Spectroscopic searches for sub-pc separation supermassive black hole binaries

- or -

Twice the Crisis

Jessie Runnoe

Quasars in Crisis, August 9, 2019

D. Doan, K. Nguyen, G. Mathes, A. Pennell, S. Brown, M. Eracleous, T. Bogdanović
T. Boroson, S. Sigurðsson, J. Halpern, J. Liu, P. Breiding, S. Burke-Spolaor

Intro: *Basics of binary evolution*

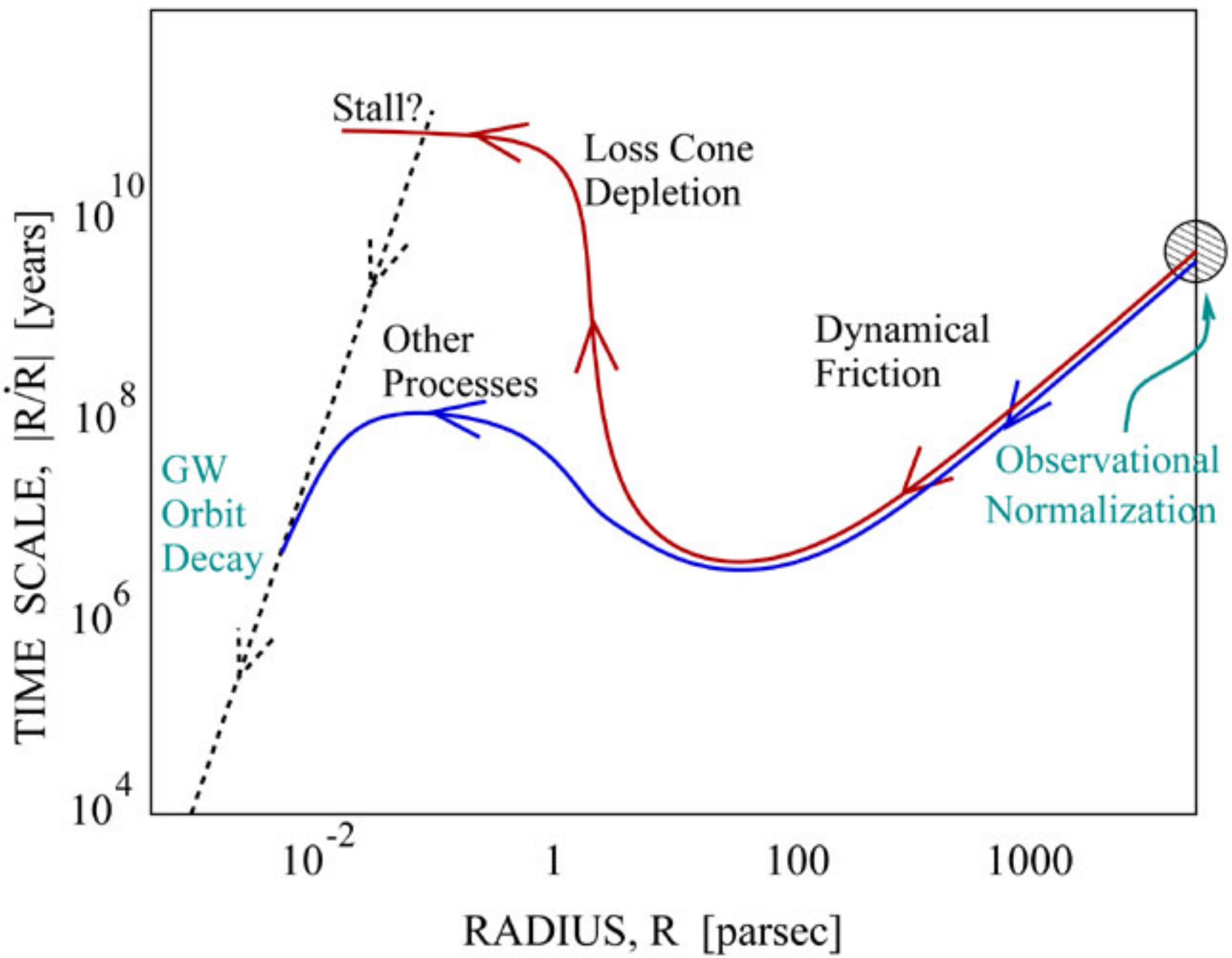

figure from Backer et al. (2003), based on the work of Begelman et al. (1980)

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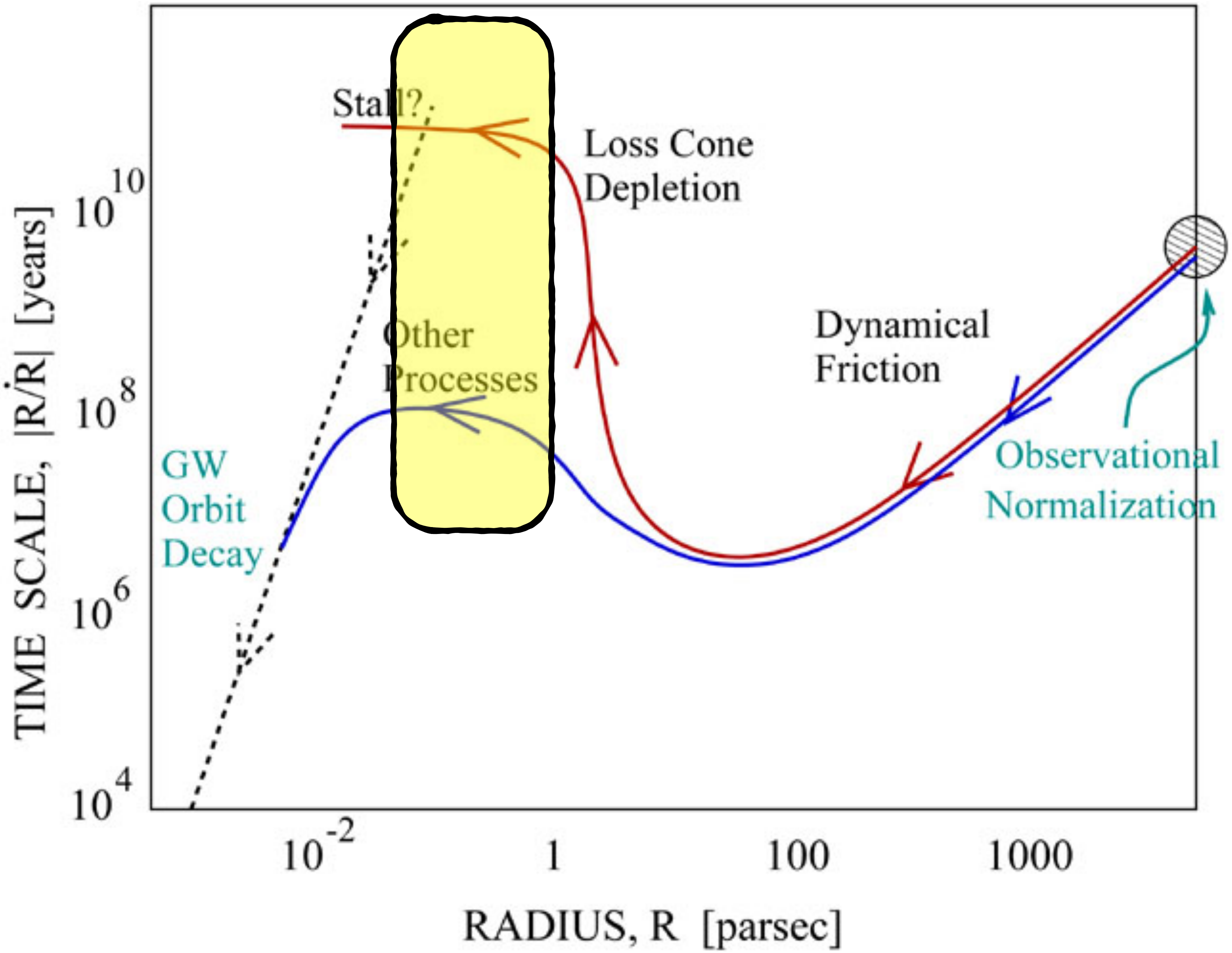

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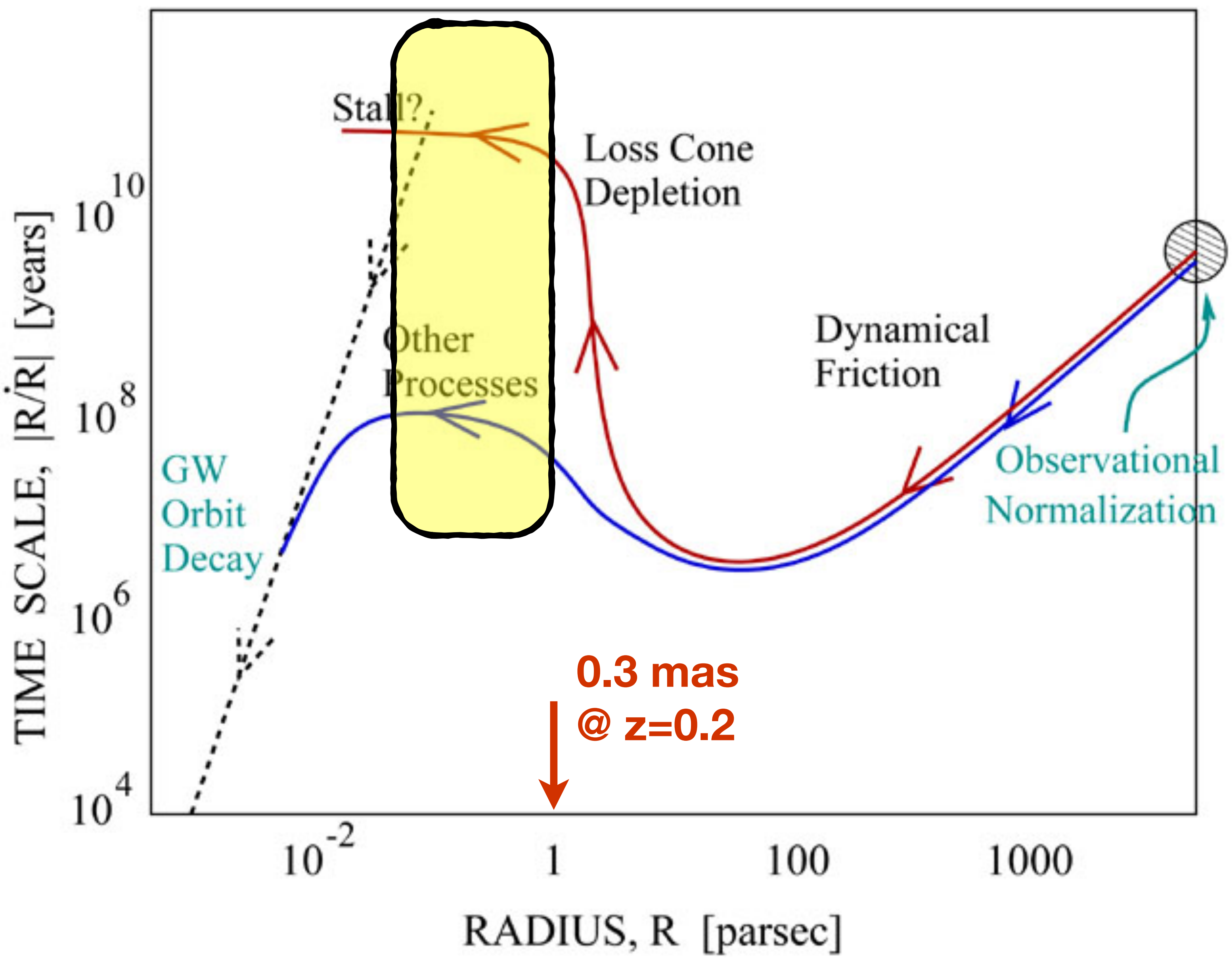

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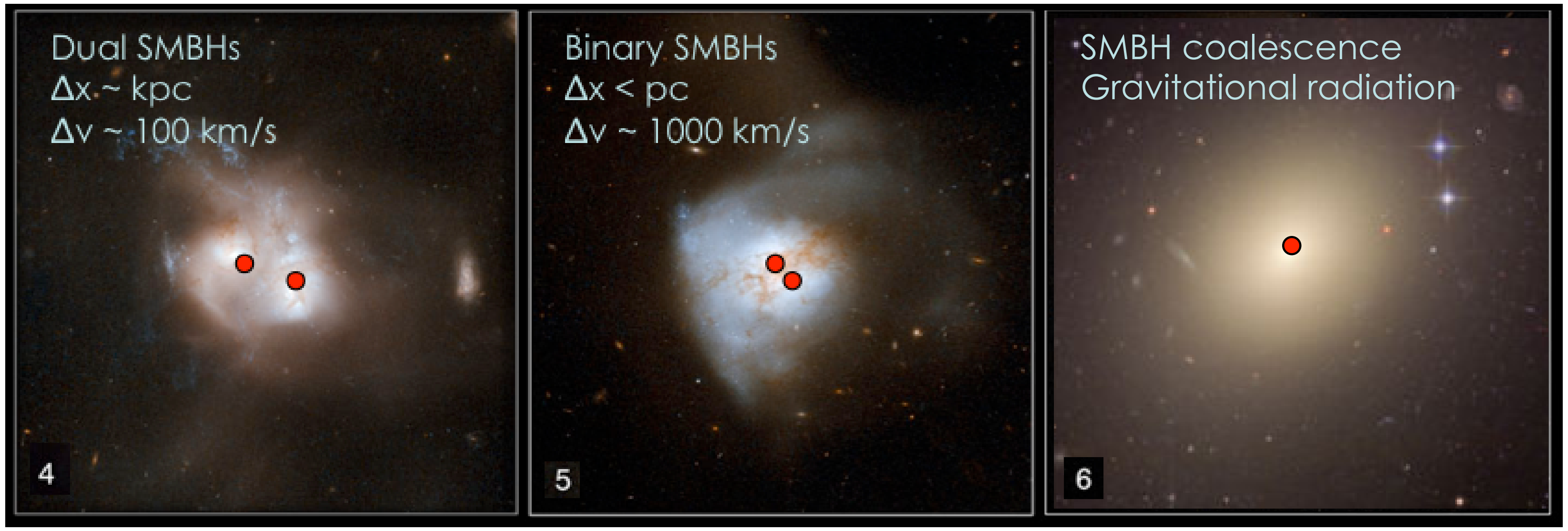
Intro: *Phases of inspiral*

figure from J. Comerford



HST/NASA/STScI/ESA

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0.1-10 kpc: X-rays, “spectro-astrometry”

Comerford et al. (2015), A. Foord (UMich) thesis

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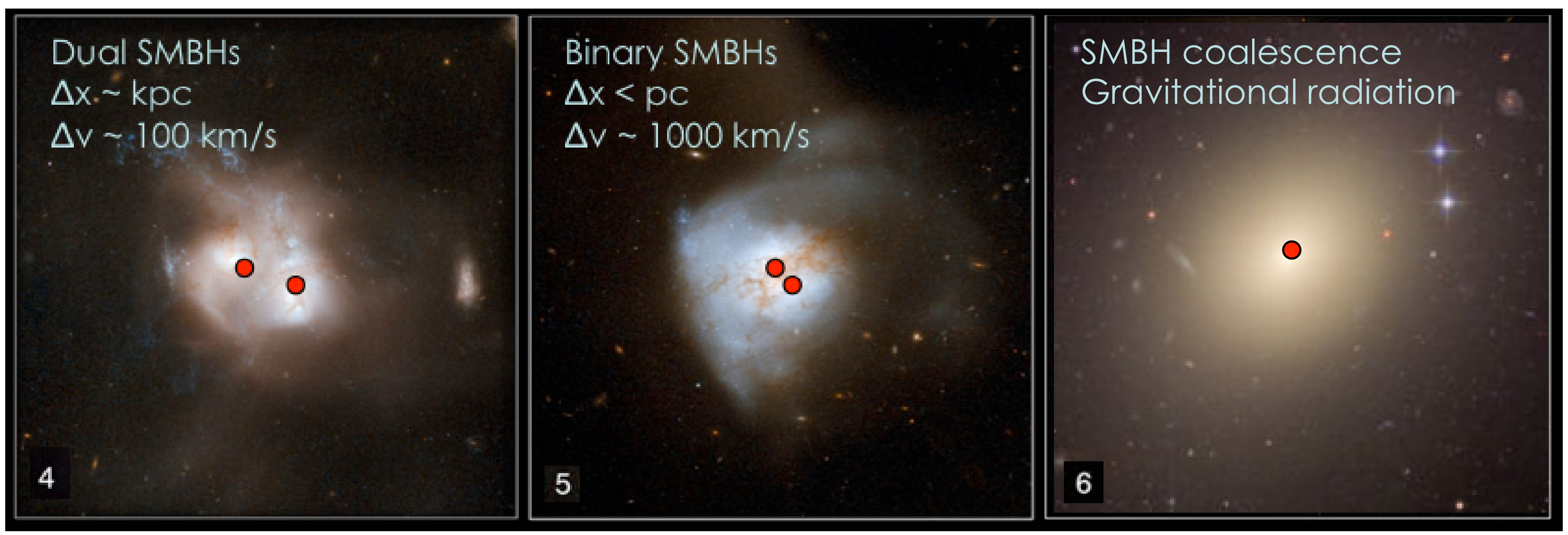

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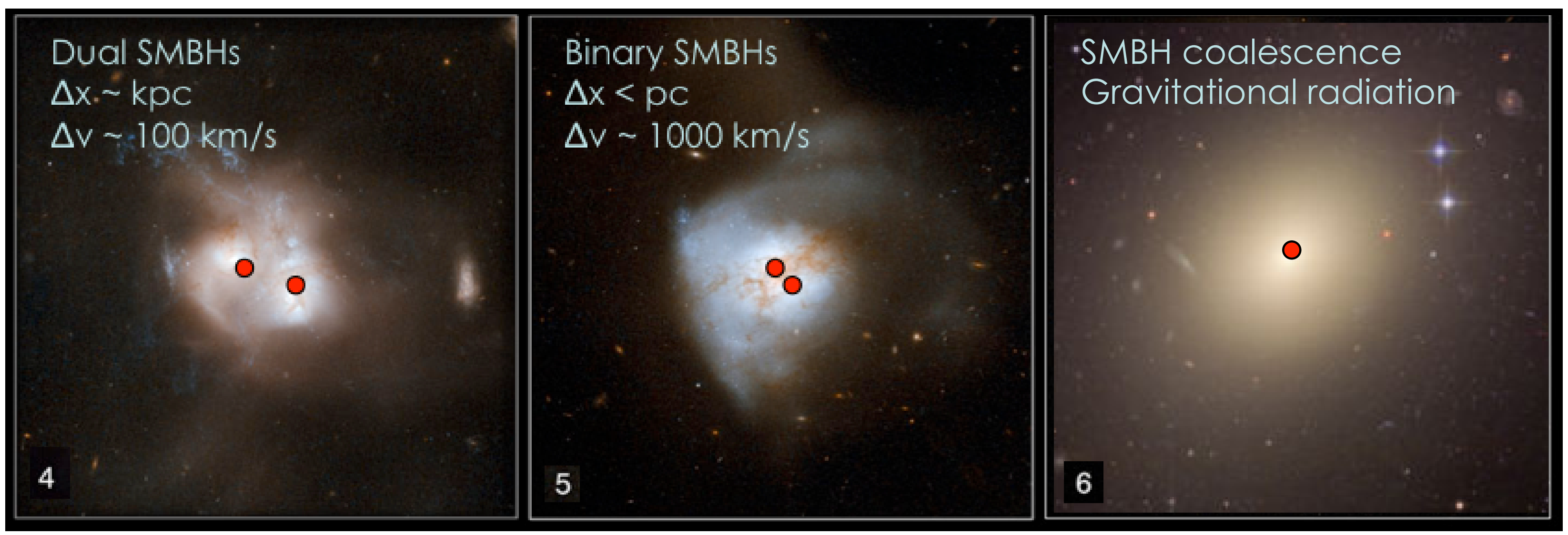

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1-100 pc: radio interferometry

Rodriguez et al. (2006), Burke-Spolaor et al. (2011), Bansal et al. (2017)

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0.01-1 pc: separate BLRs

radial velocity method (this talk)

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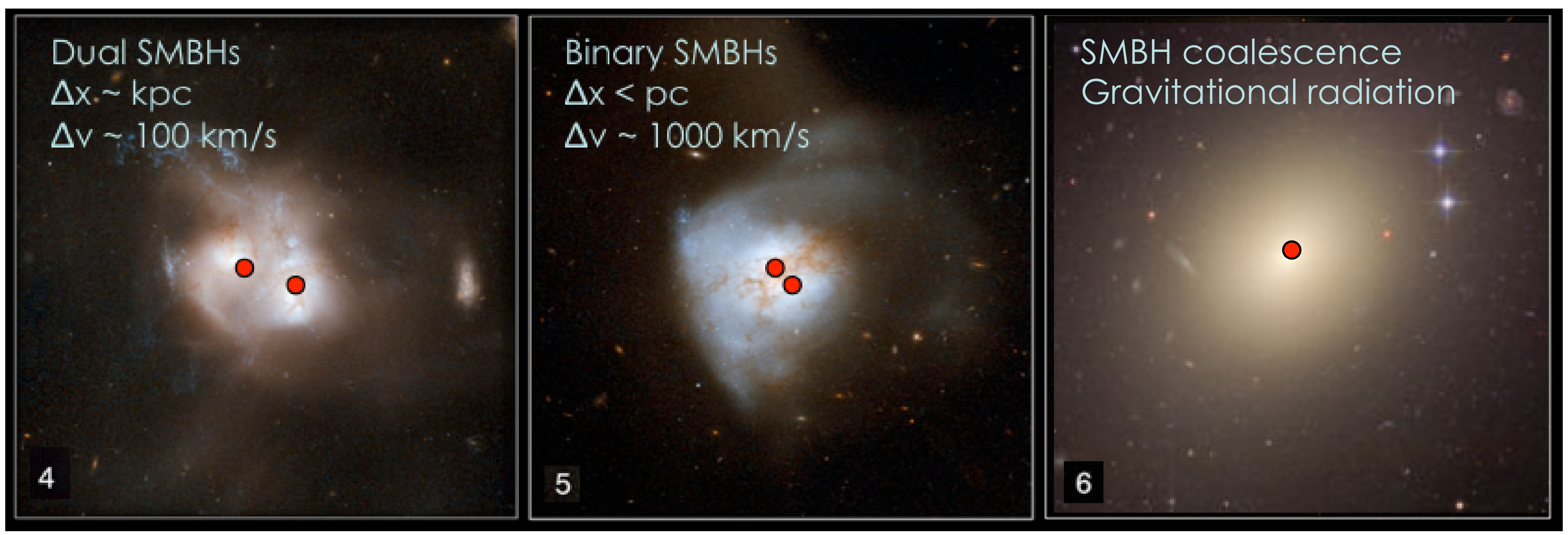

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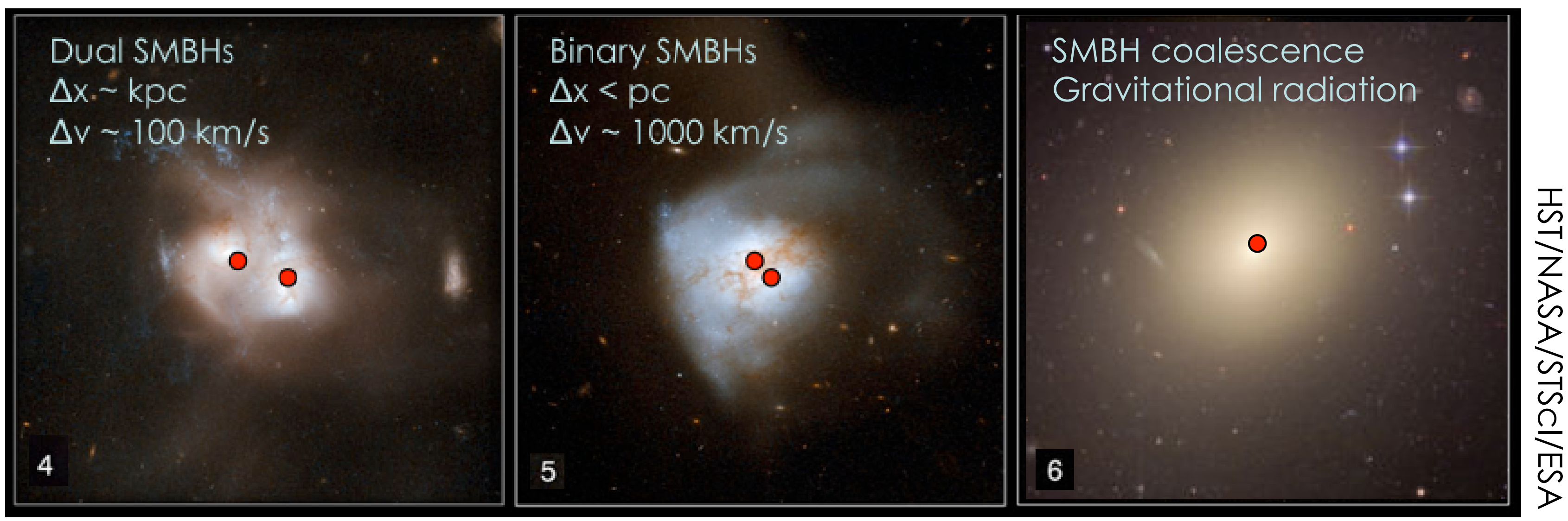

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1-10 millipc: Fe Kα, SED, light curves
McKernan et al. (2013)
Gültekin & Miller (2012)
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See also Vaughan et al. (2016), Sesana (2018)

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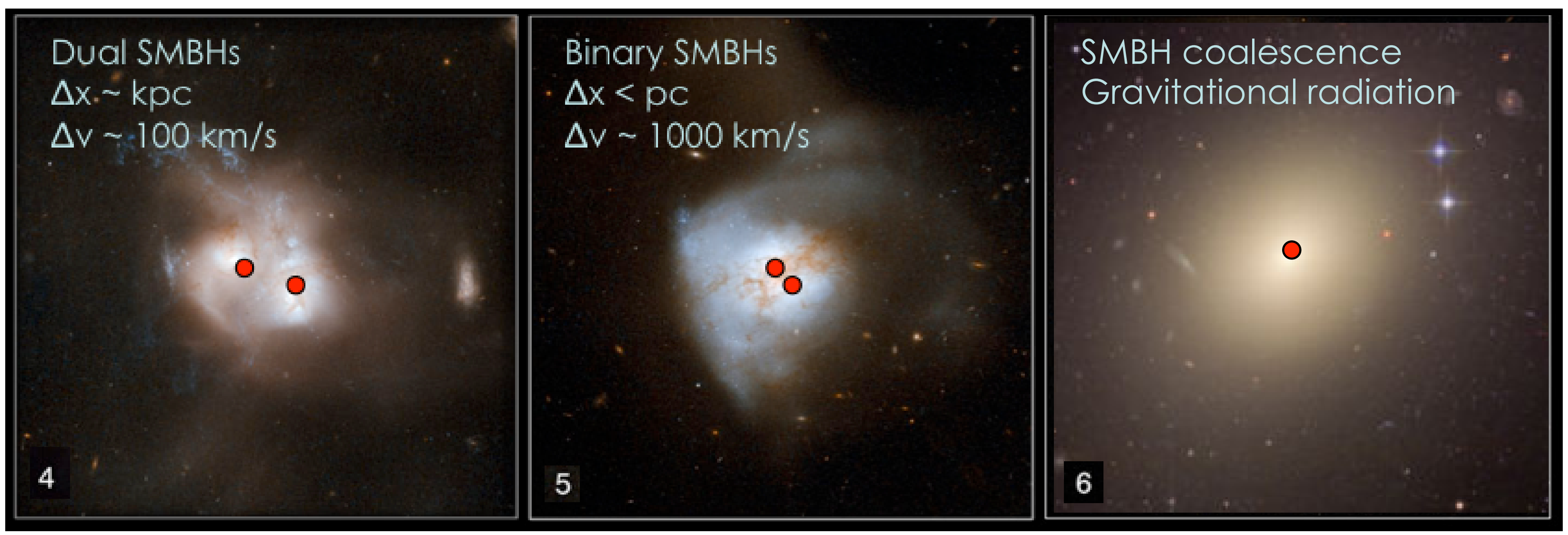

HST/NASA/STScI/ESA

1-1 AU: PTAs, LISA
Sesana (2015),
Klein et al. (2016)

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Indirect detection via radial velocity changes:

Tsalmantza et al. (2011)
Eracleous et al. (2012), Runnoe et al. (2015, 2017)
Decarli et al. (2013)
Ju et al. (2013)
Shen et al. (2013)
Liu et al. (2014), Guo et al. (2019)

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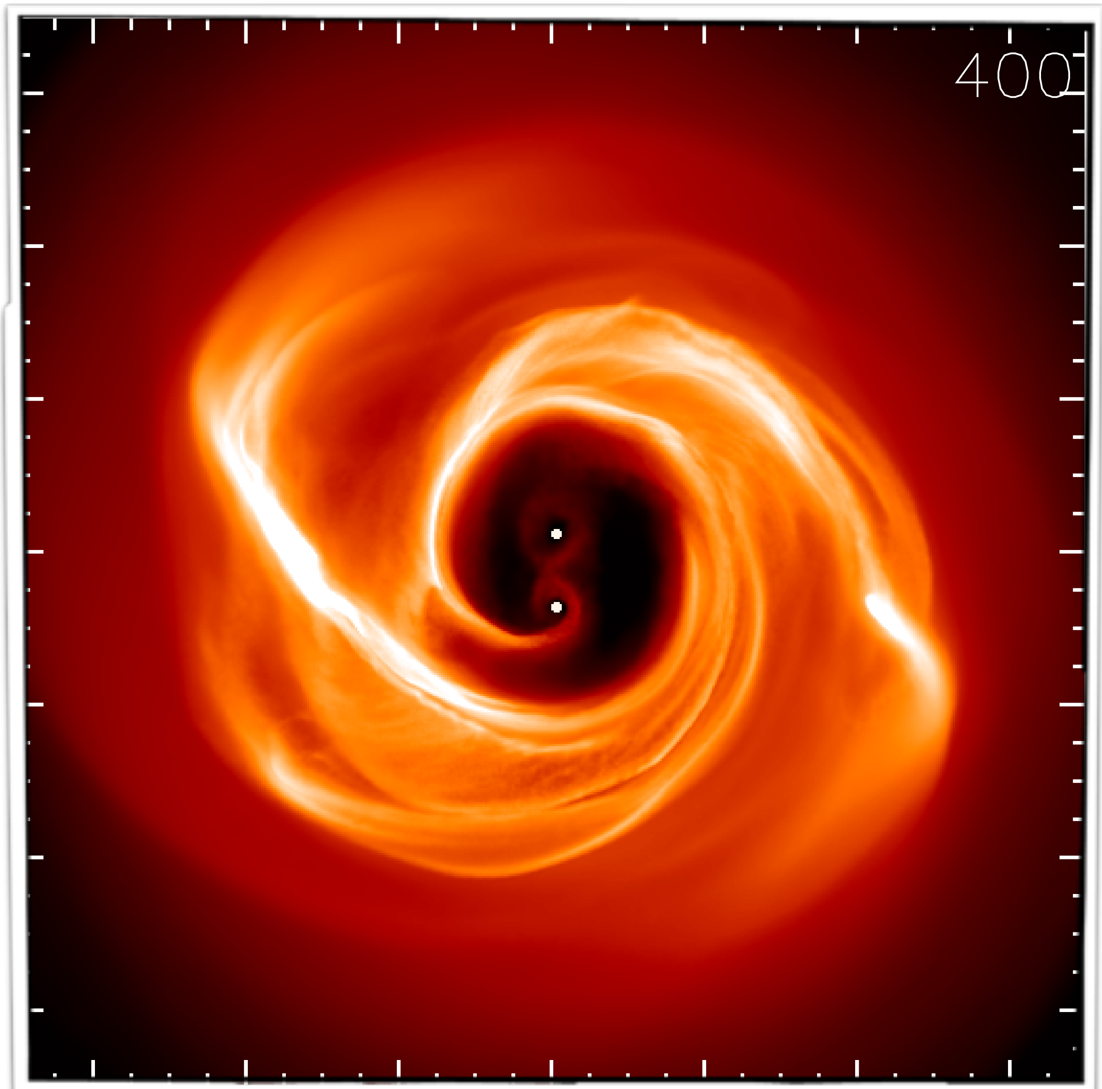
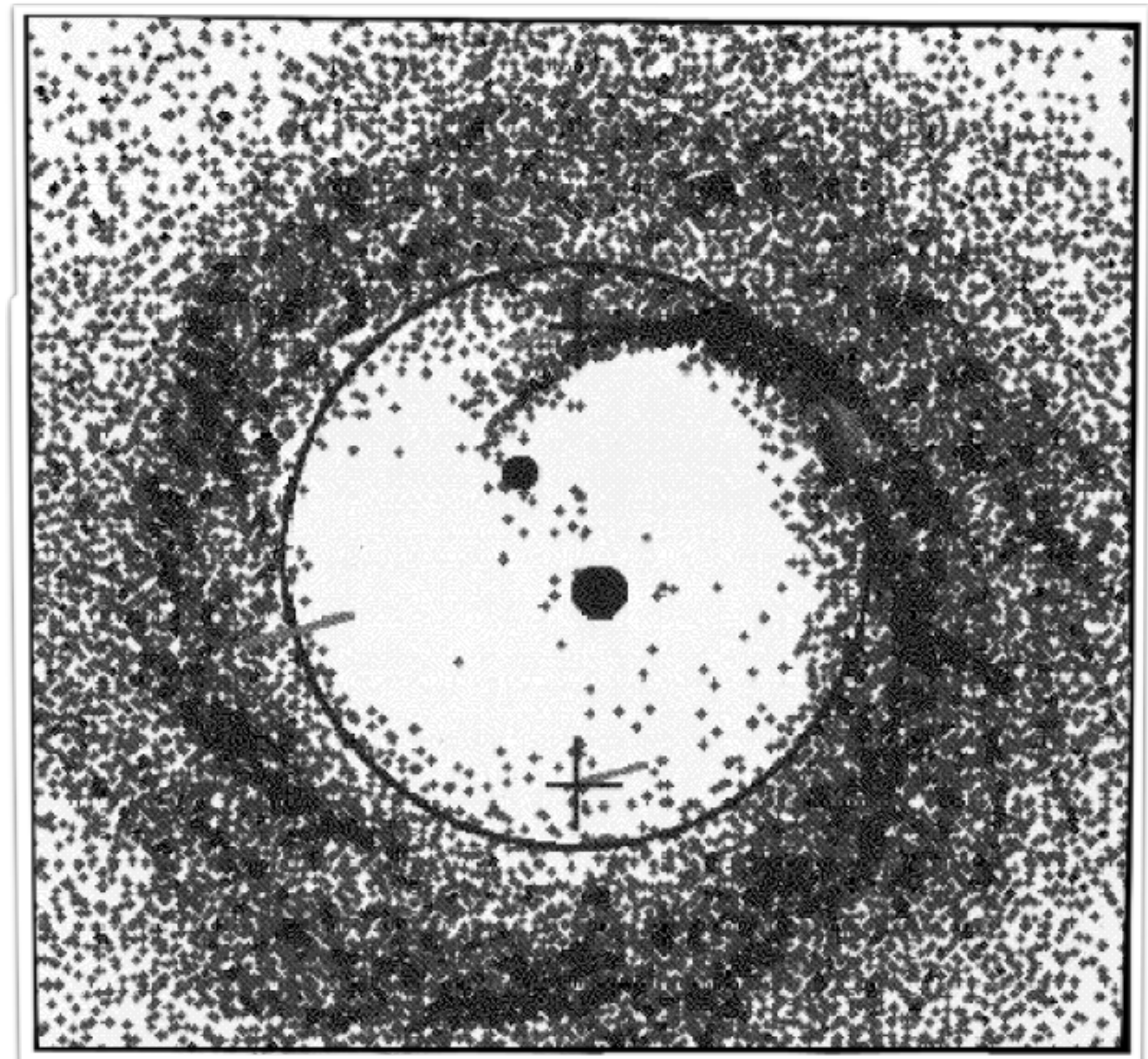
Spectroscopic Searches: *The physical picture*

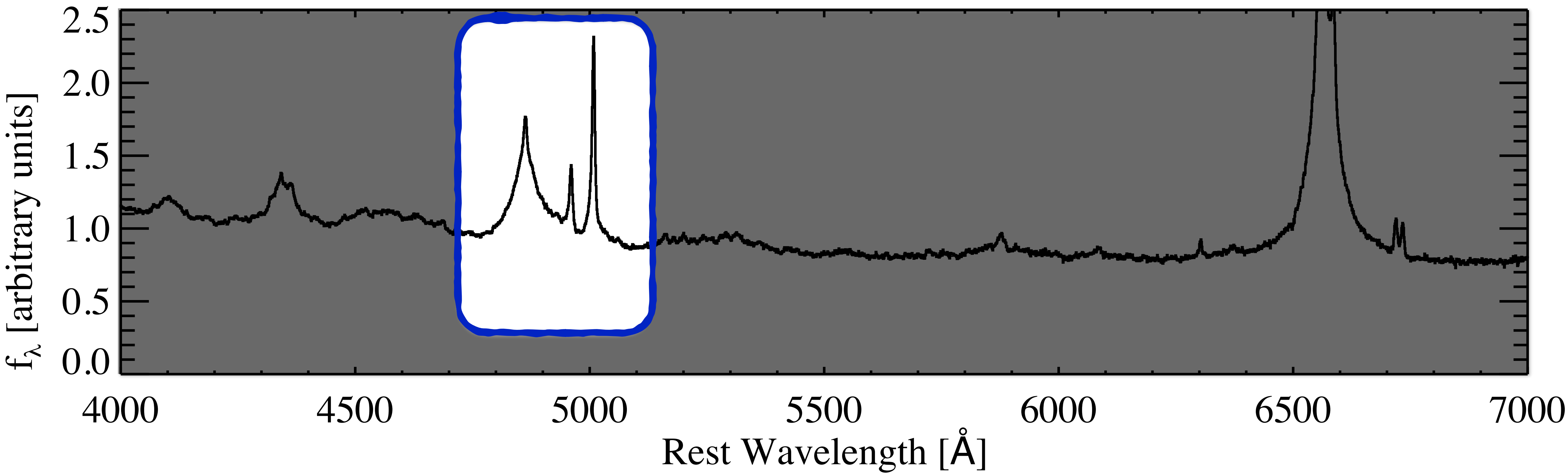


Cuadra et al. (2009),
See also Hayasaki et al. (2007).



Artymowicz & Lubow (1996)

Spec. Search: *Selection from the SDSS*



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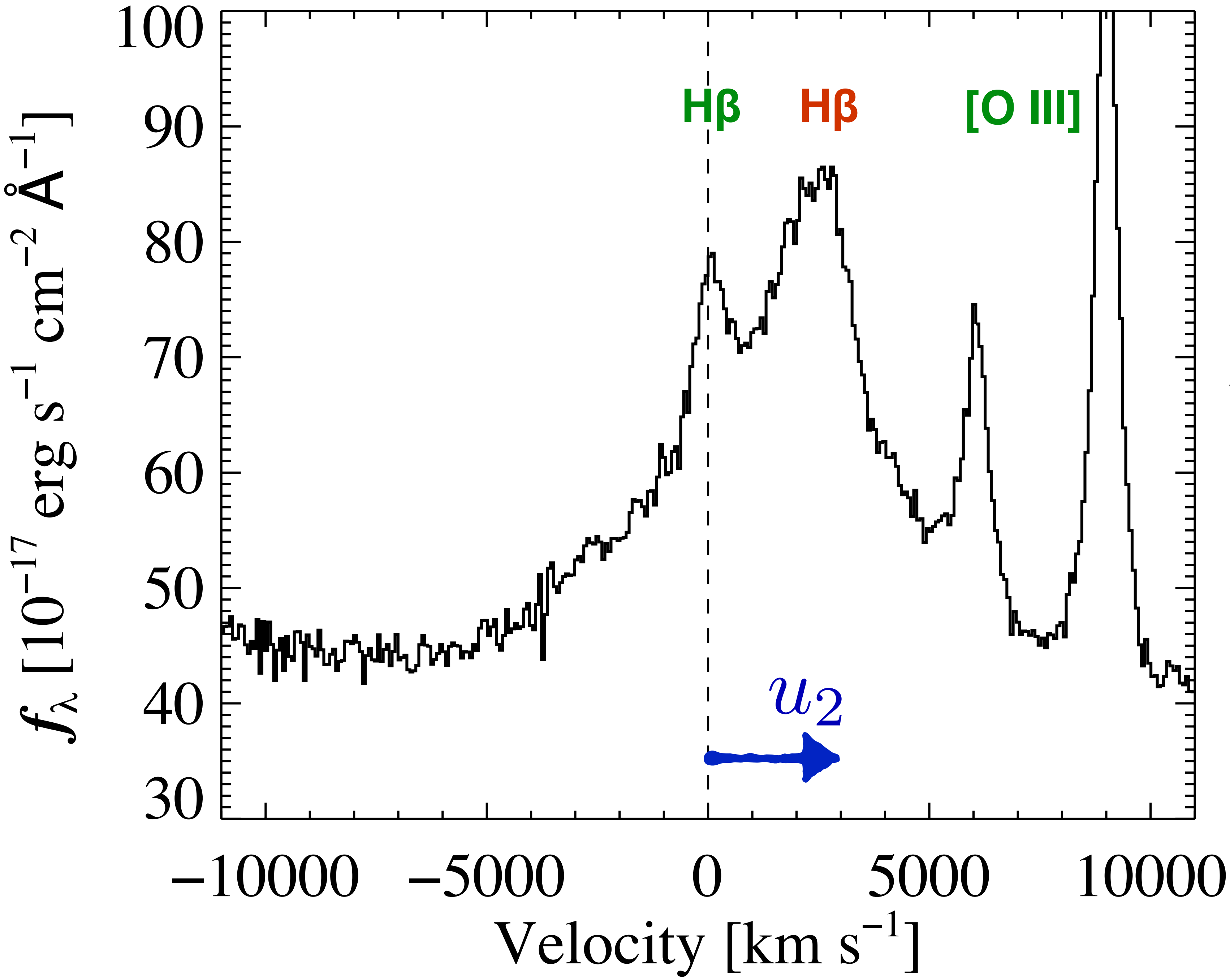


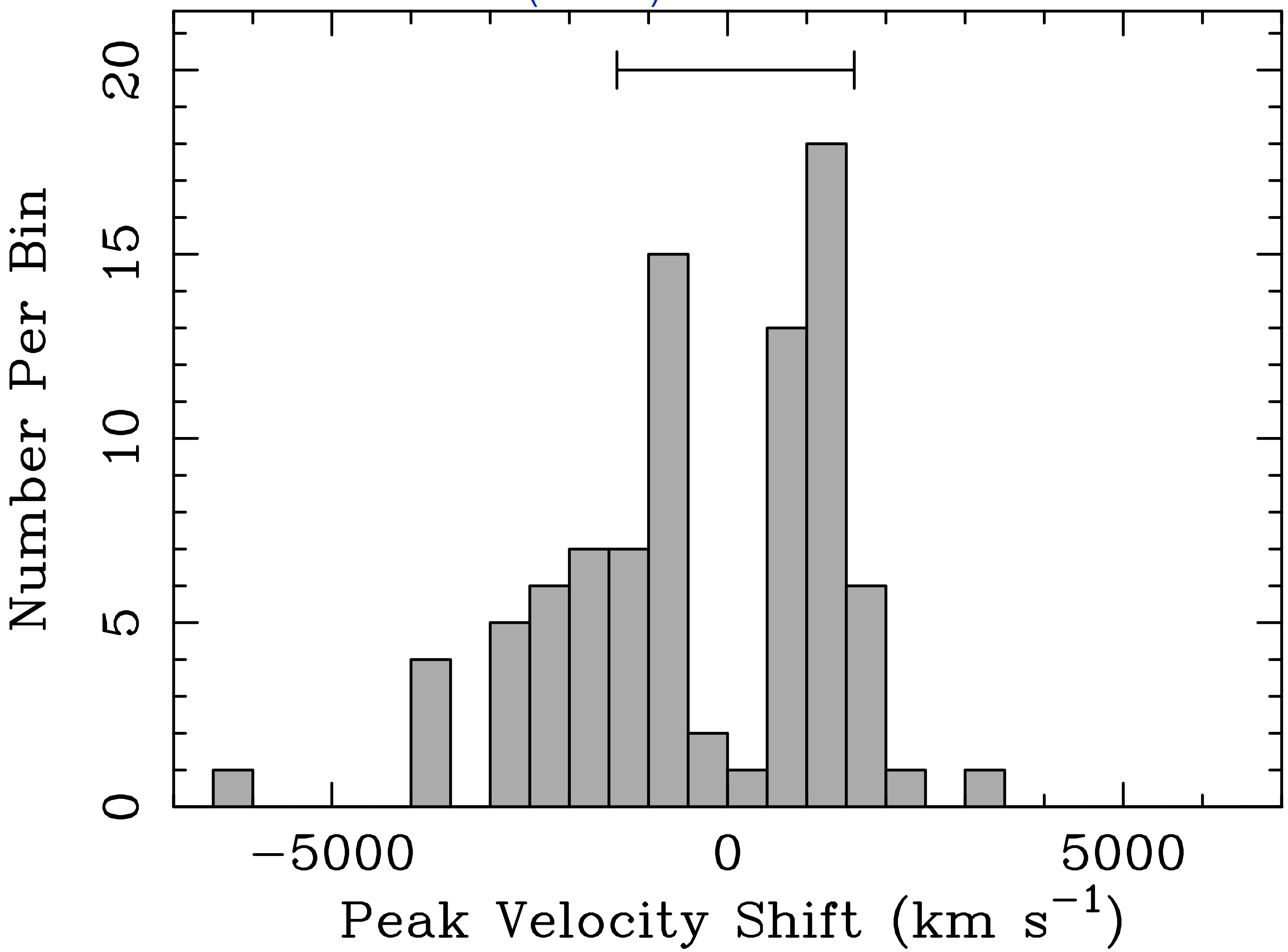
The observable:

$$u_2 = V_2 \sin i \sin \phi$$

$$u_{2,3} = \frac{V_2 \sin i \sin \phi}{10^3 \text{ km s}^{-1}}$$

Spec. Search: *88 binary candidates*

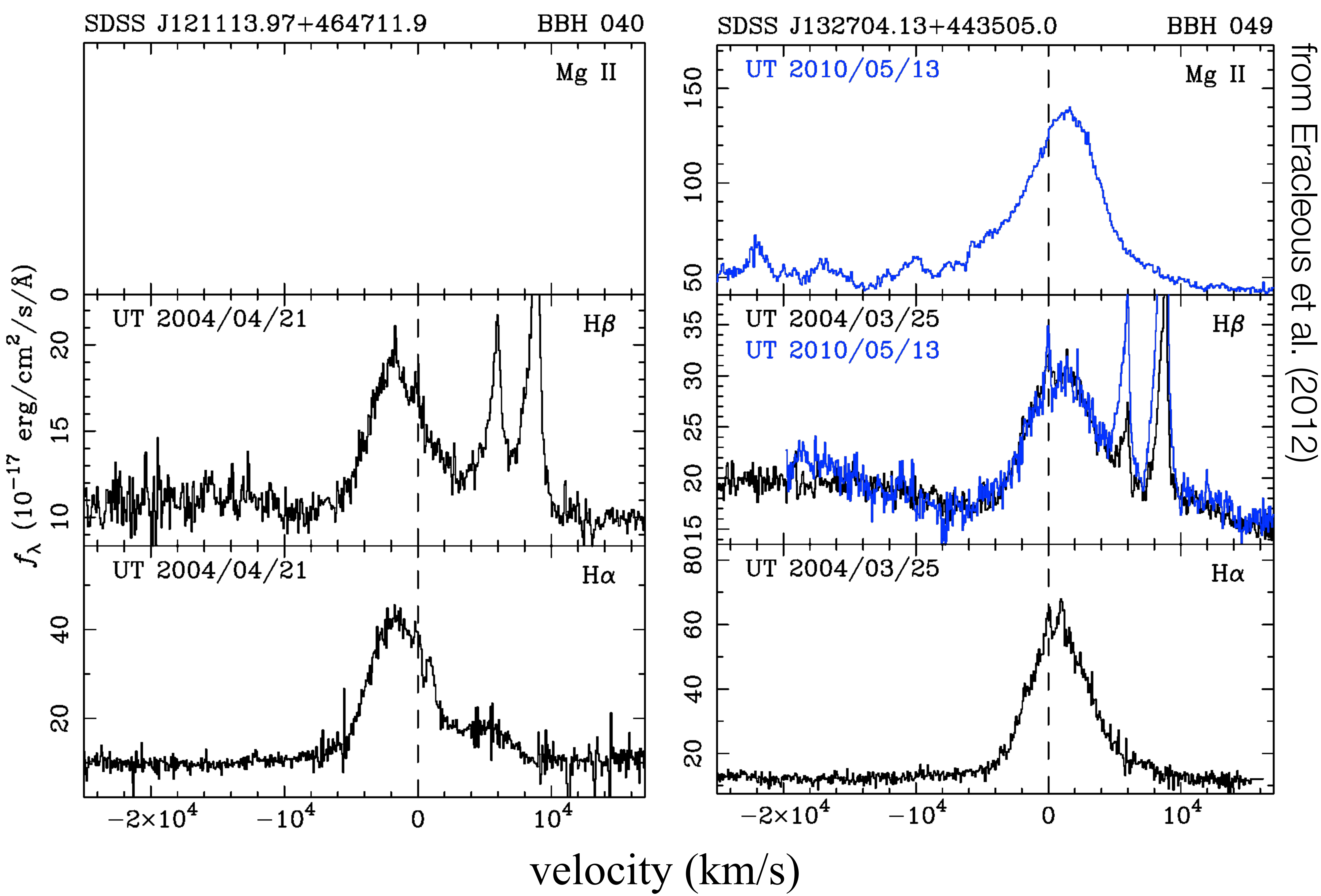
Eracleous et al. (2012)



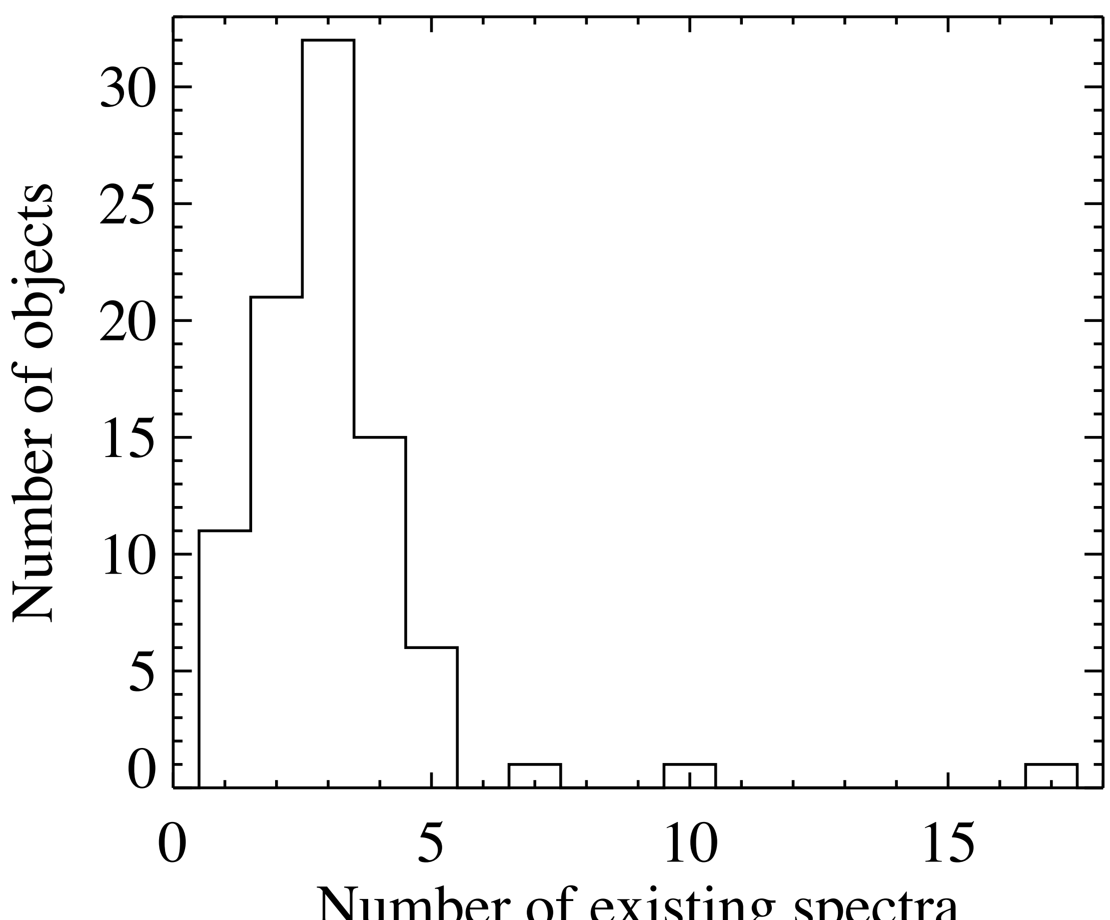
88/15,900 SDSS DR7 AGN w/:

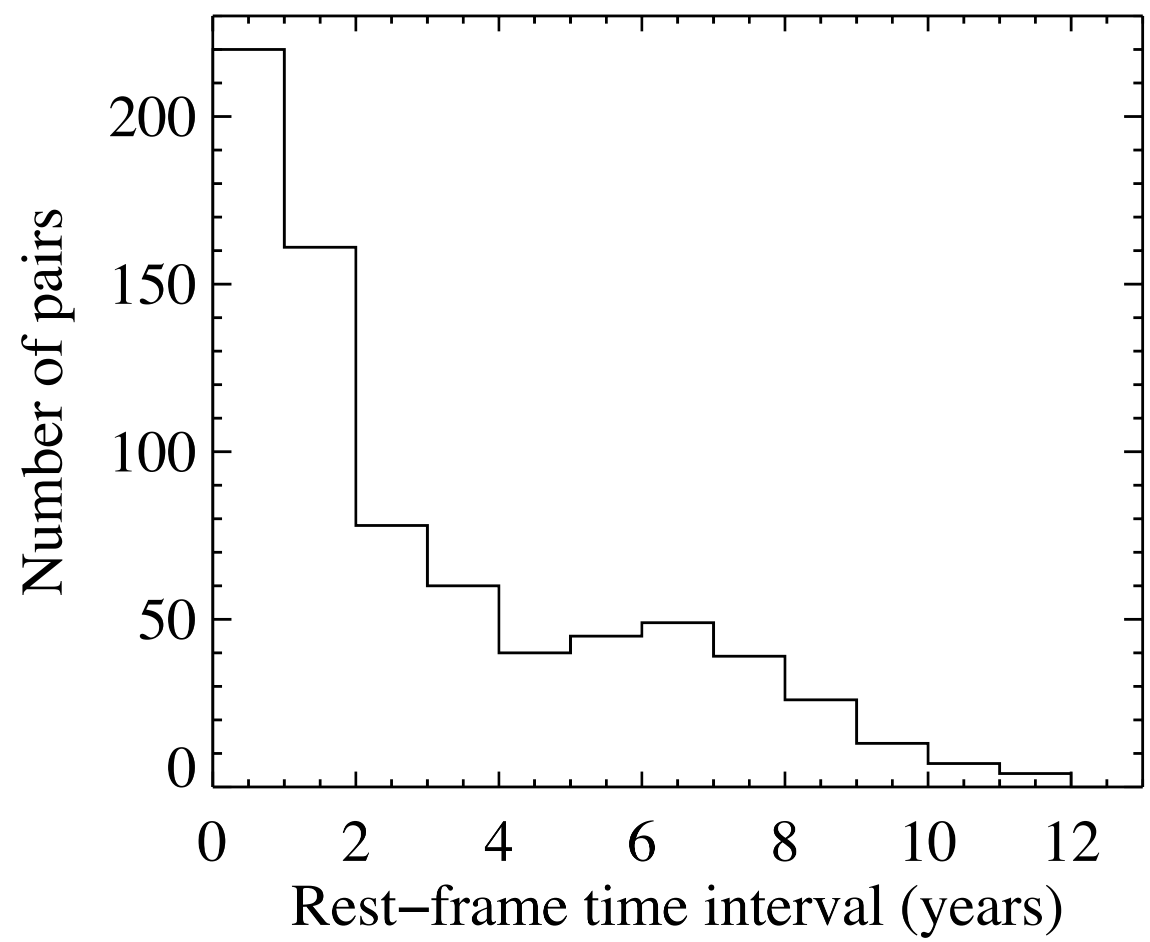
- *$z < 0.7$*
- *Single-peaked, velocity offset broad Balmer lines.*

Spec. Search: *Examples of their spectra*



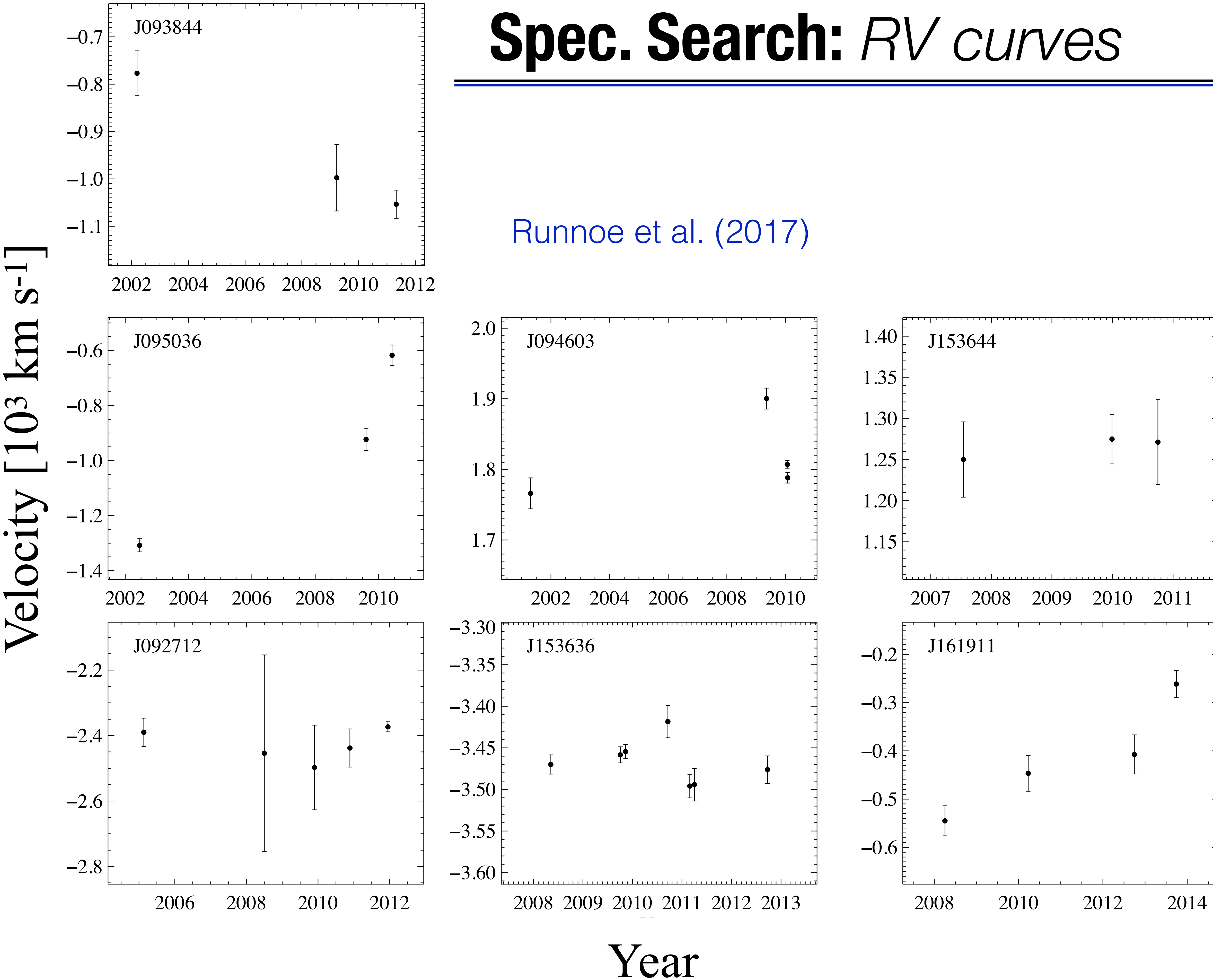
Spec. Search: *Spectroscopic monitoring*





Spec. Search: *RV curves*

Runnoe et al. (2017)



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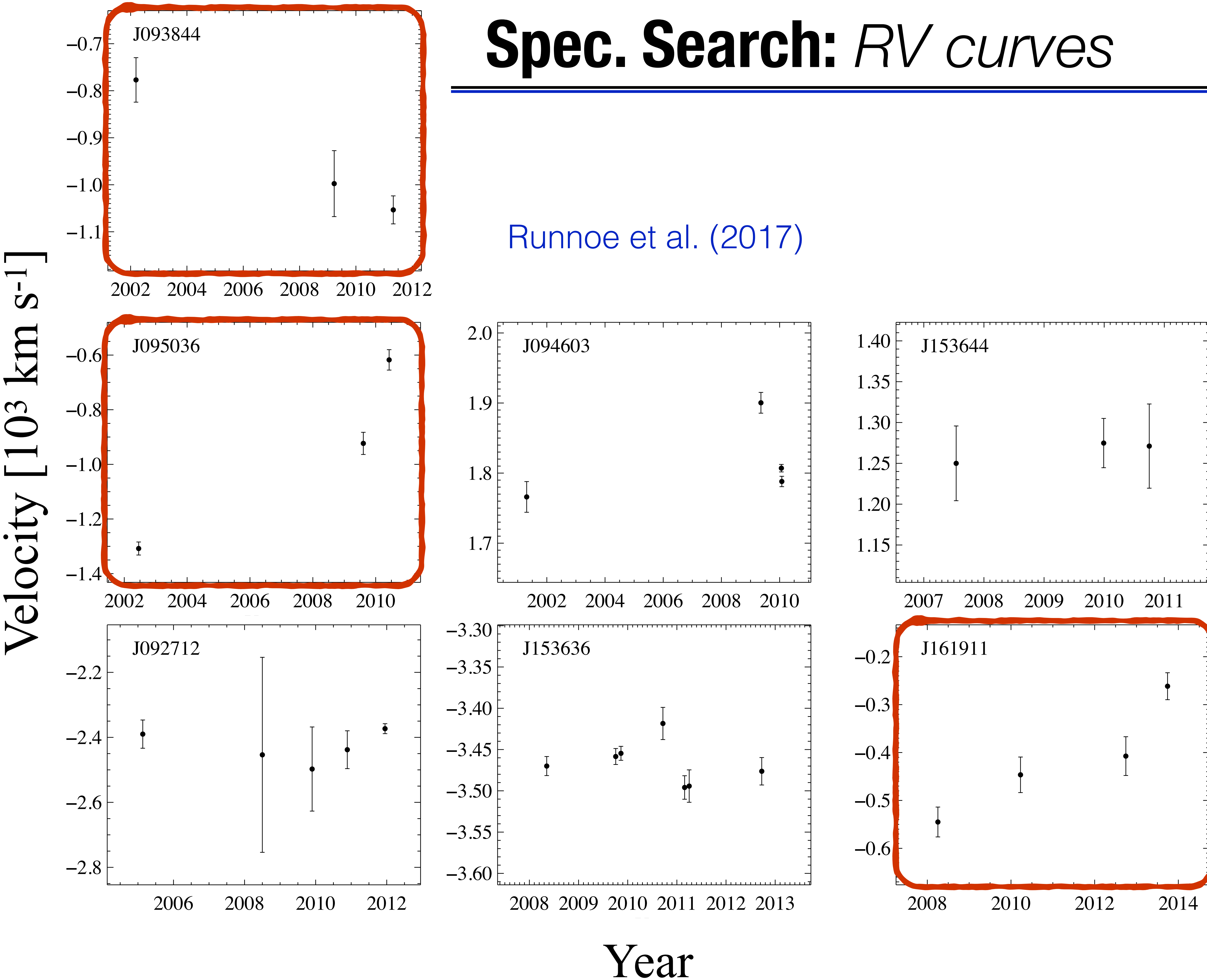
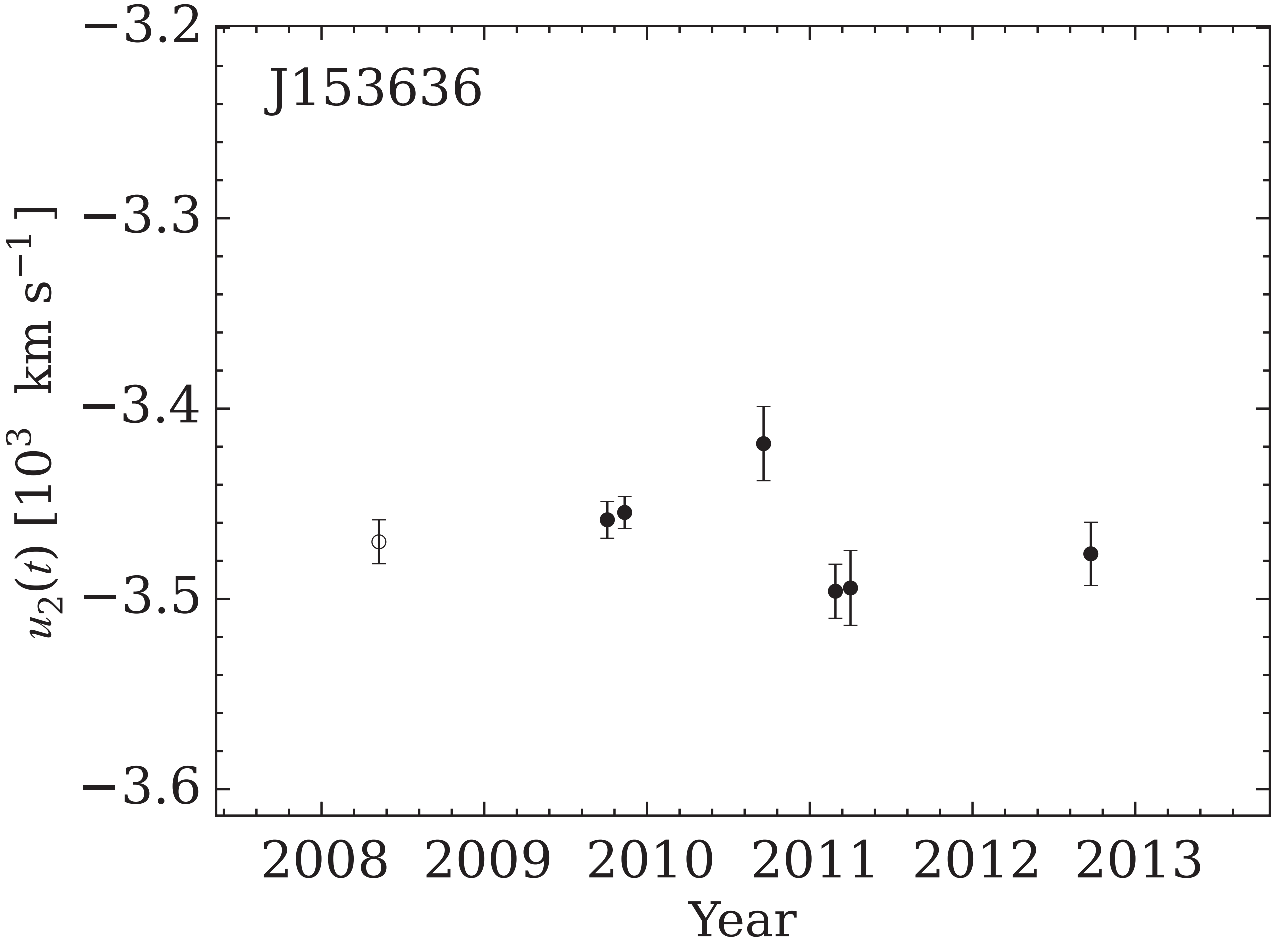


Hypothesis: *Quasars with single-peaked, velocity-offset broad lines are the active secondary in a binary.*

Spec. Search: *Limits on the SBHB properties*

Runnoe et al. (2017)



$$u_{2,3}(t) = v \sin i \sin\left[\frac{2\pi}{P}(t - t_0)\right]$$

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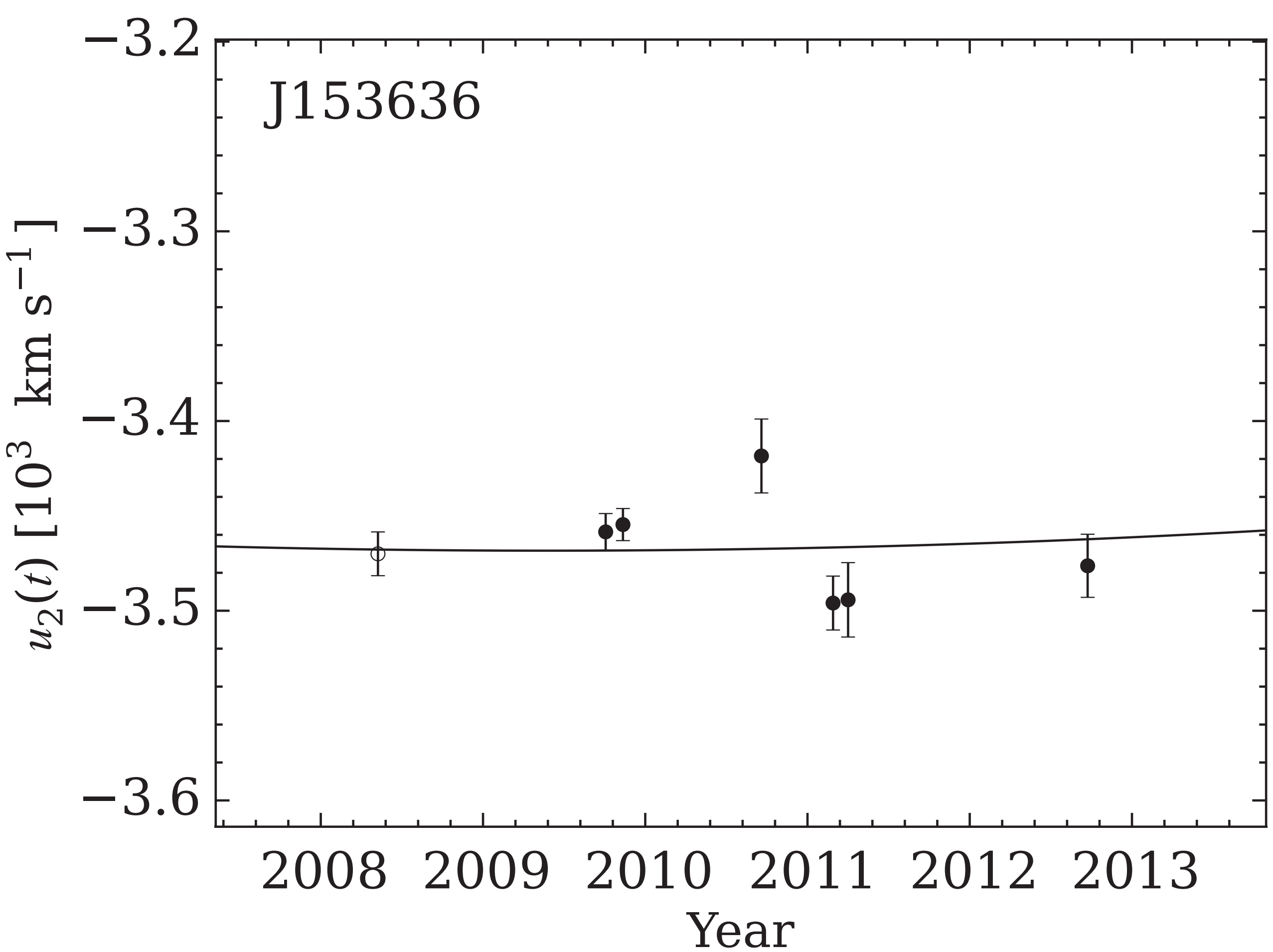
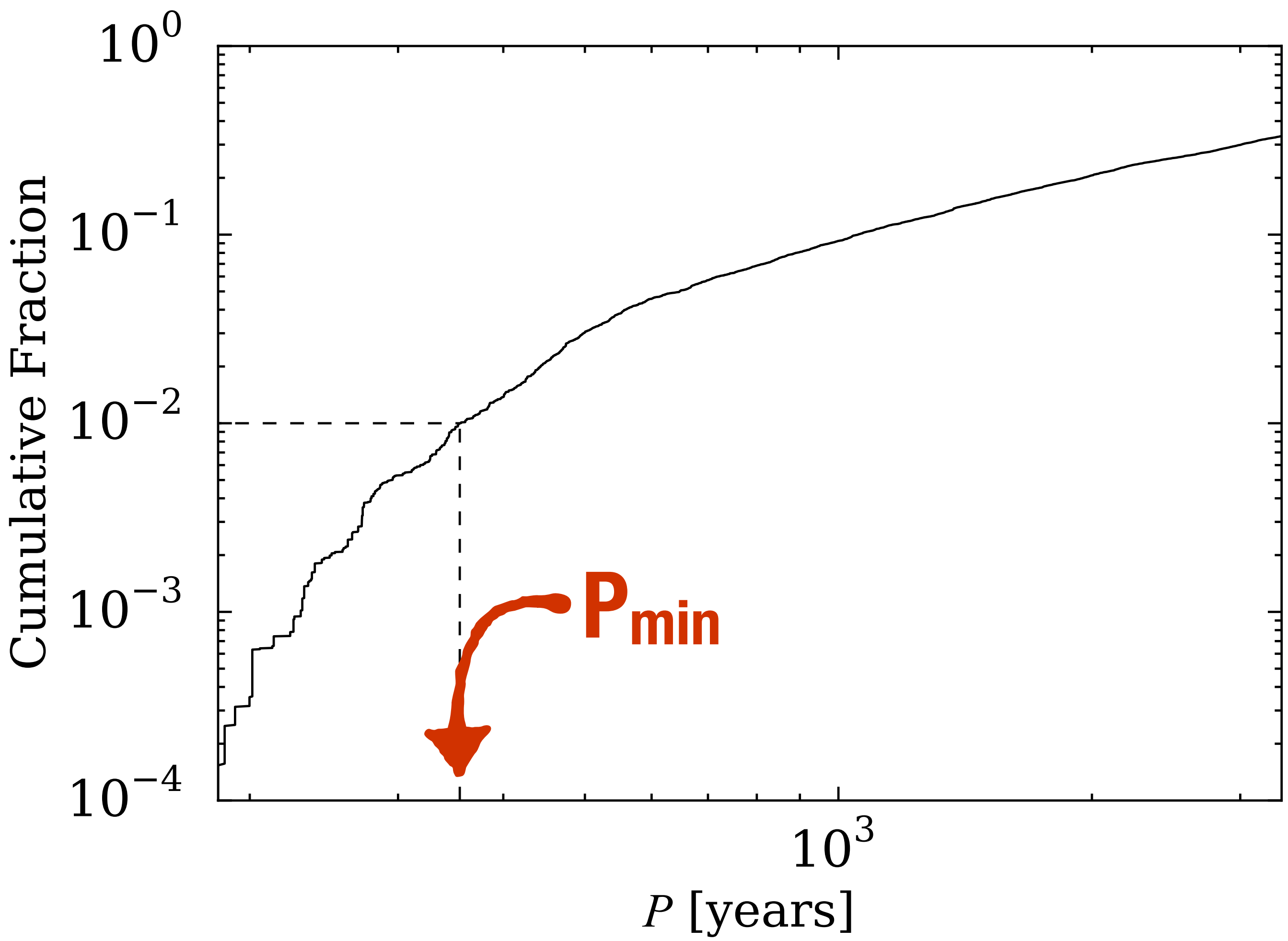


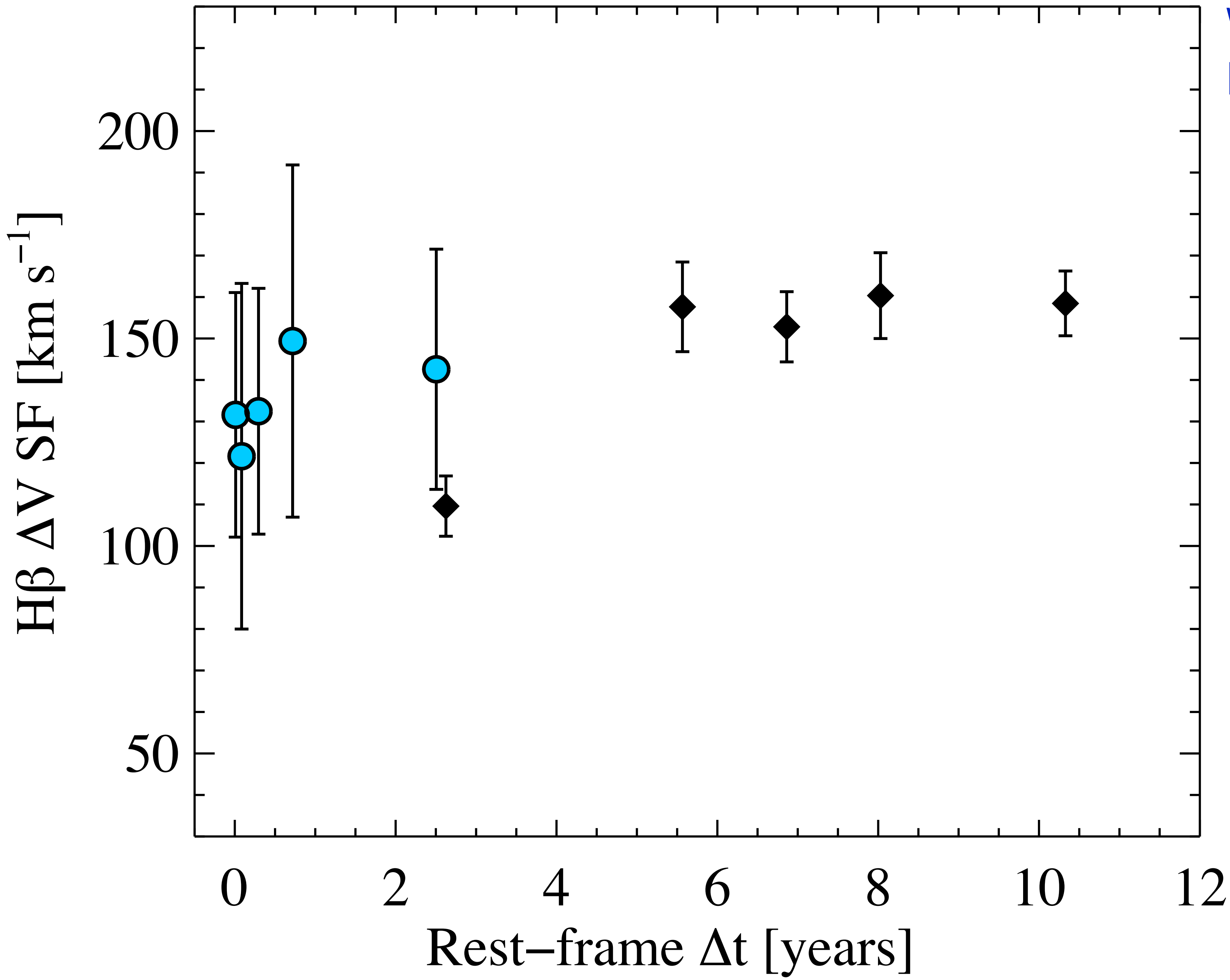


P_{min} = 260 years

$M_{min} = 4.1 \times 10^8\ M_\odot$

Quasar variability: *Radial velocity jitter*

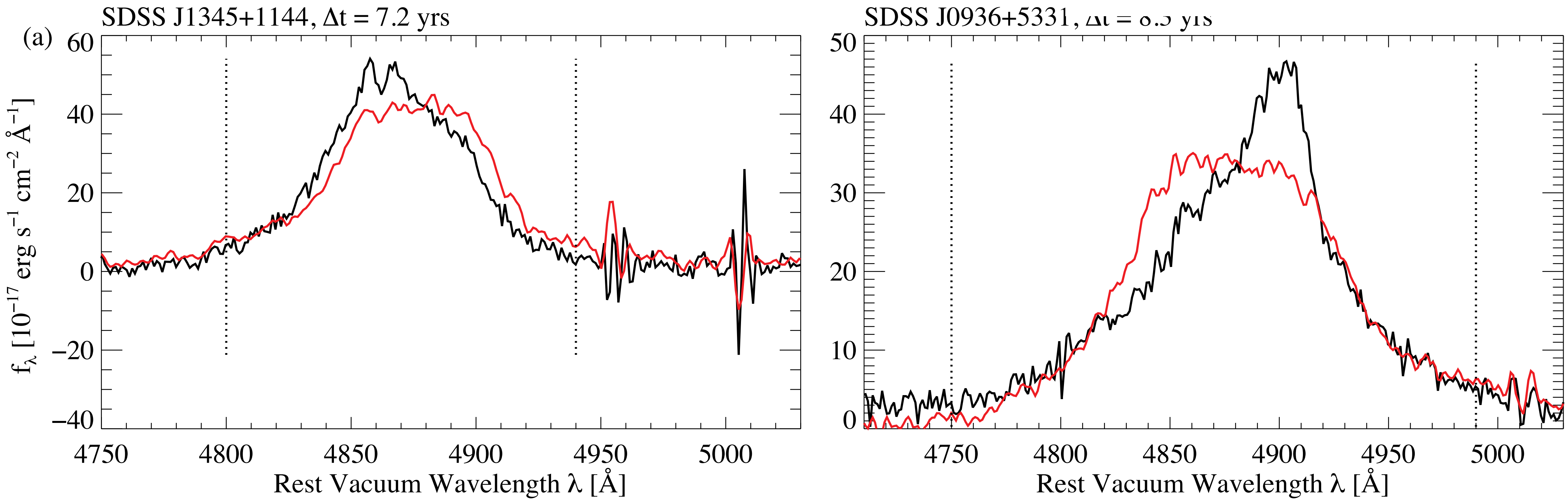
Preliminary velocity **"jitter"** structure function for SBHBs



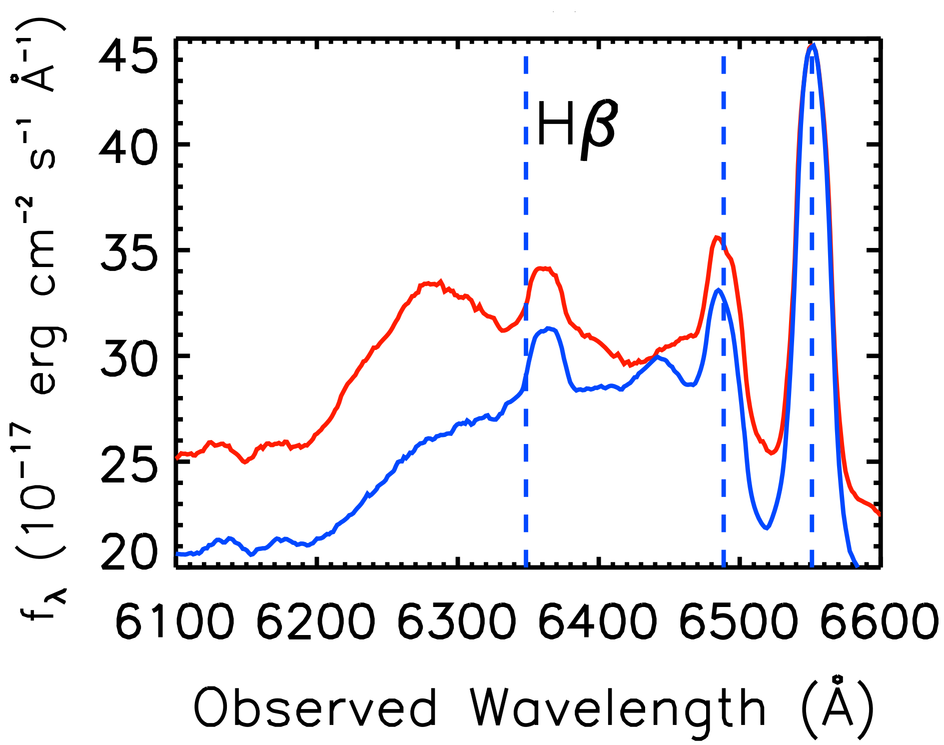
With data from Runnoe et al. (2015)

Quasar variability: *Changes in profile shape*

Recall this example from Mike's talk:



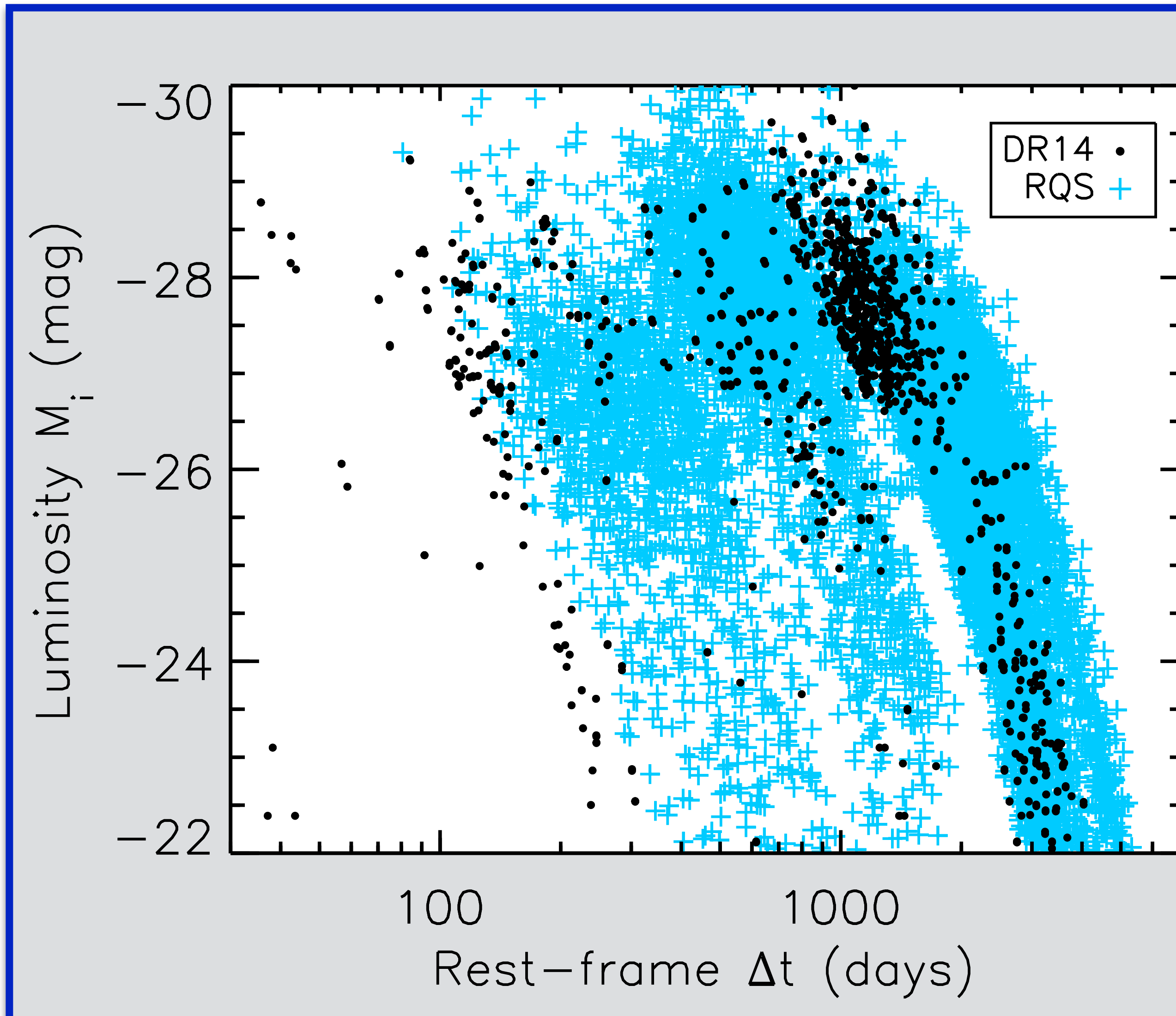
Liu et al. (2014)



MacLeod et al. (2018)

Quasar variability: *Time-domain surveys*

Industrial-scale **time-domain spectroscopy** with SDSS IV/V.



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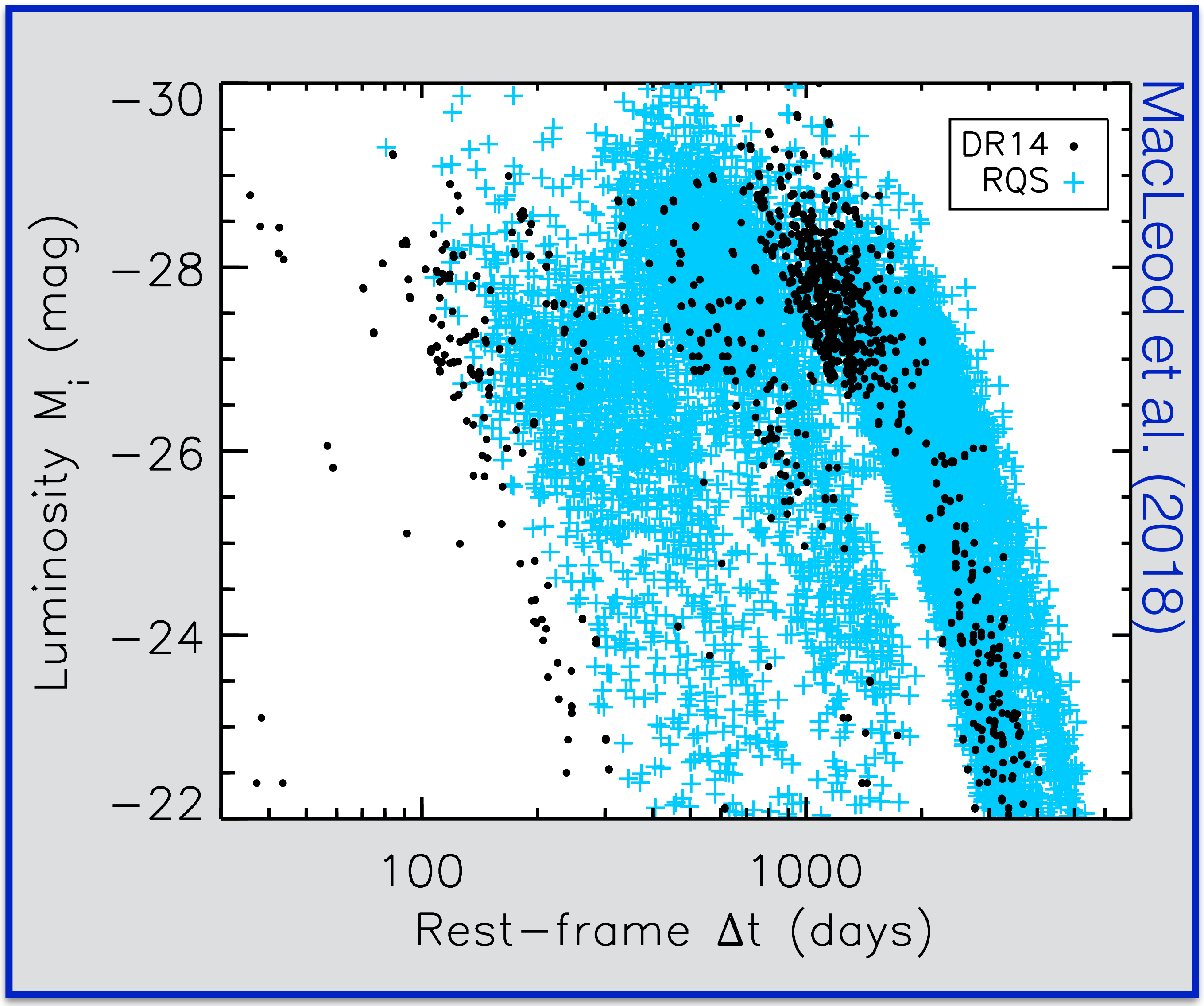

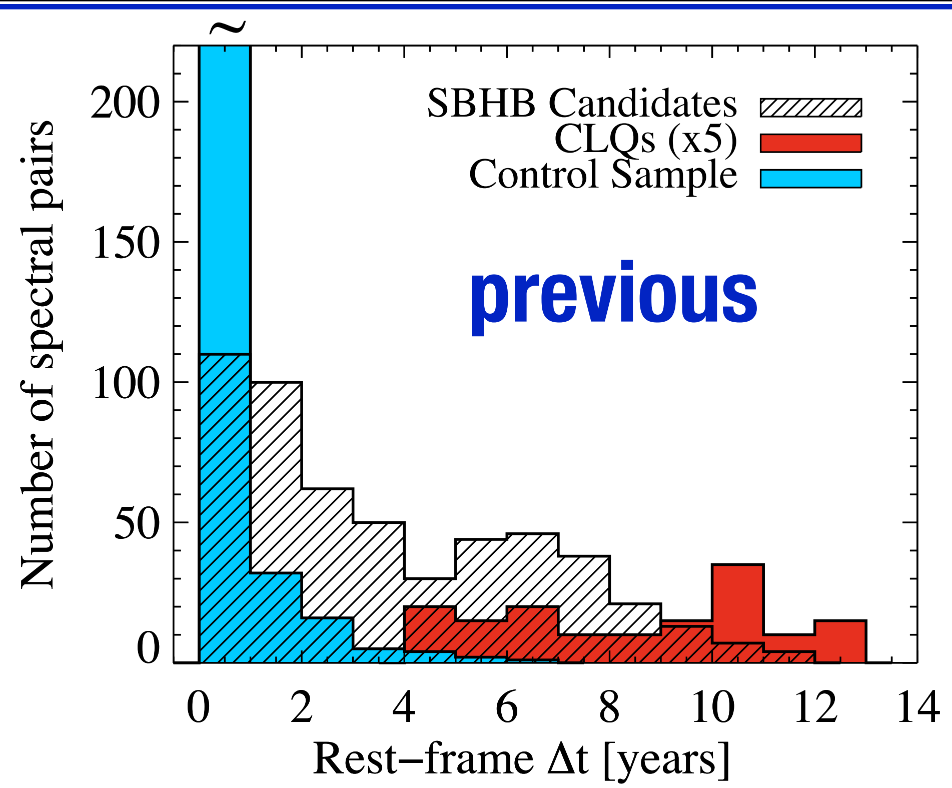

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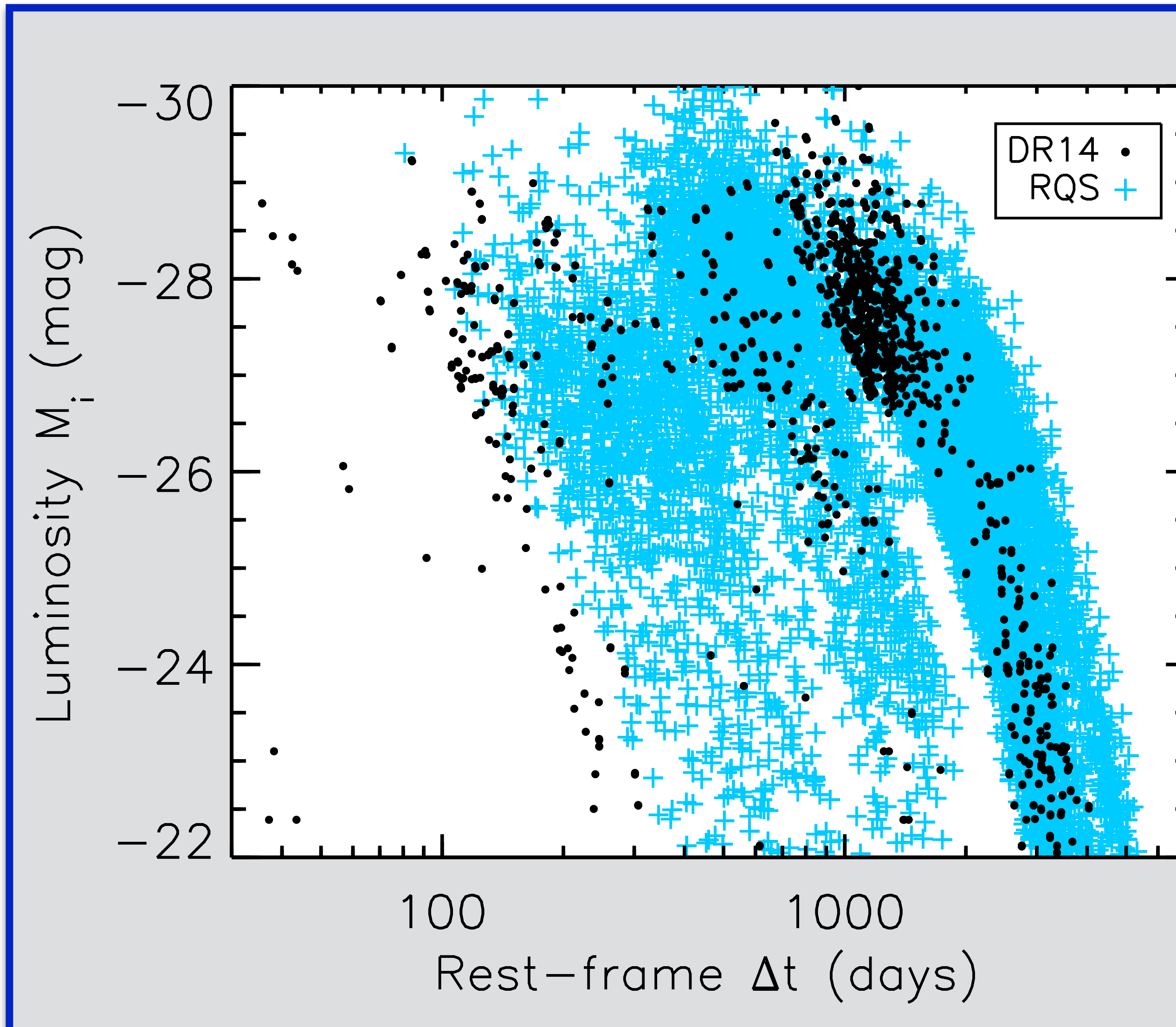

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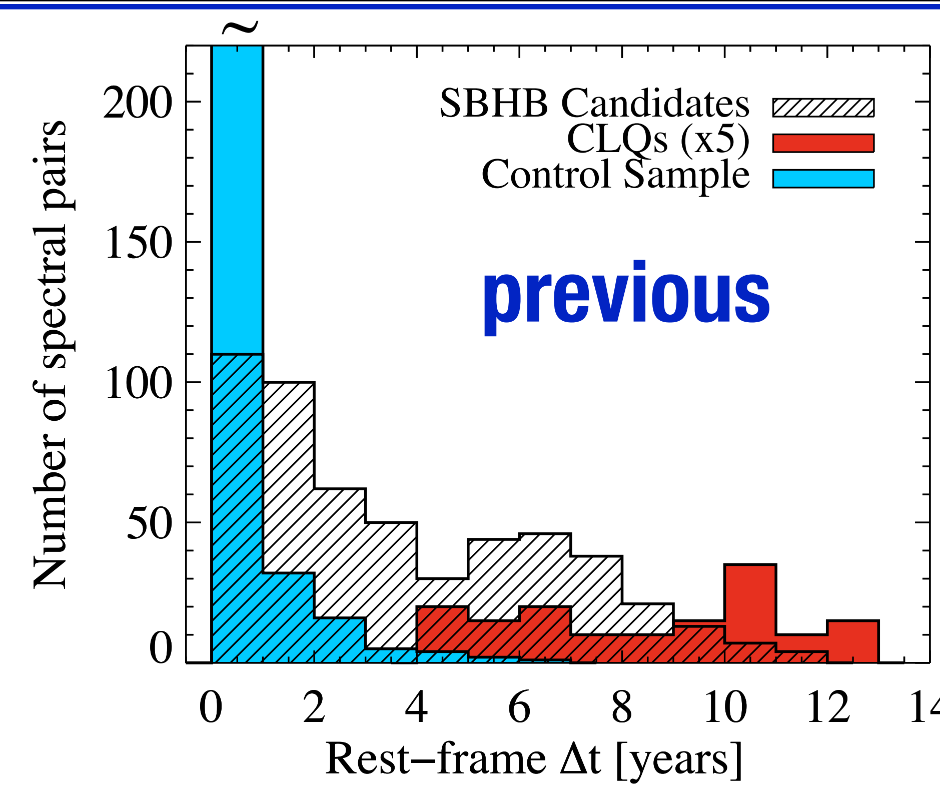

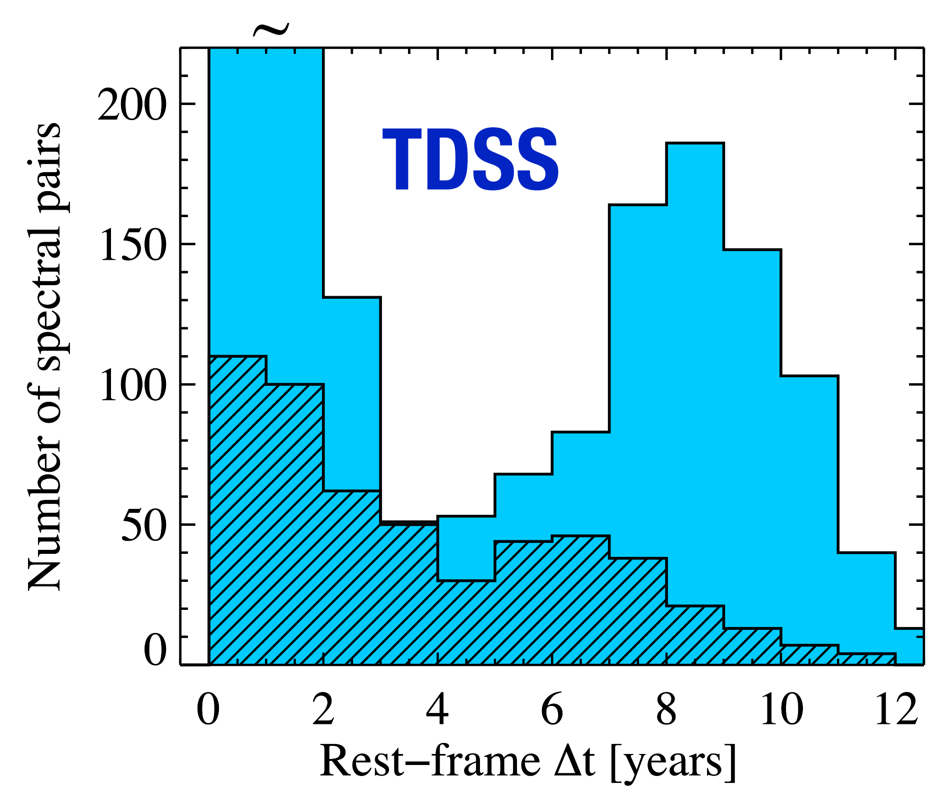

With data from
Runnoe et al. (2015)

Conclusions: *Where do we go from here?*

Search status: cautiously optimistic

Spectroscopic monitoring is ongoing and we have demonstrated the methodology for placing limits on the properties of the hypothetical binaries. This has yielded 3 excellent candidates.

Regular quasar variability

The biggest caveat to this approach is that the spectroscopic signals we seek are not unique, they can be produced by regular quasars. Upcoming spectroscopic surveys and RM will tackle this.

Complementary tests are critical

With the exception of GWs, observational signatures of SBHBs are not unique. Thus, conducting complementary tests of a candidate's nature is critical to finding them. See upcoming talks.