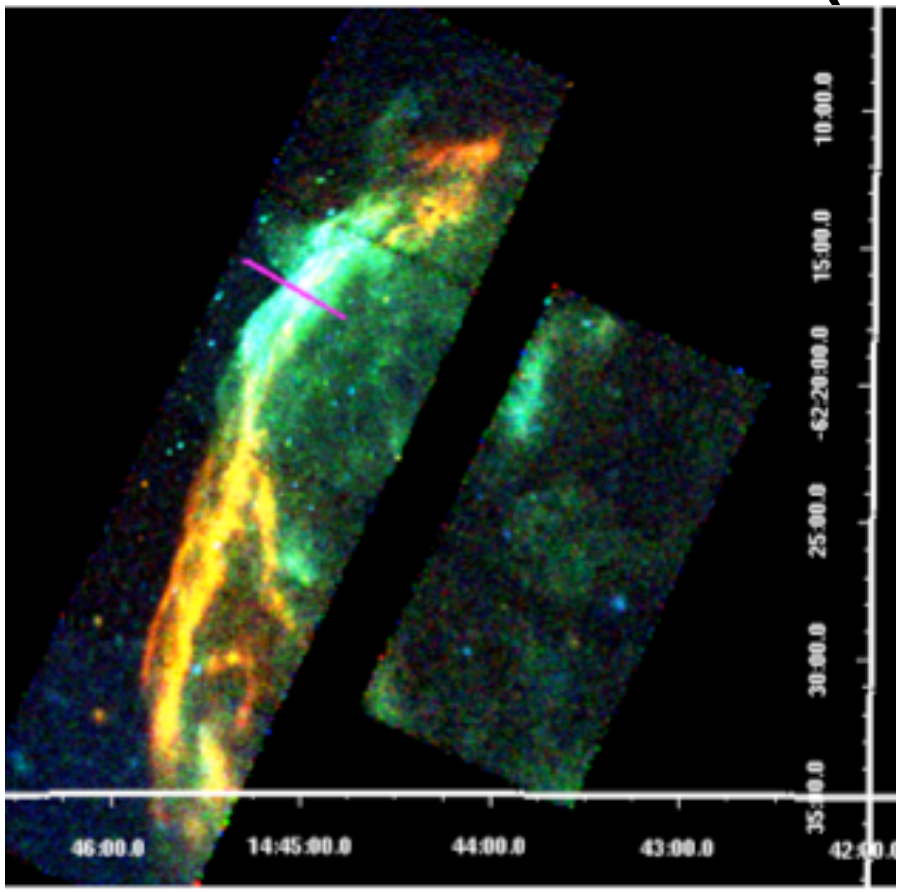
Cosmic ray acceleration in the MSH 14-63 supernova remnant (RCW 86)



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together with:

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Supernova remnants as CR accelerators

- To maintain energy budget, ~10% of the energy of a SNR needs to go into cosmic rays
- X-ray synchrotron emission has been detected at shock fronts of several supernova remnants
- Several remnants have been observed in gamma-rays

Imprints of CR acceleration

- Post-shock compression ratio > 4 (Warren+ 2005, Cassam-Chenaï+ 2008, Miceli+ 2009)
- Lower post-shock temperature (Hughes+ 2000)

from conservation of

- mass
- momentum
- and energy

$$kT = (3/16)\, mV^2$$

$$\beta = \frac{kT_p}{3/16 m_p V^2}$$

Method

- Measure velocity and temperature
  - V: compare 2 images
  - T:
    - electron temperature contributes only minor part to post-shock pressure, and hard to obtain in spectra dominated by synchrotron emission
    - Ion temperatures hard to measure
      - done in UV (Raymond+ 1995, Ghavamian+ 2007)
      - done in X-ray (Vink+ 2003)

- Use optical spectrum to determine proton temperature:

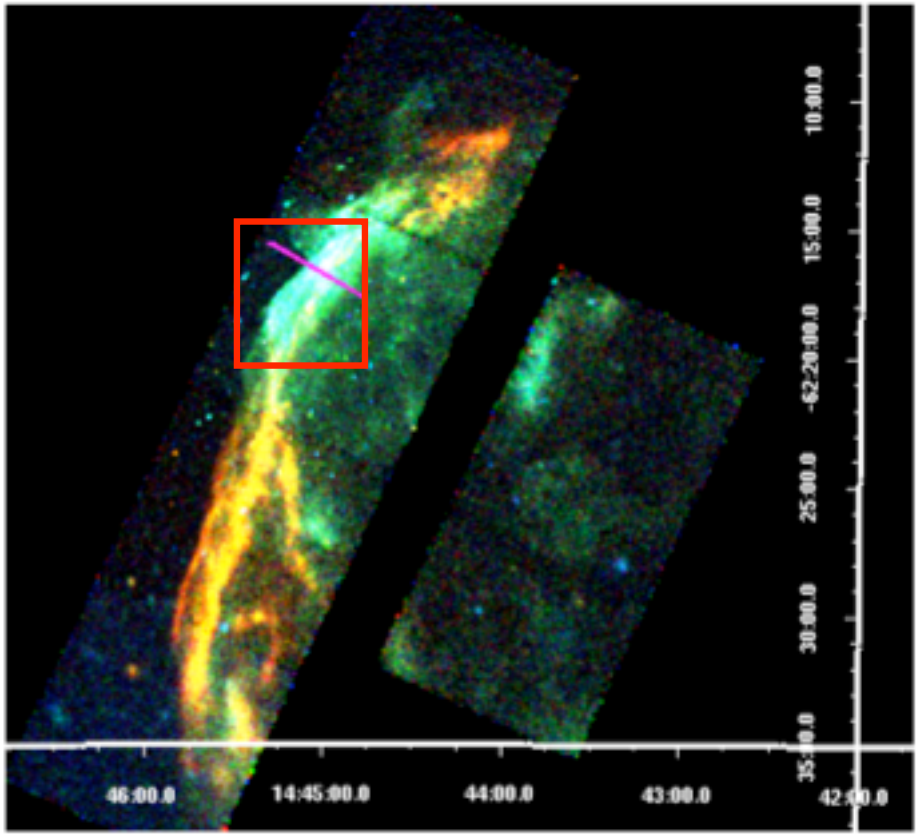
  H-lines consist of 2 superimposed peaks:

  - narrow reflects T_{ISM}
  - broad reflects T_p (Chevalier+ 1980)

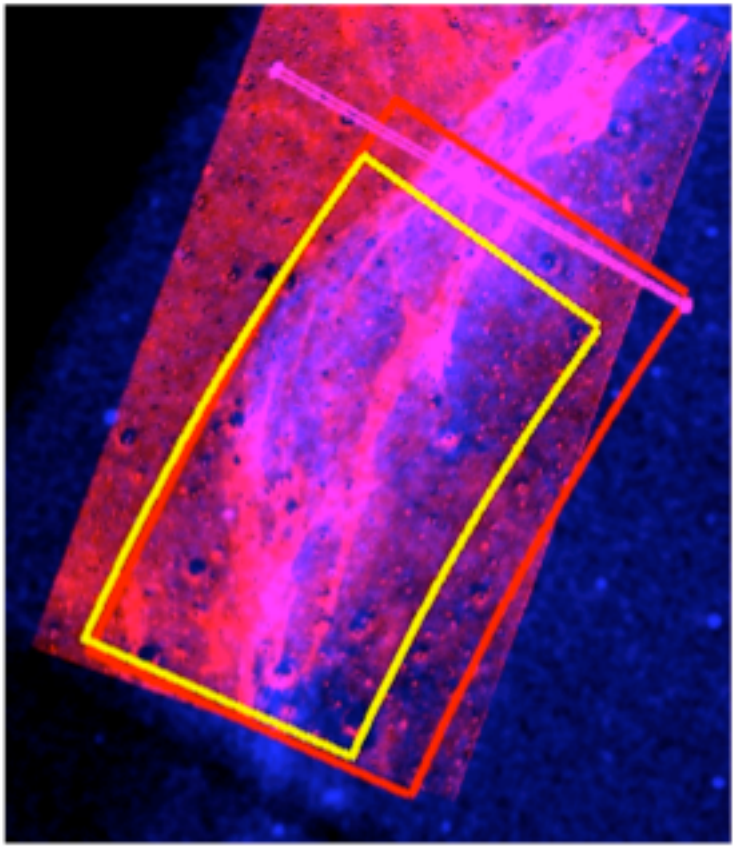
RCW 86

- Observed in TeV gamma-rays (Aharonian+ 2009)
- Parts of the rim show X-ray synchrotron emission (Bamba+ 2000, Borkowski+ 2000)
- Can measure the post-shock proton temperature at location of X-ray synchrotron (Smith 1997)

RCW 86

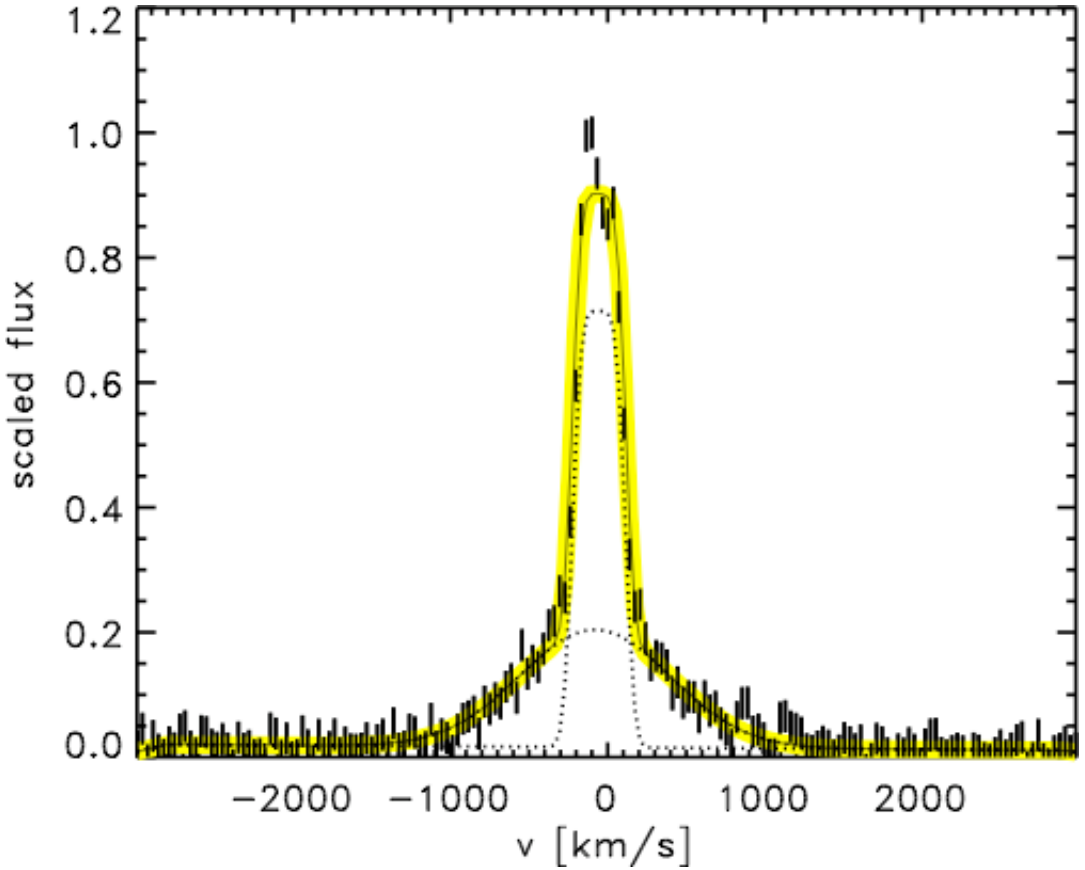


X-ray (Chandra)



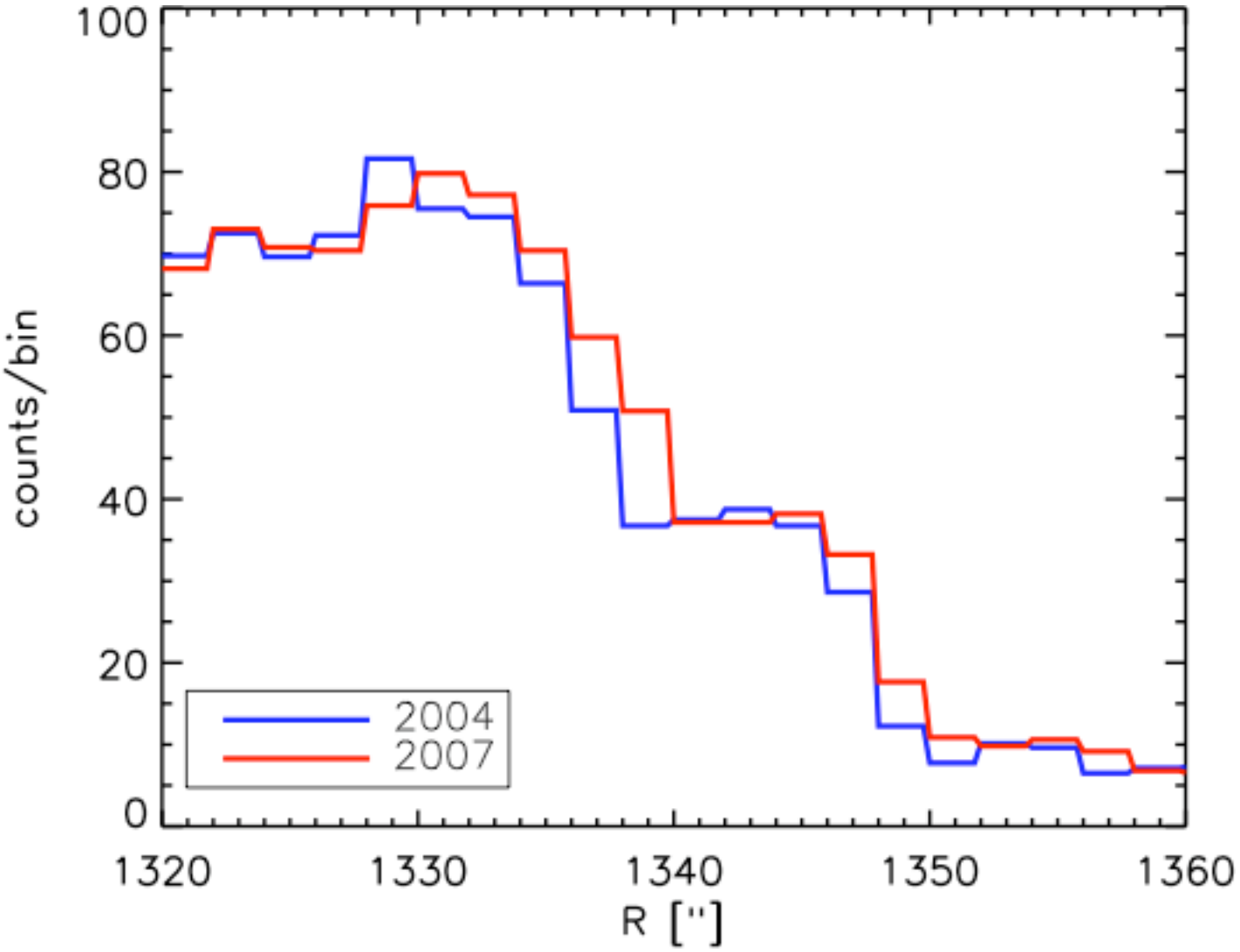
X-ray (blue) + Hα (red)

Temperature (Hα line)

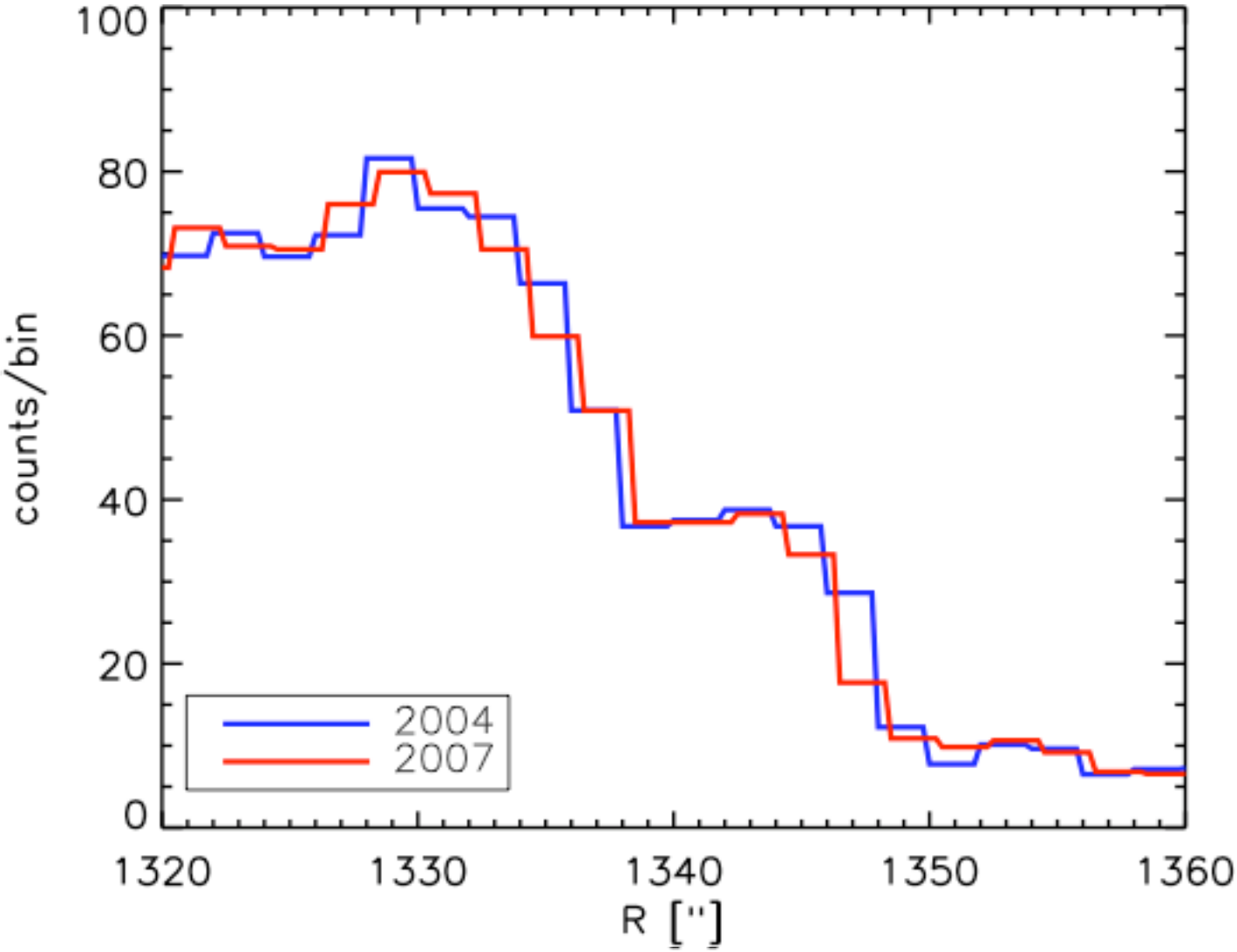


FWHM = 1100 km/s => T_p= 2.3 keV

Cosmic ray acceleration in the RCW86 SNR



Cosmic ray acceleration in the RCW86 SNR



Distance

- OB association at 2.5 kpc (Westerlund 1969)
- Local V_{ISM} combined with Galactic rotation curve gives ~2.5 kpc (Rosado+ 1996, Sollerman+ 2003)
- Blowout seen in CO with same velocity (Matsunaga+ 2001)

Numbers

- Shock velocity is 6000 ± 2800 km/s
- FWHM broad line 1100 ± 60 km/s
- This would correspond to a shock velocity of ~ 1100 km/s

$$\beta = \frac{kT_p}{3/16 m_p V^2}$$

- We observe the effect of cosmic ray acceleration

Equations

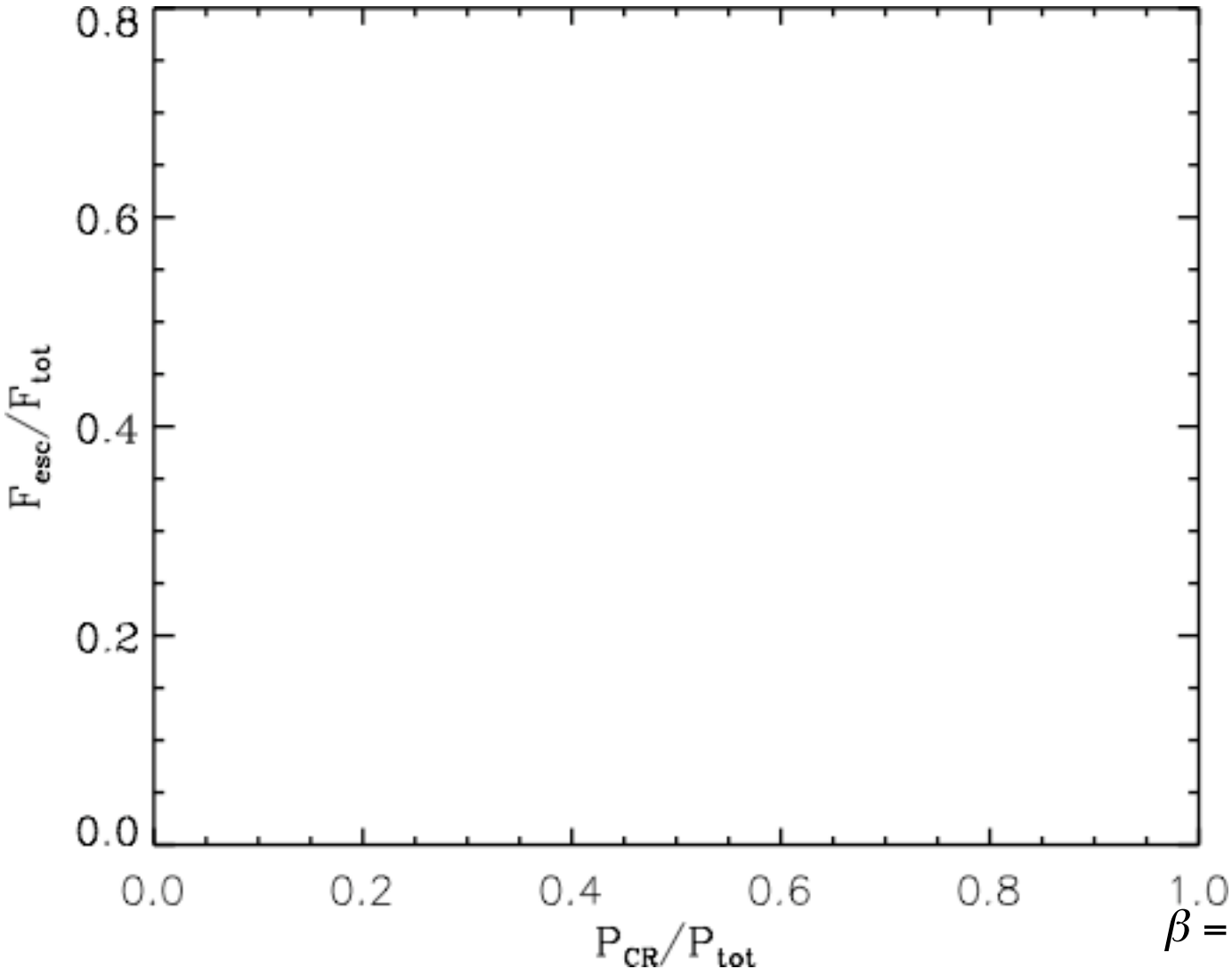
- Add term for cosmic ray pressure and energy absorbed by cosmic rays to the conservation laws.
- Equation of state goes from 5/3 to 4/3 as pressure gets more cosmic ray dominated

P_{CR}/P_{Total}

F_{CR}/F_{tot}

$$\beta = \frac{kT_p}{3/16 m_p V^2}$$

Cosmic ray acceleration in the RCW86 SNR



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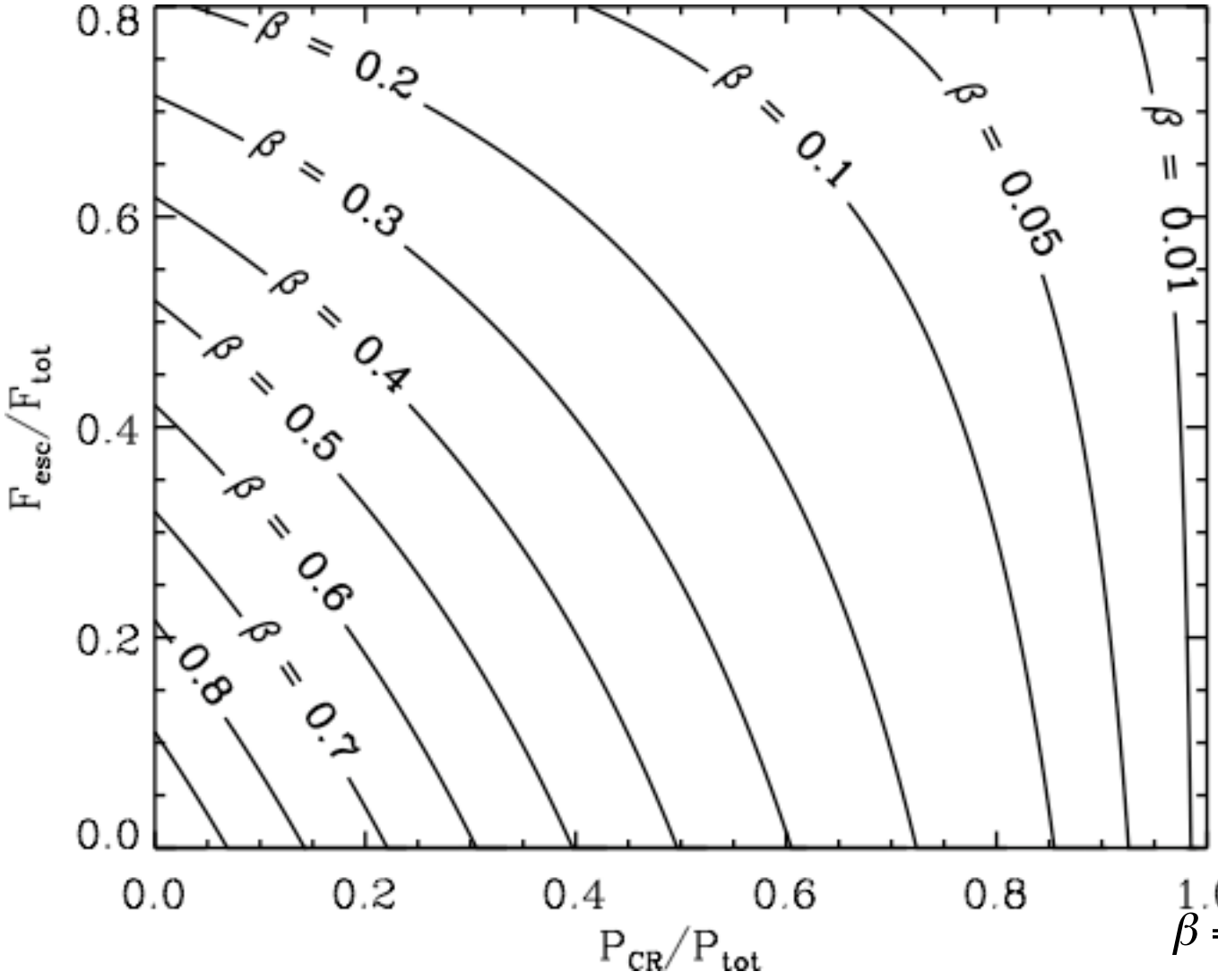
Cosmic ray acceleration in the RCW86 SNR



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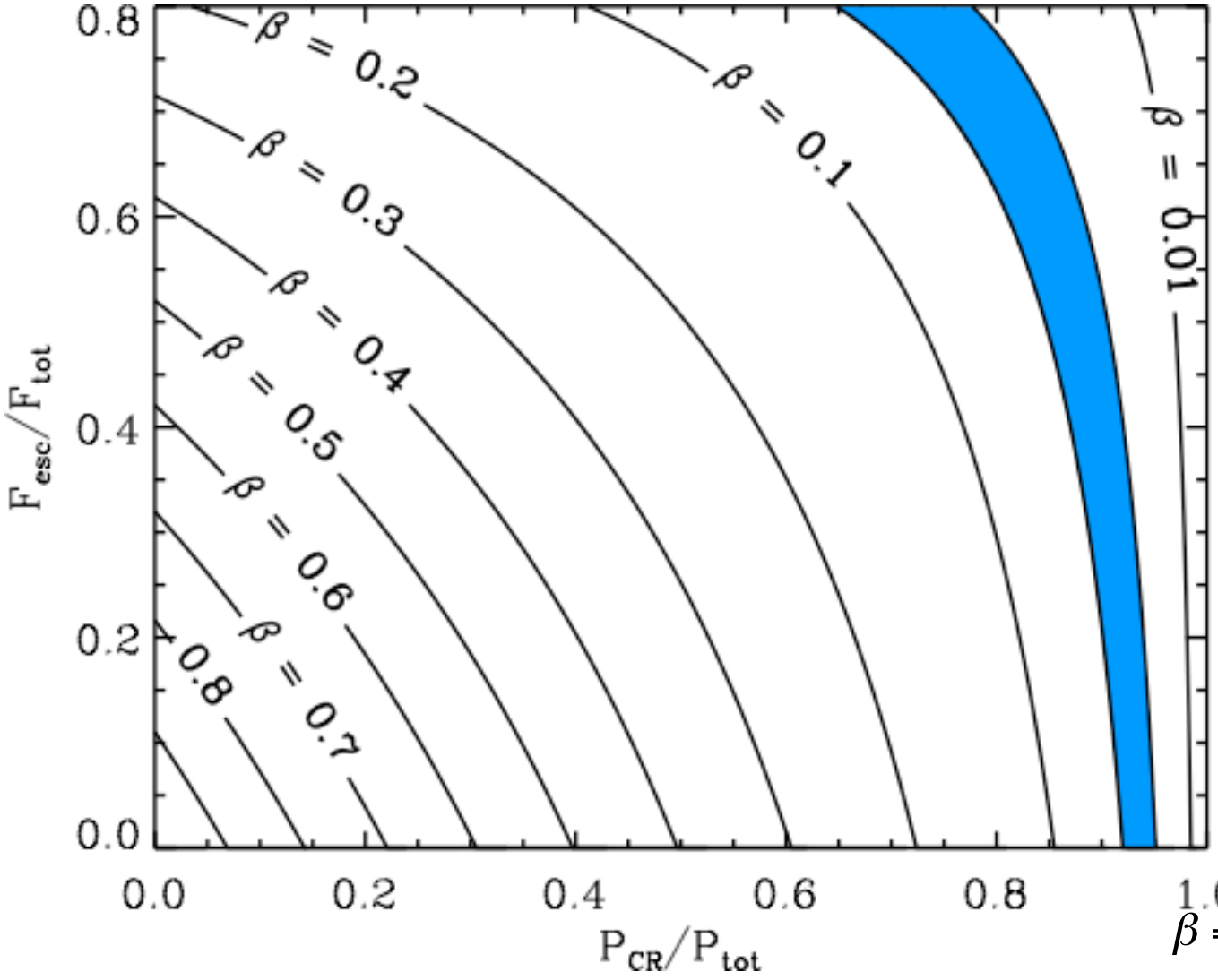
Cosmic ray acceleration in the RCW86 SNR



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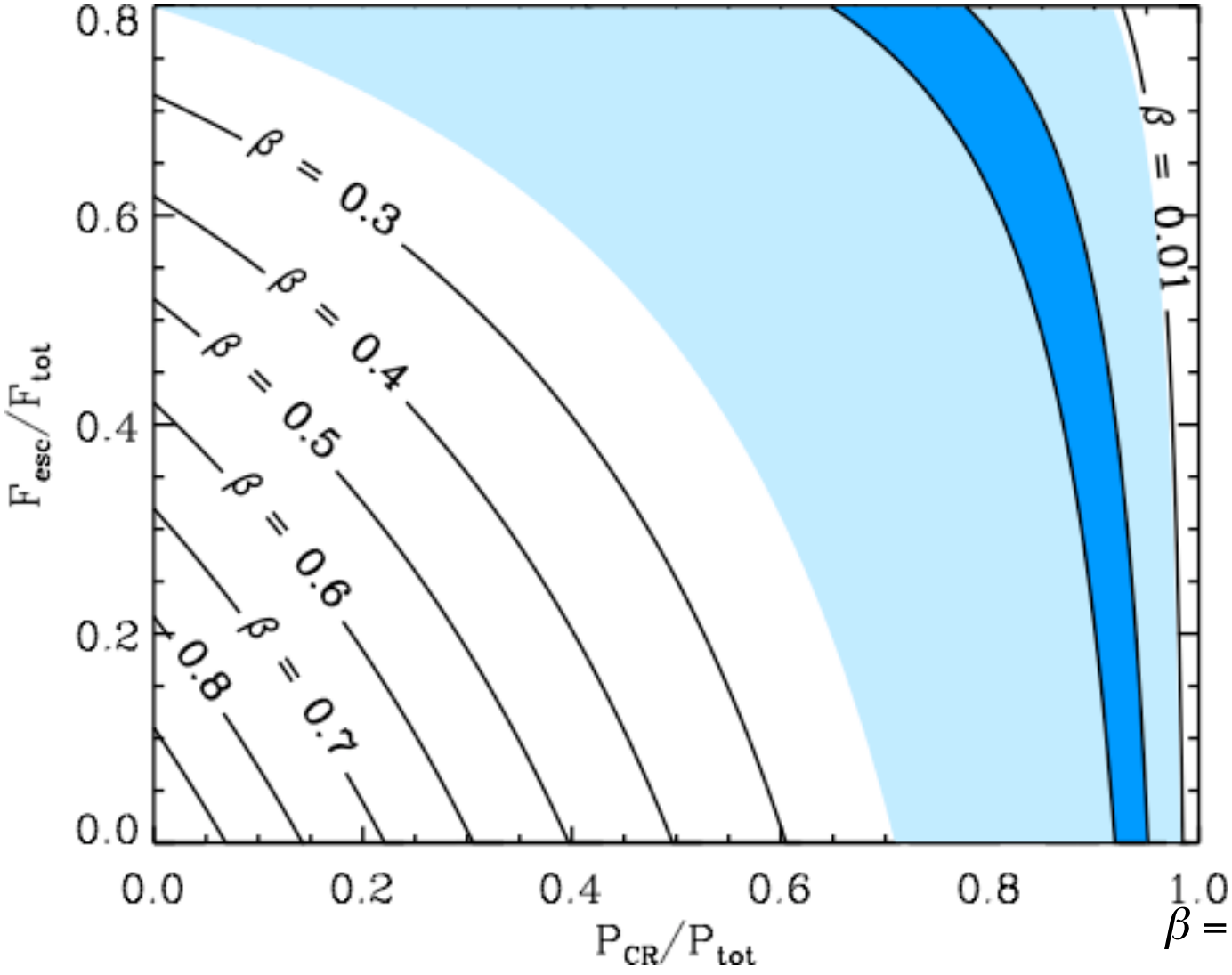
Cosmic ray acceleration in the RCW86 SNR



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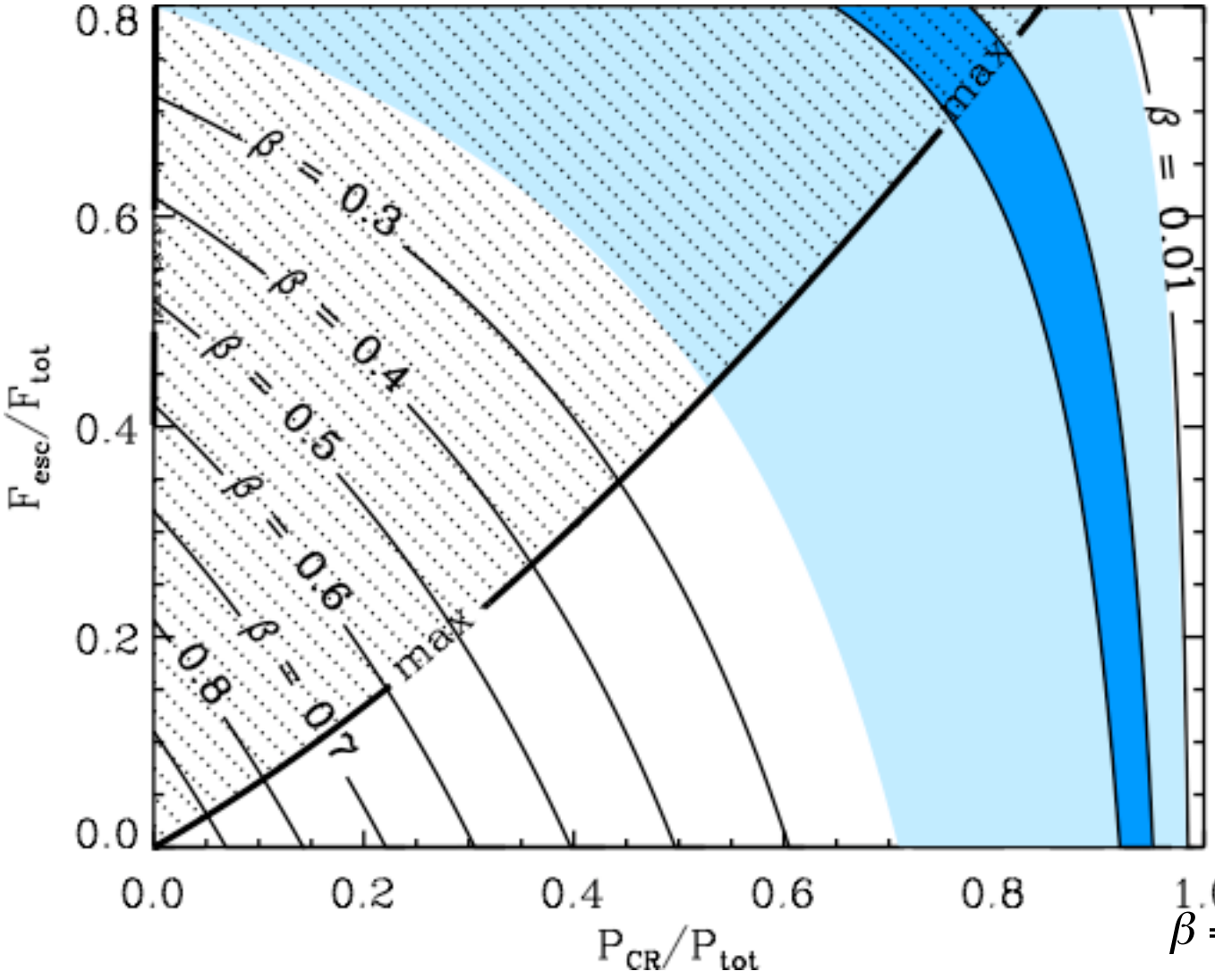
Cosmic ray acceleration in the RCW86 SNR



$$\beta = \frac{kT_p}{3/16 m_p V^2}$$

Conclusions

- The effect of cosmic ray acceleration on the kinematics of RCW 86 can not be ignored
- The lower limit to the pressure, contributed by cosmic rays is 50% of the total pressure

Future work

- Include cross sections for charge exchange in calculating proton temperature
- Measure proper motion using Hα images