A Cool Mist in a Warm Wind: A Physical Origin for the Broad Emission Line Region

arXiv:1703.02956

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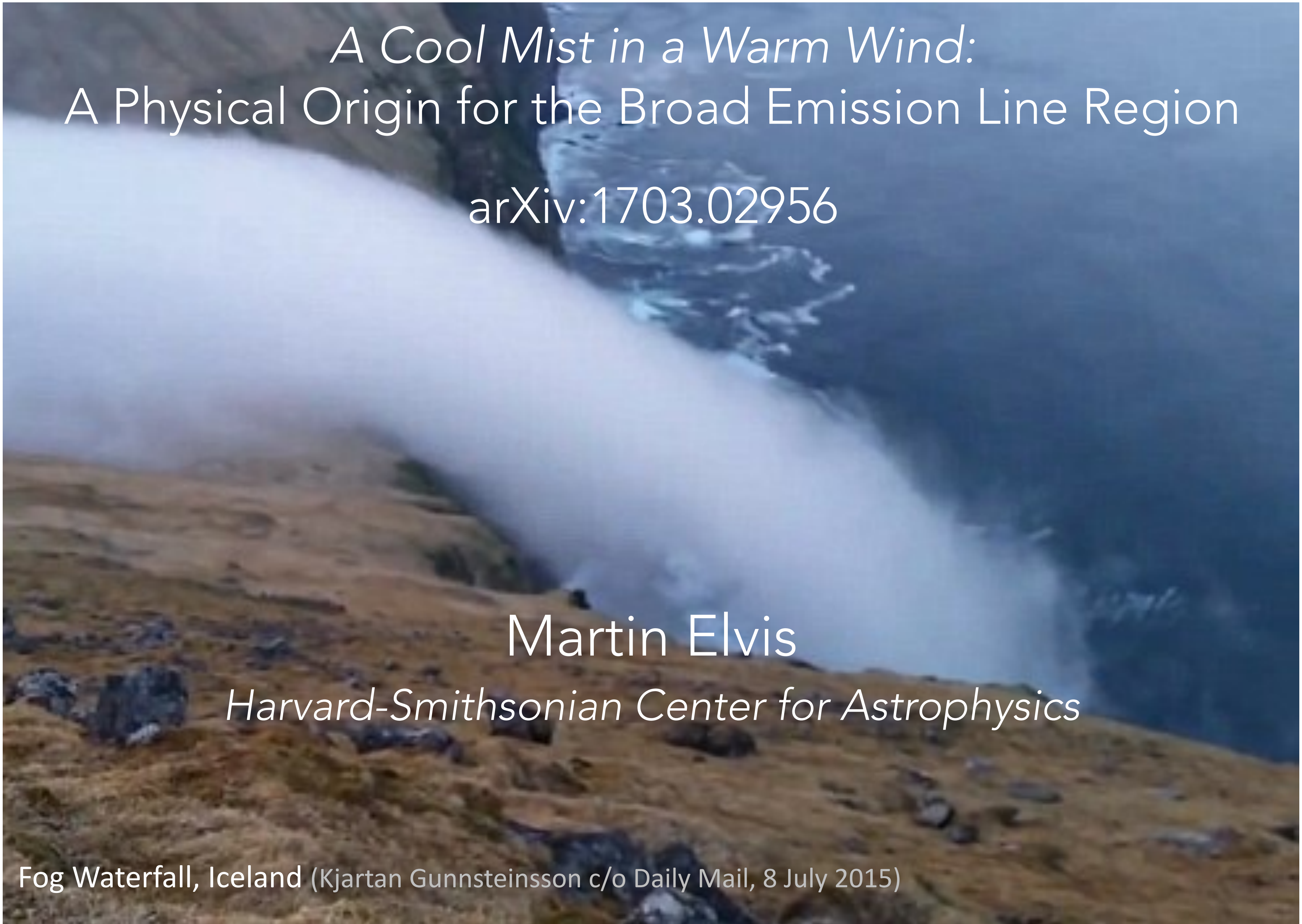
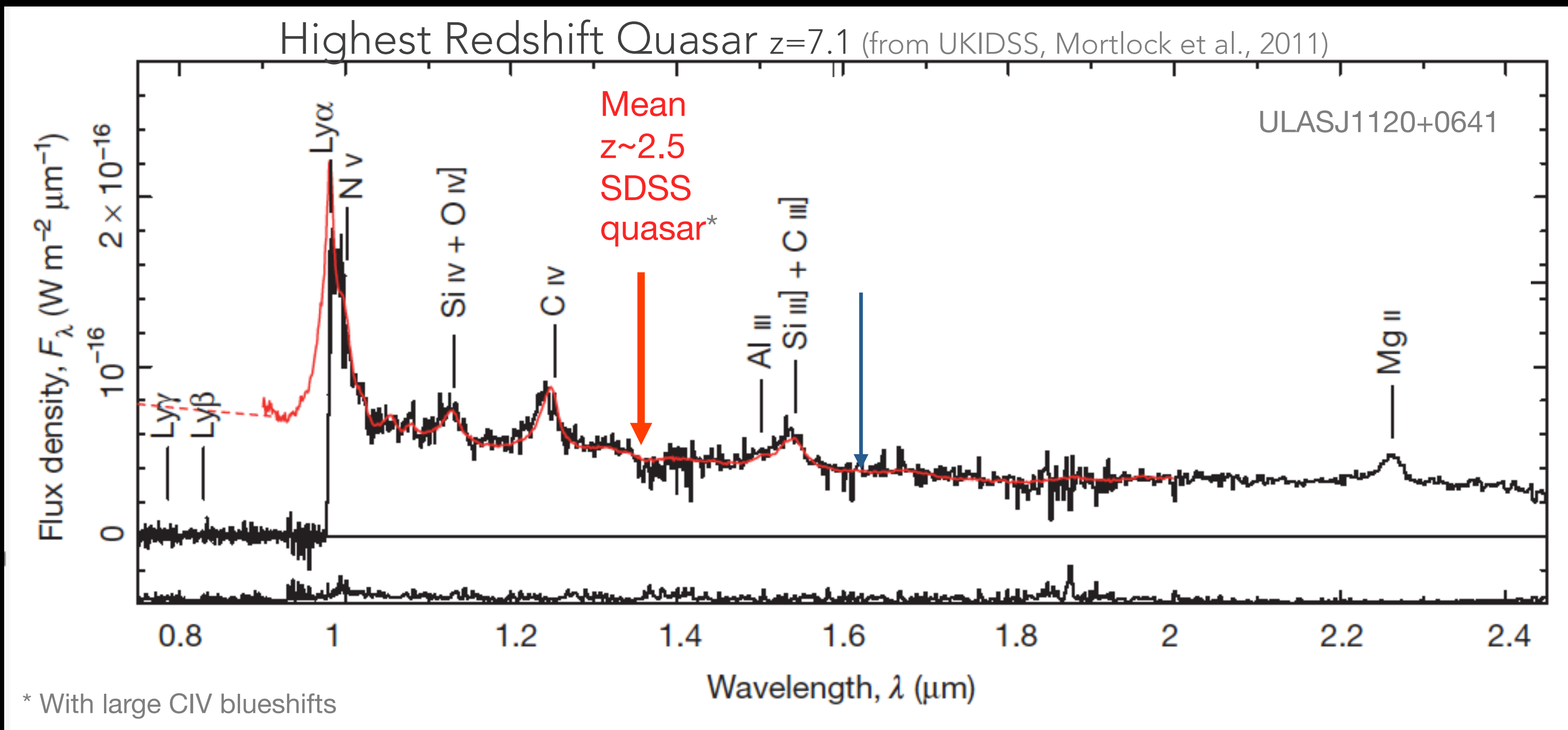


Fog Waterfall, Iceland (Kjartan Gunnsteinsson c/o Daily Mail, 8 July 2015)

Broad Emission **Lines:** Invariant with Redshift, Luminosity

The Physics must be robust and inevitable.
Not a function of host galaxy

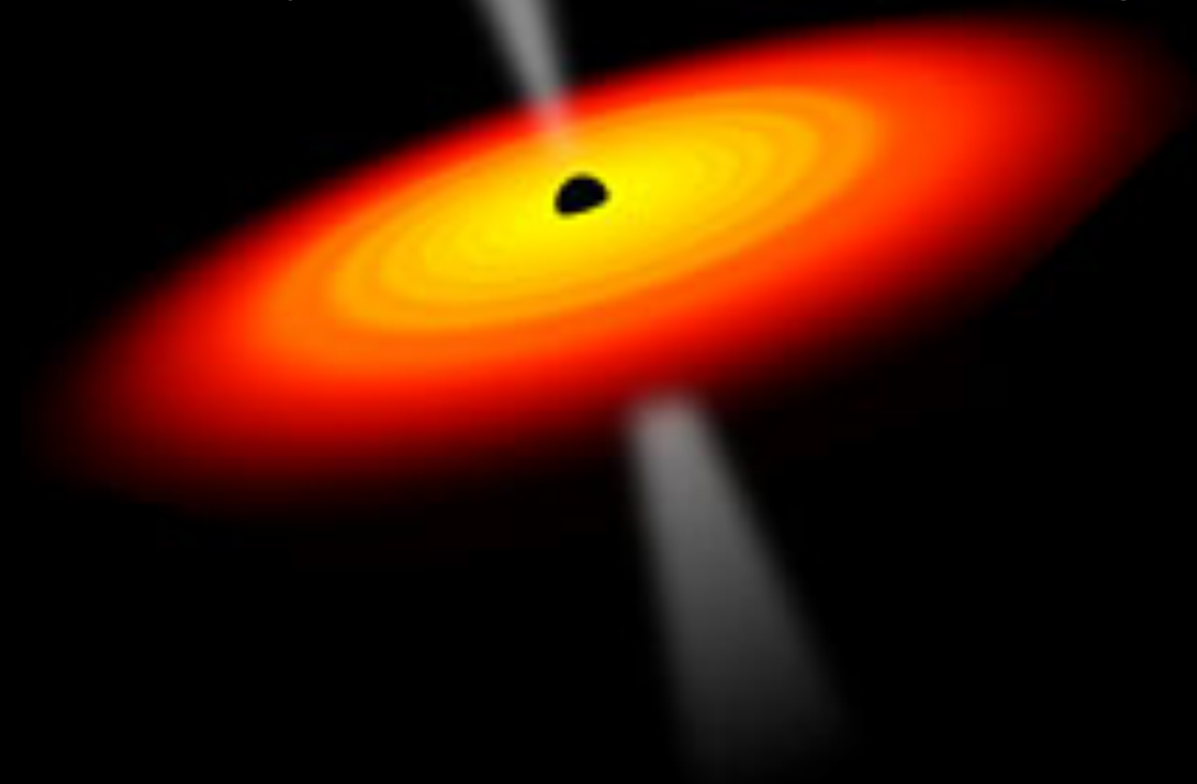


All of the complex quasar phenomenology
must fall out of a simple theory

The Black Hole + Disk + Jet Paradigm has no atomic features

So Where do all the emission and absorption lines come from?

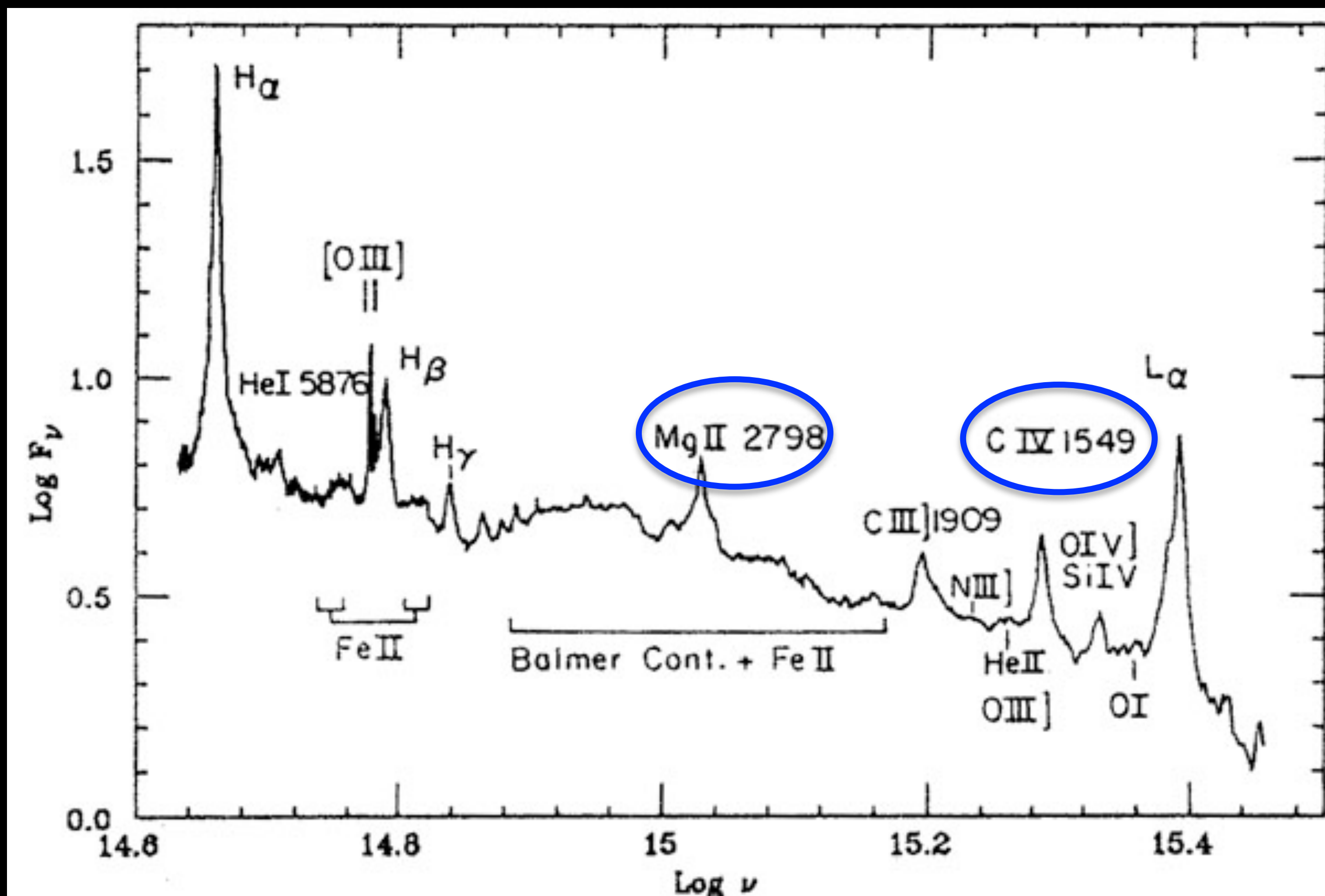
Especially the Broad Emission Line Region



What do we know about the Broad Emission Line Region?

Basics - 1:

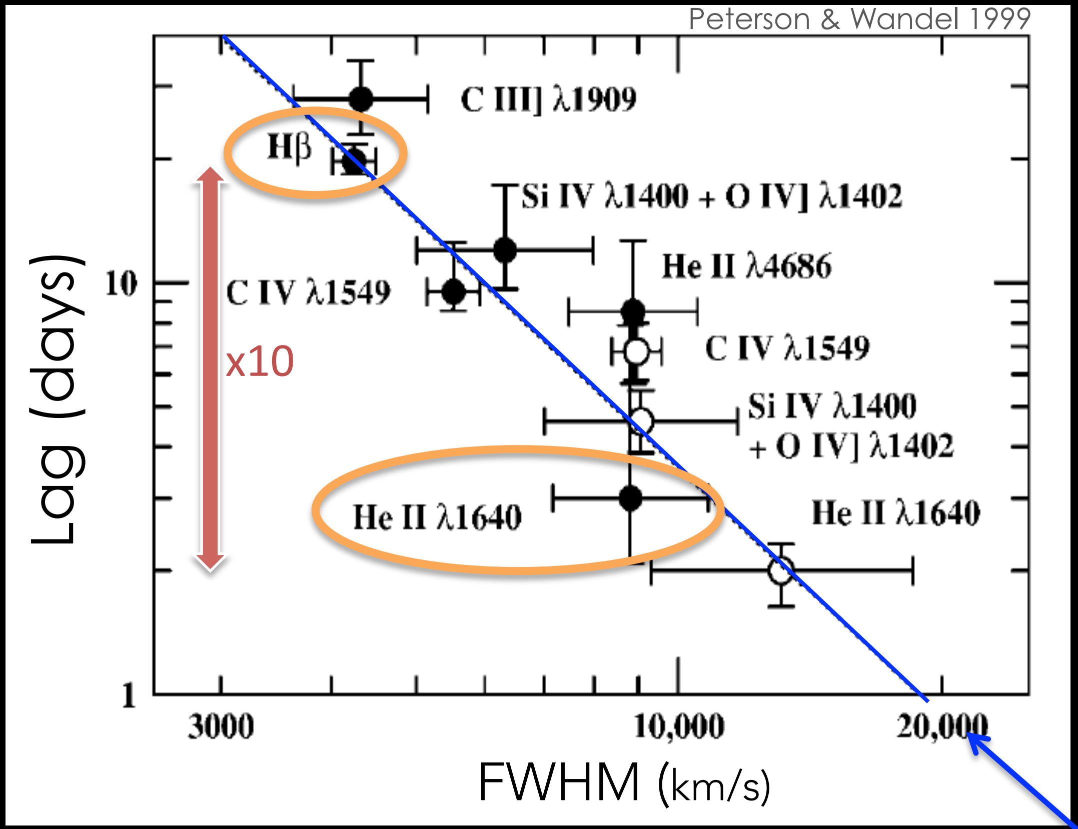
- High densities: $10^9 – 10^{12}$ cm^{-3}
- FWHM ~ 1% - 3% *c* → ~$10^3 – 10^4$ R_g
- Wide range of ionization: FeII, MgII → CIV, OVI



Broad Emission Line Region Basics - 2

- Spans factor 10 in radius
- Keplerian → black hole masses
- Stratified higher mean ionization parameter at small radii

Peterson & Wandel 1999

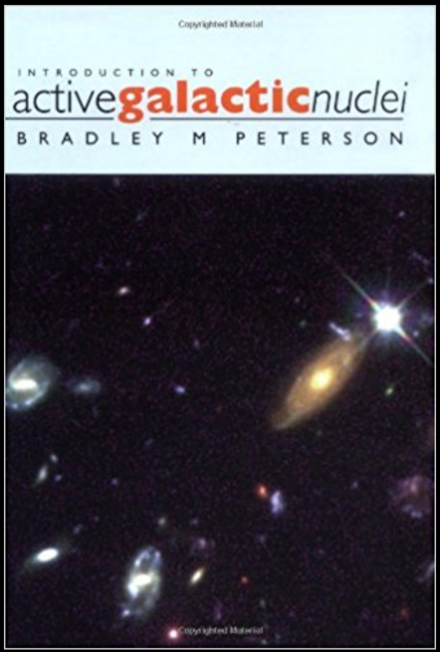


v^2r=GM, i.e. Keplerian

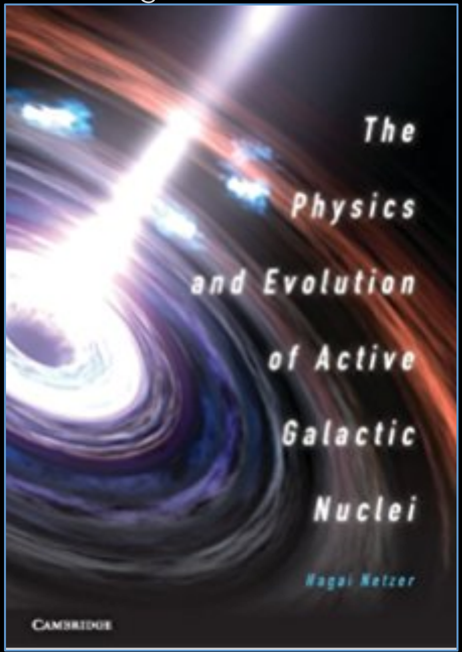
Broad Emission Line Region - Geometry

- Covering factor ~10%
  ("textbook result")
- Reverberation mapping shape: thick disk
  (Pancoast et al., 2014)

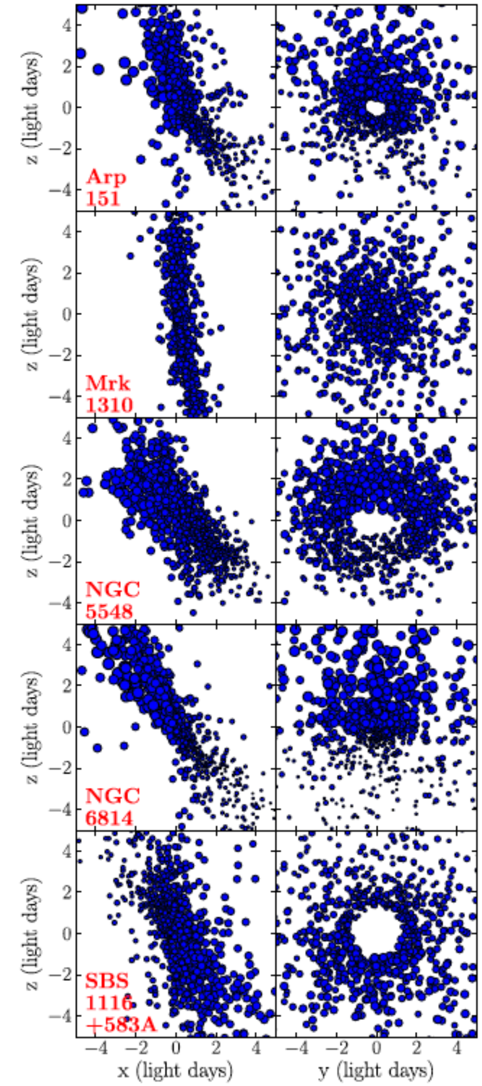
Brad Peterson,1997



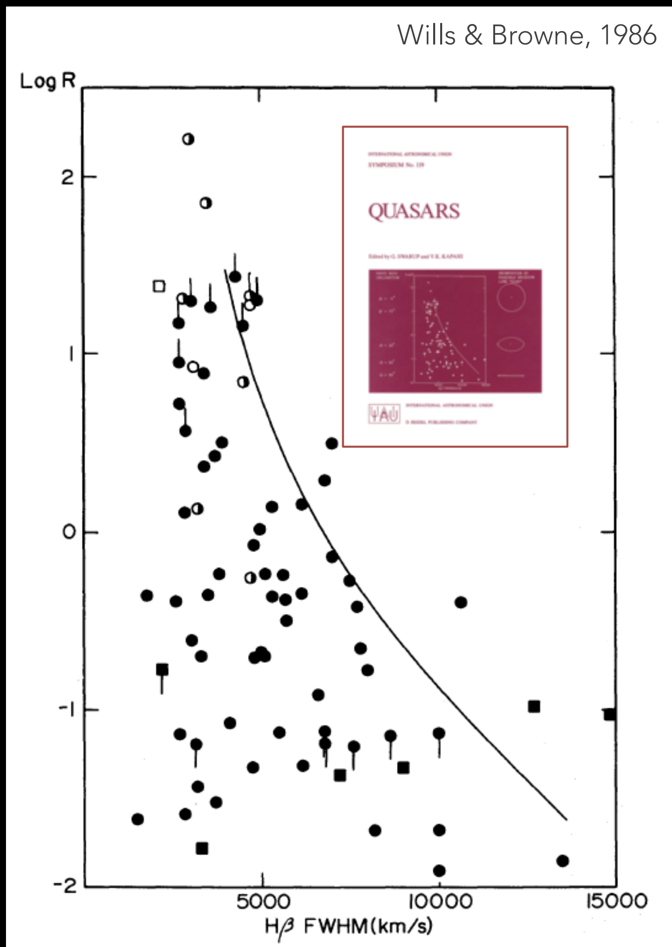
Hagai Netzer, 2013

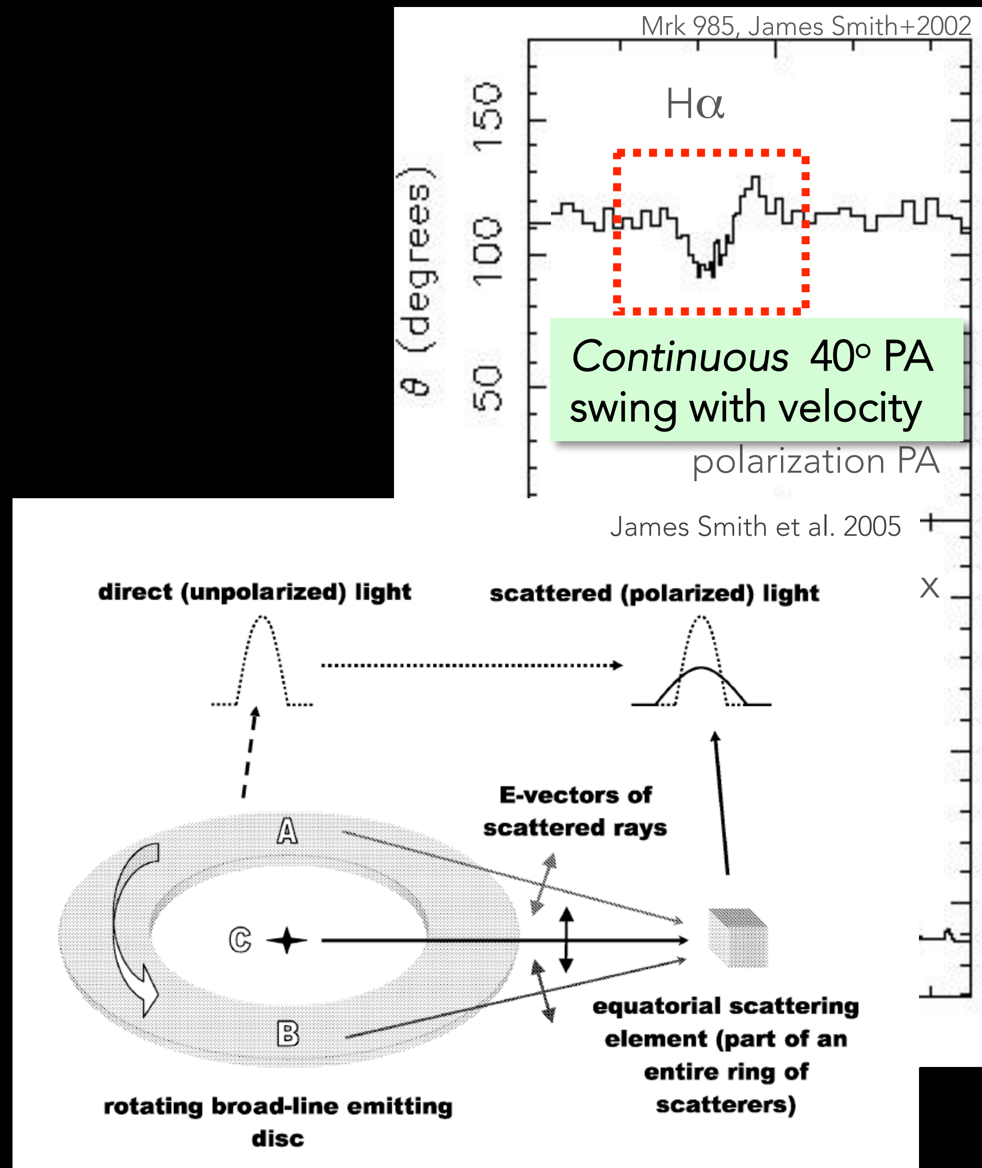


Pancoast et al. 2014



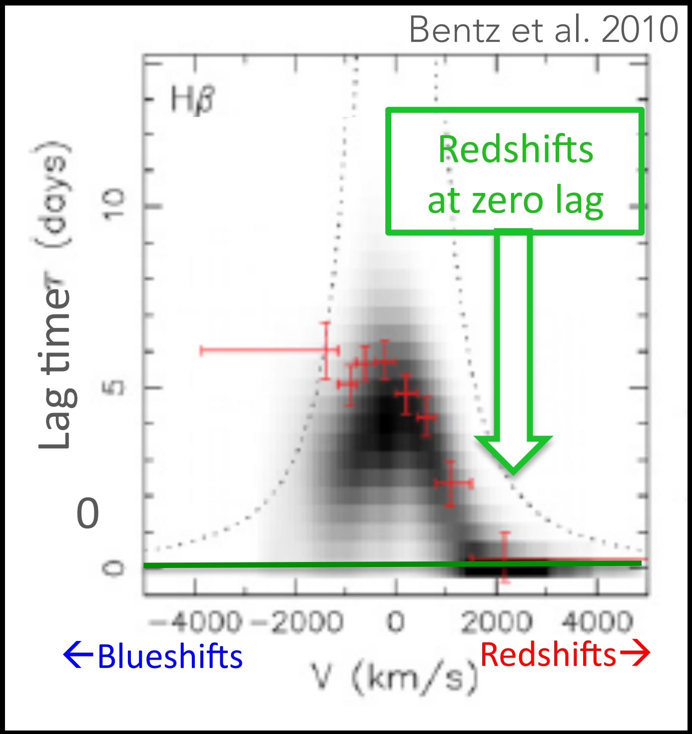
Broad Emission Line Region Kinematics: mostly Rotation

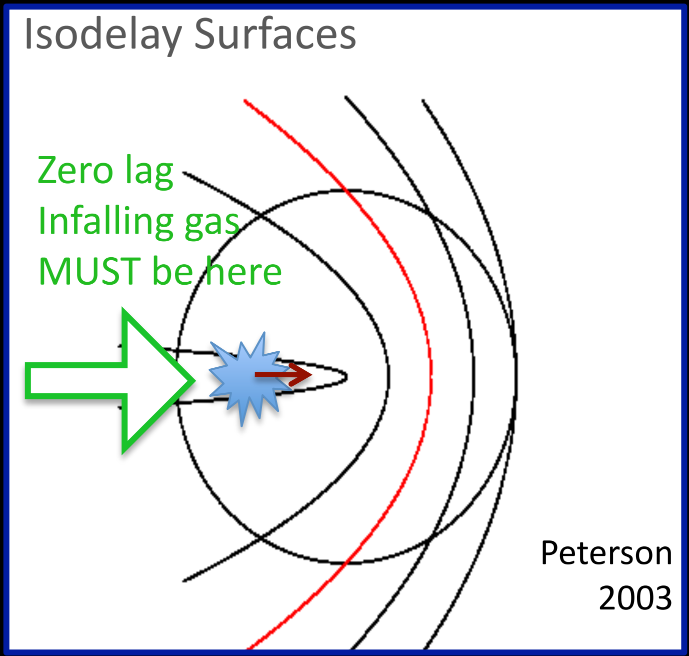




Broad Emission Line Region Kinematics: also Inflows

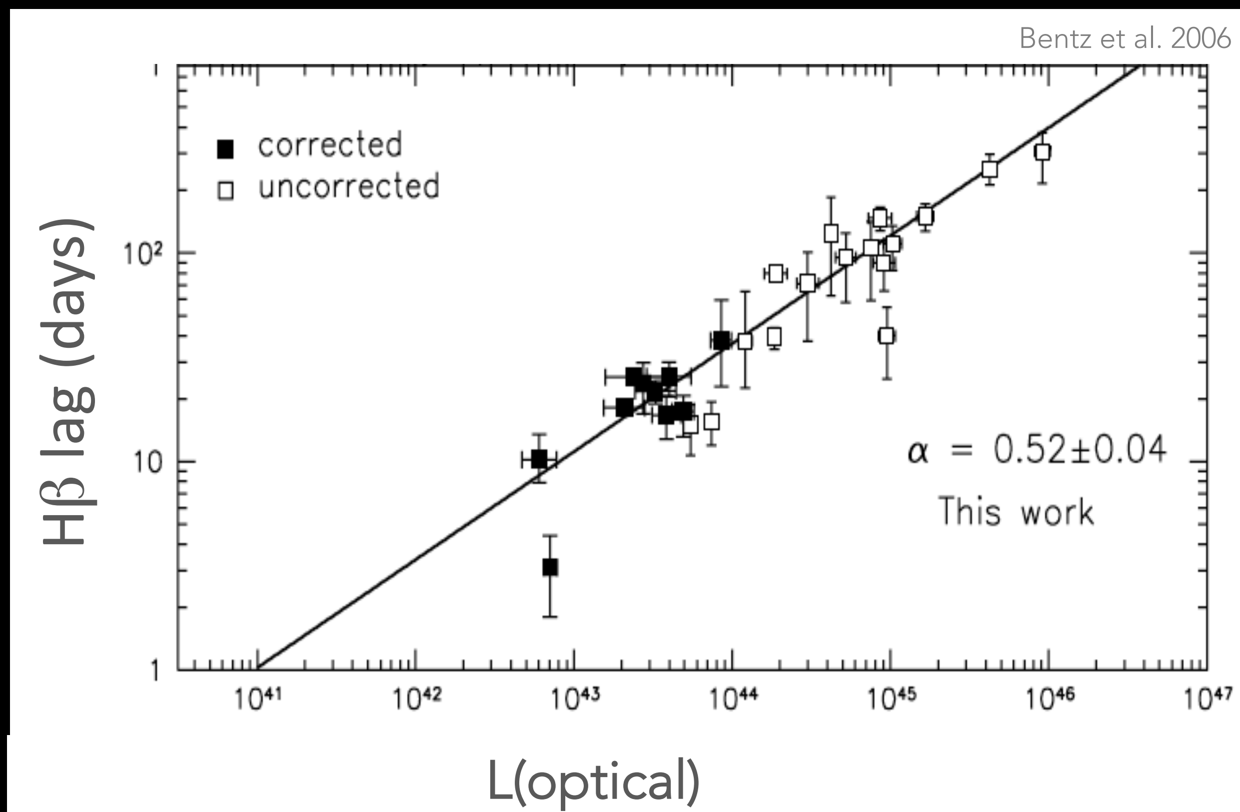
- Velocity Resolved Reverberation Mapping
  Bentz et al. 2010, Grier et al. 2013, Pancoast et al. 2014
- Redshifts at zero lag
  → *Infall*





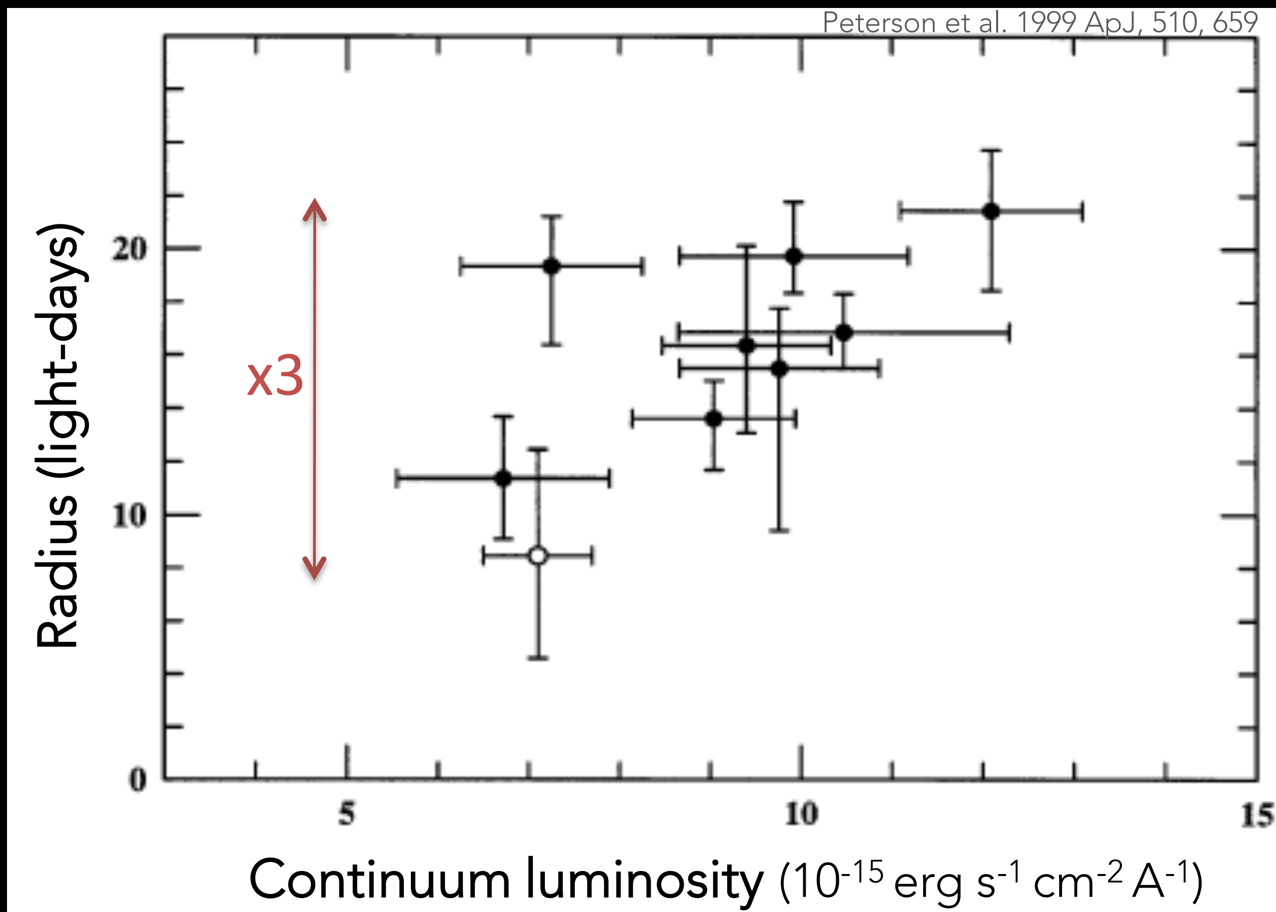
Scaling Relations for Broad Emission Lines

Hβ Broad Emission Line Region size grows as $L^{1/2}$
Object to object relation
Hβ cloud density ~ constant



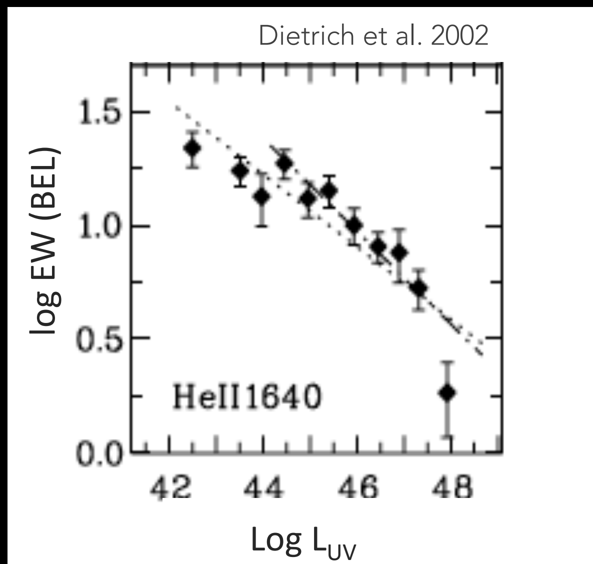
"Breathing" Broad Emission Line Region

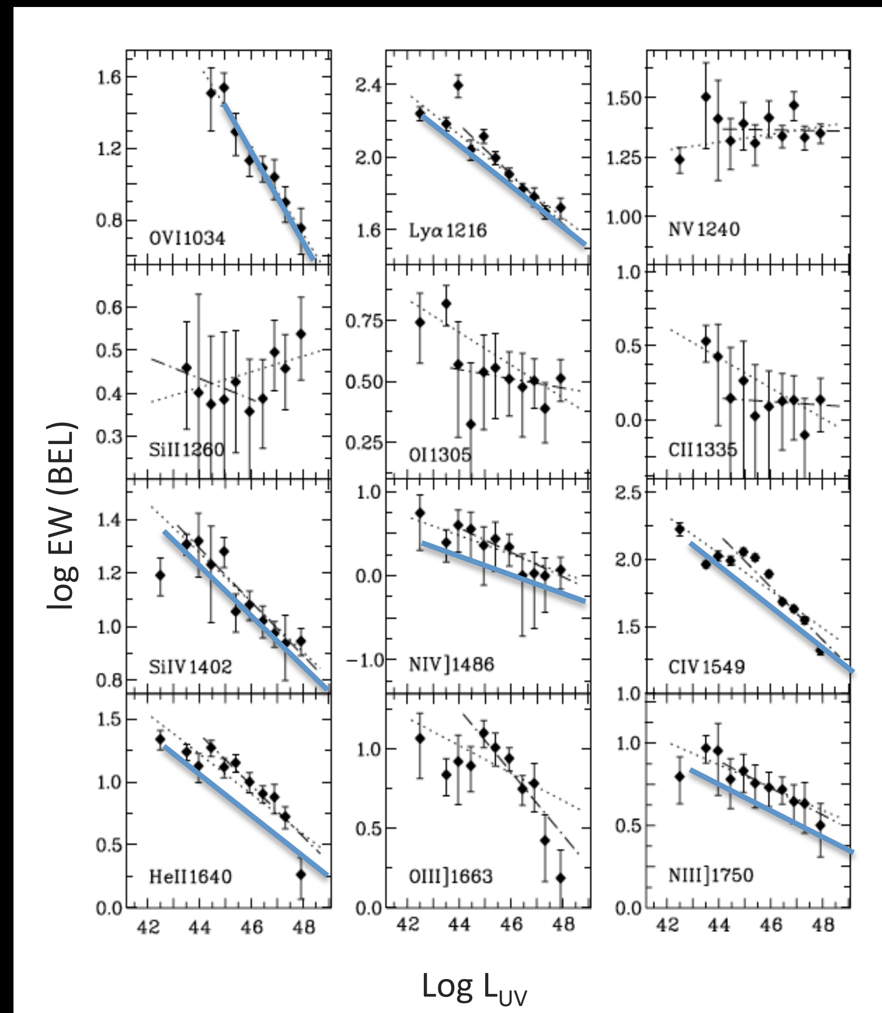
Radius of Hβ BELR grows as $L^{1/2}$ in year-on-year changes
Single object relation
Hβ Cloud density ~ constant



Baldwin Effect

Broad emission line EW lower at high L_{UV} Baldwin 1977





Dietrich et al. 2002

The Broad Emission Line Region

…is a heavily constrained system

Any model must explain all the observed phenomenology

Quite a challenge!

Standard view of Broad Emission Line Clouds

Locally Optimally Emitting Clouds (LOC) Model

Clouds have a random distribution
of density and input ionizing flux [n(H), φ(H)].
Clouds at the optimum conditions
for each line emit most strongly.

Works…
But frustrating:
No physical insight into origin of BELR.

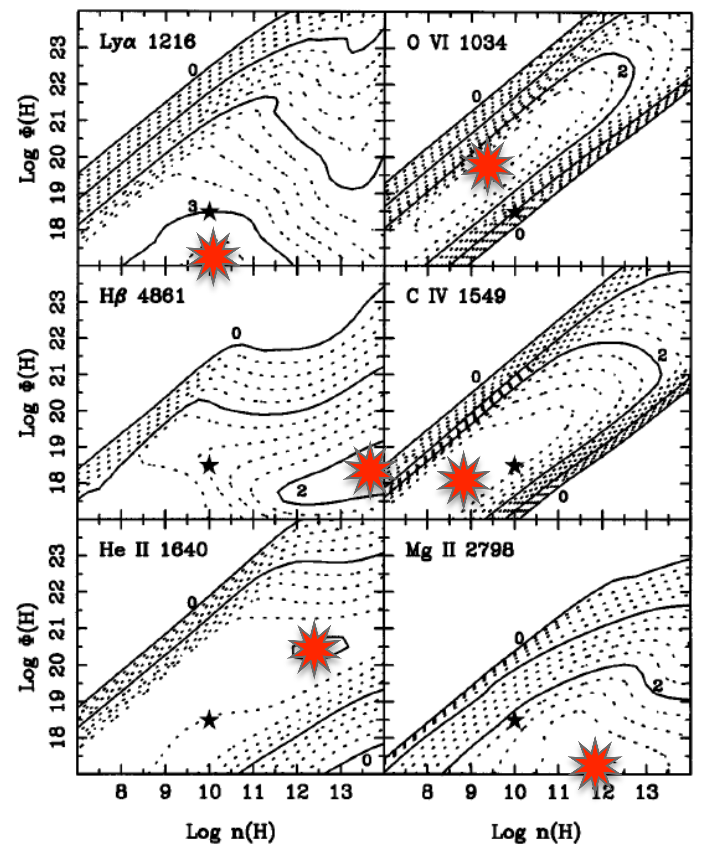
Many LOC papers, including:

Baldwin et al. 1995; Korista et al. 1997;

Korista & Goad, 2000, 2004;

Goad & Korista, 2015.

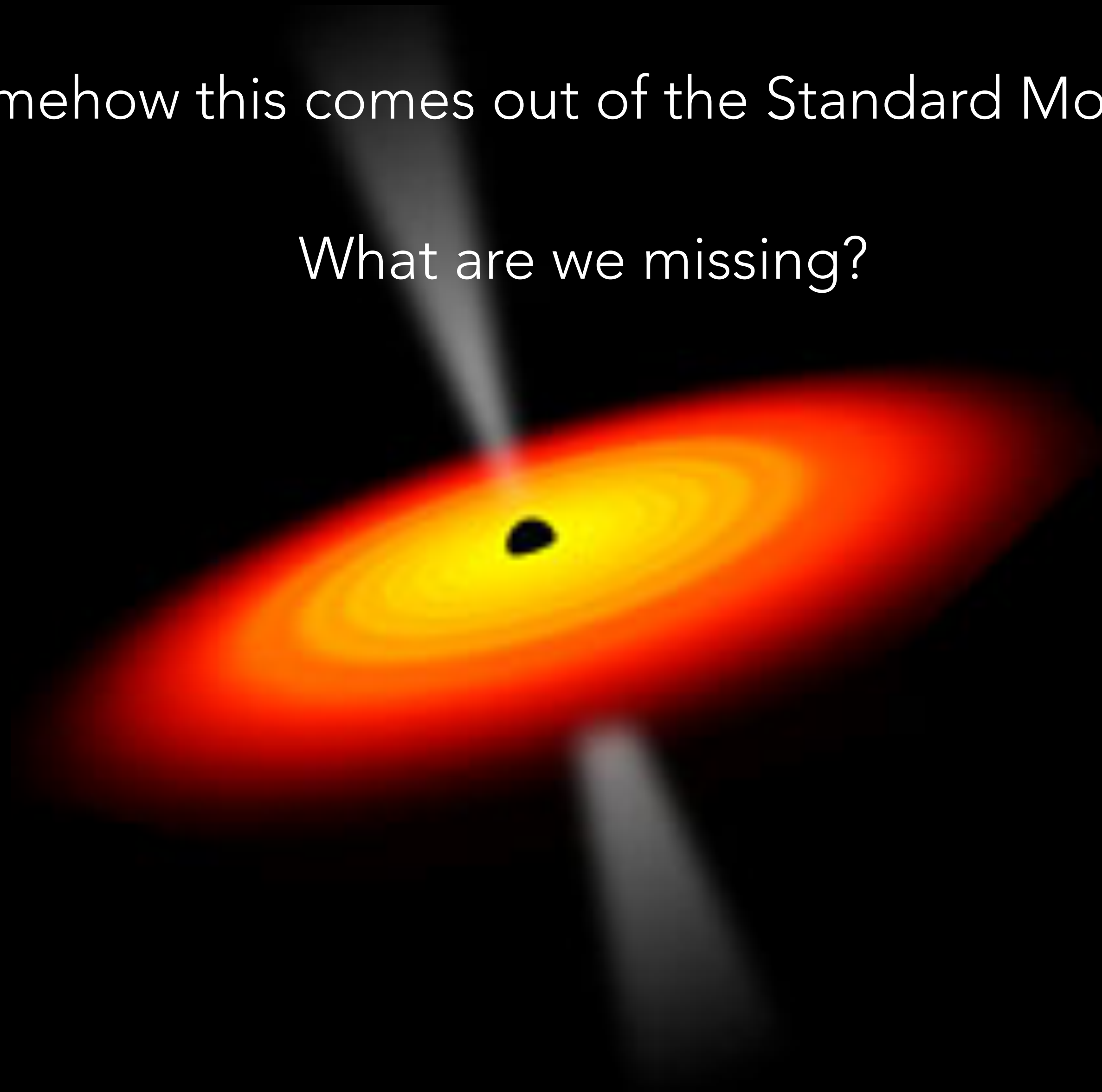
BEL EW contours



We need a Physical Origin for the Broad Emission Line Region

Somehow this comes out of the Standard Model

What are we missing?



 Martin Elvis, elvis@cfa.harvard.edu

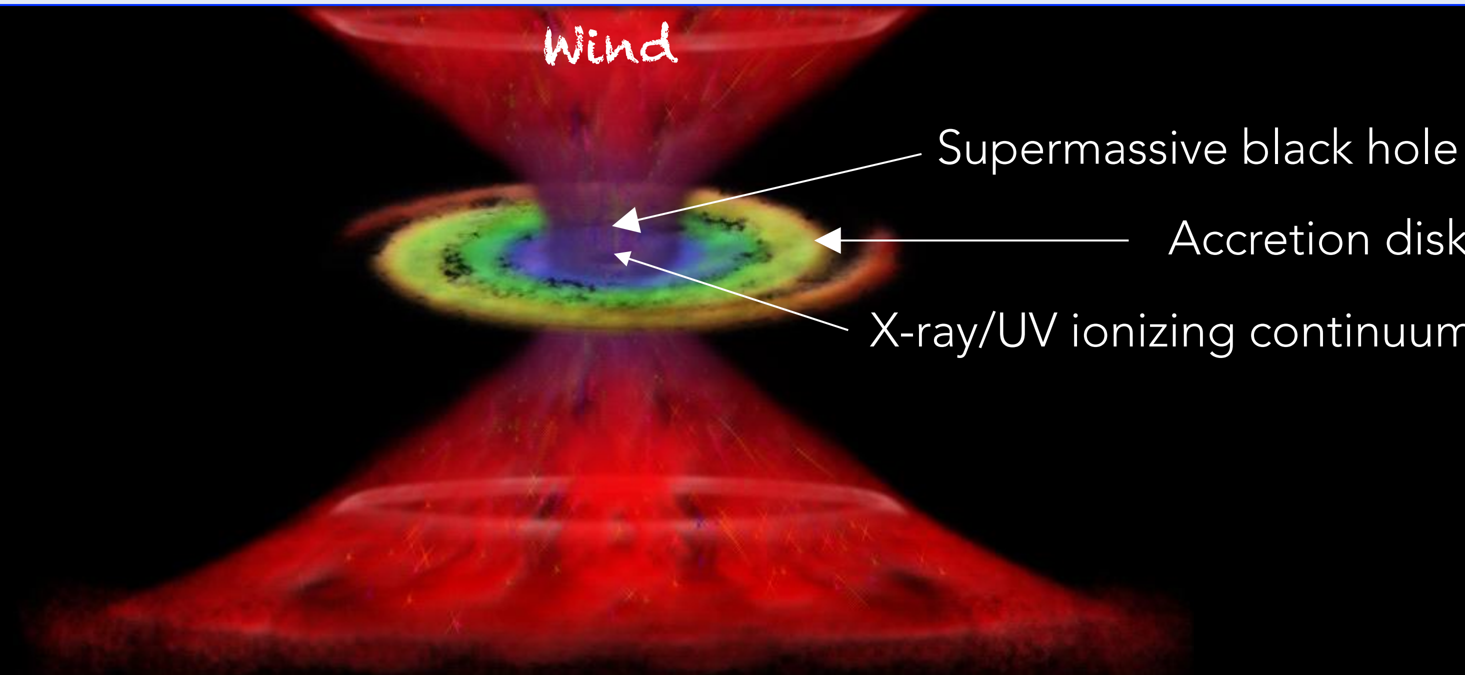
Disk Winds are the new-ish piece of the Standard AGN Model

Radiation Line Driven Winds arise naturally from an accretion disk

Murray et al. 1995, Murray & Chiang 1995, Proga 2000

My suggestion:

Physics of Disk Winds produce the Broad Emission Line Clouds



Accelerating hollow bi-conical disk wind

Elvis, 2000

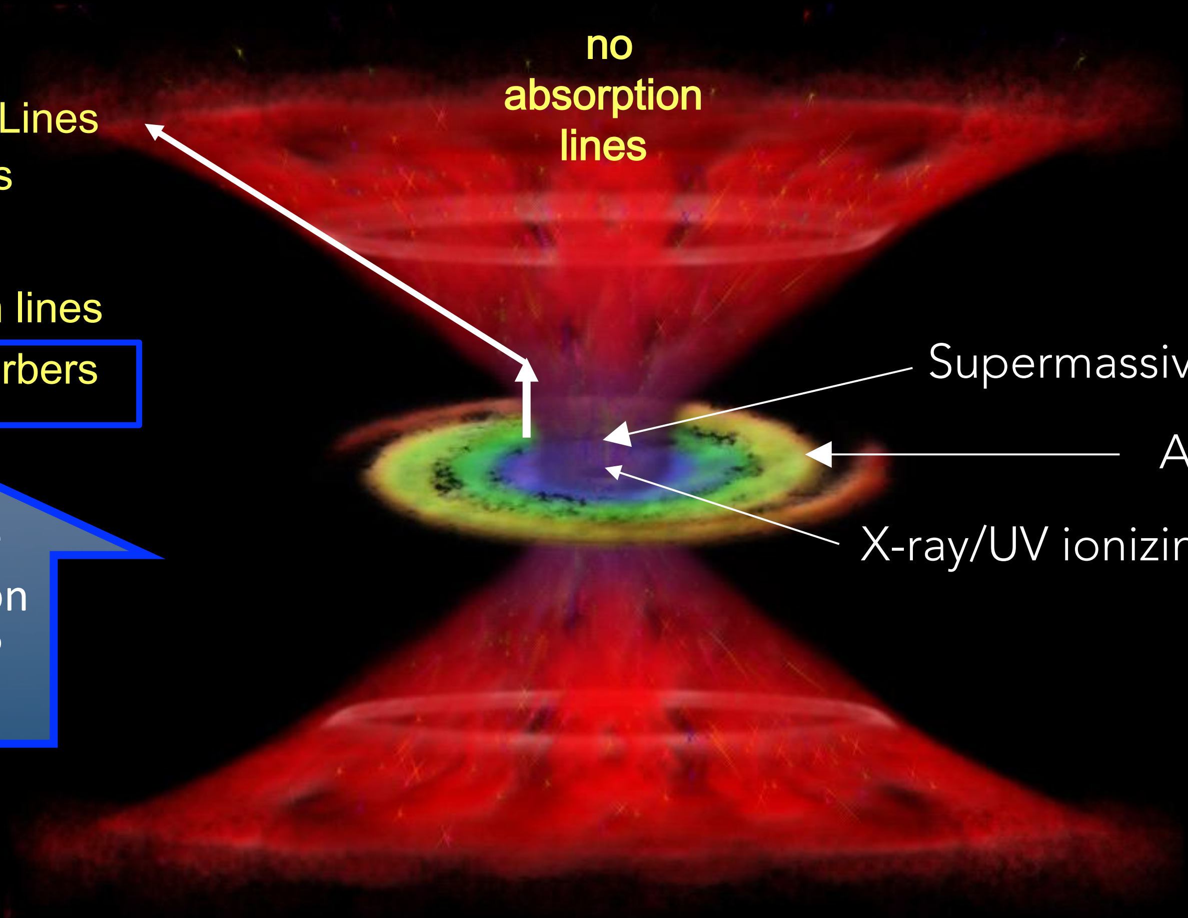
Disk Winds can explain many Quasar Atomic Features

Bi-conical Narrow Line Region

- Broad Absorption Lines
- Reflection features

- Narrow absorption lines
- X-ray `warm' absorbers

Origin of the Broad Emission Line Region?



Gas Illuminated by a Quasar Continuum is unstable

- Makes 2 - 3 co-existing stable phases
  Krolik et al. 1981, Chakravorty+08,09, 12
- Warm phase is X-ray/UV Warm Absorber
- Cool phase is at BELR temperatures

"A cool mist in a warm wind"

Elvis, 2016, ApJ, in press

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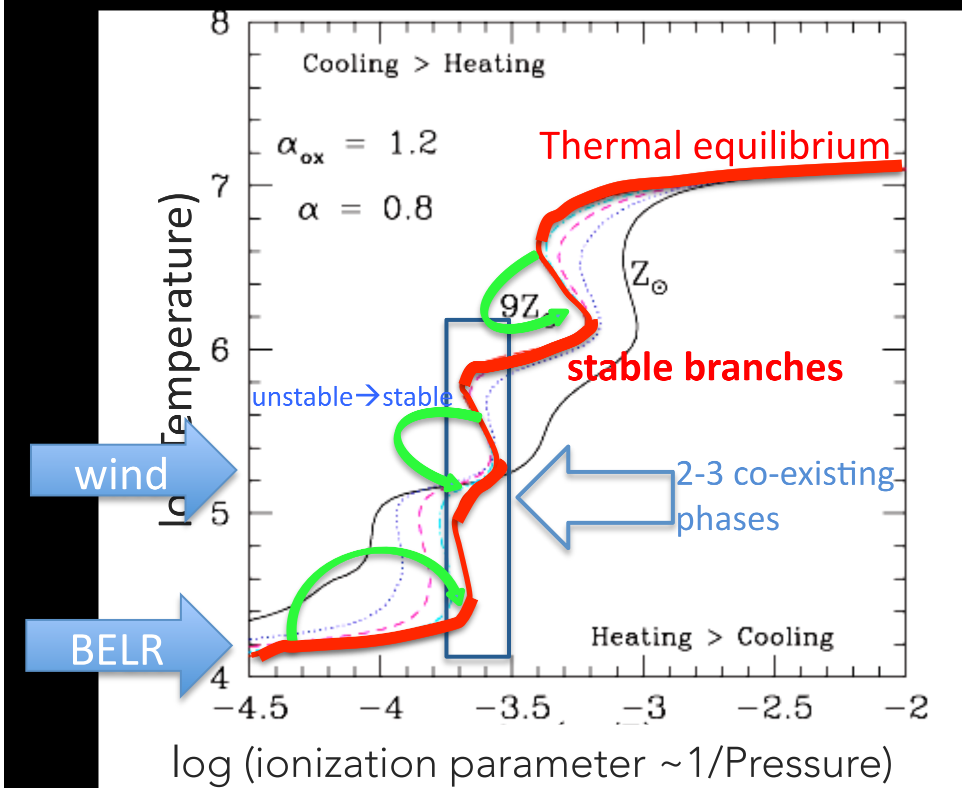

Physics:

- Clouds condense out of the wind
  - in ~days << escape time
- Driven to stable (P,T) regions
  - by UV/X-ray variability
  - changes force multiplier in line driven wind
  - rapidly changing acceleration i.e. a "jerk"

Cool clouds cannot accelerate & fall back, making "Quasar Rain"

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Elvis, 2016, ApJ, in press

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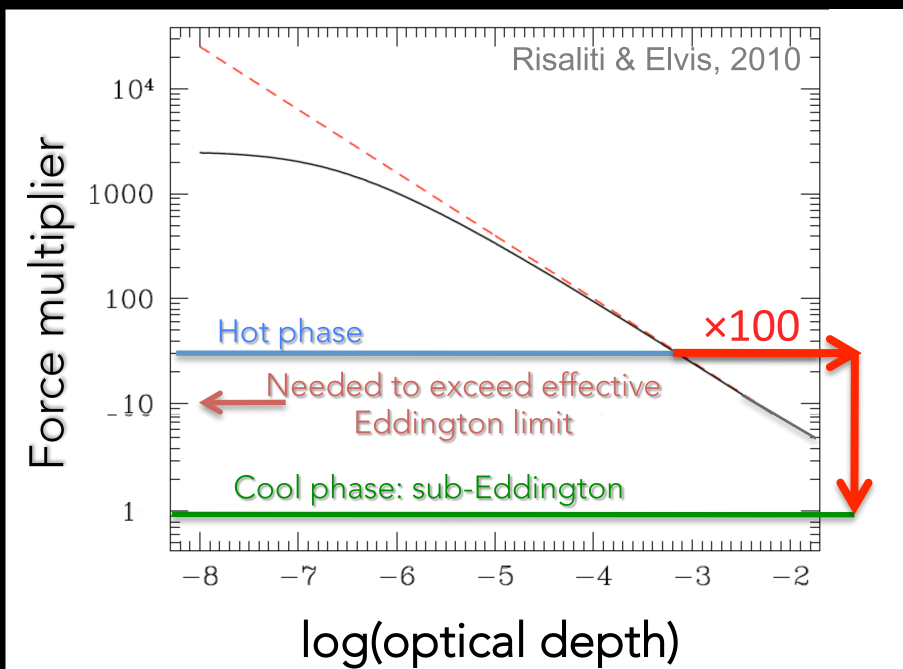
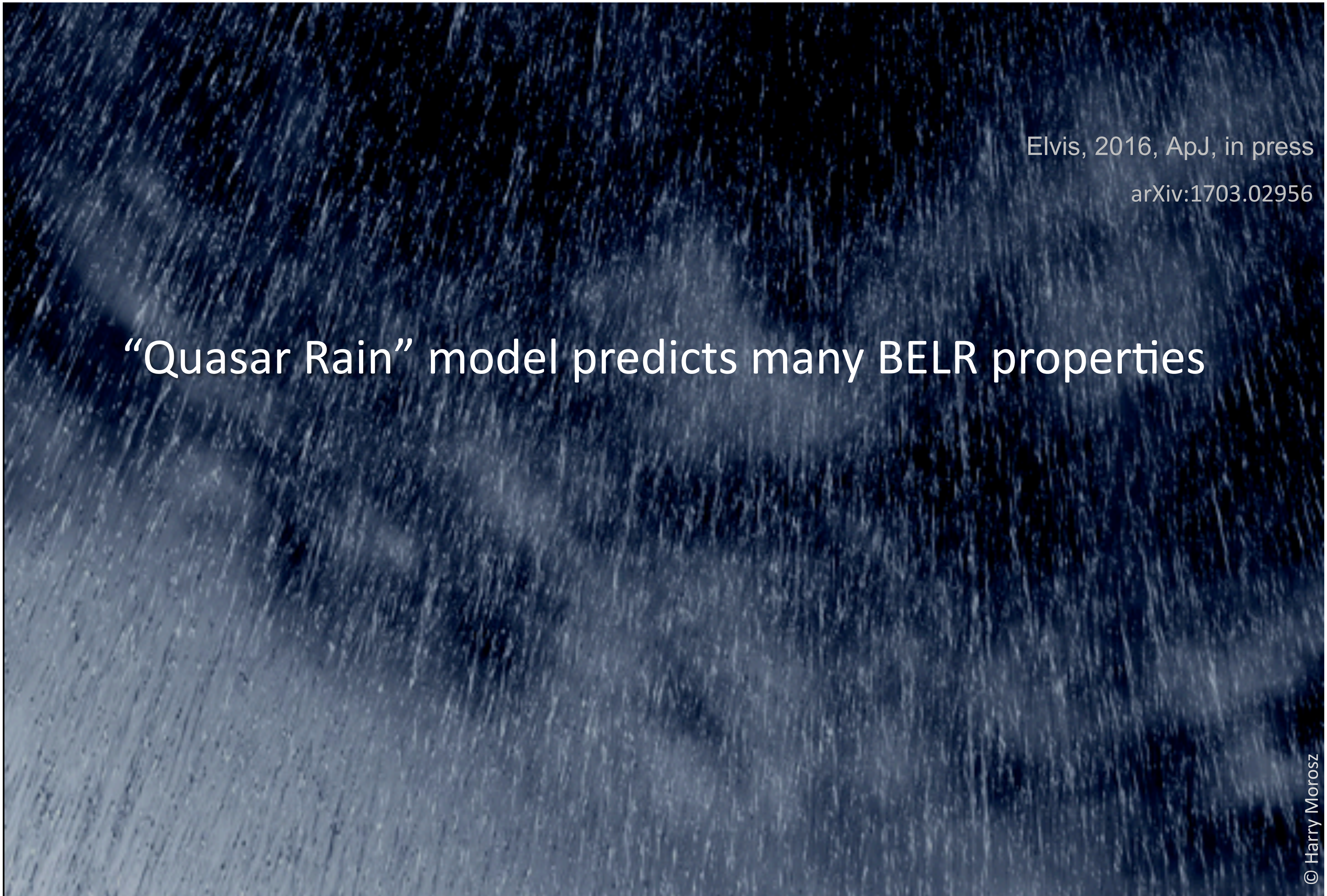
Force multiplier due to radiation line driving drops to 1 in cool clouds.
Clouds become ballistic.



Cool clouds now sub-Eddington
Can't reach escape velocity

Fits the rotating, infalling kinematics of the Broad Emission Line Region
Large scale height likely [TBC]



"Quasar Rain" model predicts many BELR properties

Infalling "raindrops" are Supersonic in the Wind

Mach ≥ 20: Clouds are ripped to shreds

Elvis, 2016, ApJ, in press

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Cloud crushing timescale, $\tau_{cc}=2\chi^{1/2}r_c/Mc_s$ = 10 – 120 days ~ months

e.g. SNR, Patnaude & Fesen (2014)

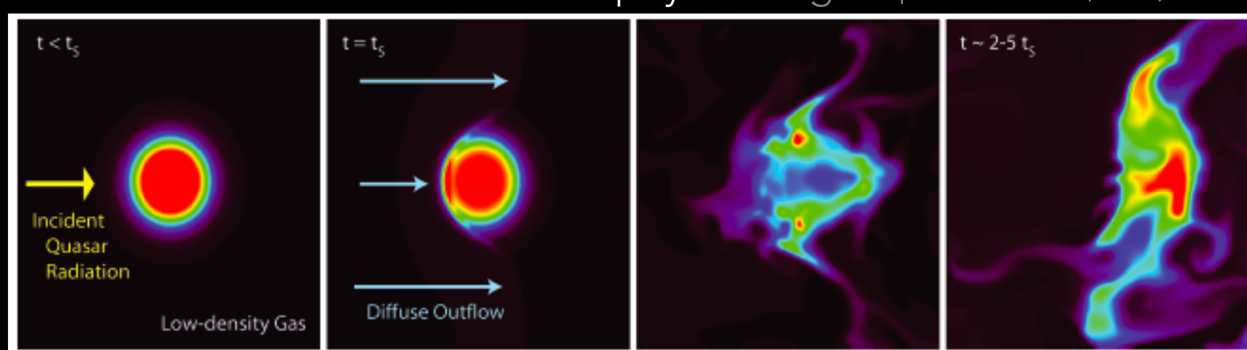
Rayleigh-Taylor unstable

Physicscentral.com, Jsmes Riordan

Kelvin-Helmholtz waves at edges

Amusingplanet.com

Common situation in astrophysics. e.g. Hopkins & Elvis (2010)



Ablating "raindrops" are seen in X-ray Eclipses

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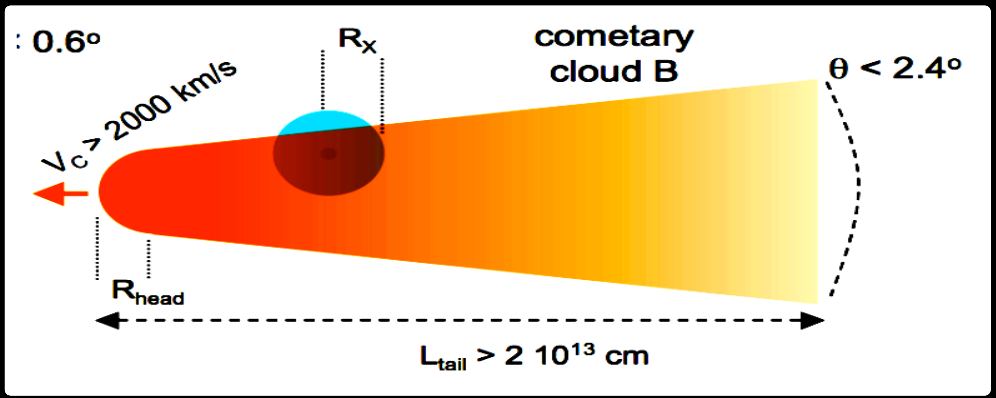
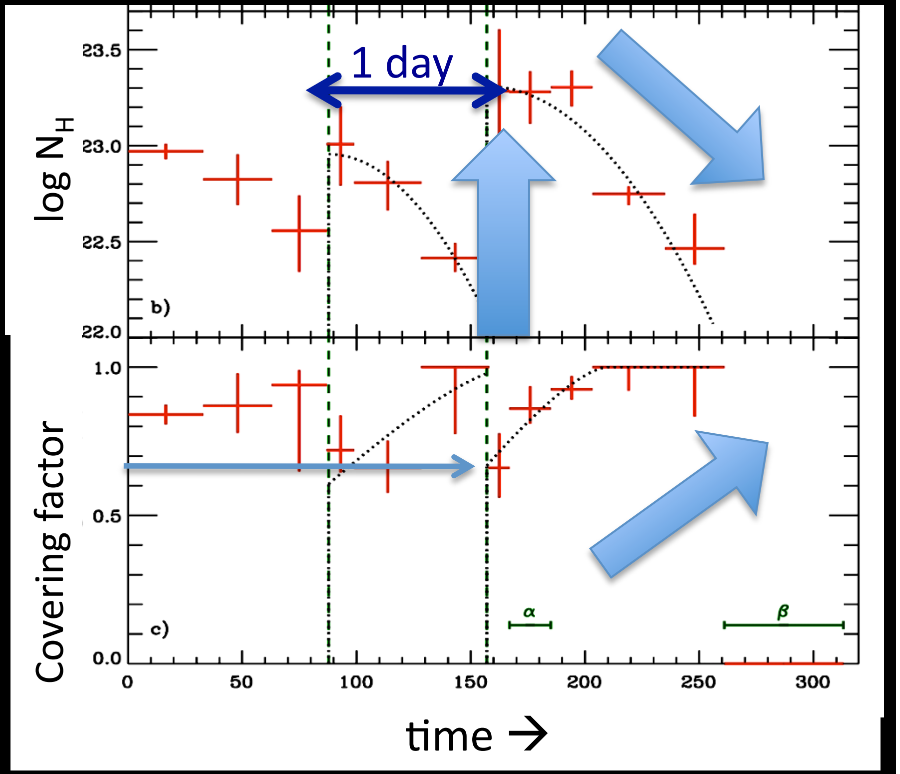
- NGC1365 X-ray eclipsing clouds
- N_H rises fast at low covering factor, f_c
- Then N_H drops as f_c increases
- "Cometary" tail – non-radial
- Broad emission line velocities ✓
- Few degree opening angle ✓
- Lifetime ~60 days ~months ✓





Maiolino et al. 2012

Explains Baldwin Effect?

Elvis, 2016, ApJ, in press

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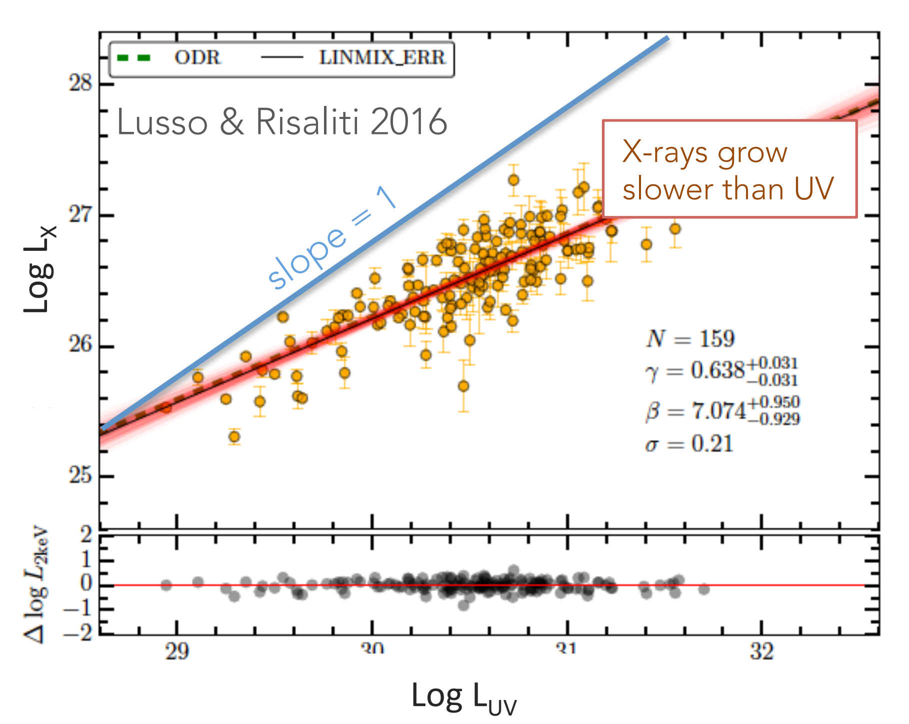
Escape time, τ_{esc} shorter for larger Force Multiplier, $\mathcal{M}$

Larger $\mathcal{M}$ if X-rays are weak. Murray et al. 1985

X-rays are weaker at high L_{UV} Lusso & Risaliti 2016

→ Less time for broad line clouds to form

→ Lower EW broad emission lines = Baldwin Effect?



Explains constant density broad line clouds?

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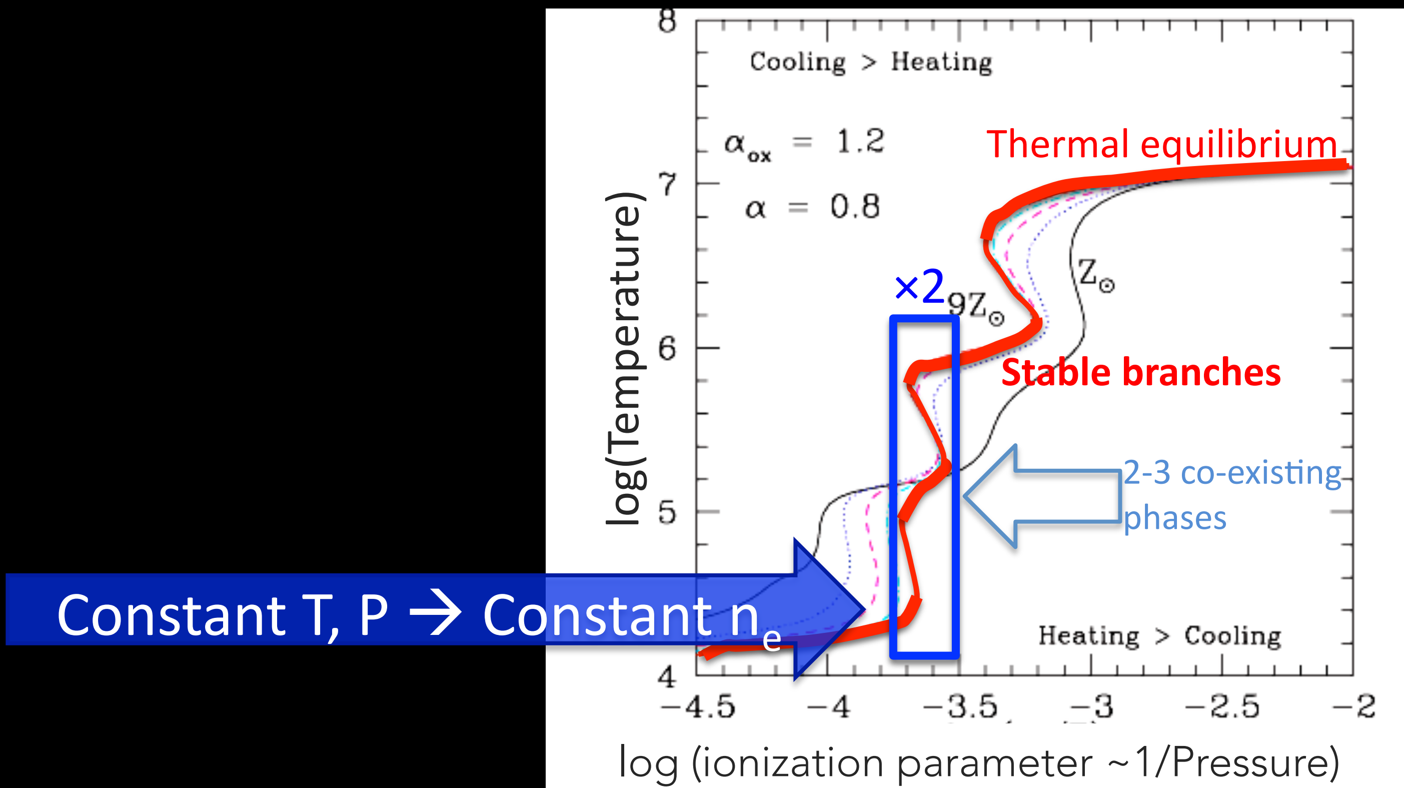
Constant density clouds due to narrow multi-phase zone?



Constant Density Broad Emission Line Clouds fit the scaling relations

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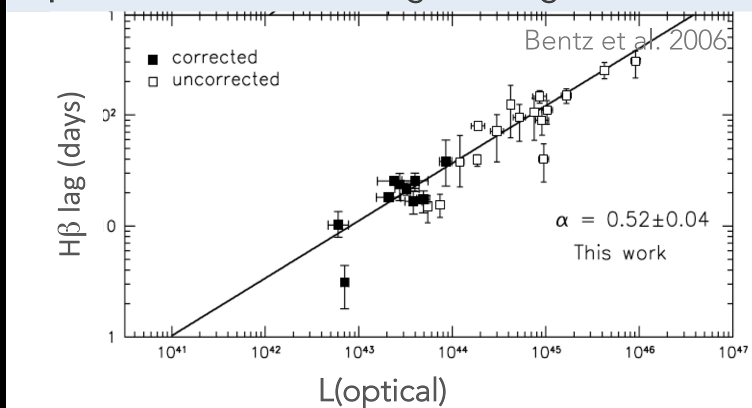
The polar opposite of the Locally Optimally Emitting Clouds model

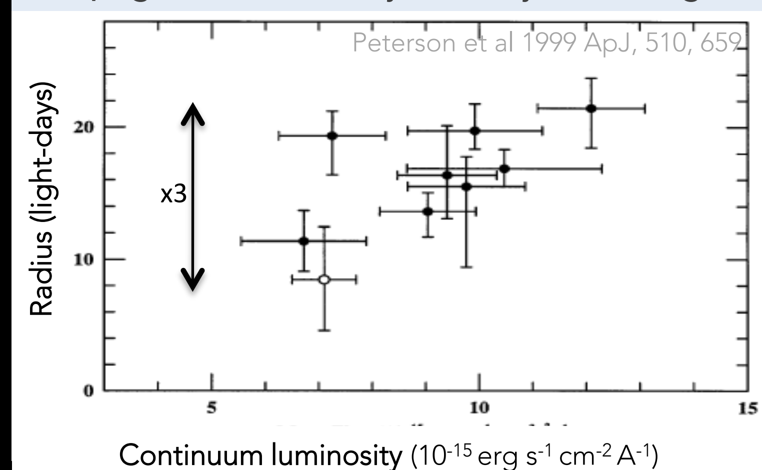
- Prediction of the quasar rain model
- A physical consequence of line-driven accretion disk winds
- Occam's quasar™ prefers the simpler approach

™ James Matthews

Hβ Broad Emission Line Region size grows as $L^{1/2}$



r (Hβ) grows as $L^{1/2}$ in year-on-year changes



Quasar Rain: Closer to Solving Quasars?

Elvis, 2016, ApJ, in press
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- Physics-based
  - Treats wind more realistically
  - Fits BELR geometry, kinematics
- Unifies:
  - Broad Line Region clouds
  - Low Ionization X-ray Warm Absorber
  - X-ray eclipsing clou
- Explains more than p
  - Cometary tails on X
  - Constant density clouds
  - Baldwin effect?
- Appealing:
  - Complex phenomenology largely explained
  - No arbitrary new "region"

Disk winds are all you need

- *Satisfies "Occam's Quasar"* ©*James Matthews*

Thank You

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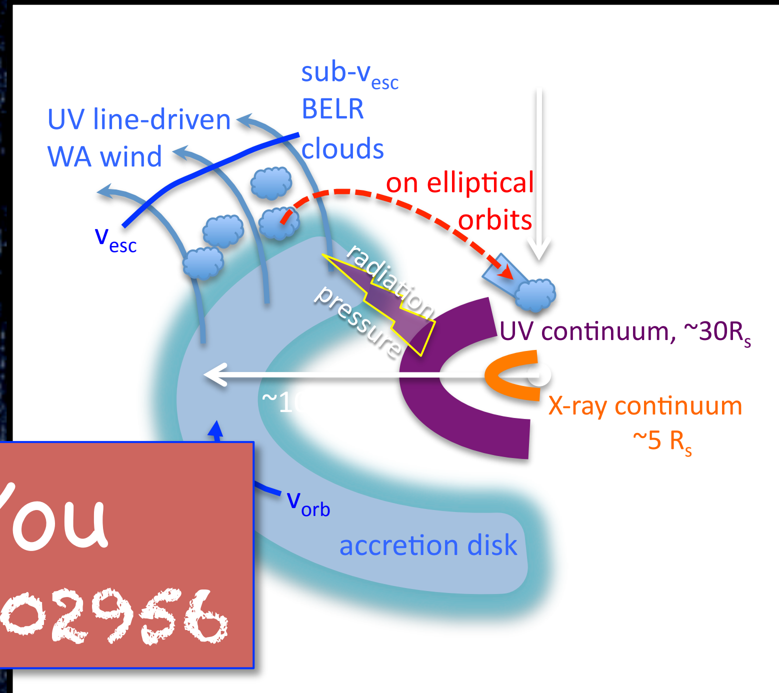

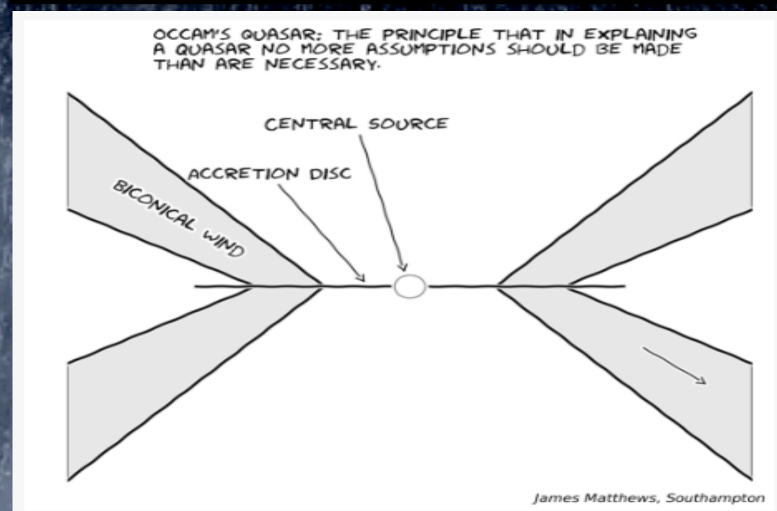

A Cool Mist in a Warm Wind

There is much to be done:

1. How is τ_{cool} is changed in a photoionized gas?
2. Can X-ray/UV variability drive WA gas to stable branches on the S-curves?
3. How are the S-curves altered when $\tau_X \sim \tau_{cool}$?
4. Can large clouds reach v_{esc} and so form the narrow emission line region?
5. Can the Baldwin effect be explained by the larger τ_{esc}/τ_{cool} ratio in high luminosity quasars?
6. What will be the scale height of different lines? (Eq. of motion approach?)
7. Do some lines (e.g. OVI) originate in the warm phase?
8. Hydrodynamic line-driven wind simulation – does it validate model?

Thank You Again

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But not … e skills.

And I am busy mining asteroids ☺

Fog Waterfall, Iceland (Kjartan Gunnsteinsson c/o Daily Mail, 8 July 2015)