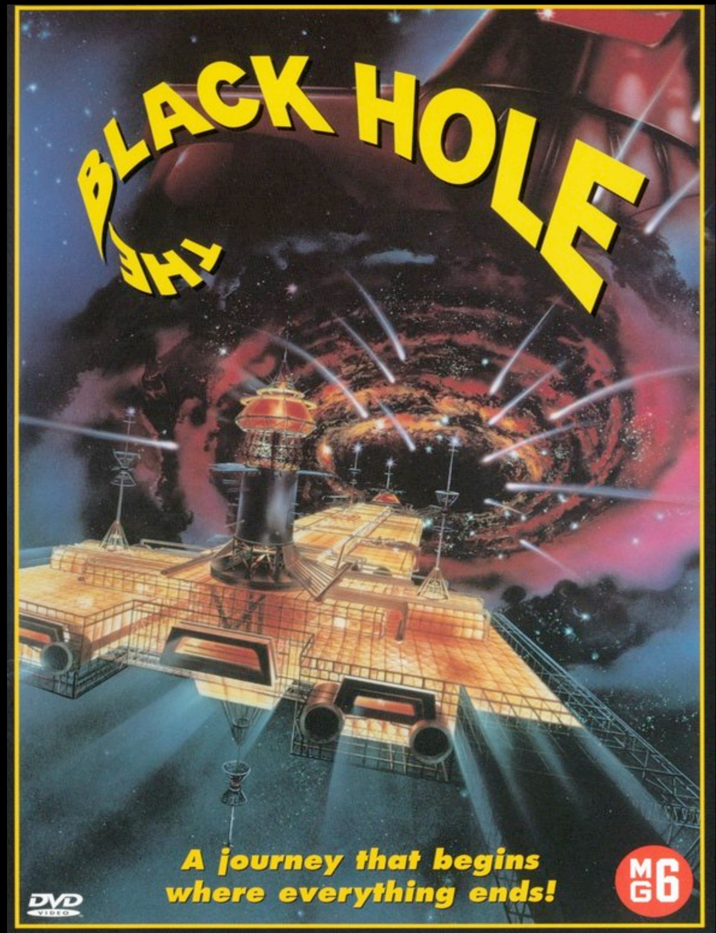
Discovery of a Double Peaked Fe Emission Line and X-ray BALs in Quasar H 1413+117



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Eric Agol, and Sarah Gallagher

Outline

- *Chandra* and *XMM-Newton* Observations of LoBAL quasar H 1413 + 117

- Constraints on quasar structure:

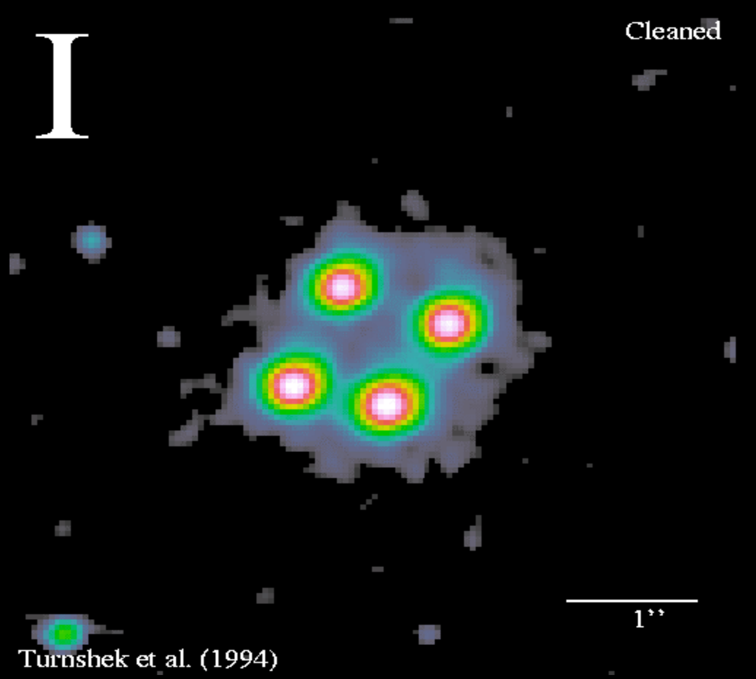
  from microlensing of Fe line,

  broad Fe absorption lines, and

  double peaked Fe emission line

- Origin of Fe lines and spectral differences between images

Chandra Observations of the Cloverleaf Quasar



HST I band image of H1413+117

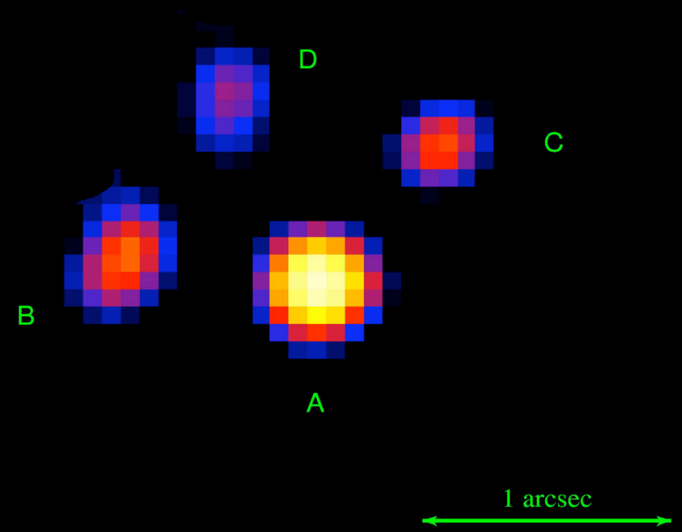
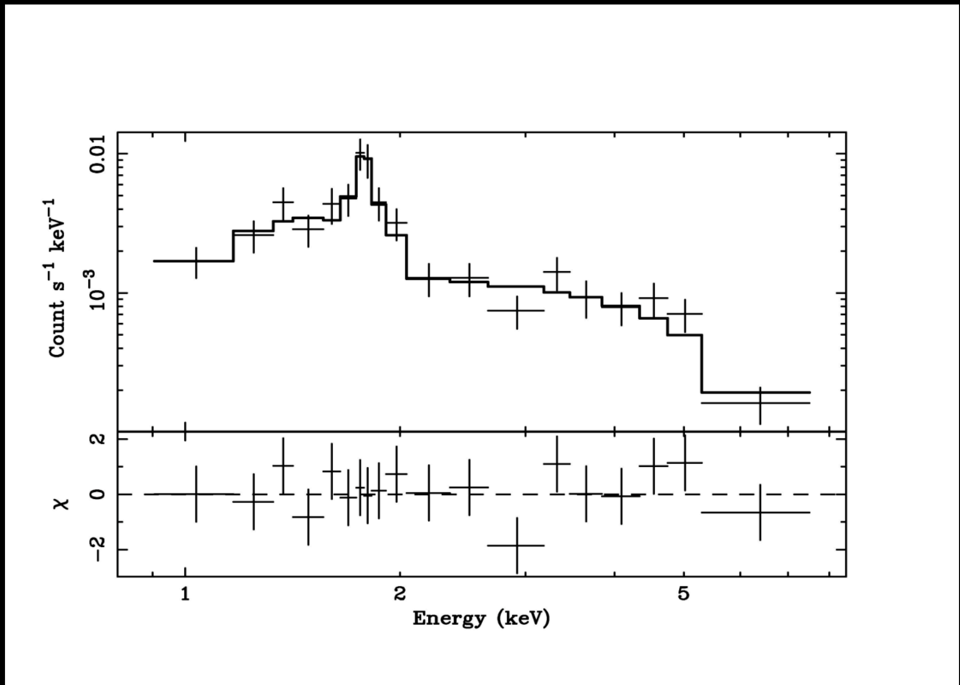


Image from a 38ks *Chandra* observation of H1413+117 performed on 2000 April 19

- $z_s = 2.56$, $z_l = 1.55$?
- Lens magnification ~ 10-20
- H1413+117 shows low ionization transitions of Mg II, Al III (LoBAL)
- Continuum polarization 1.5-3.5%

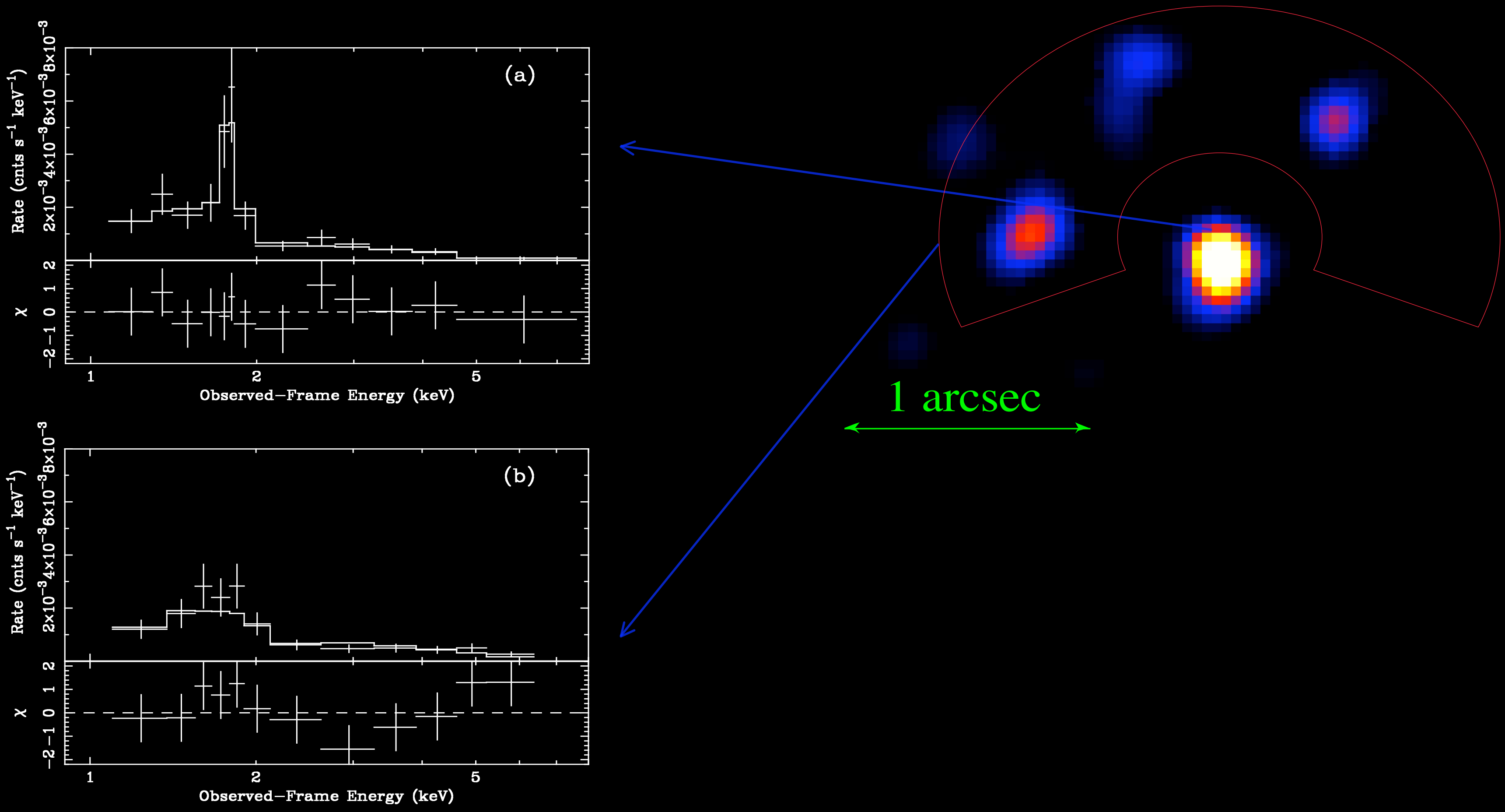
Chandra Observations of the Cloverleaf Quasar



- A remarkable iron emission feature at E ~ 6.2keV was discovered in the combined spectrum of all lensed images (Oshima et al. 2000).

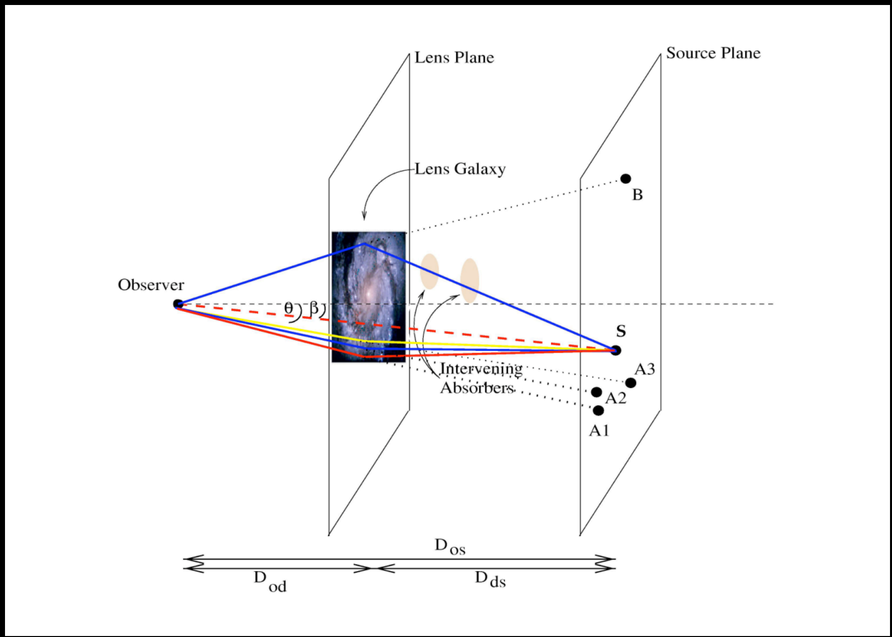
- This intriguing result suggests that X-rays are reflected off of the far side of the BAL wind.

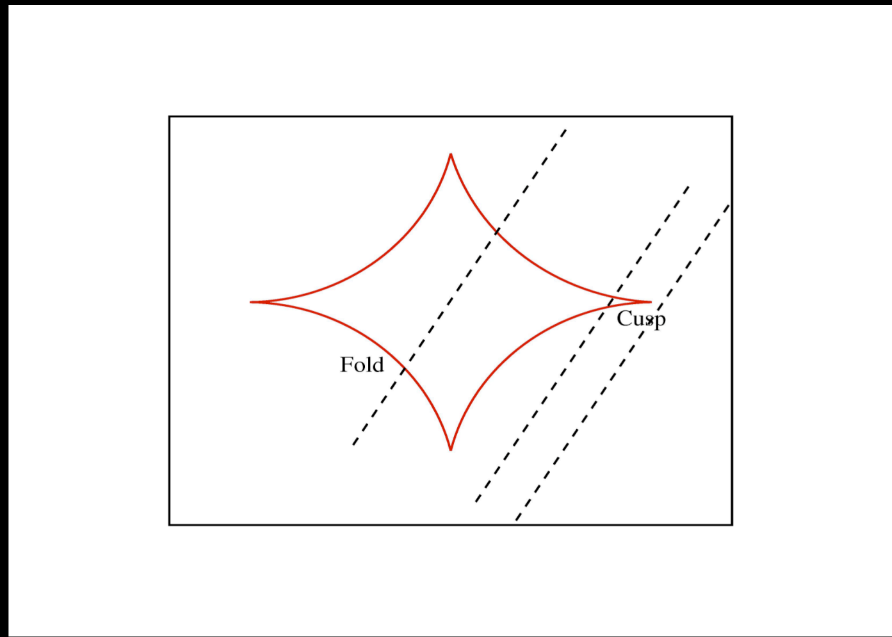
Chandra Observations of the Cloverleaf Quasar



A likely explanation of the observed differential X-ray magnification is a microlensing event in image A.

Chandra Observations of the Cloverleaf Quasar





Caustic of a single star plus shear. Three tracks are shown of sources crossing fold and cusp caustics.

- A useful scale in microlensing is the Einstein Radius:

$$\zeta_E = (4GM_{star}/c^2)(D_{os}D_{ls}/D_{ol})^{1/2}$$

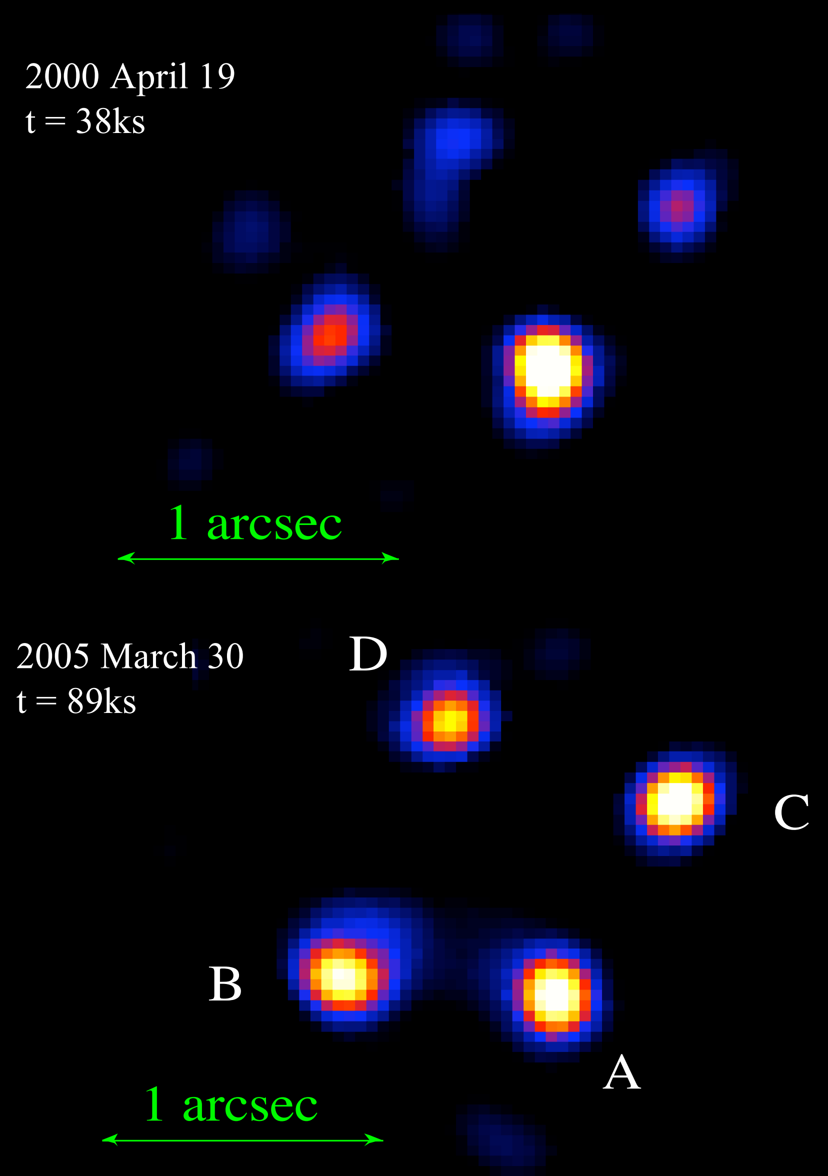
$$\zeta_E \sim 2 \times 10^{16} (M_{star}/M_{solar})^{1/2}\ h^{-0.5}\ \mathrm{cm}$$

- Crossing time scales:

$$t_E \sim \zeta_E/v_t$$

$$t_{HME} \sim r_s/v_t$$

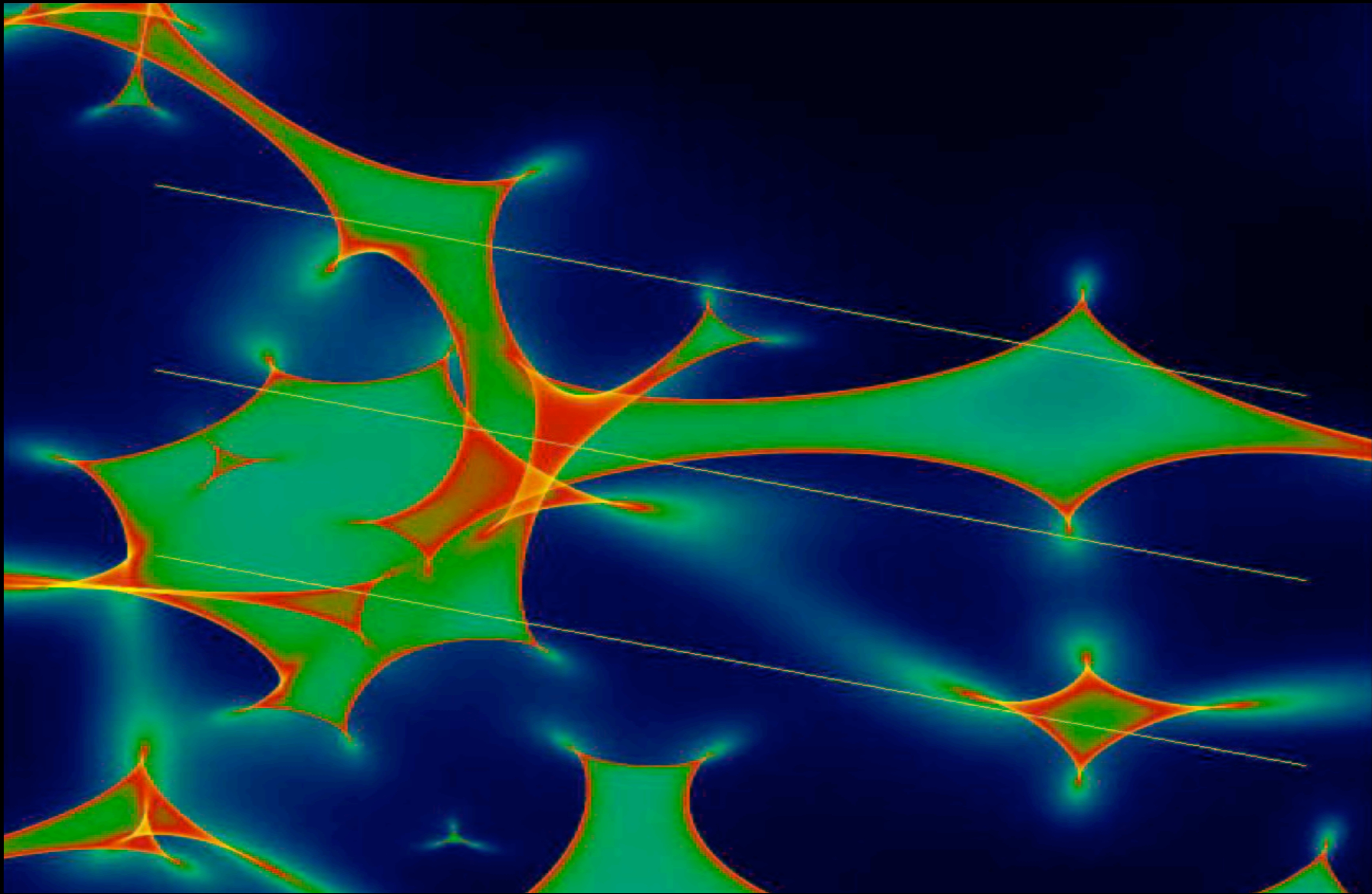
Chandra Observations of the Cloverleaf Quasar



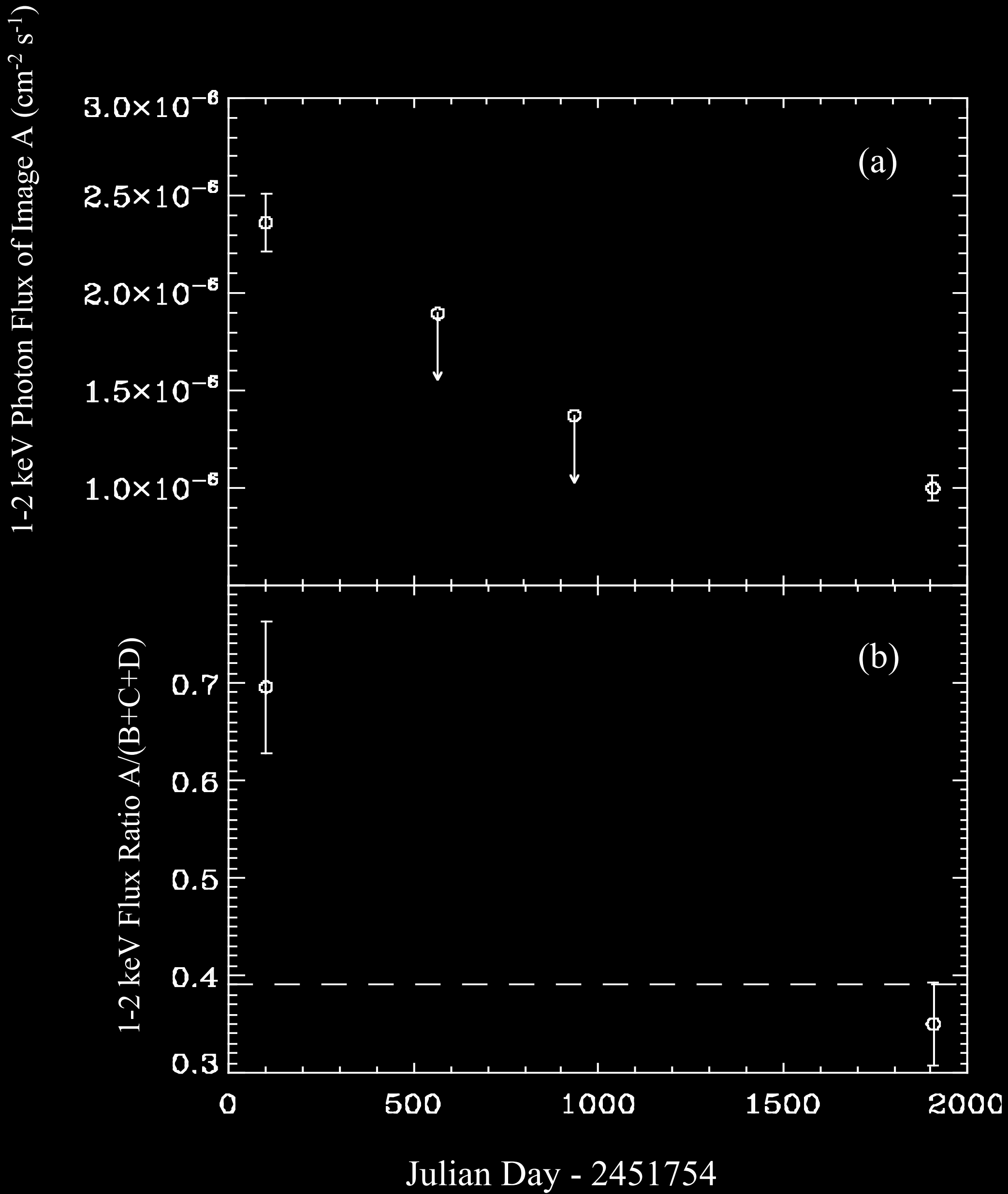
Microlensing Event Confirmed

- The X-ray flux ratios for the 2005 observation of Cloverleaf are consistent with the *HST R*-band flux ratios.
- The 0.2-8 keV count-rate of image A decreased by a factor of ~2 while the 0.2-8 keV count-rates of the other images remained the same.

Cloverleaf Quasar: Constraints from microlensing



Cloverleaf Quasar: Constraints from microlensing



(panel a) The 1- 2 keV photon flux of image A for the four observations of Cloverleaf.

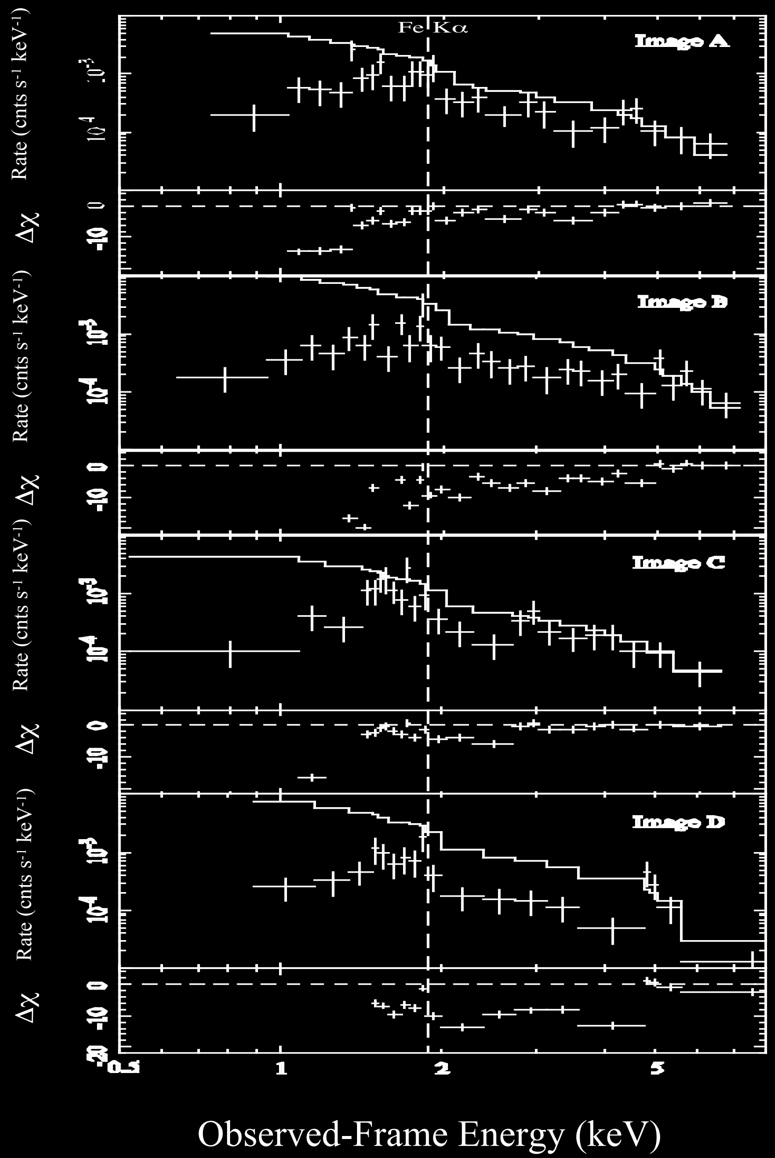
The two *XMM* observations do not resolve image A and we therefore provide upper limits for these epochs.

(panel b) The ratio of the 1-2 keV fluxes between image A and images B+C+D for the two *Chandra* observations of Cloverleaf. We have also overplotted with a dashed line the ratio of the *HST R*-band fluxes between image A and images B+C+D.

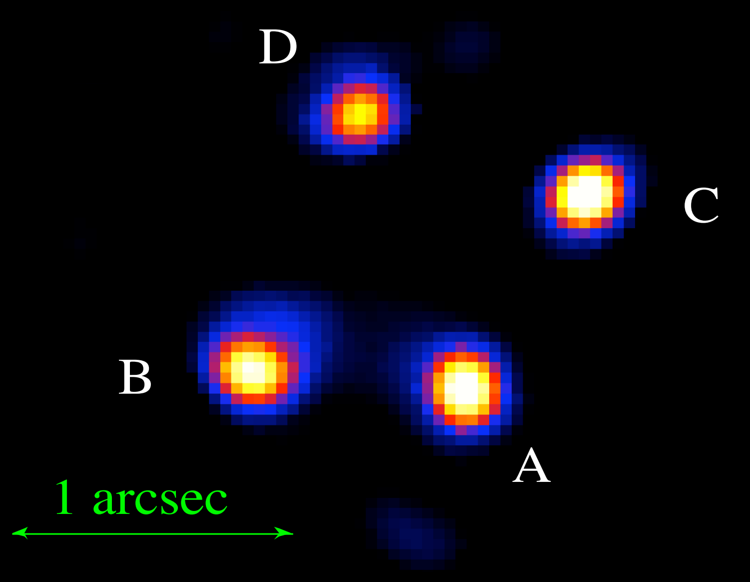
The sizescale of the source region being microlensed is:

$R_{src} = v_t\, t_e \sim 3.4 \times 10^{13}$ m $\sim 14\ r_g$

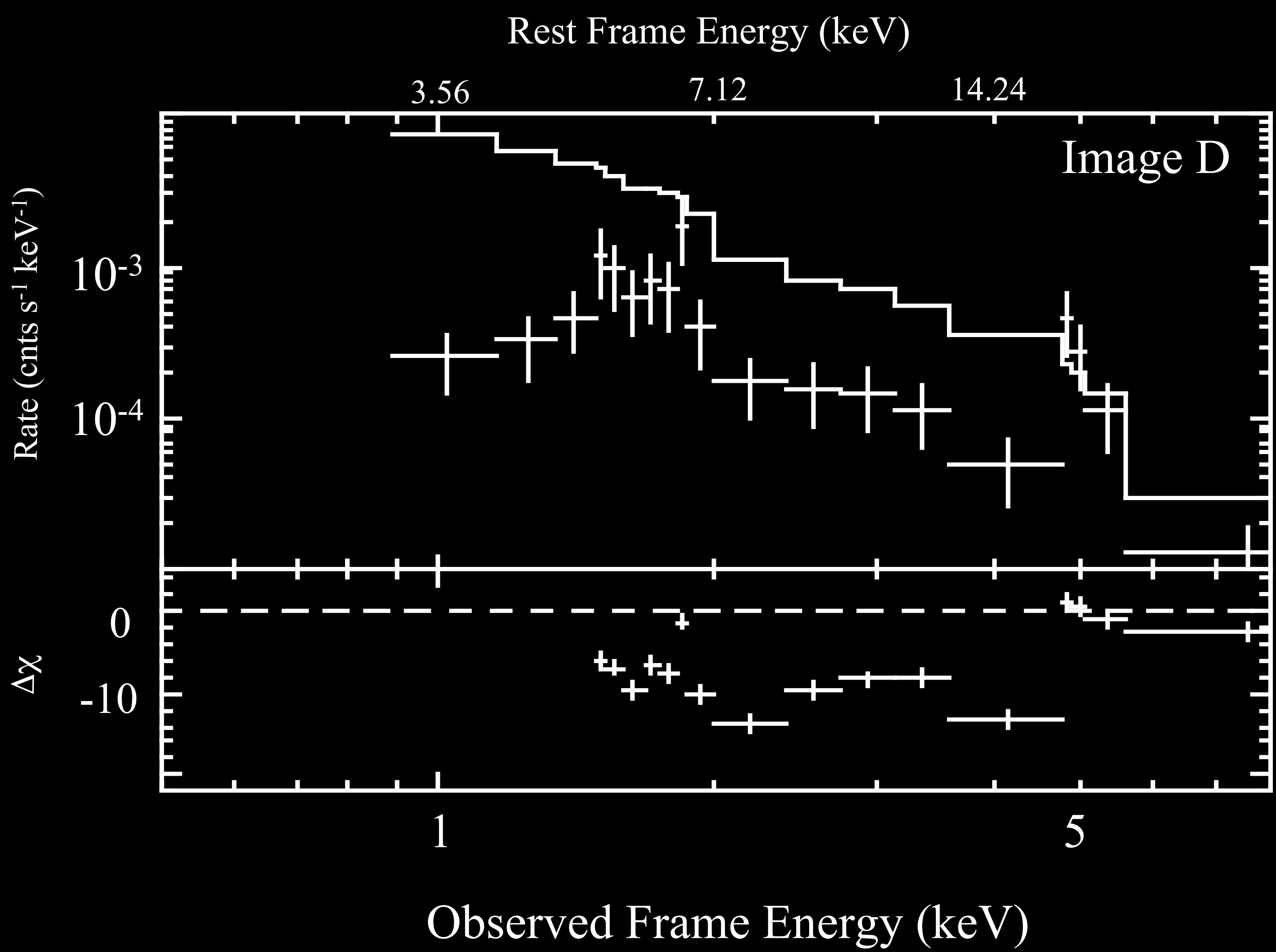
Cloverleaf Quasar: Constraints from broad Fe Absorption Lines



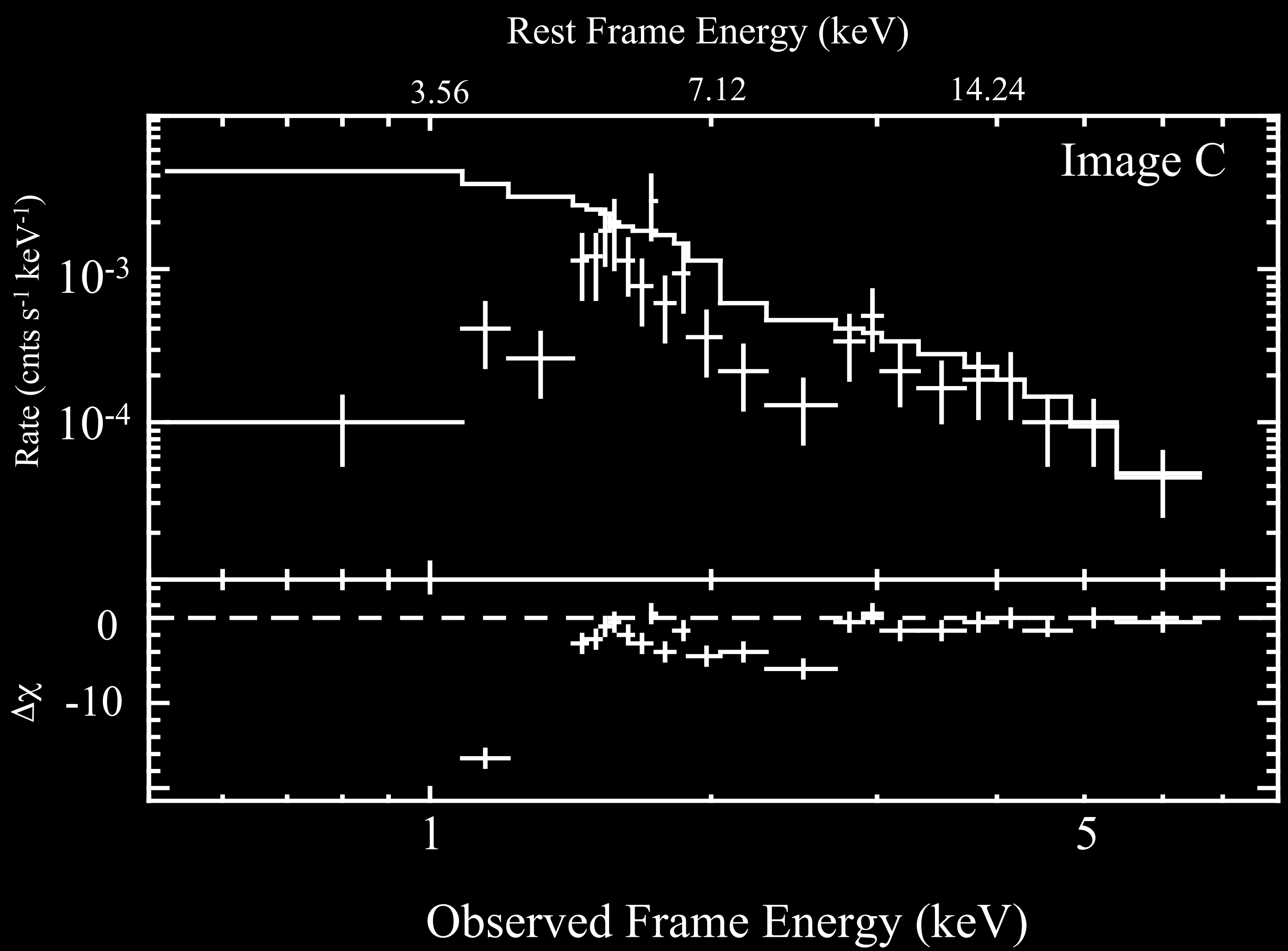
The spectra of images A, B, C, and D for the 89 ks *Chandra* observation of Cloverleaf fit with a power-law model at high energies and Galactic absorption.



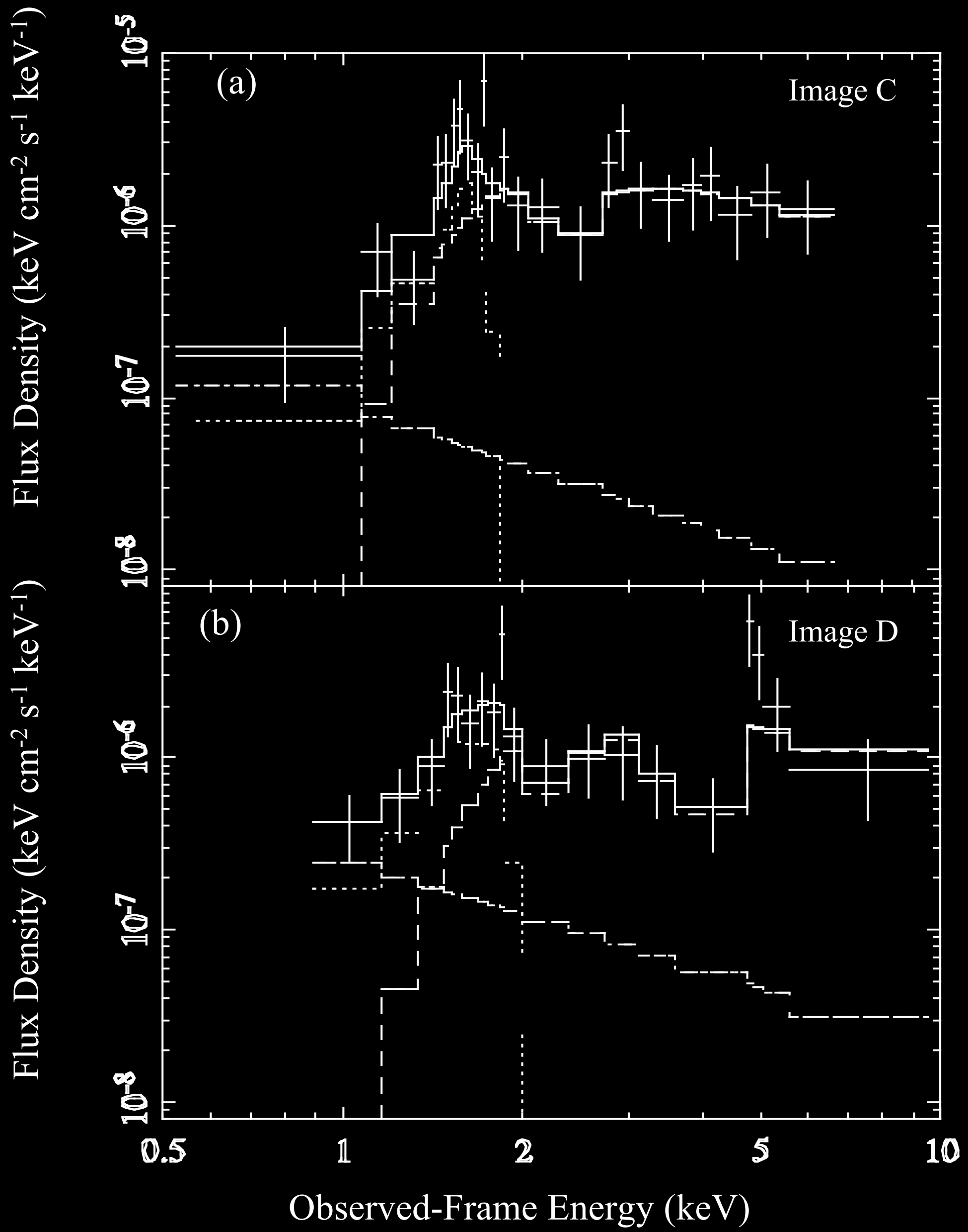
Cloverleaf Quasar: Constraints from broad Fe Absorption Lines



Cloverleaf Quasar: Constraints from broad Fe Absorption Lines



Cloverleaf Quasar: Constraints from broad Fe Absorption Lines

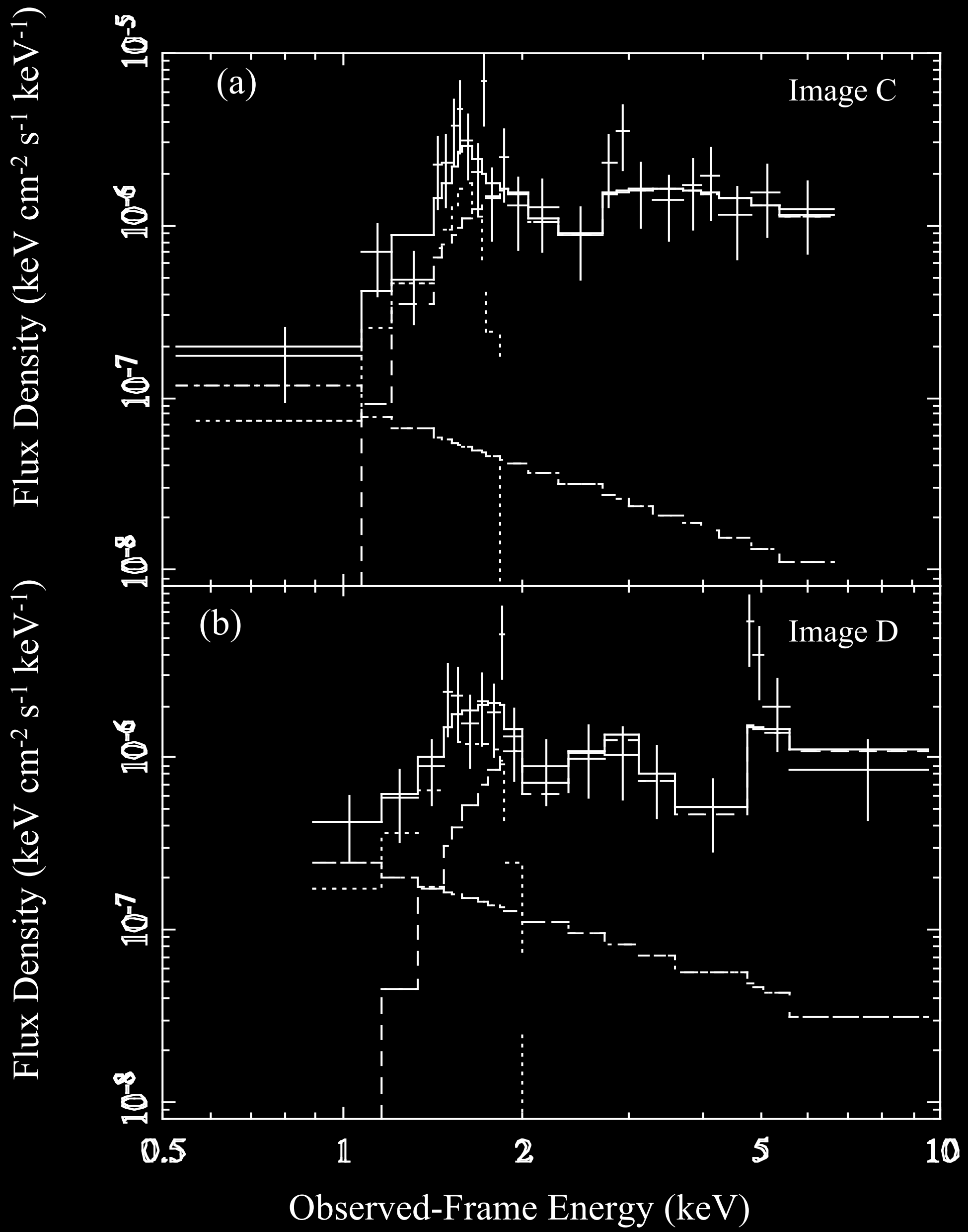


The unfolded spectra of images C (panel a) and D (panel b) of Cloverleaf plotted with the best-fit models that consist of the following components:

- Galactic absorption,
- direct emission of a power-law modified by intrinsic neutral absorption (dashed line),
- scattered emission of a power law assuming simple Thomson scattering (dot-dashed line),
- a fluorescent Fe line from an accretion disk around a black hole where the Fe line model includes GR effects (dotted line),
- saturated absorption centered at and energy E_{BAL} and within E_{BAL} +/- $w_{BAL}/2$

Absorption features are significant at the > 95% confidence level

Cloverleaf Quasar: Constraints from broad Fe Absorption Lines



Results from Fits:

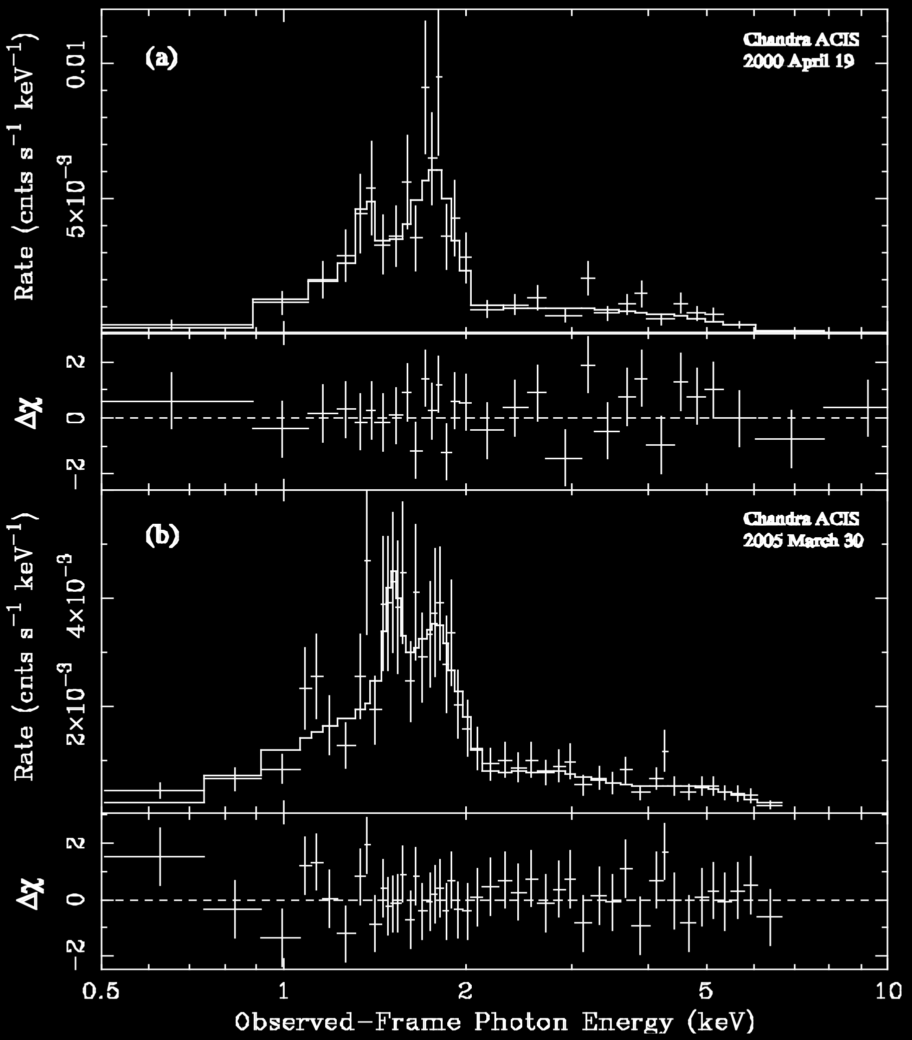
Image C
E_{BAL} = 8.6 +/- 0.1 keV
w_{BAL} = 0.5 +/- 0.3 keV

Image D
E_{BAL} = 14.0 +/- 0.2 keV
w_{BAL} = 2.3 +/- 0.4 keV

Interpretation of X-ray BALs:
They are resonance transitions in highly ionized Fe XXV and/or Fe XXVI outflowing from the accretion disk.

$Vmax_C = 0.29c$
$Vmax_D = 0.67c$

Cloverleaf Quasar: Constraints From Double Peaked Fe Emission Lines



The spectra of combined images A, B, C, and D of the Cloverleaf quasar for (a) the 38 ks *Chandra* observation and (b) the 89 ks *Chandra* observation.

Spectral fits indicate the significant presence of emission lines at rest-frame energies of:

2000 April 19 Observation:

E_{emis1} = 4.90 +/- 0.35 keV

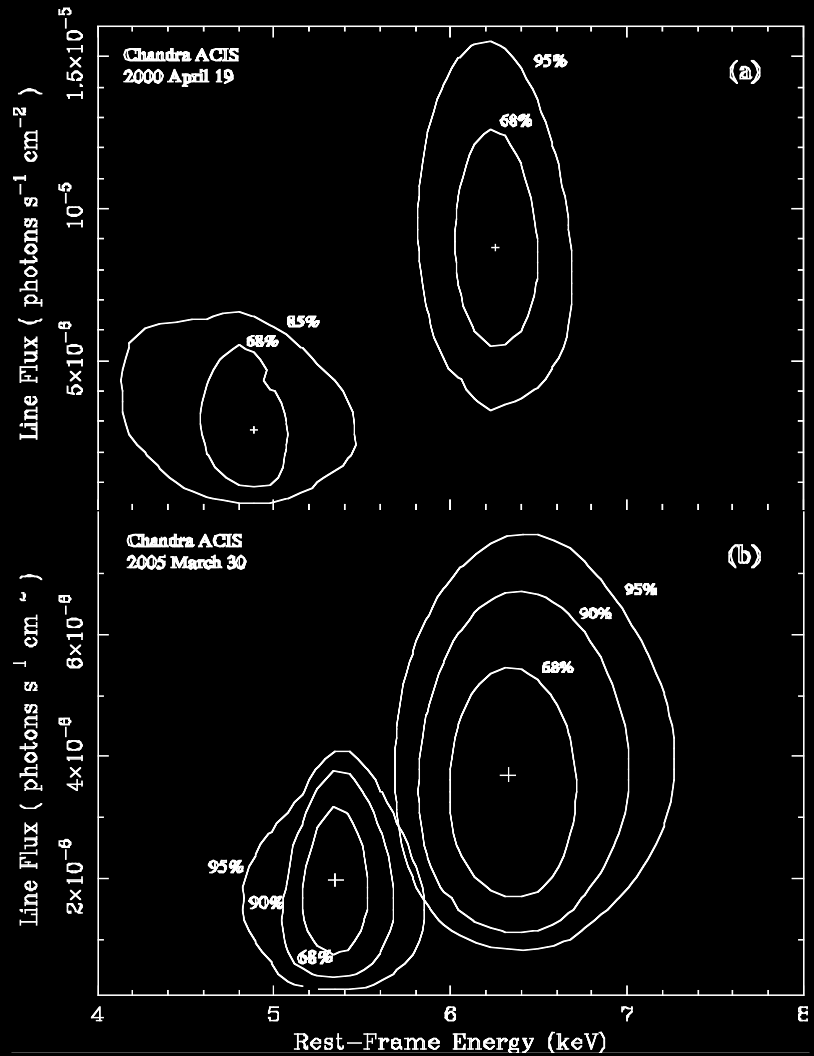
E_{emis2} = 6.25 +/- 0.25 keV

2005 March 30 Observation:

E_{emis1} = 5.35 +/- 0.23 keV

E_{emis2}= 6.32 +/-0.4 keV

Cloverleaf Quasar: Constraints From Double Peaked Fe Emission Lines

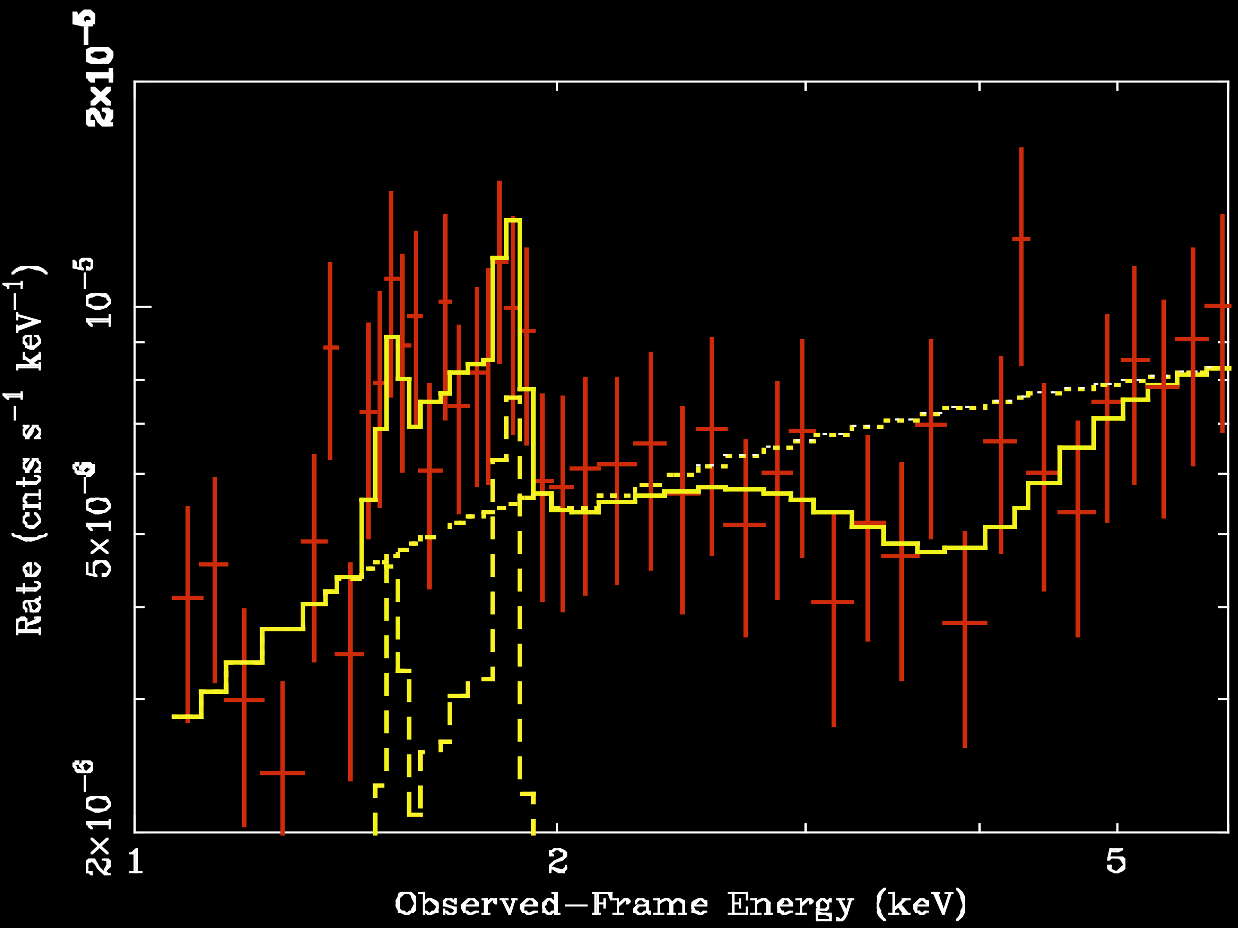


Confidence contours between the flux and energy of the two Fe Kα emission lines detected in the combined spectra of all images of the

(a) 38 ks *Chandra* observation and

(b) the 89 ks *Chandra* observation of the Cloverleaf.

Cloverleaf Quasar: Constraints From Double Peaked Fe Emission Lines



Schwarzschild black hole model:

EW = 1.2 +/- 0.5 keV

r_{in} = 15.7 r_g

r_{out} = 15.8 r_g

q = -4

i = 26 +/- 10

Kerr black hole model:

EW = 1.6 +/- 0.0 keV

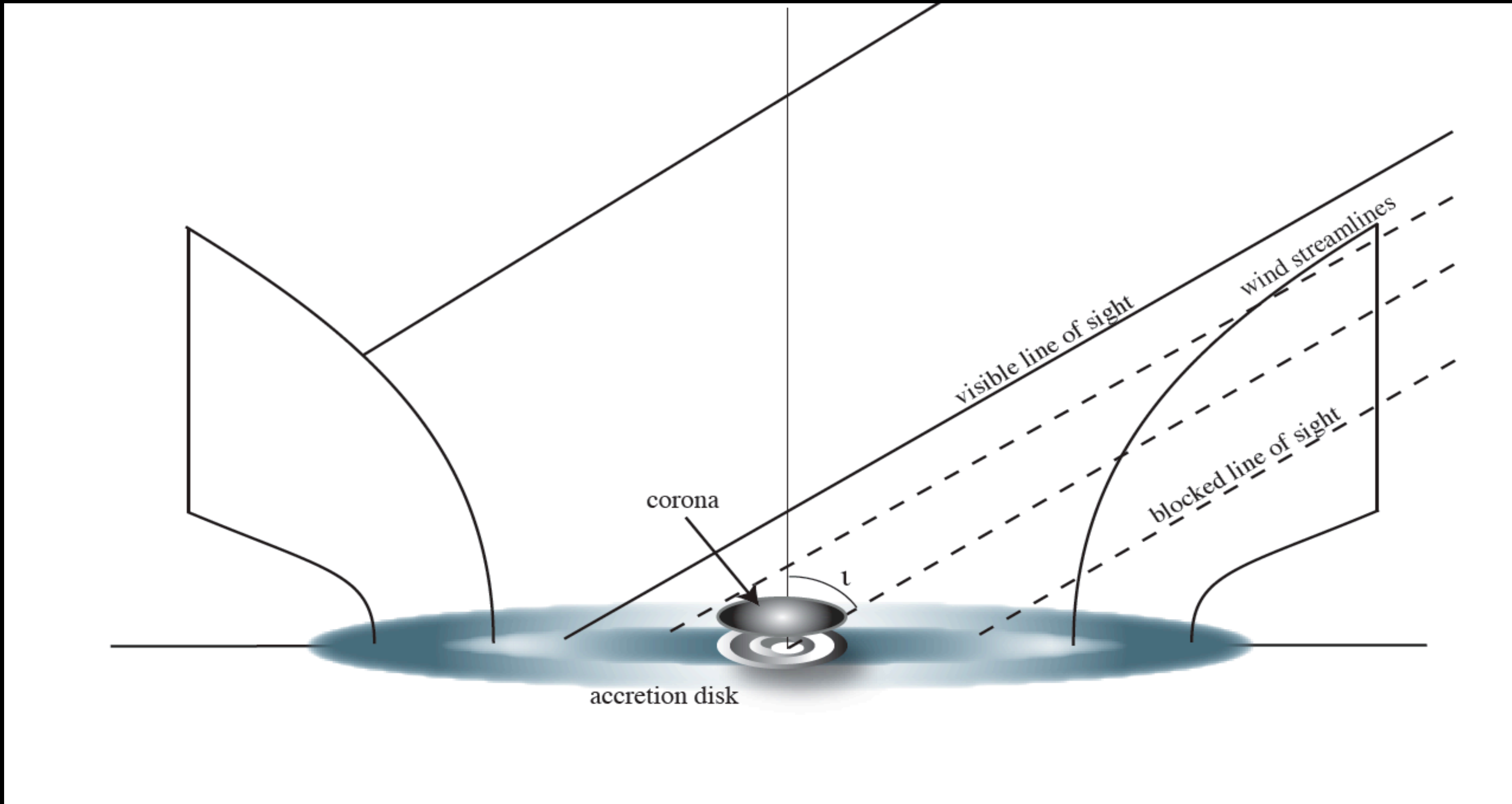
r_{in} = 1.46 r_g

r_{out} = 1.83 r_g

q = -4

i = 70 +/- 10

Cloverleaf Quasar: Origin of Fe Emission Lines



Schematic diagram of a proposed geometry for the outflow and accretion disk of the Cloverleaf quasar. X-ray emission from the near side of the accretion disk and the central continuum source is blocked by the Compton thick absorbing wind. Scattered and fluorescent emission from the far side of the accretion disk and outflow may reach the observer.

Cloverleaf Quasar: Origin of Fe Emission Lines

(a) The line emission originates from fluorescent Fe emission of the far side of the inner accretion disk.

pros

- observed energies and widths of the iron lines
- the estimated size of the microlensed Fe emission region is ~14rg.

cons

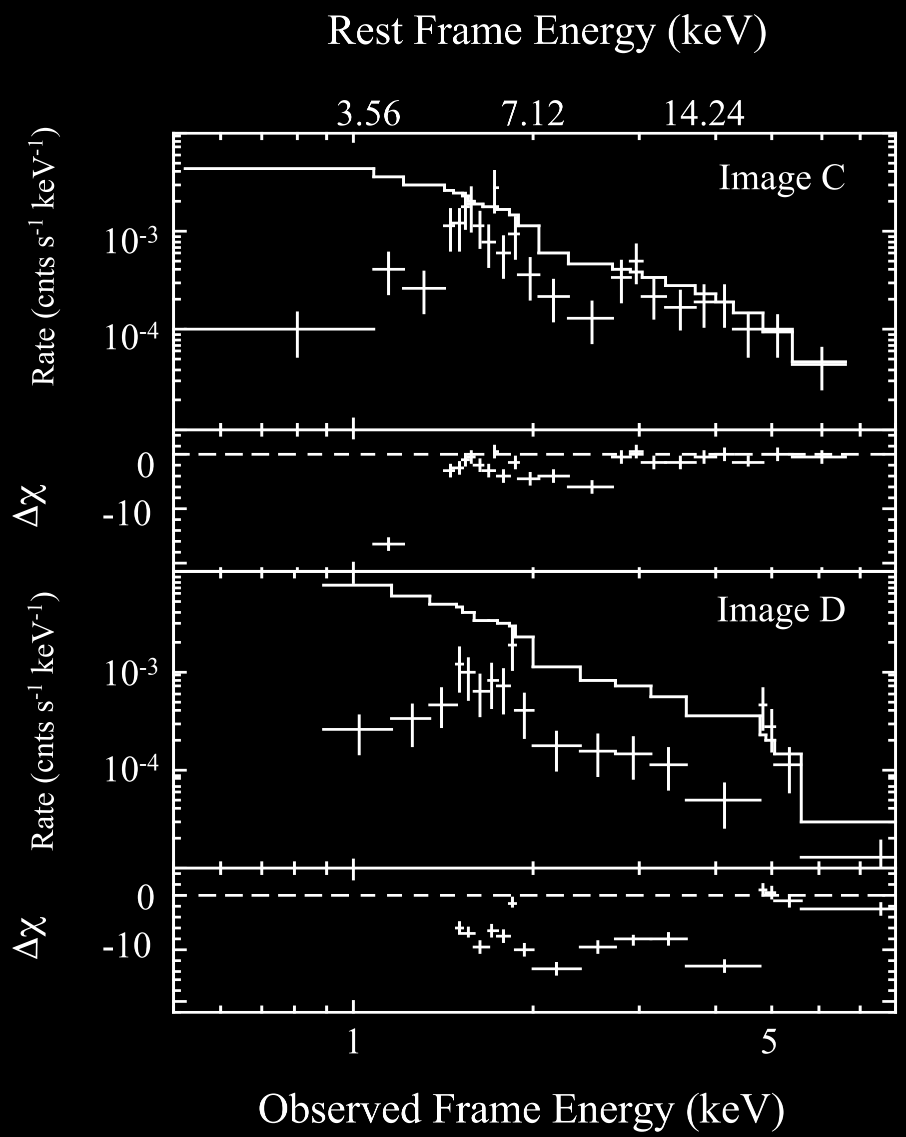
- difficulty with this interpretation arises if the hot corona and Fe fluorescent regions are located close to each other and are of comparable size

(b) The Fe line emission is produced by fluorescent Fe emission originating from the back-side of the wind.

In this scenario the wind would have to be launched near the black hole and the fluorescent Fe emission would have to originate from a narrow region.

The Fe line energy separation of ~ 1 keV implies velocities of ~ 50,000 km/s. For Keplerian rotation this would imply that the outflowing Fe emitter was located at a radius of $R_{outflow} < 100\ R_s$.

Cloverleaf Quasar: Origin of Spectral Differences Between Images



Possible interpretations;

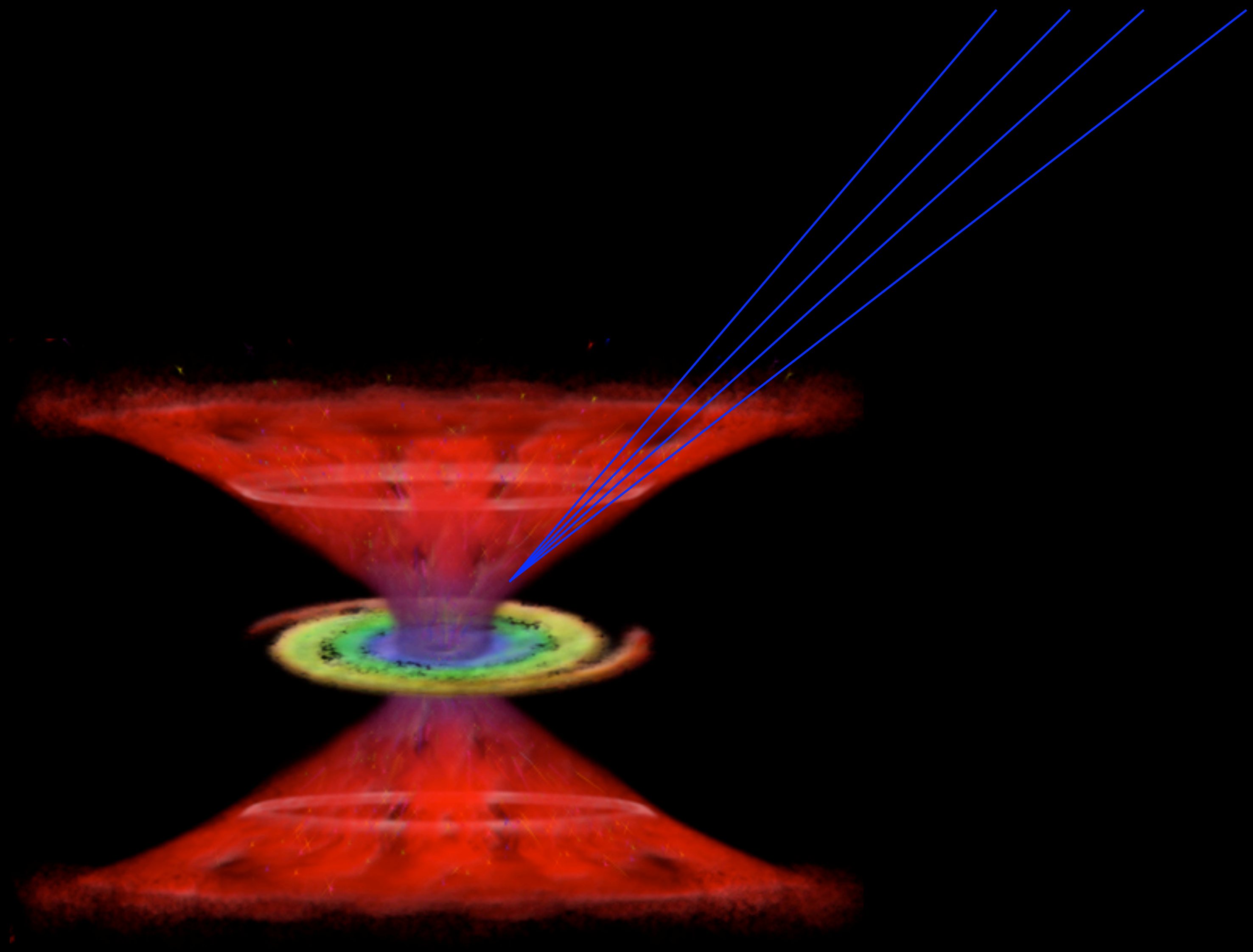
(a) Significant inhomogeneities in the outflow properties along the lines of sight corresponding to different images.

(b) Variability of the outflow on time-scales that are shorter than the time-delay between the images.

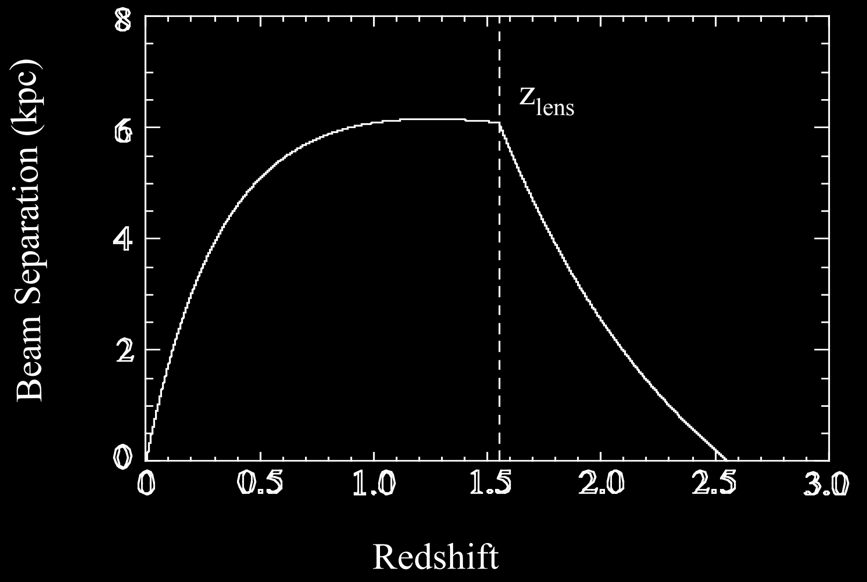
(c) Microlensing in at least two of the images.

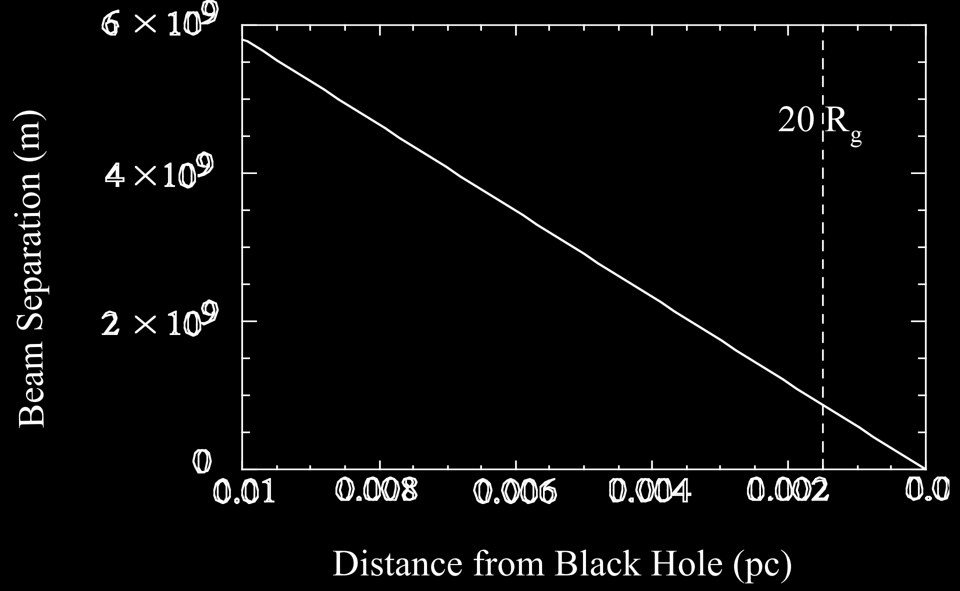
Cloverleaf Quasar: Origin of Spectral Differences Between Images

Multiple line interpretation



Cloverleaf Quasar: Origin of Spectral Differences Between Images





Multiple line interpretation:

For outflowing absorbers at distances in the range of :

$$R_{abs} = 10 - 10^3\ r_g$$

the corresponding linear beam separations at these locations lie in the range of :

$$D_{sep} = 4.3 \times 10^8 \mathrm{m} - 4.3 \times 10^{10} \mathrm{m}$$

A conservative source size:

$$R_{source} = 10 r_g \sim 2.3 \times 10^{13} \mathrm{m}$$

$D_{sep} << R_{source}$ ---> different lines of sight of the Cloverleaf observed with *Chandra* sample the same regions of the outflow

Cloverleaf Quasar: Origin of Spectral Differences Between Images

Variability interpretation:

- Minimum variability time-scale in the observed-frame is $t_{min} = 6(1 + z)r_g/c \sim 2$days.
- The dynamical time-scale near the event horizon is $t_{dyn} = (r/r_g)^{1/2} t_{min} \sim 5$days.

Variability of the outflow over time-scales that are shorter than the time-delays between images can result in spectral difference between images.

We conclude that variability of the outflow can be the cause of the observed spectra differences since t_{dyn} is less than the time-delays.

CONCLUSIONS

- Based on the caustic crossing time of ~2000days we estimate that the sizescale of the microlensed Fe emission region in H1413+117 is of the order of 14rg.

- The individual spectra of the images show high energy BALs between rest-frame energies of 6.4-15 keV. These energies imply outflow velocities of 0.29*c* and 0.67*c*

- Variability on time scales shorter than the time-delays between images is the most likely cause of the spectral differences between images.

- In the combined spectrum emission lines at E_{emis1}=5.35+/-0.23keV and E_{emis2}= 6.32+/-0.4keV are detected at the > 95% significance level.

- We propose as plausible origins of the emission lines fluorescence from the far side of the accretion disk and/or from the far side of the outflowing wind.