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with:
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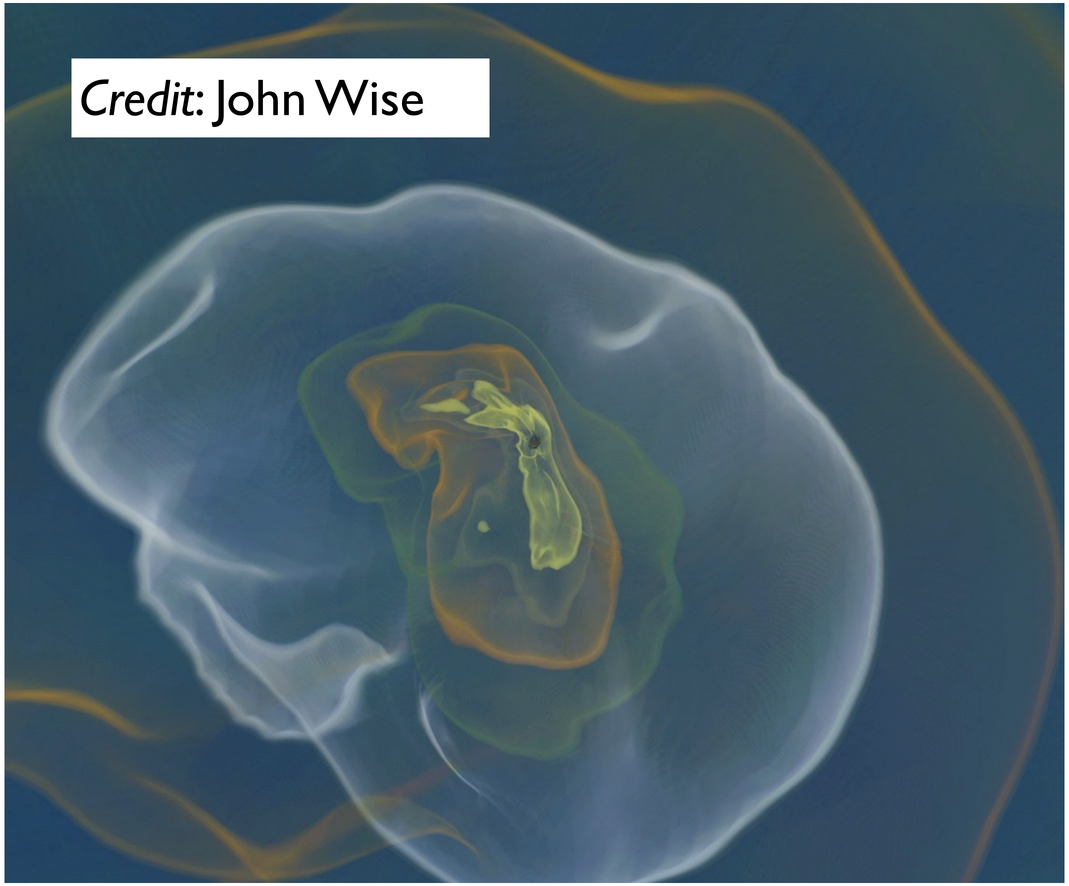
arXiv:**1601.04712** (ApJ accepted), Dijkstra, Sethi & Loeb
arXiv:**1602.07695** (resubmitted to ApJ), Dijkstra, Gronke & Sobral

The Direct Collapse Black Hole Scenario

`....as long as H_2 formation is suppressed, these massive clumps do not fragment but rather cool and continue to collapse isothermally at a temperature of ~10^4 K.... '

from Bromm & Loeb 2003



The Direct Collapse Black Hole Scenario

Extremely interesting from a [Lyα] radiative transfer (RT) point of view:

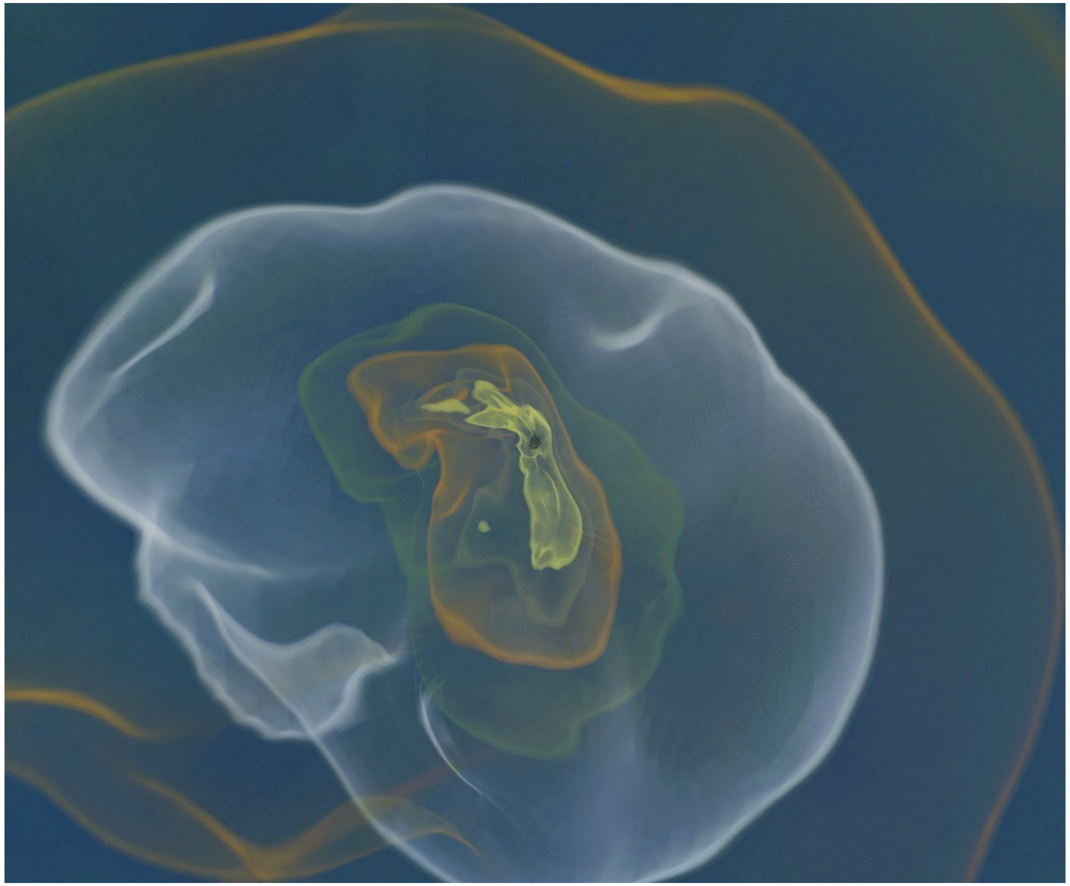
1. Pristine environment
2. Suppressed fragmentation
3. Suppressed H_2 content.
4. No star formation & stellar feedback, dust.

Ordinary challenges one faces when modelling interstellar Lyα RT are absent.

Lyα `survival probability’ is maximised.

Observational Signature of DCBHs I: Lyα

Study Lyα RT through simplified models of DCBH formation.



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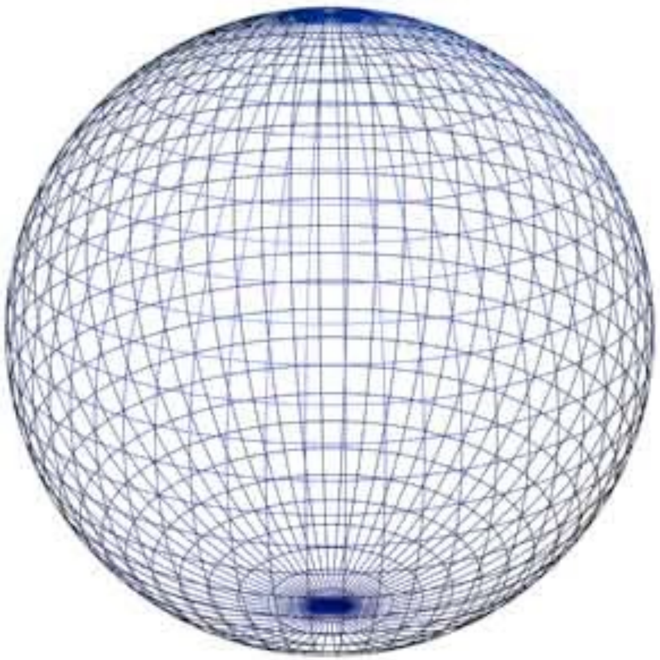

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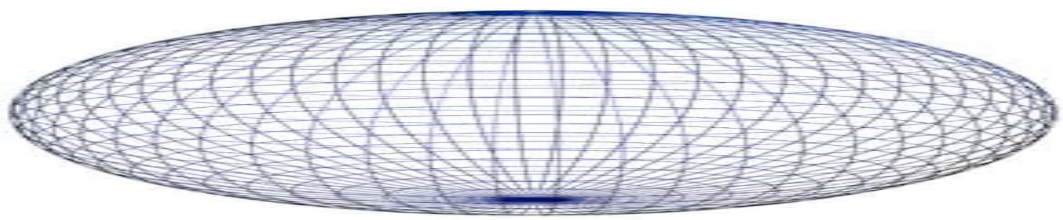
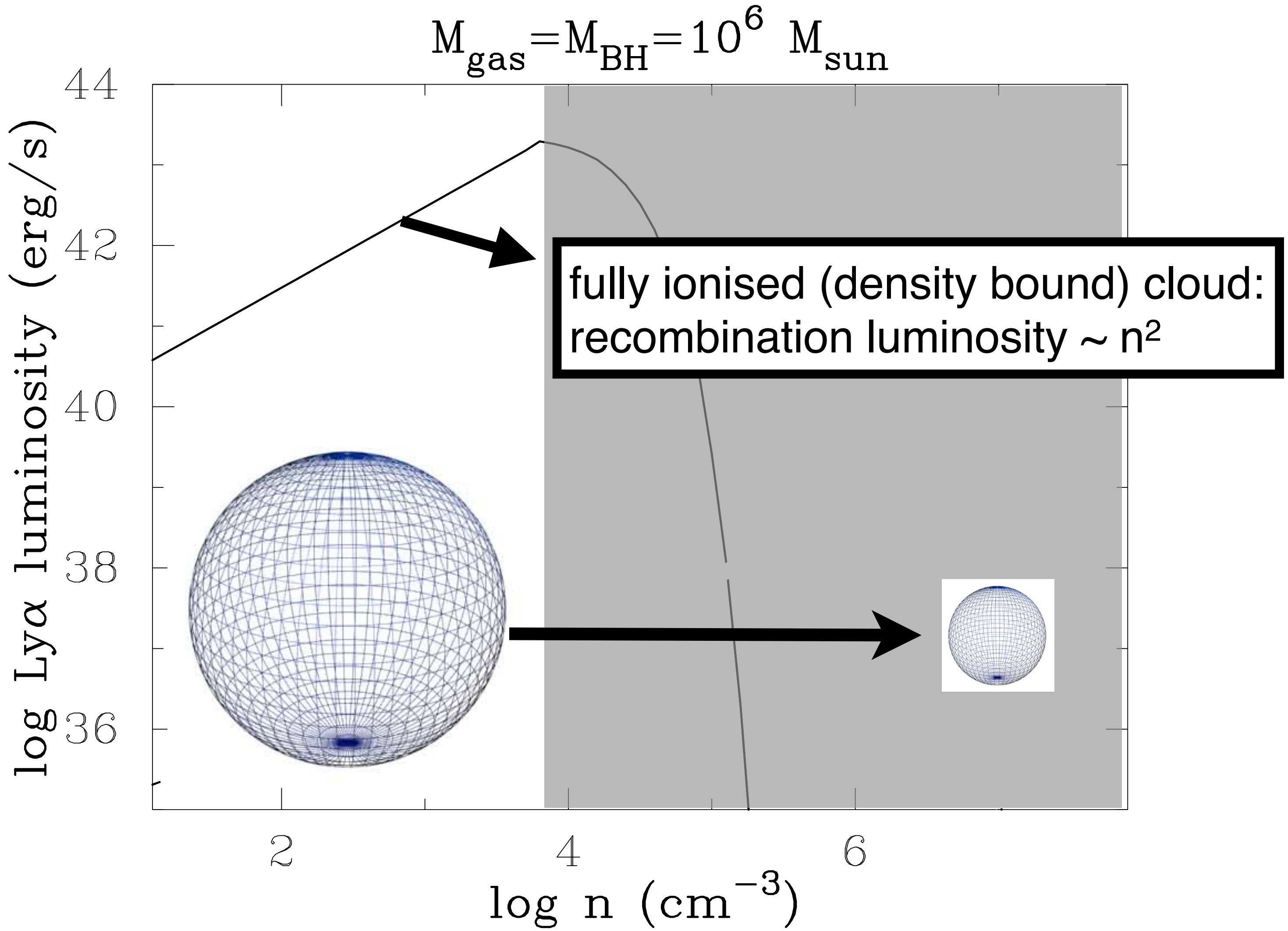


Results I: Lyα Luminosity

Lyα luminosity as function of mean cloud density for cloud photoionized by central ionising source (powered by in place DCBH of mass M_{BH})



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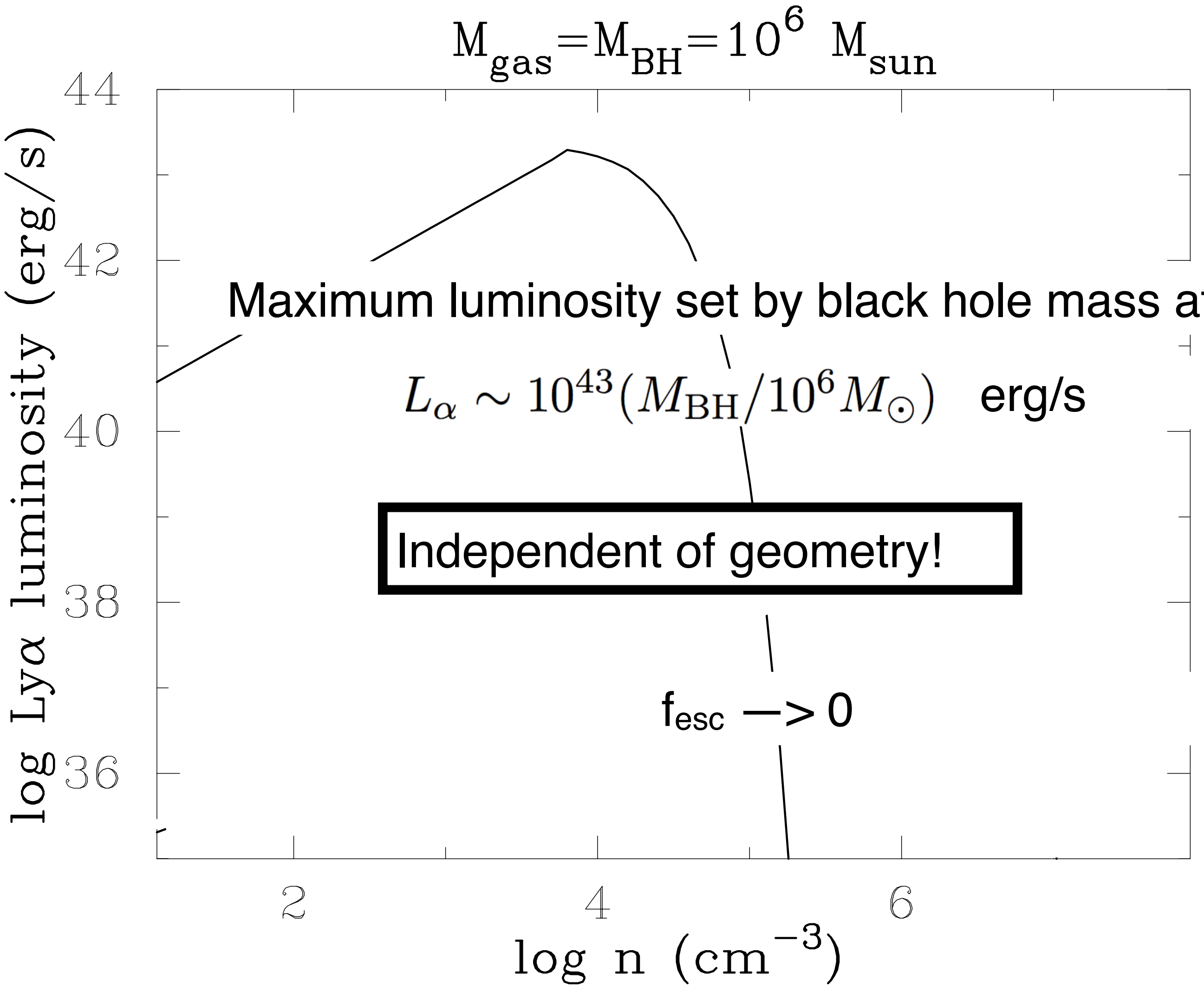


Maximum luminosity set by black hole mass at ~

$$L_\alpha \sim 10^{43}(M_{\rm BH}/10^6 M_\odot) \quad \text{erg/s}$$

Independent of geometry!

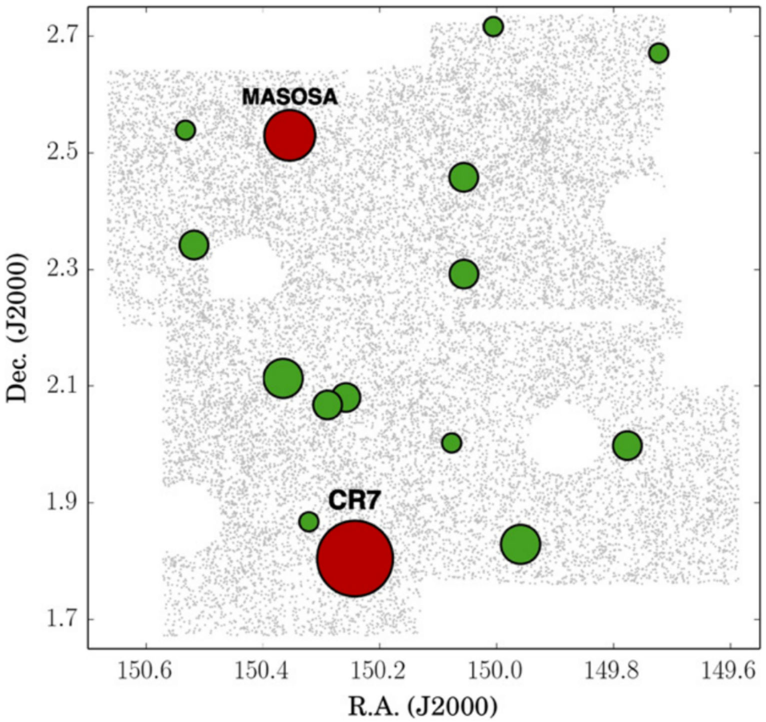
f_{esc} —> 0

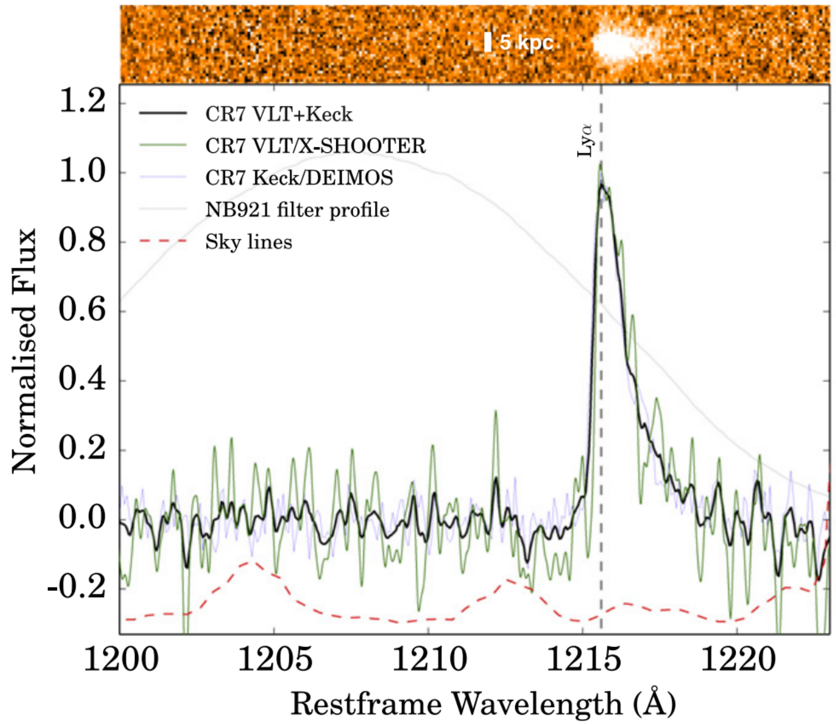
For predictions of emerging spectra, see Dijkstra, Gronke & Sobral 2016

Results II: Comparison to CR7

Cosmos **R**edshift 7 (CR7, Sobral et al. 2015) is first candidate for a DCBH:

- extraordinary bright in Lyα (L~10^{44} erg/s)
- extraordinary bright in He1640 —> hard ionising spectrum $T_{eff} > 10^5$ K (Sobral et al. 2015)
- absence of other metallic lines: $Z < 0.02\ Z_{sol}$ (Sobral et al. 2015; Hartwig et al.2015)
- blue young galaxy close to old red galaxy: prediction of DCBH scenario (Dijkstra et al. 2008, Agarwal et al. 2012)





Lyα luminosity alone requires that if CR7 harbours a BH, then $M_{BH} > 10^7\ M_{sun} > M_{DCBH}$

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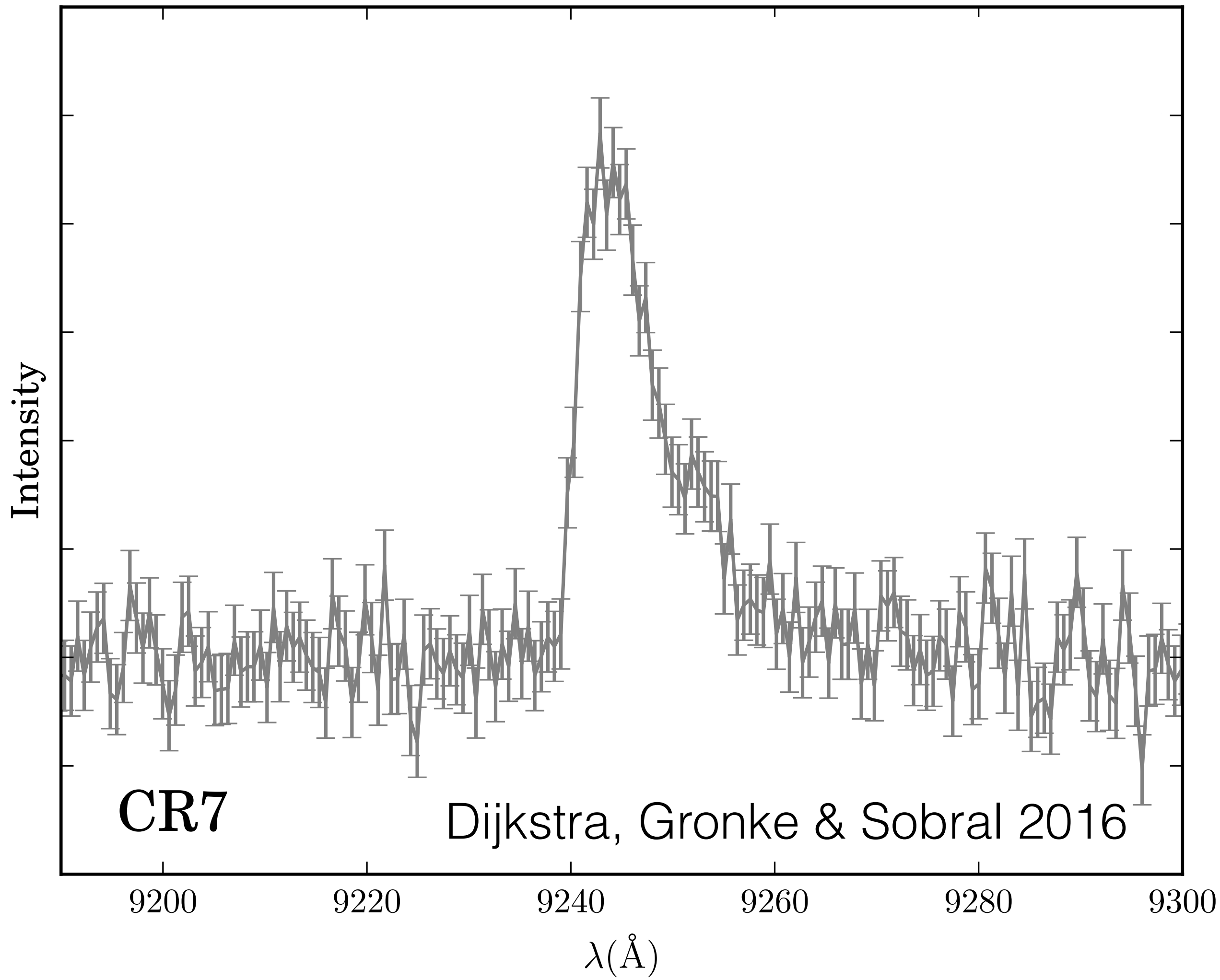
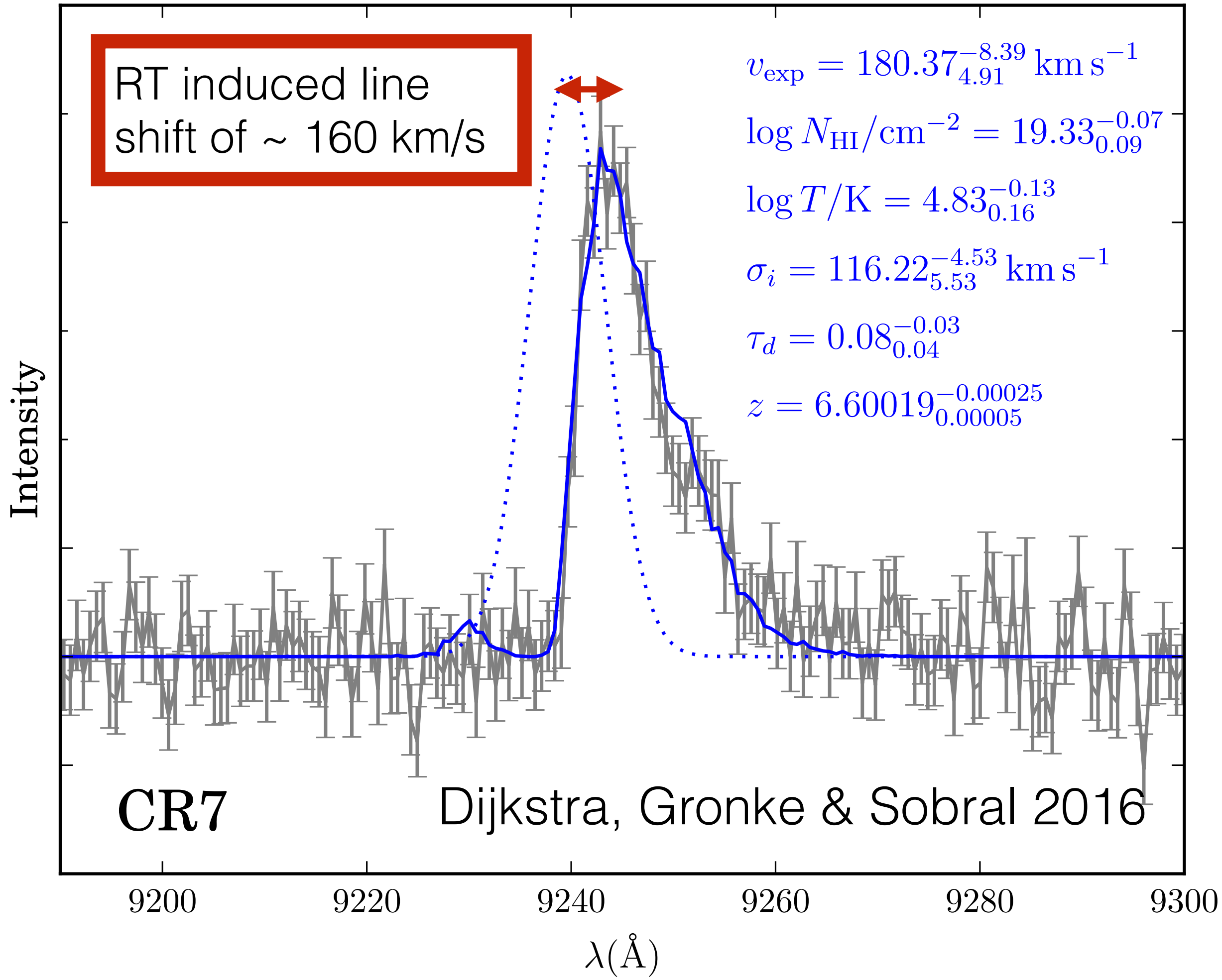


If CR7 hosts a DCBH, then it must have evolved since the DCBH formed. Modelling Lyα from first principles reliably no longer possible. Must use sub grid prescription.

Results II: Lyα Spectra

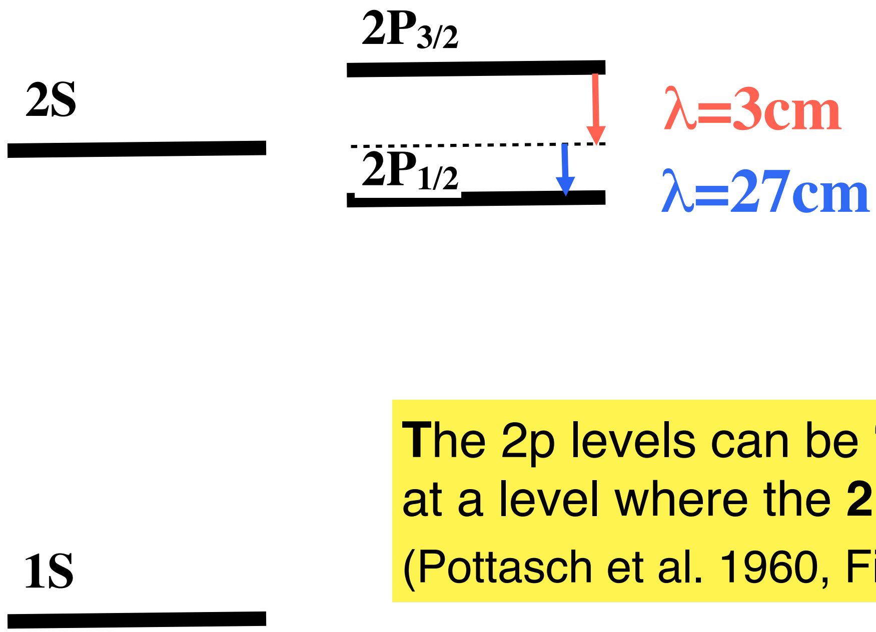
Use sub grid prescription - the `shell model' - to model Lyα spectral line shape (Gronke et al. 2015, also see talk by M. Gronke for more details.)



Best-fit shell model parameters reminiscent of those inferred for z~2.2 LAEs (Hashimoto et al. 2015, z~0.3 green pea galaxies (Yang et al. 2016). *ISM of CR7 affected by stellar feedback?*

3-cm Masers: A Smoking Gun Signature of DCBH

Spin-orbit coupling introduces energy differences between 2s-2p levels (Wild 1952).



The 2p levels can be “pumped” by Lyα photons, and possibly at a level where the **$2P_{3/2}$** level is overpopulated w.r.t. **2s**.
(Pottasch et al. 1960, Field & Partridge 1961, ...)

STIMULATED EMISSION OF THE 3.04-CM FINE-STRUCTURE LINE OF HYDROGEN IN DIFFUSE NEBULAE

George B. Field and Robert B. Partridge
Princeton University Observatory
Received June 9, 1961

The optical de ... ive,
and we can ge

The Matching Requirements of 3-cm Masers & DCBH Formation

The DCBH scenario requires isothermal collapse **at T~1e4 K** of pristine gas, free of H_2.

At T~1e4 K the gas cools through collisional excitation of hydrogen, mostly through Lyα *production*.

At T~1e4 K the gas is highly neutral, and we build up large column densities of hydrogen, which *increases the scattering (and thus the pumping) rate*.

The Matching Requirements of 3-cm Masers & DCBH Formation

The DCBH scenario requires isothermal collapse at T~1e4 K **of pristine gas, free of H_2.**

In pristine gas - free of H_2 - usual **Lyα eliminators** are absent, which maximizes Lyα pumping.

↓

dust

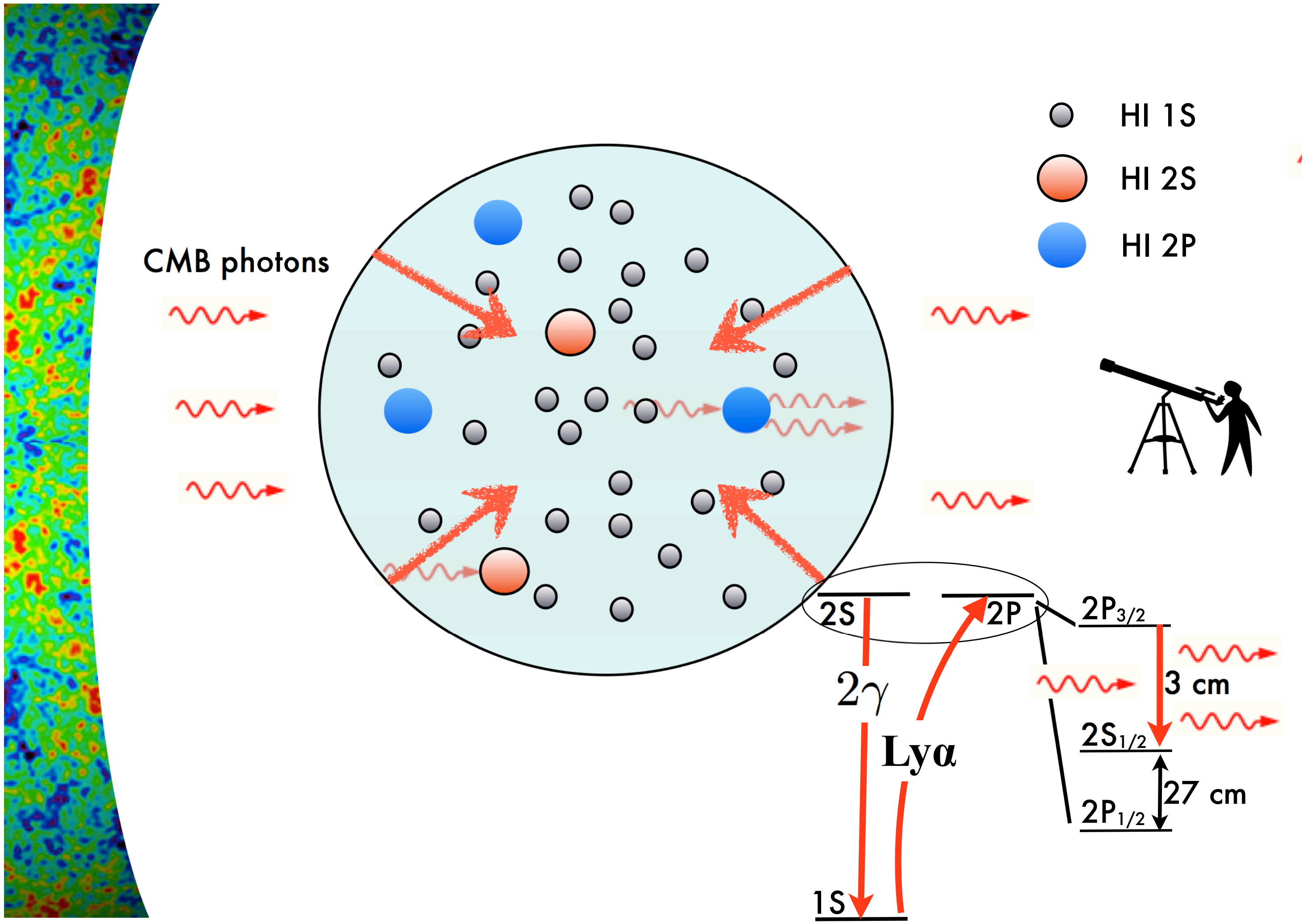
H_2

H^-

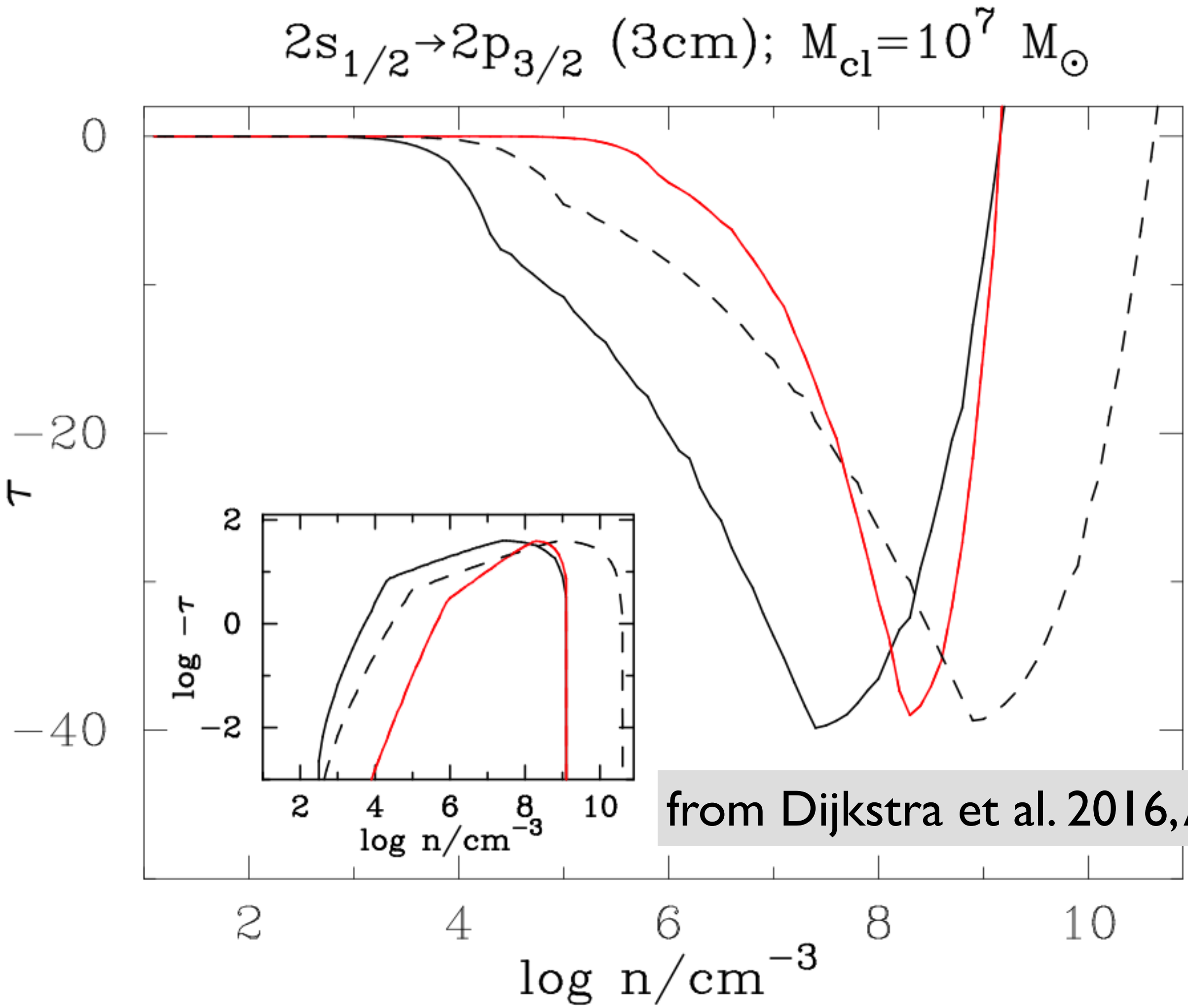
collisional mixing 2s-2p

Required conditions for DCBH scenario, are ideal for Lyα pumping.

3-cm Masers: Geometry & Maser Cycle



The 3-cm Optical Depth through Clouds Collapsing into a BH

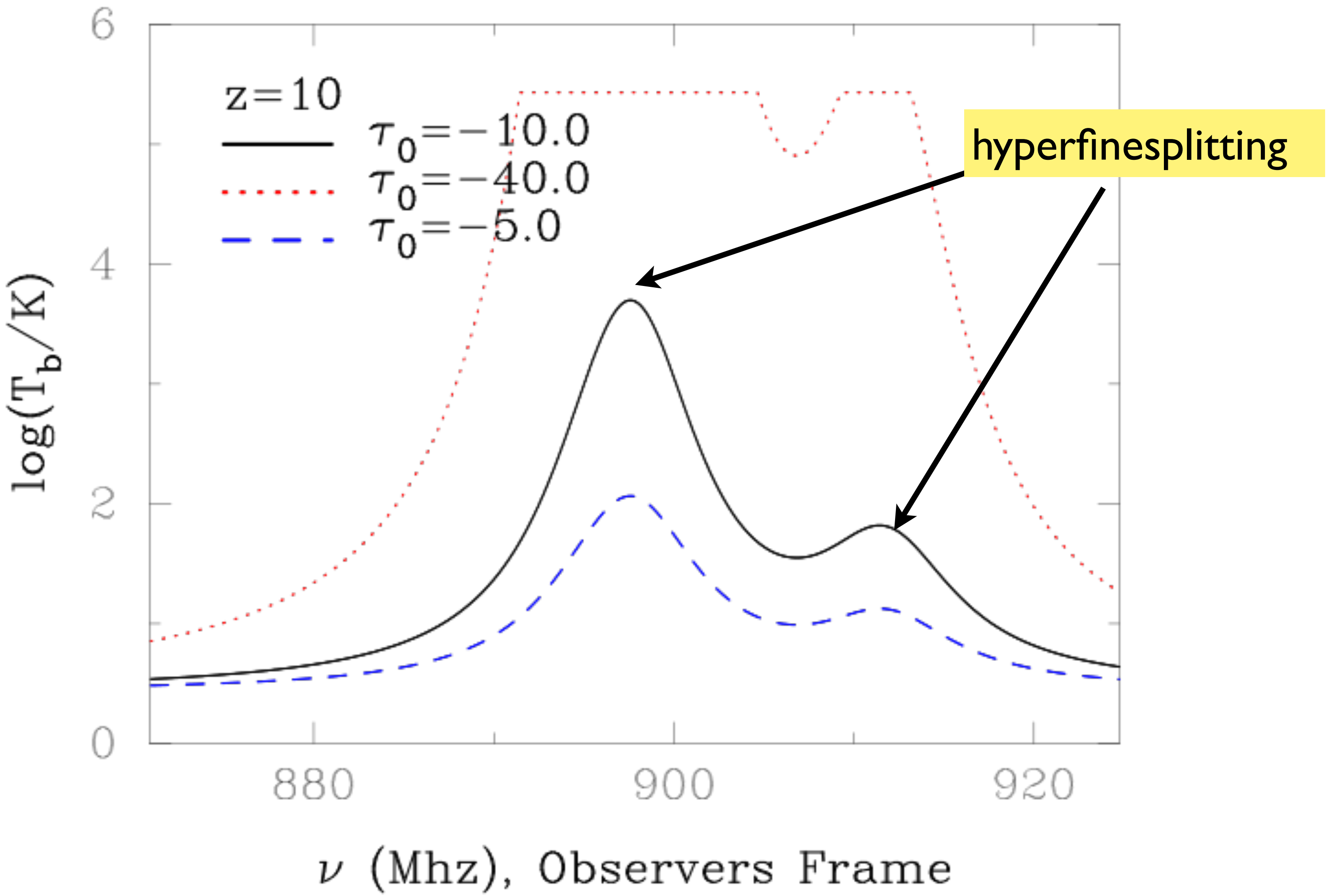


from Dijkstra et al. 2016, ApJ, in press

For negative tau DCBH the background CMB is amplified by a factor of

$$e^{|\tau_{\rm FS}|}$$

The `Strange' Spectral Signature of 3-cm Masers



Hyperfine splitting of 3-cm transition gives rise to three distinct lines with line strength ratios 1:5:2 (Wild 1952). Predicted line shape depends *only* on atomic physics.

Conclusions

Lyα and 3-cm Maser Signatures from Direct Collapse Black Holes

- Conditions that allow DCBH formation ideal for Lyα RT modelling
- DCBH of mass M_{BH} illuminating surrounding gas can give rise to a maximum Lyα luminosity of $L_\alpha \sim 10^{43}(M_{\rm BH}/10^6 M_\odot)$ erg/s.
- CR7's Lyα luminosity requires $M_{BH} > 10^7\ M_{sun} > M_{DCBH}$. BH mass *must* have grown. Galaxy *must* have evolved: consistent with Lyα spectral line shape which resembles that of LAEs.
- Conditions that allow DCBH formation ideal for Lyα pumping of H fine structure levels. The resulting 3-cm maser provides a smoking gun signature of the DCBH formation scenario.
- Maser amplification saturates at $\sim 10^5$. Predicted flux densities ~ 1 muJy. *Detectable with SKA!*
- **3**-cm masers give rise to characteristic line whose structure is set entirely by hyperfine splitting, with delta nu / nu ~ 0.03, and would be easily identifiable.