Optical studies of an ultraluminous X-ray source: NGC1313 X-2

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in collaboration with
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OUTLINE

• background: ultraluminous X-ray sources
• a case study: NGC1313 X2
  • X-ray observations
  • optical observations
    • astrometry
    • photometry
    • color-magnitude diagram
    • spectral energy distribution
• discussion
  • IMBH formation
  • period?
  • radial velocity
ULTRALUMINOUS X-RAY SOURCES
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• ULXs are non-nuclear X-ray point sources with $L_x > 2 \times 10^{39}$ erg/s, i.e., more luminous than the Eddington luminosity for stellar mass black holes, and could be intermediate mass black holes of $30 \times 10^5$ Ms
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  • how do they radiate if stellar mass black holes?
ULXs in NGC 1313

- A barred SB(s)d galaxy at 3.7Mpc
- Low metallicity of 0.1-0.2 Zs
- Irregular SW satellite regions - a tidally disrupted companion galaxy? a collision of huge HI clouds with the disk?
- ULXs: X1, X2, and SN1978K
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X-ray observations: light curves

Zampieri et al. 2004
X-RAY OBSERVATIONS: LIGHT CURVES

Feng & Kaaret 2006
X-ray observations: spectroscopy

- light curves
  - observed since EINSTEIN
  - variability on time scales from days to months to years
  - maximum $L_x$ up to $3 \times 10^{40}$ erg/s

- X-ray spectra
  - can be fitted with a power-law ($\Gamma \sim 2.3$, 63%) plus a cool accretion disk ($\sim 160$ eV, 37%) suggestive of a IMBH of $\sim 10^3$ Ms (Miller et al. 2003)
  - but the cool accretion disk component is dominated by the power-law component, and the fit is not unique
  - it can also be fitted with a power-law ($\Gamma \sim 2.9$, 64%) plus a hot disk ($\sim 2.7$ keV, 36%). (Stobbart et al. 2006)
OPTICAL OBSERVATIONS

ESO 3.6m R

Zampieri et al. 2004

counterpart: C (later resolved to C1 and C2)
Table 1. The HST ACS observations for NGC1313 X-2

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<th>ID</th>
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<th>$Z_{VEGA}$</th>
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OPTICAL OBSERVATIONS: ASTROMETRY
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acis3550: reconstructed

F555W 2003
OPTICAL OBSERVATIONS: ASTROMETRY

x3: foreground star
x4: background AGN
OPTICAL OBSERVATIONS: ASTROMETRY

ACS/WFC F555W

X4

ULX

CR

C1

C2

ACS/WFC F555W
OPTICAL OBSERVATIONS: ASTROMETRY

Counterpart: C1
OPTICAL OBSERVATIONS: ENVIRONMENTS
OPTICAL OBSERVATIONS: PHOTOMETRY

- IRAF/DAOPHOT was used
- VEGAmag and STMAG were computed

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only 12 out of 400 stars are variable above 3 sigma

counterpart: $\Delta F_{555W} = 0.153\pm0.047$ mag
COLOR-MAGNITUDE DIAGRAMS

- use HST ACS/WFC VEGAmag photometric system for data and isochrones
- Z=0.2Zs isochrones (Leo Girardi), E(B-V)=0.11
- (a) \(t=1\times10^7,5\times10^7,2\times10^8,5\times10^8\) years (b) \(t=1\times10^7,5\times10^7,3\times10^8,1\times10^9,3\times10^9\)
COLOR-MAGNITUDE DIAGRAMS

- two populations
  - young: < a few $10^7$ years
  - old: 3-30$x10^8$ years
- ULX age for $E(B-V)=0.11$ mag
  - $10^7$ years from F435W-F555W
  - $3x10^7$ years from F555W-F814W
- two ages converge at $5 \times 10^6$ years for $E(B-V)=0.33$ mag [$E(B-V)=0.44$ mag from X-ray absorption]
  - initial/current mass of $52/8.5$ Ms, radius of $7$ Rs
SPECTRAL ENERGY DISTRIBUTION
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The graph illustrates the spectral energy distribution with wavelength on the x-axis and $F_\lambda$ (erg/s/cm$^2$/Å) on the y-axis. Different symbols and line styles represent various stellar types:

- **05V** represented by green circles
- **07V** represented by pink squares
- **09V** represented by green dots
- **B1 III** represented by black triangles

A label indicates $ULX$$: E(B-V) = 0.11$. The graph shows a linear decrease in $F_\lambda$ with increasing wavelength, which is typical for stars in these spectral types.
SPECTRAL ENERGY DISTRIBUTION
counterpart identified with C1
showed 15% variability
SED consistent with O7V (Zs, 30Ms, 9Rs) for $E(B-V) = 0.33$ mag
$E(B-V) = 0.33$ mag, $Z = 0.2Zs$: an age of 5 million years, mass 8.5 Ms, and radius 7 Rs
on the edge of a young open cluster, amid dominant old stars
IMBH formation
IMBH FORMATION

- If an IMBH, cannot form from evolution of high metallicity stars ...
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X2’s location close to a young open cluster, the low Z, and possible collision/disruption may point to the merging of proto stars in proto clusters
• estimate the period assuming C1 overflows its Roche lobe
• Roche lobe size \( R_{cr} = a \cdot f(q) \)
  - \( q = \frac{M_{sec}}{M_{primary}} \)
  - Kopal tabulation (1959)
  - Paczynski approximation (1971)
  - Eggleton approximation (1983)
• equating \( R_{sec} = R_{cr} \) ...
  - shorter \( P \) for larger \( q \)
  - \( \rho = \frac{110}{P^2} \) for \( q < 0.3 \)
• constraints
  - \( P = 56 \) hr?
  - \( P < 56 \) hr \( \Rightarrow \) \( M < 15 \) Ms
• propose observations to detect such a period
RADIAL VELOCITY

![Graph showing radial velocity versus primary mass](image)

- (8.5M_☉ 7R_☉) secondary
- (8.5M_☉ 7R_☉) primary
- (30M_☉ 9R_☉) secondary
- (30M_☉ 9R_☉) primary

rotational velocity (km/s)

primary mass (M_☉)
Radial velocity

HeII line FWHM: 600 km/s
line shift: 300 km/s

Pakull et al. 2006
RADIAL VELOCITY
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  - emission lines from X-ray illuminated accretion disks are broad, >1200 km/s
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