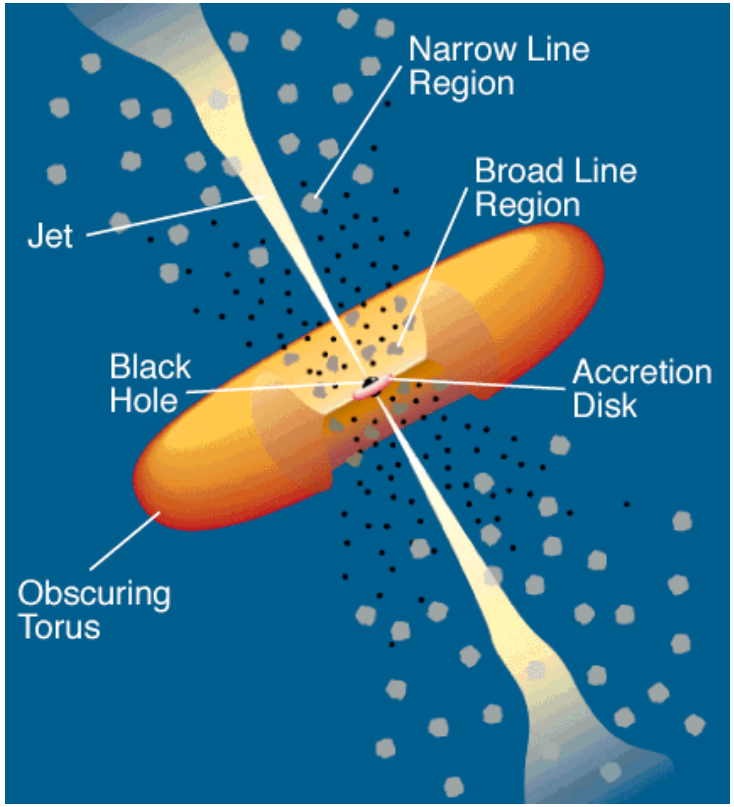
Echo Mapping of the Broad Emission-Line Region in NGC 5548

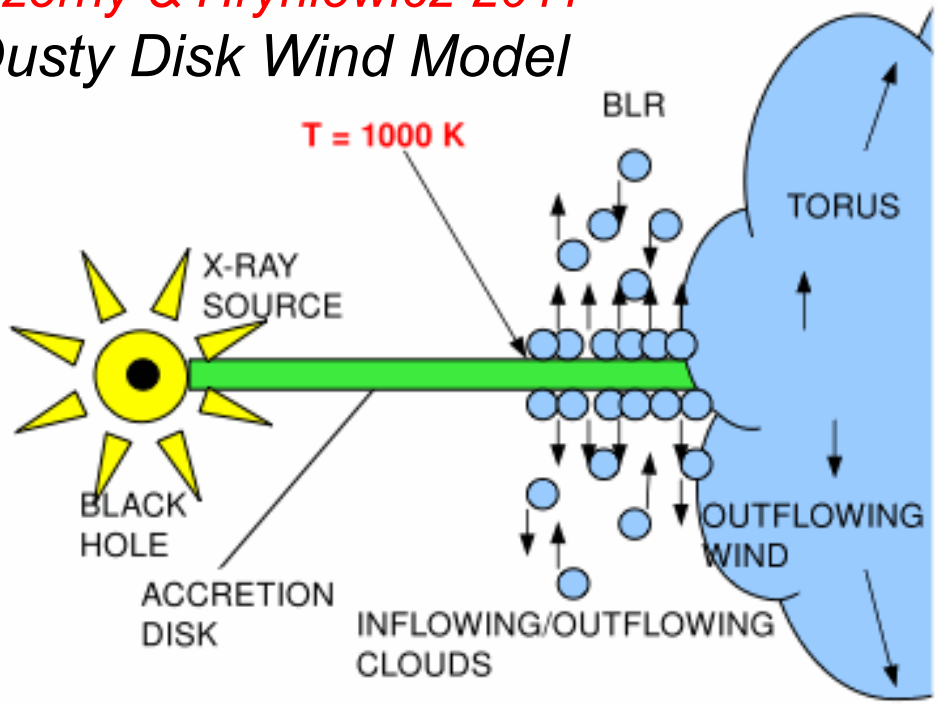
Keith Horne : SUPA/St Andrews
and the AGN STORM Collaboration



Urry & Padovani 1995

Czerny & Hryniewicz 2011

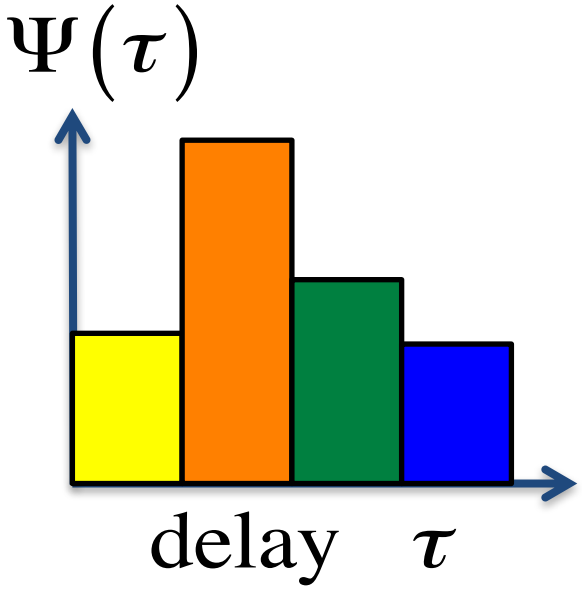
Dusty Disk Wind Model

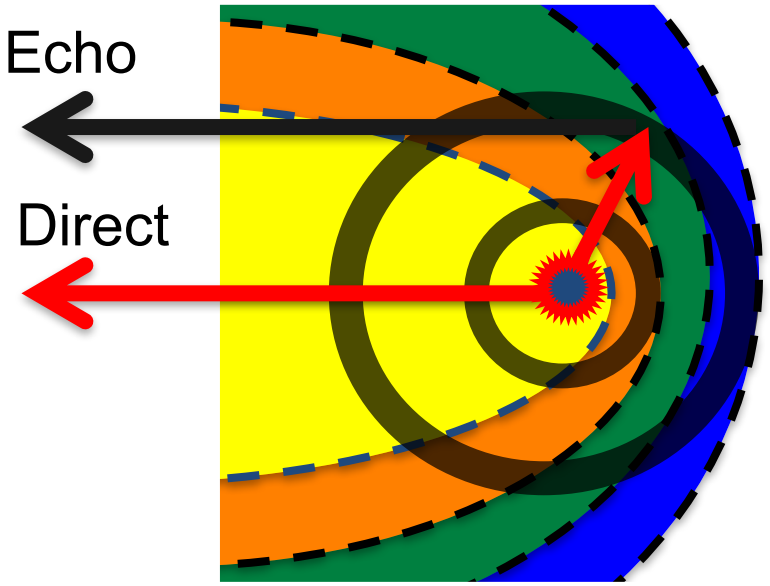


BH	Disk	BLR	Torus
hours	days	weeks	months

Echo Tomography
= "Quasar Mircoscopy"

Light travel time delay τ "slices up" the region on iso-delay paraboloids. => micro-arcsec resolution.





$$\tau = \frac{R}{c}(1+\cos\theta)$$

MEMEcho fits

Lightcurves => Delay Maps : $\Psi(\tau)$

Emission-Line Lightcurve

L(t)

\+

Continuum Lightcurve

C(t)

\+

Maximum Entropy Fit

=

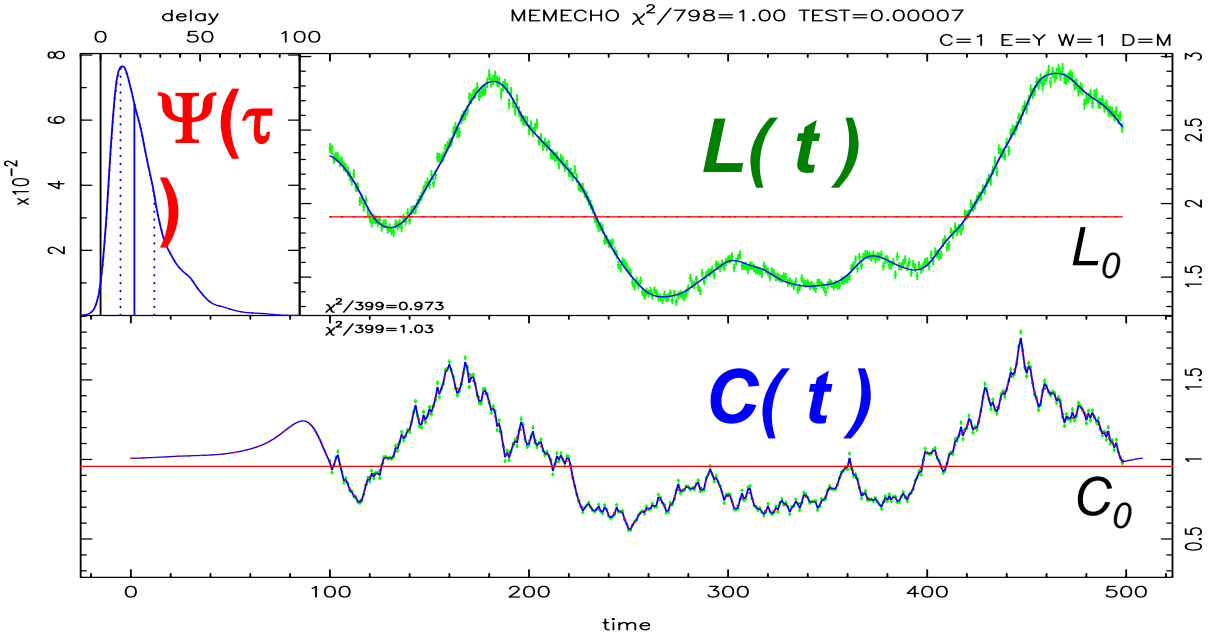
Delay Map

Ψ(τ)

Linearised echo model:

Continuum: $C(t) = C_0 + \Delta C(t)$

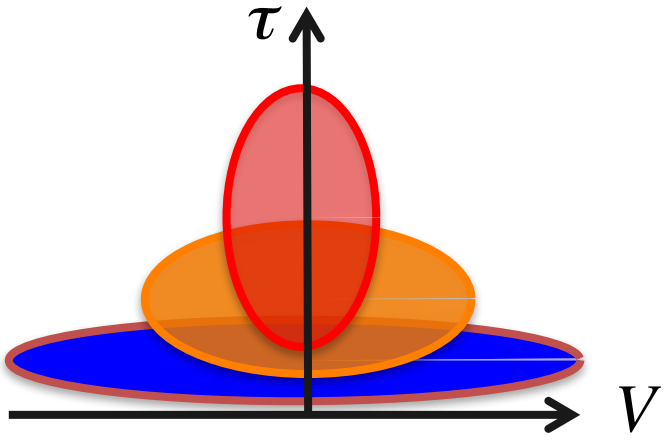
Line: $L(t) = L_0 + \int_0^{\tau_{max}} \Psi(\tau)\, \Delta C(t-\tau)\, d\tau$



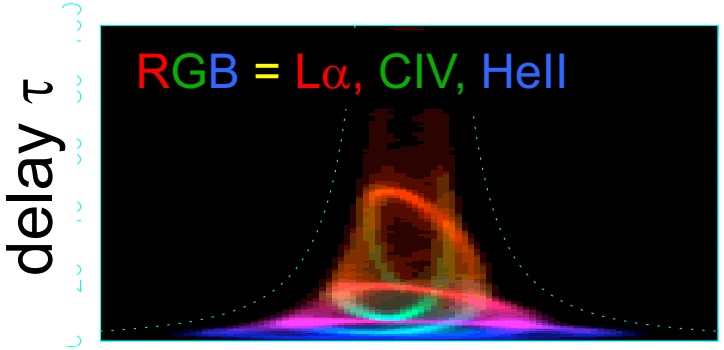
model parameters : $C(t)$, L_0, $\Psi(\tau)$.

Simplest (smoothest) model that fits the data.

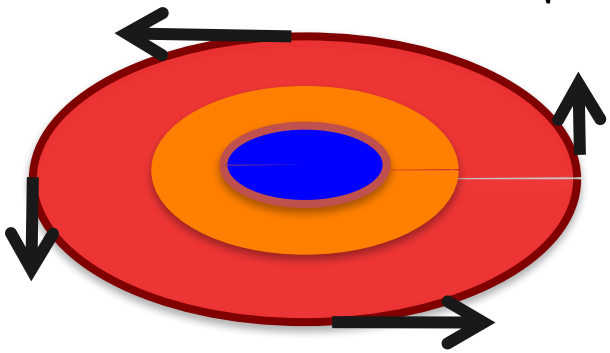
2D : Velocity-Delay Maps $\Psi(v, \tau)$



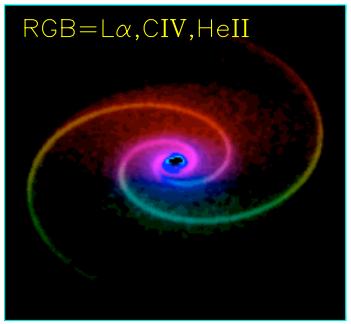
Simulation: Photo-ionised Keplerian disc with spiral density waves



$$\tau = \frac{R}{c}\left(1 + \sin i \cos\theta\right) \qquad V = \sqrt{\frac{GM}{R}} \sin i \sin\theta$$



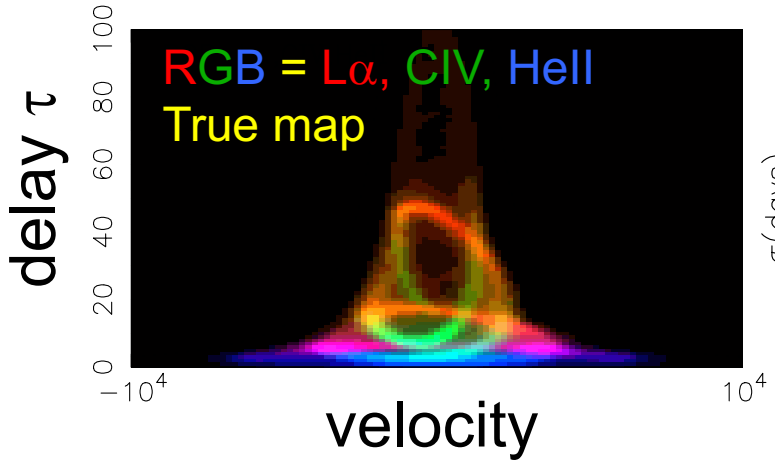
sky view:

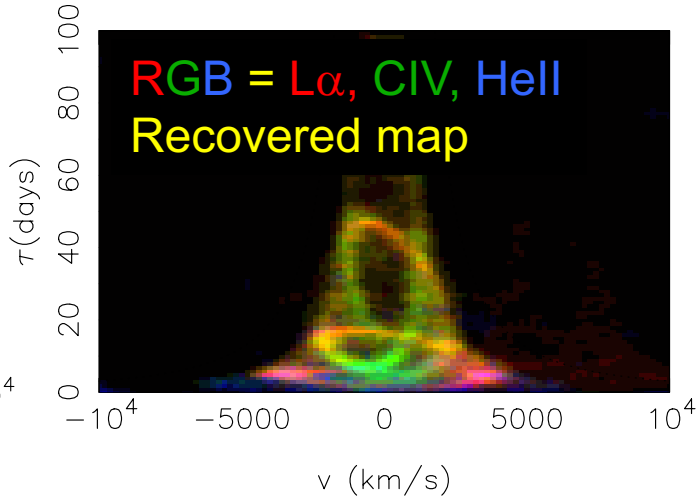


Horne et al. 2004

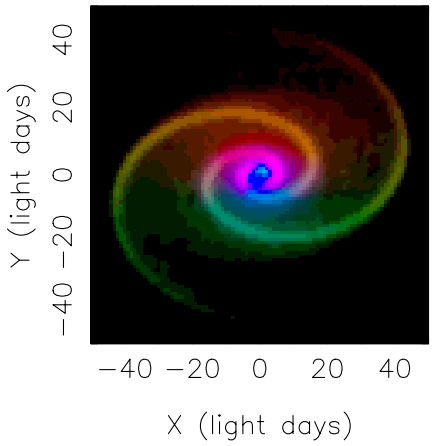
Velocity-Delay Maps : $\Psi(v, \tau)$ recovery from simulated HST/COS data

MEMEcho recovers $\Psi(v,\tau)$ from simulated HST data





sky view:



Evident features:

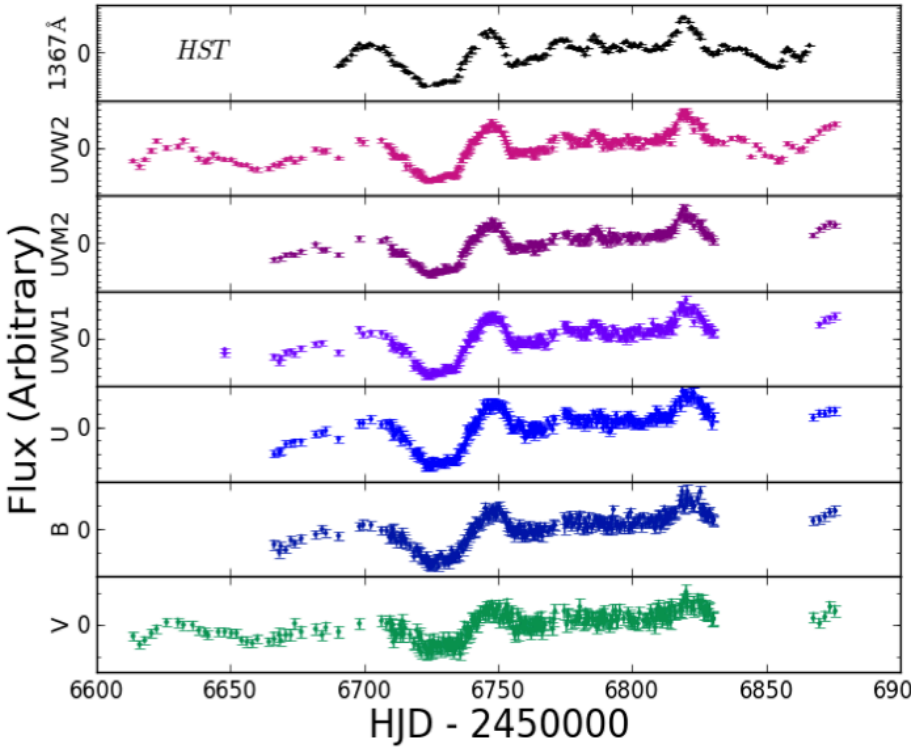
- Virial envelope
- Spiral structure
- Radial ionisation
- Azimuthal anisotropy

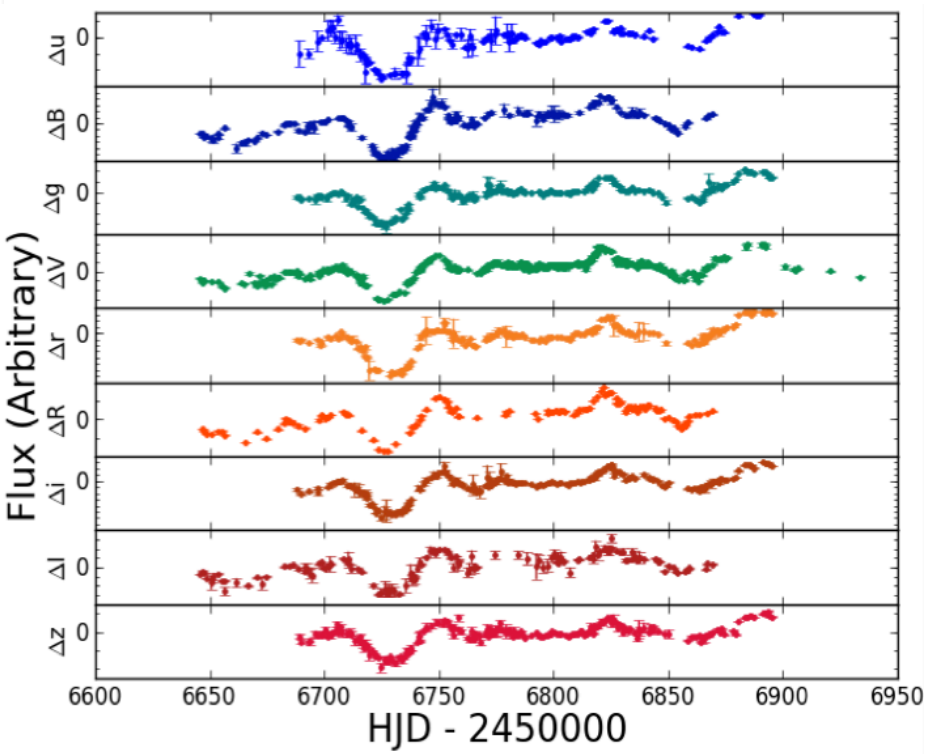
Horne et al. 2004

2014 STORM : UV, optical lightcurves

HST: 1/day SWIFT: 2 /day

Ground-based > 600 epochs

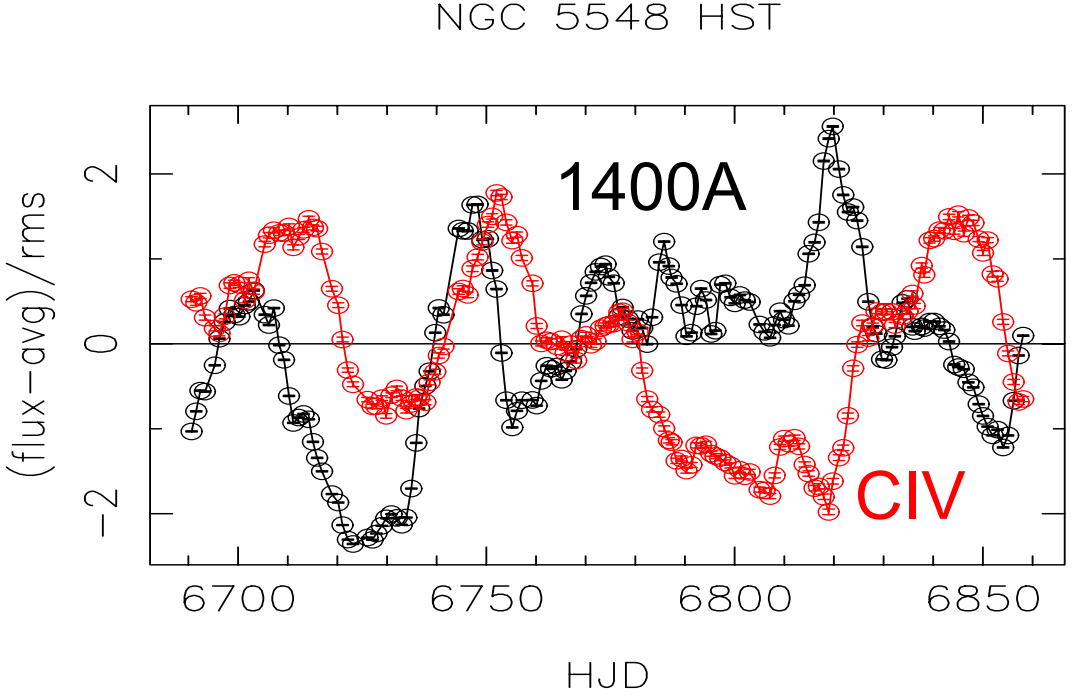




Edelson et al. 2015

Fausnaugh et al. 2016

Emission-line variations are NOT simple continuum echos ☹



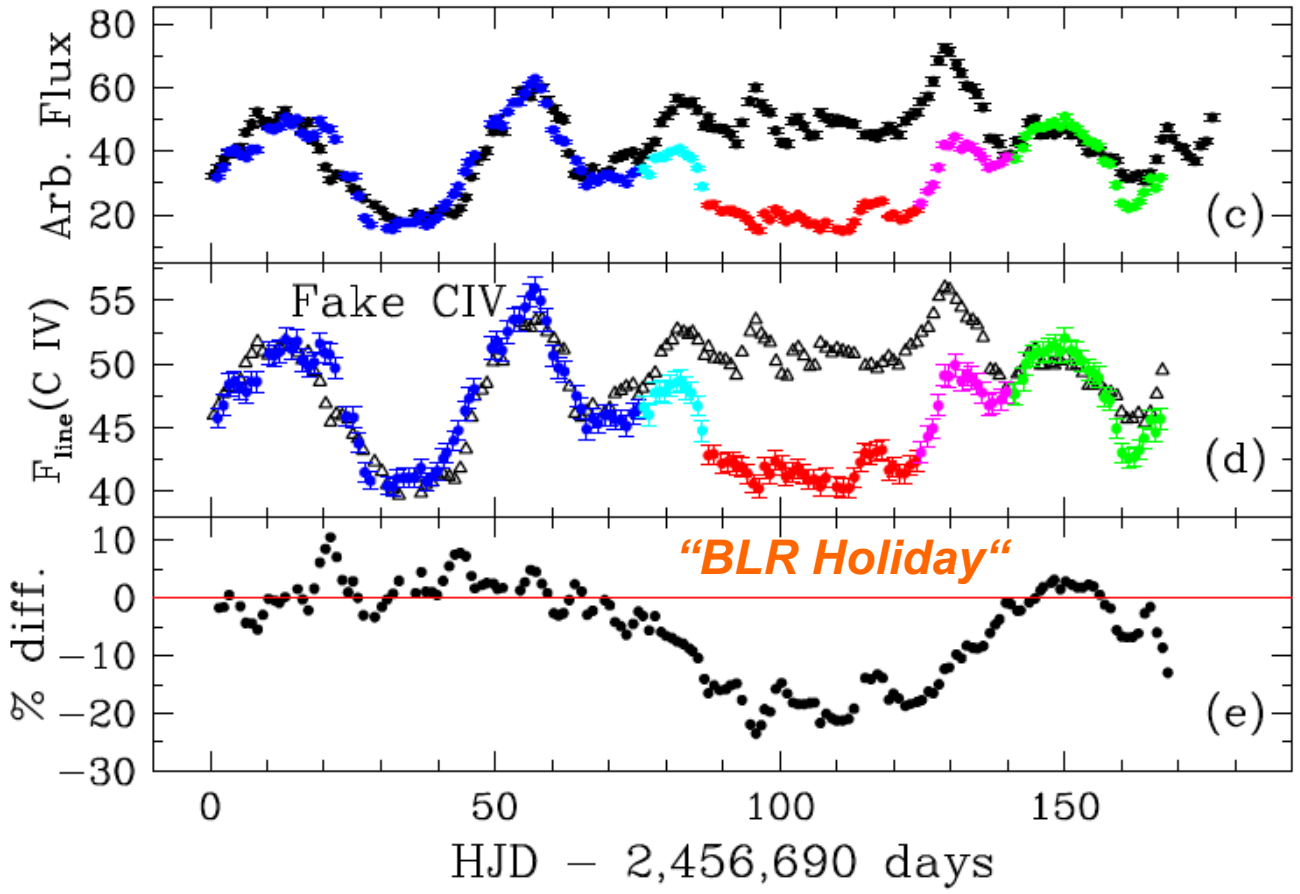
- Fast (5-20d) variations correlate, with clear (5-10d) lags.
- Slow (100d) variations may anti-correlate.

- **Linerarised echo model fails to fit the line variations ☹.**

“BLR Holiday” :

Line responses temporarily weaker

Temporary Obscuration ? Change in the SED ?



20% drop
In CIV flux

Goad, Korista et al. 2016

HST Lightcurves -> Delay Maps : $\Psi(\tau)$

Linearised Echo Model Fails !

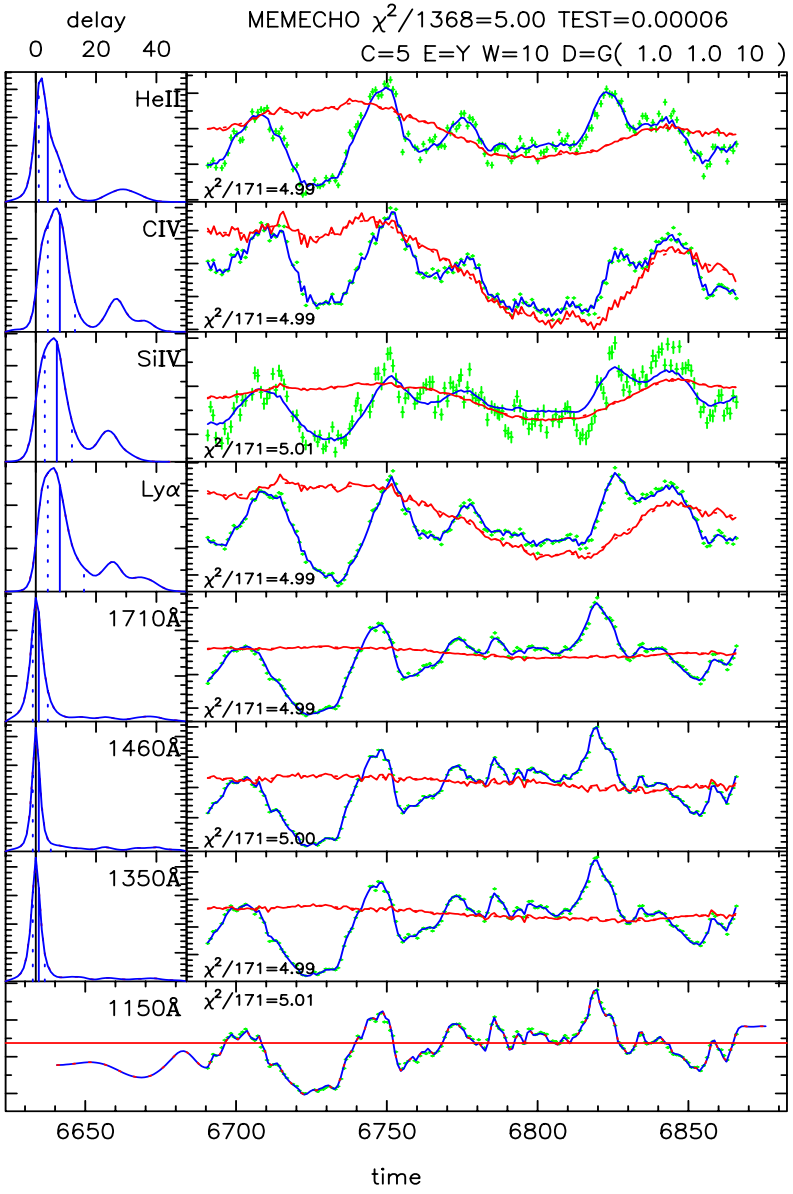
Model lines as

continuum echos

+

slow variations

Adequate approximation



He II

C IV

Si IV

Lyα

1710A

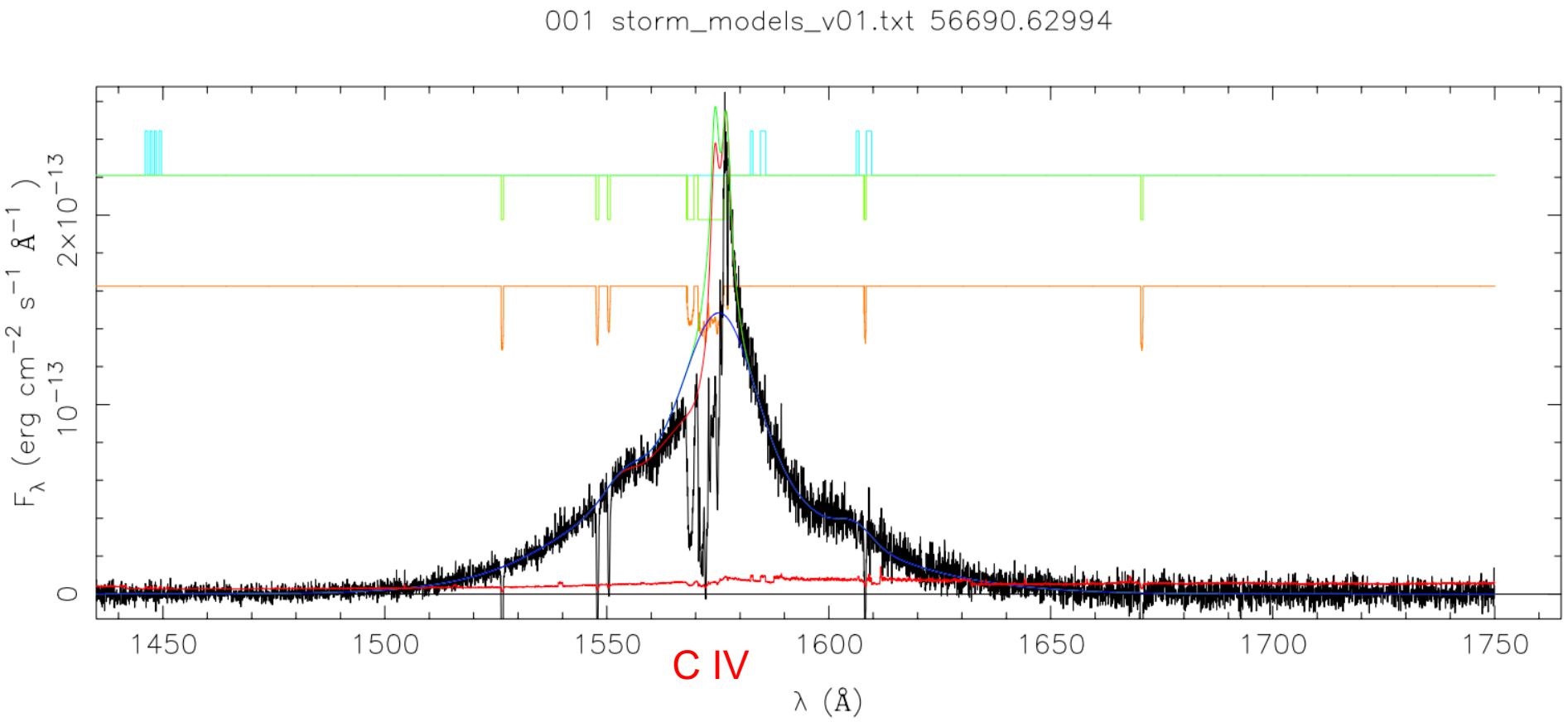
1460A

1360A

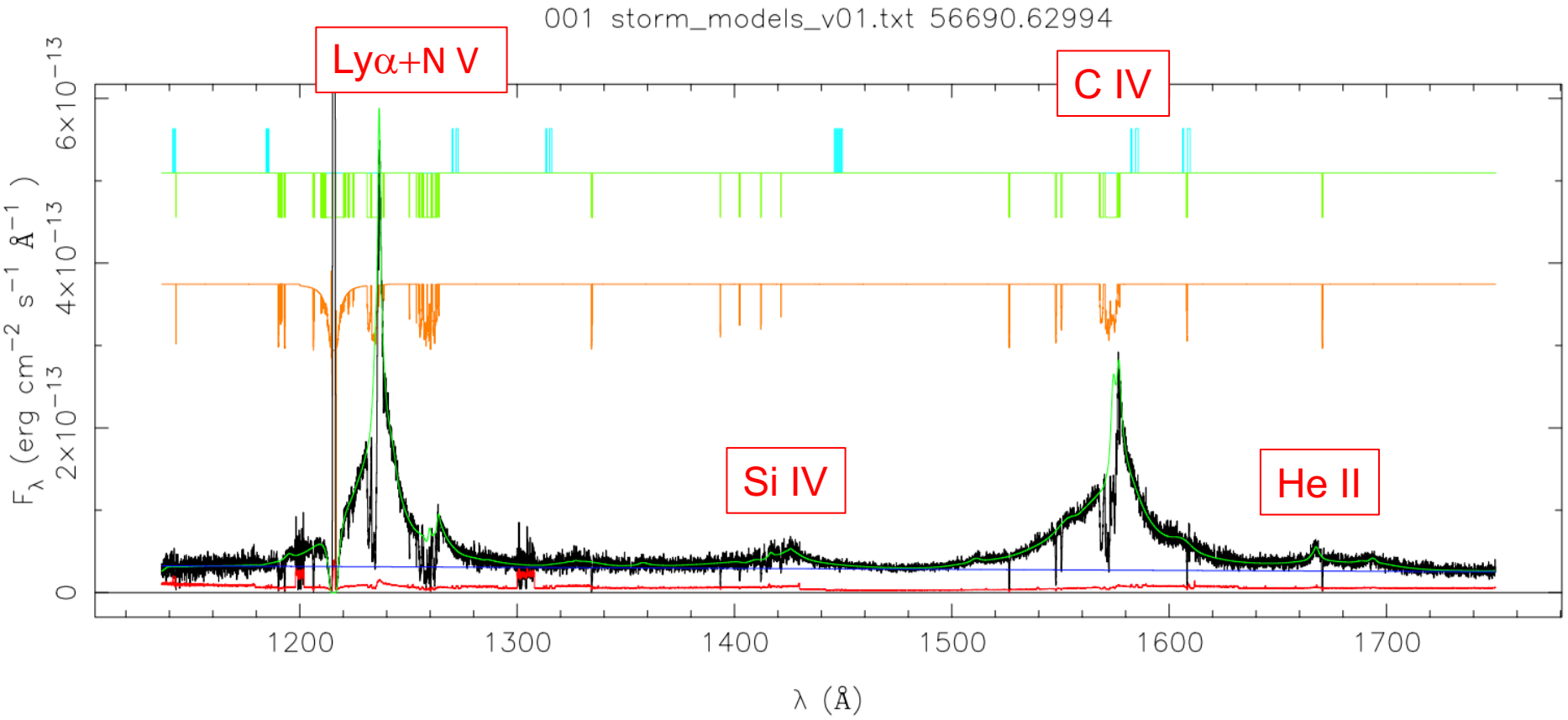
1150A

Spectral Modeling analysis (2016 Jul)

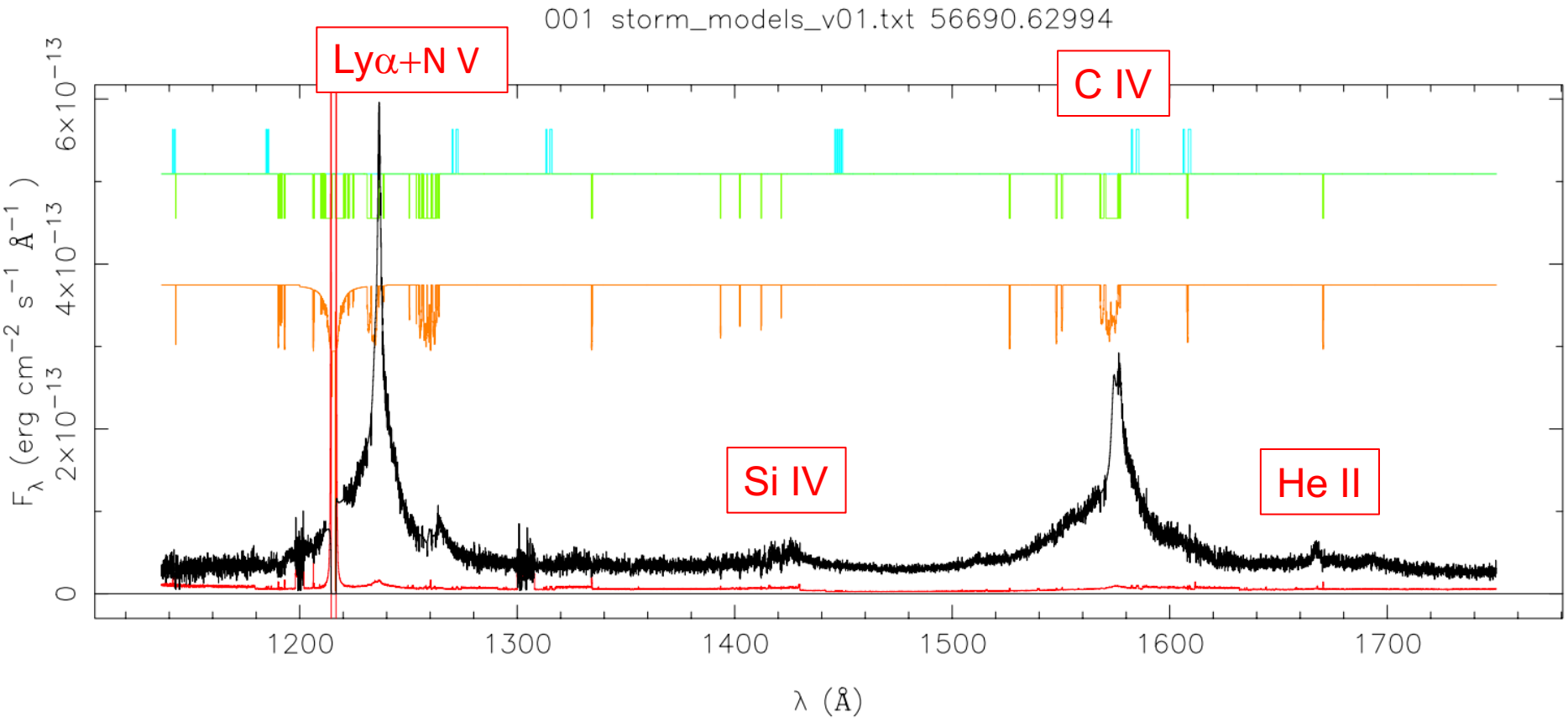
(de Rosa, Ely, Kriss) Use to remove absorption lines.



Absorption Lines Modeled



Absorption Lines Removed ☺



Velocity-Delay Maps : f(λ,t) -> Ψ(v,τ)

HST spectra

f(λ, t)

=>

500 lightcurves

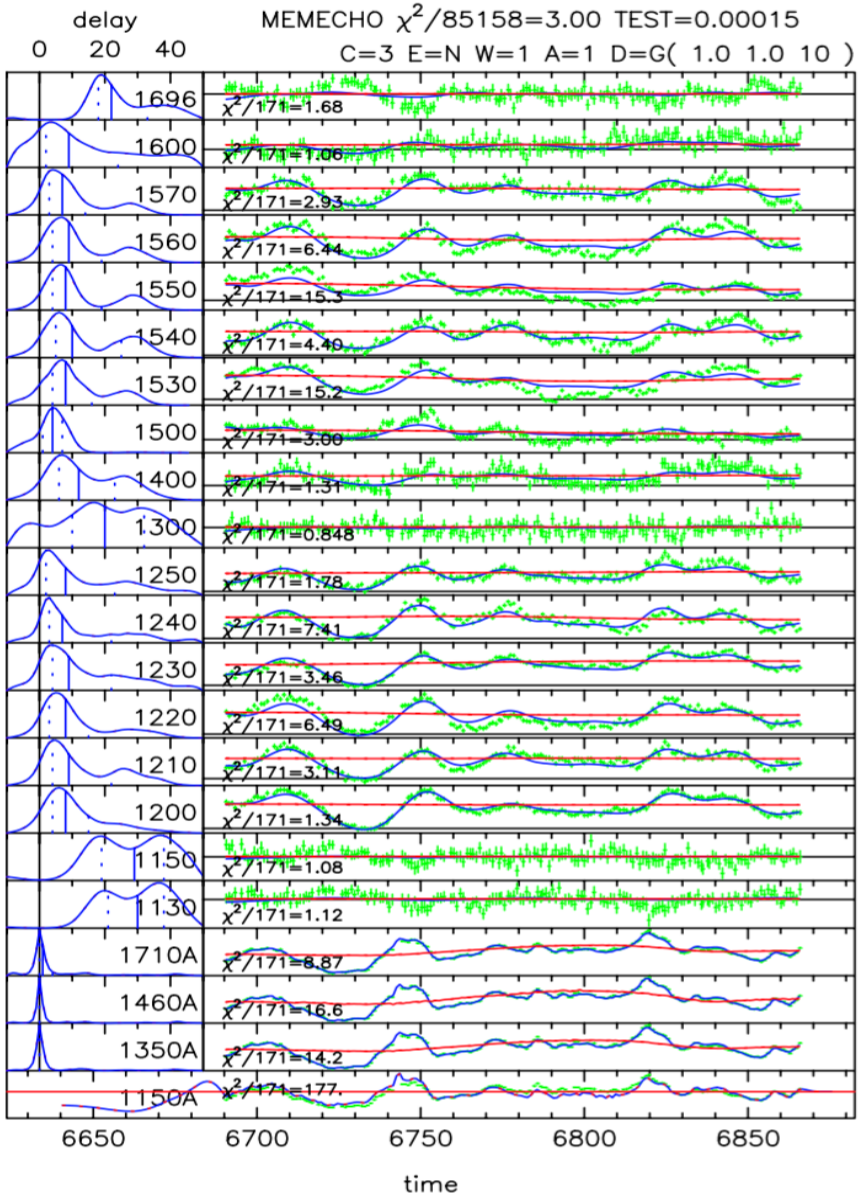
+

MEMEcho fit

=>

500 delay maps

Ψ(v, τ)



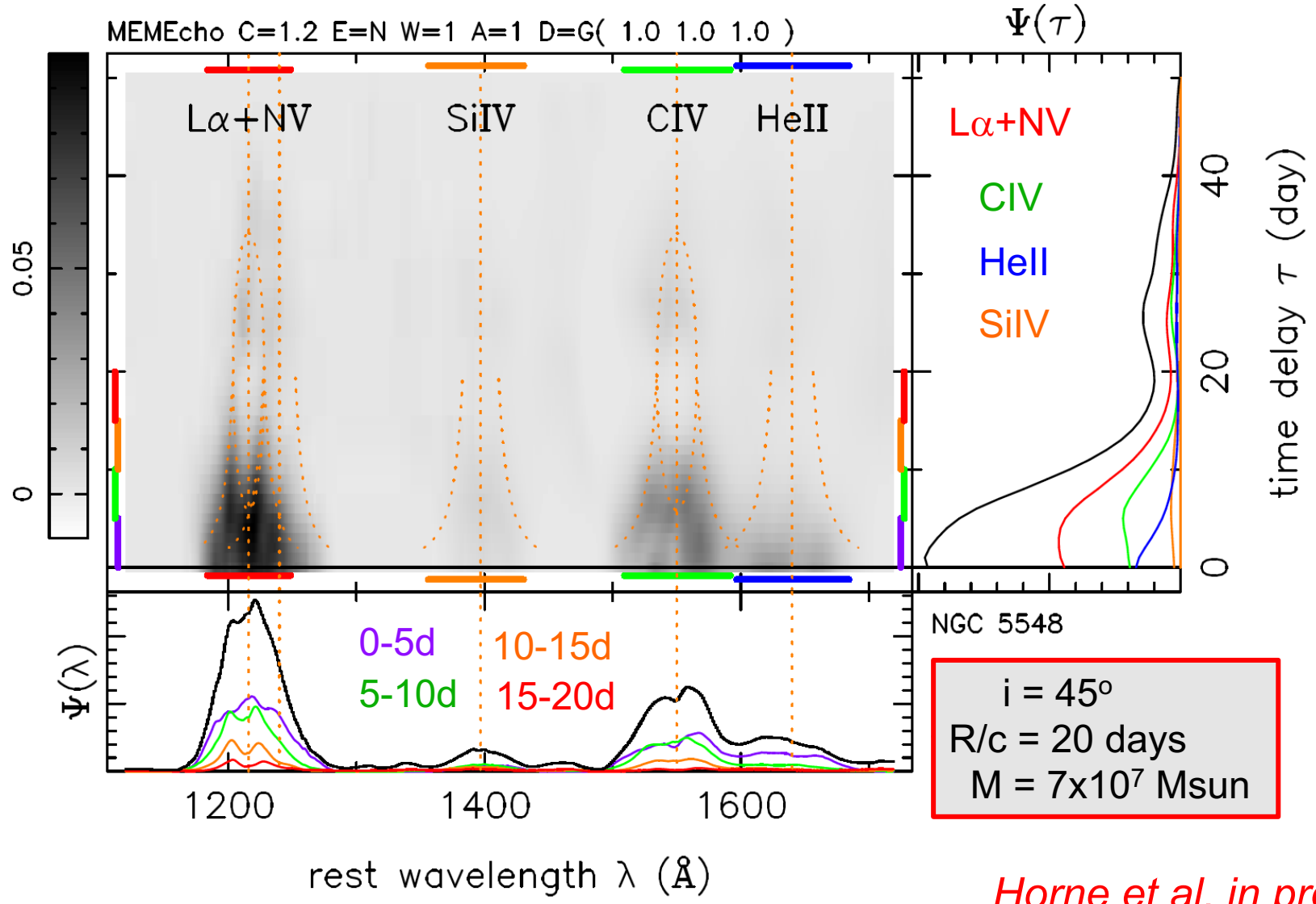
C IV

Lyα

1150-1710 continuum

HST (UV lines) Velocity-Delay Map

MEMEcho fit to HST data from *de Rosa et al*. 2017

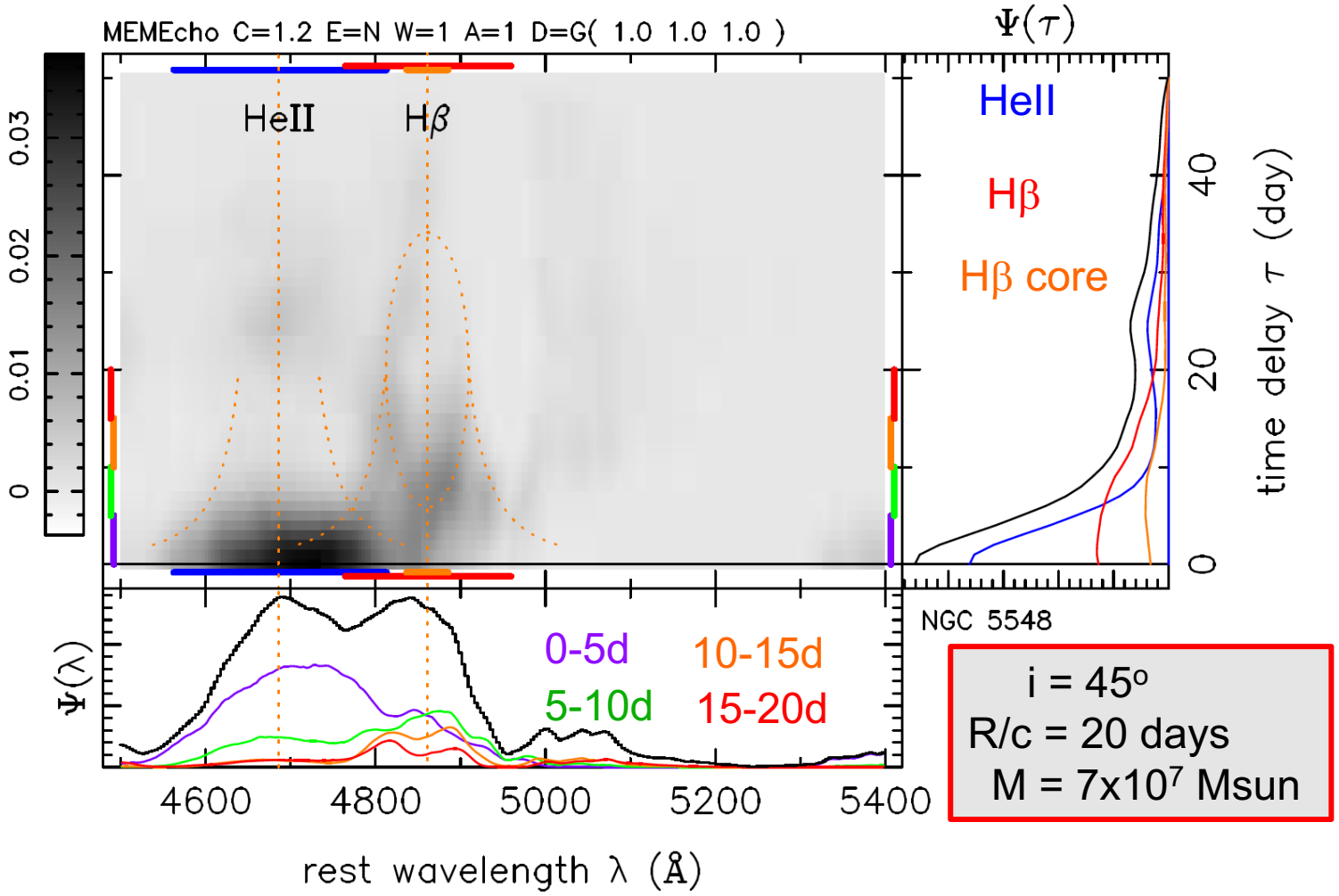


i = 45°
R/c = 20 days
M = 7x10^7 Msun

Horne et al. in prep

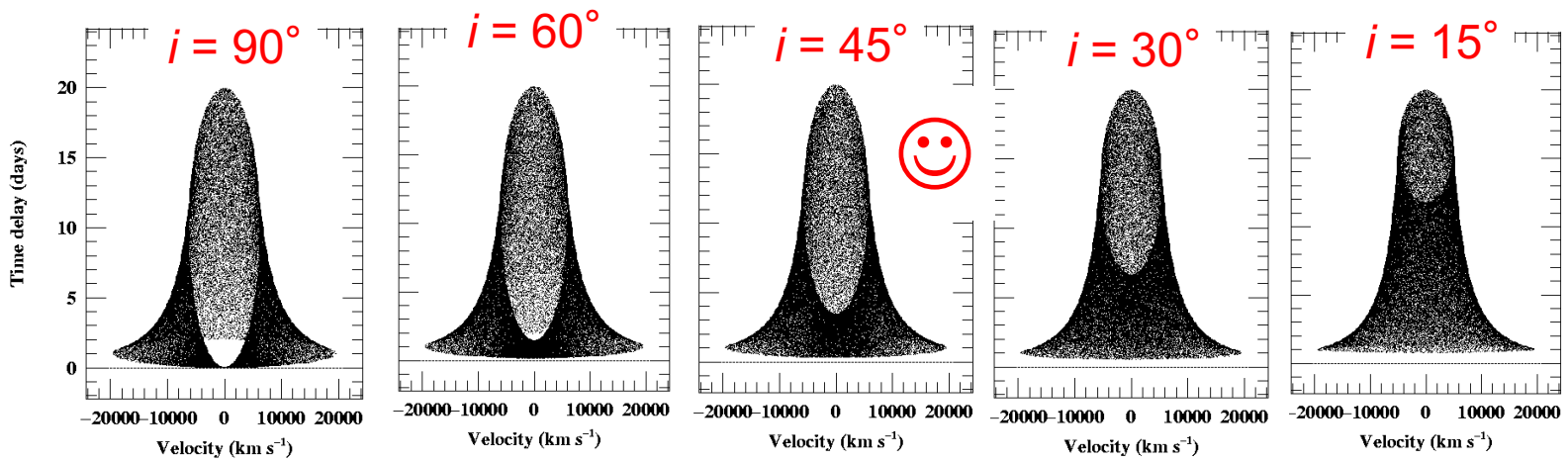
Optical lines : Velocity-Delay Map

MEMEcho fit to MDM data from *Pei et al*. 2017



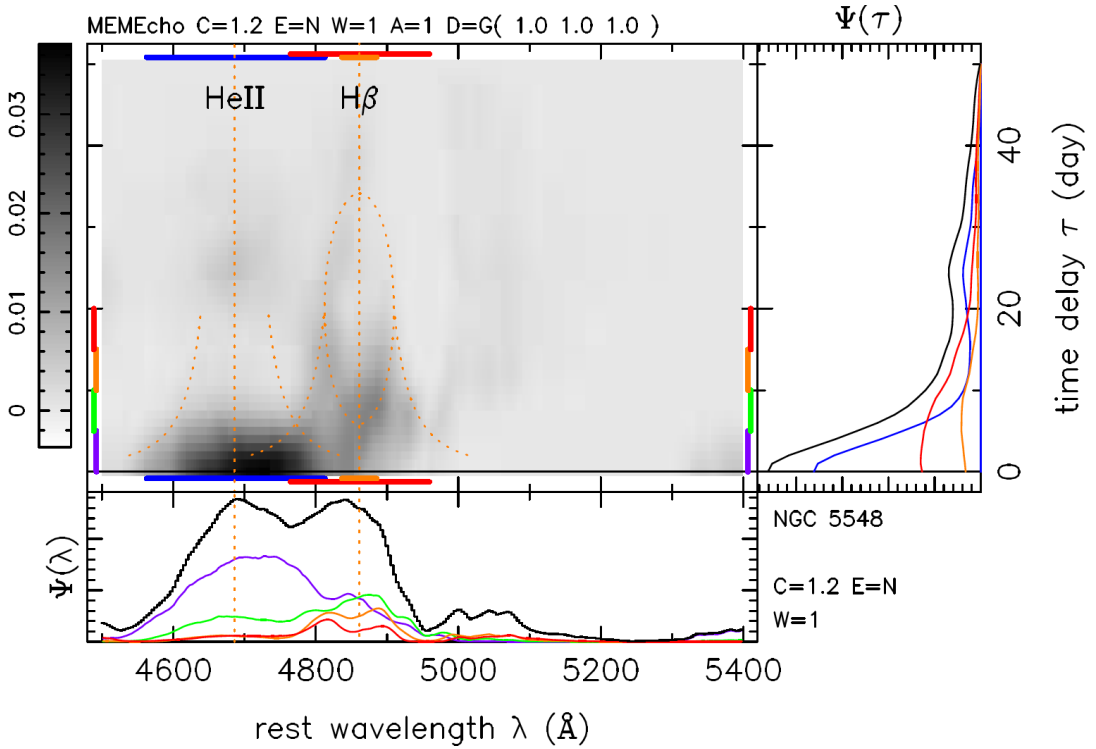
Interpretation: Radial ionisation structure evident. Keplerian envelope from 2 to 20 light days. Elliptical ring from 20 light day orbit. Far side obscured or not responding. Inclination 45°. Mass 7x10^7 Msun. Expect ~20% uncertainty .

Comparison with Inclined Disc BLR Models



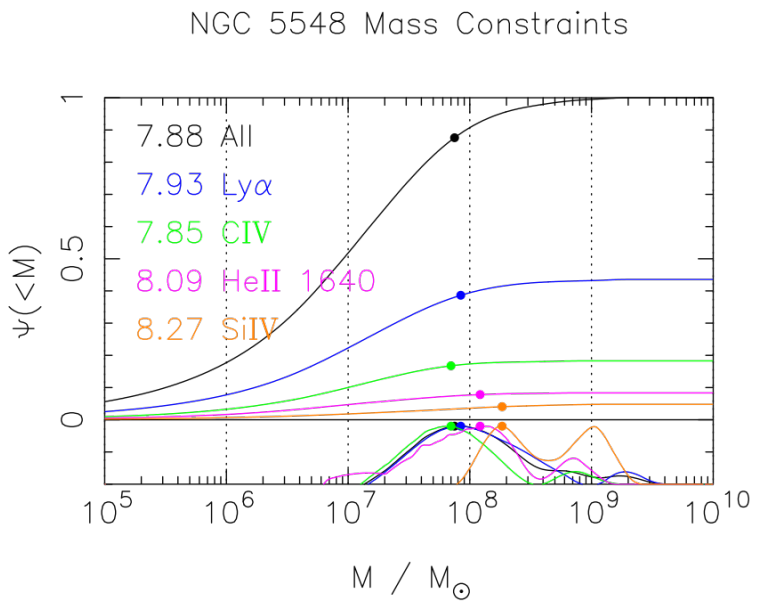
Keplerian Envelope
+ Elliptical Ring
➔
Disc-like Geometry
and Kinematics
2 to 20 light days

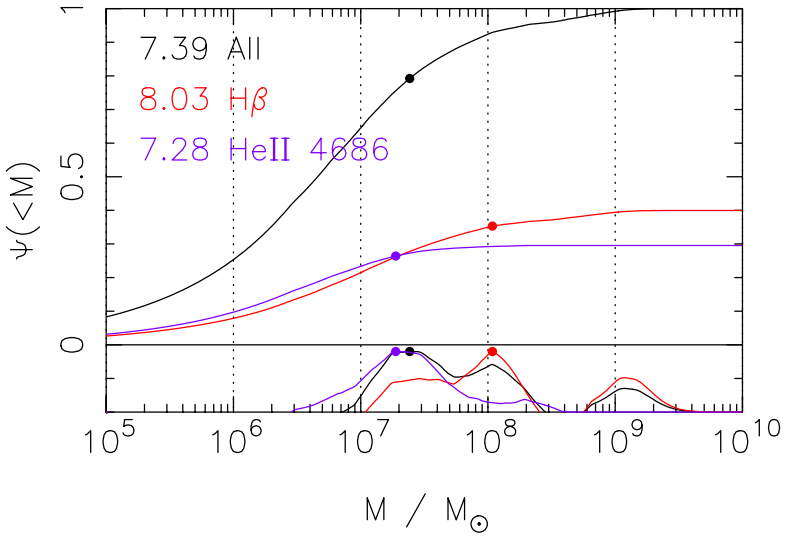
i = 45°
R/c = 20 days
M = 7x10^7 Msun



Attempt to quantify Mass Constraint

- Basic idea:
- Cumulative response inside virial envelopes.
- Result not as sharp as hoped for.
- Larger mass (0.5 dex) from UV lines.
- More refined analysis needed.





Echo Mapping of NGC 5548

- Time-resolved spectrophotometry provides a "**Quasar Microscope**": using time delays to resolve micro-arcsecond structure of AGN accretion discs and broad-line regions.
- AGN STORM Campaign (180 days in 2014) resolved the accretion disc and BLR of NGC 5548.
- Velocity-Delay maps probe the BLR
- BLR from 2-20 light days has radially stratified ionisation with Keplerian Disc kinematics, $M_{BH}=7x10^7 M_{sun}$, $i = 45^o$.

  (Far side of BLR disc may be fainter than expected).