Non-thermal radiation from disk-cloud interactions in Active Galactic Nuclei

Ana Laura Müller
ELI Beamlines, Institute of Physics of the Czech Academy of Sciences

In collaboration with Mohammad-Nassan Naddaf (CFT & CAMK, PAS), Michal Zajaček (DTPA, MU; CFT, PAS), Bożena Czerny (CFT, PAS), Anabella Araudo (LUMP; FZU, CAS; ASU, CAS), and Vladimír Karas (ASU, CAS)

Cologne–Prague–Brno Meeting – 03.06. 2022

analaura.muller@eli-beams.eu

Motivation

Does the **dynamics of the broad-line region** imprint **non-thermal features** in the **spectra** of active galactic nuclei?

Non-thermal model

A&A 636, A92 (2020)
https://doi.org/10.1051/0004-6361/202037639

Astronomy & Astrophysics

Radiation from the impact of broad-line region clouds onto AGN accretion disks

A. L. Müller[1,3,4] and G. E. Romero[1,2]

[1] Instituto Argentino de Radioastronomía (CCT-La Plata, CONICET; CICPBA), C.C. No. 5, 1894 Villa Elisa, Argentina
e-mail: almuller@iar.unlp.edu.ar
[2] Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque, 1900 La Plata, Argentina
e-mail: romero@iar.unlp.edu.ar
[3] Institute for Nuclear Physics (IKP), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[4] Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM), Buenos Aires, Argentina

Received 1 February 2020 / Accepted 10 March 2020

+

Broad-line region model

The Astrophysical Journal, 920:30 (21pp), 2021 October 10 https://doi.org/10.3847/1538-4357/ac139d

CrossMark

The Picture of BLR in 2.5D FRADO: Dynamics and Geometry

Mohammad-Hassan Naddaf[1,2], Bożena Czerny[1], and Ryszard Szczerba[3]
[1] Center for Theoretical Physics, Polish Academy of Sciences, Lotnikow 32/46, 02-668 Warsaw, Poland; naddaf@cft.edu.pl
[2] Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Bartycka 18, 00-716 Warsaw, Poland
[3] Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Rabianska 8, 87-100 Torun, Poland
Received 2021 January 30; revised 2021 July 8; accepted 2021 July 11; published 2021 October 8

Motivation

Does the **dynamics of the broad-line region** imprint **non-thermal features** in the **spectra** of active galactic nuclei?

Non-thermal model

A&A 636, A92 (2020)
https://doi.org/10.1051/0004-6361/202037639

Astronomy & Astrophysics

Radiation from the impact of broad-line region clouds onto AGN accretion disks

A. L. Müller[1,3,4] and G. E. Romero[1,2]

[1] Instituto Argentino de Radioastronomía (CCT-La Plata, CONICET; CICPBA), C.C. No. 5, 1894 Villa Elisa, Argentina
e-mail: almuller@iar.unlp.edu.ar
[2] Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque, 1900 La Plata, Argentina
e-mail: romero@iar.unlp.edu.ar
[3] Institute for Nuclear Physics (IKP), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[4] Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM), Buenos Aires, Argentina

Received 1 February 2020 / Accepted 10 March 2020

+

Broad-line region model

The Astrophysical Journal, 920:30 (21pp), 2021 October 10 https://doi.org/10.3847/1538-4357/ac139d

CrossMark

The Picture of BLR in 2.5D FRADO: Dynamics and Geometry

Mohammad-Hassan Naddaf[1,2], Bożena Czerny[1], and Ryszard Szczerba[3]
[1] Center for Theoretical Physics, Polish Academy of Sciences, Lotnikow 32/46, 02-668 Warsaw, Poland; naddaf@cft.edu.pl
[2] Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Bartycka 18, 00-716 Warsaw, Poland
[3] Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, Rabianska 8, 87-100 Torun, Poland
Received 2021 January 30; revised 2021 July 8; accepted 2021 July 11; published 2021 October 8

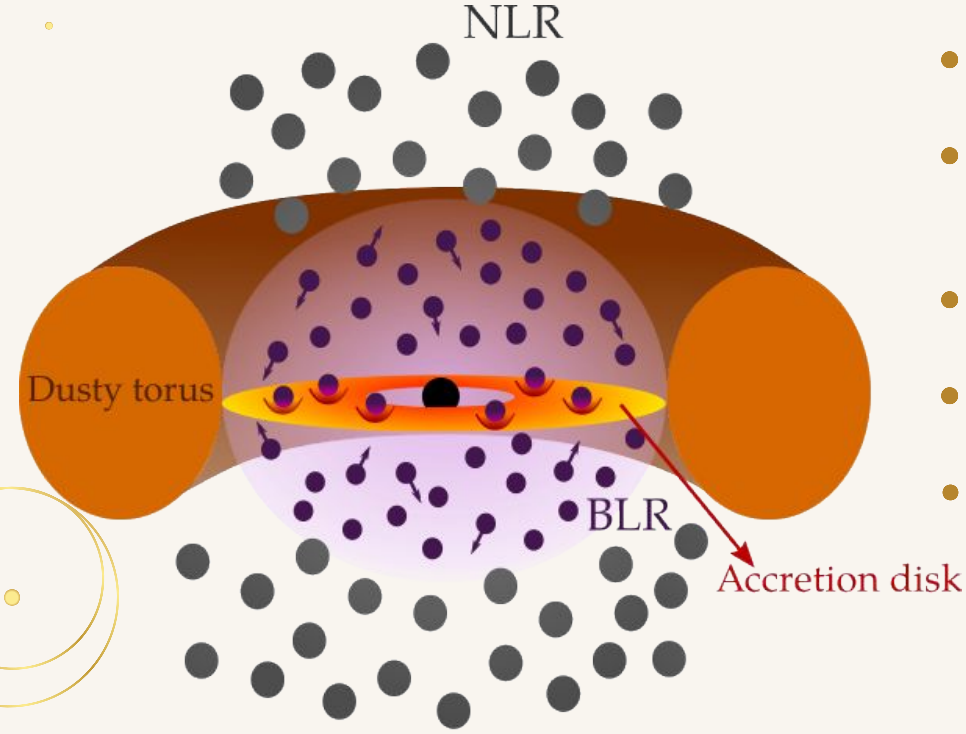
OPEN ACCESS

Nonthermal Emission from Fall-back Clouds in the Broad-line Region of Active Galactic Nuclei

Ana Laura Müller[1], Mohammad-Hassan Naddaf[2,3], Michal Zajaček[2,4], Bożena Czerny[2], Anabella Araudo[1,5,6], and Vladimír Karas[6]

Published 2022 May 23 • © 2022. The Author(s). Published by the American Astronomical Society.
The Astrophysical Journal, Volume 931, Number 1

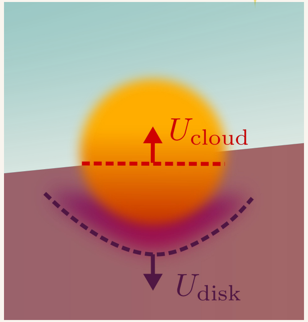
Broad-line region



Müller, PhD Thesis, 2020

- Region **close to the central black hole** (< 1 pc)
- Keplerian orbits with **velocities $10^3 - 10^4$ km s^{-1}**
- Typical **cloud radius ~ 1 AU**
- **Total number** of clouds ~ 10^8 or more
- The clouds reprocess the disk emission and **emi photons with ~ 10 eV**

Non-thermal model



- **Clouds** are moving with **supersonic** velocities and **co-existing** with the **accretion disk**
- The **collisions** produce **shock waves (Müller & Romero, A&A, 2020)**
- **Diffusive shock acceleration** in strong, adiabatic, and super-Alfvénic shocks as observed in supernova remnants **(Krymskii 1977; Bell 1978; Blandford & Ostriker 1978)**
- Significant **non-thermal radiation** can be produced in the **X-ray** and **gamma-ray bands,** assuming **spherical broad-line region** and **clouds homogeneously distributed.** Gamma-ray spectrum of NGC 1068 can be modeled **(Müller & Romero, A&A, 2020)**

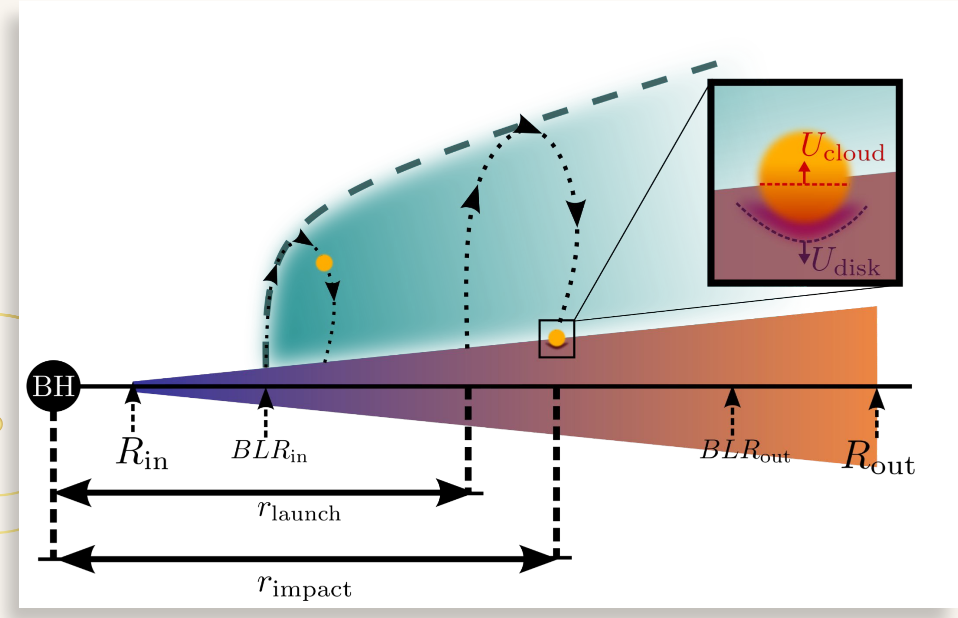
But...

- Observational evidence for **flattened** broad-line regions **(Gravity Collaboration et al. 2018)**
- The origin of the clouds and the **accretion disk** should be related

FRADO model

- Failed Radiatively Accelerated Dusty Outflow (**Czerny & Hryniewicz 2011; Czerny et al. 2015, 2016, 2017; Naddaf et al. 2020, 2021**).

- Clouds motion led by the **radiation pressure** of the accretion disk **on the dust.**



Müller et al. (2022)

- Temperature below the dust sublimation but radiation pressure enough to expel matter from the disk

- Once the cloud elevates above the disk, the hotter radiation sublimates the dust

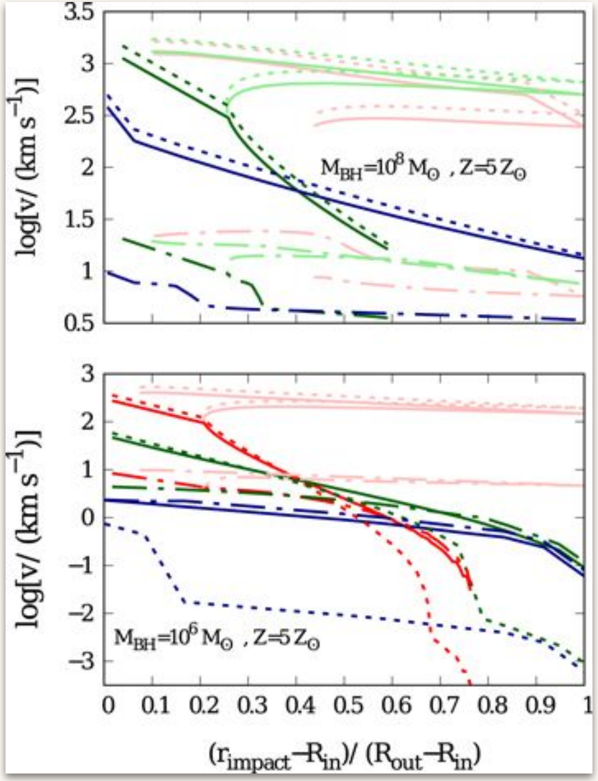
- The cloud follows then a ballistic motion

Shock wave results

- Only **high accreting systems** have clouds with velocities large enough to produce strong shocks

- The **metallicity** plays an important role. The velocity of the clouds increases with the metallicity. Only high metallicity systems produce strong shocks.

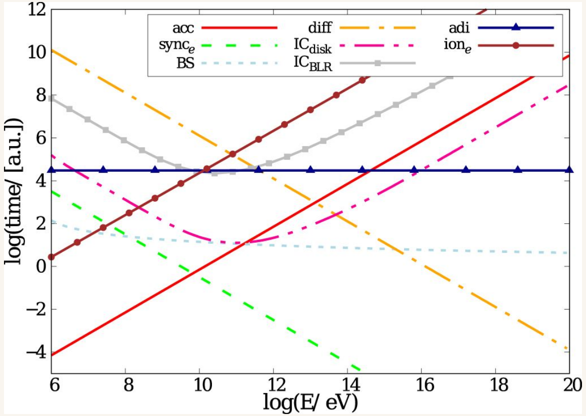
Müller et al. (2022)

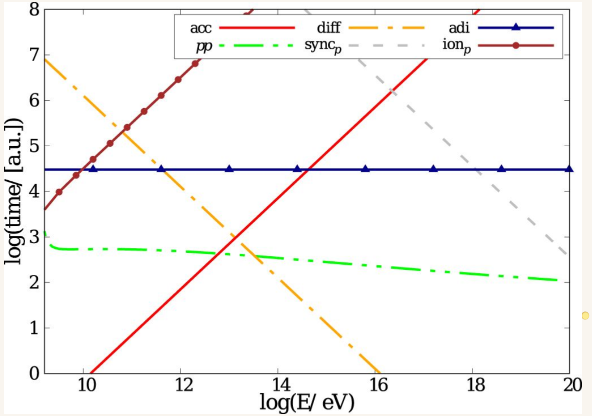


Solid lines: impact velocity. Dotted line: reverse shock. Dash-dotted line: forward shock. Blue, green, red are different accretion rates: 0.01, 0.1, and 1, respectively.

Maximum energies and distributions

Electrons

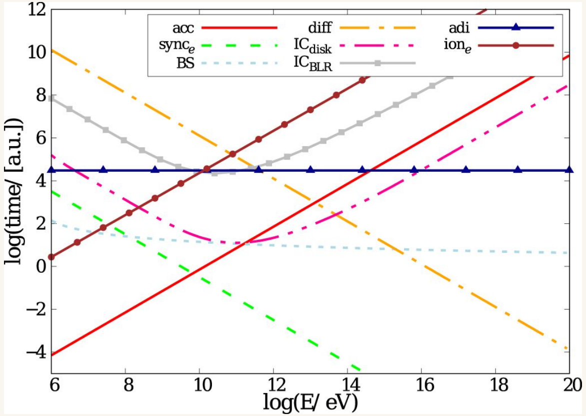


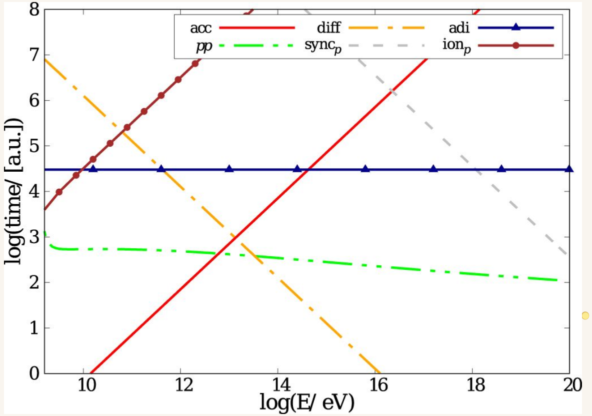


Protons

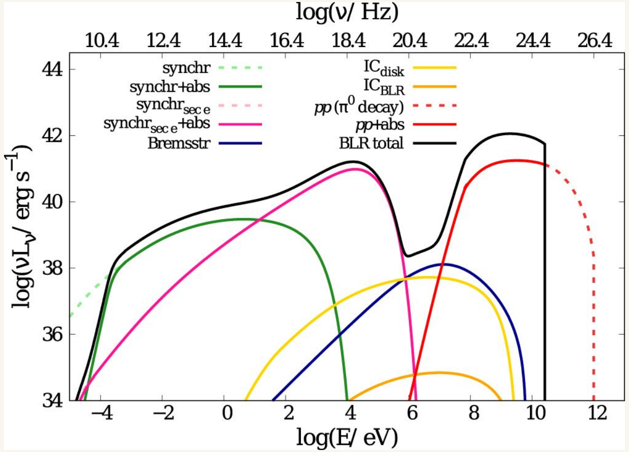
Maximum energies and distributions

Electrons



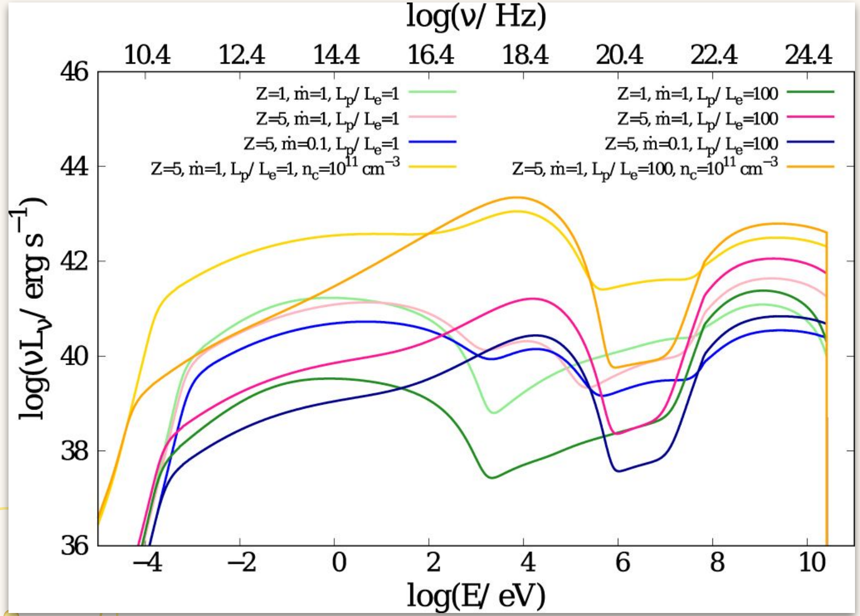


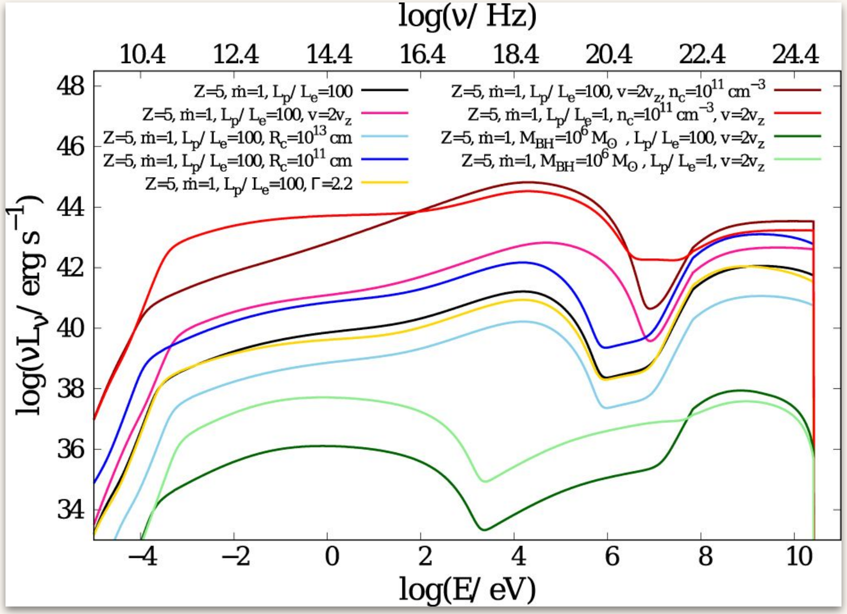
Protons



Spectral energy distribution for one impact

Total spectral energy distributions

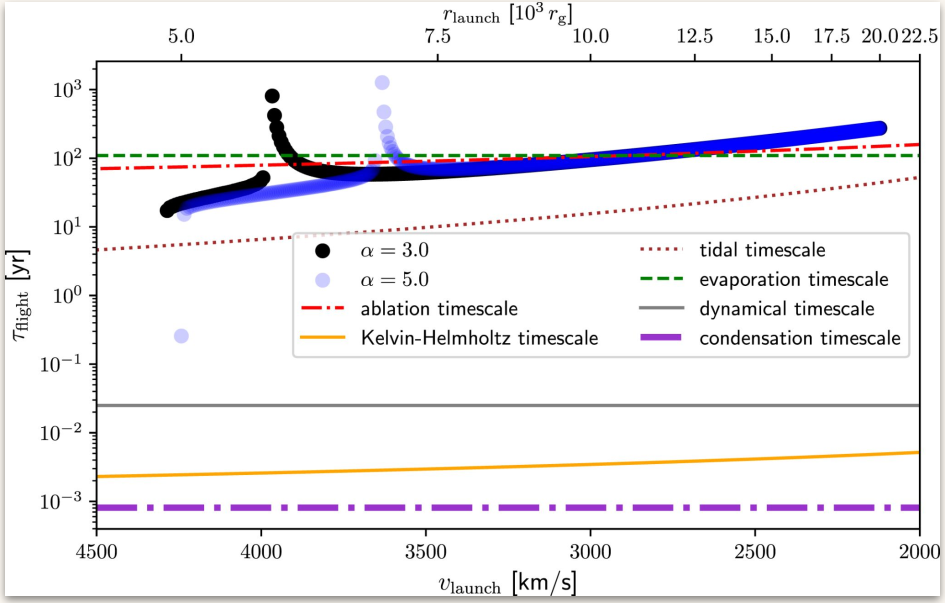




- The **innermost clouds** are the main contributors to the non-thermal emission
- The **velocities limit** the maximum energy of the particles and define the shape of the SED at MeV energies
- If the effective cloud velocity for the shock production is approx. twice the vertical velocity component, **spectra similar to gamma-ray narrow line Seyfert 1 galaxies**

Stability of the clouds

Extended **appendix** discussing the **formation** and **destruction** of clouds.



Summary and conclusions

- **Collisions of BLR clouds** with the accretion disk could lead to the **production of relativistic** particles and **non-thermal emission**
- Important in **high-accreting systems** ➡ contribution to the **gamma-radiation** of non-jetted systems
- **Gamma-emission in Seyfert** galaxies
- Significant non-thermal **X-ray emission** ➡ complements the corona
- **Maximum energies of the particles linked to the impact velocities** predicted by the BLR model ➡ the electromagnetic radiation of non-thermal origin can be used **to test BLR models**

THANK YOU!