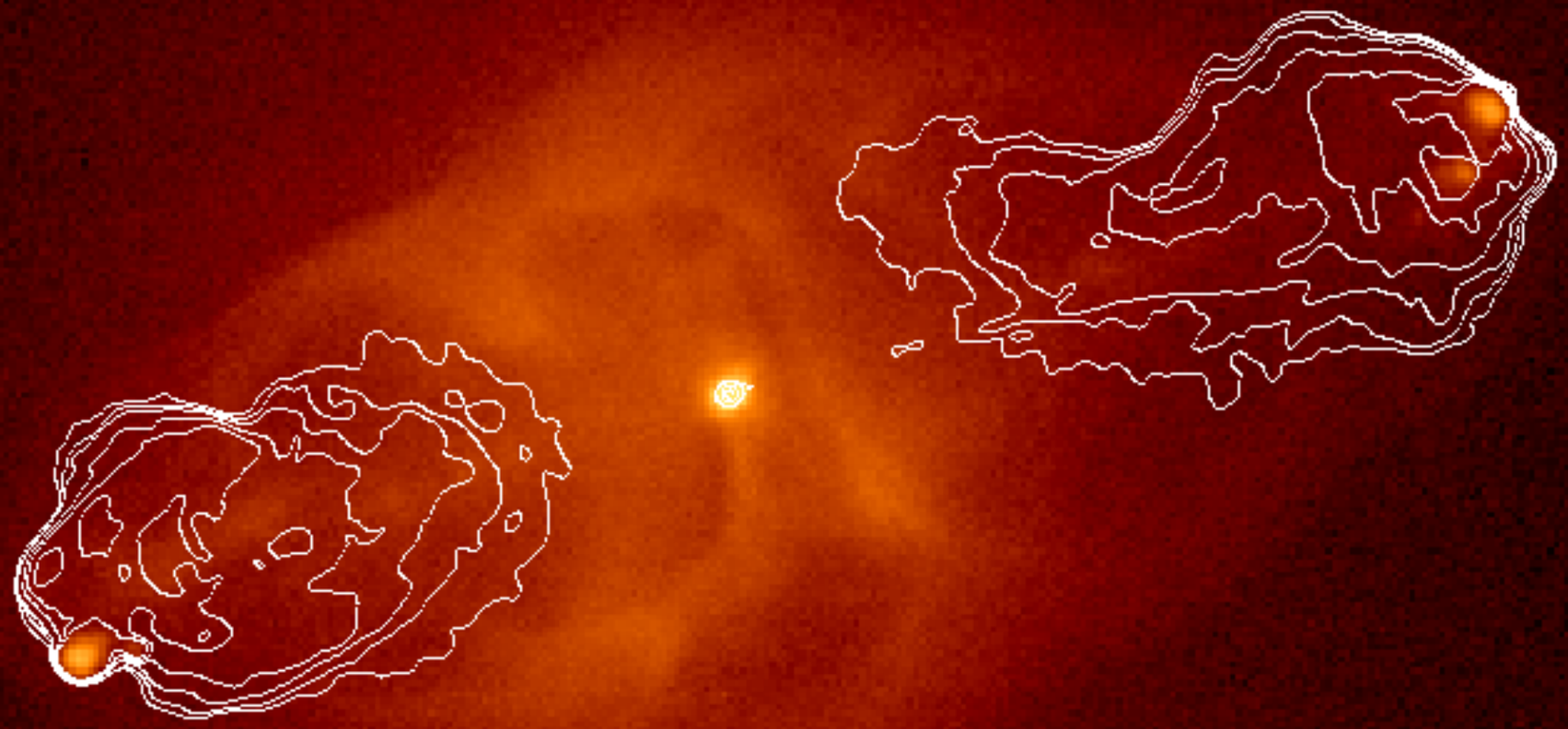
Analyzing Cocoon Shocks in Radio Galaxies: Predictions for Lynx



Bradford Snios

Chandra-to-Lynx Conference

08/09/17

Cygnus A Collaboration

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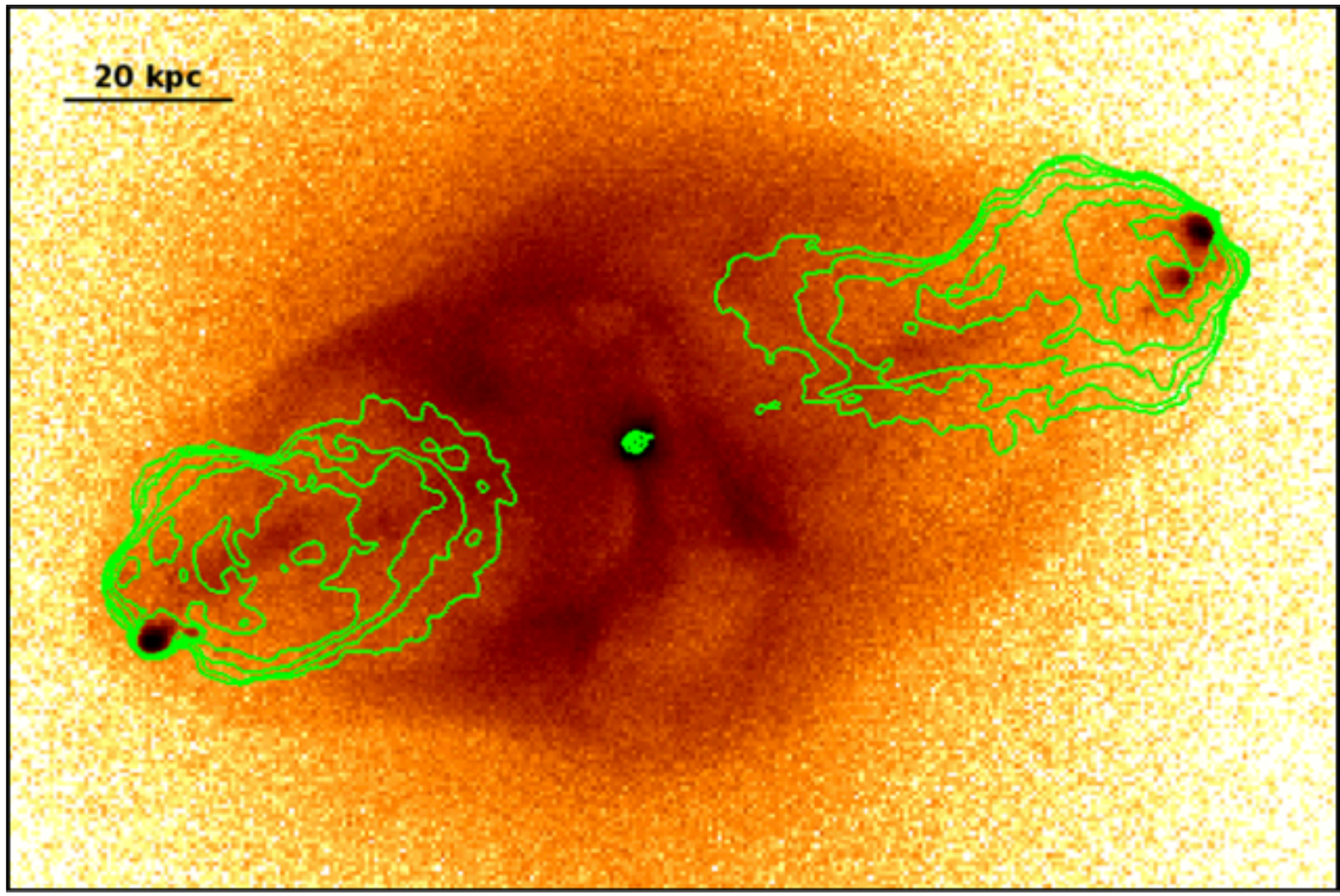
Cygnus A: Archetype Radio Galaxy

- Fanaroff-Riley II Radio Galaxy
- Powerful
- z = 0.056
- Hosted by BCG in cool-core cluster
- 2.0 Msec obs
- Prominent cocoon shock

0.5-7.0 keV *Chandra*



Cocoon Shock Mach Numbers

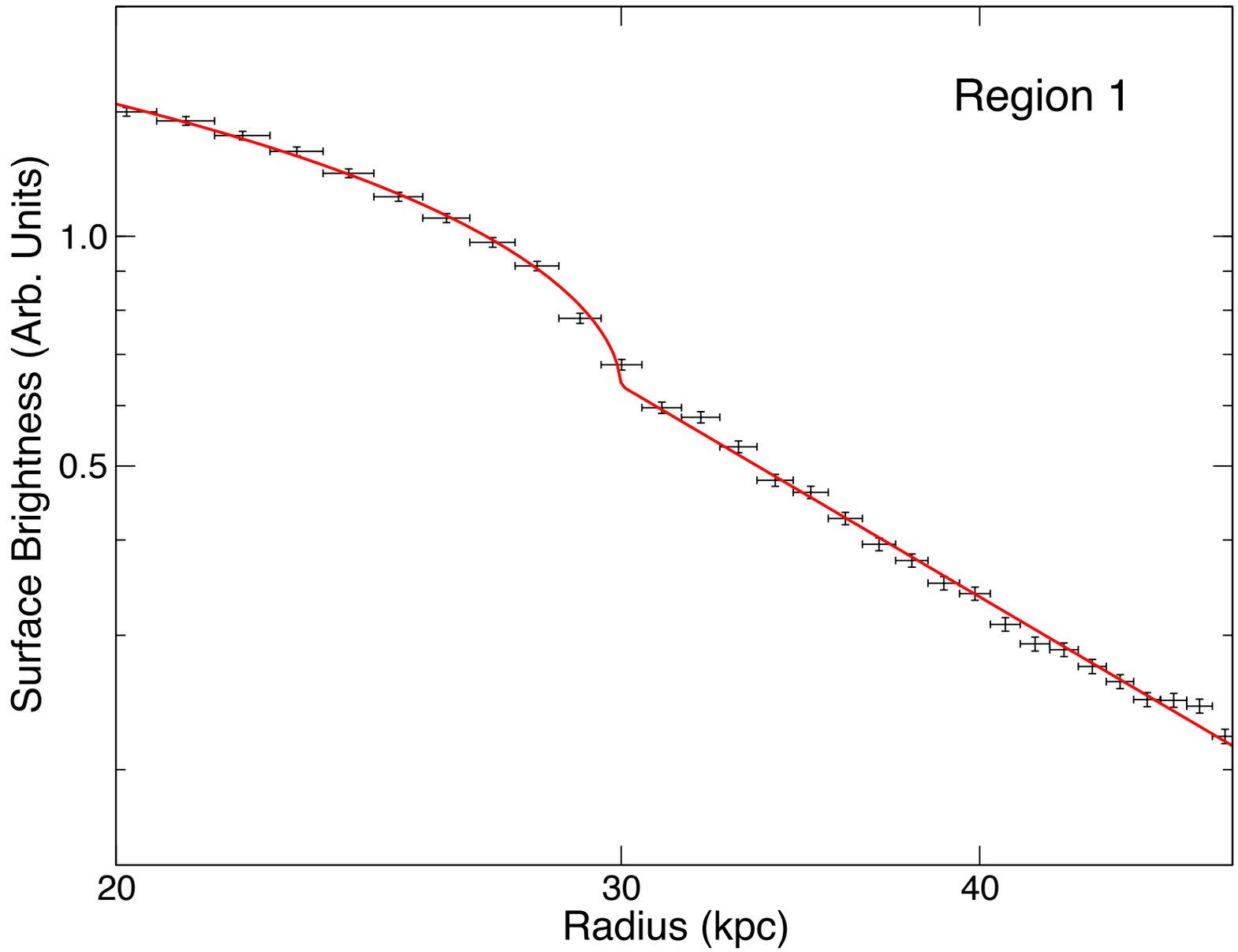
- Fit surface brightness profiles with 1D hydro model

  $M_{\rm range}$ = 1.2-1.7

  $T_{\rm age}$ = 20 Myr

  P = 10^{46} erg/sec

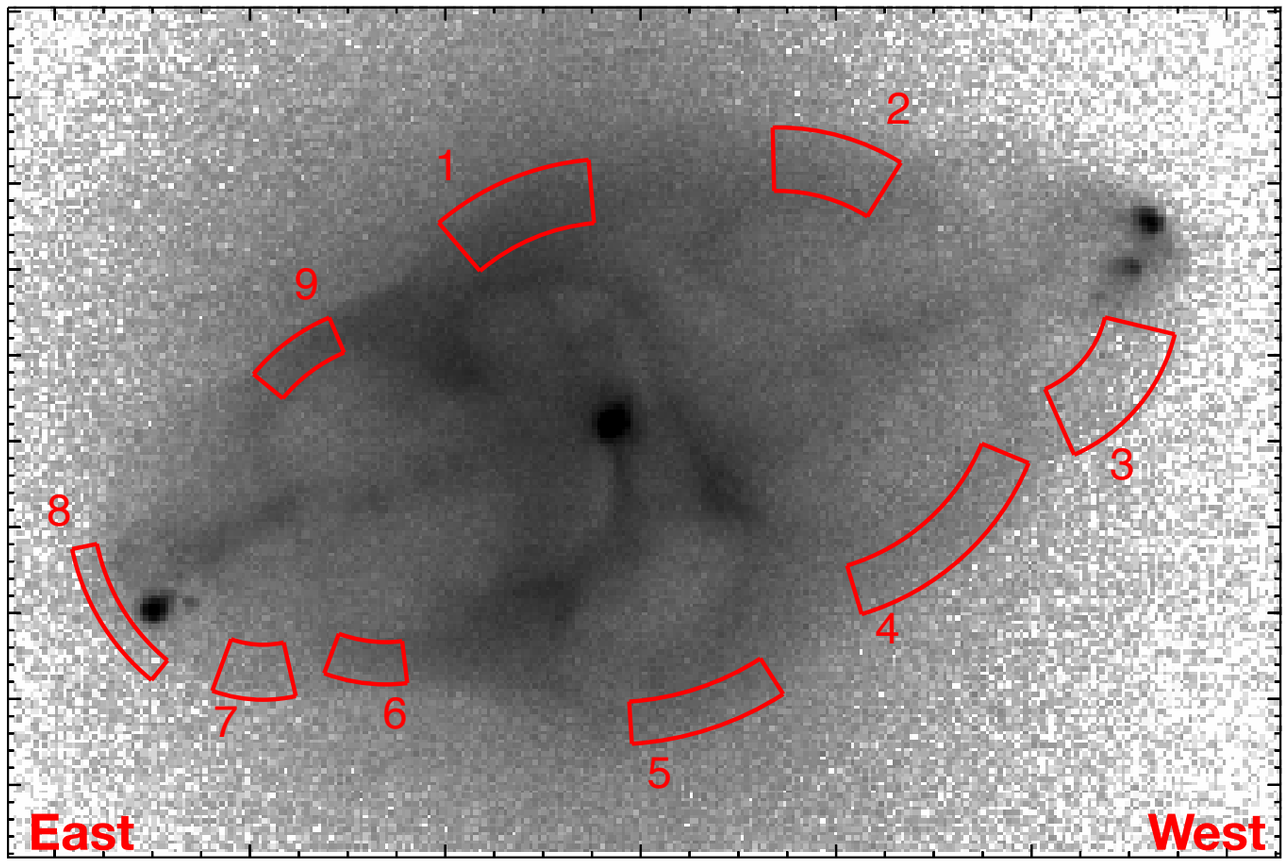
- Agrees with models of Cygnus A



Lobe Pressures

- Use preshock pressures and Mach numbers to measure postshock pressures
- Compare to pressure estimates from thermal model fits of emission spectra from shocked gas rim
- Rim pressures provide good measure of lobe pressures

$$p_{\rm avg} = 8.7 \times 10^{-10} \text{ erg cm}^{-3}$$



20% difference in lobes

$$p_{\rm east} = 10.4 \pm 0.4 \times 10^{-10} \text{ erg cm}^{-3}$$

$$p_{\rm west} = 8.4 \pm 0.2 \times 10^{-10} \text{ erg cm}^{-3}$$

Instantaneous vs Average Hotspot Speed

- Estimate hotspot pressure assuming constant shape cocoon

  $M_{\rm hs}$ = 2.5

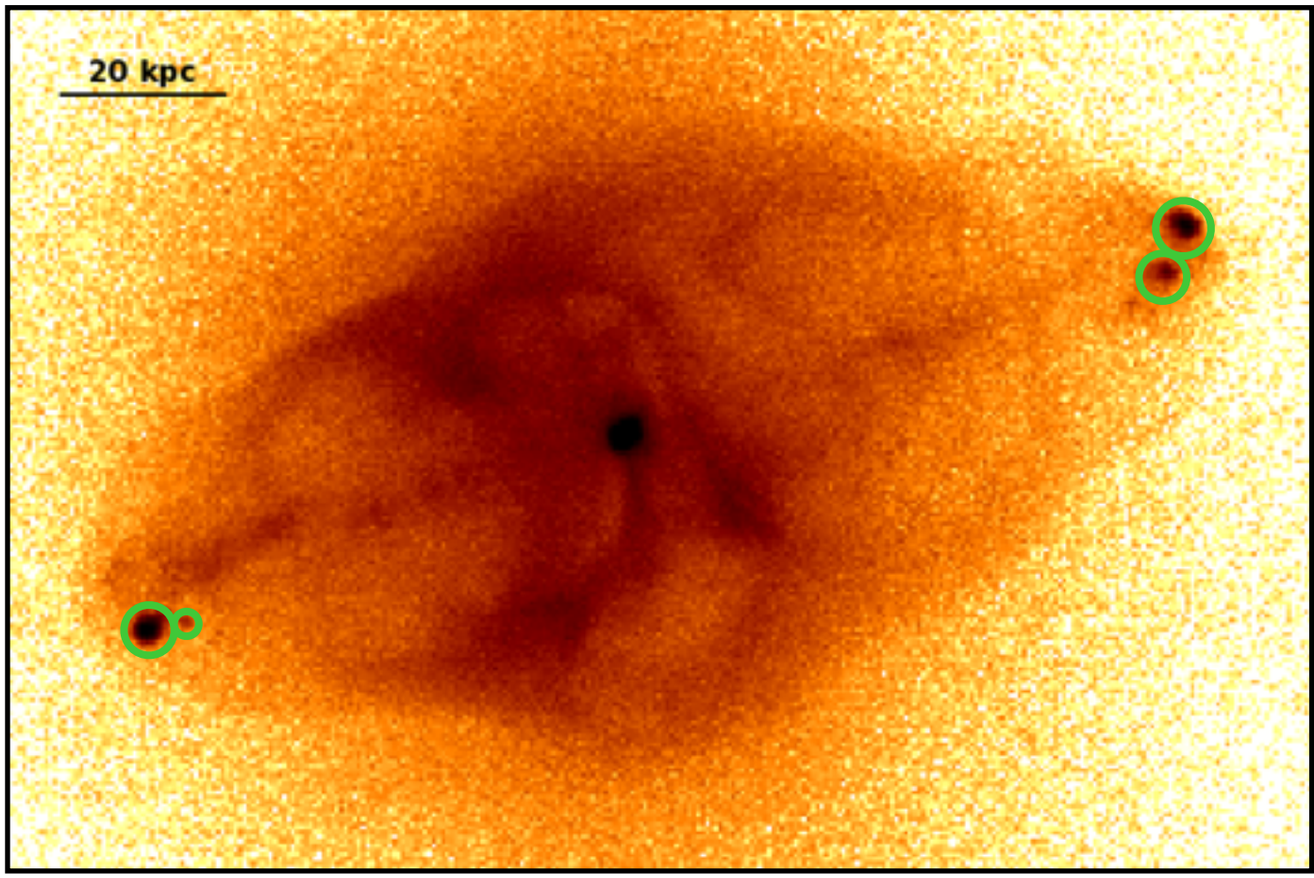
  $p_{\rm hs}$ = 1.4×10^{-9} erg cm^{-3}

- Estimate pressure using SSC model with parameters from Stawarz+07

  $p_{\rm hs}$ = 6.8×10^{-9} erg cm^{-3}

  $M_{\rm hs}$ = 5.5

- Pressure difference consistent with ‘dancing’ hotspot



- Excess due to ram pressure; jet momentum dominated

X-ray Jet Properties

- Use momentum flux and power with 1D relativistic, steady flow model for a jet to find jet speed and mass flow rate

<u>West</u>

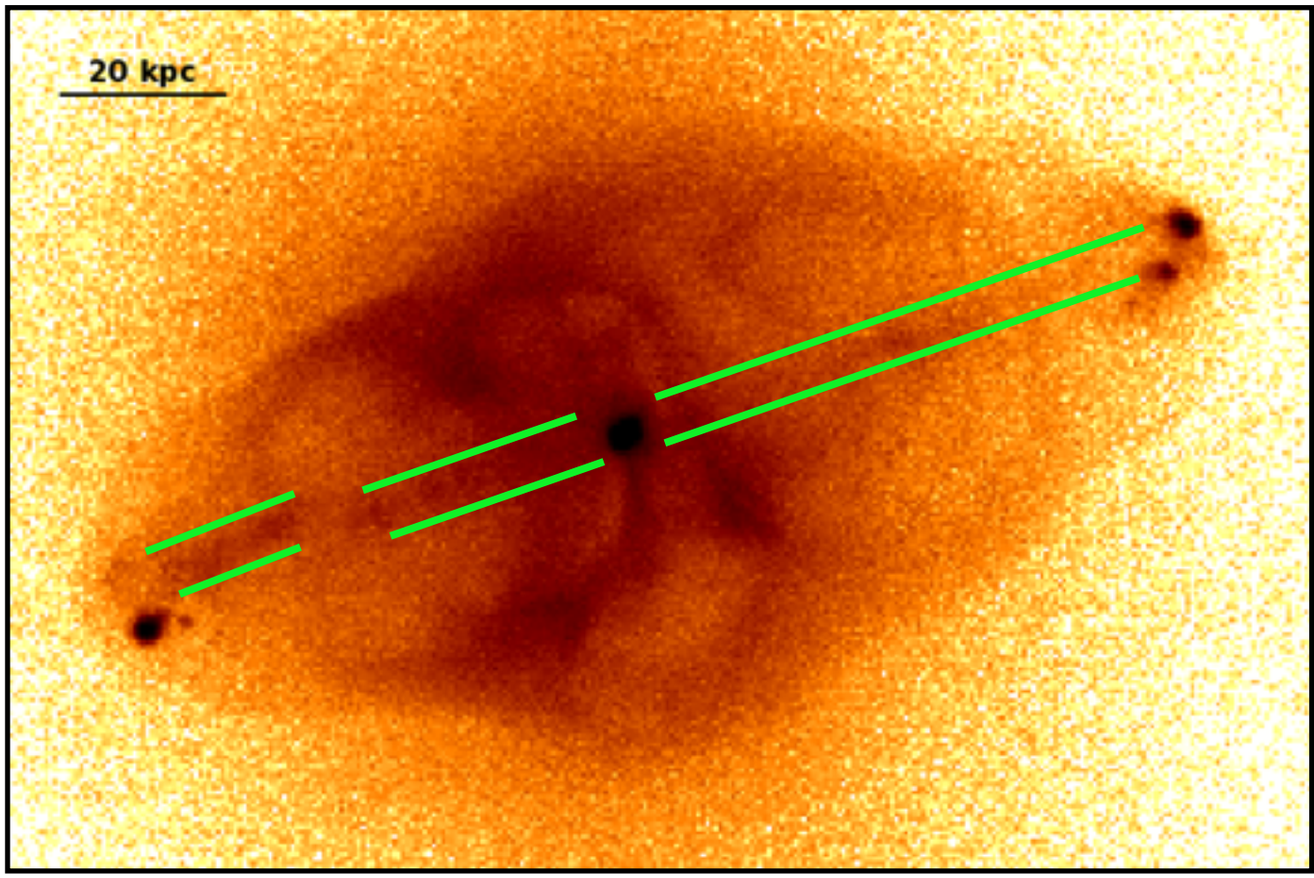
$\beta = 0.25c$

$\dot{M} = 2.0\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$

<u>East</u>

$\beta = 0.20c$

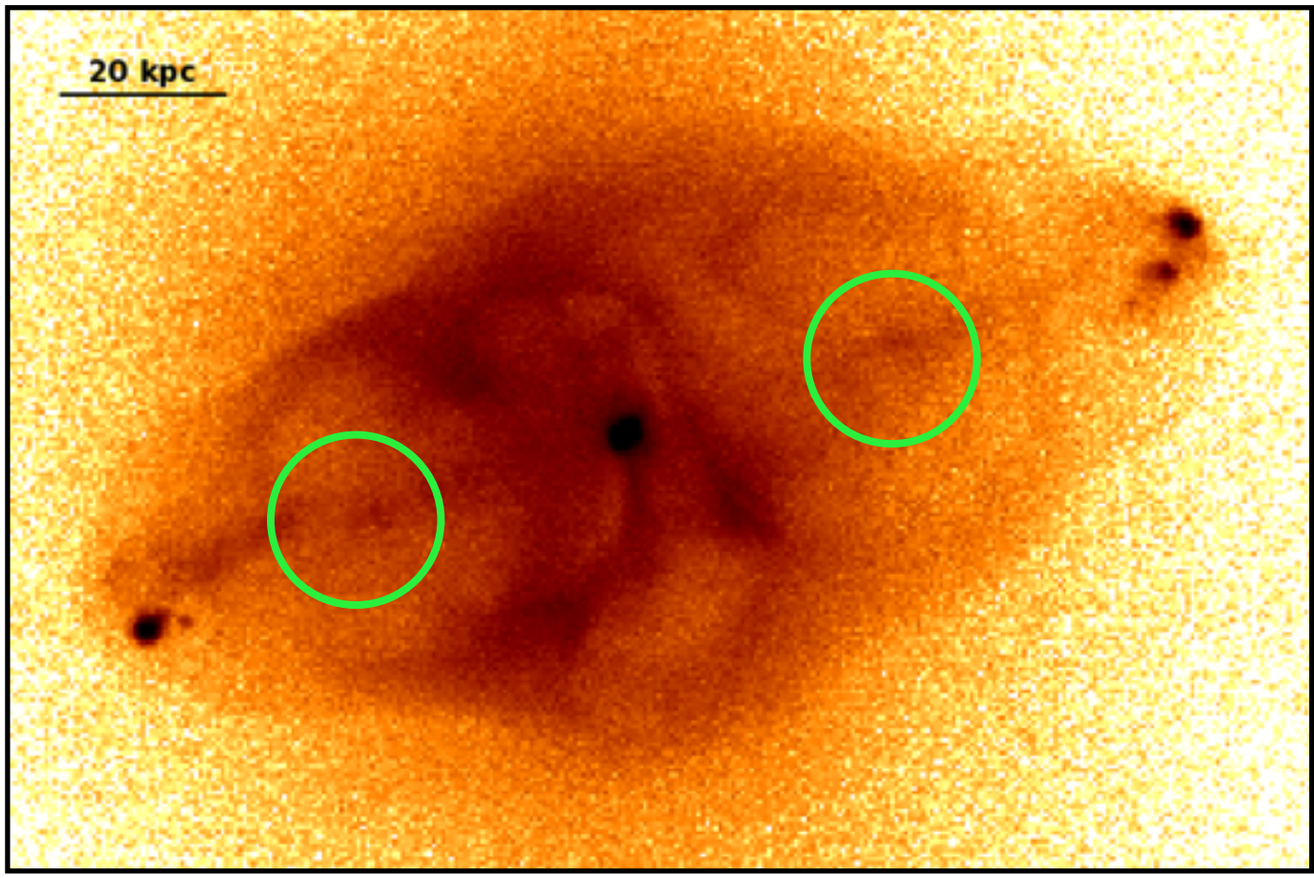
$\dot{M} = 1.2\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$



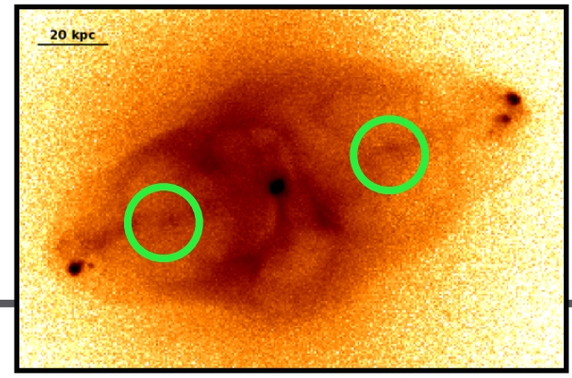
- Jets are internally supersonic $(M = 1.9)$
- Jets are subsonic with respect to lobes $(M = 0.9)$

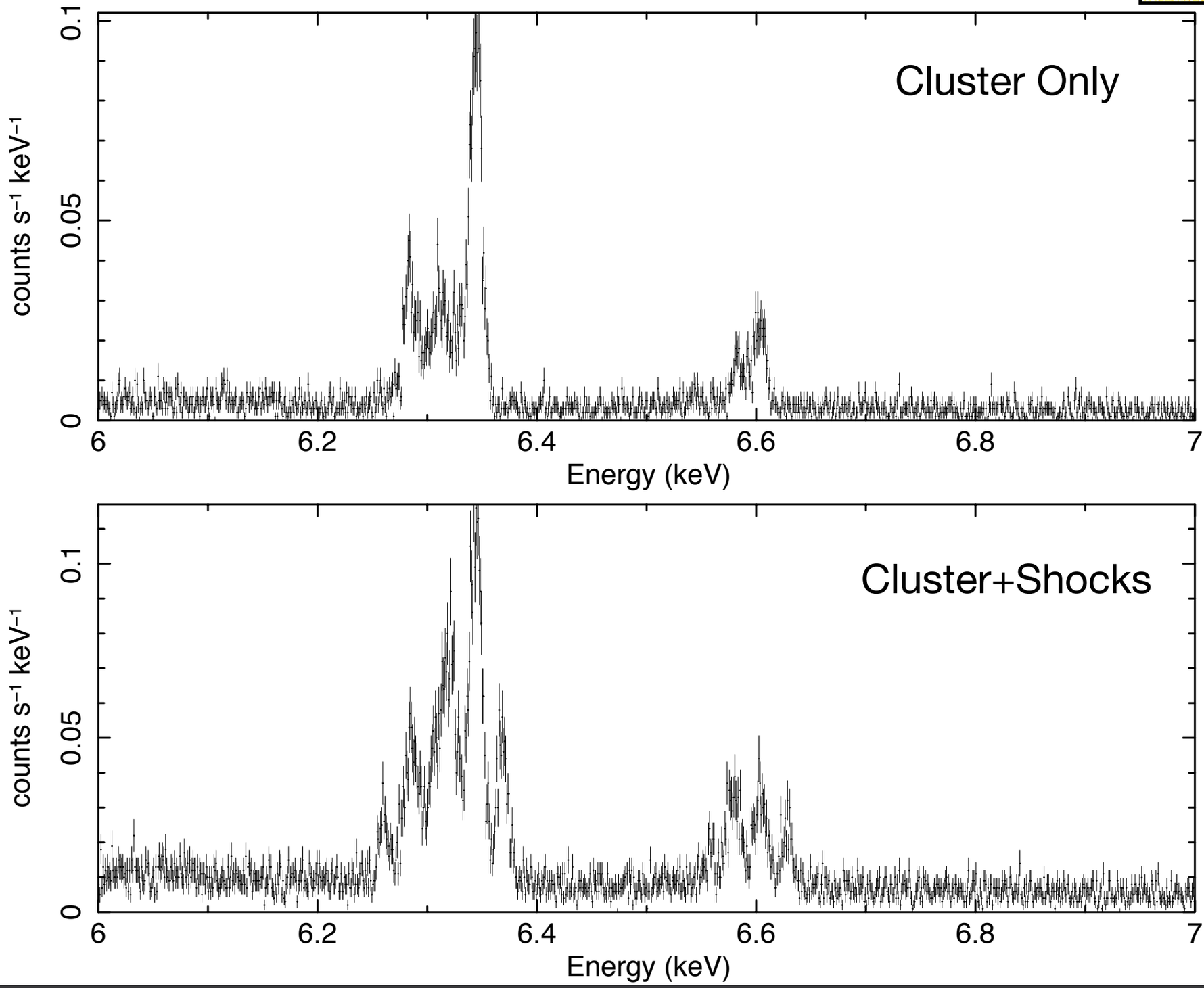
Simulating Spectra with Lynx

- Results dependent on cocoon shock speed estimates
- Most decisive method to measure shock speed is through direct measurement of shocked gas velocities via high-resolution spectroscopy



Simulating Spectra with Lynx





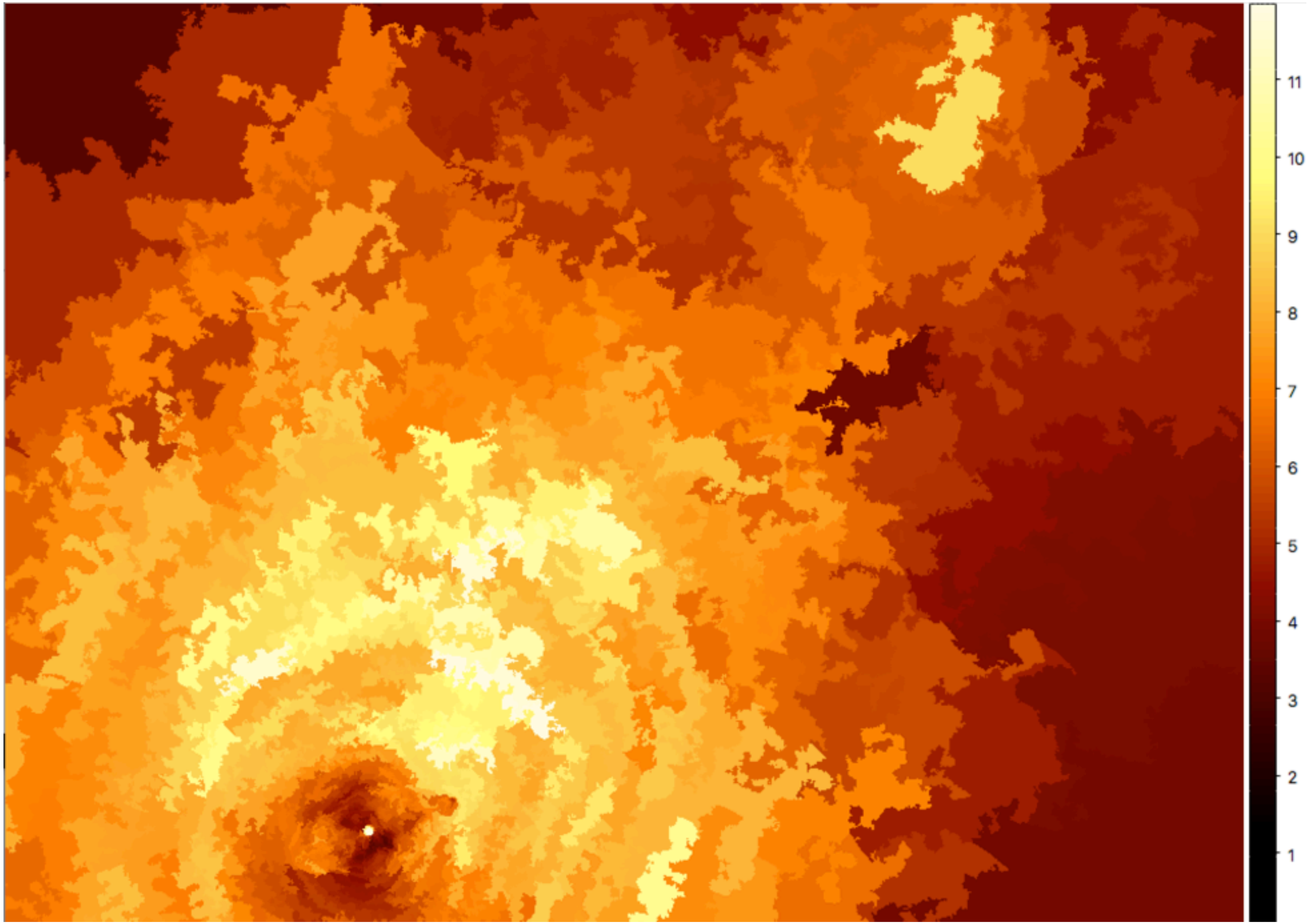
T_{exp} = 750 ksec

Model parameters based on *Chandra* data

Conclusions

- Uniform pressures and speeds observed across cocoon shock of Cygnus A
- From outburst model: $T_{\rm age}$ = 20 Myr, P = 10^{46} erg/sec
- Jets properties consistent with models
- Jet flow speeds are internally supersonic; jets are subsonic with respect to the lobes
- Lynx will enable direct measurements of shock strength from gas velocities

Thank You


11
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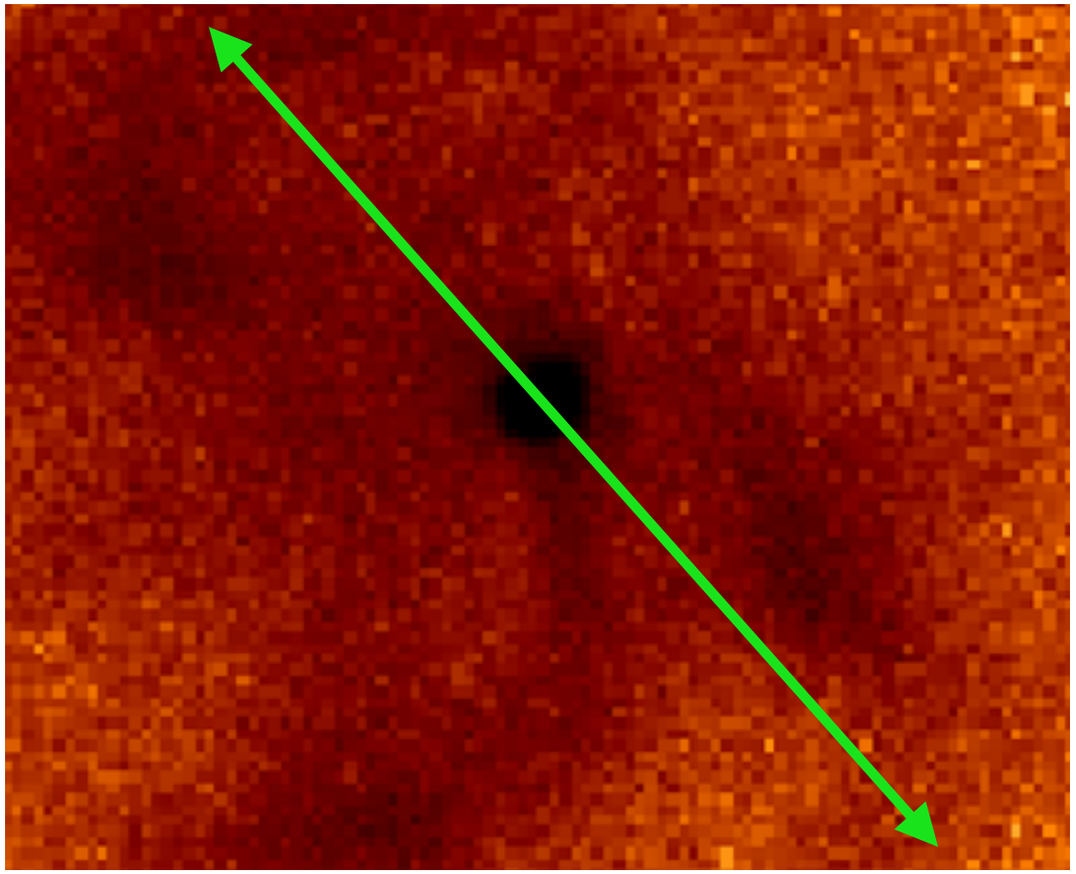
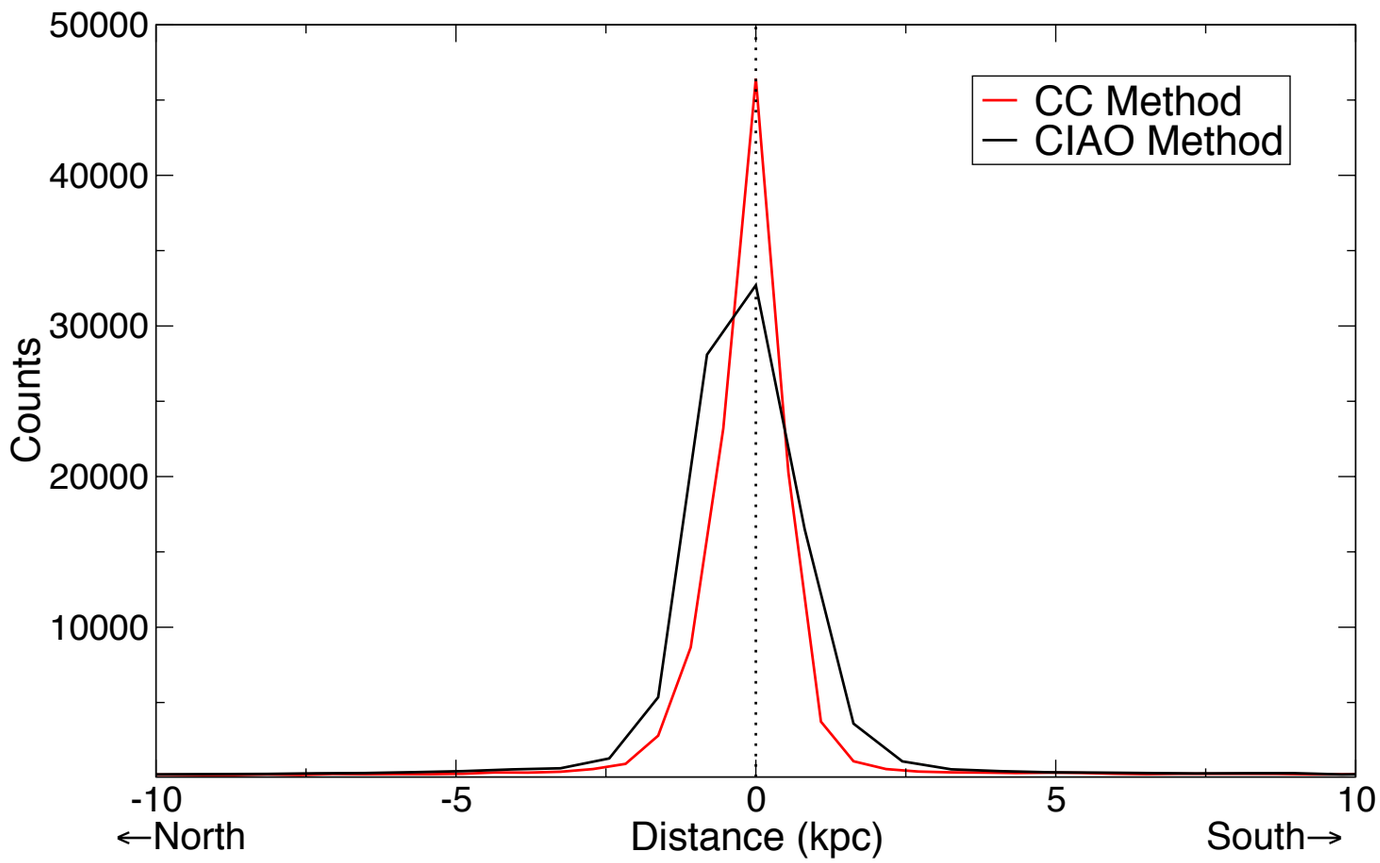
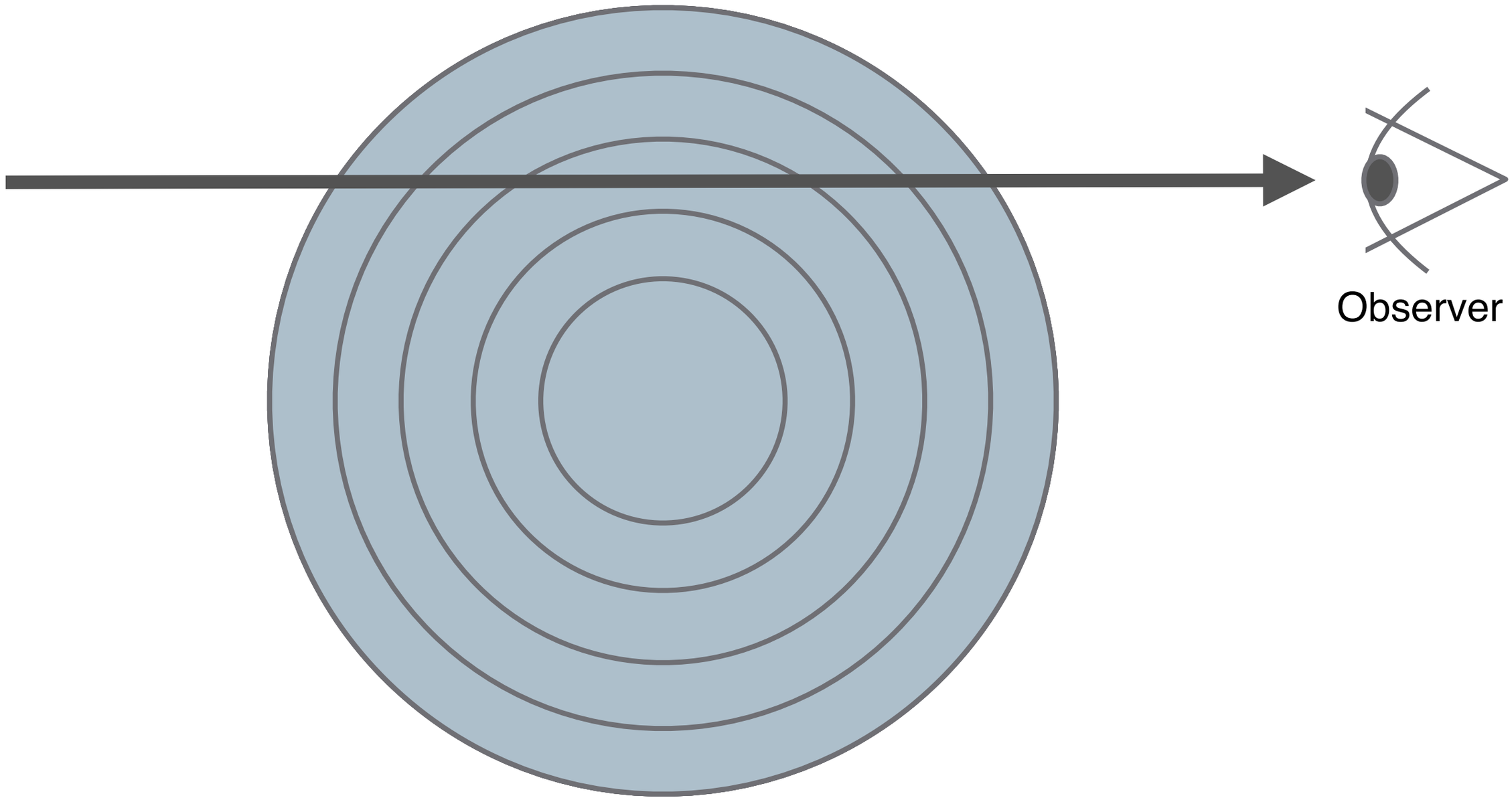
Data Reduction

- Received 2.0 Msec of *Chandra* observation time
- Used CIAO for background subtraction and merging
- Cross correlation method used for astrometric corrections

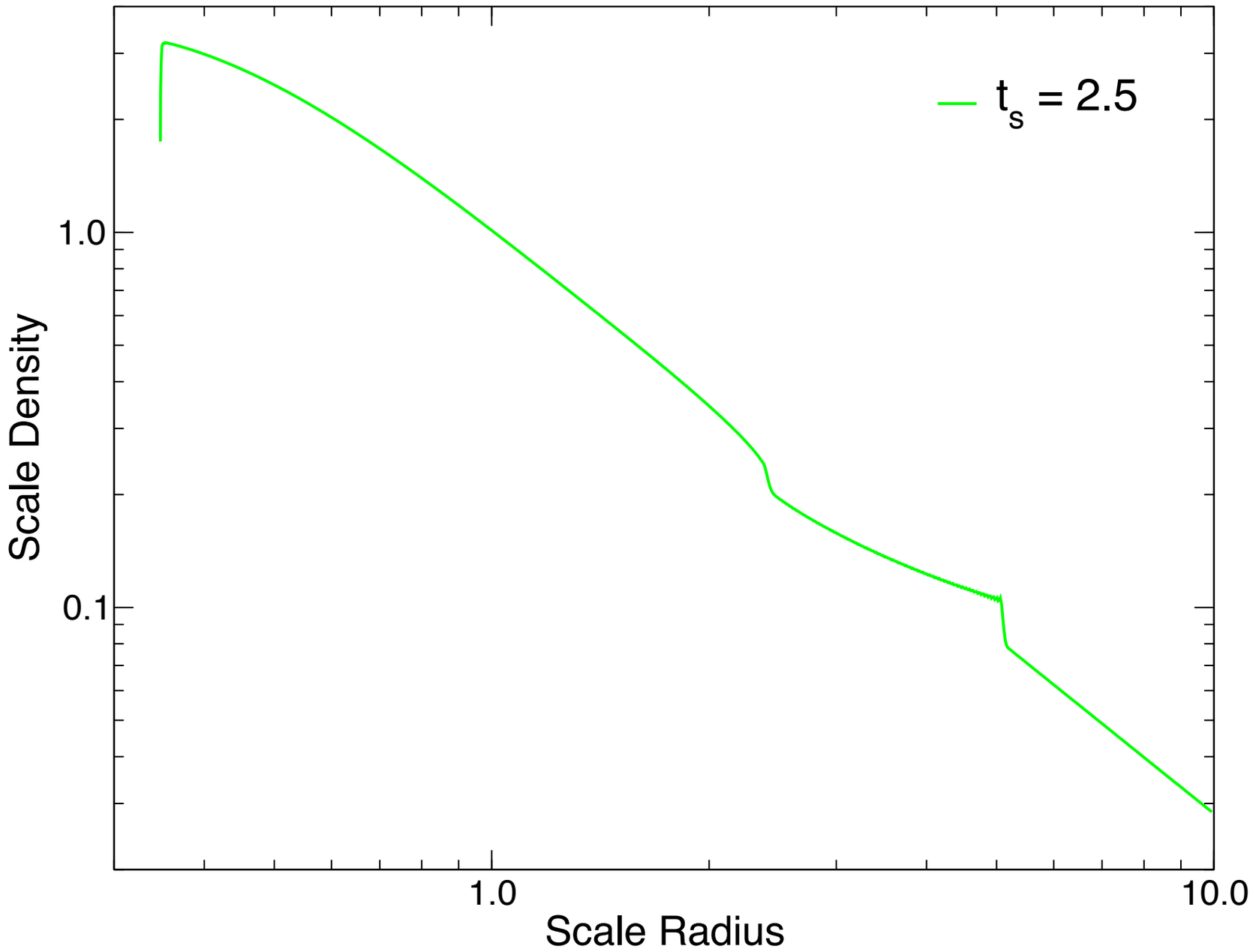




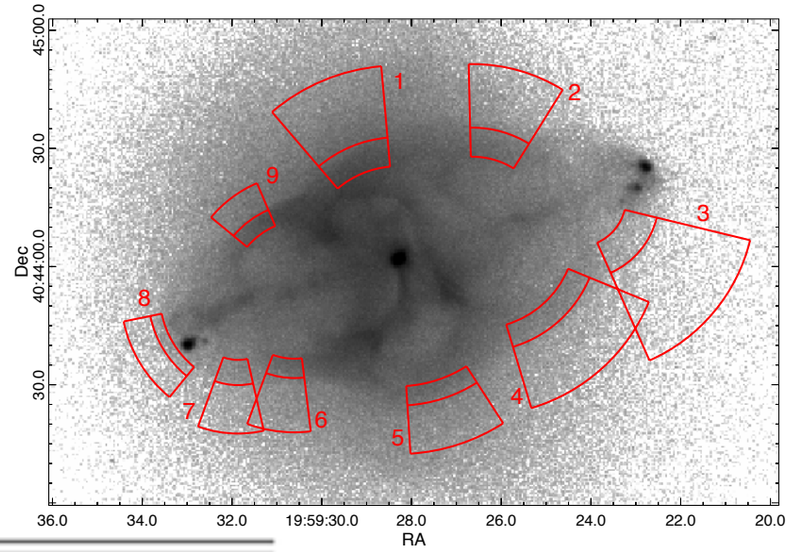
Deprojection



Hydrodynamic Model

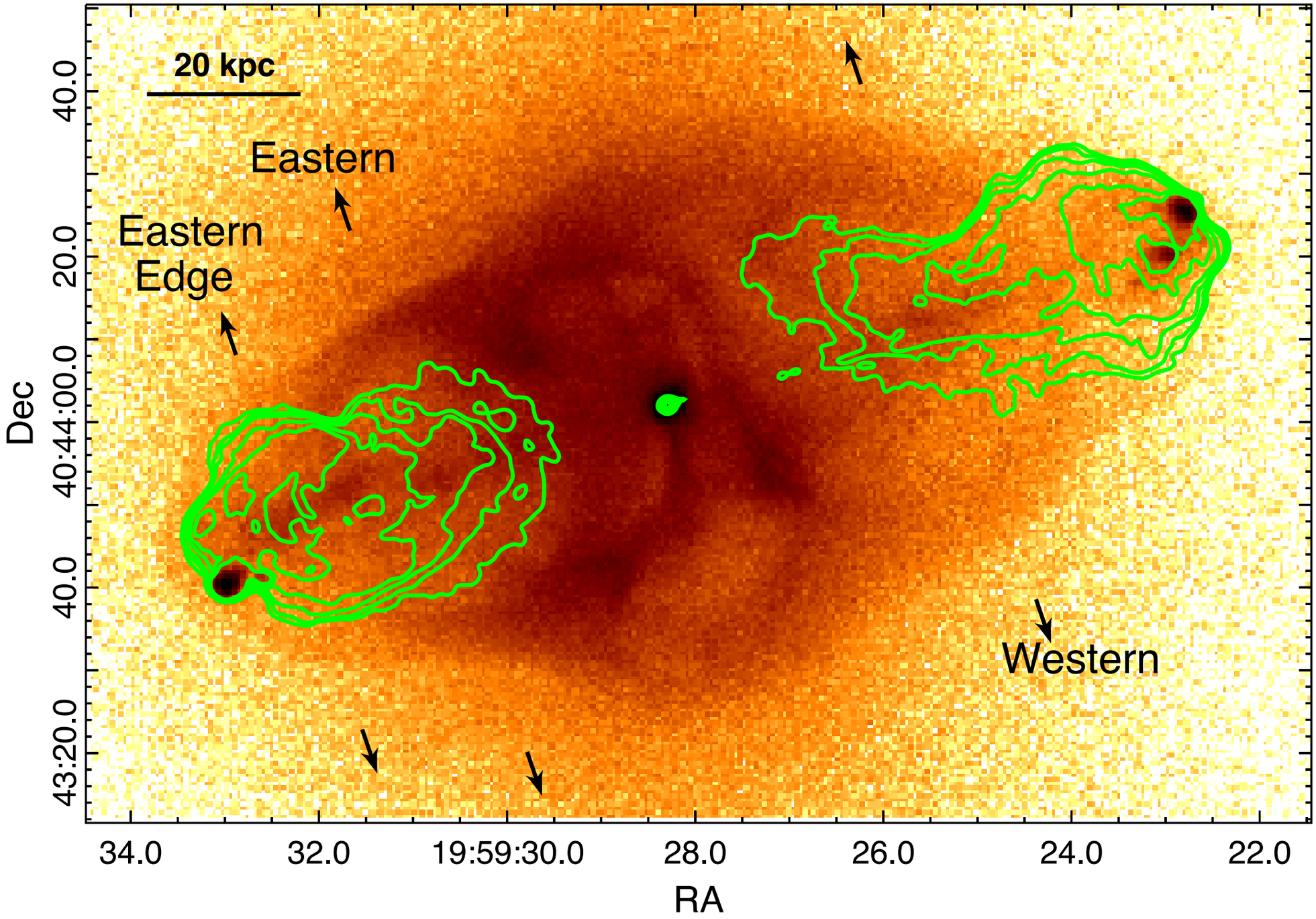


Fitting Shock Fronts

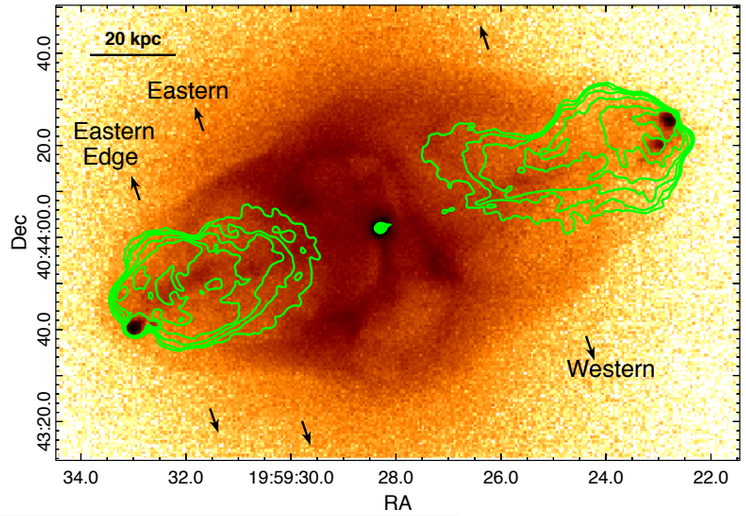


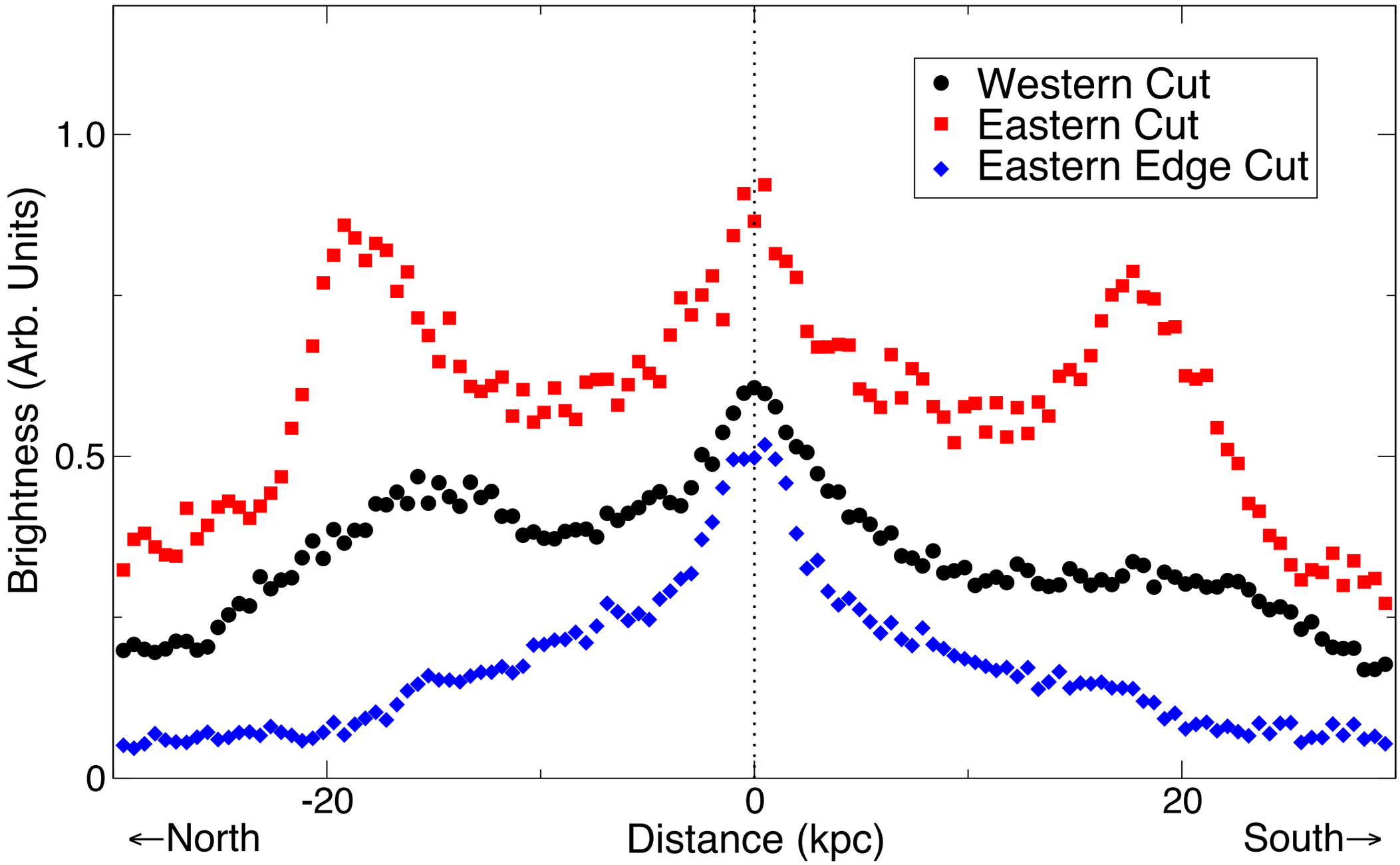
	Broken Power Law		1-D Hydro Model	
Region	Density Jump	Mach Number	Density Jump	Mach Number
1	$1.31^{+0.02}_{-0.02}$	$1.21^{+0.01}_{-0.01}$	$1.31^{+0.01}_{-0.01}$	$1.21^{+0.01}_{-0.01}$
2	$1.55^{+0.05}_{-0.04}$	$1.38^{+0.03}_{-0.03}$	$1.61^{+0.01}_{-0.01}$	$1.42^{+0.01}_{-0.01}$
3	$1.55^{+0.11}_{-0.07}$	$1.38^{+0.08}_{-0.05}$	$1.56^{+0.05}_{-0.09}$	$1.39^{+0.03}_{-0.07}$
4	$1.55^{+0.06}_{-0.06}$	$1.38^{+0.04}_{-0.05}$	$1.65^{+0.04}_{-0.04}$	$1.45^{+0.03}_{-0.03}$
5	$1.32^{+0.05}_{-0.06}$	$1.22^{+0.04}_{-0.04}$	$1.46^{+0.01}_{-0.02}$	$1.31^{+0.01}_{-0.01}$
6	$1.58^{+0.08}_{-0.07}$	$1.40^{+0.06}_{-0.05}$	$1.70^{+0.05}_{-0.06}$	$1.49^{+0.04}_{-0.05}$
7	$1.73^{+0.22}_{-0.04}$	$1.51^{+0.18}_{-0.03}$	$1.87^{+0.11}_{-0.12}$	$1.62^{+0.10}_{-0.09}$
8	$1.94^{+0.36}_{-0.22}$	$1.68^{+0.32}_{-0.17}$	$2.00^{+0.26}_{-0.24}$	$1.73^{+0.24}_{-0.19}$
9	$1.85^{+0.15}_{-0.13}$	$1.60^{+0.13}_{-0.09}$	$1.91^{+0.03}_{-0.08}$	$1.65^{+0.03}_{-0.06}$

Shock Compression



Shock Compression





Lobe Pressures