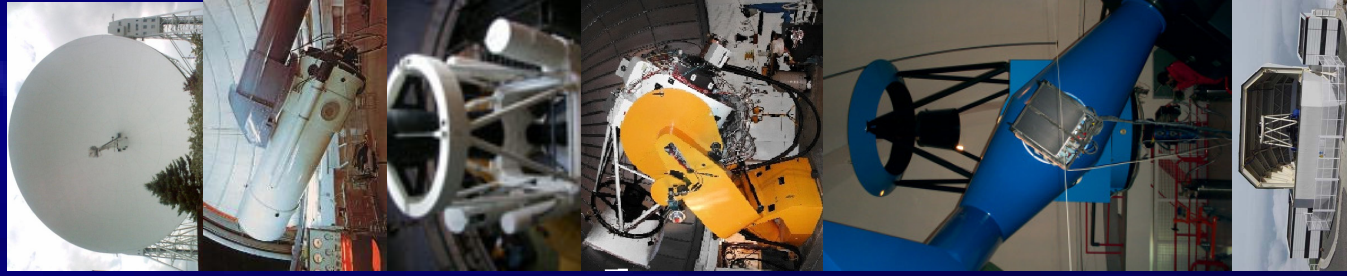
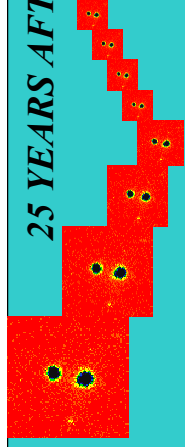


25 YEARS AFTER THE DISCOVERY: SOME CURRENT TOPICS ON LENSED QSOs

Santander (Spain), 15th-17th December 2004



Continuum and Emission Line Variability Induced by Microlensing

Cristina Abajas Bustillo

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Dr. Rodrigo Gil-Merino (Departamento de Física Moderna,
Universidad de Cantabria)



Standard Model of QSOs

QSO

=

MBH + Accretion
disc

+

Ionized Clouds
with
High Velocities

UV
Continuum

0.001 pc

Rees, 1984

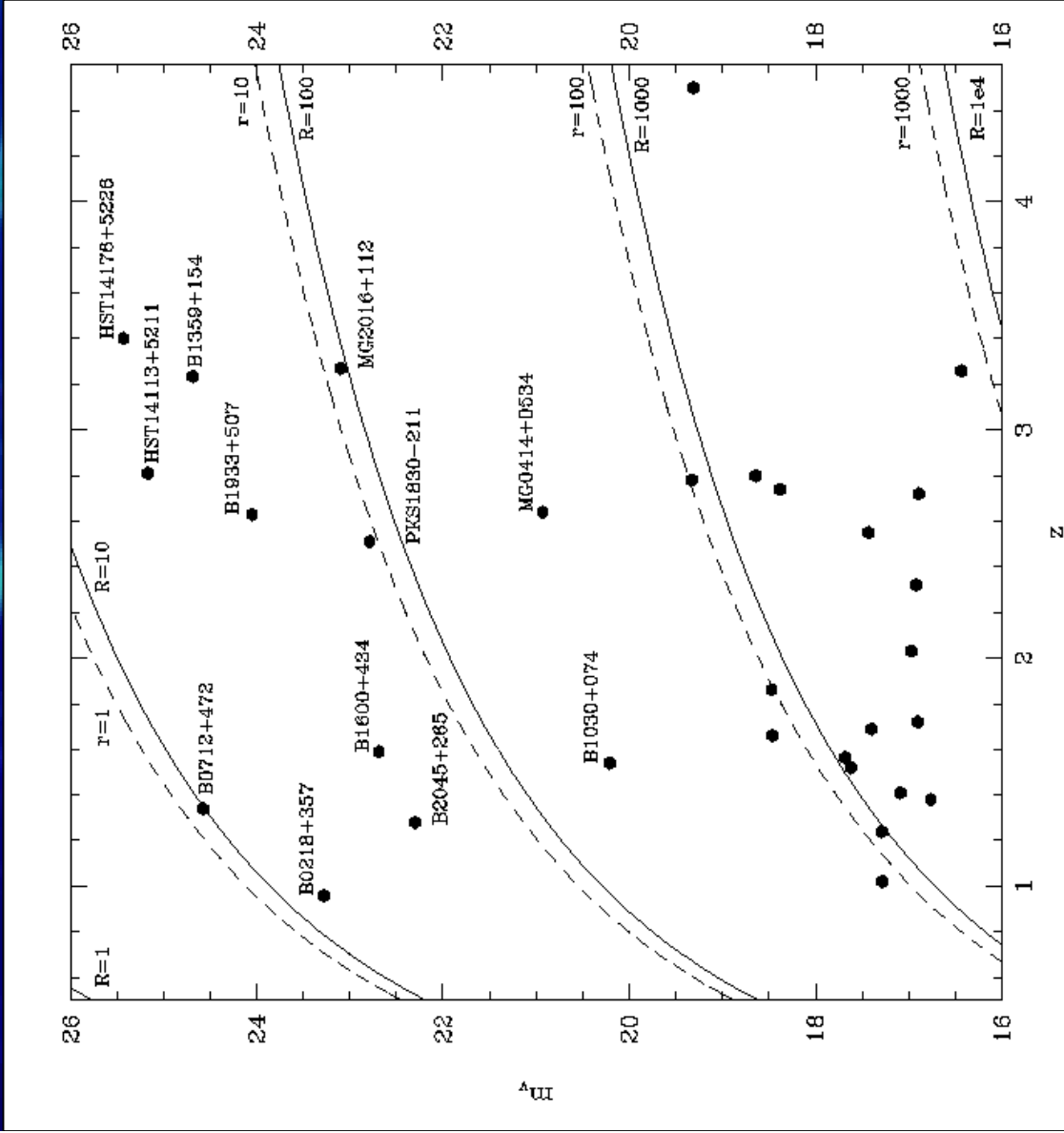
Broad
Emission
Lines

0.1 - 1pc

Nemiroff, 1988

- ☺ Taking into account these previous studies, gravitational lenses would not be a good tool to study the outer regions of AGNs (?).
- ☺ However, more realistic studies about sizes of broad line regions of quasars had appeared (reverberation mapping method). Sizes of BLRs are an order of magnitude lower.
- ☺ Then it is important a revision of the influence of microlensing on the different quasars emission regions.

¿Is there any QSO with $r_{\text{BLR}} < \eta_0$ among the known GLs?



$$r_{\text{BLR}} \leq \eta_0$$

$$\eta_0 \sim 20(M/M_\odot)^{1/2} \text{ l-d}$$

$$r_{\text{BLR}} \propto L^{0.7}$$

(Kaspi et al. 2000)

$r=10$ light-days

$R=100$ light-days



$$M_r = 0.25 M_\odot$$

Models

$$F_{\lambda} = \int_V \varepsilon(r) \delta \left[\lambda - \lambda_o \left(1 + \frac{v''}{c} \right) \right] \mu(r) dV$$

$$\varepsilon(r) = \varepsilon_o \left(\frac{r}{r_{in}} \right)^{\beta}$$

$$v(r) = v_o \left(\frac{r}{r_{in}} \right)^p$$

PARAMETERS:

- β (emissivity law)
- p (velocity law)
- Geometry (QSO, i)
(Robinson, 1995)
- Position (Lens $\leftarrow \rightarrow$ Source)
- Lens Mass ($\eta_o \leftarrow \rightarrow r_{BLR}$)

$$\mu = \frac{u^2 + 2}{u\sqrt{u^2 + 4}}; \quad \left(u = \frac{r}{\eta_o} \right)$$

☒ Spherical Model

$$v_{\infty}(r) = v_o \left(\frac{r}{r_{in}} \right)^p \cos \theta$$

☒ Bi-conical Model

$$v_{\infty}(r) = v_o \left(\frac{r}{r_{in}} \right)^p (\sin \theta \sin \varphi \sin i + \cos \theta \cos i)$$

☒ Keplerian Model

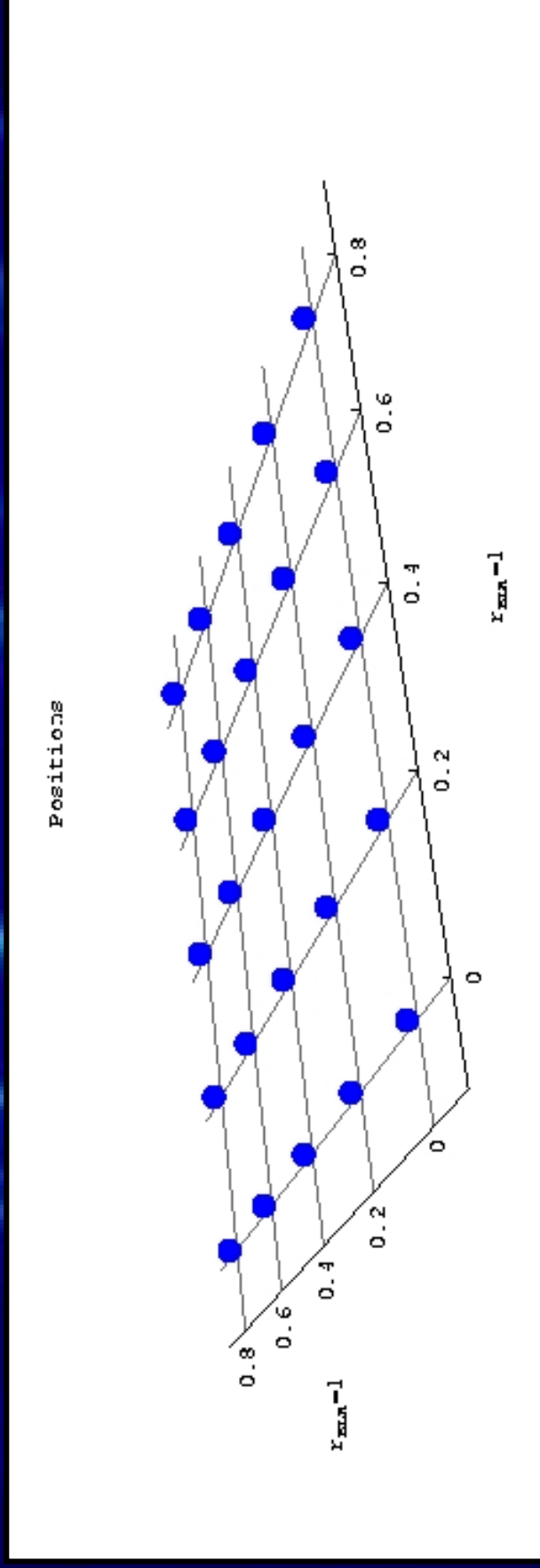
$$v_{\infty}(r) = v_o \left(\frac{r}{r_{in}} \right)^p \cos \theta \sin i$$

☒ Modified Keplerian Model

$$v_{\infty}(r) = v_o \left(\frac{\frac{1}{r} - \frac{1}{r_{BLR}}}{\frac{1}{r_{in}} - \frac{1}{r_{BLR}}} \right)^{-p} \cos \theta \sin i$$

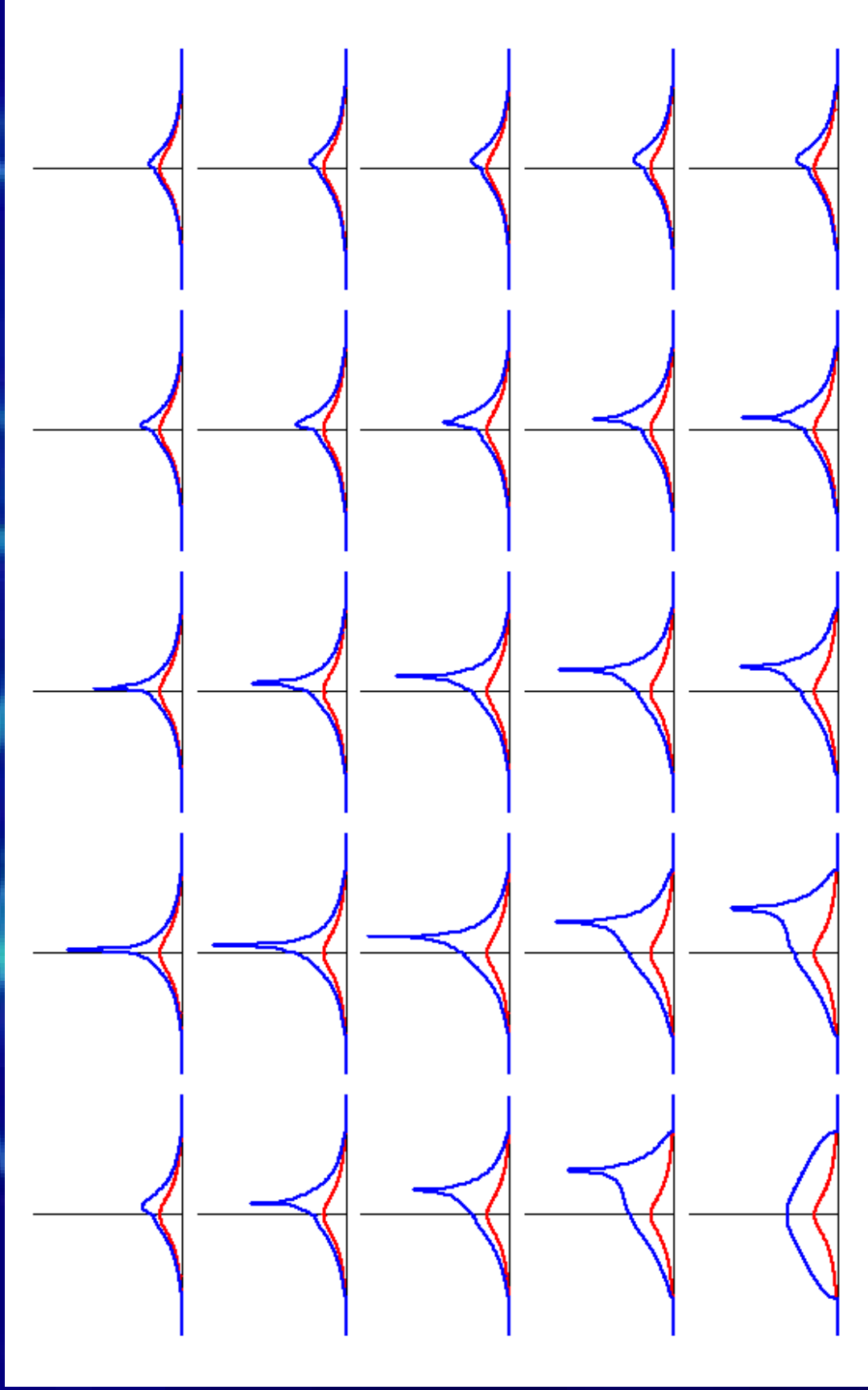
Modified Keplerian Disc

- **Emissivity law:** $\beta = -1.5$
- **Velocity law:** $p = -0.5$
- **Geometry:** disc with $i = 45^\circ$
- **Lens Mass:** $\eta_0 = r_{\text{BLR}}, \eta_o = r_{\text{BLR}}/4$
- **Position:**



Modified Keplerian disc

AMPLIFICATION



$\eta_0 = r_{BLR}$

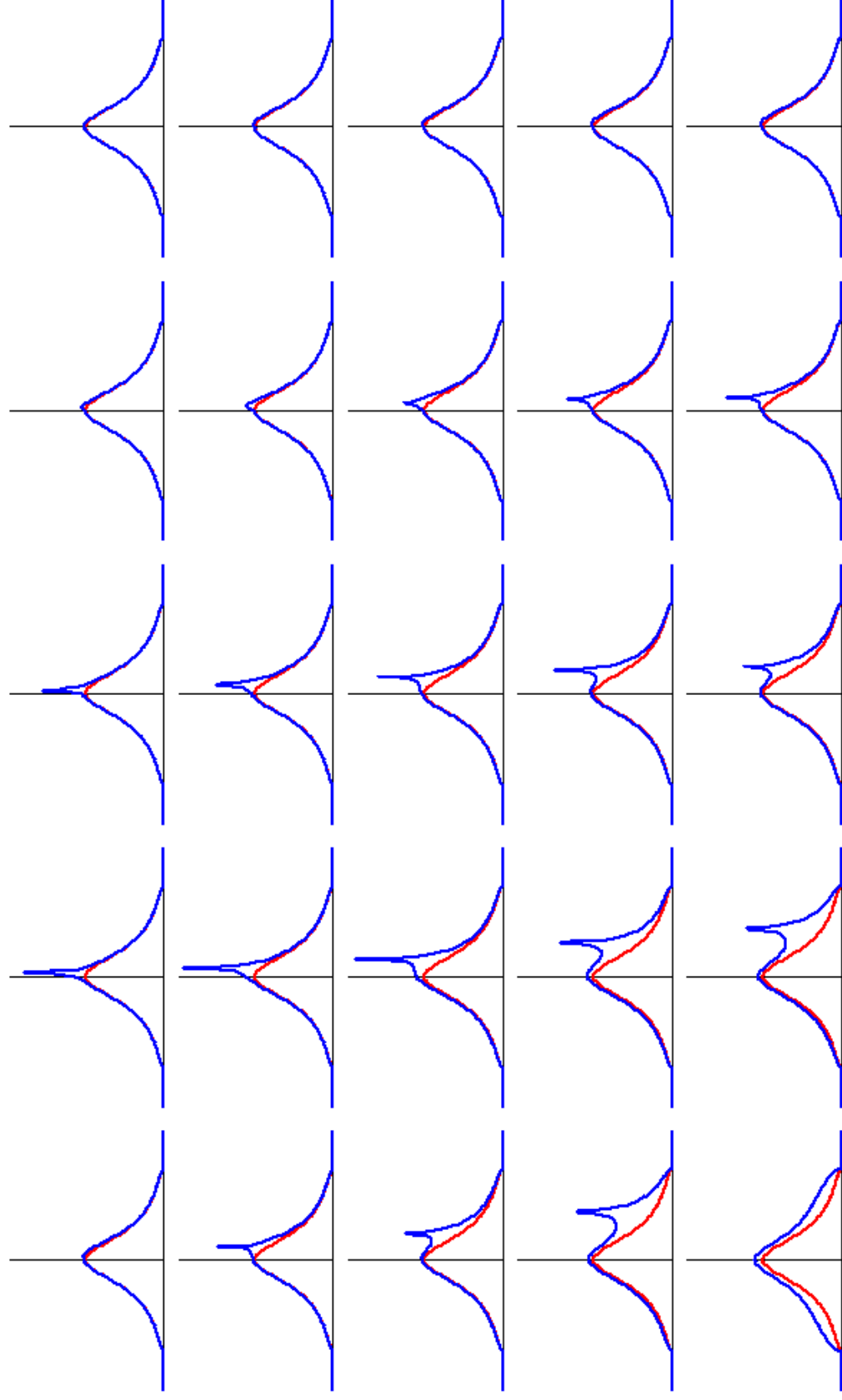
$M_{ML} = 0.25 M_{\odot}$

X

$$X = c(\lambda - \lambda_0) / (v_{\max} \lambda_0^2)$$

Modified Keplerian disc

AMPLIFICATION



$$\eta_0 = r_{\text{BLR}}/4$$



$$M_{\text{ML}} = 0.015 M_{\odot}$$



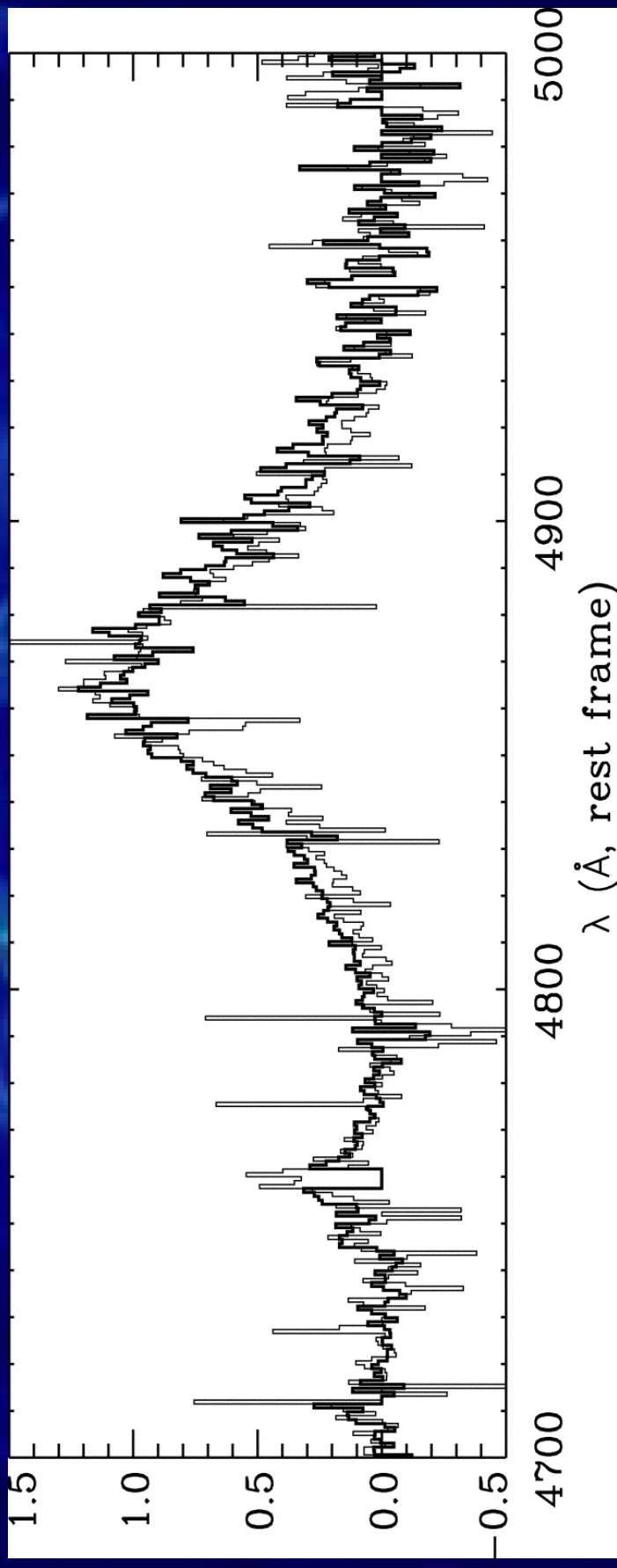
Observational Data

● Optic

✪ In the quadruple system SDSS J1004+4112

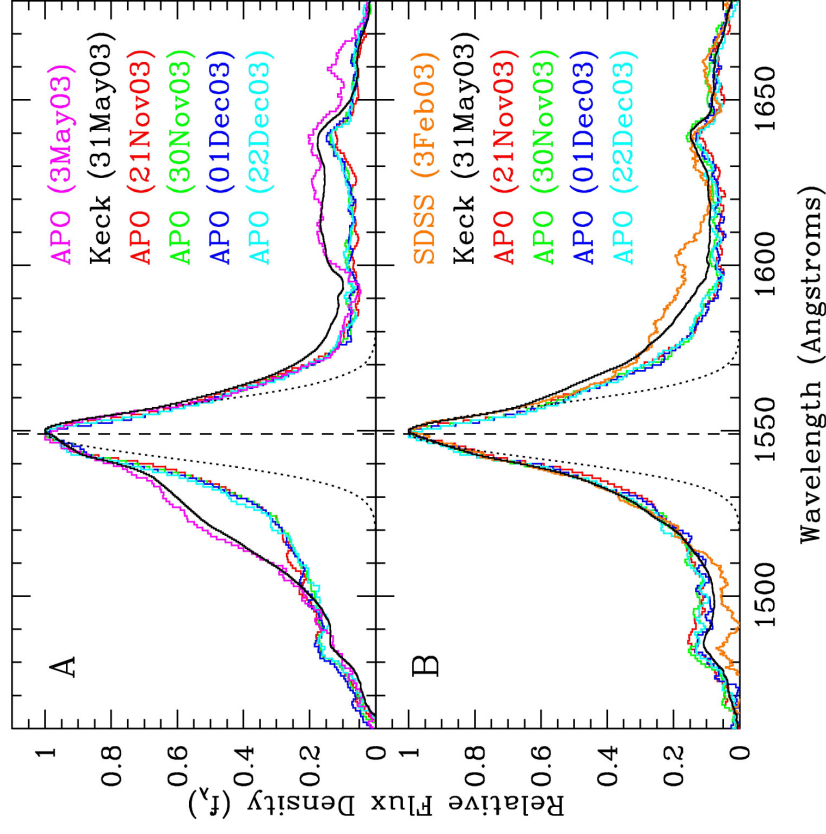
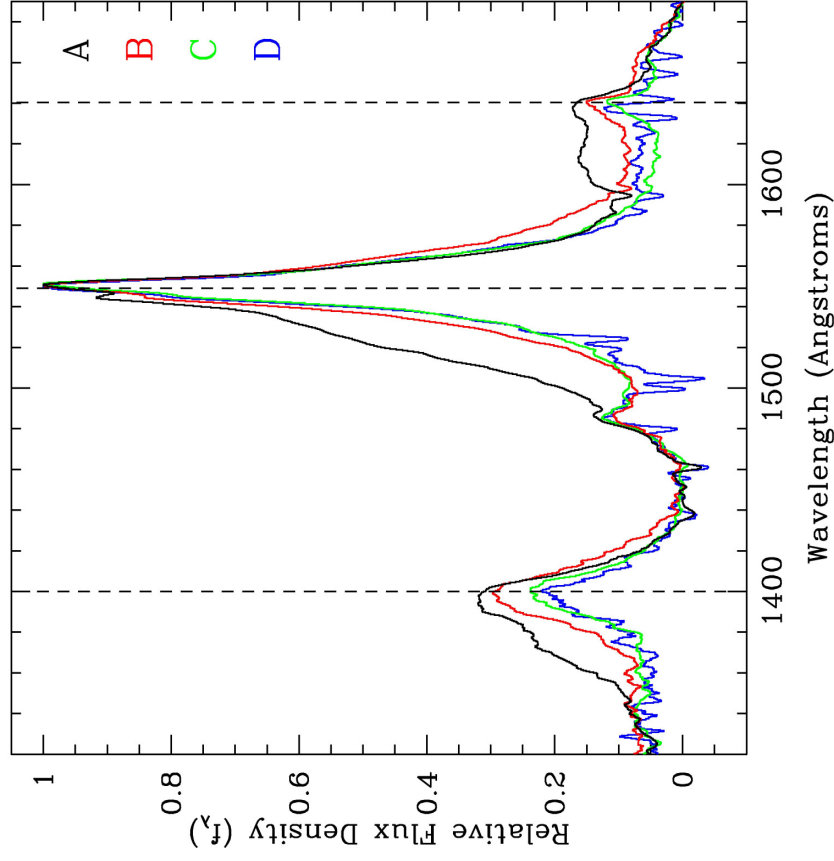
(Richards et al. ApJ 610, 679, 2004)

Low Ionization Lines



H β

High Ionization Lines



Si IV/O IV], C IV & HeII HIGH IONIZATION LINES

Observational Data

- **Optic**
 - ✿ In the quadruple system SDSS J1004+4112
(Richards et al. ApJ 610, 679, 2004)
- **X-rays**
 - ✿ Chandra observations of QSO 2237+0305
(Dai et al. ApJ 589,100, 2003)
 - ✿ Microlensing studies on X-rays region
(Popovic et al. A&A 398, 975, 2003, Zakharov et al. A6a 420,881, 2004)

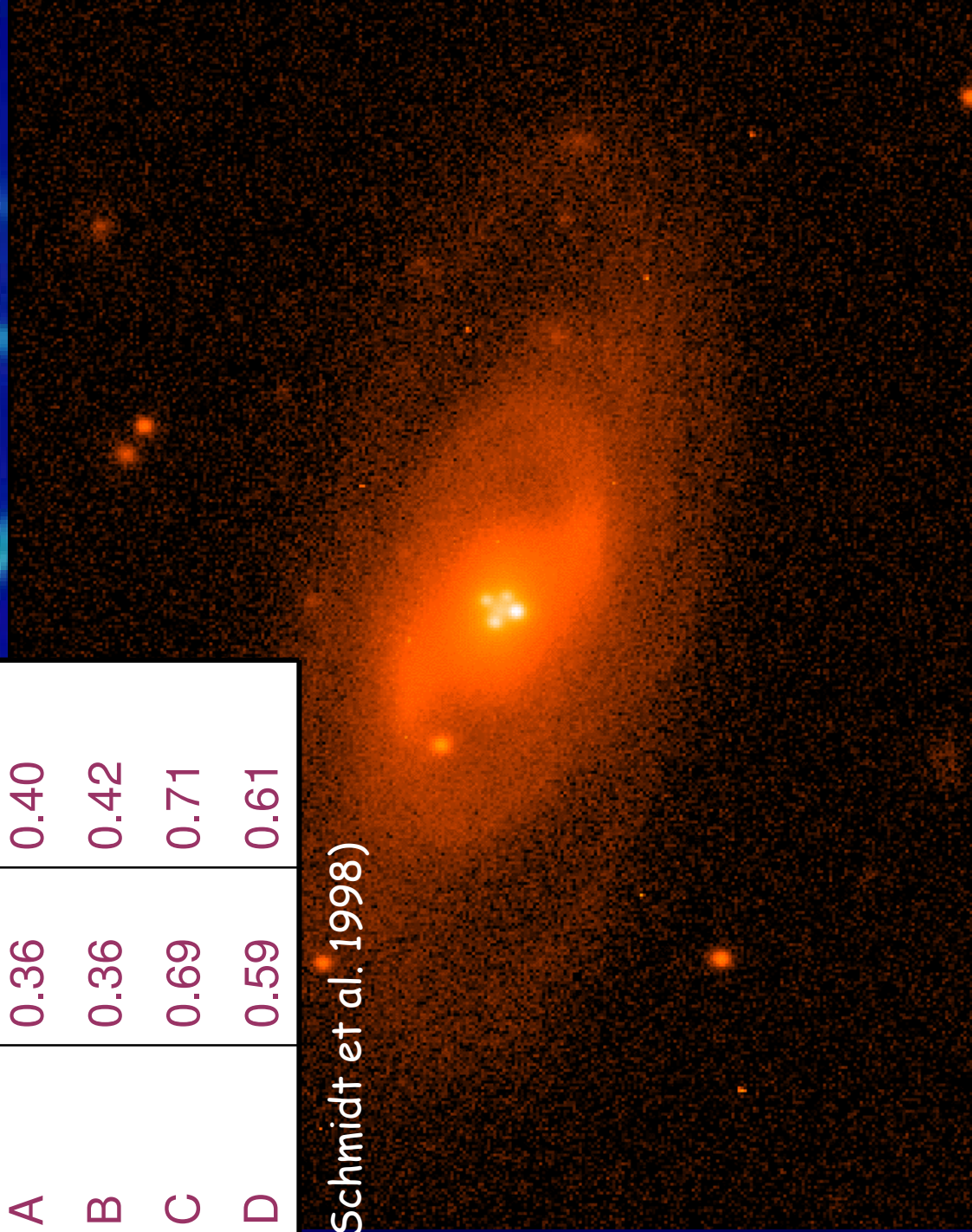
Theoretical Simulations

- **Lewis & Ibata 2004**
 - ✿ Using the models from Abajas et al. 2002, they investigate the influence on ML at high optical depth.

C

Image	Kappa	Gamma
A	0.36	0.40
B	0.36	0.42
C	0.69	0.71
D	0.59	0.61

(Schmidt et al. 1998)



B

$Q 2 2 3 7 + 0 3 0 5$

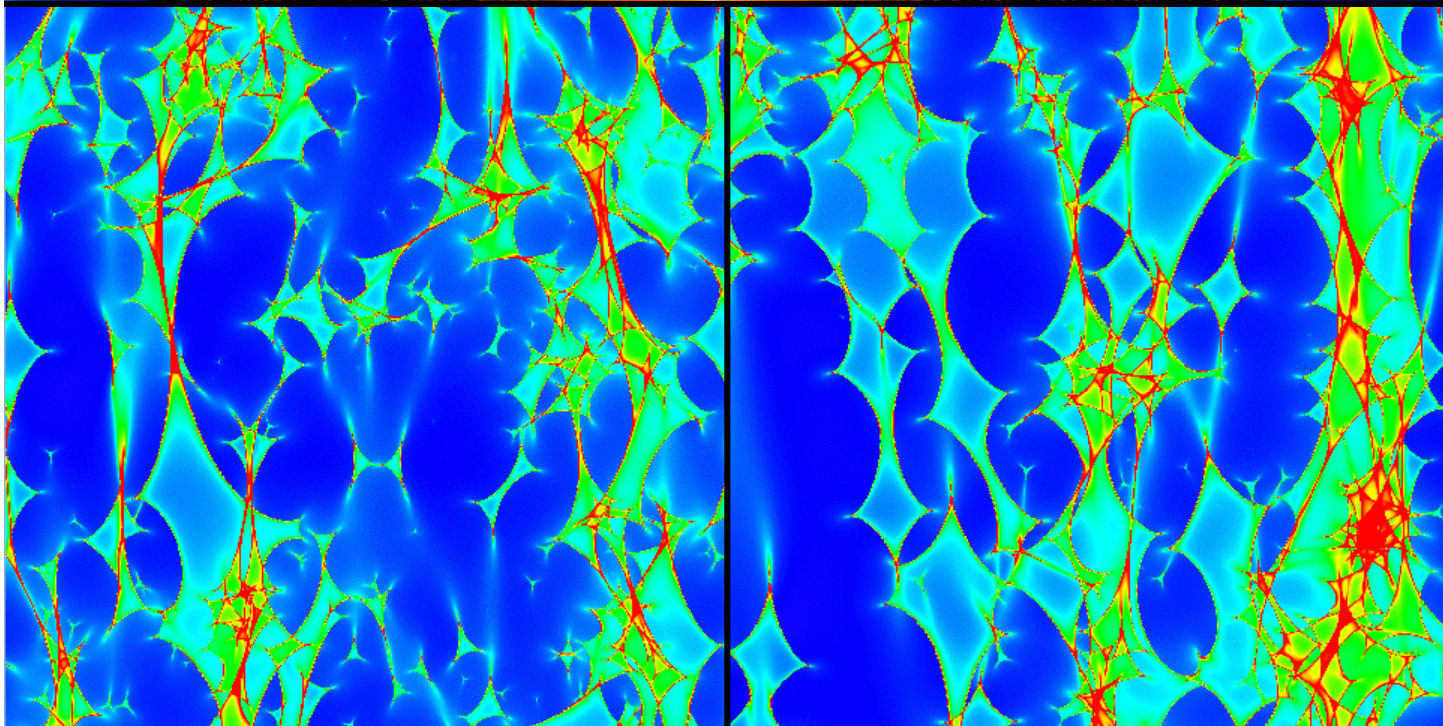
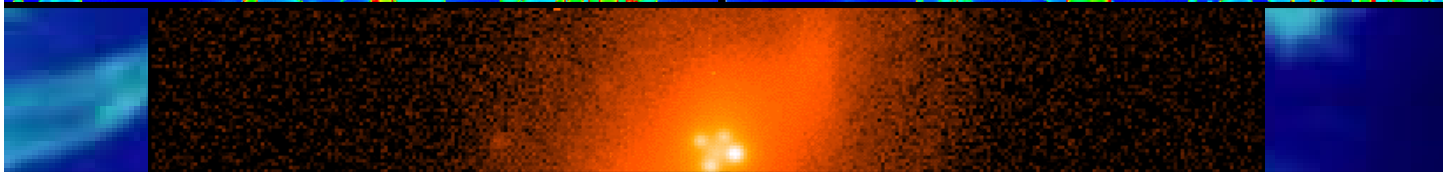
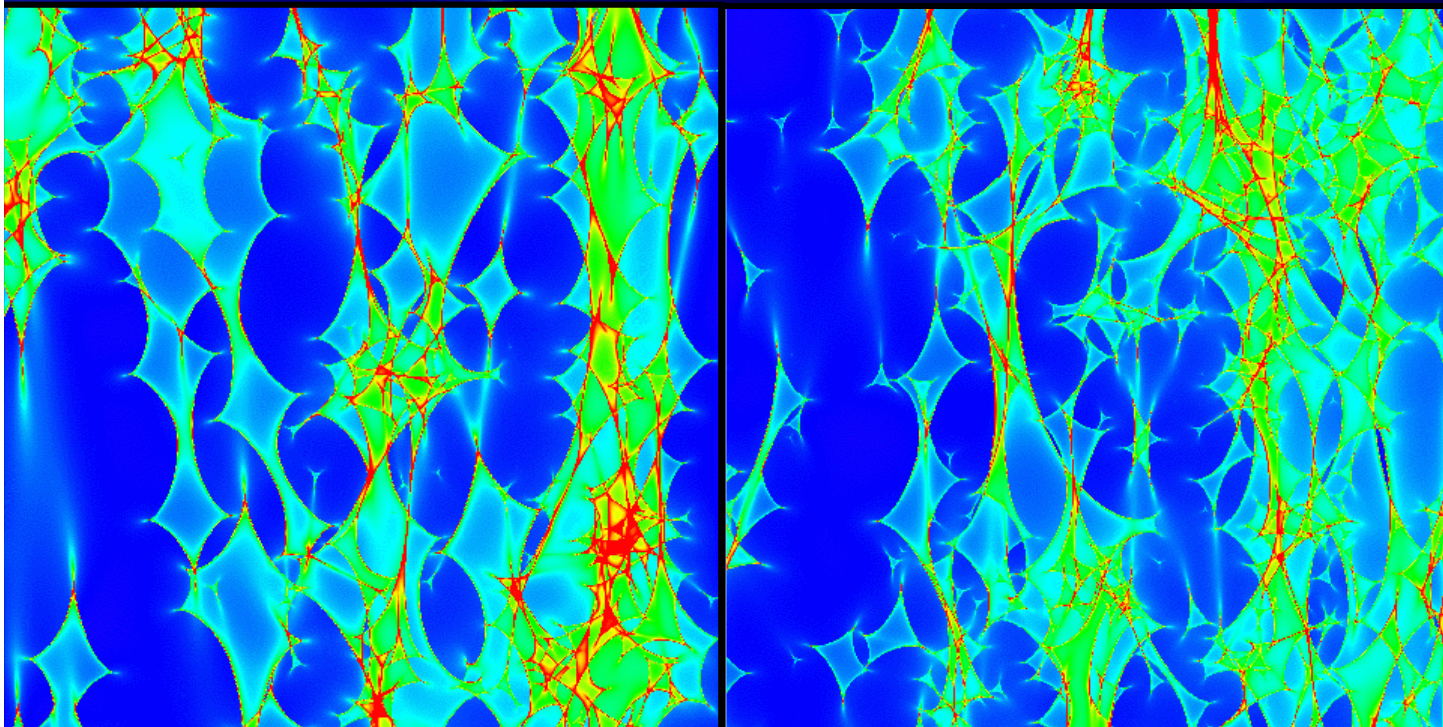
D

B

Q 2 2 3 7 + 0 3 0 5

D

14



C

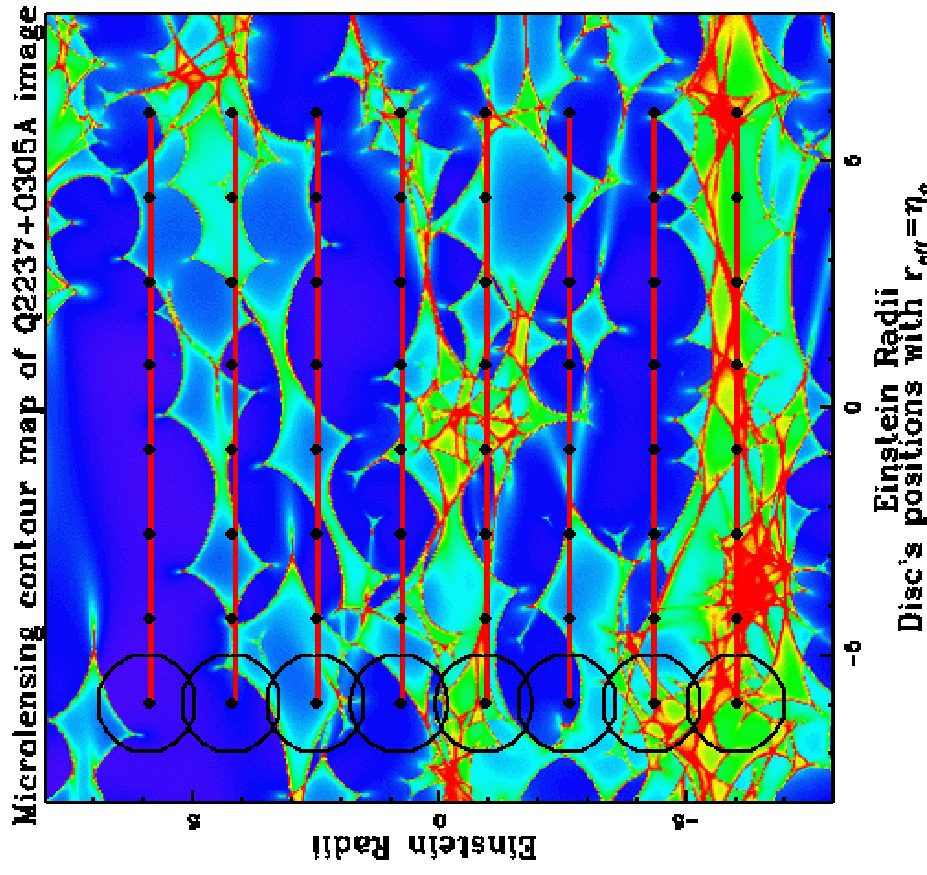
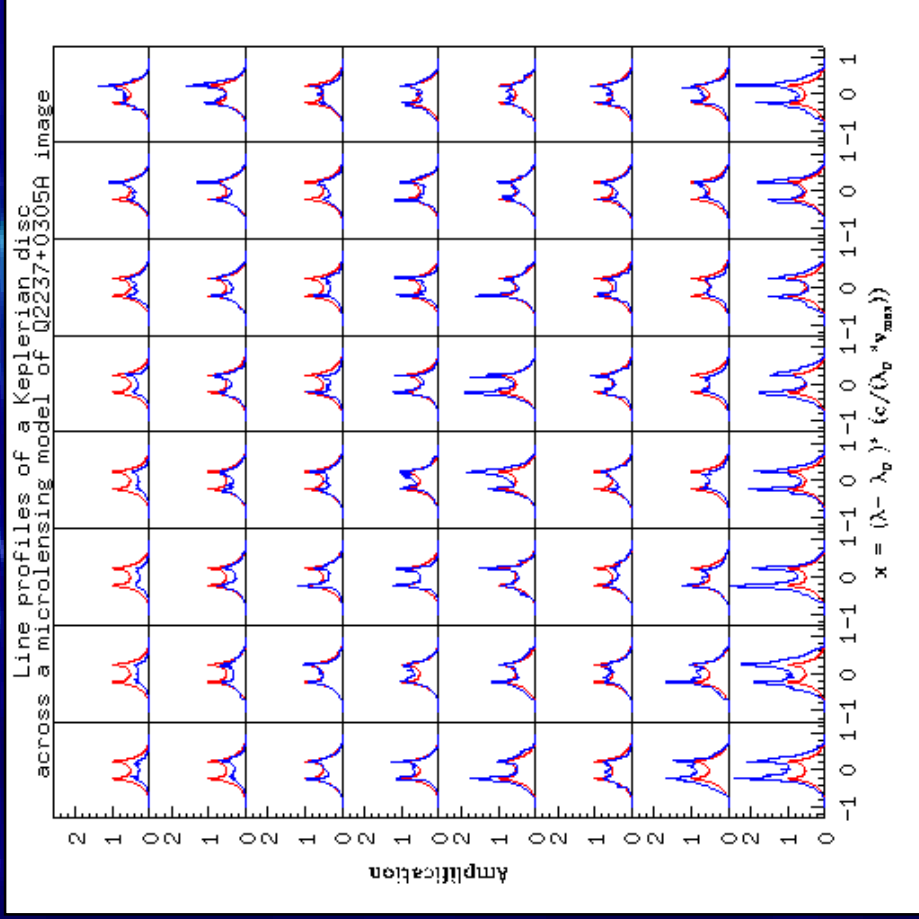
A

Q2237+0305

Image A

Broad lines region: High ionization

Keplerian disc model

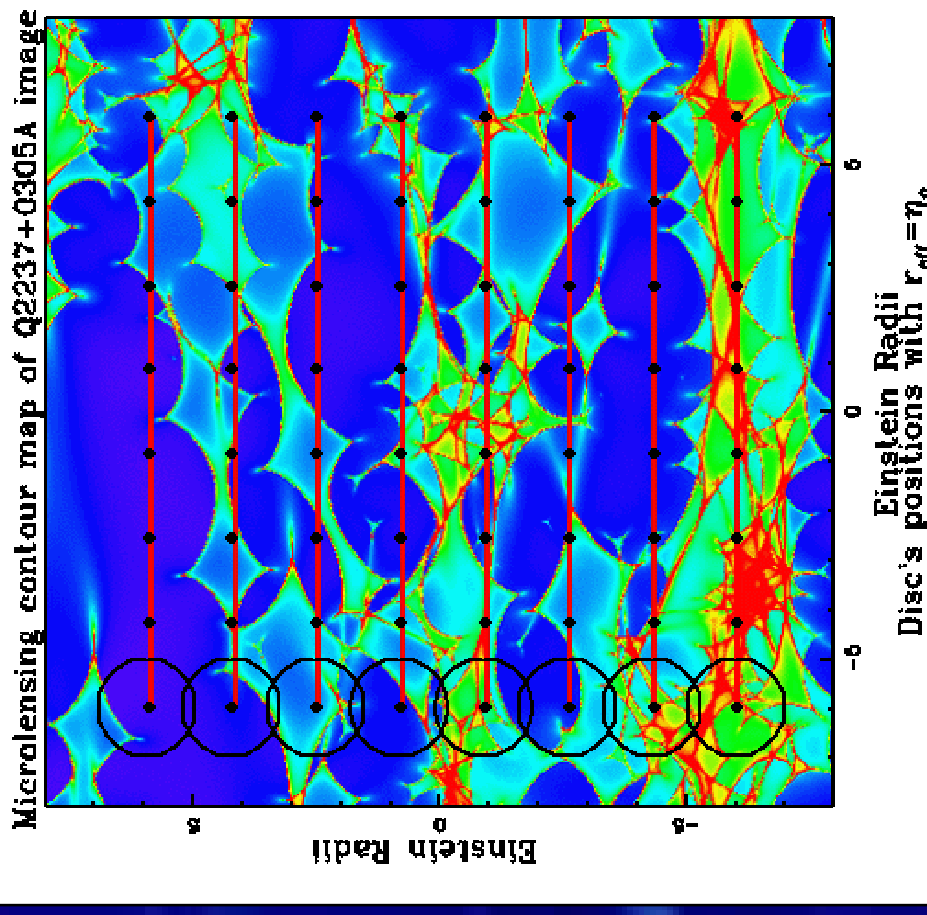
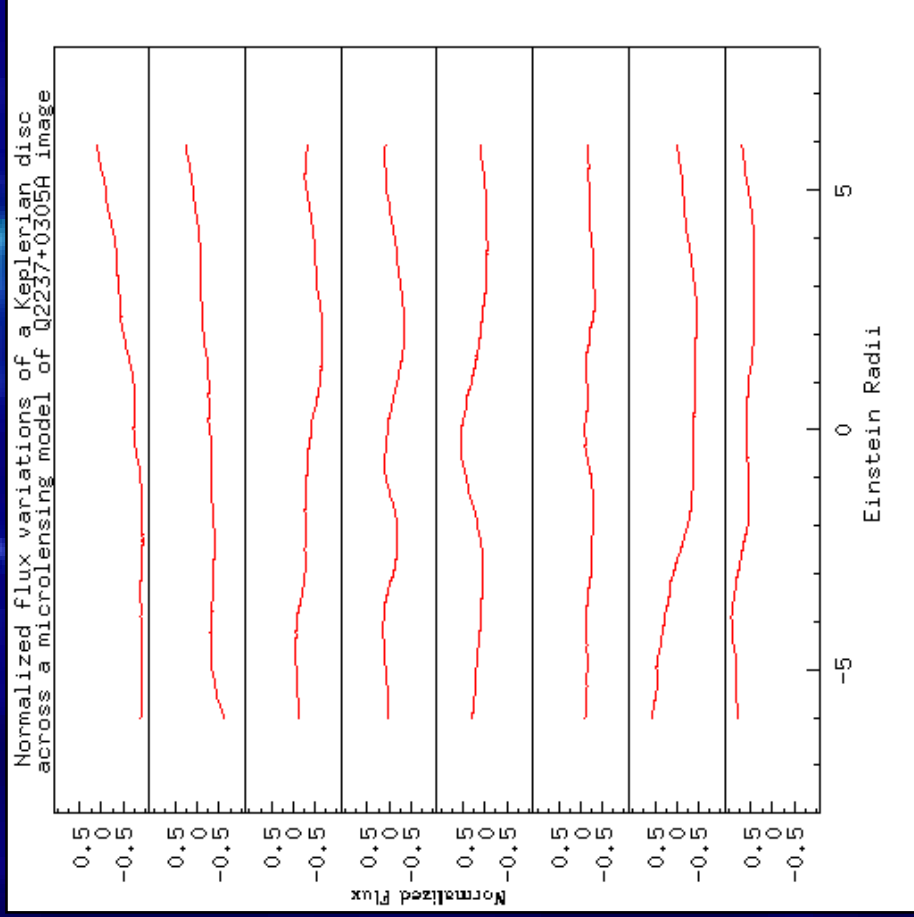


Q2237+0305

Image A

Broad lines region: High ionization

Keplerian disc model

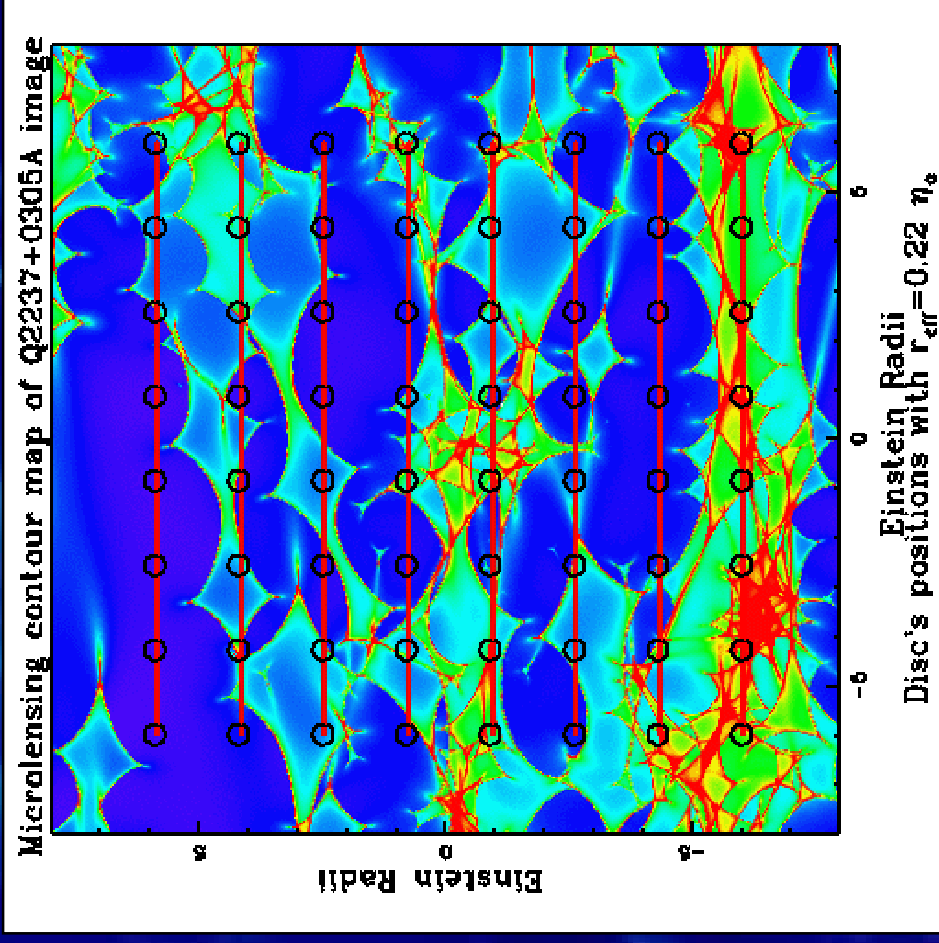


Q2237+0305

Image A

Continuum source

Power-law model



$$I_{opt}(r) = 2^{p_{opt}} I_{opt} \left(1 + \frac{r^2}{R_{opt}^2} \right)^{-p_{opt}}$$

$$R_{opt} = r_c \left(10^{1/(p_{opt}-1)} - 1 \right)^{-1/2}$$

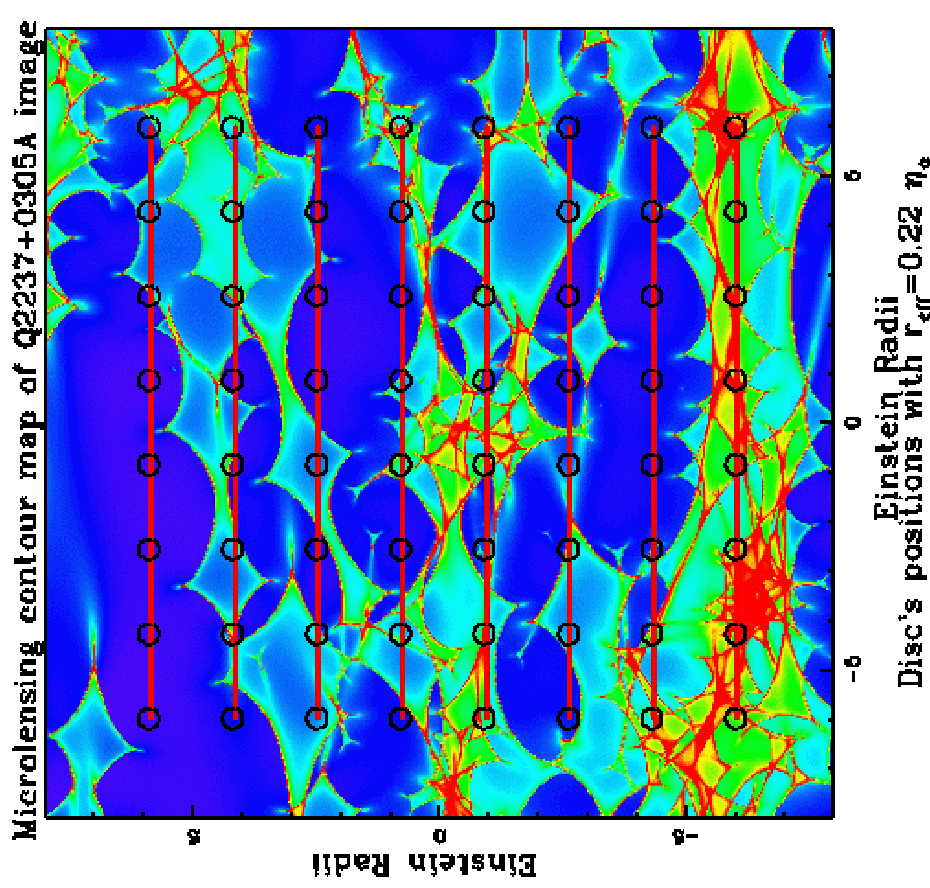
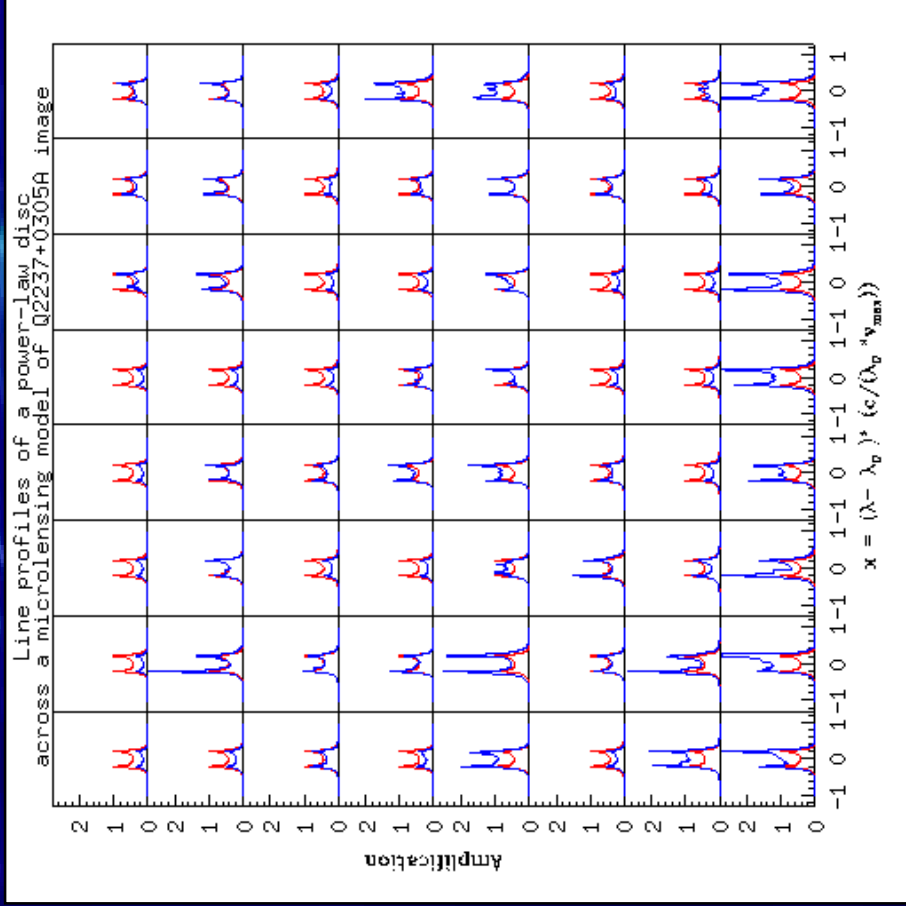
(Shalyapin et al. 2002)

Q2237+0305

Image A

Continuum source

Power-law model

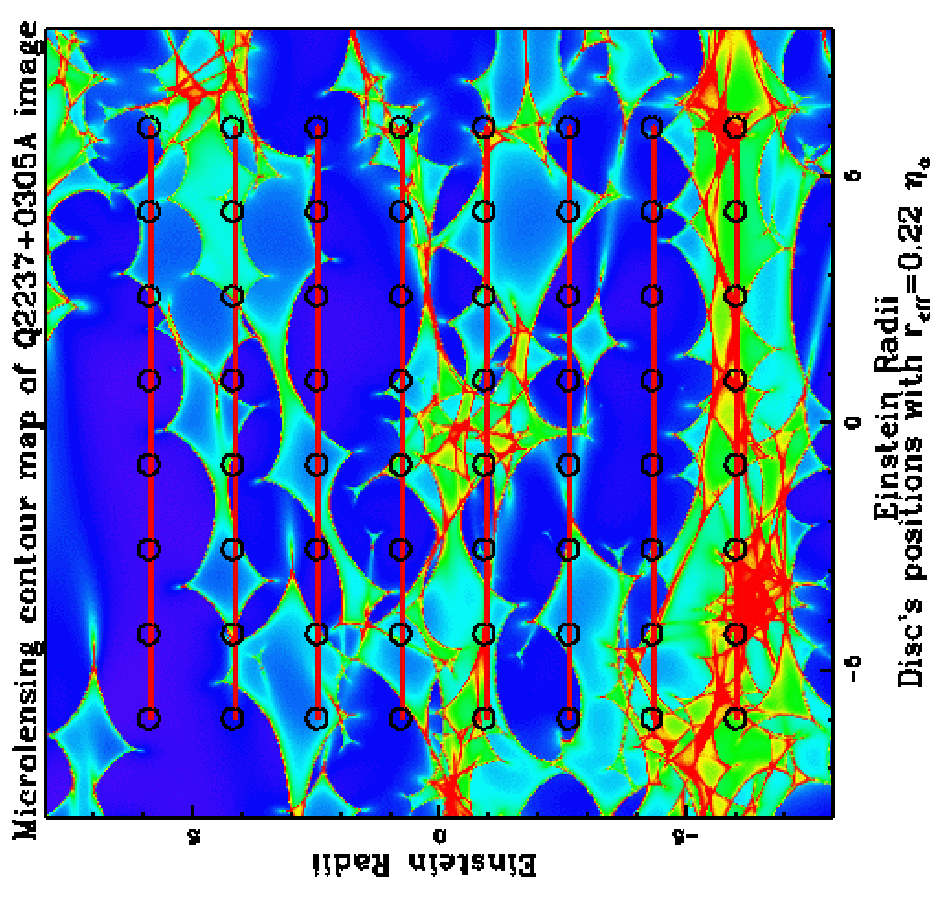
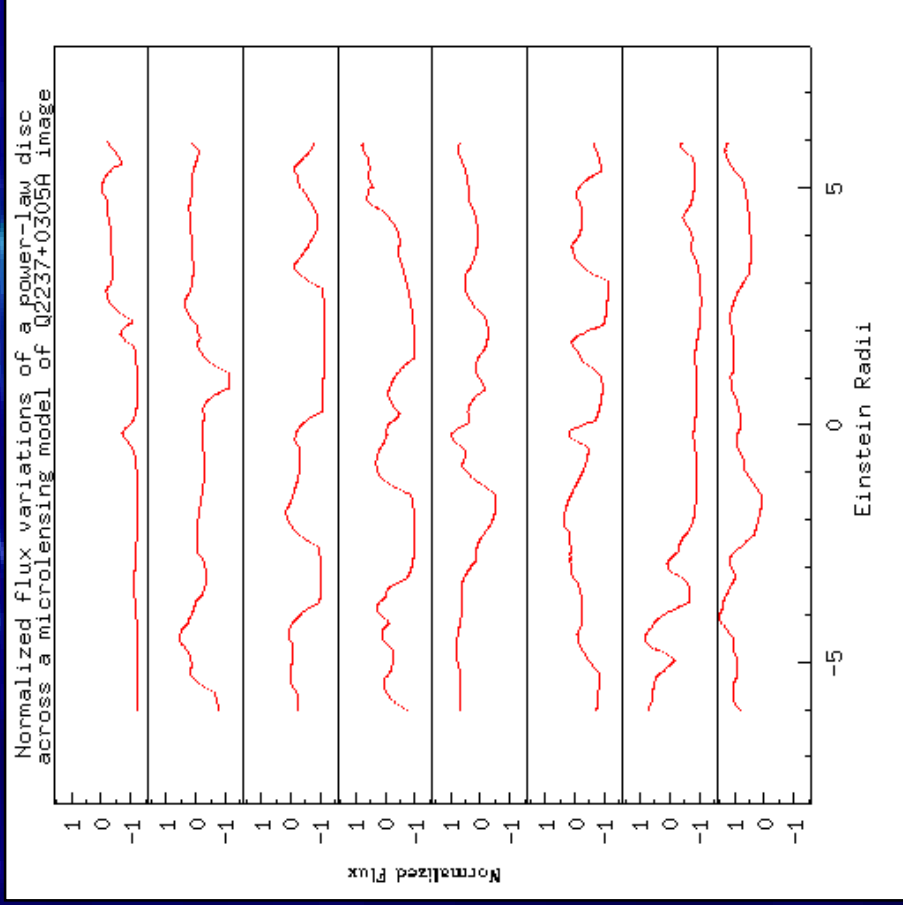


Q2237+0305

Image A

Continuum source

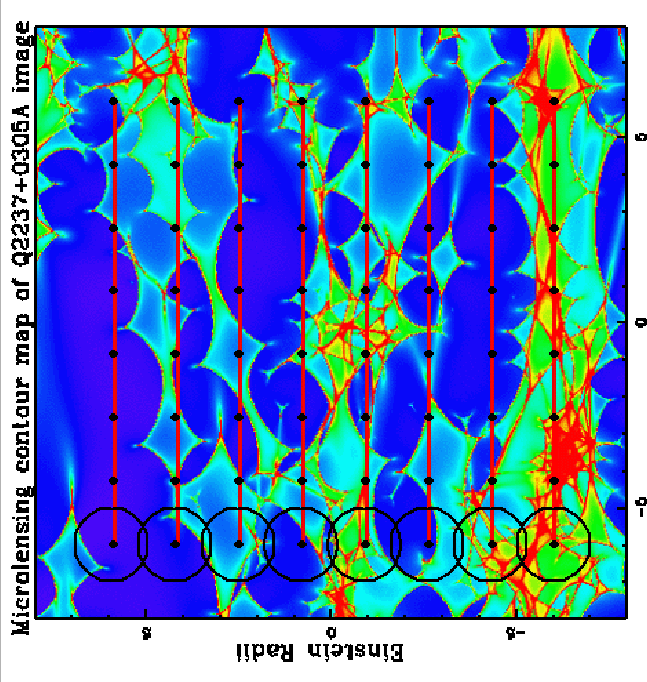
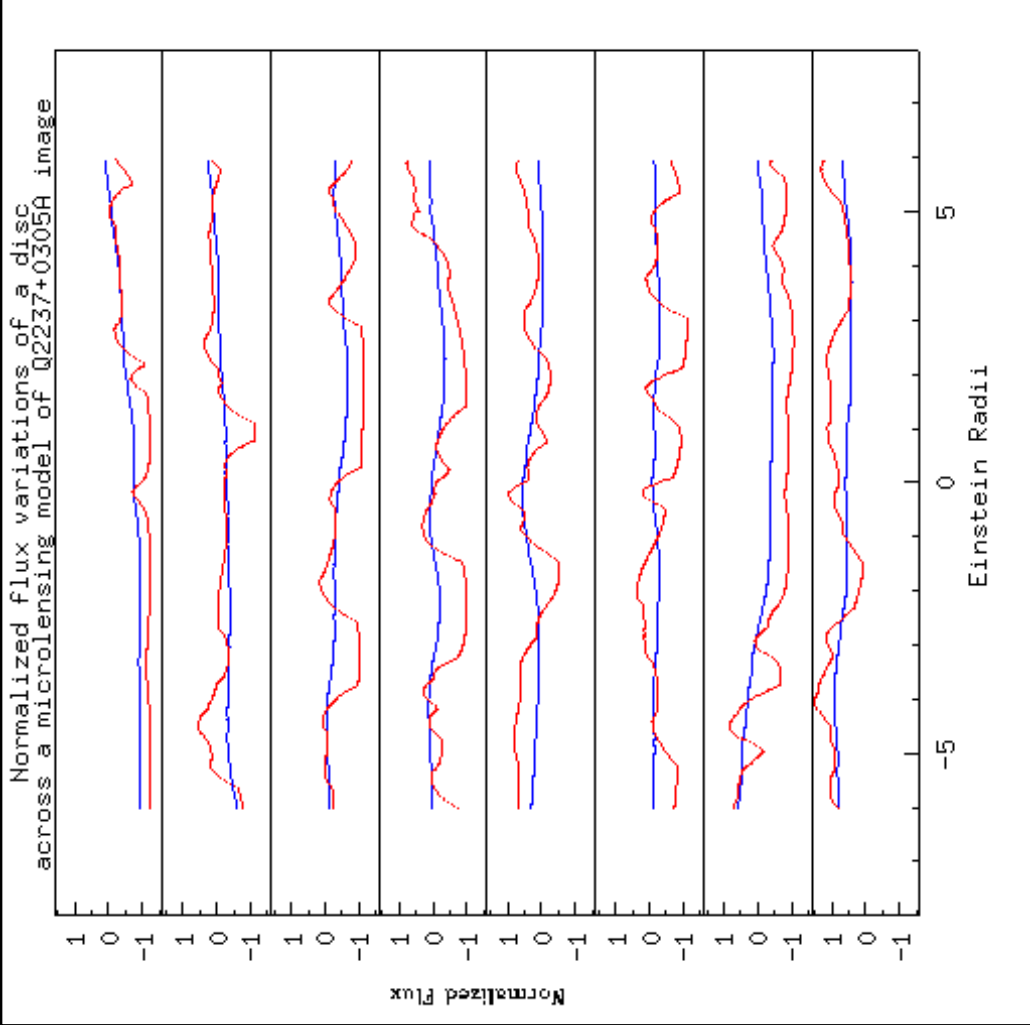
Power-law model



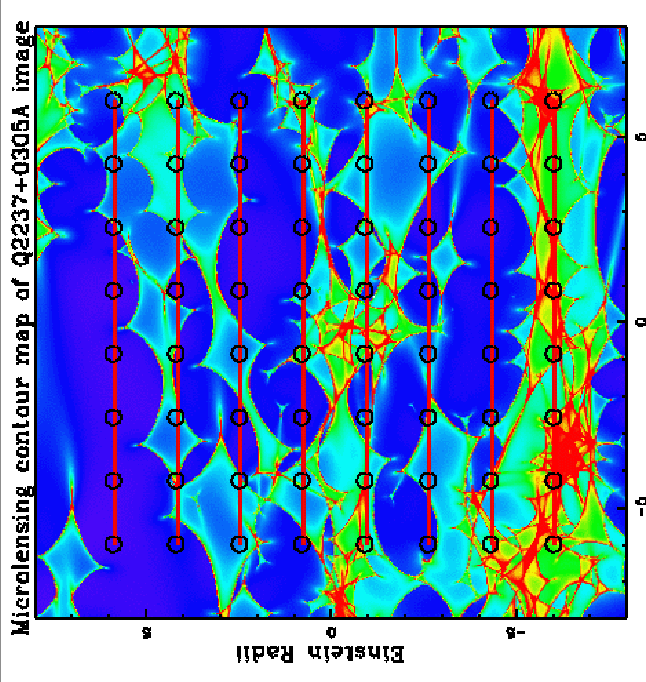
Q2237+0305

Image A

Blue: Brod line region + Keplerian disk model
Red: continuum source + power law model



Disc's positions with $r_{\text{eff}} = \eta_0$

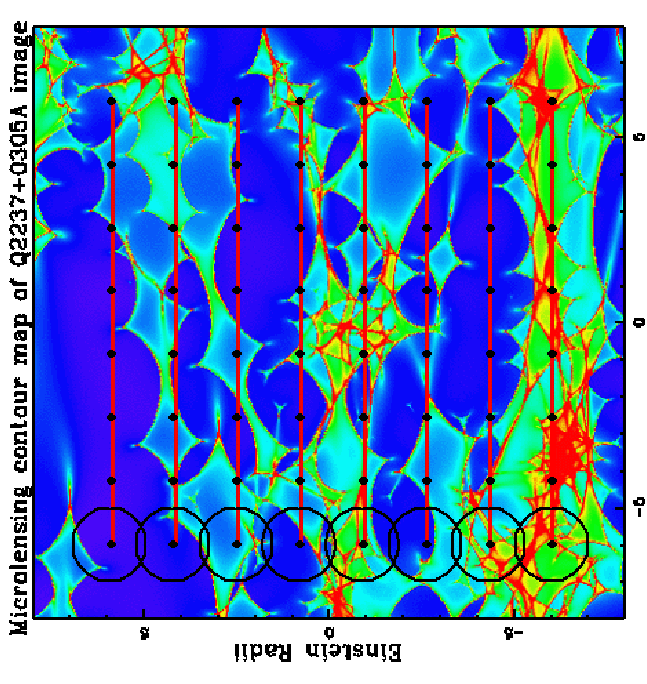
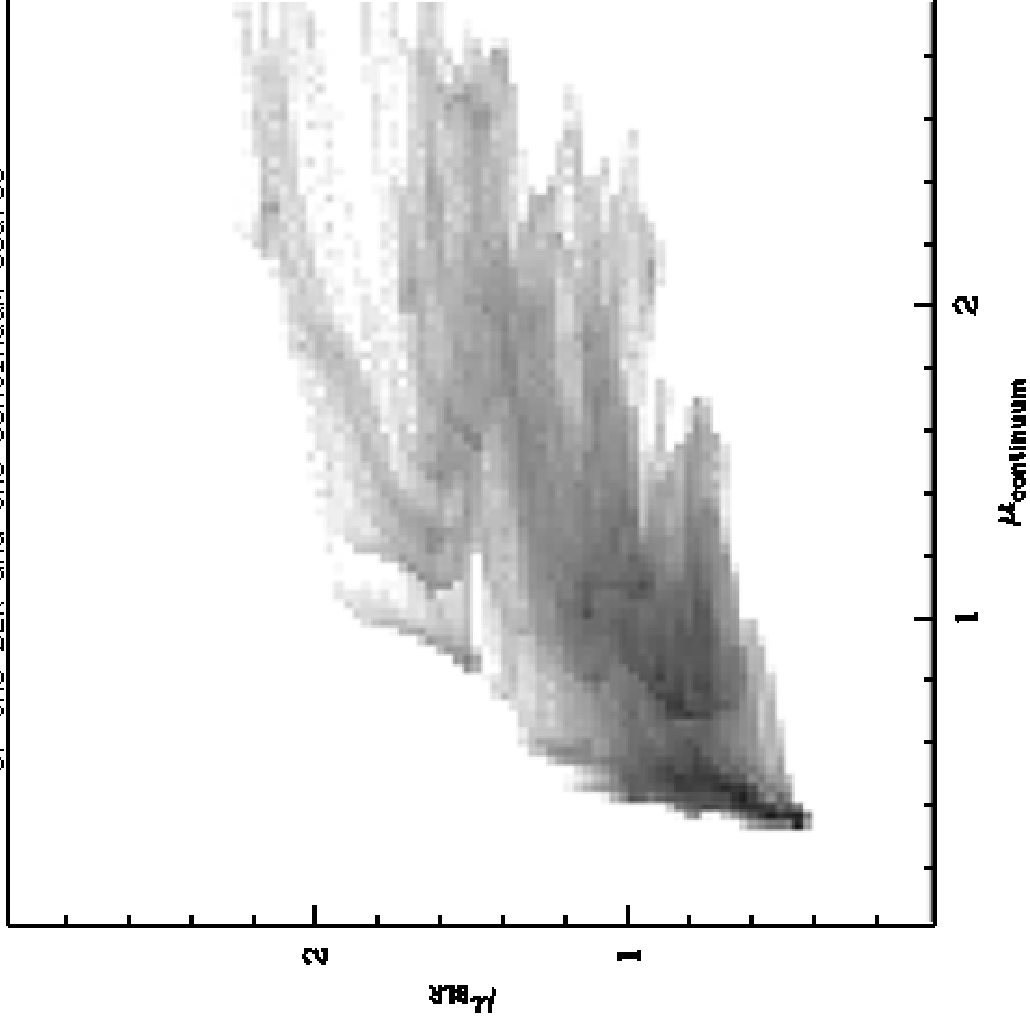


Disc's positions with $r_{\text{eff}} = 0.22 \eta_0$

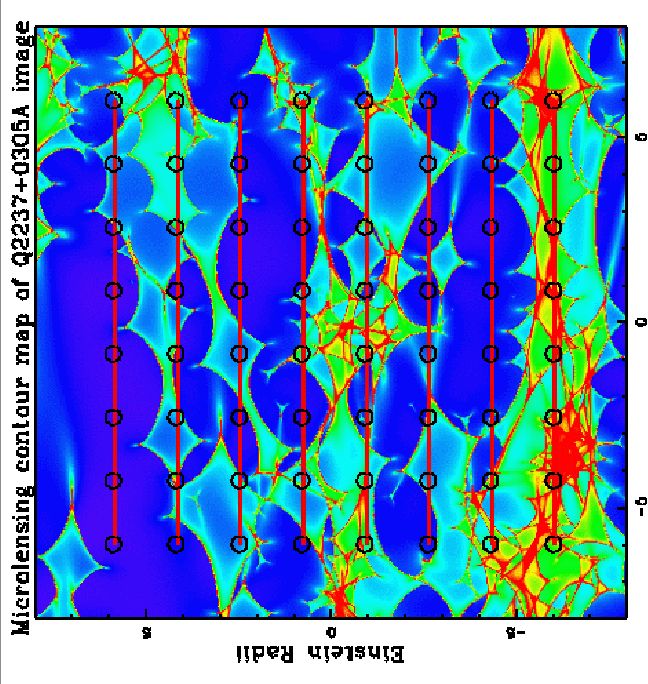
Q2237+0305

Image A

Correlation between the magnification
of the BLR and the continuum source



Einstein Radii
Disc's positions with $r_{eff} = \eta_0$

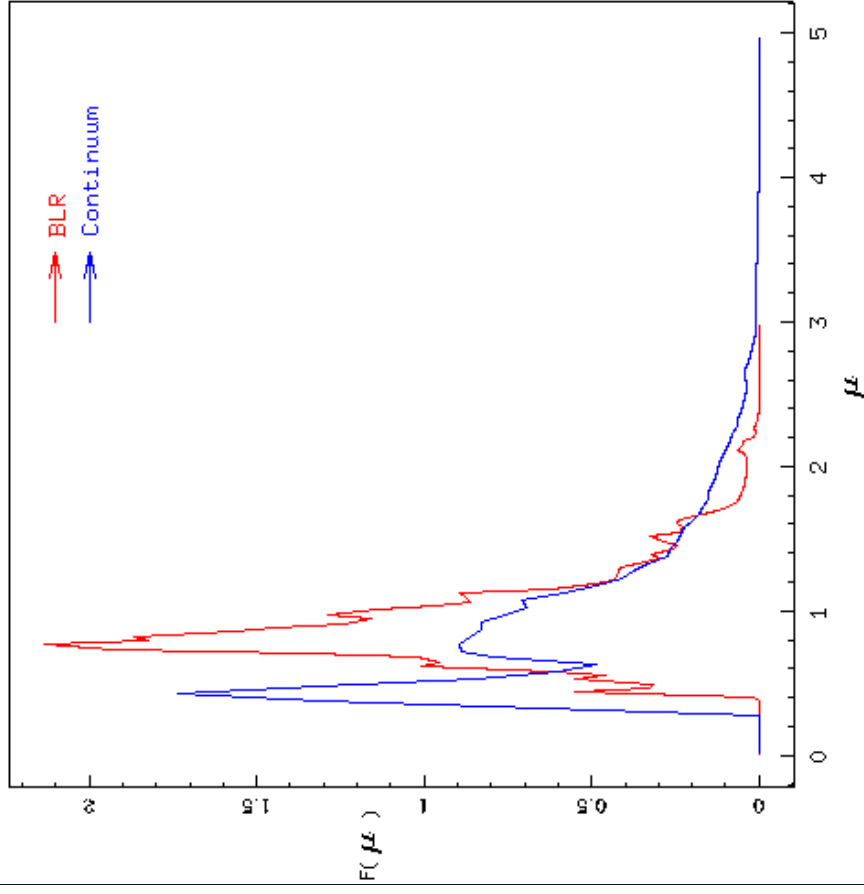


Einstein Radii
Disc's positions with $r_{eff} = 0.22 \eta_0$

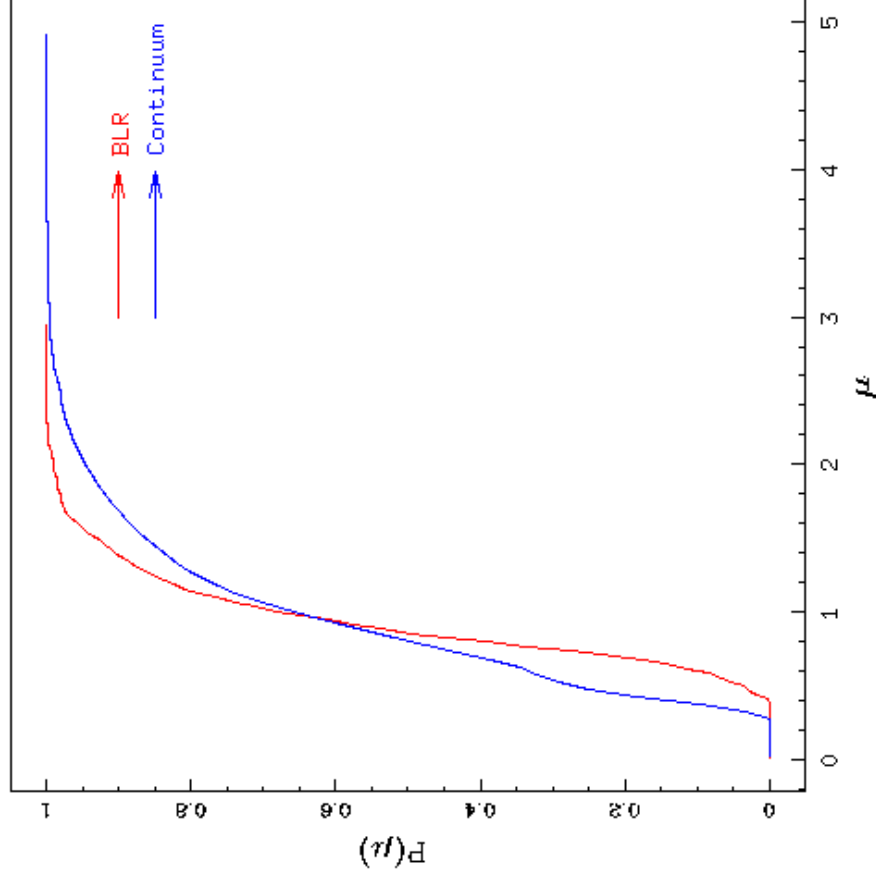
Q2237+0305

Image A

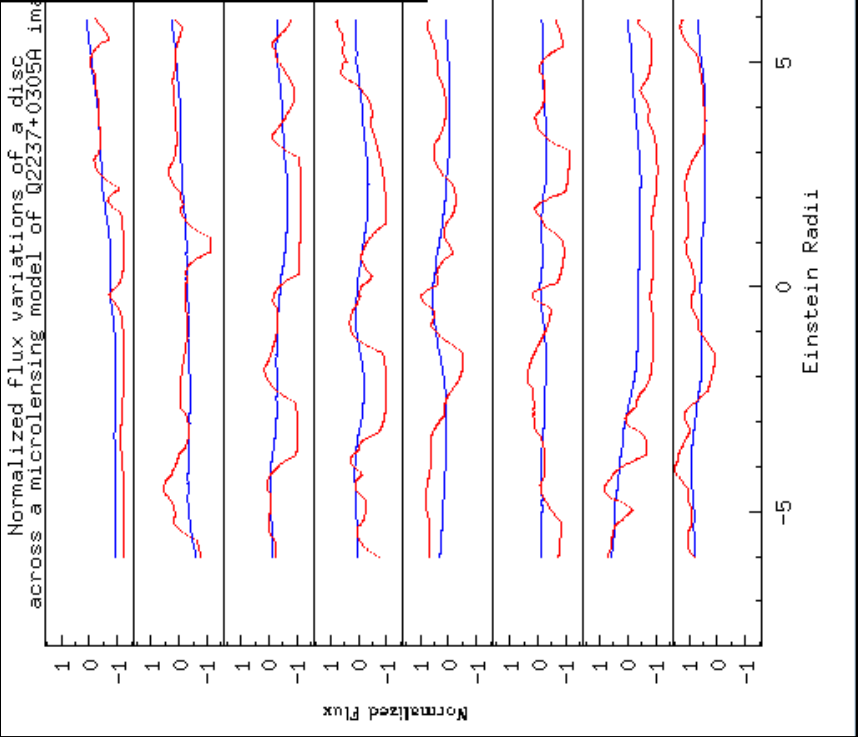
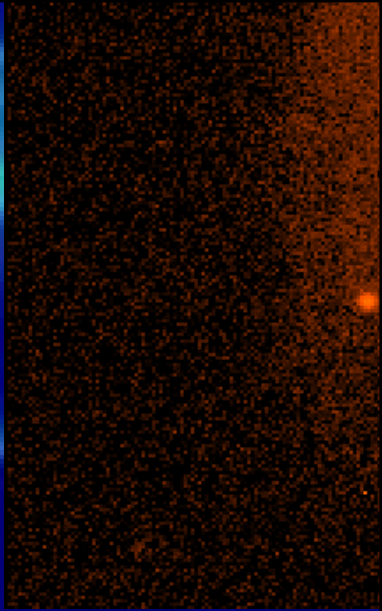
Distribution of Probability in Q2237+0305A



Probability in Q2237+0305A

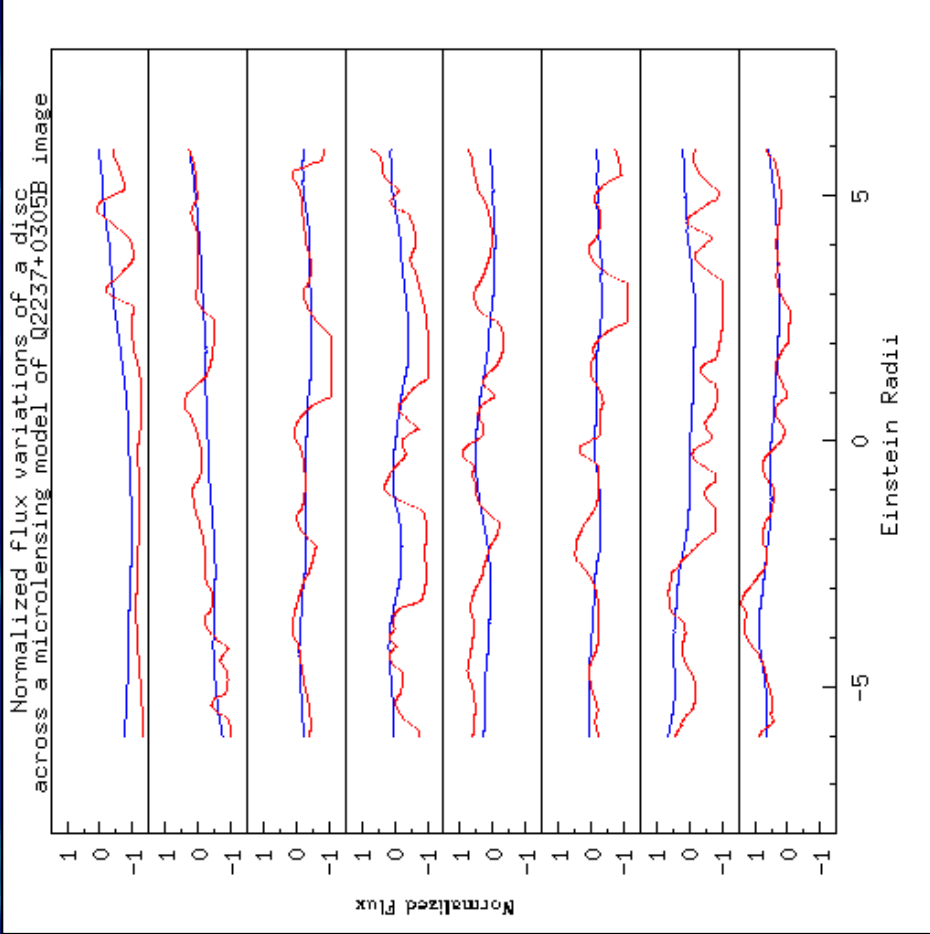


C



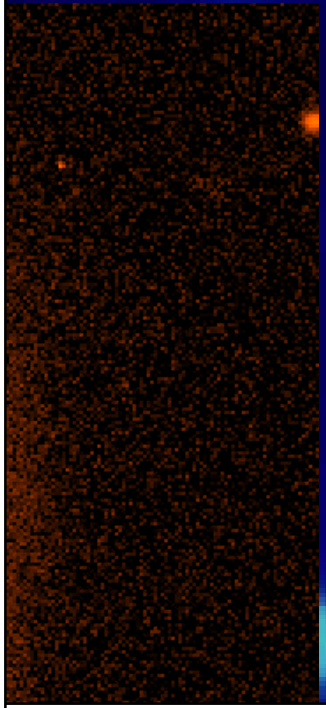
A

B



Q 2 2 3 7 + 0 3 0 5

D

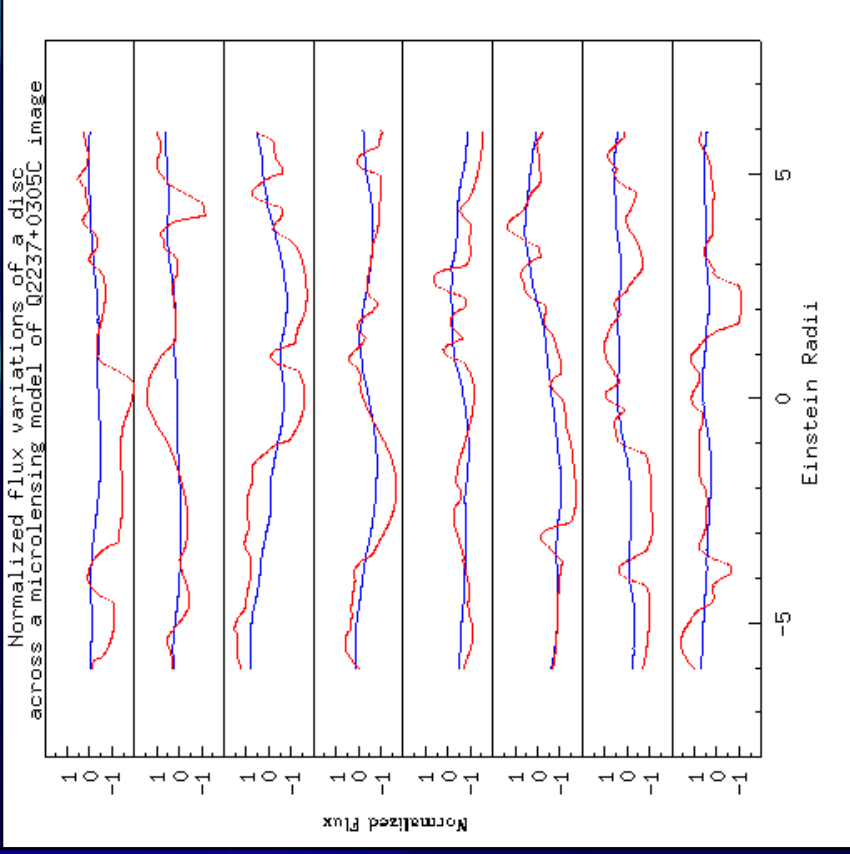
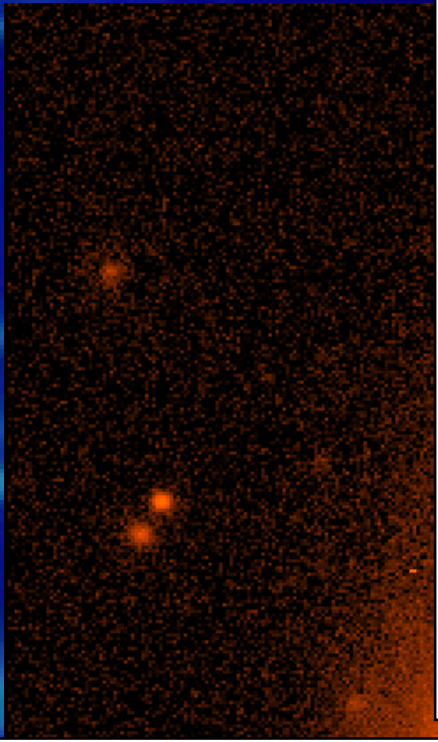


Q 2 2 3 7 + 0 3 0 5

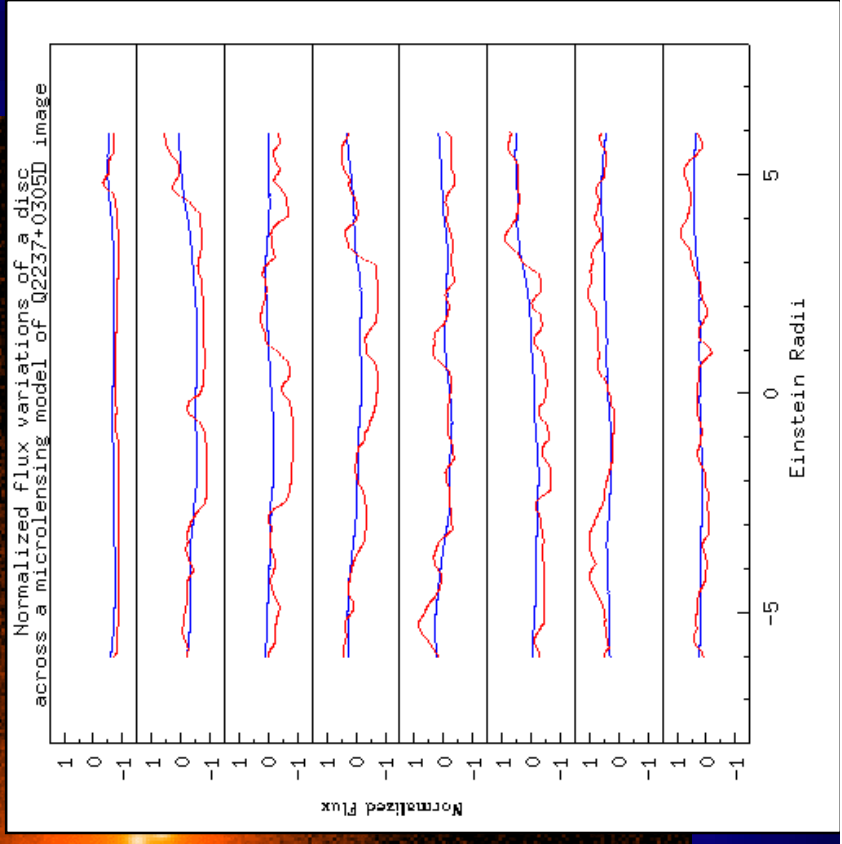
B

D

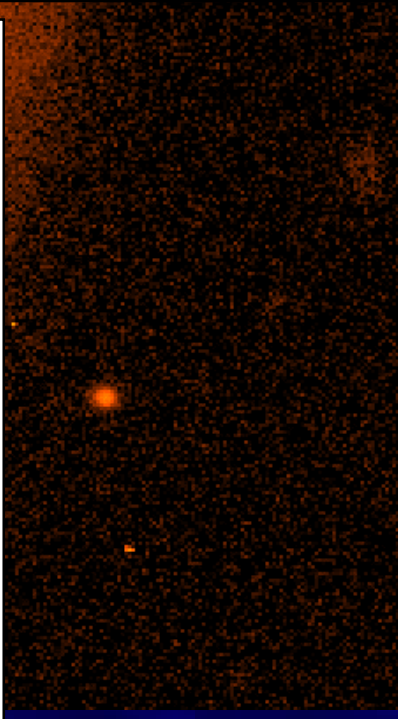
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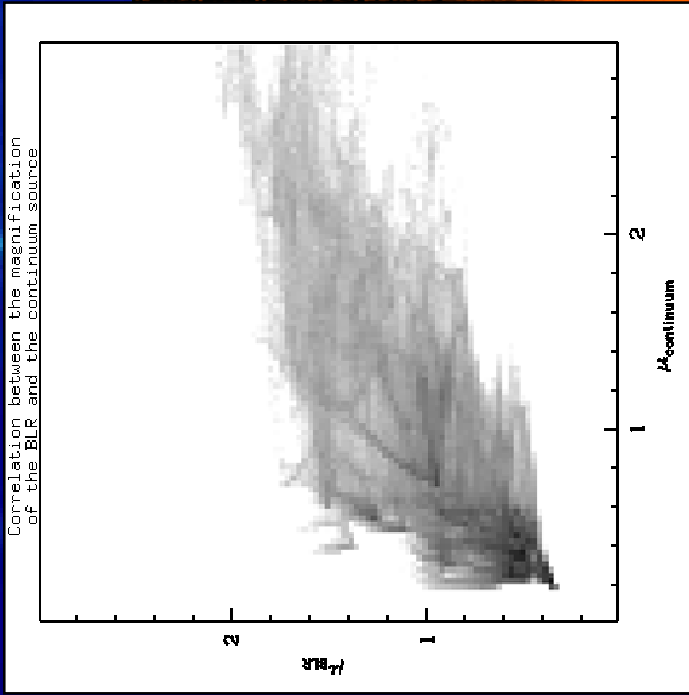
C



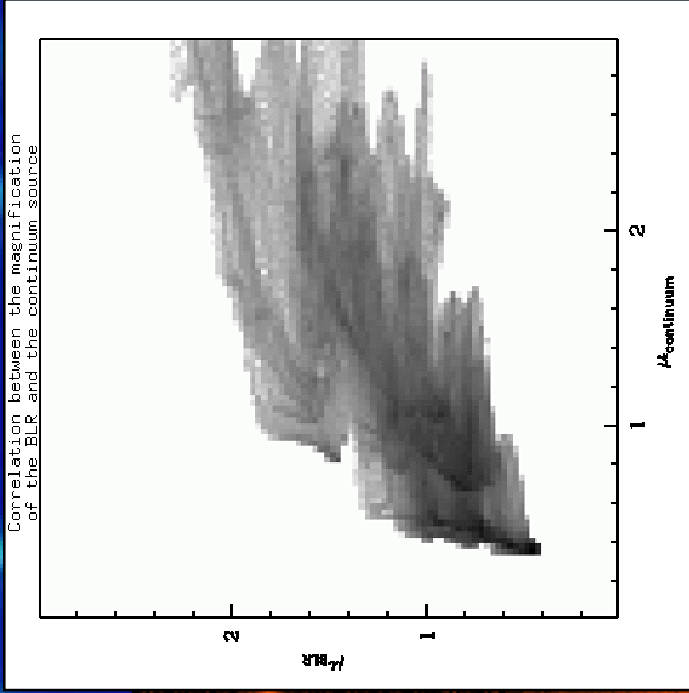
A



C

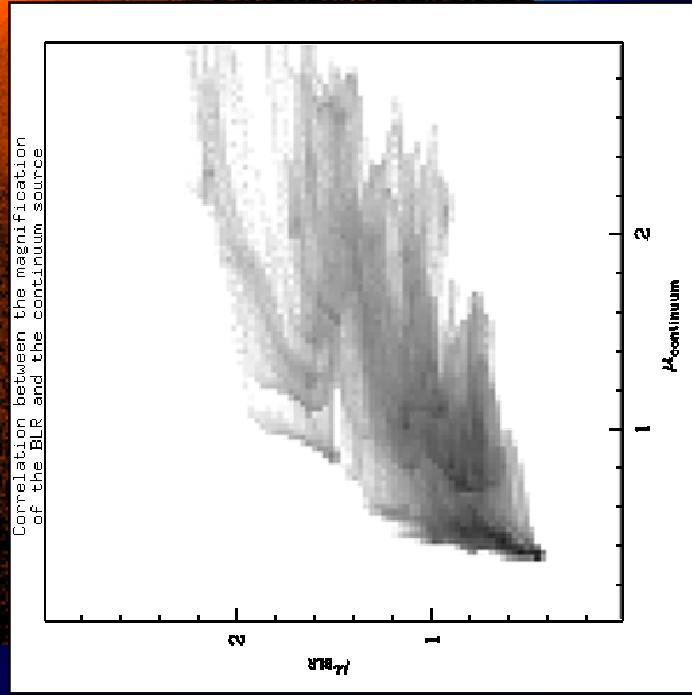


B

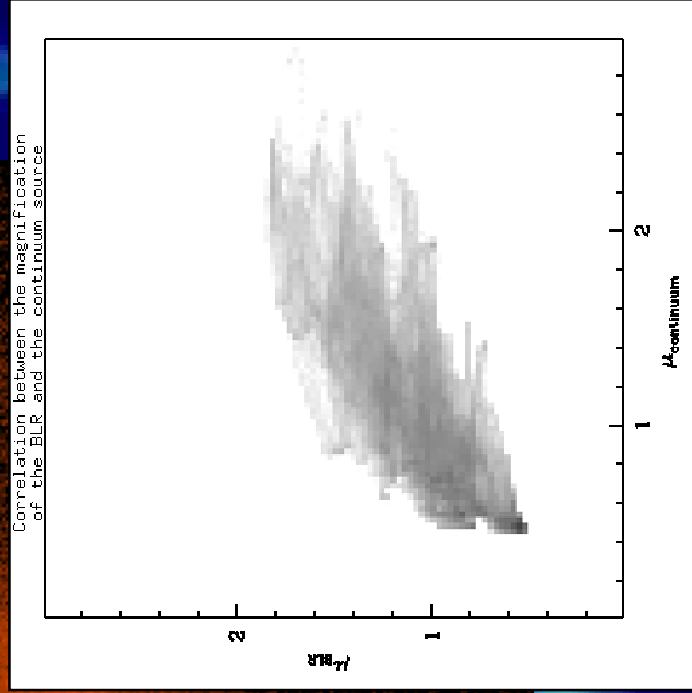


Q 2 2 3 7 + 0 3 0 5

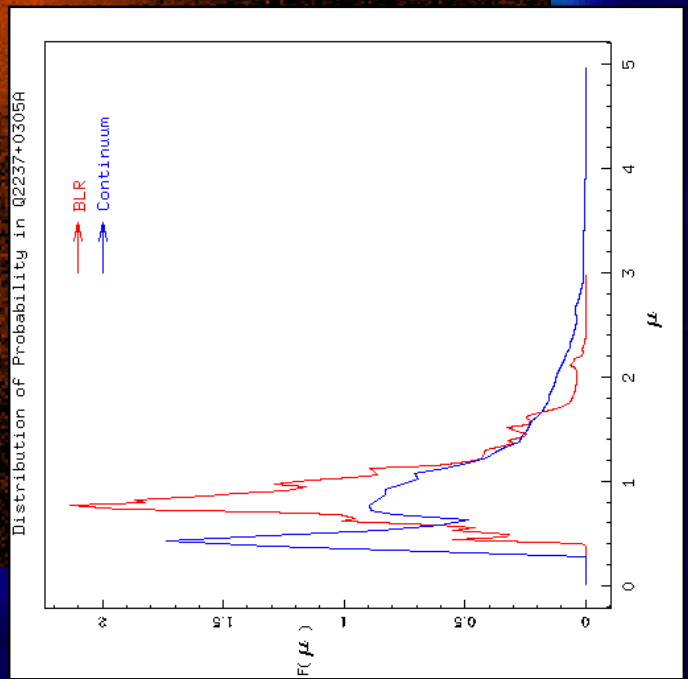
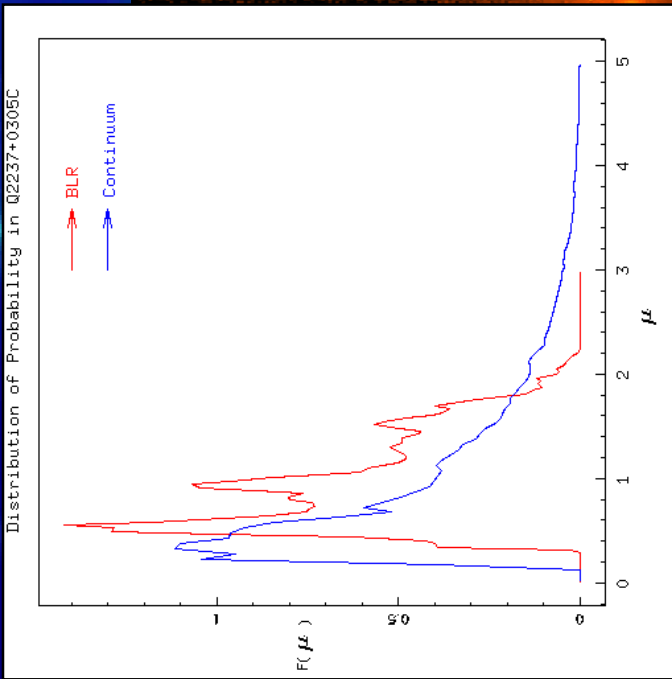
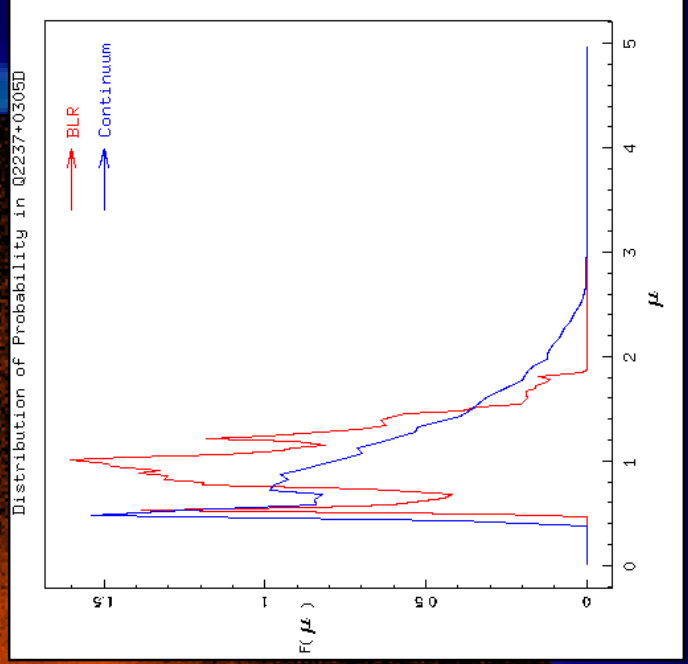
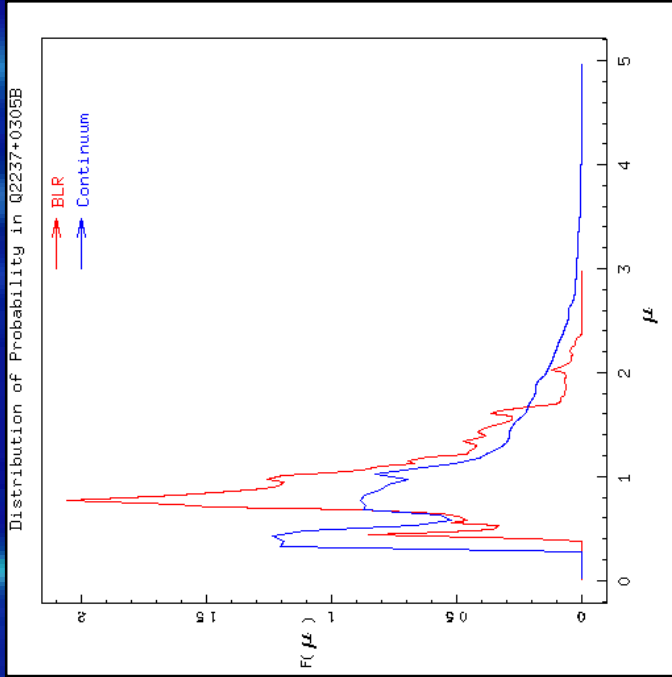
A



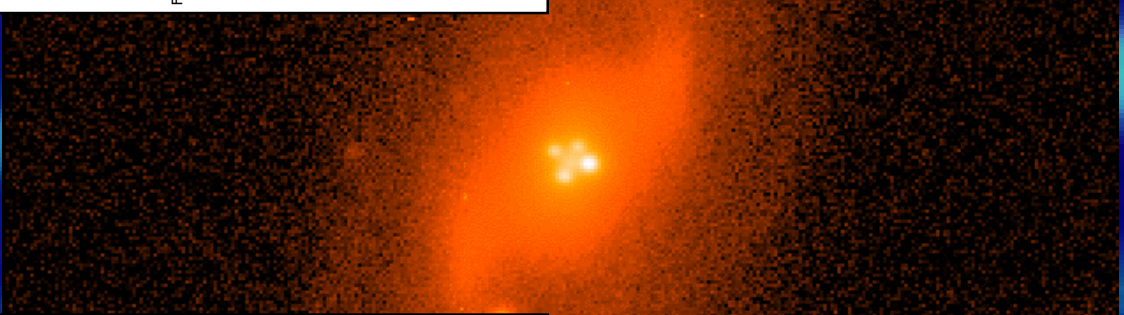
D



B Q2237+0305 D

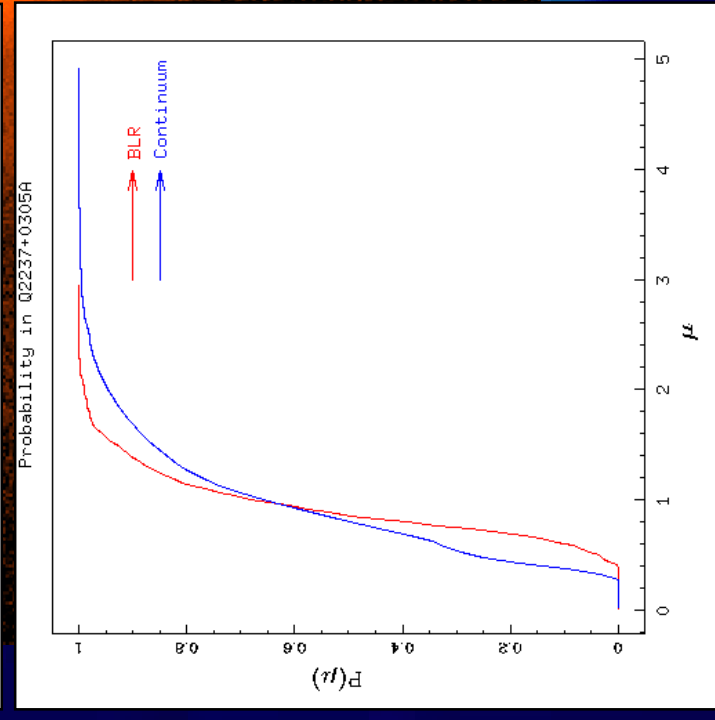
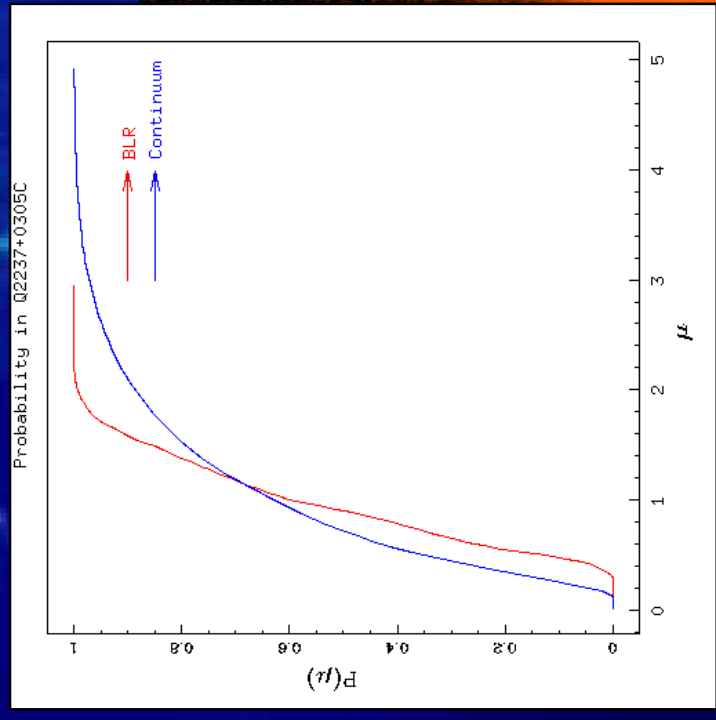
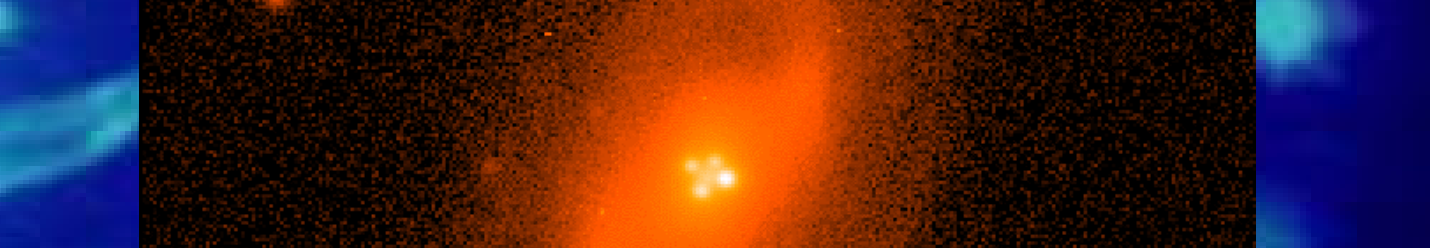
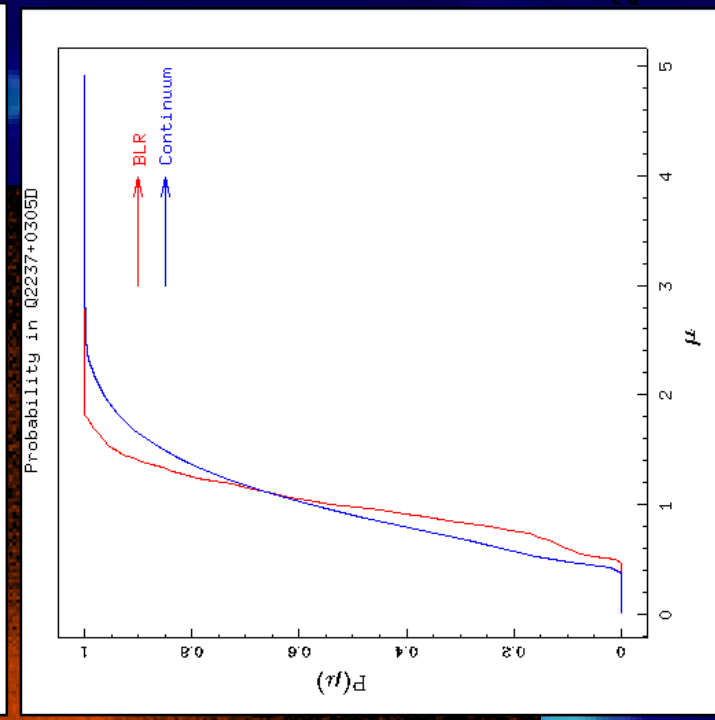
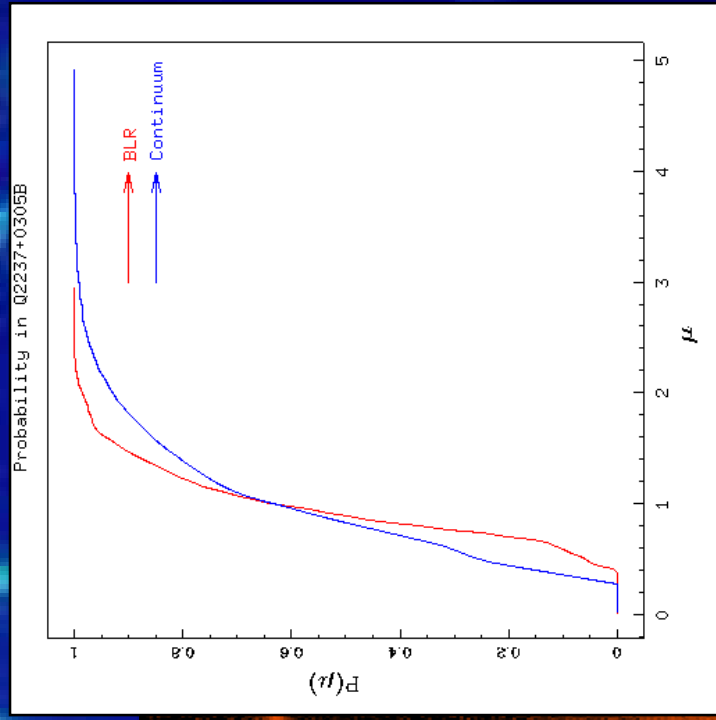


C A



B Q2237+0305B + 0305D

27

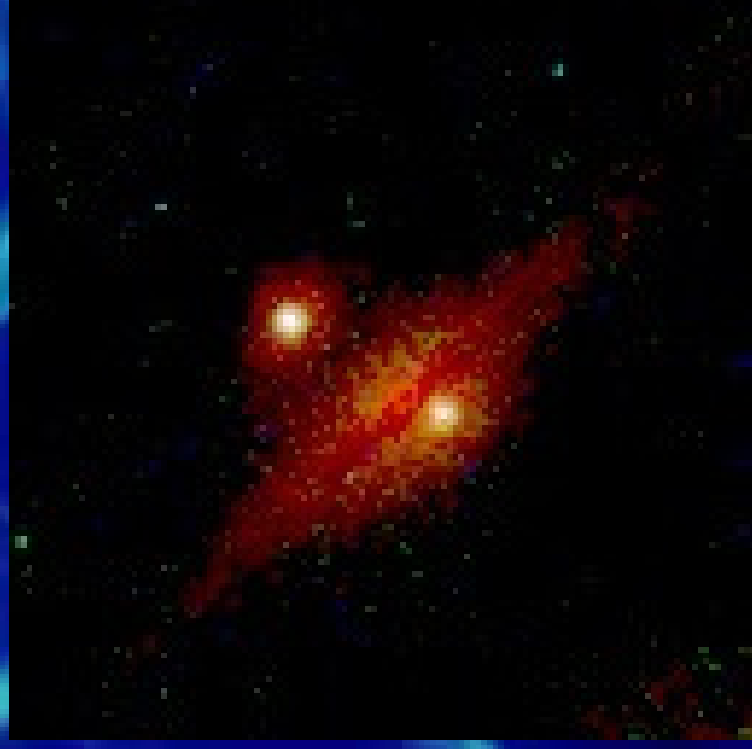


C A

Image	Kappa	Gamma
A	0.30	0.16
B	0.80	0.72

A

SIS+External
Shear



B1600+434

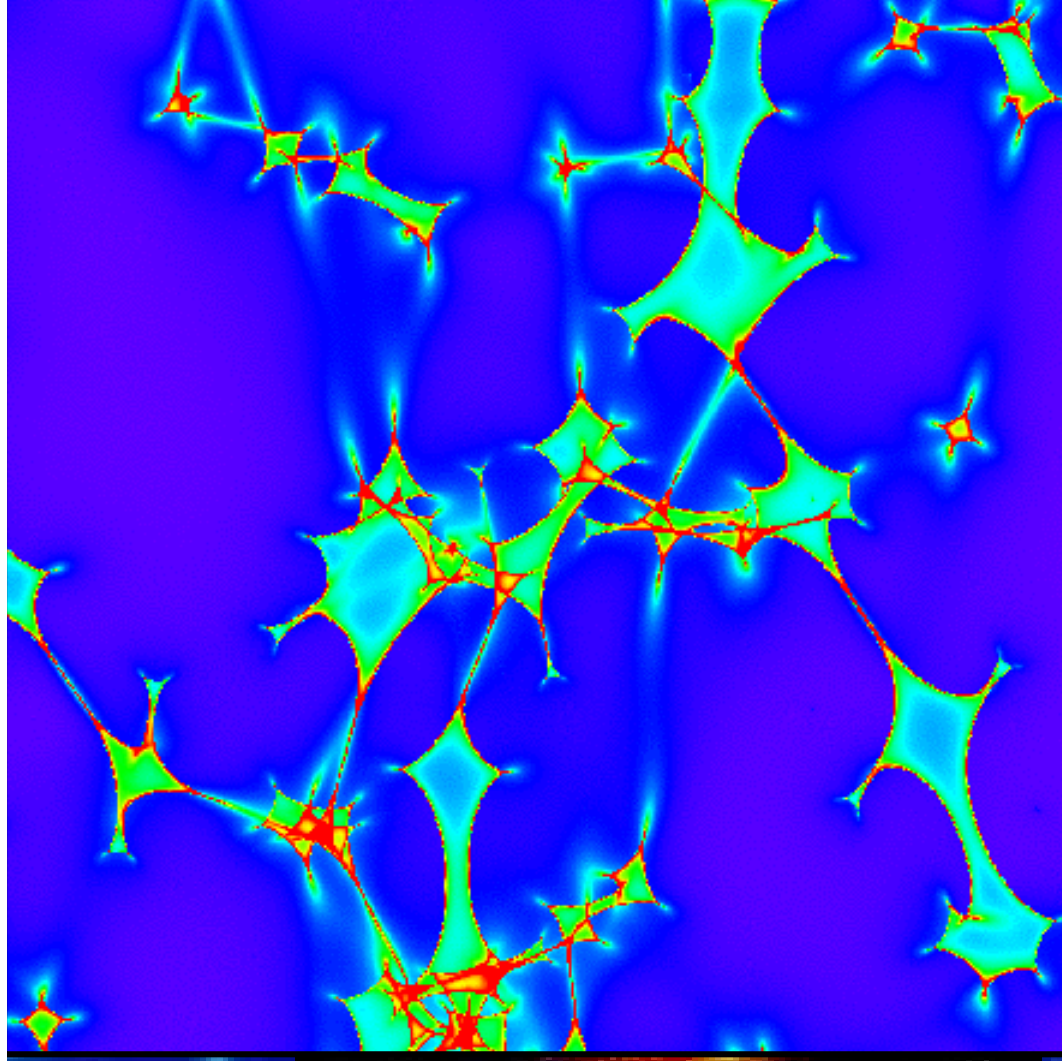
28

B

Image	Kappa	Gamma
A	0.30	0.16
B	0.80	0.72

A

SIS+External
Shear



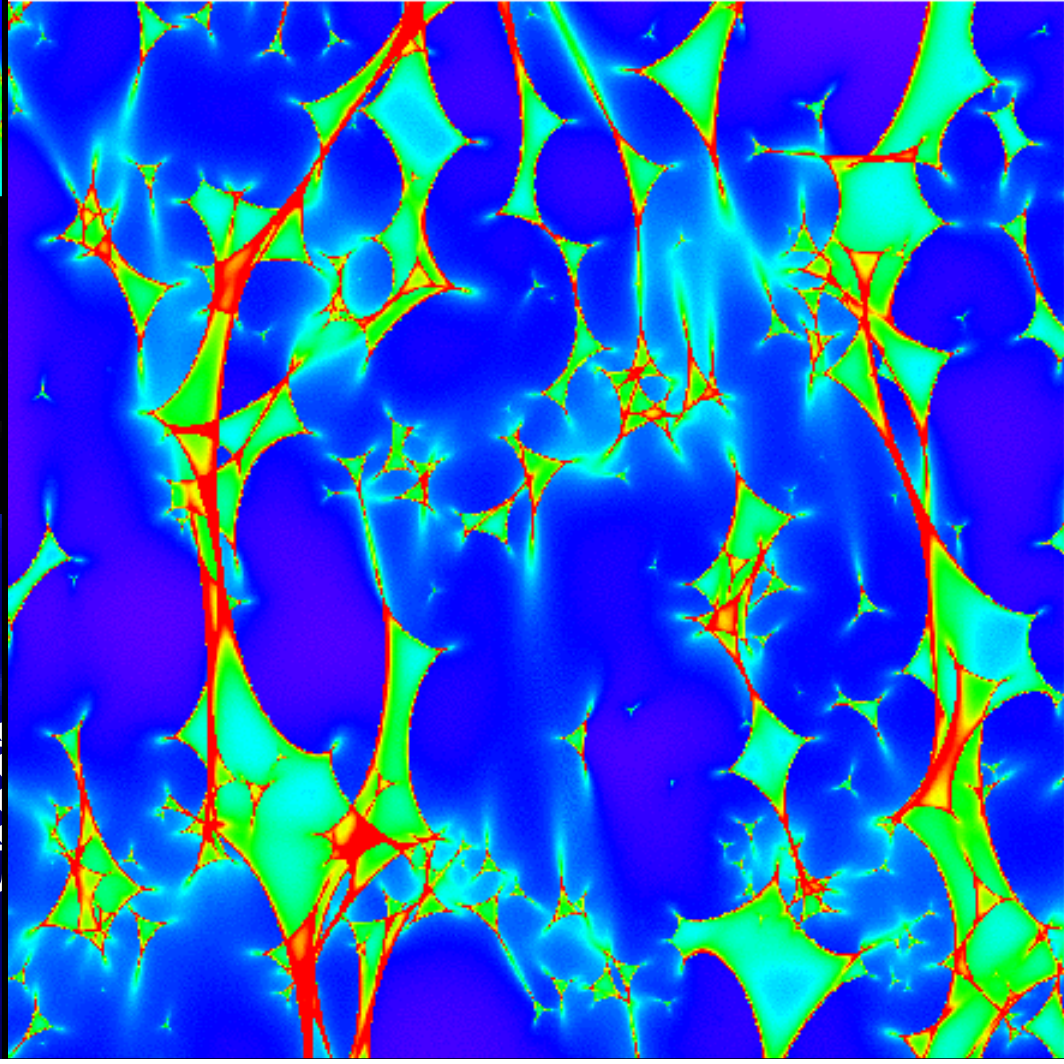
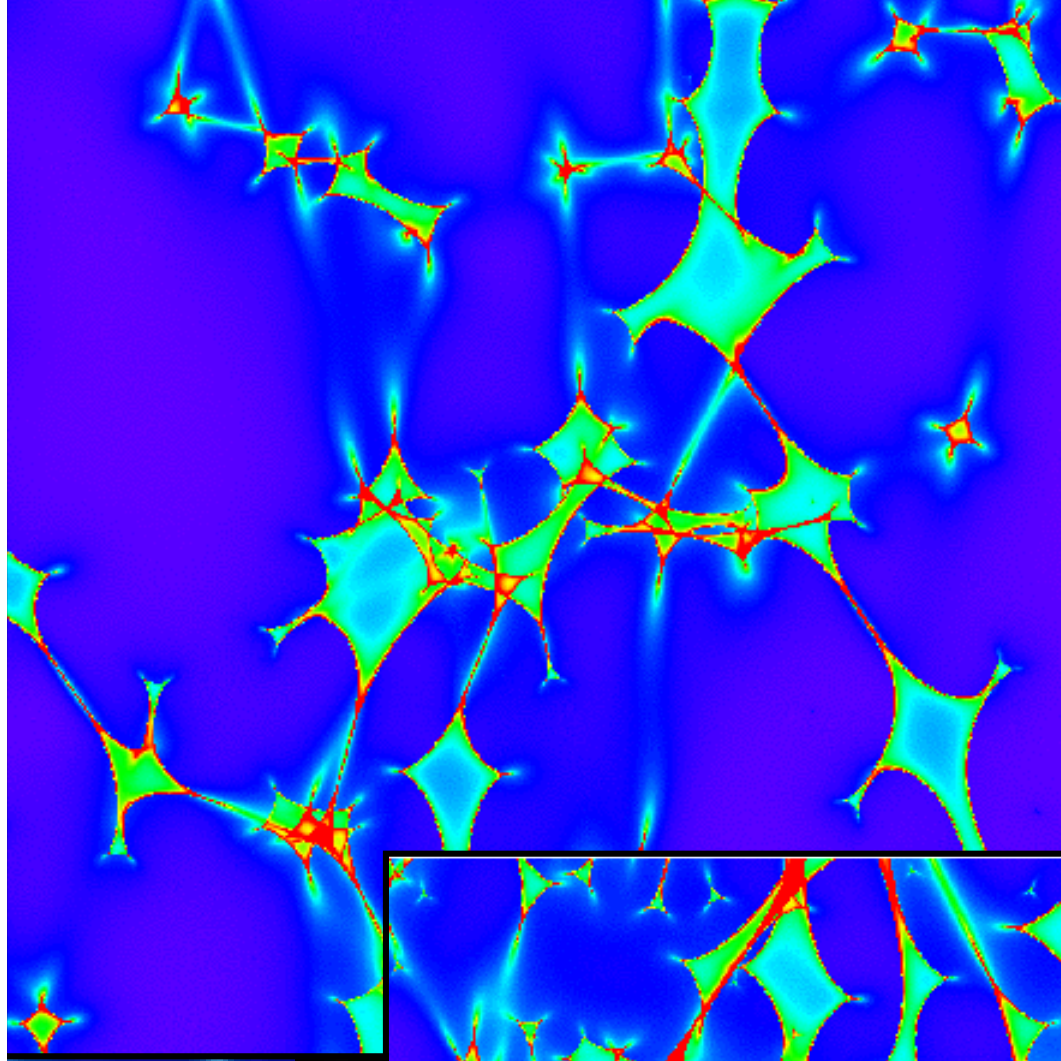
B1600+434

B

Image	Kappa	Gamma
A	0.30	0.16
B	0.80	0.72

SIS+External

clusters



B1600+434

30

B

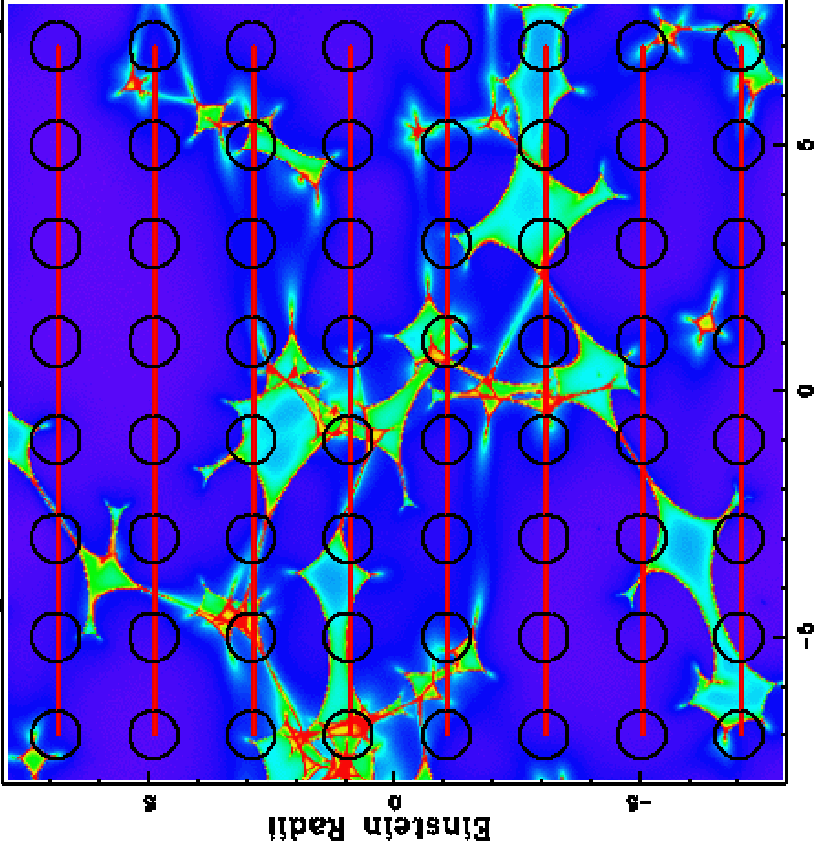
B1600+434

Image A

Broad lines region: High ionization
Keplerian disc model

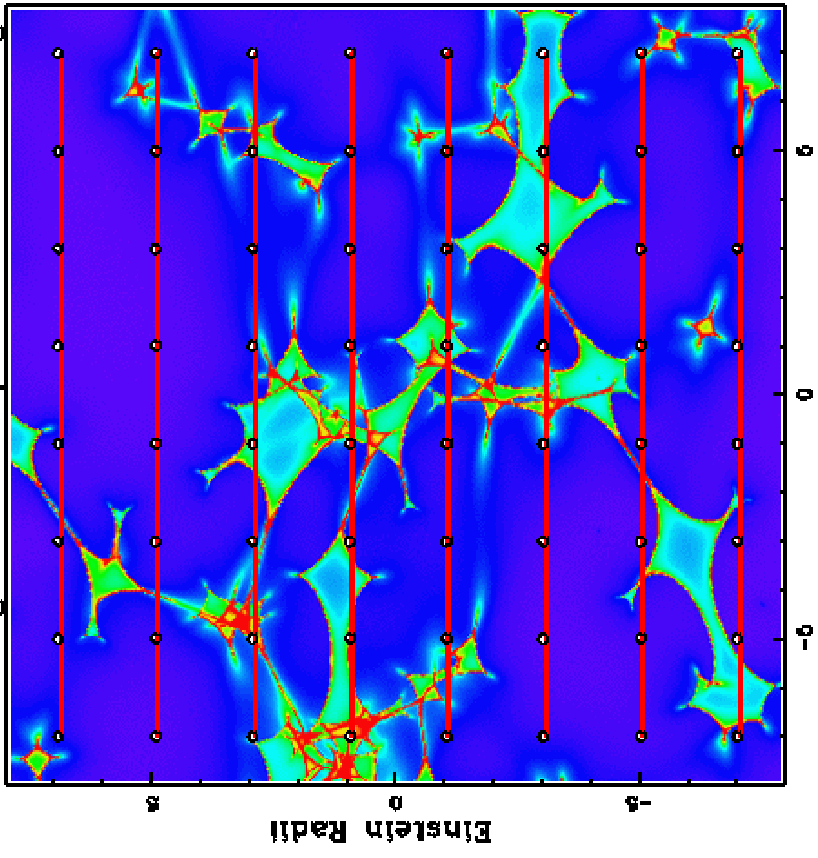
Continuum source
Power-law model

Microlensing contour map of B1600+434A image



Einstein Radii
Disc's positions with $r_{err}=0.5 r_e$

Microlensing contour map of B1600+434A image



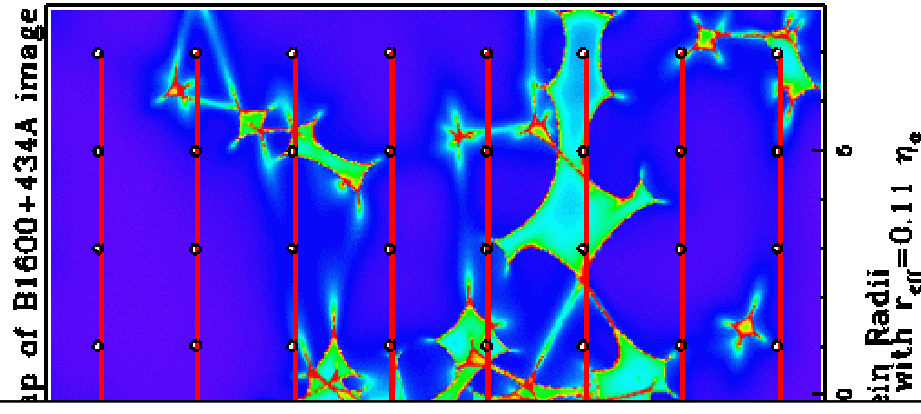
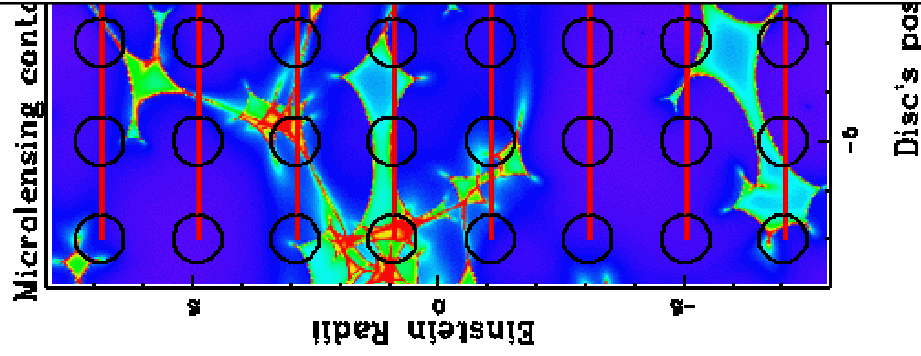
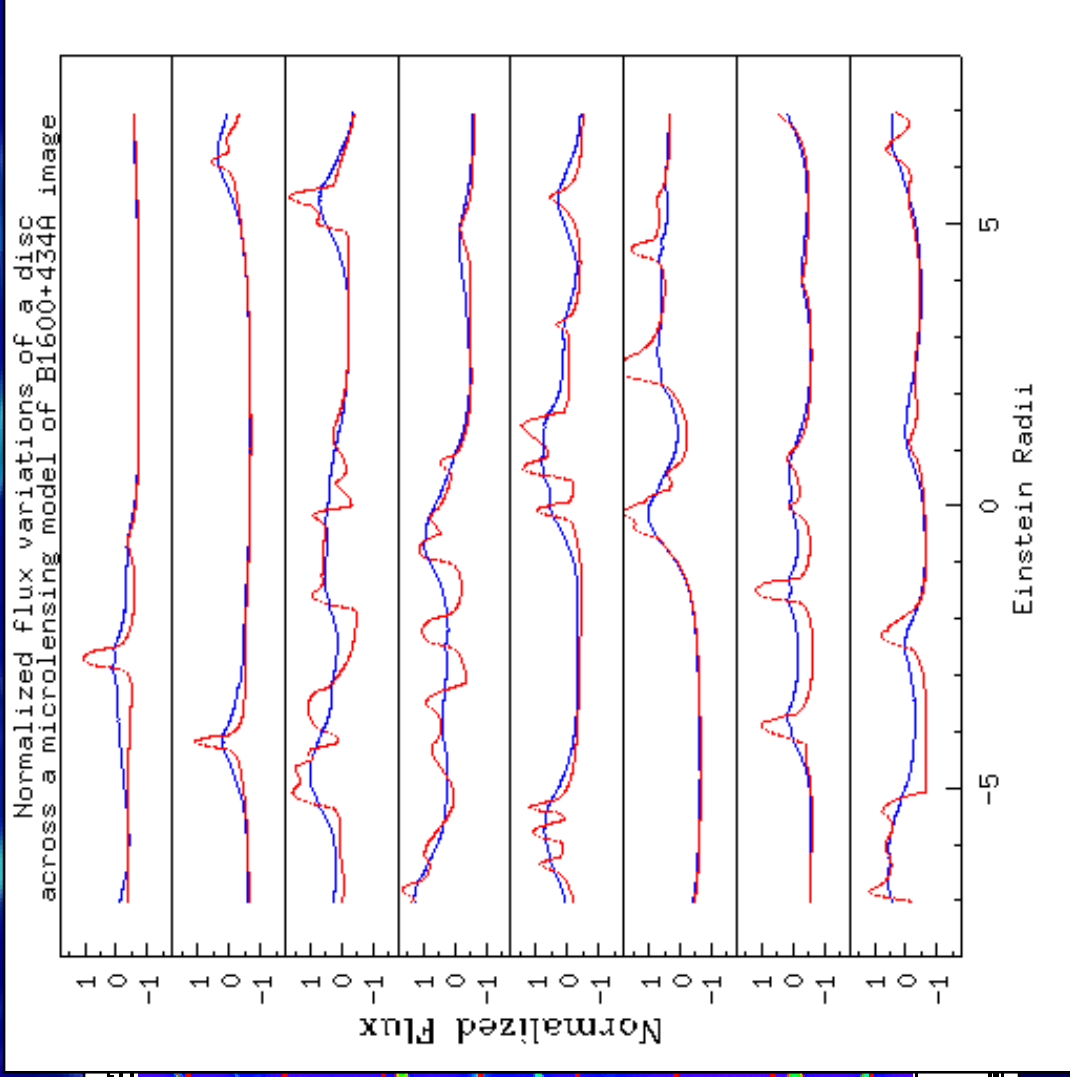
Einstein Radii
Disc's positions with $r_{err}=0.11 r_e$

B1600+434

Image A

Blue: Brod line region + Keplerian disk model

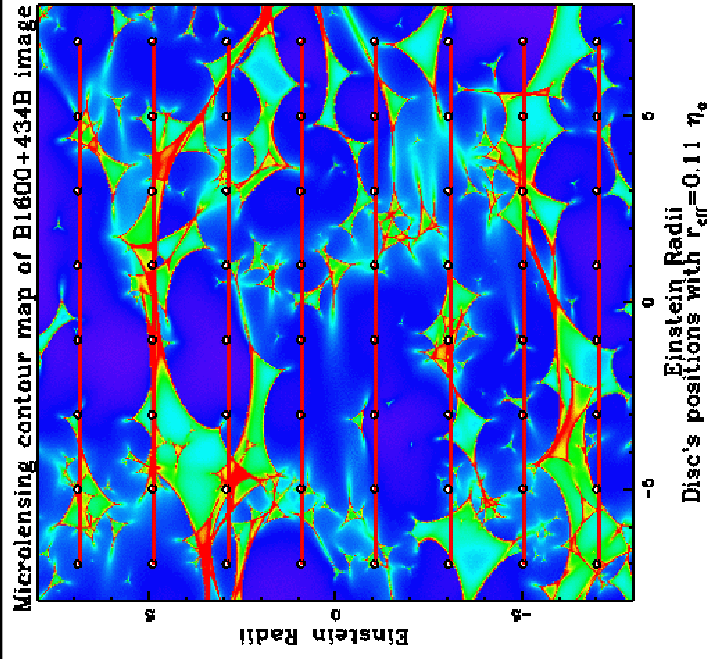
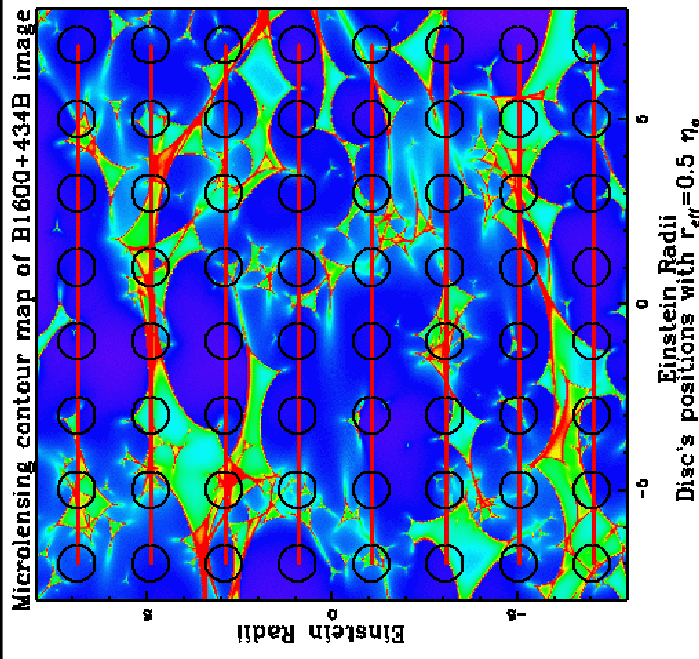
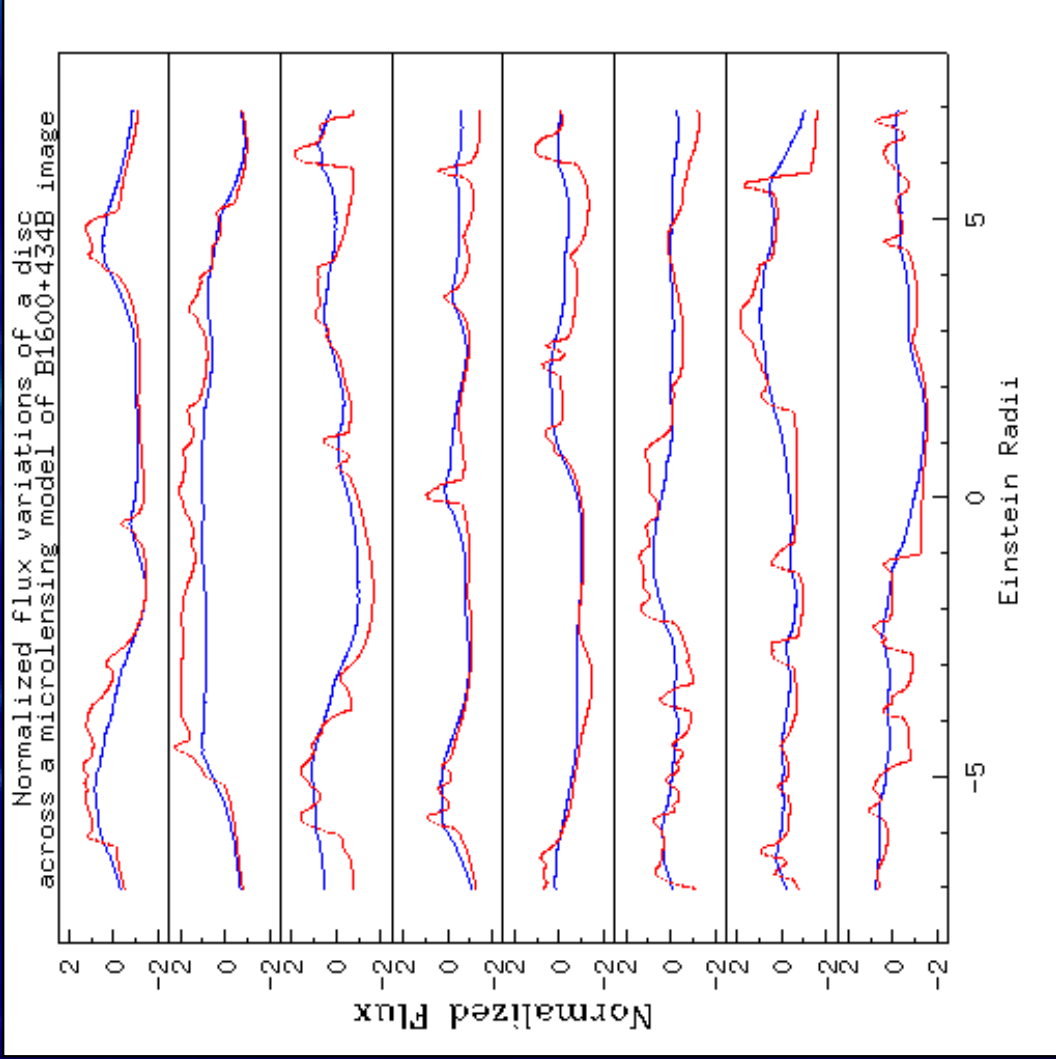
Red: continuum source + power law model



B1600+434

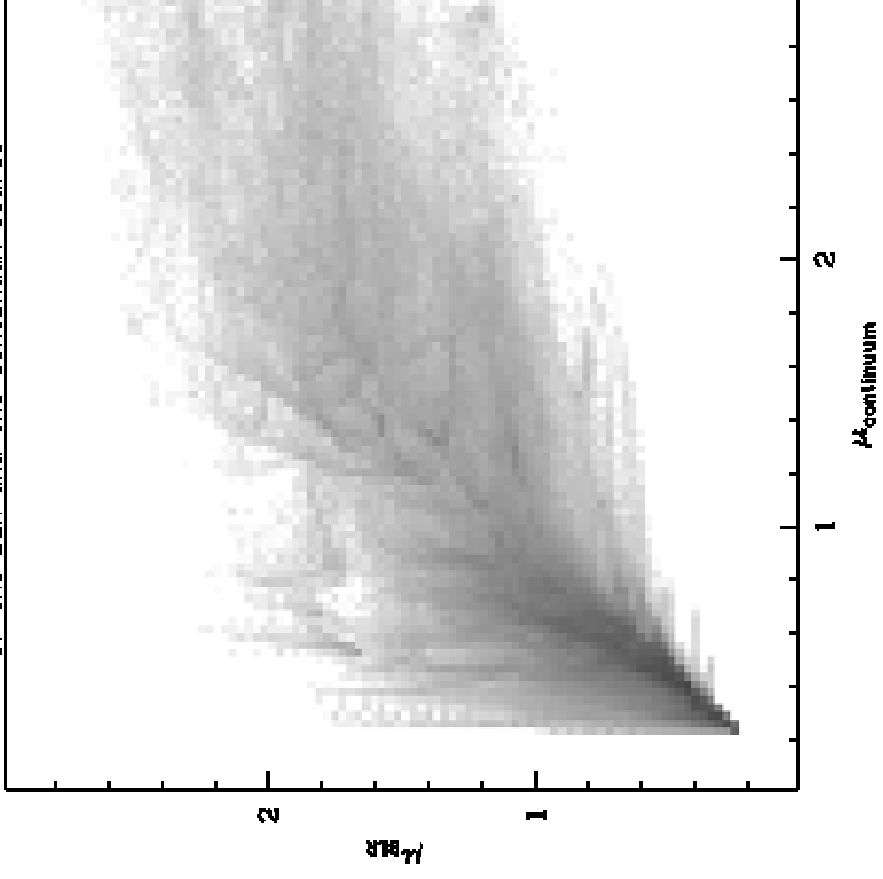
Image B

Blue: Brod line region + Keplerian disk model
Red: continuum source + power law model

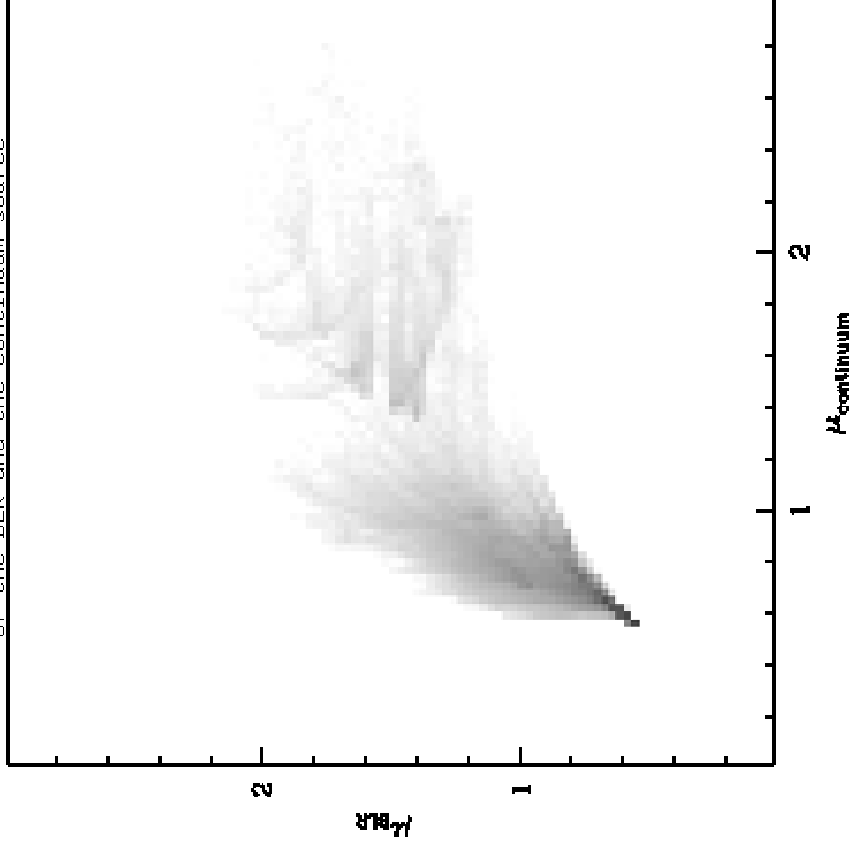




Correlation between the magnification of the BLR and the continuum source



Correlation between the magnification of the BLR and the continuum source



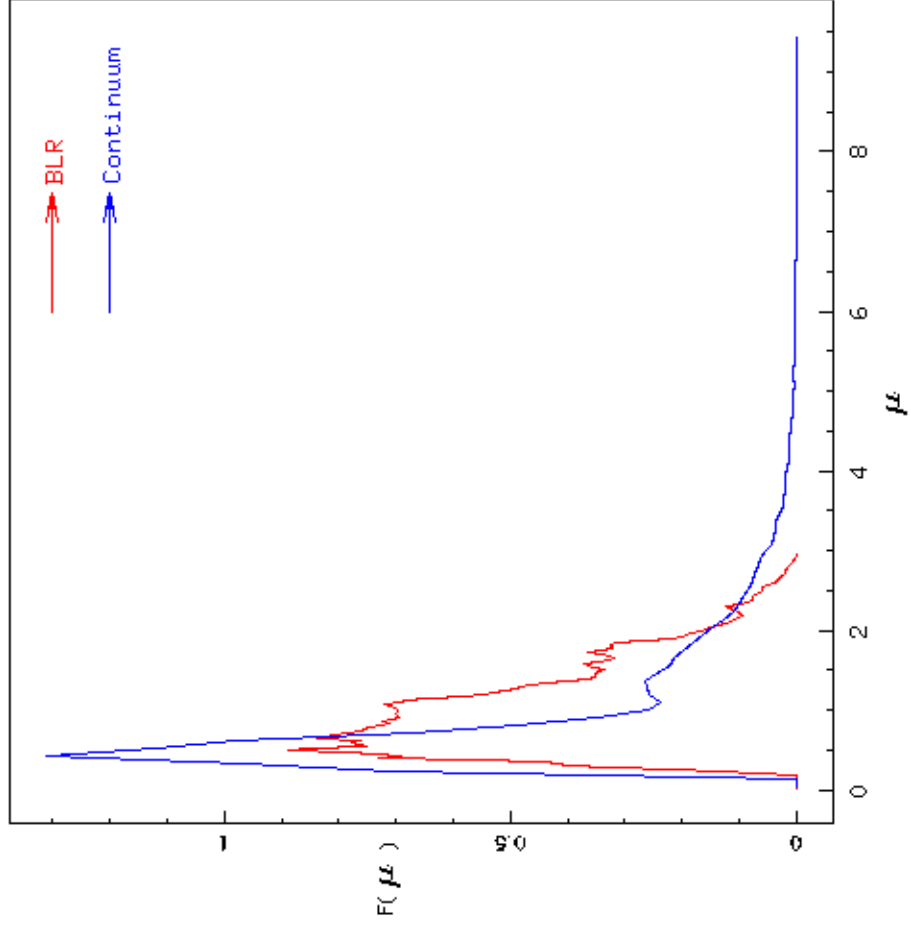
B

B1600+434

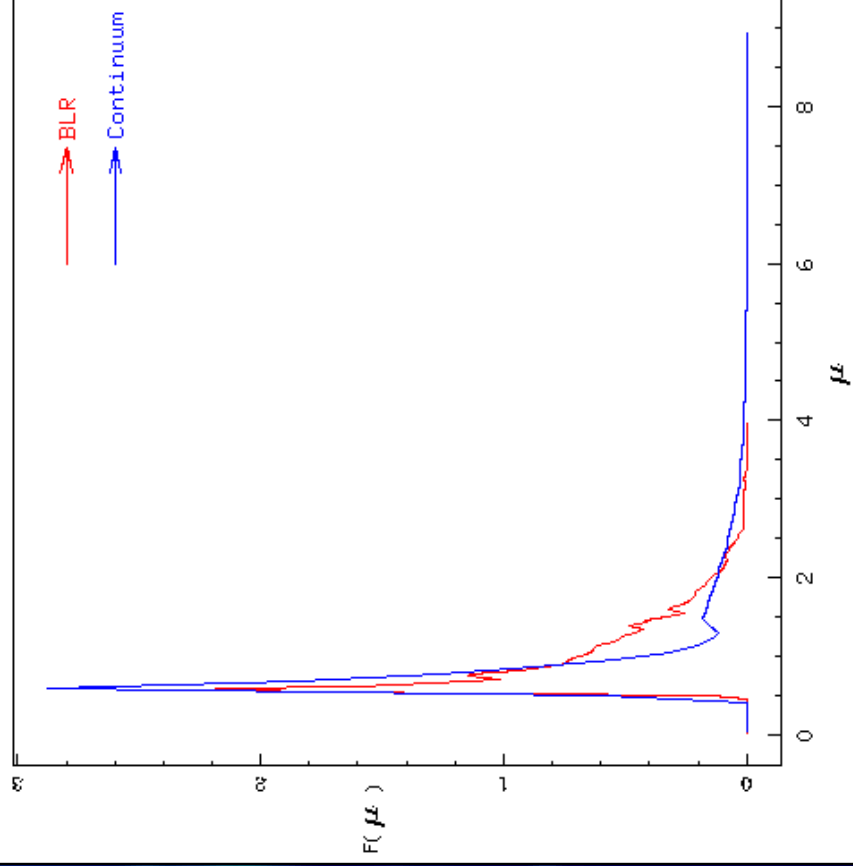


A

Distribution of Probability in B1600+434B

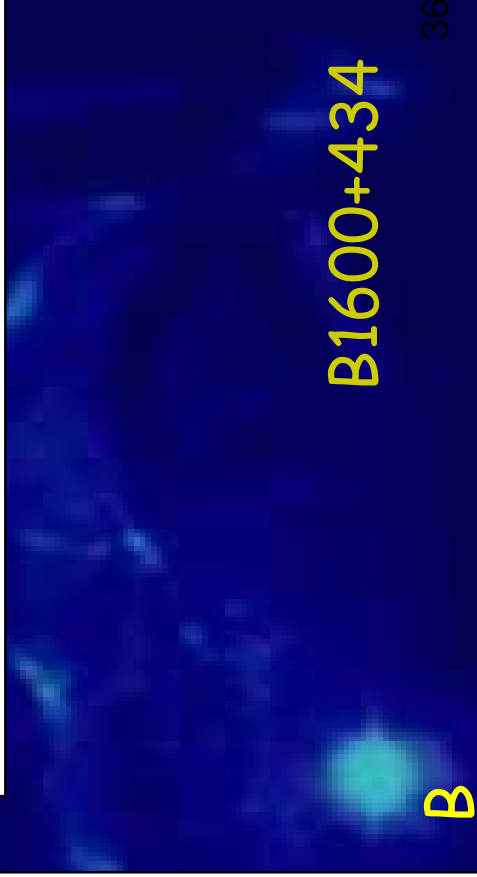
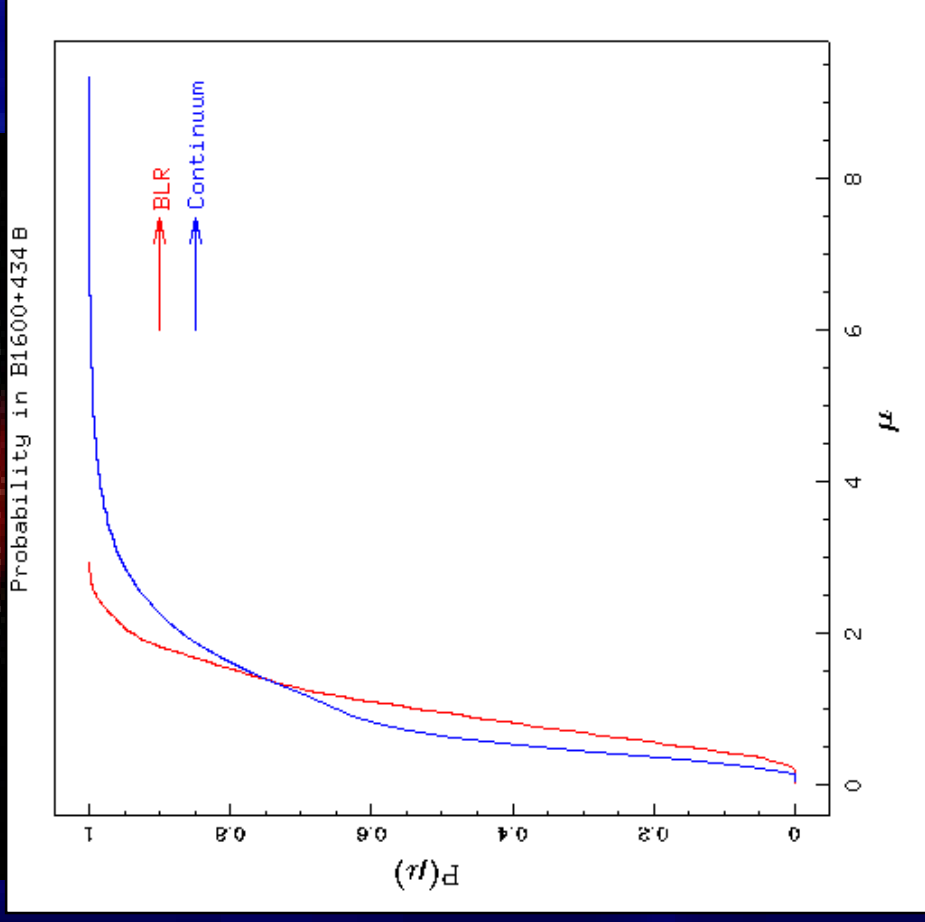
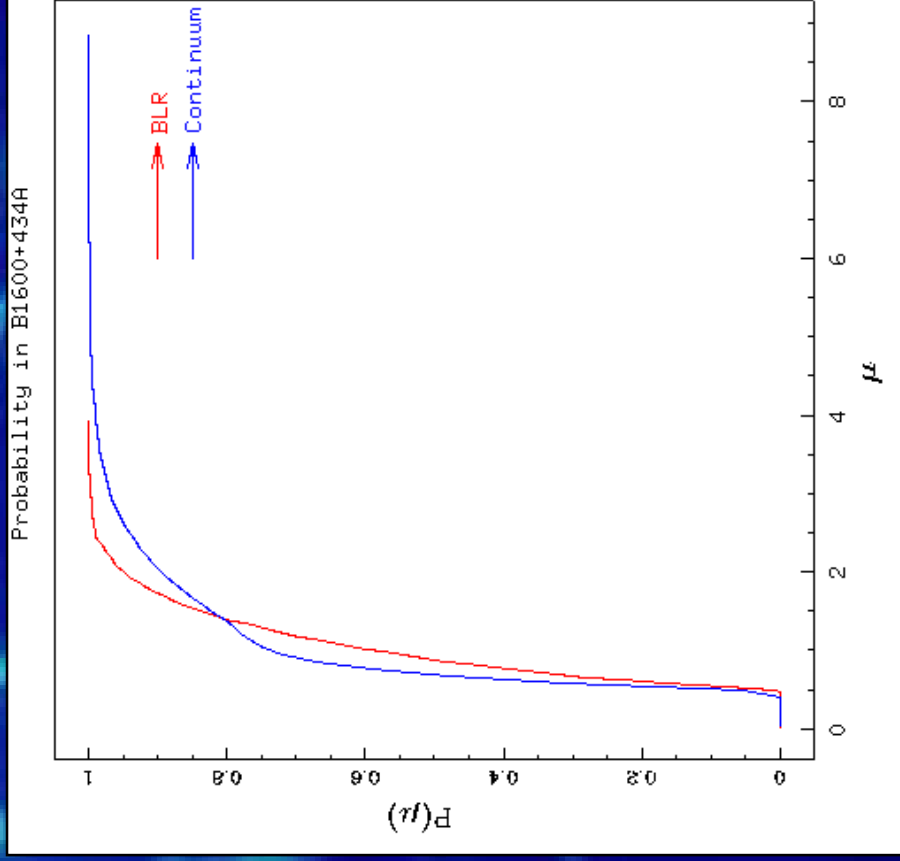
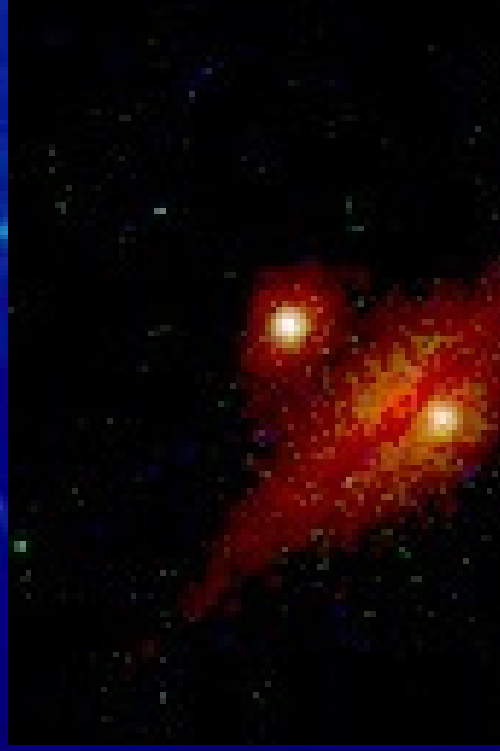


Distribution of Probability in B1600+434A



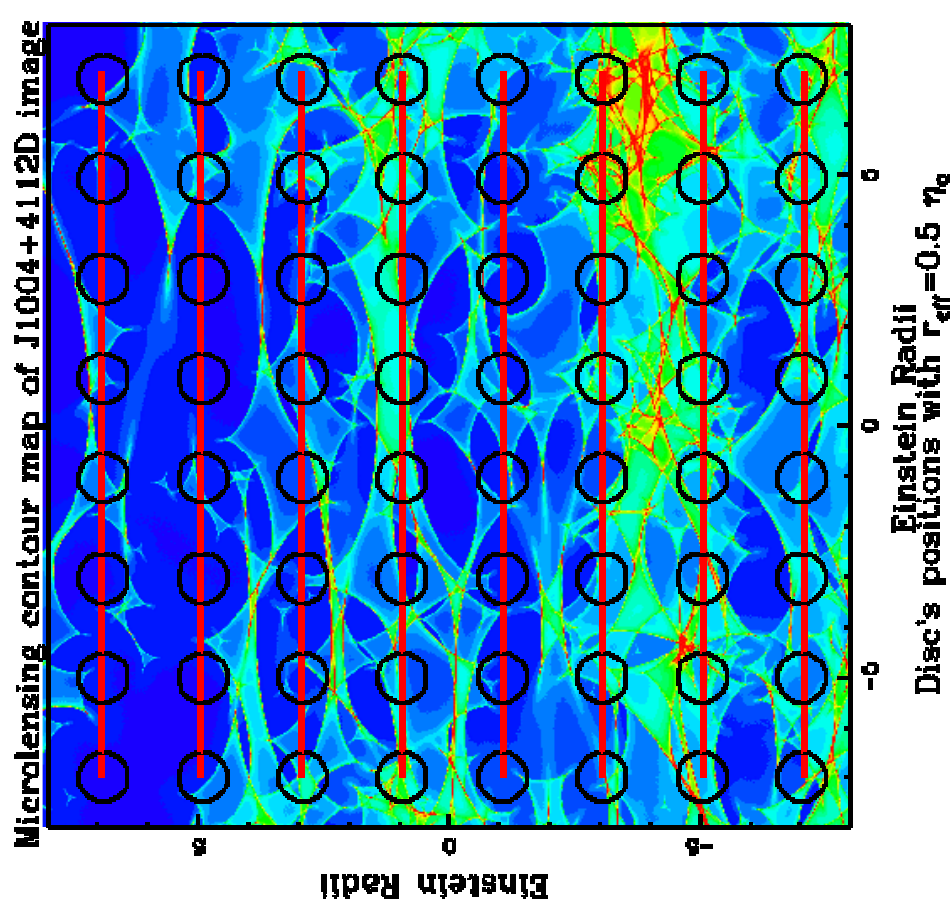
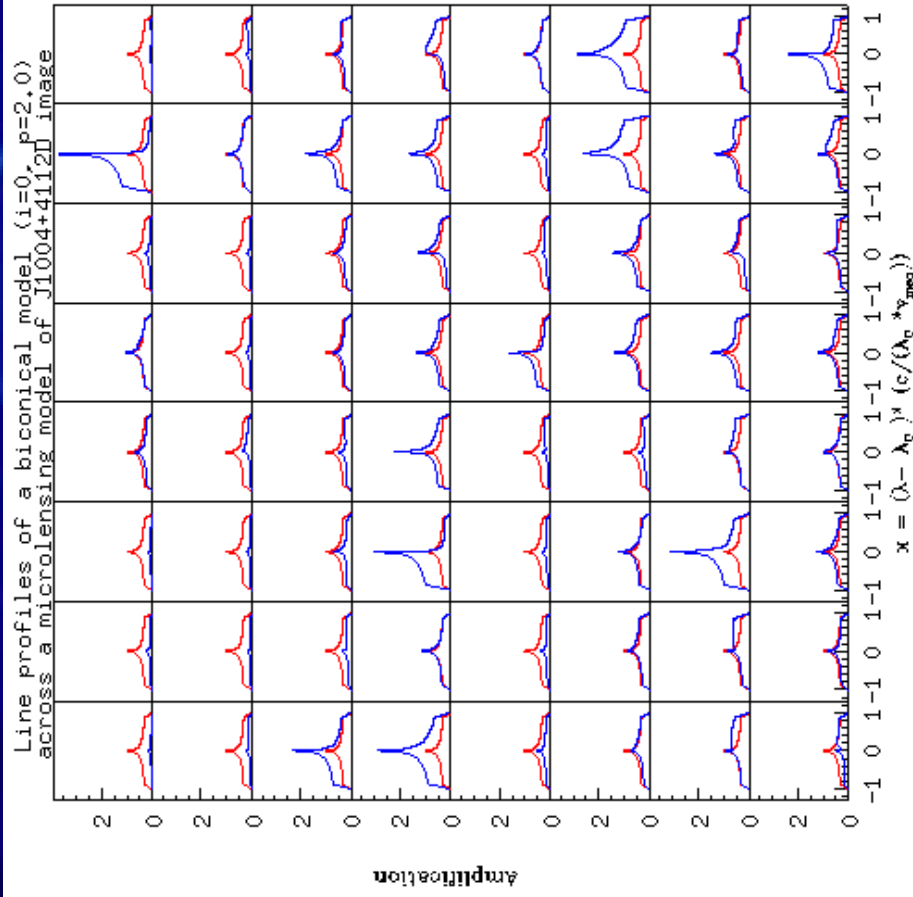
B

B1600+434



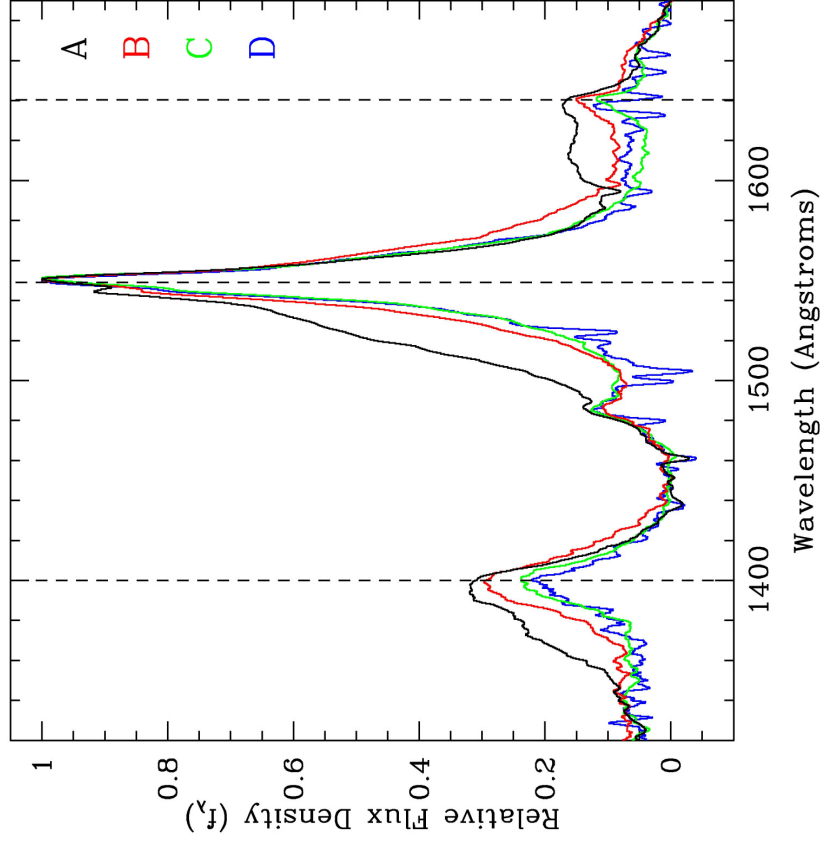
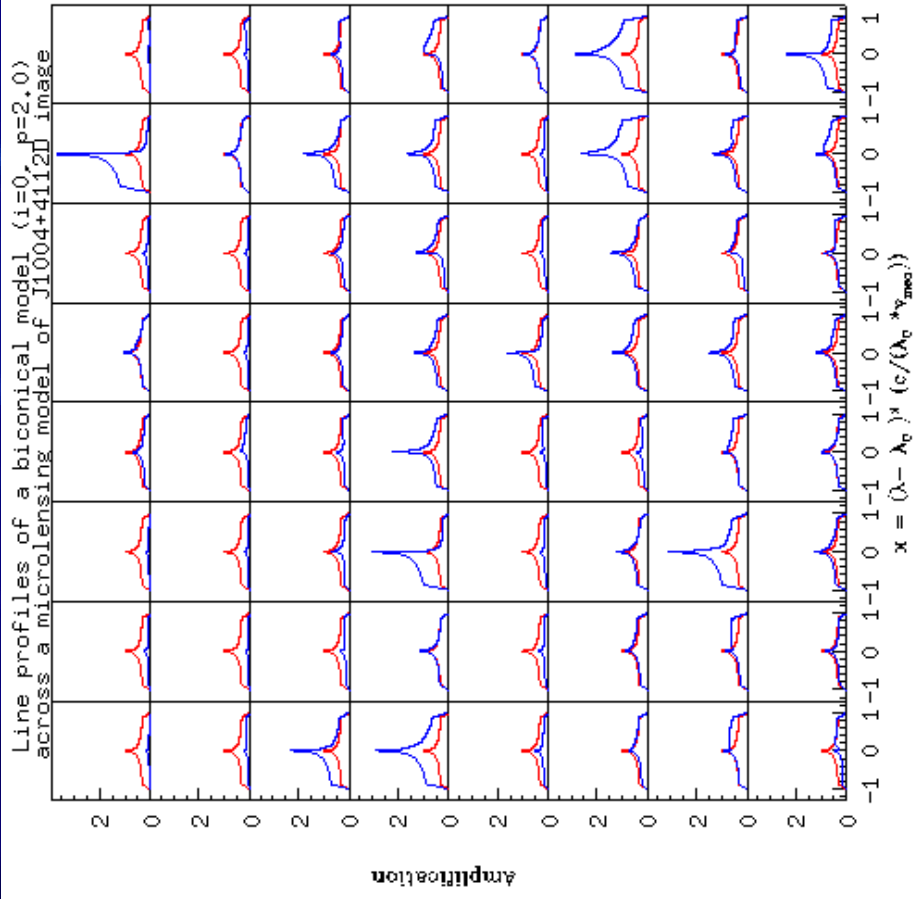
B1600+434

SDSS J1004+4112: Bi-conical model on BLR Image D



SDSS J1004+4112: Bi-conical model on BLR

Image D



Conclusions

- Microlensing on the BEL can open a new window to understand the physics of the BLR.
- Using conservative values for the BLR size of B1600+434 we found a probability around 20% to obtain amplifications $> 50\%$.
- Using a finite size for the QSO continuum the magnification variations between the BLR and the continuum show some correlations.
- The behaviour of the BEL amplification observed in SDSS J1004+4112 can be easily reproduced using a bi-conical model for the BLR.