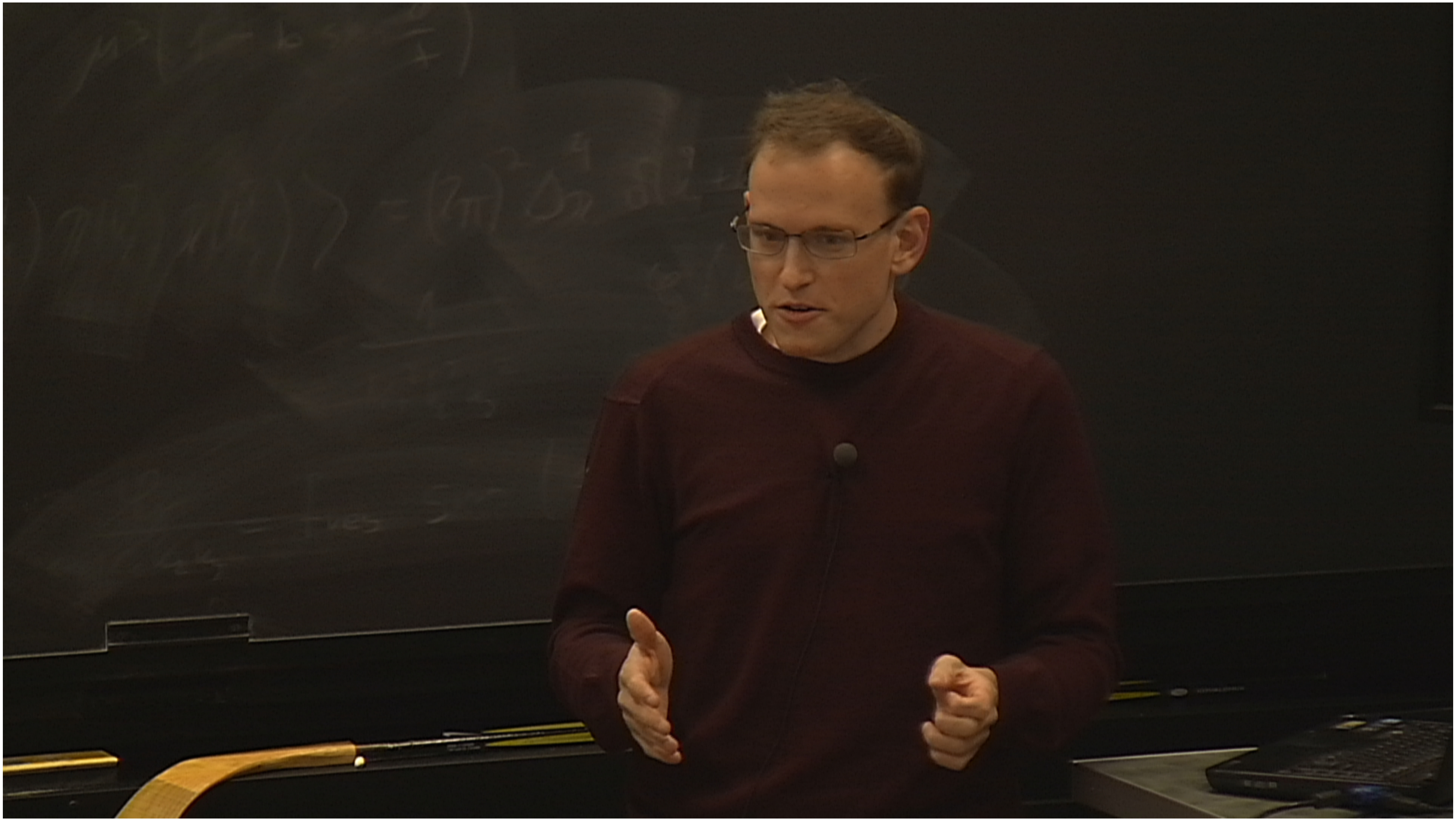
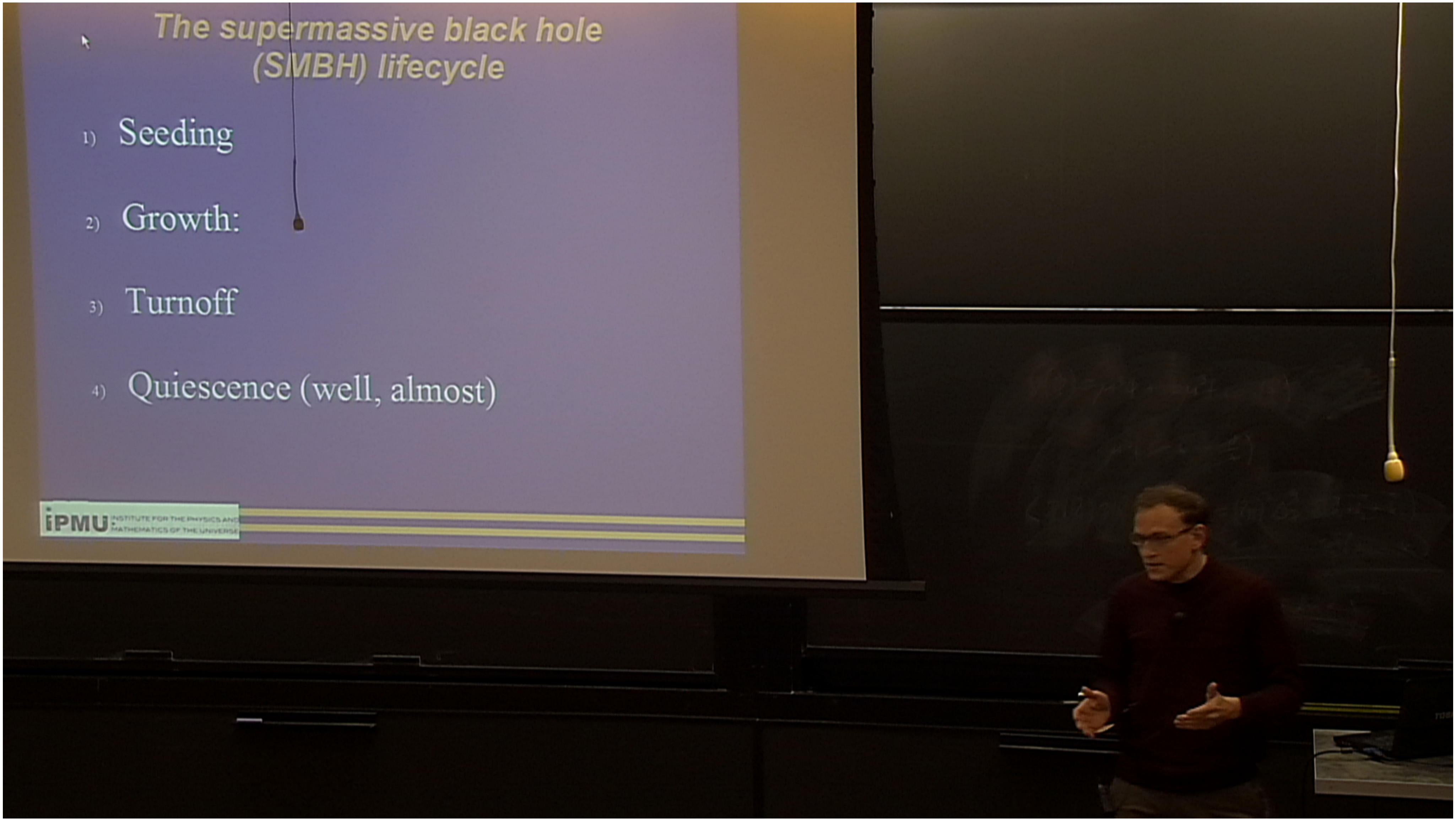
Title: Puzzling Features of Quasar Accretion

Date: Nov 22, 2011 02:00 PM

URL: http://pirsa.org/11110116

Abstract: The development of virial mass estimates for the central black hole using one quasar spectrum has allowed a dramatic improvement in our understanding of supermassive black hole evolution. I will describe several new puzzles arising from the combination of virial masses with luminosity and redshift measurements, many of which are inconsistent with our current understanding of quasar evolution. I will also describe a new class of quasars that does not appear to fit easily into current models for quasar accretion.





The supermassive black hole (SMBH) lifecycle

1) Seeding
2) Growth:
3) Turnoff
4) Quiescence (well, almost)

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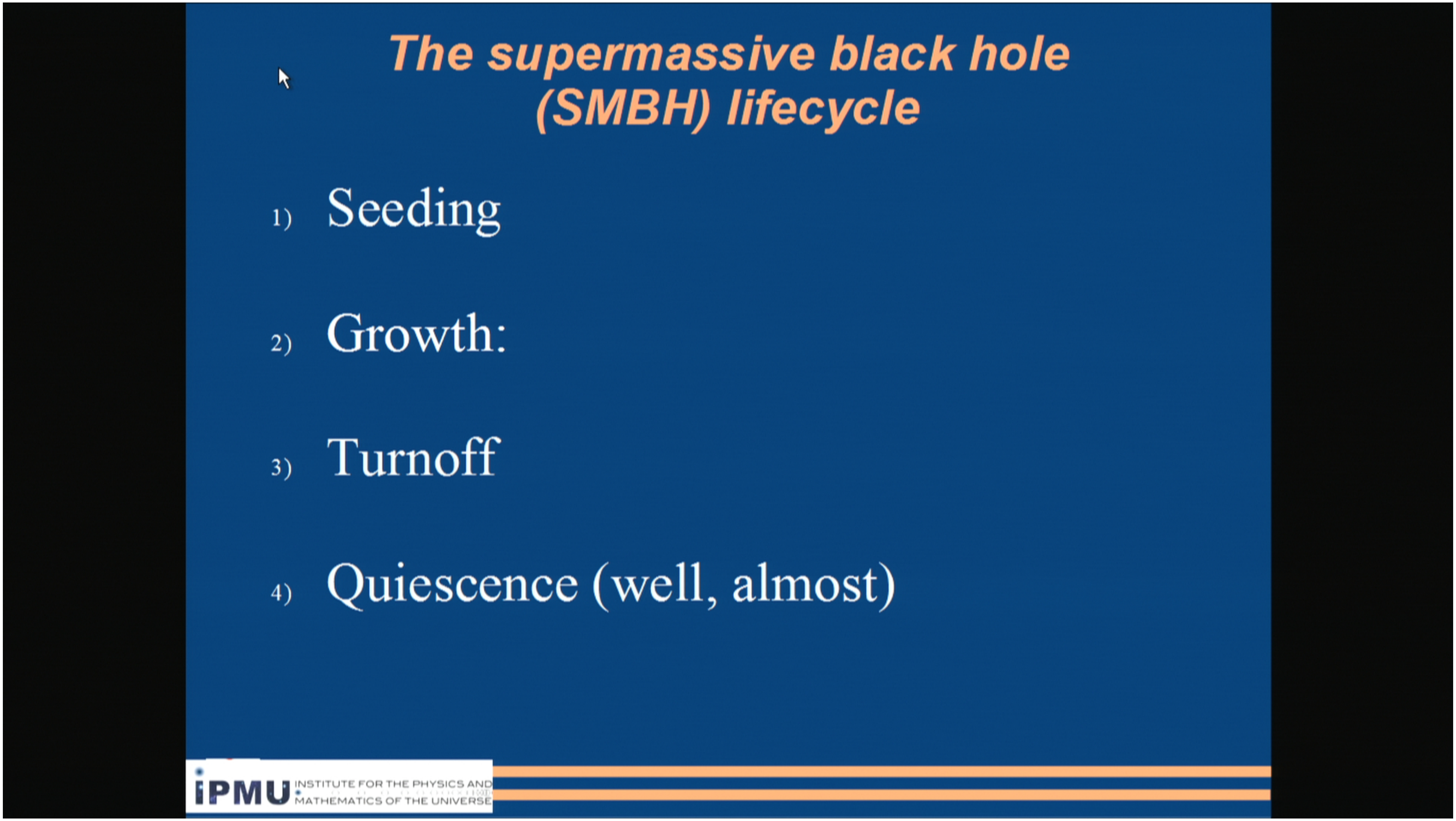

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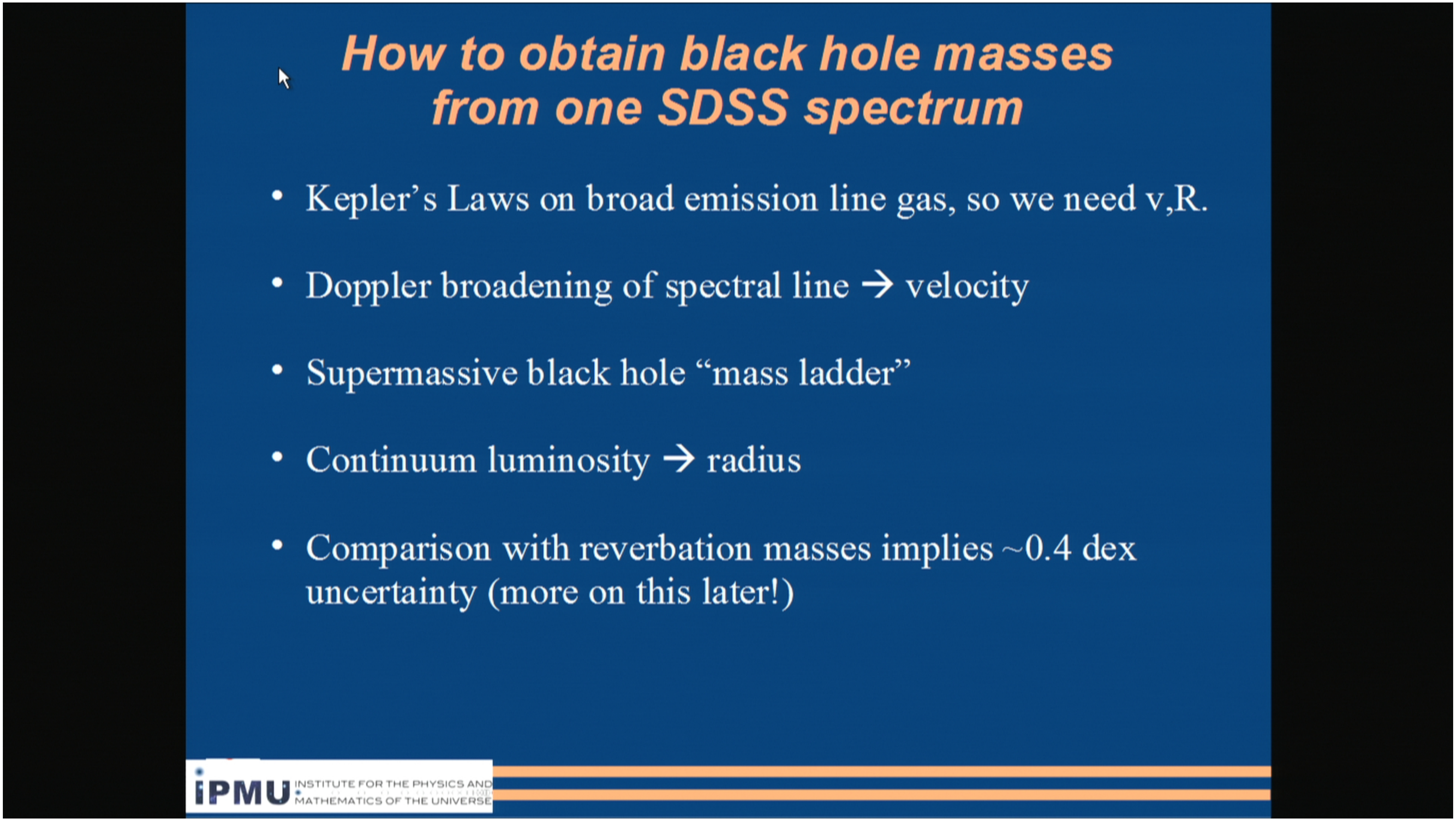

How to obtain black hole masses from one SDSS spectrum

- Kepler's Laws on broad emission line gas, so we need v,R.
- Doppler broadening of spectral line → velocity
- Supermassive black hole "mass ladder"
- Continuum luminosity → radius
- Comparison with reverbation masses implies ~0.4 dex uncertainty (more on this later!)

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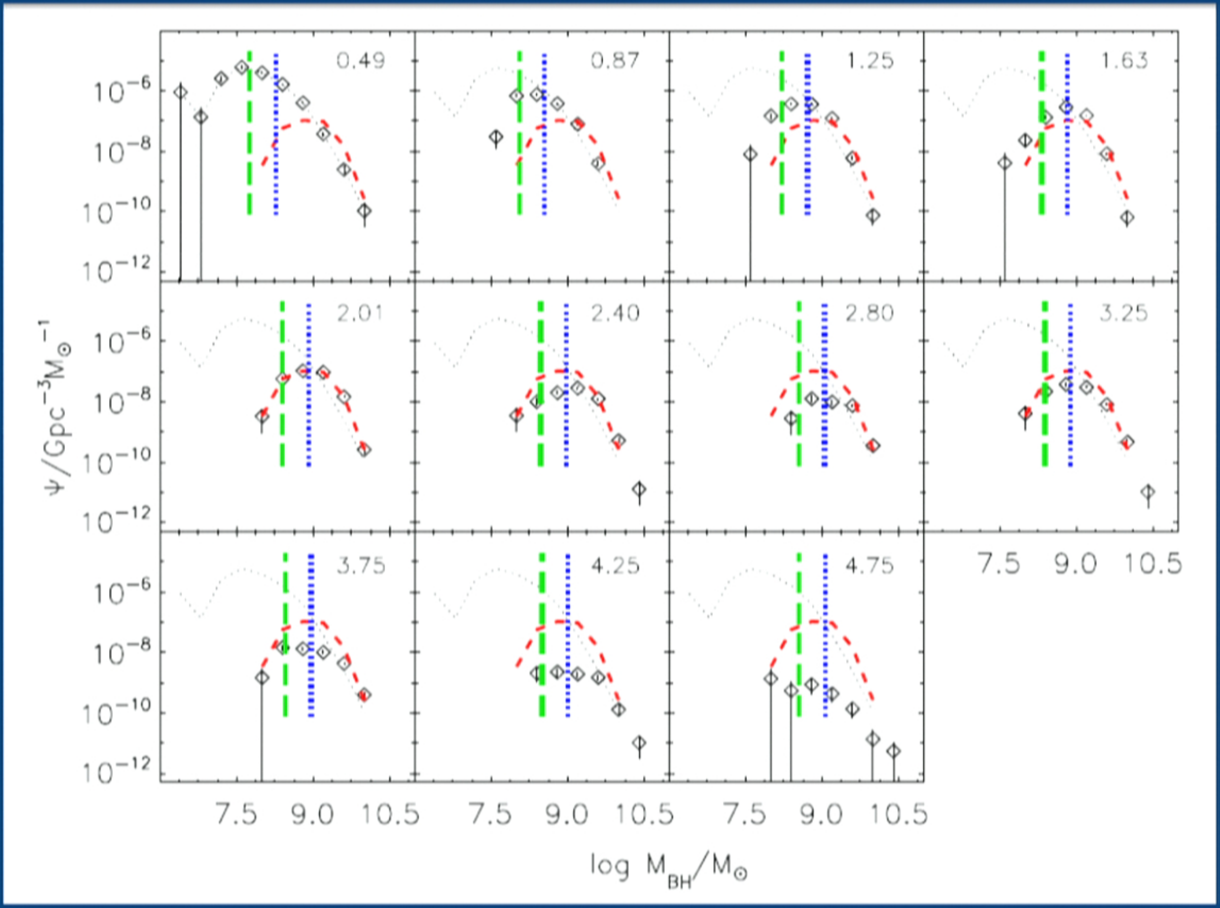
Quasar Mass Function



Vestergaard et al. (2008)

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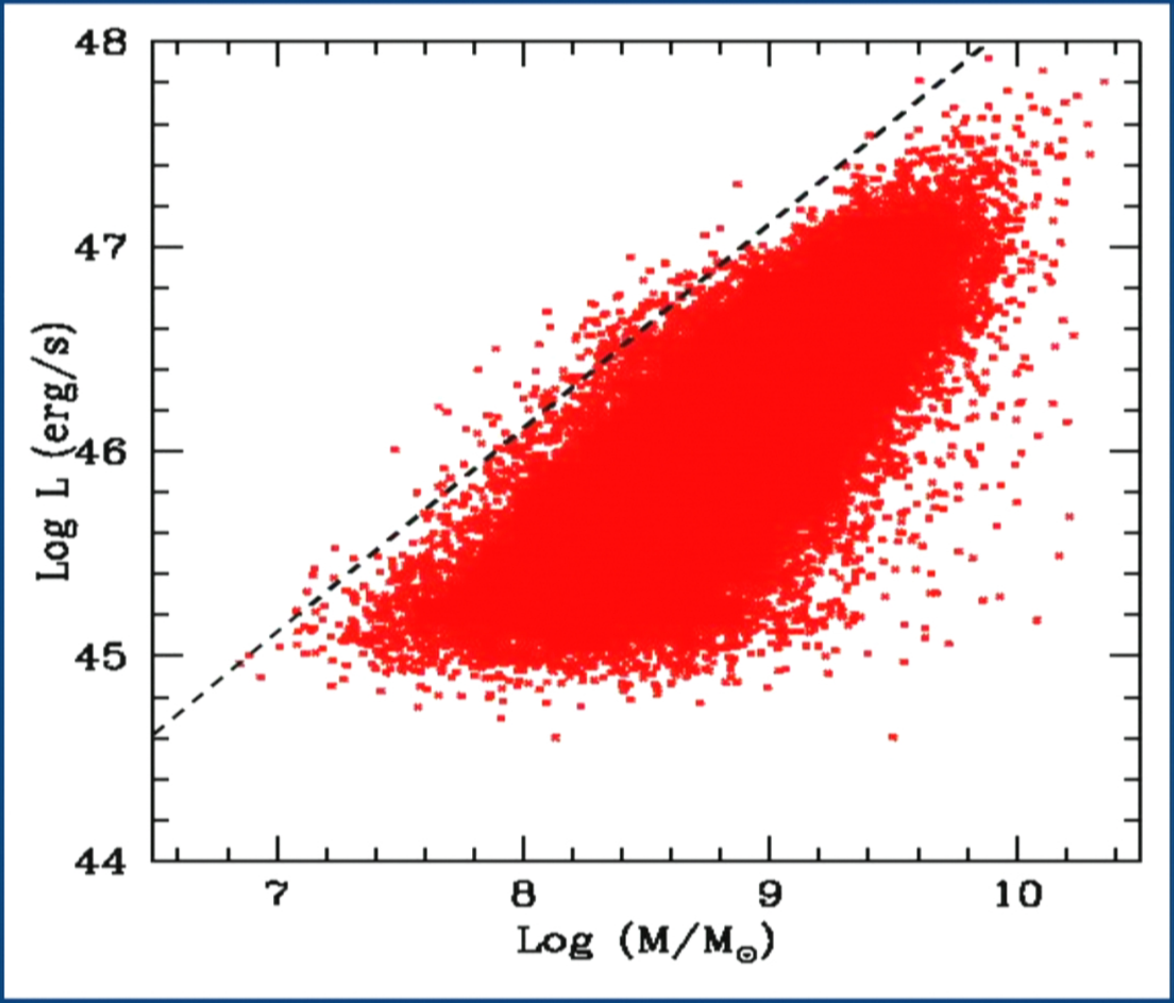

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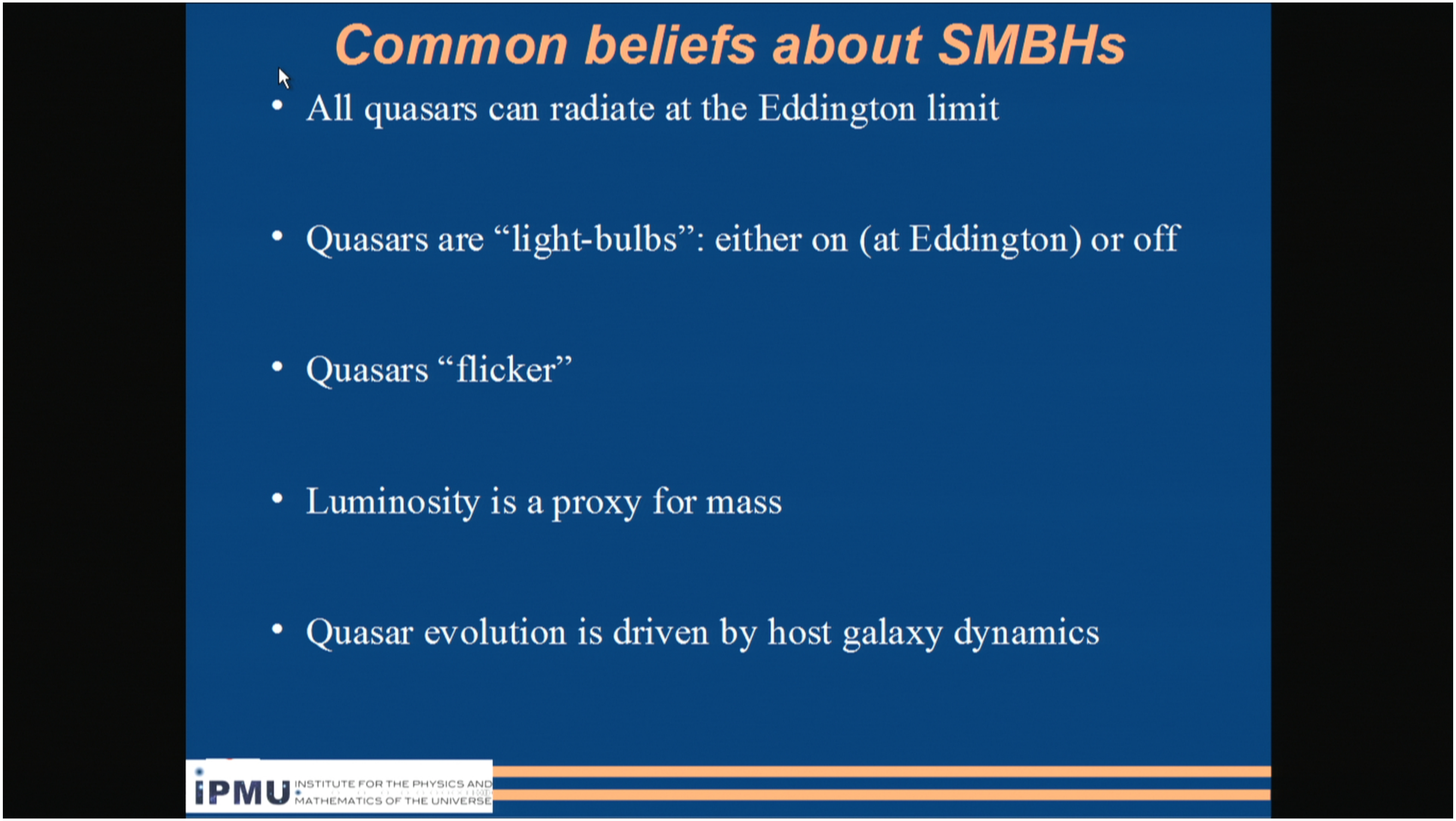

Common beliefs about SMBHs

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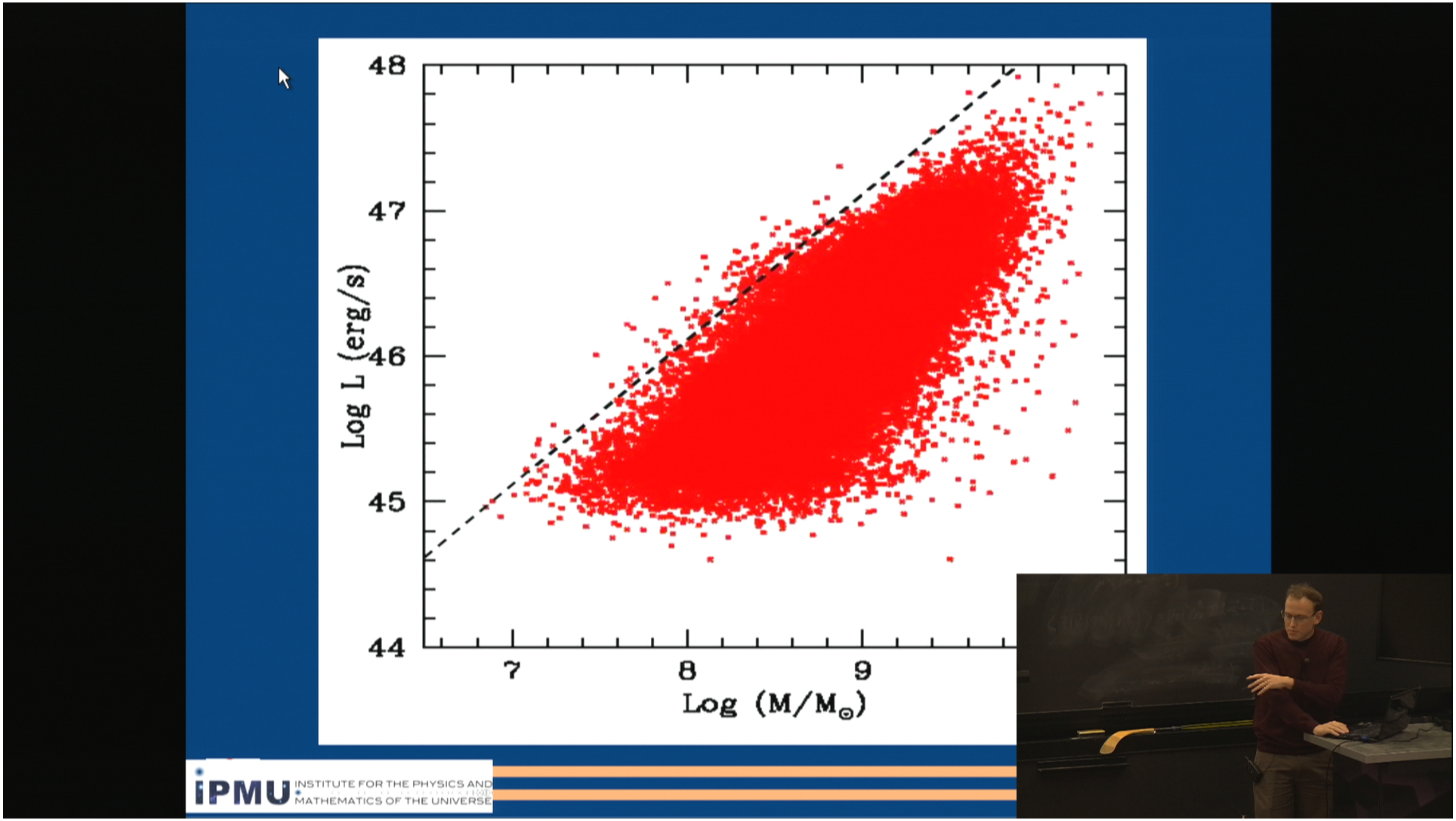
48
47
46
45
44
Log L (erg/s)
7
8
9
Log (M/M$_\odot$)
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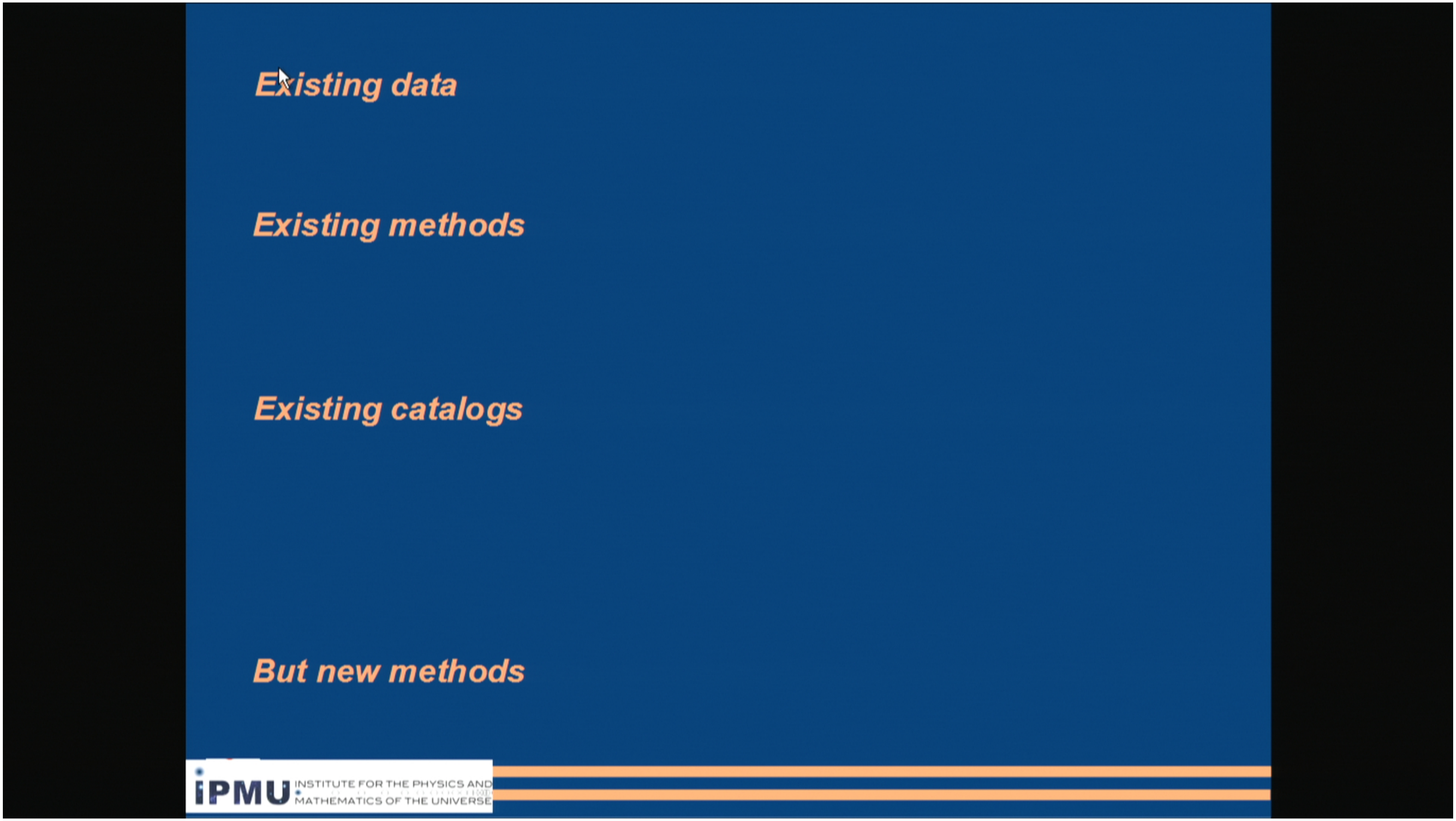

Existing data

Existing methods

Existing catalogs

But new methods

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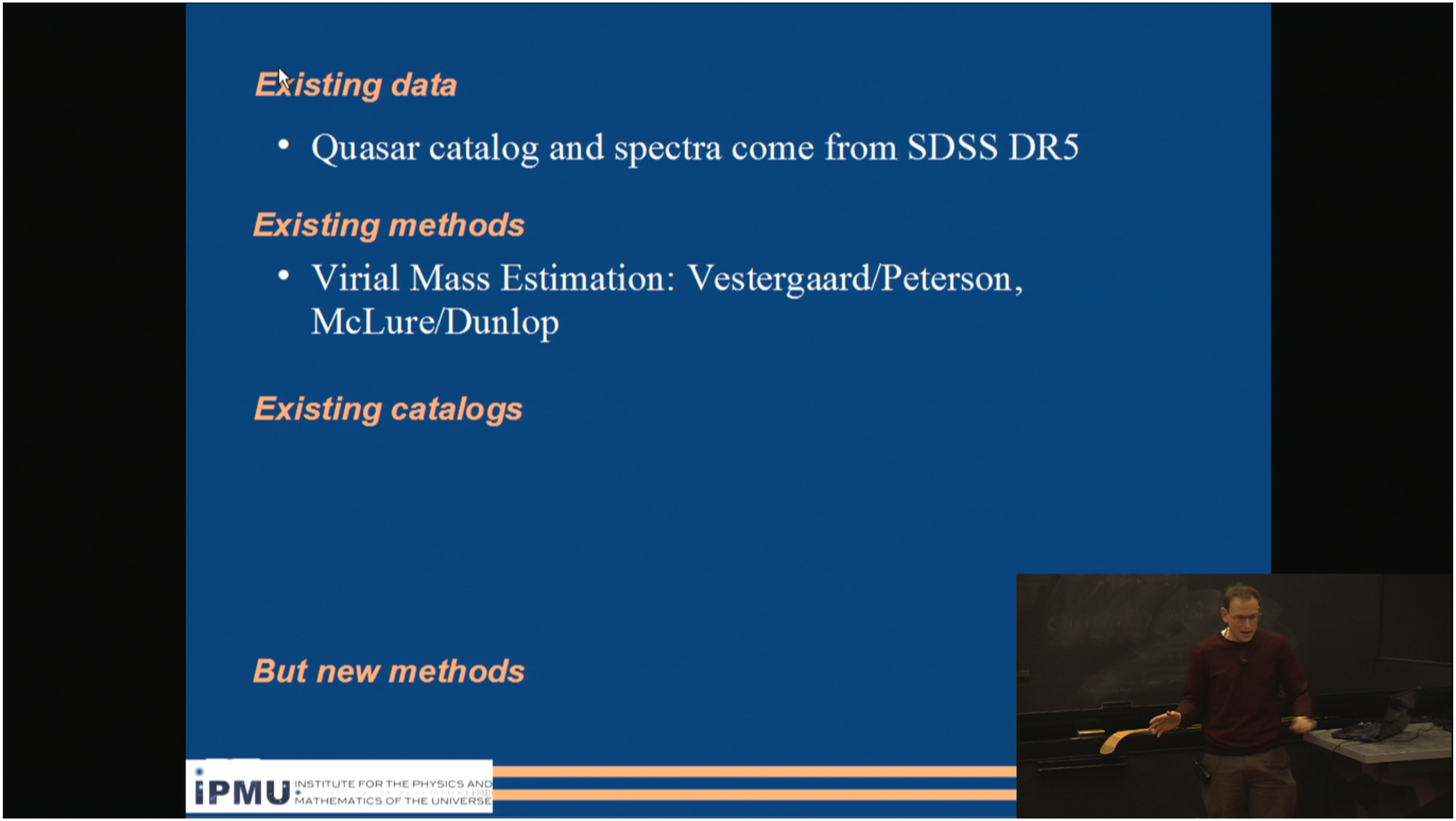

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- Quasar catalog and spectra come from SDSS DR5

Existing methods

- Virial Mass Estimation: Vestergaard/Peterson, McLure/Dunlop

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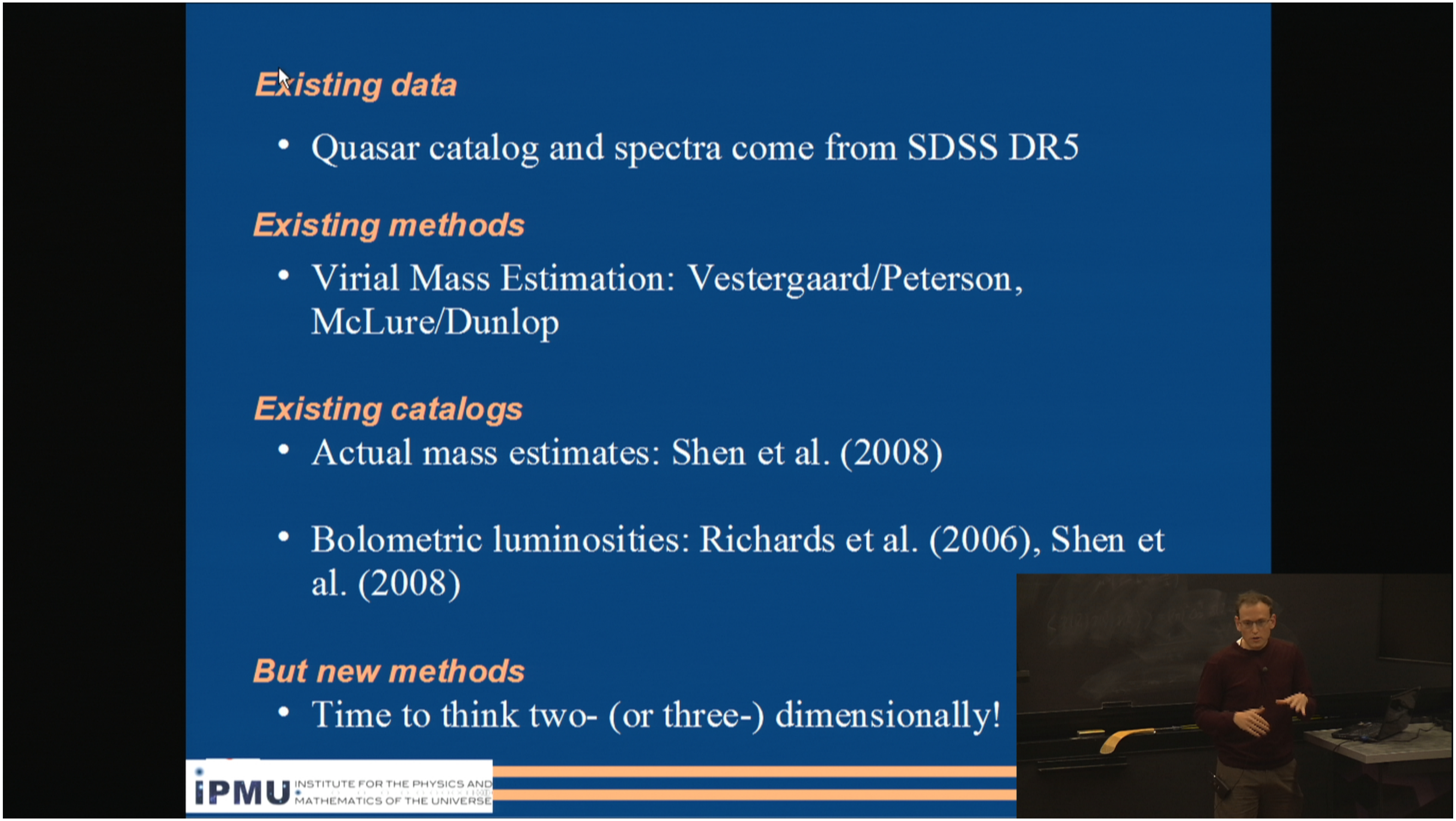

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Existing catalogs

- Actual mass estimates: Shen et al. (2008)
- Bolometric luminosities: Richards et al. (2006), Shen et al. (2008)

But new methods

- Time to think two- (or three-) dimensionally!

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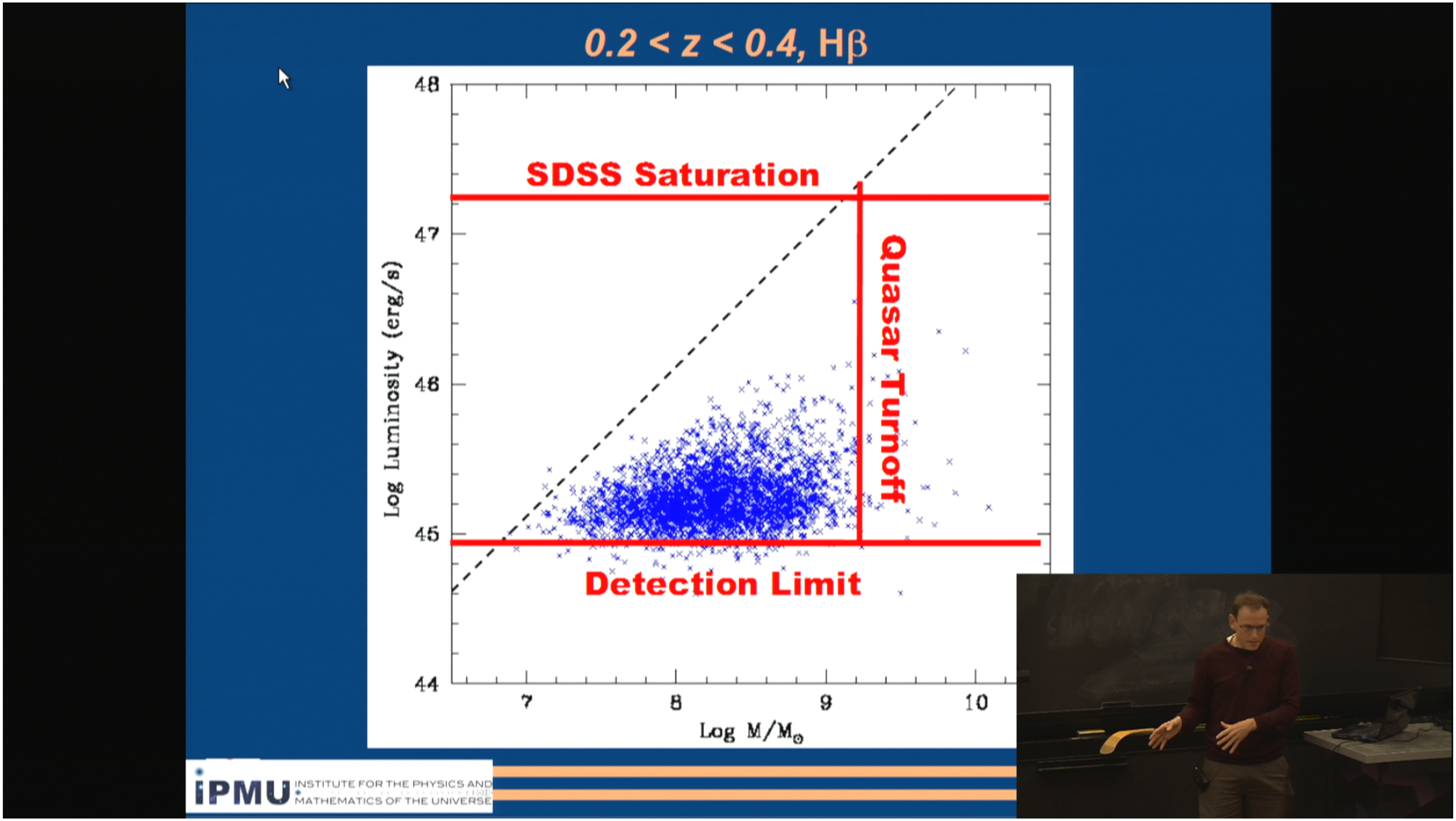
$0.2 < z < 0.4$, Hβ



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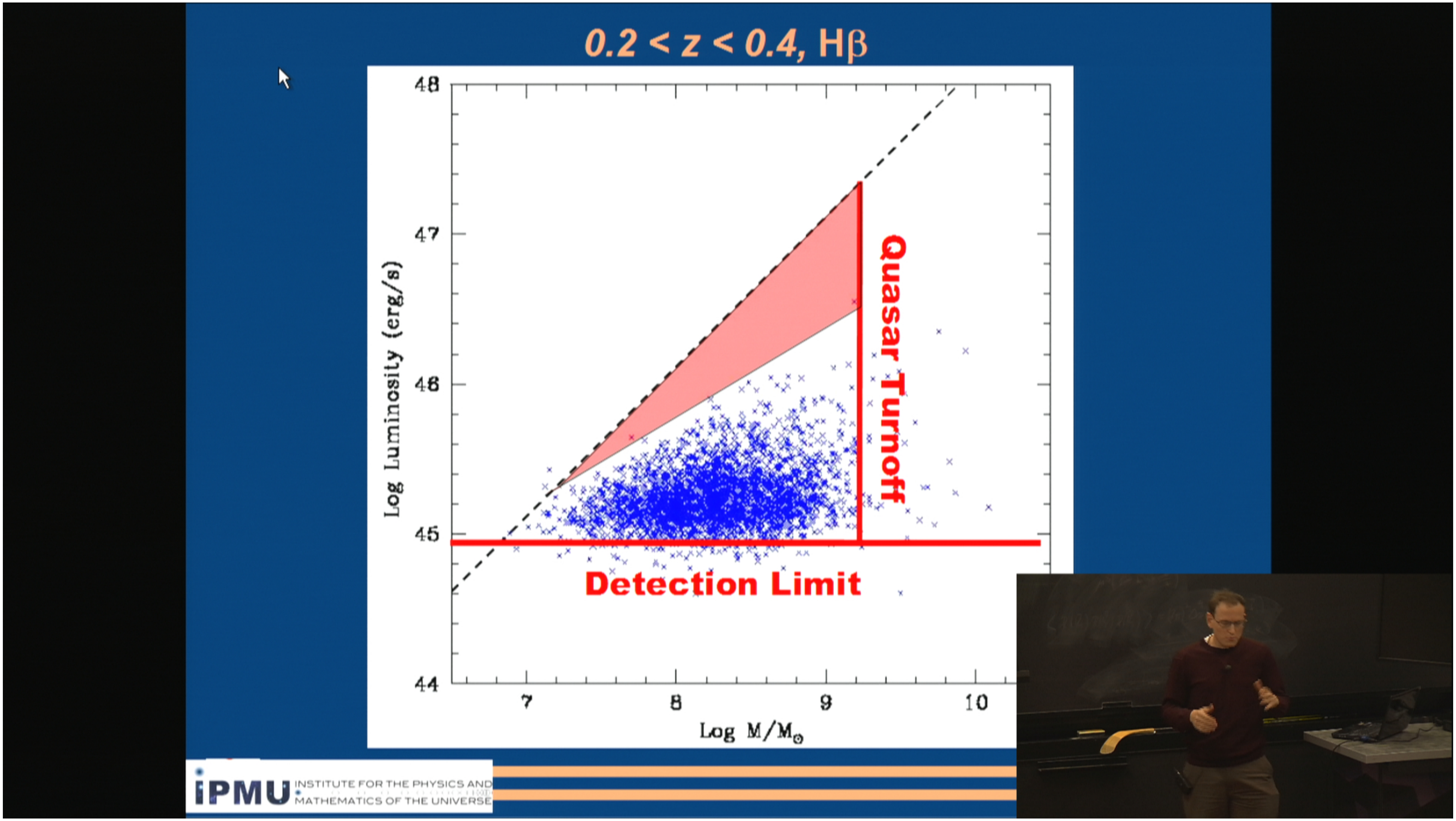

$0.2 < z < 0.4$, Hβ

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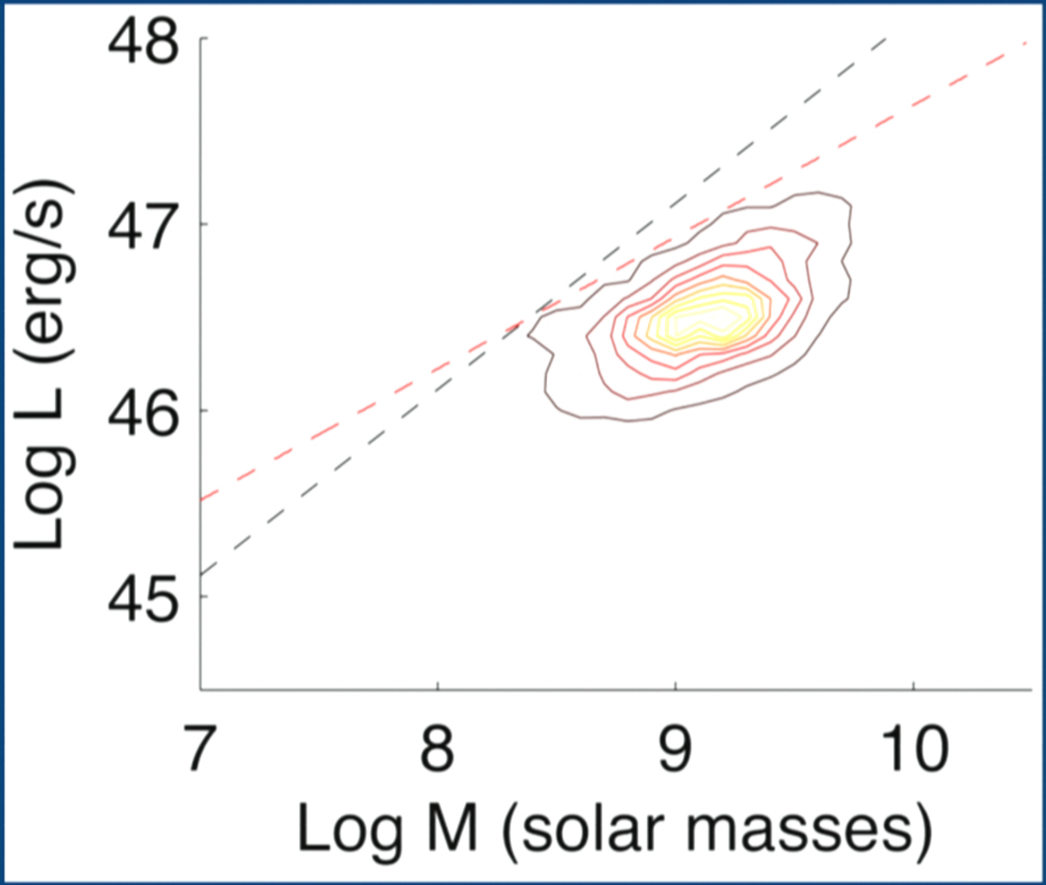
Quasars at $1.6 < z < 1.8$



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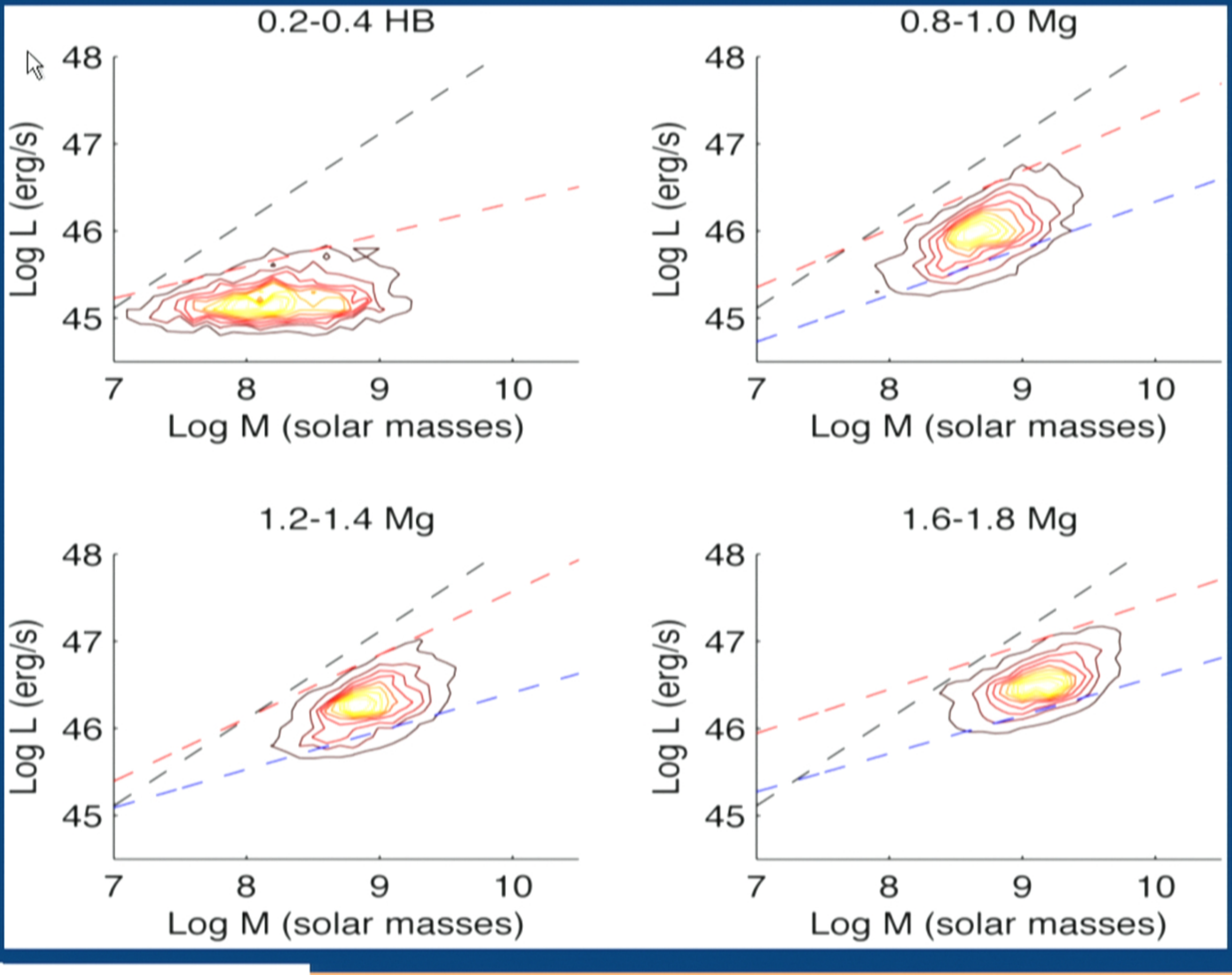

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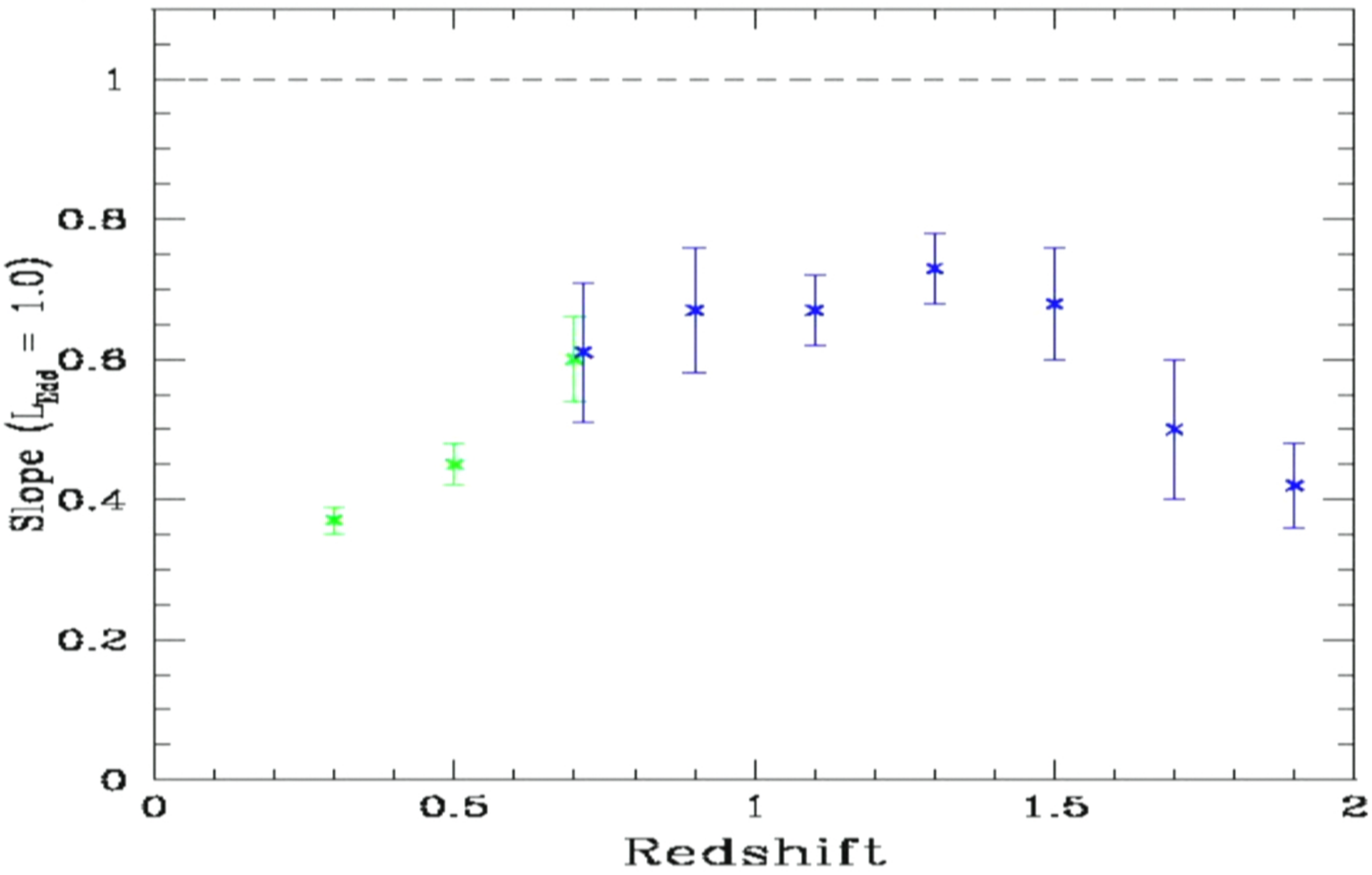
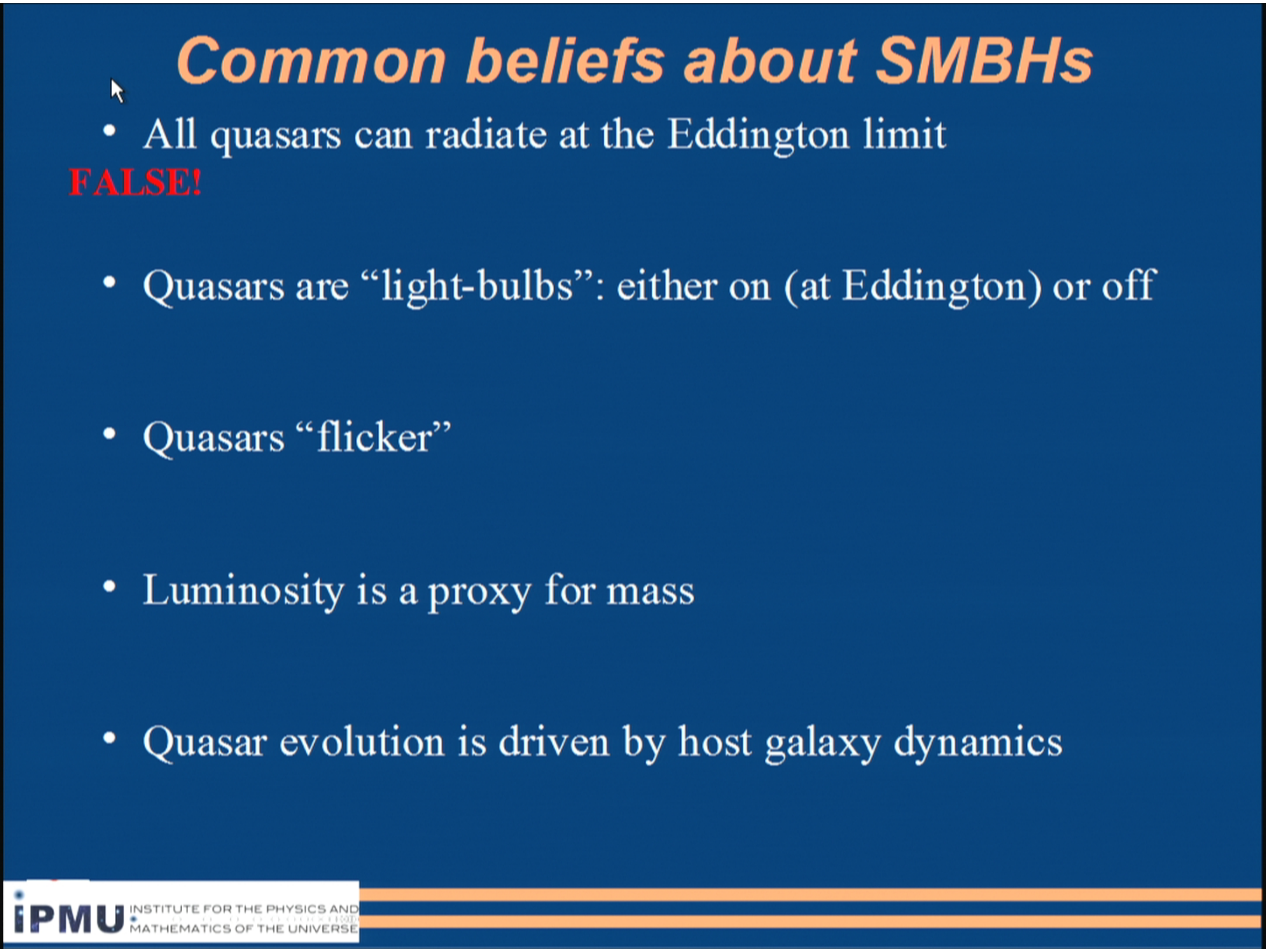
Best-fit sub-Eddington boundary slopes





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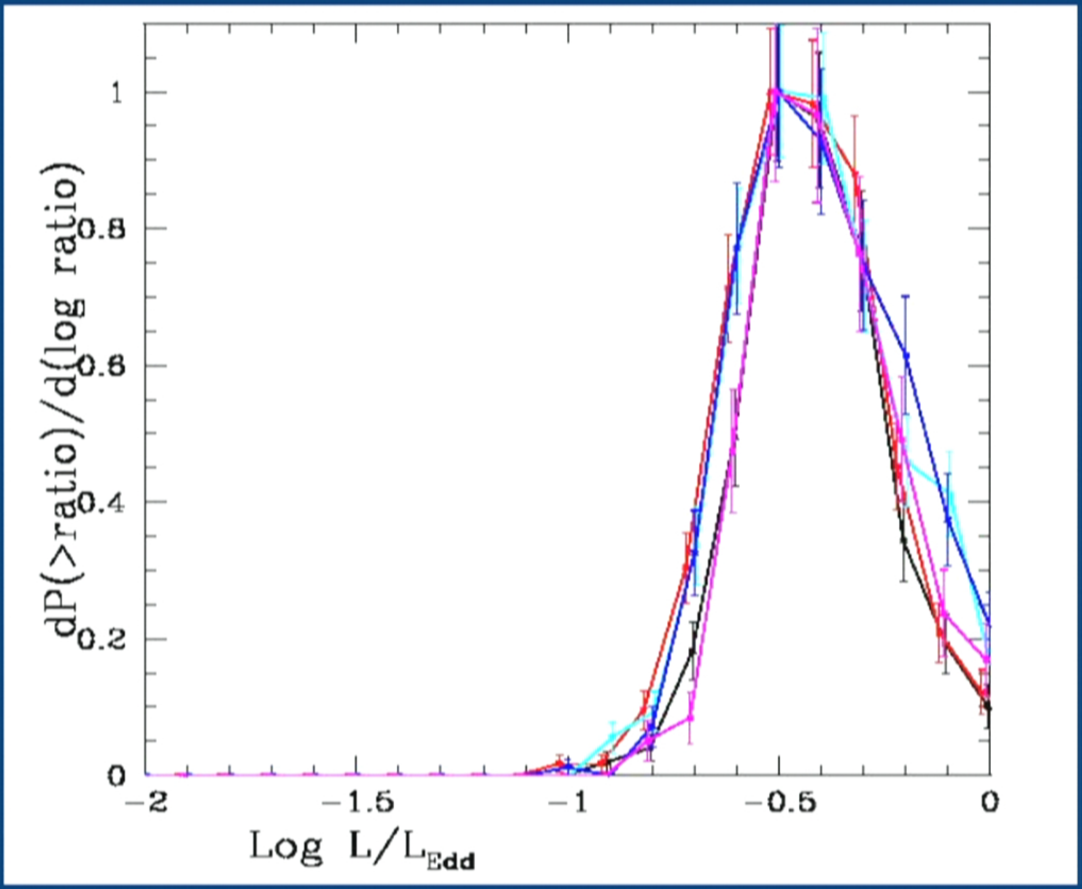
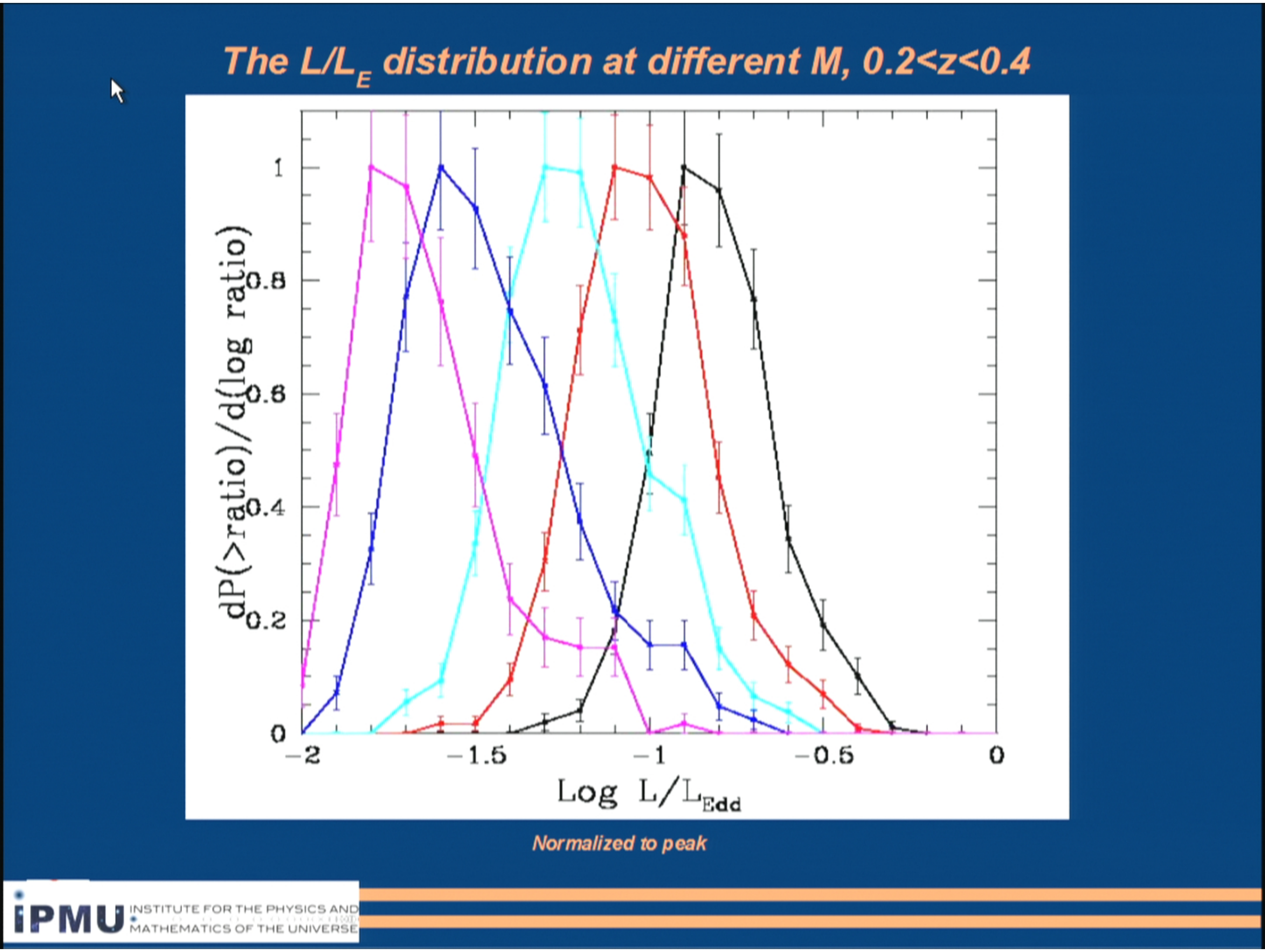
Expected L/L_E distribution at different M, 0.2<z<0.4



Normalized to peak



The L/L$_E$ distribution at different M, 0.2<z<0.4

Normalized to peak

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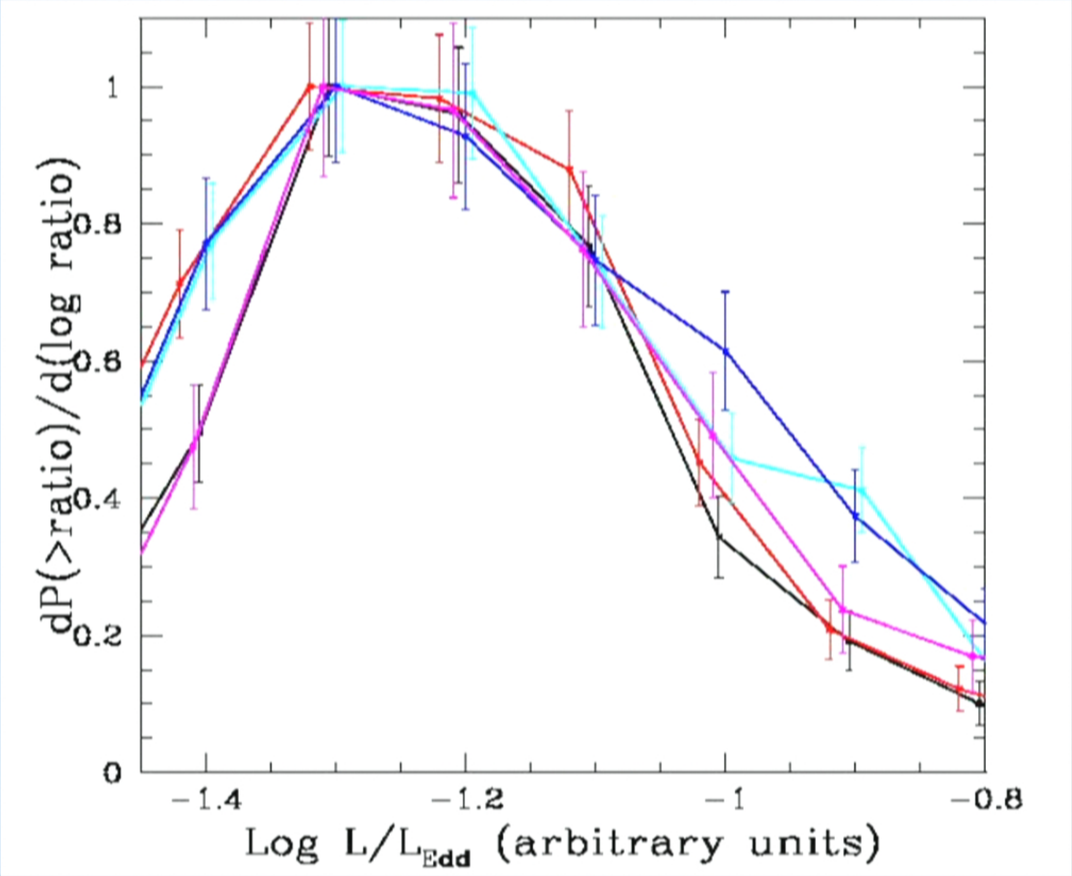
The L/L_E distribution at different M, $0.2<z<0.4$



Normalized to peak

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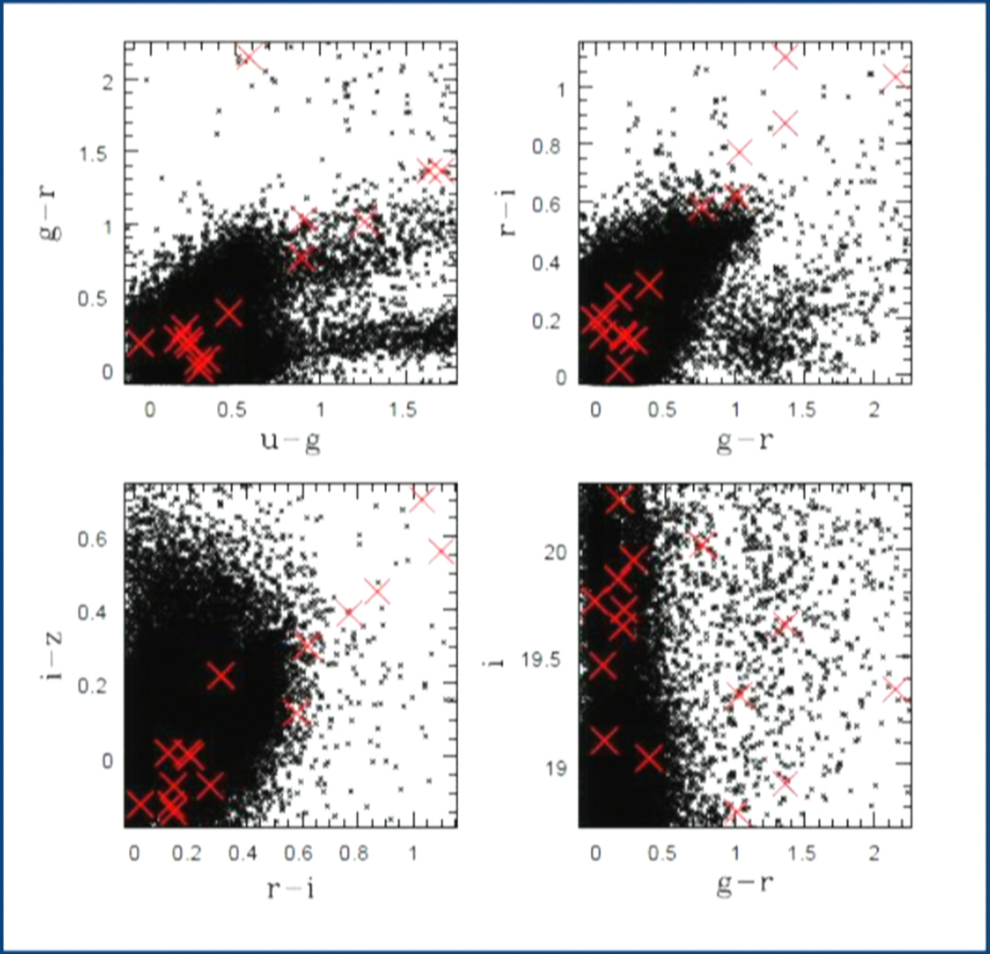
SDSS quasar colors at high mass, low luminosity



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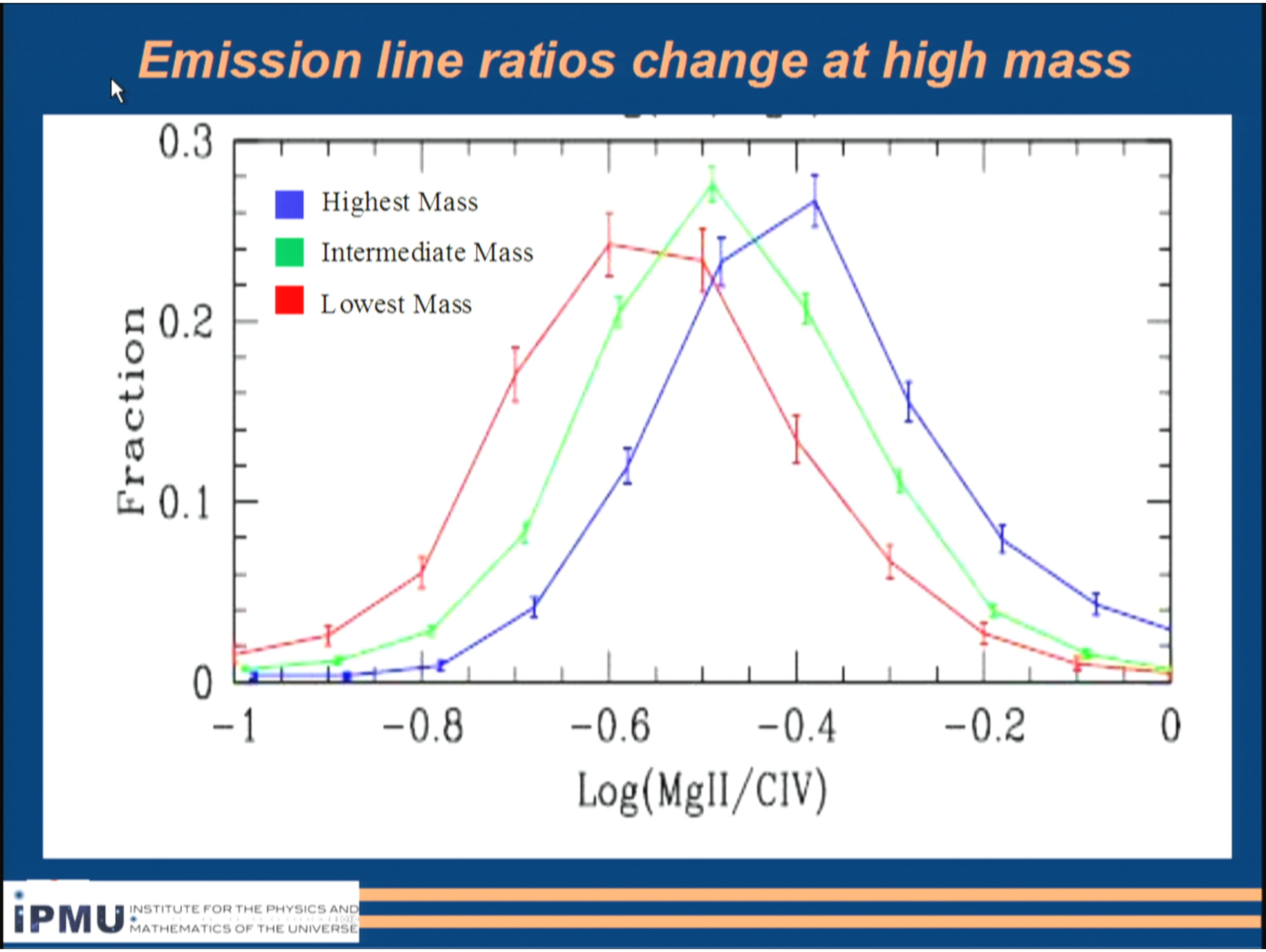
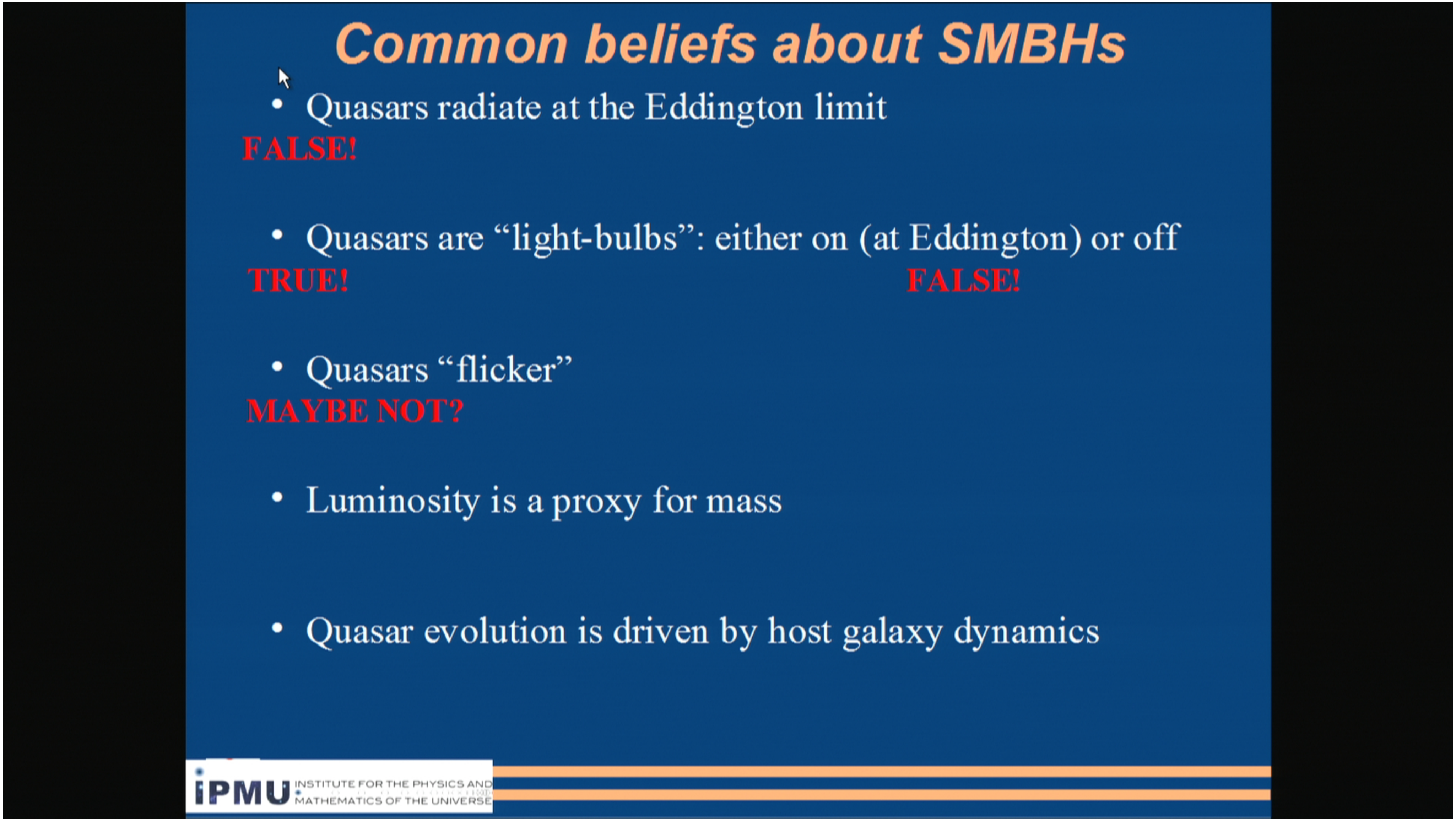


Emission line ratios change at high mass



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MAYBE NOT?

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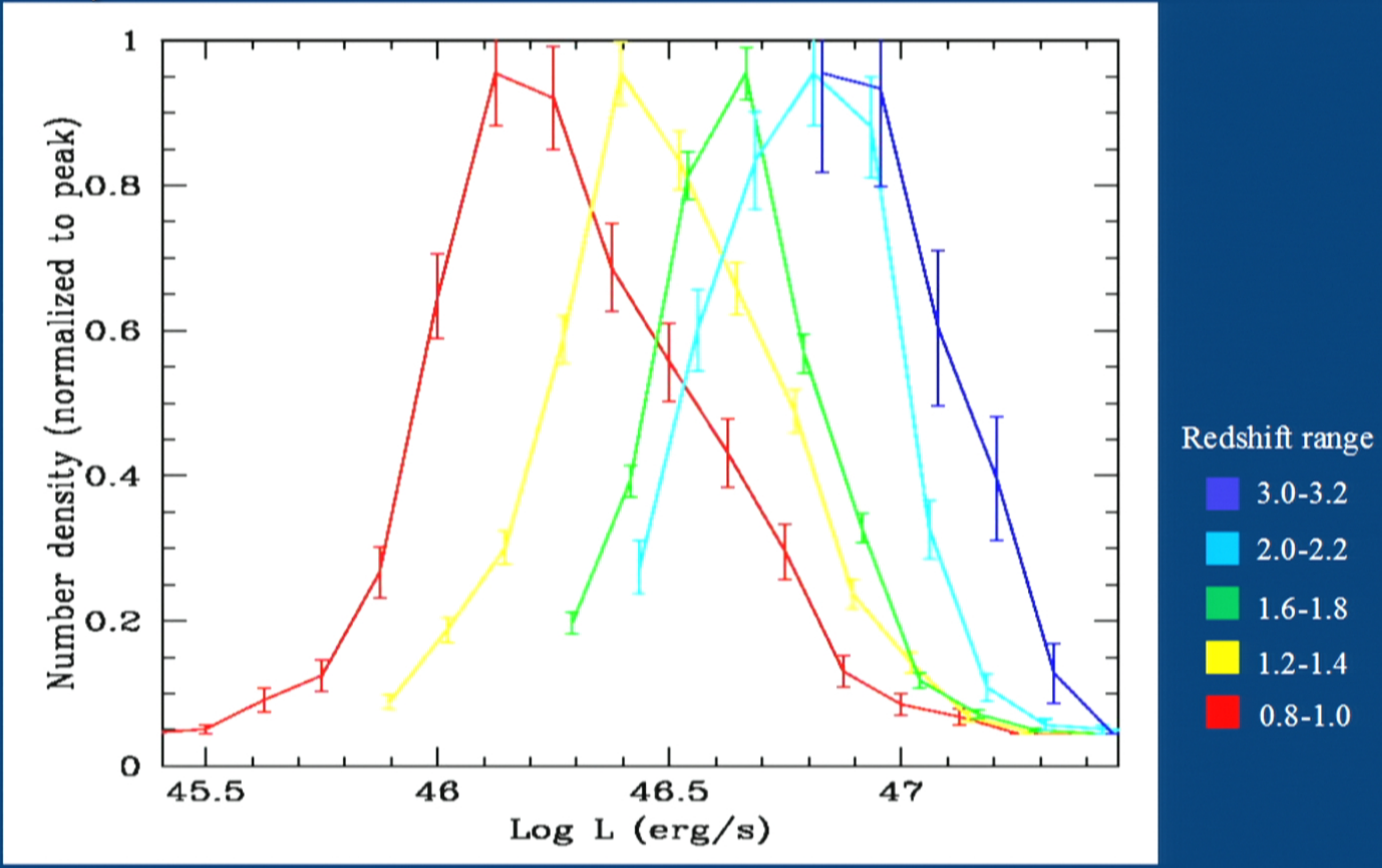
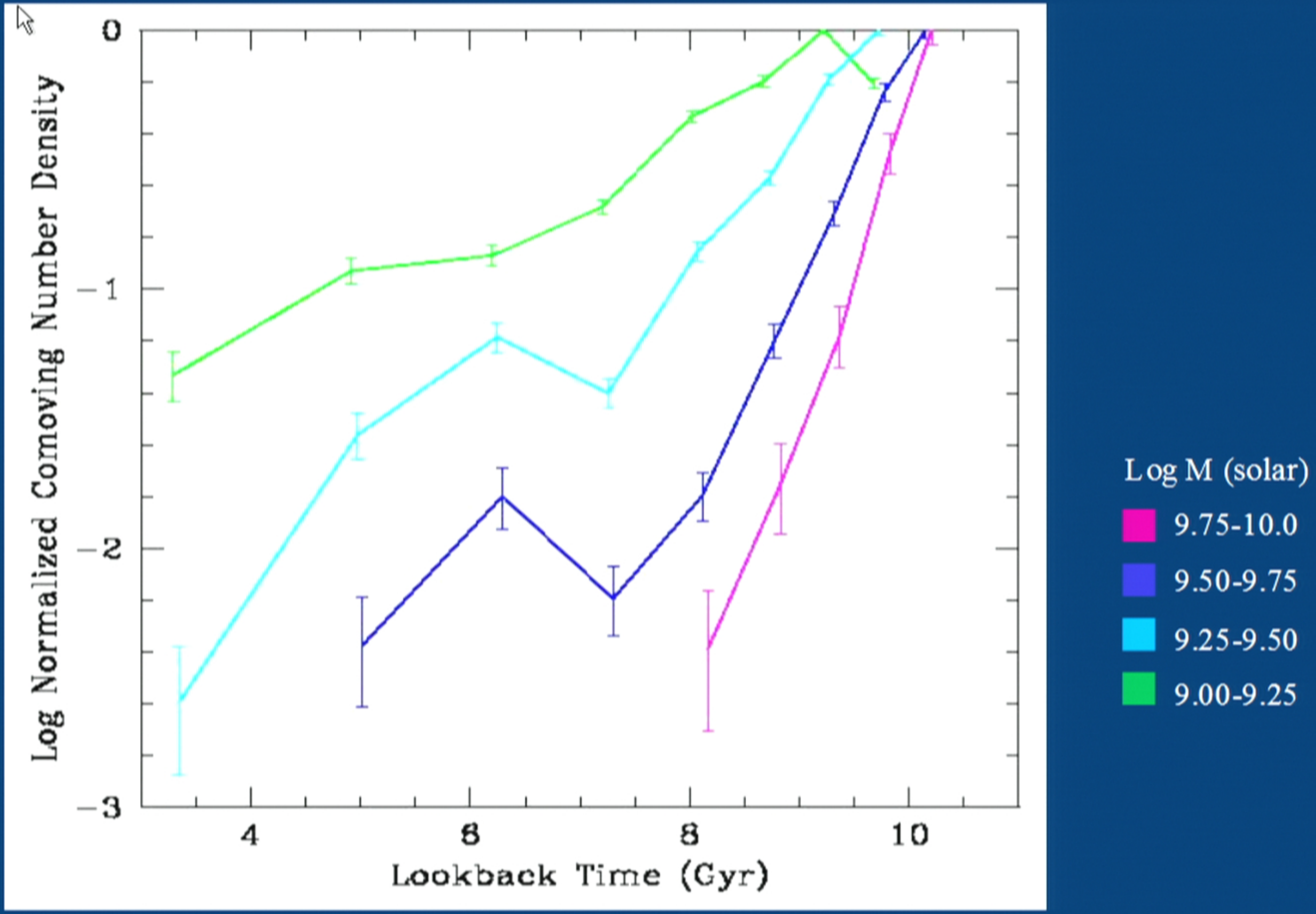
Luminosity at fixed mass, different z



Comoving number density declines at different rates for different masses



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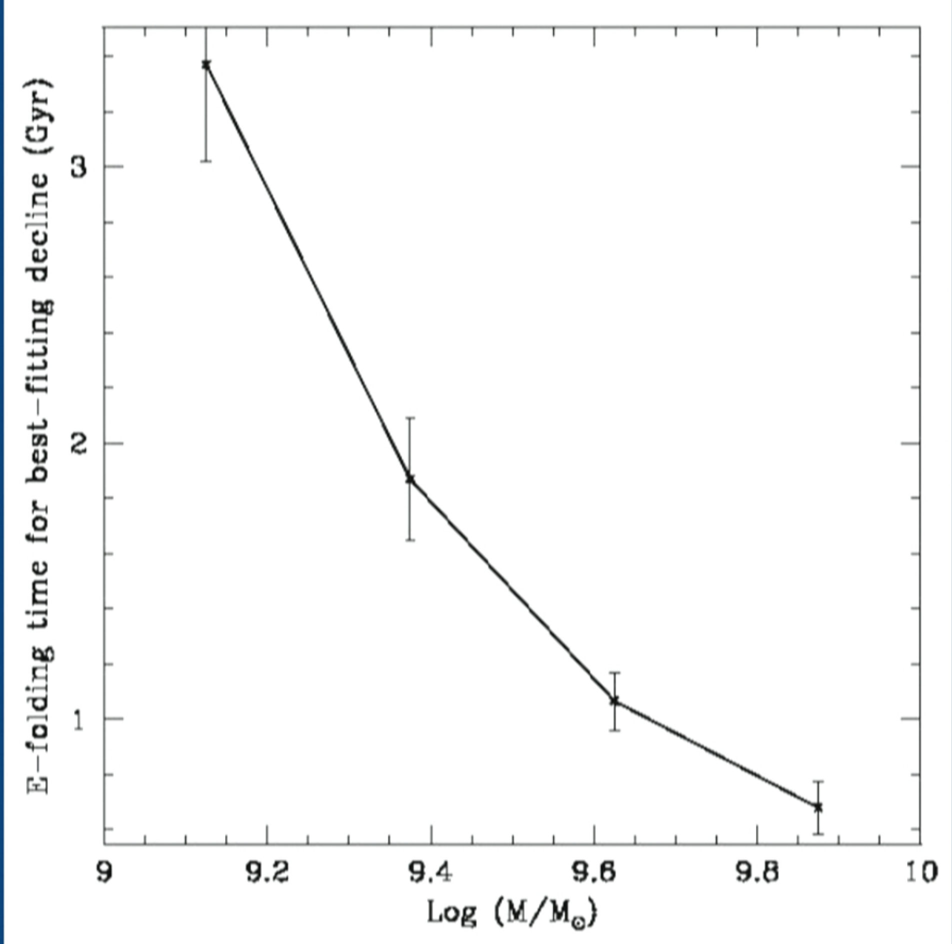
Timescales $\tau(M)$, $N(t) = N_0 e^{-t/\tau(M)}$



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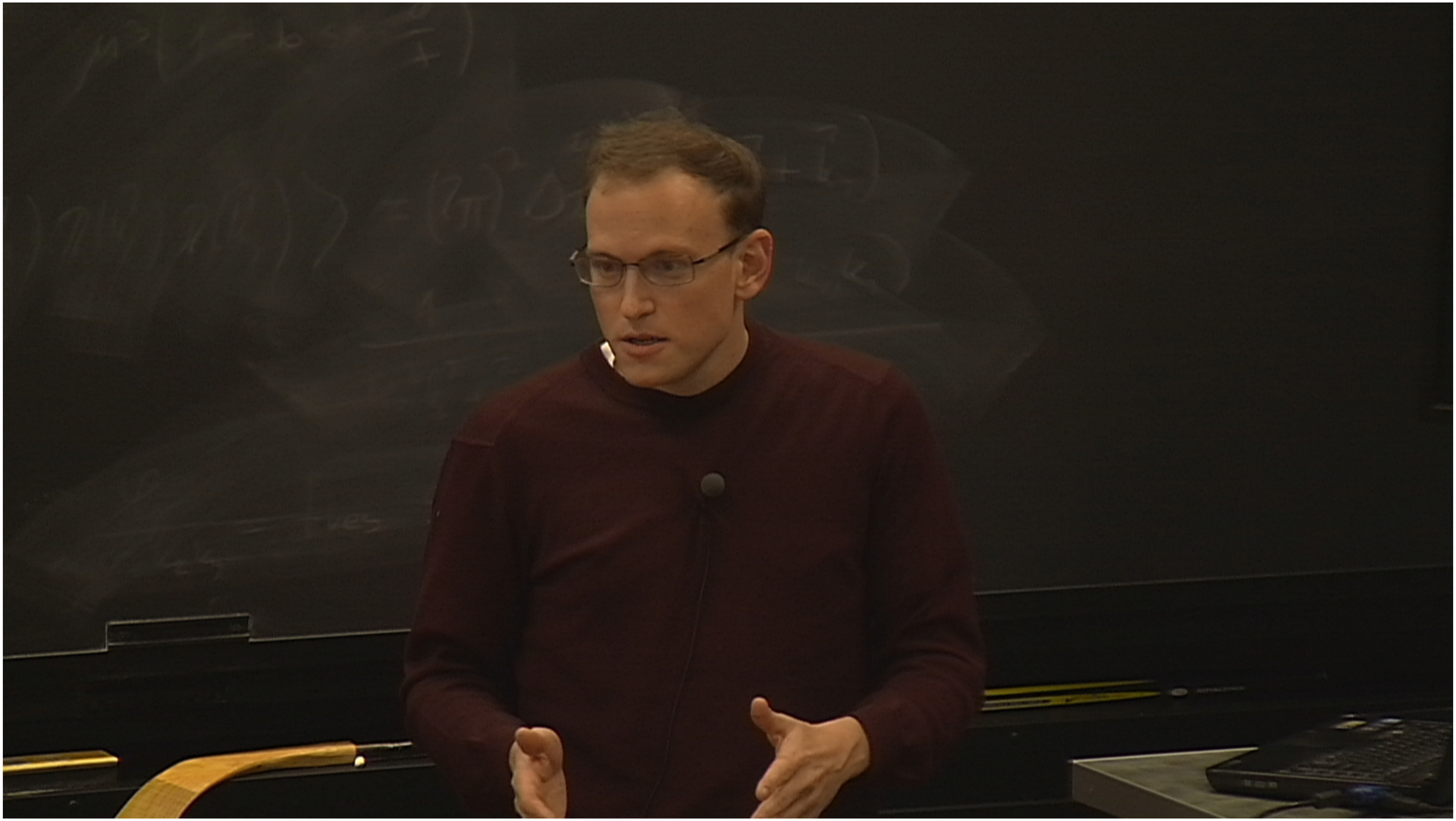

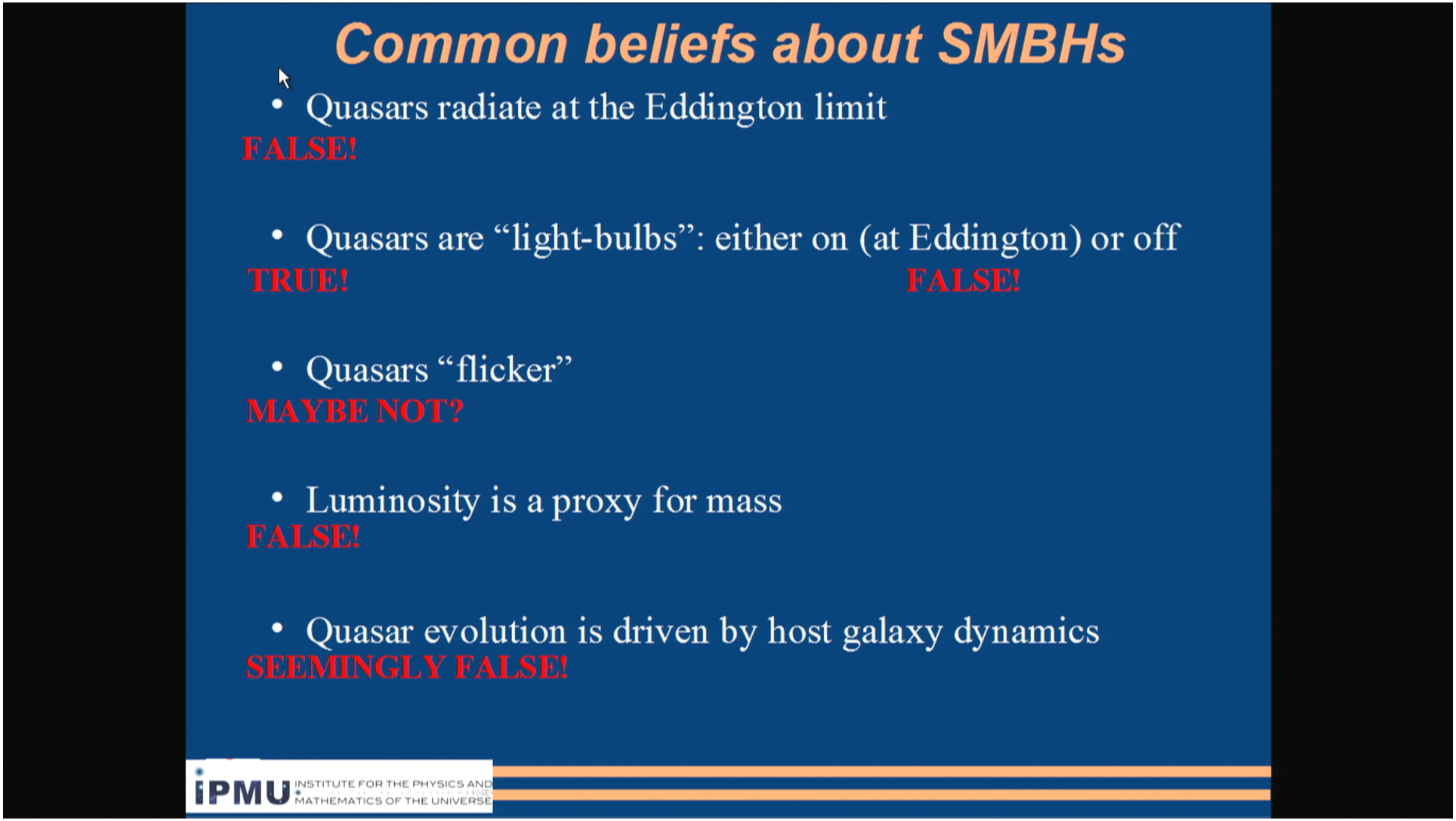

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SEEMINGLY FALSE!

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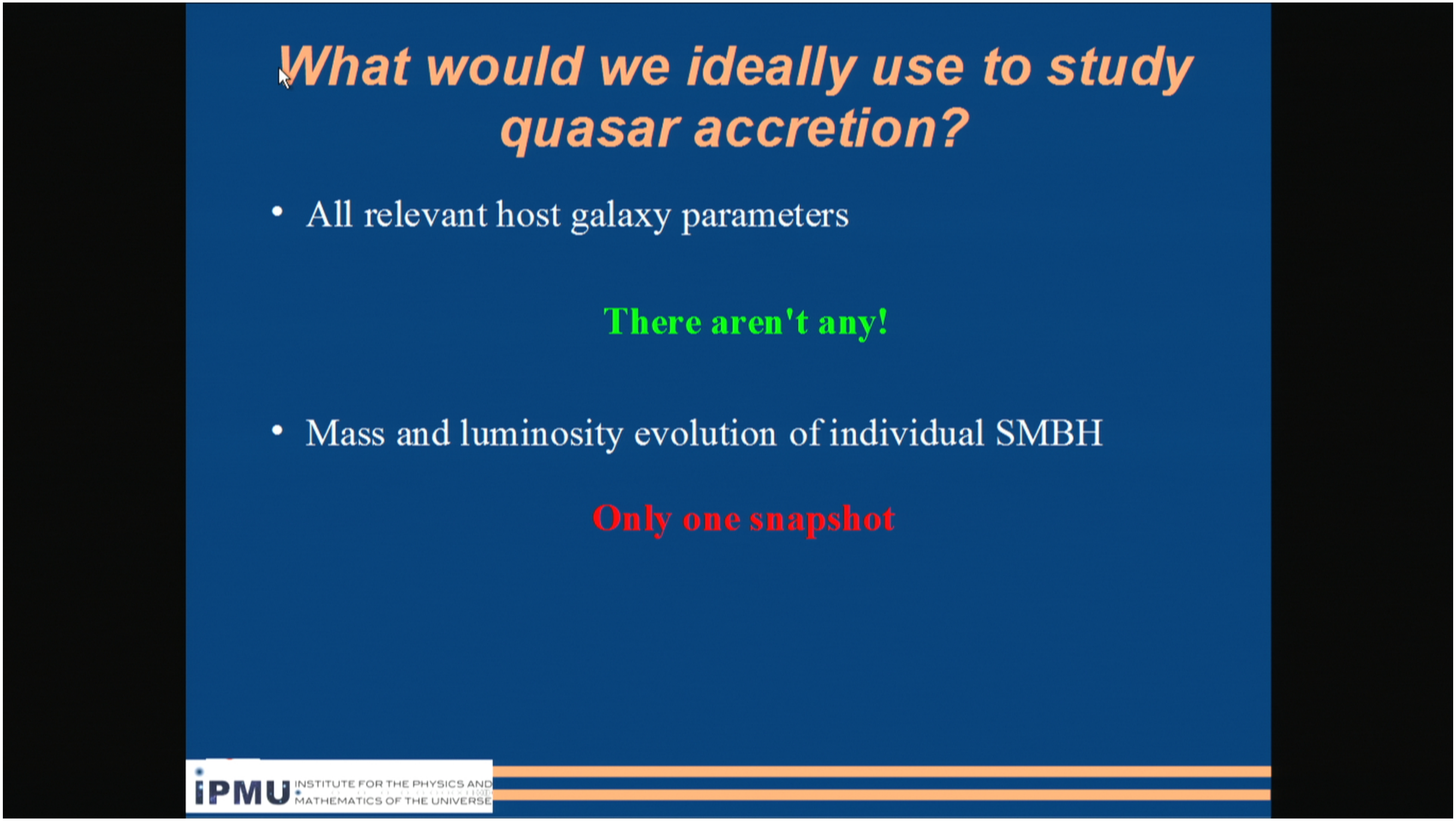

What would we ideally use to study quasar accretion?

- All relevant host galaxy parameters

There aren't any!

- Mass and luminosity evolution of individual SMBH

Only one snapshot

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Quasars ARE like light bulbs!

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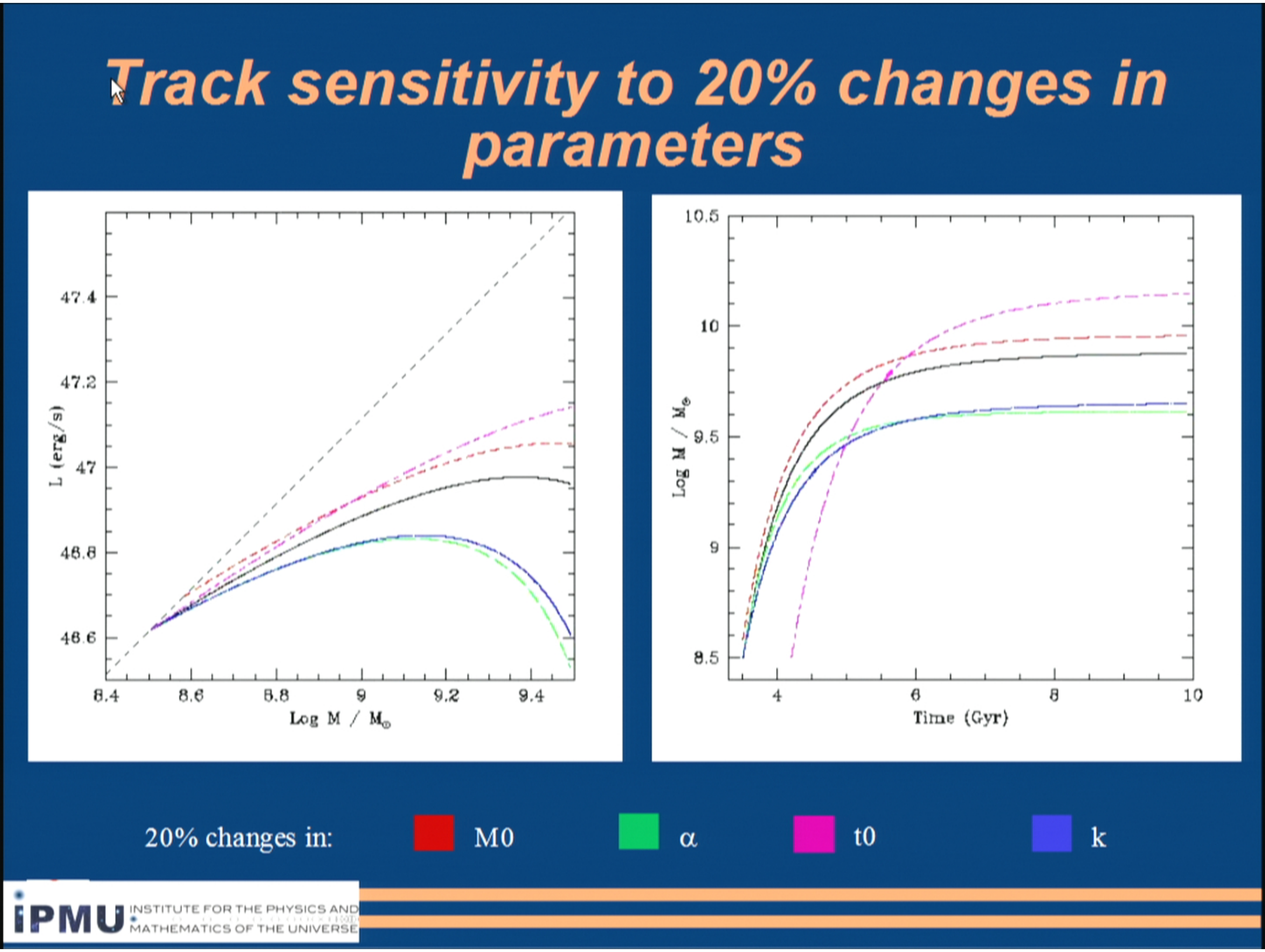
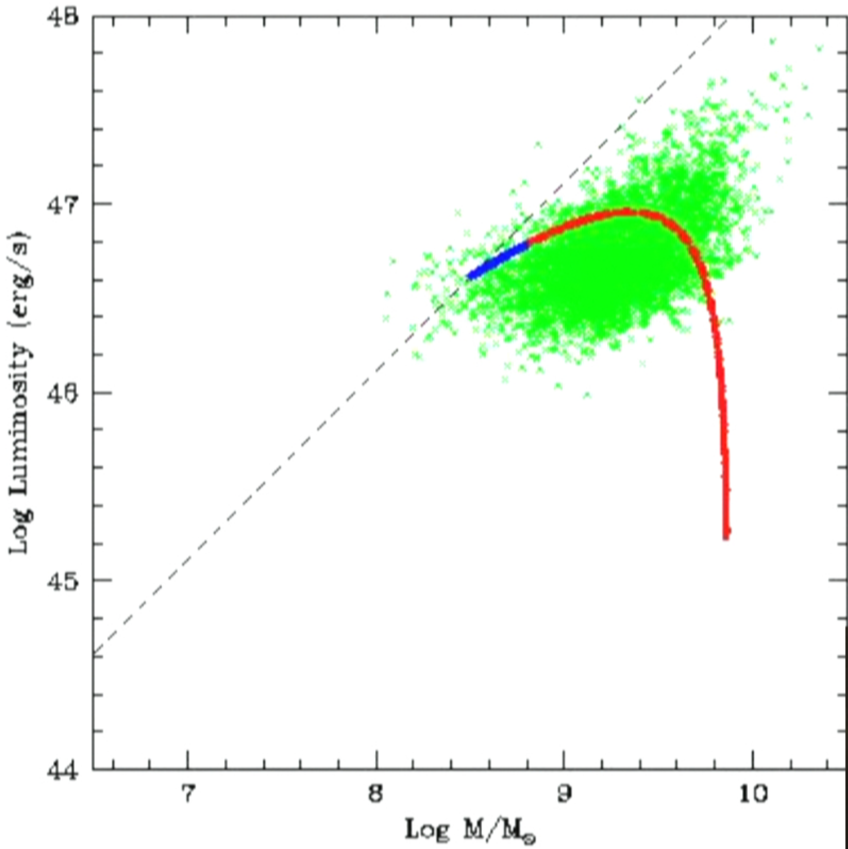
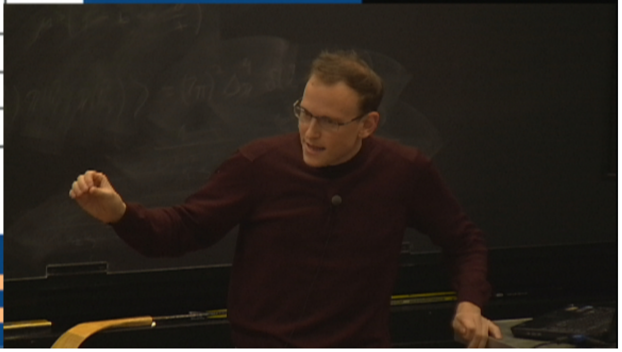


Track sensitivity to 20% changes in parameters

20% changes in: 🟥 M0 🟩 α 🟪 t0 🟦 k

Sample Track: 1.8 < z < 2.0





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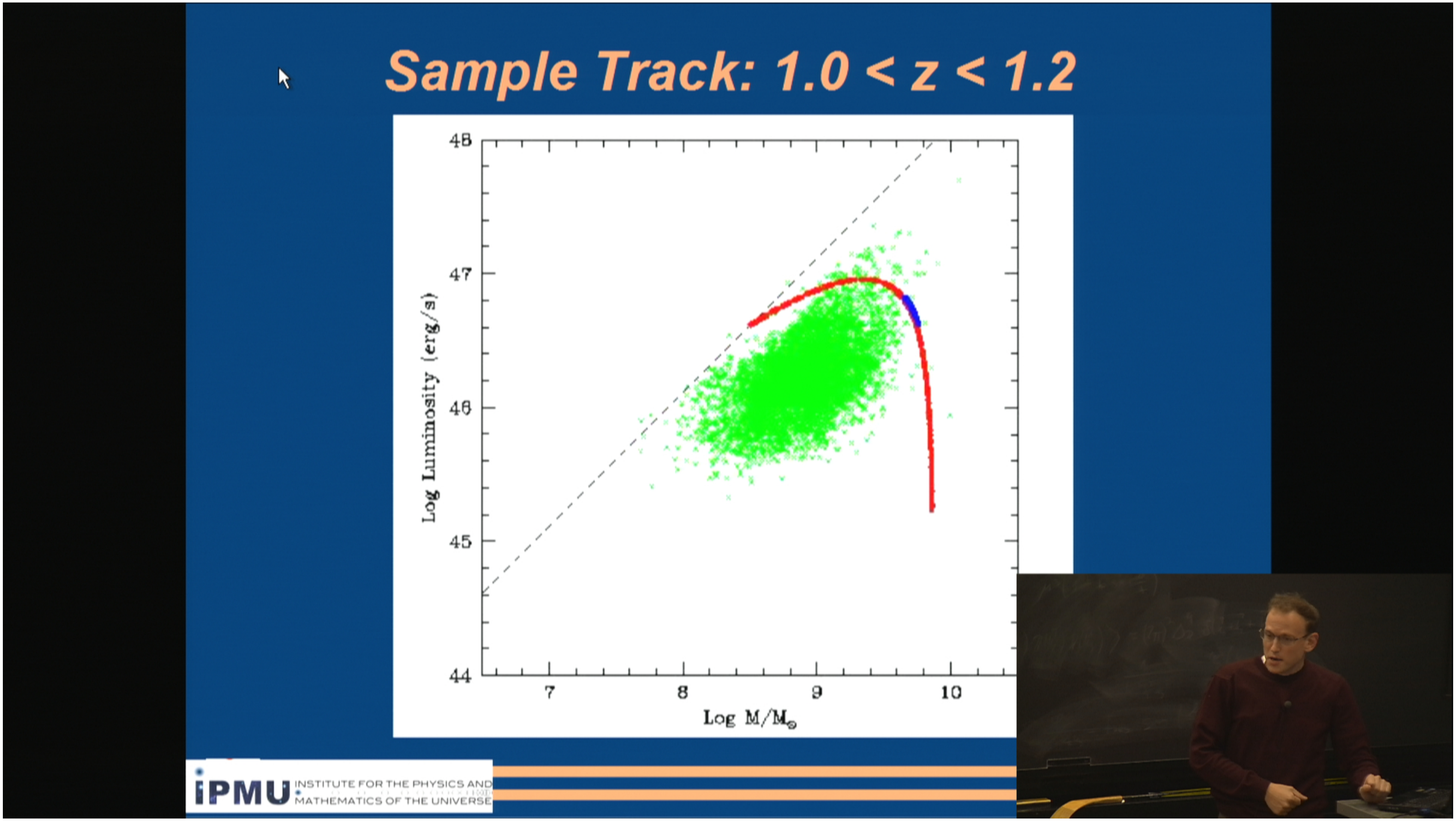

Sample Track: 1.0 < z < 1.2

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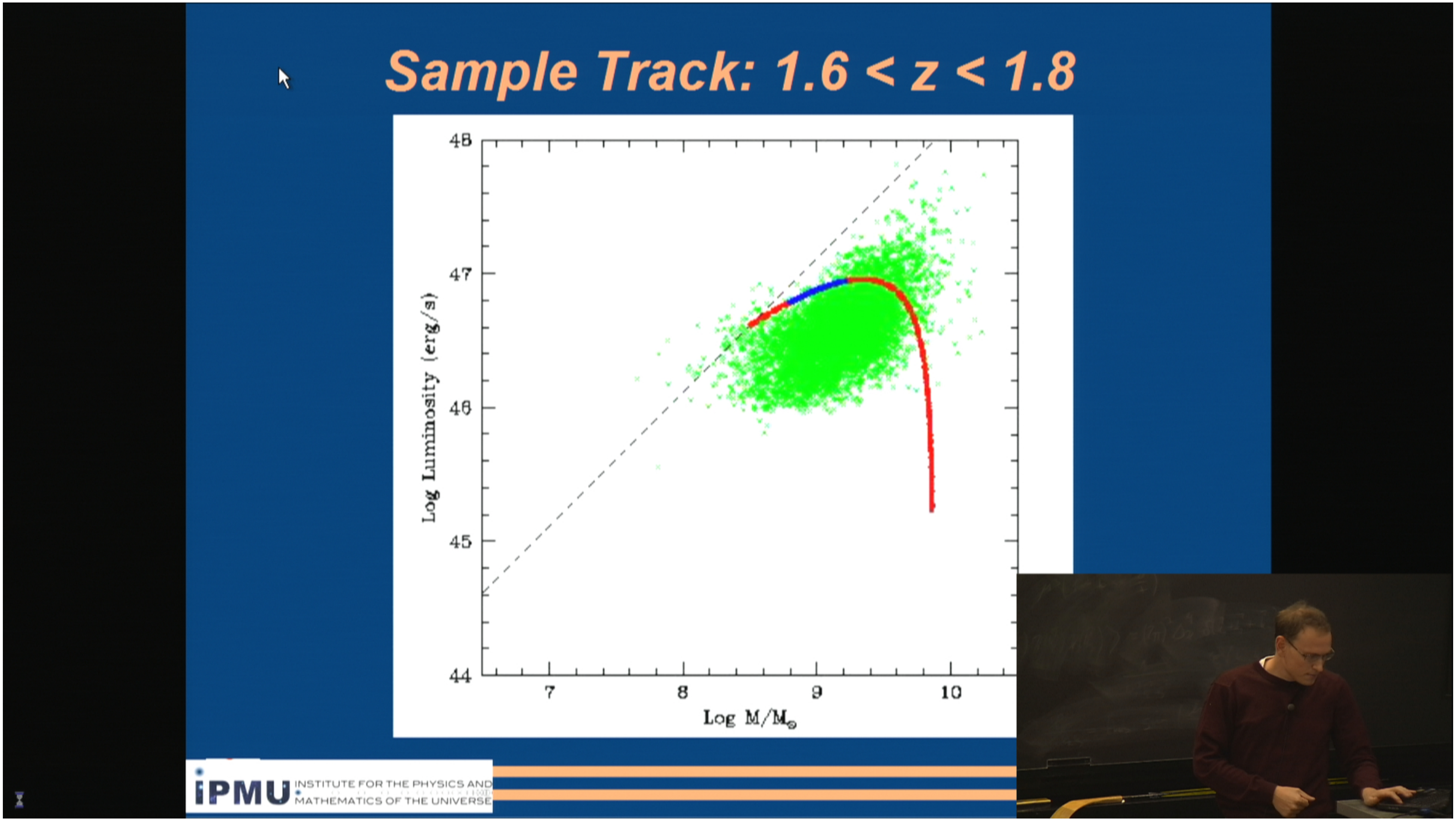
Sample Track: 1.6 < z < 1.8



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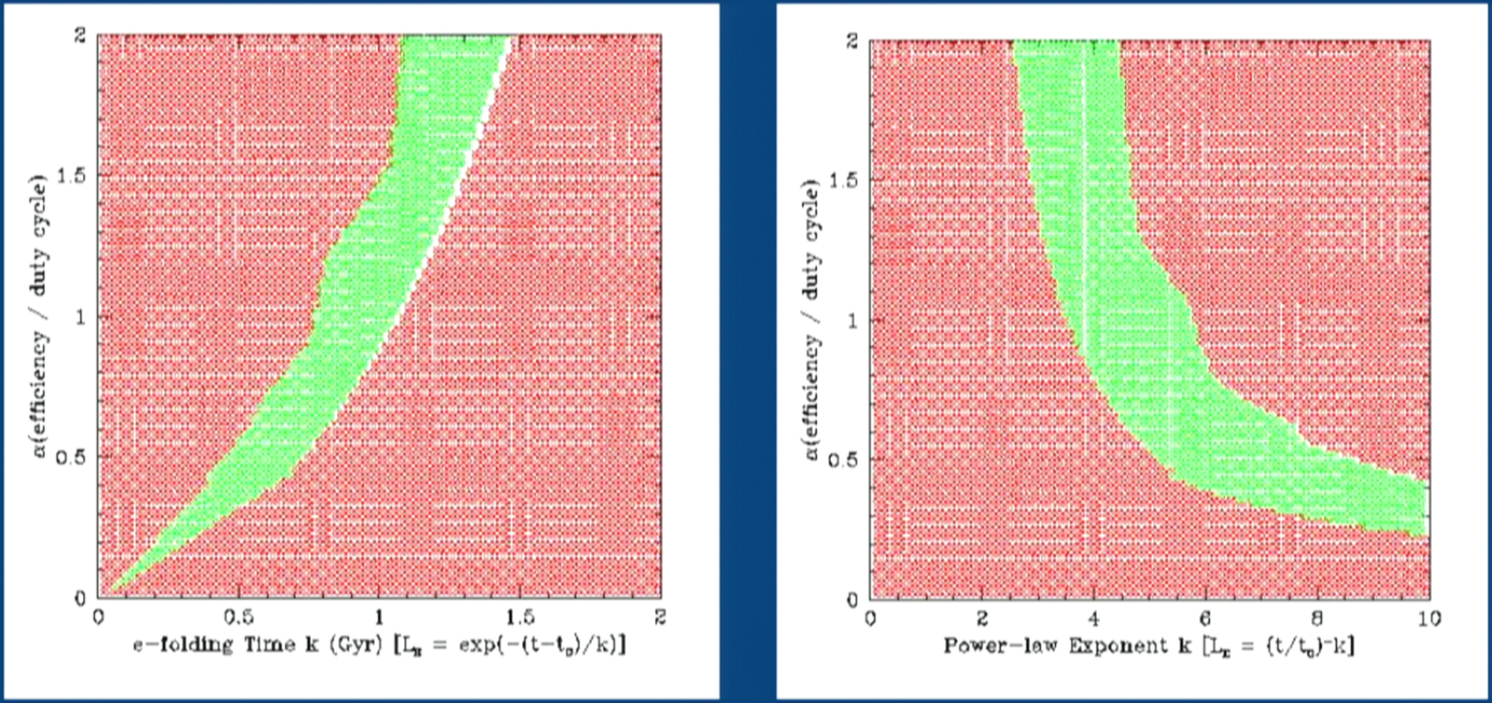
Allowed track parameters at M0=8.5, t0=3.5 Gyr



Quasars are typically on for just 1-2 Gyr!

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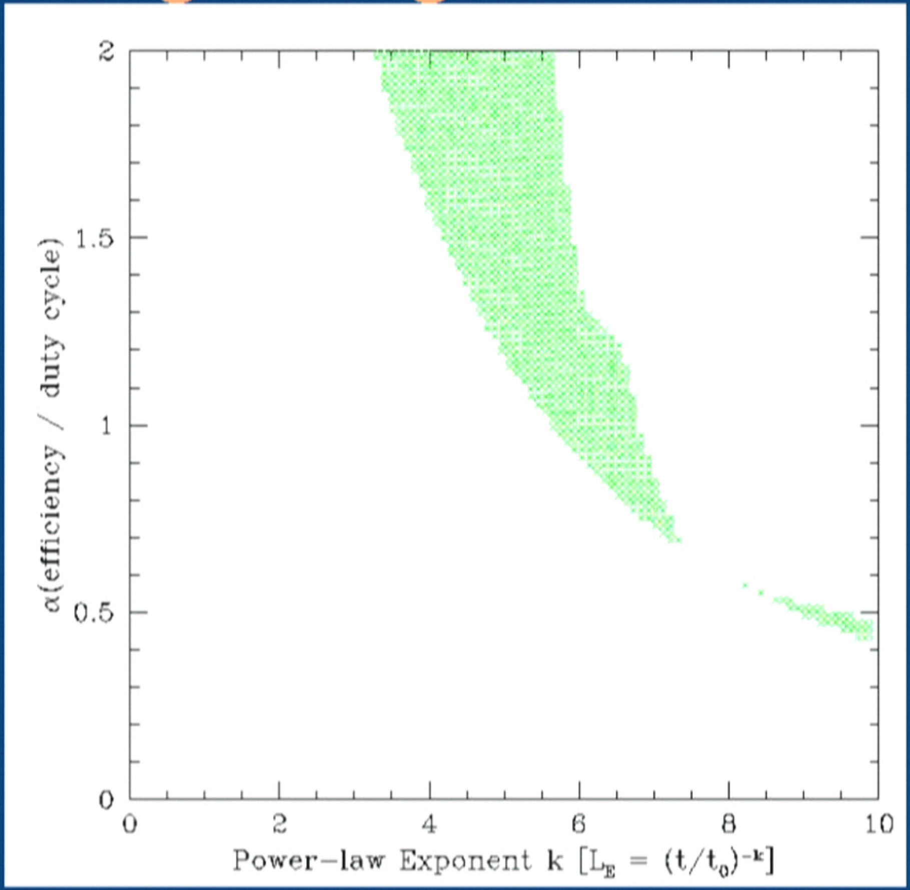
Allowed parameters for tracks originating at all times



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The supermassive black hole lifecycle: new, open questions

Seeding

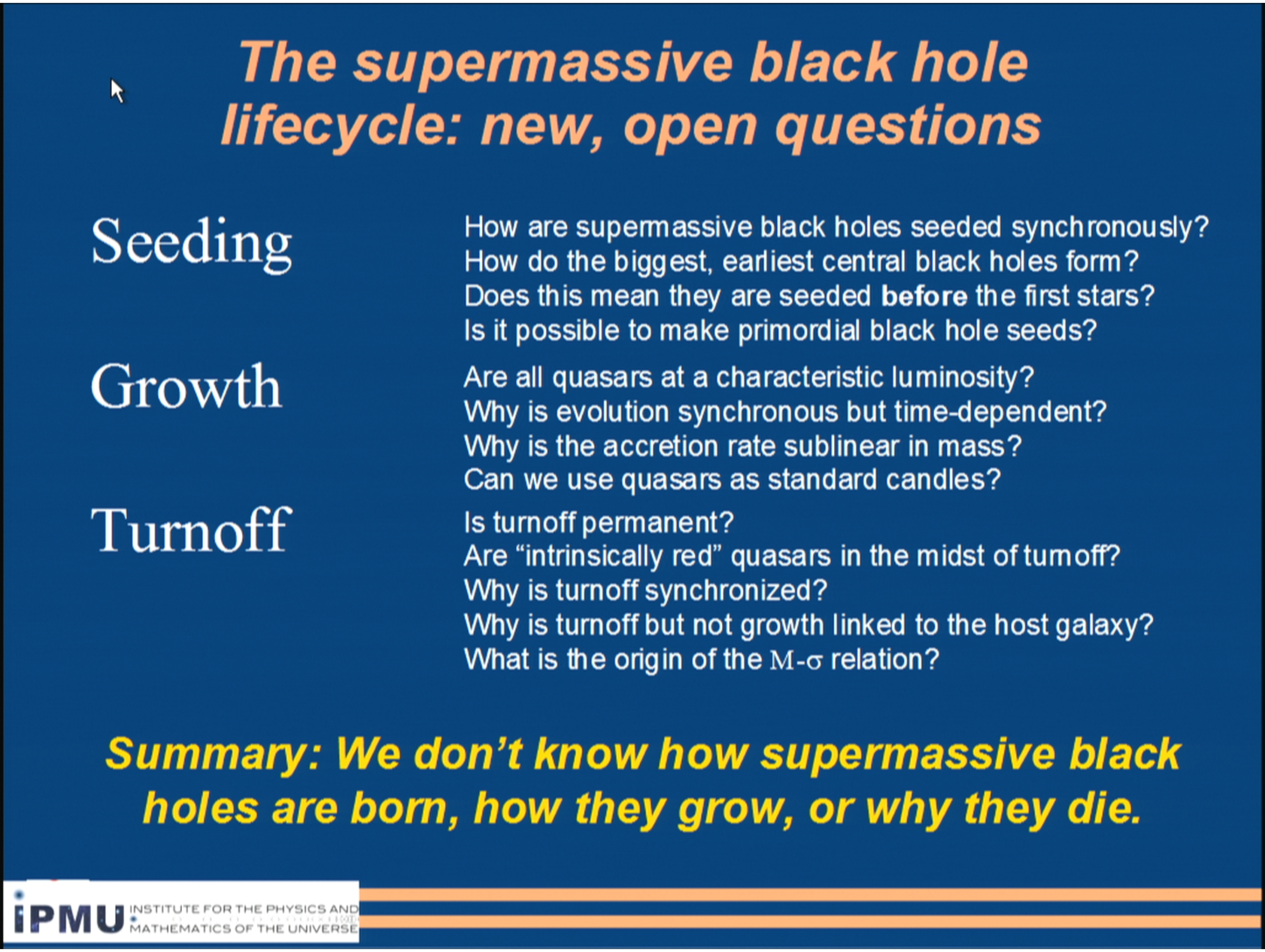
How are supermassive black holes seeded synchronously?
How do the biggest, earliest central black holes form?
Does this mean they are seeded **before** the first stars?
Is it possible to make primordial black hole seeds?

Growth

Are all quasars at a characteristic luminosity?
Why is evolution synchronous but time-dependent?
Why is the accretion rate sublinear in mass?
Can we use quasars as standard candles?

Turnoff

Is turnoff permanent?
Are "intrinsically red" quasars in the midst of turnoff?
Why is turnoff synchronized?
Why is turnoff but not growth linked to the host galaxy?
What is the origin of the M-σ relation?



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Summary: We don't know how supermassive black holes are born, how they grow, or why they die.

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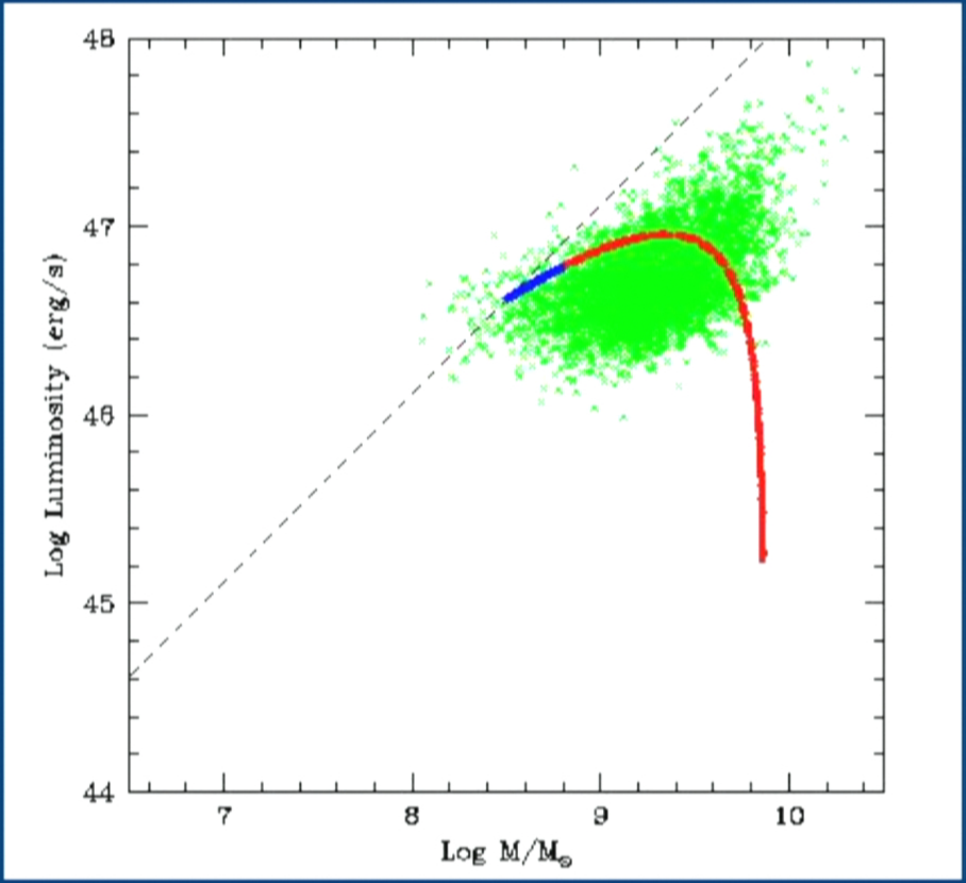
Sample Track: 1.8 < z < 2.0



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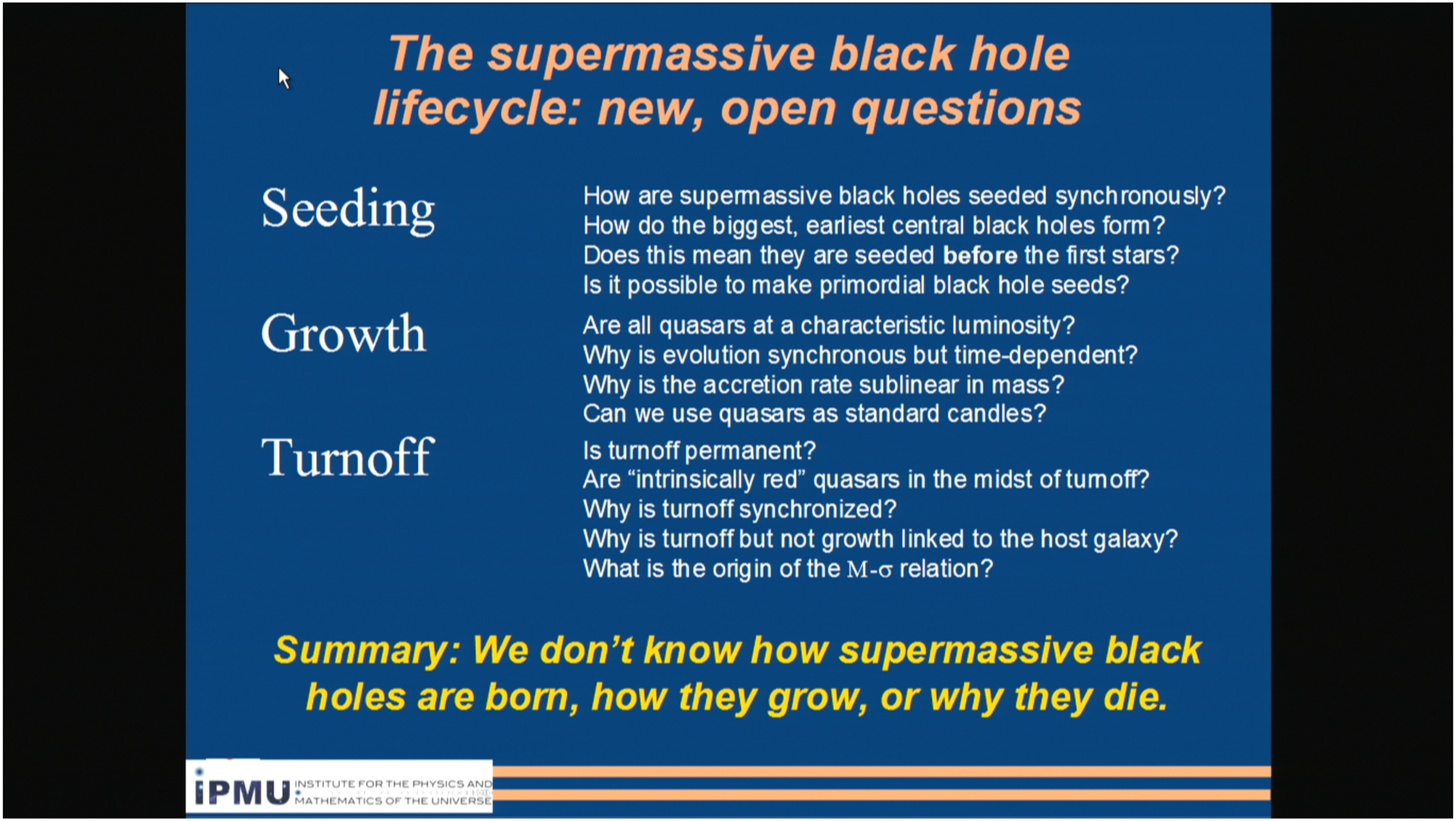

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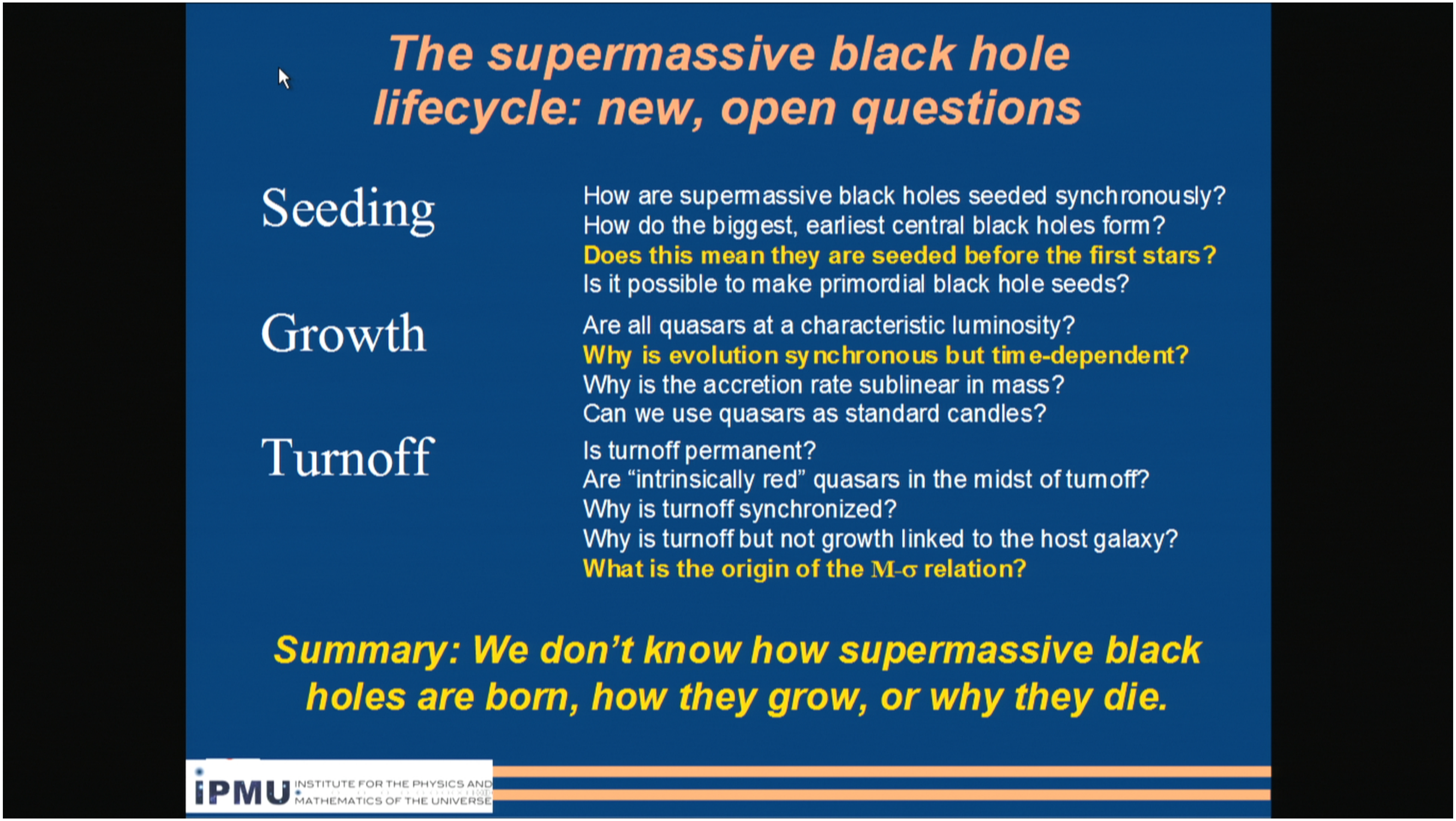

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Summary: Something exciting is about to happen!

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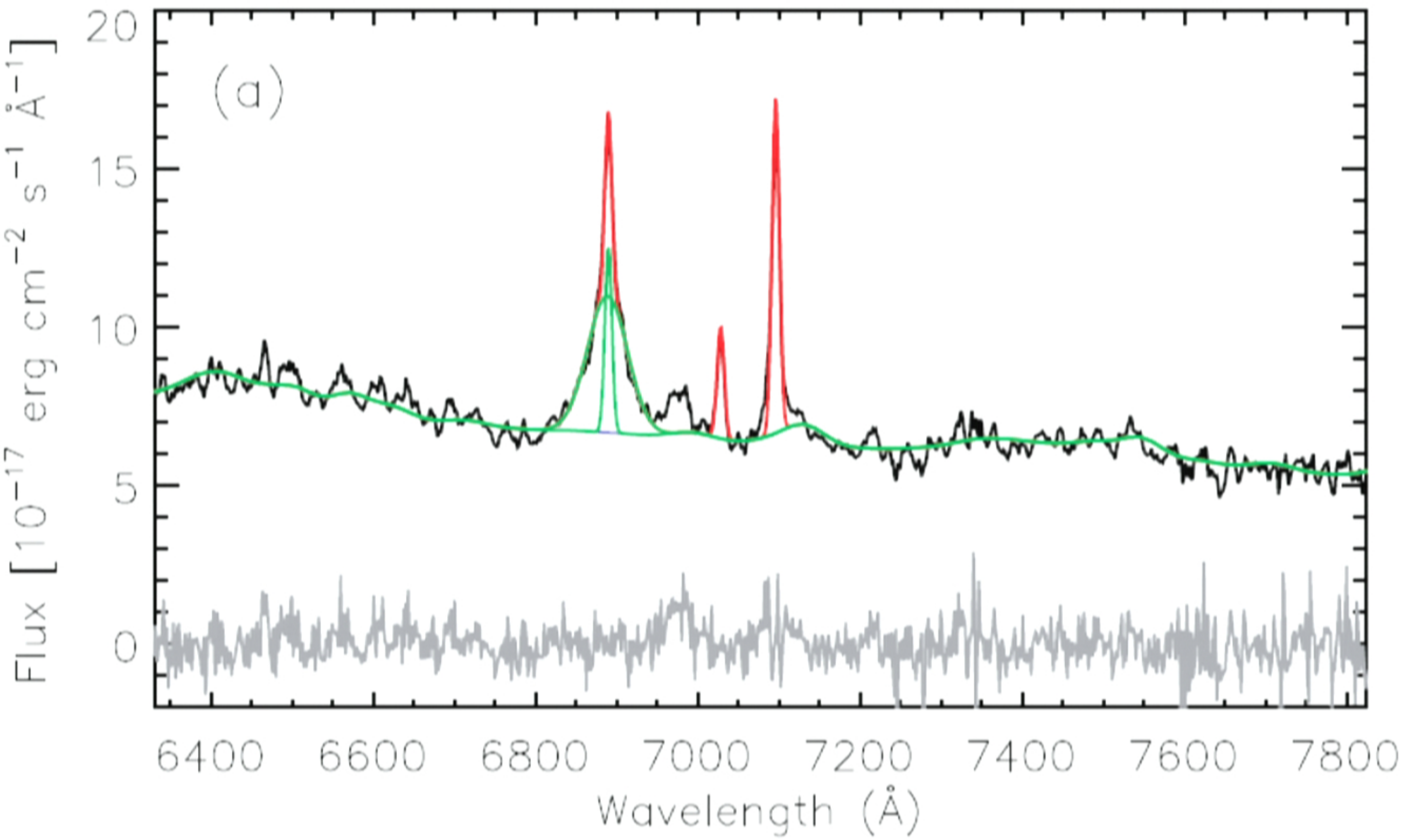
Typical QSO: HB + OIII



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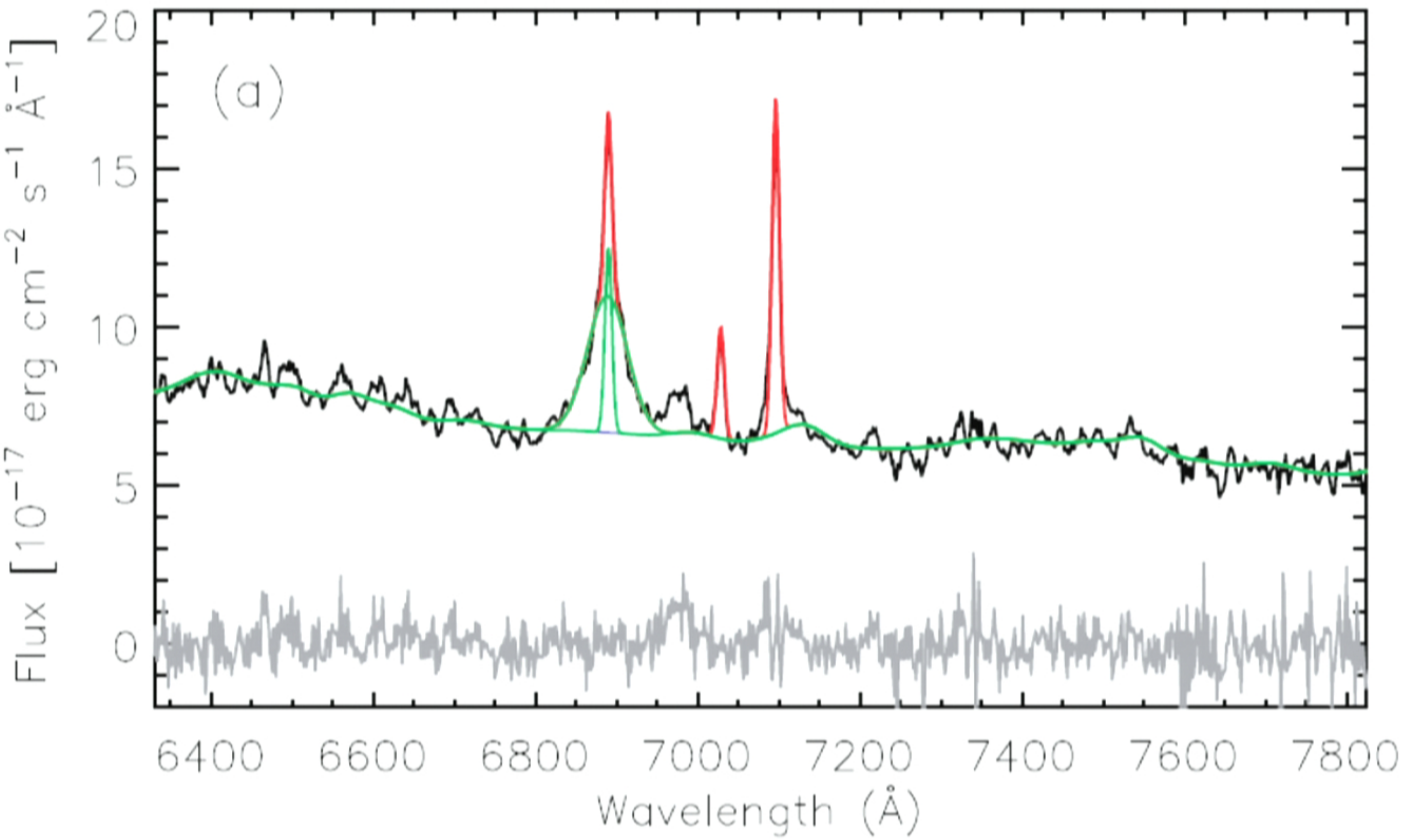
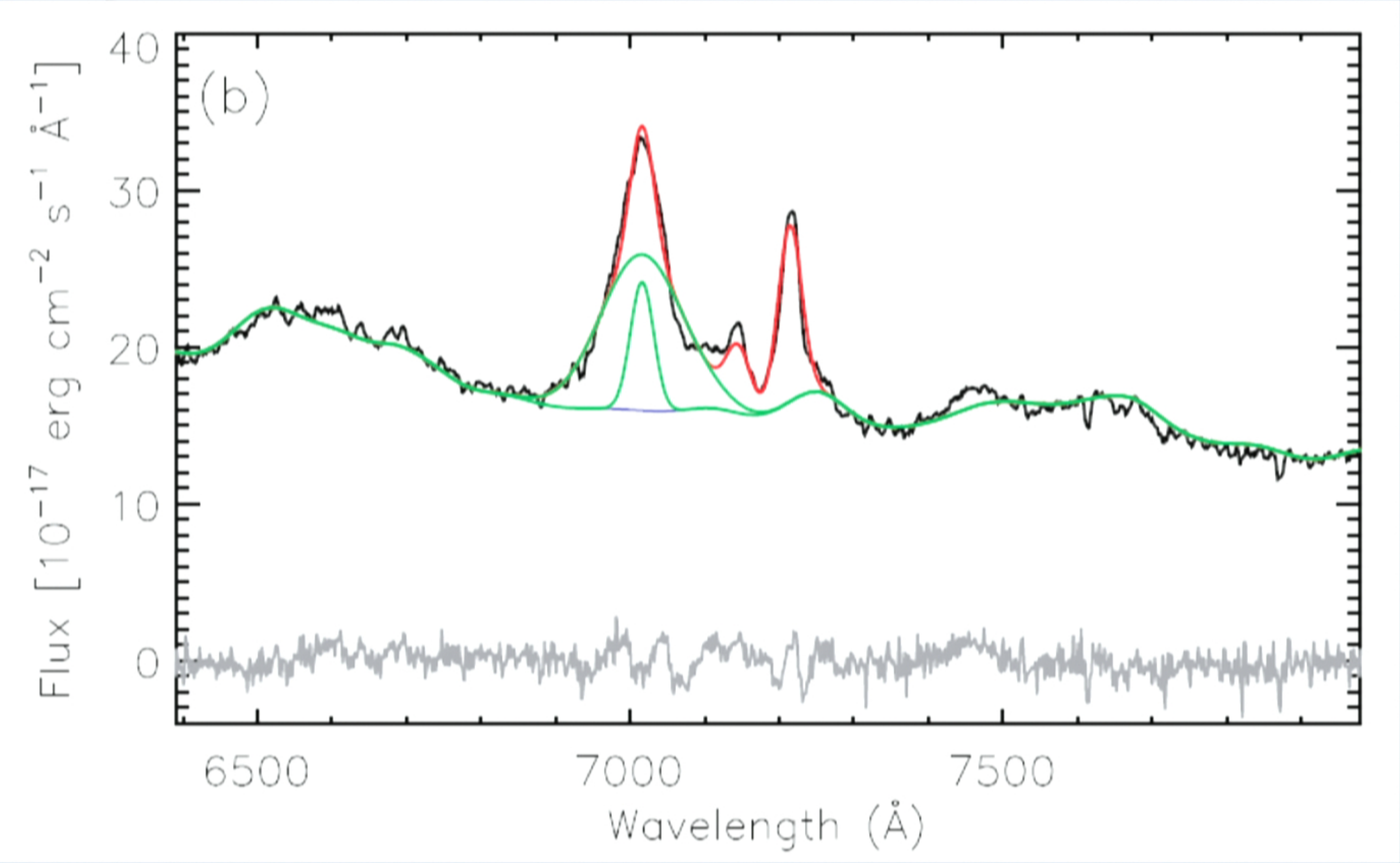
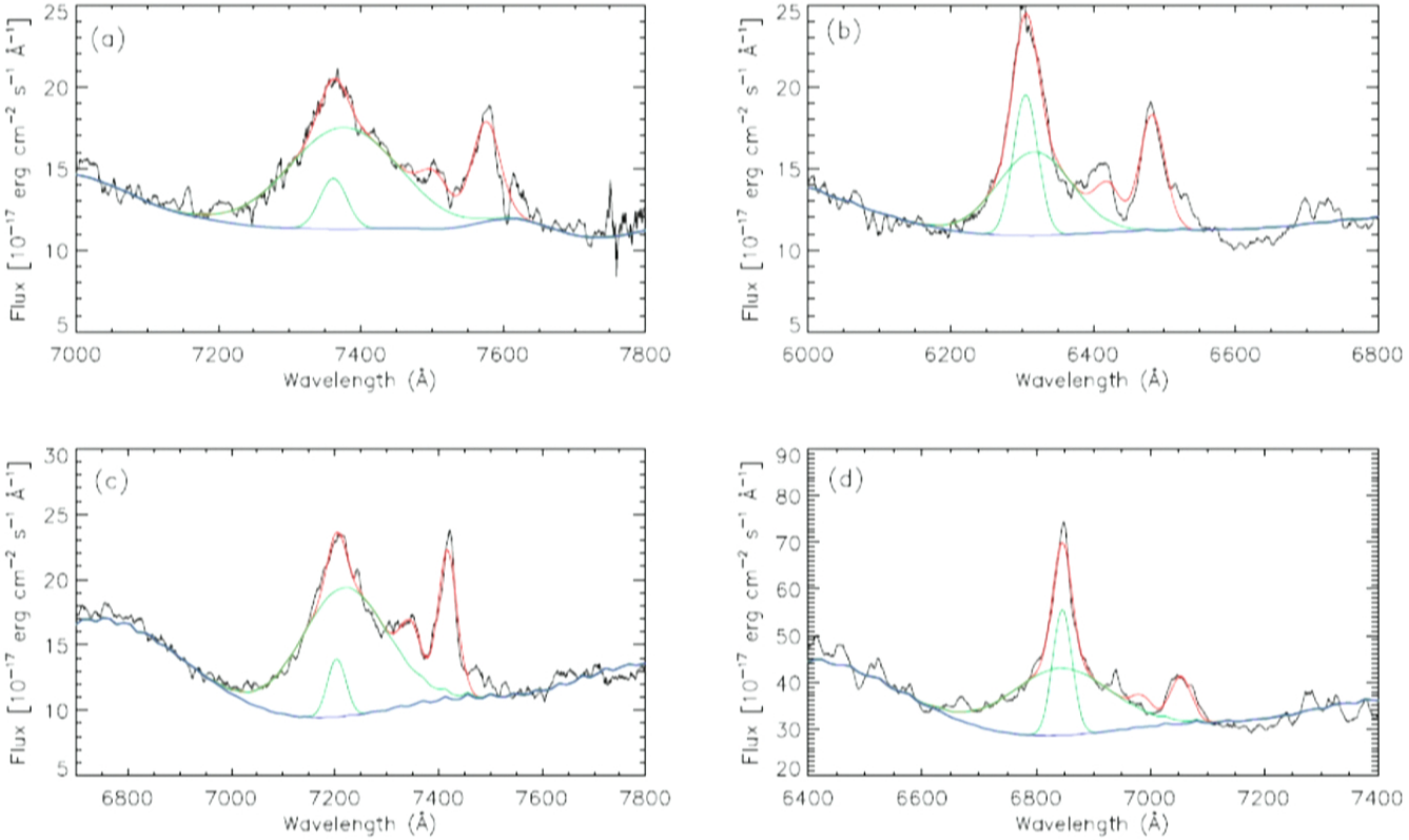
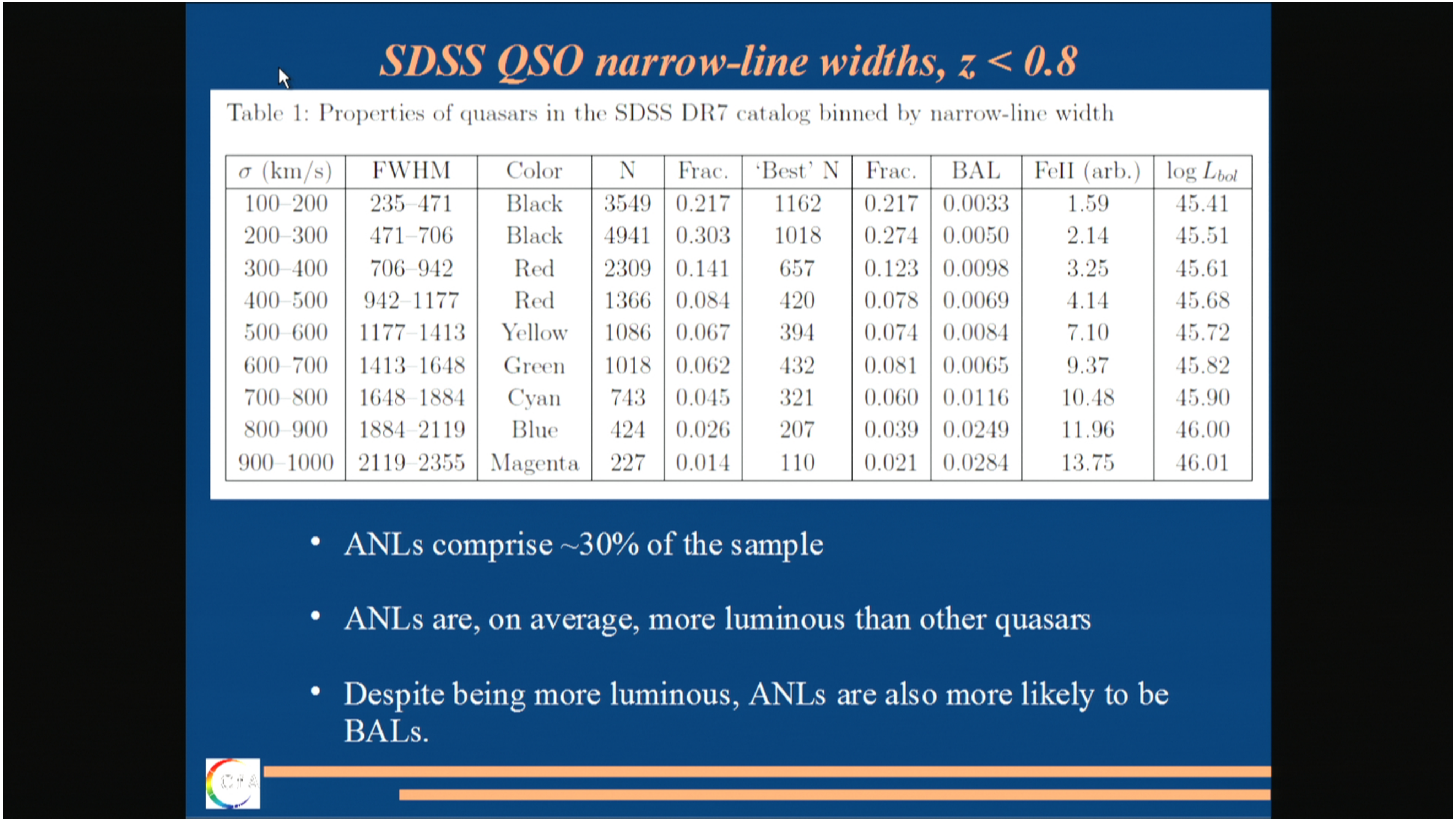


Broad OIII (FWHM 1860 km/s)



More ANLs with broad [OIII]



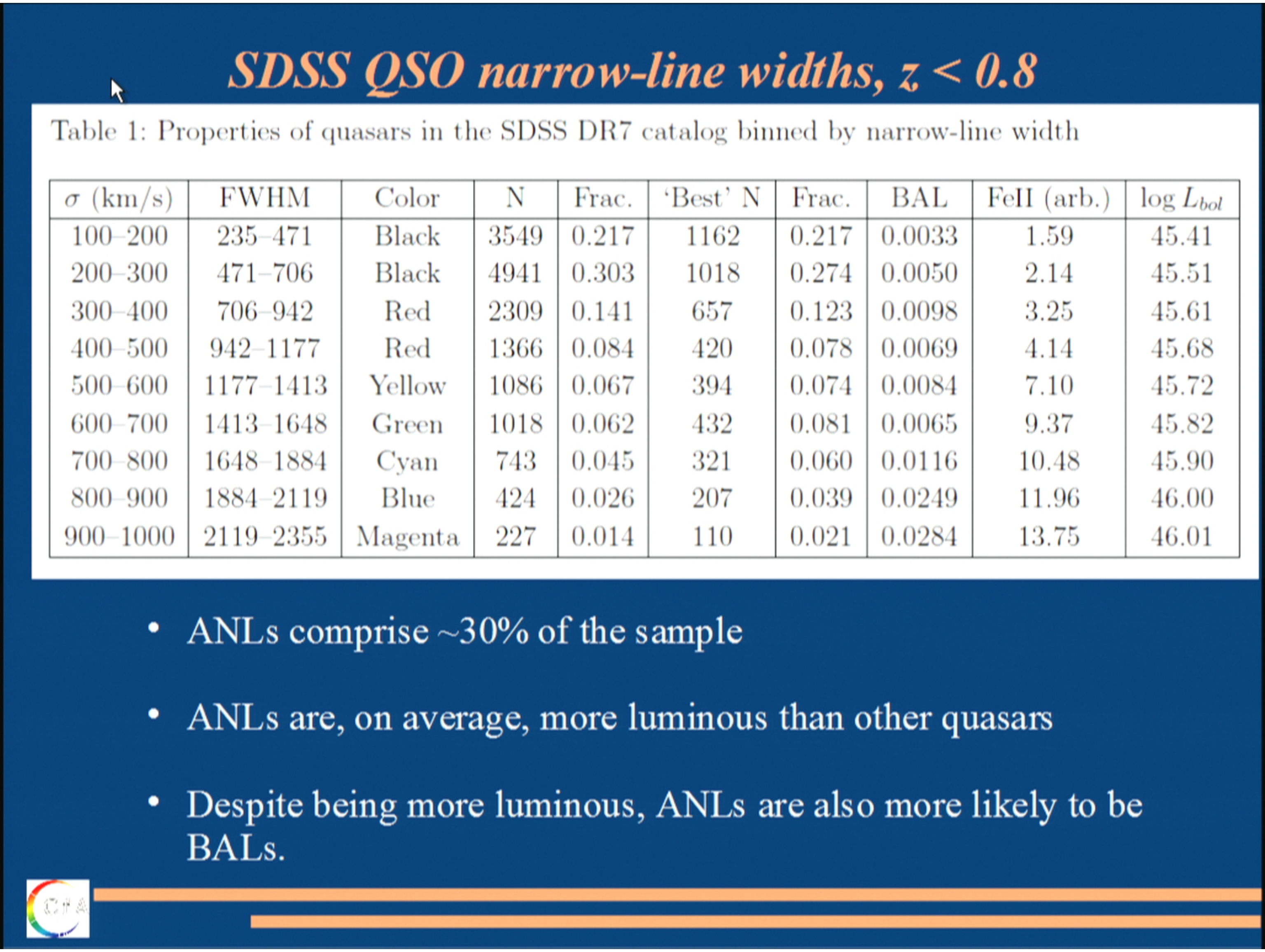


SDSS QSO narrow-line widths, $z < 0.8$

Table 1: Properties of quasars in the SDSS DR7 catalog binned by narrow-line width

σ (km/s)	FWHM	Color	N	Frac.	'Best' N	Frac.	BAL	FeII (arb.)	log L_{bol}
100–200	235–471	Black	3549	0.217	1162	0.217	0.0033	1.59	45.41
200–300	471–706	Black	4941	0.303	1018	0.274	0.0050	2.14	45.51
300–400	706–942	Red	2309	0.141	657	0.123	0.0098	3.25	45.61
400–500	942–1177	Red	1366	0.084	420	0.078	0.0069	4.14	45.68
500–600	1177–1413	Yellow	1086	0.067	394	0.074	0.0084	7.10	45.72
600–700	1413–1648	Green	1018	0.062	432	0.081	0.0065	9.37	45.82
700–800	1648–1884	Cyan	743	0.045	321	0.060	0.0116	10.48	45.90
800–900	1884–2119	Blue	424	0.026	207	0.039	0.0249	11.96	46.00
900–1000	2119–2355	Magenta	227	0.014	110	0.021	0.0284	13.75	46.01

- ANLs comprise ~30% of the sample
- ANLs are, on average, more luminous than other quasars
- Despite being more luminous, ANLs are also more likely to be BALs.



SDSS QSO narrow-line widths, $z < 0.8$

Table 1: Properties of quasars in the SDSS DR7 catalog binned by narrow-line width

σ (km/s)	FWHM	Color	N	Frac.	'Best' N	Frac.	BAL	FeII (arb.)	log L_{bol}
100–200	235–471	Black	3549	0.217	1162	0.217	0.0033	1.59	45.41
200–300	471–706	Black	4941	0.303	1018	0.274	0.0050	2.14	45.51
300–400	706–942	Red	2309	0.141	657	0.123	0.0098	3.25	45.61
400–500	942–1177	Red	1366	0.084	420	0.078	0.0069	4.14	45.68
500–600	1177–1413	Yellow	1086	0.067	394	0.074	0.0084	7.10	45.72
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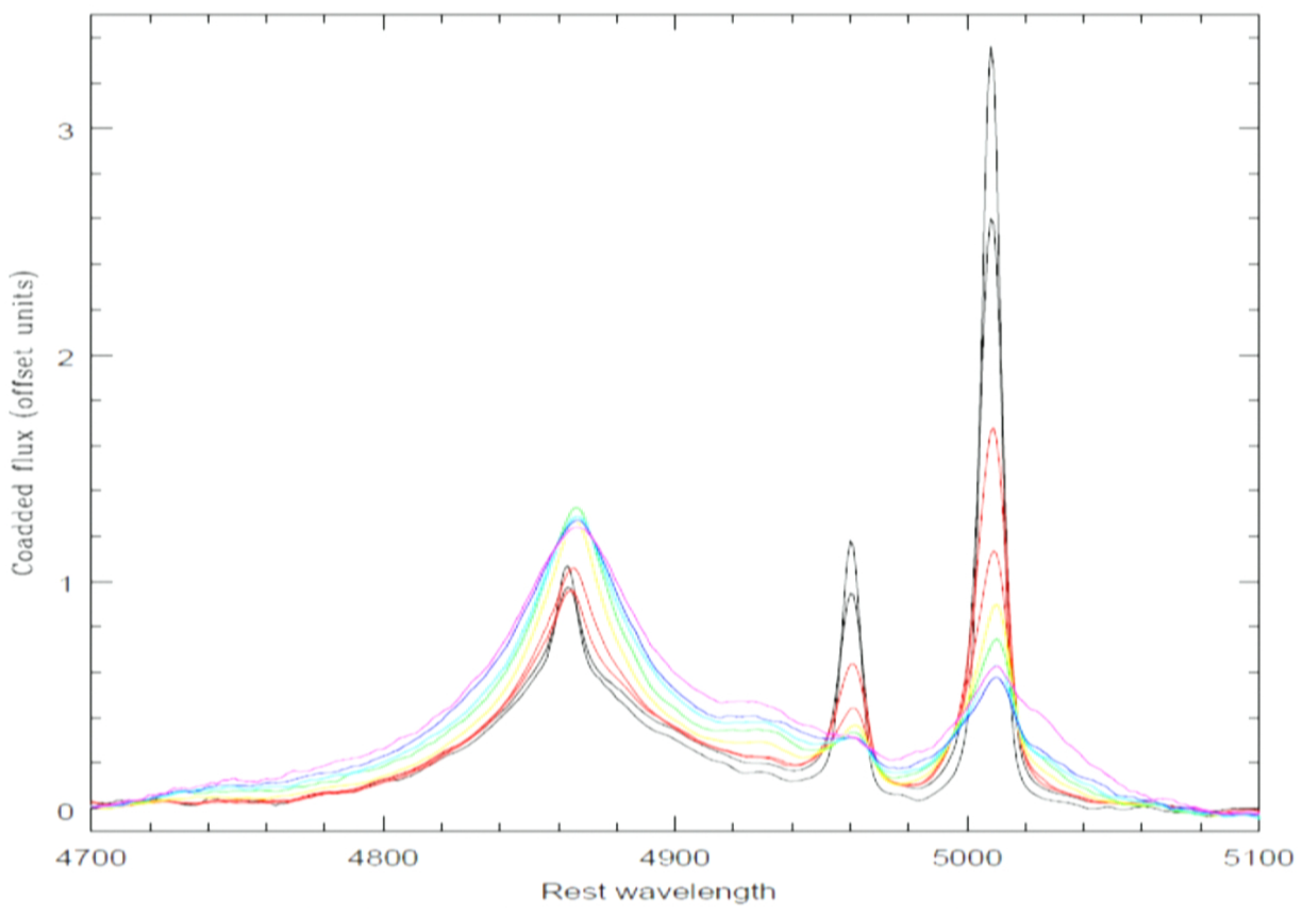
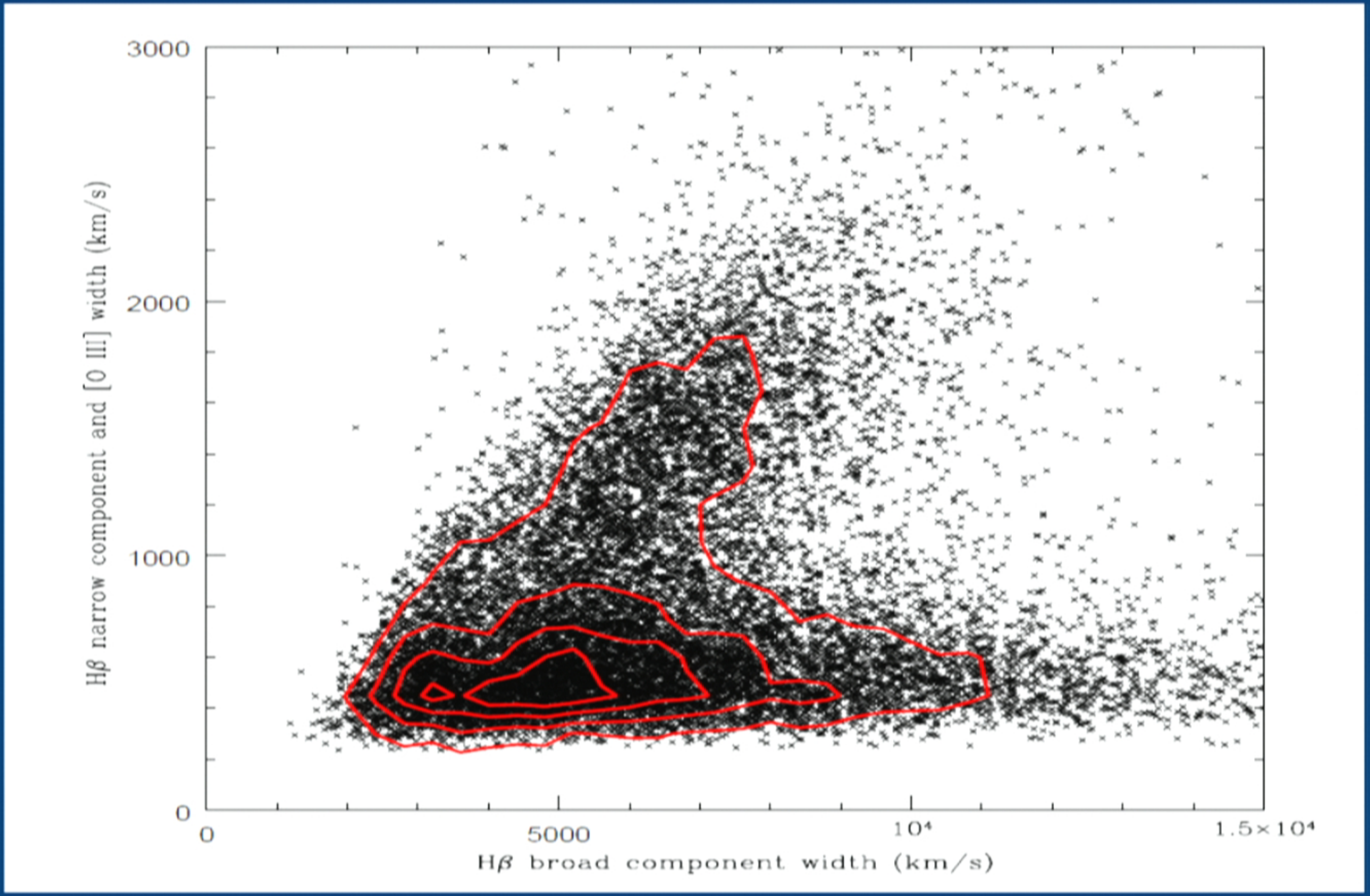
Co-added spectra near HB, [OIII]



"Narrow" vs. "broad" HB velocities, all quasars



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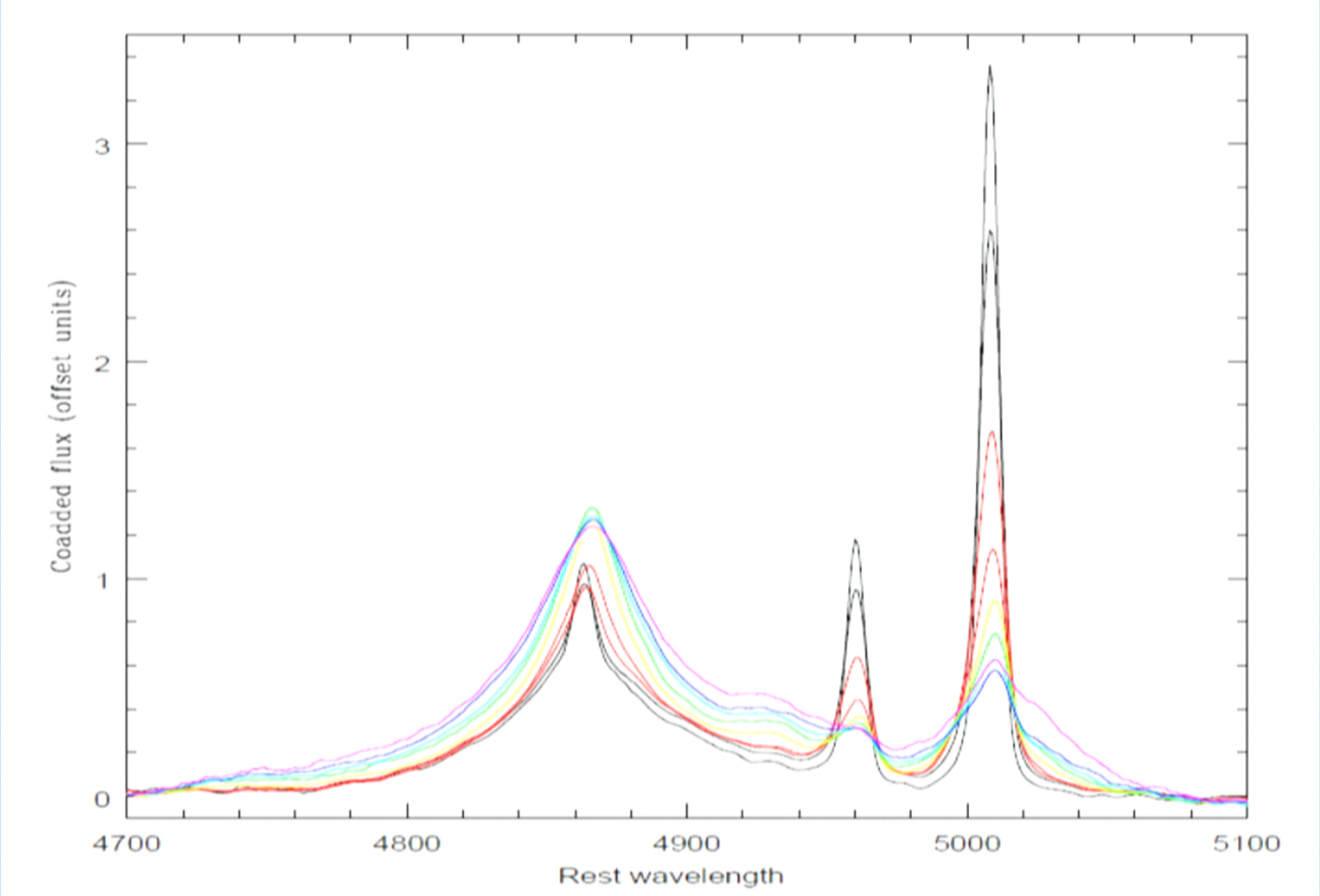
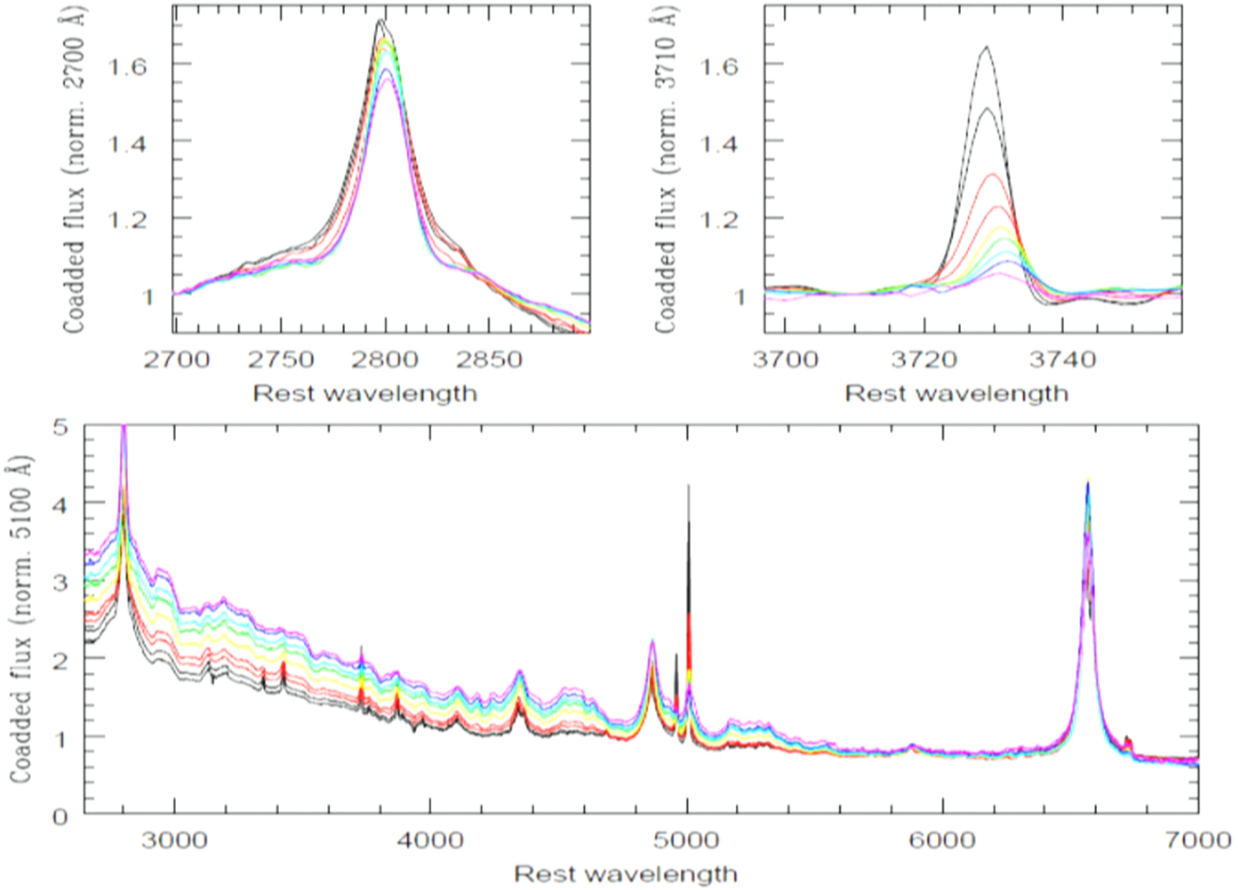


Co-added spectra, full and near MgII, [OII]



Open Questions

Structure

What are ANL Quasars?
Are they a phase of quasar activity?
Are they geometry?
Are they a new type of object?

Outflow

Are broadened "narrow lines" due to a strong outflow?
Does this mean virial mass estimates are wrong?
Why is MgII not broadened?

Feedback

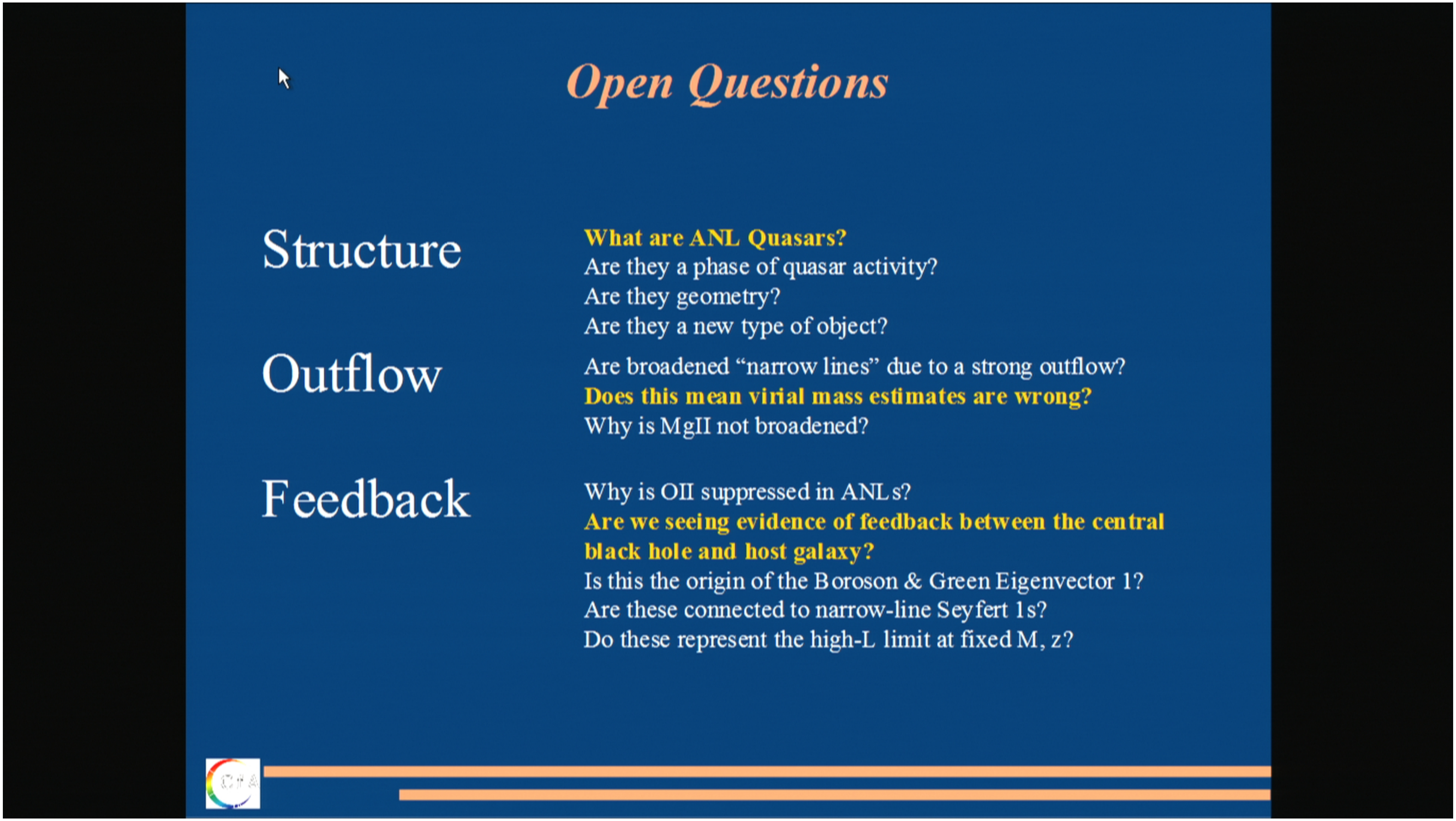
Why is OII suppressed in ANLs?
Are we seeing evidence of feedback between the central black hole and host galaxy?
Is this the origin of the Boroson & Green Eigenvector 1?
Are these connected to narrow-line Seyfert 1s?
Do these represent the high-L limit at fixed M, z?

Possible explanations

Are ANLs due to a strong outflow?

Is [OIII] emitted in the broad-line region?

Are ANLs due to the viewing angle?



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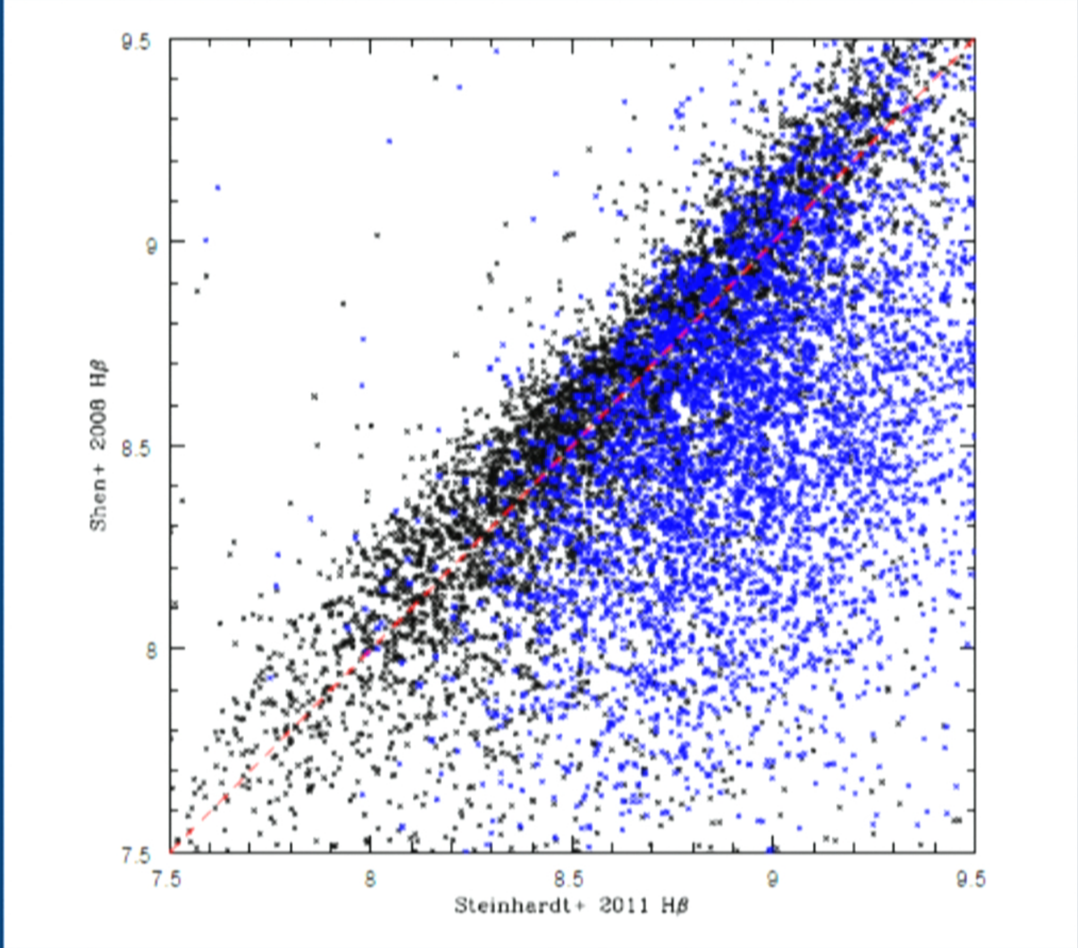
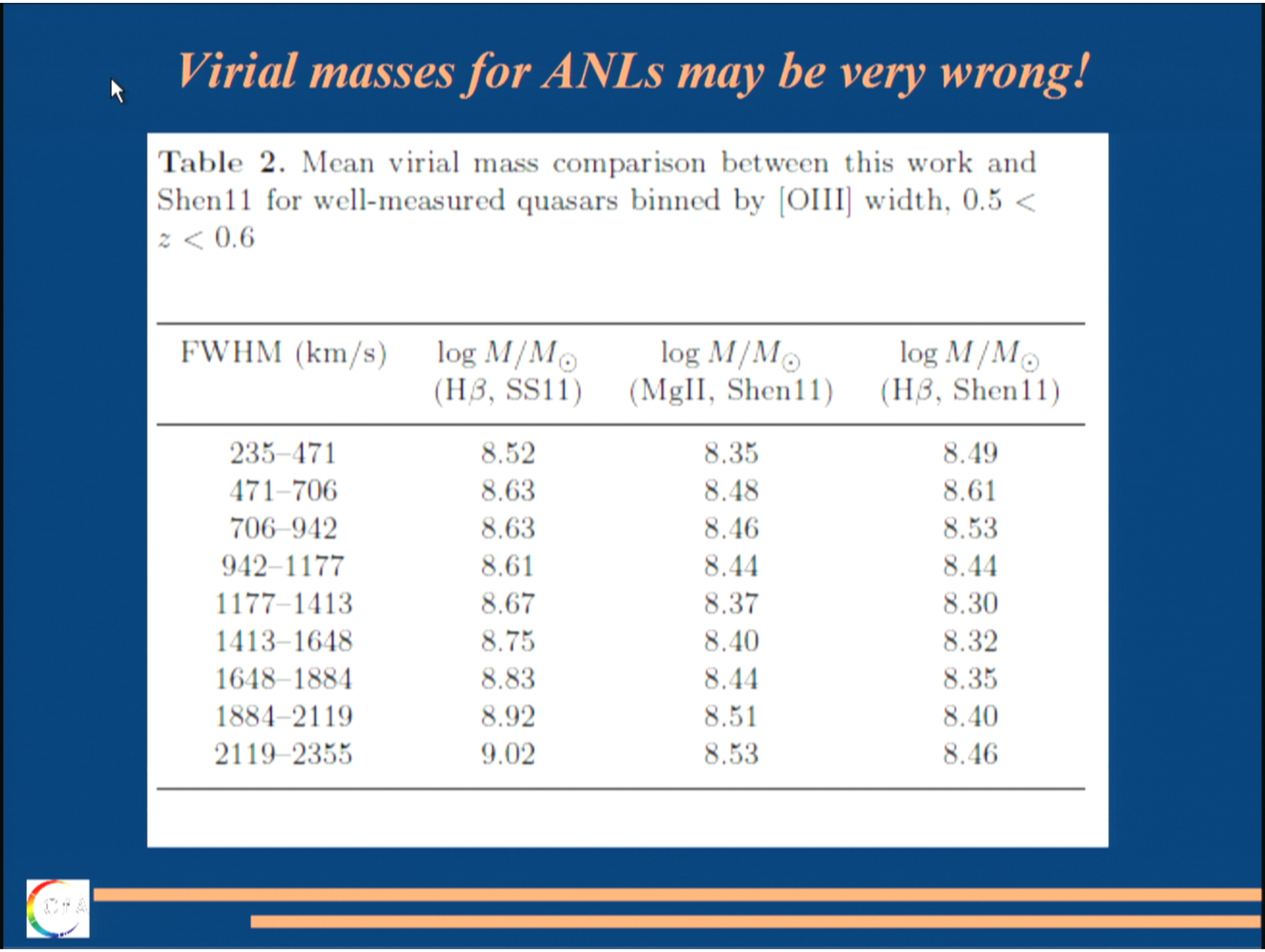
Virial masses for ANLs may be very wrong!



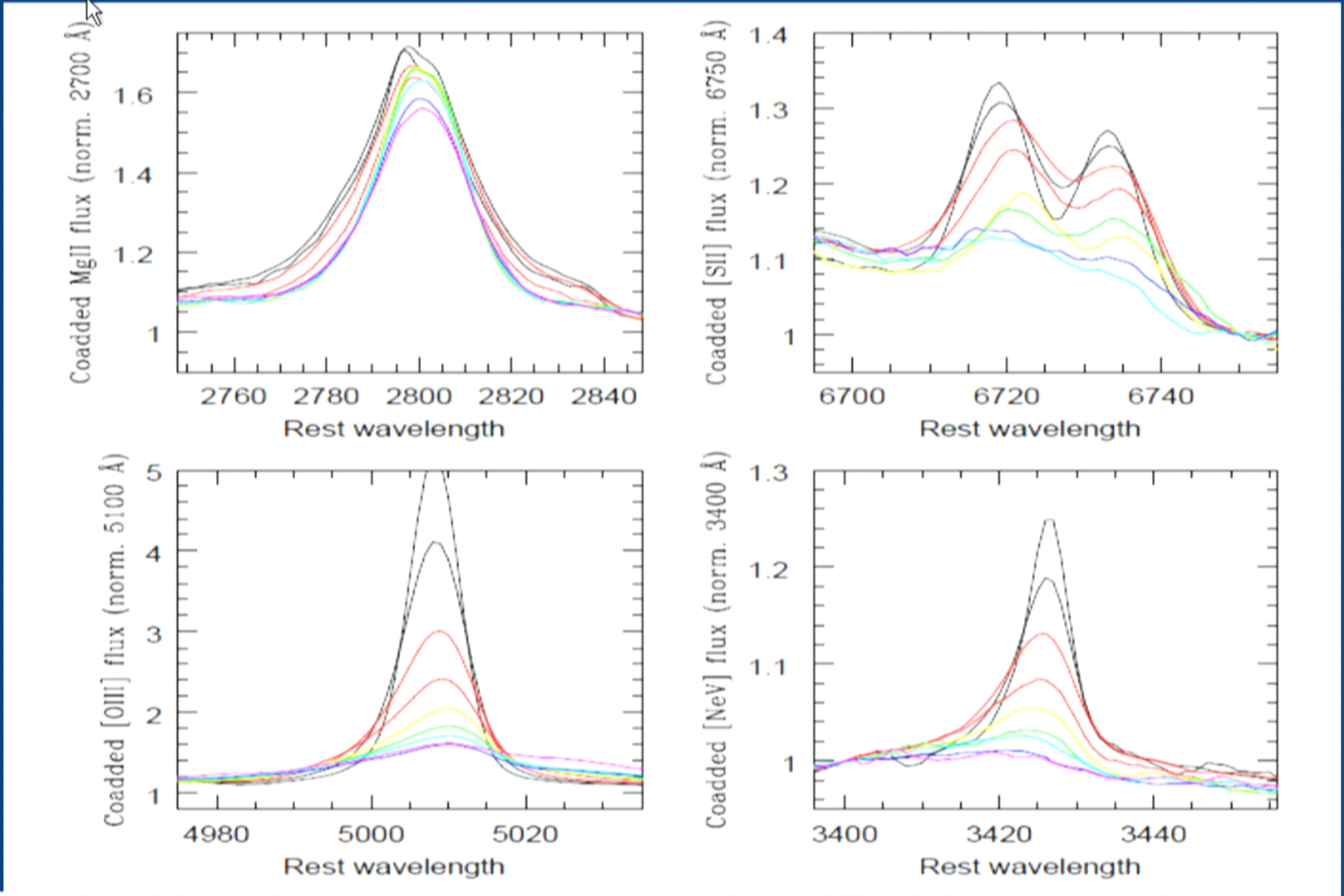


Virial masses for ANLs may be very wrong!

Table 2. Mean virial mass comparison between this work and Shen11 for well-measured quasars binned by [OIII] width, $0.5 < z < 0.6$

FWHM (km/s)	$\log M/M_\odot$ (Hβ, SS11)	$\log M/M_\odot$ (MgII, Shen11)	$\log M/M_\odot$ (Hβ, Shen11)
235–471	8.52	8.35	8.49
471–706	8.63	8.48	8.61
706–942	8.63	8.46	8.53
942–1177	8.61	8.44	8.44
1177–1413	8.67	8.37	8.30
1413–1648	8.75	8.40	8.32
1648–1884	8.83	8.44	8.35
1884–2119	8.92	8.51	8.40
2119–2355	9.02	8.53	8.46

And, we might not be able to identify ANLs easily



A physical model for non-virial motion is needed

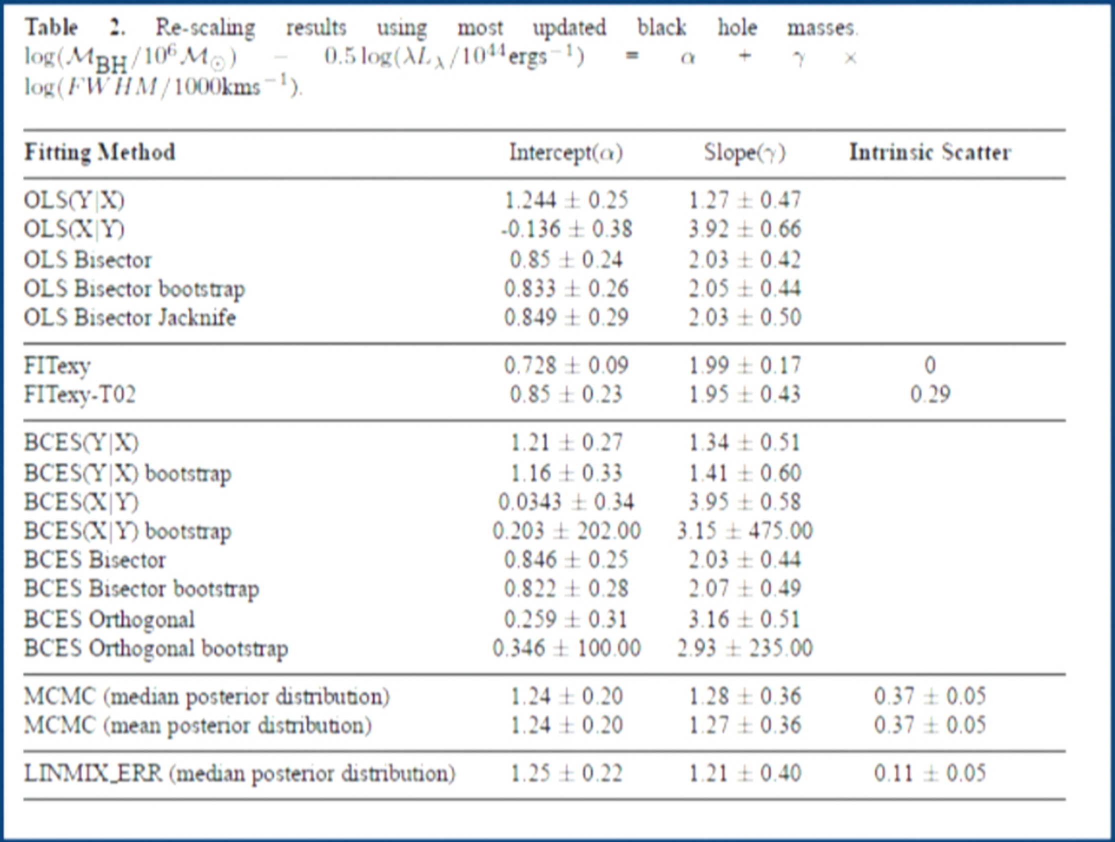
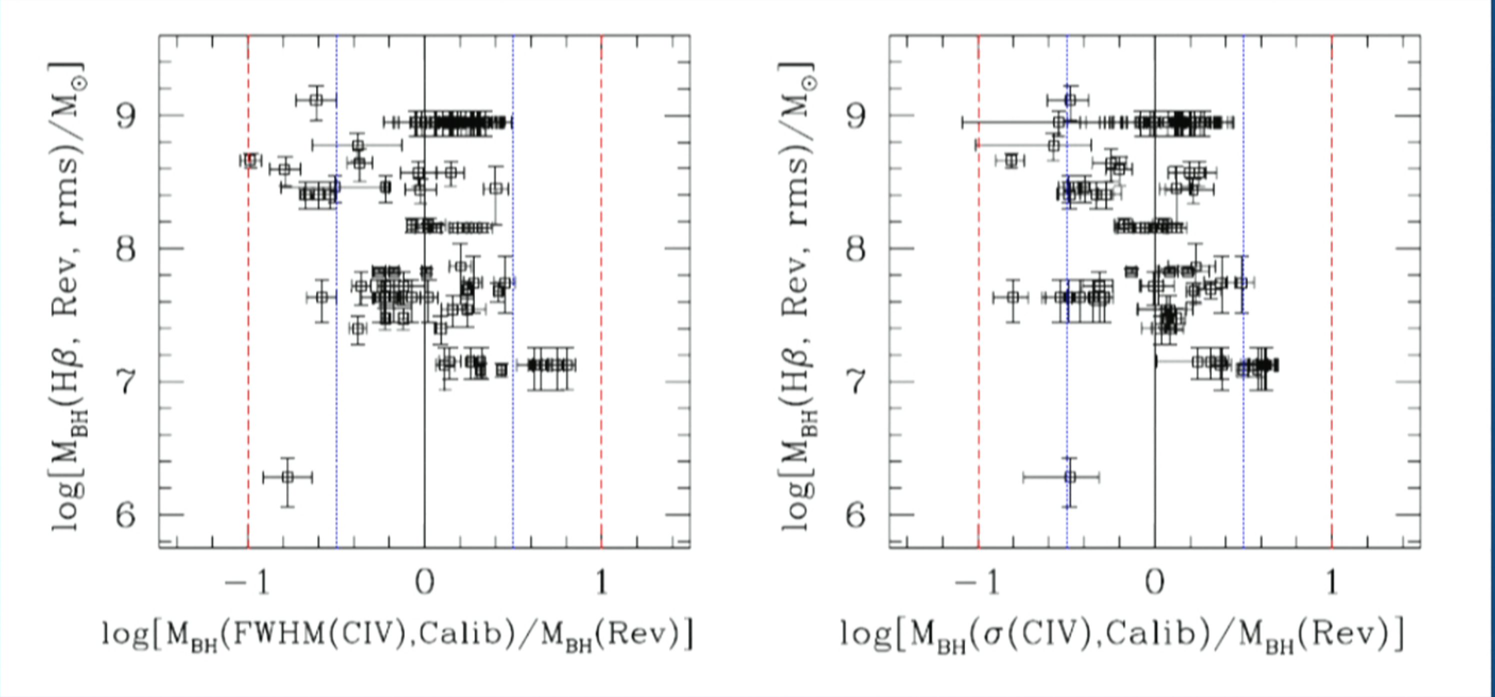


Table 2. Re-scaling results using most updated black hole masses. $\log(\mathcal{M}_{BH}/10^6\mathcal{M}_\odot) - 0.5\log(\lambda L_\lambda/10^{44}\mathrm{ergs}^{-1}) = \alpha + \gamma \times \log(FWHM/1000\mathrm{kms}^{-1})$.

Fitting Method	Intercept(α)	Slope(γ)	**Intrinsic Scatter**
OLS(Y|X)	1.244 ± 0.25	1.27 ± 0.47	
OLS(X|Y)	-0.136 ± 0.38	3.92 ± 0.66	
OLS Bisector	0.85 ± 0.24	2.03 ± 0.42	
OLS Bisector bootstrap	0.833 ± 0.26	2.05 ± 0.44	
OLS Bisector Jacknife	0.849 ± 0.29	2.03 ± 0.50	
FITexy	0.728 ± 0.09	1.99 ± 0.17	0
FITexy-T02	0.85 ± 0.23	1.95 ± 0.43	0.29
BCES(Y|X)	1.21 ± 0.27	1.34 ± 0.51	
BCES(Y|X) bootstrap	1.16 ± 0.33	1.41 ± 0.60	
BCES(X|Y)	0.0343 ± 0.34	3.95 ± 0.58	
BCES(X|Y) bootstrap	0.203 ± 202.00	3.15 ± 475.00	
BCES Bisector	0.846 ± 0.25	2.03 ± 0.44	
BCES Bisector bootstrap	0.822 ± 0.28	2.07 ± 0.49	
BCES Orthogonal	0.259 ± 0.31	3.16 ± 0.51	
BCES Orthogonal bootstrap	0.346 ± 100.00	2.93 ± 235.00	
MCMC (median posterior distribution)	1.24 ± 0.20	1.28 ± 0.36	0.37 ± 0.05
MCMC (mean posterior distribution)	1.24 ± 0.20	1.27 ± 0.36	0.37 ± 0.05
LINMIX_ERR (median posterior distribution)	1.25 ± 0.22	1.21 ± 0.40	0.11 ± 0.05

Rafiee & Hall, 2011

HB and CIV calibration



Vestergaard & Peterson 2006