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The Design and Construction of the Muon Arm in PHENIX

Final Report

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Submitted by

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United States Department of Energy

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Introduction

This is the final report for Grant DE-FG05-88ER-40445, and, as such, will comprise both a retrospective view of the past twenty-five years and a summary of progress during the immediate past. There is no accompanying proposal for renewal.

Personnel

Both research associate Zhi-fu Wang and technician Ying-chao Wang have left the employ of LSU. Zhi-fu Wang resigned his position during the summer of 1997, and Ying-chao Wang followed suite in the spring of 1998. Zhi-fu Wang, in particular, served LSU and the DOE well for many years, and it is indeed a pleasure to express our thanks to him for years of distinguished service at this time.

Unfortunately, Zhi-fu had never been happy within the PHENIX Collaboration, and for this reason he accepted an offer of more lucrative and congenial employment at the Los Alamos National Laboratory. His contributions to PHENIX were enormous, however, most notably in regard to the design and construction of the tracking chambers. The loss of his quiet, unassuming competence and personal modesty were serious blows to the collaboration.

Finally, after several years' affiliation with this group, Mr. James Gregurich also resigned his position in order to pursue his interests in computers. Had he remained in our group he would, in our judgment, have been uniquely qualified to contribute effectively to the analysis of data logged with PHENIX. Nonetheless, we were not able to offer him an assistantship that was sufficiently attractive, and, not surprisingly, he chose to affiliate with those who could.

A Retrospective View

This laboratory was established during the mid-1970s after the arrival of the principal investigator from the University of California, San Diego. Beginning from an empty laboratory and unswept floor, funding was secured and apparatus was constructed over a period of years with minimal assistance. Nonetheless, during the term of this grant, funds provided by the DOE and its administrative predecessors, the AEC and ERDA, were used to support experimental programs at the Bevalac, KEK, the AGS, and RHIC. Shown below is a list of publications that are attributable either in part or in whole to this grant and its predecessors. This list comprises only refereed papers in well-established, internationally recognized journals. Contributions to the proceedings of conferences and references to the Bulletin of the American Physical Society have been deleted.

1. Response of Plastic Scintillation Counters to Relativistic Heavy Ions, C.L. Ruiz, et al., Nucl. Instrum. & Methods 159, (1979) 55-60.

2. Zero-degree Fragmentation of Relativistic Li-6, C.L. Ruiz, et al., Phys. Rev. Lett. **43**, (1979) 334-337.

3. The Monte-Carlo Simulation of Three-Body Phase Space Distributions, C.L. Ruiz, et al., Nucl. Instrum. & Methods **169**, (1980) 199-213.

4. Forward-Backward Particle Correlation Measurements in Proton-Carbon Collisions at 2.1 GeV, R.N. Treuhaft, et al., Phys. Rev. C **30**, (1984) 616-632.

5. Particle-Gamma Coincidence Measurements in C-12 + C-12 and C-12 + Pb Collisions at 2.1 GeV/Nucleon Incident Energy, G. Roche, et al., Nucl. Phys. A **439**, (1985) 721-740.

6. Subthreshold Negative Pions and Energetic Protons Produced at $\Theta_{cm} = 90°$ in 246 MeV/Nucleon La-139 + La-139 Collisions, G.F. Krebs, et al., Phys. Lett. B **171**, (1986) 37-40.

7. Measurements of R and a Search for Heavy Quark Production in e^+e^- Annihilation at $\sqrt{s} =$ 50 and 52 GeV, E. Sagawa, et al., Phys. Rev. Lett. **60**, (1988) 93-96.

8. Search for Isolated Leptons in Low-Thrust e^+e^- Annihilation Events at $\sqrt{s} = 50$ and 52 GeV, S. Igarashi, et al., Phys. Rev. Lett. **60**, (1988) 2359-2362.

9. Experimental Mass Limit for a Fourth-Generation Sequential Lepton from e^+e^- Annihilation at $\sqrt{s} = 56$ GeV, G.N. Kim, et al., Phys. Rev Lett. **61**, (1988) 911-914.

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12. Measurement of the e^+e^- Total Hadronic Cross Section and A Determination of M_z and $\Lambda_{\overline{ms}}$, T. Mori, et al., Phys. Lett. B **218**, (1989) 499-507.

13. Design of the Bevalac Heavy Ion Spectrometer System and Its Performance In Studying C-12 Fragmentation, J. Engelage, et al., Nucl. Instrum.. & Methods A **277**, (1989) 431-444.

14. Experimental Evidence for the Non-Abelian Nature of QCD from a Study of Multijet Events Produced in e^+e^- Annihilations, I.H. Park, et al., Phys. Rev. Lett. **62**, (1989) 1713-1716.

15. Subthreshold Anti-Proton Production in Si-28 + Si-28 Collisions at 2.1 GeV/Nucleon, J.B. Carroll, et al., Phys. Rev. Lett. **62**, (1989) 1829-1832.

16. Threshold Behavior of Electron Pair Production in P-Be Collisions, C. Naudet, et al., Phys. Rev. Lett. **62**, (1989) 2652-2655.

17. Dielectron Production in Ca + Ca Collisions at 1.0 and 2.0 A GeV, G. Roche, et al., Phys. Lett. B **226**, (1989) 228-232.

18. Search for non-minimal Higgs Production in e^+e^- Annihilations at $\sqrt{s} \approx 56$ GeV, E. H. Low, et al., Phys. Lett. B 228, (1989) 548-552.

19. Mass and Transverse Momentum Dependence of the Dielectron Yield in p - Be Collisions at 4.9 GeV, A. Letessier-Selvon, et al., Phys. Rev. C 40, (1989) 1513-1516.

20. Search for the Substructure of Leptons in High Energy QED Processes at TRISTAN, S.K. Kim., et al., Phys. Lett. B 223, (1989) 476-484.

21. Search for Unstable Heavy Neutral Leptons in e^+e^- Annihilations at $\sqrt{s}$ from 50 to 60.8 GeV, N.M. Shaw, et al., Phys. Rev. Lett. 63, (1989) 1342-1345.

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26. Mid-rapidity π^+/π^- ratios in 1.05 GeV/nucleon Ca-40 + Ca-40 Collisions, J.W. Harris, et al., Phys. Rev. C 41, (1990) 147-151.

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39. Dielectron Yields in p+d and p+p Collisions at 4.9 GeV, H.Z. Huang, et al, Phys. Lett. B 297, (1992) 233-237.

40. Measurement of Dielectron Production in Niobium-Niobium Collisions at 1.05 GeV/Nucleon, S. Beedoe, et al., Phys. Rev. C 47, (1993) 2840-2845.

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42. Measurement of α_s From the Moment of Particle Momenta Within Jets from e^+e^- Annihilation, K.B. Lee, et al., Phys. Lett. B 313, (1993) 469-474.

43. Mass Dependence of Pion Production in Heavy Ion Collisions Near, but Below, Threshold, J. Miller, et al., Phys. Lett. B 314, (1993) 7-12.

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46. Forward-backward Charge Asymmetry of Quark Pairs Produced at the KEK TRISTAN e^+e^- collider, D. Stuart, et al., Phys. Rev. D 49, (1994) 3098-3105.

47. Measurements of Cross Section and Asymmetry for $e^+e^- \rightarrow b\bar{b}$ and Heavy Quark Fragmentation at KEK Tristan, F. Liu, et al., submitted to Phys. Rev. D 49, (1994) 4339-4347.

48. Measurements of the inclusive jet cross section in photon-photon interactions at TRISTAN, B.J. Kim, et al., Phys. Lett. B 325, (1994) 248-256.

49. Measurement of Cross Section and Charge Asymmetry for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ at $\sqrt{s}$ = 57.8 GeV, C. Velissaris, et al., Phys. Lett. B 331, (1994) 227-235.

50. A High-Q^2 Measurement of the Photon Structure Function F_2^γ, S. K. Sahu, et al., Phys. Lett. B **346**, (1995) 208-216.

51. A Determination of α_s in e^+e^- Annihilation at $\sqrt{s} = 57.3$ GeV, Y. K. Li, et al., Phys. Lett. B **355**, (1995) 394-400.

52. A Measurement of Bose-Einstein Correlations in e^+e^- Annihilation at TRISTAN, S. K. Choi, et al., Phys. Lett. B **355**, (1995) 406-414.

53. Measurement of Charm Production in Two-Photon Processes Using Inclusive Lepton Events at TRISTAN, T. Aso, et al., Phys. Lett. B **363**, (1995) 249-258.

54. Study of Two Particle Azimuthal Correlations in e^+e^- Annihilation at $\sqrt{s} = 58$ GeV, S. Kanda, et al., Phys. Rev. D **52**, (1995) 4872-4876.

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57. Measurement of the Forward-Backward Asymmetry in $e^+e^- \to b\bar{b}$ and the b-quark Branching Ratio to Muons at TRISTAN Using Neural Networks, K. Ueno, et al., Phys. Lett. B **381**, (1996) 365-371.

58. Measurement of $D^{*}\pm$ Production in Two-Photon Processes at TRISTAN, N. Takashimizu, et al., Phys. Lett. B **381**, (1996) 372-378.

59. Measurement of $D^{*}\pm$ Production in Two-Photon Processes at TRISTAN, N. Takashimizu, et al., Phys. Lett. B **384**, (1996) 481-486.

60. A Measurement of the Photon Structure Function F_2^γ at $Q^2 = 6.8$ GeV^2, T. Kojima, et al., Phys. Lett. B **400**, (1997) 395-400.

61. Dielectron Cross Section Measurements in Nucleus-Nucleus Reactions at 1.0A GeV, R. J. Porter, et al., Phys. Rev. Lett. **79**, (1997) 1229-1232.

62. Measurement of α_s Using NLLA + $O(\alpha_s^2)$ in e^+e^- Annihilation at $\sqrt{s} = 58.0$ GeV, D. Y. Kim, et al., Phys. Lett. B **420**, (1998) 233-240.

63. Observation of Exclusive η_c Production in Two Photon Interactions at TRISTAN, M. Shirai, et al., Phys. Lett. B **424**, (1998) 405-410.

64. An Experimental Study of the Process $e^+e^- \to e^+e^-\mu^+\mu^-$, H. S. Ahn, et al., Phys. Lett. B **440**, (1998) 179-188.

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This grant, and its administrative predessors, are thus wholly or partially responsible for the publication of approximately 2.5 papers per year, and if the number or publications should be averaged only over the years following the establishment of the laboratory, the yield would be approximately 3.4 publications per year.

Numbers alone, however, are not necessarily a reliable assessment of achievement, and in retrospect it seems to us that our most significant contributions transpired during the years in which the Di-Lepton Spectrometer (DLS) was in operation. The DLS Collaboration was sufficiently small in size that our group could, and did, contribute in major ways to the experimental program. As just one example, we designed, built, installed, and maintained the two forward drift chambers, which were by a wide margin the most reliable and dependable detectors in the apparatus. We were fortunate in having in our employ during that time Mr. Steve Christo, whose phenomenal technical talents served the collaboration well. In addition, during the latter stage of the collaboration, Zhi-fu Wang and Ying-chao Wang carried a heavy load, most notably when unknown persons inadvertently destroyed a portion of one of our chambers only a few hours before beam time, thereby necessitating repairs that were carried out around the clock.

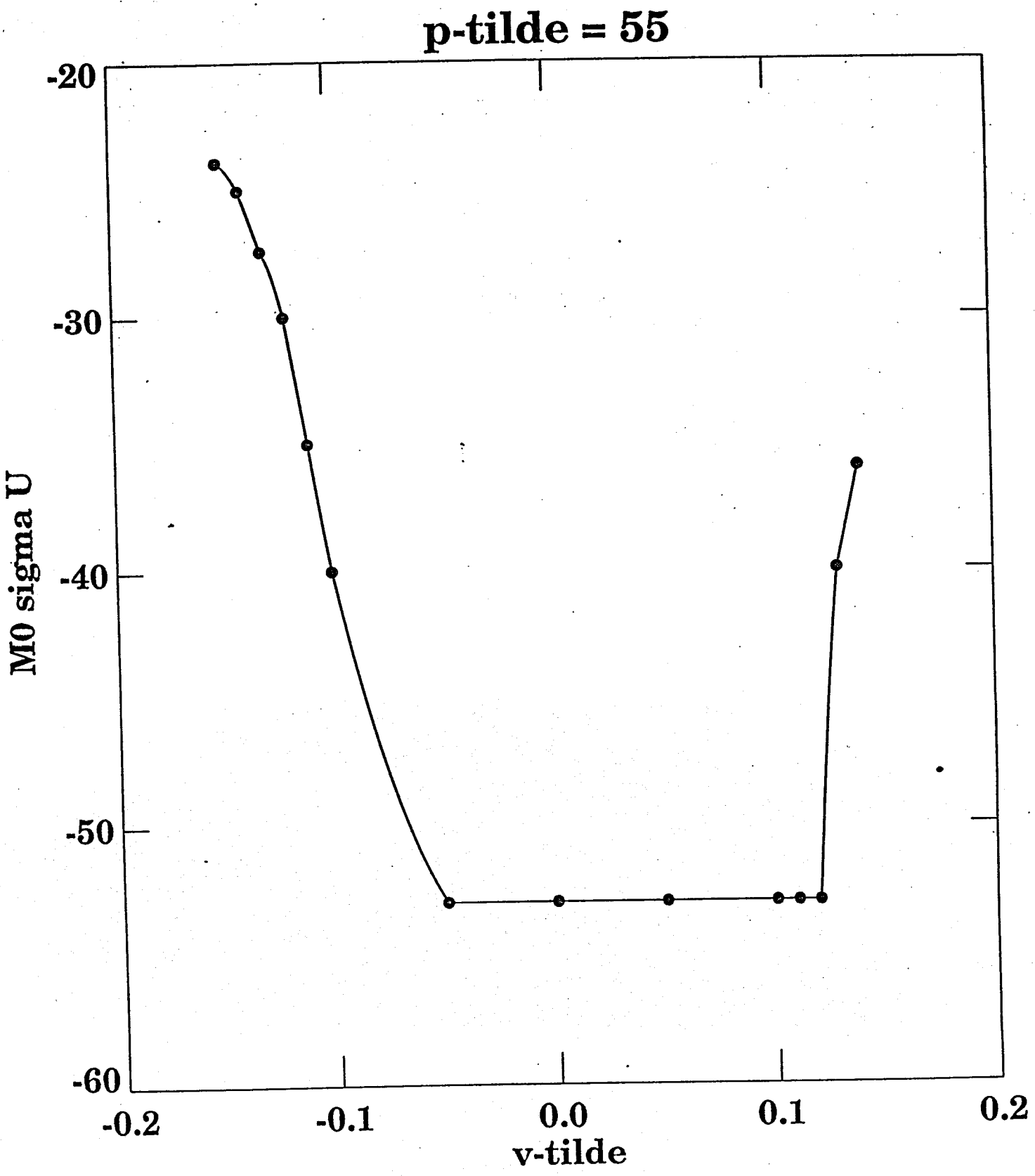
The group also contributed in significant ways to the AMY Collaboration at KEK. Specifically, with Mr. Christo's inspired assistance we built the two ring veto counters using - literally - scraps of scintillator from our own laboratory and from the laboratories of our collaborators. The counters worked very well indeed and served the AMY Collaboration for a long time before eventually being replaced by wire chambers. On the whole, however, it seems to me that our contributions to AMY were less visible that our contributions to the DLS, due in large measure to our having joined AMY at a late stage in the formation of the collaboration. All positions of visibility had been taken at the time we joined, and it was difficult for our small group to remain visible in the midst of such a large collaboration. In addition, the style of management of AMY, not unlike the style of management at DOE, might perhaps be called the method of maximal bravado and bombast, and, as such, it neither inspired loyalty from collaborators nor did it elicit from the collaborators that additional measure of dedication, self-sacrifice, and initiative upon which serious physics is predicated.

In retrospect the most significant shortcoming of the group, in our opinion, was our inability to attract talented graduate students. On the other hand we were more successful in attracting undergraduate physics majors here at LSU, and some of them were conspicuously talented. Many of our student employees have pursued graduate studies at major universities such as Rice, Maryland, Illinois, Stony Brook, and MIT. Nonetheless, the education of graduate students is a fundamental component of our responsibilities, and we acknowledge deficiencies in this regard. It is difficult to see how we might have been more effective in attracting students. No more than a handful of the graduate students at LSU are seriously interested in experimental physics, and those that do, on average, prefer to study solid state physics because of its immediate relevance to the marketplace.

Recent Activities

Until July, 1997, our effort was concentrated at the Los Alamos National Laboratory in New Mexico, where Zhi-fu Wang and Ying-chao Wang were in residence. The Wangs, as is their custom, established for themselves an important niche within the muon subgroup. Working closely with Mr. Matt Murray and under the general supervision of Dr. David Lee, the Wangs contributed in major ways to the design and construction of the muon tracking chambers. Unfortunately the Wangs were less than enchanted at the prospects of moving to Long Island for the installation of the chambers, and, rather than uproot themselves once more, they resigned their positions to accept offers of more lucrative employment elsewhere in Los Alamos.

Finally, the calculation of the resolution function of the DLS has been discussed in our annual progress reports for years now, and rather than repeat yet again explanations that have appeared previously on numerous occasions we shall refer the interested reader to previous reports and conclude this report with a presentation of results. Of the thousands of graphs that could be appended to this report we include here only fourteen that have been selected at random. These graphs illustrate the accuracy with which we were able to fit the parameters of the GUF with our programs. It is truly a pleasure to thank Mr. James Gregurich for his years of service and Mr. Anthony Zegura for assistance with running the software.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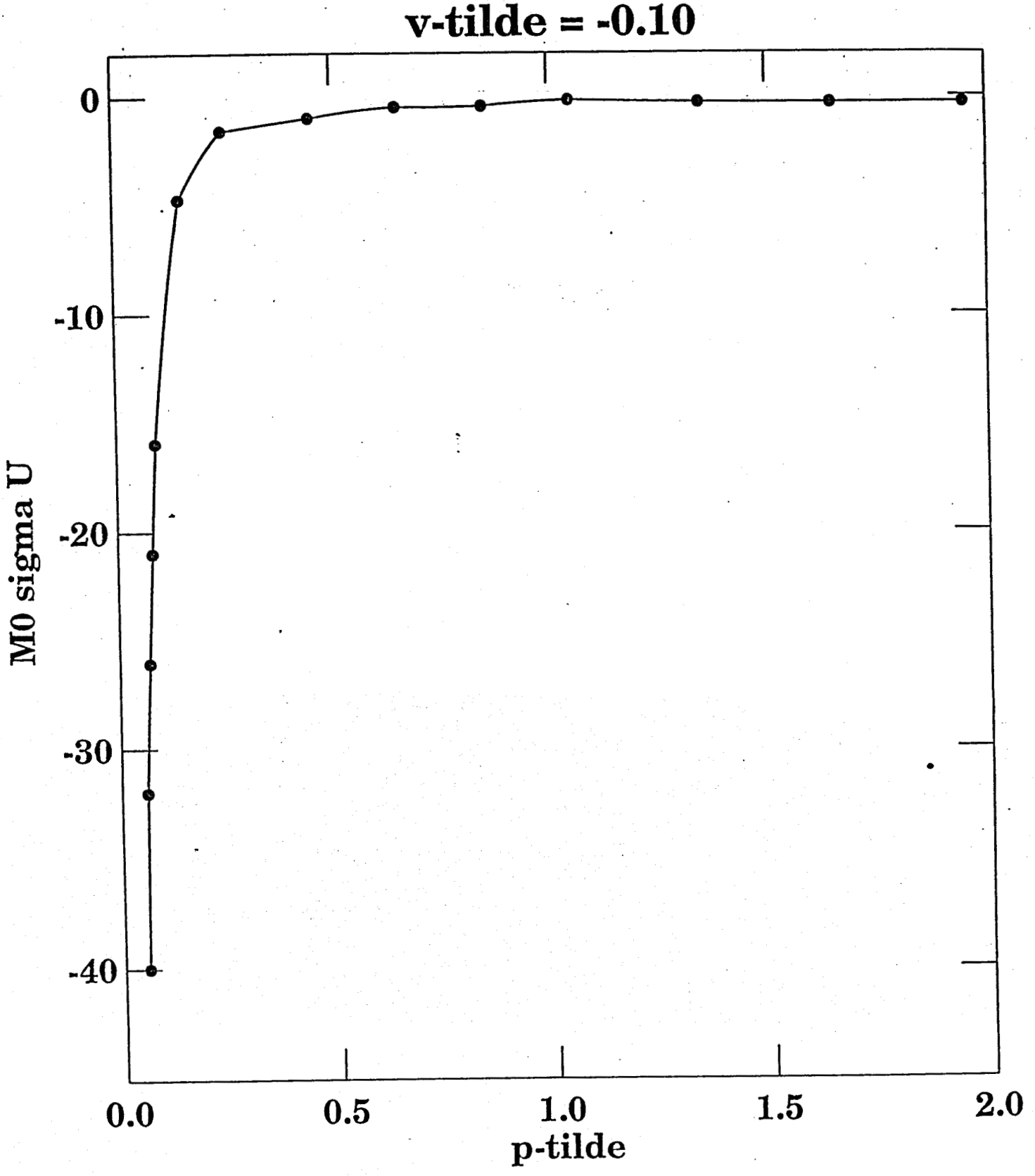
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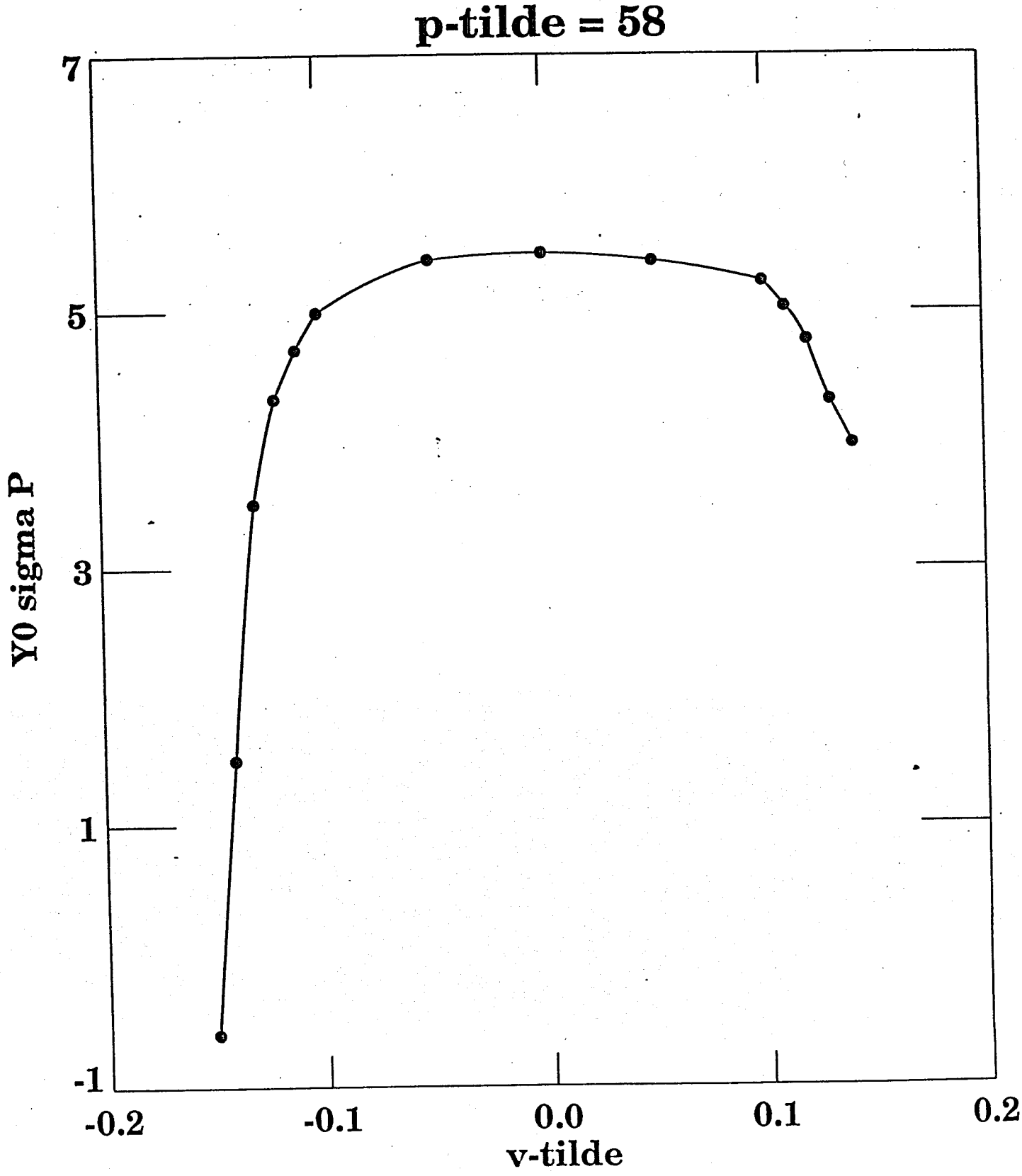
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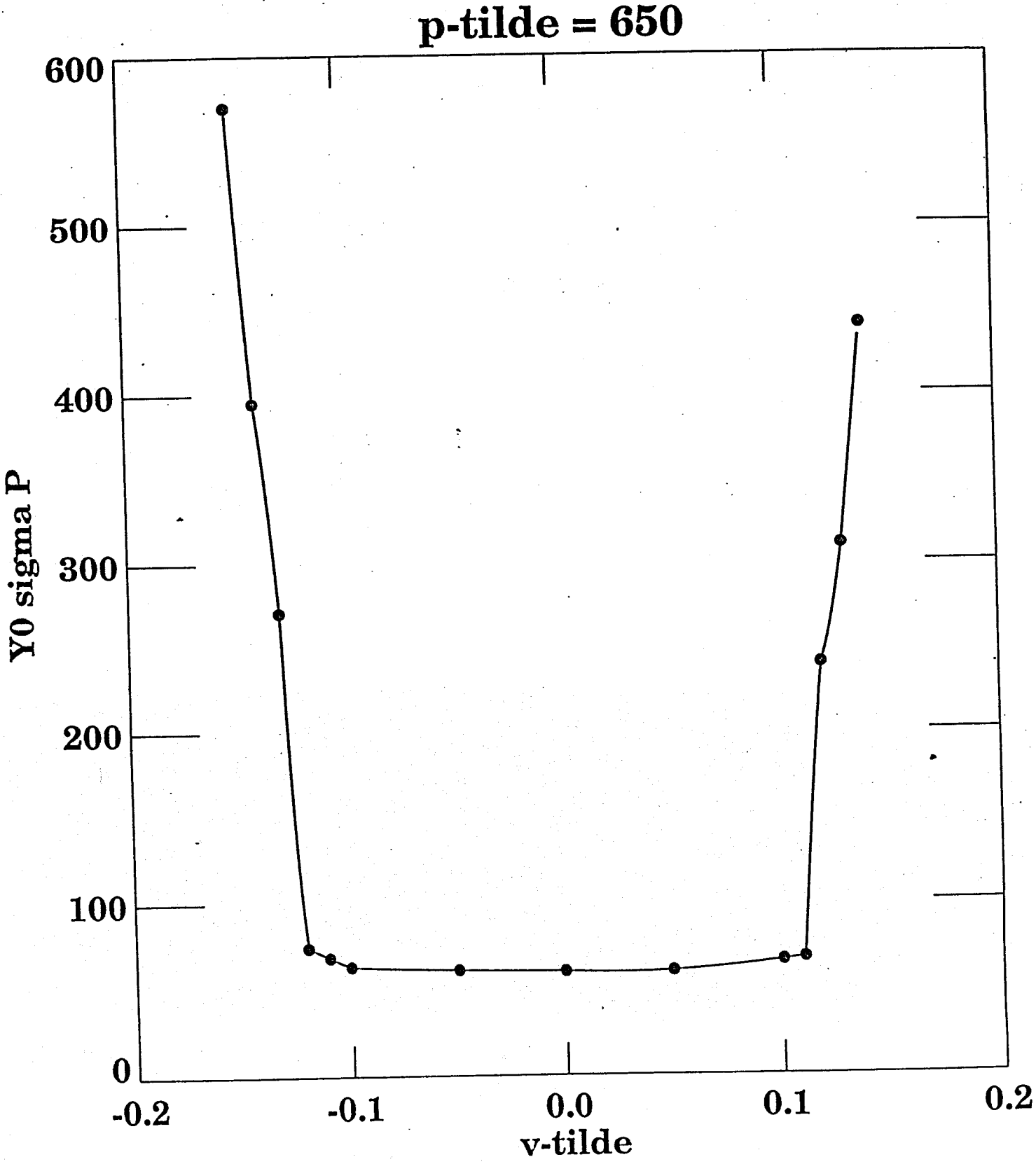
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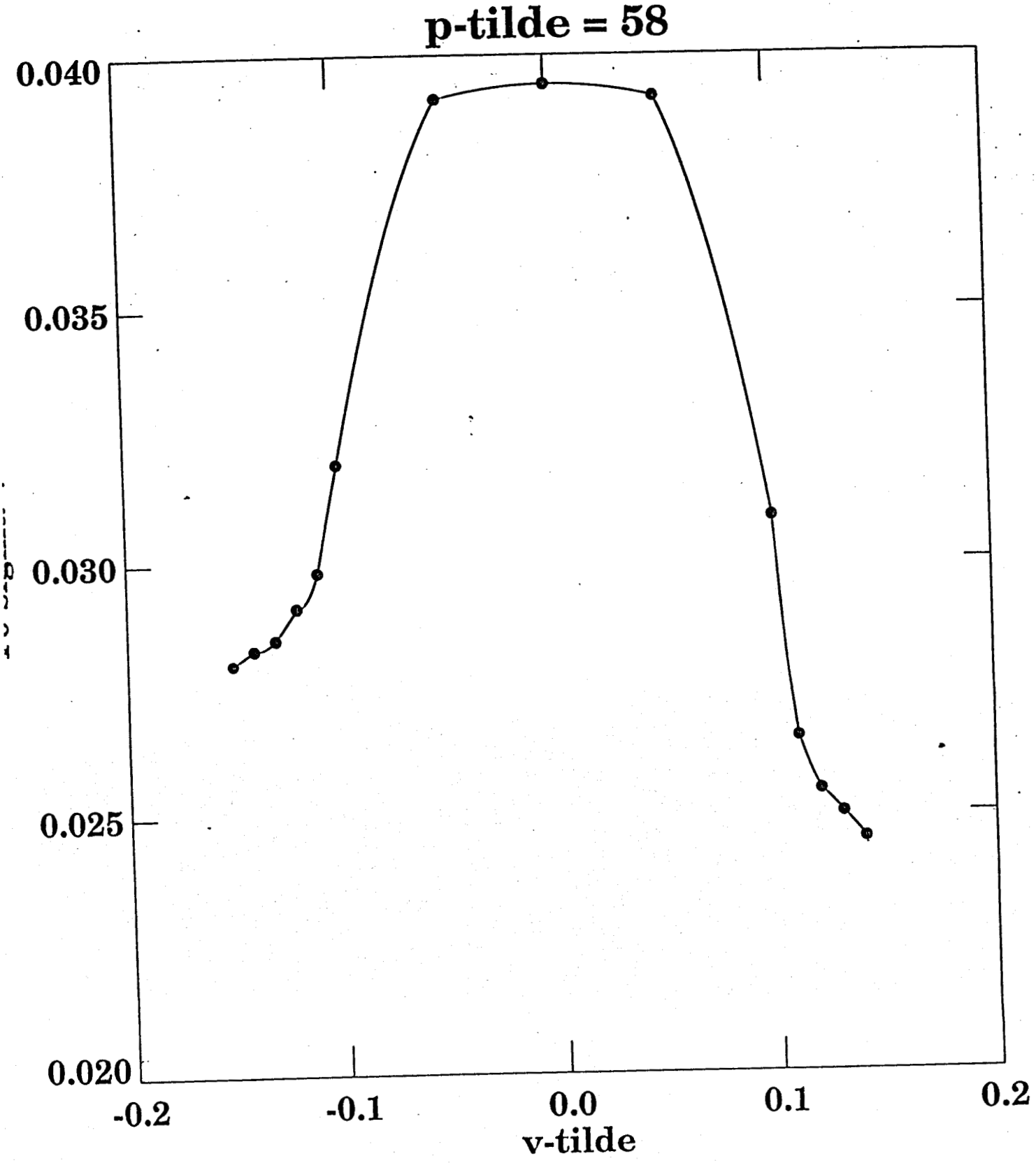
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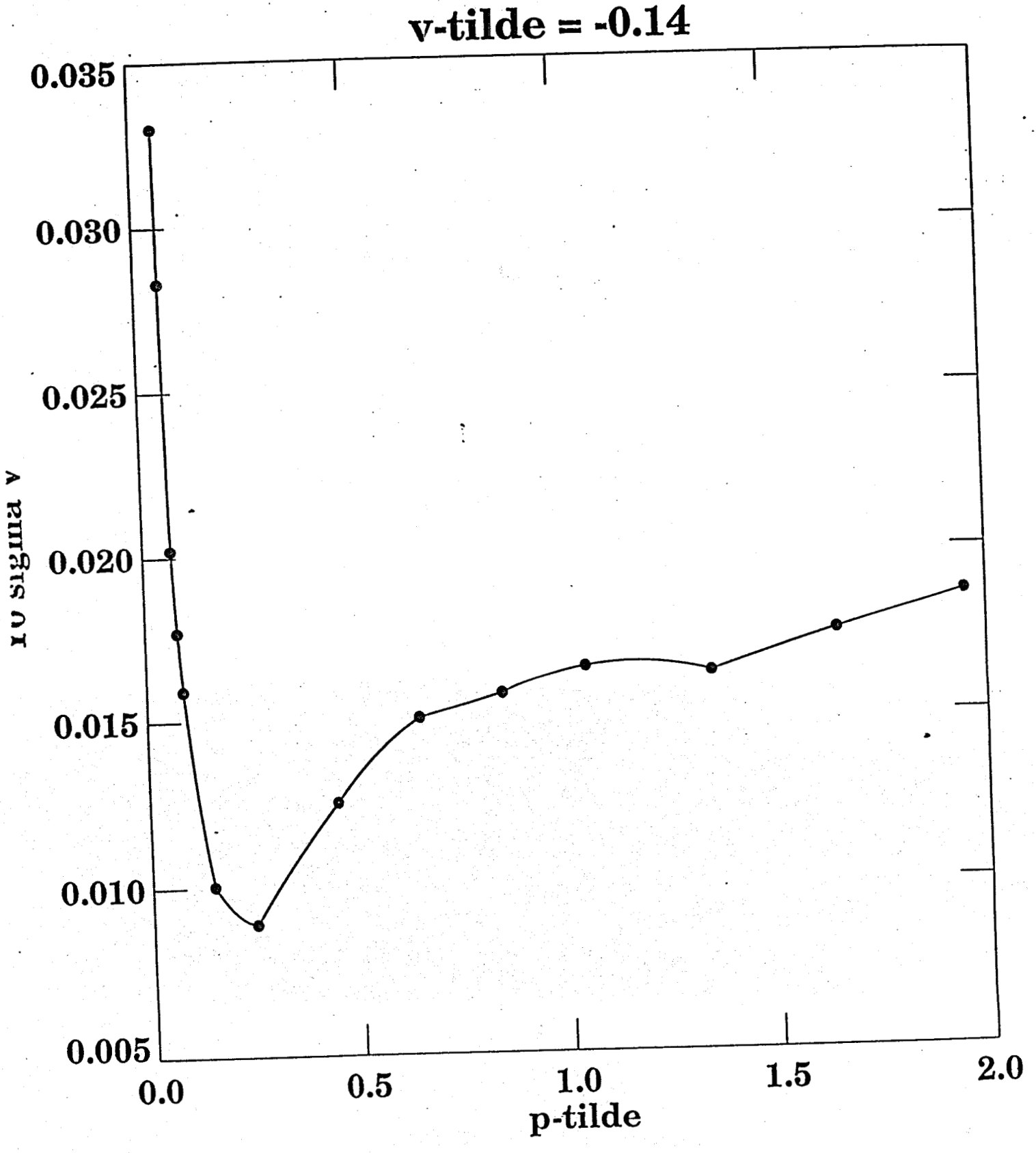
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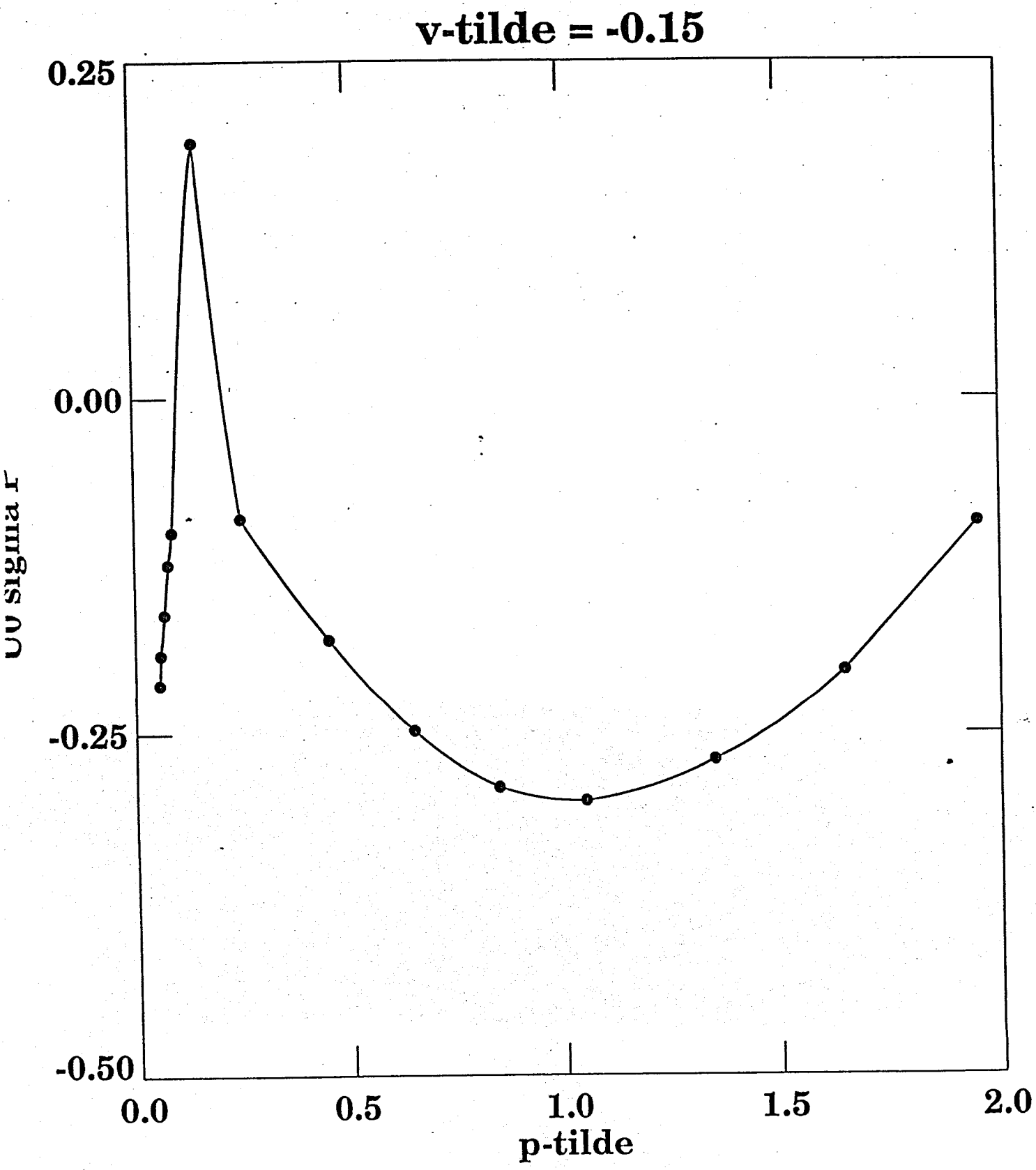
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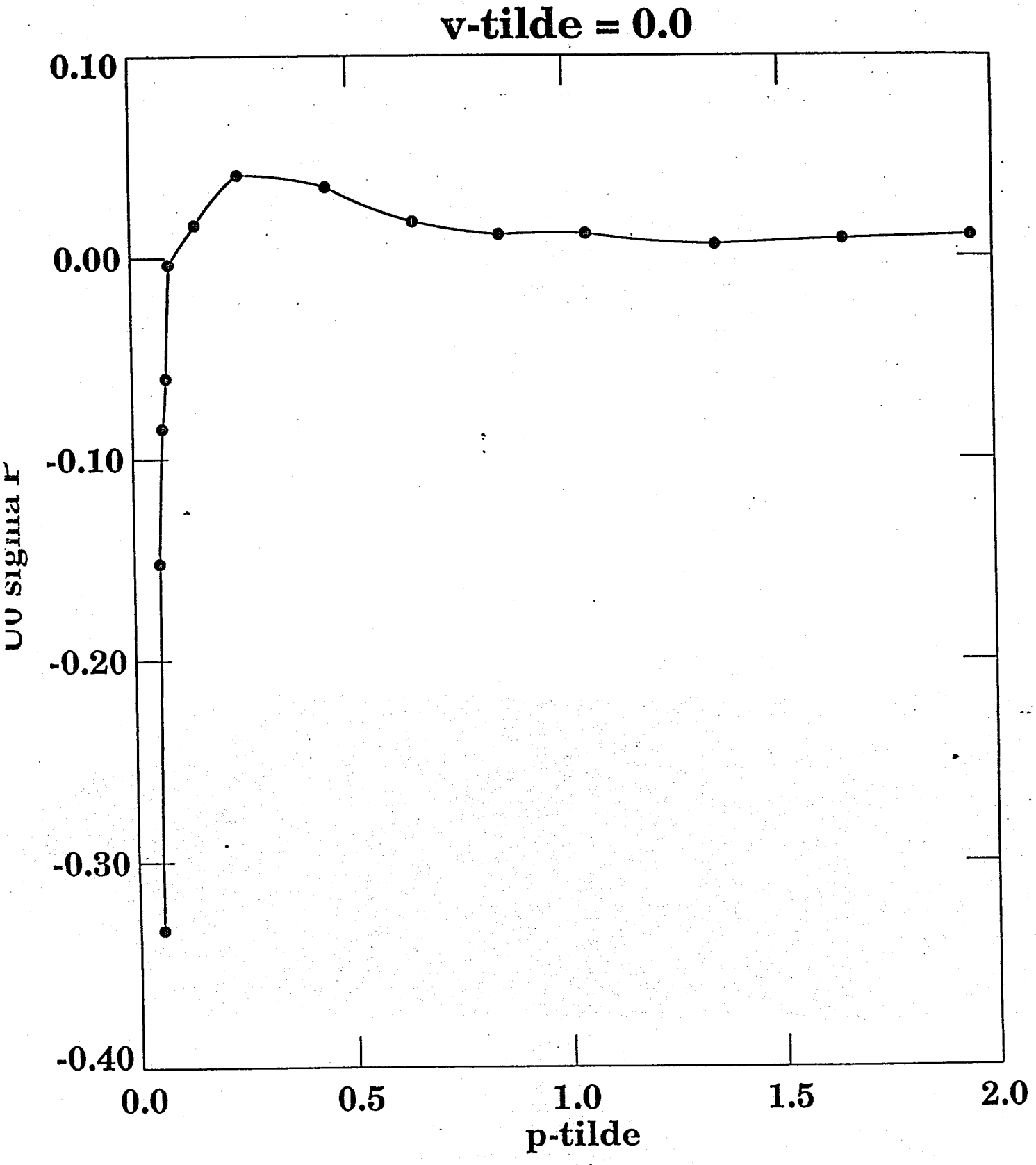
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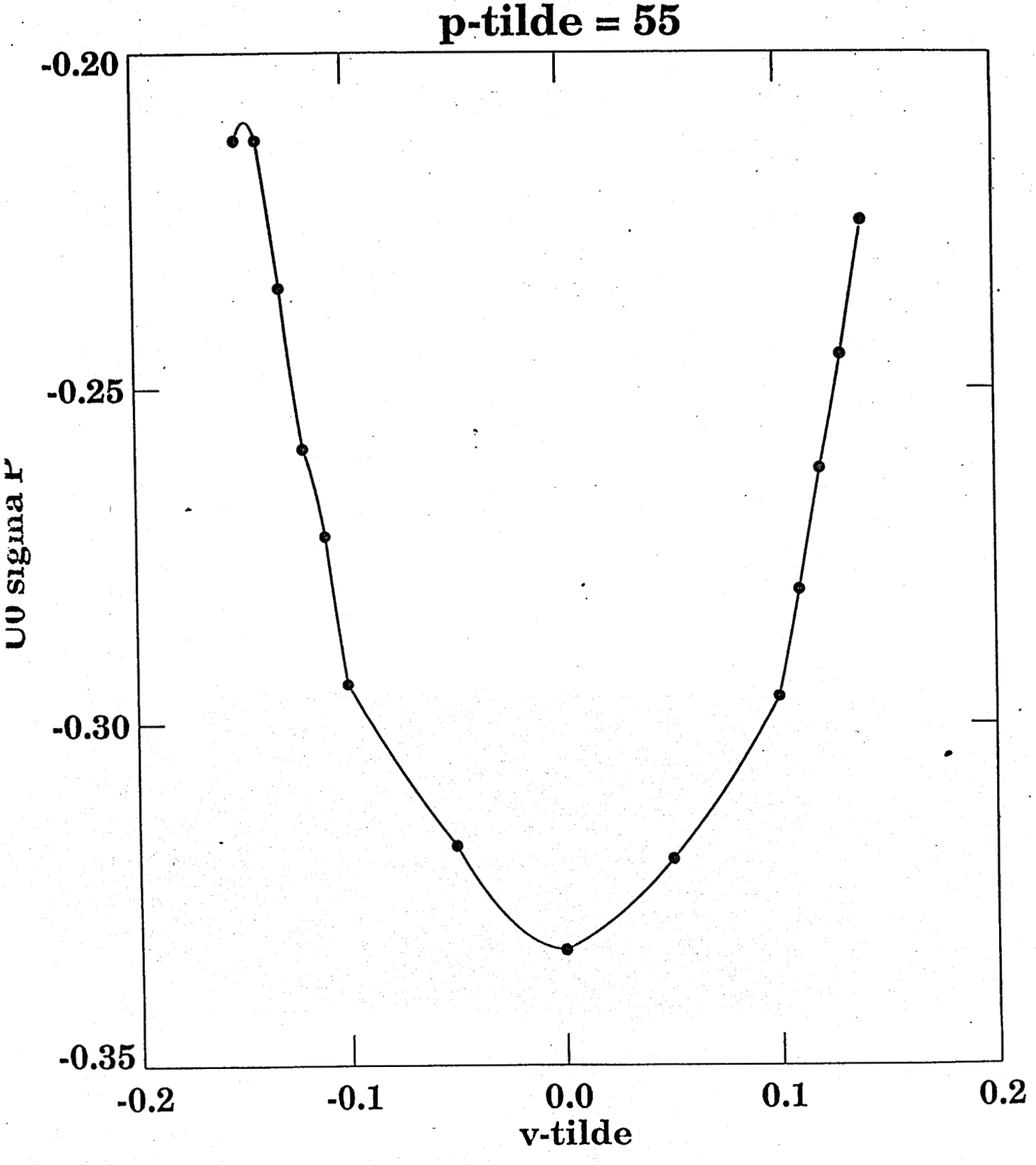
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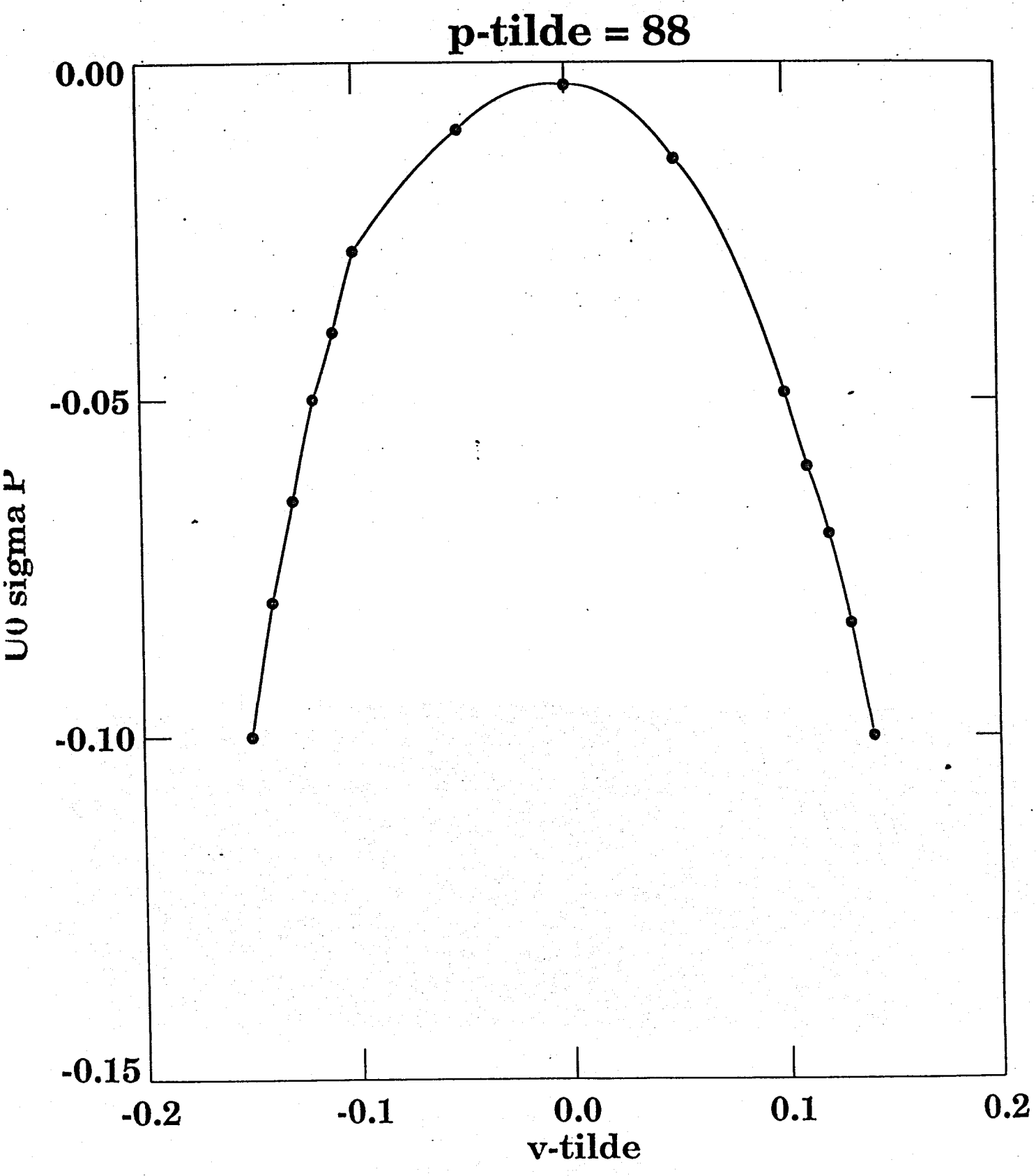
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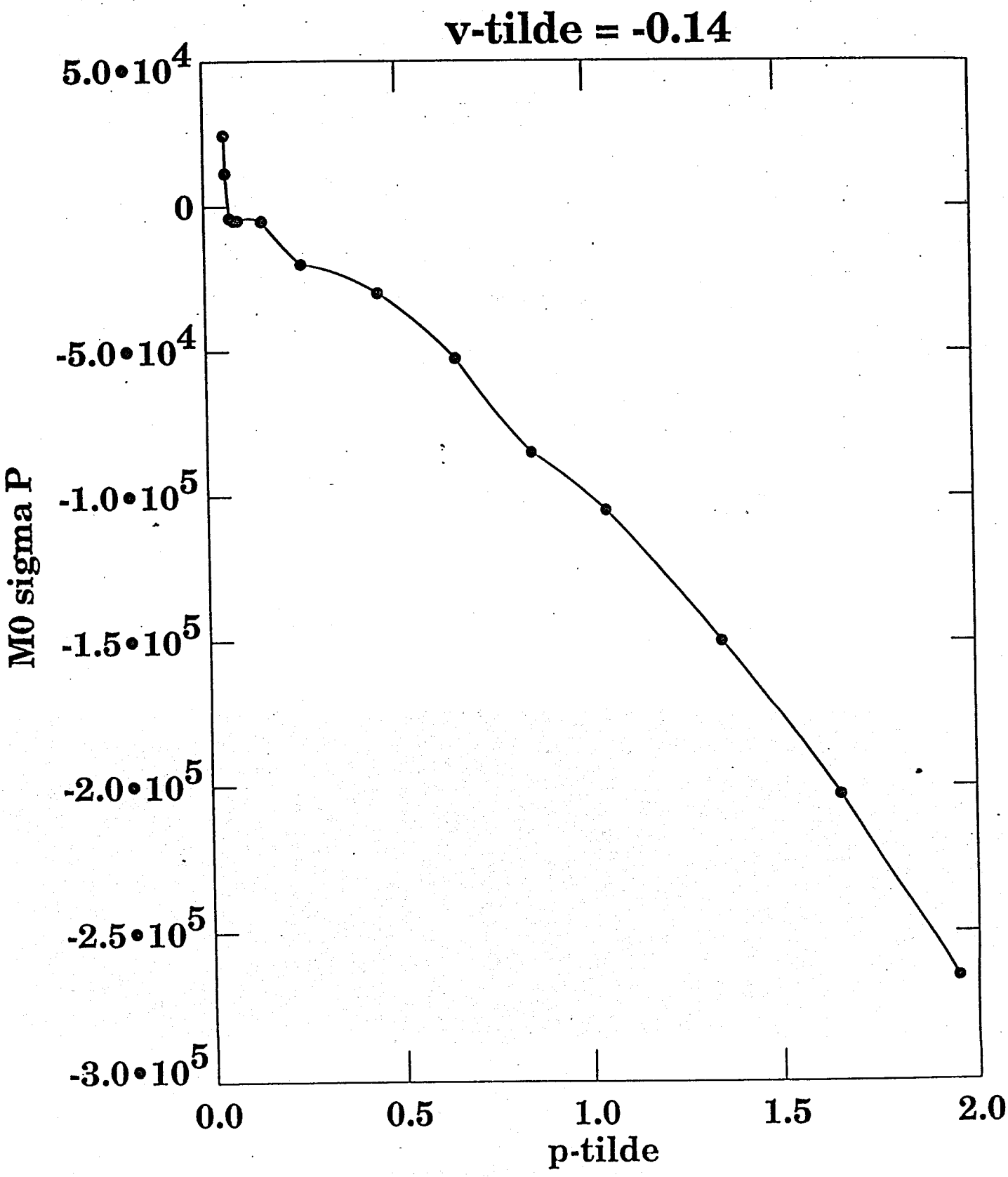
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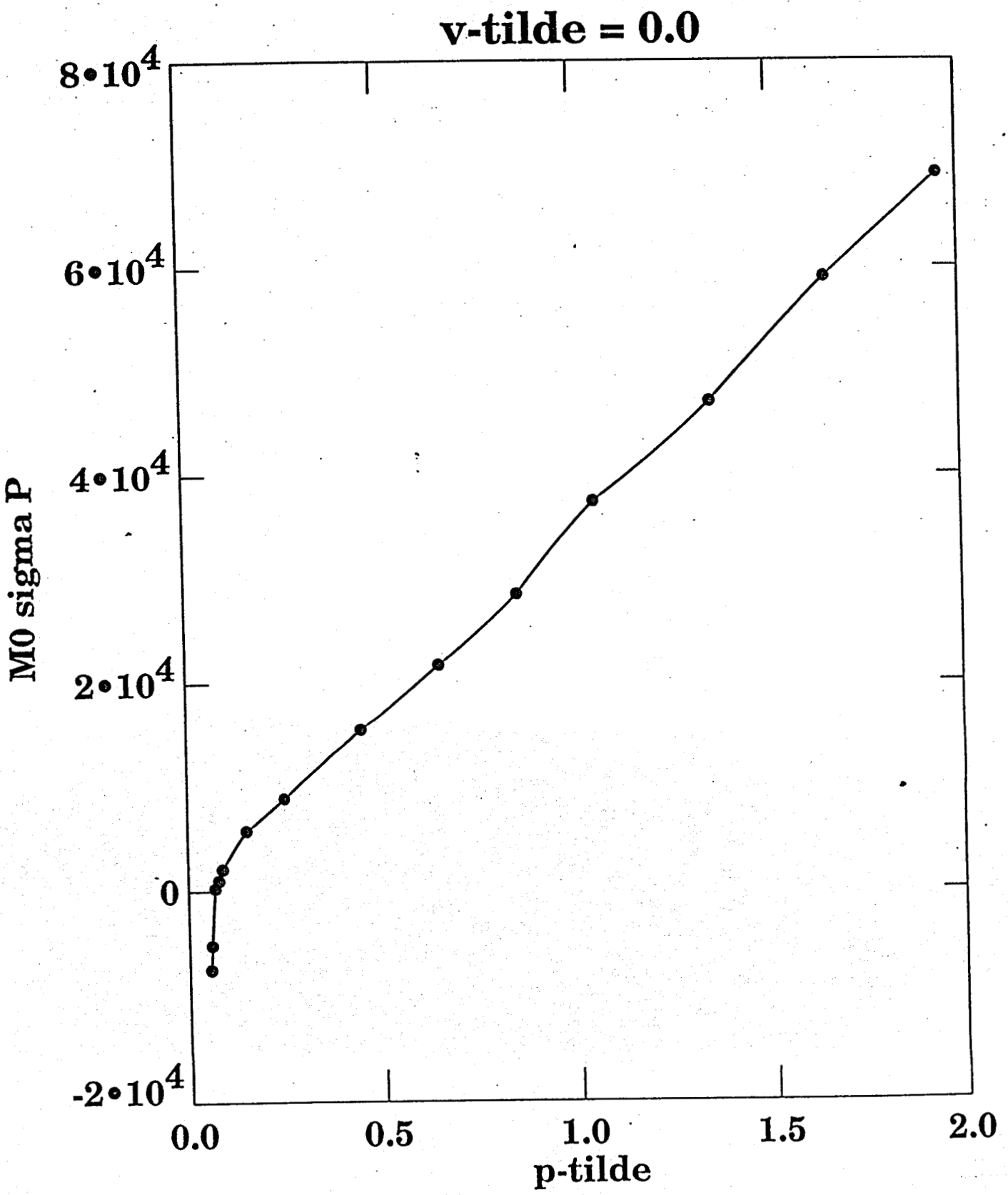
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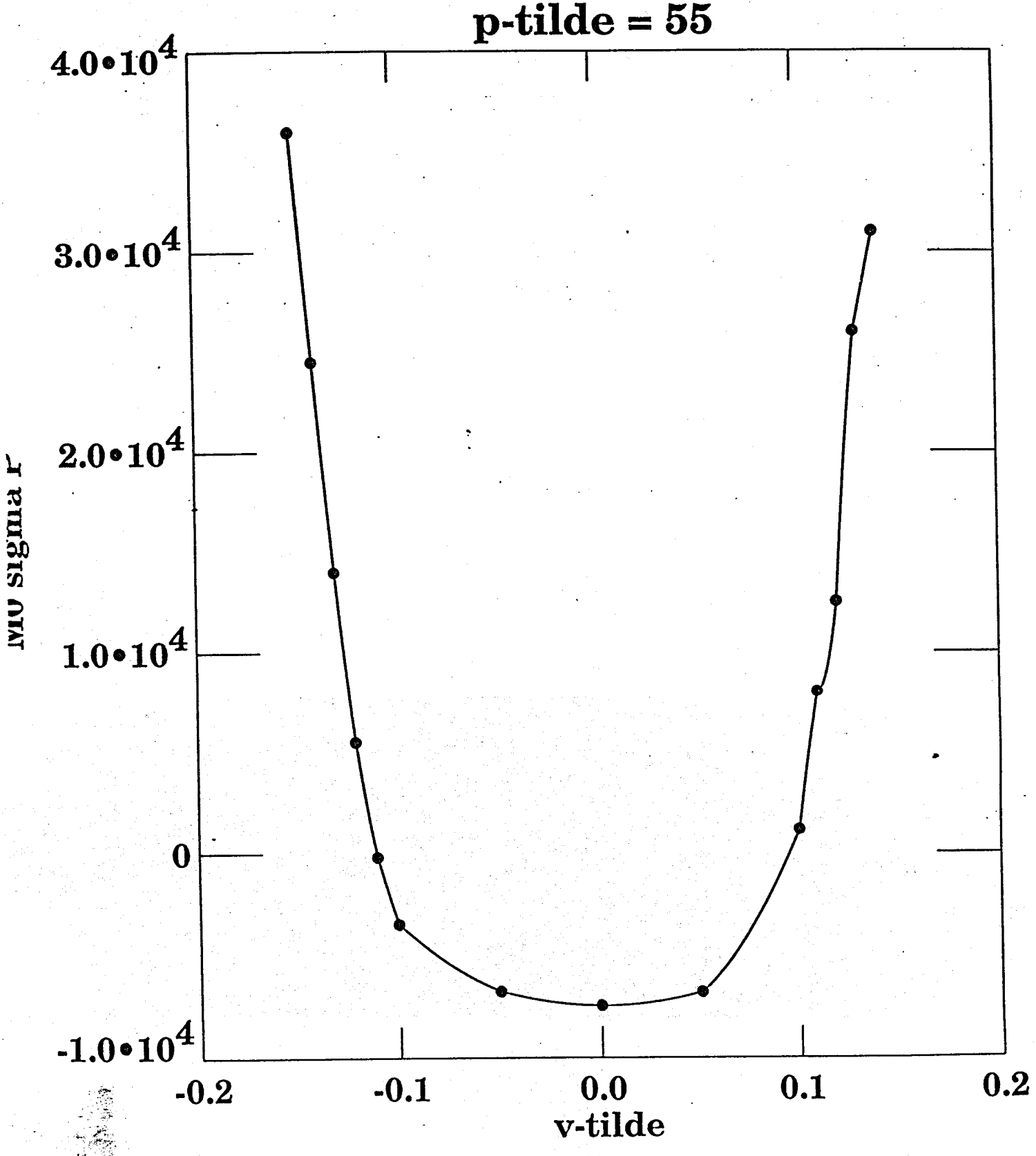
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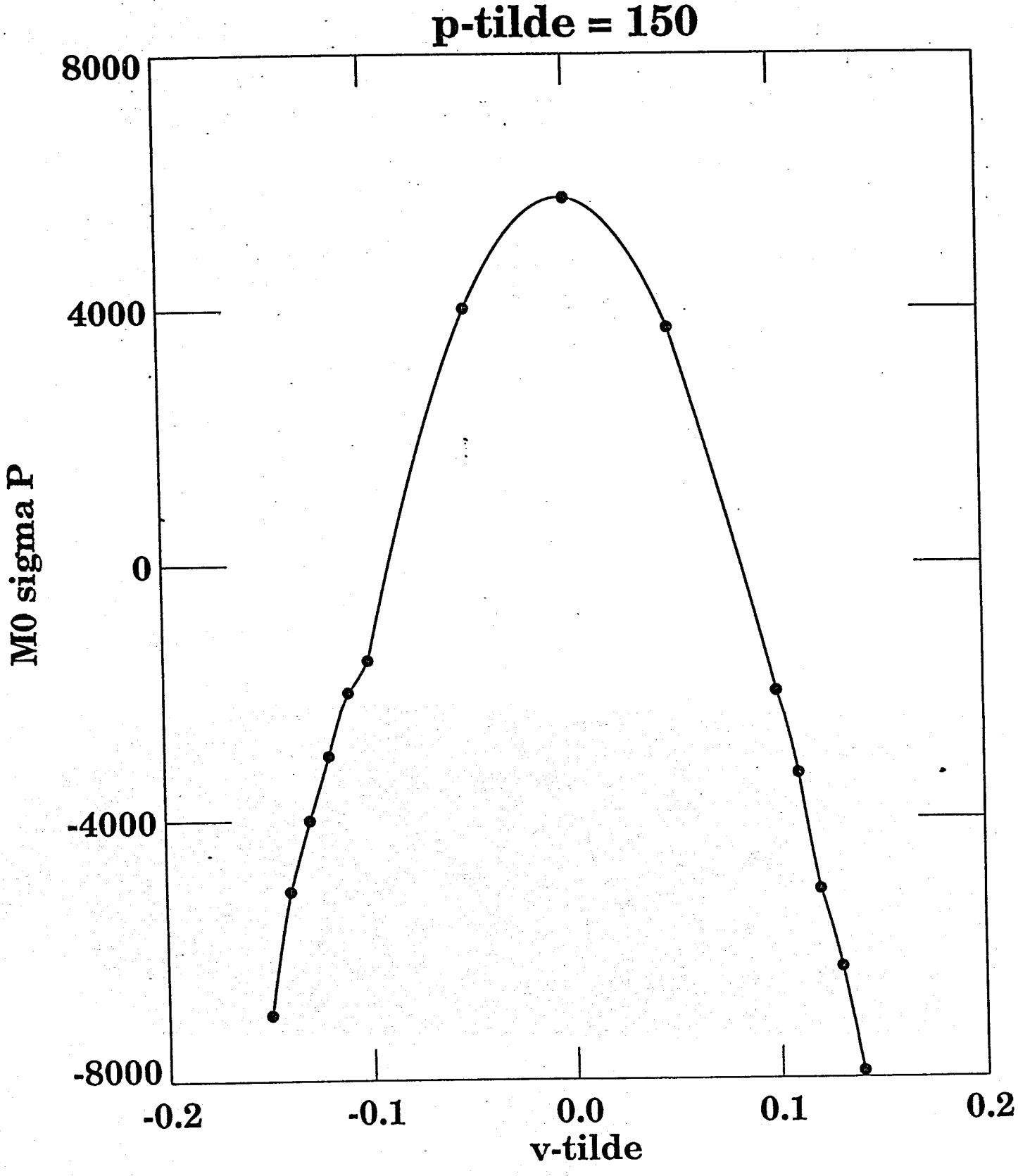
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Appendix A

(Publications)