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A film review of *Black Holes: The Edge of All We Know*, directed by Peter Galison. Collapsar, Sandbox Films, 2020.

Grace Field [a], Emilie Skulberg [b,*]

[a] Department of History and Philosophy of Science, University of Cambridge, UK
[b] Institute of Physics, University of Amsterdam, NL

Covering ground from black hole imaging to gravitational wave astronomy, *Black Holes: The Edge of All We Know* provides a beautiful and thought-provoking view of contemporary research on black holes. Peter Galison's film is structured around recent developments in two research projects: the Event Horizon Telescope (EHT) Collaboration, and a Cambridge-based collaboration of theoretical physicists dedicated to resolving the infamous black hole information-loss paradox.

Galison's own role in the EHT Collaboration and the Black Hole Initiative—which is significant—is barely featured in the film. Instead, its emphasis lies on the process of research in the two projects. The EHT collaborators famously released the first ever image of the shadow of a black hole in April 2019, and the film gives an inside view of their journey to producing that result. The second project—smaller in size but not importance or scope—is a collaboration between former PhD student Sasha Haco (University of Cambridge), the late Professor Stephen Hawking (University of Cambridge), Professor Malcolm Perry (University of Cambridge, Queen Mary University of London), and Professor Andy Strominger (Harvard University). The film follows their attempt to account for the information lost in black holes by adding up the effects of 'soft hair', or 'soft charges'—features of black holes that have not typically been accounted for.

The no-hair theorem states that every black hole is completely characterized by its angular momentum, mass, and charge. If this is true, then we will never be able to recover information about how particular black holes were formed. Haco, Hawking, Perry, and Strominger push back against this 'information paradox' by challenging the no-hair theorem. Photons on the black hole event horizon, they suggest, could provide the missing degrees of freedom.

Both projects have ties to the Black Hole Initiative at Harvard University, where Galison is now Director. The Initiative's interdisciplinary approach shines through in the film, which focuses on how researchers tied to different projects try to push at the boundaries of our knowledge about black holes, but each in a different way. By taking this focus, Galison showcases the diversity of practice that exists even within black hole research communities—from the spaces in which scientific work takes place to differences in scale, research culture, tools, and ultimately, people.

While Galison has touched upon many of these themes in his written work, his aim in *Black Holes: The Edge of All We Know* is to use film to visually showcase the materiality and collaboration involved in scientific research (see also Daston, Galison, and Schaffer (2021)). The viewer watches EHT researchers fiddle with instruments and grapple with poor weather conditions. They see frustration on the faces of the information-loss theorists as they stare at a half-empty blackboard, strained body language during meetings where opinions differ, and the excited conversation that takes place before a press conference—all real and pervasive features of scientific collaboration that are nevertheless usually hidden from public view.

Echoing Galison's interest in the history of objectivity (see especially Daston and Galison (1992, 2007)), the film shows how the EHT collaboration approached the challenge of imaging something which had never before been observed. How could the scientists be sure that their images were accurate, and not influenced by what they *expected* a black hole to look like? The severity of this problem is emphasized, and the viewer is then introduced to its main solution: a strict division of labour. The film shows how the Imaging Group was divided into four teams that worked entirely independently; each team made their images without looking at results from other teams. The four sets of images were then checked for mutual consistency at the end of the analysis process, in a tense and ultimately gratifying 'big reveal'.

In this and other ways, Galison's film focuses on the limits of what can be observed. While limits to observation have already been explored in scholarship on imaging in astronomy and physics (Elkins, 2008; Galison, 1997; Hentschel, 2014; Kemp, 2006; Kessler & Galison, 2019), Galison here showcases how collaborative practices evolved in an attempt to represent an object so difficult to grasp. By following along as that evolution unfolds, the viewer encounters various representations of black holes: images, simulations, physical models, and mathematical description. They are forced to think about how different scientific tools and methods can teach us about domains that we either cannot manipulate or cannot access directly—a theme that has recently risen to prominence in the philosophy of science literature (see, for example, Evans and Thébault (2020)).

Black Holes: The Edge of All We Know presents its subject matter in an

* Corresponding author.
E-mail address: na.e.g.skulberg@uva.nl (E. Skulberg).

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unusual style. Most documentaries on black holes employ quick cuts between sequences, colourful images, and music that could have easily been lifted from an action movie—often emphasising the celestial objects' destructive power (see, for example, the BBC documentary which also portrays the EHT but in a different style (Bulling & Fraser, 2019)). Instead, *Black Holes: The Edge of All We Know* begins with Stephen Hawking's characteristic vocal synthetizer (for this, see Mialet (2012)), alongside atmospheric background music, and continues in a calm pace to paint a picture of what black hole research looks like behind the scenes. Throughout, black holes and the questions they raise are beautifully illustrated in black and white animations by Ruth Lingford. The film, therefore, not only presents the viewer to the various representations employed in black hole research, but is itself a contribution to the iconography of black holes.

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