Hα Emission from the CR Precursor of the Supernova Shock

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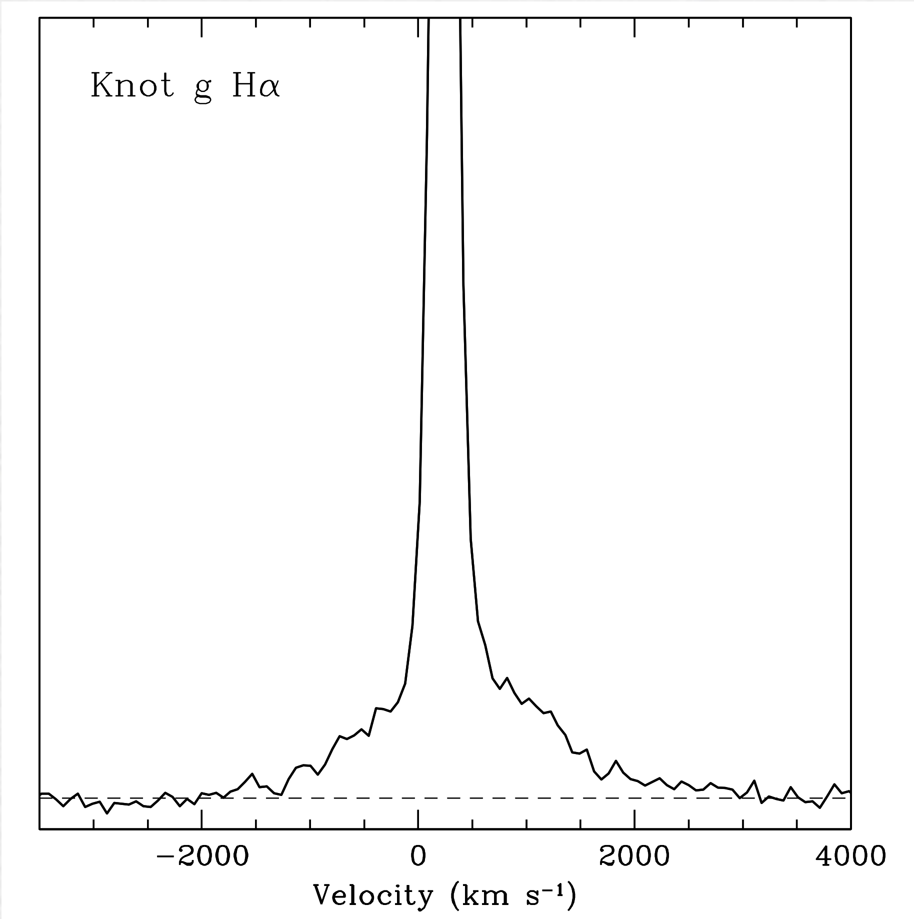
Hα emission from fast Non-Radiative shocks

- Velocity distribution of the postshock gas
- Velocity distribution of the preshock gas
- Structure of the Shock (precursor)

- Diffusive shock acceleration requires a precursor. (e.g., Blandford and Eichler, 1987)
- Observation of the precursor can constrain the key parameters of CR accelerations, e.g., diffusion coefficient.

Balmer-Dominated Filaments

- Non-radiative shock into a partially neutral medium.
- Preshock neutral hydrogens pass through the shock front and collisionally exited by postshock e^- & p^+
- Neutral hydrogens will also be collisionally exited in the precursor
  - ⋆ Ha emission in the precursor represents neutral hydrogens excited by electrons.



Ha profile of Tycho (Ghavamian, 2001)

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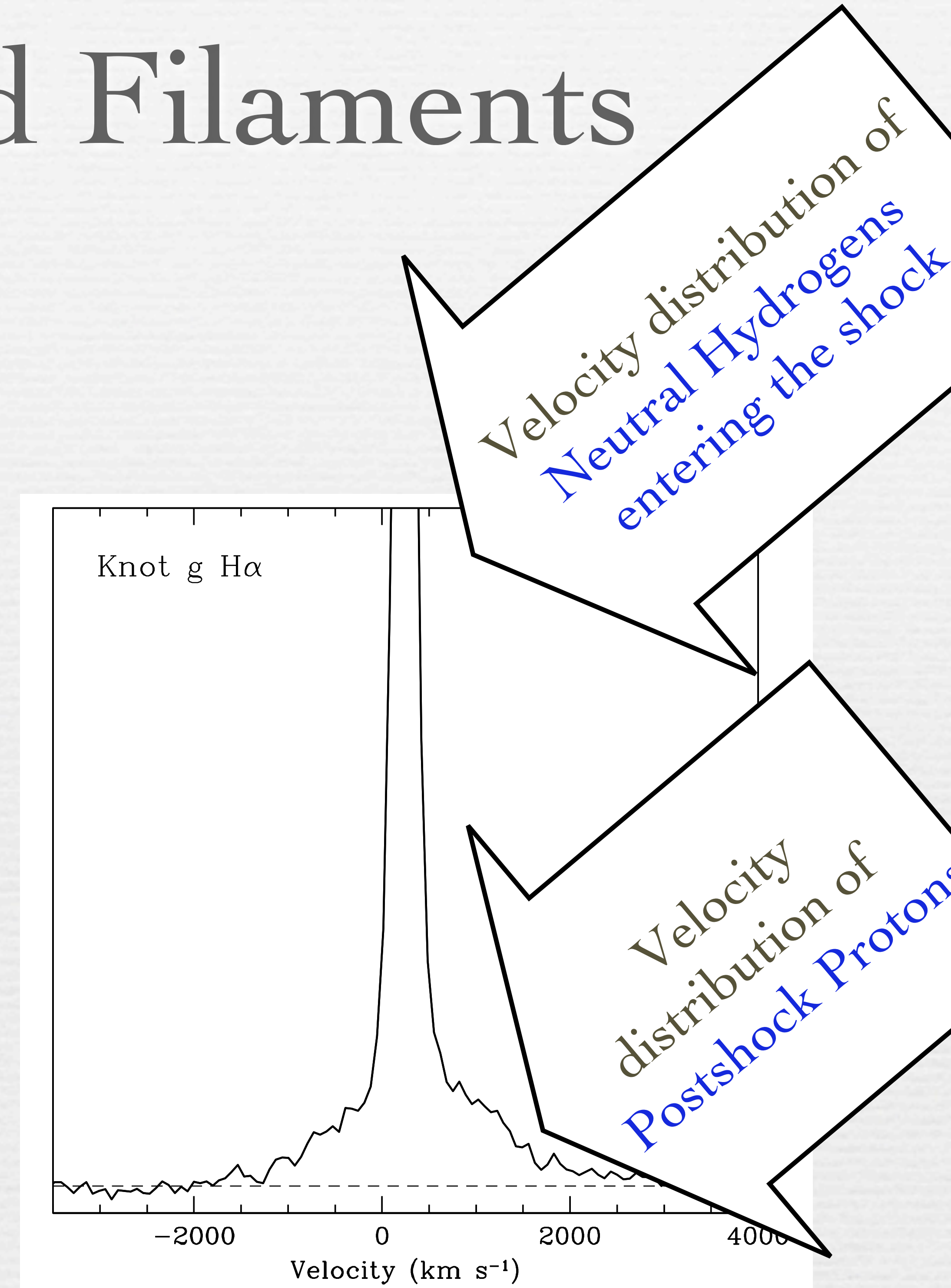

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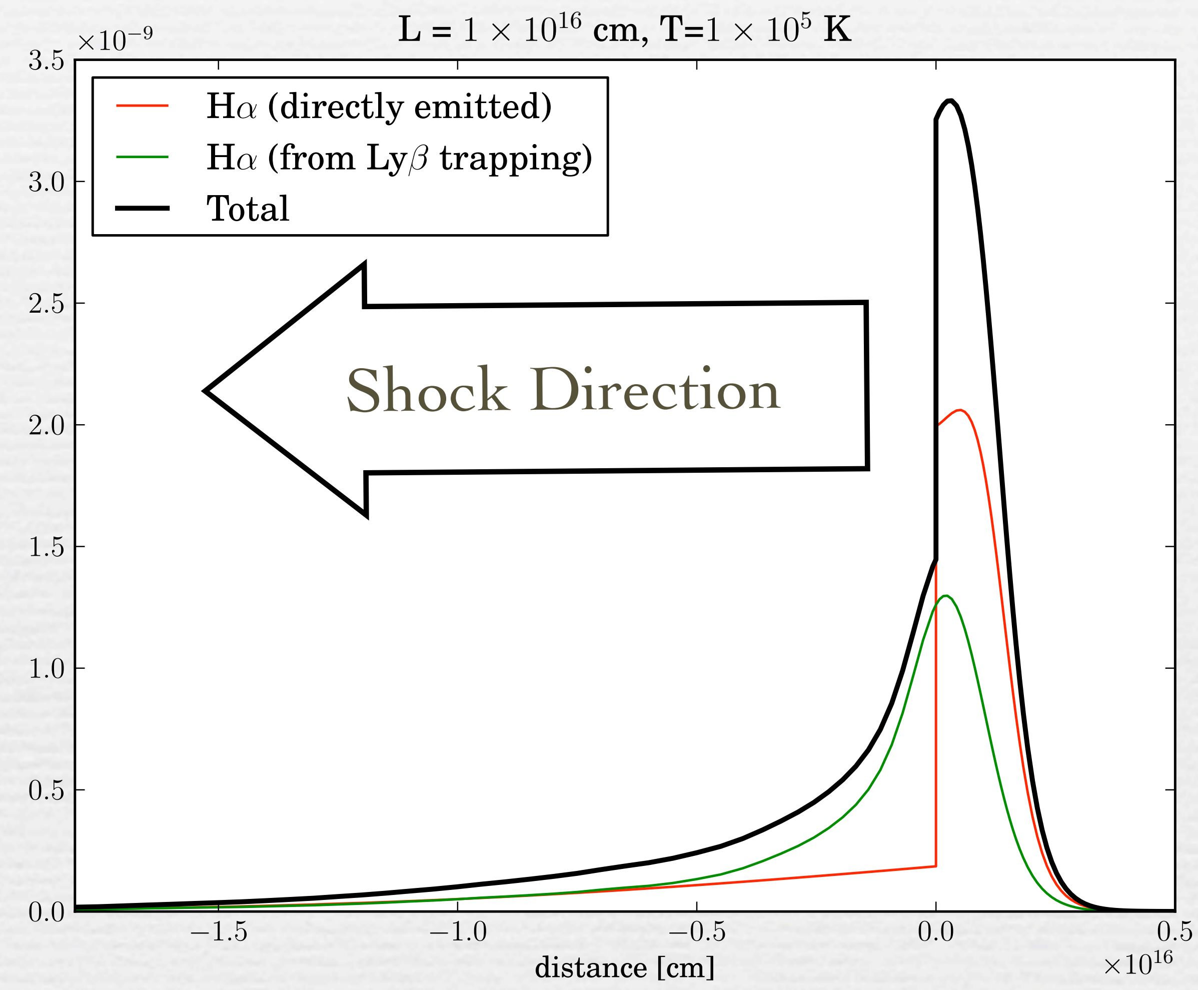
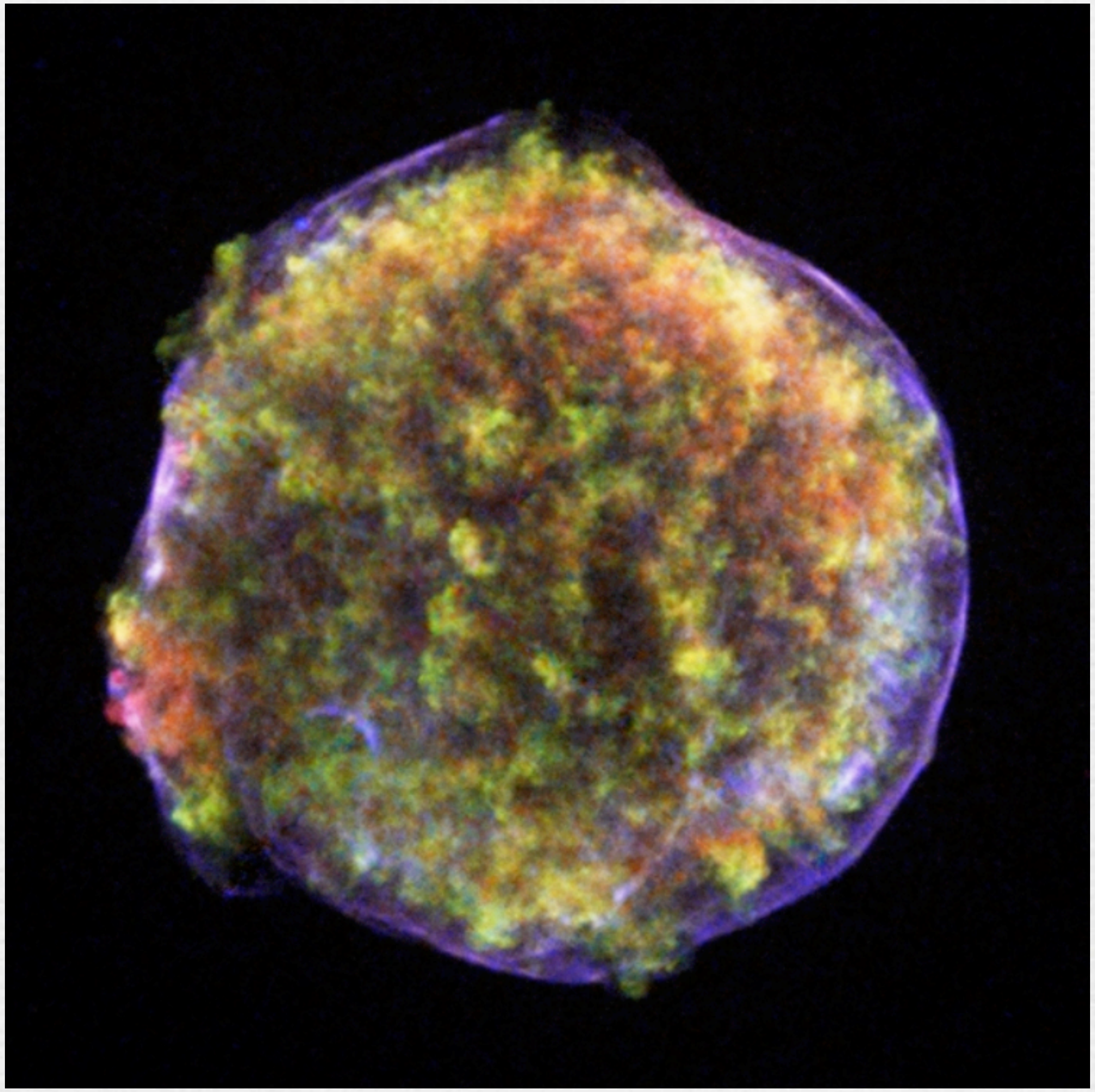


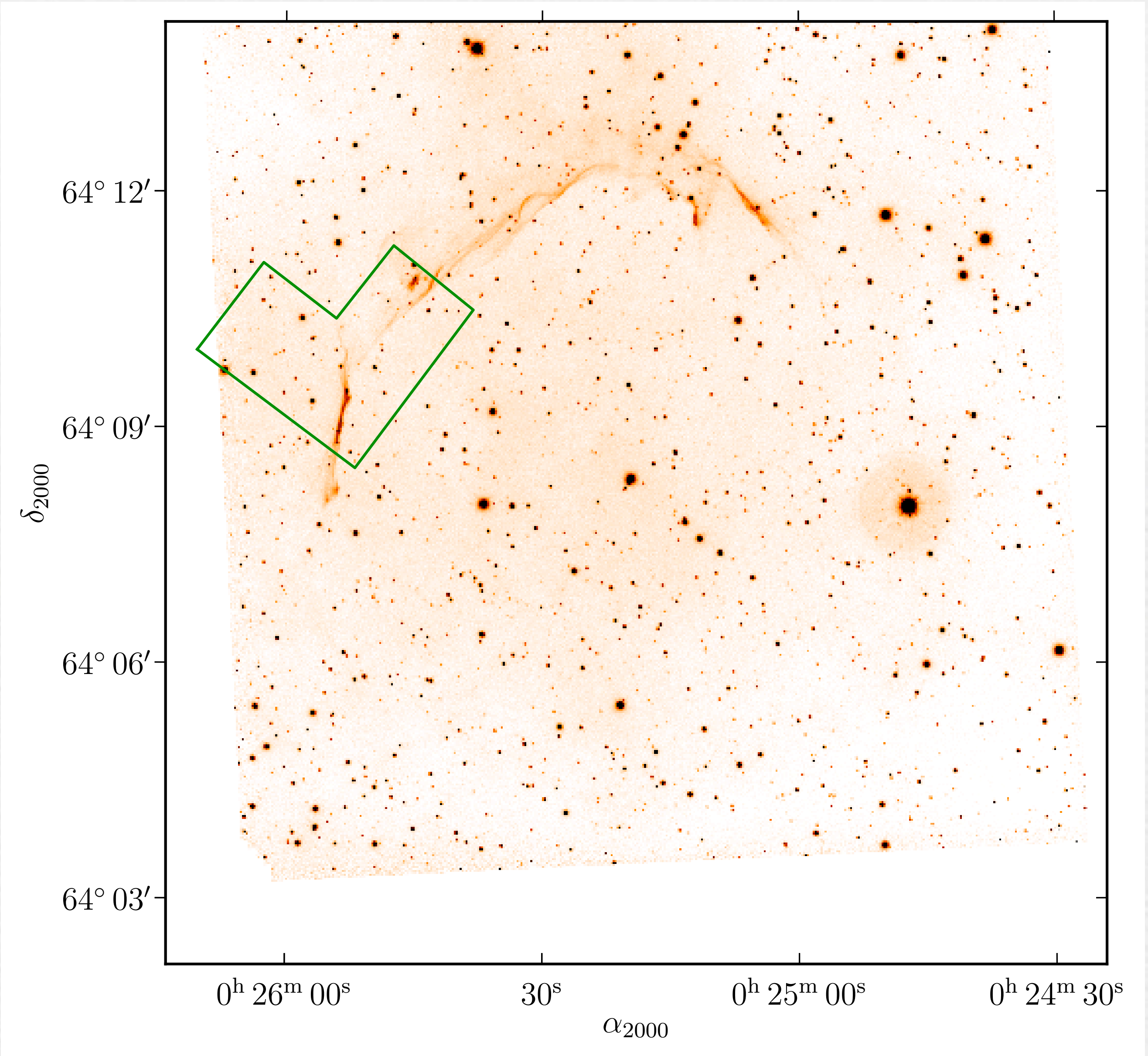
A model Ha emission from Balmer-dominated shock with CR precursor (Lee et al., in prep.)

Tycho



Tycho in X-ray (Chandra)

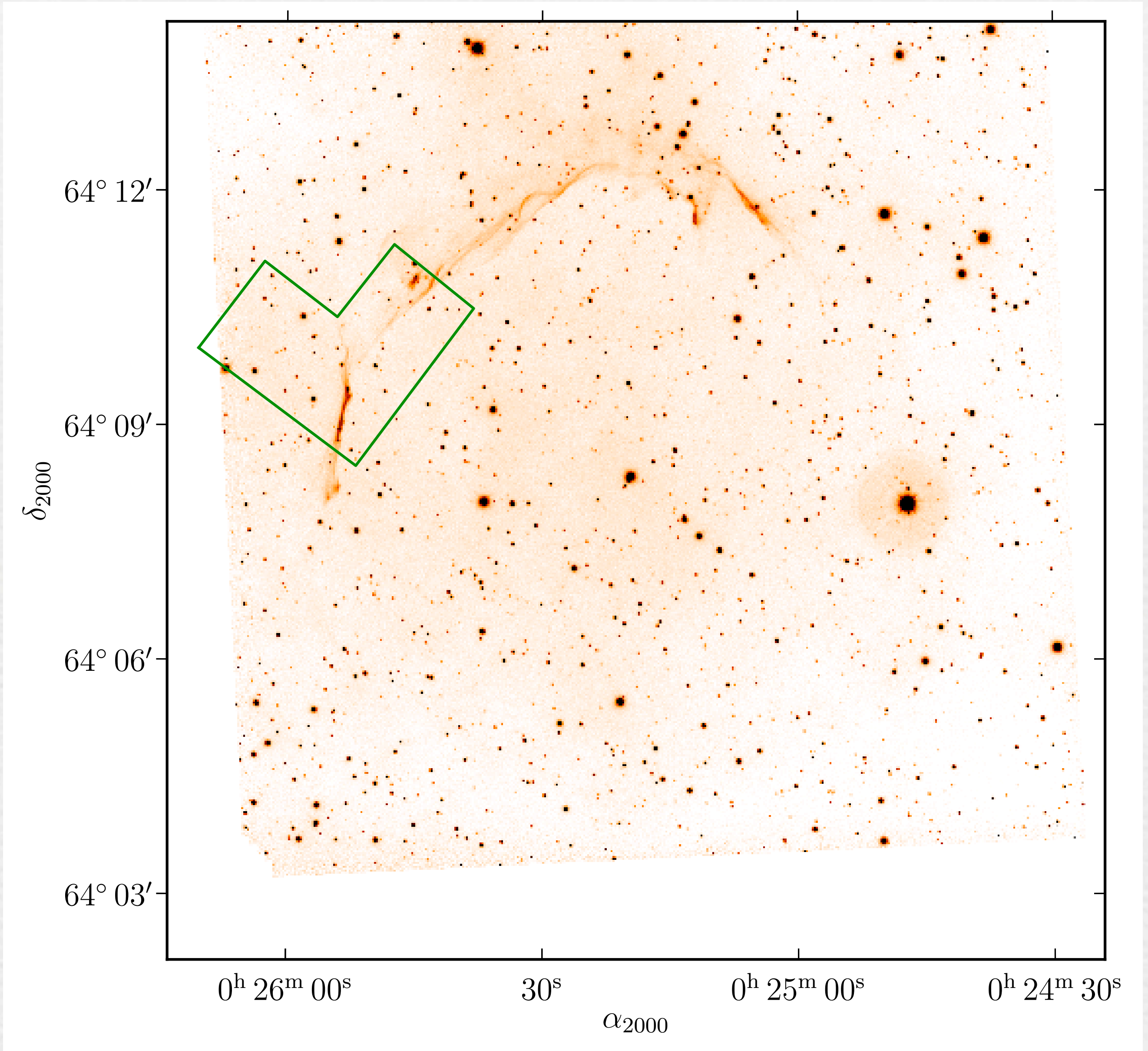
Credit: NASA/CXC/Rutgers/J.Warren & J.Hughes et al.



Tycho in Hα (KPNO)

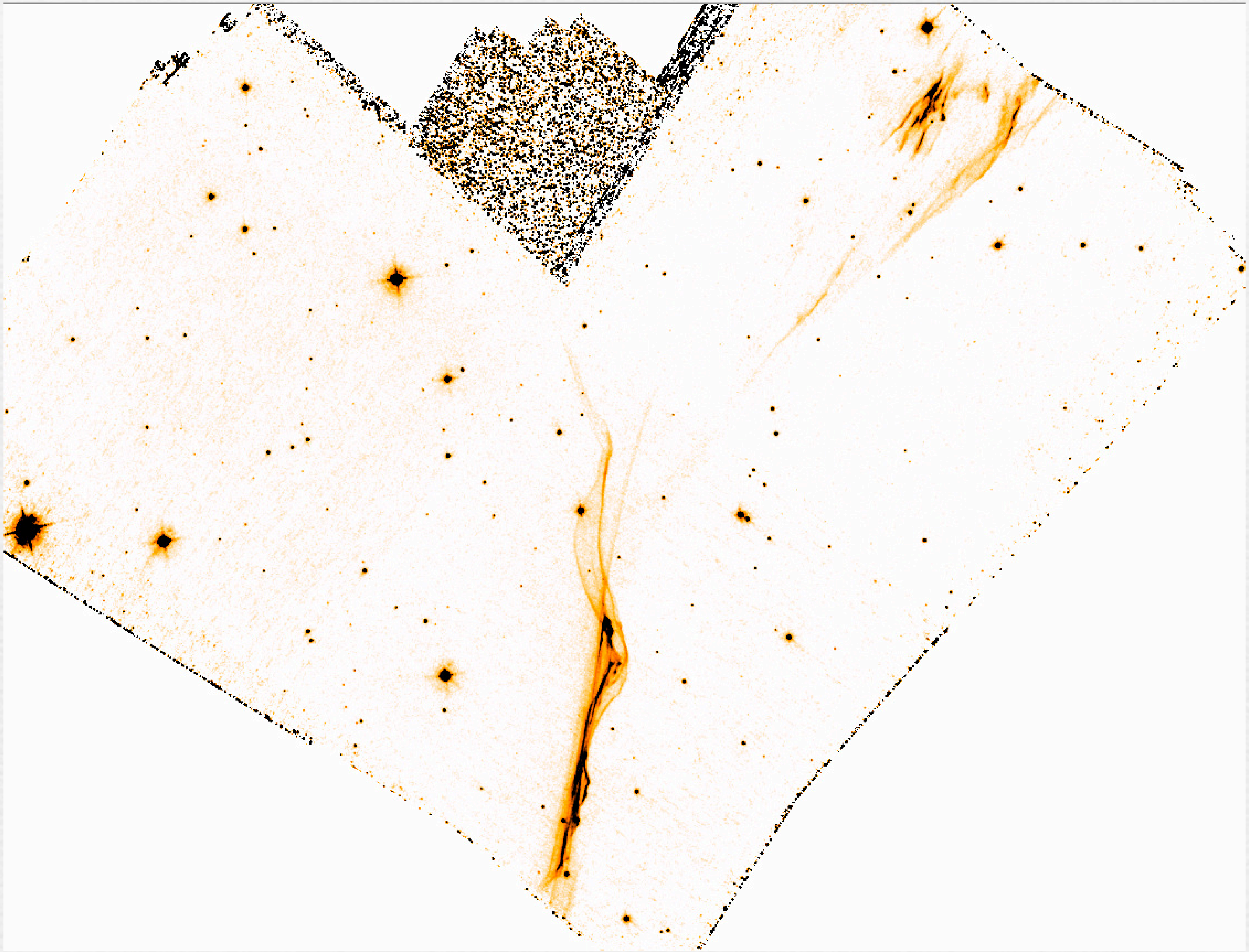
Tycho

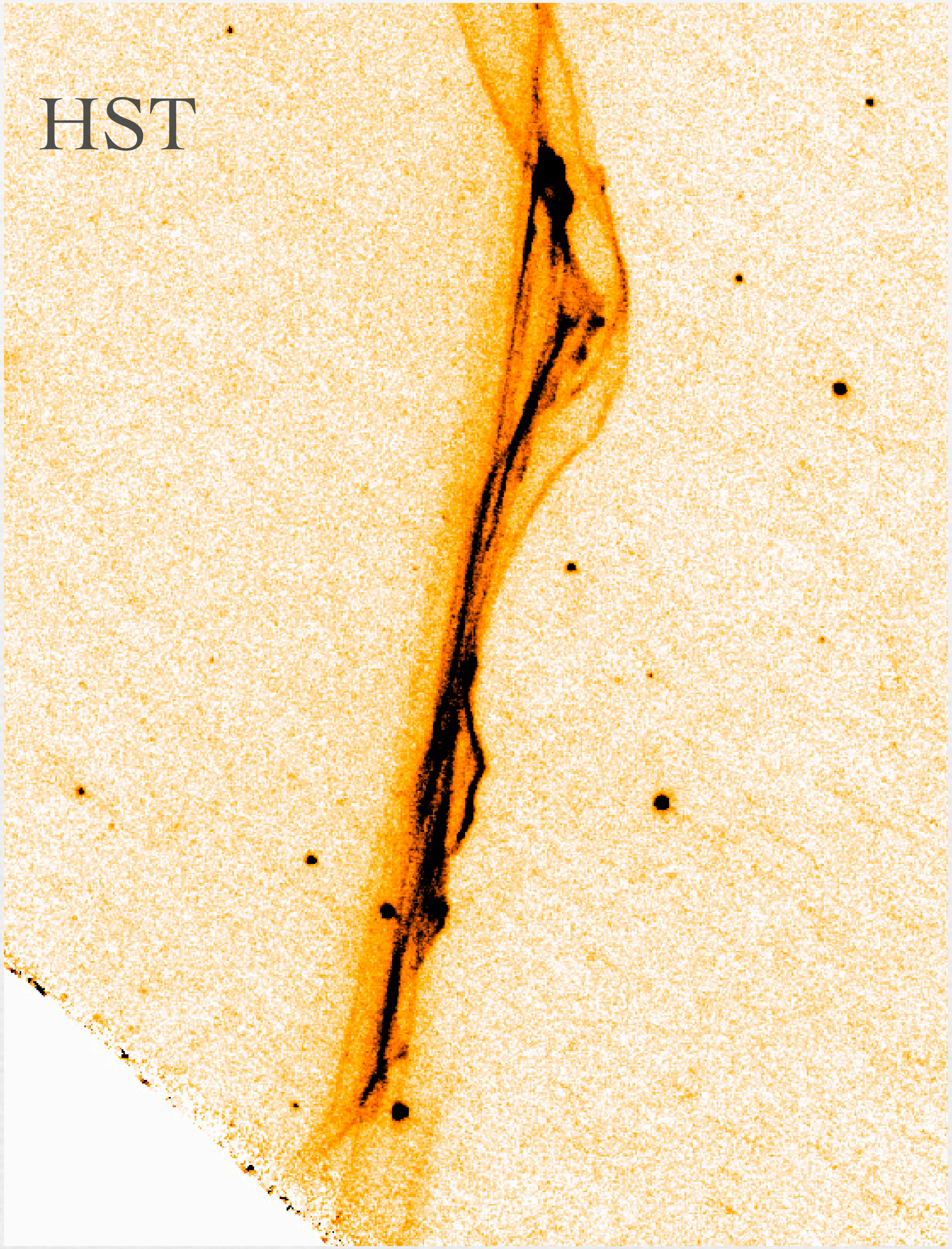
- Tycho : preshock gas has enough of neutral hydrogens (n_H~1 cm^{-3}, f_{HI} ~ 80%) for the precursor to be visible.
- HST Observation of knot g, one of the brightest knots (Lee et al., in prep.)
  - March, 2008 : WFPC2

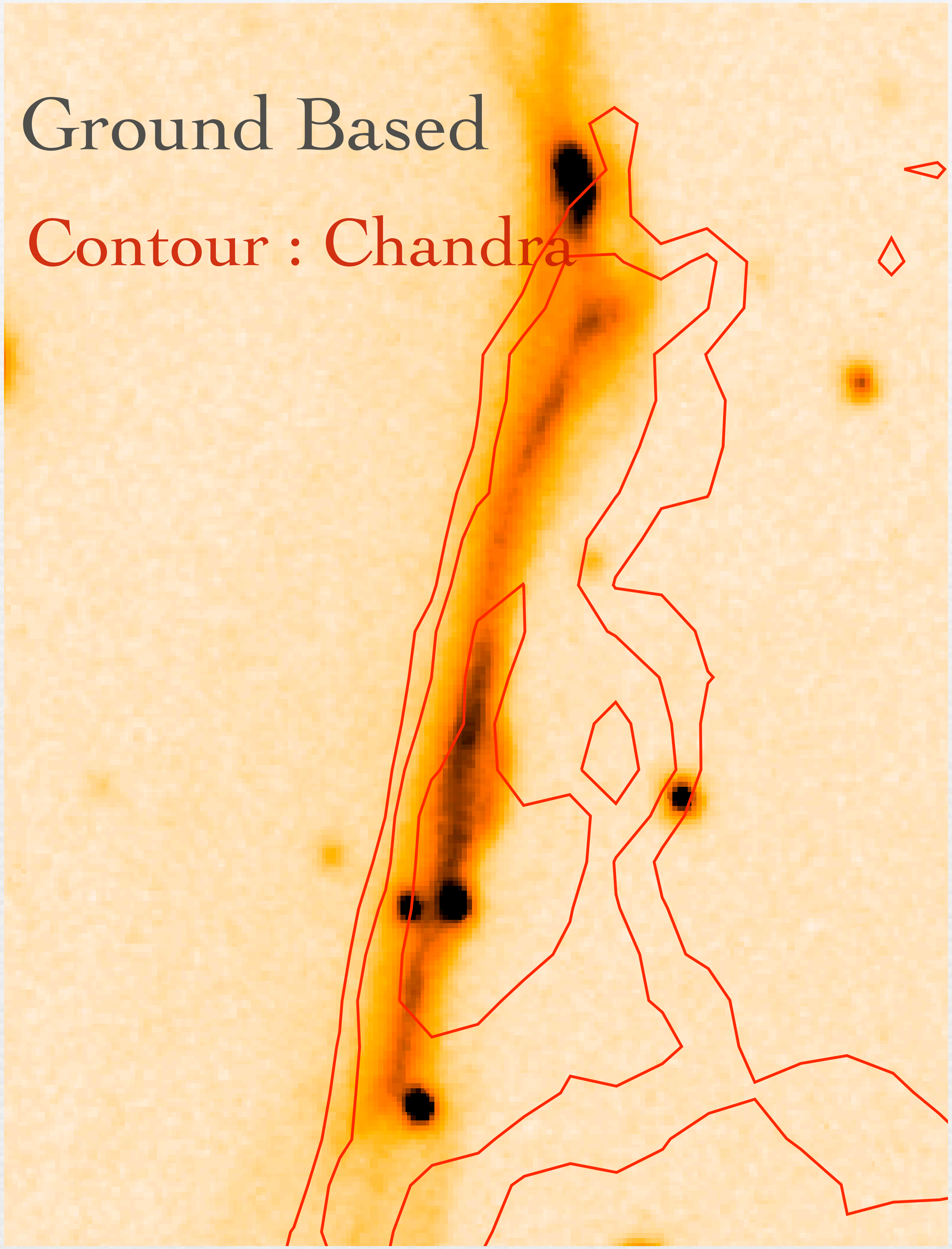


Tycho in Hα (KPNO)

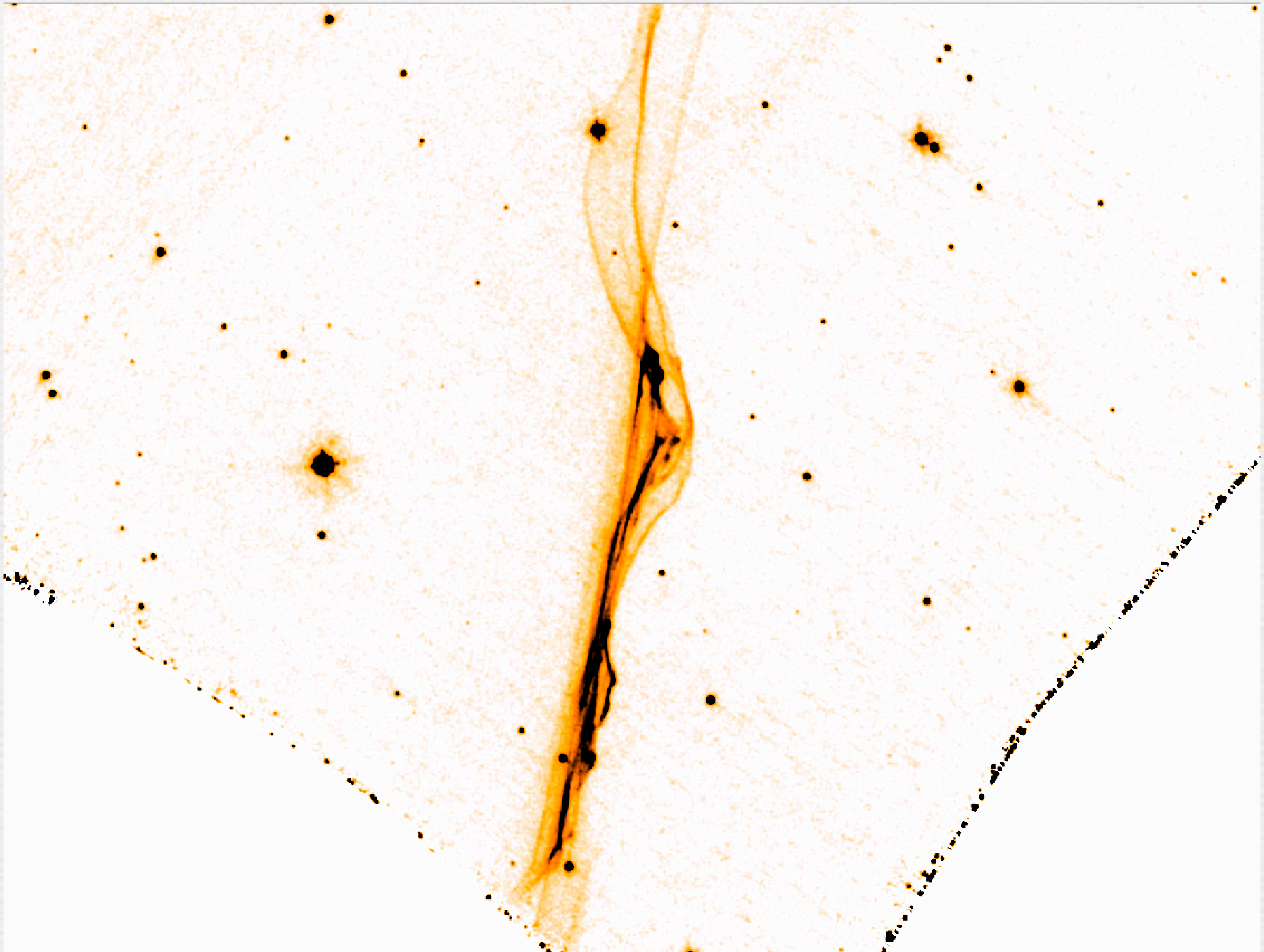
HST Image of knot g




HST


Ground Based
Contour : Chandra

HST Image of knot g



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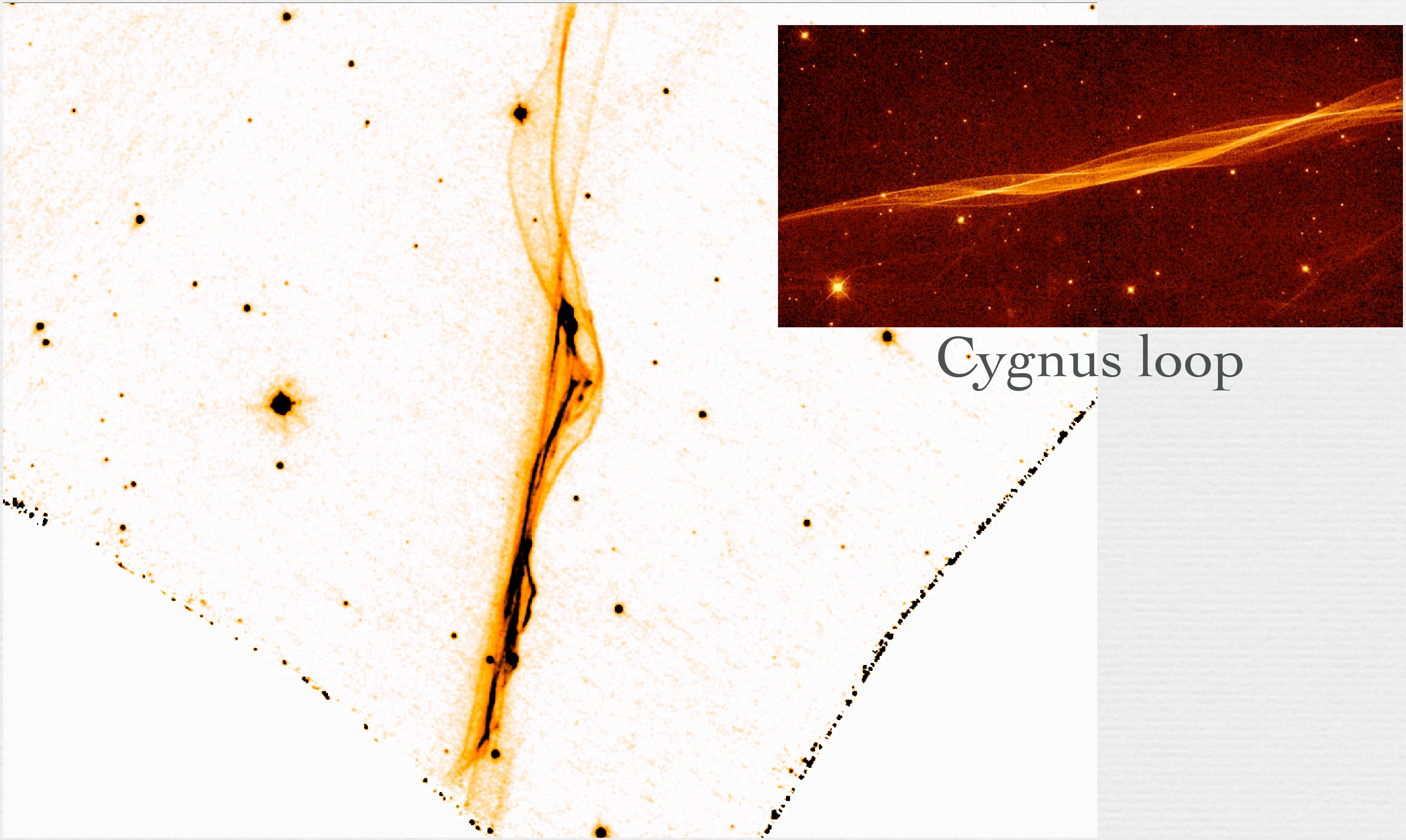
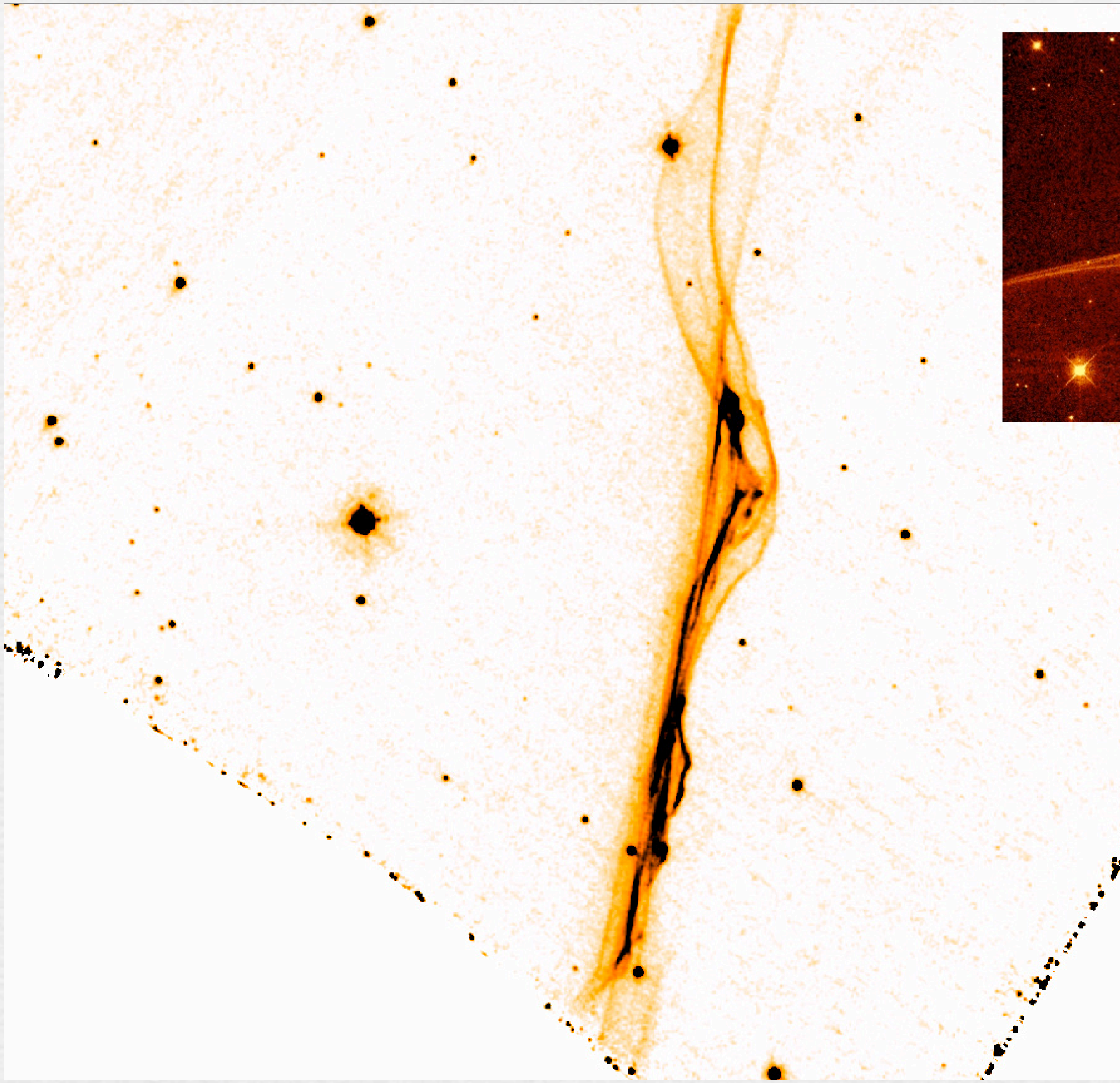
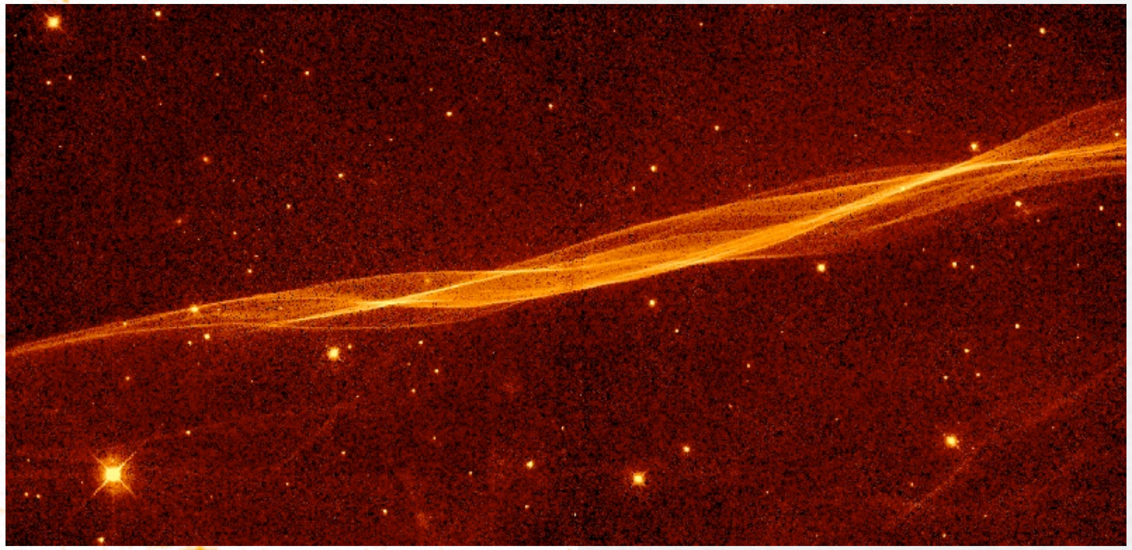


Cygnus loop

HST Image of knot g

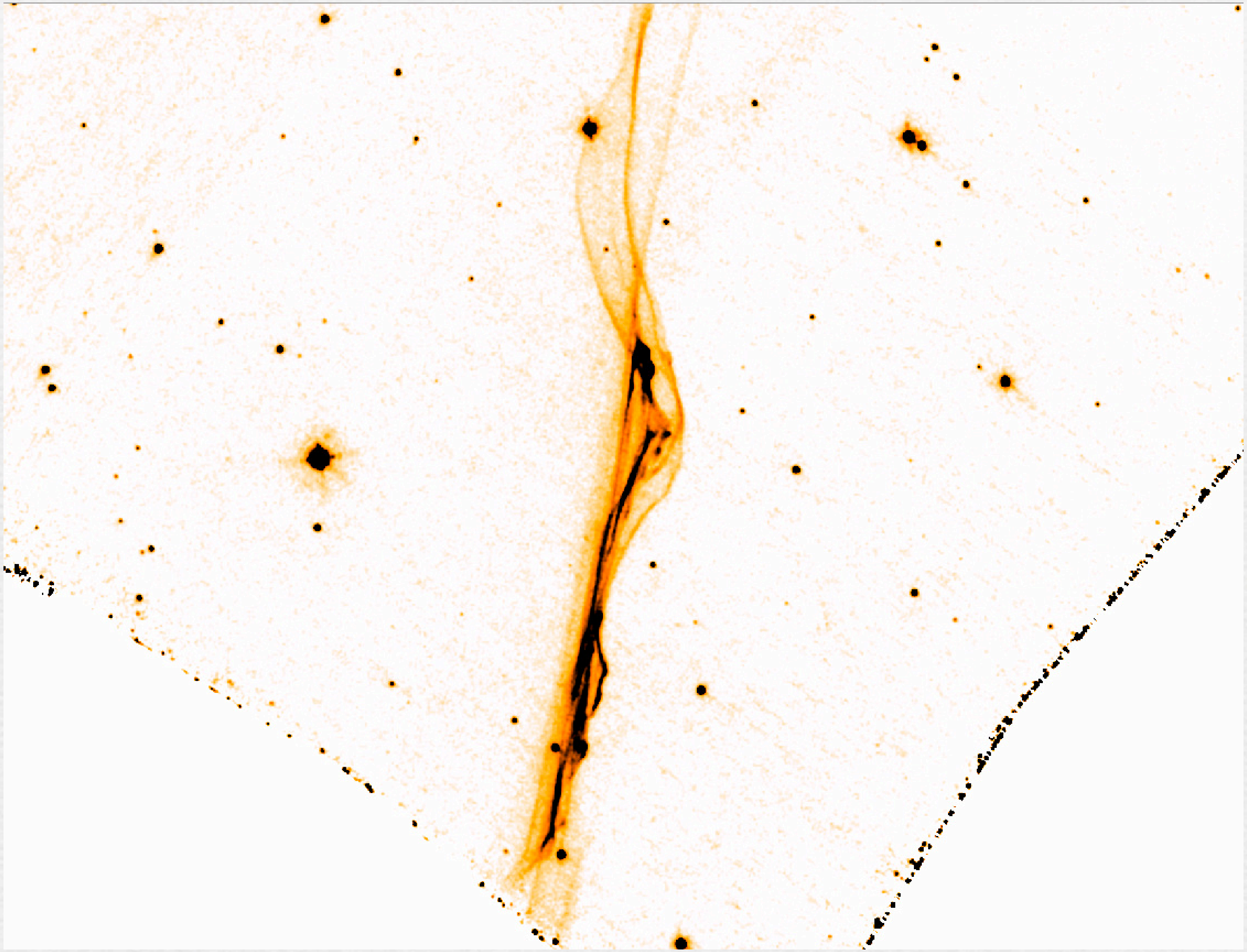




Cygnus loop

SN1006

HST Image of knot g



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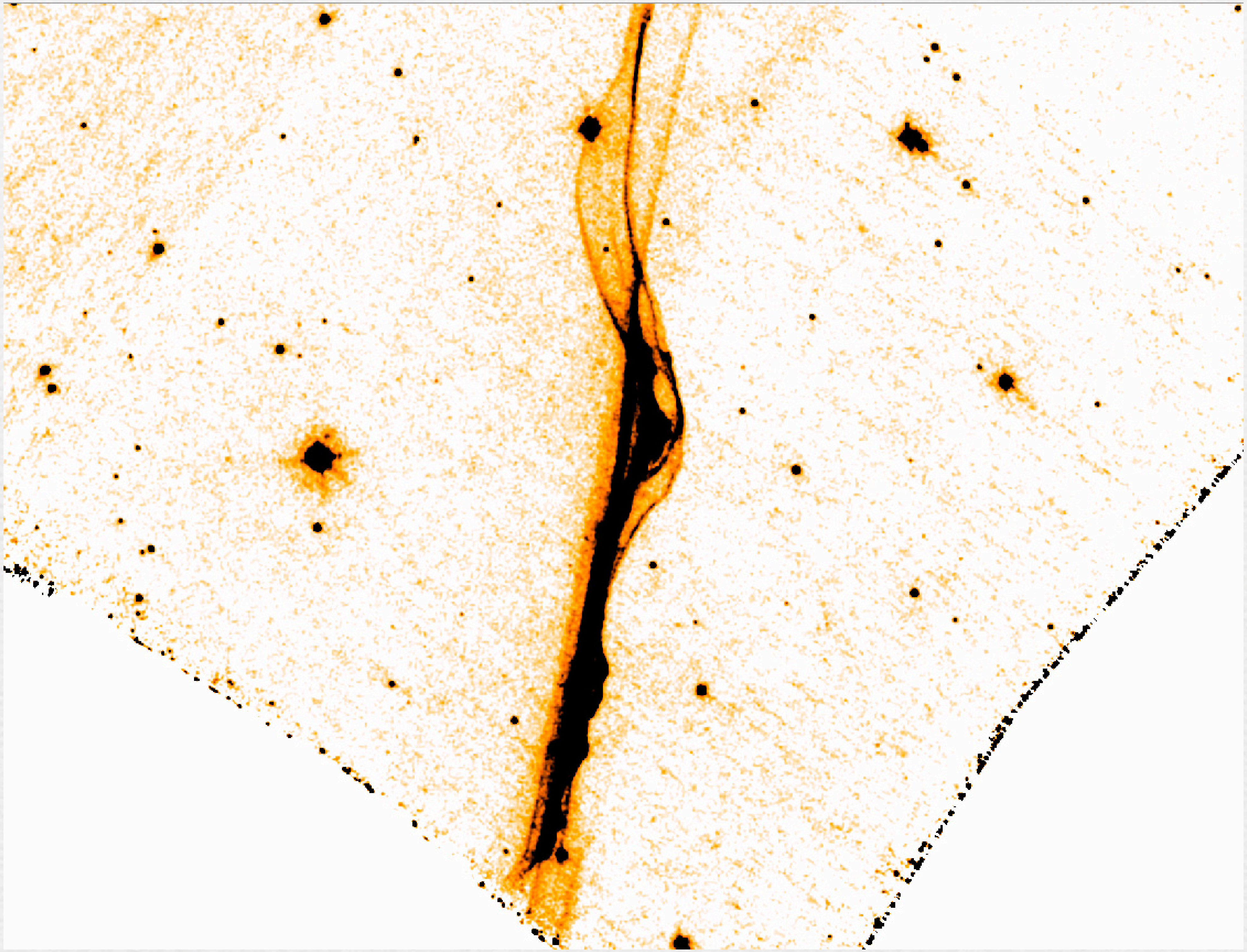
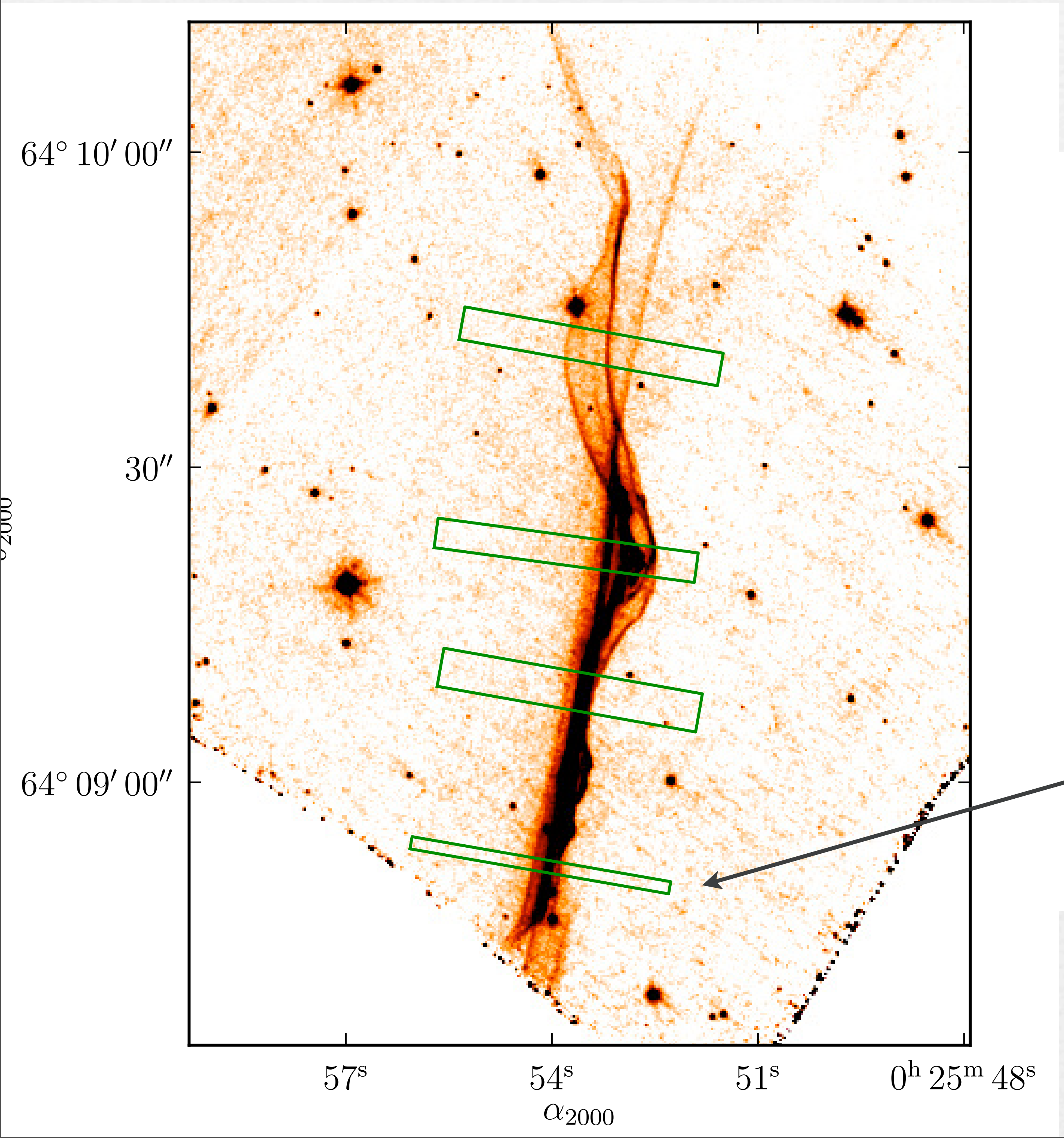
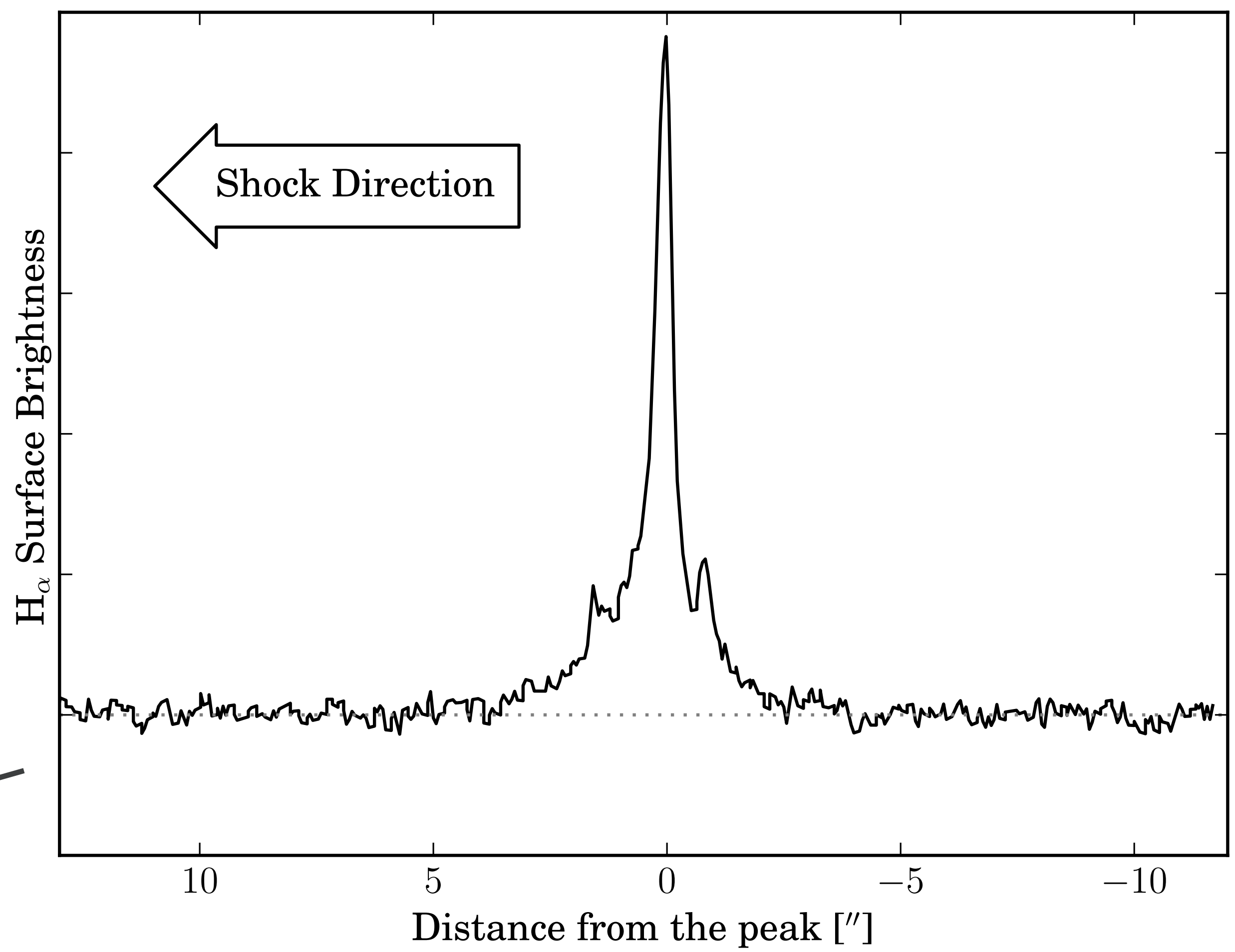


Crosscuts Perpendicular to the Local Shock Fronts





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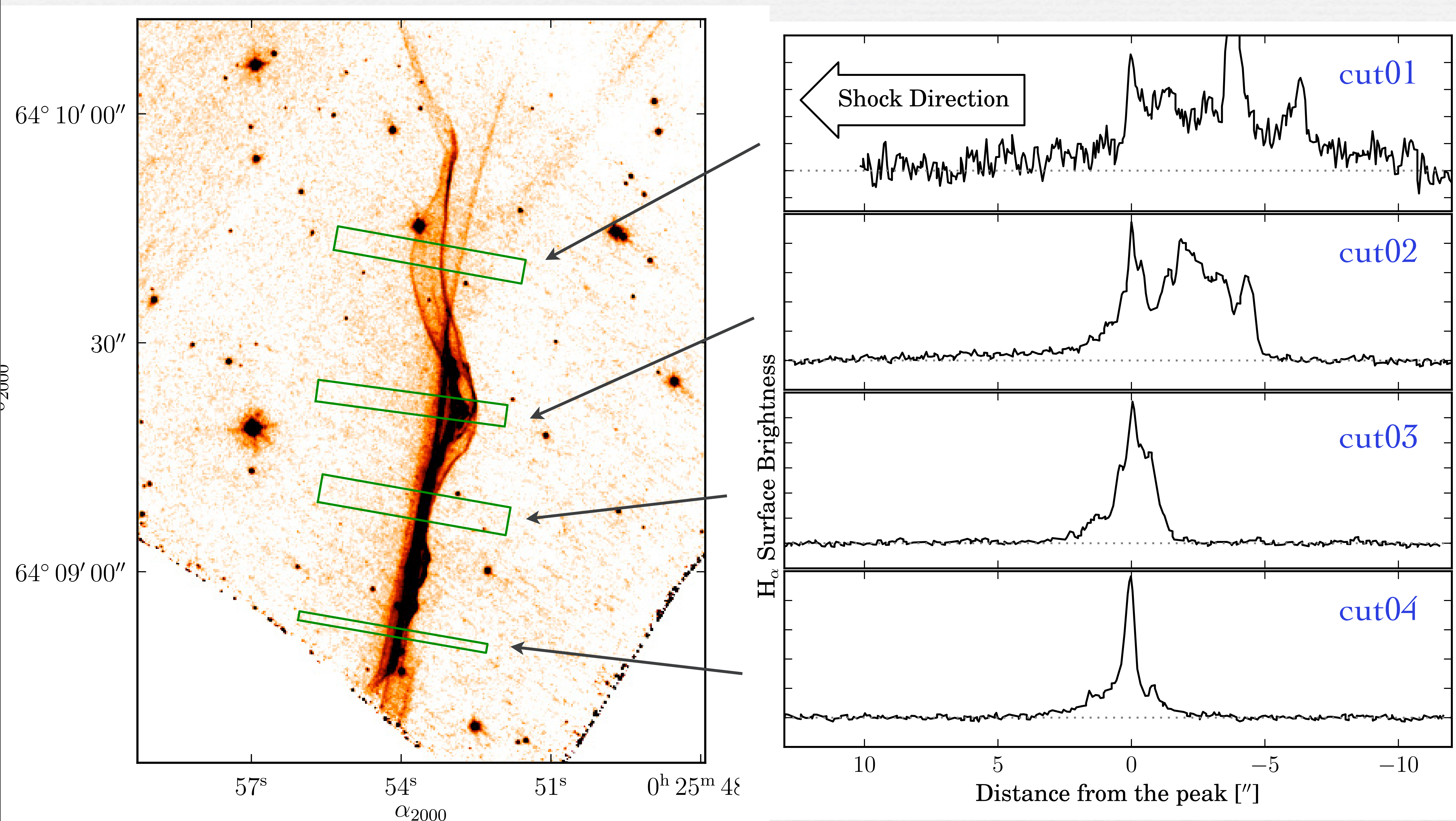
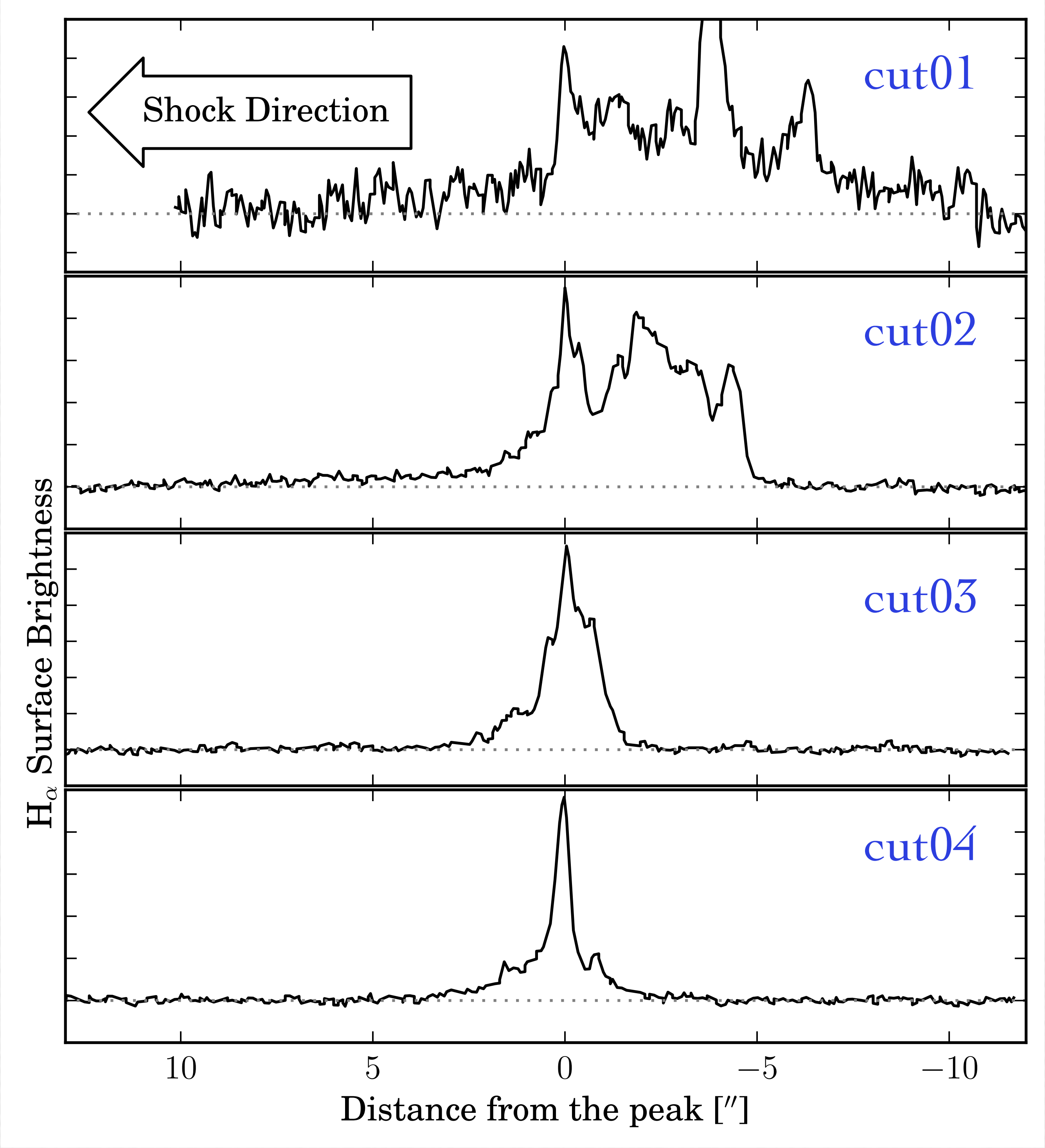


- Projection of another shocks?
- Curved shock fronts?
  - ★ cannot be applied to cut01.
  - ★ cannot explain the changes of linewidth (Lee et al., 2007)

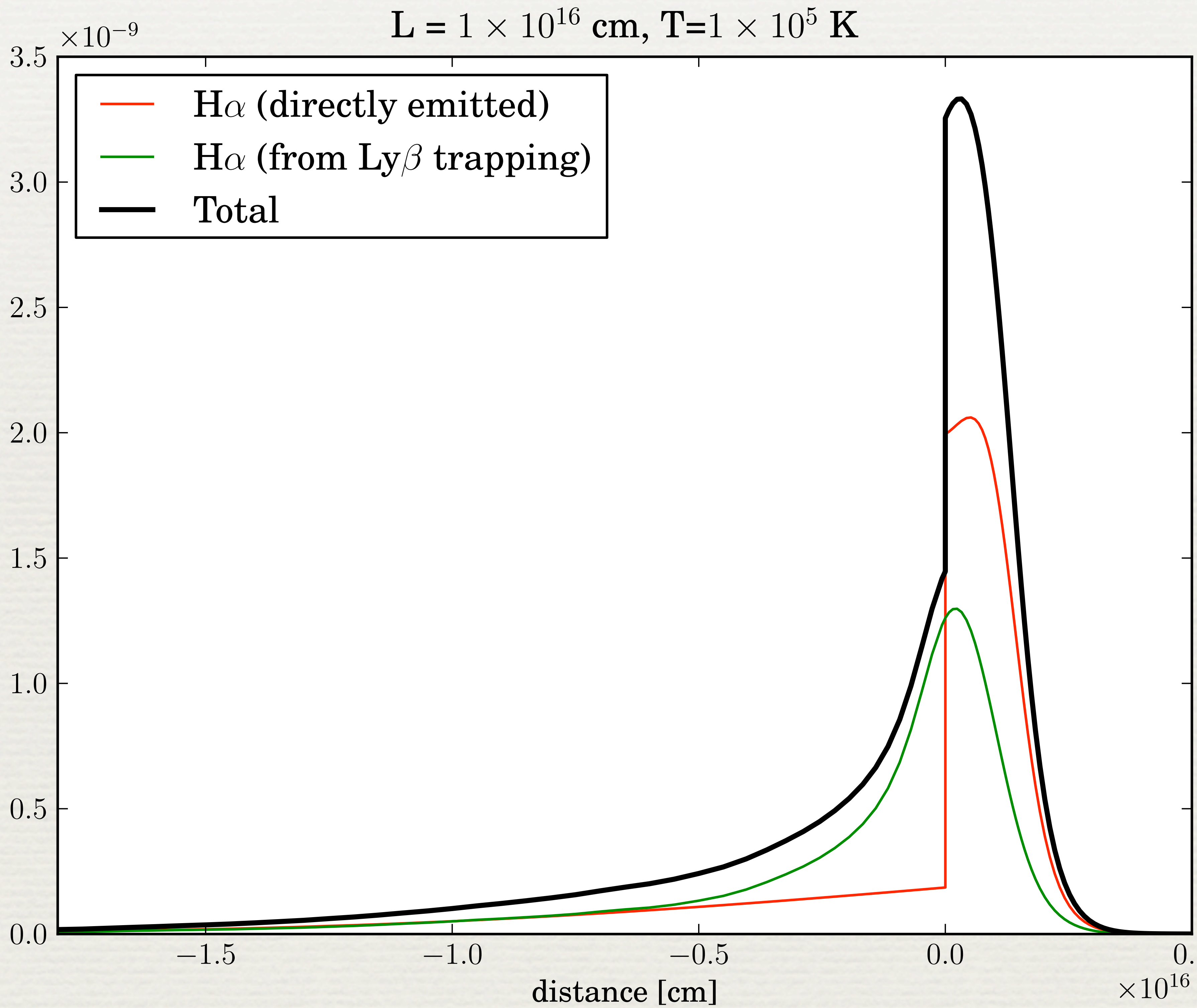


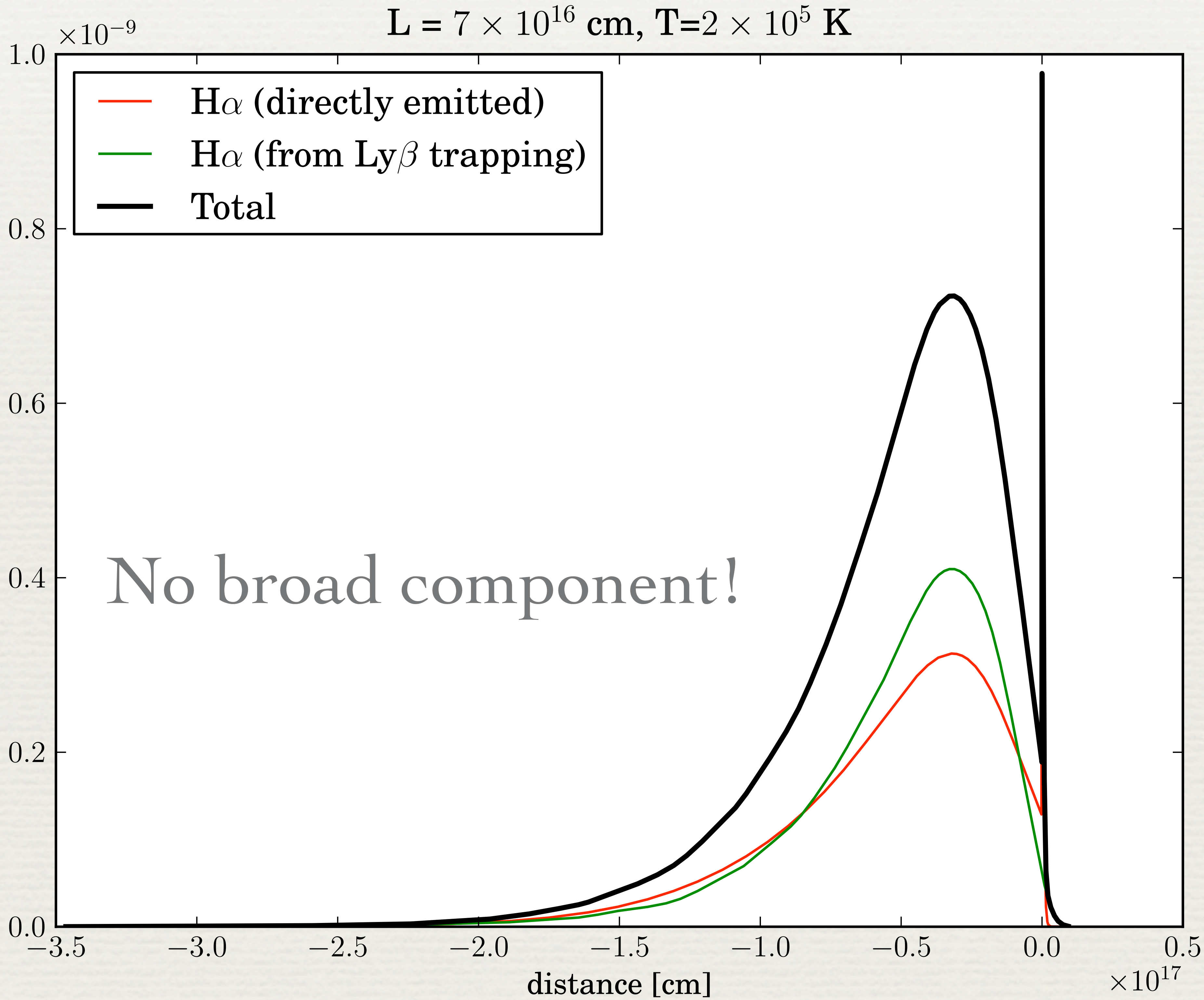
- HST image of Tycho shows faint extended emission toward the upstream of the shock, which we suggest to be the emission from the precursor.
- Precursor emission can contribute ~50% of total narrow component flux.
    - contribution to observed long slit obs. would be lower, but still could be significant.

Comparison w/ Model Profiles

- Ha emission from the precursor (Lee et al., in prep.)
  - Given the precursor profile, Ionization structure in the shock (precursor + postshock) is calculated.
  - Ha emission profile is calculated accounting the radiative transfer of Lyβ photons
    - Lyβ photons are converted to Hα photons
    - radiative transfer w/ monte carlo method

❧ Toy Precursor model : $T(x) = T_{peak}\, e^{-x/L}$

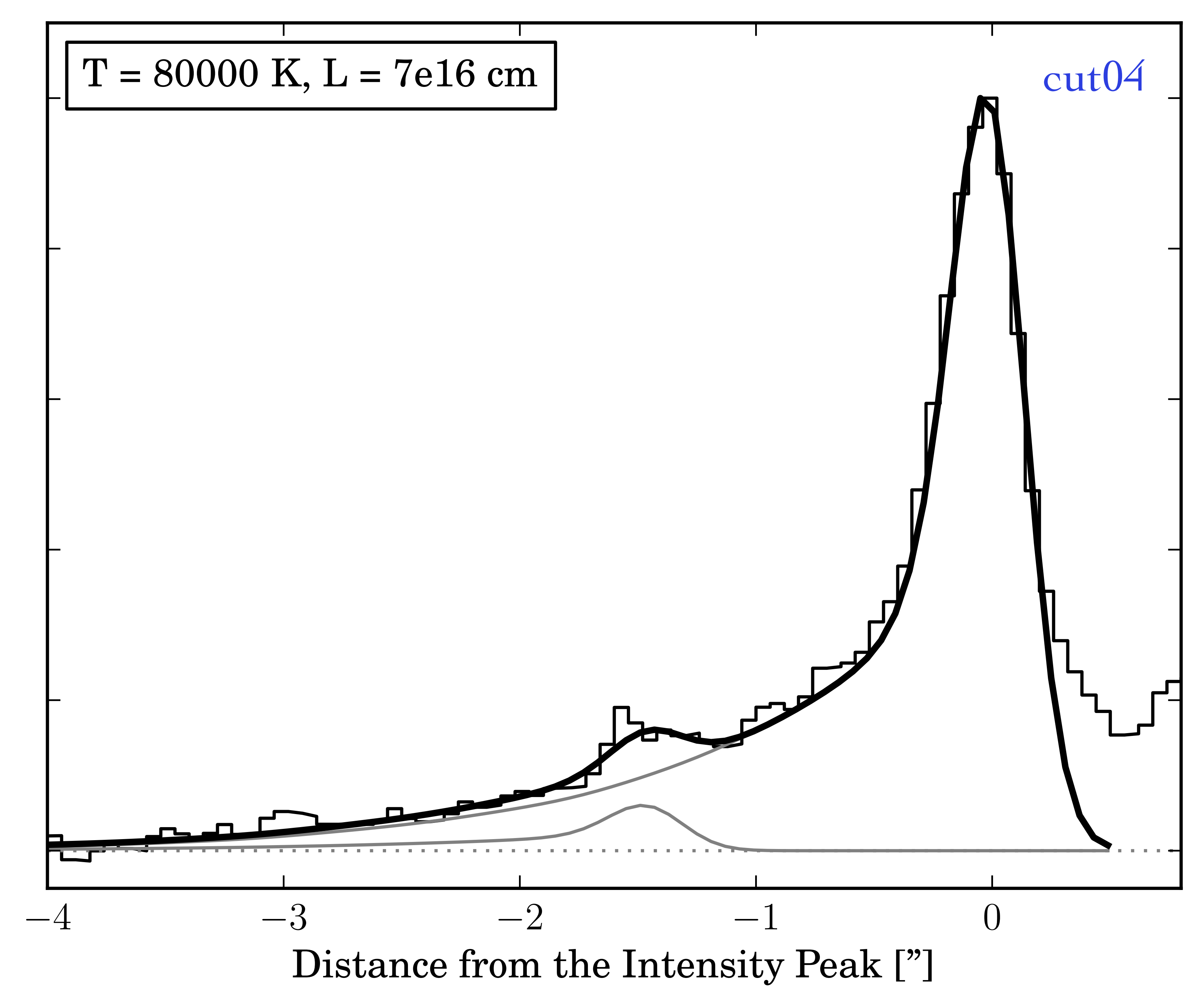




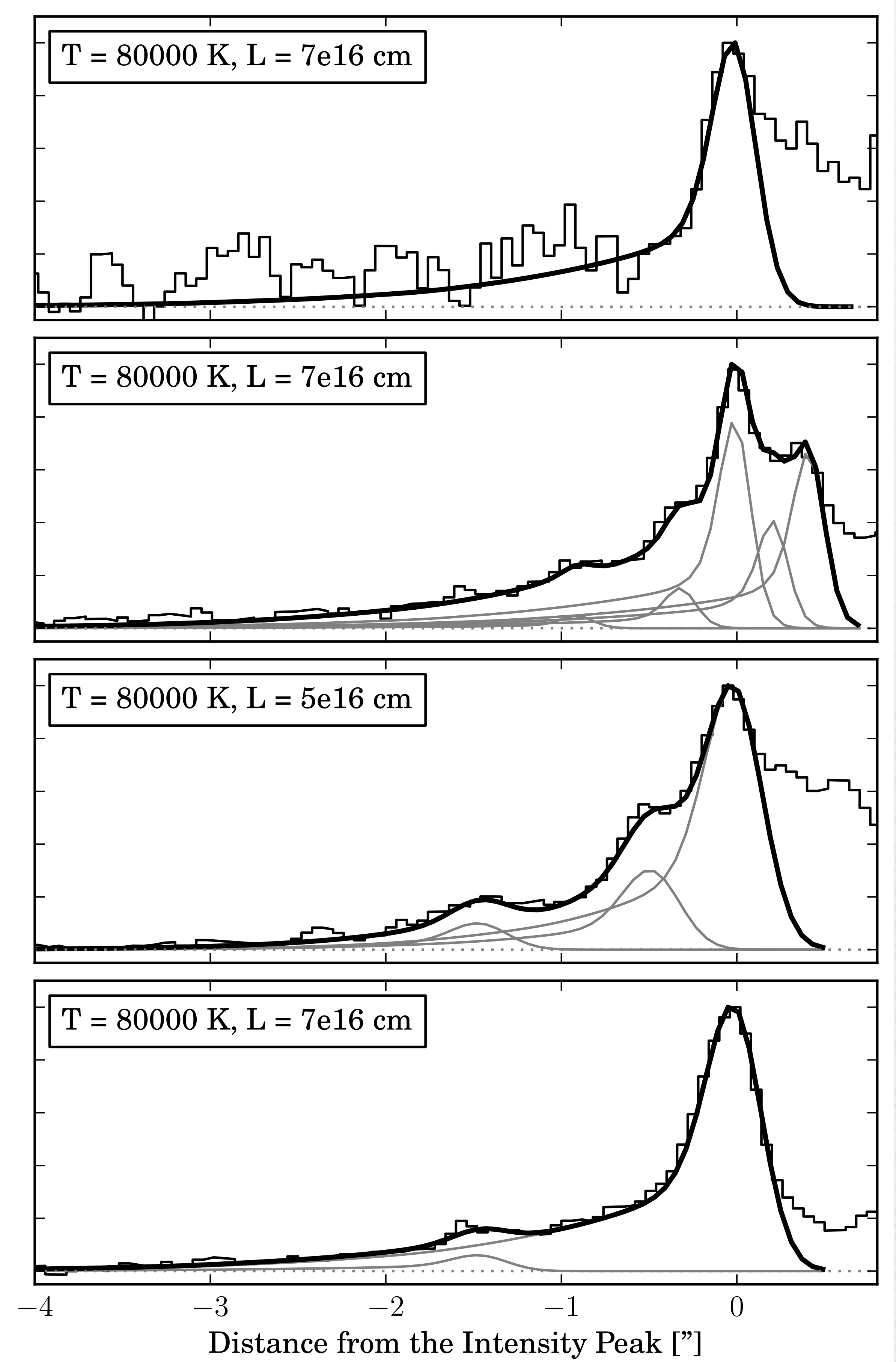
L = 7 × 10^16 cm, T=2 × 10^5 K
×10^−9
1.0
0.8
0.6
0.4
0.2
0.0
Hα (directly emitted)
Hα (from Lyβ trapping)
Total
No broad component!
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
distance [cm]
×10^17

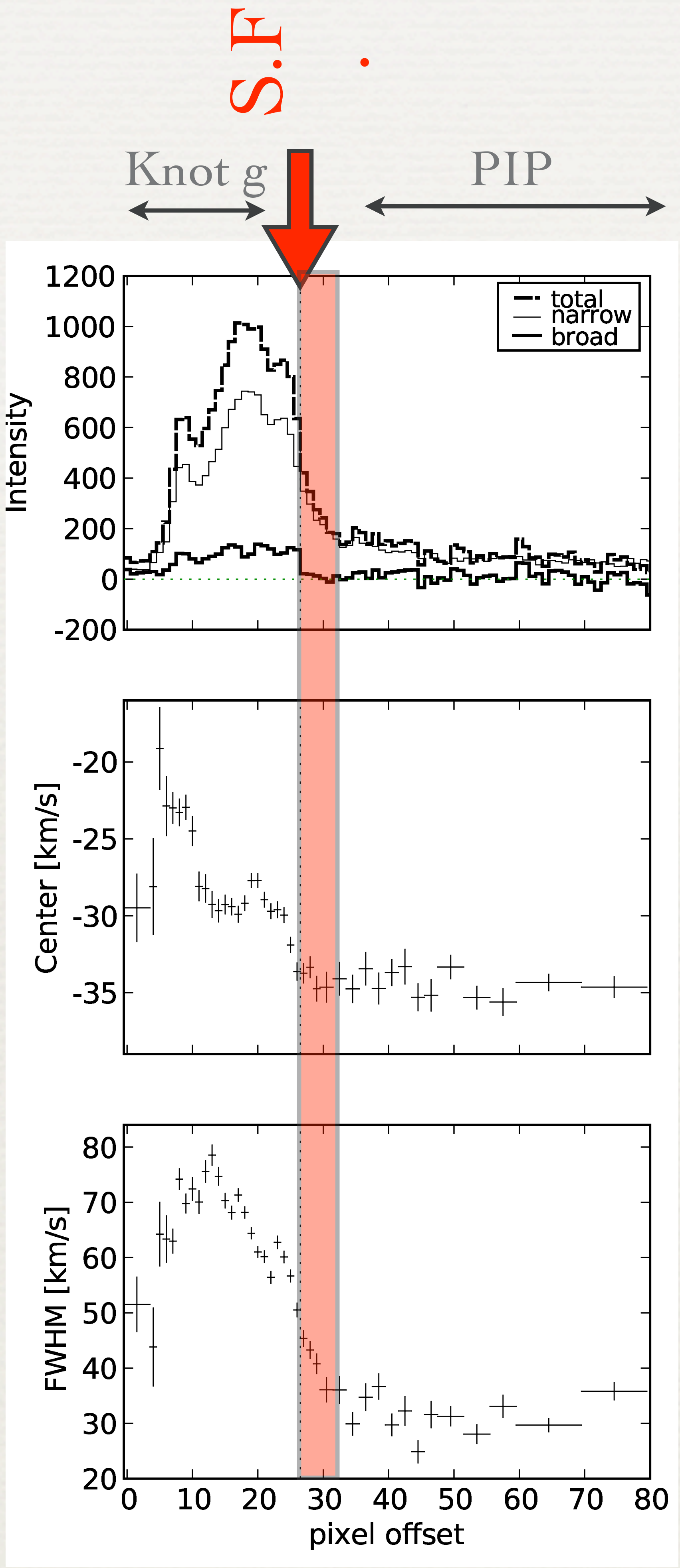
Comparison w/ Model Profiles

- Properties of the shock is well determined
  - v_{shock} (~2000 km/s), n_{HI} (~1 cm^{-3}), f_{HI}(~0.8)
  - assume constant density (ΔV in the precursor = 100 km/s)
  - Te/Tp in the postshock : but insensitive


T = 80000 K, L = 7e16 cm
cut04
−4
−3
−2
−1
0
Distance from the Intensity Peak ["]

- T_{peak} = 80000~100000 K
- L = 5 - 7 × 10^{16} cm





- Location of Shock Front
  - sudden increase of broad component
- Narrow precursor w/ gradual increase of intensity & FWHM
- Change in centroid velocity (~5 km/s). Corresponds to ΔV ~ 60 - 130 km/s

Lee et al. (2007)

- Constraints : T_{peak}, ΔV (~100 km/s), L
- A time-dependent cosmic-ray (CR) modified shock model (Wagner et al., 2009)
  - Two-fluid approximation
  - Particle injection
  - Precursor heating due to the acoustic instability.
- Results
  - Diffusion Coefficient : $\kappa = 2 \times 10^{24}$ cm^2 s^{-1}
  - Injection Parameter : 4.2×10^{-3}
  - Energy Transfer Timescale : $\tau = 420$ yr

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The thermal pressure still dominates
and ~10% of the shock energy has gone into CRs

  - Energy Transfer Timescale : $\tau = 420$ yr

- Partially neutral medium makes the precursor observable.
- Partially neutral medium makes the model more complicated.

- Our hydrodynamic simulation assumes fully ionized plasma. But the neutral fraction is about 80%.
- T_e : Ha intensity profile
- T_{HI} : narrow component width
- v_{HI} : centroid velocity of the narrow component

- T_e (10^5 K) > T_{HI} (40000 K, from the narrow component linewidth) ??
  - non-Gaussian line profiles (Raymond et al., in prep.)
  - $T_{HI} < T_p \sim T_e$: Charge exchange
  - $T_{HI} \sim T_p < T_e$: Heating by high frequency waves?

Summary

- HST image of Tycho reveals a faint extension of the Ha emission to the upstream, which we suggest to be the emission from the CR precursor.
- The observed intensity profile is well fitted by our precursor emission model and is used to constrain some of the CR acceleration parameters.