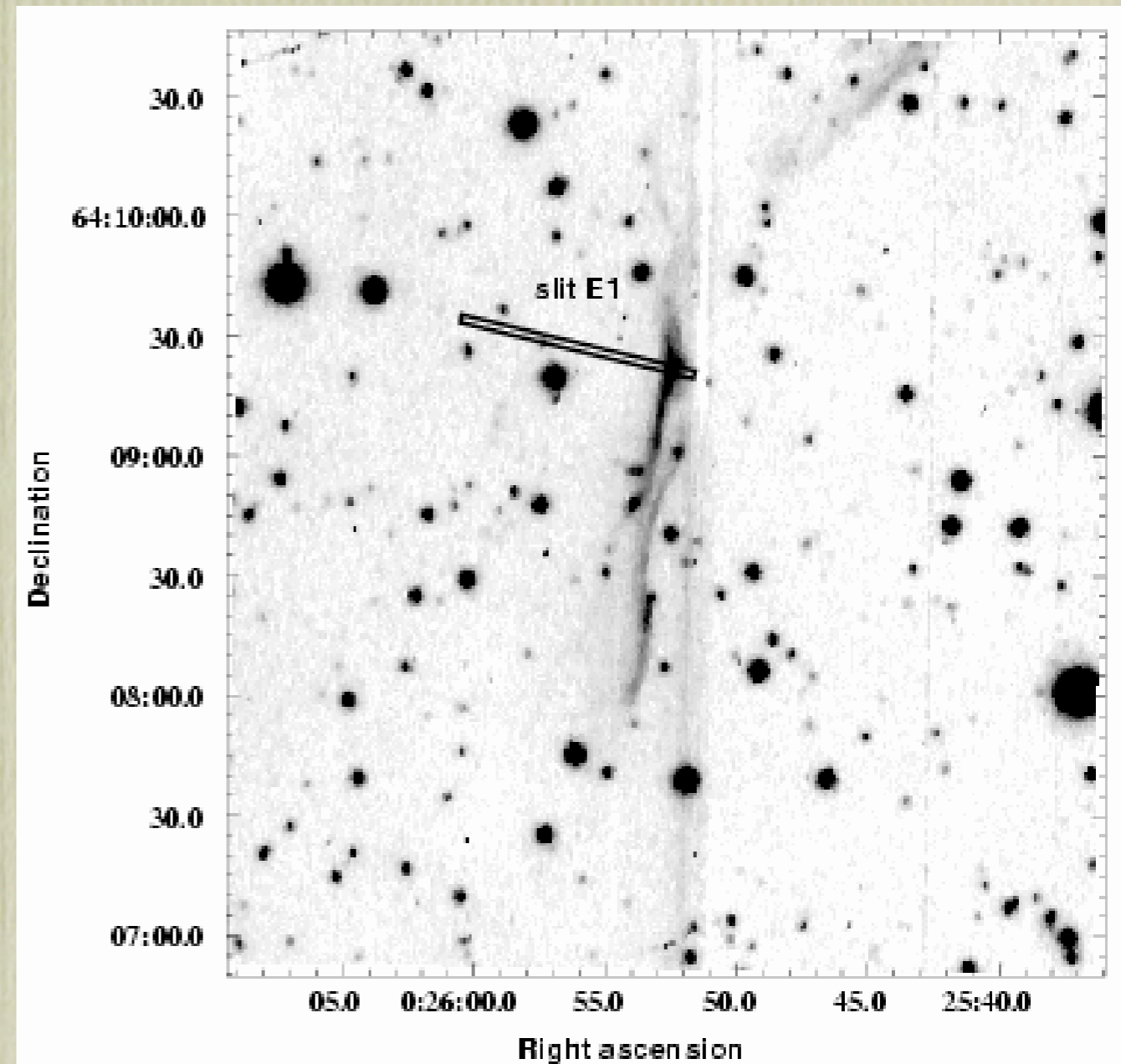
Unperturbed

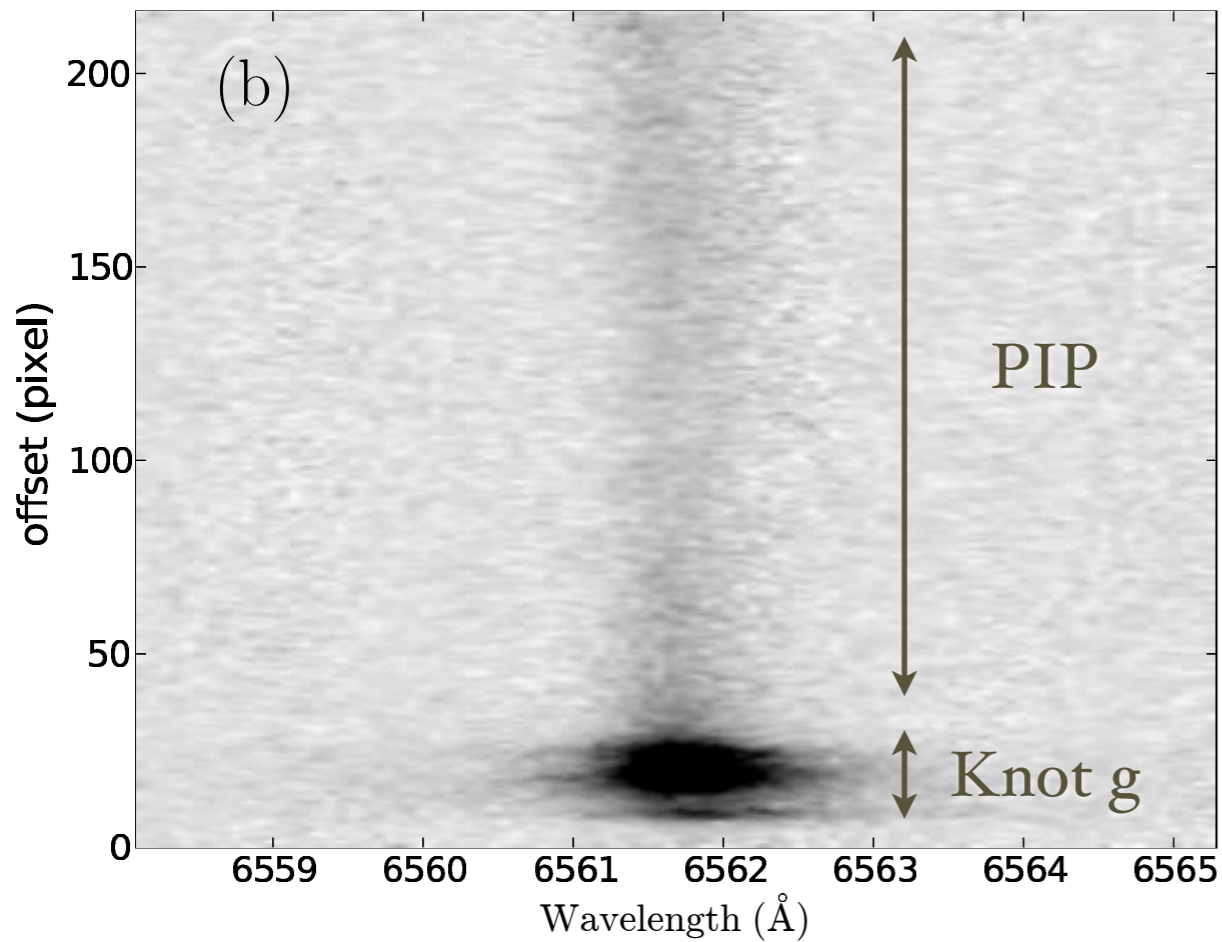
PIP vs. Knot g

Perturbed

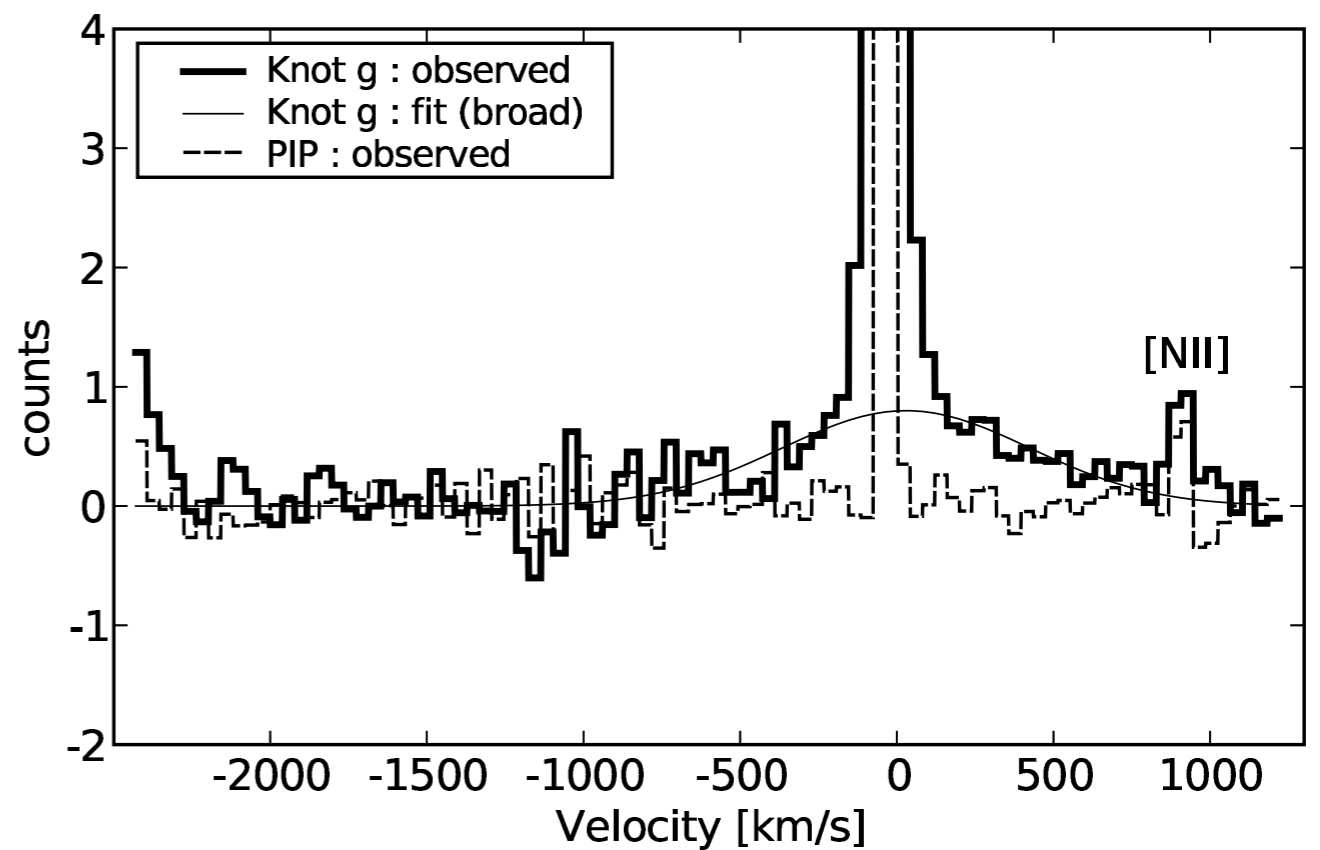
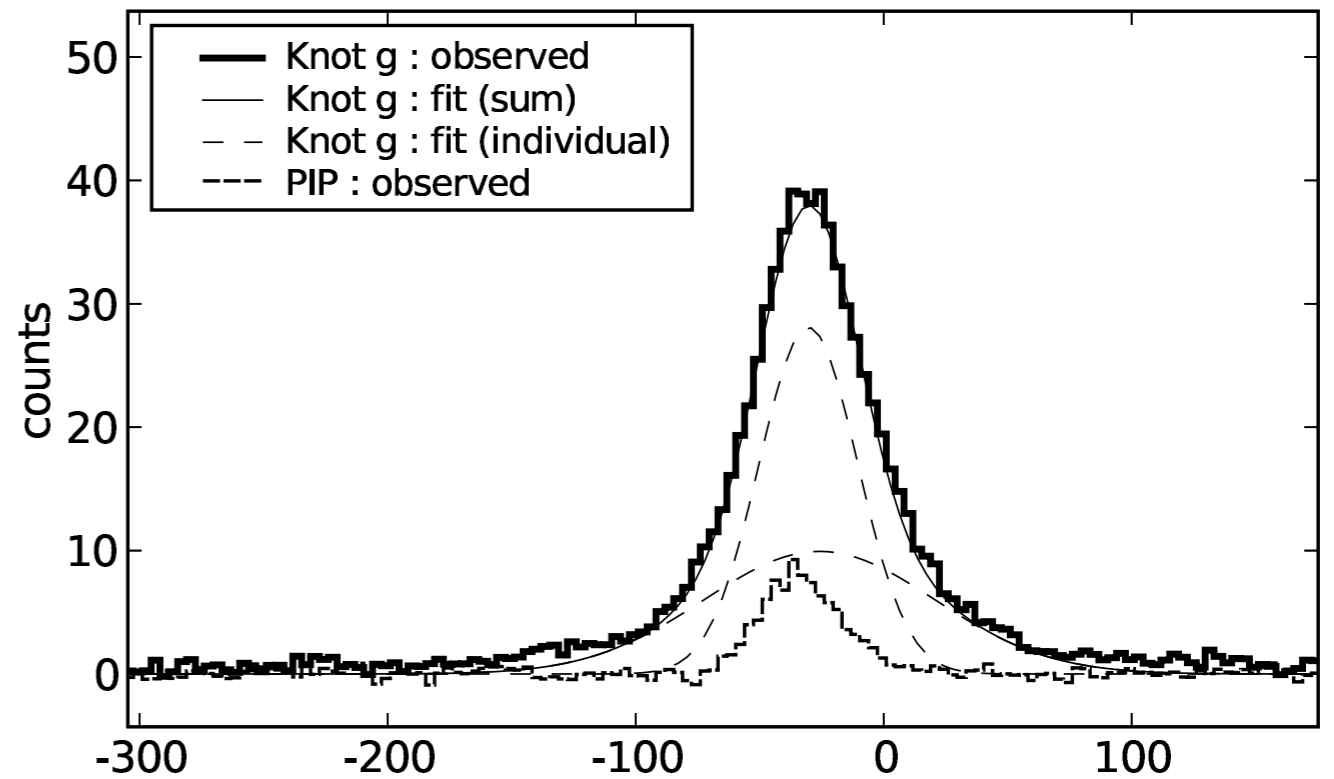
SUBARU H α Echelle Long slit

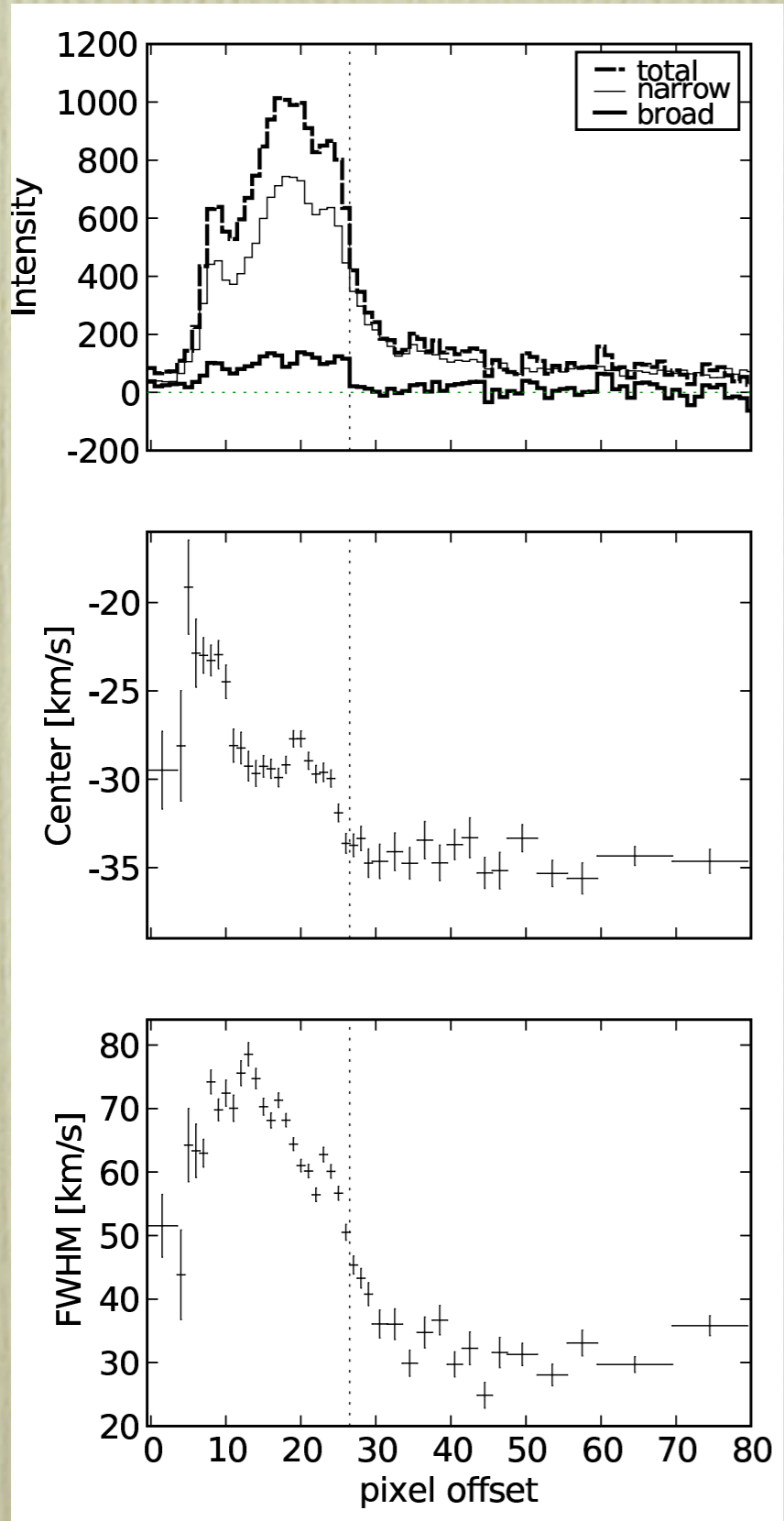
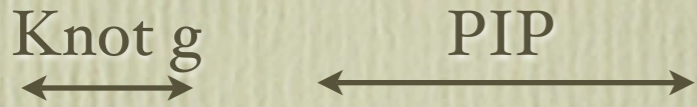
- SUBARU 8m telescope
- Echelle : $dV \sim 10$ km/s
- long slit : spatial variation of H α profile





Ha profile of Knot g shows
broadening & doppler shift
 relative to that of PIP

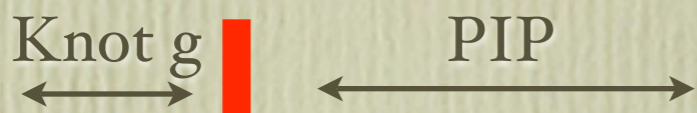




- Ha profile of Knot g shows both broadening and doppler shift relative to the PIP
- FWHM of the narrow component alone of Knot g is about 45-50 km/s.

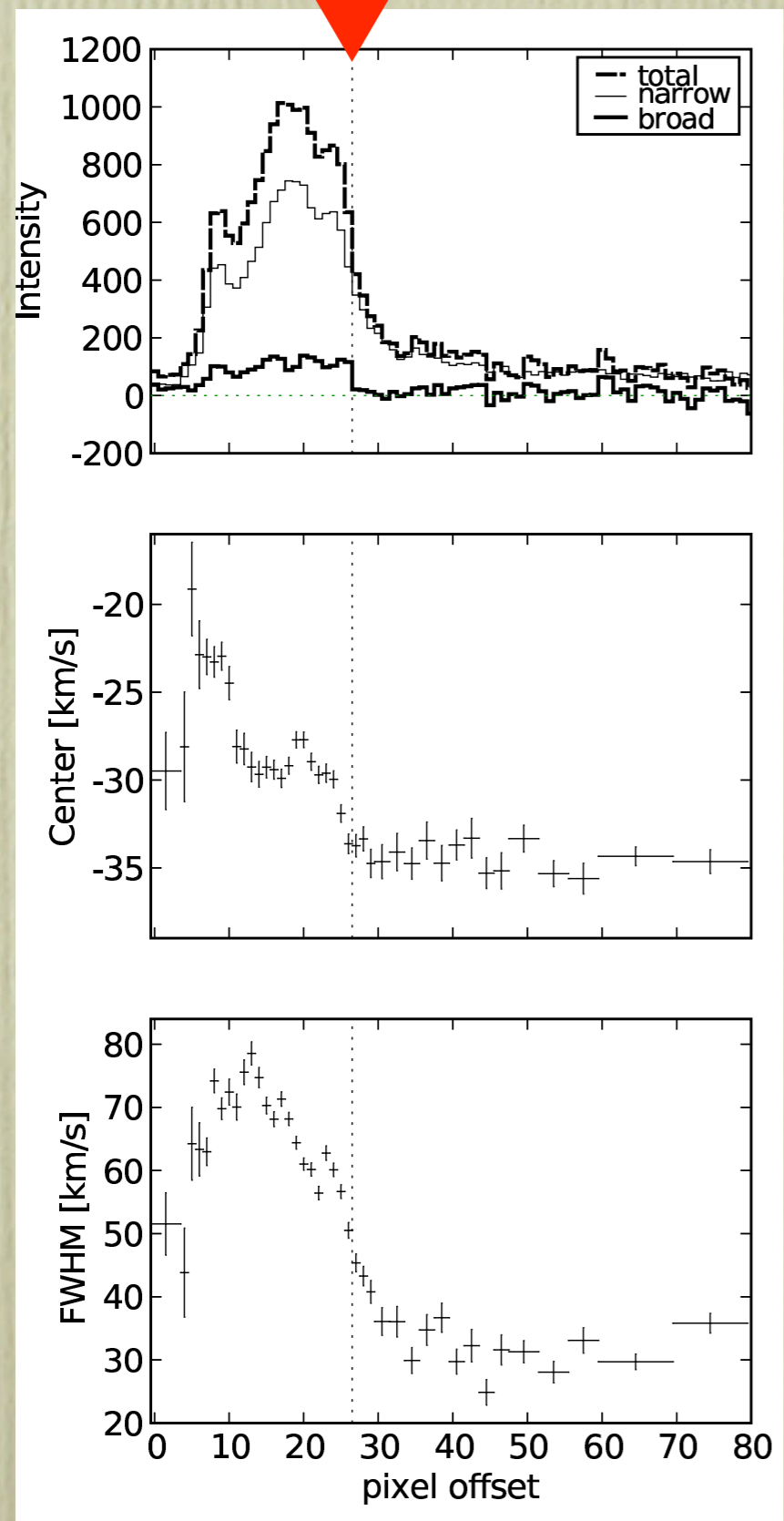
Single Gaussian fit along the slit

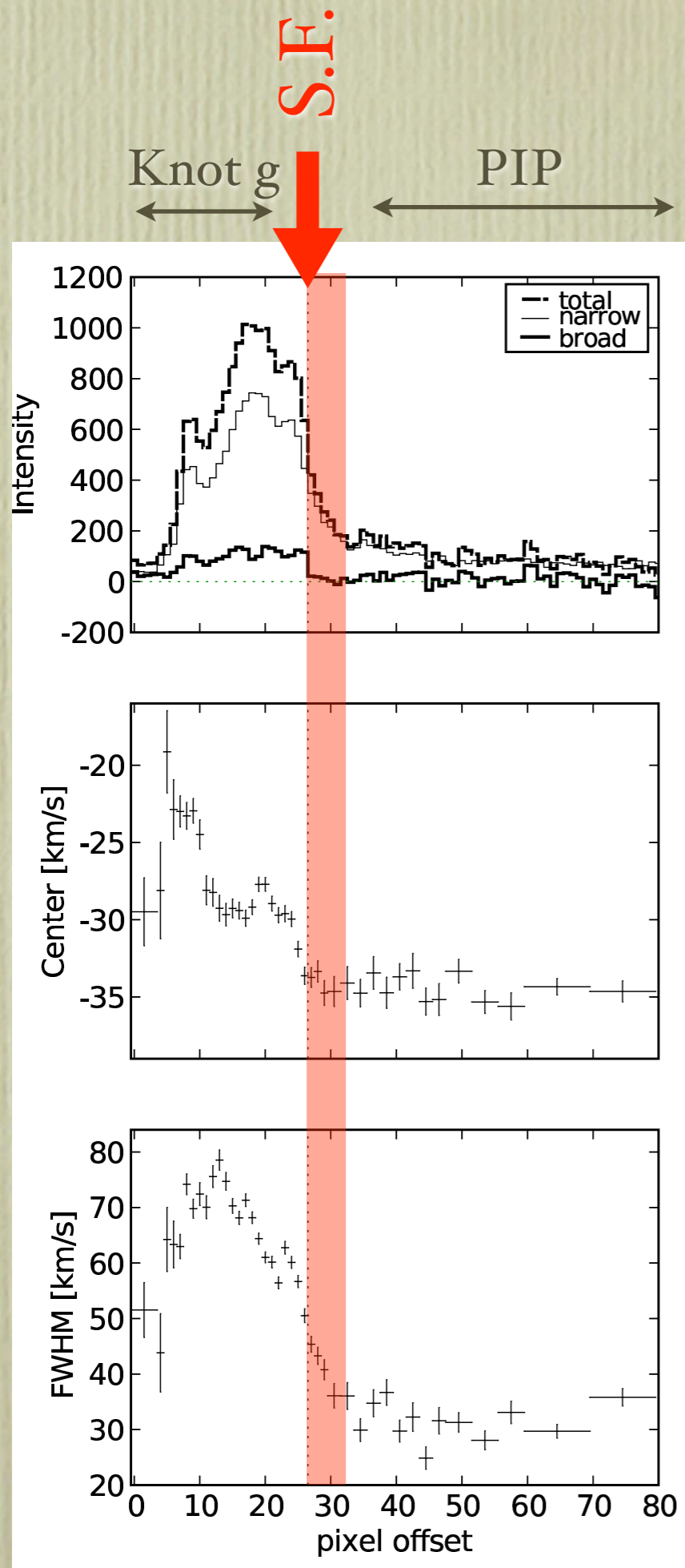
S.F.



● Location of Shock Front

● sudden increase of broad component





- Location of Shock Front
 - sudden increase of broad component
- Narrow precursor w/ gradual increase of intensity & FWHM

A CR precursor?

A possible CR Precursor

- Thickness $\sim 10^{16}$ cm
- Line width gradually increase from 30 km/s to 45 km/s.
- H α intensity increase of factor a few (emissivity increase \sim a few hundred)
- $\Delta V_r \sim 5$ km/s ($\Delta V \sim 60 - 130$ km/s)
- Significant fraction of the line broadening is non-thermal in origin (~ 20 uG)

- Thickness of the precursor is $\sim \kappa/V_s$, where κ is diffusion coefficient.

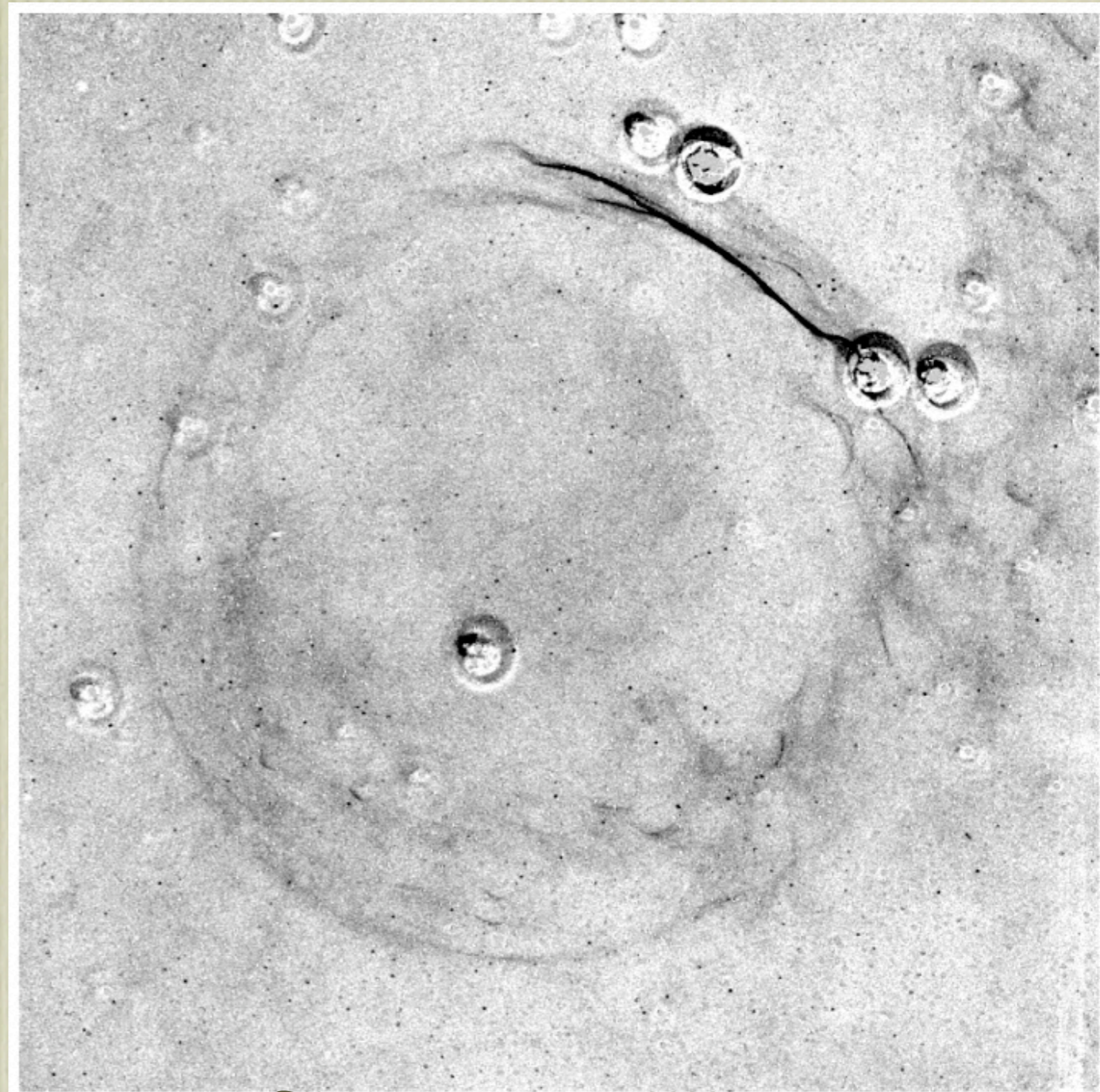
$$\Rightarrow \kappa \sim 2 \times 10^{25} \text{ cm}^2 \text{ s}^{-1}$$

- This should be regarded a lower limit as we may have underestimated the precursor thickness
- small $\Delta V \sim 100 \text{ km/s}$ (cf. $V_s \sim 2,000 \text{ km/s}$) \Rightarrow CR pressure does not dominate the gas pressure.

It seems that the **Balmer-dominated filaments** is only seen where the **CR acceleration** is not efficient enough.



SN1006 in X-ray



SN1006 in Ha

Summary

- Diagnostics of Balmer-dominated shock serve as a useful tool for CR precursor study.
- Narrow ($\sim 10^{16}$ cm) precursor with gas heating and acceleration is observed in Tycho, which is likely to be a CR precursor.
- Dissipation of MHD turbulence in the precursor seems to be inefficient
- A CR pressure may not dominate Gas pressure in the Balmer-dominated filaments.

Thank you.

Instead of a precursor,
can it be due to a **geometrical projection?**

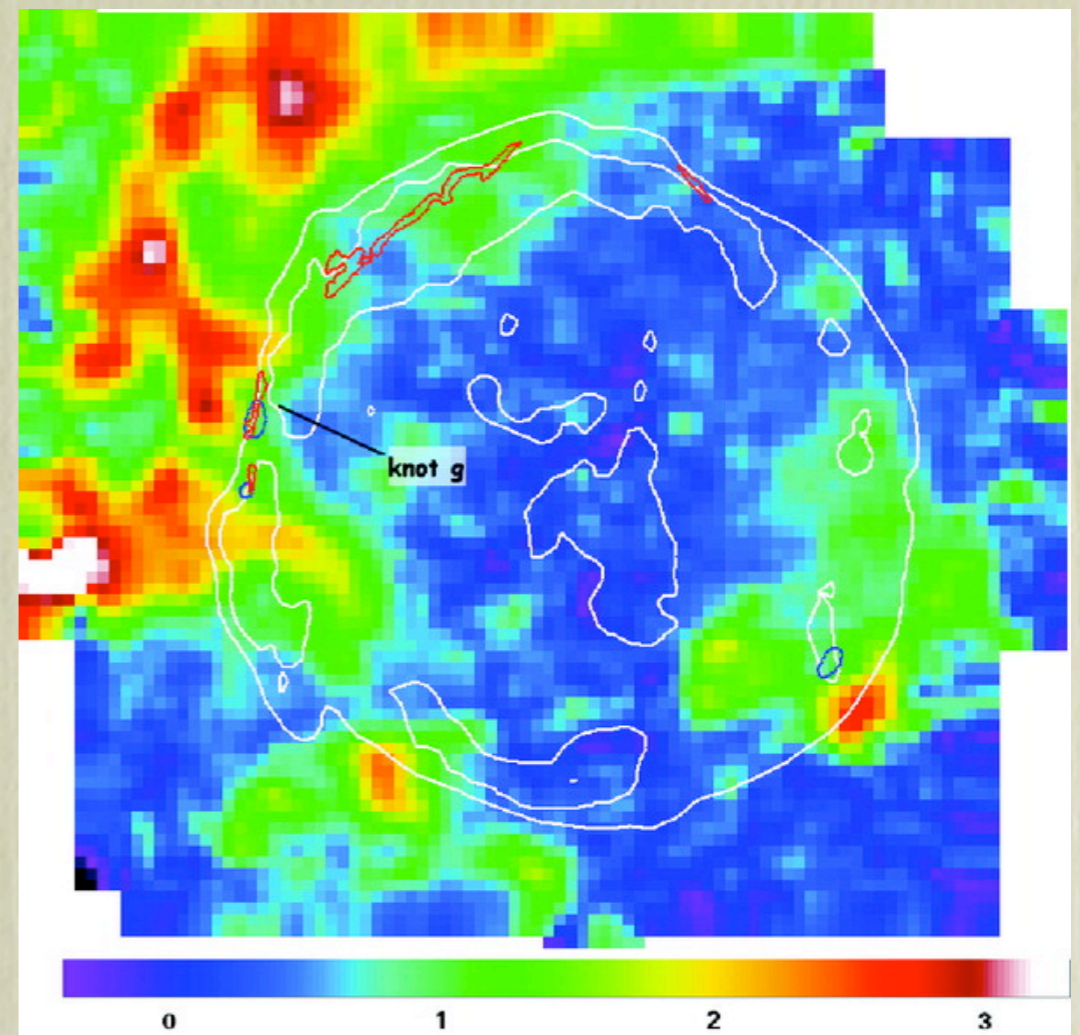
No

Can it be **other kind of precursor**
instead of CR precursor?

It seems **NOT**,
but no hard evidence against this.

Gas Acceleration in Precursor

- Possible interaction with Molecular Cloud (Lee et al, 2004)
- Non-negligible velocity difference (~ 10 km/s) between MC & Ha narrow component.
- Lee et al (2004) attributed this to a gas acceleration in the precursor.



Tycho in $^{12}\text{CO}(1-0)$
(Lee et al, 2004)