The Black Hole in NGC 1313 X-2

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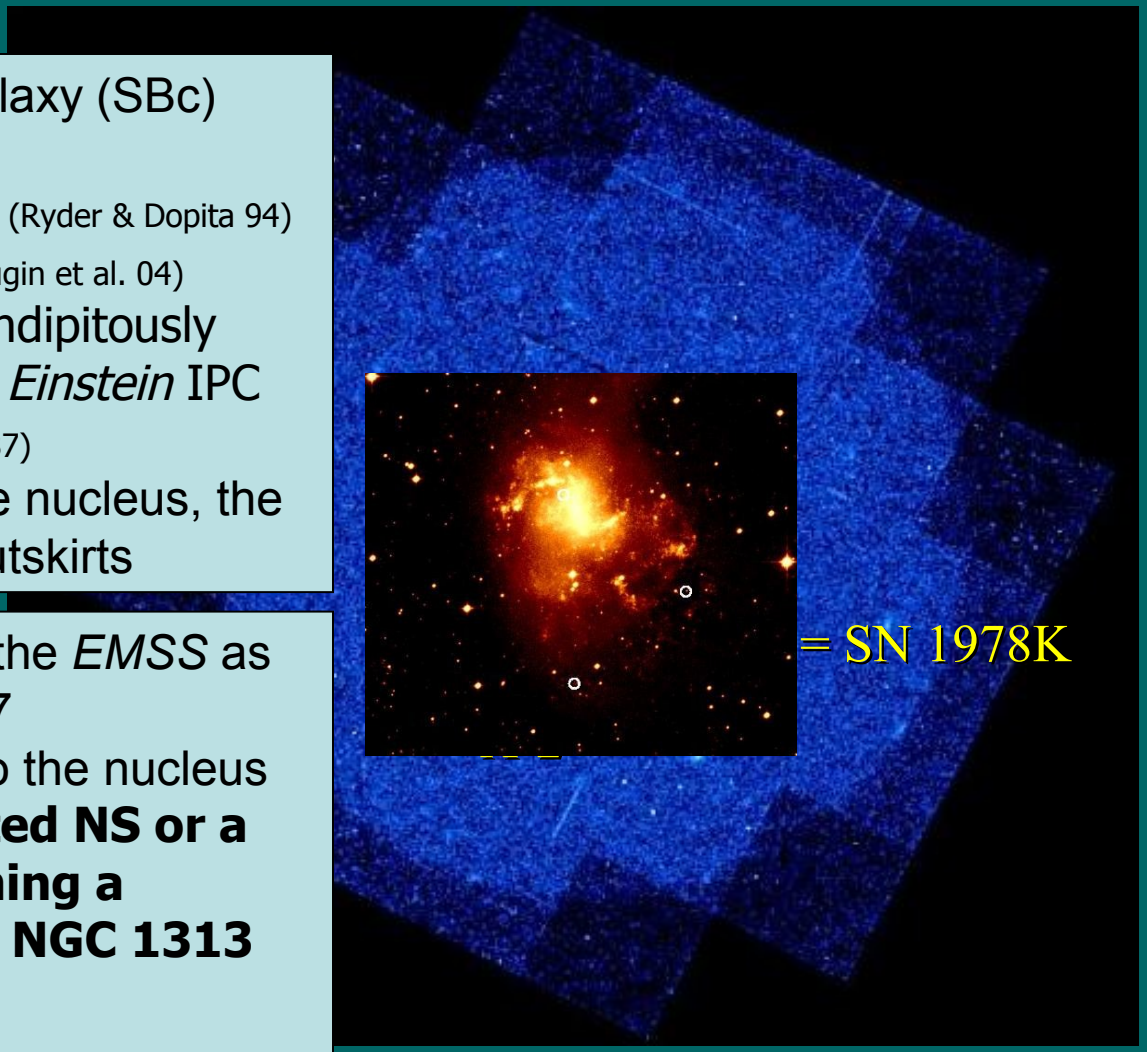
Outline

- A bit of history
- Revisiting X-ray and optical observations of NGC 1313 X-2
- Evolution of the binary system
- NGC 1313 X-2 in context
- Conclusions and future perspectives

NGC 1313 and its ULXs

- Barred spiral galaxy (SBc) at ~4 Mpc
- SFR~1 Msun/yr (Ryder & Dopita 94)
- Z~0.1 Zsun (Pilyugin et al. 04)
- 2+1 ULXs, serendipitously discovered with *Einstein* IPC (Fabbiano & Trinchieri 87)
- One close to the nucleus, the other 2 at the outskirts

- X-2 included in the *EMSS* as MS 0317.7-6647
- Located ~6' S to the nucleus
- **Galactic isolated NS or a binary containing a massive BH in NGC 1313** (Stocke et al. 95)



A bit of history: X-ray

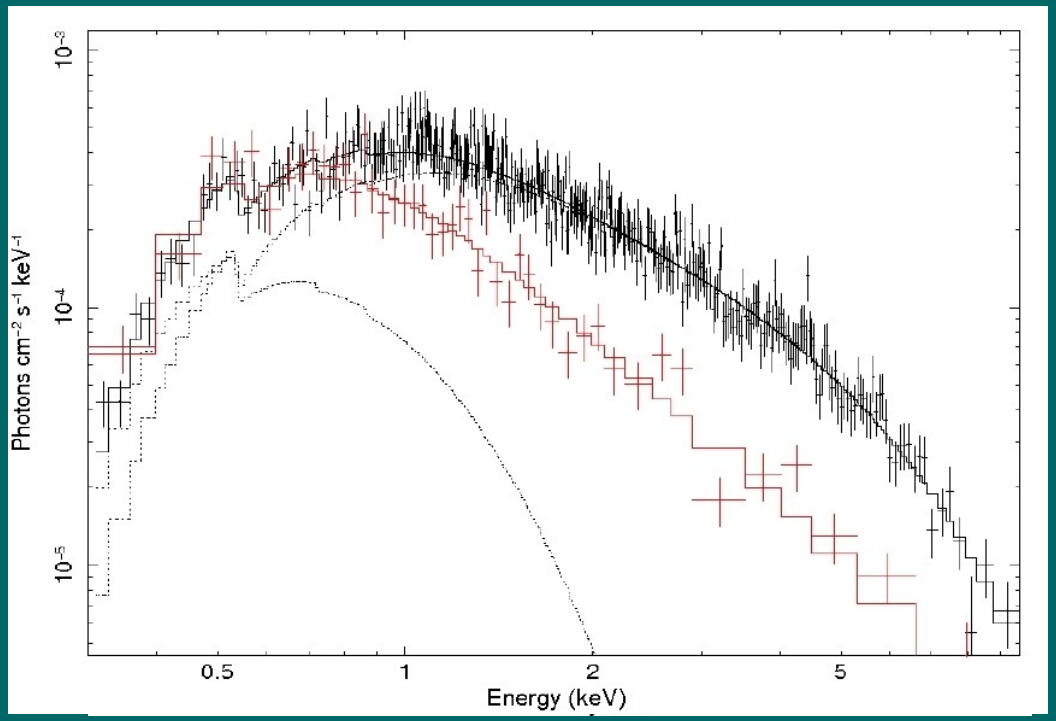
X-ray observations

Einstein 1980 (Fabbiano & Trinchieri 1987)

ROSAT 1991-1998 (Stocke et al. 95, Colbert et al. 95, Miller et al. 98, Schlegel et al. 00)

ASCA 1993-1995 (Petre et al. 94, Makishima et al. 00)

Chandra and XMM-Newton 2000-2006



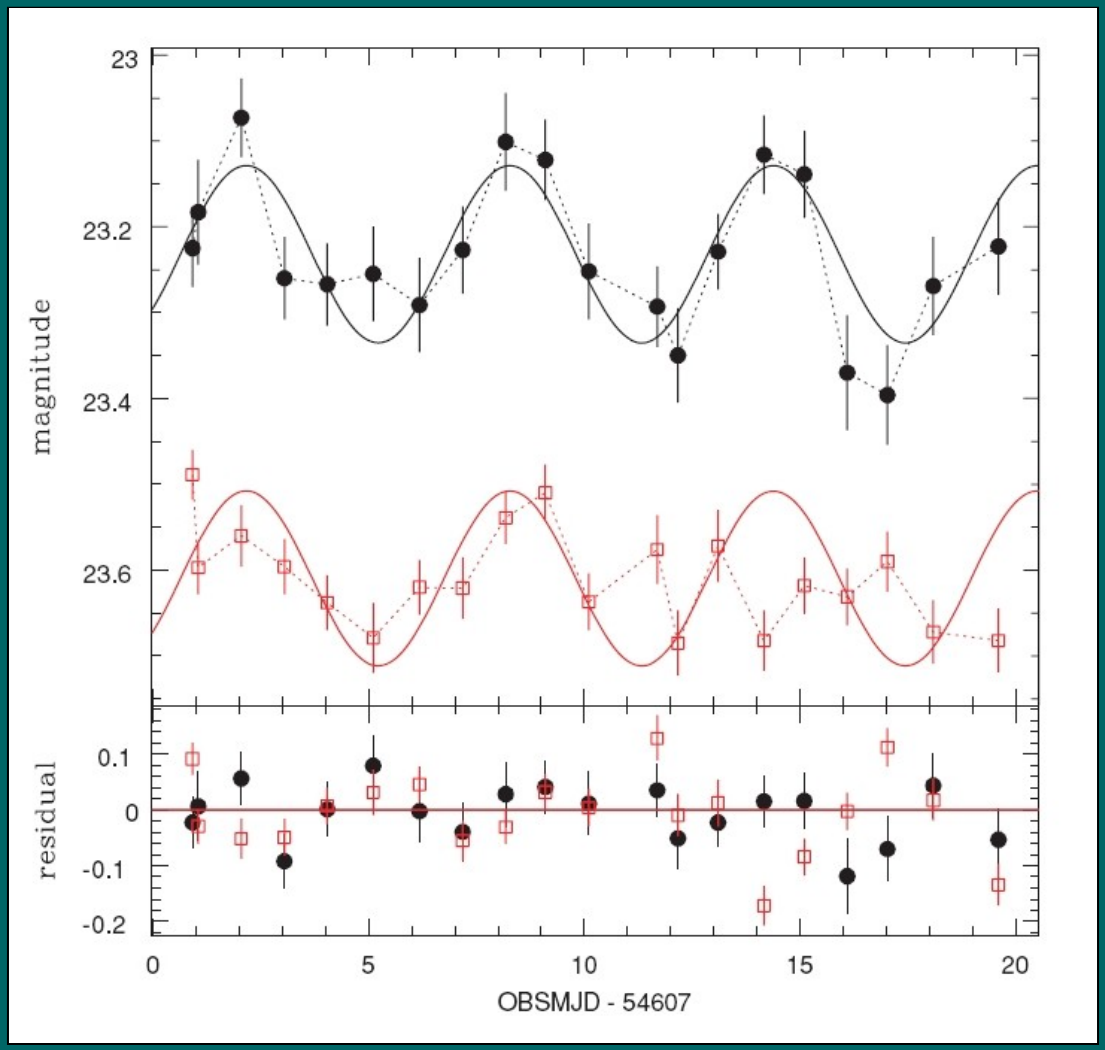
High statistics XMM spectra: physical disc+corona models → thick coronae, no BH mass (e.g. Stobbart et al. 06; Gladstone et al. 09)

Two spectral states (Fabio Pintore's talk):

(1) Lx=2e39-1e40 erg/s
Tc~1.5 keV, tau~10,
Tin~250 eV

(2) Lx=2e39 erg/s
Tc~3 keV, tau~5

A bit of history: optical counterpart

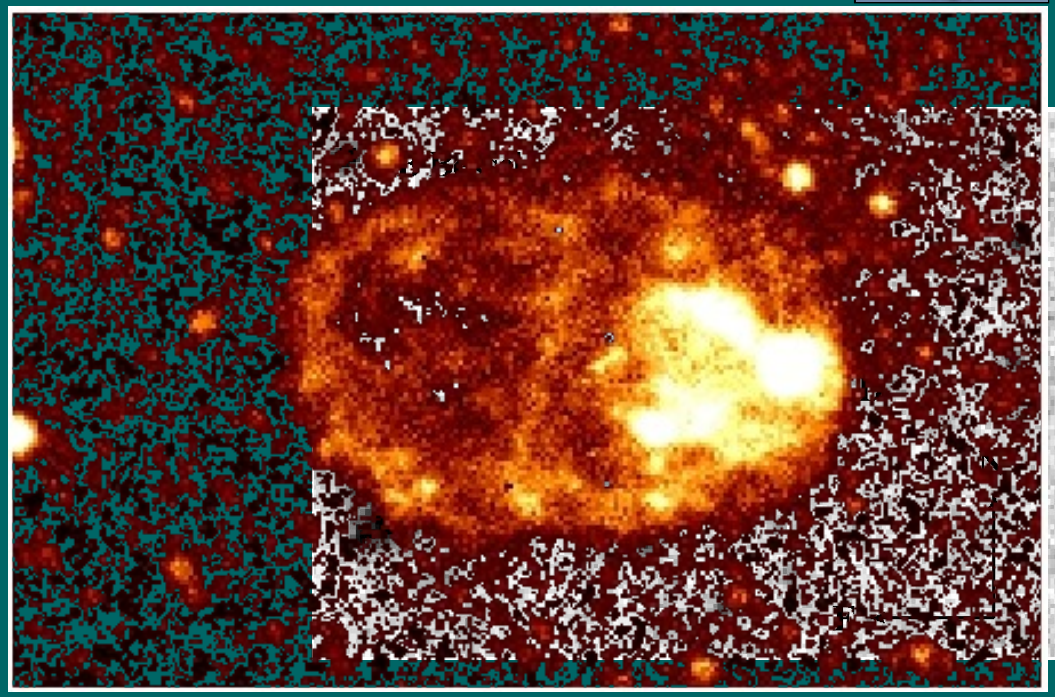


Optical observations

- Object C (C1+C2) identified thanks to accurate Chandra astrometry, after registering with SN 1978K (Zampieri et al. 04; Mucciarelli et al. 05,07) or a background AGN (Liu et al. 07): B=23.67+/-0.10, V=23.70+/-0.08
- VLT+FORS1 spectrum of C1: evidence of a broad 4686 He II line produced by X-ray irradiation: Mbh<50 Msun (Pakull et al. 06; Grise` et al. 08)
- HST+WFPC2 monitoring: tentative orbital period P=6.12+/-0.16 days (Liu et al. 09)

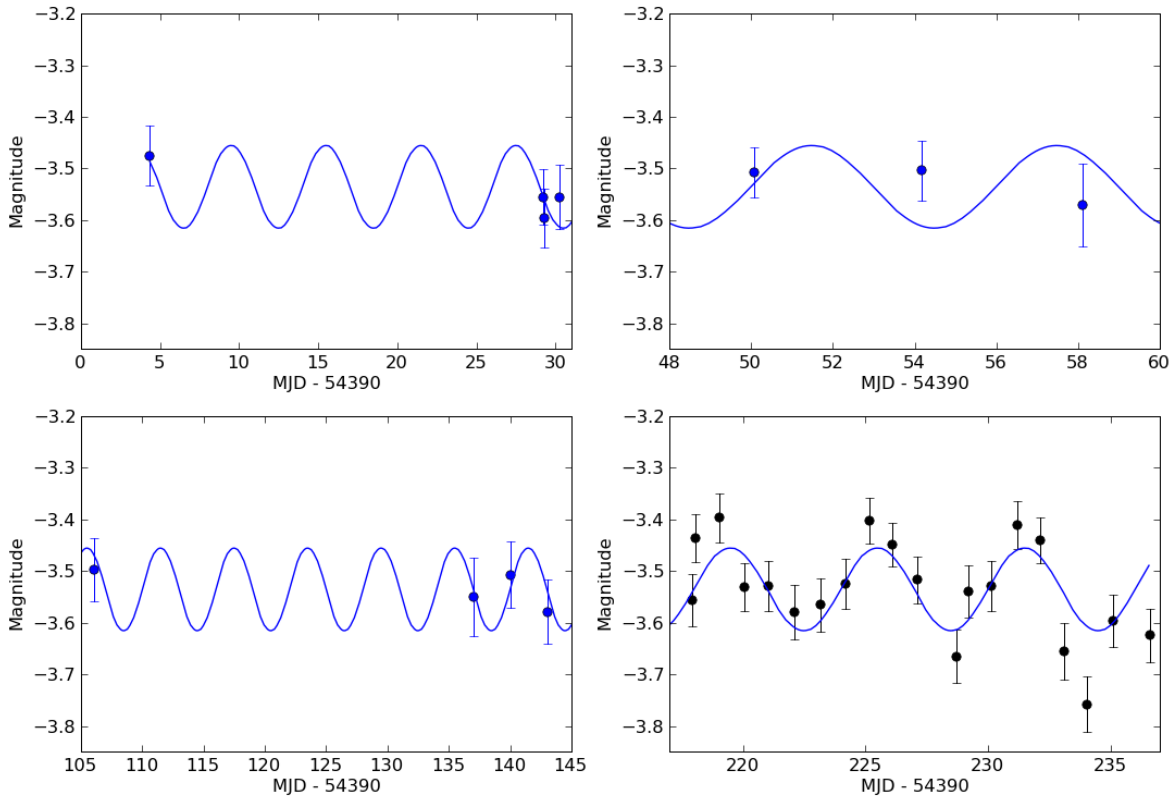
A bit of history: optical environment

- Extended (~400 pc) bubble nebula detected in Halpha (Pakull & Mirioni 02; Pakull et al. 2006)
- SN explosion(s) or wind/jet activity:
  * Energy~1e51-1e53 erg
  * Power~1e38-1e40 erg/s
  * Lifetime~1 Myrs
- Parent stellar association: two groups of (a few) young stars, spread out over ≈ 200 pc (Pakull et al. 2006; Liu et al. 07)
- Age of largest association 20+/-5 Myrs (Grise et al. 08,09)



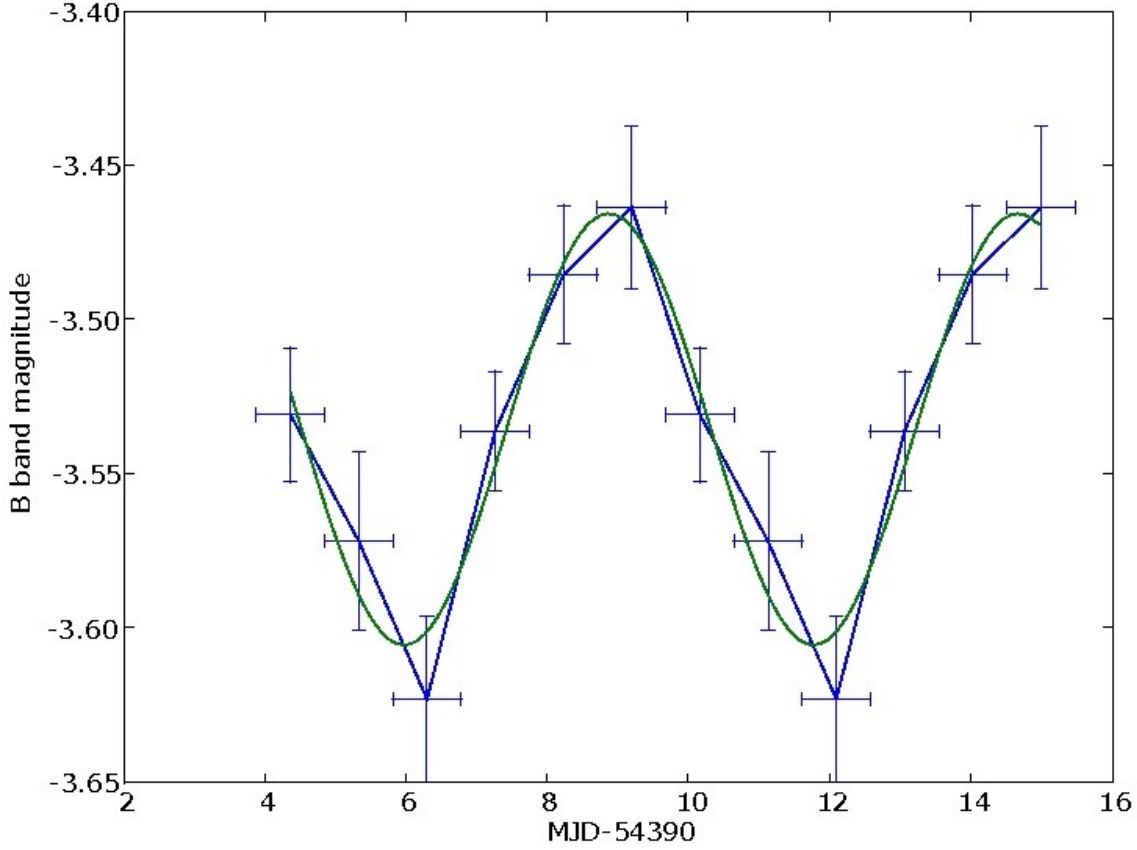
Revisiting VLT+HST photometry

11 VLT+FORS1 epochs (October 2007 - March 2008; Grise` et al. 2009) plus 20 HST+WFPC2 epochs (May-June 2008; Liu et al. 2009) → Domenico Impiombato's poster #1



- Differential photometry in the B band
- Short term variability:
  VLT~0.04 mag
  HST~0.1 mag
- Part likely due to X-ray irradiation
- Part apparently sinusoidal
- Best fitting sinusoid:
  P=6+/-0.1 days
  A= 0.09+/- 0.01

6 (or 12) days optical period?



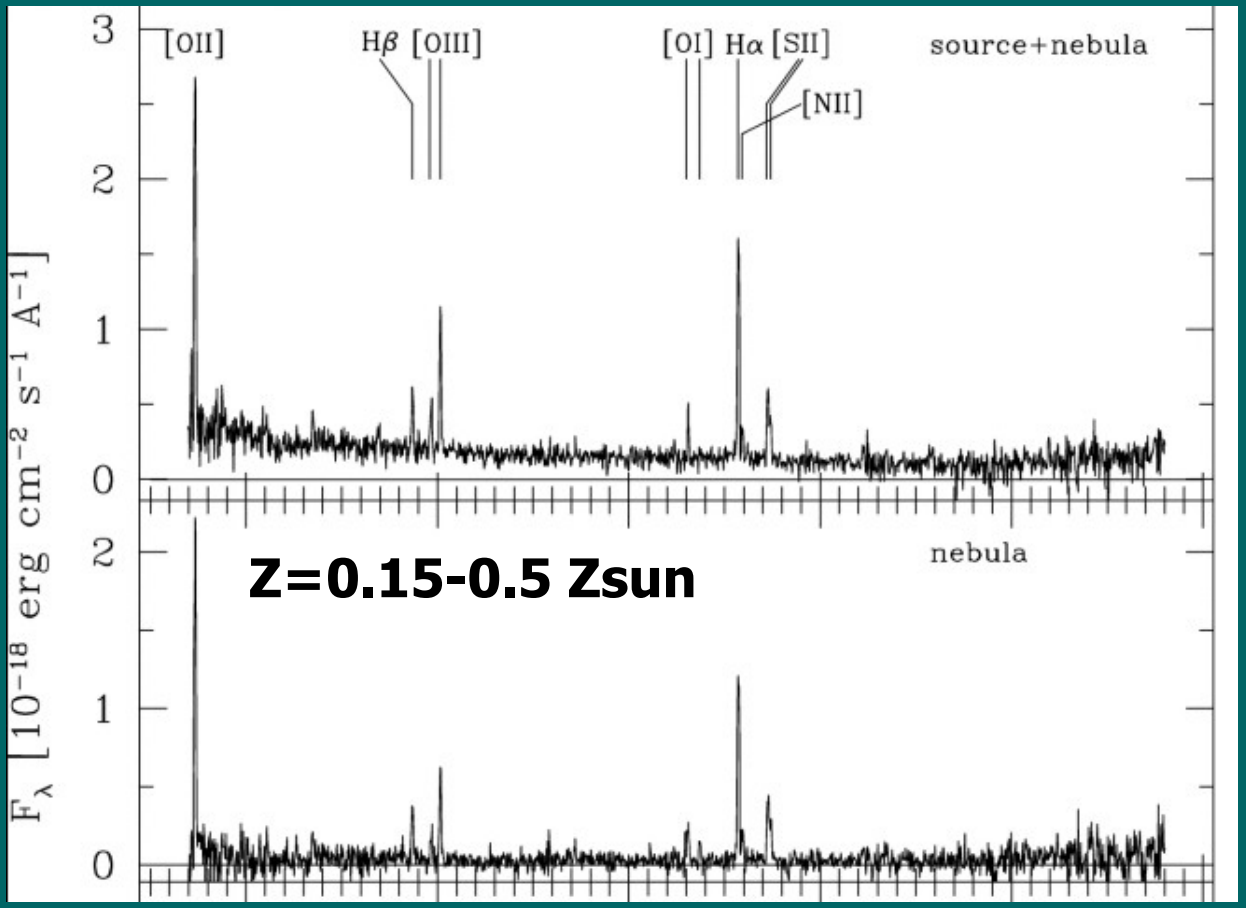
- Significance: ~2-3 sigma (from Lomb-Scargle periodogram and epoch folding)
- VLT data alone do not show periodicity, but are consistent with it
- HST V band data: no statistically significant modulation → <0.06 mag
- If interpreted as orbital period: 6 or 12 days, depending on the extent of ellipsoidal modulations

Metallicity of the bubble nebula

Metallicity of HII regions: Z = 0.2 Zsun (Ryder 1993) and Z = 0.5 Zsun (Hadfield & Crowther 2007; Walsh & Roy 1997)

- Abundance analysis from nebular lines (only photoionization accounted for) → Emanuele Ripamonti's talk
- **Cloudy** (Ferland 1996):

  * star (Teff=25000-45000 K)+disc
  * standard dust/gas
  * n=1-100 cm-3
  * Nh=1e19-2e21 cm^{-2}
  * N/H=1/3 solar (e.g. Pilyugin et al. 04)



Evolution of the binary system

ULX binary model (Patruno & Zampieri 08, 10)

- Eggleton code, non-conservative evolution with wind loss and gravitational wave emission

  Z=0.2-0.5 Zsun: minimal effect on tracks (Z=0.01)

- UV/optical luminosity computed summing to the donor emission the contribution of the accretion disc, and including the effects of X-ray reprocessing

- Geometrically thin optically thick accretion disc (e=0.1)

  If Mdot > MdotEdd, we impose Mdot = MdotEdd → excess mass expelled from the system

- Depending on initial separation, RLOF may start

  * during MS: **case AB**

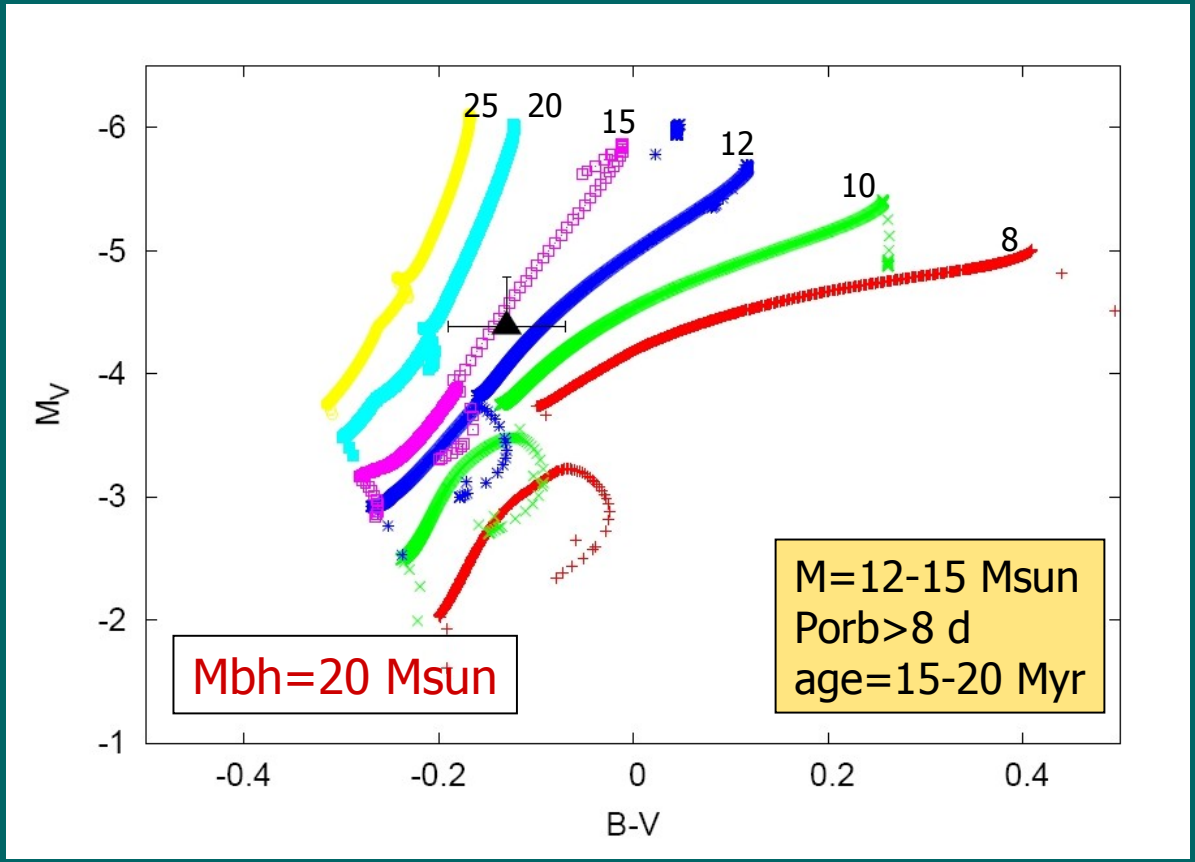
  * after MS: **case B** → contact phase too short with respect to the characteristic age of the nebula (~1 Myrs)

Evolution of the binary: 20 Msun BH

- 10-20 Msun donor consistent with C1 during H-shell burning
- Consistency with parent cluster age (15-25 Myrs) : Mdonor=12-15 Msun

  Mass transfer rate above Eddington → excess mass expelled

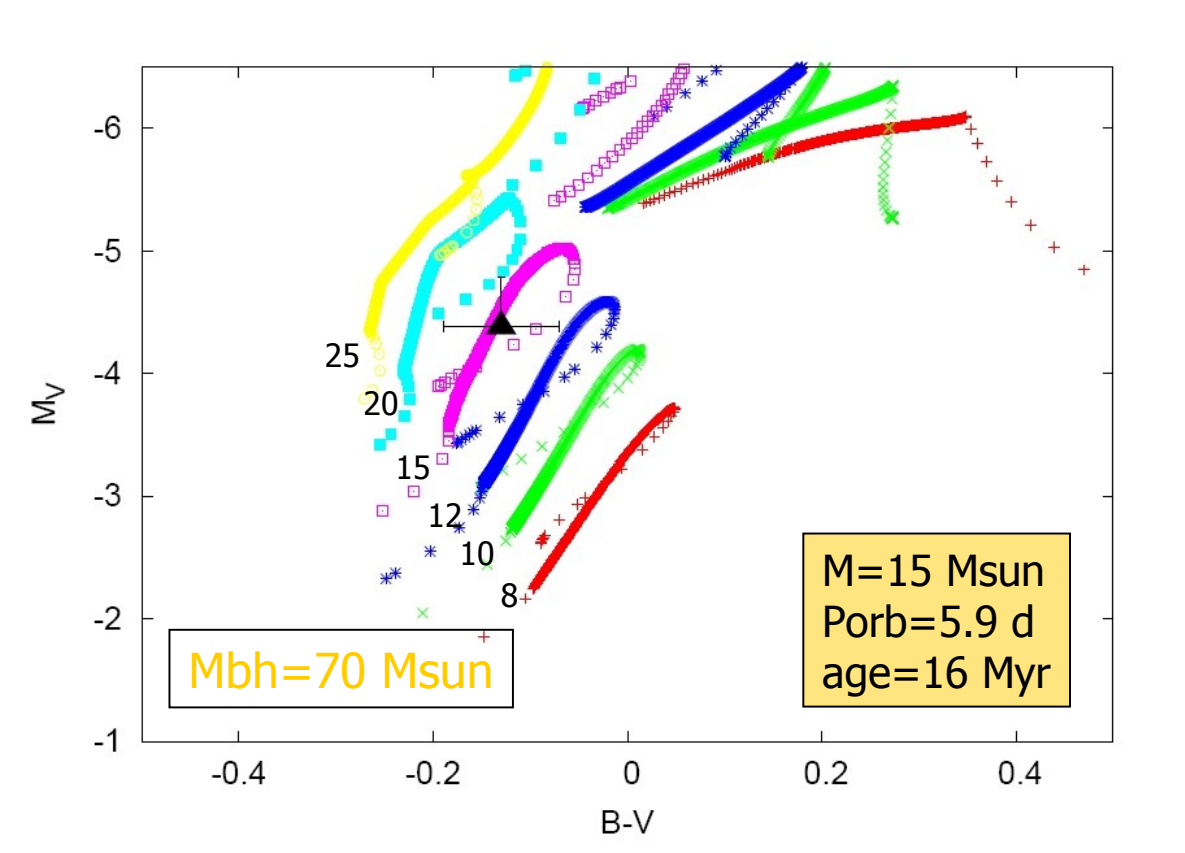
- First contact phase during MS sufficiently long to inject the required energy in the nebula



Evolution of the binary: 70 Msun BH

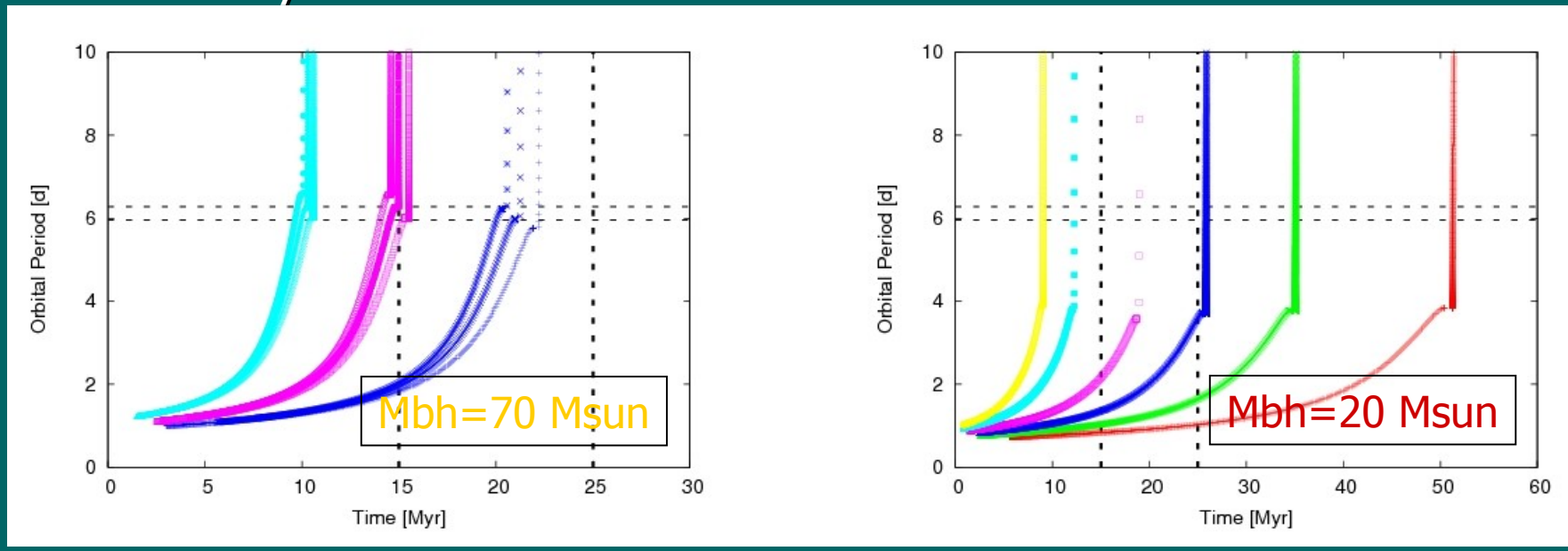
- 12-20 Msun donors consistent with C1 during terminal age MS
- Consistency with parent cluster age (15-25 Myrs) and average mass transfer rate (1e-6 Msun/yr) → Mdonor=12-15 Msun

- Similar result for BHs between 50 and 100 Msun



Constraint from orbital period

- Mbh = 50-100 Msun + MS donor (P=1-6 days)
  * Mdonor=12-15 Msun crosses C1 with P~5-6 days
- Mbh = 20 Msun + H-shell burning donor (P=4-20 days)
  * Mdonor=12-15 Msun crosses C1 with 8<P<10 days
  * If P~12 days, Mdonor~20 Msun in order to cross C1
  * Beaming/no-irradiation: Mdonor~15 Msun crosses C1 with P~15 days



If P is different from 6 or 12 d?

- P=5-6 days

  Mbh = 50-100 Msun + MS 12-15 Msun
- P>8 days

  Mbh = 20 Msun + H-shell burning 12-15 Msun
- P<4 days

  SuperEddington luminosity
- For Mbh between 20 and 50 Msun there may also be agreement with observations for different values of P

- Modelling the light curve may give additional clues

  * X-ray irradiation (0.05–0.15 mag; unless the source is beamed)+ellipsoidal modulations (0.1–0.2 mag)+disc emission

  * Superposition gives an asymmetric modulation

NGC 1313 X-2 in context

50-100 Msun BH + 12-15 Msun MS donor

- Such a system fits well within **a low-metallicity formation scenario** (Mapelli et al. 2009, 2010; Zampieri & Roberts 2009) → Michela Mapelli's talk

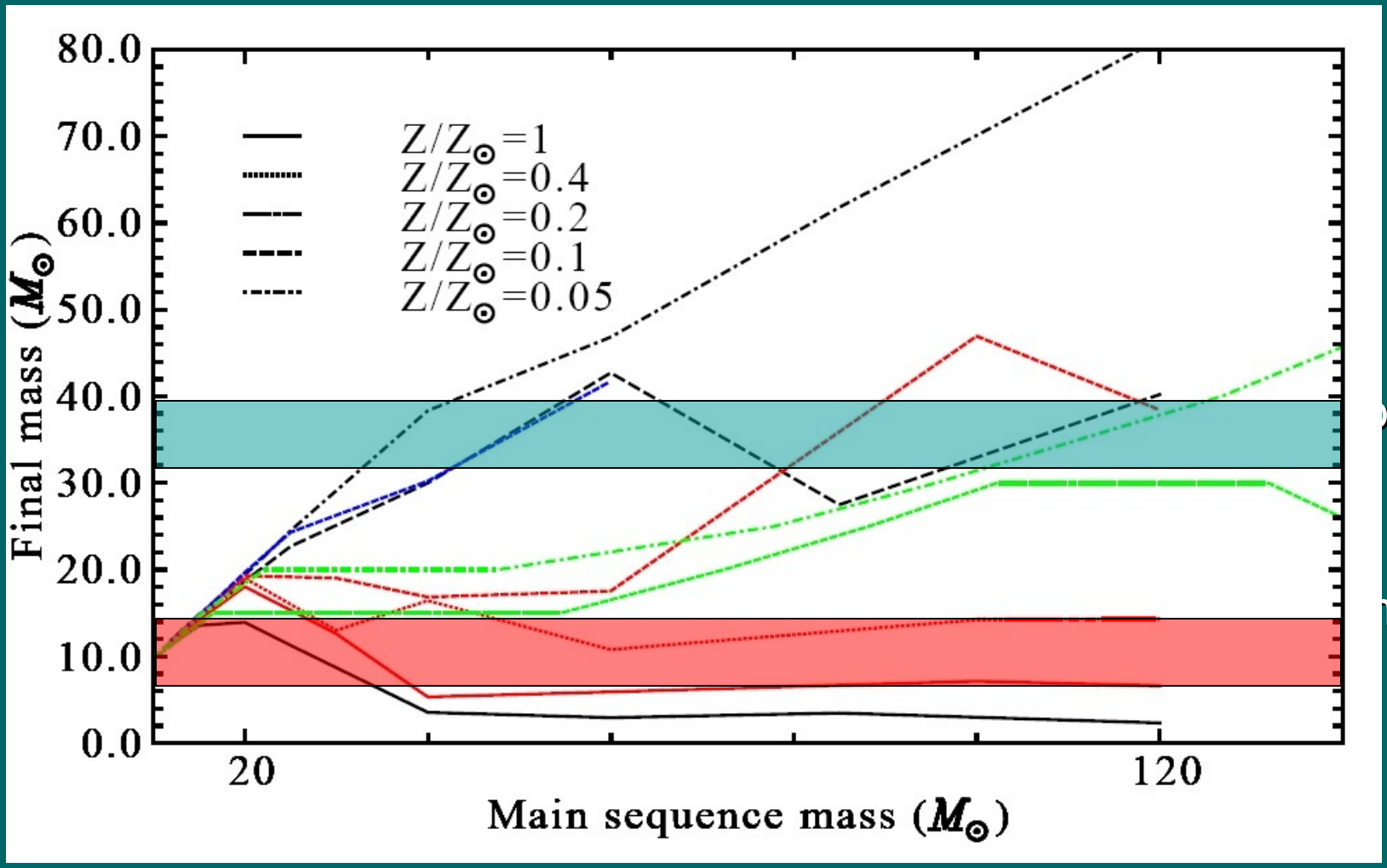
  * If an envelope more massive than ~30-40Msun is retained at the time of explosion, a low metallicity (Z~0.1Zsun) star may collapse directly to form a BH (Heger et al. 2003; Belczynski et al. 2009)

  * The supernova shock wave loses too much energy in trying to unbind the envelope until it stalls and most of the star collapses into a BH of mass comparable to its final mass (>30-40 Msun; Fryer 1999; Zampieri 02)

- Only modest beaming (bf ~ 0.5) or slight violations of the Eddington limit (a factor of a few) would be needed for bright (> 1e40 erg/s) ULXs
- Essentially isotropic irradiation of the X-ray photoionised nebulae explained

NGC 1313 X-2 in context

50-100 Msun BH + 12-15 Msun MS donor



Conclusions and future perspectives

NGC 1313 X-2

- Revisted X-ray and optical observations
- Optical modulation (~2-3 sigma)?

  If confirmed, orbital period P=6 days or P=12 days
- Modelling the binary evolution subject to all the X-ray and optical observational constraints provides different outcomes:

  P=5-6 days → Mbh = 50-100 Msun + MS 12-15 Msun

  8<P<10 days → Mbh = 20 Msun + H-shell burning 12-15 Msun

  P>10 days → 20-50 Msun and/or no-irradiation

  P<4 days → superEddington luminosity in any case
- More robust assessment of P needed!