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EL OBSERVATORIO DE SAN PEDRO MÁRTIR: A WORLD-CLASS SITE FOR LARGE TELESCOPES

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RESUMEN

Se describen las características de San Pedro Mártir como un sitio superior para telescopios astronómicos de gran tamaño. El cielo extremadamente oscuro, el alto porcentaje de noches despejadas durante todo el año, el seeing excelente, el bajo contenido de vapor de agua y los aspectos logísticos relacionados hacen a SPM el sitio número uno para nuevos proyectos de grandes telescopios. Ciertamente, SPM es un sitio muy atractivo, al cual se puede llegar fácilmente por tierra, mar y aire con rutas de abastecimiento significativamente cortas y que permite acceder en un solo día desde Santa Cruz, Pasadena, Tucson, San Diego, la Cd. de México y otros centros astronómicos.

ABSTRACT

This paper outlines the characteristics of San Pedro Mártir as a super site for major astronomical telescopes. The extremely dark sky, high percentage of clear nights year round, excellent seeing, low water vapor content, and related logistical matters make SPM the number one choice for major new telescope projects. Clearly, SPM is a most attractive site, affording ease of access by land, sea, and air, with significantly shorter supply lines and same day access from Santa Cruz, Pasadena, Tucson, San Diego, Mexico City, and other astronomical centers.

Key Words: **SITE TESTING**

1. INTRODUCTION

This paper is based on a talk given at UNAM in November 2005. It describes the past, present, and possible future development of San Pedro Mártir as a world-class site including a partnership for an international observatory. Details are provided on the Sierra San Pedro Mártir site, related logistics, and characterization of the site for astronomical observations. The history of astronomy in Baja California goes back to the 1860's when UNAM established the Institute of Astronomy in the coastal town of Ensenada with a 15-cm refractor (see Figure 1). Baja California has a low population density that is considered remote when viewed from the perspective of Mexico City. Figure 1 of González et al. (2007) shows a satellite image of the region with San Pedro Mártir being about 450 km from Tucson.

Fig. 1. The 15-cm refractor telescope, constructed in the 1860's, on display at the UNAM Institute of Astronomy in Ensenada, Baja California.

2. FROM SAN DIEGO TO ENSENADA TO SAN PEDRO MÁRTIR

Today UNAM has a campus in Ensenada including its Institute of Astronomy. San Pedro Mártir (SPM) is about 400 km from San Diego. The weather is dominated by the prevailing westerly air flow off the Pacific. While the weather is similar to California, the sky is among the darkest of any accessible mountaintop location in the North American continent.

Visitors coming from afar arrive at either the San Diego International Airport or Tijuana Airport. Travel by car to Ensenada takes about 90 minutes on a divided highway (with tolls). Ensenada is a town with much tourism and thus both Spanish and En-

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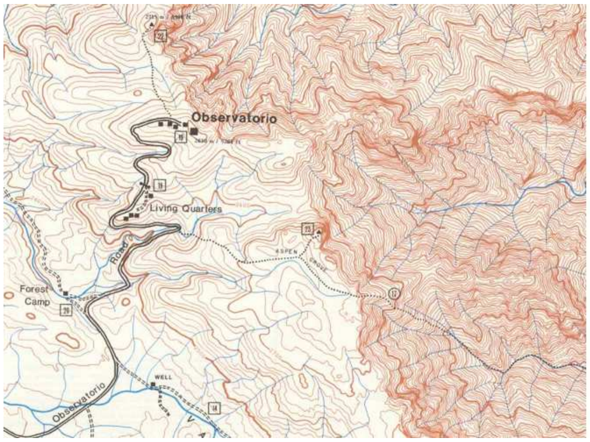

Fig. 2. Topographic map showing the region of the SPM Observatory. Cerro Botella Azul (2860 meters) and Pico el Diablo (3000 meters) are in the center and center right of the map, respectively.

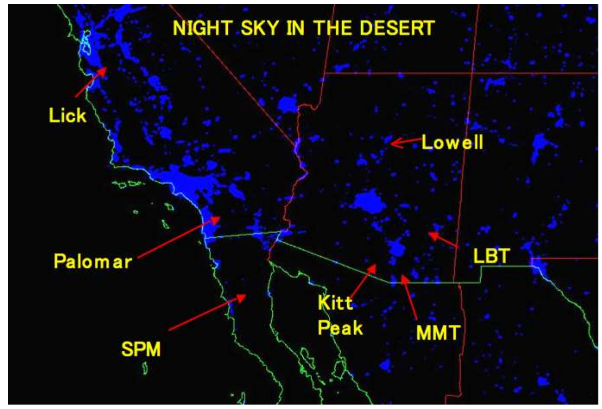

Fig. 3. Southwestern United States and northwestern Mexico as seen at night. The sky brightness at SPM is B > 22.3 mag per square arc second.

glish are widely spoken. The route from Ensenada southward to SPM follows the coast (El Camino Trans-Pacifica) for about 140 km where we then take the road to the summit of SPM for the last 100 km. Over the past three years (2005-2007) this road has been fully paved with asphalt at a cost of US$ 10M. Travel time over the approximately 240 km from Ensenada to the summit of SPM is about three hours.

While en route from the coast to the summit, about 60 km from the coastal highway, we pass the Melling Ranch (elevation∼ 700 m) with an airfield 880 m in length. Rancho Melling (also known as Rancho San Jose) was established by a Norwegian family in 1913. If one flies to Melling Ranch, sufficient aviation fuel must be on-board for the return flight: the nearest aviation fuel is at San Felipe. About 25 km beyond Melling Ranch we enter El Parque Nacional de San Pedro Mártir. A topographic map of the area near the summit is shown in Figure 2. Arriving to SPM, the first observatory buildings are living quarters, and then maintenance buildings and finally five domes near the end of the road. There are many hundreds of hectares of land situated on the SPM ridge within a kilometer northwest or southeast of the existing 2.1-m telescope at 2825–2835 m elevation where other, larger telescopes might be located. Most of the trees near the summit are ponderosa pine, juniper, fir, and oak, looking much like the Sierra Nevada range in California.

3. VERY DARK SKY

A major distinction of SPM is the dark sky, where the only major cities are to the north, i.e., San Diego and Yuma. A map of the night sky for the extended Sonoran Desert and Baja California is shown in Figure 3. Note that all the sites in Arizona and California are near major cities. Detail of the night sky surface brightness is mapped in Figure 2 of González et al. (2007). On SPM the sky is presently (2006) darker that 22.3 mag/sq arc second in the Johnson B filter. Fifty years ago when Harold Johnson himself was testing various sites in Arizona, he argued for sites with pine forests, i.e., in the Coconino National Forest near Flagstaff, rather than on open desert terrain lacking any foliage because the open desert has a significantly higher albedo, thus increasing the night sky brightness. With its pine forest, SPM met Johnson's requirements.

3.1. *Abundant Clear Sky with Excellent Seeing*

During the past five years there has been extensive site testing including the installation of seeing monitors. The highest peak in the SPM range is Pico el Diablo (also known as Cerro Encantado) at 3100 m elevation. However, access to the summit of El Diablo is very difficult. A summary of the weather statistics and seeing conditions is given in Table 1.

Careful continuous records of the cloud cover over SPM have been documented by Maurico Tapia (UNAM Ensenada) for over twenty years, starting in 1984. Additional satellite imaging data which covers only one year, compiled by Andre Erasmus, brackets the percentage clear sky at 73% between photometric (63%) and spectroscopic (81%).

In the present decade the median seeing measurements were obtained using a DIMM. Earlier seeing measures were made repeatedly over the past 40 years by Harold Johnson, Gerald Kuiper, Merle

TABLE 1

SUMMARY OF CLIMATIC & SEEING CONDITIONS

Photometric[a]	63%
Satellite Imaging[b]	73%
Spectroscopic[a]	80%
Seeing (median)	0.59 arc sec (FWHM)
Seeing (1st Quart)	0.47 arc sec (FWHM)
Night sky (in B)	22.3 mag/sq arc sec

[a]Tapia 2003.
[b]Erasmus & van Staden 2002.

TABLE 2

SAN PEDRO MÁRTIR SITE CHARACTERISTICS

Water Vapor Content[a]	$\sim$ 2.50 mm	
Mean Extinction[b] (mag/airmass)	0.14 at 549 nm 0.055 at 800 nm	
Sky Brightness[c]		
Pass Band	Dark Moon	Bright Moon
U	21.5	19.3
B	22.3	19.8
V	21.2	19.7
R	20.7	19.6
I	19.2	18.4
J	16.4	—
H	14.1	—
K	14.9	—

[a]Echevarría 2003, Hiriart 2003.
[b]Parrao & Schuster 2003.
[c]Richer 2006; sky brightness units are magnitudes per square arc sec.

Walker, and Richard Cromwell. The median seeing quoted in Table 1 (by Raul Michel) is in close agreement with Cromwell's measurement in 1994-95 at $\sim$ 0.6 arc sec. Water vapor and extinction characteristics are given in Table 2.

The sky over SPM is significantly darker than that of the developed Chilean sites at Cerro Tololo and Cerro Pachon. Those sites in Chile were selected more than 40 years ago. However, in the interim, there has been significant population growth around La Serena, Vicuna, and other villages along the El Qui river valley. However, ESO's La Silla and the Carnegie Observatory's Las Campanas are quite comparable to SPM.

Another difference between Baja California and Chile is the presence of the South Atlantic geomagnetic anomaly (centered over Chile and Argentina) which contributes to the night sky brightness in the southern hemisphere, particularly in the oxygen green line (5577 Å).

In Figure 4 we show graphs of monthly variations in the percentage of spectroscopic and photometric clear weather for SPM and for comparison, CTIO, KPNO, and Mt. Graham. Note that KPNO and Mt. Graham are affected by the summer "monsoons", i.e., thunder storms created by the moist air flow from the Gulf of Mexico, while Chile and Baja California are not.

The integrated spectrum of the night sky near the zenith can be seen in Figure 5 of Tapia, Cruz-González, & Avila (2007). Note that typically bright night sky lines arising from ground-based lighting such as Hg I at 5461 Å and Na I at 5889–95 Å are very weak. In Figure 5 and Table 3 the distribution of seeing measurements acquired using a DIMM on SPM shown for the seasons. These data were obtained by Michel et al. (2003) who have compiled

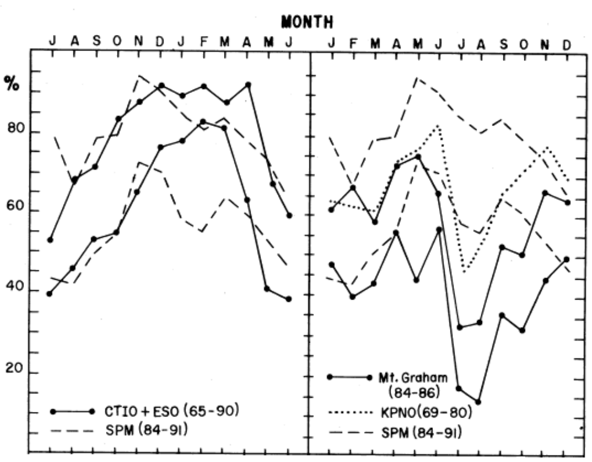

Fig. 4. Monthly variations in the percentage of spectroscopic and photometric nights. SPM has an average of 81% spectroscopic and 63% photometric nights.

comparative seeing measurements using DIMM techniques for various sites around the world. The top three sites in the list are SPM with a median seeing of 0.59 arc sec, Cerro Chico, Chile (0.61 arc sec), and La Palma, Spain (0.69 arc sec).

4. VISTAS OF SAN PEDRO MÁRTIR — A POSSIBLE AIR FIELD

Using Google Earth, we show the region surrounding the buildings and domes of UNAM's SPM

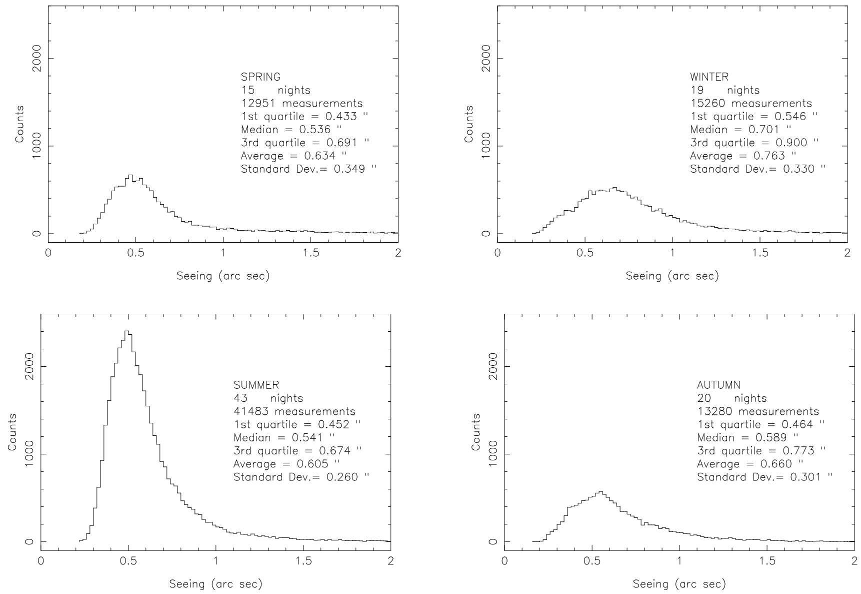

Fig. 5. Seasonal seeing measurements at SPM, from Michel et al. (2003). Spring and summer (top left and bottom left, respectively) have FWHM seeing of 0.54 arc seconds. Winter (top right) has a seeing of 0.70 arc seconds while autumn (bottom right) has a seeing of 0.59 arc seconds.

Fig. 6. The clearing seen in the center of the satellite image is the potential air field. The Observatory buildings are seen several kilometers to the north west.

Observatory (Figure 6). The clearing at the center of the image is proposed as an ideal location for an airfield. The elevation from end to end of a possible airfield varies by only ±4–5 m over the 2 km clearing where very few trees would have to be removed. The observatory is seen as a cluster of buildings several kilometers to the northwest of the clearing.

Having such an accessible airfield would make SPM extremely attractive and would simplify the logistics when construction and commissioning of instruments is under way. One comment that followed my talk was made by Joe Miller. He noted that one of the Lick staff members, Remington Stone, who is an experienced pilot, has flown over SPM and inspected this clearing. He said that Stone suggested that it would make an ideal airfield. Miller further remarked that the logistics compared with sites in Chile would make instrument assembly, troubleshooting, testing, and operation vastly simpler to sites that are 10,000–12,000 km away. The distance from the proposed airfield to the SPM 2.1-m telescope is only about 5 km while the airfield at Melling Ranch is 40 km and the San Diego Airport is about 400 km away. There is one hurdle that would have to be resolved: the Mexican National Parks would have to give a permit for an airfield and there would likely be some restrictions on its use.

5. SPM OBSERVATORY — PAST AND PRESENT

Constructed by UNAM's Institute of Astronomy, under the direction of Arcadio Poveda, the largest telescope on SPM is a 2.1-m reflector, completed in 1979 with optics made by Norman Cole (Tucson) and a mounting manufactured by L&F Machine Co. (Los Angeles); see Figure 7. There are several

TABLE 3

OTHER SITE CHARACTERISTICS FOR SPM

Seasonal Integrated Seeing (FWHM)[a]	
Spring	0.58″
Summer	0.58″
Autumn	0.68″
Winter	0.69″
Annual Mean	0.61″
Water Vapor Content	
Mean PWV satellite	2.63 mm[b]
Mean PWV radiometer	2.40 mm[c]
Mean wind speed[d]	
GGUAS[e]	27.0+3.6 m s^{-1}
NCEP[f]	26.5+1.7 m s^{-1}
Optical Turbulence[d]	
Altitude (km)	Seeing (arc sec FWHM)
2–4	0.44
4–9	0.17
9–16	0.24
16–21	0.08
21–25	0.02
Surface Layer Seeing	0.11 arc sec

[a]Echevarría 2003.
[b]Erasmus & Staden 2002.
[c]Hiriart 2003.
[d]Carrasco & Sarazin 2003.
[e]Global Gridded Upper Air Statistics (NASA).
[f]National Center for Environmental Prediction.

Fig. 7. The 2.1-m telescope was completed in 1979, under the direction of Arcadio Poveda.

Fig. 8. The recently completed living quarters at SPM, with 45 guest rooms, a dining hall, conference room, and computer lab.

smaller telescopes including a 1-m reflector originally on loan from the University of Arizona and installed by Harold Johnson in the late 1960's.

Voice and data communications from the present site are via a microwave link to San Felipe and then by fiber-optics cable to Mexicali, Tijuana, and Ensenada. Between the UNAM campus in Ensenada and the University of California in San Diego, there is a high-speed link (Internet-2) which could provide access to the UCSD Supercomputer. UNAM is considering the installation of a fiber-optics link from SPM to Ensenada at a cost of ∼US$ 4M.

In 2003, new living quarters were completed (see Figure 8) with 45 rooms, a dining hall, a conference room, and computer lab. Several additional views help to give one a sense of the spectacularly clear sky. Figure 9 is a view from the catwalk of the 2.1-m telescope looking toward the Sea of Cortez. Figure 10 shows the Botella Azul ridge (elevation about 2840 meters) which is more accessible than the Pico el Diablo.

The 30-m telescope project (TMT) led by Caltech and the University of California and their partners, has been doing site testing on SPM for nearly two years.

6. CONSIDERATIONS FOR LARGER TELESCOPES

Much of the discussion of plans for new instruments, led by Mexican astronomers, has centered upon two 6.5-m telescopes modeled after the Magellan telescopes at Las Campanas Observatory (see

Fig. 9. A view of the Sea of Cortez, seen towards the east from the catwalk of the 2.1-m telescope. The distance to the coast is about 200 km.

Fig. 10. The Botella Azul ridge, with an elevation of about 2840 meters, as seen from the catwalk of the 2.1-m telescope.

Figure 5 of González et al. 2007). The current plan is for one telescope to have a wide-field (1–1.5° diameter) f/5 Cassegrain, for use with a many-fiber (∼1000) fed spectrograph. The other telescope would be of a standard field size, ∼15–20 arc min, with adaptive optics following the design developed for the 6.5-m MMT (on Mt. Hopkins). Following the MMT design, the AO system would have 336 actuators, controlled by acoustical voice coils, operating at a refresh rate of 50–100 Hz. The thin-shell AO mirror would be 65 cm in diameter and 1.9 mm thick (see Figure 11). At 2–5 microns the resolution would be of order 0.06 arc sec. Discussions with potential partners have been in progress for several years (see Table 4).

Fig. 11. The thin-shell AO mirror of the MMT. It is 64 cm in diameter, with a 1.9 mm thick glass facesheet, and 336 rear-mounted magnets.

TABLE 4

POSSIBLE COLLABORATORS OUTSIDE MEXICO

University of Arizona (Tucson)
University of Alabama (Tuscaloosa)
University of Florida (Gainesville)
University of Central Florida (Orlando)
University of Illinois (Urbana)
Durham University (UK)
Johns Hopkins University (Baltimore)
Korean Astronomy & Space Science Institute
Princeton University (Princeton)

7. SOME CLOSING REMARKS — THE NIGHT SKY ON SAN PEDRO MÁRTIR

After the November 2005 meeting in Mexico City, I made a second visit to San Pedro Mártir on May 24–26, 2006 in the dark of the Moon. I was able to see things that I have not seen at other sites in Arizona, Chile, Spain, Australia, and the Indian Himalayas. Here are some of the remarkable vistas I saw:

1. The integrated light of the night sky oxygen green line at 5577 Å was visible up to about 15–20° elevation (above the horizon). Don Hunten (KPNO and LPL) told me about this feature in the night airglow. However, recently he said that it has been at least 40–45 years since he has seen the integrated light of the green line from Kitt Peak.

2. Initially I had difficulty locating the familiar "keystone" in Hercules, but after some searching around, I found it. The problem was that there were so many faint starts in the region of the keystone that it was difficult to identify! Then I could easily pick out the well-known globular cluster M13, about 6.3 mag.

3. Then I looked at Arcturus and it appeared rather unusual. There was no twinkling — no turbulence — i.e., very, very good seeing. Arcturus was completely steady as a function of time over a few minutes.

4. In the course of about 90 minutes in the dark, away from any ground-based lights, I became quite well dark-adapted. I could see no ground-based light pollution in any direction although the line-of-sight to San Felipe was blocked by the uppermost ridge of SPM and intervening low level hills to the east. I looked at Leo, moving eastward from Regulus to Denebola in the "tail" of Leo, and then I looked a little farther east into Coma Bernices, where I was able to see numerous faint galaxies. Then I looked a little farther south toward Virgo, where I was able to see several dozen faint objects which were undoubtedly members of the Virgo cluster of galaxies. These galaxies are of order 7 to 8 mag. Upon returning to Tucson, I carefully checked sky charts that go to about 9th magnitude and I was able to confirm the groups of galaxies that I saw in Coma Bernices and Virgo. Some critics might say, this guy had too much wine with dinner — but I had none: it is against the rules on SPM. While I have written to various people about seeing the Virgo Cluster of Galaxies, no one had written me saying that they have seen much the same vista from some other site.

Please keep in mind that over the years (1963–2007), I have been on numerous observing runs at other sites around the world including Kitt Peak, Lowell Observatory, Mt Hopkins (MMT), Lick Observatory, Mauna Kea, Mt Haleakala, Cerro Tololo, ESO's La Silla, Siding Spring (Australia), Hanle in the Himalayas (Indian Kashmir), Wise Observatory in the Negev Desert (Israel), and Calar Alto (Spain).

San Pedro Mártir is absolutely a rare gem on our small blue planet. The weather is as good as or better than Chile, the sky is darker than in Chile, and has better seeing than in Chile, with the median seeing on SPM being 0.5 to 0.6 arc sec (FWHM). We must do everything we possibly can to keep SPM dark. UNAM, CONACyT and the Mexican Government, might purchase all the property in the coastal village of San Felipe to reduce light pollution to zero. Short of that, funds should be found to equip existing lighting at San Felipe and other coastal villages with low pressure sodium street lights shielded in the downward direction. If President Teddy Roosevelt had his way one hundred years ago, Baja might have become part of the USA and its priceless dark skies would have been lost forever. In fairness, I should add that the astronomers in Ensenada are taking steps to encourage legislation in the Baja state government to control, reduce, and minimize ground-base light pollution.

San Pedro Mártir is not affected by the annual monsoon season that occurs in July, August and early September, in Arizona, New Mexico, Sonora, and Texas. Instead, Baja California has dry, cold air, dominated by the prevailing westerly winds off the Pacific Ocean. Thus, the frequency of thunderstorms on SPM is 5–10% of the number that occurs in Arizona. During the summer your Mexican colleagues observing on SPM have watched thunderstorms raging to the northeastern horizon over Kitt Peak.

Without question, this site needs to be preserved and developed for astronomy. SPM is one of the few dark sites with excellent weather around the world. The night sky on SPM is, I would guess, comparable to what Walter Baade experienced on Mt. Wilson during the blackouts in World War II and what Hale and Hubble saw with the 100 inch in 1920.

In 2006 the LSST site selection committee voted for SPM over Cerro Pachon and Las Campanas, but contrary to their decision, some partners in LSST decided that Cerro Pachon was better for logistical reasons. SPM has better seeing, more clear weather, and is significantly darker than Cerro Tololo and Cerro Pachon.

If one were to make arguments based on logistics and infrastructure, SPM wins hands down in many ways. It has plenty of nearly level ground for an airfield at 2430 meters elevation that is at least 2 km long. The supply line to SPM is 10,000 km closer than Cerro Pachon. Access to the UCSD Supercomputer Center is very attractive for data processing. Astronomers involved in large telescope projects, for example, the 30-m TMT, have told me that they would put the TMT on SPM in a heart beat (Joe Miller at Lick Observatory) and another said that SPM is the best site in the northern hemisphere (George Djorgovski at Caltech). Other astronomers in Pasadena have remarked that Gordon Moore, the founder of Intel and a potential donor, would like very much to see the TMT located in the USA or in a site very near by. The only site that would qualify is SPM. As an addendum I should point out that in August 2006 a judge in Hawaii ruled out any further telescopes on Mauna Kea and Haleakala. In June 2007 the US Forest Service seriously questioned Haleakala as the site for ATST (the Advanced Technology Solar Telescope).

More than 30 years ago the French, Canadians, and the University of Colorado were very interested in SPM as a site for a 4-m telescope, but Hawaii won out when the state of Hawaii stepped in and replaced Colorado. Thus the CFHT was created. As early as 1968, Merle Walker (Lick Observatory), plus Harold Johnson and Gerard Kuiper (University of Arizona) clearly recognized SPM as a first class site. Keep in mind that SPM is not plagued by sand storms that affect the Canary Islands, usually in April, due to winds coming off the Sahara Desert.

Finally, the time has come for major new telescopes to be located on San Pedro Mártir. This site is a rare gem that must be protected much like the endangered California condor and carefully developed for future generations of astronomers.

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