A Simple Proof for the Generalized Frankel Conjecture

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Abstract In this short paper, we will give a simple and transcendental proof for Mok’s theorem of the generalized Frankel conjecture. This work is based on the maximum principle in [4] proposed by Brendle and Schoen.

1. Introduction

Let $M^n$ be an $n$-dimensional compact Kähler manifold. The famous Frankel conjecture states that: if $M$ has positive holomorphic bisectional curvature, then it is biholomorphic to the complex projective space $CP^n$. This was independently proved by Mori [9] in 1979 and Siu-Yau [10] in 1980 by using different methods. Mori had got a more general result. His method is to study the deformation of a morphism from $CP^1$ into the projective manifold $M^n$, while Siu-Yau used the existence result of minimal energy 2-spheres to prove the Frankel conjecture. After the work of Mori and Siu-Yau, it is natural to ask the question for the semi-positive case: what the manifold is if the holomorphic bisectional curvature is nonnegative.
This is often called the generalized Frankel conjecture and was proved by Mok [8]. The exact statement is as follows:

**Theorem 1.1** Let \((M, h)\) be an \(n\)-dimensional compact Kähler manifold of nonnegative holomorphic bisectional curvature and let \((\tilde{M}, \tilde{h})\) be its universal covering space. Then there exist nonnegative integers \(k, N_1, \ldots, N_l\) and irreducible compact Hermitian symmetric spaces \(M_1, \ldots, M_p\) of rank \(\geq 2\) such that \((\tilde{M}, \tilde{h})\) is isometrically biholomorphic to

\[
(C^k, g_0) \times (\mathbb{C}P^{N_1}, \theta_1) \times \cdots \times (\mathbb{C}P^{N_l}, \theta_l) \times (M_1, g_1) \times \cdots \times (M_p, g_p)
\]

where \(g_0\) denotes the Euclidean metric on \(C^k\), \(g_1, \ldots, g_p\) are canonical metrics on \(M_1, \ldots, M_p\), and \(\theta_i, 1 \leq i \leq l\), is a Kähler metric on \(\mathbb{C}P^{N_i}\) carrying nonnegative holomorphic bisectional curvature.

We point out that the three dimensional case of this result was obtained by Bando [1]. In the special case, for all dimensions, when the curvature operator of \(M\) is assumed to be nonnegative, the above result was proved by Cao and Chow [5].

By using the splitting theorem of Howard-Smyth-Wu [7], one can reduce Theorem 1.1 to the proof of the following theorem:

**Theorem 1.2** Let \((M, h)\) be an \(n\)-dimensional compact simply connected Kähler manifold of nonnegative holomorphic bisectional curvature such that the Ricci curvature is positive at one point. Suppose the second Betti number \(b_2(M) = 1\). Then either \(M\) is biholomorphic to the complex projective space or \((M, h)\) is isometrically biholomorphic to an irreducible compact Hermitian symmetric manifold of rank \(\geq 2\).

In [8], Mok proved Theorem 1.2 and hence the generalized Frankel conjecture. His method depended on Mori’s theory of rational curves on Fano manifolds, so it was not completely transcendental in nature. The purpose of this paper is to give a completely transcendental proof of Theorem 1.2.

Our method is inspired by the recent breakthroughs in Ricci flow due to [2, 3, 4]. In [2], by developing a new method constructing the invariant cones to Ricci flow, Böhm and Wilking proved the differentiable sphere theorem for manifolds with positive curvature operator. Recently, Brendle and Schoen [3] proved the \(\frac{1}{4}\)-differentiable sphere theorem by using method of [2]. Moreover in [4], the authors
gave a complete classification of weakly $\frac{1}{4}$-pinched manifolds. In this paper, we will use the powerful strong maximum principle proposed in [4] to give Theorem 1.2 a simple proof.

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2. The Proof of the Main Theorem

Proof of the Main Theorem 1.2. Suppose $(M, h)$ is a compact simply connected Kähler manifold of nonnegative holomorphic bisectional curvature such that the Ricci curvature is positive at one point. We evolve the metric by the Kähler Ricci flow:

$$
\begin{align*}
\frac{\partial}{\partial t} g_{i\bar{j}}(x, t) &= -R_{i\bar{j}}(x, t), \\
g_{i\bar{j}}(x, 0) &= h_{i\bar{j}}(x).
\end{align*}
$$

According to Bando [1], we know that the evolved metric $g_{i\bar{j}}(t), t \in (0, T)$, remains Kähler. Then by Proposition 1.1 in [8], we know that for $t \in (0, T)$, $g_{i\bar{j}}(t)$ has nonnegative holomorphic bisectional curvature and positive holomorphic sectional curvature and positive Ricci curvature everywhere. Moreover, according to Hamilton [6], under the evolving orthonormal frame $\{e_\alpha\}$, we have

$$
\frac{\partial}{\partial t} R_{\alpha\bar{\alpha}\beta\bar{\beta}} = \Delta R_{\alpha\bar{\alpha}\beta\bar{\beta}} + \sum_{\mu, \nu}(R_{\alpha\bar{\mu}\bar{\nu} \beta\bar{\beta}} - |R_{\alpha\bar{\mu}\beta\bar{\beta}}|^2 + |R_{\alpha\bar{\mu}\beta\bar{\beta}}|^2).
$$

Suppose $(M, h)$ is not locally symmetric. In the following, we want to show that $M$ is biholomorphic to the complex projective space $CP^n$.

Since the smooth limit of locally symmetric space is also locally symmetric, we can obtain that there exists $\delta \in (0, T)$ such that $(M, g_{i\bar{j}}(t))$ is not locally symmetric for $t \in (0, \delta)$. Combining the Kählerity of $g_{i\bar{j}}(t)$ and Berger’s holonomy theorem, we know that the holonomy group $\text{Hol}(g(t)) = U(n)$.

Let $P = \bigcup_{p \in M}(T^{1,0}_p(M) \times T^{1,0}_p(M))$ be the fiber bundle with the fixed metric $h$ and the fiber over $p \in M$ consists of all 2-vectors $\{X, Y\} \subset T^{1,0}_p(M)$. We define a function $u$ on $P \times (0, \delta)$ by

$$
u(\{X, Y\}, t) = R(X, \overline{X}, Y, \overline{Y}),$$

3
where \( R \) denotes the pull-back of the curvature tensor of \( g_{i\bar{j}}(t) \). Clearly we have \( u \geq 0 \), since \((M, g_{i\bar{j}}(t))\) has nonnegative holomorphic bisectional curvature. Denote \( F = \{(\{X, Y\}, t) \mid u(\{X, Y\}, t) = 0, X \neq 0, Y \neq 0 \} \subset P \times (0, \delta) \) of all pairs \((\{X, Y\}, t)\) such that \( \{X, Y\} \) has zero holomorphic bisectional curvature with respect to \( g_{i\bar{j}}(t) \).

Following Mok [8], we consider the Hermitian form \( H(\alpha, \gamma, X, Y) = R(e_{\alpha}, e_{\beta}, X, Y) \), for all \( X, Y \in T_{p}^{1,0}(M) \) and all \( p \in M \), attached to \( e_{\alpha} \). Let \( \{E_{\mu}\} \) be an orthonormal basis associated to eigenvectors of \( H_{\alpha} \). In the basis we have
\[
\sum_{\mu, \nu} R_{\alpha\mu\nu} R_{\nu\bar{\mu}\bar{\beta}} = \sum_{\mu} R(e_{\alpha}, e_{\mu}, E_{\mu}, \bar{E}_{\mu}) R(E_{\mu}, \bar{E}_{\mu}, e_{\beta}, \bar{e}_{\beta}),
\]
and
\[
\sum_{\mu, \nu} |R_{\alpha\mu\nu}|^{2} = \sum_{\mu, \nu} |R(e_{\alpha}, E_{\mu}, e_{\beta}, \bar{E}_{\nu})|^{2}.
\]

First, we claim that:
\[
\sum_{\mu, \nu} R_{\alpha\mu\nu} R_{\nu\bar{\mu}\bar{\beta}} - \sum_{\mu, \nu} |R_{\alpha\mu\nu}|^{2} \geq c_{1} \cdot \min \{0, \inf_{|\xi|=1, \xi \in V} D^{2}u(\{e_{\alpha}, e_{\beta}\}, t)(\xi, \bar{\xi})\},
\]
for some constant \( c_{1} > 0 \), where \( V \) denotes the vertical subspaces.

Indeed, inspired by Mok [8], for any given \( \varepsilon_{0} > 0 \) and each fixed \( \chi \in \{1, 2, \ldots, n\} \), we consider the function
\[
\tilde{G}_{\chi}(\varepsilon) = (R + \varepsilon_{0}R_{0})(e_{\alpha} + \varepsilon E_{\chi}, e_{\alpha} + \varepsilon \bar{E}_{\chi}, e_{\beta} + \varepsilon \sum_{\mu} C_{\mu} E_{\mu}, e_{\beta} + \varepsilon \sum_{\mu} C_{\mu} E_{\mu}),
\]
where \( R_{0} \) is a curvature operator defined by \((R_{0})_{i\bar{j}k\bar{l}} = g_{i\bar{j}}g_{k\bar{l}} + g_{i\bar{k}}g_{j\bar{l}} \) and \( C_{\mu} \) are complex constants to be determined later. For the simplicity, we denote \( \tilde{R} = R + \varepsilon_{0}R_{0} \), then
\[
\tilde{G}_{\chi}(\varepsilon) = \tilde{R}(e_{\alpha} + \varepsilon E_{\chi}, e_{\alpha} + \varepsilon \bar{E}_{\chi}, e_{\beta} + \varepsilon \sum_{\mu} C_{\mu} E_{\mu}, e_{\beta} + \varepsilon \sum_{\mu} C_{\mu} E_{\mu}).
\]

Then a direct computation gives
\[
\frac{1}{2} \cdot \frac{d^{2} \tilde{G}_{\chi}(\varepsilon)}{d\varepsilon^{2}}|_{\varepsilon=0} = \tilde{R}(E_{\chi}, \bar{E}_{\chi}, e_{\beta}, \bar{e}_{\beta}) + \sum_{\mu} |C_{\mu}|^{2} \tilde{R}(e_{\alpha}, e_{\beta}, E_{\mu}, \bar{E}_{\mu})
\]
\[+ 2Re \sum_{\mu} C_{\mu} \tilde{R}(e_{\alpha}, E_{\chi}, e_{\beta}, \bar{E}_{\mu}) + 2Re \sum_{\mu} C_{\mu} \tilde{R}(e_{\alpha}, \bar{e}_{\beta}, E_{\mu}, \bar{E}_{\chi}).\]
Writing \( C_\mu = x_\mu e^{i\theta_\mu}, \) (\( \mu \geq 1 \)), for \( x_\mu, \theta_\mu \) are constants to be determined later, the above identity is:

\[
\frac{1}{2} \cdot \frac{d^2 \tilde{G}_\chi(\varepsilon)}{d\varepsilon^2}\bigg|_{\varepsilon=0} = \tilde{R}(E_\chi, \overline{E_\chi}, e_\beta, \overline{e_\beta}) + \sum_\mu |x_\mu|^2 \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})
+ 2\sum_\mu x_\mu \cdot \text{Re}(e^{-i\theta_\mu} \tilde{R}(e_\alpha, \overline{e_\alpha}, e_\beta, \overline{E_\mu}) + e^{i\theta_\mu} \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})).
\]

Following Mok [8], by setting \( A_\mu = \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu}), B_\mu = \tilde{R}(e_\alpha, \overline{E_\chi}, e_\beta, \overline{E_\mu}), \) we have:

\[
\frac{1}{2} \cdot \frac{d^2 \tilde{G}_\chi(\varepsilon)}{d\varepsilon^2}\bigg|_{\varepsilon=0} = \tilde{R}(E_\chi, \overline{E_\chi}, e_\beta, \overline{e_\beta}) + \sum_\mu |x_\mu|^2 \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})
+ \sum_\mu x_\mu \cdot (e^{-i\theta_\mu} B_\mu + e^{i\theta_\mu} B_\mu + e^{i\theta_\mu} A_\mu + e^{-i\theta_\mu} A_\mu)
= \tilde{R}(E_\chi, \overline{E_\chi}, e_\beta, \overline{e_\beta}) + \sum_\mu |x_\mu|^2 \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})
+ \sum_\mu x_\mu \cdot (e^{i\theta_\mu}(A_\mu + B_\mu) + e^{i\theta_\mu}(A_\mu + B_\mu))
\]

By choosing \( \theta_\mu \) such that \( e^{i\theta_\mu}(A_\mu + B_\mu) \) is real and positive, the identity becomes:

\[
\frac{1}{2} \cdot \frac{d^2 \tilde{G}_\chi(\varepsilon)}{d\varepsilon^2}\bigg|_{\varepsilon=0} = \tilde{R}(E_\chi, \overline{E_\chi}, e_\beta, \overline{e_\beta}) + \sum_\mu |x_\mu|^2 \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})
+ 2\sum_\mu x_\mu \cdot |A_\mu + B_\mu|.
\]

If we change \( e_\alpha \) with \( e^{i\varphi} e_\alpha \), then \( A_\mu = \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu}) \) is replaced by \( e^{i\varphi} A_\mu, \) and \( B_\mu = \tilde{R}(e_\alpha, \overline{E_\chi}, e_\beta, \overline{E_\mu}) \) is replaced by \( e^{-i\varphi} B_\mu, \) we have:

\[
\frac{1}{2} \cdot \frac{d^2 \tilde{G}_\chi(\varepsilon)}{d\varepsilon^2}\bigg|_{\varepsilon=0} = \tilde{R}(E_\chi, \overline{E_\chi}, e_\beta, \overline{e_\beta}) + \sum_\mu |x_\mu|^2 \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})
+ 2\sum_\mu x_\mu \cdot |e^{i\varphi} A_\mu + e^{-i\varphi} B_\mu|,
\]

where
\[
\tilde{F}_\chi(\varepsilon) = \tilde{R}(e^{i\varphi} e_\alpha + \varepsilon E_\chi, e^{i\varphi} e_\alpha + \varepsilon E_\chi, e_\beta + \varepsilon \sum_\mu C_\mu E_\mu, e_\beta + \varepsilon \sum_\mu C_\mu E_\mu).
\]

Since the curvature operators \( R \) and \( R_0 \) have nonnegative and positive holomorphic bisectional curvature respectively, we know that the operator \( \tilde{R} = R_0 + \varepsilon_0 R_0 \) has positive holomorphic bisectional curvature. Now by choosing \( x_\mu = -\frac{|e^{i\varphi} A_\mu + e^{-i\varphi} B_\mu|}{R(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})}, \) for \( \mu \geq 1 \), it follows that

\[
\frac{1}{2\pi} \int_0^{2\pi} (\frac{1}{2} \cdot \frac{d^2 \tilde{F}_\chi(\varepsilon)}{d\varepsilon^2}\bigg|_{\varepsilon=0}) d\varphi = \tilde{R}(E_\chi, \overline{E_\chi}, e_\beta, \overline{e_\beta}) - \sum_\mu \frac{|A_\mu|^2 + |B_\mu|^2}{R(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})}
\]
and then
\[ \tilde{R}(e_\alpha, \overline{e_\alpha}, E_X, \overline{E_X}) \cdot \frac{1}{2\pi} \int_0^{2\pi} (\frac{1}{2} \cdot \frac{d\tilde{F}_\alpha(\varepsilon)}{d\varepsilon})|_{\varepsilon=0} d\varphi \]
\[ = \tilde{R}(e_\alpha, \overline{e_\alpha}, E_X, \overline{E_X}) \tilde{R}(E_X, \overline{E_X}, \varepsilon_\beta, \overline{\varepsilon_\beta}) - \sum_\mu \frac{|A_\mu|^2 + |B_\mu|^2}{R(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})} \tilde{R}(e_\alpha, \overline{e_\alpha}, E_X, \overline{E_X}). \]

Note that
\[ \tilde{F}_\alpha(\varepsilon) = \tilde{R}(e^{i\varphi} e_\alpha + \varepsilon E_X, e^{i\varphi} e_\alpha + \varepsilon E_X, e_\beta + \varepsilon \sum_\mu C_\mu E_\mu, \overline{e_\beta + \varepsilon \sum_\mu C_\mu E_\mu}) \]
\[ = \tilde{R}(e_\alpha + \varepsilon e^{i\varphi} E_X, e_\alpha + \varepsilon e^{i\varphi} E_X, e_\beta + \varepsilon \sum_\mu C_\mu E_\mu, \overline{e_\beta + \varepsilon \sum_\mu C_\mu E_\mu}). \]

Interchanging the roles of \( E_X \) and \( E_\mu \), and then taking summation, we have
\[ \sum_\chi 2 \tilde{R}(e_\alpha, \overline{e_\alpha}, E_X, \overline{E_X}) \tilde{R}(E_X, \overline{E_X}, \varepsilon_\beta, \overline{\varepsilon_\beta}) \]
\[ \geq c_1 \cdot \min \{0, \inf_{|\xi|=1, \xi \in V} D^2 \tilde{u}((\{e_\alpha, e_\beta\}, t)(\xi, \xi)) \}
\[ + \sum_{\mu, \chi} \left( |A_\mu|^2 + |B_\mu|^2 \right) \left( \frac{\tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})}{R(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})} + \frac{\tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})}{R(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu})} \right) \]
\[ \geq c_1 \cdot \min \{0, \inf_{|\xi|=1, \xi \in V} D^2 \tilde{u}((\{e_\alpha, e_\beta\}, t)(\xi, \xi)) \} + 2 \sum_{\mu, \chi} |\tilde{R}(e_\alpha, \overline{E_X}, \varepsilon_\beta, \overline{E_\beta})|^2, \]

where \( \tilde{u}((\{X, Y\}, t) = \tilde{R}(X, \overline{X}, Y, \overline{Y}) = R(X, \overline{X}, Y, \overline{Y}) + \varepsilon_0 R_0(X, \overline{X}, Y, \overline{Y}) \) and \( c_1 \) is a positive constant that does not depend on \( \varepsilon_0 \).

Hence
\[ \sum_\mu \tilde{R}(e_\alpha, \overline{e_\alpha}, E_\mu, \overline{E_\mu}) \tilde{R}(E_\mu, \overline{E_\mu}, \varepsilon_\beta, \overline{\varepsilon_\beta}) - \sum_{\mu, \nu} |\tilde{R}(e_\alpha, \overline{E_\mu}, \varepsilon_\beta, \overline{E_\nu})|^2 \]
\[ \geq c_1 \cdot \min \{0, \inf_{|\xi|=1, \xi \in V} D^2 \tilde{u}((\{e_\alpha, e_\beta\}, t)(\xi, \xi)) \}. \]

Since \( \varepsilon_0 > 0 \) is arbitrary, we can let \( \varepsilon_0 \to 0 \), then we obtain that:
\[ \sum_{\mu, \nu} R_{\alpha\mu\beta} R_{\nu\beta\overline{\beta}} - \sum_{\mu, \nu} |R_{\alpha\beta\overline{\mu}}|^2 \geq c_1 \cdot \min \{0, \inf_{|\xi|=1, \xi \in V} D^2 u((e_\alpha, e_\beta), t)(\xi, \xi) \}, \]
for some constant \( c_1 > 0 \). Therefore we proved our first claim.

By the definition of \( u \) and the evolution equation of the holomorphic bisectional curvature, we know that
\[ \frac{\partial}{\partial t} u((X, Y), t) = \Delta u((X, Y), t) + \sum_{\mu, \nu} R(X, \overline{X}, e_\mu, \overline{e_\nu}) R(e_\nu, \overline{e_\mu}, Y, \overline{Y}) \]
\[ - \sum_{\mu, \nu} |R(X, \overline{e_\mu}, Y, \overline{e_\nu})|^2 + \sum_{\mu, \nu} |R(X, Y, e_\mu, \overline{e_\nu})|^2. \]
Combining the above inequality, we obtain that:
\[
\frac{\partial u}{\partial t} \geq Lu + c_1 \cdot \min\{0, \inf_{|\xi|=1, \xi \in V} D^2 u(\xi, \xi)\},
\]
where \(L\) is the horizontal Laplacian on \(P\), \(V\) denotes the vertical subspaces. By Proposition 2 in [4], (Actually, the same argument still holds for the bundle \(P\) in [4] changed by the bundle \(P\) defined in our paper.), we know that the set
\[
F = \{ \{(X, Y), t\} | u(\{X, Y\}, t) = 0, X \neq 0, Y \neq 0 \} \subset P \times (0, \delta)
\]
is invariant under parallel transport.

Next, we claim that \(R_{\alpha\bar{\alpha}\beta\bar{\beta}} > 0\) for all \(t \in (0, \delta)\).

Indeed, suppose not. Then \(R_{\alpha\bar{\alpha}\beta\bar{\beta}} = 0\) for some \(t \in (0, \delta)\). Therefore
\[
(\{e_\alpha, e_\beta\}, t) \in F.
\]
Combining \(R_{\alpha\bar{\alpha}\beta\bar{\beta}} = 0\) and the evolution equation of the curvature operator and the first variation, we can obtain that:
\[
\begin{cases}
\sum_{\mu, \nu}(R_{\alpha\bar{\mu}\nu}R_{\nu\bar{\mu}\beta\bar{\beta}} - |R_{\alpha\bar{\mu}\beta\bar{\nu}}|^2) = 0, \\
R_{\alpha\bar{\beta}\mu\nu} = 0, \quad \forall \mu, \nu, \\
R_{\alpha\bar{\alpha}\mu\bar{\beta}} = R_{\beta\bar{\beta}\mu\bar{\alpha}} = 0, \quad \forall \mu.
\end{cases}
\]
We define an orthonormal 2-frames \(\{\tilde{e}_\alpha, \tilde{e}_\beta\} \subset T^1_p(M)\) by
\[
\tilde{e}_\alpha = \sin \theta \cdot e_\alpha - \cos \theta \cdot e_\beta, \\
\tilde{e}_\beta = \cos \theta \cdot e_\alpha + \sin \theta \cdot e_\beta.
\]
Then
\[
\bar{e}_\alpha = \sin \theta \cdot \tilde{e}_\alpha - \cos \theta \cdot \tilde{e}_\beta, \\
\bar{e}_\beta = \cos \theta \cdot \tilde{e}_\alpha + \sin \theta \cdot \tilde{e}_\beta.
\]
Since \(F\) is invariant under parallel transport and \((M, g(t))\) has holonomy group \(U(n)\), we obtain that
\[
(\{\bar{e}_\alpha, \bar{e}_\beta\}, t) \in F,
\]
that is,
\[
R(\bar{e}_\alpha, \bar{e}_\alpha, \bar{e}_\beta, \bar{e}_\beta) = 0.
\]
On the other hand,

\[ R(\widehat{e}_\alpha, \overline{e}_\alpha, \widehat{e}_\beta, \overline{e}_\beta) = \sin^2 \theta \cos^2 \theta R_{\alpha\bar{\alpha}\alpha\bar{\alpha}} + \sin^2 \theta \cos \theta R_{\alpha\bar{\alpha}\alpha\beta} + \sin^3 \theta \cos \theta R_{\alpha\bar{\alpha}\beta\bar{\beta}} \]

\[ + \sin^4 \theta R_{\alpha\bar{\alpha}\beta\bar{\beta}} - \sin \theta \cos^3 \theta R_{\alpha\bar{\alpha}\beta\bar{\alpha}} - \sin^2 \theta \cos^2 \theta R_{\alpha\bar{\alpha}\beta\bar{\beta}} \]

\[ - \sin^2 \theta \cos^2 \theta R_{\alpha\bar{\beta}\beta\bar{\beta}} - \sin^2 \theta \cos \theta R_{\alpha\bar{\beta}\beta\bar{\alpha}} - \cos^3 \theta \sin \theta R_{\beta\bar{\alpha}\alpha\bar{\alpha}} \]

\[ - \sin^2 \theta \cos^2 \theta R_{\beta\bar{\alpha}\beta\alpha} - \sin^2 \theta \cos^2 \theta R_{\beta\bar{\alpha}\beta\bar{\beta}} - \cos \theta \sin^3 \theta R_{\beta\bar{\alpha}\beta\bar{\alpha}} \]

\[ + \cos^4 \theta R_{\beta\bar{\alpha}\beta\bar{\beta}} + \cos^3 \theta \sin \theta R_{\beta\bar{\alpha}\beta\bar{\beta}} + \cos^3 \theta \sin \theta R_{\beta\bar{\alpha}\beta\bar{\beta}} \]

\[ + \cos^2 \theta \sin^2 \theta R_{\beta\bar{\alpha}\beta\bar{\beta}} \]

\[ = \cos^2 \theta \sin^2 \theta (R_{\alpha\bar{\alpha}\alpha\bar{\alpha}} + R_{\beta\bar{\beta}\beta\bar{\beta}}). \]

So we have \( R_{\beta\bar{\beta}\beta\bar{\beta}} + R_{\alpha\bar{\alpha}\alpha\bar{\alpha}} = 0, \) if we choose \( \theta \) such that \( \cos^2 \theta \sin^2 \theta \neq 0. \) And this contradicts with the fact that \((M, g_{ij}(t))\) has positive holomorphic sectional curvature. Hence we proved that \( R_{\alpha\bar{\alpha}\beta\bar{\beta}} > 0, \) for all \( t \in (0, \delta). \)

Therefore by the Frankel conjecture, we know that \( M \) is biholomorphic to the complex projective space \( CP^n. \)

This completes the proof of Theorem 1.2.

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