

Zeitschrift: L'Enseignement Mathématique
Herausgeber: Commission Internationale de l'Enseignement Mathématique
Band: 31 (1985)
Heft: 1-2: L'ENSEIGNEMENT MATHÉMATIQUE

Artikel: NOTE ON LEVI'S PROBLEM WITH DISCONTINUOUS FUNCTIONS
Autor: Coltoiu, Mihnea
DOI: <https://doi.org/10.5169/seals-54571>

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A NOTE ON LEVI'S PROBLEM WITH DISCONTINUOUS FUNCTIONS

by Mihnea COLTOIU

§ 1. INTRODUCTION

In [3] Fornaess and Narasimhan proved that a complex space X which carries a strongly plurisubharmonic exhaustion function $\varphi: X \rightarrow \mathbf{R}$ is a Stein space. It is a remarkable fact that φ is supposed only upper semicontinuous.

A natural question which arises when we consider the Levi problem with upper semicontinuous functions is the following: what would happen if we allowed φ to take on the value $-\infty$. Simple examples (compact complex spaces, the blowing up of \mathbf{C}^n at the origine...) show us that X is not necessarily Stein. The best result one might hope to obtain is X being 1-convex.

The aim of this short note is to give an affirmative answer to this question, hence to prove the following theorem conjectured by Fornaess and Narasimhan:

THEOREM 1. *Let X be a complex space which admits a strongly plurisubharmonic exhaustion function $\varphi: X \rightarrow [-\infty, \infty)$. Then X is 1-convex.*

If φ is supposed real-valued it follows easily, from the maximum principle, that the exceptional set of X is empty, hence X is Stein. This is exactly Fornaess-Narasimhan's theorem.

§ 2. PRELIMINARIES

All complex spaces are assumed to be reduced and countable at infinity.

An upper semicontinuous function $\varphi: X \rightarrow [-\infty, \infty)$ is called plurisubharmonic if for every holomorphic map $\tau: W \rightarrow X$ ($W =$ the unit disc in \mathbf{C}) it follows that $\varphi \circ \tau$ is subharmonic on W (possibly $\equiv -\infty$). φ is said

to be strongly plurisubharmonic if for every C^∞ real-valued function θ with compact support there exists an $\varepsilon_0 > 0$ such that $\varphi + \varepsilon\theta$ is plurisubharmonic for $|\varepsilon| \leq \varepsilon_0$.

A main result in [3] tells us that the above definition agrees with the usual one as given in [6].

Let us also recall that a complex space X is said to be 1-convex if there exist:

- i) a compact analytic set $S \subset X$ with $\dim_x S > 0$ for any $x \in S$,
- ii) a Stein space Y , a finite set $A \subset Y$ and a proper holomorphic map $p: X \rightarrow Y$ inducing a biholomorphism $X \setminus S \cong Y \setminus A$ and which satisfies $p_* \mathcal{O}_X \cong \mathcal{O}_Y$.

S is called the exceptional set of X and Y the Remmert reduction of X .

Remark. Using the analytic version of Chow's lemma (Hironaka [5]) it was proved in [2] that any 1-convex space X carries a strongly plurisubharmonic exhaustion function $\varphi: X \rightarrow [-\infty, \infty)$, i.e. the converse of Theorem 1 holds too.

§ 3. THE PROOF OF THEOREM

We shall apply Andreotti-Grauert's technique [1] with suitable modifications required by the upper semicontinuity. Throughout this section \mathcal{F} will denote a coherent sheaf on X and $X_c = \{x \in X \mid \varphi(x) < c\}$.

To prove Theorem 1 we need some lemmas.

LEMMA 1. *For any $c \in \mathbf{R}$ there exists $\varepsilon > 0$ such that restriction map $H^1(X_{c+\varepsilon}, \mathcal{F}) \rightarrow H^1(X_{c+\varepsilon'}, \mathcal{F})$ is surjective for any $0 \leq \varepsilon' \leq \varepsilon$.*

Proof. We may assume $c = 0$. Set $K = \overline{\{\varphi < 1\}}$ and let $\{U_1, \dots, U_m\}$ be a covering of K with Stein open sets, $U_i \subset \subset X$ and $h_i \in C_0^\infty(U_i)$, $h_i \geq 0$ such that $\varphi - \sum_{i=1}^r h_i$ is strongly plurisubharmonic for $r = 1, \dots, m$ and $\sum_{i=1}^m h_i > 0$ on K . Choose $\alpha > 0$ such that $\sum_{i=1}^m h_i(x) \geq \alpha$ for any $x \in K$ and take $0 < \varepsilon < \min(\alpha, 1)$. We shall prove that this ε satisfies the conditions required in Lemma 1.

For any $0 \leq \varepsilon' \leq \varepsilon$ we set $X_{\varepsilon'}^r = \{x \in X \mid \varphi(x) < \varepsilon' + h_1(x) + \dots + h_r(x)\}$ for $r = 0, \dots, m$ (by definition $X_{\varepsilon'}^0 = X_{\varepsilon'}$).

We make the following remark: for any $0 \leq \varepsilon' \leq \varepsilon$ we have $X_\varepsilon \subset X_{\varepsilon'}^m$. Indeed, let $x \in X$ such that $\varphi(x) < \varepsilon$. In particular $\varphi(x) < 1$, hence $x \in K$. From the definition of α it follows that $\sum_{i=1}^m h_i(x) \geq \alpha$ and from the inequalities

$$\varphi(x) < \varepsilon < \alpha \leq \sum_{i=1}^m h_i(x) \leq \varepsilon' + \sum_{i=1}^m h_i(x) \text{ we get } x \in X_{\varepsilon'}^m.$$

Due to this remark Lemma 1 will be proved if we prove that the restriction map $H^1(X_{\varepsilon'}^m, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}, \mathcal{F})$ is surjective for any $0 \leq \varepsilon' \leq \varepsilon$. The inclusions $X_{\varepsilon'} = X_{\varepsilon'}^0 \subset X_{\varepsilon'}^1 \subset \dots \subset X_{\varepsilon'}^m$ show that it suffices to prove that the restrictions $H^1(X_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^r, \mathcal{F})$ are surjective for $r = 0, \dots, m-1$. If we set

$$V_{\varepsilon'}^{r+1} = \{x \in U_{r+1} \mid \varphi(x) < \varepsilon' + h_1(x) + \dots + h_{r+1}(x)\}$$

then $V_{\varepsilon'}^{r+1}$ and $X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}$ are Stein open sets. On the other hand $X_{\varepsilon'}^{r+1} \setminus X_{\varepsilon'}^r \subset \text{supp}(h_{r+1}) \subset U_{r+1}$ and so $X_{\varepsilon'}^{r+1} = X_{\varepsilon'}^r \cup V_{\varepsilon'}^{r+1}$. From the Mayer-Vietoris exact sequence:

$$H^1(X_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^r, \mathcal{F}) \oplus H^1(V_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}, \mathcal{F})$$

it follows that the restriction map $H^1(X_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^r, \mathcal{F})$ is surjective and so Lemma 1 is proved.

LEMMA 2. For any $\alpha \leq \beta$ the restriction map $H^1(X_\beta, \mathcal{F}) \rightarrow H^1(X_\alpha, \mathcal{F})$ is surjective.

Proof. Set $M(\alpha) = \{\delta \geq \alpha \mid \text{for any } \alpha \leq \gamma \leq \delta \text{ the restriction map}$

$$H^1(X_\delta, \mathcal{F}) \rightarrow H^1(X_\gamma, \mathcal{F}) \text{ is surjective}\}.$$

From Lemma 1 and Lemma [1, p. 241] we deduce that $M(\alpha) = [\alpha, \infty)$ which proves Lemma 2.

LEMMA 3. For any $\alpha \in \mathbf{R}$ $H^1(X_\alpha, \mathcal{F})$ has finite dimension.

Proof. Choose $\beta > \alpha$ such that $\bar{X}_\alpha \subset X_\beta$. From Lemma 2 the restriction map $H^1(X_\beta, \mathcal{F}) \rightarrow H^1(X_\alpha, \mathcal{F})$ is surjective and from [1, p. 240]

$$\dim_{\mathbf{C}} H^1(X_\alpha, \mathcal{F}) < \infty.$$

LEMMA 4. For any $c \in \mathbf{R}$ there exists $\varepsilon > 0$ such that the restriction map $\Gamma(X_{c+\varepsilon}, \mathcal{F}) \rightarrow \Gamma(X_{c+\varepsilon'}, \mathcal{F})$ has dense image for any $0 \leq \varepsilon' \leq \varepsilon$.

Proof. We may assume $c = 0$ and choose $\varepsilon > 0$ as in Lemma 1. Exactly as in the proof of Lemma 1 it suffices to prove that the restriction map $\Gamma(X_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow \Gamma(X_{\varepsilon'}^r, \mathcal{F})$ has dense image for $r = 0, \dots, m - 1$.

Consider the Mayer-Vietoris exact sequence:

$$\begin{aligned} \Gamma(X_{\varepsilon'}^{r+1}, \mathcal{F}) &\rightarrow \Gamma(X_{\varepsilon'}^r, \mathcal{F}) \oplus \Gamma(V_{\varepsilon'}^{r+1}, \mathcal{F}) \xrightarrow{\alpha} \Gamma(X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}, \mathcal{F}) \\ &\rightarrow H^1(X_{\varepsilon'}^{r+1}, \mathcal{F}) \end{aligned}$$

Since $(X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}, V_{\varepsilon'}^{r+1})$ is a Runge pair it follows that α has dense image. On the other hand, applying Lemma 3 to the function

$$\varphi - \varepsilon' - h_1 - \dots - h_{r+1}$$

we deduce that $H^1(X_{\varepsilon'}^{r+1}, \mathcal{F})$ has finite dimension, in particular it is separated, hence α has closed image. Consequently α is surjective. From the open mapping theorem it follows easily that the restriction map

$$\Gamma(X_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow \Gamma(X_{\varepsilon'}^r, \mathcal{F})$$

has dense image and so Lemma 4 is proved.

LEMMA 5. *For any $\alpha \leq \beta$ the restriction map $\Gamma(X_{\beta}, \mathcal{F}) \rightarrow \Gamma(X_{\alpha}, \mathcal{F})$ has dense image.*

Proof. Lemma 5 is an immediate consequence of Lemma 4 and of Lemma [1, p. 246].

LEMMA 6. *For any $c \in \mathbf{R}$ there exists $\varepsilon > 0$ such that the restriction map $H^1(X_{c+\varepsilon}, \mathcal{F}) \rightarrow H^1(X_{c+\varepsilon'}, \mathcal{F})$ is bijective for any $0 \leq \varepsilon' \leq \varepsilon$.*

Proof. We may assume $c = 0$ and choose $\varepsilon > 0$ as in Lemma 1. Due to the inclusions $X_{\varepsilon'} \subset X_{\varepsilon} \subset X_{\varepsilon}^m$ and using Lemma 2 it follows that it suffices to show that the restriction map $H^1(X_{\varepsilon}^m, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}, \mathcal{F})$ is bijective. The inclusions $X_{\varepsilon'} = X_{\varepsilon'}^0 \subset X_{\varepsilon'}^1 \subset \dots \subset X_{\varepsilon'}^m$ show that it is enough to prove that the restrictions $H^1(X_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^r, \mathcal{F})$ are bijective for $r = 0, \dots, m - 1$.

Consider the Mayer-Vietoris exact sequence:

$$\begin{aligned} \Gamma(X_{\varepsilon'}^r, \mathcal{F}) \oplus \Gamma(V_{\varepsilon'}^{r+1}, \mathcal{F}) &\rightarrow \Gamma(X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^{r+1}, \mathcal{F}) \\ &\rightarrow H^1(X_{\varepsilon'}^r, \mathcal{F}) \oplus H^1(V_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}, \mathcal{F}) \end{aligned}$$

As remarked in the proof of Lemma 4 the map

$$\Gamma(X_{\varepsilon'}^r, \mathcal{F}) \oplus \Gamma(V_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow \Gamma(X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}, \mathcal{F})$$

is surjective. Since

$$H^1(V_{\varepsilon'}^{r+1}, \mathcal{F}) = H^1(X_{\varepsilon'}^r \cap V_{\varepsilon'}^{r+1}, \mathcal{F}) = 0$$

it follows that the restriction map

$$H^1(X_{\varepsilon'}^{r+1}, \mathcal{F}) \rightarrow H^1(X_{\varepsilon'}^r, \mathcal{F})$$

is bijective and so Lemma 6 is proved.

LEMMA 7. For any $\alpha \leq \beta$ the restriction map $H^1(X_\beta, \mathcal{F}) \rightarrow H^1(X_\alpha, \mathcal{F})$ is bijective.

Proof. Set $M(\alpha) = \{\delta \geq \alpha \mid \text{for any } \alpha \leq \gamma \leq \delta \text{ the restriction map}$

$$H^1(X_\delta, \mathcal{F}) \rightarrow H^1(X_\gamma, \mathcal{F}) \text{ is bijective}\}$$

and let $\alpha_0 = \sup M(\alpha)$.

From Lemma 2 it follows that if $\delta \in M(\alpha)$ then $[\alpha, \delta] \subset M(\alpha)$, consequently $[\alpha, \alpha_0) \subset M(\alpha)$. To prove Lemma 7 we have to show that $\alpha_0 = \infty$. Suppose that $\alpha_0 < \infty$. From Lemma 5 and Lemma [1, p. 250] we deduce that $\alpha_0 \in M(\alpha)$. From Lemma 6 there exists $\varepsilon > 0$ such that $\alpha_0 + \varepsilon \in M(\alpha)$. This contradicts the definition of α_0 , and so Lemma 7 is proved.

We are now in a position to prove Theorem 1. Choose $\alpha \in \mathbf{R}$ and take $\alpha = \alpha_0 < \alpha_1 < \dots < \alpha_n < \dots$ an increasing sequence of real numbers tending to ∞ . By Lemma 7 the restriction map $H^1(X_{\alpha_{n+1}}, \mathcal{F}) \rightarrow H^1(X_{\alpha_n}, \mathcal{F})$ is bijective and by Lemma 5 the restriction map $\Gamma(X_{\alpha_{n+1}}, \mathcal{F}) \rightarrow \Gamma(X_{\alpha_n}, \mathcal{F})$ has dense image. It follows then from Lemma [1, p. 250] that the restriction map $H^1(X, \mathcal{F}) \rightarrow H^1(X_\alpha, \mathcal{F})$ is also bijective and from Lemma 3 $H^1(X, \mathcal{F})$ has finite dimension. Theorem V. in [6] tells us that X is 1-convex, as required.

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(Reçu le 10 décembre 1984)

Mihnea Coltoiu

Department of Mathematics
INCREST, B-dul Păcii 220
R-79622 Bucharest
Romania